CoolSNAP Interline Cameras

The objective of this technical note is to familiarize you with interline-CCD technology and Roper Scientific's implementation of this technology in the CoolSNAP family of cameras, specifically the CoolSNAP$_{HQ}$™ and CoolSNAP$_{fx}$™.

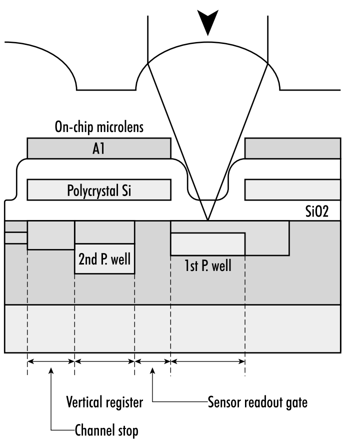


Figure 1.

Technology

An interline-transfer CCD has a parallel register that is subdivided into alternate columns of sensor and storage areas. The image accumulates in the exposed area of the parallel register and during CCD readout the entire image is shifted under the interline mask into a hidden shift register. Readout then proceeds in normal CCD fashion. Since the signal is transferred in microseconds, smearing is undetectable for typical exposures. However, a drawback to interline-transfer CCDs has been their relatively poor sensitivity to photons since a large portion of each pixel is covered by the opaque mask. As a way to increase a detector's fill factor, high-quality interline-transfer devices have microlenses that direct the light from a larger area down to the photodiode.

Hyper HAD

The CoolSNAP cameras use interline-transfer CCDs from Sony. Sony was the first to implement the interline-transfer CCD and on-chip microlenses (see **Figure 1**). By collecting some of the light falling on the masked area, which is otherwise lost, microlens technology improved the quantum efficiency (QE). Furthermore, microlenses increase the effective fill factor of the CCD from approximately 40% to greater than 75%. Sony subsequently improved the microlens technology and manufacturing process with the introduction of the Hyper Hole-Accumulation-Diode (HAD) CCD. Hyper HAD CCDs have much closer spacing between microlenses, thus further increasing the light-collection efficiency, even with reduced pixel sizes (see **Figure 2**).

Super HAD
Recently, Sony has developed the Super HAD interline CCD with an additional layer of on-chip microlenses very close to the pixel area (see **Figure 2**). When used with wider f-number lenses, a single array of microlenses cannot focus the higher-angle light rays onto the sensing area of the pixel and sensitivity is reduced. A second layer of microlenses helps alleviate this problem by further condensing the beam path, thereby increasing QE. Another improvement in this technology is thinning of the insulating layer between the silicon substrate and polysilicon gate structures, which reduces the light leaking under the mask (smear factor).

EXview
With the introduction of EXview HAD CCDs, Sony took interline technology another step by improving the QE in the near-infrared (NIR) region. Since NIR photons are absorbed at deeper levels in the silicon, using thicker silicon in the chip increases the probability of photon-silicon interaction and thus further increases QE.

Wfine
Interline CCDs that are run in progressive-scan mode, have square pixels, and have a Bayer color filter array are labeled Wfine by Sony. These devices are used extensively in consumer markets and are perfect for photo-documentation applications.

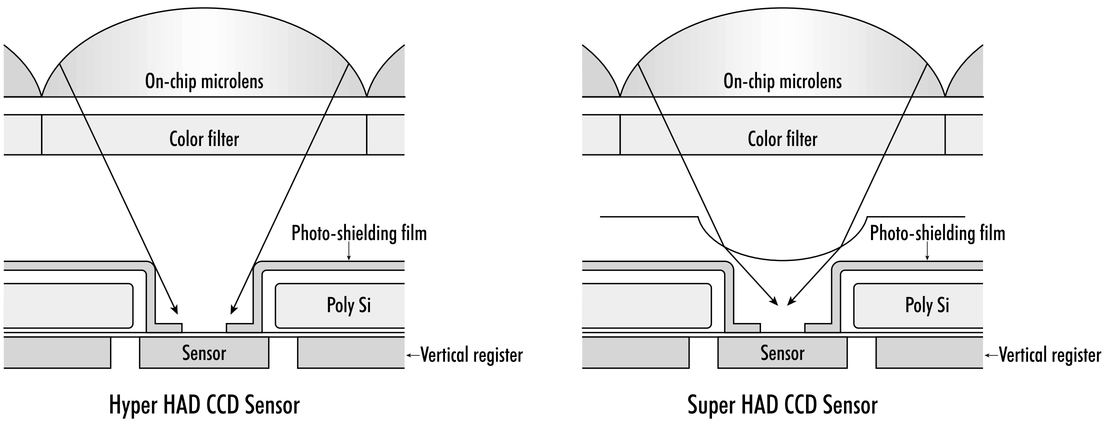


Figure 2.

Implementation by Roper Scientific
The CoolSNAP$_{HQ}$ uses the Sony ICX285 sensor, developed with EXview, Super HAD technology (see **Table 1**). Roper Scientific provides tremendous flexibility to the end user by incorporating this CCD into the CoolSNAP$_{HQ}$. The following innovative CoolSNAP$_{HQ}$ features (many of which are also found on the CoolSNAP$_{fx}$) take full advantage of the Sony CCD's potential and can be easily tailored to specific applications for optimum performance and easy integration.

Camera	CCD	Sony technology	Features
CoolSNAP$_{HQ}$ Monochrome	ICX285AL	EXview, Super HAD	High QE, NIR, high frame rates
CoolSNAP$_{fx}$ Monochrome	ICX061	Hyper HAD	High dynamic range, high frame rates
CoolSNAP$_{cf}$ Monochrome	ICX205AL	Hyper HAD	High frame rates, small pixels
CoolSNAP$_{fx}$ Color	ICX085	Hyper HAD, Wfine	High dynamic range, color, small pixels
CoolSNAP$_{cf}$ Color	ICX205AK	Hyper HAD, Wfine	High frame rates, color

Table 1. *CCDs used in CoolSNAP cameras*

(1) *Cooling:*
CoolSNAP$_{HQ}$ and CoolSNAP$_{fx}$ are cooled to -30°C, minimizing the dark charge to 0.05 e-/pixel/sec. CCD temperature is regulated to ±0.05°C and is settable between room temperature and -30°C.

(2) *Dual-speed operation:*
CoolSNAP$_{HQ}$ is implemented with 10-MHz and 20-MHz speeds with two different analog circuits leading to the analog-to-digital converter (ADC). This enables optimum noise performance at both speeds. At 20 MHz, it offers 10 frames per second (fps) with a read noise of 8 e- rms, whereas the 10-MHz operation allows lower read noise at the expense of frame rate.

(3) *Dual-clocking schemes:*
A unique feature of CoolSNAP$_{HQ}$ is that it allows two different CCD clocking schemes that best bring out the advantages of the EXview technology in terms of both speed and NIR sensitivity. In the PVCAM® implementation, the clocking schemes are referred to as "normal" and "alternate normal" (see Figure 3).

Figure 3.

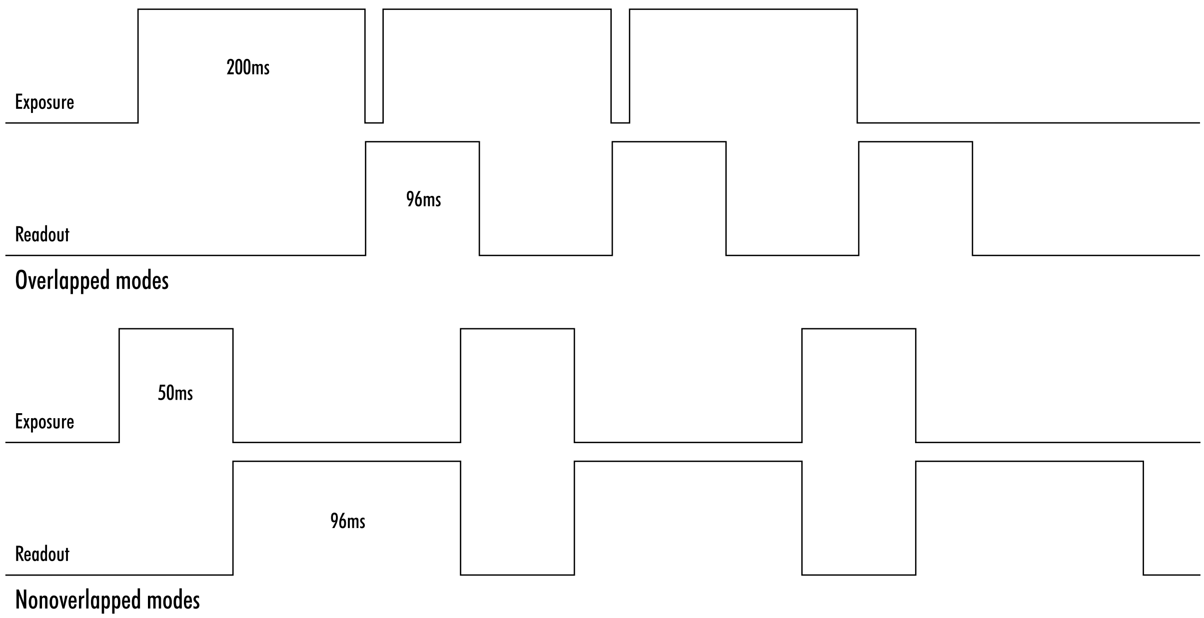


Figure 4.

For example, in **Figure 4**, the readout time for one full frame at 20 MHz is approximately 96 ms. If the exposure time is 200 ms and the camera is in normal mode, the readout of a frame occurs during the exposure of the next frame. The time required to acquire a three-image sequence is 696 ms (3 x 200 + 96) and the frame rate is approximately 5 fps.

If the exposure time is 50 ms, which is less than the readout time, the camera operates in "nonoverlapped" mode (see **Figure 4**). The effective frame rate for this is 6.84 fps (1/[0.05+0.096]). While in normal mode, the camera firmware automatically calculates the readout times, taking into account binning and/or subregion, and carries out the exposure-readout sequence to maximize the frame rate.

In the "alternate normal" clocking scheme, it is possible to achieve higher QE in the NIR (peak QE of approximately 65%) by manipulating the CCD clock voltages (**Figure 5**). Also, in this high-sensitivity mode, the preamplifier is switched off during the exposure to eliminate the background generated by preamplifier glow. In this clocking scheme, regardless of what the exposure time is, the camera operates in "nonoverlapped" mode.

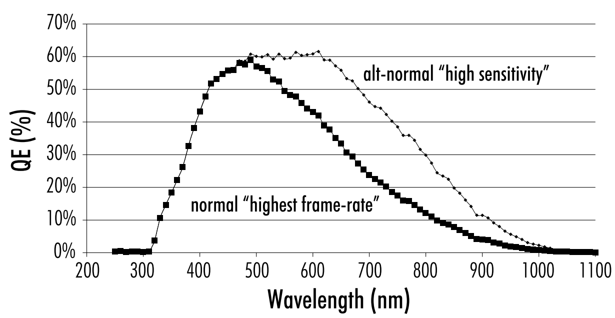
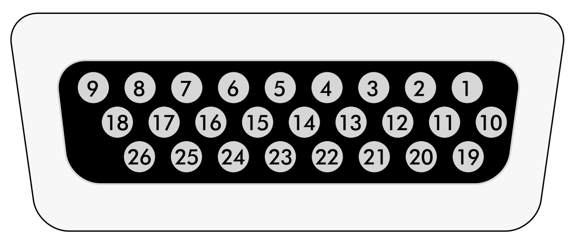


Figure 5.

(4) *Antiblooming:*
Typically, interline CCD devices are designed with antiblooming capabilities. To prevent excess electronic charge from migrating to adjacent pixels, "drains" are built into the CCD. These drains remove any excessive charge generated from an overexposed pixel. Sony interline CCDs will prevent blooming for optical signals greater than 1000 times the full well capacity of a single pixel. However, the extended QE capabilities of the Sony ICX285 reduce the antiblooming suppression for certain modes. In normal mode, the CCD operates with typical antiblooming suppression. But in alternate normal mode, the enhanced sensitivity causes a reduction in antiblooming to greater than 100 times single-pixel full well capacity.

(5) *Trigger modes:*
CoolSNAP$_{HQ}$ and CoolSNAP$_{fx}$ offer several methods of integration with external trigger sources, such as delay generators or laser pre-triggers. Each camera has a 26-pin, high-density connector on the back for trigger-in/out and various TTL input and output operations (see **Figure 6**). A special cable is available to access primary signals such as "Trigger-in," "Trigger-invert," "Expose out," "End of frame," and "Interline shift." In the default mode, the camera triggers on the rising edge of a TTL signal. To invert the triggering polarity, the "Trigger-invert" must be grounded, which can be done with a 50-ohm terminator.



1. Filtered Trigger Input
2. Trigger Invert Input
3. GND
4. DAC 1
5. DAC 2
6. GND
7. Frame Readout
8. Camera Exposing Output
9. Interline Shift
10. TTL I/0 data bit 0
11. TTL I/0 data bit 1
12. TTL I/0 data bit 0
13. TTL I/0 data bit 1
14. TTL I/0 data bit 0
15. TTL I/0 data bit 1
16. TTL I/0 data bit 0
17. TTL I/0 data bit 1
18. GND
19. Power Status
20. GND
21. (not used)
22. (not used)
23. (not used)
24. (not used)
25. GND
26. GND

Figure 6.

The CoolSNAP cameras support several trigger modes (all operated in "nonoverlapped" mode):

Trigger-first mode — In this mode, the camera requires only one trigger to acquire a sequence of frames. Each frame is exposed for a length of time entered into the software and read out. Once the trigger is received, the camera is inhibited from taking any further triggers until the entire sequence is completed (see **Figure 7**).

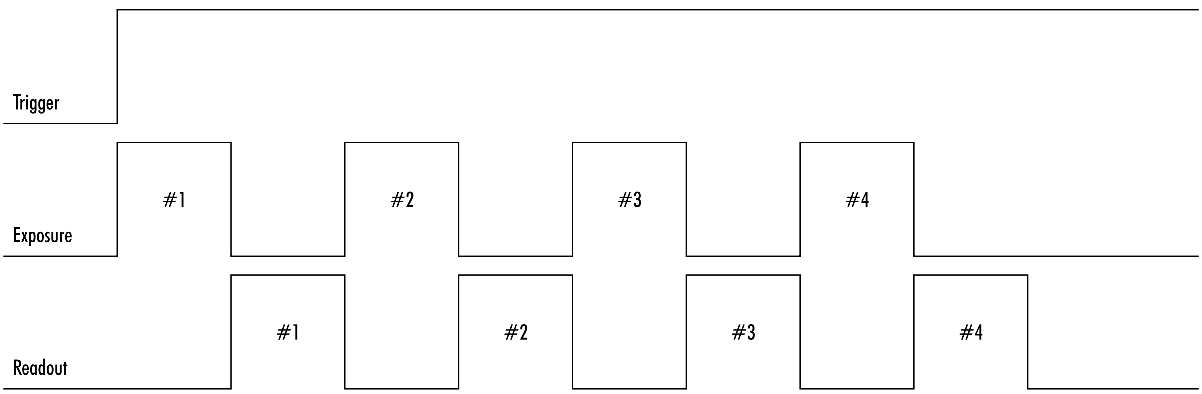


Figure 7.

Strobe mode — In this mode, each frame in a sequence requires a trigger. Each frame is exposed for a length of time entered into the software and is then read out. If the trigger arrives during the exposure-readout of the previous frame, it is ignored (see **Figure 8**). For a sequence of one frame, strobe mode and trigger-first mode are the same.

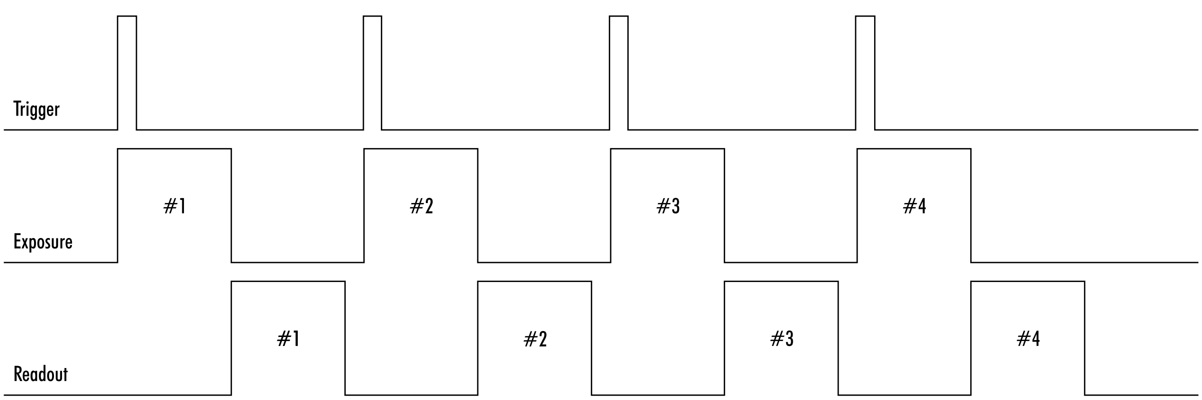


Figure 8.

Bulb mode — In this mode, exposure time for each frame is determined by the trigger pulse width. Exposure time entered into the software is not used in this mode (see **Figure 9**).

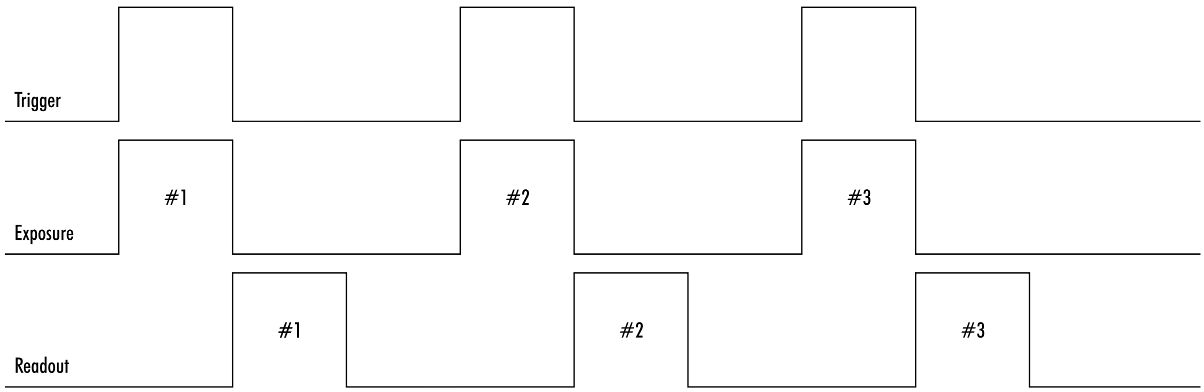


Figure 9.

(6) *RS-170/PAL operation:*
Both CoolSNAP$_{HQ}$ and CoolSNAP$_{fx}$ offer monochrome video output on the back of the PCI card, selectable between NTSC and PAL. The video signal is derived from the digital data being transferred from the camera through the PCI interface card. Thus, simultaneous video output and data transfer is accomplished. If the image resolution is greater than the video format (640x480 for RS-170) then the 0,0 to 640,480 region is displayed. For image sizes less than the video format, the entire region is displayed. Since video output comes from raw data, the signal is monochrome only.

Application Examples

Example 1

"I have a CoolSNAP$_{HQ}$ and want to operate the camera in the most sensitive setting for taking high-resolution, single images."

For this application, the camera should be operated in "alternate normal" mode to provide the best quantum efficiency. Furthermore, the readout speed of the camera should be set to 10 MHz to reduce the read noise. Finally, the camera gain should be set to 2. These settings will operate the camera in its most sensitive mode.

Example 2

"I would like to acquire sequences of images with a CoolSNAP$_{HQ}$ to study time-correlated phenomena. My light level is fairly high and I want to optimize the acquisition rate of the camera."

First, the camera speed should be set to 20 MHz. In addition, the camera should be put into "normal" mode to take advantage of the overlapping of the readout with the integration time. Finally, the "clearing" mode of the camera should be set to "clear pre-sequence" to remove the clearing overhead between frames. Of course, reducing the region of interest and increasing binning will always increase the frame rate further.

Example 3

"I would like to use either a CoolSNAP$_{HQ}$ or a CoolSNAP$_{fx}$ to study the immediate response of a specimen to an electrical stimulus."

The camera should be set up as in Example 2 for optimum time resolution. Furthermore, the camera should be set to "Trigger-first" mode. The same TTL signal that is providing the electrical stimulus should be sent to pin number 1 on the I/O port on the back of the camera.

Contact **Roper Scientific, Inc.** for more information:

3660 Quakerbridge Road Trenton, NJ 08619
tel: 609.587.9797
fax: 609.587.1970
email: info@roperscientific.com
web: www.roperscientific.com

3440 East Britannia Drive Tucson, AZ 85706
tel: 520.889.9933
fax: 520.573.1944
email: info@roperscientific.com
web: www.roperscientific.com