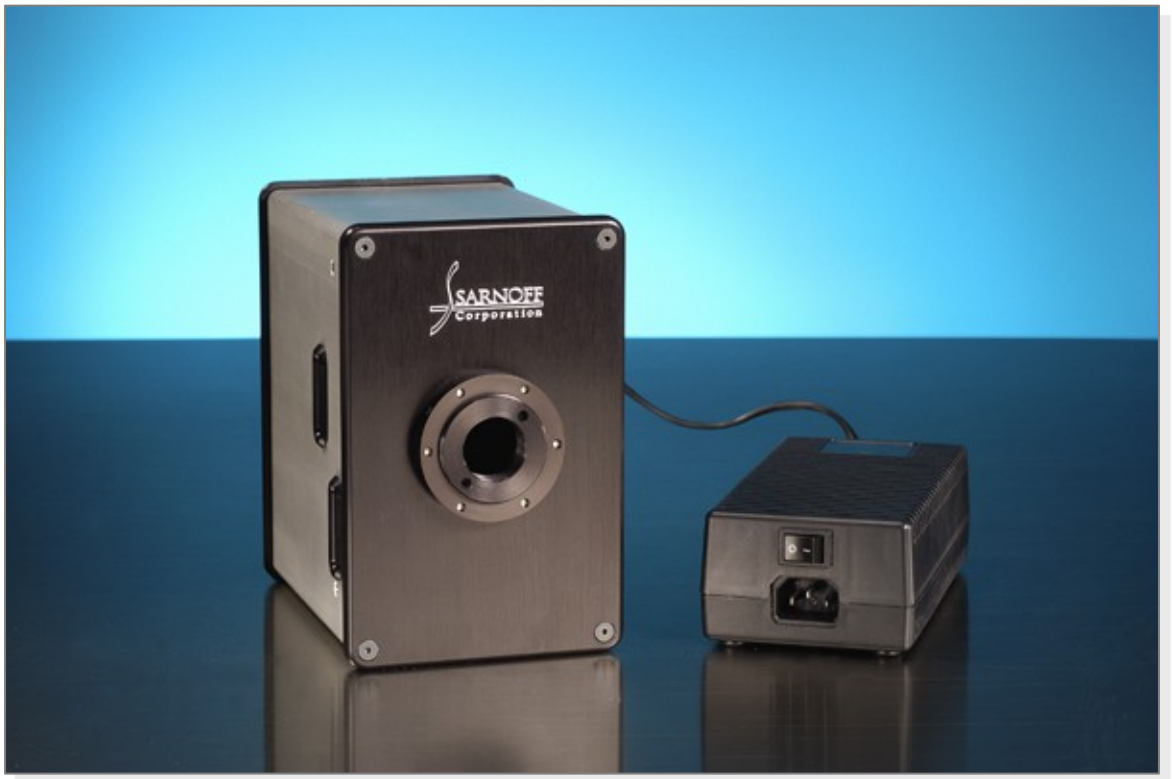
From: Steve Ross 2-9510, skross @ anl.gov
To: Detector Pool
Date: 12/07 onward…
Subject: Sarnoff CAM1M100 Camera

# Sarnoff CAM1M100 High Frame Rate CCD camera.

**REVISION HISTORY:**
Initial version 2/14/2008

This memo provides the specifications for the APS Detector Pool high frame rate visible light Sarnoff CCD camera. It also is a User's Guide for operation.




## 1.0 ADVANTAGES OF THIS CAMERA:

A charge coupled device (CCD) camera relies on transferring charge from an imaging pixel to the output amplifier by a so-called bucket brigade, moving the photo-charge one row of pixels to the next (vertical transfer), then shifting a given row out through a readout amplifier (horizontal transfer). This readout amplifier can have higher and higher bandwidth, but at the expense of electronic noise. Hence after a certain point, a better

way to achieve fast frame readout is to increase the number of output amplifiers, while keeping each at a lower readout speed for lower noise. The Sarnoff series is one of the main commercial cameras to take this approach, having 16 output amplifier ports. Hence when you look at an image, you will see 16 sub-regions in the raw data. It is never possible to make all regions exactly the same light-to-signal gain, exactly the same dc offset. It is straight forward to correct this in later software.

**Compared with other visible light CCD cameras, the Sarnoff camera has a very good quantum efficiency (thus raising sensitivity), low noise, true 12 bit dynamic range at 10 millisecond readout. It is a full-frame CCD, the entire area is part of the imaging area (not interline, not frame transfer.) Hence it typically requires a shutter.**

## 2.0 DETECTOR POOL TAG NUMBERS:

| | |
|---|---|
| DP00244 | Sarnoff Fast visible CCD camera |
| DP00245 | Sarnoff fast shutter |
| DP00246 | Sarnoff fast shutter controller |

## 3.0 SPECIFICATIONS:

**Format:** Silicon Charge coupled device (CCD) 1024 x 1024 pixels, back side thinned.
**Optical Lens Mount**: C mount
**Pixel Size**: 16 um x 16um
**Visible light quantum efficiency**: about 70%, see curve below,
There is no window in front of the CCD in the camera housing
**Number of output ports**: 16
**Readout time**: 10 milliseconds full frame.
**Typical Operating temperature**: Cooled by 2 stage thermo electric coolers to –30C
**Electronic Noise** at 100 frames/sec (essentially no integration time) 20eRMS (see data below).
**Dynamic Range, Linearity, and full well capacity:**
The amount of charge a CCD can hold in its imaging pixel is set by the bias on the CCD, and by the doping of the semiconductor itself. This is an upper bound on the "full well" capacity, but not universally useful because linearity (digital signal out versus photons in) degrades before this limit is reached. The Sarnoff quoted camera pixel full well capacity of 140,000 electrons is instead set by the full scale of the 12 bit analog to digital converter (ADC). That is, the gain on the pixel amplifier chains is such that 140,000 electrons equal 4095 DN. The camera is linear better than <0.26% through the full scale. **(see data below).**
Note we estimate the dynamic range of CCD (as opposed to the ADC)
: 140,000 / 25eRMS = 5600 dynamic range of CCD
12 bits = 4096

Measured at frame rate is 100 fps full frame, or 200 fps binned by 2x2

**Offset:** 128 DN is the dark offset value as set in the standard camera.
Dark current <1na/cm2 at 20C, which means <200e/pix/sec at –30C
So with exposures longer than about 15 sec the dark current would be a factor. (See appendix section of dark current noise, if you wish to estimate this for yourself.)

Other definitions: "Back side thinned". The "front side" of a CCD is defined at that part of the silicon which has the gate structure, the lines on the silicon which brings the clock phases to the pixel. This structure can attenuate light, blue (400 nm) more than red (800 nm). Hence we can thin the back of the silicon wafer down from hundreds of microns to very thin few microns, and call this the photo active side. The advantage is better visible light quantum efficiency, but the expense is a more fragile wafer, one that probably cannot be bonded to anything else mechanically. The Sarnoff CCD is this back side thinned.

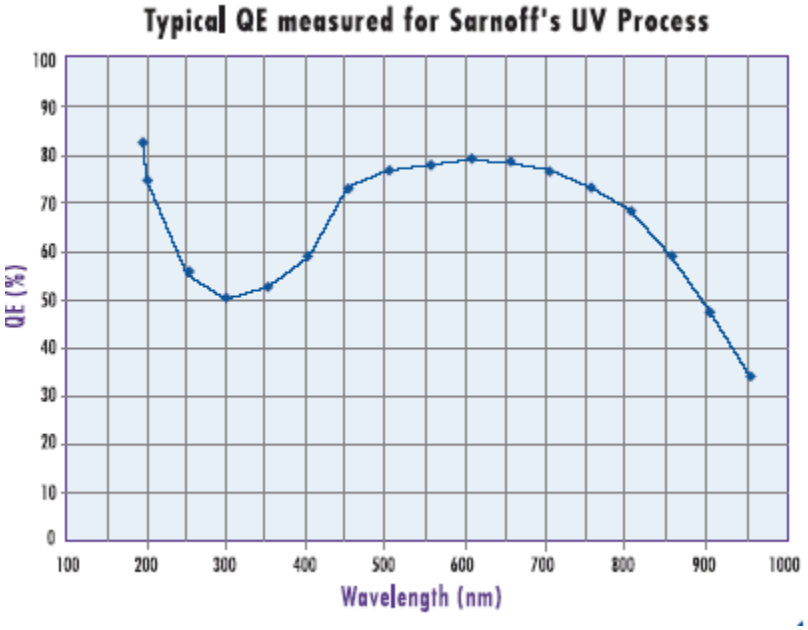
## SPECIFICATIONS (TYPICAL)

| | |
|---|---|
| Resolution | 1024 x 1024 pixels |
| Pixel Size | 16 um x 16 um |
| Aperture | 16.4 mm x 16.4 mm |
| Max. Frame Rate [1] | 100 fps or 200 fps binned by 2 |
| Binning | 2 x 2 or Programmable |
| Scanning | Split Full Frame |
| Camera Outputs | 2 x 50 MHz LVDS via MDR26 |
| Data Format | 12 bit (4096 DN) |
| Dynamic Range | 3200:1 |
| Antibloom | 2:1 |
| Lens Mount | F-mount, C-mount |
| Camera Size [2] (HWD) | 17.2 cm x 11.2 cm x 17.7 cm |
| Mass [2] | < 1.5 kg |
| Operating Temp. | 10 to 35° C |
| Power Supply | 90-260 VAC, 47-63 Hz |
| Power Supply Size | 16.4 cm x 8.5 cm x 5.5 cm, 0.6 kg |
| Power Dissipation | < 50 Watts |

1 Thermal management is required at the highest frame rates • 2 Without lens

## 4.0 MEASURED PERFORMANCE DATA:

4.1 Visible light Quantum efficiency curve is given below. Typical phosphors and scintillator emit at about 550 nm, but this does vary.




**4.2 Pixel Defect spec**: No bad columns. Pixel responsivity: Non uniformity in bright frames will be within (at 390 nm Typical) [-15%, +20%]. This applies to all pixels, excluding the first 3 and last 3 columns and first 3 and last 3 lines. The following exceptions are allowed: Up to 500 pixels could be defined as blemishes. A blemish is defined as a pixel, which gives a signal within -50% of the average signal. Any pixel outside the [- 50%,+20%] range will be considered a defect pixel. Up to 50 defect pixels are allowed that fall outside the blemish requirements. For each blemish pixel, the average of 8 Nearest Neighbors will not be less than 45% of the overall average.

The camera consists of four internal printed circuit boards into a fifth mother board, or focal plane array board.

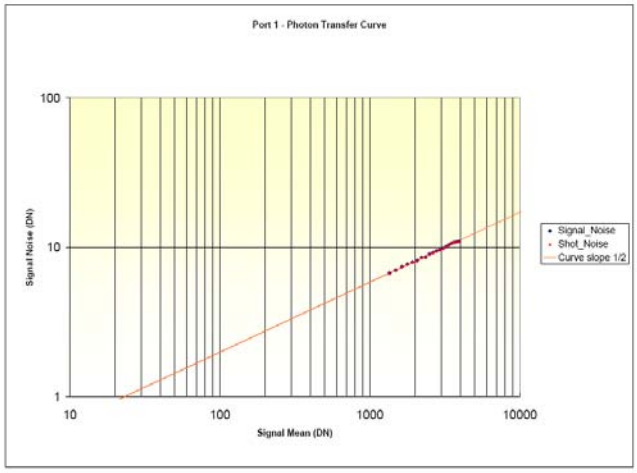
## 4.3 **TYPICAL CAMERA NOISE DATA**:

This data was taken by the manufacturer, running at the full frame rate (about 100 fps). We provide this as backup to the specifications listed above.

PhotonTransfer

| Port 1 - PTC DATA | | | | | |
|---|---|---|---|---|---|
| Exp Time (ms) | Signal_Mean | Signal_Noise | Read_Noise | Shot_Noise | Signal_Variance |
| 10 | 1352.051 | 6.751 | 0.763 | 6.708 | 45.579 |
| 15 | 1490.445 | 7.039 | 0.861 | 6.998 | 49.554 |
| 20 | 1634.471 | 7.443 | 0.87 | 7.404 | 55.399 |
| 25 | 1778.736 | 7.739 | 0.733 | 7.701 | 59.889 |
| 30 | 1923.315 | 7.995 | 0.793 | 7.958 | 63.913 |
| 35 | 2067.63 | 8.176 | 0.709 | 8.14 | 66.844 |
| 40 | 2212.095 | 8.567 | 0.787 | 8.533 | 73.387 |
| 45 | 2356.018 | 8.598 | 0.787 | 8.564 | 73.922 |
| 50 | 2499.323 | 9.06 | 0.912 | 9.027 | 82.079 |
| 55 | 2642.859 | 9.271 | 0.823 | 9.239 | 85.945 |
| 60 | 2786.001 | 9.487 | 0.82 | 9.456 | 89.997 |
| 65 | 2930.738 | 9.672 | 0.804 | 9.642 | 93.551 |
| 70 | 3074.484 | 9.843 | 0.803 | 9.813 | 96.876 |
| 75 | 3219.383 | 10.142 | 0.894 | 10.113 | 102.857 |
| 80 | 3364.492 | 10.402 | 0.89 | 10.374 | 108.206 |
| 85 | 3508.592 | 10.699 | 0.783 | 10.672 | 114.474 |
| 90 | 3653.248 | 10.84 | 0.783 | 10.813 | 117.496 |
| 95 | 3797.131 | 10.933 | 0.787 | 10.906 | 119.52 |
| 100 | 3942.63 | 10.965 | 0.735 | 10.939 | 120.238 |

| Adjust Best Fit Line for Slope = 1/2 | | |
|---|---|---|
| e-/DN = | 23 | <= Adjust this |
| Slope= | 0.5 | <= Until this is 0.5 |
| | | |
| Camera System Inputs: | | |
| ASIC Gain = | 2 | |
| Signal Attenuation= | 1 | |
| Dark Offset (DN) | 5 | |
| **Gain Constant** | | |
| K (e-/DN): | 23 | |
| **Sensitivity** | | |
| CCD Sensitivity (uV/e-) | 10.6 | |
| **Read Noise** | | |
| Ave Read Noise (DN) | 0.8 | |
| Ave Read Noise (e-) | 19 | |
| **Dynamic Range (SNR)** | | |
| SNR | 5042 | |
| SNR (dB) | 74 | |

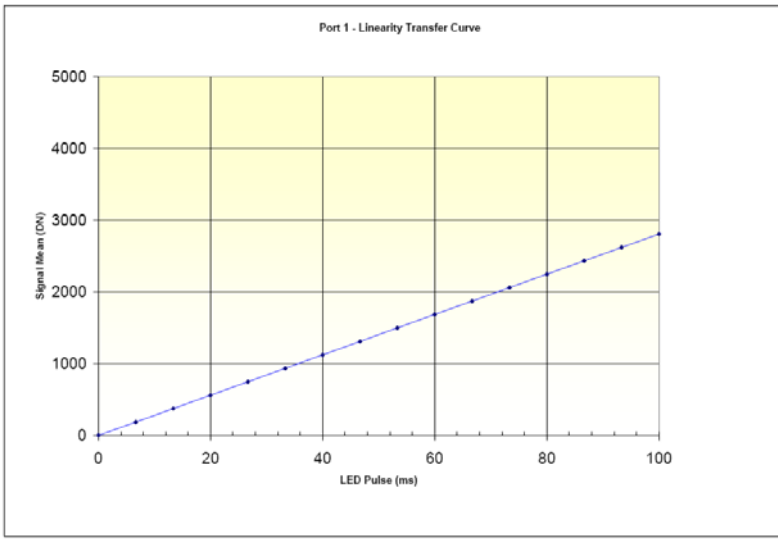


## 4.4 TYPICAL CAMERA LINEARITY DATA: This data was provided by the manufacturer, and serves as backup to the specifications listed above.

| Non-Linearity | |
|---|---|
| Non-linearity (%) | 0.26 |

| Port 2 - Linearity Data | | | |
|---|---|---|---|
| LED Pulse (ms) | Signal_Mean | Best Fit Line | Deviation |
| 0 | 1.743 | 2.49 | -0.75 |
| 6.66668 | 197.775 | 200.73 | -2.95 |
| 13.33332 | 396.939 | 398.97 | -2.03 |
| 20 | 596.211 | 597.21 | -0.99 |
| 26.66668 | 794.371 | 795.44 | -1.07 |
| 33.33332 | 993.69 | 993.68 | 0.01 |
| 40 | 1192.049 | 1191.92 | 0.13 |
| 46.66668 | 1391.217 | 1390.16 | 1.06 |
| 53.33332 | 1590.399 | 1588.40 | 2.00 |
| 60 | 1789.416 | 1786.63 | 2.78 |
| 66.66668 | 1986.993 | 1984.87 | 2.12 |
| 73.33332 | 2185.931 | 2183.11 | 2.82 |
| 80 | 2384.466 | 2381.35 | 3.12 |
| 86.66668 | 2581.472 | 2579.59 | 1.89 |
| 93.33332 | 2779.257 | 2777.82 | 1.43 |
| 100 | 2976.897 | 2976.06 | 0.83 |
| 106.66668 | 3173.06 | 3174.30 | -1.24 |
| 113.33332 | 3369.612 | 3372.54 | -2.93 |
| 120 | 3564.547 | 3570.78 | -6.23 |

| m |
|---|
| 29.73571799 |
| b |
| 2.49086775 |



# 5.0 USERS GUIDE:

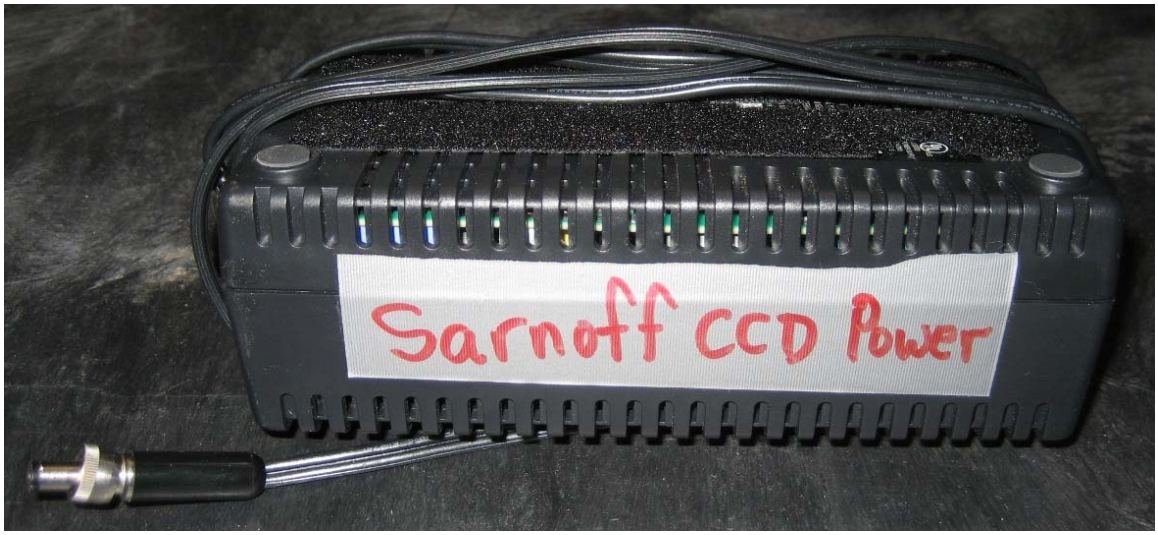
## 5.1 OVERALL CAMERA SYSTEM –

Camera (no lens attached, just the aluminum mounting bracket).


Rear view of camera.


Items of interest:
(1)Note the trigger IN connector (SMB I think, anyway don't loose this cable!). This goes back to the control/interlock box.
(2) The DB9 connector on top right is for the TEC, which really can only be used if dry gas is set up on the CCD/lens, and the water chiller.
(3) There is a connector for the dry gas N2 in (top/middle), and vented out.
(4) There are water in/out connections on the bottom middle.
(5) And finally on the bottom there are the two camera link data output ports. Cable these to the frame grabber, wire 1 to input 1, wire 2 to input 2, as labeled.

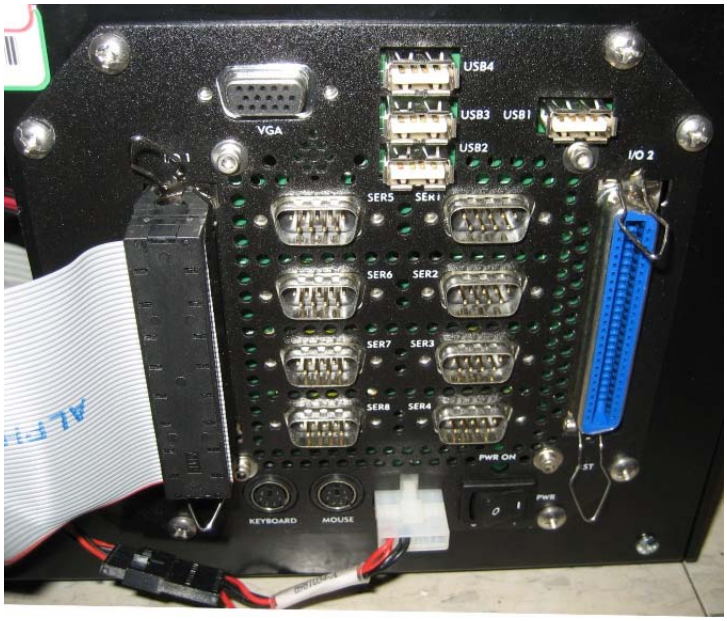
Sarnoff Power Supply




Water Chiller (on cart)


Interlock system


E-BRICK




X-ray Shutter

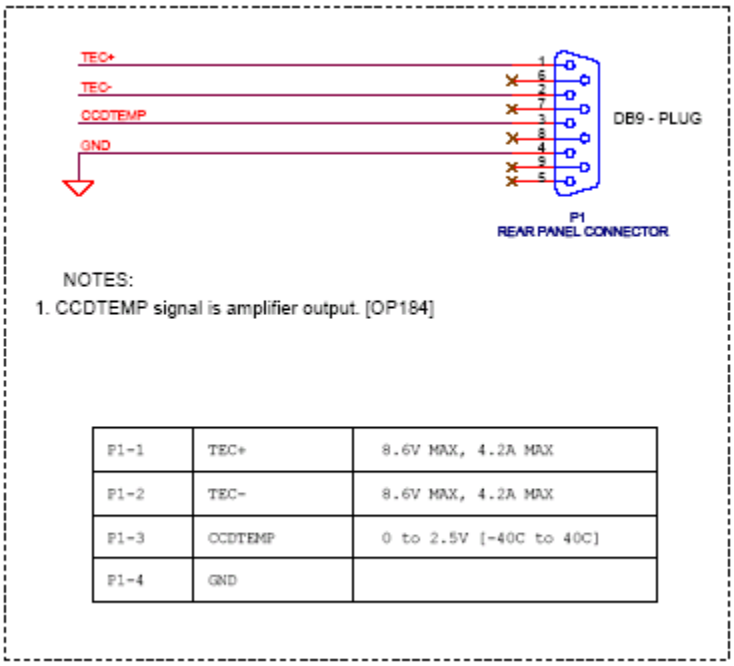

Shutter Controller


# APPENDIX. SUPPLEMENTAL INFORMATION.

**THERMO ELECTRIC COOLING SYSTEM.** There is a DB9 connector on the side of the camera which allows the user to input current for the TEC system, and to read out the camera's temperature. See TEC Interface Drawing.pdf, the interface to the thermo electric coolers:

(email 5/26/2005)

- TEC Interface (see attached drawing)
- TEC data:
- Mode: spectroscopic (128_bin)
- Frame period: 200us
- Twater: 20C
- CCDTEMP=1.25V (0C); Vtec=1.3V, Itec=0.6A
- CCDTEMP=0.94V (-10C); Vtec=2.6V, Itec=1.2A
- CCDTEMP=0.62V (-20C); Vtec=4.4V, Itec=2.2A
- CCDTEMP=0.33V (-30C); Vtec=7V, Itec=3.6A




| | | |
|---|---|---|
| P1-1 | TEC+ | 8.6V MAX, 4.2A MAX |
| P1-2 | TEC- | 8.6V MAX, 4.2A MAX |
| P1-3 | CCDTEMP | 0 to 2.5V [-40C to 40C] |
| P1-4 | GND | |

## ANL SUPPLIED COMPUTER:

SOFTWARE.
We are currently using Sarnoff supplied software which can only take and store one image at a time. This software needs to be replaced by Brian Tieman-like software. This is under development.

**SOFTWWARE AND CONTROL, and FIRMWARE.** Sarnoff will provide a C++ based SDK **(optional)** for software control of the camera system. The camera will have multiple clocking "modes" of operation, including a spectroscopy thin strip exposure mode.

HARDWARE.

(Ref: Tad's email of 6/2/2005). We purchase a computer with faster SCSI disks. It will run Windows XP, but could run LINUX etc. Inside this computer is a camera-link based Coreco frame grabber.

| Item / description | Part no. | Unit price | Quantity | Ext.price |
|---|---|---|---|---|
| » **HP Workstation xw4200 Microsoft® Windows®** | Base | $4,380.01 | 1 | $4,380.01 |
| HP Workstation xw4200 | DU936AV | | | |
| Microsoft® Windows® XP Professional | DY527AV#ABA | | | |
| Intel® Pentium® 4 3.80GHz/1MB 800FSB w/EM64T | DY536AV | | | |
| ATI FireGL V3100 128MB PCI-E | PE950AV | | | |
| 2GB (4x512) DDR2-533 ECC unb | PB340AV | | | |
| 146GB U320 SCSI 15K (1st) | DY556AV | | | |
| 146GB U320 SCSI 15K (2nd) | DY568AV | | | |
| 16X DVD+/-RW, DL, LightScribe, Win (1st) | PR509AV | | | |
| U320 SCSI Controller - no RAID, no external connector | DZ541AV | | | |
| Floppy Disk Drive | DY569AV | | | |
| HP PS/2 Standard Keyboard | DY577AV#ABA | | | |
| HP USB Optical Scroll Mouse | DY581AV | | | |
| HP xw4200 Localization kit | DY526AV#ABA | | | |
| Symantec Norton Antivirus 2004 | DY588AV#ABA | | | |
| **Warranty** 3/3/3 (parts/labor/next business day on-site) limited warranty | | | | |
| | | | **Cart Total:** | **$4,380.01** |

## CORECO FRAME GRABBER (PCI bus, into above computer).

X64-CL-Full_Dsheet_web_March04.pdf

### Specifications*

| | |
|---|---|
| **Board** | Half length PCI 2.1 64-bit 66MHz compliant<br>5V and 3.3V slot compatible |
| **Acquisition** | Acquisition rates: up to 680MB/s<br>Horizontal Size (min/max): 8 byte/256KB<br>Vertical Size (min/max):<br>Linescan cameras: 1 line to Infinity<br>Area scan cameras: 1 line to 16 million/frame<br>variable length frames<br>Onboard frame buffer memory up to 2GB (32MB standard)<br>One 1024 x 1024 or 1024 x 256 input lookup table[2]<br>Single slot solution supports 1 Medium, 1 Base or 2 synchronized Base Camera Link cameras<br>Interfaces to digital area scan or linescan color or monochrome cameras<br>Supports standard multi-tap Camera Link configurations:<br>1 Full cameras: 8 x 8-bit<br>1 Medium cameras: 4 x 8-bit, 4 x 10-bit, 4 x 12-bit, 1 x 30-bit/RGB and 1 x 36-bit<br>1 Base cameras: 3 x 8-bit, 2 x 10-bit, 2 x 12-bit, 1 x 14-bit, 1 x 16-bit, and 1 x 24-bit/RGB<br>Alternate multi-tap Camera Link configurations support: 4 x 14-bit, 4 x 16-bit, 1 x 48-bit or 1 x 64-bit |
| **Pixel Formats** | Monochrome 8, 10, 12, 14, 16, or 36-bit/RGB |
| **Transfers** | Real-time transfers to system memory:<br>PCI-32 bus: 32 bits @ 33MHz<br>PCI-64 bus: 64 bits @ 66MHz<br>PCI-X bus: 64 bits @ 66MHz<br>On-the-fly tap adjustments for multiple tap area scan and linescan cameras |
| **Controls** | Comprehensive event notification includes start/end-of-frame, sequence or N-line events<br>One independent TTL/LVDS trigger input programmable as active high or low (edge or level trigger)<br>One strobe TTL output for area scan and linescan cameras<br>One PC independent RS-232 COM port provides seamless interface to MS Windows applications<br>Quadrature (AB) shaft-encoder inputs for external web synchronization; supports cascaded divide and multiply<br>Up to 12 interrupt driven I/Os[3] permit external event synchronization |
| **Power Output** | Power-on-reset fused +12V/+5V DC output at 1.5A |
| **Software** | Microsoft Windows NT 4.0, Windows 2000, and Windows XP compliant<br>Full support of the Sapera programming package<br>Compatible with Microsoft Visual Studio 6.0 and .Net (unmanaged code only), Visual Basic 6.0 and Borland C++ Builder 5.5 or higher |
| **System Requirements** | PCI-64 or PCI-32 compliant system and 64MB system memory |
| **Dimensions** | 8.27" (21cm) Length x 4.20" (10.7cm) Height |
| **Temperature** | 0° C (32° F) to 55° C (131° F)<br>Relative Humidity: up to 95% (non-condensing) |
| **Markings** | FCC class B - approved<br>CE class B - approved |

* Data updated April 2004

**Notes:**

1. Please contact Coreco Imaging for more information on these formats
2. For 8 x 8bit/tap or 8 x 10bit/tap maximum
3. Optional module requires auxiliary slot

CORECO iMAGING

## SHUTTER

Strictly speaking, the shutter really is the beamline's "problem", we do not adequately support this part of CCD cameras yet. To allow testing in my lab, I purchased a Uniblitz x-ray shutter capable of fast bursts. We know that this shutter is not perfect for beamlines, and we can discuss.

### XRS6 SHUTTER SPECIFICATIONS

Page 1 of 2

**Vincent Associates** 803 Linden Avenue, Rochester, NY 14625
**web** www.uniblitz.com **e-mail** vincentassociates@uniblitz.com **toll-free** 800.828.6972

UNIBLITZ® BY VINCENT ASSOCIATES

#### FEATURES

- 6mm diameter aperture
- Pt-Ir shutter blade, capable of blocking x-ray energy up to 30Kev.
- Exposure repetition rate continuously variable from DC-50Hz.
- Electronic synchronization system included.
- Activated by an electronic pulse through *UNIBLITZ*® patented shutter drive systems.
- Non-resonant design allows instantaneous changes in repetition rate and duty cycle.
- No optical surface when open provides 100% transmittance

The *UNIBLITZ*® XRS6 series is especially designed for x-ray applications. The innovative blade design allows beam extinction >$10^4$ up to 30Kev x-ray energy. The XRS6 shutter is well suited for specific x-ray applications such as x-ray crystallography and can open within 3.2msec at a maximum rate of 50 exposures per second. Precision control and reliability can be expected as with all *UNIBLITZ* products.

This shutter is programmable, and is activated by an electronic pulse generated by Vincent's patented *UNIBLITZ* drive systems. The shutter will follow this pulse, which allows the user to program the exposure duration and frequency.

The XRS6 has a 6mm clear aperture and equipped with the electronic synchronization system. A vacuum compatible version is also available, please consult customer service for further information.

#### ELECTRICAL

| | |
|---|---|
| Coil Resistance | 12 ohms |
| Pulse Voltage to Open | +65VDC |
| Hold Voltage[1] | +5VDC |

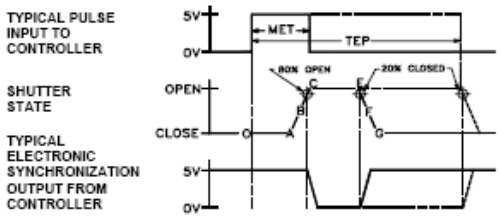
#### MECHANICAL

| | |
|---|---|
| Wgt. Un-Cased | 1.20 oz (.03 kg) |
| Wgt. Cased | 7.46 oz (.21 kg) |
| Operating Temp. | 0°C to +80°C |
| Max. Opening Bounce | 15% |
| Max. Closing Bounce | 5% |
| Max. Frequency of Operation (CONT/BURST)[2] | 10 Hz / 50 Hz |
| Number of Blades | 1 |

#### TIMING

Typical timing values (msec.) using UNIBLITZ drive equipment and measured with UNIBLITZ shutters equipped with .010" Ptlr shutter blades.

TIMING OF PULSE INPUT AND SYNCHRONIZATION OUTPUT RELATIVE TO SHUTTER STATE




(Timing in msec.)

| | |
|---|---|
| O-A Delay time on opening after current is applied | 1.2 |
| A-C Transfer time on opening | 3.2 |
| O-C Total opening time | 4.4 |
| B-F Min. equivalent exp. time | 5.6 |
| C-E Min. dwell time with min. input pulse | 2.0 |
| E-G Transfer time on closing | 3.8 |
| A-G Total window time | 5.0 |
| MET: Min. exposure time | 6.4 |
| TEP: Typical exposure pulse | >6.4 |

The question regarding enhancement of shutter speed with the application of user supplied lubricants has been repeatedly asked. It is our experience that lubricating the shutter blades will actually slow the shutter down and eventually render the shutter inoperable. UNDER NO CIRCUMSTANCES SHOULD ANY TYPE OF LUBRICANT BE APPLIED TO THE SHUTTER BLADE AREA.

#### PRODUCT OPTIONS

XRS6S 2 P 0 -100

| APERTURE SIZE | HOUSING | BLADE FINISH | ELECTRONIC SYNCHRONIZATION | MOUNTING OPTIONS |
|---|---|---|---|---|
| XRS6S - 6mm | 1 - UNCASED<br>2- #2 CASE | P - .010" THICK PtIr (10% IRIDIUM, 90% PLATINUM) | 0 - OMIT SYNC.<br>1 - ELECTRONIC SYNC. | - 21 ZEISS ASCOVERT TYPE<br>- 22 OLD STYLE NIKON TYPE<br>- 23 OLYMPUS TYPE<br>- 24 OLYMPUS TYPE<br>- 26 LEICA TYPE<br>- 27 NIKON TYPE<br>- 28 OLYMPUS IX TYPE<br>- 29 NIKON TYPE<br>- 30 LEICA TRANSMITTED TYPE<br>- 31 NIKON/CONFOCAL TYPE<br>- 32 NIKON BX TYPE<br>- 100 MOUNTING RING<br>- 105 C-MOUNT ADAPTER (MALE)<br>- 106 C-MOUNT ADAPTER (FEMALE)<br>- 110 T-MOUNT ADAPTER |

[1]Voltage level required across actuator coil when being held in the open position.
[2]CONTinuous frequency rating specified at shutter's minimum exposure pulse. BURST frequency rating specified for (4) four seconds maximum with (1) one minute minimum between bursts. Frequency measurements are taken in free air, 25° C ambient, actuator coil equipped with heat sink. For additional information on maximum sustained frequencies obtainable, please contact one of our technical represen-

## DIGITAL FRAME GRABBER:

(1) Coreco X64-CL-FULL, frame grabber, with on-board 2GB, 85 MHZ (see below)
(2) Coreco Sapera Lite Software
(3) High end PC Computer, running WindowsXP, with fast SCSI disks, see spec's below.
(4) Water Chiller, Model Thermo-Electron/Neslab Merlin series M-25, part number 262 112 030 000, high temperature audible alarm, temp range +5 to +35C, cooling 810 watts at 20 C, pump PD-1, 1.5 gpm at 60 psi, temp stability 0.1C, power from 110 VAC.
Pump: www.thermo.com/com/cda/product/detail/1,1055,1000001155234,00.html
Thermo Electron Corp/ Neslab phone (603)430 2297, fax (603)436-8411, Attn: Scott.
(5) DC power source (greater than 2 amps) for the TE cooler.
(6) To monitor the temperature Argonne will supply a digital meter (similar to a DVM).

# OPTICS.

Need to discuss typical lens tube – microscope objective then imaging lens, essentially a microscope. C mount. Same as CoolSnap, but someday might modify to include a fast shutter. I have researched shutters, and rejected 2 so far, settling on the UniBlitz.

Emil Trakhtenberg modified the tube lens to allow focus. I have the drawings. Tube lens was supplied by Desna Laboratories (914) 948 9502, see “Tube lens quote.PDF”