CONF-9309256--2
ANL/XFD/CP-80856

A VXI-Based High Speed X-ray CCD Detector

Qiang Huang, Ron Hopf, and Brian Rodricks

Advanced Photon Source

Argonne National Laboratory

Argonne, IL 60439

Abstract

For time-resolved x-ray scattering, one ideally wants a high speed detector that also is capable of giving position sensitive information. Charge Coupled Devices (CCDs) have been used successfully as x-ray detectors. Unfortunately, they are inherently slow because of the serial readout. EEV has developed a CCD that has eight channels of parallel readout, thus increasing the speed eight fold. Using state-of-the-art VXI electronics, we have developed a readout system that could read the entire array in 2.5 ms using a 20-MHz readout clock. For testing and characterization the device was clocked at a significantly slower speed of 30 kHz. The data is preamplified and all eight channels of output are simultaneously digitized to 12 bits and stored in buffer memory. The system is controlled by a 486-based PC through an MXI bus and VXI controller using commercially available software. The system is also capable of real-time image display and manipulation.

DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

MASTER

DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED

Introduction

Until now, high-speed time-resolved x-ray studies have been both flux and detector limited. There are not enough commercially available x-ray detector systems capable of very high speed data acquisition and collection. Further, there are not many beamlines at x-ray synchrotron sources that have the brilliance necessary to perform experiments at high speed on extremely small samples. Using the pump-probe technique, laser annealing of a sample of silicon was performed with nanosecond time resolution [1]. In this experiment, the time resolution was defined as the time between the laser pulse and the x-ray beam. Others have done single bunch x-ray scattering from a protein sample [2] during a special run on the Cornell Electron Storage Ring (CESR) when an undulator was installed in the straight section of the storage ring [3]. This increased the brilliance from the ring, thus enabling this sort of extremely important experiment to be performed. At the National Synchrotron Light Source (the only dedicated hard x-ray synchrotron source of its kind in operation), a few insertion devices, namely wigglers and undulators, have been inserted in straight sections of the storage ring, thus enhancing the flux available for novel experiments.

Currently, the European Synchrotron Radiation Facility (ESRF) and the Advanced Light Source (ALS) are operational and undergoing diagnostic testing. Within the next few years, the Advanced Photon Source (APS) and Super Photon Ring (SPring) will be operational. All these machines are high-brilliance third-generation insertion-device-based synchrotron-

radiation sources. These new sources are going to make it possible to perform experiments that until now have been impossible.

Unfortunately, although the brilliance has increased significantly from synchrotron sources, detector research has not been as successful. Ideally for time-resolved x-ray studies, one would like a position-sensitive detector that has high dynamic range ($>10^3$), good position information (100 μm), good quantum efficiency ($>50\%$) and high time resolution ($>10^{-3}$ secs). There are many detector systems that have a few of these characteristics but not all.

Charge Coupled Devices (CCDs) have successfully been used for x-ray applications in the past [4,5,6]. They are still being investigated for use in large area detectors with front ends composed of a fiber-optic taper and/or with image intensifiers and lenses (see paper on large area detectors in this edition). Unfortunately, the sequential readout of a CCD limits its readout speed [7]. A 512 x 512 device readout consists of an image transfer clock followed by a minimum of 512 serial transfer clocks. This pattern is repeated 512 times to read out the entire device. A typical CCD has one serial register and one on-chip amplifier. It is obvious from this that the readout is inherently limited by the serial readout of the output register. EEV, a subsidiary of The General Electric Company p.l.c. of England, has developed a CCD that can be read out in eight parallel channels. The EEV CCD has modified the device such that data is transferred in parallel to two serial registers and each serial register can be read out through four output amplifiers, thus the readout speed is increased eight fold. The technical specification for this device running at a 22-MHz rate

give a readout speed of 2.5 ms per frame. Compared to a typical CCD which has time resolution in the 500 ms or greater, 2.5 ms per frame is a significant improvement..

However, for certain kinds of time-resolved experiments, this speed is not fast enough. A major advantage of CCDs over image plates or photographic film is the resulting digital data that is available immediately for analysis or diagnostic purposes. With a premium paid on synchrotron beam time, this turns out to be a tremendous advantage.

Electronic Control System

Scientific CCDs are devices that need to have their parameters tuned for low noise and/or high speed applications. The readout of such a device requires fast and flexible control electronics. This kind of fast and flexible control coupled with a high speed data acquisition system for CCD-based detector systems must generally be custom designed. Further it must be designed such that it can be adapted to devices with slightly varying characteristics and be able to readout more channels if needed. The general problem with scientific CCDs is that the chip manufacturers do not get involved in the electronics necessary to readout and control such a device. They only specify the characteristics for their devices. Companies that develop electronics for CCDs do so for the consumer market, namely video cameras, and not scientific applications. As a result, all electronics for scientific applications must be customized.

To develop a fast flexible readout and control system, we designed a system based on state-of-the-art VXI [8,9] architecture. Figure 1 shows the general architecture of the system.

There are six major components that comprise the system. They are 1) a set programmable waveform generator to provide the necessary complex wave patterns for a particular CCD chip, 2) a vacuum chamber with cooler and header board that serves as a chip mounting interface with wave drivers and signal output; 3) a signal conditioner for shifting and amplifying the signals from CCD outputs 4) a set of high speed A/D converters for acquisition images from the CCD 5) Random Access Memory (RAM) for storing the images without needing to transfer them to the hard disk, and 6) software to control and synchronize the whole system.

The electronics system designed to control the CCD is VXIbus-based. In essence, VXI combines the best technology from GPIB instruments, modular plug-in data acquisition boards, and a modern computer-VMEbus standard. Like GPIB, VXI offers a wealth of sophisticated instruments from a wide variety of the world's leading instrument vendors. A general VXI system consist of a VXI crate with plug-in boards all interconnected through a computer backplane. VXI offers modularity, flexibility, and high performance. Because VXI combines a sophisticated instrument environment with a modern computer backplane, VXI instruments have the ability to communicate at very high speeds using the best techniques of both GPIB instruments and plug-in data acquisition board. VXI systems are used in a wide variety of traditional test and measurement applications, as well as data acquisition and control systems. The modular form of VXI instruments which reduce instrumentation system physical size, have tight timing, and a faster transfer rate, and synchronize multiple instruments, is an ideal platform for developing a flexible CCD control and readout system.

A set of complicated, synchronized waveforms needed to readout and control a CCD is generated by Wavetek's new 50 MHz arbitrary waveform generator modules. These programmable modules can generate time-critical, complex waveforms up to 50 MHz (with a rise time less than 9 ns) and high output potential (30V peak-to-peak). They can produce multiple outputs with precise time/phase relationships and capitalize on the VXI features such as SUMBUS and local Bus to produce a spectrum of signal outputs. The whole CCD13 readout and control system consist of eight modules of Wavetek's 1395 arbitrary waveform generator modules. They will produce eight channels of high speed, high output potential and completely synchronized waveforms required to control and readout the eight channel CCD13 device. Figure 2 shows the clocking waveforms generated for CCD13 by these modules.

The electrical signals generated by the CCD must first be converted into a form that data acquisition modules can accept. Eight wide-band-biased amplifiers, with the maximum voltage swing equal to the maximum input voltage of the A/D converter, amplify the output from each channel. The bias adjust provides 20 fine turns for about a 3 V adjustable range. These amplifiers are placed close to the CCD in order to minimize interference due to noise pick up on the line between the CCD and the data acquisition/readout system.

The A/D converter is the KSC-V425 from KeneticSystem Corporation. This is an eight channel digitizer with sample rates of 30 Ksa/s and 12-bits resolution. The amplified output from biased amplifiers is then directly fed into the digitizer. This digitizer is not very fast but helps us understand the behavior of the CCD. Also on the VXI crate are two 128-

Mbyte memory modules that are available to store the data from the digitizer. This should minimize the time it would take to transfer the data to the hard disk on the control computer.

The VXI controller is a VXI-AT2000 interface kit from National Instruments Corporation, which links a PC AT computer directly to the VXIbus. The system software is NI-VXIbus interface software from National Instrument Corporation. It is a comprehensive software package for configuring, programming, and troubleshooting a VXI system. NI-VXI features intuitive tools for interacting with VXI, comprehensive high performance routines for programming VXI using industry-standard programming languages, multiple-mainframe-configuration capability and software compatibility across a variety of operating systems, embedded, and MXI-equipped VXI controller platforms. Software developed with NI-VXI can execute on both external and embedded VXI controllers. The software is available for a variety of hardware platforms including the embedded VXIpc-486 series, VXIcd-030, and MXI-equipped PC AT, EISA, PS/2, Macintosh, Sun SPARC station, IBM RS/6000, and DEC station 5000 computers running a variety of operating systems including DOS, Windows, OS/2, Macintosh, UNIX, and real-time operating systems. We can choose whichever platform makes the most sense for our development needs and for our final system configurations.

The application software tools are Labwindows, which provide power tools for programming. An extensive library and complete high level instrument drivers are available for popular VXI instruments, which will help with rapid prototype development, and operation of the systems. The colorful user interface allows users to change operational parameters easily and displays the real-time images.

The system, because it uses a set of arbitrary waveform drivers, can be easily modified to suit various kinds of CCD chips. The modifications are achieved by simply loading another set of software and changing to another CCD mounting header.

Testing and Discussion

For testing purposes, we installed an industrial grade CCD13 from EEV. The device was cooled by means of a thermoelectric cooler to -40 deg C in a vacuum chamber fitted with a quartz window. An optical image of a fixed pattern was focused on the detector. Figure 3 is a postscript plot of one such image. No attempts were made to improve the quality of the image by means of a uniform light source or a good mask. The image being displayed is a raw image. This was the first attempt at testing the device and the intent was to demonstrate that it worked reasonably well. Attempts were made to smooth out the input waveforms so as to reduce the read noise. The figure does display the large number of bad columns that the device possessed. (Figure 4 is a cross section through a certain column of the device.)

We have demonstrated that the VXI-based electronics and control system work. The device can be read out from speeds as low as a few Hertz to 25 MHz. The integration time can be changed from a few microseconds to minutes and longer if necessary. We plan to improve the noise performance by using surface mounted CDS preamplifiers that will reside in the vacuum chamber. We also plan to cool the device with liquid nitrogen as our preliminary studies suggest that the dark current is reduced significantly as a function of decreasing temperature. One drawback to high speed data rate is the difficulty associated in the

storage. We are consulting with a company that will custom design an eight channel digitizer coupled to a RAM disk that can store 512 frames of data before it has to be transferred to hard disk.

Acknowledgments

Many thanks to Gopal Shenoy and Dennis Mills for their support in all our detector projects. Thanks to Cheryl Zidel for her assistance in everything. Thanks also to Susan Picologlou for editing the manuscript. This work supported by U. S. Dept. of Energy, BES-Materials Science, under grant contract No. W-31-109-ENG-38.

References

- [1] B. C. Larson, C. W. White, T. S. Noggle, and D. M. Mills, Phys. Rev. Lett. **48**(337) 1982.
- [2] D. M. E. Szebenyi, D. H. Bilderback, A. LeGrand, K. Moffat, W. Schildkamp, B. Smith Temple, and T. Teng, J. Appl. Cryst. **25**(1992), 414-423.
- [3] D. H. Bilderback, B. W. Batterman, M. J. Bedzyk, K. Finkelstein, C. Henderson, A. Merlini, W. Schildkamp, Q. Shen, J. White, E. B. Blum, P. J. Viccaro, D. M. Mills, S. Kim, G. K. Shenoy, K. E. Robinson, F. E. James, and J. M. Slater, Rev. Sci. Instrum. **60**(7) (July 1989) 1419-1425.
- [4] K. L. D'Amico, H. W. Deckman, J. H. Duunsmuir, B. P. Flannery, W. G. Roberge, Rev. Sci. Instrum. **60**(7), (July 1989), 1524.

- [5] R. Clarke, W. DosPassos, W. Lowe, B. G. Rodricks, and C. Brizard, Phys. Rev. Lett., **66** (3) (Jan 1991).
- [6] C. Brizard, B. Rodricks, E. Alp, and B. MacHarrie, J. Mater. Sci. **28**(1993) 1503-1508.
- [7] B. Rodricks, and C. Brizard, Nucl. Instrum. and Met. in Phys. Res. **A311** (1992) 613-619.
- [8] *The VMEbus Handbook*, VFEA International Trade Association, Scottsdale, AZ 85253.
- [9] *VXIbus, VMEbus Extensions for Instrumentation*, VFEA International Trade Association, Scottsdale, AZ85253.

Figure Captions:

Fig. 1 General architecture of the VXI control electronics for the detector

Fig. 2 Waveform timing and sequence needed to readout the device

Fig. 3 Image of a test pattern obtained using visible light as a source of radiation.

Fig. 4 Cross-section through a column of the image shown in Fig. 3

Fig 1

F192

1193

Fig 4

END

DATE

FILMED

12/20/93

END

**DATE
FILMED**

12/20/93