DEVELOPMENT OF AN X-RAY BEAM SIZE MONITOR WITH SINGLE PASS MEASUREMENT CAPABILITY FOR CESRTA*

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Abstract

The CESR Test Accelerator (CesrTA) program targets the study of beam physics issues relevant to linear collider damping rings. This endeavour requires new instrumentation to study the beam dynamics along trains of ultra low emittance bunches. A key element of the program has been the development of an x-ray beam size monitor (xBSM) capable of collecting single pass measurements of individual bunches in a train over thousands of turns. This instrument utilizes custom, high bandwidth amplifiers and digitization hardware to collect signals from a linear InGaAs diode array. The digitizer is synchronized with the CESR timing system and is capable of recording beam size measurements for bunches spaced by as little as 4ns. The x-ray source is a bending magnet with Ec=0.6keV during 2GeV CesrTA operations. For these conditions the amplifier dynamic range was optimized to allow measurements with 3e9 to 1e11 particles per bunch. Initial testing is complete. Data analysis and examples of key measurements which illustrate the instrument's performance are presented. This device offers unique measurement capabilities applicable to future high energy physics accelerators and light sources.

INTRODUCTION

At present two xBSM instruments have been installed in experimental areas of the Cornell High Energy Synchrotron Source (CHESS). Each setup has it's own x-ray source which is a bending magnet, within the Cornell Electron Storage Ring (CESR), with Ec=0.6keV during 2GeV CesrTA operations. A set of in-vacuum optics focuses the photon flux and directs it on to the detector. The geometry of the line provides an optical magnification factor of 2.34 for the positron line and 2.52 for the electron line. The first instrument capable of resolving 4 ns spaced bunches has been installed and tested in the electron line. This paper will focus on the design and capabilities of the data acquisition system used for this instrument. An overview of the system is provided in order to present a complete picture. The following figure shows the functional layout of the positron line. The electron line is a mirror image.

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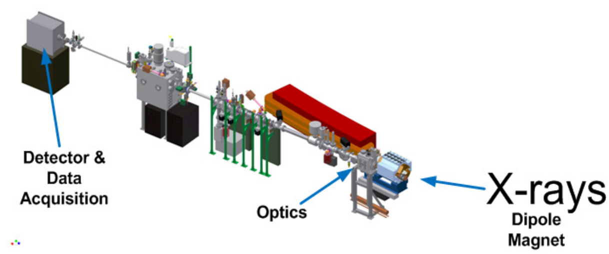

Figure 1: Layout of the xBSM positron line.

OPTICS

Three unique optical elements are provided for focusing the photon flux, a vertically limiting slit, a Fresnel zone plate and a coded aperture. The different elements can be moved into the beam path remotely.

The vertically limiting slit is used as a pinhole lens for beam sizes greater than 16 µm. It is largely insensitive to wavelength within the synchrotron radiation spectrum.

The Fresnel zone plate provides a diffractive image and in theory can provide a central peak with a width of one detector diode for the smallest beam size.

The image provided by the coded aperture is a combination of diffraction and transmission. This provides multiple peaks which can be used to determine the beam size. Theoretically these optics provide more resolving power and allows the measurement of beams as small as 10 µm. All of the optics elements are discussed in more detail elsewhere [1].

DETECTOR

The detector is a vertical array of 32 InGaAs diodes with a 50µm pitch and horizontal width of 400 µm. The InGaAs layer is 3.5 µm thick, which absorbs 73% of photons at 2.5keV; there is a 160nm Si_3N_4 passivation layer. The time response of the detector is sub-nanosecond.

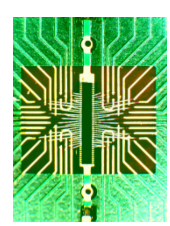

Figure 2: Diode detector.

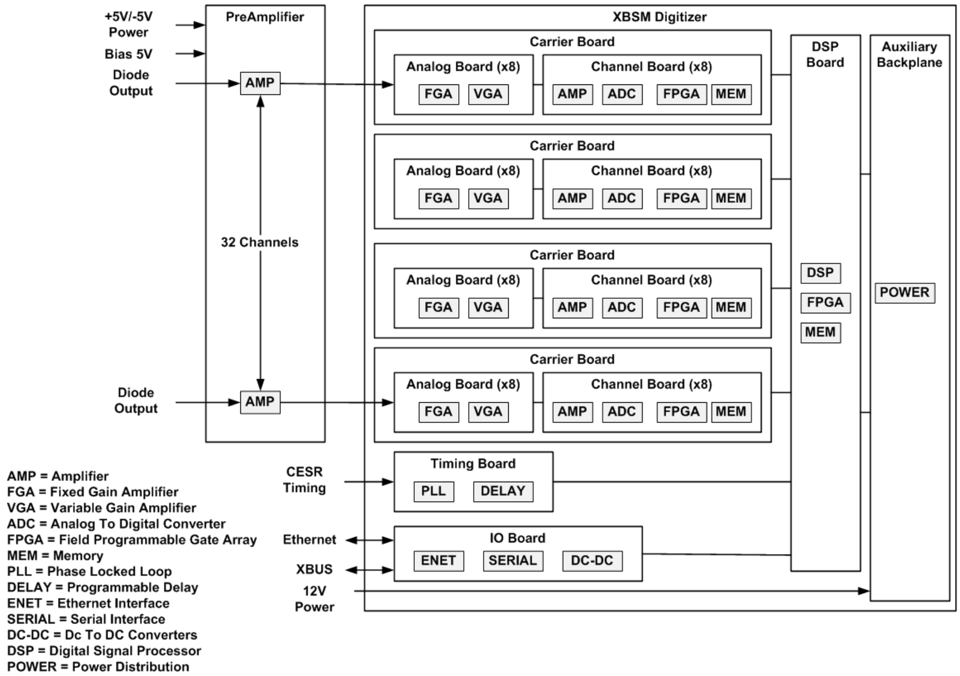

Figure 3: xBSM data acqusition system architecture.

ARCHITECTURE

The data acquisition system used in the xBSM is a collection of custom designed hardware and software. This design uses a modular approach and occupies space both inside and outside of the detector box. Figure 3 presents an overview of this system.

The signals from the diode detector are received, amplified and converted to differential signals prior to being delivered out of the detector box in bundles of 8 channels of twin-axial cable.

The bundle of 8 differential signals is received by a carrier board which contains 8 channels of signal conditioning and digitization. Each channel provides 12 dB of fixed gain and -4 dB to 20 dB of digitally controllable gain. Figure 4 shows the functional blocks of a single channel's signal chain.

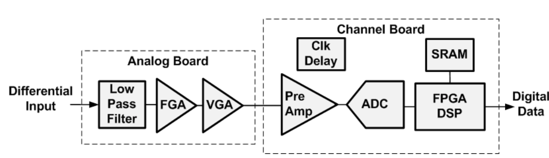

Figure 4: xBSM signal chain.

A 300 MSPS, 10 bit analog to digital converter is utilized to provide the capability of digitizing 4 ns spaced bunches. The data from the converter is streamed through a local FPGA and is stored locally for each channel in an 18 Mbit SRAM. This allows for 1 million samples to be captured on each channel (without data compression). Each channel receives its own sampling clock and has an in-channel configurable delay to allow for channel to channel synchronization, as described below. Figure 5 shows an 8 channel carrier board module assembled.

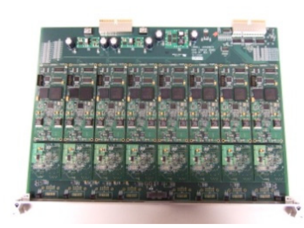

Figure 5: Assembled carrier board.

The digital data from each channel is funnelled into the digital signal processing board. This board allows for on-instrument processing and data manipulation. It also provides the link to the ethernet interface which is contained on the io board. All controls and data retrieval are accomplished via the ethernet interface. A diagnostic interface is provided via a serial fieldbus (XBUS) connection on the io board. Power is delivered to the various boards via the auxiliary backplane.

MACHINE TIMING AND SYNCHRONIZATION

The xBSM is synchronized to the CESR accelerator timing system via a 24 MHz encoded data signal provided from the CESR timing system. This signal is synchronized to the CESR RF system and also contains revolution markers (turn markers) as well as acquisition triggers. This same signal is also delivered to all of the storage ring beam position monitors. This allows for synchronized turn by turn measurements between the two systems.

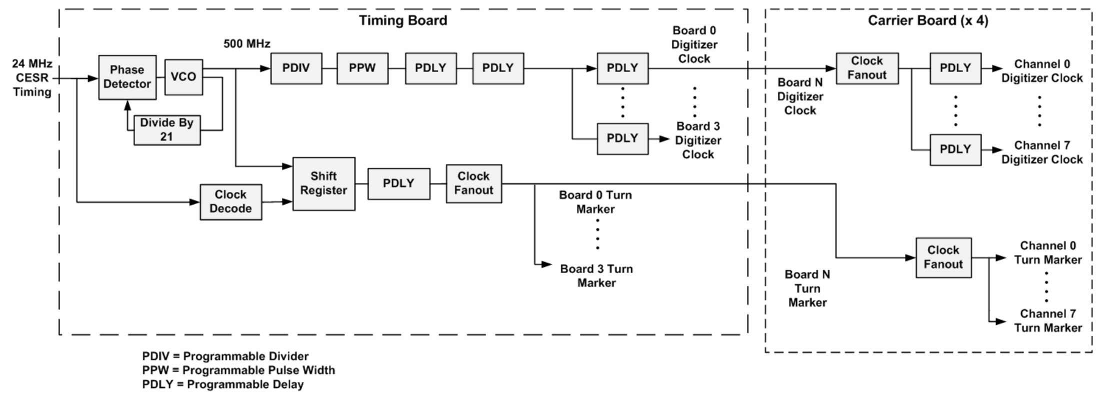

Figure 6: xBSM timing system.

XBSM INTERNAL TIMING

An overview of the internal timing control and distribution is provided in Fig 6. The 24MHz encoded signal is received by the timing board. This signal is used to synchronize an on board voltage controlled oscillator which generates a 500 MHz source clock. This clock drives a programmable divider with a programmable pulse width to provide a fully configurable sampling clock. The sampling clock passes through a series of programmable delays prior to being fanned out to each of the four carrier boards. Each carrier board then fans the clock out to the 8 sampling channels. Every channel has its own programmable delay which allows for precise adjustment of the sample point.

The timing board also extracts the turn marker from the 24 MHz encoded signal. The turn marker then passes through its own set of programmable delays and is fanned out to all 4 carrier boards where it is delivered to the individual channels. Each channel can then be synchronized to the accelerator revolution frequency. The digitizers run continuously and a bunch pattern is provided to all channels and serves as a gating signal which determines when the sample is to be stored in the local SRAM.

MEASUREMENTS

During CesrTA machine studies periods, 4 ns spaced bunches have been measured. The digitizers can be run in in waveform capture mode by shifting the sample time of subsequent measurements in 10 ps steps. This method was used to determine the level of bunch to bunch signal crosstalk. Figure 7 shows the digitized signal of two 4 ns spaced bunches of electrons:

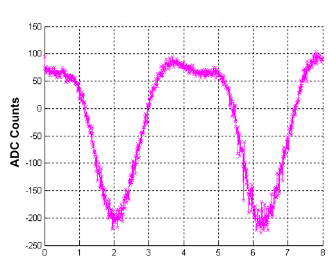

Figure 7: 4 ns spaced electron signals.

Measurements of beam sizes have been undertaken by the 4 ns system under 2GeV electron conditions. All three optics elements have successfully been imaged. The data collected is analyzed using Matlab. Currently, the analysis tools allow for turn-by-turn fitting of the images produced by the vertically limiting slit. Pedestal subtraction and gain scaling of the raw data is available. Figure 8 shows a single turn, single bunch beam image. Each bin represents the current in one of the 32 detector diodes.

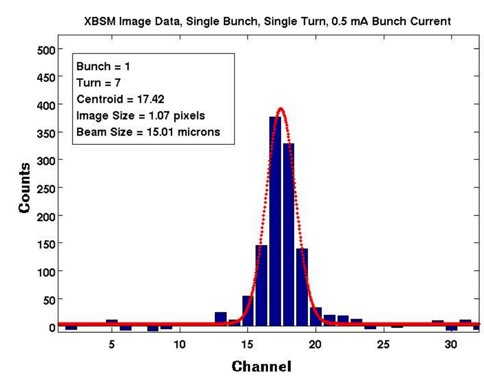

Figure 8: Vertically limiting slit image.

SUMMARY

The development of the 4 ns capable xBSM has provided a useful tool for studying beam dynamics. The 4 ns instrument has been tested during CesrTA machine studies and has proven accurate and useful. Future efforts will focus on data analysis and presentation.

REFERENCES

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