ISBN: 978-3-95450-132-8 doi:10.18429/JACoW-IPAC2014-THPME113

COMMISSIONING OF AN ULTRA-FAST DATA ACQUISITION SYSTEM FOR COHERENT SYNCHROTRON RADIATION DETECTION

M. Caselle*, M. Brosi, S. Chilingaryan, T. Dritschler, E. Hertle, V. Judin, A. Kopmann, A.-S. Müller, J. Raasch, M. Schleicher, N. J. Smale, J. Steinmann, M. Vogelgesang, S. Wuensch, M. Siegel, M. Weber, KIT, Karlsruhe, Germany

Abstract

The commissioning of a new real-time and high-accuracy data acquisition system suitable for recording individual ultra-short coherent pulses detected by fast terahertz detectors will be presented. The Karlsruhe Pulse Taking Ultra-fast Readout Electronics (KAPTURE) is able to monitor turn-by-turn all buckets in streaming mode. KAPTURE is based on a direct sampling pulse operating with a minimum sampling time of 3 ps and a total time jitter less than 1.7 ps. A very low noise layout design combined with wide dynamic range and bandwidth of the analog front-end enables the sampling of signals generated by different GHz/THz detectors. The system has already been used with NbN and YBCO superconductor film detectors as well as zero biased Schottky diode detectors. The digitized data is transmitted to a DAQ system by a FPGA high throughput board with data transfer rates of 4 GByte/s. The setup is accomplished by a real-time data processing unit based on high-end graphics processor units (GPUs) for on-line analysis of the frequency behaviour of the coherent synchrotron emission. The system has been successfully used to study the beam properties of the ANKA synchrotron radiation source located at the Karlsruhe Institute of Technology.

INTRODUCTION

At the synchrotron light source ANKA up to 184 electron packages (bunches) can be filled with a distance between two adjacent bunches of 2 ns corresponding to the 500 MHz frequency of the accelerating RF system. Since a few years Coherent Synchrotron Radiation (CSR) generated by short electron bunches is provided by ANKA [1]. To detect and study the emission characteristics of CSR in the THz range over multiple revolutions several detector systems are available. Both cryogenic and room temperature detectors have been used to detect and study the coherent radiations in different spectral ranges. The cryogenic detectors are based on Niobium nitride (NbN) [2] and Yttrium barium copper oxide (YBCO) [3] superconductor films. The NbN detector is sensitive in a spectral range from 150 GHz up to 1.5 THz and has a response time of less than 165 ps. The sensitive spectral range of the YBCO detector depends on the antenna shape. The range can cover up to several THz with an intrinsic response time of 1 ps. The room temperature zero biased Schottky diode has a sensitive spectral range of several hundred GHz with a response time of 100 ps or less.

An ideal data acquisition system for picosecond pulses requires ultra-wideband analog electronics and a very fast digitizer stage. Available commercial DAQ systems and real-time oscilloscopes for high bandwidth above 60 GHz are very expensive. Due to limited internal memory and missing fast readout interfaces they are not suitable for long term bunch-to-bunch CSR studies. To circumvent these limitations the digitizer system KAPTURE for fast and continuous sampling of the individual ultra-short THz pulses has been developed. In this paper we present the KAPTURE system, the performances and the measurements of CSR at the ANKA synchrotron light source.

KAPTURE SYSTEM

The KAPTURE system is able to record individual pulses continuously with a millivolt resolution and a relative jitter between two consecutive pulses in the picosecond time resolution. KAPTURE is a flexible system and can be easily configured for the requirements of others synchrotron facilities.

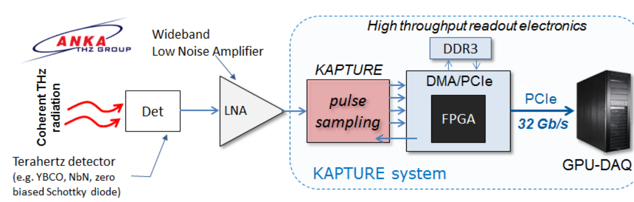

Figure 1: KAPTURE system and the readout chain.

The KAPTURE system is shown in Fig 1. It consists of a picosecond pulse sampling stage called “KAPTURE board”, a high throughput readout board and a high-end Graphics Processing Unit (GPU). The KAPTURE board receives the analog pulses from a wideband Low Noise Amplifier (LNA), and acquires it with 4 sample points with a programmable sampling time between 3 and 100 ps. The basic concept of the picosecond KAPTURE board and the architecture have been reported previously [4,5]. The high throughput readout board uses a new PCIe-DMA engine [6] to transfer the digital samples from the KAPTURE board to a high-end GPU server. For continuous data acquisition a bandwidth of 24 Gb/s (12 bits @ 2 ns * 4 digital samples) is necessary. The DMA architecture based on a bus master DMA policy connected to PCI Express core logic developed meets this requirements with a high data throughput of up to 32 Gb/s.

ISBN: 978-3-95450-132-8 doi:10.18429/JACoW-IPAC2014-THPME113

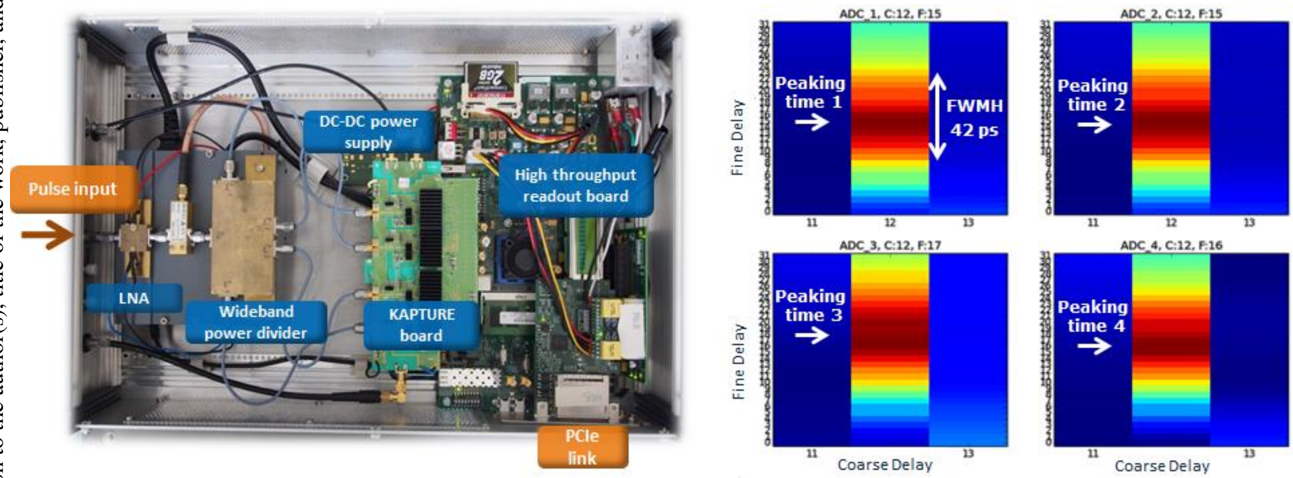

Figure 2: View inside the KAPTURE system (left); characterization of the KAPTURE system with a short pulse provided by an YBCO detector with FWHM of 42 ps and amplitude of 45 mV (right).

The GPU computing node is used for a reconstruction of the pulse from the 4 digital samples in real-time. Afterwards the peak amplitude of each pulse and the time between two consecutive pulses/buckets with a picosecond time resolution are calculated. The GPU node performs on-line also a Fast Fourier Transform (FFT) for the frequency analysis of the CSR fluctuations.

The internal organization of the KAPTURE system and it's components is shown in Fig 2 (left). The detector signal is applied to the LNA by a wideband V-connector and then propagated to the power divider by a tee-bias device. In the system proposed a novel wideband architecture for a power divider has been designed and constructed [7]. It is used to split the incoming pulses in four identical signals, one for each sampling channels, of the KAPTURE board. The LNA gain has been chosen in order to compensate the power divider insertion loss with a minimum additional noise contribution. The KAPTURE board consists of four parallel fast sampling stages each operating at 500MS/s, synchronous to the ANKA RF-system. It is connected to the high throughput readout board by two high-speed and high-density FMC-SAMTEC connectors. The readout board is equipped with a Virtex 6 FPGA that receives the digitalized samples, tag them with the current bunch number and send the data to GPU server by the PCIe data uplink.

CHARACTERIZATION

The picosecond time characterization is fundamental to understand the performance of the KAPTURE system. For this purpose very short pulses with a FWHM of a few tens of picosecond and a time jitter of few picoseconds are required. Due to limitation of commercial pulse generators, we have performed the characterization using short pulses generated by an YBCO detector illuminated with coherent synchrotron radiations. The input pulse with a FWHM of 42 ps and amplitude of 45 mV was previously measured with a real-time oscilloscope. For the time characterization we configured the KAPTURE system to operate in an equivalent time sampling mode with sampling time of 3 ps. In this way, we have sampled the 40 ps input pulse with an equivalent sampling rate of more than 300 GS/s four times, one for each channel, simultaneously. The pulses acquired from the four sampling channels are shown in Fig. 2 (right), the x-axis reports the coarse delay used to synchronize the detector signal with the ANKA clock, the y-axis represents the fine delay set with the picosecond delay chip with a step of 3 ps. All four channels have acquired the detector pulse with a correct shape; we can distinguish the fast rise-time, the Gaussian region of the pulse and the long tail. Moreover, the FWHM measured by KAPTURE on the acquired pulses is 42 ps in agreement with the previous measurement by real-time oscilloscope. The last result confirms also the wideband and the low noise design. Moreover, the total mismatch due to skew between channels, including the channels skew of the power divider, cables, sampling time and chock signals at level of PCB routing, etc. can be measured. Considering the peaking-time measured from each channel, Fig. 2 (right), we can measure a total time skew between the four outputs of 2 counts (y-axis) corresponding at only 6 ps. This is a systematically mismatch that is always presents, which can be compensated by an FPGA setting.

RESULTS

The KAPTURE system has been used to measure ultra-short CSR emission acquired with YBCO detector and Shottky diode readout by the KAPTURE system. Fig. 3 shows the peak amplitude of each THz pulse (buckets) acquired by YBCO detector. The x-axis represents the numbers of revolutions. In the plot only the first 3000 turns from a data set with more than 1 million of turns are displayed. The y-axis shows the buckets position in the orbit. The z-axis reports the fluctuation of the CSR emission that it is proportional to the amplitude measured for each single pulse. Fig. 3 shows also a possible filling pattern of the ANKA storage ring, with two trains separated by a gap of several ns and one additional single bunch filled at position 135.

ISBN: 978-3-95450-132-8 doi:10.18429/JACoW-IPAC2014-THPME113

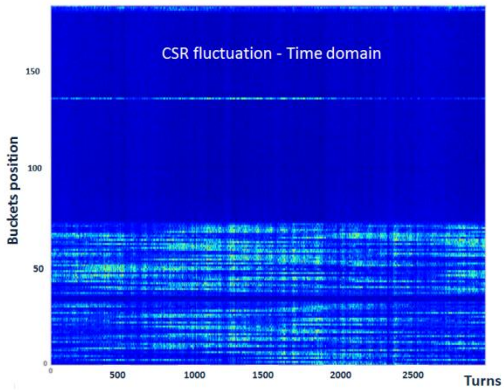

Figure 3: CRS measured with YBCO detector and the KAPTURE system.

The readout system is able to resolve turn-by-turn CSR signals for all 184 bunch positions and record this data for nearly arbitrary observation times. Due to this resolution, the system is able to study single bunch fluctuations in multi-bunch filling patterns [8]. The pulse amplitude is used for the statistical studies of the beam properties and for an on-line Fast Fourier Transform (FFT). Figure 4 shows a different measurement the frequency analysis of the CSR emission of each bucket detected with a Schottky diode. An optimized GPU algorithm has been developed in order to calculate and visualize the FFT in real-time.

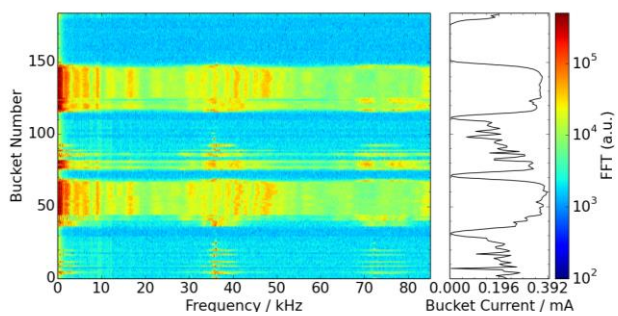

Figure 4: Fast Fourier Transform of the CSR emissions of all buckets, detected with the Schottky diode.

Due to electron density modulations inside an electron bunch the emitted CSR intensity is fluctuating. These so called bursting occur only for certain ANKA machine settings and bunch currents. On the right hand side in Fig. 4 the current in all buckets is displayed and shows the filling pattern containing 4 trains. Bunches with a big difference in their current are in different bursting regimes and therefore their emitted CSR intensity is fluctuating with different frequencies. On the left hand side, where the frequencies of the fluctuation for each bucket are shown, these differences are nicely visible. The synchrotron frequency of 8.9 kHz is visible for all bunches, also for the ones which have a current below the bursting threshold and who's radiation is not fluctuating. For bunches with currents above the bursting threshold frequencies ranging from a few hundred Hz up to several kHz occur depending on their bunch current.

CONCLUSION

In this paper, we have presented the continuous data acquisition system KAPTURE designed for bunch-by-bunch sampling of CSR pulses with fast THz detectors for long observation times. The system is able to measure amplitude and timing of individual pulses with a rate of 500 MHz. A very low noise design and a wide dynamical range resulted in a timing accuracy of less than 3 ps. The readout system, combined with different terahertz detectors like YBCO, NbN and Zero Biased Schottky Diode, has been proven to be an indispensable tool for analysis of CSR fluctuations in single- and multi-bunch mode.

REFERENCES

[1] A.-S. Müller, "Observation of coherent THZ radiation from the ANKA and MLS storage rings with a hot electron bolometer", as proceedings of the 23rd Particle Accelerator Conference (PAC09), Vancouver Canada (2009).

[2] D. Rall et al., Energy relaxation time in NbN and YBCO thin films under optical irradiation, J. Phys. Conf. Ser. 234 (2010) 042029.

[3] P. Thoma et al., High-speed Y-Ba-Cu-O direct detection system for monitoring picosecond THz pulses, IEEE Trans. THz Sci. Technol. 3 (2013) 81.

[4] M. Caselle et al. "Ultra-fast Data Acquisition System for Coherent Synchrotron Radiation Based on Superconducting Terahertz Detectors", as proceeding of 4th IPAC 2013. 12-17 May 2013. Shanghai China. ISBN 978-3-95450-122-0, WEOBB202.

[5] M. Caselle et al. "An ultra-fast data acquisition system for coherent Synchrotron radiation with terahertz detectors ", as proceeding of TWEPP 2013, Perugia, Italy. 2014 JINST 9 C0102.

[6] L.Rota, M. Caselle et al. "A New DMA PCIe Architecture for Gigabyte Data Transmission", as proceeding of 19th Real-Time conference IEEE-RT 2014, Nara, Japan.

[7] M.Caselle et al. "An Ultra-fast Digitizer with Picosecond Sampling Time for Coherent Synchrotron Radiation", as proceeding of 19th Real-Time conference IEEE-RT 2014, Nara-Japan.

[8] A.-S. Müller, V. Judin, M. Caselle et al. "Studies of bunch-bunch interactions in the ANKA storage ring with Coherent Synchrotron Radiation using an Ultra-fast Terahertz Detector System", as proceeding of 4th IPAC 2013. 12-17 May 2013. Shanghai China. MOPEA019.