MTCA UPGRADE OF THE READOUT ELECTRONICS FOR THE BUNCH ARRIVAL TIME MONITOR AT FLASH

Jaroslaw Szewinski*, Grzegorz Boltruczyk, Stefan Korolczuk, NCBJ Swierk, Otwock, Poland
Samer Bou Habib, Jaroslaw Dobosz, Dominik Sikora, ISE WUT, Warsaw, Poland
Christopher Gerth, Holger Schlarb, DESY, Hamburg, Germany

Abstract

Bunch Arrival time Monitor (BAM) is an electro-optical device used at FLASH accelerator in DESY for the high precision, femtosecond scale, measurements of the moment when electron bunch arrives at the reference point in the machine. The arrival time is proportional to the average bunch energy, and is used to calculate the amplitude correction for the RF field control. Correction is sent to the LLRF system in less than 10 us, and this creates a secondary feedback loop (over the regular LLRF one), which is focused on beam energy stabilization - beam feedback. This paper presents new MTCA BAM readout electronics design based on the MTCA.4 - “MTCA for Physics”, and FMC mezzanine boards standards. Presented solution is a replacement for existing, VME based BAM readout devices. It provides higher efficiency by using new measurement techniques, better components (such as ADCs, FPGAs etc.), and high bandwidth MTCA backplane. MTCA provides also different topology for data transfers in the crate, which all together opens new opportunities for the improvement of the overall system performance.

INTRODUCTION

Bunch Arrival Time Monitors (BAMs) are precise beam measurement devices used to measure with femtosecond precision, moment when particular bunch is passing reference point. Electric signal from the beam pickup is used to control electro-optical modulator (EOM), which modulates amplitude of the laser pulses. Detailed operation of BAM is described in [1]. Information from this detector is available as laser pulses with modulated amplitude, and the aim of readout electronics is to measure their the relative height. Bunch arrival time is proportional to beam energy, because electrons with different energies travels over different trajectories (shorter or longer) in the bunch compressor. Average bunch energy estimation is used to calculate correction for the LLRF system amplitude control.

BEAM FEEDBACK AT FLASH

The LLRF systems are focused on the RF field (amplitude and phase) stabilization, and they do not know much about the actual beam conditions (except beam loading). This is not enough to stabilize beam parameters directly, and additional devices are needed. FLASH accelerator is equipped with many different beam parameters detectors. Two types of these detectors, BAMs and Pyroelectric bunch compression monitors (PYROs) has been used to implement feedback beam feedback loops. BAMs has been used for energy stabilization by correcting RF field amplitude, and PYROs has been used for compression stabilization by adjusting phase of the RF field. More about beam feedback at FLASH can be found in [1], this paper will focus on improvements of the BAM readout system.

EXISTING VME BASED BAM SYSTEM

The first, VME based BAM electronic readout system has been made of two units, digital and analog. Digital part was FPGA based VME carrier board (Fig. 1(a)), and optical-analog electronics has been implemented as custom (non-standardized) mezzanine unit placed in the shielded box (Fig. 1(b)). This system has been used successfully for several years[1, 2, 3, 4], but now it’s performance is limited by used technology.

Main limitation is amount of data which can be transferred between accelerator pulses from the acquisition board to the CPU board via VME bus. If the data transfer will not complete before the next pulse, then data is not consistent (some of it is from old pulse, some data is from new pulse), and such pulse has to be dropped. A lot of effort and overhead (on both, hardware and software side) was made to keep data consistency.

Existing system is equipped in 125 MSPS 16-bit ADCs, which in case of 216 MHz laser pulse repetition rate is enough only to sample every second laser pulse. Another inconvenience was that VME based devices are not hot-swap capable, and it was required to shutdown whole crate, with all (not only broken) devices, to do any hardware change.

In one case, it was confirmed, that when BAM readout devices has been placed in one crate with other system, which was also transferring a lot of data over the VME after each pulse, it was falling into a deadlock. BAM control server has been blocked on the VME access in such a way, that is was an unkillable process in the Solaris operating system, and CPU power cycle was required. This error was difficult to track, because it was occurring with a period of several weeks.

* J.Szewinski@ncbj.gov.pl

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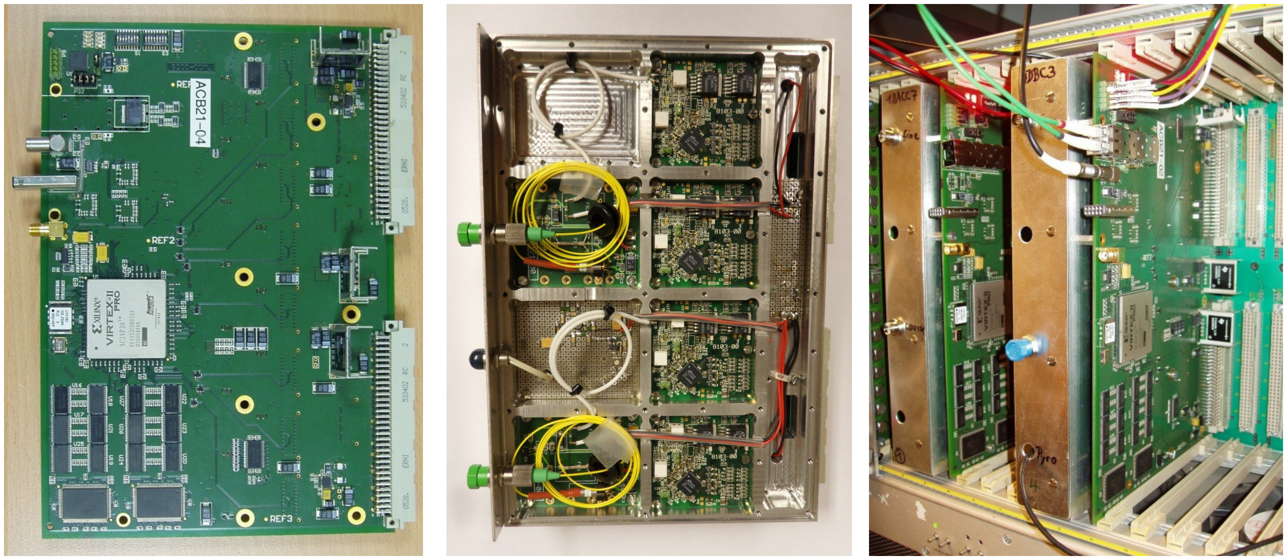

(a) VME carrier board (b) Optical and analog input unit (c) Installation in VME crate

Figure 1: VME based BAM readout electronics.

NEW MTCA BAM SYSTEM

The new proposed setup will solve many issues of the existing VME system. Except of using newer electronic devices such as better FPGA, faster 16-bit ADCs which can sample data up to 250 MSPS, allowing to sample each laser pulse with 216 MHz repetition rate etc., the MTCA.4 standard has several features increasing the reliability of the system.

All devices in MTCA crate such as boards, power supplies and fans are hot-swap capable, and can be exchanged individually, without affecting the rest of the system. MTCA provides also a different backplane topology, instead of multi-drop shared bus, point-to-point high speed differential connections, which can handle such protocols like PCI Express, Gigabit Ethernet or Serial ATA are provided. In this case, failure of one board will not affect communication between other units, as it was in the VME based system. Fast PCIe communication will solve the problem of limited data transfer to CPU board between pulses.

Similarly to the VME system, the new design is also made up of analog and digital part (Fig. 2). Carrier board is made in the MTCA form factor, and the optical-analog board is implemented as dual FMC mezzanine card.

The general concepts of the carrier board Fig. 2(a), has been described in [5]. The aim was to provide MTCA dual FMC carrier, with both FMC in HPC (High Pin Count) variant. Board has been designed with Virtex-5 FPGA as a main data processing device, and as a backplane protocol PCI Express has been chosen. The prototype carrier board (Fig. 2(a)) has been designed as a platform for fast ADC evaluation, in such way, that it could be later used for BAM electronics upgrade.

The prototype mezzanine board (Fig. 2(b)) is designed in the similar way as it was done in the VME based system, except that clock signal is distributed entirely on the mezzanine board. In the VME based system clock signal, was going down from the mezzanine to the to the carrier, and then back to the ADCs. In the new design, the optical clock input goes to the photo diode on the mezzanine, and then it is directly connected to clock distribution device, which provides clock signals for the ADCs. The chosen clock distribution device has ability of precise phase adjustment for each ADC channel. The block diagram of the FMC mezzanine board is presented in the Fig. 4, more about BAM FMC design can be found in [6].

After successful tests with the presented prototypes, decision has been made to upgrade BAM readout system to the MTCA standard. At this point, additional requirements (such as addition of the RTM - Rear Transition Module interface) has been added for the carrier board. Finally the functionality has been defined, in the form which is shown in the block diagram (Fig, 3).

RESULTS

As it was mentioned, the aim of the BAM readout electronics is to measure relative height of the laser pulse, which is modulated by the traveling bunch. To do this, signal from the photo diode is split and provided in the symmetric way to two ADCs. These ADCs are sampling same signal, but they have clock signals slightly shifted in phase in such way, that one ADC is sampling peaks of the laser pulses, and second one is sampling baseline (Fig 5). Phase difference between particular ADC channels is adjusted by clock distribution chip, which is equipped in precise phase shifting blocks called *fine delay*, or by changing optical path length between channels.

To check performance of the system, it was necessary to over-sample the whole laser pulse. For the measure-

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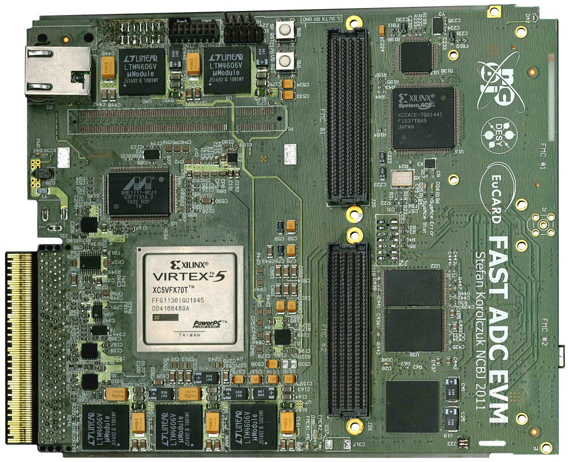
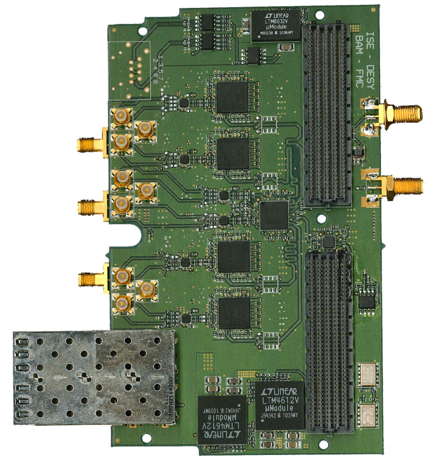


(a) Prototype FMC carrier



(b) Prototype FMC mezzanine with ADCs

Figure 2: Prototype devices, MTCA FMC Carrier (a) and ADC mezzanine (b).

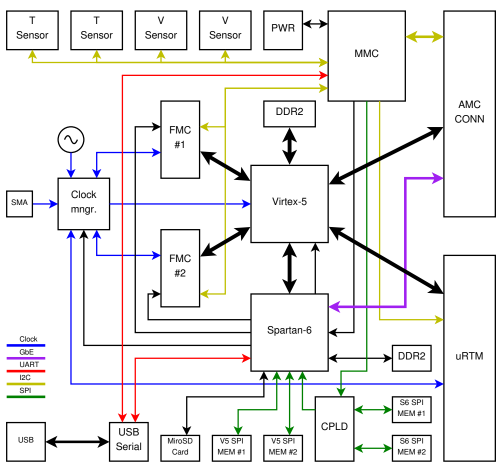


Figure 3: FMC carrier block diagram.

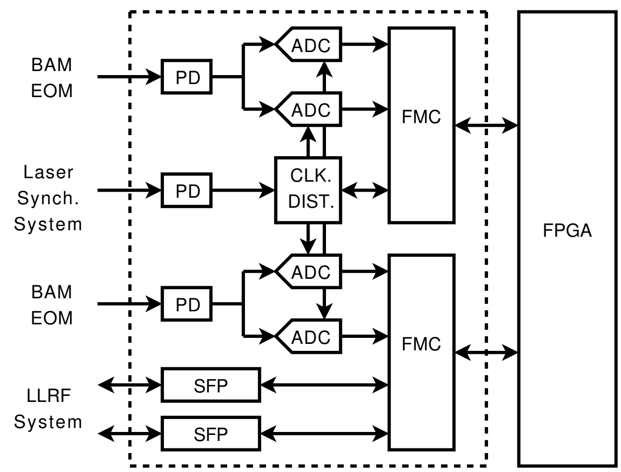


Figure 4: BAM FMC mezzanine block diagram.

ment, two optical fibers with laser pulses generated with 216 MHz repetition rate has been used. One link was used as source of the 216 MHz sampling clock for ADCs, and pulses from the second fiber has been measured. In such configuration, with constant phase shift, one sample is taken per one laser pulse. To perform full measurement, phase shift between two fibers had to be changed. For the precise short range shifting, fine delay blocks in the clock distribution chip has been used. This could cover a range of about 1 ns. To make wide range phase shifts, the optical length between fibers was changed. To measure the pulse shape (Fig. 6), it was required to make difference in length between fibers up to 85 cm. For the comparison, the best pulse measurement made with the VME system is presented in the Fig. 7

By the analysis of the standard deviation (STD) of the measured ADC data in the flat regions and on the rising edge of the pulse (Fig. 8), the relative jitter of about 1 ps has been estimated between two fibers. According to the AD9516 clock chip datasheet, 1 ps of additive jitter is contributed by the fine delay blocks used for phase adjustment (lasers are expected to have femtosecond stability). More about this jitter estimation can be found in [7].

CONCLUSION & OUTLOOK

The prototype MTCA BAM readout electronics was able to provide in the first measurements session, without special tuning or optimization, very good results - much better than existing VME based system. Except the data readout and signal processing itself, the MTCA based environment will solve many problems with long-term operation stability and system maintenance. Performed tests and measurements confirms design assumptions, and opens the way for porting algorithms from the VME based solution and implementing new energy beam feedback loop.

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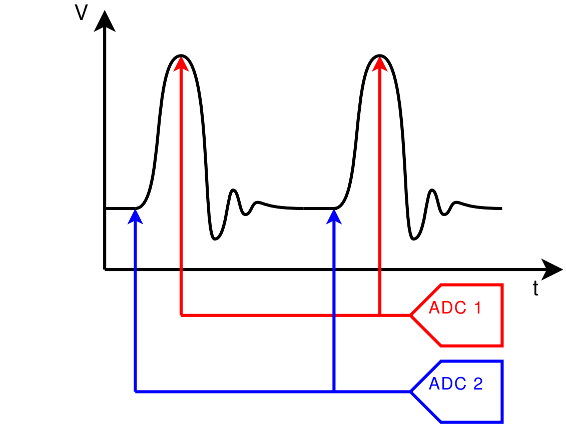
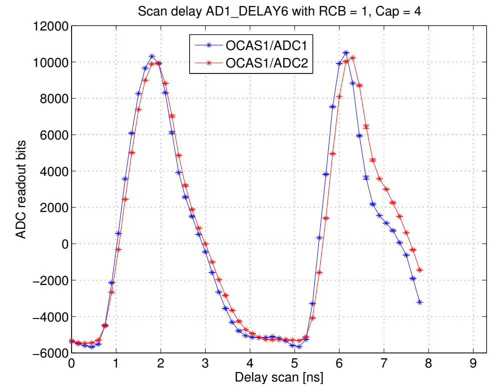


Figure 5: Peak and baseline sampling principle with two ADCs with shifted clock phase.



source: FLA Logbook, DESY

Figure 7: Laser pulse measured in the best conditions using VME based system [3, 4].

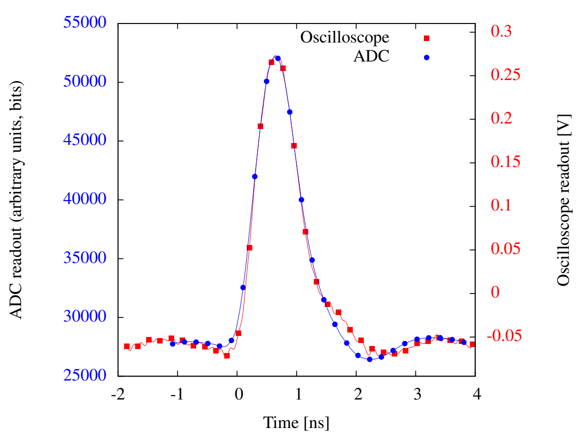


Figure 6: Laser pulse measured with the new MTCA BAM prototype devices and 8 GHz bandwidth oscilloscope.Marks in this figure does not indicate sampling points, but they are placed to identify two nearly overlapping pulses.

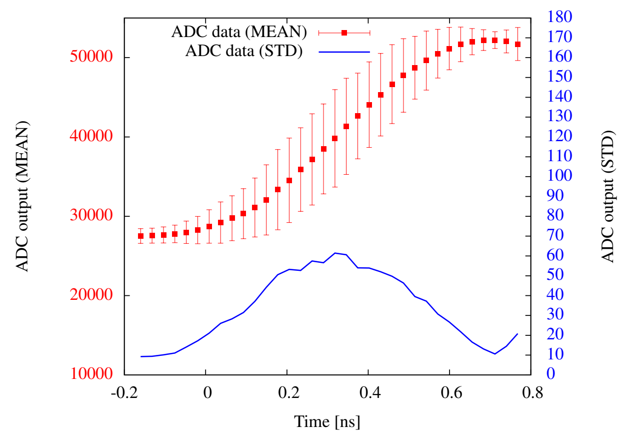


Figure 8: Single measurement of the rising edge of the laser pulse. Error bars around the mean values (red color) has been intentionally magnified,the numerical values of the STD are show on the sub-plot (blue color) on right vertical scale.

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