XFEL BEAM LOSS MONITOR SYSTEM

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Abstract

European XFEL will have a sophisticated Machine Protection System, part of which - Beam Loss Monitors(BLM). The monitors will detect losses of electron beam, in order to protect the components of the XFEL from damage and excessive activation. For protection of undulators, BLMs with a scintillator rod will be used. BLMs at places with high radiation load will be equipped with fused silica rods. The BLMs were tested with an electron test-beam facility at DESY, as well as at FLASH. Due to large amount of light produced by scintillator, no optical grease is needed, while cathode potential of R5900 PMT is 500-600 volt. Comparable signal from a prototype with a quartz glass was obtained with typically 150 volt higher cathode potential than the prototype with scintillator. Unexpectedly slower rise and fall time of the signal has been observed, presumably due to radio-luminescence in the used quartz glass rod. No distortion of signal observed with a synthetic fused silica rod. It is planned to use same types of BLMs also for the FLASH II project. Current status of the XFEL BLM system development will be presented.

INTRODUCTION

The goal of the Beam Loss Monitor (BLM) system at the XFEL is to detect losses of the XFEL electron beam. As a part of the Machine Protection System (MPS) the BLM system will provide an abort signal for the machine operation, in the case losses are too high.

Beam loss monitors are located at injectors, bunch compressors, collimator, undulators sections and beam dumps. In order to sustain the quality of the light produced by the XFEL, the permanent magnets of the undulators must be protected from radiation. Two BLMs are placed in vicinity of each undulator. In total it is expected to have more than 300 detectors. Most of them will be installed in undulator sections.

During the commissioning of the XFEL, the BLM system will play a crucial role in reduction of the radio-activation of the tunnel components. It is essential to minimize beam losses in order to reduce risk of a failure of an electronic system and to keep the overall radio-activation level as low as possible.

DETECTOR DESIGN

Beam electrons which escape the vacuum chamber of the XFEL produce a number of secondary particles. These secondary particles can be detected by a beam loss monitor. The key principle – light is generated by secondary particles in a sensitive medium of the detector and measured with a photo-multiplier tube (PMT). A scintillator (with a light-guide) or a Cherenkov light radiator are used as sensitive media.

BLMs with a scintillator are planned to be used in injector and undulator sections. BLMs with a Cherenkov radiator will be installed at bunch compressors, collimator and beam dumps. In the case of beam dumps, fused silica fibers will be used. All other Cherenkov radiators use a fused silica rod.

All BLMs will have the same type of housing. An aluminum cylindrical cover protects scintillator/Cherenkov radiator from mechanical damage. The cover is screwed to the housing, such that the screw threads compose a light-tight maze/barrier. In the case of dump BLMs, an opto-mechanical interface to the fibers will be attached to the housing. A prototype of the XFEL BLM shown in the Fig. 1.

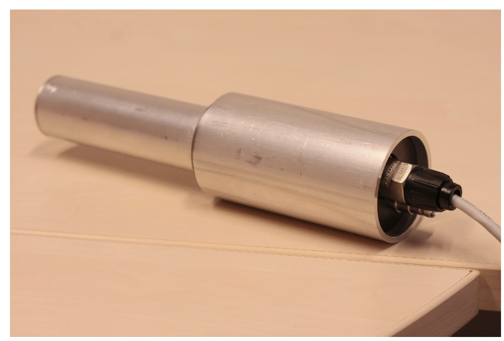

Figure 1: XFEL BLM prototype.

The BLM housing incorporates a PMT base – a circular printed circuit board, where an R5900 Hamamatsu photomultiplier[1] placed on a socket. The voltage potentials for the PMT are prepared with a Cockroft-Walton multiplier directly on the PMT base. The Cockroft-Walton multiplier is powered by an oscillator inside of the BLM. The oscillator is based on Gallium-Nitride (GaN) transistors. Radiation hardness of the transistors has been tested at DESY at the converter target (positron production from 450 MeV electrons) of the LINAC-II. The gate threshold of transistors does not substantially change up to 20 kSv dose. The equivalent dose was measured with TLD-800 dosimeters. This corresponds to the absorbed dose of 20 kGy, if one assumes negligible contribution to the dose from alpha particles, protons, neutrons and pions with high quality factor. Unfortunately, exact composition of the radiation field in the vicinity of the converter target is unknown. This first test has increased confidence in the radiation hardness[2] of the GaN transistor.

Further radiation hardness tests are being prepared and

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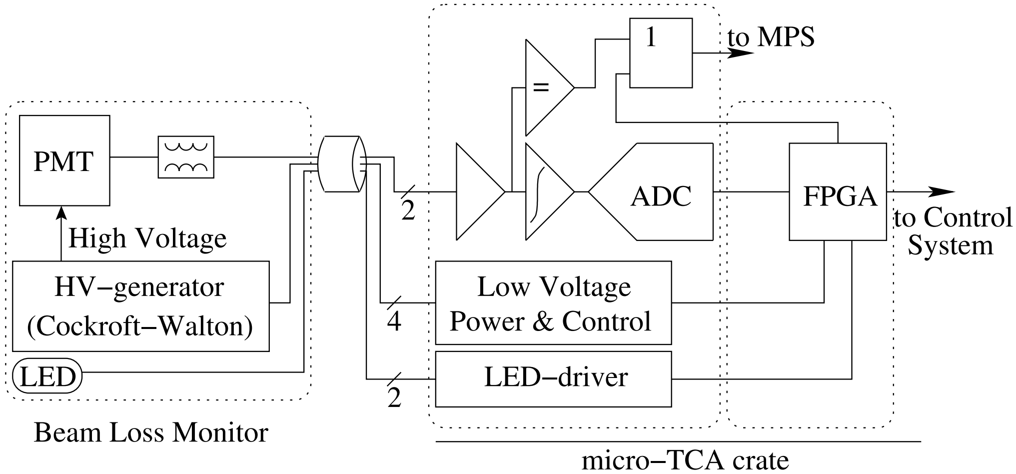

Figure 2: BLM signal processing chain.

will include a PMT-base with optimized Cockroft-Walton multiplier.

SIGNAL PROCESSING

The BLM signal processing chain is shown in Fig. 2. The signal from the R5900 PMT is very short, ∼20 ns after 50 m twisted pair cable. An active signal shaper is used to"stretch" the signal, in order to obtain at least 5 data samples with a 50 MSPS 14-bit ADC. The data from the ADC are read out and processed by an FPGA. Also the signal from the BLM is fed into an analog comparator.

All control tasks are performed by the FPGA: ADC read out, data processing, LED pulsing, threshold update, etc. Data processing includes three "alarm-algorithms":

- "Single bunch": an alarm signal is produced upon detection of data above a predefined value(Threshold #1).
- "Multiple bunches": upon detection of data above predefined value(Threshold #2) this event is counted, and if the count result exceeds some predefined value(Threshold #3) – an alarm signal will be produced.
- "Integral over bunch train": the current sum (at a certain moment during the bunch train) of all ADC samples has to be compared with a predefined value(Threshold #4), if larger – an alarm signal will be produced. The correct pedestal of the ADC has to be taken into account.

Two modes of data transfer from the FPGA are possible:

- transfer of raw data samples for the duration of the XFEL bunch train
- bunch-by-bunch loss measurements based on a signal feature extraction

The transfer of raw data will be limited only for the case of system commissioning/debugging and is not intended to be used during normal operation. A "post-mortem" analysis requires that the raw data from, at least, one last bunch train stored in the memory of the FPGA. In normal operation losses will be represented by only some extracted features of the signal from a BLM: pulse amplitude, number of pulses above threshold, etc.

Interface to the Machine Protection System

The analog comparator provides limited independence from the operation of the FPGA and fast reaction time to a high beam loss signal. Alarm signals from the comparator and the FPGA will be OR-ed and the result is sent to the MPS system. From the MPS system an alarm signal is send via an optical fiber to a "Machine Protection System actuator", which stops the electron beam.

Reaction time to beam losses is mainly defined by the propagation time of signals in cables. The maximum length of a BLM twisted pair cable is defined to be 50 m, with the signal propagation time of around 200 ns. In the case an alarm is produced, the propagation time of an alarm signal is defined by the length of an MPS optical fiber and varies from ∼2 μs (from the end of the *bunch compressor 2* to *injector*) to 6 μs (from *Dump 1* to the *switch yard*). The time of data processing in the FPGA should be only a small fraction of this time.

TEST AT FLASH

Two BLM prototypes are installed in the FLASH Bunch Compressor 2. A differential signal receiver and a digital oscilloscope are used for data taking. The PMT' voltage potentials were prepared with an "equal stages" resistor divider externally powered by a High Voltage power supply.

A BLM with an inexpensive quartz glass (HOQ310) has been tested already in January 2011. Since the end faces of the quartz glass were not polished, an optical grease was applied between the PMT window and the rod. Slow rise of the signal from this BLM, is presumably due to radioluminescence in the quartz glass, Fig. 3(oscilloscope chan-

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nel #1).

A BLM with a synthetic fused silica rod (SQ1) demonstrates no such distortion of the dark current signal, Fig. 4(oscilloscope channel #1). No optical grease is used between the PMT' window and the fused silica rod.

The second BLM at the Bunch Compressor 2 has a scintillator rod (BC-408) glued to a plastic light-guide. No optical grease is used between the PMT' window and the light-guide, Fig. 3 and Fig. 4(oscilloscope channel #2).

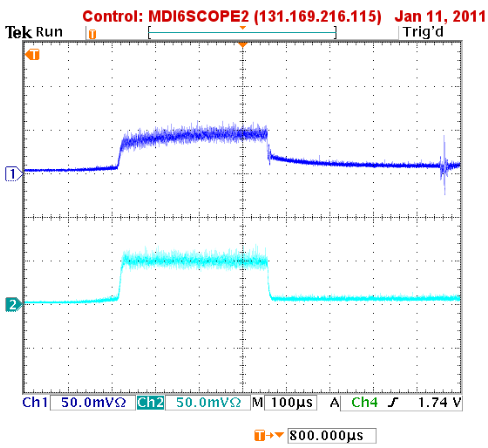

Figure 3: BLM signals from dark current at FLASH (January 2011): BLM with HOQ310 quartz glass (top, HV=650 V) and BLM with a scintillator (HV=550 V).

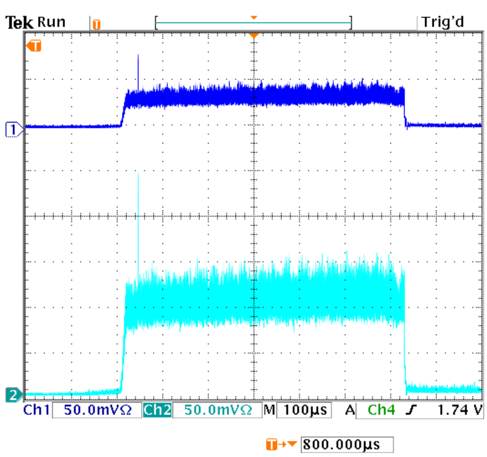

Figure 4: BLM signals from a single bunch and dark current at FLASH (April 2012): BLM with SQ1 synthetic fused silica (top, HV=700 V) and BLM with a scintillator (HV=550 V).

CONCLUSIONS

The detector design is in the optimization stage. First test of radiation hardness of Gallium-Nitride transistors for the BLM's Cockroft-Walton HV multiplier has been performed.

FPGA firmware ready for the three alarm algorithms, the connection to the Timing and Control Systems are still need to be done.

A BLM with synthetic fused silica rod has been tested at FLASH. No significant signal distortions were observed.

Mass production of mechanical components is being ramped up. Production of scintillators and light guides is being prepared at IHEP (Protvino).

ACKNOWLEDGEMENTS

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[1] Hamamatsu Photonics, R5900U-00-M4 data-sheet, 1999.

[2] "Enhancement Mode Gallium Nitride (eGaNTM) FET Characteristics under Long Term Stress", A. Lidow, J. B. Witcher, K. Smalley, `http://www2.microsemi.com/literature/Enhancement_Mode_Gallium_Nitride_FET_Characteristics_Under_Long_Term_Stress.pdf` , accessed 11 April 2012.

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