Design of an Ultra-Compact Stripline BPM Receiver Using MicroTCA for LCLS-II at SLAC

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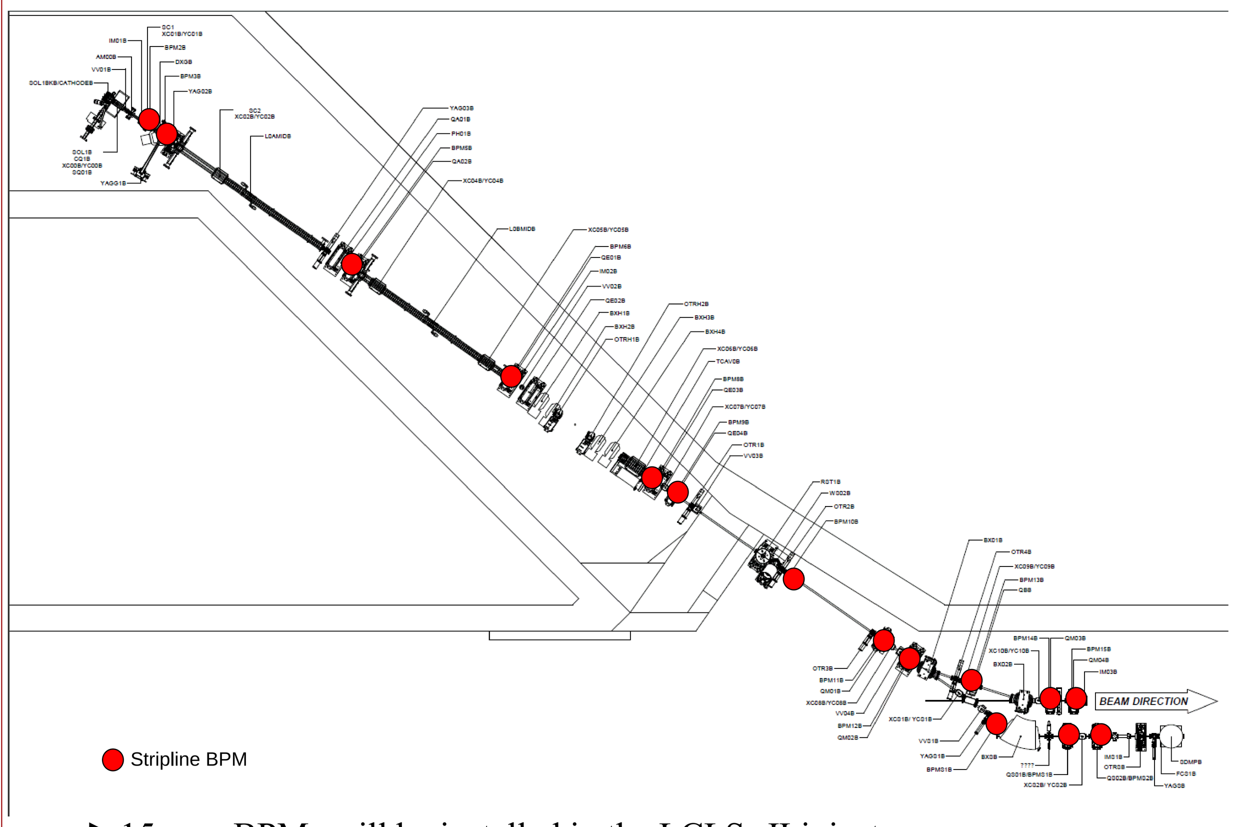
Abstract

The Linac Coherent Light Source II (LCLS-II) is a free electron laser (FEL) light source. LCLS II will produce 0.5 to 77 Angstroms soft and hard x-rays. In order to achieve this high level of performance, the beam position measurement system needs to be accurate so the electron beam can be stable. The LCLS-II stripline Beam Position Monitor (BPM) system has a dynamic range of 10pC to 1nC bunch charge. The system has a resolution requirement of 5μm. The BPM system uses the MicroTCA (Micro Telecommunication Computing Architecture) physics platform that consists of an analog front-end (AFE) and a 16-bit analog to digital converter (ADC) module. This paper will discuss the hardware design, architecture, and performance measurements of this system using the SLAC LINAC. The hardware architecture includes bandpass filter at 300MHz with a 15 MHz bandwidth, and an automated BPM calibration process.

Introduction and Background

The LCLS-II project is primarily modelled after the LCLS-I project design with enhancements and minor modifications. The LCLS-II project will be able to provide users with two independently controlled x-ray sources in a new undulator hall. It will be possible to simultaneously provide tunable hard and soft x-ray beams, one optimized for 250 to 2,000eV photons and the other optimized for 2-13keV photons. The high beam stability and accuracy needed for FEL generation requires the BPM system to meet the requirements shown in table below.

The BPM system provides repeatable transverse beam position data to the Main Control Center and the SLAC global feedback system. In order to meet the stringent requirements, the BPM system performs a self-calibration process between each beam pulse.



►15 new BPMs will be installed in the LCLS- II injector

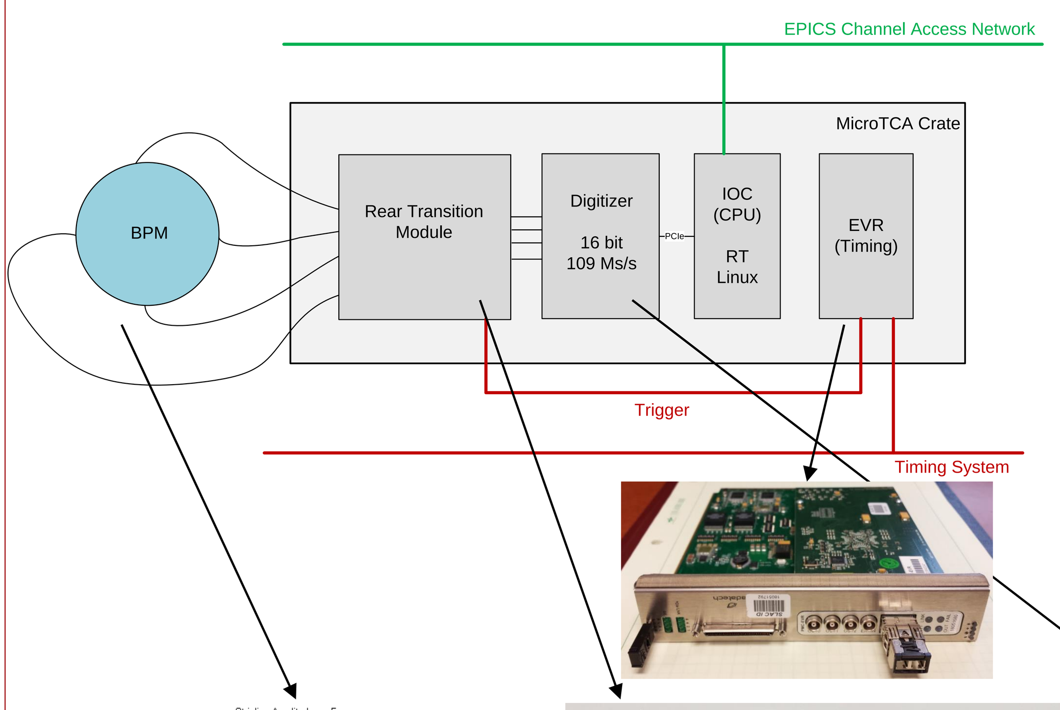
Requirement	Value	Units
Resolution and noise for single pulse measurement, over 10% of the aperture at 250pC	5	microns
Resolution and noise for charge < 250pC	1250/Q	Microns * pC
Dynamic range	10 – 1000	pC
Maximum drift	5	Microns/hour
Maximum electrical offsets	100	Microns
Maximum mechanical and alignment offsets:	100	Microns
Calibration scale error	< 10	%
Maximum non-linear position error at a beam position equal to one-half the aperture radius after software correction	20	%
Charge sensitivity - BPM must meet the above position resolution and noise requirements for charge variations of	<5	%RMS
2-bunch cross talk	10	%
Repetition rate	120	Hz

$$\left[\frac{(S_{41}-S_{21})+(S_{43}-S_{23})}{S_{21}+S_{41}+S_{23}+S_{43}}\right]\times PCMM = offset(mm) \quad (1)$$

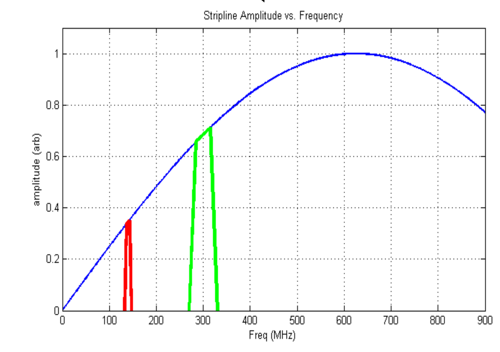
Each BPM has a diameter of 0.87in with a 7% azimuthal coverage. There are four striplines inside the structure, spaced by 90 degrees. The striplines are 4.75in long. To verify each BPM structure does not exceed the maximum acceptable offset, each BPM is tested using a network analyzer. The network analyzer measures the strip to strip coupling coefficient. To increase efficiency a Python script was created to automate the testing process. Equation 1 shows the formula used to calculate the horizontal (X) and vertical (Y) axis offset. PCMM is the measured radius of the BPM structure and S represents the coupling coefficients between electrodes.

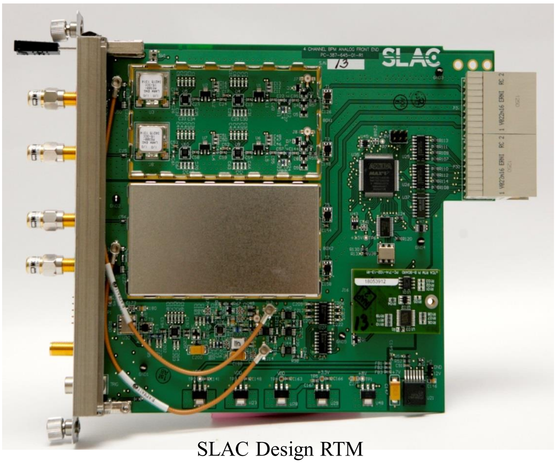
►Old stripline BPM design. It was very bulky, costly, and hard to maintain/repair.

System Overview

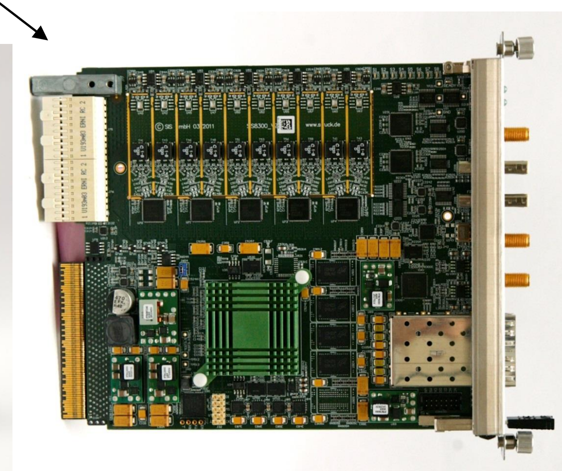


Seven BPMs operating in a 12 slot ELMA crate





SLAC Design RTM



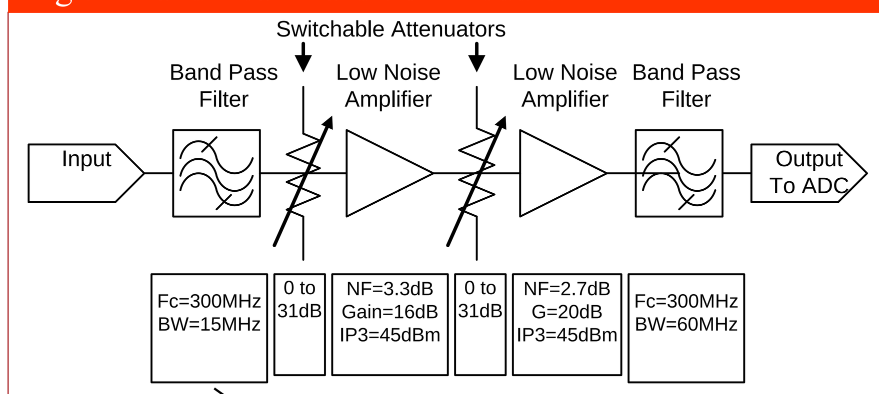
Struck SIS8300 16bits ADC

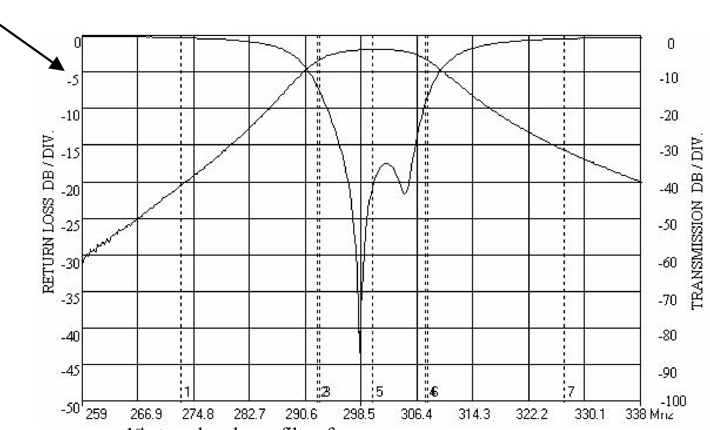
The stripline BPMs are installed in the injector, LINAC and transport line sections of the LCLS-II. The motivation for this new design is to have a compact stripline BPM system with high reliability and scalability, while maintaining the performance of original LCLS-I design. The system is realized using the MicroTCA platform with a SLAC built rear transition module (RTM) and Struck SIS8300 digitizer module sampling at 109MHz.

The original AFE processed the BPM signal at 140MHz, which is 35% of the maximum frequency response from the BPM structure. The new AFE/RTM processes the BPM signal at 300MHz, where the signal amplitude is 4.6dB higher in comparison.

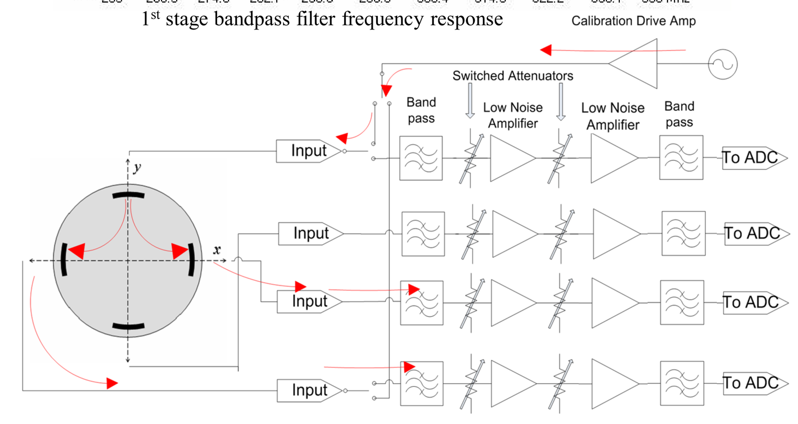
The RTM performs a self-calibration process at 120Hz by injecting a 300-MHz tone at a known amplitude into one stripline of each plane. The Y-plane tone calibrates the X-plane via stripline to stripline coupling and the Y-plane is calibrated via injecting a tone on the X-plane.

Digitizer and Rear Transition Module





1st stage bandpass filter frequency response

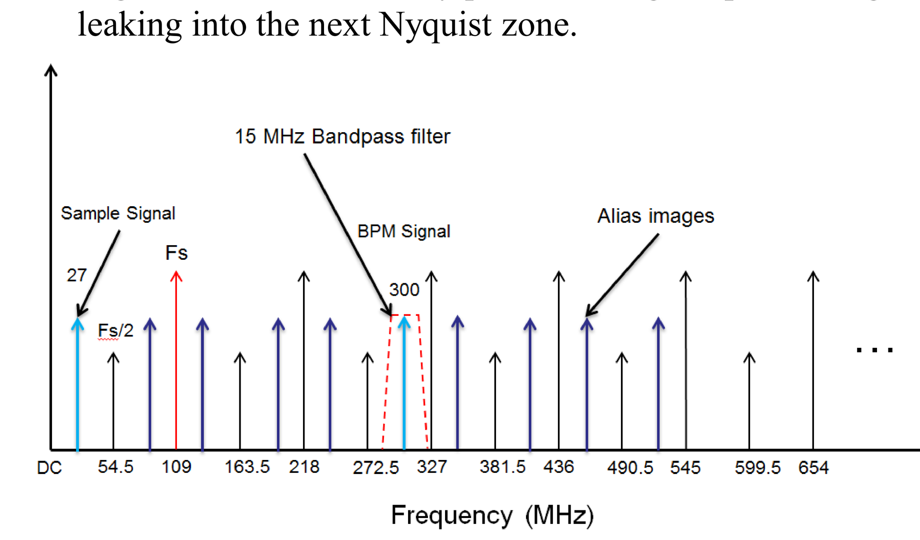


Rear Transition Module:

- ► Four processing channels, one calibration network.
- ► Two variable attenuators and RF amplifiers to meet the 10pC to 1nC dynamic range requirement.
- ► Altera MAX-V CPLD controlling the self-calibration state machine and attenuator settings.

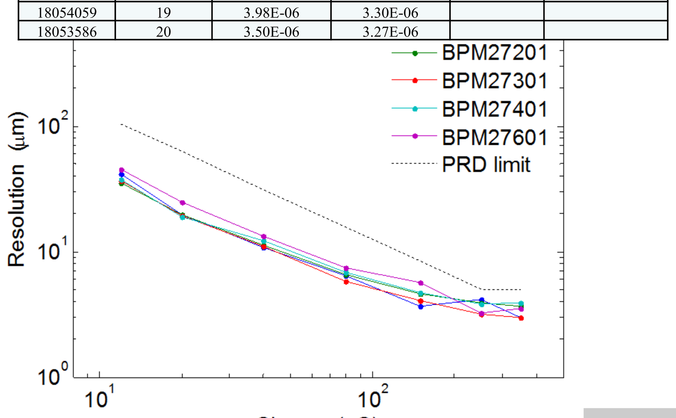
Digitizer

- ► Struck SIS8300 16bit 10 channel ADC module.
- ► Uses a band-pass sampling technique
- ► 109MHz sampling clock to under-sampling 300MHz BPM signal.
- ► 109MHz sampling clock will place the BPM signal in the middle of the Nyquist zone, thus maximize the signal captured.
- ► First stage bandpass filter has 30dB attenuation at 327MHz and 40dB attenuation at 272.5MHz.
- ► High attenuation at the Nyquist zone edge to prevent signals from leaking into the next Nyquist zone.

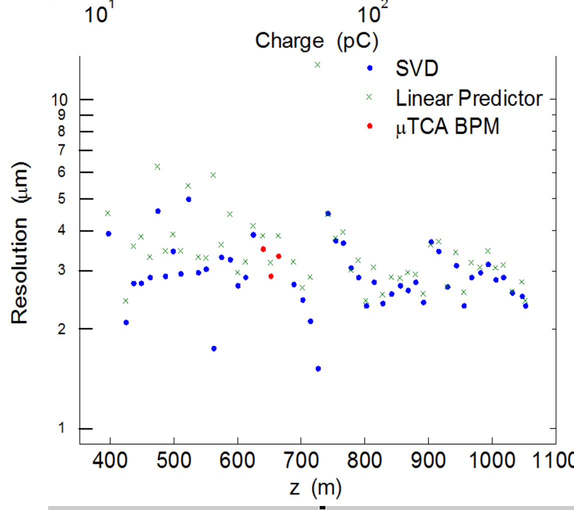


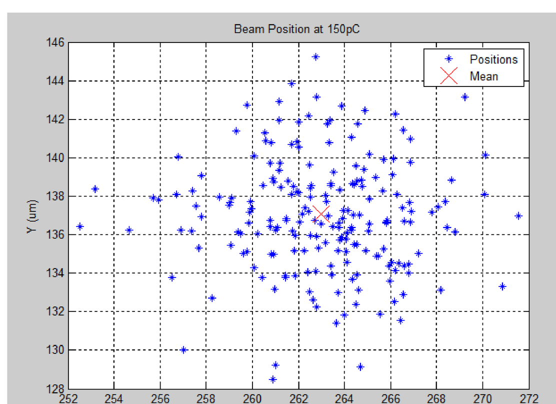
Test Results

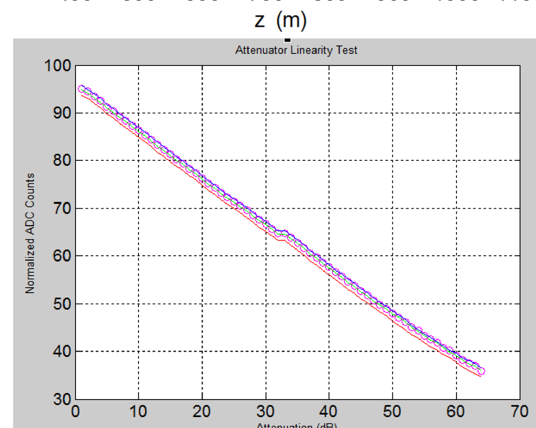
Struck SN	RTM SN	X resolution (m)	Y resolution (m)	STD X (m)	STD Y (m)
18053922	06	3.39E-06	2.79E-06	3.49E-07	2.02E-07
18053923	07	3.36E-06	3.12E-06	Mean X	Mean Y
18053920	08	3.86E-06	3.16E-06	3.49E-06	3.11E-06
18054052	09	3.58E-06	3.25E-06		
18054061	10	3.17E-06	2.86E-06	Input voltage	Width
18053919	11	2.48E-06	3.35E-06	1.35V	600ps
18054108	12	3.83E-06	3.05E-06		
18054060	13	3.61E-06	3.39E-06		Requirement (m)
18053587	14	3.78E-06	3.06E-06		8.33E-06
18053911	15	3.23E-06	2.96E-06		
18054056	16	3.56E-06	2.69E-06		
18054057	17	3.52E-06	3.26E-06		
18054058	18	3.54E-06	3.12E-06		
18054059	19	3.98E-06	3.30E-06		
18053586	20	3.50E-06	3.27E-06		

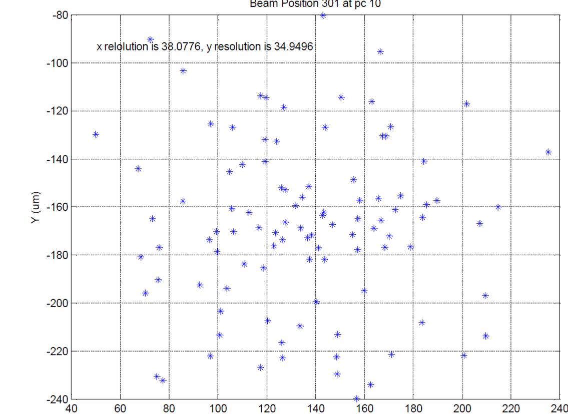


- ► Test results show resolution between 3.11μm to 3.49μm at 150pC. (8.33μm requirement)
- ► Test results show ~36μm resolution at 10pC. (125μm requirement)
- ► Two stage attenuator sweep shows a linear relation between ADC reading and attenuation.
- ► The BPM system has a 70dB of SNR.

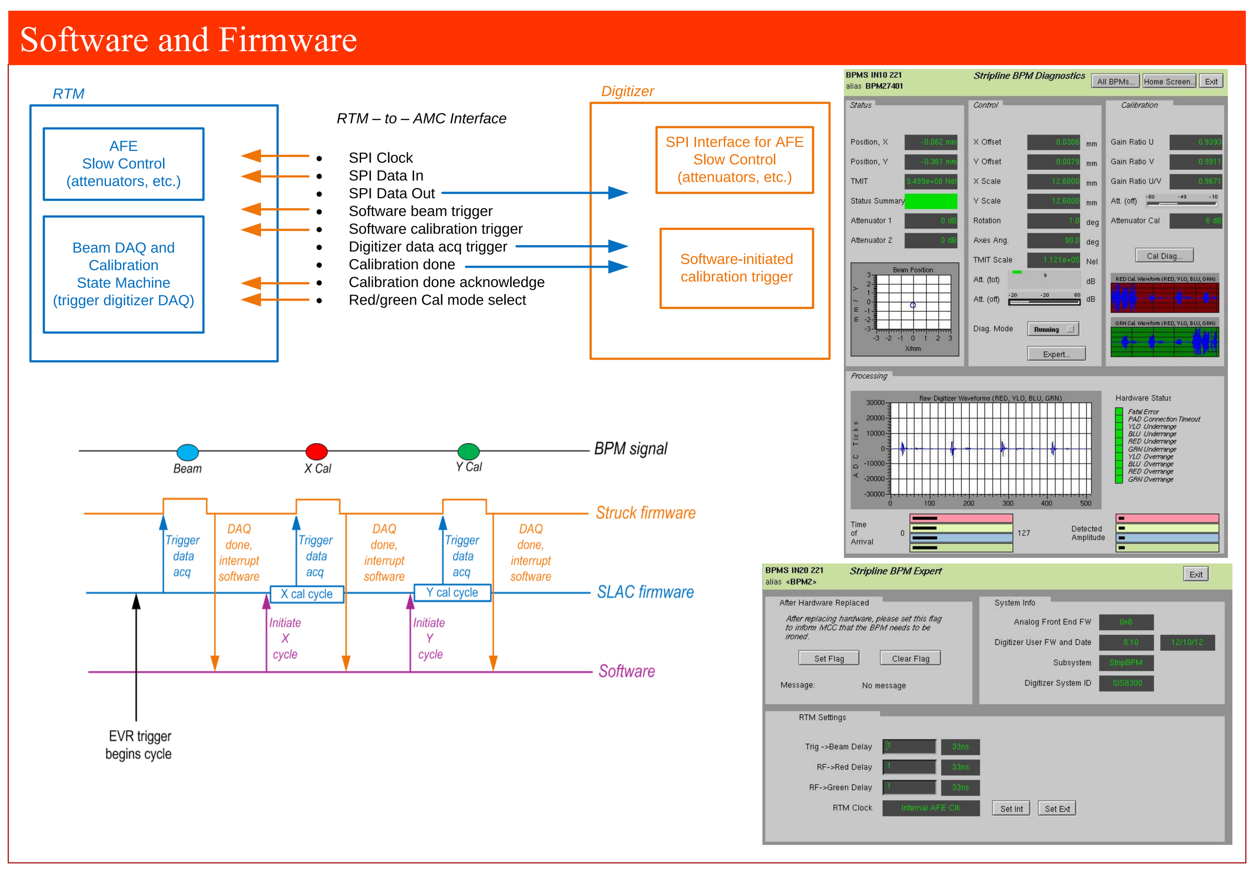








Software and Firmware



MicroTCA System

The BPM system is currently using; ELMA 12-slot crate, NAT mTCA.4 MCH, Wiener 800W Power supply, Struck SIS8300 ADC, MRF PMV EVR, and Vadatech AMC100 PMC carrier. This configuration has allowed the BPM system to have eight RTM and eight SIS8300 in a single crate. (Figure 11) Each pair of modules consumes ~70W of power. The Wiener power supply is the only power module that has the power handling capability and has the fewest IPMI communication issues with the MCH.

Summary and Future Directions

The three BPMs were installed into the LCLS-I facility in December 2012. Since then, the BPMs have been collecting data like other BPMs. No complain was filed from operations. 15 new BPMs were built, tested, and delivered to the LCLS-II injector project.

Pohang Light Source has ordered 9 stripline BPMs. For this system, SLAC is planning to use the new 250MSPS Struck ADC to improve resolution even further. In addition, SLAC is looking at using the 250MSPS Struck ADC to achieve multi-bunch setup for the LCLS-I facility.

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