NEW LOW COST X-BAND CAVITY BPM RECEIVER*

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Abstract

SLAC is developing a new X-band Cavity BPM receiver for use in the LCLS-II for use in the LCLS_II. The Linac Coherent Light Source II (LCLS-II) will be a free electron laser (FEL) at SLAC producing coherent 0.5-77 Angstroms hard and soft x-rays. To achieve this level of performance precise, stable alignment of the electron beam in the undulator is required. The LCLS-II cavity BPM system will provide single shot resolution better than 50 nm resolution at 200 pC[1]. The Cavity BPM heterodyne receiver is located in the tunnel close to the cavity BPM. The receiver processes the TM010 monopole reference cavity signal and a TM110 dipole cavity signal at approximately 11 GHz using a heterodyne technique. The heterodyne receiver will be capable of detecting a multibunch beam with a 50ns fill pattern. A new LAN communication daughter board will allow the receiver to talk to an input-output-controller (IOC) over 100 meters to set gains, control the programmable dielectric resonator oscillator, enable self-test, and monitor the status of the receiver. We will describe the design methodology including noise analysis, distortion analysis.

BPM REQUIREMENTS

The LCLS-II Project concept has been developed to provide the new facilities with two new, independently controllable x-ray sources in a new undulator hall, it will be possible to simultaneously provide tunable soft and hard x-ray beams, one optimized for 250-2,000 eV photons and the other optimized for 2-13 keV. Each undulator segment will be a variable gap permanent-magnet planar hybrid device with a nominal minimum gap height of 7.2 mm and a total segment length of 3.40 m. The Hard X-ray (HXR) Undulator is made up of 26 individual undulator segments, each with 106 32- mm-long periods. The Soft X-ray (SXR) Undulator is made up of 15 individual undulator segments, each with 61 55-mm-long periods. Table 1 illustrates the design differences between LCLS-I and LCLS-II.

Table 1: Specifications Differences

	LCLS-I	LCLS-II	Comments
Frequency	11.384 GHz	11.424 GHz	multibunch
Output	Waveguide	coax	More flexible
Tuning	12 tuning stubs	<= 4 tuners	Lower cost
Receiver	14dB I.L. with 28 dB Gain step	<= 3dB I.L. 1 dB step	Improved noise figure and dynamic range
Digitizer	SLAC/VME	uTCA	Lower cost
Ref. cavity	Single output	2 couplers	Improved mode centering

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SYSTEM DESIGN

The major subsystems for the LCLS undulator BPM system are the cavity BPM, receiver, and data acquisition components. The cavity BPM and downconverter reside in the tunnel while the analog-to-digital converters (ADC) and processing electronics are in surface buildings.

Forty-one BPMs are installed on both HXR and SXR undulator girders while there are placed in the linac-to-undulator (LTU) transport line. The BPMs provide stable and repeatable beam position data for both planes on a pulse-to-pulse basis for up to a 120-Hz repetition rate.

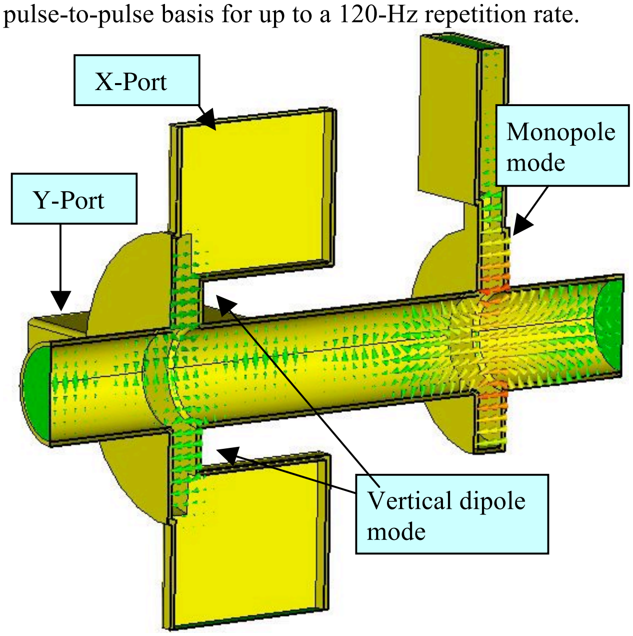

Figure 1: BPM Cavity schematic with electric fields of position (dipole) and reference (monopole) cavities.

X-Band Cavity

Figure 1 shows the electric field vectors in the cavity BPM simulated when the beam is offset [2,3]. Beam passes through the monopole reference cavity on the right, exciting the TM_{010} monopole mode signal resonant at 11.424 GHz.

Table 2: Reference Cavity Specifications

Parameter	Value
Nominal Frequency TM_{010}	11.424 GHz
Tolerance $TM0_{10}$	+-10 MHz
Loss Factor	≥ 30 V/nC
R/Q	≥ 12 Ω
Q	2000-3000
Other modes	TM_{110}, TM_{020}

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The TM_{110} dipole cavity is located 36 mm downstream through the 10-mm-diameter beam pipe. The position cavity dipole mode is resonant at 11.424 GHz, its output proportional to the product of beam position and bunch charge. The X and Y position modes are nominally degenerate in frequency, with the appropriate component chosen by the geometry of the couplers. The dipole coupler geometry is chosen to reject (the generally larger) monopole modes [2-6]. The dipole cavity was designed as a 4-port device with two opposing X couplers orthogonal to two opposing Y couplers. This is useful for cold testing and preserves symmetry. Unused ports are terminated with the potential for using them for future diagnostics.

BPMs will be built to a tolerance of ±10 MHz of design frequency. Accomplishing this without demanding unrealistic machining tolerances requires tuning. First, parts are inspected and cleaned. End caps are fitted to the body and clamped to a test fixture. Frequency and bandwidths are measured, and then endcap beam pipe inner diameters are micro-machined as needed. BPMs are reassembled and checked to ensure the cavities are within the tolerance of +0, -10 MHz to compensate for frequency shift in the brazing process. End cap brazing was strictly controlled and a 10 MHz frequency shift was typically measured after the braze.

Table 3: Position Cavity Specifications

Parameter	Value
Frequency TM_{110}	11.424 GHz
Tolerance TM_{110}	+-10 MHz
Loss Factor	≥ 13 V/mm^2/nC
R/Q	≥ 2 Ω/mm^2
Q	2000-3000
Mode centering	< 30 micron
Offset due to Ref cavity coupling	< 30 micron
Mode frequency splitting	ΔF < 2 MHz
Other modes	TM_{010},TM_{020},TM_{210}, TM_{120}
Distance to ref. cavity	>= 4 pipe diameters

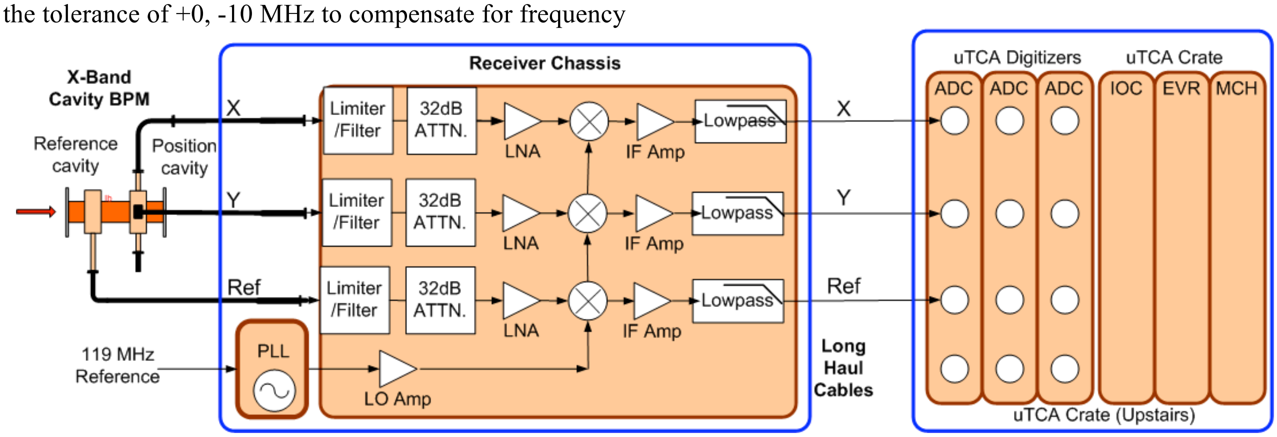

Figure 2: System block diagram. The receiver is mounted on the undulator stand while the digitizers are upstairs.

Receiver

Since LCLS turn-on the cavity BPM receivers have been losing gain due to hydrogen poisoning, SLAC has chosen to design a new receiver for LCLS-II that is low cost and with not have the effects of hydrogen poisoning using off-the-shelf integrated circuits. A three-channel heterodyne receiver (Figure 3) mixes incoming X-band signals to a 25-60 MHz intermediate (IF) frequency. The receiver is designed to detect the beam when the FEL is configured for multi-bunch operation. Each receiver input is limited to a 35 MHz bandwidth around 11.424 GHz. Out-of-band filtering of -60 dB prevents higher modes from saturating the receiver input. After the filter a limiter protects against high-power surges that is rated for 50 W peak. A programmable attenuator was added to handle the dynamic range of the electronics instead of having a discrete gain switching of the receiver as in LCLS-I. Signals are amplified in a low noise stage (LNA), and then translated to the lower IF by using an image rejection mixer with a local oscillator (LO). Using Agilent Advanced design System (ADS) and S-parameters for the vendor, figure 3 illustrates the simulated image rejection of the receiver ~21dB.

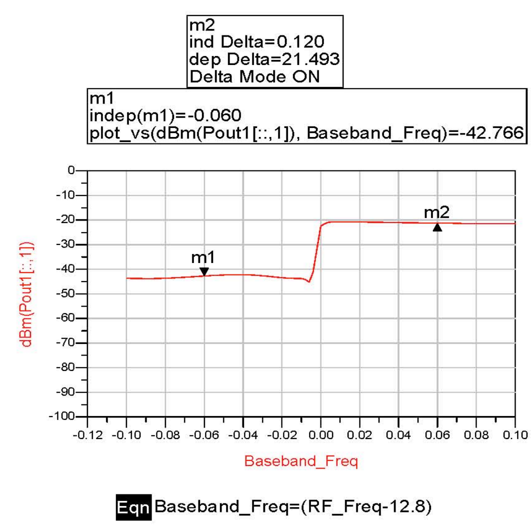

Figure 3: Image rejection of then receiver.

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Further improvements have be made in communication with the receiver using a daughter card that contains a small form pluggable that can communicate over the large area network (LAN) to an input-output-controller (IOC) over 100 meters. This will allow the operators to set gains, control the programmable dielectric resonator oscillator, enable self-test, and monitor the status of the receiver.

The receiver is built on a composite board of Rogers material 4350 and FR-4. The Rogers material is the top and bottom cores while the FR-4 is the middle cores. This allows for the board to be rigid but have the dielectric constant for high frequency operation. The LO is generated using a low noise phase-locked dielectric resonant oscillator (PDRO) locked to the 119-MHz timing reference is on another daughter card. It is important to note that the receiver board was designed at a very broad frequency range from 8.5GHz to 13GHz. The only parts that narrow operating range of the cavity BPM are the filters and the PDROs.

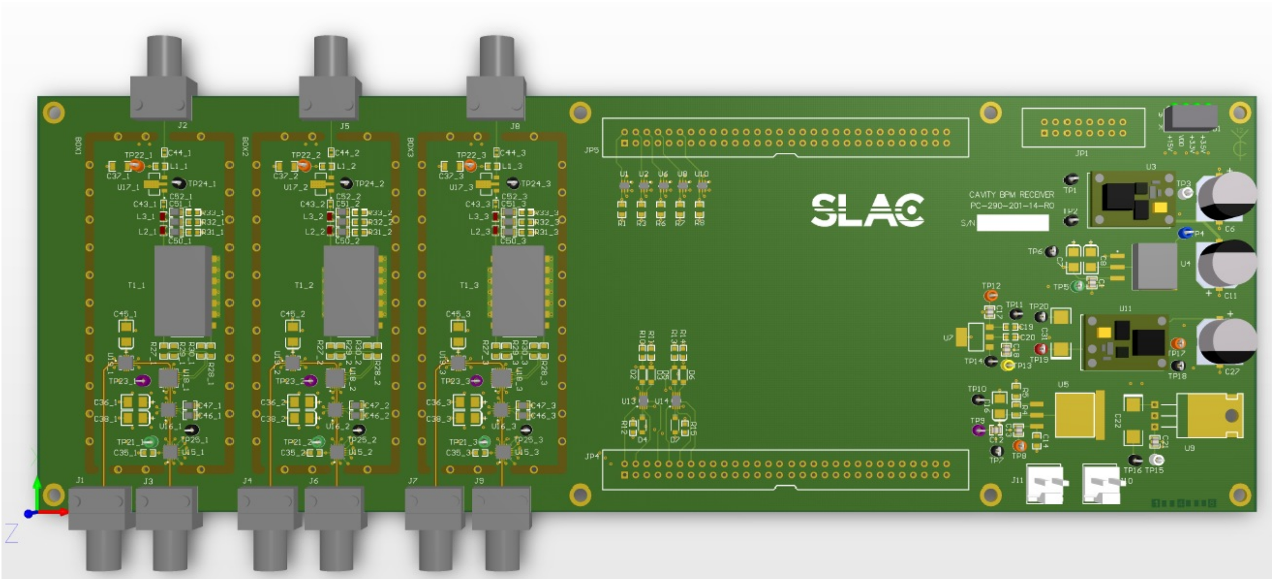

Figure 4: Three-channel heterodyne receiver board.

Digitizer

SLAC has upgraded from VME to µTCA as their new hardware platform. The X, Y, and Reference signals are digitized to 16 bits at a 119 MHz sampling rate in 4-channel µTCA digitizers designed by SIS. Waveforms are transmitted over the backplane to a µTCA processor which reduces raw waveforms to beam position and charge. Figure 4 illustrate the µTCA rear transition module RTM and the digitizer an AMC module.

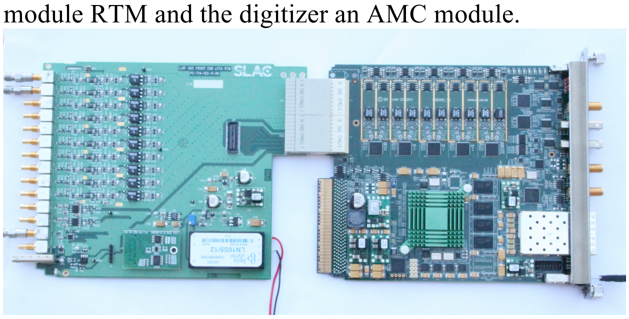

Figure 5: uTCA RTM and 119 MHz Digitizer

The initial test on the digitizer has shown to have 11 effective number of bits with noise floor approximately -120dB.

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