Stanford Linear Accelerator Center
Stanford Synchrotron Radiation Laboratory

LCLS Engineering Specification Document # 1.4-117 LCLS Document # L14501-00001	Undulator Cavity BPM System	Revision 00

RF Beam Position Monitor Engineering Specification (UD5)

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Brief Summary: This document defines requirements for the Cavity Beam Position Monitors (BPMs) that are to be used in the Linear Coherence Light Source undulator system and LTU.

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Key WBS#'s: TBD

Change History Log

Rev No.	Revision Date	Sections Affected	Description of Change

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1.0 INTRODUCTION

1.1 Purpose

This Engineering Specification Document (ESD), in conjunction with the associated fabrication specifications and drawings, defines the requirements for the Cavity BPM system that is to be used in the Linac Coherence Light Source (LCLS) undulator system and Linac-to-Undulator (LTU) transport line.

The purpose of the Cavity BPM system is to provide high-resolution measurements of the electron beam trajectory on a pulse-to-pulse basis and over many shots.

1.2 Scope

This ESD defines the requirements for the design, materials, inspection, and packaging of the LCLS Cavity BPM system.

1.3 Description

The primary requirements for the LCLS undulator system are described in PRD 1.4-001, which includes tight tolerances for positioning the electron beam close to the undulator axis, as defined during the tuning procedure. The trajectory of the beam is determined by the beamline quadrupoles and the correcting magnets, but the location of the beam is measured by the Cavity BPMs. The Cavity BPMs are critical for beam-based alignment and operations. Their inherent precision and small physical size make them the optimal choice for beam location measurement. There are two units placed in the LTU line and 34 in the undulator beamline.

1.4 Summary of Physics Requirements

The engineering design requirements described in this document for the LCLS undulator and LTU BPM systems are derived from the Physics Requirements Document # 1.4-001, rev. 3. The system specifications described in Table 1 will dictate the required performance of the BPM system comprised of the Cavity BPM, receiver electronics, and data acquisition.

Table 1: System Requirements

Parameter	Specification Limit	Condition
Resolution	< 1μm	0.2 – 1.0 nC; ± 1 mm range
Offset Stability	< ± 1μm	1 hour; ± 1 mm range; 20.0 ± 0.56 Celsius
Offset Stability	< ± 3μm	24 hours; ± 1 mm range; 20.0 ± 0.56 Celsius
Gain Error	< ± 10 %	± 1 mm range; 20.0 ± 0.56 Celsius
Dynamic Range, Position	± 1 mm	10-mm-diameter vacuum chamber
Dynamic Range, Intensity	> 14 dB	PC Gun; 0.2 – 1.0 nC

1.5 Required Equipment

This ESD specifies the requirements for the design and fabrication of the cavity BPM system assembly. The Cavity BPM system is comprised of three major subsystems: the cavity BPM, receiver, and data acquisition components.

The equipment required for inspection and testing of the final article will be specified in a separate document.

1.6 Proposed Design Concept

The RF Beam Position Monitor is comprised of the beam position detector body (sometimes called the cavity), the connecting RF waveguide and the down-converter receiver electronics. The detector body is made up of two sections: the dipole cavity for X-Y position measurements and a monopole cavity for phase and amplitude reference information. The waveguide transitions from the cavities are terminated with a glass RF window that also acts as a vacuum barrier. The waveguide is WR75 copper waveguide filled with air. The receiver electronics are mounted near the body attached to the undulator girder.

2.0 TECHNICAL REQUIREMENTS

The Advanced Photon Source/Argonne National Laboratory (APS/ANL) shall supply the detailed drawings and procurement specifications for fabrication of parts and purchasing of catalog items. Vendors shall supply parts in accordance with these documents. Any deviations from these documents must be approved in writing by APS/ANL.

General requirements for materials, fabrication, cleaning and surface treatment, handling and assembly, welding and brazing, quality assurance and testing, and preparation for delivery will be specified in a separate document.

2.1 X-Band Cavity

The X-band cavity BPM inherently has the capability of resolving beam position in the tens of nanometers, far exceeding the 1-micron resolution requirement indicated in Table 1. The single-shot resolution will be limited by receiver and data acquisition electronic noise, which will be discussed in the following section. The X-band cavity BPM offers the advantage of being a small compact detector that inherently reads zero when the beam is centered in the chamber. The X-band cavity BPM size, simple fabrication, and high resolution due to the cylindrical geometry make it an ideal choice for the LCLS beam position detection. Figure 1 shows the cross section of the cavity BPM. The beam passes through the first upstream reference cavity, shown in Figure 1 on the left, which excites the TM_{010} monopole mode signal at 11.384 GHz, proportional to the beam intensity or charge. The second cavity, which is 37 mm downstream, is the TM_{110} dipole cavity shown to the far right in Figure 1. The beam pipe diameter is 10 mm. The amplitude of the dipole signal produces a signal that is directly proportional to the beam displacement. Both of these signals are required in order to extract a normalized position for both horizontal and vertical planes. The cavities are designed from the requirements in Table 2 and the mechanical parameters given in Table 3.

The rectangular waveguide outputs shown in Figure 1 are at right angles to the dipole cavity, which couples magnetically to the dipole mode and not the monopole. This selective coupling technique, pioneered by SLAC, has been incorporated in this design. SLAC has collaborated on the cavity design, and many of the innovations, such as selective coupling, have been incorporated in this design. The outputs of the cavity are fed into waveguide transitions. The vacuum windows are brazed into the WR75 waveguide flanges. There are two waveguide outputs for each plane on the dipole cavity. The output flanges are connected directly to the flexible WR75 waveguide to ensure mechanical decoupling of any shock or vibration from the rest of the components.

Figure 1: X-band Cavity BPM Cross Section

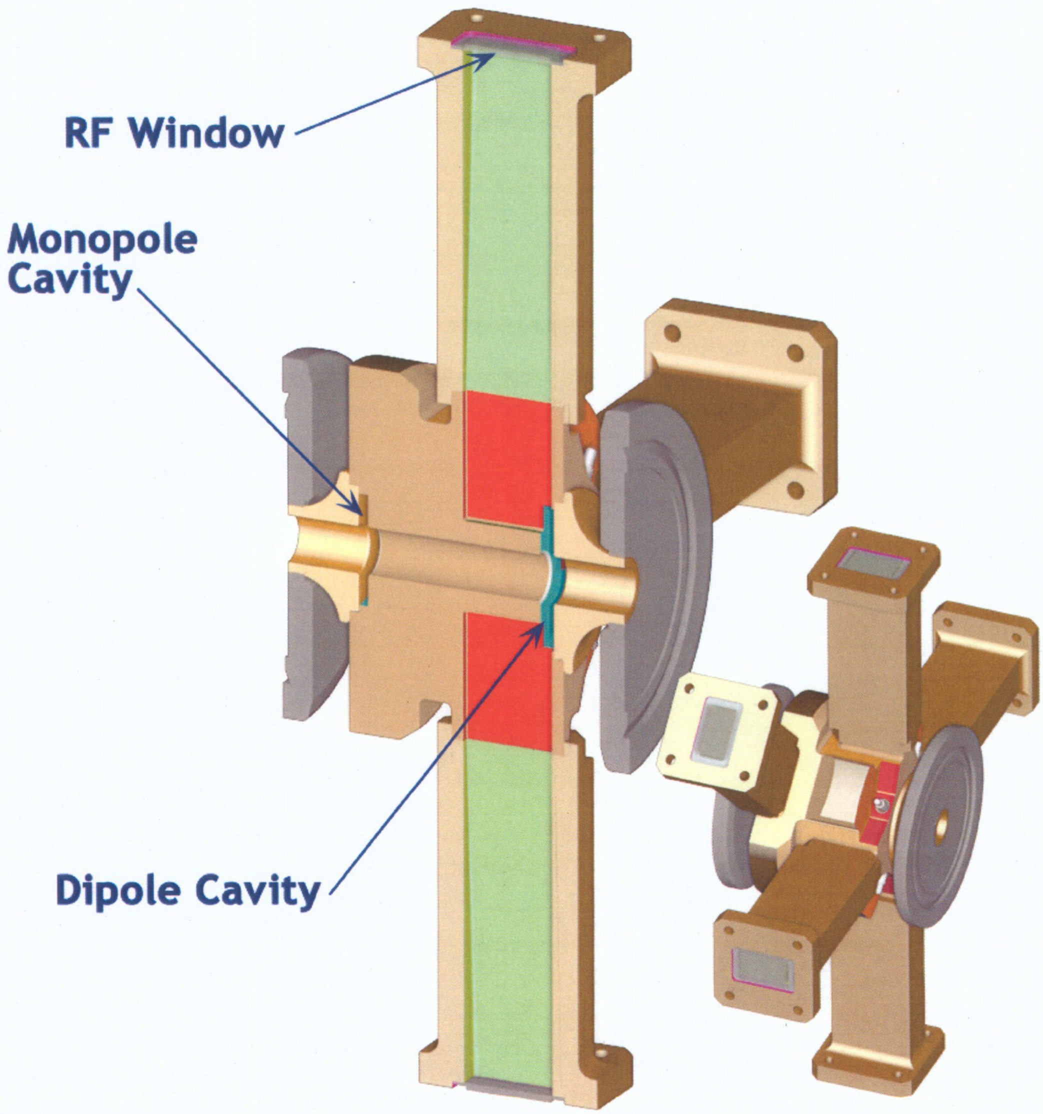

Table 2: X-Band Cavity Requirements

Parameter	Specification Limit	Condition
TM_{110} Frequency Dipole Cavity	11.384 GHz	20.0 ± 0.56 Celsius
Loaded Q factor Dipole Cavity	3000 ± 200	20.0 ± 0.56 Celsius
Power Output TM_{110} Dipole Cavity	-10 dBm	20.0 ± 0.56 Celsius 1-nC, 1-mm offset, 200-fs BL
X/Y Cross Talk Dipole Cavity	< -20 dB	± 1 mm range 20.0 ± 0.56 Celsius
TM_{010} Frequency Monopole Cavity	11.384 GHz	20.0 ± 0.56 Celsius
Loaded Q factor Monopole Cavity	3000 ± 200	20.0 ± 0.56 Celsius
Power Output TM_{010} Monopole Cavity	-10 dBm	20.0 ± 0.56 Celsius 1-nC, ± 1-mm offset range, 200-fs bunch length

Table 3: Cavity Mechanical Parameters

Mechanical Design Parameters	Design Values for Dipole	Design Values for Monopole
Beam pipe radius	5 mm	5 mm
Cavity radius	14.937 mm	11.738 mm
Cavity gap	3 mm	2 mm
Beam axis to bottom of WG	9.5 mm	1.734 mm
Coupling Slot	n/a	4 x 2 mm
Waveguide	19.05 mm × 3.0 mm	19.05 mm × 3.0 mm

2.1.1 Cavity BPM Fabrication

The cavity beam position monitor (BPM) is a brazed assembly made up of the body, waveguide transitions, end caps RF windows, and end EVAC-type vacuum flanges. The parts shall be machined per the specifications of the supplied drawings. The monopole and dipole cavities, the beam port, and waveguide outputs are machined into a single piece of oxygen-free electronic (OFE) copper. To facilitate alignment, the outer surface of the BPM body is machined to 0.025 mm of its diameter true position. This surface will be used to align the BPM during installation in the LTU. The cavities dimensions are machined within a +0.000/-0.015 mm tolerance, with a surface finish of 0.1 μm (4 μin Ra) or better. The maximum -0.015 mm machining tolerance deviation will equate to a frequency increase of 7.5 MHz which is within the system tuning capability. The beam port dimensions are machined within ±15 μm tolerance, with a surface finish of 0.1 μm (4 μin Ra) or better. Each beam tube and end cap feature is also machined into one piece of OFE copper. The end caps surface that encloses the cavity gap and the beam ports are machined to a surface finish of 0.1 μm (4 μin Ra) or better. All surfaces with a 0.1 μm (4

μin Ra) finish shall be done using a process that will prevent contaminants to be embedded in these surfaces. The end caps are brazed over the cavity gaps, using a gold copper filler alloy to enclose each cavity gap. The final assembly includes waveguide transitions brazed onto the waveguide outputs from the BPM body with a gold copper filler alloy. Included in this final assembly are RF windows that are made from glass fused onto a kovar base. The kovar is plated with nickel and then copper to facilitate brazing. The windows are brazed into the waveguide transitions. End flanges are of the EVAC CeFix type, made from 316L stainless steel, are machined and brazed unto the end caps such that the beam will be exposed to copper surfaces only, as it passes through the BPM. All brazing is done in a vacuum atmosphere back-filled with dry hydrogen. The final assembly must be vacuum leak tight when checked with a helium mass spectrometer leak detector with a minimum sensitivity of 2×10^{-10} Std. atm.-cc/sec (helium) as defined by the American Vacuum Society Standards 2.1 and 2.2. The brazed assembly shall be packaged in a manner that will prevent damage to the part in shipment. The brazed assembly will be wrapped in oil-free aluminum foil and placed in a sealed plastic bag that is filled with dry nitrogen gas.

2.2 Receiver Electronics Assembly

The receiver topology used is a single-stage three-channel heterodyne receiver shown in Figure 2. The cavity BPM X-band signals are mixed down to a 25-50 MHz intermediate frequency (IF) in the accelerator tunnel. Cavity X-band signals are first amplified in a Low Noise Amplification (LNA) stage, then translated to a lower Intermediate Frequency (IF): $f_{IF} = f_{LO} - f_{RF}$. The Local Oscillator (LO) can be phase-locked to the SLAC 119-MHz timing. A single LO will drive all three channels and will be housed in the receiver chassis. The LNA is protected against high-power surges by a limiter that is rated at 50 watts peak. After the X-Band signals are down-converted, they are filtered and then amplified. The signals are now ready to be cabled out of the tunnel. Table 4 specifies the electrical parameters for the receiver.

Figure 2: System Block Diagram for In-Tunnel Electronics

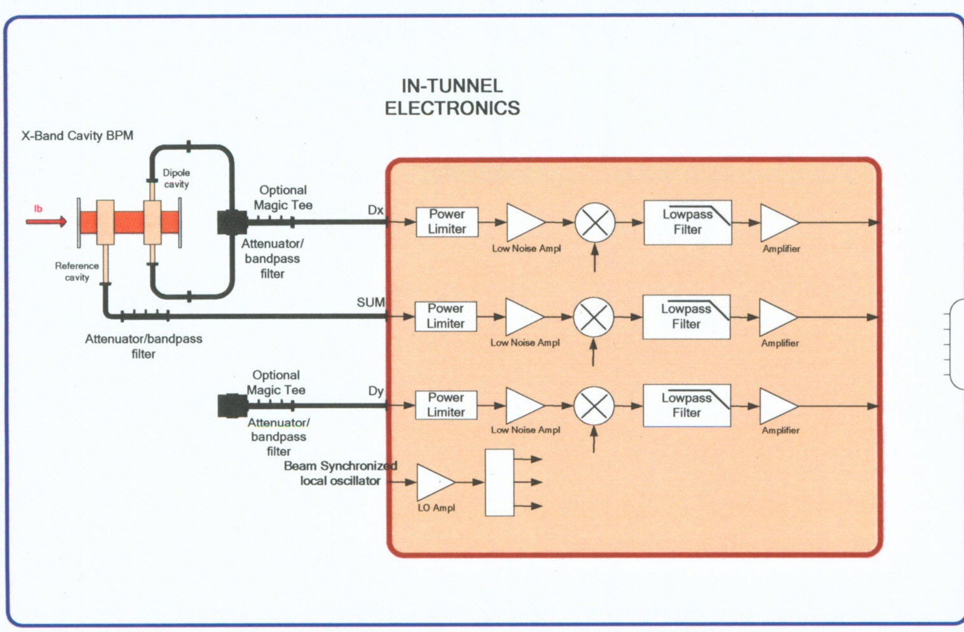

Table 4: Receiver Electrical Parameters

Parameter	Specification Limit	Condition
RF Frequency	11.384 GHz	20.0 ± 0.56 Celsius Dx, Dy, Intensity
Input Peak Power	50 watts peak	No damage (limiter protection)
LO Frequency	11.424 GHz (2856 MHz*4)	20.0 ± 0.56 Celsius 1nC, 1mm offset, 200fs BL
LO Power Range	+10 dBm Max.	Provide LO for 3 downconverters
IF Frequency	25-50 MHz.	20.0 ± 0.56 Celsius
Noise Figure	2.7 dB Max.	20.0 ± 0.56 Celsius
Noise Figure Intensity (reference)	4.0 dB Max.	20.0 ± 0.56 Celsius
LO to RF Isolation	40 dB Min.	20.0 ± 0.56 Celsius
LO to IF Isolation	45 dB Min.	20.0 ± 0.56 Celsius
Output Power	+14 dBm	1 dB compression
Conversion Gain	25 dB typical	20.0 ± 0.56 Celsius

2.2.1 Receiver Mechanical

The unit shall meet the following mechanical specifications:
Enclosure: The unit shall be packaged in a 3" height × 12" width × 12" depth shielded enclosure.
Connectors: 3-WR 90 waveguide flanges (RF Inputs)
3-Type "N" bulkhead connectors (IF Outputs)
1- 9 pin "D" type connector (control and power)
1- SMA female type connector (119 MHz LO sync)

2.2.2 Environmental

The unit is installed in the LCLS tunnel. The electronics will be designed in a radiation-hardened box sealed from moisture. The operating temperature range is 20 to ± 0.56ºC. The unit will not dissipate more that 20 watts and can be heat sunk. Special consideration shall be given to reducing possible EMI susceptibility and emissions by using DC blocks on the inputs, EMI gaskets, feedthrough pins, and proper grounding.

2.3 Data Acquisition

It is Argonne's intent to use the same data acquisition system that SLAC uses on the LINAC BPM upgrade. The minimum requirements will be 14-bit, 105 MSPS converter with a 270-MHz input bandwidth. The ADCs can be synchronized to the frequency of the 119-MHz timing system of the SLAC linac. The expected output of the receiver will be a bi-polar +/- 1 volt exponentially decaying sine wave between 175-260 ns (Q=2000-3000) duration at full scale. The proposed system can measure up to 24 points on the video waveform with 14-bit resolution.

2.4 BPM Support System

The BPM will be supported independently of all devices upstream and downstream of its installation. The support system will provide for manual adjustments in the X and Y planes. Adjustments will be done using screws with compound thread systems that will provide 141-μm adjustments per turn. The supports and BPM mounting pillars will be made of titanium or AR 36 steel.

3.0 OTHER REQUIREMENTS

3.1 Cabling

The receiver will be separated by a maximum distance of 300 feet from the data acquisition. The cables from the down-converted output will be transmitted via ¼-inch Andrew Corp FSJ150 heliax cables. The DC and control will be transmitted via a shielded twisted pair cable. The detailed design of the cabling will be specified at a later date. SLAC is responsible for establishing general guidelines for acceptable cables. ANL will submit all proposed designs to SLAC for final approval before installation.

3.2 Packaging and Shipping

The brazed assembly will be wrapped in oil-free aluminum foil and placed in a sealed plastic bag that is filled with dry nitrogen gas. It will then be packaged in a reusable molded plastic case with foam of minimum thickness 6 inches all around and shipped to Argonne by air.