LCLS-II HIGH POWER RF SYSTEM OVERVIEW AND PROGRESS*

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Abstract

A second X-ray free electron laser facility, LCLS-II, will be constructed at SLAC. LCLS-II is based on a 1.3 GHz, 4 GeV, continuous-wave (CW) superconducting linear accelerator, to be installed in the first kilometer of the SLAC tunnel. Multiple types of high power RF (HPRF) sources will be used to power different systems on LCLS-II. The main 1.3 GHz linac will be powered by 280 1.3 GHz, 3.8 kW solid state amplifier (SSA) sources. The normal conducting buncher in the injector will use four more SSAs identical to the linac SSAs but run at 2 kW. Two 185.7 MHz, 60 kW sources will power the photocathode dual-feed RF gun. A third harmonic linac section, included for linearizing the bunch energy spread before the first bunch compressor, will require sixteen 3.9 GHz sources at about 1 kW CW. A description and an update on all the HPRF sources of LCLS-II and their implementation is the subject of this paper.

INTRODUCTION

The Linac Coherent Light Source II (LCLS-II) is being designed and constructed at SLAC due to the high user demand of the successful operation of the first LCLS at SLAC, the only light source of its kind in the world to date [1]. LCLS-II will use a 4 GeV continuous wave (CW) superconducting 1.3 GHz linac [2]. Figure 1 shows the basic layout of LCLS-II, consisting of a dual-feed photocathode RF gun; a normal conducting double cavity 1.3 GHz buncher, each cavity fed by two RF sources; 280 superconducting 1.3 GHz linac cavities, each fed by its own solid state amplifier (SSA) and grouped into cryomodules (CM) of eight cavities that form each of the linac regions: L0 consisting of one CM, L1 consisting of two CM, L2 consisting of twelve CM and L3 consisting of twenty CM; a laser heater (LH) after L0; two magnetic bunch compressors BC1 and BC2 after L1 and L2 respectively; and sixteen 3.9 GHz superconducting cavities, also fed by individual RF sources and grouped in two cryomodules of eight cavities each to form the Harmonic Linearizer between L1 and BC1 to linearize the beam energy spread prior to the first magnetic bunch compressor.

Table 1 lists all the RF systems in LCLS-II. LCLS-II is currently in the design phase in partnership with FNAL, JLAB, LBNL, ANL and Cornell University. A wider status report is given in [3], while this report focuses on the high power RF (HPRF) system. The initial thrust of the HPRF systems tasks has been to specify the RF sources for the L-band linac, lay out the source rack and waveguide configurations, specify the various waveguide components such as isolator and directional coupler, and resolve any space co-occupancy conflicts such as with low level RF (LLRF) racks, cable conduits and penetration shields. Some preliminary design for the S-band linearizer RF and considerations about the gun and buncher RF and non-ionizing radiation protection (NIRP) are also in progress, but a more substantial report about these systems will be presented in the future.

Table 1: LCLS II HPRF Sources

Region / **RF Source**	**Frequency** (MHz)	**Power** (kW)	**Quantity**
Gun / TBD, likely SSA	185.7	60	2
Buncher / SSA	1,300	3.8	4
Linac (L0– L3) / SSA	1,300	3.8	280
Harmonic Linearizer / TBD, likely SSA	3,900	~1	16

L-BAND SOLID STATE AMPLIFIERS

A total of 284 L-band SSAs will power the L-band systems on LCLS-II. The SSAs need to supply up to 3.8 kW of RF power with a 10 dBm or less (preferably $\leq$ 5 dBm) RF drive signal. The small signal, 1 dB bandwidth should be $\geq$ 1 MHz, amplitude flatness < 5%, and phase deviation < 5° within 100 kHz of the nominal frequency. The nominal maximum power must be achieved at 1 dB compression, and the harmonic power output must be < -30 dBc. The overall efficiency of the SSA from wall AC to output power must be > 40%, the SSA power supply efficiency should be > 90% and its power factor should be > 0.9 to meet the electric company's requirement for harmonics returned to the power lines.

The SLAC facility requirements for each L-band SSA are 11 KVA of 480 V power, 250 VA of 120 V power, and low conductivity water (LCW) of 30 °C at 40–70 psi, with $\leq$ 30 psi pressure drop across the SSA. In case of accidental failures of the LCW controls upstream, the SSA should be able to withstand an LCW pressure of as high as 150 psi. All RF connections inside the SSA are to be RF tight so as to comply with NIRP requirements for

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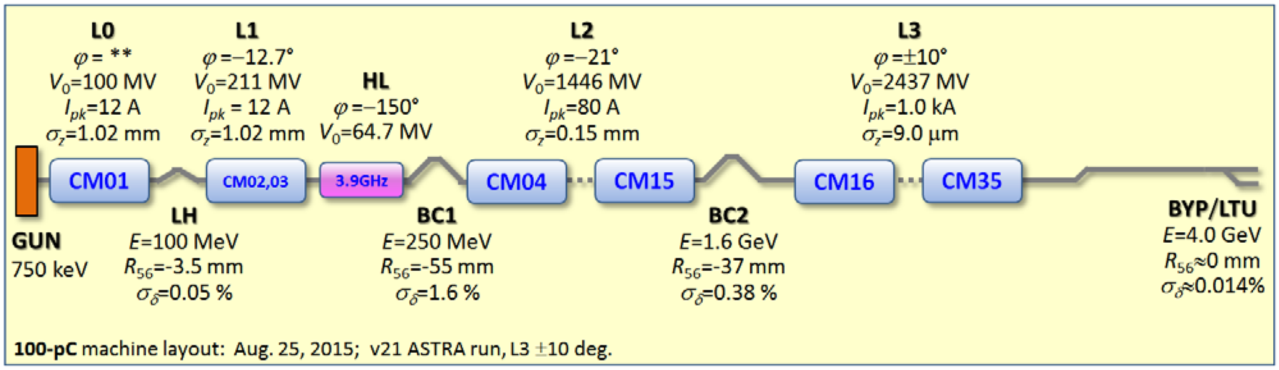

Figure 1: LCLS II Beamline Diagram

personnel safety and must withstand up to 4 psig of positive gas pressure on a continuous basis. The SSA racks are closed from all sides and the ambient environment inside is to be ≤ 45°C. The racks, though placed indoors, are not in a temperature-controlled environment and must operate successfully in the northern California weather of 4 °C < T < 45 °C, 10% to 100% relative humidity and 10 °C dew point. The mean time between failures (MTBF) of major components such as the power supply system should be ≥ 30,000 hours, and ≤ 1% of the transistor pallets should fail in 2,000 hours. The failure of at least one transistor pallet must not inhibit the operation of the SSA due to reflected power thresholds on the other pallets. The SSA is to protect itself from large RF reflections, accidents that may cause overheating, water leaks and other failures that may damage the SSA. Various electrical and ergonomic safety, as well as seismic, requirements are imposed on the SSA racks, based on national standards and SLAC procedures.

The footprint of each SSA may not exceed 30″ (front and back) × 50″ (sides), and the SSAs must be able to be lifted by forklifts from either direction. The mounting bolt hole pattern is specified so that SSAs supplied by multiple vendors will be interchangeable with each other. The output waveguide is to be L-band WR650, with a projection in the geometric center of the bolt hole pattern, oriented with the broad side perpendicular to the side and the top of the flange 84″ from the floor, such that interchanging SSAs from different manufacturers does not require waveguide reconfiguration.

Taking advantage of the existing building infrastructure at SLAC, LCLS-II has been laid out to occupy the first one third of the SLAC linac housing. The linac housing includes an RF source and utilities gallery, historically called the Klystron Gallery, and the accelerator tunnel. The gallery and the tunnel are connected with each other by many 25 ft.-deep penetrations, at 20 ft. intervals,

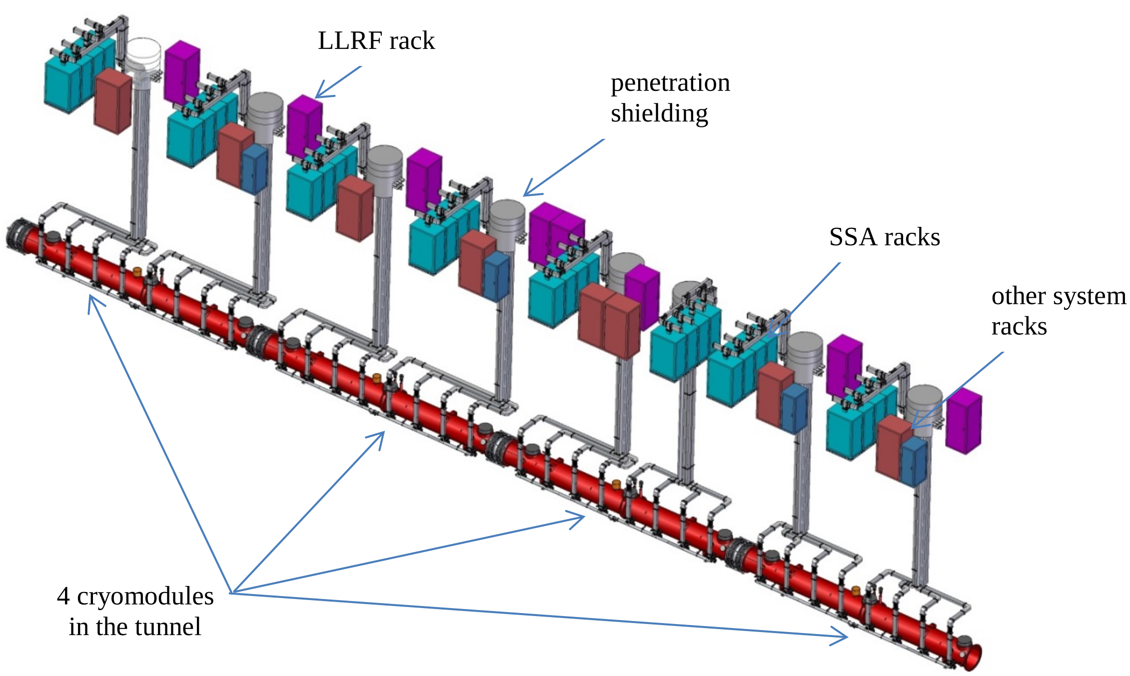

Figure 2: Gallery and tunnel layout of eight penetration or four cryomodule section of LCLS II

through which are routed RF waveguides, conduits, cables and utilities from the gallery to the tunnel. Each cryomodule, containing eight cavities powered by eight SSAs, spans approximately two of these 27″ diameter penetrations, as shown in a four-cryomodule layout in Figure 2.

The installation around each penetration shaft thus contains four SSA racks, one LLRF rack and one or two other system racks, as illustrated in Figure 3. Many safety and accessibility requirements had to be met in laying out these racks near the penetrations: the backs of the SSA racks (and other racks), where the 480 V and 120 V SLAC AC power are connected, must be at least 48″ from the nearest obstruction; the SSA must be accessible to be moved by a forklift after it and all the other racks near it have been located; the LLRF rack must be as close to the penetration as possible and not too far from the SSAs; a 2 to 3 ft. thick (depending on location along the linac) concrete radiation shielding cap must be placed over the penetration, while allowing the waveguides and cable conduits to pass through it and respecting the rack clearances; and the north and south gallery aisles must be kept clear. The final arrangement is illustrated in a plan view of the systems around one shaft in Figure 3.

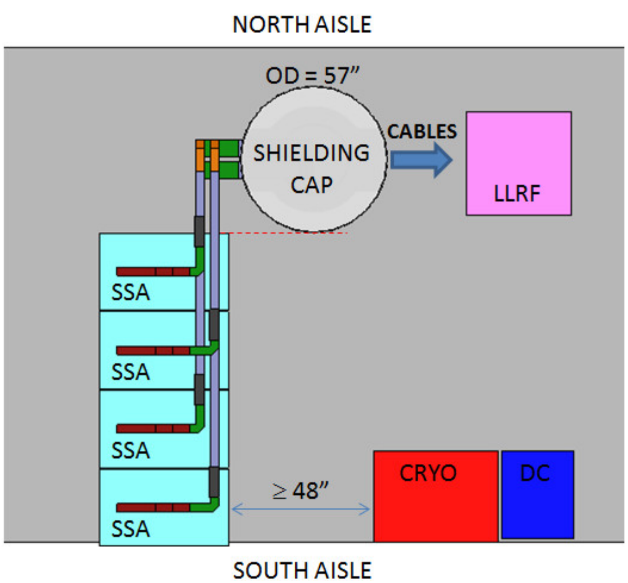

Figure 3: Projection of a single penetration layout.

The first batch of LCLS-II SSAs, which will be used at partner labs FNAL and JLAB for cryomodule testing, are expected to arrive in the fall of 2015.

L-BAND WAVEGUIDE SYSTEM

The RF power from each SSA is transported to the cryomodule via a WR650 waveguide feed line. The waveguide system includes an isolator, a bi-directional coupler, two semi-flex guides, various straight sections, and E and H-plane bends, as shown in Figure 4. The isolator, which is to protect the SSA from reflected and discharged power, is placed right above the SSA output waveguide port, followed by an E-plane bend and then a semi-flex guide to facilitate connection. The directional coupler is located in the tunnel, close to the input of the cavity fundamental power coupler on the cryomodule,

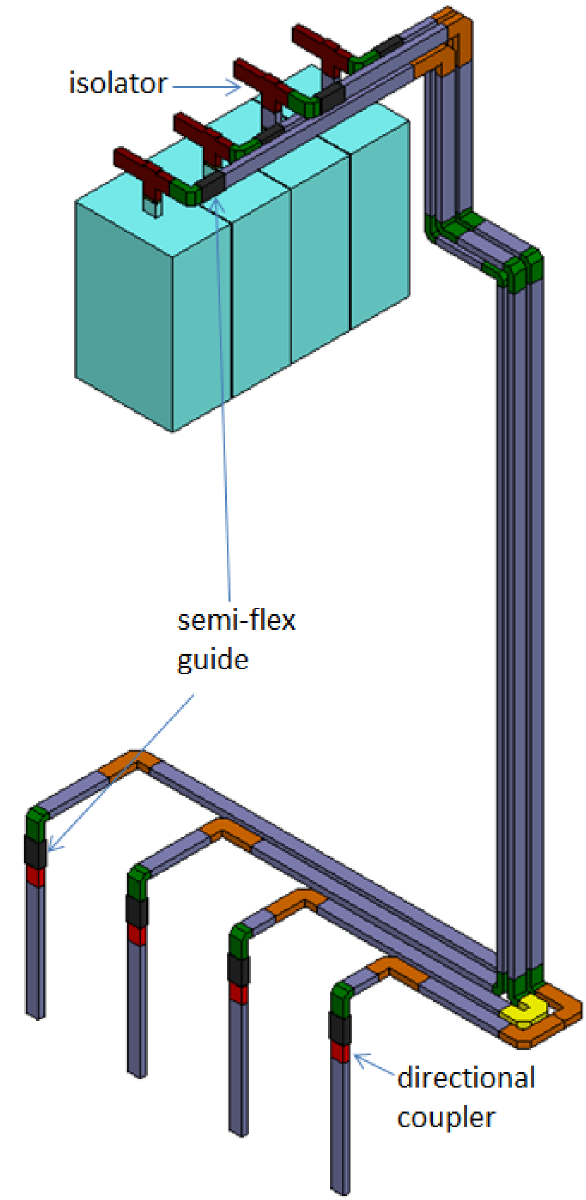

Figure 4: Waveguide system layout from four L-band SSAs to four cavity couplers through one penetration.

though not right on it to avoid evanescent fields from its matching section. Above the directional coupler is another semi-flex guide. The waveguide runs from the SSA all the way to the bottom of the penetration are identical for every penetration, and the vertical sections from the cryomodule to the tunnel ceiling are identical for all the L-band cryomodules. Only the horizontal distribution near the tunnel ceiling varies from penetration to penetration, because the alignment along the tunnel of the cryomodules is not fixed relative to the utilized penetrations, requiring customized lengths. As seen in

Figure 2, the combination of directions of the feeds along the tunnel also varies. For spatial considerations, such as accommodating cable trays, the waveguide distribution is restricted to one layer in the tunnel.

The waveguide system will slightly pressurized with dry air to about 2 to 4 psig positive pressure to keep it clean as well as to be used in the non-ionizing radiation protection plan. The isolators will be designed to absorb the full 3.8 kW of reflected power at any phase with more than 25 dB isolation. They are cooled from the LCW water system exiting their respective SSAs. The directional couplers will provide both forward and reflected power signals, with better than 40 dB directivity, to LLRF controls.

ALL OTHER HPRF SYSTEMS

Other HPRF systems include the the 3.9 GHz harmonic linearizer RF, the 187.5 MHz gun power and 1.3 GHz buncher RF, and the Non Ionizing Radiation Protection system. These systems are in their early development stages and will be reported on in future papers. The final design review of the LCLS-II L-band high power RF system is currently scheduled for April 2016.

SUMARY

The design of the LCLS-II high power RF system is currently progressing on schedule, with the L-band systems at a very mature stage and the other systems to follow. Designing and laying out the LCLS-II high power RF systems involves coordination of with many other systems, such as accelerator, controls, cable plant, facilities and safety. Final design reviews of LCLS-II High Power RF will be held in April 2016 for the main L-band systems and in August 2016 for the remainder.

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