OVERVIEW OF THE RF SYSTEMS FOR LCLS*

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Abstract

The Linac Coherent Light Source (LCLS) at SLAC, when it becomes operational in 2009, will provide its user community with an X-ray source many orders of magnitude brighter than anything available in the world at that time [1]. The electron beam acceleration will be provided by existing and new RF systems capable of maintaining the amplitude and phase stability of each bunch to extremely tight tolerances. RF feedback control of the various RF systems will be fundamental in ensuring the beam arrives at the LCLS undulator at precisely the required energy and peak current phase. This paper details the requirements for RF stability for the various LCLS RF systems and also highlights proposals for how these injector and Linac RF systems can meet these tight constraints.

INTRODUCTION

RF stability is of primary concern when evaluating the various RF requirements for LCLS. Right from the birth of electrons off the main LINAC axis at the RF gun (see Figure 1), through their capture into the first accelerating LINAC section in L0. The beam is then transferred into the main SLAC LINAC and subsequent pre-acceleration in L1, before being decelerated in a harmonic RF system at LX to linearize the energy-time curvature imparted by the preceding S-band accelerators. It then enters the first bunch compressor BC1 and subsequently accelerated up to 4.3 GeV in the L2 LINAC. A final bunch compression stage BC2 is then followed with final acceleration up to 13.6 GeV in L3 before transporting in to the main Undulator. At each and every stage of the acceleration process, errors in the beam transport can destroy the coherent nature of the synchrotron radiation produced for users in the Undulator hall. Amplitude and phase feedback control of the various RF acceleration stages will be critical in achieving the stringent stability required for LCLS.

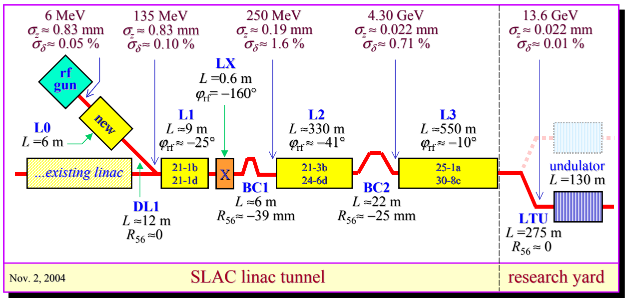

Figure 1: LCLS LINAC Schematic.

Mechanisms for achieving the required stability have been investigated and hardware and software is currently being developed for phased implementation, starting with the injector system for proposed first use in early 2007.

RF STABILITY

In order to set up precise energy position correlations for the five LCLS LINACs along the bunch for compression to a level of 80 fs, the phase and amplitude regulation of all the associated RF components is critical. Table 1 shows the required amplitude and phase stability tolerances needed for each LCLS RF system in order to achieve the required beam quality at the main undulator.

There are a total of eight klystrons in the LCLS design in the injector and early part of the bunch compression process that will require both phase and amplitude feedback. Measurements have shown that the stability required for LCLS of the SLAC LINAC RF stations can be maintained over several seconds by the existing control systems. To achieve a level of stability at <2 second sampling, additional phase and amplitude feedback will be needed, in addition to beam-based feedback [2]

Table 1: LCLS RF System Stability Requirements

For $|(\Delta E/E_o)| < 0.1\%$ **and** $|\Delta I/I_o| < 12\%$.

Parameter	Symbol	LCLS$^{\forall}$	Unit
Gun Timing jitter	Δt_o	0.50	ps
Initial Bunch Charge	$\Delta Q/Q_o$	2.0	%
Mean L0 RF Phase	φ_o	0.1	Deg
Mean L1 RF Phase	φ_1	0.1	Deg
Mean LX RF Phase X-band	φ_x	0.5	X-Deg
Mean L2 RF Phase	φ_2	0.07	Deg
Mean L3 RF Phase	φ_3	0.15	Deg
Mean L0 RF Voltage	$\Delta V_o/V_o$	0.1	%
Mean L1 RF Voltage	$\Delta V_1/V_1$	0.1	%
Mean LX RF Voltage	$\Delta V_x/V_x$	0.25	%
Mean L2 RF Voltage	$\Delta V_2/V_2$	0.1	%
Mean L3 RF Voltage	$\Delta V_3/V_3$	0.08	%

$^{\forall}$All values are rms and pertain to time scales < 2 s.

LCLS RF REQUIREMENTS

RF Gun

The 2856 MHz LCLS RF gun is a modified version of the UCLA/BNL/SLAC 1.6-cell S-Band RF gun [3]. A more detailed description of the LCLS RF Gun design (see Figure 2) can be found elsewhere [4][5], however its design parameters are shown in Table 2.

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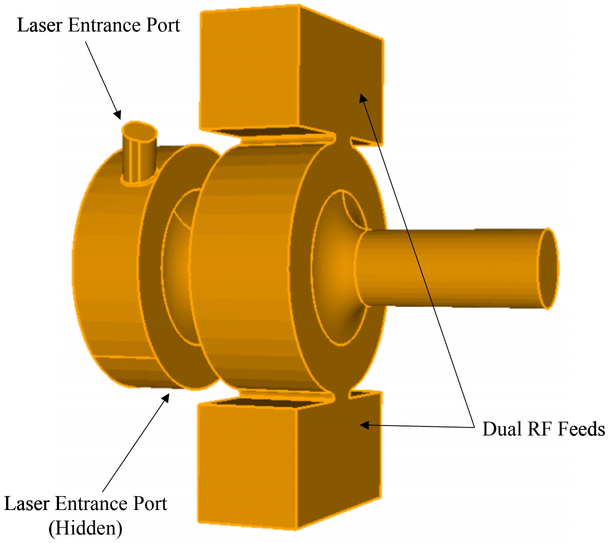

Figure 2: LCLS Dual-feed RF Gun Design.

The changes that have been incorporated include: a larger π to 0-mode frequency separation (15 MHz c.f. 3.5 MHz), a larger radius at the iris between the 2 cells, a reduced surface field on the curvature of the iris between the two cells, increased cooling channels for operation at 120 Hz, dual RF feeds, deformation tuning of the full cell and field probes in both cells. Temporal shaping of the klystron pulse is also to be adopted, to reduce the average power dissipated in the RF gun assembly. All of these are employed to try and mitigate electro-magnetic and/or mechanical mechanisms for instability growth in the RF gun.

Table 2: LCLS RF Gun Design Parameters

Parameter	Value	Unit
Operating Frequency	2856	MHz
Mode Separation	15	MHz
Coupling Factor	2	
Shunt Impedance	49	MΩ/m
Unloaded Quality Factor	12000	
Loaded Quality Factor	4000	
Accelerating Gradient	120	MV/m
RF Power (peak)	30	MW
Duty Cycle	120	Hz
RF Pulse Length	3	μs

The waveguide from a single existing S-band klystron (20-6) will be re-routed to power the new LCLS RF Gun. Both phase and amplitude control will be required for this source, necessitating it to be run out of saturation to achieve the 30 MW of peak power required at the gun input.

LINAC L0

For the L0 LINAC, two accelerating structures L0-a and L0-b will have similarly re-deployed S-band klystrons (20-7 and 20-8) again being run un-saturated for stability control reasons. L0-a needs an accelerating gradient of 19.5 MV/m, requiring 35 MW of peak power, whilst L0-b is to be run at a higher gradient of 24 MV/m requiring 46 MW at the structure.

LINAC L1

A single klystron (21-1) will feed three accelerating structures in L1 and will also operate un-saturated to allow for fast amplitude feedback control. RF power will be split in the ratio of 50:25:25 % for the accelerating sections to achieve the required total energy gain of 130 MeV for L1.

LINAC LX

A 4th harmonic RF system (LX), operating at 11.424 GHz [6][7] will be utilized to remove the non linear components of the energy gradient across the bunch as it exits L1, to allow for more efficient bunch compression at the downstream bunch compressor chicanes BC1 and BC2. A 60cm long NLCTA X-band accelerating structure will provide the 19 MV decelerating voltage, powered by 21 MW from an XL-4 klystron.

LINAC L2

A total of 28 klystrons (21-3 to 24-6) will be employed for L2, which include three operational stand-by units if needed. All but 2 of the 25 klystrons will operate fully saturated, so that no amplitude feedback is to be implemented for these klystrons. The remaining 2 klystrons (at the end of L2) will operate un-saturated to enable amplitude feedback regulation at high energy only. The average L2 phase control will be achieved via phase-feedback on the final sector klystrons (24-1 to 24-6) in L2.

LINAC L3

L3 will operate with 48 klystrons (25-1 to 30-8) fully saturated, 4 of which are operational stand-by units. Phase and amplitude control of L3 will be done by phase adjustments of the last two sectors. Opposing phase adjustments will be used to adjust amplitude and synchronous adjustments used to adjust phase to match into the LCLS undulator.

RF TIMING AND DISTRIBUTION

The main LCLS LINAC RF and Timing signals will be coupled off the 476 MHz reference Main Drive Line (MDL), 2/3 down the SLAC 2-mile LINAC at the end of sector 20. A local oscillator will be phase locked to this reference and will be used as the RF source for the RF Gun Laser, L0, L1 and LX. LCLS will use the existing timing and RF distribution systems of the MDL for L2 and L3. The phase stability of the MDL system will not however currently meet LCLS specifications for the RF Gun Laser, L0, and L1, therefore a new system is being developed (see Figure 3) to reduce phase noise levels and eliminate the phase and frequency shift as seen on the MDL.

LCLS will run at a duty cycle of 120 Hz and during every 3rd cycle of the 360 Hz timing system, the RF will be stable for a period of 2.8 mS. A phase locked loop (PLL) is used to sample and hold at 120 Hz during this phase stable period. Outside of this LCLS timing window the 476MHz RF reference will change by as much as 720º, but will return to the original phase before the next 120Hz cycle. The phase noise of this system must be stable to within 50 fs rms during LCLS beam operation. The laser phase lock reference will come from this system and a second PLL will lock the output of the 119 MHz laser oscillator to the 476 MHz reference.

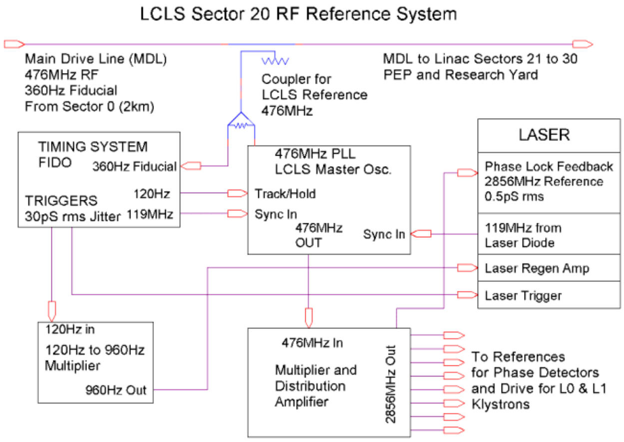

Figure 3: New LCLS Timing System Front-end.

RF FEEDBACK AND CONTROLS

Variations in phase or amplitude of the LCLS LINAC RF systems will result in energy and bunch length deviations, which have to be minimized wherever possible. All LCLS klystrons will use their existing phase and amplitude control systems to set the klystron phase and amplitude stability to within 10º (S-band) and 2 % respectively.

A proposed beam-based RF feedback system is being developed which reacts to system variations, providing an improved level of stability regulation to achieve the LCLS stability levels identified in Table 1. As well as using accelerating structure phase and amplitude diagnostics, beam-based feedback will also be employed to provide the high degree of fast feedback control needed; beam energy will be measured using a BPM in a high dispersion region and bunch length will be measured using Coherent Synchrotron Radiation (CSR) calibrated with an RF deflecting cavity. The phase and amplitude of the respective accelerating structures will also be precisely controlled by a new control system to a level of 0.1º (S-band) and 0.08 %.

It is not possible to get an accurate measurement of the phase in an accelerating structure as seen by the beam from simply looking at the input or output RF signals alone. It is however possible to determine the phase as seen by the beam to better accuracy if the input phase, output phase, and temperature of the structure are known. The standard SLAC 10ft accelerator structure temperature coefficient is 8º (S-band)/ºF and water temperature stability is regulated to 0.1º F. The new LCLS control system will support feedback for critical klystrons based on these parameters.

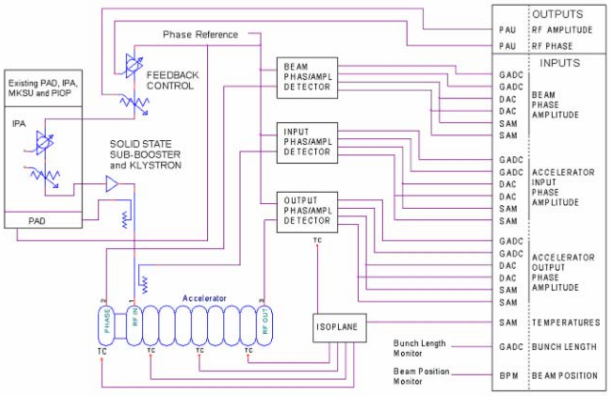

Figure 4: Typical LCLS Klystron Feedback.

CONCLUSIONS

Reconfiguration of existing SLAC LINAC RF components has been identified to facilitate the requirements for LCLS, whilst also retaining the capability for efficient injection into PEP-II and the ability to accelerate beams up to 50 GeV for high intensity users.

The new LCLS RF system will be able to attain LCLS requirements for at least several seconds. Beyond this, temperature variation in cables and RF structures will cause the system to drift outside LCLS specifications. Beam-based feedback will be implemented for fine corrections on the RF to achieve LCLS goals for beam stability and bunch compression.

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