LCLS LLRF System*

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Abstract

The bunch compression techniques used to achieve the high brightness for LCLS at SLAC impose challenging tolerances on the accelerator RF phase and amplitude. The existing SLAC linac RF phase and amplitude stability and the requirement of the new RF system for LCLS is summarized The improved low noise RF distribution system and the control and monitoring system will be described in this paper.

1. Instruction

The LCLS linac is broken down into 4 separate linac sections. The LCLS injector L0, which has 2 S-Band klystrons, will reside in an off axis tunnel at the end of sector 20 of the SLAC main linac. Linac 1 will have 1 S-band klystron and 1 X-band klystron. LCLS linacs 2 (28 klystrons) and 3 (48 klystrons) are made up of the last third of the main linac sectors 21 to 30 as shown in figure 1[1].

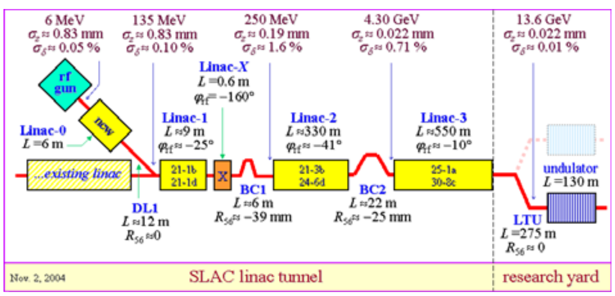

Figure.1 The LCLS Linac

To set up energy position correlations along the bunch for compression to 80fS lengths, the phase and amplitude settings of the RF are critical. The existing timing and RF distribution system of the main linac will not meet LCLS specifications for the laser, RF Gun, linac 0, and linac 1.

2. LCLS RF Stability Requirements

LCLS specifications require RF stability of 0.1%rms in amplitude and 100fSrms in 850nS fill time S-Band structure, but the tightest tolerance is 125fSrms in a 100nS fill time X-Band structure. The phase and amplitude of each of the 3 klystrons in linac 0 and the S-band and X-band klystrons of linac 1 must be held to the specifications listed in Table 1[2]. Tests on the linac's high power S-Band systems show this stability can be maintained over the several seconds by the existing systems[1]. Beyond 2 seconds feedback will be required to adjust the phase and amplitude of the above listed systems. The peak to peak diurnal variations in the existing system are within ±2% amplitude and ±5° S-Band over 10 sectors as seen by looking at many parameters in the control system. For the multi-klystron linacs, individual klystrons are allowed higher jitter as long as the linac total RF phase jitter as seen by the beam if within the tolerance. The accuracy of the phase measurement system needs to be within 1pS, where beam based feedback[3] will be able to make corrections.

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Parameter	Symbol	$\lvert \Delta I/I0 \rvert$ < 12%	$\lvert\langle \Delta E/E0 \rangle\rvert$ < 0.1%	Unit
mean L0 rf phase	φ_0	**0.10**	0.10	deg
mean L1 rf phase	φ_1	**0.10**	0.10	deg
mean LX rf phase	φ_X	**0.5**	0.5	deg
mean L2 rf phase	φ_2	**0.07**	0.07	deg
mean L3 rf phase	φ_3	0.5	**0.15**	deg
mean L0 rf voltage	$\Delta V_0/V_0$	**0.10**	0.10	%
mean L1 rf voltage	$\Delta V_1/V_1$	**0.10**	0.10	%
mean LX rf voltage	$\Delta V_X/V_X$	**0.25**	0.25	%
mean L2 rf voltage	$\Delta V_2/V_2$	**0.10**	0.10	%
mean L3 rf voltage	$\Delta V_3/V_3$	0.5	**0.08**	%
BC1 chicane	$\Delta B_1/B_1$	**0.01**	0.01	%
BC2 chicane	$\Delta B_2/B_2$	**0.05**	0.05	%
Gun timing jitter	Δt_0	**0.8**	0.8	psec
Initial bunch charge	$\Delta Q/Q_0$	**2.0**	4.0	%

Table 1 RMS tolerance budget for <12% rms peak-current jitter (column 3) or <0.1% rms final $e-$ energy jitter (column 4). The tighter tolerance is in BOLD, underlined text and both criteria, $\lvert DI/I0 \rvert < 12\%$ and $\lvert\langle DE/E0 \rangle\rvert < 0.1\%$, are satisfied with the tighter tolerance applied. All tolerances are rms levels and the voltage and phase tolerances per klystron for L2 and L3 are $\sqrt{Nk}$ larger, assuming uncorrelated errors, where Nk is the number of klystrons per linac.

The bandwidth of the RF measurement system will be determined based on a lower limit set by electron beam interaction with the RF. The fill time of a standard SLAC S-band structure is 850nS. Frequency variations outside 1.2MHz are filtered due to the integrating effect of the structure. The X-Band structure has a fill time of 100nS. Systems noise levels will be analyzed to determine the upper bandwidth of the system. It is desired to have a measurement system bandwidth of about 10MHz in order to detect rise times of RF modulated signals on the order of 30nS.

3. Low Noise RF Distribution System

3.1 Noise floors in the RF system

The LCLS RF distribution system consists of two parts, the existing SLAC linac 2 mile distribution system and the new sector 20 LCLS distribution system. The existing reference system uses 2 miles of 3 1/8 inch rigid coax at 476MHz to run the length of the linac. The new system is located in sector 20 and consists of 1/2 inch heliax with the longest length being about 150ft.

Measurements show that the RF reference system on the old SLAC linac has a noise floor of -136dBC/Hz at 476MHz, which corresponds to 170fS rms jitter in 5MHz BW. The new master oscillators have a SSB noise floor of -157 dBc/Hz at 476MHz, corresponding to 15fS rms jitter in 5MHz BW or 43 fS rms jitter in 40MHz BW. One of these oscillators is installed at the frond end of the main linac. The spectral data from the end of the main linac (L2, L3) has been measured, the SSB noise floor is -144dBc/Hz[4]. Further improvements will be made by upgrades to the PEP phase shifter and master amplifier which are located between the master oscillator and the Main Drive Line These improvements are expected to reduce the noise floor by at least 6dB.

The 119MHz oscillator phase locked to the main linac reference in the new distribution system at sector 20 for has a noise floor of -174dBc/Hz. The expected noise floor for the 2856MHz reference system is -158dBc/Hz. If this noise floor can be achieved, the phase noise of the reference system integrated over 10MHz will be about 3fS rms.

Multipliers are currently being built to measure the noise floor of the X-band system.

3.2 The LCLS L0 RF Dist. System

The RF distribution system for LCLS is shown in Fig. 2.

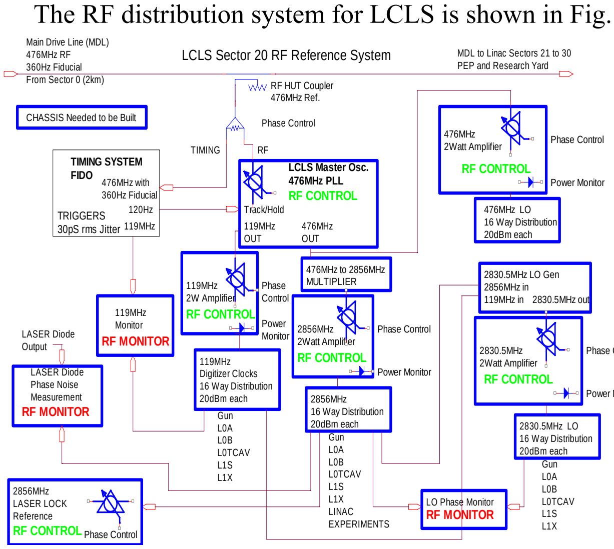

Figure. 2 The RF Distribution System for LCLS

A 20dB coupler is used to pick off 476MHz at 3mW, from the 2 mile Main Drive Line (MDL). This signal is split and half run to an FIDO for timing and the other half to the RF distribution system. The phase locked oscillator helps to eliminate phase adjustments which occur periodically on the MDL. The LCLS 476MHz reference will be multiplied up to 2856MHz and then distributed to the gun laser, RF gun, L0-A, L0-B, transverse accelerator, L1-X and L1-S drive and monitoring systems. All the electronics for this system will be housed in a temperature controlled room. The critical components will be mounted on water cooling plates with the water temperature being help within 0.3F. Andrews Heliax cable will be used to distribute the various RF signals.

The 476MHz PLL uses a Wenzel 119MHz crystal osc which will be multiplied up to 476MHz and then phase locked to the linac MDL. The Master Oscillator will require a track and hold to be built in and clocked by a linac timing system FIDO chassis at 120Hz. The LCLS will run at 120Hz using every 3rd fiducial of the 360Hz linac timing system. The PLL of the oscillator must track and hold at 120Hz in order to be phase stable during the 1/3rd of the time that the LCLS is running. The phase noise of this system must be stable to within 50fSrms during LCLS beam time. A similar system is in use at SPPS where beam to laser timing measurements show jitter of less than 150fS[5].

Four different RF signals will be produced, amplified and distributed from the LCSL RF hut: 119MHz, 476MHz, 2856MHz, and the 2830.5MHz L.O. It was initially planned to clock the digitizers at 119MHz. This frequency may be changed to 102MHz, 4X the LO, based on measurements of the new LTC2208 ADC. The 2856MHz will be used to drive the RF systems. The 2830.5MHz will be used to drive the LO of the IQ demodulators and give an IF of 25.5MHz. The 476MHz will be used as a reference to lock the drive laser oscillator. Two types of divide by 16 distribution chassis have been built. One type of chassis distributes the 119 and 476MHz signals and the other distributes the 2856 and 2830.5MHz signals.

The phase adjustment and amplification chassis for each frequency will include an IQ modulator, for phase and amplitude control and a 2W amplifier. Each chassis will be connected to the LAN via a micro controller running EPICS. The controller will receive commands over Ethernet for adjusting the RF signal and a diode RF detector will be incorporated in each chassis to provide a RF power read back. RF monitors will be used to measure phase differences in the reference system and resynchronize the system in event of a power outage or glitch.

The LCLS Local Oscillator (LO) generator will provide 2830.5MHz to the IQ demodulators. The

119MHz signal is multiplied by 3/14 to creates a 25.5MHz. The 25.5MHz will be SSB modulated with 2856MHz creating the 2830.5MHz LO signal. This signal is then amplified and distributed to the demodulators via heliax cables.

4. RF Control and Monitoring System

Most of the RF control and half of the monitoring sub-systems are located at klystron stations. The phase critical monitoring points are located in the temperature stabilized RF Hut in sector 20 at the end LCLS L0. The control and monitoring points are summarized in Table 2. The embedded

RF Gun	1 Klystron	3 RF monitors
Beam Phase Cavity	1 IQ modulator	1 RF monitor
L0-A Accelerator	1 Klystron	2 RF monitors
L0-B Accelerator	1 Klystron	2 RF monitors
L0-T Transverse Accelerator	1 Klystron	2 RF monitors
L1-S Station 21-1 B, C, and D accelerators	1 Klystron	4 RF monitors
L1-X X-Band Accelerator	X-Band	
S25-Tcav	1 Klystron	2 RF monitors
S24-1, 2, & 3 Feedback	3 Klystrons	
S29 and S30 Feedback	2 IQ modulators 476MHz	
Totals 2856MHz	10 modulators	16 monitors

Table 2 The Control and Monitoring Points Summary

controller will use an RTEMS operating system running EPICS. All control points allow pulse to pulse corrections and waveform generation. The RF Monitors will digitize waveforms and give information on the phase and amplitude of the signals.

4.1 The RF Control System

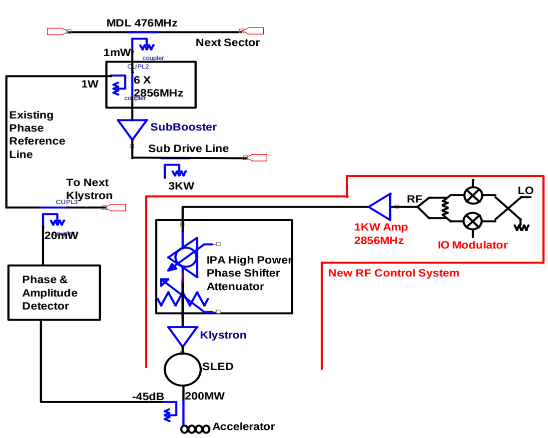

Figure3 The change of the RF control system

The existing RF phase and amplitude control system for driving each 5045 klystron uses an IPA unit, which includes a high power phase shifter and an attenuator. The step motor controlled phase shifter is not fast and accurate enough for LCLS control. In the new system, an I-Q modulator will control the phase and amplitude at the input to a 1KW solid-state amplifier to drive the 5045 klystron. This system will tie into the IPA Chassis. Fig. 3 shows the integration of the new control system. The RF reference for the new control system will be from the existing phase reference line or the injector new RF reference. I and Q will be controlled with a 16bit DAC running at 119MHz. Waveforms to the DAC will be set in an FPGA through a microcontroller running EPICS on RTEMS.

4.2 RF Monitor System

The phase critical RF monitoring units will be located in the RF Hut. Temperature stabilized 1/2 inch heliax will be used to carry signals from high power pickoffs in the tunnel next to beamline components to the measurements unit in the RF Hut. The cables will be routed through the tunnels and up through a penetration into the RF Hut. The longest cables will be about 100ft, or 114nS. The cables have temperature coefficients of about 4ppm/ºC. The environment is expected to be stable to within 0.5 ºC. Errors due to cables is expected to be within 250fS.

4.2.1 RF Monitor

The existing design under evaluation for the RF monitor will consist of a double balanced mixer with the LO at 2830.5MHz and the RF at 2856MHz. The IF, 25.5MHz, is 3 times 8.5MHz to remain in sync with timing fiducial. This results in waveform data of the digitized IF to be the same from pulse to pulse and simplifies analysis. The system is shown is figure 4.

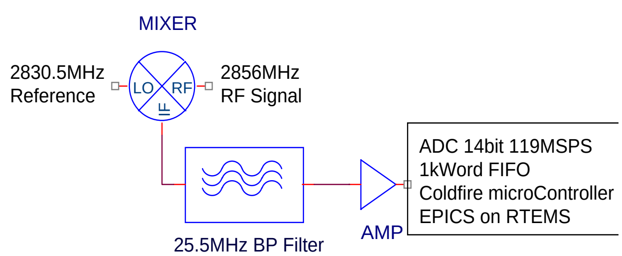

Figure 4 RF Monitor

4.2.2 Monitor Noise Levels

The RF reference system has the potential to achieve a noise floor of -156dBc/Hz. To utilize this low of a noise floor, work will be needed to further stabilize the klystron high power modulators. Using 13dBm mixers allows an RF level of 3dBm and an IF level of -3dBm in a typical mixer. The noise floor of the IF at the output of the mixer is then -159dBm/Hz, 15dB above the thermal noise floor of -174dBm. If we have a 10MHz bandwidth the input noise to the ADC is -83dBc. The LTC2208 has the following prereleased typical specifications for a 130MSPS, 30MHz input signal -1dBFS:

SNR = 77.6dBFS
SFDR = 95dB
SINAD = 77.5, ENOB of 12.6

SFDR at -25dBFS = 115dBFS, Dither "ON"
The ADC will dominate the noise levels in the system. The white noise in a single measurement, assuming a signal level of -6dBFS, 71dB, SNR will be 16fS rms. Averaging can reduce this further.

5. Status

Design of the phase reference system is well underway for LCLS. Preliminary design of phase control and monitor systems has begun. By January 2007 the LCLS injector RF system should be up and running. Stability over the last kilometer of the linac and out to the near and far halls will be addressed beginning in October of 2006.

6. References

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