LCLS RF Reference and Control

R. Akre Last Update 5-19-04

Sector 0 RF and Timing Systems

The reference system for the RF and timing starts at the 476MHz Master Oscillator, figure 1.

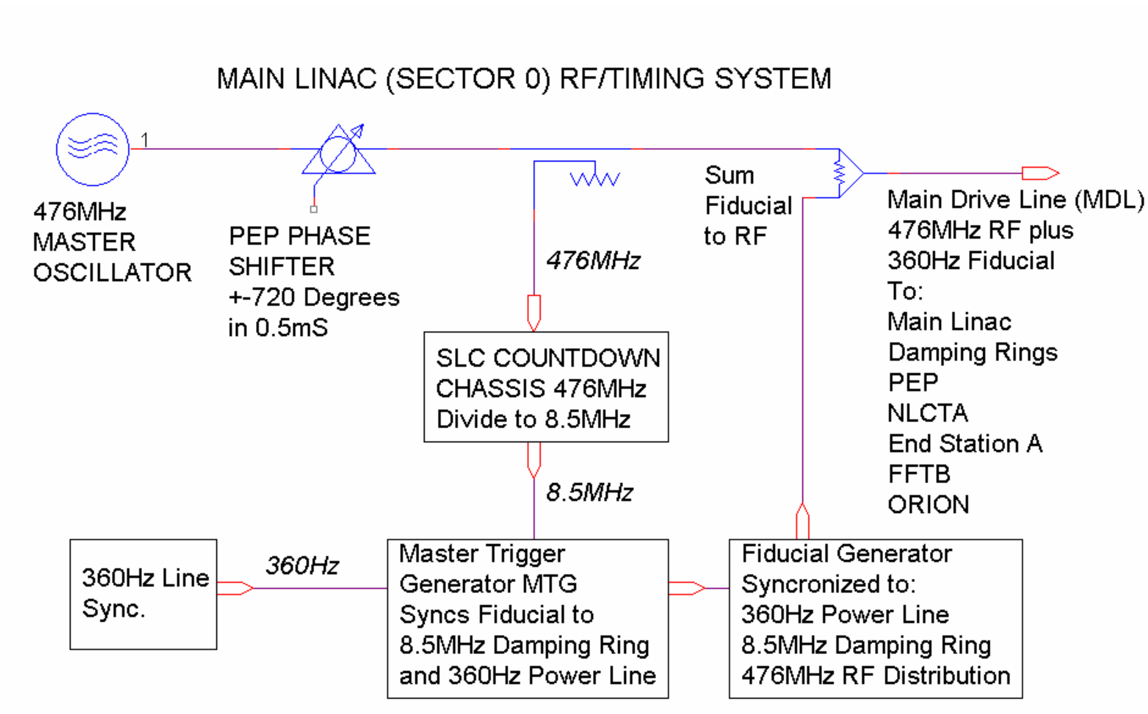

Figure 1. Front end phase and timing reference.

The 476MHz RF from the Master Oscillator next passes through a 1440º phase shifter which is used to fill different buckets in PEP. The PEP ring has a local oscillator of which the phase and frequency tracks and holds the linac phase and frequency at rate of 120Hz. During the hold time the PEP ring can be unlocked from the linac and the linac phase shifted by plus or minus two cycles at 476MHz, figure 2. It is then relocked, track mode, and injection occurs into a different bucket. This operation causes phase and frequency changes throughout the linac phase distribution system.

The 476MHz is divided down to 8.5MHz by the SLC Count Down Chassis. The Master Trigger Generator (MTG) selects the 8.5MHz cycle which occurs just after the 360Hz 3 phase power line zero crossing and sends out a trigger to the Fiducial trigger generator. The MTG can also delay the trigger a preselected number of 8.5MHz Damping Ring turns. The Fiducial Generator gets the 360Hz and 8.5MHz locked trigger and generates a 476MHz ½ cycle pulse locked to the

476 MHz on the drive line. This ½ cycle pulse is then added to the Main Drive Line (MDL) RF, figure 3, and used for timing throughout SLAC.

This RF system, figure 1, must have phase noise levels low enough to meet LCLS specifications. The existing Master Oscillators will be replaced with units that meet LCLS specifications. Once the system in running off the existing Master Oscillator we can measure phase noise contributions of the next upstream component. Components with excessive phase noise will be sequentially replaced or upgraded to meet the specifications.

The list of these components is as follows:

Master Oscillator
Master Source Phase Shifter 345-803
Master Source RF Distribution 801-059-02
Master Source Phase Shifter 801-059-07
Master Source Master Amplifier 801-059-04
Fiducial Generator Switch 125-290
Fiducial Generator 135-903

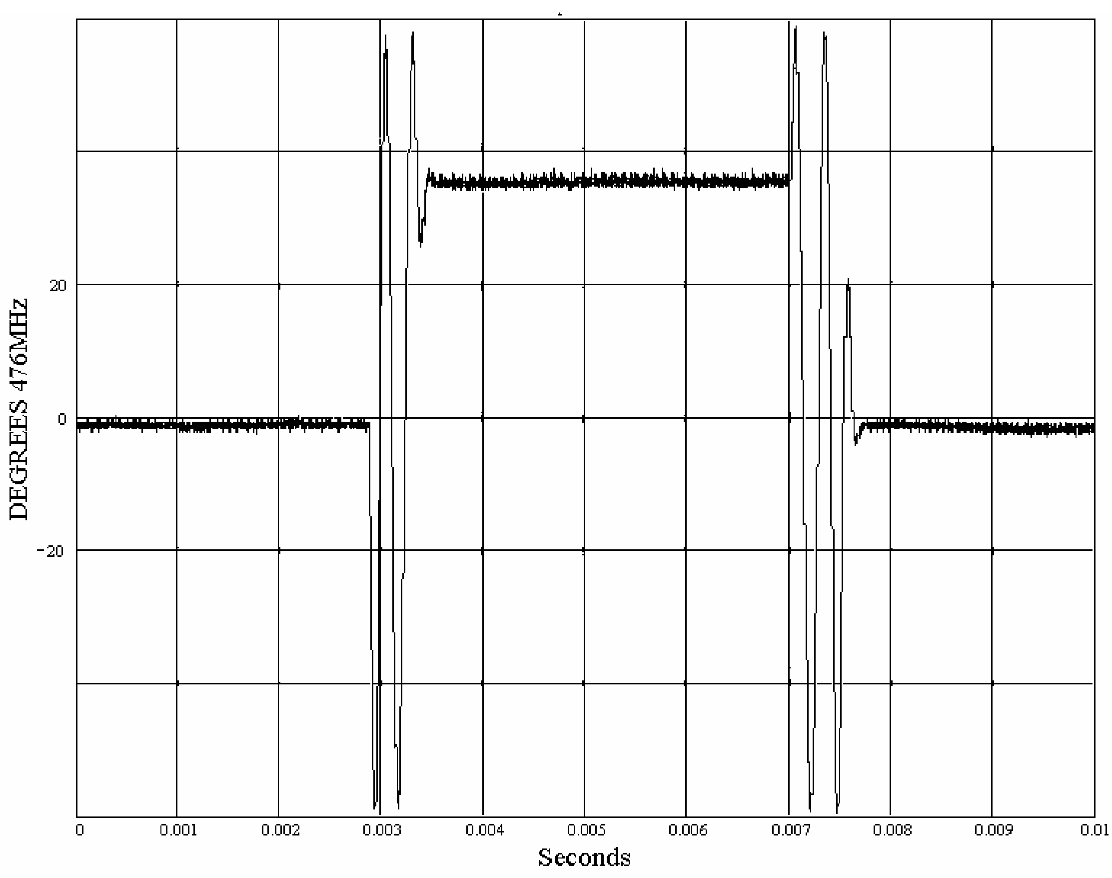

Figure 2. Main Drive Line Phase (Degrees 476 MHz)
2.8mS of 8.33mS (120Hz) cycle will be phase stable.

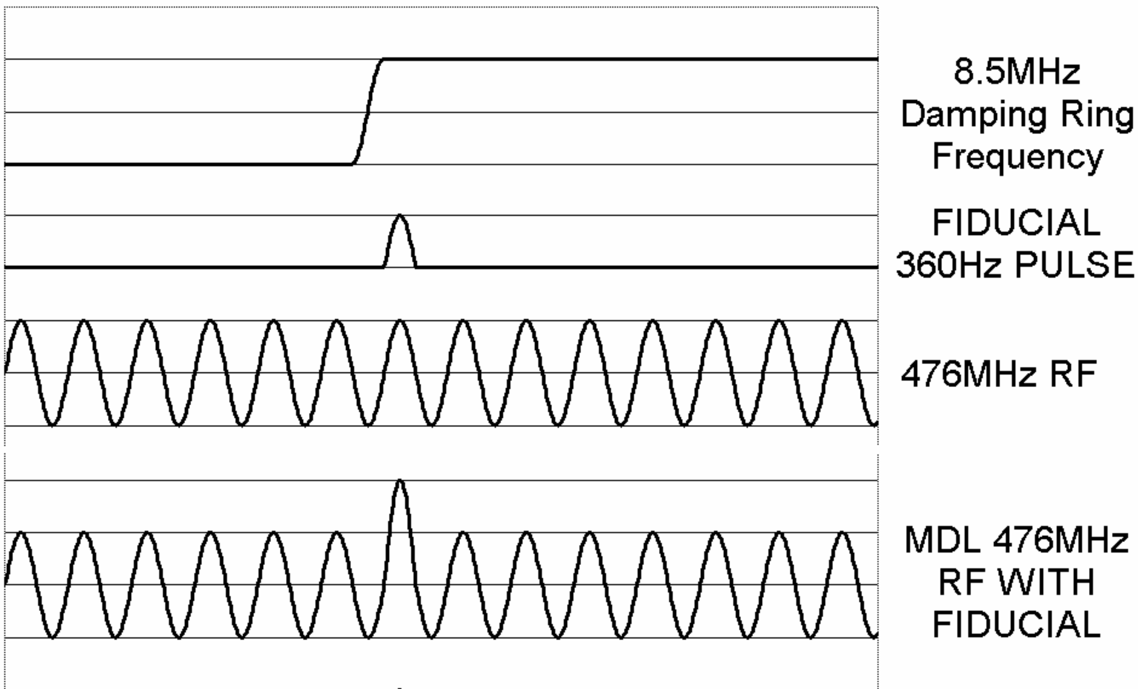

Figure 3. 360Hz Fiducial Relation to the 476MHz and 8.5MHz

Sector 20 RF and Timing Systems

The LCLS injector will reside in an off axis tunnel at the end of sector 20. The main linac RF and Timing signals will be coupled off the Main Drive Line (MDL) at the end of sector 20 in a temperature controlled hut. The system in the hut will control the laser, RF Gun, linac 0, and linac 1 RF. The injector has 4 klystrons. Linac 1 has 1 S-band klystrons and 1 X-band klystron. The LCLS project will use the existing timing system and RF distribution system for the main linac, LCLS linacs 2 and 3. LCLS linacs 2 and 3 are made up of the main SLAC linac sectors 21 to 30, figure 5.

The phase system of the main linac will not meet LCLS specifications for the laser, RF Gun, linac 0, and linac 1. A new system will be added to reduce phase noise levels and eliminate the phase and frequency shift on the main linac. This system is shown in figure 4 and except for the MDL is all new components.

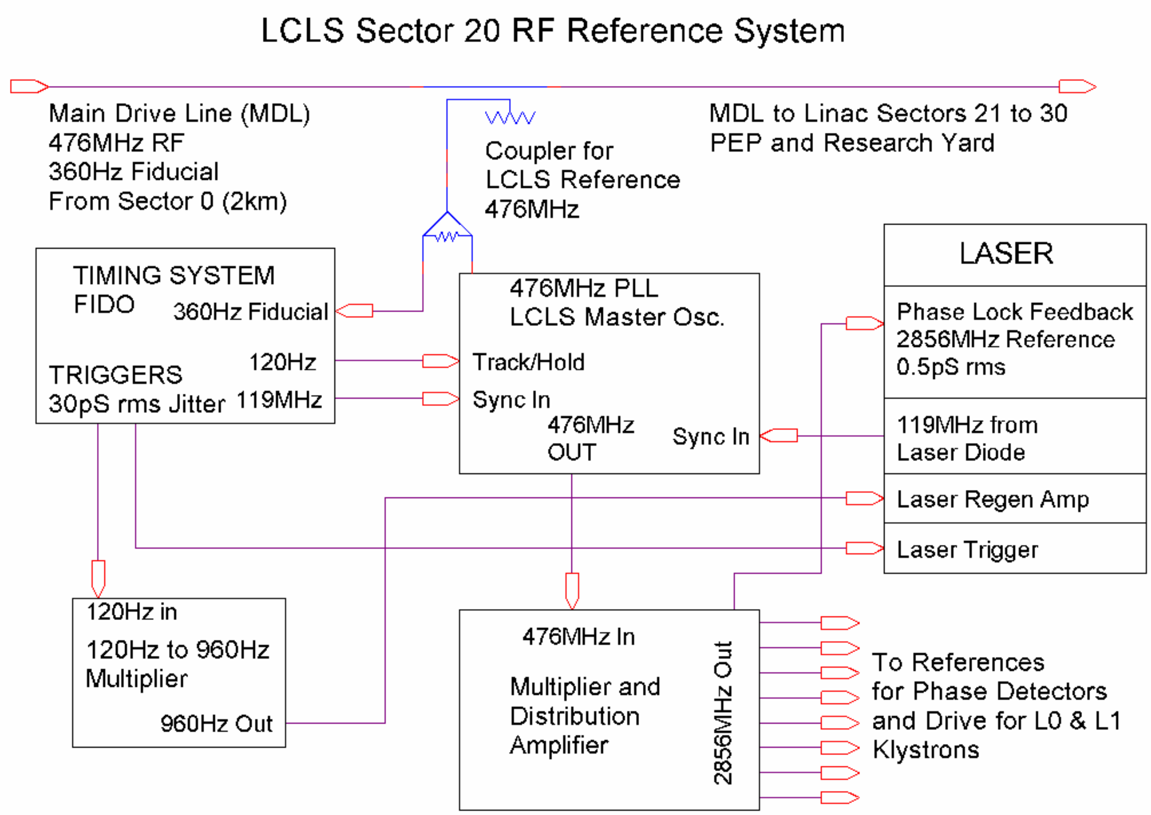

Figure 4. Sector 20 RF Reference System.

LCLS will run at 120Hz. During every 3rd cycle of the 360Hz timing system the RF will be stable for a period of 2.8mS. The PLL must sample and hold at 120Hz during the phase stable time. Outside of the phase stable time the 476MHz RF reference will change by as much as 720º, but will return to the original phase before the next 120Hz cycle as shown in figure 2. The phase noise of this system must be stable to within 50fS rms during LCLS beam time.

A laser pulse must be locked to the timing fiducial for LCLS to operate. With a laser frequency of 119MHz, every 14th pulse will be aligned with the 8.5MHz used to synchronize the fiducial pulse. Every third fiducial pulse will be used to trigger LCLS at a 120Hz rate.

The laser phase lock reference will come from this system. A second PLL will be designed and built to lock the output of the 119MHz laser oscillator to the 476MHz reference. The Regen amplifier on the Laser should run at 960Hz, eight times the 120Hz rate, to insure a laser pulse is synchronized with the timing system.

Feedback System

The LCLS linac is broken down into 4 linacs, L0, L1, L2, and L3, shown in figure 5. To set up energy position correlations along the bunch for compression to 50fS lengths, the phase and amplitude settings of the RF are critical. The LCLS Machine Stability Tolerance Budget for the RF system is shown in figure 5.1. There are 9 klystrons in the LCLS design that will require RF feedback. 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. Tests show this stability can be maintained over the several seconds by the existing systems figures 6,7. Beyond 2 seconds feedback will be required to adjust the phase and amplitude of the above listed systems figures 8,9. The peak to peak diurnal variations in the existing system are within ±2% amplitude and ±5° S-Band over 10 sectors.

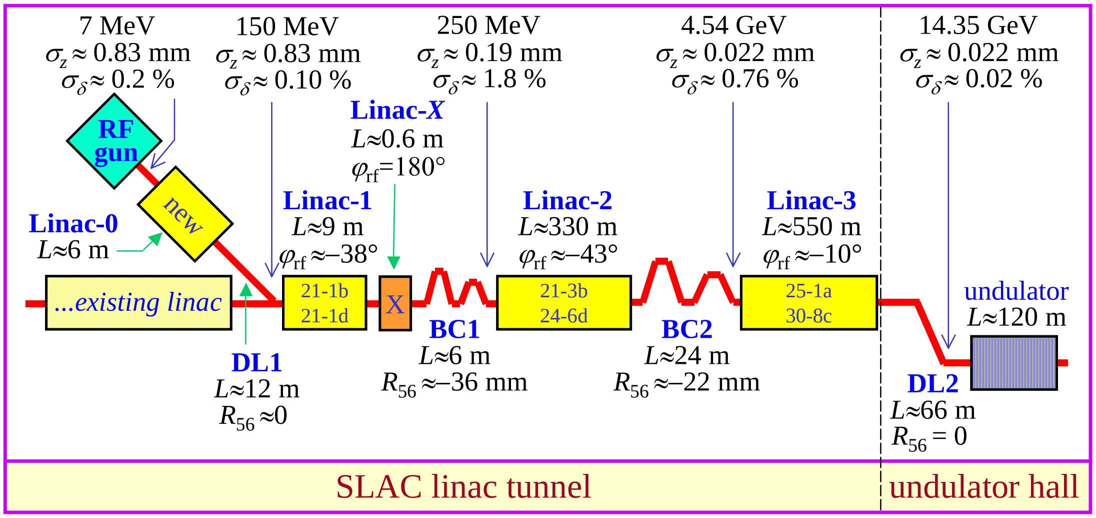

Figure 7.1-1. LCLS compression and acceleration schematic. The 'dog-legs' (DL1 and DL2) are simple transport lines and have no effect on bunch length. The compressors are double-chicanes to better decouple coherent synchrotron radiation (CSR) from horizontal emittance. Acceleration crest is defined at φ_{rf} = 0.

Figure 5. Taken from LCLS CDR Figure 7.1-1 - P. Emma

LCLS Machine Stability Tolerance Budget

$|\langle \Delta E/E_0 \rangle| < 0.1\%$ and $|\Delta I/I_0| < 12\%$

Parameter	Symbol	LCLS	Unit
Gun timing jitter	Δt_0	0.80	psec
Initial bunch charge	$\Delta Q/Q_0$	2.0	%
mean L0 rf phase	φ_0	0.10	deg
mean L1 rf phase	φ_1	0.10	deg
mean L*h* rf phase X-band	φ_h	0.50	X-deg
mean L2 rf phase	φ_2	0.07	deg
mean L3 rf phase	φ_3	0.15	deg
mean L0 rf voltage	$\Delta V_0/V_0$	0.10	%
mean L1 rf voltage	$\Delta V_1/V_1$	0.10	%
mean L*h* rf voltage	$\Delta V_h/V_h$	0.25	%
mean L2 rf voltage	$\Delta V_2/V_2$	0.10	%
mean L3 rf voltage	$\Delta V_3/V_3$	0.08	%

All values are rms tolerances and pertain to time scales < 10 seconds

updated since CDR (June, 2003 - PE)

Figure 5.1. LCLS Machine Stability Tolerance Budget

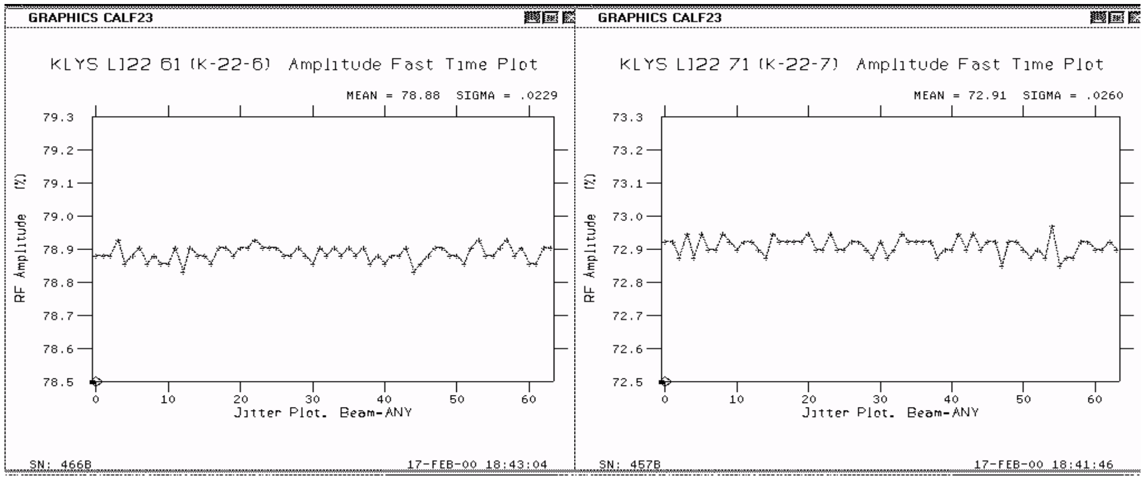

Figure 6. Amplitude fast time plots show pulse to pulse variation at 30Hz. Standard deviation in percent of average amplitude over 2 seconds are 0.026% for 22-6 and 0.036% for 22-7.

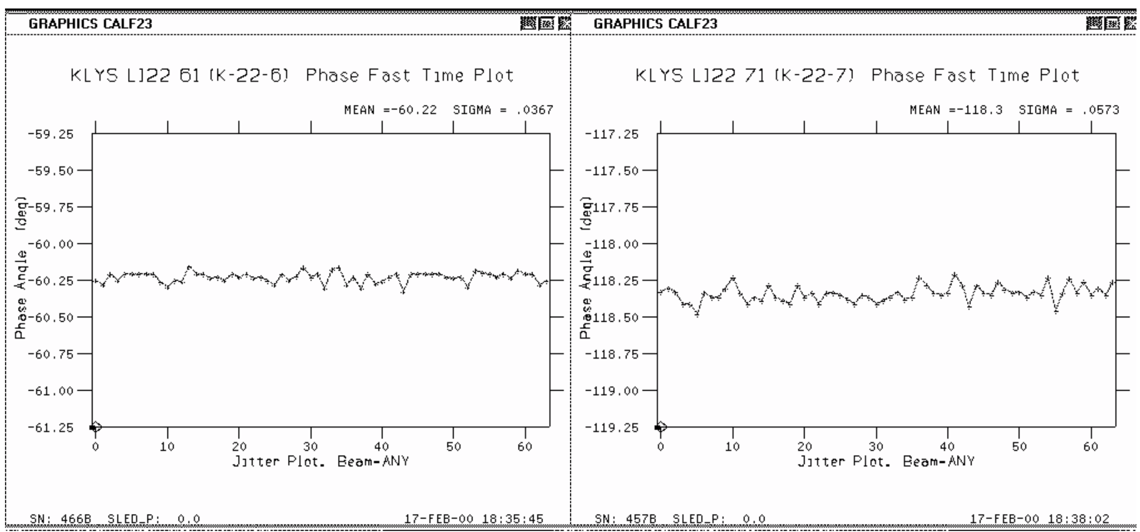

Figure 7. Phase fast time plots show pulse to pulse variation at 30Hz. Standard deviation in degrees of 2856MHz over 2 seconds for the three stations are 0.037° for 22-6, 0.057° for 22-7, and 0.066° for 22-8.

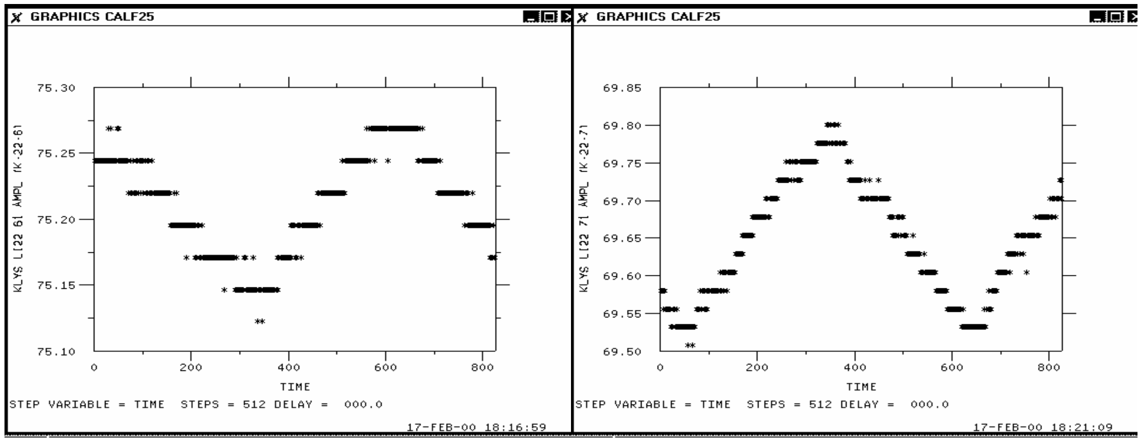

Figure 8. 14 minutes data taken using the SCP correlation plot Amplitude variations 0.2% for 22-6, 0.43% for 22-7, and 0.13% for 22-8

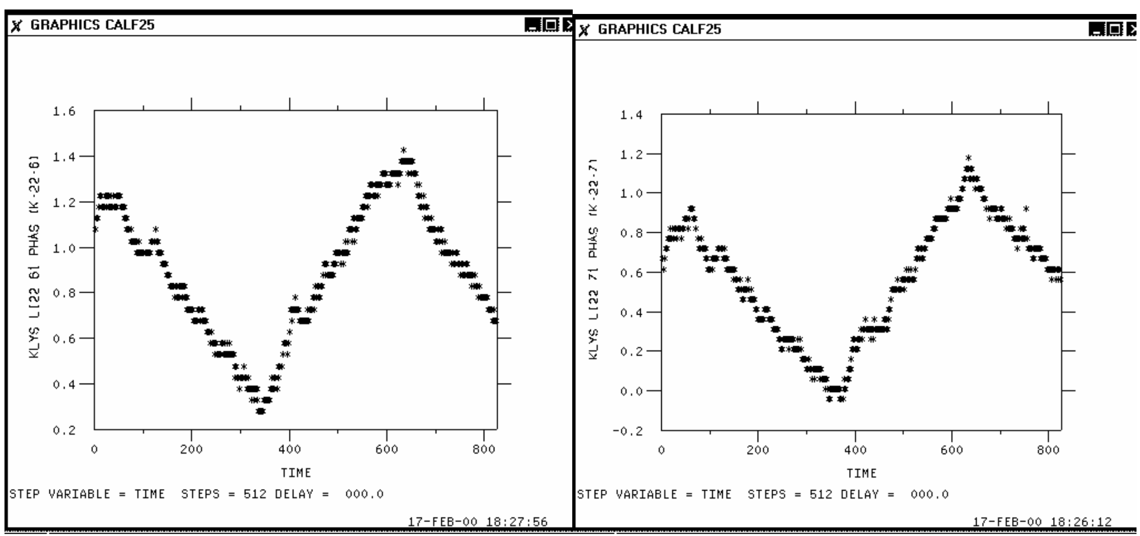

Figure 9. Data over 14 minutes was taken using the SCP correlation plot program. The phase variations seen below are all correlated and would occur for the entire sector. The phase jump in 22-8 is due to a klystron trim. The klystrons are set to trim when they are out of tolerance, 1.25°. The klystron phase is checked at about 6-minute intervals and trimmed if necessary.

All klystrons will use the existing phase and amplitude control system to set the klystron phase to within 10pS and amplitude to within 2%.

A change in phase or amplitude of the above listed systems will result in a change in energy and bunch length of the beam. The energy of the beam will be measured with a BPM in a high dispersion region. The Bunch Length Monitor

(BLM) will use a synchrotron radiation monitor, RF cavity, or some other device to measure bunch length.

It is not possible to get an accurate measurement of the phase in an accelerating structure as seen by the beam from the input or output RF alone. It is 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 first 5 accelerating klystrons will have phase and amplitude measurements at the input and output of the structures. Each of the RF structures will also have 3 thermocouples on it to measure its temperature. Thermocouples will also be placed on waveguide and SLED cavities where applicable. A new RF feedback system will use these inputs to actuate additional phase and amplitude control units to keep the RF as seen by the beam to within LCLS specifications. A diagram of this system for a single klystron is shown in figure 10.

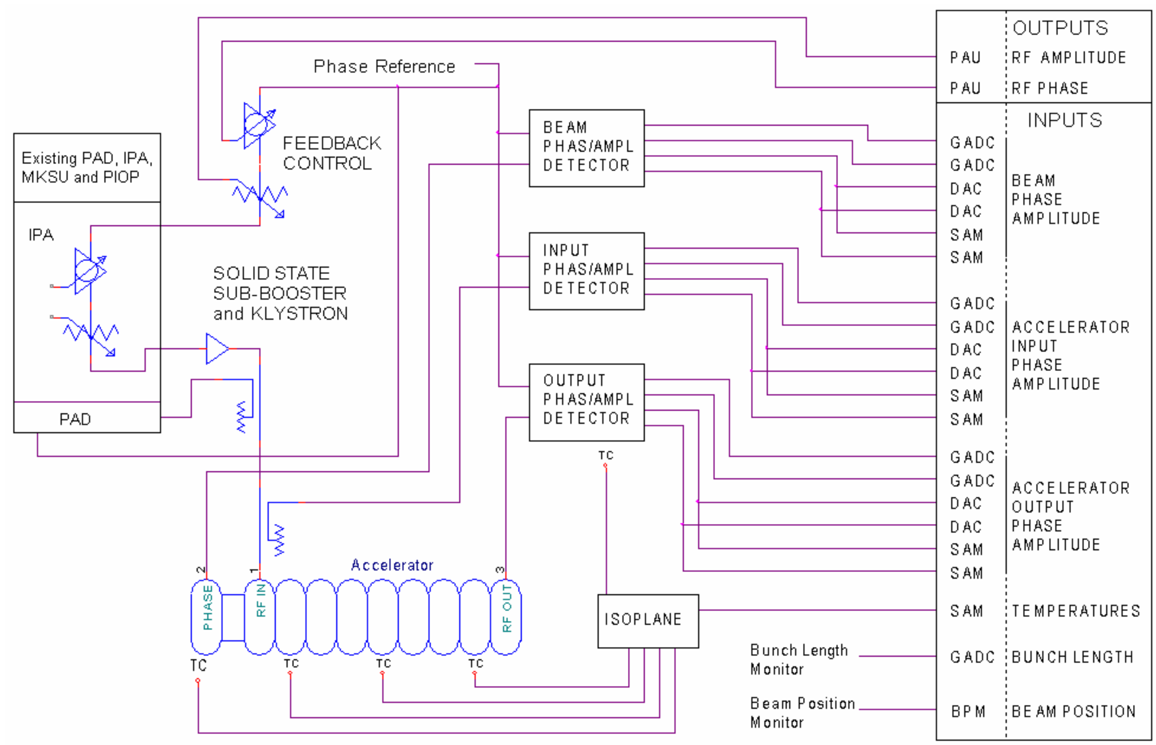

Figure 10. Feedback around a single klystron and RF station.

Modifications to existing IPA chassis will be required to run the klystrons with solid state sub-boosters. Breakout chassis to interface the RF electronics to the DAC's and SAM's of the control system will be designed and built.

LCLS Injector Klystron Power Levels

Device	Operating Point	Required Power	Loss + Overhead	Notes
Gun (20-6)	30MW (7MV)	44MW	-1.7dB	1,7
L0 20-7,8	46MW (75MV)	61MW	-1.2dB	1
X-band 21-2	17MW (22MV)	24MW	-1.5dB	2,3,4,5
Deflector	3MW	48MW	-12dB	1,6

Notes:

1. 150ft of WR284 S-band rectangular guide has 1dB of loss.
2. 10m of WR100 X-band guide has 1dB of loss.
3. 10m of WC293 X-band guide has 0.04dB of loss.
4. Assume 0.6m X-band structure has shunt impedance of 30MΩ
5. X-band klystron XL-4 50MW at 410kV 315A
6. The output of the D accelerator structure in 20-5 will be used as the RF Source for the RF Deflector.
7. Phase stability of Gun RF from 225ft of WR284 (0.014°S/(ft-°F)) Water 0.1°F => 0.3°S Requires phase correction.