LCLS-II Technical Note

A 650 MHz Injector ?

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1 Introduction

Use of 650 MHz SC accelerating structures in the injector/L1 in conjunction with a 1.3 GHz linearizer[1] has been suggested as a possible alternative to the current LCLS-II baseline. This variant has some appeal, mostly as a back-up option in case the employment of the 3.9 GHz modules in the baseline were to run against technical or other difficulties. In addition, a lower rf-frequency booster/linearizer system has the potential to deliver better beam quality as a result of weaker longitudinal rf wakefields and the capability of accepting longer bunches.

Unfortunately, a significant drawback of using a 2$^{\text{nd}}$-harmonic linearizer (*vs*. 3$^{\text{rd}}$ –harmonic as in the current baseline) is a reduction of overall acceleration efficiency. This implies additional cost and/or cost-reduction strategies that would affect the design parameters (*e.g*. beam energy at BC1) and are possibly harmful to beam quality.

In this Note we work out the basic voltage requirements and sketch a conceptual layout. A characterization of the beam dynamics and study of various trade-offs are beyond our scope here but are going to be needed before the viability of this option can be fully assessed.

2 Formulas

To simplify the analysis we consider a setting in which all the 650 MHz cavities (injector and L1) are operated on crest with the 2$^{\text{nd}}$ harmonic 1.3 GHz structure providing both linearization and the linear chirp needed for magnetic compression in BC1. At the bunch compressor the energy of a particle with longitudinal coordinate z can then be written as

$$E(z) = E_i + V_A \cos(k_A z + \phi_A) + V_L \cos(k_L z + \phi_L) \ , \qquad (1)$$

where V_A, V_L are the total voltages of the accelerating (650 MHz) and linearizing (1.3 GHz) structures, $\phi_A = 0$ and ϕ_L the corresponding rf phases, and $k_A = \frac{k_L}{2} = 13.6$ m^{-1}. The beam energy E_i at the exit of the gun is small (~1 MeV) and for our purposes it can be neglected.

There are three constraints set by *i)* the desired beam energy E_{BC}, *ii)* linear energy chirp h_1 at the bunch compressor, and *iii)* linearization condition[2]:

i) $E(0) = E_{BC}$

ii) $h_1 = \frac{-V_L k_L \sin\phi_L}{E_{BC}}$

iii) $\frac{V_A k_A^2 + V_L k_L^2 \cos\phi_L}{2\, E_{BC}} = \frac{T_{566}}{R_{56}} h_1^2$

and three unknowns V_A, V_L, and ϕ_L. Solving for $\tan\phi_L$ and V_L we find

[1] 1.3GHz rf structures can still be used for acceleration in L2 and L3, as in the current baseline.

[2] P. Emma, LCLS-TN-01-1, (2001).

$$\tan\phi_L = \frac{3h_1k_A}{2k_A^2 + 6h_1^2} \qquad (2)$$

$$V_L = \frac{E_{BC}}{6k_A^2}\sqrt{(3h_1k_A)^2 + (2k_A^2 + 6h_1^2)^2} \qquad (3)$$

and hence $V_A = E_{BC} - V_L \cos\phi_L$. Note that V_L scales linearly with E_{BC}.

3 Voltage requirements

If we enforce the current LCLS-II baseline specifications for BC1, with compression factor $C_{BC} = 4$, $R_{56} = -0.06$ m, $h_1 = \frac{C_{BC}{}^{-1} - 1}{R_{56}} = 12.5$ m^{-1}, and beam energy $E_{BC} = 250$MeV, it is immediately clear that a 650 MHz booster system would be prohibitively expensive: Eq. (3) implies a $V_L = 315$ MV (!) voltage for the linearizer and $V_A = 544$ MV for the booster.

A reasonable system should have at most V_L~100 MV (which can be supported with an 8-cavity module identical to those used for acceleration in L2 and L3.) Assuming a BC1 chicane close to the baseline design with $R_{56} \simeq -0.07$ m and $C_{BC} = 4$, a voltage V_L~100 MV can be attained only if the beam energy at BC1 is lowered to $E_{BC} \simeq 100$ MeV. The requirement for the accelerating (650 MHz) structure is $V_A \simeq 200$ MV, see Table 1, Settings #1 column. In this scenario the 650 MHz booster would consist of possibly two (more ?) cryomodules with the laser heater placed in between (see Fig. 1). The second cryomodule could be operated off crest to chirp the beam for compression but this is less efficient than dephasing the 1.3 GHz linearizer. See Fig. 1.

Table 1. *Two possible parameter settings for the injector with 100 and 150 MeV beam energy at the bunch compressor(BC1)*

	Settings #1	Settings #2
Accelerating structures voltage, V_A	195 MV	245 MV
Accelerating structures phase, ϕ_A	0	0
Linearizer voltage, V_L	103 MV	104 MV
Linearizer phase, ϕ_L	-157.6 deg	-156.6 deg
Bream energy at BC1, E_{BC}	100 MeV	150 MeV
BC1 momentum compaction, R_{56}	-0.07 m	-0.1 m
BC1 compression factor C_{BC}	4	4

A way to increase the beam energy at the compressor while keeping the same voltage requirement for the linearizer is to increase the magnitude of the momentum compaction in BC1 (for a fixed momentum compaction this has the result of decreasing h_1: from Eq. (3) observe that V_L decreases with h_1.) With $R_{56} = -0.1$ m we obtain $E_{BC} = 150$ MeV, see Table 1, Settings #2.

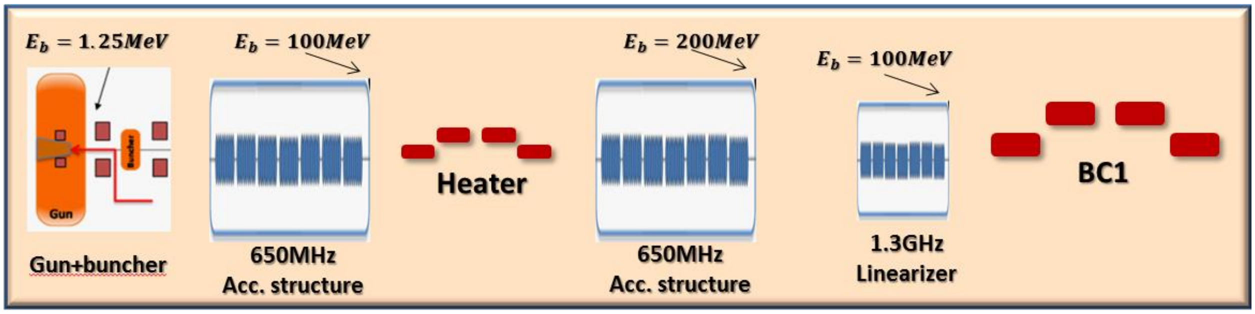

Figure 1 *Schematic layout of the LCLS-II injector with 650 MHz accelerating structures and 1.3 GHz linearizer, with the 650 MHz booster consisting of two cryomodules, each accelerating the beam by about 100 MeV. The 1.3 GHz buncher cavity right after the gun, operated at zero-field crossing, is the same as in the current baseline. Acceleration downstream of BC1 can still be carried out by 1.3 GHz structures, as in the baseline design.*

4 Conclusions

The concept of a 650 MHz structure based injector with a 1.3 GHz linearizer is an interesting alternative to the current LCLS-II baseline design. However, the inherent inefficiency of a low-harmonic number linearizer poses a severe constraint to the maximum acceptable beam energy at BC1 if the rf voltage specs are to stay within reason. From a beam dynamics standpoint a low beam energy at the bunch compressor in the 100-150 MeV range could work, considering the beam low peak current (few Amperes) and moderate compression in BC1, but CSR and space charge effects should be carefully evaluated before this concept is given further consideration.