

# PARAMETRIC STUDIES WITH PARMELA TO IMPROVE SLC PERFORMANCE\*

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## Abstract

The PARMELA particle dynamics code has been used at SLAC to simulate the SLC injector from the electron gun through the first accelerator section. The strength of injector components was set and tuned based on the simulation results. Parametric studies with PARMELA were conducted in which injector components were varied in an incremental fashion to study their effects on beam parameters such as transmission of current, capture of the charge in 20° of S-Band, required for satisfactory spectrum, and emittance. We discuss the results of our simulation and its application to optimizing the performance of the injector.

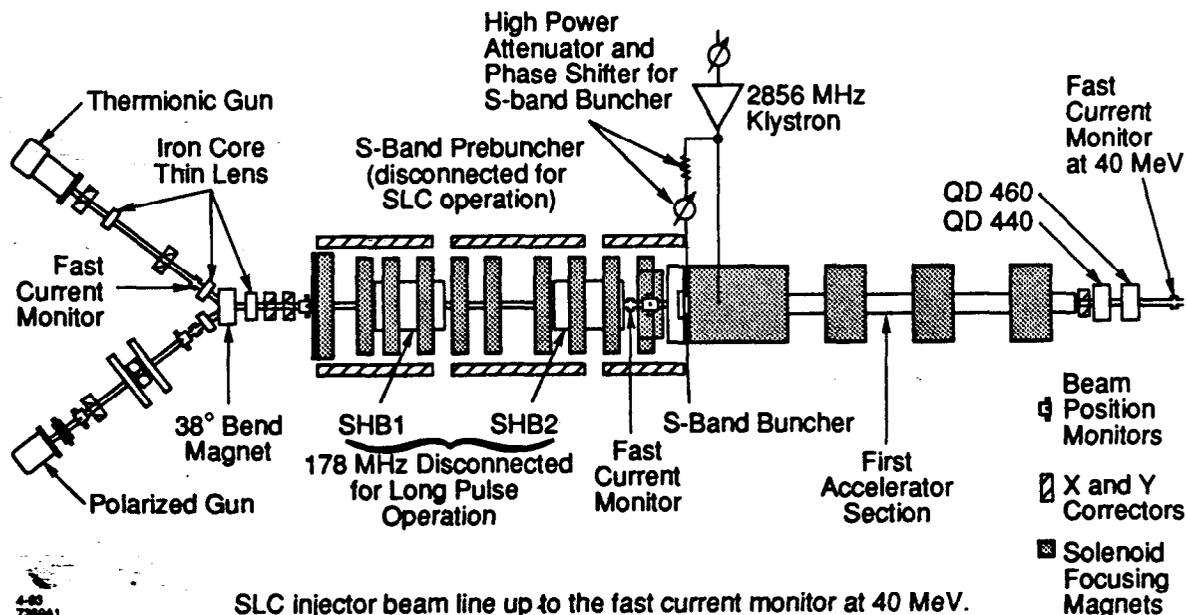
## I. Introduction

The SLC Injector is designed to deliver two bunches of electrons to a damping ring whose energy is nominally 1.2 GeV. These bunches must be 61 ns apart, with greater than  $6 \times 10^{10}$  electrons in 20 ps per bunch, at a repetition rate of up to 120 Hz, with less than 2% intensity jitter[1]. We try to reduce the intensity jitter due to individual components to less than 0.2%. In an effort to fulfill these conditions, the

PARMELA simulation has been used to study the stability and optimization of various parameters in the injector, most recently the amplitude of the S-Band (2856 MHz) buncher.

## II. The Injector

The Injector, Fig. 1, consists of two electron guns, each at a 38 degree angle from the accelerator centerline, a switching magnet to allow operation of either gun, a bunching section consisting of two subharmonic bunchers at 178.5 MHz, a 4 cell S-band (2856 MHz) buncher, and a 3 m traveling wave S-band accelerating section which contributes to bunching as well as accelerating the beam to 40 MeV. The power into the S-Band buncher is obtained from the Klystron to the first accelerator section through a 7 dB coupler. There are a high power attenuator and a phase shifter to adjust the amplitude and phase of the S-Band buncher RF independently of the accelerator section. The injector compresses the beam from 2.5 ns at the gun to less than 20 ps at 40 MeV. Beyond the gap intensity monitor at 40 MeV, there is a series of accelerating sections which further accelerate the beam to 1.2 GeV [2]



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 SLC injector beam line up to the fast current monitor at 40 MeV.  
 Figure 1. SLC injector beamline up to the current monitor at 40 MeV.

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### III. The Simulations

#### A. Simulation Procedure

PARMELA, a 3D ray trace code with a 2D space charge model, was used to simulate the beamline [3] and the beam parameters at the gun were calculated with EGun [4]. The magnetic field profile due to magnet optics was calculated using POISSON [5]. Results of these codes show good correspondence to past experiments [6].

Using our simulation tools we optimized the bunching and the magnet optics to maximize electron capture into  $20^\circ$  of S-Band starting with a gun pulse of  $12.4 \times 10^{10}$  e- in a 3.2 ns FW, 2.5 ns FWHM truncated Gaussian distribution.

Using PARMELA, the S-Band buncher amplitude was varied in an incremental fashion, with all other electric field parameters optimized and held constant. The corresponding effects on capture, transmission of total current, and emittance were noted at the location corresponding to the intensity monitor at 40 MeV, where the beam is well bunched and relativistic.

#### B. Simulation Results

The damping ring acceptance is  $\leq \pm 1\%$  energy spread. For this study, we define capture to include only those particles falling within a final bunch length of  $20^\circ$  of S-Band, resulting in an energy spread of about  $\pm 0.75\%$ .

We plotted the fraction of electrons captured in  $20^\circ$  S-Band as a function of S-Band buncher amplitude. As shown in Fig. 2, the resulting graph has an almost parabolic dependence, although a fourth order equation was used in order to closely fit the points around the peak. The peak lies at an amplitude of 6 MV/m.

Figure 3 shows the percent intensity change per percent amplitude change as a function of amplitude for charge captured within  $20^\circ$  of S-Band, and shows the sharp rise in jitter that occurs as we move away from the optimum amplitude.

The amplitude jitter of the S-Band buncher is 0.4%, mostly due to multipactor in the high power phase shifter. We are particularly concerned with how this amplitude jitter affects the intensity jitter as a function of S-Band buncher amplitude. That is, if the S-Band buncher is set at some nominal amplitude around which it is allowed to vary by 0.4%, by how much does the intensity vary?

Using Taylor series expansion and the fourth order polynomial fitted to the capture vs. S-Band buncher amplitude curve, we calculate that for 0.4% amplitude jitter, the captured electron intensity jitter is essentially zero at the optimum amplitude setting of 6 MV/m. At 3.5 MV/m, where the amplitude was set, before the PARMELA simulations of the injector were conducted, the calculated captured electron intensity jitter is 0.3%.

We also plotted total charge as a function of S-band buncher amplitude (Fig. 4). Total charge is of interest since it is easily observed on the toroids, and is often used as a diagnostic in actual machine tuning. Total charge has a parabolic dependence on amplitude and peaks somewhere around an amplitude

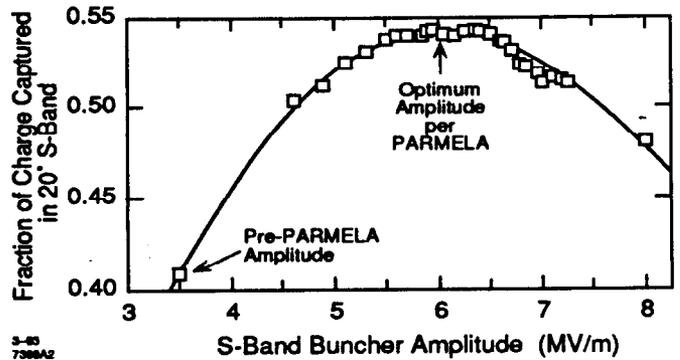


Figure 2. Capture vs. S-Band buncher amplitude.

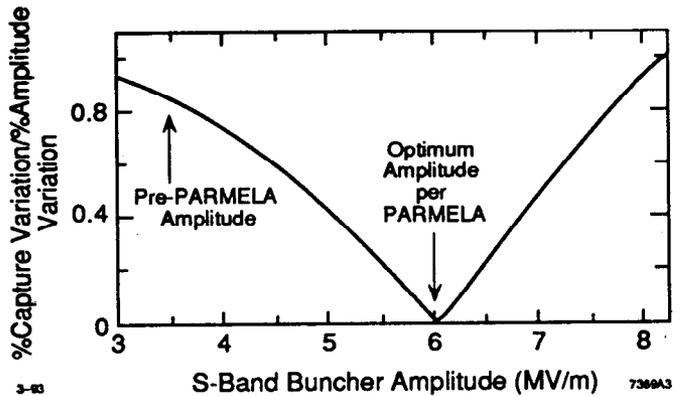


Figure 3. Percent intensity change per percent amplitude change vs. S-Band buncher.

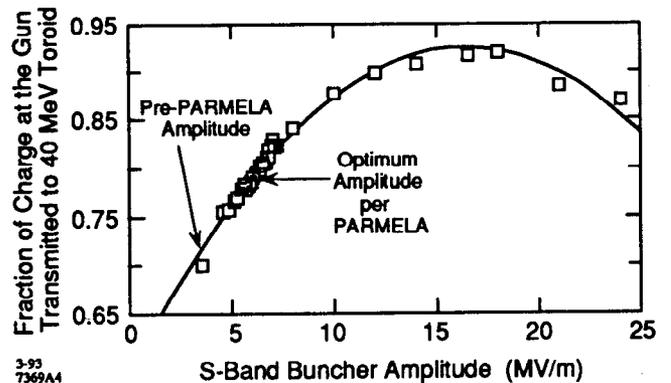


Figure 4. Total charge vs. S-Band buncher amplitude.

of 15 MV/m, which is much higher than the amplitude for optimum bunching. This graph, together with the capture vs. amplitude graph, demonstrates that tuning for optimum bunching will actually mean less total transmission from the gun to the 40 MeV point. This is because the gun pulse width at 3.2 ns FW is too long for 100% capture by the 178.5 MHz subharmonic buncher system.

X and Y normalized emittances for RMS and for 90% of transmitted particles were plotted (Figs. 5, 6, 7, and 8). These graphs show that the emittance rises as the S-Band buncher amplitude is increased, leveling off somewhere around 15 MV/m.

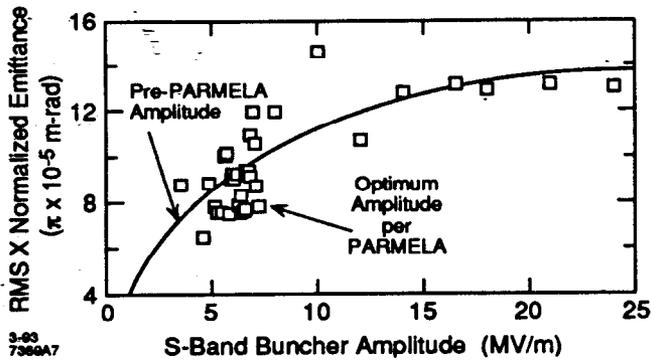


Figure 5. RMS X normalized emittance vs. S-Band buncher amplitude.

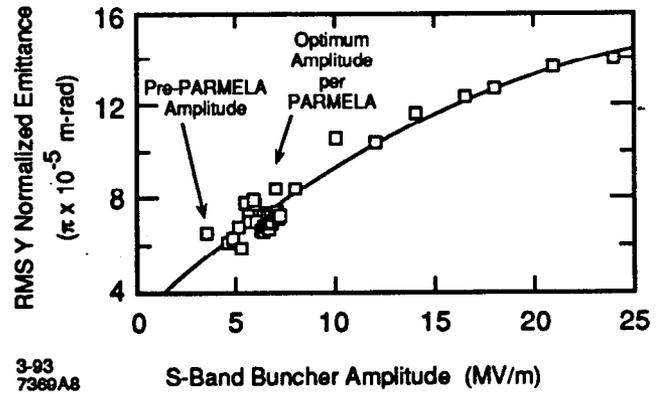


Figure 6. RMS Y normalized emittance vs. S-Band buncher amplitude.

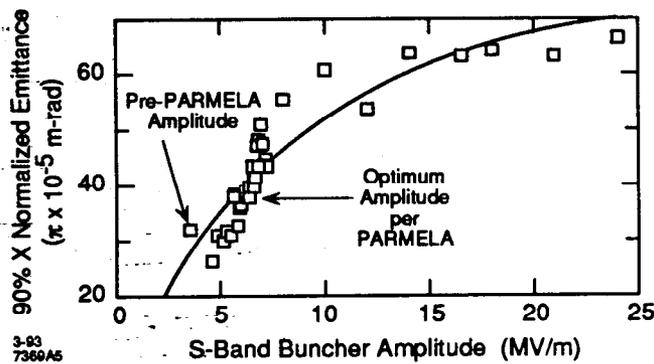


Figure 7. 90% X normalized emittance vs. S-Band buncher amplitude.

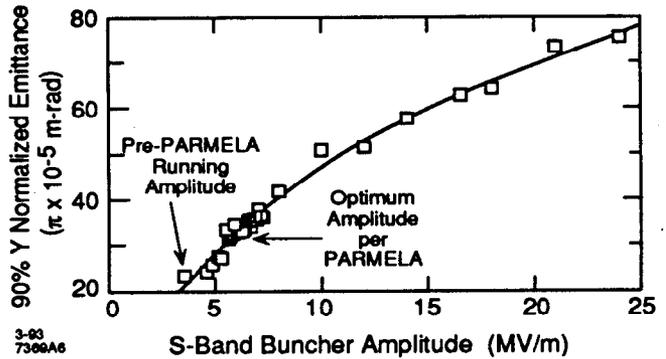


Figure 8. 90% Y normalized emittance vs. S-Band buncher amplitude.

#### IV. Summary of Results

The nominal gradient in the S-Band buncher for the SLC injector before modeling with PARMELA was 3.5 MV/m. On the basis of PARMELA-derived results, we have been running with a gradient of about 6 MV/m. This has improved bunching and allowed for larger S-Band buncher RF amplitude jitter tolerances.

Machine studies designed specifically to support or refute these results have not been performed. However, we do have history plots of the S-Band buncher RF amplitude which show that during the period in which the S-Band buncher was set to 3.5 MV/m, it was necessary to have amplitude jitter tolerances of 0.03% to minimize intensity jitter in the captured charge. Recently, with the buncher set to 6 MV/m, S-Band amplitude jitter reached as high as 0.6% with no noticeable ill effect on the intensity jitter. This difference of greater than an order of magnitude seems to support the model results.

#### V. References

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