DEVELOPMENT OF A 4 GS/s INTRA-BUNCH INSTABILITY CONTROL SYSTEM FOR THE SPS - NEXT STEPS*

J.D. Fox, J. M. Cesaratto, J. Dusatko, K. Pollock, C. Rivetta, O. Turgut,
Stanford Linear Accelerator Center Stanford, CA, USA
W. Hofle, G. Kotzian, U. Wehrle CERN Geneva, Switzerland
S. De Santis LBL Berkeley, CA, USA

Abstract

We present the expanded system architecture in development for the control of intra-bunch instabilities in the SPS. Earlier efforts concentrated on validating the performance of a single-bunch demonstration processor. This minimal system was successfully commissioned at the SPS just prior to the LS1 shutdown. The architecture is now in expansion for more complex functionality, specifically multi-bunch control, control during energy ramps, and the expansion of the system front-end dynamic range with more sophisticated orbit offset techniques. Two designs of wideband kicker are being developed for installation and evaluation with the beam. With these GHz bandwidth devices and new RF amplifiers we anticipate being able to excite and control internal motion of the beam consistent with modes expected for Ecloud and TMCI effects. We highlight the expanded features, and present strategies for verifying the behavior of the beam-feedback system in the next series of machine measurements planned after the LS1 shutdown.

OVERVIEW

The high-current operation of the SPS for HL-LHC injection will require mitigation of possible Ecloud and TMCI effects [1]. A single-bunch wideband digital feedback system was initially commissioned at the CERN SPS in November 2012 and used in a series of measurements until the February 2013 SPS LS1 shutdown. These first studies demonstrated the control of an unstable beam and quantified the available damping against simulation predictions, though control was restricted by the use of a temporary low-bandwidth beam kicker [2]. The project is part of a larger LHC injector upgrade which includes simulation studies [3] and a machine measurement (MD) program.

EXPANDING THE INITIAL DEMONSTRATION PROTOTYPE

During the CERN LS1 interval we are upgrading the Demonstration system to add functions necessary to validate a full-featured control system. Shown in Fig. 1, the most important are wideband kicker structures and associated RF amplifiers. Also addressed in the first upgrade are more robust timing and synchronization which will allow simpler and more repeatable system timing and setup. Future work

will expand the necessary control of the front-end and back-end timing to allow feedback control during energy ramping. Because of the 4 GS/s processing rate, it is vital to maintain phase synchronization of the signals and beam in the pickups and kicker elements as the beam accelerates during the ramp. To simplify the first tests, all initial measurements were made at the injection energy.

As part of ongoing upgrades, the processing capabilities will be extended to allow control of a train of roughly 16 bunches. This FPGA function expansion is a straightforward expansion of the earlier 16-tap FIR structure to multiple bunches in a sequential processing path.

The high-speed A/D functions are 8-bit digital systems, and with the analog receivers and input equalization functions set the system processing input dynamic range and signal/noise ratio at the receiver. The receiver $\Delta\Sigma$ processing generates individual error signals for each bunch slice, but orbit offset still appears and must be budgeted in the input dynamic range (the offsets are removed by the filter processing and do not appear at the output). We are exploring two complementary methods to increase the input dynamic range through orbit offset rejection. One approach takes advantage of the differential input of the A/D system, and can increase the dynamic range by a factor of 4. A complementary approach adjusts precision attenuators in the 4 pickup signal paths to suppress static orbit offsets.

DEVELOPMENT OF WIDEBAND KICKER STRUCTURES, POWER AMPLIFIER REQUIREMENTS

A kicker structure to apply correction fields to the beam is a critical system function. A July 2013 design report summarized requirements and three possible technical implementations [4]. A formal review approved both stripline and slotline technologies for fabrication and prototype testing. The stripline design is more mature, and two kicker prototypes will be available for installation December 2014. The slotline design is still in the optimization phase, but should be fabricated starting winter 2015.

Either wideband kicker design requires suitable RF amplifiers to drive them. We have begun a process of evaluating commercial RF power amplifiers, with wideband 40 - 1000 MHz response and power levels in the 100 - 500W range. While the majority of commercial applications are specified in the frequency domain, we also must test time domain responses, and understand the beam kick delivered for various kinds of distortion and frequency response imperfections
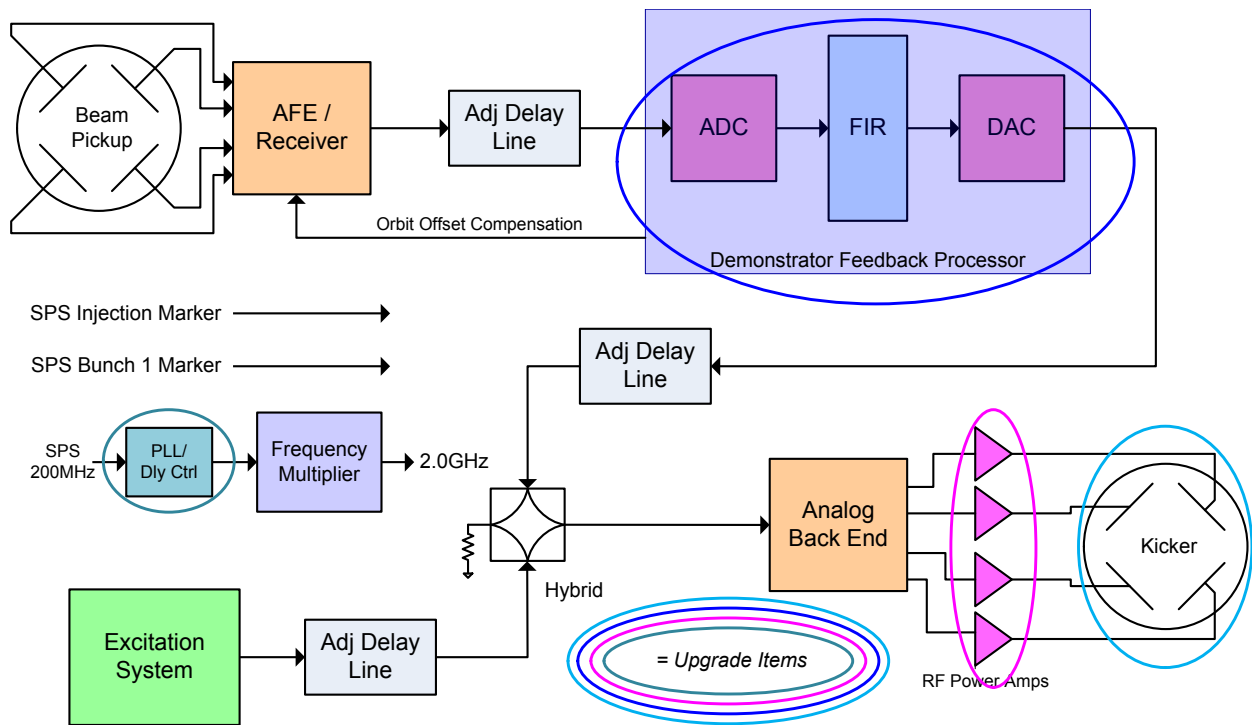
Figure 1: System block diagram highlighting the expansion in progress to the Demonstration system. The first expansions are related to the new wideband kicker structures and amplifiers, and the improvements to the high speed timing and synchronization to the SPS RF.

in the amplifiers, cable plant and kicker responses. Besides nonlinear effects such as saturation and harmonic generation, most of the wideband amplifiers tested show ringing (oscillatory impulse responses). For our application the significant response is the interval of the signal which is in the kicker and interacting with the beam. As seen in Fig. 2, as long as the amplifier response does not extend into the next bunch, such "tails" on the amplifier response are not of significance.

FEATURES SUGGESTED BY SIMULATION STUDIES

The simulation and modeling effort uses nonlinear time-domain codes (such as HeadTail and CMAD) as well as linear state space models of bunch motion. Simulation studies of future operating points suggest that the FIR filters originally designed for control with Q26 ($\nu_\beta = 0.185$ $\nu_s = 0.006$) SPS optics are not optimal for the control with the Q20 ($\nu_\beta = 0.185$ $\nu_s = 0.017$) tunes [5] [6]. Two alternative approaches have been explored. An IIR filter with carefully tailored phase vs. frequency has shown useful control with Q20 tunes, but this filter requires increased dynamic range in the processing channel and requires care to not saturate on out-of-band signals. A second approach in study uses two front-end pickups, processed through independent FIR filters, and the output signals are vector combined with additional filters in the back-end digital functions. This approach effectively increases the system sampling rate and reduces the group delay slope of the overall control loop. We plan future reconfiguration of the Demonstration system to allow
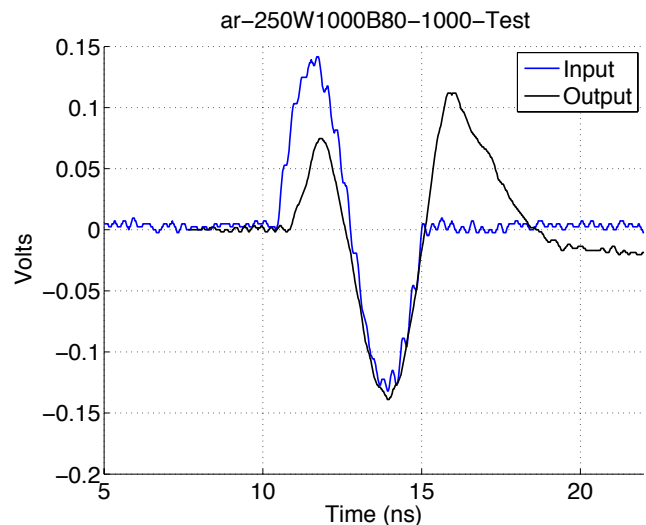

Figure 2: Example time domain amplifier test waveform for a mode 1 (head-tail) excitation signal. This amplifier has a smaller "head" response, followed by a secondary output swing after the main bipolar signal. The impact of this kind of time response on the 2.4 ns σ_z beam must be understood in selecting suitable amplifiers for this feedback application. The amplifier response has been attenuated by more than 55 dB to allow comparison with the input signal.

either control approach. The FPGA resources can be configured as a single-bunch IIR filter, with 16 independent control slices. Alternatively, the dual ADC structure of the system
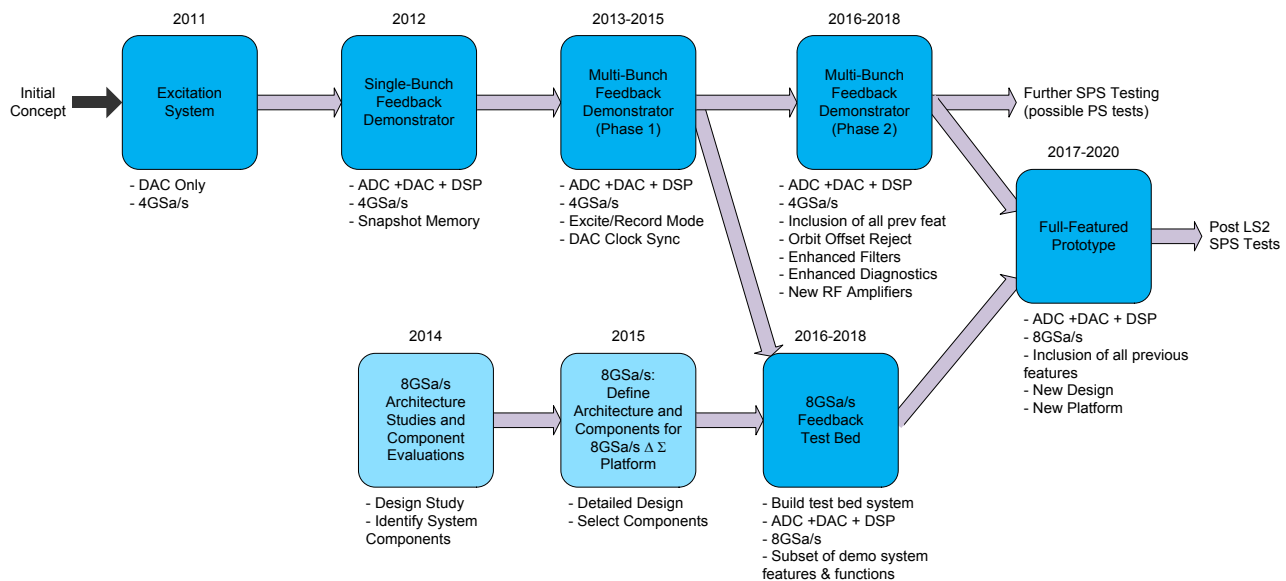
Figure 3: The technology development plan for the LARP Wideband Feedback effort, showing the path of expansion of the Demonstration system, and a parallel technology path with a higher sampling rate. We anticipate that the operational experience from the demonstrator system will guide the features to be implemented in the full-featured prototype in 2017

can be split to allow two independent pickups, though each running at a 2 GS/s rate. This path would allow measurements and system tests of the two pickup method, important if the simulations suggest the control is more robust at the higher effective sampling rates from two pickups.

TECHNOLOGY IMPLEMENTATION ROADMAP

The goal of developing a full-function instability control system for the SPS is envisaged to span two generations of prototype hardware. Figure 3 shows a multi-year program to expand the Demonstration system, validate the kicker and control technologies, and learn from the SPS MD experiments. In parallel, we want to explore a second hardware platform, based on a higher sampling rate A/D and D/A processing system, with associated higher-capacity FPGA processing functions. This increased processing capacity may be needed to support architectures with multiple pickups, or possible two-channel processing streams which use both the Δ signal (beam motion) and the Σ signal (bunch charge) as part of the computation of a correction signal.

SUMMARY AND PLANS FOR NEXT MD STUDIES

The upgraded demonstration system will be recommissioned at the SPS post LS-1 in Fall 2014, with opportunities to continue the control studies with the new wideband kickers starting in 2015. We anticipate continuing the series of driven tests, where excitation signals are used to measure the beam responses with and without the feedback in various configurations. Studies, and comparisons with beam instability simulations, are vital to predict the operation and margins of this beam feedback at the anticipated HL intensities and filling patterns. We plan on continuing to add features to the demonstration prototype while in parallel developing the platform for the full-featured prototype system to be commissioned after the LS2 shutdown.

REFERENCES

[1] E. Shaposhnikova, "Intensity Upgrade Plans for CERN-LHC Injectors", 42nd ICFA Advanced Beam Dynamics Workshop Nashville, Tenn., USA, 2008, CERN-AB-2008-065.

[2] J. D. Fox, J *et al.*, "First Results and Analysis of the Performance of a 4 GS/s Intra-Bunch Vertical Feedback System at the SPS," WEPME060, IPAC'13, Shanghai, China.

[3] K. Li, *et al.*, "Modelling and Studies for a Wideband Feedback System for Mitigation of Transverse Single Bunch Instabilities", WEPME042 IPAC'13, Shanghai, China.

[4] J. M. Cesaratto, *et al.*, "SPS Wideband Transverse Feedback Kicker: Design Report," SLAC-R-1037.

[5] C. Rivetta, *et al.*, " Feedback System Design Techniques for Control of Intra-bunch Instabilities at the SPS", *These Proceedings*, TUPRI086, IPAC'14, Dresden, Germany.

[6] H. Bartosik, "Beam Dynamics and Optics Studies for the LHC injectors Upgrade", CERN-THESIS-2013-257 2013.