Operation and Performance of a Longitudinal Feedback System Using Digital Signal Processing[*]

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Abstract

A programmable longitudinal feedback system using a parallel array of AT&T 1610 digital signal processors has been developed as a component of the PEP-II R&D program. This system has been installed at the Advanced Light Source (LBL) and implements full speed bunch by bunch signal processing for storage rings with bunch spacing of 4ns. Open and closed loop results showing the action of the feedback system are presented, and the system is shown to damp coupled-bunch instabilities in the ALS. A unified PC-based software environment for the feedback system operation is also described.

INTRODUCTION

The PEP-II machine will require feedback to control multibunch instabilities [1]. A longitudinal feedback system prototype has been installed and tested at the Advanced Light Source at the Lawrence Berkeley Laboratory. This system uses a bunch by bunch processing scheme and employs digital signal processing to calculate a correction signal for each bunch. As shown in Fig. 1, signals from four button-type pickups are combined and fed to the stripline comb generator. The generator produces an eight cycle burst at the sixth harmonic of the ring RF frequency (2998 MHz). The resultant signal is phase detected, then digitized at the bunch crossing rate. The detector is designed to have 400MHz bandwidth which allows measurement of the each bunch's synchrotron motion independently for the 4 ns bunch spacing. A correction signal for each bunch is computed by a digital signal processing module and applied to the beam through a fast D/A, an output modulator, a power amplifier and a kicker structure [2, 3].

The signal processing is implemented by four AT&T 1610 processors operating in parallel. These 16 bit processors are equipped with 16K of dual port memory on-chip and allow 25 ns instruction cycle time for cached instructions [4]. The feedback algorithm is downloaded to the prototype through JTAG interface from a IBM PC-compatible computer. This approach allows the user to quickly alter the feedback parameters as well as run a multitude of diagnostics, signal recorders and

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other programs.

As the synchrotron oscillation frequency in the ALS (10 kHz) is much less than the revolution frequency (1.5 MHz) the processing is implemented as a downsampled system, in which a correction signal for each bunch is computed once every n revolutions, where n is a downsampling factor. The four-processor prototype system allows control of up to 84 bunches when using a six-tap FIR filter algorithm. The maximum number of bunches varies depending on the filter processing time
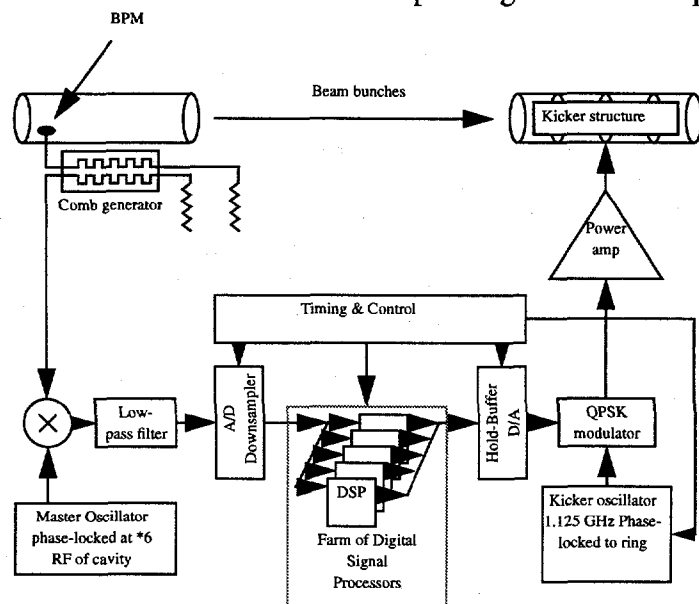

Figure 1. Block diagram of the longitudinal feedback system.

and fill pattern [5]. Design of the signal processing hardware and the front-end electronics has been addressed in the earlier publications [6]. Two important system components; the QPSK (quad phase shift keyed) modulator and the support software have not been described previously and are presented in the following sections.

QPSK MODULATOR OPERATION

The QPSK modulator function is implemented in the back-end signal processing and is used to transfer the baseband computed correction signal into a modulation on a kicker oscillator signal. The need for such a a modulator arises from the design of the kicker structure, which produces a maximum in longitudinal impedance at 1125 MHz, or 2.25 times the ring RF frequency (this choice minimizes the impedance presented at the bunch crossing frequency and higher harmonics) [7]. The QPSK modulator is implemented using a 2 GHz bandwidth gilbert multiplier, 500 MHz ECL counter circuitry, and a passive 90 degree hybrid. The QPSK circuit acts to shift the phase of an 1125 MHz carrier by -90 degrees every 2 ns to align the kick phase for the next bucket. Figure 2 shows the QPSK modulated carrier wave-

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form as well as unmodulated 1125 MHz signal while Fig. 3 illustrates the resultant carrier spectrum. Most of the power is at 1 GHz with a strong component at 1.25
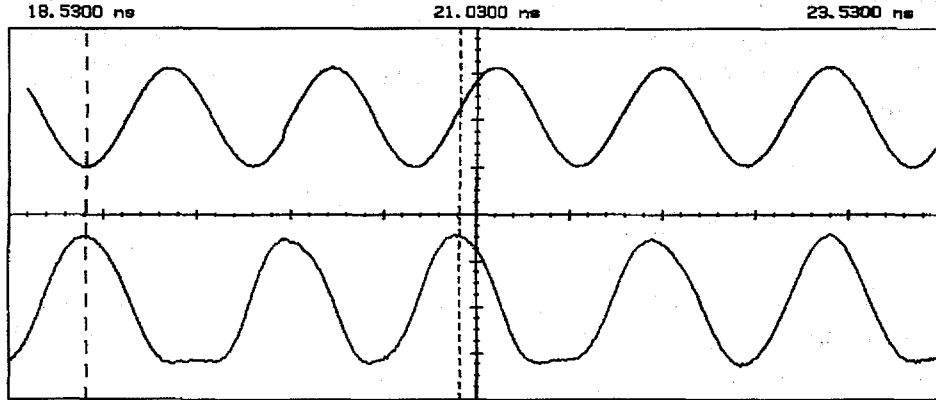

Figure 2. Oscilloscope photograph of the 1125 MHz carrier and QPSK modulated 1125 MHz carrier. The two cursors are 2ns apart to show the spacing of two adjacent bunches at 500 MHz.
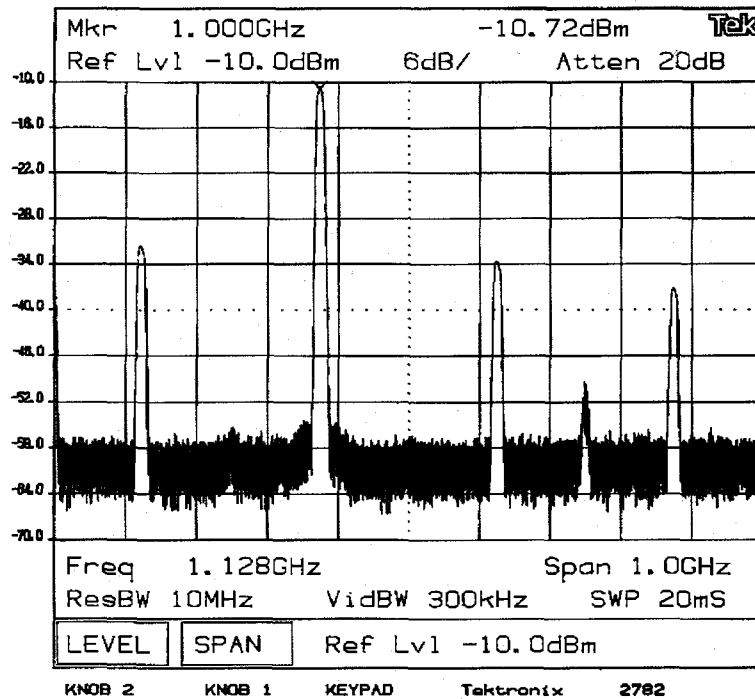

Figure 3. Spectrum of the QPSK modulated carrier.

GHz. Other spectral lines such as 0.75 GHz and 1.5 GHz fall outside the kicker bandwidth and do not affect the beam. This QPSK modulated 1125MHz signal, if applied to the beam, would produce a DC correction signal - the final function in the QPSK modulator is an amplitude modulator which multiplies the QPSK'ed signal by the baseband correction signal from the output D/A. This modulation adjusts the magnitude of the kicker drive signal every 4 ns to provide bunch by bunch correction signals (negative kicks require phase inversion of the kicker signal). The

resulting output spectrum for multi-bunch operation fills in the 250 MHz bandwidth between 1000 and 1250 MHz and covers all coupled-bunch modes in the storage ring. The circuitry as implemented has a 48 dB dynamic range and can be operated at any RF/4 ring harmonic up to 2 GHz with the full 500 MHz QPSK modulation rate.

UNIFIED SOFTWARE ENVIRONMENT

During the quick prototype development as the number and the sophistication of the DSP programs grew, management of the many configurations and feedback filter programs became a serious concern.

To coordinate the development of various operational programs and accelerator diagnostics a unified software environment has been created. This environment uses a text-based parameter file to specify the operational modes of the quick prototype system. All of the variables for a given experimental configuration, such as the machine revolution time, synchrotron frequency, filter gain, filter phase, etc. are contained in the parameter file. The file is read in turn by a number of relatively simple C programs which generate binary tables for downloading into the DSP memory and include files for the assembly language DSP code. The DSP code and tables are downloaded through the JTAG interface using the AT&T DSP1610 development system. All of these activities are coordinated by the UNIX make program. Using file timestamps and dependencies defined in a makefile make program ensures that tables and code downloaded to the DSP correspond to the variables in the parameter file.

SYSTEM TESTS AT ALS

The prototype system including a high-gain longitudinal kicker has been installed at the ALS and is being used to gain operational experience and to verify the system design for the PEP-II system. Figure 4 shows the longitudinal transfer function of a single bunch measured with no feedback, positive feedback, and negative feedback with two different loop gains. The action of the feedback system is seen in the higher or lower Q of the synchrotron resonance for positive or negative feedback respectively [8]. The graph shows that for a gain change of 8 (18dB) we get a change in damping of about 15dB.

Presently the ALS kicker is driven by a 10W power amplifier. This power limits the total current which can be controlled. It is interesting to note that relatively high ring currents (up to 125mA) can be controlled with relatively low voltage correction kick as long as the feedback system is turned on during injection, and the injection process injects only a single bunch at a time. This injection method allows the feedback system to damp the excitations caused by the injected bunch in the existing stored beam, and damp the resulting motion before the next injection cycle. If

the feedback system is turned off for any substantial current (above 10mA) the bunch motion becomes very large (greater than 10 degrees at the 500 MHz RF frequency) and turning the feedback system back on does not control the synchrotron motion. This happens because the feedback system saturates and cannot generate enough voltage to control the large amplitude motion once it grows from the quiescent state. Figure 5 shows the bunch spectrum obtained from a BPM for 8 groups of 2 bunches equally spaced around the ring at 100mA. Data shows that the longitudi-
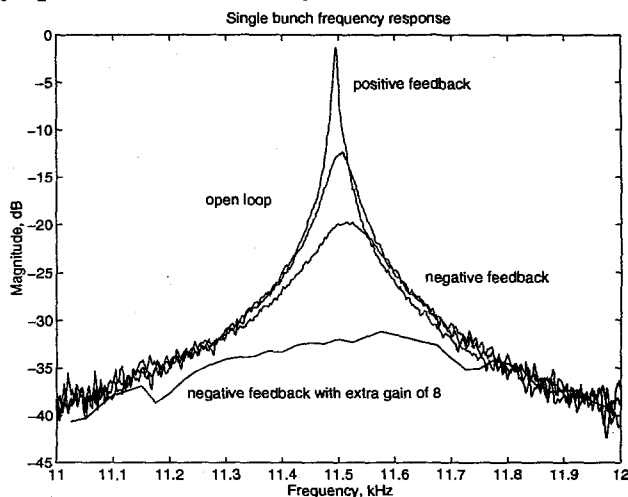
Figure 4. Single bunch transfer functions measured at the ALS. The open loop synchrotron resonance at 11.5 kHz can be damped or excited via negative or positive feedback respectively.
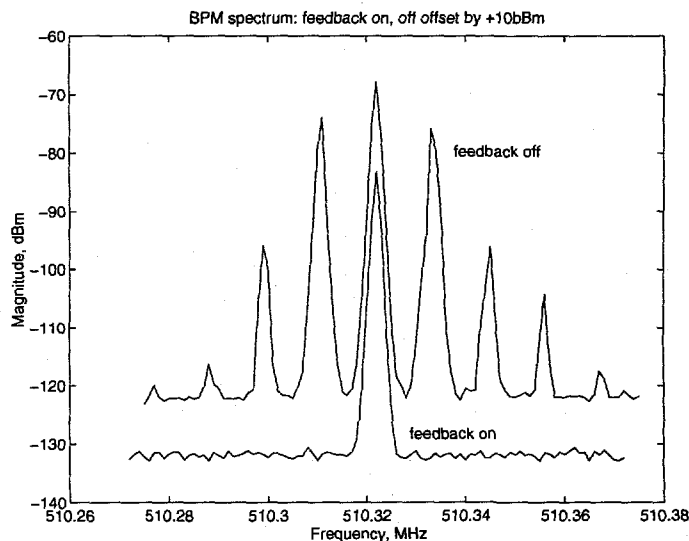

Figure 5. Spectrum of a BPM signal.

nal feedback suppresses the synchrotron oscillations (manifested as 10 kHz sidebands) from -73dBm to the noise floor of spectrum analyzer, i.e. suppression of 50dB.

Since ALS is a light source machine is it possible to utilize optical diagnostics to investigate the performance of the longitudinal feedback system. Experiments have been conducted at the ALS to measure the optical spectrum with and without feedback. Figure 6 presents an undulator spectrum taken at a 108mA ring current with 84 bunch fill pattern. The feedback system increases the optical intensity by a factor of 2.5 and narrows the peak width to almost 1/4 of that of the undamped system. For synchrotron light users who are conducting narrowband spectroscopic measurements such an improvement in machine performance is very desirable. It is interesting to speculate on the bimodal structure visible in the "feedback off" spectrum which appears to be due to the coherent dipole mode longitudinal oscillations.
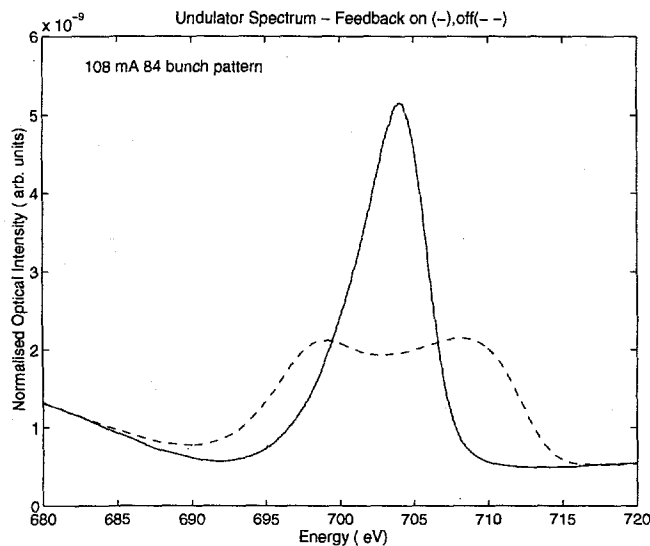

Figure 6. Undulator spectrum.

SUMMARY

The longitudinal bunch-by-bunch feedback system quick prototype is operated at the ALS at Lawrence Berkeley Laboratory. It includes all of the subsystems required for the PEP-II machine. The quick prototype system is used for algorithm development and various accelerator measurements. Closed-loop feedback operation has been demonstrated and longitudinal instabilities have been controlled for an 84 bunch fill pattern with 125mA ring current. We expect to be able to damp longitudinal motion at the 400mA design current when the high-power output amplifier is installed. The information gained from the quick prototype system has been incorporated in the PEP-II system design [9]. A complete PEP-II prototype for ALS operations is in construction and should be installed and commissioned at the ALS in early 1995.

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