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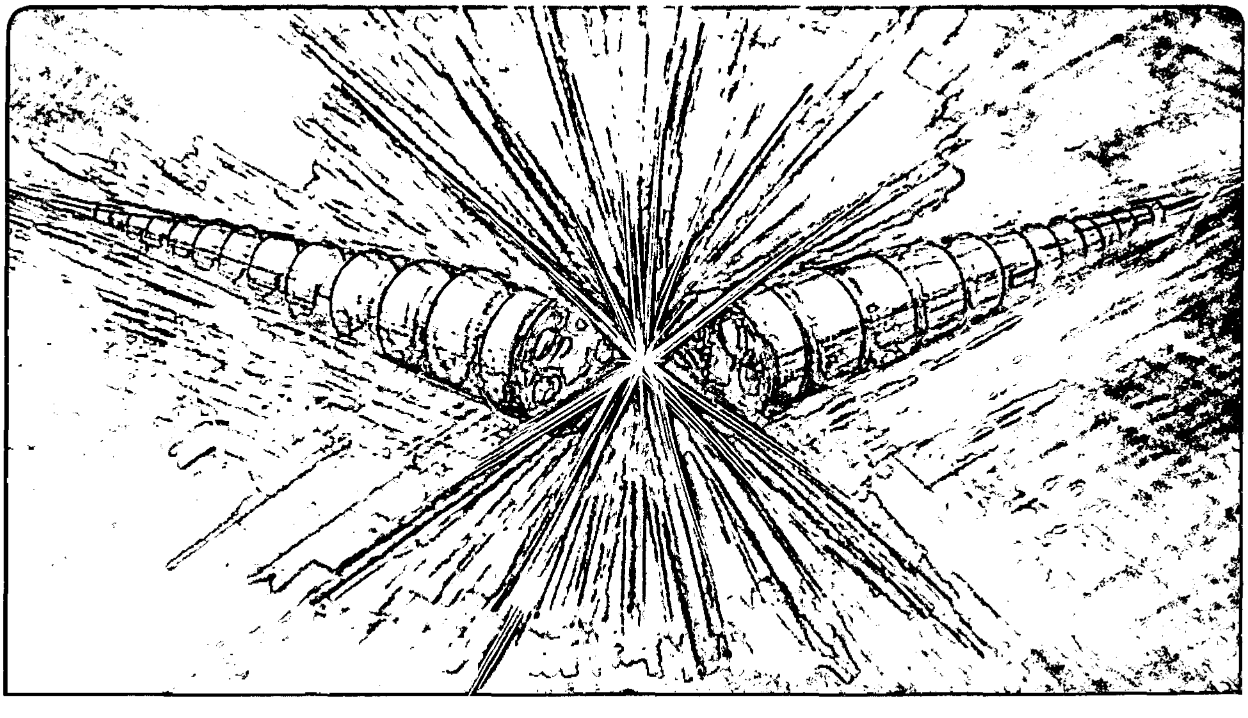

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TRANSVERSE FEEDBACK SYSTEMS FOR THE PEP-II B-FACTORY*

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Introduction

Growth rates of coherent beam oscillations are faster than the natural damping mechanisms for the parameters of the PEP-II B-factory storage rings at nominal currents, even with damping of cavity higher order modes (HOM's) [1,2]. With 1658 bunches separated by 4.2 ns, and a large current of up to 3A (2.14 A nominal in the low energy ring), many coupled-bunch modes are excited by the resistive wall impedance and cavity higher order mode impedance. Fastest growth times of transverse rigid-bunch modes of approximately 300 μs are expected, two orders of magnitude faster than the radiation damping time. We will provide broadband, bunch-by-bunch feedback to suppress this coherent motion of the beam [3]. Experience gained with a prototype system, installed and successfully operating at the LBNL Advanced Light Source (ALS), has been used extensively in developing the design of the PEP-II systems.

System design

The transverse coupled-bunch feedback systems for PEP-II will be bunch-by-bunch systems, with two receivers detecting beam moment ($I_{bunch}\Delta x$); gain control and summation to provide appropriate combination of the receiver signals; digitization of the kick signal; digital delay and single bunch excitation scheme; and baseband power amplifiers and kickers. A schematic layout of the system is shown in figure 1. The systems will provide up to 3.4 kV transverse kick voltage, sufficient to control a mode amplitude of up to 0.23 mm [3]. The required feedback gain is then 14.6 kV/mm. The required dynamic range, based on a maximum mode amplitude of 0.23 mm and a damped mode amplitude of 0.016 mm ($0.1\sigma_y$), is 23 dB. The actual dynamic range of the systems is 42 dB, determined by the 8-bit ADC (7 useful bits).

From the beam moment information obtained at two discrete points in the lattice the transverse phase space may be calculated, knowing the lattice functions of the machine. We compute a corrective kick for each bunch by summing the beam moment signals from each receiver in the appropriate ratio. This is achieved by adjusting the gain on the beam moment signals from each receiver before summing them in a broadband power combiner. Having thus generated the appropriate kick signal for each bunch, this signal is digitized and delayed in memory by a time appropriate to allow the kick signal to be applied to the same bunch that generated the beam moment signals, within a single turn. The digital electronics will also incorporate a method of inverting the sign of the kick signal to allow positive feedback on a selected bunch. This bunch is then driven to large amplitude by the feedback system, in a short time to minimize decoherence, in order that charge may be lost at the minimum machine aperture (probably a scraper inserted for this purpose). This is expected to have application in optimizing injection conditions, by kicking out trial bunches injected into the bunch train gap, and maintaining a uniform bunch filling pattern by removing some charge from individual bunches as required. The impedance of the transverse kicker structure, a simple stripline pair, peaks at low frequencies, and for efficiency we operate the power amplifiers and kickers at baseband frequencies. A system bandwidth of 119 MHz is required to suppress all beam oscillation modes for the nominal case of alternate RF buckets filled (4.2 ns bunch spacing), however, we design the electronics of the system to have sufficient

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bandwidth to operate with all buckets filled (238 MHz). The kickers are optimized for the 4.2 ns bunch spacing and would need to be replaced with a shorter electrode design if operating with 2.1 ns bunch spacing.

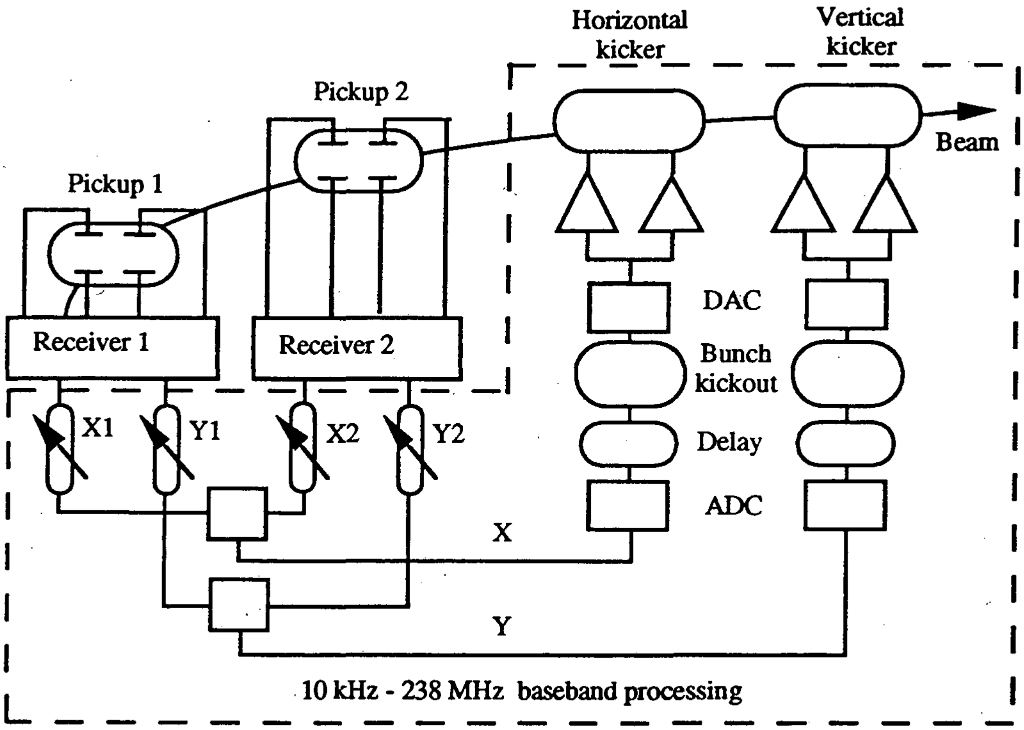


Figure 1. Transverse feedback system schematic

Receivers design

Two receivers will be used to provide beam moment information for each bunch on each turn from two sets of four button pickups located at different points in the lattice. The signal from each button is bandpass filtered at a center frequency three times the RF frequency (1.428 GHz), and minimum bandwidth of 238 MHz. A commercially available monopulse comparator is then used to generate the horizontal and vertical beam moment signals from the four button signals. A heterodyne detection scheme is used to generate baseband signals which are low-pass filtered (minimum 238 MHz passband) and amplified before leaving the receiver chassis. Figure 2 shows a schematic of the receiver design. Orbit offset, either through beam misalignment, BPM misalignment, or imbalance in components, is rejected by subtraction of the common mode signal in a feedback loop. The baseband signal is integrated and the resulting dc signal is used to control the gain of a loop which subtracts the BPM sum signal from the horizontal and vertical beam moment signals on a bunch-by-bunch basis. A rejection of 11 dB is required [3]. Details of the electronics design for this scheme are being developed.

Mixing chassis design

The mixing chassis must sum the beam moment signals from the two receivers over a bandwidth of 13 kHz - 238 MHz. The low frequency limit is determined by the highest operating fractional tune $\Delta Q_{x,y}$ of the machine (taken to be 0.9), which results in an anti-damped resistive wall mode at $(1-\Delta f_{x,y})f_0 \approx 13$ kHz. The high frequency limit is determined by the minimum bunch spacing (taken to be 2.1 ns, every bucket filled), for which the highest frequency mode can be detected with a minimum of two samples per period, or equivalently a sampling frequency of half the bunch repetition frequency. A scheme is being developed using broadband analog multipliers to provide variable gain, including sign inversion, over this frequency range. By appropriate combination of beam moment signals from the two receivers, a purely resistive feedback signal may be generated in quadrature with the beam position. Alternatively, reactive feedback may generated, with possible application in reducing the transverse mode coupling instability threshold.

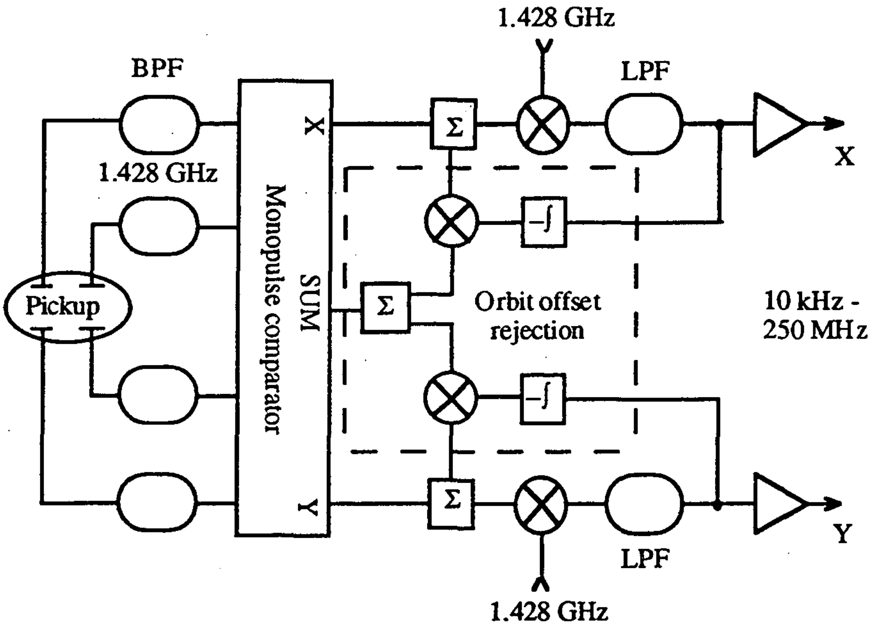


Figure 2. Receiver details.

Digital electronics

Digitization of the kick signal derived in the mixing chassis, at the maximum bunch repetition rate of 476 MHz, is provided by Tektronix 500 MHz ADC's. Appropriate delay is provided by a circular memory buffer. The details of this memory design are being developed - fast ECL 8-bit memory is becoming increasingly difficult to obtain commercially, and a 4-bit wide source may be used to ensure a continuing supply. Single-bunch kickout simulations with non-linearities ($\partial Q_x/\partial x$, $\partial Q_y/\partial y$) indicate that the single-bunch excitation scheme will work, with acceptably small perturbations to following bunches [4]. Implementation of the scheme is expected to involve two parallel signal channels and a fast multiplexer triggered by a signal from the control system. One digital signal passes through an inverting gain stage, the other does not and is the regular feedback channel. Selecting the inverted signal path gives positive feedback for that bunch.

Power amplifiers and kickers

Commercially available solid state, class A, 10 kHz - 250 MHz, 150 W power amplifiers have been delivered. Gain and phase linearity are better than 1.5 dB and ±45° respectively. One power amplifier will be used to drive each electrode, i.e. two per plane per ring. Stripline kickers have been designed and a prototype kicker is being tested. The kicker is 60 cm long, half the nominal bunch spacing, with a shunt impedance varying from 24 kΩ to 10 kΩ over the operating frequency band of 10 kHz to 119 MHz. Beam induced currents cause heating of the electrodes, dissipating 7 W per electrode at 3 A beam current [5]. At nominal bunch spacing there is (ideally) no power induced at the kicker terminals. In this case the forward and reverse signals on the stripline cancel as a new bunch arrives in the kicker at the same time as the reverse signal reaches the upstream end of the electrode.

Preliminary system results from the ALS

The Advanced Light Source (ALS) at Berkeley is an ideal test-bed for R&D on B-Factory feedback systems [6,7,8]. The transverse and longitudinal feedback systems for PEP-II are both prototyped as ALS systems, and are operational during user beam at the light source. The ALS is similar to PEP-II in terms of collective effects, with growth times of less than 1.0 ms for transverse coupled bunch instabilities.

The ALS storage ring typically uses 320 bunches separated by 2 ns, 400 mA average current, and a 250 MHz bandwidth feedback system to suppress all beam oscillation modes. The circumference of the ALS is approximately 1/10 that of the PEP-II B-factory. Two receivers operating at 3 GHz provide beam moment information from button pickups, this beam moment information is used to compute a corrective kick for each bunch. Appropriate delay is provided by a coaxial line (the machine circumference of 200 m allows the use of a relatively short coaxial delay line). A two-tap FIR correlator filter is used to avoid amplifier saturation by orbit harmonics. Figure 3 shows a schematic layout of the ALS transverse feedback systems.

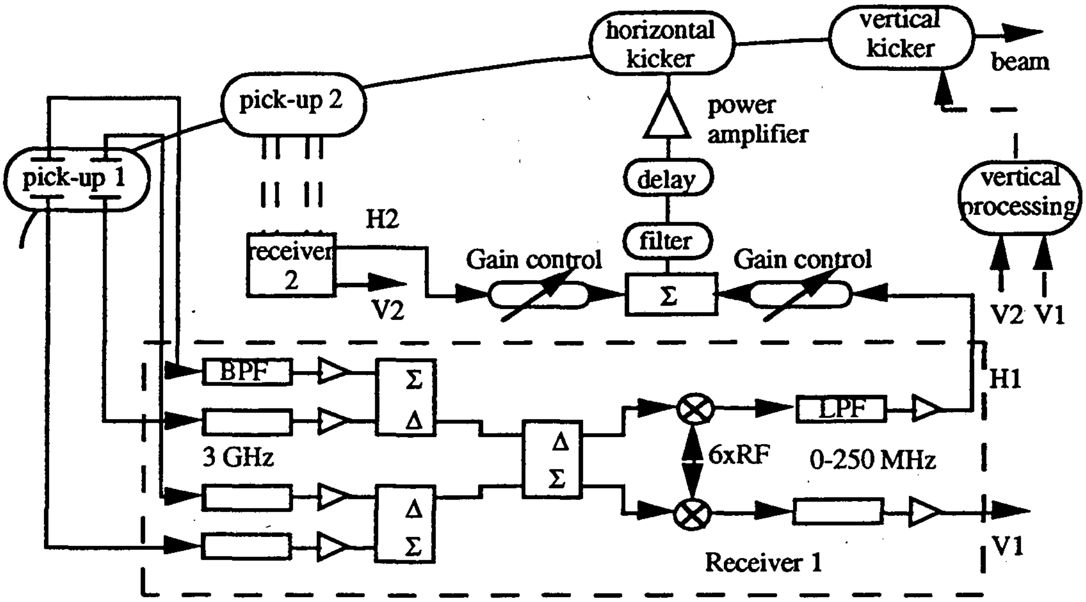
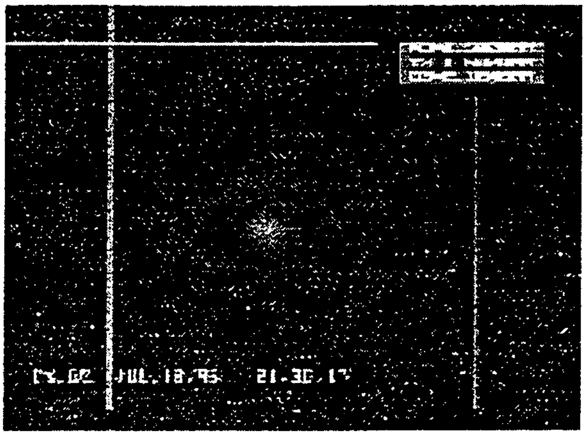


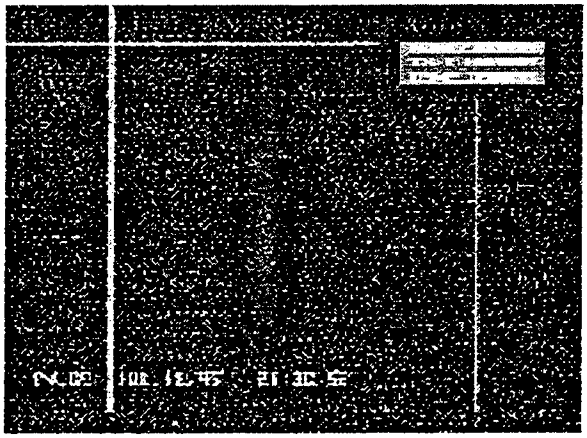
Figure 3. ALS transverse feedback systems.

Figure 4 shows images from the ALS diagnostic beamline under different conditions of coupled-bunch feedback. Note the increase in beamsize with the transverse feedback systems off. The scale is given by 1.5 mm spacing between the vertical white lines towards the edges the images.

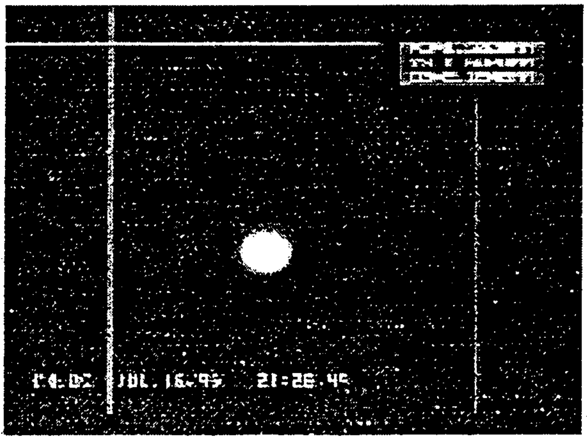
Growth times as short as 200 μs have been measured, and feedback system damping times of 50 μs. Growth rates of particular modes are sensitive to cavity temperatures and tuner positions, and some modes have been correlated with known cavity higher order modes [9]. Detailed characterization of the systems is in progress.



a. Horizontal feedback off, vertical and longitudinal feedback on, 380 mA.



b. Vertical feedback off, horizontal and longitudinal feedback on, 320 mA.



c. Vertical, horizontal and longitudinal feedback on, 400 mA.

Figure 4. ALS diagnostic beamline images showing transverse beamsize under different conditions of coupled-bunch feedback.

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