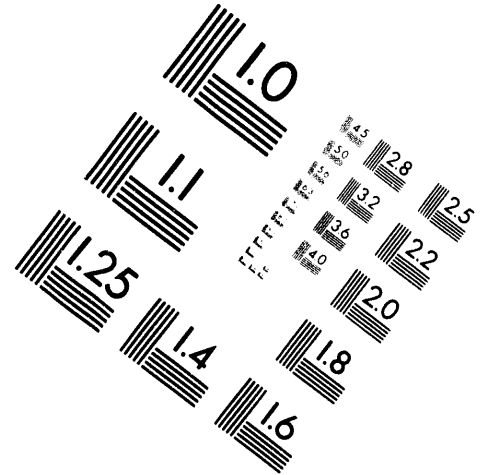
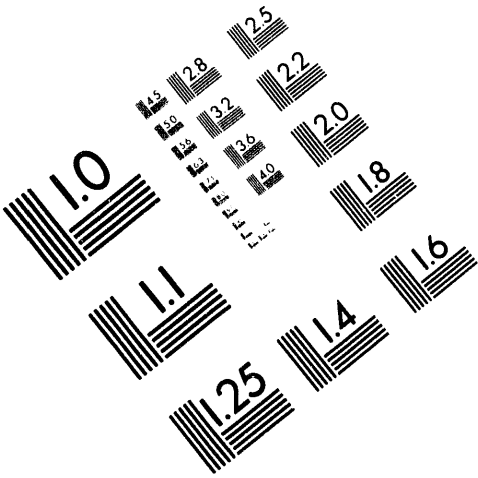




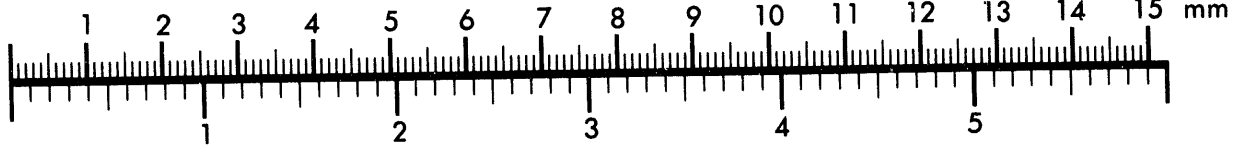
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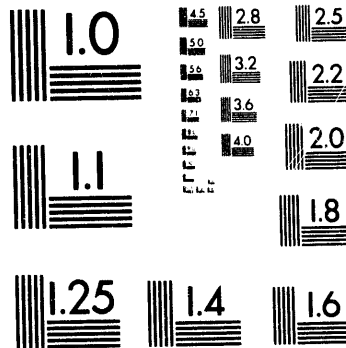
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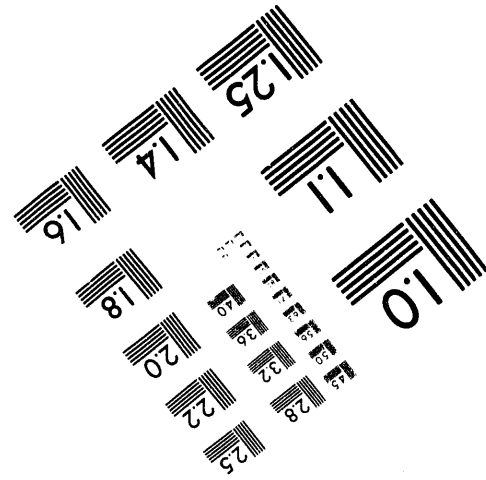
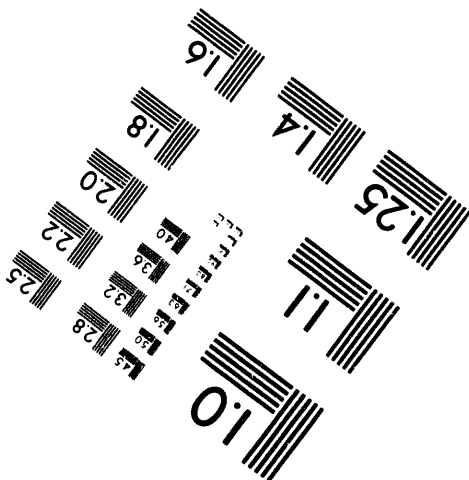
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# TRANSVERSE COUPLED-BUNCH FEEDBACK IN THE ADVANCED LIGHT SOURCE (ALS)\*

W. Barry, J. Byrd, J. Corlett, G. R. Lambertson, and C. C. Lo  
Center for Beam Physics  
Lawrence Berkeley Laboratory  
Berkeley, California, 94720

## Abstract

In order to effectively control a large number of transverse coupled-bunch modes in the LBL Advanced Light Source (ALS) storage ring, a broad-band, bunch-by-bunch feedback system has been designed [1], and is beginning to undergo testing and commissioning. This paper addresses the major electronic components of the feedback system. In particular, the components described include: broad-band microwave position detection receivers, closed orbit offset signal rejection circuitry, and baseband quadrature processing circuitry. Initial commissioning results are also presented.

## INTRODUCTION

The LBL Advanced Light Source (ALS) is a third generation 1.5 GeV electron storage ring for producing synchrotron radiation in the 0.5 - 10000 eV range [2]. Because of the high average beam current in the ring (400 mA), active feedback systems for damping longitudinal and transverse coupled-bunch instabilities are required. The storage ring is designed to accommodate a large number of bunches, up to 328 in buckets separated by 2 ns (500 MHz RF). As a result, a broad spectrum of transverse coupled-bunch modes are driven by the higher-order transverse modes of the RF cavities and the transverse resistive-wall impedance [3]. In order to effectively damp and control growth of these modes, a 250 MHz bandwidth, bunch-by-bunch feedback system has been designed, and is presently being commissioned at the ALS.

## ELECTRONIC SYSTEMS

The transverse feedback system concept is shown in Figure 1. The system utilizes two pickups, each of which detects both horizontal and vertical beam moment ( $I\Delta X_{\perp}$ ). By summing moment signals from the two pickups in proper proportion, kick signals that are exactly in quadrature with horizontal and vertical beam position at the kickers can be produced. For low per-turn gain feedback systems such as this one, the kick/position quadrature condition results in optimal damping. Because the relative contributions of the two pickups is adjustable, this technique allows for arbitrary kicker placement and can accommodate a wide range of betatron tunes.

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The pickups consist of LEP buttons modified to suppress high frequency resonances [4]. Separate horizontal and vertical stripline kickers are used to obtain maximum efficiency by optimizing the electrode coverage factor [5]. The electronics systems consist of two microwave receivers for detecting horizontal and vertical beam moment, a system (shown as two variable attenuators) for mixing the signals from the two pickups, two single turn (656 ns) coaxial notch filters, and two coaxial delay lines. Finally, four broad-band power amplifiers are used to drive each electrode of the two kickers.

The 500 MHz bunch rate in the ALS dictates a minimum 250 MHz base-bandwidth for a bunch-by-bunch feedback system. As long as this bandwidth criterion is met, moment detection as well as kicking may be performed using any harmonic of the 500 MHz bunch rate as a carrier. Because of the efficiency advantages of low-frequency transverse kickers, the baseband range (~ 150 kHz - 250 MHz) is used for kicking the beam. Four 150W, 10 kHz - 220 MHz, commercial power amplifiers are used to drive the electrodes of the two kickers (300 W per kicker). The amplifier/kicker combination provides per-turn kicks ranging from 2.3 kV at 100 kHz to 1.6 kV at 220 MHz. At the nominal betatron tunes, these voltages and frequency range are sufficient to control any expected transverse coupled-bunch motion.

In contrast to the kicker band of operation, detection is performed at 3 GHz where the pickups are most sensitive. As indicated in Figure 1, the front-end receivers detect horizontal and vertical moment as amplitude modulation of the  $n = 6$  harmonic of the 500 MHz bunch rate. At present, the receivers allow for either heterodyne or homodyne demodulation. In heterodyne mode, the horizontal and vertical signals are synchronously demodulated to baseband with a 3 GHz local oscillator locked to the storage ring RF. This scheme results in a low noise, high dynamic range system which is linear with respect to beam moment. A potential problem with heterodyne demodulation arises when large synchrotron oscillations are present on the beam. In this case, the oscillating arrival time of the bunches with respect to the fixed phase local oscillator causes the effective gain of the feedback to be amplitude modulated at the synchrotron frequency. Consequently, the average gain is diluted, and in fact, the system can become unstable if the synchrotron oscillations are too large. In homodyne mode, the moment signals are demodulated with an amplitude limited reference signal derived from the sum of the four button signals. This greatly reduces the sensitivity to synchrotron oscillations.

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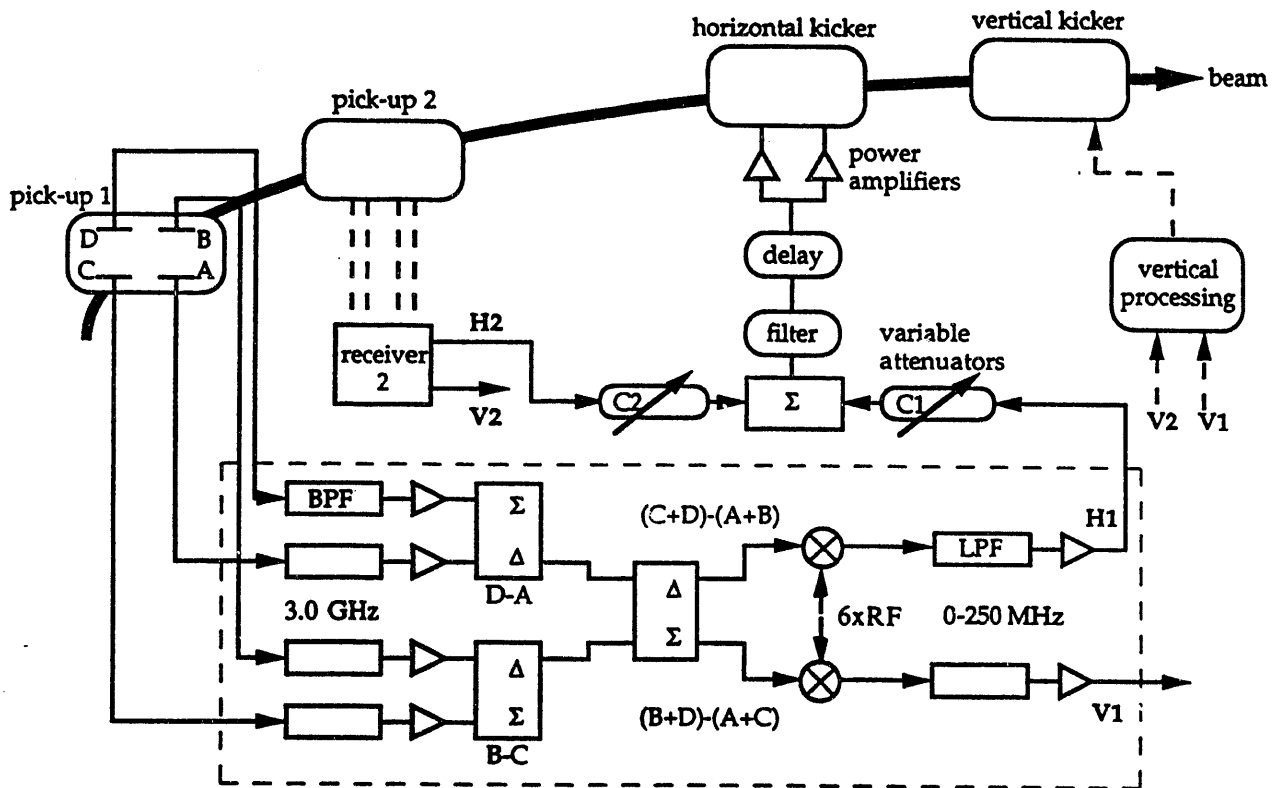


Figure 1 ALS Transverse Feedback System

However, this technique suffers from a limited dynamic range and other problems associated with the non-linear devices used to limit the reference signal. At present, both techniques have been used to successfully damp transverse oscillations at the ALS. Further experimental and theoretical investigations into optimal demodulation schemes are ongoing.

Because broad-band RF power is expensive, it is important not to feedback on signals which are due to static orbit offset and transfer function imbalances among the four receiver channels. Rejection of these signals which appear as orbit harmonics is accomplished with standard one-turn coaxial notch filters. Using 656 ns, 7/8" helix cables and precision 100 kHz - 300 MHz hybrids, the ALS notch filters provide better than 30 dB rejection of the 1.5 MHz orbit harmonics over the entire baseband frequency range.

#### INITIAL COMMISSIONING RESULTS

Initial results at the ALS were obtained with a partial system consisting of a single pickup and receiver operating in the x (horizontal) plane. In this case, a single electrode of the horizontal kicker was driven as part of the feedback system. The other electrode of the kicker was reserved for driving the beam in order to make frequency domain measurements.

Setup and timing of the system as well as the first measurements were done in single-bunch mode. Figure 2 shows the response of a single 2 mA average current bunch to a swept excitation about a particular betatron line with and without the feedback system turned on. In this case, the receiver was operating in heterodyne mode. It should be

noted that the line widths in Figure 2, especially in the undamped case, are artificially broad because of the resolution bandwidth of the spectrum analyzer and tune jitter. As a result, the 20 dB difference between peaks in the damped and undamped cases is certainly a lower bound on the open loop gain of the system.

The natural damping time for a single bunch was measured directly in the time domain by impulsively exciting the bunch with the injection bump magnets and observing the decay in amplitude of a single betatron line as a function of time. Using this technique, the natural decay time was measured to be 5 ms or about 8000 turns. For an 8000 turn natural time constant and a 20 dB open loop gain, the per-turn or feedback gain is given approximately by  $10/8000 = 1.25 \times 10^{-3}$ .

The single-bunch frequency domain measurement was repeated with the receiver in homodyne mode (with less gain) as shown in Figure 3. Note that in both cases, the resonant peak is shifted upwards in frequency with the feedback on. This means that both the real and imaginary parts of the complex resonant frequency are changed by the feedback because the single pickup/receiver system cannot meet the kick/position quadrature condition at the kicker. The full two-pickup system can be adjusted to utilize the full gain to address only the damping component of the complex resonant frequency for any tune setting.

An example of a multi-bunch measurement of the system is shown in Figure 4. In this case, a 220 mA beam consisting of 82 equally spaced bunches (every fourth bucket) gives rise to significant coupled-bunch motion as evidenced by the betatron sideband spectrum with the feedback turned off. With the feedback system turned on in

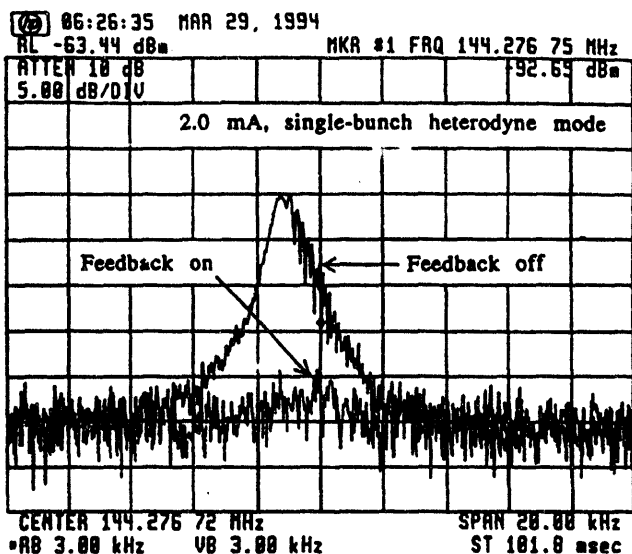


Figure 2 Transfer functions -- heterodyne mode

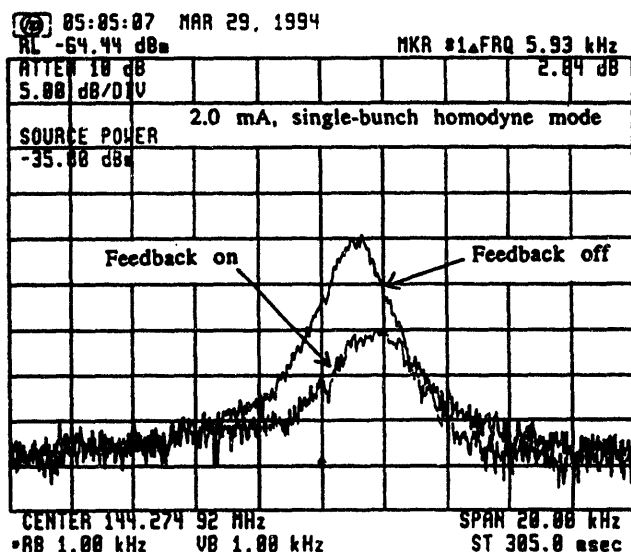


Figure 3 Transfer functions -- homodyne mode

homodyne mode, the motion is reduced to levels at or below what can be measured due to the noise floor of the spectrum analyzer. The x axes of Figure 4 are in units of revolution frequency. Because only every fourth bucket is filled, it is only necessary to look at one fourth of the full 250 MHz baseband or about 41 harmonics to cover all coupled-bunch modes. Thus, this measurement exercises only one fourth of the system bandwidth. Mode damping for the 82 bunch, 220 mA case in heterodyne mode was also demonstrated.

Finally, measurements similar to those of Figure 4 were performed with 320 bunches at 385 mA which is approximately the nominal ALS beam. In this case, damping of the betatron motion below the noise floor of the spectrum analyzer was also demonstrated.

### CONCLUSION

A broad-band feedback system for controlling transverse coupled-bunch instabilities in the ALS has been designed,

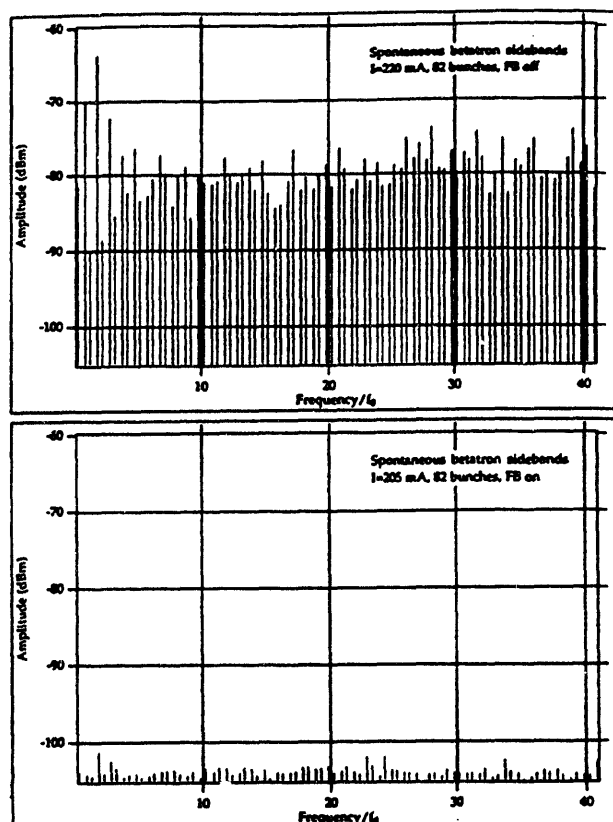


Figure 4 Multi-bunch damping

installed, and partially commissioned. In particular, damping of coupled-bunch motion in the horizontal plane under nominal beam conditions has been demonstrated. Present efforts are being directed towards commissioning the full two-pickup quadrature system for both planes.

### ACKNOWLEDGMENTS

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