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Low-Mode Coupled Bunch Feedback Channel for PEP-II[*]

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Abstract

Both the HER and LER of PEP-II use broadband longitudinal multi-bunch feedback systems which process all coupled-bunch modes in the machine spanning a 119 MHz bandwidth. Roughly 1 MHz of this bandwidth includes modes driven by impedance related to the RF cavity fundamental.

The longitudinal modes within the cavity bandwidth are processed by the all-mode broadband systems, though the correction signal is applied to the beam via a path through the broadband kicker, as well as through a special woofer channel which uses the RF system to apply low-mode correction signals to the beam. As there are two correction paths, with differing group delay and frequency response, yet only one adjustable processing channel, it is difficult to get an optimal low-frequency ("woofer") response if the broadband feedback path is configured to best control HOM driven instabilities.

A new low-mode processing channel has been designed to provide an independent means of providing the low-mode correction signal. It is a digital channel, operating at a 10 MHz sampling rate, and incorporating programmable 12 tap FIR control filters. This channel, implemented using EPLD technology, allows more optimal gain and phase adjustment of the woofer control path, with lower group delay allowing higher gain. This extra flexibility and higher gain will be useful in future high-current PEP-II operation. The design of the control channel is illustrated, and a possible control filter with system dynamics is described.

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1 Introduction

The RF systems in PEP-II use room temperature copper cavities, with HOM damping and complex LLRF feedback loops to control the impedances seen by the circulating beam [1, 2]. This RF system has been successfully operated at design currents, though the growth rates of low longitudinal modes within the RF system bandwidth have been measured to be significantly (factors of 5 to 20) higher than estimated by simulations during system design [3]. To control these low longitudinal modes the systems have been using a processing channel [4] to extract low mode longitudinal motion signals from the broadband control path and inject this correction signal in the RF system itself, using the klystrons as a power source to make correction fields.

The maximum damping rate that this “woofer” can provide is limited by the combination of the bandwidth of control required, the gain required, phase non-linearities in the control path and the time delay around the control path, which physically spans several sections of the 2.2 kilometer machine circumference. The broadband multi-bunch feedback control filters are optimized to have best damping for signals applied to the beam via the broadband all-mode kickers and power amplifiers. Using the RF cavities as a kicker path requires extra time delays to align the correction signal with the proper bunches (which can be up to 12/3 of a revolution), and the phase response of the control filter is not optimum for this longer path. Figure 1 shows the maximum damping rate the existing woofer implementation can provide as a function of feedback path gain. The maximum damping rate of -1.5 ms^{-1} at the 1580 mA current limits the allowable instability growth rates of the low modes – turning up the gain in the channel simply reduces the damping while adding a large reactive tune shift. As the growth rates increase with current, the measured results suggest that the existing implementation will become marginal in effectiveness at operating currents much above the design level.

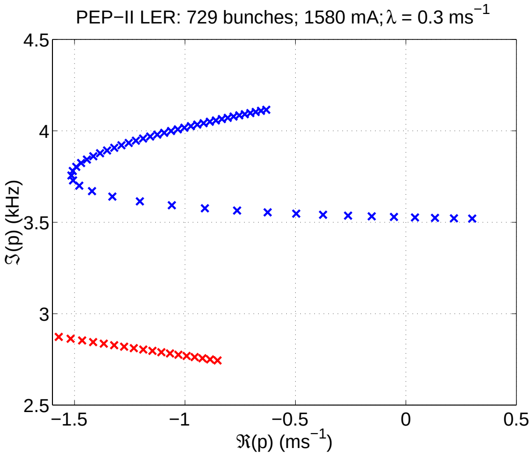

Figure 1: Gain-locus plot showing the maximum damping possible through the woofer in the PEP-II LER. With no gain the instability growth rate for the most unstable mode is 0.3 ms^{-1}. With increasing woofer gain a maximum damping of -1.5 ms^{-1} is reached. Increasing the channel gain beyond this point simply produces greater reactive tune shift, as well as less resistive damping.

2 A low-group delay woofer

One path to achieving control at higher operating currents is to reduce the time delay around the feedback loop, which allows higher loop gain. To implement this path requires a control channel independent of the existing downsampled DSP farm. This non-downsampled path can sample at a rate lower than the bunch crossing rate if it is only to control a fraction of the 119 MHz bandwidth (just the low-modes within the cavity bandwidth), rather than the full span of coupled-bunch modes. Such a channel is also advantageous in that it can be independently adjusted to optimize the control loop gain and phase to achieve best damping using the RF cavities in the control loop.

The low group delay woofer is based around a 10 MHz sampling rate FIR filter, structured so that the delay between taps is exactly one revolution period at the sampling rate. The system can be thought of as a macrobunch-by-macrobunch feedback system, where the information on the oscillation coordinates of a group of bunches is averaged into a "macrobunch". In essence the lowest normal modes of bunch motion involve small variations in oscillation phase between neighbor bunches, so that the motion of a "macrobunch" is a good measure of the collective low-mode motion of that sub-group of bunches.

3 Design features

The sampling clock is derived from the RF system master oscillator in the existing back-end module, using a PLL to generate a bunch synchronous sampling clock at 72x the revolution frequency. The baseband bunch phase oscillation signal from the broadband longitudinal system is split off, low pass filtered and digitized with 12 bit resolution. The output data path is converted back to baseband in a 12 bit D/A, and this computed correction is then re-sampled in the existing back-end module and transmitted to the RF stations. [5]

As shown in Figure 2 the data path is 8 bits wide, and the filter implements 16 bit coefficients with a 28 bit output accumulator. To allow final gain adjustment, independent of the coefficient values, the design includes a "shift gain" output register that allows post-computation shifting of the output result of up to 15 bits (scaling the gain by 2^N), and includes arithmetic saturation in the output logic.

The filter coefficients are stored as a set of 2 possible coefficient sets, so that the filter can be changed on the fly by selecting a filter set. This structure allows a number of transient-domain measurements of the dynamics to be made [6]. A 128 KB block of diagnostic memory is included in the design, and this memory can either record beam motion while the filter runs (or switches), or play back sequences though the output D/A to drive the system for diagnostic or measurement purposes.

The prototype is controlled via a parallel interface from a host computer, and the interface memory maps the various control registers, coefficient registers, and diagnostic memory. A simple user interface has been prototyped allowing the selection of filter coefficient sets, shift gains, etc. via a graphical panel.

The design has been prototyped using a commercial Xilinx evaluation board from GV Associates [7], which includes a pair of Xilinx XC4085XLA FPGA devices, the A/D and D/A

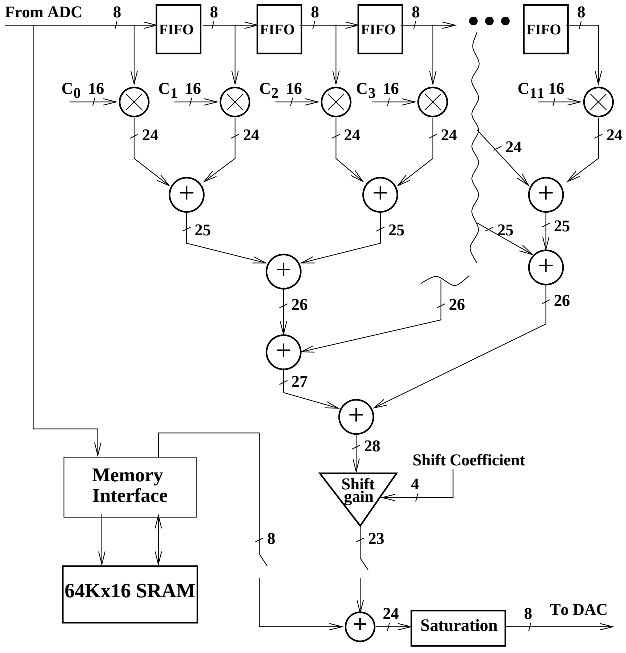

Figure 2: Block Diagram of the EPLD implemented 12 tap FIR filter. The figure explicitly shows 5 taps; the structure of the adder tree is shown where it is extended for the 12 tap filter, with 12 coefficients and multipliers. Also shown is a diagnostic memory used for transient domain measurements.

components, diagnostic memories and a general purpose parallel interface. The evaluation board environment is an excellent platform to evaluate various architectures and test this approach on real beam signals.

4 Simulations of the Dynamics of Low-modes

To estimate the performance of this system, a simple dynamic model has been constructed, which models the low-mode feedback filter, RF system and beam, though the beam model is a simplified treatment of an unstable harmonic oscillator with parameters derived from measurements of the actual machine. There are numerous possible control filters, and Figure 3 presents the baseband frequency response for the filter used in our initial simulations. This baseband control filter is then folded around all the 36 revolution harmonics in the system bandwidth.The frequency response of this filter peaks at 12 KHz, a frequency well above the 5.5 KHz synchrotron frequency. This high-frequency gain is a consequence of the low-group delay processing. A filter more narrowly peaked around the synchrotron frequency must inherently have a longer processing or group delay as it must take more samples and time to define the synchrotron frequency. Hence this processing approach achieves the low group delay, as desired, but the system is now sensitive to extraneous noise or beam signals above the synchrotron frequency, and the system must not saturate on these signals, even though the filter has 10 dB more gain at these high frequencies compared to the synchrotron

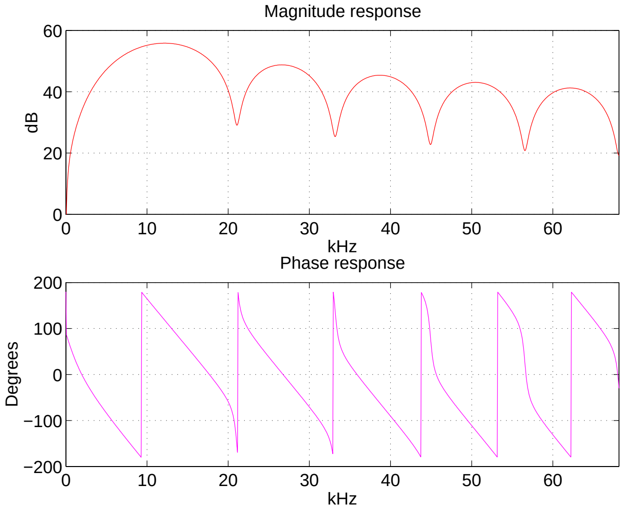

Figure 3: Magnitude and phase responses for a proposed 12 tap FIR filter for the low group delay processing channel. This filter is designed for the PEP-II HER, with a synchrotron frequency of 5.5 KHz. The low group delay filter provides the damping phase shift of 90 degrees with 44 dB of gain at this frequency, though the 54 dB maximum gain of the filter is found at 12 KHz

frequency.

5 A low-group delay woofer

Figure 4 presents a gain locus plot for a possible filter candidate. The filter shows the unstable pole with no feedback, and shows the damping increasing with increasing system gain. There is a maximum useful gain, above which the damping decreases with significant tune shifts. This simulation result suggests this type of filter could provide damping rates in the PEP-II HER of the order of 4 ms^{-1} before excessive tune shifts are created, or roughly a factor of three better than the existing implementation. Such an improvement would be a significant increase in the operating margins and headroom at the design current, though exactly what ultimate higher operating current such a filter might control requires more study.

6 Conclusions and future directions

The core processing functions are compiled and functioning, as is the interface to the FIR filter functions from a host PC. We are in the process of verifying the dynamic range and functioning of the processing channel, and comparing the measured behavior to that expected from simulations. We expect to be able to run the low-mode woofer as a control element of the PEP-II LER in summer machine physics opportunities. A careful study is necessary to verify that this approach is feasible, given the concerns about noise saturation of the filter, and that it actually offers a damping rate improvement over the existing control path in

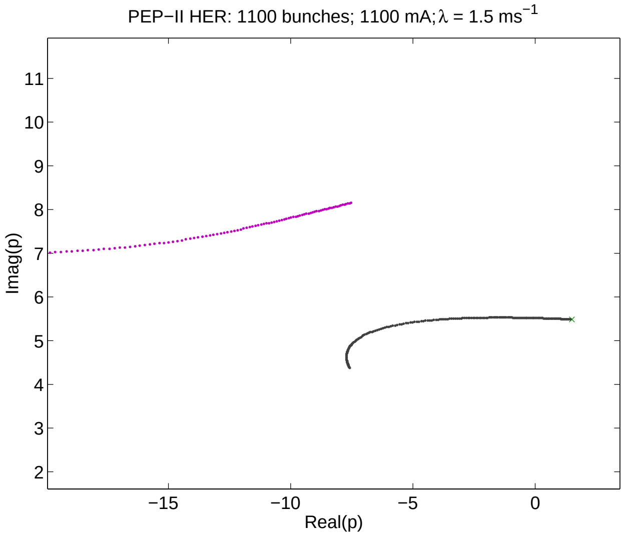

Figure 4: Gain locus study for a proposed woofer filter for the PEP-II HER. The unstable growth rate without feedback is 1.5 ms^{-1} at 1100 mA. Increasing the woofer gain to the 44 dB of Figure 3 produces damping rates of -4 ms^{-1}.

the broadband feedback. Finally, there is considerable room to develop optimized filters, of various forms, that may well offer better control dynamics and allow higher gain. Efforts to understand these options are at very preliminary stages.

7 Acknowledgments

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