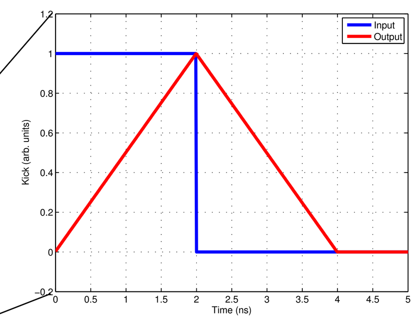
Optimization of Bunch-to-Bunch Isolation in Instability Feedback Systems

Dmitry Teytelman, Dimtel, Inc., San Jose, CA, USA

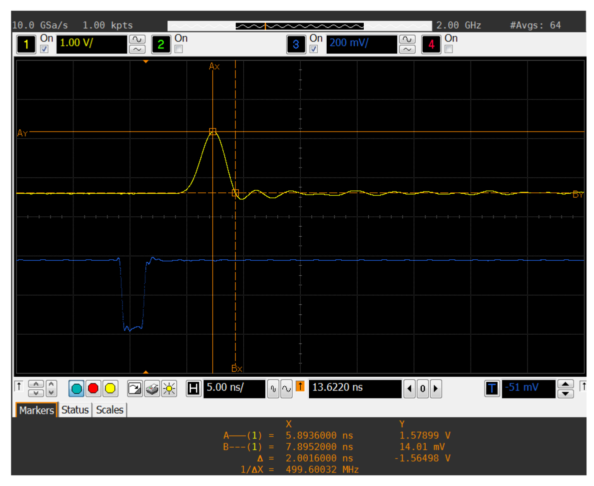
Abstract

Bunch-by-bunch feedback formalism is a powerful tool for combating coupled-bunch instabilities in circular accelerators. Imperfections in the analog front and back ends lead to coupling between neighboring bunches. Such coupling limits system performance in both feedback and diagnostic capacities. In this paper, techniques for optimizing bunch-to-bunch isolation within the system will be presented. A new method for improving the performance of the existing systems will be described. The novel approach uses a "shaper" filter in the digital signal processor to compensate for the imperfect response of the power amplifier and kicker combination. An objective optimization method to derive the optimal back end configuration will be presented and illustrated with measurements from several accelerators.

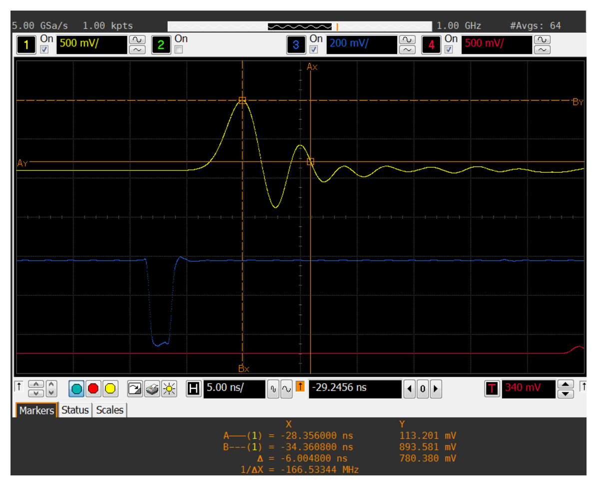
Stripline kicker response



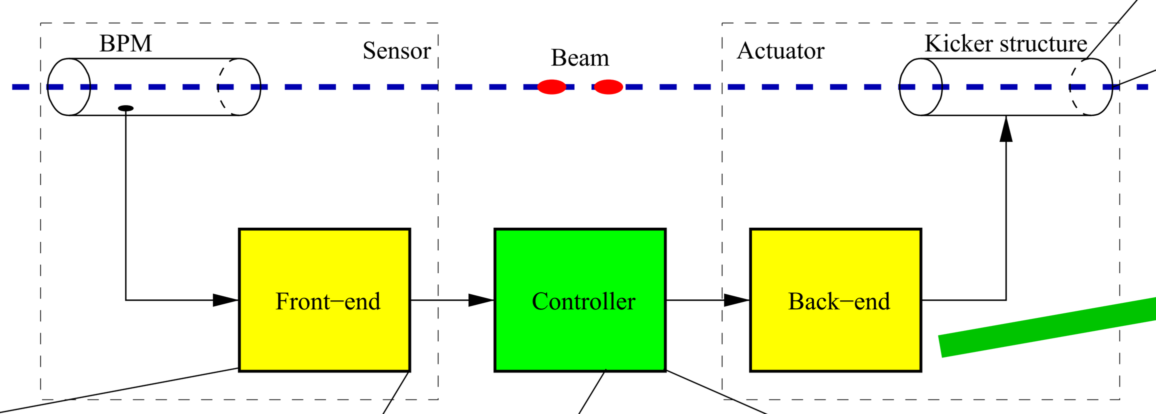
The Good

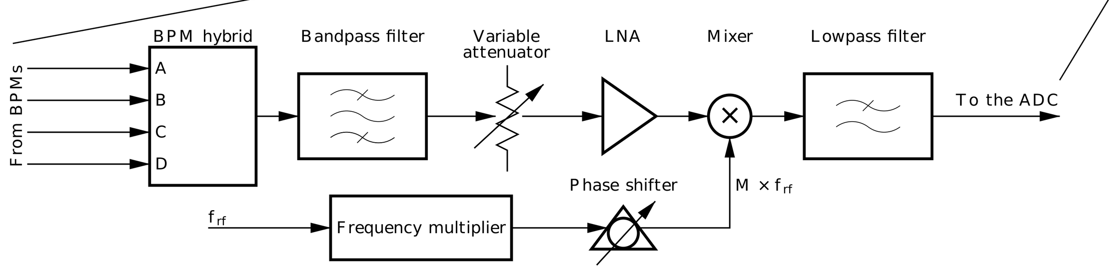


The Ugly



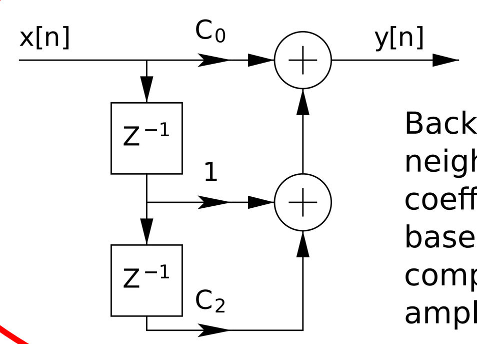
Modern bunch-by-bunch feedback system





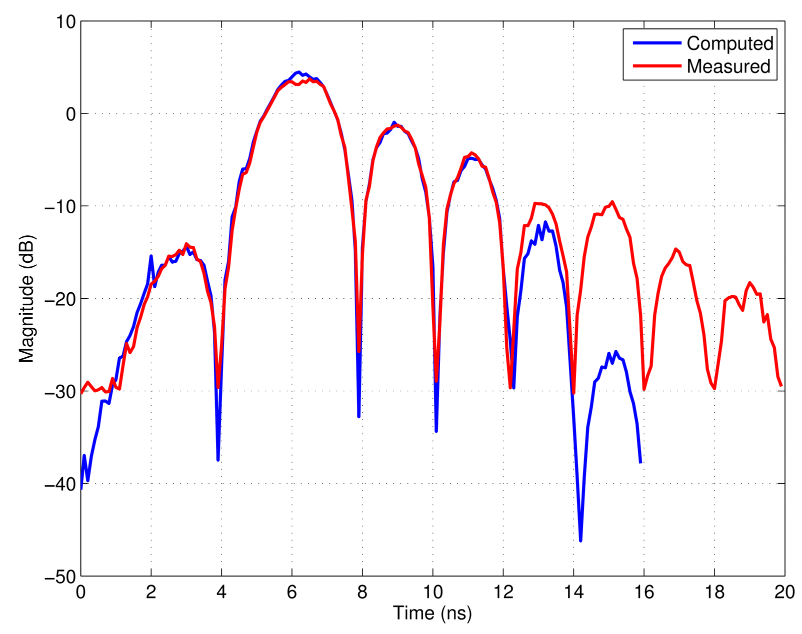
Beam signal is detected by a heterodyne front end. Bandpass and lowpass filters must be carefully selected to ensure well controlled time domain response that settles within a single RF period. Bandpass filtering is often implemented using feedforward comb filters.

Back end shaper



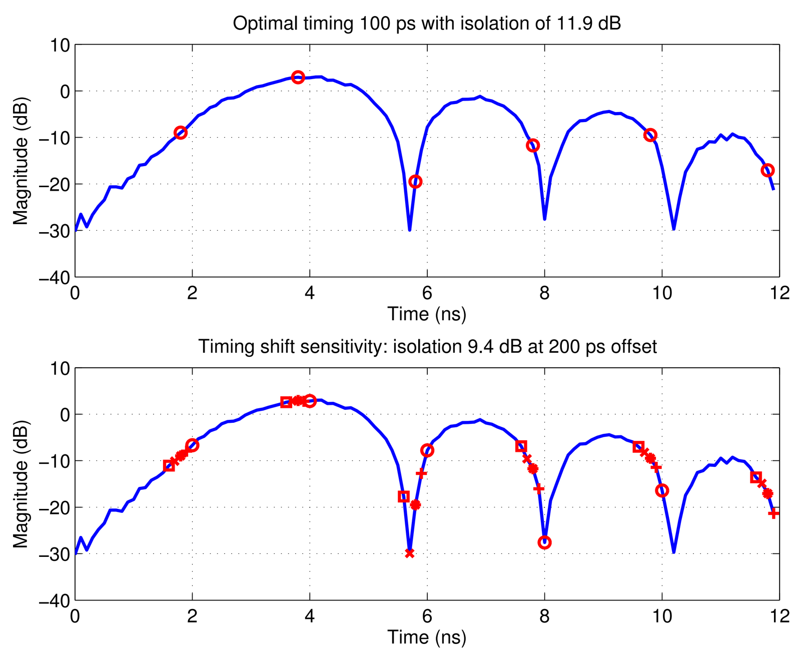
Back end shaper is an FIR filter, working on three neighboring bunches. With the two adjustable coefficients it provides the flexibility to pre-distort baseband controller output in a way that compensates for the response of the power amplifier and the kicker.

Empirical shaper optimization



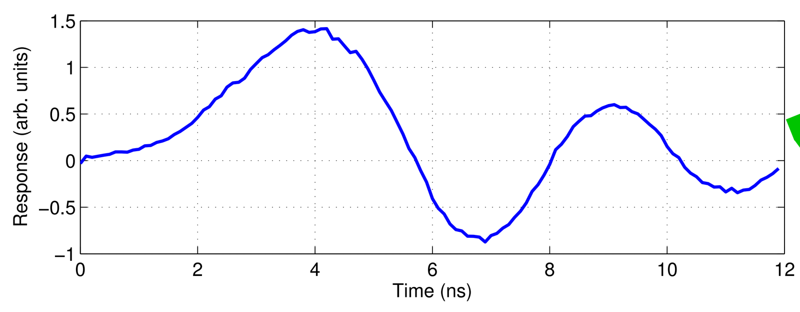
Shaper coefficients set to [-0.3 1 0.15] improve back end coupling to -18.6 dB. Good agreement between analytically computed and measured responses.

Back end response measurement BESSY II vertical plane



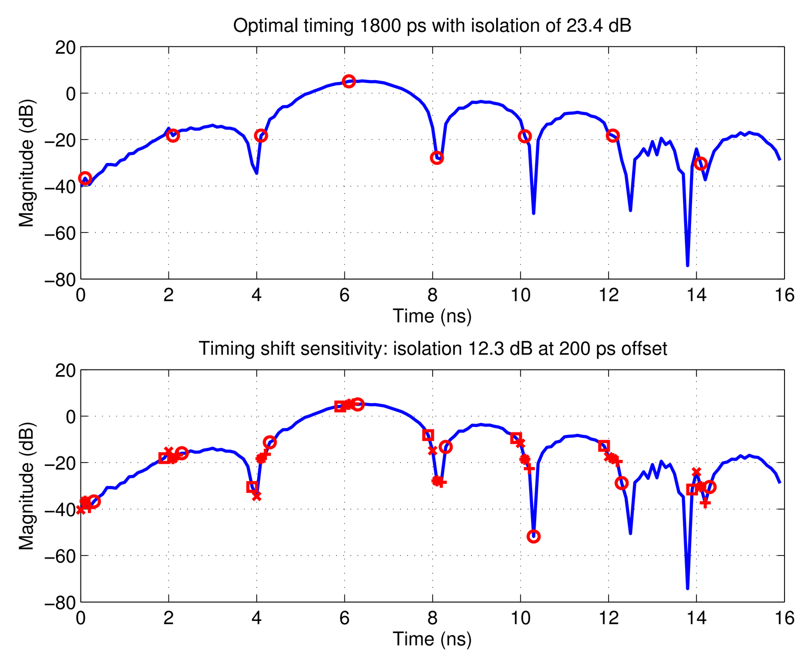
BESSY II uncorrected vertical back end response shows -12 dB coupling to multiple bunches.

Extract pulse response



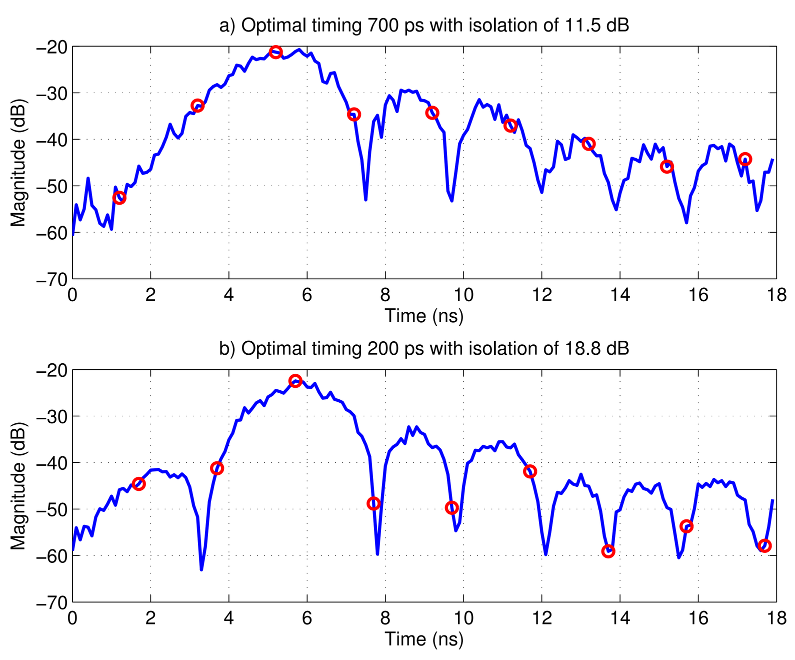
Back end pulse response is automatically extracted by inverting the signal at the minima. This response is then used to model the shaped output by convolving three pulse response copies, delayed by 2 ns. Numerical optimization of C_0, C_2, and timing delay T is then performed. The optimization goal is to minimize the maximum coupling. For a given combination of parameters, we generate the effective output signal and compute kick levels at all bunch positions. Ratio of the largest to second largest kick defines the maximum coupling.

Optimization to minimize coupling



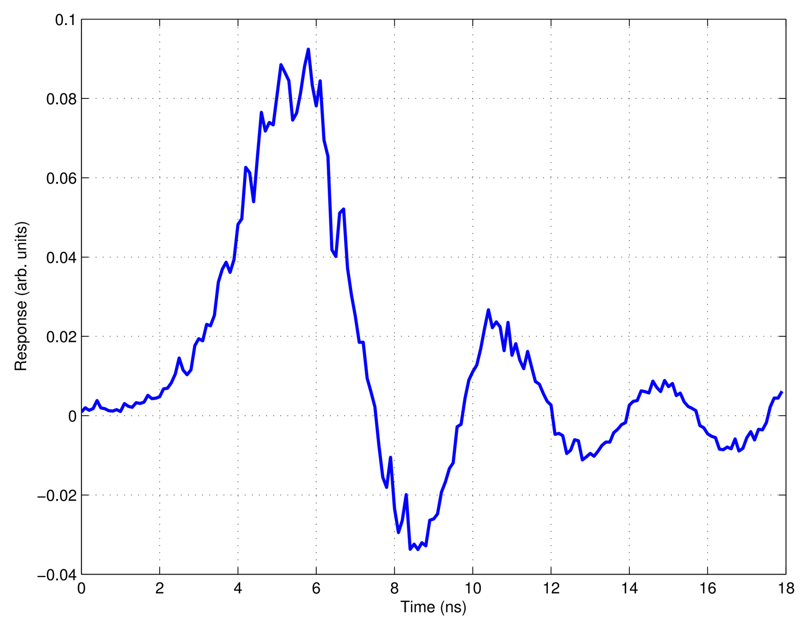
Numeric optimization generates a coefficient vector of [-0.31 1 0.42], predicting coupling improvement to -23.4 dB. The correction holds up even at offset timing, degrading to -12.3 dB for 200 ps shift in timing.

Back end response measurement TLS horizontal plane



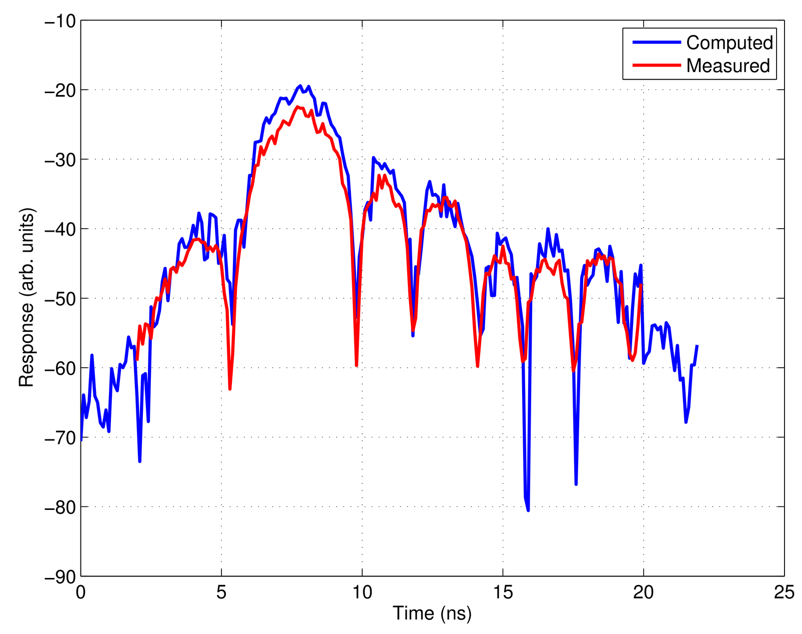
Impulse response measurement is much noisier than that at BESSY II, mostly due to significant tune frequency variation in the TLS.

Estimated pulse response



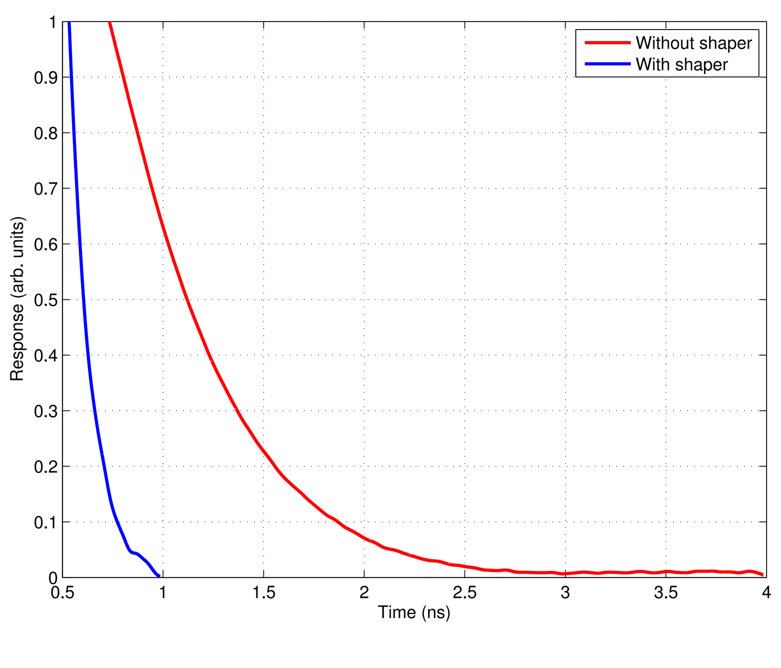
Numeric optimization of the shaper configuration is quite sensitive to the quality of the estimated pulse response. Noisy pulse response measurement leads to errors in shaper coefficients and projected coupling estimates.

Optimal shaper configuration



Numeric optimization generates a coefficient vector of [-0.32 1 0.24], predicting coupling improvement to -23.2 dB. In reality we measure -18.8 dB coupling. Computed and measured responses agree reasonably well apart from saturation in the main lobe. Due to shaping, the amplifier is driven to higher peak voltages, causing some saturation.

Damping transients with and without the shaper



The plot shows damping transients, measured at the same feedback gains, with and without the shaper. Due to parasitic coupling in the back end, feedback is much less effective without the shaper.

SUMMARY

Bunch-to-bunch isolation in the multibunch feedback signal chain is important for system performance. While many components in the front and back end signal chains have potential to contribute to parasitic coupling, experience shows that the overall coupling is typically dominated by the power amplifier.

A digital pre-distortion filter has been successfully tested at several bunch-by-bunch feedback system installations. The filter implementation, together with the measurement and optimization procedure has been shown to halve the parasitic bunch-to-bunch coupling in transverse feedback applications.