

A DIGITAL RING TRANSVERSE FEEDBACK LOW-LEVEL RF CONTROL SYSTEM

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Abstract

A digital wide-band system for damping ring instabilities in an accelerator is presented. With increased beam intensity, the losses of an accumulator ring tend to increase due to the onset of various instabilities in the beam. An analog feedback damper system has been implemented at Los Alamos National Laboratory. This analog system, while functional, has certain limitations and a lack of programmability, which can be overcome by a digital solution. A digital feedback damper system is being designed through a collaborative effort by researchers at Oakridge National Laboratory, Los Alamos National Laboratory, and the University of Wisconsin. This system, which includes analog-to-digital converters, field programmable gate arrays and digital-to-analog converters can equalize errors inherent to analog systems, such as dispersion due to amplifiers/cables, gain mismatches, and timing adjustments. The digital system features programmable gains and delays, and programmable equalizers that are implemented using digital FIR and comb filters. The flexibility of the digital system allows it to be customized to implement different configurations and extended to address other diagnostic problems.

INTRODUCTION

A mixed-signal wide-band system for damping ring instabilities based on the analog feedback damper system, implemented at Los Alamos National Laboratory [1], is presented in this paper. This system, which includes analog-to-digital converters (ADCs), field programmable gate arrays (FPGAs), and digital-to-analog converters (DACs) implements simple DSP algorithms that equalize errors inherent to analog systems, such as dispersion due to amplifiers/cables, gain mismatches, and timing adjustments. The digital part of the system features programmable gains and delays and programmable equalizers that are implemented using digital FIR and comb filters.

The flexibility of the digital system allows it to be customized to implement different configurations and extended to address other diagnostic problems.

With increased beam intensity, the losses of an accumulator ring tend to increase due to the onset of various instabilities in the beam. Such E-P (electron-Proton) instabilities are observed in the PSR (Proton Storage Ring) at LANSCE. A wide-band analog feedback damper system was designed and implemented to reduce these instabilities. This analog system, while functional, has certain limitations and lacks programmability, which can be overcome by a mixed-signal solution. The goal of this project is to build a mixed-signal control system that can overcome these limitations and can be used to both monitor and control the beam of protons in a storage ring and an accelerating ring with proper clock.

SYSTEM DESCRIPTION

The pickup and kicker are two separate devices, located at different positions in the accelerator ring. The pickup is a pair of electrodes used to obtain the transverse position of the beam. Voltage signals from the pickup are sent to the ADCs along with a clock signal that is locked to an integer multiple of the ring revolution frequency. For the SNS system, the frequency of the clock was envisioned to be a factor of 450 higher than the ring frequency, which may be too high for the limitations of the present digital design. The external clock source must be perfectly synchronized to the ring frequency for the mixed-signal damper system to function.

The voltage signals are converted to digital signals using two ADCs and fed to the system through two channels. These signals are amplified or attenuated before taking a difference. This weighted-difference gives a number that is proportional to both the amount of current

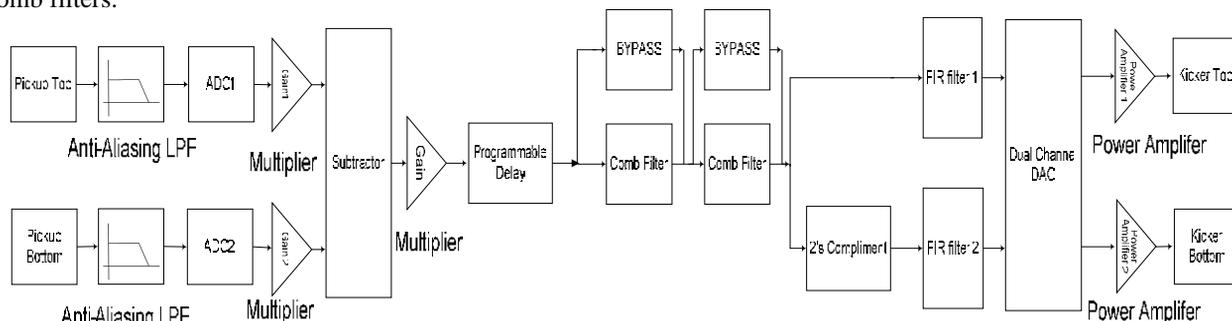


Figure 1: Block Diagram of the Mixed-Signal feedback Damper System

in the ring and to the position of the beam from the electrical axis of the electrode.

Programmable Delay

The feedback damper system works only for the real part of the signals. To maintain negative feedback, this implies that the phase difference between the pickup and kicker should always be between -90 and 90 degrees. Any change in this delay changes the phase difference between the pickup and kicker and based on the frequency of the instabilities the phase difference can go into the range 90 - 270 degrees. Whenever this happens the system drives the beam instead of damping the instabilities.

Comb filters

The voltage signals obtained from the pickup have information about both the ring harmonics and the instability. The harmonics are a function of the closed orbit offset. The instabilities present in the beam are modulated by the ring frequencies. The Fourier spectrum of the beam observed at LANSCE is presented in Fig. 2.

The major part of the spectral power is due to the ring harmonics due to closed orbit. Since we are interested in damping the instabilities, notching out the ring harmonics will not affect the feedback on the instability but will greatly reduce the power associated with the spectral content. Using a comb filter will greatly help in saving the available power in the power amplifiers by notching out the ring harmonics.

The frequency response of a comb filter with cut-off frequency of 1 MHz is given in Fig. 3. The effect of using this comb filter on the beam spectrum is depicted in Fig. 4. From Figure 4, we can observe that by using comb filters we can save considerable power while not losing any valuable information about the beam spectrum.

FIR filters

The FIR filters implemented in this design are equalizers designed to correct for the dispersion and gain mismatches in the system [2]. Dispersion observed in the system can be due to both the cables used in the system as well as the anti-aliasing LPFs used to band limit the signal.

Dispersion due to cable

The FIR filter coefficients are calculated from a calibrated vector network analyzer measurement of the transmission i.e. S_{21} characteristics of the cables. This measured data can be transformed into the time domain to obtain its impulse response. Since the bandwidth of the system is known, a window function is applied to this transformation. The inverse function of the cable is then

calculated and then transformed back into the time domain. This inverse function of the cable is known as the equalizer, and when measurement data is applied to the equalizer, the effects of the measurement cable can be removed. The phase response a cable used for measuring ring information and the phase response of its equalizer and an ideal are shown in Fig. 5. From figure 5 we can observe that the equalizer can successfully remove the dispersion associated with the cable.

Dispersion due to anti-aliasing Low Pass Filters

The maximum frequency of operation obtained for our design is 400 MHz. The Nyquist Theorem states that for exact reconstruction of a continuous-time baseband signal from its samples, the sampling rate must be greater than twice the signal bandwidth. In order to achieve this, the input signals are to be band limited to 180 MHz. This is achieved using anti-aliasing Low Pass Filters with cut-off frequency of 180 MHz. Similar to a cable, the dispersion associated with the LPFs used in the system can also be equalized using equalizers.

RESULTS

The Mixed-signal Feedback Damper system and all its components have been designed used Verilog HDL and simulation tests have been run. The functional verification of the individual components and the system has been tested using Verilog HDL and MATLAB models. The maximum frequency of operation obtained for the intended target FPGA is found to be 401.75 MHz according to simulation. Currently, parallel architectures for the system and alternative implementations of the components are being tested.

CONCLUSION

Even though the mixed-signal damper system has advantages over the analog damper system, it still has some disadvantages. The analog damper system can function at higher frequencies than the mixed-signal damper system. This is because the functioning of the mixed-signal damper system is dependent on the maximum clock frequency that can be handled by the FPGA. In our system setup, the maximum clock frequency that can be handled is 500 MHz. The Nyquist Theorem implies that this would band-limit the input signals that can be used with this system to less than 250 MHz. Also, since the mixed-signal system design deals with digital signals, there are issues of quantization and lower SNR values when compared with its analog counterpart. But once the mixed-signal damper system is designed, it can be easily modified and parameterized. Moreover, the ability of the mixed-signal damper system to correct for the dispersion throughout the system can outweigh these disadvantages.

REFERENCES

[1] Craig Deibele et al, "Design and Implementation of Analog Feedback Damper System for an Electron-Proton Instability at the Los Alamos Proton Storage Ring," PAC'05

[2] A.Polisetti et al, "De-embedding a cable using FIR Signal Processing Techniques", <http://it.sns.ornl.gov/asd/public/pdf/sns0171/sns0171.pdf>

[3] Simulation Figures 2, 3 and 4 provided by Zaipeng Xie, University of Wisconsin, Madison, based on data provided by Robert J. Macek , LANL

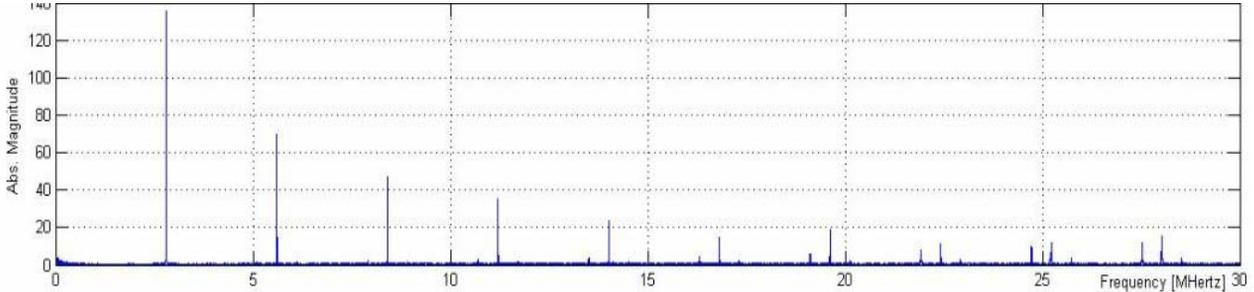


Figure 2: Frequency Spectrum of the beam observed at LANSCE.

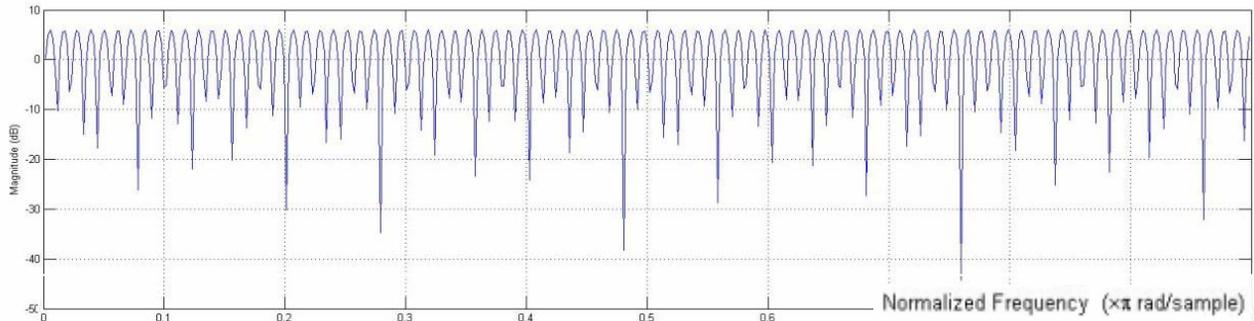


Figure 3: Frequency response of a Comb filter with cut-off frequency 2. 7951 MHz , ring frequency of LANSCE

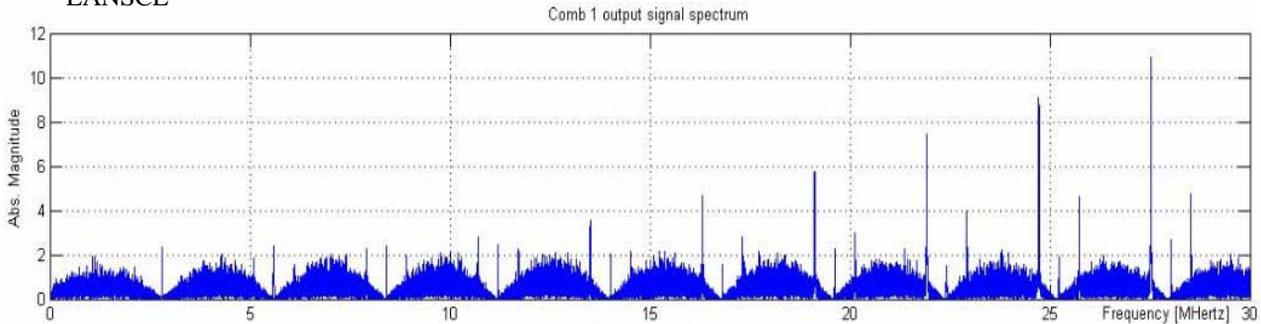


Figure 4: Frequency Spectrum of the beam after application of the Comb Filter shown in Fig 3 . Note the change of magnitude scale between Fig 2. and Fig 4.

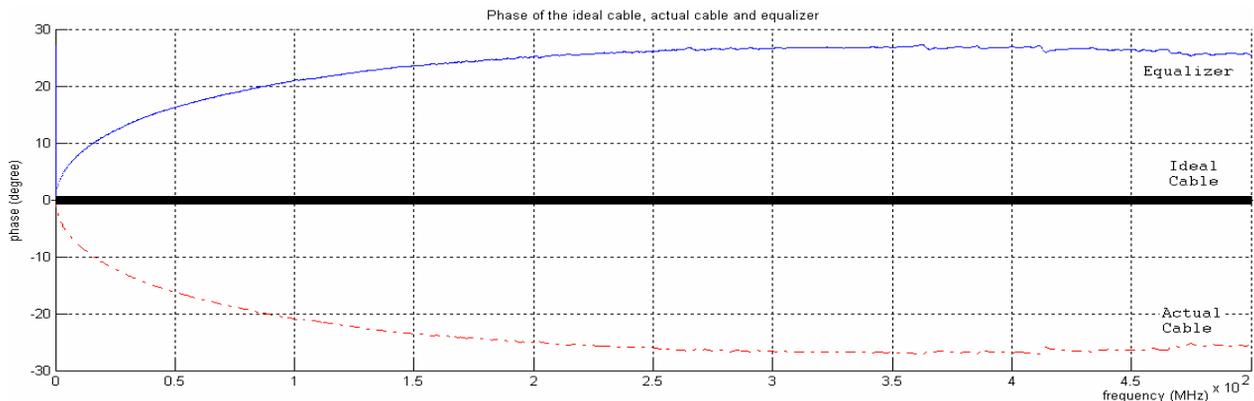


Figure 5: Phase responses of an ideal cable, an actual cable used for measuring beam characteristics, equalizer for the cable.