COMBATING MULTI-BUNCH INSTABILITIES WITH THE LIBERA BUNCH-BY-BUNCH UNIT

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Abstract

Libera Bunch-by-Bunch is the digital processing unit for a bunch by bunch feedback system. The upgraded unit has a digital signal processing core application featuring a 16-tap FIR filter for each bunch. DSP processing is organized in chains, following the HW implementation of A/D conversion and the machine's specific harmonic number.

Besides setting of FIR filter coefficients in each processing chain, one bunch per chain can have different FIR filter coefficients and provides an option for 4 single-bunch processing. All FIR filter coefficients are double buffered. Delays maximally equal to a revolution period are implemented before and after the FIR block. As an additional feature, a phase-shift block is introduced that precisely shifts the phase of the output signal in the vicinity of a determined frequency. The core application is accompanied with a Matlab GUI, with an additional window for data acquisition. This system accompanied by a Front-End unit provides a complete solution for combating multi-bunch beam instabilities.

INTRODUCTION

Combating multi-bunch instabilities is realized through feedback loop that includes pickups, RF front-end, analogue or digital signal processing block, amplifier and kicker. Block scheme is depicted in figure 1. Libera Bunch-by-Bunch unit performs digital signal processing (DSP) of each bunch. Unit's output is applied to the amplifier and consequently to the kicker. Reducing betatron and longitudinal oscillations of the individual bunches are the targets of the feedback systems. Betatron oscillations exist in two coordinates, consequently two feedback systems should be built. This paper will focus on combating betatron oscillations, though it can be accounted for combating longitudinal oscillations as well.

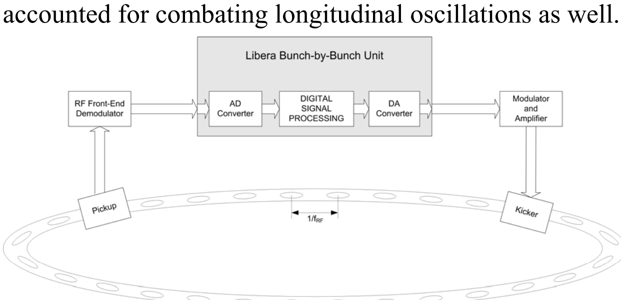

Figure 1: Simplified Bunch-by-Bunch feedback scheme.

Data processed by RF front-end is the input for Libera Bunch-by-Bunch unit. Input signal is sampled either by four 14-bit analogue-to-digital (AD) converters at 125 MHz sampling rate, or by one 500 MHZ 12-bit AD converter. Samples are processed on bunch-by-bunch basis. Output of signal processing is sent to digital-to-analogue (DA) converter. Analogue output of bunch-by-bunch unit is forwarded to modulator/amplifier and finally to the kicker.

DIGITAL SIGNAL PROCESSING

Digital signal processing is the core of the Bunch-by-Bunch unit [1]. Compound rate of digital processing is equal to the RF frequency of the machine (couple of hundred megahertz). Logical requirement is to apply as powerful processing as possible. Taking into account contemporary technologies for digital signal processing, digital signal processors and field programmable gate array (FPGA) chips, leads to obvious choice of platform for processing data: FPGA based hardware, because of its parallelism in resource usage.

Digital processing is done separately for every bunch, meaning that digital processing is done per bunch and performed on the samples belonging to that particular bunch. This leads to the fact that the sampling rate for singular bunch processing is equal to the revolution rate of the machine.

The prevailing oscillations that need to be reduced in the transverse are betatron oscillations. Having in mind the previous fact, that the sampling rate of digital processing per bunch is equal to the revolution frequency, this imposes the goal of reducing the frequencies equal to the fractional part of the machine’s betatron frequencies.

The method used in the most solutions for extracting the information about target oscillations, is the one implemented here: finite impulse response (FIR) filtering per bunch. FIR filter is the band-pass filter centered on betatron frequency i.e. around the fractional part of the betatron frequency. This is the essential and most important part of the digital signal processing. Solution implemented by Instrumentation Technologies provides 16-tap FIR filtering for up to 4000 or 5000 bunches, depending if the solution with four or five processing chains is used, respectively.

Block scheme of the digital processing block is depicted on figure 2. This is the solution with one AD converter at 500 MHz sampling rate, and five processing chains. Each chain is running at 100 MHz. In each FPGA clock cycle every processing chain performs 16-tap FIR filtering: 80 multiplications at 100 MHz rate, just for basic FIR filtering. The processing is pipelined. Implementation applies same FIR filter coefficients to all FIR processing paths in one chain: different chains are independent among each other.

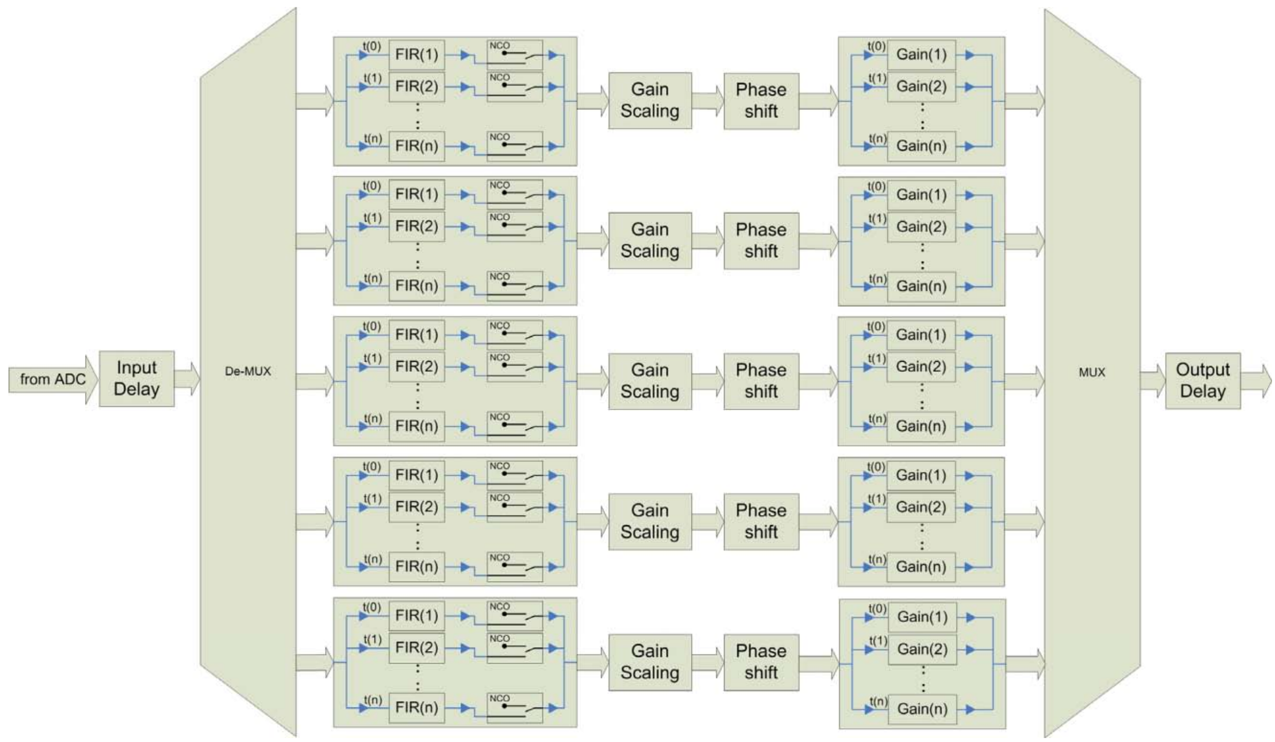

Figure 2: Digital Signal Processing block.

Additional option is to have one bunch individually filtered (per processing chain) enabling the single bunch processing.

After the input signal is filtered, additional processing is required to reduce the oscillations. At the kicker the processed signal needs to arrive at the exact moment when the bunch, data source for the processed signal, is bypassing. To achieve this, delay tuning is required. Basic tuning is performed in steps equal to the RF period (~ 2ns): it is implemented by the blocks 'input delay' and 'output delay' from figure 2. Maximum delay of both blocks is equal to one revolution period. Fine delay tuning is achieved by using special analogue units with resolution around and below 10ps.

Another important feature of the signal applied at the kicker is that its phase must be $\pi/2$ shifted compared to the source signal: this value of phase difference reduces the oscillations. This feature is implemented through 'phase shift' blocks from figure 2. Phase shift settings are unique for all bunches.

The last important parameter for feedback loop is the amplitude of the analogue signal. Block 'gain scaling' in figure 2 enables right or left shift of the processed signal up to 8 bits, resulting in gain from 2^{-8} up to 2^{8}. As the 'phase shift', this is applicable to all bunches.

The previously commented features [2] are the basic features needed to close the feedback loop, confirmed by the on-site tests. Besides these, some additional features are implemented, as can be seen on figure 2.

Gain per bunch, in the range (-1,1), enables individual gain settings for each bunch.

One of the applications for Bunch-by-Bunch unit, besides beam stabilization, is the bunch purification i.e. bunch cleaning [3]. This is the technique for cleaning the unwanted bunches i.e. the particles at the positions of these bunches. Solution implemented in Libera Bunch-by-Bunch is based on boosting the parasitic bunches at the betatron frequency and in its vicinity: it boosts betatron oscillation of particular bunches, compared to the oscillation reduction in the feedback loop. This is achieved by using the numerically controlled oscillator (NCO). It generates set of frequencies in the proximity of the betatron oscillation. Coupled with adequate amplitude (available through gain settings), Bunch-by-Bunch unit 'drives' the particles to unstable state sending them 'away' (out from the tube). For each bunch it can be selected if the NCO signal or processed signal is propagated to the DA converter, enabling precise selection of bunches in the ring which undergo 'bunch cleaning' process.

GRAPHICAL USER INTERFACE - GUI

Depicted in figure 3 is the snapshot of the graphical user interface for Libera Bunch-by-Bunch unit. GUI is developed in Matlab: requires only the basic Matlab installation without any toolboxes. All signal processing parameters can be managed through GUI. Communication with Libera can be accomplished through standard protocols and programs for remote execution: rexec, ssh etc. Matlab's interoperability on different operating systems is maintained for GUI also. All commands generated and sent by GUI can be saved in ASCII file, enabling the user easy and fast introduction with Libera Bunch-by-Bunch management. GUI can be used for closing the feedback loop (or bunch cleaning) as a standalone application, but can be also used as a starting point for user generated applications, part of their own control system.

Data acquisition, an important feature of the Bunch-by-Bunch unit, can also be accomplished through GUI's window.

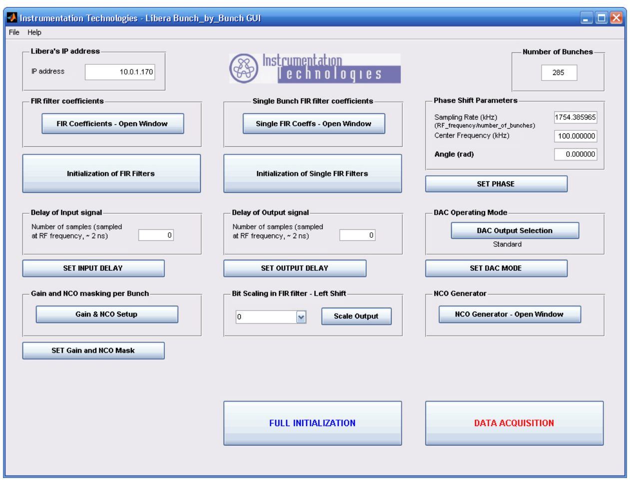

Figure 3: Graphical User Interface for Bunch-by-Bunch unit.

SUMMARY

Libera Bunch-by-Bunch unit was successfully tested at Diamond Light Source, England, in April 2008. The feedback loop in transverse plane (horizontal coordinate) was closed. System performed well under even the worst conditions: high instability of the beam, high gain and feedback loop off (resulting in random high amplitudes of the processed signal). After the feedback was turned on, simply by enabling the output of the DA converter, system stabilized and reduced oscillations of the beam.

Further developments will include additional features like FPGA implementation of grow/dump transients, or resetting of signal processing chain to bunch zero.

REFERENCES

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