EVALUATION OF A NEW 500 MHz DIGITIZER AT ELETTRA AND FERMI

G.Brajnik, S.Bassanese, R. De Monte, Elettra-Sincrotrone Trieste, Trieste, Italy

P.Leban*, M.Znidarcic, Instrumentation Technologies, Solkan, Slovenia

Abstract

A new digitizer was evaluated in ELETTRA storage ring and FERMI linear accelerator. The A/D conversion is done with 14-bits at 500 MS/s. The sampling clock is hard-locked to the Master Oscillator and has a jitter of a maximum 10 ps. The AC coupled version has an analog bandwidth up to 2 GHz and was used to measure the fill pattern. The bunch flat-top is very narrow (10-15 ps). To reach better stability, various external filtering components were used. Bunch-by-bunch beam position was calculated offline and compared to a standard BPM electronics. The DC coupled version was used to sample pulses from the integrating current transformer at FERMI. A software interface can configure data acquisition length and fill buffer segments with pre-defined number of triggers. Native TANGO and EPICS interfaces allow for fast integration with CSS and other display tools.

INTRODUCTION

First beam tests were done at ELETTRA Sincrotrone Trieste. Main goal of the tests was to prove both, the DC and AC coupled digitizer versions provide data properly and consistently with other solutions. Access to data is available from TANGO, EPICS, MATLAB and other clients, including web clients. Data was taken mostly in parasitic mode during user runs. A special attention was put into phase adjustment of the reference clock for the AC coupled version and in the pickup electrode type where the signal was taken from.

BEAM CHARGE MEASUREMENT

Integrating current transformers (ICT) are pick ups commonly used to measure beam charge. The positive area of the output pulse is proportional to the beam charge. This pickup can be connected to oscilloscopes making the area measurement or dedicated front end electronics board are commonly used to integrate the signal and produce an output signal having amplitude proportional to the input charge. A DC digitizer is then used to interface the control system. In both cases, it is difficult to obtain precise measurements in presence of disturbance signals while a waveform digitizer helps adaptive signal processing. The purpose of this measurement was to prove that Libera Digit 500 is capable to successfully measure signals from Bergoz ICT. The final idea is to provide a compact solution capable to read signals from four ICTs and provide data directly to the operators in the control room.

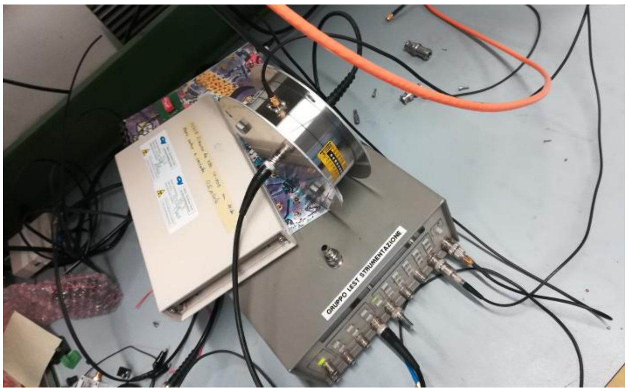

Figure 1: ICT test bench.

A current generator was connected directly to the ICT test bench (Figure 1). A short few nanosecond long pulse was injected to the ICT and pulse shape was observed with the Libera Digit 500 instrument. A clean pulse with an expected shape was read from the digitizer. The pulse contained a little DC offset.

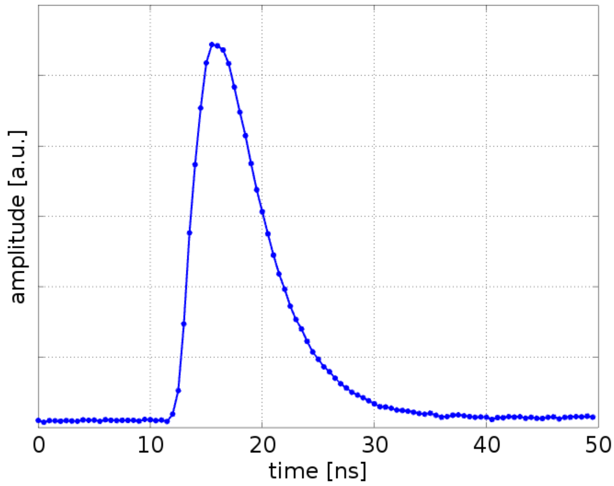

Figure 2: Beam pulse from ICT and recorded by Libera Digit 500.

After bench test, the instrument was connected to one of the ICTs installed at FERMI FEL linac. A pulse shape recorded by Libera Digit 500 is shown in Figure 2. Result proves the instrument is capable to provide measurements equivalent to more expensive and space requiring solutions.

FILL PATTERN MEASUREMENT

Fill pattern in Elettra storage ring was measured with an AC coupled version of the Libera Digit 500. Beam signal was taken from a standard button BPM pickup. Measurement setup is shown in Figure 3.

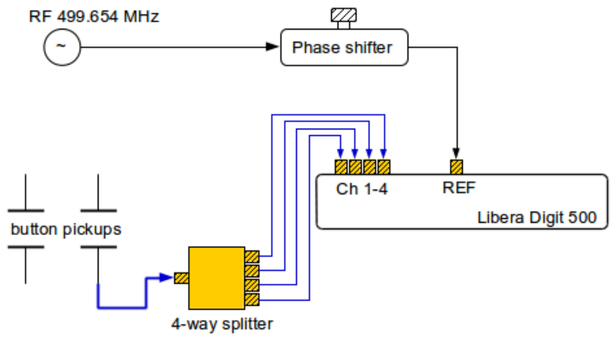

Figure 3: Measurement setup for the fill pattern and bunch-by-bunch position measurement.

A 499.654 MHz reference signal was used to lock the sampling clock of the ADCs. Bunch flat-top is only about 10-15 ps (Figure 4) which requires fine-tuning of the sampling clock reference. Phase of the reference signal was slowly changed with a phase shifter and amplitudes were monitored at the same time. When maximum amplitude was reached, the phase was considered as optimum. Phase alignment is essential to achieve proper measurement results.

Figure 4: Oscilloscope capture of bunch pulse.

Referring to Figure 4, higher-order harmonics (about 1.5 GHz) are observed in the signal. Oscillations are phase inverted in 2 channels. This behaviour is related to the splitter's frequency response, even if its bandwidth is up to 6 GHz.

The analog front-end of the instrument does not contain any filtering component hence provides the maximum ADC bandwidth. In order to avoid unwanted oscillations, external filters can be installed. For our tests, a comparison between no filtering, 570 MHz low-pass filter (with insertion loss of about 0.5 dB) and a band-pass filter centred at 500 MHz (with insertion loss of about 15 dB) with a 54 MHz bandwidth was done. To characterize the (analog) filter's response, a single bunch was used. Results are shown in Figure 5. With no filtering, the response is "clean" and causes no overlapping to adjacent data points. The 570 MHz low-pass filter introduces insertion loss and re-shapes the response in the neighbour data sample. The band-pass filter has a big impact to amplitude and stretches the response over several data points but removes the higher-order frequency components from the spectra. Moreover, undershoot of the low-pass filter produces an erratic interpretation in particular for single bunch data. This means that the filter has to be chosen very carefully, and depends strictly on target application.

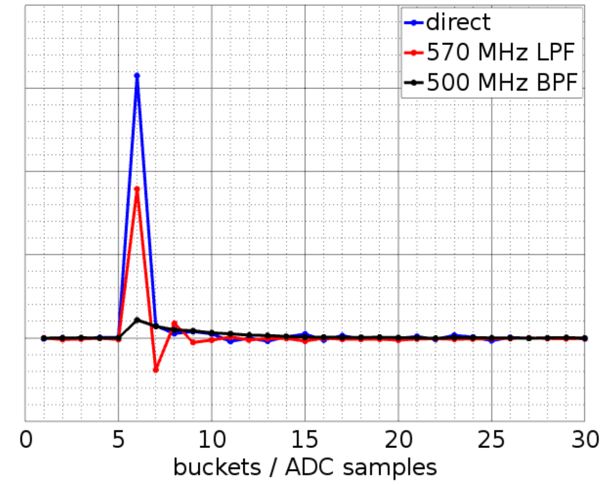

Figure 5: Effect from different analog filters to input signal.

The fill pattern was measured with Elettra machine running in hybrid mode. This means that over the 432 buckets, almost 250 of them were filled with a constant charge of ~1 mA for each, a linear decay of the charge in the next 50 buckets, a single bunch of ~3 mA in bucket number 340 during the dark gap (of about 80 buckets), and a linear increase of the charge in the last 50 buckets. The revolution period is 864 ns. The total current of 310 mA is kept constant by the top-up feedback. Fill pattern was measured by the Digit 500 with no external filters installed. Result is shown in Figure 6.

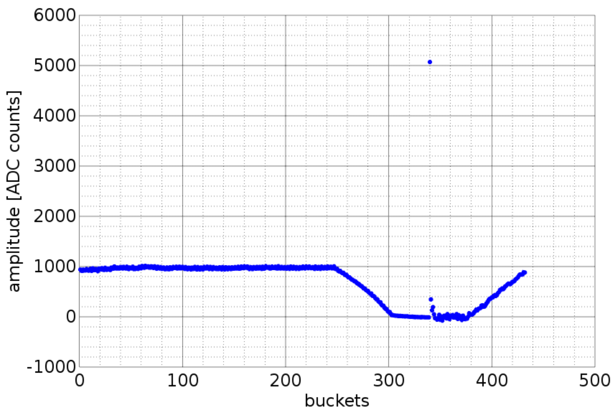

Figure 6: Fill pattern measured with no external filters.

Figure 7 shows for comparison the fill pattern as detected by a stripline BPM coupled with an oscilloscope.

Figure 7: Fill pattern measured with an oscilloscope.

BUNCH-BY-BUNCH POSITION

After the fill pattern was measured successfully, the data from four channels was used for position calculation. A first goal was only to see if data has any potential use. A simple delta-over-sum equation was used with 10 mm scaling factor. Amplitudes were epressed in ADC counts (full scale is ±8191). Figure 8 shows horizontal position of every bunch/bucket within a single turn. As expected from the fill pattern shape, stable position was read from buckets 0 to 300 followed by noise around a single bunch. Position over the bunch train varied for approximately 120 µm.

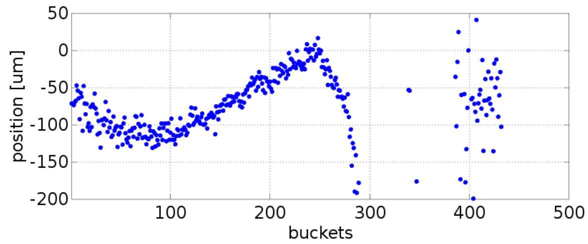

Figure 8: Position of every bunch within a turn. 10 mm scaling factor was used.

The raw ADC buffer length was set to about 64 µs which was sufficient to calculate position over 75 turns. For easier comparison to standard turn-by-turn BPM electronics, position of individual bunches was averaged over each turn. A script averaged first 300 bunches and output 1 position. In addition, it calculated position of a single bunch (bucket 340). As a result, there were vectors with 75 positions from the bunch train and from a single bunch. Data is shown in Figure 9.

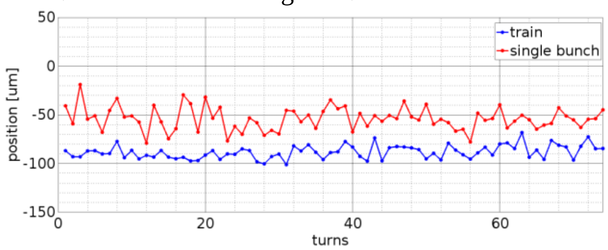

Figure 9: Turn-by-turn positions averaged from the bunch-by-bunch positions.

Same test was repeated with 570 MHz low-pass and with 500 MHz band-pass filters. Table 1 shows peak-to-peak position variation over 75 turns. Best results were achieved with no filtering. Results with 570 MHz low-pass filter were worst and are not given in the table, due to the undershoot that changes the shape dramatically.

Table 1: Peak to Peak Position Variation

Fill	No filter	BPF
bunch-train	25 µm	42 µm
single bunch	60 µm	300 µm

CONCLUSION

A wide-band digitizer with its sampling clock locked to the RF opens new opportunities for diagnosing the fill pattern shape or observe position from a selected bunch within a turn. Direct sampling requires perfectly phase matched cables and properly fine-tuned reference clock with respect to bunch arrival. The system is capable to read the fill pattern and store up to 1 second of bunch-by-bunch data. A real-time bunch-by-bunch position monitoring is not implemented yet but initial results show promising measurement capabilities.

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