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# EVALUATION OF PILOT-TONE CALIBRATION BASED BPM SYSTEM AT ELETTRA SINCROTRONE TRIESTE

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*Abstract*

Stable and reliable beam position measurement is of paramount importance for the present and future light sources. Stabilization with a pilot-tone technique was developed by Elettra Sincrotrone Trieste and supported in the commercial BPM electronics Libera Spark. Both system components (the pilot-tone front-end and BPM electronics) are controlled through a common software interface which is compatible with TANGO, EPICS and LabVIEW/MATLAB clients. The system provides a reliable self-diagnostics, cable and button diagnostics and drifts compensation. This paper presents results from beam measurements under different environmental and beam conditions.

## INTRODUCTION

The system consists of the pilot tone injector front-end and readout BPM electronics. A major improvement from the last report [1] was done on the real-time signal processing. The new implementation requires more FPGA resources to provide essential data all in parallel. The FPGA chip was upgraded to a higher speed grade. The updated BPM electronics does not contain any specific band-pass filters and can be used in principle with any accelerator RF (e.g. ~352 MHz or ~500 MHz), relying on the front-end for analog conditioning of the signals. The pilot-tone central frequency and filtering properties can be adjusted runtime just with uploading new filter coefficients.

## CONFIGURABLE FILTERING SCHEME

Compared to earlier processing scheme [1], a new implementation uses three parallel turn-by-turn processing branches (Figure 1). The time-domain processing is used for studies that don't use the pilot-tone frequency component. The frequency-domain processing branches are two:

- DDC for beam RF signals
- DDC for pilot tone signal

Output of both DDCs are four I & Q amplitude pairs. The "DDC for RF" data is written to a circular buffer. The filtering block in the "DDC for PT" contains a narrow band-pass filter with steep sidebands (Figure 2). The filtering coefficients and gains are normalized. The I&Q amplitudes from each of the DDC blocks are led to cordic blocks where the amplitudes A, B, C, D are calculated.

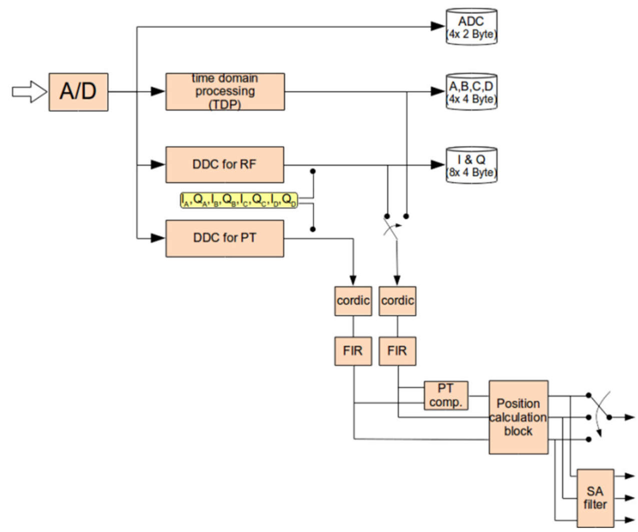


Figure 1: Processing scheme in the BPM electronics.

After the two parallel cordic blocks, the amplitudes pass the poly-phase FIR filter block which reduces the data rate and bandwidth of the amplitudes to FA data (10 kS/s). Resulting RF amplitudes are divided with the PT amplitudes. Values are close to 1 but scaled to ensure enough bit width for the resulting values. The result is one FA data (10 kS/s) stream with selectable source and three independent SA data (10 S/s) streams.

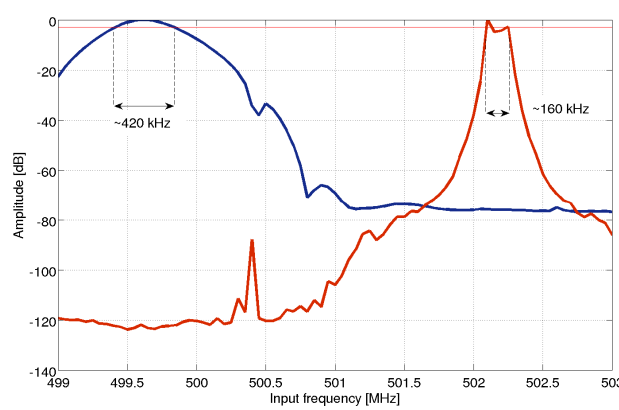


Figure 2: Digital DDC filters in the BPM electronics.

## PILOT-TONE INJECTOR UPDATES

The BPM electronics that works with a pilot-tone injector does not contain analog band-pass filtering components but just the low-pass (e.g. 570 MHz). The band-pass filter and the first low-noise amplification stage are implemented in the pilot-tone injector. Frequency and time response of the filter have an important impact to beam position processing especially when the fill pattern contains single bunch or mixed modes. In this case, for a comparison, two

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different versions of Elettra eBPM analog front end were used: one with a classical LC band-pass filter, one with a helical filter, both centered at 500 MHz and with a bandwidth of approximately 10 MHz.

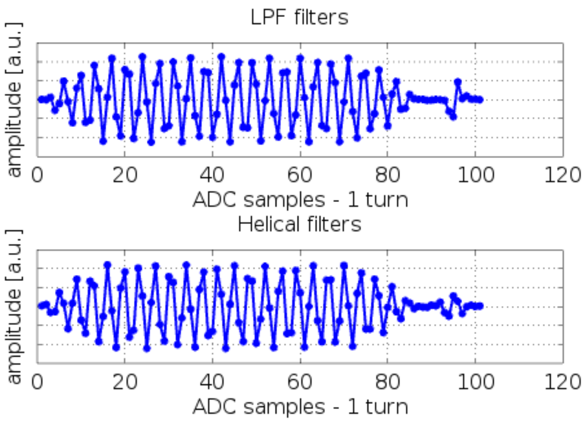


Figure 3: Comparison between the LC and helical filters.

During the hybrid fill pattern, the raw ADC data was recorded simultaneously with the two pilot-tone injectors. Response to the multi-bunch train was comparable in amplitude and length. The difference was in amplitude response to a single bunch (Figure 3).

## FILL PATTERN DEPENDENCE

The fill pattern was changed from a multi-bunch to a hybrid mode. The hybrid mode contains a multi-bunch fill followed by a 3 mA single bunch in the gap (Figure 4).

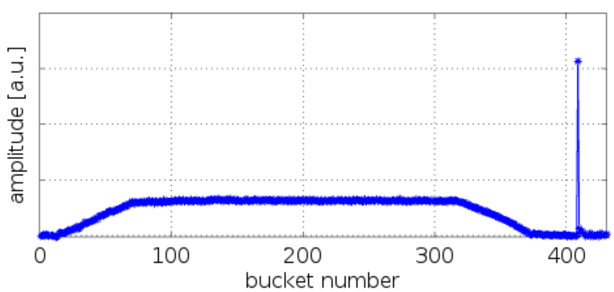


Figure 4: Hybrid fill pattern used during tests.

Position logging started with a standard multi-bunch fill pattern. After approximately 30 minutes, a single bunch was injected and filled with charge until it reached 3 mA. It took few injection cycles. Figure 5 contains three plots: top plot shows a peak ADC value with 4 obvious peaks (injections). Middle and lower plots show horizontal and vertical positions, respectively. Position values were normalized to show deviation from the starting point (0 µm). Blue lines are positions from a standard DDC processing block with no compensation. During initial injection (~30 minutes into the measurement), there is a larger (about 0.3 µm) glitch observed in the horizontal position, followed by a similar, less significant, position offset during minutes 75-80. Red lines are positions, compensated by a pilot tone. Besides lower peak-to-peak noise, the compensated positions don't show any glitch or position offset before, during or after injections. During the measurement, internal temperature (of the Zynq) varied for approximately 0.8 °C peak-to-peak. Both, the pilot-tone injector and BPM electronics were left at room temperature.

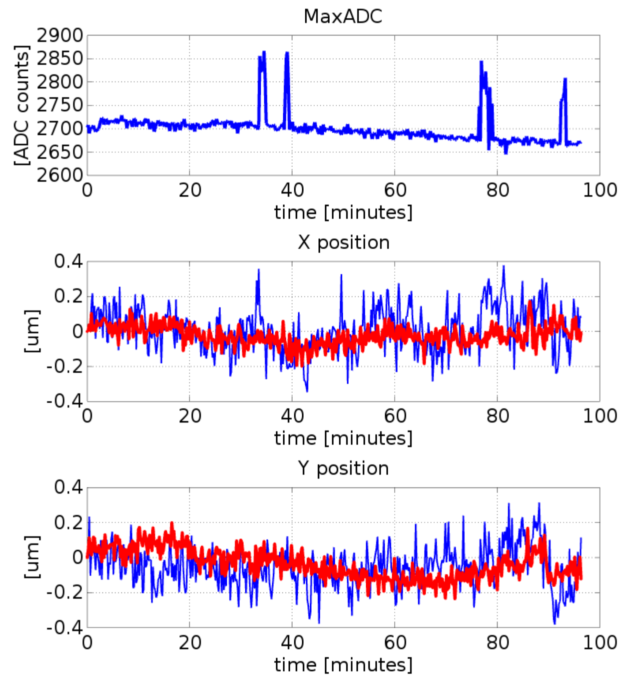


Figure 5: Transition from standard to hybrid fill pattern. Red line shows the compensated positions.

## PROCESSING CROSS-TALK

Beam position processing must be unaffected by the pilot tone. It is essential to ensure sufficient gap between the band-pass regions of the RF and PT DDC processing blocks. Figure 2 shows the frequency responses of both digital filters. Pass characteristics meet at -70 dB which should be sufficient to neglect the effect of the pilot-tone to the real beam signal. For testing purpose, the pilot tone was turned ON/OFF, and its frequency was shifted out off the DDC filter's band-pass. Results are presented in Figure 6. The upper plot shows the standard position from the beam, the middle plot shows the pilot-tone's position and the lower plot shows a compensated position.

Goal of the test was to recognize any (standard) position offset when the pilot-tone is modified either in frequency or amplitude. The pilot-tone was enabled in first ~55 seconds. Then, the pilot-tone's frequency was set out of the pass-band. Under these conditions, the ADC load was kept same to avoid intensity dependence but the PT DDC block considered there was no pilot tone signal (55-85 seconds time region). From 110 seconds onwards, the pilot tone was turned off completely.

There was a position offset observed in both cases (pilot tone off-band and pilot tone off) which contributed about 0.5 µm.

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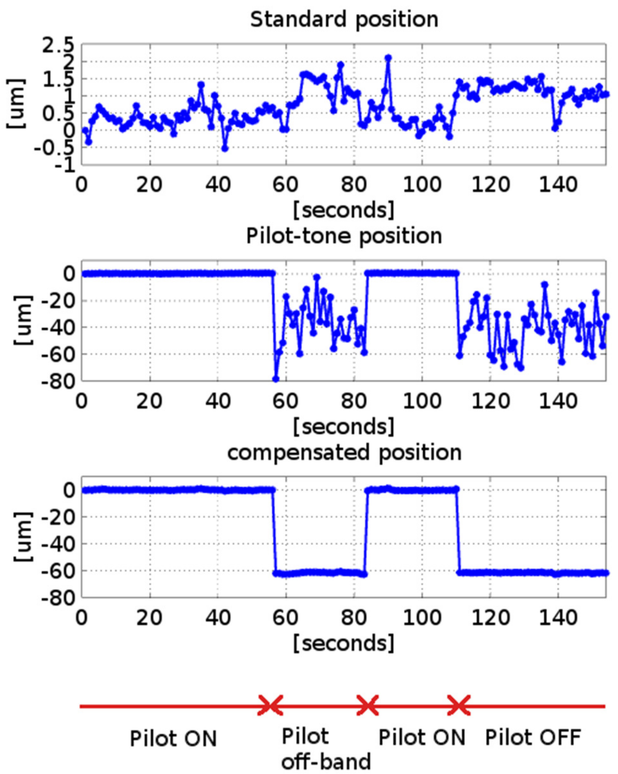


Figure 6: Cross-talk test between the RF and PT DDC processing blocks.

## LONGTERM POSITION DRIFT

One of the most important benefits of using the pilot-tone is the long-term drift compensation. To exclude real beam movement from the measurement, the signal was taken from one button only and split to four with a resistive splitter, in order to have a flat response over frequency up to 6 GHz. This setup was also used in the previous tests. The pilot-tone injector and BPM electronics were kept in accelerator's environment at room temperature. Position data (standard and compensated) was logged over several days. Figure 7 shows a four-day log during user run (top-up, multi-bunch fill pattern). The upper plot shows the peak ADC count, the middle two plots show horizontal and vertical positions, respectively, and the lowest plot shows Zynq's internal temperature. Standard position (blue lines) drifted for approximately 2 µm peak-to-peak in both planes. Compensated position was more stable and drifted for ~0.7 µm. Environmental temperature was not logged whereas the Zynq's temperature varied for about 2 °C.

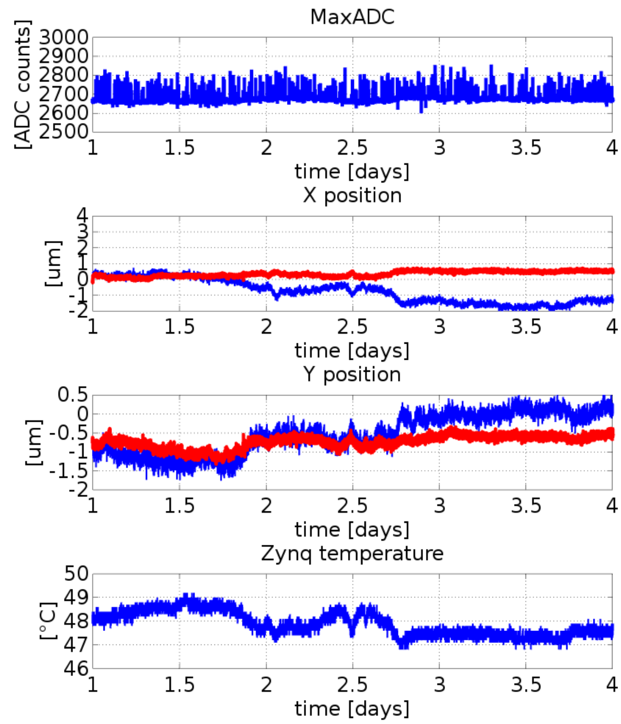


Figure 7: A four-day position drift test.

## CONCLUSION

Latest FPGA and software upgrades in the BPM electronics brought a pilot-tone compensated system closer to users and made complete system easy to use and transparent to operators. Effort was put into various evaluations in the filtering properties of the pilot-tone injector. Position drift of a compensated system was proved sub-micron. The fill pattern dependence is acceptable; however, further evaluation can be done with a pilot tone set farther from the beam RF.

## ACKNOWLEDGEMENTS

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## REFERENCES

[1] M. Cargnelutti, S. Bassanese, G. Brajnik, S. Cleva, R. De Monte, and P. Leban, "Stability Tests with Pilot-Tone Based Elettra BPM RF Front End and Libera Electronics", in *Proc. 7th International Beam Instrumentation Conference (IBIC'18)*, Shanghai, China, Sep. 2018, pp. 289-292, doi:10.18429/JACoW-IBIC2018-TUPB13