# FIRST OPERATIONAL EXPERIENCE WITH THE DIGITAL BEAM POSITION MONITORING SYSTEM FOR THE SWISS LIGHT SOURCE

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*Abstract*

The paper presents first operational experience with the new digital beam position monitoring system for the Swiss Light Source (DBPM). The system permits for the first time to have a single position monitoring system that measures both the slow and the fast aspects of beam position. When set to "slow", the DBPM allows position measurements with high precision, stability and reproducibility and is ideally suited for closed orbit measurements and feedback systems. When set to "fast", the DBPM turns into a powerful beam dynamics tool that permits to extract more dynamic parameters of the beam/machine from turn-by-turn position readings. The key strengths of the system is its programmability that delivers an arbitrary FIR low pass transfer function with a bandwidth spanning from few hundred Hz to over 1 MHz, good reproducibility obtained through the use of a pilot signal and excellent linearity that relies on the direct sampling of the intermediate frequency signal (IF). The core components of the system are the RF front end, the digital receiver and the DSP board and are all housed in a VME crate. The DBPM was developed at Paul Scherrer Institut for the Swiss Light Source in collaboration with the Instrumentation Technologies company.

## 1 SLS DBPM SYSTEM OVERVIEW

The SLS digital beam position monitor (DBPM) system has been developed to deliver beam position data from all parts of the SLS accelerator facility. It is a four channel system, which provides high speed / medium precision (up to 1 MHz bandwidth with < 20 μm resolution) as well as low to medium speed / high precision (up to 10 kHz bandwidth with < 1 μm resolution) data in several operation modes. The modes of operation are software selectable and will be implemented at SLS as follows:

- Three stripline BPMs [1] are installed in the pre-injector linac respectively in each transfer line (linac-booster and booster-storage ring). They are operated in the so called *pulsed mode*, which delivers one position sample during every injection cycle (at SLS: 3 Hz). During first turns (for booster and storage ring commissioning) the booster and storage ring BPMs will also be operated in the *pulsed mode.*
- The 54 button BPM stations in the booster synchrotron will be operated in the *booster mode*, where the operator can select, if he wants to display a single BPM station respectively a group of them in time domain in order to track beam positions during the ramp or if he wants to display the booster closed orbit at selectable time intervals.
- For machine study purposes in the booster synchrotron and the storage ring, a *turn-by-turn mode* is available, which takes up to 8192 successive measurements per SYNC cycle.
- The 72 button pick-up storage ring BPMs will mainly be operated in *closed orbit mode*, where position measurements are continuously taken and displayed in the control room. The bandwidth of the DBPM system is selectable (> 4 kHz) and further averaging can be done on the DSP or IOC level. The data throughput is determined by transfer rates of EPICS control system.
- A *feedback mode* is implemented for the SLS global closed orbit feedback. Here, the DBPM system operates with 4 kHz bandwidth. Position readings are continuously processed in the DSP part of the system. Optical SHARC links provide fast data exchange between adjacent sectors to allow orbit corrections up to 100 Hz, using SVD algorithms [2].
- In *tune mode*, data is taken in the same way as in turn-by-turn mode. However software algorithms on the DSP calculate FFT and extract tunes.

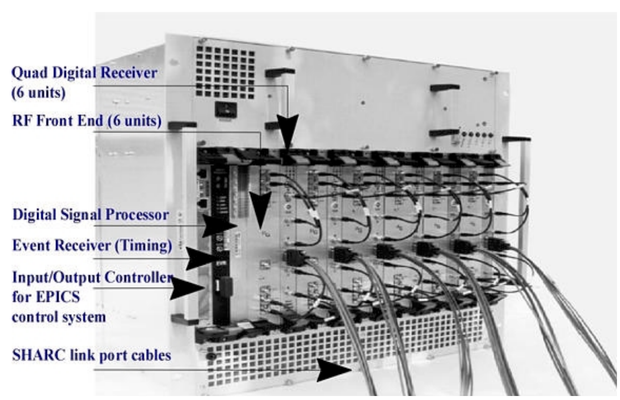


Figure 1: DBPM VME crate for SLS booster commissioning, starting in July 2000. The complete installation includes (from left): one IOC, one timing card, one DSP, 6 RF front ends and 6 QDRs with SHARC link cables.

The key components of the DBPM system are a RF front end, a quad digital receiver (QDR) and a DSP unit. While each RF front end and QDR serves one BPM station, a single DSP module processes data and controls communication of up to six BPMs. In case of SLS, the interface to the EPICS control system is done via an Input / Output controller (IOC). Synchronisation with external events (e.g.: injection, extraction etc.) is possible through a modified APS timing card [3]. A completely assembled DBPM electronics crate as used for the SLS booster synchrotron is shown in figure 1.

The RF front end is a double widths VME module, which is housed in a solid Al enclosure for shielding purposes and to increase channel to channel isolation. It tunes to 499.654 MHz (carrier), the first harmonic of the machine. The four button signals are mixed to an intermediate frequency of 36.029 MHz and then pass through a 5 MHz wide Surface Acoustic Wave (SAW) filter. The same processing chain is passed by a pilot signal, which is about 1.5 MHz below the carrier frequency and will be used for on-line calibration and minimisation of beam current dependence. Gain control is provided via a serial link between the DSP and the RF front end. Five on-board 16 bit DACs are adjusting the gain of the four individual channels and the pilot signal level. Automatic gain control allows to keep the output signal level of the down-converted carrier signal at 0 dBm for input signal levels between -65 dBm and -5 dBm.

The four carriers and the pilot signal enter the QDR, where they get sampled by 12 bit AD9042 analog-to-digital converters from Analog Devices. The ADC part is designed as a "piggy back" on the QDR to ease further upgrades in the future. The remainder of the processing is done in digital way by four digital down converters (HSP50214B from Intersil Corporation). They translate the carrier respectively the pilot signal to baseband and apply filtering and decimation. Both processes are very important, since filtering defines the bandwidth of the system, which affects the measurement fluctuation and decimation reduces the output data rate with respect to the input and therefore reduces the downstream digital signal processing requirements. Each processing channel of the QDR is equipped with an 8 k (optionally 16 k) deep FIFO. ALTERA FLEX re-programmable kernel (FPGA) adds flexibility for user specified functionality. Data output can be selected over VME64 bus or dedicated costumisable DSP port (SHARC link, C40 comm port etc). At SLS, we decided for the SHARC link, since it's potentialities fits best in our global closed orbit feedback geometry [2]. The QDR complies with VME64x specifications, which include live insertion, geographical addressing, 3.3 V supply voltage and optional connector.

The DSP module is a commercially available board WS2126 from Wiese Signalverarbeitung company. It is equipped with two ADSP 21062 SHARCs from Analog Devices, each of them providing 6 SHARC link ports to the front panel. At SLS, we use one DSP for calculation of beam positions and application of correction factors, while a second one performs FFTs and supervises feedback communication to VME crates in adjacent sectors which are connected via fiber optic SHARC links.

## 2 FIRST OPERATIONAL EXPERIENCE

Several sets of measurements in the laboratory and on accelerators have been made to demonstrate the performance of the SLS DBPM system. A prototype system could already been tested in July 1999 at the ELETTRA storage ring to demonstrate feasibility of the design and turn-by-turn capability [4.5]. In April 2000, the final system was again tested at ELETTRA and in the SLS linac to show it's performance in all operation modes, which are mandatory for SLS booster commissioning. Some of the results are presented in the following.

Measurements for beam current dependence and long term stability have been performed in the laboratory using a signal generator as a RF source and a 50 Ω terminated button BPM simulation chamber. Without correction of systematic errors the beam current dependence was measured to be within ± 30 µm over the specified dynamic range of the system (-8 dBm to -65 dBm). In a so called 1 to 5 range, which is of special importance for storage rings (e.g.: beam current reaches from 400 mA to 80 mA), the beam current dependence is less than ± 5 µm. Long term stability of ± 1.5 µm was measured with a constant input power level of -12 dBm for a period of 15 hours over night starting at 18:00 in the evening until 9:00 in the morning. Figures 2a and 2b show these results.

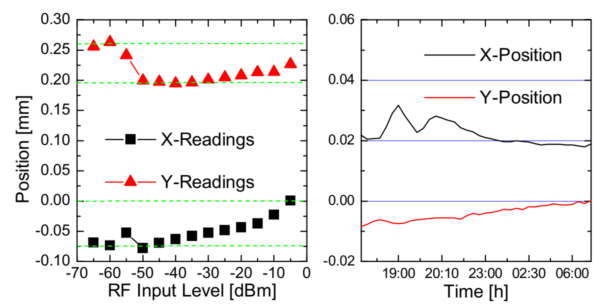


Figure 2a: Beam current dependence of DBPM system. 2b: Long term stability of RF front end. The large movement in x-direction between 18:30 and 20:30 (zoomed out) is due to mechanical deformation caused by heat up while the sun was directly shining on the BPM simulation chamber.

Acquisition of turn-by-turn data at the ELETTRA storage ring, requires tuning of the QDR bandwidth to 500 kHz. This is shown in figure 3a.

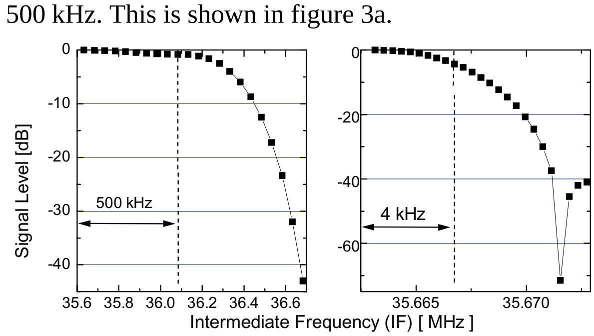


Figure 3: Programmable bandwidth of QDR. (a) 500 kHz for turn-by-turn mode, (b): 4 kHz for closed orbit mode.

From the signal processing point of view, the turn-by-turn mode is realised in batch processing, which means, that the QDR acquires a batch of samples (up to 8192) in it's FIFO and sends it to the DSP, when the FIFO is filled. Figure 4a shows a complete data set of 8192 samples in turn-by-turn mode taken from one QDR channel. A zoom into a data set (first 500 samples out of 8192), shows more clearly the injection kick and the damping of the electrons afterwards. A quite noticeable synchrotron oscillation can also be seen. The measurement was done during injection into ELETTRA storage ring in multi-bunch mode at 0.9 GeV and 150 mA beam current.

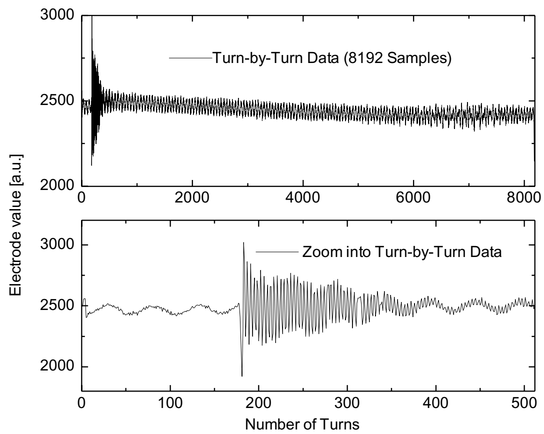


Figure 4: Measurements with DBPM system in turn-by-turn mode. (a) Complete data set from one QDR channel (8192 samples). (b) Zoom into above data (first 500 samples).

The related synchrotron sideband at 22 kHz as well as the horizontal tune of the storage ring at 300 kHz were determined by applying FFT to the turn-by-turn data set. This procedure corresponds to the tune mode of the system. The result is shown in figure 5.

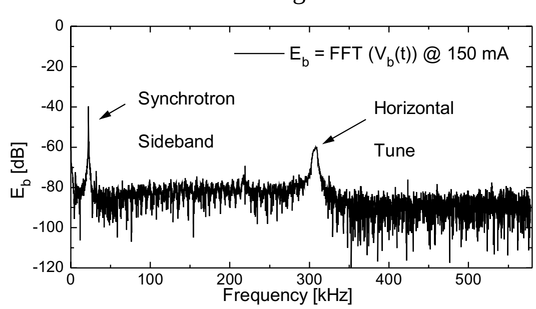


Figure 5: FFT of the turn-by-turn data (see figure 4). Horizontal tune at 300 kHz and synchrotron sideband at 22 kHz can be seen.

The rms resolution of the DBPM system in turn-by-turn mode was determined by calculating the signal to noise ratio from the noise floor and the number of samples. For the SLS BPM chamber geometry we found a rms resolution of 10 µm.

Acquisition of data in closed orbit respectively in feedback mode of the DBPM system needs tuning of the QDR to 4 kHz bandwidth as shown in figure 3b. Signal processing and data transfer is done in real time. Measurements were taken at ELETTRA storage ring during injection. The raw data of the four channels from the QDR are shown in fig. 6a, while the resulting beam positions, which were calculated in the DSP are shown in fig. 6b.

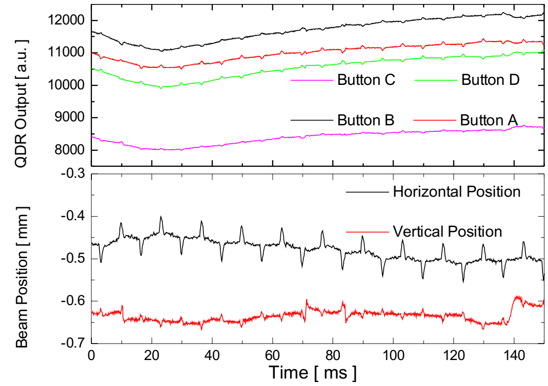


Figure 6: Measurements with DBPM system in closed orbit mode taken at ELETTRA during injection.

The "spikes" and "dips", which occur especially in the horizontal direction correspond to real beam motion as indicated by the raw data. The slow drift in the signal levels of the raw data do not show up in the processed beam positions. They can only be interpreted as beam density changes (longitud. effects), which occur during injection.

From the electronics point of view, the pulsed mode with single (high charge) bunches represents the most critical. It has to be ensured, that the RF front end is not saturating and that it's impulse response is long enough to allow clean sampling at the QDR input. Very recently, measurements could be performed at the SLS pre-injector linac in single bunch mode with bunch charges of 1 nC. Figure 7 shows, that the system behaves as expected with rms resolutions of about 100 µm.

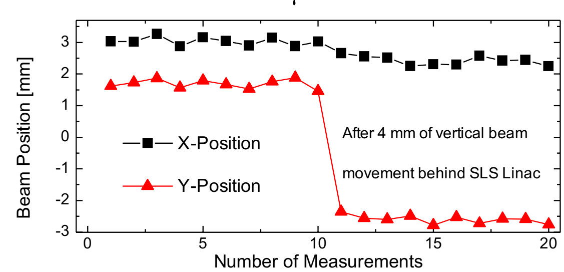


Figure 7: Measurements of DBPM system in pulsed mode performed at SLS linac with single bunches of 1 nC.

## REFERENCES

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