BPM ELECTRONICS FOR THE ELBE LINEAR ACCELERATOR - A COMPARISON

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Abstract

The ELBE linear accelerator supports a great variety of possible beam options ranging from single bunches to 1.6 mA CW beams at 13 MHz bunch repetition rate. Accordingly high are the dynamic range requirements for the BPM system. Recently, we are testing the Libera Spark EL electronics to supplement our home-built BPM electronics for low repetition rate operation. Here, we discuss the advantages and disadvantages of the two completely different detection schemes. For integration of the Libera Spark EL into our accelerator control system we are implementing an OPC-UA server embedded into the device. The server is based on the free Open62541 protocol stack which is available as open source under the LGPL.

THE HZDR BPM ELECTRONICS

Figure 1: The HZDR BPM electronics comes in a 1U 19" rack-mount enclosure.

The BPM electronics currently used at ELBE is an in-house design which has been presented at IBIC2013 [1]. It's RF front-end detects the fundamental frequency of 1.3 GHz from the $\lambda/4$ strip-line sensors used at ELBE. This signal after some filtering and amplification/attenuation (see Fig. 2) is mixed down to a 19.5 MHz intermediate frequency. The IF signal is sampled and digitized at 52 MS/s rate. The digital signal is then processed with an I/Q-demodulation over 512 samples yielding a system bandwidth of 95 kHz. This bandwidth was chosen to give a sufficiently fast response but at the same time to integrate the least possible amount of noise

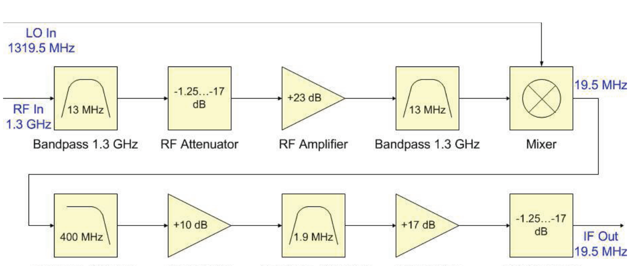

Figure 2: The analog front-end of the HZDR BPM electronics.

in order to reach a high signal-to-noise ratio and dynamic range. A difference-over-sum formula is used to convert the measured signal amplitudes into a position information.

ELBE ist mostly run at 13 MHz bunch repetition rate but frequencies down to 100 kHz or single pulses with arbitrary repetition rates are available. At all frequencies above 100 kHz more than a single bunch is detected in every acquisition frame. The according averaging effect further improves the signal-to-noise ratio. This signal processing, however, is not optimized for low bunch repetition rates. The duration of a single-bunch signal is less than 1 μs according to the 1.9 MHz bandwidth of the analog front-end while the noise is integrated over the full 10 μs duration of the sample frame.

THE LIBERA SPARK EL BPM ELECTRONICS

Figure 3: The Libera Spark EL BPM Electronics.

The Libera Spark EL [2] manufactured by Instrumentation Technologies in the tests reported here was connected to an identical strip-line pickup mounted back-to-back with the one used for the HZDR electronics. This device uses a rather different analog front-end and detection scheme. Right at the input the signal is filtered with a SAW resonator centered at a frequency of 500 MHz. The filtered and amplified/attenuated signal is then directly sent to an ADC with a fast sample-and-hold input stage. Sub-sampling at 117 MS/s the signal is mirrored to a 32 MHz base-band frequency. The signal amplitude is then determined by integrating over a fixed number of samples including a few pre-trigger samples. We have chosen 100 post-trigger samples to capture the waveform shown in Fig. 4. Again, we use a linear difference-over-sum formula to derive the position information from the 4 channel amplitudes.

The bandwidth of the whole system is solely determined by the filter bandwidth which is specified in the datasheet to 8 MHz full width. The time-domain approach to the signal detection is very well suited to the measurement of single bunches at low repetition rates. One may note that actually no harmonic of the 13 MHz bunch repetition rate falls into

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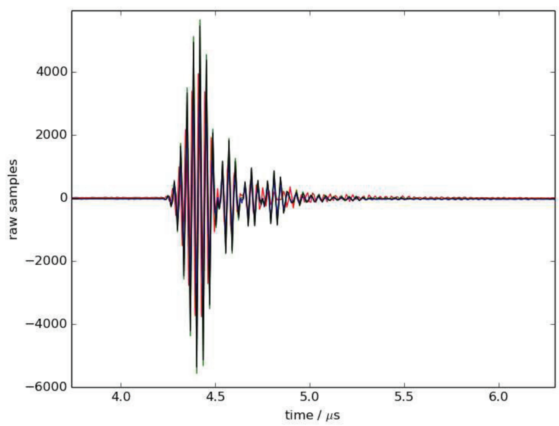

Figure 4: The Libera Spark single-bunch waveforms.

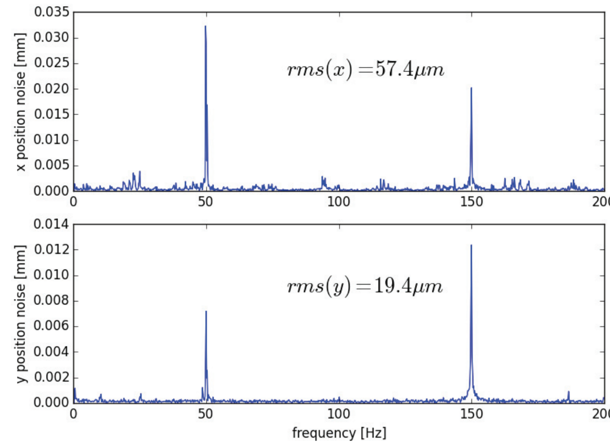

Figure 6: Spectral distribution of the measured beam position noise.

the input filter bandwidth. This surely impairs the results of the measurements shown here. We have recently received a customized version of the instrument with an adapted input filter with 416 MHz central frequency but we didn't have time to test it yet.

NOISE MEASUREMENTS

For comparative measurements the two electronics were connected to two strip-line pickups mounted back-to-back at the ELBE linac1 beamline. This setup does not allow a distinction between the noise contributions carried by the beam and those introduced by the devices but a third sensor could not be mounted. The beam shows a position fluctuation dominated by power-line frequencies. The corresponding signal frequencies have been filtered out in the measurements shown here.

At 13 MHz bunch repetition rate (see Fig. 5) both devices show a quite similar position noise. The acquisition time of the Libera instrument was increased to 1000 samples for this measurement to have a direct comparison to our device. Very likely the noise floor at 10 μm was caused by the beam itself – both devices have shown a <5 μm resolution in other measurements. Also Fig. 6 indicates that there are more spurious noise frequencies modulated onto the beam. The resolution obtained for the Libera Spark EL for single bunches quite well matches the values published by Instrumentation Technologies [3] given the pulse amplitude of 0.3 V we are measuring from our strip-line pickups at 70 pC bunch charge. At 100 kHz (see Fig. 7) the Libera Spark EL demonstrates the superiority of the bandwidth-matched time-domain data evaluation for evaluation of single bunches. A similar algorithm is under development for our device but has not yet been tested with the beam.

CONTROL SYSTEM ACCESS BASED ON OPC-UA

OPC Unified Architecture (UA) is an industry standard communication protocol developed for M2M interoperability. It provides a cross-platform service-oriented architecture using secure communication channels. The standard was released in 2010/2011 under IEC-62541 [4]. There exist many different implementations of the OPC UA standard. APIs for C/C++, .NET, Java or Python are available, LabView,

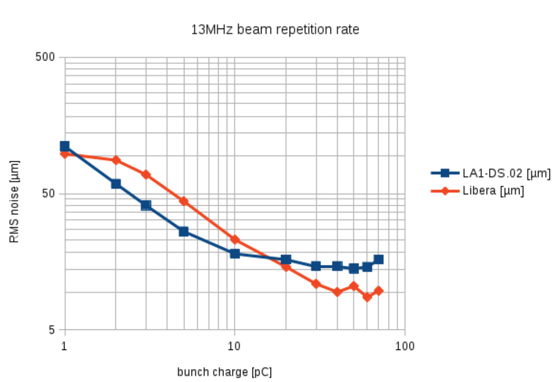

Figure 5: Measured beam position noise at 13 MHz bunch repetition rate.

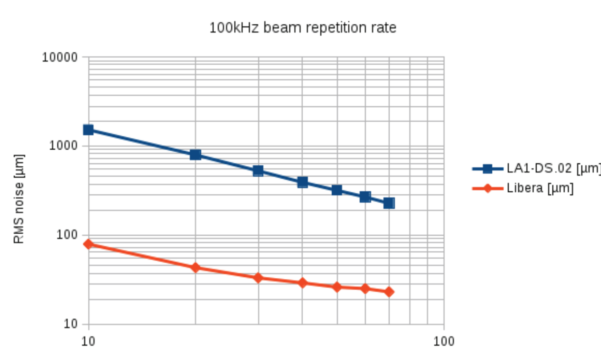

Figure 7: Measured beam position noise at 100 kHz bunch repetition rate.

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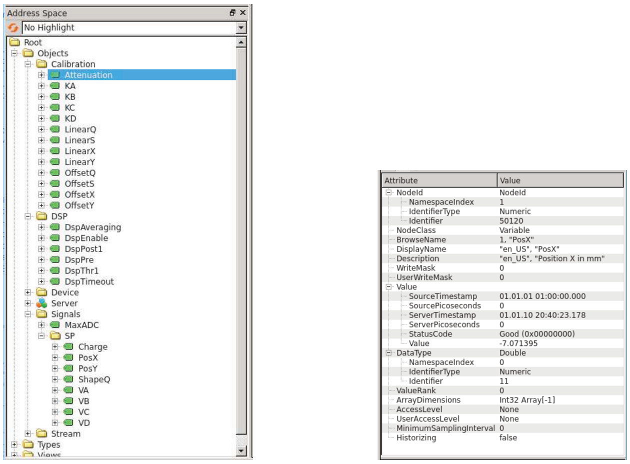

Figure 8: The OPC information model presents itself as a hierarchy of folders, items and properties. All nodes possess attributes delivering meta-data and diagnostic information in addition to the payload data.

EPICS and other control systems also support OPC UA. The standard guarantees interoperability between all the different implementations across all supported platforms (see Fig. 8 on information model). There exist protocol stacks with low resource usage to allow an implementation into embedded devices.

We have chosen an open-source free protocol stack implemented in C and licensed under the LGPL with static linking exception [5] to create a server application embedded into the Libera Spark EL operating system. This allows direct access with the Siemens PLCs and the WinCC control system used at the ELBE facility. Specialized operator panels generated with LabView or programmed in Python can be used in parallel. In addition to that, the server provides a low-latency UDP data stream of the position data for feedback applications.

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