UPGRADE OF SIGNAL PROCESSING OF BPM SYSTEM AT THE SPring-8 STORAGE RING

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Abstract

In the SPring-8 storage ring, new signal processing circuit for a COD measurement has been developed with a target of a few microns of position resolution at 1 kHz bandwidth and around one hundred of measurements per second. In the new circuit, a multiplexing method is employed and the IF signal is directly sampled with a 2 MSPS 16-bit ADC. The digitized signal is processed with DSP and beam positions are obtained. In this paper, schematics and performance of the new circuit are reported. In addition, we briefly discuss a possibility of a fast orbit measurement as a further application of the circuit.

INTRODUCTION

SPring-8 is a 3rd generation synchrotron light source, which is operated stably since 1997. For synchrotron light sources, smaller emittance of electron beam and stable beam orbits are important. In the SPring-8 storage ring, a BPM system and steering magnets are used for a sequential orbit correction. The BPM system consists of 288 sets of 4 electrode pickups which are welded directly to vacuum chambers and 24 sets of signal processing circuits which are currently in operation. In the circuit, a multiplexing method is employed and amplitude at the frequency of acceleration frequency, that is 508.58 MHz, is detected. One set of the circuit processes 48 signals. One of 48 signals is selected by RF switches, filtered by a BPF, down-converted to IF frequency, demodulated to DC signal and digitized by an ADC. Other signals are detected sequentially in the same way. Digitized signals are sent to workstations via VME computers and beam positions are calculated.

This BPM system is used not only for the orbit correction but also for a correction of the ring circumference deviation, which is caused by the tidal effect[1]. For a sufficient resolution of the circumference correction, a beam position resolution of sub-microns is necessary[2]. In the circuit currently in operation, every beam signals are integrated by the ADC for 250 ms. Besides, the positioin resolution of sub-microns is achieved with that long integration time, about 20 seconds is needed to obtain all beam positions.

In the usual operation, the beam orbit is measured every 30 seconds and corrected every 60 seconds. For the purpose of a faster orbit correction and a better position resolution, upgrading of the signal processing has been desired.

TARGET PERFORMANCE AND DESIGN OF THE NEW CIRCUIT

While processing signals in parallel is appropriate by necessity for a measurement of beam position with faster repetition rate, it is required for the new BPM circuit that beam position must not change artificially; if characteristics of circuits such as drift and linearity was not good, stable beam orbit would not be achieved for a long time and independently of the beam current and the beam filling patterns. For these requirements, we adopted the multiplexing method to the new circuit at the expense of fast repetition rate in the orbit measurement.

The target performance of the new circuit is followings; (1) With 1 kHz bandwidth, a position resolution of submicrons must be achieved at the beam current of 100 mA. (2) The repetition of measurement for all BPMs is about 100 measurements per second. (3) Artificial change in beam position when the beam current changes and when different beam filling pattern is stored must be less than 1 μm. (4) A long term stability less than 1 μm is preferable as well.

A block diagram for one set of the new circuit is shown in Fig. 1. As shown in the figure, there are 4 signal paths in one set of the circuit. According to the function of signal processing, individual circuits are made as NIM modules; those are filter and switch modules, a RF amplifier module, a mixer module, an IF amplifier module and a local oscillator module. In each module, paths are separated by thick aluminum cases not to have a crosstalk among paths. In the new circuits, followings were taken into consideration based on the above mentioned target performance. (1) Since the position resolution is determined by signal to noise ratio, the most attention was paid to the noise figure through the circuit. (2) In order to minimize a dead-time during multiplexing, that is determined by settling time of multiplexer, a RF switch which has fast settling time was adopted[3]. In addition, since multiplexing and digitalization of signals are controlled by FPGA and DSP, short dead-time during multiplexing is realized. (3) For a good linearity, RF components with good linearity were selected and a SAW bandpass filter with its bandwidth of 300 kHz at its center frequency of 508.58 MHz was used. With this SAW filter, most harmonics of the revolution frequency, which is 209 kHz, around the acceleration frequency are eliminated. (4) As already mentioned, signals from pickups are multiplexed in order to cancel out fluctuation of the circuit. Moreover all the analog components are equipped in a temperature controlled cabinet, in which temperature is controlled within $\pm$ 0.1 °C.

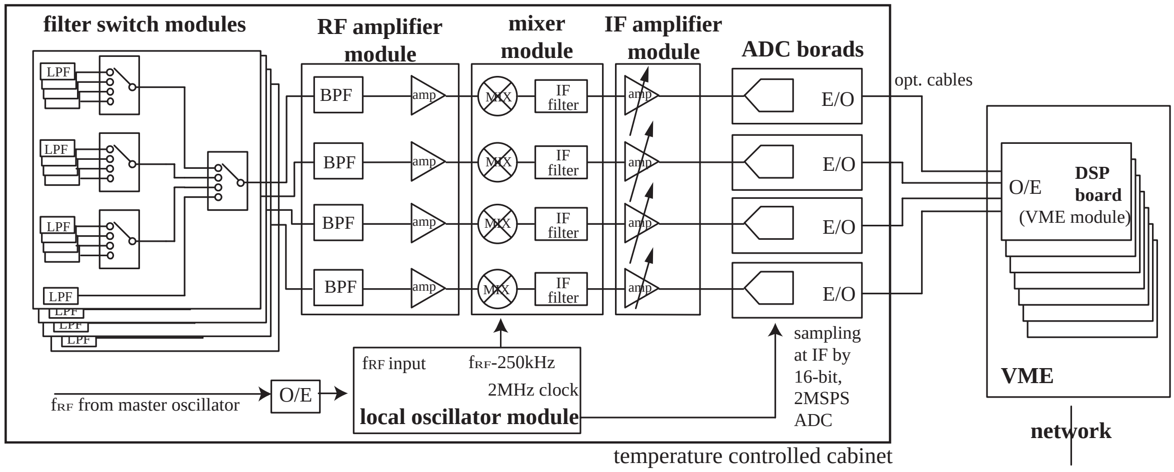

Figure 1: Block diagram of the new signal processing circuit.

PERFORMANCE OF THE NEW CIRCUIT

We have developed one set of the new circuit as a prototype. Performance of the circuit was evaluated using a low noise signal generator (SG).

The position resolution was measured with changing an effective bandwidth. The bandwidth was changed by averaging data on DSPs. Signal of the SG was divided and put into 12inputs of the filter switch module. In Fig. 2 the position resolution is plotted as a function of the number of averaging; averaging of 10 times is corresponding to 10 ms integration time (100 Hz bandwidth). In the figure, position resolutions in vertical direction were 1.5 times larger than that of horizontal one. This difference arises from a fact that a sensitivity constant for horizontal and vertical direction is different; those are 14.5 mm and 21.7 mm for horizontal and vertical direction, respectively. As can be seen in the figure, resolution became better proportional to inverse square root of number of average. Position resolution of 0.2 μm and 0.3 μm for horizontal and vertical directions, respectively, were obtained at 1 kHz bandwidth.

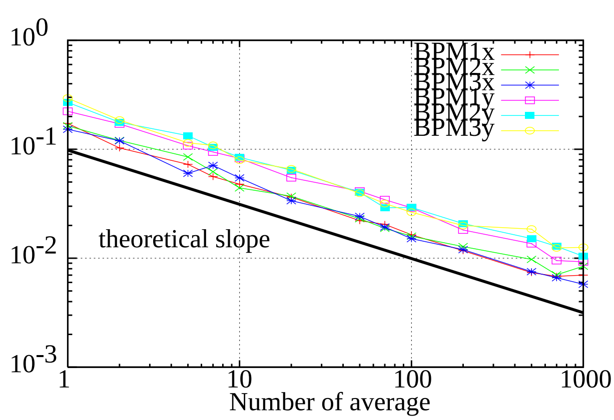

Figure 2: Dependence of position resolution on measurement bandwidth of the new circuit when the signal source is SG.

The long term stability was evaluated by measurement of the SG signals. Setup for this measurement is the same as that of the measurement on bandwidth dependence. With the setup, beam positions were measured every second with 1 kHz bandwidth. In fig. 3, position data measured for 11 days are plotted. In the figure, the data are averaged for successive 120 points in order to emphasize small fluctuation in position. We observed small position fluctuation in an order of 0.1 μm. This fluctuation seemed to have correlation with ambient temperature outside of the rack. Which part of circuit is affected by the temperature is not understood yet.

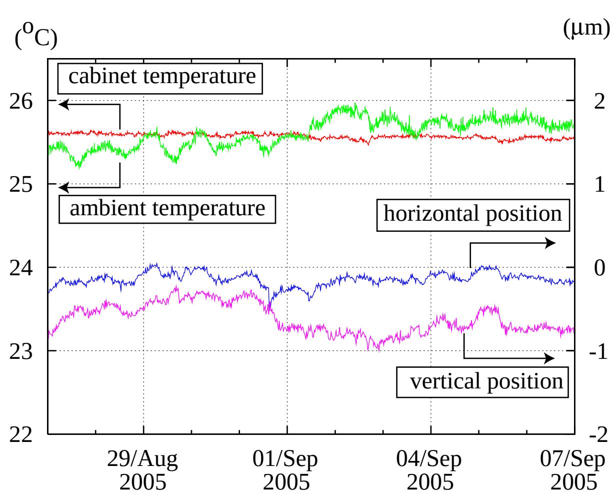

Figure 3: Long term stability of the new circuit measured for 11 days. Averaged data for 120 data are plotted. Temperature around and in the cabinet are also shown.

The dependence on the signal intensity was measured by changing the signal intensity. The intensity was changed by a variable attenuator, which was inserted to the output of the SG. In Fig. 4, measured positions are plotted as a function of the beam current which was converted from the intensity. We observed that deviation in position was less than 0.5 μm when the signal level was higher than that of the beam current of 30 mA. Position deviated as much as 2 μm in the region of the signal level which corresponding to 10 mA. Position deviation became larger at lower the signal level. We estimated non-linear characteristics of the circuit from a two-tone measurement. It was found that position deviation of microns due to the non-linearity of the circuit would appear at signal intensity which corresponds to the beam current of around 1000 mA. The intensity dependence observed in this measurement can be explained by offsets of the circuit.

Since, the SPring-8 usually operated with top-up injection at the beam current of 100 mA at now, this current dependence would not become a serious problem during user operations.

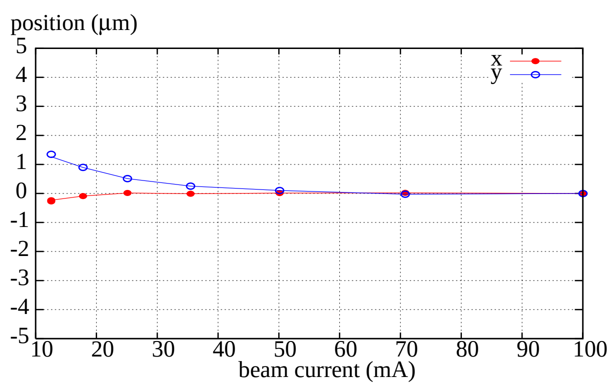

Figure 4: Dependence on signal intensity of the new circuit. Signal intensity was converted to corresponding beam current.

FAST ORBIT MEASUREMENT

As described in previous section, there are 4 signal paths and 4 ADCs in one set of the new circuit. Four signals from one BPM can be processed simultaneously when each signal of one BPM is connected to each path. We measured signal of the SG and that of the beam during user operation. In this measurement beam position was obtained every 1 ms. FFT spectra calculated from the measured data of the SG and the beam are shown in fig. 5 and fig. 6, respectively. From the spectra in the figures, spectrum level of the beam signal was more than 10 times larger than that of the SG signal. That result was same for horizontal and vertical directions.

It is notable that the amplitude of the beam signal in vertical direction was one-tenth of that in horizontal direction, despite the conversion coefficient in vertical direction is 1.5 larger than that in horizontal. Difference in the noise level between the beam signal and the SG signal reflects beam orbit fluctuation. This result was consistent qualitatively with another measurement[4]. We conclude that the new circuit has a possibility for the beam orbit measurement in a fast repetition rate from around 100 Hz to 1 kHz.

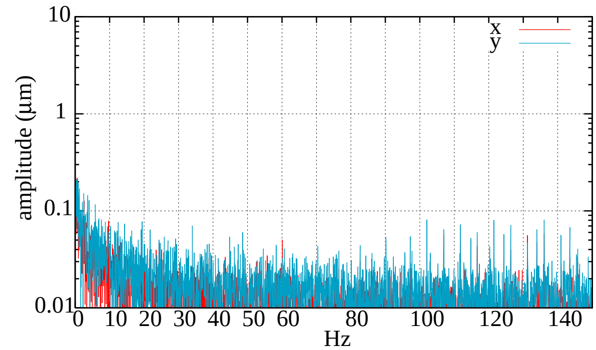

Figure 5: FFT spectra measured with the new circuit when signal source was the SG.

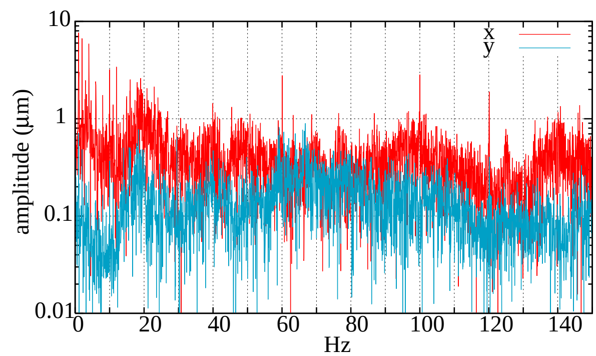

Figure 6: FFT spectrum measured with the new circuit when signal source was beam signal.

SUMMARY

We developed a new signal processing circuit to measure beam positions in the SPring-8 storage ring. We evaluated the performance of the new circuit, such as position resolution dependence on measurement bandwidth, position dependence on signal intensity and long term stability. It was found that target performances based on the requirements are satisfied. This circuit can process 4 pickup signals of one BPM in parallel when wiring of pickup signals are modified. From data obtained with the parallel processing, it was found that this circuit had a possibility of a fast orbit measurement. This new circuit is going to be installed during the summer shutdown of the year 2006.

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