# BEAM OSCILLATION MONITOR FOR THE MULTI-BUNCH BEAM

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*Abstract*
In order to observe the motion of bunch-by-bunch beam oscillation of multi-bunch in the storage ring, we developed two measurement tools. One is a signal process electronics circuit using fast analogue switches. The circuit picks up one of the selected bunch signal of the beam position monitor from the multi-bunch. The selected beam position signal can be processed as a single bunch beam. By changing the gate timing, arbitrary bunch signal can be selected. The other is a waveform memory using a high bandwidth oscilloscope. The long waveform memory of the oscilloscope has a capability to acquire the multi-turn waveform of the button electrode signals. The beam test of the circuit has been carried out at KEK-ATF damping ring in the cases of 2.8 ns bunch spacing and 5.6 ns bunch spacing, respectively. The detail of the hardware and the result of the beam test are reported.

## INTRODUCTION

The Accelerator Test Facility (ATF) [1] in KEK is a test accelerator for developing future accelerator technologies, especially focused on the production of the extremely low emittance beam. The ATF consists of a 1.3GeV S-band linac, a damping ring (DR) and an extraction line. The ATF2 [2] experiment to produce 37nm of the vertical beam size is in progress at the end of the extraction line.

The ATF has several operation modes, one, two or three bunch trains can be stored to the DR, each of which is injected by one pulse of the injector linac. Each train consists of 1 to 20 bunches with 2.8ns spacing or 1 to 10 bunches with 5.6ns. In the case of three trains and 20 bunches per train, total current up to 70mA can be stored in the DR. At the multi-bunch/multi-train operation, we some times experienced the instabilities. The beam position monitor(BPM) measures the mean value of the multi-bunch beam [3]. The electronics digitizes the down converted frequency 15MHz, which cannot resolve signal of individual bunch of the multi-bunch/multi-train beam.

To observe oscillation of individual bunch of the multi-bunch/multi-train beam, we developed two measurement tools. One is a single bunch signal selection using fast analogue switches. The tune and the other oscillation modes of the selected bunch signal can be measured using the existing tune monitor electronics. The other is a long waveform memory using a wideband oscilloscope. All of bunch signal during many turns is acquired directly. This monitor is developed for the response measurement of the fast kicker for the linear collider [4]. The fast kicker has to have a function to kicked out a selected bunch without any affect for the residual bunches.

## FAST ANALOGUE SWITCH

Figure 1 shows the layout of the selected bunch turn-by-turn monitor. The fast analogue switch (FAS) gates the arbitrary bunch signal from a multi-bunch beam with 2.8 ns spacing. Signal of one bunch is selected by adjusting the gate timing. After the FAS, the beam signal is processed as a single bunch signal. The turn-by-turn BPM electronics is a different electronics for the other BPM electronics of the DR, which consists of a low pass filter (100MHz), a sample hold, 14bits ADC (AD9243: maximum conversion rate 3MSPS) and a 64K words memory.

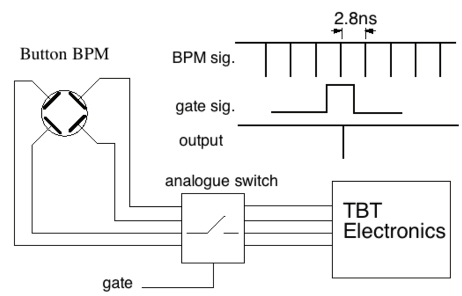


Figure 1: Layout of the selected bunch turn-by-turn monitor.

HM234C8 (Hittite Microwave Co., Frequency DC-8GHz, Insertion loss 1.6dB at 6GHz, Isolation:52dB at 2GHz)[5] is used for the FAS. The HM234C8 has a switching noise. Figure 2 shows the waveforms of the single chip of the HM234C8 at a three-bunches operation, the orange line shows the input and the green line shows the output. The gate timing is set to the first bunch of the input signal. The unwanted noise signal was observed at the timing of the front and rear of the beam signal, which affects the beam position measurement. This noise needs to be eliminated.

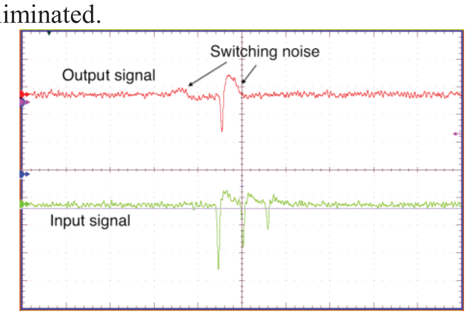


Figure 2: Waveform of HM234C8 single chip.

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### *Noise Cancelation Circuit*

We developed a noise cancelation circuit to avoid the switching noise of the FAS. Figure 3 shows a simplified diagram of the circuit. The input signal is divided into two signals by a 180 degree RF splitter. The divided signals have opposite polarity. Two pairs of HM234C8 are used to keep enough isolation. The switching noise of each HM234C8 has the same amplitude and the same polarity. Two signals are recombined by a 180 degree RF combiner. The signals are combined with the opposite phase and the switching noises are canceled out. Figure 4 shows the picture of the fabricated noise cancelation circuit. Figure 5 shows the input/output waveforms of the noise cancelation circuit at a three-bunch operation. The switching noise was completely canceled out and the beam signal was same as the input.

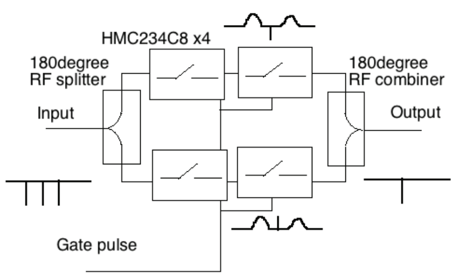


Figure 3: Simplified circuit diagram of the noise cancelation circuit.

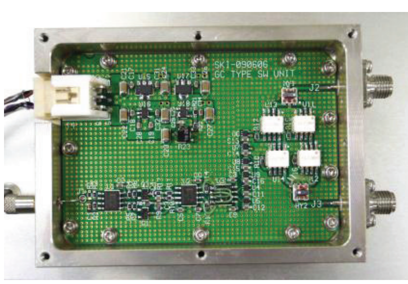

Figure 4: Picture of the noise cancelation circuit.

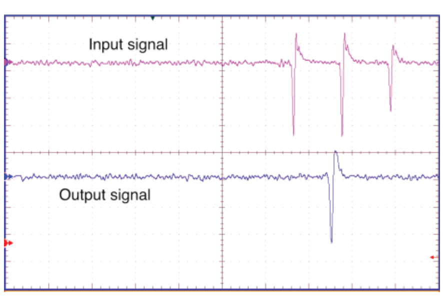


Figure 5: Input/output waveforms using the noise cancelation circuit.

Figure 6 shows the example of the tune measurement at a multi-bunch operation using the FAS. The spectrum of the oscillation was obtained as same as the single bunch operation. The measured tunes of x and y were, first bunch: 0.1677, 0.5382, second bunch: 0.1680, 0.5379, third bunch: 0.1675, 0.5381, respectively. No clear differences of the tunes were observed.

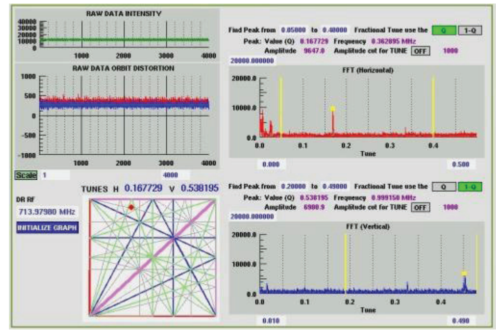

Figure 6: Tune measurement of the first bunch at three bunches operation.

## WAVEFROM MEMORY

In the method of the FAS data of different bunches are taken at different times. To measure the oscillation of multi-bunches simultaneously, the same shot of the beam for all bunch, a long waveform memory using a wideband oscilloscope was tested. Signal of BPM electrodes are acquired by using DPO7254 oscilloscope (Tektronix Co., Bandwidth 2.5GHz, Sampling rate 0.1ns, Wave memory 50Mwords/ch) [6], directly. Figure 7 shows the configuration of the oscillation measurement. The signals are fed to the oscilloscope through the 20dB amplifiers. The data of the waveform are transferred to the computer through a network then estimated the beam position.

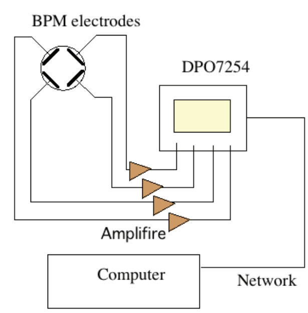


Figure 7: configuration of the oscillation measurement.

The memory can save up to 5ms of the waveform with 0.1 ns time resolution, which correspond to 10000turns of ATF DR. The amplitude resolution of DPO7254 is 8 bits. For measuring small oscillations, 8bits of the amplitude resolution is not enough. Some offset is added to the signal and reduced the dynamic range to increase the amplitude resolution, effectively.

### *Observation of Oscillation*

Figure 3 shows the waveforms of four BPM electrodes at three-bunch operation. The waveforms are overlapped each other. The time scale is expanded to see the single turn. The vertical scale is 50 mV/div and the offset is -100 mV. The stored current is 8 mA and the charges of the three bunches are different. The mean value of the bunch charge is 1.2 nC.




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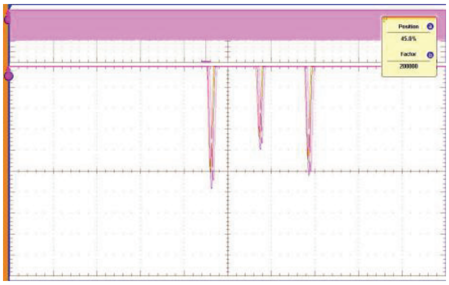

Figure 8: waveforms of four BPM electrodes at three bunches operation with 2.8ns spacing (5ns/div, 50mV/div, -100mV offset).

To observe the bunch oscillation, the selected bunch is pinged by a strip-line kicker for the vertical direction. The applied pulse was a single pulse and very short, less than 3ns [4]. The timing was adjusted to the 2nd bunch, precisely. Figure 9 shows the oscillations in 10000 turns after the 2nd bunch was pinged. The amplitude of the oscillation was +/-1mm, which was damped gradually. The 3rd bunch was not oscillating at the beginning, but the oscillation increased gradually up to 5000 turns and decreased after that. The peak amplitude of the 3rd bunch was larger than the peak amplitude of the 2nd bunch. The ping effect did not transfer to the vertical direction of the 1st bunch and the horizontal direction of the all bunches. When the 1st bunch pinged vertically, it induced vertical oscillations of the 2nd and 3rd bunches. These behavior are explained as an effect of transverse wakefields, which remains in the bunch spacing (2.8 ns), but be damped between different turns (462 ns).

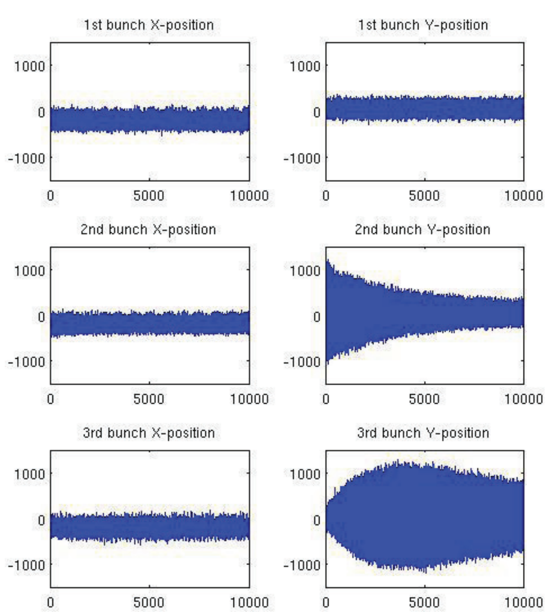


Figure 9: Beam oscillation for each bunch when the 2nd bunch was pinged vertically. (Vertical scale: μm, Horizontal scale: turn number).

## SUMMARY

We developed two measurement tools for monitoring oscillations of multi-bunch beam in a storage ring. One is a bunch signal selection using fast analogue switches. The noise cancellation circuit is very effective to reduce the switching noise. This monitor is used for measuring tunes of individual bunches. The other is a waveform memory using a high bandwidth oscilloscope. Using this monitor, oscillations of all bunches can be measured simultaneously. Exciting oscillation of a bunch by a fast kicker, we could observe induced oscillations of following bunches with 2.8 ns bunch spacing, which was considered to be effect of wakefield.

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