

## DEVELOPMENT OF A BEAM CURRENT TRANSFORMER FOR THE X-FEL PROJECT IN SPRING-8

Atsushi Higashiya<sup>#</sup>, Hirokazu Maesaka and Yuji Otake

SPring-8 Joint-project for XFEL/RIKEN, 1-1-1, Kouto, Sayo-cho, ayo-gun, Hyogo JAPAN  
679-5148.

### Abstract

The SCSS prototype accelerator has been constructed at SPring-8. The output signal of a current transformer (CT) for measuring the electron-beam current in the SCSS prototype accelerator had a few megahertz (MHz) noise emitted from the thyatron of a klystron modulator, a ringing signal caused by the weak field of the electron beam. The long-period undulation of an electrical ground level at the CT monitor output also occurred due to a large electric current generated by the klystron modulator, which flows into ground. As a result, it is difficult to correctly measure the beam current. Therefore, we devised a new CT monitor and the differential circuit from CT monitor in order to improve the problem mentioned above.

The improved points are: (I) We think that the thyatron noise and undulation of the ground level comprise common mode noise. Therefore, these noises were reduced by using a differential detection circuit, and contacting between the ground of the CT case and the outer surface of a CT signal cable. (II) The ringing signal was suppressed by intercalating a dumping resistance material into the space between the case and the ferrite core of the CT monitor. By these developments, the environmental influence to the CT monitor could be suppressed in its output circuit. In an experiment to evaluate the CT monitor, the output waveform of the CT monitor was very clean without any noises as mentioned above.

### INTRODUCTION

The X-FEL prototype accelerator (SCSS project) was constructed at SPring-8. SASE (self amplification of spontaneous emission) at a wavelength of about 50 nm and was successfully observed during the last year. The X-FEL project, based on SASE, is currently in progress.[1,2]

In generally, it is important to correctly investigate the beam properties such as the current of an electronic beam. For this reason, in the SCSS prototype accelerator, we use CT monitors.

In commissioning of the prototype accelerator, we found that the CT output signal was influenced by the environment such as noise produced by high-voltage switching in the thyatron of a klystron modulator and occurred due to large electric current flow into the ground, which is also generated by the klystron modulator. Figure 1 (a) shows the ringing noise in the CT

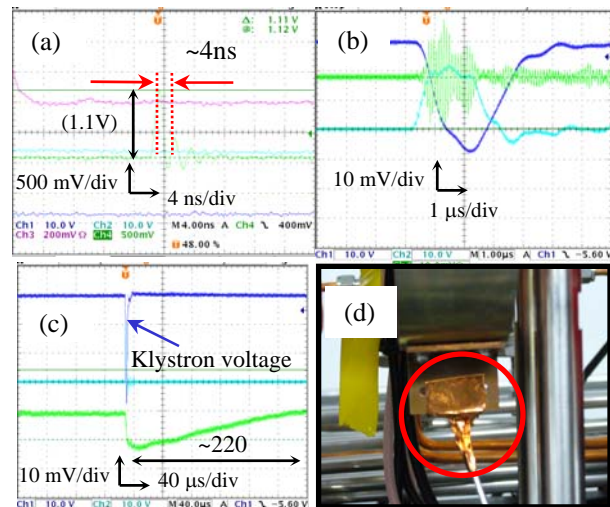


Figure 1: (a) Ringing of the CT output. (b) A few megahertz noise at CT output. (c) Long-period undulation of the electrical ground level at the CT output. (d) Picture of CT at the SCSS prototype accelerator.

output. The ringing has a period of about 4 ns (500 MHz). Figure 1 (b) also shows a few megahertz noise emitted from the thyatron. First, in order to eliminate the thyatron noise, we made a contact between the ground of the CT case and the outer surface of the CT signal cables as shown in Fig.1 (d) (indicated by a red circle). As a result of the contact, the noise seemed to be suppressed. However, instead of this noise, a long-period undulation of the electrical ground level (about 220ms) appears as shown in Fig.1 (c). Therefore, it was difficult to correctly determine the beam current (electrons charge amount) due to these problems.

In order to improve the problems of the few megahertz noise, the ringing signal and the long-period undulation of the electrical ground level, we devised a differential output-type CT monitor with two output ports and a differential detection circuit to modulate the undulation.

In this paper, we introduce the points of our improvements in the CT used at the prototype accelerator, the detailed configuration of the differential detection circuit, and also demonstrate the clean output waveform without any noises obtained by the differential output-type CT.

<sup>#</sup>codbelo@spring8.or.jp

## SYSTEM OF DIFFERENTIAL OUTPUT-TYPE CT MONITOR WITH TWO OUTPUT PORTS

Figure 2 shows a schematic cross-sectional view of the differential output-type CT monitor with two output ports. In this figure, the CT monitor has an amorphous ferrite core with two-one turn coils and two output ports located above and below the core. The upper and lower ports are designed to make opposite signs of the output signals. The amorphous core makes the time response of the CT monitor faster.

As the cause of the ringing signal, we suggested that a

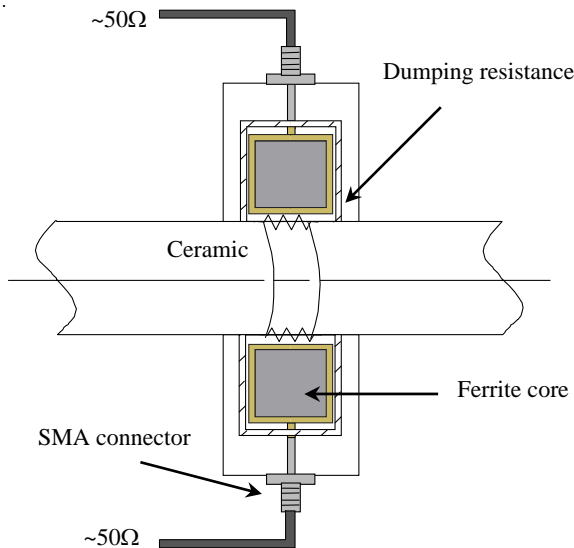


Figure 2: Cross-sectional view of the differential output-type CT monitor.

weak field generated by the electron beam produced ringing. The outer case of the CT monitor could behave as a resonant cavity. To suppress the effect of the wake field, we considered that the damping parameter to the field in the cavity was effective. Therefore, we intercalated the dumping resistance material into the space between the aluminium case and the ferrite core of the CT, shown as the hatched part of Fig. 2. To calculate the resistance at the design stage, a cavity resonant frequency of about 500 MHz was estimated from the case diameter as the cavity, effect of the permeability of the core, and the measured time between the broken red lines, as shown in Fig. 1 (a). The equation of the resonant cavity for an evaluation circuit is represented by

$$L(d^2q/dt^2)+R(dq/dt)+(1/C)q=0, \quad (1)$$

where L, R, q and C are the inductance and the wall resistance of the cavity, the cavity wall current charge induced by the electron beam and the capacitance of the accelerating gap of the cavity, respectively. According to the equation, an adjustment of R was needed to obtain the proper damping effect to suppress the ringing. Namely, it was necessary to fit R to the value of the critical damping condition of the equation. From a straightforward calculation using this equation and the resonance

frequency obtained from Fig. 1 (a), a cavity surface resistivity of more than  $3.0 \times 10^{-12} \text{ m}^2\Omega$  is required to satisfy the condition. Consequently, we achieved this condition by coating a Ni film of 10  $\mu\text{m}$  on the inner surface of the CT case after coating a chrome film of 30  $\mu\text{m}$ . Figure 3 shows the frequency response of the CT monitor having a dumping resistance, which was obtained

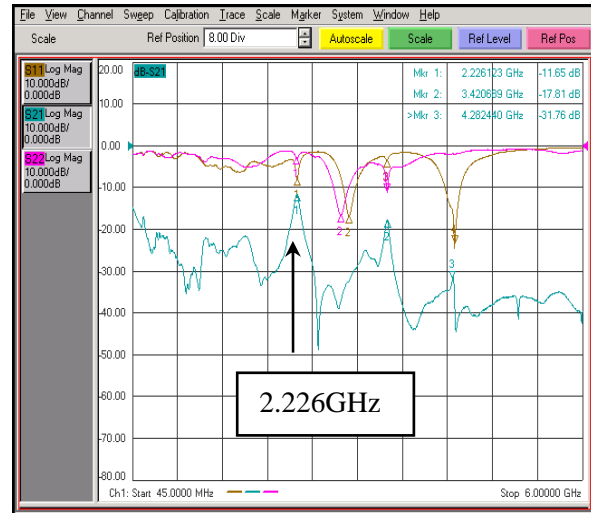


Figure 3: Frequency characteristics of the CT by means of a network analyser.

by a measurement using a network analyzer. A resonant peak at a frequency of 500 MHz existed before coating these films. After the coating, the 500 MHz peak disappears as shown in Fig. 3. However, we can find another resonant peak located at a higher frequency of about 2.2 GHz instead of the 500 MHz peak.

When we thought about the problem of a long-period undulation of the ground level, the undulation was thought to be common mode noise. We then considered how the CT monitor outputs the signal, and devised the following ideas. The devised CT monitor has two output ports at opposite poisons of the case circumference, and the detection circuit is the differential circuit shown in Fig. 4. The two output signals from the CT monitor, indicated as (I) and (II) in Fig. 4, are transmitted to the differential detection circuit by using a 100-ohm differential cable. Then, these signals are terminated by a 100  $\Omega$  resistance and imported into the differential circuit. Since the noise of the output waveform is the common mode, the noise components of the wave forms have the same signs, as indicated by the two solid lines of (I) and (II) in Fig. 4. On the other hand, the two necessary signals generated by the electron beam are of the opposite signs, as shown by the dashed lines of (I) and (II) in Fig. 4. Therefore, the common noise of the signals at the circuit input is suppressed when these signals pass through a differential amplifier just in front of an AD converter (ADC), as indicated by the solid line (III) in Fig. 4. In addition, the necessary signal at the converter input makes its voltage double by adding signals (I) and (II), as shown

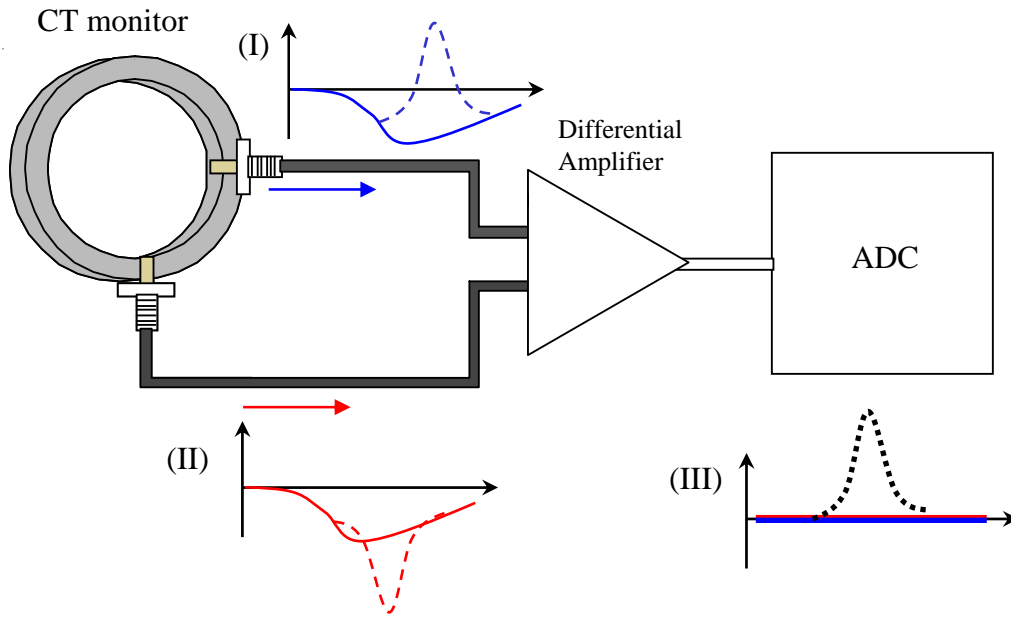


Figure 4: Schematic circuit diagram for the differential reception.

by the dashed line (III). The output signal from the differential amplifier is transferred to the ADC.

Figure 5 shows the detailed configuration of the differential detection circuit for the CT monitor. The differential circuit is composed of a preamplifier, a 100 ohm differential cable, a main amplifier, and a VME ADC module. The output signal from the CT monitor is transferred to the preamplifier. Then and there, the gain adjustment to the amplitude of the CT signal by the

**DETAILED CONFIGURATION OF DIFFERENTIAL DETECTION CIRCUIT FOR CT MONITOR**

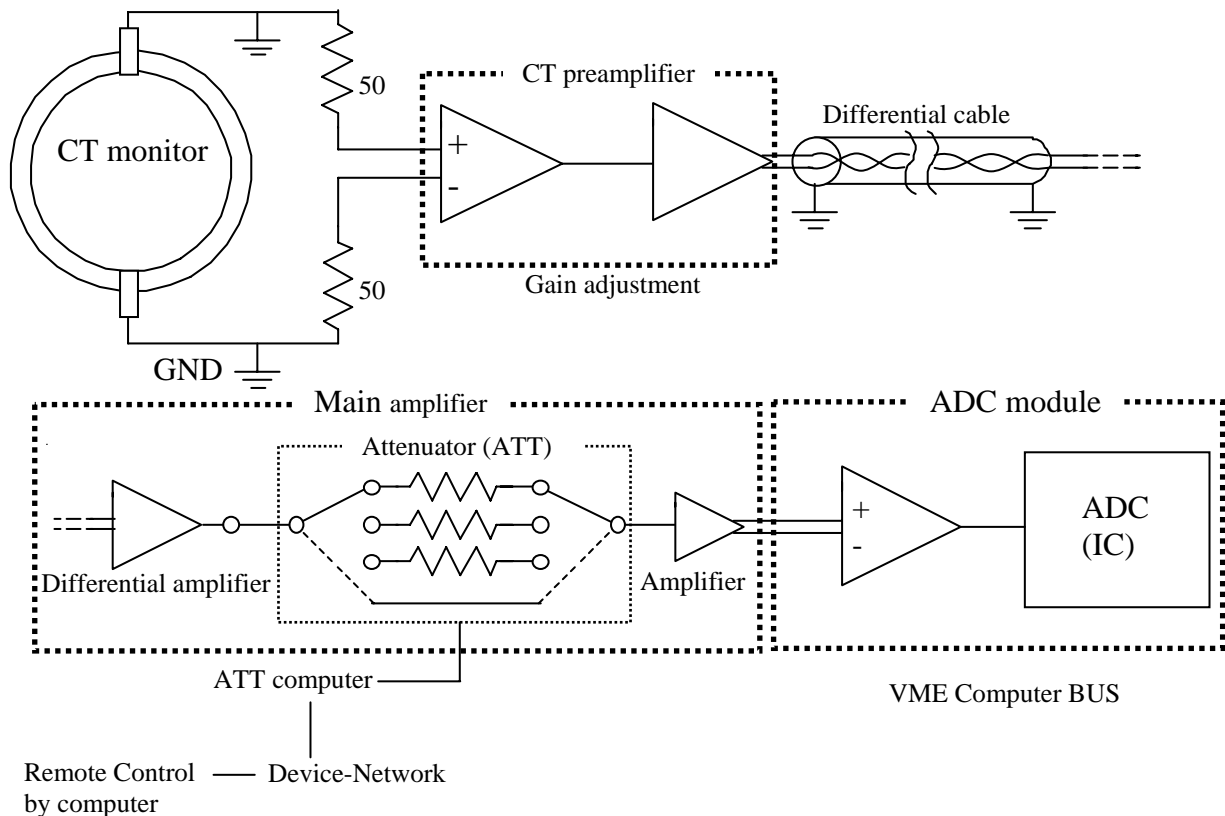


Figure 5: Differential circuit design of CT monitor

preamplifier is done. After then, the signal is transferred to the main amplifier through the differential cable, in which its cable length is about from 10 m to 20 m. The main amplifier includes differential amplifiers and a switching attenuator array. The attenuator array also adjusts the amplitude of an input signal from the CT monitor. The switching of the attenuator is remotely controlled from a computer through the Device-Network. The output signal from the main amplifier is transfer to the VME ADC module that works like an oscilloscope having a differential input, a 12 bits dynamic range, a 238 MHz clock drive circuit. At the present, this differential detection system is under development. However, we believe that a genuine large beam current signal with noise suppressed by the system could be successfully obtained.

### TEST OF DIFFERENTIAL OUTPUT-TYPE CT MONITOR

We installed a differential output-type CT monitor to the SCSS prototype accelerator (as shown in Fig. 6 (a)) for a test, and directly measured the output wave forms from the CT monitor, induced by the beam, by using an oscilloscope having a measurement bandwidth from DC to 12 GHz. Figures 6 (b) and (c) show the obtained output wave forms. In these figures, the green, yellow, and red lines are the signal from port 1 and port 2, and their difference (port1-port2), respectively. As shown by the red line, the long-period undulation disappears and the ground level is nearly flat due to the common mode-rejection effect.

### SUMMARY

In order to eliminate the ringing signal caused by the weak field of the electron beam, the few MHz noise and the long-period undulation of the ground level at the CT output, we devised a differential output-type CT monitor.

The waveforms obtained by the CT monitor showed

clear output signals, which indicated that our improvement could successfully suppress the noise from the environment around the CT monitor. The ringing effect caused by the weak field induced by the electron beam is successfully suppressed by inserting the dumping resistance. Furthermore, the CT monitor time response was fast due to the time response of the amorphous ferrite core with the one-turn coils, and due to the frequency response of the effective permeability of the core up to about 1 GHz. The waveform rise time is less than 200 ps. The obtained signal waveforms had a few structures. At the present time, the reason why the waveform had the structure is not clear. There is some possibility that the true waveforms could have a different shape, and could be hidden due to the limited bandwidth of the oscilloscope. Therefore, we need more accurate measurements using an oscilloscope with higher bandwidth than 12 GHz, or streak camera in order to verify the true waveforms. The differential detection circuit for this CT monitor is still under development, and however, it will be tested within several months. Consequently, we think that it is possible to measure the beam current (the electrons charge amount) more precisely.

### ACKNOWLEDGMENT

We thank the members of the SCSS prototype accelerator group for their help with the experiment. For CT monitor production, we are grateful for the effort of Mr. Koji Kase (Toyama corporation, 4-13-16 Hibarigaoka 4-chome, Zama-shi, Kanagawa Prefecture, JAPAN 228-0003).

### REFERENCES

- [1] SCSS X-FEL R&D Group (<http://www-xfel.spring8.or.jp/>)
- [2] H. Tanaka, et al., Beam Performance of the SCSS Prototype Accelerator, The 3rd Annual Meeting of Particle Accelerator Society of Japan (2006).

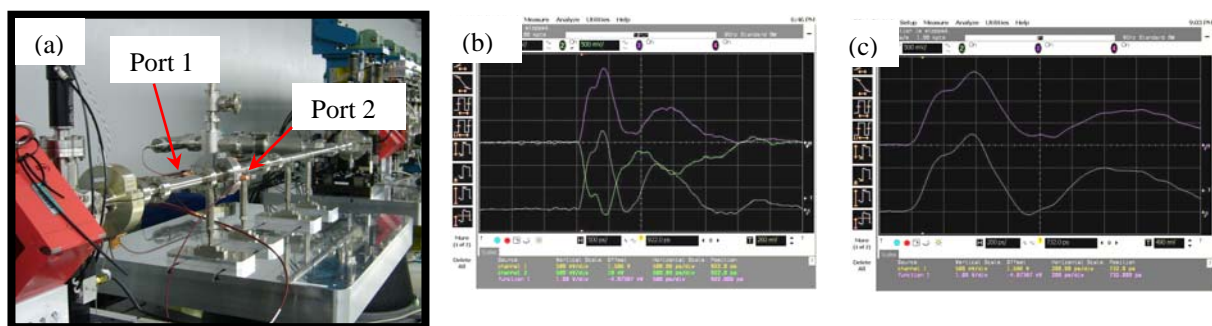


Figure 6: (a) Picture of the CT monitor installed in the SCSS prototype accelerator. (b) Output waveforms induced by the electron beam displayed in the wider time span (500ps/1div). (c) Output waveforms displayed in the narrower time span (200ps/1div.).