High Speed SW Current measurement by Rogowski Coil Current Probe

1. Outline

Introduction

Rogowski Coil Current Probe can measure the switching characteristics of high speed and large current.

This application note introduces important points to keep in mind for the accurate and safety measurement.

Points to keep in mind

1. Do not exceed the absolute maximum rating that is defined as the slope of current change (di/dt).
2. Pay attention to effects on the surrounding electric field.
3. Put your mind to the delay time difference between the probe and the actual current.

2. Absolute maximum rating

2.1. Absolute maximum rating

Maximum allowable current at measuring Rogowski Coil Current Probe is determined by the slope of current change (di/dt). This means allowable current changes along with frequency of current being measured and the rising time.

Table 1
Absolute maximum rating
of current being measured

Modelname	Peak [kA/μs]	RMS [kA/μs]
SS-281A,282A	80	1
SS-283A,284A,285A	80	1.5
SS-286A	80	2

※Ｐｅａｋ: Number of Single Pulse Signal. Never exceed this number.

※RMS: Number of Continuous Signal. Never exceed this number.

※In case of exceeding the absolute maximum rating, probes may be damaged, smoking or sparking.

2.2. Sine waveform

Slope (di/dt) of current change of sine wave signal is calculated by differentiating sine wave signal, and the maximum slope is 2xπx frequency x signal amplitude.

2.3.Pulse waveform

Slope of current change (di/dt) of Single shot pulse = Max. current value / Rising time (or falling time)

In continuous pulse signal, calculate di/dt of current pulse at rising/falling time and calculate the effective value from the cycle T. This value must not exceed the absolute max. rating RMS value.

$$\frac{d}{dt}Is(t)=\sqrt{\left(\frac{Is}{Tr}\right)^2\times\frac{Tr}{T}+\left(\frac{Is}{Tf}\right)^2\times\frac{Tf}{T}}$$

※For details please refer to Application Note R014069 “Rogowski Coil Current Probe Maximum Allowed Current”.

3.Effects of voltage noise

3.1.Measurement Points

When the current being measured becomes high speed, effects of the surrounding voltage noise becomes a big problem. Rogowski Coil Current Probe measures current by detecting the change of magnetic field.

In the high frequency, however, the effects on the voltage change by electrostatic coupling between the coil and the electrode being measured or the close electrode cannot be ignored. Accordingly, when the frequency range exceeds 10MHz or pulse rising time is about 30ns, it will become difficult to reproduce the measurement value and to keep the reliability. Please follow the steps below to avoid being affected.

① Measure the current at the place (node) where the voltage amplitude is as small as possible.

② Separate Rogowski coil from the floating capacity as long as possible to reduce the effects.
(Do not make contact between the coil and the object to be measured.)

③ Use a current probe for the suitable range. If you measure low current with a high range current probe, the Signal-to-Noise (S/N) ratio becomes worse and the measurement is affected easily.

④ Try not to change the physical place of the probe in order to improve the reproducibility.

⑤ Use an appropriate bandwidth limit so that unnecessary element can be dropped.

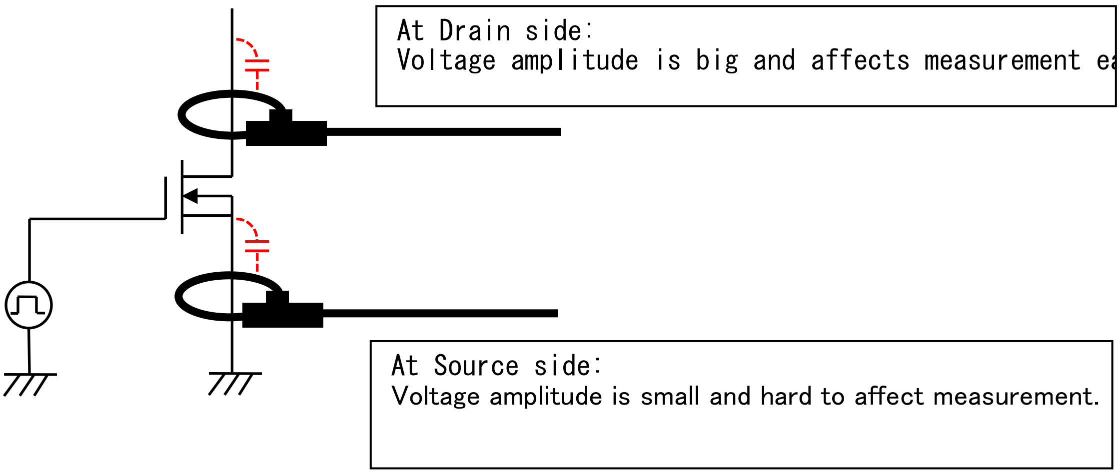


Figure 1 Switching current measurement at low side

3.2. Measurement sample

3.2.1. How to evaluate the measurement result

We measured how much the waveform change appears with the electrostatic coupling stated above.

The output of Pulse Generator is terminated with 50Ω resistance. The current, whose value is output voltage divided by 50, floats to the resistance. We look into where we measure this current leads to the waveform changes.

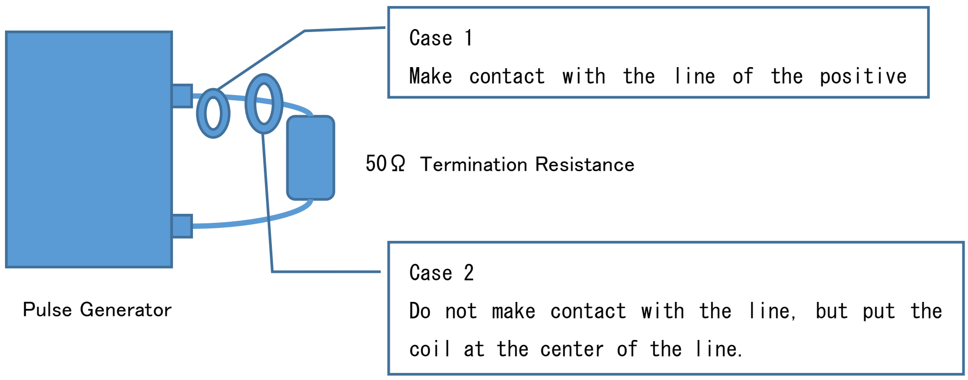
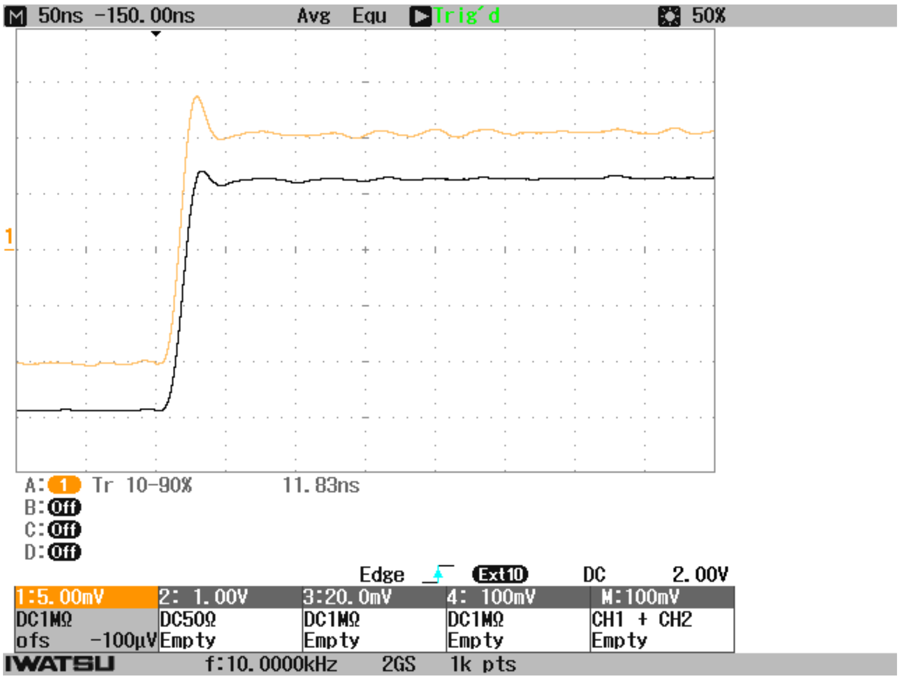


Figure 2 Evaluation of effects on electrostatic coupling

3.2.2.Measurement result (Positive side)

In case 1, the coil touches the line of which voltage is fluctuating and the monitor shows that the overshoot appears because the voltage noise is superimposed by electrostatic coupling.

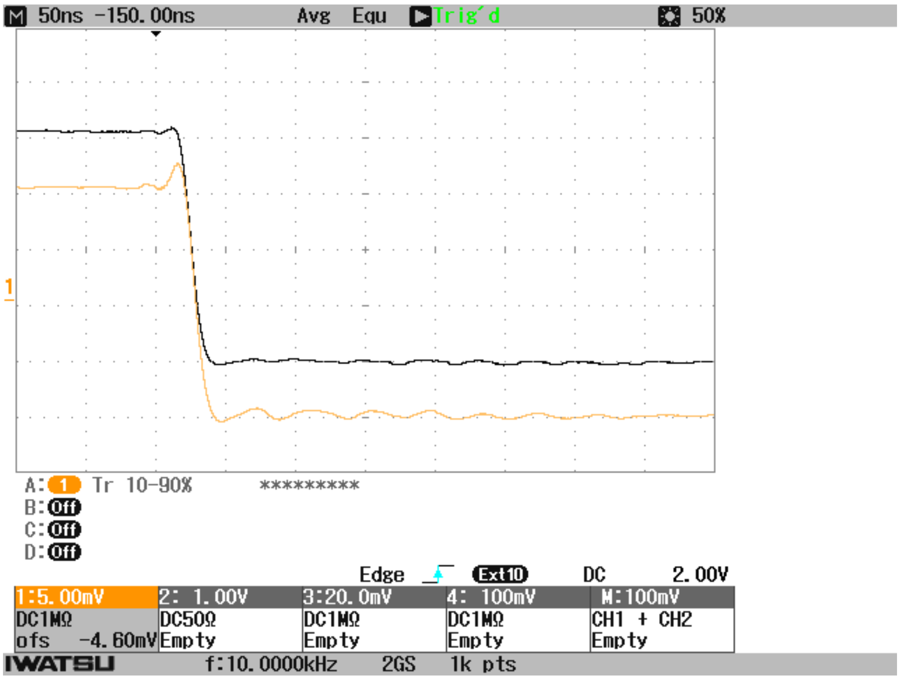
CH1 (Yellow): Case 1
REF (Black) : Case 2



3.2.1.Measurement result (Negative side)

The following shows that the installation direction of Rogowski coil is reversed so that the polarity of the current is reversed. Although the polarity of the current is in reverse, the polarity of superimposed voltage noise is unchanged. This time, a waveform such as preshoot appears.

CH1 (Yellow): Case 1
REF (Black) : Case 2

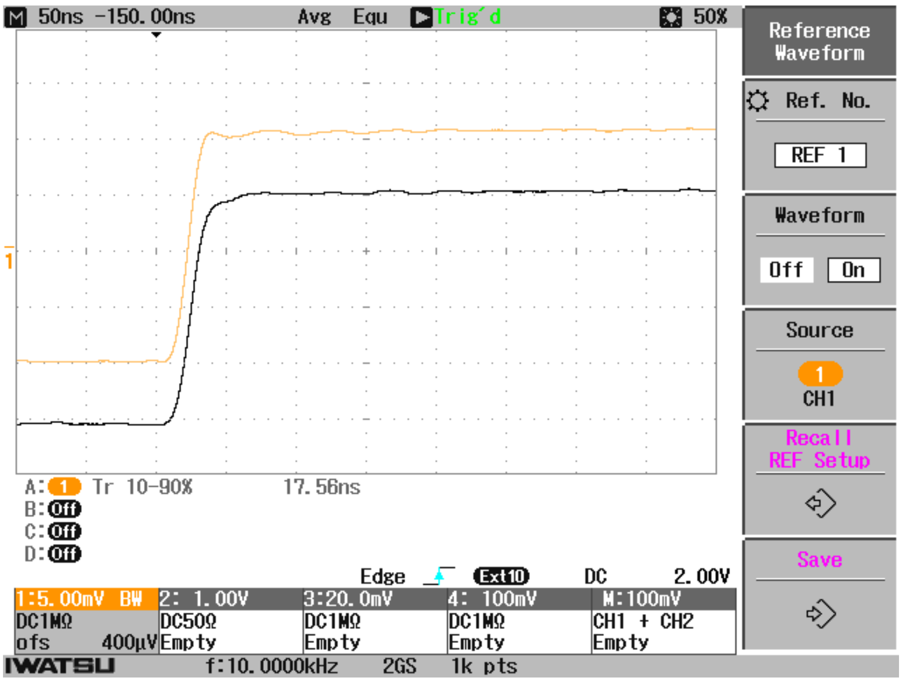


3.2.1.Measurement result (Band limitation 20MHz)

The following shows the measurement result when the bandwidth of an oscilloscope is limited up to 20MHz, with the other conditions same as the positive polarity case as the above mentioned. The waveform changes less than the above. Especially this is effective when there is a power source with high didt closed to device.

CH1(Yellow):Measurement condition 1

REF (Black) :Measurement 2



4.Delay time

4.1.Importance of Delay time

When we evaluate switching characteristics of instruments such as inverters, we sometimes evaluate switching loss by measuring the voltage and the current. In this case, the margin of the error may appear unless the delay time between the voltage and the current measurement matches.

The following shows an example of power loss calculation of FET via measuring Vds and Id. When the delay time appears on the current measurement area, it looks as if the power loss was smaller at the timing of FET ON and it looks as if the power loss was bigger at the timing of FET OFF. Therefore, as we discussed, we cannot evaluate properly.

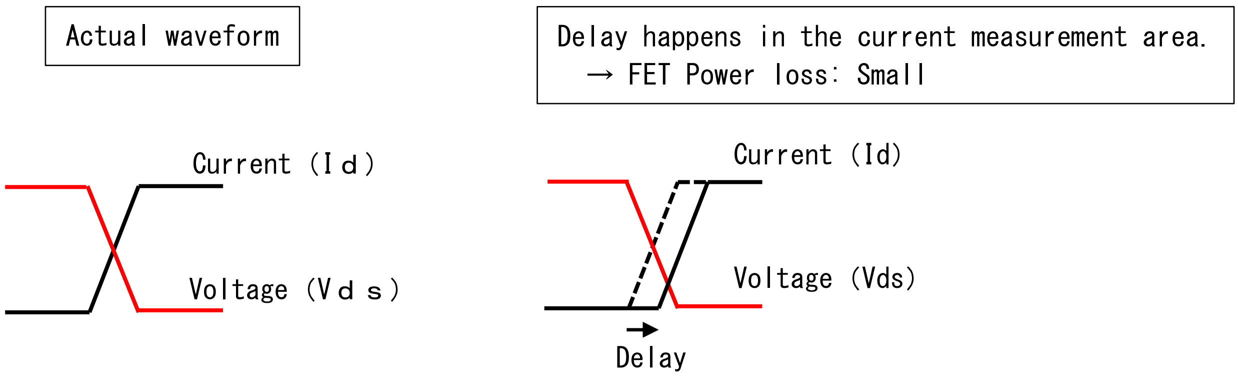


Figure 3 Effects on Delay time

4.2.Correction method of the delay time difference

4.3.Factors in delay time

The absolute delay time of Rogowski Coil Current Probe is about 26～28ns observationally (including Output coaxial cable 0.5m). Analyzing each factor, we find approx. 7.5ns delay happens because of approx. 1.5m cable length at the sensor part. In addition, 2.5ns delay happens by 1.5m output coaxial cable and remaining 17ns (= 27ns - 7.5ns - 2.5ns) happens by the delay time of Integrator (A coaxial cable has approx. 5ns/m delay time).

If you already know the delay time of the voltage probe, it is possible to correct the time base on approx. 27ns as the delay time of Rogowski Coil Current Probe, however, for more precise and accurate measurement you need to correct the delay time difference by the measurement written later.

4.3.1.Measurement method

Please perform the measurement using a probe you actually use and an oscilloscope like Figure 2 so that you can correct the delay time difference (skew) between the voltage and the current measurement systems. The output of High Speed/High Amplitude Pulse Generator will be connected to 50Ω terminator and at the same time, Coil for detection is inserted to GND side so that you can detect the current. Then please measure the current floating the detection part by Rogowski Coil Current Probe and measure the output voltage of Pulse Generator by the voltage probe.

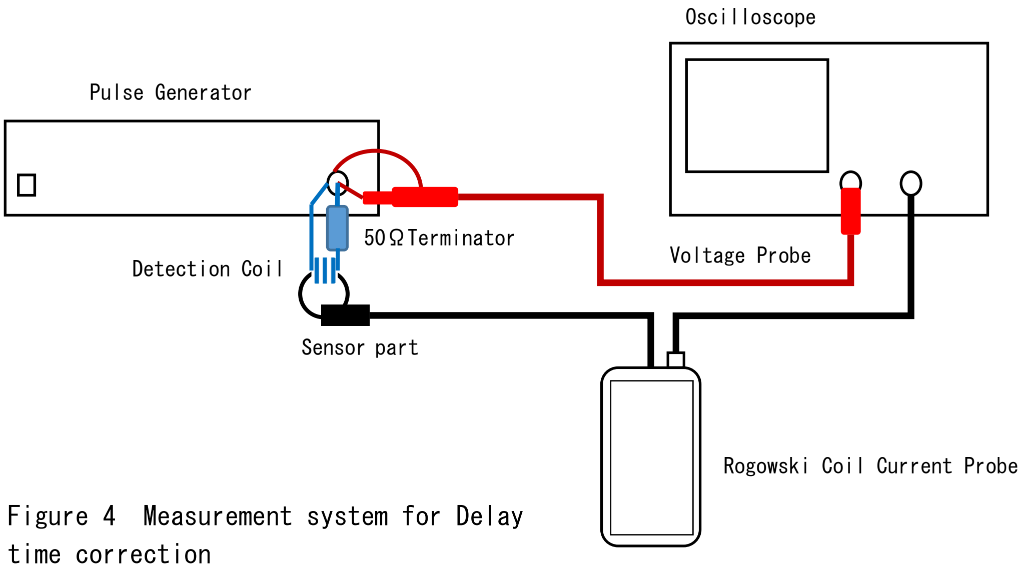


Figure 4 Measurement system for Delay time correction

※As we cannot measure the voltage accurately if the pulse rising is slow, a pulse generator with approx. 10ns rising time is needed.

※If you want to increase the equivalent current, increase the winding number of the coil. In that case,
the coil should be small and turns should be limit to 5, as the high inductance would make delays between current and voltage.

4.3.2.Example of Correction

＜Used Equipment＞

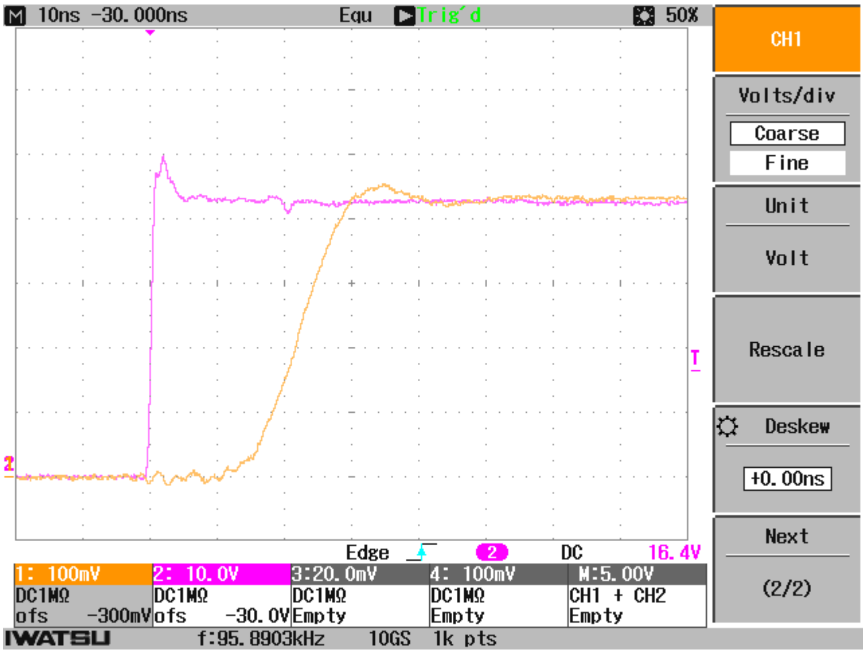
Pulse Generator：PSPL2600 (manufactured by PSPL)
Oscilloscope：DS-5554 (manufactured by IWATSU)
Voltage Probe：PHV633L (manufactured by PMK)
Current Probe：Rogowski Coil Current Probe SS-282A

＜Measurement method＞

Output approx. 42[V] pulse from the Pulse Generator. Connect the Generator to 50Ω terminator with 5 turns coil, In this example, the measured current shall be 42[V]÷50[Ω]×5[turn]＝4.2A and adjust the probe so that the polarity becomes positive. When you perform this correction, connect the current probe to the Pulse Generator with the shortest lead. If you use GND lead, the waveform would be deformed.

＜Waveform at the initial condition＞

You can find there is 14ns delay in Rogowski Coil Current Probe compared to the voltage probe. Please bear in mind that this is the relative delay to the voltage probe.

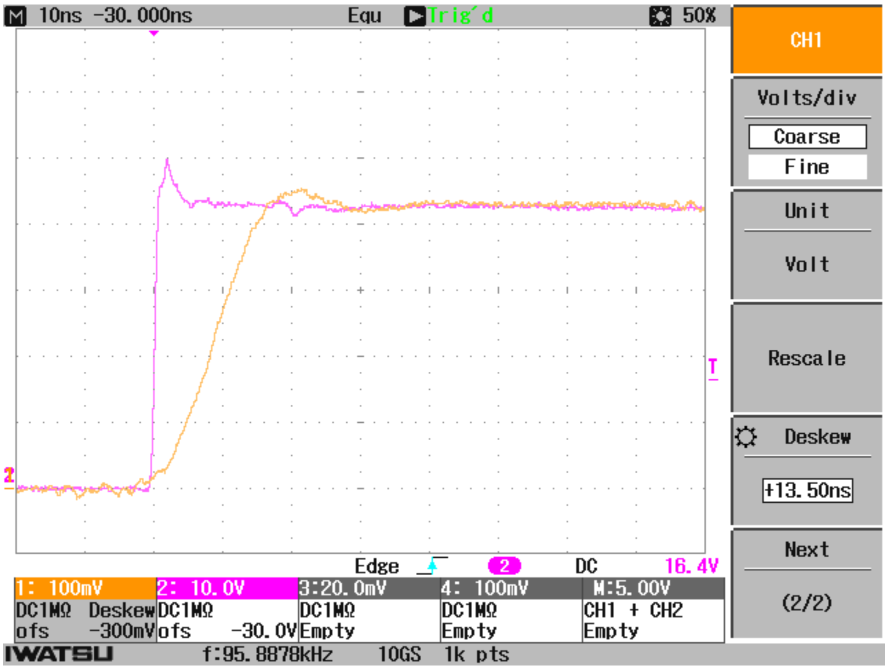


CH1 : Current waveform by SS-282A
CH2 : Voltage waveform by Voltage Probe (PHV633L)

＜Waveform after Correction＞

Set 13.5 ns to adjust the rising points of the current waveform and the voltage waveform using“Deskew” function of Oscilloscope.

CH1 : Current waveform by SS-282A
CH2 : Voltage waveform by Voltage Probe (PHV633L)



※In this example, as the voltage probe's bandwidth is more than 100MHｚ and the current probe's is approx. 30MHz, the rising time difference appears. In this case, adjust the rising time points.

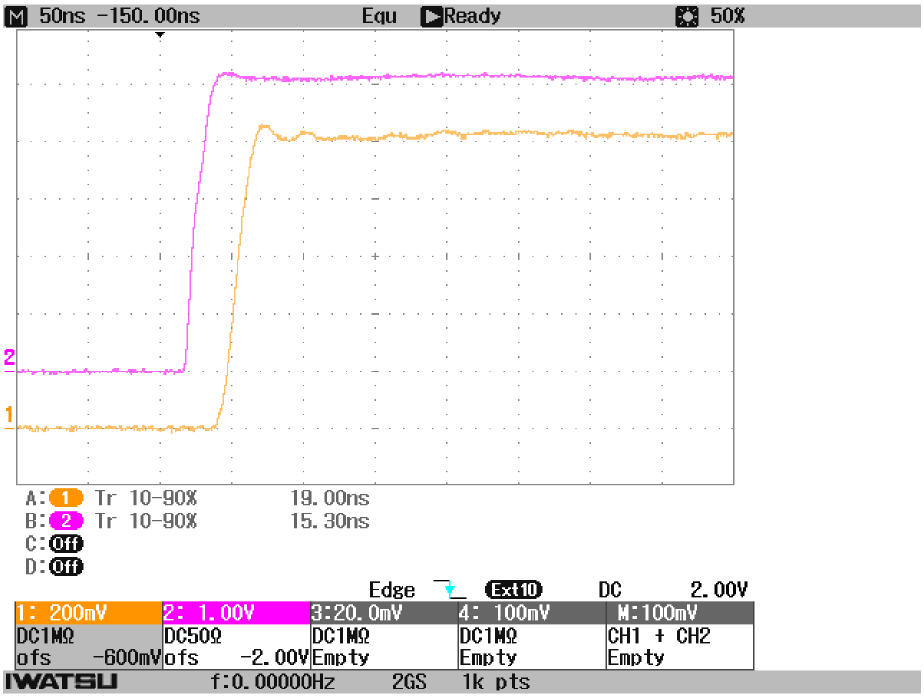
5.Waveform comparison with Current Transformer (CT)

The following shows waveform comparison of the probe and Current Transformer that is often used as a standard tool for the evaluation of high speed current waveforms.

Rogowski Coil Current Probe : SS-282A
Current Transformer : 2877 (manufactured by Pearson, Bandwidth: 200MHz)
Signal being measured : Custom Current Pulse Generator 10A, Tr=15ns

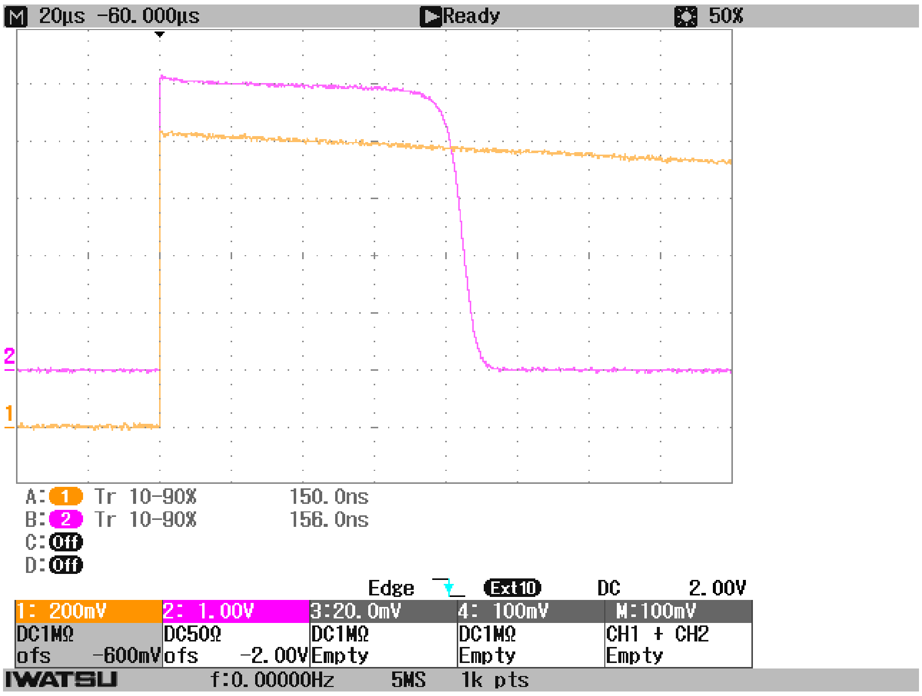
<Rising waveform>

CH1 : SS-282A, CH2 : Current transformer



<Whole waveform>

The following waveform measured by current transformer (CT) shows that CT cannot measure around 80μs because of magnetic saturation, however, SS-282A can measure with no problem. (Rogowski Probe never gets saturated in principle.)



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