SiC Power Device Series

Method for Monitoring Switching Waveform

To monitor a location where switching is performed by a power device element, for example, in a switching power supply or a motor drive circuit, an oscilloscope and a voltage probe are commonly used. The switching waveform is a rectangular wave, and contains high frequencies with high power in the case of power circuits. The correct waveform cannot be monitored unless the probe, which is the entrance of the waveforms, is appropriately used. This application note explains how to correctly monitor the switching waveforms.

Switching location

For example, even if a switching power supply circuit is created and produces a correct value of the output voltage, it is still necessary to confirm that the switching operation does not malfunction and the switching waveform does not exceed the rated voltage of the element. Since the switching waveform is a rectangular wave and contains high order harmonic components, the frequency may reach several GHz. In addition, since the power processed by power circuits is large, high voltage is generated with minimal influence from the parasitic elements (the inductance component, especially).

Figure 1. Monitoring of switching location with voltage probe; the ground side connected with the ground lead with attached alligator clip.

Waveform monitoring with voltage probe

Ideally, a differential probe should be used to monitor switching locations. However, since differential probes are expensive, a passive voltage probe is frequently used for low voltage circuits with a voltage of 300 V or less in general. The photograph in Figure 1 shows monitoring of a switching location with a voltage probe. The end of the probe is connected to the switching location, and the ground side is connected with the attached ground lead with alligator clip. Figure 2 shows the waveforms monitored. The top shows the switching waveform and the bottom shows the output waveform of the DC/DC converter. Ringing is observed when the switching signal changes abruptly.

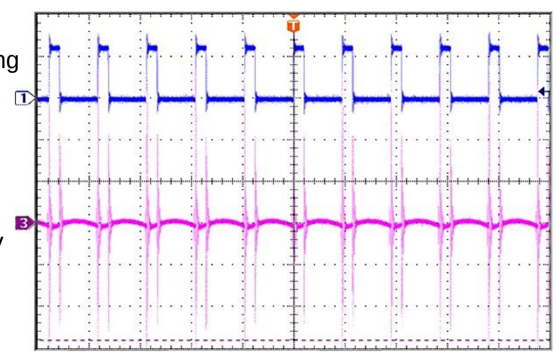

Figure 2. Waveforms monitored using the probe connected with the ground lead with alligator clip

Since the ground lead of the probe is added as inductance, this ringing is caused by a series resonance with the input capacitance of the probe. Therefore, the correct waveforms cannot be monitored with this method.

Figure 3 shows an example of an equivalent circuit to the probe. In addition, the resonance equation is expressed as Equation (1). When the ground lead is 160 mm in length and the inductance per 1 mm is estimated at 1 nH, the inductance is 160 nH. From Equation (1), the resonance frequency is approximately 200 MHz.

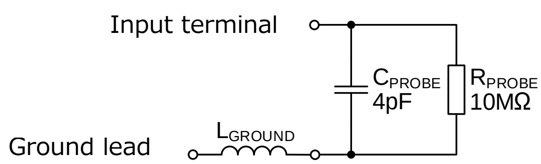

Figure 3. Example of an equivalent circuit to the probe

$$f_r = \frac{1}{2\pi\sqrt{L_{GROUND} \times C_{PROBE}}} \quad [Hz] \qquad (1)$$

To prevent the resonance and obtain the correct waveforms, the inductance added by the ground lead should be reduced. By shortening the ground lead and reducing the inductance, the resonance frequency can be increased beyond the frequency band of the measuring equipment.

Figures 4 and 5 show examples of a short ground lead. Figure 4 shows a type to be mounted on the PCB, and Figure 5 shows a type to be contacted with the PCB. Especially probe tip adapters have a ground lead of a few mm in length, reducing the inductance to a few nH. These accessories are sold together with voltage probes.

Figure 4. Probe tip adapter (Tektronix)

Figure 5. Ground spring (Tektronix)

The state where the switching location is monitored using the probe tip adapter is shown in Figure 6. The measurement result is shown in Figure 7. Compared with the above waveforms that are monitored using the probe connected with the ground lead with alligator clip (Figure 2), the ringing caused by the probe almost disappears and the obtained waveform is faithful to the original waveform.

The above method is effective if the operating voltage of the circuit is low. However, correct waveforms cannot be obtained if the operating voltage is high. In such cases, use a high voltage differential probe or an optically isolated differential probe.

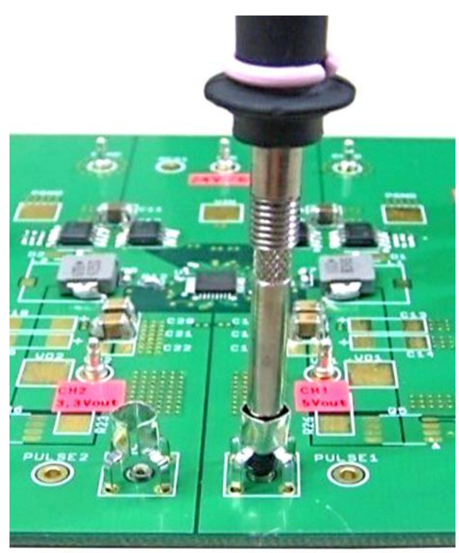

Figure 6. State where the switching location is monitored using the probe tip adapter

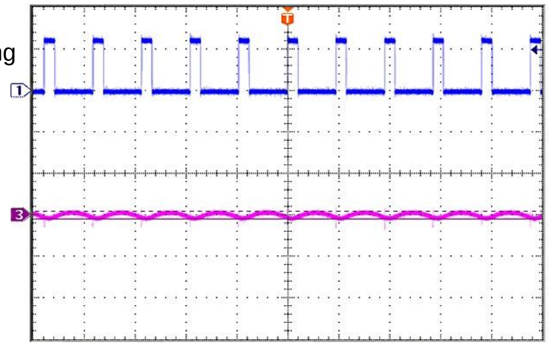

Figure 7. Waveforms monitored with the probe using the probe tip adapter

Figure 9. Creating the tip (end) support part of the adapter

Simplified probe tip adapter

As mentioned above, the probe tip adapters are highly effective. However, when they are not available at hand, a simplified device may be used as a substitute. The procedure to self-build the simplified device is described below.

1. Wind a leaded resistor or 0.5 mm tinned wire around the ground part of a probe to create the ground support part of the adapter (Figure 8).
2. Wind a leaded resistor or 0.5 mm tinned wire around the tip of a tweezer to create the tip (end) support part of the adapter (Figure 9).
3. Figure 10 shows the created adapter and the probe to be used.
4. Mount the adapter on the board with soldering before using (Figure 11).

Figure 10. Created simplified probe tip adapter

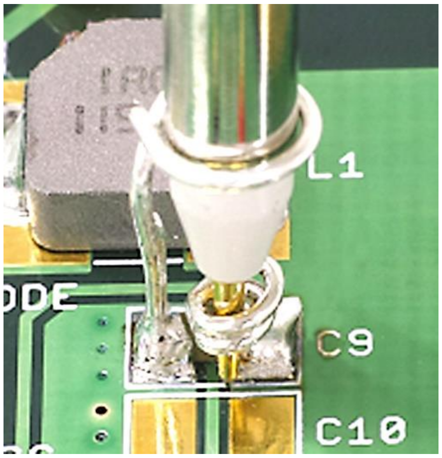

Figure 11. State where the adapter is mounted on the board

Figure 8. Creating the ground support part of the adapter

Influence of probe in simulations

There may be cases where the simulation results do not match the waveforms that are actually measured. One of the causes is difference in the measurement system. Since the measurement probe in simulations is an ideal probe, its input impedance is infinite. On the other hand, since the measuring equipment is connected to the monitoring point in actual measurements, various parasitic impedances are added. Since the ground lead of the probe mentioned above is one of such parasitic components, if a simulated waveform does not match the waveform that is actually measured, it is also necessary to add the equivalent circuit of the measuring equipment to the simulation circuit and perform verification.

Figure 12 shows a circuit diagram to simulate the switching by MOSFETs and Figure 13 shows the result. In this result, a waveform with almost no ringing is monitored.

Next, on the assumption that a probe is used for monitoring, Figure 14 shows a circuit diagram where the simulation is performed with the addition of the equivalent circuit in Figure 3. The result is shown in Figure 15. The ground lead is assumed to be 160 mm in length, having 160 nH of inductance. A large ringing occurs in the waveform, showing a major difference from the original waveform.

Although the above is one example, it can be seen that the equivalent circuit added by the measurement system affects the monitored waveform.

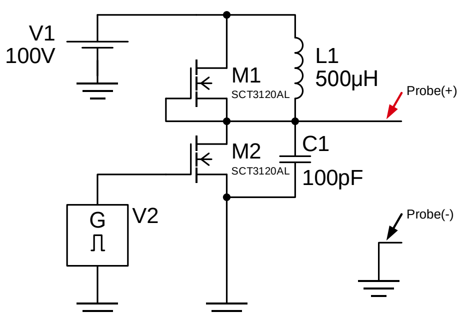

Figure 12. Circuit to simulate the switching by MOSFETs

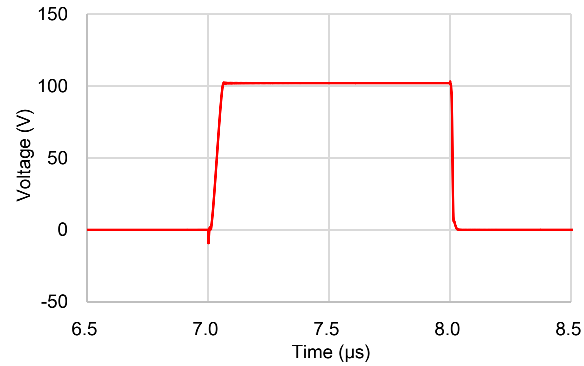

Figure 13. Waveform resulting from the simulation in Figure 11

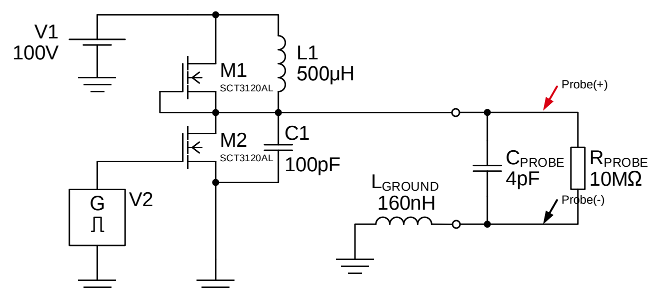

Figure 14. Simulation circuit with the addition of an equivalent circuit to the probe

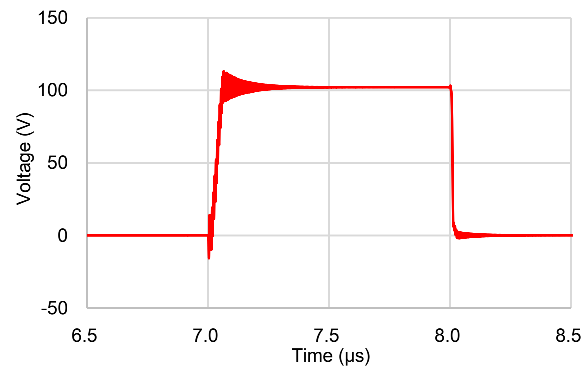

Figure 15. Waveform resulting from the simulation in Figure 13