Introduction

These course notes are to be read in association with the PI University video course, Techniques for Measuring Drain Voltage and Current. In this course, you will learn how to accurately measure MOSFET drain voltage and current on a Power Integrations device. The course covers the use of different types of current probes, the correct current measurement point and techniques for accurate voltage measurements.

Although the examples used apply specifically to flyback converters, the general principles outlined in this course are applicable to most topologies. In these course notes, a 12-watt Universal Input CV Adapter using a TinySwitch™-III device is used as an example. For further information, see Power Integrations’ Design Idea DI-91 and Reference Design Report RDR-91.

Equipment Required

To complete this course, you will need a functional power supply and a standard set of test equipment. The standard set of test equipment for working with power electronics should include a current probe. This is not typically considered a standard piece of lab equipment, so the expense may seem unnecessary or difficult to justify. However, measuring current waveforms in a power supply is critical for both fault finding and design verification. Therefore, the use of a current probe will save significant development time and greatly improve the quality of your design.

If a current probe is not available, you may be tempted to connect a resistor in series with the Source pin and monitor the voltage drop across it to derive the drain current. However, this procedure is not recommended because the resistor will modulate the controller ground and prevent the device from functioning properly.

The two most important considerations when purchasing a current probe are the required current rating and whether an AC or DC probe is needed. Select a current rating that is slightly larger than the peak currents you will need to measure in your design. For example, in the 12-watt design described in RDR-91, you would expect to see peak currents of about 4 amps on the secondary side. Thus, you can use a standard current probe rated for 50 amps peak to measure most current waveforms in this design. However, when measuring peak inrush current at startup, or when working with higher power designs, it may be necessary to select a higher rated probe to achieve accurate results.
Comparison of DC and AC Probes

DC current probes are active devices that use a Hall Effect sensor to measure both AC and DC currents. They require a matching probe amplifier which may be a stand-alone unit, but for newer scopes is often built in. AC current probes are simply current transformers and do not require a probe amplifier, but they cannot measure DC current levels.

DC current probes are better for power electronics work, because they can be used for a wider range of measurements. For instance, a DC current probe can be used to measure and characterize your load, or to measure inductor currents in other topologies such as buck converters. If the extra cost of a DC probe cannot be justified in your situation, then an AC current probe can be used for about 80% of the typical power supply measurements, including the drain current waveform. An AC probe is typically half the cost of a DC current probe and amplifier.

Setup for Drain Current Measurement

To measure drain current, you first need to insert a wire loop for the current probe to be placed in the circuit. The wire loop should be inserted in the circuit so that only the drain current flows through it. Make a break in the printed circuit board drain node trace between the Drain pin of the PI device and any components in the primary clamp circuit. Solder a small wire loop across the break you just made. To minimize noise coupling and leakage inductance, this loop should be just large enough to allow your current probe to clamp around it.
Making the break in the PCB trace

Current loop with DC probe in position

The current loop should always be removed before running EMI scans to prevent it from acting as a loop antenna, coupling high frequency noise which results in poor EMI.

**Oscilloscope Setup for Current Measurement**

Connect the current probe to the oscilloscope. If the bandwidth on the scope input is user selectable, set a range of 20 MHz or higher. The setup procedure for AC and DC current probes is slightly different, and will be addressed separately here.

**DC Probe Setup Procedure**

For a DC probe, check the required scope input impedance needed by the probe amplifier. Most probe amplifiers require a value of 50 Ω. If your scope does not have a 50 Ω setting, an impedance-matching adapter can be used. When the current probe interfaces directly with the scope, this is often handled automatically. Next, deghost the probe using the button or setting on the amplifier. Make sure your probe is disconnected from the circuit before deghosting, as this will prevent induced currents which may damage your circuit.

Now clamp the probe on the current loop, and latch it closed. To ensure correct orientation, make sure the arrow marked on the probe, which indicates the direction of current flow, is pointing towards the Drain pin. Set the scope gain to match the output of the probe amplifier and adjust the DC offset level on the probe amplifier to zero the current level on the scope.
AC Probe Setup Procedure

For an AC probe, verify that the input impedance of your scope matches that required by the probe. Most AC probes have a 1 MΩ input and do not require an impedance-matching adapter. Clamp the probe around the current loop and latch it closed. Make sure the arrow on the probe is pointed in the correct direction of current flow, towards the Drain pin. Set the scope gain to provide a clear and readable waveform. Look at the datasheet for the Power Integrations device in your design and determine its current limit. Then select a scope channel gain which will provide approximately five divisions of resolution between ground and peak drain current. After the supply is running, adjust the gain as needed to make measurements. When the supply is running, you will see that the output of the AC probe is an AC signal centered on ground.

By adjusting a few settings on the oscilloscope, you can make the AC probe signal look like the output from a DC probe. First, set the scope input to DC coupling. Then adjust the offset level on the scope until the current level when the MOSFET is off is seen at scope ground. Next, for both AC and DC probes, examine the current waveform you obtain when the supply is running. Adjust the gain of the probe amplifier and time base of the oscilloscope to obtain a clear, measurable waveform. For an AC probe, adjusting the gain will adjust the entire waveform and require you to re-center the ground by again adjusting the DC offset.

Note that the example design described in RDR-91 uses a TinySwitch-III device which employs on/off control. Rather than controlling the duty cycle to control power transfer, as with PWM products, on/off control devices skip entire cycles. This can appear as instability in the design, but is in fact normal operation for the product.

If the waveform you see is inverted, then the arrow on the current probe is pointed in the wrong direction. Switch the orientation of the current probe on the loop.

When the probe is connected and properly configured, the drain current waveform in a flyback design should fall to zero, unhindered, within approximately 100 ns.
If you see a waveform where the current fall is significantly longer than this, then check that the current loop is inserted at the right point. If the loop is placed between the transformer pin and the clamp components, the probe will also measure current that flows into the clamp network.

Note that a current probe will introduce a delay in the current waveforms you view. This delay is typically in the region of 10 to 15 ns for a probe with a 50 MHz bandwidth. The delay needs to be considered when measuring switching losses or making time-sensitive comparisons between the current waveform and other waveforms on the screen.

Now you are ready to measure drain current.

**Setup for Drain Voltage Measurement**

To measure switching voltages across the MOSFET, you will need a 100x voltage probe rated for at least 1000 V. The bandwidth of both the scope and probe used to view the drain voltage waveforms should be 100 MHz or greater.

Before connecting the probe to your circuit, you will need to make sure it is correctly compensated. First, connect the voltage probe to the scope. Hook the probe to the compensation terminal on the scope and adjust the scope voltage and time base settings so that the rising and falling edges of the test signal fill the screen. Now, using the non-metallic probe adjustment tool provided with the probe, adjust the compensation capacitor until any undershoot or overshoot on the waveform is minimized.
Adjusting the Compensation Capacitor to Minimize Overshoot or Undershoot

Adjusting the probe compensation is important because it ensures the most accurate voltage measurements. For example, in the figure on the right you see three measurements of the same drain voltage waveform with a probe that is under compensated, over compensated, and correctly compensated. On both of the improperly-compensated probes, the difference in the measured peak drain voltage from the correct peak drain voltage is more than 50 V and for the under-compensated probe, is more than 100 V.

Also, check the calibration of the oscilloscope itself by measuring a fixed DC voltage using both a calibrated digital multimeter and the scope. Because high-voltage probes are somewhat inaccurate when measuring low voltages, it is best to do this comparison with a high-voltage source. If a high-voltage source is not available, the easiest way to create a fixed, high-voltage DC level is to rectify high-voltage AC and filter it using a large value capacitor. In this example, a 265 VAC input is being rectified and then filtered using a 22 μF capacitor.

In our example, the multimeter reads a voltage of 374 V DC, while the scope reads 376 V DC. This gives a high level of confidence that the measurements will be accurate.
Remember to safely discharge the capacitor after completing this test. Next, connect the scope probe to the drain node and clip the ground to the Source pin. To reduce noise pick-up, wrap the ground wire around the probe to reduce its loop area before connecting it to the board.

Turn on the supply, and adjust the vertical gain and time base of the scope to allow the drain voltage waveform to be seen clearly. For the most stable measurements, trigger the scope on the falling edge of the voltage waveform. Finally, set the digitizing sample rate of the scope to the highest possible non-repetitive value. Also set the scope and input channel to the maximum bandwidth and turn off all additional filtering provided by the scope. These steps will ensure the highest possible accuracy.

A high scope bandwidth is especially important when measuring peak drain voltage to ensure accurate measurements. For example, here you see three peak voltage measurements made with a bandwidth of 20 MHz, 100 MHz, and 250 MHz. The difference in peak voltage between the 20 MHz and the 250 MHz measurement is more than 3V.
For critical measurements of drain voltage, for example where absolute value of peak voltages is important, best results are achieved by replacing the scope tip with a ripple probe. This minimizes the loop area of the probe ground and reduces noise pickup. Using a ripple probe will typically result in a lower peak measurement by 5 to 10 volts.

You are now ready to measure drain voltage.

For More Information
If you have any questions or comments about the information presented in this course, please email PIUniversity@powerint.com.