Chapter 2 – Using Power Device Analysis

Matching the Time Delay in Your Measurements System

Because the signals associated with power devices are relatively fast, it is important to determine whether the time delay for the current and voltage signal paths are the same. Signal delay characteristics of the voltage and current probes as well as the distance the signals must travel from the probe tips to the input of the DSO can cause time-coincident points on the voltage and current signals to be sampled by the DSO at different times. A small time difference can cause significant errors to occur in the measurements.

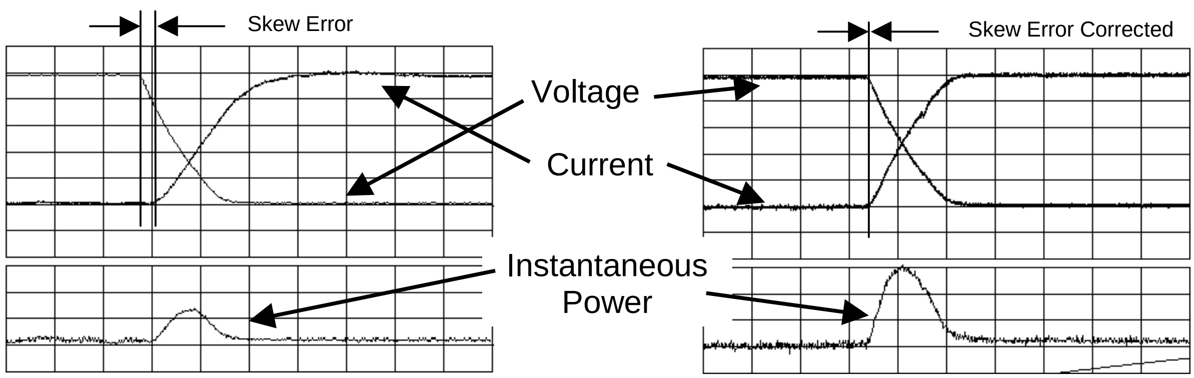


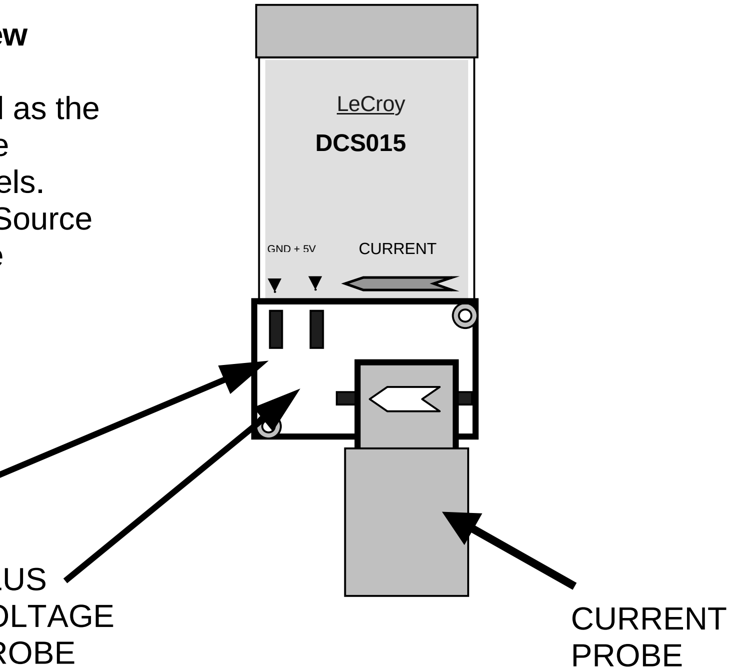
Figure 2.1: *Significant error occurs in an instantaneous power measurement when the current signal takes longer than the voltage signal to get to the DSO, because the current's signal path is longer. This error can be corrected by matching the delay of the voltage and current signal paths using the deskew function.*

It is advisable to use the deskew function to check and match, if necessary, the time delay of the current and voltage channels. This is very important if these signals are going to be used to make Instantaneous Power, Safe Operating Area, or Dynamic On-Resistance measurements.

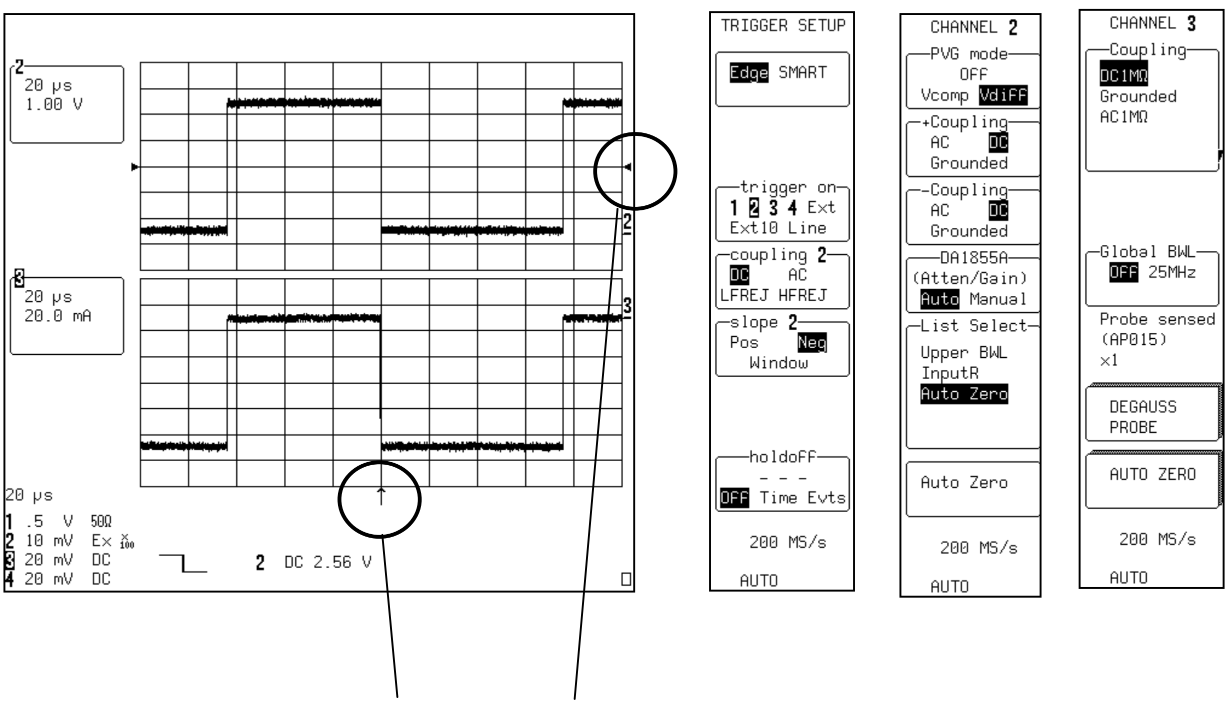
Checking Channel-to-Channel Time Skew

Select which DSO channels are to be used as the voltage and current inputs, and connect the voltage and current probes to those channels. Connect the DCS015 Deskew Calibration Source to the DSO's calibrator output or one of the unused channels.

Connect the voltage and current probes to the DCS015 as shown. Be sure to observe polarity on the current and voltage signals.



INITIAL SETUP



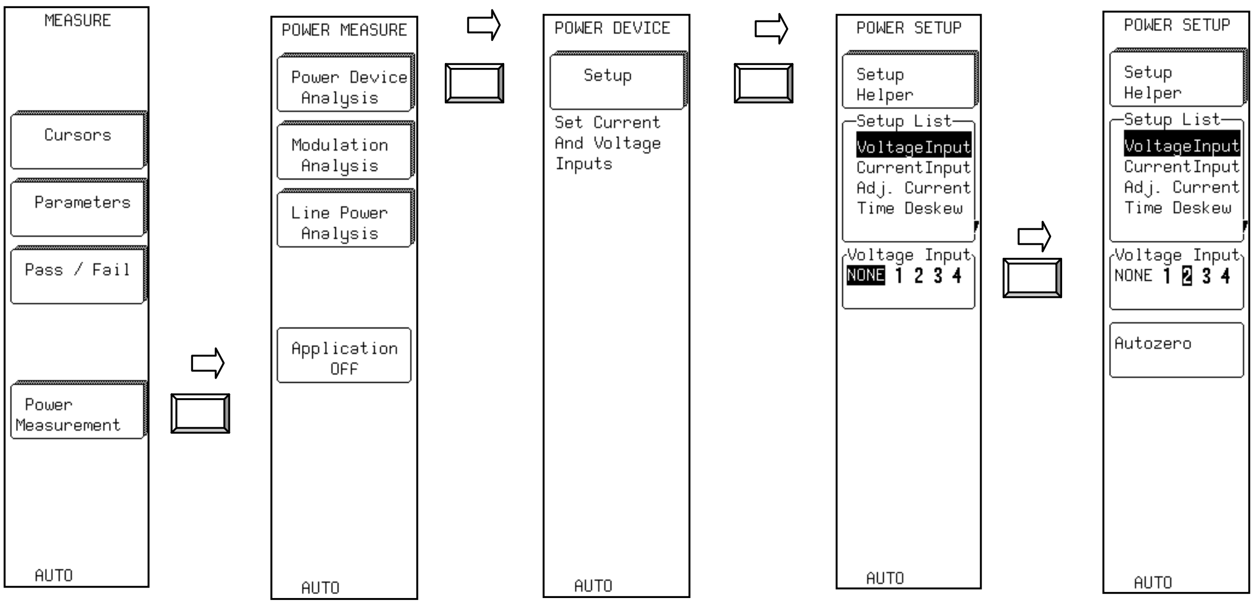
Set the time/div, trigger delay, trigger level, voltage, and current channel coupling to obtain the display as shown above. It is important to trigger on the negative slope of the voltage waveform. Position both traces around the center screen, and set the trigger level and delay as shown. **Note**: The choice of which channel to use for current and voltage is arbitrary. For consistency, all examples use Channel 2 for voltage and Channel 3 for current.

Deskew Setup (Voltage Channel)

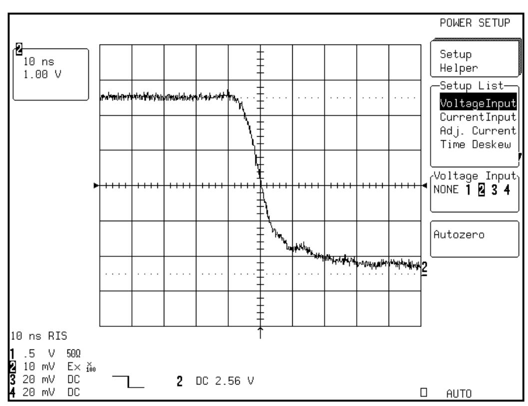
Once the DCS015's voltage and current waveforms are properly displayed, use the PMA1 software to match the time delay in the voltage and current channels.

Press the **MEASURE TOOLS** (LT Series) or **CURSORS/MEASURE** (LC Series) button on the DSO front panel to bring up the ***MEASURE*** menu, which includes the ***Power Measurement*** selection.

Follow the menu sequence given below:



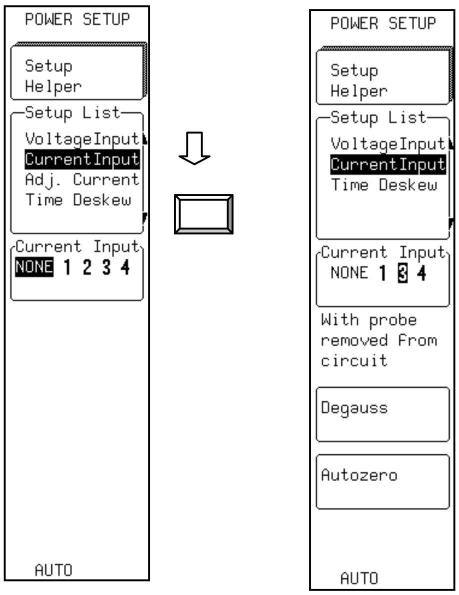
Change the horizontal time/division to 10 nsec/div.

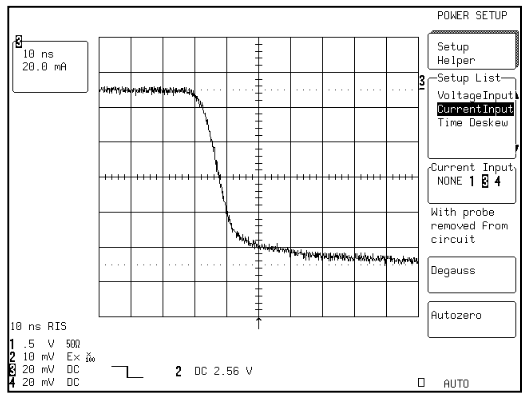


The display should appear similar to this.

Deskew Setup (Current Channel)

After the voltage channel is properly set up, follow the menu sequence given below to set up the current channel:



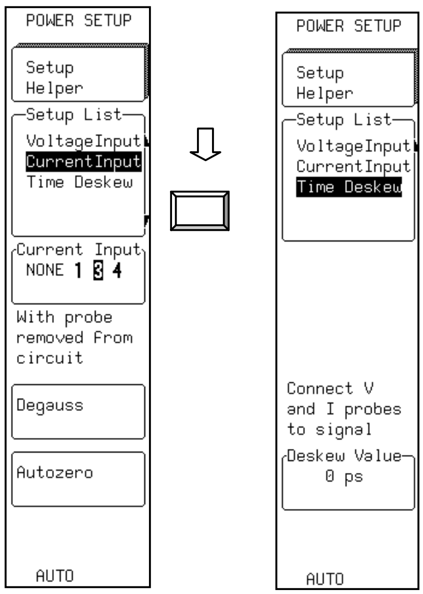


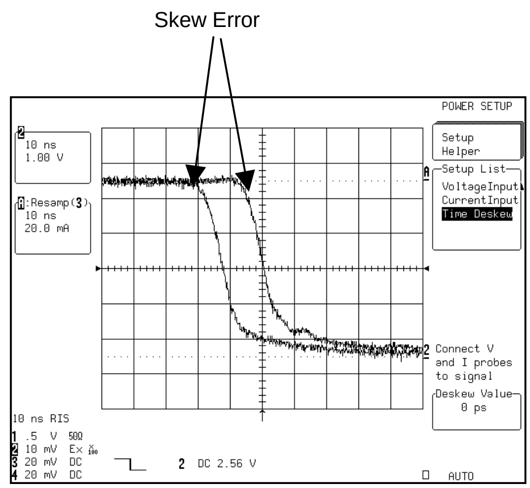
Display should appear similar to this.

The channel selected as the ***Current Input*** channel will be assigned Ampere units even if a voltage or nonProBus®-compatible current probe is used.

Channel-to-Channel Propagation Delay (Skew) Matching

After the voltage and current channels are properly set up, follow the menu sequence given below:



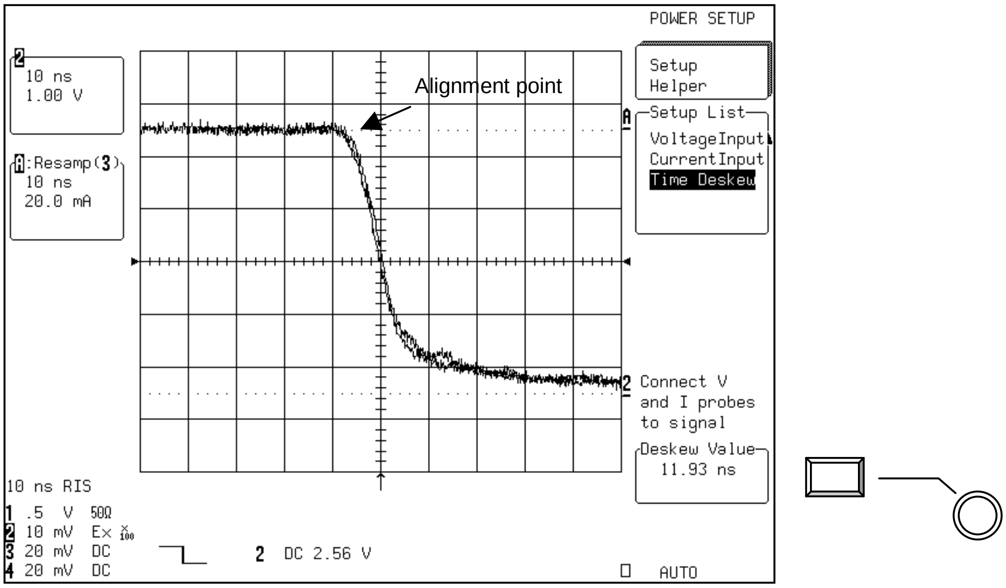


The display should appear similar to this.

The signal time skew will be shown as delay difference between the voltage and current waveform. The original current waveform is replace by a “resampled” math waveform that can be delayed up to ± 2 msec. In this example the delay difference (time skew) is a little more than one 10 nsec per division. The amount of delay will depend on which voltage and current probes are used, as well as the length of the probes and the coaxial cable used to connect the DA1855A to the DSO.

When the DA1855A Differential Amplifier (connected with a 1.2 m coaxial cable), DXC100A Differential Passive Probe Pair, and AP015 Current Probe are used, the time delay is matched and no deskew adjustment is needed.

Channel-to-Channel Propagation Delay (Skew) Matching - continued



Adjust the deskew value until the current waveform coincides with the voltage waveform. If the current waveform’s fall time is slower than that of the voltage, align the beginning of the wavefroms (alignment point).

Turn the until the alignment points on the current and voltage waveforms coincide.

Pressing the will return the ***Deskew Value*** to zero.

The time delays of these two channels are now matched, and they can be used to make accurate measurements that require precise time alignment of the current and voltage waveforms. This deskew value is only valid for this particular setup. Changing probes or bandwidth for either the current or voltage channel requires the channel’s time-delay difference be checked and possibly corrected.

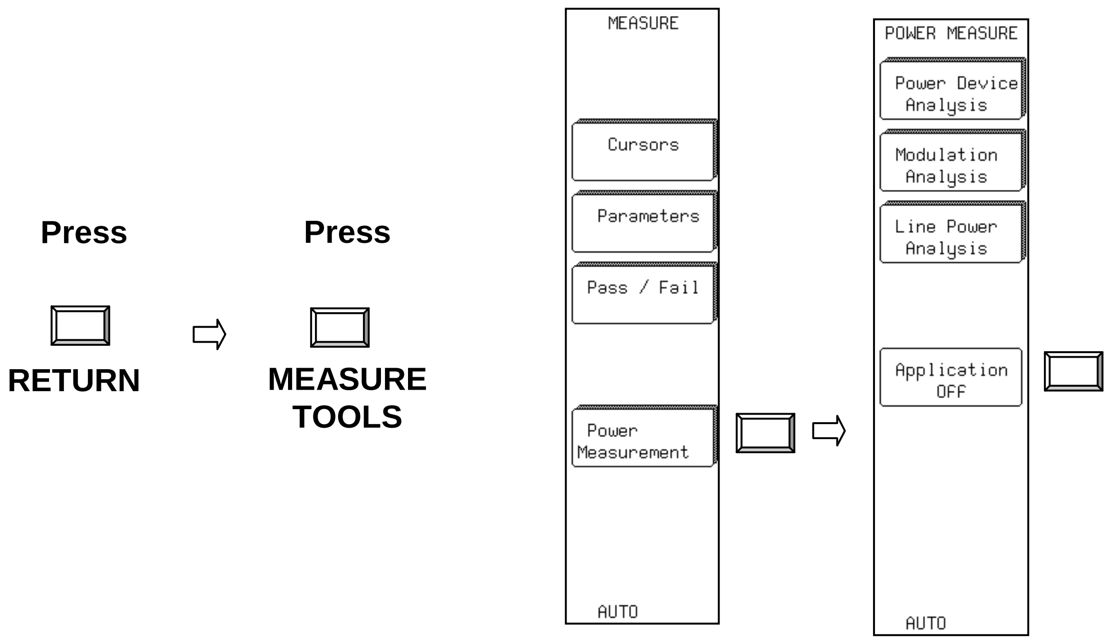
This process can be used to characterize and correct the delay difference between more than one current and one voltage channel. For instance, if the user plans to use one voltage channel and alternate measurements between two current channels, the relationship between the voltage channel and each of the current channels can be characterized. The amount of deskew required for each combination should be recorded for later use.

Proceed directly to the power device measurement section by pressing the **RETURN** **(**See page 2-8.) If the Power Measurement Application is not going to be used immediately, it should be turned off by following the instructions on the next page.

Clearing the Deskew Setup

If no immediate use of the PMA1 software is planned, the channel assignments and other alterations made during the deskew process should be cleared.

Press the **RETURN** until the on-screen menu is cleared. Then press the **MEASURE/TOOLS** to bring up the ***MEASURE*** menu.



Selecting ***Application OFF*** in the Power Measure menu changes the ***Voltage Input*** and ***Current Input*** assignments to ***NONE***. The ***Deskew Value*** remains unchanged. The assignment of Ampere units to the channel selected as the ***Current Input*** channel will be removed.

The Power Device Analysis portion of PMA1 lets the user make difficult device measurements on the devices while they operate in circuit. The exact setup for each measurement will differ depending on what device type is to be analyzed and where it is located in the circuit. It will make the setup easier if the measurements are planned and set up in advance. If possible, obtain representative waveforms of the voltage, current, and trigger inputs before evoking PMA1 software.

The following diagram shows a typical setup used to analyze the power FET in an off-line switching power supply. A differential amplifier is used to acquire the voltage across the device, and a current probe is used to acquire the current through it.

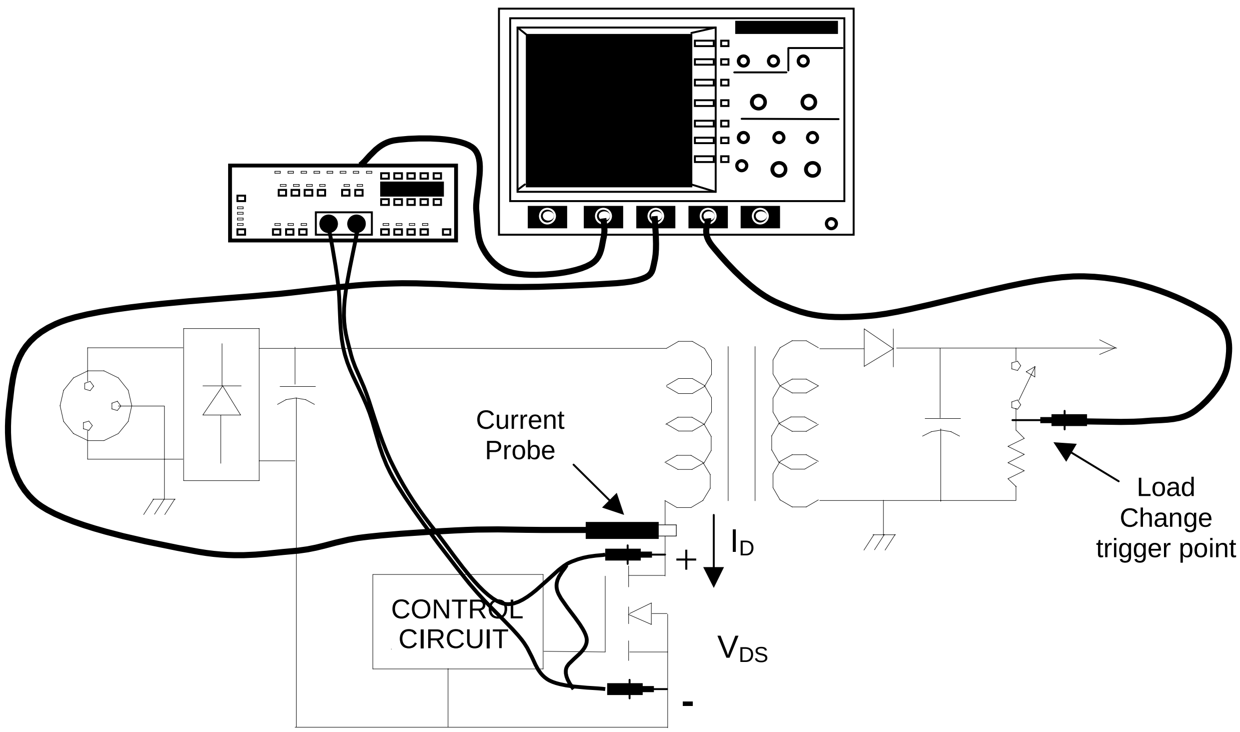


Figure 2.2: *Typical connections to a circuit under test required to make instantaneous power, safe operating area, saturation voltage, and dynamic on-resistance measurements.*

The circuit shown is an off-line flyback power supply. Examples in this section are based on similar connections to a circuit of this type. Measurements also can be made on devices such as power transistors, snubber diodes, or similar devices in other topologies.

Configure for Device Measurements

Plan the measurement in advance and do a preliminary setup before evoking the PMA1 Power Measurement menus. This will minimize the number of times it is necessary to leave the menu structure.

Select which DSO channels are to be used as voltage and current inputs. Follow the procedure contained in the ***Matching the Time Delay in Your Measurement System*** section to correct any delay difference between the current and voltage.

Connect the voltage and current probes to the appropriate points in the circuit under test. Figure 2.2 can be used as a guide. If measurements are to be made on the device as a function of an event such as load change or start up, select a signal to be used as a trigger for this event. The example in Figure 2.2 uses the DSO's Channel 4 to acquire a trigger signal indicating when the load changes from maximum to minimum. The DSO's **EXT** trigger input also could be used.

Preliminary Trigger Setup

Before entering the Power Measurement software menu, it is important to determine the source and setup of the triggers. Identify the signal on which the main measurement will be triggered, as well as the signal on which the acquisition of an extended measurement record is to be triggered. The main trigger can be the device's voltage or current signal while the event trigger is usually associated with load change or turn-on and turn-off. Establish the event trigger first (if required), then set up the main trigger. Choose the desired trigger signal and establish a stable display.

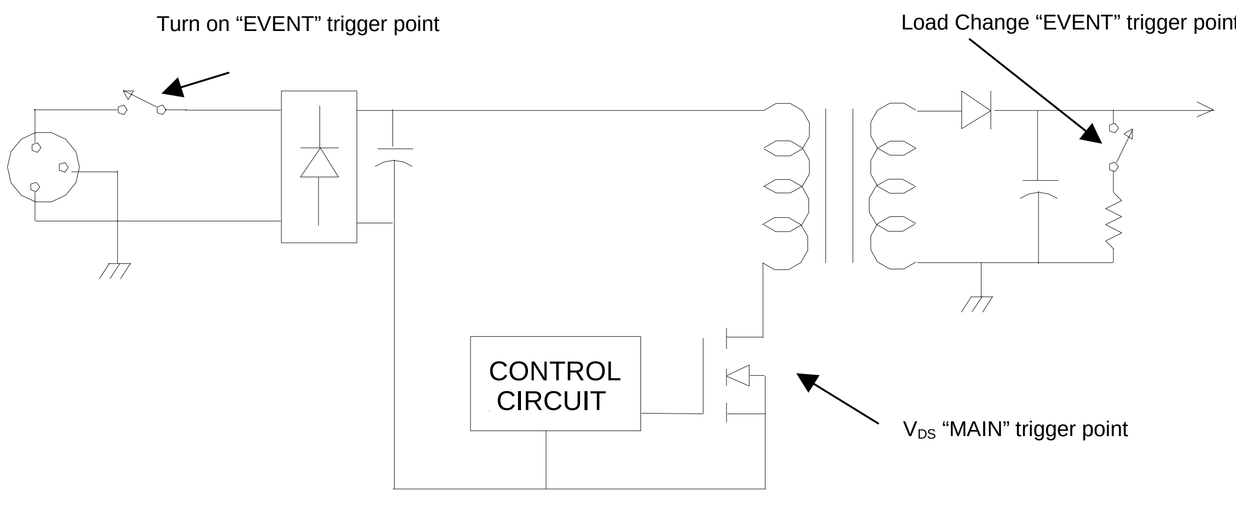
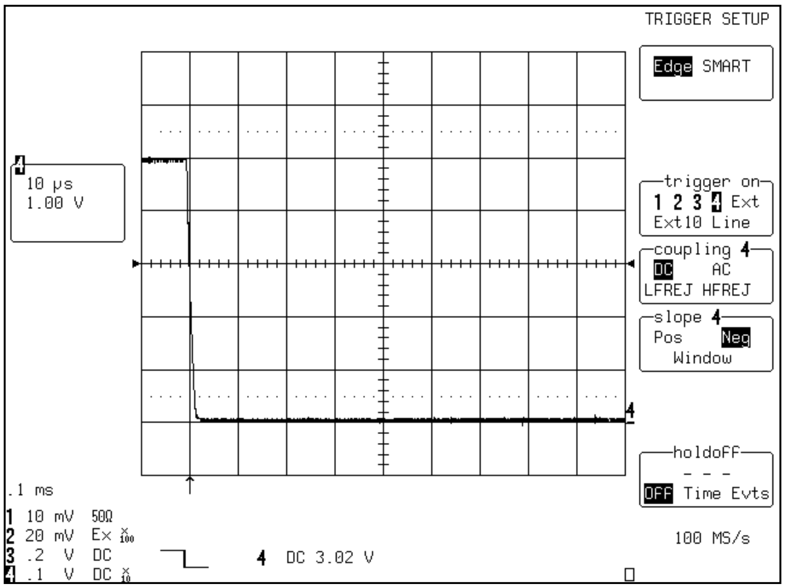


Figure 2.3: *Typical connections to circuit under test for MAIN and EVENT triggers.*

INITIAL SETUP (Optional Event Trigger)

Determine the event around which a change in the operation requires recording an extended record of information. Examples of such an event include the change from maximum to minimum load, and start up. Presetting the trigger of such an event will make the final power measurement setup easier.

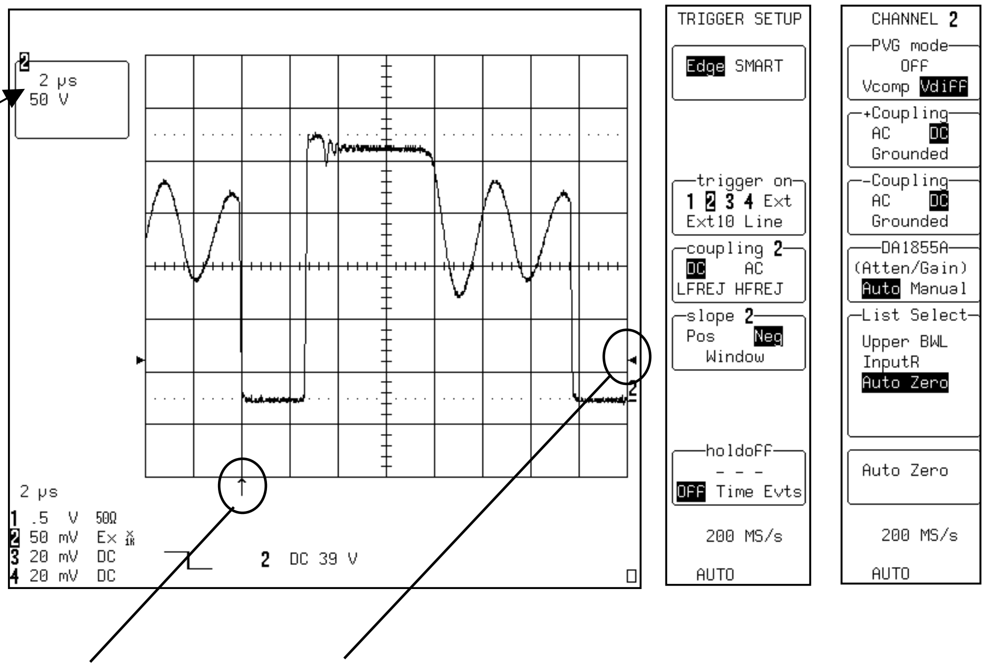


In this example, Channel 4 is used to acquire a signal that indicates the power supply's load changes from maximum to minimum. Set up the trigger so the acquisition of a record can be initiated from this event. The Load Change "EVENT" trigger shown in Figure 2.3 was used in this example. The event you want to trigger on may be different.

INITIAL SETUP (Main trigger)

The following example uses the power transistor’s drain-to-source voltage as a trigger source. This is the same signal that will be used to measure the device’s instantaneous power loss or safe operating area performance.

V/div and time/div settings will depend on the particular circuit under test.



Set the time/div, trigger delay, trigger level, and voltage channel coupling to obtain a display similar to that shown above. It is usually desirable to trigger on the negative slope of the voltage waveform.

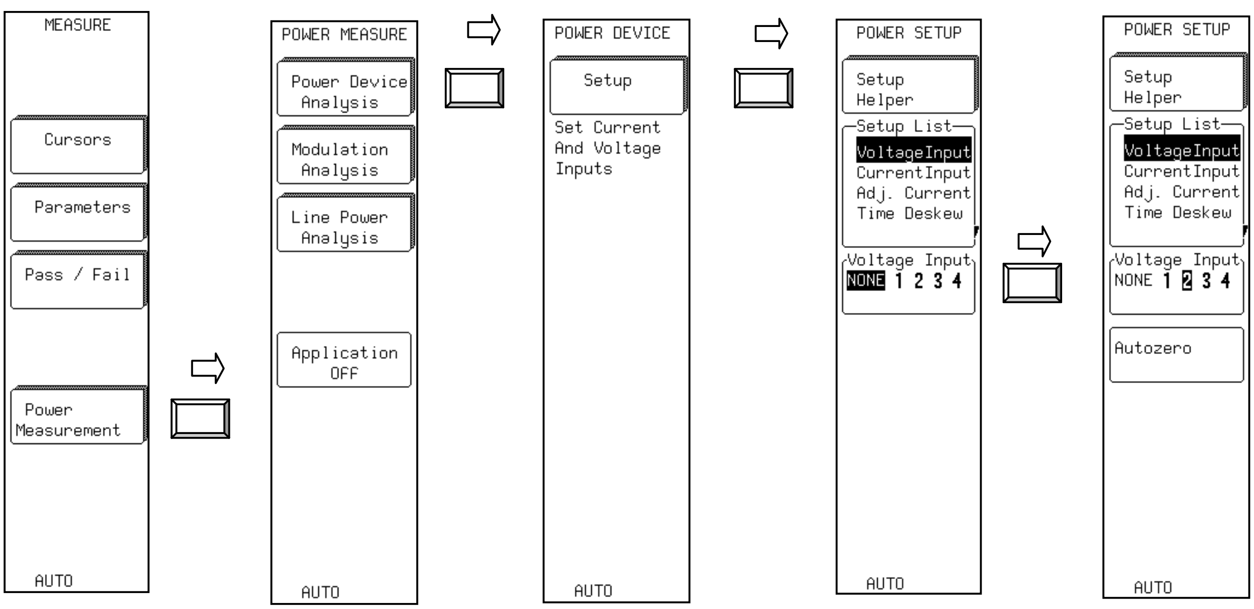
Setup for Power Device Analysis

After the measurement is planned, the voltage and current channels are identified and deskewed, and preliminary triggering is established, use the PMA1 software to finish the setup and make the measurements.

Power Device Analysis Setup

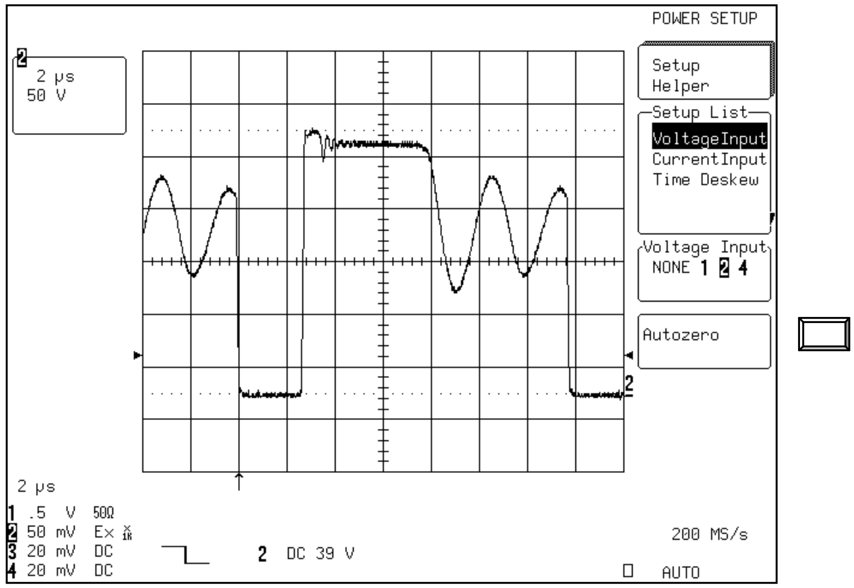
Press the **MEASURE TOOLS** (LT Series) or **CURSORS/MEASURE** (LC Series) button on the DSO front panel to bring up the ***MEASURE*** menu, which includes the ***Power Measurement*** selection.

Follow the menu sequence given below:



Power Device Analysis Setup - continued

In the ***Setup List*** menu, select the channel that is connected to the voltage measurement point. In the example, it is Channel 2. Adjust the volts/div and time/div to obtain a stable display of at least one cycle of the voltage signal across the device.



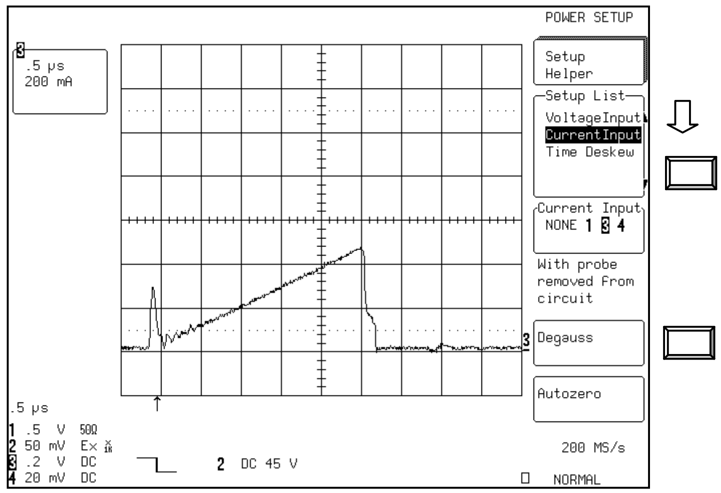
The display should appear similar to this.

It is important to set the V/div to allow the largest expected voltage excursion to remain on screen during the all conditions of the test. If the voltage signal goes off screen during the test, erroneous results will be obtained.

It is good practice to balance the DC offset of the voltage probe at this step. Press the ***Autozero*** to autobalance the DA1855A amplifier.

Power Device Analysis Setup - continued

In the ***Setup List*** menu, select ***Current Input***. Select the channel that is connected to the current measurement point. In the example, it is Channel 3. Adjust the A/div and time/div to obtain a stable display of at least one cycle of the current signal through the device.



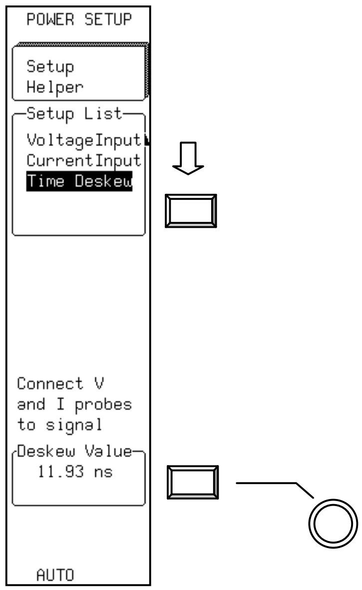
The display should appear similar to this.

The channel selected as the ***Current Input*** channel will be assigned Ampere units even if a voltage or nonProBus-compatible current probe is used.

It is important to set the A/div to allow the largest expected current excursion to remain on screen during the all conditions of the test. If the current signal goes off screen during the test, erroneous results will be obtained.

It is good practice to degauss the current probe at this step. Remove the current probe from the circuit under test, close the probe and press the ***Degauss*** . Return the current probe to the circuit under test.

Power Device Analysis Setup (Deskew Value Check)



After the voltage and current channels are assigned, the value of time delay correction required between the two can be checked by selecting ***Time Deskew*** from the ***Setup List*** menu. If the deskew value was set using the process on page 2-5, that value will be displayed in the ***Deskew Value*** menu readout.

The deskew value can be changed in this menu by turning the . Pressing the will return the value to zero.

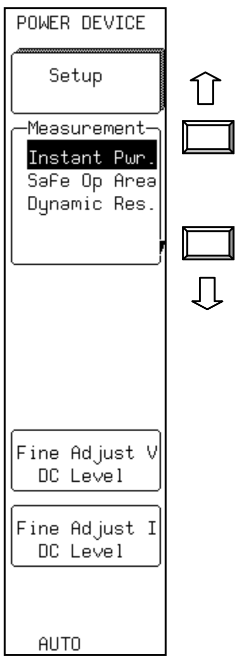
NOTE: The deskew value should not be changed in this menu unless the correct value is known. Voltage and current signals that occur in the circuit under test may not be properly phase-related, and using them for deskew purposes can cause major errors to occur in the measurements. Time-coincident voltage and current signals such as those provide by the **DCS015** Deskew Calibration Source should be used.

Power Device Analysis Measurements

Note: The previous sections should be completed before making these measurements.

After the channel-to-channel propagation delay is matched and the previous measurement setup is completed, measurements on the device under test can proceed.

Press the **RETURN** to bring up the following menu:



Select ***Instant Pwr*** to measure the instantaneous power loss in the power FET.

Select ***Safe Op Area*** to measure the power FET's Safe Operating Area.

Select ***Dynamic Res.*** to measure the power FET's saturation voltage and its dynamic on-resistance.

The ***Fine Adjust V DC Level*** and ***Fine Adjust I DC Level*** knobs corrects small DC offset errors in the voltage and current probes without removing the voltage or current probe from the circuit. Pressing either returns the respective offset to zero.

NOTE: The ***Measurement*** menu selections ***Instantaneous Pwr***, ***Safe Op Area***, and ***Dynamic Res.*** will not be available unless both voltage and current channels were assigned in the ***Setup*** menu. Press the ***Setup*** in the Power Device menu to return to the ***Setup*** menu to assign the voltage and current channels or to change them.

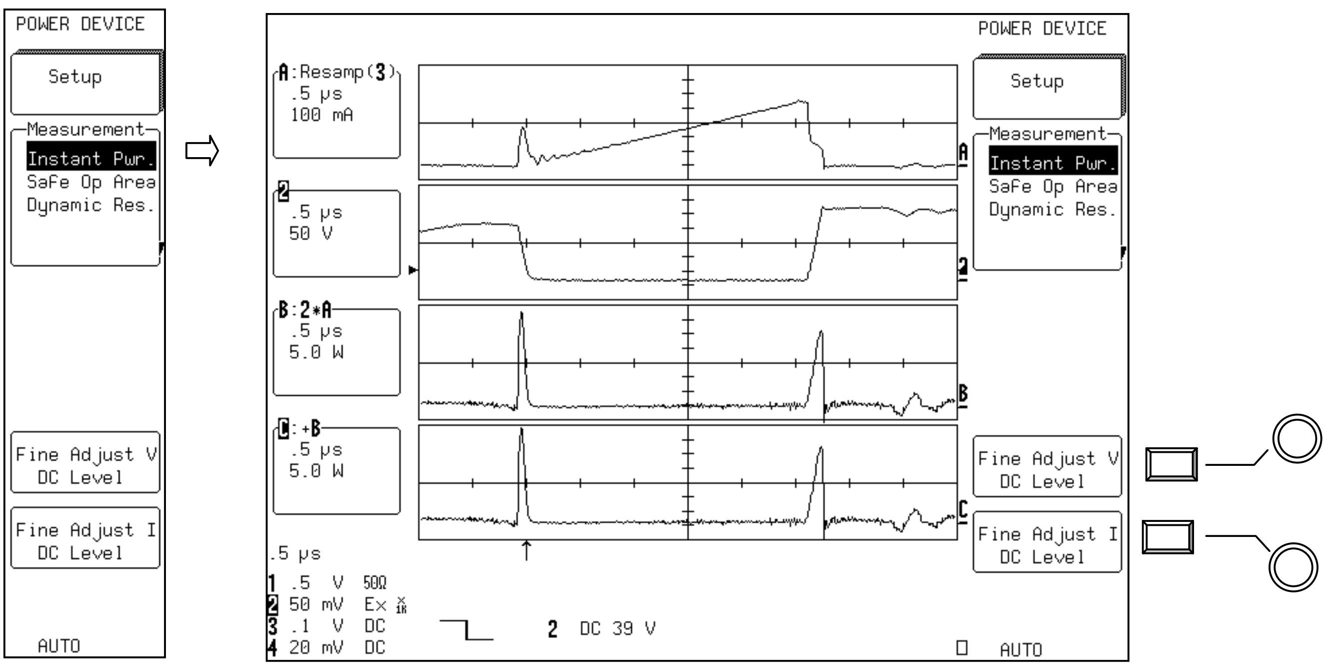
Instantaneous Power Measurement – Steady State

Note: The previous sections should be completed before making these measurements.

Selecting ***Instant Pwr.*** in the ***Measurement*** menu brings up the following display. The deskewed current waveform (**A**) is displayed in the first grid, and the voltage waveform (**2**) is displayed in the second.

The instantaneous power waveform (**B**) is displayed in the third grid. Use the DSO's **ZOOM + MATH** position and zoom controls to obtain the desired display.

The fourth grid (**C**) displays a copy of the instantaneous power waveform (**B**) and is used to expand the waveform B so individual cycles of a multiple cycle record can be viewed.



Fine Adjust V DC Level and ***Fine Adjust I DC Level*** are provided to allow the user to compensate for any residual DC offset that the voltage and current probes may exhibit. Because the magnitude of residual DC offset error is usually unknown, use of these adjustments requires user knowledge of the waveforms.

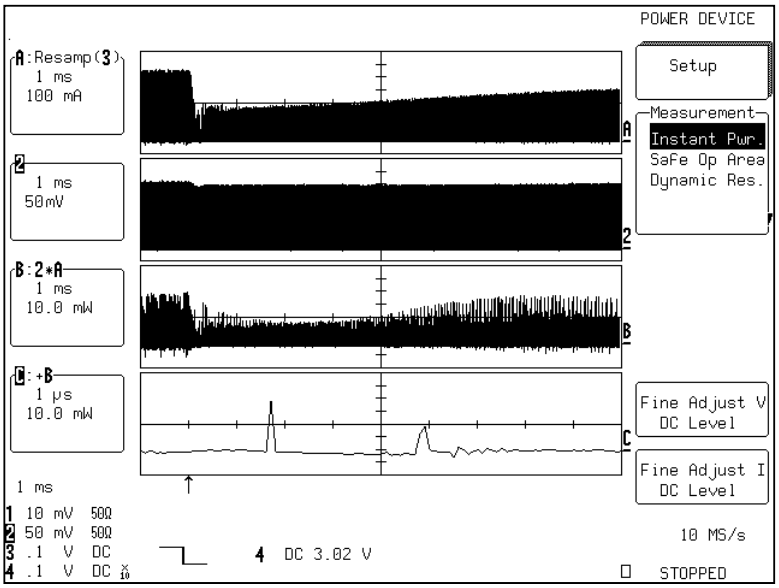
Turn the to adjust the DC Offset Level to the desired level. Pressing the will return the offset to zero.

For a detailed explanation on how to adjust the DC Offset Level, see page 2-22.

Instantaneous Power Measurement – Event Triggered

Note: The previous sections should be completed before making these measurements.

To analyze the instantaneous power of the power device during transitions such as turn-on and load change, trigger the acquisition on an "EVENT" trigger.

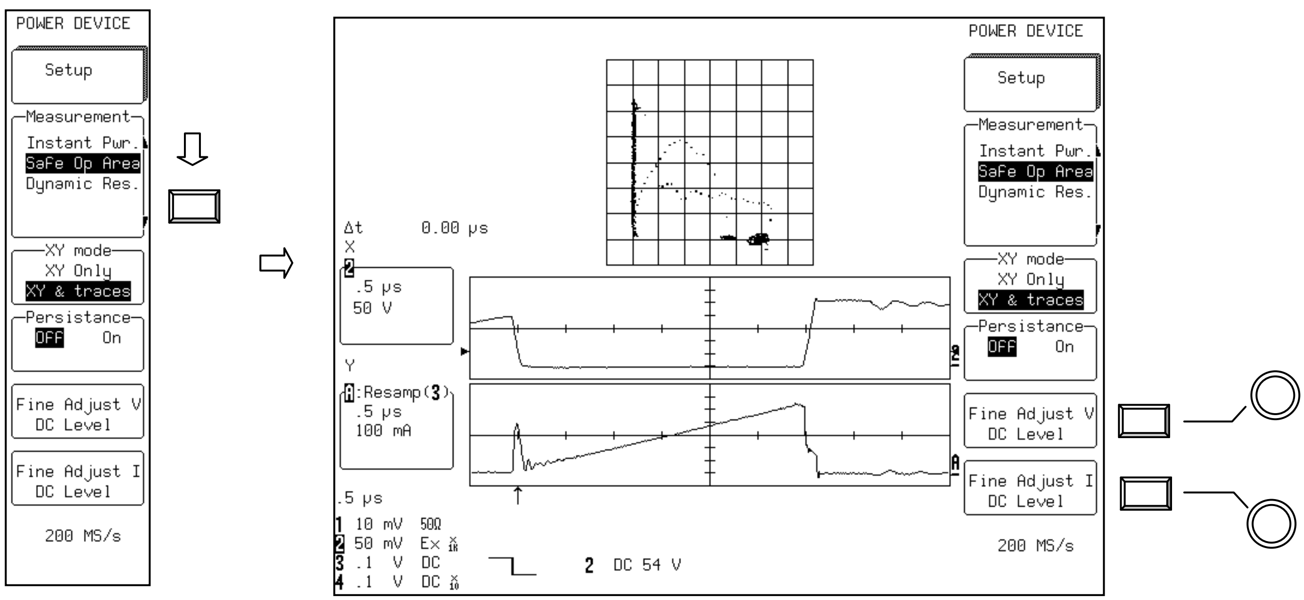


The above is a 10 msec window of a power FET's drain-source voltage, drain current (deskewed), and instantaneous power dissipation that occurs during the circuit's transition from maximum to minimum load. The ZOOM of the instantaneous power waveform (**B**) is used to examine the instantaneous power dissipation during one cycle in trace (**C**). In this case, the acquisition of the 10 msec record was triggered by the "EVENT" trigger previously set up on Channel 4.

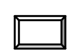
Safe Operating Area Measurement – Steady State

Note: The previous sections should be completed before making these measurements.

Selecting ***Safe Op Area*** in the ***Measurement*** menu brings up the following display. The voltage waveform (**2**) is displayed in the first grid and the deskewed current waveform (**A**) is displayed in the second grid. In the XY plot, voltage points are plotted on the horizontal axis, while current is plotted on the vertical. The delay difference between the voltage and current samples have been removed by the deskew function.



Fine Adjust V DC Level and ***Fine Adjust I DC Level*** are provided to allow the user to compensate for any residual DC offset that the voltage and current probes may exhibit. Because the magnitude of residual DC offset error is usually unknown, use of these adjustments requires user knowledge of the waveforms.

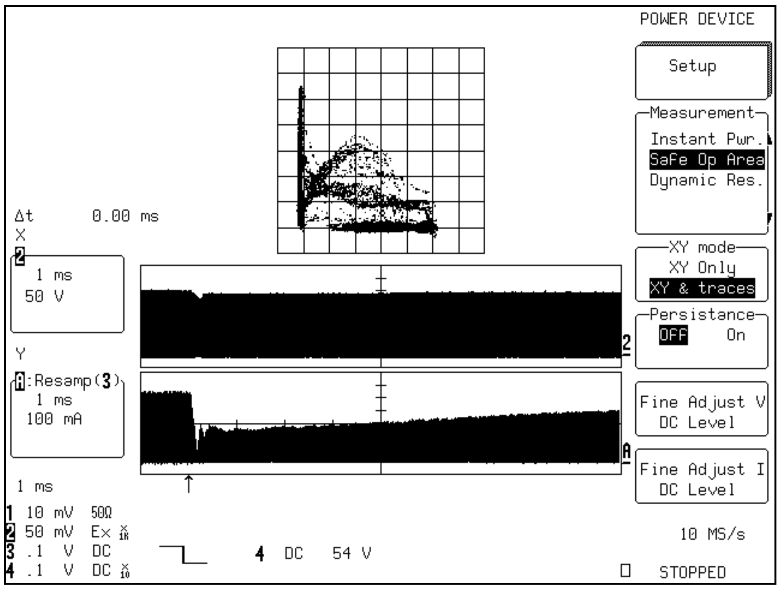
Turn the  to adjust the DC Offset Level to the desired level. Pressing the  will return the offset to zero.

For a detailed explanation on how to adjust the DC Offset Level, see page 2-22.

Safe Operating Area Measurement – Event Triggered

Note: The previous sections should be completed before making these measurements.

To analyze the safe operating area performance of the power device during a transition such as turn on or load transition, trigger the acquisition on an "EVENT" trigger.



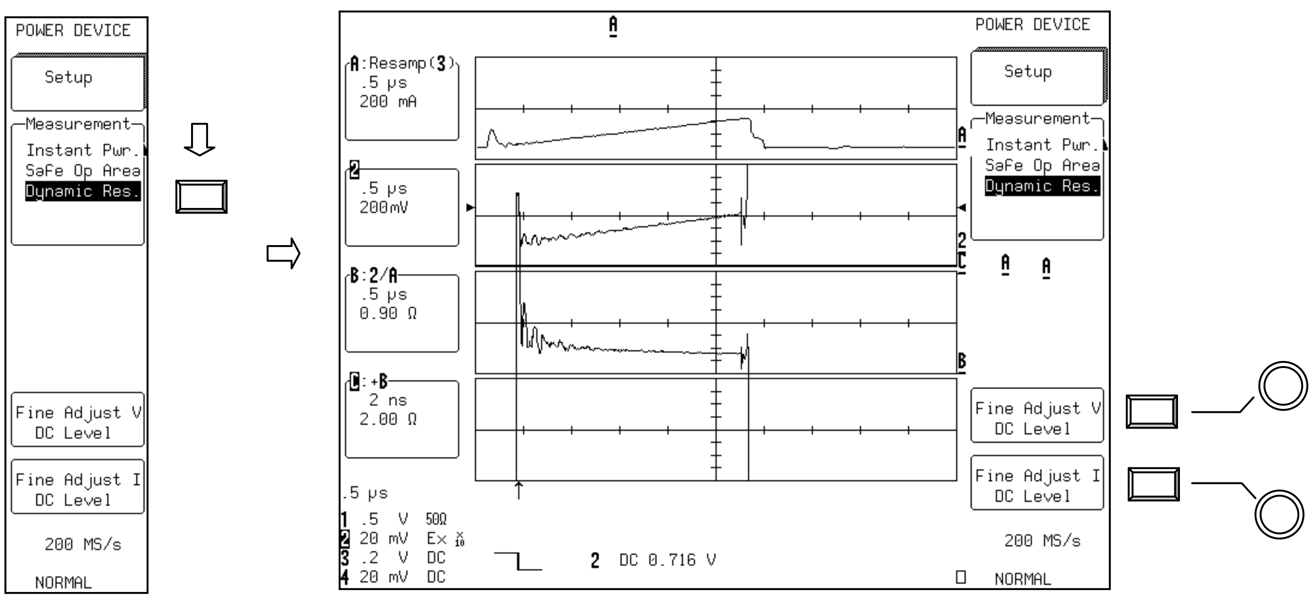
The above is a 10 msec window of a Power FET's drain-source voltage, drain current (deskewed), and safe operating area measurement that occurs during the circuits transition from maximum to minimum load. In this case, the acquisition of the 10 msec record was triggered by the "EVENT" trigger previously set up on Channel 4.

Saturation Voltage and Dynamic On-resistance Measurement

Note: The previous sections should be completed before making these measurements.

Selecting ***Dynamic Res.*** in the ***Measurement*** menu brings up the following display. The deskewed current waveform (**A**) is displayed in the first grid and the voltage waveform (**2**) is displayed in the second grid. The delay difference between the voltage and current samples have been removed by the deskew function. By changing the DSO’s V/div setting and adjusting the trigger level, the voltage waveform displayed is the device saturation voltage. [**Note**: A DA1855(A) differential amplifier and DXC100A is required to make this measurement.] The voltage waveform is divided by the deskewed current waveform, and the resulting resistance waveform is displayed in the third grid (**B**). Trace (**C**) is a ZOOM of the resistance trace (**B**) to be used to examine detail.

Because the device saturation voltage waveform (**B**) is off screen during the non-saturation portion of the waveform, the math-generated resistance waveform should be ignored during this time.



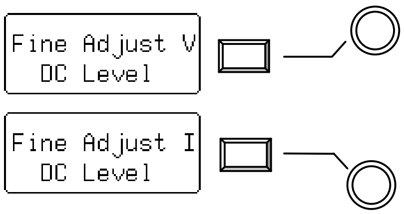
Fine Adjust V DC Level and ***Fine Adjust I DC Level*** are provided to allow the user to compensate for any residual DC offset that the voltage and current probes may exhibit. Because the magnitude of residual DC offset error is usually unknown, use of these adjustments requires user knowledge of the waveforms.

Turn the to adjust the DC Offset Level to the desired level. Pressing the will return the offset to zero.

For a detailed explanation on how to adjust the DC Offset Level, see page 2-22.

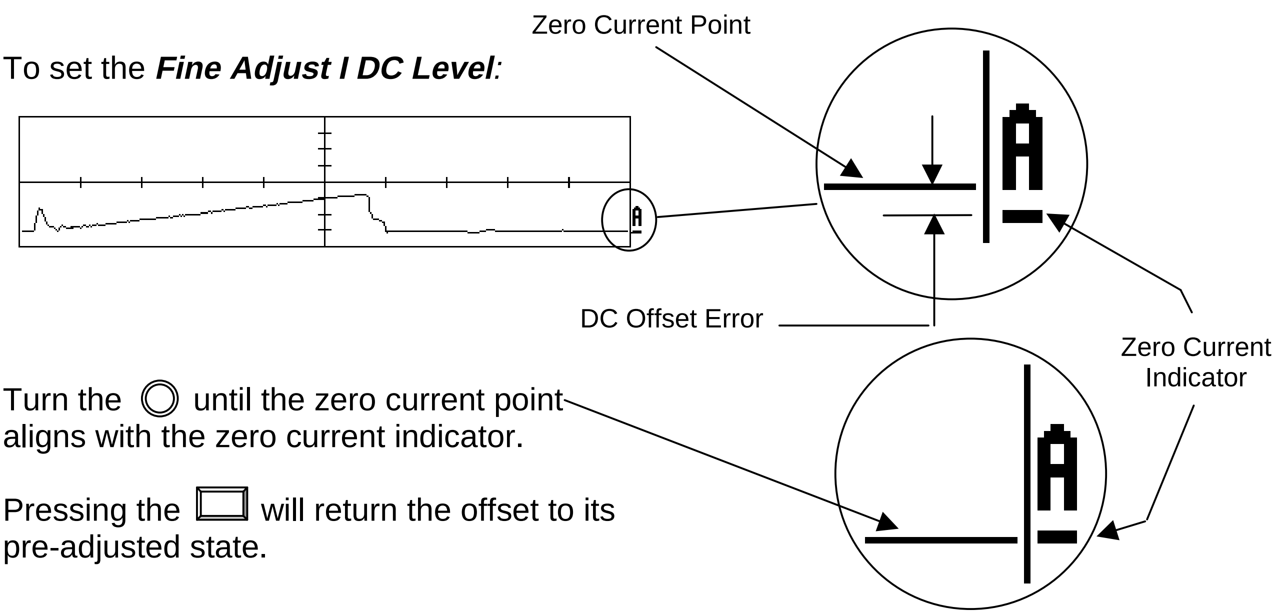
Fine DC Level Adjustment

Measurement errors caused by channel-to-channel time-delay differences can be corrected using PMA1's deskew capability. Another major cause of errors is DC offset in the measurement equipment. Minor DC offset errors in the current or voltage channel can cause major errors in power calculations. Because it is not possible to design amplifiers and current probes with zero DC offset, PMA1 provides fine DC offset adjustments to correct these errors in both the current and voltage channels.



To use these adjustments it is necessary to know where zero is on a current or voltage waveform. The following illustrates how to compensate for residual DC offset in a current probe when the zero current point on the waveform is known.

To set the ***Fine Adjust I DC Level***:



Turn the knob until the zero current point aligns with the zero current indicator.

Pressing the button will return the offset to its pre-adjusted state.

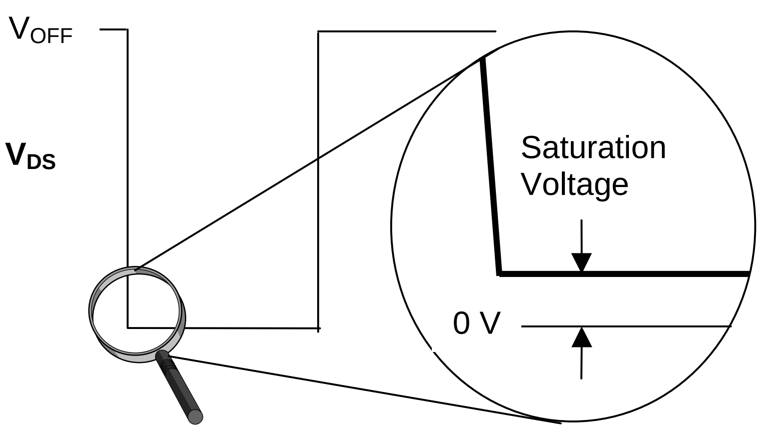
Adjustment of the ***Fine Adjust DC V Level*** operates in the same fashion. Placing the voltage plus and minus differential probes on the same point in the circuit will provide a zero voltage reference point for the adjustment.

NOTE: These adjustments remain in effect until ***Application Off*** is pushed (see page 2-25). Failure to turn this function off after using PMA1 can cause errors in subsequent measurements.

Effects of Probe Compensation on Saturation Voltage Measurements

To measure a switching device's saturation voltage while the device is operating in circuit requires the combination of several capabilities in the measurement system. First, because the measurements are not ground referenced, differential voltage measurement is needed. The amplifier also must be able to quickly recover from overdrive, and the amplifier as well as the probes must have low high-frequency aberrations.

An example:



To measure the saturation voltage of a device to 100 mV accuracy when the off voltage is 400 V requires 250 ppm meaurement capability.

It is obvious that the DSO input or an input preamplifier such as the DA1855A needs to recover and settle to a value greater than 250 ppm before the measurement can be made. The DA1855A is designed with this capability.

From this example, the probe's high-frequency performance required for this measurement is clear.

Less obvious is how the probe's LF compensation adjustment can have a large effect on the accuracy of device saturation voltage measurement. Most DSO users are familiar with the requirement of adjusting passive probes for low-frequency compensation. Under normal usage, the entire waveform is on-screen when a passive voltage probe's low-frequency compensation is adjusted. A low-frequency compensation adjustment made with the entire waveform on-screen is usually adequate for most measurements

However, when a signal's amplitude is greatly magnified as it is during a saturation voltage measurement, a small error in the LF compensation flatness can cause a major error in the saturation voltage measurement. The following figures illustrate how this seemingly minor adjustment can make the saturation voltage's DC level appear to be incorrect.

Effects of Probe Compensation on Saturation Voltage Measurements - continued

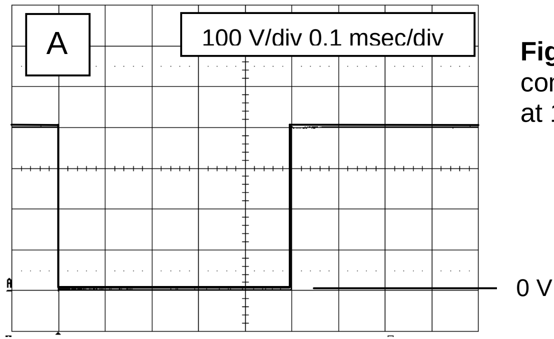


Figure A: A voltage probe appears to be properly compensated on a 400 V squarewave when viewed at 100 V/div.

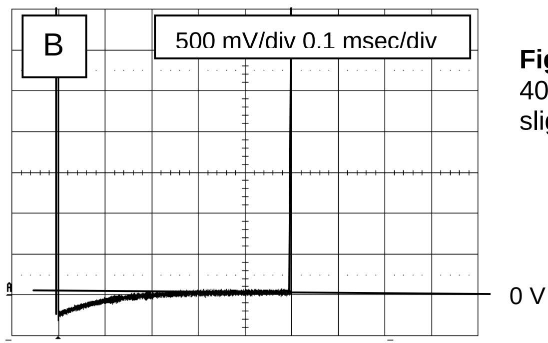


Figure B: When viewed at 500 mV/div, the same 400 V squarewave shows the probe compenstion is slightly peaked.

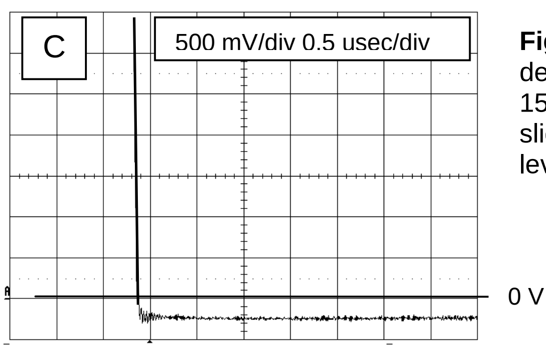


Figure C: When the horizontal time per division is decreased to a value normally used to view 20 to 150 kHz swictchmode power conversion circuits, the slightly peaked LF compensation appears as a DC level shift.

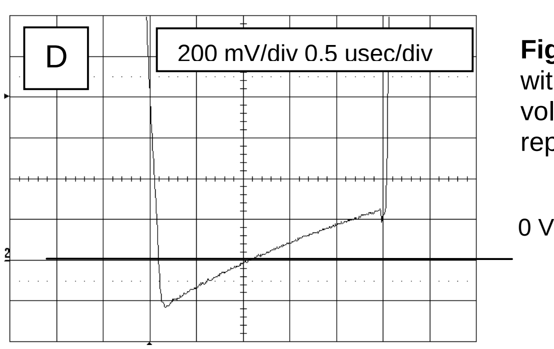
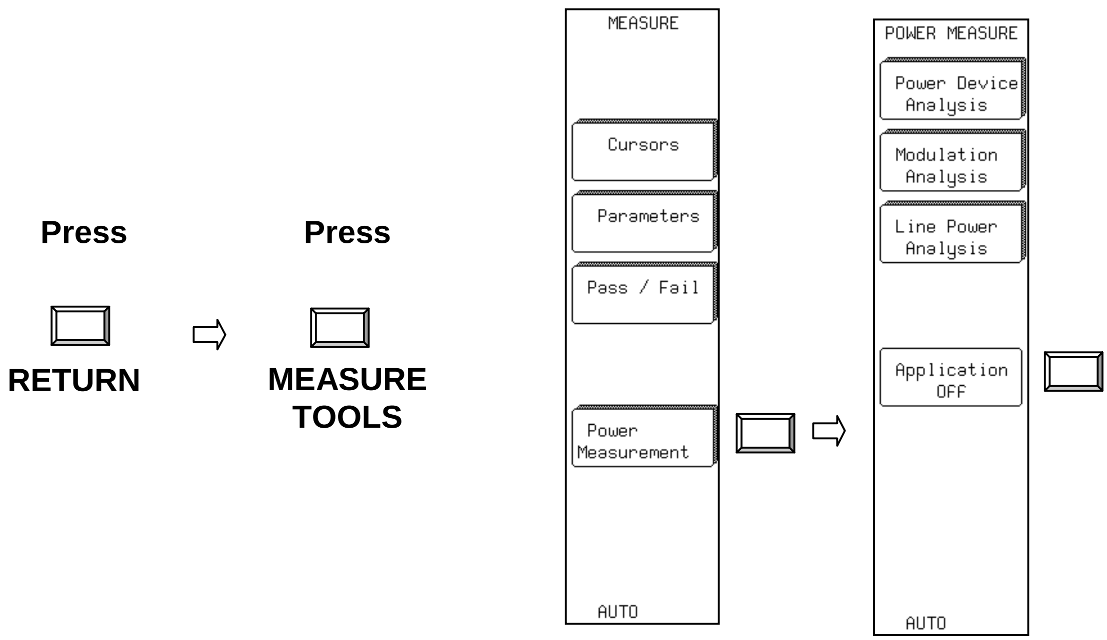


Figure D: Viewing a power FET's saturation voltage with the slightly peaked LF compensation makes the voltage appear to go negative. In this example, the repetition rate of the power supply is 60 kHz.

Clearing the Power Device Analysis Setup

After using PMA1's Power Device Analysis section, it is important to clear the channel assignments and other alterations that were made while making power device measurements. Press the **RETURN** until the onscreen menu is cleared. Then press the **MEASURE/TOOLS** to bring up the ***MEASURE*** menu.

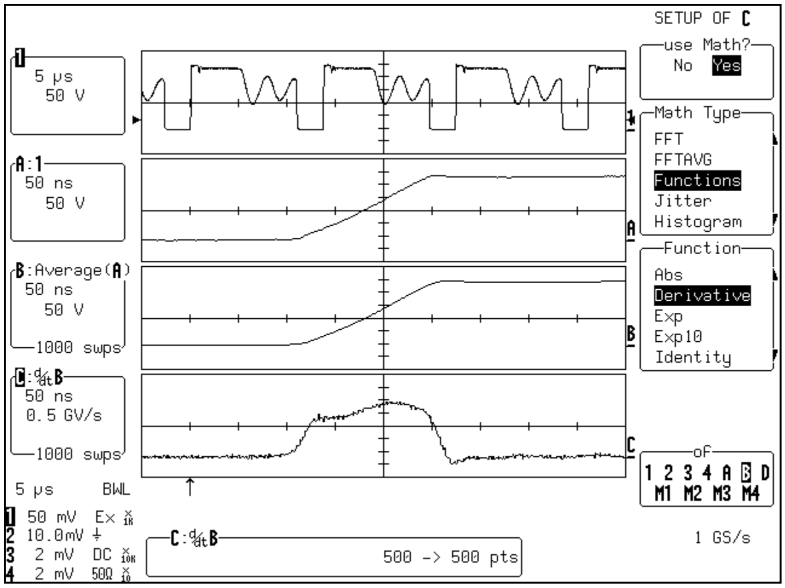


Selecting ***Application OFF*** in the Power Measure menu changes the ***Voltage Input*** and ***Current Input*** assignments to ***NONE*** and removes any DC offset adjustment made while using the ***Fine Adjust V DC Level*** and ***Fine Adjust I DC Level*** features. Any ***Deskew Value*** set while deskewing channel-to-channel delay remains unchanged. The assignment of Ampere units to the channel selected as the ***Current Input*** channel will be removed.

Measuring Device dv/dt

The speed of a power device's dv/dt during turn-on and turn-off can be measured using PMA1's derivative math function.

Note: This measurement does not require the use of the PMA1 menus.



In the example above, a power device's Drain to Source Voltage (V_{DS}) signal (**1**) is set up to be displayed in the first grid.

Math Channel A is used as a ZOOM of the Drain to Source voltage (**A**), and the trace is ZOOMed to 50 ns/div showing the voltage change as the device turns from on to off.

In the third trace (**B**), math Channel B is used to average trace A to remove noise from the V_{DS} signal before its derivative is taken.

In the fourth trace (**C**), math Channel C uses the derivative math function to display the waveforms dv/dt.

Cursors can be used to find the signal's dv/dt at any point.