

# **User Manual**



## **TPS2PWR1 Power Analysis Application 071-1452-01**

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## **WARRANTY**

### **TPS2PWR1 Application**

Tektronix warrants that the product listed above will be free from defects in materials and workmanship for a period of one (1) year from the date of original purchase from an authorized Tektronix distributor. If any such product proves defective during this warranty period, Tektronix, at its option, either will repair the defective product without charge for parts and labor, or will provide a replacement in exchange for the defective product. Batteries are excluded from this warranty. Parts, modules and replacement products used by Tektronix for warranty work may be new or reconditioned to like new performance. All replaced parts, modules and products become the property of Tektronix.

In order to obtain service under this warranty, Customer must notify Tektronix of the defect before the expiration of the warranty period and make suitable arrangements for the performance of service. Customer shall be responsible for packaging and shipping the defective product to the service center designated by Tektronix, shipping charges prepaid and with a copy of Customer proof of purchase. Tektronix shall pay for the return of the product to Customer if the shipment is to a location within the country in which the Tektronix service center is located. Customer shall be responsible for paying all shipping charges, duties, taxes, and any other charges for products returned to any other locations.

This warranty shall not apply to any defect, failure or damage caused by improper use or improper or inadequate maintenance and care. Tektronix shall not be obligated to furnish service under this warranty a) to repair damage resulting from attempts by personnel other than Tektronix representatives to install, repair or service the product; b) to repair damage resulting from improper use or connection to incompatible equipment; c) to repair any damage or malfunction caused by the use of non-Tektronix supplies; or d) to service a product that has been modified or integrated with other products when the effect of such modification or integration increases the time or difficulty of servicing the product.

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**TPS2PWR1 Application**

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# General Safety Summary

Review the following safety precautions to avoid injury and prevent damage to this product or any products connected to it.

To avoid potential hazards, use this product only as specified.

*Only qualified personnel should perform service procedures.*

## To Avoid Fire or Personal Injury

**Use Proper Power Cord.** Use only the power cord specified for this product and certified for the country of use.

**Connect and Disconnect Properly.** Do not connect or disconnect probes or test leads while they are connected to a voltage source.

**Connect and Disconnect Properly.** Connect the probe output to the measurement instrument before connecting the probe to the circuit under test. Disconnect the probe input and the probe reference lead from the circuit under test before disconnecting the probe from the measurement instrument.

**Observe All Terminal Ratings.** To avoid fire or shock hazard, observe all ratings and markings on the product. Consult the product manual for further ratings information before making connections to the product.

**Use Proper Probe.** To avoid shock hazard, use a properly rated probe for your measurement.

**Floating.** Do not float the P2220 probe reference lead to  $> 30 \text{ V}_{\text{RMS}}$ . Use the P5120 (floatable to  $600 \text{ V}_{\text{RMS}}$  CAT II or  $300 \text{ V}_{\text{RMS}}$  CAT III) or similarly rated, passive, high voltage probe or an appropriately rated, high voltage differential probe when floating the reference lead above  $30 \text{ V}_{\text{RMS}}$ , subject to the ratings of such high voltage probe.

**Powering Off.** The power cord provides Mains disconnect.

**Replace Batteries Properly.** Replace batteries only with the proper type and rating specified.

**Recharge Batteries Properly.** Recharge batteries for the recommended charge cycle only.

**Use Proper AC Adapter.** Use only the AC adapter specified for this product.

**Do Not Operate Without Covers.** Do not operate this product with covers or panels removed.

**Avoid Exposed Circuitry.** Do not touch exposed connections and components when power is present.

**Do Not Operate With Suspected Failures.** If you suspect there is damage to this product, have it inspected by qualified service personnel.

**Environment.** Pollution Degree 2 (As defined in IEC61010-1:2001). Do not operate in an environment where conductive pollutants may be present. See Appendix A of the TPS2000 Oscilloscope User Manual for Environmental characteristics.

**Do Not Operate in Wet/Damp Conditions.**

**Do Not Operate in an Explosive Atmosphere.**

**Keep Product Surfaces Clean and Dry.**

**Provide Proper Ventilation.** Refer to the manual's installation instructions for details on installing the product so it has proper ventilation.

**Avoid Electric Overload.** To avoid injury or fire hazard, do not apply potential to any input, including the reference inputs, that varies from ground by more than the maximum rating for that input.

**Avoid Exposed Circuitry.** Do not touch exposed connections and components when power is present.

**Avoid Electric Shock.** To avoid injury or loss of life, do not connect or disconnect probes or test leads while they are connected to a voltage source.

**Keep Probe Surface Clean and Dry.** To avoid electric shock and erroneous readings, keep probe surface clean and dry.

**Attached the Reference Leads Correctly.** If you are using multiple oscilloscope channels, you must attach the probe reference lead for each channel directly to the circuit common reference that you are measuring. These connections are required because the oscilloscope channels are electrically isolated. They do not share a common chassis connection. Use the shortest possible reference lead with each probe to maintain good signal fidelity.

**If Question Marks are Displayed.** If a measurement display is followed by a question mark, or a question mark is displayed instead of a value, you have encountered an overrange condition or other error, the reading may be invalid, and hazardous voltages may be present. Readjust the vertical scale or position or press the front-panel **AUTOSET** button.



## Symbols and Terms

**Terms in This Manual.** These terms may appear in this manual:



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**WARNING.** *Warning statements identify conditions or practices that could result in injury or loss of life.*

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**CAUTION.** *Caution statements identify conditions or practices that could result in damage to this product or other property.*

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**Terms on the Product.** These terms may appear on the product:

DANGER indicates an injury hazard immediately accessible as you read the marking.

WARNING indicates an injury hazard not immediately accessible as you read the marking.

CAUTION indicates a hazard to property including the product.

**Symbols on the Product.** These symbols may appear on the product:



CAUTION  
Refer to Manual



Standby



Chassis Ground

# Contacting Tektronix

**Phone** 1-800-833-9200\*

**Address** Tektronix, Inc.  
Department or name (if known)  
14200 SW Karl Braun Drive  
P.O. Box 500  
Beaverton, OR 97077  
USA

**Web site** [www.tektronix.com](http://www.tektronix.com)

**Sales support** 1-800-833-9200, select option 1\*

**Service support** 1-800-833-9200, select option 2\*

**Technical support** Email: [techsupport@tektronix.com](mailto:techsupport@tektronix.com)  
1-800-833-9200, select option 3\*  
1-503-627-2400  
6:00 a.m. – 5:00 p.m. Pacific time

\* **This phone number is toll free in North America. After office hours, please leave a voice mail message. Outside North America, contact a Tektronix sales office or distributor; see the Tektronix web site for a list of offices.**



# Getting Started





# Getting Started

The TPS2PWR1 Power Analysis application software adds power measurements to a TPS2000 series oscilloscope.

Specific features include:

- Power Analysis - Calculates the true power, reactive power, power factor, and phase angle for a pair of voltage and current waveforms.
- Waveform Analysis - Calculates the RMS value, crest factor, and frequency for a waveform.
- Phase Angles - Calculates the phase angle between each pair of three voltage or current waveforms.
- Harmonics - Calculates up to 50 harmonics and can display each harmonic's phase angle with respect to the fundamental frequency, its percent of the fundamental frequency, and the THD/TDD value for the entire waveform.
- Switching Loss - Calculates the turn-on switching loss, turn-off switching loss, conduction loss, and total switch loss for a pair of voltage and current waveforms.
- $dV/dt$  and  $di/dt$  cursors - Calculates  $dv/dt$  or  $di/dt$  between two cursors on a waveform.

## Basic Operation

See the TPS2000 User Manual, the P2220 Instructions, and the P5120 Instructions for information on ratings and on basic operations, including safety, installation, functional checks, probe attenuation and scaling settings, and self calibration.

## Ratings

### TPS2000

The TPS2000 oscilloscopes are rated to 300 V CAT II signal to common (IEC 61010) and 600 V CAT II floating reference to earth ground reference.

### P2220

The rating for the P2220 passive probe is:

X10 position: 300 V<sub>RMS</sub> CAT II probe tip to earth ground

X1 position: 150 V<sub>RMS</sub> CAT II probe tip to earth ground

The probe reference lead is rated to float 30 V max to earth ground.

### P5120

The rating for the P5120 passive high voltage probe is:

1000 V<sub>RMS</sub> CAT II probe tip to earth ground.

The probe reference lead is rated to float to 600 V<sub>RMS</sub> CAT II to earth ground.

### **Overvoltage categories**

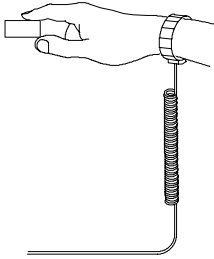
Overvoltage categories are defined as follows:

- CAT III: Distribution level mains, fixed installation
- CAT II: Local level mains, appliances, portable equipment
- CAT I: Signal level, special equipment or parts of equipment, telecommunications, electronics

More complete product specifications are contained in the User Manual for the TPS2000 and for the various probes.

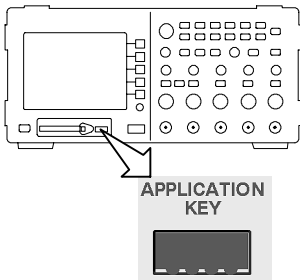
## Start Up

To install a TPS2PWR1 application module on your TPS2000 series oscilloscope, follow these steps.



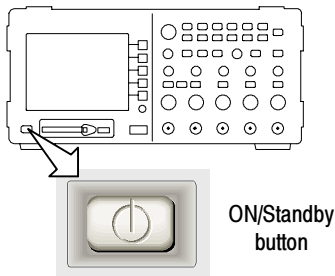
### Observe ESD precautions.

To avoid damage to the oscilloscope or the application module, observe proper electrostatic discharge (ESD) precautions. Use an ESD strap.



### Insert the application key.

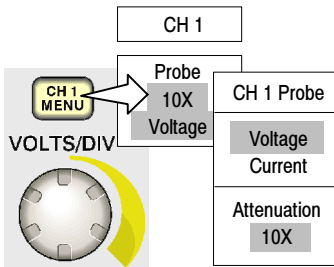
While the oscilloscope is turned off, insert the power analysis application key in the indicated slot, below and to the right of the display. The key's label should face up.



### Power on the oscilloscope.

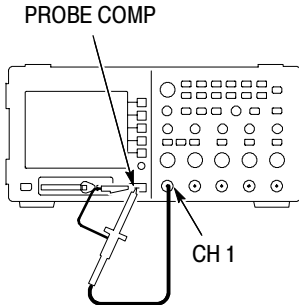
Wait until the display appears. Push the side-menu **OK** button to continue.





### Attach the probes to the oscilloscope and set up the probes.

Press the appropriate front-panel **CH 1**, **CH 2**, **CH 3**, or **CH 4 Menu** buttons and the appropriate **Voltage** or **Current** side menu selection and the **Attenuation** side menu selection.

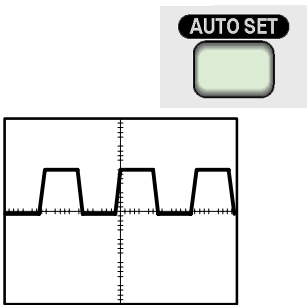


### Compensate the voltage probes.

For a P5120 probe, connect the probe to channel 1 on the oscilloscope. To do this, align the slot in the probe connector with the key on the CH 1 BNC, push to connect, and twist to the right to lock the probe in place.

Connect the probe tip and reference lead to the **PROBE COMP** terminals. Repeat this process for each probe.

Degauss current probes, if required.

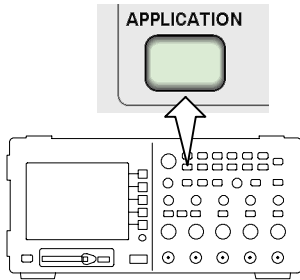


For examples of probe connections to circuits, refer to the Application examples provided in the Reference section of this manual.

If you see a question mark on the screen, you might press the front-panel **AUTOSET** button or adjust the oscilloscope as described below.

To optimize the automated measurements in the Power Analysis, Waveform Analysis, and Phase Angles menus, adjust the oscilloscope so that:

- the TPS2000 displays at least one complete cycle of the waveform
- the amplitude of each waveform is more than two divisions
- all waveform data points are on the screen
- each cycle occupies at least one horizontal division



### Start the application.

Push the front-panel **APPLICATION** button to access the power application functions. The power application menu will appear in the oscilloscope's right-side menu. It will present the power measurement choices shown below.

Power applications	Description
Power Analysis	True power, reactive power, true power factor, phase angles
Waveform Analysis	Cyc RMS, crest factor, frequency
Phase Angles	Phase angle, in degrees, between each of CH1, CH2, and, for 4 channel models, CH3
Harmonics	Fundamental RMS, Harmonics phase, frequency, and RMS.
Switching Loss	Turn-on, turn-off, conduction, and total loss

For further information on general set up of the oscilloscope, refer to the *TPS2000 User Manual*.

## Checking Module Installation

Use the following table to check that an application module is installed. If the oscilloscope does not show the application module menu items, do the steps in *Troubleshooting Module Installation* on page 1-9.

<b>To check this module</b>	<b>Push this front-panel button</b>	<b>Check for</b>
TPS2PWR1	APPLICATION	A menu appears on the right-side of the screen with the title labelled: <b>Power</b>

## Troubleshooting Module Installation

If the oscilloscope does not recognize the application module at power-up, perform these steps:

1. Turn off the oscilloscope.
2. Follow the ESD precautions shown previously.
3. Remove the application module.
4. Examine the application module contacts for damage.
5. Reinsert the application module into the oscilloscope.
6. Power on the oscilloscope. If the oscilloscope still does not show the application menu item, you have a problem with the application module or the module slot. Contact the nearest Tektronix service center to resolve the problem.





# Reference

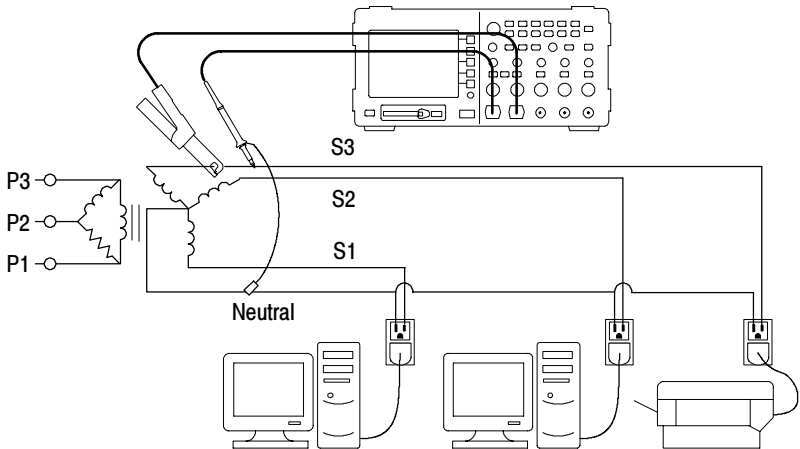




# Power Analysis

You can use the power analysis menu functions to check out the general power quality in your location, such as an office or industrial plant. Find out how efficiently your facility is using its electrical power or troubleshoot malfunctioning equipment.

To begin, hook up your TPS2000 and an appropriate passive voltage probe (such as the P5120) and current probe (such as the A622 or TCP305) to the portion of the power distribution system that you wish to test, as shown below. Your specific circuit may have different probe requirements than those just mentioned.



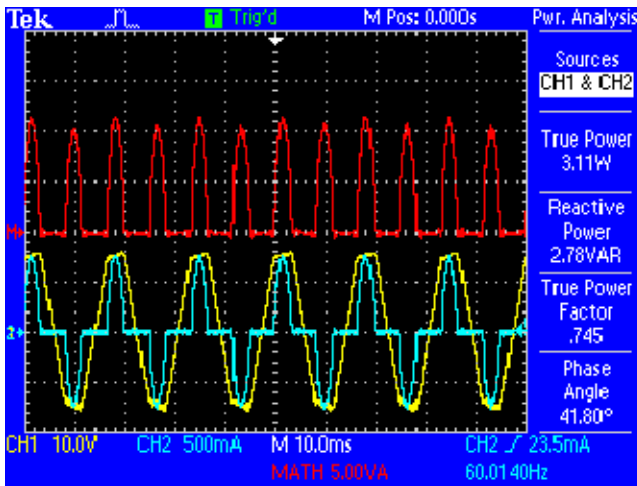
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**WARNING.** Do not float the P2220 probe reference lead to  $> 30 V_{RMS}$ . Use the P5120 (floatable to  $600 V_{RMS}$  CAT II or  $300 V_{RMS}$  CAT III) or similarly rated, passive, high voltage probe or an appropriately rated, high voltage, differential probe when floating the reference lead above  $30 V_{RMS}$ , subject to the ratings of such high voltage probe.

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Push the **Power Analysis** button to show the Power Analysis Menu. The oscilloscope will display the voltage and current source waveforms and display related measurement values. It will also automatically set up and display a Math waveform of the instantaneous power function ( $V \cdot A$ ).

These power analysis functions analyze the interaction of the source current and voltage waveforms. These operations require the use of both a voltage and a current probe.



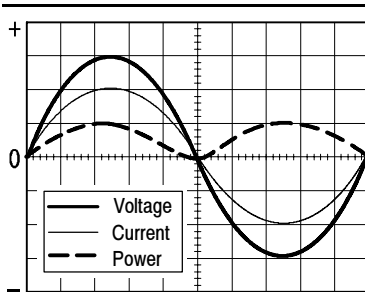
The menu includes the following choices and values:

<b>Menu item</b>	<b>Description</b>
Sources	Selects a channel pair. On a four-channel oscilloscope, choose either: (CH1 and CH2) or (CH3 and CH4).  On a two-channel oscilloscope, the sources are fixed as CH1 & CH2.  (CH1 and CH2) and (CH3 and CH4) should be pairs of (voltage, current) waveforms. The math multiply waveform is always set to use the selected sources.
True Power	Displays the true power. Calculated by taking the mean value of the math (V*A) waveform.
Reactive Power	Displays the reactive power. (Volts-Amps Reactive). Calculated by multiplying together the RMS value of the voltage waveform, the RMS value of the current waveform, and the sine of the phase angle. The computation of phase angle is explained in the phase angle section of the manual.

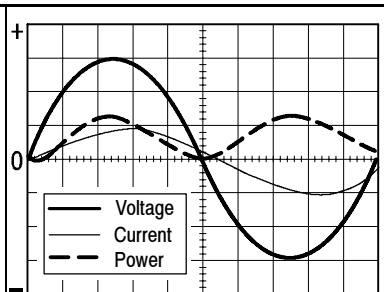
<b>Menu item</b>	<b>Description</b>
True Power Factor	<p data-bbox="378 302 937 407">Displays the ratio (0 to 1) of true power to apparent power. Apparent power is calculated by multiplying the RMS value of the voltage waveform by the RMS value of the current waveform.</p> <p data-bbox="378 431 933 483">Typically, a higher power factor means more efficient use of energy.</p> <p data-bbox="378 508 916 560">A purely resistive circuit would have a power factor of 1.0. A purely inductive one would have a power factor of 0.0.</p>
Phase Angle	<p data-bbox="378 583 931 719">Displays the angle (<math>-90^{\circ}</math> to <math>+90^{\circ}</math>) whose cosine is the true power factor. For sinusoidal waveforms, this value is the same as the phase angle measured in the Phase Angles menu. For non-sinusoidal waveforms, the two phase angle measurements may differ.</p> <p data-bbox="378 743 931 849">The angle is positive if the CH1 waveform (typically voltage) leads the CH2 waveform (typically current). The angle is negative if the CH1 waveform lags behind the CH2 waveform.</p>

### Sample Results

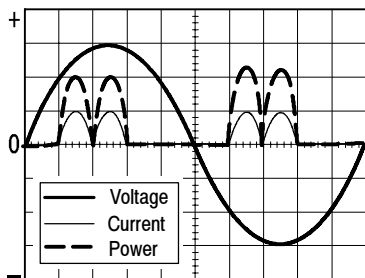
Next analyze your results. The figures below show stylized examples.



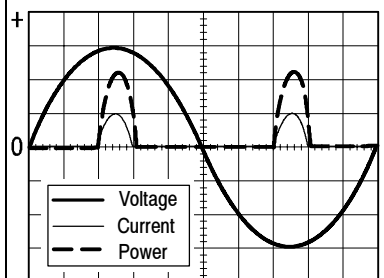
Power factor = 1.  
Phase angle =  $0^\circ$ .  
Voltage and current are in phase.  
Resistive circuit



Power factor = 0.707.  
Phase angle =  $45^\circ$ .  
Current lags voltage by  $45^\circ$ .  
Circuit is partially inductive.



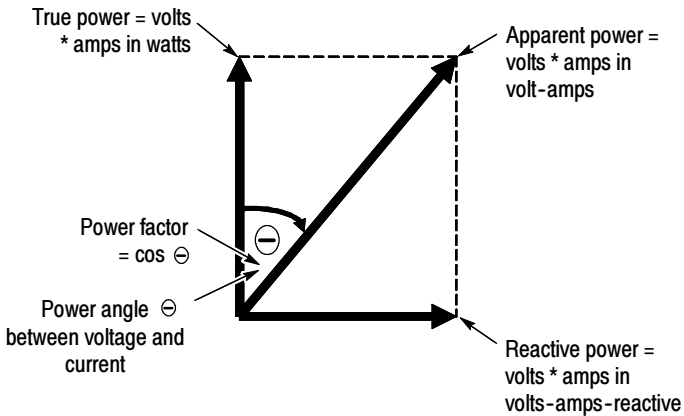
Power factor = 0.9.  
Phase angle =  $0^\circ$ .  
Voltage and current are in phase.  
Unbalanced current typical of an adjustable speed motor drive.



Power factor = 0.9.  
Phase angle =  $0^\circ$ .  
Voltage and current are in phase.  
Unbalanced current typical of a switching power supply.

### Operating Tips

- When you enter the Power Analysis menu, the oscilloscope automatically turns on the channels selected as sources. It also turns on the math multiply ( $V \cdot A$ ) power waveform. It does not make any other changes to your setup.
- The power measurements in this menu are based on all the complete cycles found in the voltage waveform record.
- The following illustration further explains the values used in this menu.



- If a measurement display is followed by a question mark, or a question mark is displayed instead of a value, you have encountered an overrange condition or other error, the reading may be invalid, and hazardous voltages may be present. Readjust the vertical scale or position or press the front-panel **AUTOSET** button.

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**NOTE.** *All power application measurements require an installed TPS2PWR1 application key.*

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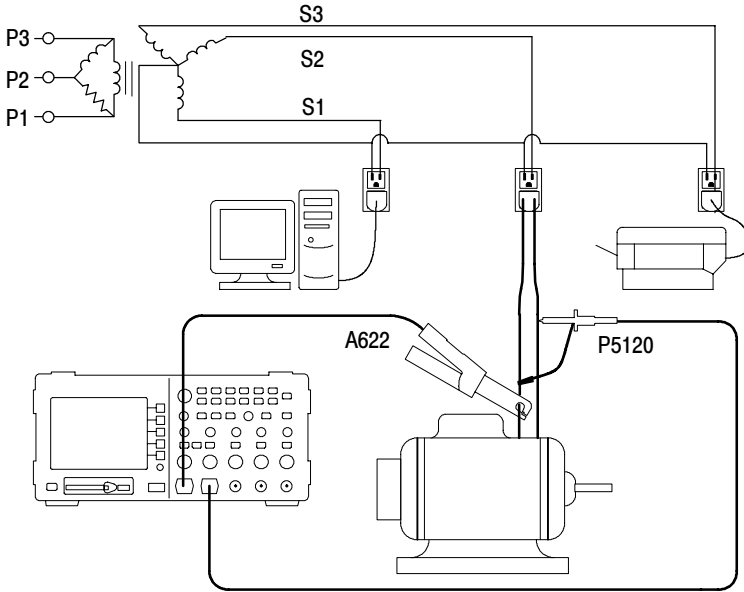




# Waveform Analysis

You can use the waveform analysis menu functions to measure the crest factor and further characterize your power quality situation. This is useful in offices or manufacturing plants where the load on a particular branch may vary, affecting the quality of the power to the attached loads.

The following figure shows example setups for measuring the crest factor for either voltage or current.

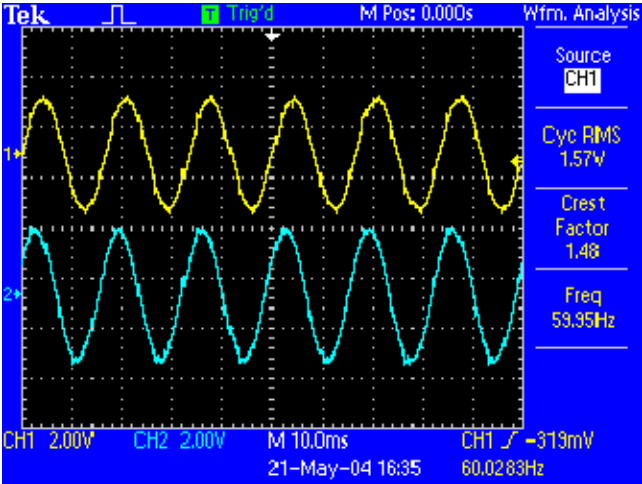


**WARNING.** Do not float the P2220 probe reference lead to  $> 30 V_{RMS}$ . Use the P5120 (floatable to  $600 V_{RMS}$  CAT II or  $300 V_{RMS}$  CAT III) or similarly rated passive high voltage probe or an appropriately rated high voltage differential probe when floating the common lead above  $30 V_{RMS}$ , subject to the ratings of such high voltage probe.

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Push the **Waveform Analysis** button to show the Waveform Analysis Menu on the right side of the screen and the source voltage or current waveform to the left of the menu. The oscilloscope will display the source waveform and measurement values.

These waveform analysis functions provide measurements to help you analyze individual waveforms. These operations require use of an individual voltage or current probe.

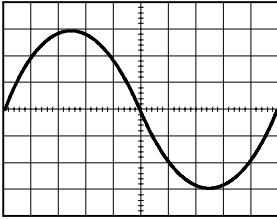


The menu offers the following choices and values.

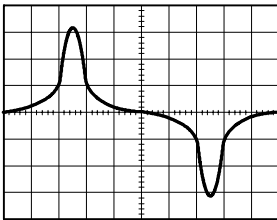
<b>Menu item</b>	<b>Description</b>
Source	Selects the channel. Choose between: CH1 or CH2 or MATH. On 4-channel models, you can also choose CH3 or CH4
Cyc RMS	Displays the RMS value of the first complete cycle of the selected waveform.
Crest Factor	Displays the ratio of the maximum value of the entire waveform to the RMS value of the first complete cycle.  The ratio of the signal's peak value to the RMS value.  It is 1.414 for a pure sine wave and 1.0 for a 50% duty cycle square wave.  The voltage crest factor indirectly specifies the purity of the AC supply.  The current crest factor indirectly specifies the ability of the load to draw high AC peak currents.
Freq	Displays the frequency (inverse of the period of the first complete cycle).

### Sample Results

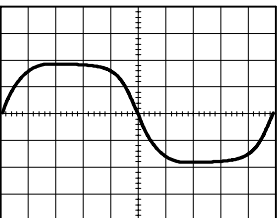
Next, analyze your results. The figures below show stylized examples.



Crest factor = 1.41.  
Clean sine wave.



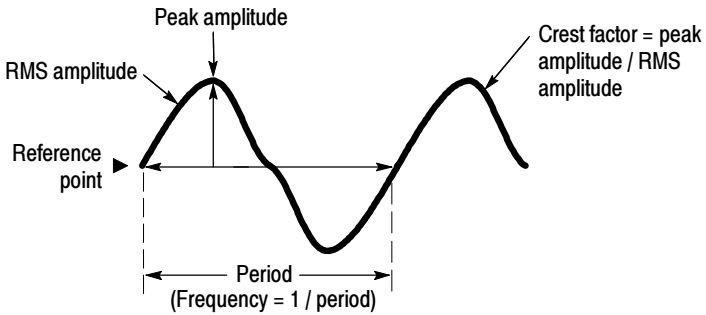
Crest factor > 1.41.  
Current spike.  
Typical of non-linear loads such as switching power supplies.



Crest factor < 1.41.  
Topped-out voltage wave.  
Typical of power supplies with non-linear loads.

### Operating Tips

- Unlike some other menus in the TPS2PWR1 Power Application, the Waveform Analysis menu does not turn any channels on or off, or otherwise change your setup.
- The following illustration further explains the values used in this menu.



- If a measurement display is followed by a question mark, or a question mark is displayed instead of a value, you have encountered an overrange condition or other error, the reading may be invalid, and hazardous voltages may be present. Readjust the vertical scale or position or press the front-panel **AUTOSET** button.

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**NOTE.** All power application measurements require an installed TPS2PWR1 application key.

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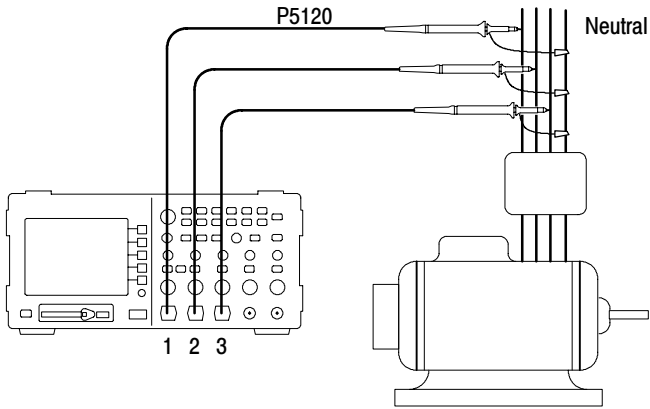
## Phase Angles

The Phase Angle menu functions help you look at the efficiency of applications such as power transmissions in industrial, 3-phase applications.

For example, you might use them to investigate whether out-of-phase voltage is contributing to overheating in a three-phase motor.

Because the channels are independently isolated, the reference lead for each probe must be separately connected to the reference point of the circuit under test.

The figure below shows one way of hooking up the oscilloscope to measure the phase angles of voltage going into a motor's variable speed drive.



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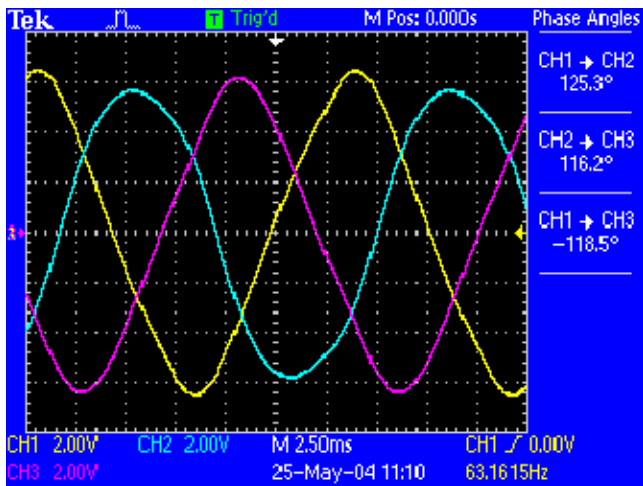
**WARNING.** Do not float the P2220 probe reference lead to  $> 30 V_{RMS}$ . Use the P5120 (floatable to  $600 V_{RMS}$  CAT II or  $300 V_{RMS}$  CAT III) or similarly rated passive high voltage probe or an appropriately rated high voltage differential probe when floating the common lead above  $30 V_{RMS}$ , subject to the ratings of such high voltage probe.

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Push **Phase Angles** to bring up the Phase Angle Menu. The menu will display the phase angle between any two of the three channels in a three-phase electrical system.

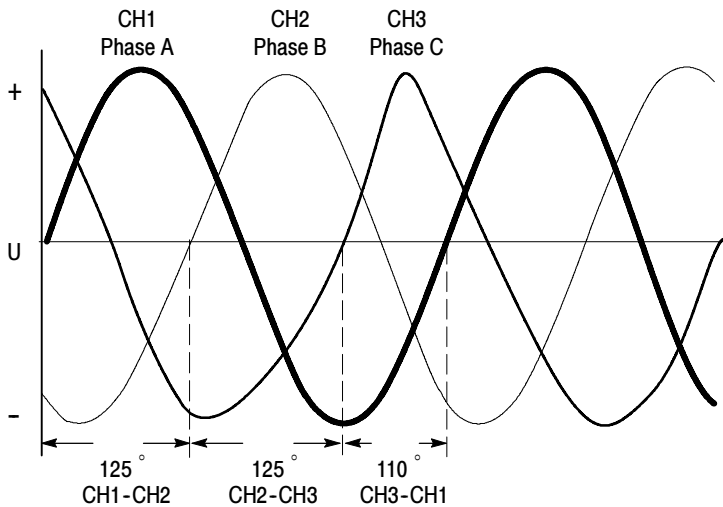
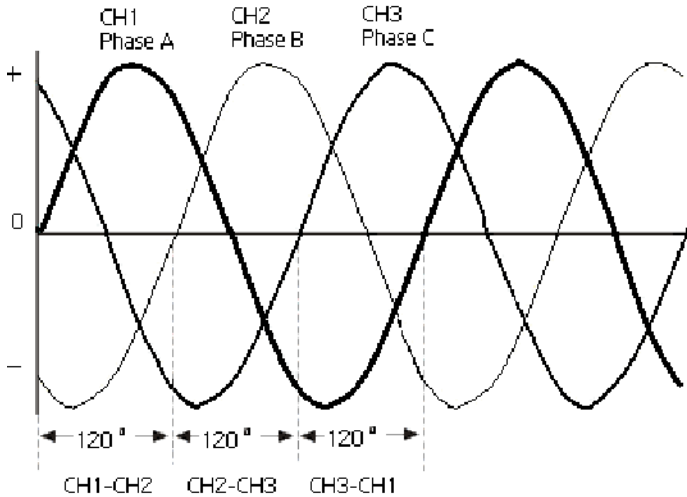
Simplify your measurements by using three voltage or current probes and a 4-channel version of the TPS2000. You can also use a 2-channel instrument if you move your probes around to make the measurements.



It displays the following measurements:

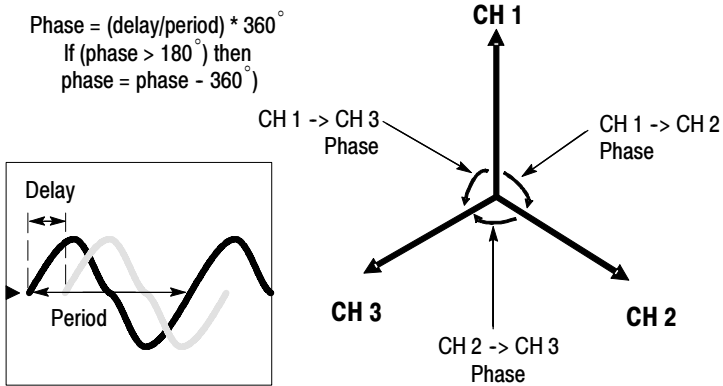
Menu item	Description
Source	<p>CH1 -&gt; CH2, CH2 -&gt; CH3, CH1 -&gt; CH3</p> <p>If you have a two channel oscilloscope, the menu will only display the phase difference between channels 1 and 2. You will need to move the probes around to make three-phase measurements.</p> <p>The angles, in degrees, range from <math>-180^{\circ}</math> to <math>+180^{\circ}</math>.</p> <p>The angle is positive if the lower-numbered channel's waveform leads the higher-numbered channel's waveform. It is negative if the lower-numbered channel's waveform lags rather than leads. For example, the angle is positive if the CH1 waveform leads the CH2 waveform. The angle is negative if the CH1 waveform lags behind the CH2 waveform.</p>

The figures below show stylized example results with a perfect 120 degrees separating each phase and with imperfect separations.



### Operating Tips

- This menu computes phase angles. To measure phase angle as the angle whose cosine is the true power factor, use the Power Analysis menu.
- The following illustration further explains the values used in this menu.



- If a measurement display is followed by a question mark, or a question mark is displayed instead of a value, you have encountered an overrange condition or other error, the reading may be invalid, and hazardous voltages may be present. Readjust the vertical scale or position or press the front-panel **AUTOSET** button.

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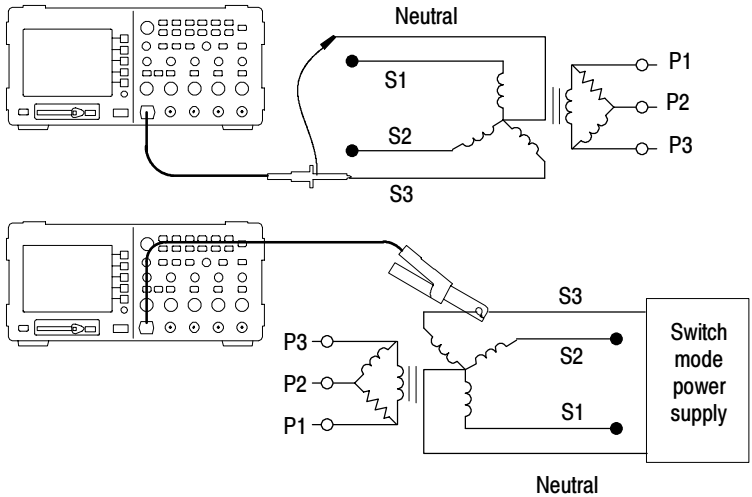
**NOTE.** All power application measurements require an installed *TPS2PWR1* application key.

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# Harmonics

You can use the Harmonics menu functions to display the frequency spectrum of the source waveform and the associated measurement values and perform in-depth troubleshooting of power quality problems.

The figures below show example setups for measuring either voltage or current harmonics in a building's wiring.



**WARNING.** Do not float the P2220 probe reference lead to  $> 30 V_{RMS}$ . Use the P5120 (floatable to  $600 V_{RMS}$  CAT II or  $300 V_{RMS}$  CAT III) or similarly rated passive high voltage probe or an appropriately rated high voltage differential probe when floating the common lead above  $30 V_{RMS}$ , subject to the ratings of such high voltage probe.

Push the **Harmonics** button to bring up the Harmonics menu. The oscilloscope will display the frequency spectrum of the source waveform and the associated measurement values.



The menu offers the following choices and values:

Menu item	Description
Source	<p>Choose a channel to measure.            Available choices are: CH1, CH2, and, on four-channel oscilloscopes, CH3, or CH4.            Use voltage or current waveforms.</p>
Setup	<p>Choose either "Automatic" (default) or "Manual".</p>
Show <value>	<p>Choose the harmonics to display.            &lt;value&gt; is "All Harmonics", "Odd Harmonics", or "Even Harmonics"</p>
Save Harmonics	<p>Saves the harmonics data to a file on a CompactFlash card.</p> <p>The file will be auto-named using the HM1234.csv format. The file will be stored in the current folder on the CompactFlash card.</p> <p>The file will contain the following for each of the 50 harmonics, and more:            Magnitude (amplitude),            Percent of the fundamental harmonic,            Frequency, and            Phase angle</p> <p>Doing a save will save the harmonics waveform and the underlying time domain waveform.</p> <p>You will typically view the contents of the harmonics .CSV file on a personal computer. You cannot recall the file to the oscilloscope.</p>

The Automatic setup control directs the oscilloscope to save your settings when you enter the harmonics menu, and restores them when you leave.

The automatic setup does the following:

- Sets the source channel vertical position to zero.
- Sets the source channel vertical coupling to DC and bandwidth limit to on.
- Adjusts the source channel vertical scale so the signal amplitude is at least two divisions.
- Sets the trigger source to the source channel.
- Sets the trigger type to edge, slope to rising, and coupling to DC.
- Adjusts the trigger level to mid-level of the source channel signal.
- Adjusts the horizontal scale to capture three to five cycles of the source channel.
- Sets the acquisition mode to average, with 16 waveforms per average.

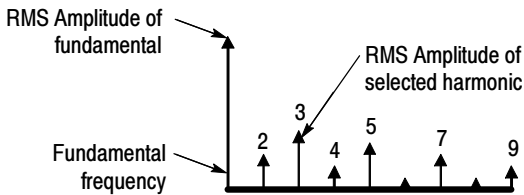


**Operating Tips**

- The oscilloscope will calculate the first 50 harmonics if you choose “All Harmonics” and the first 25 odd or even harmonics otherwise.
- The oscilloscope will show:
  - the number of the selected harmonic
  - the frequency of the selected individual harmonic
  - the magnitude and percent of the fundamental for the selected harmonic
  - the phase angle of the selected individual harmonic relative to the fundamental
- To see details on individual harmonics, turn the oscilloscope multipurpose knob. Turn the knob clockwise to increase the selected harmonic number (e.g. 1, 2, 3, 4, ...) or turn it counterclockwise to decrease the selected harmonic number.
- The oscilloscope will display 13 consecutive harmonics at a time. To see harmonics not currently displayed, simply turn the multipurpose knob clockwise beyond the first one shown to see a harmonic that follows the last one currently displayed or counterclockwise beyond the first one shown to see a harmonic that precedes the first one currently displayed.

- The harmonics application only displays harmonics data on signals with frequencies of 40 Hz to 450 Hz. To view the harmonics of a signal with a fundamental frequency outside those ranges, or to see spectrum information for frequencies that are not harmonics of the fundamental, use the FFT function in the MATH menu. The FFT function does not provide the same display as the harmonics application.
- If the harmonics menu setup control is set to Automatic, then when you enter the harmonics menu, the oscilloscope will adjust various settings to optimize the harmonics display. When you exit the menu, the oscilloscope will restore itself to the previous settings.
- **Manual Setup:** If you choose to manually set up your waveform for the harmonics functions, the oscilloscope will not return to your prior setup when exiting the harmonics menu.

- The following illustration further explains the values used in this menu.



Total harmonic distortion = ratio of  
power in harmonics to power in  
fundamental

- If a measurement display is followed by a question mark, or a question mark is displayed instead of a value, you have encountered an overrange condition, the reading is invalid, and hazardous voltages may be present. Readjust the vertical scale or press the front-panel **AUTOSET** button.

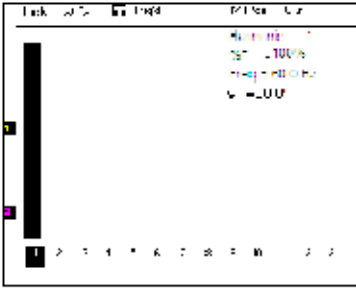
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**NOTE.** All power application measurements require an installed *TPS2PWR1* application key.

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### Sample Results

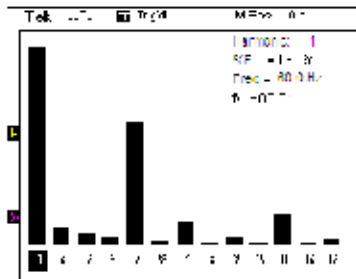
Next, analyze your results. The figures below show some examples.



Clean harmonics for a line voltage signal with no secondary harmonics and no load.

$$V(\text{RMS}) = 120 \text{ V}$$

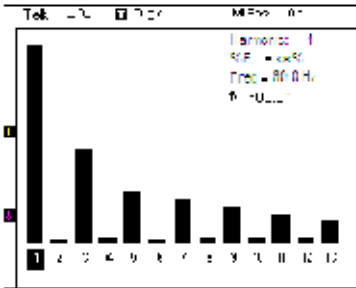
$$\text{THD} = 0$$



5th, 7th, 11th, and 13th harmonics for the voltage of an adjustable speed drive of a motor, with 6 rectifiers.

$$V(\text{RMS}) = 120 \text{ V}$$

$$\text{THD} = 135\%$$



Odd-ordered harmonics (3rd, 5th, 7th, 9th, 11th, and 13th) for the voltage from a switched power supply.  $V(\text{RMS}) = 120 \text{ V}$

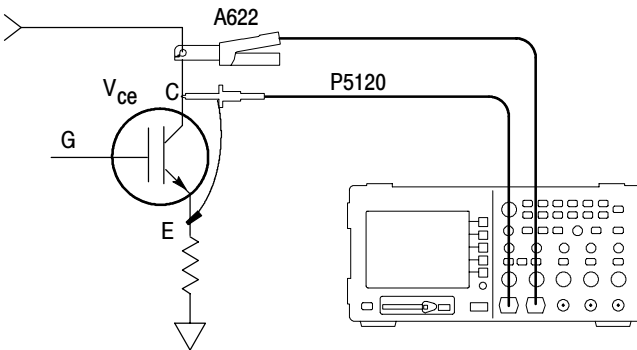
$$\text{THD} = 90\%$$

# Switching Loss

Use the switching loss functions to characterize power losses in IGBT switching power supplies and similar circuits, as they switch on and off. Switching loss operations require the use of a voltage and a current probe.

Switching loss measurements can characterize the efficiency of an adjustable speed drive.

The figure below shows an example setup for measuring switching loss. Place an isolated, floating voltage probe, like the P5120, or a differential voltage probe, like the P5205 probe with an 1103 power supply, across the devices collector and emitter. Place a current probe, like the A622, to measure the collector current.

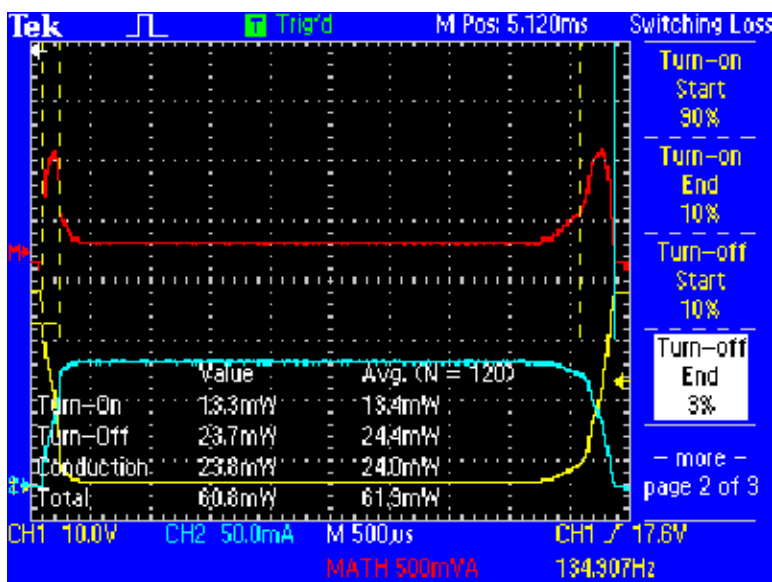


**WARNING.** Do not float the P2220 probe reference lead to  $> 30 V_{RMS}$ . Use the P5120 (floatable to  $600 V_{RMS}$  CAT II or  $300 V_{RMS}$  CAT III) or similarly rated passive high voltage probe or an appropriately rated high voltage differential probe when floating the common lead above  $30 V_{RMS}$ , subject to the ratings of such high voltage probe.



**WARNING.** To avoid an electric shock, do not use probes that require a ground connection, such as the Tektronix P5200 High Voltage Differential Probe, with the TPS2000 series oscilloscopes. The P5200 High Voltage Differential Probe requires an oscilloscope with grounded inputs and the TPS2000 series oscilloscopes have floating inputs (isolated inputs).

Push the **Switching Loss** button to show the Switching Loss Menu. The oscilloscope will display the voltage and current source waveforms, related measurement values, and will automatically set up and display a Math waveform of the instantaneous power function ( $V \cdot A$ ).



Page 1 of the Switching Loss menu offers the following choices:

<b>Menu item</b>	<b>Description</b>
Sources	Choose (CH1 & CH2) or (CH3 & CH4) where each pair contains a voltage and a current waveform. If you have a two channel oscilloscope, the menu will only display the (CH1 & CH2) choice.
V SAT	Enter the saturation voltage across the switch when the device-under-test (DUT) is on. The DUT's data sheet may contain this value.  Enter this value with the front-panel multipurpose knob.
Use Default Levels	Push to instruct the oscilloscope to use default levels for determining the turn-on, conduction, and turn-off regions.
Save Meas	Push to save the switching loss measurements to a CSV file on a CompactFlash card.

Page 2 of the Switching Loss Menu offers the following choices:

<b>Menu item</b>	<b>Description</b>
Turn-on Start	Push this button and use the multipurpose knob to move the cursor to select a voltage waveform edge percentage level other than the 90% default
Turn-on End	Push this button and use the multipurpose knob to move the cursor to select a voltage waveform edge percentage level other than the 10% default
Turn-off Start	Push this button and use the multipurpose knob to move the cursor to select a voltage waveform edge percentage level other than the 10% default
Turn-off End	Push this button and use the multipurpose knob to move the cursor to select a current waveform edge percentage level other than the 10% default



Page 3 of the Switching Loss Menu offers the following choices:

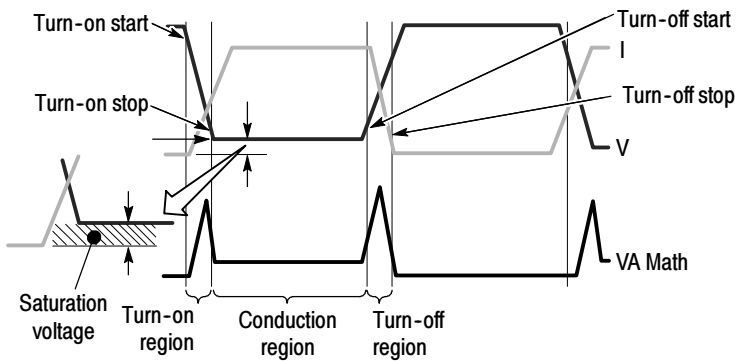
<b>Menu item</b>	<b>Description</b>
Acquire Continuously	Push this button to instruct the oscilloscope to continuously acquire waveforms, calculate measurements, and display them.
Stop After N Meas	Push this button and use the multipurpose knob to set the number of measurements. In this mode, the oscilloscope performs measurements on N different acquisitions and then stops. The oscilloscope saves the measurements internally. It displays the averages of the measurements on the screen. You can save the details of each of the N measurements to a file by pushing Save Meas. on page 1 of the Switching Loss menu.
Units	Choose whether to display the measurement results in watts or joules. You might choose watts to determine how much power is being used by the device-under-test and joules to compare the device to its specification.

The following switch loss measurements are displayed on the graticule:

<b>Menu item</b>	<b>Description</b>
Turn-on Loss	<p>Displays the power loss of the device in watts or joules when the device is transitioning between its off and on states.</p> <p>Turn-on loss is the area under the VA waveform during the time period between turn-on start and turn-on stop.</p>
Turn-off Loss	<p>Displays the power loss of the device in watts or joules when the device is transitioning between its on and off states.</p> <p>Turn-off loss is the area under the VA waveform during the time period between turn-off start and turn-off stop.</p>
Conduction Loss	<p>Displays the power loss of the device in watts or joules when the device is conducting in its on state.</p> <p>Conduction loss is calculated by multiplying the current waveform by the saturation voltage of the device, and integrating over the time period defined by the edge levels. The algorithm uses the user-entered saturation voltage, rather than the voltage waveform, because the level of the voltage waveform is usually too small to measure during conduction.</p>
Total Loss	<p>Displays the sum of the turn-on, turn-off, and conduction losses.</p>

### Operating Tips

- The switching loss algorithm measures power over three time periods: turn-on, conduction, and turn-off. The algorithm determines the three time periods by finding the four time points that bound them. These are:
  - Turn-on start is a level (default = 90%) of the falling edge of the voltage waveform.
  - Turn-on stop is a level (default = 10%) of the falling edge of the voltage waveform.
  - Turn-off start is a level (default = 10%) of the first rising edge of the voltage waveform.
  - Turn-off stop is a level (default = 10%) of the first falling edge of the current waveform that occurs after the turn-off start. Unlike the other time points, which are determined from the voltage waveform, this time point is determined from the current waveform.
- The following illustration further explains the values used in this menu.



- You can use page 2 of the menu to turn on cursors that show where the percentage levels fall on the waveforms. Use the multipurpose knob to move the cursors and change the percentage levels.

### **Watts and Joules:**

The losses for one switching cycle are calculated in joules. One joule is one Volt-Amp-second. By default, the losses are reported in watts. You can choose to have them reported in joules. The watts value is calculated by multiplying the joules value by the trigger frequency, which is assumed to be the switching frequency.

**Setup Sequence:**

Start by setting up your oscilloscope to view one switching cycle. A typical setup sequence might include:

1. Set up channel 1 with a voltage probe. Use the channel menu to set the voltage probe attenuation. Connect the voltage probe tip to the IGBT collector. Connect the reference lead to the emitter.
2. Set up channel 2 with a current probe. Use the channel menu to set the current probe scale factor. Connect the current probe in the collector leg. Alternatively, you may connect the current probe in the emitter leg. However, the emitter current includes the gate drive current, which may be significant.
3. Set the trigger source to channel 1.
4. Press the **AUTOSET** button to get a preliminary setup.
5. Set the trigger slope to **Falling**.
6. If any of the signals are noisy, you may want to press the front-panel **ACQUIRE** button and then the side-menu **Average** menu item.
7. Press the front-panel **APPLICATION** button and then the side-menu **Switching Loss** menu item.
8. Adjust the horizontal scale and position to show one falling edge and one rising edge of the voltage waveform.
9. Adjust channel 1, channel 2, and math vertical scale and vertical position so that each waveform amplitude is more than two divisions, but is not clipped.

The oscilloscope will display the loss measurements in the lower part of the graticule area. If the waveform information needed for a measurement is not on the screen, the oscilloscope will display a question mark in place of the measurement.

### **Measurement Strategies:**

Different power supplies require different measurement strategies.

If your supply has a constant switching frequency, a constant duty cycle, and conduction time is relatively short, the setup described earlier should give you good results.

If your signal has a constant switching frequency and a constant duty cycle but conduction time is long relative to turn-on and turn-off, it may not be possible to accurately measure all three regions at the same time. In this case, you can use the horizontal position and horizontal scale controls to zoom and pan to the turn-on region and measure the turn-on loss. Next, zoom and pan to the turn-off region and measure the turn-off loss. Finally, change the setup to display the full cycle and measure the conduction loss.

If your signal has a constant switching frequency but a varying duty cycle, you may be able to use the Stop After N Measurements feature to obtain good measurements. Do the following:

1. Set up the oscilloscope so that a single acquisition covers events with the longest duty cycle.
2. Go to page 3 of the Switching Loss menu and select the **Stop After N Measurements** mode.
3. Rotate the multipurpose knob to set N to a value large enough to collect a good sample of measurements with a variety of duty cycles. This may require experimentation.
4. Push the **RUN** button.
5. After the oscilloscope completes the specified number of measurements, examine the average values reported on the screen. To examine the results from individual acquisitions, go to page 1 of the switching loss menu and push the **Save Meas** button. This saves the detailed data to a .CSV file on a Compact-Flash card.

- If a measurement display is followed by a question mark, or a question mark is displayed instead of a value, you have encountered an overrange condition or other error, the reading may be invalid, and hazardous voltages may be present. Readjust the vertical scale or position or press the front-panel **AUTOSET** button.

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**NOTE.** *All power application measurements require an installed TPS2PWR1 application key.*

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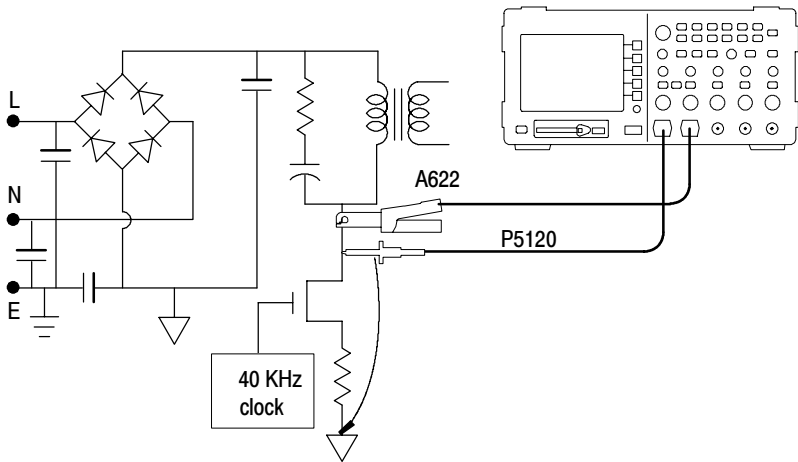


# dY/dt Measurements

Use this menu to measure the slope (rate of change) of signals.

Y can refer to voltage, current, or a product of voltage and/or current.

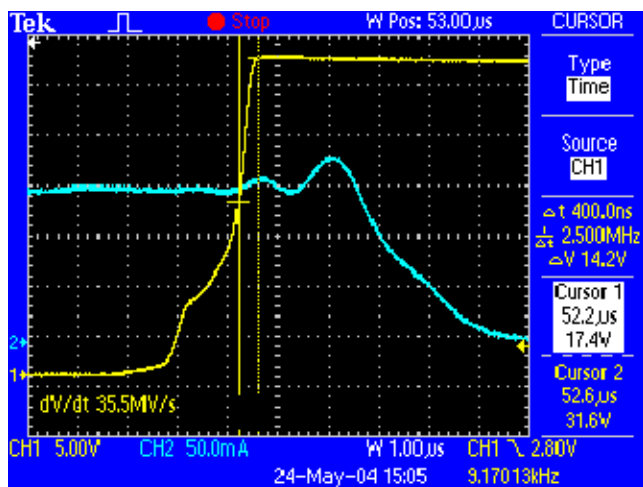
The figure below shows an example setup for measuring dY/dt results.



**WARNING.** Do not float the P2220 probe reference lead to  $> 30 V_{RMS}$ . Use the P5120 (floatable to  $600 V_{RMS}$  CAT II or  $300 V_{RMS}$  CAT III) or similarly rated passive high voltage probe or an appropriately rated high voltage differential probe when floating the common lead above  $30 V_{RMS}$ , subject to the ratings of such high voltage probe.

Push the **Cursor** front-panel button and the **Type** button in the resulting Cursor side menu to select the dY/dt measurement. The measurement will appear in the lower-left graticule area.

Adjust the cursors to vary the portion of the waveform over which to measure. The dY/dt measurements are only available when the power application key is installed.



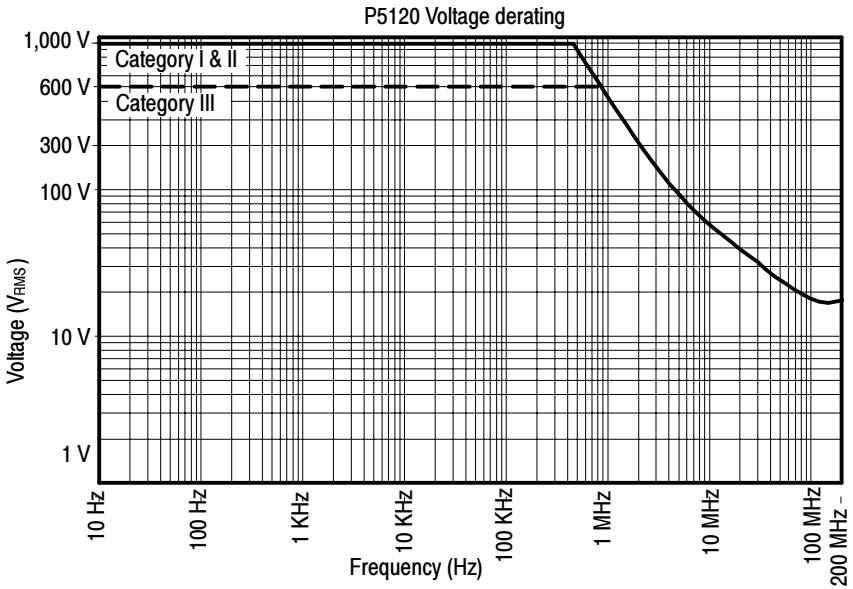
# P5120 Specifications

The P5120 warranted specifications of Table 2-1 that appear in boldface type are specifications checked in the *Performance Verification* section of the *P5120 Passive High-Voltage Probe Instructions* (Tektronix part number 071-1463-00). Specifications that are not warranted are typical (Tables 2-2 and 2-3) and are provided as general information for your convenience.

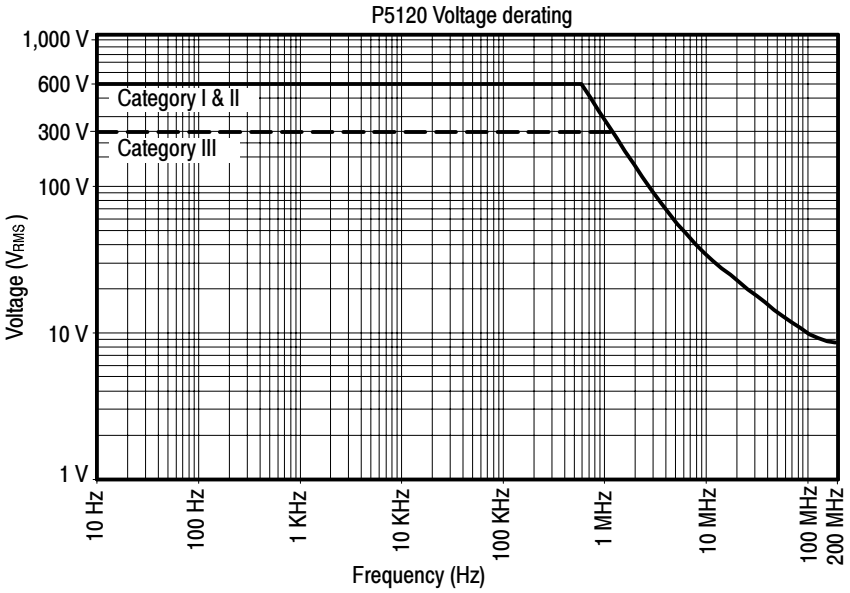
The specifications apply to a P5120 probe installed on a Tektronix TPS2000 series oscilloscope. The instrument must have a warm-up period of at least 20 minutes and be in an environment that does not exceed the limits described in Table 2-4.

**Table 2-1: Warranted electrical specifications**

Attenuation (DC coupled system)	20X, $\pm 2\%$	
<b>Bandwidth</b> (-3 dB, DC coupled system)	<b>DC to 200 MHz</b> (TPS2024) DC to 100 MHz (TPS2012, TPS2014)	
Maximum Rated Input Voltage	IEC 1010-1 Installation Category	
	II	III
Between probe tip and probe reference or between probe tip and earth ground (Refer to Figure 2-1)	1000	600
Between probe reference and earth ground (Refer to Figure 2-2)	600	300
Safety	UL 61010B-2-031; 2003 CSA 22.2 No. 1010.2-031, 1994 EN 61010-031 2002	
IEC Installation Category	Category II	
IEC Pollution Degree	Degree 2	



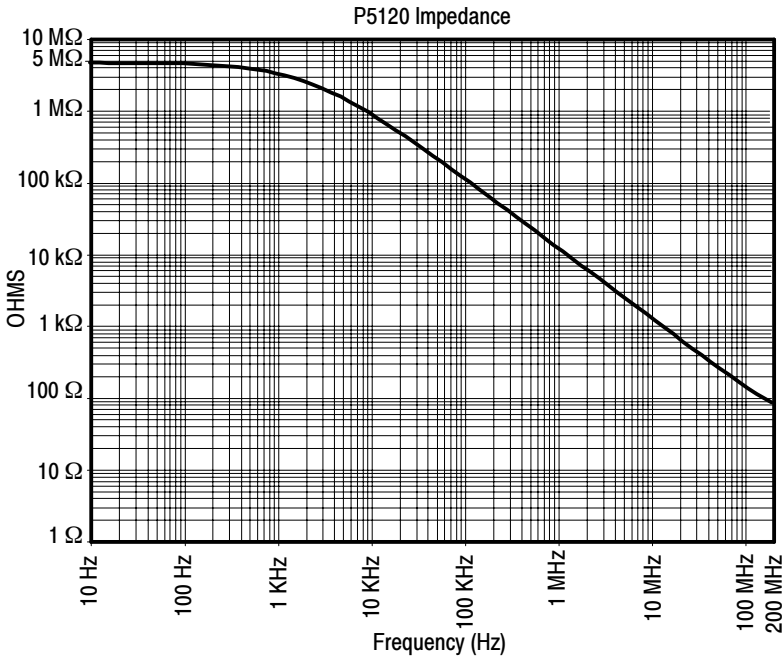
**Figure 2-1: Maximum voltage derating curves ( $V_{RMS}$ , DC coupled), probe tip to reference or earth ground**



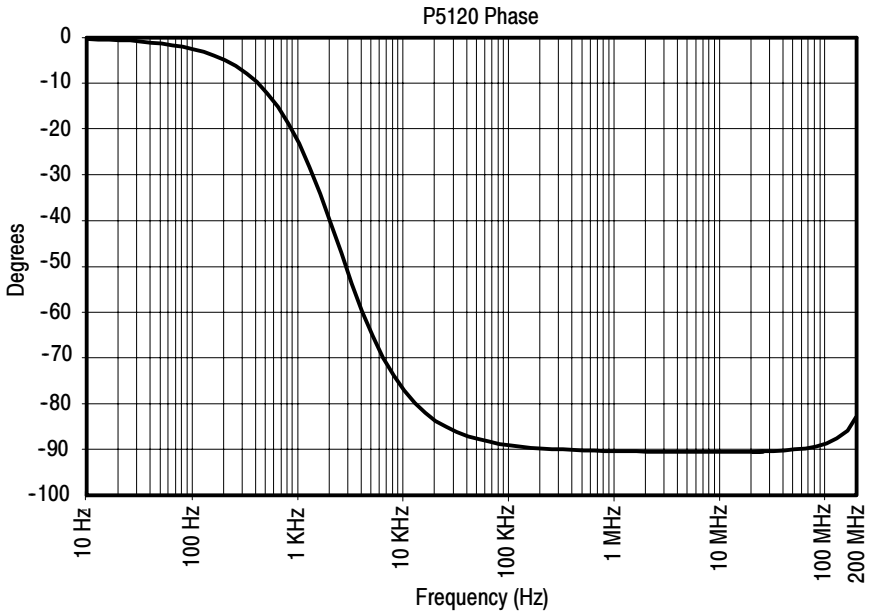
**Figure 2-2: Maximum voltage derating curves ( $V_{RMS}$ , DC coupled), probe reference to earth ground**

**Table 2-2: Typical electrical characteristics**

Rise Time (System) Checked using optional BNC adapter	< 3.6 ns (TPS2012, 2014) < 2.2 ns (TPS2024) Typical
Input Resistance (System) See Figure 2-3	5 MΩ
Input Phase (System)	(See Figure 2-4)
Compensation Range	15 pF to 25 pF
Input Capacitance (System) Probe connected to instrument and properly compensated. Checked at 1 MHz	11.2 pF



**Figure 2-3: Typical input impedance**



**Figure 2-4: Typical input phase**

**Table 2-3: Typical mechanical characteristics**

Net Weight (including accessories)	0.26 kg (0.57 lb)
Cable Length	3 m (+- 3 cm) (9.84 ft)

**Table 2-4: Environmental specifications**

Temperature	Operating:	0 °C to +50 °C (+32 °F to +122 °F)
	Nonoperating:	-40 °C to +71 °C (-40 °F to +159 °F)
Humidity	Operating:	
	High:	50 °C (122 °F)/60% RH
	Low:	30 °C (86 °F)/60% RH
	Nonoperating:	
	High:	55 °C to 71 °C (131 °F to 160 °F), 60% RH
	Low:	0 °C to 30 °C (32 °F to 86 °F), ≤ 90% RH
Transportation	Tektronix Standard 062-0937-00 Revision C	
Altitude	Operating:	4,600 m (15,092 ft)
	Nonoperating:	12,192 m (40,000 ft)