

# Fundamentals of Floating Measurements and Isolated Input Oscilloscopes



This guide will provide you with a fundamental glossary of power measurement terms, explain the different options available for making floating measurements, and highlight the advantages and trade-offs of each option.

The most demanding floating measurement requirements are found in power control circuits, such as motor controllers, uninterruptible power supplies, and industrial equipment. In such application areas, voltages and

currents may be large enough to present a hazard to users and test equipment. There are many options to consider when measuring high voltage signals that are floating. Each option has its advantages and trade-offs.

## Differential vs. Floating Measurements

All voltage measurements are *differential measurements*.

A differential measurement is defined as the voltage difference between two points. Voltage measurements fall into two sub-categories:

1. ground-referenced measurement
2. non-ground-referenced measurement  
(also known as *floating measurement*)

## Traditional Oscilloscopes

Most traditional oscilloscopes have their “signal reference” terminal connected to the protective grounding system, commonly referred to as “earth” ground or just “ground”. This is done so that all signals applied to, or supplied from, the oscilloscope have a common connection point.

This common connection point is usually the oscilloscope chassis and is held at (or near) zero volts by virtue of the third-wire ground in the power cord for AC-powered equipment. This means each input channel reference is tied to ground.

A traditional passive probe should not be used to directly make floating measurements on a ground referenced oscilloscope. Depending on the amount of current trying to flow through the reference lead, it will either get hot or become a fuse for a very short length of time and melt to open.

## Floating Measurement Techniques

The different options available for making high voltage floating measurements are:

- Isolated-input Oscilloscopes and Floating Measurements
- Differential Probe Measurement Technique
- Voltage Isolator Measurement Technique
- “A minus B” Measurement Technique
- “Floating” the Oscilloscope Technique

## Glossary

### Common-Mode Signal

The component of an input signal which is common (identical in amplitude and phase) to both inputs.

### Common-Mode Range

The maximum voltage (from ground) of common-mode signal which a differential amplifier can reject.

### Common-Mode Rejection Ratio

The performance measure of a differential amplifier’s ability to reject common-mode signals. Because common-mode rejection generally decreases with increasing frequency, CMRR is usually specified at a particular frequency.

### Differential Mode

The signal which is different between the two inputs of a differential amplifier. The differential-mode signal (VDM) can be expressed as:

$$\text{VDM} = (\text{V}+\text{input}) - (\text{V}-\text{input})$$

### Differential-Mode Signal

The signal which is different between two inputs.

### Differential Measurement

The voltage difference between two points.

### Differential Probe

A probe designed specifically for differential applications. Active differential probes contain a differential amplifier at the probe tip. Passive differential probes are used with differential amplifiers and can be calibrated for precisely matching the DC and AC attenuation in both signal paths (including the reference lead).

### Floating Measurement

A differential measurement where neither point is referenced to ground (earth potential).

## Glossary (continued)

### Ground Loops

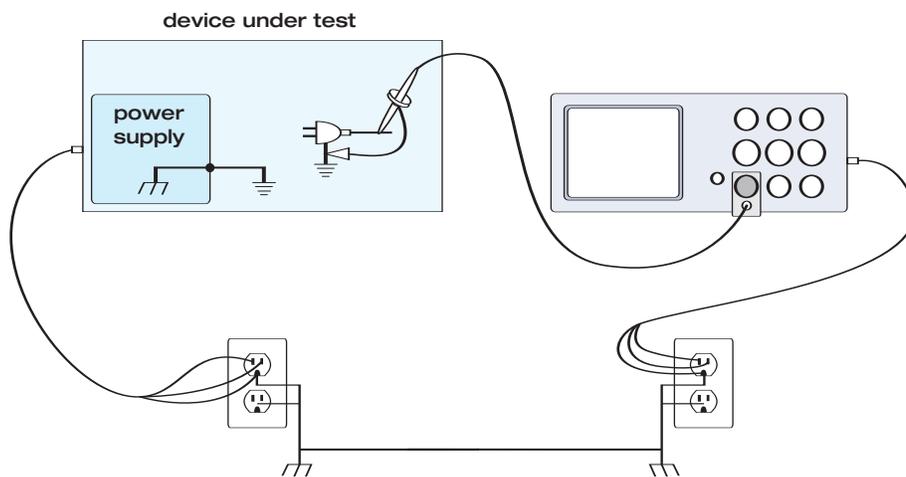
A ground loop results when two or more separate ground paths are tied together at two or more points. The result is a loop of conductor. In the presence of a varying magnetic field, this loop becomes the secondary of a transformer which acts as a shorted turn. The magnetic field which excites the transformer can be created by any conductor in the vicinity which is carrying a non-DC current. AC line voltage in mains wiring or even the output lead of a digital IC can produce this excitation. The current circulating in the loop develops a voltage across any impedance within the loop. Thus, at any given instant in time, various points within a ground loop will not be at the same AC potential.

Connecting the ground lead of an oscilloscope probe to the ground in the circuit-under-test results in a ground loop if the circuit is “grounded” to earth ground. A voltage potential is developed in the probe ground path resulting from the circulating current acting on the impedance within the path.

Thus, the “ground” potential at the oscilloscope’s input BNC connector is not the same as the ground in the circuit being measured (i.e., “ground is not ground”). This potential difference can range from microvolts to as high as hundreds of millivolts. Because the oscilloscope references the measurement from the shell of the input BNC connector, the displayed waveform may not represent the real signal at the probe input. The error becomes more pronounced as the amplitude of the signal being measured decreases.

### “A Single”

Battery-operated oscilloscopes with grounded input channels when operated from AC line power and using a standard 3 wire power cord, exhibit the same limitations as traditional oscilloscopes. However, when operating on battery power, these oscilloscopes allow you to make **a single**, safe floating measurement up to 30V<sub>RMS</sub> at a time. Remember that all input commons are tied together.



► Connecting the ground lead of an oscilloscope probe to the ground in the circuit-under-test results in a ground loop if the circuit is “grounded” to earth ground.

## Isolated Input Oscilloscopes Measurements

### Description

Oscilloscopes with IsolatedChannel™ input architecture, such as the TPS2000 Series, provide true and complete channel-to-channel and channel-to-power line isolation. Each channel is individually isolated from one another and other non-isolated components.

When making floating measurements with an IsolatedChannel™ oscilloscope, one must use specifically designed passive probes, such as the P2220 to float up to 30 Vrms and the P5120 to float up to 600 Vrms. Unlike the passive probes used with most conventional oscilloscopes,

the P2220 and P5120 are insulated at the BNC connection for shock protection and the reference lead is designed to withstand the rated float voltage. (For more information please refer to the discussion entitled “Mind your CATs and Volts” later in this application note).

## Differential Probe Measurements

Differential probe systems enable floating measurements to be made with the Tektronix TDS and most other grounded oscilloscopes. Some differential probes such as the P6246, P6247, P6248, and P6330 are optimized for fast, lower amplitude signals. Others such as the P5200, P5205, and P5210 handle slower

signals with higher voltage amplitudes. The ADA400A differential preamplifier provides the capability to display low frequency, very low amplitude differential signals even in high noise environments.

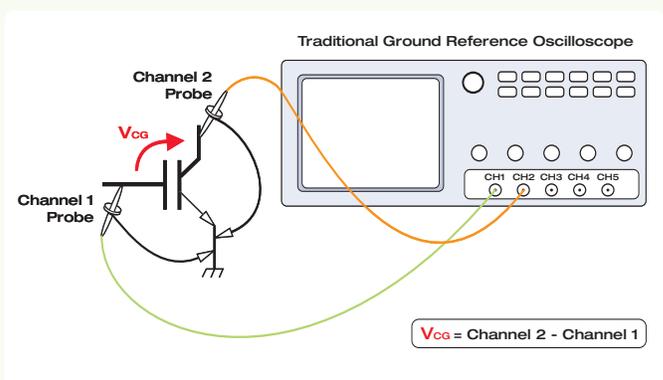
## Voltage Isolator Measurements

As the name implies, isolators do not have direct electrical connection between the floating inputs and their

ground-referenced outputs. The signal is coupled via optical or split-path optical/transformer means.

## “A minus B” Measurements (Also known as the Pseudo-Differential Measurements)

The “A minus B” measurement technique allows the use of a conventional oscilloscope and its passive voltage probes to indirectly make floating measurements. One channel measures the “positive” test point and another channel measures the “negative” test point. Subtracting the second from first removes the voltage common to both test points in order to view the floating voltage that could not be measured directly. Oscilloscope channels must be set to the same volts/division; the probes should be matched to maximize common mode rejection ratio.



► Example of two probes measuring ground reference voltages.

## “Floating” a Conventional Grounded Oscilloscope

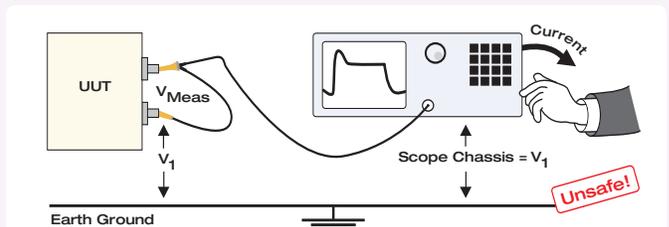
A common but risky practice is to float the oscilloscope through the use of an isolation transformer that does not carry the ground through to the secondary or by disconnecting the oscilloscope’s AC mains power cord grounding connector.

“Floating” a ground referenced oscilloscope puts all accessible metal including the chassis, casing, and connectors at the same voltage as the test point that the probe reference lead is connected.

**WARNING**

**This is an unsafe and dangerous practice and should never be done!**

**Failure to follow safety warnings can result in serious injury or loss of life.**



► A floating measurement in which dangerous voltages occur on the oscilloscope chassis. V1 may be hundreds of volts!

## Advantages & Trade-Offs

### Advantages

Isolated input channel oscilloscopes offer a safe and reliable way to make floating measurements. An obvious benefit of channel-to-channel and channel-to-ground isolation is the ability to simultaneously view multiple signals referenced to different voltages.

Another benefit is the ability to do this without the added cost of specialized probes or expensive and bulky voltage isolators. Channel-to-power line isolation eliminates the path between ground of the signal source and the oscilloscope.

### Trade-Offs

Unlike a differential probe, an isolated input channel does not provide a balanced floating measurement. The impedance to earth ground is different in the tip (+) input and reference (-) input. Since the reference (-) input of the isolated channel does not have a default reference level like a grounded oscilloscope, you must connect the

reference lead of the probe to the reference on the DUT.

There is no shunting to ground, therefore line frequency fields radiated from fluorescent lighting and building wiring can result in more baseline noise on the oscilloscope reading. Using averaging acquisition mode can mitigate this increase in baseline noise.

### Advantages

Differential probes provide a safe method to adapt a grounded oscilloscope to make floating measurements. In addition to the safety benefits, the use of these probes can improve measurement quality. Differential probes provide balanced measurement input capacitance so any point in the

circuit can be safely probed with either lead, and they typically have better CMRR performance at higher frequencies than voltage isolators.

Another benefit is the full use of the oscilloscope's multiple channels with the simultaneous viewing of multiple signals, referenced to different voltages.

### Trade-Offs

The probes still have a resistive path to ground - so if a circuit is sensitive to leakage currents then differential probes may not be the best solution.

Other trade-offs include an added layer of cost - depending on the oscilloscope capability an independent power supply may be required, adding

cost and bulk. The gain and offset characteristics must be factored manually into every measurement.

### Advantages

Voltage isolators provide a means of safely measuring floating voltages. Because isolators have no resistive

path to ground, they are a good choice for applications which are extremely sensitive to leakage currents.

### Trade-Offs

Voltage isolators add a layer of cost. An independent power supply and isolation amplifier box must

be used. The gain and offset characteristics must be factored manually into every measurement.

### Advantages

The advantage of this technique is that it can be easily done with almost any oscilloscope and its standard probes. Keep in mind that both test points must be referenced to ground. Thus this method will not work if either test point is floating or if the entire system is floating.

### Trade-Offs

Two oscilloscope channels are used to make one "A minus B" measurement. The primary limitation of this technique is the rather small common-mode range, which results from the oscilloscope's vertical channel dynamic range. Generally this is less than ten times the volts/division setting from ground. Whenever common mode voltage is greater than differential mode voltage, the "A minus B" technique can be thought of as

extracting the small differences from two large voltages. This technique is suitable for applications where the common-mode signal is the same or lower amplitude than the differential-mode signal, and the common-mode component is DC or low frequency, such as 50 or 60 Hz power line. It effectively eliminates ground loop voltages from the measurement when measuring signals of moderate amplitude.

### Advantages

Although this technique is a method to use existing equipment to make floating measurements and remove ground loops on lower frequency signals, it is an unsafe and dangerous practice and should never be done.

### Trade-Offs

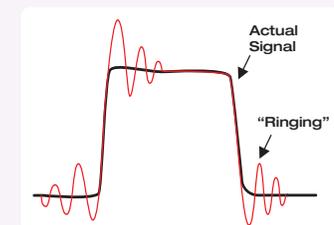
This technique is dangerous, not only from the standpoint of elevated voltage present on the oscilloscope (a shock hazard to the operator), but also due to cumulative stresses on the oscilloscope's power transformer insulation. This stress may not cause

immediate failure but can lead to future dangerous failures (a shock and fire hazard), even after returning the oscilloscope to properly grounded operation.

At higher frequencies, severing the ground may not break the ground loop as the line-powered instrument exhibits a large parasitic capacitance when floated above earth ground. The floating measurement can be corrupted by ringing. Floating oscilloscopes do not have balanced inputs. The reference side (the "ground" clip on the probe) has a significant capacitance to ground.

Any source impedance the reference is connected to will be loaded during fast common-mode transitions, attenuating the signal. Worse yet, the high capacitance can damage some circuits. Connecting the oscilloscope common to the upper gate in an inverter may slow the gate-drive signal, preventing the device from turning off and destroying the input bridge. This failure is usually accompanied by a miniature fireworks display right on your bench.

Yet another trade-off is that only one measurement may be made at a time - remember all the input references are



▶ Ringing caused by parasitic inductance and capacitance distorts the signal and invalidates measurements.

tied to each other. Once you have floated one input references, all input references are now floating at the same level.

## Tektronix TPS2000 Series IsolatedChannel™ Oscilloscope

The TPS2000 Series is the first product family to bring full-featured, four isolated channel oscilloscope performance to a portable platform designed for making measurements on products operating on industrial power.

Each of the three models deliver performance levels and features unmatched in their class, especially when paired with the optional power bundle (TPS2PBND), which includes four passive, high voltage probes (P5120) and the power measurement and analysis software package (TPS2PWR1). The power measurement and analysis software package offers power analysis measurements

### Mind your CATs and Volts

#### Selecting the proper voltage probe for making floating measurements

How to select probe and oscilloscope combination:

##### 1. Determine measurement (or overvoltage) category

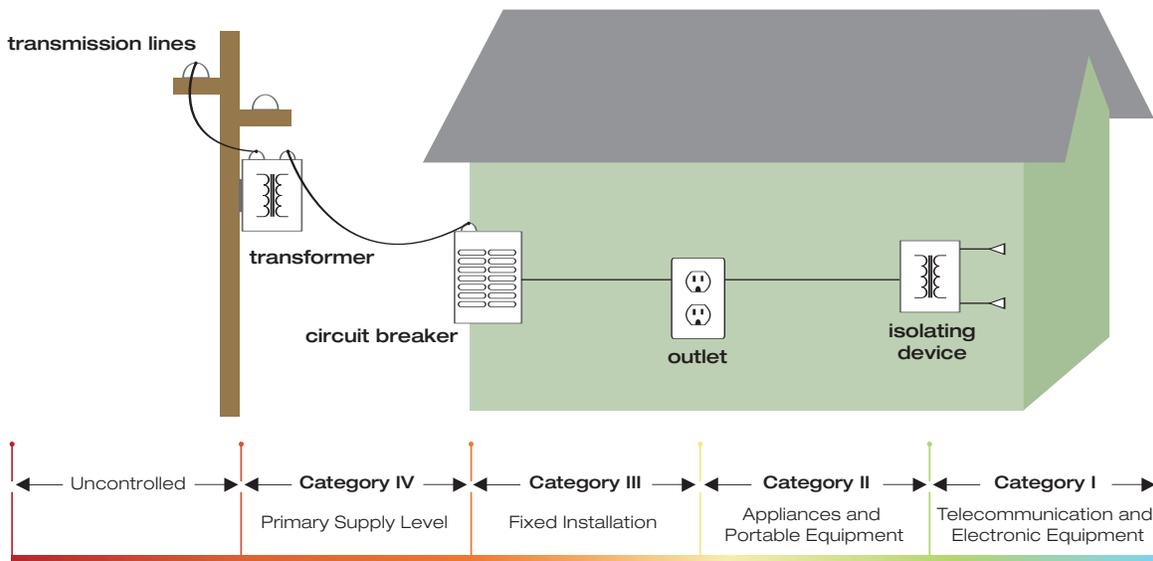
The IEC 61010-1 international standard defines four overvoltage categories for voltage-measuring instruments. The overvoltage categories I through IV are defined by how much electrical energy could be present during a transient.

Based on IEC 61010-1, voltage-measuring instruments are rated on their ability to withstand a voltage transient.

#### Summary Description of Categories

<b>CAT IV</b>	For measurements performed at the source of a low voltage installation ( $\leq 1,000$ V).
<b>CAT III</b>	For measurements performed in the building installation.
<b>CAT II</b>	For measurements performed on circuits directly connected to the low voltage installation.
<b>CAT I</b>	For measurements performed on circuits not directly connected to MAINS.

2. Determine maximum floating voltage.
3. Determine maximum tip to ground voltage.
4. Determine the maximum voltage from probe tip to the reference lead.
5. Determine maximum peak to peak reading desired on screen.



► IEC Installation Categories.

(true power, reactive power, true power factor, phase angle), waveform analysis measurements (RMS, crest factor, frequency), harmonic measurements, and switching loss measurements.

Designers of products operating on industrial power perform power measurements for design validation, troubleshooting, certification and more.

The devices under test range from industrial motor controllers to power quality correctors. This work often involves higher voltages and currents and requires the designers to measure floating voltages.

## Mind your CATs and Volts (continued):

### Selecting the proper voltage probe for your TPS2000 Series Oscilloscope

	Probe Name			
	P2220	P5120	P5205*	P5210*
Maximum tip to ground voltage	300 V <sub>RMS</sub> CAT II	1000 V <sub>RMS</sub> CAT II	1000 V <sub>RMS</sub> CAT II	1000 V <sub>RMS</sub> CAT III
Maximum ref. to ground (floating) voltage	30 V <sub>RMS</sub>	600 V <sub>RMS</sub> CAT II		
Differential mode voltage			1300V DC + pk AC [1000 V <sub>RMS</sub> CAT II]	5600V DC + pk AC [1000 V <sub>RMS</sub> CAT II]
Attenuation settings	1x / 10x	20x	50x / 500x	100x / 500x
Probe type	passive	passive	differential	differential

\*1103 power supply required to operate with TPS2000 Series.

#### Example:

Need to measure peak to peak voltages on Line-to-Line 240V<sub>RMS</sub> 3-phase wye Active Harmonic Filter.

#### 1. Installation category: CAT III

To determine the maximum rated input voltage at a higher category than is marked on a product, simply step down to the next designated voltage level. The levels are:

1,000V | 600V | 300V | 150V | 50V

#### 2. Maximum floating voltage (ground to reference voltage):

approximately 140V<sub>RMS</sub>

Must use at least P5120 probe.

#### 3. Maximum tip to ground voltage:

approximately 140V<sub>RMS</sub>

All four probes meet this requirement.

#### 4. Maximum voltage from probe tip to the reference lead:

240V<sub>RMS</sub>

Must use at least P5120 probe.

#### 5. Attenuation needed.

Calculate peak to peak voltage of 240V<sub>RMS</sub>.

Viewing voltage desired:

$$240V_{RMS} \times \sqrt{2} \times 2 = 679 V$$

TPS2000 Series maximum vertical setting is 5V/div and there are 8 divisions.

Probe attenuation needed = viewing voltage / 5 / 8

$$679 V / 5 / 8 = 17 x$$

Must use at least P5120 probe.

## Contact Tektronix:

ASEAN / Australasia / Pakistan (65) 6356 3900  
Austria +41 52 675 3777  
Balkan, Israel, South Africa and other ISE Countries +41 52 675 3777  
Belgium 07 81 60166  
Brazil & South America 55 (11) 3741-8360  
Canada 1 (800) 661-5625  
Central East Europe, Ukraine and the Baltics +41 52 675 3777  
Central Europe & Greece +41 52 675 3777  
Denmark +45 80 88 1401  
Finland +41 52 675 3777  
France & North Africa +33 (0) 1 69 86 81 81  
Germany +49 (221) 94 77 400  
Hong Kong (852) 2585-6688  
India (91) 80-22275577  
Italy +39 (02) 25086 1  
Japan 81 (3) 6714-3010  
Luxembourg +44 (0) 1344 392400  
Mexico, Central America & Caribbean 52 (55) 56666-333  
Middle East, Asia and North Africa +41 52 675 3777  
The Netherlands 090 02 021797  
Norway 800 16098  
People's Republic of China 86 (10) 6235 1230  
Poland +41 52 675 3777  
Portugal 80 08 12370  
Republic of Korea 82 (2) 528-5299  
Russia & CIS 7 095 775 1064  
South Africa +27 11 254 8360  
Spain (+34) 901 988 054  
Sweden 020 08 80371  
Switzerland +41 52 675 3777  
Taiwan 886 (2) 2722-9622  
United Kingdom & Eire +44 (0) 1344 392400  
USA 1 (800) 426-2200

For other areas contact Tektronix, Inc. at: 1 (503) 627-7111  
Updated 15 June 2005

### For Further Information

Tektronix maintains a comprehensive, constantly expanding collection of application notes, technical briefs and other resources to help engineers working on the cutting edge of technology. Please visit [www.tektronix.com](http://www.tektronix.com)



Copyright © 2005, Tektronix, Inc. All rights reserved. Tektronix products are covered by U.S. and foreign patents, issued and pending. Information in this publication supersedes that in all previously published material. Specification and price change privileges reserved. TEKTRONIX and TEK are registered trademarks of Tektronix, Inc. All other trade names referenced are the service marks, trademarks or registered trademarks of their respective companies.  
09/05 DM/WOW 3AW-19134-0

**Tektronix**  
Enabling Innovation

