



A New Approach to Quick, Accurate, Affordable Floating Measurements

Technical Brief

Tektronix IsolatedChannel™ Technology

Engineers and technicians often need to make “floating” measurements where neither point of the measurement is at ground (earth) potential. This measurement is often referred to as a differential measurement. “Signal common” may be elevated to hundreds of volts from earth.

In addition, many of these differential measurements require the rejection of high common-mode signals*1 in order to evaluate low-level differential signals. Unwanted ground

currents can also add bothersome hum and ground loops. Too often, users resort to the use of potentially dangerous measurement techniques to overcome these problems.

The TPS2000B Series oscilloscopes use innovative IsolatedChannel technology to deliver the world’s first 4-isolated-channel, battery-operated oscilloscope to allow engineers and technicians to make multi-channel isolated measurements quickly, accurately and affordably—all designed with your safety in mind.

*1 A “common-mode signal” is defined as a signal that is present at both points in a circuit. Typically referenced to ground, it is identical in amplitude, frequency, and phase. Making a floating measurement between two points requires rejecting the “common-mode signal” so the difference signal can be displayed.

Floating an Oscilloscope: A Definition

“Floating” a ground-referenced oscilloscope is the technique of defeating the oscilloscope’s protective grounding system—disconnecting “signal common” from earth, by either defeating the grounding system or using an isolation transformer. This technique allows accessible parts of the instrument such as chassis, cabinet, and connectors to assume the potential of the probe ground lead connection point. This technique is dangerous, not only from the standpoint of elevated voltages 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 may lead to future dangerous failures (a shock and fire hazard), even after returning the oscilloscope to properly grounded operation.

Not only is floating a ground-referenced oscilloscope dangerous, but the measurements are often inaccurate. This potential inaccuracy results from the total capacitance of the oscilloscope chassis being directly connected to the circuit-under-test at the point where the ground lead is connected.

A Guide to Making Quick, Accurate and Affordable Floating Measurements

There are several products that enable you to make floating measurements, but they may lack the versatility, accuracy or affordability that you need. In addition, there are four key

measurement considerations that a user needs to take into account when selecting the right product to make an accurate floating or differential measurement:

1. What is the differential measurement range?
2. What is the common mode measurement range?
3. What are the loading characteristics of the probe? Are they balanced or unbalanced?
4. What is the Common Mode Rejection Ratio (CMRR) over the measurement frequency range?

Management and Safety in the Workplace

While the subject of this technical note is floating measurements, some definitions of terms and general precautions must be understood before proceeding. Historically, floating measurements have been made by knowingly defeating the built-in safety ground features of oscilloscopes or measurement instruments in various manners.

THIS IS AN UNSAFE AND DANGEROUS PRACTICE AND SHOULD NEVER BE DONE!

Instead, this technical note describes instruments, accessories, and practices that can make these measurements safely as long as standard safety practices and precautions are observed.

When making measurements on instruments or circuits that are capable of delivering dangerously high-voltage, high-current power, measurement technicians should always treat exposed circuits, bus-bars, etc., as being potentially “live,” even when circuits have been shut off or disconnected. This is particularly true when connecting or disconnecting probes or test leads.

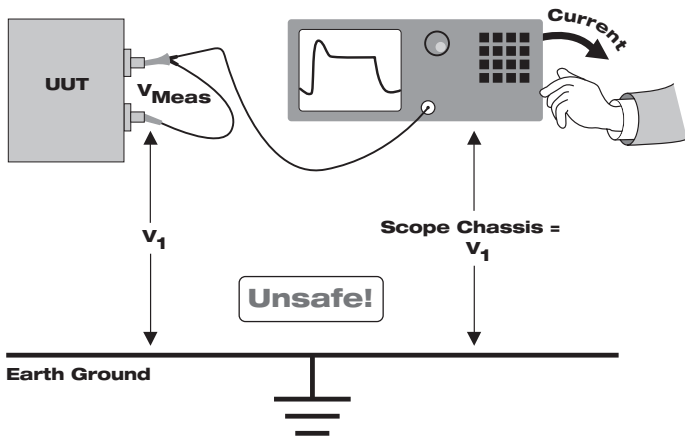


Figure 1. A floating measurement in which dangerous voltages occur on the oscilloscope chassis. V_1 may be hundreds of volts!

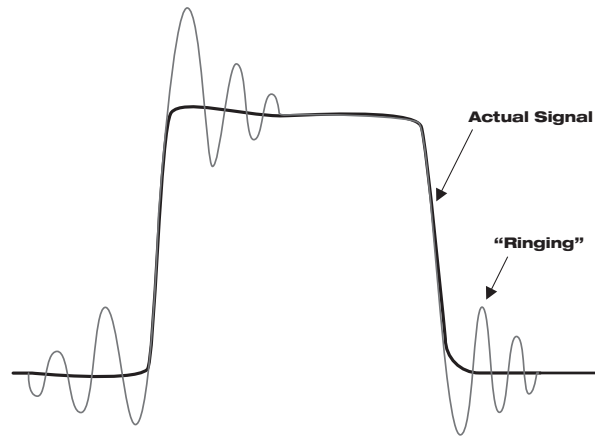


Figure 2. Ringing caused by parasitic inductance and capacitance distorts the signal and invalidates measurements.

Traditional Oscilloscopes

Traditional oscilloscopes are limited to making ground-referenced measurements. Let's examine why:

- Most oscilloscopes have their “signal common” 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 very near to) zero volts by virtue of the third-wire ground in the power cord for AC-powered equipment. It also means that, with few exceptions, all measurements must be made with respect to earth ground. This constrains the typical oscilloscope (at least in a single measurement) from being used to measure potential differences between two points where neither point is at earth ground.
- A common, but risky, practice is to disconnect the oscilloscope's AC main power cord ground and attach the probe ground lead to one of the test points. Tektronix strongly recommends against this unsafe measurement practice. Unfortunately, this practice puts the instrument chassis, which is no longer grounded to earth, at the same voltage as the test point that the probe ground lead is connected to. The user touching the instrument becomes

the shortest path to earth ground. Figure 1 illustrates this dangerous situation. V_1 is the “offset” voltage above true ground, and V_{Meas} is the voltage to be measured. Depending upon the unit-under-test (UUT), V_1 may be hundreds of volts, while V_{Meas} might be a fraction of a volt.

- Floating the chassis ground in this manner threatens the user, the UUT, and the instrument. In addition, it violates industrial health and safety regulations, and yields poor measurement results. Moreover, line-powered instruments exhibit a large parasitic capacitance when floated above earth ground. As a result, floating measurements will be corrupted by ringing, as shown in Figure 2.
- Battery-operated oscilloscopes, such as the TDS3000C Series oscilloscopes, when operated from AC line power using a standard power cord, exhibit the same limitations as traditional oscilloscopes. However, AC power is not always available where you want to make oscilloscope measurements. In the case of the TDS3000C Series oscilloscopes, the optional battery pack (TDS3BATC) allows you to operate the oscilloscope without the need for AC power. However, it can only make safe floating measurements up to 30 VRMS.
- Traditional oscilloscopes emphasize performance (bandwidth, versatility), trading off the ability to make floating measurements.

Differential or Isolated Probes

Differential or isolated probes offer a safe and reliable way to adapt a grounded oscilloscope to make floating measurements. Neither of the two probe contacts need be at earth ground and the probe system as a whole is isolated from the oscilloscope's chassis ground.

Differential probes offer a balanced impedance load to the device-under-test (DUT). However, they add a layer of cost and complexity to the measurement apparatus. They may require an independent power supply, and their gain and offset characteristics must be factored into every measurement. Differential probe-equipped oscilloscopes emphasize performance and safety (bandwidth, isolation), trading off form-factor benefits such as portability and cost.

Signal Fidelity Begins at the Probe Tip

An oscilloscope is actually a measurement system consisting of preamplifiers, acquisition/measurement circuits, displays, and probes. The role of the probe is sometimes overlooked. Nevertheless, improper probes or probing techniques can affect the measurement outcome. Obviously, it's essential to use compatible probes that match the instrument's bandwidth and impedance.

Less understood is the effect of ground-lead inductance. As lead length increases, parasitic inductance increases ($L_{\text{parasitic}}$ in Figure A). $L_{\text{parasitic}}$ is in the signal path and forms a resonant LC circuit with the inherent parasitic capacitance of the oscilloscope ($C_{\text{parasitic}}$). As $L_{\text{parasitic}}$ increases, the resonant frequency decreases, causing "ringing" (see Figure 2) that visibly interferes with the measured signal. Simply stated, the common lead must be as short as physical constraints of the circuit-under-test will allow.

In regard to capacitance, even isolated, battery-powered oscilloscopes exhibit capacitance with respect to earth ground. In Figure A, $C_{\text{parasitic}}$ describes the oscilloscope's parasitic capacitance from its ground reference (through the isolated housing) to earth ground. Like parasitic inductance, $C_{\text{parasitic}}$ must be kept to a minimum in order to force the resonant frequency of the LC circuit as high as possible. If $C_{\text{parasitic}}$ is large, ringing may occur within the test frequency range, hampering the measurement.

An instrument's parasitic capacitance to ground is dictated by its internal design. The physical environment can also prompt ringing. Holding the instrument or placing it on a large conductive surface during measurements can actually increase $C_{\text{parasitic}}$ and lead to ringing. For extremely sensitive measurements, it might even be necessary to suspend the oscilloscope in mid-air!

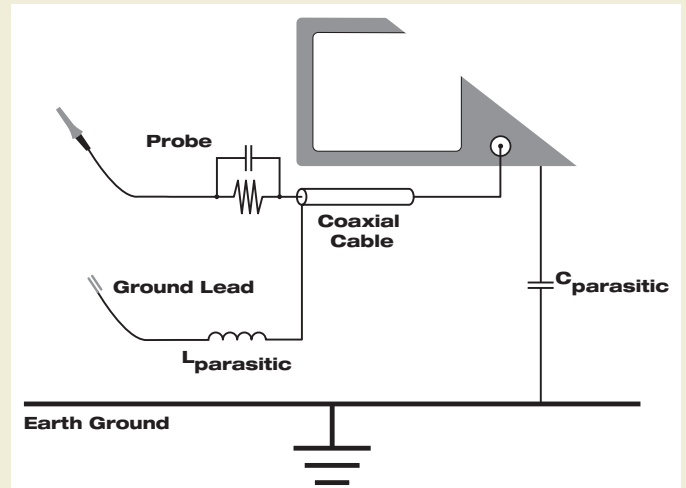


Figure A. Parasitic inductance and capacitance can affect measurement quality.

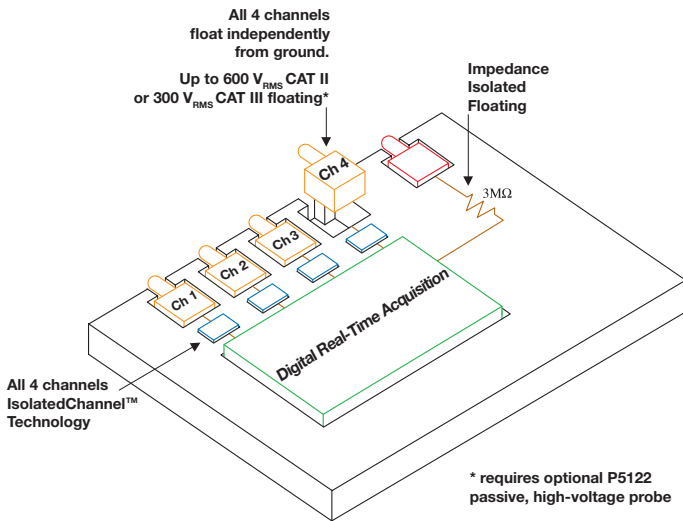


Figure 3. TPS2000B Series oscilloscope's IsolatedChannel architecture provides complete isolation from dangerous voltages.

A New Approach to Quick, Accurate, Affordable Floating Measurements

The most common method of isolation in a wide bandwidth oscilloscope system in use today is a two-path approach in which the input signal is broken up into two signals: low frequency and high frequency. This approach requires expensive optocouplers and wideband linear transformers for each input channel.

The TPS2000B Series uses an innovative approach, IsolatedChannel technology, which eliminates the two-path method and uses only one wideband signal path for each input channel—from DC to the bandwidth of the oscilloscope. This patent-pending technology enables Tektronix to offer the world's first four-input IsolatedChannel, low-cost, battery-operated oscilloscope, featuring eight hours of continuous battery operation. The TPS2000B Series oscilloscopes are ideal for engineers and technicians who need to make four-channel isolated measurements and need the performance and ease-of-use of a low-cost, battery-operated oscilloscope.

The TPS2000B Series' four IsolatedChannel input architecture provides true and complete channel-to-channel isolation for both the "positive" input and the "negative reference" leads, including the external trigger input. Figure 3 illustrates the IsolatedChannel concept.

The most demanding floating measurement requirements are found in power control circuits, such as motor controllers and uninterruptible power supplies, and industrial equipment. In such application areas, voltages and currents may be large enough to present a threat to users and test equipment.

IsolatedChannel technology is the preferred solution for measurement quality and is designed with your safety in mind.² The TPS2000B oscilloscopes offer an ideal solution when a large common mode signal is present. True channel-to-channel isolation minimizes parasitic effects; the smaller mass of the measurement system is less prone to interaction with the environment. A properly isolated battery-powered instrument doesn't concern itself with earth ground. Each of its probes has a "Negative Reference" lead that is isolated from the instrument's chassis, rather than a fixed ground lead. Moreover, the "Negative Reference" lead of each input channel is isolated from that of all other channels. This is the best insurance against dangerous short circuits. It also minimizes the signal-degrading impedance that hampers measurement quality in single-point grounded instruments.

The TPS2000B Series oscilloscope inputs are always floating whether operated from battery power or connected to AC power through an AC power adapter. Thus, these oscilloscopes do not exhibit the same limitations as traditional oscilloscopes.

Speed Debug and Characterization with DRT Sampling Technology

The TPS2000B Series oscilloscopes offer digital real-time (DRT) acquisition technology that allows you to characterize a wide range of signal types on up to four channels simultaneously. Up to 2 GS/s real-time sample rate is the key to the extraordinary bandwidth—200 MHz in the TPS2024B. This bandwidth/sample rate combination makes it easy to capture the high-frequency information, such as glitches and edge anomalies, that eludes other oscilloscopes in its class, so that you can be sure to get a complete view of your signal to speed debug and characterization.

² Do not float the P2220 probe common lead to > 30 VRMS. Use the P5122 probe (floatable to 600 VRMS CAT II or 300 VRMS CAT III) or a similarly rated passive high-voltage probe, or an appropriately rated high-voltage differential probe when floating the common lead above 30 VRMS, subject to the ratings of such high-voltage probe.

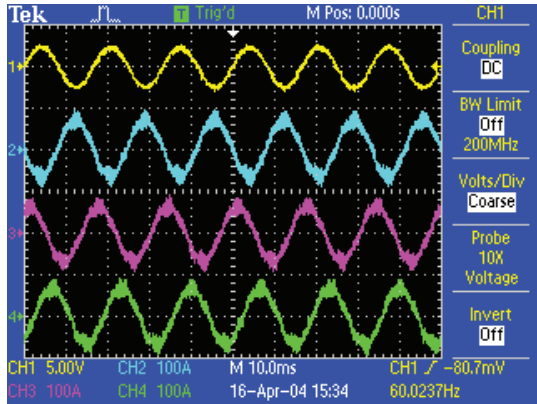


Figure 4. The 4-channel TPS2024B oscilloscope’s channel-to-channel isolation eliminates cross-talk effects when large and small signals are captured simultaneously.

Making Quick, Accurate Floating Measurements with TPS2000B Series Oscilloscopes

Power Control Circuits

Power control technologies use both high-power silicon components and low-power logic circuits. The switching transistors at the heart of most power control circuits require measurements not referenced to ground. Moreover, the power circuit may have a different ground point (and therefore a different ground level) than the logic circuit, yet the two often must be measured simultaneously.

The channel-to-channel isolation of the TPS2000B Series provides a real-world measurement advantage in addition to its obvious safety benefits. Figure 4 is a screen image depicting waveforms taken at two different points in a power control circuit. Notice that the lower waveforms are about 200 A_{p-p}, while the upper trace is about 5 V_{p-p}. Because each of the TPS channels is fully isolated from the other (including the negative reference leads), and equipped with its own uncompromised Digital Real Time digitizer, there’s no cross-talk between the two signals. Were the oscilloscope channels not adequately isolated, there might be misleading artifacts coupled from the 200 A signal to the smaller waveform; these might be misinterpreted as a circuit problem when in reality it’s an instrument problem. The ability of the TPS Series to discretely capture two waveforms of vastly differing amplitudes reduces guesswork and improves productivity.

Harmonics Measurements Reveal Unseen Power Problems

An understanding of the harmonics within a power grid is essential to the safe and cost-effective use of electrical power. Line harmonics are a growing problem in a world moving increasingly toward nonlinear power supplies for most types

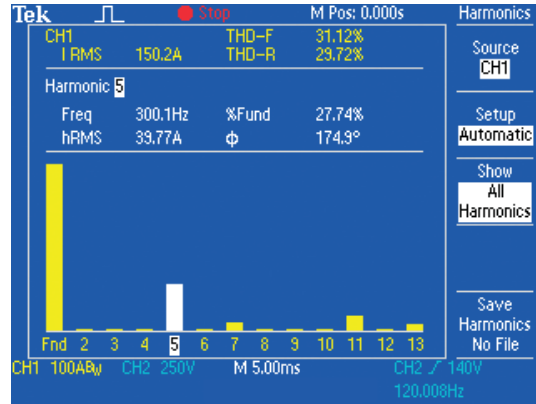


Figure 5. Harmonic distortion measurements.

of electronic equipment. Nonlinear loads, such as switching power supplies, tend to draw non-sinusoidal currents. Their impedance varies over the course of each cycle, creating sharp positive and negative current peaks rather than the steady curve of a sine wave. The rapid changes in impedance and current in turn affect the voltage waveform on the power grid. As a result, the line voltage is corrupted by harmonics; the normally sinusoidal shape of the voltage waveform may be flattened or distorted.

There’s a limit to the amount of harmonic distortion that equipment can tolerate. Load-induced harmonics can cause motor and transformer overheating, mechanical resonances, and dangerously high currents in the neutral wires of three-phase equipment. In addition, line distortions may violate regulatory standards in some countries.

The TPS2024B’s comprehensive, four-channel capability, along with its optional power analysis software, enables connection to all three conductors of a three-phase system to measure and analyze line harmonics. Its “Harmonics” mode—invoked with a single button—captures the fundamental frequency plus harmonics through 50. Using only the oscilloscope’s standard voltage probe, it’s possible to execute a harmonic voltage measurement. An optional current probe acquires current harmonics with the same ease.

Figure 5 illustrates a current harmonic measurement. The amplitudes are computed by the instrument’s internal DFT (Discrete Fourier Transform) algorithm. In this case the bar graph reveals a very strong fifth harmonic level. Excessive fifth harmonic levels (along with certain other odd harmonics) are a classic cause of neutral-wire currents in three-phase systems.

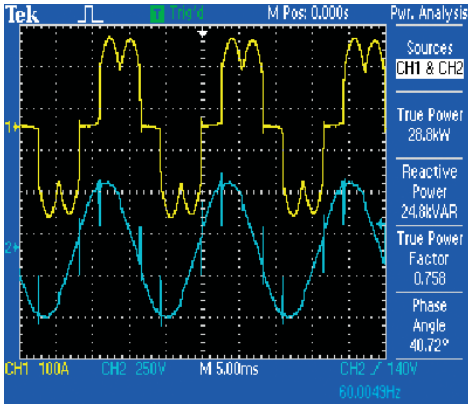


Figure 6. TPS Series' instantaneous power analysis.

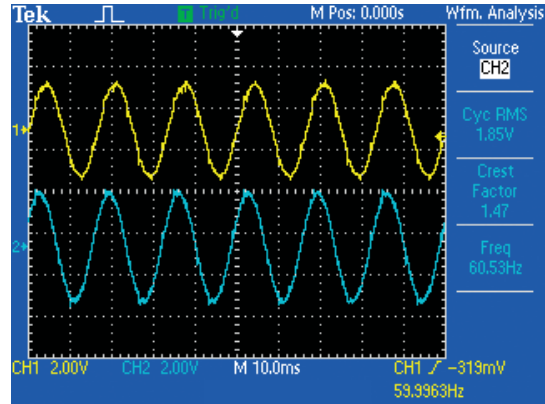


Figure 7. TPS Series' waveform analysis.

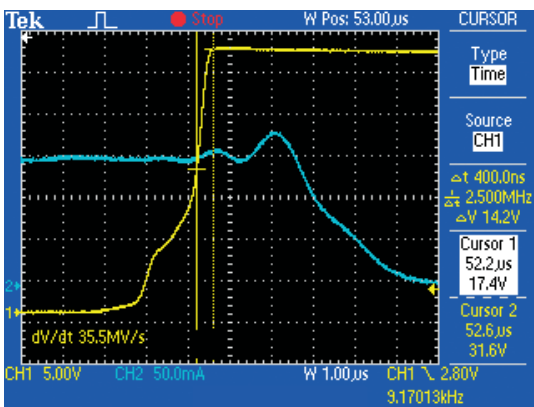


Figure 8. TPS Series' dv/dt and di/dt cursors (dv/dt cursors shown).

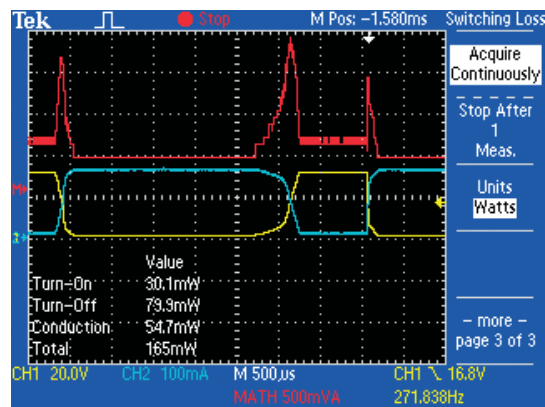


Figure 9. TPS Series' switching loss display showing turn-on, turn-off and conduction losses

Power Readings—More than Just Watts

Voltage and current measurements are by nature straightforward and absolute. A test point has only one voltage and one current value at a given instant in time. In contrast, power measurements are voltage-, current-, time-, and phase-dependent. Terms like “reactive power” and “power factor,” which were devised to characterize this complex interaction, are not so much measurements as computations.

The power factor is of particular interest in these computations. This is because many electrical power providers charge a premium to users whose power factor is not sufficiently close to 1.0, the ideal value. At a power factor of 1.0, voltage and current are in phase. Inductive loads—especially large electric motors and transformers—cause voltage and current to shift phase relative to each other, reducing the power factor. Some utility companies apply a surcharge in such cases because the inefficiency causes energy loss in the form of heat in the power lines. There are procedures to remedy power factor problems, but first the power characteristics must be quantified.

The TPS Series embraces a full suite of power measurements. Among these are true power, reactive power, crest factor, phase relationships, di/dt and dv/dt, and of course power factor. Figures 6, 7 and 8 show TPS Series screen images summarizing these and other power measurements. All of the measurements, with the exception of waveform analysis and phase relationships, require a current probe (or its equivalent) and a voltage probe working in tandem. All of these measurements employ the instrument's one-button application function.

Measuring Switching Loss to Improve Product Efficiency

Today's power designers face increasing pressure to improve the efficiency of their power designs. A major factor affecting the efficiency is the power loss occurring in the switching section of the design. Optimizing this factor can prove complex.

The TPS Series allows the designer to look at switching losses in their design through the instrument's one-button application function. The switching loss will be characterized as turn-on loss, turn-off loss, conduction loss and total device loss.

Conclusion

Engineers and technicians confront high voltages and currents and must often make potentially hazardous floating measurements. Where other alternatives may lack the versatility, accuracy or affordability to make floating measurements, the TPS2000B Series employs unique IsolatedChannel technology to allow engineers and technicians to make these measurements quickly, accurately and affordably.

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