Tektronix

Technical Brief

Floating Oscilloscope Measurements … And Operator Protection

Introduction

Oscilloscope users often need to make "floating" measurements where neither point of the measurement is at ground (earth) potential. "Signal common" may be elevated to hundreds of volts from earth. In addition, many of these measurements require the rejection of high common-mode signals[1] in order to evaluate low-level 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.

Limitations of Traditional Oscilloscopes

Traditional oscilloscope designs cannot effectively handle these problems alone. 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 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.

Tektronix provides several solutions for "floating" measurements which are not only safe but also much more accurate than the sometimes used potentially dangerous procedures (see Table 1).

These solutions meet the safety engineering principles stated in the sidebar on page 2. They fall into four general categories:

- Battery-powered oscilloscopes
- Monolithic isolation amplifiers
- Differential measurement systems
- Isolated input oscilloscopes

[1] **A "common-mode signal" is defined as a signal which is present at both points in a circuit. Typically referenced to ground, it's 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.**

Management And Safety In The Workplace

WARNING

While the subject of this technical note is about 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 which can make these measurements safely as long as standard safety practices and precautions are observed.

WARNING

Whenever making measurements on instruments or circuits which 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.

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, either by defeating the grounding system or using an isolation transformer. This allows accessible parts of the instrument such as chassis, cabinet, and connectors to assume the potential of the probe ground lead connection point. This 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 results from the total capacitance of the oscilloscope chassis being directly connected to the circuit under test at the point where the common lead is connected.

TEKTRONIX RECOMMENDS ONLY THOSE MEASUREMENT TECHNIQUES THAT COMPLY WITH SAFETY ENGINEERING PRINCIPLES AND ENSURE ACCURATE MEASUREMENTS.

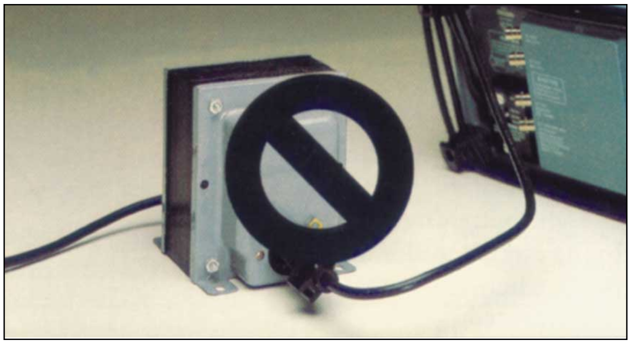
Safety Engineering Principles

Tektronix has adopted many safety principles in the design of their products. Of particular concern to making electrical and electronic measurements are these principles:

- When the instrument is used properly, accessible parts shall not become hazardously live, even in the event of the single worst-case fault.
- Electronic devices (those devices employing conduction in a vacuum, gas, or semiconductor) shall not be relied upon for providing operator protection from electric shock.
- Products should not develop insidious hazards during proper operation (an insidious hazard is a hazard which can develop in a way as to be well established before becoming apparent).
- The operator shall not need to defeat a protective system to make the measurement.

Safety – A Shared Responsibility

The operator and employer share in the responsibility of meeting these principles – through proper operation and measurement techniques.



WARNING

Never attempt to defeat the protective grounding system of your oscilloscope by using an isolation transformer (left) or disconnecting the ground connector on the power plug (right). Failure to follow safety warnings can result in serious injury or loss of life.

Table 1. Methods of Making “Floating” Measurements Using Tektronix Instrumentation

	Meets Safety Engineering Principle	Dynamic Range/ Bandwidth	Ease of Operation	Common-Mode Voltage (Float)	Differential Mode Voltage (Signal)	Common-Mode Reject
Isolation Amplifiers (A6907 and A6909)	✔	High	Medium	<850 V_{RMS}	<850 V_{RMS}	High
Active High Voltage Differential Probes (P5200 Series)	✔	Medium	High	<2,200 V_{RMS}	<4,400 V_{RMS}	Medium
Differential Amplifiers (P6135A)	✔	Medium (+)	Medium (–)	<353 V_{RMS}	<353 V_{RMS}	High
Battery Powered Oscilloscopes (TDS3000 Series)	✔ CAUTION!	Low	High	<30 V_{RMS} ONLY	<30 V_{RMS} ONLY	Low
Isolated Input Oscilloscopes (THS700 Series)	✔	High	High	<600 V_{RMS}	<1,000 V_{RMS}	Low
Isolation Transformers	**WARNING! This Is An Unsafe And Dangerous Practice And Should Never Be Done!**					
Defeating Grounds	**WARNING! This Is An Unsafe And Dangerous Practice And Should Never Be Done!**					

Battery-Powered Oscilloscopes

The TDS3000 Series (see Figure 1), when operated from AC line power using its standard power cord, exhibits the same limitations as traditional oscilloscopes discussed previously.

However, AC power is not always available where you want to make oscilloscope measurements. The TDS3000 Series optional battery pack (TDS3BAT) allows you to operate the oscilloscope without the need for AC power. Observing the following precautions will provide safe operation of the TDS3000 Series oscilloscopes when battery powered.

Figure 2 shows the warning that is displayed on the TDS3000 Series screen when in battery operation mode.

This warning applies to circuits that have voltages of greater than 30 V_{RMS} (>42 V_{pk}). If the circuit under test has voltages that exceed 30 V_{RMS} (>42 V_{pk}), the TDS3000 Series chassis needs to be connected to earth ground using the grounding wire provided with the instrument (Battery Pack) to prevent electrical shock to the operator.

If you do not attach the grounding wire, you are not protected against electrical shock if you connect the oscilloscope to a hazardous voltage.

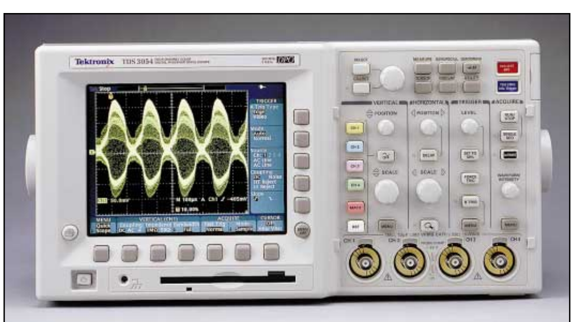
WARNING

Such electrical shock could result in serious personal injury or loss of life.

While in battery operation and following environmental specification limits for the TDS3000 Series, it is safe to “float” the “signal common” for making measurements provided you do not connect a signal greater than 30 V_{RMS} (>42 V_{pk}) from earth ground to either the probe tip or common lead. For measurements where higher voltages {>30 V_{RMS}, >42 V_{pk}) are present, the instrument’s chassis must be connected to earth ground using the supplied grounding wire to prevent electrical shock to the operator.

WARNING

If there is any doubt whether more than 30 V_{RMS} is present or not, the supplied grounding wire should always be used and floating measurements SHOULD NOT BE ATTEMPTED! Be aware that hazardous voltages may exist in unexpected places due to faulty circuitry in the device-under-test.



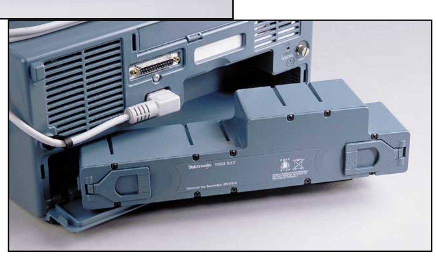


Figure 1. TDS30xx Digital Phosphor Oscilloscope (above). Optional TDS3BAT Battery Pack (right).

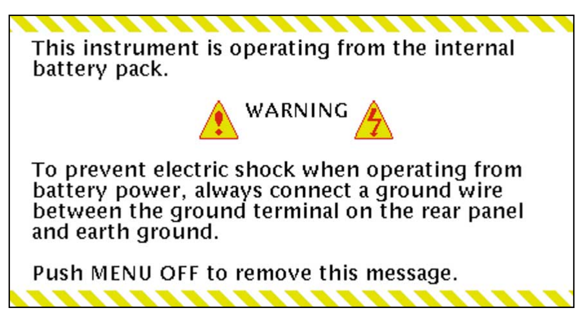


Figure 2. Warning displayed by TDS3000 Series when operating in battery mode.

It's important to remember that the "signal commons" for all channels are at the same potential and are **NOT** independent. Ensure that all probe common leads are connected to the same voltage or common point.

Do not connect a grounded device, such as a printer or computer, to the oscilloscope unless the oscilloscope's grounding wire is connected to earth ground!

In order to perform differential measurements with independent "signal grounds," true differential probes such as the P5205 or P5210 must be used.

Monolithic Isolation Amplifiers

The Tektronix A6900 Series monolithic isolation amplifiers (see Figure 3) connect between the oscilloscope and the circuit-under-test. The signal is coupled across an electro-optical isolation barrier, providing the necessary isolation. Monolithic voltage isolators provide multiple channels with different "common" potentials in a convenient portable package. These units are designed to be used next to the measurement instrument where physical separation is not a requirement.

Because multiple channels are contained within a single unit, the cost per channel is lower and the actual circuit-to-instrument connections are simplified.

The A6900 Series monolithic voltage isolators are essential tools for power conversion design. The A6907 and A6909 offer safety, performance, multiple isolated channels (A6907 – four channels, A6909 – two channels), direct connection to the measurement instrument, and simplified controls in a single instrument package.

Total Galvanic isolation is accomplished through the use of electro-optical and optical-electro converters. The isolator chassis is referenced to ground to ensure safety while making floating measurements.

The A6900 Series isolators feature a bandwidth of 60 MHz and GPIB control (standard on the A6907; available as Option 10 for the A6909), in a compact package. The CMRR is 105 dB (178,000:1) at 60 Hz, 60 dB (1,000:1) at 1 MHz and 50 dB (316:1) at 10 MHz. The 850 V probes plug directly into the isolators and are specifically designed for safe connection to floating circuits and enhanced CMRR.

These microprocessor controlled instruments feature push-button self-calibration of offset and gain for increased accuracy. Coupling and attenuation for each channel can be individually set.

The A6907 and A6909 satisfy third party safety standards.

Figure 3. A6905 two-channel isolation amplifier (right); A6907 four-channel isolation amplifier (left). Shown with probes.

Differential Measurement System

Pseudo-Differential Techniques. The most popular solution to the need for a "floating" measurement is the "A minus B" pseudo-differential technique. Most general-purpose dual-trace oscilloscopes have an ADD Mode where the two channels can be electrically subtracted (invert CH 2), giving a display of the difference signal. Higher voltage probes such as the P5100 (2,500 V, 100X – see Figure 4) are used, but they limit minimum sensitivities. This can be a problem when attempting to examine low-level control signals in the presence of high common-mode voltages. Also, the common-mode dynamic range is severely limited (+1 division beyond screen height) and common-mode rejection ratio (CMRR) is low – approximately 20 to 1.

True Differential Techniques. True differential amplifiers feature complementary inputs (+ and –) and offer high CMRR – as high as 10,000 to 1 or higher for many instruments. Since the amplifier's ability to reject the common-mode component depends on the degree to which the two channels remain balanced, its common-mode rejection ratio will decrease with frequency (imbalance due to effects of stray C, etc.) and with the magnitude of the common-mode signal (imbalance due to effects of amplifier overdrive).

Use of a differential probe pair such as the P6135A (see Figure 5) is essential to maintain maximum CMRR.

Figure 4. P5100 High Voltage Passive Probe.

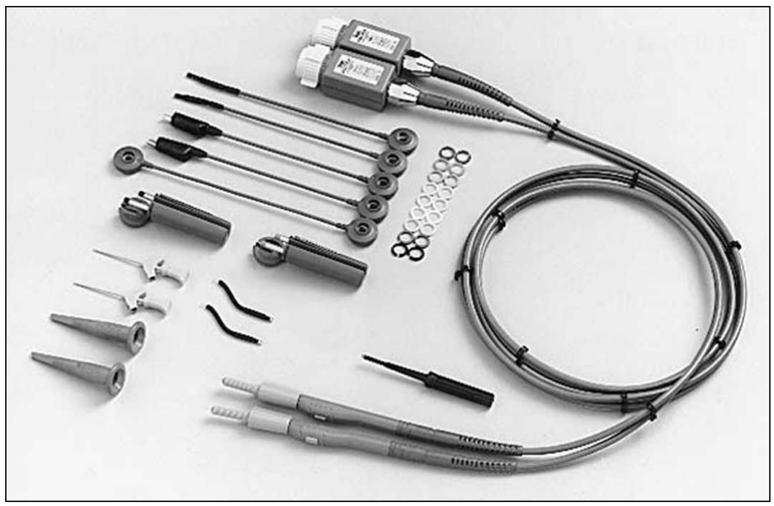


Figure 5. P6135A Differential Passive Voltage Probe pair.

High-Voltage Active Differential Probes. The P5200 Series High Voltage Active Differential Probes are economical, heavy-duty solutions for making safe, accurate floating measurements with any oscilloscope. With true differential amplifiers in the probe heads, the compact P5200 Series are rated for differential voltage measurements up to 4,400 V_{RMS} (5,600 V (DC + pk AC)) depending on the probe chosen.

Circuit connections are made by leads terminated by standard 4 mm shrouded banana plugs. The included crocodile clips and insulated plunger style clamps enable safe, easy connections to a wide range of test points from bus bars to IC legs, even when "hot."

The P5200 (see Figure 6) connects directly to the BNC input of the measurement instrument and is powered by a 9 V wall adapter. The P5200 has a bandwidth of 25 MHz with CMRR of 50 dB at 1 MHz.

The P5205 (Figure 7) and P5210 (Figure 8) use the Tektronix, Inc. TekProbe® interface system found on the TDS3000, TDS 400, TDS 500, TDS 600, and TDS 700 oscilloscope systems. The TekProbe interface provides probe power, readout, and many other features not readily available on common probes.

The P5205 has a bandwidth of 100 MHz and a voltage level of 1,300 V_{RMS}. At 4,400 V_{RMS}, the P5210 can measure frequencies up to 50 MHz. Both probes provide a CMRR of 50 dB at 1 MHz.

The P5200 Series High Voltage Active Differential Probes satisfy today's third party safety standards

Figure 6. P5200 High Voltage Active Differential Probe.

Figure 7. P5205 High Voltage Active Differential Probe.

Figure 8. P5210 High Voltage Active Differential Probe.

Isolated-input Oscilloscopes

Isolated-input oscilloscopes such as the Tektronix THS700 Series (THS710A, 60 MHz; THS720A, 100 MHz; THS730A, 200 MHz; THS720P, 100 MHz – see Figure 9) are hand-held, battery operated oscilloscopes that feature dual input channels, individually isolated from the oscilloscope's chassis as well as from each other. This allows dual-trace waveform comparisons to be made, with each of the two channels referenced to its own common. The safe operating voltage of these oscilloscopes depends on the probes used.

The standard 10X P6117 probe is rated for IEC category II applications up to 300 V_{RMS} tip-to-common, with the common lead floating up to 30 V_{RMS} above earth ground. This range is suitable for most typical measurements on low-voltage electronics circuits.

For higher voltage applications, the THS710A, THS720A, THS720P, and THS730A, with the 10X P5102 Probe (see Figure 10), are rated for IEC category II applications up to 1,000 V_{RMS} tip-to-common, with the common lead floating up to 600 V_{RMS} above earth ground. This combination of scope and probe takes full advantage of the THS700 Series IsolatedChannel™ architecture and allows safe probing of floating signals, providing protection to both the user and the equipment under test.

Conclusion

Tektronix has reviewed these methods in an effort to increase user awareness regarding the potential dangers inherent in the improper operation of oscilloscopes.

Our commitment to Test and Measurement Product Safety has resulted in the isolated input oscilloscope, isolation amplifiers, and differential products described here. If you feel your applications would be more safely and accurately served by these products, please contact your nearest Tektronix representative.

Figure 9. THS720P TekScope Isolated Channel oscilloscope.

Figure 10. P5102 High Voltage Probe for the THS700 Series.

For further information, contact Tektronix:

Worldwide Web: For the most up-to-date product information, visit our web site at www.tektronix.com.

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