FLOATING OSCILLOSCOPE MEASUREMENTS ... AND OPERATOR PROTECTION

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INTRODUCTION

The Measurement Need

Oscilloscope users often have 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 in order to evaluate low level signals. Unwanted ground currents can also add bothersome hum and ground loops to displays. Too often, these problems force users into using dangerous measurement techniques.

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. The reason for this is that all signals applied to or supplied from the oscilloscope must have a common connection point. This is usually the oscilloscope chassis, and is at zero voltage. To stop one input or output from becoming live when another is connected to a signal, the common connection point is connected to the oscilloscope's protective grounding system. It also means that, with few exceptions, all measurements must be made with respect to earth. This constrains the ubiquitous oscilloscope (at least in a single measurement) from being used to measure potential differences where neither point is at earth.

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MANAGEMENT AND SAFETY IN THE WORKPLACE

Most managers are well aware of the need for safety in the workplace. In this brochure we review ten popular methods of making floating oscilloscope measurements. Four of these methods violate two or more safety engineering principles. Tektronix strongly discourages these methods.

Floating Scopes: A Definition

"Floating" a scope is the technique of defeating the scope's protective grounding system — disconnecting "signal common" from earth — allowing accessible parts such as chassis, enclosure, and connectors to assume the potential of whatever the probe ground lead is connected to. This is dangerous, not only from the standpoint of immediately elevated voltages present on the scope (a shock hazard to the operator), but also due to the cumulative stresses on the scope's power transformer insulation. This stress may cause future dangerous failures (a shock and fire hazard), even after returning the oscilloscope to proper grounded operation!

Tektronix recommends only those measurement techniques that comply with safety engineering principles.

Safety Engineering Principles

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

- Accessible parts shall not be 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 so gradually as to be well established before becoming apparent).
- The operator shall not need to defeat a protective system to make his measurement.
- No switch shall be placed in series with the protective grounding conductor.

Of course, the operator and employer share in the responsibility of meeting these principles — through proper operation and measurement techniques.

METHODS OF MAKING FLOATING SCOPE MEASUREMENTS

	Meets Safety Principles	Dynamic Range/ Bandwidth	Flexibility	Ease of Operation	Isolation Voltage	Cost
1. Isolation Amplifiers	✓	High	High	High	A6902 ≤1500 V	Moderate
2. Indirect Grounding	✓	High	High (−)	High	A6901 ≤40 V	Low
3. Differential Techniques	✓	Medium (+)	Medium (−)	Medium (−)	7A13 ≤500 V	Moderate
4. ALL Insulated Oscilloscopes	✓	Medium (−)	Medium (−)	Medium (+)	221 ≤250 V/≤750 V	Moderate
5. Grounded Oscilloscope	✓	High	High	High	7854 ≤250 V	High
6. IC Isolation Amplifiers	✓	Low (−)	Low (−)	High	≤2000 V	Low
7. Isolation Transformers	⊘			See Text		
8. Double Insulated Mains	⊘			See Text		
9. Isolating Circuits	⊘			See Text		
10. Defeating Grounds	⊘			See Text		

SOLUTIONS WHICH MEET SAFETY PRINCIPLES

Isolation Amplifiers

The isolating amplifier is connected between the signal under investigation and the oscilloscope. With respect to the signal, it is all-insulated, with no accessible conductive parts. The signal is coupled across an insulating barrier to the oscilloscope. Use of the isolation amplifier maintains the usability of all scope functions.

The Tektronix A6902 Isolator is an isolation amplifier comprised of two identical amplifiers, isolated from each other, isolated from accessible parts, isolated from the mains, and isolated from ground. It is capable of enabling a scope to measure potentials from ±20 mV to as much as ±1500 V. Each signal "common" lead can be independently connected to separate voltages up to + or − 1500 V. The A6902 provides measurement capability of two such signals simultaneously, with any dual trace oscilloscope.

The A6902 is designed to meet worldwide safety standards. These include UL1244, IEC 348, VDE 0411, BS 4743, and CSA Electrical Bulletin 556B.

A Solution with Protection: A6902 Isolator.

Indirect Grounding

Safety standards specify indirect grounding as an alternative to direct grounding. All of the grounding requirements apply, except that the grounding circuit need not be completed until such time as the available voltage or current exceeds a prescribed amount. This is one solution to floating that also provides protection.

The Tektronix A6901 Ground Isolation Monitor is an indirect grounding device. It is connected between the mains and the oscilloscope. When activated, it disconnects the scope's protective grounding system and monitors the voltage and current on the isolated ground. If this voltage exceeds 40 volts peak and a preselected current (0.5 ma, 3.5 ma, or 5.0 ma), the A6901 disconnects the power to the scope, sounds an audible alarm, and re-connects the scope's protective grounding conductor.

The A6901 can be used with any grounded oscilloscope. It also tests ground continuity of the system it is operated in and will not activate if the system ground is inadequate. It solves the problems of defeating the protective ground and provides the means by which to make valid measurements with any oscilloscope.

The A6901 is designed to meet worldwide safety standards. These include UL1244, IEC 348, VDE 0411, BS 4743, and CSA Electrical Bulletin 556B.

A Solution with Protection: A6901 Ground Isolation Monitor.

Differential Techniques: Quasi and True Differential

The most popular solution to the need for a "floating" measurement is the A minus B quasi-differential technique. Most general purpose dual trace scopes have an ADD Mode where the two channels (invert CH 2) can be electrically subtracted, giving a display of the difference signal. Higher voltage probes such as the P6009, (1500 V, 100X) are used, but limit minimum sensitivities to .05 V/Div to 1 V/Div. 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 (±6 divisions beyond screen height) and CMRR is low, approximately 40 db.

A Solution with Protection: 465B Oscilloscope.

True differential solutions are amplifiers specifically designed to have good rejection of the common-mode signal and display only the difference signal. Because these amplifiers are, basically, two ground-referenced amplifiers, they have limited "floating" or common-mode capability. Furthermore, their ability to display a small signal in the presence of a large common-mode signal changes as a function of the absolute magnitude of the common-mode signal, as well as the ratio of the common-mode signal to the difference signal. And, there are bandwidth limitations. The Tektronix 7A13 provides 500 V of common-mode dynamic range at 0.1 V/Div with a CMRR of at least 60 db and a bandwidth up to 105 MHz.

A Solution with Protection: 7A13 Differential Comparator.

ALL-Insulated Oscilloscopes

The all-insulated oscilloscope has no accessible conductive parts. All accessible parts are made of insulating material. No protective system is defeated to make the measurement.

The all-insulated scope provides true isolation from both the mains and the "signal common." It is not grounded but does not suffer the problems of being "floated." It is not a differential amplifier and therefore does not suffer previously mentioned performance problems. But, it cannot be interconnected with other equipment because its internal common is at the elevated potential of whatever the probe ground lead is connected to.

The Tektronix 200-Series Oscilloscopes are all-insulated scopes. They are rated to 250 V with respect to their mains insulation, and 700 V Peak with respect to the signal being measured (when operated on internal batteries). The 200-Series Scopes offer 3 x 5 cm display and bandwidths up to 5 MHz, with sweep speeds to 100 ns/Div. These scopes are especially suitable for power supply and mechanical measurement applications.

A Solution with Protection: 221 Miniscope.

Grounded Oscilloscopes

A grounded oscilloscope is capable of making floating measurements by making two separate measurements, recording them, and subtracting the common-mode signal. This requires an oscilloscope system capable of waveform processing such as the Tektronix 7854. The 7854 is capable of digitizing and storing the two waveforms and subtracting the common-mode signal mathematically. The 7854 is a highly sophisticated scope with microprocessor-based waveform processing capability. The 7854 is especially suitable for those floating measurement applications that justify a substantial instrumentation investment.

A Solution with Protection: 7854 Oscilloscope.

Integrated Circuit Amplifiers

Some products purported to be "isolators" are nothing more than limited-performance IC differential amplifiers. They not only suffer from the same problems of all differential amplifiers (limited dynamic range and ability to display small difference signals in the presence of large common-mode signals), they also suffer from lack of control and versatility. Impressive performance specifications disappear when probes, attenuators, power supply, and display connections are considered.

Isolation Amplifiers, Indirect Grounding devices, Differential Techniques, ALL-Insulated Oscilloscopes, or Grounded Oscilloscopes are Solutions with Protection.

METHODS WHICH VIOLATE SAFETY PRINCIPLES

Isolation Transformers

Isolation transformers sometimes are employed between the mains and the oscilloscope to enable "floating" the scope. To do this, the scope's protective grounding system is defeated resulting in violation of one safety principle: accessible parts are live due to the potential to which the signal common lead is connected.

The isolation transformer can provide some degree of protection in the event of a scope's mains insulation failure — assuming the "isolated" mains does not have ground reference. If the transformer does not have a secondary ground reference, then a single insulation failure in the scope will not result in a hazard — even though it is insidious.

If the "isolated" main is ground-referenced (grounded neutral or grounded center-tap) then no protection is provided.

Interestingly, during "floating," the insulations of both the isolation transformer and the oscilloscope's mains transformers are subjected to a voltage stress that is the sum of the mains voltage *plus* the "signal common" or floating voltage. This is because the two primary windings form a capacitive voltage divider between the "floating" chassis to the scope's primary to the isolation transformer's primary. This voltage is extra — over and above the mains rating. Thus, the mains insulation system is stressed and therefore subject to early failure or breakdown. If the mains insulation does break down and the scope is not grounded, then an insidious hazard exists where the chassis will be live and the operator has no indication of a problem. If grounded, smoke and fire may be the result. Using an isolating transformer to make a scope "safe" to float, is a futile gesture and provides a false sense of security.

This Solution Lacks Protection.

Double Insulated Mains

Some measuring equipment safety standards allow double insulation of the mains circuits in lieu of grounding (2-wire mains in lieu of 2-wire mains with earth connection). Ordinarily, double insulation provides protection equivalent to grounding. This is not true for measuring equipment, since measuring equipment has a second source of hazardous potentials — the circuit under test! Equal protection must be provided from all hazardous circuits, not just the mains circuits.

Ungrounded scopes are available where protection from the mains is provided by double insulation, but where the "signal common" remains connected to the chassis enclosure and connectors. With respect to the signal being measured, these designs are the equivalent of defeating the protective grounding system.

Incidentally, unlike indirect grounding solutions that complete the protective grounding circuit when excessive voltage or currents are applied, this solution gives no warning to the operator that dangerous voltages and currents are present on the scope chassis.

This Solution Lacks Protection.

Isolating Circuits

Some users, and at least one scope manufacturer, have placed semiconductor devices (back-to-back parallel rectifiers or zener diodes) in series with the protective grounding conductor. The purpose is to limit the excursion of voltage on accessible parts to a "safe" level. One scope has a switch in parallel with the semiconductors to restore the ground when isolation is not required.

Unfortunately, these techniques violate two safety principles and lead to another insidious hazard.

Most safety standards assume failure of semiconductors. Should a diode fail, there is no indication to the operator and an insidious hazard exists.

Also, safety standards commonly specify no switch in the protective grounding conductor; a switch defeats the protective grounding system just as cutting off the ground prong of the mains plug.

This Solution Lacks Protection.

Defeating Grounds

Operators often defeat a scope's protective grounding system by cutting off the ground prong or by using a 3-to-2 wire adapter. This technique allows the scope chassis, enclosure, and connectors to assume the potential of whatever the probe ground lead is connected to.

The only protection for both the operator and nearby persons where a scope is being floated, is to maintain distance and avoid simultaneously touching the scope and earth. Some safety officers require the work area to be roped off, a warning to be posted, and an observer to maintain surveillance on the operator. Some enforcement agencies accept these precautions under the heading of "reasonable caution" and choose not to cite violators. Although these precautions are laudatory, we have described earlier the dangers, often insidious dangers, inherent in "floating" oscilloscopes by defeating their protective grounding systems.

The operator and his employer voluntarily accept the responsibility for protection once the scope's protection system is deliberately defeated.

This Solution Lacks Protection.

TWO SOLUTIONS WITH PROTECTION FOR FLOATING ANY OSCILLOSCOPE

The A6901 Ground Isolation Monitor

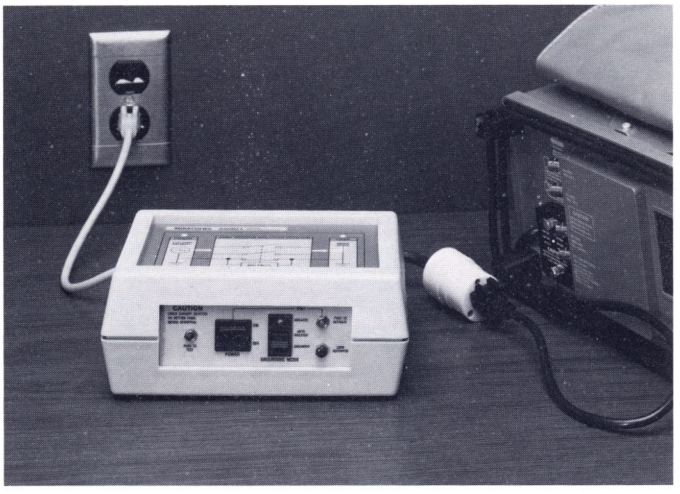
The A6901 Ground Isolation Monitor is an indirect grounding device which isolates an equipment's protective grounding system, monitors voltage and current on the isolated system, and, when the voltage or current exceeds predetermined levels, interrupts all poles of the supply, sounds an alarm, and connects the isolated ground to the protective grounding conductor.

In addition, the A6901 tests the ground continuity of the system which it is intended to operate in, and, if the impedance of the protective grounding connector exceeds five ohms, the A6901 will not activate.

A6902 Isolator

The A6902 Isolator is an isolation amplifier, a dual trace DC-15 MHz optical and transformer-coupled voltage isolator capable of making low level signal measurements in the presence of up to ±1500 VDC + PK AC common-mode voltage. The Isolator allows any test instrument to perform floating measurements while safely grounded. No hazardous voltages are accessible by the operator beyond the point of the probe connection at the circuit under test.

We have outlined ten popular methods for making floating oscilloscope measurements, four of which should be discontinued in favor of the half-dozen that meet all the basic Safety Principles outlined earlier.



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 two new Isolator products mentioned earlier. If you feel your applications would be better served by either or both of these products, please contact your nearest Tektronix representative listed on the back cover of this brochure.

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