Keep Yourself, Your DUT, and Your Power Supply Safe with Advanced Power Supply Protection Features

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KEYSIGHT TECHNOLOGIES

Agenda

- Introduction
- Protecting the user
- Protecting the DUT
- Protecting the power supply
- Summary
- Power supply safety feature demos

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Introduction

Power supply safety

- Electronic devices are used everywhere in our society
- All electronics must be powered
- Electronic devices are tested in all phases of their lifecycle
  - Design
  - Manufacturing
  - Repair
- Test and measurement AC and DC power supplies are used during test in all phases of a product's lifecycle, so they are used everywhere
- Proper design and feature sets of power supplies is important to ensure the safety of the user, the device under test, and the power supply itself

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Protecting the User

International standards

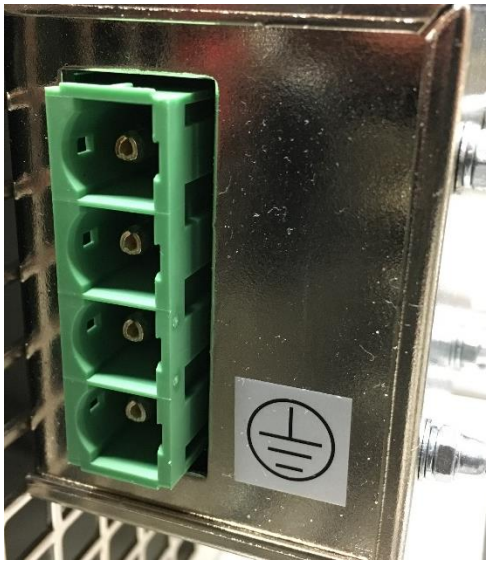
– "Safety requirements for electrical equipment for measurement, control, and laboratory use – Part 1: General requirements"
  - USA: ANSI/UL 61010-1:2012
  - Canada: CAN/CSA C22.2 No 61010-1-12
  - Europe: IEC 61010-1:2010/ EN61010-1:2010

– Examples of protection requirements covered by standards
  - Electric shock
  - Mechanical hazards
  - Mechanical stresses
  - Spread of fire
  - Temperature limits
  - Liberated substances, explosion, and implosion
  - Interlocks
  - Application hazards (reasonably foreseeable misuse)

Protecting the User

International standards

- Earth-grounded chassis
  - Users will contact only safe voltages
- Limit surface temperature
  - Users will contact only safe temperatures
- Chassis contains emissions
  - Users will be protected from
    - Fire
    - Exploding components, such as resistors, capacitors, semiconductors, PC board tracks, etc.



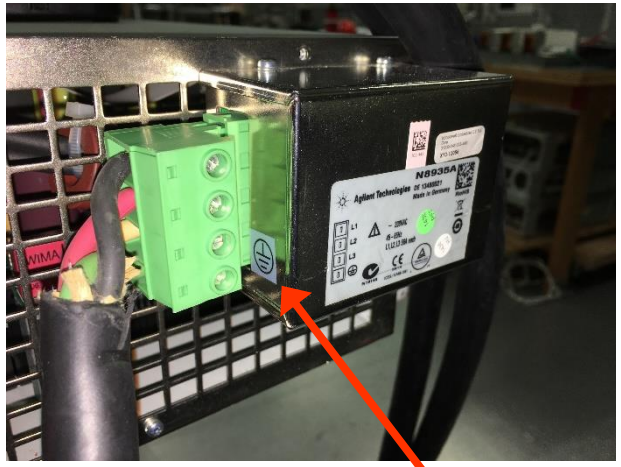
WARNING Product Grounding

The instrument is a Class 1 product and is provided with a grounding-type power cord set. The instrument chassis and cover are connected to the instrument electrical ground to minimize shock hazard. The ground pin of the cord set plug must be firmly connected to the electrical ground (safety ground) terminal at the power outlet. Any interruption of the protective earth (grounding) conductor or disconnection of the protective earth terminal will cause a potential shock hazard that could result in personal injury or death.

Protecting the User

International standards – ground symbols

– Earth ground terminal
  - Indicates functional earth ground
  - No fault current carrying requirements



Protective earth ground symbol and internal wire connection

– Frame or chassis terminal
  - Terminal connects to chassis only

– Protective conductor terminal
  - Indicates protective earth ground
  - Must carry fault current with no more than specified voltage drop (mainly used on AC input connector)

Protecting the User

International standards

WARNING Do Not Remove Instrument Cover
Only qualified, service-trained personnel should remove the cover from the instrument.
Service: Unplug instrument from wall outlet, remove power cord, and remove all connections from all terminals before servicing.

- Accessibility
  - Safety covers
    - Protect users from shock hazard due to high voltage
    - Protect users from metal in contact with high current
  - Restrict access to moving parts
    - Fan guards protect users from moving fan blades

High current bus bar – system has lockable door

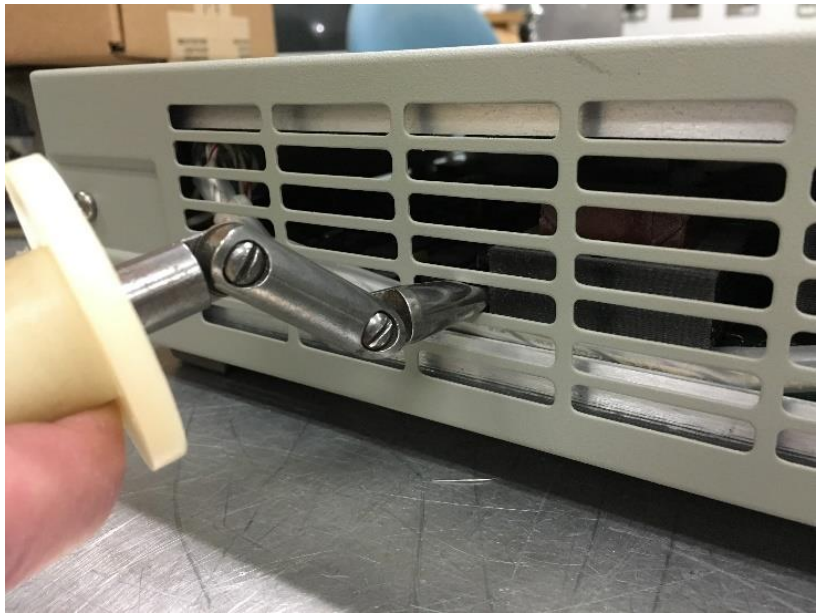
Fan grille

Protecting the User

International standards

WARNING Do Not Remove Instrument Cover
Only qualified, service-trained personnel should remove the cover from the instrument. Service: Unplug instrument from wall outlet, remove power cord, and remove all connections from all terminals before servicing.

– Accessibility
  - Eliminate sharp edges
  - Restrict access to unsafe conditions such as high voltage, hot surfaces, or moving parts such as fan blades
    - Specific example: jointed test finger

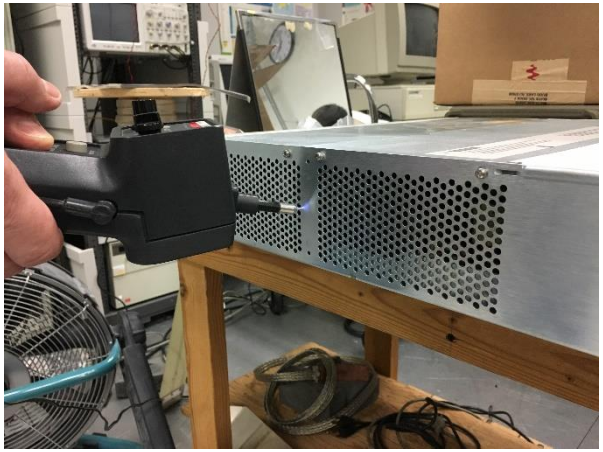


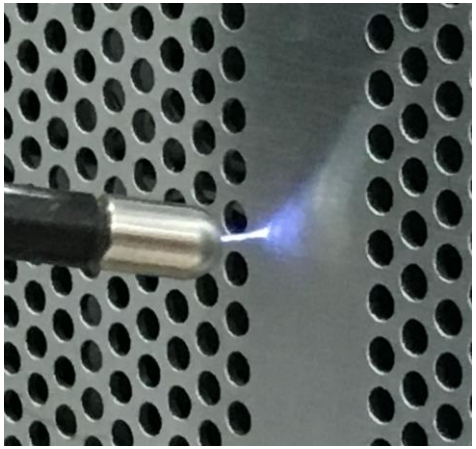
Protecting the User

International standards

- Product susceptibility tests
  - ESD (electrostatic discharge)
    - Static discharge cannot cause the power supply to enter an unsafe state
  - EMC (electromagnetic compatibility)
    - No external stimuli of defined strength can put the power supply in an unsafe state
      - Conducted RFI (radio frequency interference)
      - Radiated RFI
      - AC line spikes

15,000 volts!



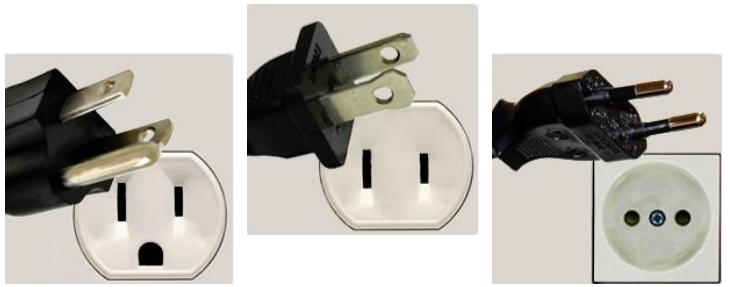


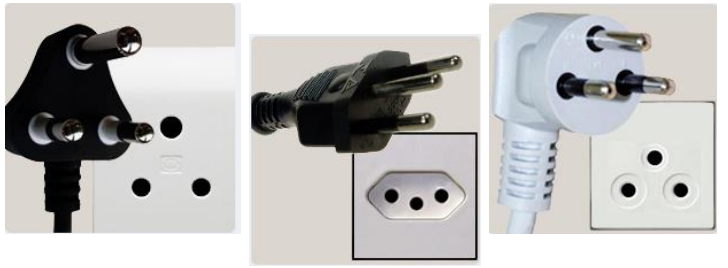
Protecting the User

International standards

– Abuse tests (reasonably foreseeable misuse)

- Plug into incorrect AC line voltage outlet
  - Fuses can open
  - Nothing unsafe can happen
- Some typical line voltages
  - US: 120 Vac; 208 Vac; 240 Vac
  - Europe: 230 Vac; 400 Vac
  - Japan: 100 Vac



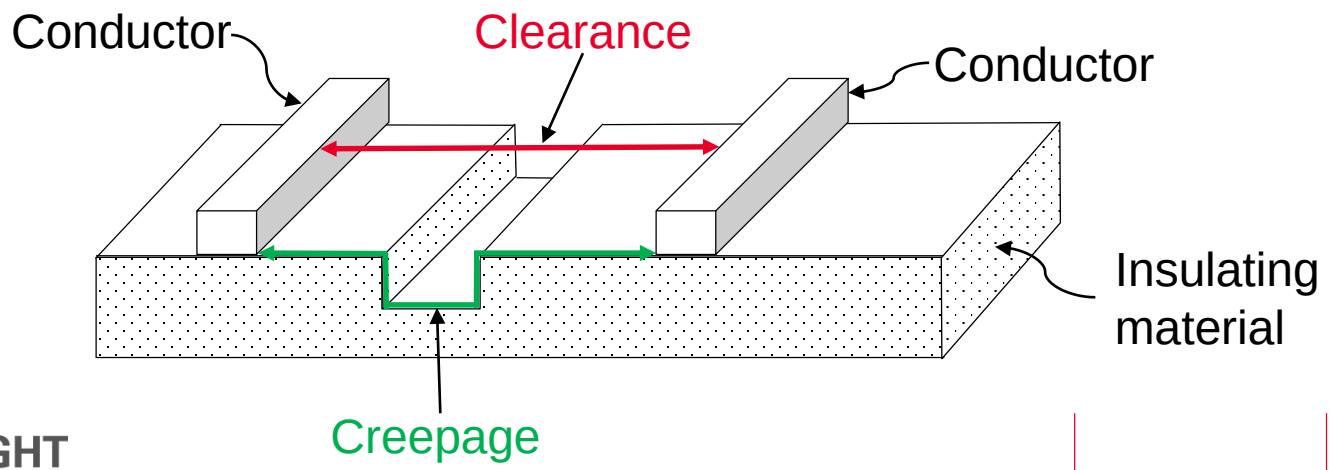


Protecting the User

International standards

– Clearance and creepage distances

- Specifies minimum distance between two conductors based on voltage between conductors to prevent voltage breakdown
- All designs must meet requirements specified in standard
- Clearance: the shortest distance in air between two conductors
- Creepage: the shortest distance between two conductors along a solid insulating surface
- For user accessible parts, reinforced insulation requirement increases distance



Protecting the User

International standards

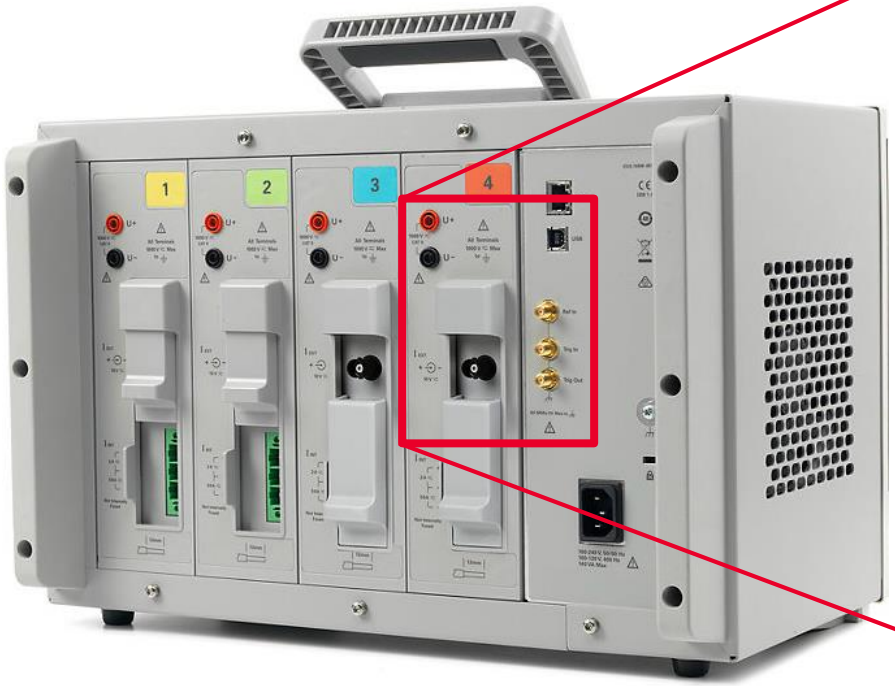
– Abuse tests (reasonably foreseeable misuse)
  - Connect cable to wrong connector
  - Design should prevent problems

Example: BNC and SMA connectors

– This product's design has different voltage ratings on different inputs/outputs
  - External current probe input limit: 1000 V to earth ground
  - Trigger In/Out, Reference In limit: 5 V to chassis

– If the same connector was used on both, user could mix up cabling with catastrophic results

– Design uses different connectors to prevent mix up
  - BNC connectors used on current probe input
  - SMA connectors used on trigger/reference inputs/outputs



Protecting the User

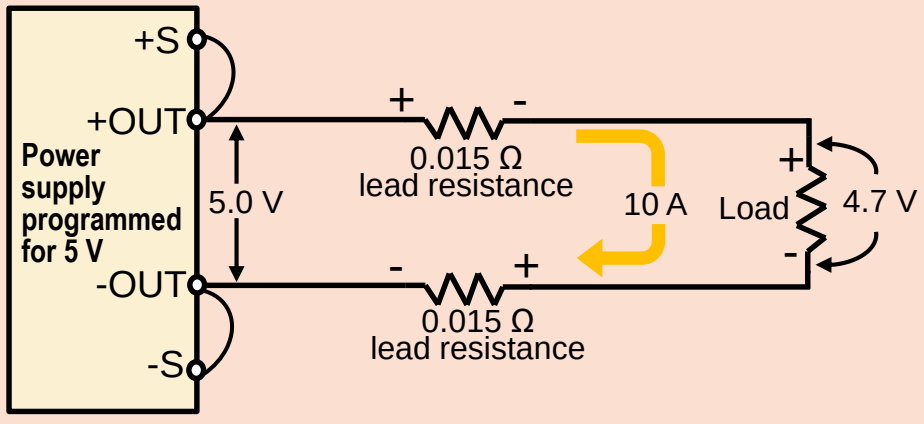
International standards

– Abuse tests (reasonably foreseeable misuse)

- Remote sense – compensates for voltage drop in load lead wire to ensure desired voltage is regulated at the load
- Remote sense wires can be miswired: open or reversed

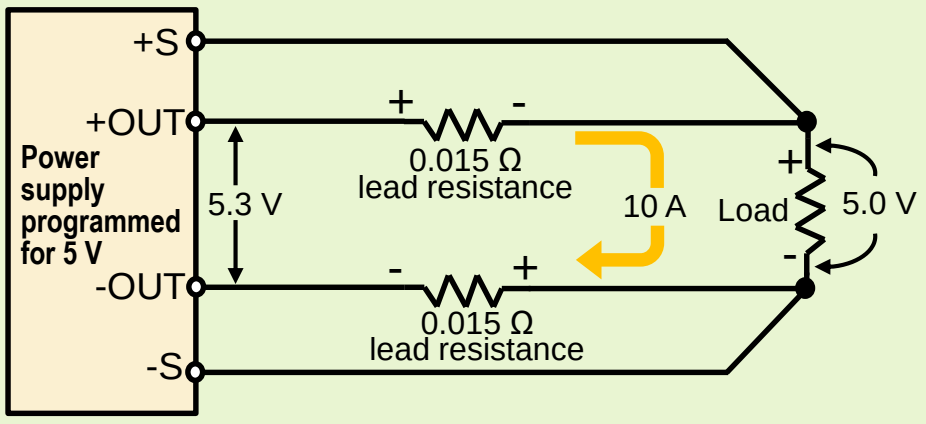
Proper wiring (no abuse)

Without remote sense (local sense)



+OUT and –OUT load leads are 6 feet, 14 AWG each

With remote sense



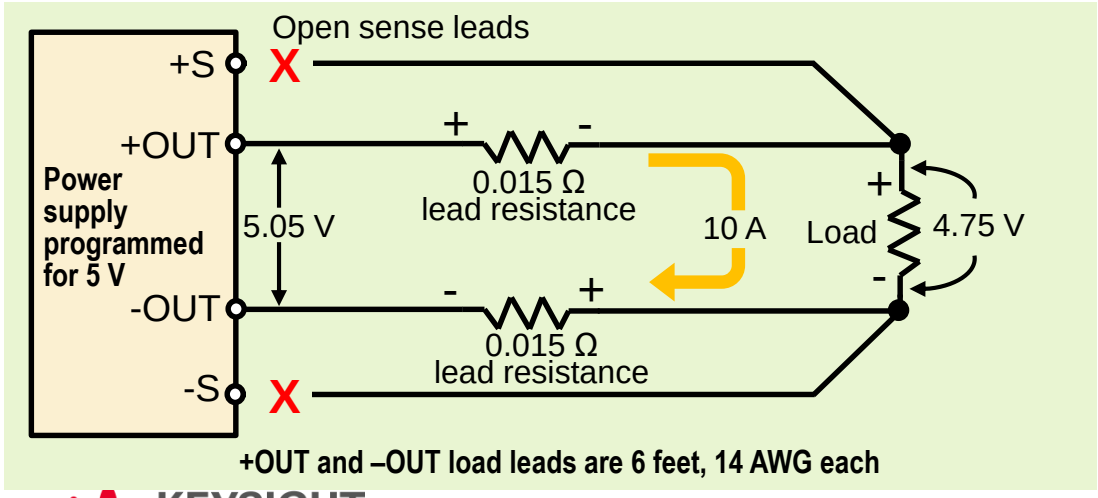
+OUT and –OUT load leads are 6 feet, 14 AWG each

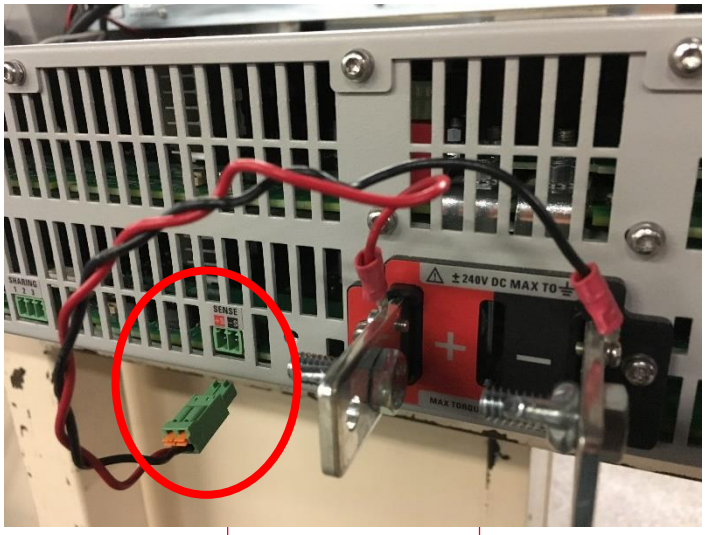
Protecting the User

International standards

– Abuse tests

- Problem or incorrect remote sense terminal wiring
  - Open sense leads
    - Poor design causes output voltage to rise uncontrolled and stay high
    - Some power supplies detect open sense leads and can take action
      - Turn off output
      - Alert user that there is a problem
    - Quality power supplies have built-in protection limiting the voltage rise to only 1 or 2 percent



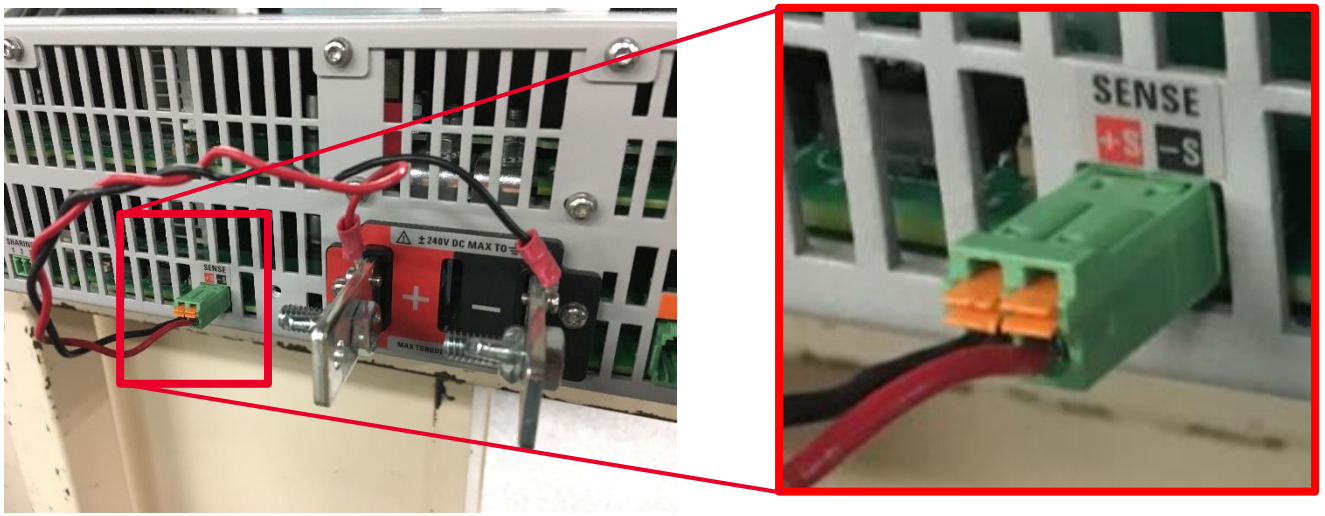


Protecting the User

International standards

– Abuse tests

- Problem or incorrect remote sense terminal wiring
  - Reversed remote sense leads
    - Poor design causes output voltage to rise uncontrolled and stay high
    - Some power supplies detect reversed leads and shut off their output
    - Quality supplies will shut off the output when the voltage reaches a predetermined value (overvoltage protection - OVP)



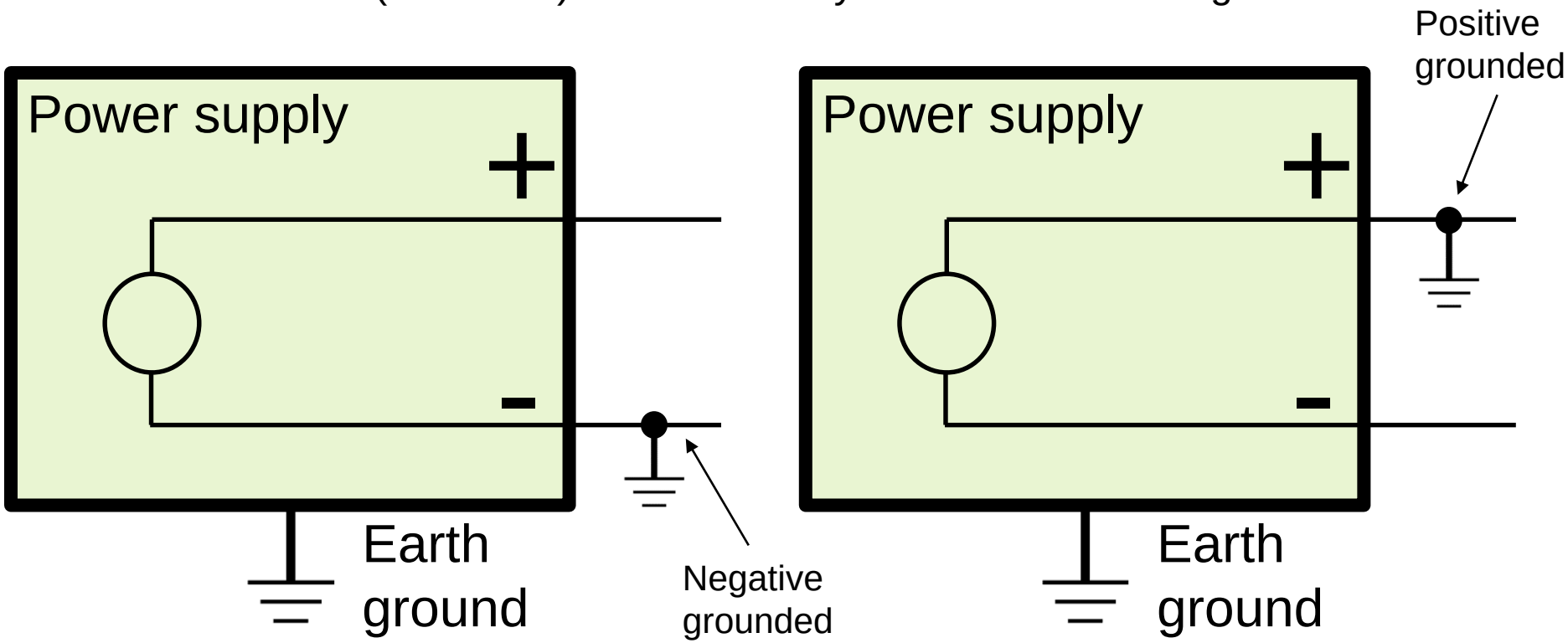
Sense leads are reversed

Protecting the User

Floating outputs

– Floating output terminals add flexibility to use

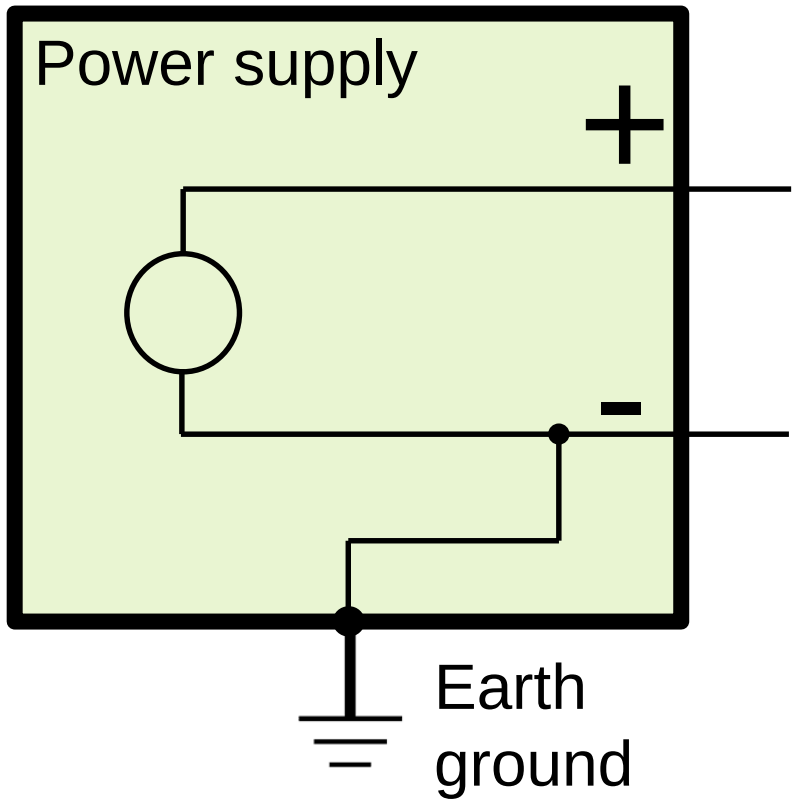
  • The output terminals of many power supplies are isolated from earth ground allowing either the positive terminal or negative terminal (or neither) to be externally connected to earth ground



Protecting the User

Floating outputs

– Example of non-floating output configuration
  - Negative output terminal is internally connected to earth ground
  - Less flexible design



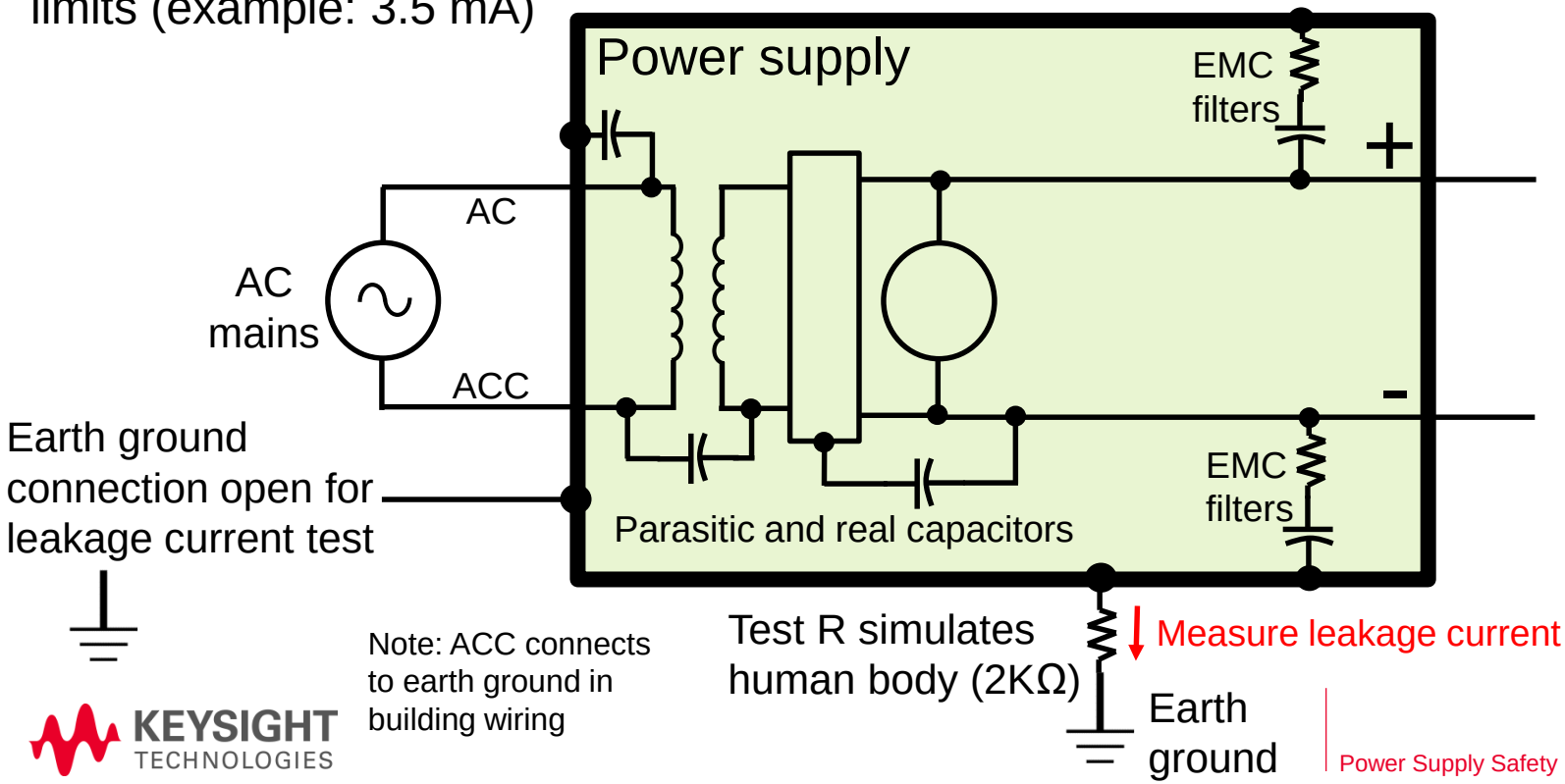
In this case, externally grounding the + terminal results in a short across the power supply

Protecting the User

Floating outputs

– Typical power supplies have EMC components connected between accessible terminals such as the output terminals and the chassis to help mitigate the effects of things like RFI and ESD so the output is not completely isolated from earth ground

– With the AC input earth ground connection open and the product operating, the design must ensure leakage currents from the chassis to earth ground are within limits (example: 3.5 mA)



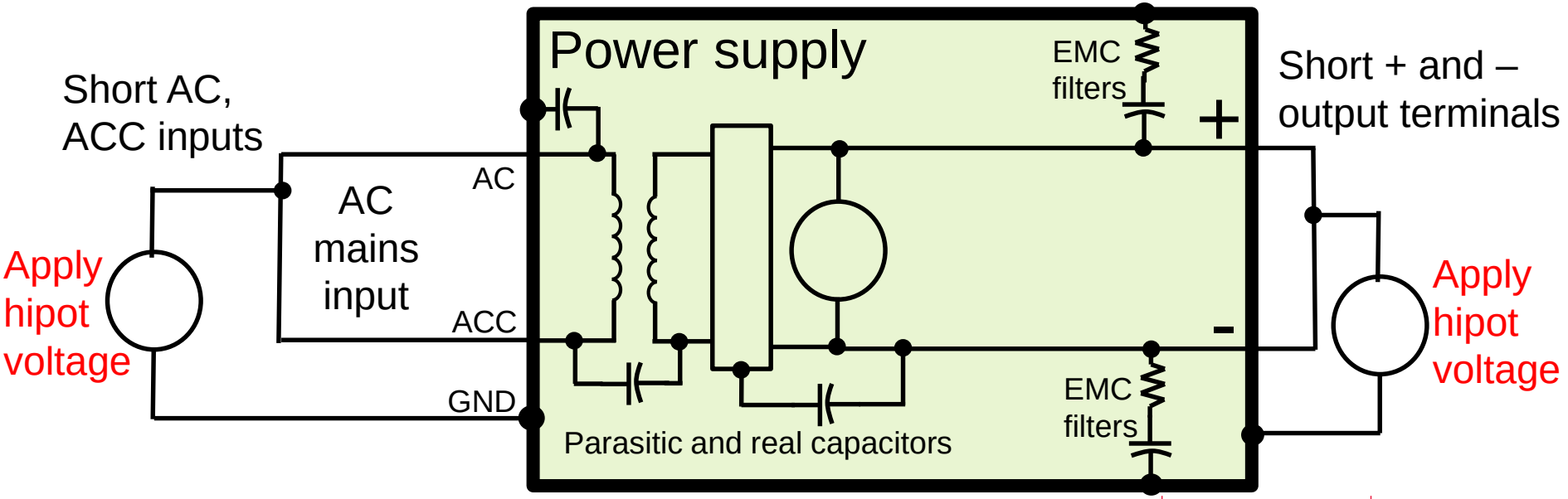
Note: ACC connects to earth ground in building wiring

Protecting the User

Floating outputs

– Hipot testing (dielectric withstand testing) should be done on every power supply that comes off of the assembly line

  - Ensures there are no insulation flaws introduced by the manufacturing process thereby protecting the user
  - AC input and DC output are hipot tested separately with the product off

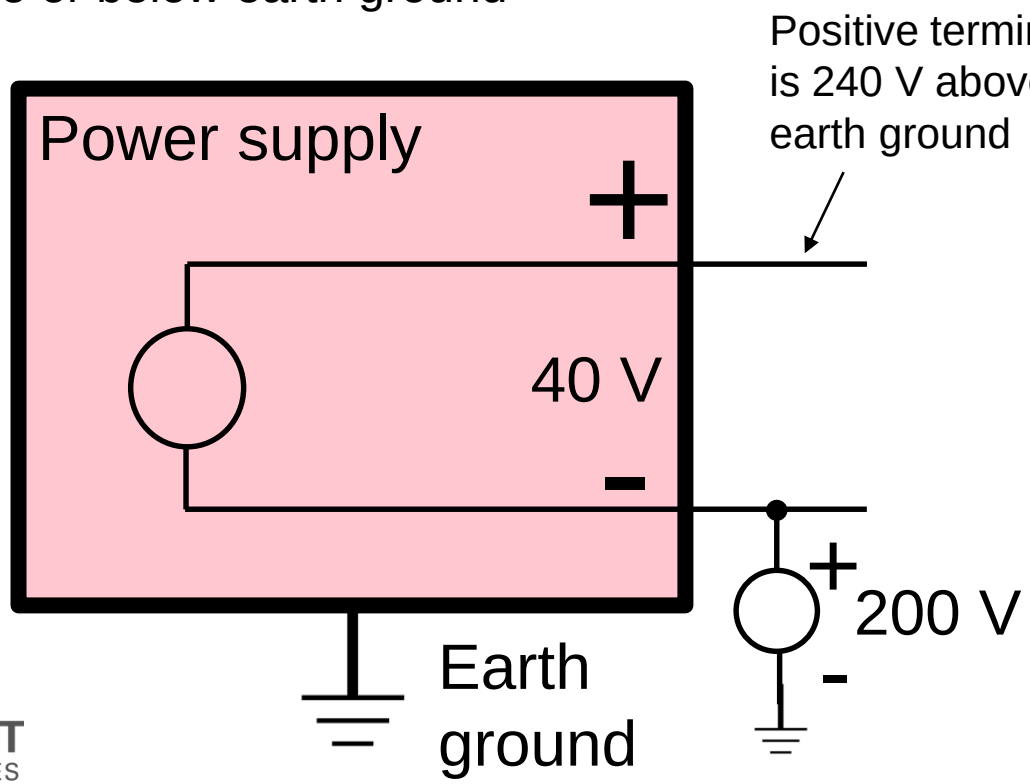


Protecting the User

Floating outputs

– Floating output terminals adds flexibility to use

- Manufacturer must specify how far off ground the outputs can float
- Warning: the output voltage can be used in such a way that the output terminals may be at a high potential (such as 240 Vdc) above or below earth ground



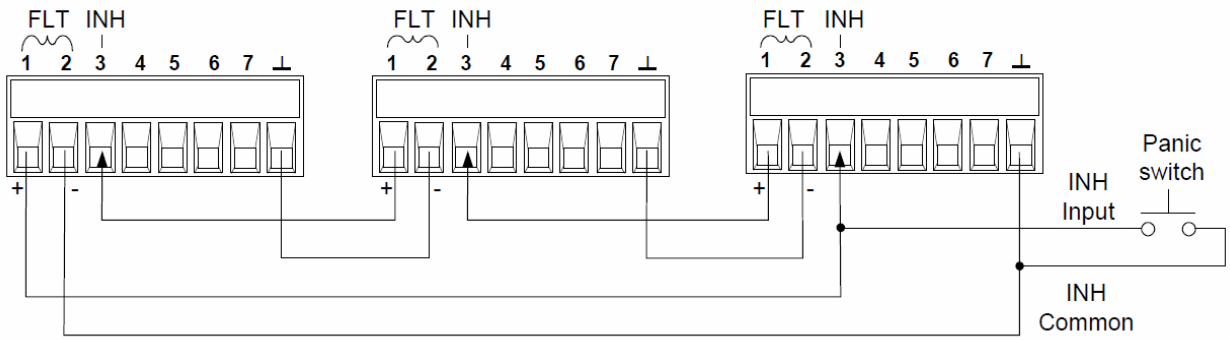
Protecting the User

Emergency shutdown

– Some power supplies have **inhibit input** terminals. When the terminals are connected together, the power supply output is disabled. These can be connected to an emergency shutdown switch.

– Some power supplies have a **fault output** that indicates a protection fault has occurred

– **Fault outputs** and **inhibit inputs** on some power supplies can be daisy-chained to disable all power supplies if any one detects a fault



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Protecting the DUT

Threats to the DUT

– Two biggest threats to your DUT
  - Excessive voltage
  - Excessive current

– Power supply features that protect the DUT
  - Remote sense fault detection
  - Remote inhibit/fault output
  - Soft limits
  - OVP – overvoltage protection
  - OCP – overcurrent protection
  - Reactive load boundaries
  - OSC - oscillation detection
  - Output relays
  - Output sequencing
  - Slew rate control
  - Watchdog timer

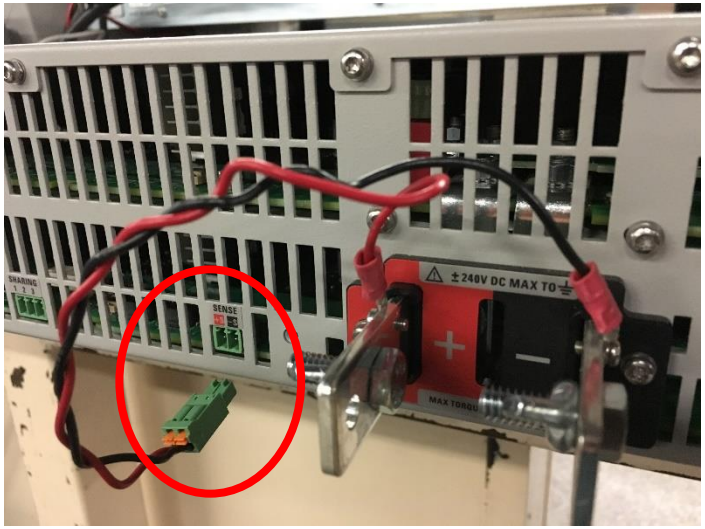
Protecting the DUT (and the user)

Remote sense fault detection

– Remote sense faults should not cause the output voltage to rise uncontrolled

- Possible faults: open or reversed sense leads
- Some power supplies detect open sense leads and can take action
  - Turn off output
  - Alert user that there is a problem
  - Quality power supplies have built-in protection limiting the voltage rise to only 1 or 2 percent

Sense leads are open

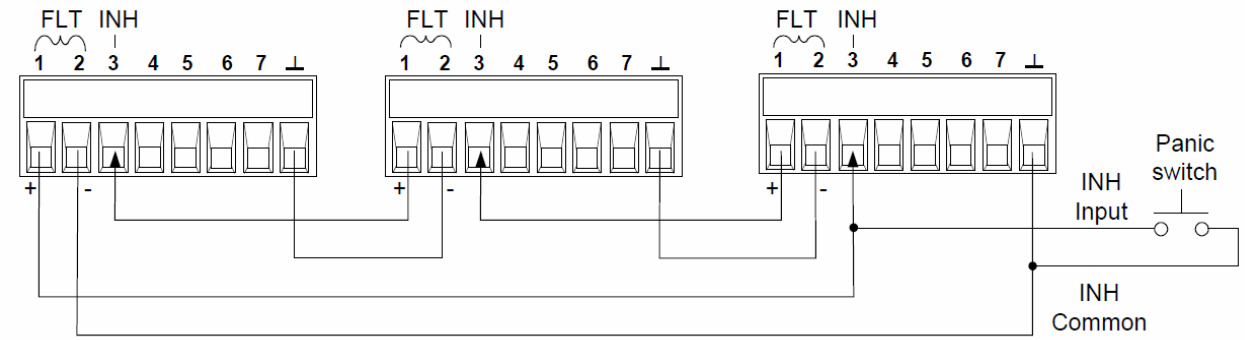


Sense leads are reversed

Protecting the DUT (and the user)

Remote inhibit/fault output

- Some power supplies have **inhibit input** terminals. When the terminals are connected together, the power supply output is disabled. These can be connected to an emergency shutdown switch.
- Some power supplies have a **fault output** that indicates a protection fault has occurred
- **Fault outputs** and **inhibit inputs** on some power supplies can be daisy-chained to disable all power supplies if any one detects a fault



Protecting the DUT

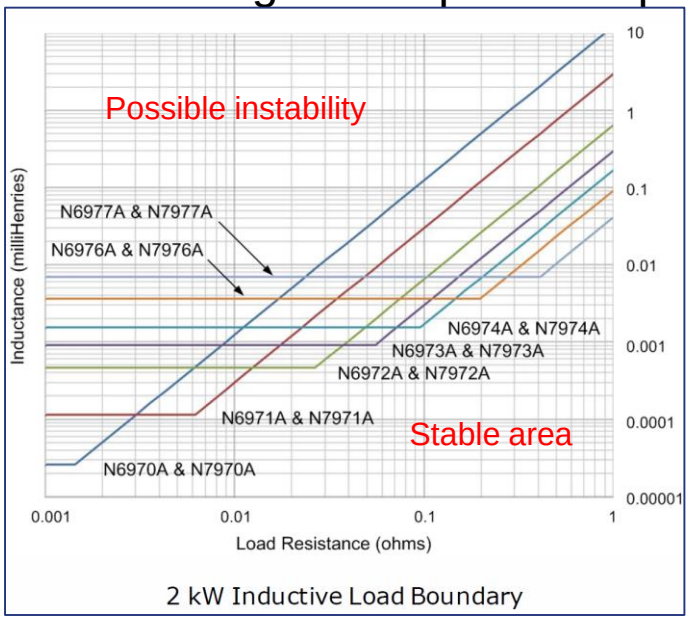
Soft limits, overvoltage protection, overcurrent protection

- Soft limits – prevent voltage and current settings from exceeding predetermined values
- OVP – if the output voltage exceeds the OVP setting, the power supply output shuts off
  - OVP is always on
- OCP – if the output current exceeds the current limit setting, the power supply output shuts off
  - OCP can be turned on or off
  - Different from constant current (CC). If OCP is off, CC mode will persist indefinitely providing constant current into the DUT; if OCP is on and output enters CC, output shuts off
  - Programmable OCP delay time is used to briefly ignore CC; prevents nuisance tripping due to short-term CC events such as inrush current at turn-on

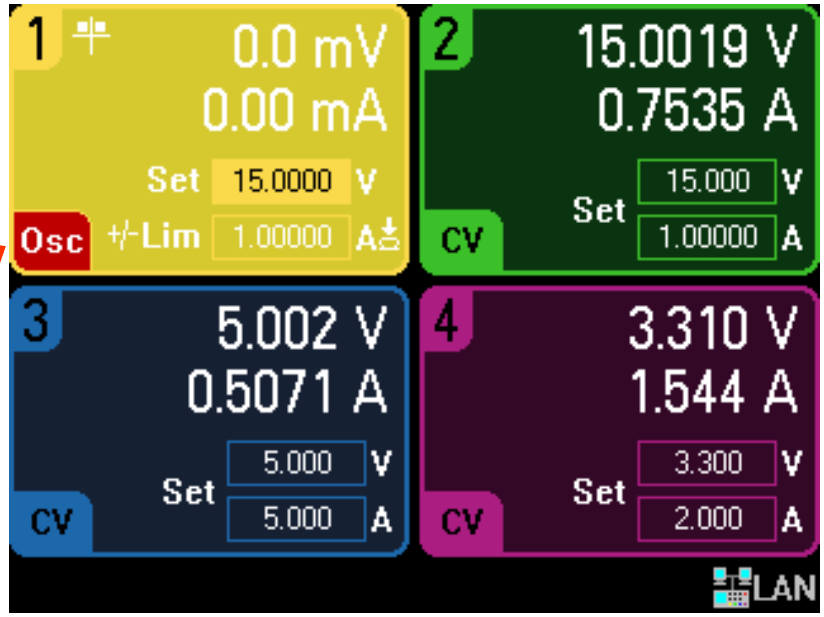
Protecting the DUT

Reactive load boundaries and oscillation detection

- Too much capacitance or inductance on the output of a power supply can cause instability resulting in output ringing or in extreme cases, oscillation
- Some power supply documentation shows the safe operating areas for reactive loads
- Some power supplies can detect an oscillating output and respond by turning the output off to protect the DUT



Oscillation detected; output #1 shuts off



Protecting the DUT

Output relays

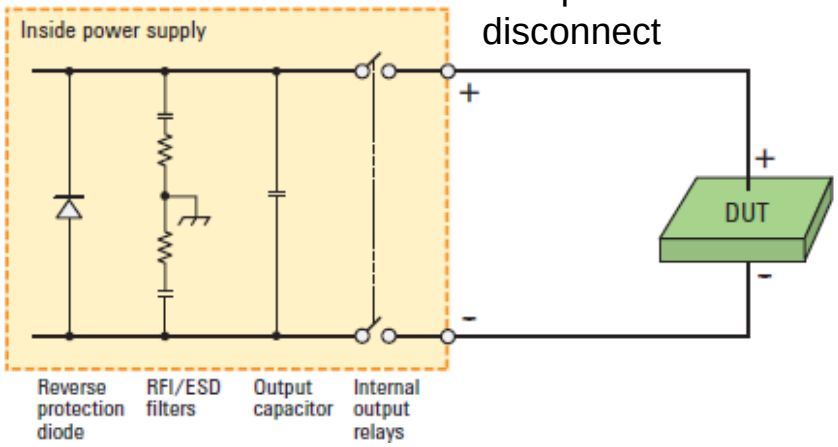
– Use output relays to physically disconnect the DUT

– If output is “off” but not disconnected, test can be adversely affected

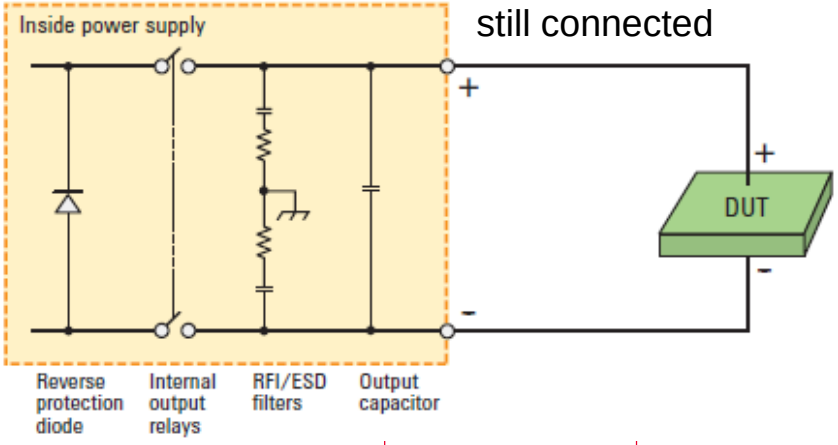
- DUT contains source of DC power that is connected directly across power supply output or in reverse-polarity configuration
- DUT is extra sensitive to extra capacitive loading
- DUT produces a changing voltage across power supply output

– Be aware of possible internal output relay locations:

Complete disconnect



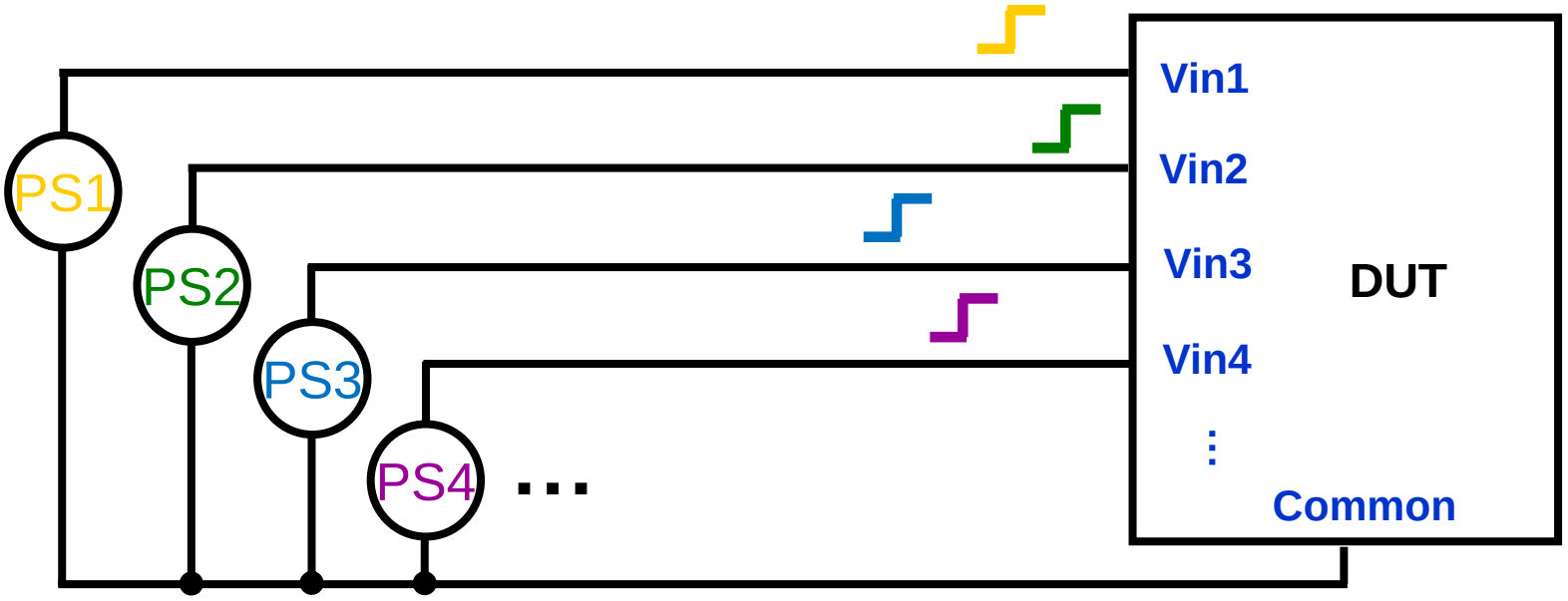
Some components still connected



Protecting the DUT

Output sequencing

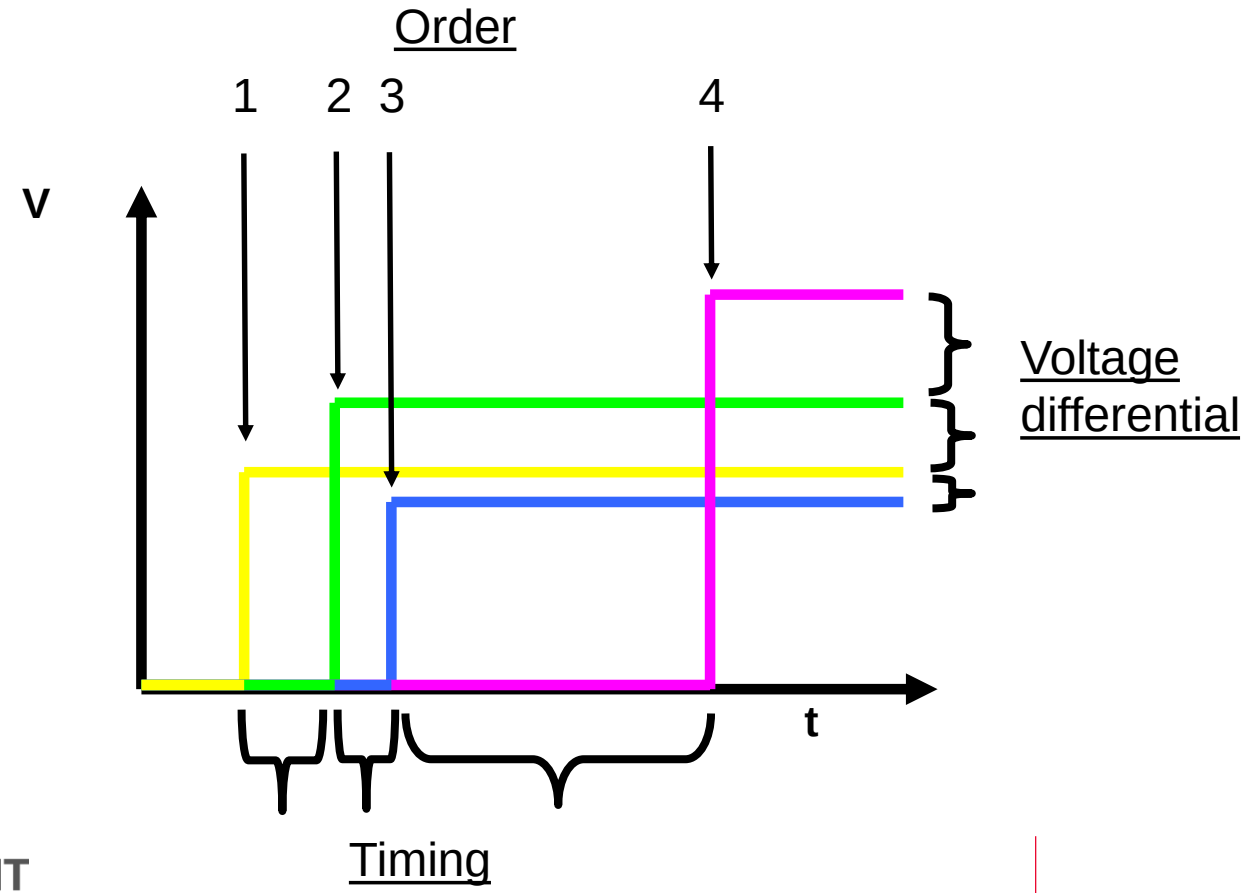
– Many DUTs are powered by multiple input voltages



Protecting the DUT

Output sequencing

– During power up or power down, these voltages must be sequenced, or turned on/off, maintaining proper order, timing, and voltage differential



Protecting the DUT

Output sequencing

– Improper sequencing could forward bias substrates

– Quote from Texas Instruments, a leader in semiconductor solutions:

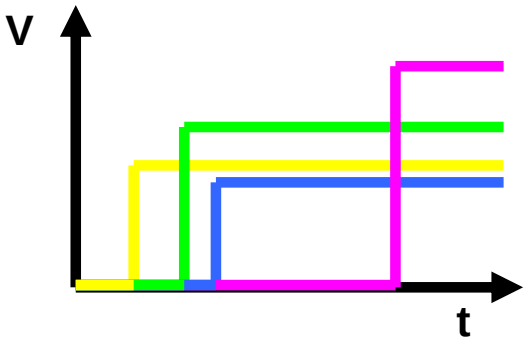
  • "*Failure to observe [sequencing] may result in the substrate being forward-biased, which is a very, very bad thing.*" (Courtesy Texas Instruments)

– Potential problems without sequencing

  • Excessive current flow
  • Excessive voltage differential
  • Latch-up

    …that can lead to…

  • Improper DUT behavior
  • Immediate DUT catastrophic failure
  • Compromised long-term reliability

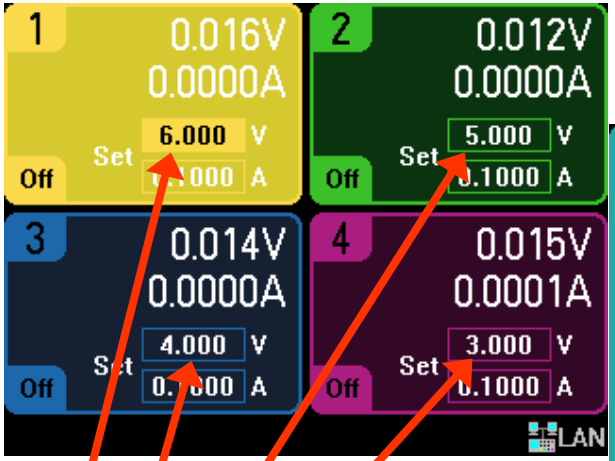


Protecting the DUT

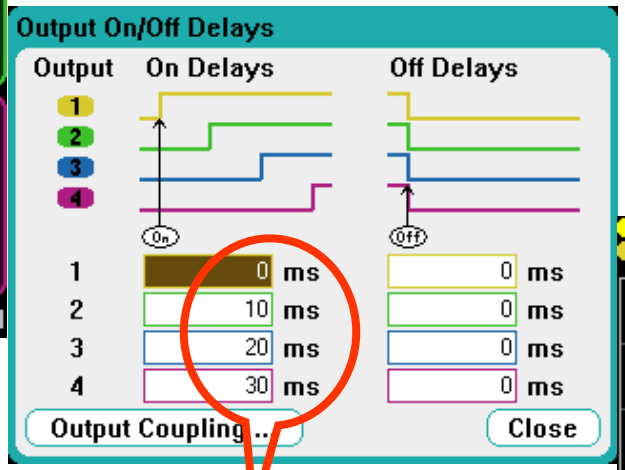
Output sequencing

– Some multiple-output power supplies provide the ability to precisely sequence their output voltages with programmable delay times on each output

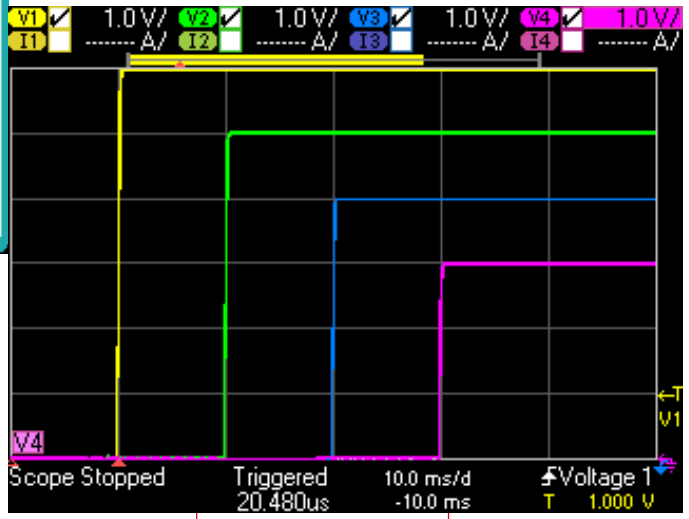
– Both on and off delay times can be set



Set the 4 voltages



Set the 4 on delay times

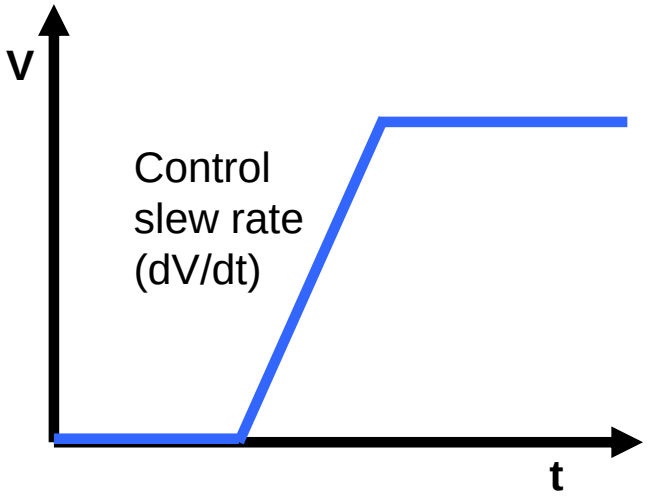


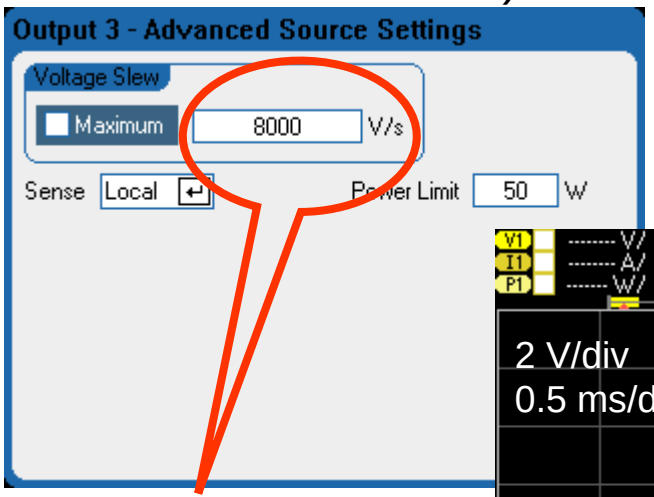
Capture the result

Protecting the DUT

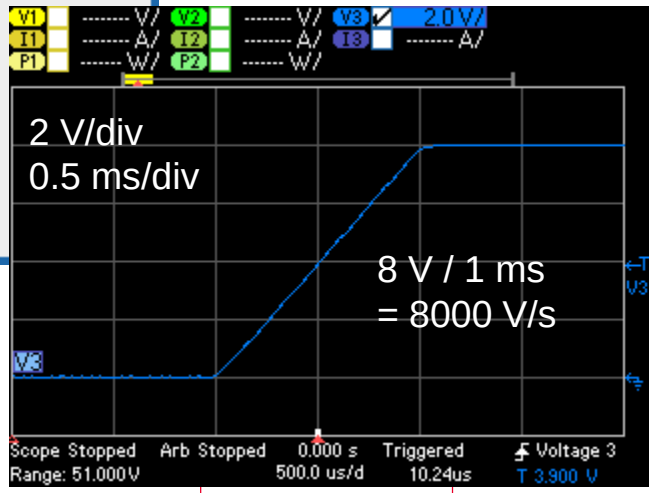
Slew rate control

- Some DUTs are sensitive to fast voltage rise times on their DC inputs
- Fast voltage changes on input capacitors cause large inrush currents
- Some power supplies have programmable slew rate to slow down the rise time (slew rate affects both rise and fall time)





Set the slew rate



Capture the result

Protecting the DUT

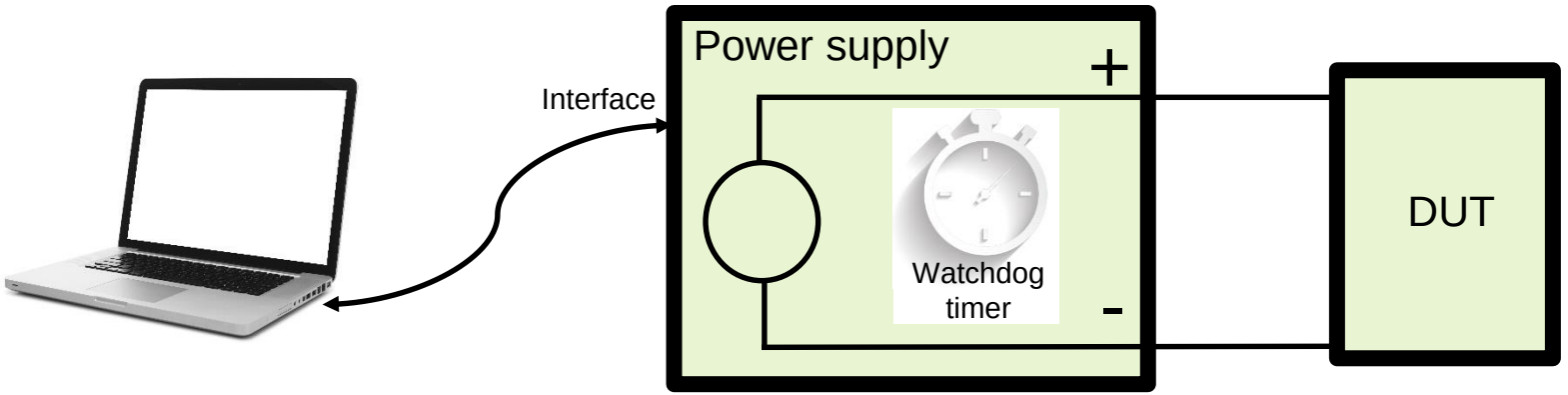
Watchdog timer

– Various power supplies can be controlled by a computer through an interface (LAN, GPIB, USB)

– The watchdog timer in the power supply looks for any power supply interface activity – protects DUT by turning outputs off if program hangs

– Upon each occurrence of new interface activity, the watchdog timer resets and starts counting down again

– If no interface activity is detected by the power supply for a time set by the user, the power supply output shuts off



Agenda

- Introduction
- Protecting the user
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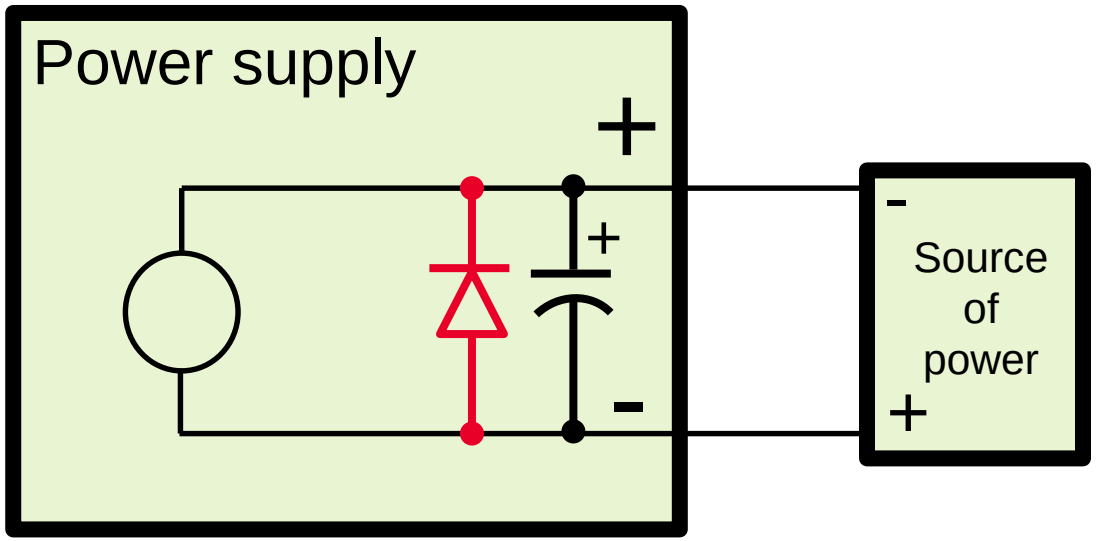
- Power supply safety feature demos

Protecting the Power Supply Itself

Reverse protection diode

– Diode is built into power supply
  - Cathode connected to positive output terminal
  - Anode connected to negative output terminal
  - Protects against external voltage applied backwards



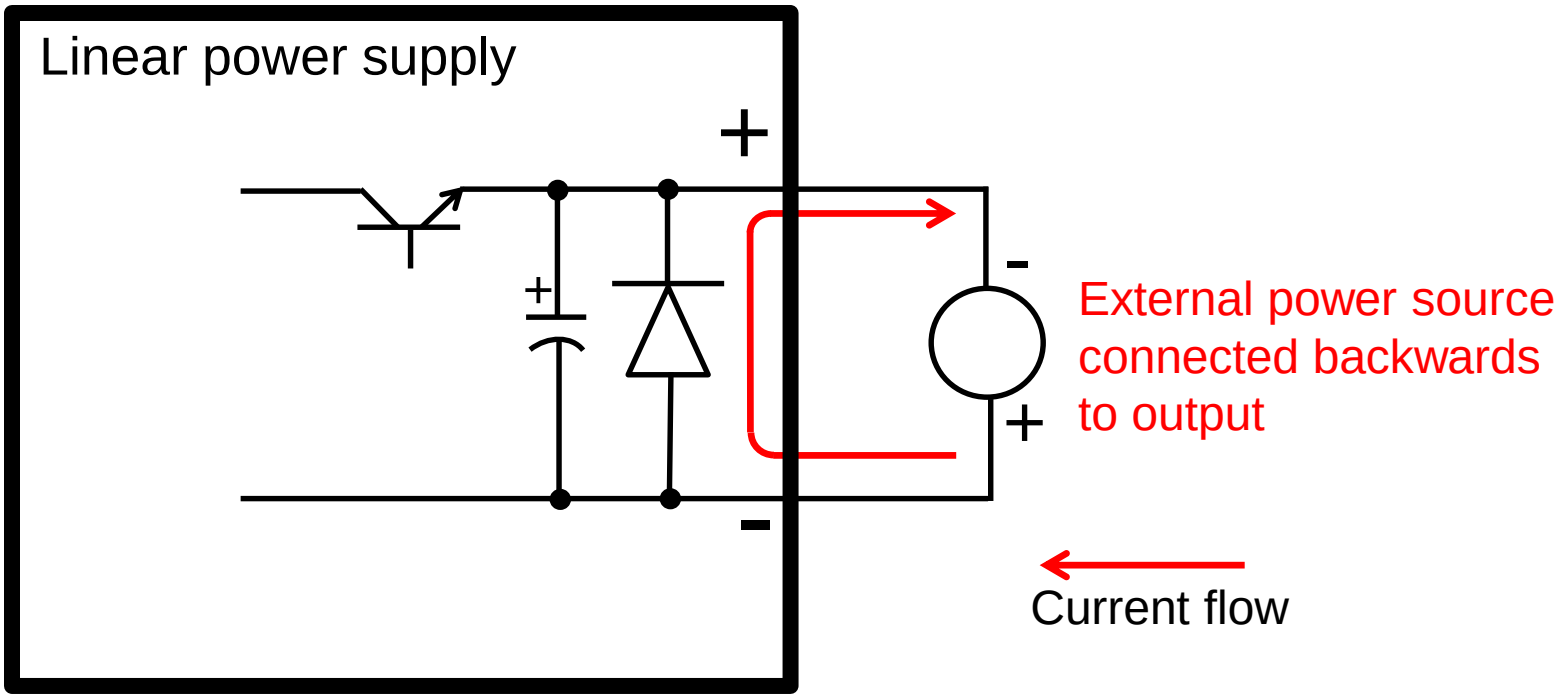
External voltage applied backwards

Protecting the Power Supply Itself

Reverse protection diode

– Diode is built into power supply to protect against an external voltage applied across the output terminals with the polarity reversed

  • Limits the reverse voltage to around a diode drop



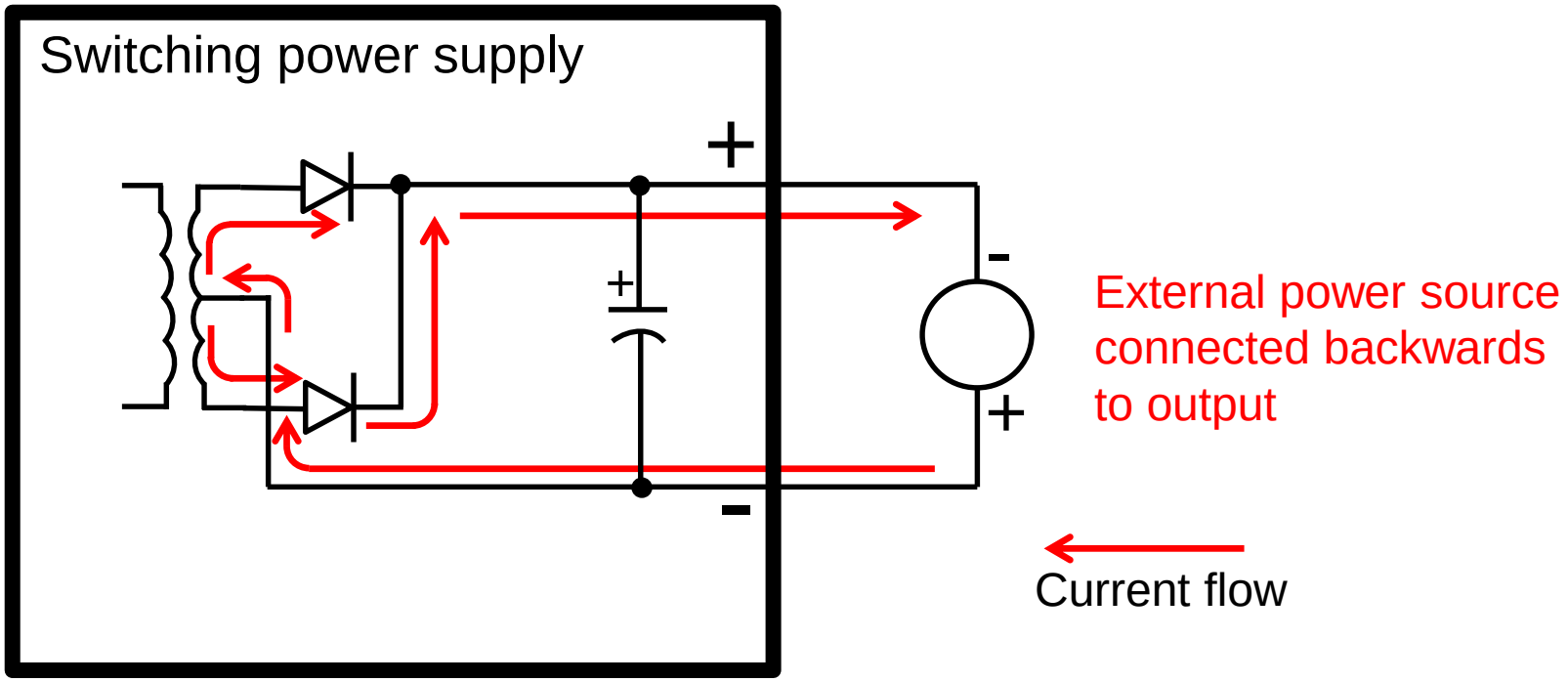
Reverse protection diode across the output of a linearly regulated power supply

Protecting the Power Supply Itself

Reverse protection diode

– The reverse protection diode(s) protects any polarized electrolytic capacitors across the output terminals

– These diodes are typically rated for the full current of the power supply

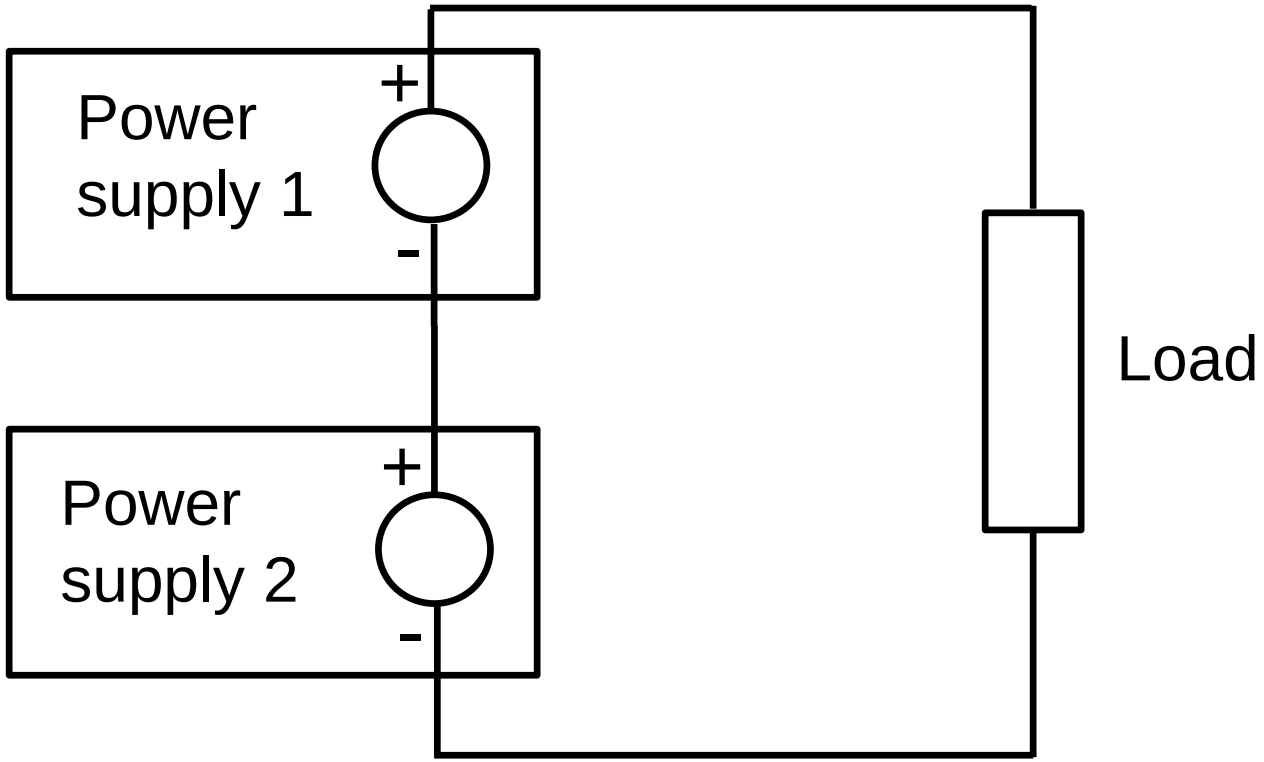


Reverse protection diodes are inherent in the design of some switching power supplies

Protecting the Power Supply Itself

Reverse protection diode

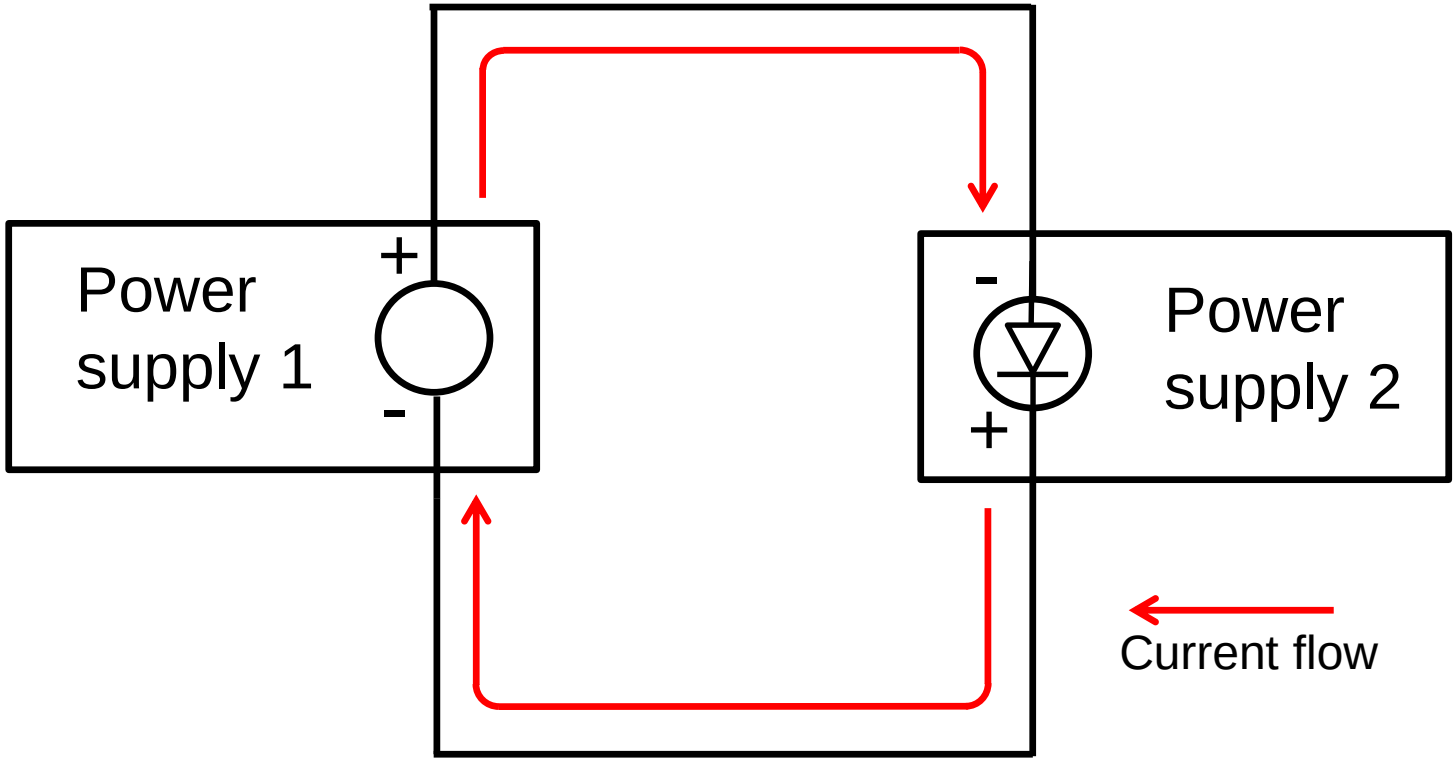
– With two power supplies in series, if the load shorts, the power supply outputs will be connected to each other backwards



Protecting the Power Supply Itself

Reverse protection diode

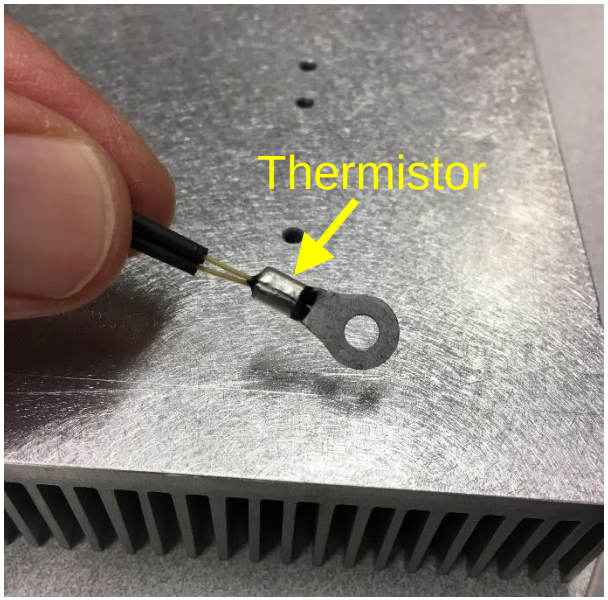
– With two power supplies in series and the load shorted, the power supply outputs are connected to each other backwards. One will overpower the other and force current through its reverse protection diode. In this case, power supply 1 operates in CC mode overpowering power supply 2.

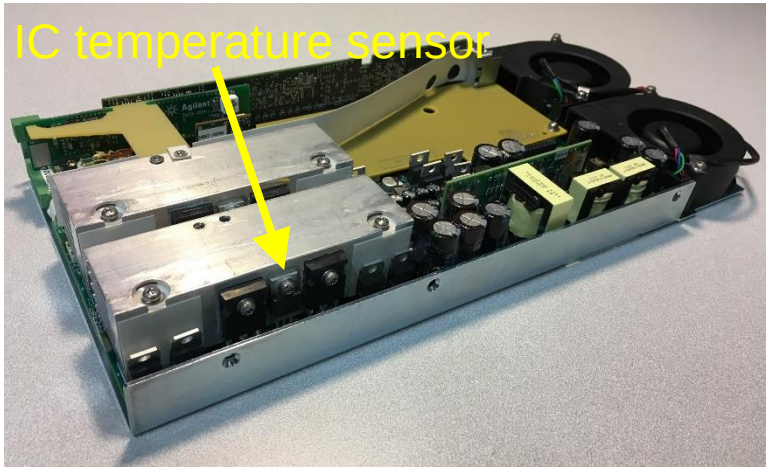


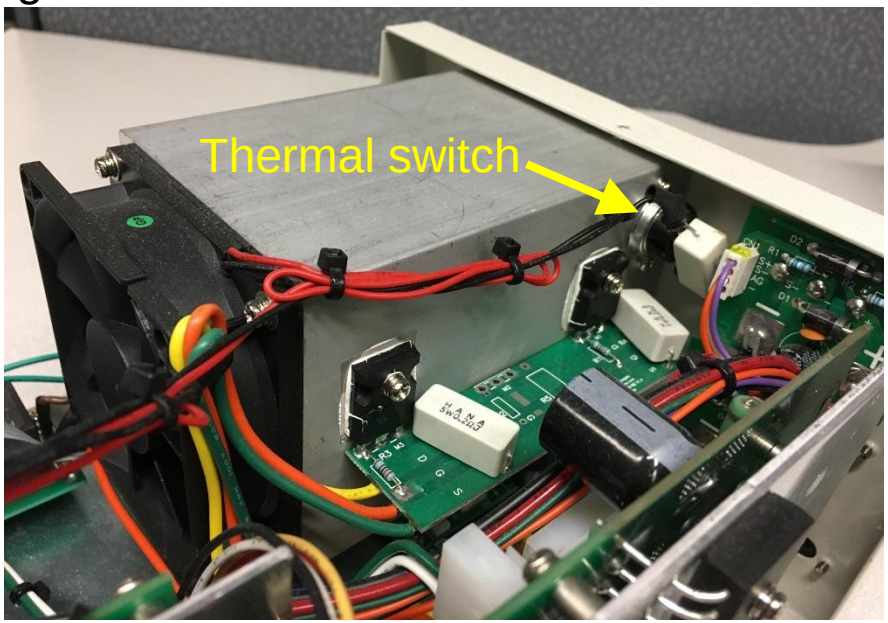
Protecting the Power Supply Itself

Overtemperature

- Monitors air intake, heatsink, and/or various component temperatures
- High temperature could result from high ambient temp, blocked or faulty fan, or malfunctioning circuit
- Turns off output if temperature gets too high; prevents other power supply components from failing that could lead to a more catastrophic condition

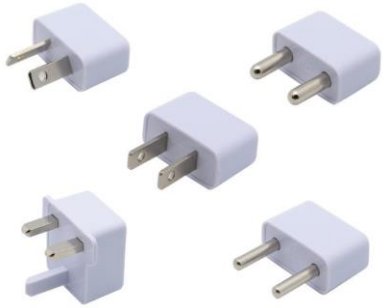






Protecting the Power Supply Itself

Universal AC input



- AC input can be plugged into standard worldwide voltages without reconfiguring the power supply
- Without protection, plugging into voltages higher than rating can put excessive voltage on capacitors and semiconductors
- Without protection, plugging into voltages lower than rating can draw excessive current overheating transformers, wires, or PC board tracks
- Internal fuses could blow; universal AC input prevents this

Protecting the Power Supply Itself

Input fuses

- AC input fuses provide protection against:
  - Incorrect AC input voltage
  - Internal power supply fault
    - Shorted transformer winding
    - Shorted capacitor
    - Shorted semiconductor
      - FET (Field-effect transistor)
      - BJT (Bipolar junction transistor)
      - Rectifying diode

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Summary

Power supply safety

- Electronic devices are ubiquitous and require extensive testing during design, manufacturing, and repair
- Test and measurement AC and DC power supplies play a necessary and important role to test electronic devices
- Power supply design and features sets must take safety into consideration
  - To protect the user
  - To protect the DUT
  - To protect the power supply itself
- Significant time and money is spent during the design of test and measurement power supplies including intelligent feature selection to ensure the safety of the operators, the DUTs, and the power supplies themselves resulting in high quality, safe, easy-to-use test instrumentation

Keysight's Power Products Offering

300+ solutions

High Performance 1U Modular Power System

AC Power Supplies

High Power Basic ATE DC Power Supplies

Bench Power Supplies

N6705B DC Power Analyzer

High Performance System DC Power Supplies

Source/Measure Units

DC Electronic Loads

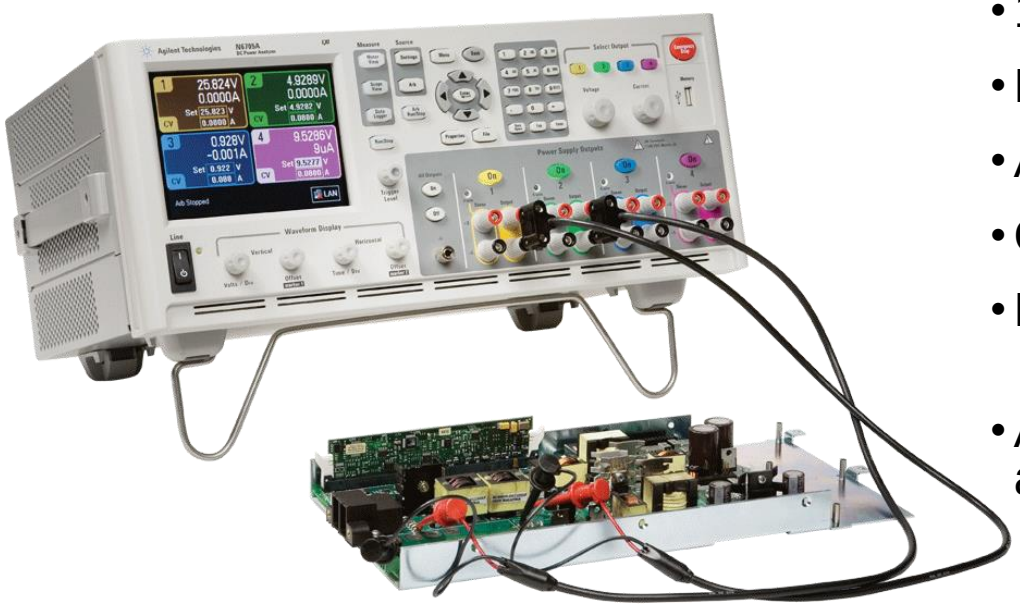
PA2203A IntegraVision AC & DC Power Analyzer

KEYSIGHT TECHNOLOGIES

Keysight's Power Products Offering

Highlight: N6705B DC Power Analyzer

Integrates multiple instrument functions into a single box



- 1 to 4 advanced power supplies
- Digital voltmeter and ammeter
- Arbitrary waveform generator
- Oscilloscope
- Datalogger

- All functions and measurements are available from the front panel

Gain insights into your DUT's power consumption
— in minutes, not hours —
without writing a single line of code!

Keysight's Power Products Offering

Highlight: N6900/7900 Advanced Power System (APS)

24 models
(1 kW & 2 kW)

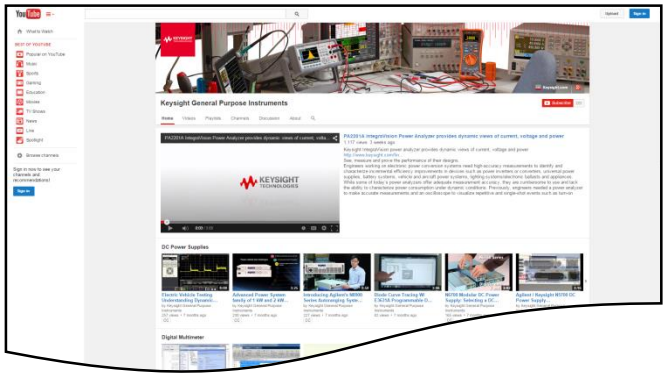
9 V, 200 A to
160 V, 12.5 A

The APS has 2 series, each optimized to meet your test needs	
N6900 Series DC Power Supply	Designed for ATE applications where high performance is critical
N7900 Series Dynamic DC Power Supply	Designed for ATE applications where high-speed dynamic sourcing and measurement is needed

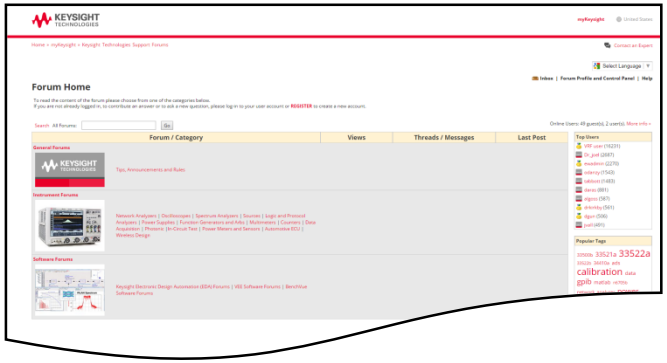
Keysight Power Products Resources

www.keysight.com/find/power

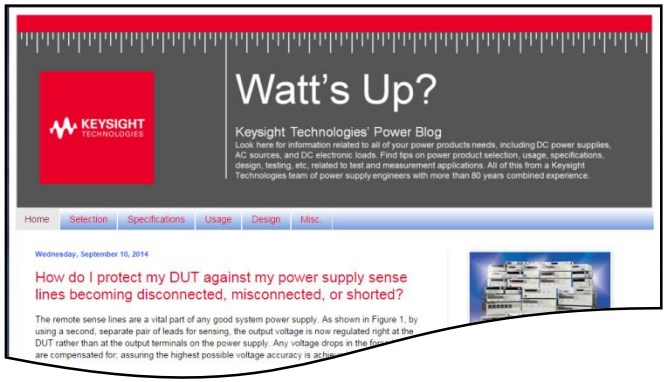
Videos www.youtube.com/user/keysightGP



Forums www.keysight.com/find/forums



Blogs www.keysight.com/find/powerblog



Power Supply Safety from Keysight Technologies

Thank you!

Questions,
comments,
& discussion

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Keysight Power Supply Safety

Possible demos

- OVP example using N6705B
- OCP example using N6705B
- Remote sense fault detection using APS
- Watchdog timer using N6705B
- Smart triggering for overpower shutdown using APS
- Ease of sequencing using N6705B
- Temperature margin using APS