Getting the Most from Modern Power Test Solutions:
Power Supplies, Electronic Loads, and Dynamic Test Techniques for R&D and ATE

Bob Zollo, Solution Architect / Product Planner for Power, EISG CoE
Keysight Technologies
5 November 2026

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May I introduce myself? Bob Zollo

- Solution Architect for Power Testing, Keysight Technologies
- Create power testing solutions roadmap
  by researching customer and industry trends
- 40 years: Keysight, Agilent, HP (one company, 3 names)
  - R&D and Marketing
  - Power supplies, electronic loads, power analysers,
    data acquisition equipment, and test systems
  - Managed battery test systems business
- Located in New Jersey, USA

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Global Leader in Test
Power Test Instrumentation
Cell/Battery Test Systems
Charger Test Systems
Grid Compliance Test

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When You Think About a Power Supply, What Do You Envision?



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When You Think About a Power Supply, What Do You Envision?





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What About a Power Source that Can …

- Measure, with DMM accuracy, the voltage, current, and power that is coming from the supply?
- Rapidly change to simulate a time varying signal?
- Capture time varying voltage or current flowing through the supply like an oscilloscope or datalogger?
- Provide DUT protection from over voltage or over current?
- Be triggered to synchronize with other events in your test?
- Can ramp up/down across multiple supplies to create a startup sequence?
- Be programmed via USB or Ethernet using high level commands from Python or C?
- Emulate a battery, including internal series resistance and battery capacity?
- Behave like a solar panel or array of panels?

Power supplies today can be simple benchtop units …



… Or sophisticated, dynamic, fast test instrumentation



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Different Performance Levels for Power Testing Instrumentation

DC Power supplies, Eloads, AC Power Supplies

	Basic	Mid-Range	Advanced
Key Characteristics and Features	• Steady DC sourcing • Slower programming requirement • Core protection (OVP/OCP) and standard remote control	• List or arbitrary waveform programming • Slew rate control • Higher power density	• Fast dynamics programming for real power events (sub-ms/µs-class capability) • High fidelity logging • Advanced analysis, record / replay profiles
Example Application	**Manufacturing burn-in / board power** Loads are mostly steady and ramps can be slow	**Power converter validation (e.g. DC/DC, 48 V bus converters)** Require controlled ramps, repeatable sequences	**Battery-powered device drain + emulation** Load steps are fast and requires ability to reproduce edge cases

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Beyond Basic Sourcing: What Tests / Use Cases?

Tests that require DC Power supplies, Eloads, AC Power Supplies

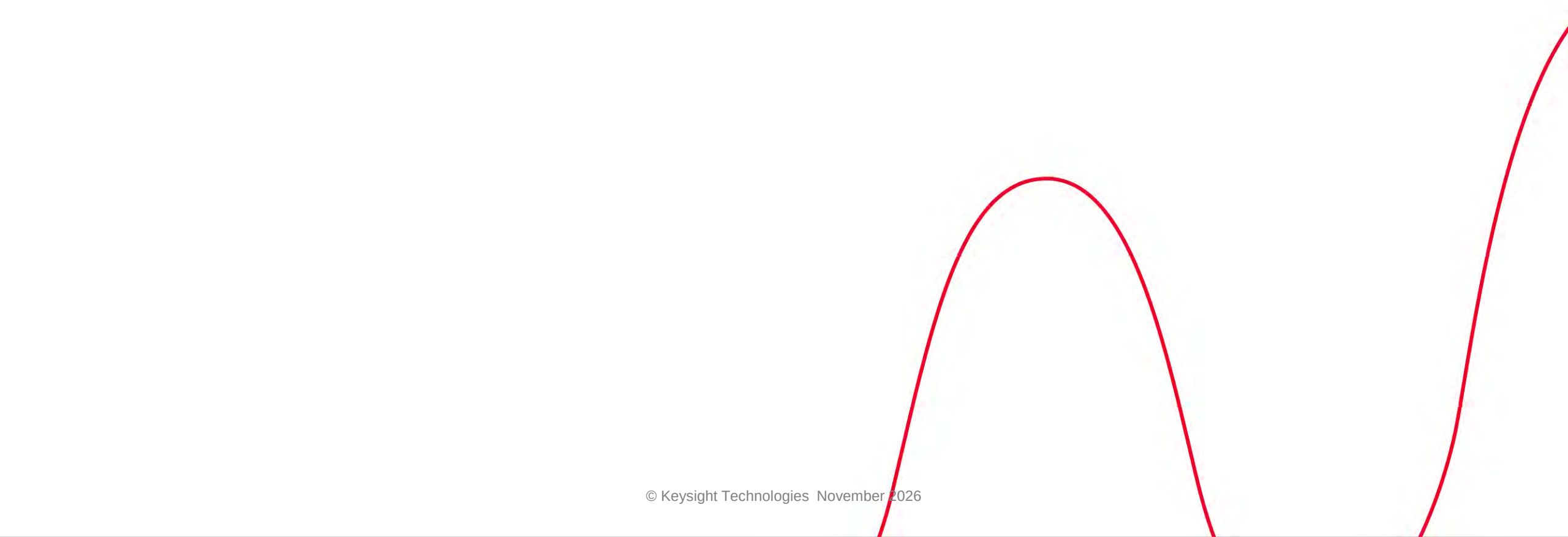
- Characterize inrush current into the DUT
- Characterize start up behavior when DUT requires sequenced power supplies during start up
- Measure DUT behavior under various power disturbances, blackout, brownout
- Validate DUT performance at different temperatures
- Testing cooling system performance by simulating heat loads using power supplies and resistors

- Measure output noise of a power source
- Measure power source behavior under fast current transients, including special pre-determined test waveforms
- Measure efficiency of a power source

Green = Challenging tests that require dynamic sources and eloads with fast slew rates and high accuracy

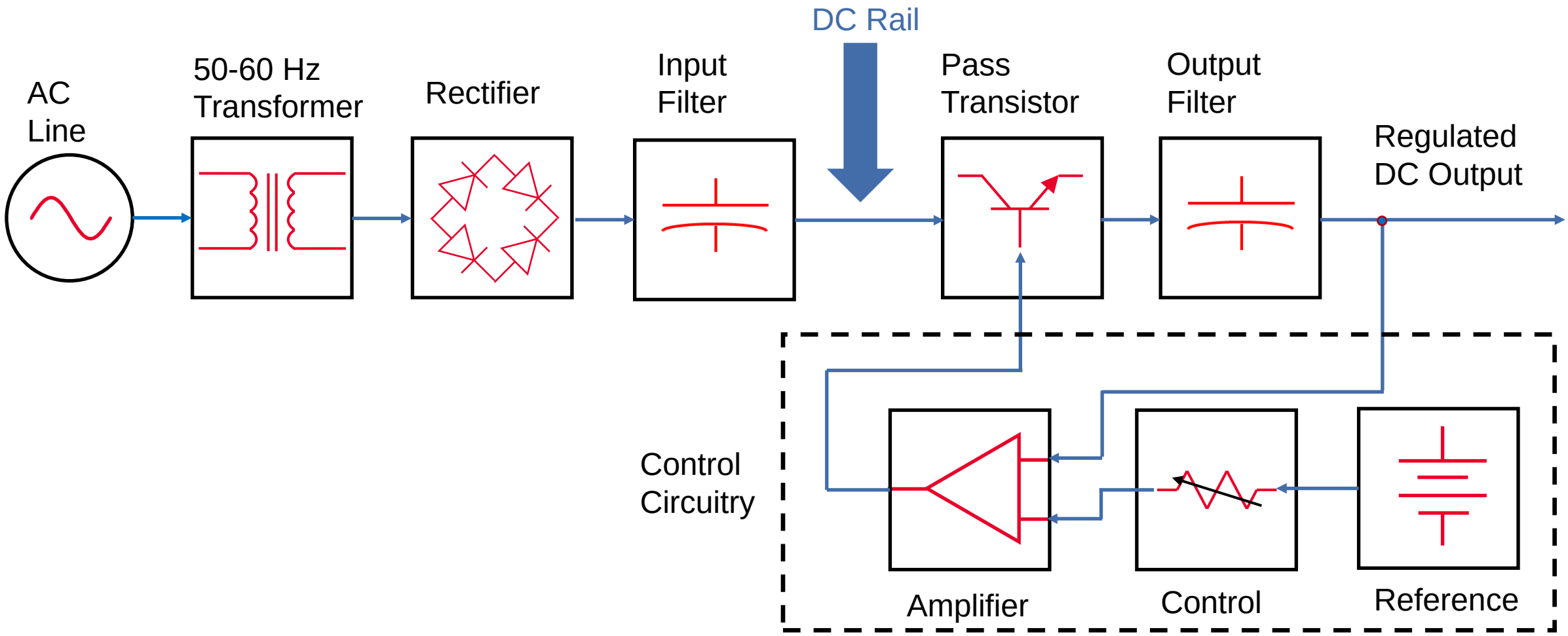
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DC Power Supplies



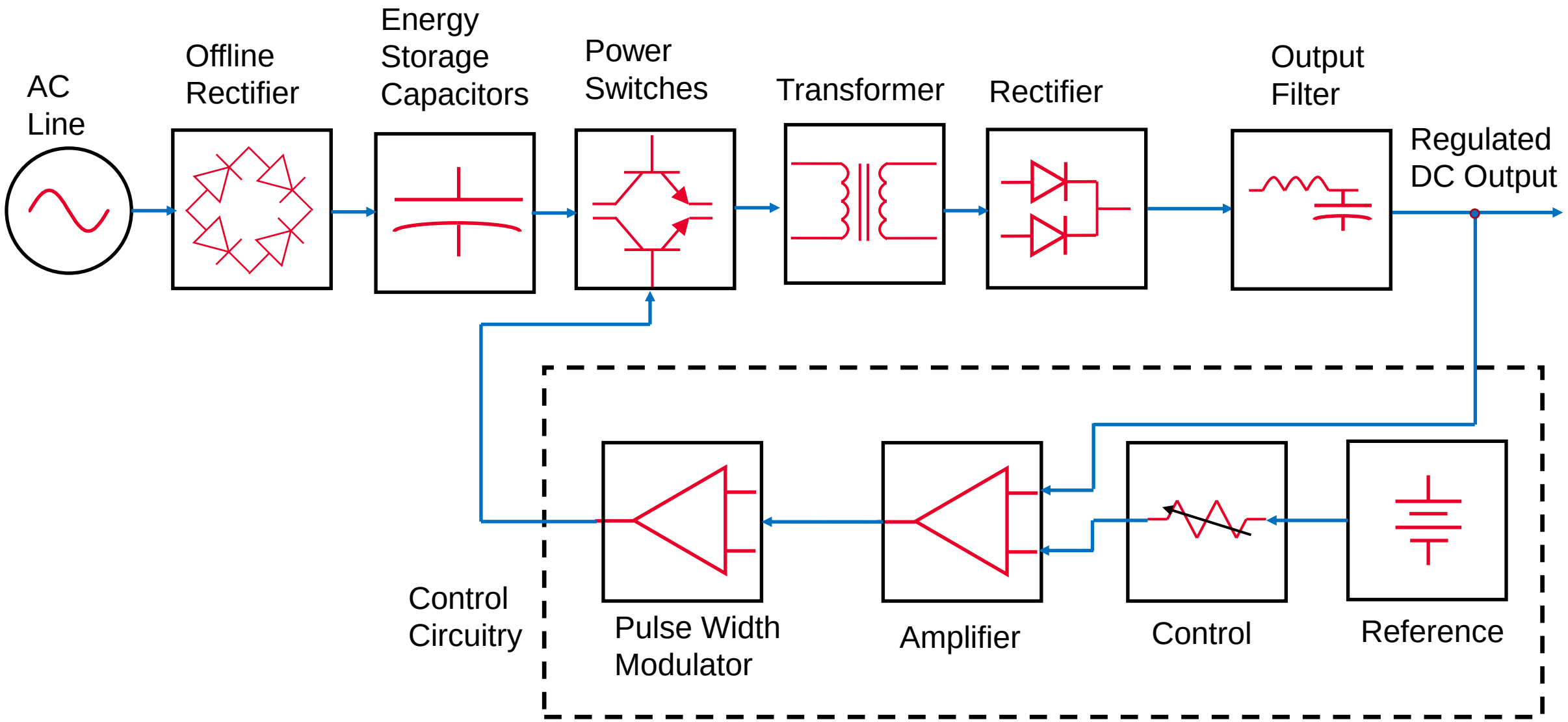
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Linear Power Supply Operation



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Switching Power Supply Operation



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Linear vs. Switching Power Supply Comparison

Efficiency, speed, noise, size and cost trade-offs at a glance

Linear

≤60%

typical efficiency at full output

STRENGTHS

- \+ Fast transient response
- \+ Low noise and ripple
- \+ Low common-mode noise
- \+ Cost-effective below 500 W

TRADE-OFFS

- – Low efficiency
- – Large and heavy
- – Costly above 500 W

Traditional switching

85%+

typical efficiency, at any output setting

STRENGTHS

- \+ High efficiency
- \+ Small and light
- \+ Cost-effective at high power

TRADE-OFFS

- – High noise and ripple
- – High common-mode noise
- – Slow transient response

High-performance switching

85%+

typical efficiency, at any output setting

STRENGTHS

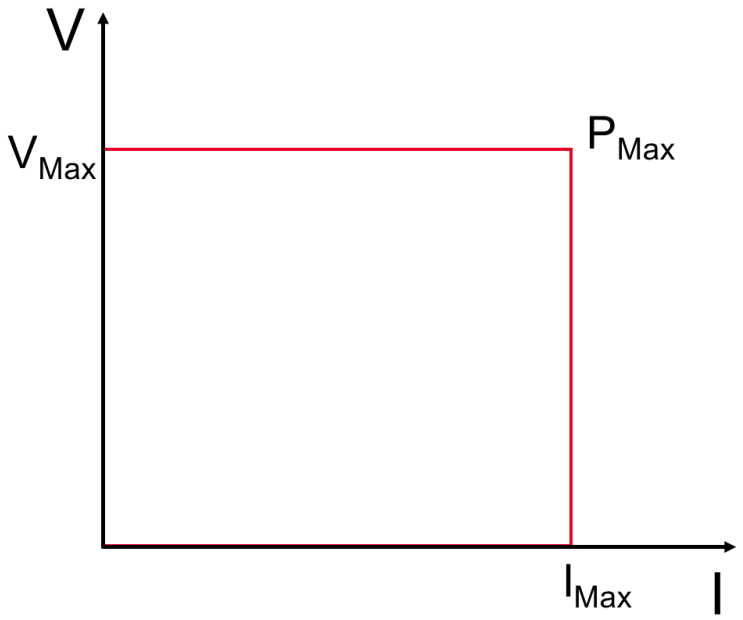
- \+ High efficiency
- \+ Small and light
- \+ Fast transient response
- \+ Low noise and ripple

TRADE-OFFS

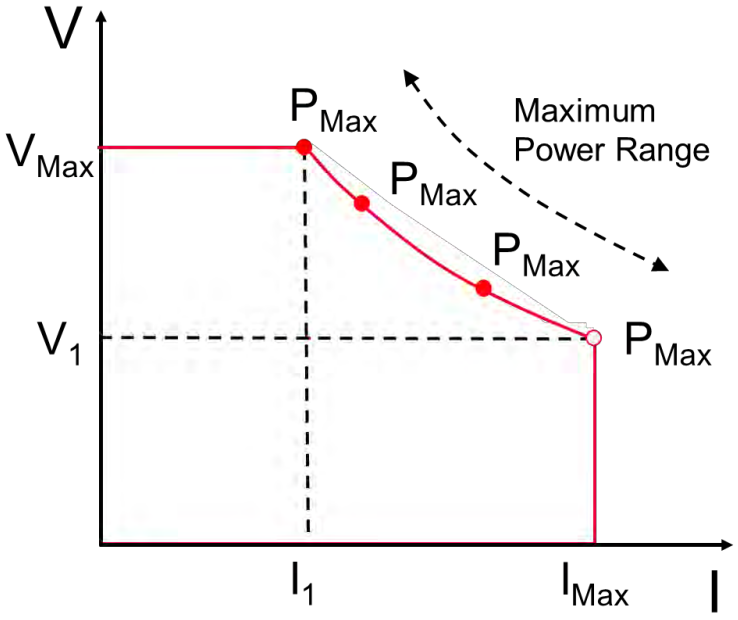
- – Typically, higher cost than traditional switching supply

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DC Power Supply Output Characteristics



Rectangular Power Supply
Easy to understand



Autoranging Power Supply
More flexible

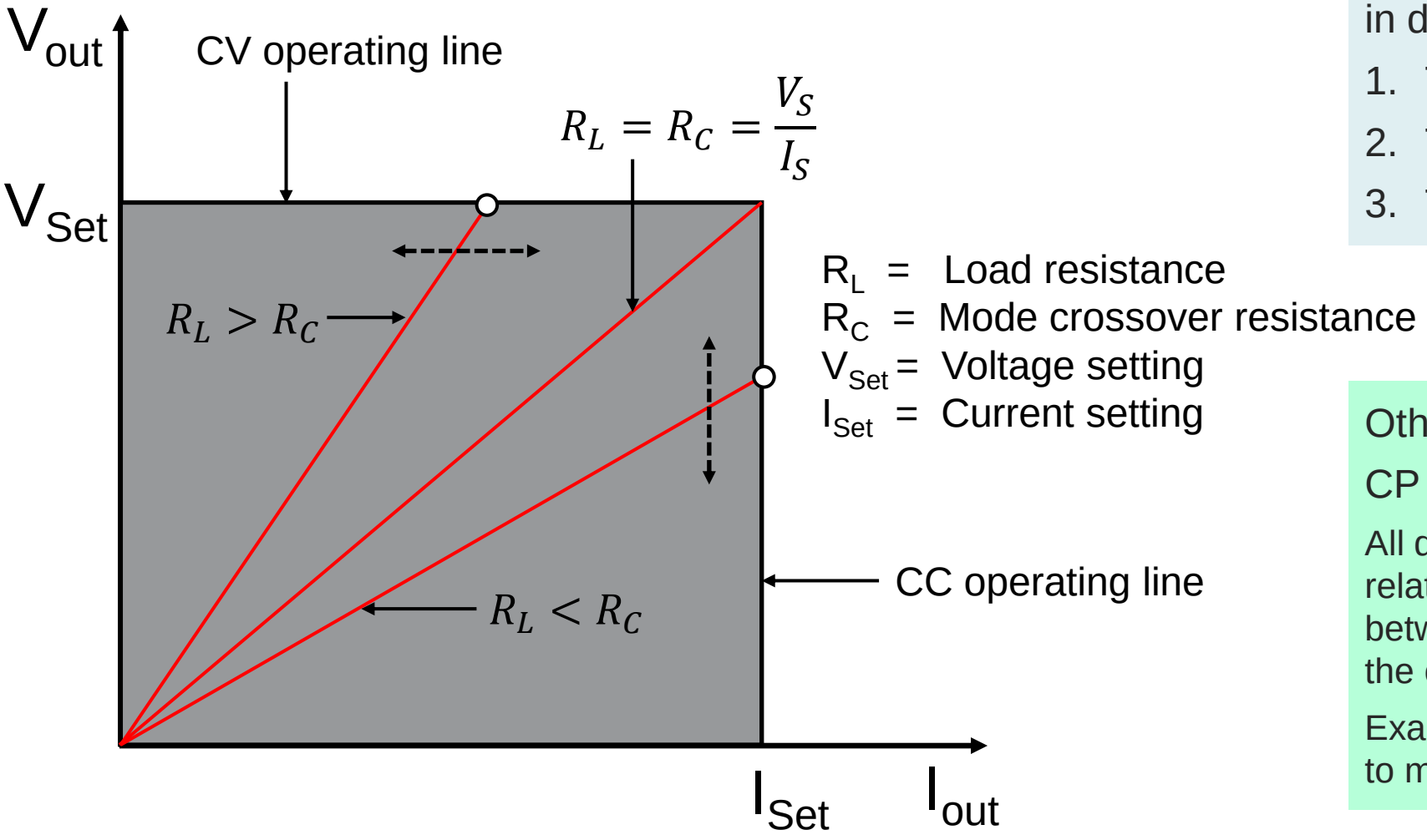
PLUS

Can be connected in **series** to **increase voltage** and **power**
Can be connected in **parallel** to **increase current** and **power**

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Power Supply Modes of Operation

You do not actually set a power supply into constant voltage or current mode



The mode a power supply operates in depends on:

1. The voltage setting
2. The current setting
3. The load resistance

Other potential mode:

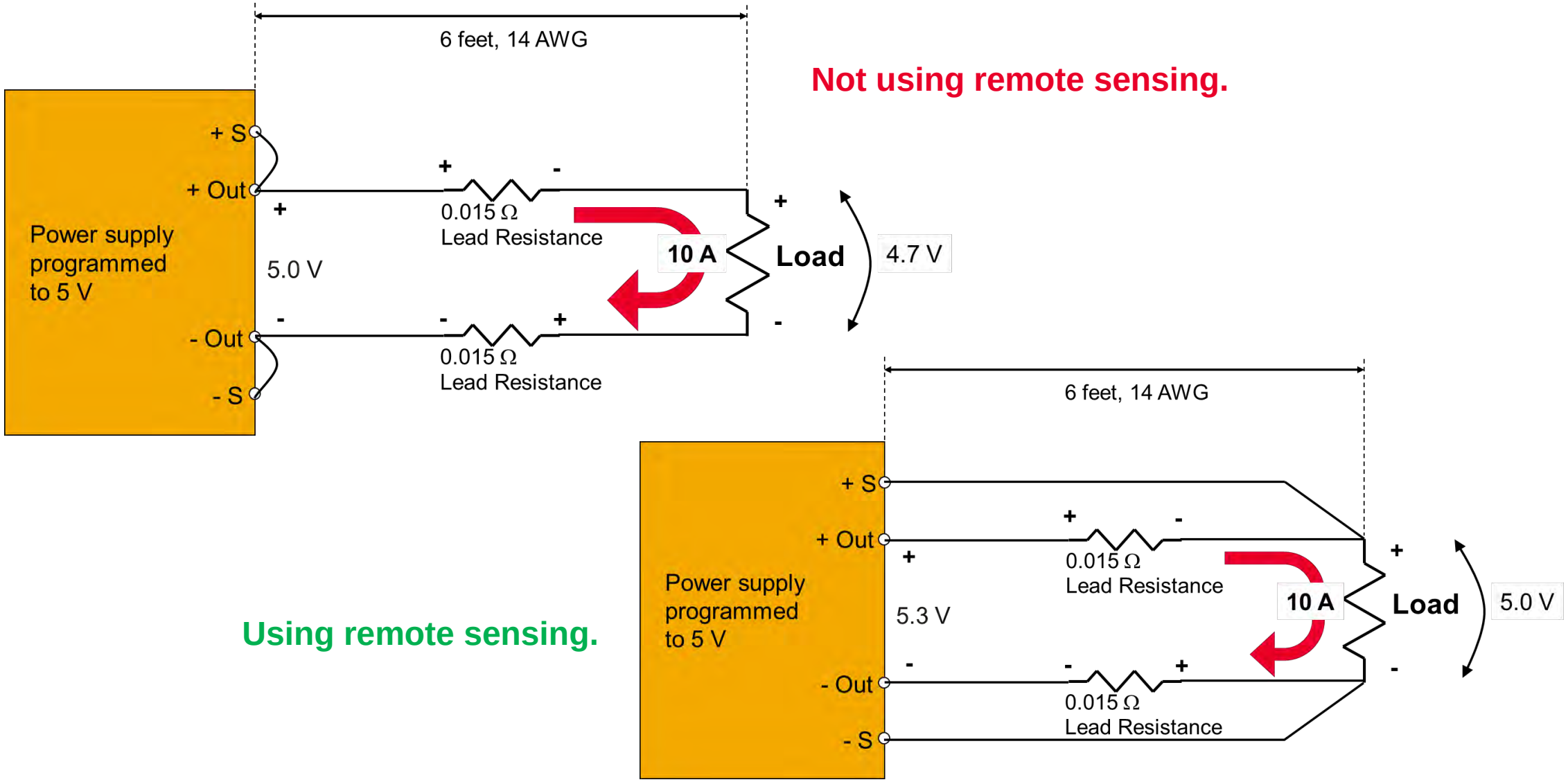
CP – Constant Power

All depend on the mathematical relationship (i.e., feedback algorithm) between the measured parameter and the control parameter.

Example for CP: Measure I, adjust V to maintain fixed power as V * I

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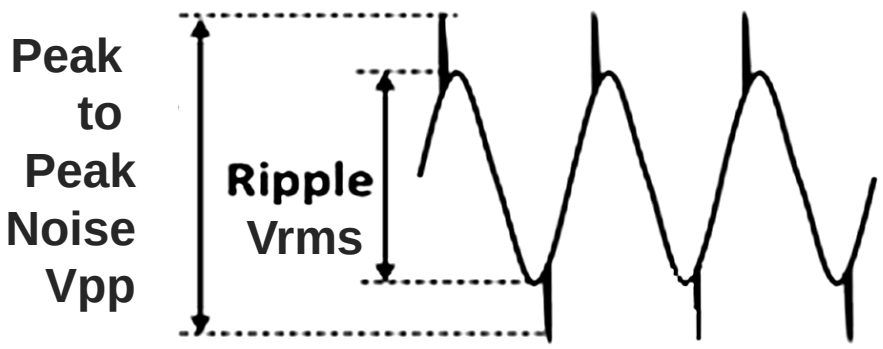
Managing Ohmic Line Drop with Remote (4-Wire) Sensing



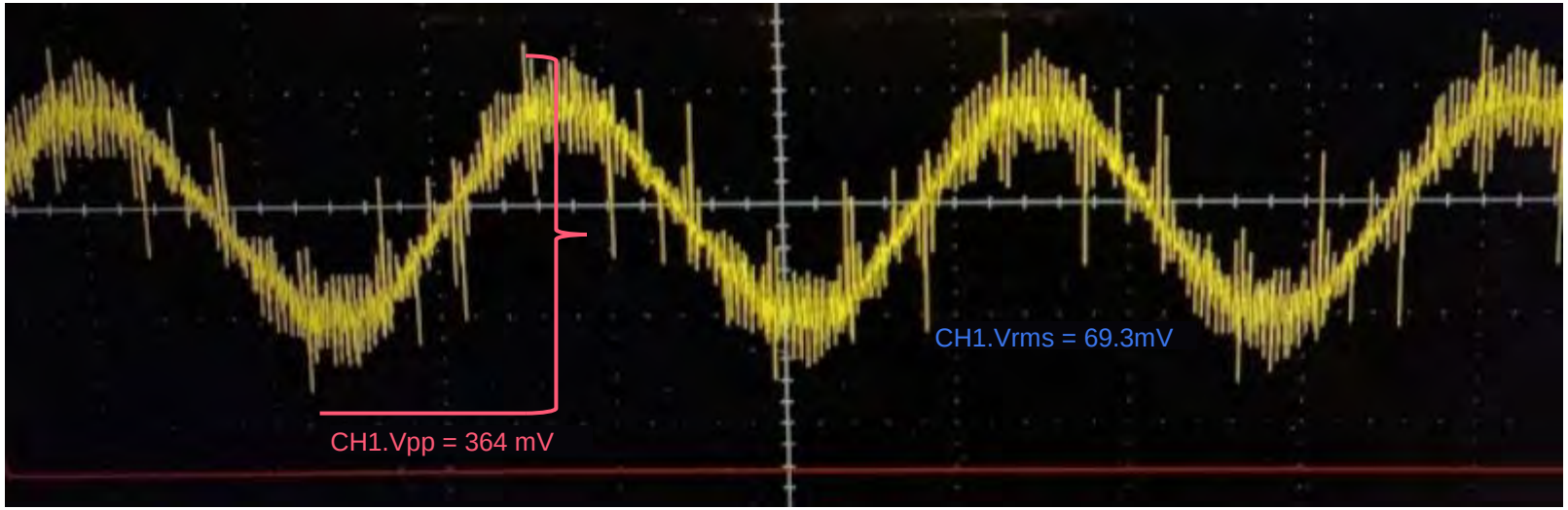
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Output Ripple and Noise (formerly PARD)

“Output ripple and noise” has replaced the older term PARD (periodic and random deviations)



- Output ripple and noise consists of both periodic (ripple) and non-periodic (noise) deviations in a power supply’s output.
- Units = mV, expressed as either RMS or peak-to-peak, measured across a specific bandwidth, typically 20 Hz to 20 MHz.
- Fluctuations below 20 Hz are considered to be the drift specification.

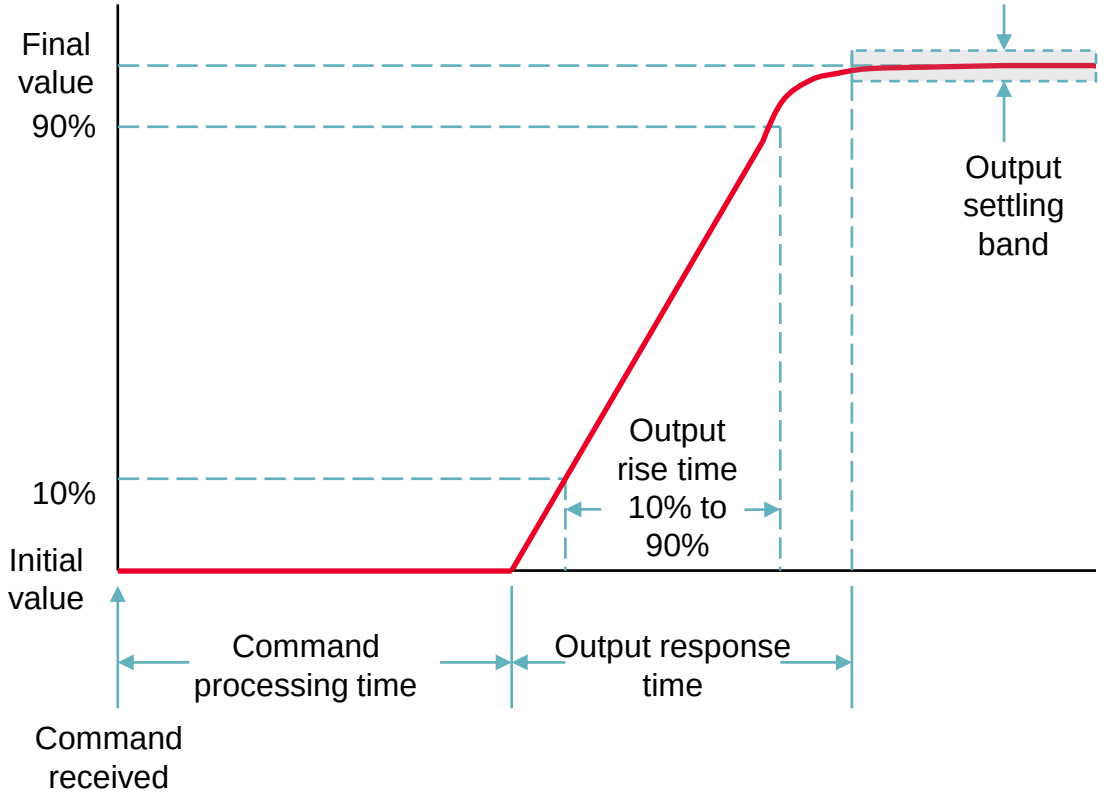


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Output Up-Programming Time

Consists of 2 parts: Command Processing and Rise Time

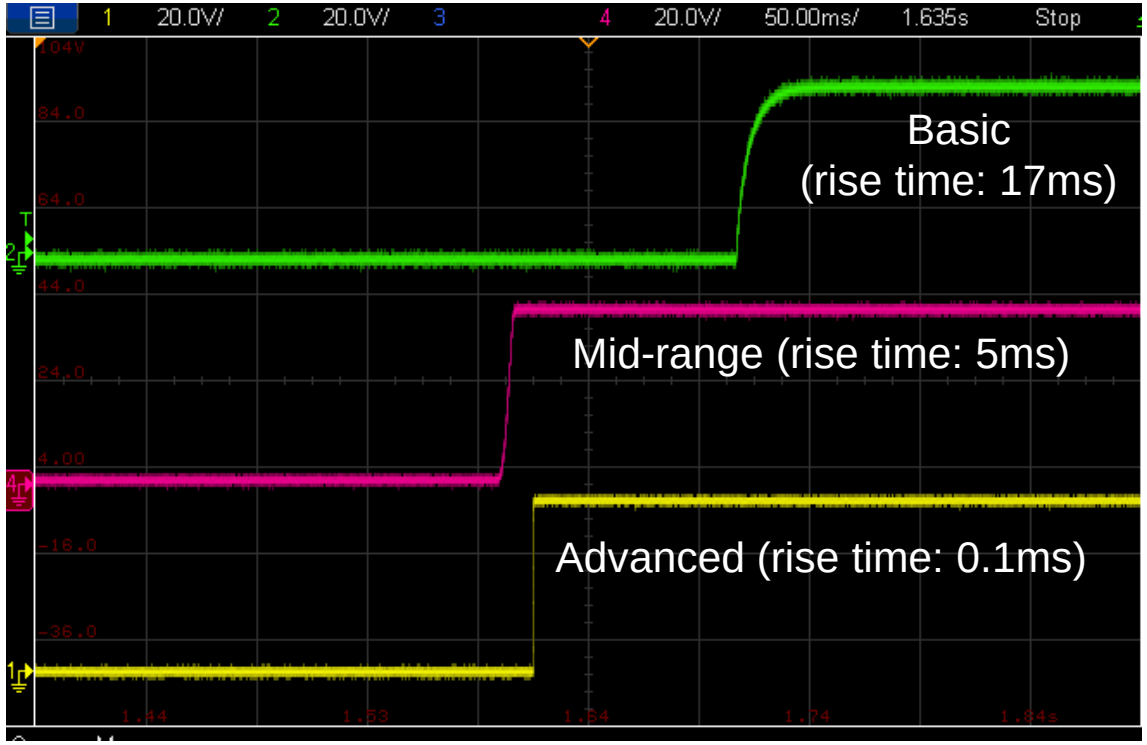
- Output command processing time can vary greatly
  - 5 to 10 ms for basic power supplies
  - 1 to 10 µs for high-performance power supplies
- Output up-programming time (rise time) can vary greatly
  - 5 to 50 ms for basic power supplies
  - 100 to 500 µs for high-performance power supplies



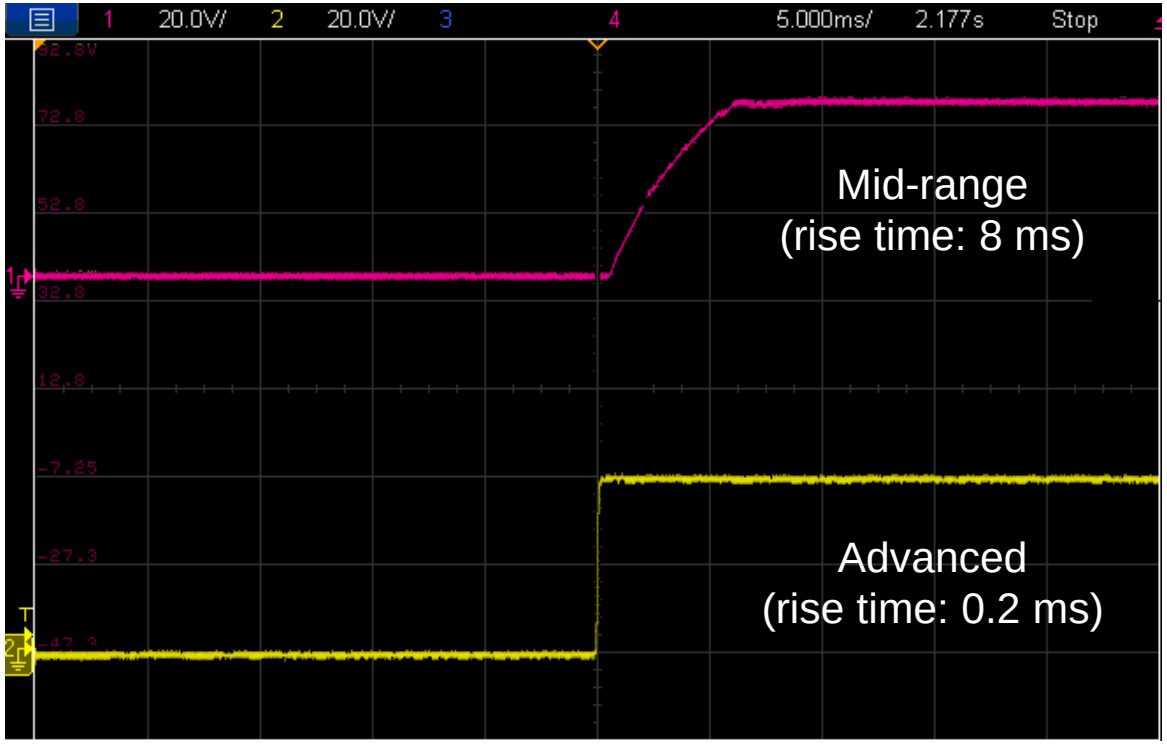
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Comparing Rise Time Performance

Visualized using Scope Traces



Ramp 0V to 40V



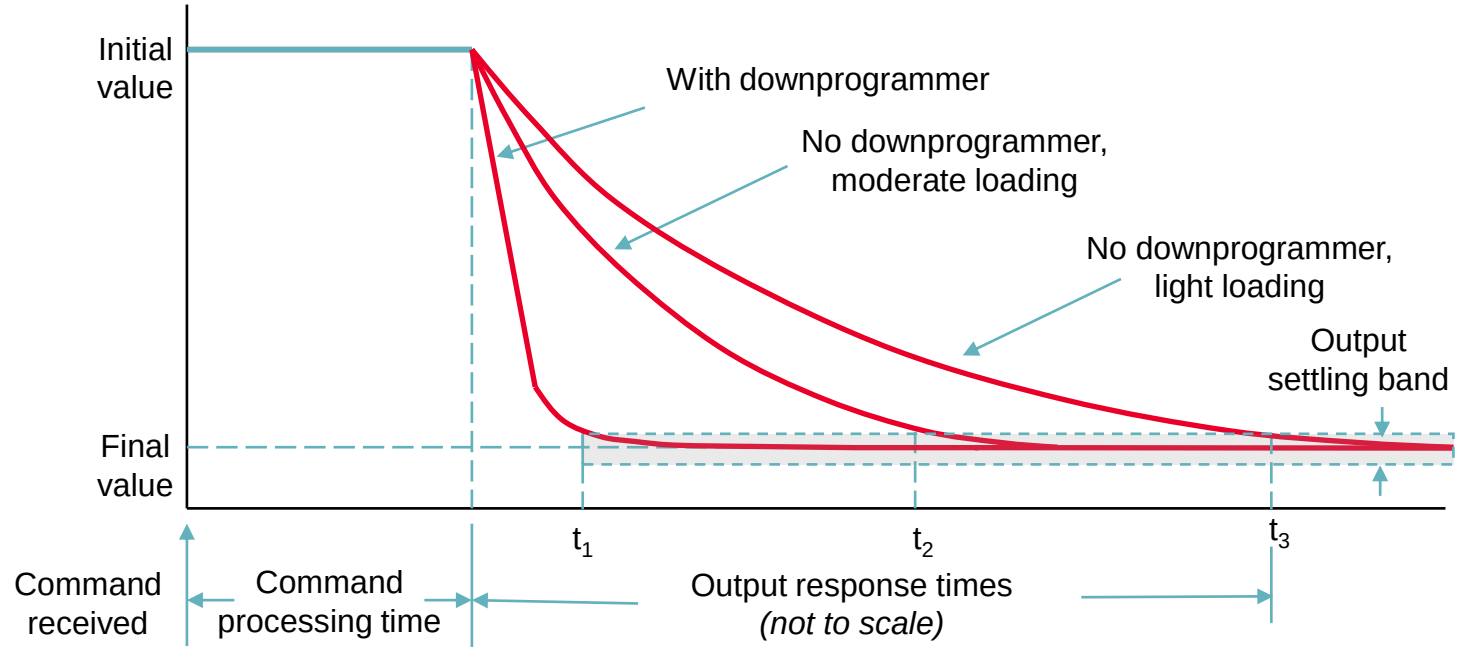
Ramp 0V to 80V

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Output Down-programming Time

Consists of 2 parts: Command Processing and Rise Time

- Most entry-level power supplies do not have an **active down-programmer**
  - Without down-programmer, energy stored in output capacitor has no where to go
  - Output voltage stays up for many 100's of ms or even seconds with very light / no loads
- High-performance power supplies have an active down-programmer
  - < 1 ms, regardless of DUT loading



When combined with fast up-programming, now you can:

Generate fast signals
Execute test programs faster

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Power Supply Protection Features

Prevent Damage to Sensitive Devices, Circuits and the Power Supply Itself

Over-voltage protection (OVP)

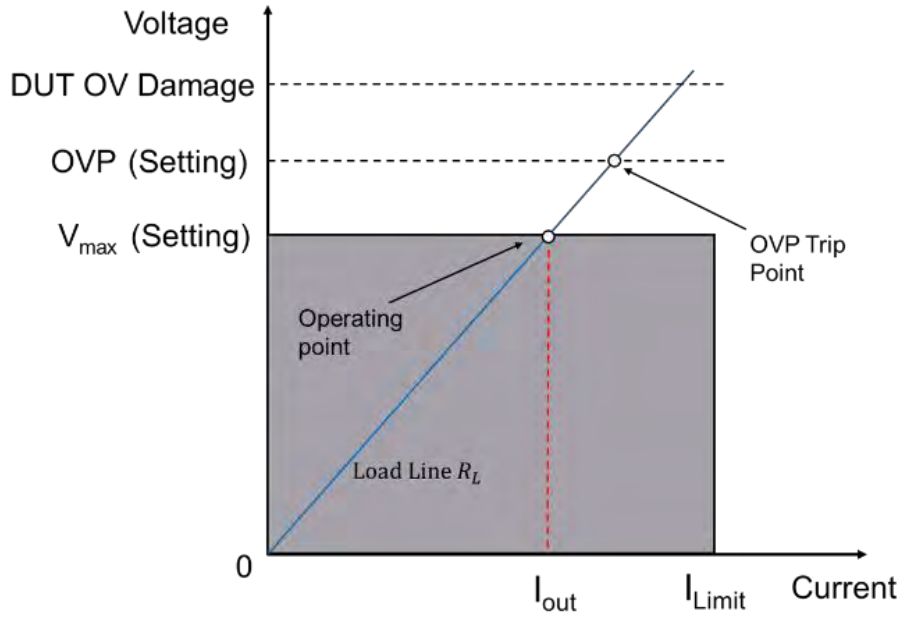
- When power supply output voltage > OVP voltage setting, OVP trips and turns off output
- Responds in microseconds
- OVP responds to voltage at output terminals not sense terminals
- TIP: set OVP voltage high enough to account for load lead voltage drops

Over-current protection (OCP)

- If power supply hits current limit value and enters CC mode, OCP trips and turns off output
- Acts like a programmable circuit breaker

Over-temperature protection (OTP)

- Monitors the temperature of the outputs and shuts down the output if any internal temperature exceeds the maximum factory-defined limits

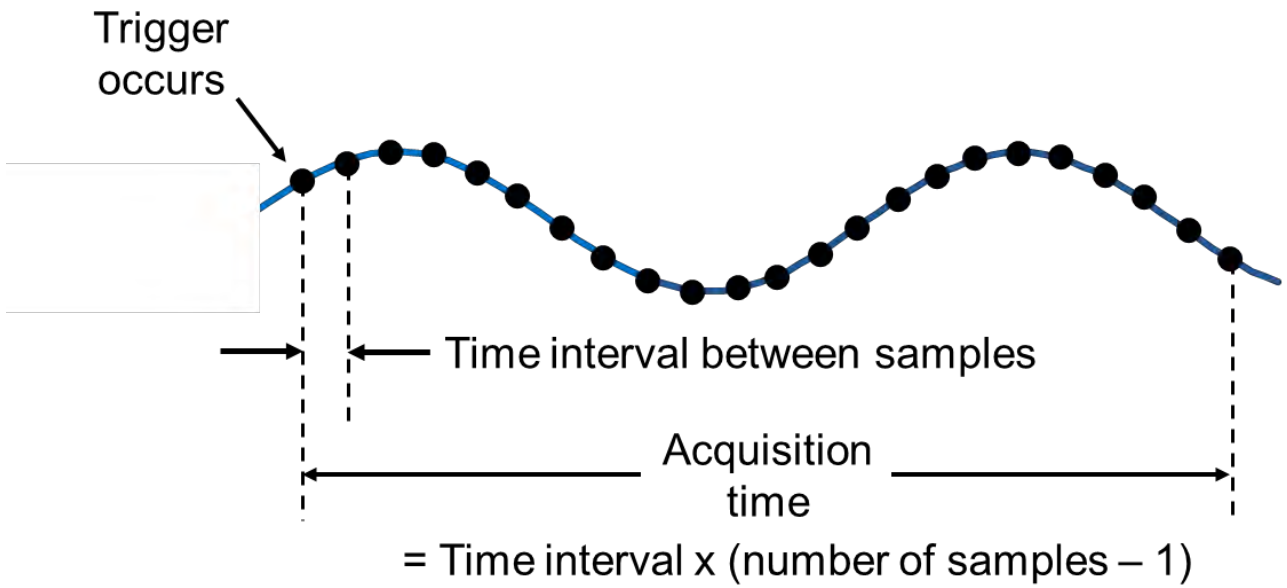


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Digitizer Capability Can be Essential

Built-in digitizers facilitate the capture of power supply voltage and current output over time

- Built-in digitizers capture dynamic voltage and current waveforms
- Set two of these three parameters
  - **Time interval** – time between samples
  - **Number of samples** – total number of samples you want to take
  - **Acquisition time** – total time during which you want to take samples



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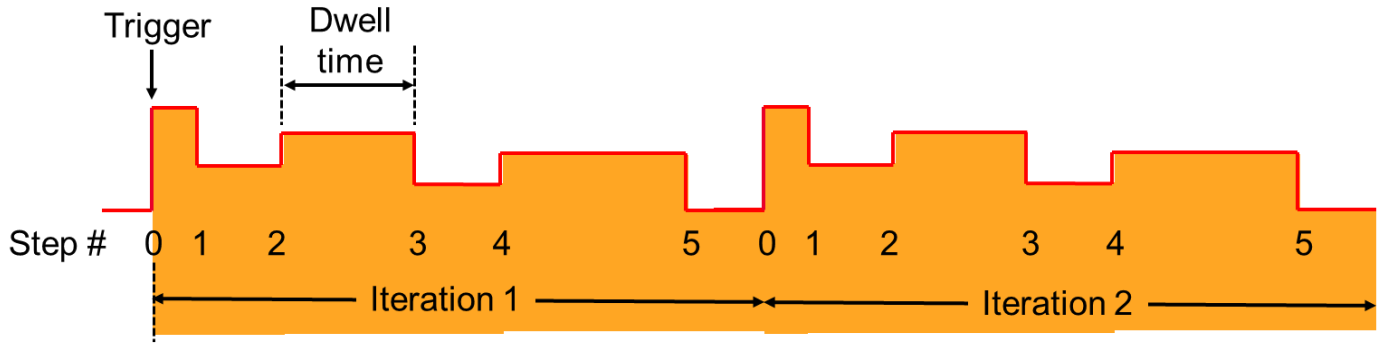
List Mode Supports Arbitrary Waveforms

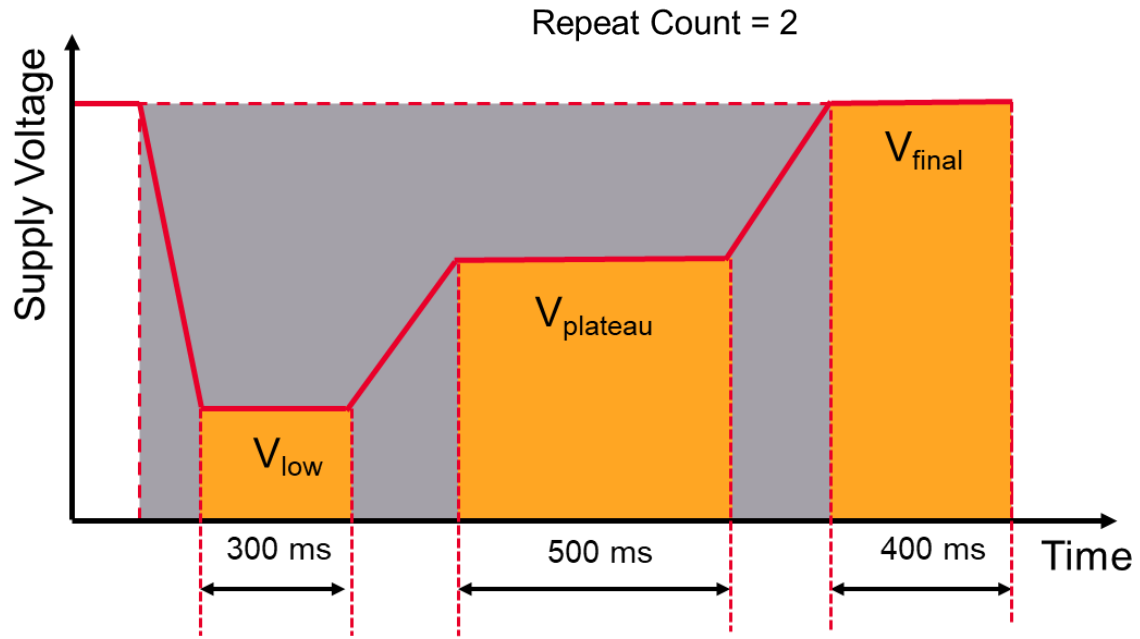
To create a list, set the following

- One or more voltage or current steps – defined voltage or current values
- **Dwell times** – duration associated with each voltage or current step
- **Repeat count** – the number of times you want the list to repeat
- Could also program like an **Arb** - Provide a list of voltages and a single interval

Application Example

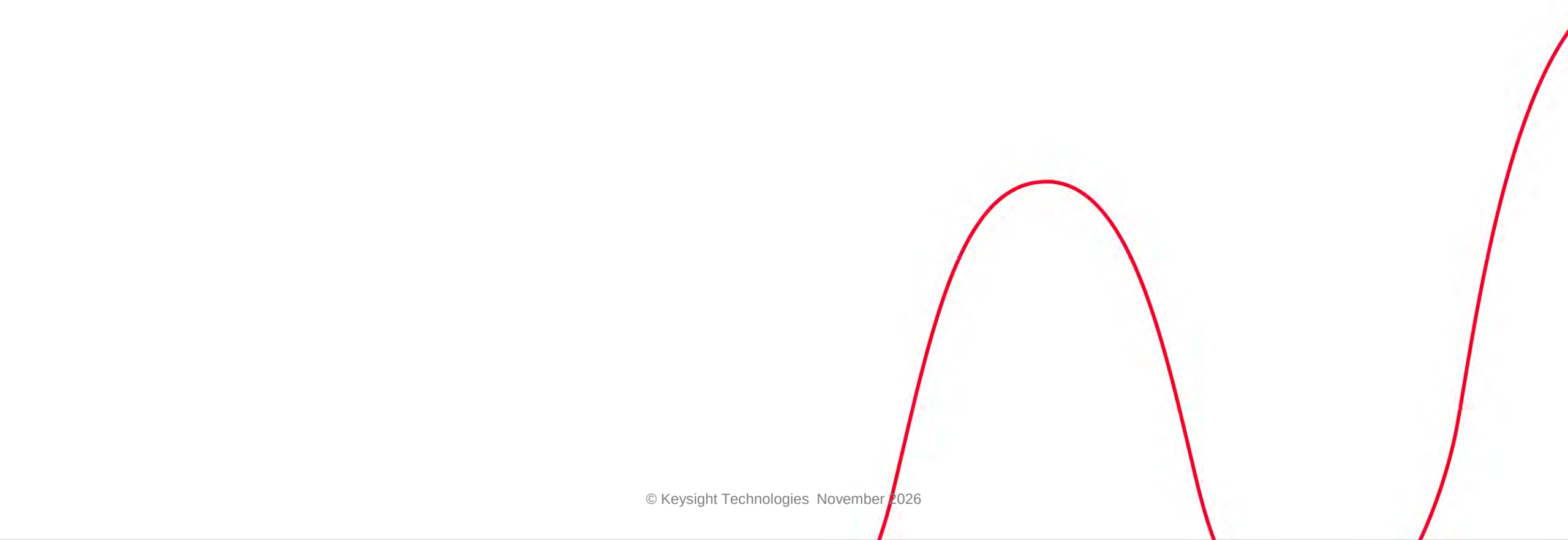
- Automotive testing – cold crank voltage profile for ECU design validation test





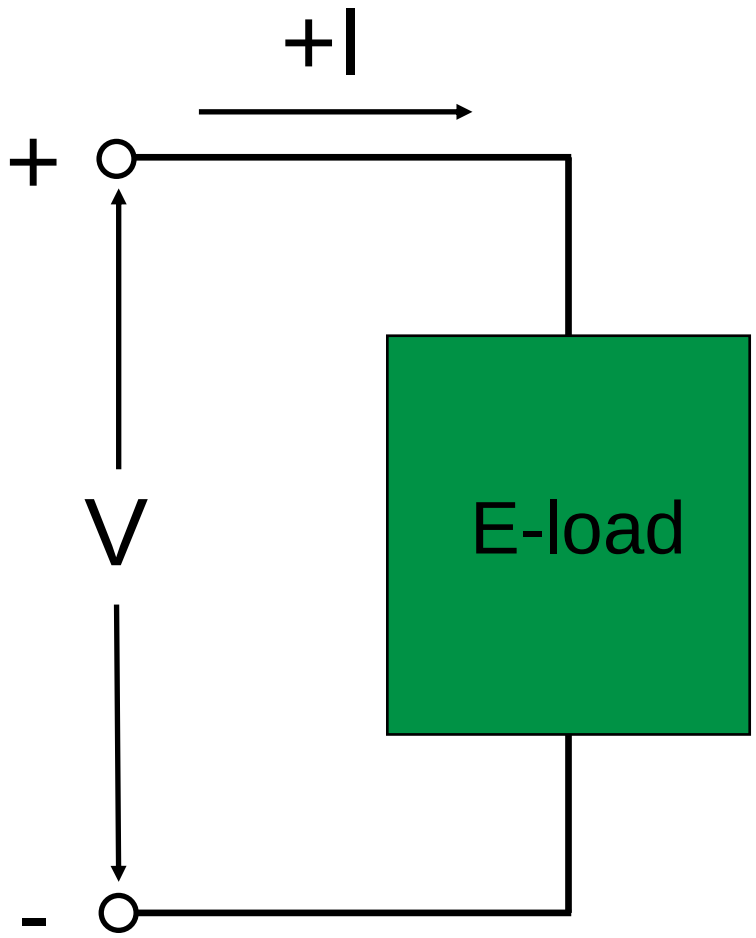
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DC Electronic Loads



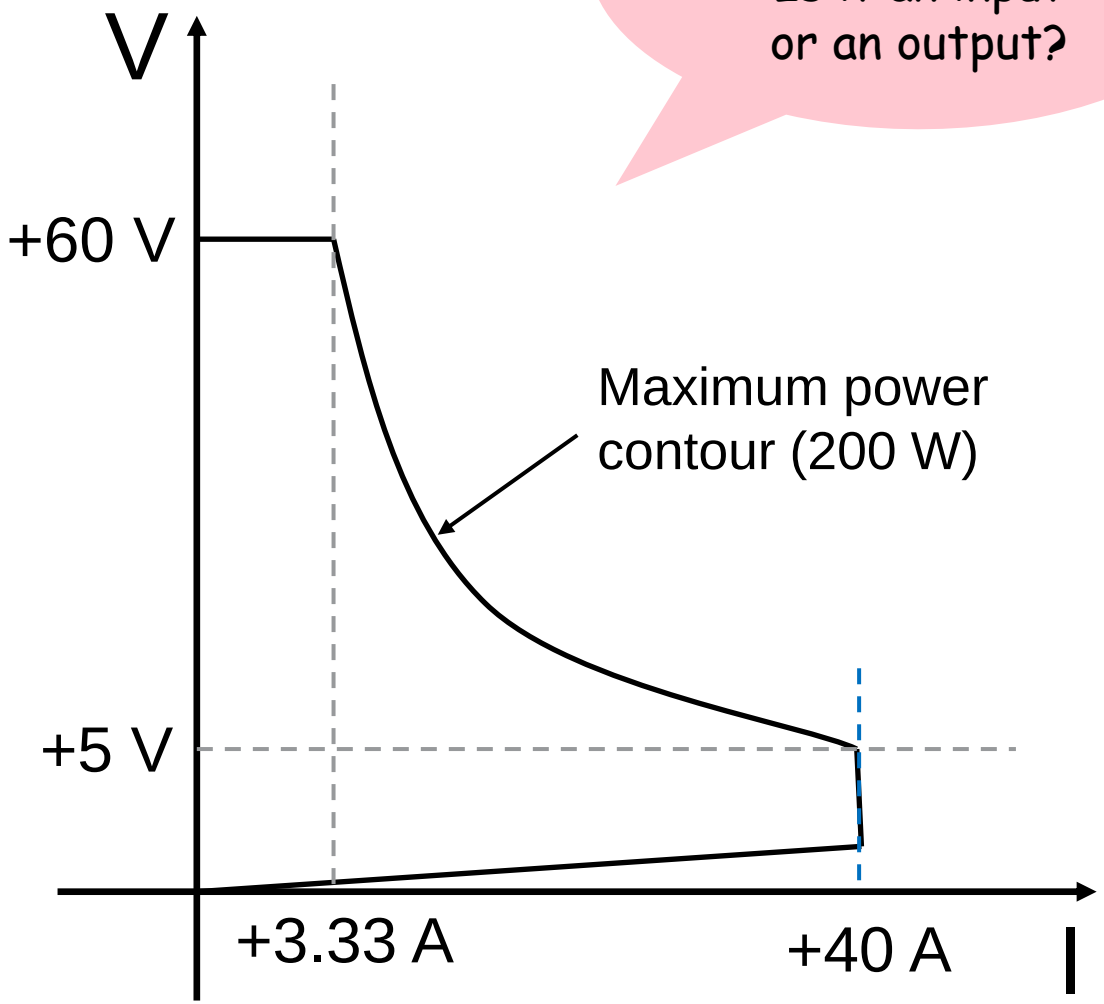
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What is an Electronic Load?



Quiz Question

Is it an input or an output?



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Loads Use FETS to Regulate Current, Voltage, Resistance, and Power

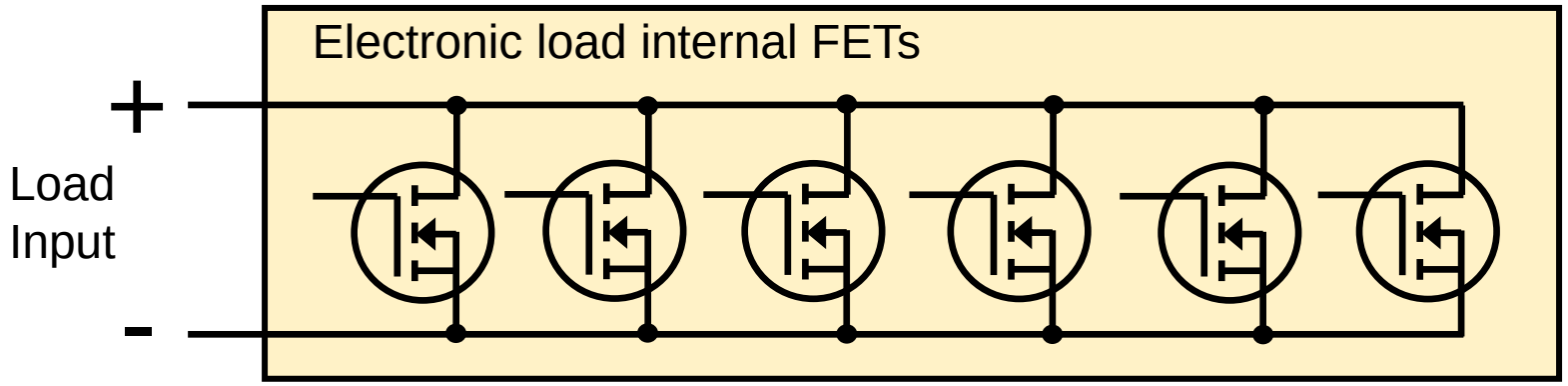
Loads change FET resistance to regulate current (measure I, adjust FET R)

When your load is set to a short

- FETs are fully turned on such that each FET is at R_on
- Input resistance is not zero; typically ranges from 10 mΩ to 100 mΩ

When your load is set to an open

- FETs are fully turned off
- Input resistance is not infinite; typically ranges from 20 kΩ to 500 kΩ





OK to connect loads in parallel to increase current and power



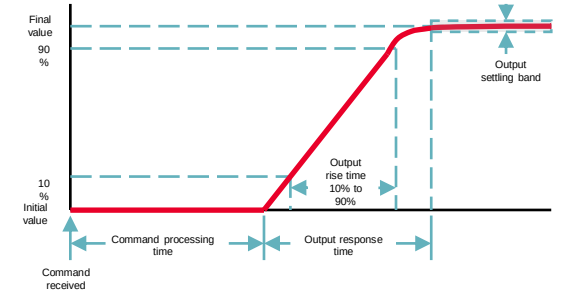
NEVER connect loads in series to increase voltage. It can easily result in damage to the load

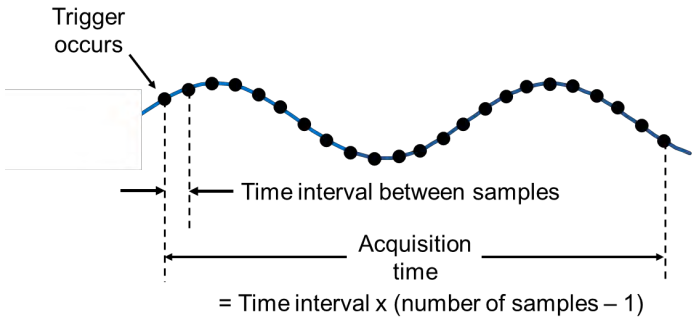
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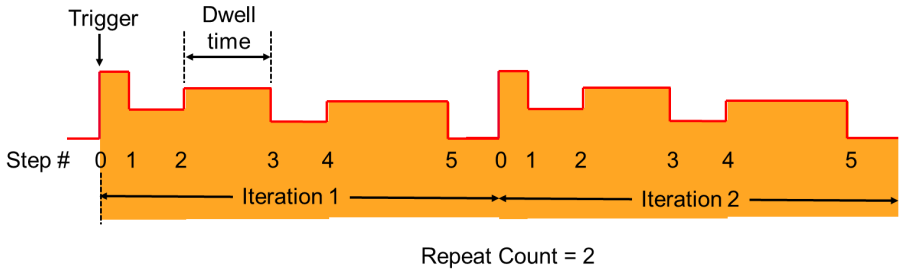
Loads Can Also Have Capabilities: Modes, Accuracy, Dynamics

Similar to Power Supplies

- **Modes:** CC, CV, CR, CP, CZ
- **Measurements:** DMM-quality measurement of voltage, current, power
- **Speed:** High-performance loads can quickly change operating point
- **Built-in Digitizer:** To capture time varying voltage and current
- **Built-in List mode / Arb:** To generate a variable load



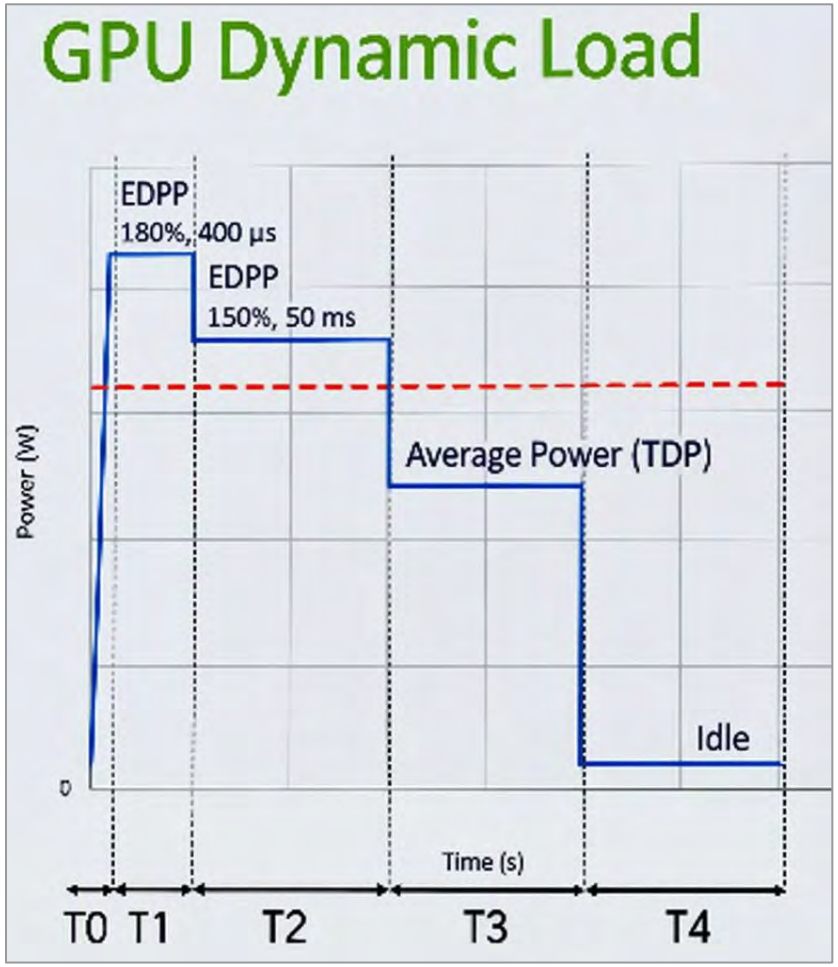




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List Mode Example: Data Center Server Rack Power Needs Fast Loads

High-Power, High-Speed Load Requirements to simulate the effects of GPUs on Server Rack Supplies



Key Characteristics of this EDPP waveform (from NVIDIA)

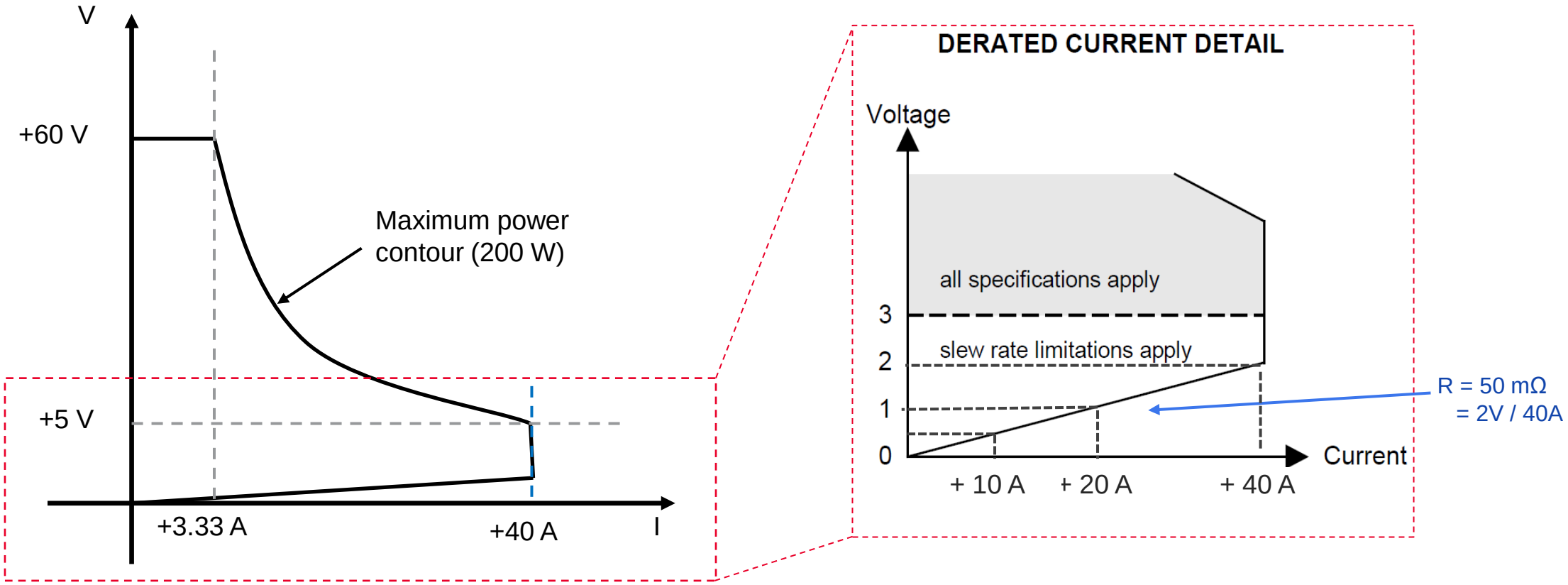
- Loading current used to check for voltage regulation
- Called EDPP (Electrical Data Peak Processing)
- Requires a load current risetime of microseconds
- Total test pattern duration = 300 ms or longer
- Requires 180% of nominal current (TDP = Thermal Design Power)

Interval	Duration per step
T0	**µs (challenging risetime)**
T1	400 µs or longer
T2	50 ms or longer
T3	100 ms or longer
T4	100 ms or longer

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FETs Limit Current at Low Input Voltages

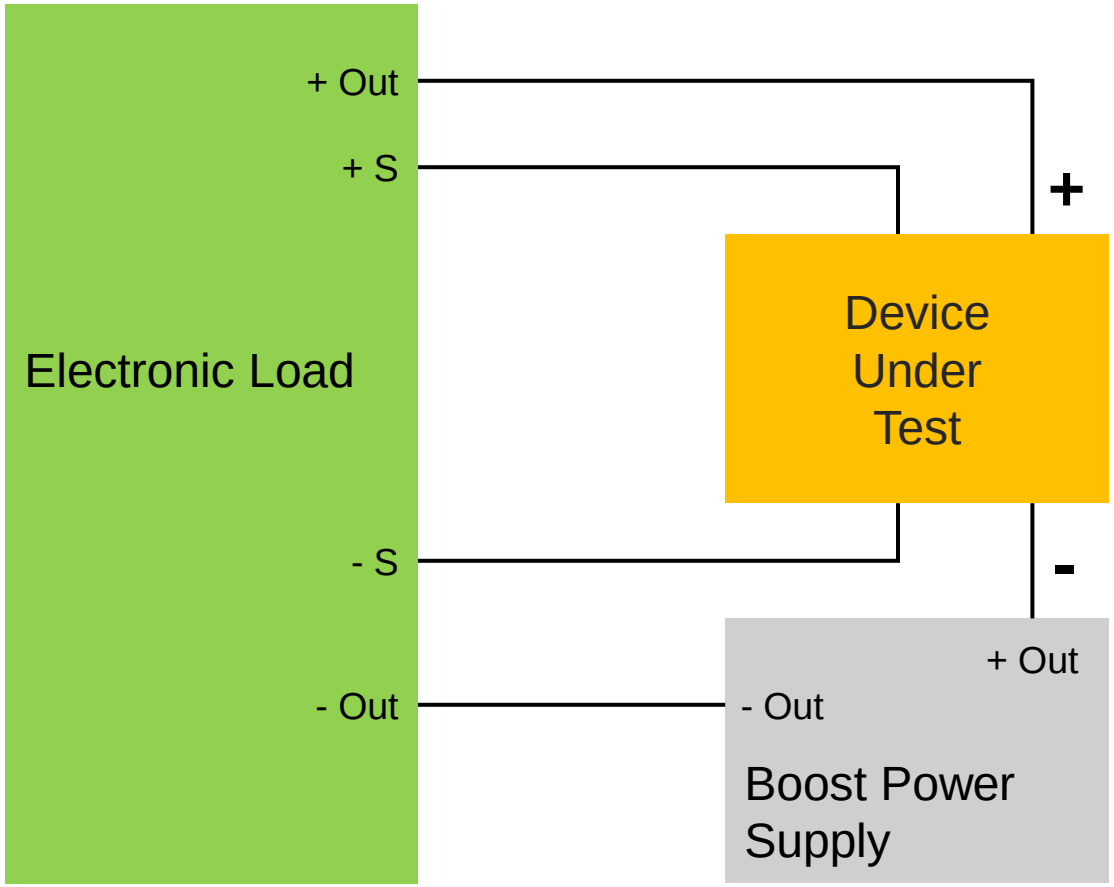
- Loads use internal power FETs to regulate current, voltage, resistance, or power
- When operating at low drain to source voltage,
  FETs are not in saturation and therefore “slow down” with reduced slew rate

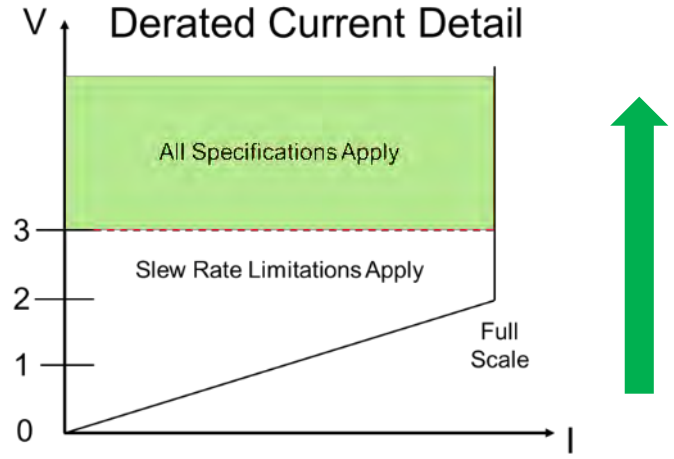


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Workaround for E-Load Low Voltage Limitations

Use a boost power supply





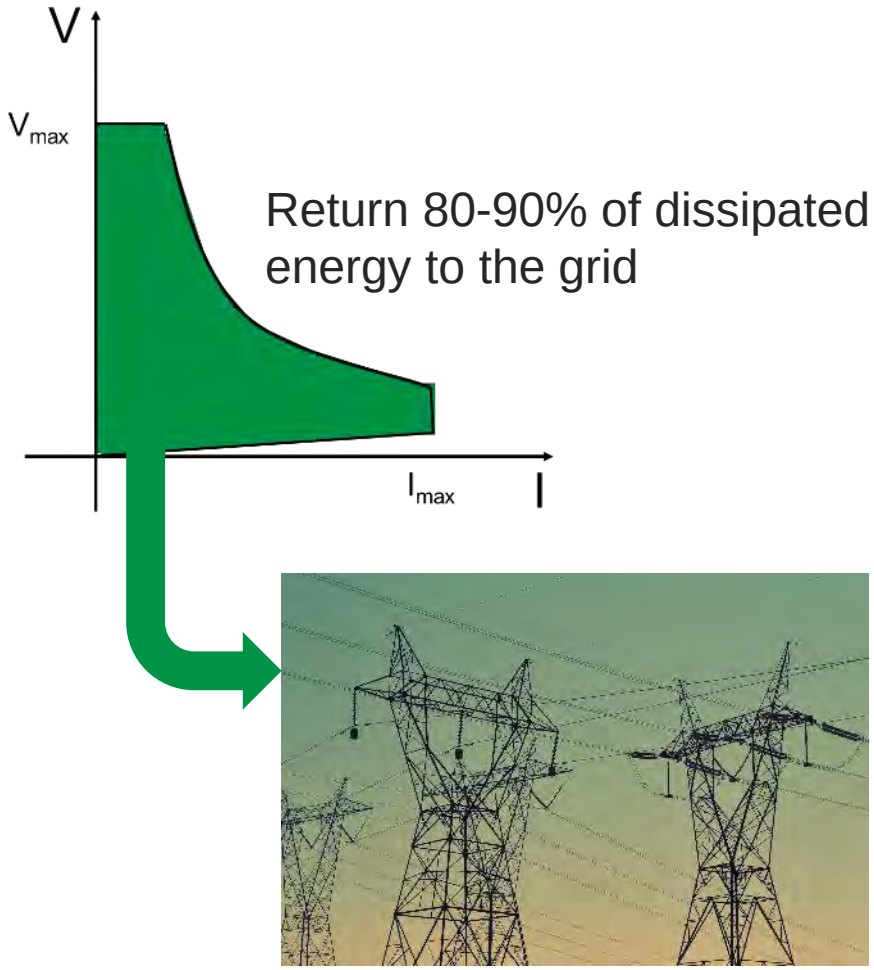
Boosts back to All Specs region

- Load input sees DUT voltage + Boost Supply voltage, pushing it up into the “All specs apply” region
- Use a low-noise boost PS to minimize noise measurements made on the PS under test.
- The electronic load must dissipate power from both the PS under test and the boost PS. Make sure the load has a sufficient power rating.

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What is a Regenerative Electronic Load?

Regenerative electronic loads return power to the grid rather than dissipating it as heat

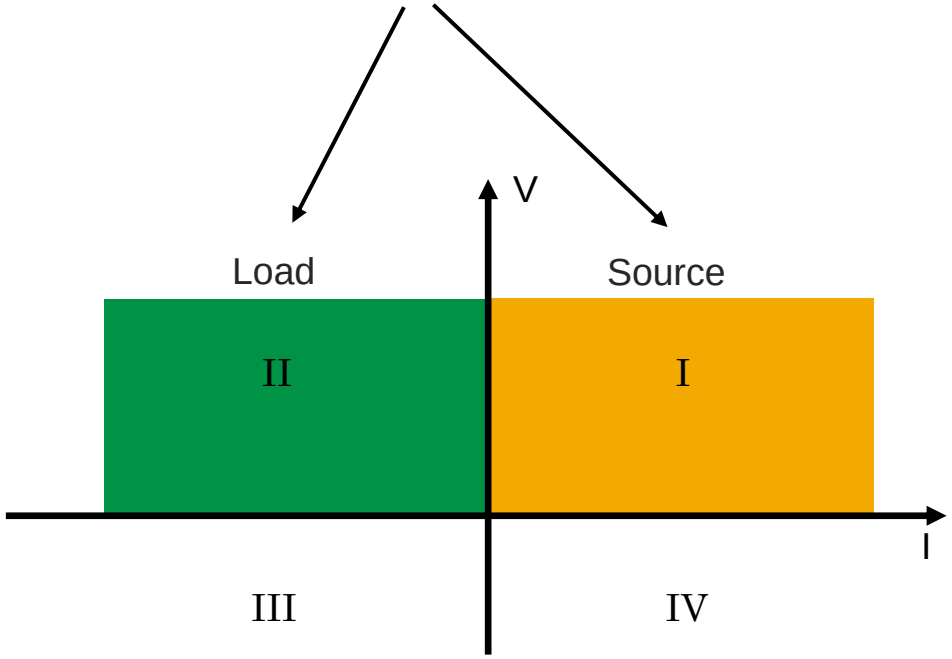


- **Advantage**
  - Many users place multiple electronic loads in parallel to handle higher power levels
  - These racked parallel setups can sink hundreds of kilowatts (thousands of Watts) of power
  - Regenerative loads return much of this power to the grid, thereby greatly reducing the cooling needed in the lab
- **Disadvantage**
  - Require three-phase connection to the ac line because returning large amounts of power to the grid is more efficient on three-phase systems.
  - Therefore, more complex to connect vs just plug into the wall.

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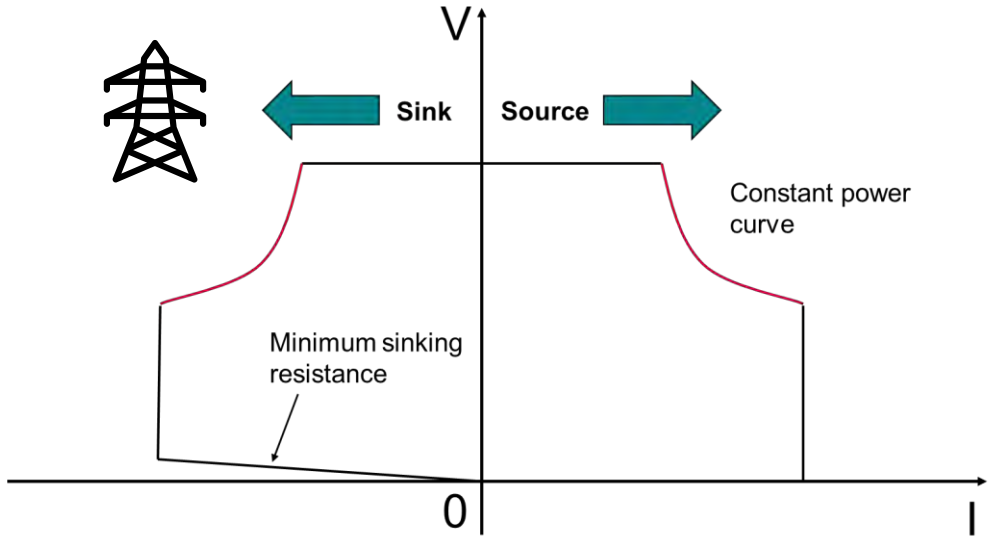
What is a Two-Quadrant Power Supply?

A two-quadrant power supply,
also called a Bi-Directional Power Supply,
can act as **both** a source and a load.



What is a Regenerative Power Supply?

A regenerative power supply is a two-quadrant power supply where the load quadrant (sink power, quadrant 2) is regenerative.



NEVER connect 2-quadrant or regenerative supplies in series to increase voltage. It can easily result in damage to the device when acting as a load. Parallel is OK.

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Summary / Key Learnings

Six takeaways to bring back to your lab

1

Match the instrument to the test

Basic, mid-range and advanced supplies serve different jobs. Choose based on how fast the events you need to test really are.

2

Speed is a real differentiator

Rise times range from ms to µs. Faster sources help you reproduce edge cases and fast changes save test time.

3

Set up the test so you can trust it

Remote sensing, ripple and noise awareness, and protection settings decide whether results are accurate and your DUT stays safe.

4

Go beyond static DC

Built-in digitizers and list mode turn a supplies and loads into dynamic stimulus/measurement tools for real-world waveforms.

5

Electronic loads and regeneration pay off

Loads emulate real devices, and regenerative units return 80-90% of energy to the grid, cutting cooling and operating cost.

6

Combine equipment with care

Parallel for more current, series for more voltage, but never series e-loads. Watch for low-voltage limits on e-loads.

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Questions?

Please feel free to contact me

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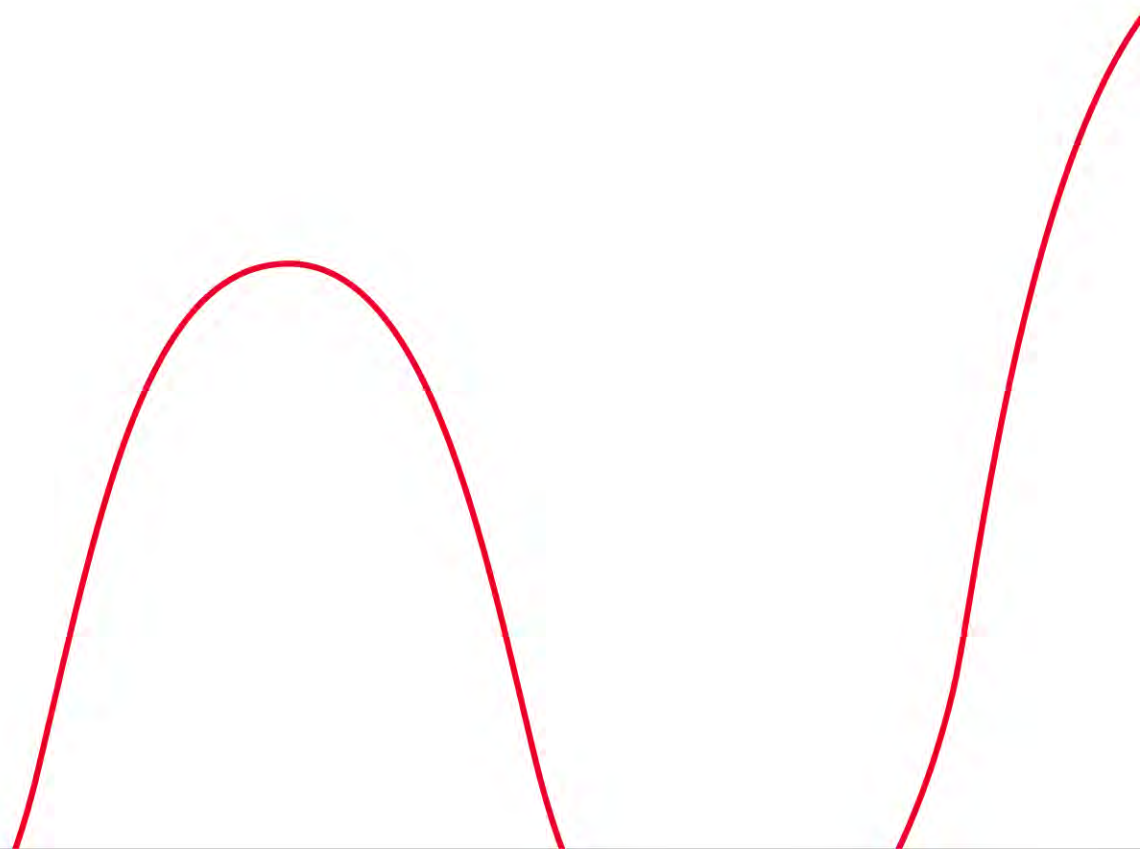
Charger Test Systems

Grid Compliance Test

I invite you to read my technical articles about many topics in cell testing, cell manufacturing, power instrumentation at https://www.electronicdesign.com/home/contact/21809010/bob-zollo

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