Photovoltaic testing for R&D, DV, and manufacturing

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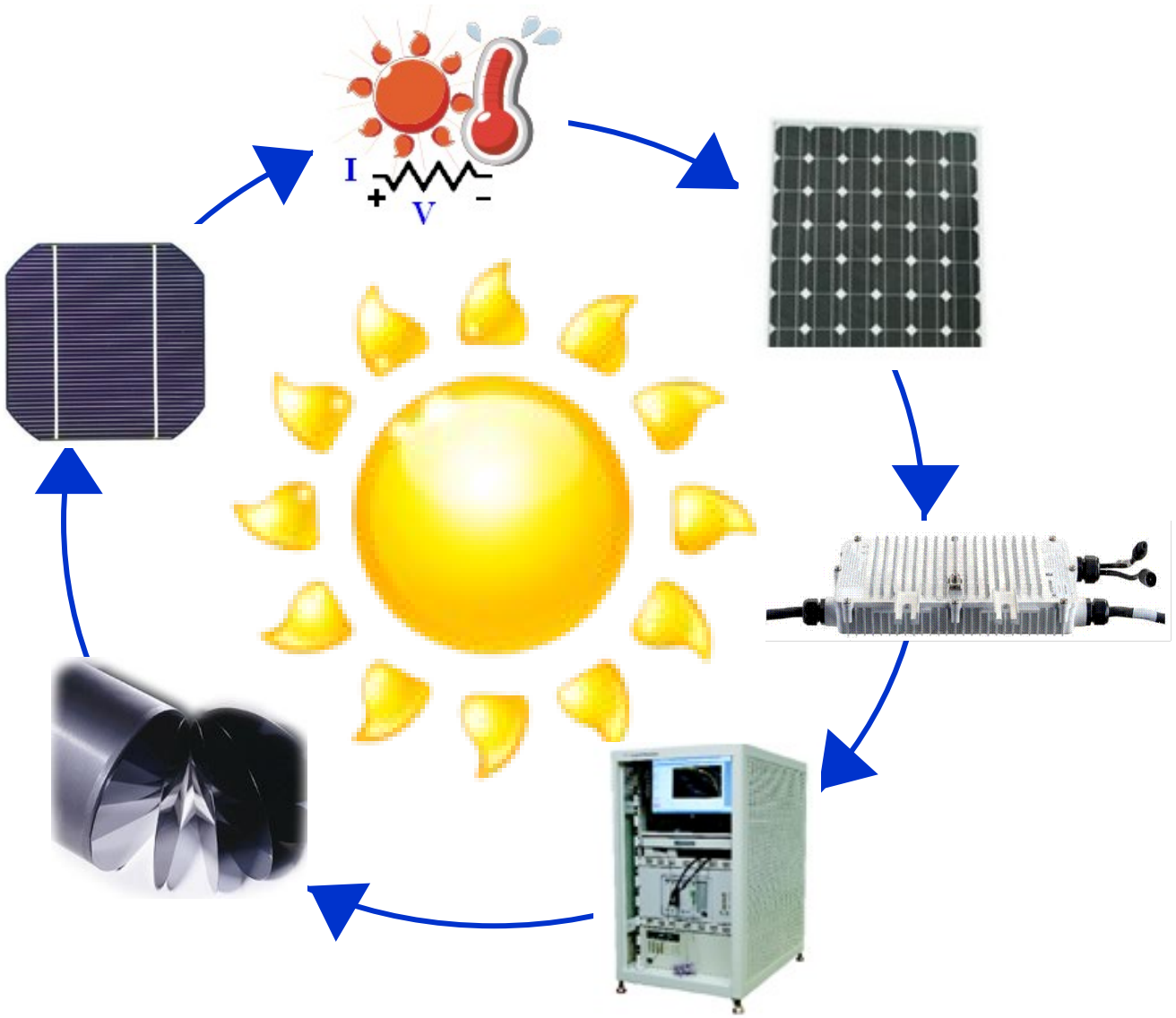

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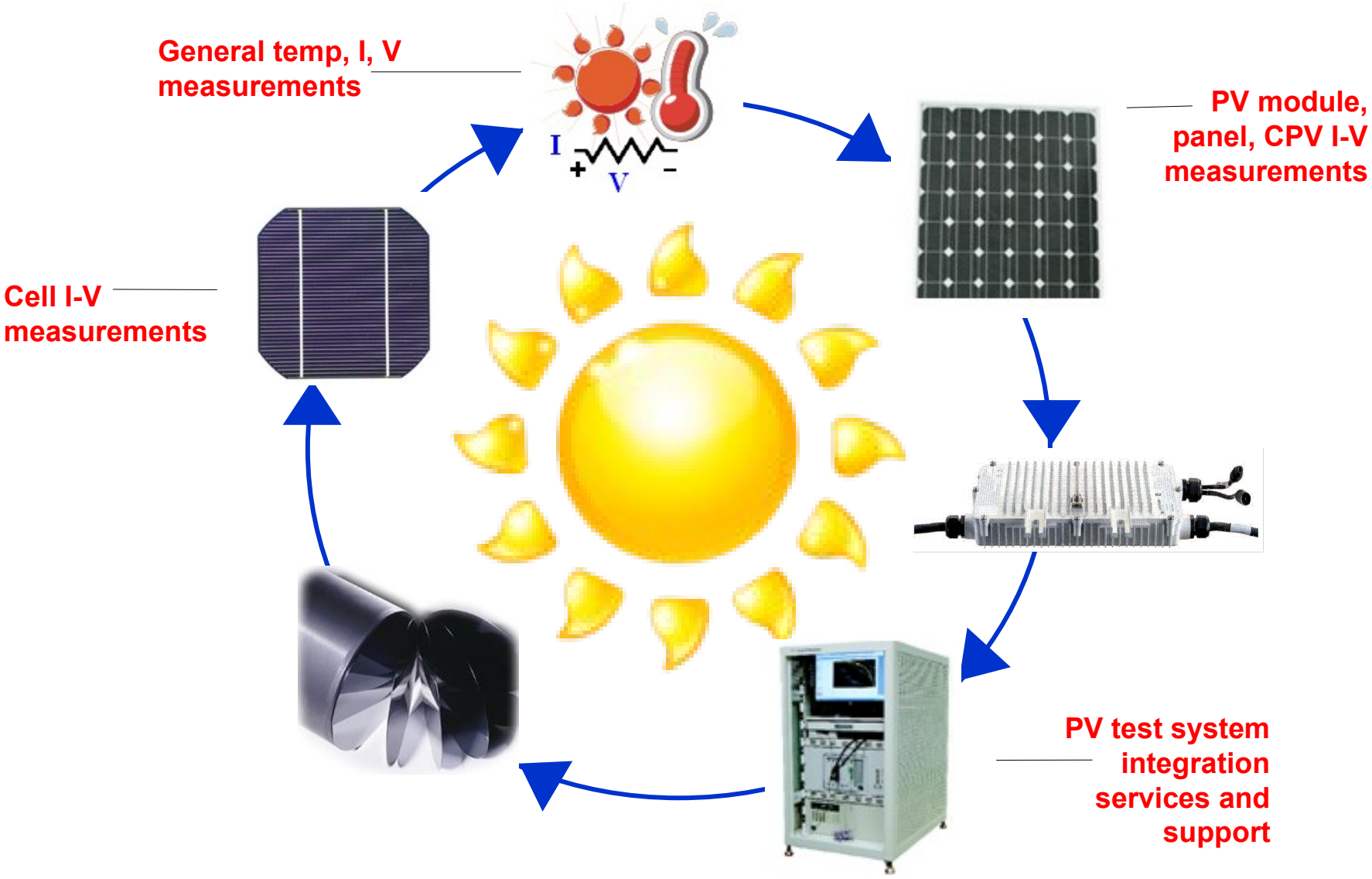
Agenda

- Introduction
- PV test and measurement solutions
- High power PV test solutions
- PV test system integration
- Conclusion and Q&A

Photovoltaic Test Areas of Focus in this Presentation



Solar Industry Continue to Grow

40% drop in cost of PV prices

Government incentives

University investment in curriculum and research

- US generating capacity grew by 37%, pushing beyond 2,000MW.
- More than 6,500MW of utility-scale projects are now in the works in the US.
- PV inverter market is set to more than double over the coming years.

Agilent recognizes the potential of the PV market and will continue to invest in expertise, test and measurement solutions, and collaboration for the PV market

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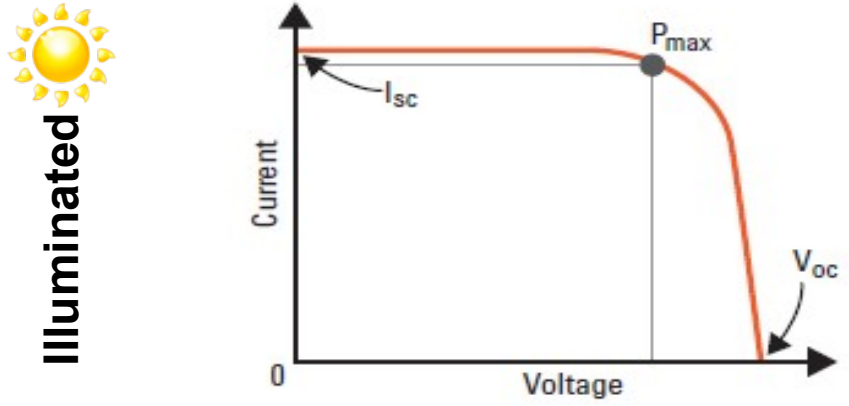
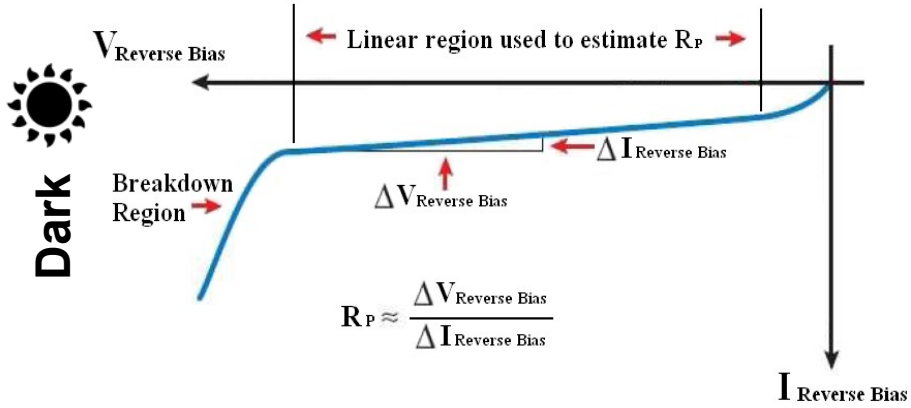
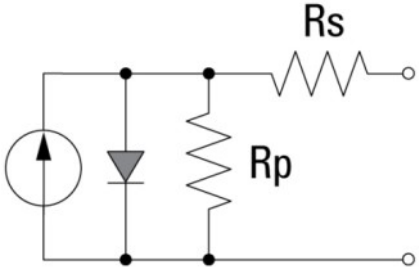
Common Measurement Needs for Photovoltaics

- Open-circuit voltage (Voc)
- Short-circuit current (Isc)
- Maximum power output of the cell (Pmax)
- Voltage at Pmax (Vmax)
- Current at Pmax (Imax)
- Conversion efficiency of the device (η)
- Fill factor (FF)
- Cell diode properties
- Cell series resistance
- Cell shunt resistance



Solar cell I-V curves



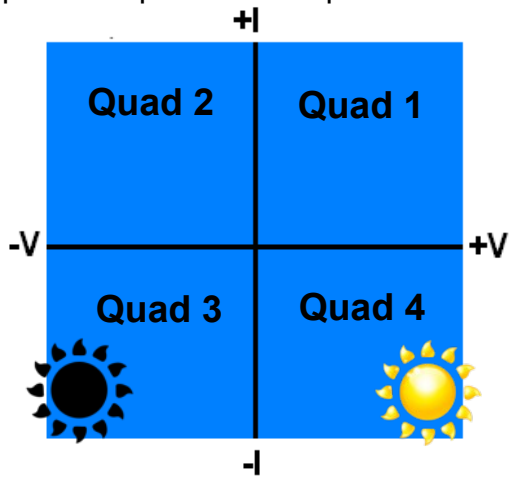


Solar cell DC circuit equivalent

Common Solutions for Photovoltaic Customers

Testing a PV Device:
- Illuminated requires quad 4, sink current
- Dark requires quad 3, source reverse current

Four possible quadrants for power instrument



Instrument	Illuminated	Dark	Power Range	Cost Per Watt	Accuracy	Notes
Four-quadrant DC source	Yes	Yes	Low	High	High	There are some higher 4-quad but accuracy limited
Two-quadrant DC source	Yes	No	Medium	Medium	Medium	Requires polarity reversal switching for dark meas.
DC Electronic Load	Yes	No	High	Low	Medium	Can handle high power so good for panels and CPV
Single-quadrant DC source	No	Yes	High	Low	Medium	Cannot sink current so only good for dark measurements

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Choices High Power PV Test (>5A)

Modules, panels, large area cells, and concentrated PV

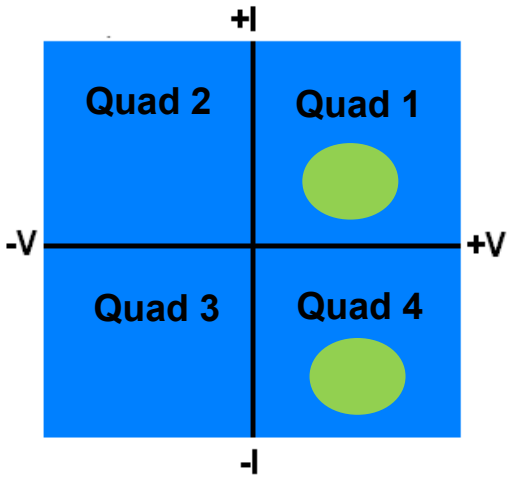
Three power product instrumentation choices:

- Two quadrant supplies
- Four quadrant supplies
- DC electronic loads

Using Two-Quadrant Power Supplies

For high power PV test

- Two-quadrant supply can source and sink current
- Fairly low cost and widely available
- Voltage step and measurement speed can be too slow for manufacturing
  - Add external analog programming and measurement
- Illuminated and dark I-V curve measurements with added hardware (discussed next)
- If you just need illuminated I-V measurements use DC electronic load



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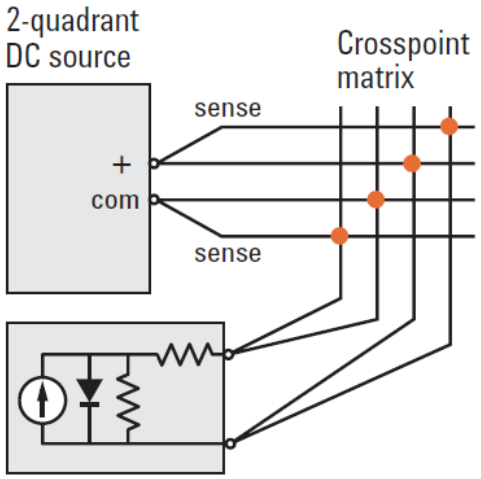
Using Two-Quadrant Power Supplies

Illuminated and dark I-V measurements with 2-quad power supplies

Configuration 1: Supply with switching

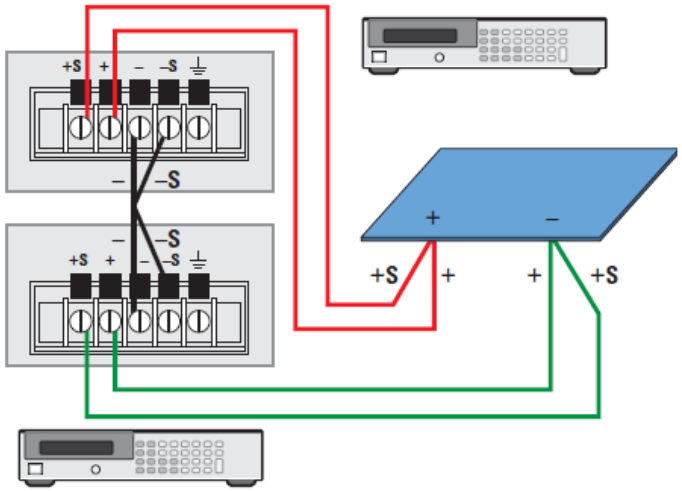
- Discontinuity at 0V
- Requires switching
- Supplies like the 6631B are available with polarity reversal relays



More info see app note 5990-3262EN

Configuration 2: two supplies in anti-series

- No discontinuity at 0V
- Requires two supplies

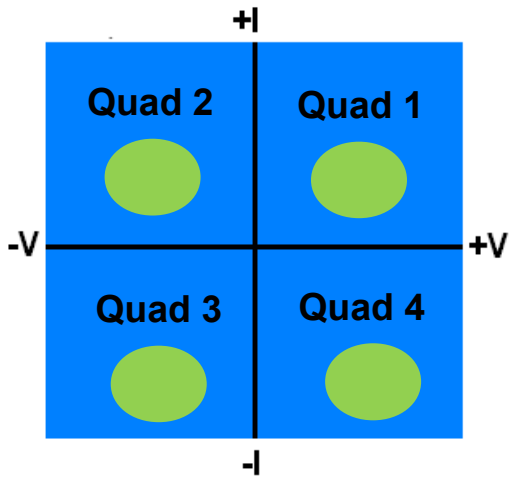


More info see app note 5990-3949EN

Using Four-Quadrant Power Supplies

For high power PV test

- **Provides illuminated and dark I-V measurement capability with no discontinuities**
- **If you just need illuminated I-V measurements use DC electronic load**
- **Access to all 4 power quadrants giving you ability to perform less common tests**
- **At these current levels 4-quad supplies are typically slow and have poor measurement accuracy**
  - **Need external instrumentation for control and I-V measurements (discussed next)**



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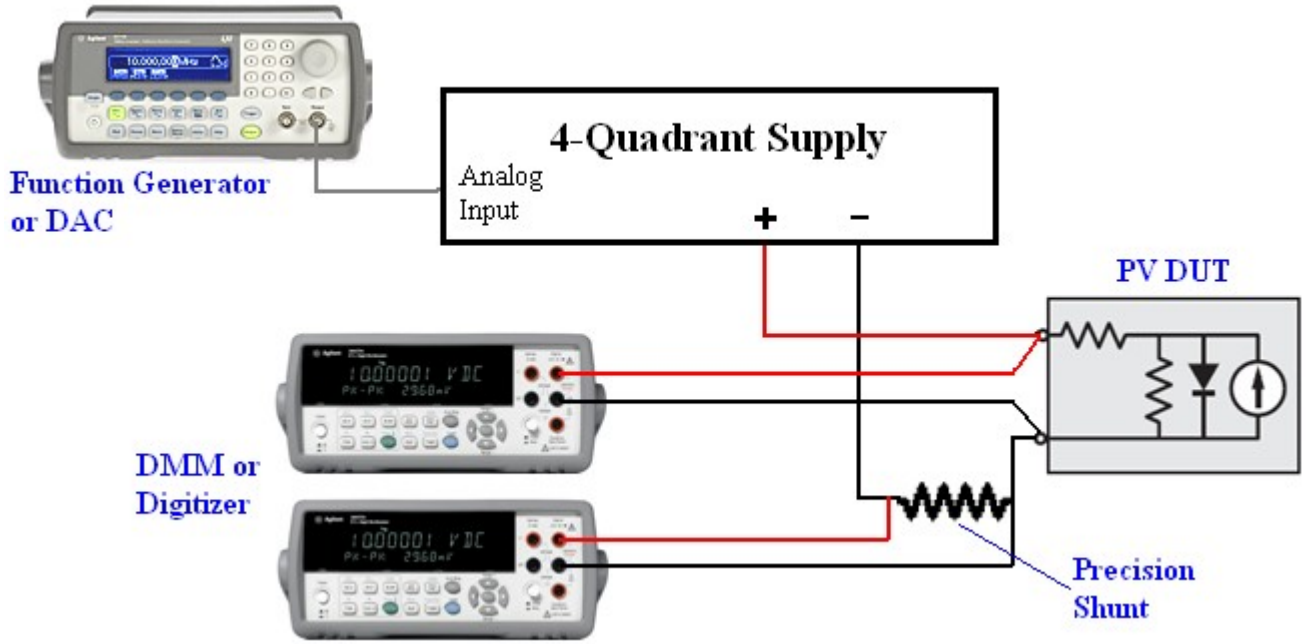
Using Four-Quadrant Power Supplies

For high power PV test

At these current levels 4-quad supplies are typically slow and have poor measurement accuracy

- **Need external instrumentation for control and I-V measurements**



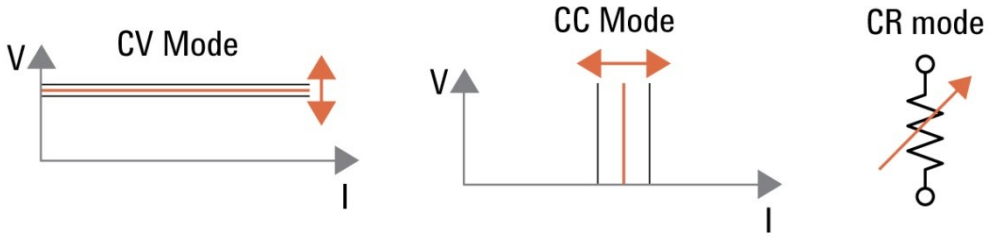
National Renewable Energy Laboratory (NREL) uses similar solution in their PV cell I-V characterization test system using Agilent's 34401A DMM (x2) and 34970A DAQ switch unit

Using DC Electronic Loads

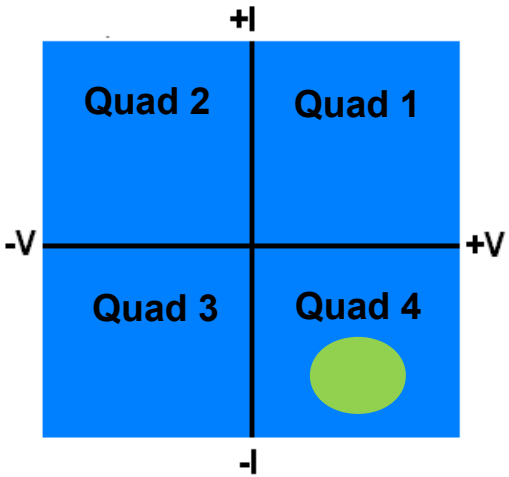
For high power PV test

- Electronic loads are a great solution for high power PV testing because they can sink a lot of current for a low cost
- Electronic loads (eload) typically have three modes of operation:

Constant Voltage (CV), Constant Current (CC), and Constant Resistance (CR)



- CV mode for capturing the I-V curve: step through voltages incrementally and measure the current



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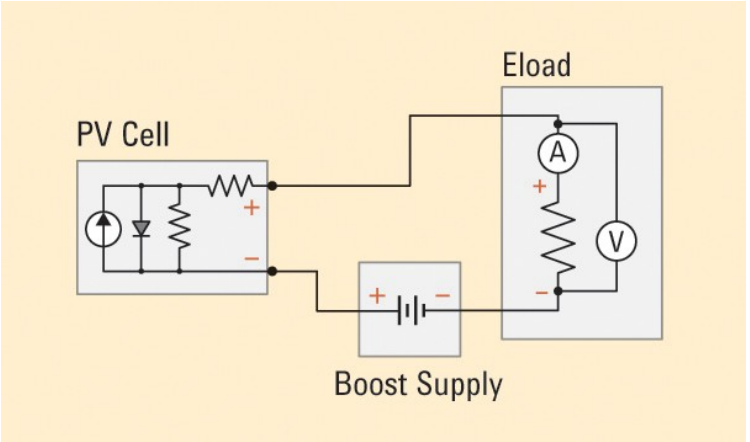
Using DC Electronic Loads

For high power PV test

- Eload specifications begin to de-rate at constant voltage levels typically < 5 V
- At 0 V, no current can flow into the eload
- Add a simple power supply in series with the eload to maintain optimum performance

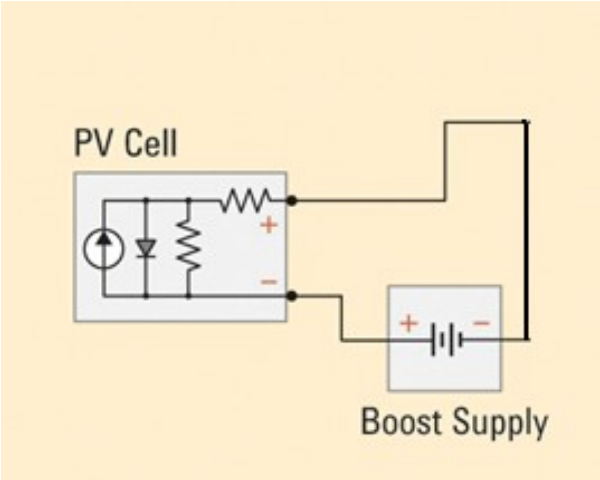


The need for a boost supply adds expense and complexity to the configuration, but as you will see next it also expands our test capabilities…….

Using DC Electronic Loads

For high power PV test

- **In the figure we removed the eload from the circuit and replaced it with a short**
- **We are left with a power supply connected in reverse bias with the PV cell**
- **If we make the power supply variable, add voltage and current measurement capabilities we have a reverse bias I-V curve measurement setup**



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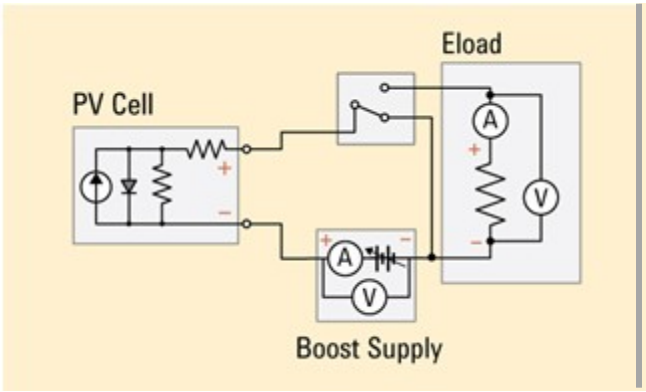
Making illuminated and Reverse Bias I-V Curve Measurements with an Eload and Boost Supply

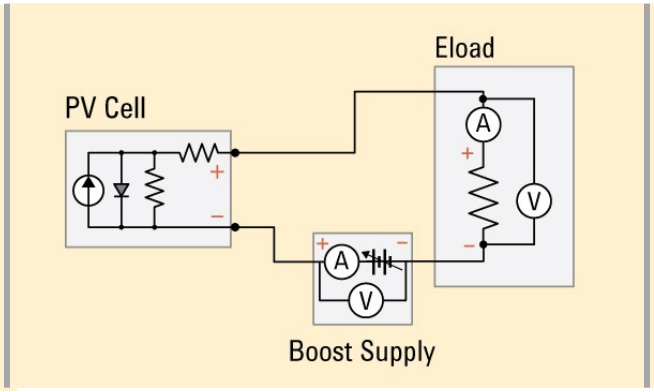
3 ways to do it with an eload and boost supply

- **Configuration 1:** Shorting the eload out of the circuit
- **Configuration 2:** Sweeping both the eload and boost supply
- **Configuration 3:** Using a fixed boost supply and sweeping the eload

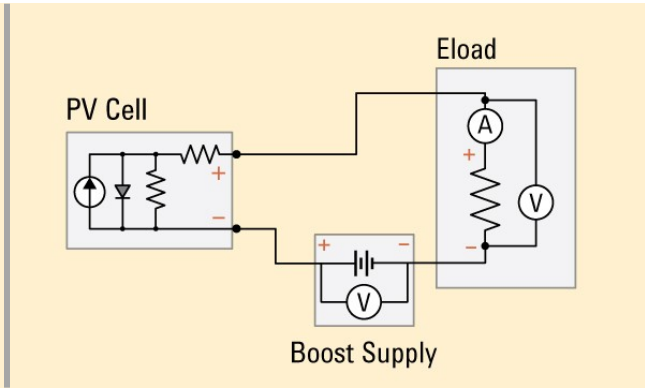
Configuration 1



Configuration 2



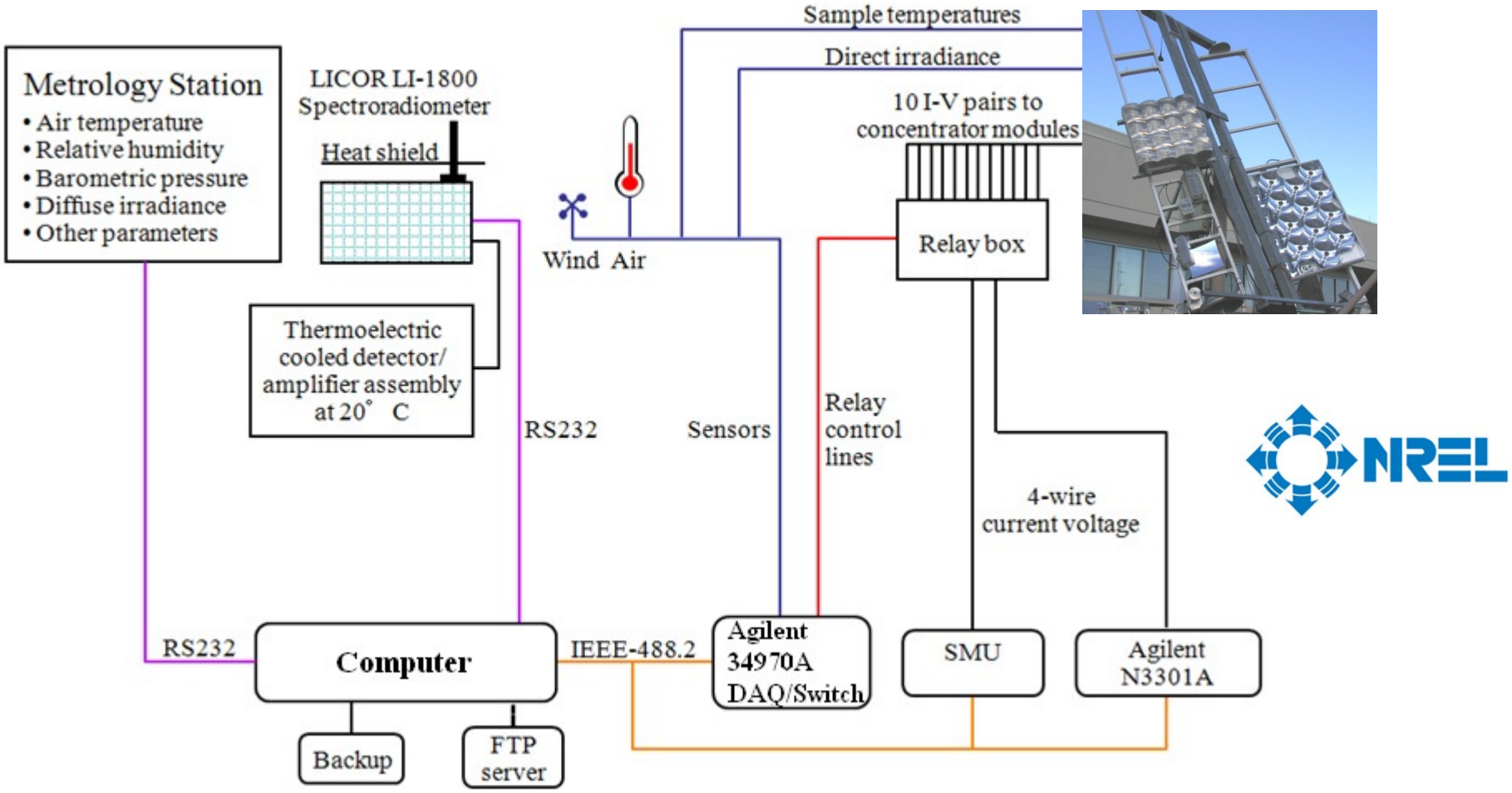
Configuration 3



More info see app note **5990-4854EN**

National Renewable Energy Laboratory PV Test System

Outdoor test system for prototype CPV and PV panel testing



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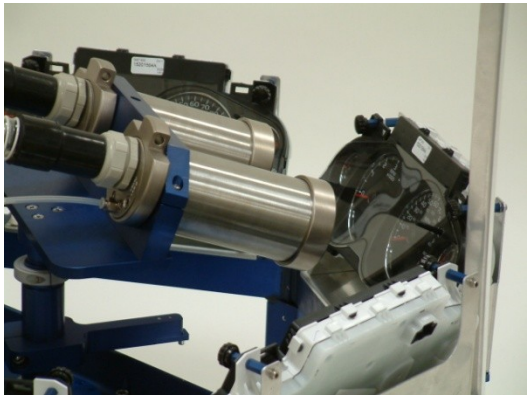
Integrator - Definition

Assist or provide the customer with a measurement system necessary to satisfy project objectives

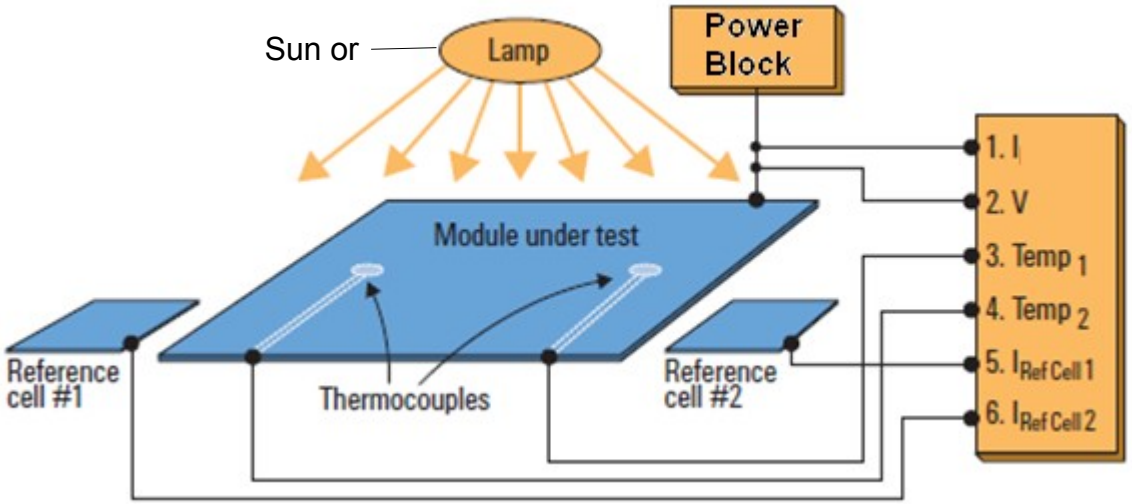
Laboratory, Design Validation and Product Validation Test Systems

Environmental Testing System



Production Testing System

Typical Integrated PV Test System



Switch and measurement or redundant DMMs/DAQ

- **I-V curve measurement**
- **Temperature measurements**
- **Calibrated reference cell measurements to measure irradiance**

- **A switch and measurement unit avoids the need for costly redundant measurement equipment**
- **Light sources have low frequency noise so using multiple DMMs/Daq units with common trigger ensures each measurement is made at a common irradiance level**

Basic System Configuration Questions

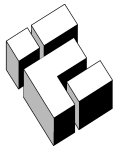
- Type of system (Laboratory, Design/Product Validation, Environmental or Production)
- Number and type of measurements to be made
- Measurement speed and accuracy
- Environmental considerations (chamber or real world)
- Test cycle time
- Calculation requirements





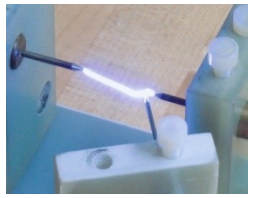


Identify specific system issues that may require specialized system integration approaches.



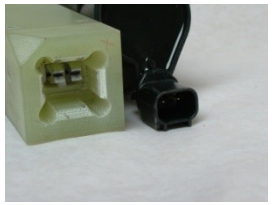
- Thermal stresses on part and fixture and test equipment (material selection, thermal expansion considerations, stand alone remote data collection)

- Effects of noise on system design (galvanic issues, synchronous detection requirements for irradiance measurements)

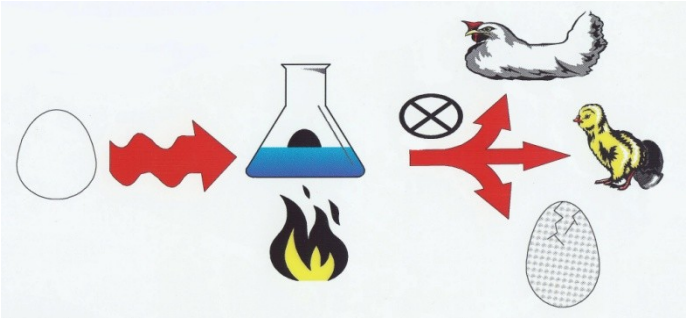


- Sensor connection requirements (strain, 4 wire, thermal couple)

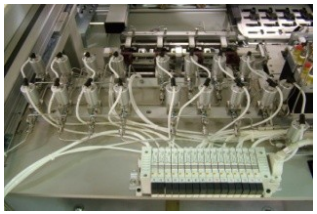
Connection Issues



- Test system design and influence on test results



Sensor Issues



Some questions to consider when selecting an integrator

- Is specialized fixture expertise required?
- Are there specific or unusual test interface or reliability requirements?

- Are there specialized thermal testing requirements?
- Are there consequences to inadequate or false “failure” detection?

- Are there MTBF or MTTR requirements?

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Conclusion

In this presentation we discussed the various types of test and measurement instrumentation available for PV test, what instruments fit where, and common PV test configurations with a focus on high power test. From there we discussed various considerations on integrating the whole test system together including: temperature considerations, fixturing, lighting, and the delicate balance of cost, speed, accuracy, and reliability.

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- Inverter testing solutions online:
www.agilent.com/find/inverter

- Neil's professional blog:
http://gpete-neil.blogspot.com/

- System Integration Assistance
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