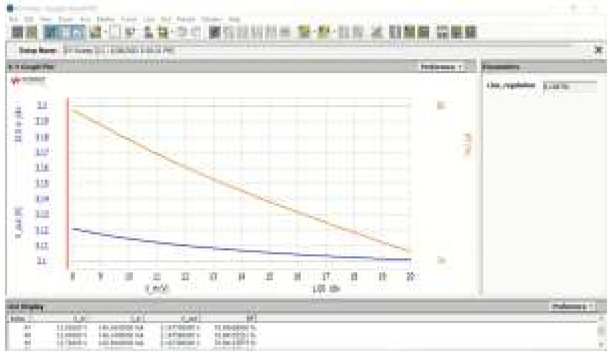
DC-DC Converter Testing with Precision Bench SMUs

KEYSIGHT TECHNOLOGIES

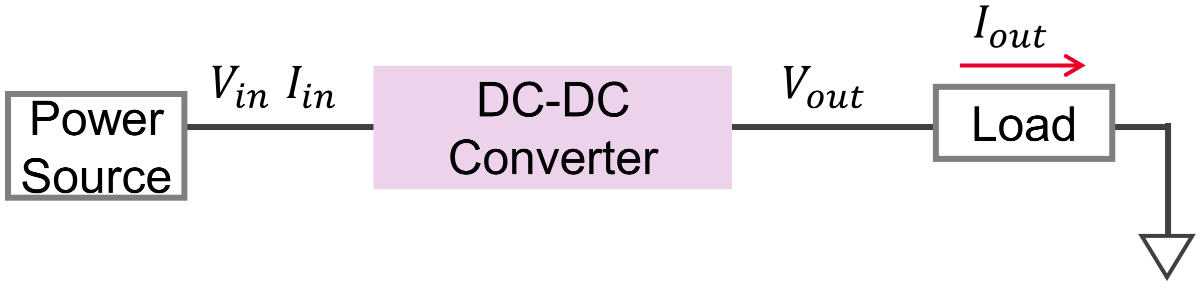
Agenda

- What is a DC-DC Converter & how does it work
- What are the key challenges of testing a DC-DC Converter
- How to accurately validate & characterize
- Real-world case study
- Solutions available
- Summary



DC-DC Converter

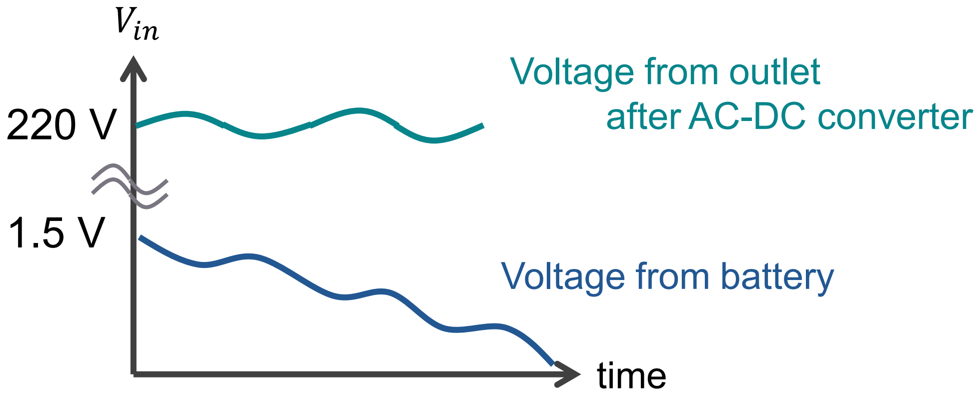
WHAT IS IT

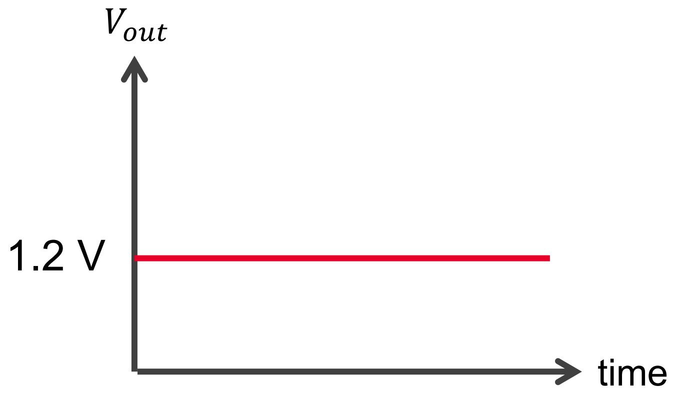


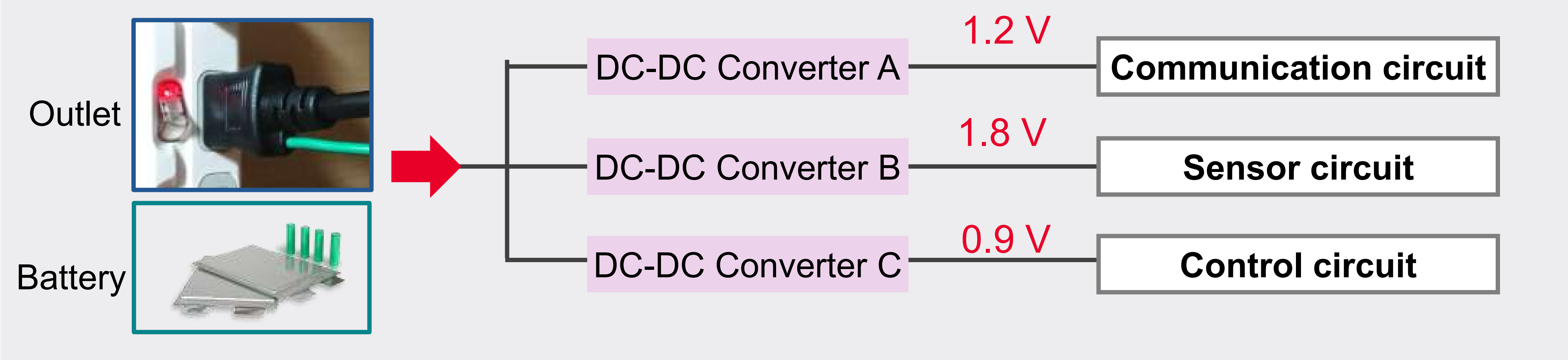
- Converts one DC Voltage to another
- Efficiently regulates a power source to achieved required output Voltage & Current
- Smoothens voltage, eliminates noise and isolator.
- And more…

DC-DC Converter

BATTERY/NON-BATTERY POWERED PRODUCTS







DC-DC Converter

WHERE IS IT USED

Key Applications & Industries

- Automotive (Electric Vehicles)
- Aerospace
- Internet of Things (Smart devices)
- Renewable Energy (Solar & Wind)
- Medical Health
- And more..

Objective of Measurement/ Validation

WHAT MAKES A “GOOD” DC-DC CONVERTER

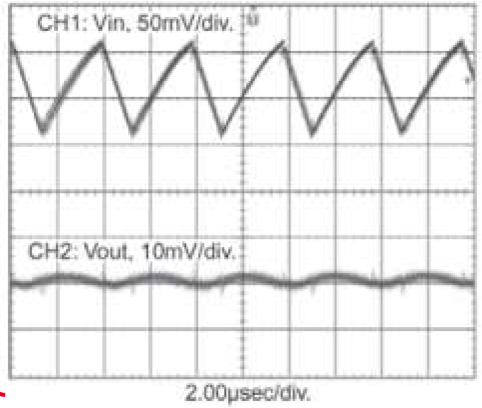
- Designing a circuit fundamentally start with a good power source.
- DC-DC Converters (power source) are measured and validated to ensure stable performance for your design.
- Datasheets of a DC-DC Converter provides data & specification under typical condition.
- As the V_{in}, I_{in} and I_{out} are dependent to the circuit, the actual output voltage (V_{out}) may differ from datasheet.

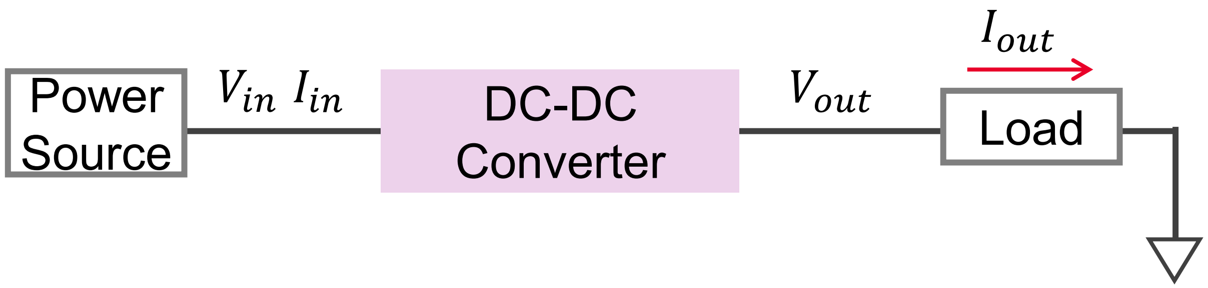
78xxSR Series Datasheet (Murata)

Input/Output			
Models	7803SR-C	7805SR-C	7812SR-C
Output Voltage	+3.3Vdc	+5.0Vdc	+12.0Vdc
Rated Output Current	0.5A	0.5A	0.4A
Output Voltage Accuracy	±2%	±2%	±2%
Input Voltage Range ①	+7.5-36Vdc	+7.5-36Vdc	+15-36Vdc
Line Regulation (100% load)	±0.3%	±0.3%	±0.3%
Load Regulation (0-100% load)	±0.2%	±0.2%	±0.2%
Quiescent Current	3mA typ., 5mA max.		
Input Current	See Performance Curves		
Efficiency	See Performance Curves		
Transient Response	See Performance Curves		
Input & Output Noise	See Performance Curves		
Short Circuit Protection ②	Continuous		
Isolation	None		
Overvoltage Protection	None		
Undervoltage Protection	None		

Typical Performance

7803SR-C Vin = 12V, ILOAD = 500mA

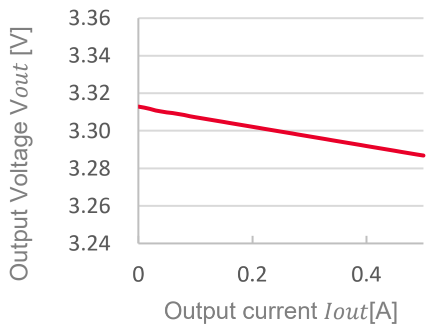




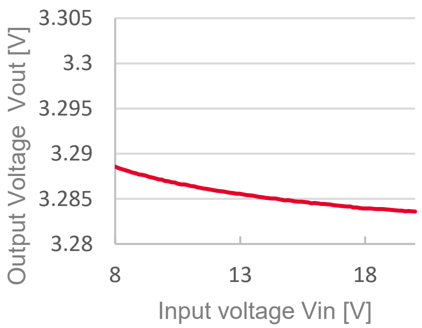
Key Characteristics & How to Validate

Features of DC-DC Converter	Ideal	Actual	Impact	Key Characteristics
High Output Stability	V_{out} always constant.	V_{out} can vary due to the DC-DC Converter's internal circuitry.	Malfunction and performance degradation	• **Load Regulation** • **Line Regulation** • **Load Transient Response**
Low Power Consumption	No power consumption during "sleep"	Conversion consumes power.	Shorten battery life & waste	• **Conversion Efficiency** • **Quiescent Current**

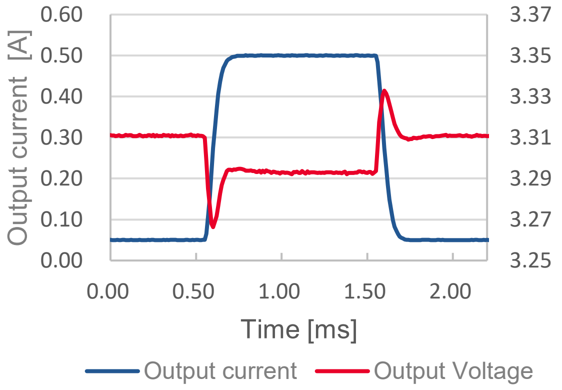
Load Regulation



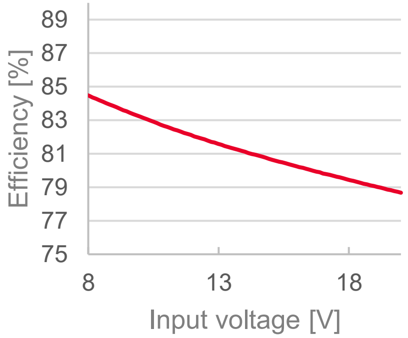
Line Regulation



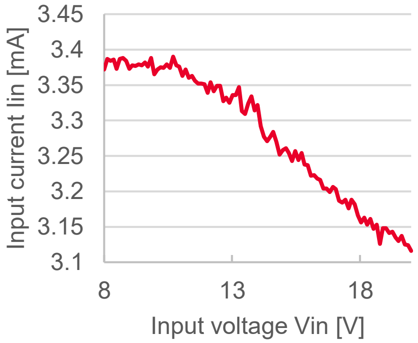
Load Transient



Conversion Efficiency



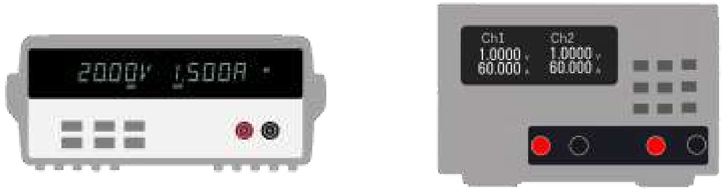
Quiescent Current



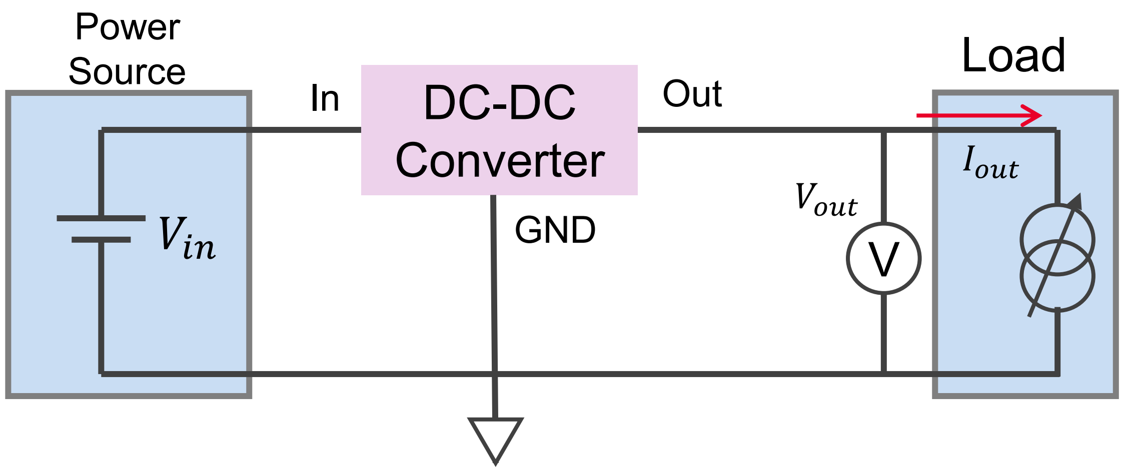
Load Regulation

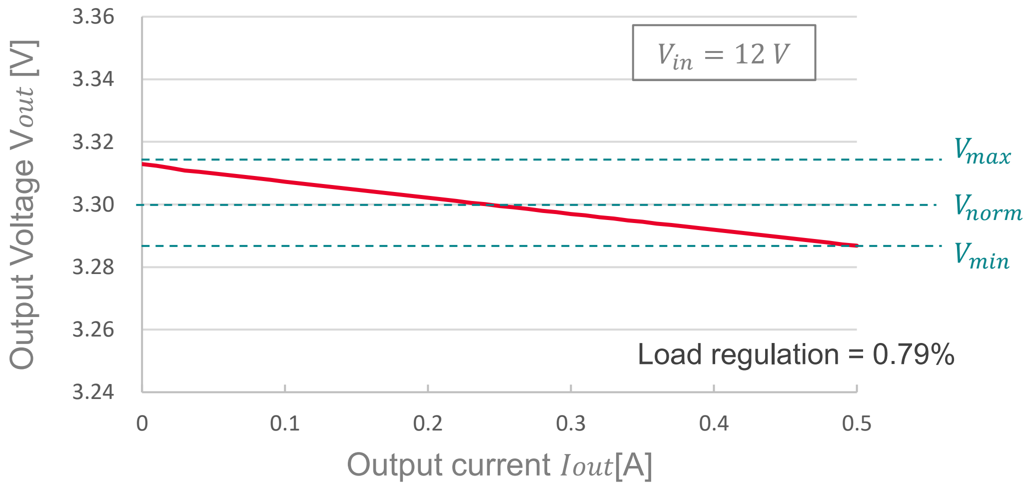
OUTPUT STABILITY

- The ability to maintain a constant output voltage despite changes the load current.
- $$\text{Load Regulation} = \frac{V_{max} - V_{min}}{V_{norm}} \times 100$$
- Why Important?
  - Devices requires a stable supply of voltage in various operation mode which drives different load current.
  - Measurement Instruments



DC Power source   Electric Load





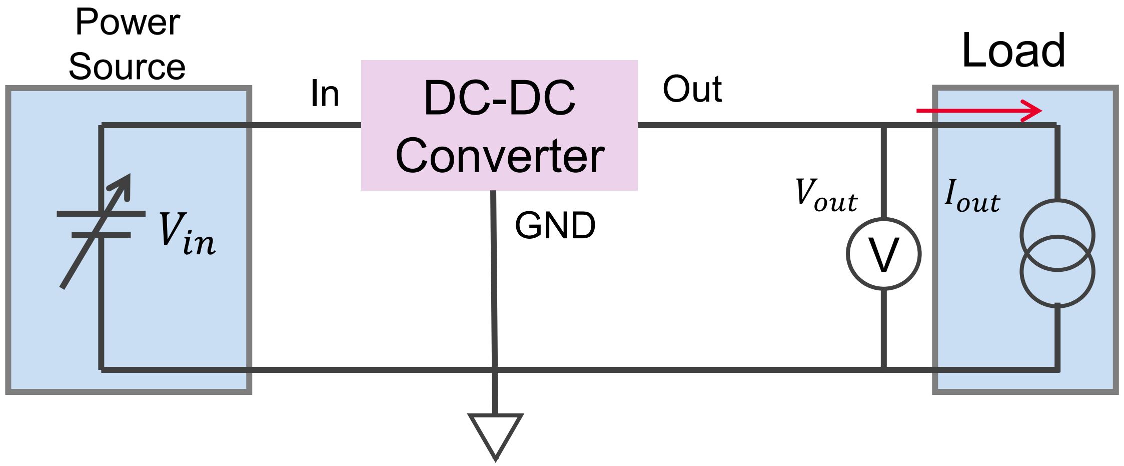
Line Regulation

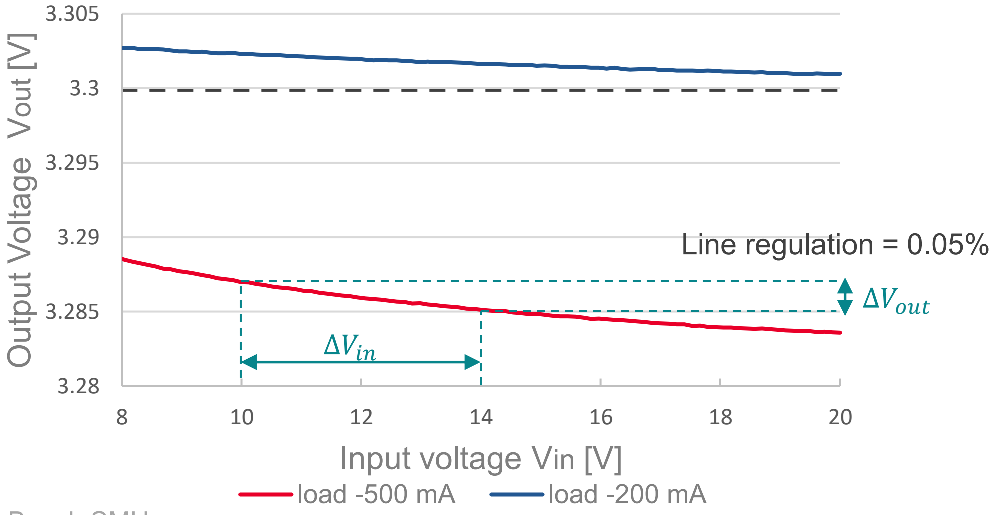
OUTPUT STABILITY

- The ability to maintain a constant output voltage despite changes the input voltage.
  - Line Regulation [%/V] $= \dfrac{\frac{\Delta V_{out}}{V_{out}} \times 100}{\Delta V_{in}}$
  - Line Regulation [%] $= \dfrac{\Delta V_{out}}{\Delta V_{in}} \times 100$
- Why Important?
  - Ensuring output voltage remains stable despite changes in the power source.
  - Measurement Instruments

DC Power Source

Electric Load

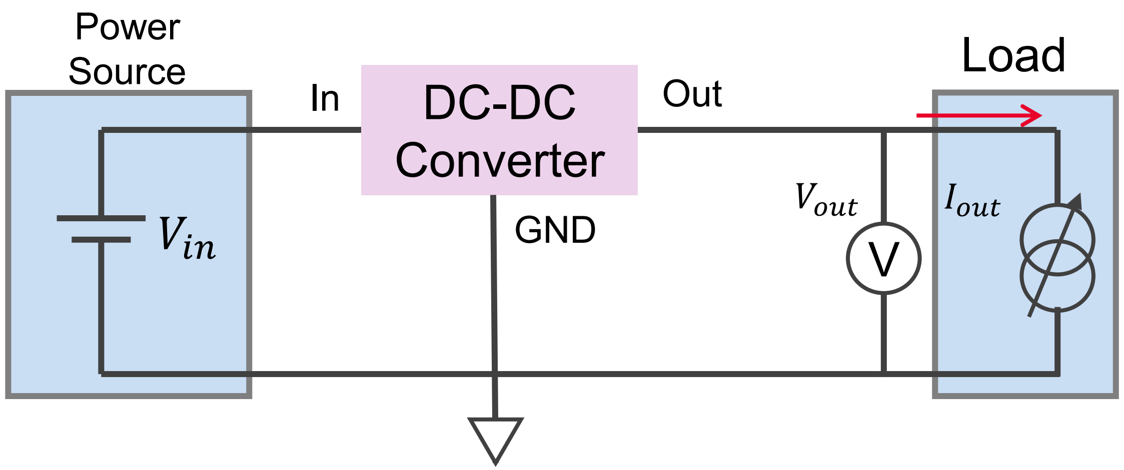


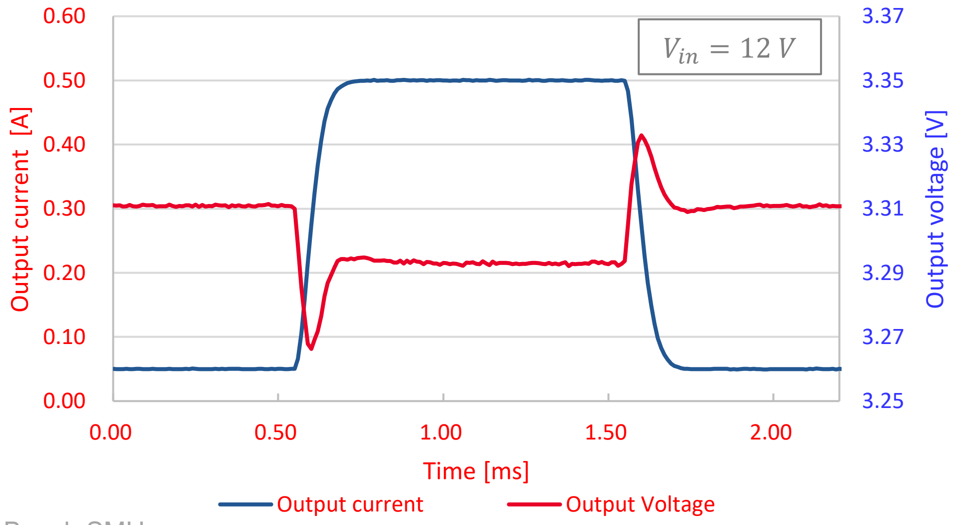


Load Transient Response

OUTPUT STABILITY

- The ability to maintain a constant output voltage despite the sudden change in load current.
- Why Important?
  - When load rises suddenly from sleep mode, the output voltage may dip (or rise) promptly before stabilizing. The amount of time for out to stabilize is the response time calculated.
- Measurement Instruments





DC Power Source

Electric Load with Pulse Capability

Oscilloscope

Conversion Efficiency

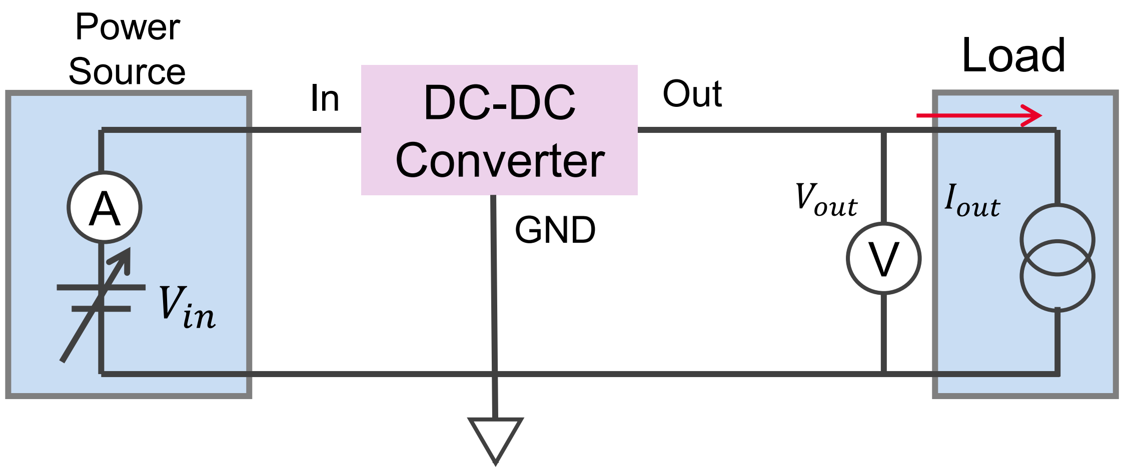
POWER CONSUMPTION

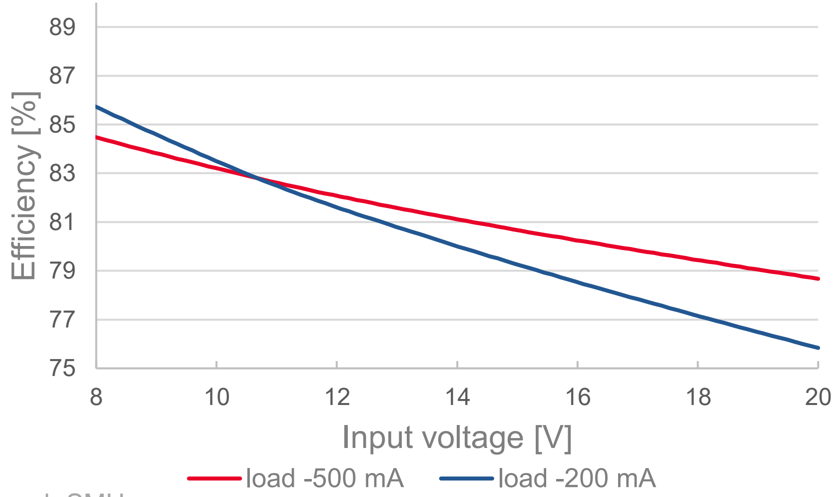
- The ratio of “input over output power"
- Efficiency $\eta = \frac{output\ power}{input\ power} = \frac{V_{out} I_{out}}{V_{in} I_{in}}$
- Why Important?
  - High efficiency ensures no power wastage during operation.
- Measurement Instruments

DC Power Source

Electric Load
with Pulse Capability

Current Meter

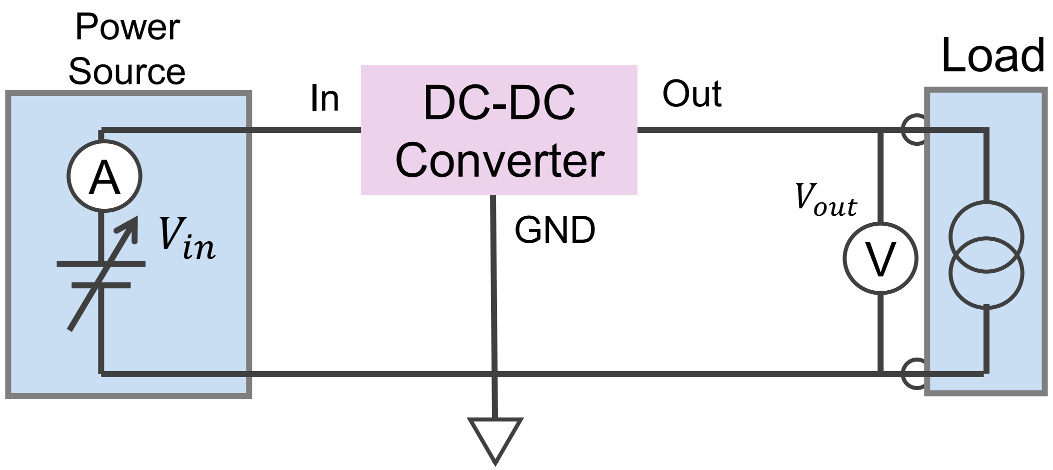


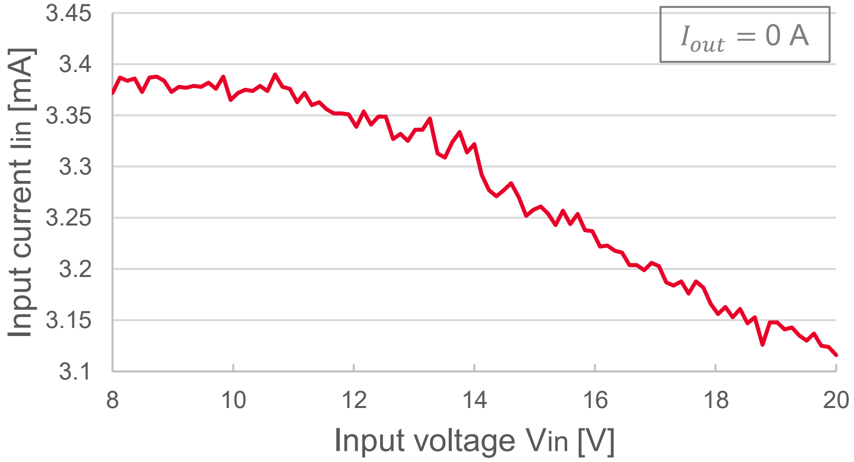


Quiescent Current (I_Q)

POWER CONSUMPTION

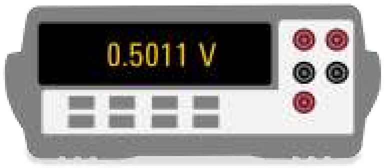
- The current required to power the DC-DC Converter's internal circuitry when the I_{load} is zero ($I_Q = I_{in}\ @\ Load\ in\ Standby\ Mode$).
- Typical Value: nA - mA
- Why Important?
  - The lower I_Q is required to increase battery life of devices, such as smart watches, spending their time in standby mode.
- Measurement Instruments





DC Power Source

Electric Load with Pulse Capability

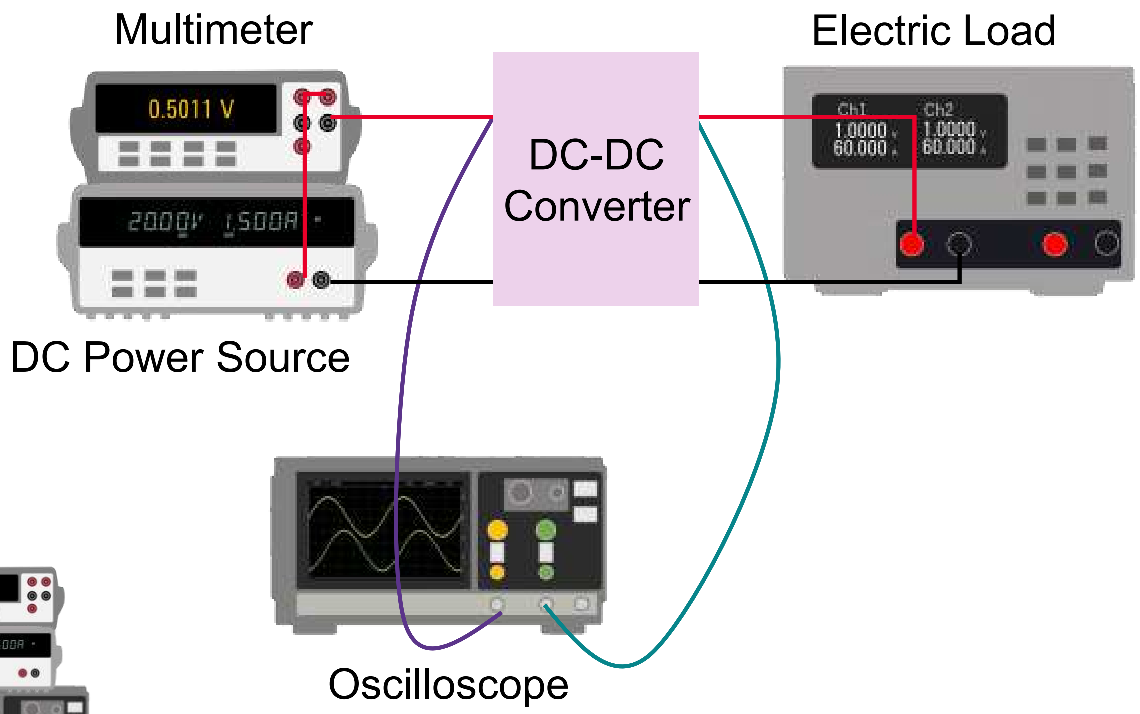


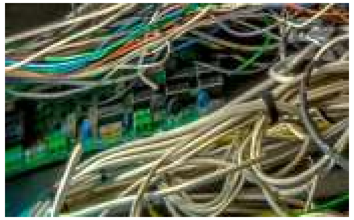
Current Meter

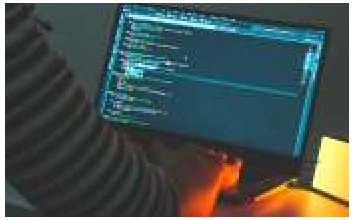
Key Challenges of DC-DC Converter Testing?

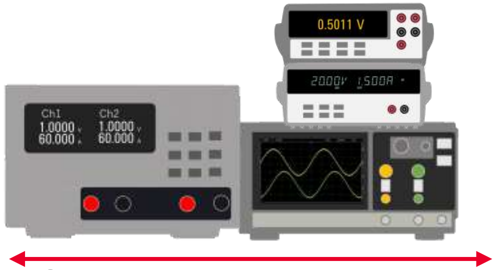
Involve several different instruments!!!

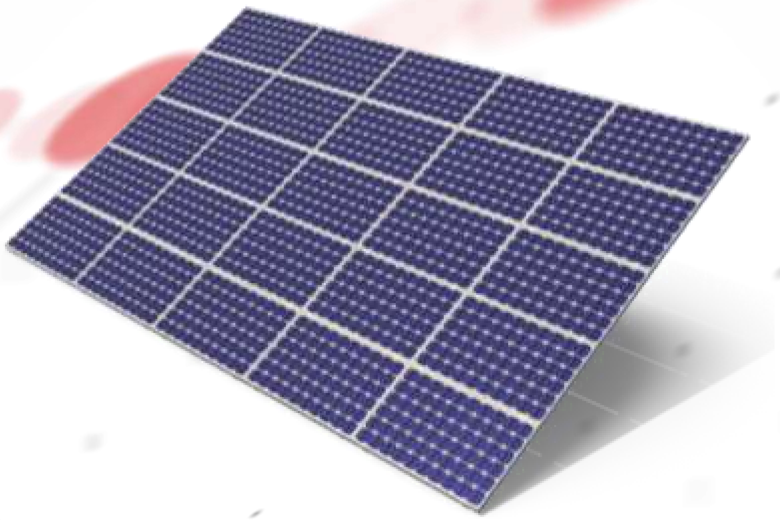
- DC Power Source capable of sweeping voltage
- Multimeter capable of measuring nA of quiescent current
- Electric Load to emulate an actual load
- Oscilloscope for measuring transient response




Complicated Wiring


Develop Test Programs


Occupy large space

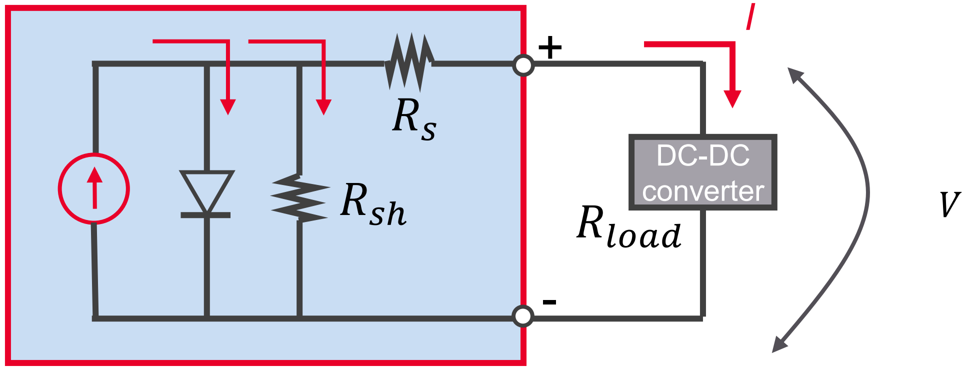


Case Study: DC-DC Converter in Solar Cells

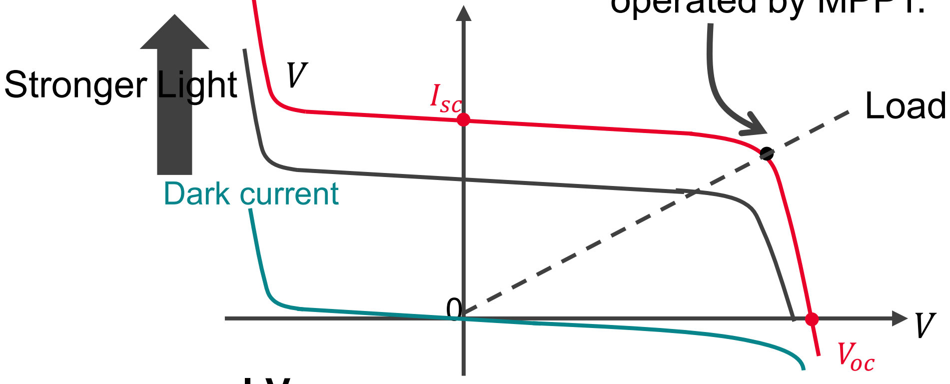
What is a Solar Cell?

- Convert light into electricity
- Work as Current source
  under constant light exposure.
- Output current depends on the load current
  because the current divides to the diode, shunt resistor and load.
- I-V characteristics can be determined by sweeping the load (i.e. change load resistance gradually)
- MPPT algorithm of DC-DC converter decides the operating point to maximize the output power, P = IV.

Single Solar Cell

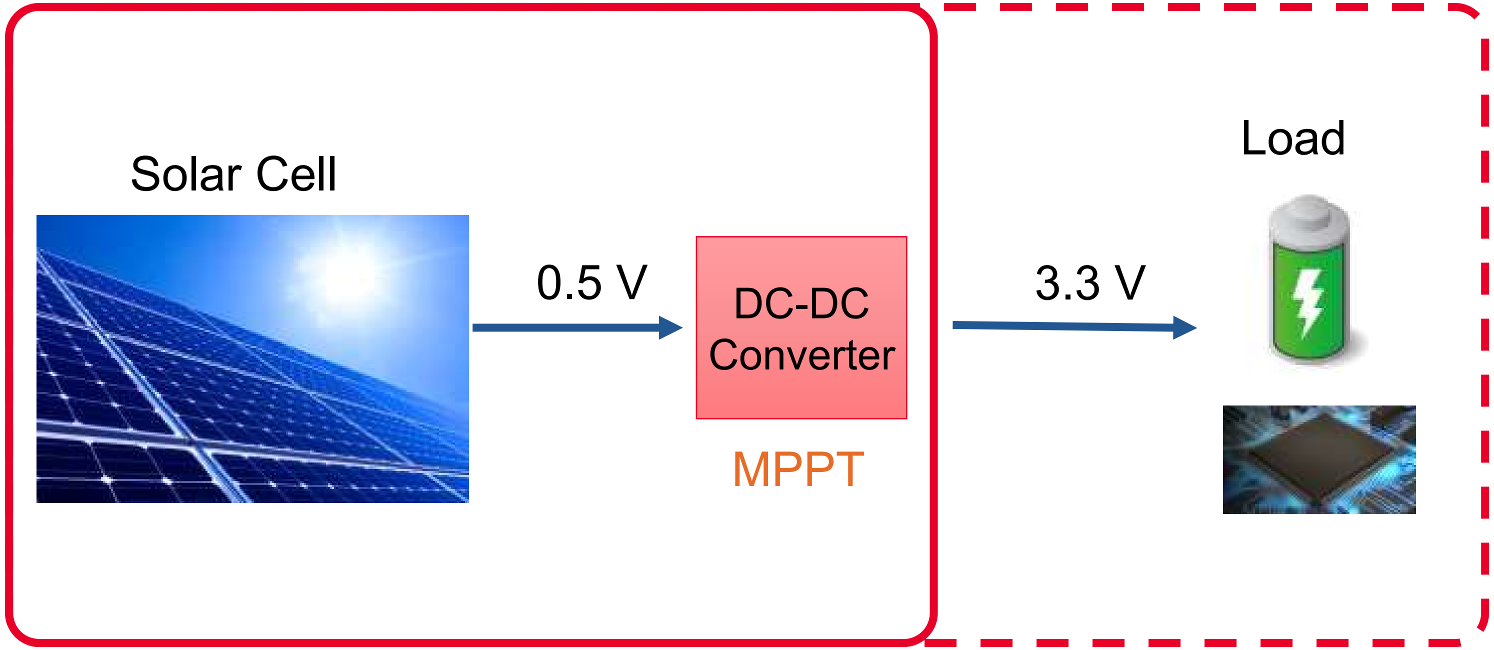


Equivalent circuit



I-V curve

DC-DC Converter in Solar Cell

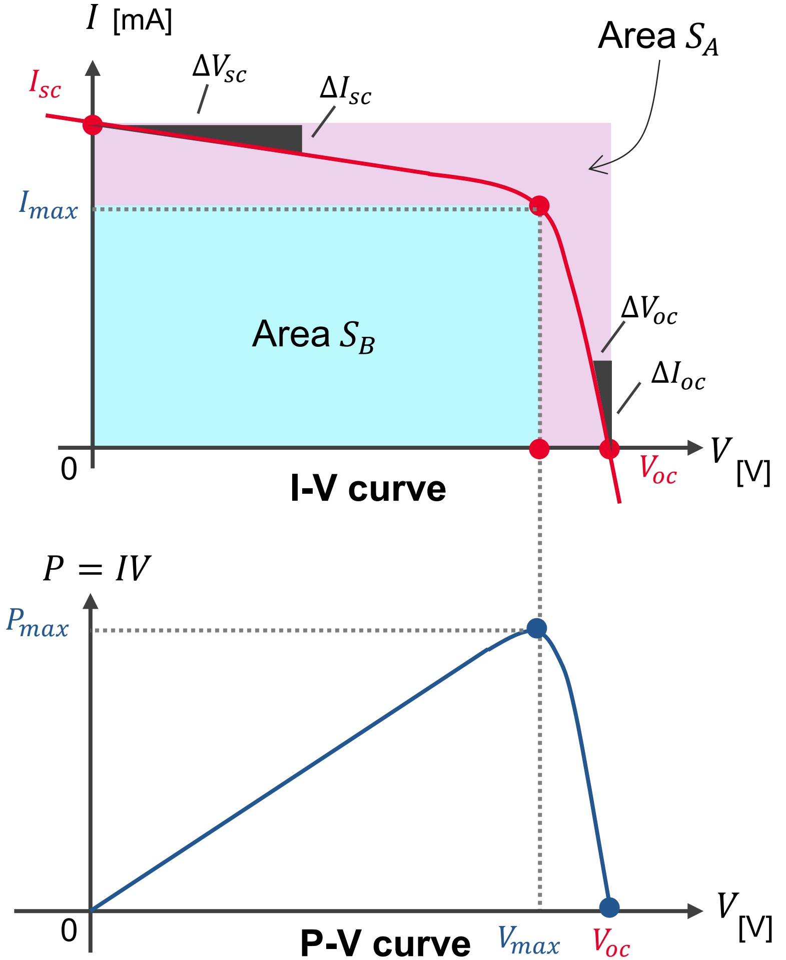


- To supply constant voltage to load
- To maximizes the energy that solar cells generates (Maximum Power Point Tracking; MPPT)

Key Parameters

WHAT IS MEASURED?

Parameters	Symbol	Unit	Description
Short circuit current	I_{sc}	[A]	the current through the solar cell at V = 0 (i.e. road resistance is 0)
Open circuit voltage	V_{oc}	[V]	the voltage across the solar cell at I = 0 (i.e. road resistance is ∞)
Maximum power Point	P_{max} I_{max} V_{max}	[W] [A] [V]	the condition under which the solar cell generates its maximum power; the current and voltage in this condition are defined as I_{max} and V_{max} (respectively).
Fill factor	FF	-	The closer to 1, the more power is extracted. $FF = \frac{P_{max}}{V_{oc} \times I_{sc}} = \frac{S_B}{S_A}$
Conversion efficiency	η	[%]	The power conversion efficiency of 1 sell or panels. $\eta = \frac{P_{max}}{\text{Input power of light [W]}}$
Shunt resistance	R_{sh}	[Ω]	R_{sh} accounts for stray currents. The larger R_{sh}, the higher the efficiency. $R_{sh} \sim -\frac{\Delta V_{sc}}{\Delta I_{sc}}$
Series resistance	R_s	[Ω]	Bulk resistance of solar cells. The smaller R_s, the higher the efficiency. $R_s \sim -\frac{\Delta V_{oc}}{\Delta I_{oc}}$



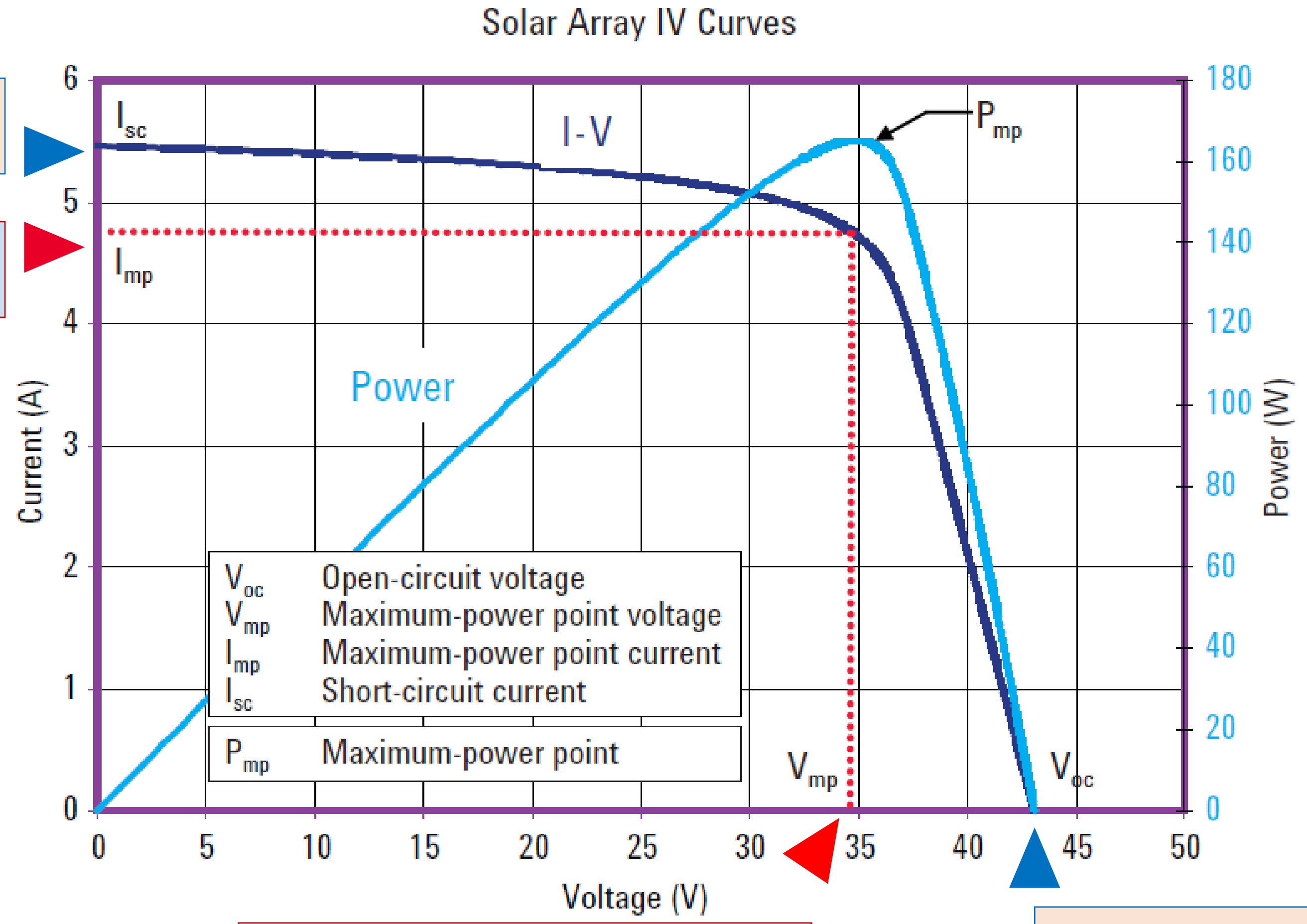
- Key parameters decides the performance of solar cells.
- Key parameters are extracted from type- I/V curve.
- Precise measurement and analyses key parameters as essential.

Solar Array IV Curves

These two distinct curves provide the variables needed to create an accurate simulation of solar cell output. A mathematical approximation of the curves includes four key parameters:

Isc: Short-circuit current.

Imp: Current at the max power.

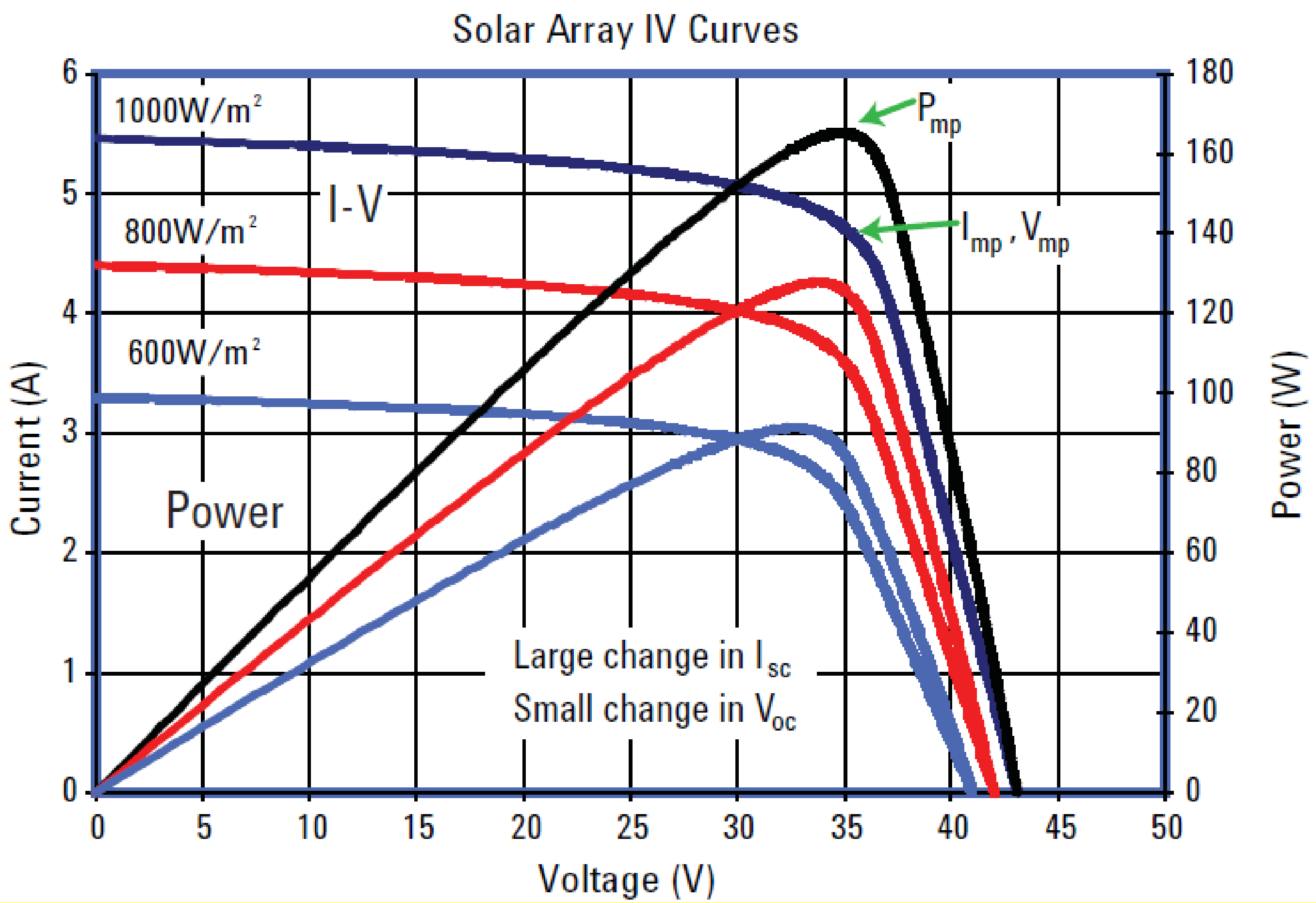


Vmp Voltage at the max power

Voc: Open-circuit voltage.

A solar array's I-V and power curves vary with irradiation level

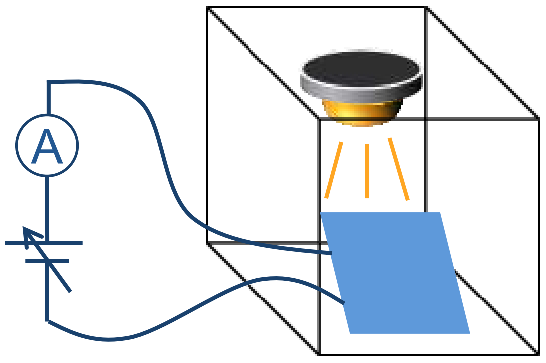
Output current varies dramatically with irradiation level. In contrast, the change in output voltage versus irradiation level is relatively small compared to the change in output current.



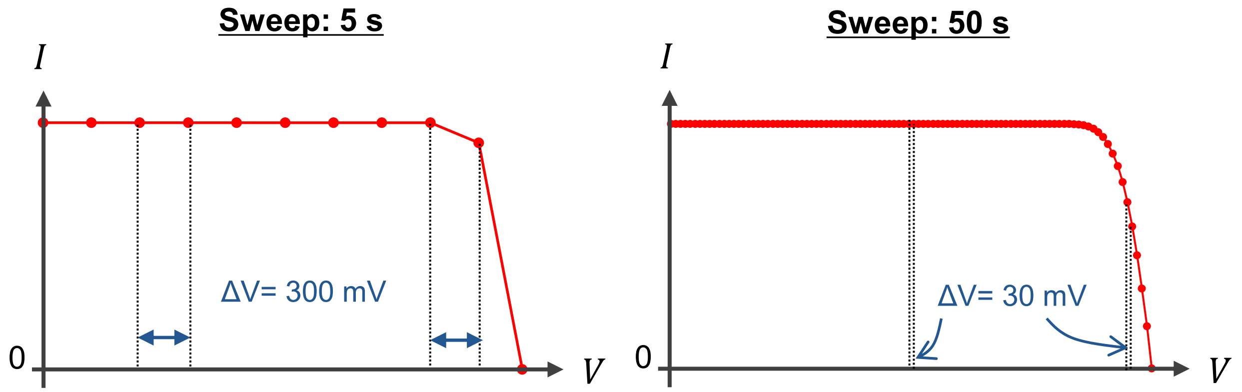
The family of power curves shows the decrease in available power at decreased irradiation

Key Challenges of Solar Cell Testing?

1 Measure current at the same time of sweeping source voltage



2 Measurement speed and accurate evaluation of I-V curve is trade-off.



3 Need high resolution at the measurement of dark current

➡ e.g. Accurate shunt resistance

$$R_{sh} = -\frac{1}{dI/dV}$$

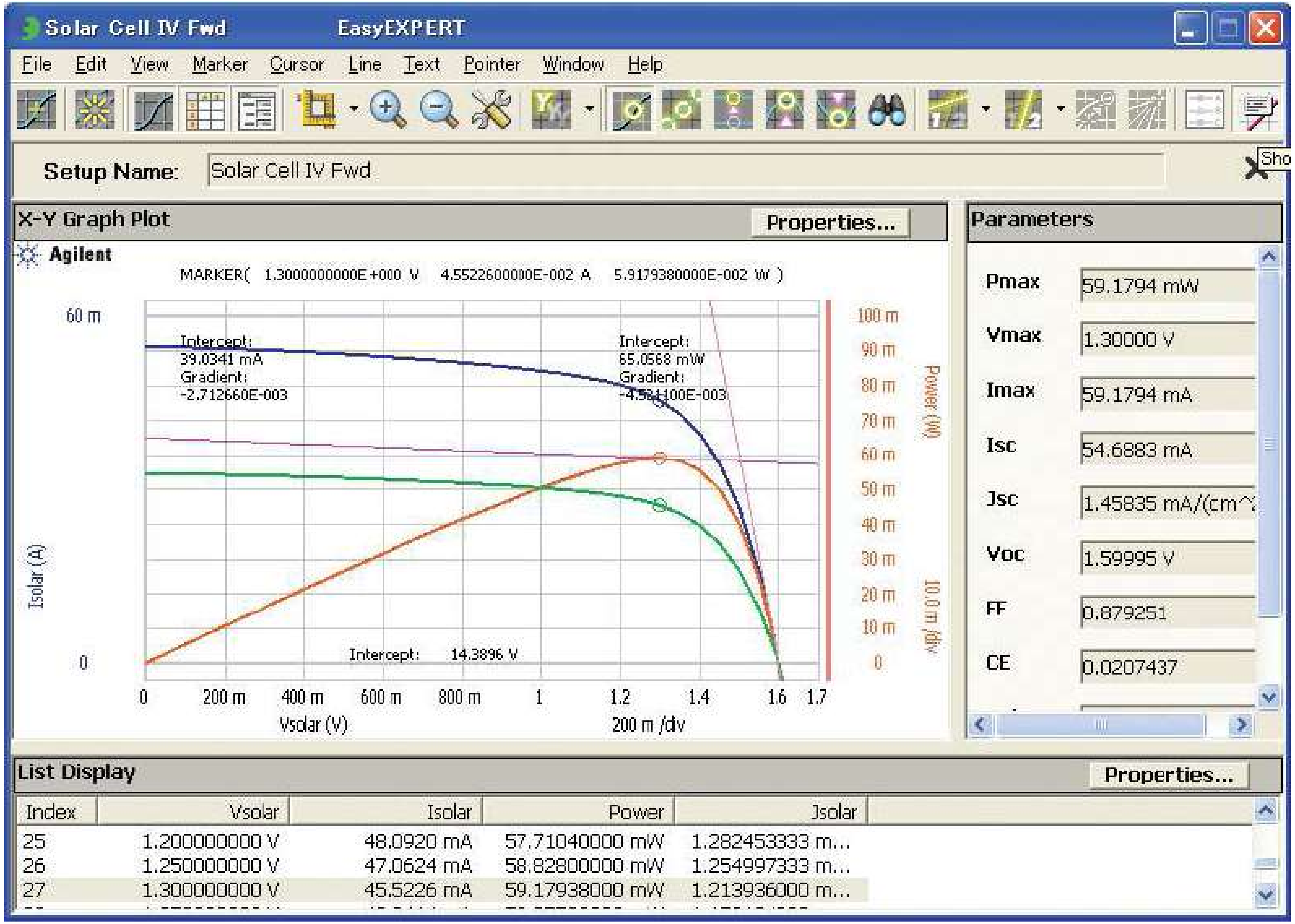
4 A lot of effort to set measurement parameters and calculating each key parameter

V_{oc} $\quad I_{sc}$ $\quad FF = \dfrac{P_{max}}{V_{oc} \times I_{sc}}$

$R_{sh} \sim -\dfrac{\Delta V_{sc}}{\Delta I_{sc}}$ $\quad R_s \sim -\dfrac{\Delta V_{oc}}{\Delta I_{oc}}$

Application test (Solar Cell IV Fwd) example

Solar Cell IV Fwd makes a forward biased IV measurement and estimates the basic static parameters of the solar cell, such as Isc, Jsc, Voc, Pmax, Imax, Vmax, FF, η, Rsh and Rs.



Application Solutions

DC-DC CONVERTER

B2900B/BL Series Precision Source/Measure Unit

A COMPLETE ONE BOX TEST SOLUTION

Broad Application Coverage By A Single Instrument

- Integrated 4-quadrant source/measure capabilities
- Wide output range up to 210 V, 3 A(DC), 10.5 A(Pulsed)

Low-Level and Pulse/Transient Measurements

- 6.5-digit high resolution down to 10 fA and 100 nV
- 10 μs high speed digitizing capability

Reduces Test Time

- Fast sweep measurement

Improve R&D Efficiency

- Intuitive graphical user interface for a quick benchtop testing, debug, and characterization

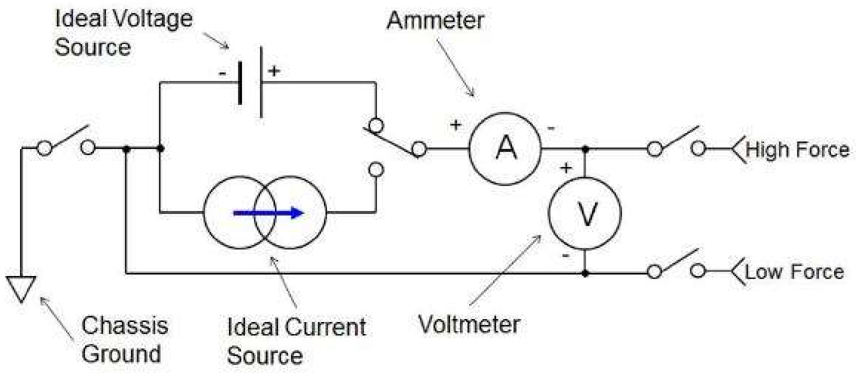
2 & 4-wire Triaxial Adapter Accessory (Optional)

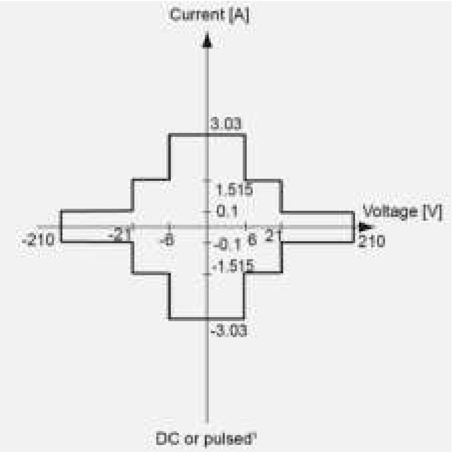
"The B2900 Graphical SMU resolves precision measurement challenges and improve test efficiency from lab to manufacturing for a wide range of applications at the best-in-class cost performance"

What is a Source/Measure Unit (SMU)?

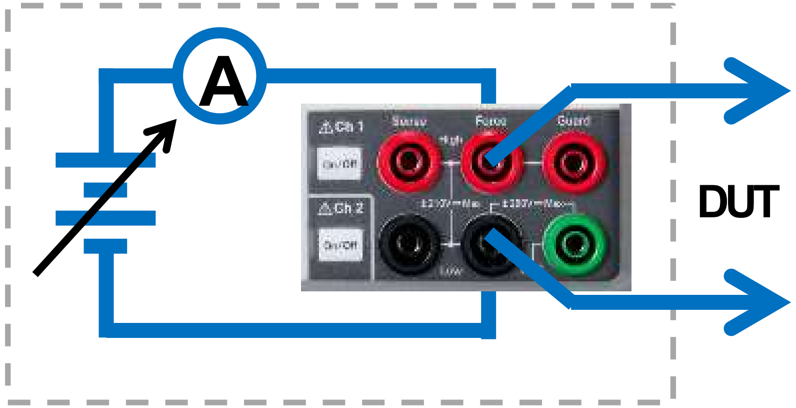
An SMU integrates the following capabilities into each channel:

- Four-quadrant (+ & -) voltage source
- Four-quadrant (+ & -) current source
- Voltage Meter
- Current Meter

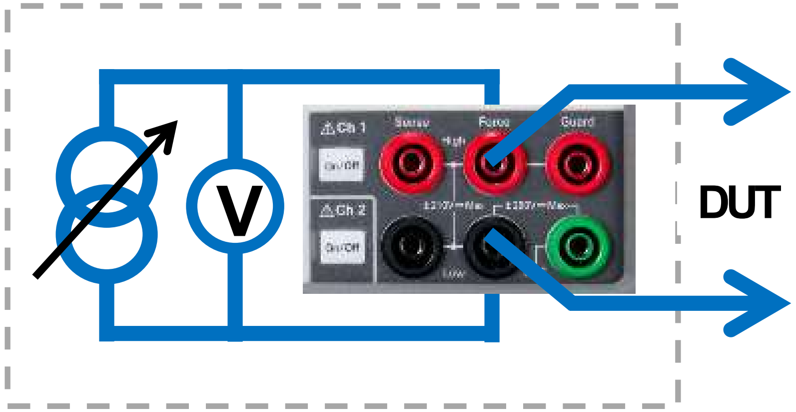




Here are the two most common modes of operation:



VFIM (Force voltage & measure current)



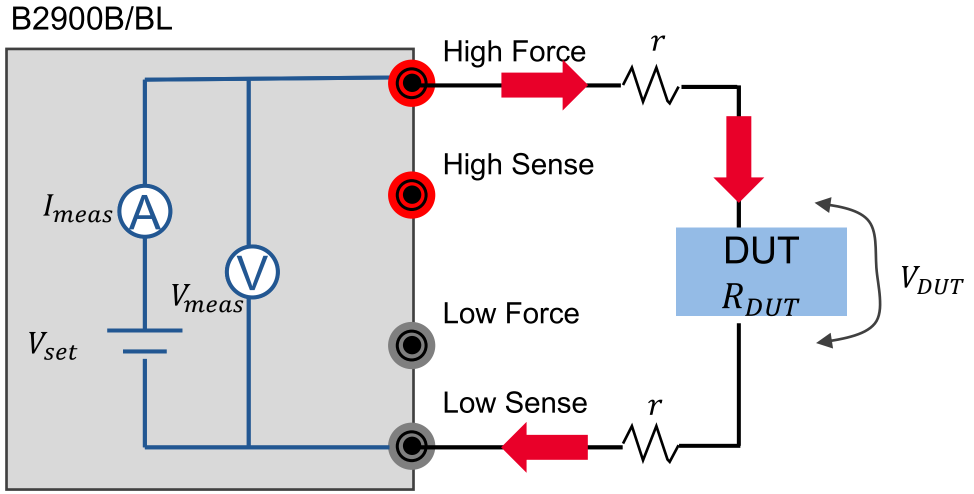
IFVM (Force current & measure voltage)

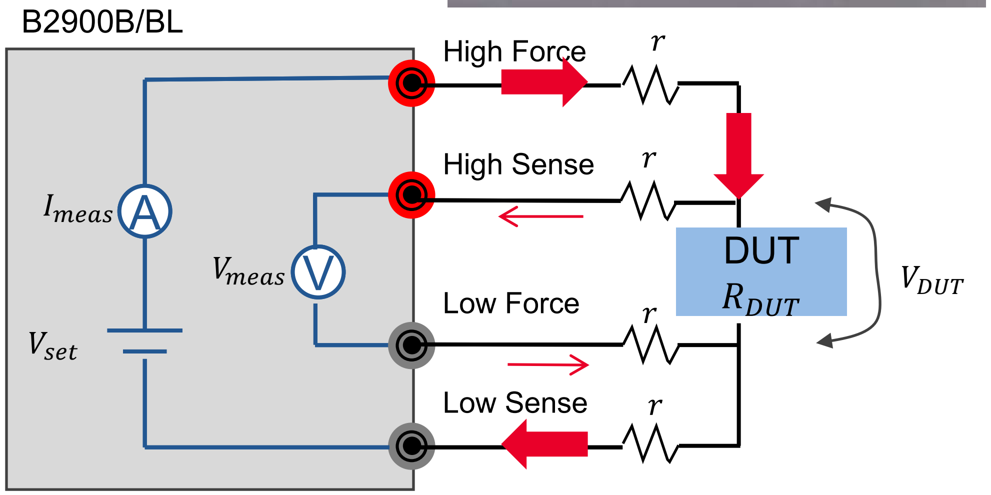
Sense Terminal

4-WIRE CONNECTION

- **2-wire connection (non-Kelvin connection)**
  - Due to voltage drop by cable resistance r,
    - applied voltage V_{DUT} deviates from measurement voltage V_{meas}.
    - Measurement resistance includes the cable resistance.

- **4-wire connection (Kelvin connection)**
  - Can measure voltage without voltage drop by cable resistance

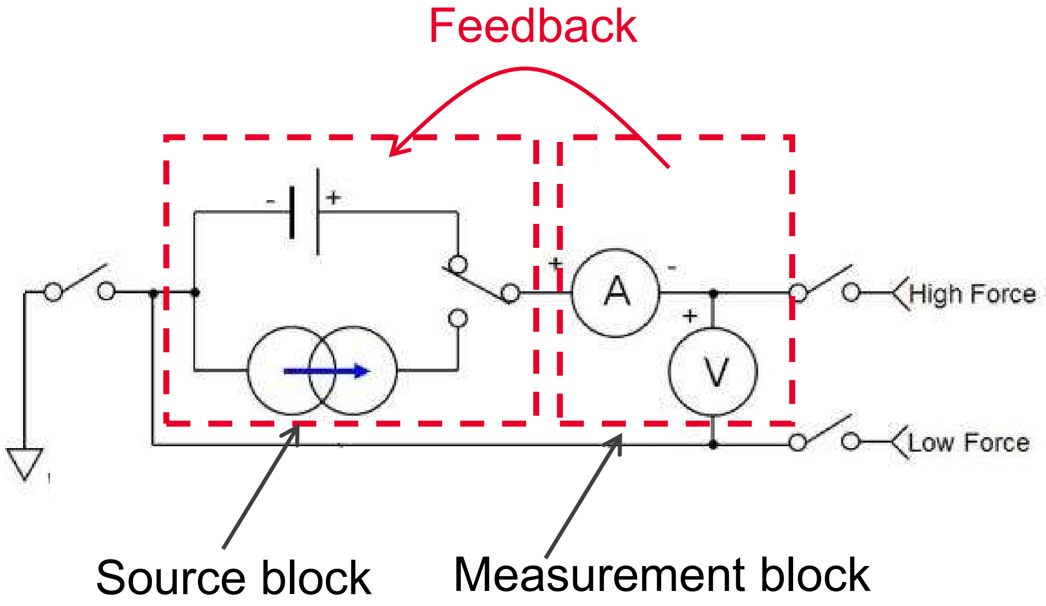




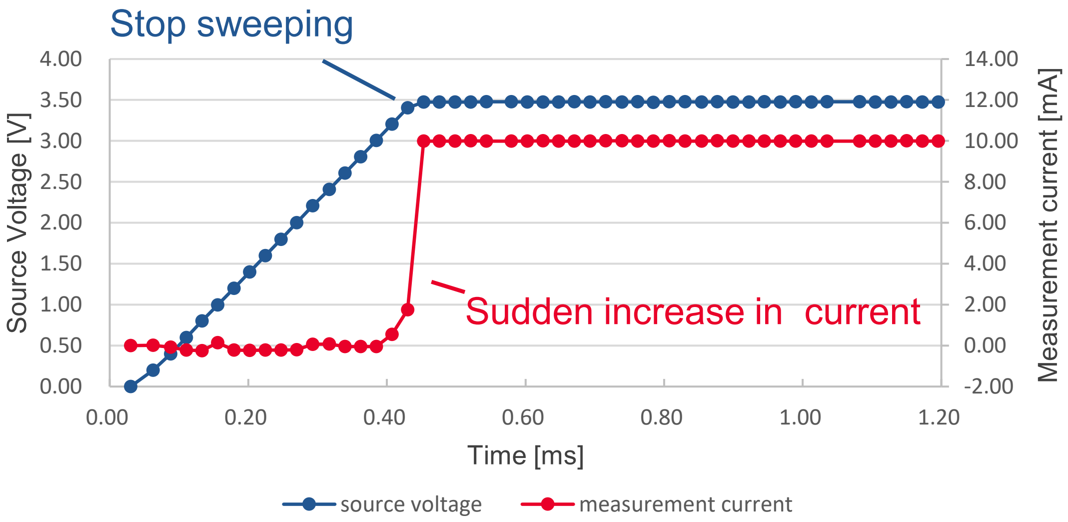
Benefit synchronizing source and measurement

DIFFERENCE BETWEEN SMU AND INDIVIDUAL INSTRUMENTS

- **Feedback mechanism stabilizes voltage and current sourcing**



- **Limit (compliance) feature prevents device damage**
  - Example: VFIM
    - Sweep Voltage from 0V to 10 V
    - Measure current
    - Set current compliance at 10 mA



B2900B’s All-in-One Test Solution for DC-DC Converter

A single instrument to address all testing needs:

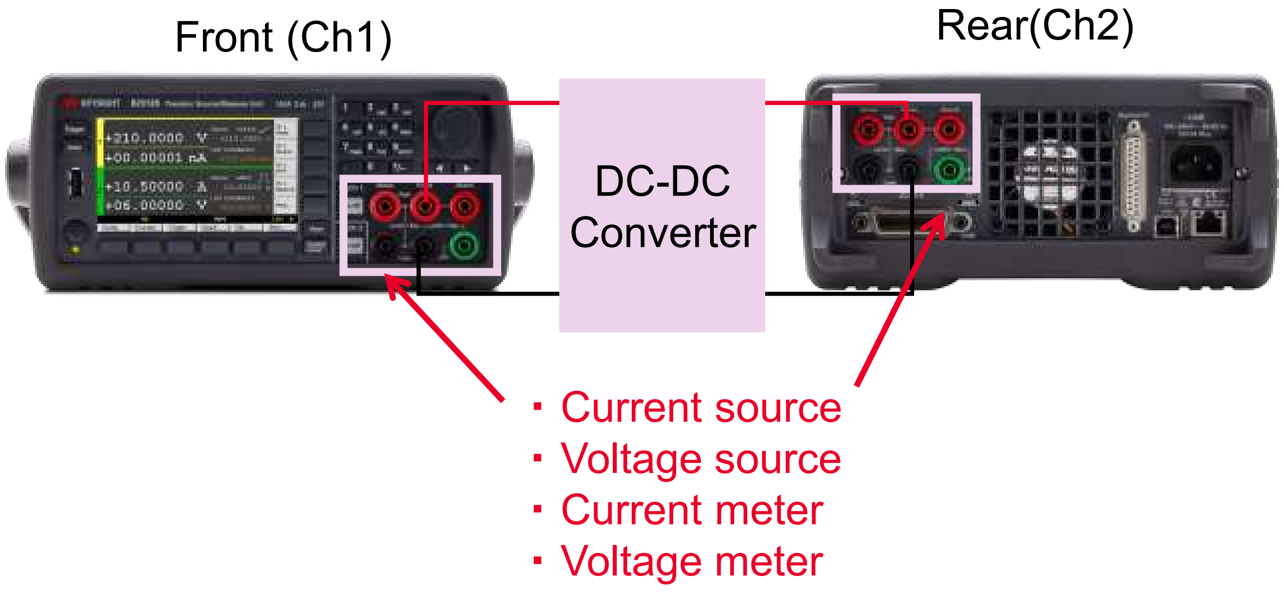
- Load Regulation
- Line Regulation
- Load Transient Response
- Conversion Efficiency
- Quiescent Current

1. B2902B/B2912B synchronizes two channels having:
   - Voltage/Current Source
   - Voltage/Current Meter

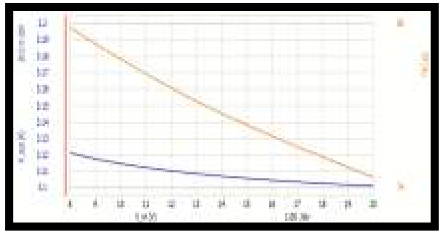
   Ch1 works as a DMM and DC power source

   Ch2 works as an electric load.

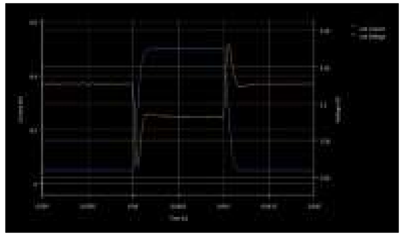
2. Front panel graphical display and software allows easy parameter measurement & calculation.



Front Panel Graphical Display



EasyExpert Group+

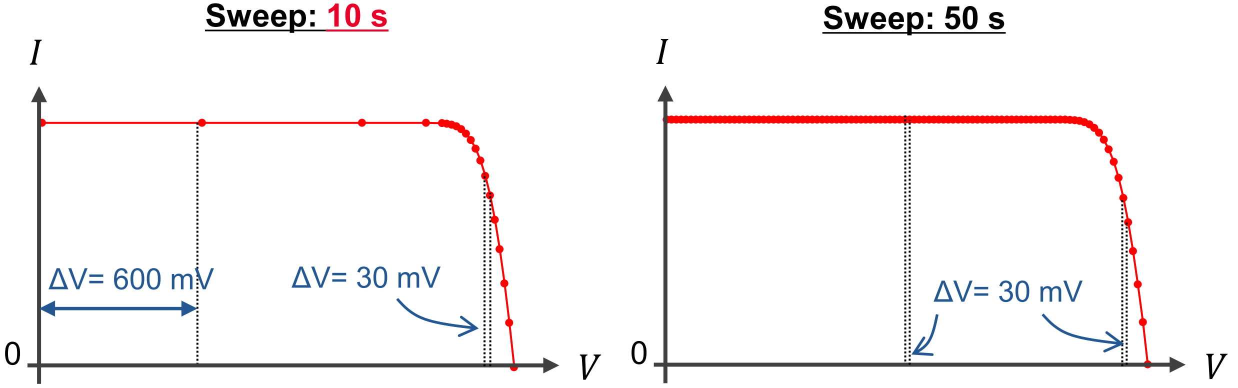


Quick IV

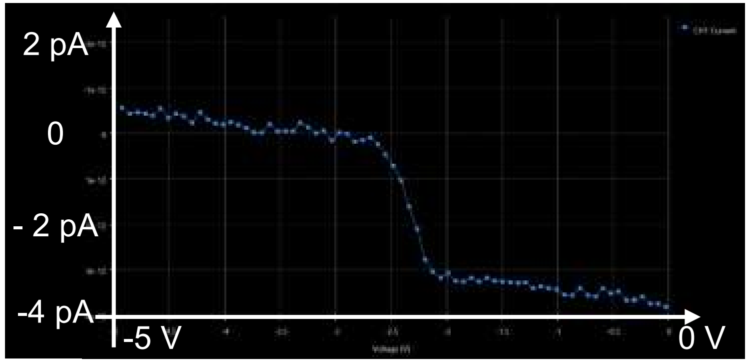
B2900B/BL's Solutions for Solar Cell Testing

1 Each channel has both Voltage/ Current Source and Meter function

2 List Sweep feature allows both the fast measurement and accurate analysis

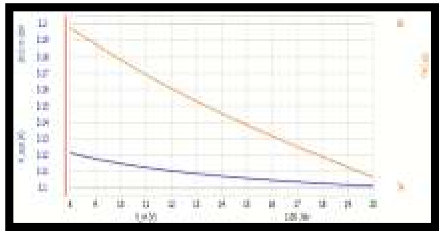


3 Minimum 10 fA resolution enables dark current measurement

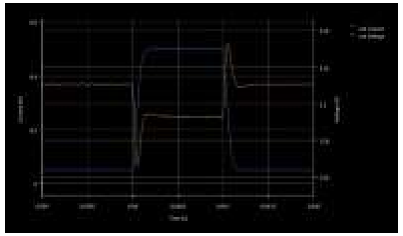


4 Front panel graphical display and software allows easy parameter measurement & calculation

Front Panel Graphical Display



EasyExpert Group+



Quick IV