

Solar/LED I–V Curve Tracer

Case Study

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1. Overview

Short description: This **Case Study** introduces the practical measurement and analysis of current–voltage characteristics of semiconductor devices using the **Digilent Analog Discovery** Product Line, **WaveForms** software, and **NI LabVIEW WaveForms Toolkit**.

The experiment focuses on two common semiconductor devices:

- Light Emitting Diode (**LED**)
- Small photovoltaic **solar** cell

The I–V curve shows how the current through a device change as the voltage across it changes. This characteristic is one of the most important methods for analyzing semiconductor behavior.

For the **LED**, the I–V curve demonstrates the nonlinear diode behavior and the forward voltage threshold. For the **solar cell**, the I–V curve shows the operating behavior of a photovoltaic source under different illumination conditions.

The main goal of this **Case Study** is to understand how voltage and current are measured, how an I–V curve is constructed, and how the measured curve can be used to identify important electrical parameters.

Objectives

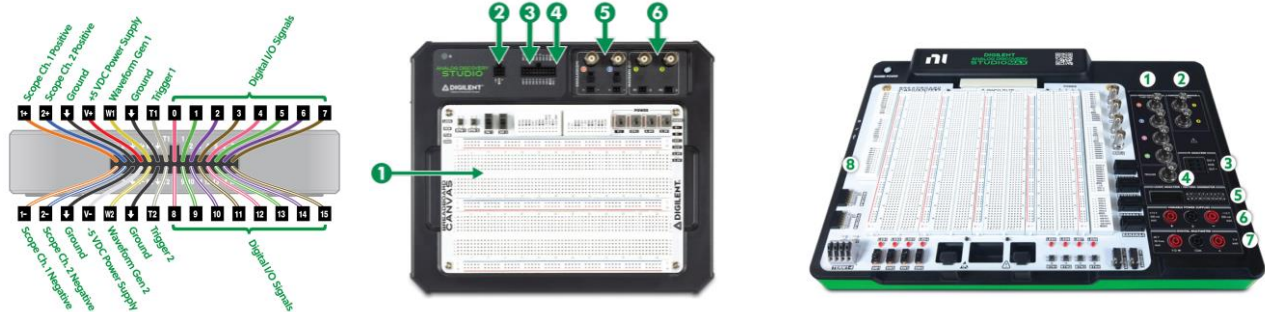
- Understand the principle of **I–V** curve measurement.
- Measure the voltage across an **LED** and calculate the current through it.
- Observe the nonlinear forward characteristic of an **LED**.
- Measure the output voltage and current of a small solar cell.
- Analyze the influence of illumination and load resistance on the solar cell I–V curve.
- Use **WaveForms** and **NI LabVIEW** to visualize and compare measured I–V characteristics.

Software & Hardware Requirements

Software		Version
Digilent WaveForms (Runtime + SDK)		Latest (64-bit)
NI LabVIEW		2025 64-bit
WaveForms Toolkit for LabVIEW		Latest
Hardware		Quantity*
Digilent Analog Discovery Product Line		
Option 1	Digilent Analog Discovery 3	1
Option 2	Digilent Analog Discovery Studio	1
Option 3	Digilent Analog Discovery Studio MAX	1
List of Components		Quantity*
Canvas Breadboard		1
LED		1
Small solar cell		1
Resistors 110 Ω		1
Resistors 220 Ω		4

2. Hardware Setup

This section describes the **Digilent Analog Discovery Product Line** hardware setup for **Case studies**. Before assembling the measurement circuit, it is essential to understand the pinout and available connections of the **Devices**. **Figure 1** highlights the pinouts and instrumentations of the **Digilent Analog Discovery product line**.¹



a. Analog Discovery 3

- Power Supplies
- Logic Analyzer and Pattern Generator
- Triggers
- Oscilloscope Waveform Generator

b. Analog Discovery Studio

1. Breadboard Canvas
2. Power Supplies
3. Logic Analyzer and Pattern Generator
4. Triggers
5. Oscilloscope
6. Waveform Generator

c. Analog Discovery Studio MAX

1. Oscilloscope
2. Waveform Generator
3. IV Analyzer
4. Trigger
5. Logic Analyzer and Pattern Generator
6. Variable Power Supplies
7. Digital Multimeter
8. Breadboard Canvas

Figure 1. Digilent Analog Discovery Products Pinout and Instrumentations

Table 1 provides a common reference for the physical connections used in the **LED** and **solar cell I–V** measurement experiments. The **LED** experiment uses a Wavegen voltage sweep and two oscilloscope channels. The **solar cell** output experiment uses the solar cell with a load resistor and a scope voltage measurement.

Table 2 provides a common reference for device names and instrument identifiers used in **NI LabVIEW** with the **WaveForms** Toolkit across the **Digilent Analog Discovery product line**. The case

¹ For detailed electrical specifications, pin descriptions, and operating limits, always refer to the official datasheets of each device (Analog Discovery 3, Analog Discovery Studio, and Analog Discovery Studio MAX). The latest datasheets are available on the Digilent website:

- [Analog Discovery 3](#)
- [Analog Discovery Studio](#)
- [Analog Discovery Studio MAX](#)

studies are designed to work with all supported devices; therefore, the generic scope channel identifiers shown in **Table 2** are used consistently throughout the **NI LabVIEW** block diagrams and configuration steps for **LED** and solar cell **I–V** measurement.

Table 1 Physical Channels Mapping for Digilent Analog Discovery Devices

<i>Channel Device</i>	<i>Analog observation point</i>	<i>Scope channel</i>	<i>+Vs</i>	<i>GND</i>
AD 3	Scope Channel 1	Scope Channel 2	+VDC Power Supply (Pin V+)	GND Pin
AD Studio ²	Scope Channel 1	Scope Channel 2	+5.0V (on canvas board)	GND Pin
AD Studio MAX ²	Scope Channel 1	Scope Channel 2	+5.0V (on canvas board)	GND Pin

Table 2 Device Names and Scope Identifiers in NI LabVIEW (WaveForms Toolkit)

<i>Identifier Device</i>	<i>Device name</i>	<i>Scope channel</i>	<i>Scope channel</i>
AD 3	Discovery3	scope/1	scope/2
AD Studio ²	DiscoveryStudio		
AD Studio MAX ²	ADS_Max		

² For the Analog Discovery Studio and Analog Discovery Studio MAX, ensure the devices are powered by turning ON the main power switch before use.

3. Background Information

I–V Curve Principle

The current–voltage characteristic describes the relationship between the voltage across an electrical device and the current flowing through it.

For a resistor, this relationship is linear:

$$V = I \cdot R$$

For semiconductor devices, such as LEDs and solar cells, the relationship is nonlinear.

The I–V curve is widely used to analyze:

- diode forward voltage,
- turn-on behavior,
- current increase region,
- photovoltaic open-circuit voltage,
- short-circuit current,
- maximum power point.

LED I–V Characteristic

An LED is a semiconductor diode that emits light when it is forward biased.

At low applied voltage, the current is very small. When the forward voltage reaches a certain threshold value, the current increases rapidly.

Typical forward voltage values are approximately:

LED Color	Typical Forward Voltage
Red	1.8–2.2 V
Green	2.0–3.0 V
Blue	3.0–3.3 V
White	3.0–3.5 V

The LED must always be connected with a current-limiting resistor to prevent excessive current.

The LED current can be calculated using:

$$I_{LED} = \frac{V_R}{R}$$

where:

- I_{LED} is the LED current,
- V_R is the voltage across the resistor,
- R is the current-limiting resistor.

Solar Cell I–V Characteristic

A solar cell converts light energy into electrical energy. Its output depends strongly on illumination intensity.

Important solar cell parameters include:

Parameter	Meaning
Open-circuit voltage, V_{oc}	Voltage when no load is connected
Short-circuit current, I_{sc}	Current when output terminals are shorted
Maximum power point, MPP	Operating point where output power is maximum
Fill factor	Quality indicator of solar cell performance

The output power is calculated as:

$$P = V \cdot I$$

where:

- P is output power, W
- V is solar cell voltage, V
- I is solar cell current, A.

Under stronger illumination, the solar cell usually produces higher current and higher available power.

As the load resistance increases, the solar cell operating point shifts toward higher voltage and lower current, while the output power changes depending on the position relative to the maximum power point.

4. Circuit Design – Step by Step Instructions

4.1 Description

Two experimental circuits are used in this **Case Study**.

The first circuit measures the I–V curve of an **LED**. A controlled voltage is applied through a current-limiting resistor. The voltage across the **LED** and the voltage across the resistor are measured using oscilloscope channels.

The second circuit measures the I–V curve of a small **solar cell**. The solar cell is connected to different load resistors. For each load value, the output voltage is measured, and the current is calculated.

4.2 LED I–V Curve Tracing Circuit

Step by Step Instructions

1. Insert the **LED** on the breadboard.
2. Connect the anode of the **LED** to one side of the current-limiting resistor.
3. Connect the other side of the resistor to the waveform generator output **W1 / V_{supply}**.
4. Connect the cathode of the **LED** to **GND**.
5. Connect **Scope Channel 1 Positive** before the resistor and **Scope Channel 1 Negative** after the resistor to measure the voltage drop across the current-limiting resistor.
6. Connect **Scope Channel 2 Positive** to the LED anode and **Scope Channel 2 Negative** to **GND** to measure the **LED** forward voltage.
7. Verify that all grounds are common.
8. Start with a low voltage and increase gradually.
9. Do not exceed the safe **LED** current.

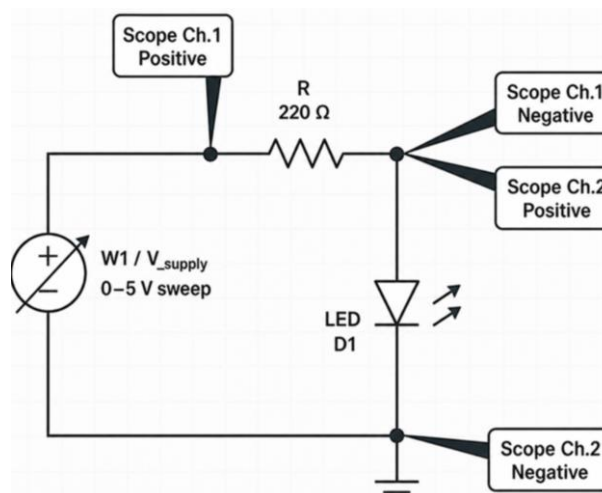


Figure 3a. LED I–V curve tracer Circuit

Current calculation for the LED circuit

For the corrected connection shown in **Figure 3a**, **Scope Ch.1** measures the voltage drop across the current-limiting resistor, and **Scope Ch.2** measures the **LED** forward voltage.

If the resistor voltage is measured:

$$I_{LED} = \frac{V_R}{R}$$

Important! Refer to **Table 1** to determine the exact physical pin, connector, or cable that corresponds to each generic connection on the specific **Digilent Analog Discovery Device** being used. The remaining rows in the table show how each generic channel maps the actual hardware connections for each device.

4.3 Solar Cell I–V Curve Tracing Circuit

Step by Step Instructions

1. Place the solar cell on the breadboard or connect it using jumper wires.
2. Connect the solar cell in the circuit as the device under test, as shown in **Figure 3b**.
3. Connect the load resistor after the solar cell. Use **R_{load} = 220 Ω, 440 Ω, and 660 Ω**, or use a variable load resistor.
4. Connect **Scope Channel 1 positive** input before the resistor and **Scope Channel 1 negative** input after the resistor to measure the resistor voltage drop.
5. Connect **Scope Channel 2 positive** input to the solar cell positive pins and **Scope Channel 2 negative** input to **GND** to measure the solar cell voltage.

Figure 3b shows the solar cell I–V curve tracing circuit using the **WaveForms Tracer** method. In this configuration, a controlled voltage sweep is applied by **W1 / V_{supply}** through the series resistor **R1**. The solar cell is used as the device under test, and the additional load resistance is varied in order to observe the effect of load resistance and illumination on the measured I–V characteristic.

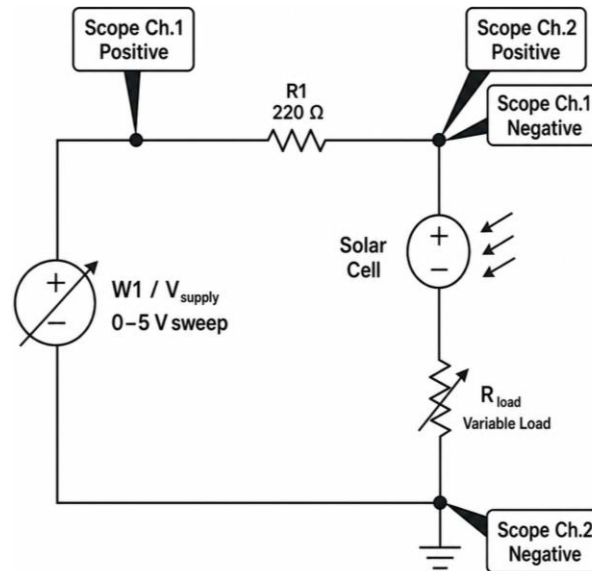


Figure 3b. Solar Cell I–V Curve Tracer Circuit

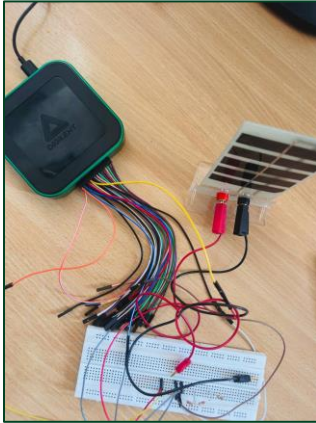
Current calculation

$$I_{solar} = \frac{V_{R1}}{R_1}$$

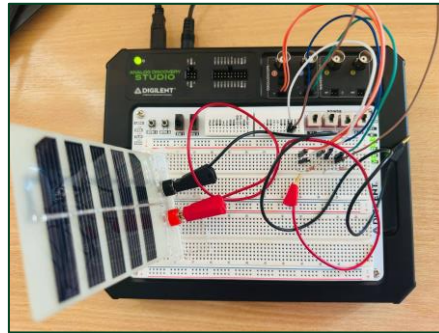
The maximum power point is found where the calculated power is the highest.

4.4 Assembled Circuit

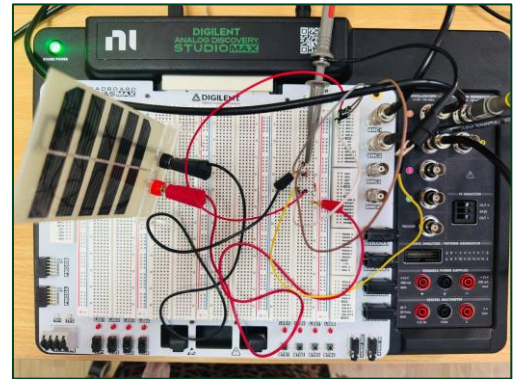
Figure 4 shows complete experimental circuits implemented on different **Digilent** devices.



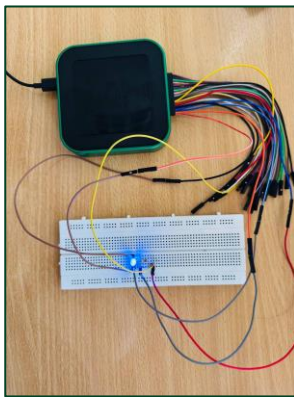
a. AD3 – Solar Cell



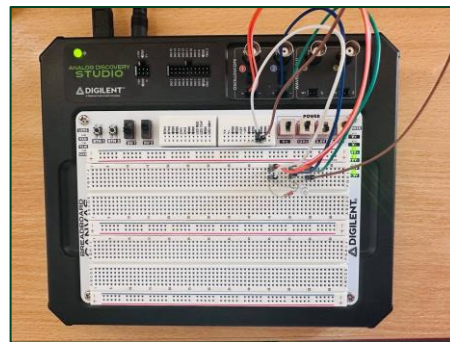
b. ADS – Solar Cell



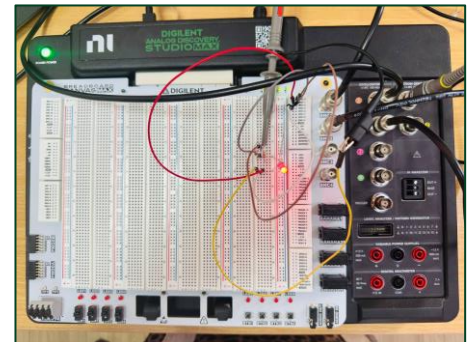
c. ADS MAX – Solar Cell



d. AD3 – LED



e. ADS – LED



f. ADS MAX – LED

Figure 4. Assembled circuits for solar cell and LED I–V curve measurements using different Digilent devices.

5. Software Setup - Step by Step Instructions

5.1 Data Visualization and Analysis in WaveForms

Step 1. Launch WaveForms and connect the device

- 1.1. Connect the **Device** to the computer via **USB**.
- 1.2. Open the **Digilent WaveForms** software.
- 1.3. Verify that the **Device** is detected and shown as *Currently Selected* in the **Device Manager** (Settings -> Device Manager).
- 1.4. Select the correct device.

Step 2. Configure the WaveForms Tracer for LED I–V measurement

- 2.1. Configure the **WaveForms** Tracer for the **LED** experiment
- 2.2. Open the Tracer instrument in **WaveForms**.
- 2.3. Select **Wavegen** as the source and set Measure to **I/V**.
- 2.4. Select **Diode** mode for the **LED** measurement.
- 2.5. Set **Vra** from **0 V to 5 V**, Samples to **101**, and step size to **50 mV**.
- 2.6. Set **R** to the actual current-limiting resistor value used in the circuit, for example **110 Ω or 220 Ω** . For safer operation, **220 Ω** is recommended.

WaveForms Tracer – LED I–V Curve Measurement Settings

Source	Measure	DUT mode	Vra	Samples	Step	R
Wavegen	I/V	Diode	0 V $\rightarrow$ 5 V	101	50 mV	110 Ω or 220 Ω

Figure 5 shows the **WaveForms** Tracer configuration and the measured **LED I–V curve** for the selected current-limiting resistor values.

Step 3. Configure the display axes

- 3.1. Configure the measurement display in **WaveForms**
- 3.2. Set the **X-axis** quantity to voltage V and the range to **0–5 V**.
- 3.3. Set the **Y-axis** quantity to current I and use an appropriate range, for example **0–50 mA**.
- 3.4. Use Single or **Run** to start the voltage sweep.
- 3.5. For the **LED** comparison, repeat the measurement for **R = 110 Ω** and **R = 220 Ω** .

Step 4. Record LED I–V data

- 4.1. Record **LED I–V** data
- 4.2. Run the voltage sweep in **WaveForms Tracer**.
- 4.3. Measure the **LED** voltage on the X-axis.
- 4.4. Calculate the **LED** current from the voltage drop across the series resistor.
- 4.5. Compare the curves obtained for **R = 110 Ω** and **R = 220 Ω** .
- 4.6. Observe how decreasing the current-limiting resistance increases the LED forward current.
- 4.7. Use the 220 Ω curve as the recommended safe operating example for the case study.

Expected observation:

$$V_{supply} = 5 \text{ V},$$

$$V_{LED} \approx 3 \text{ V},$$

$$R = 220 \, \Omega,$$

$$V_R = V_{supply} - V_{LED}$$

The current is:

$$I_{LED} = \frac{V_R}{R} \approx \frac{5 - (3.0 \dots 3.2)}{220} \approx 8 - 9 \text{ mA}$$

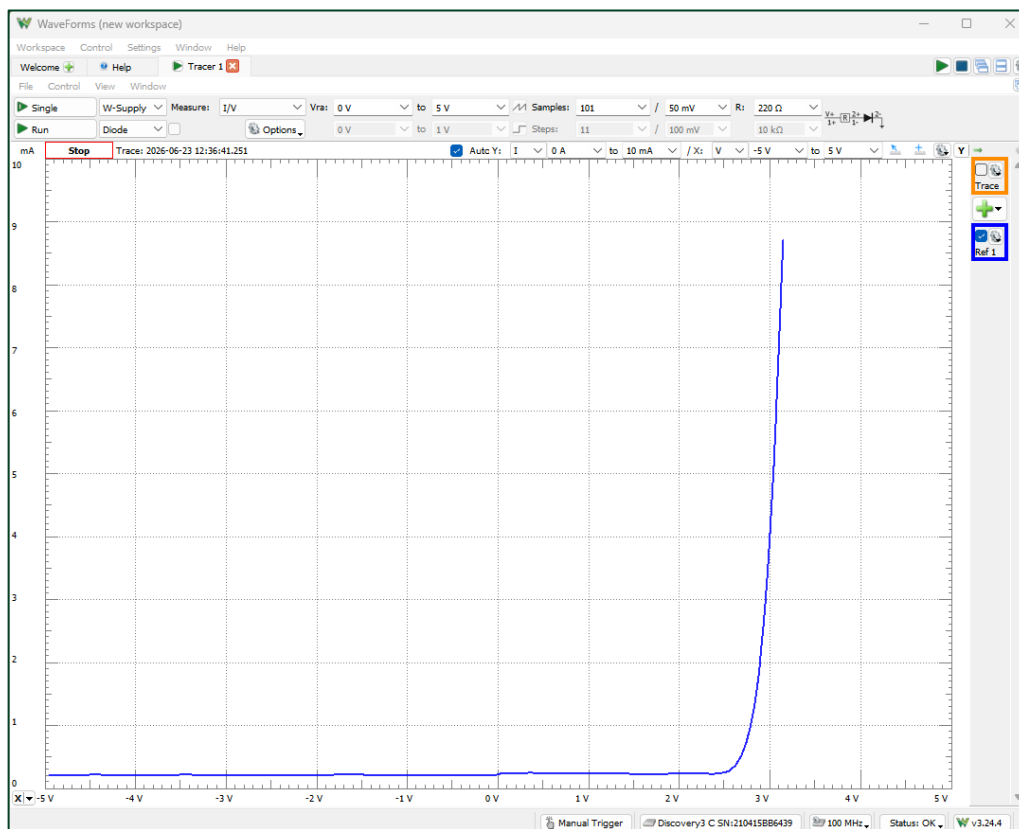


Figure 5. Example LED I-V curve obtained using the WaveForms Tracer instrument

Step 5. Record solar cell I-V data

- 5.1. Keep the **WaveForms Tracer I/V** measurement configuration similar to the **LED I-V** measurement setup.
- 5.2. Replace the LED with the solar cell circuit shown in **Figure 3b**.
- 5.3. Set the sweep voltage range from **0 V to 5 V**.
- 5.4. Use **R1 = 220 Ω** as the series resistor.
- 5.5. Change the load resistance values: **R_{load} = 220 Ω, 440 Ω, and 660 Ω**.
- 5.6. Repeat the measurement under normal room illumination, bright illumination, and dark conditions.

5.7. Save the obtained curves and compare the effect of load resistance and illumination.

Expected observation:

The measured curves change depending on both the illumination level and the selected load resistance. Brighter illumination generally increases the generated photocurrent component, while different load values modify the operating point and the slope of the measured I–V characteristic. In dark conditions, the solar cell behaves more like a semiconductor diode with a much smaller photo-generated contribution.

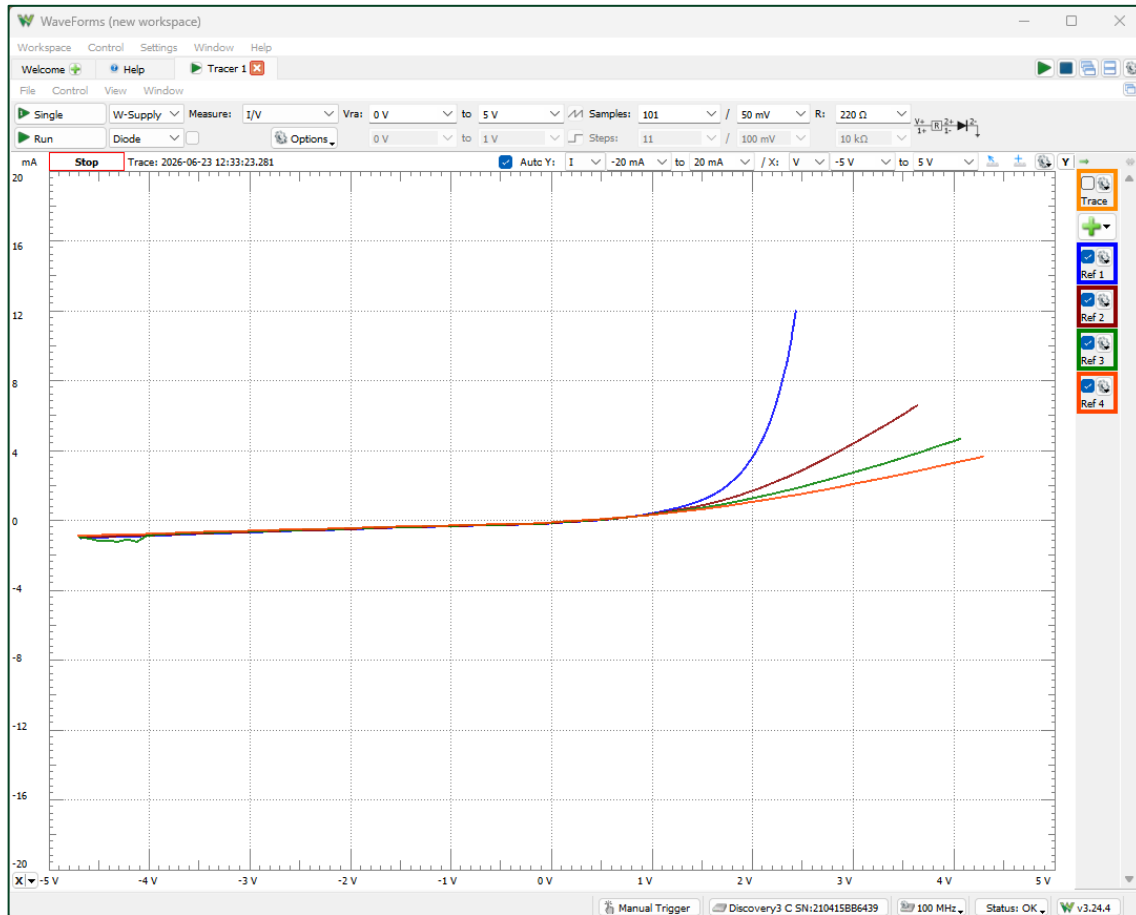


Figure 6. Solar cell I–V curves obtained using the WaveForms Tracer for different load resistances and illumination conditions.

Important note: Do not use the WaveForms Tracer NPN mode ($I_c/V_{ce}(I_b)$) for this solar cell experiment. That mode is intended for transistor characterization. For the present solar cell measurement, use the WaveForms Tracer I/V measurement mode with the circuit shown in Figure 3b, and repeat the measurement for different load resistances and illumination conditions.

5.2 Solar/LED I-V Curve Tracer Visualization Using NI LabVIEW WaveForms Toolkit

Step 1. Launch NI LabVIEW and connect the Device

- 1.1. Connect the **Device** to the computer via USB.
- 1.2. Open **Digilent WaveForms** and verify that **Device** is detected and shown as *Currently Selected* in the **Device Manager** (Settings -> **Device Manager**).
- 1.3. Close **Digilent WaveForms** software³.
- 1.4. Open the **NI LabVIEW** software.
- 1.5. Create a new NI LabVIEW VI (**File->New VI**)

Step 2. Create Block Diagram and Front Panel in NI LabVIEW

- 2.1. Modify the block diagram as shown in **Figure 7**.

The complete NI LabVIEW VI for this experiment is included as **Demo_Case_study_SolarLED I-V Curve Tracer.vi**. This file contains the block diagram and front panel used for the Solar/LED I-V curve measurement.

Figure 7 shows the LabVIEW block diagram used for automated **Solar/LED I-V curve** measurement. The VI generates the voltage sweep, reads the oscilloscope channels, calculates the current, and displays the measured I-V curve on the **XY Graph**.

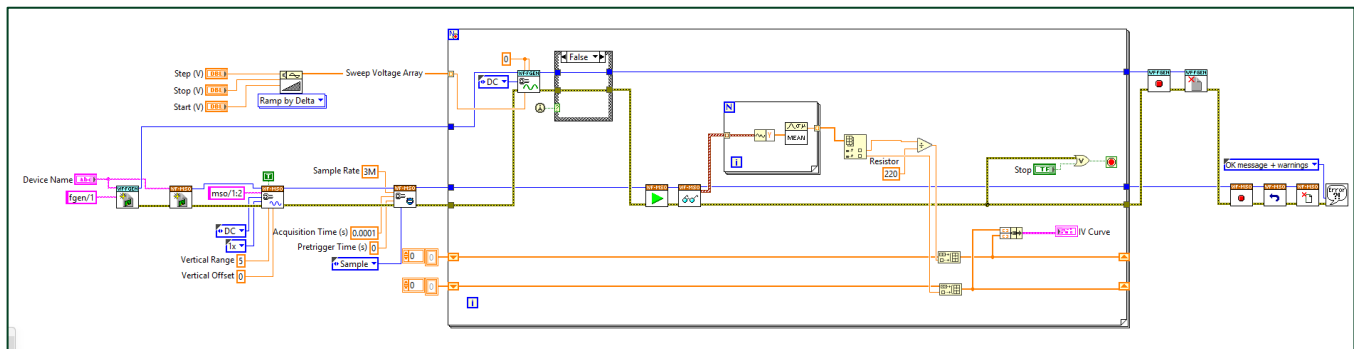


Figure 7. VI Block Diagram

- 2.2. Modify the front panel shown in **Figure 8**. Inside **Device name** String Control write your corresponding **Device** name from **Table 2**.

³ Before running NI LabVIEW, please ensure that the Digilent WaveForms software is closed.

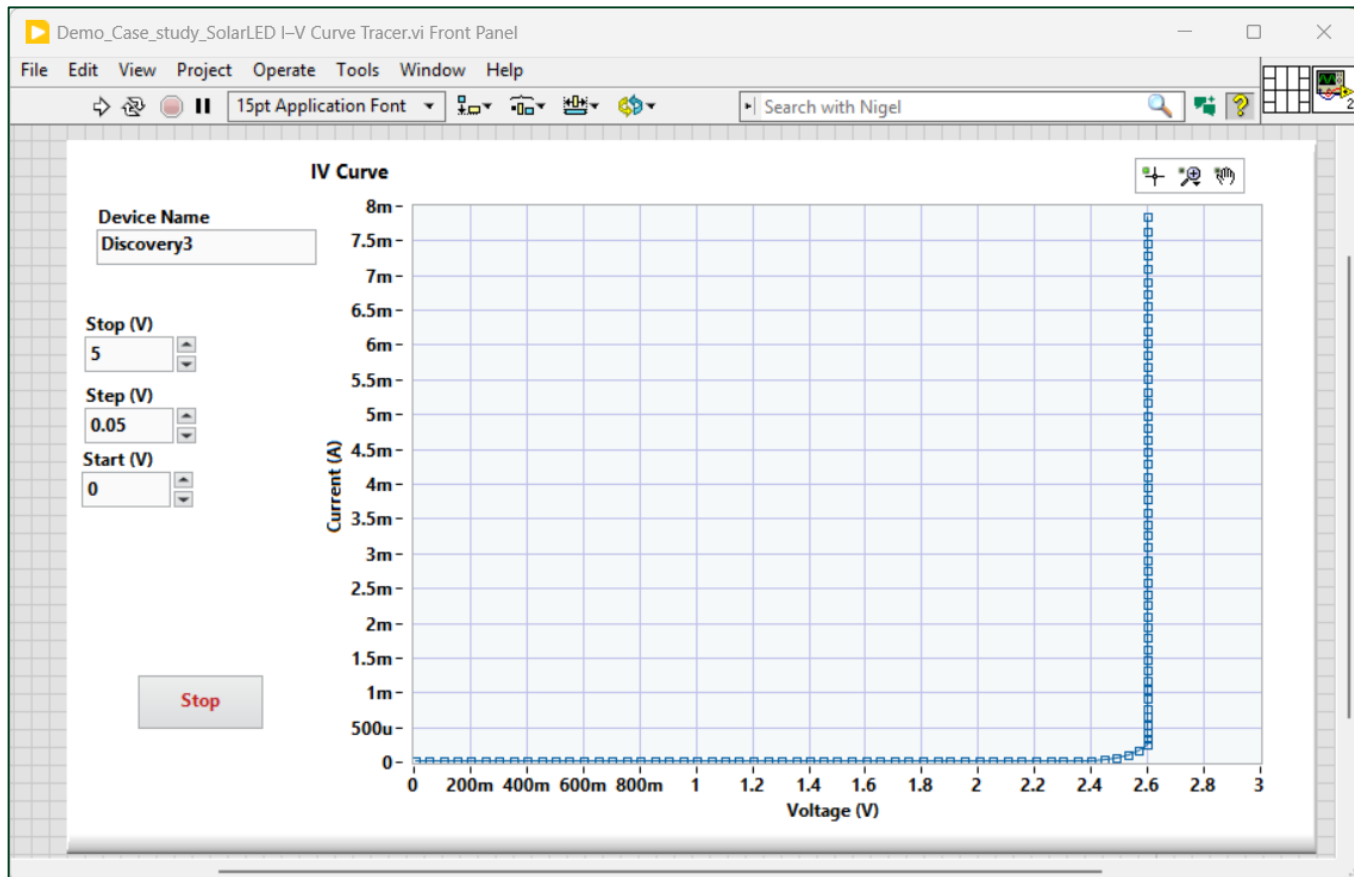


Figure 8. VI Front Panel

2.3. Save the VI.

Step 3. Run the VI and observe LED and solar cell I-V measurement results.

- 3.1. Click the **Run** button.
- 3.2. Set **Device Name** according to the connected **Device**.
- 3.3. Set the **Start**, **Stop**, and Step voltage values.
- 3.4. Apply a voltage sweep for LED measurement or repeat the measurement for the selected solar cell load resistance and illumination condition.
- 3.5. Observe the measured voltage and calculated current.
- 3.6. Display the **I-V curve** on the **XY Graph**.
- 3.7. Press **Stop** to end the VI.