

Agilent B2961A/B2962A Low Noise Power Source

**Programmable Output Resistance
Using VI Emulation Mode**

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1. Introduction

Ideal voltage source has zero- Ω output impedance and ideal current source has infinite output impedance. Generally, such ideal source is suitable for a device/module characterization. However in the real application environments, you cannot anticipate such ideal condition. You may be surprised by seeing your device/module behave strangely. And in a bad situation, you may stop working due to the voltage drop across the intolerable residual resistance, wire, output resistance of power supply, and so on.

The voltage drop can be given by a function of the current which varies according to the load resistance. So you can observe the affect of the voltage drop by emulating the voltage which will be actually applied to the load. Then, you have to calculate and adjust the voltage (V_{Load}) to satisfy $V_{Load} = V_0 - I_{Load} \times R_{Residual}$ (V_0 : output voltage at open, I_{Load} : load current, $R_{Residual}$: residual resistance).

Instead of above tasks, you may connect a real resistor to the instrument terminal externally. Then you have to prepare variety of resistors and replace the resistor manually to observe its dependency and change the resistance.

To avoid these troublesome tasks, you can use the Agilent B2961A/B2962A which provides the programmable output resistance function. The B2961A/B2962A supports two operation modes, constant and VI emulation, for this function. The constant mode lets the B2961A/B2962A channel work as a voltage source with built-in constant series resistor (R_s) or a current source with a built-in constant shunt resistor (R_{sh}). And the VI emulation mode lets the channel work as a voltage source or current source with a built-in resistor which has a non-linear I-V characteristics. By using this function, DC I-V characteristics of device/module such as a battery can be emulated easily and effectively.

This document introduces the VI emulation mode of the programmable output resistance function and the application examples by using the B2961A/B2962A. For the constant mode, see another document *"Using Constant Mode"*, publication number B2960-90041.



2. VI Emulation Mode

The VI emulation mode lets the B2961A/B2962A channel work as a source with a built-in non-linear resistor. The channel can emulate an electronic devices or circuits which have a non-linear four quadrant I-V characteristics. The characteristics is emulated by using the impedance $Z(I)$ which is a function of current and the admittance $Y(V)$ which is a function of voltage.

Simplified I-V characteristics of a battery cell is shown in Figure 1. When you draw a tangent line at an operating point P in Figure 1 (a), its slope ($\Delta V / \Delta I$) is the impedance Z of the device at the point $P(V_p, I_p)$.

$$Z(I_p) = \left. \frac{\Delta V}{\Delta I} \right|_{I=I_p}$$

And its reciprocal is the admittance Y .

$$Y(V_p) = \left. \frac{\Delta I}{\Delta V} \right|_{V=V_p}$$

As shown above, Z and Y are the function of V or I . Using this fact, the I-V characteristics is transformed into the Z-I (impedance-current) plane as shown in Figure 1 (b). Thus, the I-V characteristics can be expressed by using the Z-I, V-Y, or their combination. For very high impedance, conductance (Y) can be used. In this case, zero impedance ($Z=0, Y=\infty$) gives the constant voltage, and zero admittance ($Y=0, Z=\infty$) gives the constant current.

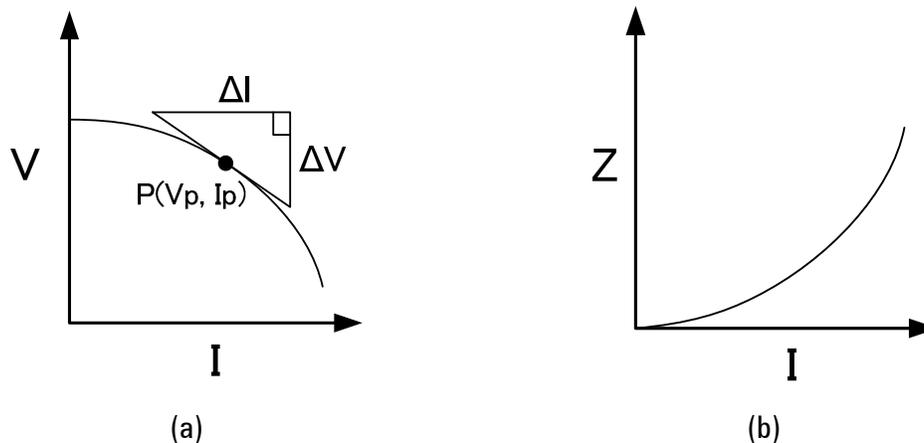


Figure 1 I-V characteristics of a battery cell and its transformation function into Z-I plane

Emulation table and PWL interpolation

The B2961A/B2962A uses a user defined emulation table and the piecewise linear (PWL) interpolation to express a non-linear DC I-V characteristics. The emulation table is considered as a data list which can store up to 16 pairs of voltage and current data. The PWL interpolation is a widely used technique in engineering for approximating a complex function by a simple (linear) function.

A pair of voltage and current data makes a point on the I-V plane as shown in Figure 2. And the B2961A/B2962A channel performs the operation of the constant mode using the resistance (R_s or R_{sh}) given by the slope between two adjacent points. Figure 3 shows an example of I-V characteristics with six I-V data.

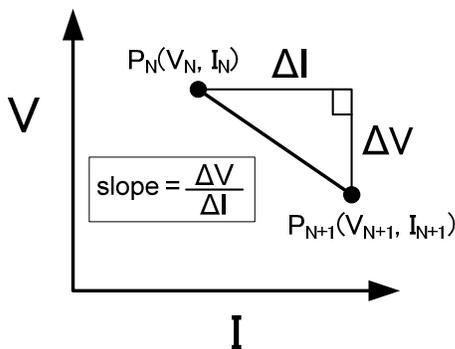


Figure 2 Emulation table data and slope

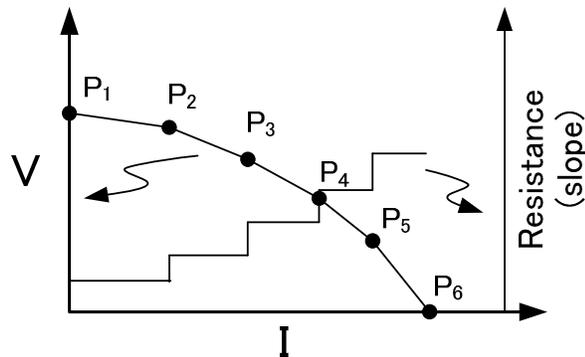


Figure 3 Example of I-V characteristics

Agilent B2961A/B2962A setting parameters:

- Primary source mode (set to B2961A/B2962A front panel Mode): voltage (V) or current (I)
- V and I source values (set to Output R (Emulation), emulation table)
- V/I mode for transition between adjacent source values (set to Output R (Emulation), emulation table)

Primary source mode and shape of I-V characteristics

Simplified block diagram of the B2961A/B2962A channel in the VI emulation mode is shown in Figure 4. The upper part of the figure represents a voltage source with series resistance (R_s) and the lower part represents a current source with shunt resistance (R_{sh}).

The channel initially works as a voltage source or a current source depending on the Mode setting. This source mode is called as the primary source mode in this document. The source mode for each transition between two adjacent points can be dynamically switched according to the V/I mode set to the emulation table. By this mechanism, various shapes of I-V characteristics can be emulated stably.

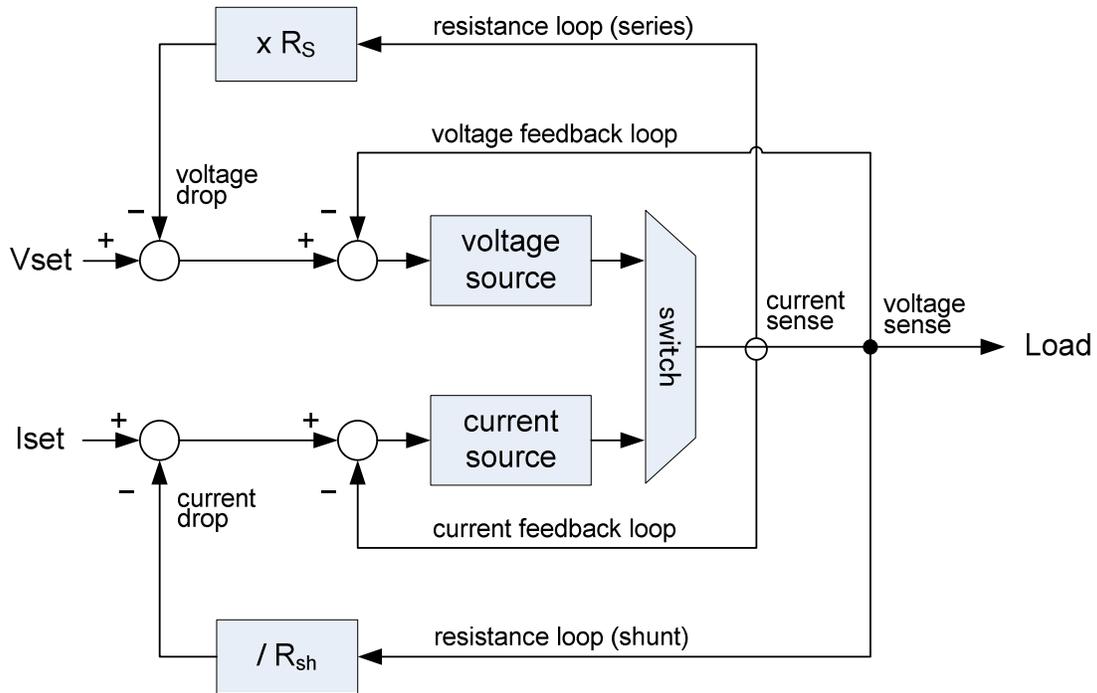


Figure 4 Simplified block diagram, VI emulation mode

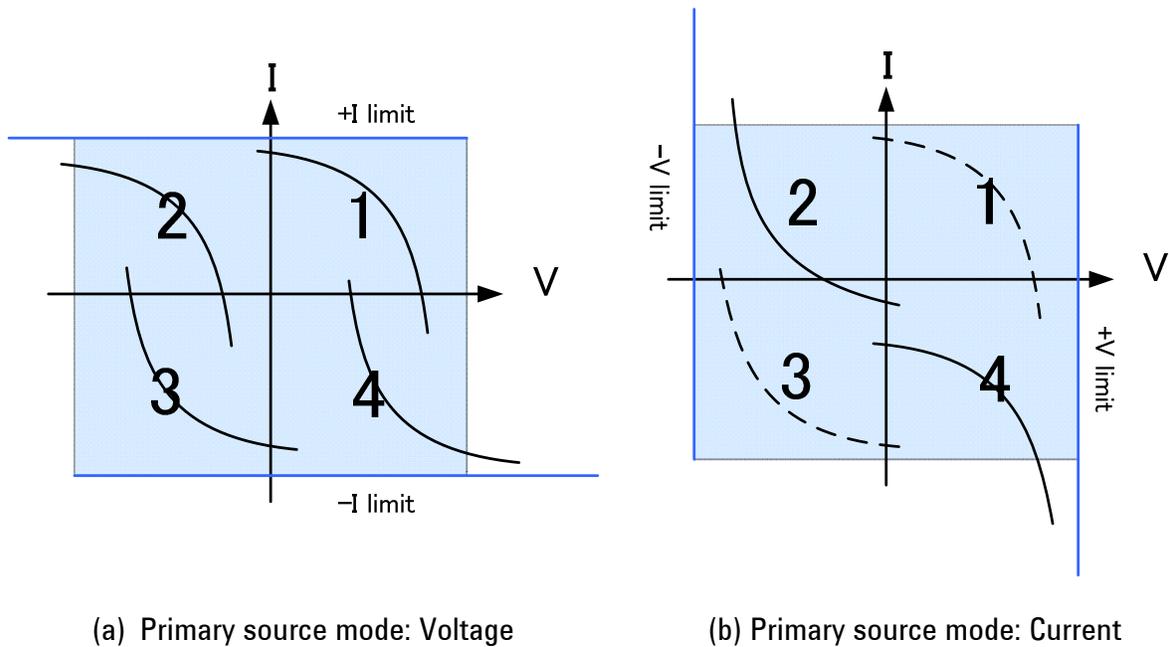


Figure 5 I-V shapes allowed in VI emulation mode

The shape of I-V characteristics to emulate must be classified into one of the patterns shown in Figure 5. For example, a battery emulation described above is classified into the pattern shown in the quadrant-1 of (a). And to emulate a lamp, the quadrant-4 of (a) should be used. In this case, V is the B2961A/B2962A channel output voltage and I is the output current. Positive current flows to load from channel.

Note that the primary source mode must be specified before the programmable output resistance function is enabled. Also, the primary source mode must be voltage for the I-V characteristics like the quadrant-1 or 3.

V/I mode setting

The emulation table is used to set the voltage and current values for each point on the DC I-V characteristics as described above. Also the table contains the V/I mode for each transition between two adjacent points which is a necessary parameter to select the B2961A/B2962A channel operation, voltage source or current source, most suitable for each point and transition.

An example of I-V characteristics is shown in Figure 6. Theoretically, this characteristics can be emulated by using either a 5 V voltage source with 1 kΩ series resistor or a 5 mA current source with 1 kΩ shunt resistor as shown in Figure 7. However, it is difficult to emulate the characteristics by using either of them due to the affect of the load resistance. Generally, the voltage source is effective for $R_{Load} \geq R_s$ and the current source is effective for $R_{Load} \leq R_{sh}$.

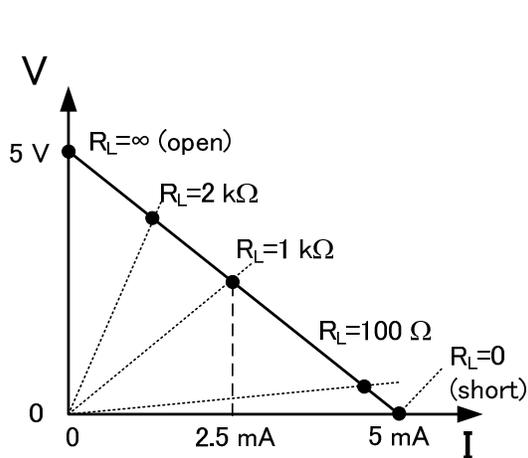


Figure 6 Linear I-V characteristics of $V_{open}=5\text{ V}$ and $I_{short}=5\text{ mA}$

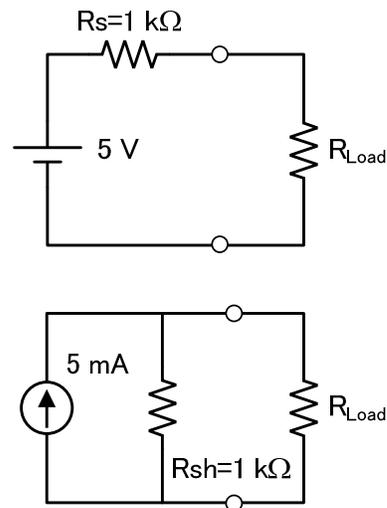


Figure 7 Two equivalent circuits to realize characteristics shown in Figure 6

Figure 8 and Figure 9 show the load voltage measurement results of the above circuit (Figure 7) with several load resistors. The voltage source (V mode) works fine for $R_{Load} \geq 1 \text{ k}\Omega$, and its output oscillates for $R_{Load} = 100 \Omega$. On the other hand, the current source (I mode) works fine for $R_{Load} \leq 1 \text{ k}\Omega$ and its output starts oscillating over $2 \text{ k}\Omega$. In this case, the critical load resistance value is $1 \text{ k}\Omega$ that is equal to R_s and R_{sh} . So the V/I mode should be switched at this point which is actually not a point but a band with some width.

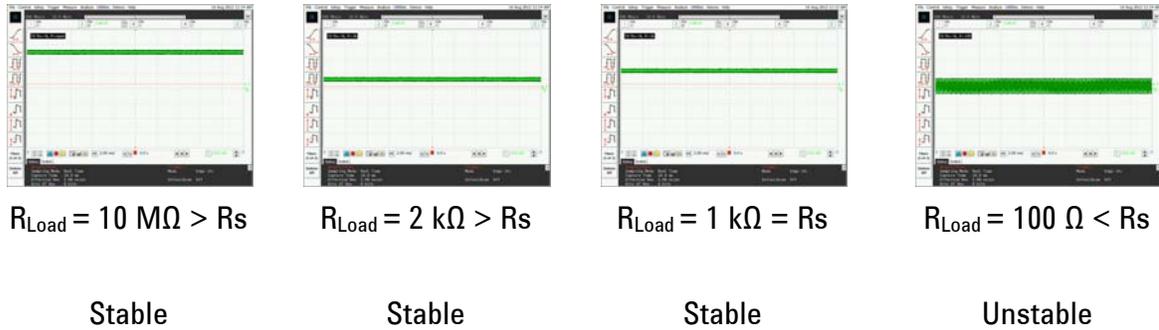


Figure 8 V mode operation with various R_{Load}



Figure 9 I mode operation with various R_{Load}

Emulation table setting example

The I-V characteristics of a typical solar cell is shown in Figure 10. Dotted lines represent load lines for several resistances. In this example, the I-V characteristics is split into 5 slopes, S1 to S5. And the output resistance (S3) becomes the same as the load resistance at the operating point P3. So the emulation table should be defined as shown in Table 1.

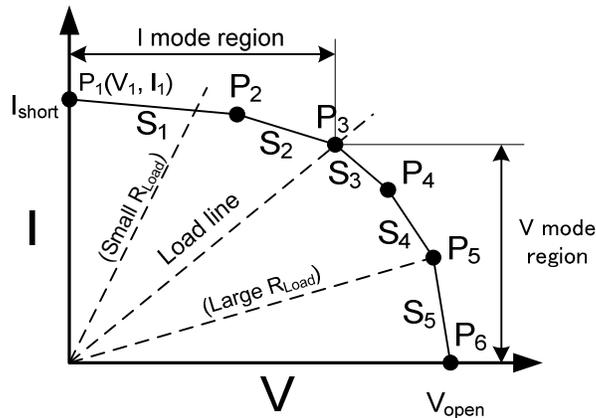


Figure 10 I-V characteristics of typical solar cell

Table 1 Voltage, Current, and V/I mode settings for above characteristics

Operating point	Voltage	Current	Slope	Output impedance	V/I mode
P ₁ (short)	V ₁ =0	I ₁			
			S ₁	$\frac{V_2 - V_1}{I_2 - I_1}$	I
P ₂	V ₂	I ₂	S ₂	$\frac{V_3 - V_2}{I_3 - I_2}$	I
P ₃	V ₃	I ₃	S ₃	$\frac{V_4 - V_3}{I_4 - I_3}$	V
P ₄	V ₄	I ₄	S ₄	$\frac{V_5 - V_4}{I_5 - I_4}$	V
P ₅	V ₅	I ₅	S ₅	$\frac{V_6 - V_5}{I_6 - I_5}$	V
P ₆ (open)	V ₆	I ₆ =0			

Note that the system requires the descending order (from large value to small value) for the Current column in the table.

This example assumes that the load capacitance is negligible and there is no internal bias source in the load. If any bias source exists in the load, the load resistance looks different and the V/I mode may need to be changed.

Combination of V/I mode

If the primary source mode is voltage

Combination of the V/I mode must be one of the following conditions (Figure 11).

- (1) V mode only
- (2) I mode ($I > 0$) to V mode
- (3) V mode to I mode ($I < 0$)
- (4) I mode ($I > 0$) to V mode to I mode ($I < 0$)

The I-V curve must be started by the positive current and ended by the negative current.

The I mode cannot be used within $\pm 1\%$ of full scale of the current range (or $\pm 10\%$ for the 10 nA range). So, the V mode must be used for this $\pm 1\%$ region (or $\pm 10\%$ region for the 10 nA range).

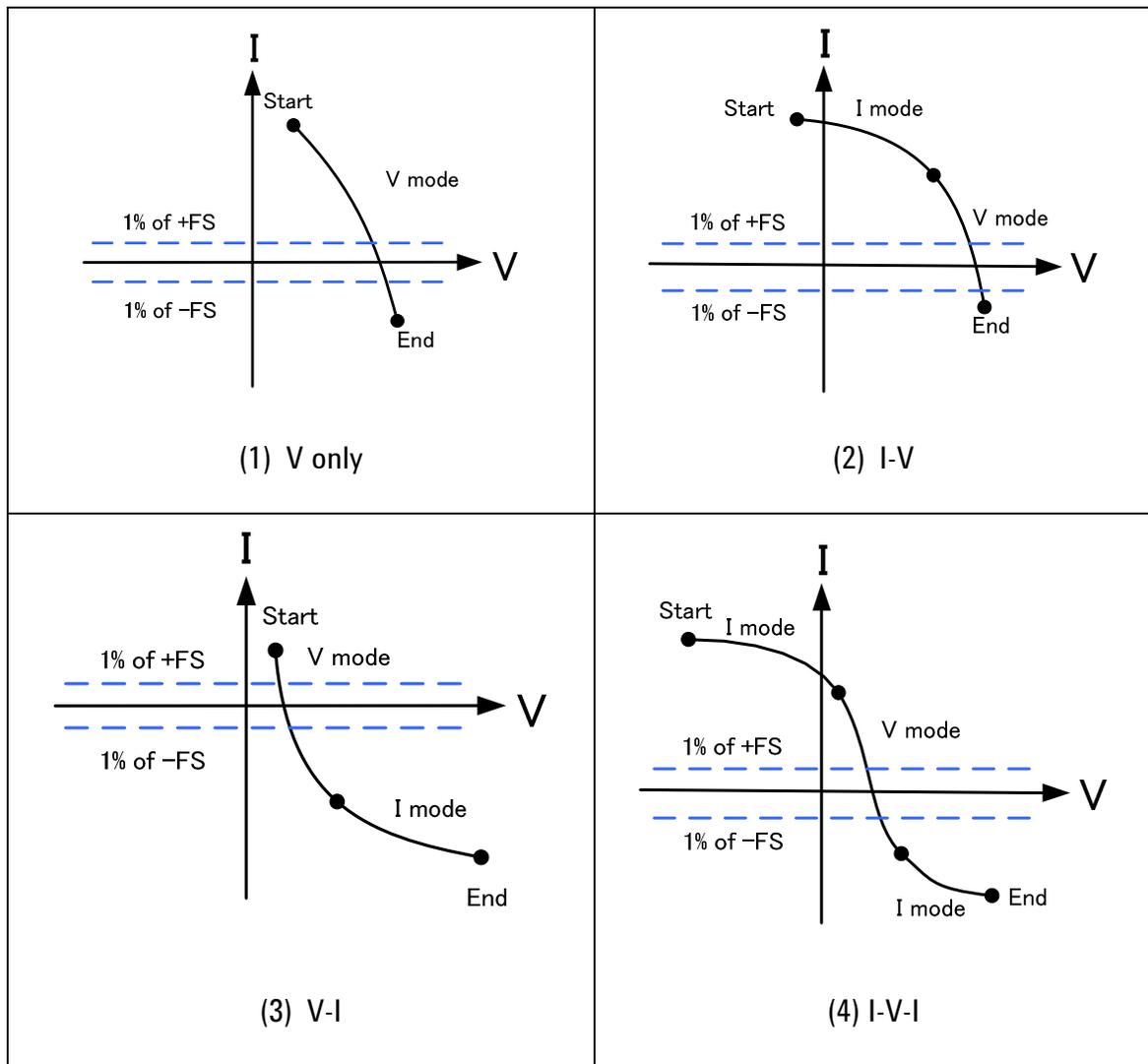


Figure 11 V/I mode when the primary source mode is voltage

If the primary source mode is current

Combination of the V/I mode must be one of the following conditions (Figure 12).

- (1) I mode only
- (2) V mode ($V < 0$) to I mode
- (3) I mode to V mode ($V > 0$)
- (4) V mode ($V < 0$) to I mode to V mode ($V > 0$)

The I-V curve must be started by the negative voltage and ended by the positive voltage.

The V mode cannot be used within $\pm 1\%$ of full scale of the voltage range (or $\pm 10\%$ for the 200 mV range). So, the I mode must be used for this $\pm 1\%$ region (or $\pm 10\%$ region for the 200 mV range).

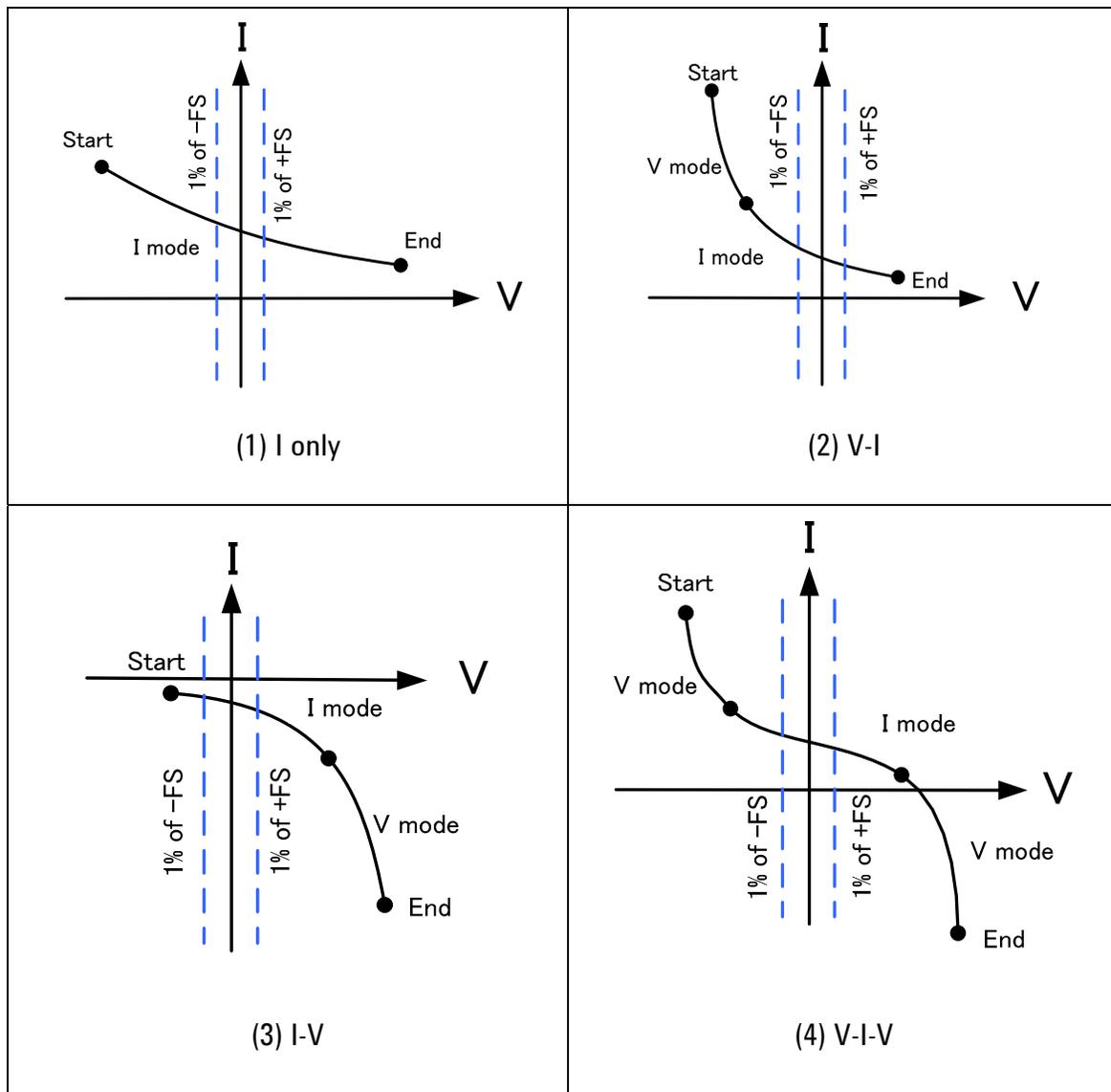


Figure 12 V/I-mode when the primary source mode is current

Bad examples

Bad examples of V/I mode combination are shown in Figure 13.

(a) is a bad example for the combination shown in Figure 11 (3). The positive current is not allowed for the I mode, also the negative resistance (R_s or R_{sh}) is not allowed.

(b) is a bad example for the combination shown in Figure 12 (3). The V mode cannot be used within $\pm 1\%$ of full scale of the voltage range (or $\pm 10\%$ for the 200 mV range).

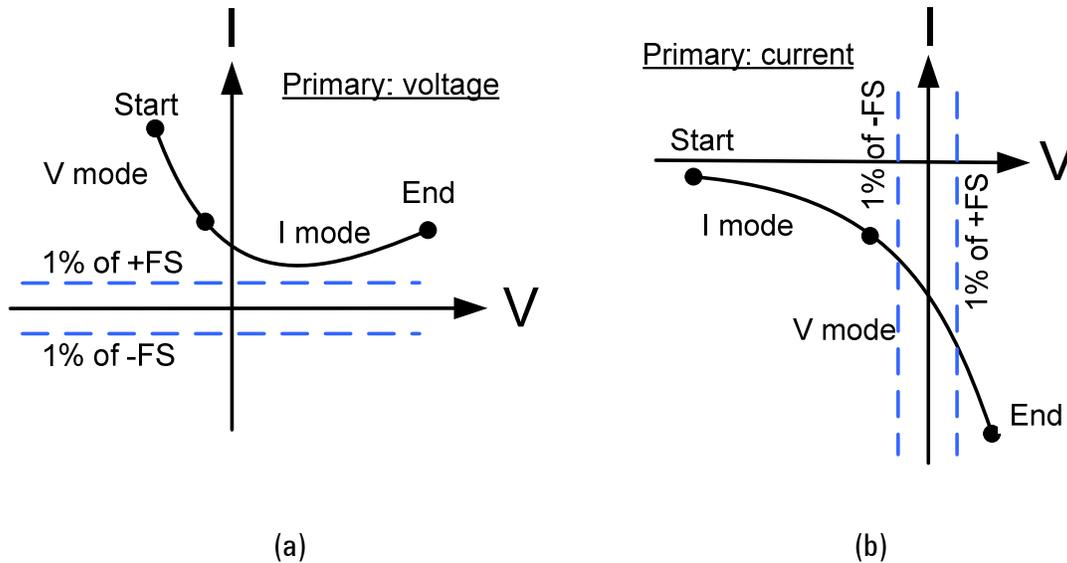


Figure 13 Bad examples of V/I mode combination

Available R_s/R_{sh} values

See the document *Using Constant Mode*, publication number B2960-90041. The available R_s/R_{sh} values for the constant mode are also effective for the VI emulation mode. However, the negative resistance/conductance is not allowed for the VI emulation mode. So, the I-V characteristics always shows the curve from upper left to lower right as shown in Figure 11 and Figure 12. Also, the shape of I-V characteristics is limited due to the internal configuration as described above.

Notes

- The channel can be used for the DC emulation. It cannot respond to the fast transition of the load voltage or current.
- The channel can be used between the minimum value and the maximum value set to the emulation table. Do not apply voltage/current outside this range to the channel.
- The channel automatically selects the voltage and current ranges according to the emulation table setting. They are the smallest range that covers all voltage values or all current values. Those ranges are fixed during source output.
- The channel output stability can be improved by increasing the time constant of the output filter. However, this increases the response time.
- Do not connect the other B2961A/B2962A channel in series or parallel to the channel which uses the programmable output resistance function.
- When the channel works as a voltage source with high R_s and high current range, undesirable noise increases. This fundamental noise cannot be eliminated but can be reduced by increasing the time constant of the output filter because it cuts off the noise.
- For the setting error of R_s/R_{sh} , see the document “Using Constant Mode”, publication number B2960-90041.
- If you confirm the emulation result, use voltage source and current meter (VSIM) for the high impedance area (I mode) of the VI emulation and use current source and volt meter (ISVM) for the low impedance area (V mode). Most suitable instrument should be used for each measurement. Otherwise, the emulation result cannot be monitored correctly. For example, as shown in the VSIM line of Figure 14, the low impedance area cannot be monitored correctly by VSIM. Similarly, the high impedance area cannot be monitored correctly by ISVM.

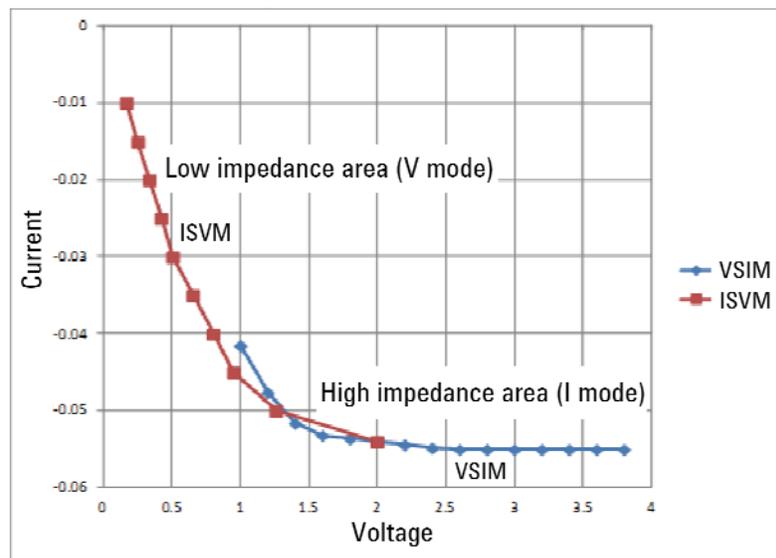


Figure 14 VI emulation result measured by external instruments

3. Application

Agilent B2961A/B2962A Power Source can be a voltage source or a current source which enables wide range voltage/current output and advanced test and evaluation. And its programmable output resistance function is effective for several applications such as error compensation, source emulation, resistance emulation, and so on. This section introduces the following examples for using this function.

- To emulate an I/O driver circuit of logic IC
- To emulate a solar cell

To emulate an I/O driver circuit of logic IC

Introduction

I-V characteristics (I_{OH} : Logic-High level output current, I_{OL} : Logic-Low level input current) of a logic IC driver circuit are shown in Figure 15. They are typical characteristics which you can obtain from an IC data sheet or an IBIS (Input/Output Buffer Information Specification) model file if available. As shown in the graph, the output resistance of the driver circuit is not linear. And the characteristics are affected by the operating conditions such as applied voltage, temperature, and so on.

For designing a device, a module, or a circuit which receives the driver output, it is important to check its operation with several variations of driver outputs. However it is difficult and inefficient to prepare several driver circuits or to realize several operating conditions. Then, the VI emulation by using the B2961A/B2962A is an effective solution to obtain the various outputs easily.

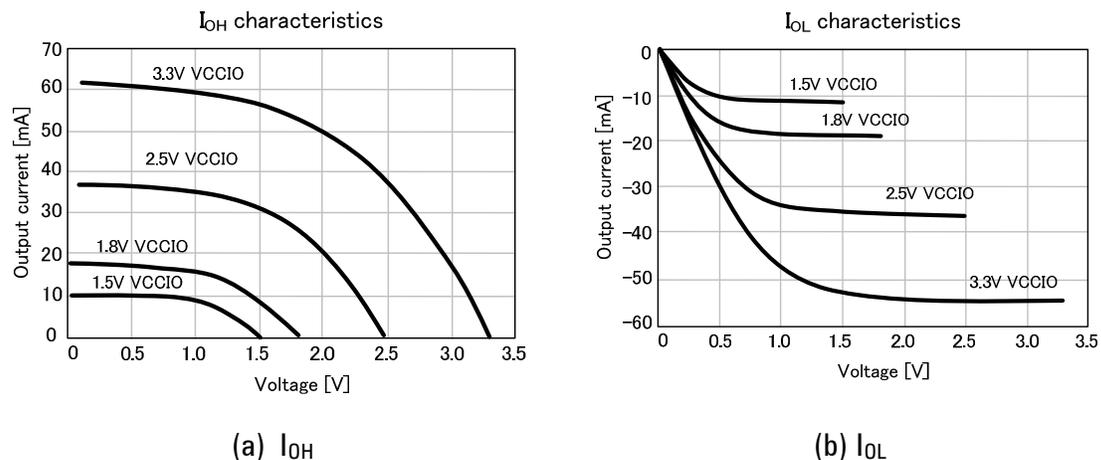


Figure 15 I-V characteristics of a driver circuit (I_{OH} and I_{OL}) for various power supply (VCCIO)

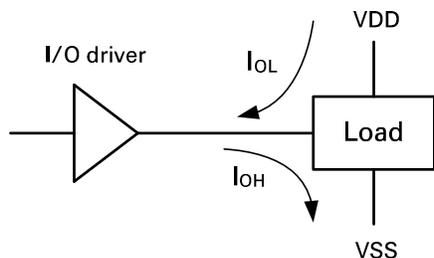


Figure 16 Current flow between I/O driver and load

Emulation example

The following example is for the I_{OH} emulation of 3.3 volts VCCIO. The settings of the B2961A/B2962A are shown below. For this emulation, the primary source mode must be voltage because the shape is similar to the pattern of the quadrant-1 shown in Figure 5 (a).

- Primary source mode (B2961A/B2962A front panel Mode setting): voltage (V)
- V and I source values (in emulation table): See Voltage and Current columns in Figure 17.
- V/I mode (in emulation table): See Mode column in Figure 17.

Figure 17 shows the setup image when the VI Emulation Sample Program is used. The program is available from Agilent B2900 web site (<http://www.agilent.com/find/b2900a>). This program automatically calculates the output resistance and conductance, and displays the I-V characteristics.

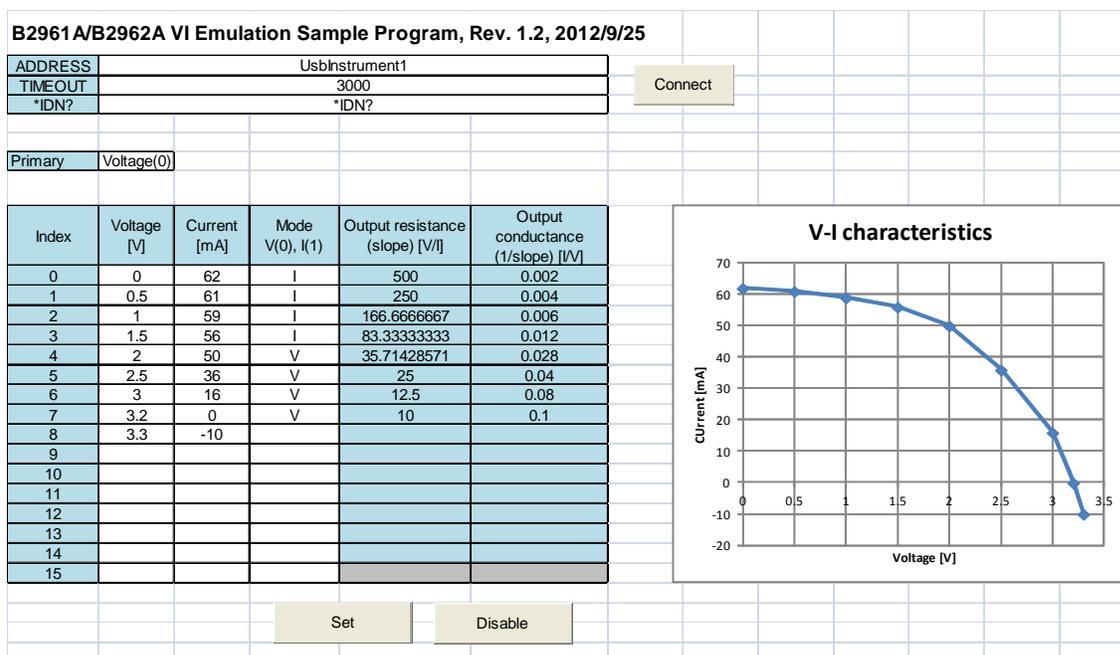


Figure 17 B2961A/B2962A VI Emulation Sample Program settings for I_{OH} emulation

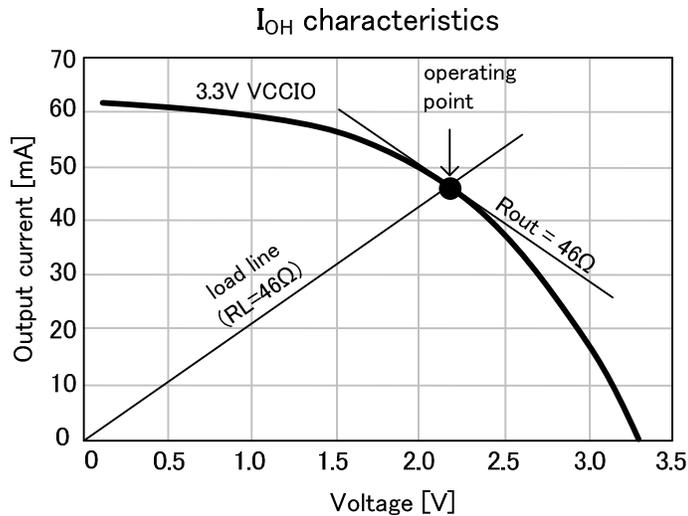


Figure 18 Load line for selecting V/I mode

The V and I source values can be selected by reading the values on the curve shown in Figure 18. This example assumes that the load does not have internal bias and the load line starts from the origin.

The V/I mode should be selected after finding the point which satisfies $R_{Load} = R_s = R_{sh}$. According to Figure 18, this point is on the 46Ω load line. So, I mode should be used for $R_{Load} \leq 46\Omega$, and V mode should be used for $R_{Load} \geq 46\Omega$. Depending on the emulation result, you may need to adjust the setting.

Figure 19 shows the emulation result. The result can be monitored by using an external instrument. Then use voltage source and current meter (VSIM) for the high impedance area (I mode) of the VI emulation, and use current source and volt meter (ISVM) for the low impedance area (V mode).

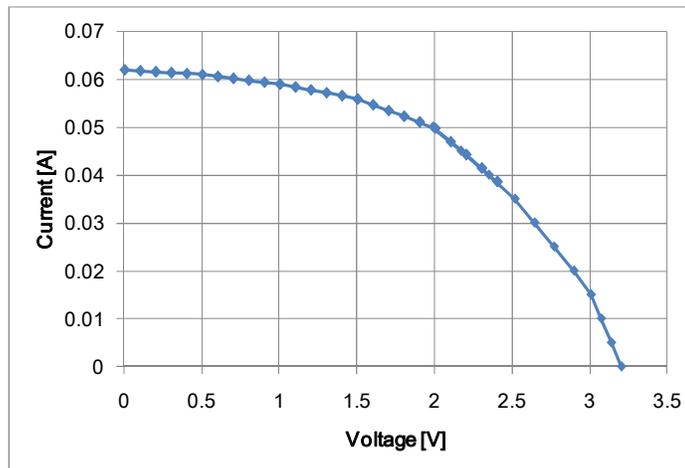


Figure 19 IOH characteristics emulation result measured by external instruments

The following example is for the I_{OL} emulation of the same device. For this emulation, the primary source mode must be voltage because the shape is similar to the pattern of the quadrant-4 shown in Figure 5 (a).

- Primary source mode (B2961A/B2962A front panel Mode setting): voltage (V)
- V and I source values (in emulation table): See Voltage and Current columns in Figure 20.
- V/I mode (in emulation table): See Mode column in Figure 20.

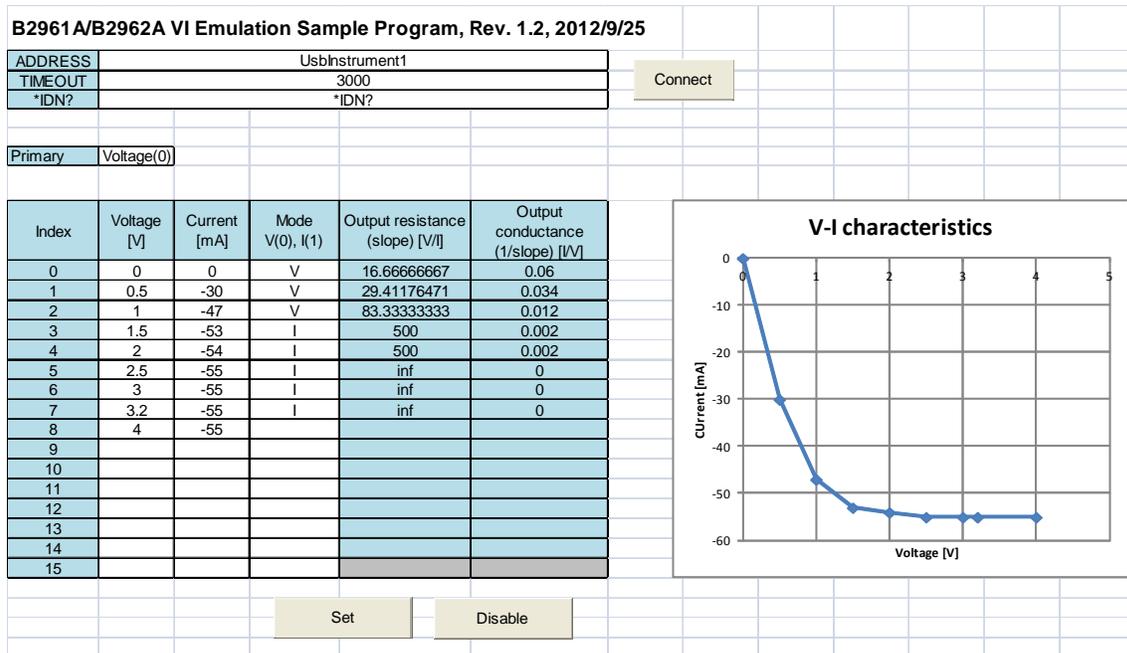


Figure 20 B2961A/B2962A VI Emulation Sample Program settings for I_{OL} emulation

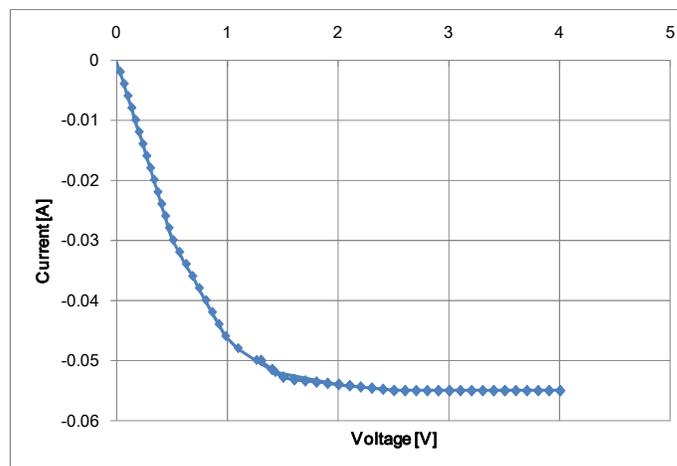


Figure 21 I_{OL} characteristics emulation result measured by external instruments

As described above, two characteristics of a logic IC driver circuit are emulated easily by using the B2961A/B2962A. Special setup for the VI emulation is the emulation table only. Just by filling the table with appropriate V and I values, the B2961A/B2962A can emulate various DC output characteristics.

To emulate a solar cell

Introduction

Solar cell is attractive device as it is a sustainable energy source, and has been used for wide applications, for example, portable devices or remote sensing units, and such. Output I-V characteristics of solar cell is affected by the operating conditions such as light power, temperature, and so on. Aging and the stain on the surface also affect the performance.

For designing a device, a module, or a circuit which uses solar cell as power source, it is important to check its operation in several operating conditions. However it is difficult and inefficient to use actual solar cell or to realize several operating conditions. Then, the VI emulation is an effective solution to obtain the various power conditions easily.

Emulation example

Simplified equivalent circuit of solar cell is shown in Figure 22. It consists of the ideal current source, a diode, a shunt resistor (R_{sh}), and a series resistor (R_s) which contains internal series resistor and external wire resistance. Generally, R_{sh} causes leakage current, and R_s causes voltage drop depending on load current.

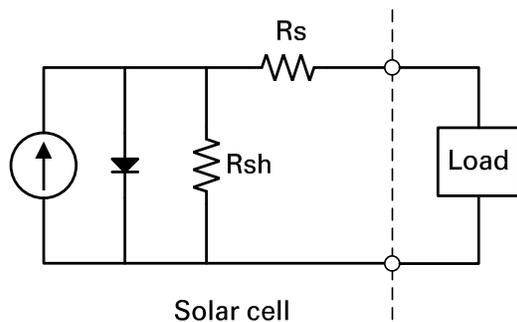


Figure 22 Simplified equivalent circuit of solar cell

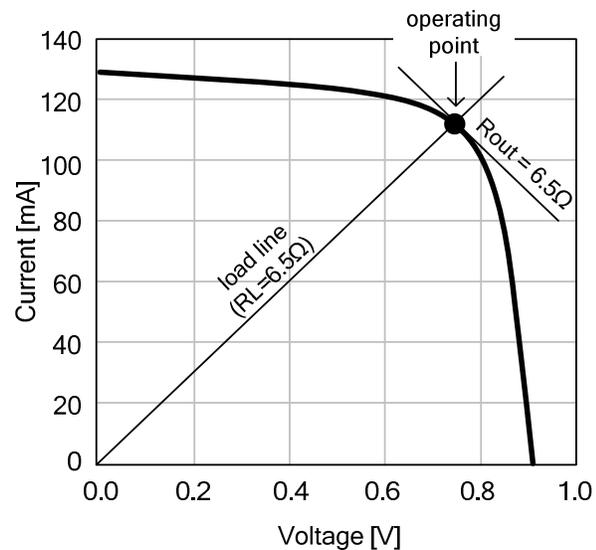


Figure 23 I-V characteristics of solar cell to emulate

Figure 23 shows I-V characteristics of a solar cell. This output characteristics can be emulated by the following setup.

- Primary source mode (B2961A/B2962A front panel Mode setting): voltage (V)
- V and I source values (in emulation table): See Voltage and Current columns in Figure 24.
- V/I mode (in emulation table): See Mode column in Figure 24.

The primary source mode must be voltage because the shape is similar to the pattern of the quadrant-1 shown in Figure 5 (a).

The V and I source values can be selected by reading the curve shown in Figure 23. The values can be also selected from calculation or simulation like SPICE for emulating the output characteristics in the several temperature conditions, various darkness conditions, and such.

The V/I mode should be selected after finding the point which satisfies $R_{Load} = R_s = R_{sh}$. According to Figure 23, this point is on the 6.5Ω load line. So, I mode should be used for $R_{Load} \leq 6.5 \Omega$, and V mode should be used for $R_{Load} \geq 6.5 \Omega$. Emulation result is shown in Figure 25. Depending on the emulation result, you may need to adjust the setting.

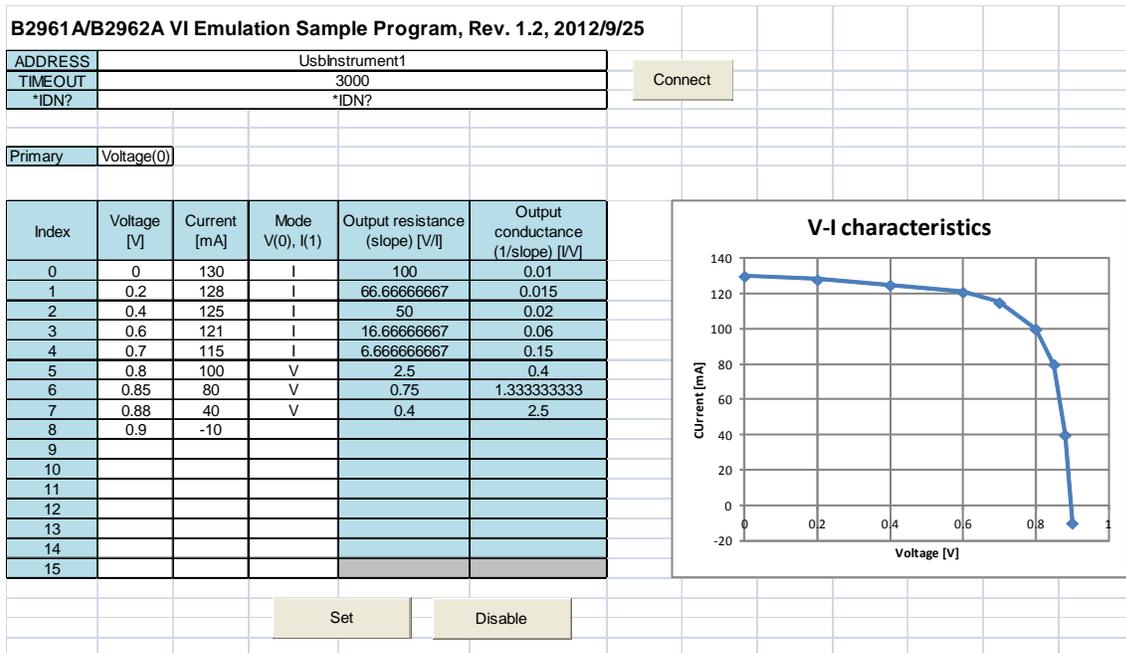


Figure 24 B2961A/B2962A VI Emulation Sample Program settings for solar cell

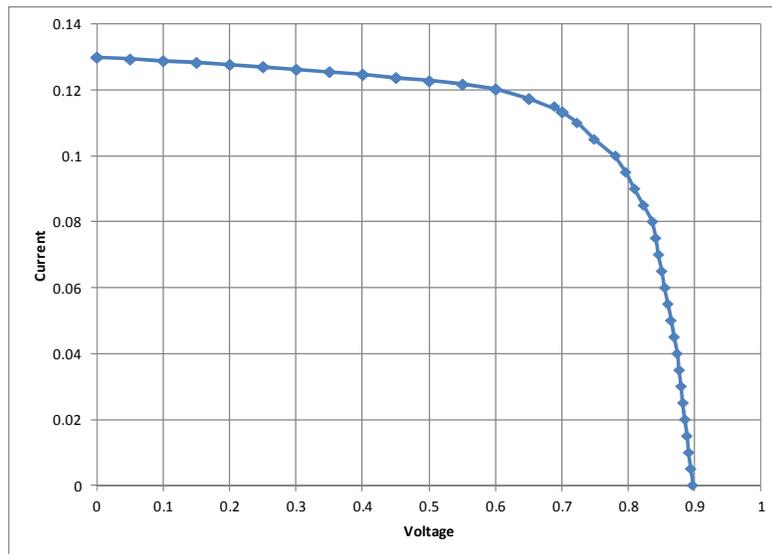


Figure 25 Solar cell I-V characteristics emulation result measured by external instruments