Keysight Technologies

Photodiode Test Using the Keysight B2980A Series

B2981A/83A Femto/Picoammeter
B2985A/87A Electrometer/High Resistance Meter

Technical Overview

KEYSIGHT TECHNOLOGIES

Introduction

A photodiode (PD) is a semiconductor device that converts light into current. When the PD is reverse-biased, a current is generated as the PD absorbs photons. The PD also produces a small amount of current when no light is present; this is known as dark current. Since the output current is directly proportional to the light intensity applied to the PD junction, it can be used to detect small quantities of light. This makes PDs useful in a wide range of applications such as optical communication, light detection, and consumer electronics.

When the PD is reverse-biased, the output current consists of dark current (no light) and photocurrent (caused by light). Dark current is a small leakage current induced by applied voltage. Photocurrent is typically constant as a function of applied voltage. The dark current is caused by thermal leakage in the PN junction, so it is frequently characterized as a function of temperature. The photocurrent and dark current measurements should be made with an instrument that can sweep voltage and measure current over a wide range (such as an electrometer or source measure unit).

Avalanche photodiodes (APDs) are high-speed photodiodes with high sensitivity, and they exhibit internal current gain when a large reverse bias is applied. By varying the magnitude of the reverse bias voltage, the gain of the APD can be controlled. In general, a larger reverse bias voltage results in higher gain. However, APDs can require high voltages (many hundreds of volts) to fully characterize them.

APDs are used in a variety of applications requiring high sensitivity to light (such as fiber optic telecommunication and laser rangefinders). Common APD electrical parameters include responsivity, breakdown voltage, and reverse bias current. The current rating for a typical APD under reverse bias is 100 µA to 10 mA, while the dark current can be as low as 1 pA or less. The maximum reverse bias voltage varies with the material from which the APD is fabricated, and for Si devices it can be as high as 500 V.

The Keysight Technologies, Inc. B2980A Series Femto/Picoammeters and Electrometer/High Resistance Meters are the world's only graphical picoammeters and electrometers that can confidently measure down to 0.01 fA and up to 10 PΩ (10^{16} Ω). These capabilities give them the ability to evaluate a variety of PDs. The B2980A Series' ammeter provides 0.01 fA current resolution and multiple current measurement ranges (from 2 pA to 20 mA), which can meet all existing and future PD low-current measurement needs. The voltage source of the B2980A Series' electrometers has 1,000 V voltage sourcing capability that can support PD evaluation requiring high voltage (such as APDs). Unlike conventional picoammeters and electrometers, the B2980A series possesses a 4.3" color LCD-based graphical user interface (GUI) that provides multiple options for viewing data. In addition to numeric format, data can also be viewed as a graph, as a histogram and as a trend chart. These unique front-panel capabilities facilitate the capture of transient behavior and provide the ability to make quick statistical analyses without the need for a PC. The B2980A Series also has external trigger in and out terminals that allow it to receive and send trigger signals from and to external instruments. This makes it easy to synchronize the B2980A Series with other instruments to make light-current-voltage (L-I-V) sweep tests to determine the operating characteristics of a laser diode (LD).

This technical overview shows how to use the B2985A/87A to evaluate PD characteristics and explains how to synchronize the B2980A Series with other instruments using the example of an L-I-V sweep test on a LD.

Photodiode Characterization Example

This section explains how to perform PD dark current measurements using the B2985A/87A.

Test System

Figure 1 shows the circuit diagram to evaluate PD characteristics using the B2985A/87A Electrometer/High Resistance Meter. The B2985A/87A's voltage source high terminal is connected to the cathode of the PD to supply a reverse bias voltage, and its ammeter is connected to the anode of the PD to measure the PD current. The voltage source's low terminal and the ammeter common are connected together internally.

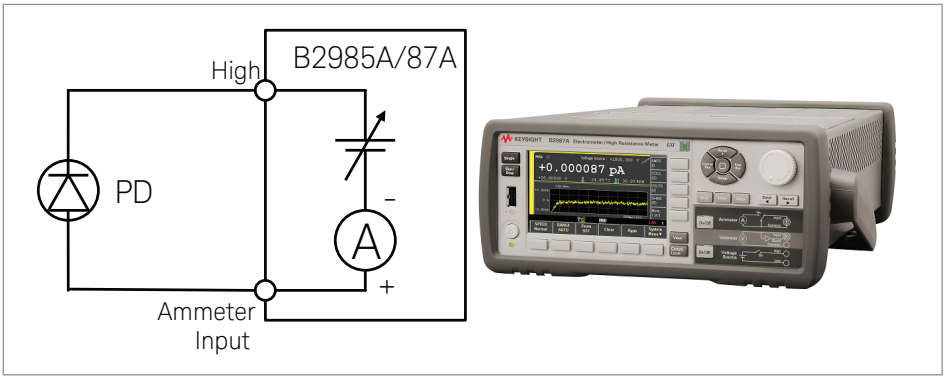


Figure 1. Circuit diagram to evaluate photodiode characteristics

Since the B2985A/87A's voltage source has the capability to sweep voltage while its ammeter synchronously measures current, the PD's current – voltage (IV) characteristics can easily be obtained. In addition, the B2985A/87A's ability to display the results as an X-Y graph permits quick examination of the results.

The following example will show how to make a silicon photodiode dark current measurement. The key measurement parameters are summarized in Table 1. The PD current is measured by the B2985A/87A's ammeter as the B2985A/87A's voltage source applies a reverse-bias voltage. The voltage is swept from 10 mV to 5 V in 10 mV steps. A fixed range of 20 pA range is used to measure the PD current since the maximum expected current is several picoamps, and using the 20 pA range provides better accuracy. The measurement trigger delay time is set at 1 s to give the measured current sufficient time to stabilize.

Of course, since the dark current measurement has to be made without light the PD is tested in an enclosed test fixture.

Table 1. Photodiode characterization key measurement conditions

B2985A/87A

Parameters		Values
PD Voltage Swept	Start	10 mV
	Stop	5 V
	Points	500
PD Current	Range	20 pA Fixed
Aperture Time (SPEED)		Normal
Trigger	Source	AUTO
	Count	500
	Measure Delay	1 s
	Period	1.2 s

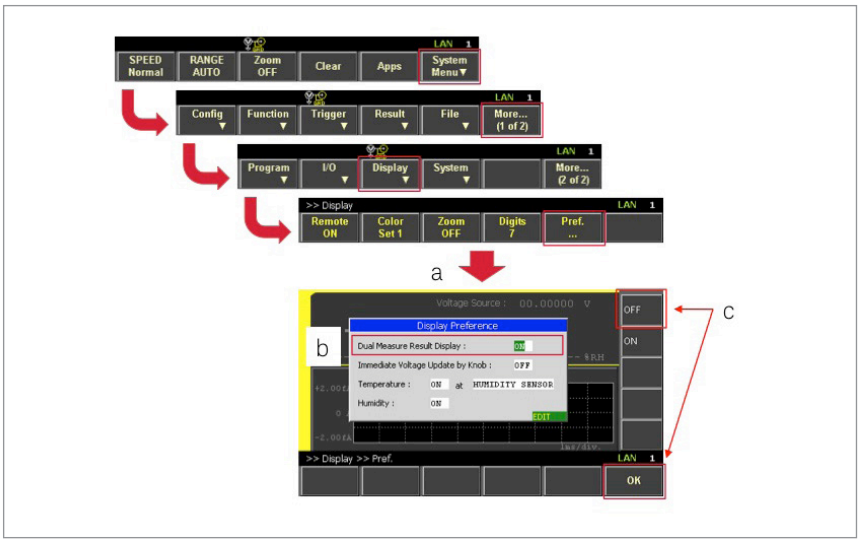
The following instructions describe how to set up the B2985A/87A to perform PD dark current measurements on the instrument front panel.

A file containing the setup used in the example can be downloaded at the following link: **www.keysight.com/find/SensitiveMeasurement**

A sample VBA program using SCPI commands to make this measurement is also available at the above link.

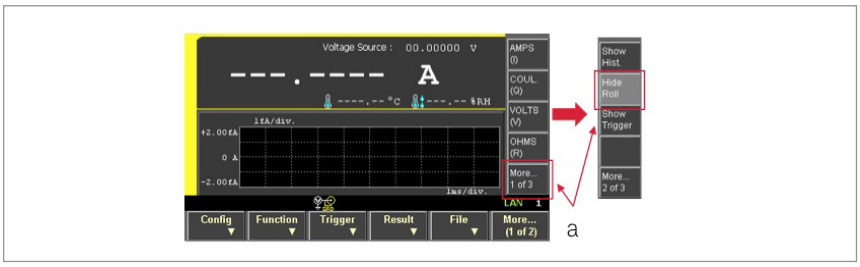
Setting up the B2985A/87A from its front panel

1. Set “Dual Measure Result Display” off to make the instrument measure only current.
   a. Open the Display Preference dialog by pressing the System Menu▼, More... (1 of 2), Display ▼, Pref. ... function keys.
   b. Press the knob to edit “Dual Measure Result Display”. After that, the field pointer is highlighted in green (EDIT).
   c. Press OFF, and then press OK to apply the settings.

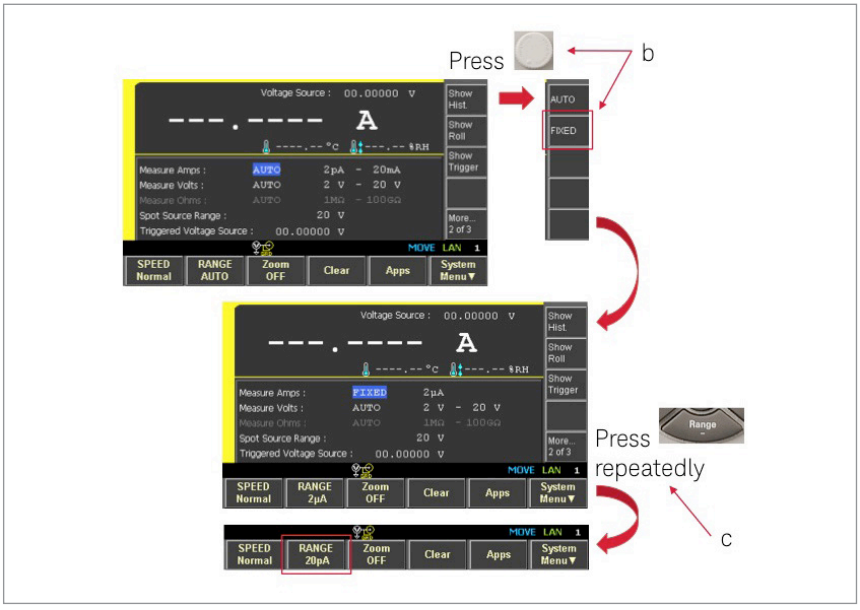


Setting up the B2985A/87A from its front panel (continued)

2. Select the current measurement range operation and set the current measurement range.
   a. Press More... 1 of 3, and then press Hide Roll to show the Range Parameters.



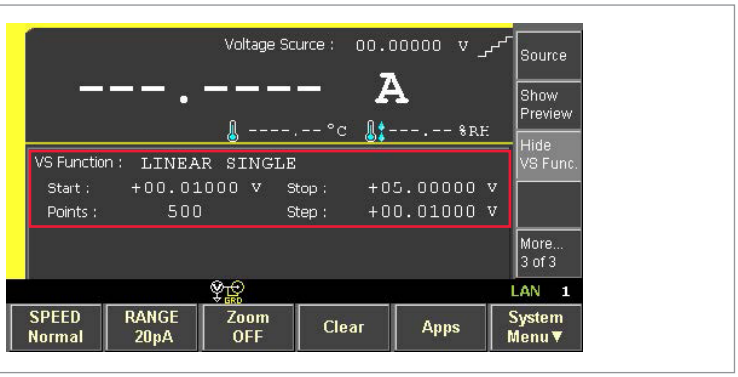
   b. Press and press FIXED to set the current measurement range operation to "FIXED".
   c. Press Range repeatedly until RANGE 20pA is displayed to set the current measurement range to 20 pA range.



Setting up the B2985A/87A from its front panel (continued)

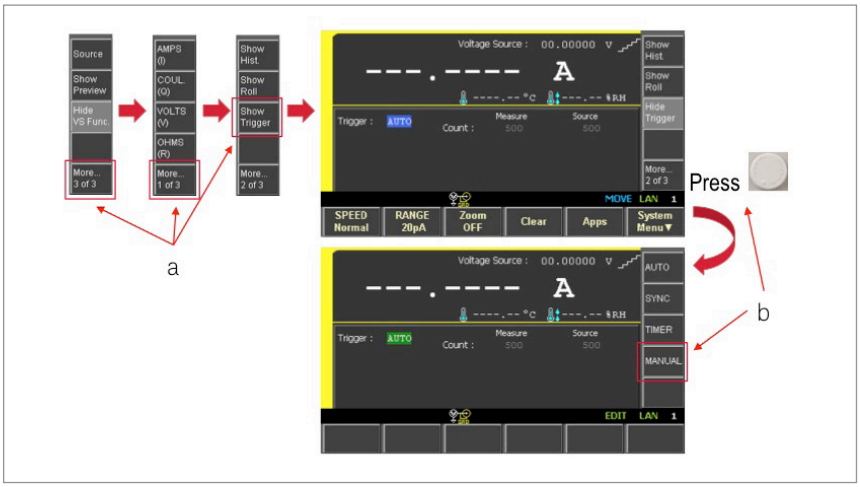
3. Set the Sweep Parameters to make the instrument perform a voltage sweep.
   a. Press More... 2 of 3, and then press Show VS Func. to show Sweep Parameters.
   b. Press and press LINEAR SINGLE to turn on Single Linear Sweep Source Mode.

   c. Rotate to select Sweep Parameters and fill in the values as shown below. Use the arrow keys to move to the digit you want to edit. (Start: 10 mV, Stop: 5 V, Points: 500)

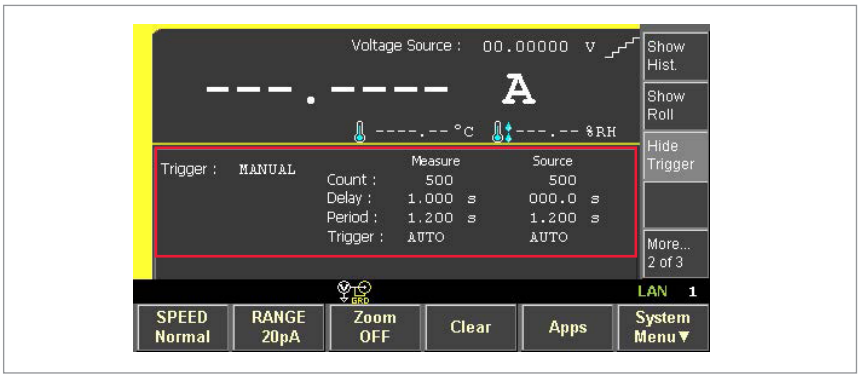


Setting up the B2985A/87A from its front panel (continued)

4. Set the Trigger Parameters to configure the Measurement Delay Time.
   a. Press More... 3 of 3, More... 1 of 3, and then press Show Trigger to show the Trigger Parameters.
   b. Press the knob and press MANUAL to set the Trigger Parameters.



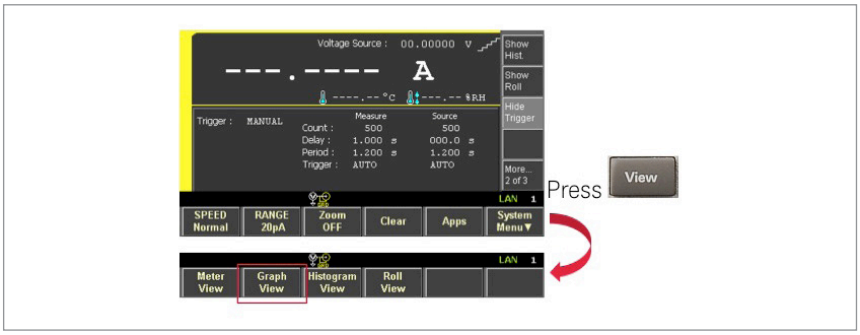
   c. Rotate the knob to select the Trigger Parameters and fill in the values as shown below. (Count: 500, Measure Delay: 1 s, Period: 1.2 s)



Setting up the B2985A/87A from its front panel (continued)

5. Select the Graph View and configure it to show results graphically.

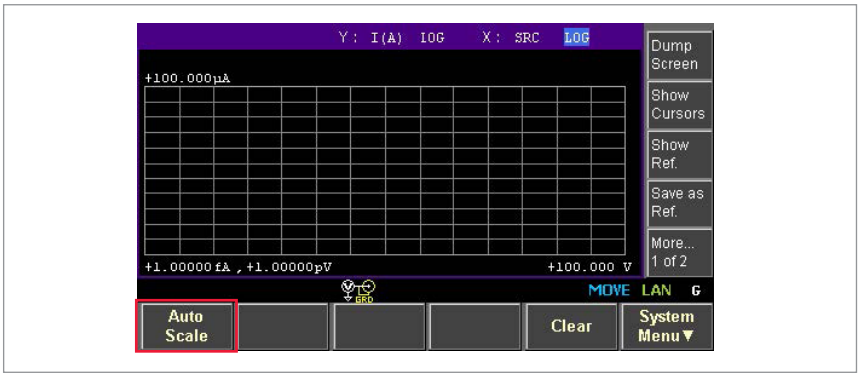
   a. Press View to show the function keys for View Modes, and then press Graph View to show the Graph View.



   b. Rotate and press to show Y-axis graph scaling, and then press LOG to set it to LOG scale.

   c. Rotate and press to show X-axis graph scaling, and then press LOG to set it to LOG scale.

   The Auto Scale function is available both during and after measurement in Graph View.



Setting up the B2985A/87A from its front panel (continued)

6. Enable the Voltage Source and Ammeter.
   a. Press Voltage Source 

to enable the Voltage Source.
   b. Press Ammeter 

to enable the Ammeter.

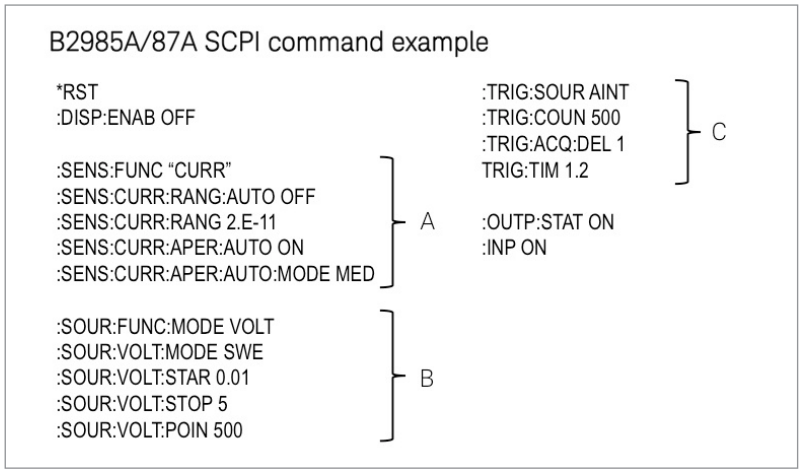
Why is a measurement delay time required?

In general, measurement paths have stray impedance that can cause leakage currents and dielectric absorption when a voltage is applied. To obtain accurate results it is necessary to wait for these transients to die away before starting measurements (especially in the case of ultra-low current measurements). The required wait time for a given measurement depends on the magnitude of the applied voltage step. Larger voltage steps require longer wait times.

Controlling the B2985A/87A using SCPI commands

If you prefer to control the B2985A/87A remotely using SCPI commands, then the following material explains how to do this.

The series of commands shown in group “A” configure measurement parameters such as measurement auto-ranging (turned off), measurement range, and aperture time, and they should be sent first. Next the series of commands shown in group “B” should be sent to set up the voltage source. Finally, the series of the commands shown in group “C” should be sent to set up the B2985A/87A’s trigger parameters.



Performing photodiode dark current measurements

After configuring the instrument, perform the following procedures to execute PD dark current measurements.

If you are using the front panel, trigger the B2985A/87A to start sweeping the reverse-bias voltage to the PD by pressing Single.

If you are controlling the instrument remotely using SCPI commands, then send the ":INIT (@1)" command to the instrument to start the dark current measurement.

The measurement results can be displayed on the B2985A/87A's graphical user interface as shown in Figure 2. The Graph View function allows you examine the measurement results quickly.

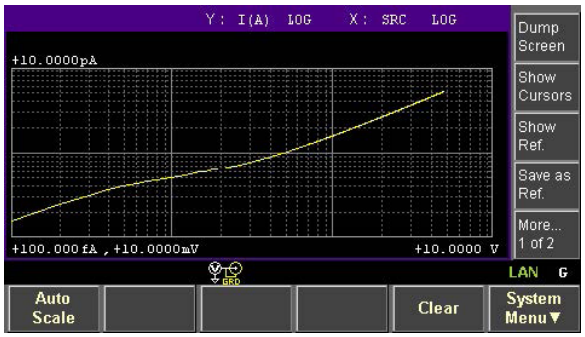


Figure 2. Photodiode dark current measurement results

The APD dark current measurements are performed by the same procedures as shown in Figure 3.

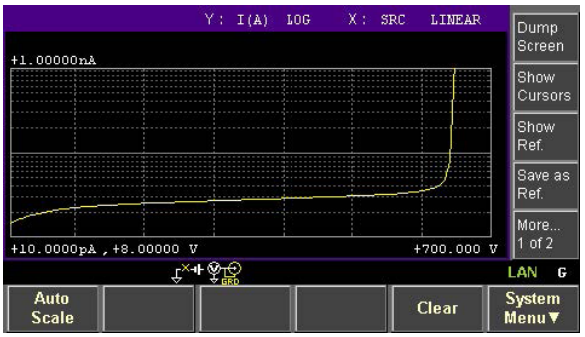


Figure 3. Avalanche photodiode dark current measurement results

L-I-V Test Example

This section explains how to synchronize the B2980A Series with other instruments using the example of a laser diode (LD) L-I-V sweep test using a photodiode (PD).

Test System

Figure 4 shows a system diagram example to evaluate the L-I-V characteristics of a LD using the B2900 Precision Instrument Family. The Keysight B2911A Precision Source/ Measure Unit (SMU) is used to apply drive current to the LD and to measure the LD's voltage. The B2911A can cover currents from 10 fA to 3 A (DC)/10.5 A (pulsed) and voltages from 100 nV to 210 V. The SMU has the capability to source and measure both positive and negative voltages and currents, so it can easily characterize the LD's DC parameters. Since the currents supplied to the LD can be quite large, a 4-wire connection (remote sensing) configuration is commonly used.

The B2985A/87A's ammeter input terminal is connected to the PD's anode and the B2985A/87A's voltage source high terminal is connected to the PD's cathode. Since the ammeter's and voltage source's low terminals are connected internally to the circuit common, the PD current can be measured by applying voltage to the PD from its voltage source.

In order to synchronize the B2985A/87A with the B2911A during the LD current sweep operation, a trigger signal is sent from the B2911A to the B2985A/87A. The N1294A-031 GPIO-BNC Trigger Adapter converts the B2911A's digital I/O output to BNC outputs. The N1294A-031 allows you to synchronize the triggering of the two units using an inexpensive coaxial cable.

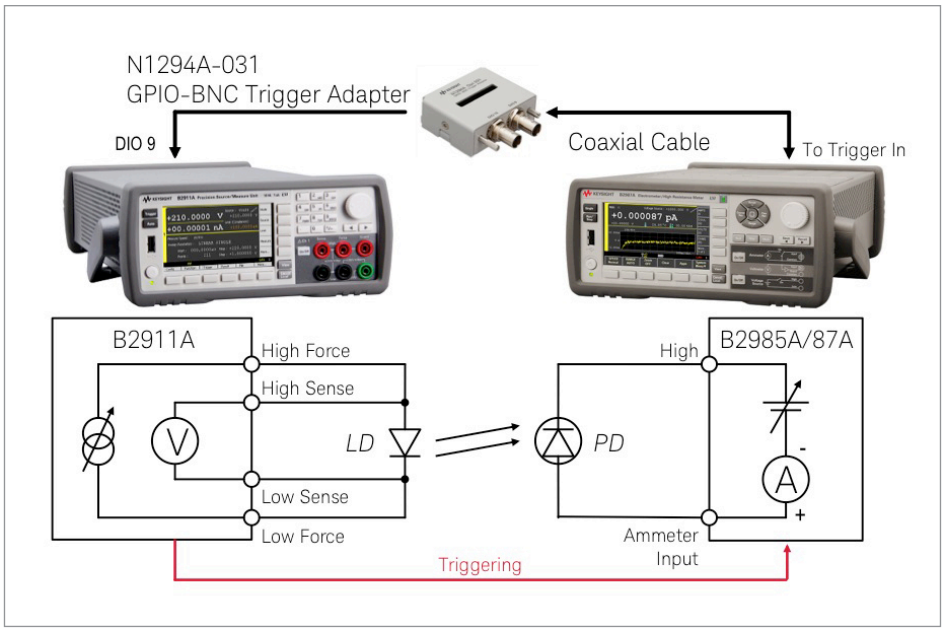


Figure 4. System configuration to evaluate the L-I-V Characteristics of a laser diode

Test System (continued)

A distributed feedback (DFB) laser diode is used in this example. The key measurement conditions are summarized in Table 2. The PD current is measured by the B2985A/87A as the drive current to the LD is swept from 0 A to 50 mA in 250 µA steps by the B2911A. In order to step currents to the LD at regular intervals, timed triggering is selected, the trigger period is set to 500 µsec and fixed measurement ranging is used. Since laser diode characteristics can be affected by self-heating, for accurate results it is essential to carefully control the LD measurement time and make it as short as possible. In this example a 500 µs trigger period and 200 µs aperture time are used.

Table 2. Summary of measurement conditions for L-I-V Testing

B2911A

Parameters		Values
LD Current Swept	Start	0 mA
	Stop	50 mA
	Points	201
LD Voltage	Limit	2.5 V
Aperture Time (SPEED)		0.01 PLC
Trigger	Type	TIMER
	Count	201
	Measurement Delay	100 µsec
	Period	500 µsec
	Output	Digital I/O Port 9

B2985A/87A

Parameters		Values
PD Voltage Constant		0.1 V
LD Current Measurement Range		2 mA Fixed
Aperture Time (SPEED)		0.01 PLC
Trigger	Type	Manual
	Count	201
	Measurement Delay	100 µsec
	Source	TRIGGER IN

A trigger signal is sent from the B2911A's digital I/O port 9 to the B2985A/87A's BNC trigger-in terminal immediately after each B2911A current step completes as shown in Figure 5.

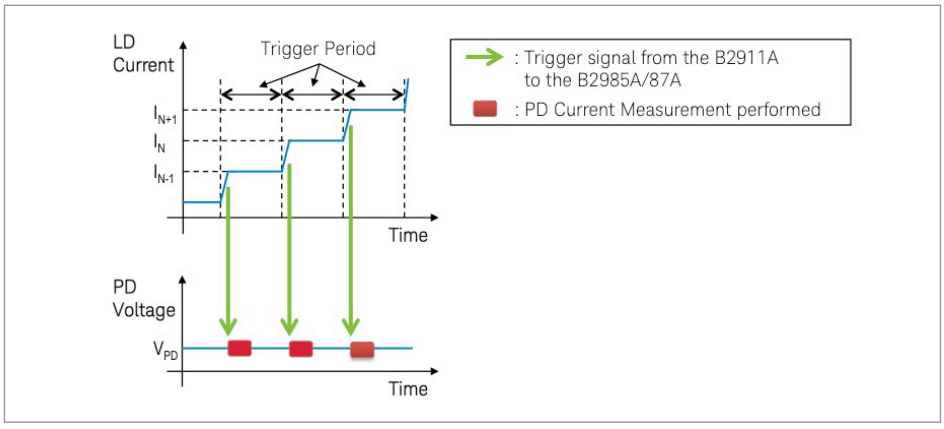


Figure 5. Triggering the B2985A/87A from the B2911A

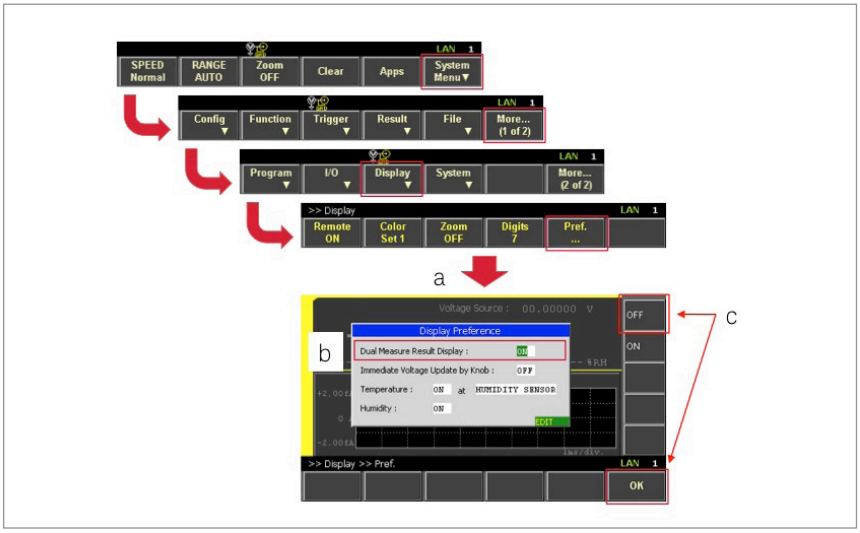
The following example describes how to set up the B2985A/87A and the B2911A to perform LIV testing on a LD.

The setup used in the example can be downloaded from the following link:
www.keysight.com/find/SensitiveMeasurement

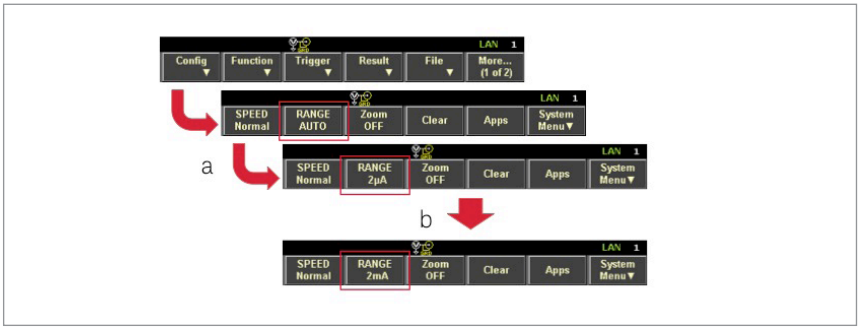
A VBA sample program using SCPI commands is also available at the link above.

Setting up the B2985A/87A from its front panel

1. Set “Dual Measure Result Display” off to make the instrument measure only current (if this has not already been done).
   a. Open the Display Preference dialog by pressing the System Menu▼, More... (1 of 2), Display ▼, Pref. ... function keys.
   b. Press  to edit “Dual Measure Result Display”. The field pointer should then be highlighted in green (EDIT).
   c. Press OFF, and then press OK to apply the settings.

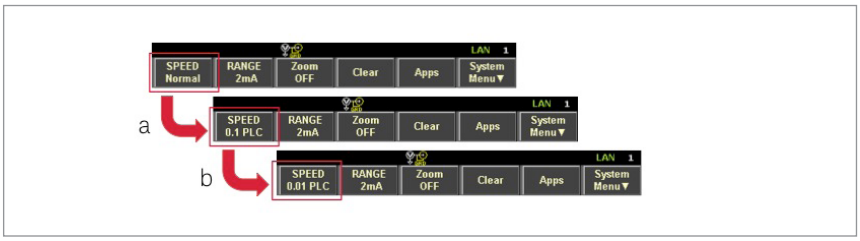


2. Set the current measurement range operation to FIXED.
   a. Press Cancel Local to show the Meter View function keys and then press RANGE AUTO to set the current measurement range operation to FIXED.
   b. Press Range repeatedly until RANGE 2mA is shown on the function key. Note: In this example the 2 mA range is best because the expected maximum current is around several hundred micro amps.



Setting up the B2985A/87A from its front panel (continued)

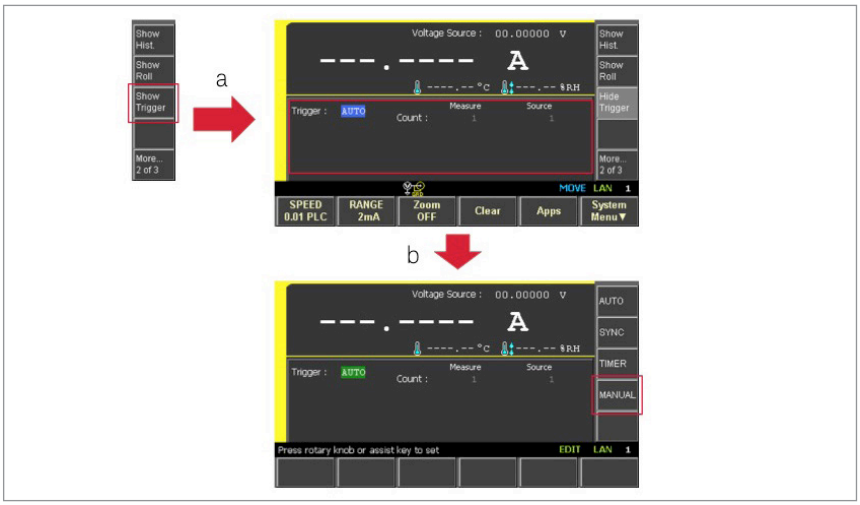
3. Select Manual Aperture Mode and set the Aperture Time
   a. Press SPEED Normal to select the manual aperture mode.
   b. Press Coarse Res to show SPEED 0.01 PLC, where PLC stands for Power Line Cycle. 0.01 PLC is the desired aperture time in this example, which is short enough to suppress self-heating affects and long enough to provide the required accuracy.



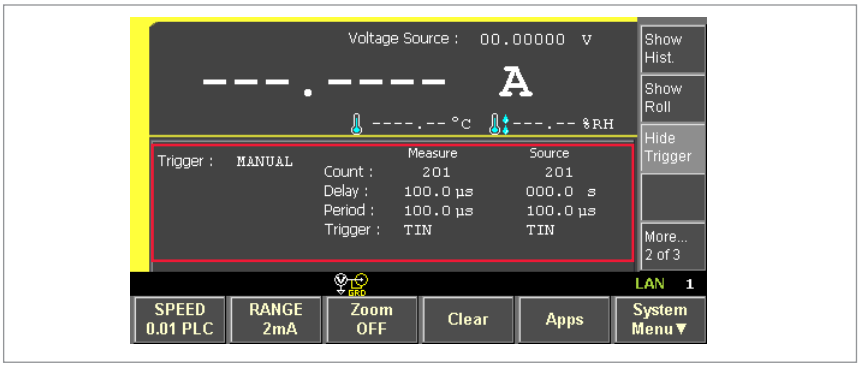
4. Set "Triggered Voltage Source" to the desired PD voltage.
   a. Hide the condensed Roll View by pressing More... 1 of 3, Hide Roll.
   b. Rotate to select "Triggered Voltage Source" and press to edit it.
   c. Set the voltage value to the desired PD voltage, which is 0.1 V in this example. Use the arrow keys to move to the digits that you want to edit.

Setting up the B2985A/87A from its front panel (continued)

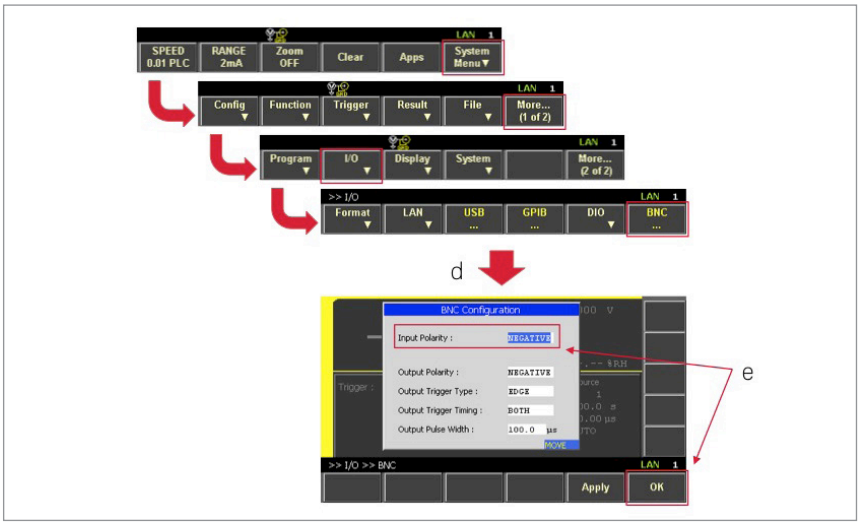
5. Set the Trigger Parameters to make the instrument perform measurements whenever it receives a trigger signal from the B2911A.
   a. Press Show Trigger to show Trigger Parameters.
   b. Press ○ and press MANUAL to select the manual trigger setting mode.



   c. Rotate ○ to select Trigger Parameters and fill in the values as shown below. (Measure Count: 201, Measure Delay: 100 µs, Measure Trigger: TIN)



   d. Press System Menu, More... (1 of 2), I/O, BNC ... to open the BNC Configuration dialog, which defines the trigger signal properties.
   e. Make sure that "Input Polarity" is set to "NEGATIVE" and then press OK. If not, set it to "NEGATIVE".



Setting up the B2985A/87A from its front panel (continued)

6. Enable the Voltage Source and Ammeter.
   a. Press Voltage Source 

to enable the Voltage Source.
   b. Press Ammeter 

to enable the Ammeter.

Controlling the B2985A/87A using SCPI commands

If you prefer to control the B2985A/87A remotely using SCPI remote commands, then the following material explains how to do this.

The series of commands shown in group “A” configure measurement parameters such as measurement range and aperture time. Next the series of commands shown in group “B” should be sent to set up the voltage source. Finally, the series of commands shown in group “C” should be sent to set up the B2985A/87A’s trigger parameters.

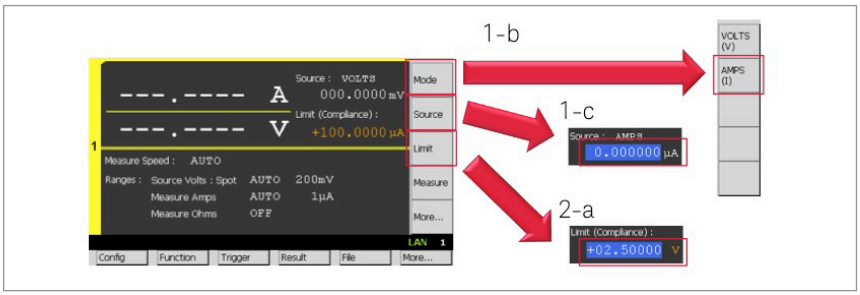
B2985A/87A SCPI command example

```
*RST
:DISP:ENAB OFF

:SENS:FUNC “CURR”
:SENS:CURR:RANG:AUTO OFF
:SENS:CURR:RANG 0.002
:SENS:CURR:NPLC:AUTO OFF
:SENS:CURR:NPLC 2E-4

:SOUR:FUNC:MODE VOLT
:SOUR:VOLT:TRIG 0.1

:TRIG:SOUR TIN
:TRIG:COUN 201
:TRIG:ACQ:DEL 1E-4
:SYST:TIN:POL NEG

:OUTP:STAT ON
:INP:STAT ON
```

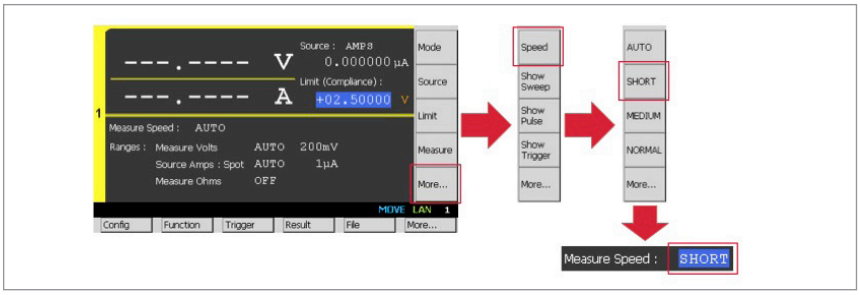
A, B, C

Set up the B2911A via front panel operation

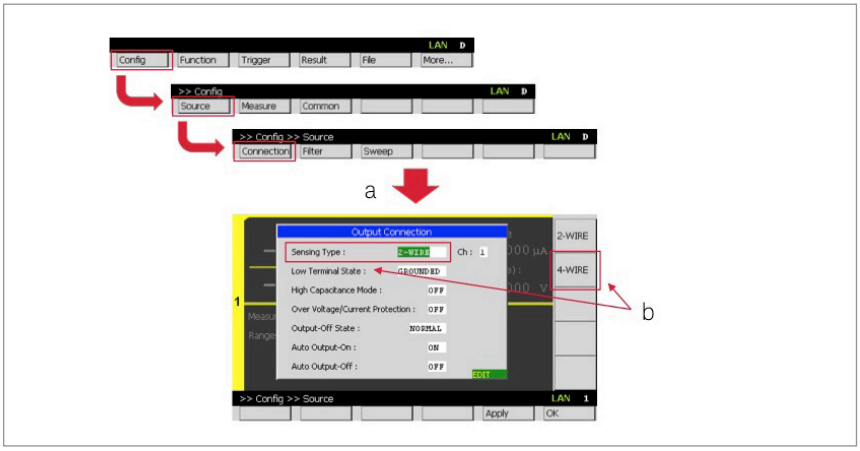
1. Set the Source Function to Current
   a. Press View repeatedly until Single View for Channel 1 is shown.
   b. Press Mode and then press AMPS (I) to set the Channel 1 Source Function to Current.
   c. Press Source and then set the Channel 1 Source Value to 0 A.
2. Set the Voltage Limit Value
   a. Press Limit and then set the Channel 1 Limit Value to 2.5 V as shown.



3. Set the Aperture Time
   a. Press More..., Speed and then press SHORT to set the Aperture Time to SHORT (0.01 PLC).



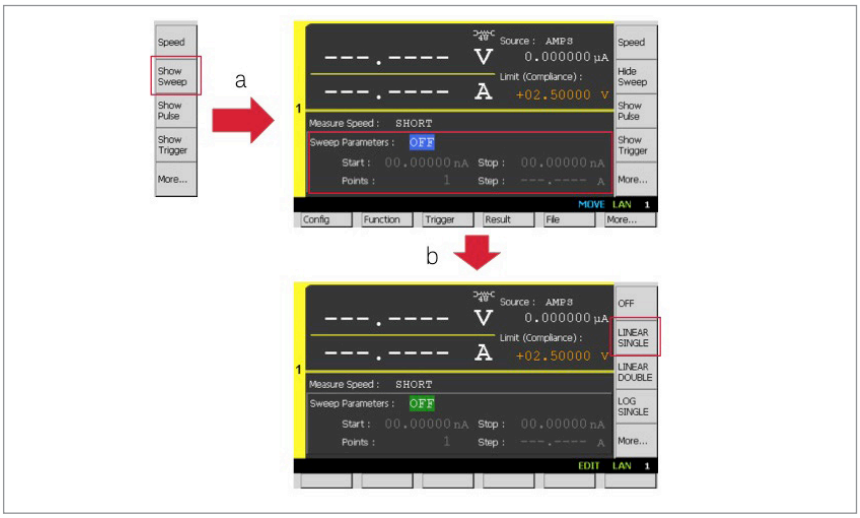
4. Enable remote sensing
   a. Press Config, Source, Connection to open the Output Connection dialog.
   b. Press to select Sensing Type and then press 4-WIRE to enable remote sensing.



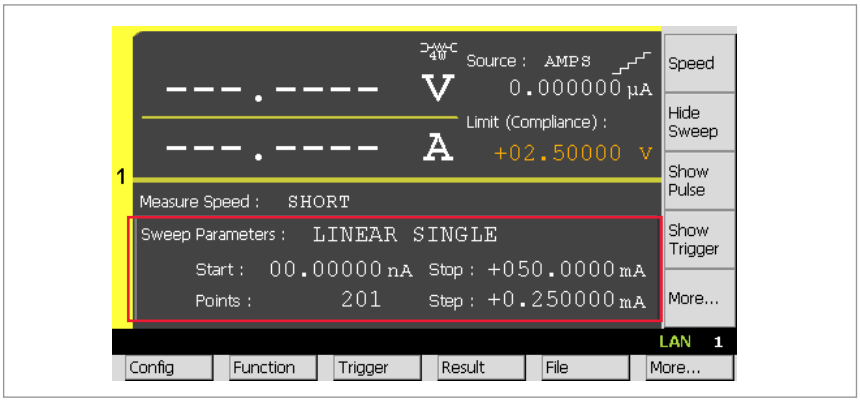
   c. Then press OK to apply the changes.

Set up the B2911A via front panel operation (continued)

5. Set up the Sweep Parameters to make the instrument perform a current sweep.
   a. Press Show Sweep to show the Sweep Parameters.
   b. Press and press LINEAR SINGLE to turn on Single Linear Sweep Source Mode.



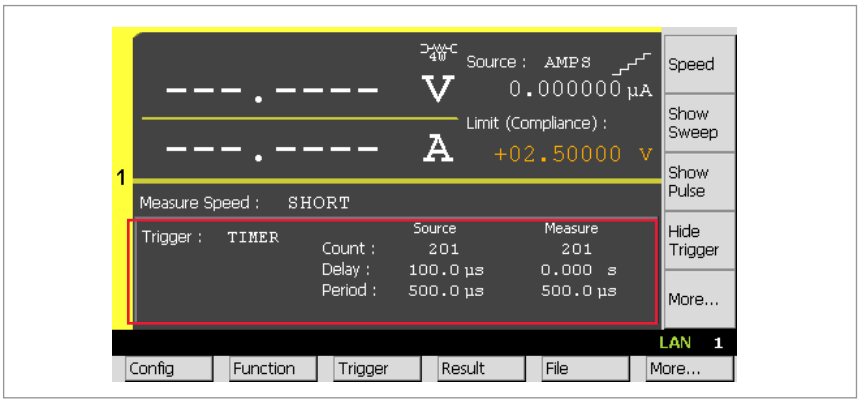
   c. Rotate to select Sweep Parameters and fill in the values as shown below. (Start: 0 A, Stop: 50 mA, Points: 201)



Set up the B2911A via front panel operation (continued)

6. Set the Trigger Parameters to make the instrument step current at regular intervals.
   a. Press Show Trigger to show the Trigger Parameters.
   b. Press and press TIMER to select Timer Trigger Setting Mode.

   c. Rotate to select Trigger Parameters and fill in the values as shown below. (Measure Count: 201, Source Count: 201, Measure Delay: 100 µs, Measure Period: 500 µs, Source Count: 500 µs)

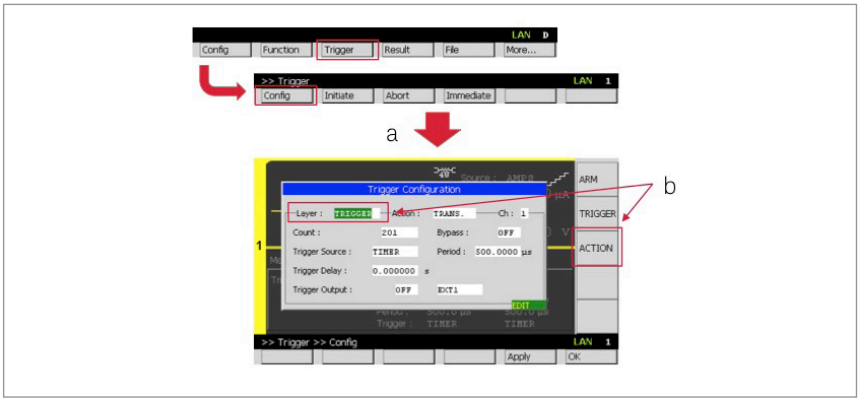


Set up the B2911A via front panel operation (continued)

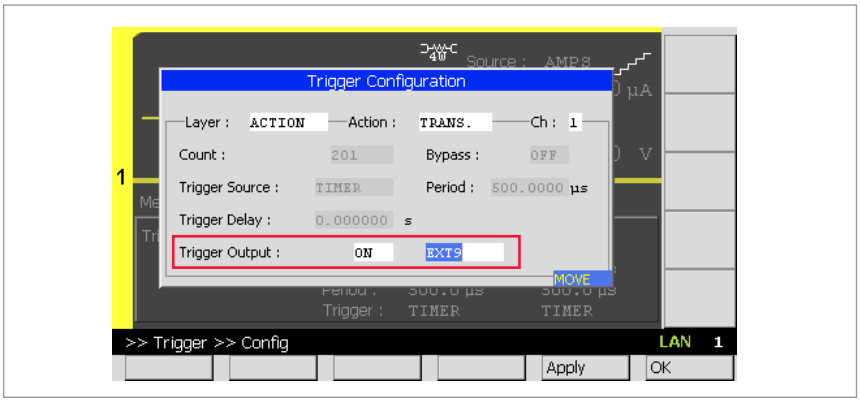
7. Set the Trigger Parameters to make the instrument output a trigger signal each time the channel steps current.

   a. Press Trigger, Config to open the Trigger Configuration dialog.

   b. Press ◯ to select Layer and then press ACTION to select ACTION for Layer.



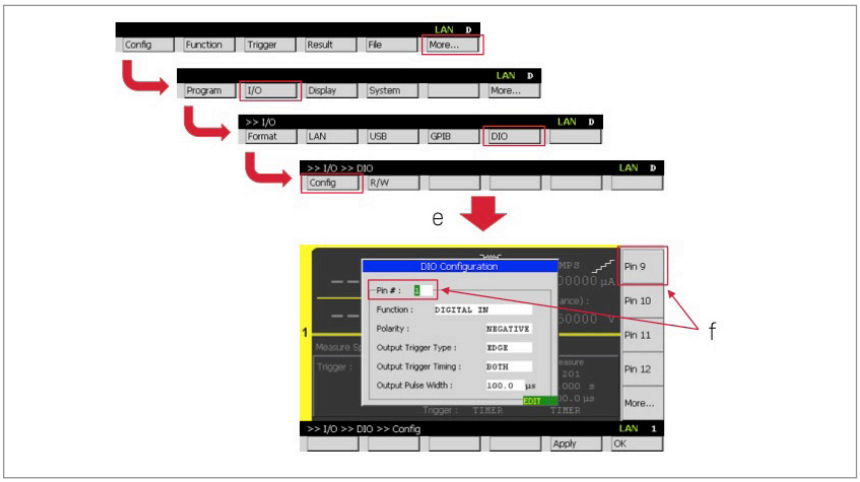
   c. Rotate ◯ to select Trigger Output and fill in the entries as shown below.



   d. Then press OK to apply the changes.

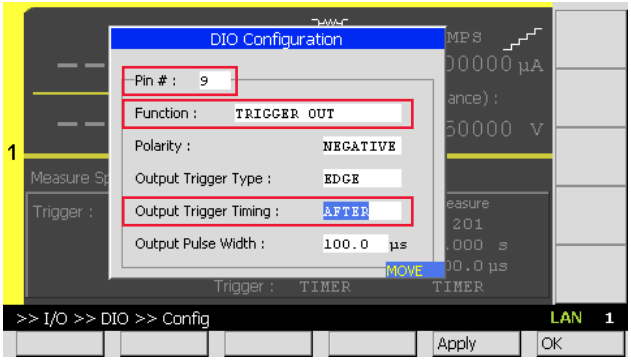
   e. Press More..., I/O, DIO and then press Config to open the DIO Configuration.

   f. Press ◯ to edit Pin # and then select Pin 9 to set it to Pin 9.



Set up the B2911A via front panel operation (continued)

g. Rotate  to select parameters and fill in the entries as shown below. (Function: TRIGGER OUT, Output Trigger Timing: AFTER)



h. Then press OK to apply the changes.

Controlling the B2911A using SCPI commands

If you prefer to control the B2911A remotely using SCPI commands, then the following material explains how to do this.

The series of commands shown in group “A” configure the source function parameters such as source mode and sweep source condition. After that the commands shown in group “B” are sent to set the measurement parameters. Next the commands shown in group “C” are sent to set up the B2911A’s trigger condition. Finally, the series of commands shown in group “D” should be sent to configure the instrument to send a trigger signal each time the channel steps current.

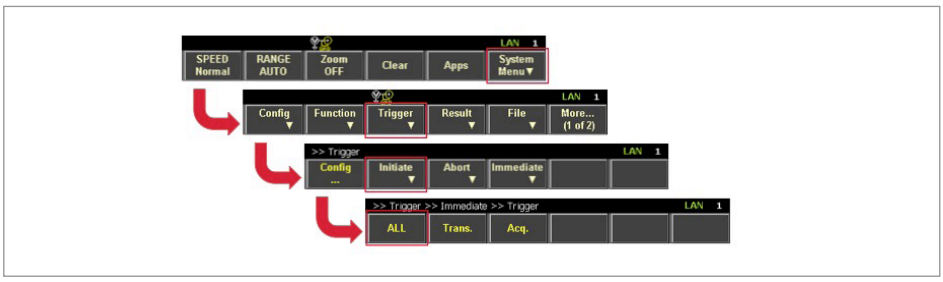
B2911A SCPI command example

```
*RST
:DISP:ENAB OFF

:SOUR:FUNC:MODE CURR
:SOUR:CURR:MODE SWE
:SOUR:CURR 0
:SOUR:CURR:STAR 0
:SOUR:CURR:STOP 0.05
:SOUR:SWE:POIN 201                    } A

:SENS:VOLT:PROT 2.5
:SENS:VOLT:NPLC:AUTO OFF
:SENS:VOLT:NPLC 2E-4
:SENS:REM ON                          } B

:TRIG:SOUR TIM
:TRIG:COUN 201
:TRIG:TIM 2E-3
:TRIG:ACQ:DEL 1E-4                    } C

:SOUR:TOUT ON
:SOUR:TOUT:SIGN EXT9

:SOUR:DIG:EXT9:FUNC TOUT
:SOUR:DIG:EXT9:POL NEG
:SOUR:DIG:EXT9:TOUT:POS AFT
:SOUR:DIG:EXT9:TOUT:TYPE EDGE
:SOUR:DIG:EXT9:TOUT:WIDT 1E-4         } D

:OUTP:STAT ON
```

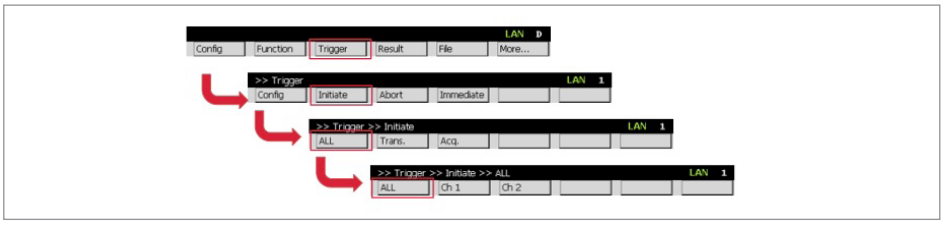
Perform LIV Sweep Measurement

After configuring each instrument, execute the following procedures to perform laser diode LIV sweep measurements.

Initiate the B2985A/87A to receive trigger signals from the B2911A by pressing System Menu▼, Trigger▼, Initiate▼, ALL.



Initiate the B2911A to start sweeping drive current to the LD and send trigger signals after each current step by pressing Trigger, Initiate, ALL, Ch 1.



If you prefer to initiate the instruments using SCPI commands, send an ":INIT (@1)" command to the B2985A/87A first, and then send an ":INIT (@1)" command to the B2911A to start the LIV sweep measurement.

The measurement results can be seen from the graphical user interfaces of the B2985A/87A and B2911A as shown in Figure 6. The Graph View function allows you to quickly examine measurement results.

Figure 6. LD voltage and PD current measurement results

Using the instruments' USB connections, a CSV file containing the measurement results can be exported to a flash drive and imported into a PC. This allows you to analyze the measurement results in detail using a spread sheet application and to plot the results of both the PD current and the LD current measurements as shown in Figure 7.

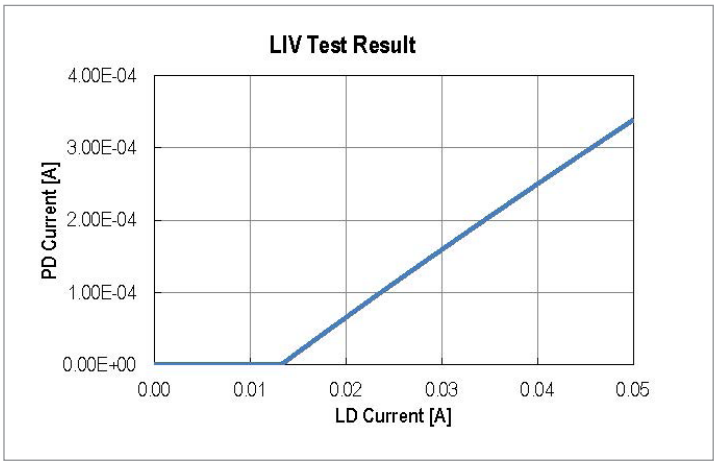


Figure 7. L-I-V test results

Conclusion

The Keysight B2985A/87A Electrometer/High Resistance Meter has a number of features that make it ideal for photodiode (PD) characterization. These include: a 0.01 fA current measurement resolution, a wide selection of current measurement ranges (from 2 pA to 20 mA) and a 1,000 V voltage sourcing capability that supports the evaluation of high-voltage devices such as avalanche photodiodes (APDs). These measurement capabilities meet virtually all existing and future low-current PD characterization needs.

Besides its impressive current and voltage specifications, the B2980A series has a number of other capabilities that aid in the evaluation of PDs. One helpful feature is its 4.3" color LCD-based graphical user interface (GUI) that provides multiple options for viewing data in different formats, including graphs, histograms and trend charts. These unique front-panel capabilities facilitate the capture of transient behavior and provide the ability to make quick statistical analyses without the need for a PC.

In addition, the B2980A Series has the ability to send trigger signals to and receive trigger signals from external instruments. This makes it easy to synchronize the B2980A series with other instruments (such as the B2900A series of SMUs), which is important when performing light-current-voltage (L-I-V) sweep tests to characterize laser diodes (LDs).

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