APPLICATION NOTE

Photodiode Test Using the Keysight B2980C Series

B2981C/83C Femto / Picoammeter

B2985C/87C Electrometer / High Resistance Meter

KEYSIGHT

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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, known as dark current. Since the output current is directly proportional to the light intensity applied to the PD junction, it can detect small quantities of light. This makes PDs useful in optical communication, light detection, and consumer electronics applications.

The output current consists of dark current (no light) and photocurrent (caused by light) when the PD is reverse-biased. Dark current is a small leakage current induced by the 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, you can control the gain of the APD. 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 applications requiring highlight sensitivity (such as fiber optic telecommunication and laser rangefinders). 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.

B2980C Series Femto / Picoammeters and Electrometers / High Resistance Meters

Keysight B2980C series Femto / Picoammeters and Electrometer / High Resistance Meters is a graphical picoammeter and electrometer that lets you confidently measure down to 0.01 fA and up to 10 PΩ (10^{16} Ω). These capabilities enable the evaluation of a variety of PDs. The B2980C 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 B2980C 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 B2980C series features a 4.3" color LCD-based Graphical User Interface (GUI) that provides multiple options for viewing data. In addition to a numeric format, you can view the data as graphs, histograms, or trend charts. These unique front-panel capabilities facilitate the capture of transient behavior and provide the ability to make quick statistical analyses without needing a PC. The B2980C series also has external trigger in and out terminals that allow it to receive and send trigger signals from and to external instruments. This simplifies and streamlines the synchronization of the B2980C 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 application note demonstrates how to evaluate PD characteristics with B2985C/87C and explains how to synchronize the B2980C series with other instruments using the example of an L-I-V sweep test on an LD.

Photodiode Characterization Example

This section explains how to perform PD dark current measurements using the B2985C/87C.

Overview

Figure 1 shows the circuit diagram for evaluating PD characteristics using the B2985C/87C Electrometer / High Resistance Meter. The B2985C/87C's voltage source high terminal supplies a reverse bias voltage to the PD cathode, and its ammeter measures the PD current. The voltage source's low terminal and the ammeter's common are connected internally.

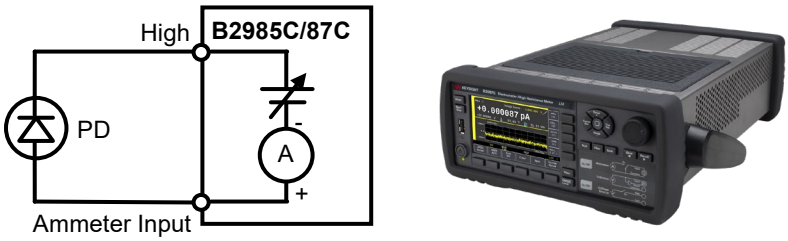


Figure 1. Circuit diagram to evaluate photodiode characteristics

Since the B2985C/87C's voltage source can sweep voltage while its ammeter synchronously measures current, the PD's current–voltage (IV) characteristics can easily be obtained. In addition, the B2985C/87C's ability to display the results as an X-Y graph permits quick examination of the results.

Measurement example

This example demonstrates how to measure the dark current of a silicon photodiode. Table 1 summarizes the key measurement parameters. The B2985C/87C's ammeter measures the PD current as the voltage source applies a reverse-bias voltage. Since the dark current measurement must be made without light, the PD is tested in an enclosed test fixture.

Parameters		Values
PD voltage swept	Start	10 mV
	Stop	5 V
	Points	500
PD current	Range	20 pA fixed
Aperture tme (SPEED)		Normal
Trigger	Source	AUTO
	Count	500
	Measure delay	1 s
	Period	1.2 s

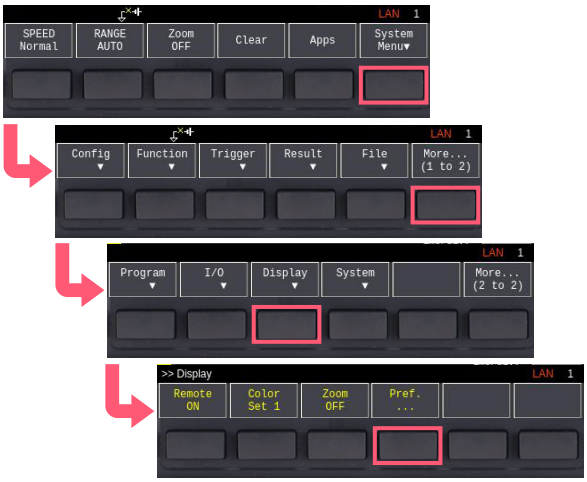
Table 1. Photodiode characterization key measurement conditions

Setting up the B2985C/87C from its front panel

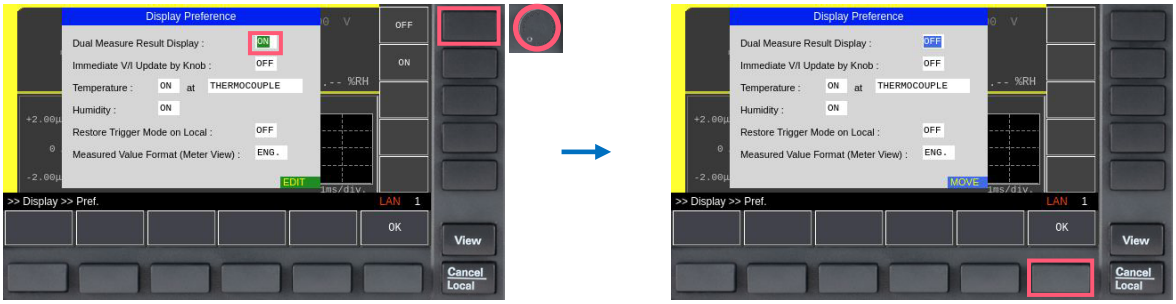
The following instructions describe setting up the B2985C/87C to perform PD dark current measurements on the instrument front panel.

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 to 2), Display ▾, and Pref. ... function keys.

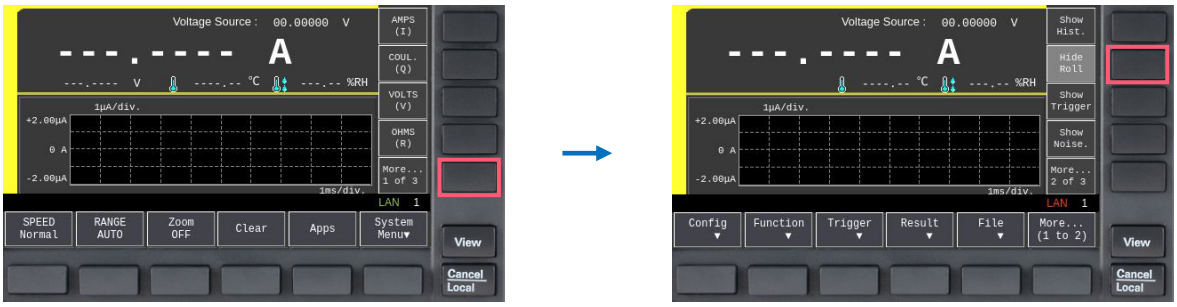


b. Press  to edit “Dual Measure Result Display”. After that, the field pointer is highlighted in green (EDIT), then press OFF, and then press OK to apply the settings.

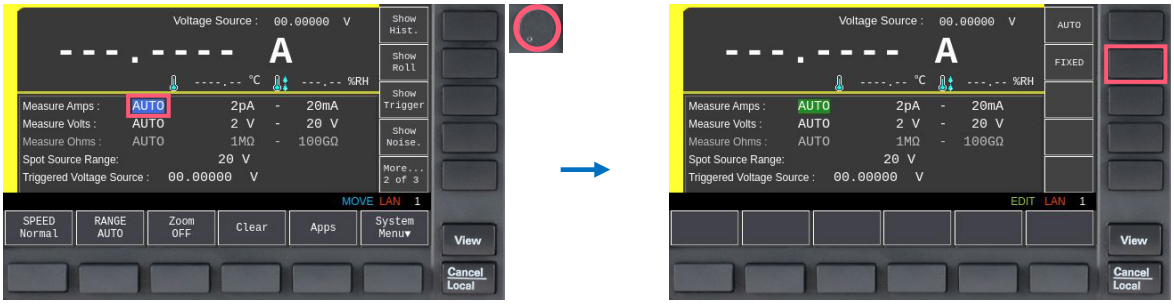


2. Select the current measurement range operation and set the current measurement range.

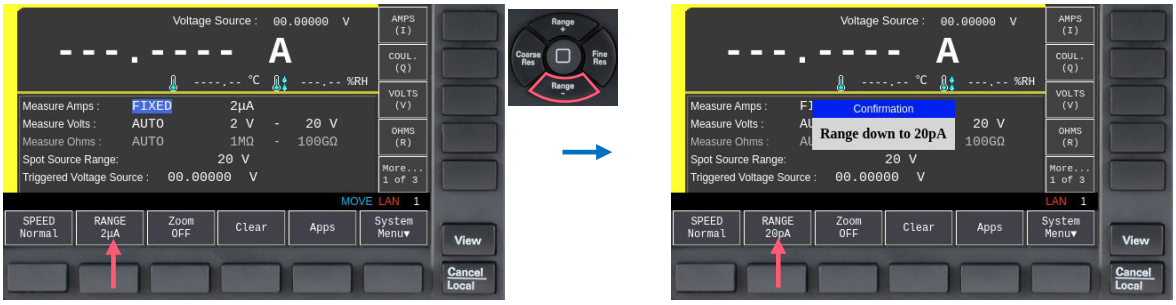
a. Press More... 1 of 3, and then press Hide Roll to show the Range Parameters



b. Press  and press FIXED to set the current measurement range operation to FIXED.

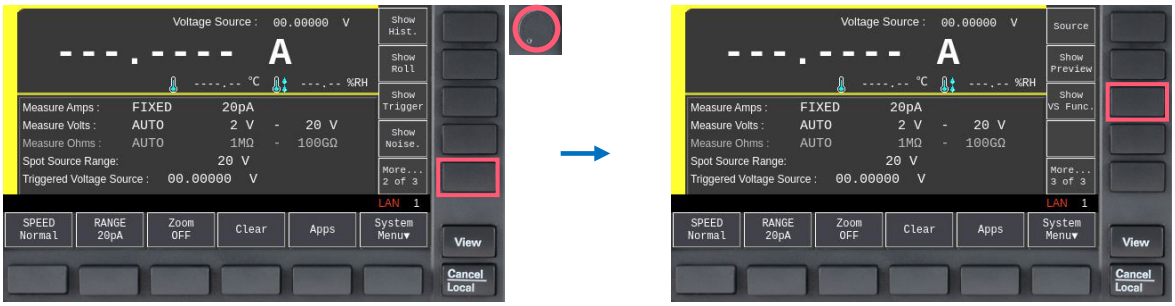


c. Press Range repeatedly until RANGE 20pA is displayed to set the current measurement range to 20 pA range.

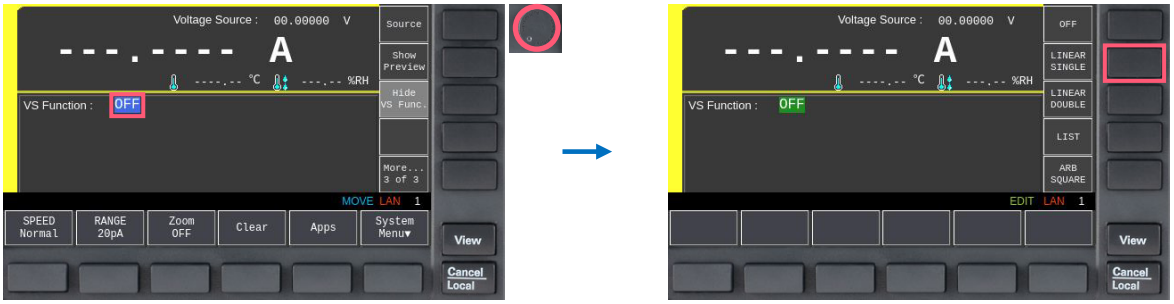


3. Set the Sweep Parameters to make the instrument perform a voltage sweep.

a. Press More... 2 of 3, and then press Show VS Func. to show Sweep Parameters. (If you can't see More... 2 of 3 in Assist keys, press More... 1 of 3, More... 3 of 3 to change the keys shown in Assist keys.)



b. Press  and press LINEAR SINGLE to turn on Single Linear Sweep Source Mode.

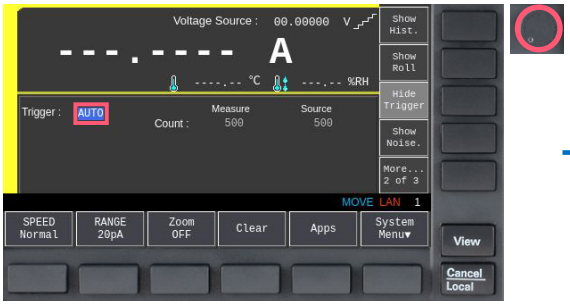


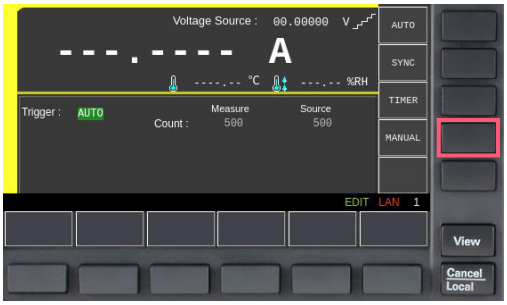
c. Rotate  to select Sweep Parameters and fill in the values as shown below. Use the arrow keys to move to the digit you want to edit. (Start: 10 mV, Stop: 5 V, Points: 500)

4. Set the Trigger Parameters to configure the Measurement Delay Time.

a. Press  , and then press  to show the Trigger Parameters. (If you can't see  in Assist keys, press  ,  to change the keys shown in Assist keys.)

b. Press  and press  to set the Trigger Parameters.

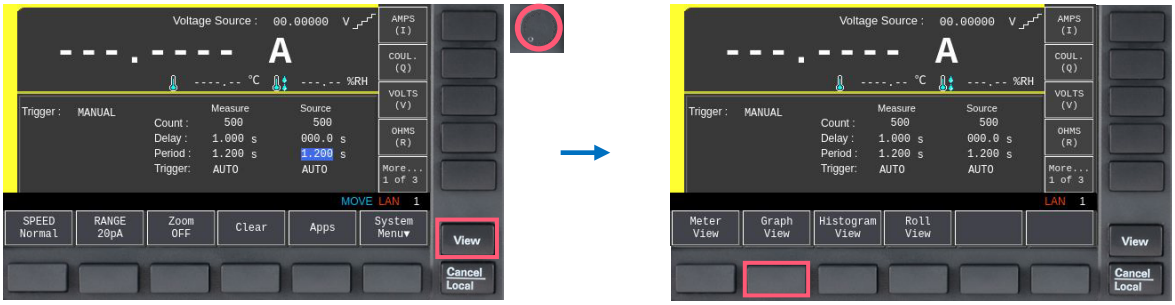




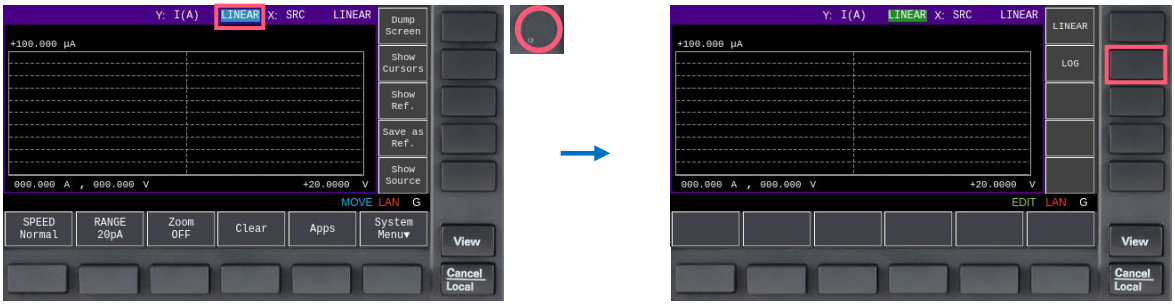
c. Rotate  to select the Trigger Parameters and fill in the values as shown below. (Count: 500, Measure Delay: 1 s, Period: 1.2 s)

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

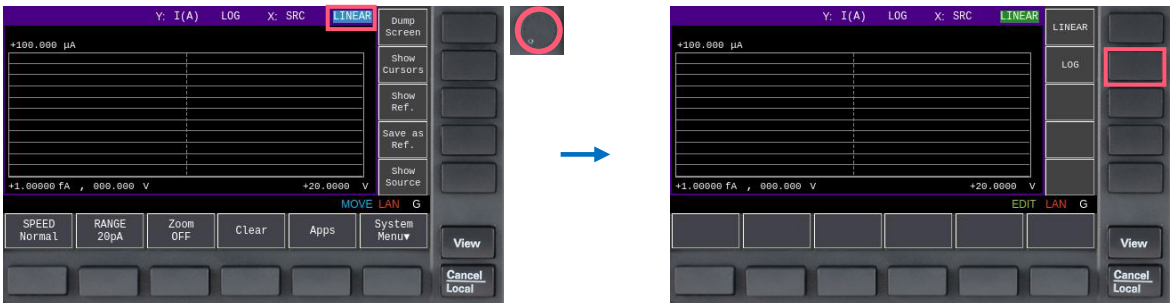
a. Press View to show the function keys for View Modes, and then press Graph View to show the Graph View.



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



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



6. Enable the Voltage Source and Ammeter.

a. Press the Voltage Source  to enable the Voltage Source

b. Press the Ammeter  to enable Ammeter.

Why is a measurement delay time required?

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 B2985C/87C using SCPI commands

The following section explains how to control the B2985C/87C remotely using SCPI commands.

B2985C/87C SCPI command example

```
*RST
:DISP:ENAB OFF

:SENS:FUNC “CURR”
:SENS:CURR:RANG:AUTO OFF
:SENS:CURR:RANG 2.E-11
:SENS:CURR:APER:AUTO ON
:SENS:CURR:APER:AUTO:MODE MED

:SOUR:FUNC:MODE VOLT
:SOUR:VOLT:MODE SWE
:SOUR:VOLT:STAR 0.01
:SOUR:VOLT:STOP 5
:SOUR:VOLT:POIN 500

:TRIG:SOUR AINT
:TRIG:COUN 500
:TRIG:ACQ:DEL 1
TRIG:TIM 1.2

:OUTP:STAT ON
:INP ON
```

A, B, C

Command groups	What does it do?
A	Configure measurement parameters such as measurement auto-ranging (turned off), measurement range, and aperture time.
B	Set up the voltage source
C	Set up the B2985C/87C’s trigger parameters

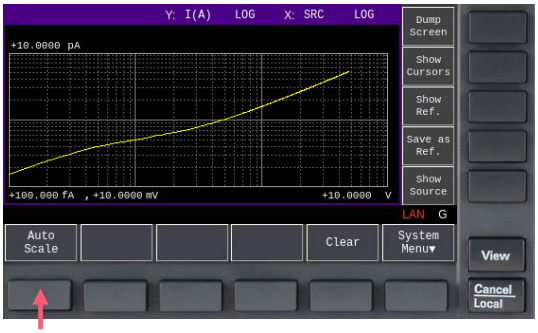
Performing photodiode dark current measurements

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

If you are using the front panel, trigger the B2985C/87C 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 B2985C/87C's graphical user interface as shown in Figure 2. The Graph View function allows you to examine the measurement results quickly.



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

Figure 2. Photodiode dark current measurement results

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

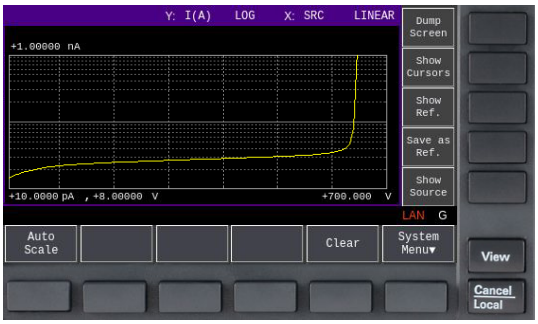


Figure 3. Avalanche photodiode dark current measurement results

L-I-V Test Example

This section explains how to synchronize the B2980C series with other instruments using the example of a Laser Diode (LD) L-I-V sweep test using a Photodiode (PD).

Overview

Figure 4 shows an example of a system diagram that evaluates the L-I-V characteristics of an LD using the B2900 Precision Instrument Family. The Keysight B2911C Precision Source / Measure Unit (SMU) is used to apply drive current to the LD and to measure the LD's voltage. The B2911C can cover currents from 10 fA to 3 A (DC) / 10.5 A (pulsed) and voltages from 100 nV to 210 V. The SMU can source and measure both positive and negative voltages and currents to easily characterize the LD's DC parameters. Since the currents supplied to the LD can be large, a 4-wire connection (remote sensing) configuration is commonly used.

The B2985C/87C's ammeter input terminal is connected to the PD's anode, and the B2985C/87C'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 a voltage to the PD from its voltage source.

To synchronize the B2985C/87C with the B2911C during the LD current sweep operation, a trigger signal is sent from the B2911C to the B2985C/87C. The N1294A-031 GPIO-BNC Trigger Adapter converts the B2911C'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.

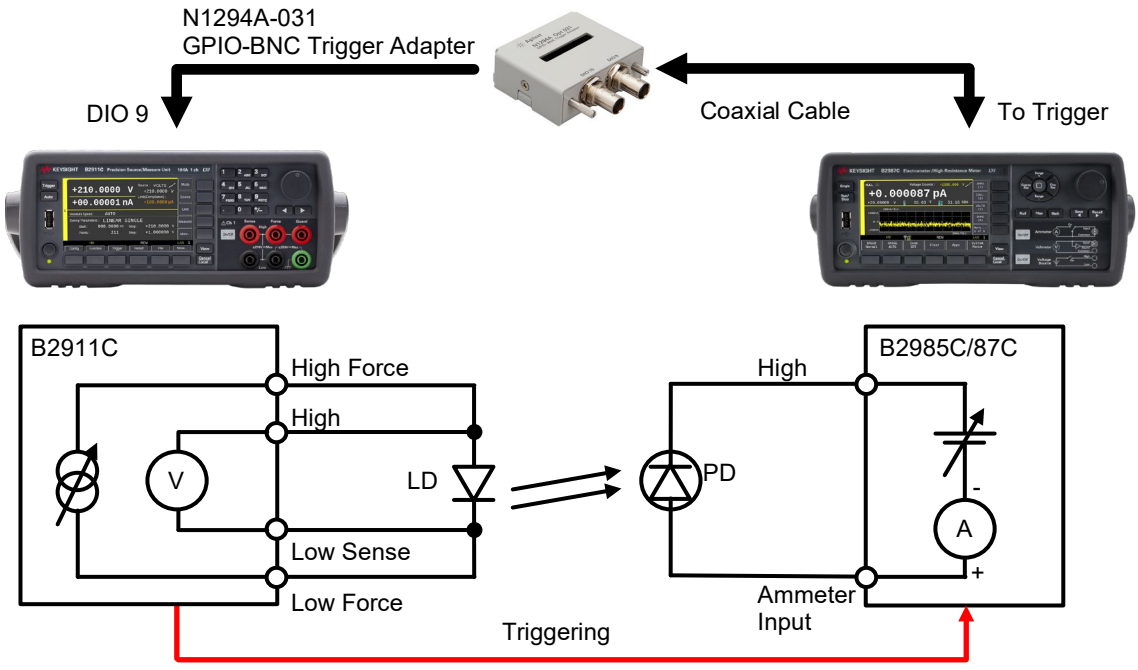


Figure 4. System configuration to evaluate the L-I-V Characteristics of a laser diode

This example uses a Distributed Feedback (DFB) laser diode, and Table 2 summarizes the key measurement conditions. The PD current is measured by the B2985C/87C as the drive current to the LD is swept from 0 A to 50 mA in 250 µA steps by the B2911C. Timed triggering is selected to step currents to the LD at regular intervals, the trigger period is set to 500 µs, and fixed measurement ranging is used. Since the self-heating can affect the laser diode characteristics, it is essential to carefully control the LD measurement time and make it as short as possible. In this example, a 500 µs trigger and 200 µs aperture time are used.

B2911C			**B2985C/87C**		
Parameters		**Values**	**Parameters**		**Values**
LD current swept	Start	0 mA	PD voltage		0.1 V constant
	Stop	50 mA			
	Points	201			
LD voltage	Limit	2.5 V	PD current measurement range		2 mA fixed
Aperture time		0.01 PLC	Aperture time		0.01 PLC
Trigger	Type	TIMER	Trigger	Type	Manual
	Source			Source	TRIGGER IN
	Count	201		Count	201
	Measurement Delay	100 µs		Measurement delay	100 µs
	Period	500 µs			
	Output	Digital I/O port 9			

Table2. Summary of measurement conditions for L-I-V testing

B2911C's digital I/O port 9 sends a trigger signal to the B2985C/87C's BNC trigger-in terminal immediately after each B2911C current step completes, as shown in Figure 5.

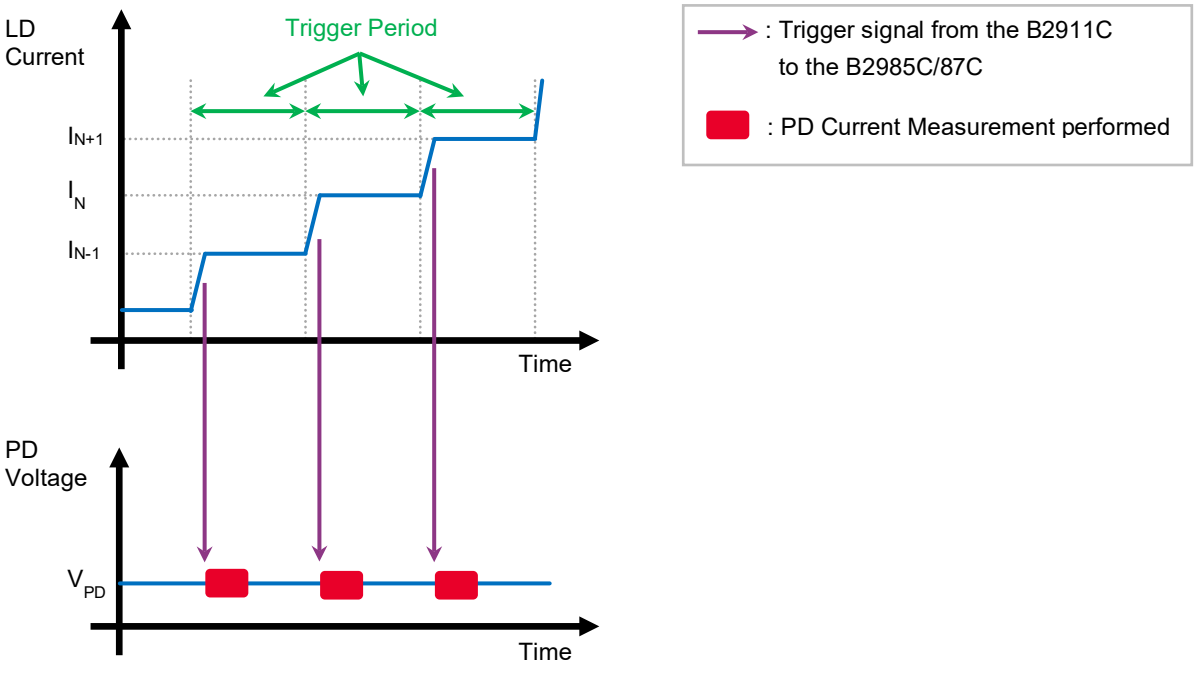


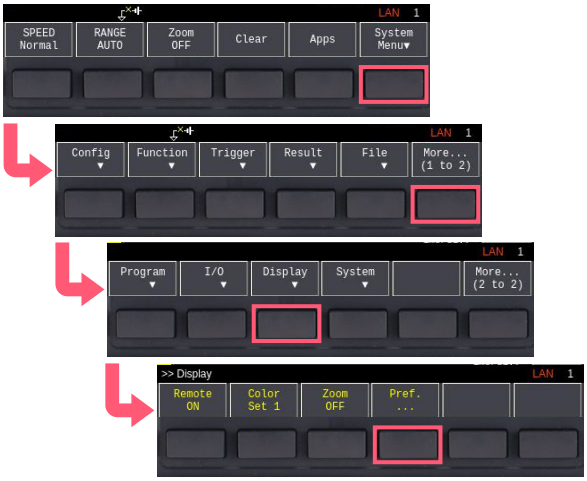
Figure 5. Triggering the B2985C/87C from the B2911C

Setting up the B2985C/87C from front panel

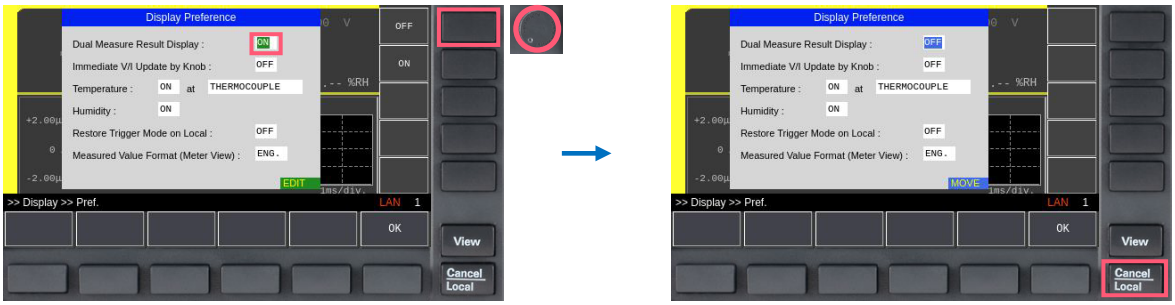
The following instructions describe setting up the B2985C/87C to perform PD dark current measurements on the instrument front panel.

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 to 2), Display ▾, and Pref. ... function keys.



b. Press the knob to edit “Dual Measure Result Display”. After that, the field pointer is highlighted in green (EDIT), then press OFF, and then press OK to apply the settings.



2. Set the current measurement range operation to FIXED.

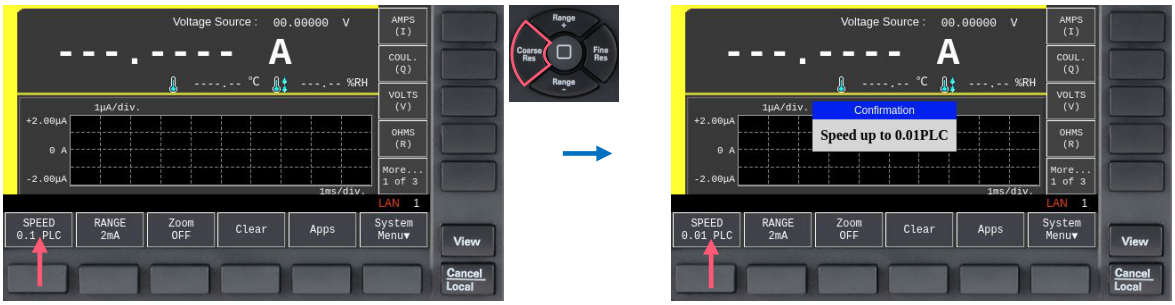
a. Press RANGE AUTO to set the current measurement range operation to FIXED. (If you cannot see RANGE AUTO, press Cancel Local to show the Meter View function keys.)

b. Press Range repeatedly until it 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 microamps.

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 effects and long enough to provide the required accuracy.



4. Set “Triggered Voltage Source” to the desired PD voltage.

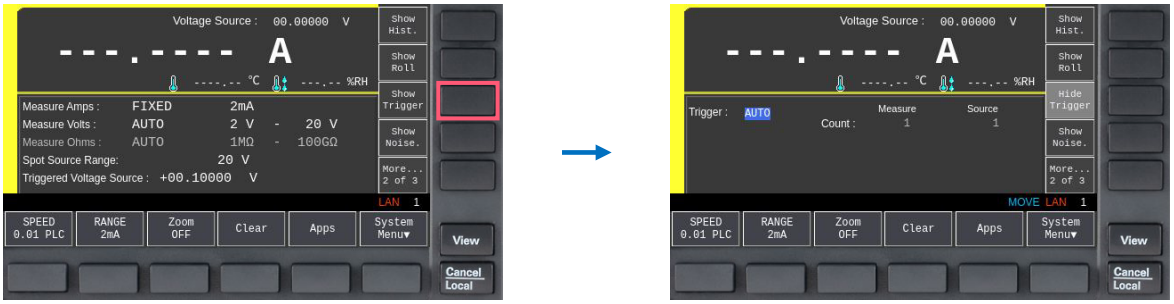
a. Hide the condensed Roll View by pressing More... 1 of 3, and Hide Roll.

b. Rotate  to select “Triggered Voltage Source” and press  to edit it.

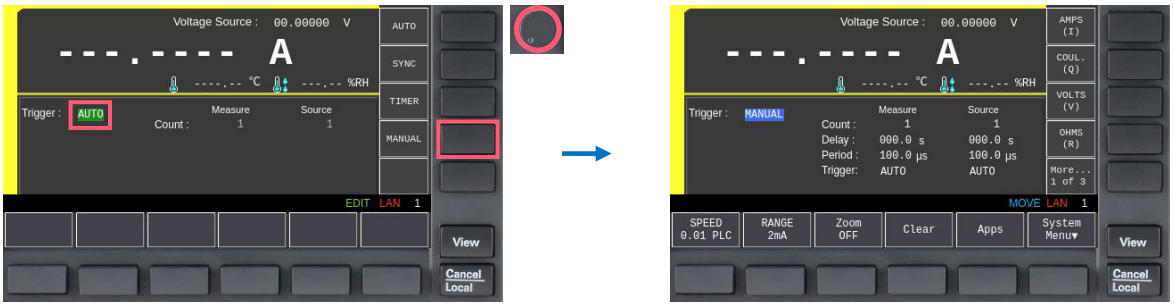
c. Set the voltage value to the desired PD voltage, which is 0.1 V in this example. Use the arrow keys to move to the digits you want to edit.

5. Set the Trigger Parameters to make the instrument perform measurements whenever it receives a trigger signal from the B2911C.

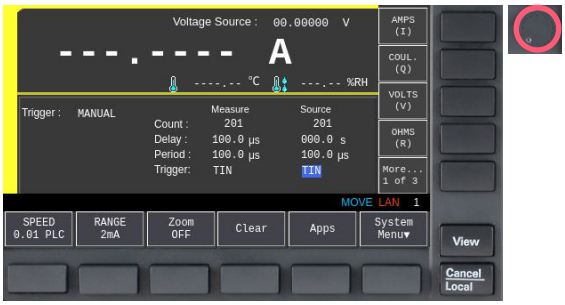
a. Press Show Trigger to show Trigger Parameters.



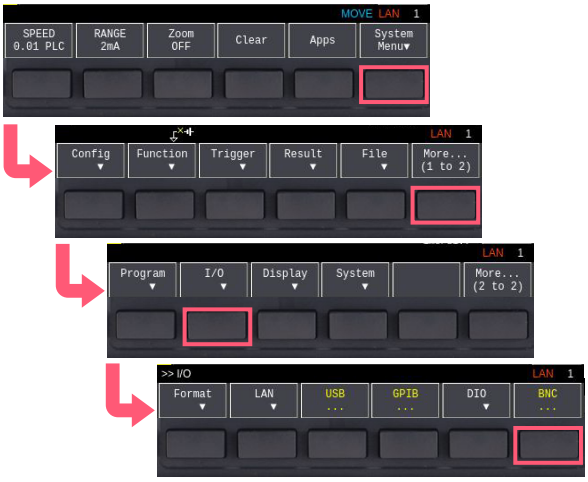
b. Press  , and to press MANUAL to select the manual trigger setting mode.



c. Press  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 to 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”.

6. Enable the Voltage Source and Ammeter.

a. Press the Voltage Source On/Off to enable the Voltage Source

b. Press the Ammeter On/Off to enable the Ammeter.

Controlling the B2985C/87C using SCPI commands

B2985C/87C 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
```

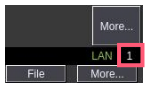
A, B, C

Command groups	What does it do?
A	Configure measurement parameters such as measurement range and aperture time.
B	Set up the voltage source
C	Set up the B2985C/87C’s trigger parameters

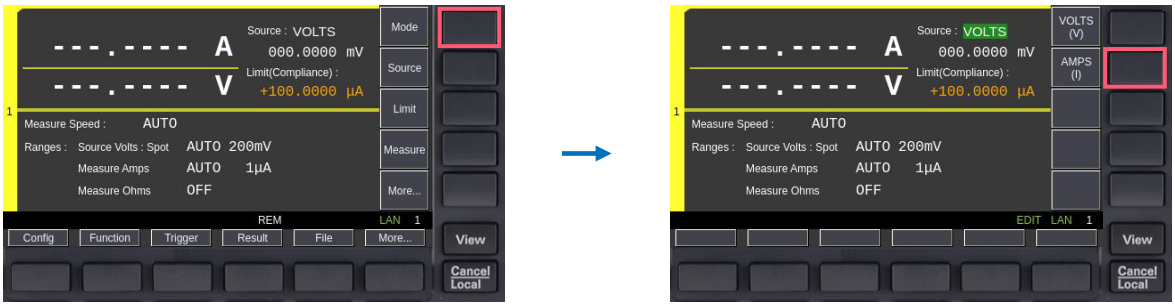
Set up the B2911C via front panel operation

1. Set the Source Function to Current

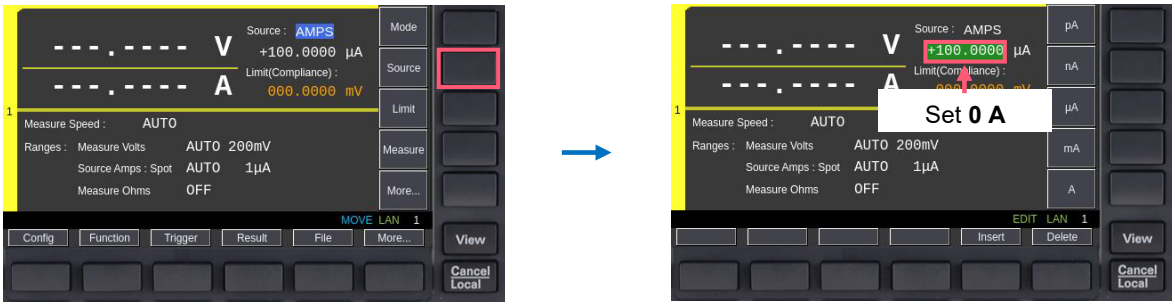
a. Press View repeatedly until Single View for Channel 1 is shown.



b. Press Mode and then press AMPS (I) to set the Channel 1 Source Function to Current.

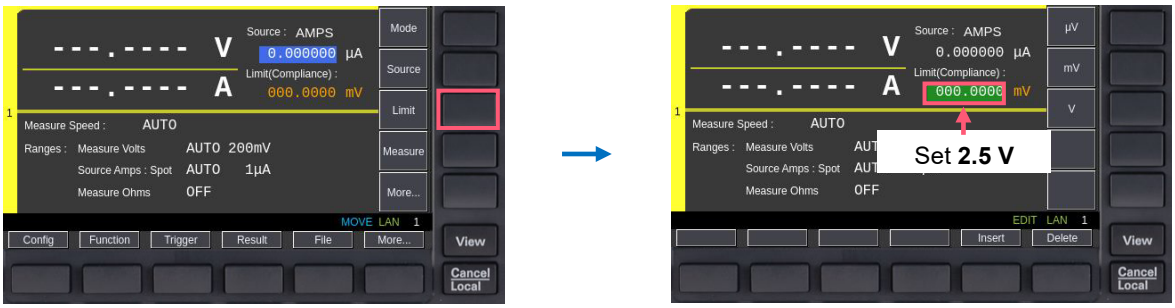


c. Press Source and then set the Channel 1 Source Value to 0 A.



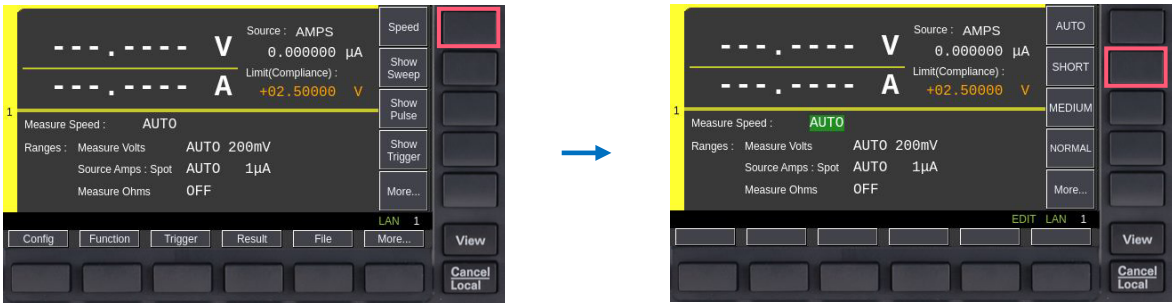
2. Set the Voltage Limit Value

a. Press Limit and then set the Channel 1 Limit Value to 2.5 V as shown.



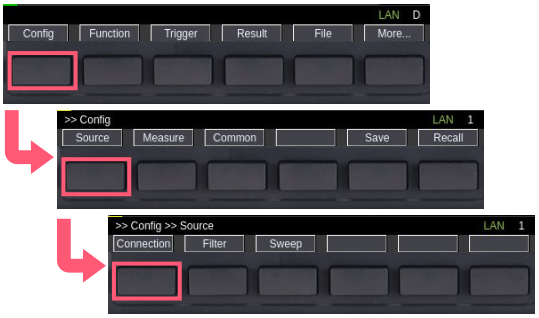
3. Set the Aperture Time

a. Press Speed to edit the measurement speed, and then select SHORT to set the Aperture Time to SHORT (0.01 PLC). (If you cannot see Speed in Assist keys, press More... to change the keys shown in Assist keys.)

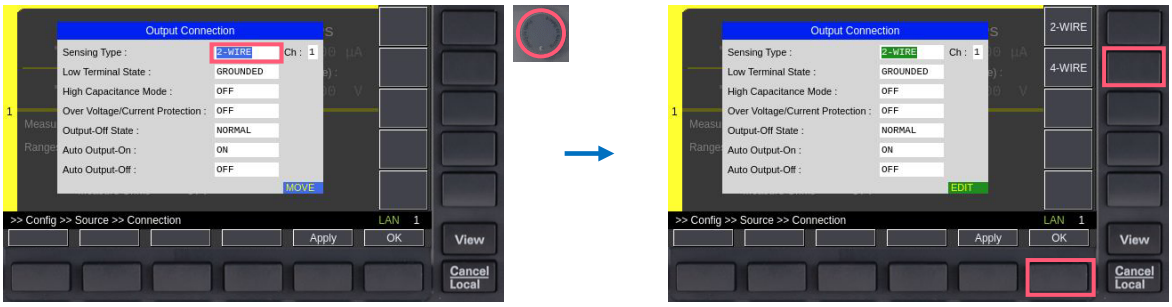


4. Enable remote sensing

a. Press Config, Source, and then press Connection to display Output Connection dialogue.

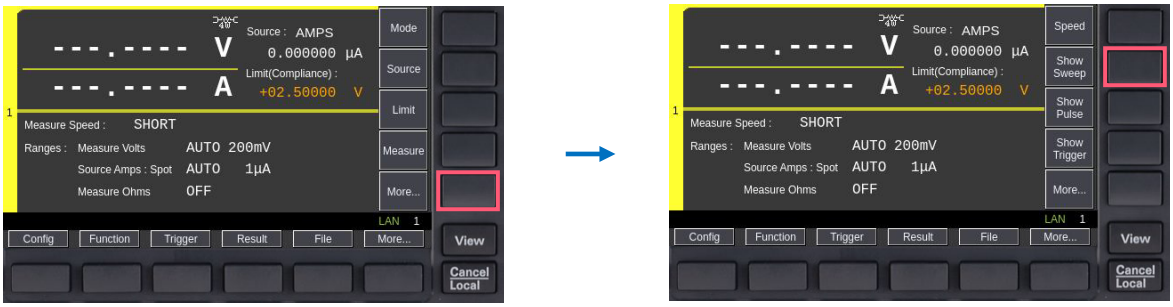


b. Press  and select 4-WIRE, and then press OK to configure to use a 4-wire connection.



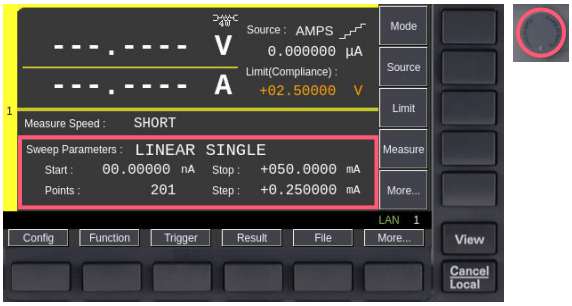
5. Set up the Sweep Parameters to make the instrument perform a current sweep.

a. Press Show Sweep to show the Sweep Sub-Panel. If you can't see Show Sweep in the Assist keys, press More... to change the keys shown in Assist keys.)



b. Press  and press LINEAR SINGLE to turn on Single Linear Sweep Source Mode.

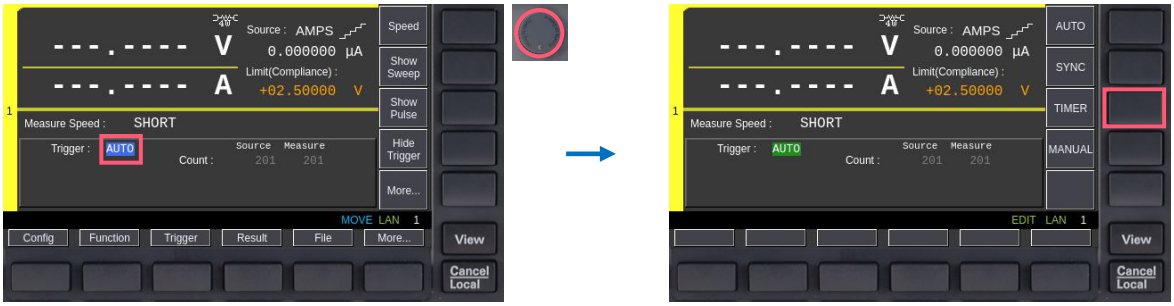
c. Rotate  to select Sweep Parameters and fill in the values as shown below. (Start: 0 A, Stop: 50 mA, Points: 201)



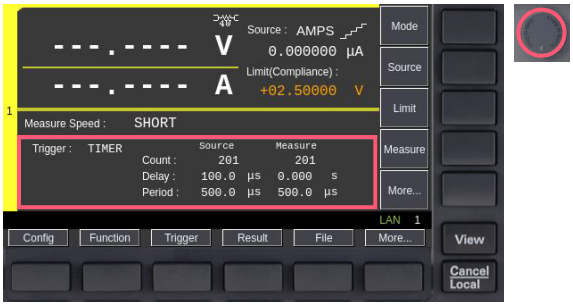
6. Set the Trigger Parameters to make the instrument step current at regular intervals.

a. Press Show Trigger to show the Sweep Sub-Panel. If you cannot see Show Trigger in the Assist keys, press More... to change the keys shown in Assist keys.)

b. Press  and press TIMER to select Timer Trigger Setting Mode.



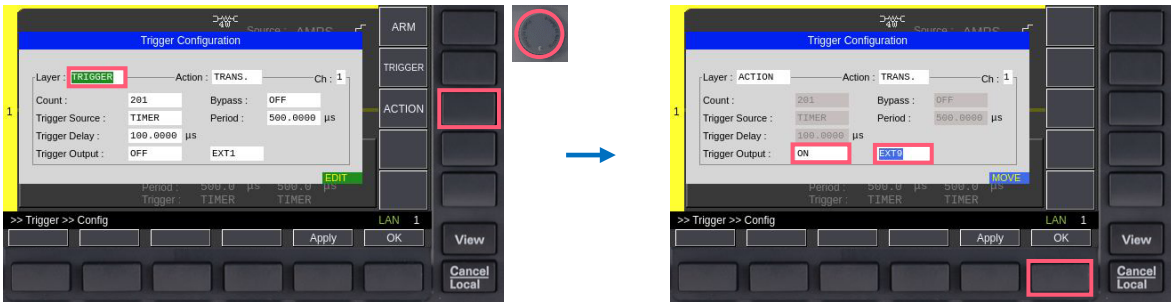
c. Rotate  to select Trigger Parameters and fill in the values as shown below. (Measure Count: 201, Source Count: 201, Measure Delay: 100 µs, Measure Period: 500 µs, Source Count: 500 µs)



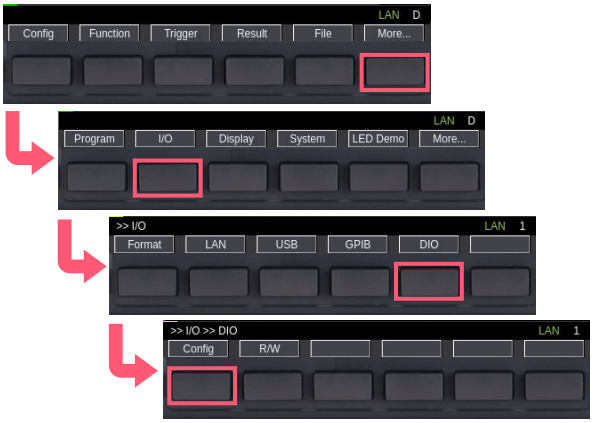
7. Set the Trigger Parameters to make the instrument output a trigger signal each time the channel steps current.

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

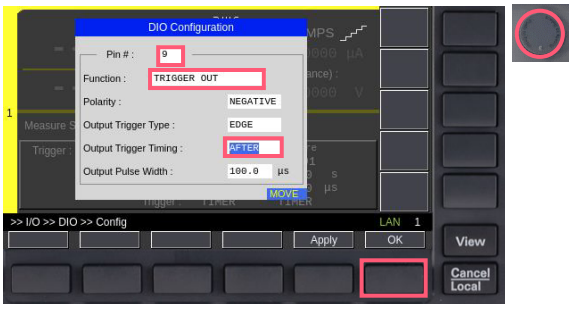
b. Press  to select Layer and then press to select ACTION for Layer. Then, rotate  to set Trigger Output ON to EXT9, then press OK to apply the changes.



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



d. Rotate  to select parameters and fill in the entries as shown below. (Function: TRIGGER OUT, Output Trigger Timing: AFTER). Then press OK to apply the changes.



Controlling the B2911C using SCPI commands

The following section explains how to remotely control the B2911C using SCPI commands.

B2911C 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

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

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

: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

:OUTP:STAT ON
```

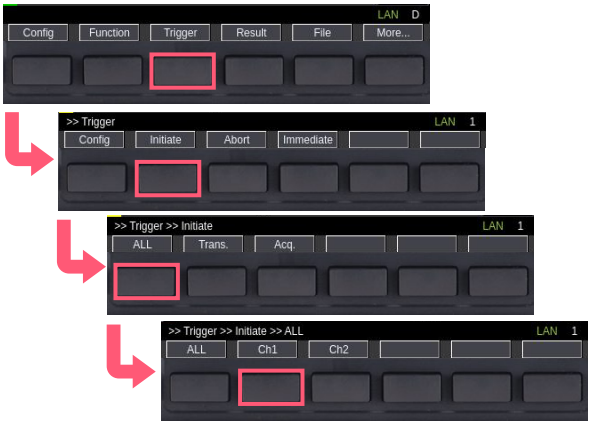
A: `*RST` through `:SOUR:SWE:POIN 201`
B: `:SENS:VOLT:PROT 2.5` through `:SENS:REM ON`
C: `:TRIG:SOUR TIM` through `:TRIG:ACQ:DEL 1E-4`
D: `:SOUR:TOUT ON` through `:SOUR:DIG:EXT9:TOUT:WIDT 1E-4`

Command groups	What does it do?
A	Configure the source function parameters, such as source mode and sweep source condition.
B	Set the measurement parameters
C	Set up the B2911C's trigger condition
D	Configure the instrument to send a trigger signal each time the channel steps current

Perform LIV sweep measurement

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

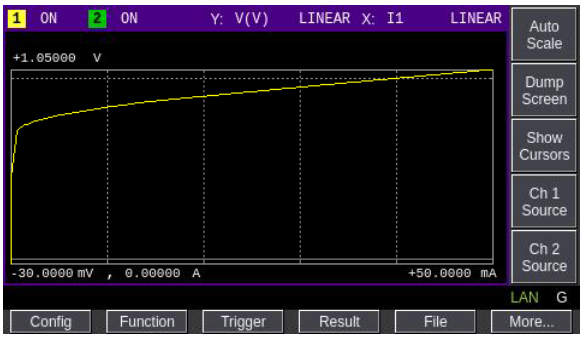
Initiate the B2985C/87C to receive trigger signals from the B2911C by pressing Initiate, Trigger, ALL and Ch1.



If you prefer to initiate the instruments using SCPI commands, send an ":INIT (@1)" command to the B2985C/87C first, and then send an ":INIT (@1)" command to the B2911C to start the LIV sweep measurement.

The measurement results can be seen from the graphical user interfaces of the B2985C/87C and B2911C as shown in Figure 6. The Graph View function allows you to quickly examine measurement results.

LD voltage measured by the B2911C



PD current measured by the B2985C/87C

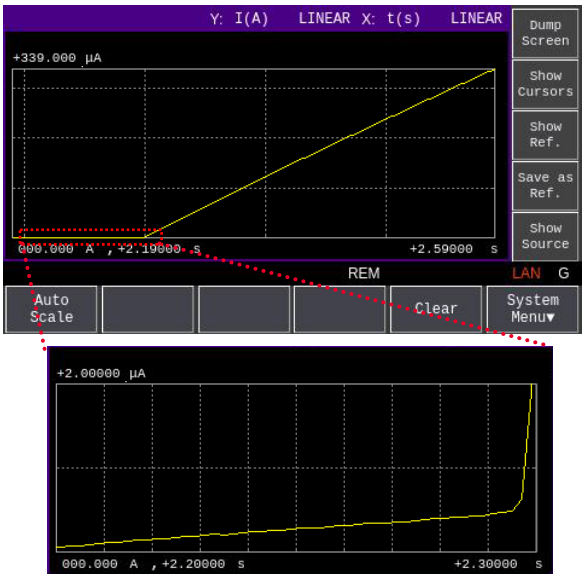


Figure 6. LD voltage and PD current measurement results

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

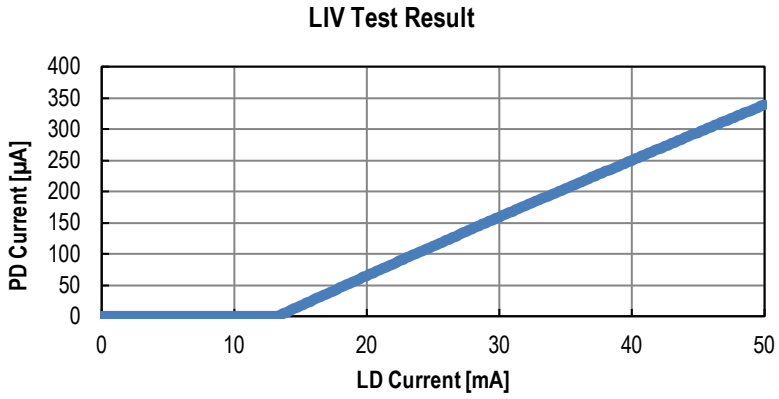


Figure 7. L-I-V test results

Conclusion

Keysight B2985C/87C Electrometer / High Resistance Meter has several 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 B2980C series has several other capabilities that aid in evaluating PDs. One helpful feature is its 4.3" color LCD-based Graphical User Interface (GUI), which 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 allow quick statistical analyses without the need for a PC.

In addition, the B2980C series can send trigger signals to and receive trigger signals from external instruments. This makes it easy to synchronize the B2980C series with other instruments (such as the B2900C series SMUs), which is important when performing Light-Current-Voltage (L-I-V) sweep tests to characterize Laser Diodes (LDs).

Keysight enables innovators to push the boundaries of engineering by quickly solving design, emulation, and test challenges to create the best product experiences. Start your innovation journey at www.keysight.com.

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