Agilent B1530A
Waveform Generator ⁄
Fast Measurement Unit

Sample Program Learning Kit
User's Guide

Agilent Technologies

Notices

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In This Manual

This manual provides the information about the sample programs and the learning kit designed for the Agilent Technologies B1530A Waveform Generator/Fast Measurement Unit (WGFMU) and consists of the following chapters.

1. Introduction

   Describes overview of the sample program learning kit, the system requirements for using the sample programs, and the device connection information.

2. Using WGFMU Application Tests

   Describes how to use the WGFMU Pattern Editor application test and the reference information of the WGFMU application tests executable on the application test environment of the EasyEXPERT software and the Desktop EasyEXPERT software.

3. Using Sample Programs

   Describes how to use the sample programs executable on an instrument controller.

4. Sample Program Reference

   Provides reference information of the sample programs.

The WGFMU application tests are included in the EasyEXPERT software and the Desktop EasyEXPERT software revision A.03.20 and later.

The WGFMU sample programs are stored in *Agilent B1530A Instrument Library and Sample Program CD* furnished with the B1530A.

NOTE   To get the latest firmware/software/manual/support information, go to www.agilent.com and type in B1530A in the Search field at the top of the page.

1   Introduction

Introduction

This chapter describes overview of the sample program learning kit, the system requirements for using the sample programs, and the device connection information. This chapter consists of the following sections.

1-1. Sample Program Learning Kit

The sample programs and the learning kit are designed for demonstrating the measurements using the Agilent B1530A Waveform Generator / Fast Measurement Unit (WGFMU). The sample programs are stored in *Agilent B1530A Instrument Library and Sample Program CD* furnished with the B1530A. The learning kit contains the following parts.

1. Demo device set, 1 set
2. RSU demo stand, 1 ea.
3. SMA(m)-SMA(m) cable, 2 ea.
4. User's guide (this document), 1 ea.

1-2. Demo Device Set

The demo device set contains four parts shown in Fig. 1-1. The parts are the assembly made from two SMA (female) connectors, a printed circuit board, and a discrete device listed below. Blank board has not mounted any device. It allows you to mount any device by yourself for performing the measurements of your device.

1. 1 kΩ axial lead resistor
2. 1 MΩ surface mount resistor
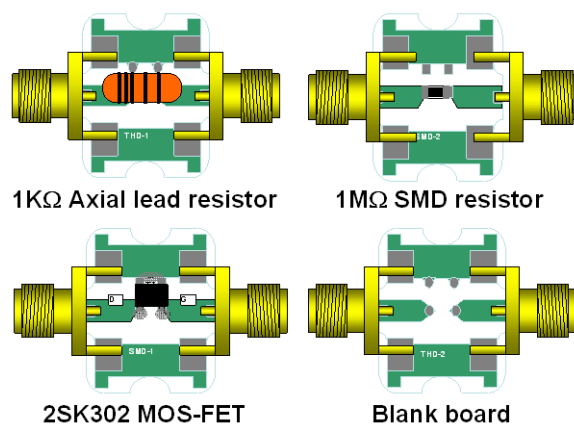3. N-MOS FET (2SK302)
4. no device on blank board

1KΩ Axial lead resistor   **1MΩ SMD resistor**

2SK302 MOS-FET   **Blank board**

Fig. 1-1 Demo device set

SMA(f)   **SMA(f)**   **SMA(f)**   **SMA(f)**
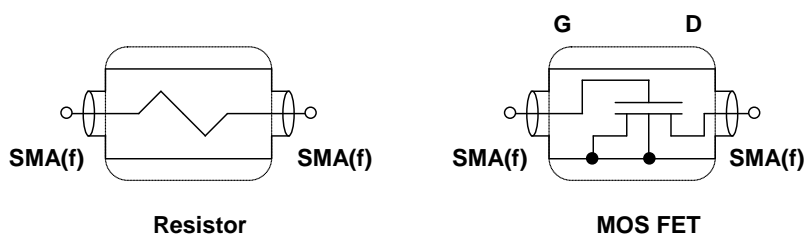
Resistor   **MOS FET**

Fig. 1-2 Circuit diagram of demo device

1-3. System Requirements

The following equipments are required for performing measurements using the WGFMU and the sample programs.

- Agilent B1500A Semiconductor Device Analyzer
  - ➢ Agilent EasyEXPERT software
  - ➢ B1530A WGFMU 1 ea.
  - ➢ SMA(m)-SMA(m) cable 2 ea. (furnished with the learning kit)
  - ➢ SMU 2 ea. or extra WGFMU 1 ea. (optional for DC bias)
  - ➢ Triaxial cable 2 ea. (optional for using SMUs)
  - ➢ SMA(m)-SMA(m) cable 2 ea. (optional for using extra WGFMU)

- Oscilloscope (optional for monitoring the output signal from the RSU)
  - ➢ BNC cable 2 ea.

- GPIB cable 1 ea. (for connecting the B1500A to an instrument controller)

- Instrument controller
  The following system environments are required for the instrument controller.
  - ➢ Computer and peripherals
    Required specifications depend on the application development environment (programming software). See manual of the programming software you use.
  - ➢ Agilent 82350B PCI GPIB interface
  - ➢ Software
    - Agilent Desktop EasyEXPERT software
    - B1530A Instrument Library
    - B1530A Sample Programs
  - ➢ Application Development Environment
    Microsoft Visual C# Express edition is required for viewing or editing source code of the sample program.

1-4. Connection between RSU and Demo Device

1-4-1. To connect demo device

Before connecting the demo device, turn the B1500A off and disconnect the cables from the RSU (Remote Sense/Switch Unit). Then place the RSU on the RSU demo stand (furnished with the learning kit). It is useful for stabilizing the RSU. After that, connect the cables between the RSU and the B1500A and an oscilloscope if you use. For the installation of the RSU, see *Agilent B1530A User's Guide*.
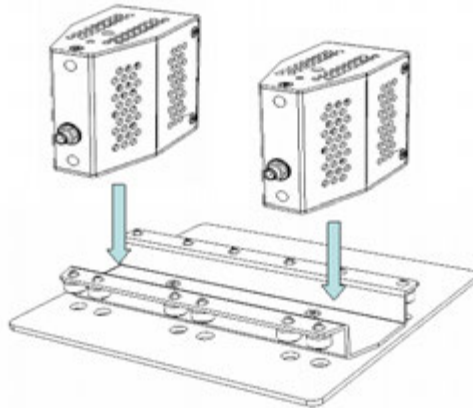

Fig. 1-3 RSU demo stand

Connect the SMA(m)-SMA(m) cable (furnished with the learning kit) between the RSU and the demo device as shown in Fig. 1-4.
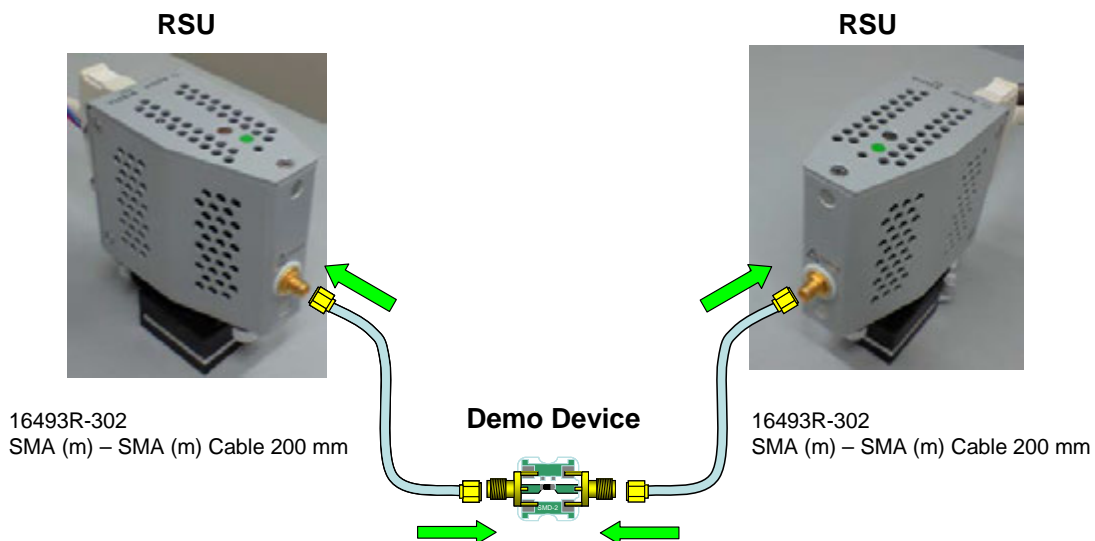

16493R-302
SMA (m) – SMA (m) Cable 200 mm

Demo Device

16493R-302
SMA (m) – SMA (m) Cable 200 mm

Fig. 1-4 Cable connection between RSU and Demo Device

1-4-2. If you monitor output signal

The RSU has a BNC connector for monitoring the WGFMU output voltage. This output is isolated from the output terminal by the ×1 buffer. So the output signal can be monitored without any side effect by probing.
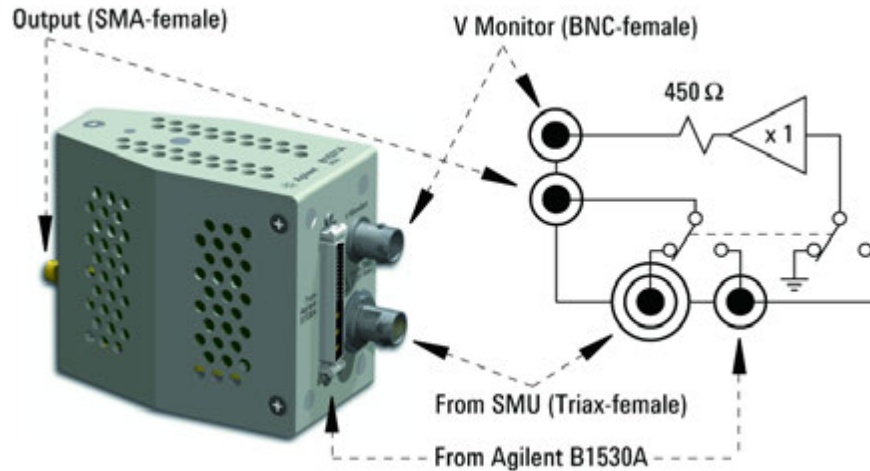

Fig 1- 5. RSU internal circuit diagram

Since the output impedance of this terminal is 450 Ω, the V Monitor signal will be 1/10 when the oscilloscope input impedance is 50 Ω. And the V Monitor signal will be ×1 when the input impedance is 1 MΩ.
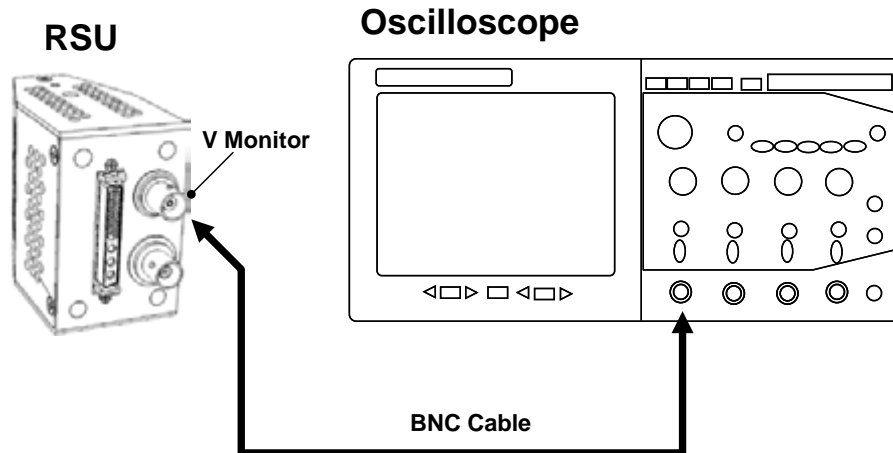

Fig. 1- 6 Connection to monitor RSU output voltage

1-4-3. To measure other devices

Discrete device other than the demo device can be measured by using the blank board or the test fixture. If you use the blank board, mount the device on the board as shown in Fig. 1-7 and solder it.
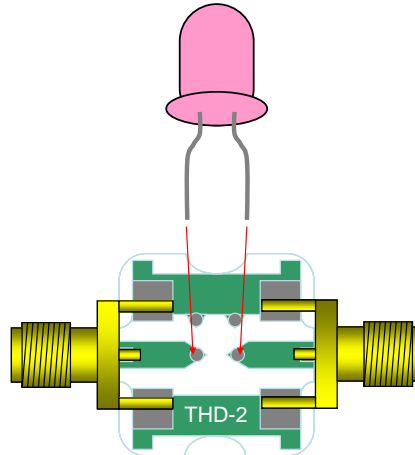

Fig 1-7 Using Blank Board

If you can have the test fixture such as Agilent 16034E/G/H and 16047A/C/D/E, connect it as shown in Fig. 1-8. Then two BNC(f)-SMA(f) adapters are additionally required for connecting the SMA(m)-SMA(m) cables from RSU to the test fixture inputs.

Connect the adapters to the Hcur input and the Lcur input of the test fixture. And leave the Hpot and Lpot inputs open or connect the BNC(f) open adapter if available to prevent these terminals from applying the WGFMU output voltage.
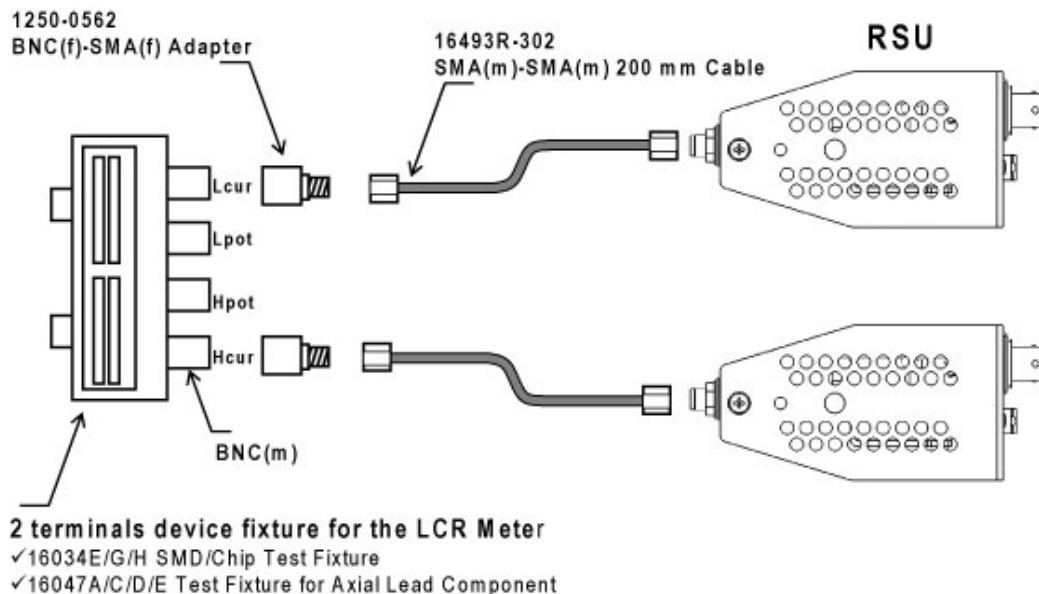

Fig 1-8 Using Test Fixture

The 16034E, 16034G, and 16034H are useful for connecting the two terminal surface mount devices or chip devices. And the 16047A, 16047C, 16047D, and 16047E are useful for the two terminal axial lead devices.

1-4-4. If you perform on-wafer measurement

If you want to measure a device on a wafer, the proper probe is required.

For the devices which have the contacts compatible to the GS or GSG type coaxial probe, use the RF probes. Then use the Agilent 16493R-302 SMA(m)-SMA(m) cable to connect the RSU and the RF probe. In this case, the input terminal of the probe must be compatible with SMA type, for example, 3.5 mm or K connector.
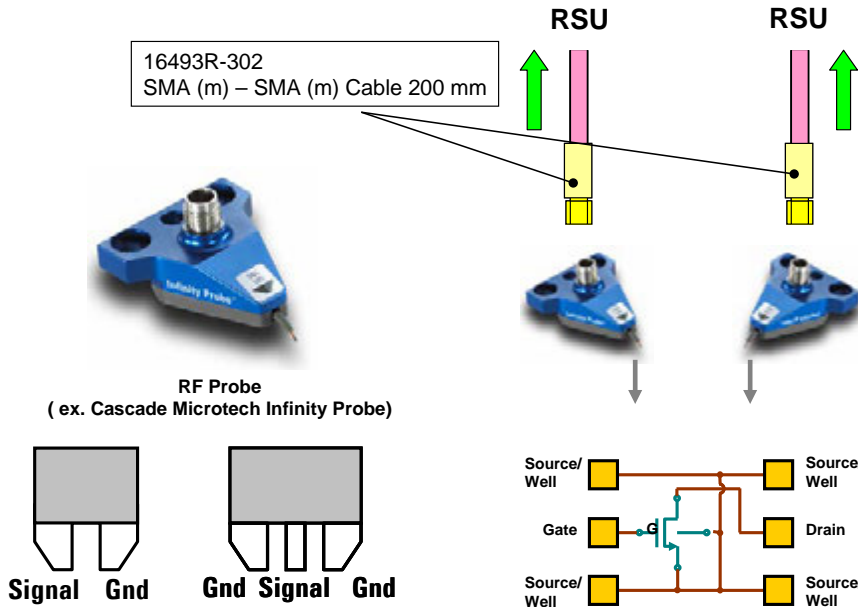

Fig 1-9. Using RF probes

If you use the DC probes for connecting a four-terminal device, use the Agilent 16493R-202 SSMC(Plug)-SMA(m) cable to connect the RSU and the DC probe. See Fig. 1-10.
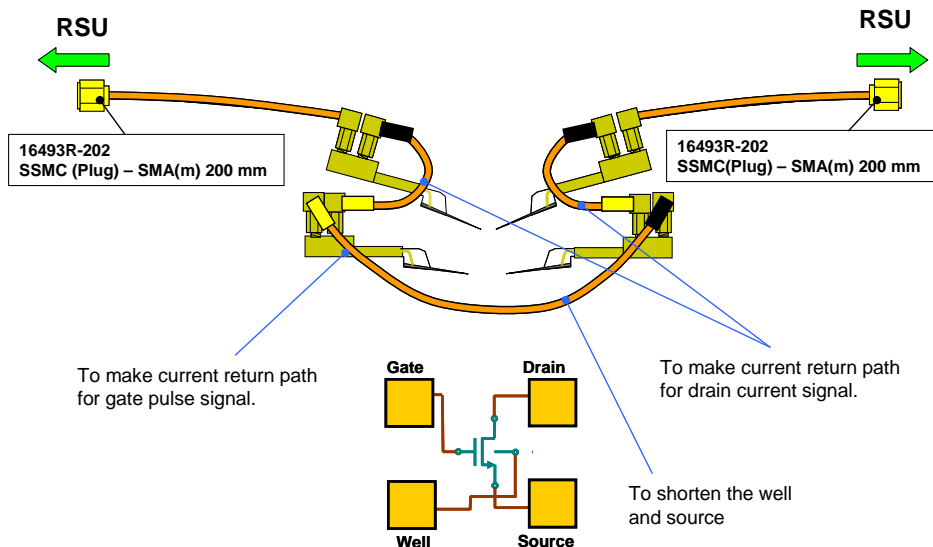

Fig. 1-10 Using DC probes for four-terminal device

In this case, three Agilent 16493R-101/102 SSMC short-open cables are additionally required to connect four DC probes. The signal line of this cable is opened at the black end and is shorted to the shield at the yellow end. See Fig. 1-11.

The cables must be connected as shown in Fig. 1-10. The black end must be the gate/drain side, and the yellow end must be the source/well/substrate side. And the third cable must be connected between the probes for the source and the well/substrate. Then the black end is the source side. This connects the shield of all probes each other. Note that the actual connection depends on the pad layout of the device.

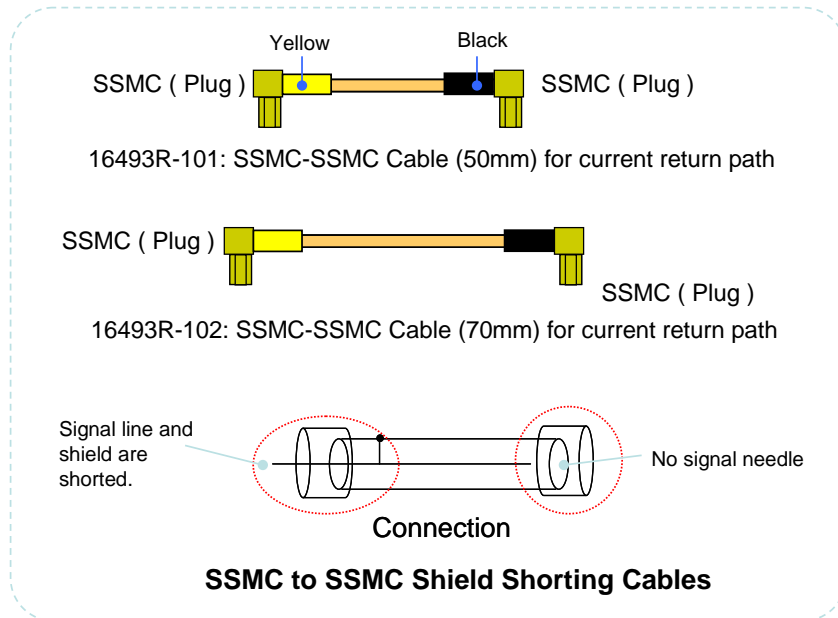**Fig 1-11 SSMC short-open cable for using DC probes**

If you use the DC probes for connecting a two-terminal device, make the current return path by connecting a cable between the shields of the DC probes as shown in Fig.1-12. The connection cable will be provided by the prober vender. Or use an alligator clip cable.
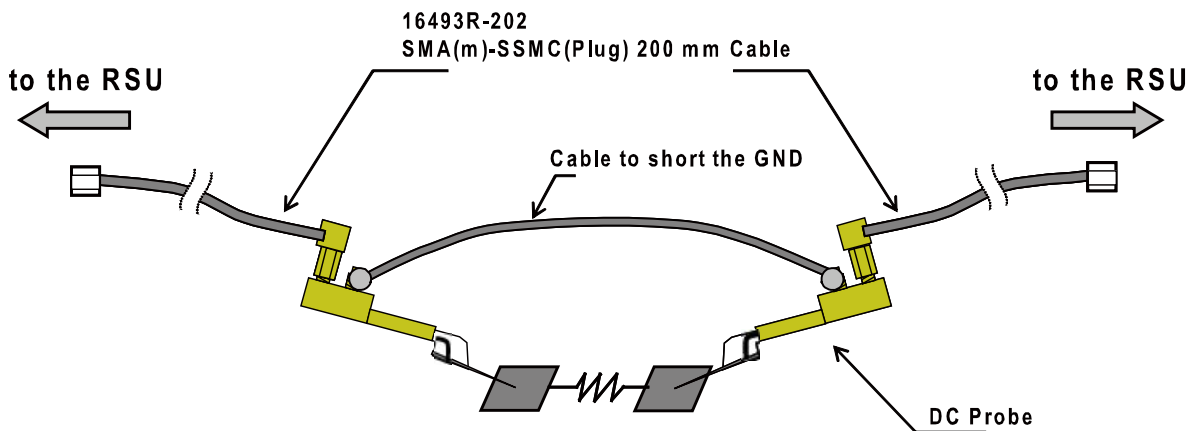
Fig 1-12 Using DC probes for two-terminal device

2   Using WGFMU Application Tests

This chapter describes how to use the WGFMU Pattern Editor application test and the reference information of the WGFMU application tests executable on the application test environment of the EasyEXPERT software and the Desktop EasyEXPERT software. This chapter consists of the following sections.

Note:

The WGFMU application tests are included in the EasyEXPERT software and the Desktop EasyEXPERT software. The application tests other than the WGFMU Pattern Editor will be usable without special instructions.

2-1. WGFMU Pattern Editor Application Test

The WGFMU Pattern Editor is one of the WGFMU application tests executable on the EasyEXPERT software and the Desktop EasyEXPERT software. This application test is very useful for understanding the basic operation of the B1530A WGFMU. The following sections describe the procedure to set the parameters to create a waveform and the parameters to perform measurements.

You will see the performance of the WGFMU by using the created test setup.

2-2. To Create Simple Waveform and Execute Measurement
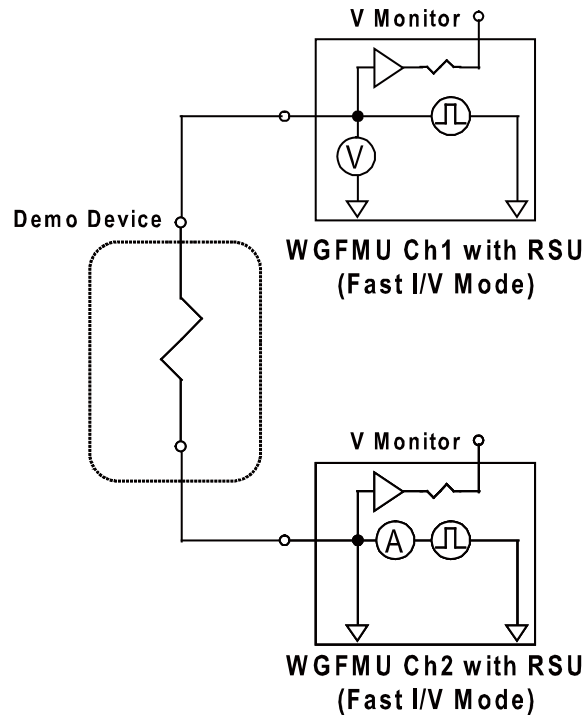
Fig. 2-1 Two-terminal resistance measurement circuit diagram

Step 1. Connect the demo device to the RSU

Connect the demo device to the RSU (see Fig. 1-4). Use the 1 kΩ demo device for this exercise.

Step 2. Connect the oscilloscope to the V Monitor terminal of the RSU (Optional)

Connect a BNC cable between the V Monitor terminal of the RSU and the oscilloscope (see Fig. 1-6).

Step 3. Plan the measurement

At first, try to measure the step response of the two-terminal resistance. Fig. 2-1 shows the circuit diagram of this measurement. The Ch1 channel is used to apply the step voltage and measure the DUT terminal voltage. The Ch2 channel is used to apply 0 V and measure the current flowing through the DUT.

Step 4. Open WGFMU Pattern Editor application test

Launch the EasyEXPERT software and open the WGFMU Pattern Editor application test definition. See Fig. 2-3 for example display of the WGFMU Pattern Editor.

Step 5. Create waveform data

Waveform you will create in this section is shown in Fig. 2-2. The Ch1channel will apply the pulse waveform with the following parameters.

✓ Top Level : 5 V

✓ Baseline Level: 0 V

✓ Pulse Period: 2 μs

✓ Pulse Width: 1 μs

✓ Rise/Fall Time: 100 ns

✓ Delay Time: 500 ns

The Ch2 channel will apply 0 Vdc. The period of the both channels must be the same.
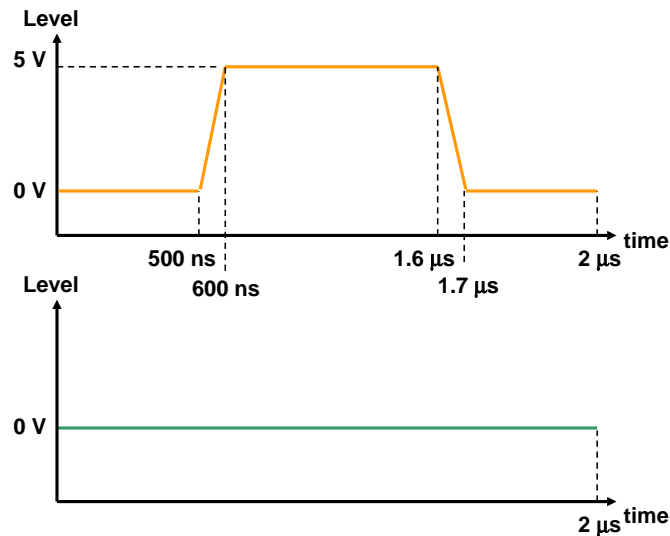
Fig. 2-2 Image of the waveform to create

The channel output can be defined by using the Define vector data dialog box opened by clicking (1) or (2) shown in Fig. 2-4. The Ch1 output can be defined by the setup shown in the left image of Fig. 2-3, and the Ch2 output can be defined by the setup shown in the right image of Fig. 2-3.

(1) WaveformCh1 setup data   **(2) WaveformCh2 setup data**

Fig. 2-3 Waveform data setup
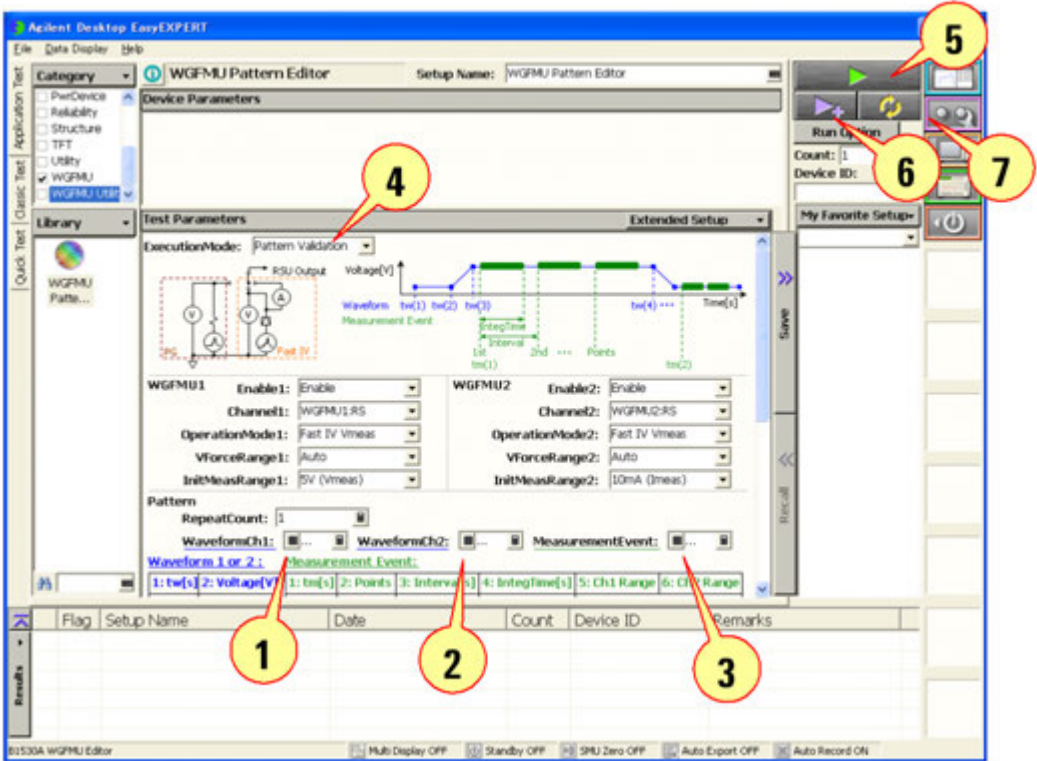
Fig. 2-4 WGFMU Pattern Editor application test

Fig. 2-5 shows the data format of the waveform data and the measurement event. The waveform data can be defined by the vector data specified by tw and Voltage. And the measurement event can be defined by the vector data specified by tm, Points, Interval, IntegTime, Ch1 Range, and Ch2 Range.
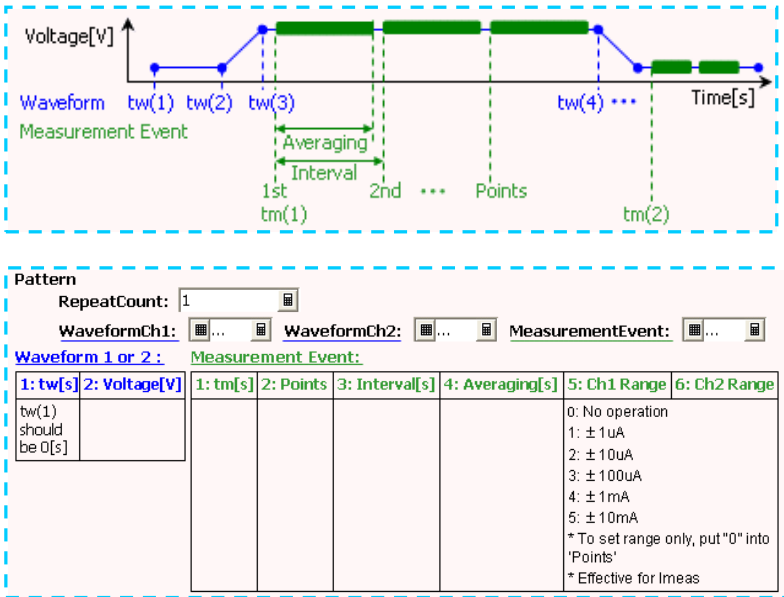
Fig. 2-5 Waveform and measurement event setup data format

Step 6. Create measurement event data

After creating the waveform data, create the measurement event data. Fig. 2-6 shows the definition of the measurement event. The WGFMU measurement channel performs the sampling measurement specified by four parameters, start time, number of measurement points, averaging time, and measurement interval. And during the averaging time, the WGFMU measurement channel performs a 5 ns interval sampling measurement and returns the averaging data.
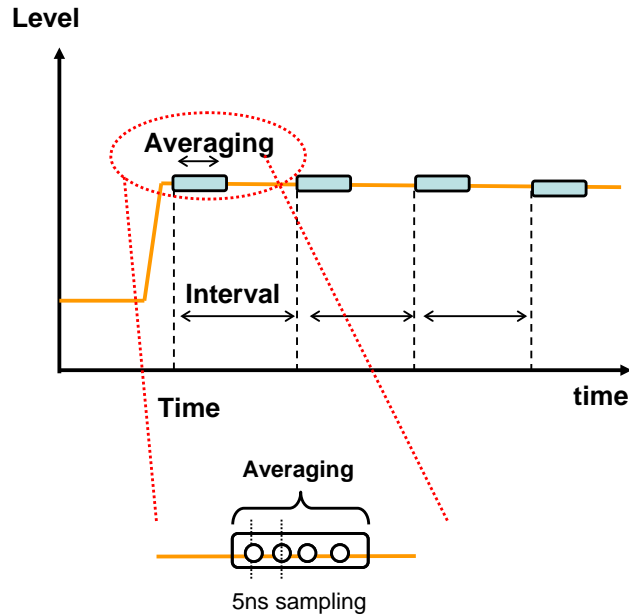
Fig. 2-6 Measurement event setup parameters

In this demonstration, you will measure the voltage and current of the entire waveform with a fastest integration time. Then set measurement parameters as shown below.

✓ Start time: 0 s

✓ Measurement Points: 200

✓ Measurement Interval: 10 ns

✓ Integration Time: 10 ns

Fig. 2-7 shows the actual setting of this measurement. The measurement event can be defined by using the Define vector data dialog box opened by clicking (3) shown in Fig. 2-4.
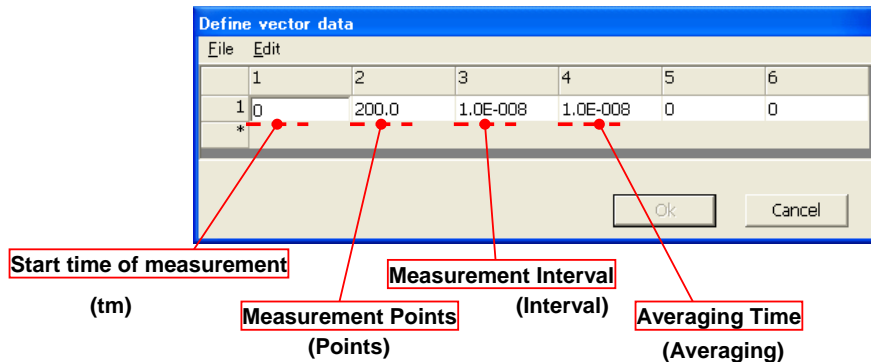
Fig. 2-7 Measurement event setup

Step 7. Select WGFMU resource and set measurement parameters

Set the operation mode, measurement mode, and measurement range.

Fig. 2-8 shows the channel setup for this demonstration.

WGFMU Ch1   WGFMU Ch2

Fig. 2-8 Channel Setup

The WGFMU 1 is used to force pulse voltage and measure voltage, so the operation mode is set as "Fast I/V Vmeas" and the measurement range, defined as an "InitMeasRange", is set as 5V.

The WGFMU 2 is used as a current measurement at lower side, the operation mode is set as "Fast I/V Imeas". Also, the measurement range is set as "10 mA". For both channel, output voltage range defined as "VFroceRange" is set as "Auto". With this mode, output voltage range is automatically selected before start forcing based on the waveform data.

Step 8. Execute measurement

To execute measurement, click (5) shown in Fig. 2-4.

Before executing the measurement, disable the intermediate data display to simplify the display of the results (Set the DataDisplay_PatternValidation field to Disable).

Fig. 2-9 shows the execution results of this demonstration.
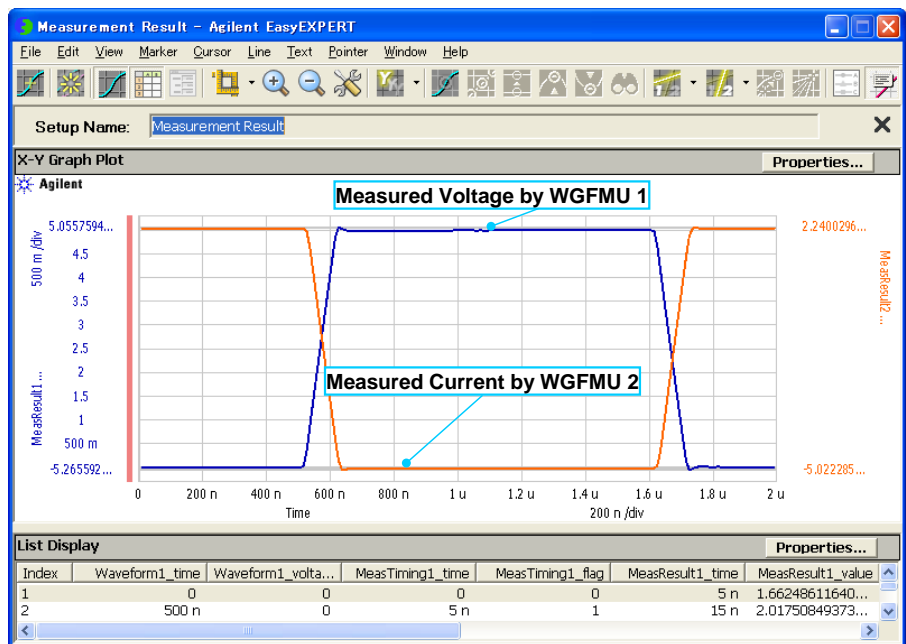
Fig. 2-9 Measurement result example

The blue line shows the voltage measured by the Ch1 and the orange line shows the current measured by the Ch2. Since the current is flowing into the Ch2, polarity of the measured current is negative.
This result shows that the WGFMU can measure the pulse current of 100 ns rise/fall time with 10 ns sampling interval clearly.

Also, Fig. 2-10 shows the output voltage monitored by the oscilloscope. Since the input impedance of the oscilloscope is set to 50 Ω, the V Monitor output is the WGFMU output × 1/10. With 100 ns rise/fall time, the monitored voltage is almost identical to the voltage measured by the Ch1. And the 0 V output by the Ch2 is kept during measurement. The response of the current measurement circuit is fast enough for this measurement condition.

This measurement demonstrates how the WGFMU can measure fast and accurately. With 10 mA measurement range, the settling time of the current meter to settle down to 0.3 % of the final value is less than 100 ns, and it is fast enough to measure current with 1 μs pulse as demonstrated here.
In the actual cases, the current measurement is performed extensively and the settling time of the WGFMU current meter depends on the current measurement range, so the measurable and minimum pulse width depends on the current range. The sample data of the settling time of each current measurement range are shown in Table 2-1.

Table 2-1 0.3 % Settling time of the current measurement (Sample data *)

Current measurement range	Settling time
10 mA**	100 ns
1 mA	300 ns
100 µA	500 ns
10 µA	2 µs
1 µA	15 µs

* Actual settling time depends on the DUT and cablings.

** When current is less than 3 mA.
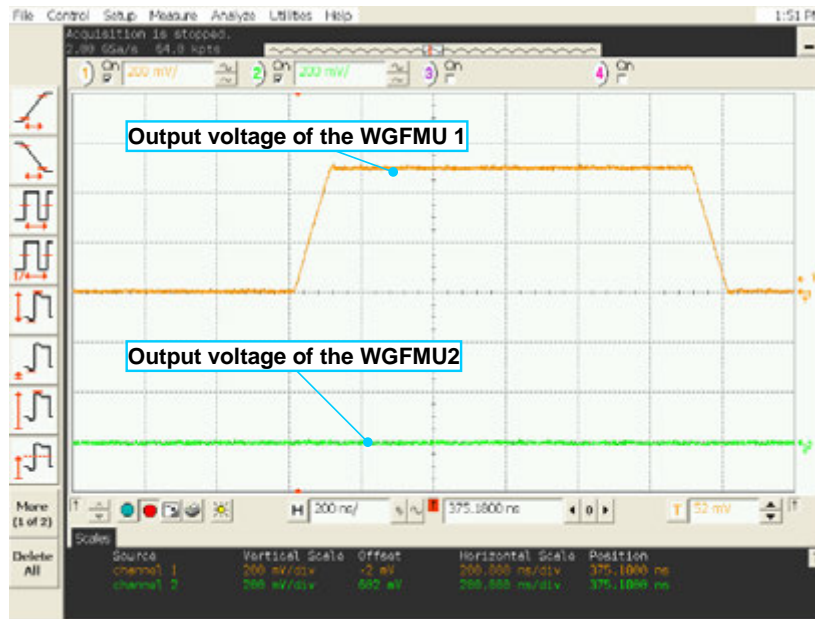
Fig. 2-10 WGFMU output voltage monitored by oscilloscope

2-3. Tips of Measurement

This section describes some tips about fast measurement using the WGFMU.

2-3-1. Wait time before measurement

As described in the previous section, the settling time is considerable for setting up the WGFMU current meter and it depends on the measurement range, so an appropriate wait time must be inserted before the measurement to obtain an accurate result.

Fig. 2-11 shows the effect of the settling time on the current measurement for the WGFMU output given by the vector setup shown in Fig. 2-12.
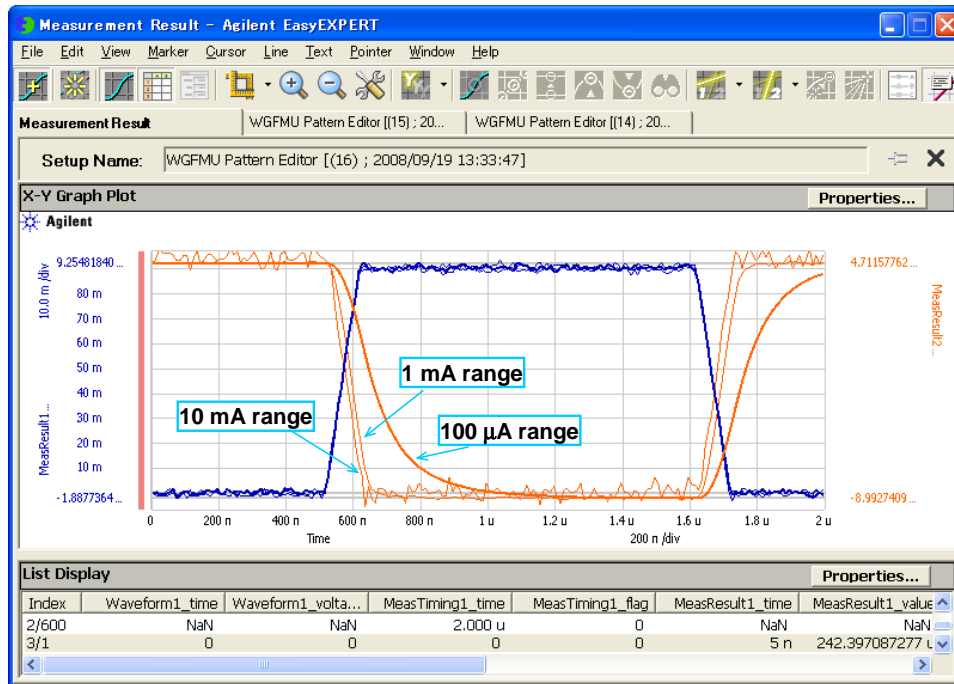
Fig. 2-11 Effect of the settling time

With the 10 mA and 1 mA range, the measured current well responds to the pulse voltage since the settling time is very fast. But the settling time of the 1 mA range is slightly longer than the 10 mA range, the measured current by the 1 mA range is slightly delayed from the results by the 10 mA range.

When using the 100 µA range, since the settling time of the 100 µA range is longer than it of the 10 mA and 1 mA range, rising and falling edge of the measured current is significantly delayed from the input pulse voltage. But when looking at the top level of the pulse, after a few hundreds nano seconds from the rising edge of the pulse, the measured current by the 100 µA range is almost settled to the final value. The appropriate wait time depends on the settling condition you desire. If it is severe, the long wait time is required before measurement. However if it can be alleviated, the wait time can be reduced.

Fig. 2-12 Waveform data of the WGFMU Ch1 for this demonstration

2-3-2. To reduce a noise by averaging

For an accurate measurement, an averaging is very useful to reduce the noise floor. Normally, if the noise is "white", the noise floor can be reduced by averaging. And the relation between the noise and the averaging number can be roughly estimated by the following formula.

$$\text{Noise Level} \propto \dfrac{1}{\sqrt{\text{Averaging Time}}}$$

But the actual reduction of noise level is limited by the resolution of the A/D convertor.

Fig. 2-13 shows the improvement of the noise floor by averaging. The current range is 10 mA. The noise measured by the 1 μsec integration time (averaging of the 200 measurement points of 5 ns sampling) is significantly improved from the 10 ns integration time (averaging of the 2 measurement points).
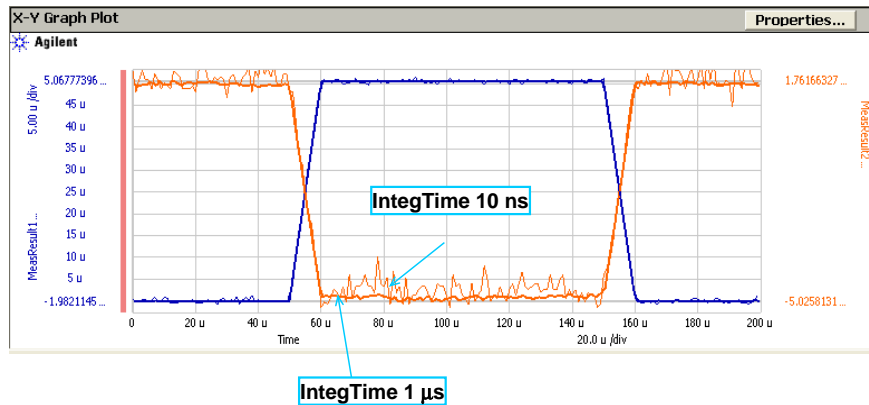
Fig. 2-13 Reducing the noise floor by the averaging function

To obtain this kind of result, use the setup shown in the Fig. 2-14. And execute measurement with the 10 ns averaging first, then change the averaging time to 1 μs and click the Append button, (6) shown in Fig. 2-4, to overlay the measurement data.

Fig. 2-14 Waveform and measurement setup of this demonstration

2-3-3. Effect of cable connection

If the pulse source WGFMU (Ch1 of Fig. 2-15) is used for the current measurement of a two-terminal device, the measured current will contain the current to charge the stray capacitance of cables additionally to the current which flows through the DUT. So, use the constant source WGFMU (Ch2 of Fig. 2-15) for the measurement.
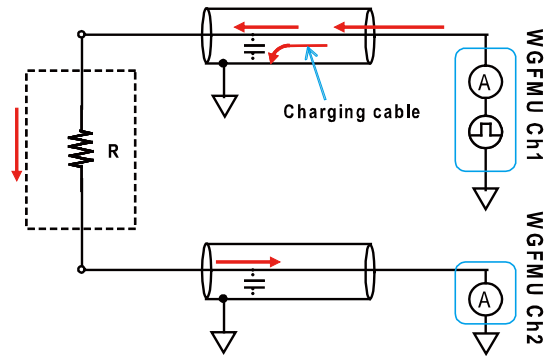
Fig. 2-15 Effect of cable-charge current

Fig. 2-16 shows the measured current by both the Ch1 and the Ch2.
On the current measured by the Ch1, large transient current is observed both at the rising edge and falling edge. At the rising edge, the cable-charge current is measured additionally to the current which flows through the DUT, and at the falling edge, the current for discharging the cables is measured too. In contrast, the current measured by the Ch2 which applies the constant voltage shows the clear rising / falling slope because there is no additional current to charge or discharge the cables.
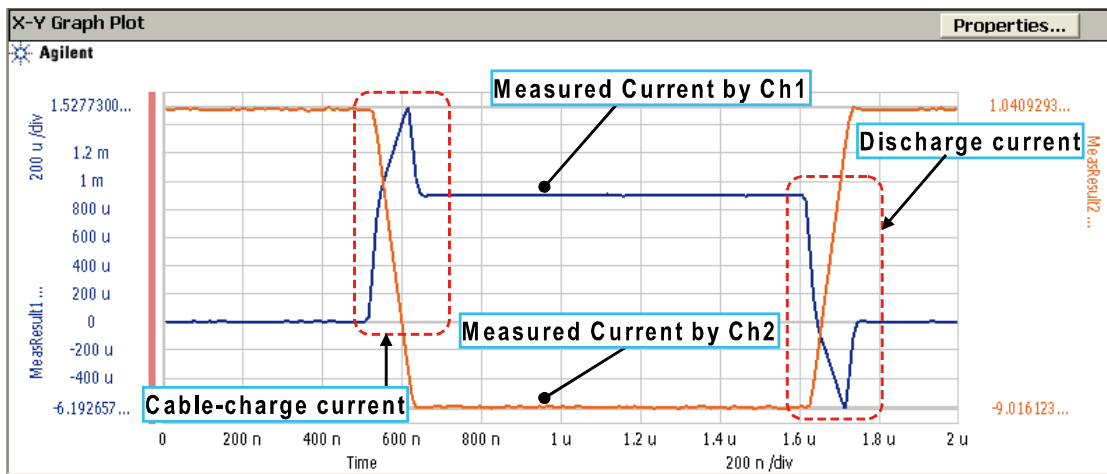
Fig. 2-16 Measurement example of cable-charge current

The waveform data, measurement parameter, and channel setup to show this demonstration are shown in Fig. 2-17, Fig. 2-18, and Fig. 2-19 respectively.

WGFMU Ch1   **WGFMU Ch2**

Fig. 2- 17 Waveform data of this demonstration

Fig. 2- 18 Measurement setup of this demonstration

WGFMU Ch1   **WGFMU Ch2**

Fig. 2- 19 Channel setup of this demonstration

2-4. Additional Application

The setup used in this chapter is also applicable for the pulse response measurement of the PD (Photo Diode) or LED (Light Emitting Diode). The WGFMU 1 to force the pulse voltage is used to drive the light source (LED) and the WGFMU 2 is used to measure the current of photo detector (PD) with a constant bias voltage. Fig. 2-20 shows the measurement circuit diagram of the pulse response of the PD / LED by using the WGFMU.
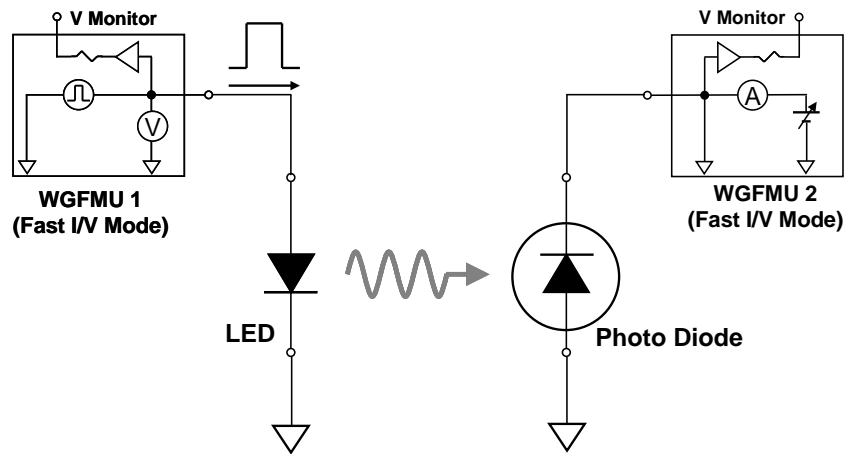
Fig. 2-20 Application for the LED measurement

2-5. WGFMU Application Test Reference

This section describes the reference information of the WGFMU application tests included in the EasyEXPERT software and the Desktop EasyEXPERT software.

2-5-1. Fast BTI(AC stress Id-Sampling):   Bias Temperature Instability Test, using WGFMU

2-5-2. Fast BTI(DC stress Id-Sampling):   Bias Temperature Instability Test, using WGFMU

2-5-3. Fast BTI(AC stress Id-Vg):   Bias Temperature Instability Test, using WGFMU

2-5-4. Fast BTI(DC stress Id-Vg):   Bias Temperature Instability Test, using WGFMU

2-5-5. TRANSIV DC IdVd: Id-Vd characteristics, using RSU

2-5-6. TRANSIV DC IdVg: Id-Vg characteristics, using RSU

2-5-7. WGFMU Pattern Editor: WGFMU Pattern Editor

2-5-1. Fast BTI(AC stress Id-Sampling): Bias Temperature Instability Test, using WGFMU

[Description]

Performs the bias temperature instability test with the AC stress, and plots the accumulated stress time vs drain current characteristics. This test is performed by repeating the following steps for the accumulated stress time defined in Accumlated_Stress_Time.

1. AC stress output

2. Drain current measurement

[Device Under Test]

MOSFET, 3 or 4 terminals

Drain and gate must be connected to WGFMU channel through RSU.

Source and substrate must be connected to WGFMU ground which is the outer conductor of the RSU Output terminals used for Drain and Gate.

[Required Modules and Accessories]

Agilent B1530A WGFMU 1 unit

Agilent B1531A RSU 2 set

[Device Parameters]

Polarity: Nch (forces specified value) or Pch (forces negative specified value)

Temp: Temperature (deg C)

L: Gate length

W: Gate width

[Test Parameters]

GateCh: WGFMU channel connected to Gate terminal

DrainCh: WGFMU channel connected to Drain terminal

IdMeasRange: Drain current measurement range (for Id measurement)

IdStressRange: Drain current measurement range (for AC stress)

RangeChangeHold: Wait time at the transition from stress to measurement

RangeChangeHold must be set to minimize the impact of the range change.

[Stress Setup]

VgStress: AC stress peak voltage for Gate terminal

VgStressBase: AC stress base voltage for Gate terminal

VdStress: AC stress peak voltage for Drain terminal

VdStressBase: AC stress base voltage for Drain terminal

StressFreq: Set frequency of stress.

StressEdge: Set rise and fall time of stress pulses.

StressDuty: Set duty ratio of stress pulses.

Accumlated_Stress_Time: Accumulated stress time

Accumulated stress time can be defined by using the Define vector data dialog box. Enter the accumulated stress time values in the first column from up to down. To open the Define vector data dialog box, click the left button in the Accumlated_Stress_Time field. Clicking the * button on the dialog box increases the entry fields.

[Meas Setup]

VgMeas: Gate voltage for Id measurement

VdMeas: Drain voltage for Id measurement

MeasDelay: Delay time until the measurement is started after the transition to the measurement voltage is started

MeasInterval: Sampling interval (for Id measurement)

MeasPoints: Number of the Id measurement points

IntegTime: Integration time for one measurement point

TransEdge: Voltage change time between the stress voltage and the measurement voltage, for both Gate and Drain terminals

SeqDelay: Device delay time

Lin_Log: Linear (linear sampling), Log10 (10 points/decade log sampling), or Log25 (25 points/decade log sampling)

PointToPlot: Data index to specify the Id measurement data used for result data plot

Device delay time must be set to avoid that the high voltage is applied to the drain and gate terminals simultaneously at the transition between stress and measurement. The value depends on the device under test, TransEdge value, and such.

PointToPlot must be 1 to MeasPoints. PointToPlot=1 specifies the first measurement data.

[Device_ID_Setup]

Device_ID_Override: Y (sets the New_Device_ID value to the Device ID) or N (does not set)

New_Device_ID: Device ID

[Pattern_Validate_Setup]

PatternValidateFile: Absolute path name of the file for checking WGFMU output waveform.

[Extended Test Parameters]

VgForceRange: Gate voltage output range

VdForceRange: Drain voltage output range

[Test Output: X-Y Graph]

Id-AccumlatedStressTime: Drain current vs Accumulated stress time characteristics

2-5-2. Fast BTI(DC stress Id-Sampling): Bias Temperature Instability Test, using WGFMU

[Description]

Performs the bias temperature instability test with the DC stress, and plots the accumulated stress time vs drain current characteristics. This test is performed by repeating the following steps for the accumulated stress time defined in Accumlated_Stress_Time.

1. DC stress output

2. Drain current measurement

[Device Under Test]

MOSFET, 3 or 4 terminals

Drain and gate must be connected to WGFMU channel through RSU.

Source and substrate must be connected to WGFMU ground which is the outer conductor of the RSU Output terminals used for Drain and Gate.

[Required Modules and Accessories]

Agilent B1530A WGFMU 1 unit

Agilent B1531A RSU 2 set

[Device Parameters]

Polarity: Nch (forces specified value) or Pch (forces negative specified value)

Temp: Temperature (deg C)

L: Gate length

W: Gate width

[Test Parameters]

GateCh: WGFMU channel connected to Gate terminal

DrainCh: WGFMU channel connected to Drain terminal

IdMeasRange: Drain current measurement range (for Id measurement)

IdStressRange: Drain current measurement range (for DC stress)

RangeChangeHold: Wait time at the transition from stress to measurement

RangeChangeHold must be set to minimize the impact of the range change.

[Stress Setup]

VgStress: Stress voltage for Gate terminal

VdStress: Stress voltage for Drain terminal

Accumlated_Stress_Time: Accumulated stress time

Accumulated stress time can be defined by using the Define vector data dialog box. Enter the accumulated stress time values in the first column from up to down. To open the Define vector data dialog box, click the left button in the Accumlated_Stress_Time field. Clicking the * button on the dialog box increases the entry fields.

[Meas Setup]

VgMeas: Gate voltage for Id measurement

VdMeas: Drain voltage for Id measurement

MeasDelay: Delay time until the measurement is started after the transition to the measurement voltage is started

MeasInterval: Sampling interval (for Id measurement)

MeasPoints: Number of the Id measurement points

IntegTime: Integration time for one measurement point

TransEdge: Voltage change time between the stress voltage and the measurement voltage, for both Gate and Drain terminals

SeqDelay: Device delay time

Lin_Log: Linear (linear sampling), Log10 (10 points/decade log sampling), or Log25 (25 points/decade log sampling)

PointToPlot: Data index to specify the Id measurement data used for result data plot

Device delay time must be set to avoid that the high voltage is applied to the drain and gate terminals simultaneously at the transition between stress and measurement. The value depends on the device under test, TransEdge value, and such.

PointToPlot must be 1 to MeasPoints. PointToPlot=1 specifies the first measurement data.

[Device_ID_Setup]

Device_ID_Override: Y (sets the New_Device_ID value to the Device ID) or N (does not set)

New_Device_ID: Device ID

[Extended Test Parameters]

VgForceRange: Gate voltage output range

VdForceRange: Drain voltage output range

[Test Output: X-Y Graph]

Id-AccumlatedStressTime: Drain current vs Accumulated stress time characteristics

2-5-3. Fast BTI(AC stress Id-Vg): Bias Temperature Instability Test, using WGFMU

[Description]

Performs the bias temperature instability test with the AC stress, and plots the accumulated stress time vs threshold voltage characteristics. This test is performed by repeating the following steps for the accumulated stress time defined in Accumlated_Stress_Time.

1. AC stress output

2. Id-Vg measurement

[Device Under Test]

MOSFET, 3 or 4 terminals

Drain and gate must be connected to WGFMU channel through RSU.

Source and substrate must be connected to WGFMU ground which is the outer conductor of the RSU Output terminals used for Drain and Gate.

[Required Modules and Accessories]

Agilent B1530A WGFMU 1 unit

Agilent B1531A RSU 2 set

[Device Parameters]

Polarity: Nch (forces specified value) or Pch (forces negative specified value)

Temp: Temperature (deg C)

L: Gate length

W: Gate width

Id_at_Vth: Drain current to decide the Vth

[Test Parameters]

GateCh: WGFMU channel connected to Gate terminal

DrainCh: WGFMU channel connected to Drain terminal

IdMeasRange: Drain current measurement range (for Id-Vg measurement)

IdStressRange: Drain current measurement range (for AC stress)

RangeChangeHold: Wait time at the transition from stress to measurement

RangeChangeHold must be set to minimize the impact of the range change.

[Stress Setup]

VgStress: AC stress peak voltage for Gate terminal

VgStressBase: AC stress base voltage for Gate terminal

VdStress: AC stress peak voltage for Drain terminal

VdStressBase: AC stress base voltage for Drain terminal

StressFreq: Set frequency of stress.

StressEdge: Set rise and fall time of stress pulses.

StressDuty: Set duty ratio of stress pulses.

Accumlated_Stress_Time: Accumulated stress time

Accumulated stress time can be defined by using the Define vector data dialog box. Enter the accumulated stress time values in the first column from up to down. To open the Define vector data dialog box, click the left button in the Accumlated_Stress_Time field. Clicking the * button on the dialog box increases the entry fields.

[Meas Setup]

VgStart: Sweep start voltage for Gate terminal

VgStop: Sweep stop voltage for Gate terminal

StepNum: Number of measurement points (number of sweep steps) per 1 sweep

StepRise: Step voltage change time (not available for the ramp sweep)

Sweep: Step (step sweep) or Ramp (ramp sweep)

Slope: Single (VgStart to VgStop) or Dual (VgStart to VgStop to VgStart)

VdMeas: Drain voltage for the Id-Vg measurement

SeqDelay: Device delay time

TransEdge: Voltage change time between the stress voltage and the measurement voltage, for both Gate and Drain terminals

IntegTime: Integration time for one measurement point

StepDelay: Step delay time

Hold: Hold time

Device delay time must be set to avoid that the high voltage is applied to the drain and gate terminals simultaneously at the transition between stress and measurement. The value depends on the device under test, TransEdge value, and such.

Step delay time is defined as the time from the step output start to the step measurement start.

Hold time is defined as the time from the measurement voltage output start to the sweep operation start. For the Dual slope, the hold time is taken at the sweep start of both forward sweep and reverse sweep.

[Device_ID_Setup]

Device_ID_Override: Y (sets the New_Device_ID value to the Device ID) or N (does not set)

New_Device_ID: Device ID

[Pattern_Validate_Setup]

PatternValidateFile: Absolute path name of the file for checking WGFMU output waveform.

[Extended Test Parameters]

VgForceRange: Gate voltage output range

VdForceRange: Drain voltage output range

StepMargin: Time from the step measurement end to the next step output start (not available for the ramp sweep)

[Test Output: X-Y Graph]

Id-t: Drain current vs Time characteristics

Id-Vg: Drain current vs Gate voltage characteristics

Vth-AccumlatedStressTime: Threshold voltage vs Accumulated stress time characteristics

2-5-4. Fast BTI(DC stress Id-Vg): Bias Temperature Instability Test, using WGFMU

[Description]

Performs the bias temperature instability test with the DC stress, and plots the accumulated stress time vs threshold voltage characteristics. This test is performed by repeating the following steps for the accumulated stress time defined in Accumlated_Stress_Time.

1. DC stress output

2. Id-Vg measurement

[Device Under Test]

MOSFET, 3 or 4 terminals

Drain and gate must be connected to WGFMU channel through RSU.

Source and substrate must be connected to WGFMU ground which is the outer conductor of the RSU Output terminals used for Drain and Gate.

[Required Modules and Accessories]

Agilent B1530A WGFMU 1 unit

Agilent B1531A RSU 2 set

[Device Parameters]

Polarity: Nch (forces specified value) or Pch (forces negative specified value)

Temp: Temperature (deg C)

L: Gate length

W: Gate width

Id_at_Vth: Drain current to decide the Vth

[Test Parameters]

GateCh: WGFMU channel connected to Gate terminal

DrainCh: WGFMU channel connected to Drain terminal

IdMeasRange: Drain current measurement range (for Id-Vg measurement)

IdStressRange: Drain current measurement range (for DC stress)

RangeChangeHold: Wait time at the transition from stress to measurement

RangeChangeHold must be set to minimize the impact of the range change.

[Stress Setup]

VgStress: Stress voltage for Gate terminal

VdStress: Stress voltage for Drain terminal

Accumlated_Stress_Time: Accumulated stress time

Accumulated stress time can be defined by using the Define vector data dialog box. Enter the accumulated stress time values in the first column from up to down. To open the Define vector data dialog box, click the left button in the Accumlated_Stress_Time field. Clicking the * button on the dialog box increases the entry fields.

[Meas Setup]

VgStart: Sweep start voltage for Gate terminal

VgStop: Sweep stop voltage for Gate terminal

StepNum: Number of measurement points (number of sweep steps) per 1 sweep

StepRise: Step voltage change time (not available for the ramp sweep)

Sweep: Step (step sweep) or Ramp (ramp sweep)

Slope: Single (VgStart to VgStop) or Dual (VgStart to VgStop to VgStart)

VdMeas: Drain voltage for the Id-Vg measurement

SeqDelay: Device delay time

TransEdge: Voltage change time between the stress voltage and the measurement voltage, for both Gate and Drain terminals

IntegTime: Integration time for one measurement point

StepDelay: Step delay time

Hold: Hold time

Device delay time must be set to avoid that the high voltage is applied to the drain and gate terminals simultaneously at the transition between stress and measurement. The value depends on the device under test, TransEdge value, and such.

Step delay time is defined as the time from the step output start to the step measurement start.

Hold time is defined as the time from the measurement voltage output start to the sweep operation start. For the Dual slope, the hold time is taken at the sweep start of both forward sweep and reverse sweep.

[Device_ID_Setup]

Device_ID_Override: Y (sets the New_Device_ID value to the Device ID) or N (does not set)

New_Device_ID: Device ID

[Extended Test Parameters]

VgForceRange: Gate voltage output range

VdForceRange: Drain voltage output range

StepMargin: Time from the step measurement end to the next step output start (not available for the ramp sweep)

[Test Output: X-Y Graph]

Id-t: Drain current vs Time characteristics

Id-Vg: Drain current vs Gate voltage characteristics

Vth-AccumlatedStressTime: Threshold voltage vs Accumulated stress time characteristics

2-5-5. TRANSIV DC IdVd: Id-Vd characteristics, using RSU

[Description]

Measures the drain current vs drain voltage characteristics of MOSFET.

[Device Under Test]

MOSFET, 3 or 4 terminals

Drain and gate must be connected to SMU through RSU.

Source and substrate must be connected to WGFMU ground which is the outer conductor of the RSU Output terminals used for Drain and Gate.

[Required Modules and Accessories]

Agilent B1530A WGFMU 1 unit

Agilent B1531A RSU 2 set

[Device Parameters]

Polarity: Nch (SMU forces specified value) or Pch (SMU forces negative specified value)

L: Gate length

W: Gate width

Temp: Temperature (deg C)

IdLimit: Drain current compliance

[Test Parameters]

Gate: SMU connected to Gate terminal, secondary sweep voltage output

VgStart: Sweep start voltage for Gate terminal

VgStop: Sweep stop voltage for Gate terminal

VgStep: Sweep step voltage for Gate terminal

Drain: SMU connected to Drain terminal, primary sweep voltage output

VdStart: Sweep start voltage for Drain terminal

VdStop: Sweep stop voltage for Drain terminal

VdStep: Sweep step voltage for Drain terminal

[Extended Test Parameters]

IgLimit: Gate current compliance

IntegTime: Integration time

HoldTime: Hold time

DelayTime: Delay time

[Measurement Parameters]

Drain current Id

[User Function]

IdPerW: Drain current per unit gate width IdPerW=Id/W

[X-Y Plot]

   X axis: Gate voltage Vd (LINEAR)

   Y1 axis: Drain current Id (LINEAR)

[List Display]

   Gate voltage Vg

   Drain voltage Vd

   Drain current Id

   Drain current per unit gate width IdPerW

2-5-6. TRANSIV DC IdVg: Id-Vg characteristics, using RSU

[Description]

Measures the drain current vs gate voltage characteristics of MOSFET.

[Device Under Test]

MOSFET, 3 or 4 terminals

Drain and gate must be connected to SMU through RSU.

Source and substrate must be connected to WGFMU ground which is the outer conductor of the RSU Output terminals used for Drain and Gate.

[Required Modules and Accessories]

Agilent B1530A WGFMU 1 unit

Agilent B1531A RSU 2 set

[Device Parameters]

Polarity: Nch (SMU forces specified value) or Pch (SMU forces negative specified value)

L: Gate length

W: Gate width

Temp: Temperature (deg C)

IdLimit: Drain current compliance

[Test Parameters]

Gate: SMU connected to Gate terminal, primary sweep voltage output

VgStart: Sweep start voltage for Gate terminal

VgStop: Sweep stop voltage for Gate terminal

VgStep: Sweep step voltage for Gate terminal

Drain: SMU connected to Drain terminal, secondary sweep voltage output

VdStart: Sweep start voltage for Drain terminal

VdStop: Sweep stop voltage for Drain terminal

VdStep: Sweep step voltage for Drain terminal

[Extended Test Parameters]

IgLimit: Gate current compliance

IntegTime: Integration time

HoldTime: Hold time

DelayTime: Delay time

[Measurement Parameters]

Drain current Id

[User Function]

IdPerW: Drain current per unit gate width IdPerW=Id/W

[X-Y Plot]

   X axis: Gate voltage Vg (LINEAR)

   Y1 axis: Drain current Id (LINEAR)

[List Display]

   Gate voltage Vg

   Drain voltage Vd

   Drain current Id

   Drain current per unit gate width IdPerW

2-5-7. WGFMU Pattern Editor

[Description]

Performs the WGFMU channel output setup and the measurement setup.

Set the ExecutionMode to Run Vector and click the Single button to perform the WGFMU channel output and measurement.

[Test Parameters]

ExecutionMode: Execution mode

Run Vector: Performs the waveform output and measurement

Pattern Validation: Displays the waveform and measurement setup, for debugging

[WGFMU1 and WGFMU2]

Enable: Enable (uses the channel) or Disable (does not use)

Channel: WGFMU channel to use

OperationMode: Operation mode

PG Vmeas (PG mode, voltage measurement)

Fast IV Imeas (Fast IV mode, current measurement)

Fast IV Vmeas (Fast IV mode, voltage measurement)

VForceRange: Voltage output range

Auto, 3V, 5V, -10V to 0V, or 0V to 10V

InitMeasRange: Measurement range

For current measurement: 1uA, 10uA, 100uA, 1mA, or 10mA

For voltage measurement: 5V or 10V

[Pattern]

RepeatCount: Repeat count of waveform data and measurement event data (see Note below)

WaveformCh1: Channel1 waveform data

WaveformCh2: Channel2 waveform data

MeasurementEvent: Measurement event data (see Note below)

Waveform data and measurement event data can be defined by using the Define vector data dialog box. To open the Define vector data dialog box, click the left button of each field. Clicking the * button on the dialog box increases the row.

Waveform 1 or 2: Waveform data

Column 1: Time (absolute value), tw[s]

Column 2: Voltage output value, Voltage[V]

Measurement Event: Measurement event data

Column 1: Sampling measurement start time (absolute value), tm[s]

Column 2: Number of measurement points per one sampling, Points (see Note below)

Column 3: Sampling interval, Interval[s]

Column 4: Averaging time per one point measurement, Averaging[s]

Column 5: Ch1 range event, Ch1 Range

Column 6: Ch2 range event, Ch2 Range

For the column 5 and 6, 0 is set normally. For the current measurement, setting a number from 1 to 5 enables the range event. This changes the current measurement range to the specified range when the sampling measurement is started.

1: 1uA, 2: 10uA, 3: 100uA, 4: 1mA, 5: 10mA

To set the range event only without the measurement event, enter 0 to the column 2 and set the column 5 and 6.

To obtain the stable result for the current measurement with range changing, set the sampling measurement start time to the value which exceeds 100 micro seconds after the range is changed.

[Output_to_File_for_PatternValidation] Not effective for Run Vector mode

Output_Enable: Enable or Disable

Enable (saves the waveform and measurement setup data to the file specified by Output_Filename)

Disable (does not save)

Output_Filename: Absolute path name of the file to save the waveform and measurement setup data

[DataDisplay_for_RunVector] Not effective for Pattern Validation mode

DataDisplay_PatternValidation: PatternValidation data display mode

Disable (does not display PatternValidation data during measurement)

Enable_Waveform (displays Waveform during measurement)

Enable_Waveform_MeasTiming (displays Waveform and MeasTiming during measurement)

DataDisplay_Mode: Data Display window display mode

x(time)_y(meas): Time for X axis and measurement data for Y axis

x(meas1)_y(meas2): Ch1 measurement data for X axis and Ch2 measurement data for Y axis

[Extended Test Parameters]

LogToFile: Enable or Disable

Enable (logs error and warning)

Disable (does not log)

LogFile: Absolute path name of the log file

WarningLevel: Warning level

Off: No warning is reported

Severe: Severe warning is reported

Normal: Normal warning is reported

Information: Information warning is reported

IForceRange1: Current measurement range when the sampling measurement is started

1uA, 10uA, 100uA, 1mA, or 10mA

This value is effective until the range is changed by the range event.

Result_Update_Interval_s: Interval of updating the measurement result. 2 to 100 seconds.

[Note]

Maximum number of total measurement points (RepeatCount * sum of all Points values):

- If ExecutionMode = Pattern Validation: 5001

- If DataDisplay_for_RunVector = Disable: 20001

- If DataDisplay_for_RunVector = Enable_Waveform: 20001

- If DataDisplay_for_RunVector = Enable_Waveform_MeasTiming: 5001

3   Using Sample Programs

This chapter describes how to use the sample programs executable on an instrument controller. This chapter consists of the following sections.

3-1. Preparation

Step 1. Install the sample software of the B1530A WGFMU

Step 2. Connect the GPIB cable between the B1500A and the instrument controller

 To install the sample programs, see Chapter 4 Sample Program Reference.

Step 3. Connect the demo device to the RSU, and execute the sample program of the target application.

3-2. NBTI / PBTI Test

Fig. 3-2-1 shows the measurement circuit of the NBTI/PBTI test using the WGFMU.

Fig. 3-2-1 Connection for the demonstration of the NBTI/PBTI test

3-2-1. To decide measurement condition

Actually, NBTI characteristics can not be observed on the MOS FET which is a demo device furnished with the learning kit, so this section describes how the waveform is observed by the "NBTI.exe" sample program. If you try to measure your device not the demo device, change the stress voltage to the appropriate value for it.

Fig. 3-2-2 shows the typical IdVg measurement result of the demo device 2SK302 which is the enhancement type of NMOS-FET. This is measured by a SMU.
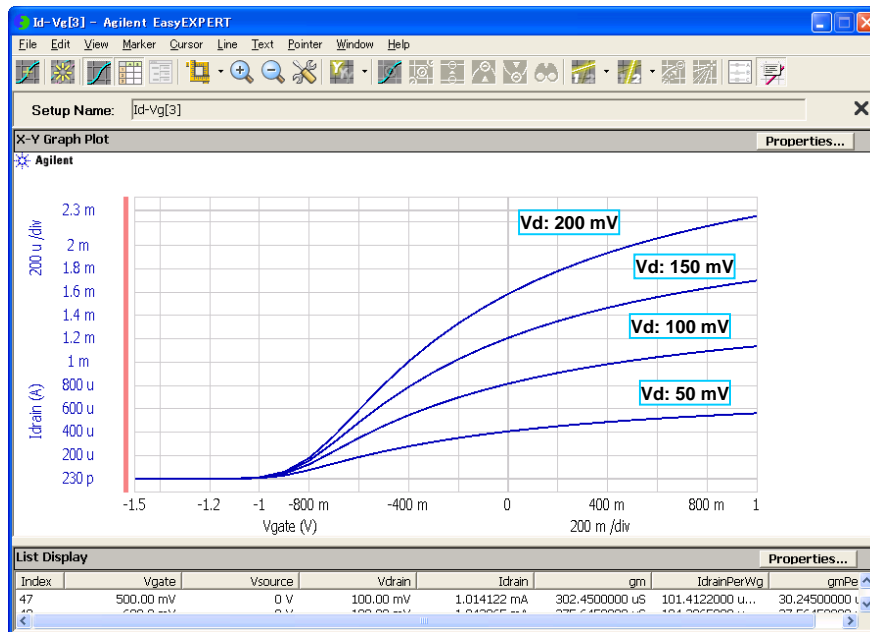
Fig. 3-2-2 SMU measurement result of the demo MOS FET IdVg characteristics

The following measurement condition can be decided to demonstrate the fastest measurement by a WGFMU using the 10 mA current measurement range.

For Spot Measurement:
✓ Vg: 0.5 V
✓ Vd: 0.1 V

For Sweep Measurement
✓ Vg:-1.5 V to 0.5 V
✓ Vd: 0.1 V

3-2-2. Fast single Id measurement

This demonstration shows how the WGFMU can minimize the interruption of the stress for the single Id measurement, less than 1 μsec.

Step 1: Confirm configuration
Run the NBTI/PBTI sample program, NBTI.exe, and check the configuration by clicking the "Config" button.

Fig. 3-2-3 Configuration panel

Set the VISA ID (Visa Name) of the GPIB interface installed in the instrument controller and the GPIB Address of the B1500A properly. To confirm the communication between the instrument controller and the B1500A, click "Initialize" button and check the list of the WGFMU modules and a response to the "UNT?" command are displayed in the "Message" box.
Also, the self calibration and self test can be triggered from this panel by clicking the buttons it's own. The results of the self calibration and self test are displayed in the "Message" box.

Step 2: Set measurement parameters
To perform this demonstration, enter the parameters as shown in Table 3-2-1.

In this demonstration, the extra bias channels are not used, so select "N/A" for both the bias source1 and bias source2. See Table 3-2-2.

To see the entire waveform on the screen of the oscilloscope, the accumulated stress time to interrupt is relatively short. See Table 3-2-3. For the actual measurement, the maximum value for the accumulated stress time is up to 1,000,000 s.

In this demonstration, only the DC stress mode is used. The setup value in the "Vg Pulse" and "Vd Pulse" group will be used in the demonstration of the section 3-2-5 AC stress.

Table 3-2-1 Gate and drain channel setup for this demonstration.

Tab Group	Tab	Group	Parameter	Unit	Type	Value
Channel Setup	Gate		Measurement	N/A	Check Box	Checked
			Gate	N/A	List Box	Channel connected to the gate terminal.
			Operation Mode	N/A	List Box	PG Mode
			Measurement Mode	N/A	List Box	V Measurement
			Voltage Force Range	N/A	List Box	Auto
			Current Range	N/A	List Box	+/- 10 mA Fixed
			Voltage Measurement Range	N/A	List Box	+/- 5V
			HW Skew	s	Double	0.0
	Drain		Measurement	N/A	Check Box	Checked
			Drain	N/A	List Box	Channel connected to the drain terminal
			Operation Mode	N/A	List Box	Fast IV Mode
			Measurement Mode	N/A	List Box	I Measurement
			Voltage Force Range	N/A	List Box	Auto
			Current Range	N/A	List Box	+/-10 mA Fixed
			Voltage Measurement Range	N/A	List Box	N/A
			HW Skew	s	Double	0.0

Table 3-2-2 Extra bias channel setup of this demonstration.

Tab Group	Tab	Group	Parameter	Unit	Type	Value
Channel Setup	Bias	Bias Source 1	Module Type	N/A	List Box	N/A
			Channel ID	N/A	List Box	N/A
			Bias	V	Double	0
			Compliance	A	Double	1.00E-04
		Bias Source 2	Module Type	N/A	List Box	N/A
			Channel ID	N/A	List Box	N/A
			Bias	V	Double	0
			Compliance	A	Double	1.00E-04

Table 3-2-3 Stress setup for this demonstration

Tab Group	Tab	Group	Parameter	Unit	Type	Value
Stress Setup	Stress Time		Accumulated Stress Time	s	Double	0: 1E-3 1: 2E-3 2: 5E-3
	Vg	Stress Type	DC Stress	N/A	Radio Button	"DC Stress" is checked.
			AC Stress			
		Bias	Vg Stress	V	Double	1
			Current Range	N/A	List Box	+/- 10 mA Fixed
			Range Change Hold	s	Double	0
		Vg Pulse	Vg Base	V	Double	0
			Frequency	Hz	List Box	1M Hz
			Duty	%	Double	50
			Rise/Fall Time	s	Double	1.00E-07
			Delay	s	Double	0
	Vd	Bias	Vd Stress	V	Double	0.2
			Current Range	N/A	List Box	+/-10 mA Fixed
			Range Change Hold	s	Double	0
		Vd Pulse	Enable Pulse Stress	N/A	Check Box	Not checked
			Vd Base	V	Double	0
			Duty	%	Double	50
			Rise/Fall Time	s	Double	1.00E-07
			Delay	s	Double	0

Table 3-2-4 Sequence setup for this demonstration

Tab Group	Tab	Group	Parameter	Unit	Type	Value
Measurement	Sequence	Measurement Item	Id Sampling	N/A	Radio Button	"Id Sampling" is checked
			Sweep IV			
			OTF			
		Output Sequence	Stress to Meas. Edge	s	Double	1.00E-07
			Vd Sequence Delay	s	Double	0
		Reference Measurement	Enable	N/A	Check Box	Not checked
			Ref. Meas to Stress Delay	s	Double	10E-6
		Post Measurement	Enable	N/A	Check Box	Not checked
			Post Meas. Delay	s	Double	10E-6
			Initial Interval	s	Double	20E-6
			Interval Mode	N/A	List	LINEAR
			Iteration Number	N/A	Integer	10

Table 3-2-5 Measurement setup for single Id measurement

Tab Group	Tab	Group	Parameter	Unit	Type	Value
Measurement	Id Sampling		Vg	V	Double	0.5
			Vd	V	Double	0.1
			Sampling Mode	N/A	List	"LINEAR"
			Stress Holds	s	Double	0
			Meas Delay	s	Double	5.00E-07
			Initial Interval	s	Double	2.00E-07
			Sampling Points	N/A	Integer	1
			Averaging Time	s	Double	2.00E-07
			Extra Delay	s	Double	2.00E-07

Step 3. Execute measurement

To execute a measurement, click "Execute" button and, then, enter the name of the file to save the results of measurement. Then the progress panel and the data view panels for the WGFMU channel assigned to the gate and drain channels are opened simultaneously. When the measurement is completed, the Progress panel is closed automatically and the data view panels remain on the screen.

Fig. 3-2-4 Progress panel

Fig. 3-2-5 Data view panels

The first column of the data view panels shows the averaging time of the measurement from the interruption of the stress.

The first row lists the name of the measurement event (see the section 4-3 NBTI Test).

The second row lists the actual time of the beginning of the measurement.

The third row lists the spot measurement results at each interruption of the stress.

Fig. 3-2-6 shows the waveform monitored by the oscilloscope connected to the V Monitor terminal of the RSU.

The upper half shows the entire waveform including the stress and measurement, and the lower half shows the magnified measurement part at the first interruption. From the setting of the Table 3-2-5, the total interruption time of the stress for executing a single Id measurement is given by the following formula.

Measurement Delay + Averaging Time + Extra Delay + Stress to Meas. Edge = 1 μs

For details of the timing, see the section 4-3 NBTI Test.

The monitored waveform shows that the measurement was performed correctly as defined in the setup panel, and the measurement was actually performed within 1 μs.
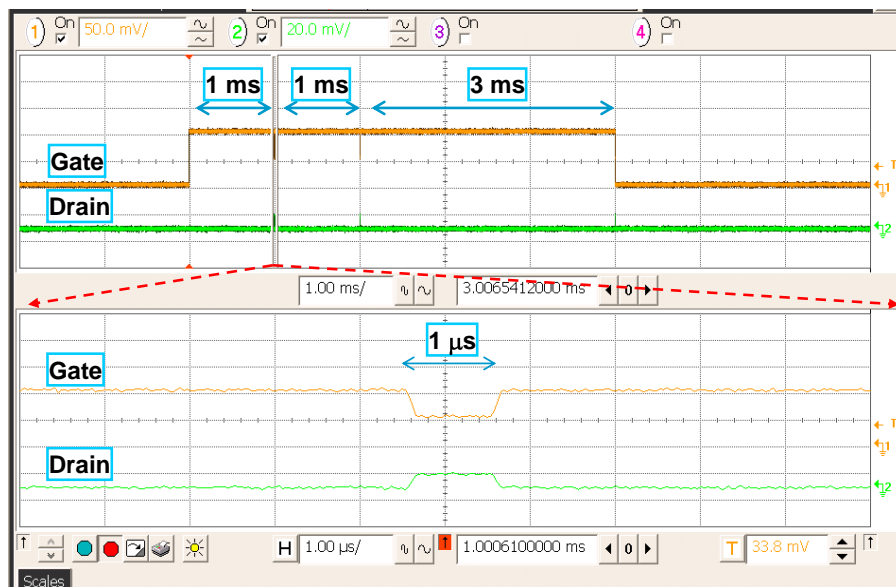

Fig. 3-2-6 Waveform example monitored by oscilloscope

3-2-3. Recovery measurement using log sampling

In addition to the single Id measurement, this software supports multi point sampling measurement with a linear interval and log interval. The log sampling function is very useful for the measurement of the long time response like a recovery effect in the NBTI test.

Step 1. Modify the parameters

To show the log sampling measurement, modify the measurement parameter as shown in Table 3-2-6.

Table 3-2-6 Stress setup for this demonstration

Tab Group	Tab	Group	Parameter	Unit	Type	Value
Stress Setup	Stress Time		Accumulated Stress Time	s	Double	0: 1E-3
Tab Group	**Tab**	**Group**	**Parameter**	**Unit**	**Type**	**Value**
Measurement Setup	Id sampling		Sampling Mode	N/A	List	"LOG10"
			Stress Holds	s	Double	0
			Meas Delay	s	Double	0.0
			Initial Interval	s	Double	1.00E-7
			Sampling Points	N/A	Integer	80
			Averaging Time	s	Double	1.00E-8

Step 2. Execute measurement

Fig. 3-2-7 shows the drain current data view panel of this measurement and the measurement result graph in the log scale. From this result, the long response from 10 ns range to 10 s range can be measured with only 80 measurement points.

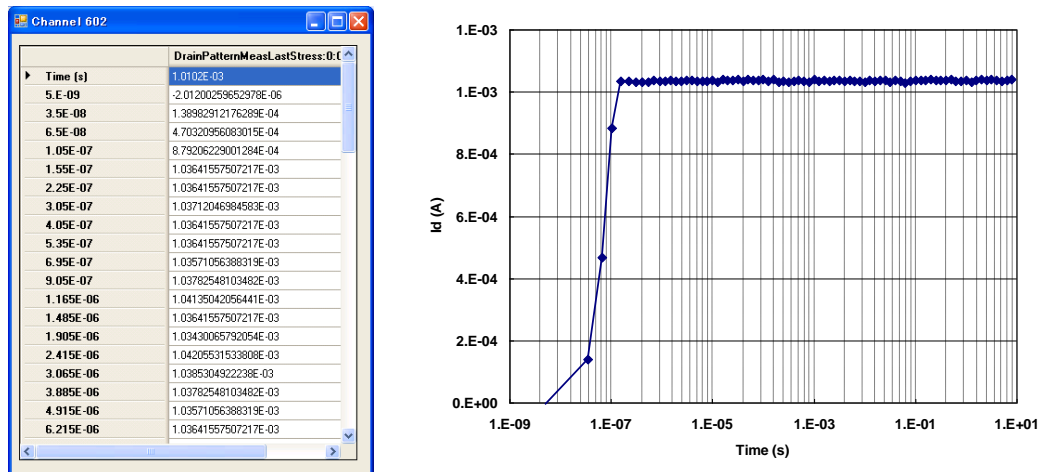**Fig. 3-2-7 Drain current data view and measurement result graph in log scale**

In the log sampling mode, the measurement starts after the delay time. And the initial interval is used for the initial decade. In the case of "LOG10" mode, the initial measurement point is treated as the beginning of the first decade, and ten measurement points are taken in one decade of the logarithmic scale with an interval.

3-2-4. Fast sweep measurement

This demonstration shows the flexibility of the WGFMU. The WGFMU can also perform the sweep measurement.

Step 1. Staircase sweep measurement
To execute the NBTI / PBTI with a staircase sweep measurement, select "Sweep IV" as a measurement item and set parameters in the "Sweep" tab as shown in Table 3-2-7.

Table 3-2-7 Measurement setup for staircase setup measurement

Tab Group	Tab	Group	Parameter	Unit	Type	Value
Measurement	Sweep		Dual Sweep	N/A	Check Box	Unchecked
			Sweep Type	N/A	List	"Staircase"
		Vg Sweep	Start V	V	Double	-1.5
			Stop V	V	Double	0.5
			Step Num	N/A	Integer	11
			Step Rise	s	Double	1.00E-07
			Hold	s	Double	0.0
			Measurement Delay	s	Double	5.00E-07
			Averaging Time	s	Double	2.00E-07
			Step Delay	s	Double	1.00E-07
			Dual Sweep Delay	s	Double	0.0
		Vd	Vd	V	Double	0.1

In this case, the list of the sweep data are displayed in the data view panel. See Fig. 3-2-8.

The data in the data view panel can be copied and pasted to the spreadsheet software such as Microsoft Excel and the IdVg curve can be drawn like Fig.3-2-9.
Since the each step of the pulse is about 900 ns by this setting, 11 points IV sweep is finished within 10 μsec.

Note:
This demo device has a self heating effect, so the result of the 10 μsec sweep is larger than the result by the SMU. To get a correlated IdVg data, set the measurement delay to approximately 20 ms which is the same level as the SMU. For easy demonstration, use a resistor demo device instead of MOS FET. It does not have the self-heating effect and shows a correlation easily even as high speed measurement.

Fig. 3-2-8 Data view panel of the sweep measurement
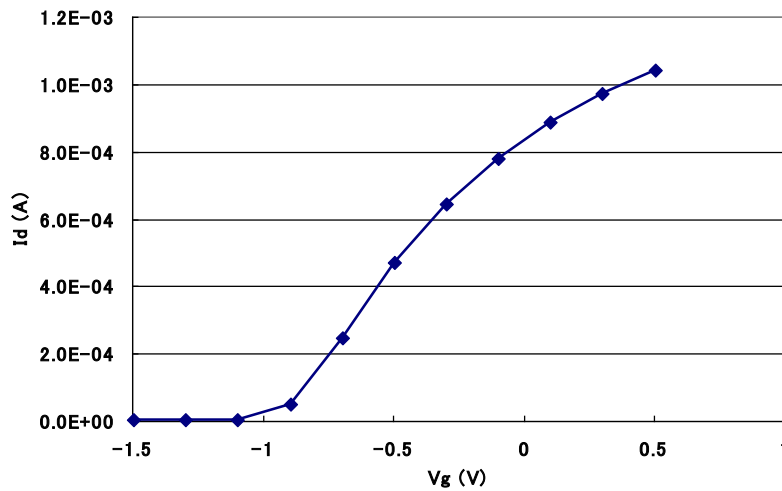
Fig. 3-2-9 IdVg characteristics measured by the WGFMU within 10 μsec
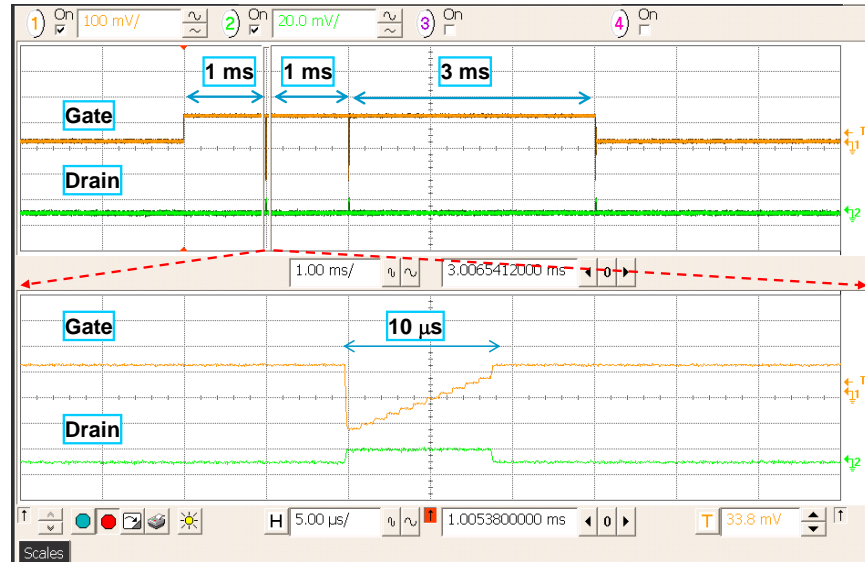
Fig. 3-2-10 Monitored waveform of the sweep measurement

Step 2. Change the sweep type to the ramp sweep

To change the sweep type to the ramp sweep, just select "Ramp" in the list of the "Sweep type". Then click "Execute" button to execute the NBTI / PBTI test with a ramp sweep measurement. Fig 3-2-11 shows the monitored waveform of the ramps sweep measurement.
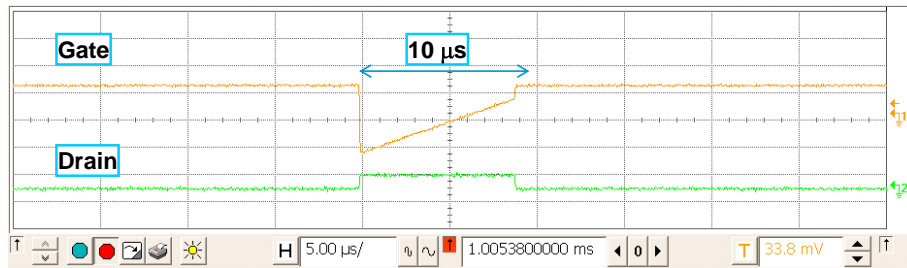
Fig. 3-2-11 Monitored waveform of the ramp sweep measurement

Step 3. Dual sweep measurement

This sample software also provide a dual sweep measurement. To make the dual sweep enable, check the "Dual Sweep" in the sweep measurement setup.

Fig 3-2-12 shows the monitored waveform when executing the dual sweep measurement of the ramp sweep.
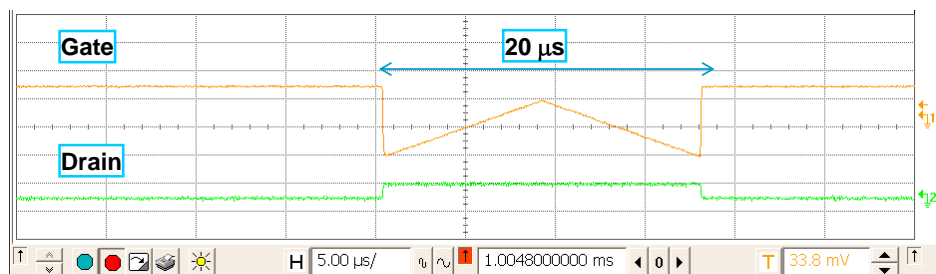
Fig. 3-2-12 Monitored waveform of the dual ramp sweep measurement

When dual sweep is enabled, both of the forward sweep measurement result and the reverse sweep measurement result are displayed in the data view panel (Fig. 3-2-13). The dual sweep mode is available for all sweep type including the staircase sweep, the ramp sweep, and the pulsed sweep.

Step 4. Pulsed sweep measurement
In addition to the staircase sweep and the ramp sweep, the pulsed sweep measurement is available in this sample program. To perform the pulsed sweep measurement, select "PIV" in the list of the sweep type and set the parameter in the "PIV" tab. In this demonstration, use the parameters listed in the Table 3-2-8.

Table 3-2-8 Measurement setup for pulsed sweep measurement

Tab Group	Tab	Group	Parameter	Unit	Type	Value
Measurement	PIV	Vg Sweep	Base	V	Double	-1.5
			Period	s	Double	2.00E-06
			Width	s	Double	1.00E-06
			Rise/Fall Time	s	Double	1.00E-07
			Pulse Delay	s	Double	0
		Vd	Enable Pulse Bias	N/A	Check Box	Unchecked
			Base	V	Double	0
			Width	s	Double	1.00E-06
			Rise/Fall Time	s	Double	1.00E-07
			Pulse Delay	s	Double	0

By this settings, the pulse period is set to 2 µs and the pulse width is set to 1 µs. Fig. 3-2-13 shows the monitored waveform of both the single channel pulsed sweep and the dual channel pulsed sweep.
To enable the pulsed biasing on the drain terminal, check the "Enable Pulse Bias" in the "Vd" group.
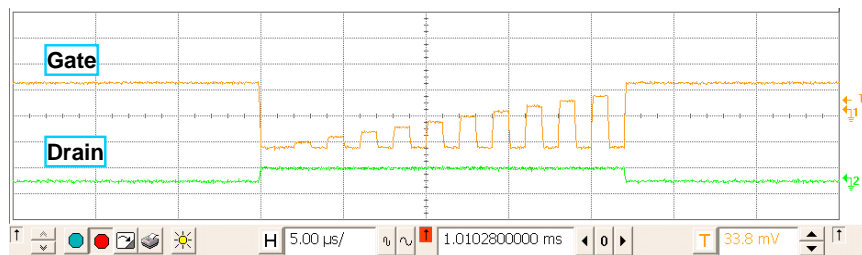
Single channel pulsed sweep
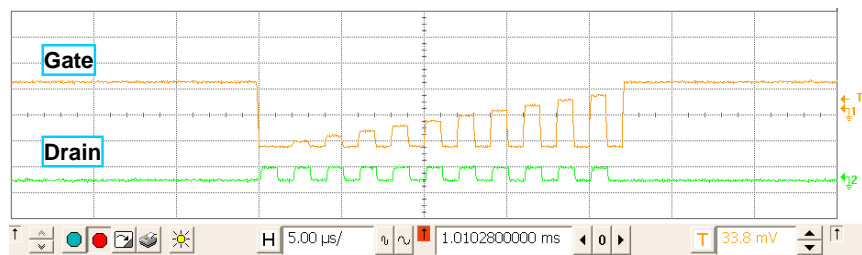
Dual channel pulsed sweep

Fig. 3-2-13 Monitored waveform of the pulsed sweep measurement

3-2-5. AC stress

This sample program can also use the AC (pulse) stress for the stress pattern.

The pulse setup parameters for the stress bias are described in Table 3-2-3. To enable the pulse bias for the gate terminal, select "AC Stress" as a stress type in the "Vg" tab of the stress tab group.

Fig. 3-2-14 shows the monitored waveform when the AC stress is selected for the gate bias of a single Id measurement.
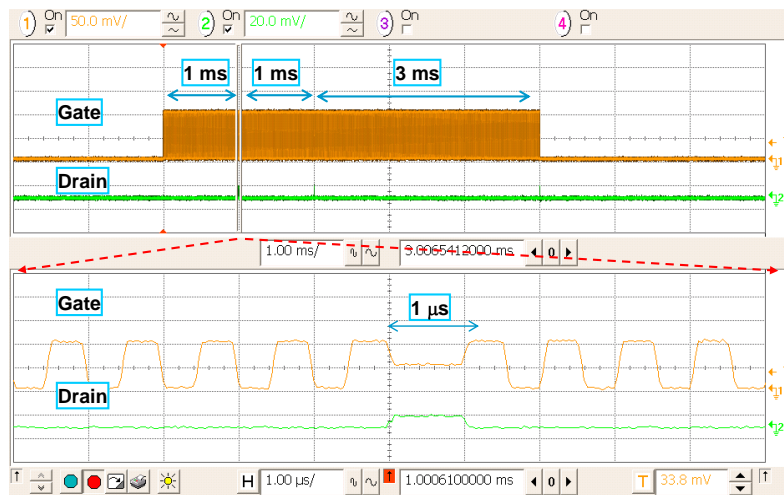
Fig. 3-2-14 Monitored waveform of the AC stress bias for the gate terminal

Comparing Fig. 3-2-14 with Fig. 3-2-6, the difference between those two measurements is the waveform of the stress phase only. There is no difference for the measurement. So the effect of the stress bias waveform can be extracted by comparing the results from those measurements.

The AC stress can also be set to the drain bias. To enable the pulse bias for the drain terminal, check the "Enable Pulse Stress" in the "Vd" tab of the stress tab group.
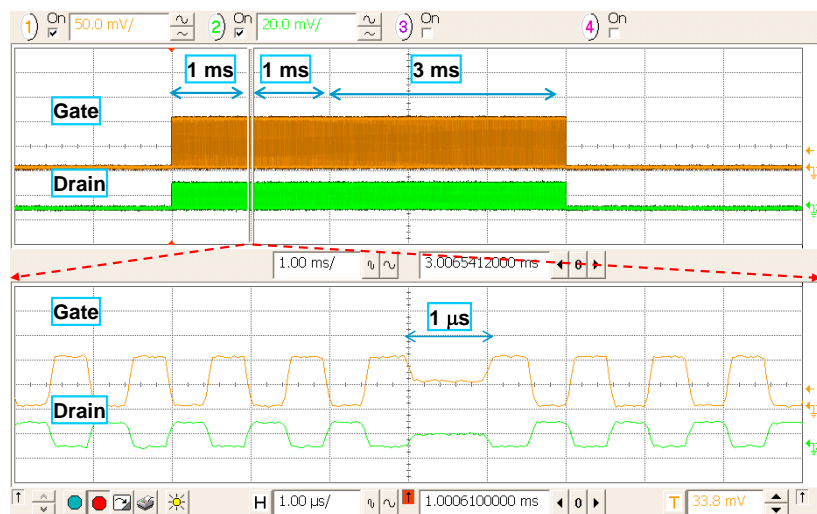
Fig. 3-2-15 Monitored waveform of the AC stress bias for the gate and drain terminals

3-2-6. Reference measurement and post iterative measurement

This sample program can also execute the measurement before applying the stress bias to use the measurement data as the reference data without stressing. Also to evaluate a recovery after the stress, this sample program can execute iterative measurement after finishing the entire stress.
To see the iterative measurement on the oscilloscope, set the stress time short as a matter of convenience.

Table 3-2-9 Accumulated stress time for this demonstration

Accumulated stress time (s)	
0	1E-5
1	2E-5
2	5E-5

Select the "Staircase Sweep" measurement type and set the parameters as shown in Table 3-2-7. And check the "Enable" in the "Reference Measurement" group of the "Sequence" tab to enable the reference measurement. Check the "Enable" in the "Post Measurement" group the "Sequence" tab to enable the post measurement.
Before executing the measurement, check the "Ref. Meas. to Stress Delay" in the "Reference Measurement" group and set the "Post Meas. Delay", "Initial Interval", "Interval Mode", and "Iteration Number" in the "Post Measurement" group as shown in Table 3-2-4.
Fig. 3-2-16 shows the monitored waveform of a reference measurement and post iterative measurements.
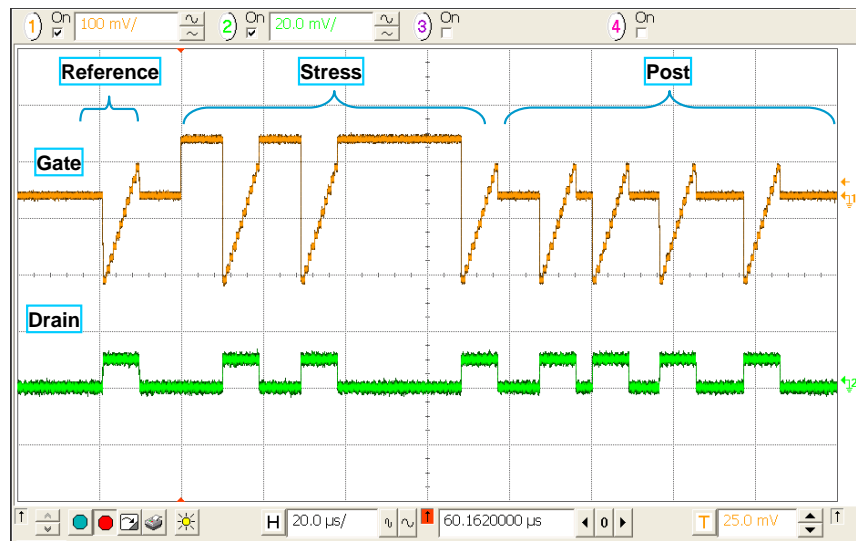
Fig. 3-2-16 Monitored waveform of the reference and post iterative measurements

The data view panel lists the all measurement data (Fig. 3-2-17).
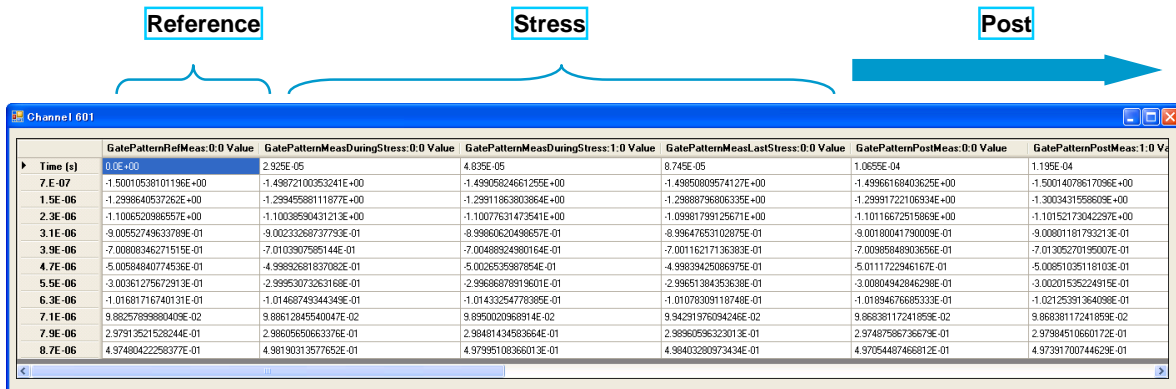
Fig. 3-2-17 Data view panel of the reference and post iterative measurements

3-3. Transient I/V Measurement

The transient I/V measurement is performed by using the "SAMPLING.exe" sample program which performs the sampling measurement. This program supports the dual sampling as a special feature which performs the measurements for two sampling conditions in one measurement execution. This demonstration shows how the dual sampling works. This demonstration is useful to see the transient characteristics.

Step 1. Connect the device to the RSU

For this demonstration, the 1M Ω resistor is used. Connect the SMA cables between the 1 MΩ demo device and two RSU. See Fig. 3-3-1.
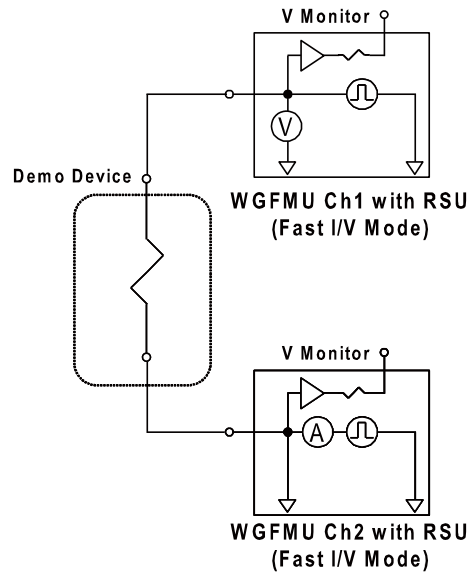
Fig. 3-3-1 Connection for the demonstration of the transient measurement

To visualize the effect of the dual sampling, use the 100 µA range, 1 µs interval, and 100 ns averaging for the fast measurement to measure the transient at the rising edge of the step voltage. And use the 100 µA range, logarithm interval, and 2 µs averaging time to measure the settling precisely.

Fig. 3-3-2 shows the concepts of the dual sampling for one sampling measurement execution.
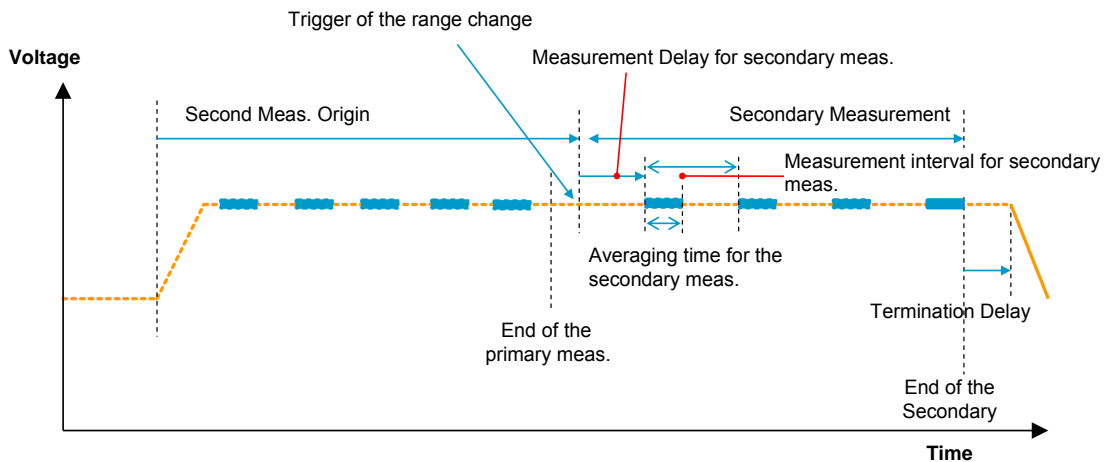
Fig. 3-3-2 Dual sampling for one measurement execution

Step 2. Input Measurement Parameters

To demonstrate the feature of the dual sampling measurement, set the parameters as shown in the following tables.

Table 3‑3‑1 Channel setup parameters of this demonstration

Tab Group	Tab	Group	Parameter	Unit	Type	Value
Channel Setup	Source 1		Measurement	N/A	Check Box	Checked
			Channel	N/A	List Box	Channel ID to use
			Operation Mode	N/A	List Box	Fast I/V Mode
			Measurement Mode	N/A	List Box	V Measurement
			Voltage Force Range	N/A	List Box	Auto
			Current Range	N/A	List Box	10 uA Fixed
			Voltage Measurement Range	N/A	List Box	+/‑5 V
			HW Skew	s	Double	0
			RawData	N/A	Check Box	Not checked
	Source 2		Measurement	N/A	Check Box	Checked
			Channel	N/A	List Box	Channel ID to use
			Operation Mode	N/A	List Box	Fast I/V Mode
			Measurement Mode	N/A	List Box	I Measurement
			Voltage Force Range	N/A	List Box	Auto
			Current Range	N/A	List Box	100 uA Fixed
			Voltage Measurement Range	N/A	List Box	+/‑5 V
			HW Skew	s	Double	0
			RawData	N/A	Check Box	Not checked

Table 3‑3‑2 Bias channel setup parameters of this demonstration

Tab Group	Tab	Group	Parameter	Unit	Type	Value
Channel Setup	Bias	Bias Source 1	Module Type	N/A	List Box	N/A
			Channel ID	N/A	List Box	N/A
			Bias	V	Double	0
			Compliance	A	Double	0
		Bias Source 2	Module Type	N/A	List Box	N/A
			Channel ID	N/A	List Box	N/A
			Bias	V	Double	0
			Compliance	A	Double	0

Table 3-3-3 Sequence setup parameters of this demonstration

Tab Group	Tab	Group	Parameter	Unit	Type	Value
Measurement Setup	Sequence		Base Holds	s	Double	0
			Base to Source Edge	s	Double	1.00E-05
			Output Sequence Delay	s	Double	0
			Termination Delay	s	Double	0

Table 3-3-4 Primary measurement setup parameters of this demonstration

Tab Group	Tab	Group	Parameter	Unit	Type	Value
Measurement Setup	Primary		Sampling Mode	N/A	List	"LINEAR",
			Meas. Delay	s	Double	0
			Initial Interval	s	Double	1.00E-06
			Sampling Points	N/A	Integer	100
			Averaging Time	s	Double	1.00E-07

Table 3-3-5 Secondary measurement setup parameters of this demonstration

Tab Group	Tab	Group	Parameter	Unit	Type	Value
Measurement Setup	Secondary		Enable Secondary Measurement	N/A	Check box	Checked
			Source 1 Measurement Range	N/A	List	+/-5 V
			Source 2 Measurement Range	N/A	List	+/-10 uA
			Sampling Mode	N/A	List	"LOG10"
			Second Meas. Origin	s	Double	2.00E-04
			Meas. Delay	s	Double	1.00E-04
			Initial Interval	s	Double	1.00E-05
			Sampling Points	N/A	Int	40
			Averaging Time	s	Double	2.00E-06

Table 3-3-6 Bias setup parameters of this demonstration

Tab Group	Tab	Group	Parameter	Unit	Type	Range
Measurement Setup	Bias	Source 1	Base	V	Double	0
			Source	V	Double	1
		Source 2	Base	V	Double	0
			Source	V	Double	0

Step 3. Execute Measurement

Click the "Execute button" to start the measurement. Data view panel lists the voltage measurement result of the WGFMU Ch1 and the current measurement result of the WGFMU Ch2. See Fig. 3-3-3.

	Src1:0:0 Time(s)	Src1:0:0 Value
▶ 0	1.5E-07	2.10372568108141E-03
1	1.15E-06	1.01807318627834E-01
2	2.15E-06	2.01652884483337E-01
3	3.15E-06	3.01320970058441E-01
4	4.15E-06	4.01556998491287E-01
5	5.15E-06	5.01225113868713E-01
6	6.15E-06	6.0139012336731E-01
7	7.15E-06	7.01448619365692E-01
8	8.15E-06	8.02075088024139E-01
9	9.15E-06	9.00571882724762E-01
10	1.015E-05	9.97187435626984E-01
11	1.115E-05	9.98145818710327E-01
12	1.215E-05	9.97968316078186E-01
13	1.315E-05	9.97542381286621E-01
14	1.415E-05	9.98039305210114E-01
15	1.515E-05	9.7779087305069E-01
16	1.615E-05	9.98749196529388E-01
17	1.715E-05	9.98181283473969E-01

Channel 601

	Src2:0:0 Time(s)	Src2:0:0 Value
▶ 0	1.5E-07	-9.62242907576183E-08
1	1.15E-06	-1.87693075304196E-07
2	2.15E-06	-2.77754651278883E-07
3	3.15E-06	-3.3615395977904E-07
4	4.15E-06	-4.47323685648371E-07
5	5.15E-06	-5.88748491736624E-07
6	6.15E-06	-6.42222573787876E-07
7	7.15E-06	-7.2454446353731E-07
8	8.15E-06	-8.50489982440195E-07
9	9.15E-06	-9.60956072049157E-07
10	1.015E-05	-1.02779870303493E-06
11	1.115E-05	-1.01865180113236E-06
12	1.215E-05	-1.06508980479703E-06
13	1.315E-05	-1.05594290289446E-06
14	1.415E-05	-1.03624199709884E-06
15	1.515E-05	-1.09956647520448E-06
16	1.615E-05	-1.03413117358286E-06
17	1.715E-05	-1.02850231087359E-06

Channel 602

Fig. 3-3-3 Data view panel of the transient IV measurement

After that, display the current - time distribution plot by using the results of the WGFMU Ch2. See Fig. 3-3-4.

In this plot, fast response at the rising edge is measured with a relatively large noise, but fast. And the following long term response is measured with a lower noise and higher resolution.
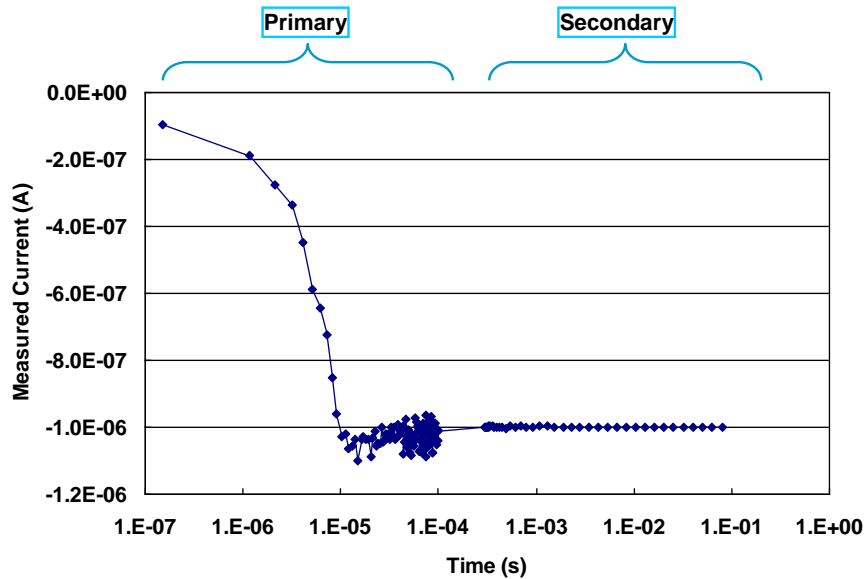

Fig. 3-3-4 Plot of the measured current by the WGFMU 2 in the logarithmic scale

3-4. Fast IV Sweep Characterization

The WGFMU has an ALWG (Arbitrarily Linear Waveform Generation) function. So the WGFMU can perform the current measurement with a more complicated waveform such as the staircase voltage sweep, ramp voltage sweep, and pulsed voltage sweep. To demonstrate a sweep measurement, use the "SWEEP.exe" sample program which supports the staircase sweep, ramp sweep, and pulsed sweep IV measurements with the single sweep option or the dual sweep (double sweep) option.

This demonstration performs these measurements and explains the effect of the insufficient wait time for the measurement result and the tips for deciding an appropriate wait time.

3-4-1. Fast measurement

Step 1. Connect the device to the RSU

The demo device of the NMOS-FET is used for this demonstration. The gate terminal of the MOS-FET is connected to the WGFMU Ch1 and the drain terminal of hte MOS-FET is connected to the WGFMU Ch2.
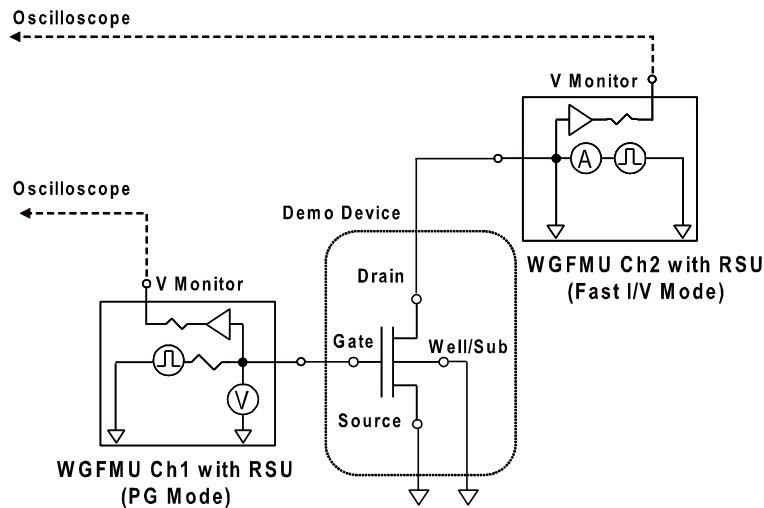
Fig. 3-4-1 Connection for the demonstration of the fast staircase / pulsed IV sweep measurement

Step 2. Set measurement parameters

To measure a reference data, set the parameters as shown in the following tables. The delay time should be longer enough than the settling time of the current measurement range to perform the accurate measurement of the reference data without the effect of the settling time.

In this case, the measurement delay time is set to 10 ms to obtain the IV measurement result without the effect of the settling time. Also the averaging time is set to 20 ms to reduce a noise floor.

Since this demo device is the enhancement type, the gate voltage is swept from -1.5 V to 0.5 V with 0.1 V step. And the current range is set to 10 mA to observe the case of the fastest measurement.

Table 3-4-1 Channel setup parameters of this demonstration

Tab Group	Tab	Group	Parameter	Unit	Type	Value
Channel Setup	Source 1		Measurement	N/A	Check Box	Checked
			Channel	N/A	List Box	Channel ID to connect to the gate terminal
			Operation Mode	N/A	List Box	PG Mode
			Measurement Mode	N/A	List Box	V Measurement
			Voltage Force Range	N/A	List Box	Auto
			Current Range	N/A	List Box	10 mA Fixed
			Voltage Measurement Range	N/A	List Box	+/-5 V
			HW Skew	s	Double	0
			RawData	N/A	Check Box	Not checked
	Source 2		Measurement	N/A	Check Box	Checked
			Channel	N/A	List Box	Channel ID to connect to the drain terminal
			Operation Mode	N/A	List Box	Fast I/V Mode
			Measurement Mode	N/A	List Box	I Measurement
			Voltage Force Range	N/A	List Box	Auto
			Current Range	N/A	List Box	10 mA Fixed
			Voltage Measurement Range	N/A	List Box	+/-5 V
			HW Skew	s	Double	0
			RawData	N/A	Check Box	Not checked

Table 3-4-2 Bias channel setup parameters of this demonstration

Tab Group	Tab	Group	Parameter	Unit	Type	Value
Channel Setup	Bias	Bias Source 1	Module Type	N/A	List Box	N/A
			Channel ID	N/A	List Box	N/A
			Bias	V	Double	0
			Compliance	A	Double	0
		Bias Source 2	Module Type	N/A	List Box	N/A
			Channel ID	N/A	List Box	N/A
			Bias	V	Double	0
			Compliance	A	Double	0

Table 3-4-3 Sequence setup parameters of this demonstration

Tab Group	Tab	Group	Parameter	Unit	Type	Value
Measurement Setup	Sequence		Sweep Source	N/A	List	Source 1
			Sweep Type	N/A	List	Staircase
			Output Sequence Delay	s	Double	0
			Termination Delay	s	Double	5.00E-08
			Dual Sweep	N/A	Check Box	Unchecked
			Dual Sweep Delay	s	Double	0

Table 3-4-4 Sweep setup parameters of this demonstration

Tab Group	Tab	Group	Parameter	Unit	Type	Value
Measurement Setup	Sweep	Sweep Source	Start V	V	Double	-1.5
			Stop V	V	Double	0.5
			Step Num	N/A	Integer	21
			Step Rise	s	Double	1.00E-07
			Hold	s	Double	1.00E-02
			Measurement Delay	s	Double	1.00E-02
			Averaging Time	s	Double	2.00E-02
			Step Delay	s	Double	1.00E-02
		Constant Bias Source	Bias	V	Double	0.1

Step 3. Execute measurement

Click "Execute" button and then enter the name of the file to save the test result. The data view panel as shown in Fig. 3-4-2 will be opened. The data view panel of the WGFMU Ch1 lists the averaged measurement time and the measured gate voltage. And the data view panel of the WGFMU Ch2 lists the averaged measurement time and the measured drain current. You can plot the IdVg curve as shown in Fig. 3-4-3 by using a spreadsheet software.

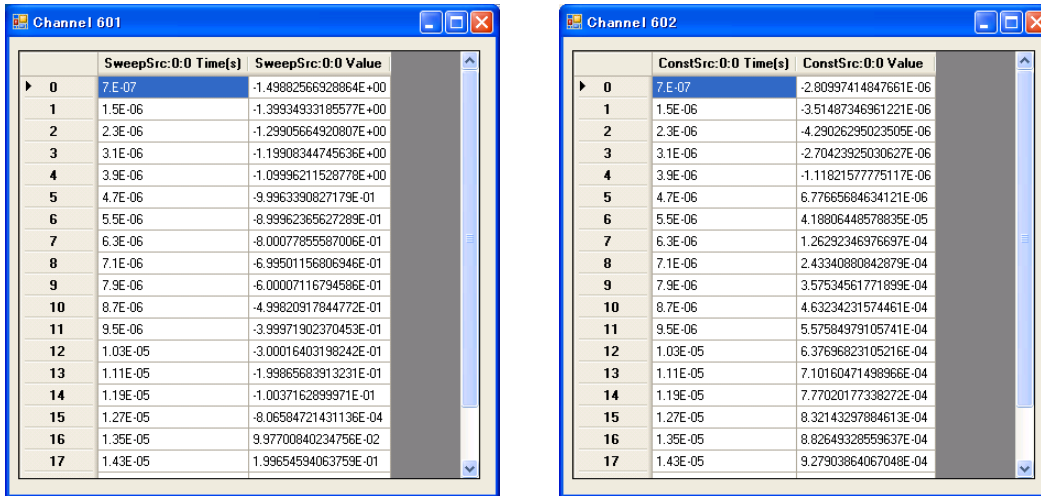|	SweepSrc:0:0 Time[s]	SweepSrc:0:0 Value			ConstSrc:0:0 Time[s]	ConstSrc:0:0 Value
0	7.E-07	-1.49882566928864E+00		0	7.E-07	-2.80997414847661E-06
1	1.5E-06	-1.39934933185577E+00		1	1.5E-06	-3.51487346961221E-06
2	2.3E-06	-1.29905664920807E+00		2	2.3E-06	-4.29026295023505E-06
3	3.1E-06	-1.19908344745636E+00		3	3.1E-06	-2.70423925030627E-06
4	3.9E-06	-1.09996211528778E+00		4	3.9E-06	-1.11821577775117E-06
5	4.7E-06	-9.9963390827179E-01		5	4.7E-06	6.77665684634121E-06
6	5.5E-06	-8.99962365627289E-01		6	5.5E-06	4.18806448578835E-05
7	6.3E-06	-8.00077855587006E-01		7	6.3E-06	1.26292346976697E-04
8	7.1E-06	-6.99501156806946E-01		8	7.1E-06	2.43340880842879E-04
9	7.9E-06	-6.00007116794586E-01		9	7.9E-06	3.57534561771899E-04
10	8.7E-06	-4.99820917844772E-01		10	8.7E-06	4.63234231574461E-04
11	9.5E-06	-3.99971902370453E-01		11	9.5E-06	5.57584979105741E-04
12	1.03E-05	-3.00016403198242E-01		12	1.03E-05	6.37696823105216E-04
13	1.11E-05	-1.99865683913231E-01		13	1.11E-05	7.10160471498966E-04
14	1.19E-05	-1.0037162899971E-01		14	1.19E-05	7.77020177338272E-04
15	1.27E-05	-8.06584721431136E-04		15	1.27E-05	8.32143297884613E-04
16	1.35E-05	9.97700840234756E-02		16	1.35E-05	8.82649328559637E-04
17	1.43E-05	1.99654594063759E-01		17	1.43E-05	9.27903864067048E-04

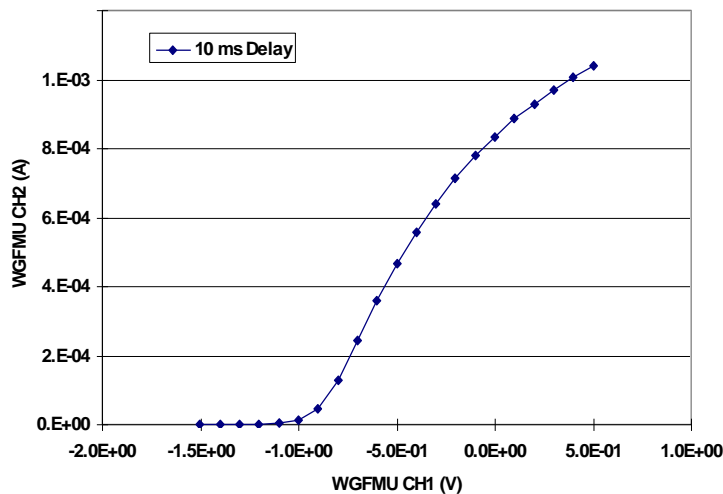Fig. 3-4-2 Data view panel of the sweep measurement

Fig. 3-4-3 IdVg curve of the reference measurement

Next, change the measurement delay time, averaged time and step delay to make duration of each step less than 1 µs. Modify the sweep measurement parameters as shown in Table 3-4-5.

Fig. 3-4-4 shows the monitored waveform by the setting of Table 3-4-5. Duration of each step is only 800 ns.

Fig. 3-4-5 shows the overlaid IdVd curve of the reference measurement and fast measurement with a step less than 1 µs. This result shows the 500 ns delay time is enough to make good correlation with slower

measurement nearly equal to a DC measurement.

Actually, the reference data of the 0.1 % settling time of the 10 mA current measurement range is less than 1 μs, 500 ns delay time is enough to settle the value within ± 0.2 or 0. 3 %.

Table 3-4-5 Sweep setup parameters of this demonstration

Tab Group	Tab	Group	Parameter	Unit	Type	Value
Measurement Setup	Sweep	Sweep Source	Step Rise	s	Double	1.00E-07
			Hold	s	Double	100E-7
			Measurement Delay	s	Double	5.00E-7
			Averaging Time	s	Double	2.00E-7
			Step Delay	s	Double	2.00E-7
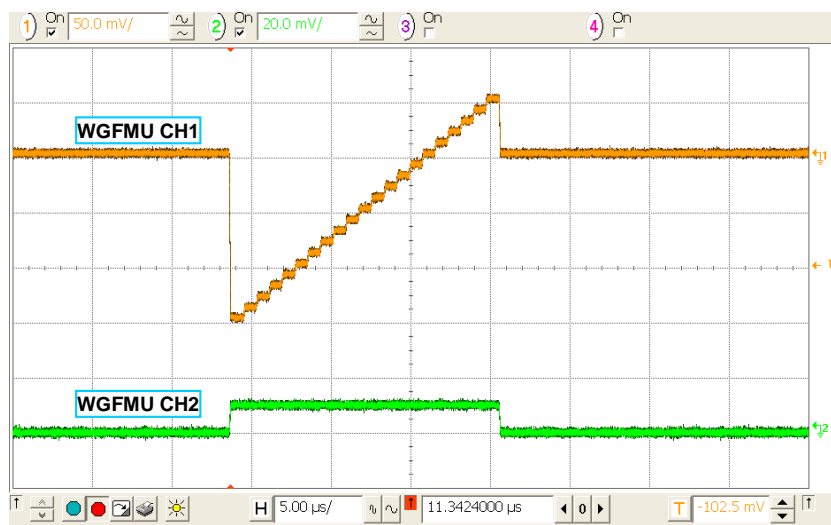
Fig. 3-4-4 Monitored waveform
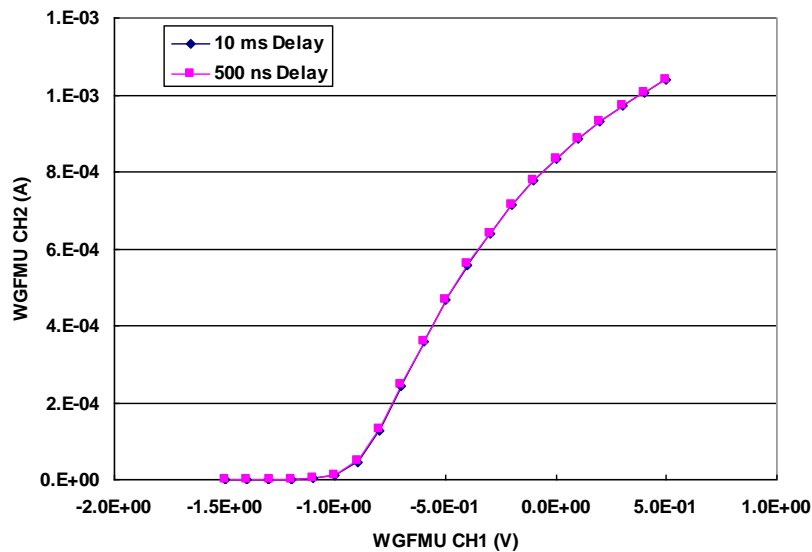
Fig. 3-4-5 Overlaid IdVg curve of the reference measurement of 10 ms delay and fast measurement of 500 ns delay

Step 4. Demonstrate a ramp sweep measurement

Next, change the sweep type to the "Ramp" sweep, execute measurement, then the similar waveform and IdVg characteristic is obtained. Fig 3-4-6 shows the monitored waveform of the ramp sweep measurement. And Fig. 3-4-7 shows the overlaid IdVg curve of the reference measurement and the ramp sweep measurement with 500 ns delay.
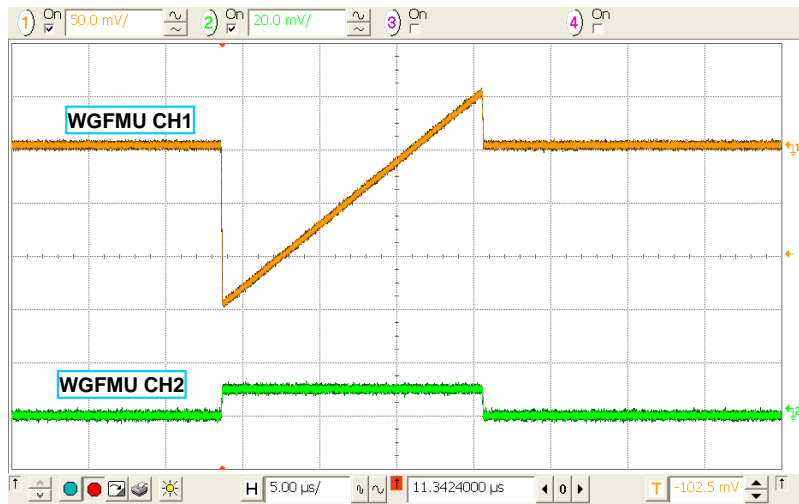

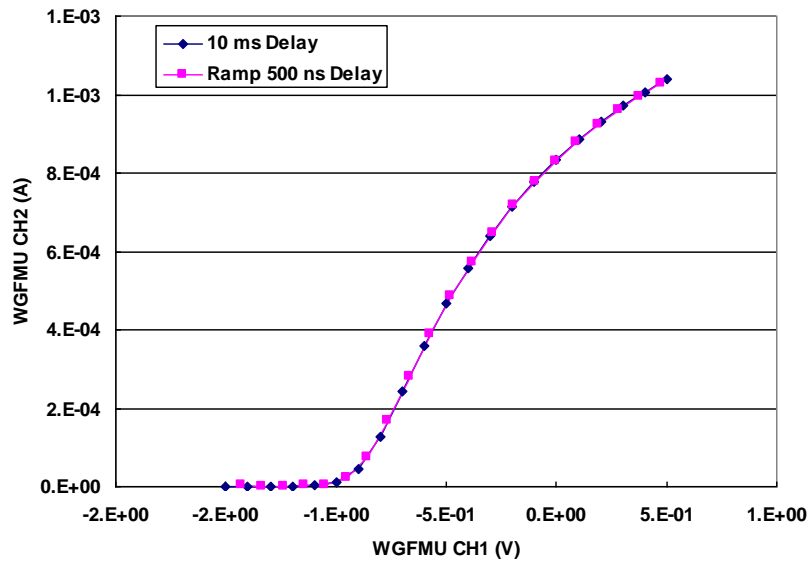**Fig. 3-4-6 Monitored waveform of the ramp sweep**

Fig. 3-4-7 Overlaid IdVg curve of the reference measurement of 10 ms delay and fast ramp sweep measurement with 500 ns delay

The gate voltage is measured during the slope of the ramp sweep. So it is shifted from the staircase sweep, but IdVg curve drawn by the measured gate voltage and measured drain current is well correlated with the reference measurement.

Step 5. Demonstrate a pulsed sweep measurement

For the pulsed sweep measurement with 1 ms pulse width, set the parameters in the "PIV" tab as shown in Table 3-4-6.

Table 3-4-6 Pulsed IV measurement parameters

Tab Group	Tab	Group	Parameter	Unit	Type	Value
Measurement Setup	PIV	Sweep Source	Base	V	Double	-1.6
			Period	s	Double	2.00E-6
			Width	s	Double	1.00E-06
			Rise/Fall Time	s	Double	1.00E-07
			Pulse Delay	s	Double	0
		Constant Bias Source	Enable Pulse Bias	N/A	Check Box	Unchecked
			Base	V	Double	0
			Width	s	Double	1.00E-06
			Rise/Fall Time	s	Double	1.00E-07
			Pulse Delay	s	Double	0

Then, select "PIV" as a sweep type and click "Execute" to execute a measurement.

Fig. 3-4-8 shows the monitored waveform when the drain pulse bias is not enabled. In this case, the gate bias is a pulsed sweep with a 1 µs pulse width.
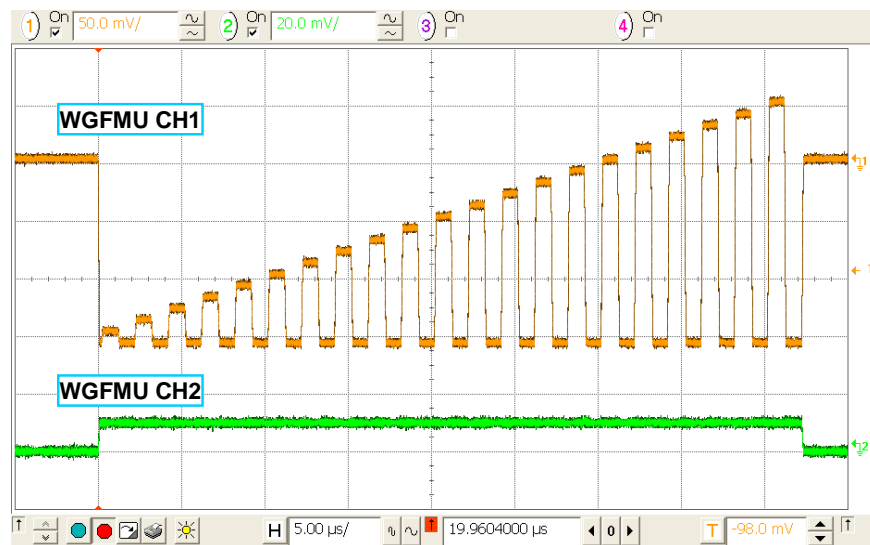
Fig. 3-4-8 Monitored waveform of the single channel pulsed IV measurement

And check the "Enable Pulse Bias" in the "Constant Bias Source", the waveform of Fig. 3-4-9 is obtained.
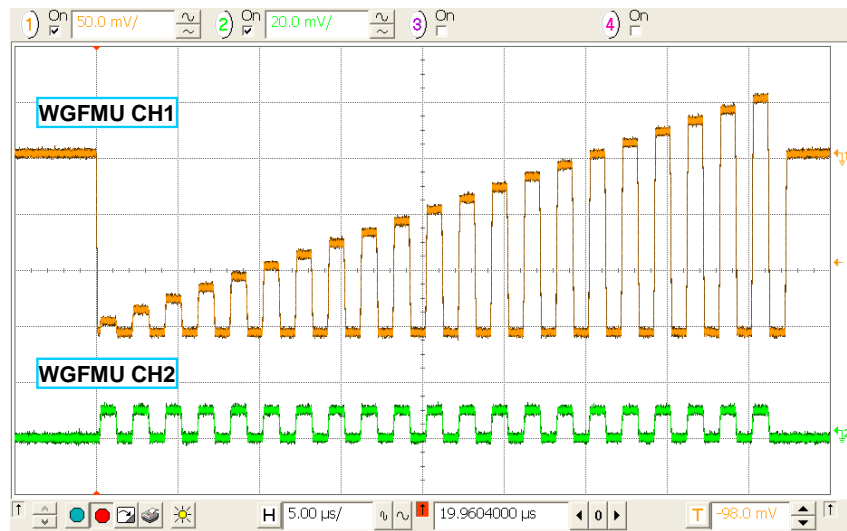

Fig. 3-4-9 Monitored waveform of the single channel pulsed IV measurement

Fig 3-4-10 is the overlaid IdVg curve of the reference measurement, single channel pulsed IV measurement and dual channel pulsed IV measurement.
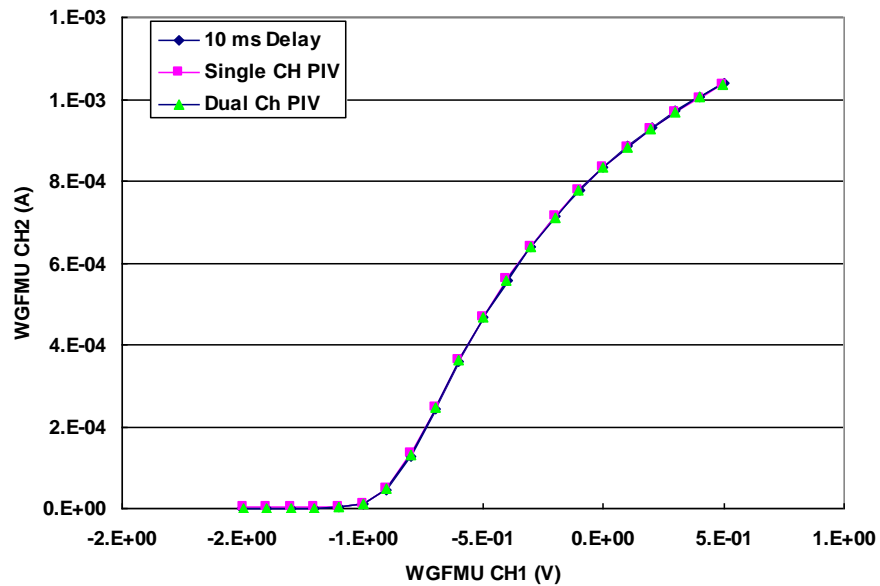

Fig. 3-4-10 Overlaid IdVg curves of the reference measurement and the pulsed IV measurement of 1 µs pulse width.

From this results, in all sweep types including the staircase sweep, ramp sweep, single channel pulsed sweep, and dual channel pulsed sweep, the WGFMU demonstrate it's capability of fast sweep measurement less than 1 µs at each step.

3-4-2. Tips for deciding the appropriate wait time

Since the current measurement circuit has its' own settling time, appropriate wait time (measurement delay time) must be inserted after changing the bias voltage before measurement.

The reference data of the settling time of the WGFMU is described in the Table 2-1.

Actual measurement delay time to make current meter settle depends on the cablings and the type of the DUT. To know an appropriate measurement delay time, dual sweep measurement is useful.

In the staircase sweep and ramp sweep measurement, insufficient measurement delay time gives hysteresis on the IV curve measured in the dual sweep mode.

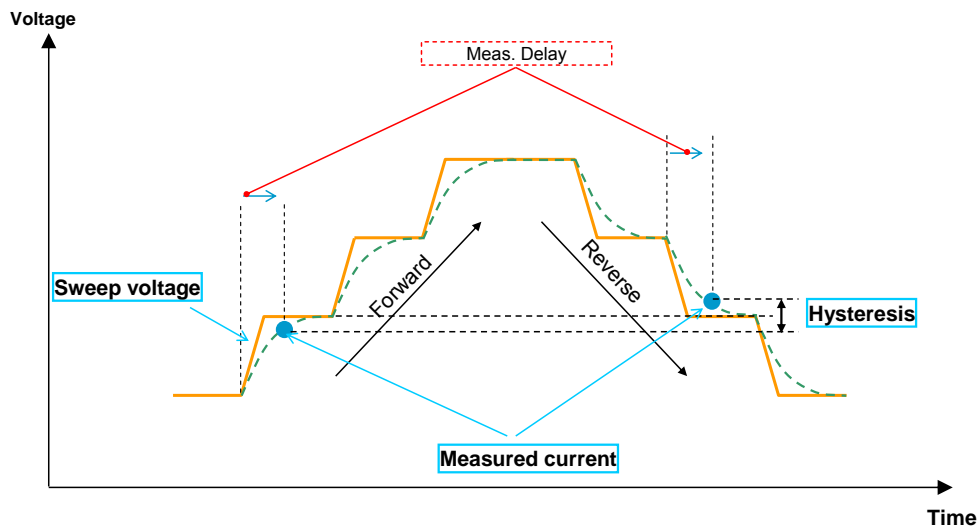Fig. 3-4-11 shows how the hysteresis is caused by the insufficient measurement delay time.

Fig. 3-4-11 Hysteresis caused by the insufficient measurement delay time

In the forward sweep, the drain current increases along with a increase of the gate voltage. Then the measured current varies from a small value to a large value. In the reverse sweep, the measured current varies from a large value to a small value. So, if the measurement delay is not long enough, the measured IV curve at the reverse sweep is larger than the forward sweep and it looks like a hysteresis as shown in Fig. 3-4-12.

To decide the appropriate measurement delay time, make measurement delay longer until this hysteresis disappears.

This demonstration also shows that the hysteresis of the IV curve may come from an insufficient measurement setup, not from the device. So, choosing the appropriate measurement delay time is important for performing the measurement of the device which has a hysteresis in the IV characteristics. Also, if the measurement speed is very fast, the propagation delay between two RSU channels may be the reason of the hysteresis comes from the measurement system.
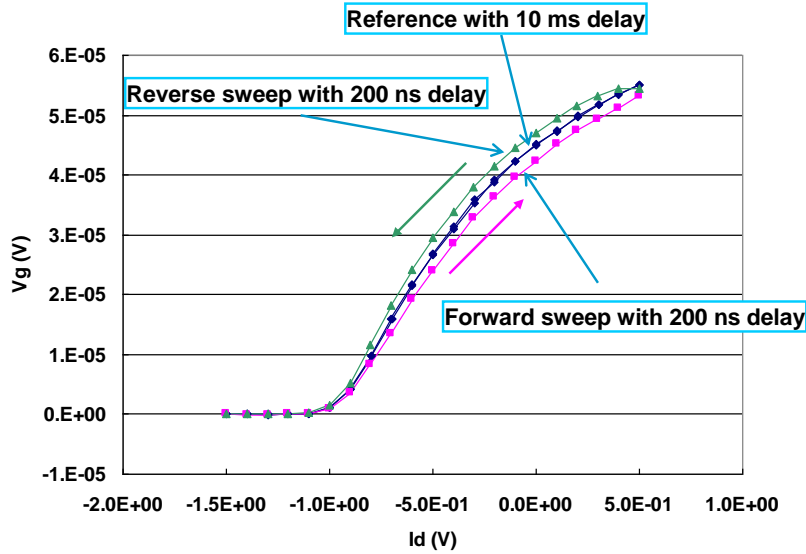
Fig. 3-4-12 Example of the hysteresis caused by the insufficient measurement delay

To observe the IdVg curve as shown in Fig. 3-4-12, use the measurement setup shown in Table 3-4-7.

Table 3-4-7 Setup for the hysteresis demonstration

Tab Group	Tab	Group	Parameter	Unit	Type	Value
Channel Setup	Source 2		Current Range	N/A	List Box	+/-100 uA Fixed

Tab Group	Tab	Group	Parameter	Unit	Type	Value
Measurement Setup	Sequence		Dual Sweep	N/A	Check Box	Checked
			Dual Sweep Delay	s	Double	0

Tab Group	Tab	Group	Parameter	Unit	Type	Value
Measurement Setup	Sweep	Sweep Source	Hold	s	Double	1E-3
			Measurement Delay	s	Double	2E-7
			Averaging Time	s	Double	1E-7
			Step Delay	s	Double	1E-7
		Constant Bias Source	Bias	V	Double	0.005

To see the effect of the settling time of current measurement, 100 µA range is used to realize the long settling time (shorter than 1.5 µs at 0.1 % settling). Also to make current lower enough, "Bias" voltage is set to "0.005 V". The other parameters are the same as the previous demonstration.

3-4-3. Hysteresis caused by the skew between the channels

When measuring IV characteristics in a very short time period, the propagation delay of the electric signal between two measurement units can be the reason of the hysteresis on a measured IV curve.

In the case of the WGFMU, the output timing of the RSU is calibrated at the output terminal of the RSU. So, the propagation delay between the measured values by each RSU will be caused by the extended measurement cable.
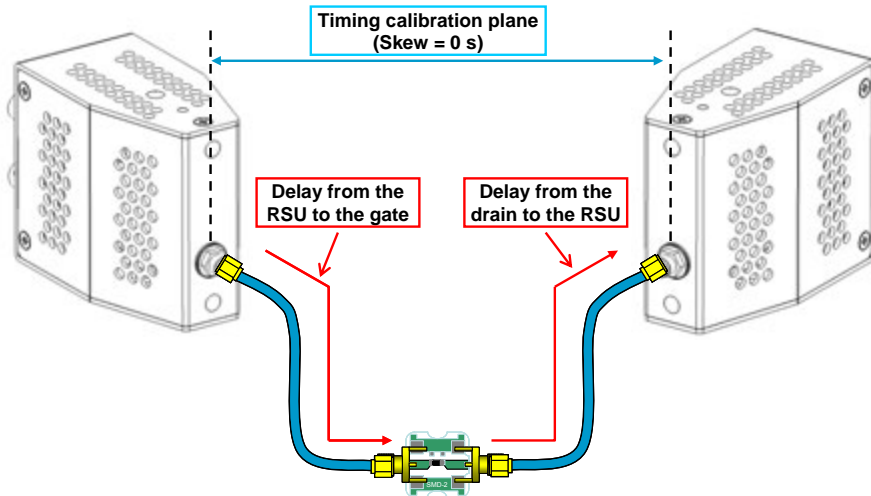

Fig. 3-4-12 RSU output connection

For example, the propagation speed of the electric signal through the coaxial cable is roughly estimated around 20 cm/ns. So if the length of the cables is 20 cm, the delay will be around 2 ns between two RSU outputs. Fig. 3-4-13 shows the measurement delay between two channels. Normally, 20 cm cable generates only 2 ns delay and it will not cause a remarkable hysteresis on the measured IV curve.
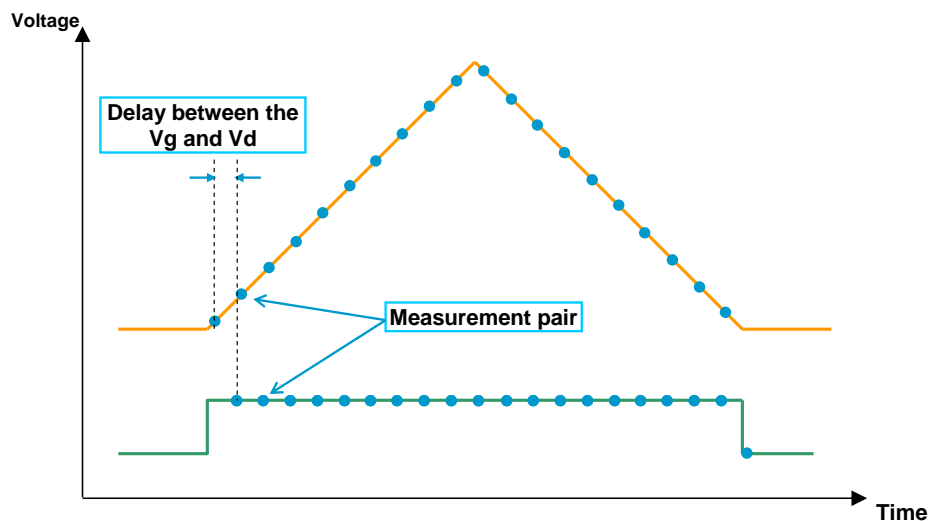

Fig. 3-4-13 Measurement delay between two RSU outputs

To simulate the hysteresis, use a long cable and use the "HW Skew" function of the WGFMU.

To observe the virtual hysteresis as shown in Fig. 3-4-14, set the parameters listed below. In this case, the drain current measurement delays 100 ns from the gate voltage measurement. So the measured drain current of the forward sweep is smaller than the reverse sweep.

Setup example to observe the hysteresis:

- WGFMU Ch1 HW skew: 50 ns
- WGFMU Ch2 HW skew: –50 ns
- Measurement delay: 200 ns
- Averaging time: 200 ns
- Step delay time: 100 ns
- WGFMU Ch2 current measurement range:10 mA range
- Bias voltage of the constant bias source: 0.1 V
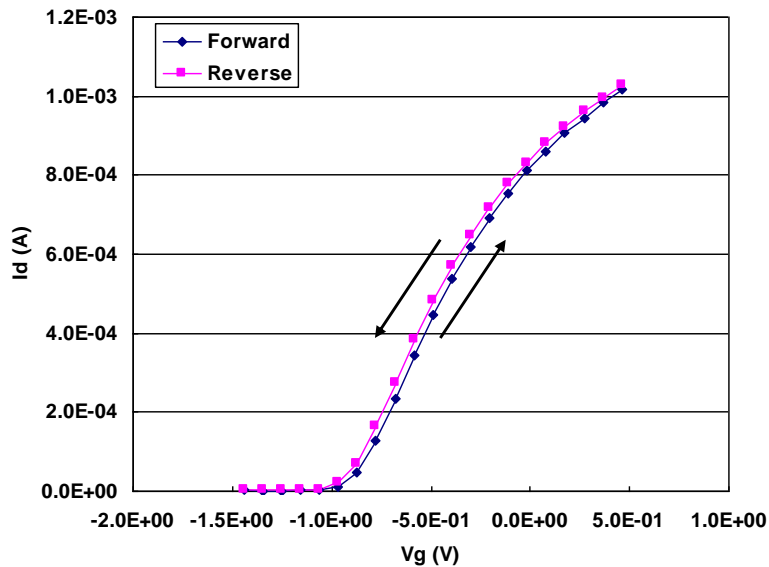
Gate to Drain: 100 ns delay

Fig. 3-4-14 Example of the hysteresis caused by the skew

3-5. Pulsed Characterization

The "PULSE.exe" sample program enables to use a pulsed bias for the sampling measurement additionally to the "SAMPLING.exe" program described in the section 3-3 Transient I/V Measurement. This program supports the dual sampling feature as same as the "SAMPLING.exe" program. Then the measurements for two sampling conditions are performed in a period of the pulse along with various pulse levels. This section describes the basic operation of the pulsed sampling program.

Step 1. Connect the device to the RSU

The pulsed sampling measurement using a single pulse and a single measurement is performed to show the fastest measurement speed. For this demonstration, the 1 kΩ resistor is used. Connect the RSU output as shown in Fig 3-5-1.
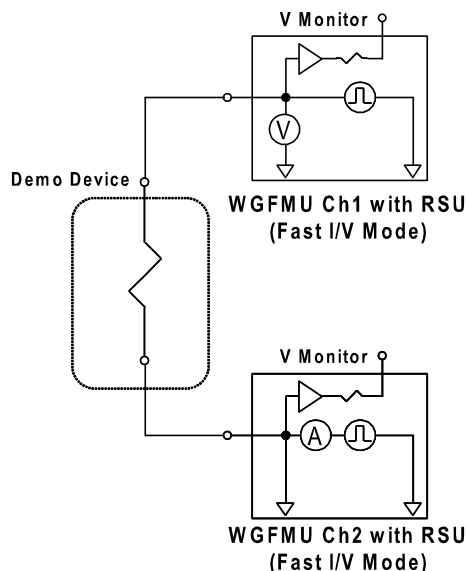

Fig. 3-5-1. Connection for the demonstration of the pulsed sampling measurement

Step 2. Single pulse and single condition sampling measurement

Fig. 3-5-2 shows the output pulse and the measurement timing. Set the following parameters for this demonstration. The measurement setup is shown in Table 3-5-1.

- Pulse period: 2 μs
- Pulse width: 1 μs
- Rise and fall time: 100 ns
- Delay time to start pulse: 100 ns

Click "Execute" button, then enter the name of the file to save the results. And the measurement will be started from the beginning of the waveform and repeated over the waveform with a 10 ns sampling rate and 10 ns averaging time. To achieve the fastest measurement, 10 mA current measurement range is used. After the measurement, the data view window will be opened as shown in Fig. 3-5-3. The measurement result graph can be displayed by using a spreadsheet software. Fig. 3-5-4 is an example graph plot of the time and the current measured by the Ch2. This graph shows the current flowing through the demo device measured by the Ch2 over the pulse wave.
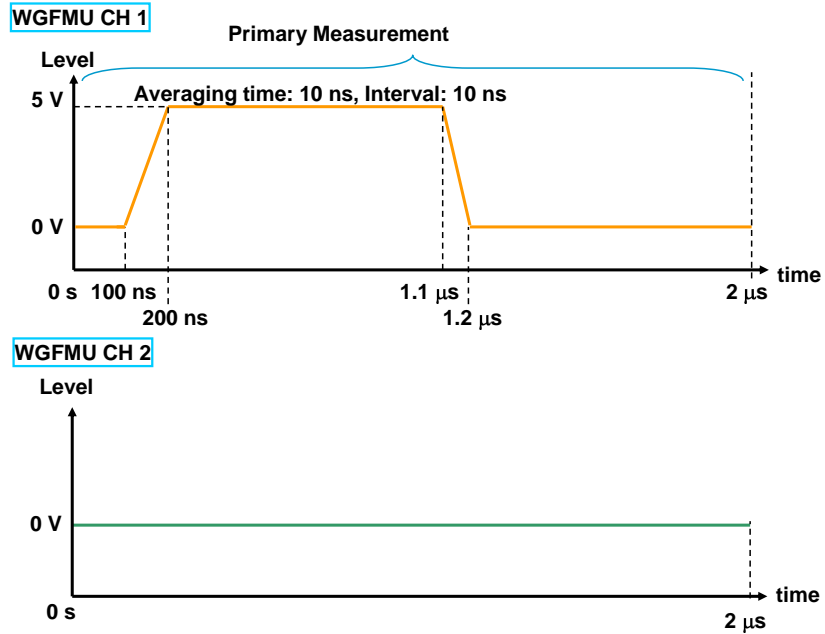
Fig. 3-5-2. Example timing chart of the single pulse and single condition sampling measurement

Fig. 3-5-3 Data view panel of the single pulse and single condition sampling measurement
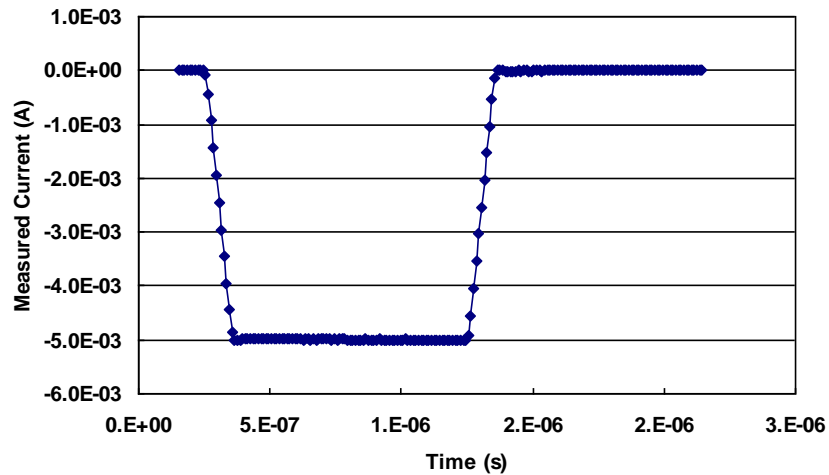
Fig. 3-5-4. Plot of the measured current in this demonstration

Table 3-5-1 Single pulse and single condition sampling measurement setup

Tab Group	Tab	Group	Parameter	Unit	Type	Value
Channel Setup	Source 1		Measurement	N/A	Check Box	Checked
			Channel	N/A	List Box	Channel ID to use as the WGFMU CH 1
			Operation Mode	N/A	List Box	Fast I/V Mode
			Measurement Mode	N/A	List Box	V Measurement
			Voltage Force Range	N/A	List Box	Auto
			Current Range	N/A	List Box	+/-10 mA Fixed
			Voltage Measurement Range	N/A	List Box	+/-5 V
			HW Skew	s	Double	0
			RawData	N/A	Check Box	Unchecked
	Source 2		Measurement	N/A	Check Box	Checked
			Channel	N/A	List Box	Channel ID to use as the WGFMU CH 2
			Operation Mode	N/A	List Box	Fast I/V Mode
			Measurement Mode	N/A	List Box	I Measurement
			Voltage Force Range	N/A	List Box	Auto
			Current Range	N/A	List Box	+/-10 mA Fixed
			Voltage Measurement Range	N/A	List Box	+/- 5V
			HW Skew	s	Double	0
			RawData	N/A	Check Box	Unchecked

Bias	Bias	Bias Source 1	Module Type	N/A	List Box	N/A
			Channel ID	N/A	List Box	N/A
			Bias	V	Double	0
			Compliance	A	Double	0
		Bias Source 2	Module Type	N/A	List Box	N/A
			Channel ID	N/A	List Box	N/A
			Bias	V	Double	0
			Compliance	A	Double	0

Tab Group	Tab	Group	Parameter	Unit	Type	Value
Measurement Setup	Sequence		Sweep Source	N/A	List	Source 1
			Hold	s	Double	0
			Output Sequence Delay	s	Double	0

Tab Group	Tab	Group	Parameter	Unit	Type	Value
Measurement Setup	Sequence		Sweep Source	N/A	List	Source 1
			Hold	s	Double	0
			Output Sequence Delay	s	Double	0

Tab Group	Tab	Group	Parameter	Unit	Type	Value
Measurement Setup	Pulse Timing	Sweep Source	Period	s	Double	2.00E-06
			Width	s	Double	1.00E-06
			Rising Edge	s	Double	1.00E-07
			Falling Edge	s	Double	1.00E-07
			Pulse Delay	s	Double	1.00E-07
		Constant Bias Source	Enable Pulse Bias	N/A	Check Box	Unchecked
			Width	s	Double	1.00E-06
			Rising Edge	s	Double	1.00E-07
			Falling Edge	s	Double	1.00E-07
			Pulse Delay	s	Double	1.00E-07
	Bias	Sweep Source	Start V	V	Double	5
			Stop V	V	Double	5
			Step Num	N/A	Integer	1
			Base Before Pulse	V	Double	0
			Base After Pulse	V	Double	0

Tab Group	Tab	Group	Parameter	Unit	Type	Value
Measurement Setup	Bias	Constant Bias Source	Bias	V	Double	0
			Base Before Pulse	V	Double	0
			Base After Pulse	V	Double	0

Tab Group	Tab	Group	Parameter	Unit	Type	Value
Measurement Setup	Primary		Sampling Mode	N/A	List	LINEAR
			Meas. Delay	s	Double	-1.00E-07
			Initial Interval	s	Double	1.00E-08
			Sampling Points	N/A	Int	200
			Averaging Time	s	Double	1.00E-08

Tab Group	Tab	Group	Parameter	Unit	Type	Value
Measurement Setup	Secondary		Enable Secondary Measurement	N/A	Check box	Unchecked
			Source 1 Measurement Range	N/A	List	+/- 5V
			Source 2 Measurement Range	N/A	List	+/-1 uA
			Sampling Mode	N/A	List	LINEAR
			Second Meas. Origin	s	Double	1.00E-03
			Meas. Delay	s	Double	1.00E-04
			Initial Interval	s	Double	1.00E-05
			Sampling Points	N/A	Integer	90
			Averaging Time	s	Double	1.00E-06

Step 3. Single pulse and dual condition sampling measurement

To demonstrate the single pulse sampling measurement with dual condition, change the device to the "1 MΩ" resistor. And set the following parameters for this demonstration. The measurement setup is shown in Fig. 3-5-5 and Table 3-5-2.

- Pulse period: 2 ms
- Pulse width: 2 ms
- Rise and fall time: 100 μs
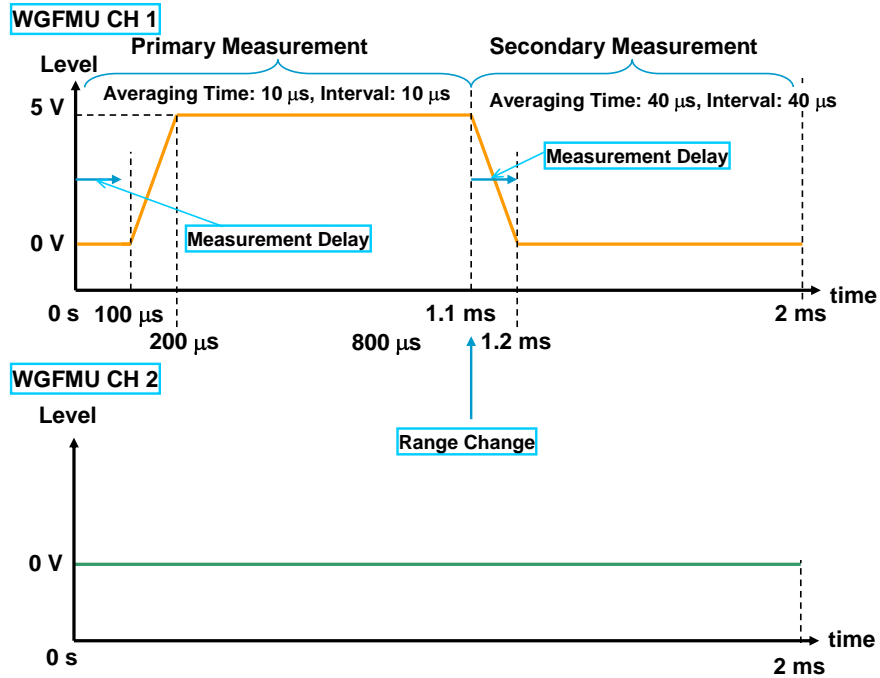- Pulse delay time: 100 μs

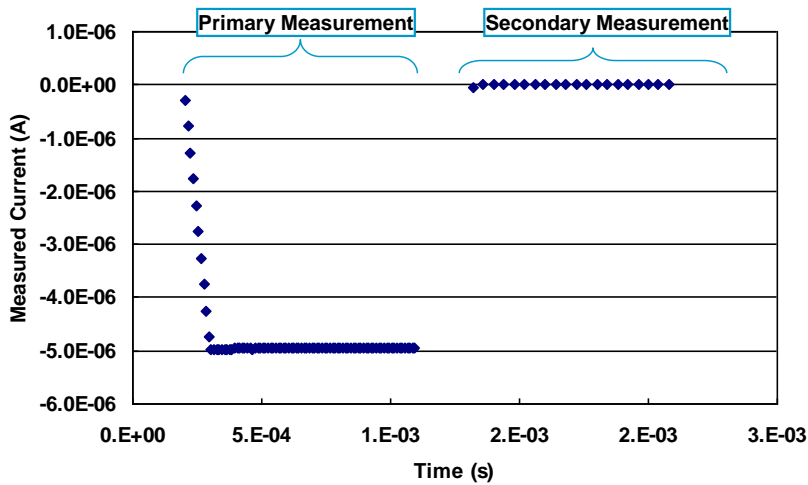Fig. 3-5-5. Example timing chart of the single pulse and dual condition sampling measurement

Fig. 3-5-6 Plot of the measured current in this demonstration

The reason why the timing range is enlarged is to show the range changing capability during the waveform and the range change has, at least, 100 μs of settling time.

Regarding the measurement parameters, the primary measurement starts from the beginning of the rising edge of the pulse. And the secondary measurement starts from the beginning of the base line voltage after the pulse.

For the primary measurement, use high current measurement range, short measurement interval, and short averaging time to observe the transient of the pulse. And for the secondary measurement, since current level becomes very small, use low current range, long measurement interval, and long averaging time to make noise level smaller. The data view format is same as a single pulse and single condition sampling measurement. See Fig. 3-5-3. The results of the primary measurement and secondary measurement are listed in the same columns in series. Fig. 3-5-6 shows the plot of the time and current measured by the Ch2.

Table 3-5-2 Single pulse and dual condition sampling measurement setup

Tab Group	Tab	Group	Parameter	Unit	Type	Value
Channel Setup	Source 2		Current Range	N/A	List Box	+/-100 uA Fixed

Tab Group	Tab	Group	Parameter	Unit	Type	Value
		Sweep Source	Period	s	Double	2.00E-03
			Width	s	Double	1.00E-03
			Rising Edge	s	Double	1.00E-04
			Falling Edge	s	Double	1.00E-04
			Pulse Delay	s	Double	100E-6

Tab Group	Tab	Group	Parameter	Unit	Type	Value
Measurement Setup	Primary		Sampling Mode	N/A	List	LINEAR
			Meas. Delay	s	Double	0.00E+00
			Initial Interval	s	Double	1.00E-05
			Sampling Points	N/A	Integer	90
			Averaging Time	s	Double	1.00E-05

Tab Group	Tab	Group	Parameter	Unit	Type	Range
Measurement Setup	Secondary		Enable Secondary Measurement	N/A	Check box	Checked
			Source 1 Measurement Range	N/A	List	+/- 5V
			Source 2 Measurement Range	N/A	List	+/-1 uA
			Sampling Mode	N/A	List	LINEAR
			Second Meas. Origin	s	Double	1.00E-03
			Meas Delay	s	Double	1.00E-04
			Initial Interval	s	Double	4.00E-05
			Sampling Points	N/A	Int	20
			Averaging Time	s	Double	4.00E-05

Step 4. Repeating the pulsed sampling measurement

Fig. 3-5-7 shows an example of the repetitive pulsed sampling measurement. The timing and the setup of this measurement are shown in Fig. 3-5-8 and Table 3-5-3. This table shows the modification of the parameter for this demonstration from the pervious setup.
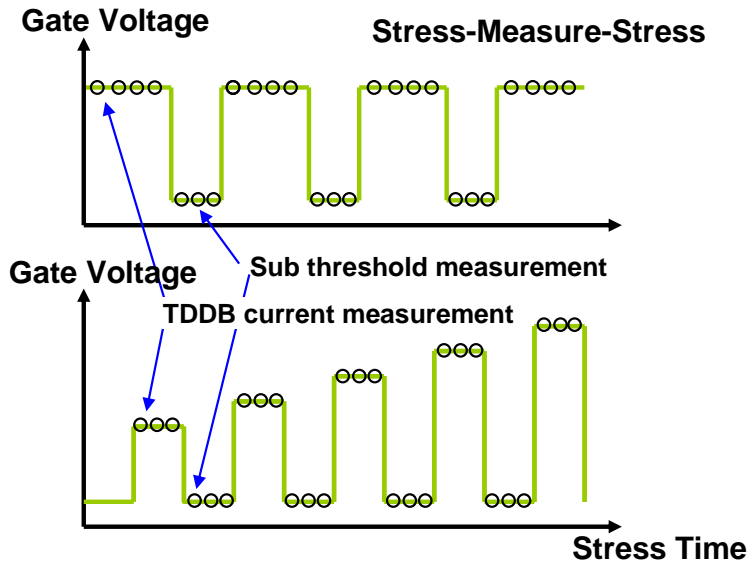

Fig. 3-5-7. Example usage of the repetitive pulsed sampling for TDDB measurement
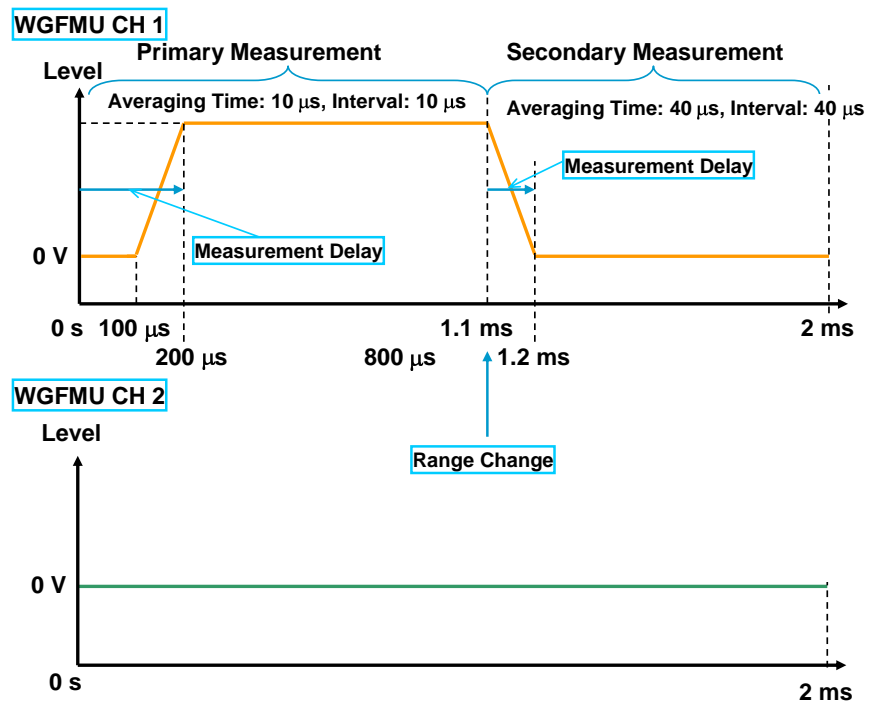

Fig. 3-5-8. Example timing chart of the repetitive pulsed sampling measurement

Table 3-5-3 Setup of the repetitive pulse sampling measurement with dual measurement conditions

Tab Group	Tab	Group	Parameter	Unit	Type	Value
Measurement Setup	Primary		Sampling Mode	N/A	List	LINEAR
			Meas Delay	s	Double	1.00E-4
			Initial Interval	s	Double	1.00E-05
			Sampling Points	N/A	Int	90
			Averaging Time	s	Double	1.00E-05

Tab Group	Tab	Group	Parameter	Unit	Type	Value
	Bias	Sweep Source	Start V	V	Double	5
			Stop V	V	Double	5
			Step Num	N/A	Integer	5
			Pulse Base	V	Double	0

Table 3-5-4 Setup change for the incremental pulse level sampling

Tab Group	Tab	Group	Parameter	Unit	Type	Value
	Bias	Sweep Source	Start V	V	Double	1
			Stop V	V	Double	5
			Step Num	N/A	Integer	5
			Pulse Base	V	Double	0
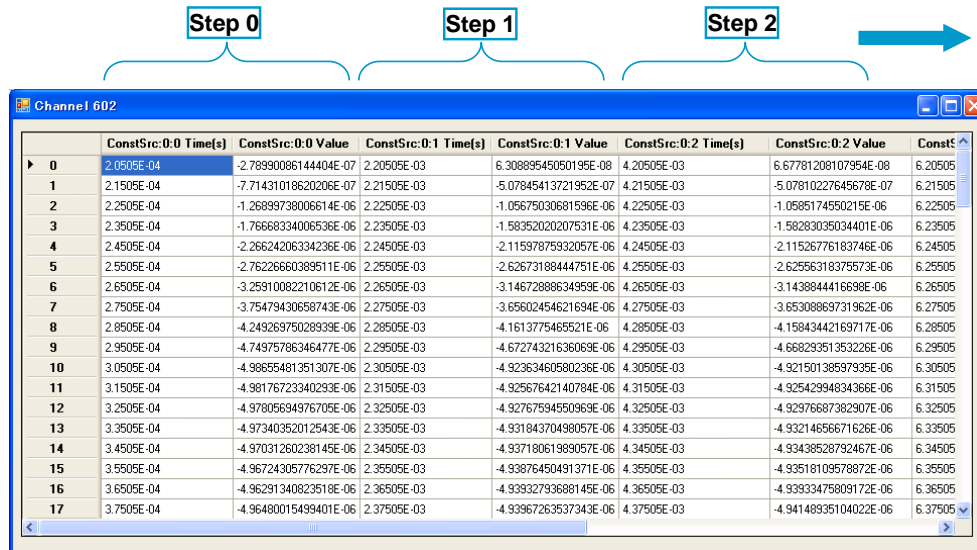
Fig. 3-5-9 Data view panel of the repetitive pulsed sampling measurement

In the data view panel of the repetitive pulsed sampling measurement, two columns are added for the time and the measured value for each step. See Fig. 3-5-9. For the data plot on a spreadsheet software, see Fig. 3-5-10.

The pulse level can be changed during the repetitive measurement like a sweep output as shown in Fig. 3-5-11. To get this kind of output, set the different value to the start and stop voltage of the sweep source. See Table 3-5-4. The data view format for this measurement result will be the same as Fig. 3-5-9.

Of course, the WGFMU can force a pulsed bias from the WGFMU Ch2. For details of the pulsed measurement sample program, see the section 4-6 Pulsed Sampling Measurement.
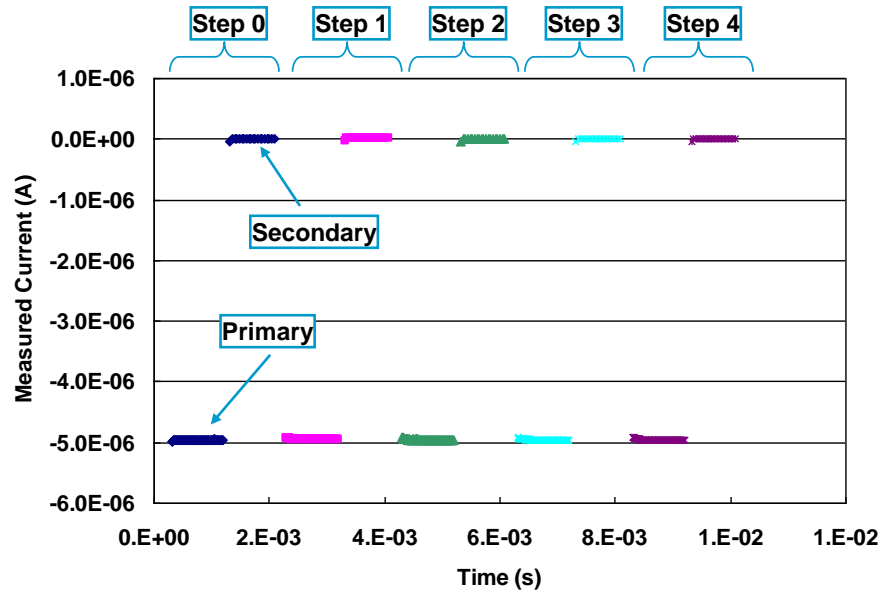

Fig. 3-5-10 Repetitive pulsed sampling measurement
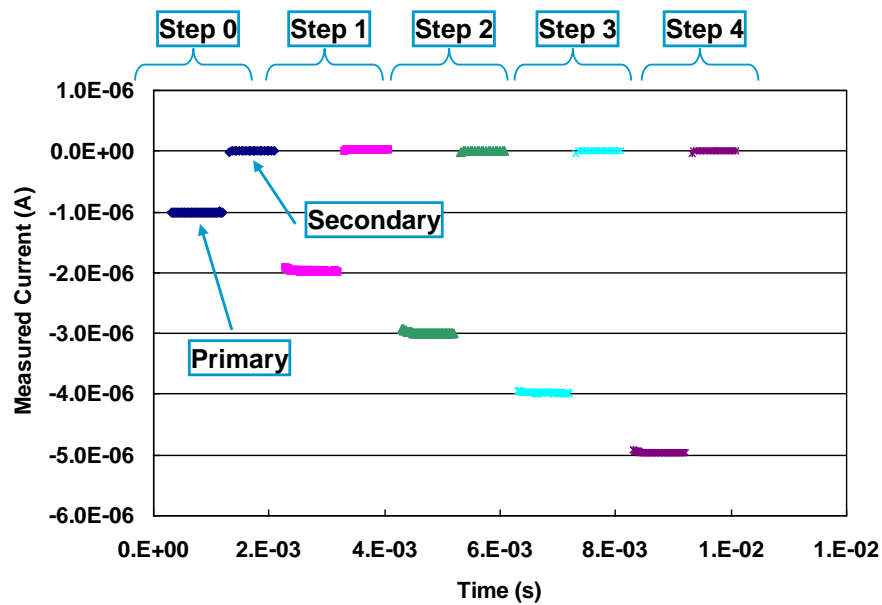
Fig. 3-5-11 Sweep repetitive pulsed sampling measurement

3-6. Time Domain I/V Sampling

The "DATASAMPLER.exe" sample program is used to collect the voltage or current in the specified sampling rate and averaging time, and save data which is a pair of the time and the measured value in a CSV (Comma Separated Value) format file. And you can analyze the data by using the "RTSDataAnalysis.exe" sample program (Random Telegraph Signal Data Analysis sample program). This section describes the usage of these sample programs.

Note: the NMOS-FET demo device does not have the RTS characteristics. So only the sample program usage is described in this section.

Step 1. Connect the device to the RSU

Fig. 3-6-1 Connection for the demonstration of the fast staircase / pulsed IV sweep measurement

Step 2. Set measurement parameters

Tab Group	Tab	Group	Parameter	Unit	Type	Value
Channel Setup	Source 1		Measurement	N/A	Check Box	Checked
			Channel	N/A	List Box	Channel ID to use as the WGFMU CH 1
			Operation Mode	N/A	List Box	Fast I/V Mode
			Measurement Mode	N/A	List Box	V Measurement
			Voltage Force Range	N/A	List Box	Auto
			Current Range	N/A	List Box	+/-10 mA Fixed
			Voltage Measurement Range	N/A	List Box	+/-5 V
			HW Skew	s	Double	Unchecked
	Source 2		Measurement	N/A	Check Box	Checked
			Channel	N/A	List Box	Channel ID to use as the WGFMU CH 2
			Operation Mode	N/A	List Box	Fast I/V Mode
			Measurement Mode	N/A	List Box	I Measurement
			Voltage Force Range	N/A	List Box	Auto
			Current Range	N/A	List Box	+/-1 mA Fixed
			Voltage Measurement Range	N/A	List Box	+/- 5V
			HW Skew	s	Double	0
Bias	Bias	Bias Source1	Module Type	N/A	List Box	N/A
			Channel ID	N/A	List Box	N/A
			Bias	V	Double	0
			Compliance	A	Double	0
		Bias Source2	Module Type	N/A	List Box	N/A
			Channel ID	N/A	List Box	N/A
			Bias	V	Double	0
			Compliance	A	Double	0

Tab Group	Tab	Group	Parameter	Unit	Type	Value
Measurement Setup	Timing		Sampling Rate	N/A	List	10k /s
			Measurement Delay	s	Double	1.00E-03
			Duration	s	Double	0.1
			Averaging Time	s	Double	1.00E-05
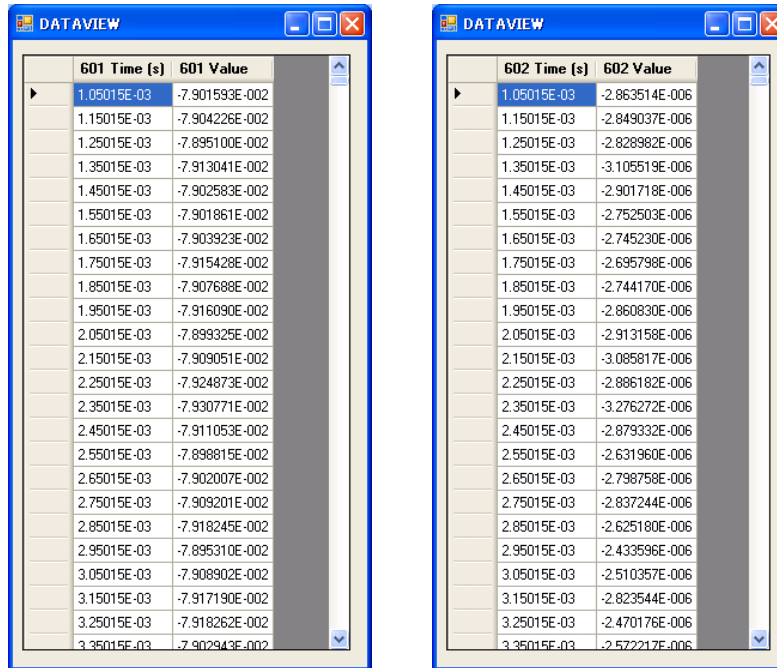
Tab Group	Tab	Group	Parameter	Unit	Type	Value
Measurement Setup	Bias	Source 1	Source	V	Double	-1.1
		Source 2	Source	V	Double	0
			Step Edge	s	Double	1.00E-07

Step 3. Execute measurement

Click the "Execute" button and enter the name of the file to save the results. After measurement, the data view panel will open. If the measurement is disabled for a channel, the data view panel of the corresponding channel is not displayed.

Note: When total number of sampling is over 10,000 points, the data view window does not open. Only the progress panel is opened to inform an expected measurement time and elapsed time.

Fig. 3-6-2 Data view panel of the data sampler program

After measurement, the "DATASAMPLER.exe" program creates multiple files. And the files can be classified by two groups. One is the test result files to store the values of the measurement parameters and result. Another one is the channel data files to store a pair of the time and measured value of each channel in the CSV format. The file name of the channel data file will be as follows.

Test Result File Name_Channel ID.csv

The "Test Result File Name" is the file name that entered when the "Execute" button is clicked, excluding it's extension. The "Channel ID" is the number of measurement channel. For example, if the file name of the test results is "RTS.csv", the name of the channel data file of the WGFMU channel 101 is "RTS_101.csv".

Step 4. Analyze data with the "RTSDataAnalysis.exe" program

Double click the "RTSDataAnalysis.exe" to run the RTS data analysis sample program. Then select the channel data file by using the file explorer on the RTS Data Analysis window. See Fig. 3-6-3. The analysis result will be automatically updated.

Note: This demo device does not have an RTS noise, so this section introduces how to use the RTS data analysis sample program.
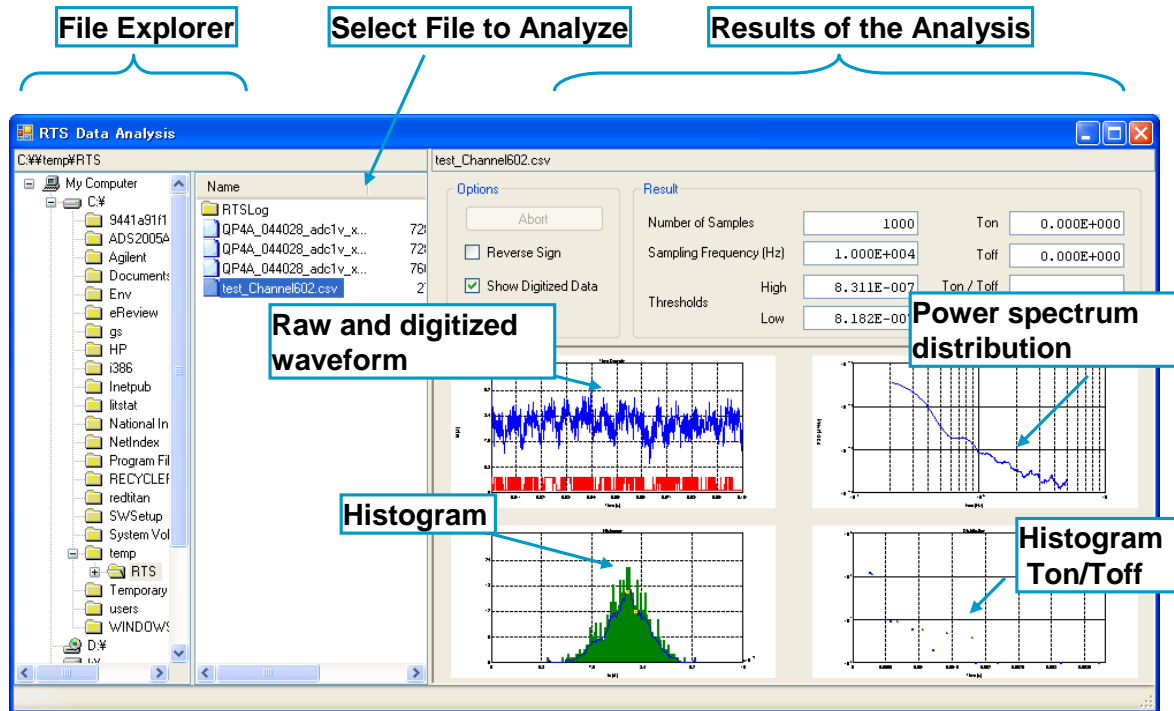

Fig. 3-6-3 Display example of the RTS data analysis sample program

Fig. 3-6-4 shows the summary section (upper right) of the RTS Data Analysis window. This section displays the basic information of the measurement such as the number of samples, frequency, threshold value to digitize the measured value, and so on. Also you can enable or disable the optional properly, reverses sign of the measured value, displays the digitized waveform, and saves the log of the analysis. The log file is stored in the "RTSLog" folder in the folder the data file is stored. The RTSLog folder will store the digitized data (.dig), FFT data (.fft), histogram (.his), power spectrum distribution (.psd), and summary of the Ton/Toff analysis.
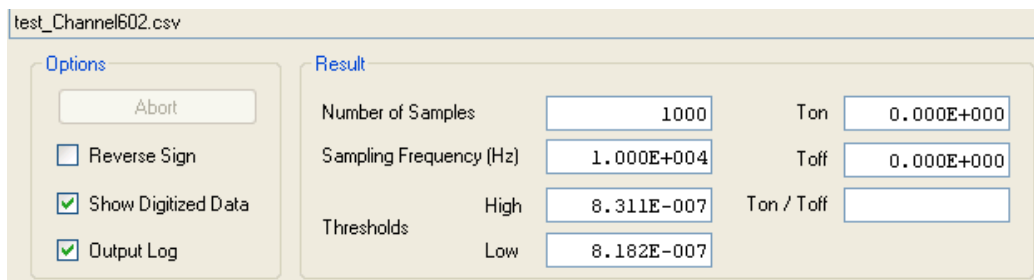

Fig. 3-6-4 Summary section of the RTS Analysis Data window

Graph section is placed under the summary section, and shows the raw sampling measurement data and the digitized data, the histogram, the power spectrum distribution, and the histogram of Ton and Toff. Each analysis graph can be magnified by double clicking it.
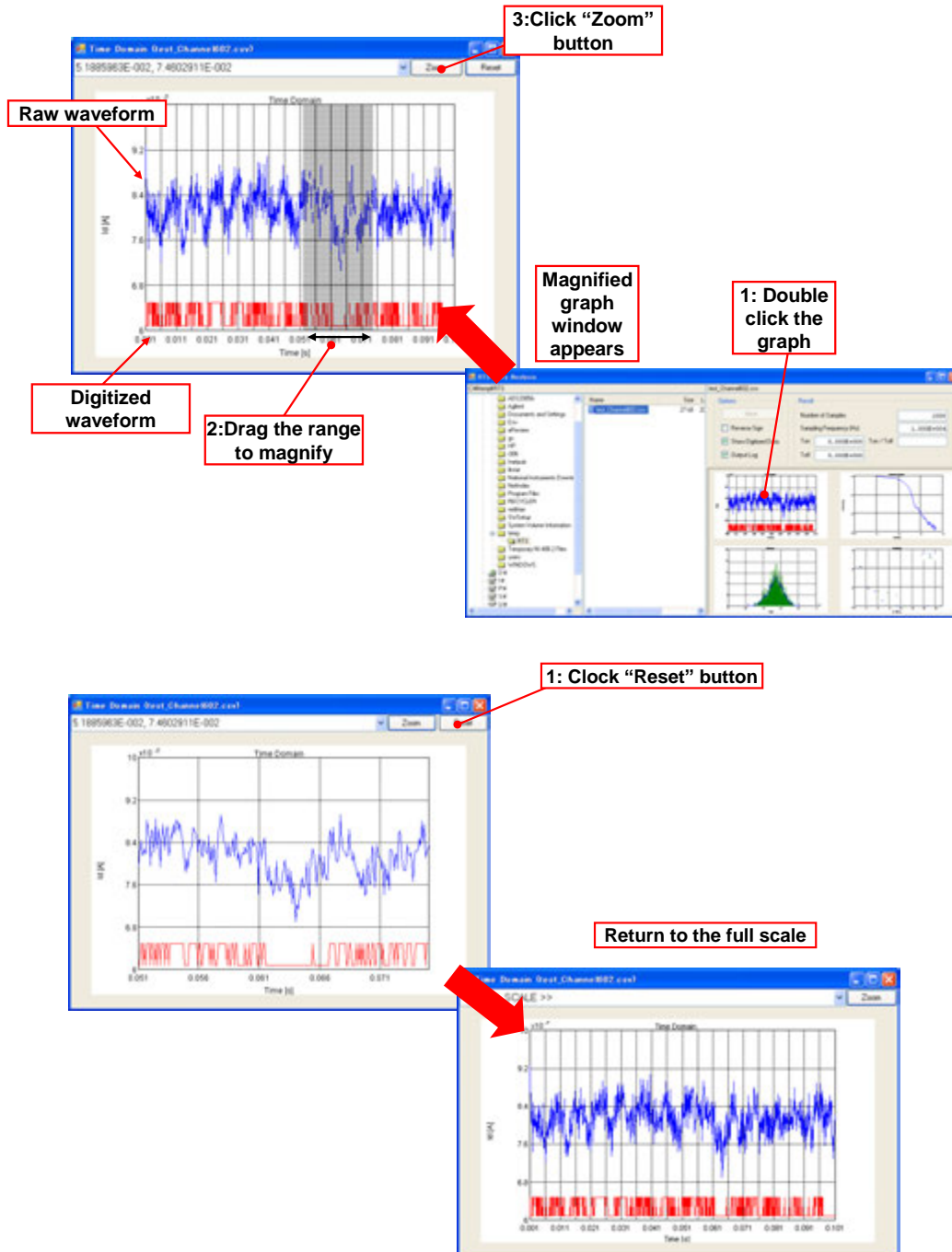

Fig. 3-6-5 RTS Data Analysis window and Data graph window

There is a zoom capability for the waveform graph and the power spectrum distribution graph. To zoom

the graph, drug the area you want to zoom then click "Zoom" button. To reset the scale, click "Reset" button.

Fig. 3-6-6 is an example of the RTS analysis of the device which has the RTS noise. The histogram shows an obvious double peak on the measured drain current.

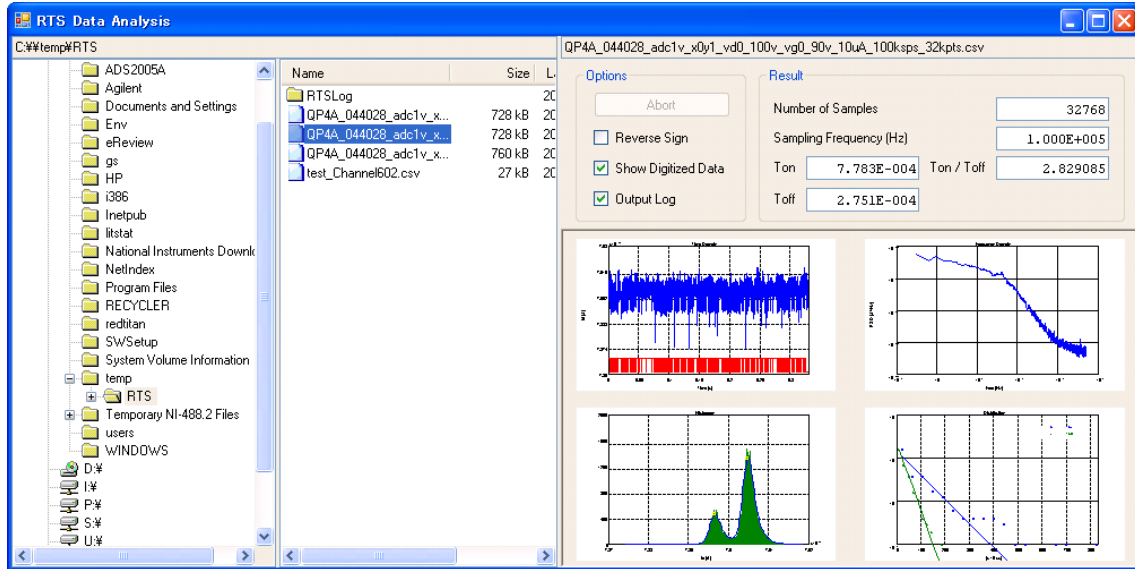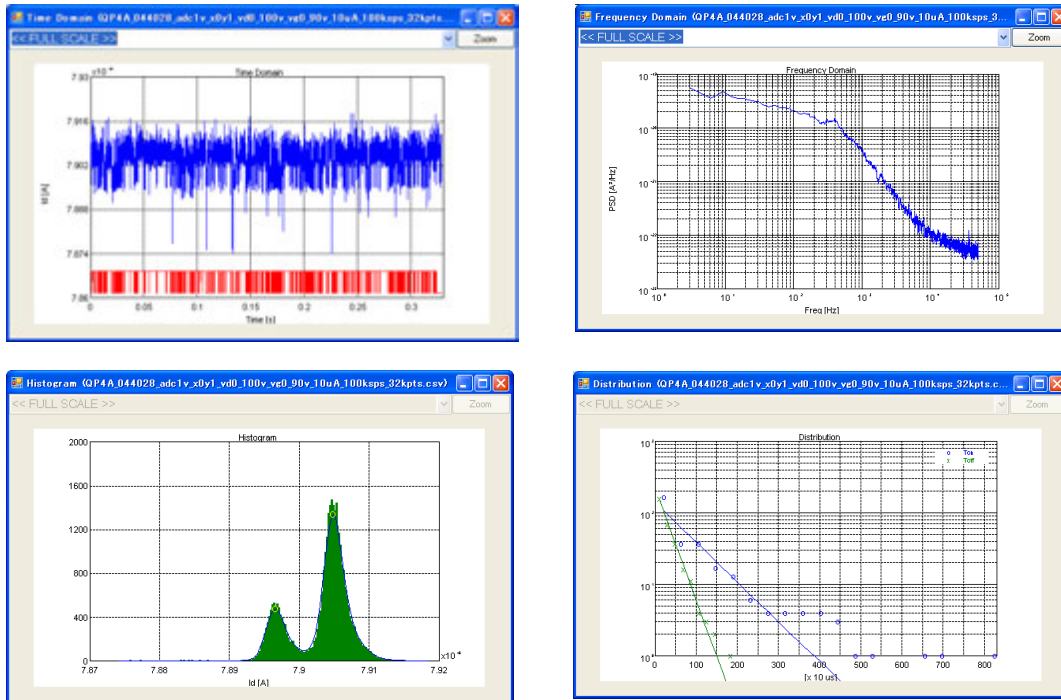Fig. 3-6-6 RTS Data Analysis Window

Fig. 3-6-7 Data graph windows

4   Sample Program Reference

Sample Program Reference

This chapter provides the reference information of the sample programs. This chapter consists of the following sections.

4-1. Overview

Agilent B1530A is furnished with *Agilent B1530A Instrument Library and Sample Program CD* which stores the WGFMU instrument library and the sample programs for controlling the B1530A easily and demonstrating a basic performance of the B1530A. The sample programs cover the following applications.

- NBTI.exe
  - ➢ Supports DC and AC stress
  - ➢ Supports various measurements, on-the-fly (OTF), fast Id measurement, staircase sweep measurement, ramp sweep measurement, and pulsed IV measurement.
  - ➢ Supports single sweep and dual sweep measurements.
  - ➢ Iterative measurement after stress to evaluate a recovery effect.

- SAMPLING.exe
  - ➢ Supports variable measurement conditions.

- SWEEP.exe
  - ➢ Supports various types of sweep, staircase sweep measurement, ramp sweep measurement, and pulsed IV measurement.
  - ➢ Supports single sweep and dual sweep.

- PULSE.exe
  - ➢ Sampling measurement with a pulsed bias.
  - ➢ Supports variable measurement conditions.

- DATASAMPLER.exe
  - ➢ Captures voltage or current with a fixed sampling rate.

- RTSDataAnalysis.exe
  - ➢ Performs RTS data analysis.

The RTS data analysis sample program is for the offline data analysis. And the other programs are for the online measurement which uses two WGFMU channels to force waveform and measure voltage or current and optionally uses additional two WGFMU or SMU channels for applying DC bias voltage.

The sample programs are the programming example for using the WGFMU instrument library. And the source codes are stored in the *Agilent B1530A Instrument Library and Sample Program CD* for your reference. The sample programs are developed on the Microsoft .Net C# 2005 environment. Prepare this software to read or edit the source code.

4-2. Installation

Prepare *Agilent B1530A Instrument Library and Sample Program CD* and the instrument controller described in the section 1-3 System Requirements. And install the sample programs.

1. Insert the CD into the CD-ROM drive of the instrument controller.
2. Copy the SamplePrograms folder on the CD and paste it onto your working folder on the instrument controller.

The SamplePrograms folder contains the followings.

- bin   stores the executable file.
- src   stores the source code.
- README.txt   provides the brief information.

Execute the following file to launch the sample program.

- bin\NBTI\NBTI.exe
- bin\SAMPLING\SAMPLING.exe
- bin\SWEEP\SWEEP.exe
- bin\PULSE\PULSE.exe
- bin\DATASAMPLER\DATASAMPLER.exe
- bin\RTSDataAnalysis\RTSDataAnalysis.exe

4-3. Action Buttons

After launching the sample program, you will see the following action buttons on the window.
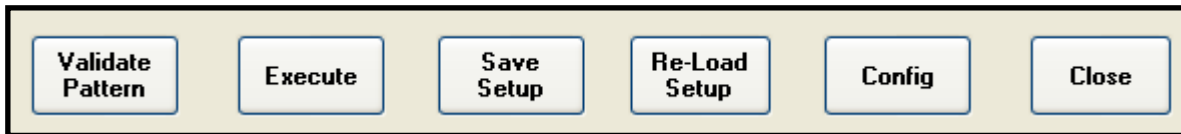

Fig. 4-3-1 Action buttons

Validate Pattern: This button is used to save the present setup on the sample program GUI as a pattern data file or waveform data file in the CSV (comma separated value) format. See the section 4-3-1 Validate pattern data for the file.

1. Click the Validate Pattern button. This opens the SAVEFILEMODE dialog box used to select the data type, pattern or waveform.
2. Click OK on this dialog box. This opens the Save As dialog box used to specify the file name.
3. Specify the folder and the file name for saving the pattern or waveform data.
4. Click the Save button on the Save As dialog box. The file will be created in the specified folder.

Clicking the Save button also creates a "prog_name.cf" file which saves the present measurement parameters in the folder which stores the sample program file now executed. Where, prog_name is the sample program name. For example, it is NBTI for the "NBTI.exe" sample program.

Execute: This button is used to trigger the measurement sequence. See the section 4-3-2 Test result data.

1. Click the Execute button. This opens the Save As dialog box used to specify the test result file name.
2. Specify the folder and the file name for saving the test result data.
3. Click the Save button on the Save As dialog box. This starts the measurement sequence.

Clicking the Save button also creates a "prog_name.cf" file which saves the present measurement parameters in the folder which stores the sample program file now executed. Where, prog_name is the sample program name. For example, it is NBTI for the "NBTI.exe" sample program.

Save Setup: This button is used to create a .cf file which saves the present measurement parameters.

1. Click the Save Setup button. This opens the Save As dialog box used to specify the file name.
2. Specify the folder and the file name for saving the present measurement parameters.
3. Click the Save button on the Save As dialog box. The .cf file will be created in the specified folder.

Re-Load Setup: This button is used to load the measurement parameters saved in the specified .cf file. It must be the file created by the "Validate Pattern", "Execute", or "Save Setup" function when performing the same sample program.

Config: This button is used to set the GPIB configuration. See the section 4-3-3 Configuration window.

Close: This button is used to exit the sample program and close the window.

4-3-1. Validate pattern data

Clicking the Validate Pattern button opens the SAVEFILEMODE dialog box used to specify the data type.
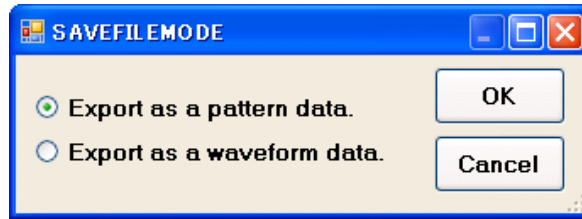
Fig. 4-3-2 Data type selection

Export as a pattern data

This mode is used to create the pattern data which can be created by using the WGFMU_exportAscii() function of the instrument library. This function exports the information of all pattern data created in the present WGFMU session. You can read the pattern data by using a spreadsheet software as shown in Fig. 4-3-3 and 4-3-4.

Fig. 4-3-3 Pattern data, pattern section

Fig. 4-3-4 Pattern data, sequence section

Export as a waveform data

This mode is used to create the waveform data which will be the entire waveform data of each output channels when running the sequence. The waveform data also includes the averaged measurement timing and the output level at the measurement. You can read the waveform data by using a spreadsheet software as shown in Fig. 4-3-5. Use the scattering chart of the spreadsheet software to make graphs. This is effective for debugging the WGFMU channel output setup.
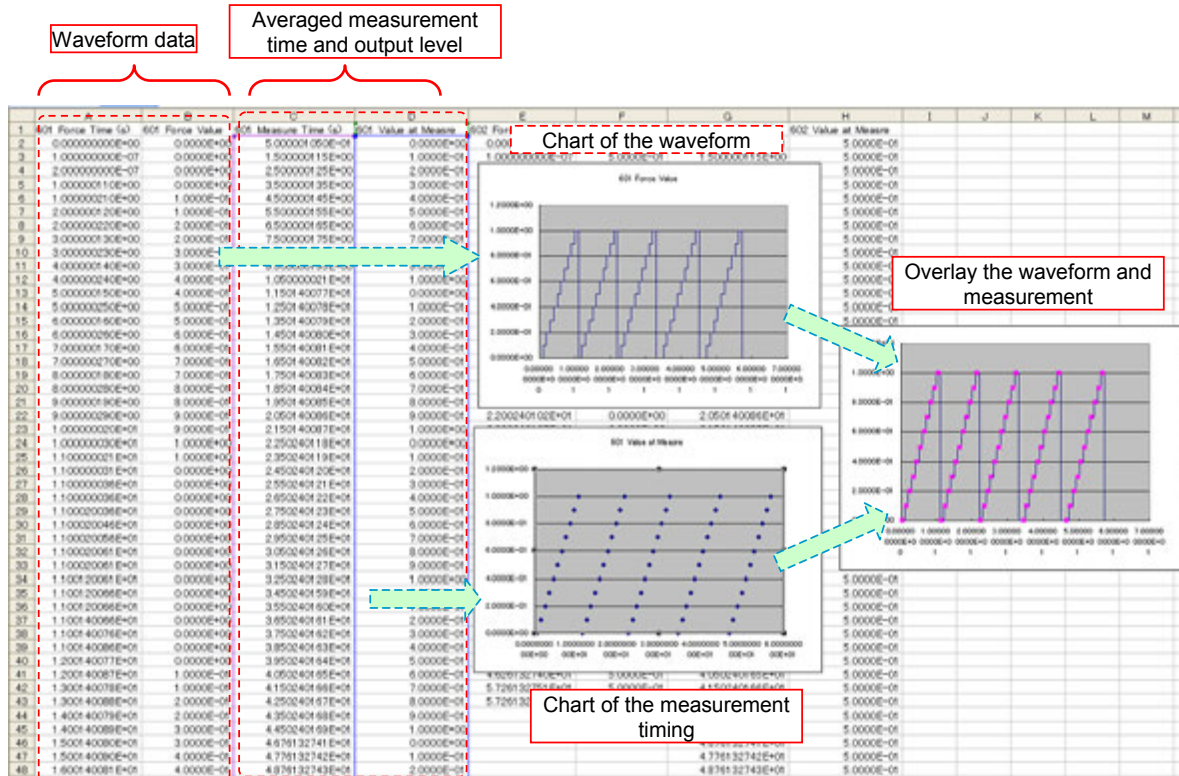
Fig. 4-3-5 Waveform data

4-3-2. Test result data

During the test execution, the sample program displays the data view panel of each channel to show the measurement data. The data view will be updated when the measurement data is ready.
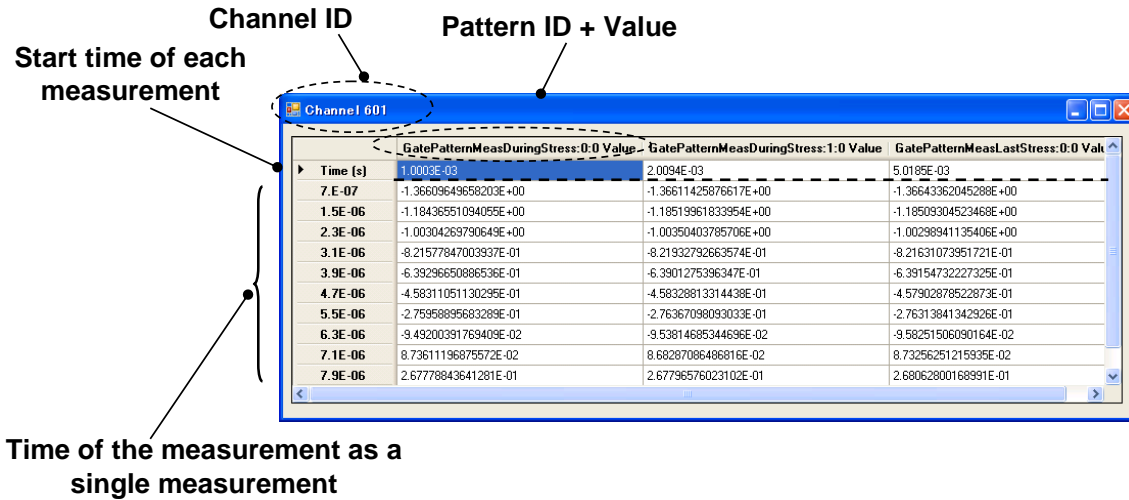
- Pattern ID = Pattern Name : Cycle No. : Loop No.
- Cycle No. = Number of appearance of the pattern started from "0".
- Loop Count: = Number of loop of the pattern started from "0".
- The 1st row indicates the time origin of the measurement.
- The 1st column shows the time of the measurement start of the origin of each measurement.

Fig. 4-3-6 Data view panel

Fig. 4-3-6 shows an example of the data view panel. The panel lists the time and the measured data for the individual measurement event specified by the pattern ID. The format of the pattern ID is as follows.

Pattern ID = PatternName: Cycle : Loop

Where,

Cycle: Count of the appearance of the "pattern" in the entire sequence. Integer, 0 or more.

Loop: Count of the loop of the "pattern". Integer, 0 or more.

Count: Count of the appearance of the "measurement event" in the same pattern. Integer, 0 or more.

By executing the test, the sample program also creates and saves the test result data. The data is saved in a file by each pattern ID individually. The file name is as follows.

Test result file name = File_Pattern_Channel.csv

Where,

File: File name specified by using the Save As dialog box when the test is started.

Pattern: Pattern ID. The character : (colon) will be automatically replaced with _ (underscore).

Channel: WGFMU channel ID.

The test result data consists of three sections, application name, test parameters, and measurement data as shown in Fig. 4-3-7.

```
<ApplicaitonName>
Application Name
</ApplicationName>
<Settings>
Control Name:value
:
</Setting>
<Result>
Measured data
:
</Result>
```

Fig. 4-3-7 Image of the test result file

NBTI Sample Program

PatternTime, Gate Pattern ID Value #1, Gate Pattern ID Value #2..... Drain Pattern ID #1, Drain Pattern Id #2, ...
Time, Init time of above pattern, ...
:

Sampling and Data Recorder Sample Program

Source1 Pattern ID Time, Source 1 Pattern ID Value, Source 2 Pattern ID Time, Source 2 Pattern ID Value
:
:

Sweep Sample Program

Sweep Source Pattern ID Time, Sweep Source Pattern ID Value, Constant Source Pattern ID Time, Constant Source Pattern ID Value
:
:

Pulse Sample Program

Sweep Source Step 1 Pattern ID Time, Sweep Source Step 1 Pattern ID Value, Sweep Source Step 2 Pattern ID Time, Sweep Source Step 2 Pattern ID Value...., Constant Source Step 1 Pattern ID Time, Constant Source Step 1 Pattnern ID Value, Constant Source Step 2 Pattern ID Time, Constant Source Step 2 Pattern ID Value....
:

Fig. 4-3-8 Measurement data section

The effective measurement data is recorded in the test result data. If measurement of the specified channel is disabled, the data for the corresponding channel is not included in the measurement data section. The channel data file consists of the pair of the measurement time and the measured value separated by comma without any headers.

4-3-3. Configuration window

This window is opened by clicking the Config button and is used to set the GPIB configuration.
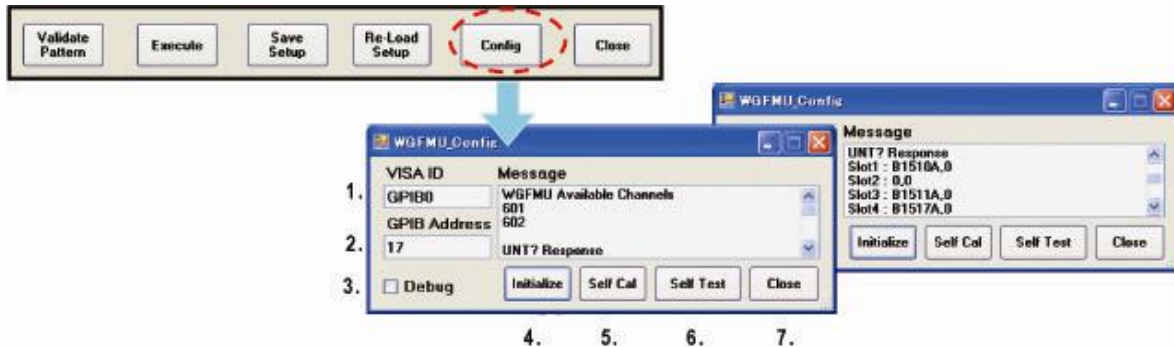
Fig. 4-3-9 Configuration window

1. Enter the VISA ID (VISA name) of the instrument controller.
2. Enter the GPIB address of the B1500A.
3. Enables or disables the logging of the WGFMU session.
    - If "Debug" has been checked, the execution error and warning are recorded in the "WgfmuLog.txt" file in the folder which stores the sample program file now executed.
4. Initializes the system.
    - Initializes the WGFMU.
    - Lists the available WGFM channels in the Message area.
    - Lists the installed modules in the Message area. This is the UNT? command response.
    - DC calibration is executed when the B1500A is turned on.
5. Executes the self-calibration.
    - Displays the self-calibration result in the Message area.
6. Executes the self-test.
    - Displays the self-test result in the Message area.
7. Closes the WGFMU_Config window.
    - The VISA ID and the GPIB Address will be stored in the setting file.

4-4. NBTI.exe

This application executes the NBTI test of the stress-measure-stress and on-the-fly sequence (OTF sequence).

Two WGFMU channels are used for the gate and drain bias and additional two WGFMU or SMU channels can be used for DC bias.

For the measurement, various type of measurements are available, Id sampling measurement, staircase sweep measurement, ramp sweep measurement, pulsed sweep measurement, and three levels on-the-fly measurement. For the sweep measurements, single sweep and dual sweep are available too.

Also, the reference measurement prior stress and the post measurement after stress are available. For the post measurement, iteration with a linear or log interval is available for evaluating a recovery effect.

Regarding a current range, different current range can be used for the stress and the measurement to expand the stress voltage and improve the measurement resolution.

–1. Channel setup
 • Gate
 • Drain
 • Bias
–2. Stress setup
 • Stress Time
 • Vg
 • Vd
–3. Measurement setup
 • Sequence
 • Id Sampling
 • Sweep
 • PIV
 • OTF
–4. Action buttons
 • Validate Pattern
 • Execute
 • Save Setup
 • Re-Load Setup
 • Config
 • Close

Fig. 4-4-1 Main panel of NBTI sample program

The main window consists of four sections, Channel Setup, Stress Setup, Measurement Setup, and action buttons. The Channel Setup section defines the channel information such as channel ID, operation mode, measurement mode, gate bias, drain bias, additional DC bias and so on. The Stress Setup section defines the stress timing and the stress bias parameters. The Measurement Setup section defines the sequence of measurement, the measurement type, and the measurement parameters. And the action button section

provides the buttons to execute specific actions as described in the section 4-3 Action Buttons.

4-4-1. Channel Setup
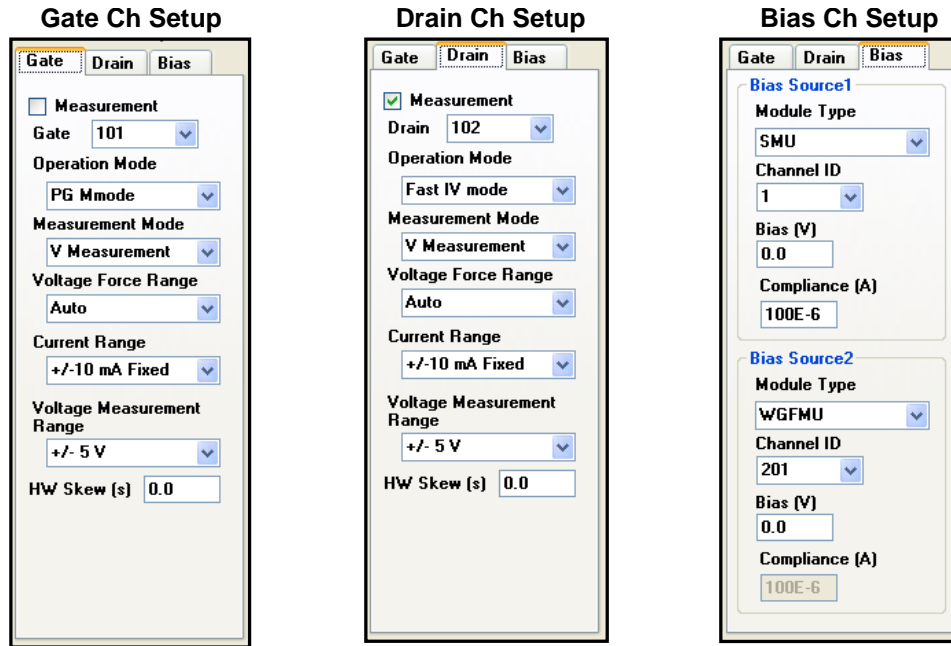
Fig. 4-4-2 Channel Setup section
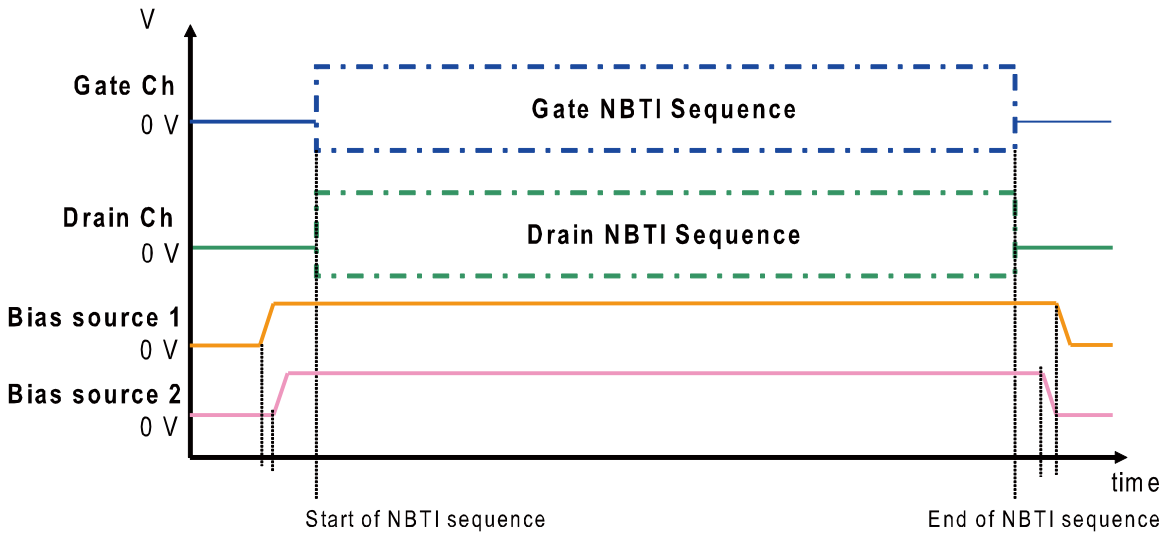
– Bias source 1 starts output before Bias source 2 starts output.
– Bias source 2 starts output before NBTI sequence starts.
– Gate Ch and Drain Ch start and stop output simultaneously.
– Bias source 2 stops output after NBTI sequence is completed including the data retrieving.
– Bias source 1 stops output after DC source 2 stops output.
– The delay time depends on the speed of the GPIB communication.

Fig. 4-4-3 Channel output sequence

Table 4-4-1 Gate channel setup parameters

Tab Group	Tab	Group	Parameter	Unit	Type	Range	Description
Channel Setup	Gate		Measurement	N/A	Check Box	Check or blank	Enables or disables the measurement by this channel.
			Gate*1	N/A	List Box	101, 102, 201, 202, 301, 302, 401, 402, 501, 502, 601, 602, 701, 702, 801, 802, 901, 902, 1001, 1002	Channel connected to the gate
			Operation Mode	N/A	List Box	PG Mode, Fast IV Mode	WGFMU operation mode
			Measurement Mode	N/A	List Box	V Measurement, I Measurement	Measurement mode If the operation mode is "PG Mode", "I Measurement" is not available.
			Voltage Force Range	N/A	List Box	Auto, +/-3 V, +/-5 V, -10 V to 0 V, 0 V to +10 V	Voltage output range
			Current Range	N/A	List Box	1 uA Fixed, 10 uA Fixed, 100 uA Fixed, 1 mA Fixed, 10 mA Fixed	Current range This range is used for the measurement for the "I Measurement" mode or the output for the "V Measurement" mode.
			Voltage Measurement Range	N/A	List Box	+/-5 V, +/-10 V	Voltage measurement range This parameter is ignored if the measurement mode is set to the "I Measurement".
			HW Skew	s	Double	-50 ns to 50 ns	Force and measurement skew of this channel

*1: The channel ID must be unique.

Table 4-4-2 Drain channel setup parameters

Tab Group	Tab	Group	Parameter	Unit	Type	Range	Description
	Drain		Measurement	N/A	Check Box	Check or blank	Enables or disables the measurement by this channel.
			Drain *1	N/A	List Box	101, 102, 201, 202, 301, 302, 401, 402, 501, 502, 601, 602, 701, 702, 801, 802, 901, 902, 1001, 1002	Channel connected to the drain
			Operation Mode	N/A	List Box	PG Mode, Fast IV Mode	WGFMU operation mode
			Measurement Mode	N/A	List Box	V Measurement, I Measurement	Measurement mode If the operation mode is "PG Mode", "I Measurement" is not available.
			Voltage Force Range	N/A	List Box	Auto, +/-3 V, +/-5 V, -10 V to 0 V, 0 V to +10 V	Voltage output range
			Current Range	N/A	List Box	1 uA Fixed, 10 uA Fixed, 100 uA Fixed, 1 mA Fixed, 10 mA Fixed	Current range This range is used for the measurement for the "I Measurement" mode or the output for the "V Measurement" mode.
			Voltage Measurement Range	N/A	List Box	+/-5 V, +/-10 V	Voltage measurement range This parameter is ignored if the measurement mode is set to the "I Measurement".
			HW Skew	s	Double	-50 ns to 50 ns	Force and measurement skew of this channel

*1: The channel ID must be unique.

Table 4-4-3 DC bias channel setup parameters

Tab Group	Tab	Group	Parameter	Unit	Type	Range	Description
Bias	Bias	Bias Source 1	Module Type	N/A	List Box	N/A, WGFMU, SMU	Type of the bias source If no bias source is used, select "N/A".
			Channel ID *1	N/A	List Box	WGFMU 101, 102, 201, 202, 301, 302, 401, 402, 501, 502, 601, 602, 701, 702, 801, 802, 901, 902, 1001, 1002 SMU 1, 2, 3, 4, 5, 6, 7, 8, 9, 10	Channel of the bias source
			Bias *2	V	Double	-10 V to 10 V	Bias voltage
			Compliance *3	A	Double	0 to 100 mA	Current compliance of this bias source Effective only for the "SMU" module type.
		Bias Source 2	Module Type	N/A	List Box	N/A, WGFMU, SMU	Type of the bias source If no bias source is used, select "N/A".
			Channel ID *1	N/A	List Box	WGFMU 101, 102, 201, 202, 301, 302, 401, 402, 501, 502, 601, 602, 701, 702, 801, 802, 901, 902, 1001, 1002 SMU 1, 2, 3, 4, 5, 6, 7, 8, 9, 10	Channel of the bias source
			Bias *2	V	Double	-10 V to 10 V	Bias voltage
			Compliance *3	A	Double	0 to 100 mA	Current compliance of this bias source Effective only for the "SMU" module type.

*1: The channel ID must be unique.

*2: Maximum voltage depends on the operation mode. Error occurs if the value is greater than its limit.

*3: Maximum value of the current compliance depends on the type of SMU. Error occurs if the value is greater than its limit.

4-4-2. Stress Setup

| Accumulated Stress Time List | Gate Stress Bias Setup | Drain Stress Bias Setup |

Fig. 4-4-4 Stress Setup section
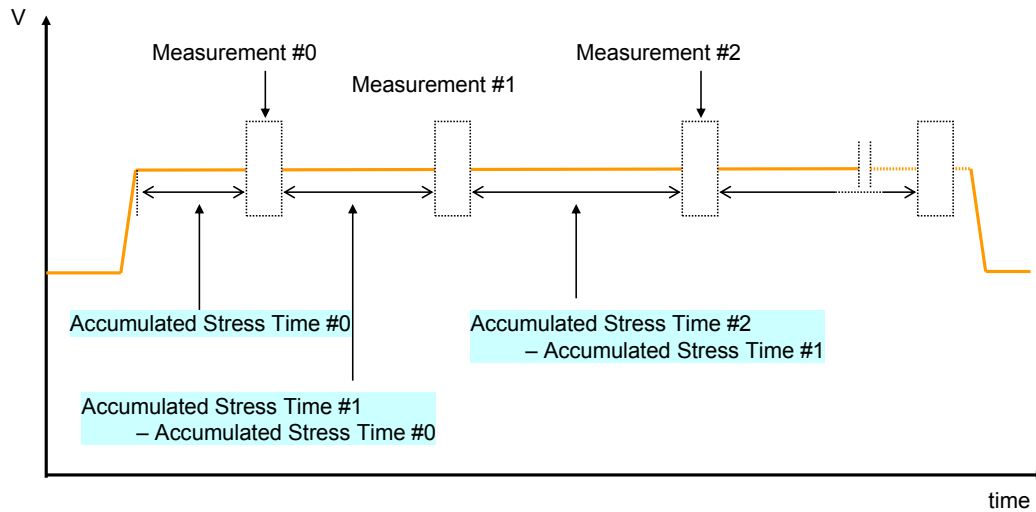
Fig. 4-4-5 Definitions of the accumulated stress time

V

DC Stress

Stress duration   Measurement

Stress Voltage

0 V

AC Stress

Rise / Fall time

Pulse period

Stress Voltage

Baseline Voltage

0 V

Pulse Delay

Pulse width

Start voltage of the measurement

Stress to Meas. Edge

Width – Rise time – Pulse Delay

Stress to Meas. Edge

time

Pulse Period = 1 / Pulse Frequency
Pulse Width = Pulse Period * Duty / 100
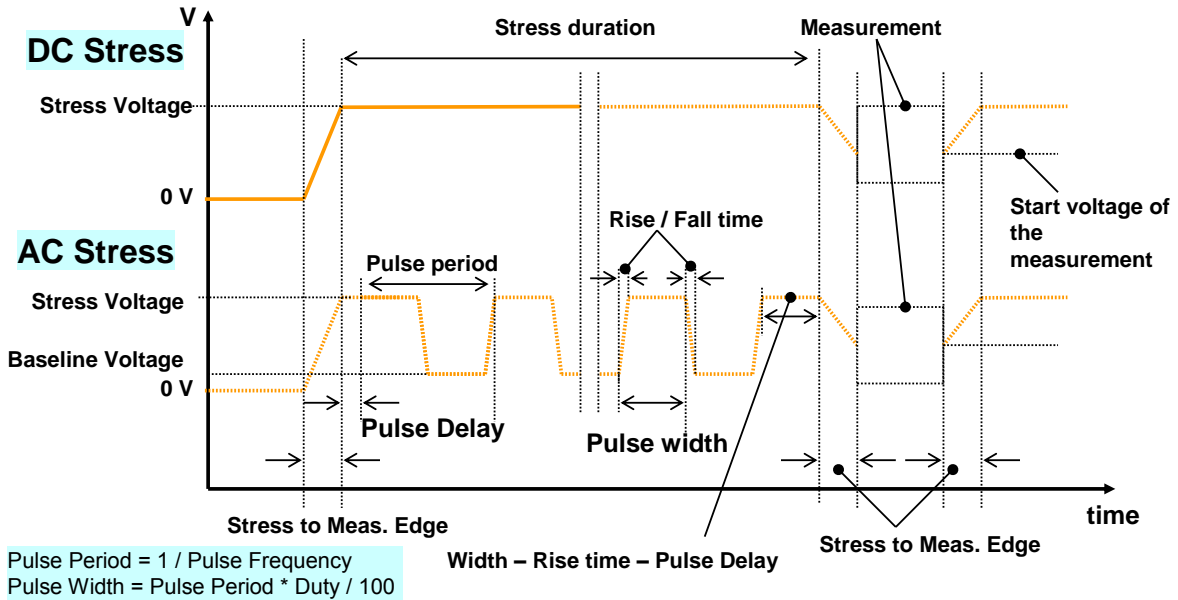
Fig. 4-4-6 Definitions of the Stress Sequence

V

Reference Measurement

Measurement during stress

Measurement at last stress

Post Measurements

Stress Voltage

0V

Set Current Range for Stress Phase

Set Current Range for stress phase

Set Current Range for Measurement before starting the sequence

Set Current Range for Measurement

Set Current Range for Measurement

Set Current Range for Measurement

time

• When the current range for the stress is same with it for the measurement phase, range change event is not added.

Fig. 4-4-7 Sequence Tab of the Measurement Setup Sections

Table 4-4-4 Stress setup parameters #1

Tab Group	Tab	Group	Parameter	Unit	Type	Range	Description
Stress Setup	Stress Time		Accumulated Stress Time	s	Double	10 ns to 1,000,000 s	Accumulated stress time to interrupt the stress to perform measurement To skip the stress phase, stay blank.
	Vg	Stress Type	DC Stress	N/A	Radio Button	Check or blank	Stress type, DC stress or AC stress
			AC Stress				
		Bias	Vg Stress *1	V	Double	Stress voltage on the gate channel.	Stress voltage applied to the gate terminal
			Current Range	N/A	List Box	1 uA Fixed, 10 uA Fixed, 100 uA Fixed, 1 mA Fixed, 10 mA Fixed	Current range used for the stress phase
			Range Change Hold	s	Double	0 s to 10,000 s	Hold time for keeping the stress voltage to wait the settling of the range change
		Vg Pulse	Vg Base *1	V	Double	-10 V to 10 V	Base-line voltage of the gate stress pulse This parameter is valid only for the "AC stress" type.
			Frequency *2	Hz	List Box	100 Hz, 1k Hz, 10k Hz, 100k Hz, 1M Hz	Frequency of the gate stress pulse This parameter is valid only for the "AC stress" type.
			Duty *2	%	Double	0 to 100	Duty ratio of the gate stress pulse This parameter is valid only for the "AC stress" type.
			Rise/Fall Time *2	s	Double	10 n to 10,000 s	Rise and fall time of the gate stress pulse This parameter is valid only for the "AC stress" type.
			Delay *2	s	Double	10n to 10,000 s	Delay time for the gate stress pulse This parameter is valid only for the "AC stress" type.

*1: Maximum voltage depends on the operation mode. Error occurs if the value is greater than its limit.

*2: The pulse parameters must satisfy the following relations.

Period = 1 / Frequency

Duty = Width / Period (%)

Rise/Fall Time < Width

Delay + Width + Rise/Fall Time < Width

When the drain pulse bias is enabled, the period of the drain pulse is the same as the period of the gate pulse.

Table 4-4-5 Stress setup parameters #2

Tab Group	Tab	Group	Parameter	Unit	Type	Range	Description
	Vd	Bias	Vd Stress *1	V	Double	-10 V to 10 V	Stress voltage applied to the drain terminal
			Current Range	N/A	List Box	1 uA Fixed, 10 uA Fixed, 100 uA Fixed, 1 mA Fixed, 10 mA Fixed	Current range used for the stress phase
			Range Change Hold	s	Double	0 s to 10,000 s	Hold time for keeping the stress voltage to wait the settling of the range change
		Vd Pulse	Enable Pulse Stress	N/A	Check Box	Check or blank	Enables or disables the pulse stress on the drain terminal.
			Vd Base *1	V	Double	-10 V to 10 V	Base-line voltage of the drain stress pulse This parameter is valid only when the drain pulse stress is enabled.
			Duty *2	%	Double	0 to 100	Duty ratio of the drain stress pulse This parameter is valid only when the drain pulse stress is enabled.
			Rise/Fall Time *2	s	Double	10 ns to 10,000 s	Rise/fall time of the drain stress pulse This parameter is valid only when the drain pulse stress is enabled.
			Delay *2	s	Double	10 ns to 10,000 s	Delay time of the drain stress pulse This parameter is valid only when the drain pulse stress is enabled.

*1: Maximum voltage depends on the operation mode. Error occurs if the value is greater than its limit.

*2: The pulse parameters must satisfy the following relations.

Period = 1 / Frequency

Duty = Width / Period (%)

Rise/Fall Time < Width

Delay + Width + Rise/Fall Time < Width

When the drain pulse bias is enabled, the period of the drain pulse is the same as the period of the gate pulse.

4-4-3. Measurement Setup
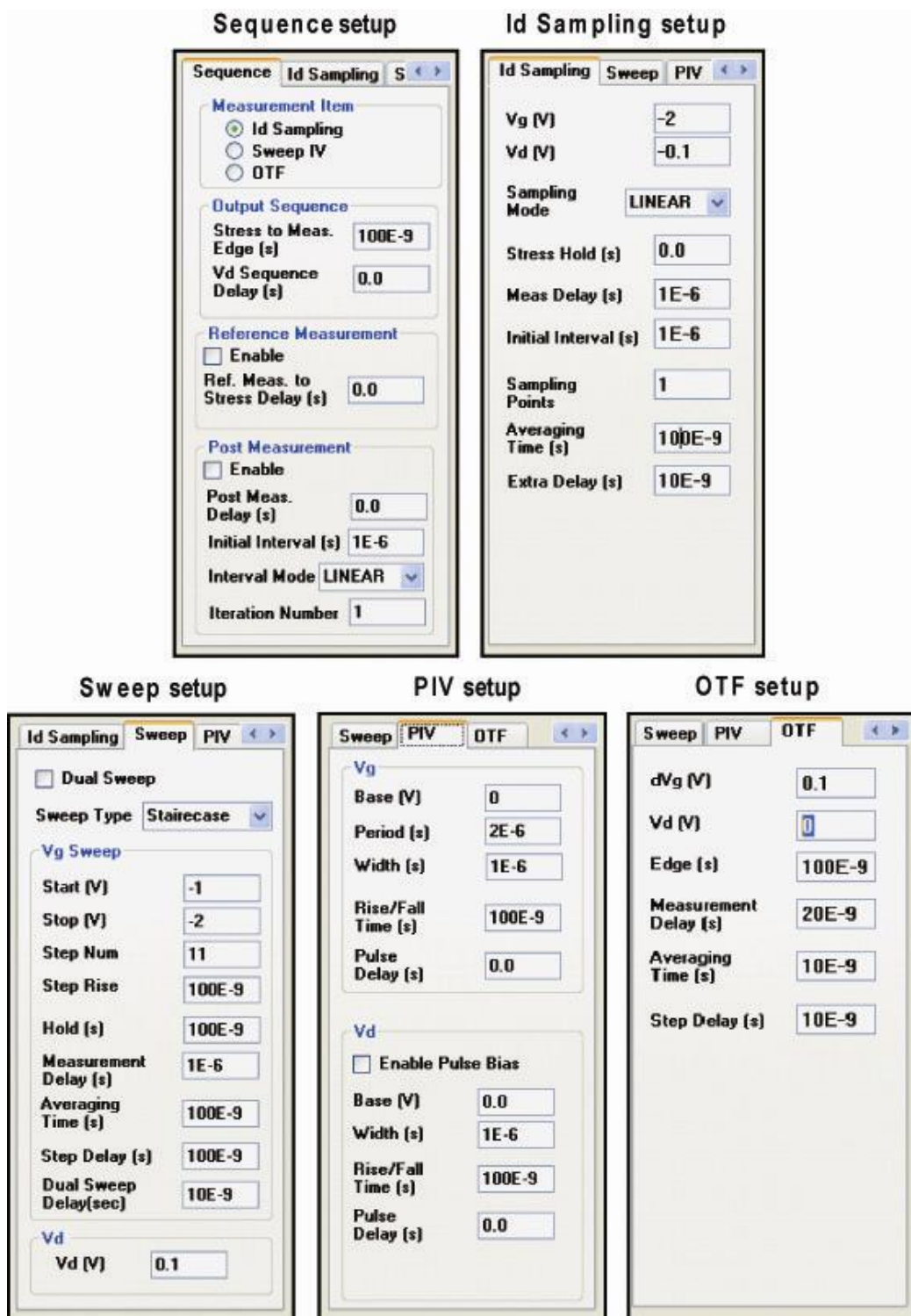
Fig. 4-4-8 Measurement Setup section

Table 4-4-6 Sequence setup parameters

Tab Group	Tab	Group	Parameter	Unit	Type	Range	Description
Measurement	Sequence	Measurement Item	Id	N/A	Radio Button	Check or blank	Measurement type
			Sampling				
			Sweep IV				
			OTF				
		Output Sequence	Stress to Meas. Edge	s	Double	10 ns to 10,000 s	Transition time from stress phase to measurement phase
			Vd Sequence Delay	s	Double	10 ns to 10,000 s	Output sequence delay between the gate voltage and drain voltage
		Reference Measurement	Enable	N/A	Check Box	Check or blank	Enables or disables the reference measurement.
			Ref. Meas. to Stress Delay	s	Double	0 s to 10,000 s	Delay time from the end of the reference measurement to the start of the stress
		Post Measurement	Enable	N/A	Check Box	Check or blank	Enables or disables the post measurement.
			Post Meas. Delay	s	Double	0 s to 10,000 s	Delay time from the end of the final stress measurement to the start of the post measurement
			Initial Interval *1	s	Double	10 ns to 10,000 s	Initial interval between the iterative post measurements
			Interval Mode *1	N/A	List	"LINEAR", "LOG10" or "LOG25"	Interval mode of the post measurement
			Iteration Number	N/A	Integer	1 to 10,000	Iteration number of the post measurement

*1: Interval between the iterative post measurements is as follows. It depends on the Interval Mode.

LINEAR: Constant as the "Initial Interval"

LOG10: Initial Interval * $10 \wedge (i * 0.1)$

LOG25: Initial Interval * $10 \wedge (i * 0.04)$

i: Index of the post measurement. Integer, 1 or more.

For the log interval, see Fig. 4-4-12.

Maximum interval calculated by above equation must be shorter than 1,000,000 s.

Table 4-4-7 Id Sampling setup parameters

Tab Group	Tab	Group	Parameter	Unit	Type	Range	Description
Measurement	Id Sampling		Vg *1	V	Double	-10 V to +10 V	Gate voltage to measure
			Vd *1	V	Double	-10 V to +10 V	Drain voltage to measure
			Sampling Mode	N/A	List	"LINEAR", "LOG10" or "LOG25"	Sampling mode
			Stress Hold *2	s	Double	0 s to 10,000s	Hold time to keep the stress voltage before move to the measurement voltage
			Meas Delay *2	s	Double	-10,000 s to 10,000 s	Measurement delay time from the start of the edge from the stress voltage to the measurement voltage
			Initial Interval *3	s	Double	10 ns to 1 s	Initial interval of the sampling measurement
			Sampling Points *3	N/A	Int	1 to 4,000,000	Number of the measurement points
			Averaging Time	s	Double	10 ns to 20 ms	Averaging time of the measurement
			Extra Delay	s	Double	0 to 10,000 s	Delay time before return to the stress voltage after the completion of the measurement

*1: Maximum voltage depends on the operation mode. Error occurs if the value is greater than its limit.

*2: Stress Hold must be greater than or equal to the |Meas Delay| value if the Meas Delay value is negative.

*3: Interval between the iterative post measurements is as follows. It depends on the Interval Mode.

LINEAR: Constant as the "Initial Interval"

LOG10: Initial Interval * 10 ^ (i * 0.1)

LOG25: Initial Interval * 10 ^ (i * 0.04)

i: Index of the post measurement. Integer, 1 or more.

For the log interval, see Fig. 4-4-12.

Maximum interval calculated by above equation must be shorter than 1,000,000 s.

Table 4- 4- 8 Sweep setup parameters

Tab Group	Tab	Group	Parameter	Unit	Type	Range	Description
	Sweep		Dual Sweep	N/A	Check Box	Check or blank	Enables or disables the dual sweep.
			Sweep Type	N/A	List	"Staircase", "Ramp" or "PIV"	Sweep type
		Vg Sweep	Start V *1	V	Double	- 10 V to +10 V	Start voltage of the gate sweep
			Stop V *1	V	Double	- 10 V to +10 V	Stop voltage of the gate sweep
			Step Num *2	N/A	Integer	1 to 101	Step number of the gate sweep
			Step Rise	s	Double	10 ns to 10,000 s	Rise time of each step of staircase sweep measurement This parameter is only valid for the staircase sweep measurement.
			Hold	s	Double	0, to 10,000 s	Hold time before starting the sweep measurement
			Measurement Delay	s	Double	0 to 10,000 s	Measurement delay time of each step from the start of the rising edge of step
			Averaging Time	s	Double	10 ns to 20 ms	Averaging time of the measurement
			Step Delay	s	Double	0 to 10,000 s	Delay time before moving to the next step after completing measurement on each step
			Dual Sweep Delay	s	Double	0 to 10,000 s	Delay time between the end of the forward sweep and the start of the reverse sweep
		Vd	Vd *1	V	Double	- 10 V to +10 V	Drain voltage in the measurement phase

*1: Maximum voltage depends on the operation mode. Error occurs if the value is greater than its limit.

*2: Sweep step voltage is given by the following formula.

Staircase, PIV: StepV = (StopV - StartV) / (StepNum - 1)

Ramp: StepV = (StopV - StartV) / StepNum

Table 4-4-9 PIV setup parameters

Tab Group	Tab	Group	Parameter	Unit	Type	Range	Description
	PIV	Vg Sweep	Base *1	V	Double	-10 V to +10 V	Base line voltage of the gate sweep pulse
			Period *2	s	Double	20 ns to 50,000 s	Period of the gate sweep pulse
			Width *2	s	Double	0 s to 20,000 s	Pulse width of the gate sweep pulse
			Rise/Fall Time *2	s	Double	10 ns to 10,000s	Rise and fall time of the gate sweep pulse
			Pulse Delay *2	s	Double	0 s to 10,000 s	Delay time of the gate sweep pulse
		Vd	Enable Pulse Bias	N/A	Check Box	Check or blank	Enables or disables the drain pulse biasing.
			Base *1	V	Double	-10 V to 10 V	Base line voltage of the drain pulse bias
			Width *2	s	Double	0 s to 20,000 s	Pulse width of the drain pulse bias
			Rise/Fall Time	s	Double	10 ns to 10,000 s	Rise and fall time of the drain pulse bias
			Pulse Delay	s	Double	0 s to 10,000 s	Delay time of the drain pulse bias

*1: Maximum voltage depends on the operation mode. Error occurs if the value is greater than its limit.

*2: The pulse parameters must satisfy the following relations.

   Rise Time <= Width

   Fall Time <= Width

   Delay + Width + Rise Time < Period

   Delay + Width + Fall Time < Period

   When the drain pulse bias is enabled, period of the drain pulse is same with a period of the gate pulse.

Setup parameters in Table 4-4-9 are valid only for the "PIV" Sweep type.

Table 4-4-10 OTF (On-The-Fly) setup parameters

Tab Group	Tab	Group	Parameter	Unit	Type	Range	Description
	OTF		dVg *1	V	Double	- 10 V to 10 V	Modulation voltage of the gate stress
			Vd *1	V	Double	-10 V to 10 V	Drain voltage to measure
			Edge	s	Double	10 ns to 10,000 s	Transition time from the stress voltage to the measurement voltage
			Measurement Delay	s	Double	0 s to 10,000 s	Measurement delay from the start of the transient of gate stress voltage
			Averaging Time	s	Double	10 ns to 20 ms	Averaging time of the measurement
			Step Delay	s	Double	0 ns to 10,000 s	Delay time before moving to the next step after completing the measurement of each step

*1: Maximum voltage depends on the operation mode. Error occurs if the value is greater than its limit.
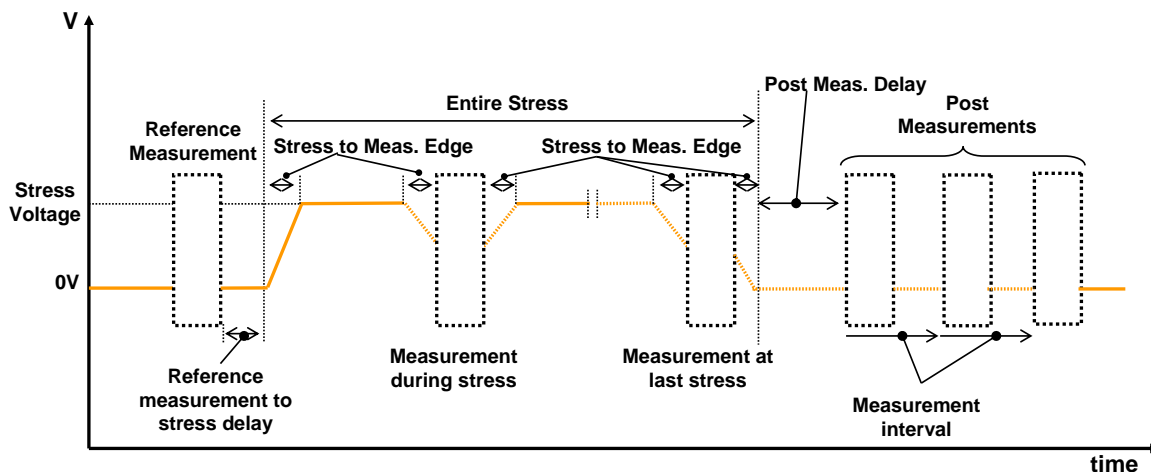
- **Measurement Interval**:
  Depends on the "Interval Mode"
  - •LINEAR: Constant as the "Initial Interval"
  - •LOG 10: Initial Interval $\times \left(10^{(0.1\times Count)} - 10^{(0.1\times Count - 1)}\right)$
  - •LOG 25: Initial Interval $\times \left(10^{(0.04\times Count)} - 10^{(0.04\times Count - 1)}\right)$

  Count: Index of the post measurement start from "1".

- **General behavior of the measurement sequences**
  - – Reference and Post Measurement
    - •Both Initial voltage and final voltage are 0 V.
  - – During stress
    - •Both Initial voltage and final voltage are stress voltage.
  - – At last stress
    - •Initial voltage is stress voltage and final voltage is 0 V.

Fig. 4-4-9 Definitions of the stress and measurement sequence

Example of the Vd sequence delay in the Id sampling measurement
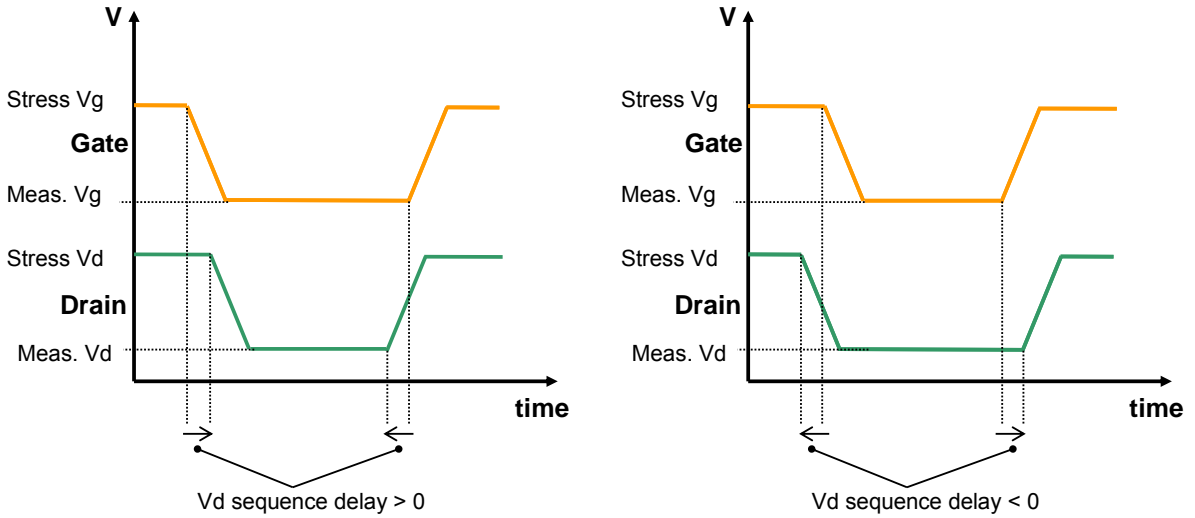
Fig. 4-4-10 Definitions of the Vd sequence delay
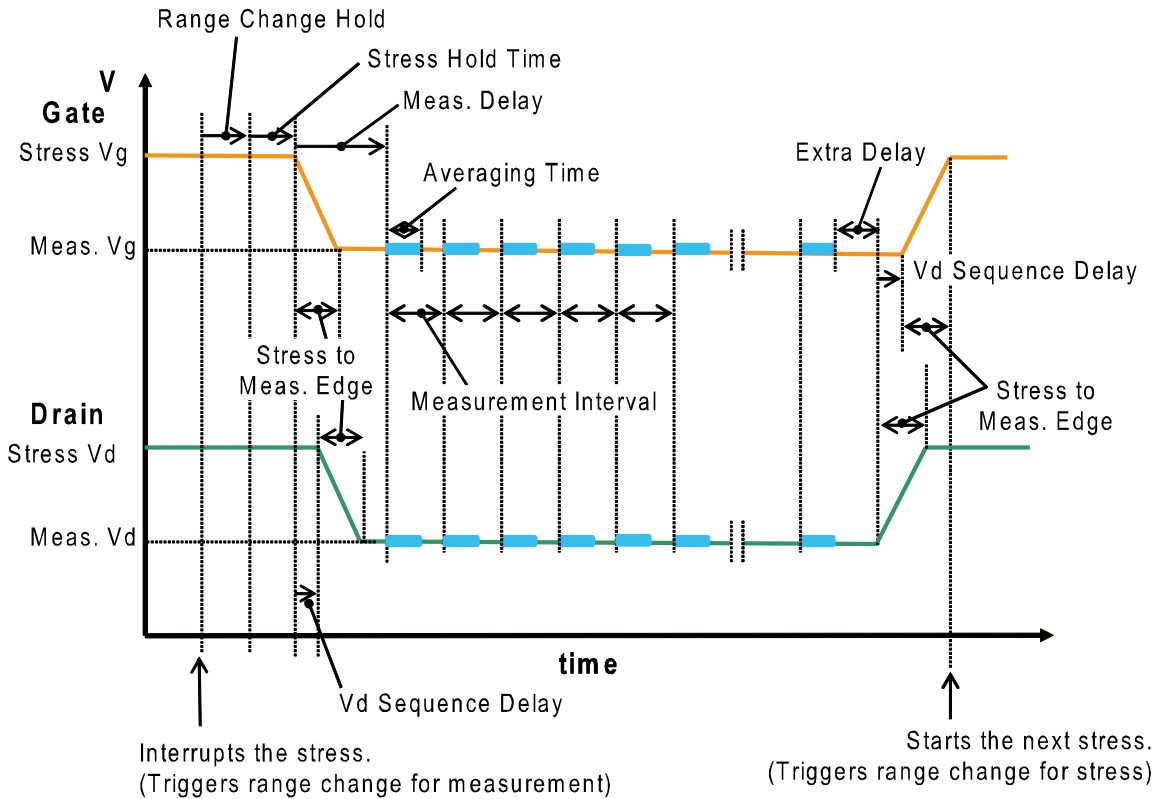
- **Also, 50 ns overhead of sequence changing is inserted between the stress and measurement**

Fig. 4-4-11 Measurement sequence of the sampling measurement

$$\text{LOG10:} \quad \text{Initial Interval} \times \left(10^{(0.1\times Count)} - 10^{(0.1\times Count - 1)}\right)$$

$$\text{LOG25:} \quad \text{Initial Interval} \times \left(10^{(0.04\times Count)} - 10^{(0.04\times Count - 1)}\right)$$
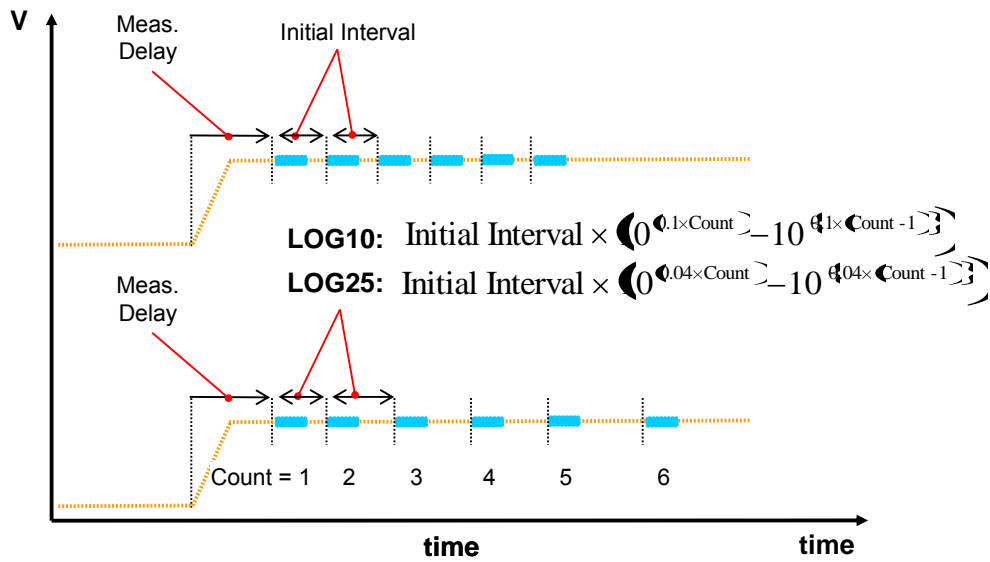
Fig. 4-4-12 Timing chart of the linear sampling mode and log sampling mode
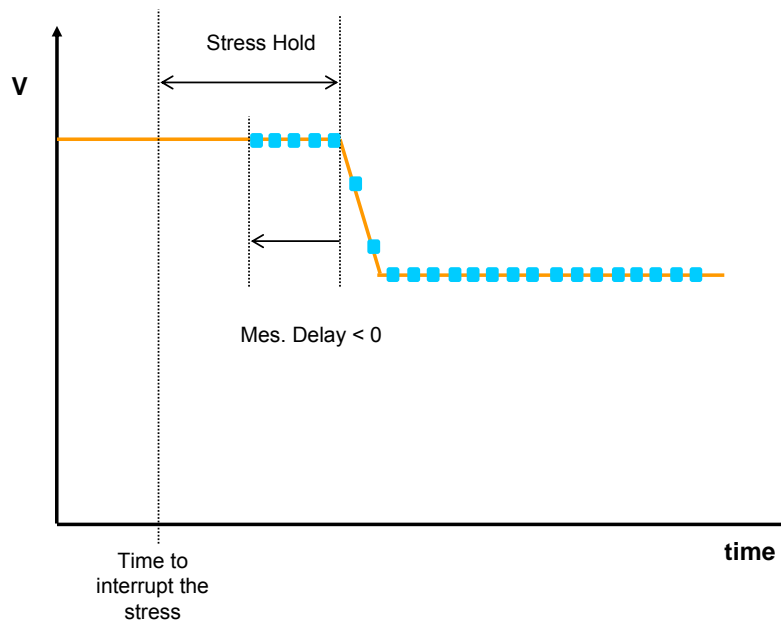
Fig. 4-4-13 Transient measurement using a negative delay time and stress hold time.

$$StepV = \frac{StopV - StartV}{StepNum - 1}$$
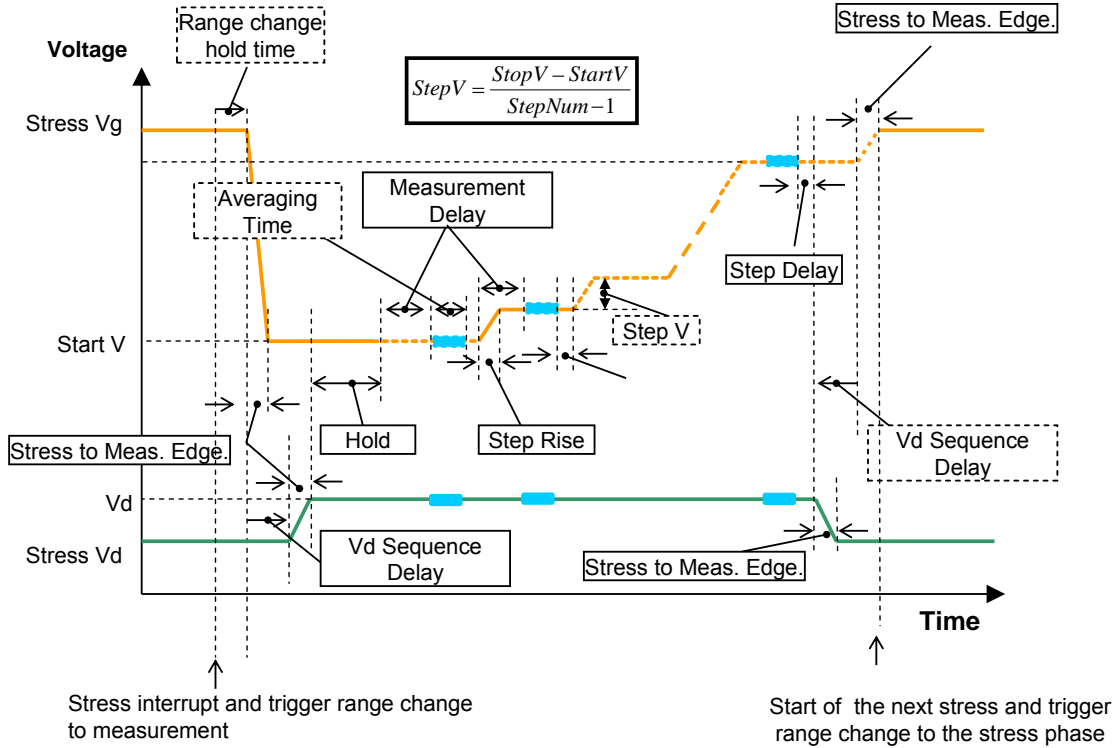
Fig. 4-4-14 Sequence of the staircase sweep measurement

$$StepV = \frac{StopV - StartV}{StepNum}$$
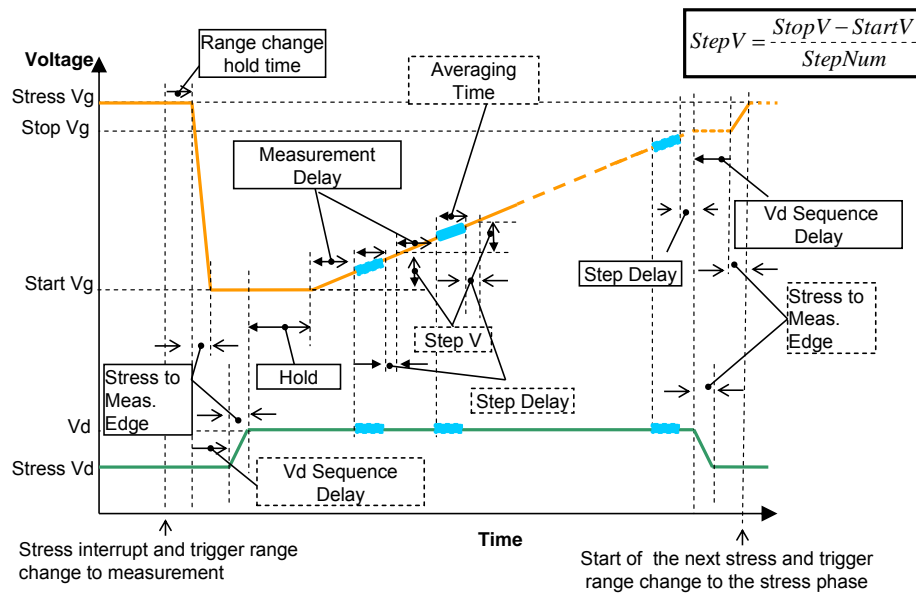
• Difference from the staircase sweep:
  – "Step Rise" is ignored (not used) in the ramp sweep.
  – Step V is different because measurement is not executed at the start voltage.

Fig. 4-4-15 Sequence of the ramp sweep measurement

$$StepV = \frac{StopV_g - StartV_g}{StepNum - 1}$$
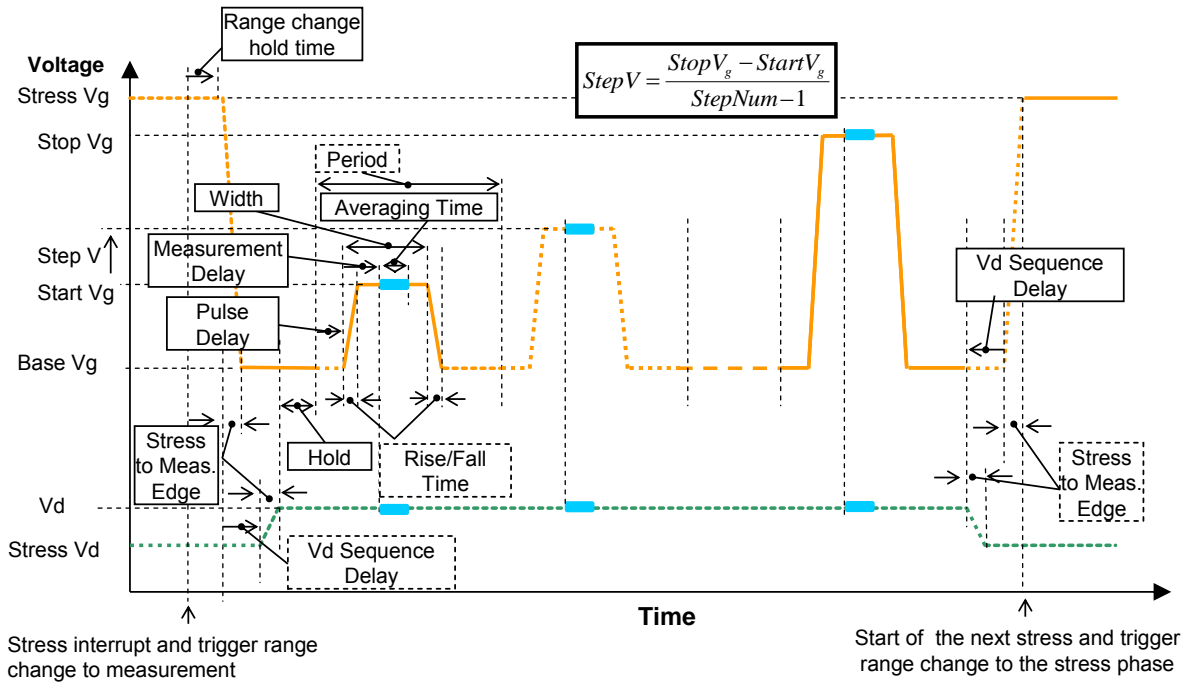
Fig. 4-4-16 Sequence of the pulsed sweep measurement
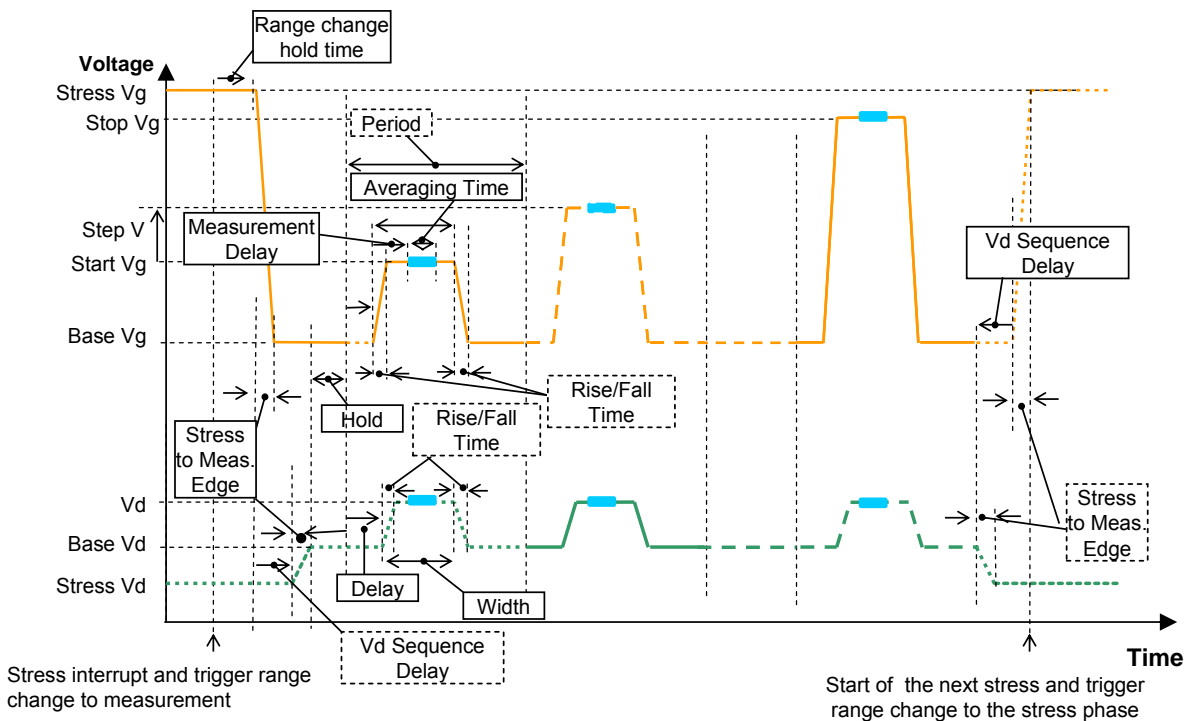
Fig. 4-4-17 Sequence of the dual channel pulsed sweep measurement
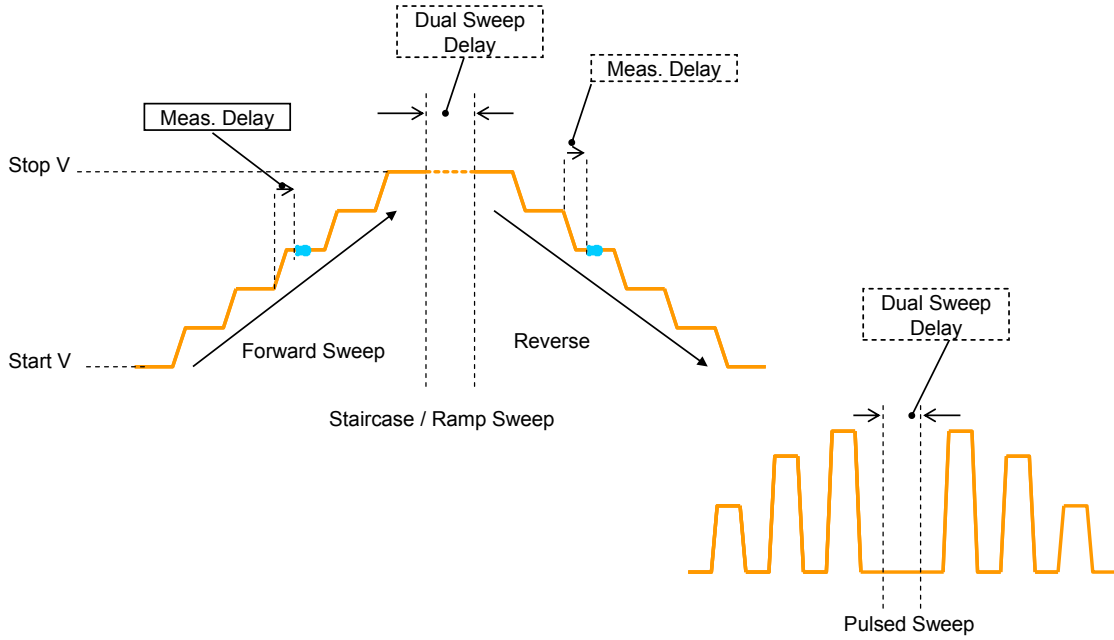
– For the pulsed sweep measurement, the dual sweep delay is inserted at the baseline voltage.

Fig. 4-4-18 Timing of the dual sweep measurement

Fig. 4-4-19 Timing of the On-The-Fly measurement

4-5. SAMPLING.exe

–1. Channel setup
  • Source 1
  • Source 2
  • Bias
–2. Measurement setup
  • Sequence
  • Primary
  • Secondary
  • Bias
–3. Action buttons
  • Validate Pattern
  • Execute
  • Save Setup
  • Re-Load Setup
  • Config
  • Close

Fig. 4-5-1 Main panel of SAMPLING sample program

Fig. 4-5-2 Channel Setup section

Table 4-5-1 Source 1 channel setup parameters

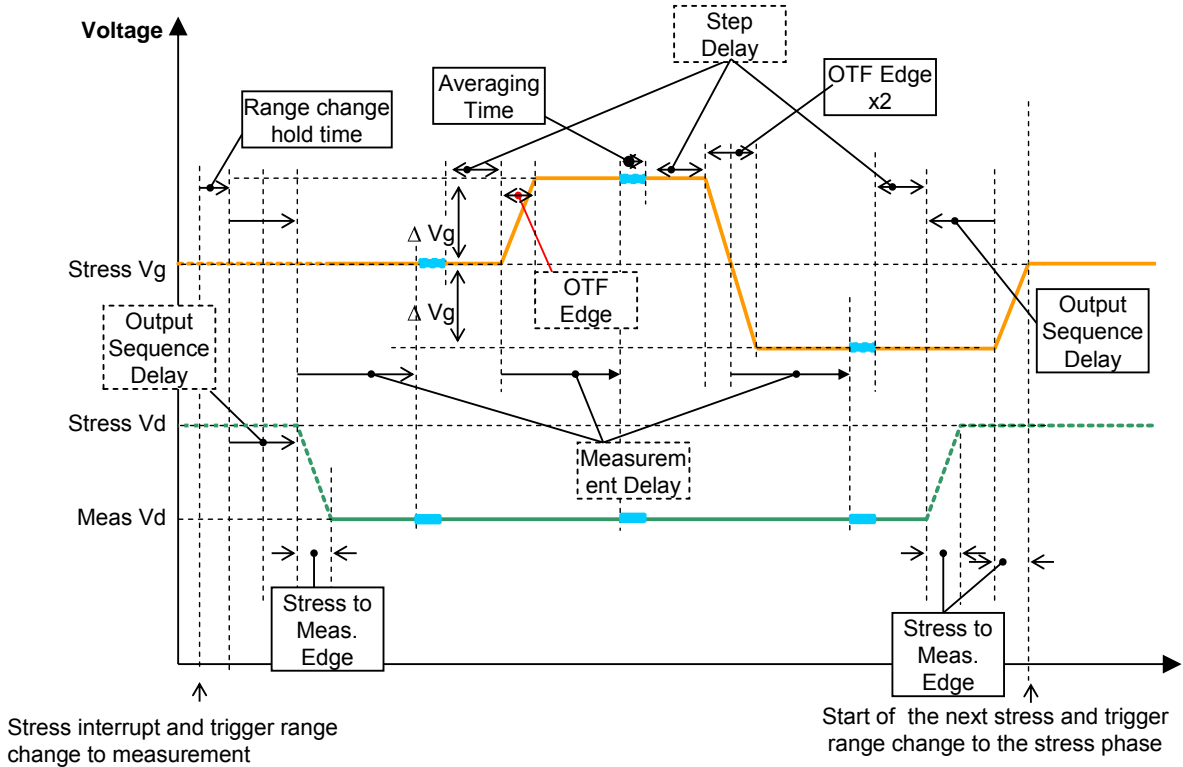| Tab Group	Tab	Group	Parameter	Unit	Type	Range	Description
Channel Setup	Source 1		Measurement	N/A	Check Box	Check or blank	Enables or disables a measurement on this channel.
			Channel *1	N/A	List Box	101, 102, 201, 202, 301, 302, 401, 402, 501, 502, 601, 602, 701, 702, 801, 802, 901, 902, 1001, 1002	Channel used for the measurement
			Operation Mode	N/A	List Box	PG Mode, Fast IV Mode	Operation mode of the WGFMU
			Measurement Mode	N/A	List Box	V Measurement, I Measurement	Measurement mode If the operation mode is "PG Mode", "I Measurement" is not available.
			Voltage Force Range	N/A	List Box	Auto, +/-3 V, +/-5 V, -10 V to 0 V, 0 V to +10 V	Voltage output range
			Current Range	N/A	List Box	1 uA Fixed, 10 uA Fixed, 100 uA Fixed, 1 mA Fixed, 10 mA Fixed	Current range This range is used for the measurement for the "I Measurement" mode or the output for the "V Measurement" mode.
			Voltage Measurement Range	N/A	List Box	+/-5 V, +/-10 V	Voltage measurement range This parameter is ignored if the measurement mode is set to the "I Measurement".
			HW Skew	s	Double	-50 ns to 50 ns	Force and measurement skew of this channel
			Raw Data	N/A	Check Box	Check or blank	Raw data (checked) or averaging data (blank)

*1: The channel ID must be unique.

Table 4-5-2 Source 2 channel setup parameters

Tab Group	Tab	Group	Parameter	Unit	Type	Range	Description
Channel Setup	Source 2		Measurement	N/A	Check Box	Check or blank	Enables or disables a measurement on this channel.
			Channel *1	N/A	List Box	101, 102, 201, 202, 301, 302, 401, 402, 501, 502, 601, 602, 701, 702, 801, 802, 901, 902, 1001, 1002	Channel used for the measurement
			Operation Mode	N/A	List Box	PG Mode, Fast IV Mode	Operation mode of the WGFMU
			Measurement Mode	N/A	List Box	V Measurement, I Measurement	Measurement mode If the operation mode is "PG Mode", "I Measurement" is not available.
			Voltage Force Range	N/A	List Box	Auto, +/-3 V, +/-5 V, -10 V to 0 V, 0 V to +10 V	Voltage output range
			Current Range	N/A	List Box	1 uA Fixed, 10 uA Fixed, 100 uA Fixed, 1 mA Fixed, 10 mA Fixed	Current range This range is used for the measurement for the "I Measurement" mode or the output for the "V Measurement" mode.
			Voltage Measurement Range	N/A	List Box	+/-5 V, +/-10 V	Voltage measurement range This parameter is ignored if the measurement mode is set to the "I Measurement".
			HW Skew	s	Double	-50 ns to 50 ns	Force and measurement skew of this channel
			Raw Data	N/A	Check Box	Check or blank	Raw data (checked) or averaging data (blank)

*1: The channel ID must be unique.

Table 4-5-3 Bias channel setup parameters

Tab Group	Tab	Group	Parameter	Unit	Type	Range	Description
Bias	Bias	Bias Source 1	Module Type	N/A	List Box	N/A, WGMFU, SMU	Type of the bias source If no bias source is used, select "N/A".
			Channel ID *1	N/A	List Box	WGFMU 101, 102, 201, 202, 301, 302, 401, 402, 501, 502, 601, 602, 701, 702, 801, 802, 901, 902, 1001, 1002 SMU 1, 2, 3, 4, 5, 6, 7, 8, 9, 10	Channel of the bias source
			Bias *2	V	Double	-10 V to 10 V	Bias voltage
			Compliance *3	A	Double	0 to 100 mA	Current compliance Effective only for the "SMU" module type.
		Bias Source 2	Module Type	N/A	List Box	N/A, WGFMU, SMU	Module type of the bias source If no bias source is used, select "N/A".
			Channel ID *1	N/A	List Box	WGFMU 101, 102, 201, 202, 301, 302, 401, 402, 501, 502, 601, 602, 701, 702, 801, 802, 901, 902, 1001, 1002 SMU 1, 2, 3, 4, 5, 6, 7, 8, 9, 10	Channel of the bias source
			Bias *2	V	Double	-10 V to 10 V	Bias voltage
			Compliance *3	A	Double	0 to 100 mA	Current compliance Effective only for the "SMU" module type.

*1: The channel ID must be unique.

*2: Maximum voltage depends on the operation mode. Error occurs if the value is greater than its limit.

*3: Maximum value of the current compliance depends on the type of SMU. Error occurs if the value is greater than its limit.

Sequence Setup

Primary Measurement Setup

Fig. 4-5-3 Measurement Setup section, Sequence and Primary

Secondary Measurement Setup

Bias Setup

Fig. 4-5-4 Measurement Setup section, Secondary and Bias

Table 4-5-4 Sequence setup parameters

Tab Group	Tab	Group	Parameter	Unit	Type	Range	Description
Measurement Setup	Sequence		Base Hold *1	s	Double	0 s to 10,000s	Hold time to keep the stress voltage before move to the measurement voltage
			Base to Source Edge	s	Double	10 ns to 10,000 s	Transition time from stress phase to measurement phase
			Output Sequence Delay	s	Double	10 ns to 10,000 s	Output sequence delay between the source 1 and the source 2
			Termination Delay	s	Double	0 to 10,000 s	Delay time after the measurement is completed before the output is changed to 0 V

*1: Base Hold must be greater than or equal to the |Measurement Delay| value if the Measurement Delay value is negative.

Table 4-5-5 Primary measurement setup parameters

Tab Group	Tab	Group	Parameter	Unit	Type	Range	Description
Measurement Setup	Primary		Sampling Mode	N/A	List	"LINEAR", "LOG10" or "LOG25"	Sampling mode
			Measurement Delay *1	s	Double	-10,000 to 10,000	Measurement delay time from the start of the rising edge of the source voltage
			Initial Interval *2	s	Double	10 ns to 1 s	Initial interval of the sampling measurement
			Sampling Points *2	N/A	Int	1 to 4,000,000	Number of the measurement points
			Averaging Time	s	Double	10 ns to 20 ms	Averaging time for the measurement

*1: Base Hold must be greater than or equal to the |Measurement Delay| value if the Measurement Delay value is negative.

*2: Interval between the iterative post measurements is as follows. It depends on the Sampling Mode.

    LINEAR: Constant as the "Initial Interval"

    LOG10: Initial Interval * 10 ^ (i * 0.1)

    LOG25: Initial Interval * 10 ^ (i * 0.04)

    i: Index of the post measurement. Integer, 1 or more.

    For the log interval, see Fig. 4-4-12.

Maximum interval calculated by above equation must be shorter than 1,000,000 s.

Table 4-5-6 Bias setup parameters

Tab Group	Tab	Group	Parameter	Unit	Type	Range	Description
Measurement Setup	Bias	Source 1	Base *1	V	Double	-10 V to +10 V	Base voltage of the source 1.
			Source *1	V	Double	-10 V to +10 V	Source voltage of the source 1.
		Source 2	Base *1	V	Double	-10 V to +10 V	Base voltage of the source 2.
			Source *1	V	Double	-10 V to +10 V	Source voltage of the source 2.

*1: Maximum voltage depends on the operation mode. Error occurs if the value is greater than its limit.

Table 4-5-7 Secondary measurement setup parameters

Tab Group	Tab	Group	Parameter	Unit	Type	Range	Description
Measurement Setup	Secondary		Enable Secondary Measurement	N/A	Check box	Check or blank	Enables or disables the secondary measurement.
			Source 1 Measurement Range *1	N/A	List	1 uA Fixed, 10 uA Fixed, 100 uA Fixed, 1 mA Fixed, 10 mA Fixed or Auto, +/-5 V, +/-10 V	Source 1 measurement range for the secondary measurement
			Source 2 Measurement Range *1	N/A	List	1 uA Fixed, 10 uA Fixed, 100 uA Fixed, 1 mA Fixed, 10 mA Fixed or Auto, +/-5 V, +/-10 V	Source 2 measurement range for the secondary measurement
			Sampling Mode	N/A	List	"LINEAR", "LOG10" or "LOG25"	Sampling mode
			Second Meas. Origin *2	s	Double	0 s to 1,000,000 s	Time origin for the secondary measurement
			Measurement Delay *3	s	Double	-10,000 s to 10,000 s	Measurement delay time from the secondary measurement time origin to the first secondary measurement point
			Initial Interval *4	s	Double	10 ns to 1 s	Initial interval of the sampling measurement
			Sampling Points *4	N/A	Int	1 to 4,000,000	Number of the measurement points
			Averaging Time	s	Double	10 ns to 20 ms	Averaging time for the measurement

*1: The same measurement mode is used for both primary and secondary measurements. Only the current measurement range can be changed.

*2: The Second Meas. Origin value must be greater than the period of the primary measurement.

*3: Base Hold must be greater than or equal to the |Measurement Delay| value if the Measurement Delay value is negative.

*4: Interval between the iterative post measurements is as follows. It depends on the Sampling Mode.

LINEAR: Constant as the "Initial Interval"

LOG10: Initial Interval * 10 ^ (i * 0.1)

LOG25: Initial Interval * 10 ^ (i * 0.04)

i: Index of the post measurement. Integer, 1 or more.

For the log interval, see Fig. 4-4-12.

Maximum interval calculated by above equation must be shorter than 1,000,000 s.
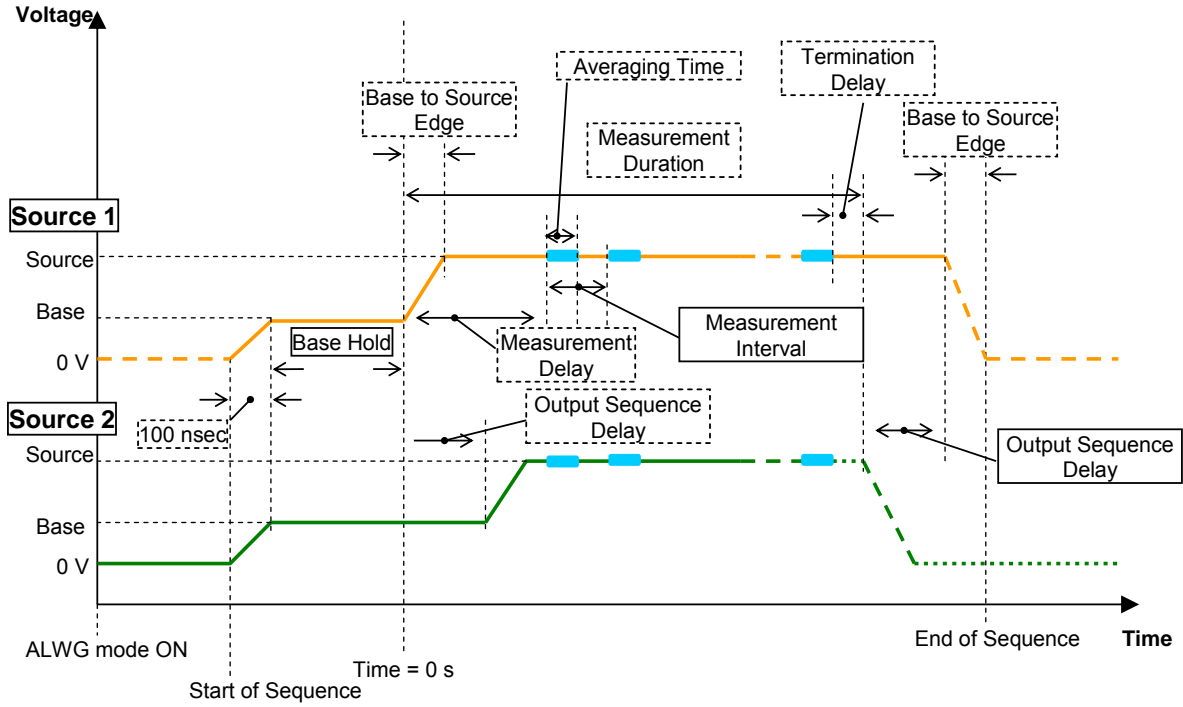
Fig. 4-5-5 Timing chart of the sampling measurement
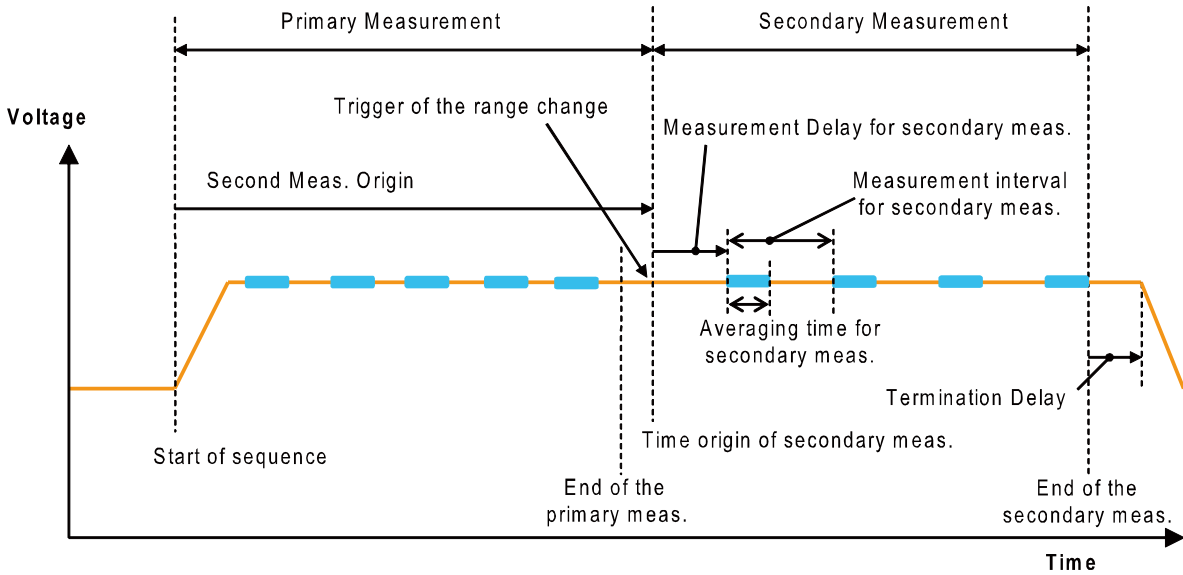
Fig. 4-5-6 Timing chart of the secondary measurement

4-6. SWEEP.exe

–1. Channel setup
  • Source 1
  • Source 2
  • Bias
–2. Measurement setup
  • Sequence
  • Sweep
  • PIV
–3. Action buttons
  • Validate Pattern
  • Execute
  • Save Setup
  • Re-Load Setup
  • Config
  • Close
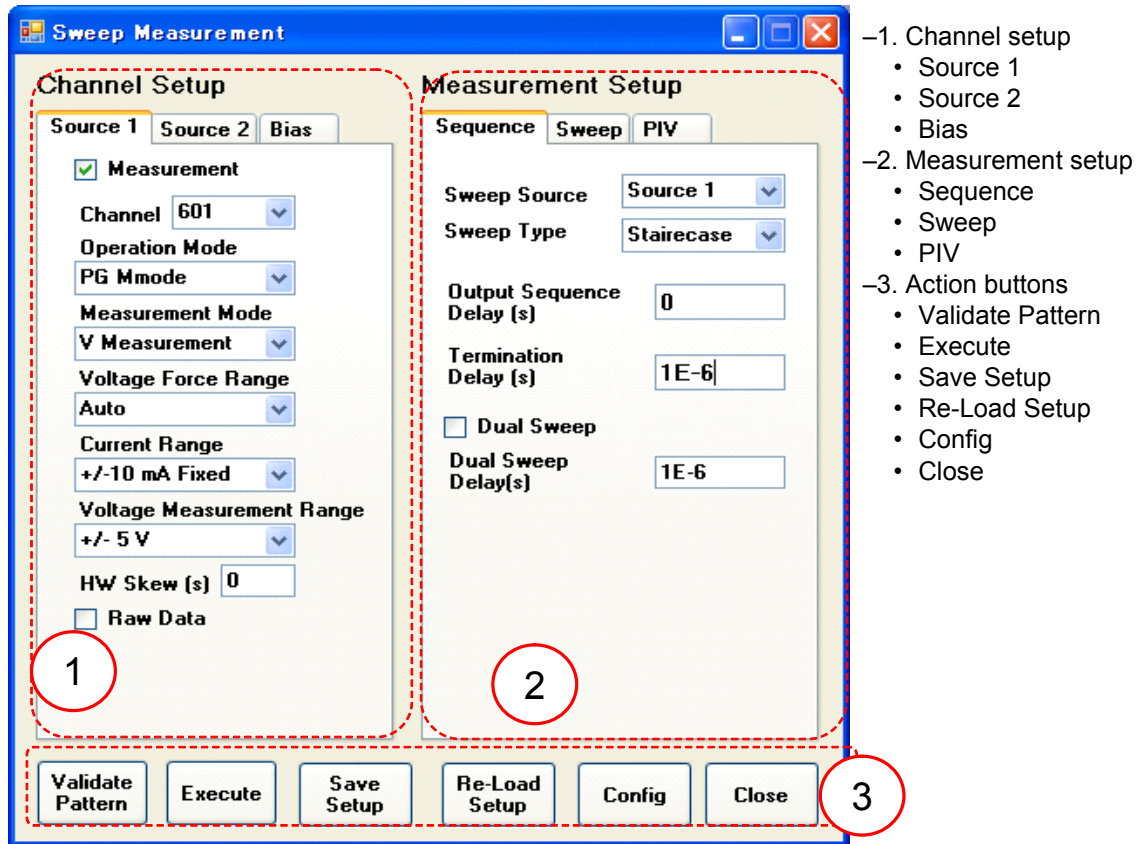
Fig. 4-6-1 Main panel of SWEEP sample program

Sequence Setup   **Sweep Setup**   **PIV Setup**

Fig. 4-6-2 Measurement Setup section

Table 4-6-1 Sequence setup parameters

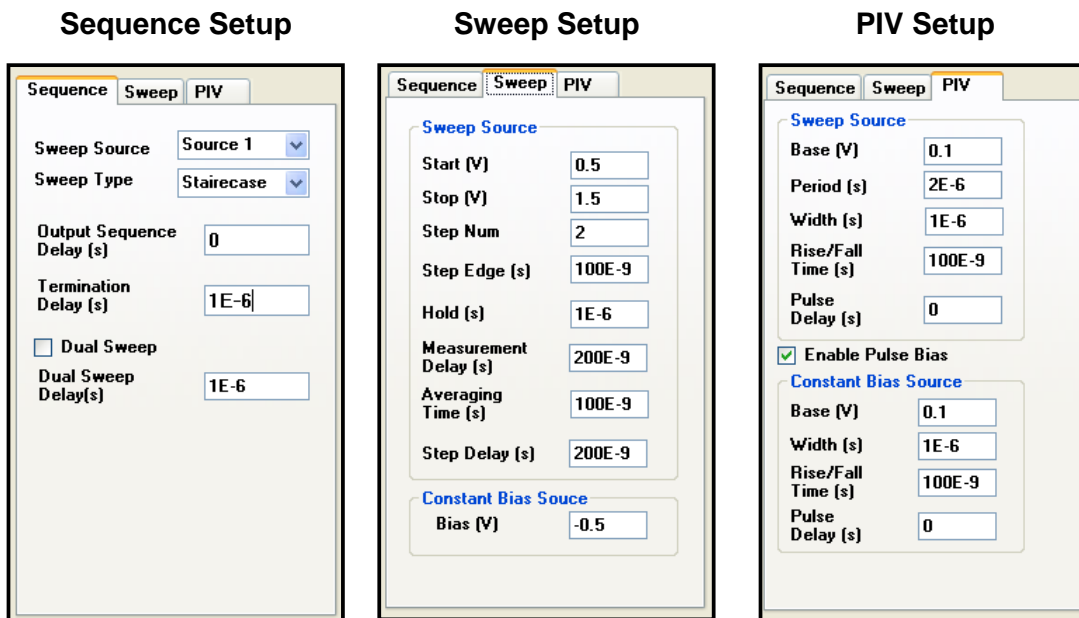| Tab Group	Tab	Group	Parameter	Unit	Type	Range	Description
Measurement Setup	Sequence		Sweep Source *1	N/A	List	Source 1, Source 2	Source ID of the sweep source
			Sweep Type	N/A	List	Staircase, Ramp, PIV	Sweep type
			Output Sequence Delay	s	Double	10 ns to 10,000 s	Output sequence delay between the source 1 and source 2
			Termination Delay	s	Double	0 to 10,000 s	Delay time after the measurement is completed before the output is changed to 0 V
			Dual Sweep	N/A	Check Box	Check or blank	Enables or disables the dual sweep.
			Dual Sweep Delay	s	Double	0 to 10,000 s	Delay time between the end of the forward sweep and the start of the reverse sweep

*1: Another channel is automatically assigned to a constant bias source.

Table 4-6-2 Sweep setup parameters

Tab Group	Tab	Group	Parameter	Unit	Type	Range	Description
Measurement Setup	Sweep	Sweep Source	Start V *1	V	Double	-10 V to +10 V	Sweep start voltage
			Stop V *1	V	Double	-10 V to +10 V	Sweep stop voltage
			Step Num *2	N/A	Integer	1 to 101	Number of the sweep steps
			Step Rise	s	Double	10 ns to 10,000 s	Rise time of each step of staircase sweep measurement This parameter is available only for the staircase sweep measurement.
			Hold	s	Double	0, to 10,000 s	Hold time before starting the sweep measurement
			Measurement Delay	s	Double	0 to 10,000 s	Measurement delay time of each step from the start of the rising edge of step
			Averaging Time	s	Double	10 ns to 20 ms	Averaging time of the measurement
			Step Delay	s	Double	0 to 10,000 s	Delay time after completing the measurement on each step before moving to the next step
		Constant Bias Source	Bias *1	V	Double	-10 V to +10 V	Voltage of the constant bias source

*1: Maximum voltage depends on the operation mode. Error occurs if the value is greater than its limit.

*2: Sweep step voltage is given by the following formula.

Staircase, PIV: StepV = (StopV - StartV) / (StepNum -1)

Ramp: StepV = (StopV - StartV) / StepNum

Table 4-6-3 PIV setup parameters

Tab Group	Tab	Group	Parameter	Unit	Type	Range	Description
Measurement Setup	PIV	Sweep Source	Base *1	V	Double	-10 V to +10 V	Base line voltage of the gate sweep pulse
			Period *2	s	Double	20 ns to 50,000 s	Period of the gate sweep pulse
			Width *2	s	Double	0 s to 20,000 s	Pulse width of the gate sweep pulse
			Rise/Fall Time *2	s	Double	10 ns to 10,000s	Rise and fall time of the gate sweep pulse
			Pulse Delay *2	s	Double	0 s to 10,000 s	Delay time of the gate sweep pulse
		Constant Bias Source	Enable Pulse Bias	N/A	Check Box	Check or blank	Enables or disables the drain pulse biasing.
			Base *1	V	Double	-10 V to 10 V	Base line voltage of the drain pulse bias
			Width *2	s	Double	0 s to 20,000 s	Pulse width of the drain pulse bias
			Rise/Fall Time *2	s	Double	10 ns to 10,000 s	Rise and fall time of the drain pulse bias
			Pulse Delay *2	s	Double	0 s to 10,000 s	Delay time of the drain pulse bias

*1: Maximum voltage depends on the operation mode. Error occurs if the value is greater than its limit.

*2: The pulse parameters must satisfy the following relations.

Rise Time <= Width

Fall Time <= Width

Delay + Width + Rise Time < Period

Delay + Width + Fall Time < Period

When the drain pulse bias is enabled, period of the drain pulse is same with a period of the gate pulse.

Setup parameters in Table 4-6-3 are valid only for the "PIV" Sweep type.

Voltage

Step Rise

Stop V

Sweep Source

$$StepV = \frac{StopV - StartV}{StepNum - 1}$$

Averaging Time

Measurement Delay

Step Delay

Start V
0V

Step V

Constant bias source

Step Rise

Hold

Step Rise

Output sequence delay

Bias V

0V

Output Sequence Delay

Step Rise

Time

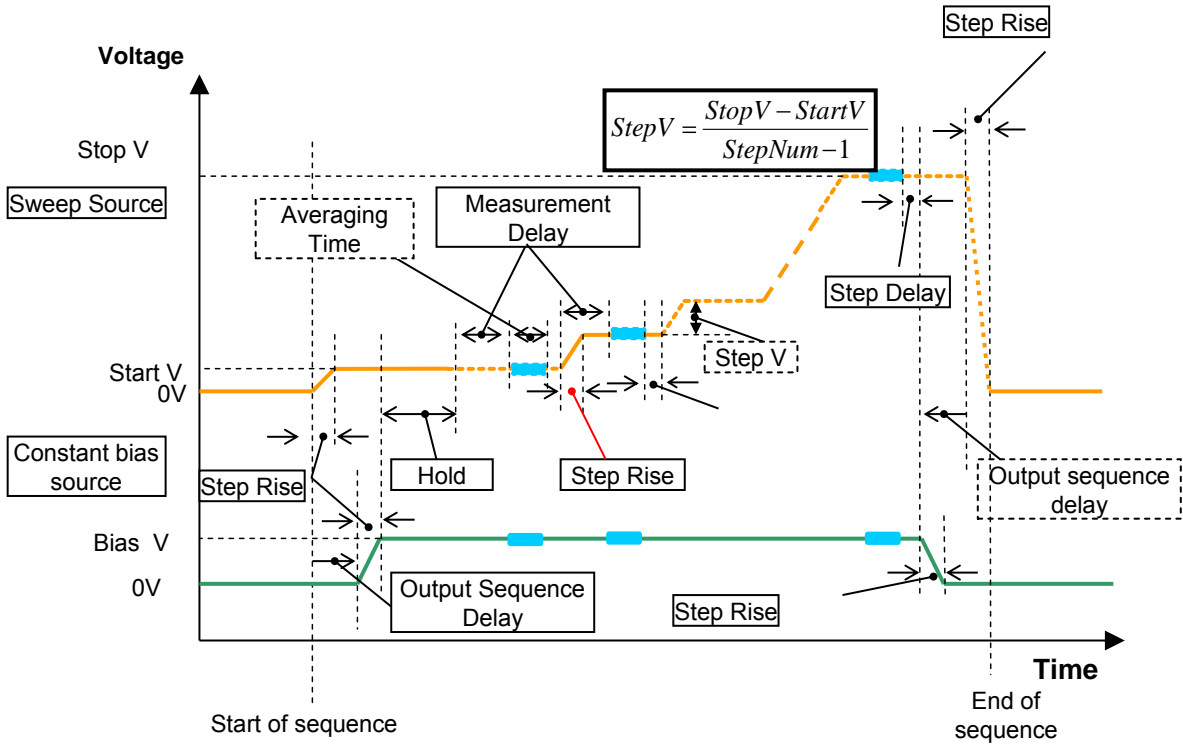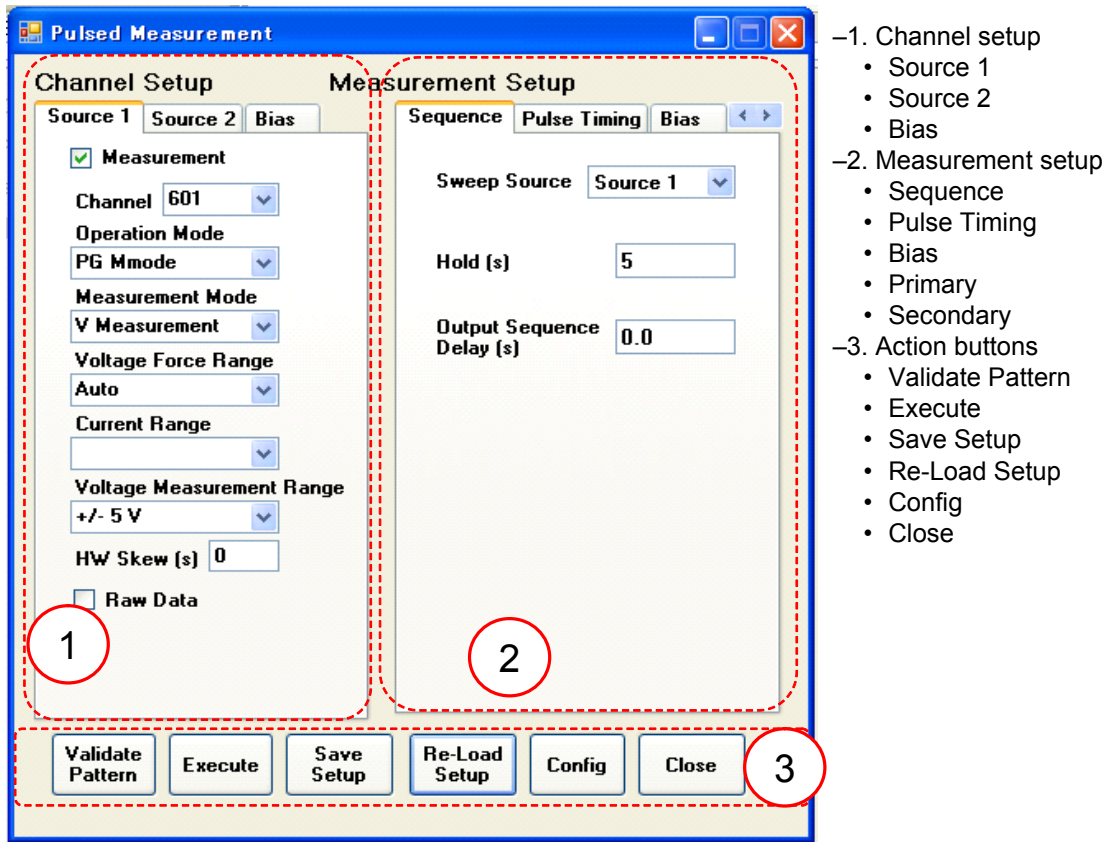Start of sequence

End of sequence

Fig. 4-6-3 Timing chart of the staircase sweep measurement

The sequence of the sweep measurement is almost same with the sweep measurement in the NBTI sample program. Only different is start voltage. In the sweep measurement program, start voltage is always 0 V. For other sweep type, see the section 4-4 NBTI.exe.

4-7. PULSE.exe

–1. Channel setup
- Source 1
- Source 2
- Bias

–2. Measurement setup
- Sequence
- Pulse Timing
- Bias
- Primary
- Secondary

–3. Action buttons
- Validate Pattern
- Execute
- Save Setup
- Re-Load Setup
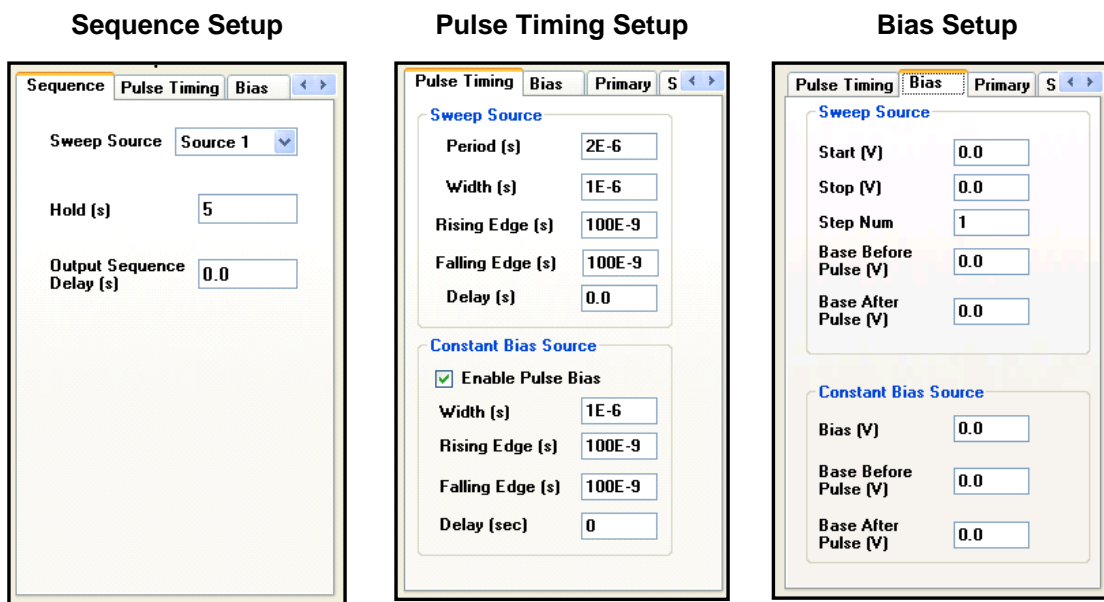- Config
- Close

Fig. 4-7-1 Main panel of PULSE sample program

Sequence Setup   Pulse Timing Setup   Bias Setup

Fig. 4-7-2 Measurement Setup section #1

Table 4-7-1 Sequence setup parameters

Tab Group	Tab	Group	Parameter	Unit	Type	Range	Description
Measurement Setup	Sequence		Sweep Source *1	N/A	List	Source 1, Source 2	Source ID of the sweep source
			Hold	s	Double	0, to 10,000 s	Hold time before starting the sweep measurement
			Output Sequence Delay	s	Double	10 ns to 10,000 s	Output sequence delay between the source 1 and source 2

*1: Another channel is automatically assigned to a constant bias source.

Table 4-7-2 Pulse timing setup parameters and Bias setup parameters

Tab Group	Tab	Group	Parameter	Unit	Type	Range	Description
Measurement Setup	Pulse Timing	Sweep Source	Base *1	V	Double	-10 V to +10 V	Base line voltage of the sweep pulse
			Period *2	s	Double	20 ns to 50,000 s	Period of the sweep pulse
			Width *2	s	Double	0 s to 20,000 s	Pulse width of the sweep pulse
			Rising Edge *2	s	Double	10 ns to 10,000 s	Rise time of the sweep pulse bias
			Falling Edge *2	s	Double	10 ns to 10,000 s	Fall time of the sweep pulse bias
			Pulse Delay *2	s	Double	0 s to 10,000 s	Delay time of the sweep pulse
		Constant Bias Source	Enable Pulse Bias	N/A	Check Box	Check or blank	Enables or disables the pulse biasing of constant bias.
			Width *2	s	Double	0 s to 20,000 s	Pulse width of the pulse constant bias
			Rising Edge *2	s	Double	10 ns to 10,000 s	Rise time of the pulse constant bias
			Falling Edge *2	s	Double	10 ns to 10,000 s	Fall time of the pulse constant bias
			Pulse Delay *2	s	Double	0 s to 10,000 s	Delay time of the pulse constant bias
	Bias	Sweep Source	Start V *1	V	Double	-10 V to +10 V	Sweep start voltage
			Stop V *1	V	Double	-10 V to +10 V	Sweep stop voltage
			Step Num *3	N/A	Integer	1 to 101	Number of the sweep steps
			Base Before Pulse *1	V	Double	-10 V to 10 V	Base line voltage before pulse of the sweep source pulse bias
			Base After Pulse *1	V	Double	-10 V to 10 V	Base line voltage after pulse of the sweep source pulse bias
		Constant Bias Source	Bias *1	V	Double	-10 V to +10 V	Voltage of the constant bias source
			Base Before Pulse *1	V	Double	-10 V to 10 V	Base line voltage before pulse of the constant source pulse bias
			Base After Pulse *1	V	Double	-10 V to 10 V	Base line voltage after pulse of the constant source pulse bias

*1: Maximum voltage depends on the operation mode. Error occurs if the value is greater than its limit.

*2: The pulse parameters must satisfy the following relations.

Rise Time <= Width

Fall Time <= Width

Delay + Width + Rise Time < Period

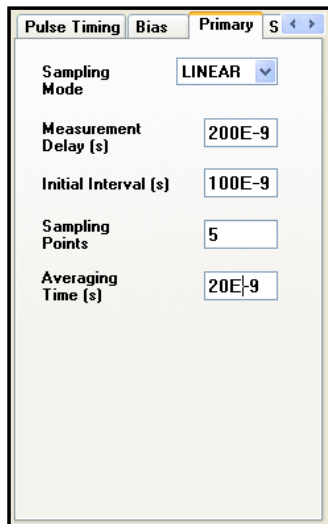Delay + Width + Fall Time < Period

When the drain pulse bias is enabled, period of the drain pulse is same with a period of the gate pulse.

*3: Sweep step voltage is given by the following formula.

Staircase, PIV: StepV = (StopV - StartV) / (StepNum - 1)

Ramp: StepV = (StopV - StartV) / StepNum

Primary Measurement Setup
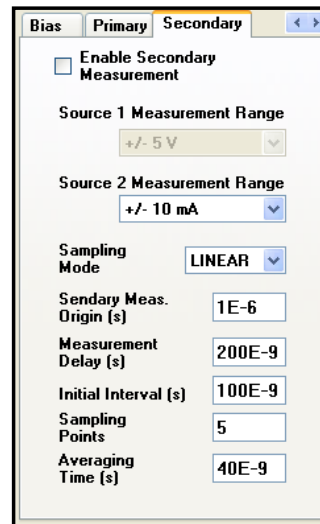
Secondary Measurement Setup

Fig. 4-7-3 Measurement Setup section #2

Table 4-7-3 Primary measurement setup parameters

Tab Group	Tab	Group	Parameter	Unit	Type	Range	Description
Measurement Setup	Primary		Sampling Mode	N/A	List	"LINEAR", "LOG10" or "LOG25"	Sampling mode
			Meas. Delay *1	s	Double	-10,000 to 10,000	Measurement delay time from the start of the rising edge
			Initial Interval *2	s	Double	10 ns to 1 s	Initial interval of the sampling measurement
			Sampling Points *2	N/A	Int	1 to 4,000,000	Number of the measurement points
			Averaging Time *2	s	Double	10 ns to 20 ms	Averaging time of the measurement

*1: The |Meas. Delay| value must be less than or equal to the Pulse Delay value if the Meas. Delay value is negative.

*2: Interval between the iterative measurements is as follows. It depends on the Sampling Mode.

LINEAR: Constant as the "Initial Interval"

LOG10: Initial Interval * 10 ^ (i * 0.1)

LOG25: Initial Interval * 10 ^ (i * 0.04)

i: Index of the post measurement. Integer, 1 or more.

For the log interval, see Fig. 4-4-12.

The measurement duration must be shorter than the pulse period.

Table 4-7-4 Secondary measurement setup parameters

Tab Group	Tab	Group	Parameter	Unit	Type	Range	Description
Measurement Setup	Secondary		Enable Secondary Measurement	N/A	Check box	Check or blank	Enables or disables the secondary measurement.
			Source 1 Measurement Range *1	N/A	List	1 uA Fixed, 10 uA Fixed, 100 uA Fixed, 1 mA Fixed, 10 mA Fixed or Auto, +/-5 V, +/-10 V	Source 1 measurement range for the secondary measurement
			Source 2 Measurement Range *1	N/A	List	1 uA Fixed, 10 uA Fixed, 100 uA Fixed, 1 mA Fixed, 10 mA Fixed or Auto, +/-5 V, +/-10 V	Source 2 measurement range for the secondary measurement
			Sampling Mode	N/A	List	"LINEAR", "LOG10" or "LOG25"	Sampling mode
			Second Meas. Origin *2	s	Double	0 s to 1,000,000 s	Time origin for the secondary measurement
			Meas Delay *3	s	Double	-10,000 s to 10,000 s	Measurement delay time from the secondary measurement time origin to the first secondary measurement point
			Initial Interval *4	s	Double	10 ns to 1 s	Initial interval of the sampling measurement
			Sampling Points *4	N/A	Int	1 to 4,000,000	Number of the measurement points
			Averaging Time *4	s	Double	10 ns to 20 ms	Averaging time for the measurement

*1: The same measurement mode is used for both primary and secondary measurements. Only the current measurement range can be changed.

*2: The Second Meas. Origin value must be greater than the period of the primary measurement.

*3: The |Meas. Delay| value must be less than or equal to the Pulse Delay value if the Meas. Delay value is negative.

*4: Interval between the iterative measurements is as follows. It depends on the Sampling Mode.
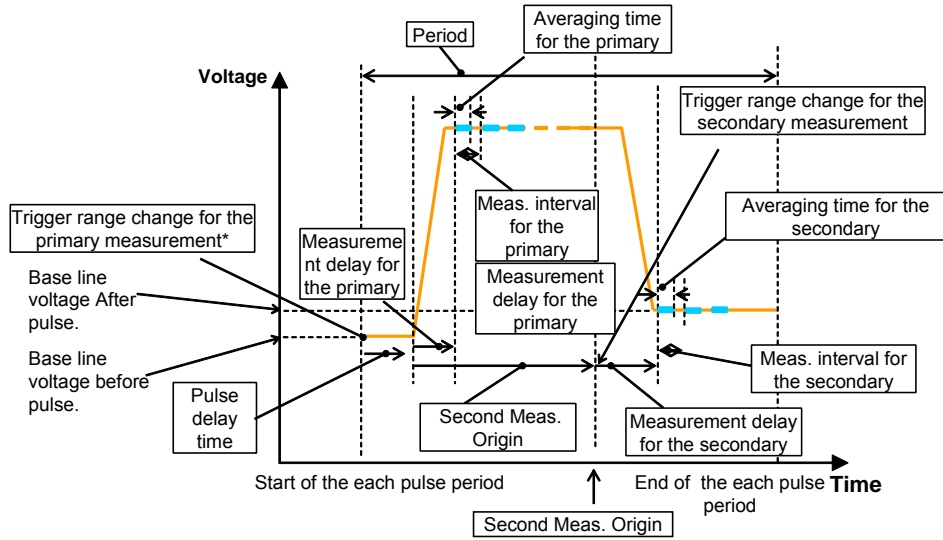
LINEAR: Constant as the "Initial Interval"

LOG10: Initial Interval * 10 ^ (i * 0.1)

LOG25: Initial Interval * 10 ^ (i * 0.04)

i: Index of the post measurement. Integer, 1 or more.

For the log interval, see Fig. 4-4-12.

Total duration of measurement must be shorter than the pulse period.

Fig. 4-7-4 Timing chart of the pulsed sampling measurement

- The primary sampling and the secondary sampling are executed in the "single pulse".
- Sweep is described as iteration of the above pulsed sampling measurement with a varied top level of pulse.
- Range change event is inserted at the beginning of the pulse for the primary measurement and at the origin of the second measurement for the secondary.

* If secondary measurement is disable, the range change event for the primary sweep is not added and use initial range set in the "Channel Setup" are used.

Fig. 4-7-5 Timing chart of the single channel, repetitive pulsed sampling measurement
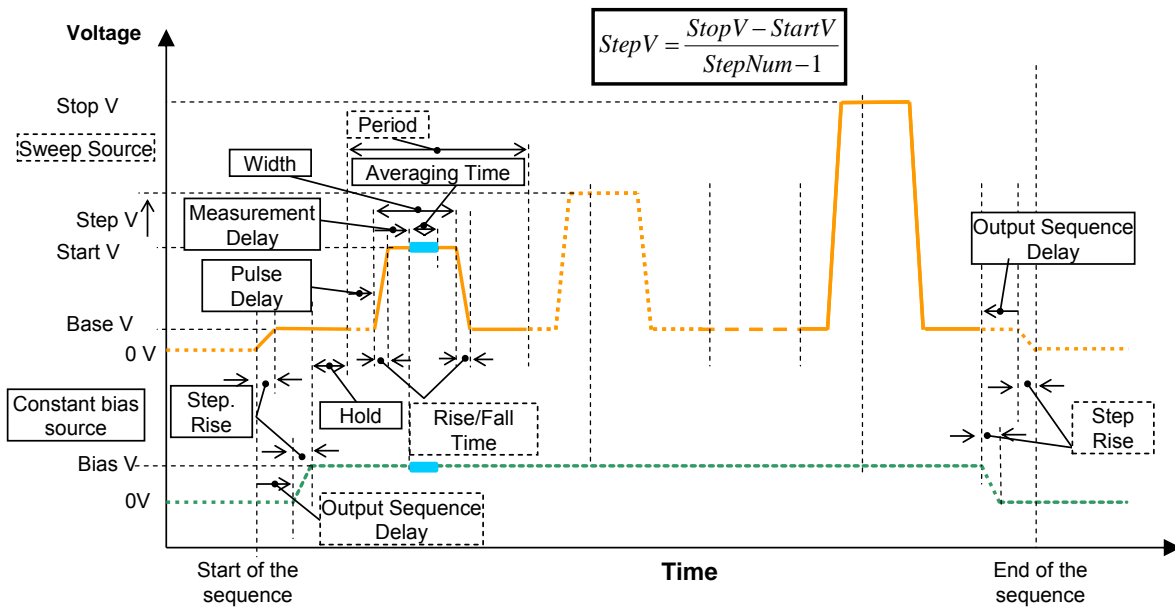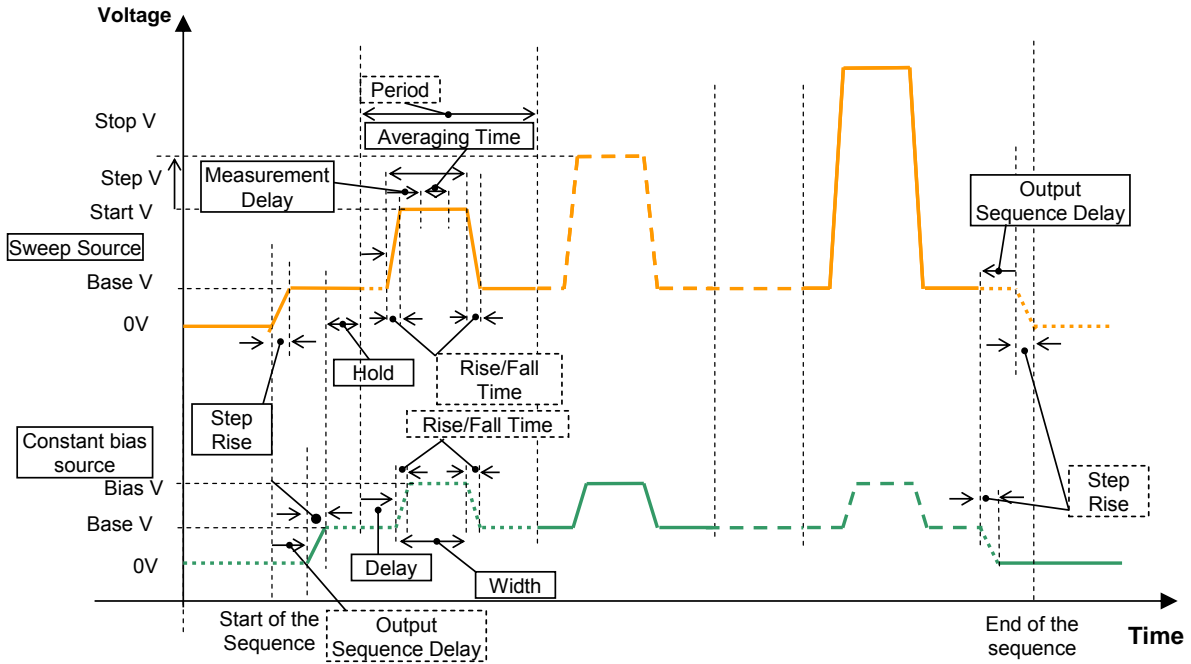
Fig. 4-7-6 Timing chart of the dual channels, repetitive pulsed sampling measurement
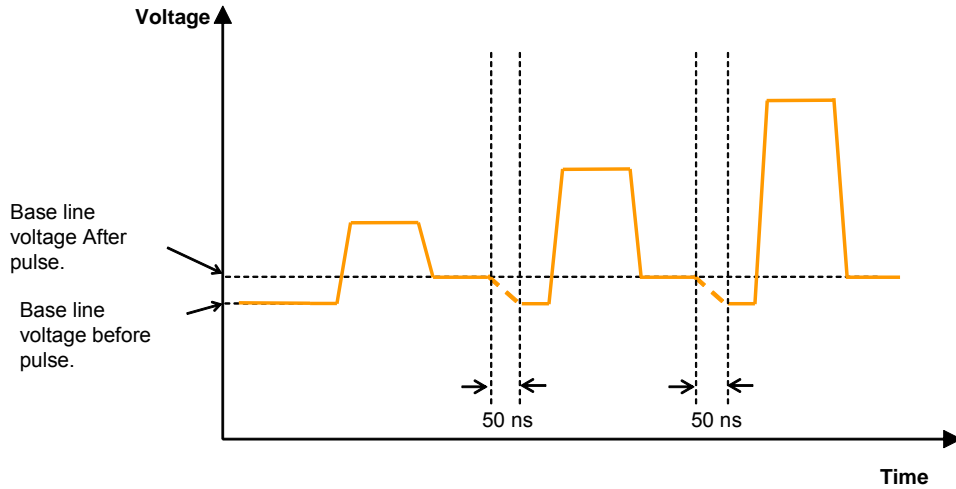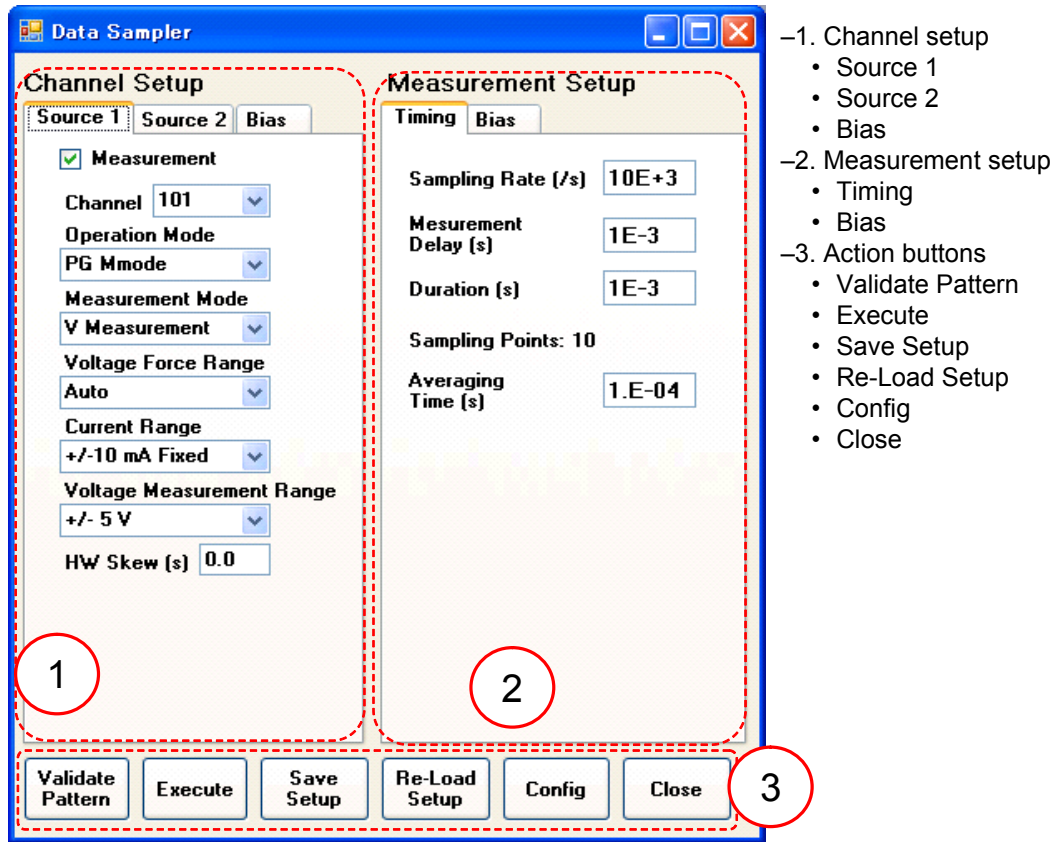

Fig. 4-7-7 Transient when the base line voltage after pulse is different from the base line voltage before pulse

4-8. DATASAMPLER.exe

–1. Channel setup
  • Source 1
  • Source 2
  • Bias
–2. Measurement setup
  • Timing
  • Bias
–3. Action buttons
  • Validate Pattern
  • Execute
  • Save Setup
  • Re-Load Setup
  • Config
  • Close

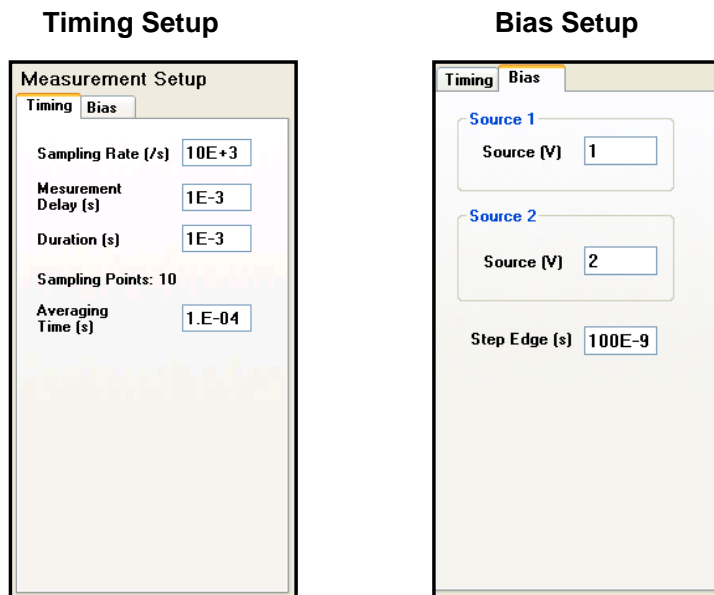**Fig. 4-8-1 Main panel of DATASAMPLER sample program**

Timing Setup   **Bias Setup**

Fig. 4-8-2 Measurement Setup section

Table 4-8-1 Timing setup parameters

Tab Group	Tab	Group	Parameter	Unit	Type	Range	Description
Measurement Setup	Timing		Sampling Rate *1 *3	N/A	Double	0.01 to 100E+6, 200E+6	Hold time to keep the stress voltage before move to the measurement voltage
			Measurement Delay *2	s	Double	0 to 10,000 s	Measurement delay time from the start of the rising edge
			Duration *3	s	Double	10 ns to 1,000,000 s	Output sequence delay between the source 1 and source 2
			Sampling Points *3	N/A	Integer		Number of the total sampling points
			Averaging Time *1	s	Double	10 ns to 20 ms	Averaging time of the measurement

*1: Sampling Rate must be longer than the averaging time. Measurement interval is calculated by 1 / Sampling Rate.

*2: Measurement delay must be shorter than the duration.

*3: Sampling Points (Duration / Sampling Rate) must be less than or equal to 4,0000,000.

Table 4-8-2 Bias setup parameters

Tab Group	Tab	Group	Parameter	Unit	Type	Range	Description
Measurement Setup	Bias	Source 1	Source *1	V	Double	-10 V to +10 V	Output voltage of the source 1
		Source 2	Source *1	V	Double	-10 V to +10 V	Output voltage of the source 2
			Step Edge	s	Double	10 ns to 10,000 s	Transition time from 0 V to the output voltage

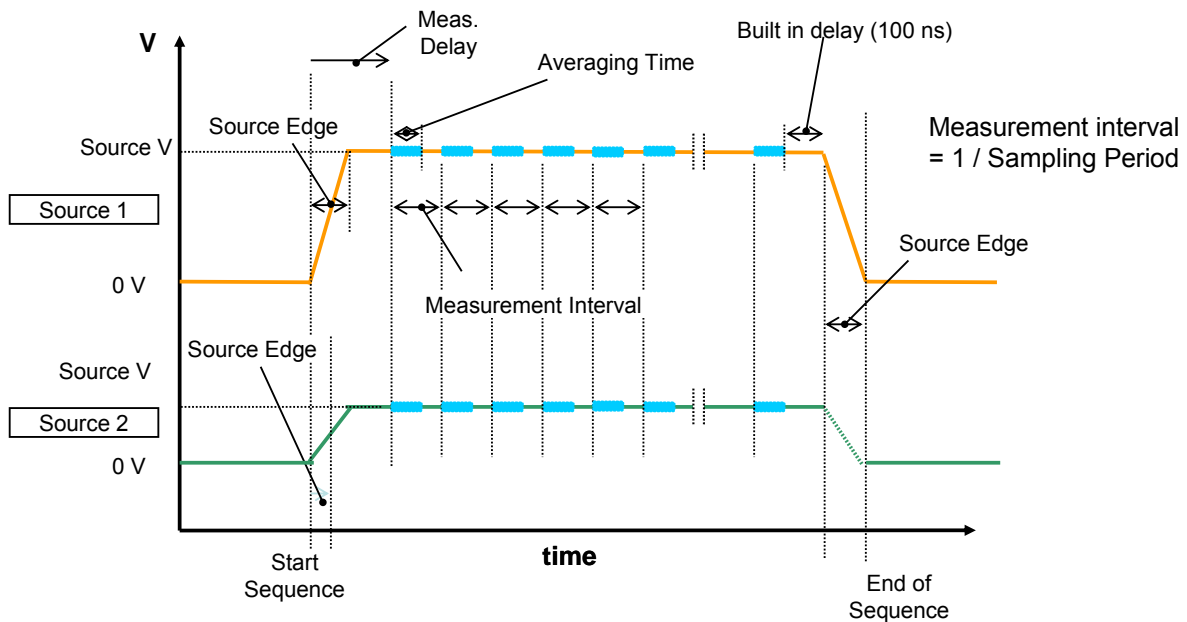*1: Maximum voltage depends on the operation mode. Error occurs if the value is greater than its limit.

Fig. 4-8-3 Timing chart of the data sampler program