

Keysight EasyEXPERT Software

Advanced NVM Application Tests

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In This Manual

This document describes the overview of how to use the Advance NVM (ReRAM, PCRAM and FeRAM) characterization application tests of Keysight EasyEXPERT group+ software.

This manual consists of the following chapters:

1. **Overview**

This chapter describes overview of Advanced NVM Application Tests List, the module requirements for NVM Application Tests, and the device connection information.

2. **Using Advanced NVM Application Tests**

This chapter describes how to use the Advanced NVM Application Tests of the EasyEXPERT group+ software.

3. **Appendix**

The appendix section describes Tips for device connection and accurate measurement, etc.

Advanced NVM Application Tests introduced in this manual are included in after Rev. A.6.2 EasyEXPERT group+ software.

Refer to the following URL link to download the latest EasyEXPERT group+ software.

<https://www.keysight.com/find/easyexpert>

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1. Overview

This chapter describes overview of Advanced NVM Application Tests List, the module requirements for NVM Application Tests, and the device connection information. This chapter consists of the following sections.

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1-1. Advanced NVM Application Tests List

Advanced NVM Application Tests of the EasyEXPERT group+ software includes three memory types of non-volatile memory (NVM) with the applications shown in the following table.

Table 1-1. Advanced NVM Application Tests List

Memory type	Application list	Application Test name	Measurement items
ReRAM	Butterfly curve	ReRAM IV-Butterfly	Butterfly curve (I-V characteristics)
	FORM test	ReRAM FORM	FORM waveform, FORM I, FORM V, FORM R
	RESET - SET / R-measure	ReRAM Reset-Set	RESET - SET waveforms, RESET V, RESET R, SET V, SET R
	RESET - SET / R-measure: SET V loop	ReRAM Reset SetV-Loop	SET R versus SET V relation graph. SET Vm @ SET R down
	RESET - SET / R-measure: RESET V loop	ReRAM Set ResetV-Loop	RESET R versus RESET V relation graph. RESET Vm @ RESET R up
	Endurance test	ReRAM Endurance	SET R, RESET R vs. Fatigue cycle graph
PCRAM	RESET - SET / R-measure	PCRAM Reset-Set	RESET R, RESET V, SET R, SET V
	RESET - SET / R-measure: SET V loop	PCRAM SetV-Loop	SET R vs. SET V graph. Extracts SET V
	RESET - SET / R-measure: RESET V loop	PCRAM ResetV-Loop	RESET R vs. RESET V graph. Extracts RESET V
	Endurance test	PCRAM Endurance	SET R, RESET R vs. Fatigue cycle graph
FERAM	Hysteresis test	FERAM Hysteresis	Hysteresis curve (Q-V, I-V, C-V), IV-t waveforms
	PUND test	FERAM PUND	IQ-t waveforms, IV-t waveforms, PUND charge, PaUaNaDa charge
	Endurance test	FERAM Endurance	PUND charge vs. Iteration/Cycle graph, Psw & Qsw vs. Iterations graph

1-2. Module Requirements for Advanced NVM Application Tests

Each NVM application test requires the measurement resources shown in the table 1-2.

Table 1-2. Module requirements for Advanced NVM Application Tests

Memory type	Application Test name	keusight B1500A requirements			Accessories requirements	Recommended Configuration
		SMU *1	WGFMU /RSU *2	SPGU *3		
ReRAM	ReRAM IV-Butterfly	2 + 1 (Opt.)	2 ch.		GNDU to Kelvin Adapter x1 *4 Triax TEE adapter (F-M-F) x1 *5 Triax (F) - BNC (M) adapter x2 *6 BNC (F-F) adapter x 1 *7 Triaxial cables (Max. 5 ea) *8 Coax cables, RSU to DUT x2	SMU x3 WGFMU x1 (RSU x2)
	ReRAM FORM	1 (Opt.)	2 ch.			
	ReRAM Reset-Set	1 (Opt.)	2 ch.			
	ReRAM Reset SetV-Loop	1 (Opt.)	2 ch.			
	ReRAM Set ResetV-Loop	1 (Opt.)	2 ch.			
	ReRAM Endurance	1 (Opt.)	2 ch.			
PCRAM	PCRAM Reset-Set		2 ch.	1 ch.	SPGU cable to RSU SPGU cable to RSU adapter x1 *9 50 ohm Triax terminator x1 *10 Coax cables, RSU to DUT x2	WGFMU x1 (RSU x2) SPGU x1
	PCRAM SetV-Loop		2 ch.	1 ch.		
	PCRAM ResetV-Loop		2 ch.	1 ch.		
	PCRAM Endurance		2 ch.	1 ch.		
FERAM	FERAM Hysteresis		2 ch.		Coax cables, RSU to DUT x2	WGFMU x1 (RSU x2)
	FERAM PUND		2 ch.			
	FERAM Endurance		2 ch.			

*1: SMU (Any of MP/HP/HRSMUs)

*2: B1530A WGFMU / RSU channels

*3: B1525A SFGU

*4: N1254A-100

*5: Keysight P/N: 12500-1551

*6: Keysight P/N: N1254-105

*7: Keysight P/N: 1250-0080

*8: Includes optional SMU to DUT Vg control cable

*9: Triax (M) - BNC (F) adapter, Keysight P/N: N1254A-106

*10: Consist of the following parts:

- Triax (M) - BNC (F) adapter, Keysight P/N: N1254A-106 x1
- 50 ohm BNC terminator, Keysight 11593A x1

2. Using Advanced NVM Application Tests

This chapter describes how to use the Advanced NVM Application Tests of the EasyEXPERT group+ software. This chapter consists of the following sections.

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2-1. ReRAM

2-1-1. What is a ReRAM test?

Table 2-1 shows the generic idea of the ReRAM test flow using the Advanced NVM Application Test.

Table 2-1. Generic idea of the ReRAM test flow.

Test Flow:	ReRAM Application Test:
1. IV characterization	• IV-Butterfly
2. Forming	• IV-Butterfly • FORM
3. FORM characterization	• FORM
4. Reset V, and Set V determination	• Reset SetV-Loop • Set ResetV-Loop
5. Reset R and Set R characterization	• Reset-Set
6. Endurance test	• Endurance

The generic idea of the ReRAM characterization starts with the IV characteristic measurements of the ReRAM resistive device by using the "ReRAM IV-Butterfly" Advanced NVM Application Test (ReRAM IV-Butterfly).

Once the device is checked as operative as the ReRAM resistive device, the low resistance state must be created by so called "forming". Forming can be made by repeating the ReRAM IV-Butterfly Application Test that use SMUs, or "ReRAM FORM" Advanced NVM application test (ReRAM FORM) which uses WGF MU.

The forming parameters such as the FORM V (voltage to change from the high resistance state to the low resistance state) can be characterized by the ReRAM FORM application test.

Once the low resistance channel is formed, the Reset voltage and Set voltage dependency can be measured by using the "ReRAM Set ResetV-Loop" Advanced NVM Application Test (ReRAM Set ResetV-Loop) and "ReRAM Reset SetV-Loop" Advanced NVM Application Test (ReRAM Reset SetV-Loop).

The ReRAM Set ResetV-Loop application test increases the Reset voltage of the reset pulse by the specified step voltage and detects the Reset voltage where the Reset resistance changes from low resistance to high resistance.

The ReRAM Reset SetV-Loop application test does the same as the Set ResetV-Loop application test, but increases the Set voltage instead of the Reset voltage and detects the Set voltage where the Set resistance changes from the high resistance state to the low resistance state. By using these two application tests, the Reset and Set pulse voltages can be quite accurately determined to ensure a stable ReRAM Set and Reset operation.

The "ReRAM Reset-Set" NVM Advanced Application Test (ReRAM Reset-Set) can be used for measuring the Reset resistance and the Set resistance after the Reset and Set pulse.

Finally, the "ReRAM Endurance" Advanced NVM Application Test (ReRAM Endurance) characterizes the fatigue or retention dependency of the Reset and Set status according to the number of Reset-Set cycles.

2-1-2. Connection diagram

When testing the ReRAM device cell, the cell current suddenly increases when the device turns on (SET) under the high voltage condition at the SET voltage and the possible overcurrent, which happens under improper current limit setting or configuration, may degrade or damage the device. Therefore, in the ReRAM characterization, a proper current limit functionality, which uses SMU's current compliance or an additional current limit device, plays an important role by limiting the excessive current flowing to the test device when the device is turned on to a low resistance state.

The next table shows four possible approaches including two ReRAM configurations that are provided by the software.

Table 2-2. Current limit approach and the ReRAM measurement configurations.

Current limiting approach	Configuration
1. As is (No action)	Standard
2. Add a series resistor	Standard
3. Device has built-in current limit capability	Standard
4. Add external current limit capability	Current limit (Vg)

The standard configuration and the current limit (Vg) configuration in Table 2-2 are explained below. The standard configuration is shown in Figure 2-1 where the ReRAM resistive device is directly connected to the measurement resources. Series resistor approach, which connects a proper value resistor in series with the ReRAM resistive device, can be included in the same figure. Figure 2-2 shows the current limit (Vg) configuration which uses an additional current limit device. This configuration can effectively limit the high speed transient current when the ReRAM device turns on, which is not possible with the standard configuration, and reduce the risk of damaging or degrading the device in the test, especially for fine geometry ReRAM devices.

Standard configuration:

The standard configuration is shown in Figure 2-1.

IV - Butterfly curve measurement is made using SMUs and GNDU either side of the RSU.

The SMU configuration for IV - Butterfly curve measurement uses two SMUs. One SMU is used for voltage source (Vs) and the other is for voltage measurement (Vm). By using this two SMU configuration, the output voltage from the SMUs can be measured (Vm SMU) while in the current limit operation of the Vs SMU. This functionality is essential for IV - Butterfly curve measurements. Other applications such as FORM, SET-RESET and Endurance test are made using WGFMU/RSUs. WGFMU and SMUs are automatically switched by RSU controlled from the ReRAM application test software.

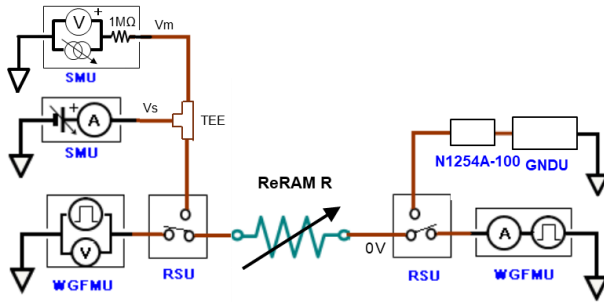


Figure 2-1. Standard ReRAM measurement configuration.

Current limit (Vg option) configuration:

The optional current limit configuration is shown in Figure 2-2.

The current limit is useful for limiting excessive current flowing in to the ReRAM test device when the ReRAM resistor suddenly changes from the high resistance state to the low resistance state (SET). The current limit device located very close to the ReRAM structure can eliminate a fast current spike flowing into the DUT and can help minimize any possible damage applied to the test device.

For example, the standard configuration for the IV - Butterfly characterization uses the current limit compliance of the SMU, but in some cases the SMU response time is not fast enough for the ReRAM characterization. In such cases, this optional current limit configuration is useful.

In extreme cases, the transient current discharged from the stray capacitance of the measurement cable may degrade the ReRAM device if the size of the test device is extremely small.

One option is to simply add a current limit capability as in the case of using WGFMU/RSU which does not have the current limit capability.

In both cases, the current limit device needs to be set very closely to the test device to be able to limit the current accurately including the high speed transient current.

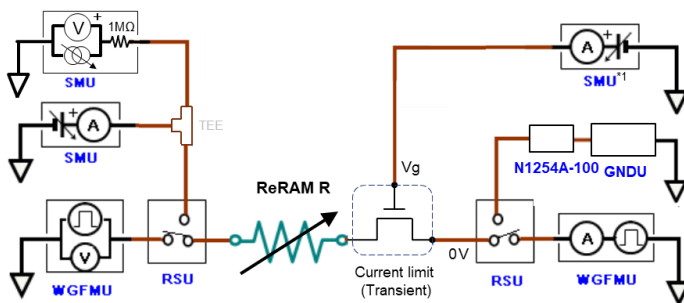


Figure 2-2. Current limit (Vg) ReRAM measurement configuration.

The differences between the current limit configuration (Vg option) and the standard configuration are:

- 1) The current limit transistor is required.
- 2) An additional SMU that controls the gate voltage of the current limit transistor is required.

The transistor can effectively limit the current flowing into the ReRAM device even in the transition timing when the ReRAM device turns on. This capability can improve the ReRAM characterization quality. More details about the current limit control operations are described in the Appendix.

Note: The current limit control transistor must be prepared by the user.

Note for current limit device:

A current limit device is typically a small signal Nch MOSFET or JFET. It is important to use a low V_{th} device for achieving a better current limit performance in the FORM or SET characteristics test.

To determine the appropriate V_g for current limiting, take I_d - V_d versus V_g curve and I_d - V_g curve at $V_d = SET_V$. Next, determine the appropriate V_g which can allow enough current for testing, but also protect your device from the over current.

The on resistance of the current limit device can be subtracted by the software.

Connection of the current limit transistor:

Connecting the SMU to the V_g of the current limit transistor requires accuracy because the WGF MU/RSU uses a coaxial measurement cable and SMU uses a Triax measurement cable. In this application, the guard of the SMU cable (inner shield of the Triax cable) needs to be disconnected when interfacing with the V_g of the current limit transistor.

Figure 2-3 shows the connection example of the ReRAM device and current limit transistor using the coax cable. The Triax cable from the SMU is converted at the close point of the V_g transistor to the coax cable using two adapters; 1) Triax (F) - BNC (M) adapter, N1254A-105, and 2) BNC (F-F) adapter, 1250-0080, then the coax cable is connected to the transistor.

By converting the Triax system to the coax system, the cables routing to the measurement fixture, including the prober, can be handled in the same manner, eliminating any connection errors.

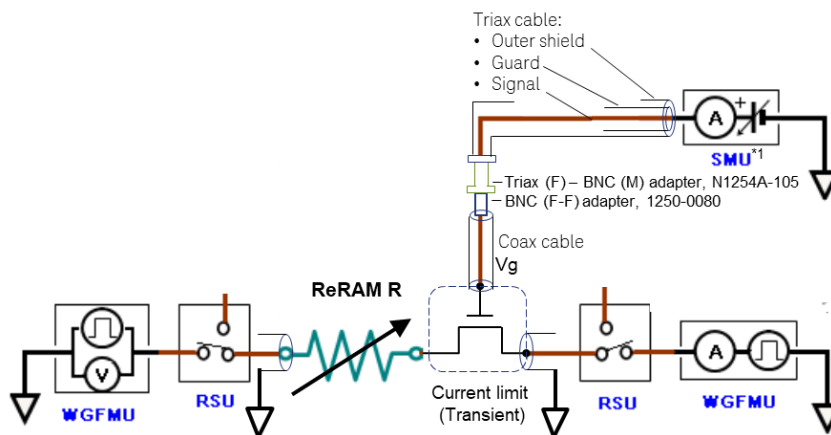


Figure 2-3. SMU connection using a coax cable to the current limit transistor.

2-1-3. ReRAM Application Tests

- **ReRAM IV-Butterfly**

General description of the ReRAM IV-Butterfly Application Test

This application test performs two double direction IV sweeps starting from 0 V to SET voltage (SetV) , and then 0 V to RESET voltage (ResetV). Y-axis display format can be selected from the "LOG absolute" or "LINEER" scale options.

A general Butterfly curve can be obtained using the "Log_Absolute" Y-axis scale.

A control option for using an external current limit device is available and this option can be activated by enabling the "Enable_SMU_Vg" parameter.

ReRAM IV - Butterfly measurement configuration

SMUs are used in the IV - Butterfly curve measurement application test as shown in Figure 2-4.

Two SMUs are used in the Vs side, one is for sourcing voltage and the other is for measuring the output voltage.

Using this configuration, the output voltage of V_s of the V_s -SMU under the current limit condition, when the ReRAM device is turned on, can be measured by the V_m -SMU which is used as a voltage measurement mode. The internal $1\text{ M}\Omega$ output resistor is set to increase the input impedance in the high frequency range which is useful, for example, when the device impedance suddenly changes. The connection diagram of the optional current limit configuration is shown in Figure 2-5. Refer to Figure 2-3 when connecting the SMU to V_g terminal of the current limit transistor.

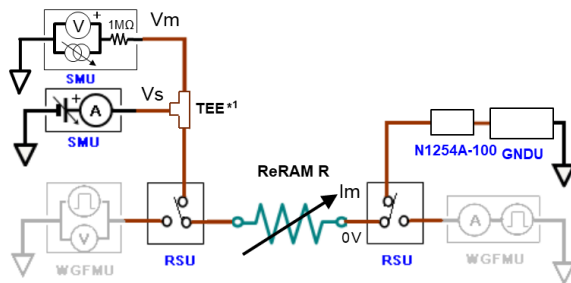


Figure 2-4. Standard configuration for IV - Butterfly curve measurement.

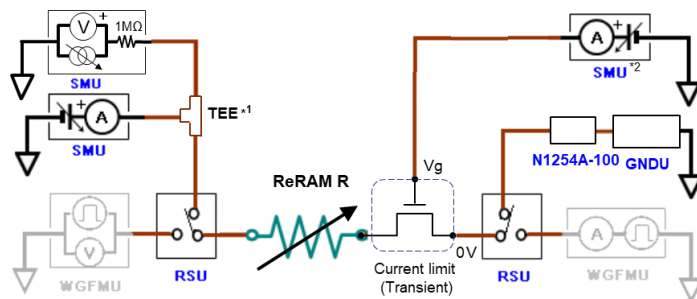


Figure 2-5. Optional current limit configuration for IV - Butterfly curve measurement.

Using Advanced NVM Application Tests ReRAM

Configure the connection setup and connect your device by referring to the connection diagram on the GUI.

Note *1: The Triax TEE consists of the following combination of adapters as shown in Figure 2-6.

*1: TEE configuration to connect between SMU_Vs and SMU_Vm.

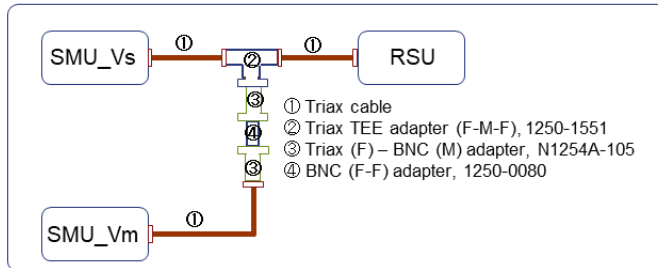


Figure 2-6. Triax TEE configuration using adapters.



The picture of the Triax TEE adapter, with the combination of adapters, is shown next.

Measurement parameter setup

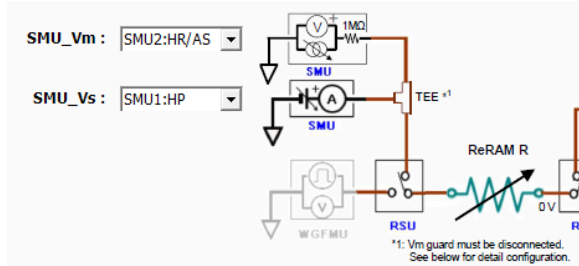
Follow the next steps to measure the ReRAM IV-Butterfly curve using the ReRAM IV-Butterfly application test.

Step 1: Assign Measurement Modules

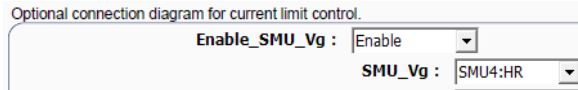
This test uses only SMUs.

Assign SMUs in the GUI of the ReRAM IV-Butterfly Application Test by referring to your B1500A SMUs configuration and the connection with your ReRAM device.

Assign the SMUs for Vs and Vm SMUs by choosing from the dropdown list of the GUI by referring to your actual connection as shown in the next figure.



Do the same for Vg SMU option if you are using the current limit option.



Step 2: Set the Output Waveform Parameters

Set the following test parameters as shown in Table 2-3 by referring to the parameters shown in Figure 2-7.

Set I compliance for Vs SMU which limits the maximum current of the low resistance state of the ReRAM structure.

Table 2-3. Waveform output setup: V Source (Vs) parameters

Parameter	Description
SetV	Maximum voltage to sweep in the SET direction.
ResetV	Maximum voltage to sweep in the RESET direction.
StepV	Step voltage of the sweep.
I_compliance	Current compliance of SMU_Vs.

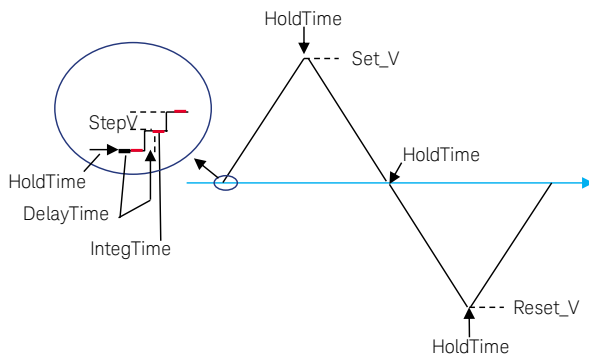


Figure 2-7. IV-Butterfly waveform parameters.

Optional Vg setting for SMU_Vg:

If the optional Vg SMU option is enabled, set the Vg voltage which limits the maximum current flowing in the ReRAM device. The Vg is output from the SMU_Vg while the measurement is taken.

Parameter	Description
Vg	Gate voltage of the current limit transistor (FET)

Step 3: Set Measurement & Display Parameters

Set the following test parameters shown in Table 2-4 referring to the parameters shown in Figure 2-7.

Table 2-4. Measurement & Display Parameters.

Parameter	Description
IntegTime	Integration time of SMU_Vs in the current measurement.
DelayTime	Delay time between the step measurements.
HoldTime	Hold time at the timing of the start, SetV, 0V to ResetV, and ResetV timing.
Display_Opt	Y axis scale selection from "Log (absolute)" and "Linear"
- LOG_Absolute	Plots absolute Im (Log Y axis) vs. Vm graph
- LINEAR	Plots Im vs. Vm graph

"Display_Opt" sets the display options for Y axis display. One for log graph and the other for linear graph.

The selection of "LOG_Absolute" takes the absolute log in the Y axis, and plots the so-called Butterfly curve (refer to Figure 2-9). Selecting "Linear" provides the linear scale measurement graph with signal polarity.

Step 4: (Optional) Set Extended Test Parameters

The following parameters shown in Table 2-5 can be optionally set in the Extended Test Parameter setup window.

The Extended Test Parameter setup window can be opened by clicking the "Extended Setup . . . " button, shown in the next figure, located in the upper right corner of the Test Parameters window of EasyEXPERT.

It is not usually necessary to change this parameter.

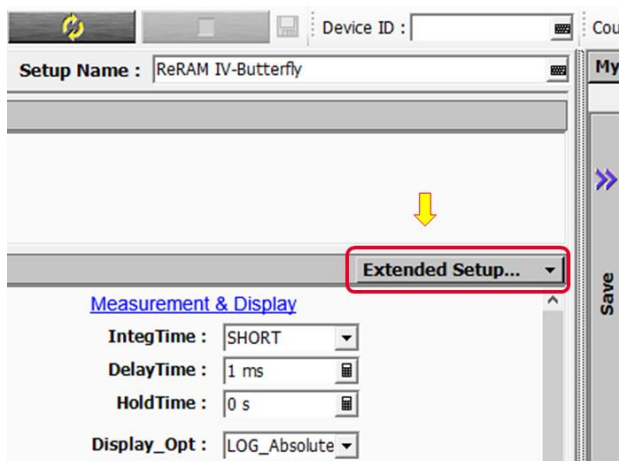


Figure 2-8. How to open the Extended Test Parameter setup window.

Table 2-5. Extended Test Parameter setup.

Parameter	Description
Vs_MinRange	Minimum current range setting of the limited auto-range of SMU_Vs.

This parameter sets the minimum current range in the limited auto-range setting. It is not usually necessary to change this parameter.

Measurement results

The output is an X-Y plot where x-axis is voltage and Y axis is a current.

Output example:

Figure 2-9 shows a measurement output example of ReRAM IV-Butterfly application test. You can access the measurement graph and the measurement data in the List Display. List Display provides the numerical measurement data including Vs, Vm and Im data. List data can easily be copied to any spreadsheet applications.

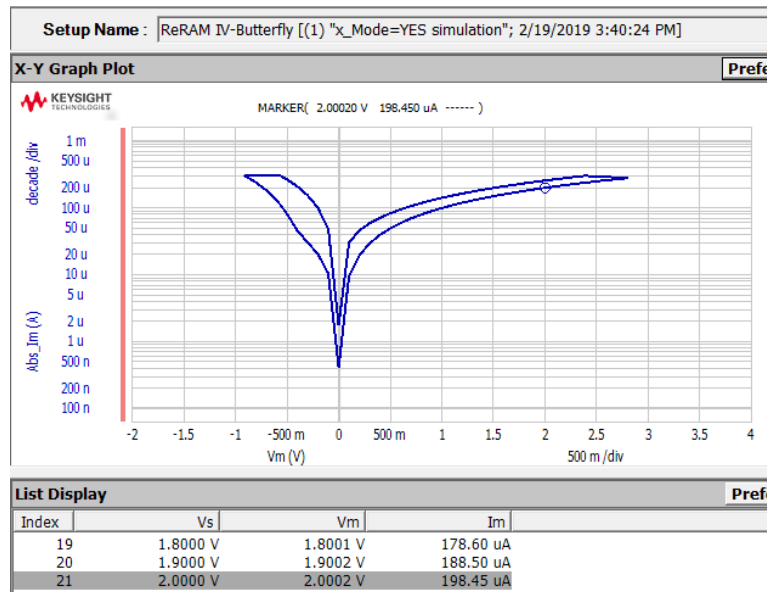


Figure 2-9. Example output of ReRAM Butterfly Application Test.

○ ReRAM FORM

General description of the FORM Application Test

This application test performs Forming process characterization and the resistance measurement just after the Forming process. The FORM characteristics measurements use a rising slope of the FORM pulse by continually sampling the slope current, as shown in Figure 2-10.

In the rise slope of the pulse, the current flowing through RERAM resistor is measured and detects a sudden increase of the current where the ReRAM resistor suddenly decreases by the FORM of a channel path. The FORM parameter is detected by the sudden increase of the ReRAM current crossing the threshold current which is set by the "FORM_detect" parameter.

The source voltage V_s just before the FORM detection is set as the FORM voltage (FORM_Vm) and the first measurement current after the FORM detection is recorded as the FORM current (FORM_Im). Those parameters are set in the form waveform parameter field and measurement parameter field. Note that measurement accuracy may depend on the rise slope time and the sampling interval. After the detection of the FORM, the FORM resistance (FormR) is measured.

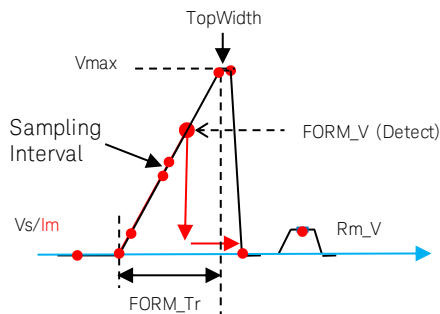


Figure 2-10. FORM pulse and waveform parameters.

ReRAM FORM measurement configuration

WGFMU RSUs are used in the FORM measurement application test as shown in Figure 2-11.

One WGFMU-RSU is used as the waveform source for ReRAM resistor device and second RSU is used to measure the current from the device with fixed zero input volts.

The connection diagram of the optional current limit configuration is shown in Figure 2-12. Refer to Figure 2-3 when connecting the SMU to V_g terminal of the current limit transistor.

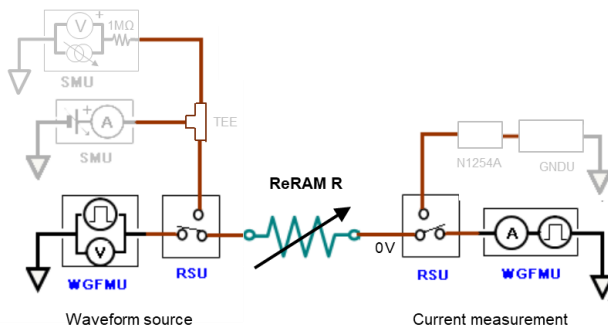


Figure 2-11. Standard configuration for FORM measurement.

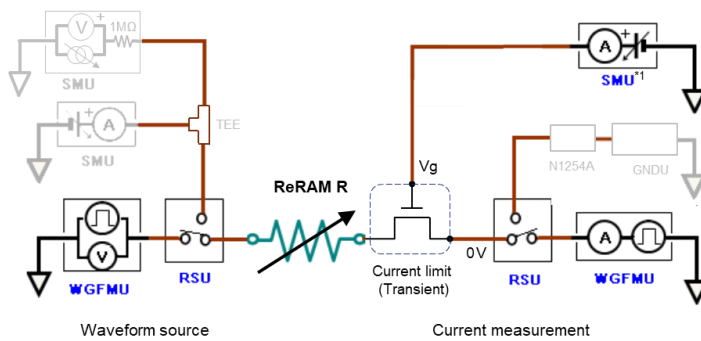


Figure 2-12. Optional current limit configuration for FORM measurement.

Configure the connection setup and connect your device by referring to the connection diagram on the GUI. Refer to Figure 2-3 when connecting the SMU for V_g .

Measurement parameter setup

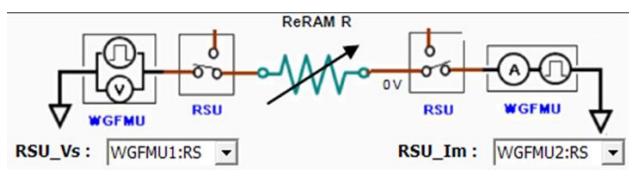
Follow the next steps to measure the FORM parameters using the ReRAM FORM application test.

Step 1: Assign Measurement Modules

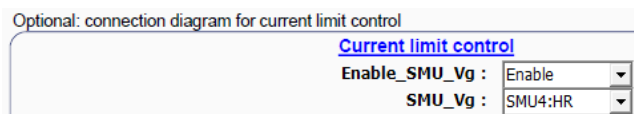
This test uses RSUs shown in the GUI of the ReRAM FORM Application Test. Before assigning the RSU in the application test GUI, refer to your B1500A WGFMU-RSUs configuration and the connection with your device.

Assign the RSUs for V_s and I_m choosing from the dropdown list of the GUI by referring to your actual connection as shown in the next figure, where:

- RSU_Vs: RSU channel of the Vs -Voltage source RSU.
- RSU_Im: RSU channel of the Im - Current measurement RSU.



Do the same for the Vg SMU option if you are using the current limit option.



Step2: Set Waveform output parameters

Set the following test parameters shown in Table 2-6 and Table 2-7 by referring to the parameters shown in Figure 2-10.

The sampling measurement is made while in the FORM_Tr slope and the voltage, when the resistor changes high resistance to low resistance state, is detected as the FORM voltage. Taking enough sampling data increase the FORM voltage resolution, hence the FORM_Tr must be set long enough compared to the FORM_SamplingInterval parameter, as shown in the next step.

Table 2-6. Waveform output setup: FORM parameters.

Parameter	Description
Vmax	Max voltage of the FORM pulse of the RSU_Vs. Set higher voltage than the actual FORM voltage of the ReRAM device.
FORM_Tr	Rise time of the FORM pulse. "FORM_Tr/ FORM_SamplingInterval >= 5" must be satisfied to detect the FORM
FORM_Tf	Fall time of the FORM pulse.
TopWidth	Top width of the FORM Pulse.

Table 2-7. Waveform output: R Measure parameter.

Parameter	Description
Rm_V	The output voltage for R measurement a after the FORM pulse.

Note: "Rm_V" must be small enough compared to Vmax to keep the low resistance state.

Step 3: Set Measurement Parameters:

Set the following measurement parameters.

Table 2-8. Measurement parameters.

Parameter	Description
FORM_SamplingInterval	Sampling interval to measure the current in the FORM pulse. To detect the FORM voltage, sampling interval must be at least 5 times shorter than FORM_Tr.
FORM_Im_range	Current range of RSU_Im (Im RSU). FORM current is measured by RSU_Im.
FORM_detect_I (optional)	Current threshold which is set smaller than the FORM current in the specified measurement condition, and used to detect FORM voltage better in the output graph.
Rm_Im_range	Current range of RSU_Im used measuring the R after the FORM pulse.
RmAveragingTime	Averaging time when measuring the R after the FORM pulse.
Rm_DelayTime	Delay time from the start of the Rm pulse to the start of the R measurement. Delay time must be larger than " RmP_RiseTime" and its transient periods.
Rm_adjust (optional)	Subtracts Rm_adjust from the Rm value for adjusting the R of the current limit transistor.

Note:

- "5 times" limit description in the "FORM_SamplingInterval" is a minimum number in the program. The actual sampling interval is better to set at < 1/50 of the "FORM_Tr" to obtain reasonably accurate test results.
- "FORM_SamplingInterval" is also an integration time of the sampling. Set a longer time if the sampling data is noisy.
- "FORM_detect_I" is only used in the FORM voltage detection algorithm and does not affect the measurement. Even the detection is failed by the detection algorithm, the actual FORM voltage can be extracted from the measurement graph.
- "Rm_adjust" subtracts this value from the measured resistance. This parameter can be used when the optional current limit transistor is used or if a series resistor is inserted to limit the maximum current.

Step 4: Set Optional Vg for SMU_Vg Parameter for current limiting

If the optional Vg SMU option is enabled, set the Vg voltage which limits the maximum current flowing in the ReRAM device. The Vg is output from the SMU_Vg while the measurement is taken.

Since WGF MU/RSU does not have the current limit capability, consider using this option or inserting a resistor in series if any noticeable degradation of the ReRAM is doubted while the measurement is taken.

Table 2-9. Optional Parameter for current limit setting.

Parameter	Description
Vg	Gate voltage of the current limit transistor (FET) to limit the maximum current of the ReRAM resistor device.

Step 5: (Optional) Set Extended Test Parameters

In addition to the parameters shown in the GUI panel, you can setup the following extended parameters shown in Table 2-10 by pressing the "Extended Setup ..." button shown in Figure 2-8.

It is not usually necessary to change these parameters.

Table 2-10. Extended Test Parameter setup.

Parameter	Description
DelayTime	Delay time.
RSU_Vs_Range	Current range of RSU_Vs (Vs RSU)
RmP_RiseTime	Rise/Fall time of R measure pulse
ExecutionMode	Choice of "Execution Mode"
- Run Vector	Measurement is made with the WGF MU/RSU
- Pattern Validation	Used to check the vector data created to run WGF MU/RSU. Can be executed without running the B1500A.
DataDisplay_PatternValidation	This parameter is effective in "Run Vector" in the execution mode setting.
- Enable	Shows "PatternValidation Data Display". (Waveform or Waveform_MeasTiming)
- Disable	Does not show "PatternValidation Data Display".

Measurement results

The test results are Displayed in the ReRAM FORM graph.

The graph displays Form_V (Y1 axis), Form_I (Y2 axis) versus FORM_TIME sampling data in X axis.

The following parameters are extracted:

- FormR: Measured R value after the FORM pulse.
- FORM_Im: Current measured just after the FORM detection.
- FORM_Vm: Source voltage just before the FORM detection.

Output example:

Figure 2-13 shows a measurement output example of a ReRAM FORM application test. The FORM_Im and FORM_Vm parameters measured at the timing of the FORM path are made in the

ReRAM resistance channel and the resistance (FormR) measured after the FORM pulse, are displayed on the Parameters area of the display.
You can access the measurement graph and the measurement data as shown in Figure 2-13.

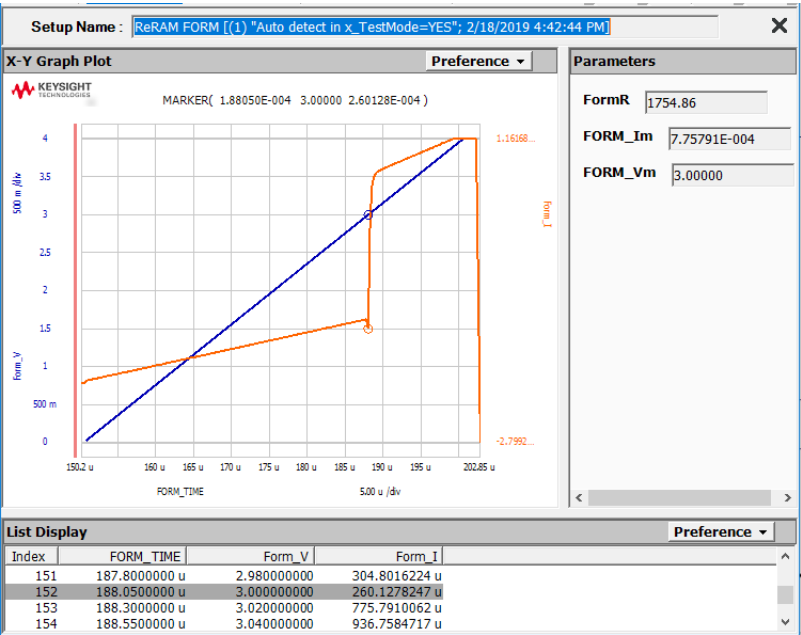


Figure 2-13. FORM measurement graph example.

○ ReRAM Reset-Set

General description of the Reset-Set Application Test

This application test performs SET characterization followed by the RESET measurements. SET characterization is very similar to the ReRAM FORM application test. The concept of the RESET measurement is similar to the SET measurement approach except that this characterization detects the sudden decrease of the current when the ReRAM resistor gets higher at RESET voltage in the RESET pulse rise slope. The RESET voltage can be set for both polarities depending on the ReRAM device type.

The measurement sequence guide is shown in the next figure.

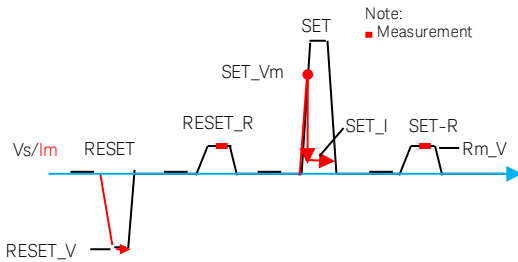


Figure 2-14. ReRAM Reset-Set pulse and waveform parameters.

A gate control option for using an external current limit device is available.

ReRAM Reset - Set measurement configuration

The measurement configuration is the same as the ReRAM FORM application test.

Refer to the relevant section of the ReRAM FORM measurement configuration. For standard configuration, refer to Figure 2-11. For the optional current limit configuration, refer to Figure 2-12.

Measurement parameter setup

Follow the next steps to characterize the Reset-Set parameters using the ReRAM Reset-Set application test.

Step 1: Assign Measurement module

The measurement module setup is the same as the ReRAM FORM application test.

Refer to the measurement module setup of the ReRAM FORM section.

Step 2: Set Waveform output parameters

Set the following test parameters shown in Table 2-11 for RESET/SET pulse and Table 2-12 for R measurement voltage, referring to the parameters shown in Figure 2-14. For SET pulse, also refer to the FORM parameters in Figure 2-10.

Table 2-11. Waveform output setup: RESET / SET output parameters.

Parameter	Description
RESET_V	RESET voltage
RESET_Tr	Rise time of the RESET pulse.
SET_Vmax	Max voltage of the SET pulse of the RSU_Vs.
SET_Tr	Rise time of the SET pulse.
TopWidth	Top width of the SET and RESET pulse.

Table 2-12. Waveform output - R Measure parameter.

Parameter	Description
Rm_V	The output voltage used for R measurement after the RESET and SET pulse.

Note: "Rm_V" must be small enough for keeping the high and low resistance state.

Step 3: Set Measurement parameters

Set the following parameters by referring to Table 2-13 for RESET/SET measurements and Table 2-14 for R measurements.

Table 2-13. Measurement parameters - RESET / SET measurement.

Parameter	Description
SamplingInterval	Sampling interval to measure the current in the SET pulse. To detect the SET voltage, sampling interval must be at least 5 times shorter than SET_Tr.
RESET_Im_range	Current range of RSU_Im (Im RSU), used in the RESET pulse stage to measure the RESET current.
RESET_detect_I	Current threshold to detect the RESET V. When the current difference between two sampling points in the RESET_Tr slope exceeds "RESET_detect_I", the voltage of the slope is recorded as RESET V.
SET_Im_range	Current range of RSU_Im (Im RSU), used in the SET pulse stage to measure the SET current.
SET_detect_I	Current threshold to detect the SET V. When the current difference between two sampling points in the SET_Tr slope exceeds "SET_detect_I", the voltage of the slope is recorded as SET

Note:

- "5 times " limit description in the "SamplingInterval" is a minimum number limited in the program. A larger number provides a higher resolution SET/RESET voltage.
- "SamplingInterval" is also an integration time of the sampling. Set longer time if the sampling data is noisy.
- "RESET_detect_I" and "SET_detect_I" are only used in the RESET/SET voltage detection algorithm and they do not affect the measurement. Even if the detection is failed by the detection algorithm, the actual RESET/SET voltage can be extracted from the measurement graph.

Table 2-14. Measurement parameters - R Measure.

Parameter	Description
SET_Rm_ImRange	Current range of RSU_Im used to measure R after the SET pulse.
RESET_Rm_ImRange	Current range of RSU_Im used to measure R after the RESET pulse.
Rm_AveragingT	Averaging time to measure SET_R & RESET_R.
Rm_DelayTime	Delay time between the start of the Rm pulse and the start of the R measurement. Delay time must be larger than " Rm_TrTf" and its transient periods.
Rm_adjust	Subtracts Rm_adjust from the Rm value for adjusting the R of the current limit transistor.

Note:

- "Rm_adjust" subtracts this value from the measured resistance. This parameter can be used when the optional current limit transistor is used or if a series resistor is inserted to limit the maximum current.

Step 4: Set Optional Vg for SMU_Vg Parameter for current limiting

If the optional Vg SMU option is enabled, set the Vg voltage which limits the maximum current flowing in the ReRAM device. The Vg is output from the SMU_Vg while the measurement is taken.

Since WGFMU/RSU does not have the current limit capability, consider using this option or inserting a resistor in series if any noticeable degradation of the ReRAM is doubted while the measurement is taken.

Table 2-15. Optional Parameter for current limit setting.

Parameter	Description
Vg	Gate voltage of the current limit transistor (FET) to limit the maximum current of the ReRAM resistor device.

Step 5: (Optional) Set Extended Test Parameters

In addition to the parameters shown in the GUI panel, you can setup the following extended parameters shown in Table 2-16 by pressing the "Extended Setup ..." button. The location of the button is shown in Figure 2-8.

It is not usually necessary to change these parameters.

Table 2-16. Extended parameter setup.

Parameter	Description
ExecutionMode	"Execution Mode" choice from the followings.
- Run Vector	Measurement is made with the WGFMU/RSU
- Pattern Validation	Used to check the vector data created to run WGFMU/RSU. Can be executed without running the B1500A.
DataDisplay_PatternValidation	(This parameter is effective in "Run Vector" in the execution mode setting.)
- Enable	Shows "PatternValidation Data Display". (Waveform or Waveform_MeasTiming)
- Disable	Does not show "PatternValidation Data Display".
DelayTime	Delay time.
SET_Tf	Fall time of the SET pulse.
RESET_Tf	Fall time of the RESET pulse.
Rm_TrTf	Rise/Fall time of R measure pulse
Vs_range	Current range of RSU_Vs (Vs RSU)

Measurement results

The measurement results display two graphs, one for RESET measurement and the other for SET measurement. Both graphs display RESEWT/SET output voltage (Y1 axis) and RESET/SET measurement current (Y2 axis) versus RESET/SET time (X axis) sampling data.

The following parameters are extracted:

- ResetR: measured RESET R
- Reset_Im: Peak current which is measured one sampling point before the RESET is detected. If RESET is not detected, 9999 is returned.
- Reset_Vm: Peak voltage which is measured one sampling point before the RESET is detected. If RESET is not detected, 9999 is returned.
- SetR: measured SET R
- SET_Im: Peak current when the SET is detected. If SET is not detected, 9999 is returned.
- SET_Vm: Peak voltage which is measured one sampling point before the SET is detected. If SET is not detected, 9999 is returned.

Output example:

Measurement examples are shown in the next two figures. Figure 2-15 shows the RESET measurement graph example and Figure 2-16 shows the SET measurement graph example. You can expect to obtain the two measurement results, one for RESET and the other for SET operation, as shown in the example output graphs.

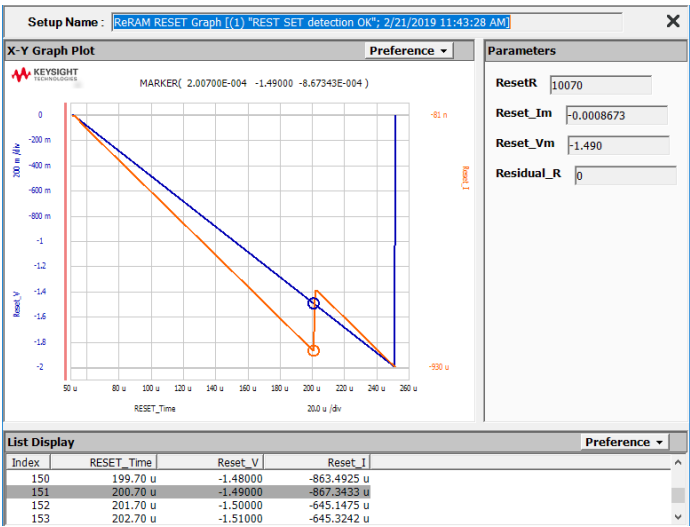


Figure 2-15. RESET measurement example.

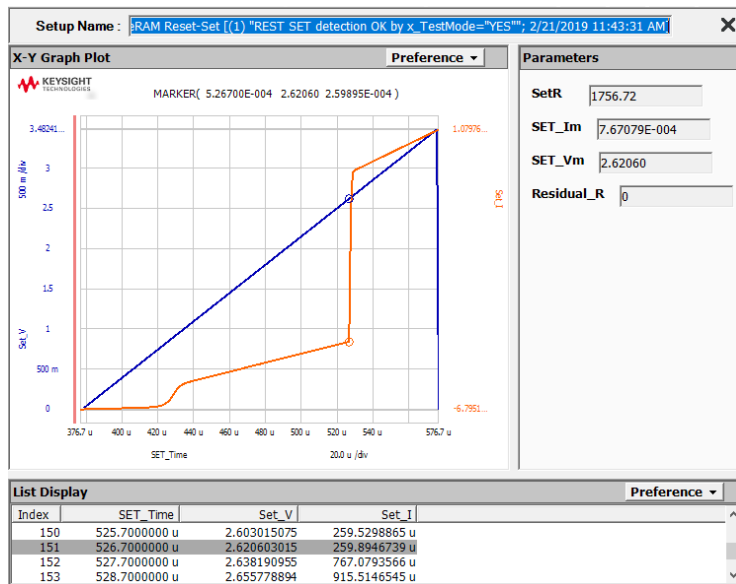


Figure 2-16. SET measurement example.

Note: To access for RESET measurement graph from the Results area, you must expand Application Test Results because the data is saved behind the main application test name.

Refer to the next figure to expand the application test results.

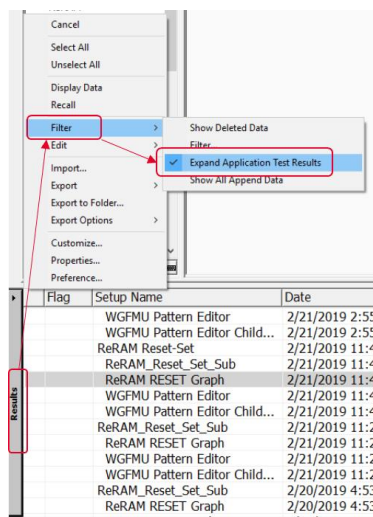


Figure 2-17. Expanding Application Test

○ ReRAM Reset SetV-Loop

General description of the Reset SetV-Loop Application Test

This application test performs repeated SET R measurements from the initial low SET voltage, where the ReRAM resistance is high and the SET voltage is incrementally increasing to find the SET voltage, where the ReRAM resistance reaches a low resistance state. The SET voltage can easily be found by carrying out this test.

The measurement sequence guide is shown in the next figure.

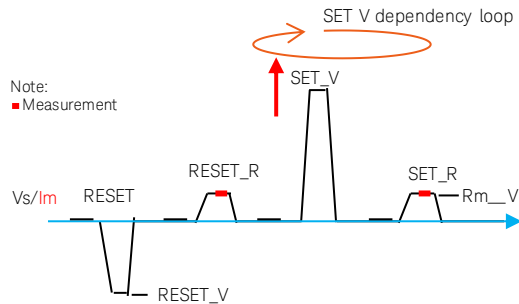


Figure 2-18. ReRAM Reset SetV-Loop pulse and waveform parameters.

A gate control option for using an external current limit device is available.

ReRAM Reset SetV-Loop measurement configuration

The measurement configuration is the same as the ReRAM FORM application test.

Refer to the section of the ReRAM FORM measurement configuration. For standard configuration, refer to Figure 2-11. For the optional current limit configuration, refer to Figure 2-12.

Measurement parameter setup

Follow the next steps to find the SET voltage using the ReRAM Reset SetV-Loop application test.

Step 1: Assign Measurement Modules

The measurement module setup is the same as the ReRAM FORM application test.

Refer to the measurement module setup of the ReRAM FORM section.

Step 2: Set Waveform output parameters

Set the following test parameters as shown in Table 2-17 for Reset SetV-Loop pulse and Table 2-18 for R measurement voltage, by referring to the parameters shown in Figure 2-18.

Table 2-17. Waveform output setup - Reset SetV-Loop RESET / SET output parameters.

Parameter	Description
RESET_V	RESET voltage
RESET_Tr	Rise time of the RESET pulse.
SET_startV	Start voltage of SET V loop
SET_stopV	Stop voltage of SET V loop
N_of_steps	Number of steps in the voltage loop.
SET_Tr	Rise time of the SET pulse.
TopWidth	Top width of the SET and RESET pulse.

Note:

- "SET_startV" must be set lower than the actual SET voltage of the DUT and "SET_stopV" must be higher, so that the actual SET voltage comes between these two sweep voltage ranges.

Table 2-18. Waveform output - R Measure parameter.

Parameter	Description
Rm_V	R measurement voltage after the SET & RESET pulse.

Step 3: Set Measurement parameters

Set the following parameters by referring to Table 2-19 for Reset SetV-Loop measurements and Table 2-20 for R measurements.

Table 2-19. Measurement parameters - Reset SetV-Loop measurement.

Parameter	Description
SamplingInterval	Sampling interval to measure the current in the SET pulse. To detect the SET voltage, sampling interval must be at least 5 times shorter than SET_Tr.
RESET_Im_range	Current range of RSU_Im (Im RSU), used in the RESET pulse stage to measure the RESET current.
SET_Im_range	Current range of RSU_Im (Im RSU), used in the SET pulse stage to measure the SET current.
SET_detect_R	Threshold SET R value to detect the SET voltage in the step loop. Detection is made when the measured R decreases the threshold R.

Note:

- "5 times " limit description in the "SamplingInterval" is a minimum number limited in the program. This condition must be met, but it does not affect the measurement results as in the case of the RESET/SET application test.

Table 2-20. Measurement parameters - R Measure.

Parameter	Description
SET_Rm_ImRange	Current range of RSU_Im used to measure R after the SET pulse.
RESET_Rm_ImRange	Current range of RSU_Im used to measure R after the RESET pulse.
Rm_AveragingT	Averaging time to measure SET_R & RESET_R.
Rm_DelayTime	Delay time between the start of the Rm pulse and the start of the R measurement. Delay time must be larger than " Rm_TrTf" and its transient periods.
Rm_adjust	Subtracts Rm_adjust from the Rm value for adjusting the R of the current limit transistor.

Note:

- "Rm_adjust" subtracts this value from the measured resistance. This parameter can be used when the optional current limit transistor is used or if a series resistor is inserted to limit the maximum current.

Step 4: Set Optional Vg for SMU_Vg Parameter for current limiting

If the optional Vg SMU option is enabled, set the Vg voltage which limits the maximum current flowing in the ReRAM device. The Vg is output from the SMU_Vg while the measurement is taken.

Since WGF MU/RSU does not have the current limit capability, consider using this option or inserting a resistor in series if any noticeable degradation of the ReRAM is doubted while the measurement is taken.

Table 2-21. Optional Parameter for current limit setting.

Parameter	Description
Vg	Gate voltage of the current limit transistor (FET) to limit the maximum current of the ReRAM resistor device.

Step 5: (Optional) Set Extended Test Parameters

In addition to the parameters shown in the GUI panel, you can setup the following extended parameters shown in Table 2-16 by pressing the "Extended Setup ..." button. The location of the button is shown in Figure 2-8.

It is not usually necessary to change these parameters.

Table 2-22. Extended parameter setup.

Parameter	Description
DataDisplay_PatternValidation:	This parameter is effective in "Run Vector" execution mode setting.
- Enable	shows "PatternValidation Data Display". (Waveform or Waveform_MeasTiming):
- Disable	Does not show "PatternValidation Data Display".
ExecutionMode	Choice of "Execution Mode"
- Run Vector	Measurement is made with the WGF MU/RSU
- Pattern Validation	Used to check the Vector Data created to Run WGF MU/RSU. Can be executed without running the B1500A.
DelayTime	Delay time.
SET_Tf	Fall time of the SET pulse.
RESET_Tf	Fall time of the RESET pulse.
Rm_TrTf	Rise/Fall time of R measure pulse
Vs_rang	Current range of RSU_Vs (Vs RSU)

Measurement results

Measurement results are shown in the Reset-Set V incremental graph.

The X_Y graph parameters are shown next:

- Y axis: SET R
- X axis: SET Pulse V

The following parameter is extracted:

- SET_Vm: The SET voltage at the point where the "SET_R" value is lower than the "SET_detect_R" value, is recorded as "SET_Vm", and the marker is shown on that voltage. If SET_Vm is not detected, "9999" is displayed.

Output example:

The measurement example is shown in Figure 2-19.

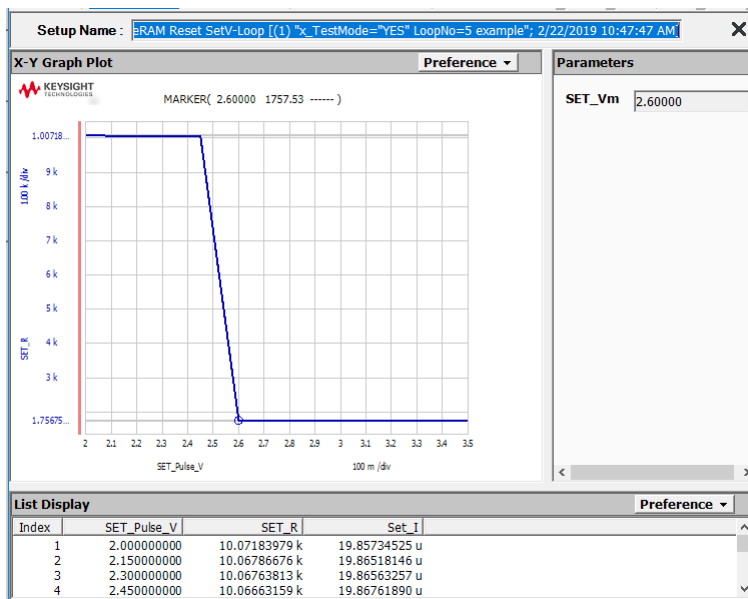


Figure 2-19. Reset SetV-Loop measurement example.

○ ReRAM Set ResetV-Loop

General description of the Reset SetV-Loop Application Test

This application test performs repeat RESET R measurements from the initial low RESET voltage, where RESET is not triggered and the RESET voltage is incrementally increasing to find the RESET voltage, where the ReRAM resistor is reset to high resistance state. The RESET voltage can easily be found by carrying out this test.

The measurement sequence guide is shown in the next figure.

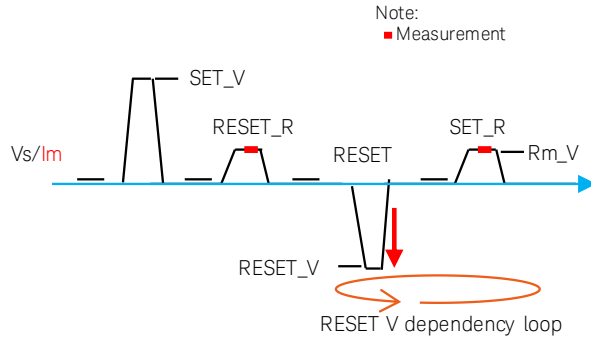


Figure 2-20. ReRAM Set ResetV-Loop pulse and waveform parameters.

A gate control option for using an external current limit device is available.

ReRAM Reset SetV-Loop measurement configuration

The measurement configuration is the same as the ReRAM FORM application test.

Refer to the section of the ReRAM FORM measurement configuration. For standard configuration, refer to Figure 2-11. For the optional current limit configuration, refer to Figure 2-12.

Measurement parameter setup

Follow the next steps to find the RESET voltage using the ReRAM Set ResetV-Loop application test.

Step 1: Assign Measurement Modules

The measurement module setup is the same as the ReRAM FORM application test.

Refer to the measurement module setup of the ReRAM FORM section.

Step 2: Set Waveform output parameters

Set the following test parameters shown in Table 2-23 for Set ResetV-Loop pulse and Table 2-24 for R measurement voltage, by referring to the parameters shown in Figure 2-20.

Table 2-23. Waveform output setup - Set ResetV-Loop output parameters.

Parameter	Description
SET_V	SET voltage
SET_Tr	Rise time of the SET pulse.
RESET_startV	Start voltage of RESET V loop
RESET_stopV	Stop voltage of RESET V loop
N_of_steps	Number of steps in the voltage loop.
RESET_Tr	Rise time of the RESET pulse.
TopWidth	Top width of the SET and RESET pulse.

Note:

- The "RESET_startV" must be set lower than the actual RESET voltage of the DUT and the "RESET_stopV" must be higher, so that the actual RESET voltage comes between these two sweep voltage ranges.

Table 2-24. Waveform output - R Measure parameter.

Parameter	Description
Rm_V	R measurement voltage after the SET & RESET pulse.

Step 3: Set Measurement parameters

Set the following parameters by referring to Table 2-25 for Set ResetV-Loop measurements and Table 2-26 for R measurements.

Table 2-25. Measurement parameters - Set ResetV-Loop measurement.

Parameter	Description
SamplingInterval	Sampling interval to measure the current in the SET pulse. To detect the SET voltage, sampling interval must be at least 5 times shorter than SET_Tr.
RESET_Im_range	Current range of RSU_Im (Im RSU), used in the RESET pulse stage to measure the RESET current.
SET_Im_range	Current range of RSU_Im (Im RSU), used in the SET pulse stage to measure the SET current.
RESET_detect_R	Threshold SET R value to detect the SET voltage in the step loop. Detection is made when the measured R decreases the threshold R.

Note:

- "5 times " limit description in the "SamplingInterval" is a minimum number limited in the program. This condition must be met, but it does not affect the measurement results as in the case of the RESET/SET application test.

Table 2-26. Measurement parameters - R Measure.

Parameter	Description
SET_Rm_ImRange	Current range of RSU_Im used to measure R after the SET pulse.
RESET_Rm_ImRange	Current range of RSU_Im used to measure R after the RESET pulse.
Rm_AveragingT	Averaging time to measure SET_R & RESET_R.
Rm_DelayTime	Delay time between the start of the Rm pulse and the start of the R measurement. Delay time must be larger than " Rm_TrTf" and its transient periods.
Rm_adjust	Subtracts Rm_adjust from the Rm value for adjusting the R of the current limit transistor.

Note:

- "Rm_adjust" subtracts this value from the measured resistance. This parameter can be used when the optional current limit transistor is used or if a series resistor is inserted to limit the maximum current.

Step 4: Set Optional Vg for SMU_Vg Parameter for current limiting

If the optional Vg SMU option is enabled, set the Vg voltage which limits the maximum current flowing in the ReRAM device. The Vg is output from the SMU_Vg while the measurement is taken.

Since WGFMU/RSU does not have the current limit capability, consider using this option or inserting a resistor in series if any noticeable degradation of the ReRAM is doubted while the measurement is taken.

Table 2-27. Optional Parameter for current limit setting.

Parameter	Description
Vg	Gate voltage of the current limit transistor (FET) to limit the maximum current of the ReRAM resistor device.

Step 5: (Optional) Set Extended Test Parameters

In addition to the parameters shown in the GUI panel, you can setup the following extended parameters shown in Table 2-28 by pressing the "Extended Setup ..." button. The location of the button is shown in Figure 2-8.

It is not usually necessary to change these parameters.

Table 2-28. Extended parameter setup.

Parameter	Description
DataDisplay_PatternValidation:	This parameter is effective in "Run Vector" execution mode setting.
- Enable	shows "PatternValidation Data Display". (Waveform or Waveform_MeasTiming):
- Disable	Does not show "PatternValidation Data Display".
ExecutionMode	Choice of "Execution Mode"
- Run Vector	Measurement is made with the WGFMU/RSU
- Pattern Validation	Used to check the Vector Data created to Run WGFMU/RSU. Can be executed without running the B1500A.
DelayTime	Delay time.
SET_Tf	Fall time of the SET pulse.
RESET_Tf	Fall time of the RESET pulse.
Rm_TrTf	Rise/Fall time of R measure pulse
Vs_rang	Current range of RSU_Vs (Vs RSU)

Measurement results

Measurement results are shown in the Set-Reset V incremental graph.

The X_Y graph parameters are shown next:

- Y axis: RESET R
- X axis: Absolute RESET Pulse V

The following parameter is extracted:

- Reset_Vm: The RESET voltage, where the "RESET_R" value is higher than "RESET_detect_R" value, is recorded as "Reset_Vm and the marker is shown on that voltage.
If Reset_Vm is not detected, "9999" is returned and displayed.

Output example:

The measurement example is shown in Figure 2-21.

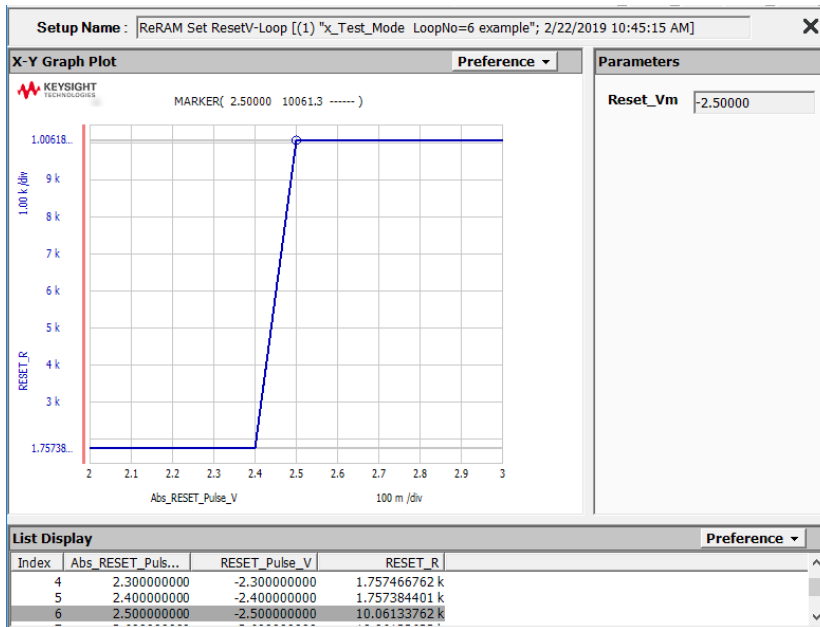


Figure 2-21. Set ResetV-Loop measurement example.

○ ReRAM Endurance

General description of the ReRAM Endurance Application Test

This application test performs an endurance repeat test of the RESET - SET pulse sequence. The test is executed as double loop cycles as shown in Figure 2-22, with a large loop (blue circle) including fatigue characterization after the short loop (red circle) stress cycles which only applies the RESET-SET pulses. The fatigue characterization measurement, shown in the right side of the large loop, measures the degree of the fatigue of the RESET - SET parameters at the specified logarithmic timing per decade base.

The pulse rise time used for RESET-SET characterization is much slower than the actual pulse used in the ReRAM memory, in order to obtain the accurate RESET-SET voltage and current. However, in the stress Reset/Set cycle shown in the small red circle, the rise time of the pulse can be set much shorter with the different parameter names "SET_Tr_Cycle" and "RESET_Tr_Cycle", hence the total test time can be minimized.

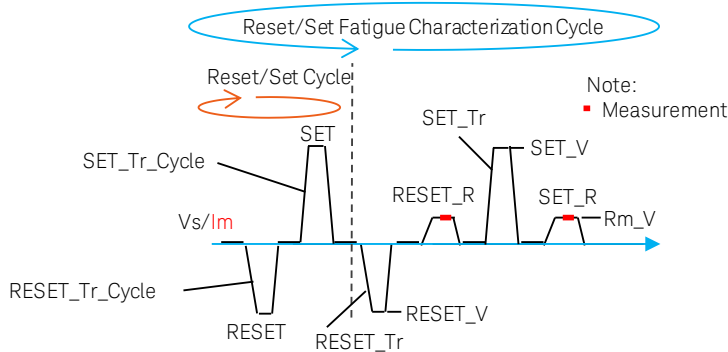


Figure 2-22. ReRAM Endurance test double cycles.

A gate control option for using an external current limit device is available.

ReRAM Endurance test configuration

The measurement configuration is the same as the ReRAM FORM application test.

Refer to the section of the ReRAM FORM measurement configuration. For standard configuration, refer to Figure 2-11. For the optional current limit configuration, refer to Figure 2-12.

Measurement parameter setup

Follow the next steps to measure the fatigue characteristics using the ReRAM Endurance application test.

Step 1: Assign Measurement Modules

The measurement module setup is the same as the ReRAM FORM application test.

Refer to the measurement module setup of the ReRAM FORM section.

Step 2: Set Waveform output parameters

Set the following parameters shown in Table 2-29 for endurance pulse output waveforms and Table 2-30 for R measurement voltage, by referring to the parameters shown in Figure 2-22.

Table 2-29. Waveform output - Endurance output parameters.

Parameter	Description
RESET_V	RESET voltage.
RESET_Tr	Rise time of the RESET pulse used for parameter measurements.
SET_V	SET voltage.
SET_Tr	Rise time of the SET pulse used for parameter measurements.
TopWidth	Top width of the SET and RESET pulse.
RESET_Tr_Cycle	Rise time of the RESET pulse used for Stress cycle.
SET_Tr_Cycle	Rise time of the SET pulse used for Stress cycle.

Note:

- "RESET_Tr" and "SET_Tr" parameters are for Reset/Set characterization and use a longer time required for the characterization.
- "RESET_Tr_Cycle" and "SET_Tr_Cycle" parameters are for Reset/Set stress cycles and use the shorter time. Using shorter time can reduce the total endurance test time.

Table 2-30. Waveform output - R Measure parameter.

Parameter	Description
Rm_V	R measurement voltage after the SET & RESET pulse.

Step 3: Set Measurement parameters

Set the following parameters by referring to Table 2-31 for endurance test timing, Table 2-32 for RESET/SET measurements and Table 2-33 for R measurements.

Table 2-31. Measurement parameters - Endurance test parameters.

Parameter	Description
Max_loops	Maximum loops of the endurance test. The RESET_SET waves are repeated, and ReRAM characterizations are made in the specified log interval.
Fatigue_C_dec	Number of fatigue measurements in one decade of endurance stress cycle.

Table 2-32. Measurement parameters - RESET/SET measurement parameters.

Parameter	Description
RESET_Im_range	Current range of RSU_Im (Im RSU), used in the RESET pulse stage to measure the RESET current.
SET_Im_range	Current range of RSU_Im (Im RSU), used in the SET pulse stage to measure the SET current.
SamplingInterval	Sampling interval to measure the current in the SET pulse. To detect the SET voltage, sampling interval must be at least 5 times shorter than SET_Tr.

Table 2-33. Measurement parameters - R Measure.

Parameter	Description
Rm_AveragingT	Averaging time to measure SET_R & RESET_R.
Rm_DelayTime	Delay time between the start of the Rm pulse and the start of the R measurement. Delay time must be larger than " Rm_TrTf" and its transient periods.
RESET_Rm_ImRange	Current range of RSU_Im used to measure R after the RESET pulse.
SET_Rm_ImRange	Current range of RSU_Im used to measure R after the SET pulse.
Rm_adjust	Subtracts Rm_adjust from the Rm value for adjusting the R of the current limit transistor.

Step 4: Set Optional Vg for SMU_Vg Parameter for current limiting

If the optional Vg SMU option is enabled, set the Vg voltage which limits the maximum current flowing in the ReRAM device. The Vg is output from the SMU_Vg while the measurement is taken.

Since WGFMU/RSU does not have the current limit capability, consider using this option or inserting a resistor in series if any noticeable degradation of the ReRAM is doubted while the measurement is taken.

Table 2-34. Optional Parameter for current limit setting.

Parameter	Description
Vg	Gate voltage of the current limit transistor (FET) to limit the maximum current of the ReRAM resistor device.

Step 5: (Optional) Set Extended Test Parameters

In addition to the parameters shown in the GUI panel, you can setup the following extended parameters shown in Table 2-35 by pressing the "Extended Setup ..." button. The location of the button is shown in Figure 2-8.

Table 2-35. Extended parameter setup.

Parameter	Description
Vg	Gate voltage of the current limit transistor (FET) to limit the maximum current of the ReRAM resistor device.
Extended parameter setup.	
Parameter	Description
Start_Fatigue_C	X-axis start number of the Fatigue count in the endurance test result display.
Do_PreTest	YES executes pre-RESET-SET test before starting the endurance stress cycle.
Rec_CharData	NO is recommended. "YES" saves all the intermediate characterization graph in the "Results area".
Rec_StrsData	NO is recommended. "YES" saves all the intermediate stress indication data in the "Results area".
Stop_by_ResetR	Flag if to terminate the endurance test. - "NO" does not terminate. - "Over" terminates when the RESET R exceeds the "Stop_ResetR". - "Down" does when the R decreases the "Stop_ResetR".
Stop_ResetR	R value to determine the "Stop_by_ResetR" condition.
Stop_by_SetR	Flag if to terminate the endurance test. - "NO" does not terminate. - "Over" terminates when the SET R exceeds the "Stop_SetR". - "Down" does when the R decreases the "Stop_SetR".
Stop_SetR	R value to determine the "Stop_by_SetR" condition.
DataDisplay_PatternValidation	This parameter is effective in "Run Vector" execution mode setting. - Enable shows "PatternValidation Data Display". (Waveform or Waveform_MeasTiming); - Disable Does not show "PatternValidation Data Display".
ExecutionMode	Choice of "Execution Mode" - Run Vector Measurement is made with the WGFMU/RSU - Pattern Validation Used to check the Vector Data created to Run WGFMU/RSU. Can be executed without running the B1500A.
DelayTime	Delay time.
SET_Tf	Fall time of the SET pulse.
RESET_Tf	Fall time of the RESET pulse.
Rm_TrTf	Rise/Fall time of R measure pulse
Vs_Im_rang	Current range of RSU_Vs (Vs RSU)

Note: The following parameters can help to monitor or control the endurance test parameters.

- "Start_Fatigue_C": The start timing of the fatigue measurement can be controlled. The default value is "1".
- "Rec_CharData": If the intermediate characterization is required, set to "YES"
- "Stop_by_ResetR": The endurance test can be terminated before reaching to the "Max_loops" if the data hits the pre-set test ResetR conditions. Refer to Figure 2-24, right side figure.
- "Stop_by_SetR": The endurance test can be terminated before reaching to the "Max_loops" if the data hits the pre-set test SetR conditions. Refer to Figure 2-24, left side figure.

Measurement results

Measurement results display several types of graphs including intermediate measurement result and stress data. This data can be saved in the EasyEXPERT data base in the Results area for checking the output data or for making further test analysis, or can be deleted while the measurements are taken by setting the "Rec_CharData" and "Rec_StrsData" parameters.

Using Advanced NVM Application Tests
ReRAM

The final output plots the Endurance test graph:

- SET R (Y1 axis)
- RESET R (Y2 axis)
- Fatigue count (X axis)

Parameter output:

The following parameter is extracted and displayed if "Do_PreTest" Extended Setup... parameter is set to "YES":

- Init_ResetR: Initial RESET R
- Init_SETR: Initial SET R

Output example:

A measurement example is shown in Figure 2-23.
The test example is a result of a 215 M stress cycle running over night for approximately 12 hours.

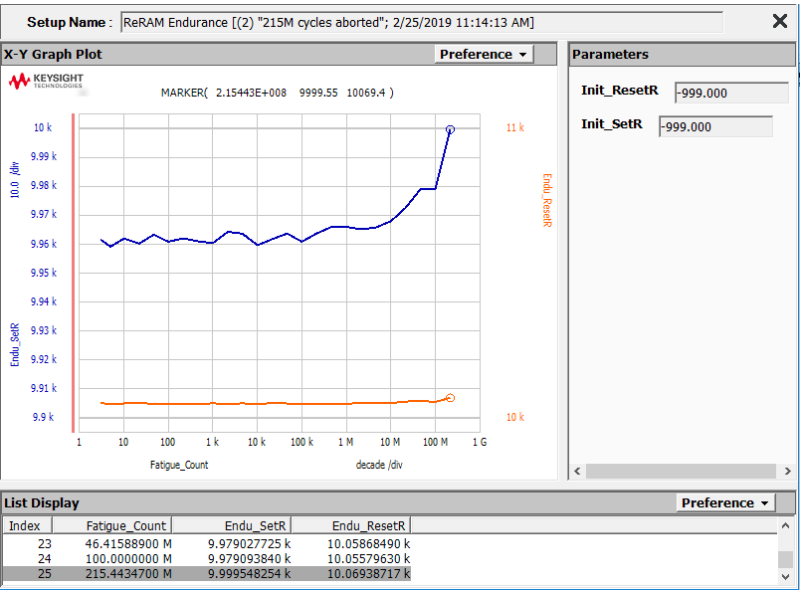


Figure 2-23. ReRAM Endurance test at 215 M stress cycle.

As a test option, a few test stop conditions can be set, except for the maximum number of stress cycles, by comparing the shift of the RESET and SET resistance changes including the direction (up or down side).

By properly setting the " Stop_by_ R" flag and "Stop_ ... R" resistance value pair in the "Extended Setup..." parameters, the endurance test can be terminated at the corresponding timing of the fatigue characterization measurements.

Figure 2-24 shows such examples using the dummy test device.

Both graphs detect at 216 fatigue measurement cycle and the left-side figure detects "Over" the specified resistance.

The right-side figure is a detection example of "Down" from the specified resistance.

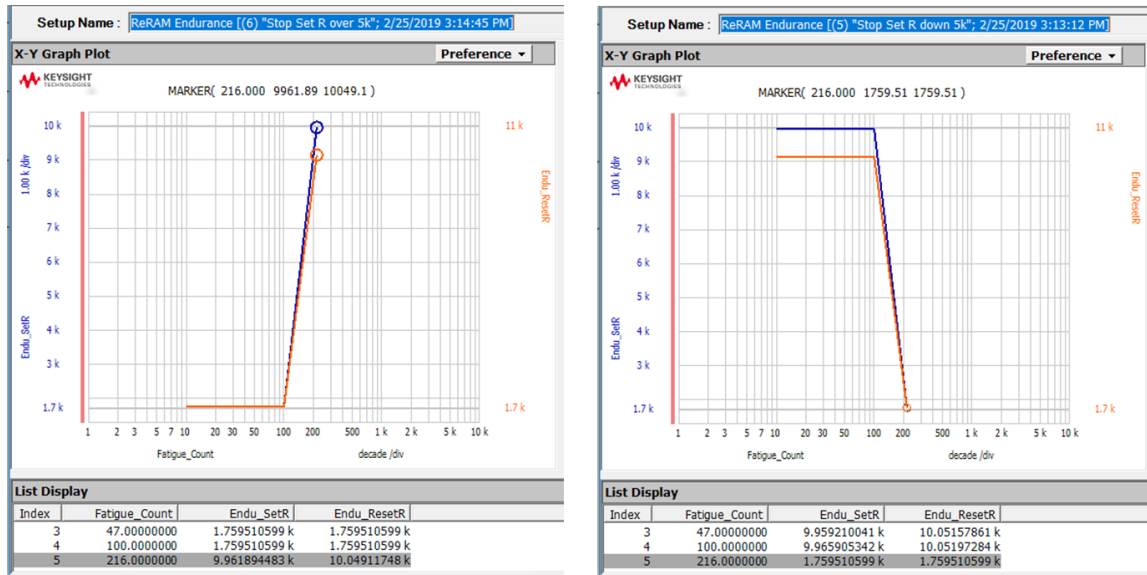


Figure 2-24. Endurance test example by "Stop by ..." condition. "Over" in right graph and "Down" in left graph.

2-2. PCRAM

2-2-1. What is a PCRAM test?

A PCRAM or phase change RAM uses both the high and low resistance states of the phase change memory cell. The low resistance state is called a SET state and it is the crystalline phase of the cell material. The high resistance state (RESET) appears in the amorphous phase of the cell material. When the crystalline material is cooled rapidly from the melted condition (typically > 600 °C) to less than the glass temperature (about 300 °C) about more or less in the 10 ns range (material dependent), the material state changes to amorphous and shows a high resistance. A high speed pulse is used to heat up and cool down the test device and the fall time condition of the pulse can generally be allowed about 3 times the maximum required cooling time, considering the voltage at about 300 °C is 70% of the pulse top voltage at 600 °C.

The material status changes to the crystalline phase by retaining the temperature between the glass state temperature and the melted condition.

Since it is not possible to directly monitor the temperature of the cell material, finding the RESET and SET condition is somewhat done by trial and error.

Table 2-36 shows a basic test flow using the Advanced NVM Application Test.

Table 2-36. Generic idea of the PCRAM test flow.

Test Flow:	ReRAM Application Test:
1. RESET V, and SET V characterization	• ResetV-Loop • SetV-Loop
2. Reset R and Set R characterization	• Reset-Set
3. Endurance test	• Endurance

2-2-2. Connection diagram

The connection diagram for PCRAM characterization is shown in Figure 2-25 where WGFMU is used for SET characterization and the resistance measurement, and PGU is used to output the fast RESET pulse. It is necessary to match to the 50 Ω impedance system to apply a good shape pulse to the DUT for the RESET pulse. The low side is terminated by the 50 Ω terminator through the RSU's Triax input port with the Triax to BNC adapter, as shown in Figure 2-26.

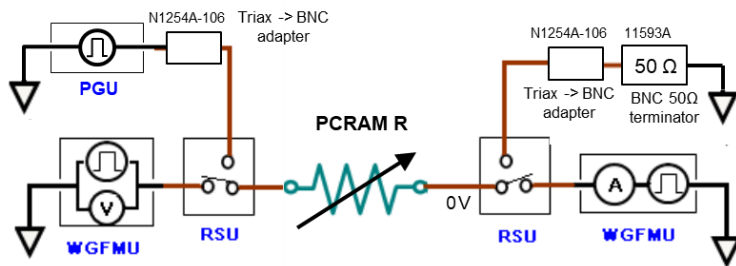


Figure 2-25. PCRAM measurement configuration.

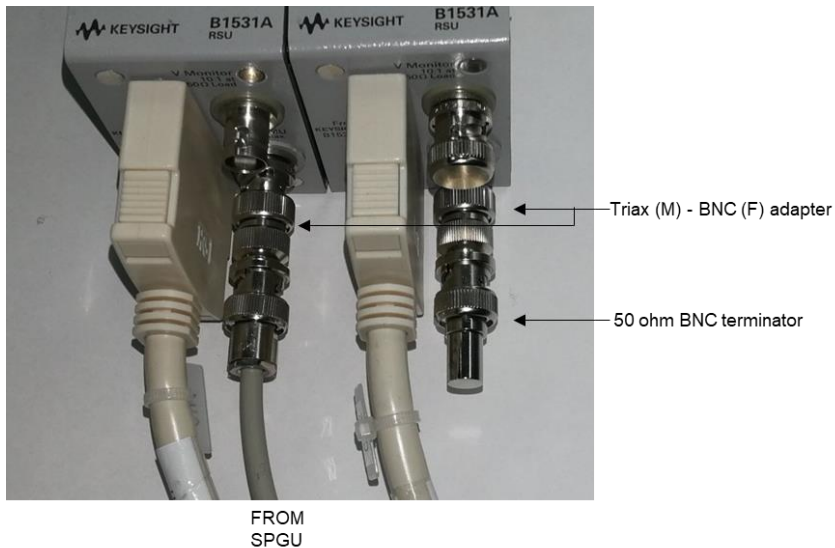


Figure 2-26. 50 Ω impedance matching and RSU input conversion to BNC.

The connection is the same for all of the PCRAM application tests introduced in the later section of this manual.

Configure the PCRAM measurement setup by referring to these figures.

For the cable routing of the PCRAM device side, refer to the corresponding section introduced in the next chapter.

2-2-3. PCRAM Application Tests

○ PCRAM ResetV-Loop

General description of the PCRAM ResetV-Loop Application Test

This application test performs repeat RESET R measurements from the initial low RESET pulse voltage where RESET state is not set and the RESET pulse voltage is incrementally increasing to find the RESET voltage, where the PCRAM resistor is reset to high resistance state. The RESET pulse voltage can easily be found by carrying out this test.

The measurement sequence guide is shown in the next figure.

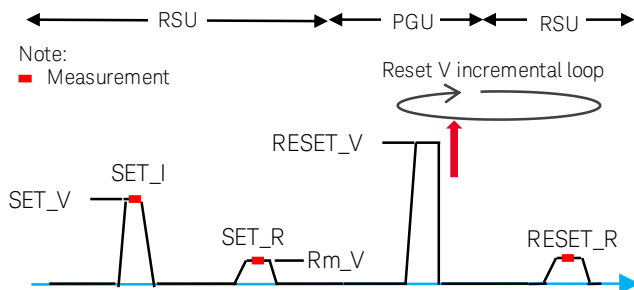


Figure 2-27. PCRAM ResetV-Loop pulse and waveform parameters.

Measurement parameter setup

Follow the next steps to measure the PCRAM ResetV using the PCRAM ResetV-Loop application test.

Step 1: Assign Measurement Modules

This test uses RSUs and SPGU as shown in the connection diagram of the PCRAM ResetV-Loop Application Test. Before assigning the RSUs and the SPGU in the application test GUI, refer to your B1500A WGFMU-RSUs configuration and the connection with your device.

Assign the RSUs for Vs and Im and SPGU by choosing from the dropdown list of the GUI by referring to your actual connection as shown in the next figure, where:

- SPGU: SPGU channel that is used as the RESET Voltage source.
- Vs: RSU channel of the Vs -Voltage source RSU.
- Im: RSU channel of the Im - Current measurement RSU.

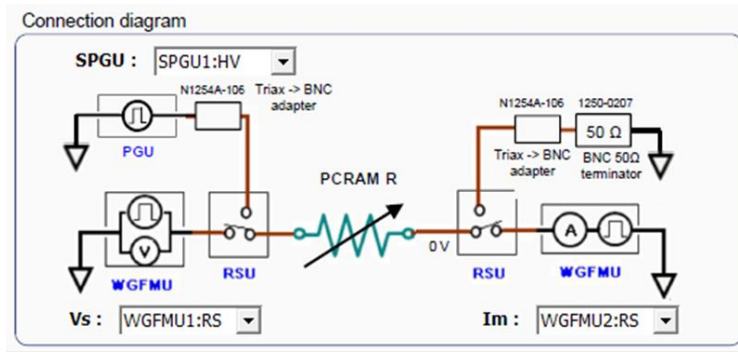


Figure 2-28. RSU and SPGU Connection GUI of the PCRAM.

Step 2: Set the Output Waveform Parameters

Set the following test parameters shown in Table 2-37 and Table 2-38, by referring to the parameters shown in Figure 2-27.

Table 2-37. Waveform output setup - RESET / SET output parameters:

Parameter	Description
SET_V	SET voltage
SET_Tr	Rise time of the SET pulse.
SET_Tf	Fall time of the SET pulse.
SET_TopWidth	Top width of the SET pulse.
RESET_StartV	Start voltage of RESET V loop.
RESET_StopV	Stop voltage of RESET V loop.
N_of_Steps	Number of steps in the voltage loop. Example: 1 = 1 measurement, 6 = Initial V + 5 steps measurements
RESET_Tr	Rise time of the RESET pulse.
RESET_Tf	Fall time of the RESET pulse.
RESET_TopWidth	Top width of the RESET pulse.

Table 2-38. Waveform output - R Measure parameter.

Parameter	Description
Rm_V	R measurement voltage after the SET & RESET pulse.

Step 3: Set Measurement Parameters:

Set the following measurement parameters as shown in Table 2-39 for SET current measurements and Table 2-40 for resistance measurements.

Table 2-39. Measurement - SET parameters.

Parameter	Description
SET_Im_range	Current range of RSU_Im (Im RSU), used in the SET pulse stage to measure the SET current.
SET_Im_DelayTime	Delay time between start of SET pulse and the start of SET_Im measurements. (SET_Im_DelayTime - SET_Tr + AveragingTime <= SET_TopWidth) must be met.
SET_Im_AveragingT	Averaging time to measure SET current. Averaging time must be shorter than "SET_TopWidth".

Table 2-40. Measurement - R Measure parameters.

Parameter	Description
SET_Rm_ImRange	Current range of RSU_Im used to measure R after the SET pulse.
RESET_Rm_ImRange	Current range of RSU_Im used to measure R after the RESET pulse.
Rm_AveragingTime	Averaging time to measure SET_R & RESET_R.
Rm_DelayTime	Delay time between the start of the Rm pulse and the start of the R measurement.
ResetLoop_Detect_R	Detect RESET V at which the RESET R exceeds this value in the V loop. "0" ohm disables this function.

Step 4: (Optional) Set Extended Test Parameters

In addition to the parameters shown in the GUI panel, you can setup the following extended parameters as shown in Table 2-41 by pressing the "Extended Setup ..." button shown in Figure 2-8.

It is not usually necessary to change these parameters.

Table 2-41. Extended parameter setup.

Parameter	Description
Rm_TrTf	Rise/Fall time of R measure pulse
DelayTime	Delay time.
Vs_Irange	Current range of RSU_Vs (Vs RSU)
DataDisplay_PatternValidation	This parameter is effective in "Run Vector" execution mode setting. - Enable shows "PatternValidation Data Display". (Waveform or Waveform_MeasTiming): - Disable Does not show "PatternValidation Data Display".
ExecutionMode	Choice of "Execution Mode" - Run Vector Measurement is made with the WGF MU/RSU - Pattern Validation Used to check the Vector Data created to Run WGF MU/RSU. Can be executed without running the B1500A.
Rec_LoopData	Selection of data save in the "Results" area. (EasyEXPERT database) - NO disables the store of the intermediate measurement results including PGU's output progress time data in the "Results" area. - YES saves all the available intermediate display graph.
Display_Control	Display graph control while in measurement. - YES disables the display of the intermediate measurement process. - NO displays all the available intermediate display graph.

Measurement results

The test results are displayed in the Parameter area of the PCRAM ResetV-Loop graph.

Plots the RESET R versus RESET pulse V graph.

- Y axis: RESET_Rm, RESET R measured in each RESET V steps.
- X axis: RESET_V, RESET Pulse V

Extracted parameter:

- ResetV_dtct: The RESET voltage detected at the " RESET_Rm" value is higher than " ResetLoop_Detect_R ".

The voltage is recorded as "ResetV_dtct and the marker is shown on that voltage.

If there is no detection, 9999 is returned and displayed.

- ResetR_Low: Lowest RESET R value in the RESET V loop.
- ResetR_High: Highest RESET R value in the RESET V loop.
- SetI: SET current measured at initial SET operation. (In the case "Rec_LoopData" = "YES")
- SetR: SET resistance measured at initial SET operation. (In the case "Rec_LoopData" = "YES")

Setup Name : PCRAM_Reset-Set_Sub [(

Parameters

Reset_R 1.75855 kohm

SetR_ 1.75855 kohm

SetI 1.15146 mA

Output example:

A measurement example is shown in Figure 2-29.

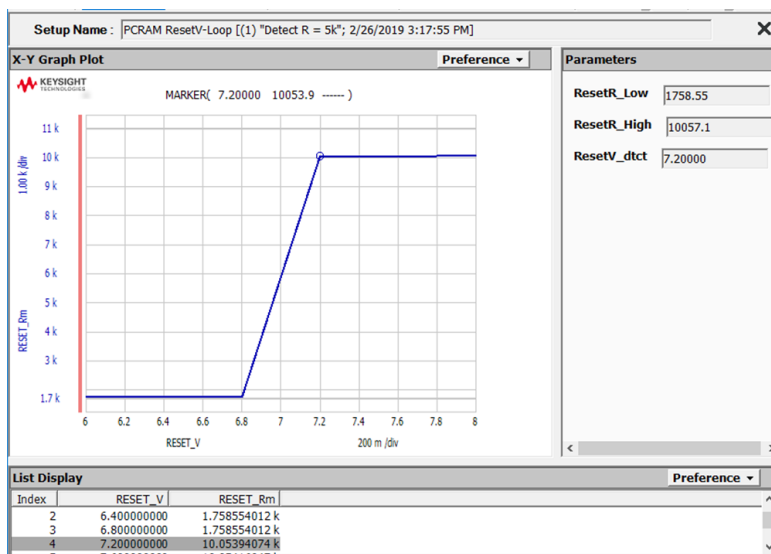


Figure 2-29. PCRAM ResetV-Loop measurement example.

○ PCRAM SetV-Loop

General description of the PCRAM ResetV-Loop Application Test

This application test performs repeat SET R measurements from the initial low SET pulse height voltage, where the SET state is not set and the SET pulse voltage is incrementally increasing to find the SET voltage where the PCRAM resistor is set to low resistance state. The SET pulse voltage can easily be found by carrying out this test.

The measurement sequence guide is shown in the next figure.

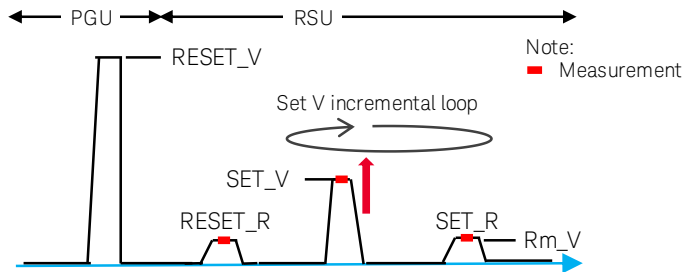


Figure 2-30. PCRAM SetV-Loop pulse and waveform parameters.

Measurement parameter setup

Follow the next steps to measure the PCRAM SetV using the PCRAM SetV-Loop application test.

Step 1: Assign Measurement modules

The measurement module setup is the same as the PCRAM ResetV-Loop application test. Refer to the measurement module setup of the PCRAM ResetV-Loop section and Figure 2-28.

Step 2: Set the Waveform output parameters

Set the following test parameters shown in Table 2-42 for RESET / SET and Table 2-43 for resistance measurement voltage, by referring to the parameters shown in Figure 2-30.

Table 2-42. Waveform output setup - RESET / SET output parameters.

Parameter	Description
RESET_V	RESET pulse voltage.
RESET_Tr	Rise time of the RESET pulse.
RESET_Tf	Fall time of the RESET pulse.
RESET_TopWidth	Top width of the RESET pulse.
SET_StartV	Start voltage of SET V loop.
SET_StopV	Stop voltage of SET V loop.
N_of_Steps	Number of steps in the voltage step loop. Example: 1 = 1 measurement, 6 = Initial V + 5 steps measurements
SET_Tr	Rise time of the SET pulse.
SET_Tf	Fall time of the SET pulse.
SET_TopWidth	Top width of the SET pulse.

Table 2-43. Waveform output - R Measure parameter.

Parameter	Description
Rm_V	R measurement voltage after the SET & RESET pulse.

Step 3: Set Measurement parameters

Set the following parameters by referring to Table 2-44 for SET parameter measurement and Table 2-45 for resistor R measurements.

Table 2-44. Measurement - SET parameters.

Parameter	Description
SET_Im_range	Current range of RSU_Im (Im RSU), used in the SET pulse stage to measure the SET current.
SET_Im_Averaging Time	Averaging time to measure SET current. Averaging time must be shorter than "SET_TopWidth".
SET_Im_DelayTime	Delay time between start of SET pulse and the start of SET_Im measurements. (SET_Im_DelayTime - SET_Tr + AveragingTime <= SET_TopWidth) must be met.

Table 2-45. Measurement parameters - R Measure.

Parameter	Description
SET_Rm_ImRange	Current range of RSU_Im used to measure R after the SET pulse.
RESET_Rm_ImRange	Current range of RSU_Im used to measure R after the RESET pulse.
Rm_AveragingTime	Averaging time to measure SET_R & RESET_R.
Rm_DelayTime	Delay time between the start of the Rm pulse and the start of the R measurement.
Set_loop_DetectR	Detect SET V at which the SET R exceeds this value in the V loop. "0" ohm disables this function.

Step 4: (Optional) Set Extended Test Parameters

In addition to the parameters shown in the GUI panel, you can setup the following extended parameters shown in Table 2-46 by pressing the "Extended Setup ..." button. The location of the button is shown in Figure 2-8.

It is not usually necessary to change these parameters.

Table 2-46. Extended parameter setup.

Parameter	Description
Rm_TrTf	Rise/Fall time of R measure pulse
DelayTime	Delay time.
Rec_SubData	Selection of data save in the "Results" area. (EasyEXPERT database) '- "NO" disables the store of the intermediate measurement results including PGU's output progress time data in the "Results" area. '- "YES" saves all the available intermediate display graph.
Vs_Irange	Current range of RSU_Vs (Vs RSU)
DataDisplay_PatternValidation	This parameter is effective in "Run Vector" execution mode setting. - Enable shows "PatternValidation Data Display". (Waveform or Waveform_MeasTiming): - Disable Does not show "PatternValidation Data Display".
ExecutionMode	Choice of "Execution Mode" - Run Vector Measurement is made with the WGFMU/RSU - Pattern Validation Used to check the Vector Data created to Run WGFMU/RSU. Can be executed without running the B1500A.

Measurement results

The test results are displayed in the Parameter area of the PCRAM SetV-Loop graph.

Plots the Set_R (Y1) and Set_I (Y2) versus SET_Pulse_V (X axis) graph.

- Y1 axis: Set_R, SET R measured at each SET V step.
- Y2 axis: Set_I, SET current measured at each SET V step.
- X axis: SET_Pulse_V, SET Pulse Voltage.

Extracted parameter:

- SetV_dtct: The SET voltage detected at the " Set_R" value is lower than " SET_loop_DetectR ".
The voltage is recorded as "SetV_dtct and a marker is shown on that voltage.
If there is no detection, -999 is returned and displayed.
- ResetV: Reset voltage used for RESET.
- Reset_R: RESEWT resistance measured at initial RESET operation.

Output example:

A measurement example is shown in Figure 2-31 below.



Figure 2-31. PCRAM SetV-Loop measurement example.

○ PCRAM Reset-Set

General description of the PCRAM Reset-Set Application Test

This application test performs SET characterization followed by the RESET pulse, as shown in the following figure. The fast RESET pulse is provided from the PGU module of the B1500A and the RESET resistance (RESET_R) is measured by the RSU. The SET pulse output and SET_R measurements are made by the RSU.

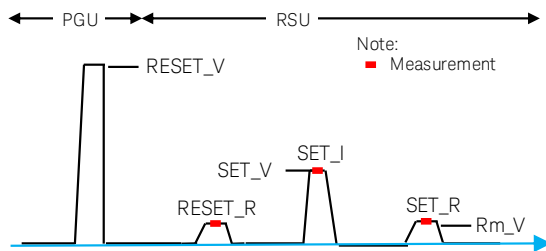


Figure 2-32. PCRAM Reset-Set pulse and waveform parameters.

Measurement parameter setup

Follow the next steps to measure the PCRAM Reset-Set characteristics using the PCRAM Reset-Set application test.

Step 1: Assign Measurement modules

The measurement module setup is the same as the PCRAM ResetV-Loop application test. Refer to the measurement module setup of the PCRAM ResetV-Loop section and Figure 2-28.

Step 2: Set the Waveform output parameters

Set the following test parameters as shown in Table 2-47 for RESET / SET and Table 2-48 for resistance measurement voltage, by referring to the parameters shown in Figure 2-32.

Table 2-47. Waveform output setup - RESET / SET output parameters.

Parameter	Description
RESET_V	RESET pulse voltage.
RESET_Tr	Rise time of the RESET pulse.
RESET_Tf	Fall time of the RESET pulse.
RESET_TopWidth	Top width of the RESET pulse.
SET_V	SET voltage.
SET_Tr	Rise time of the SET pulse.
SET_Tf	Fall time of the SET pulse.
SET_TopWidth	Top width of the SET pulse.

Table 2-48. Waveform output - R Measure parameter.

Parameter	Description
Rm_V	R measurement voltage after the SET & RESET pulse.

Step 3: Set Measurement parameters

Set the following parameters by referring to Table 2-49 for SET parameter measurement and Table 2-50 for resistor R measurements.

Table 2-49. Measurement - SET parameters.

Parameter	Description
SET_Im_range	Current range of RSU_Im (Im RSU), used in the SET pulse stage to measure the SET current.
AveragingTime	Averaging time to measure SET current. Averaging time must be shorter than "SET_TopWidth".
SET_Im_DelayTime	Delay time between start of SET pulse and the start of SET_Im measurements. (SET_Im_DelayTime - SET_Tr + AveragingTime <= SET_TopWidth) must be met.

Table 2-50. Measurement parameters - R Measure.

Parameter	Description
RESET_Rm_ImRange	Current range of RSU_Im used to measure R after the RESET pulse.
SET_Rm_ImRange	Current range of RSU_Im used to measure R after the SET pulse.
Rm_DelayTime	Delay time between the start of the Rm pulse and the start of the R measurement.
Rm_AveragingTime	Averaging time to measure SET_R & RESET_R.

Step 4: (Optional) Set Extended Test Parameters

In addition to the parameters shown in the GUI panel, you can setup the following extended parameters shown in Table 2-51 by pressing the "Extended Setup ..." button. The location of the button is shown in Figure 2-8.

It is not usually necessary to change these parameters.

Table 2-51. Extended parameter setup.

Parameter	Description
Rm_TrTf	Rise/Fall time of R measure pulse
DelayTime	Delay time.
Rec_SubData	Selection of data save in the "Results" area. (EasyEXPERT database) '- "NO" disables the store of the intermediate measurement results including PGU's output progress time data in the "Results" area. '- "YES" saves all the available intermediate display graph.
Vs_Irange	Current range of RSU_Vs (Vs RSU)
DataDisplay_PatternValidation	This parameter is effective in "Run Vector" execution mode setting. - Enable shows "PatternValidation Data Display". (Waveform or Waveform_MeasTiming): - Disable Does not show "PatternValidation Data Display".
ExecutionMode	Choice of "Execution Mode" - Run Vector Measurement is made with the WGFMU/RSU - Pattern Validation Used to check the Vector Data created to Run WGFMU/RSU. Can be executed without running the B1500A.

Measurement results

The test results are displayed in the Parameter area of the PCRAM Reset-Set graph.

X-Y Plot: Measurement Parameters:

- There is no graph available.

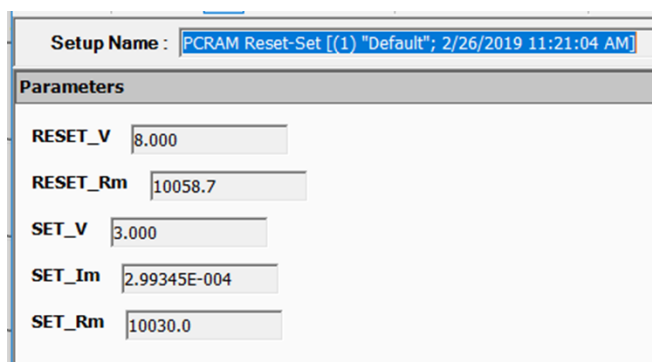
Parameters section:

The following parameters are extracted:

- RESET_V: RESET pulse V applied to the DUT.
- RESET_Rm: RESET R measured after the RESET pulse.
- SET_V: SET pulse V applied to the DUT.
- SET_Im: SET current measured at the top of the SET pulse.
- SET_Rm: SET R measured after the SET pulse.

Output example:

Figure 2-33 shows an example measurement output of PCRAM Reset-Set application test. 10 k Ω resistor is used as the DUT in the example measurement and its measured value is shown in the RESET_Rm and SET_Rm parameters. SET_Im parameter is the current measured at the top of the SET pulse.



The screenshot displays a software window titled "PCRAM Reset-Set [(1) 'Default'; 2/26/2019 11:21:04 AM]". Below the title bar is a section labeled "Parameters" containing five input fields with their respective values:

Parameter	Value
RESET_V	8.000
RESET_Rm	10058.7
SET_V	3.000
SET_Im	2.99345E-004
SET_Rm	10030.0

Figure 2-33. Output example of PCRAM Reset-Set Application Test.

○ PCRAM Endurance

General description of the PCRAM Endurance Application Test

This application test performs an endurance repeat test for RESET - SET pulse sequence. The test is executed as double loop cycles as shown in Figure 2-34, with a large loop (blue circle) including fatigue characterization (right side of the figure) after the short loop (red circle) stress cycles which only applies RESET-SET pulses from the PGU. The fatigue characterization measurement in the large loop measures the degree of the fatigue of the RESET - SET parameters at the specified logarithmic timing per decade base.

The pulse top width (SET_Im_TopWidth) used for SET characterization in the right side of the figure is much longer than the actual pulse used in the PCRAM memory, in order to obtain the accurate SET current. However, in the PGU stress cycle shown in the left side short circle, the pulse-top width (SET_TopWidth) for the SET can be set much shorter than for the RSU's which measures the SET current. Because of this, the pulse-top width for the PGU and the RSU are designed with different parameter names "SET_TopWidth" for PGU and "SET_Im_TopWidth" for RSU characterization, hence the total test time can be minimized.

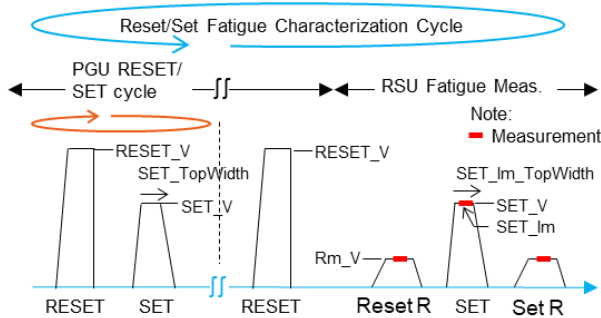


Figure 2-34. PCRAM Endurance test double cycles.

Measurement parameter setup

Follow the next steps to measure the PCRAM fatigue characteristics using the PCRAM Endurance application test.

Step 1: Assign Measurement modules

The measurement module setup is the same as the PCRAM ResetV-Loop application test. Refer to the measurement module setup of the PCRAM ResetV-Loop section and Figure 2-28.

Step 2: Set Waveform output parameters

Set the following test parameters as shown in Table 2-52 for RESET/SET and Table 2-53 for resistance measurement voltage, by referring to the parameters shown in Figure 2-34.

Table 2-52. Waveform output setup - RESET / SET output parameters.

Parameter	Description
RESET_V	RESET pulse voltage.
RESET_Tr	Rise time of the RESET pulse.
RESET_Tf	Fall time of the RESET pulse.
RESET_TopWidth	Top width of the RESET pulse.
DelayTime	Delay Time
SET_V	SET voltage.
SET_Tr	Rise time of the SET pulse.
SET_Tf	Fall time of the SET pulse.
SET_TopWidth	Top width of the SET pulse.
SET_Im_TopWidth	op width of the SET pulse of RSU (Characterization phase).

Note: "DelayTime" is the time before the start of the SET and RESET pulses.

Table 2-53. Waveform output - R Measure parameter.

Parameter	Description
Rm_V	R measurement voltage after the SET & RESET pulse.

Step 3: Set Measurement parameters

Set the following parameters by referring to Table 2-54 for endurance timing setup, Table 2-55 for resistance R measurement setup and Table 2-56 for SET parameter measurements.

Table 2-54. Measurement - Endurance parameters.

Parameter	Description
Max_loops	Maximum loops of the endurance test. The RESET_SET waves are repeated, and PCRAM characterizations are made in the specified log interval.
Fatigue_C_dec	Number of fatigue measurements in one decade of endurance stress cycle.

Table 2-55. Measurement parameters - R Measure.

Parameter	Description
RESET_Rm_ImRange	Current range of RSU_Im used to measure R after the RESET pulse.
SET_Rm_ImRange	Current range of RSU_Im used to measure R after the SET pulse.
Rm_AveragingTime	Averaging time to measure SET_R & RESET_R.
Rm_DelayTime	Delay time between the start of the Rm pulse and the start of the R measurement.

Table 2-56. Measurement parameter - SET.

Parameter	Description
SET_Im_range	Current range of RSU_Im (Im RSU), used in the SET pulse stage to measure the SET current.

Step 4: (Optional) Set Extended Test Parameters

In addition to the parameters shown in the GUI panel, you can setup the following extended parameters shown in Table 2-57 by pressing the "Extended Setup ..." button. The location of the button is shown in Figure 2-8.

It is not usually necessary to change these parameters.

Table 2-57. Extended parameter setup.

Parameter	Description
SET_Im_Averaging Time	Averaging time to measure SET current. Averaging time must be shorter than "SET_TopWidth".
SetIm_DelayTime	Delaytime between start of SET pulse and the start of SET_Im measurements. (SET_Im_DelayTime - SET_Tr + AveragingTime <= SET_TopWidth) must be met.
Stop_by_ResetR	Flag if to terminate the endurance test. - "NO" does not terminate. - "Over" terminates when the RESET R exceeds the "Stop_ResetR". - "Down" does when the R decreases the "Stop_ResetR".
ResetR_to_Stop	R value to determine the "Stop_by_ResetR" condition.
Stop_by_SetR	Flag if to terminate the endurance test. - "NO" does not terminate. - "Over" terminates when the SET R exceeds the "Stop_SetR". - "Down" does when the R decreases the "Stop_SetR".
SetR_to_Stop	value to determine the "Stop_by_SetR" condition.
Start_Fatigue_C	X-axis start number of the Fatigue count in the endurance test result display.
Do_PreTest	YES executes pre-RESET-SET test before starting the endurance stress cycle.
Rec_CharData	NO is recommended. "YES" saves all the intermediate characterization graph in the "Results area".
Rec_StrsData	NO is recommended. "YES" saves all the intermediate stress indication data in the "Results area".
Rm_TrTf	Rise/Fall time of R measure pulse
Vs_Irange	Current range of RSU_Vs (Vs RSU)
Vs_Irange	Current range of RSU_Vs (Vs RSU)
DataDisplay_Pattern Validation	This parameter is effective in "Run Vector" execution mode setting. - Enable shows "PatternValidation Data Display". (Waveform or Waveform_MeasTiming): - Disable Does not show "PatternValidation Data Display".
ExecutionMode	Choice of "Execution Mode" - Run Vector Measurement is made with the WGFMU/RSU - Pattern Validation Used to check the Vector Data created to Run WGFMU/RSU. Can be executed without running the B1500A.

Measurement results

The measurement results display several types of graphs including intermediate measurement result and stress data. This data can be saved in the EasyEXPERT data base in the Results area for checking the output data or for making further test analysis, or can be deleted while the measurements are taken by setting the "Rec_CharData" and "Rec_StrsData" parameters.

The final output plots the Endurance test graph:

Plots Endurance test graph: SET R (Y1) and RESET R (Y2) vs. Fatigue count (X axis)

- X-axis: Fatigue_Count - Fatigue count in log scale
- Y1 axis: Endu_SetR - SET R plot vs. Fatigue_Count.
- Y2 axis: Endu_ResetR - RESET R plot vs. Fatigue_Count.

Parameter output:

Displays the following parameters in the Parameters area:

- Init_ResetR: Initial RESET R
- Init_SETR: Initial SET R

Output example:

The example measurement graph using a dummy test device is shown in Figure 2-35. The test example is a result of 100 M stress cycle, and the test time is less than 10 minutes. By running over night, a 10 G cycle stress cycle can be achieved.

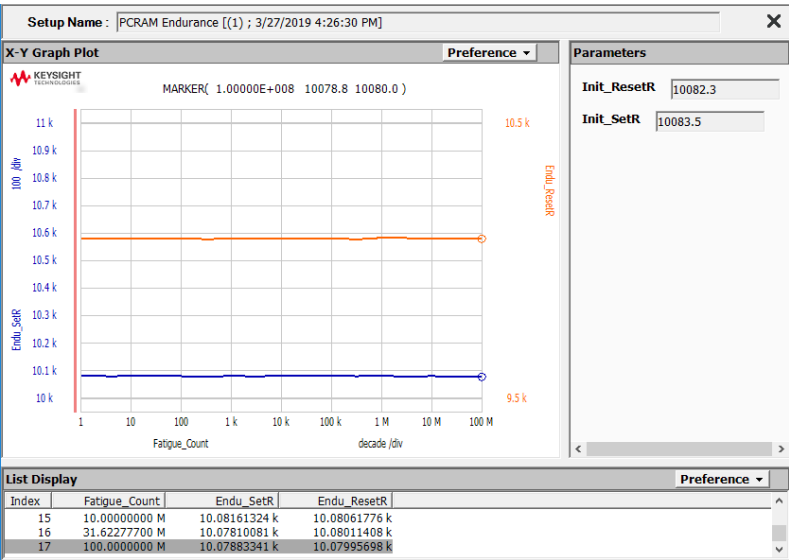


Figure 2-35. PCRAM Endurance test example (100 Mega stress cycles in less than 10 minutes).

By properly setting the " Stop_by_ R" flag and "SetR_to_Stop" or "ResetR_to_Stop" resistance value pair in the "Extended Setup...", the endurance test can be terminated at the corresponding timing of the fatigue characterization measurements.

Figure 2-36 shows such measurement examples.

Both graphs detect a 317 fatigue measurement cycle and left-side figure detects "Down" the specified resistance.

The right-side figure is a detection example of "Over" from the specified resistance.

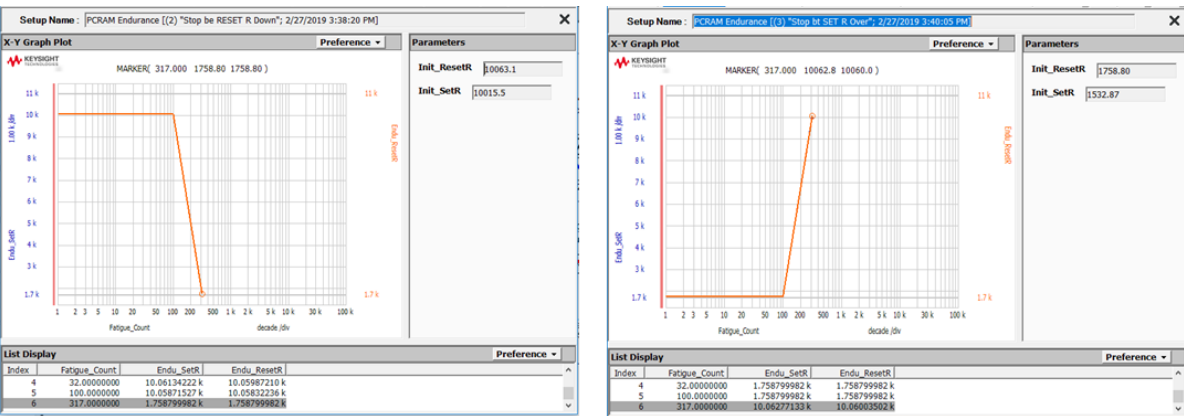


Figure 2-36. Endurance test example by "Stop by ..." condition. "Down" in right graph and "Over" in left graph.

2-3. FeRAM

2-3-1. What is an FeRAM test?

The memory cell of an FeRAM or Ferro-electric RAM is basically a capacitor construction, and the dielectric material uses the electric polarization characteristics of the ferroelectric materials. The polarization characteristics or hysteresis of QV curve of ferroelectric capacitor depends on many factors such as the ferroelectric materials, dimension or thickness, temperature, stress cycles, and so on. Because of this, hysteresis characterization is essential for FeRAM testing.

In addition, a so called PUND test shows the basic characteristics or performance as the FeRAM memory cell. Finally, the endurance test, which is basically the repetition of the PUND test, can verify the lifetime performance of the FeRAM.

Table 2-58 summarizes the FeRAM test flow and the corresponding FeRAM application test included in the EasyEXPERT group+ Advanced NVM Application Tests.

Table 2-58. FeRAM test flow and FeRAM Application Test.

Test Flow:	FeRAM Application Test:
1. Polarization or hysteresis characteristics measurements of the ferroelectric memory cell.	• Hysteresis
2. Measure the displacement charge of each pulse edge of the memory write and erase cycle.	• PUND
3. Memory degradation in write=erase cycles.	• Endurance

2-3-2. Connection diagram

The connection diagram for FeRAM characterization is shown in Figure 2-37 where WGFMU/RSU is used as the voltage source V_s and the current measurement I_m which input voltage is fixed to 0 V.

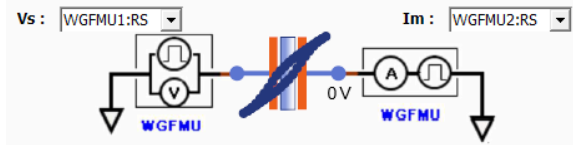


Figure 2-37. FeRAM measurement configuration.

The connection is the same for all of the FeRAM application tests introduced in the later section of this manual.

For the cable routing of the FeRAM device side, refer to the corresponding section introduced in Chapter 3.

2-3-3. FeRAM Application Tests

○ FeRAM Hysteresis

General description of the FeRAM Hysteresis Application Test

This application test performs the hysteresis characteristics measurements of the Ferro-electric material.

Triangular wave as shown in the next figure are applied and measure the displacement current flowing through the Ferro-electric material. The hysteresis charge is displayed, and the hysteresis parameters are extracted.

Triangular waveforms and parameters

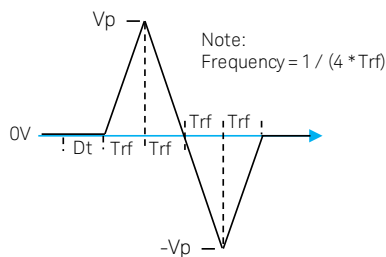


Figure 2-38. FeRAM Hysteresis waveform parameters.

Measurement parameter setup

Follow the next steps to measure the FeRAM Hysteresis characteristics using the FeRAM Hysteresis application test.

Step 1: Assign Measurement Modules

This test uses the WGFMU - RSUs connection shown in the connection diagram section 2-3-2, Figure 2-37.

Before assigning the RSUs in the application test GUI, refer to your B1500A WGFMU-RSUs configuration and the connection with your device.

Assign the RSUs for V_s and I_m choosing from the dropdown list of the GUI by referring to your actual connection as shown in Figure 2-37, where;

- V_s : RSU channel of the V_s -Voltage source RSU.
- I_m : RSU channel of the I_m - Current measurement RSU.

Step 2: How to set the Output Waveform Parameters

Set the following test parameters shown in the next table by referring to Figure 2-38.

Table 2-59. Waveform output parameters (Vs).

Parameter	Description
Vp	Peak voltage for both + & - triangular pulse
Frequency	Frequency of the Triangular waveform.
Dt	Delay time. Only set in the beginning of the test wave.

Note: "Dt (Delay time)" is not set during the repeat triangular waves.

Step 3: Set Measurement & Display Parameters

Set the following test parameters shown in the next table.

Table 2-60. Measurement and display parameters.

Parameter	Description
Meas_Points	Total measurement points. Multiples of 4 are required for assigning the same sampling data points for the 4 slopes of the double triangular waveforms.
IrangeIm	Current range of the Im RSU
Display_Mode	Output data choice of the output display.
- Charge	Displays charge vs. voltage x-y graph
- ChargeAndCurrent	Displays charge(Y1) and current(Y2) vs. voltage x-y graph
- ChargeAndCapacitor	Displays charge(Y1) and capacitor(Y2) vs. voltage x-y graph

Step 4: (Optional) Set Extended Test Parameters

In addition to the parameters shown in the GUI panel, you can setup the following extended parameters as shown in Table 2-61 by pressing the "Extended Setup ..." button. The location of the button is shown in Figure 2-8.

It is not usually necessary to change these parameters.

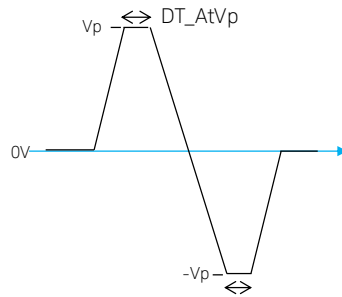
Table 2-61. Extended parameter setup.

Parameter	Description
Dt_AtVp	Put a delay time at the top of the Vp before the start of the next slope. If "0 ns", the next measurement point is the 2nd points of the next slope.
Freq_WarningP	Frequency range warning percent limit.
Repeat	Assign the repeat of the double triangular waveforms. Maximum 10 repeats can be possible.
IV_CurvePosition	Specified number is used when plotting the IV curve when the triangular waveform is repeated.
IrangeVs	Output current range of the Vs.
DataDisplay_Pattern Validation	This parameter is effective in "Run Vector" execution mode setting.
- Enable	shows "PatternValidation Data Display". (Waveform or Waveform_MeasTiming):
- Disable	Does not show "PatternValidation Data Display".
ExecutionMode	Choice of "Execution Mode"
- Run Vector	Measurement is made with the WGFMU/RSU
- Pattern Validation	Used to check the Vector Data created to Run WGFMU/RSU. Can be executed without running the B1500A.

Note:

- "Dt_AtVp" parameter: Refer to the next figure where the "Dt_AtVp" is inserted.

Optional triangular waveform parameters: Dt_AtVp



- "Freq_WarningP" parameter: what is this parameter?

Actual measurement frequency is determined by the minimum sampling interval (10 ns) and the total sampling points in a waveform. Therefore, there is only a limited frequency available in a certain frequency range.

Because of this, the software calculates the closest frequency which does not exceed the user specified frequency.

If the calculated frequency is within the "Freq_WarningP" % range of the user specified frequency, the test is executed automatically using the calculated frequency.

If the calculated frequency exceeds this warning percentage, a message is displayed asking the user if the test can be executed.

Example "Freq_WarningP = 10": If the difference between the user specified frequency and the actual frequency calculated by the software is more than 10%, a warning message pops up. The user can then decide whether or not to continue with the proposed frequency from the software, or re-do the test with different parameters for better parameter matching.

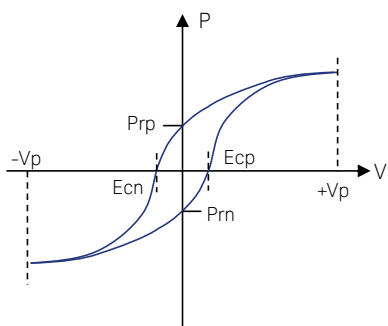
Measurement results

There are three measurement options for the X-Y Plot output/measurement parameters as follows:

- Charge vs. voltage x-y graph:
Extracted parameters:
 - Frequency_kHz: Frequency used for the measurements.
 - Prp, Prn, Ecp, Ecn
- Charge and current vs. voltage x-y graph:
Extracted parameters:
 - Frequency_kHz: Frequency used for the measurements.
 - Prp, Prn, Ecp, Ecn
- Charge and capacitor vs. voltage x-y graph:
Extracted parameters:
 - Frequency_kHz: Frequency used for the measurements.
 - Prp, Prn, Ecp, Ecn

The extracted parameters are shown in the next graph.

Extracted Parameters



Output example:

Figure 2-39 shows an example measurement output of an FeRAM Hysteresis application test. The capacitance of the sample device is about 2.2 pF in peak value and the test is made at about 200 kHz.

There are a few options in the measurement display in the Y axis from the following parameters:

- Charge
- Current
- Capacitance

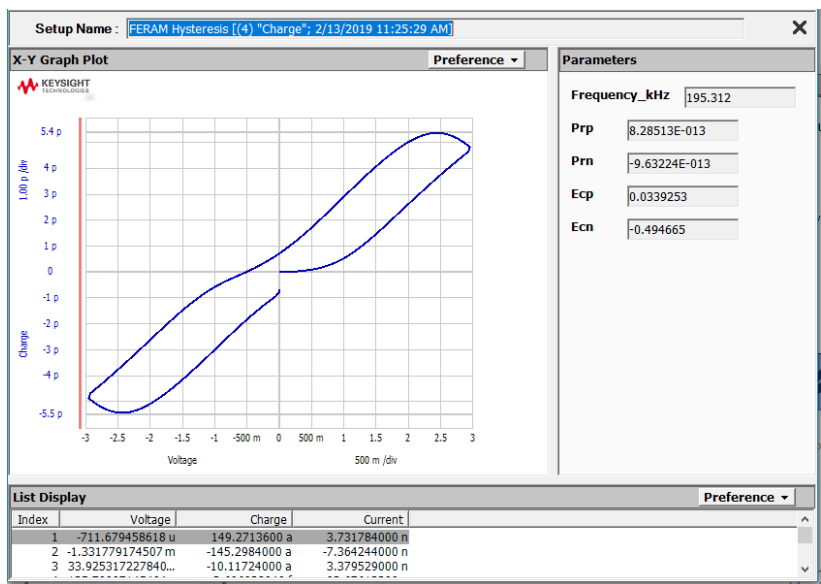


Figure 2-39. FeRAM Hysteresis measurement example (Charge in Y axis).

○ FeRAM PUND

General description of the FeRAM PUND Application Test

This application test performs the FeRAM PUND characteristics measurements of the FeRAM cell of the Ferro-electric material.

The PUND waveforms shown in the next figure are applied to the test device and measure the displacement current through the Ferro-electric capacitor cell.

The applied voltage, current and charge are displayed with the extracted PUND parameters.

PUND waveform parameters

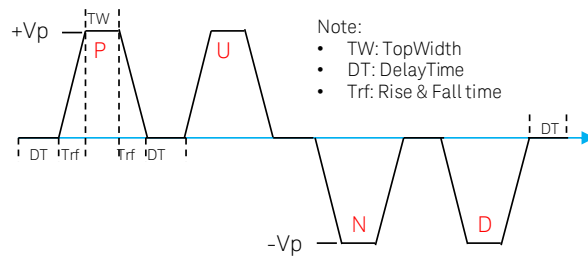


Figure 2-40. FeRAM PUND waveform parameters.

Measurement parameter setup

Follow the next steps to measure the FeRAM PUND characteristics using the FeRAM PUND application test.

Step 1: Assign Measurement Modules

This test uses the WGFMU - RSUs connection shown in the connection diagram section 2-3-2. Refer to the measurement module setup of the FeRAM Hysteresis section and Figure 2-37.

Step 2: How to set Output Waveform Parameters

Set the following test parameters as shown in the next table by referring to Figure 2-40.

Table 2-62. Waveform parameters (Vs).

Parameter	Description
Vp	Peak voltage for both + & - triangular pulse
Trf	Rise time (Tr) and Fall time (Tf)
TopWidth	Pulse top width
DelayTime	Delay time. Only set in the beginning of the test wave.

Note: "DelayTime" is not set between the repeat triangular wave.

Step 3: Set Measurement parameters

Set the following parameters by referring to the next table.

Table 2-63. Measurement(I_m) parameters.

Parameter	Description
I _{rangeIm}	Current range of the I _m RSU

Step 4: (Optional) Set Extended Test Parameters

In addition to the parameters shown in the GUI panel, you can setup the following extended parameters as shown in Table 2-64 by pressing the "Extended Setup ..." button. The location of the button is shown in Figure 2-8.

It is not usually necessary to change these parameters.

Table 2-64. Extended parameter setup.

Parameter	Description
Sampling_interval	Minimum sampling interval used for obtaining the proper test parameters for RSU. - "Trf/Sampling interval >10" are required.
Display_Mode	Output data selection of the output display.
- Charge	Displays charge vs. time x-y graph
- ChargeAndCurrent	Displays charge(Y1) and current(Y2) vs. time x-y graph
I _{rangeVs}	Output current range of the Vs.
DataDisplay_Pattern Validation	This parameter is effective in "Run Vector" execution mode setting.
- Enable	shows "PatternValidation Data Display". (Waveform or Waveform_MeasTiming):
- Disable	Does not show "PatternValidation Data Display".
ExecutionMode	Choice of "Execution Mode"
- Run Vector	Measurement is made with the WGF MU/RSU
- Pattern Validation	Used to check the Vector Data created to Run WGF MU/RSU. Can be executed without running the B1500A.

Measurement results

There are two measurement graphs with the X-Y Plot output/measurement parameters.

The Y axis parameters can be set by the "Display_Mode" extended parameter.

- Charge vs. Time x-y graph:
 - X axis: Time
 - Y axis: Charge
 - Extracted parameters:
 - ChargeP, ChargeU, ChargeN, ChargeD, ChargePa, ChargeUa, ChargeNa, ChargeDa.
- Charge and current vs. Time x-y graph:
 - X axis: Time
 - Y axis: Charge and current
 - Extracted parameters:
 - ChargeP, ChargeU, ChargeN, ChargeD, ChargePa, ChargeUa, ChargeNa, ChargeDa.

Output example:

Figure 2-41 and Figure 2-42 show the example measurement outputs from the FERAM PUND application test.

The DUT is a 10 pF capacitor which is suitable to show the PUND characteristics.
Figure 2-41 shows an example at $T_r=T_f=100$ ns and pulse $TopWidth=200$ ns.
Figure 2-42 is an example for slow rise and fall time of 1 μ s. It clearly shows the displacement current of the T_r and T_f slope.
The PUND charges displayed in the Parameter field example are reasonably accurate.

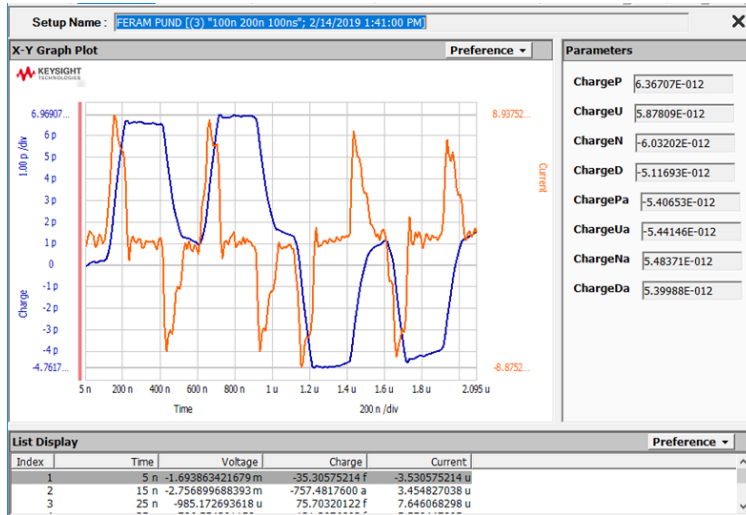


Figure 2-41. FERAM PUND ($T_r=T_f=100$ ns, $TopWidth=200$ ns) example

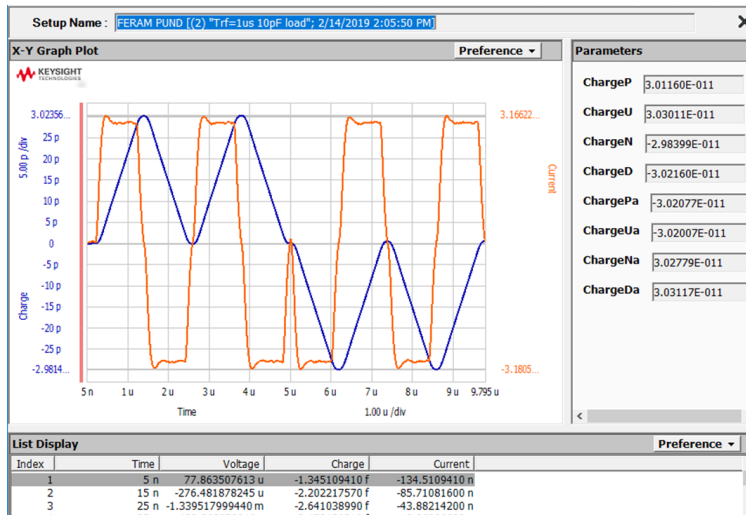


Figure 2-42. FERAM PUND ($T_r=T_f=1$ μ s, $TopWidth=200$ ns) example.

○ FeRAM Endurance test

General description of the FeRAM Endurance Application Test

This application test performs stress/measure cycle endurance repeat tests for user specified PUND pulse sequences as shown in Figure 2-43.

The test repeats the PUND waveform stress cycles until the specified fatigue characterization measurement timing where the PUND parameters are measured. The fatigue characterization measurement is made in the specified numbers of per decade base.

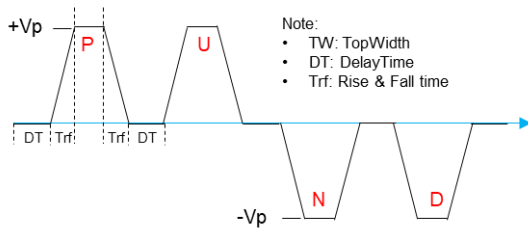


Figure 2-43. FeRAM Endurance test: PUND waveform.

Measurement parameter setup

Follow the next steps to measure the fatigue characteristics of FeRAM using the FeRAM Endurance application test.

Step 1: Assign Measurement Modules

This test uses the WGFMU - RSUs connection shown in the connection diagram section 2-3-2. Refer to the measurement module setup of the FeRAM Hysteresis section and Figure 2-37.

Step 2: Set the Output Waveform Parameters

Set the following test parameters as shown in the next table by referring to Figure 2-43.

Table 2-65. Waveform parameters (Vs).

Parameter	Description
Max_loops	Maximum loops of the endurance test.
Vp	Peak voltage for both + & - triangular pulse
Trf	Rise time (Tr) and Fall time (Tf)
TopWidth	Pulse top width
DelayTime	Delay time. Only set in the beginning of the test wave.

Note:

- "Max_loops": The Figure 2-43 waveforms are repeated for fatigue repeat cycles.
- "DelayTime" is not set between the repeat triangular wave.

Step 3: Set Measurement parameters

Set the following parameters by referring to the next table.

Table 2-66. Measurement - Endurance parameters.

Parameter	Description
Fatigue_C_dec	Specify the number of fatigue measurements in one decade of endurance stress cycle.
Sampling_Interval	Sampling interval in the fatigue PUND test to measure the PUND charge. - "Trf/Sampling interval >10" are required.
Irangelm	Current range of the Im RSU

Step 4: (Optional) Set Extended Test Parameters

In addition to the parameters shown in the GUI panel, you can setup the following extended parameters shown in Table 2-67 by pressing the "Extended Setup ..." button. The location of the button is shown in Figure 2-8.

It is not usually necessary to change these parameters.

Table 2-67. Extended parameter setup.

Parameter	Description
Start_Fatigue_C	X-axis start number of the Fatigue count in the endurance test result display.
Rec_CharData	NO is recommended. "YES" saves all the intermediate characterization graph in the "Results area".
Rec_StrsData	NO is recommended. "YES" saves all the intermediate stress indication data in the "Results area".
DataDisplay_Pattern Validation	This parameter is effective in "Run Vector" execution mode setting. - Enable shows "PatternValidation Data Display". (Waveform or Waveform_MeasTiming); - Disable Does not show "PatternValidation Data Display".
ExecutionMode	Choice of "Execution Mode" - Run Vector Measurement is made with the WGF MU/RSU - Pattern Validation Used to check the Vector Data created to Run WGF MU/RSU. Can be executed without running the B1500A.
Irangle_Vs	Output current range of the Vs RSU.

Measurement results

The following two X-Y Plot graphs are output.

- FERAM Psw Qsw endurance graph:
 - X axis: Fatigue_Count
 - Y1 axis: Psw charge
 - Y2 axis: Qsw charge
- FERAM PUND endurance graph
 - X axis: Fatigue_Count
 - Y axis: Charge_P (Y1), Charge_U (Y2), Charge_N (Y3), Charge_D (Y4), vs. Fatigue_Count (X)

Note: To access to the Psw and Qsw measurement graphs from the Results area, you must expand Application Test Results because the data is saved behind the main application test name.

To expand the Application Test Results, refer to Figure 2-17.

Output example:

The next figures show example measurement outputs of FERAM Endurance application tests.
The DUT is a fixed capacitor.

Figure 2-44 is an example of a PUND charge endurance graph for 100 M cycles.

Figure 2-45 is the same measurement for Psw and Qsw data.

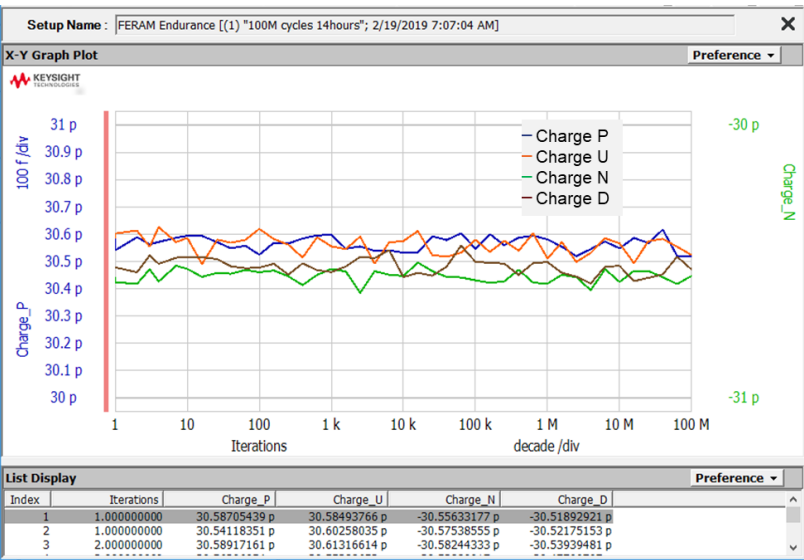


Figure 2-44. PUND 100 M cycle endurance test example for Charge characteristics.

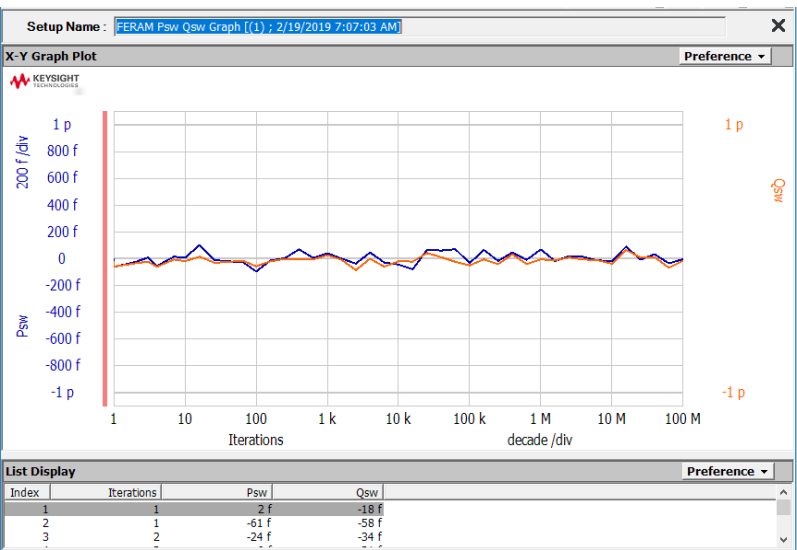


Figure 2-45. PUND 100 M cycle endurance test example for Psw and Qsw.

3. Appendix

The appendix section describes the following information.

Tips for device connection 77

How to connect the discrete device 77

How to connect the on-wafer device 78

Current limit (optional) control operation 80

Tips for accurate measurement (Avoiding the charge current effect) 83

Importing the Advanced NVM Application Tests to the existing Workspace 85

The installation order of the Advanced NVM Application Test library 86

How to install the ReRAM Application Test 87

3-1 Tips for device Connection

3-1-1. How to connect the discrete device

Before connecting the test device (DUT), turn the B1500A off and disconnect the cables from the RSU (Remote Sense/Switch Unit). For the installation of the RSU, see [Keysight B1530A User's Guide](#). Connect the DUT using the SMA(m)-SMA(m) cables as shown in Figure 3-1 below. Use the SMA connector at the RSU side. The DUT side connection depends on the DUT interface.

Please note that the outer shield of the coax cables must be connected at the DUT connection points. In the example as shown in Figure 3-1, the outside metal of the SMA connectors either side of the DUT must be connected.

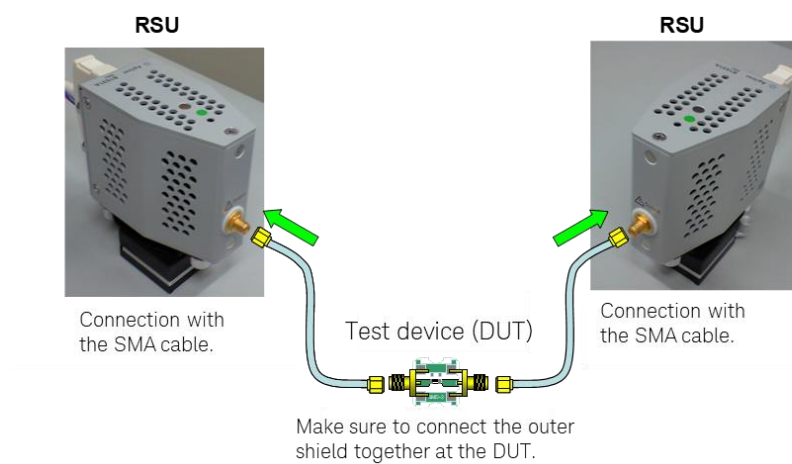


Figure 3-1. Connection example of a discrete device.

3-1-2. How to connect the on-wafer device

A prober and manipulators are required for on-wafer measurements.

Figure 3-2 shows the DC probes examples for connecting the two terminal DUT. Use the Keysight 16493R-202 SSMC(Plug)-SMA(m) cable to connect the RSU and the DC probe.

Make sure to create the current return path by using a connecting cable between the shields of the DC probes as shown in Figure 3-2. The connection cable will be provided by the prober vender. Alternatively, you can use an alligator clip cable.

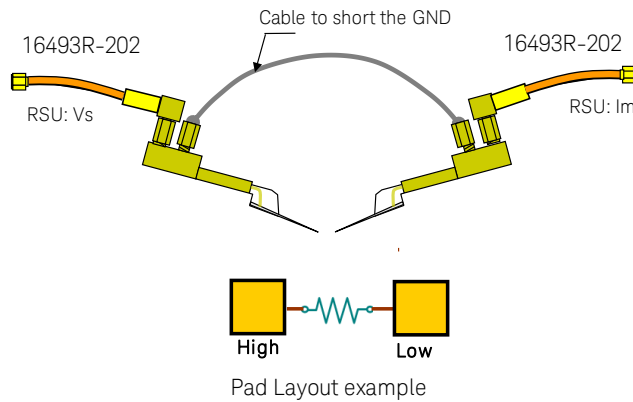


Figure 3-2. Current return path by shorting manipulator GND.

3-pads ReRAM current limit connection:

In case the current limit transistor is layout on a wafer, the next example shown in Figure 3-3 can be useful. When using the SMU as the gate source of the current limit transistor, convert the SMU output from the triaxial to the coaxial as shown in in Figure 2-3. The SMU Vg bias voltage is a pure DC and it is not necessary to consider the current return path for the SMU.

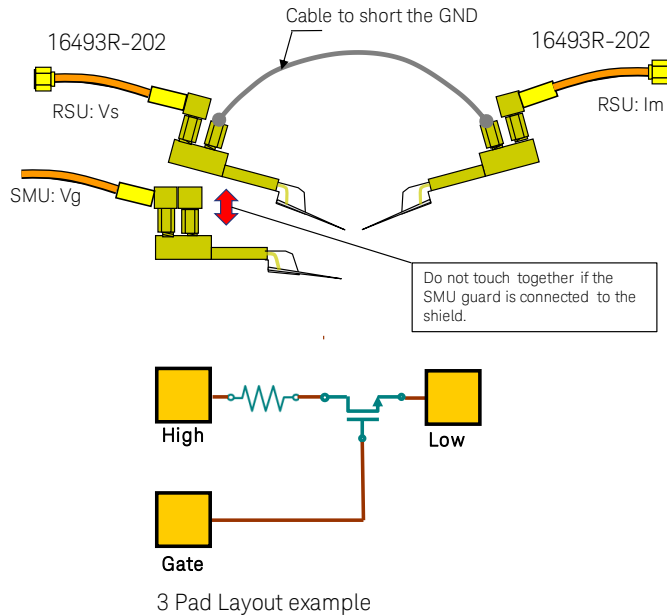


Figure 3-3. 3 pad connection example for ReRAM current limit option.

Warning:

If the outer shield of the manipulator used for the gate bias is connected to the SMU guard, do not connect its outer shield to other manipulator's shields that are connected to the WGFMU/RSU. This may damage the WGFMU/RSU.

3-2 Current limit (optional) control operation

The current limit device or transistor located besides the ReRAM resistor device can reduce the excessive transient current flowing through the ReRAM resistor when the resistor sharply changes in the RESET - SET transition timing.

Using this optional current limit setup can eliminates the excessive transient discharge current flowing from the capacitance component of the measurement cables and the test equipment, resulting in more accurate test results.

Note: The current limit device must be prepared by the user side. To effectively limit the current, the stray capacitor between the RERAM resistive device and the current limit transistor must be as small as possible.

Figure 3-4 shows a more detailed connection diagram with the cable capacitor C_s in the V_s side and the electric signs to explain the effect of inserting the current limit transistor.

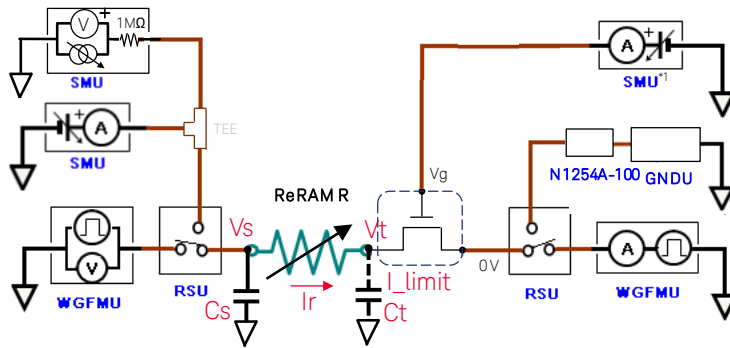


Figure 3-4. Stray components of the ReRAM measurement system.

1. Case study: The SMU current compliance is ideally fast?

Let's consider if the SMU compliance is ideally fast and suitable for ReRAM breakdown characterization? Let's consider for example, the Vs cable length is 2 m and the stray capacitance Cs between the center conductor and the outer shield is 200 pF. Suppose the ReRAM resistor changes from 100 kΩ to 1 kΩ in the SET transition at 3 V SET voltage.

In the case where there is no current limit transistor, a large initial current 3 mA ($= 3\text{ V} / 1\text{ k}\Omega$) flows when the ReRAM resistor turns on because the current is supplied by the charge stored in the Cs capacitor. The time constant set by the Cs 200 pF and 1 kΩ ReRAM ON state resistor is 200 ns ($= 200\text{ pF} \times 1\text{ k}\Omega$), and the current flowing through ReRAM resistor (I_r) can be drawn as shown in Figure 3-5.

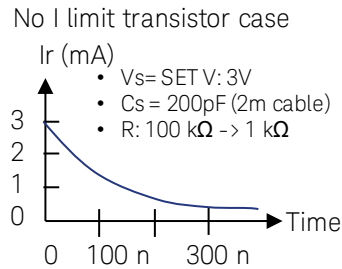


Figure 3-5. Simulation of the rush current flowing through the ReRAM resistor.

Suppose if the SET current is limited to $100\text{ }\mu\text{A}$, the 3 mA initial current is too large, and it may damage or degrade the device.

By adding the current limit transistor beside the ReRAM resistor, the current can be limited effectively fast because the stray capacitance C_t of the current limit transistor can be minimized to a greater degree than the cable capacitance C_s .

2. Case study: combining the SMU and the external current limit transistor.

There are two good points when combining the SMU and the current limit transistor which resides close to the ReRAM resistor.

Both devices have their good and bad points which complement each other as follows:

1. The current compliance of the SMU is accurate, but slow in response.
2. The current limit transistor is fast, but current limit accuracy is poor.

The SMU's current compliance can limit the current flowing to the device even when the resistance changes under the relatively slow transition condition, say 10's micro seconds range at the fastest. It means that the 3 mA SET current continues to flow until the current compliance effectively settles in the compliance current. Using a current limit device which reside very close to the ReRAM resistive device or is built into the test structure can rapidly limit the current. Therefore, by combining these current limit devices as shown in Figure 3-4 can rapidly limit the current in the transient, and set the accurate current limit when the SMU settles in the steady state as shown in Figure 3-6 below.

Appendix

Current limit (optional) control operation

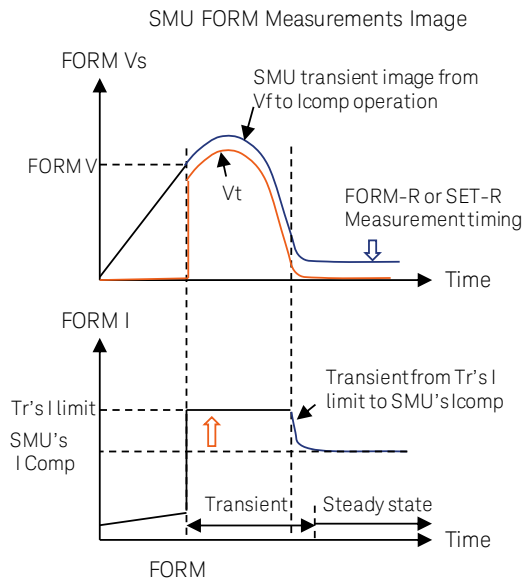


Figure 3-6. The voltage and current waveforms combined with the SMU's current compliance and the current limit transistor.

By setting the Current limit level of the limit transistor at a slightly larger level than the SMU compliance, the current compliance of the SMU takes over the current limit capability when the SMU returns to a steady operating condition as shown in Figure 3-6.

In this way, the current limit configuration shown in Figure 3-4 can be effectively used for the ReRAM device which has a local current limit device and control input.

Note: Do not set the Tr's current limit setting any lower than the SMU I compliance. If you do, the Tr's current limit becomes effective even in the stable state after the transition, and SMU's I compliance does not work effectively. As a result, the V_t voltage (current limit Tr's drain-source voltage) changes as the V_s voltage increases, and the voltage between the ReRAM resistor cannot be measured from the V_s side.

3-3 Tips for accurate measurement (Avoiding the charge current effect)

NVM characterizations such as ReRAM and FERAM intensively uses the DUT current while the test signal is slewing in the pulse rise and fall timing. Figure 3-7 shows the basic NVRAM measurement block diagram where ch1 WGFMU sources test voltage. It is very important to use the correct WGFMU for current measurement.

If the pulse source WGFMU (Ch2 of Figure 2-4) 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 (i_c) additionally to the current which flows through the DUT, but Ch2 measures only the current through the DUT. It is, therefore important to use the constant voltage source WGFMU (Ch2 of Figure 2-4) for the current measurement.

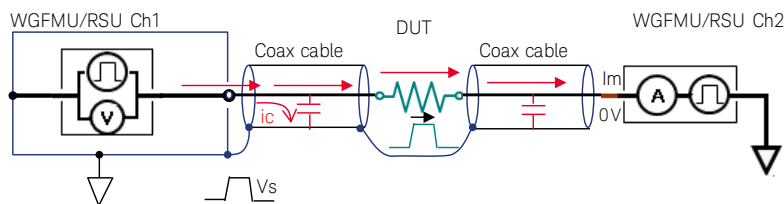


Figure 3-7. Effect of the cable-charge current.

Figure 3-8 shows the measured current by both the WGFMU-Ch1 and the WGFMU-Ch2 of Figure 3-7. On the Ch1 current waveform, two large transient current blocks are observed both at the rising edge and falling edge of the V_s pulse. 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 also measured. In contrast, the current waveform measured by the WGFMU-Ch2, with an output applied at constant zero volts, shows proportionally the same rising / falling slope of V_s as the current flowing through the DUT because there is no additional current to charge or discharge the cables.

Appendix
Tips for accurate measurement (Avoiding the charge current effect)

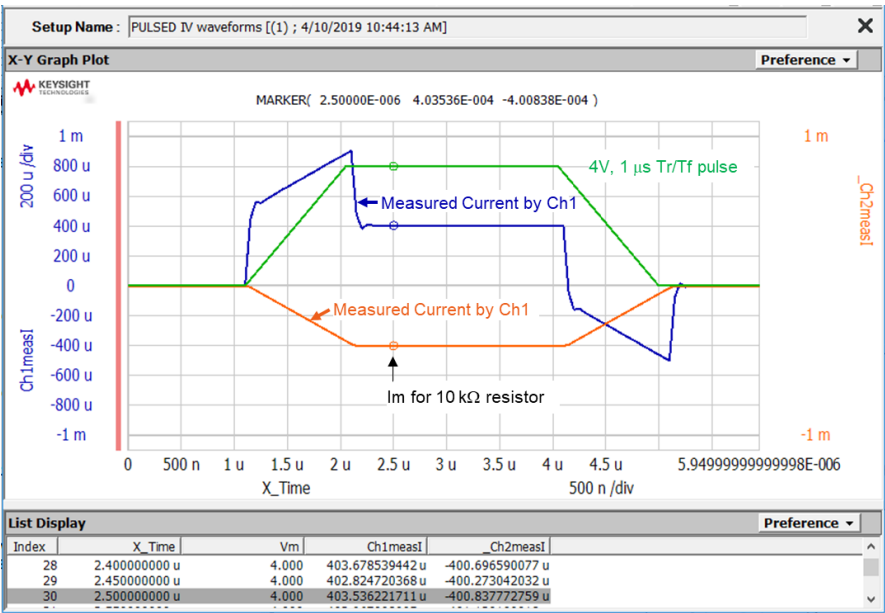


Figure 3-8. Measurement example of a cable-charge current.

Note: The shorting of the shield of the two measurement cables in the DUT side is very important to achieve the accurate measurement results as demonstrated. Since the short of the shields at both sides of the DUT has a role in returning the high speed measurement current flowing through the DUT to the Vs side through the shield line, it is considered a part of the DUT. Do not forget to connect them!

3-4 Importing the Advanced NVM Application Tests to the existing Workspace

Advanced NVM Application Tests of the EasyEXPERT group+ software are available from the Revision 6.2 and you can use them by upgrading the EasyEXPERT software. However, the new Advanced NVM Application Tests are only installed in new Workspace. This section introduces how to install the Advanced NVM Application Tests to your existing Workspace.

How to install the Application Test:

You can install the Advance NVM application Test from the following Windows "Program Files (x86)" folder as shown in Figure 3-9.

Note: By default, the files under the Windows system folder area are often hidden and cannot be seen by the user. To access to the specific files described in this section, you may need to change the File Explore setting.

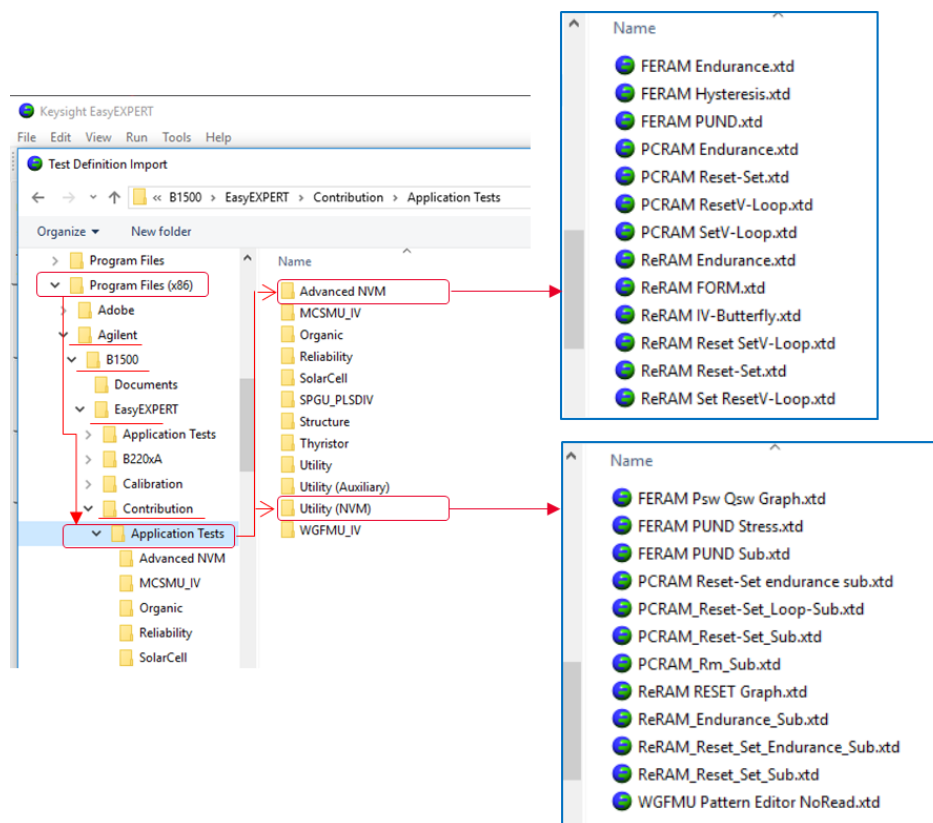


Figure 3-9. Advanced NVM Application Test folder link.

Access the following Windows folder link:

C: Program Files (x86) -> Agilent -> B1500 -> EasyEXPERT -> Contribution -> Application Tests -> then Advanced NVM and Utility (NVM) folder.

The application tests in the Utility (NVM) folder are the sub programs taken from the other NVM application tests.

The following sections describe how to install each group of the Advanced NVM Application Test.

3-4-1 The installation order of the Advanced NVM Application Test library

Installation order:

The NVM Application Tests must be installed in a specific order. This is because the tests are made by sub-programs or Application Test routines taken from other Application Tests. It is therefore necessary to install them before the installation of the parent program.

Table 3-1 shows the installation order for each NVM group.

First, the installation is made from the Application Test in the "Library" field of the "Utility (NVM) category..." of the EasyEXPERT by following the installation order shown as "1st and 2nd" columns shown in Table 3-1.

Second, the Application Test in the "Advanced NVM Category..." is installed by following the order shown as "3rd and 4th" columns in Table 3-1.

Table 3-1. Advanced NVM installation order.

NVM Group	Installation order 1: Utility (NVM) Category ...		Installation order 2: Advanced NVM Category ...	
	1st	2nd	3rd	4th
ReRAM	ReRAM RESET Graph WGFMU Pattern Editor NoRead	ReRAM_Endurance_Sub ReRAM_Reset_Set_Endurance_Sub ReRAM_Reset_Set_Sub	ReRAM IV-Butterfly ReRAM FORM ReRAM Set ResetV-Loop ReRAM Reset SetV-Loop ReRAM Reset-Set ReRAM Endurance	
PCRAM	PCRAM_Reset-Set_Sub	PCRAM Reset-Set endurance sub PCRAM_Reset-Set_Loop-Sub PCRAM_Rm_Sub	PCRAM Reset-Set	PCRAM ResetV-Loop PCRAM SetV-Loop PCRAM Endurance
FERAM	WGFMU Pattern Editor NoRead	FERAM Psw Qsw Graph FERAM PUND Stress FERAM PUND Sub	FERAM Hysteresis FERAM PUND FERAM Endurance	

3-4-2 How to install the ReRAM Application Test

The Advanced NVM Application Test can be installed unit by unit of each NVM group.

The step by step instructions for installing the ReRAM NVM group to the existing Workspace are shown. Follow the steps below for ReRAM Installation order, 1st column of Table 3-1, by referring to the corresponding numbers as shown in the installation example at Figure 3-10.

1. Left click the "Library" button.
2. Left click on "Import ..."
Test definition Import File Explore opens,
3. Scroll to the Utility (NVM) folder, and left click opens the NVM utility Application Test program.
4. Select the "ReRAM RESET Graph" Application Test by left clicking on the file.
5. Continue to select "WGFMU Pattern Editor NoRead" Application Test by +Ctrl key and left clicking on the file.
6. Click on "Open" to install the selected Application Tests.

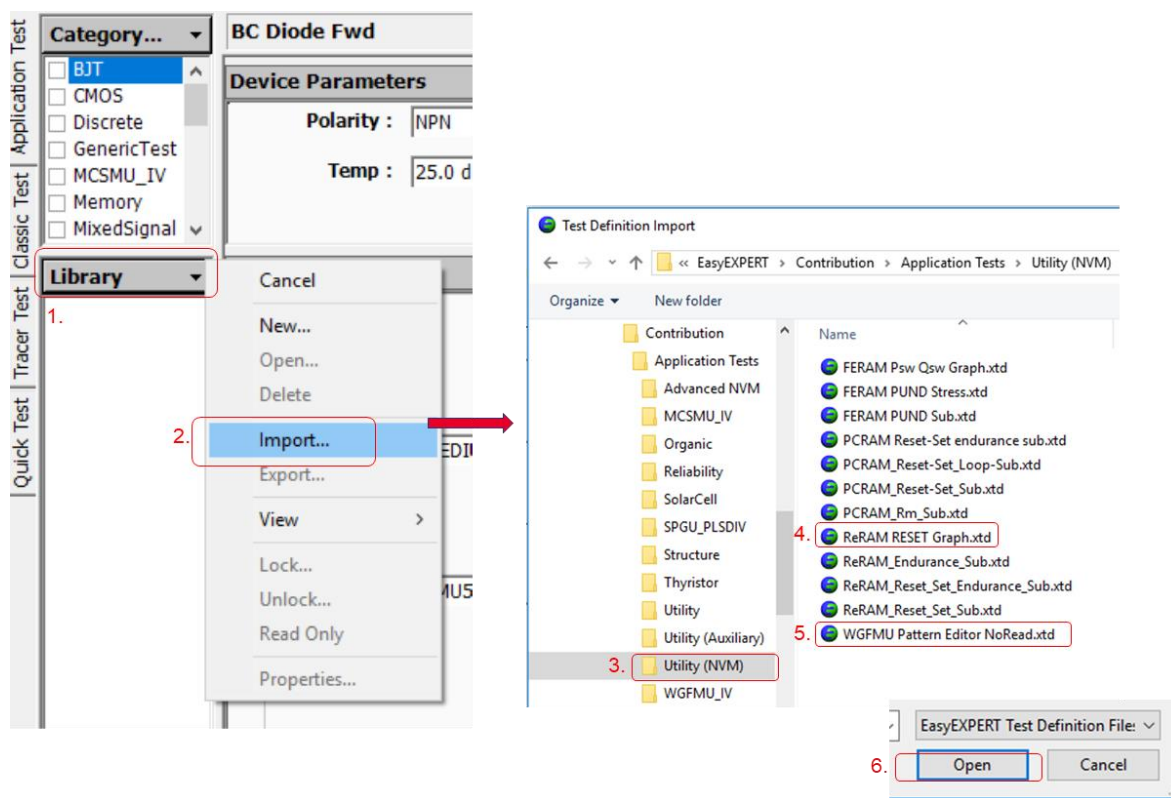


Figure 3-10. ReRAM Application Test installation example.

Repeat the same steps for ReRAM Installation order, 2nd column and Installation order 2, 3rd column of Table 3-1.

The installation of the PCRAM and FERAM can be down by doing the same way by following this example steps.

Note: If it is not possible to access the "Program files (x86)", the installation can be done in the same way by using the "Export" Library function as follows:

1. Create a new Workspace.
2. Export the necessary Application Tests to the local file folder by referring to the NVM group and Application Test list in Table 3-1.
3. Install the Application Test to the existing Workspace in the same way as shown in Figure 3-10.

This information is subject to change without notice.
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