Agilent N1267A

HVSMU/HCSMU Fast Switch

Dynamic On-Resistance Measurement in GaN FET

Agilent Technologies

Notices

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Contents

1. Introduction

1-1. Overview of dynamic on-resistance (Ron) measurement in GaN FET

The N1267A High Voltage SMU (HVSMU) / High Current SMU (HCSMU) Fast Switch is an accessory to measure dynamic on-resistance (Ron) in GaN power devices including FET and diode.

The dynamic Ron in GaN power devices is a change of the Ron after switching it from its off-state to on-state. This change of Ron has a dependency on the off-state voltage. The Ron just after switching increases along with the increase of applied drain voltage and it recovers to the normal value during its on-state.

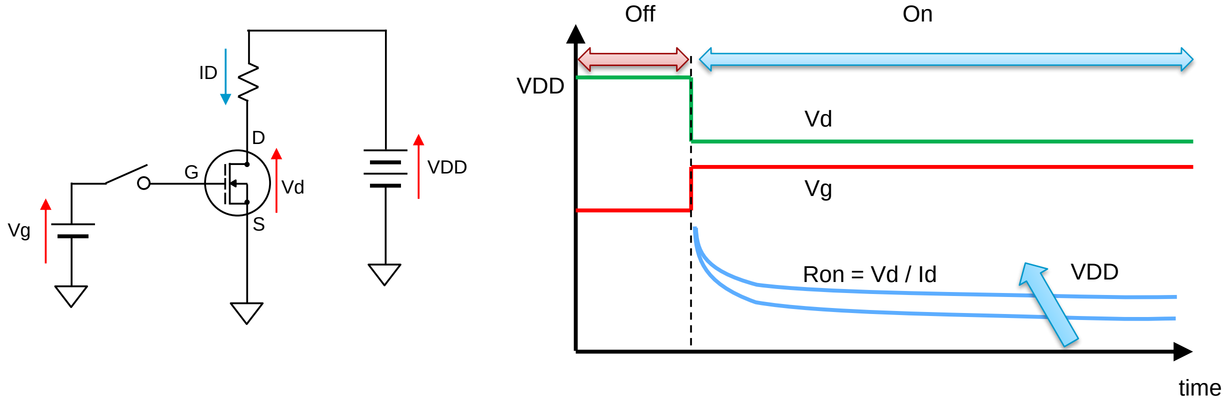


Fig. 1-1 Example of dynamic Ron change of GaN FET

This behavior is also known as a current collapse in GaN FET. The current collapse is observed as a decrease of on-current when increasing a power supply voltage (VDD) contrary to the normal expectation of increase of it.

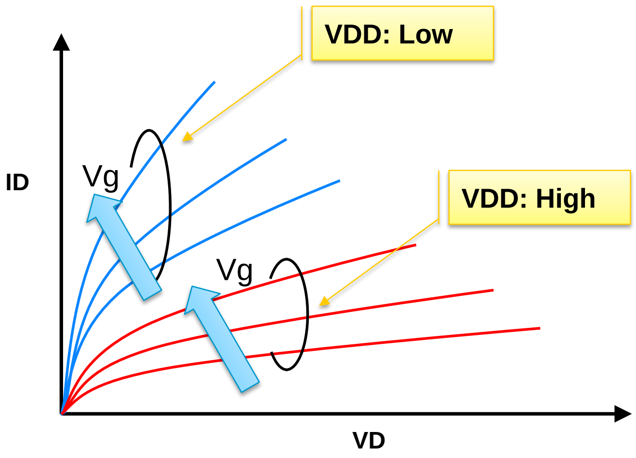


Fig. 1-2 Current Collapse of GaN FET

This decrease of on-current is caused by the higher voltage applied to the DUT during its off-state as a similar manner with the dynamic Ron behavior.

On B1505A, to measure the dynamic Ron, it is necessary to switch HVSMU and HCSMU fast enough to see the recovery of the Ron.
The HVSMU can output a maximum of 3000 V, and it is enough to apply the off-state voltage for GaN power devices (currently, a 600 V GaN power device is edging closer to practical use). But its maximum current is just 8 mA in the 1500 V range and 4 mA in the 3000 V range, and those are not enough to supply the on-current of the device normally. Also, its maximum slew rate is 0.4 V / µs and it cannot switch between the off-state and the on-state fast enough (250 µs is required to switch from 100 V to 0 V). Also, to measure the on-current of the device, HCSMU is necessary in many cases. The N1267A HVSMU/HCSMU fast switch can switch HVSMU and HCSMU synchronized with the switching of the DUT within 20 µs (min.).

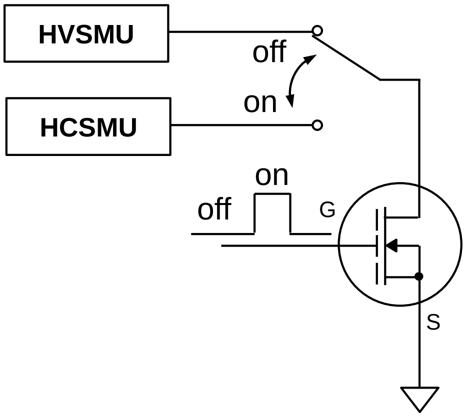


Fig. 1-3 Switching of the HVSMU and HCSMU synchronized with device

1-2. Software equipped in B1505A for GaN dynamic Ron measurement

To measure dynamic Ron and current collapse behavior, the B1505A is shipped with several application test definitions and Tracer Test presets to make it possible to start measurement easily and quickly.

Here is a list of available application tests and pre-sets of Tracer Test for this application.

Application Test Definitions
For GaN FET

- FET Current Collapse IV-t Sampling
- FET Current Collapse Signal Monitor
- FET Current Collapse IV-t Sampling (I Force)
- FET Current Collapse Signal Monitor (I Force)
- Id-Vds Current Collapse

For GaN Diode

- Diode Current Collapse IV-t Sampling
- Diode Current Collapse Signal Monitor

Preset of Tracer Test
For GaN FET

- ID-VDS
- ID(off)-VDS
- ID-VDS Current Collapse
- FET Current Collapse Oscilloscope View

For GaN Diode

- IF-VF
- IR-VR
- IF-VF Current Collapse
- Diode Current Collapse Oscilloscope View

Some of the presets for the Tracer Test mode are doing DC IV measurement to make sure the DUT to be measured is alive or dead prior to the current collapse measurement. ID-VDS, ID(off)-VDS, IF-VF and IR-VR are presets for this purpose.

Application test definitions and presets named Id-Vds Current Collapse, ID-VDS Current Collapse and IF-VF Current Collapse measure a set of Id-Vd (or IF-VF) curves after applying a stress voltage for the specified duration. By running those measurements with different stress voltages, you can observe the change of ID-VDS (or IF-VF) curves caused by the stress voltage like in figure 1-2.

Details of each application test and preset are described in section 5 and section 6. Also, you can learn the way to use them in section 4.

2. Basic Operation of N1267A HVSMU/HCSMU fast Switch

2-1. Connections and definition of terms used in Application Test Library for GaN FET or Diode Current Collapse Measurement

The N1267A HVSMU/HCSMU fast switch is used to switch HVSMU and HCSMU synchronized with the switching of the device under test (DUT) itself. But, direct switching between the HVSMU and HCSMU will cause some glitch or spike because it is switched while each module is outputting voltage or current (wet switching).

To avoid this kind of unexpected spike or glitch, N1267A employs a diode to switch between them. Figure 2-1-1 shows operations of the diode switch in the N1267A.

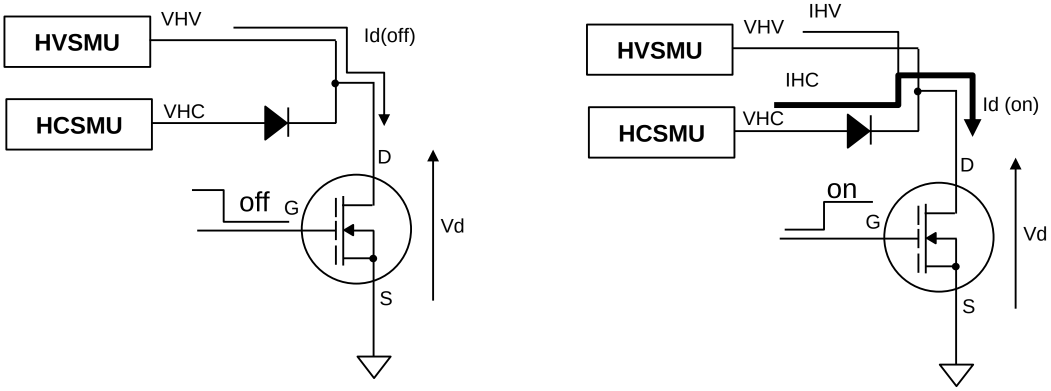


Fig. 2-1-1. How the diode switch works in N1267A

During the off-state of the device, if Id(off) is smaller than the maximum output current, the output voltage of the HVSMU is fully applied onto the DUT. During this, the output voltage of the HCSMU is set around on-state voltage of the device, and the diode switch is reverse-biased and the HCSMU is disconnected from the DUT.
When the DUT is turned on, a drain current starts flowing into the DUT as Id(on). If the Id(on) is larger than the maximum current capability, the output voltage is driven down by the DUT. And it moves into its constant current mode with its current compliance.

Once the drain voltage is driven down, the diode switch becomes forward-biased and the drain current starts flowing from the HCSMU. Of course, to push the current through the diode, the output voltage has to be larger than the forward voltage (Vf) of the diode switch.
Even if the diode switch is turned on, the HVSMU keeps outputting its maximum current too. So the drain current becomes a sum of the output current of the HCSMU (IHC) and the HVSMU (IHV). Also, the drain voltage is slightly different from the output voltage due to the forward voltage of the diode switch.

Based on the operation of the diode switch explained above, if the on-current is smaller than the maximum current of the HVSMU, the diode switch is not turned on even if the DUT is turned on. The maximum setting current of the HVSMU is 8 mA in its 1500 V range and 8 mA in the 3000 V range, but it can output around 12 mA during its transient condition between the voltage output mode and the compliance mode (constant current mode). Also, to make switching speed faster, the compliance current of the HVSMU is normally set as its maximum current value. So, if the on-current is about 12 mA or less, the diode switch does not work well.

To switch the HVSMU and HCSMU in such a situation, the N1267A has a FET switch in parallel to the diode switch of it.

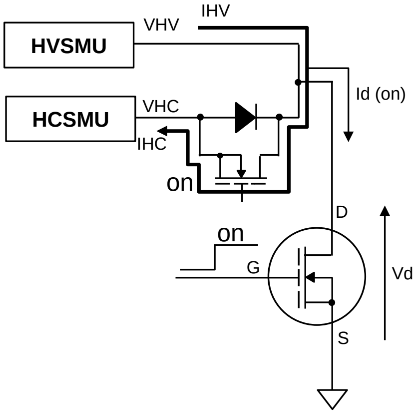


Fig. 2-1-2. FET switch used to bypass the HVSMU current for small Id(on) case

In this case, the output voltage of the HVSMU is driven down by the HCSMU, and a part of output current of the HVSMU is flowing into the HCSMU and the DUT. So, still the on-current is the sum of the IHV and IHC based on the Kirchhoff's Current Law.

This switch is also used to discharge a stray capacitance of cabling. The cabling connecting the HVSMU to the DUT has its own stray capacitance. During the off-state of the DUT, a certain amount of electrons is stored in this stray capacitance.

In the sub threshold level of the gate voltage, the drain current starts flowing into the DUT from the stray capacitance. This current is not controlled, and it covers the safe operation area of the DUT and causes damage to the DUT in some cases, especially for smaller devices (refer to figure 2-1-3).

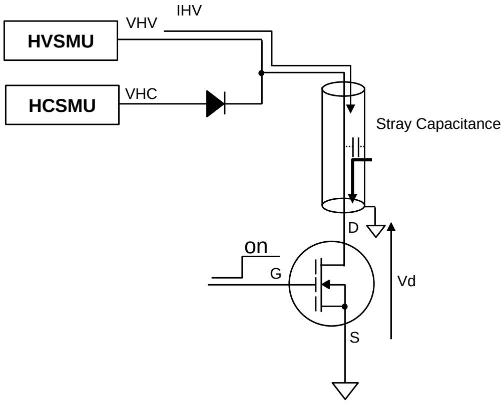


Figure 2-1-3 Unexpected current from the tray capacitance of cabling

To avoid such unexpected device damage, it is effective to discharge the stray capacitance at the same time or prior to turning on the DUT (refer to figure 2-1-4).

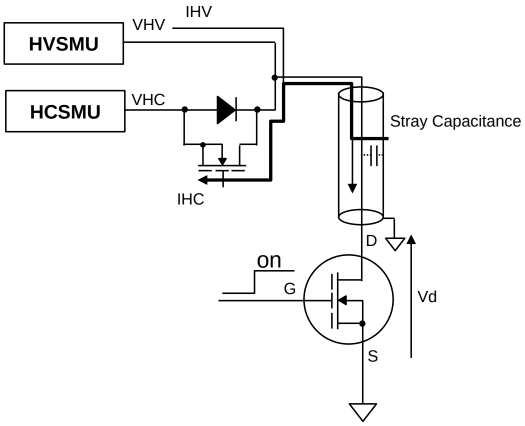


Fig. 2-1-4 Discharge the stray capacitance through the switch

Figure 2-1-5 shows examples of the transient path from the off-state to the on-state.

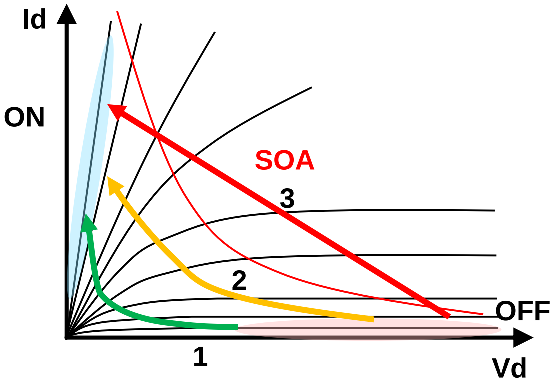


Figure 2-1-5 Transient path from the off-state to the on-state

If the transient path crosses the DUT SOA (path 3), the DUT is broken during switching.
If the transient path goes through the near SOA (path 2), the DUT is possibly damaged.
If the transient path goes through the lower power area, the DUT is not damaged at all.

Using the discharge switch ensures that the transient path is passing the lower power consumption area (path 1). If the DUT is turned on very quickly and has enough power rating, the DUT is not damaged even if the discharge switch is not used.

Figure 2-1-7 shows a block diagram of the N1267A. The discharge switch is controlled by the MCSMU. GNDU is connected to the low side of the HCMSU to keep the reference voltage of the HCMSU identical with the HVSMU. And the gate of the device is controlled by another MCSMU.

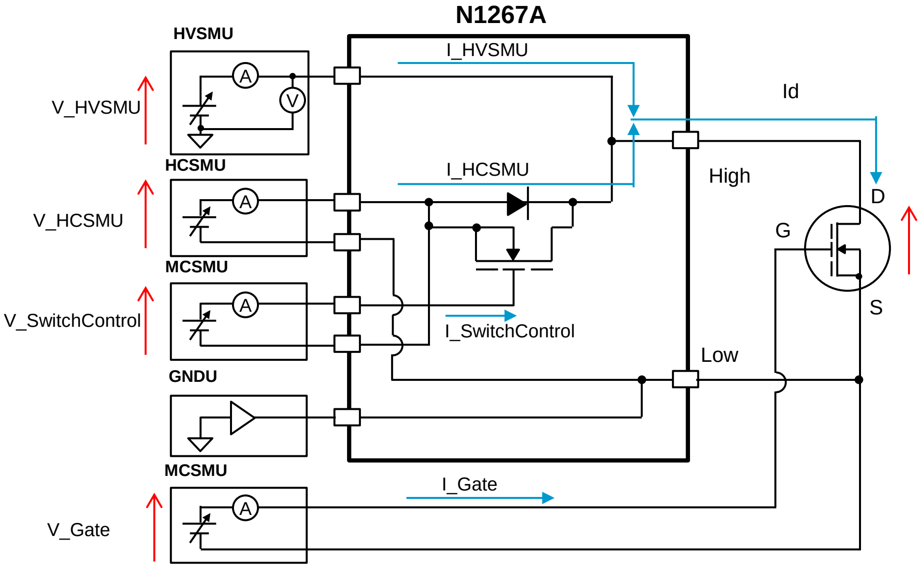


Figure 2-1-6 Block diagram of the N1267A

2-2. Switch Status, Voltage and Current at Each Terminal

2-2-1. Off-State of GaN FET

To create the off-state stress condition, the gate voltage applied to the DUT is set as its off-state voltage (VgOff). Also, the stress voltage from the HVSMU (VdsOff) should be at least 1 V higher than the setting voltage of the HCMSU (VdsOn) to put the diode switch in the N1267A to the reverse-biased condition. Figure 2-2-1 shows a relationship of voltage and current at the off-state of the DUT.

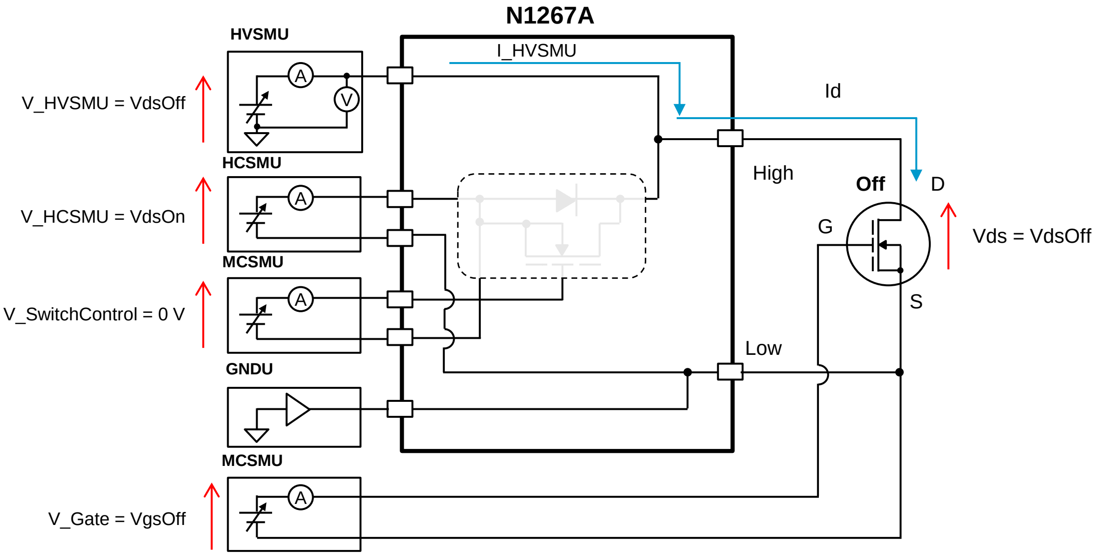


Figure 2-2-1 Relationship of voltage and current at the off-state of FET

Since the DUT is turned off, the output voltage from the HVSMU is fully applied to the drain terminal of the DUT and the diode switch is settled to its reverse-biased condition. The off-state leakage current of the DUT must be lower than the maximum output current of the HVSMU (8 mA for 1500 V range and 4 mA for 3000 V range) to apply the specified off-state voltage.

2-2-2. On-state of GaN FET when Id is Large

If the drain current (Id) is larger than the maximum output current from the HVSMU, the FET switch in the N1267A is normally turned off. The output voltage of the HVSMU is automatically lowered by the drain current. Then, the diode switch in the N1267A assumes the forward-biased condition, and the output current from the HCSMU becomes a major source of the drain current (refer to figure 2-2-2).

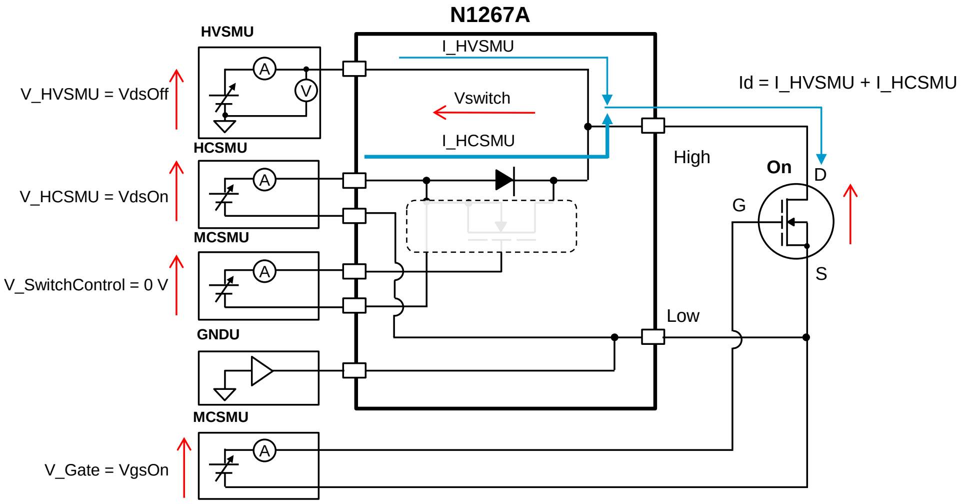


Figure 2-2-2 Relationship of voltage and current at the on-state of FET

Due to the voltage drop at the switch in the N1267A, the drain voltage (Vds) becomes lower than the setting voltage of the HCSMU (VdsOn). To acquire an exact Id-Vds characteristics, the Vds is measured by the HVSMU instead of the HCSMU.

2-2-3. On-state When Id is Smaller than HVSMU output current

If the drain current (Id) is smaller than the maximum output current of the HVSMU, the FET switch in the N1267A has to be turned on to switch from the off-state to the on-state, because the output voltage of the HVSMU cannot be lowered by the drain current of the DUT. In this case, the extra current from the HVSMU has to be pulled by the HCSMU through the FET switch to lower the output voltage of the HVSMU (refer to figure 2-2-3).

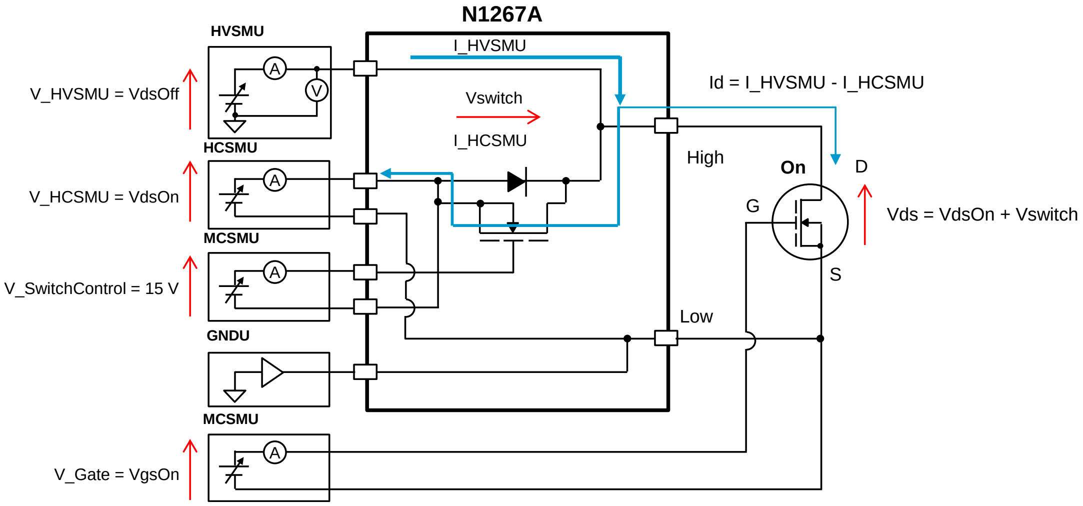


Figure 2-2-3 Relationship of voltage and current at the on-state of FET (Id < I_HVSMU)

In this case, the Vds becomes higher than the setting voltage of the HCMSU (VdsOn).

2-2-4. ID-VDS for Device Verification

To measure the on-characteristics of device, Id-Vds, to verify the DUT functionality through the N1267A, both the diode switch and the FET switch of the N1267A are turned on to minimize a voltage drop at the switch. Figure 2-2-4 shows the relationship of voltage and current to verify the on-characteristics of the DUT.

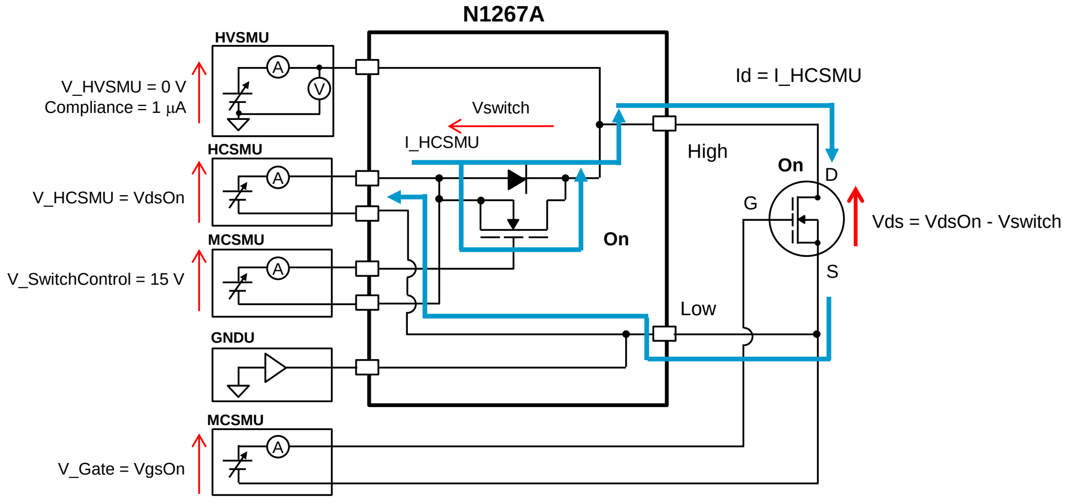


Figure 2-2-4 Relationship of voltage and current for on-state verification

The output voltage of the HVSMU is set as 0 V, and its compliance current is set small enough compared to the on-current of the DUT. With these settings, the HVSMU is used just as a voltage meter.

The output voltage of the HCMSU is swept as a primary sweep parameter (VAR1) to measure the Id-Vds curve. The minimum voltage VAR1 has to be larger than 1 V to push its output current to the DUT over the built-in voltage of the switch.

Also, the gate voltage is swept from the off-state voltage (VgOff) to the on-state voltage (VgOn) as a secondary sweep parameter (VAR2).

The FET switch is always turned on by applying 15 V DC bias.

2-2-5. ID(off)-VDS for Device Verification

The setting to measure ID(off)-VDS to verify the DUT leakage is the same as the setting to apply the off-state stress voltage to the DUT (refer to figure 2-2-5).

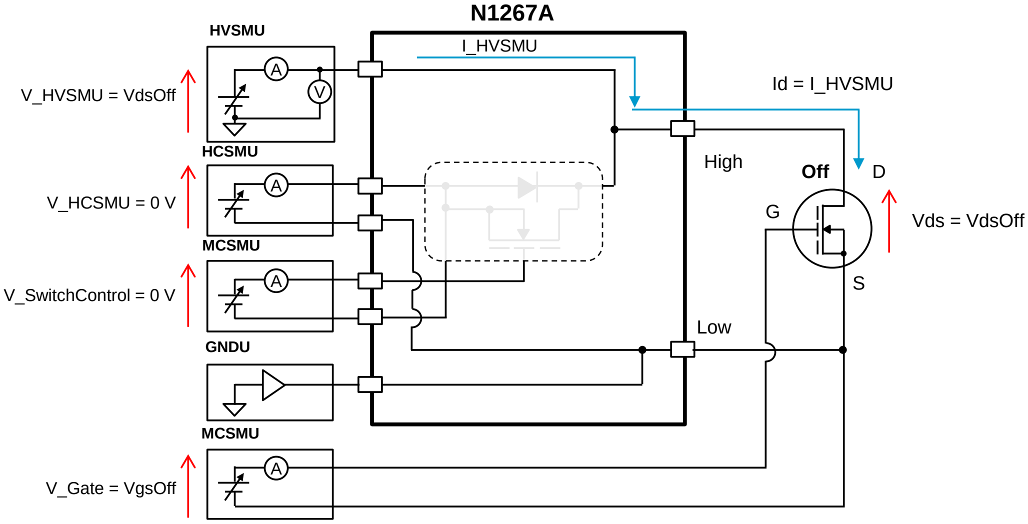


Figure 2-2-5 Relationship of voltage and current for device leakage check

The output voltage of the HCMSU is set as 0 V to make sure that the diode switch of the N1267A is reverse biased (off). The internal FET switch of the N1267A is also turned off.
The gate bias is set as voltage to make the DUT turned off, and the output voltage of the HVSMU is swept to measure the leakage current of the DUT.
Both the voltage and current applied to the DUT are measured by the HVSMU connected to the drain terminal of the DUT.

2-2-6. Off-State of GaN Diode

This setup is used to apply the off-state stress voltage to the diode.

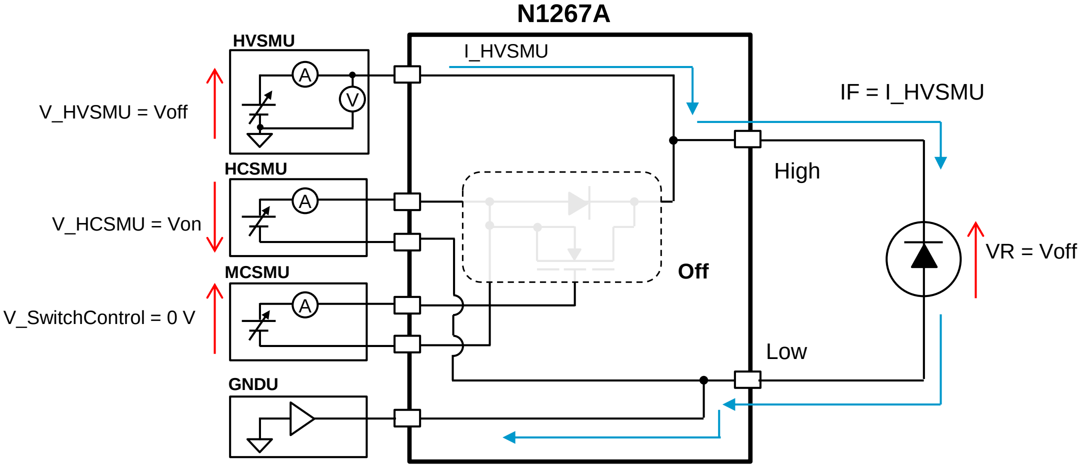


Figure 2-2-6 Relationship of voltage and current at the off-state of diode

The output voltage of the HVSMU is set as the off-state stress voltage, and the output of the HCMSU is set as the on-state measurement voltage. The internal FET switch has to be turned off.

2-2-7. On-State of GaN Diode

To change the device status from the off-state to the on-state, the internal switch of the N1267A is turned on.

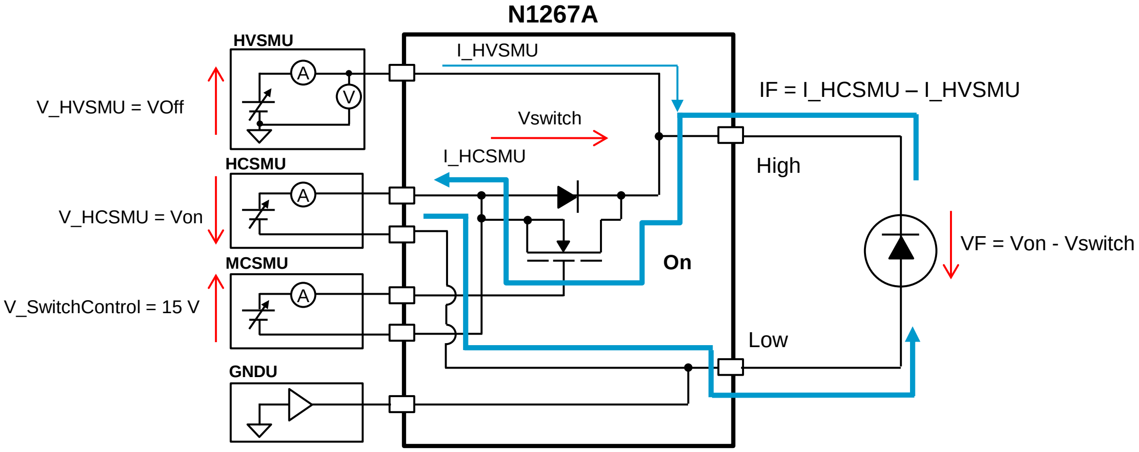


Figure 2-2-7 Relationship of voltage and current at the on-state of diode

The output voltage of the MCSMU to control the FET switch is set as 15 V, and the output voltage of the HVSMU is pulled down by the HCSMU. Then, the forward current of the diode starts flowing.

2-2-8. IF-VF for Device Verification

This setup is used to measure the IF-VF characteristics of the diode to verify the functionality of the DUT.

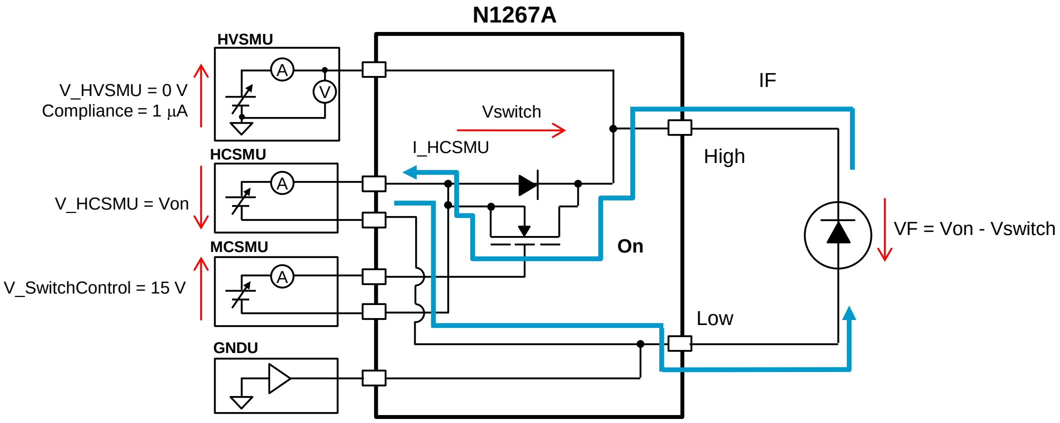


Figure 2-2-8 Relationship of voltage and current for IF-VF check of diode

The output of the HVSMU is set as 0 V, and current compliance is set small enough (1 µA) to use it as a voltage meter. The switch of the N1267A is turned on to connect the HCSMU to the DUT. Then, the output of the HCSMU is swept into negative voltage, and the forward current of the DUT is measured.

2-2-9. IR-VR for Device Adequateness Check

This setup is used to measure the IR-VR characteristics to verify the leakage current of the DUT.

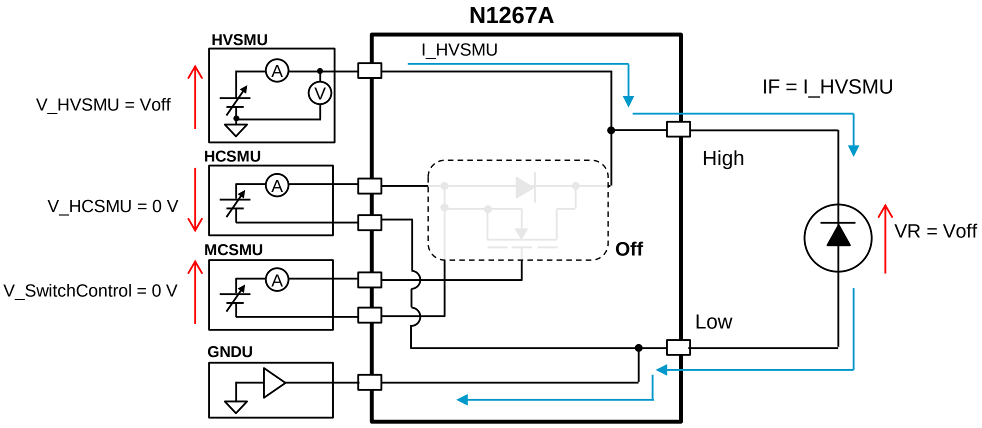


Figure 2-2-9 Relationship of voltage and current for leakage current check of diode

The switch of the N1267A is turned off, and the output of the HVSMU is connected to the DUT directly to measure the IR-VR characteristics.

3. Switching and Measurement Performance

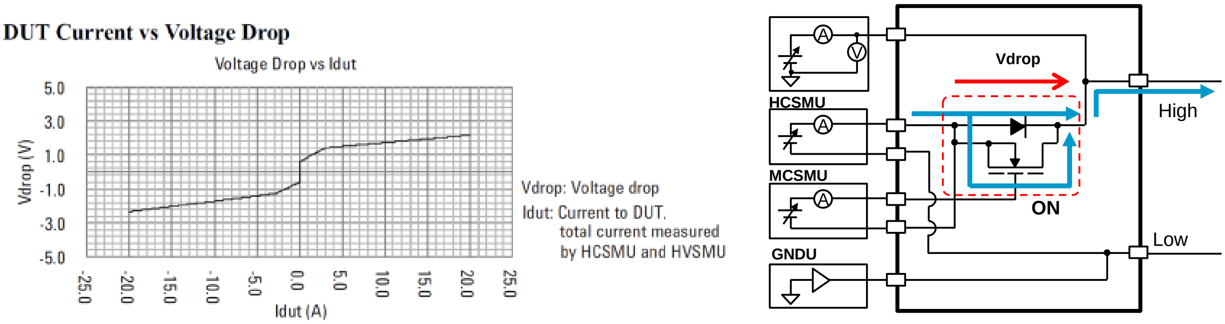
The minimum switching time of the N1267A is about 20 µs. But, in the actual measurement situation, the switching time is influenced by many factors like the response of equipment, impedance of the DUT, self-heating of the switch etc. In this section, the switching performance of the N1267A under various conditions is explained. Also, the technique to improve the switching time and the key concepts to observe the dynamic Ron characteristics correctly are explained.

3-1. Measurement Fundamentals

Basically, this system is designed to measure a dynamic change of the on-resistance of the DUT (Ron). Even if the system can measure a voltage and current applied to the DUT, those values possibly include some influences of the system components.

For example, since voltage drop at the switch in the N1267A has a dependency on the current flowing through it, the voltage applied to the DUT also has a dependency on the measured current itself.

Figure 3-1-1 shows the change of the voltage drop of the switch based on the change of the current flowing through it.



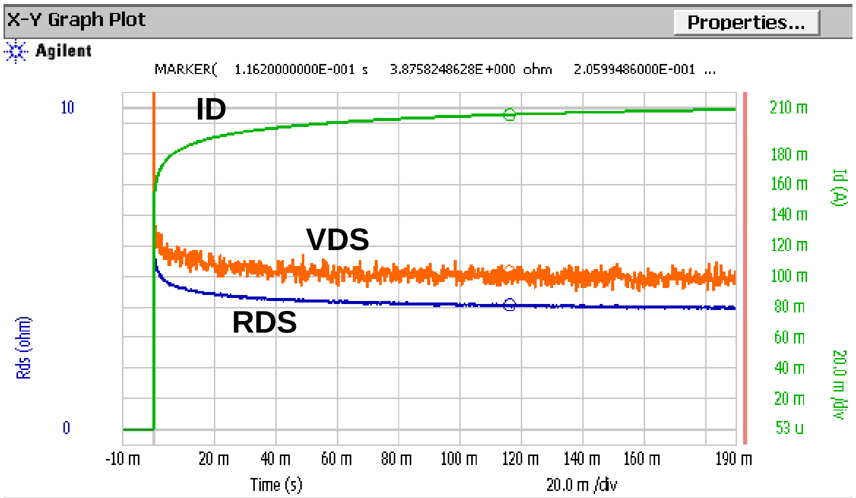
Voltage Drop

Transistor measurement		Diode measurement	
Voltage drop	Current I_0 [a]	Voltage drop	Current I_0 [a]
$20 \times I_0$	$I_0 \le 30$ mA	$58 \times I_0$	$I_0 \le 10$ mA
$0.6 + 0.27 \times I_0$	30 mA $< I_0 \le 3$ A	$0.6 + 0.24 \times I_0$	10 mA $< I_0 \le 3$ A
$1.3 + 0.043 \times I_0$	3 A $< I_0 \le 20$ A	$1.1 + 0.062 \times I_0$	3 A $< I_0 \le 20$ A

a. I_0: HCSMU output current (A)

Fig. 3-1-1 Current V.S. voltage drop at the switch

Figure 3-1-2 is an example of dynamic Ron measurement in GaN FET.



MARKER(1.1620000000E-001 s 3.8758248628E+000 ohm 2.0599486000E-001 ...

Fig. 3-1-2 Dynamic Ron measurement example in GaN FET

In this result, the drain current (ID) increases and the drain to source resistance (Rds) decreases with time. This is a typical recovery of RDS from the current collapse situation. But when looking at the drain voltage (VDS), it also decreases with time even if the output voltage of the HCSMU is set as a constant voltage. This is caused by the voltage drop at the switch. With the increase of the ID, the voltage drop also increases. Then, the VDS decreases with the increase of the ID.
In this result, the increase of the ID is a combination of the recovery from the current collapse and decrease of the VDS. Fundamentally, those cannot be separated, because the voltage drop at the switch itself has a time dependency as described in a later part of this section.

But, if this measurement is done at the linear region of the ID-VDS curve, the slope of the ID-VDS curve is not influenced by the decrease of the drain voltage.

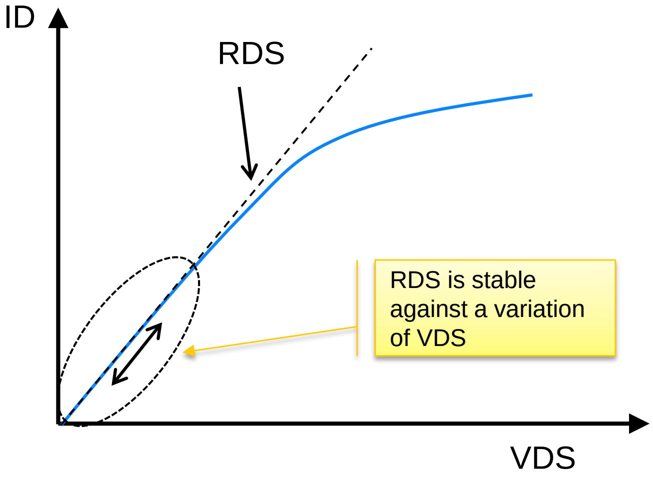


Fig. 3-1-3 Measurement of RDS at linear region of ID-VDS curve

So, the measured RDS at this region is free from the variation of the VDS, and it reflects the change of device characteristics by the current collapse phenomenon.

The voltage drop at the switch is also changed by self-heating of the switch itself, especially if the ID is larger than 100 mA.
So, observing the change of drain current as an indicator of the current collapse is considered not reasonable when using this system. It is the same as the system which uses a shunt resistor to monitor the change of RDS, too. In that system, the drain voltage is also changed by the voltage drop at the shunt resistor as described in figure 3-1-4.

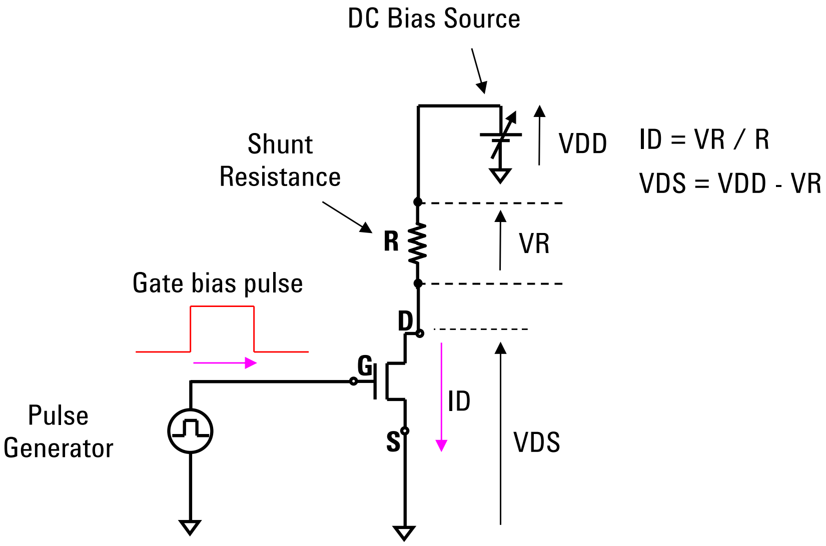
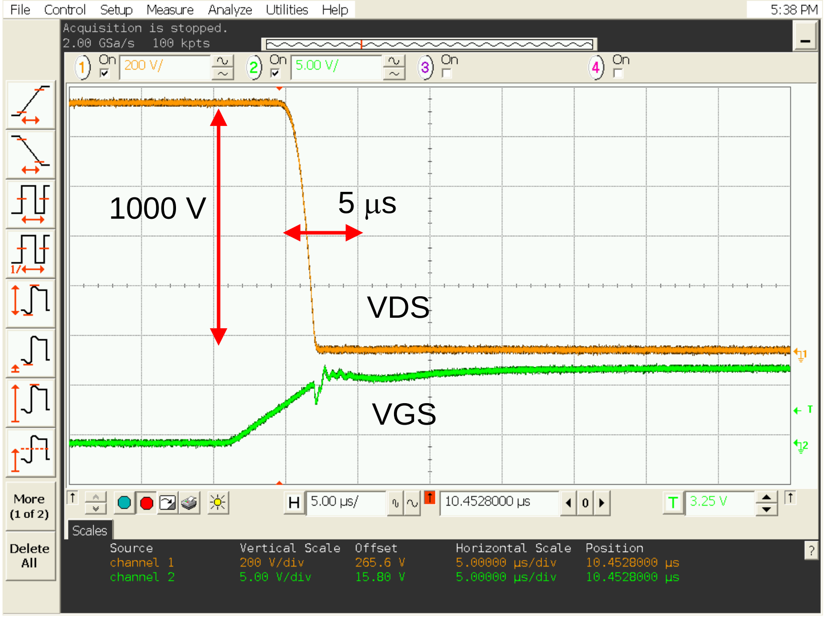


Fig. 3-1-4 Dynamic Ron measurement system using a shunt resistor

From those reasons, the change of the RDS is the parameter to be evaluated. That’s why this measurement is a so-called “Dynamic On-Resistance Measurement”.

3-2. Switching Speed

Figure 3-2-1 shows a waveform of the VDS and VGS switching from the off-state to the on-state of the DUT. The DUT is a high voltage MOS-FET which does not have any current collapse characteristics.



```
Acquisition is stopped.
2.00 GSa/s   100 kpts
```

```
Source       Vertical Scale  Offset     Horizontal Scale  Position
channel 1    200 V/div       265.6 V    5.00000 µs/div    10.4528000 µs
channel 2    5.00 V/div      15.80 V    5.00000 µs/div    10.4528000 µs
```

Fig. 3-2-1 Waveform from the off-state to the on-state

The off-state stress voltage is 1,000 V and it sinks to the on-state voltage (about 5 V) within 5 µs. In this case, the gate waveform is fluctuated by the transient signal injected into the gate terminal from the drain terminal through the capacitive coupling between them. This transient signal is caused by the sudden drop of the drain voltage.

The fluctuation of gate voltage is settled within 20 µs in this case, and if the gate voltage is high enough to turn on the DUT, this fluctuation does not affect the measured on-resistance as observed as the flatness of the VDS.

From this, the switching time itself is faster than 20 µs, but the practical range of effective switching time to evaluate a dynamic Ron depends on the combination of modules and the device itself.

3-3. Response of HCMSU

3-3-1. Band Width of HCMSU

The SMU has a feedback loop to keep its output voltage as a setting value with a varied load. Due to this feedback loop, the output resistance of the SMU is considered as “ZERO” Ohm and it can be used as a combination of an ideal voltage source and current meter. Figure 3-3-1 shows a simplified circuit diagram of SMU.

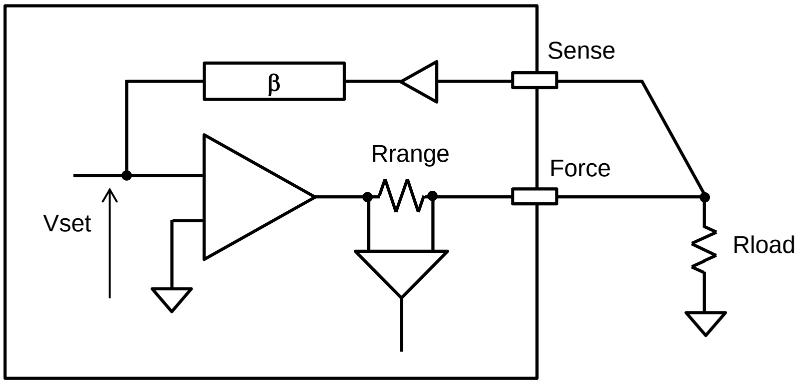


Fig. 3-3-1 Simplified Circuit Diagram of the HCMSU

The voltage monitored by the sense terminal is fed back to the output amplifier through the sense buffer. Its feedback factor at open condition is described as β in figure.
Also, the SMU has a range resistor, Rrange, to measure its output current. Due to this resistor, the total feedback factor is reduced to Rload / (Rload + Rrange). The Rload is a resistance of the DUT.

Since the bandwidth of the feedback loop is related to the total feedback factor, a smaller Rload makes its bandwidth lower, and the rise time of the pulse becomes slower.

Fig. 3-3-2 shows an example of step response of HCMSU with various load resistances.

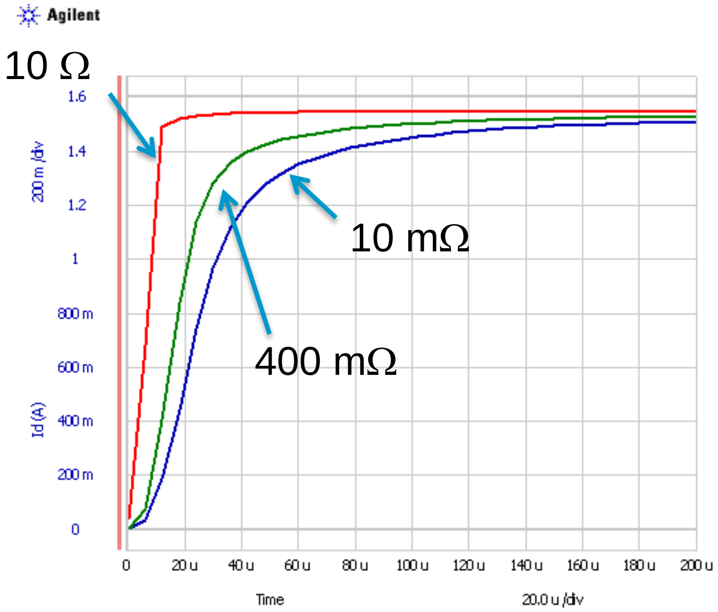


Fig. 3-3-2 Step response of measured current by HCSMU

From this example, to measure the drain current after 20 µs from switching, at least a few Ohms of load resistance are necessary.
If the DUT itself has a resistance lower than 1 Ω, it is possible to make the response of the HCSMU faster by adding a series resistance between the HCSMU output and the DUT (refer to figure 3-3-3).

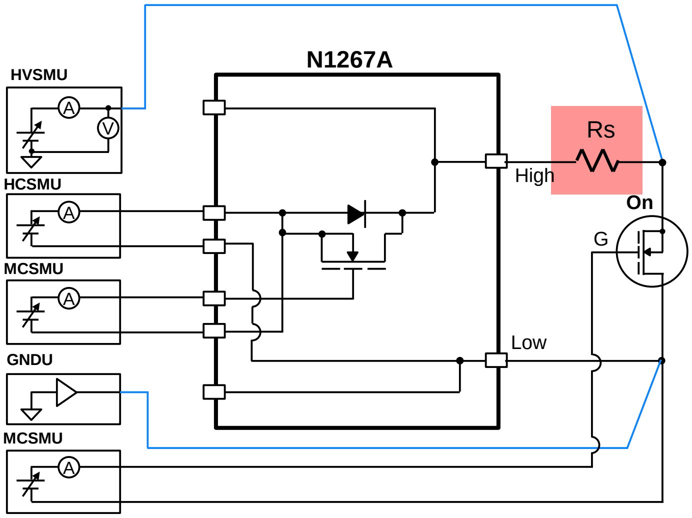


Fig. 3-3-3. Adding series resistance to improve the response time of the HCMSU

To add series resistance, the connection using N1267A has to be a Kelvin connection as described in figure 3-3-3. In this case, the voltage applied to the DUT is monitored by the HVSMU correctly even if there is an IR voltage drop at the series resistance between the N1267A and the DUT. But the maximum allowable current is limited by this output resistance. For example, since the maximum output voltage of the HCSMU is 20 V in pulse mode, the maximum current of HCSMU is limited to 2 A if a 10 Ω series resistance is used.

Figure 3-3-4 shows available accessories to insert the series resistance to improve the HCSMU response for various cases.

N1259A-035 Universal R-Box for N1259A

N1265A-035 Universal R-Box for N1265A

N1262A-021 Universal R-Box for On-Wafer Measurement

Fig. 3-3-4. Accessories to insert the series resistance

3-3-2. Operation Mode Change When Using "I Force" Mode

The "FET Current Collapse IV-t Sampling (I Force)" and "FET Current Collapse Signal Monitor (I Force)" use a constant output current mode of the HCMSU to measure the Ron at constant current condition.
Since other application tests use a constant voltage output mode, the operation point of the DUT is moving during a measurement because the drain voltage is modulated by the change of the drain current. This drain voltage change is caused by the change of the voltage drop at the N1267A switch as discussed in section 3-1. On the other hand, by using a constant current mode, it is possible to fix the operation point at the specific drain current. But using the constant current mode has some disadvantages.

When the DUT is turned off, the output voltage of the HCMSU rises to its compliance level because the specified current cannot flow into the DUT through the switch. At this moment, operation mode of the HCSMU moves to the constant voltage output mode to limit its output voltage.

After the DUT is turned on, the output current of the HCMSU starts flowing to the DUT and it goes back to the constant current mode again. But switching from the constant voltage mode to the constant current mode requires a certain amount of time, around 50 µs.

Figure 3-3-5 shows an example of the transient on the drain current measured by the HCSMU in the constant voltage mode (V Force) and the constant current (I Force) mode.

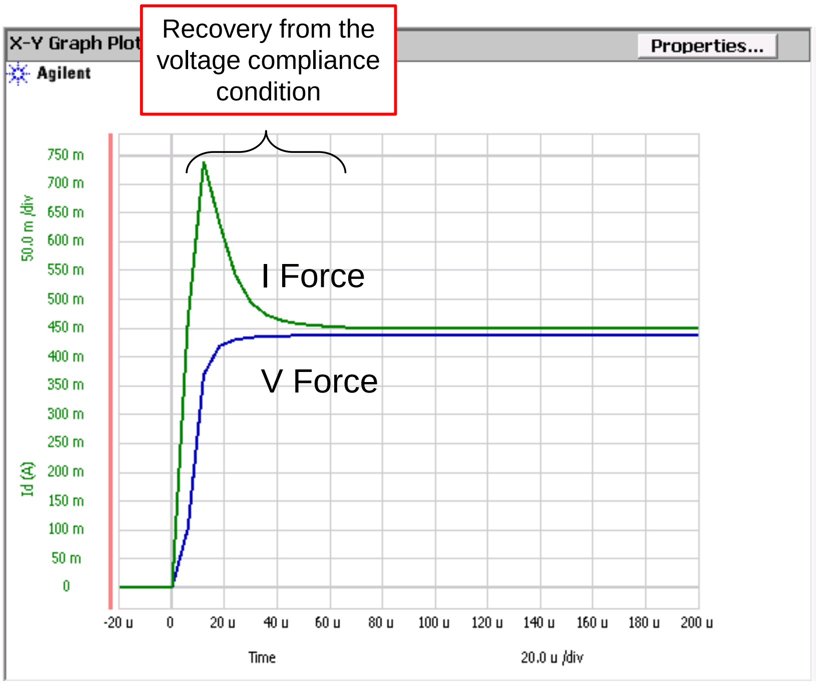


Fig. 3-3-5 Response speed difference between the V Force and I Force mode

In this example, measurement is performed without a stress voltage to remove the influence of the overcurrent condition of the HVSMU (it is explained in the next section).

According to this example, at least 50 µs to 60 µs is required to settle the transient from the voltage compliance to the constant current mode of the HCMSU. So, if you want to see the dynamic Ron response within 50 µs, it is necessary to use the constant voltage mode instead of the constant current mode.

Hence, the dynamic Ron characteristics is measured at the linear region of the Id-Vds curve, and a slight change of the Id does not affect the measured Ron in both operation modes. So, if you do not have any specific reason to see the Ron at the specified current, it is recommended to use the constant voltage mode.

3-4. Response of the HVSMU

3-4-1. Delay of Voltage Measurement Circuit

When using N1267A, the drain voltage Vds is measured by the HVSMU connected to the drain terminal of the DUT. Since the voltage measurement circuit of the HVSMU has a limitation on its operation speed, the measured voltage delays along with the increase of the stress voltage (VdOff). Figure 3-4-1 shows an example of delay on the measured voltage by the HVSMU with various stress voltages from 10 V to 500 V.

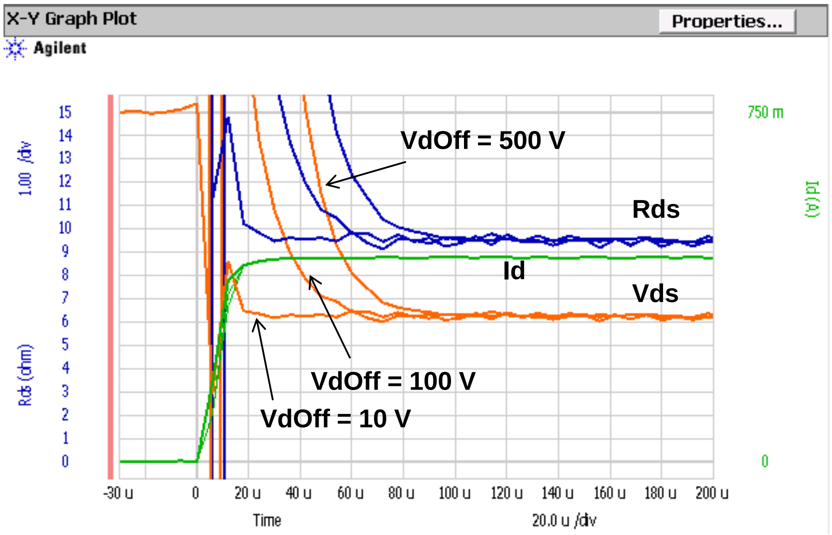


Fig. 3-4-1 Delay of voltage measurement by HVSMU

From this example, the settling time of the measured drain voltage (Vds) is getting longer along with the increase of the VdOff.
But when looking at the measured drain current (Id), it looks not affected by this delay. This indicates that the delay of the Vds is not a physical one. It is a delay on the measured result.

In fact, the drain voltage monitored by the oscilloscope does not have a such delay even if the VdOff is 1000 V (refer to figure 3-2-1).

Since the drain to source resistance (Rds) is calculated by Vds/Id, the Rds also has the same delay as the Vds. Sometimes, it is misunderstood as the recovery from the current collapse caused by the higher stress voltage. But it is caused by the delay on voltage measurement itself. This delay on the measured result is fundamental to HVSMU, and it cannot be removed.

So, if you want to see the dynamic change of the DUT faster than this delay, the Id is the parameter to be evaluated instead of the Rds. But, if the Id is dramatically changed by the increase of the stress voltage, it is difficult to compare the measured Id with various off-state stress voltages directly, because the change of Id causes the change of the Vds again.

In this case, comparing the normalized Id would be helpful to check if the delay is added by the stress voltage or not. Figure 3-4-2 is an example of dynamic Ron measurement in GaN HEMT with 10 V and 100 V off-state stress voltages.

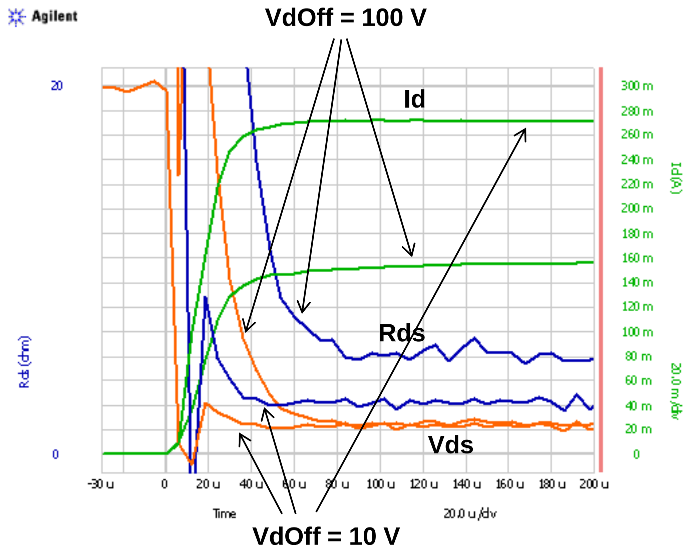


Fig. 3-4-2 Delay of voltage measurement by HVSMU

In this example, Id shows a significant current collapse behavior. The delay time of the Rds looks larger than the delay of the Id. This is a result of the delay time of the Vds. When looking at the drain current with 100 V stress, the Vds at its on-state is slightly larger than the case of 10 V stress due to the smaller voltage drop at the switch. So, the difference between the amplitude of the Id is a combination of change of the Id itself and change of the Vds. To evaluate the amount of degradation during the off-state stress, the Rds have to be compared after the Vds is settled (100 µs in this case).

To see the difference of the time constant due to the current collapse phenomenon, comparing the normalized Id is useful. Figure 3-4-3 shows the comparison of the normalized drain current with 10 V and 100 V stress.

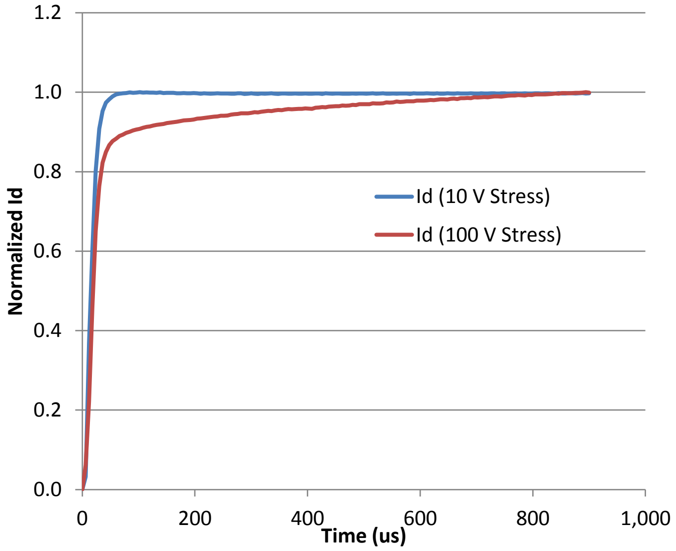


Fig. 3-4-3 Comparison of normalized drain current of GaN HEMT

This result shows that the 100 V stress causes some kind of damage to the device, and it has an additional time constant to recover to its normal condition.

3-4-2. Recovery from Transient Status of the HVSMU

Basically, HVSMU has the same kind of feedback loop like HCSMU (refer to figure 3-3-1). When the DUT or the switch of the N1267A is turned on, the HVSMU tries to keep its output voltage. But, if the output current is over its compliance value, the HVSMU moves into the constant current mode (current compliance), and its output voltage is pulled down by the DUT or the HCSMU. To switch the constant voltage mode to the compliance mode, a specific time to respond is required. During this transient period, the HVSMU falls into its overcurrent condition, and it outputs higher current than its specified compliance current (about 12 mA).

Figure 3-4-4 shows the transient of the HVSMU output between the off-state and the on-state.

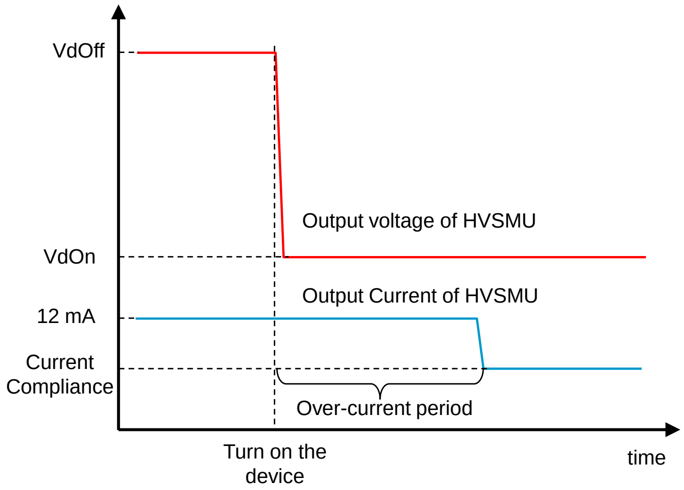


Fig. 3-4-4 Transient of the HVSMU output between the off-state to the on-state

The over-current period is related to the voltage change from the off-state to the on-state and the current compliance value. The over-current period is about 2.5 μs / V × (VdOff – VdOn) with 4 mA compliance, and 5 μs / V × (VdOff – VdOn) with 8 mA compliance setting.
This change of current also modulates the voltage applied to the DUT.

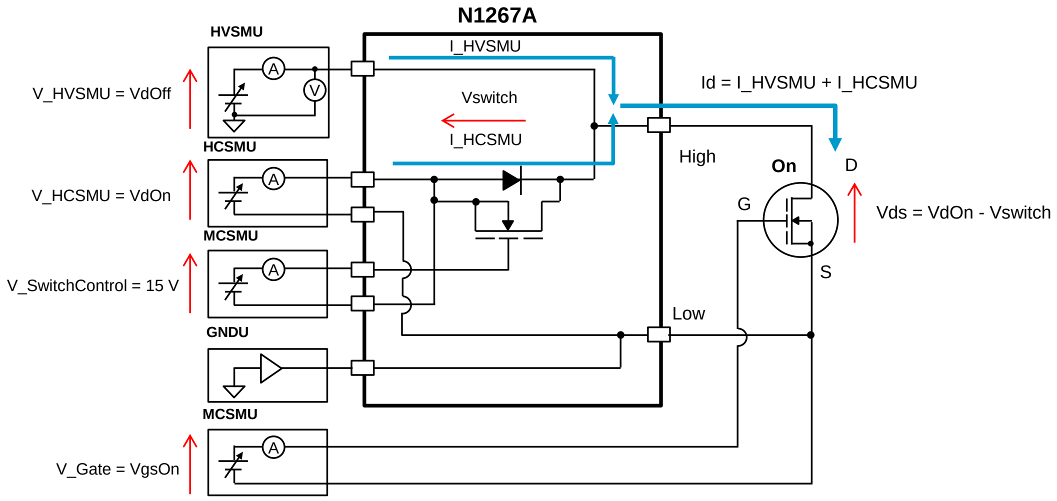
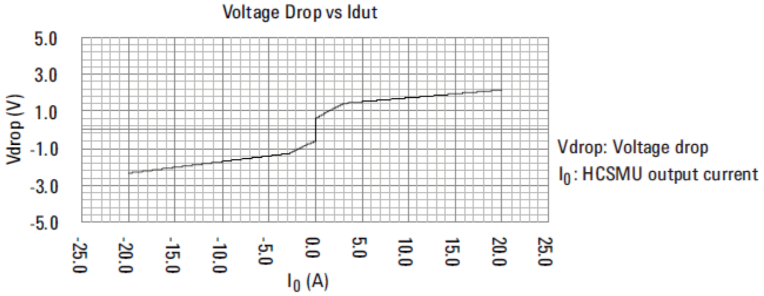


Fig. 3-4-5 Current and voltage when device is turned on

Again, the drain voltage is not the same as the output voltage of the HCMSU due to the voltage drop at the switch (refer to figure 3-4-5). Since the drain current (Id) is a combination of the output current of the HVSMU (I_HVSMU) and HCSMU (I_HCSMU) , the I_HCSMU is also changing when the I_HVSMU changes. This change of the I_HCSMU changes the voltage drop at the switch and Vds, too.

Figure 3-4-6 shows a dependency of the voltage drop at the switch of the N1267A on to the output current from the HCSMU.

HCSMU Output Current vs Voltage Drop



Voltage Drop

Transistor measurement		Diode measurement	
Voltage drop	**Current I_0 [a]**	**Voltage drop**	**Current I_0 [a]**
$20 \times I_0$	$\lvert I_0 \rvert \leq 30$ mA	$58 \times I_0$	$\lvert I_0 \rvert \leq 10$ mA
$0.6 + 0.27 \times I_0$	30 mA $< \lvert I_0 \rvert \leq 3$ A	$0.6 + 0.24 \times I_0$	10 mA $< \lvert I_0 \rvert \leq 3$ A
$1.3 + 0.043 \times I_0$	3 A $< \lvert I_0 \rvert \leq 20$ A	$1.1 + 0.062 \times I_0$	3 A $< \lvert I_0 \rvert \leq 20$ A

a. I_0: HCSMU output current (A)

Fig. 3-4-6 Voltage drop at built-in switch of the N1267A and output current of the HCMSU

From this, the influence of voltage drop becomes remarkable when the current from the HCSMU (I_0) is relatively small (smaller than 30 mA when the FET switch of the N1267A is turned on, or, smaller than 10 mA when the internal FET switch is turned off).

For example, when the Id is 30 mA, the I_HVSMU is 12 mA, and the current from I_HCSMU is 18 mA during the overcurrent status of the HVSMU. After moving to the compliance status of the HVSMU, the I_HVSMU becomes 8 mA, and the I_HCSMU becomes 22 mA. When the FET switch is used, the change of voltage drop at the switch is about 80 mV. Since the drain voltage decreases due to this voltage drop change, the drain current decreases, too. For example, if the on-resistance of the device (Ron) is 10 Ω, the drain current decreases about 8 mA.

In a practical sense, the actual drop of drain current is smaller than above. When the drain current decreases, the output current of the HCMSU also decreases. It makes the voltage drop at the switch smaller, and it suppresses the step decrease of the drain current.

It is the case when the voltage force (V Force) mode of the HCMSU is used. When the current force mode is used, since the output current of the HCMSU is constant, a 4 mA change of the I_HVSMU directly changes the drain current by the same amount.

Figure 3-4-7 illustrates the difference of influence of the overcurrent condition in both constant voltage mode and constant current mode.

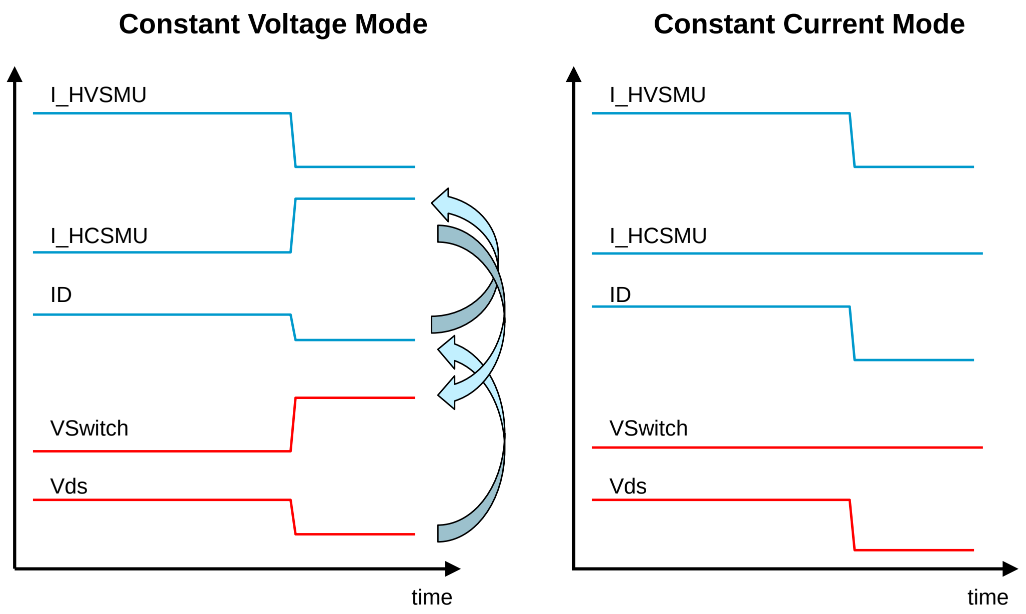


Fig. 3-4-7 Influence from the transient condition of the HVSMU

Figure 3-4-8 is an example of measurement in constant voltage mode (V Force) and constant current mode (I Force).

As you can see in this example, using the V Force mode reduces the step caused by the overcurrent condition of the HVSMU.

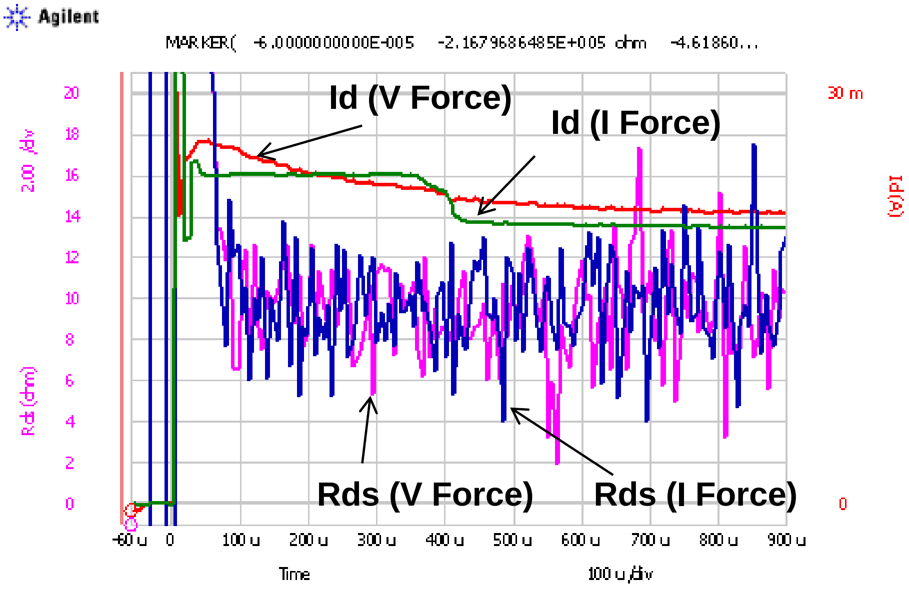


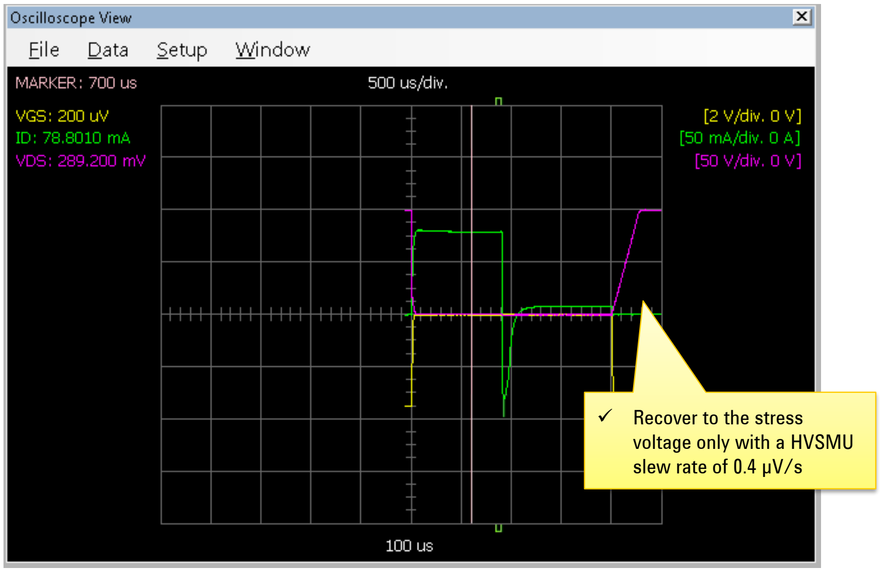
Fig. 3-4-8 Example of transient of the HVSMU

The amount of the step caused by the overcurrent status change depends on the DUT. If the drain current is over 30 mA, the voltage drop at the switch changes only by 0.27 × 4 mA = 1.08 mV when the FET switch is used. If the drain current is over 3 A, it is just 0.043 x 4 mA = 0.172 mV. Those amounts are very small. For example, if the drain current is 1A and its Ron is 100 mΩ, the Vds is about 100 mV, and the 1.08 mV drop can be ignored.
Also, the duration of the overcurrent status depends on the stress voltage and current range. For example, if the stress voltage is 500 V, the overcurrent status continues longer than 1 ms and cannot be observed when measuring a current collapse with over 1 A drain current, because the maximum pulse width of the HCMSU is 1 ms at that current range.
Note that, even if measured drain current shows the step caused by the over-current status of the HVSMU, the measured Rds is not influenced when it is measured at the linear region of the DUT (refer to figure 3-1-3). From this point, the Rds is the parameter that should be used to evaluate a quantitative evaluation of the current collapse as we discussed in section 3-1.

3-4-2. Recovery from on-state to off-state

When using the N1267A, the minimum achievable switching time from the off-state to the on-state of the DUT is 20 µs. This fast switching is realized by pulling the output voltage of the HVSMU down by the DUT or the HCSMU. On the other hand, the transient time back to the off-state from the on-state of the DUT is determined by the maximum slew rate of the HVSMU, 0.4 V/µs.

Figure 3-4-9 shows an example waveform monitored by the Oscilloscope View function of EasyEXPERT. The pulse width of the HCSMU to measure the on-state current is 1 ms, and the gate voltage to turn on the DUT is applied 1 ms more in addition to the HCSMU pulse.



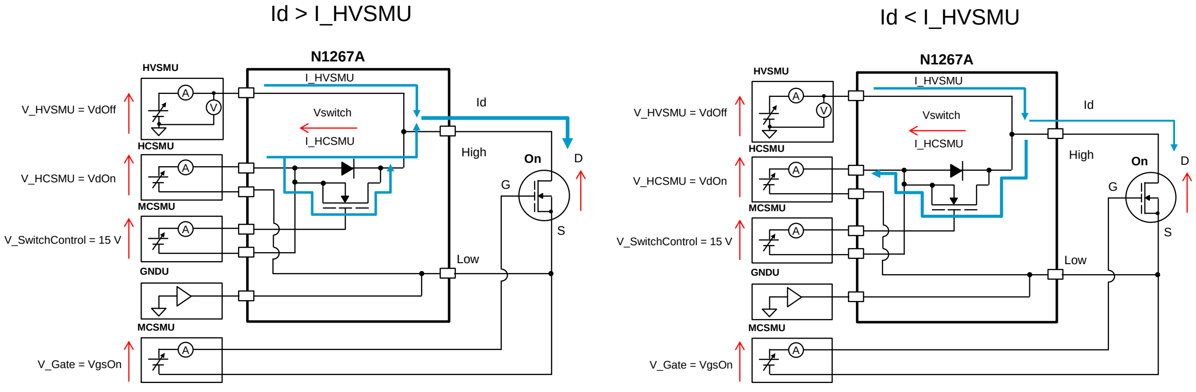
✓ Recover to the stress voltage only with a HVSMU slew rate of 0.4 µV/s

Fig. 3-4-9 Slow recovery of the HVSMU from the on-state to the off-state

According to this example, the recovery speed from the on-state to the off-state is much slower than the switching time from the off-state to the on-state. For example, to recover from 1 V to 100 V, it requires 99 V ÷ 0.4 V/ µs = 247.5 µs. So, the maximum switching frequency when using the N1267A is limited by this recovery time.

3-5. Response of FET Switch in N1267A

Normally, the internal FET switch of the N1267A is turned on when the drain current is smaller than the output current of the HVSU to pull down the output voltage of it by the HCSMU. But, in some cases, to avoid device damage caused by an unexpected current from the charge of cabling, the FET switch is turned on primary to turning on the DUT (refer to section 2-1).



(a) (b)

Fig. 3-5-1 Current flow when the internal FET switch is turned on (a) Id > I_HVSMU, (b) Id < I_HVSMU

When the Id is larger than the I_HVSMU, the output current from the HCSMU is flowing through both the diode switch and the FET switch. In the FET switch, the current is flowing from the source to the drain terminal. In this case, due to the inherent characteristics of the FET switch, the rise time of the drain current has some delay compared to the case when only the diode switch is used. Figure 3-5-1 shows the comparison of rising edge of the drain current for both cases.

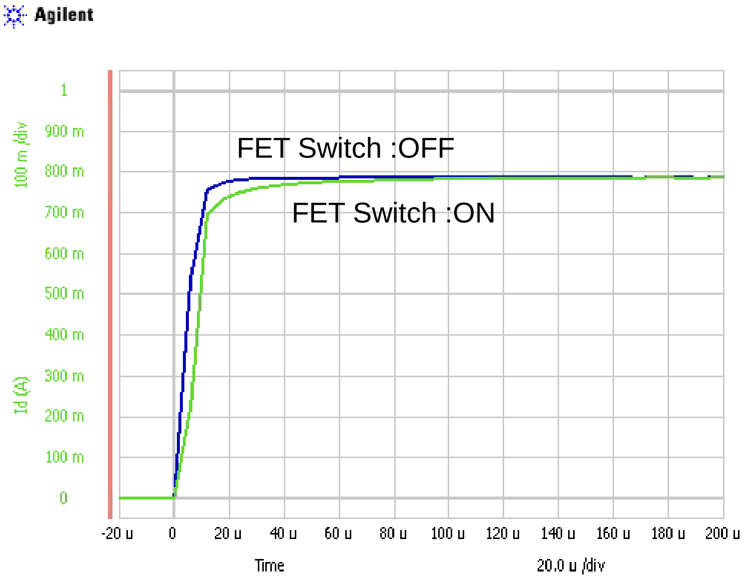


Fig. 3-5-2 Comparison of rising edge (Id >> I_HVSMU)

In this example, the settling of about 100 µs is observed, and this must not be misunderstood as a device characteristics.

This 100 µs delay is observed when the output current from the I_HCSMU is over 30 mA. Figure 3-5-3 shows an example of delay time with different I_HCSMU levels.

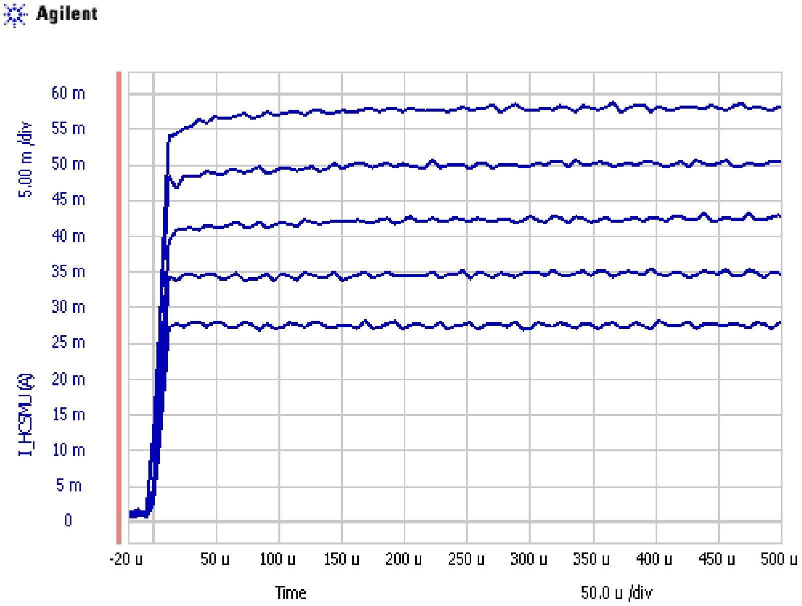


Fig. 3-5-3 Setting of I_HCSMU with different current level

So, if the drain current is less than about 38 mA, the use of the FET switch does not show the additional delay, and it is possible to use the FET switch even if the drain current is larger than the output current of the HVSMU.

From the argument above, when the drain current is over 38 mA, the internal switch should not be used to see the fast response of the DUT. But, according to the situations, the internal switch has to be used to discharge the cabling to avoid damage of the DUT.
In this case, turning on the FET switch just before turning on the DUT helps avoid such unexpected device damage.
Figure 3-5-4 shows a timing chart when to discharge cabling before turning on the DUT.

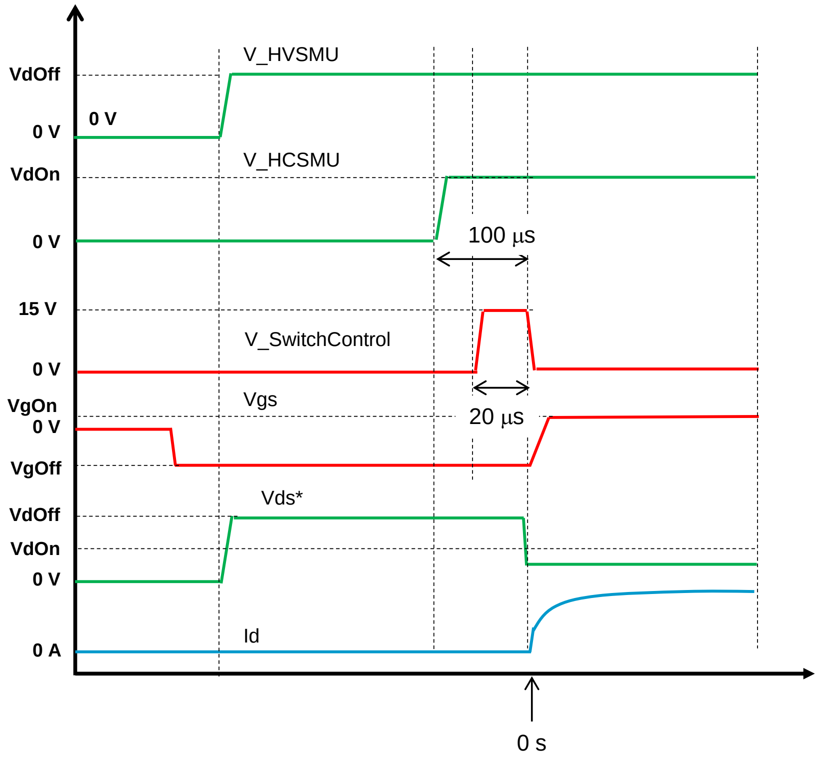
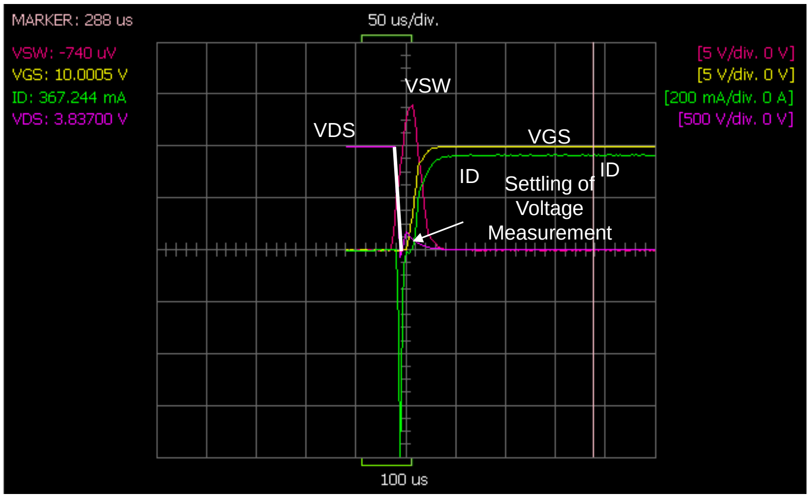


Fig. 3-5-4 Pulse timing chart for cable discharging before applying gate pulse

The FET switch of the N1267A is turned on just before applying the gate bias to the DUT. Since the maximum slew rate of the MCSMU is 1 V / µs, a rising time of at least 15 µs is necessary to apply the 15 V bias to turn on the FET switch. So, using a 20 µs pulse width is recommended to gain enough time to discharge the cabling.

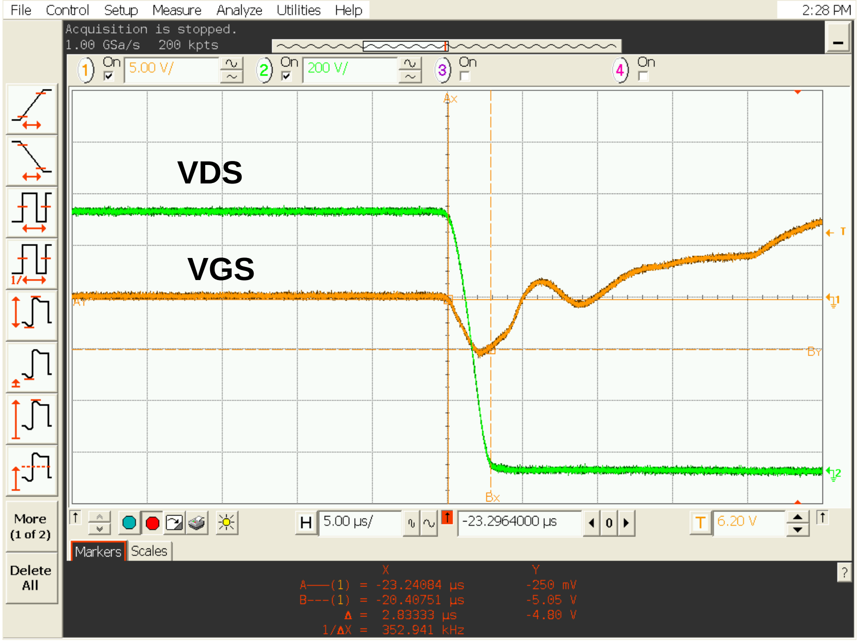
Figure 3-5-5 shows an example of cable discharging using the FET switch. The DUT is 2SK3745 and the off-state stress voltage is 1000 V. The FET switch is driven by 20 µs pulse and the delay time is 86 µs.

Figure 3-5-5 (a) shows the waveform captured by the Oscilloscope View function of EasyEXPERT, and figure 3-5-5 (b) shows the actual gate voltage and drain voltage applied to the DUT captured by the oscilloscope.



```
MARKER: 288 us
VSW: -740 uV
VGS: 10.0005 V
ID: 367.244 mA
VDS: 3.83700 V
```

(a) Waveform captured by the Oscilloscope View (VSW: 20 µs width, 86 µs delay)



```
Acquisition is stopped.
1.00 GSa/s   200 kpts
```

```
                 X                      Y
A——(1)  = -23.24084 µs          -250 mV
B---(1) = -20.40751 µs          -5.05 V
      Δ =  2.83333 µs           -4.80 V
   1/ΔX =  352.941 kHz
```

(b) Waveform captured by the Oscilloscope (VSW: 20 µs width, 86 µs delay)

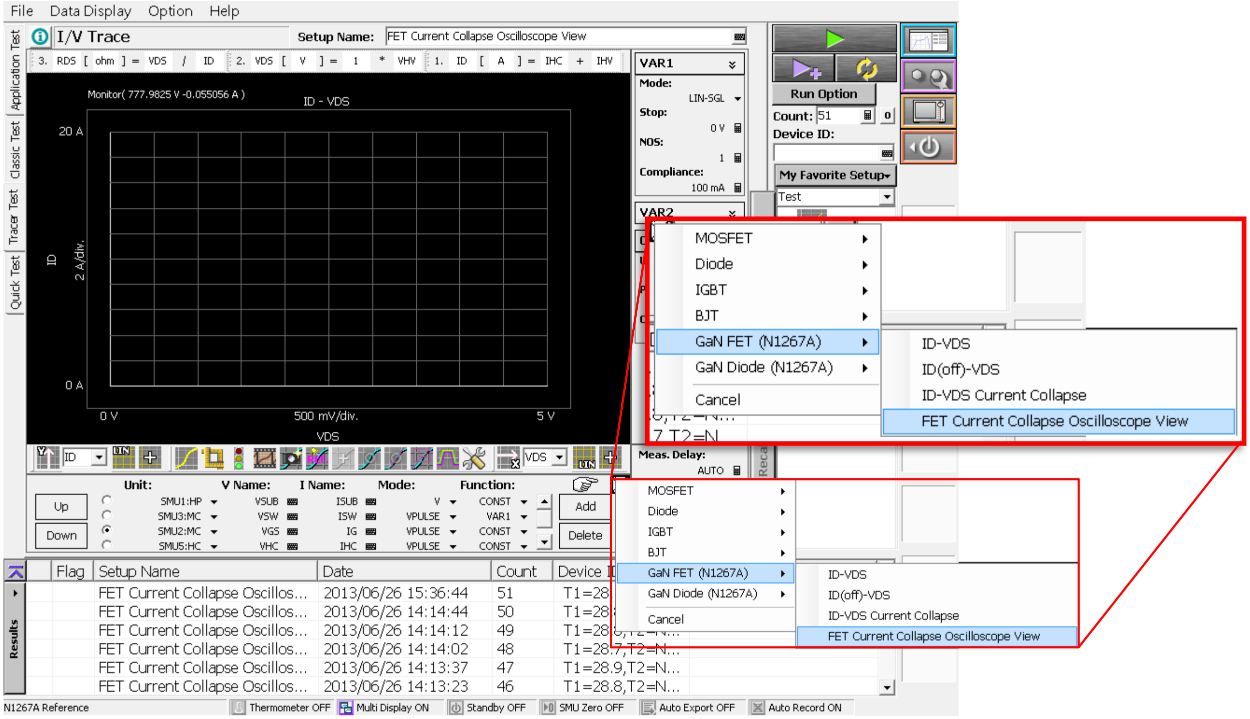
Fig. 3-5-5 Waveform of discharging by the FET switch

According to figure 3-5-5 (a), the VDS starts to drop at the rising edge of the switch control pulse (VSW) and it goes down to the on-state level just before applying the gate voltage (VGS). The monitored drain voltage (VDS) shows some rebound on it. But it is not an actual voltage, just a response of the voltage meter of the HVSMU as discussed in section 3-4.
According to Figure 3-5-5 (b), the VDS drops rapidly, and it takes just 3 µs to move from 1000 V to a few volts. The ringing of the VGS is caused by the capacitive coupling between the drain and the gate terminals.

When looking at the drain current in figure 3-5-5 (a), it does not show the delay time when using the FET switch of the N1267A even if the drain current is relatively high.

Currently, the pre-installed application test definitions do not have the capability to adjust a timing of the VSW pulse. So, it is necessary to use the Tracer Test mode to use the FET switch for this purpose.

In the Tracer Test mode, the “FET Current Collapse Oscilloscope View” is available in the “GaN FET” preset group. It is almost the same as the “FET Current Collapse Signal Monitor” application test definition in the “GaN FET” category.



Setup Name: FET Current Collapse Oscilloscope View

3. RDS [ohm] = VDS / ID
2. VDS [V] = 1 * VHV
1. ID [A] = IHC + IHV

VAR1
Mode: LIN-SGL
Stop: 0 V
NOS: 1
Compliance: 100 mA

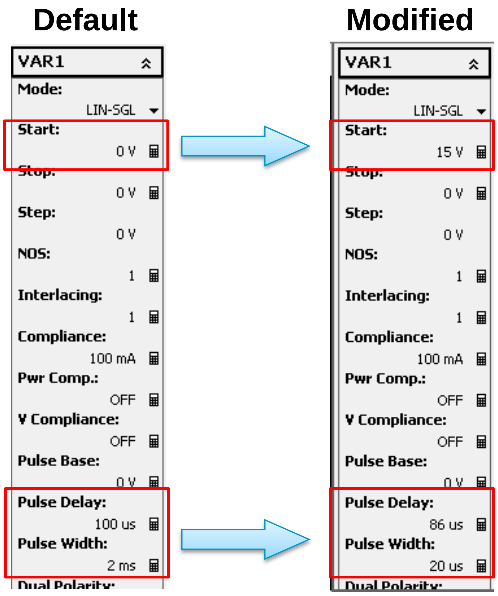
Count: 51
Device ID:
Test
Meas. Delay: AUTO

Unit:	V Name:	I Name:	Mode:	Function:
○ SMU1:HP	VSUB	ISUB	V	CONST
○ SMU3:MC	VSW	ISW	VPULSE	VAR1
● SMU2:MC	VGS	IG	VPULSE	CONST
○ SMU5:HC	VHC	IHC	VPULSE	CONST

Flag	Setup Name	Date	Count	Device ID
	FET Current Collapse Oscillos...	2013/06/26 15:36:44	51	T1=28
	FET Current Collapse Oscillos...	2013/06/26 14:14:44	50	T1=28
	FET Current Collapse Oscillos...	2013/06/26 14:14:12	49	T1=28
	FET Current Collapse Oscillos...	2013/06/26 14:14:02	48	T1=28.7,T2=N...
	FET Current Collapse Oscillos...	2013/06/26 14:13:37	47	T1=28.9,T2=N...
	FET Current Collapse Oscillos...	2013/06/26 14:13:23	46	T1=28.8,T2=N...

Fig. 3-5-6 FET current collapse measurement pre-set in the Tracer Test Mode

In this pre-set, choosing the appropriate SMU for each terminal and modification of some parameters are necessary to be able to discharge the cabling before turning on the DUT (for more details of the “FET Current Collapse Oscilloscope View, please refer to section 5-4).
In this setup, the VSW is assigned as the “VAR1” and the change of its Start voltage as 15 V to turn on the FET switch. Then, the Pulse Delay is changed to 86 μs and the Pulse Width to 20 μs (refer to figure 3-5-7).



Default

VAR1

Mode: LIN-SGL

Start: 0 V

Stop: 0 V

Step: 0 V

NOS: 1

Interlacing: 1

Compliance: 100 mA

Pwr Comp.: OFF

V Compliance: OFF

Pulse Base: 0 V

Pulse Delay: 100 us

Pulse Width: 2 ms

Modified

VAR1

Mode: LIN-SGL

Start: 15 V

Stop: 0 V

Step: 0 V

NOS: 1

Interlacing: 1

Compliance: 100 mA

Pwr Comp.: OFF

V Compliance: OFF

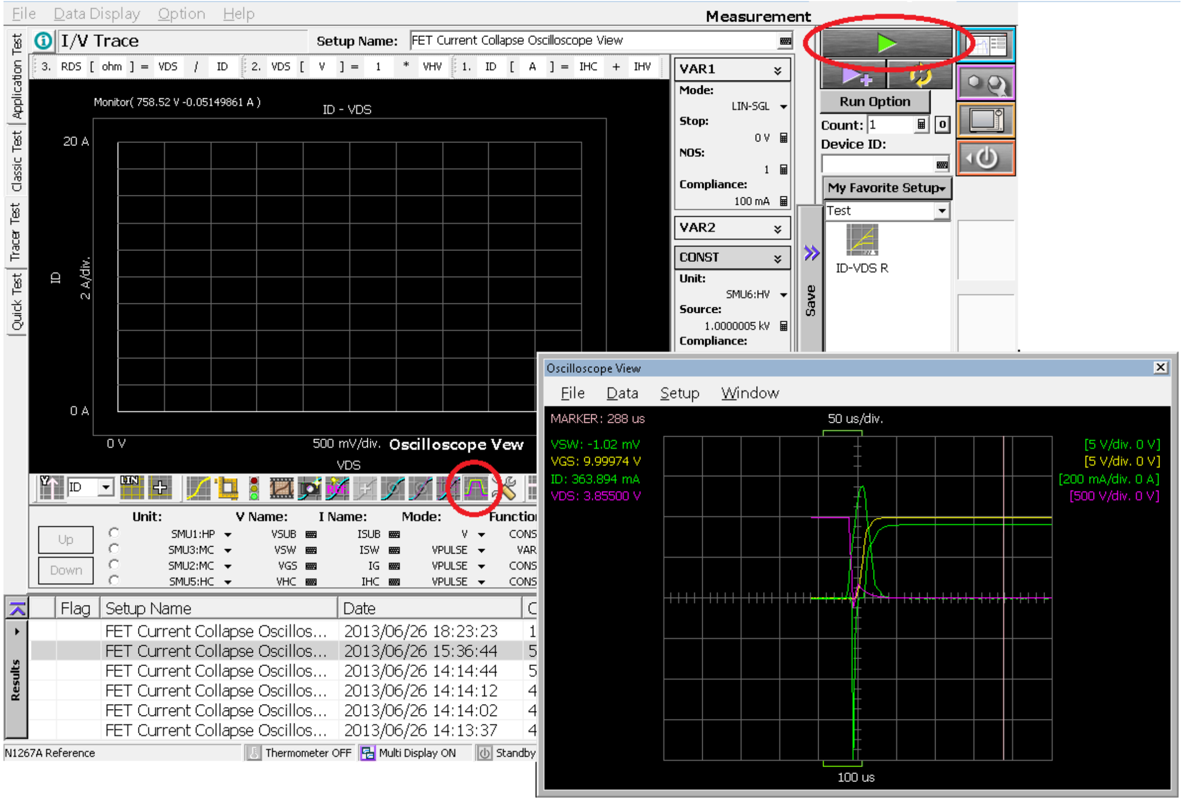
Pulse Base: 0 V

Pulse Delay: 86 us

Pulse Width: 20 us

Figure 3-5-7 Modification of the GaN Current Collapse Oscilloscope View to discharge cablings.

To see the results, display the Oscilloscope View, then click the “Measurement” button (refer to figure 3-5-8).



Setup Name: FET Current Collapse Oscilloscope View

Monitor(758.52 V -0.05149861 A)

VAR1

Mode: LIN-SGL

Stop: 0 V

NOS: 1

Compliance: 100 mA

VAR2

CONST

Unit: SMU6:HV

Source: 1.0000005 kV

Count: 1

Device ID:

Test

Unit:	V Name:	I Name:	Mode:	Function
SMU1:HP	VSUB	ISUB	V	CONS
SMU3:MC	VSW	ISW	VPULSE	VAR
SMU2:MC	VGS	IG	VPULSE	CONS
SMU5:HC	VHC	IHC	VPULSE	CONS

Flag	Setup Name	Date
	FET Current Collapse Oscillos...	2013/06/26 18:23:23
	FET Current Collapse Oscillos...	2013/06/26 15:36:44
	FET Current Collapse Oscillos...	2013/06/26 14:14:44
	FET Current Collapse Oscillos...	2013/06/26 14:14:12
	FET Current Collapse Oscillos...	2013/06/26 14:14:02
	FET Current Collapse Oscillos...	2013/06/26 14:13:37

MARKER: 288 us

VSW: -1.02 mV [5 V/div. 0 V]

VGS: 9.99974 V [5 V/div. 0 V]

ID: 363.894 mA [200 mA/div. 0 A]

VDS: 3.85500 V [500 V/div. 0 V]

Fig. 5-5-8 Running the FET Current Collapse Oscilloscope View

3-7. Self-Heating of Switch

Figure 3-7-1 shows an example of the “FET Current Collapse I/V-t Sampling” application test. When looking at a transient of the drain current, it looks like recovering from the current collapse during the measurement.
But while increasing the drain current (Id), the measured drain voltage (Vds) and the on-resistance (Rds) are also increasing. This does not match the expected behavior of the device with the current collapse.

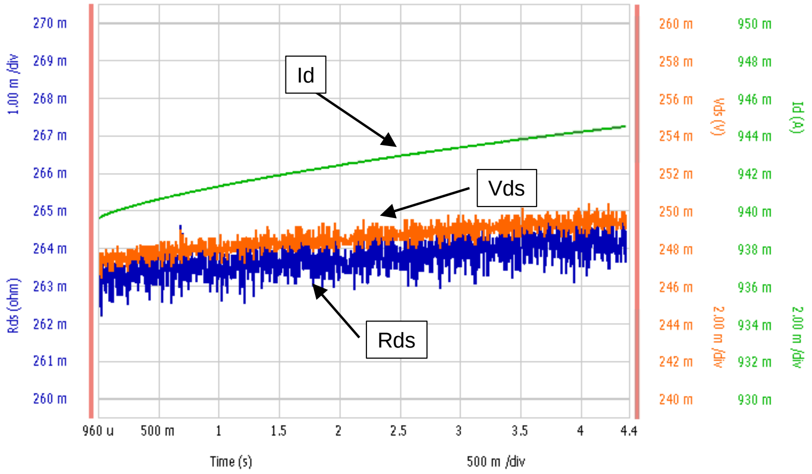


Fig. 3-7-1 Example of transient behavior measured by the FET Current Collapse I/V-t Sampling application test.

Figure 3-7-2 shows an exact example of the current collapse measurement in GaN HEMT. Normally, when measuring a current collapse, both the measured Rds and Vds are getting smaller during a measurement.

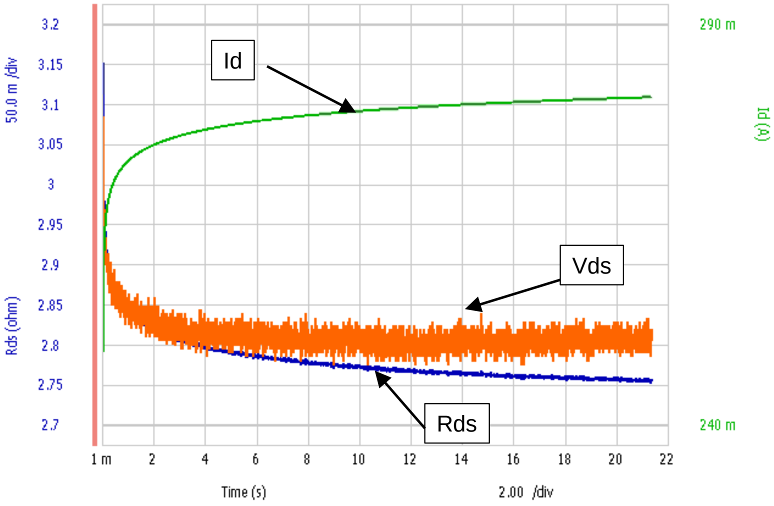


Fig. 3-7-2 Example of Current Collapse Measurement

The reason why the Vds is decreasing is an increase of the voltage drop at the switch in the N1267A. It is caused by the increase of the Id.
When looking at figure 3-7-1, the Rds and Vds are also increasing with the increase of the Id. This effect is caused by self-heating of the switch of the N1267A. In the case of figure 3-7-1, the Rds

increases due to self-heating of the DUT itself. Even if the Rds increases, the Id increases too. This is caused by the decrease of the voltage drop at the switch due to the self-heating of it. The voltage drop across the switch decreases during measurement and it increases the Vds. Finally, the Id increases too.

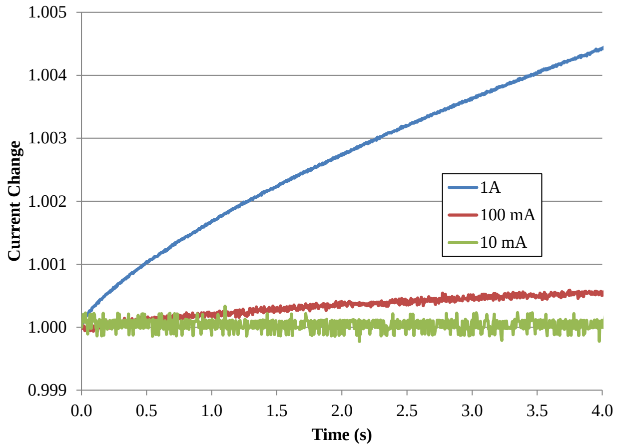


Fig. 3-7-3 Id change by self-heating of the N1267A switch

Due to this voltage drop change at the switch, basically, the current collapse measured with the N1267A should be evaluated by the change of the measured Rds, not by the Id. Since the voltage at the drain terminal is monitored by the HVSMU, the self-heating of the switch does not affect the measured Rds.

From this example, when the drain current range is 10 mA, self-heating of the switch can be ignored. When looking at the beginning of the transient, the change of the Id by self-heating of the switch is relatively small. According to figure 3-7-4, even if the Id is about 1 A, the change in 1 ms is less than 0.1 %.

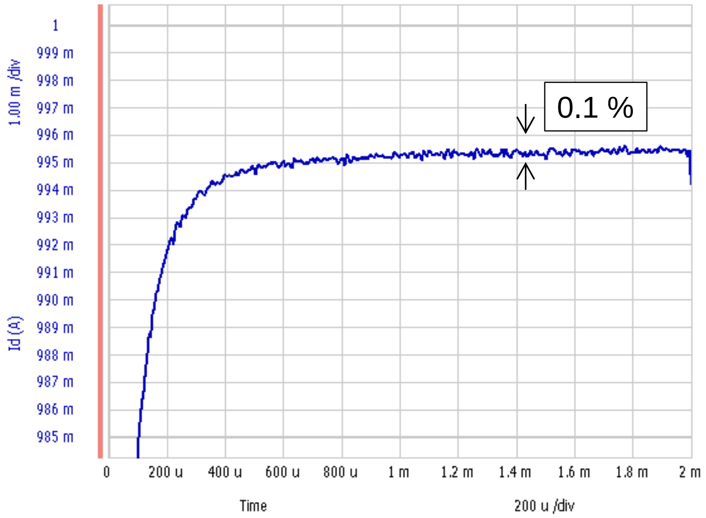


Fig. 3-7-4 Example of short term Id change

From these examples, it is possible to say the Id can be used to monitor the current collapse in short term measurement. But for long term measurement, the Rds should be used if the Id is larger than 100 mA.

3-8. Repeatability of Measured Resistance

The resistance of the DUT is calculated from the measured current and voltage. For example, in the case of GaN FET, the Rds is calculated by

$$\mathrm{Rds} = \frac{\mathrm{VDS}}{\mathrm{ID}}$$

When using the N1267A, the drain voltage is measured by the HVSMU, and its measurement resolution is determined by its voltage range to apply the off-state stress voltage. Table 5-8-1 shows the voltage measurement resolution of each output range.

Table 5-8-1

Range	Measurement Resolution
200 V	200 µV
500 V	500 µV
1500 V	1.5 mV
3000 V	3 mV

So, the resolution of measured resistance depends on the stress voltage, not the voltage range at the on-state measurement.

Figure 3- 8-1 shows an example of the measured Rds with different stress voltage.

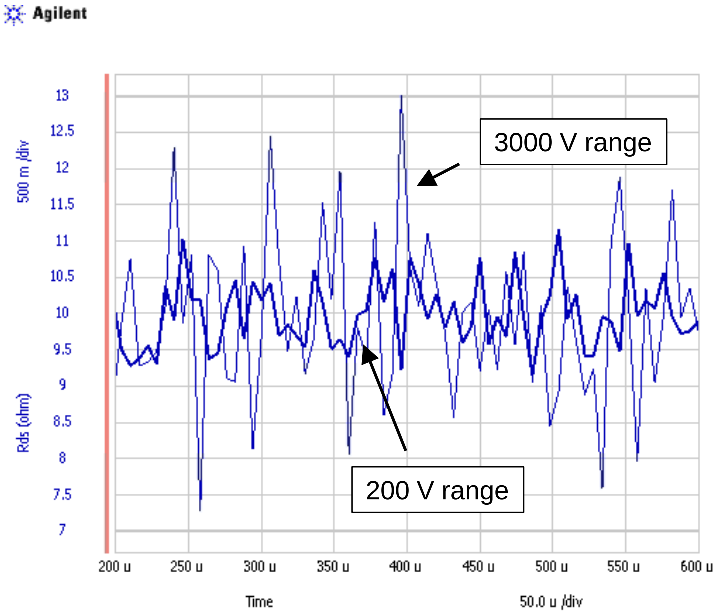
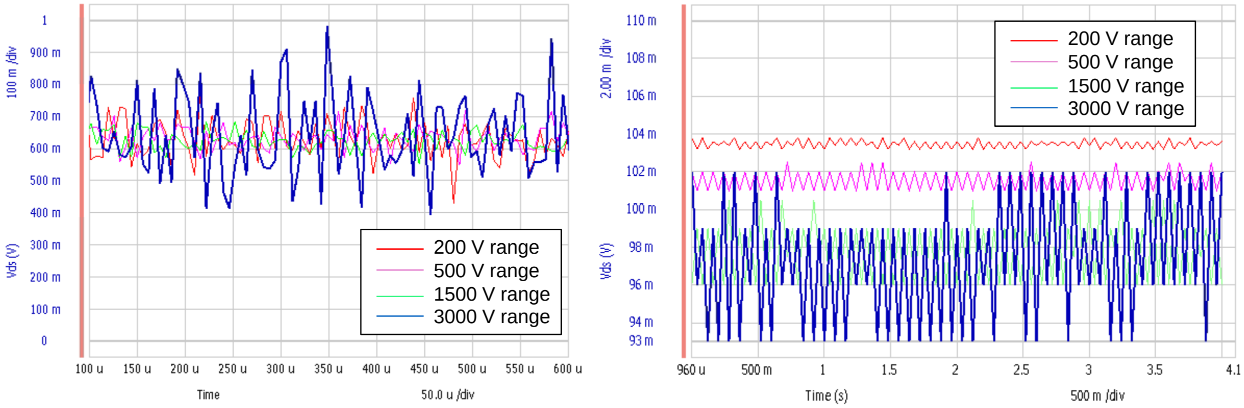


Fig. 3-8-1 Repeatability of measured Rds by stress voltage

A 200 V stress voltage is used for the 200 V range, and 1510 V is used for the 3000 V range. The 20 A range is used for on-state current measurement in both cases. The repeatability using the 3000 V range becomes about 2 times worse than the case with the 200 V range. Since this is a rare data measured in a 2-µs sampling interval, the difference between those two ranges is not as much as the resolution difference due to the noise floor of the HVSMU.
Also, since the Vds is measured by the HVSMU, repeatability of the measured Rds is not as good as measured by the HCSMU.

Typically, the noise floor of voltage measurement by HVSMU is bigger than that of current measurement by HCSMU. So, repeatability of measured resistance almost depends on the repeatability of the measured voltage by the HVSMU.

Figure 3-8-2 shows the example of voltage measurement repeatability by HVSMU in different measurement times.



(a) 6 µs sampling (b) 20 ms measurement time

Fig. 3-8-2 Examples of voltage measurement repeatability

From these examples, when using the measurement time long enough, repeatability of the measured voltage almost reaches the voltage measurement resolution. But in the fast sampling measurement, the repeatability of the 200 V, 500 V and 1500 V ranges is almost the same (100 mVp-p). In the 3000 V range, it becomes about 600 mVp-p. For example, when measuring a100 mΩ Rds with 100 mA Id, the measured Vds becomes only10 mV. In this case, the measured Rds is buried under the voltage measurement noise when using a fast sampling mode. This fast sampling mode is used in the “FET Current Collapse Signal Monitor” application test. In this case, only the measured Id is useful to see the change of the DUT characteristics.

3-9. Low Resistance Measurement

Basically, the N1267A is designed to evaluate devices which have a relatively high resistance above 10 Ω. This is based on the idea that the target device is a shrunk test device.
So, when using the N1267A with its normal connection, the measured on-resistance includes the residual resistance of the wiring. The total residual resistance of the wiring is determined by the length of the measurement cable, and it is about 200 mΩ to 300 mΩ.
To eliminate the influence of the residual resistances, a Kelvin connection is possible with the N1267A. Figure 3-9-1 shows wiring diagrams of non-Kelvin and Kelvin connection using the N12767A.

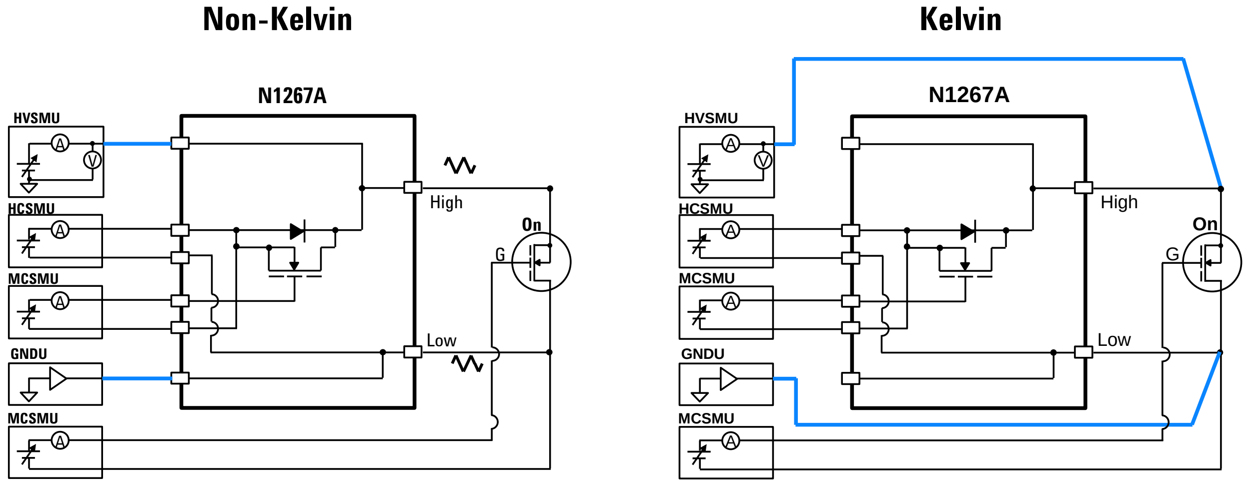


Fig. 3-9-1 Non-Kelvin connection and Kelvin connection

To configure the Kelvin connection, the outputs of the HVSMU and GNDU are connected to the DUT directly. By this, the voltage monitoring points are moved to the DUT, and the influence from the residual resistances of the wiring can be eliminated.
Figure 3-9-2 is an example of the Rds measured by non-Kelvin and Kelvin connection.

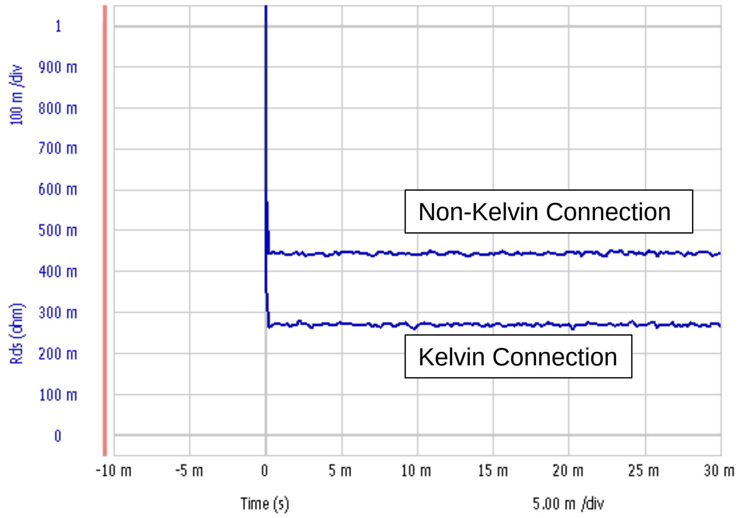


Fig. 3-9-2 Effect of Non-Kelvin connection

In this case, a 3.0 m HV coaxial cable and a 1.5 m GNDU cable are used, and the total residual resistance is about 170 mΩ. From this example, it is recommended to use the Kelvin connection if the Rds of the DUT is 10 Ω or less to make the measurement error less than 1 %. Also, the Kelvin connection is recommended for on-wafer measurement to remove an influence from the unstable contact resistance between the probe needles and the contact pads.

Non-Kelvin connection is simple and requires less options and accessories. So if the DUT is a packaged device and has a resistance of 10 Ω or larger, the non-Kelvin configuration is a reasonable choice.

4. Step-by-Step Measurement Example

4-1. Choosing Connection Type

At first, it is necessary to choose an appropriate cable connection type. If the on-resistance of the DUT is lower than 10 Ω, a Kelvin connection is recommended because the residual resistance of the wiring is sub Ω level. Also, for an on-wafer measurement, a Kelvin connection is recommended, too, to eliminate the influence of unstable contact resistances between the probe needles and the contact pads. But, to configure the Kelvin connection, additional options, accessories and cables are required. Also, the wiring between the B1505A and the DUT becomes more complicated compared to the case of the non-Kelvin configuration.

Based on the range of the Rds of DUT to be measured, choose an appropriate connection type. The details of wiring for each connection type are described in the following sections.

In this section, the B1505A with the following modules is used as an example.

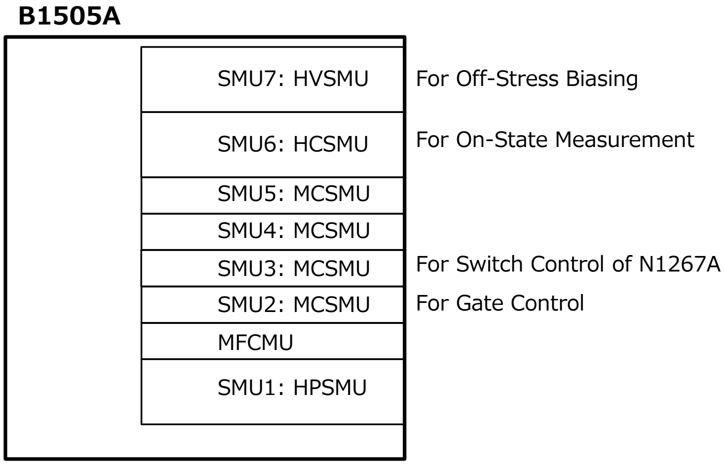


Fig. 4-1-1 Module configuration of B1505A used in this section

And, the 3-pin in-line socket module is used for both N1259A and N1265A test fixtures.

A GaN FET is used as a sample of this hands-on section. For GaN diodes, basically the measurement technique is almost the same as the one for GaN FET. So, it is not difficult to measure GaN diode based on that similarity to the measurement techniques for GaN FET. Differences from the FET measurement are,

- Diode measurement does not require a gate bias,
- Polarity of drain bias for the on-state measurement is negative.

4-1-1 Non-Kelvin Connection using N1259A Test Fixture

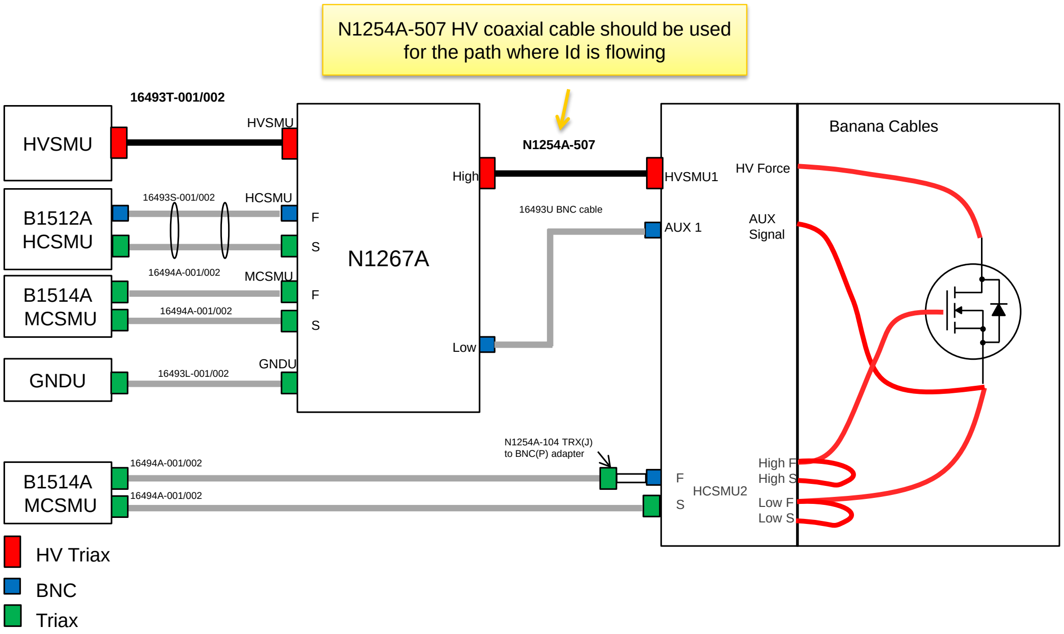


Fig. 4-1-1Wiring diagram of non-Kelvin connection with N1259A

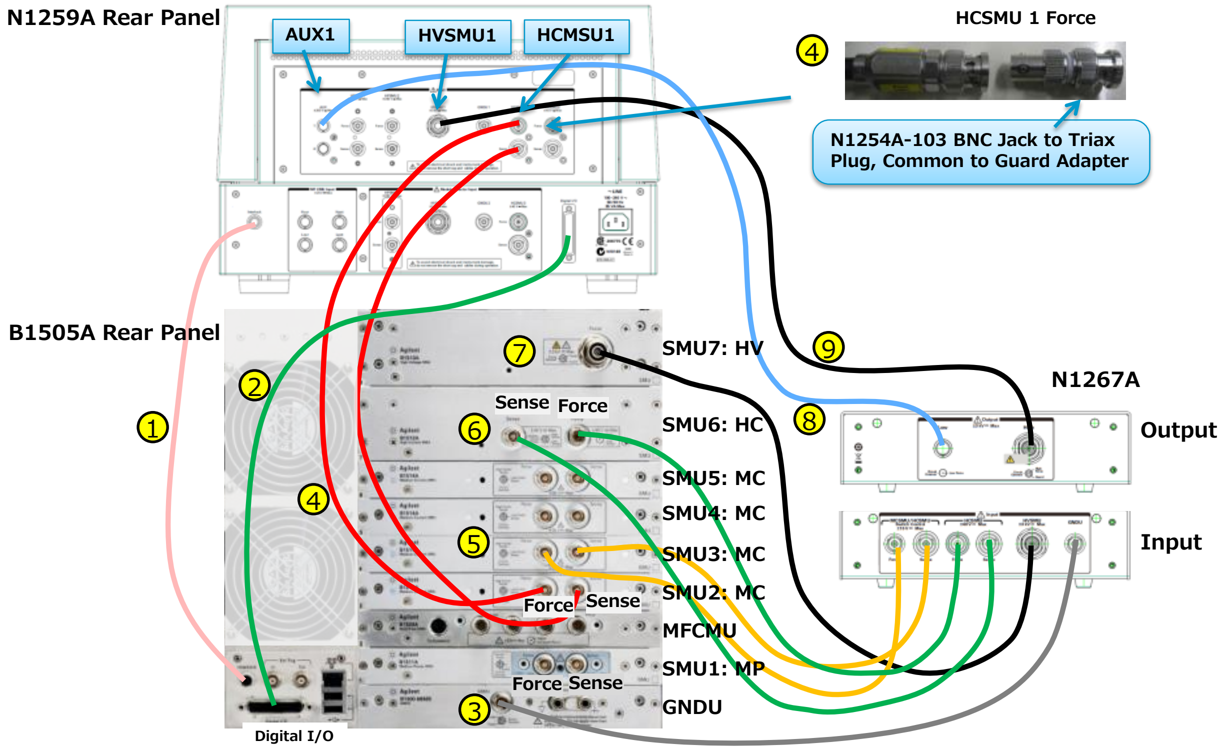


Fig. 4-1-2 Connection between B1505A, N1267A and N1259A (Non-Kelvin)

1. Connect the interlock cables between the B1505A and the N1259A.
2. Connect the digital I/O output of the B1505A to the digital I/O input of the N1259A by the digital I/O cable.
3. Connect the GNDU output of the B1505A to the GNDU input of the N1267A by the GNDU cable.
4. Connect the SMU2: MCSMU outputs of the B1505A to the HCSMU1 input of the N1259A by the triax cables. To connect the triax outputs of SMU to the BNC inputs of the HCMSU Force on the N1259A, use the N1254A-103 BNC jack adapter.
5. Connect the SMU3: MCSMU outputs of the B1505A to the switch control input of the N1267A by the triax cable.
6. Connect the HCSMU outputs of the B1505A to the HCSMU inputs of the N1267A by the HCSMU cable.
7. Connect the HVSMU output of the B1505A to the HVSMU input of the N1267A by the HV triax cables.
8. Connect the Low output of the N1267A to the AUX1 input of the N1259A by the HC coaxial cable.
9. Connect the High output of the N1267A to the HVSMU1 input of the N1259A by the HV Triax cable.

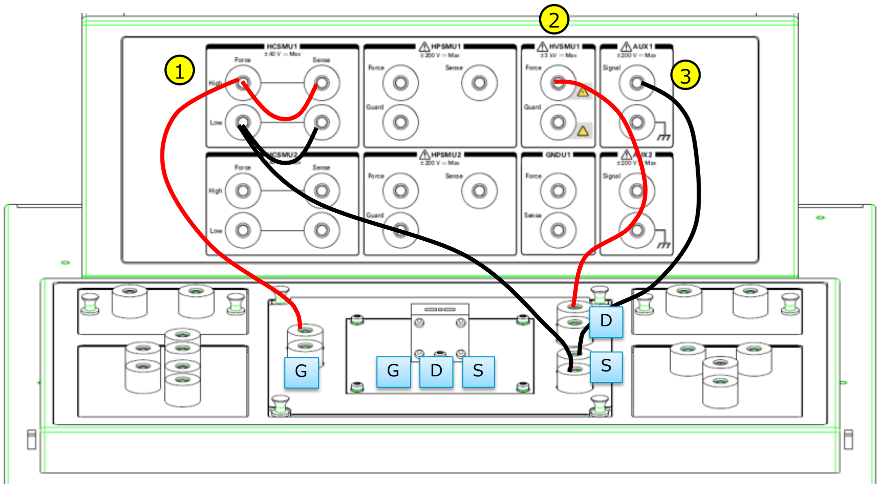


Fig. 4-1-3 Connection to the DUT to be measured (Non-Kelvin)

1. Connect the HCSMU outputs as follows.
    - The High Force and the High Sense
    - The Low Force and the Low Sense
    - The High Force to the Gate Force
    - The Low Force to the Source Force
    - The High Sense to the Gate Sense
2. Connect the HVSMU1 Force to the Drain Force
3. Connect the AUX1 Signal to the Source Force

4-1-2 Kelvin Connection using N1259A Test Fixture

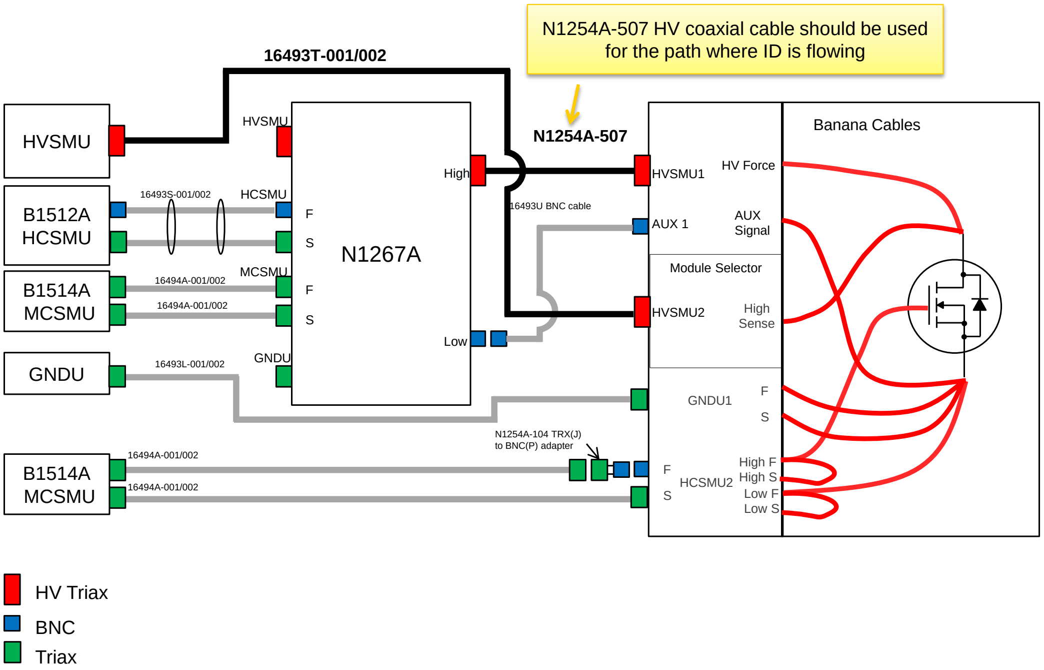


Fig. 4-1-4 Wiring diagram of Kelvin connection with N1259A

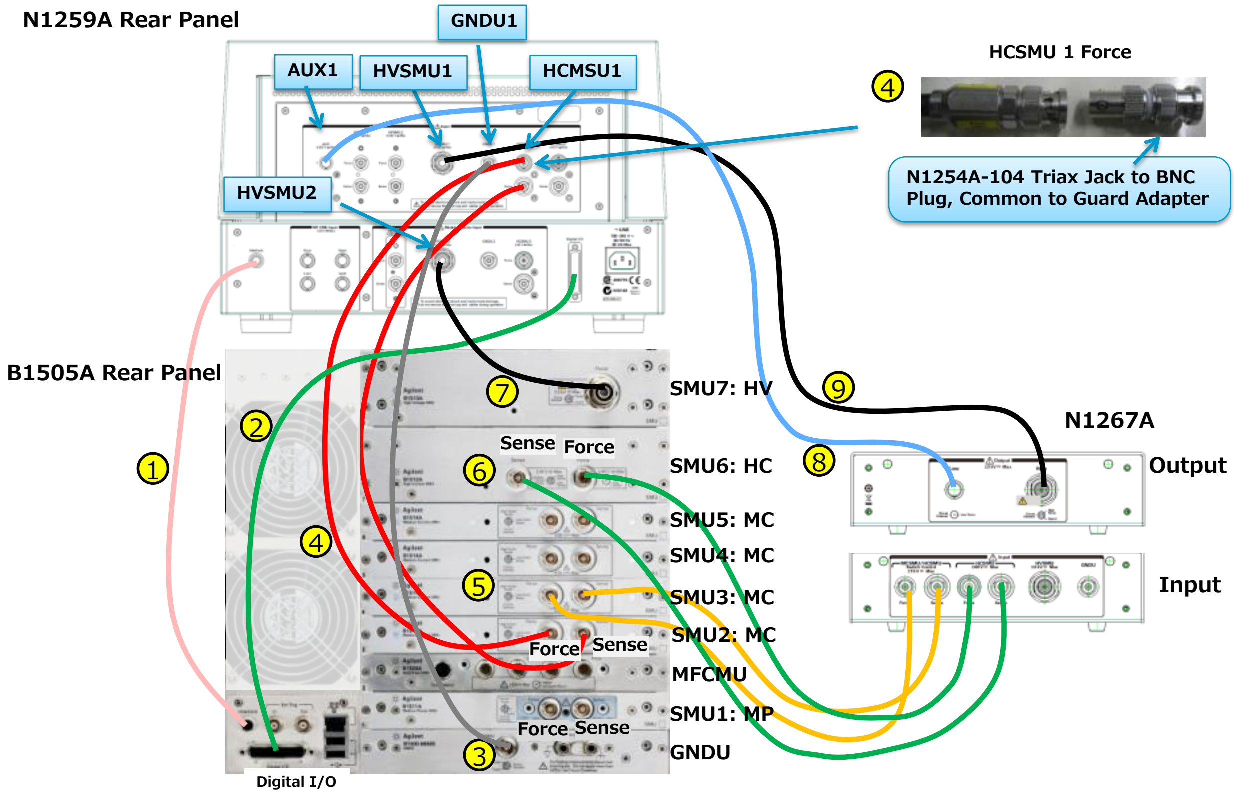


Fig. 4-1-5 Connection between B1505A, N1267A and N1259A (Kelvin)

1. Connect the interlock cables between the B1505A and the N1259A.
2. Connect the digital I/O output of the B1505A to the digital I/O input of the N1259A by the digital I/O cable.
3. Connect the GNDU output of the B1505A to the GNDU1 input of the N1259A by the GNDU cable.
4. Connect the SMU2: MCSMU outputs of the B1505A to the HCSMU1 input of the N1259A by the triax cables.
   To connect the triax outputs of SMU to the BNC inputs of the HCMSU Force on the N1259A, use the N1254A-103 BNC jack adapter.
5. Connect the SMU3: MCSMU outputs of the B1505A to the switch control input of the N1267A by the triax cable.
6. Connect the HCSMU outputs of the B1505A to the HCSMU inputs of the N1267A by the HCSMU cable.
7. Connect the HVSMU output of the B1505A to the HVSMU2 input of the N1259A by the HV triax cables.
8. Connect the Low output of the N1267A to the AUX1 input of the N1259A by the HC coaxial cable.
9. Connect the High output of the N1267A to the HVSMU1 input of the N1259A by the HV Triax cable.

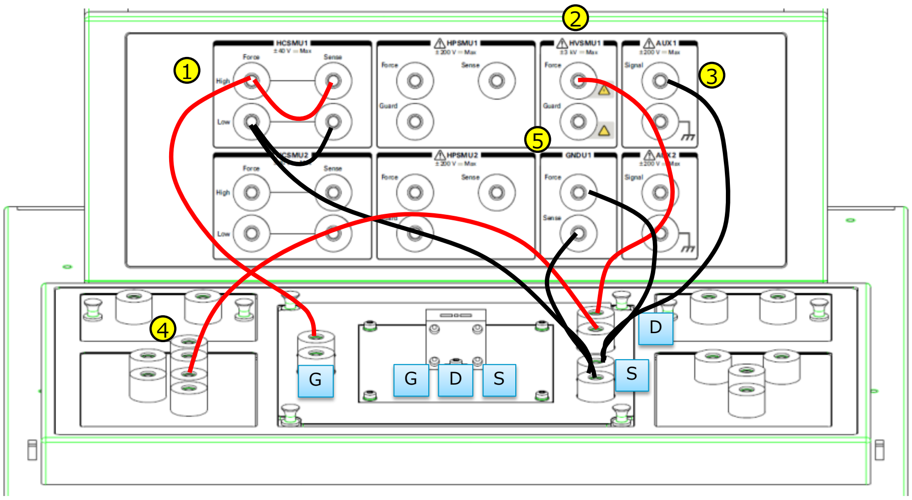
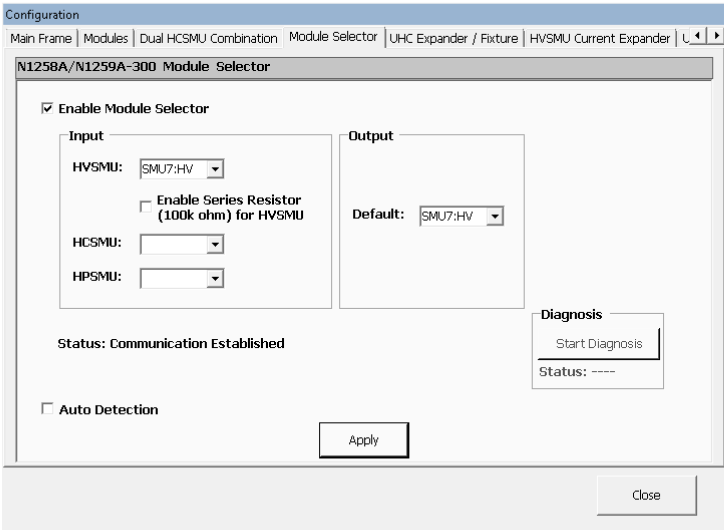


Fig. 4-1-6 Connection to the DUT to be measured (Kelvin)

1. Connect the HCSMU outputs as follows.
   - The High Force and the High Sense
   - The Low Force and the Low Sense
   - The High Force to the Gate Force
   - The Low Force to the Source Force
   - The High Sense to the Gate Sense
2. Connect the HVSMU1 Force to the Drain Force
3. Connect the AUX1 Signal to the Source Force
4. Connect the High Sense of the module selector output to the Drain Sense
5. Connect the GNDU outputs as followings
   - The Sense to the Source Sense
   - The Force to the Source Sense

And, to enable the voltage monitoring by the HVSMU, configure the module selector as follows.

- Check the “Enable Module Selector”
- Select the HVSMU to be connected to the HVSMU2 input as the “HVSMU:”
  (DO NOT check the “Enable Series Resistor” here)
- Select the HVSMU to monitor the drain voltage as the default output of the selector
- Click the “Apply” button to make this setup effective



N1258A/N1259A-300 Module Selector

☑ Enable Module Selector

Input

HVSMU: SMU7:HV

☐ Enable Series Resistor (100k ohm) for HVSMU

HCSMU:

HPSMU:

Output

Default: SMU7:HV

Status: Communication Established

Diagnosis

Status: ----

☐ Auto Detection

Fig. 4-1-7 N1259A module selector setup for Kelvin connection

4-1-3 Non-Kelvin Connection using N1265A Test Fixture

In this case, to convert the HV triax output of the N1267A to the SHV, the N1262A-021 Universal R-Box is used. Before using the N1262A-021, short the HVSMU input and the SHV output of the R-BOX internally.

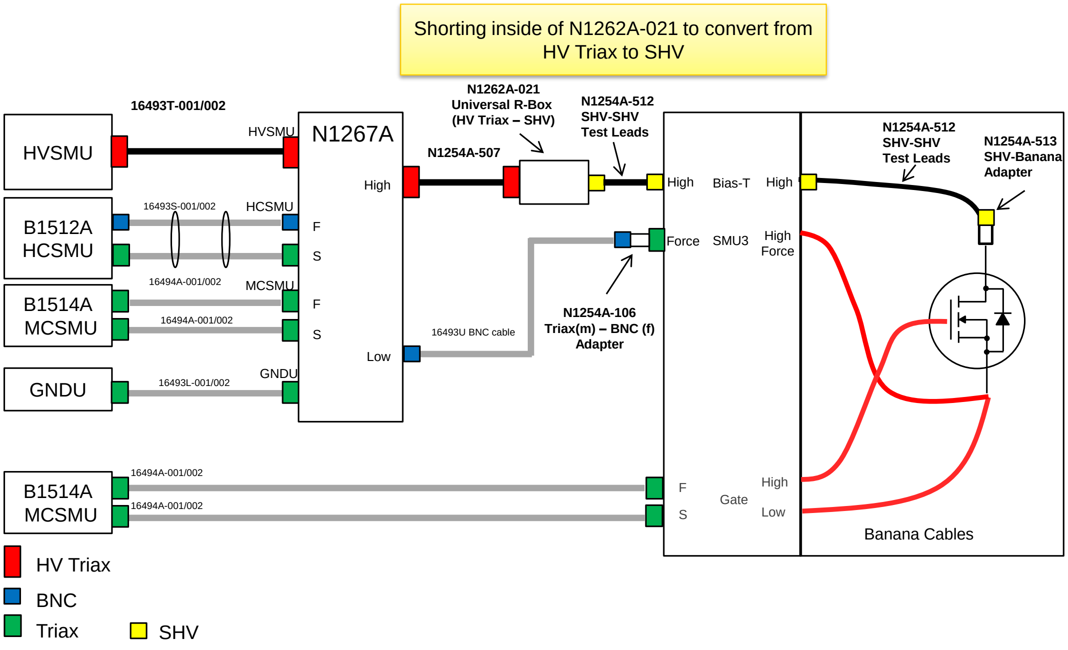


Fig. 4-1-8 Wiring diagram of non-Kelvin connection with N1265A

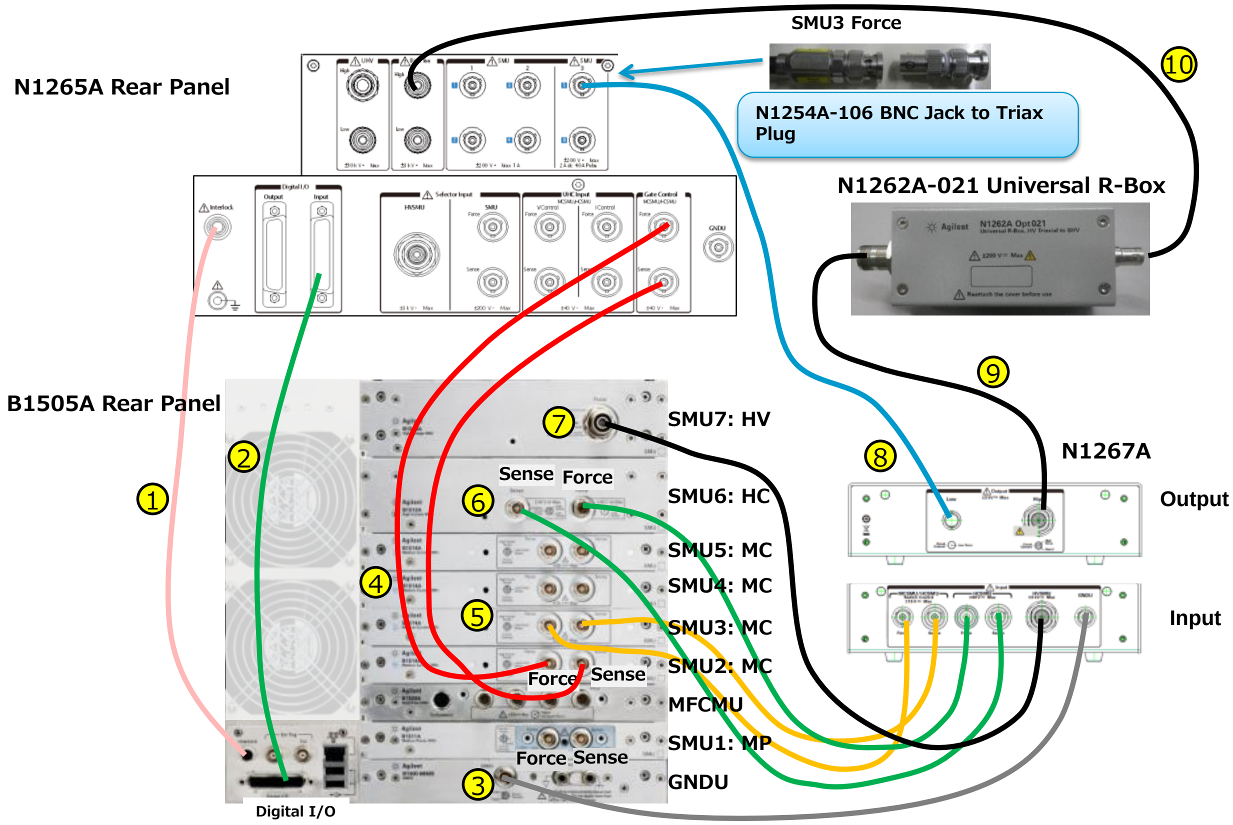


Fig. 4-1-9 Connection between B1505A, N1267A and N1265A (Non-Kelvin)

1. Connect the interlock cables between the B1505A and the N1265A.
2. Connect the digital I/O output of the B1505A to the digital I/O input of the N1265A by the digital I/O cable.
3. Connect the GNDU output of the B1505A to the GNDU input of the N1267A by the GNDU cable.
4. Connect the SMU2: MCSMU outputs of the B1505A to the Gate Control input of the N1265A by the triax cables.
5. Connect the SMU3: MCSMU outputs of the B1505A to the switch control input of the N1267A by the triax cable.
6. Connect the HCSMU outputs of the B1505A to the HCSMU inputs of the N1267A by the HCSMU cable.
7. Connect the HVSMU output of the B1505A to the HVSMU input of the N1267A by the HV triax cables.
8. Connect the Low output of the N1267A to the SMU3 Force input of the N1267A by the HC coaxial cable.

   To connect the coaxial output of the N1267A to the triax inputs of SMU1, use the N1254A-106 BNC Jack to Triax Plug adapter.
9. Connect the High output of the N1267A to the HV triax input of the N1262A-021 by the HV triax cable.
10. Connect the SHV output of the N1262A-021 to the Bias-T High input by the SHV cable.

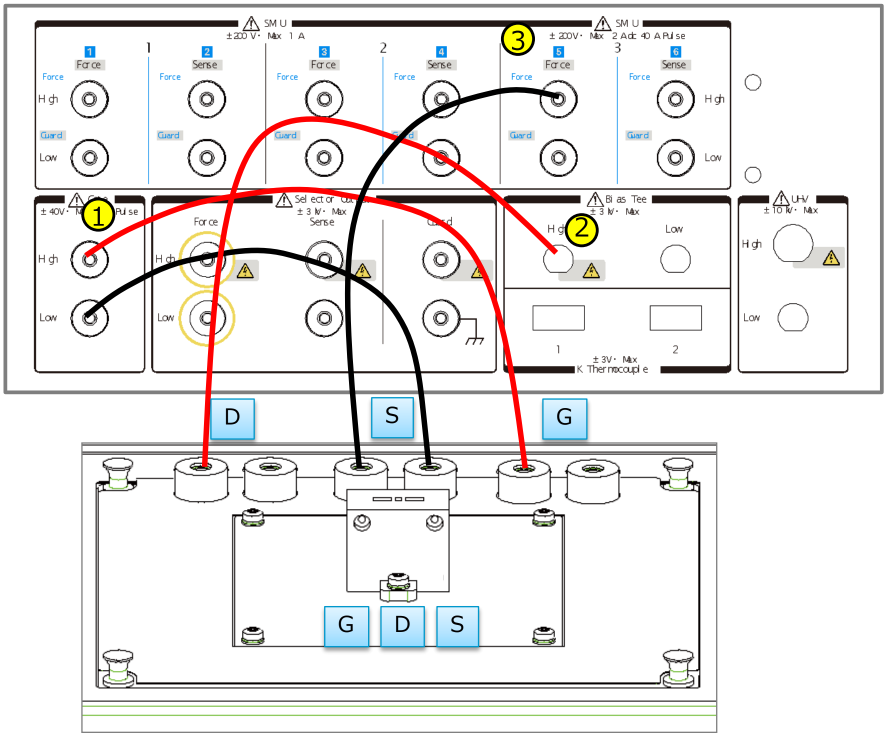
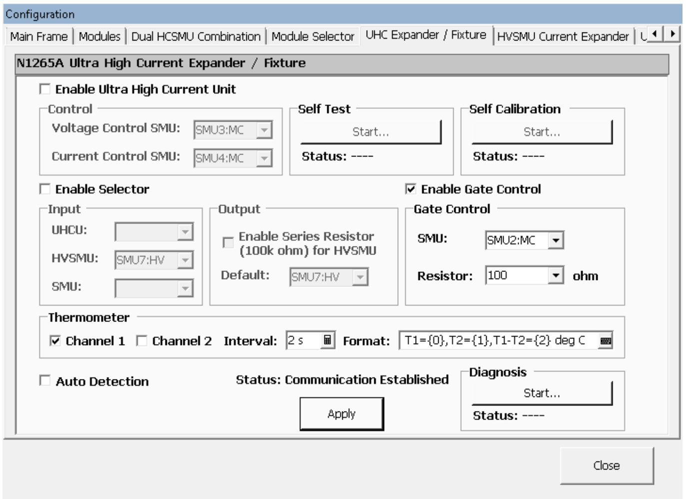


Fig. 4-1-10 Connection to the DUT to be measured (Non-Kelvin)

1. Connect the Gate outputs as follows.
   - The High to the Gate Force
   - The Low to the Source Sense
2. Connect the Bias-T High to the Drain Force
3. Connect the SMU3 High Force to the Source Force

And to enable the gate control terminal of the N1267A, configure the UHC Expander/Fixture as follows.

- Check the "Enable Gate Control"
- Select the MCSMU to connected to the Gate Control input of the N1265A
- Select the appropriate series resistance (Ex. 100 Ohm) to avoid device oscillation.
- Click the "Apply" button to make this setup effective



N1265A Ultra High Current Expander / Fixture

☐ Enable Ultra High Current Unit

Control
Voltage Control SMU: SMU3:MC
Current Control SMU: SMU4:MC

Self Test
Status: ----

Self Calibration
Status: ----

☐ Enable Selector

Input
UHCU:
HVSMU: SMU7:HV
SMU:

Output
☐ Enable Series Resistor (100k ohm) for HVSMU
Default: SMU7:HV

☑ Enable Gate Control

Gate Control
SMU: SMU2:MC
Resistor: 100 ohm

Thermometer
☑ Channel 1 ☐ Channel 2 Interval: 2 s Format: T1={0},T2={1},T1-T2={2} deg C

☐ Auto Detection

Status: Communication Established

Diagnosis
Status: ----

Fig. 4-1-11 N1265A gate control setup for non-Kelvin connection

4-1-4 Kelvin Connection using N1265A Test Fixture

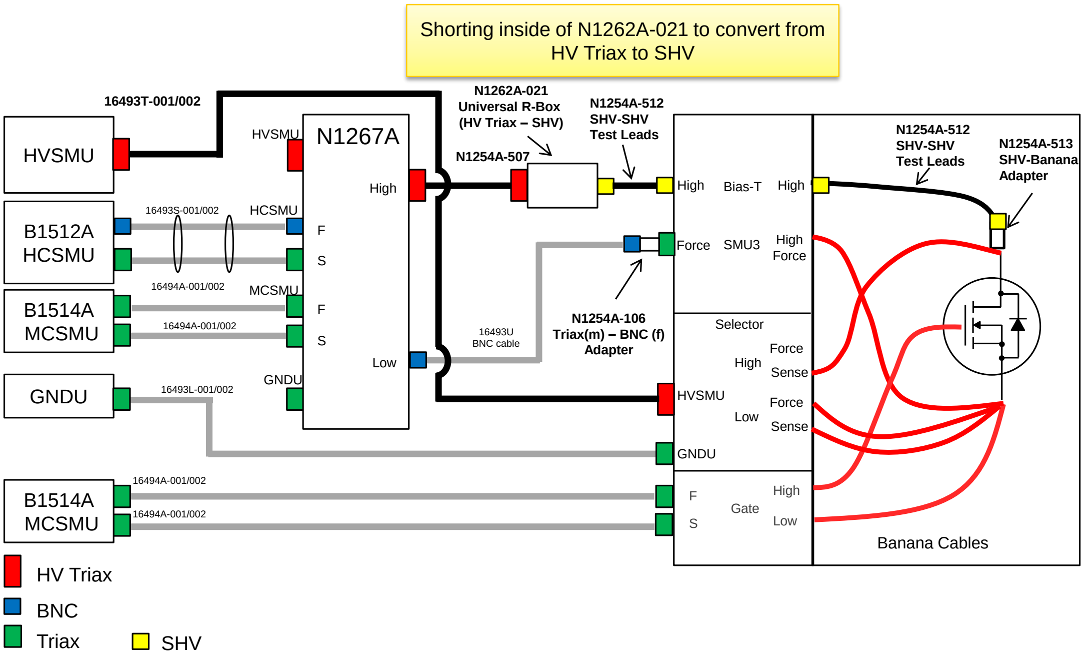


Fig. 4-1-12 Wiring diagram of Kelvin connection with N1259A

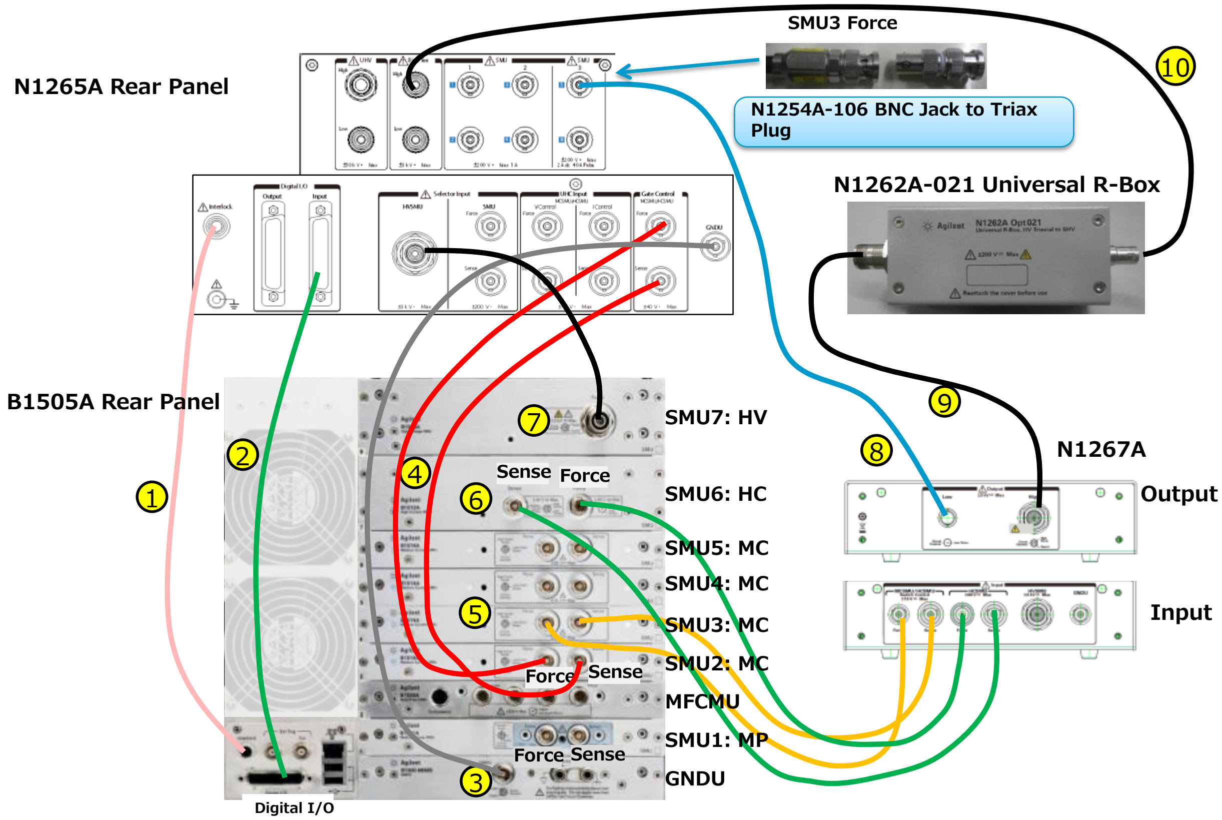


Fig. 4-1-13 Connection between B1505A, N1267A and N1265A (Kelvin)

1. Connect the interlock cables between the B1505A and the N1265A.
2. Connect the digital I/O output of the B1505A to the digital I/O input of the N1265A by the digital I/O cable.
3. Connect the GNDU output of the B1505A to the GNDU input of the 1265A by the GNDU cable.
4. Connect the SMU2: MCSMU outputs of the B1505A to the Gate Control input of the N1265A by the triax cables.
5. Connect the SMU3: MCSMU outputs of the B1505A to the switch control input of the N1267A by the triax cable.
6. Connect the HCSMU outputs of the B1505A to the HCSMU inputs of the N1267A by the HCSMU cable.
7. Connect the HVSMU output of the B1505A to the HVSMU input of the N1265A by the HV triax cables.
8. Connect the Low output of the N1267A to the SMU3 Force input of the N1267A by the HC coaxial cable.

   To connect the coaxial output of the N1267A to the triax inputs of SMU1, use the N1254A-106 BNC Jack to Triax Plug adapter.
9. Connect the High output of the N1267A to the HV triax input of the N1262A-021 by the HV triax cable.
10. Connect the SHV output of the N1262A-021 to the Bias-T High input by the SHV cable.

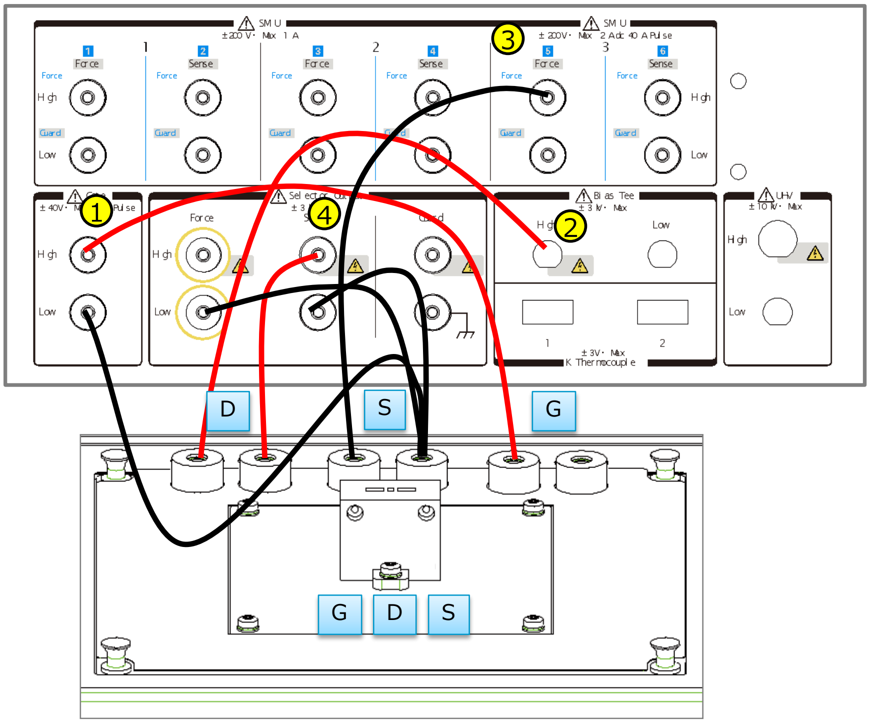
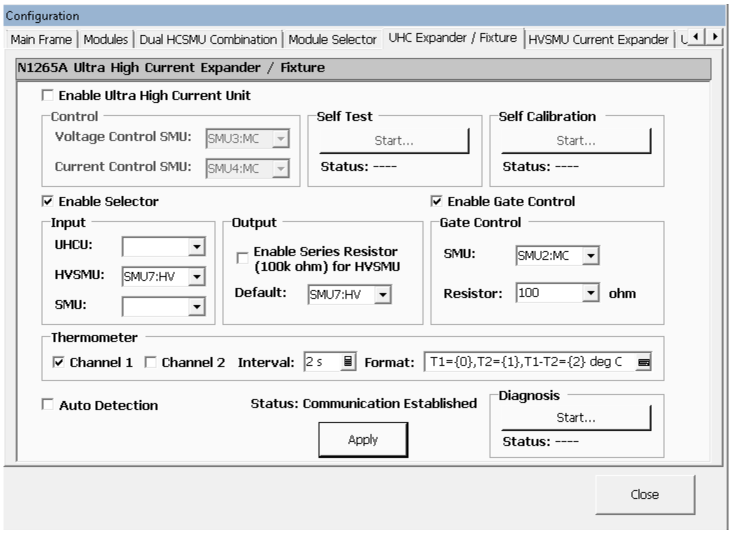


Fig. 4-1-14 Connection to the DUT to be measured (Kelvin)

1. Connect the Gate outputs as follows.
    - The High to the Gate Force
    - The Low to the Source Sense
2. Connect the Bias-T High to the Drain Force
3. Connect the SMU3 High Force to the Source Force
4. Connect the Selector Output as followings
    The High Sense to the Drain Sense
    The Low Sense to the Source Sense
    The Low Force to the Source Force

And to enable the gate control and voltage monitoring by the HVSMU, configure the UHC Expander/Fixture as follows.

- Check the “Enable Gate Control”
- Select the MCSMU to connected to the Gate Control input of the N1265A
- Select the appropriate series resistance (Ex. 100 Ohm) to avoid device oscillation.
- Check the “Enable Selector”
- Select the HVSMU to monitor the drain voltage as the “HVSMU:”.
  (DO NOT check the “Enable Series Resistor” here)
- Select the HVSMU to monitor the drain voltage as the default output of the selector
- Click the “Apply” button to make this setup effective
–



N1265A Ultra High Current Expander / Fixture

☐ Enable Ultra High Current Unit

Control
Voltage Control SMU: SMU3:MC
Current Control SMU: SMU4:MC

Self Test
Status: ----

Self Calibration
Status: ----

☑ Enable Selector

Input
UHCU:
HVSMU: SMU7:HV
SMU:

Output
☐ Enable Series Resistor (100k ohm) for HVSMU
Default: SMU7:HV

☑ Enable Gate Control

Gate Control
SMU: SMU2:MC
Resistor: 100 ohm

Thermometer
☑ Channel 1 ☐ Channel 2 Interval: 2 s Format: T1={0},T2={1},T1-T2={2} deg C

☐ Auto Detection

Status: Communication Established

Diagnosis
Status: ----

Fig. 4-1-15 N1265A module selector setup for Kelvin connection

4-2. Verification of Device Functionality

Before proceeding with the current collapse measurement, it is necessary to verify that the DUT is not damaged and that it is functioning correctly. The presets for the ID-VDS and ID(off)-VDS measurement are available to verify the on-characteristics and the off-characteristics of GaN FET. For GaN diode, the IF-VF and IR-VR are available for the same purpose.

In the following sections, a GaN FET which has the following characteristics is used as a sample device. Some of the measurement parameters and settings have to be modified based on the characteristics of your device and its measurement condition.

Table 4-2-1 Electric parameters of sample device

Parameter	Value
VDSS	120 V
VGS(off)	-3.5 V
Rds(on)	2.7 Ω

4-2-1. Verifying On-Characteristics of Device

To measure the on-characteristics of the DUT, the ID-VDS preset of the Tracer Test mode is used. Choose “ID-VDS” from the “GaN FET (N1267A) category of the preset (refer to figure 4-2-1).

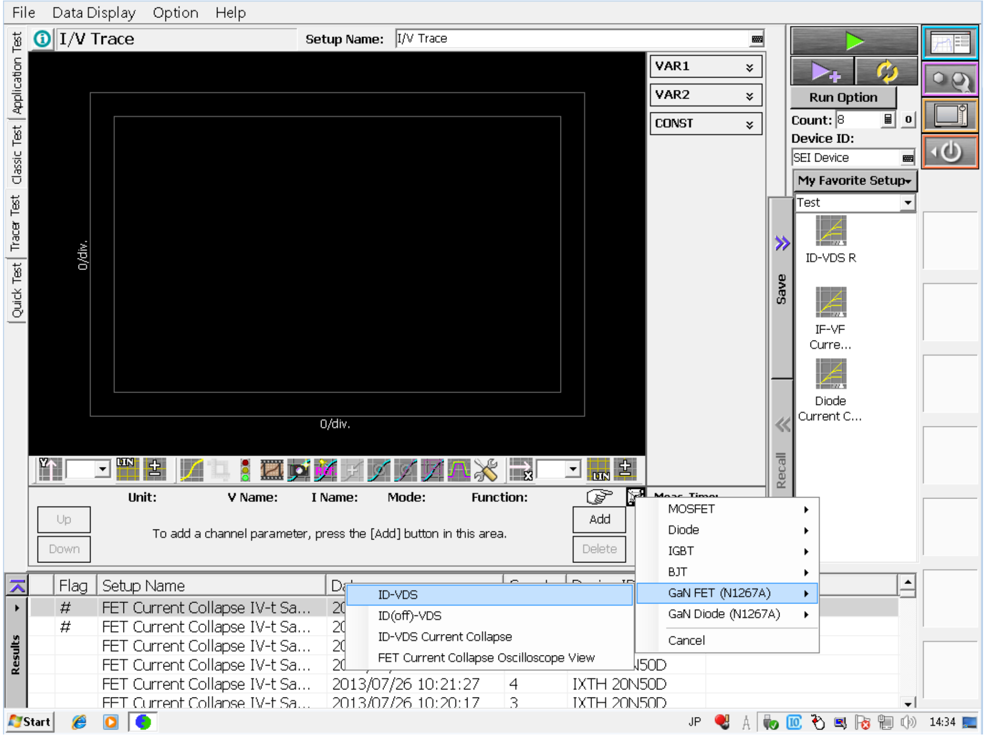
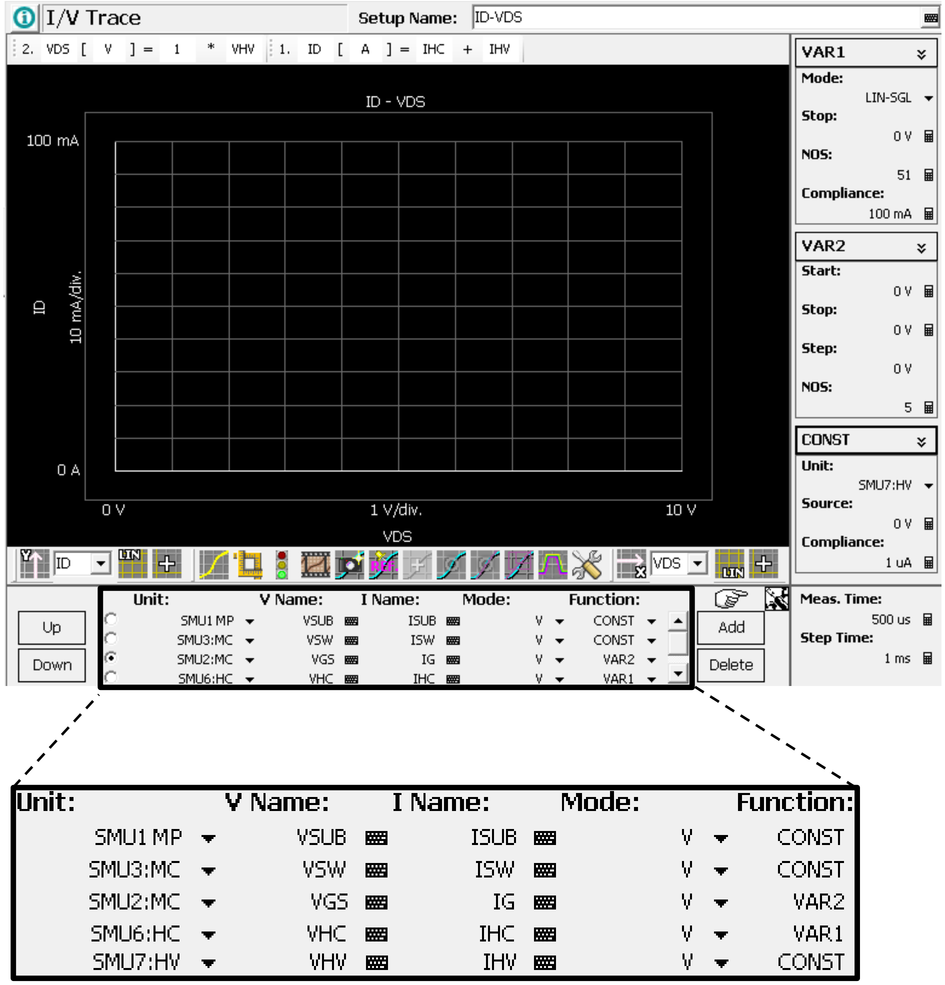


Fig. 4-2-1. Choosing ID-VDS from the preset group

Choose appropriate SMUs for each terminal. If the configuration of your system is not the same as this example, modify the channel assignment to match your system.



Setup Name: ID-VDS

2. VDS [V] = 1 * VHV

1. ID [A] = IHC + IHV

VAR1
Mode: LIN-SGL
Stop: 0 V
NOS: 51
Compliance: 100 mA

VAR2
Start: 0 V
Stop: 0 V
Step: 0 V
NOS: 5

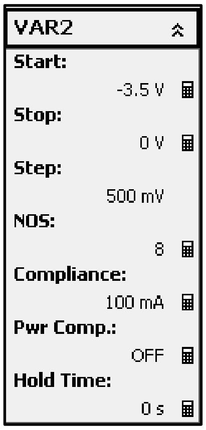
CONST
Unit: SMU7:HV
Source: 0 V
Compliance: 1 uA

Meas. Time: 500 us
Step Time: 1 ms

Unit:	V Name:	I Name:	Mode:	Function:
SMU1 MP	VSUB	ISUB	V	CONST
SMU3:MC	VSW	ISW	V	CONST
SMU2:MC	VGS	IG	V	VAR2
SMU6:HC	VHC	IHC	V	VAR1
SMU7:HV	VHV	IHV	V	CONST

Fig. 4-2-2 Assignment of SMUs for each terminal

Next, set the gate bias sweep (VAR2) as below.



VAR2
Start: -3.5 V
Stop: 0 V
Step: 500 mV
NOS: 8
Compliance: 100 mA
Pwr Comp.: OFF
Hold Time: 0 s

Fig. 4-2-3 Setup for the gate bias sweep

The start voltage of the gate bias sweep should be low enough to make the DUT turned off and the stop voltage should be high enough to turn on the DUT completely. The NOS (Number of Step) is selected to make the Step voltage small enough to see the series of the Id-Vds curves.

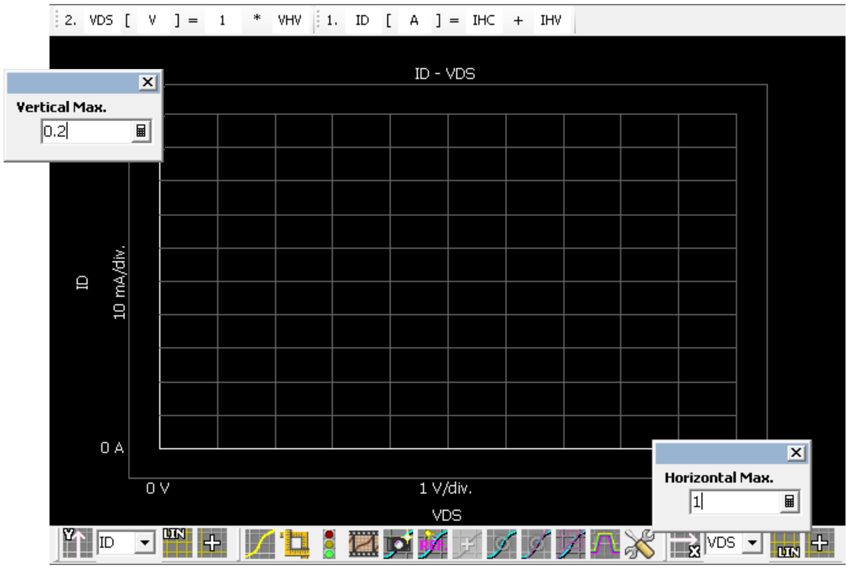
[Tips]

Normally, 100 mA current compliance is high enough to drive the gate terminal.
If the DUT requires more, change the mode of the MCSMU assigned for the VGS to the VPULSE mode.

● SMU2:MC | VGS | IG | VPULSE | VAR2

In the VPULSE mode, the maximum output current of the MCSMU is extended to 1 A. If the DUT requires more than 1 A, it is necessary to use the HCSMU instead of the MCSMU to apply the gate bias. Also, sometimes, inserting a 50 Ω shunt resistor in parallel to the gate and source terminals is useful to stop oscillation of the DUT. In this case, 100 mA compliance limits the output voltage range within +/-5 V. If the DUT requires more, it is necessary to use the VPULSE mode instead of the V mode, too.

Next, change the scale of the display to match your expected VDS and ID ranges. To change the scale, click the number of the scale at the end of each axis and input the number of them respectively (refer to figure 4-2-4).



2. VDS [V] = 1 * VHV

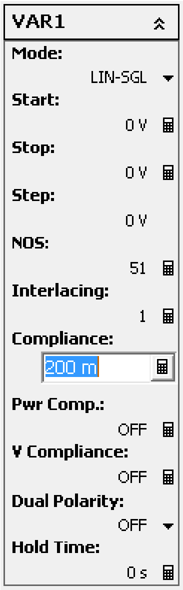
1. ID [A] = IHC + IHV

Vertical Max.: 0.2

Horizontal Max.: 1

Fig. 4-2-4 Change the scale of the display

Next, set the current compliance in the VAR1 sweep lower than the allowable drain current limit of the DUT to protect the DUT during a measurement (refer to figure 4-2-5).



VAR1

Mode: LIN-SGL

Start: 0 V

Stop: 0 V

Step: 0 V

NOS: 51

Interlacing: 1

Compliance: 200 m

Pwr Comp.: OFF

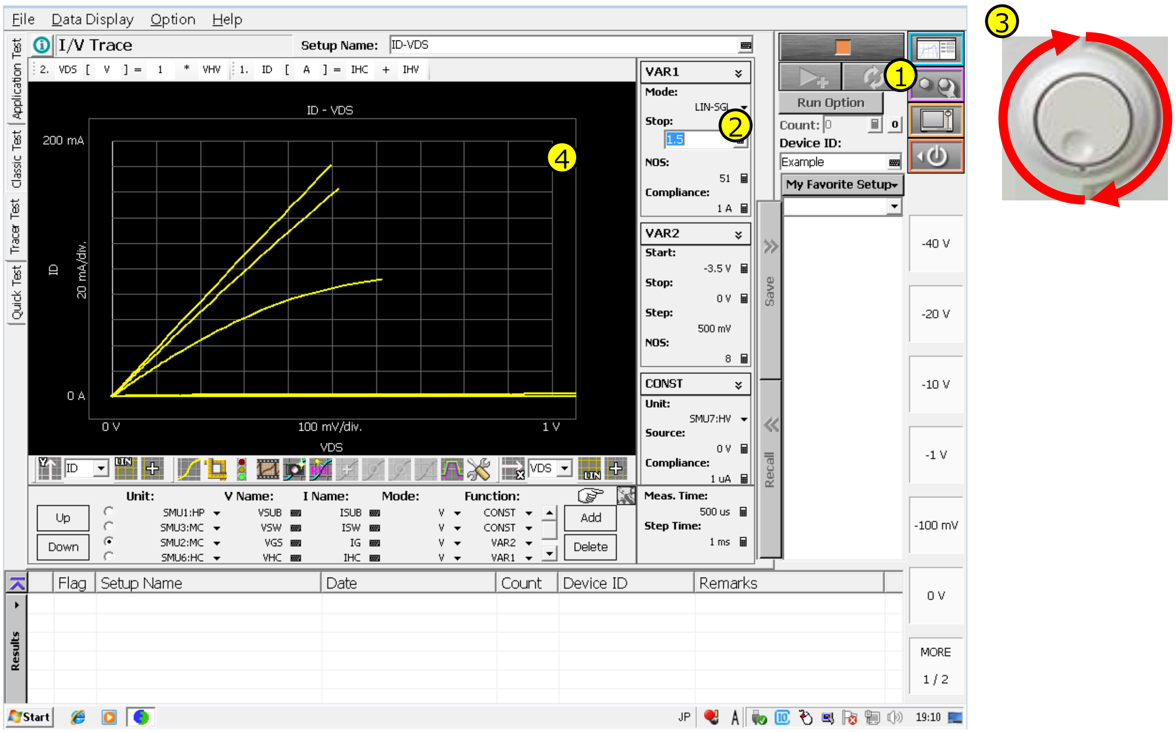
V Compliance: OFF

Dual Polarity: OFF

Hold Time: 0 s

Fig. 4-2-5 Setting an appropriate current compliance

Then, verify the Id-Vds characteristics of the device by using the interactive operation capability of the Tracer Test mode.



Setup Name: ID-VDS

VAR1
Mode: LIN-SGL
Stop: 1.5
NOS: 51
Compliance: 1 A

VAR2
Start: -3.5 V
Stop: 0 V
Step: 500 mV
NOS: 8

CONST
Unit: SMU7:HV
Source: 0 V
Compliance: 1 uA

Meas. Time: 500 us
Step Time: 1 ms

Count: 0
Device ID: Example
My Favorite Setup

	Unit:	V Name:	I Name:	Mode:	Function:
○	SMU1:HP	VSUB	ISUB	V	CONST
○	SMU3:MC	VSW	ISW	V	CONST
●	SMU2:MC	VGS	IG	V	VAR2
○	SMU6:HC	VHC	IHC	V	VAR1

Flag	Setup Name	Date	Count	Device ID	Remarks

Fig. 4-2-6 Verifying Id-Vds characteristics by interactive operation of the Tracer Test mode

1. Click the Repeat button.
2. Select the Stop voltage of the VAR1 sweep.
3. Rotate the knob of the B1505A clockwise to increase the Stop voltage until the expected Id-Vds curves are displayed on the screen.

[Tips]

Due to the voltage drop at the switch of the N1267A, the voltage at the end of each trace is not the same as the Stop voltage specified in the VAR1.

When measuring a relatively lower current, the measured traces will get noisier. In that case, incresing the Meas. Time will help get smoother traces.

Meas. Time: 500 us

Step Time: 1 ms

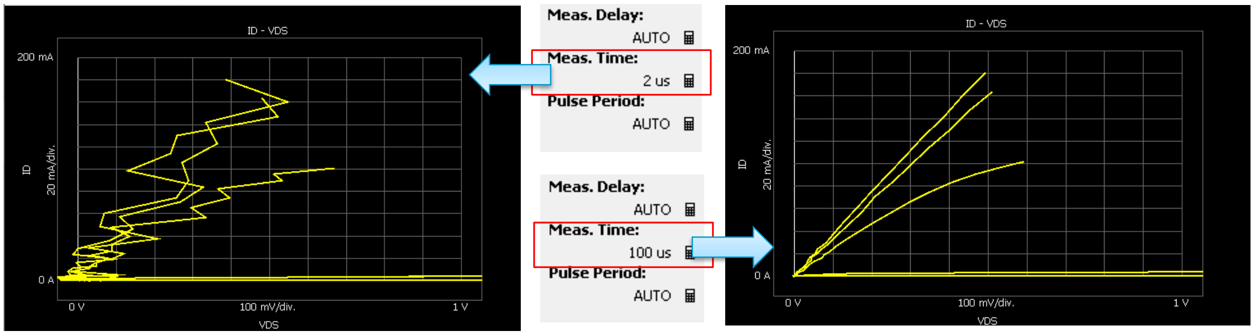
Fig. 4-2-7 Measurement time setting

Just increasing the Meas. Time is enough. The Step Time is automatically increased if it is not enough for the modified measurement time.

[Tips]

If you want to measure the drain current higher than 1 A, change the mode of the HCSMU assigned for VHC to the “VPULSE” mode. It can extend its maximum current up to 20 A. In this case, the initial pulse width is 1 ms and the measurement time is 2 µs. It is necessary to make measured traces smoother, increase the measurement time until the traces become smooth enough. Figure 4-2-8 shows an example of the ID-VDS curves measured with 2 µs and 100 µs measurement time.

It is obvious that the 2 µs measurement time is not enough even for the 100 mA current measurement.



Meas. Delay: AUTO

Meas. Time: 2 us

Pulse Period: AUTO

Meas. Delay: AUTO

Meas. Time: 100 us

Pulse Period: AUTO

Fig. 4-2-8 Improvement of smoothness by increasing the measurement time

---

[Tips]

If an unexpected fluctuation is observed on the measured ID-VDS traces, one possible case is the DUT oscillation.

Figure 4-2-9 shows an example of the ID-VDS traces with a device oscillation. The one trace goes down after a certain drain voltage and gets bumpy. To check the DUT oscillation, the Oscilloscope View function of EasyEXPERT is really helpful. The Oscilloscope View can monitor the voltage and current at each SMU in a minimum 2 µs sampling interval. If the frequency of the DUT oscillation is slower than the sampling interval, the oscillation can be observed by the Oscilloscope view.

Figure 4-2-9 shows the example of the ID-VDS curve with device oscillation and drain current waveform monitored by the Oscilloscope View.

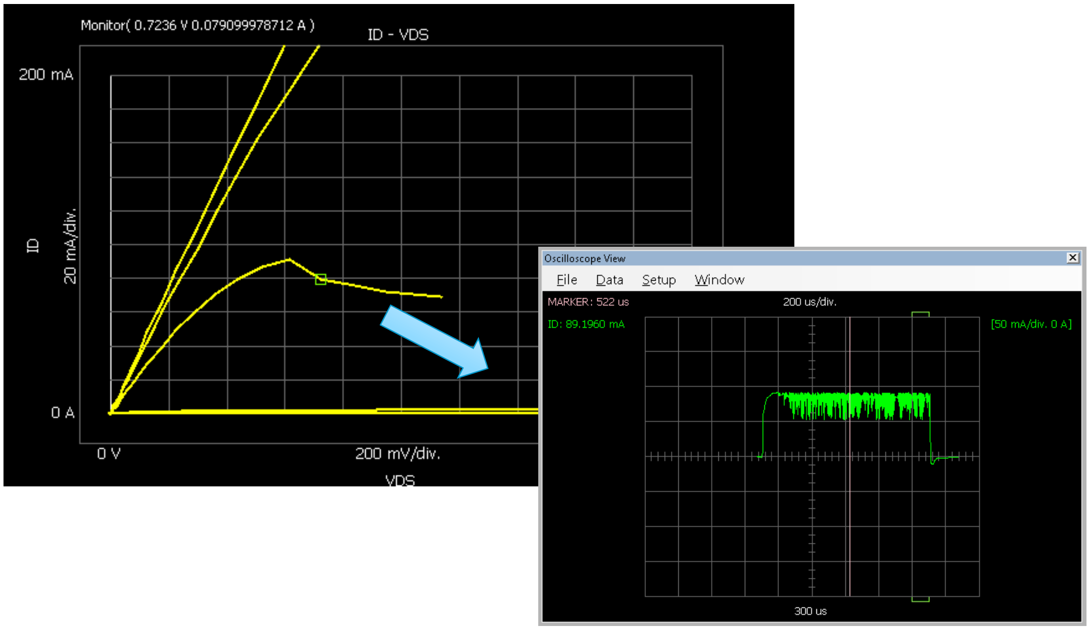


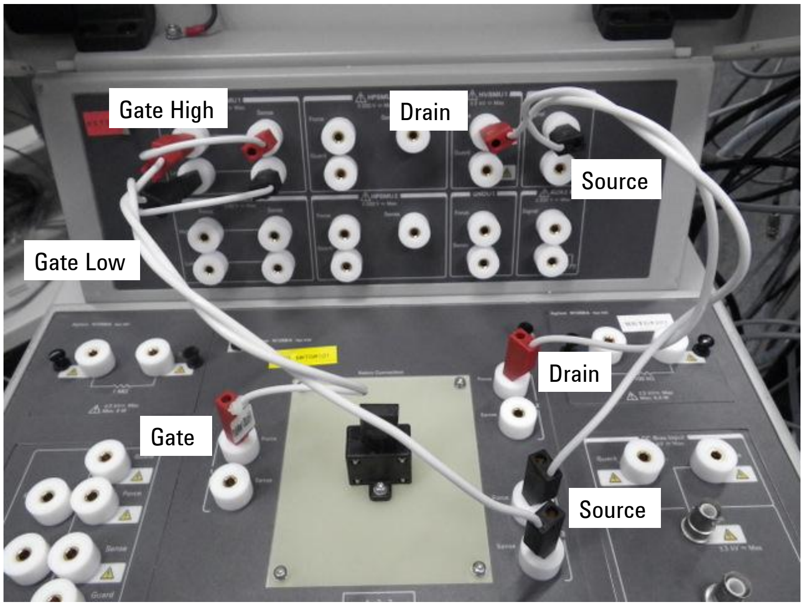
Fig. 4-2-9 Example of fluctuated ID-VDS curve by device oscillation and its waveform

The waveform at the rectangular marker on the ID-VDS curve is displayed in the Oscilloscope view window, and it shows an oscillation.

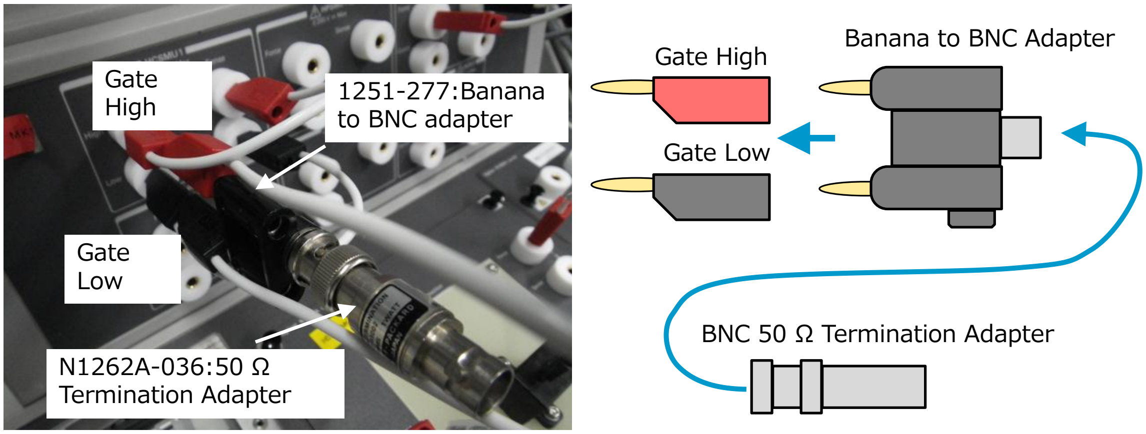
To enable the Oscilloscope view, at least one measurement channel has to be operated in the “PULSE” mode (VPULSE or IPULSE). In this case, the HCSMU to measure the on-state current is operated in the “VPULSE” mode.

For more details about the Oscilloscope View, please refer to chapter 4 of the “Quick Start and Demonstration Guide of B1505A UHCU, HVMCU and UHVU”.

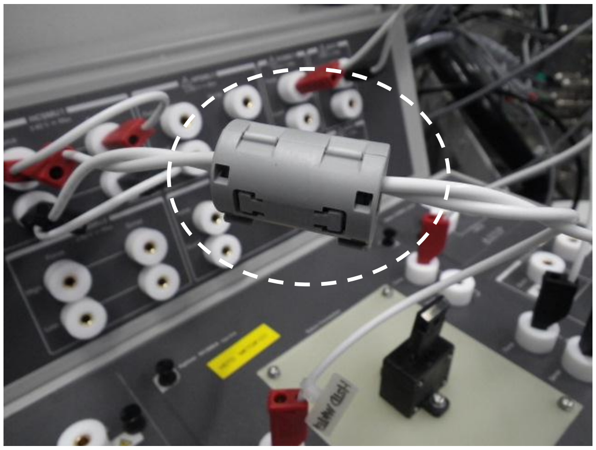
There are several techniques to stop the DUT oscillation. The easiest method is just twisting the measurement cables. For example, twist the high and low cables to apply the gate bias. Also, twist the cable connected to the drain and source, too. Twisting those cables reduces inductive components created by the current loop created by them. Also, inserting a 50 Ω resistance between the gate and source or adding a ferrite core to the cabling will be useful to stop the oscillation in many cases. When using the N1265A, changing the series resistance of the Gate drive is also useful. Figure 4-2-10 shows examples of techniques to stop the device oscillation.



(a) Twisting measurement cables



(b) Inserting 50 Ω resistor to the Gate drive

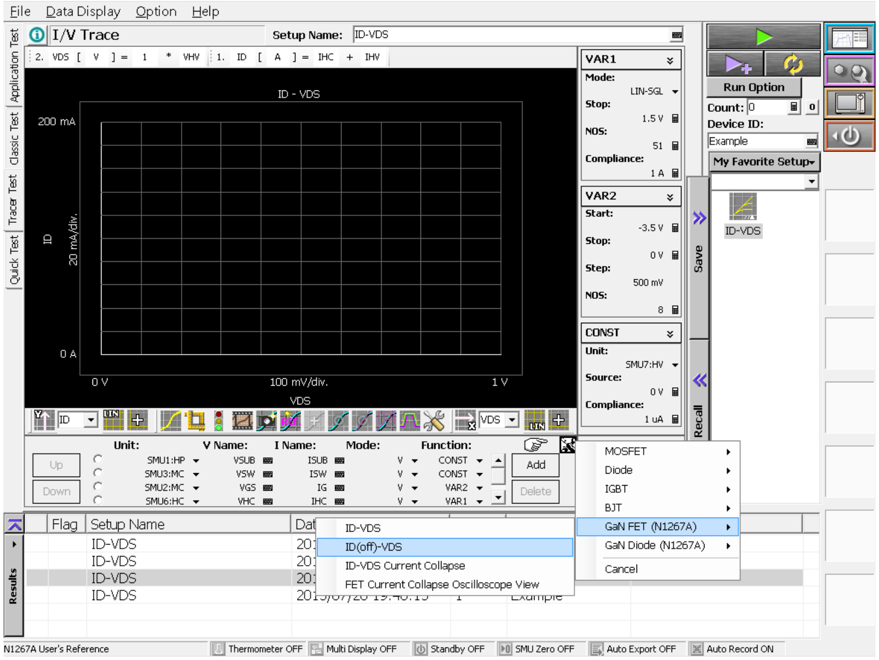


(c) Adding ferrite core

Fig. 4-2-10 Examples of techniques to stop device oscillation

4-2-2. Verifying Off-leakage Current of Device

In this step, the off-leakage characteristic of the DUT is verified. If the measured off-leakage current at the target off-state stress voltage is larger than the maximum output current of the HVSMU, the HVSMU cannot apply the required voltage. The maximum output current range of the HVSMU is 8 mA if its output voltage is less than or equal to 1500 V, and 4 mA if it is over 1500 V. First, choose “ID(off)-VDS” from the preset group of “GAN FET (N1267)” (refer to figure 4-2-11).



Setup Name: ID-VDS

VAR1
Mode: LIN-SGL
Stop: 1.5 V
NOS: 51
Compliance: 1 A

VAR2
Start: -3.5 V
Stop: 0 V
Step: 500 mV
NOS: 8

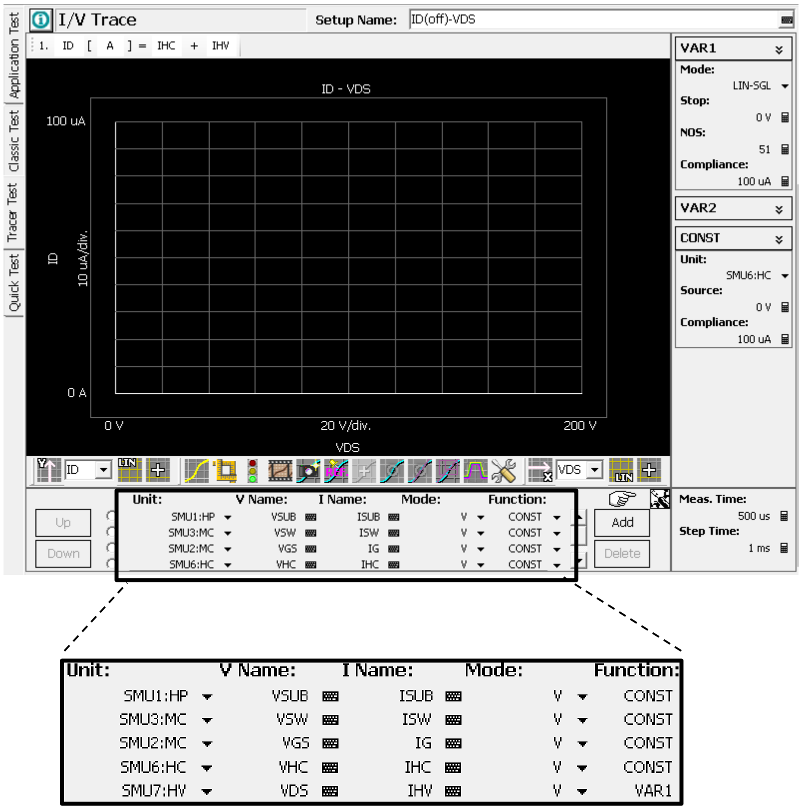
CONST
Unit: SMU7:HV
Source: 0 V
Compliance: 1 uA

Count: 0
Device ID: Example

Unit:	V Name:	I Name:	Mode:	Function:
SMU1:HP	VSUB	ISUB	V	CONST
SMU3:MC	VSW	ISW	V	CONST
SMU2:MC	VGS	IG	V	VAR2
SMU6:HC	VHC	IHC	V	VAR1

Fig. 4-2-11 Choosing ID(off)-VDS from the Preset Group

Next, choose appropriate SMUs for each terminal. If the configuration of your system is not the same as this example, modify the channel assignment to match your system (refer to figure 4-2-12).



I/V Trace

Setup Name: ID(off)-VDS

1. ID [A] = IHC + IHV

VAR1
Mode: LIN-SGL
Stop: 0 V
NOS: 51
Compliance: 100 uA

CONST
Unit: SMU6:HC
Source: 0 V
Compliance: 100 uA

Meas. Time: 500 us
Step Time: 1 ms

Unit:	V Name:	I Name:	Mode:	Function:
SMU1:HP	VSUB	ISUB	V	CONST
SMU3:MC	VSW	ISW	V	CONST
SMU2:MC	VGS	IG	V	CONST
SMU6:HC	VHC	IHC	V	CONST
SMU7:HV	VDS	IHV	V	VAR1

Fig. 4-2-12 Assignment of SMUs for each terminal

And, specify the appropriate current compliance to protect the DUT from a sudden and unexpected breakdown during a measurement (refer to figure 4-2-13).

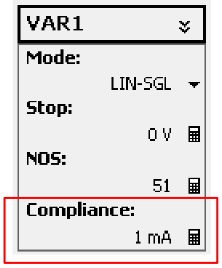
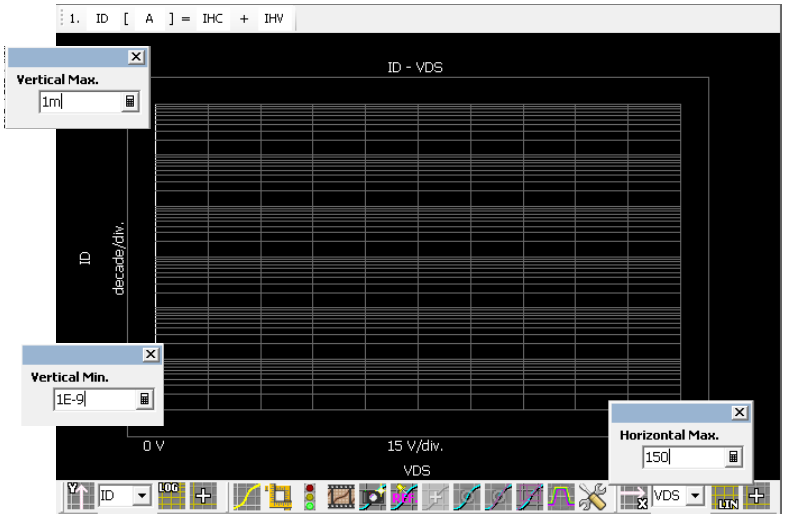

VAR1
Mode: LIN-SGL
Stop: 0 V
NOS: 51
Compliance: 1 mA

Fig. 4-2-13 Specify current compliance

Next, set the appropriate vertical and horizontal scale (refer to figure 4-2-14).


1. ID [A] = IHC + IHV

Vertical Max. 1m

Vertical Min. 1E-9

Horizontal Max. 150

Fig. 4-2-14 Change the scale of the display and the vertical axis type

In this case, since the VDSS of the DUT is 120 V, 150 V is selected as the maximum value of the horizontal scale including some margin of the spec.
The vertical scale is changed into log scale mode to see a small change of the leakage current to find a predictor of the breakdown. The minimum and maximum values of the vertical axis are chosen based on the expected leakage current of the DUT.

[Tips]
Normally, the gate leakage current of GaN FET is larger than that of Si MOS FET. If the current compliance of SMU used for gate biasing is not large enough, the SMU cannot drive the gate deep enough, and the DUT is not turned off. In that case, the HVSMU cannot keep its output voltage, and the measured current is stuck to the vertical axis as below.

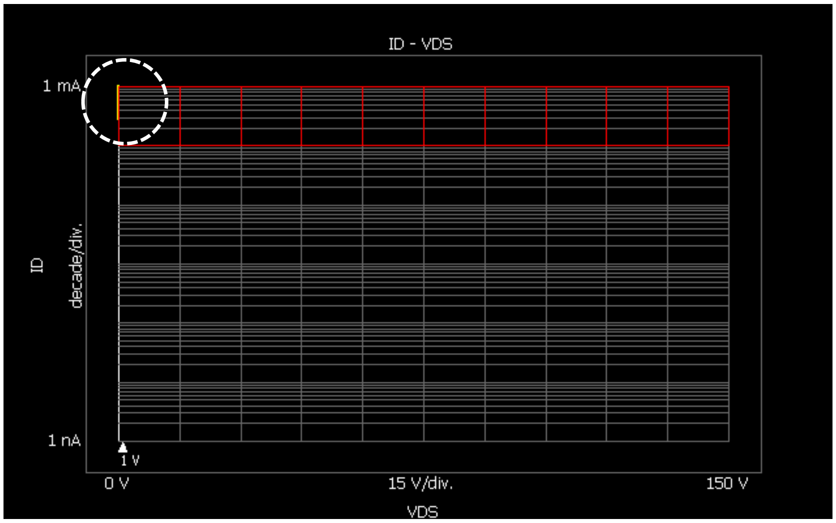
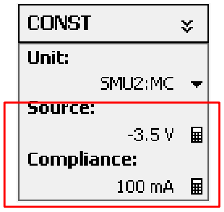


Fig. 4-2-15 ID stuck to the vertical axis due to insufficient current compliance

So, it is necessary to specify the current compliance of gate biasing SMU large enough based on the expected gate leakage current of the DUT you want to measure (refer to figure 4-2-16).



CONST

Unit: SMU2:MC

Source: -3.5 V

Compliance: 100 mA

Fig. 4-2-16 Specify an appropriate current compliance to drive the gate bias deep enough

---

Before starting measurement, specify the stop area to protect the DUT from an unexpected breakdown of it. To specify the stop area, first click the stop light icon located in the icon bar (refer to 1 of figure 4-2-17). Then drag the stop area from the left top to the right end of the trace area (2 of figure 4-2-17).

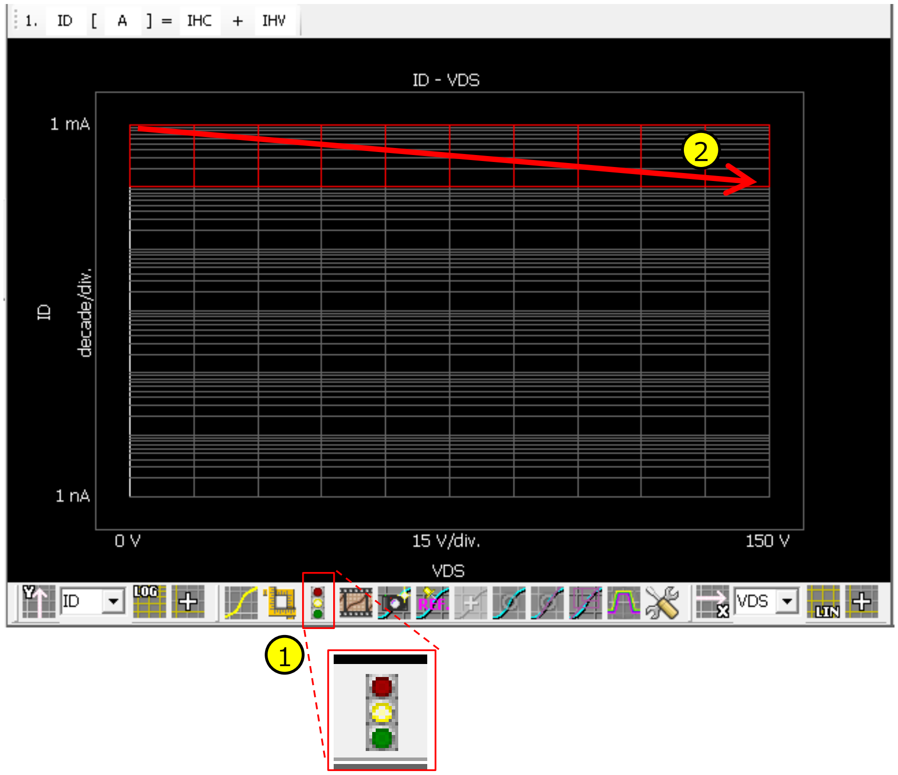


Fig. 4-2-17 Specify the stop area

During an interactive / repetitive measurement, once the measured data gets in the stop area specified above, repetitive measurement is aborted not to overwrite the existing trace with the new one of the broken DUT. repetitive

---

[Tips]

Normally, the GaN FET is delicate and it may be totally broken and become useless if the leakage current is over its limitation. Even if the current compliance is specified, there is still a possibility of device destruction because of the overcurrent situation of the SMU.

So, during the off-leakage measurement, behavior of the leakage current should be monitored carefully. The log scale of the B1505A is very useful for this purpose because it can show a small change of the leakage current and makes it possible to detect a predictor of the DUT breakdown. If the slope of the leakage current shows a remarkable increase, it is recommended to stop the measurement and not apply a higher voltage anymore.

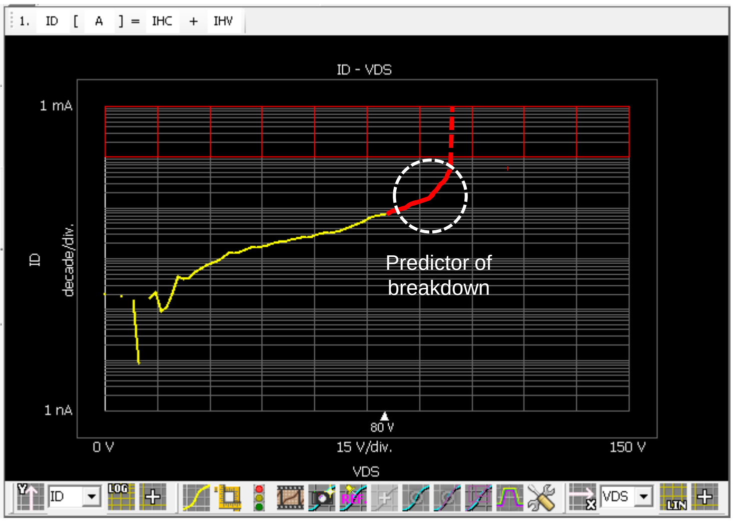


Fig. 4-2-18 Increase of the leakage current and example of predictor of the DUT breakdown

4-3. Current Collapse Measurement

4-3-1. Selection of Measurement Application

The presets of the Tracer Test mode and test definitions of the Application Test mode for GaN current collapse measurement are included in EasyEXPERT. For the details of the application test definitions and presets of the Tracer Test, please refer to section 5 and section 6.
As a first step, using the application test library is recommended because of its ease of test and availability of the discharge switch.
A fill-in-the-blanks operation is possible to use the application test. But to use the preset of the Tracer Test, it is necessary to adjust the measurement parameters of each SMU individually.

In the case of the ID-VDS current collapse measurement, due to the limitation of the Tracer Test functionality, the discharge switch has to be always off. So it is not possible to use it for a small device with a drain current of less than 8 mA.
On the other hand, if you want to make pulse sequences not supported by the pre-installed application tests as introduced in section 3-5, the preset of the Tracer Test would be a good template for modification. After finishing modification, it can be transferred into the Classic Test mode via the My Favorite setup. And it is possible to use this Classic Test as a component in the newly defined application test.
Also, currently, the ID-VDS current collapse measurement for more than 1 A drain current is only available with the Tracer Test mode.

If you want to see the measured data or status of other channels not displayed on the Tracer Test mode screen, it is necessary to use the application test or classic test setup because the only two data series displayed as the trace are saved in EasyEXPERT database when using the Tracer Test mode.
Figure 4-3-1 shows the typical flow to choose an appropriate Tracer Test preset or application test for the Id-Vds current collapse measurement.

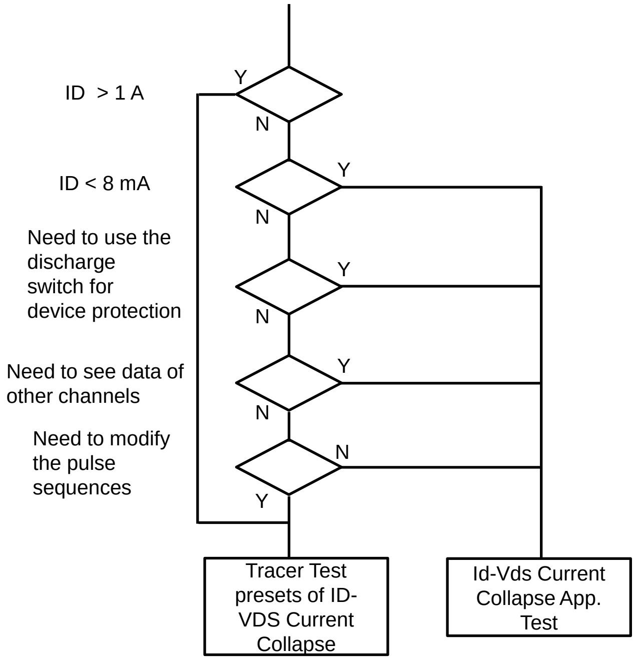


Fig. 4-3-1 Flow to choose the Tracer Test preset or the application test for Id-Vds current collapse measurement

4-3-2. ID-VDS Current Collapse Preset

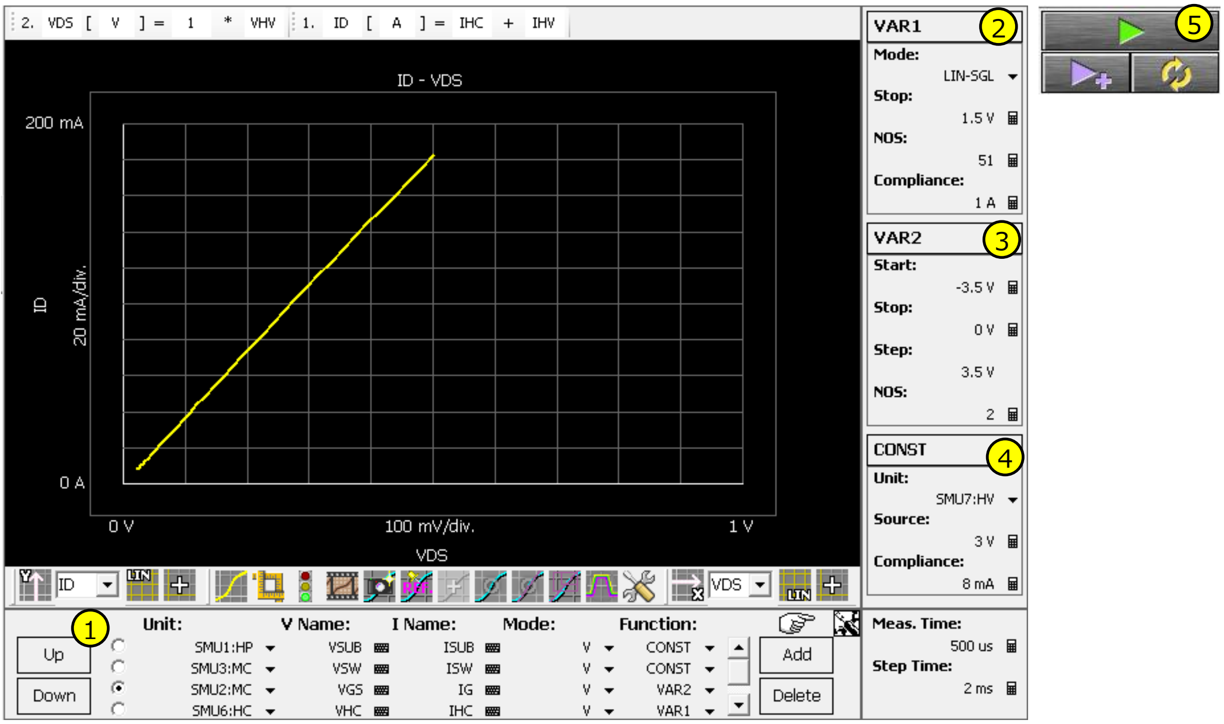
This Tracer Test preset measures Id-Vds after applying the off-state stress voltage. The Drain current over 1 A can be measured by using the PULSE mode.

[Note]

Since the discharge switch of the N1267A cannot be used in this preset, this preset is not applicable for the DUT if its drain current is lower than 8 mA. Also, if the DUT is too delicate, there are potential risks of device damage by the current to discharge the cabling (refer to section 2-1).

Step 1. Measuring reference ID-VDS curve

As a first step, the ID-VDS curve without an off-state stress voltage is measured as reference data. Later, this reference is compared with the ID-VDS curve with the specified off-state stress voltage to see if the current collapse exists or not.



2. VDS [V] = 1 * VHV | 1. ID [A] = IHC + IHV

VAR1
Mode: LIN-SGL
Stop: 1.5 V
NOS: 51
Compliance: 1 A

VAR2
Start: -3.5 V
Stop: 0 V
Step: 3.5 V
NOS: 2

CONST
Unit: SMU7:HV
Source: 3 V
Compliance: 8 mA

Meas. Time: 500 us
Step Time: 2 ms

	Unit:	V Name:	I Name:	Mode:	Function:
○	SMU1:HP	VSUB	ISUB	V	CONST
○	SMU3:MC	VSW	ISW	V	CONST
●	SMU2:MC	VGS	IG	V	VAR2
○	SMU6:HC	VHC	IHC	V	VAR1

Fig. 6-3-2 Step to measure the reference ID-VDS curve

1. Assign the SMU for each terminal
2. Specify the Stop voltage of the drain voltage sweep of the VAR1. The default Start voltage is 0 V. Also, the current compliance has to be large enough to cover the expected drain current range.
3. Specify the Start voltage and Stop voltage of the VAR2. The Start voltage is the off-gate voltage and the Stop voltage is the on-gate voltage. The NOS have to be kept as default value, 2.
4. Specify the Source voltage of the HVSMU . It should be low enough not to cause a current collapse and at least 1 V larger than the Stop voltage of the VAR1 sweep.
5. Click the "Measure" button (green right-pointing triangle), then the single ID-VDS trace will be displayed on the screen.

When looking at the start point of the trace, it is not started from 0 V. When the ID is lower than the current compliance (8 mA in this case), the HVSMU can keep its output voltage at the specified source voltage and the diode switch in the N1267A is reverse-biased (off). During this, the measured data is located at the off-state stress voltage. When ID becomes larger than 8 mA, the VDS moves to the on-state voltage (refer to figure 4-3-3).

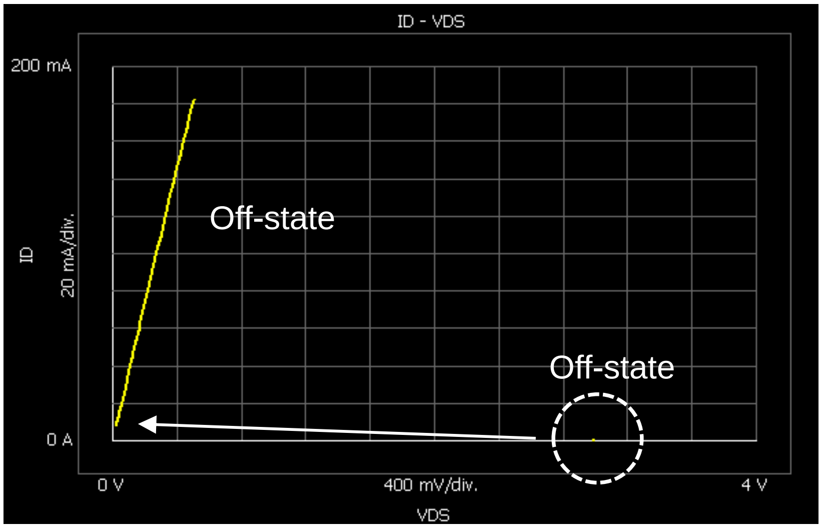


Fig. 4-3-3 Transition from the off-state to the on-state

After measuring the reference ID-VDS curve, click the “Reference” button to save it as a reference. The saved reference curve is displayed in blue.

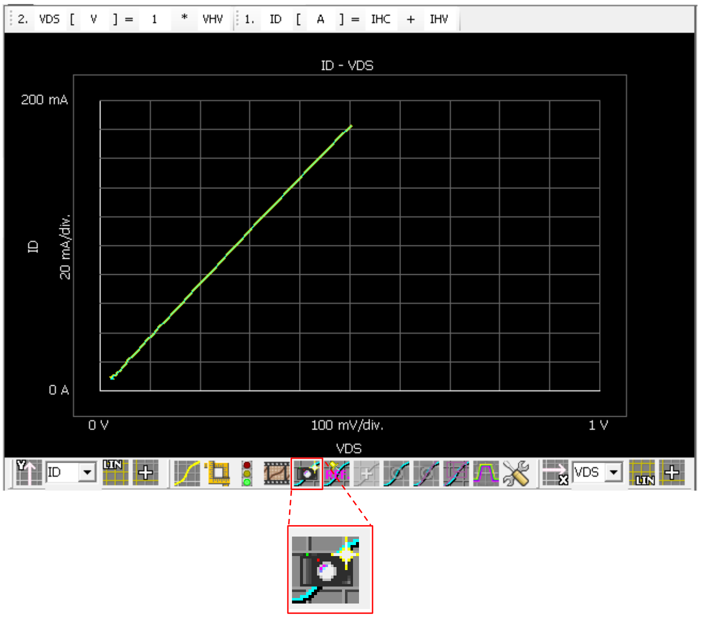
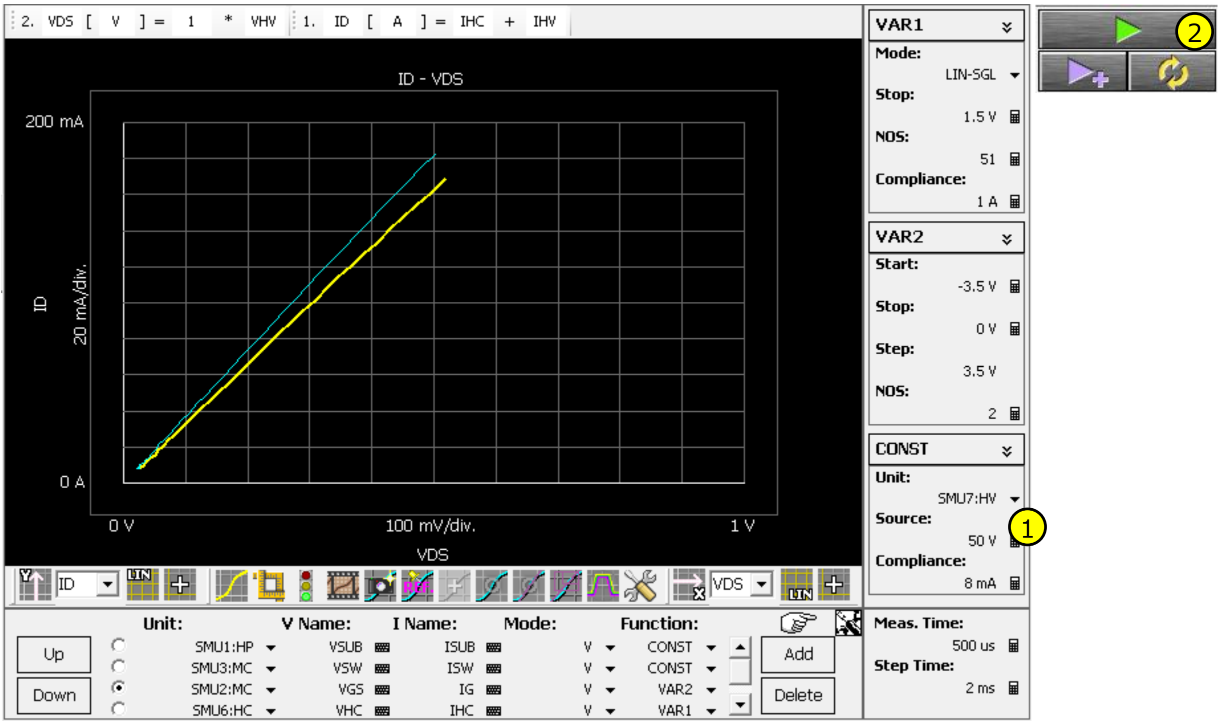


Fig. 4-3-4 Capture ID-VDS curve as a reference

Step 2. Overlaying ID-VDS after applying stress voltage

Next, measure the ID-VDS curve with the off-state stress voltage and compare it with the reference curve measured in the previous step.



2. VDS [V] = 1 * VHV
1. ID [A] = IHC + IHV

Y: ID
X: VDS

VAR1
Mode: LIN-SGL
Stop: 1.5 V
NOS: 51
Compliance: 1 A

VAR2
Start: -3.5 V
Stop: 0 V
Step: 3.5 V
NOS: 2

CONST
Unit: SMU7:HV
Source: 50 V
Compliance: 8 mA

Meas. Time: 500 us
Step Time: 2 ms

	Unit:	V Name:	I Name:	Mode:	Function:
○	SMU1:HP	VSUB	ISUB	V	CONST
○	SMU3:MC	VSW	ISW	V	CONST
●	SMU2:MC	VGS	IG	V	VAR2
○	SMU6:HC	VHC	IHC	V	VAR1

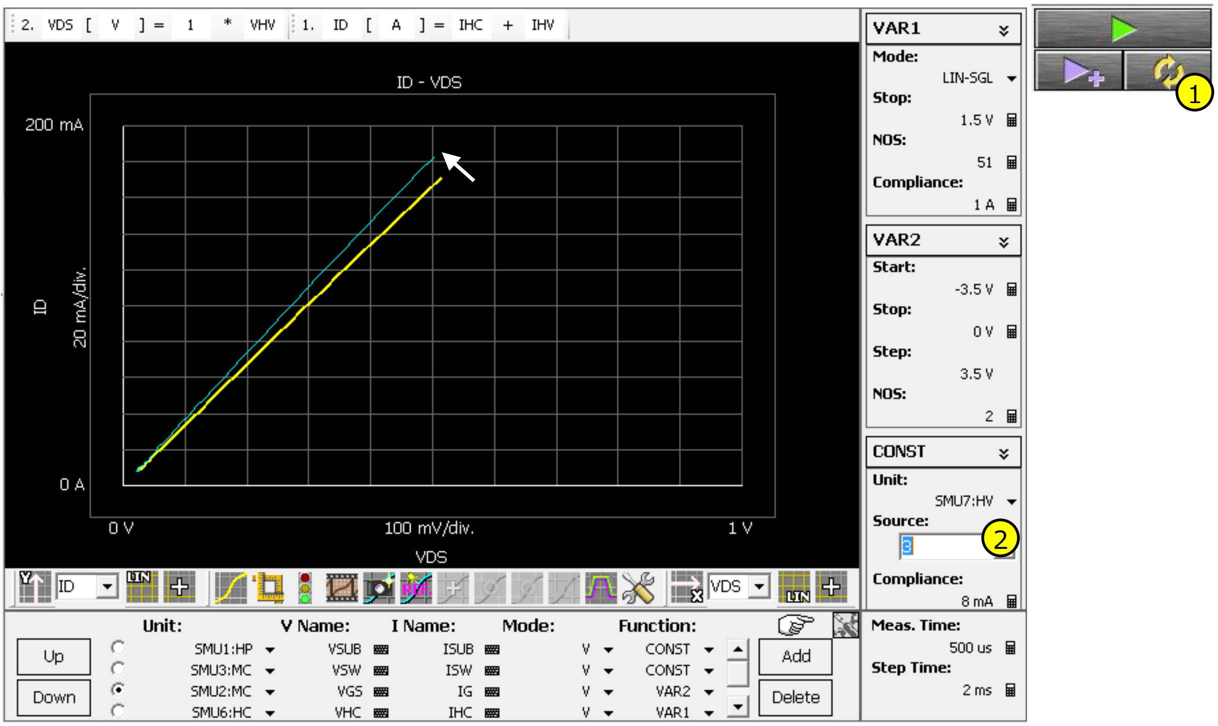
Fig. 4-3-5 Measuring the ID-VDS with an increased stress voltage

1. Change the Source voltage of the HVSMU to the desired stress voltage.
2. Click the “Measure” button. Then the newly measured ID-VDS curve is overlaid on the reference curve.

If current collapse exists in the DUT, the ID-VDS curve with the stress voltage becomes lower than the reference curve as shown in figure 4-3-5.

Step 3. Observing recovery by repeating measurement

By using the repeat measurement function of EasyEXPERT, it is possible to see a recovery from the current collapse.



2. VDS [V] = 1 * VHV
1. ID [A] = IHC + IHV

VAR1
Mode: LIN-SGL
Stop: 1.5 V
NOS: 51
Compliance: 1 A

VAR2
Start: -3.5 V
Stop: 0 V
Step: 3.5 V
NOS: 2

CONST
Unit: SMU7:HV
Source: 3
Compliance: 8 mA

Meas. Time: 500 us
Step Time: 2 ms

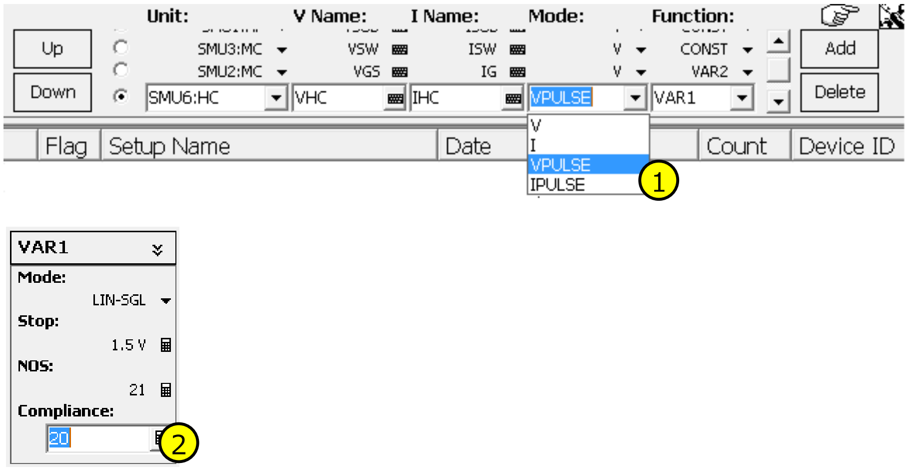
	Unit:	V Name:	I Name:	Mode:	Function:
○	SMU1:HP	VSUB	ISUB	V	CONST
○	SMU3:MC	VSW	ISW	V	CONST
●	SMU2:MC	VGS	IG	V	VAR2
○	SMU6:HC	VHC	IHC	V	VAR1

Fig. 4-3-6 Observing a recovery from the current collapse situation

1. Click the "Repeat" button with the specified stress voltage, then the ID-VDS curve on the screen starts updating repeatedly.
2. Change the Source voltage of the HVSMU to the non-stress voltage during the repeating measurement. Then the measured curve starts going back to the reference curve in every repeating sweep.

[Note]
To accelerate the recovery from the current collapse condition, irradiating or heating the DUT is effective.

[Tips]
To measure ID over 1 A, it is necessary to use the "VPULSE" mode instead of the "V" mode for the HCSMU to supply the on-state drain current.



Unit:	V Name:	I Name:	Mode:	Function:
SMU3:MC	VSW	ISW	V	CONST
SMU2:MC	VGS	IG	V	VAR2
SMU6:HC	VHC	IHC	VPULSE	VAR1

VAR1
Mode: LIN-SGL
Stop: 1.5 V
NOS: 21
Compliance: 20

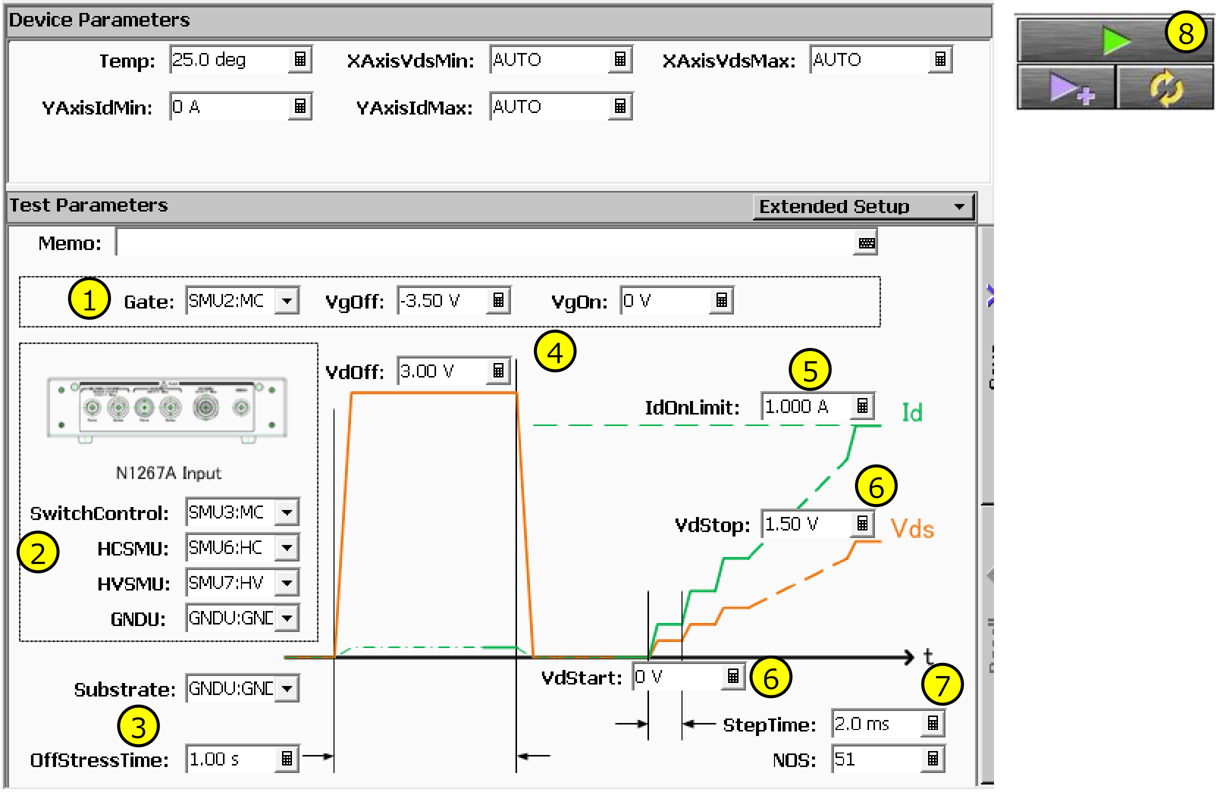
Fig. 4-3-7 Changing operation mode to the “VPULSE” mode.

1. Click “Mode” of the HCSMU (VHC) and select “VPULSE”. Keep the operation mode of the MCSMU for gate drive (VGS) as “V” to keep the DUT turned on during the measurement.
2. Change the current compliance of the VAR1 to the upper range.

4-3-3. Id-Vds Current Collapse Application Test

This application test definition measures Id-Vds after applying the off-state stress voltage.

Step 1. Measuring reference ID-VDS curve



Device Parameters

Temp: 25.0 deg
XAxisVdsMin: AUTO
XAxisVdsMax: AUTO
YAxisIdMin: 0 A
YAxisIdMax: AUTO

Test Parameters

Extended Setup

Memo:

Gate: SMU2:MC
VgOff: -3.50 V
VgOn: 0 V
VdOff: 3.00 V
IdOnLimit: 1.000 A
VdStop: 1.50 V
SwitchControl: SMU3:MC
HCSMU: SMU6:HC
HVSMU: SMU7:HV
GNDU: GNDU:GNE
Substrate: GNDU:GNE
OffStressTime: 1.00 s
VdStart: 0 V
StepTime: 2.0 ms
NOS: 51

Fig. 4-3-8 Setup parameters for Id-Vds current collapse application test

1. Assign the MCSMU for the Gate drive. Then, set the gate off-state voltage (VgOff) and the on-state gate voltage (VgOn).
2. Assign the SMUS for each terminal to control the N1267A.
3. Specify the duration to apply the off-state stress voltage.

[Note]
Actual duration of the off-state stress includes an additional overhead time (few hundreds of milliseconds).

---

4. Input the off-state voltage (VdOff) low enough not to cause the current collapse, and it should be at least 1 V larger than the stop voltage of the drain voltage sweep (VdStop).
5. Specify the maximum current limit of the drain current to be measured (IdOnLimit).
6. Specify the start voltage (VdStart) and stop voltage (VdStop) of the drain voltage sweep.
7. Specify the step time and the number of sampling (NOS) for the drain voltage sweep.
8. Click the “Measure” button then the measured Id-Vds curve will be displayed in the Data Display panel. The scale of each axis is determined by the specified current limit and the off-state stress voltage.

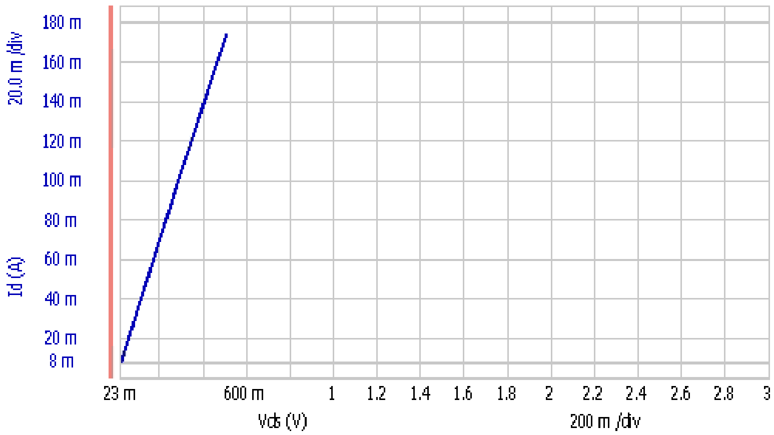
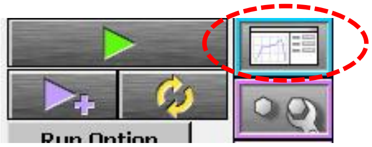


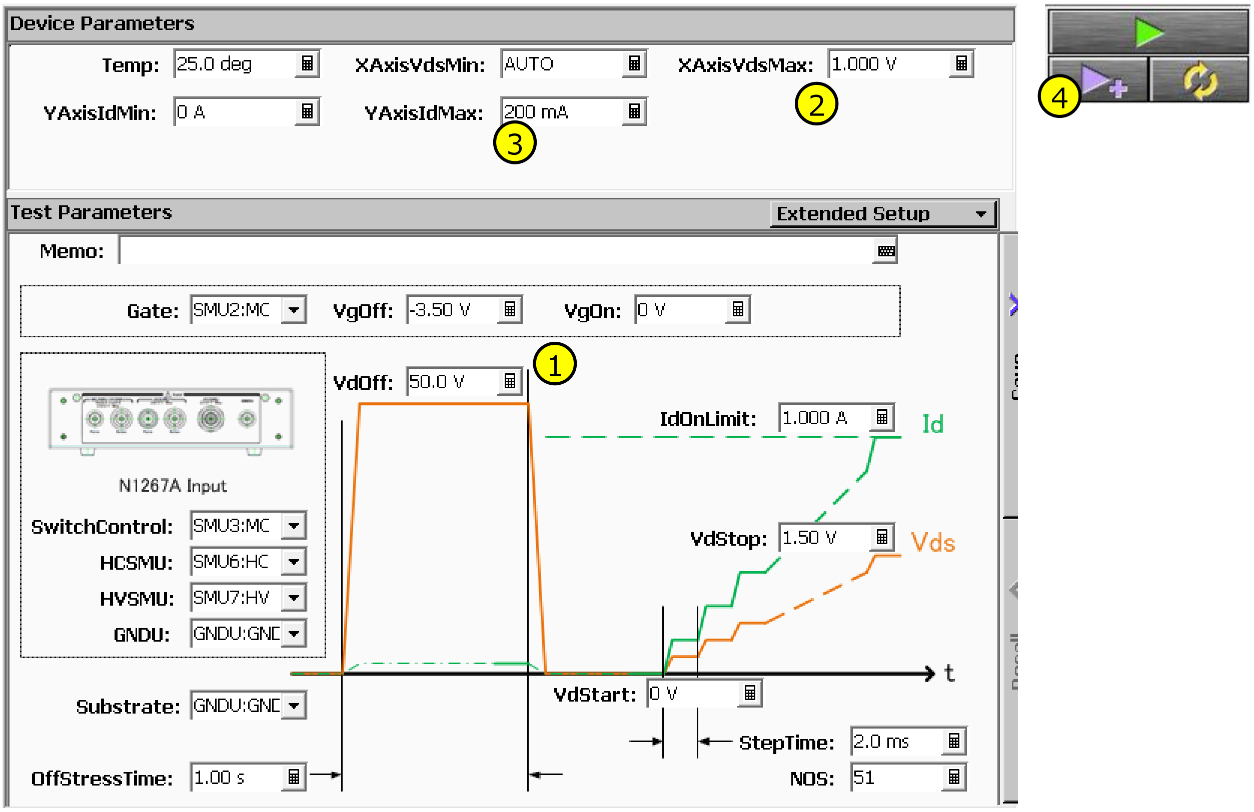
Fig. 4-3-9 Example of measured Id-Vds curve as a reference.

[Tips]
If the data display panel does not appear after completing the measurement, click the "Data Display" button located at the right side of the "Measure" button.



Step 2. Appending ID-VDS after applying stress voltage

Next, the stress voltage is applied and the result is compared with the result of the previous measurement. To see the change caused by the stress voltage, it is better to adjust the scales of the graph before running the measurement.



Device Parameters

Temp: 25.0 deg
XAxisVdsMin: AUTO
XAxisVdsMax: 1.000 V
YAxisIdMin: 0 A
YAxisIdMax: 200 mA

Test Parameters

Extended Setup

Memo:

Gate: SMU2:MC
VgOff: -3.50 V
VgOn: 0 V
VdOff: 50.0 V
IdOnLimit: 1.000 A
VdStop: 1.50 V
SwitchControl: SMU3:MC
HCSMU: SMU6:HC
HVSMU: SMU7:HV
GNDU: GNDU:GNE
Substrate: GNDU:GNE
VdStart: 0 V
StepTime: 2.0 ms
NOS: 51
OffStressTime: 1.00 s

Fig. 4-3-10 Changing the stress voltage and the scales of the graph

1. Change the stress voltage (VdOff) to the desired voltage.
2. Change the scale of each axis based on the result of the previous measurement.
3. Click the “Append” button, then the newly measured data is overlaid onto the result of the previous measurement by a thicker line.

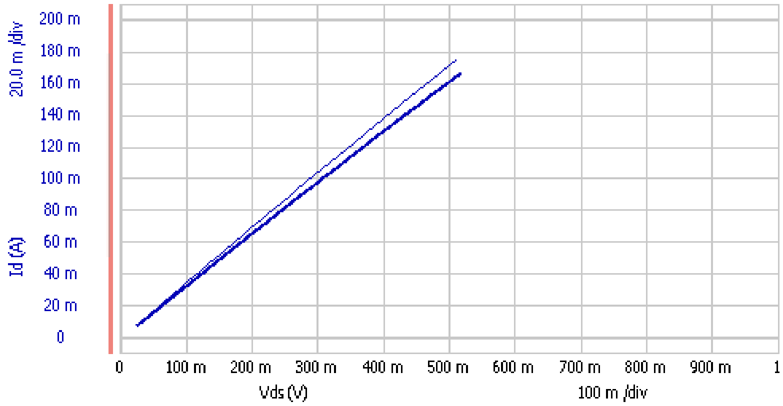
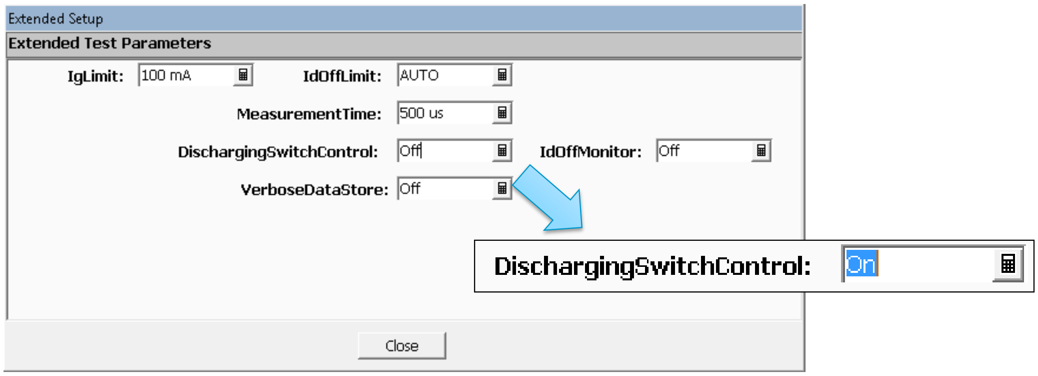


Fig. 4-3-11 Example of Id-Vds curve with and without a current collapse

If the DUT has a current collapse, the new curve is lower than the privious one.

Step 3. Example of Smaller ID less than 8 mA

If the drain current of the DUT is lower than the maximum current of the HVSMU, the discharging switch of the N1267A has to be turned on at the on-state measurement. The maximum current of the HVSMU is 8 mA if the VdOff is equal to or lower than 1500 V, and 4 mA if it is larger than 1500 V. The parameter to enable the discharging switch is “DischargeingSwitchControl” and it is located in the Extended Setup panel (refer to figure 4-3-12).



Extended Setup

Extended Test Parameters

IgLimit: 100 mA
IdOffLimit: AUTO
MeasurementTime: 500 us
DischargingSwitchControl: Off
IdOffMonitor: Off
VerboseDataStore: Off

DischargingSwitchControl: On

Fig. 4-3-12 Enable the discharge switch

Figure 4-3-13 shows an example of the measured Id-Vds curve with the DUT whose drain current is lower than 8 mA.

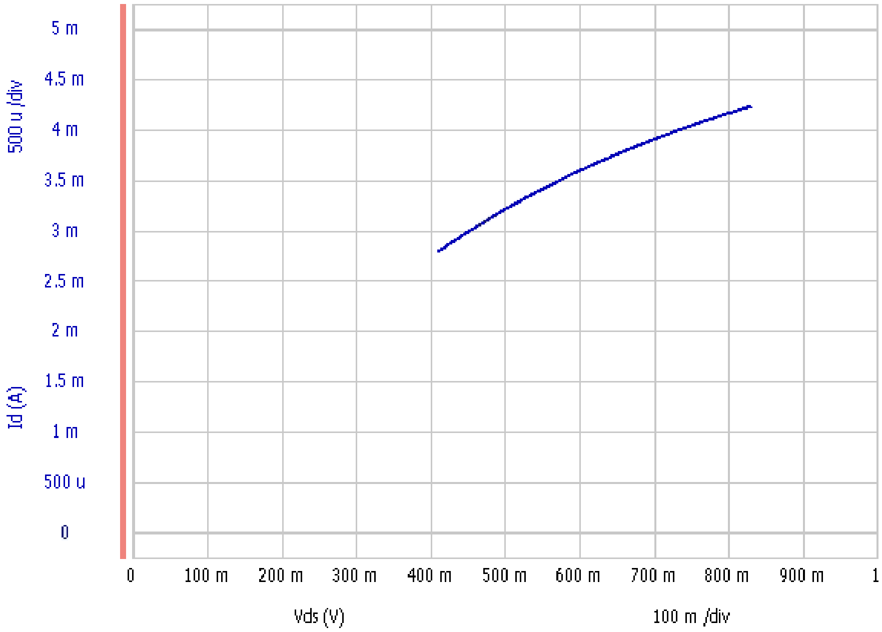
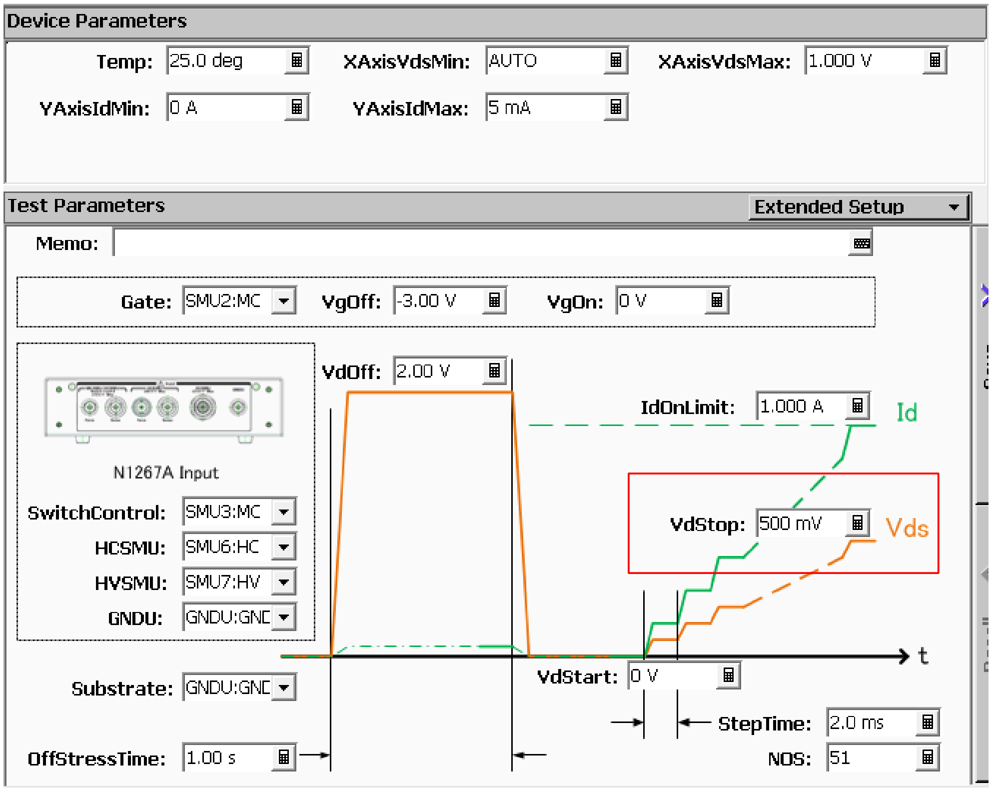


Fig. 4-3-13 Example of Id-Vds curve lower than the maximum current of the HVSMU

The curve is not started from 0 V even if the start of the drain voltage sweep (VdStart) is 0 V. Also, the drain voltage at the end of the curve is larger than the specified stop voltage (VdStop). Figure 4-3-14 shows the measurement setup to get this result.



Device Parameters

Temp: 25.0 deg
XAxisVdsMin: AUTO
XAxisVdsMax: 1.000 V
YAxisIdMin: 0 A
YAxisIdMax: 5 mA

Test Parameters

Memo:

Gate: SMU2:MC
VgOff: -3.00 V
VgOn: 0 V

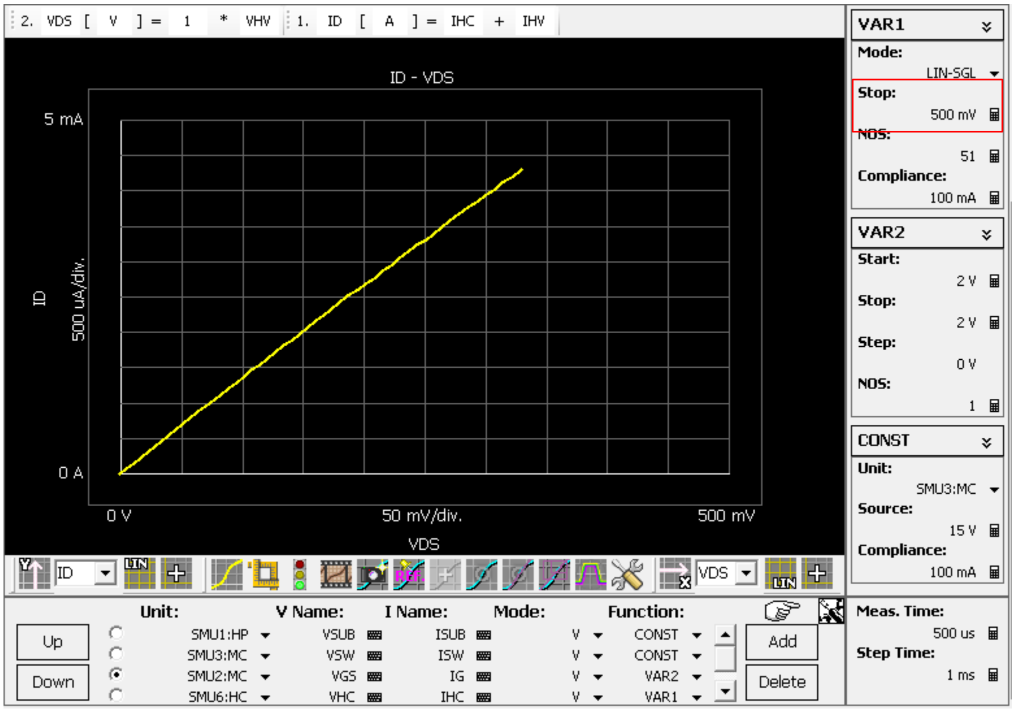
N1267A Input

SwitchControl: SMU3:MC
HCSMU: SMU6:HC
HVSMU: SMU7:HV
GNDU: GNDU:GNE
Substrate: GNDU:GNE
OffStressTime: 1.00 s

VdOff: 2.00 V
IdOnLimit: 1.000 A
VdStop: 500 mV
VdStart: 0 V
StepTime: 2.0 ms
NOS: 51

Fig. 4-3-14 Measurement setup to get result of figure 4-3-13

And this result is different from the ID-VDS curve by the “ID-VDS” preset of the Tracer Test mode even if the same start and stop voltages are used.



2. VDS [V] = 1 * VHV
1. ID [A] = IHC + IHV

VAR1
Mode: LIN-SGL
Stop: 500 mV
NOS: 51
Compliance: 100 mA

VAR2
Start: 2 V
Stop: 2 V
Step: 0 V
NOS: 1

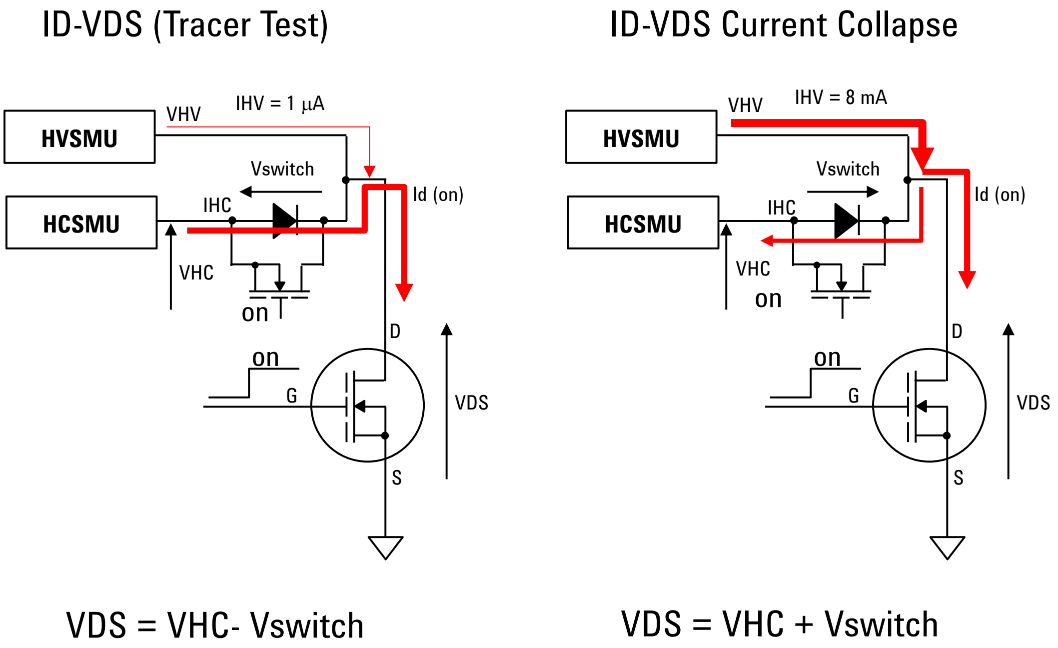
CONST
Unit: SMU3:MC
Source: 15 V
Compliance: 100 mA

Meas. Time: 500 us
Step Time: 1 ms

	Unit:	V Name:	I Name:	Mode:	Function:
○	SMU1:HP	VSUB	ISUB	V	CONST
○	SMU3:MC	VSW	ISW	V	CONST
●	SMU2:MC	VGS	IG	V	VAR2
○	SMU6:HC	VHC	IHC	V	VAR1

Fig. 4-3-15 Measured Id-Vds with the same start and stop voltage by the ID-VDS preset of the Tracer Test mode.

This difference is caused by the difference of the voltage drop at the switch. Figure 4-3-16 explains the relationship of current and voltage for both cases.


ID-VDS (Tracer Test)

ID-VDS Current Collapse

VDS = VHC- Vswitch

VDS = VHC + Vswitch

Fig. 4-3-16 Difference of the voltage drop at the switch

Actually, the VdStart and the VdOff are the setting voltage of the HCSMU to measure the on-state current. In the “ID-VDS” preset of the Tracer Test mode, the output current limit of the HVSMU is set as 1 µs to use it just as a voltage meter. In this case, almost all of the drain current is supplied from the HCSMU. Due to the voltage drop caused by the current from the HCSMU, the drain voltage becomes lower than the output voltage of the HCSMU (VHC).

On the other hand, in the case of the “Id-Vds Current Collapse” application test, the drain current is composed predominantly of the current supplied from the HVSMU. Since the output current of the HVSMU is larger than the drain current, excess current is flowing into the HCSMU from the drain terminal. This current generates an opposite voltage drop. So the drain voltage becomes higher than the output voltage of the HCSMU.

4-4. Dynamic Ron Measurement

For dynamic Ron measurement, there are two measurement types. One is to see the fast switching characteristics from the off-state to the on-state. For this purpose, the preset for the Tracer Test and the definitions for the Application Test are available. For long term measurement to see the recovery from the current collapse, only the definition for the Application is available.

Since the I/V-t sampling measurement is used for the long-term Ron measurement, the maximum drain current is limited at 1 A supported in the DC mode of the HCMSU. Also, the timing to turn on the discharge switch is fixed and synchronized with the gate bias. If the DUT is extremely delicate and needs adjustment of discharging timing to avoid its damage, these application test definitions for the long-term Ron measurement cannot be used.

For both the fast and the long-term Ron measurement, application test definitions using a V force mode and I force mode for the on-state measurement are available. If you want to observe the change of the Ron at the specified drain current, using the I force mode is useful. But the minimum switching time when using the I force mode is slower than the V force mode as discussed in section 3-3-2.

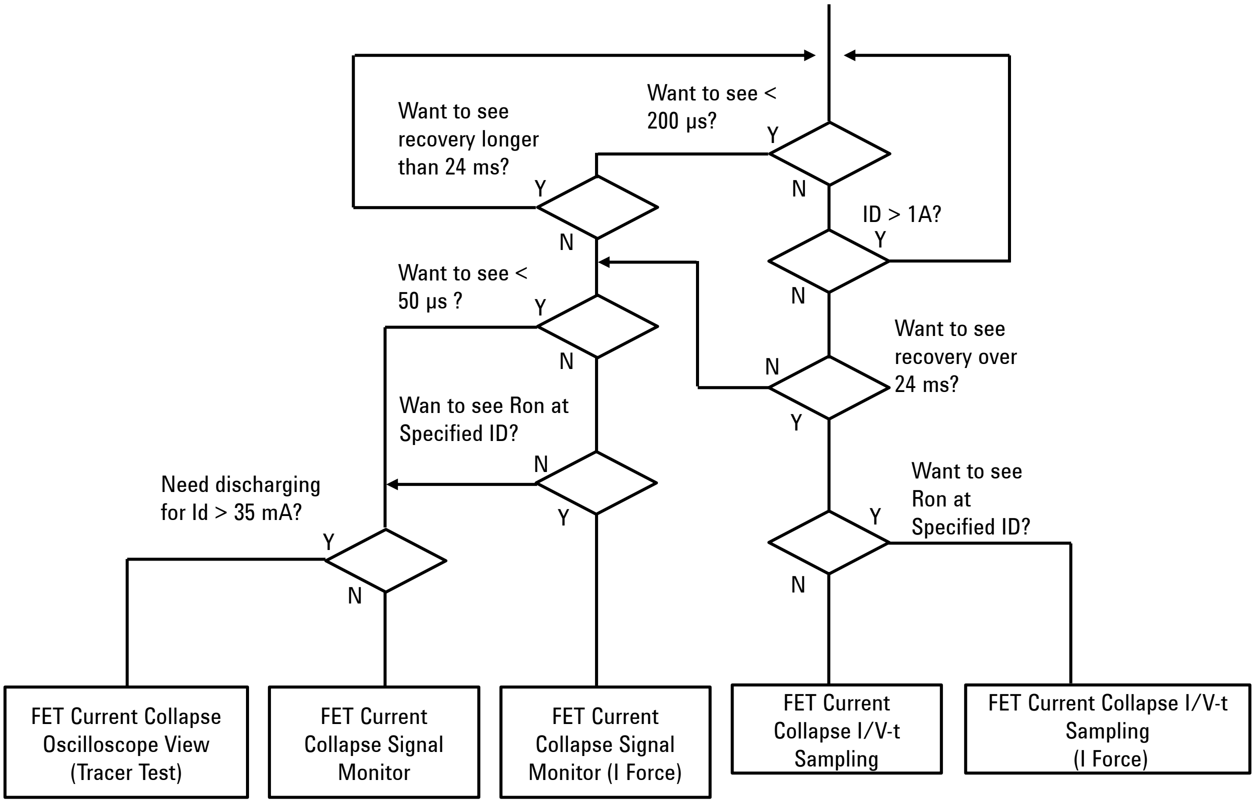


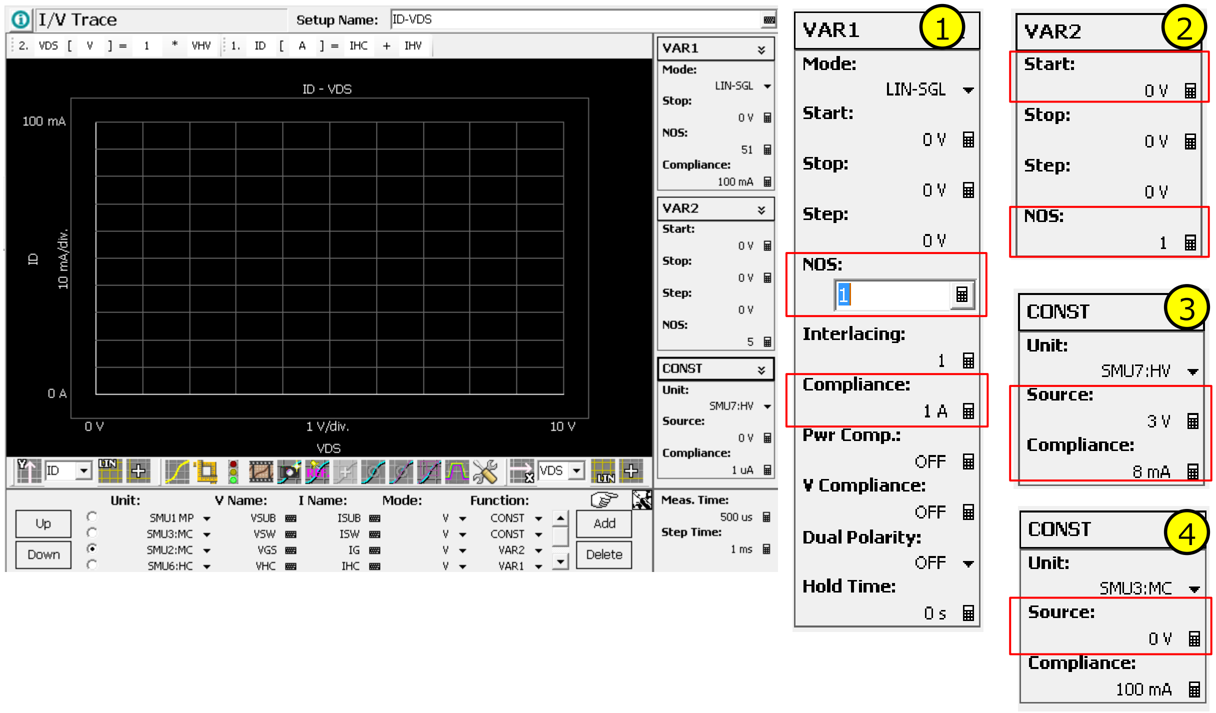
Fig. 4-4-1 Flow to choose the Tracer Test preset or the application test for dynamic Ron measurement

4-4-2. FET Current Collapse Signal Monitor Application Test

This application test measures the transient waveform from the off-state to the on-state.

Step 1. Determine on-state measurement voltage

The voltage to measure the on-state current is specified as the output voltage of the HCSMU. But, due to the voltage drop at the switch in the N1267A, the drain voltage actually applied to the DUT is not the same as the output voltage of the HCSMU.
So, before performing the dynamic Ron measurement, setting voltage of the HCSMU has to be determined to acquire waveforms at the desired drain voltage or current.
To find an appropriate setting voltage of the HCSMU, the "ID-VDS" preset of the Tracer Test mode is used.


I/V Trace Setup Name: ID-VDS

2. VDS [V] = 1 * VHV
1. ID [A] = IHC + IHV

VAR1: Mode: LIN-SGL; Stop: 0 V; NOS: 51; Compliance: 100 mA
VAR2: Start: 0 V; Stop: 0 V; Step: 0 V; NOS: 5
CONST: Unit: SMU7:HV; Source: 0 V; Compliance: 1 uA
Meas. Time: 500 us
Step Time: 1 ms

	Unit:	V Name:	I Name:	Mode:	Function:
○	SMU1 MP	VSUB	ISUB	V	CONST
○	SMU3:MC	VSW	ISW	V	CONST
●	SMU2:MC	VGS	IG	V	VAR2
○	SMU6:HC	VHC	IHC	V	VAR1

VAR1 ①
Mode: LIN-SGL
Start: 0 V
Stop: 0 V
Step: 0 V
NOS: 1
Interlacing: 1
Compliance: 1 A
Pwr Comp.: OFF
V Compliance: OFF
Dual Polarity: OFF
Hold Time: 0 s

VAR2 ②
Start: 0 V
Stop: 0 V
Step: 0 V
NOS: 1

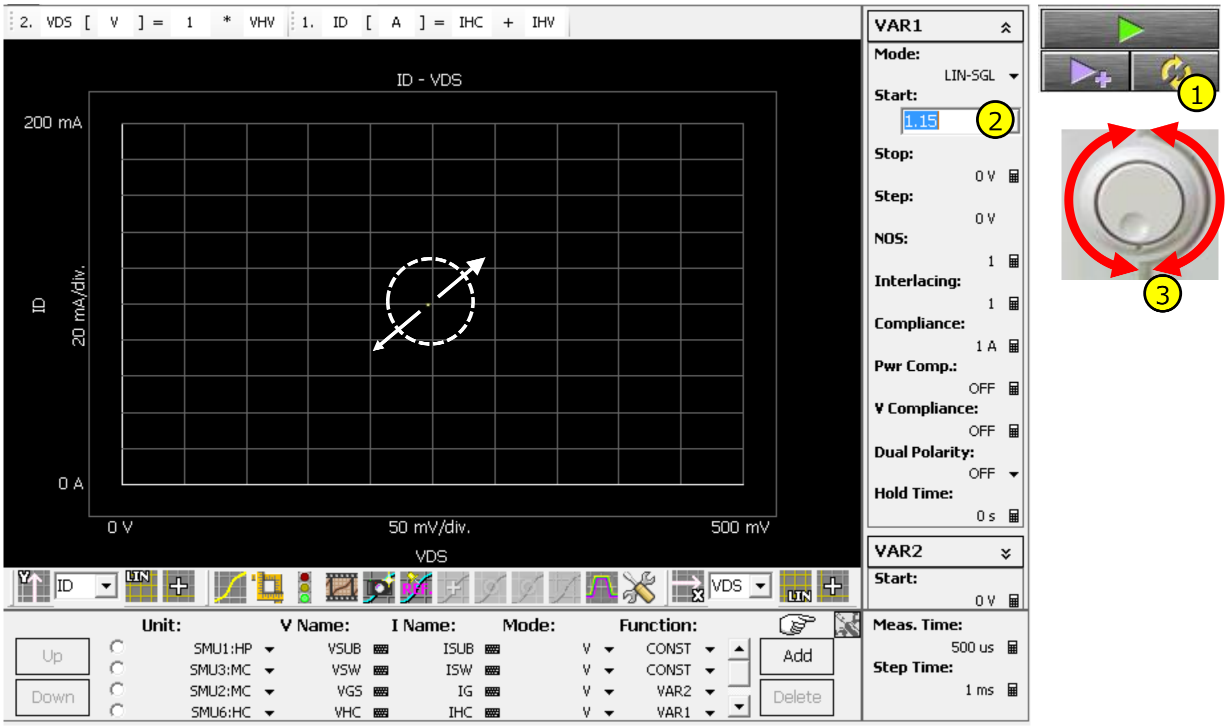
CONST ③
Unit: SMU7:HV
Source: 3 V
Compliance: 8 mA

CONST ④
Unit: SMU3:MC
Source: 0 V
Compliance: 100 mA

Fig. 4-4-2 Set up of "ID-VDS" preset to determine the setting voltage for on-state measurement.

1. Modify the number of step (NOS) of VAR1 (HCSMU) to 1. And make sure the compliance is larger than the expected drain current range.
2. Set the Start voltage of VAR2 (gate voltage) as the gate voltage to make the DUT turned on (0 V this case). And modify the NOS to 1.
3. Set the Source voltage of the HVSMU to a small voltage in order not to subject the DUT to stress. But it has to be at least 1 V larger than the expected stop voltage of the VAR1.
4. If the discharging switch of the N1267A will not be used for the dynamic Ron measurement, specify 0 V as the Source voltage of the MCMU for switch control (VSW). If the discharge switch is used, modify it to 15 V.

Next, a setting voltage of the HCSMU to apply the desired voltage or current to the DUT will be found by interactive operation of the Tracer Test mode.



2. VDS [V] = 1 * VHV
1. ID [A] = IHC + IHV

Unit:	V Name:	I Name:	Mode:	Function:
SMU1:HP	VSUB	ISUB	V	CONST
SMU3:MC	VSW	ISW	V	CONST
SMU2:MC	VGS	IG	V	VAR2
SMU6:HC	VHC	IHC	V	VAR1

VAR1
Mode: LIN-SGL
Start: 1.15
Stop: 0 V
Step: 0 V
NOS: 1
Interlacing: 1
Compliance: 1 A
Pwr Comp.: OFF
V Compliance: OFF
Dual Polarity: OFF
Hold Time: 0 s

VAR2
Start: 0 V

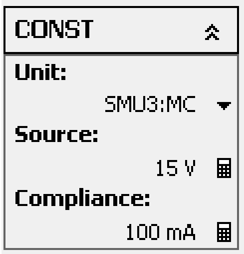
Meas. Time: 500 us
Step Time: 1 ms

Fig. 4-4-3 Performing interactive spot measurement

1. Click the “Repeat” button, then a single-point measurement is started.
2. Click the Start voltage of the VAR1.
3. Rotate the knob on the B1505A to increase the Start voltage.

With the change of the Start voltage, a single dot appears at the measured drain voltage and current. Adjust the position of this dot by rotating the knob until the measured drain voltage or current reaches the desired value. In this example, the setting voltage of the HCSMU to make the drain current 100 mA is found as 1.15 V. The drain voltage actually applied to the DUT is about 250 mV this time. So, there is a voltage difference of about 900 mV between the output voltage of the HCSMU and the drain voltage due to the voltage drop at the switch of the N1267A.

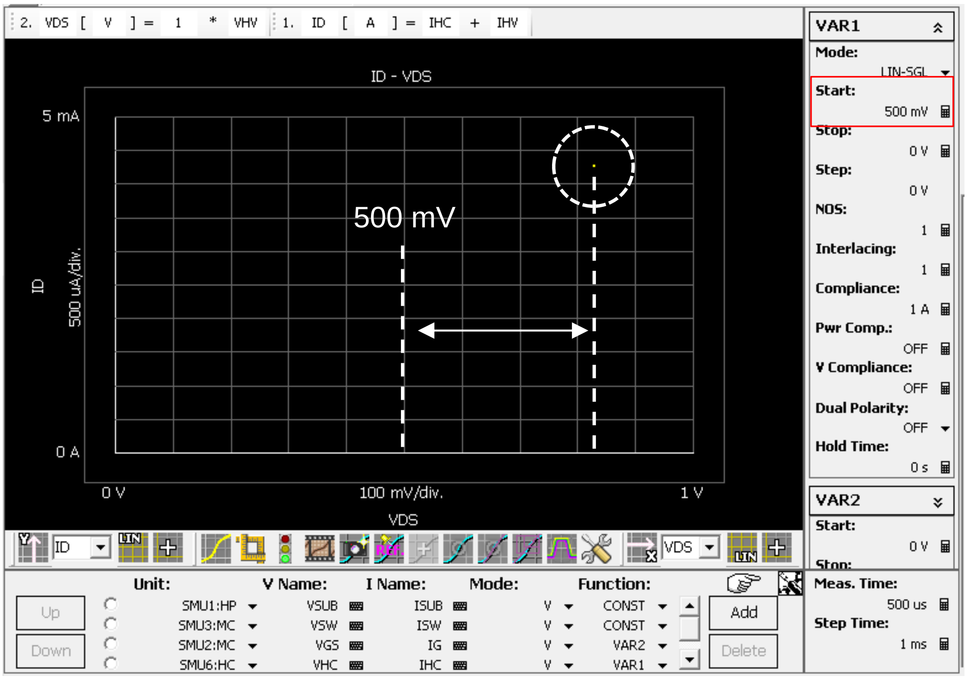
To measure the DUT whose drain current is lower than the output current limit of the HVSMU, the discharging switch of the N1267A has to be turned on. Figure 4-4-4 shows the setting to turn on the discharging switch.



CONST
Unit: SMU3:MC
Source: 15 V
Compliance: 100 mA

Fig. 4-4-4 Setting of the switch control MCSMU for lower current device

In this case, the measured drain voltage becomes higher than the setting voltage of the HCSMU as demonstrated in figure 4-4-5. In this case, the measured drain voltage is 820 mV while the Start voltage of VAR1 is 500 mV.



2. VDS [V] = 1 * VHV | 1. ID [A] = IHC + IHV

VAR1

Mode: LIN-SGL

Start: 500 mV

Stop: 0 V

Step: 0 V

NOS: 1

Interlacing: 1

Compliance: 1 A

Pwr Comp.: OFF

V Compliance: OFF

Dual Polarity: OFF

Hold Time: 0 s

VAR2

Start: 0 V

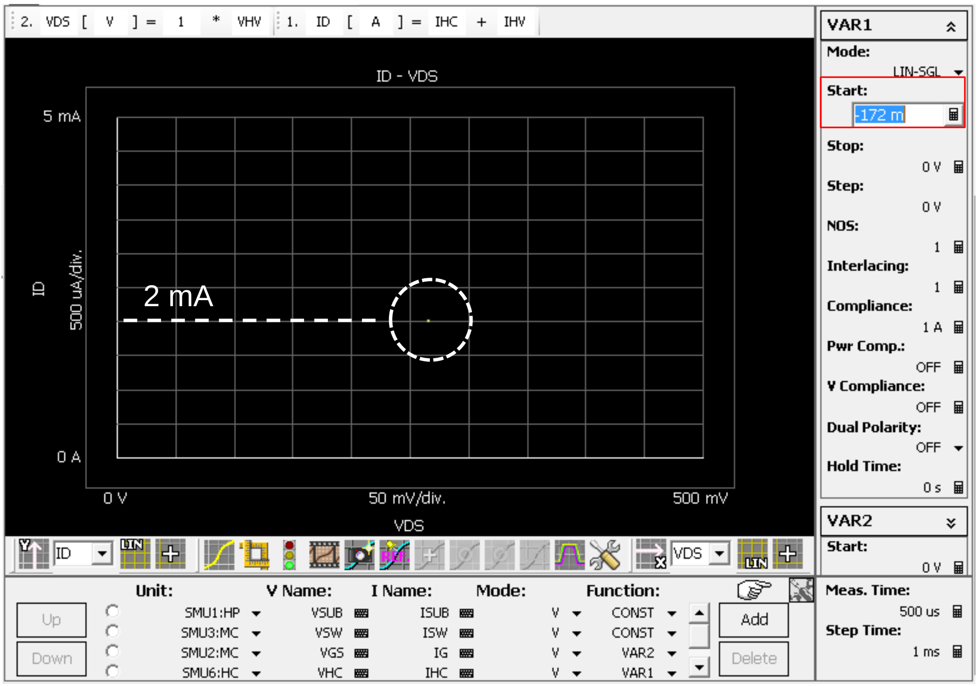
Meas. Time: 500 us

Step Time: 1 ms

Unit:	V Name:	I Name:	Mode:	Function:
SMU1:HP	VSUB	ISUB	V	CONST
SMU3:MC	VSW	ISW	V	CONST
SMU2:MC	VGS	IG	V	VAR2
SMU6:HC	VHC	IHC	V	VAR1

Fig. 4-4-5 Voltage difference between the setting voltage and the measured voltage

According to the level of the desired drain current, the setting voltage of the HCSMU becomes negative. Figure 4-4-6 shows an example of it. In this case, the setting voltage of the HCSMU is -172 mV to make the drain current 2 mA.



2. VDS [V] = 1 * VHV | 1. ID [A] = IHC + IHV

VAR1

Mode: LIN-SGL

Start: -172 m

Stop: 0 V

Step: 0 V

NOS: 1

Interlacing: 1

Compliance: 1 A

Pwr Comp.: OFF

V Compliance: OFF

Dual Polarity: OFF

Hold Time: 0 s

VAR2

Start: 0 V

Meas. Time: 500 us

Step Time: 1 ms

Unit:	V Name:	I Name:	Mode:	Function:
SMU1:HP	VSUB	ISUB	V	CONST
SMU3:MC	VSW	ISW	V	CONST
SMU2:MC	VGS	IG	V	VAR2
SMU6:HC	VHC	IHC	V	VAR1

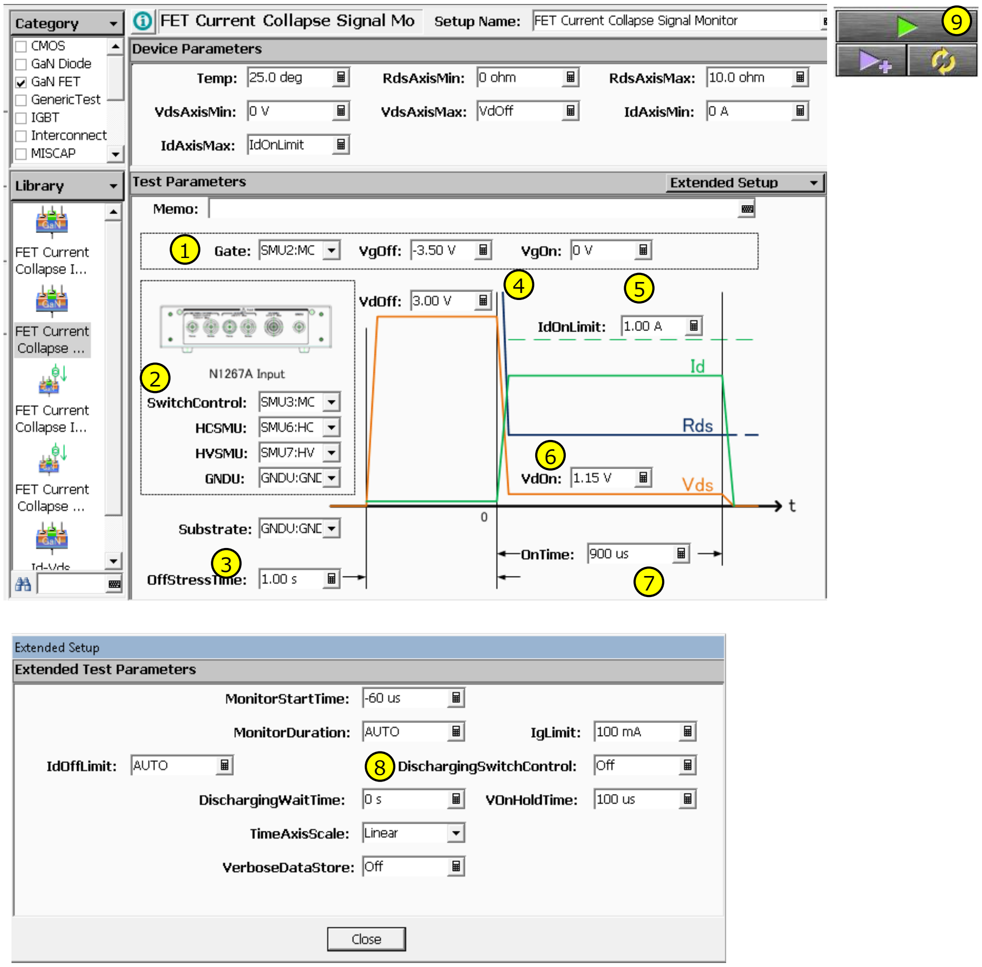
Fig. 4-4-6 Example of negative start voltage setting to make drain current lower

---

[Note]
If the dynamic Ron measurement is done during the overcurrent condition, more excess current flows into the HCSMU and makes the voltage difference between the setting voltage and drain voltage larger. Since the overcurrent condition cannot be regenerated without applying the stress voltage, the setting voltage of the HCSMU has to be estimated by the equation introduced in section 3-1.
For example, if the off-state stress voltage is equal to or less than 1500 V, the current limit of the HVSMU is 8 mA. Since a current of about 12 mA is flowing during the overcurrent condition, the additional voltage difference caused by the 4 mA additional current has to be considered. In this case, the 4 mA additional current flowing into the HCSMU generates an additional 58 × 4 mA = 232 mV difference. So, the setting voltage to make drain current 2 mA will be -304 mV.

Step 2. Measuring reference data

After determining the setting voltage of the HCSMU for the desired on-state condition, the waveform without a stress voltage is measured as a reference.



FET Current Collapse Signal Mo Setup Name: FET Current Collapse Signal Monitor

Device Parameters

Temp: 25.0 deg RdsAxisMin: 0 ohm RdsAxisMax: 10.0 ohm
VdsAxisMin: 0 V VdsAxisMax: VdOff IdAxisMin: 0 A
IdAxisMax: IdOnLimit

Test Parameters Extended Setup

Memo:

① Gate: SMU2:MC VgOff: -3.50 V VgOn: 0 V

② SwitchControl: SMU3:MC
HCSMU: SMU6:HC
HVSMU: SMU7:HV
GNDU: GNDU:GNC

VdOff: 3.00 V ④
⑤ IdOnLimit: 1.00 A
⑥ VdOn: 1.15 V
Substrate: GNDU:GNC
③ OffStressTime: 1.00 s
OnTime: 900 us ⑦

Extended Setup
Extended Test Parameters

MonitorStartTime: -60 us
MonitorDuration: AUTO IgLimit: 100 mA
IdOffLimit: AUTO ⑧ DischargingSwitchControl: Off
DischargingWaitTime: 0 s VOnHoldTime: 100 us
TimeAxisScale: Linear
VerboseDataStore: Off

Close

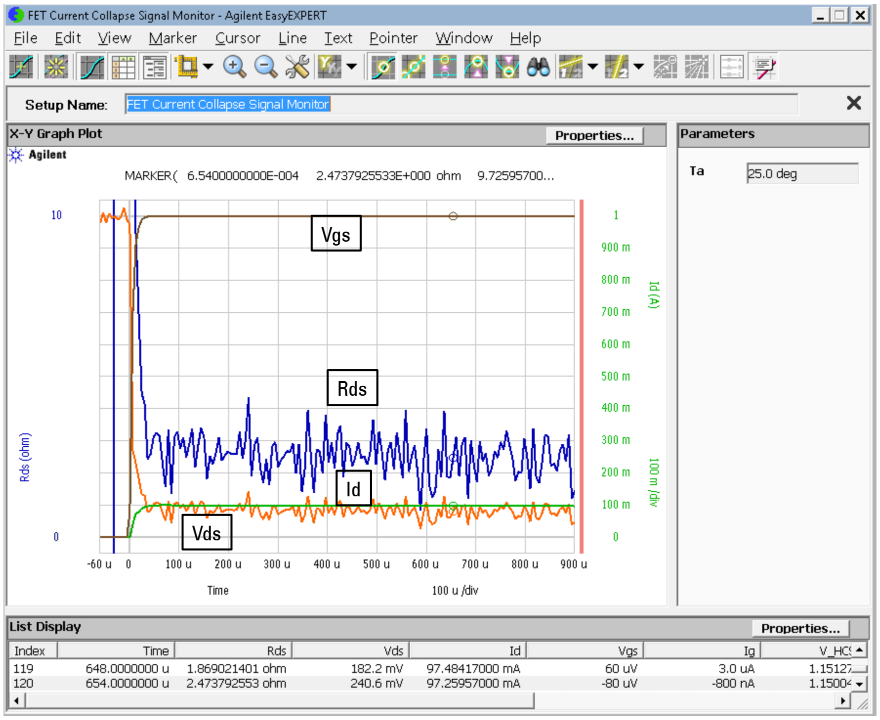
Fig. 4-4-5 Setup example for "Id-Vds Current Collapse Signal Monitor" application test

1. Assign the MCSMU for gate drive. Then, set the gate off-state voltage (VgOff) and the on-state gate voltage (VgOn).
2. Assign the SMUS for each terminal to control the N1267A.
3. Specify the duration to apply the off-state stress voltage.

[Note]
Actual duration of the off-state stress includes an additional overhead time (few hundreds of milliseconds).

---

4. Input a voltage low enough not to cause the current collapse, and it should be at least 1 V larger than the stop voltage of the drain voltage sweep (VdStop).
5. Specify the maximum current limit of the drain current to be measured. To make the switching time fast enough, using 1 A or larger is recommended.
6. Specify the setup voltage of the HCSMU (VdsOn) to measure the on-state current determined in the previous step.
7. Specify the duration to capture the waveform.
8. If the discharging switch of the N1267A is not to be used for this measurement, specify “Off” for the “DischargingSwitchingControl”.
9. Click the “Measure” button, then the measured waveforms of Rds, Vds, Id and Vgs will be displayed in the data display panel.



Setup Name: FET Current Collapse Signal Monitor

MARKER(6.5400000000E-004 2.4737925533E+000 ohm 9.72595700...

Ta 25.0 deg

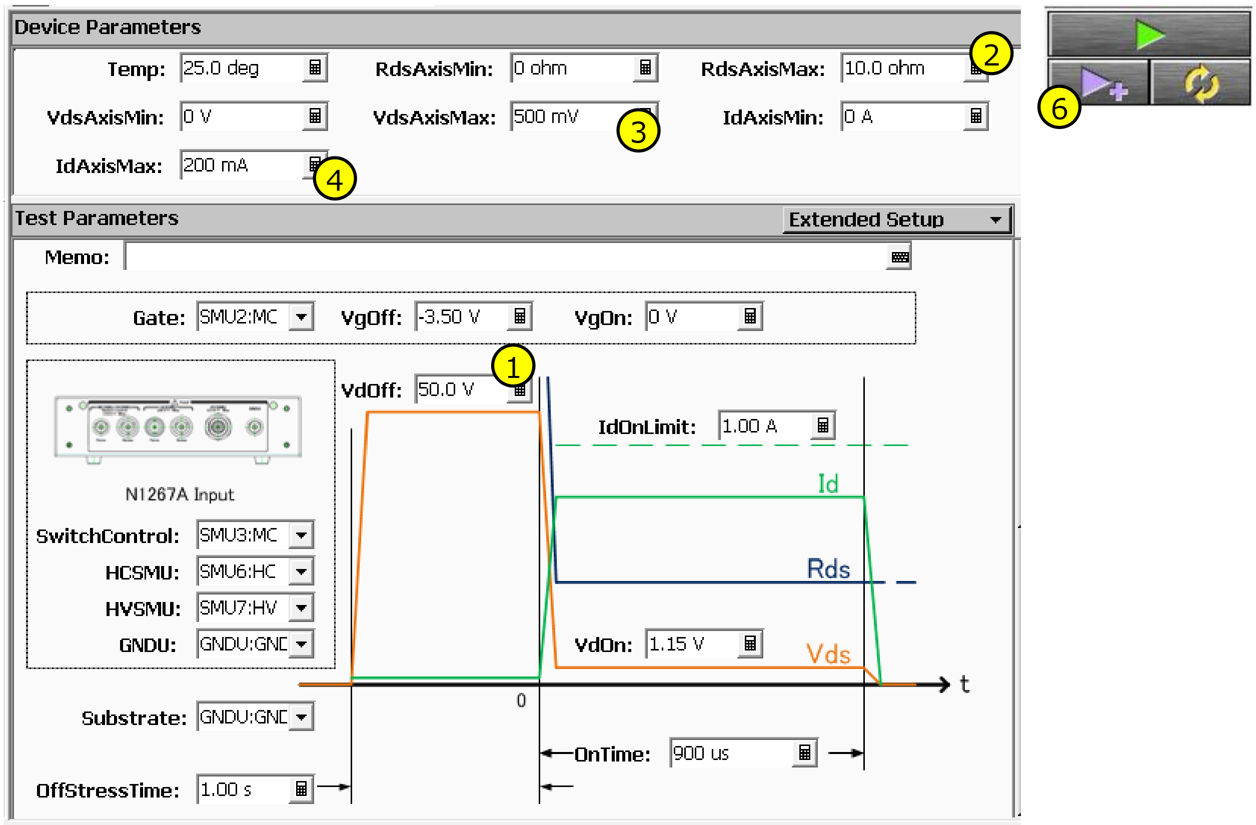
Index	Time	Rds	Vds	Id	Vgs	Ig	V_HC
119	648.0000000 u	1.869021401 ohm	182.2 mV	97.48417000 mA	60 uV	3.0 uA	1.15127
120	654.0000000 u	2.473792553 ohm	240.6 mV	97.25957000 mA	-80 uV	-800 nA	1.15004

Fig. 4-4-6 Measured result example

In this example, the scale of the horizontal axis and sampling interval are automatically determined by the specified measurement duration (OnTime). The scale of the vertical axis for Id and Vds is determined by the on-state current limit (IdOnLimit) and the off-state stress voltage (VdOff).

Step 3. Changing off-state stress voltage and compare results

Next, apply the off-state stress voltage to the DUT and compare its result with the previous one to see if the influence of the current collapse exists or not.



Device Parameters

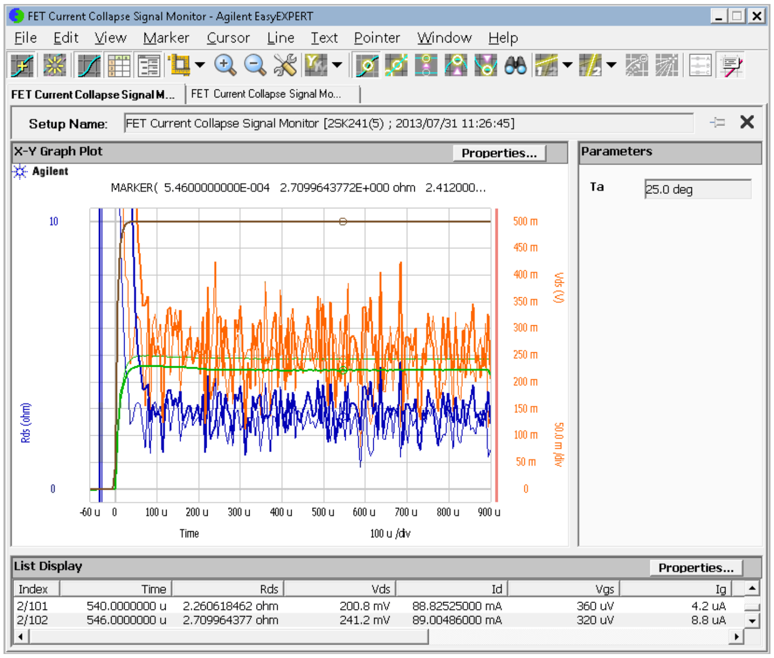
Temp: 25.0 deg
RdsAxisMin: 0 ohm
RdsAxisMax: 10.0 ohm
VdsAxisMin: 0 V
VdsAxisMax: 500 mV
IdAxisMin: 0 A
IdAxisMax: 200 mA

Test Parameters Extended Setup

Memo:
Gate: SMU2:MC
VgOff: -3.50 V
VgOn: 0 V
VdOff: 50.0 V
IdOnLimit: 1.00 A
SwitchControl: SMU3:MC
HCSMU: SMU6:HC
HVSMU: SMU7:HV
GNDU: GNDU:GNE
VdOn: 1.15 V
Substrate: GNDU:GNE
OnTime: 900 us
OffStressTime: 1.00 s

Fig. 4-4-7 Modifying the setup to apply the off-state stress voltage

1. Modify the VdOff high enough to produce a current collapse on the DUT.
2. Modify the scale of the vertical axis of the Rds to make it easy to compare the result.
3. Modify the scale of the vertical axis of the Vds to make it easy to compare the result.
4. Modify the scale of the vertical axis of the Id to make it easy to compare the result.
5. Click the “Append” button, then the newly measured waveforms are overlaid on the waveforms measured in the previous step by thicker lines.



Setup Name: FET Current Collapse Signal Monitor [2SK241(5) ; 2013/07/31 11:26:45]

MARKER(5.4600000000E-004 2.7099643772E+000 ohm 2.412000...

Ta 25.0 deg

Index	Time	Rds	Vds	Id	Vgs	Ig
2/101	540.0000000 u	2.260618462 ohm	200.8 mV	88.82525000 mA	360 uV	4.2 uA
2/102	546.0000000 u	2.709964377 ohm	241.2 mV	89.00486000 mA	320 uV	8.8 uA

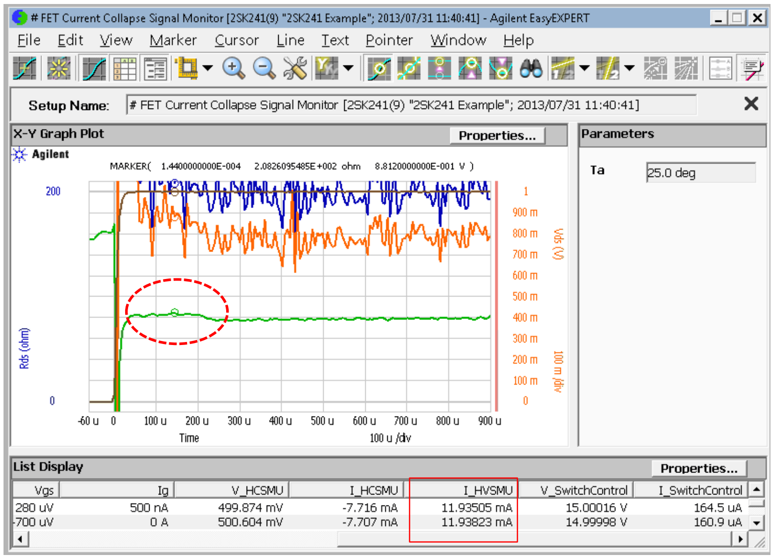
Fig. 4-4-8 Example of overlaid waveforms

In this example, the drain current after applying the 50 V stress decreases clearly. Also, the on-resistance and the drain voltage increases, too. From these changes, this device is considered to have a current collapse with the 50 V off-state stress voltage.

[Trouble Shooting]

[Case 1] If you see the step on the drain current waveform

When measuring a device with a relatively small drain current, a step change is observed on the measured drain current waveform, and its duration increases with an increase of the stress voltage as shown in figure 4-4-9.



Setup Name: # FET Current Collapse Signal Monitor [2SK241(9) "2SK241 Example"; 2013/07/31 11:40:41]

MARKER(1.4400000000E-004 2.0826095485E+002 ohm 8.8120000000E-001 V)

Ta 25.0 deg

Vgs	Ig	V_HCSMU	I_HCSMU	I_HVSMU	V_SwitchControl	I_SwitchControl
280 uV	500 nA	499.874 mV	-7.716 mA	11.93505 mA	15.00016 V	164.5 uA
-700 uV	0 A	500.604 mV	-7.707 mA	11.93823 mA	14.99998 V	160.9 uA

Fig. 4-4-9 Step on the drain current waveform caused by the overcurrent condition

This step is created by the overcurrent condition of the HVSMU when switching from the high voltage of the off-state stress state to the low voltage of the on-state measurement as discussed in section 3-4-2. To check if it is under the overcurrent situation or not, checking the output current of the HVSMU is useful.

- Place the marker on the step.
- Check the output current of HVSMU (I_HVSMU) in the List Display.

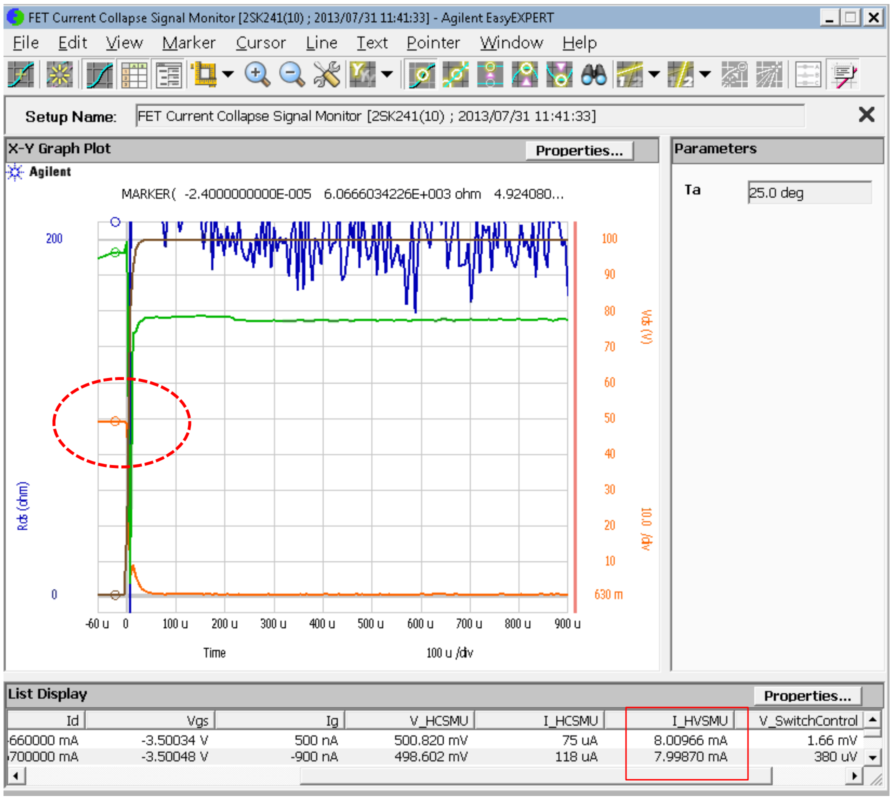
If the HVSMU is under overcurrent situation, I_HVSMU is about 12 mA even if the current compliance of the HVMSU is 8 mA or 4 mA.

This is the fundamental operation of the HVSMU and cannot be removed. Even if the step exists on the waveform, the measured Rds will not have the step if the drain current is measured at the resistive region of the Id-Vds curve.

[Case 2] Specified off-state stress voltage is not applied

If the DUT has a leakage current larger than the current limit of the HVSMU, the HVSMU cannot apply the specified off-state stress voltage to the DUT.

In figure 4-4-10, the actual off-state stress voltage is about 50 V even if the VdOff is 100 V.



Setup Name: FET Current Collapse Signal Monitor [2SK241(10) ; 2013/07/31 11:41:33]

MARKER(-2.4000000000E-005 6.0666034226E+003 ohm 4.924080...

Ta 25.0 deg

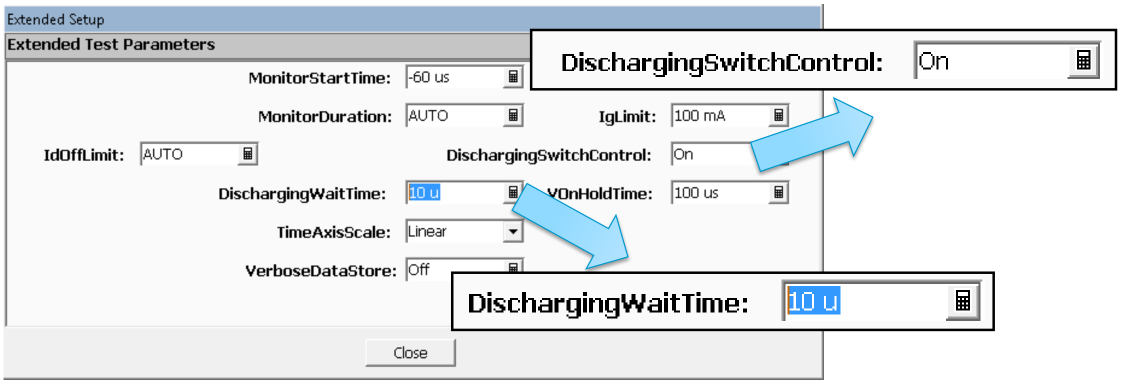
Id	Vgs	Ig	V_HCSMU	I_HCSMU	I_HVSMU	V_SwitchControl
660000 mA	-3.50034 V	500 nA	500.820 mV	75 uA	8.00966 mA	1.66 mV
700000 mA	-3.50048 V	-900 nA	498.602 mV	118 uA	7.99870 mA	380 uV

Fig. 4-4-10 Example of insufficient stress voltage

Looking at the output current of the HVSMU at the off-state stress duration, it reaches the current limit of the HVSMU. Unfortunately, HVSMU cannot apply the specified voltage if its output current is over the limitation.

[Case 3] Device is broken at a voltage lower than the expected breakdown voltage

If the DUT is broken below the expected breakdown voltage of the DUT while increasing the off-state stress voltage, there is a possibility of device damage due to the cable discharge current at the sub threshold gate voltage level as discussed in section 2-1. To avoid this unexpected device damage, using the discharging switch of the N1267A will be effective. To make the discharging switch effective, choose “On” for “DischargeSwitchControl”.



MonitorStartTime: -60 us
MonitorDuration: AUTO
IgLimit: 100 mA
IdOffLimit: AUTO
DischargingSwitchControl: On
DischargingWaitTime: 10 u
VOnHoldTime: 100 us
TimeAxisScale: Linear
VerboseDataStore: Off

DischargingSwitchControl: On

DischargingWaitTime: 10 u

Fig. 4-4-11 Enabling the discharging switch and changing its timing

If the DUT is too delicate so that it is damaged even if the discharging switch is turned on, turning on the switch previously to turning on the gate voltage will be effective. To adjust the timing of the discharging switch, specify the “DischargingWaitTime” in seconds. The gate voltage waits to change its output from the off-gate to the on-gate voltage during this period.

[Case 4] Observed switching time is slower than 20 μs

If the Ron of the DUT is lower than 1 Ω, the response time of the HCSMU to measure the on-current becomes slower. One possible way to resolve it is using the “FET Current Collapse Signal Monitor (I Force)” instead of the “FET Current Collapse Signal Monitor” because the response time of the HCSMU feedback circuit in constant current mode is faster than the constant voltage mode for such low impedance. But due to the slow transient time switching from the voltage compliance status at the off-state to the current output mode at the on-state, the switching time is still not as fast as 20 μs (50 μs to 60 μs depending on the Rds).
To improve the switching time, inserting resistance between the output of the N1267A and the DUT will be helpful. For more details about the response time of the HCSMU and the way to improve it, please refer to section 3-3.

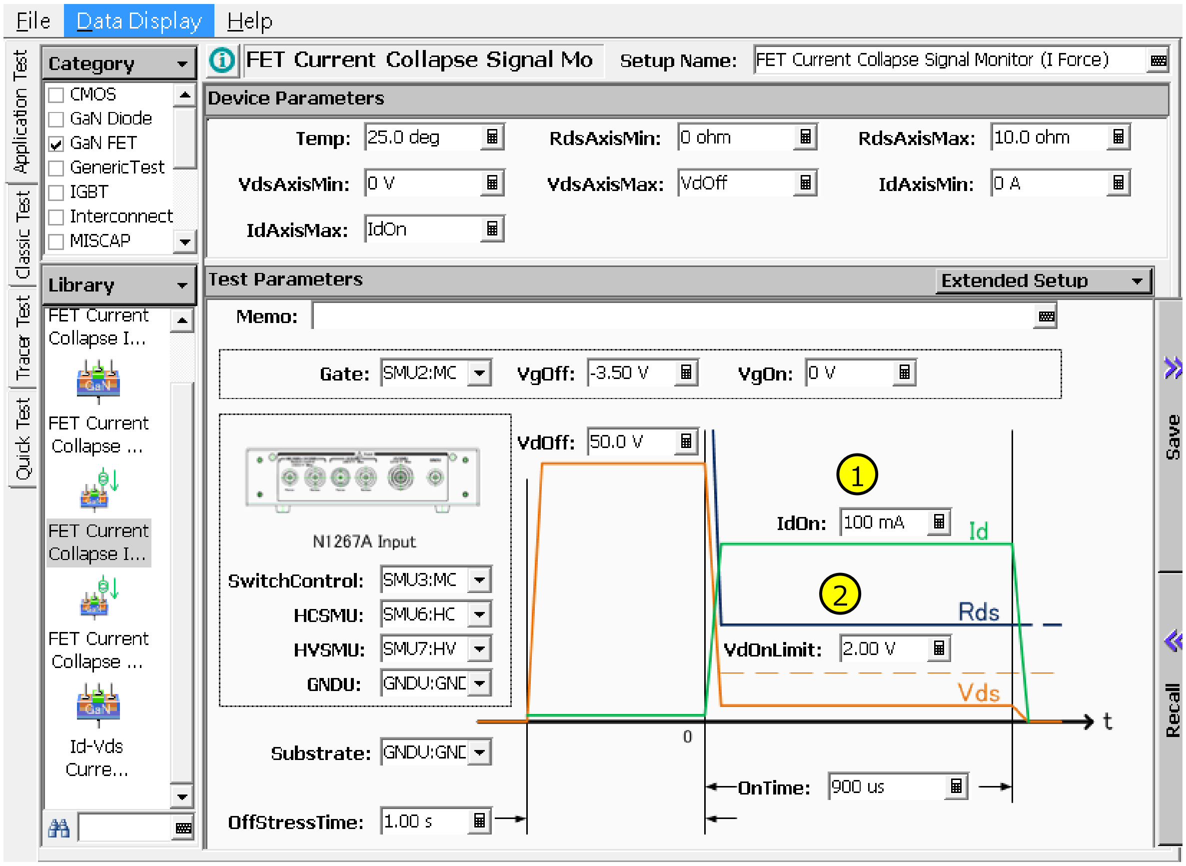
[Case 5] Measured Rds has a long delay time compared to the drain current

If the measured Rds shows a delay time compared to the drain current by increasing the off-state stress voltage, it is caused by the delay time of the voltage measurement circuit of the HVSMU. Unfortunately,since it is based on the internal circuit design of the HVSMU, do not use the Rds before settling the measured drain voltage (100 μs ore more) as an indicator of the current collapse. For more details of the response time of the HVSMU, please refer to section 3-4-1.

Step 5. Using I Force Mode

When using the “FET Current Collapse Signal Monitor” application test, the drain current is changed during changing of the off-state stress voltage due to the voltage drop at the switch of the N1267A.
If you want to measure the dynamic Ron at the specified current, the “FET Current Collapse Signal Monitor (I Force)” application test is useful.

[Note]
Due to the response time of the HCSMU from the voltage compliance status during the off-state stress situation to current force mode in the on-state measurement, the minimum achievable switching time is slower than the “FET Current Collapse Signal Monitor” which uses the constant V force mode.



☐ CMOS
☐ GaN Diode
☑ GaN FET
☐ GenericTest
☐ IGBT
☐ Interconnect
☐ MISCAP

Setup Name: FET Current Collapse Signal Monitor (I Force)

Device Parameters

Temp: 25.0 deg
RdsAxisMin: 0 ohm
RdsAxisMax: 10.0 ohm
VdsAxisMin: 0 V
VdsAxisMax: VdOff
IdAxisMin: 0 A
IdAxisMax: IdOn

Test Parameters — Extended Setup

Memo:
Gate: SMU2:MC
VgOff: -3.50 V
VgOn: 0 V
VdOff: 50.0 V
IdOn: 100 mA
VdOnLimit: 2.00 V
SwitchControl: SMU3:MC
HCSMU: SMU6:HC
HVSMU: SMU7:HV
GNDU: GNDU:GNE
Substrate: GNDU:GNE
OffStressTime: 1.00 s
OnTime: 900 us

Fig. 4-4-12 Setup example of the “FET Current Collapse Signal Monitor (I Force)

Almost all of the parameters are the same with the “FET Current Collapse Signal Monitor”. Specify the IdOn and the VdOnLimit instead of the IdOnLimit and the VdOn of the “FET Current Collapse Signal Monitor”.

1. Set the current level to measure the on-state characteristics (IdOn). This is the output current from the HCSMU to measure the on-state characteristics.
2. Set the voltage limit at the on-state (VdOnLimit). This is the voltage compliance of the HCSMU to measure the on-state characteristics. The VdOnLimit is high enough to supply the IdOn including the voltage drop at the switch in the N1267A.

Figure 4-4-13 shows the measurement example with an off-state stress voltage of 3 V and 50 V. The thicker line is the measured result with 50 V stress voltage.

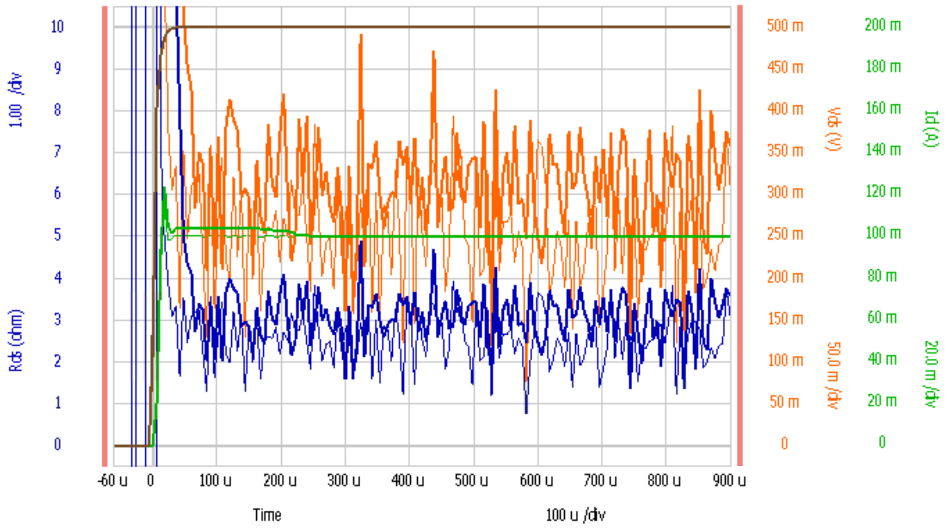


Fig. 4-4-13 Example of measurement using the I Force

At the beginning of the drain current step, there is a step caused by the overcurrent of the HVSMU. In this case, since the HCSMU outputs constant current, the measured drain current reflects the change of the output current due to the overcurrent situation directly. After the step, the measured drain current does not change from the reference data measured with 3 V off-state voltage. But the on-resistance and the drain voltage increase due to the current collapse caused by 50 V stress voltage.

4-4-3. FET Current Collapse I/V-t Sampling

To measure a recovery from the current collapse in a long time scale, this application test is used.

[Note]

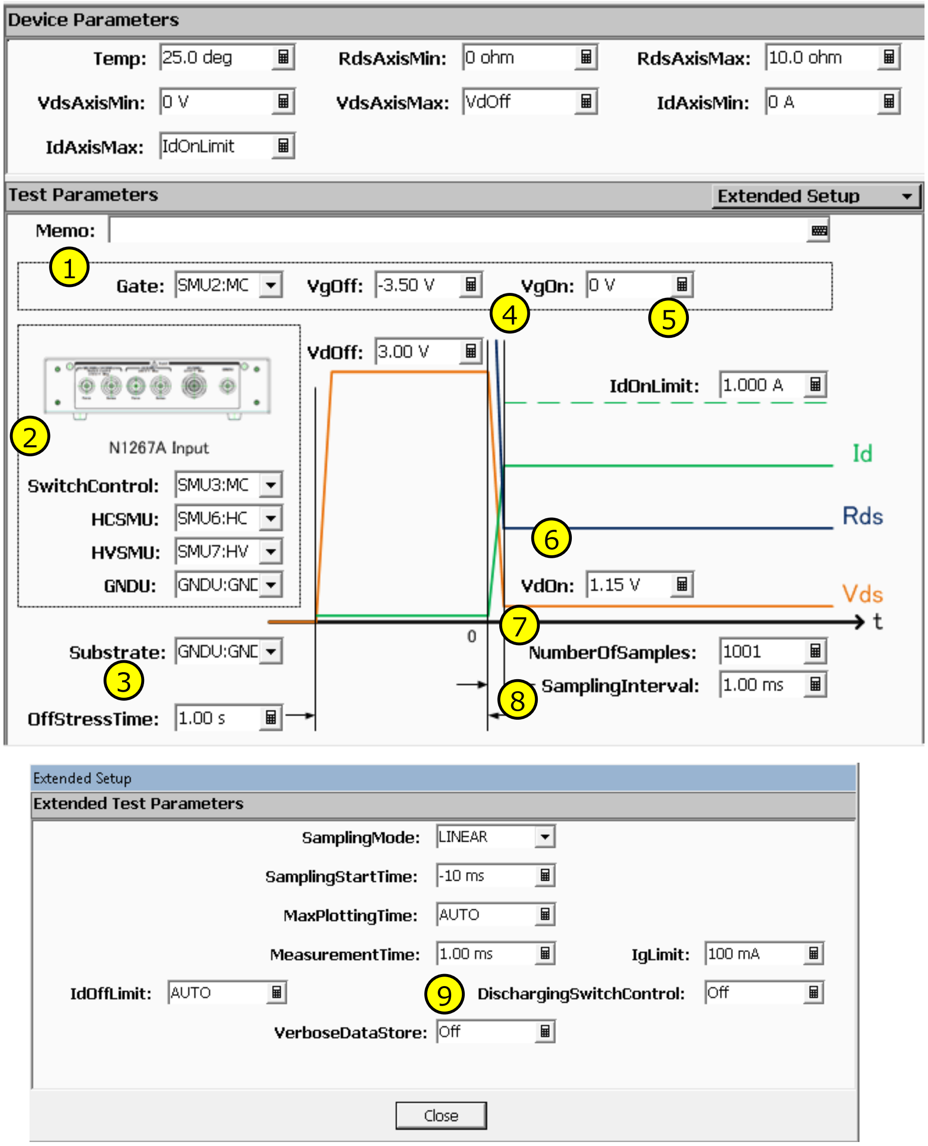
Since this application test uses the I/V-t sampling function of the HCSMU, the maximum current is limited at 1 A because the I/V-t sampling mode is only available for DC mode.

Step 1. Determine on-state measurement voltage

It is the same as the “FET Current Collapse Signal Monitor”.

Step 2. Measuring reference data

After determining the setting voltage of the HCSMU for desired on-state condition, IV-t sampling data of the DUT without a stress voltage is measured as a reference.



Device Parameters

Temp: 25.0 deg
RdsAxisMin: 0 ohm
RdsAxisMax: 10.0 ohm
VdsAxisMin: 0 V
VdsAxisMax: VdOff
IdAxisMin: 0 A
IdAxisMax: IdOnLimit

Test Parameters

Memo:
Gate: SMU2:MC
VgOff: -3.50 V
VgOn: 0 V
VdOff: 3.00 V
IdOnLimit: 1.000 A
SwitchControl: SMU3:MC
HCSMU: SMU6:HC
HVSMU: SMU7:HV
GNDU: GNDU:GNE
VdOn: 1.15 V
Substrate: GNDU:GNE
NumberOfSamples: 1001
SamplingInterval: 1.00 ms
OffStressTime: 1.00 s

Extended Setup

Extended Test Parameters

SamplingMode: LINEAR
SamplingStartTime: -10 ms
MaxPlottingTime: AUTO
MeasurementTime: 1.00 ms
IgLimit: 100 mA
IdOffLimit: AUTO
DischargingSwitchControl: Off
VerboseDataStore: Off

Fig. 4-4-14 Setup example of the “Current Collapse I/V-t Sampling”

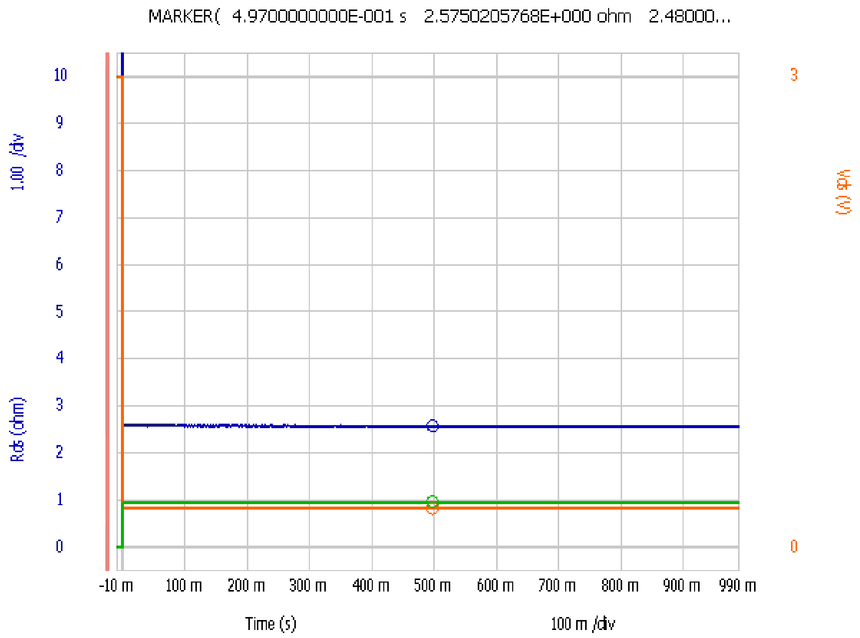
1. Assign the MCSMU for gate drive. Then, set the gate off-state voltage (VgOff), and the on-state gate voltage (VgOn).
2. Assign the SMUS for each terminal to control the N1267A.
3. Specify the duration to apply the off-state stress voltage.

[Note]
Actual duration of the off-state stress includes an additional overhead time (few hundreds of milliseconds).

---

4. Input a voltage low enough not to cause the current collapse (VdOff), and it should be at least 1 V larger than the stop voltage of the drain voltage sweep (VdStop).
5. Specify the maximum current limit of the drain current to be measured. To make the switching time fast enough, using 1 A or larger is recommended.
6. Specify the setup voltage of the HCSMU (VdsOn) to measure the on-state current determined in the previous step.
7. Specify the number of sampling.
8. Specify the sampling interval. Total sampling duration is determined by the sampling number and the sampling interval.
9. If the discharging switch of the N1267A is not to be used for this measurement, specify "Off" for the "DischargingSwitchingControl".

After clicking the "Measure" button, the measured sampling data of Rds, Vds and Id will be displayed in the Data Display panel (refer to figure 4-4-15)

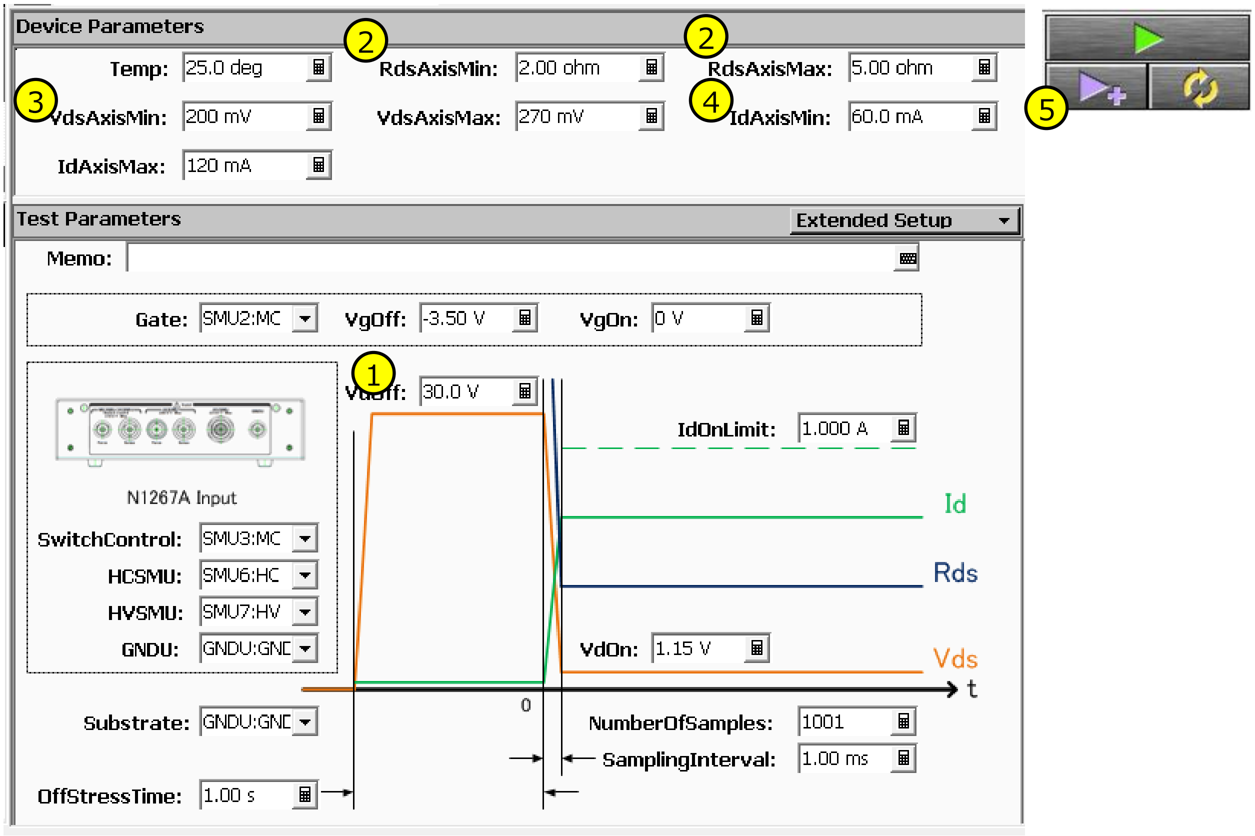


MARKER(4.9700000000E-001 s 2.5750205768E+000 ohm 2.48000...

Fig. 4-4-15 Example of measured reference data

Step 3. Changing off-state stress voltage and compare results

Next, apply the off-state stress voltage to the DUT, and compare its result with the previous one to see if the influence of the current collapse exists or not.



Temp: 25.0 deg
RdsAxisMin: 2.00 ohm
RdsAxisMax: 5.00 ohm
VdsAxisMin: 200 mV
VdsAxisMax: 270 mV
IdAxisMin: 60.0 mA
IdAxisMax: 120 mA

Memo:
Gate: SMU2:MC
VgOff: -3.50 V
VgOn: 0 V
VdOff: 30.0 V
IdOnLimit: 1.000 A
SwitchControl: SMU3:MC
HCSMU: SMU6:HC
HVSMU: SMU7:HV
GNDU: GNDU:GN
VdOn: 1.15 V
Substrate: GNDU:GN
NumberOfSamples: 1001
SamplingInterval: 1.00 ms
OffStressTime: 1.00 s

Fig. 4-4-16 Setup to apply the off-state stress voltage

1. Modify the VdOff high enough to produce a current collapse on the DUT.
2. Modify the scale of the vertical axis of the Rds to make it easy to compare the result.
3. Modify the scale of the vertical axis of the Vds to make it easy to compare the result.
4. Modify the scale of the vertical axis of the Id to make it easy to compare the result.
5. Click the “Append” button, then the newly measured waveforms are overlaid on the waveforms measured in the previous step by thicker lines.

Figure 4-4-17 shows the appended test results with various stress voltages, 30 V, 50 V and 70 V. By repeating the “Append” measurement, it is possible to overlay the multiple test results, and it is very useful to see the change of the influence of current collapse at each stress voltage.

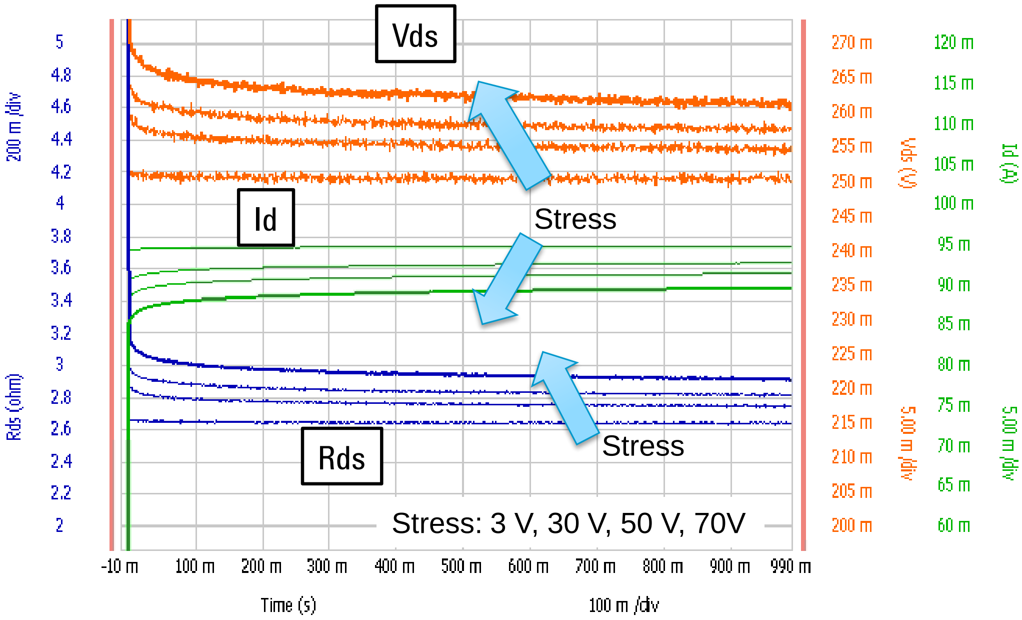


Fig. 4-4-17 Overlaid results with varying stress voltage

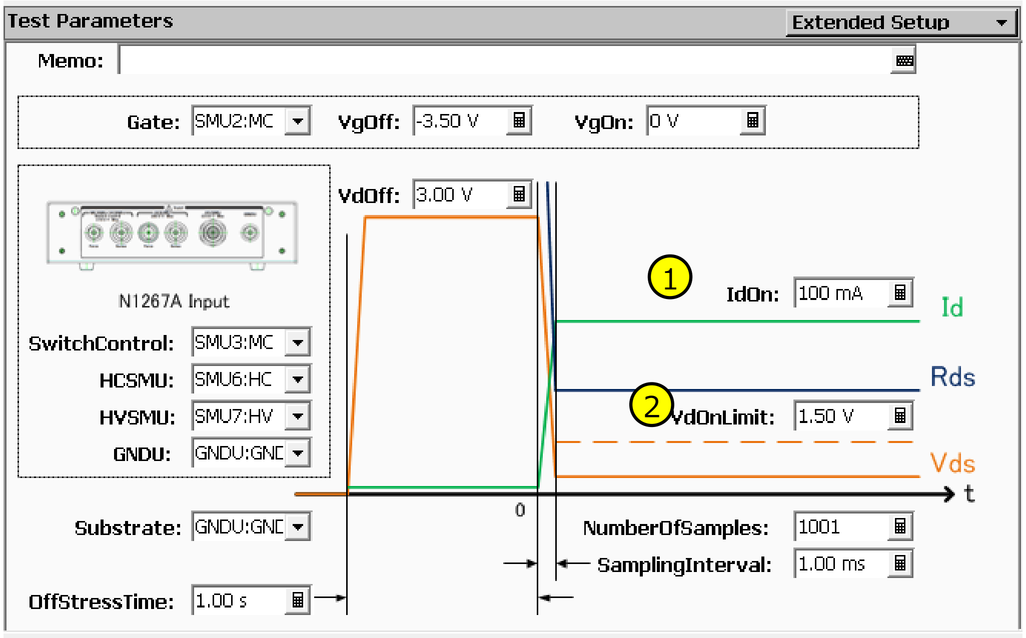
[Trouble Shooting]

[Case] Change of Id is not directly related to the change of the Rds

When measuring a relatively high current over 100 mA, the drain voltage is changing during measurement due to self-heating of the switch in the N1267A. It means the change of the drain current includes both the current collapse of the DUT and the self-heating of the switch. The measured Rds is the only useful parameter to evaluate the influence of the current collapse quantitatively. For more details about the self-heating of the switch, please refer to section 3-7.

Step 4. Using I Force Mode

Like the “FET Current Collapse Signal Monitor (I Force)”, the “FET Current Collapse I/V-t Sampling (I Force)” is useful to measure the recovery from the current collapse at the specified current.



Memo:

Gate: SMU2:MC VgOff: -3.50 V VgOn: 0 V

VdOff: 3.00 V

SwitchControl: SMU3:MC

HCSMU: SMU6:HC

HVSMU: SMU7:HV

GNDU: GNDU:GN

IdOn: 100 mA

VdOnLimit: 1.50 V

Substrate: GNDU:GN

NumberOfSamples: 1001

SamplingInterval: 1.00 ms

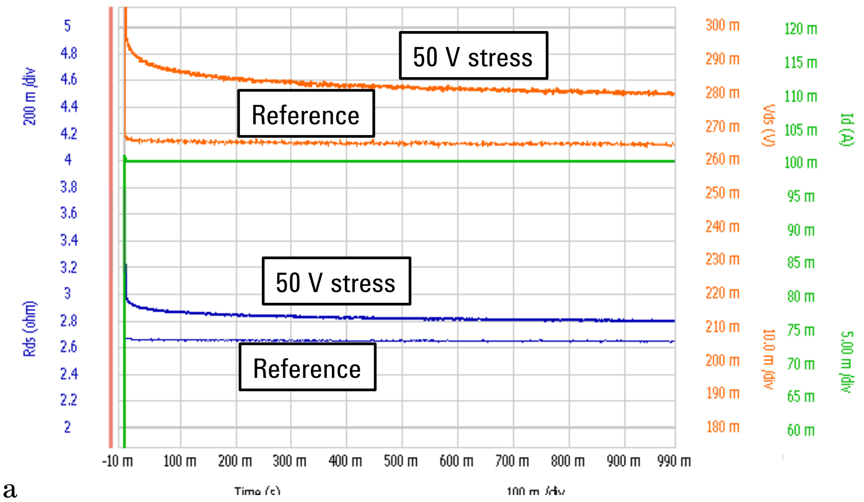
OffStressTime: 1.00 s

Fig. 4-4-18 Setup example for "FET Current Collapse I/V-t Sampling (I Force)"

Almost all of the parameters of the "FET Current Collapse I/V-t Sampling (I Force)" are the same as the "FET Current Collapse I/V-t Sampling". Specify the IdOn and the VdOnLimit instead of the IdOnLimit and the VdOn of the "FET Current Collapse I/V-t Sampling".

1. Set the current level to measure the on-state characteristics (IdOn). This is the output current from the HCSMU to measure the on-state characteristics.
2. Set the voltage limit at the on-state (VdOnLimit). This is the voltage compliance of the HCSMU to measure the on-state characteristics. VdOnLimit is high enough to supply the IdOn including the voltage drop at the switch in the N1267A.

Figure 4-4-19 shows an example of measured results overlaying the reference data and the results with 50 V stress voltage. The result with a 50 V stress voltage is drawn by the thicker lines.



a

Fig. 4-4-19 Measured example by using the I Force mode

If the overcurrent situation of the HVSMU continues at the beginning of the sampling, the step is observed on the measured drain current and the drain voltage as shown in figure 4-4-20.

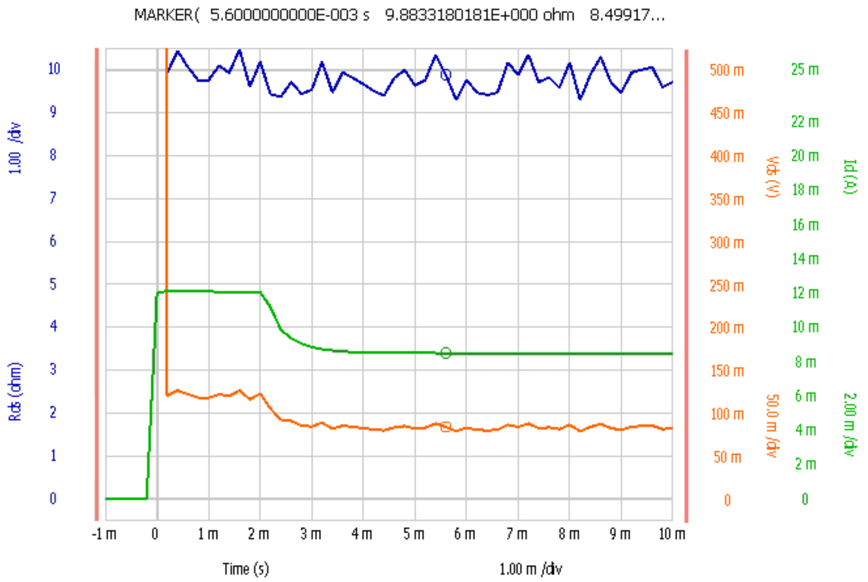


Fig. 4-4-20 Step on Id and Vds during the overcurrent situation

The duration of the step depends on the stress voltage. For example, if the stress voltage is 100 V, it continues about 1000 V ÷ 0.4 V/μs = 2.5 ms.

4-4-4. FET Current Collapse Oscilloscope View

This is a preset for the Tracer Test Mode to measure the fast switching characteristics of the Ron of the DUT.

Basically, to measure dynamic Ron characteristics, the application test definitions demonstrated in the previous sections are recommended, because

- Easy to use by filling in the blank setup,
- Append function is available to compare the results with different off-state stress voltages,
- The result of measurement is automatically stored in EasyEXPERT database.

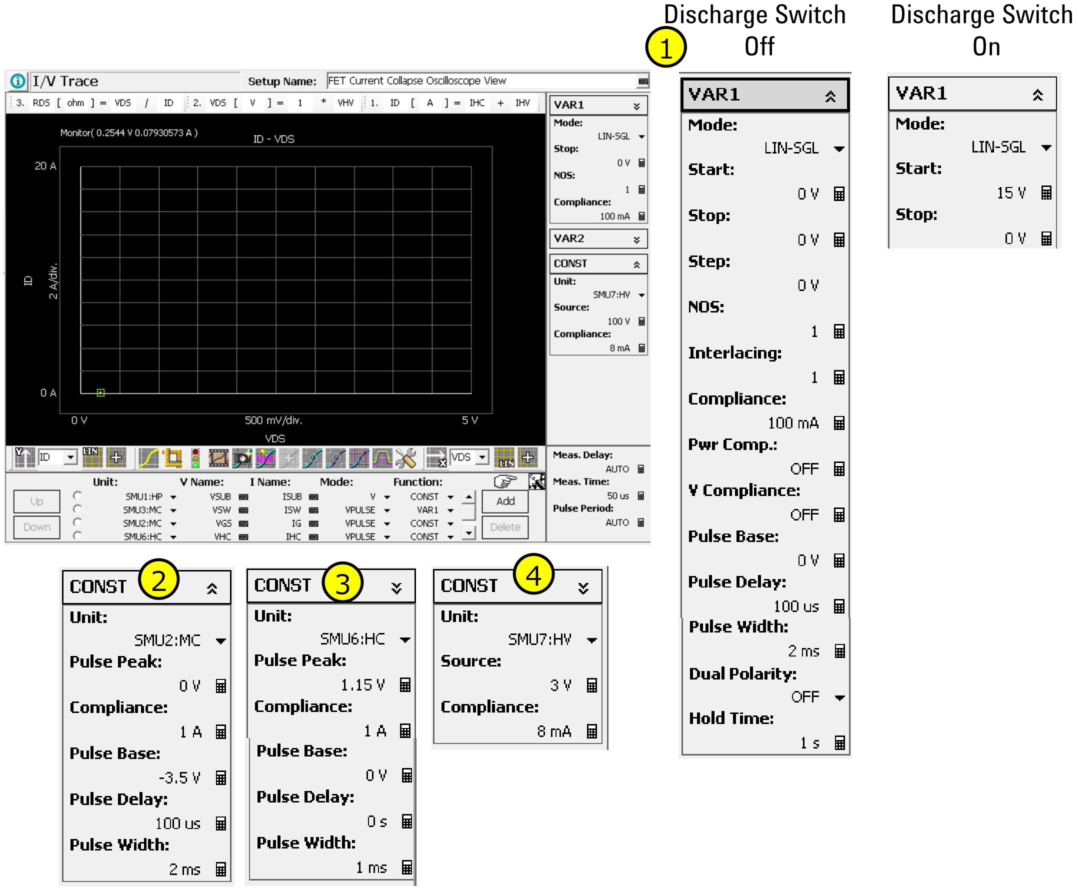
This preset has a default value for each parameter to be used by just changing a small number of parameters like the off-state stress voltage, on-measurement voltage, current compliance, etc. But if you want to change a timing parameter like “pulse delay” or “pulse width”, you have to change those of each SMU manually.

Also, in this preset, the results are monitored by the Oscilloscope View function. They have to be saved by using the save menu, and it is necessary to input the file name manually.

But through a measurement using this preset, it is possible to learn the basic ideas of how the N1267A works to measure the fast switching characteristics of the GaN FET or the diode.

Step 1. Measuring reference data

Figure 4-4-21 shows the example setup to measure the reference data without a current collapse on the DUT.



Setup Name: FET Current Collapse Oscilloscope View

3. RDS [ohm] = VDS / ID
2. VDS [V] = 1 * VHV
1. ID [A] = IHC + IHV

Unit:	V Name:	I Name:	Mode:	Function:
SMU1:HP	VSUB	ISUB	V	CONST
SMU3:MC	VSW	ISW	VPULSE	VAR1
SMU2:MC	VGS	IG	VPULSE	CONST
SMU6:HC	VHC	IHC	VPULSE	CONST

VAR1
Mode: LIN-SGL
Stop: 0 V
NOS: 1
Compliance: 100 mA

VAR2

CONST
Unit: SMU7:HV
Source: 100 V
Compliance: 8 mA

Meas. Delay: AUTO
Meas. Time: 50 us
Pulse Period: AUTO

① Discharge Switch Off

VAR1
Mode: LIN-SGL
Start: 0 V
Stop: 0 V
Step: 0 V
NOS: 1
Interlacing: 1
Compliance: 100 mA
Pwr Comp.: OFF
V Compliance: OFF
Pulse Base: 0 V
Pulse Delay: 100 us
Pulse Width: 2 ms
Dual Polarity: OFF
Hold Time: 1 s

Discharge Switch On

VAR1
Mode: LIN-SGL
Start: 15 V
Stop: 0 V

② CONST
Unit: SMU2:MC
Pulse Peak: 0 V
Compliance: 1 A
Pulse Base: -3.5 V
Pulse Delay: 100 us
Pulse Width: 2 ms

③ CONST
Unit: SMU6:HC
Pulse Peak: 1.15 V
Compliance: 1 A
Pulse Base: 0 V
Pulse Delay: 0 s
Pulse Width: 1 ms

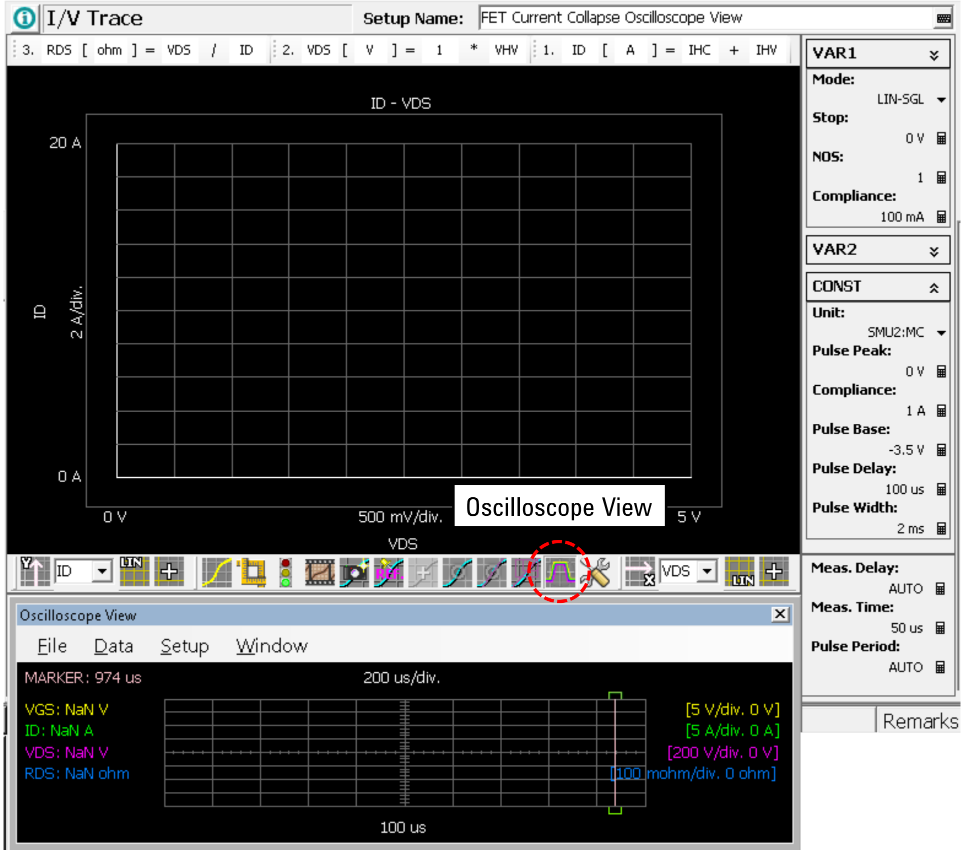
④ CONST
Unit: SMU7:HV
Source: 3 V
Compliance: 8 mA

Fig. 4-4-21 Example setup to measure the reference data

As the default, the measurement duration is 900 µs, and the discharging switch is not used (turned off). So the pulse width of the HCSMU is 1 ms, and the delay time for the gate voltage pulse and the discharging switch control is 100 µs.

1. To enable the discharging switch, specify 15 V as the Start voltage of VAR1.
2. Specify the Pulse Base and the Pulse Peak voltage. The Pulse Base is the gate voltage to turn off the DUT, and the Pulse Peak is the gate voltage to turn on the DUT.
3. Specify the Pulse Peak voltage of the HCSMU to measure the on-state current.
4. Specify the Source voltage of the HVSMU, and it should be low enough not to cause a current collapse to the DUT. And it should be at least 1 V larger than the Pulse Peak of the HCSMU to measure the on-state current.

Before performing the measurement, the Oscilloscope has to be enabled. To enable the Oscilloscope View, click the icon of the Oscilloscope view as shown in figure 4-4-22.



Setup Name: FET Current Collapse Oscilloscope View

3. RDS [ohm] = VDS / ID
2. VDS [V] = 1 * VHV
1. ID [A] = IHC + IHV

VAR1
Mode: LIN-SGL
Stop: 0 V
NOS: 1
Compliance: 100 mA

VAR2

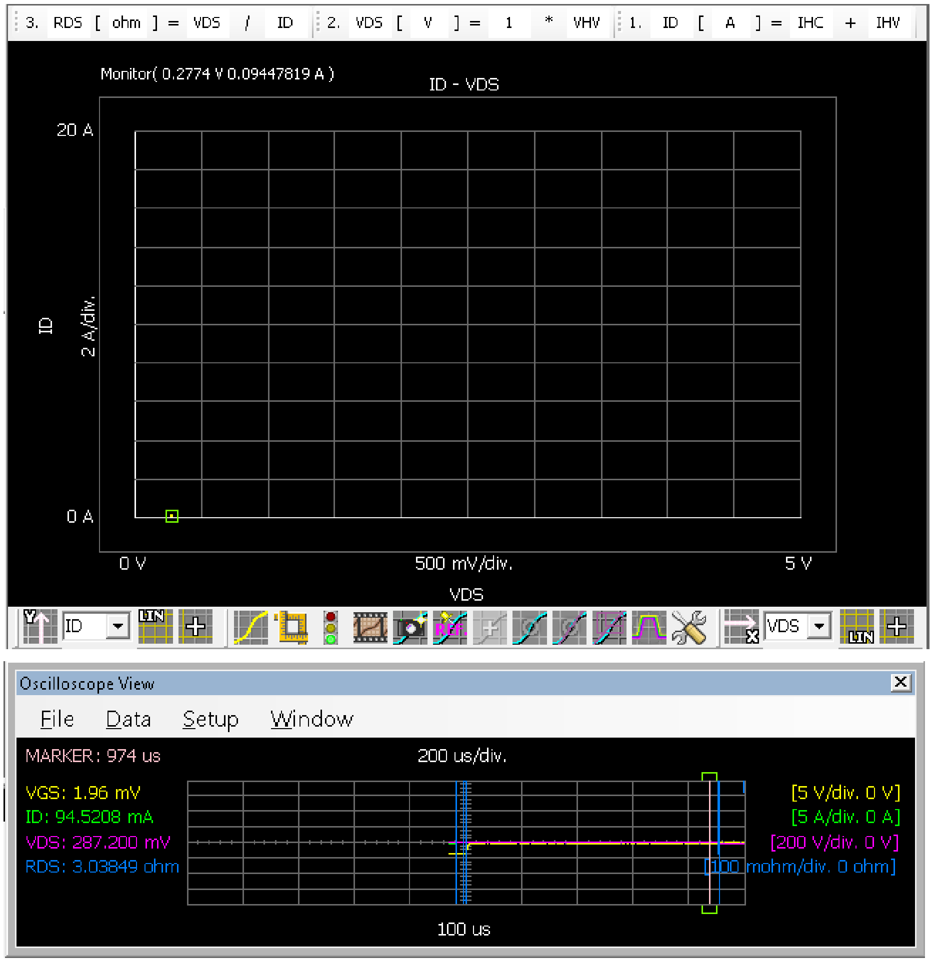
CONST
Unit: SMU2:MC
Pulse Peak: 0 V
Compliance: 1 A
Pulse Base: -3.5 V
Pulse Delay: 100 us
Pulse Width: 2 ms

Meas. Delay: AUTO
Meas. Time: 50 us
Pulse Period: AUTO

MARKER: 974 us
VGS: NaN V
ID: NaN A
VDS: NaN V
RDS: NaN ohm

Fig. 4-4-22 Enabling the Oscilloscope View

Then, click the “Measure” button once, and the waveform of the VGS, ID, VDS and RDS are displayed in the Oscilloscope View panel like in the figure below.



3. RDS [ohm] = VDS / ID
2. VDS [V] = 1 * VHV
1. ID [A] = IHC + IHV

Monitor(0.2774 V 0.09447819 A)

MARKER: 974 us

VGS: 1.96 mV

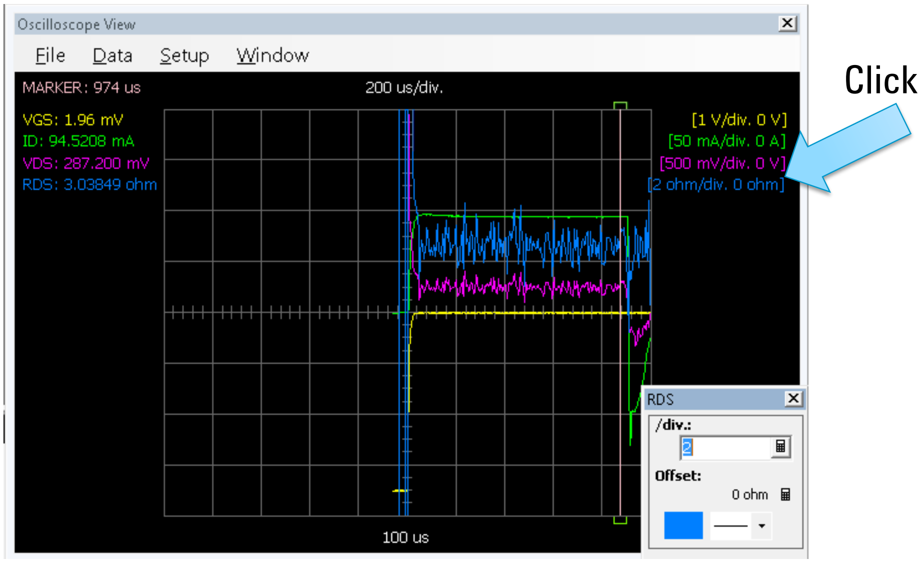
ID: 94.5208 mA

VDS: 287.200 mV

RDS: 3.03849 ohm

Fig. 4-4-23 Measurement results

To expand the Oscilloscope View, it is possible to adjust the size of the window by dragging the edge of the window. Also selecting “Window” → “Large” is useful to make it large.
Then, adjust the vertical scale for each waveform to see them in details. To change the vertical scale, click the scale on the right side edge of the screen of each trace, and change the scale value displayed in the separate window as shown in figure 4-4-24.



MARKER: 974 us

200 us/div.

VGS: 1.96 mV
ID: 94.5208 mA
VDS: 287.200 mV
RDS: 3.03849 ohm

[1 V/div. 0 V]
[50 mA/div. 0 A]
[500 mV/div. 0 V]
[2 ohm/div. 0 ohm]

100 us

/div.: 2

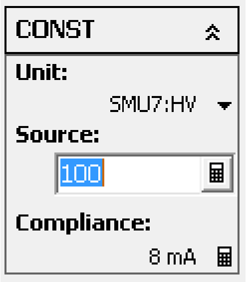
Offset: 0 ohm

Click

Fig. 4-4-24 Changing the vertical scale of each waveform

Step 2. Changing off-state stress voltage

Next, apply the off-state stress voltage to the DUT, and compare its result with the previous one to see if the influence of the current collapse exists or not.
To change the off-state stress voltage, change the Source voltage of the HVSMU as shown in figure 4-4-25.



Unit: SMU7:HV

Source: 100

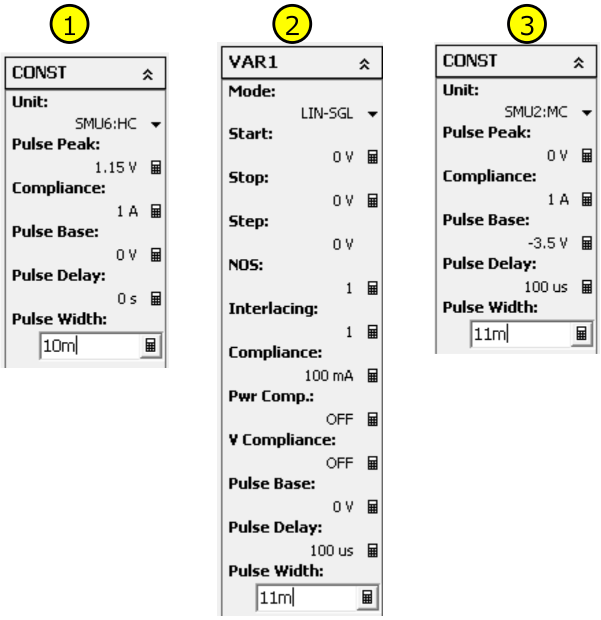
Compliance: 8 mA

Fig. 4-4-25 Setting to apply the stress voltage

Then, click the “Measure” button, and the waveforms displayed on the Oscilloscope view are updated.

Step 3. Changing timing parameters

If you want to change the measurement duration, at first, it is necessary to change the pulse width of each SMU.



CONST
Unit: SMU6:HC
Pulse Peak: 1.15 V
Compliance: 1 A
Pulse Base: 0 V
Pulse Delay: 0 s
Pulse Width: 10m

VAR1
Mode: LIN-SGL
Start: 0 V
Stop: 0 V
Step: 0 V
NOS: 1
Interlacing: 1
Compliance: 100 mA
Pwr Comp.: OFF
V Compliance: OFF
Pulse Base: 0 V
Pulse Delay: 100 us
Pulse Width: 11m

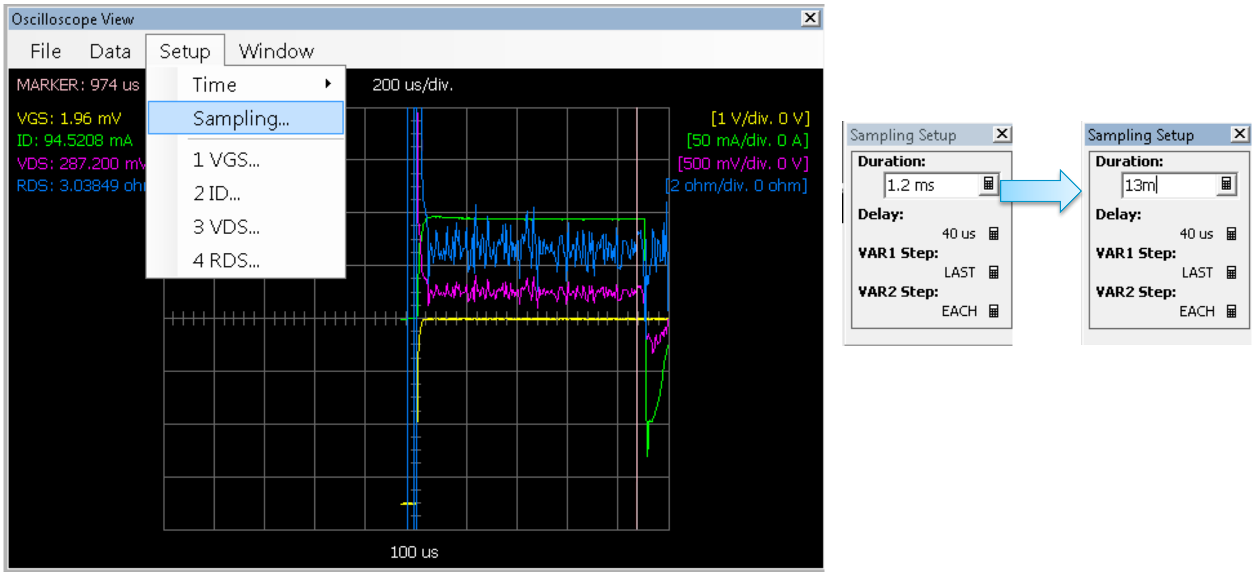
CONST
Unit: SMU2:MC
Pulse Peak: 0 V
Compliance: 1 A
Pulse Base: -3.5 V
Pulse Delay: 100 us
Pulse Width: 11m

Fig. 4-4-26 Changing pulse with of each SMU

In this case, the measurement duration is extended to 9.9 ms.

1. Change the pulse width of the HCSMU to 10 ms. Since the HCSMU starts output at 100 µs before starting to output the gate voltage pulse, the measurement duration of the on-state is 9.9 ms.
2. Change the pulse width of the MCSMU for the discharging switch control to 11 ms.
3. Change the pulse width of the MCSMU for the gate biasing to 11 ms.

Also, the sampling duration of the Oscilloscope view has to be modified to capture the extended waveform.



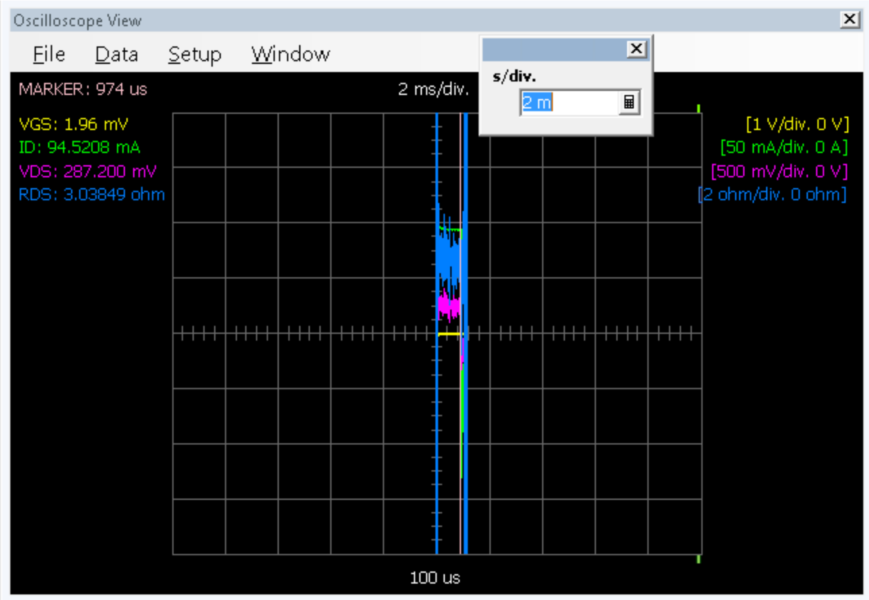
MARKER: 974 us
VGS: 1.96 mV
ID: 94.5208 mA
VDS: 287.200 m
RDS: 3.03849 oh

Duration: 1.2 ms
Delay: 40 us
VAR1 Step: LAST
VAR2 Step: EACH

Duration: 13m
Delay: 40 us
VAR1 Step: LAST
VAR2 Step: EACH

Fig. 4-4-27 Changing the sampling duration of the oscilloscope view

To change the sampling duration, select “Sampling...” from the “Setup” menu, then change the durations in the “Sampling Setup” window.
And, the horizontal scale of the Oscilloscope View is modified to display the captured waveform.

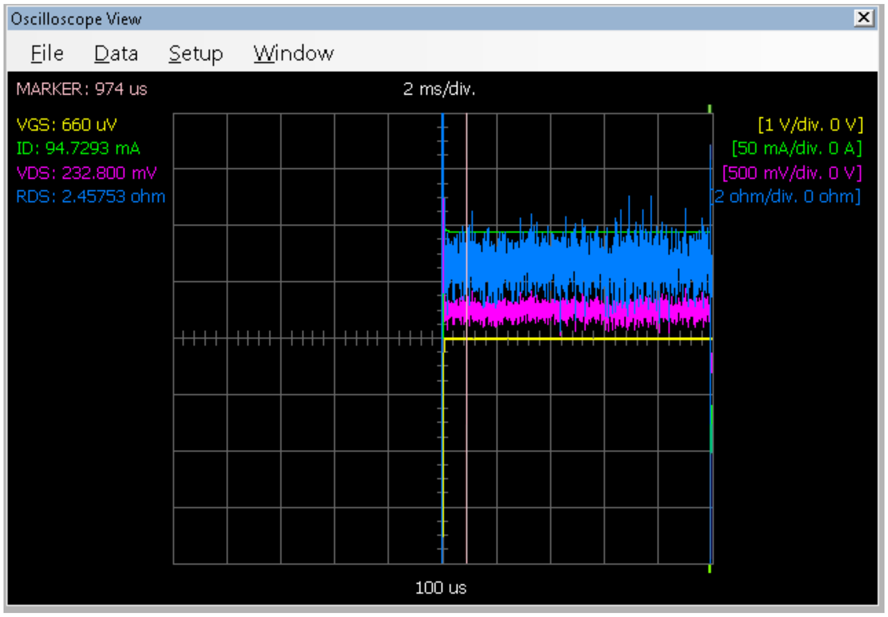


MARKER: 974 us
2 ms/div.
s/div. 2 m
VGS: 1.96 mV
ID: 94.5208 mA
VDS: 287.200 mV
RDS: 3.03849 ohm
[1 V/div. 0 V]
[50 mA/div. 0 A]
[500 mV/div. 0 V]
[2 ohm/div. 0 ohm]
100 us

Fig. 4-4-28 Changing the horizontal scale

To change the horizontal scale, click the horizontal scale on the screen, and modify the scale in the “s/div” window.

Then, click the “Measure” button, and the waveforms are updated as shown in figure 4-4-29.



MARKER: 974 us
2 ms/div.
VGS: 660 uV
ID: 94.7293 mA
VDS: 232.800 mV
RDS: 2.45753 ohm
[1 V/div. 0 V]
[50 mA/div. 0 A]
[500 mV/div. 0 V]
[2 ohm/div. 0 ohm]
100 us

Fig. 4-4-29 Updated test results for extended pulse width

5. GaN Current Collapse Application Test Reference

5-1. Overview

Here is a summary of purpose, advantage and disadvantage of each application tests, and pre-sets of Tracer Test.

Table 5-1-1. Summary of Application Test and preset of Tracer Test for GaN FET

Name	Min. Switching Time	Max. Meas. Duration	Min. Sampling Interval	Capture Id-Vd curves after Stress	Measure at Constant Id	Discharge Switch for low Id Measurement	Timing control of discharge switch
Application Test							
FET Current Collapse IV-t Sampling	200 µs	Longer than 5 s (almost infinite by using a log sampling mode)	200 µs	--	--	√	--
FET Current Collapse Signal Monitor	20 µs	24 ms (1 ms)*2	6 µs*3	--	--	√	√
FET Current Collapse IV-t Sampling (I Force))	200 µs	Longer than 5 s (almost infinite by using a log sampling mode)	200 µs	--	√	√	--
FET Current Collapse Signal Monitor (I Force	50 µs	24 ms (1 ms)*2	6 µs*3	--	√	√	√
Id-Vds Current Collapse	N/A	N/A	N/A	√	--	√	--
Preset of Tracer Test							
ID-VDS*1	N/A	N/A	N/A	N/A	N/A	N/A	N/A
ID(off)-VDS*1	N/A	N/A	N/A	N/A	N/A	N/A	N/A
ID-VDS Current Collapse	N/A	N/A	N/A	√	--	--	--
FET Current Collapse Oscilloscope View	20 µs	24 ms (1 ms)*2	2 µs*4	--	--	√	√

*1: The ID-VDS and Id(off)-VDS presets are used to check the functionality of the device before doing a series of current collapse measurements.

*2: If the current is over 1 A, the maximum duration of sampling is limited at the 1 ms maximum pulse width of the HCMSU.

*3: The sampling interval is automatically determined by the specified measurement duration and the maximum memory depth. The available sampling intervals are 6 µs and 12 µs for this application test, and the maximum memory depth is 2,000. The rounded out value of (Measurement duration / 2000) in the above 2 intervals is automatically selected.

*4: 2 µs is valid for HCSMU and MCSMU. For HVSMU, the minimum sampling interval is 6 µs. The measured value by HVSMU is interpolated to the same sampling interval with HCSMU or MCSMU. The sampling interval is automatically determined by the specified measurement duration and the maximum memory depth. The available sampling intervals are 2 µs,4 µs, 6 µs and 12 µs for this application test, and the maximum memory depth is 2,000. The rounded out value of (Measurement duration / 2000) in those intervals is automatically selected.

- The ID-VDS and Id(off) –VDS are not used for the current collapse measurement itself. Those are used to measure the on-characteristics and off-characteristics of devices prior to performing a series of current collapse measurements to verify the DUT functionality. Also, it is useful to find an appropriate bias setting of the HCMSU for current collapse measurement, because the drain voltage differs from the setting voltage of the HCMSU due the voltage drop at the internal switch of the N1267A.
- The Ids-Vds Current Collapse of Application Test and the ID-VDS Current Collapse in the Tracer Test are used to observe a change of the Id-Vds traces after applying the off-state stress voltage in the specified duration like in figure 1-2. The difference is in the control of the FET switch of the N1267A. In the Tracer Test, it is not possible to control the FET switch (always off) because only a single VAR2 source can be used in it. So it is not possible to use it for low current device measurement (Id < 8 mA). So, for smaller device measurement, the Id-Vds current collapse in the Application Test has to be used.
- The FET Current Collapse I/V-t Sampling and FET Current Collapse I/V-t Sampling (I Force) are used to measure a long term variation of the on-resistance after changing from the off-state to the on-state. These application tests utilize the I/V-t sampling function of the Classic Test mode. The minimum sampling interval is limited at 200 µs due to the internal circuit response during the change of state from the high voltage of the off-state to the low voltage of the on-state. The maximum measurement duration is extremely long when using the log sampling mode. In this application test, it is possible to use the FET switch in the N1267A, but the timing to turn it on is synchronized with other biases like Vds and Vgs (no delay time can be set between them).
- The FET Current Collapse Signal Monitor, FET Current Collapse Signal Monitor (I Force) and FET Current Collapse Oscilloscope View are used to see the fast switching behavior of the device. The minimum sampling interval is 2 µs for HCSMU or MCSMU. It is 6 µs for HVSMU and it comes from the hardware limitation of the HVSMU itself. In the Tracer Test mode, the sampling interval of the HVSMU is converted to the same interval with the HCSMU and MCSMU by interpolation.
- In the Application Tests, the minimum sampling interval of the HCMSU and MCSMU is limited at the same interval with the HVSMU.
- The “I Force” mode of FET Current Collapse I/V-t and Signal Monitor application tests measure on-state characteristics by using the constant current force mode. It is useful if you want to measure the on-resistance of devices with the specified current. But since the HCSMU is in the compliance status during the off-state (voltage force mode), at least 50 µs transient exists from the compliance state to the normal operation when switching from the off-state to the on-state.
- For GaN diode, following application tests and presets of Tracer Test are available.

Table5-1-2 Summary of Application Test and preset of Tracer Test for GaN Diode

Name	Min. Switching Time	Max. Meas. Duration	Min. Sampling Interval	Capture IF-VF curve after Stress
Application Test				
Diode Current Collapse IV-t Sampling	200 µs	Longer than 5 s (almost infinite by using a log sampling mode)	200 µs	--
Diode Current Collapse Signal Monitor	20 µs	24 ms (1 ms)*2	6 µs*3	--
Preset of Tracer Test				
IF-VF*1	N/A	N/A	N/A	N/A
IR-VR*1	N/A	N/A	N/A	N/A
IF-VF Current Collapse	N/A	N/A	N/A	√
Diode Current Collapse Oscilloscope View	20 µs	24 ms (1 ms)*2	2 µs*4	--

*1: ID-VDS and Id(off)-VDS presets are used to check the functionality of the device before performing a series of current collapse measurements.

*2: If current is over 1 A, the maximum duration of the sampling is limited by the 1 ms maximum pulse width of the HCMSU.

*3: The sampling interval is automatically determined by the specified measurement duration and the maximum memory depth. The available sampling intervals are 6 µs and 12 µs for this application test, and the maximum memory depth is 2,000. The rounded out value of (Measurement duration / 2000) in the above 2 intervals is automatically selected.

*4: 2 µs is valid for HCSMU and MCSMU. For HVSMU, the minimum sampling interval is 6 µs. The measured value by HVSMU is interpolated to the same sampling interval with HCSMU or MCSMU. The sampling interval is automatically determined by the specified measurement duration and the maximum memory depth. The available sampling intervals are 2 µs,4 µs, 6 µs and 12 µs for this application test, and the maximum memory depth is 2,000. The rounded out value of (Measurement duration / 2000) in those intervals is automatically selected.

Those are almost identical with the corresponding application tests and presets of GaN FET.

- The IF-VF and IR-VR are used to check the functionality of the device before performing current collapse measurements.
- The IF-VF Current Collapse is used to observe the change of IF-VF curve after applying a stress voltage in a specified duration.
- The Diode Current Collapse I/V-t Sampling is used to measure a long term variation of the forward current of the diode.
- The Diode Current Collapse Signal Monitor and Diode Current Collapse Oscilloscope View are used to see the fast switching behavior of the forward current.

5-2. FET Current Collapse IV-t Sampling

GaN FET Current Collapse characteristics (using N1267A) (A.05.02)

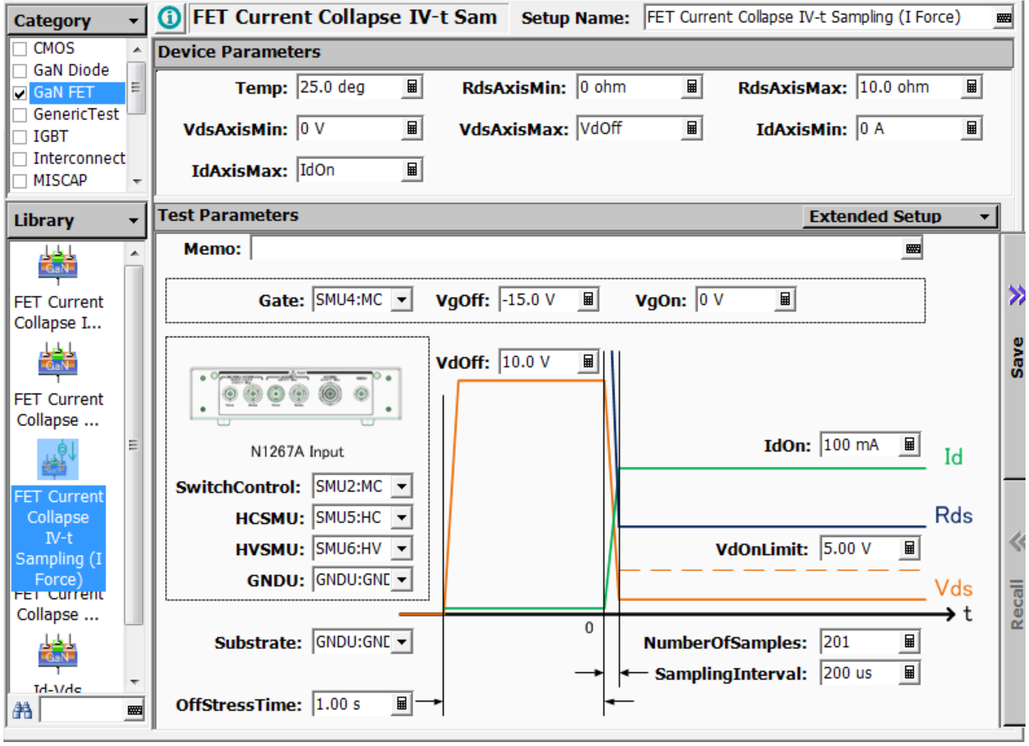
[Description]

Measures Current Collapse of GaN FET.
On-state current, voltage and resistance after off state are sampled using N1267A.

[Device Under Test]

GaN FET, 4 terminals

[Input Parameters]



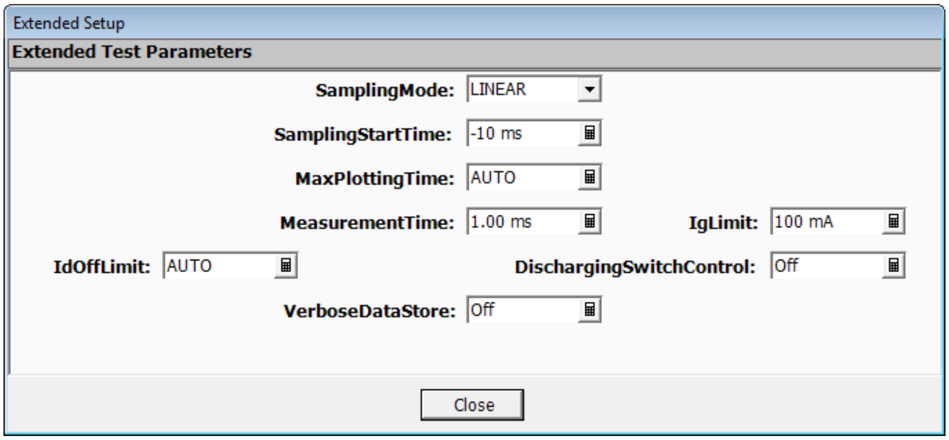
Setup Name: FET Current Collapse IV-t Sampling (I Force)

Device Parameters

Temp: 25.0 deg
RdsAxisMin: 0 ohm
RdsAxisMax: 10.0 ohm
VdsAxisMin: 0 V
VdsAxisMax: VdOff
IdAxisMin: 0 A
IdAxisMax: IdOn

Test Parameters

Memo:
Gate: SMU4:MC
VgOff: -15.0 V
VgOn: 0 V
VdOff: 10.0 V
IdOn: 100 mA
VdOnLimit: 5.00 V
SwitchControl: SMU2:MC
HCSMU: SMU5:HC
HVSMU: SMU6:HV
GNDU: GNDU:GND
Substrate: GNDU:GND
NumberOfSamples: 201
SamplingInterval: 200 us
OffStressTime: 1.00 s



Extended Test Parameters

SamplingMode: LINEAR
SamplingStartTime: -10 ms
MaxPlottingTime: AUTO
MeasurementTime: 1.00 ms
IgLimit: 100 mA
IdOffLimit: AUTO
DischargingSwitchControl: Off
VerboseDataStore: Off

Device Parameters

Name	Description	Default	Unit	Range	Digits	Resolution	Symbols
Temp	Temperature	25	deg C	-100 to 100	4	100 mdegC	N/A
RdsAxisMin	Minimum value of Y1 Axis(Rds)	0	Ohm	0 to 100	3	1 mOhm	N/A
RdsAxisMax	Maximum value of Y1 Axis (Rds)	10	Ohm	-infinity to +infinity	3	1 mOhm	N/A
VdsAxisMin	Minimum value of Y2 Axis (Vds)	0	V	-infinity to +infinity	3	1 mV	N/A
VdsAxisMax	Maximum Y2 Axis (Vds)	VdOff	V	-infinity to +infinity	3	1 mV	N/A
IdAxisMin	Minimum value of Y3 Axis (Id)	0	A	-infinity to +infinity	3	1 µA	N/A
IdAxisMax	Maximum Y3 Axis (Id)	IdOnLimit	A	-infinity to +infinity	3	1 µA	N/A

Test Parameters

Name	Description	Default	Unit	Range	Digits	Resolution	Symbols
Memo	Memorandum	N/A	N/A	N/A	N/A	N/A	N/A
GNDU	GNDU connected to N1267A GNDU input	GNDU	N/A	GNDU	N/A	N/A	N/A
HVSMU	HVSMU connected to N1267A HVSMU input	HVSMU	N/A	HVSMU	N/A	N/A	N/A
HCSMU	HCSMU connected to N1267A HCSMU input	HCSMU	N/A	HCSMU	N/A	N/A	N/A
SwitchControl	MCSMU connected to N1267A Switch Control	MCSMU	N/A	MCSMU	N/A	N/A	N/A
Gate	MCSMU/HCSMU connected to Gate terminal	MCSMU	N/A	MCSMU, HCSMU	N/A	N/A	N/A
Substrate	SMU/GNDU connected to substrate	GNDU	N/A	SMU*, GNDU	N/A	N/A	N/A
VgOff	Gate voltage for turning DUT off	-15 V	V	-40 V to 40 V	3	1 mV	N/A
VgOn	Gate voltage for turning DUT on	0 V	V	-40 V to 40 V	3	1 mV	N/A
VdOff	Drain voltage applied to DUT turned off	10 V	V	1 V to 3 kV	3	1 mV	N/A
VdOn**	Drain voltage applied to DUT turned on	5 V	V	-1 V to 40 V	3	1 mV	N/A
IdOnLimit	Drain current compliance applied to DUT turned on	100 mA	A	20m A to 1 A	4	1 mA	N/A
OffStressTime	DUT off-state stress time	1 s	s	0 s to 655.35 s	5	10 ms	N/A
SamplingInterval	Sampling interval	200 µs	S	200 µs to 65.535 s	5	10 µs	N/A
NumberOfSamples	Number of samples	201	N/A	1 to 12500	6	1	N/A

*SMU: MPSMU, HPSMU, HVSMU, HCSMU, MCSMU
**Setting voltage of the HCMSU connected to the N1267A during the on-state measurement. Actual Vds is different from it due to voltage drop at the switch in the N1267A.

Extended Parameters

Name	Description	Default	Unit	Range	Digits	Resolution	Symbols
SamplingMode***	Options for linear or log sampling	Linear	N/A	Linear / Log	N/A	N/A	N/A
SamplngStartTime****	Time offset from turning DUT on to starting sampling	-10 ms	s	-90 ms to 655.35 s	5	10 ms	N/A
MaxPlottingTime	Max time of graph X axis for plotting	AUTO	S	0 to infinity	4	10 ms	Auto: Automatically determined by the SamplingInterval and NumberOfSamples
MeasurementTime	Measurement time (Aperture time, effective in case of 2 ms or above SamplingInterval)	200 μs	s	2 μs to 20 ms	3	2 μs	Minimum : 2 μs
IgLimit	Gate current compliance	100 mA	A	1 nA to 1A	3	1 nA	N/A
IdOffLimit	Drain current compliance applied to DUT turned off	AUTO	A	0 A to 8 mA	3	1 nA	AUTO: Use the maximum current compliance of the HVSMU
DischargeSwitchControl	Option for discharging by N1267A Switch Control	Off	V	0 V, 15 V	2	15 V	Off: 0V On: 15 V
VerboseDataStore	Option for verbose data store for embedded classic test setup	Off	N/A	0, 1	1	1	Off: 0 On: 1

***Log sampling is only valid when the SamplingInterval is equal to or longer than 2 ms.
****Negative value is only valid when the SamplingInterval is smaller than 2 ms.

[Measurement Parameters]

Name	Description	Unit
Time	On state time	s
V_HCSMU	Voltage measured by HCSMU	V
I_HCSMU	Current measured by HCSMU	A
V_HVSMU	Voltage measured by HVSMU	V
I_HVSMU	Current measured by HVSMU	A
V_SwitchControl	Voltage measured by Switch Control MCSMU	V
I_SwitchControl	Current measured by Switch Control MCSMU	A
V_Gate	Voltage measured by SMU to Gate drive	V
I_Gate	Current measured by SMU to Gate drive	A

[User Function]

Name	Description	Unit
Vds	Drain-Source voltage (= V_HVSMU)	A
Id	Drain current (= I_HCSMU + I_HVSMU)	V
Rds	Drain-Source resistance (= Vds / Id)	Ohm
Vgs	Gate-Source voltage (= V_Gate)	V
Ig	Gate current (= I_Gate)	I
Ta	Temperature (= Temp)	degree C

[X-Y Plot]

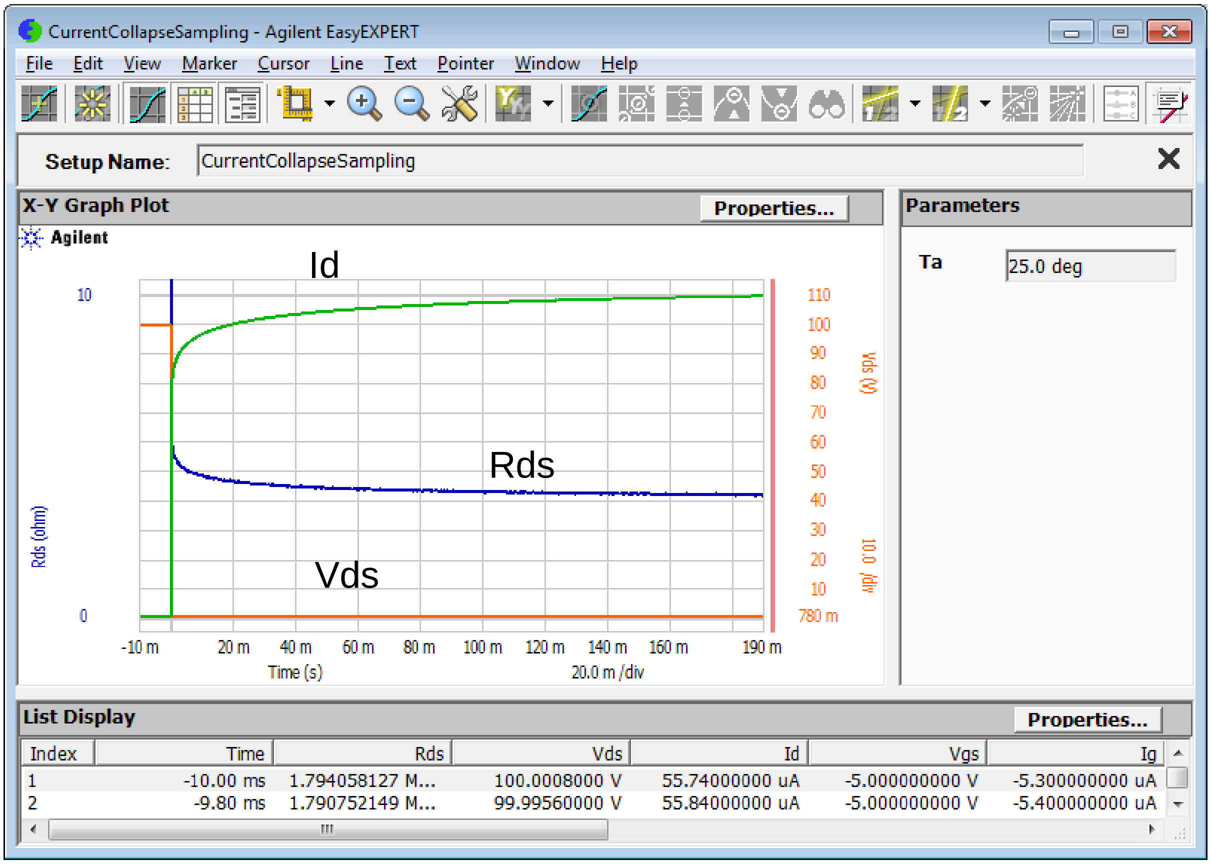
Axis	Item	Unit
X Axis	Time	s
Y1 Axis	Rds	Ohm
Y2 Axis	Vds	V
Y3 Axis	Id	A

[List Display]

Name	Description	Unit
Time	On state time	S
Rds	Drain-Source resistance (= Vds / Id)	Ohm
Vds	Drain-Source voltage (= V_HVSMU)	V
Id	Drain current (= I_HCSMU + I_HVSMU)	A
Vgs	Gate-Source voltage (= V_Gate)	V
Ig	Gate current (= I_Gate)	A
V_HCSMU	Voltage measured by HCSMU	V
I_HCSMU	Current measured by HCSMU	A
V_HVSMU	Current measured by HVSMU	V
I_HVSMU	Voltage measured by HVSMU	A
V_SwitchControl	Voltage measured by SMU for switch control	V
I_SwitchControl	Current measured by SMU for switch control	A

[Output Parameters]

Name	Description	Unit
Ta	Temperature (= Temp)	Degree C



Setup Name: CurrentCollapseSampling

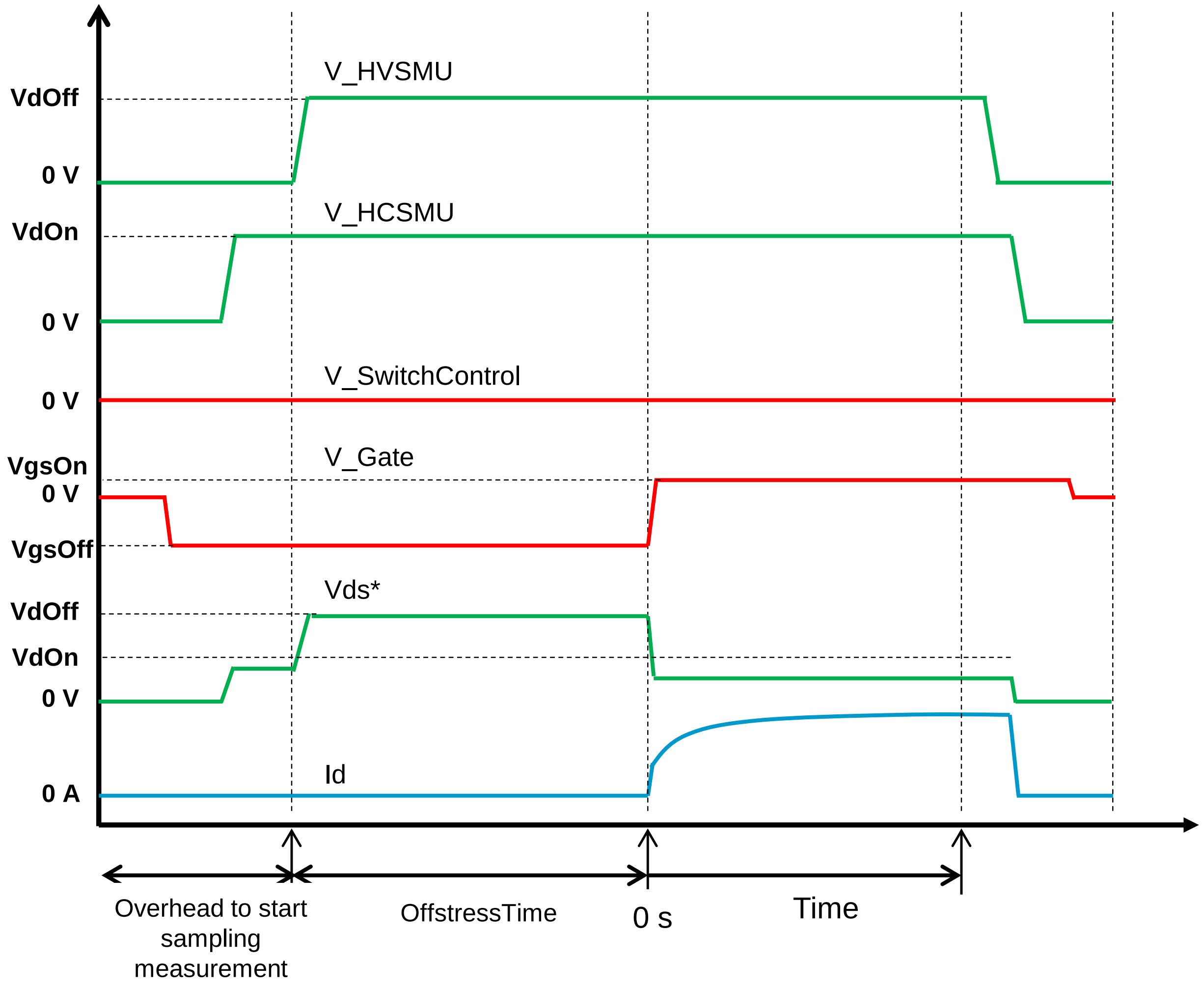
Ta 25.0 deg

Index	Time	Rds	Vds	Id	Vgs	Ig
1	-10.00 ms	1.794058127 M...	100.0008000 V	55.74000000 uA	-5.000000000 V	-5.300000000 uA
2	-9.80 ms	1.790752149 M...	99.99560000 V	55.84000000 uA	-5.000000000 V	-5.400000000 uA

[Pulse Timing Chart]

Case 1: DischargeSwitchControl is "Off"

- When the drain on current is larger than 8 mA, the "DischargeSwitchControl" should be OFF.

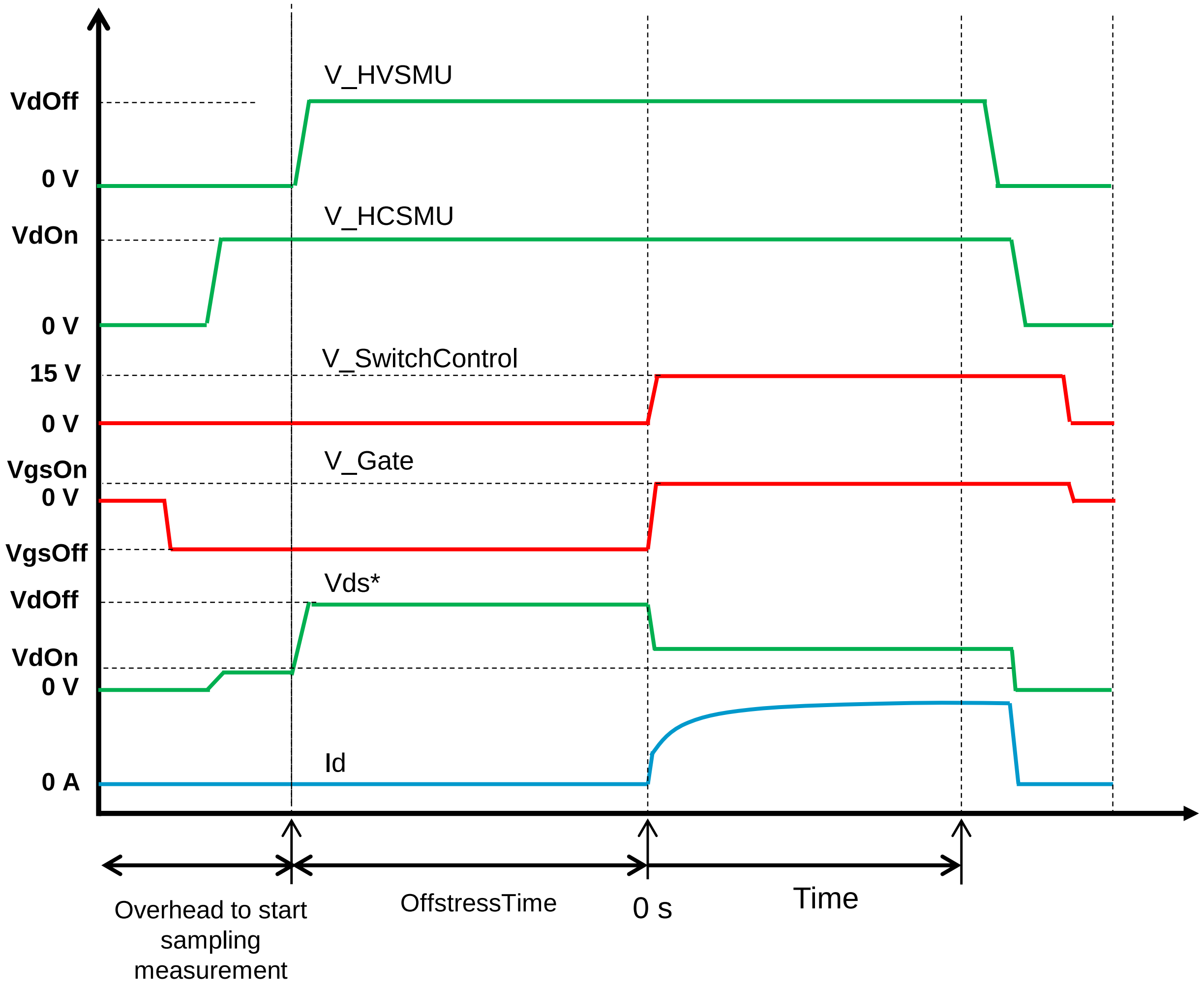


Order to output voltage: Substrate→Switch Control→ Gate→ HCSMU→HVSMU

*: Vds at on-state is lower than the "VdOn" due to the voltage drop at the switch inside of the N1267A.

Case 2: DischargeSwitchControl is "On"

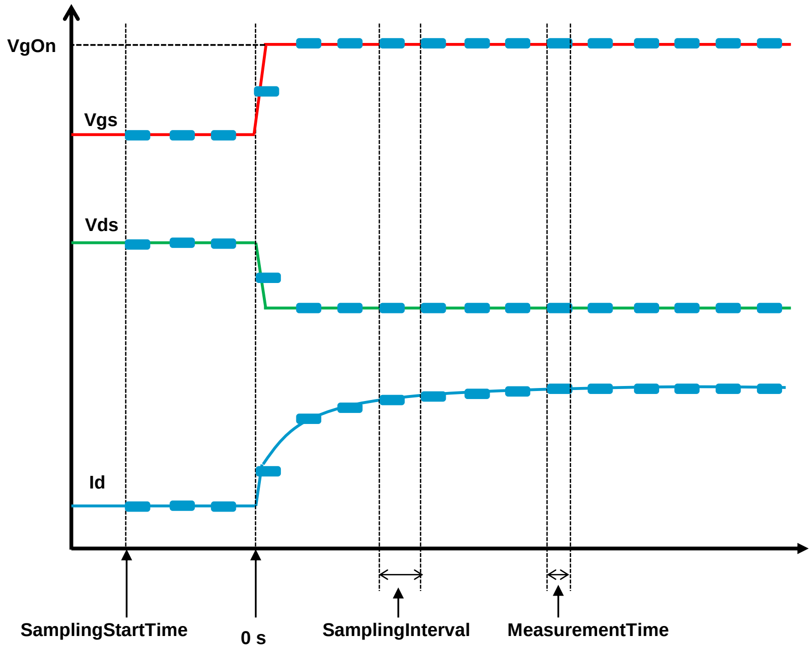
- When the drain on current is smaller than 8 mA, the "DischargeSwitchControl" should be On.



Order to output voltage: Substrate→Switch Control→ Gate→ HCSMU→HVSMU

*: Vds at on-state is higher than the "VdOn" due to the voltage drop at the switch inside of the N1267A.

[Measurement Timing]



*If the MeasurementTime is longer than SamplingInterval, measurement points during the MeasurementTime are skipped.

5-3. FET Current Collapse Signal Monitor

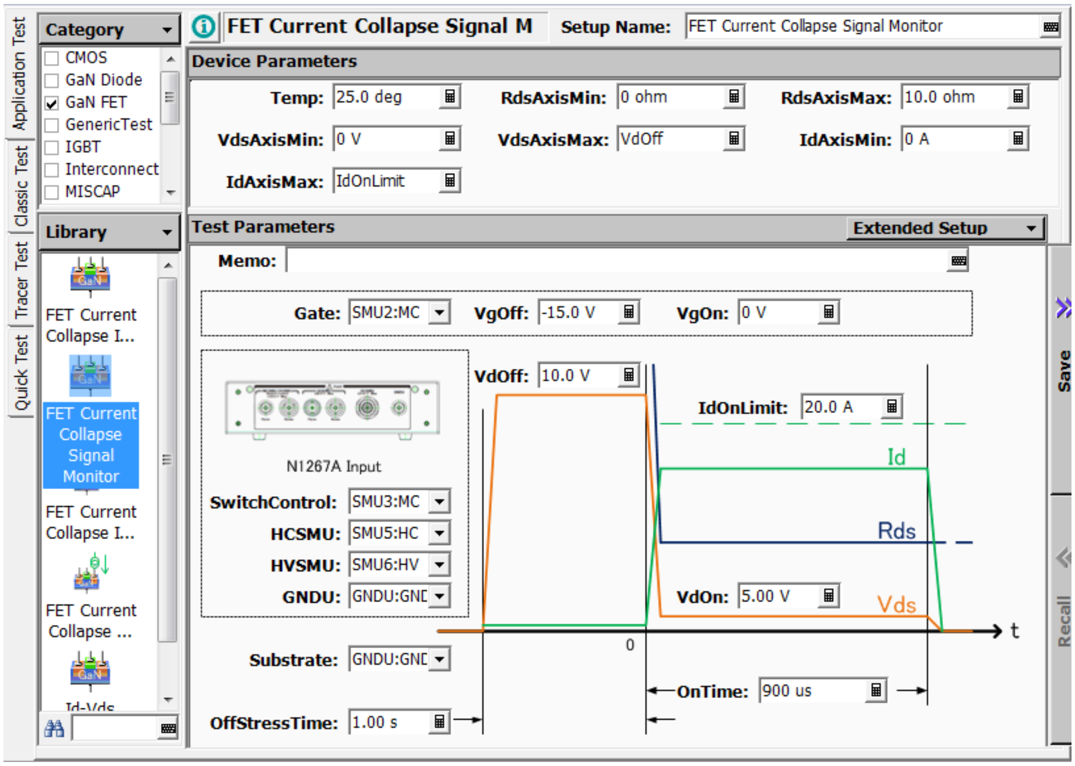
[Description]

Measures Current Collapse of GaN FET.
On-state current, voltage and resistance after off state are measured by pulse and signal monitor using N1267A.

[Device Under Test]

GaN FET, 4 terminals

[Input Parameters]



Category:
- ☐ CMOS
- ☐ GaN Diode
- ☑ GaN FET
- ☐ GenericTest
- ☐ IGBT
- ☐ Interconnect
- ☐ MISCAP

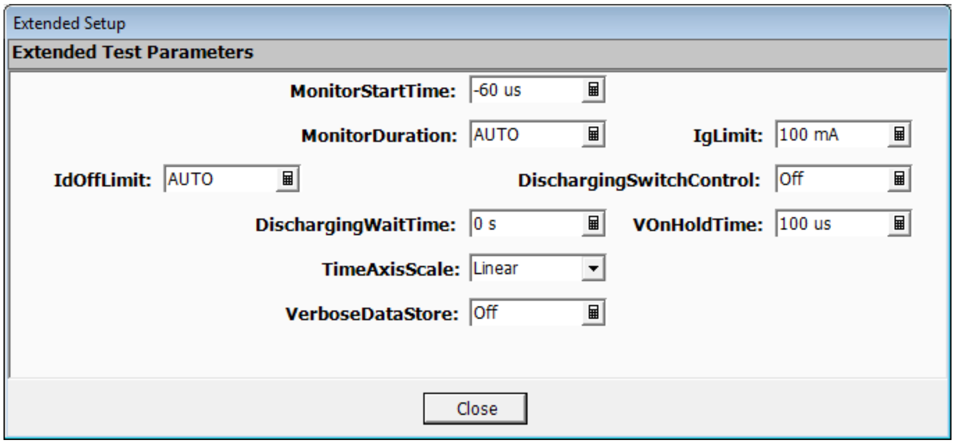
FET Current Collapse Signal M   **Setup Name:** FET Current Collapse Signal Monitor

Device Parameters

Temp: 25.0 deg
RdsAxisMin: 0 ohm
RdsAxisMax: 10.0 ohm
VdsAxisMin: 0 V
VdsAxisMax: VdOff
IdAxisMin: 0 A
IdAxisMax: IdOnLimit

Test Parameters

Memo:
Gate: SMU2:MC
VgOff: -15.0 V
VgOn: 0 V
VdOff: 10.0 V
IdOnLimit: 20.0 A
SwitchControl: SMU3:MC
HCSMU: SMU5:HC
HVSMU: SMU6:HV
GNDU: GNDU:GNC
VdOn: 5.00 V
Substrate: GNDU:GNC
OnTime: 900 us
OffStressTime: 1.00 s



Extended Test Parameters

MonitorStartTime: -60 us
MonitorDuration: AUTO
IgLimit: 100 mA
IdOffLimit: AUTO
DischargingSwitchControl: Off
DischargingWaitTime: 0 s
VOnHoldTime: 100 us
TimeAxisScale: Linear
VerboseDataStore: Off

Device Parameters							
Name	**Description**	**Default**	**Unit**	**Range**	**Digits**	**Resolution**	**Symbols**
Temp	Temperature	25	deg C	0	4	100 mdegC	N/A
RdsAxisMin	Minimum value of Y1 Axis(Rds)	0	Ohm	0 to 100	3	1 mOhm	N/A
RdsAxisMax	Maximum value of Y1 Axis (Rds)	10	Ohm	-infinity to +infinity	3	1 mOhm	N/A
VdsAxisMin	Minimum value of Y2 Axis (Vds)	0	V	-infinity to +infinity	3	1 mV	N/A
VdsAxisMax	Maximum Y2 Axis (Vds)	VdOff	V	-infinity to +infinity	3	1 mV	N/A
IdAxisMin	Minimum value of Y3 Axis (Id)	0	A	-infinity to +infinity	3	1 µA	N/A
IdAxisMax	Maximum Y3 Axis (Id)	IdOnLimit	A	-infinity to +infinity	3	1 µA	N/A

Test Parameters							
Name	**Description**	**Default**	**Unit**	**Range**	**Digits**	**Resolution**	**Symbols**
Memo	Memorandum	N/A	N/A	N/A	N/A	N/A	N/A
GNDU	GNDU connected to N1267A GNDU input	GNDU	N/A	GNDU	N/A	N/A	N/A
HVSMU	HVSMU connected to N1267A HVSMU input	HVSMU	N/A	HVSMU	N/A	N/A	N/A
HCSMU	HCSMU connected to N1267A HCSMU input	HCSMU	N/A	HCSMU	N/A	N/A	N/A
SwitchControl	MCSMU connected to N1267A Switch Control	MCSMU	N/A	MCSMU	N/A	N/A	N/A
Gate	MCSMU/HCSMU connected to Gate terminal	MCSMU	N/A	MCSMU, HCSMU	N/A	N/A	N/A
Substrate	SMU/GNDU connected to substrate	GNDU	N/A	SMU*, GNDU	N/A	N/A	N/A
VgOff	Gate voltage for turning DUT off	-15 V	V	-40 V to 40 V	3	1 mV	N/A
VgOn	Gate voltage for turning DUT on	0 V	V	-40 V to 40 V	3	1 mV	N/A
VdOff	Drain voltage applied to DUT turned off	10 V	V	1 V to 3 kV	3	1 mV	N/A
VdOn**	Drain voltage applied to DUT turned on	5 V	V	-1 V to 40 V	3	1 mV	N/A
IdOnLimit	Drain current compliance applied to DUT turned on	20 A	A	20 mA to 20 A	4	1 mA	N/A
OffStressTime	DUT off-state stress time	1 s	s	0 s to 655.35 s	5	10 ms	N/A
OnTime***	Duration of VdOn application	900 µs	S	50 µs to 24 ms	5	2 µs	N/A

*SMU: MPSMU, HPSMU, HVSMU, HCSMU, MCSMU

** The setting voltage of the HCMSU connected to the N1267A during the on-state measurement. The actual Vds is different from it due to the voltage drop at the switch in the N1267A.

***When The IdOnLimit is equal to or lower than 1 A, maximum on-time is 24 ms. If it is larger than 1 A, it is 900 μs due to the limitation of the maximum pulse width of the HCMSU.

Extended Parameters							
Name	**Description**	**Default**	**Unit**	**Range**	**Digits**	**Resolution**	**Symbols**
MonitorStartTime	Signal Monitor start time	-60 μs	s	-120 μs to 0 s	4	6 μs	N/A
MonitorDuration:	Signal Monitor duration	AUTO	s	0 μs to 24 ms	4	6 μs	AUTO: Automatically determined by the “OnTime”
IgLimit	Gate current compliance	100 mA	A	1 nA to 1A	3	1 nA	N/A
IdOffLimit	Drain current compliance applied to DUT turned off	AUTO	A	0 A to 8 mA	3	1 nA	AUTO: Use the maximum current compliance of the HVSMU
DischargeSwitchControl	Option for discharging by N1267A Switch Control	Off	V	0 V, 15 V	2	15 V	Off: 0V On: 15 V
DischargingWaitTime	Wait time for outputting gate on voltage after starting discharging by N1267A internal switch (effective in case of DischargingSwitchControl On)	0 s	s	0 s to 4.98999 s	6	2 μs	N/A
VOnHoldTime:	Hold time of VdOn output by HCSMU before turning DUT on	100 μs	s	0 s to 4.99 s	6	2 μs	N/A
TimeAxisScale:	Option for scale of X axis (Time)	Linear	N/A	Linear, Log	N/A	N/A	N/A
VerboseDataStore	Option for verbose data store for embedded classic test setup	Off	N/A	0, 1	1	1	Off: 0 On: 1

[Measurement Parameters]

Name	Description	Unit
Time	On state time	s
V_HCSMU	Voltage measured by HCSMU	V
I_HCSMU	Current measured by HCSMU	A
V_HVSMU	Voltage measured by HVSMU	V
I_HVSMU	Current measured by HVSMU	A
V_SwitchControl	Voltage measured by Switch Control MCSMU	V
I_SwitchControl	Current measured by Switch Control MCSMU	A
Vgs	Voltage measured by SMU to Gate drive	V
Ig	Current measured by SMU to Gate drive	A

[User Function]

Name	Description	Unit
Vds	Drain-Source voltage (= V_HVSMU)	A
Id	Drain current (= I_HCSMU + I_HVSMU)	V
Rds	Drain-Source resistance (= Vds / Id)	Ohm
Ta	Temperature (= Temp)	degree C

[X-Y Plot]

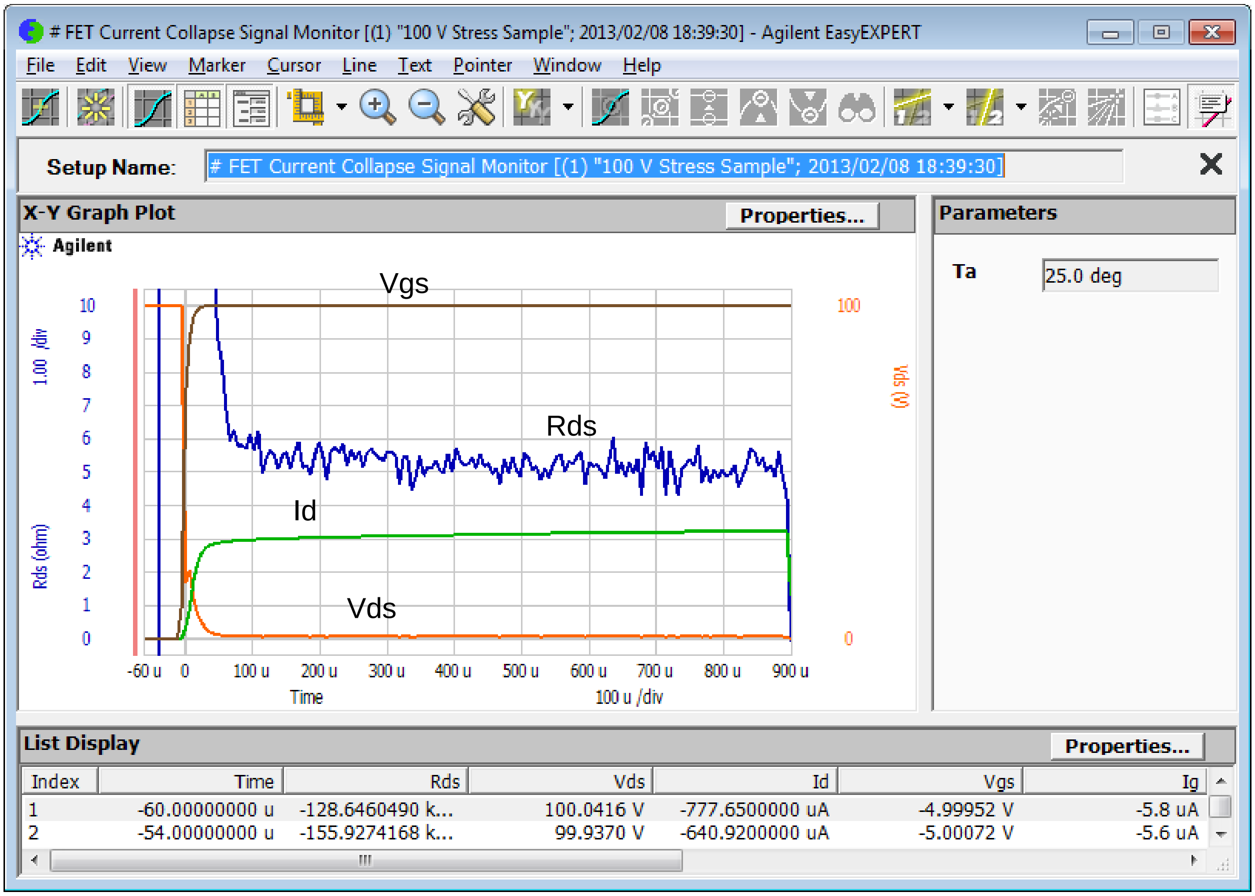
Axis	Item	Unit
X Axis	Time	s
Y1 Axis	Rds	Ohm
Y2 Axis	Vds	V
Y3 Axis	Id	A
Y4 Axis	Vgs	V

[List Display]

Name	Description	Unit
Time	On state time	S
Rds	Drain-Source resistance (= Vds / Id)	Ohm
Vds	Drain-Source voltage (= V_HVSMU)	V
Id	Drain current (= I_HCSMU + I_HVSMU)	A
Vgs	Gate-Source voltage (= V_Gate)	V
Ig	Gate current (= I_Gate)	A
V_HCSMU	Voltage measured by HCSMU	V
I_HCSMU	Current measured by HCSMU	A
V_HVSMU	Current measured by HVSMU	V
I_HVSMU	Voltage measured by HVSMU	A
V_SwitchControl	Voltage measured by SMU for switch control	V
I_SwitchControl	Current measured by SMU for switch control	A

[Output Parameters]

Name	Description	Unit
Ta	Temperature (= Temp)	Degree C



FET Current Collapse Signal Monitor [(1) "100 V Stress Sample"; 2013/02/08 18:39:30] - Agilent EasyEXPERT

Setup Name: # FET Current Collapse Signal Monitor [(1) "100 V Stress Sample"; 2013/02/08 18:39:30]

Parameters

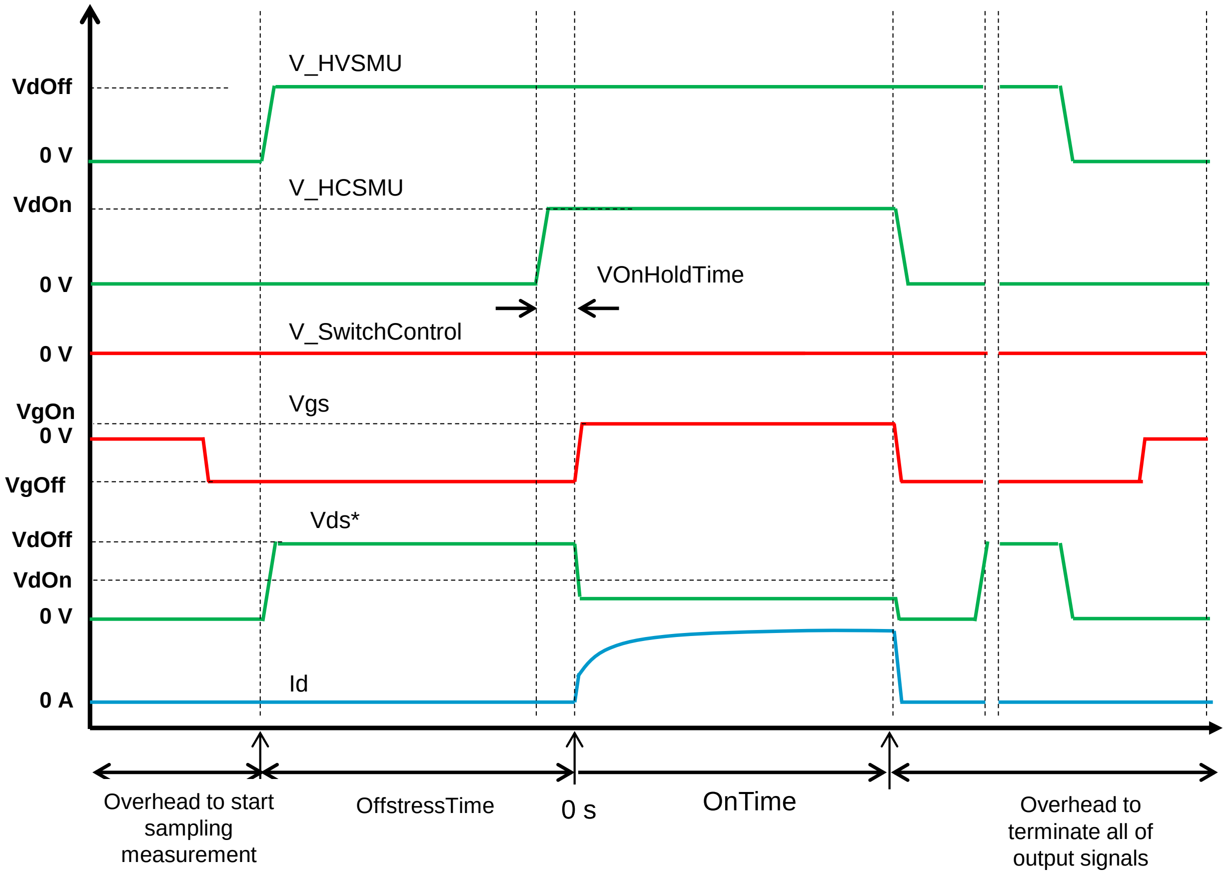
Ta 25.0 deg

Index	Time	Rds	Vds	Id	Vgs	Ig
1	-60.00000000 u	-128.6460490 k...	100.0416 V	-777.6500000 uA	-4.99952 V	-5.8 uA
2	-54.00000000 u	-155.9274168 k...	99.9370 V	-640.9200000 uA	-5.00072 V	-5.6 uA

[Pulse Timing Chart]

Case 1: DischargeSwitchControl is "Off"

- When the drain on current is larger than 8 mA, the "DischargeSwitchControl" should be OFF.

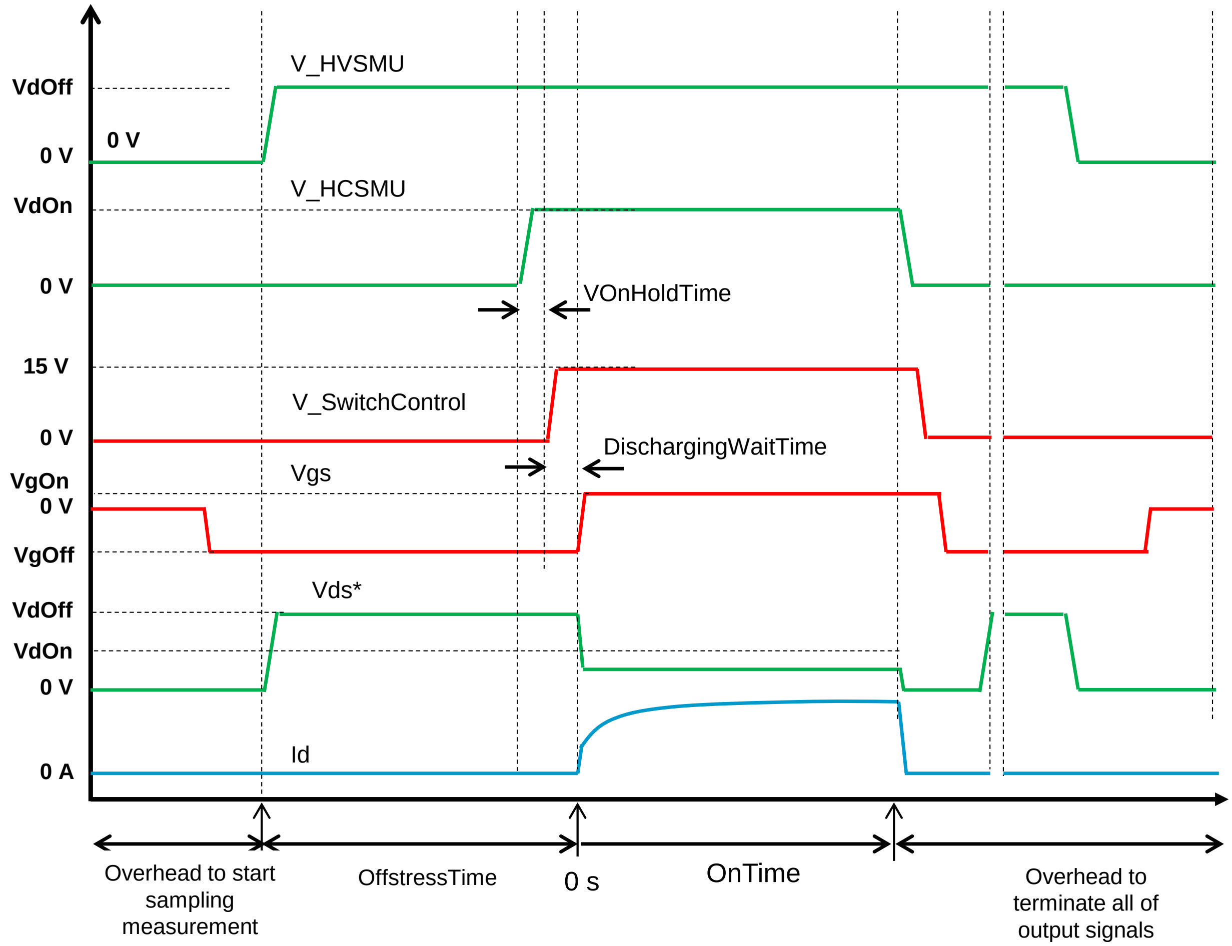


Order to output voltage: Substrate→Switch Control→ Gate→ HCSMU→HVSMU

*: Vds at on-state is lower than the "VdOn" due to the voltage drop at the switch inside of the N1267A.

Case 2: DischargeSwitchControl is "On"

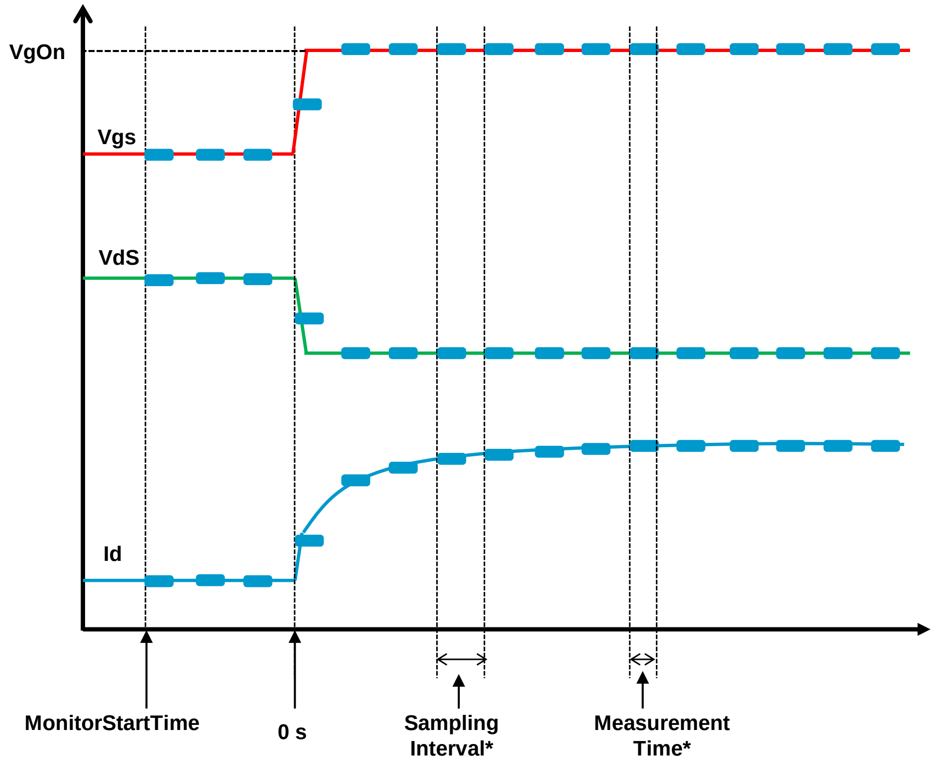
- When the drain on current is smaller than 8 mA, the "DischargeSwitchControl" should be On.



Order to output voltage: Substrate→Switch Control→ Gate→ HCSMU→HVSMU

*: Vds at on-state is higher than the "VdOn" due to the voltage drop at the switch inside of the N1267A.

[Measurement Timing]



* Minimum sampling interval is 6 μs. Sampling Interval and Measurement Time are adjusted automatically by the “MeasurementDuration”.

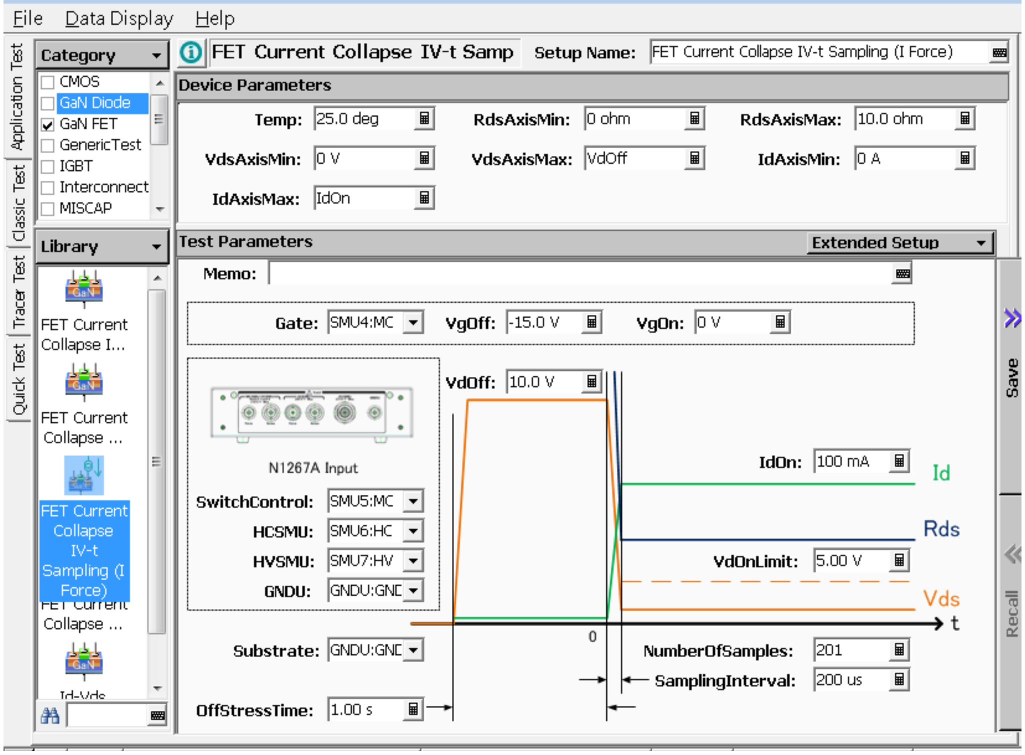
5-4. FET Current Collapse IV-t Sampling (I Force)

GaN FET Current Collapse characteristics (using N1267A) (A.05.02)

[Description]
Measures Current Collapse of GaN FET.
On state current, voltage and resistance after off state are sampled using N1267A.

[Device Under Test]
GaN FET, 4 terminals

[Input Parameters]



Category:
☐ CMOS
☐ GaN Diode
☑ GaN FET
☐ GenericTest
☐ IGBT
☐ Interconnect
☐ MISCAP

FET Current Collapse IV-t Samp

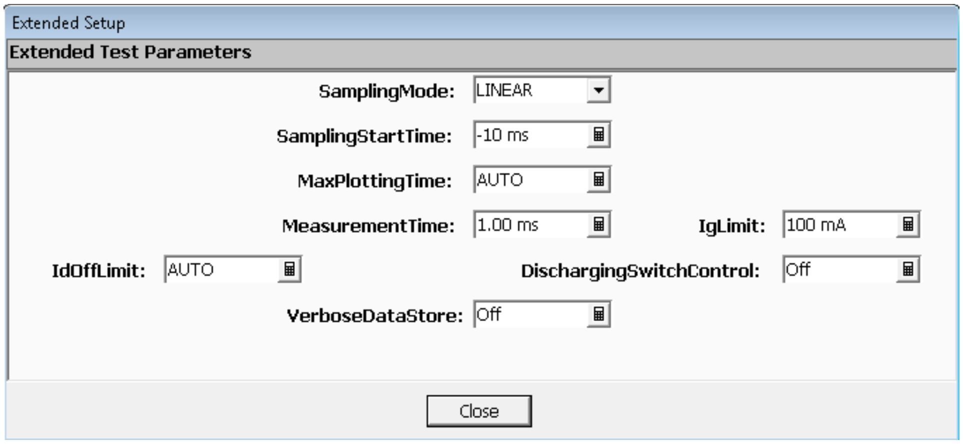
Setup Name: FET Current Collapse IV-t Sampling (I Force)

Device Parameters

Temp: 25.0 deg
RdsAxisMin: 0 ohm
RdsAxisMax: 10.0 ohm
VdsAxisMin: 0 V
VdsAxisMax: VdOff
IdAxisMin: 0 A
IdAxisMax: IdOn

Test Parameters Extended Setup

Memo:
Gate: SMU4:MC
VgOff: -15.0 V
VgOn: 0 V
VdOff: 10.0 V
IdOn: 100 mA
VdOnLimit: 5.00 V
SwitchControl: SMU5:MC
HCSMU: SMU6:HC
HVSMU: SMU7:HV
GNDU: GNDU:GNE
Substrate: GNDU:GNE
OffStressTime: 1.00 s
NumberOfSamples: 201
SamplingInterval: 200 us



Extended Test Parameters

SamplingMode: LINEAR
SamplingStartTime: -10 ms
MaxPlottingTime: AUTO
MeasurementTime: 1.00 ms
IgLimit: 100 mA
IdOffLimit: AUTO
DischargingSwitchControl: Off
VerboseDataStore: Off

Device Parameters

Name	Description	Default	Unit	Range	Digits	Resolution	Symbols
Temp	Temperature	25	deg C	-100 to 100	4	100 mdegC	N/A
RdsAxisMin	Minimum value of Y1 Axis(Rds)	0	Ohm	0 to 100	3	1 mOhm	N/A
RdsAxisMax	Maximum value of Y1 Axis (Rds)	10	Ohm	-infinity to +infinity	3	1 mOhm	N/A
VdsAxisMin	Minimum value of Y2 Axis (Vds)	0	V	-infinity to +infinity	3	1 mV	N/A
VdsAxisMax	Maximum Y2 Axis (Vds)	VdOff	V	-infinity to +infinity	3	1 mV	N/A
IdAxisMin	Minimum value of Y3 Axis (Id)	0	A	-infinity to +infinity	3	1 µA	N/A
IdAxisMax	Maximum Y3 Axis (Id)	IdOnLimit	A	-infinity to +infinity	3	1 µA	N/A

Test Parameters

Name	Description	Default	Unit	Range	Digits	Resolution	Symbols
Memo	Memorandum	N/A	N/A	N/A	N/A	N/A	N/A
GNDU	GNDU connected to N1267A GNDU input	GNDU	N/A	GNDU	N/A	N/A	N/A
HVSMU	HVSMU connected to N1267A HVSMU input	HVSMU	N/A	HVSMU	N/A	N/A	N/A
HCSMU	HCSMU connected to N1267A HCSMU input	HCSMU	N/A	HCSMU	N/A	N/A	N/A
SwitchControl	MCSMU connected to N1267A Switch Control	MCSMU	N/A	MCSMU	N/A	N/A	N/A
Gate	MCSMU/HCSMU connected to Gate terminal	MCSMU	N/A	MCSMU, HCSMU	N/A	N/A	N/A
Substrate	SMU/GNDU connected to substrate	GNDU	N/A	SMU*, GNDU	N/A	N/A	N/A
VgOff	Gate voltage for turning DUT off	-15 V	V	-40 V to 40 V	3	1 mV	N/A
VgOn	Gate voltage for turning DUT on	0 V	V	-40 V to 40 V	3	1 mV	N/A
VdOff	Drain voltage applied to DUT turned off	10 V	V	1 V to 3 kV	3	1 mV	N/A
IdOn	Drain current applied to DUT turned on	100 mA	A	0A to 1 A	4	1 mA	N/A
VdOnLimit**	Drain voltage compliance applied to DUT turned on	5 V	V	0 V to 40 V	3	1 mV	N/A
OffStressTime	DUT off-state stress time	1 s	s	0 s to 655.35 s	5	10 ms	N/A
SamplingInterval	Sampling interval	200 µs	S	200 µs to 65.535 s	5	10 µs	N/A
NumberOfSamples	Number of samples	201	N/A	1 to 12500	6	1	N/A

*SMU: MPSMU, HPSMU, HVSMU, HCSMU, MCSMU

** The setting voltage of the HCMSU connected to the N1267A during the on-state measurement. The actual Vds is different from it due to the voltage drop at the switch in the N1267A.
**The VdOnLimit must be smaller than VdOff.

Extended Parameters							
Name	**Description**	**Default**	**Unit**	**Range**	**Digits**	**Resolution**	**Symbols**
SamplingMode***	Options for linear or log sampling	Linear	N/A	Linear / Log	N/A	N/A	N/A
SamplngStartTime****	Time offset from turning DUT on to starting sampling	-10 ms	s	-90 ms to 655.35 s	5	10 ms	N/A
MaxPlottingTime	Max time of graph X axis for plotting	AUTO	S	0 to infinity	4	10 ms	Auto: Automatically determined by the SamplingInterval and NumberOfSamples
MeasurementTime	Measurement time (Aperture time, effective in case of 2ms or above SamplingInterval)	200 μs	s	2 μs to 20 ms	3	2 μs	Minimum : 2 μs
IgLimit	Gate current compliance	100 mA	A	1 nA to 1A	3	1 nA	N/A
IdOffLimit	Drain current compliance applied to DUT turned off	AUTO	A	0 A to 8 mA	3	1 nA	AUTO: Use the maximum current compliance of the HVSMU
DischargeSwitchControl	Option for discharging by N1267A Switch Control	Off	V	0 V, 15 V	2	15 V	Off: 0V On: 15 V
VerboseDataStore	Option for verbose data store for embedded classic test setup	Off	N/A	0, 1	1	1	Off: 0 On: 1

***Log sampling is only valid when the SamplingInterval is equal to or longer than 2 ms.
****Negative value is only valid when the SamplingInterval is smaller than 2 ms.

[Measurement Parameters]

Name	**Description**	**Unit**
Time	On state time	s
V_HCSMU	Voltage measured by HCSMU	V
I_HCSMU	Current measured by HCSMU	A
V_HVSMU	Voltage measured by HVSMU	V
I_HVSMU	Current measured by HVSMU	A
V_SwitchControl	Voltage measured by Switch Control MCSMU	V
I_SwitchControl	Current measured by Switch Control MCSMU	A
V_Gate	Voltage measured by SMU to Gate drive	V
I_Gate	Current measured by SMU to Gate drive	A

[User Function]

Name	Description	Unit
Vds	Drain-Source voltage (= V_HVSMU)	A
Id	Drain current (= I_HCSMU + I_HVSMU)	V
Rds	Drain-Source resistance (= Vds / Id)	Ohm
Vgs	Gate-Source voltage (= V_Gate)	V
Ig	Gate current (= I_Gate)	I
Ta	Temperature (= Temp)	degree C

[X-Y Plot]

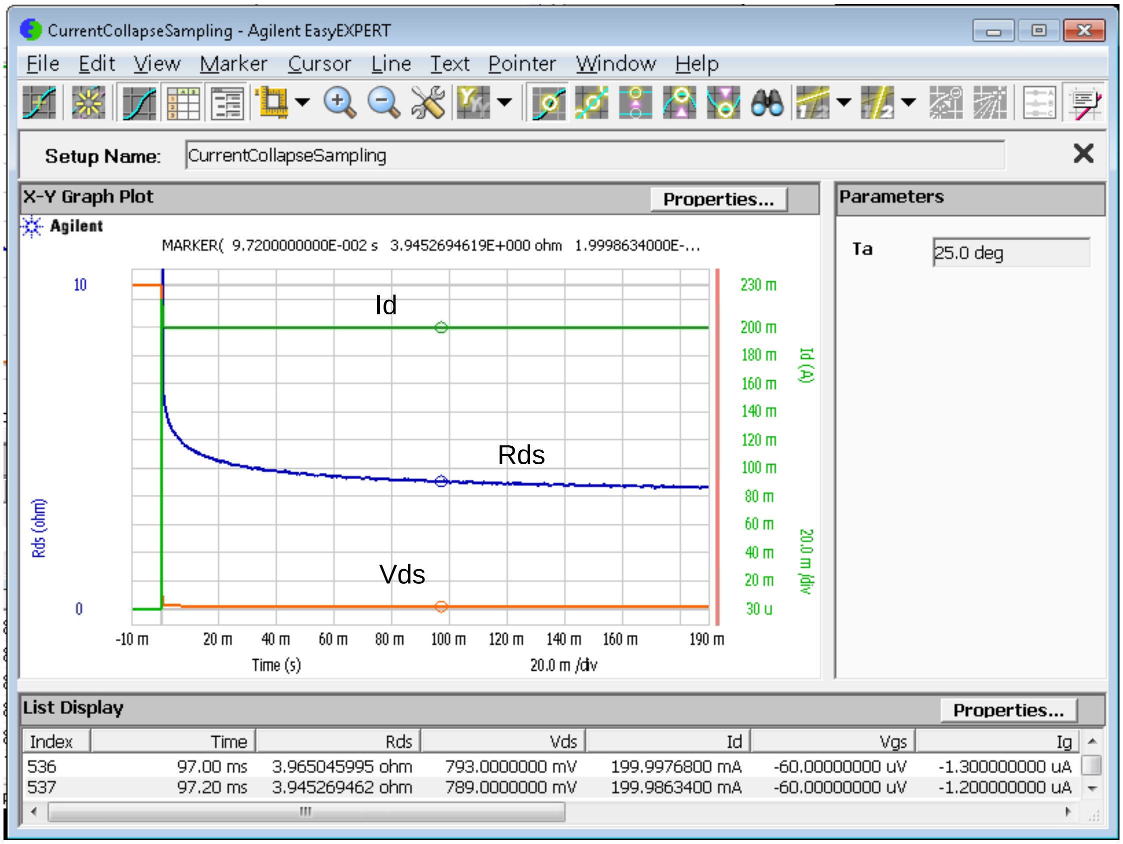
Axis	Item	Unit
X Axis	Time	s
Y1 Axis	Rds	Ohm
Y2 Axis	Vds	V
Y3 Axis	Id	A

[List Display]

Name	Description	Unit
Time	On state time	S
Rds	Drain-Source resistance (= Vds / Id)	Ohm
Vds	Drain-Source voltage (= V_HVSMU)	V
Id	Drain current (= I_HCSMU + I_HVSMU)	A
Vgs	Gate-Source voltage (= V_Gate)	V
Ig	Gate current (= I_Gate)	A
V_HCSMU	Voltage measured by HCSMU	V
I_HCSMU	Current measured by HCSMU	A
V_HVSMU	Current measured by HVSMU	V
I_HVSMU	Voltage measured by HVSMU	A
V_SwitchControl	Voltage measured by Switch Control	V
I_SwitchControl	Current measured by Switch Control	A

[Output Parameters]

Name	Description	Unit
Ta	Temperature (= Temp)	Degree C



Setup Name: CurrentCollapseSampling

MARKER(9.7200000000E-002 s 3.9452694619E+000 ohm 1.9998634000E-…

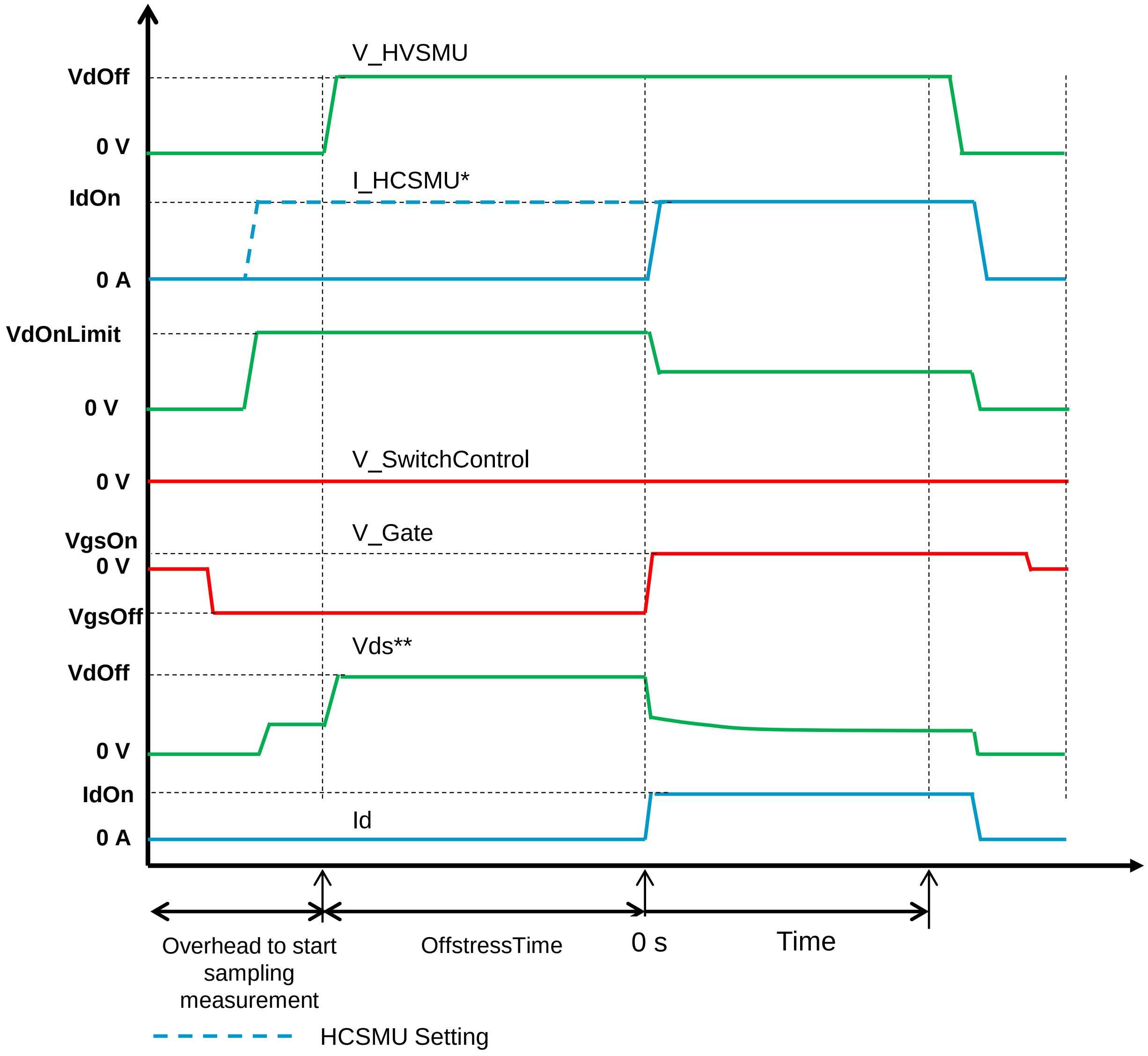
Ta 25.0 deg

Index	Time	Rds	Vds	Id	Vgs	Ig
536	97.00 ms	3.965045995 ohm	793.0000000 mV	199.9976800 mA	-60.00000000 uV	-1.300000000 uA
537	97.20 ms	3.945269462 ohm	789.0000000 mV	199.9863400 mA	-60.00000000 uV	-1.200000000 uA

[Pulse Timing Chart]

Case 1: DischargeSwitchControl is “Off”

- When the drain on current is larger than 8 mA, the “DischargeSwitchControl” should be OFF.



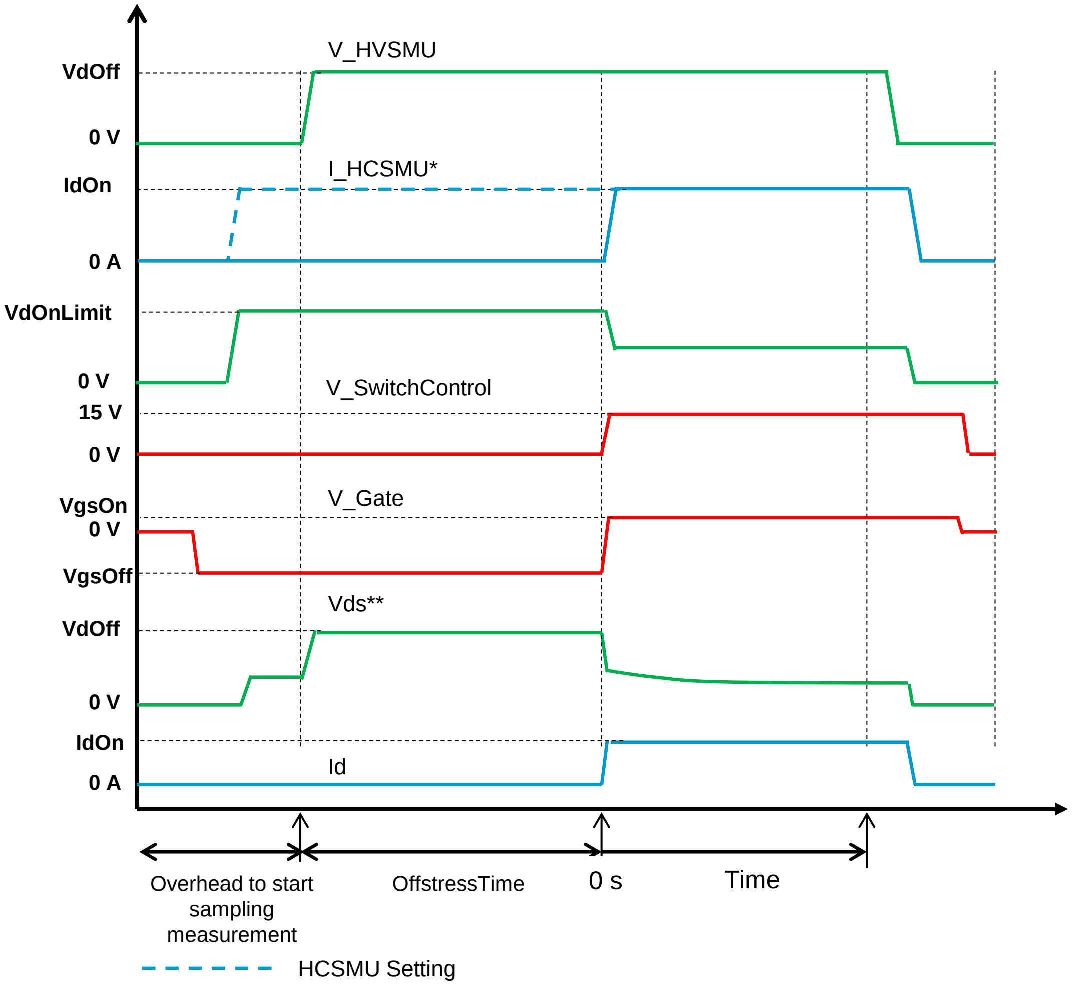
Order to output voltage: Substrate→Switch Control→ Gate→ HCSMU→HVSMU

*: During the time DUT is turned off, the output voltage of the HCMSU goes up to its compliance level specified as VdsOn limit.

**: During the on-state, the Vds is changing by the change of Ron of the DUT.

Case 2: DischargeSwitchControl is "On"

- When the drain on current is smaller than 8 mA, the "DischargeSwitchControl" should be On.



Order to output voltage: Substrate→Switch Control→ Gate→ HCSMU→HVSMU

*: During the time DUT is turned off, the output voltage of the HCMSU goes up to its compliance level specified as VdsOn limit.

**: During the on-state, the Vds is changing by the change of Ron of the DUT.

[Measurement Timing]

Same as the "FET Current Collapse I/V-t Sampling".

5-5. FET Current Collapse Signal Monitor (I Force)

Measures Current Collapse of GaN FET.

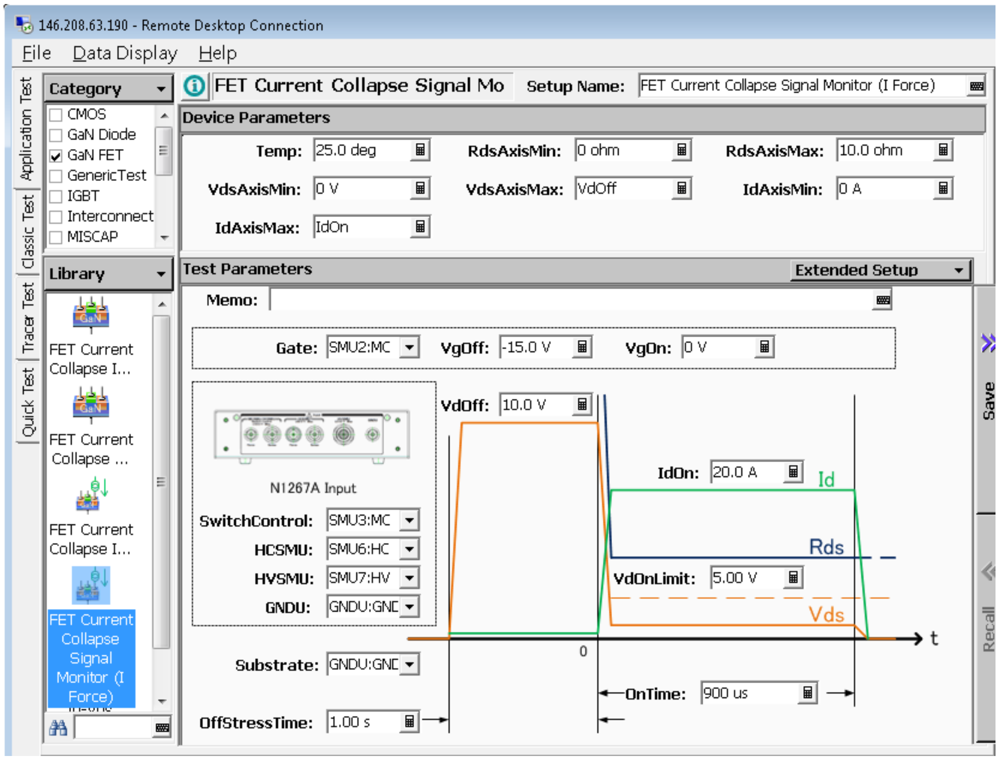
[Description]

On-state current, voltage and resistance after off state are measured by pulse and signal monitor using N1267A.

[Device Under Test]

GaN FET, 4 terminals

[Input Parameters]



Category: ☐ CMOS ☐ GaN Diode ☑ GaN FET ☐ GenericTest ☐ IGBT ☐ Interconnect ☐ MISCAP

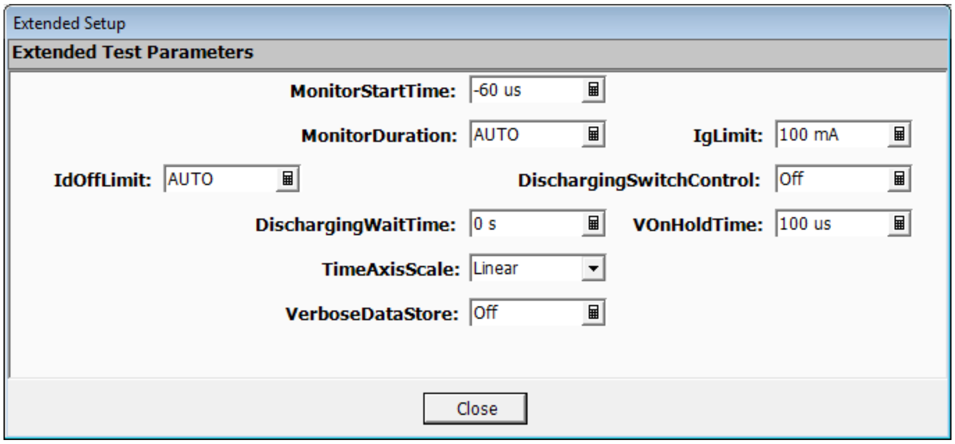
FET Current Collapse Signal Mo — Setup Name: FET Current Collapse Signal Monitor (I Force)

Device Parameters

Temp: 25.0 deg
RdsAxisMin: 0 ohm
RdsAxisMax: 10.0 ohm
VdsAxisMin: 0 V
VdsAxisMax: VdOff
IdAxisMin: 0 A
IdAxisMax: IdOn

Test Parameters — Extended Setup

Memo:
Gate: SMU2:MC
VgOff: -15.0 V
VgOn: 0 V
VdOff: 10.0 V
IdOn: 20.0 A
VdOnLimit: 5.00 V
SwitchControl: SMU3:MC
HCSMU: SMU6:HC
HVSMU: SMU7:HV
GNDU: GNDU:GNE
Substrate: GNDU:GNE
OnTime: 900 us
OffStressTime: 1.00 s



Extended Setup

Extended Test Parameters

MonitorStartTime: -60 us
MonitorDuration: AUTO
IgLimit: 100 mA
IdOffLimit: AUTO
DischargingSwitchControl: Off
DischargingWaitTime: 0 s
VOnHoldTime: 100 us
TimeAxisScale: Linear
VerboseDataStore: Off

Device Parameters

Name	Description	Default	Unit	Range	Digits	Resolution	Symbols
Temp	Temperature	25	deg C	0	4	100 mdegC	N/A
RdsAxisMin	Minimum value of Y1 Axis(Rds)	0	Ohm	0 to 100	3	1 mOhm	N/A
RdsAxisMax	Maximum value of Y1 Axis (Rds)	10	Ohm	-infinity to +infinity	3	1 mOhm	N/A
VdsAxisMin	Minimum value of Y2 Axis (Vds)	0	V	-infinity to +infinity	3	1 mV	N/A
VdsAxisMax	Maximum Y2 Axis (Vds)	VdOff	V	-infinity to +infinity	3	1 mV	N/A
IdAxisMin	Minimum value of Y3 Axis (Id)	0	A	-infinity to +infinity	3	1 μA	N/A
IdAxisMax	Maximum Y3 Axis (Id)	IdOnLimit	A	-infinity to +infinity	3	1 μA	N/A

Test Parameters

Name	Description	Default	Unit	Range	Digits	Resolution	Symbols
Memo	Memorandum	N/A	N/A	N/A	N/A	N/A	N/A
GNDU	GNDU connected to N1267A GNDU input	GNDU	N/A	GNDU	N/A	N/A	N/A
HVSMU	HVSMU connected to N1267A HVSMU input	HVSMU	N/A	HVSMU	N/A	N/A	N/A
HCSMU	HCSMU connected to N1267A HCSMU input	HCSMU	N/A	HCSMU	N/A	N/A	N/A
SwitchControl	MCSMU connected to N1267A Switch Control	MCSMU	N/A	MCSMU	N/A	N/A	N/A
Gate	MCSMU/HCSMU connected to Gate terminal	MCSMU	N/A	MCSMU, HCSMU	N/A	N/A	N/A
Substrate	SMU/GNDU connected to substrate	GNDU	N/A	SMU*, GNDU	N/A	N/A	N/A
VgOff	Gate voltage for turning DUT off	-15 V	V	-40 V to 40 V	3	1 mV	N/A
VgOn	Gate voltage for turning DUT on	0 V	V	-40 V to 40 V	3	1 mV	N/A
VdOff	Drain voltage applied to DUT turned off	10 V	V	1 V to 3 kV	3	1 mV	N/A
IdOn	Drain current applied to DUT turned on	100 mA	A	0A to 20 A	4	1 mA	N/A
VdOnLimit***	Drain voltage compliance applied to DUT turned on	5 V	V	0 V to 40 V	3	1 mV	N/A
OffStressTime	DUT off-state stress time	1 s	s	0 s to 655.35 s	5	10 ms	N/A
OnTime****	Duration of VdOn application	900 μs	S	50 μs to 24 ms	5	2 μs	N/A

*SMU: MPSMU, HPSMU, HVSMU, HCSMU, MCSMU

** The setting voltage of the HCMSU connected to the N1267A during the on-state measurement. The actual Vds is differed from it due to the voltage drop at the switch in the N1267A.

*** The VdOnLimit must be smaller than the VdOff.

**** When IdOnLimit is equal to or lower than 1 A, maximum on-time is 24 ms. If it is larger than 1 A, it is 900 μs due to the limitation of the maximum pulse witch of the HCMSU.

Extended Parameters							
Name	**Description**	**Default**	**Unit**	**Range**	**Digits**	**Resolution**	**Symbols**
MonitorStartTime	Signal Monitor start time	-60 μs	s	-120 μs to 0 s	4	6 μs	N/A
MonitorDuration:	Signal Monitor duration	AUTO	s	0 μs to 24 ms	4	6 μs	AUTO: Automatically determined by the "OnTime"
IgLimit	Gate current compliance	100 mA	A	1 nA to 1A	3	1 nA	N/A
IdOffLimit	Drain current compliance applied to DUT turned off	AUTO	A	0 A to 8 mA	3	1 nA	AUTO: Use the maximum current compliance of the HVSMU
DischargeSwitchControl	Option for discharging by N1267A Switch Control	Off	V	0 V, 15 V	2	15 V	Off: 0V On: 15 V
DischargingWaitTime	Wait time for outputting gate on voltage after starting discharging by N1267A internal switch (effective in case of DischargingSwitchControl On)	0 s	s	0 s to 4.98999 s	6	2 μs	N/A
VOnHoldTime:	Hold time of VdOn output by HCSMU before turning DUT on	100 μs	s	0 s to 4.99 s	6	2 μs	N/A
TimeAxisScale:	Option for scale of X axis (Time)	Linear	N/A	Linear, Log	N/A	N/A	N/A
VerboseDataStore	Option for verbose data store for embedded classic test setup	Off	N/A	0, 1	1	1	Off: 0 On: 1

[Measurement Parameters]

Name	**Description**	**Unit**
Time	On state time	s
V_HCSMU	Voltage measured by HCSMU	V
I_HCSMU	Current measured by HCSMU	A
V_HVSMU	Voltage measured by HVSMU	V
I_HVSMU	Current measured by HVSMU	A
V_SwitchControl	Voltage measured by Switch Control MCSMU	V
I_SwitchControl	Current measured by Switch Control MCSMU	A
Vgs	Voltage measured by SMU to Gate drive	V
Ig	Current measured by SMU to Gate drive	A

[User Function]

Name	Description	Unit
Vds	Drain-Source voltage (= V_HVSMU)	A
Id	Drain current (= I_HCSMU + I_HVSMU)	V
Rds	Drain-Source resistance (= Vds / Id)	Ohm
Ta	Temperature (= Temp)	degree C

[X-Y Plot]

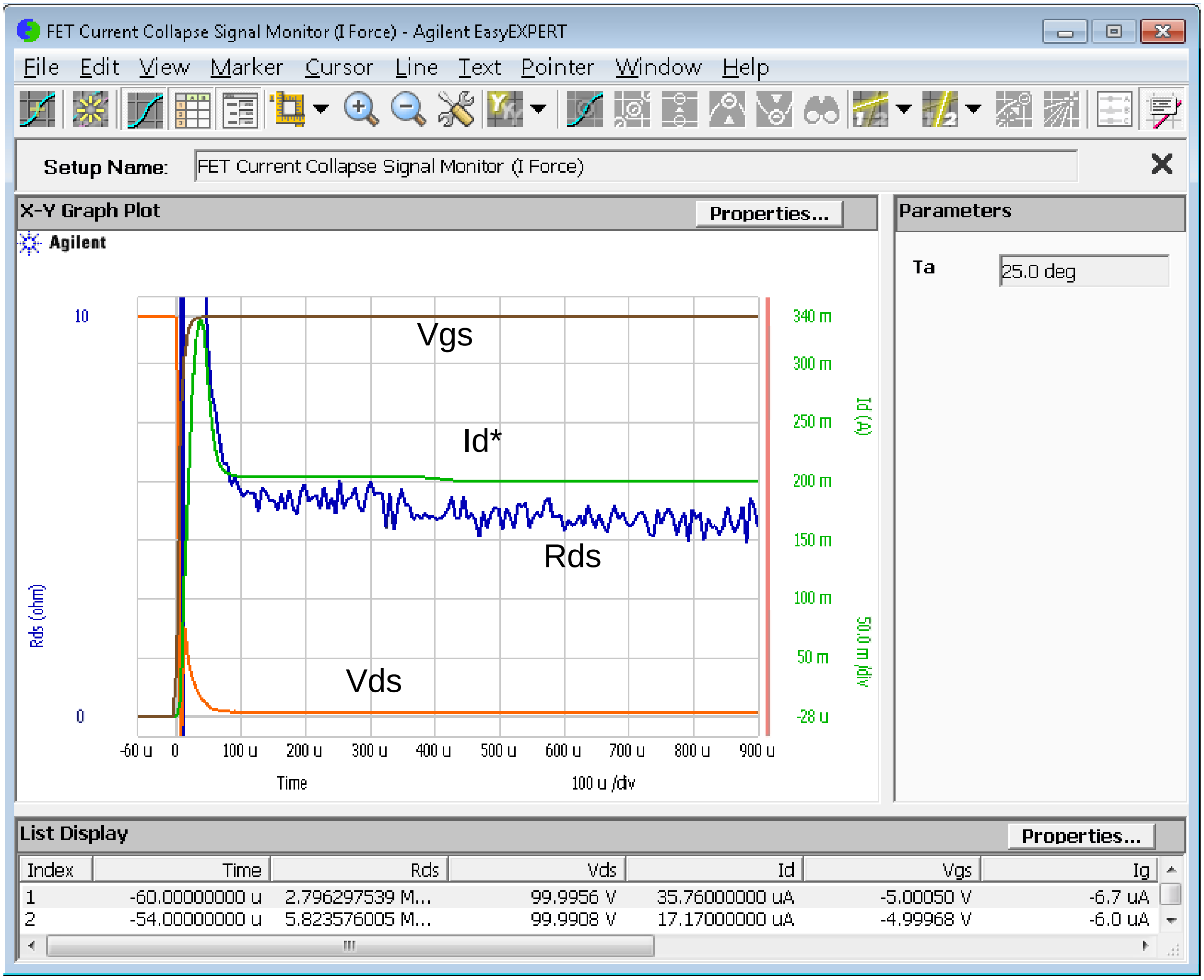
Axis	Item	Unit
X Axis	Time	s
Y1 Axis	Rds	Ohm
Y2 Axis	Vds	V
Y3 Axis	Id	A
Y4 Axis	Vgs	V

[List Display]

Name	Description	Unit
Time	On state time	S
Rds	Drain-Source resistance (= Vds / Id)	Ohm
Vds	Drain-Source voltage (= V_HVSMU)	V
Id	Drain current (= I_HCSMU + I_HVSMU)	A
Vgs	Gate-Source voltage (= V_Gate)	V
Ig	Gate current (= I_Gate)	A
V_HCSMU	Voltage measured by HCSMU	V
I_HCSMU	Current measured by HCSMU	A
V_HVSMU	Current measured by HVSMU	V
I_HVSMU	Voltage measured by HVSMU	A
V_SwitchControl	Voltage measured by SMU for switch control	V
I_SwitchControl	Current measured by SMU for switch control	A

[Output Parameters]

Name	Description	Unit
Ta	Temperature (= Temp)	Degree C



Setup Name: FET Current Collapse Signal Monitor (I Force)

Ta 25.0 deg

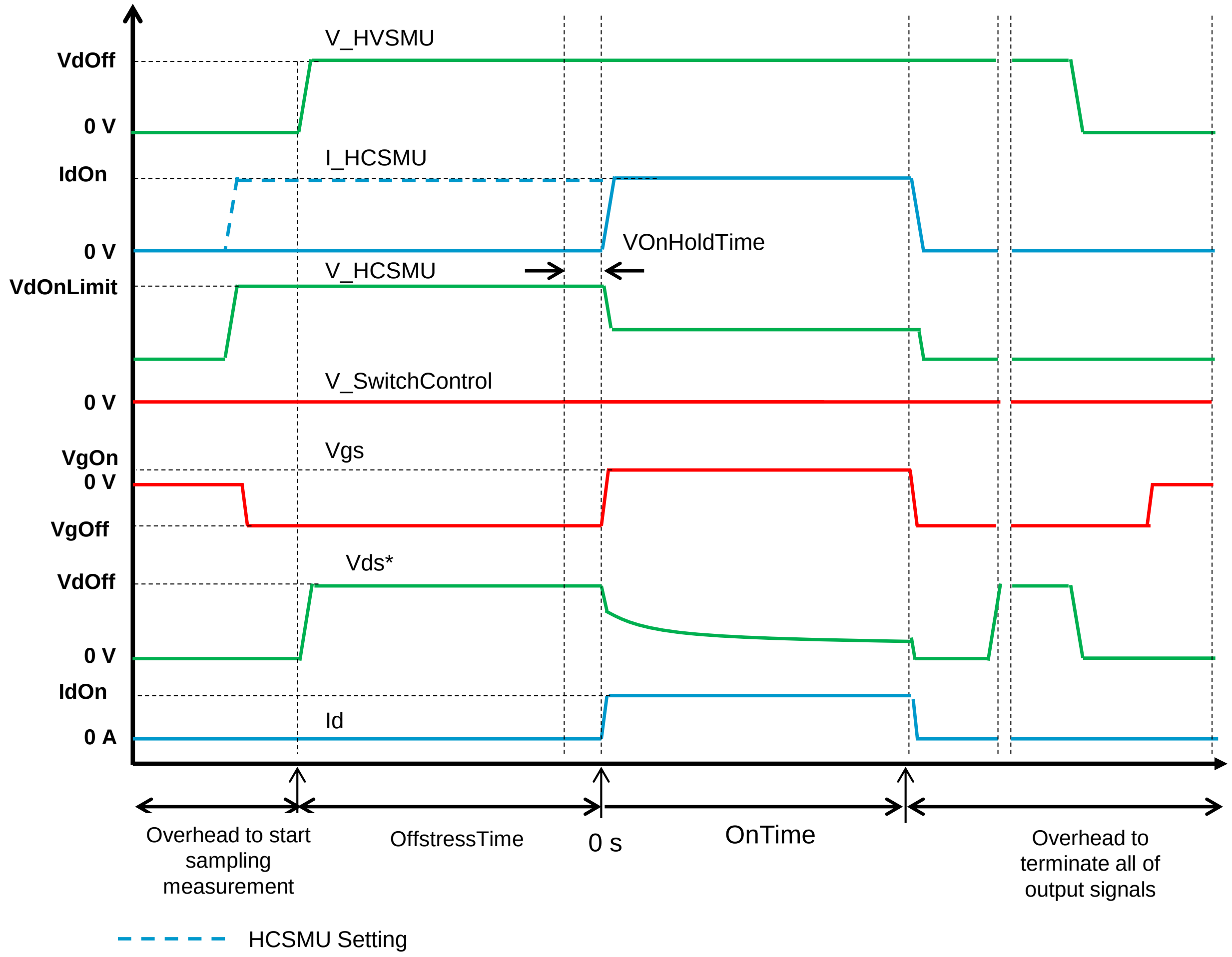
Index	Time	Rds	Vds	Id	Vgs	Ig
1	-60.00000000 u	2.796297539 M...	99.9956 V	35.76000000 uA	-5.00050 V	-6.7 uA
2	-54.00000000 u	5.823576005 M...	99.9908 V	17.17000000 uA	-4.99968 V	-6.0 uA

*The step on the Id is due to the overcurrent status of the HVSMU (12 mA). Please refer to section 3, “ Switching Performance”.

[Pulse Timing Chart]

Case 1: DischargeSwitchControl is “Off”

- When the drain on current is larger than 8 mA, the “DischargeSwitchControl” should be OFF.



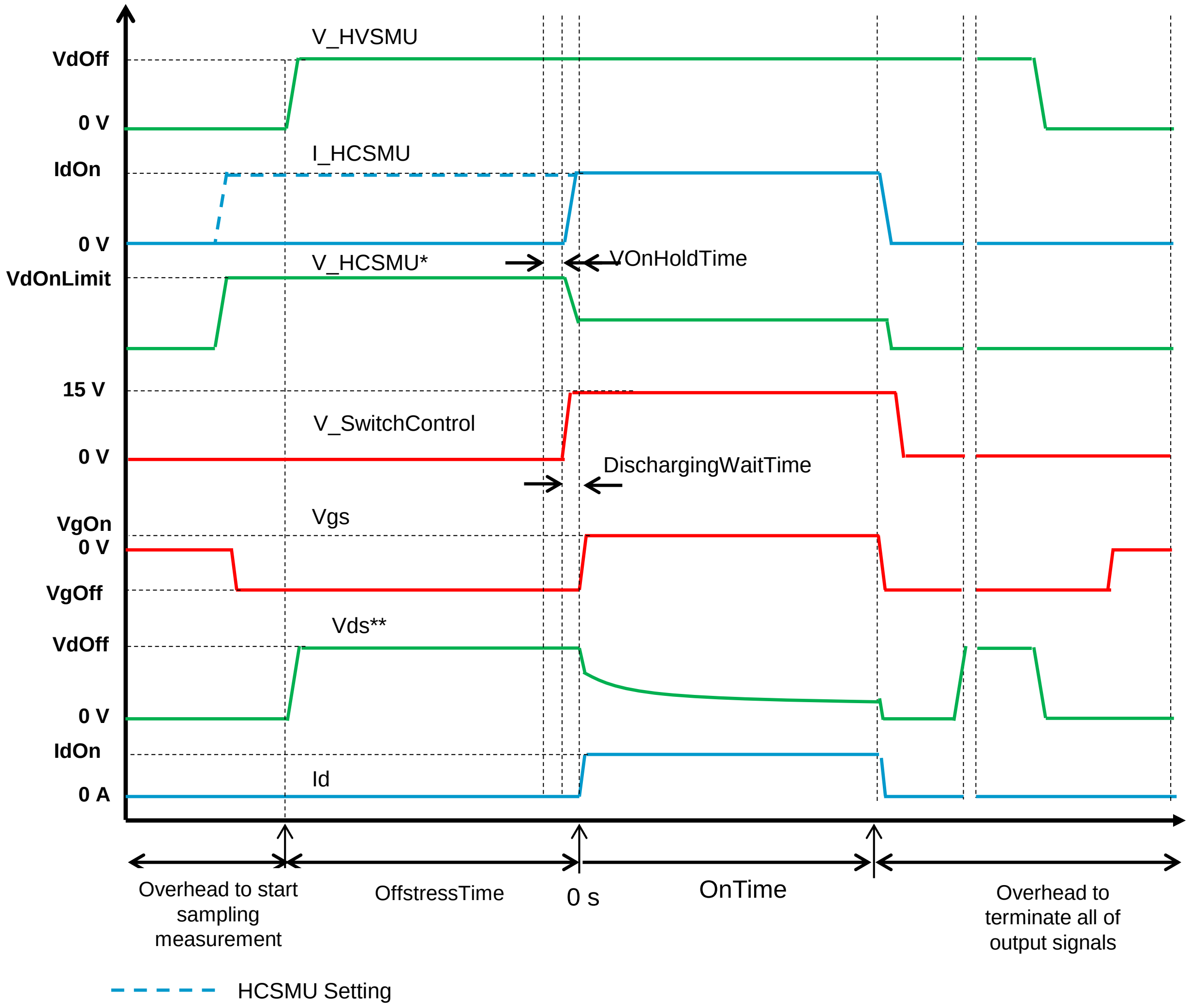
Order to output voltage: Substrate→Switch Control→ Gate→ HCSMU→HVSMU

*: During the time DUT is turned off, the output voltage of the HCMSU goes up to its compliance level specified as VdsOn limit.

**: During the on-state, the Vds is changing by the change of Ron of the DUT.

Case 2: DischargeSwitchControl is “On”

- When the drain on current is smaller than 8 mA, “DischargeSwitchControl” should be On.



Order to output voltage: Substrate→Switch Control→ Gate→ HCSMU→HVSMU

*: During the time DUT is turned off, the output voltage of the HCMSU goes up to its compliance level specified as VdsOn limit.

**: During the on-state, the Vds is changing by the change of Ron of the DUT.

[Measurement Timing]

Same as the “FET Current Collapse Signal Monitor”.

5-6. Id-Vds Current Collapse

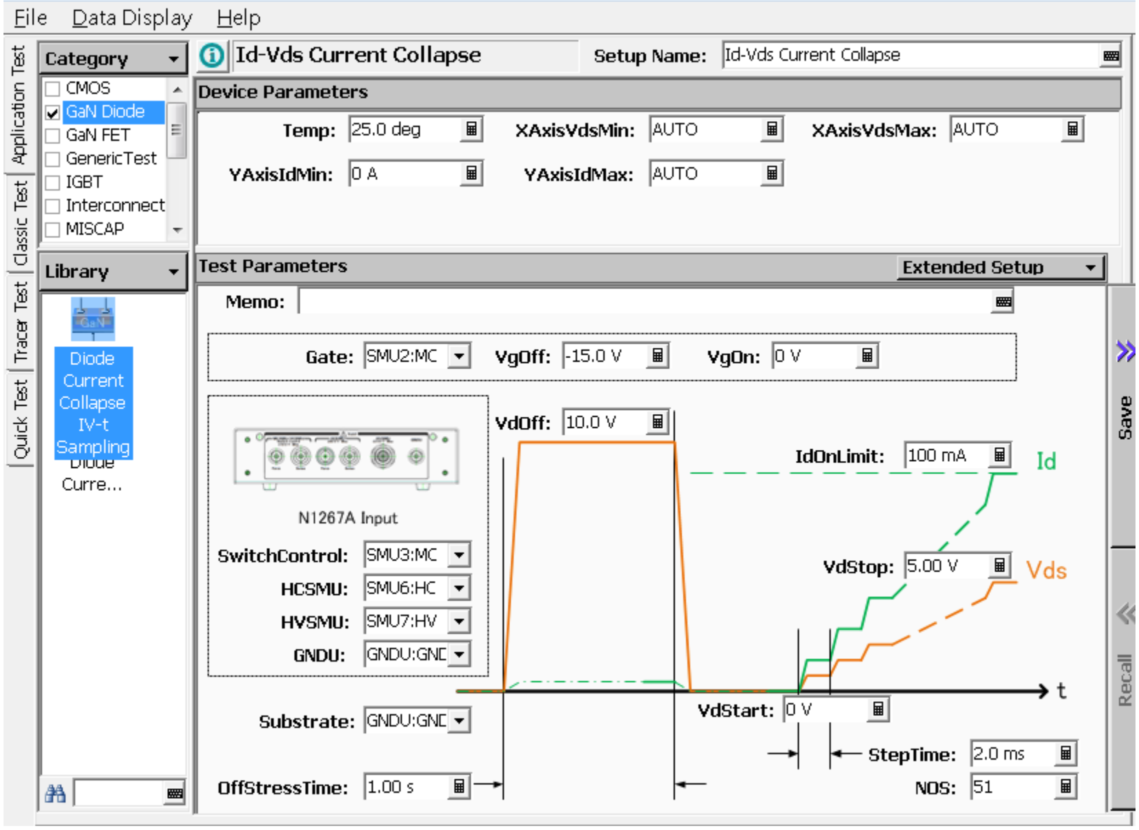
[Description]

Measures Current Collapse of GaN FET.
Id-Vds in on-state is measured after applying off-state stress using N1267A.

[Device Under Test]

GaN FET, 4 terminals

[Input Parameters]



Category:
- ☐ CMOS
- ☑ GaN Diode
- ☐ GaN FET
- ☐ GenericTest
- ☐ IGBT
- ☐ Interconnect
- ☐ MISCAP

Id-Vds Current Collapse

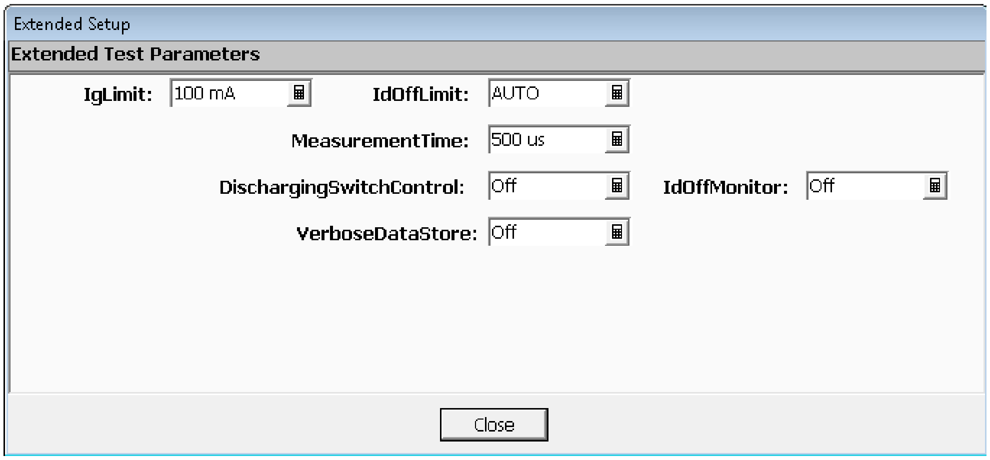
Setup Name: Id-Vds Current Collapse

Device Parameters

Temp: 25.0 deg
XAxisVdsMin: AUTO
XAxisVdsMax: AUTO
YAxisIdMin: 0 A
YAxisIdMax: AUTO

Test Parameters

Memo:
Gate: SMU2:MC
VgOff: -15.0 V
VgOn: 0 V
VdOff: 10.0 V
IdOnLimit: 100 mA
VdStop: 5.00 V
SwitchControl: SMU3:MC
HCSMU: SMU6:HC
HVSMU: SMU7:HV
GNDU: GNDU:GNE
Substrate: GNDU:GNE
VdStart: 0 V
StepTime: 2.0 ms
NOS: 51
OffStressTime: 1.00 s



Extended Test Parameters

IgLimit: 100 mA
IdOffLimit: AUTO
MeasurementTime: 500 us
DischargingSwitchControl: Off
IdOffMonitor: Off
VerboseDataStore: Off

Device Parameters

Name	Description	Default	Unit	Range	Digits	Resolution	Symbols
Temp	Temperature	25	deg C	0	4	100 mdegC	N/A
XAxisVdsMin	X axis (Vds) minimum value	AUTO	V	-1m V to +Infinity	4	1 mV	AUTO : - 1 mV
XAxisVdsMax	X axis (Vds) maximum value	AUTO	V	-1m V to +Infinity	4	1 mV	AUTO : - 1 mV
YAxisIdMin	Y axis (Id) minimum value	0	A	-infinity to +infinity	4	1 mA	N/A
YAxisIdMax	Y axis (Id) maximum value	AUTO	A	-1 mA to +infinity	4	1 mA	AUTO : - 1 mA

Test Parameters

Name	Description	Default	Unit	Range	Digits	Resolution	Symbols
Memo	Memorandum	N/A	N/A	N/A	N/A	N/A	N/A
GNDU	GNDU connected to N1267A GNDU input	GNDU	N/A	GNDU	N/A	N/A	N/A
HVSMU	HVSMU connected to N1267A HVSMU input	HVSMU	N/A	HVSMU	N/A	N/A	N/A
HCSMU	HCSMU connected to N1267A HCSMU input	HCSMU	N/A	HCSMU	N/A	N/A	N/A
SwitchControl	MCSMU connected to N1267A Switch Control	MCSMU	N/A	MCSMU	N/A	N/A	N/A
Gate	MCSMU/HCSMU connected to Gate terminal	MCSMU	N/A	MCSMU, HCSMU	N/A	N/A	N/A
Substrate	SMU/GNDU connected to substrate	GNDU	N/A	SMU*, GNDU	N/A	N/A	N/A
VgOff	Gate voltage for turning DUT off	-15 V	V	-40 V to 40 V	3	1 mV	N/A
VgOn	Gate voltage for turning DUT on	0 V	V	-40 V to 40 V	3	1 mV	N/A
VdOff	Drain voltage applied to DUT turned off	10 V	V	1 V to 3 kV	3	1 mV	N/A
VdStart**	Start value of drain voltage sweep for on	0 V	V	0 V to 40 V	3	1 mV	N/A
VdStop**	Stop value of drain voltage sweep for on	5 V	V	0 V to 40 V	3	1 mV	N/A
IdOnLimit	Drain current compliance for on state	100 mA	A	0 A to 1 A	4	1 mA	N/A
OffStressTime	Duration of VdOff application	1 s	s	0 s to 655.35 s	5	10 ms	N/A
StepTime	Step time of drain voltage sweep	2 ms	s	500 μs to 5 s	4	100 μs	N/A
NOS	Number of steps of drain voltage sweep	51	N/A	1 to 1001	4	1	N/A

*SMU: MPSMU, HPSMU, HVSMU, HCSMU, MCSMU

** The setting voltage of the HCMSU connected to the N1267A during the on-state measurement. The actual Vds is different from it due to the voltage drop at the switch in the N1267A.

Extended Parameters							
Name	**Description**	**Default**	**Unit**	**Range**	**Digits**	**Resolution**	**Symbols**
IgLimit	Gate current compliance	100 mA	A	1 nA to 1A	3	1 nA	N/A
IdOffLimit	Drain current compliance applied to DUT turned off	AUTO	A	0 A to 8 mA	3	1 nA	AUTO: Use the maximum current compliance of the HVSMU
MeasurementTime:	Actual measurement time for each step of drain voltage sweep	0 s	s	0 s to 4.98999 s	6	2 µs	N/A
DischargeSwitchControl	Option for discharging by N1267A Switch Control	Off	V	0 V, 15 V	2	15 V	Off: 0V On: 15 V
IdOffMonitor:	Option for measurement of drain current in off-state	Off	N/A	0. 1	1	1	Off: 0 On: 1
VerboseDataStore	Option for verbose data store for embedded classic test setup	Off	N/A	0, 1	1	1	Off: 0 On: 1

[Measurement Parameters]

Name	Description	Unit
Time	On state time	s
V_HCSMU	Voltage measured by HCSMU	V
I_HCSMU	Current measured by HCSMU	A
V_HVSMU	Voltage measured by HVSMU	V
I_HVSMU	Current measured by HVSMU	A
V_SwitchControl	Voltage measured by Switch Control MCSMU	V
I_SwitchControl	Current measured by Switch Control MCSMU	A
V_Gate	Voltage measured by SMU to Gate drive	V
I_Gate	Current measured by SMU to Gate drive	A

[User Function]

Name	Description	Unit
Vds	Drain-Source voltage (= V_HVSMU)	A
Id	Drain current (= I_HCSMU + I_HVSMU)	V
Vgs	Gate to Source voltage (= V_Gate)	V
Ig	Gate current (= I_Gate)	A
Ta	Temperature (= Temp)	degree C

[X-Y Plot]

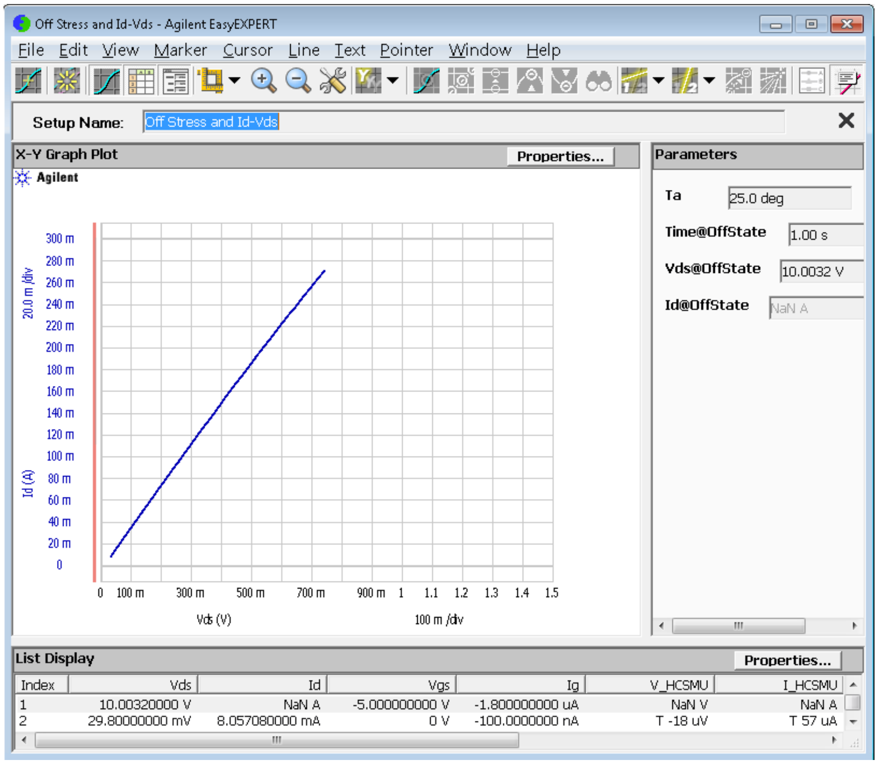
Axis	Item	Unit
X Axis	Vds	V
Y1 Axis	Id	A

[List Display]

Name	Description	Unit
Vds	Drain-Source voltage (= V_HVSMU)	V
Id	Drain current (= I_HCSMU + I_HVSMU)	A
Vgs	Gate-Source voltage (= V_Gate)	V
Ig	Gate current (= I_Gate)	A
V_HCSMU	Voltage measured by HCSMU	V
I_HCSMU	Current measured by HCSMU	A
V_HVSMU	Current measured by HVSMU	V
I_HVSMU	Voltage measured by HVSMU	A
V_SwitchControl	Voltage measured by SMU for switch control	V
I_SwitchControl	Current measured by SMU for switch control	A

[Output Parameters]

Name	Description	Unit
Ta	Temperature (= Temp)	Degree C



Setup Name: Off Stress and Id-Vds

Ta: 25.0 deg

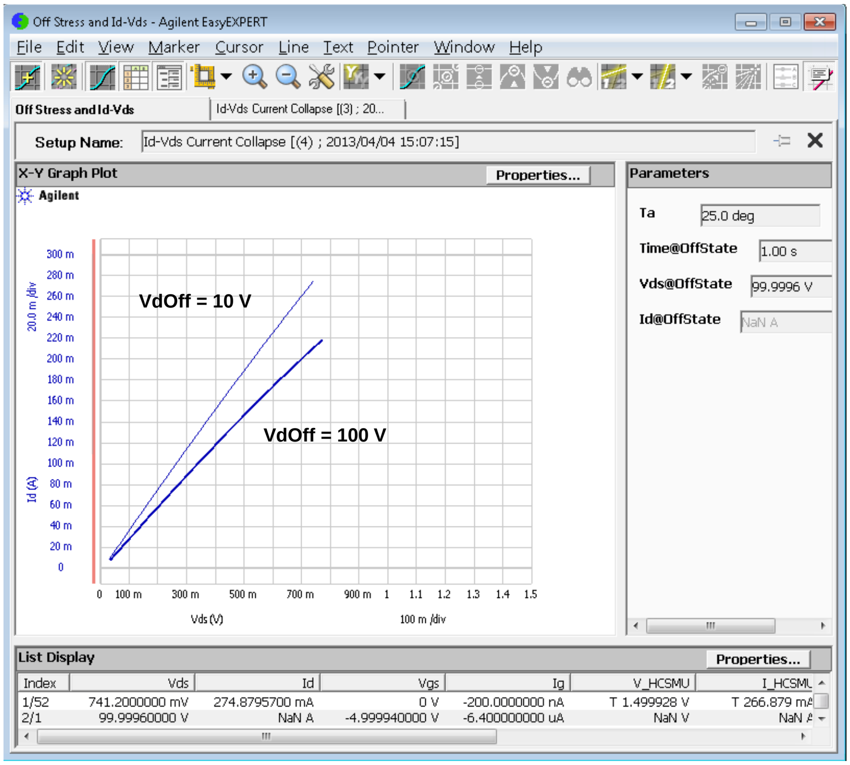
Time@OffState: 1.00 s

Vds@OffState: 10.0032 V

Id@OffState: NaN A

Index	Vds	Id	Vgs	Ig	V_HCSMU	I_HCSMU
1	10.00320000 V	NaN A	-5.000000000 V	-1.800000000 uA	NaN V	NaN A
2	29.80000000 mV	8.057080000 mA	0 V	-100.0000000 nA	T -18 uV	T 57 uA

By appending the Id-Vds curve with different VdOff (stress voltage), the current collapse behavior of device can be observed as below.



Setup Name: Id-Vds Current Collapse [(4) ; 2013/04/04 15:07:15]

Ta 25.0 deg

Time@OffState 1.00 s

Vds@OffState 99.9996 V

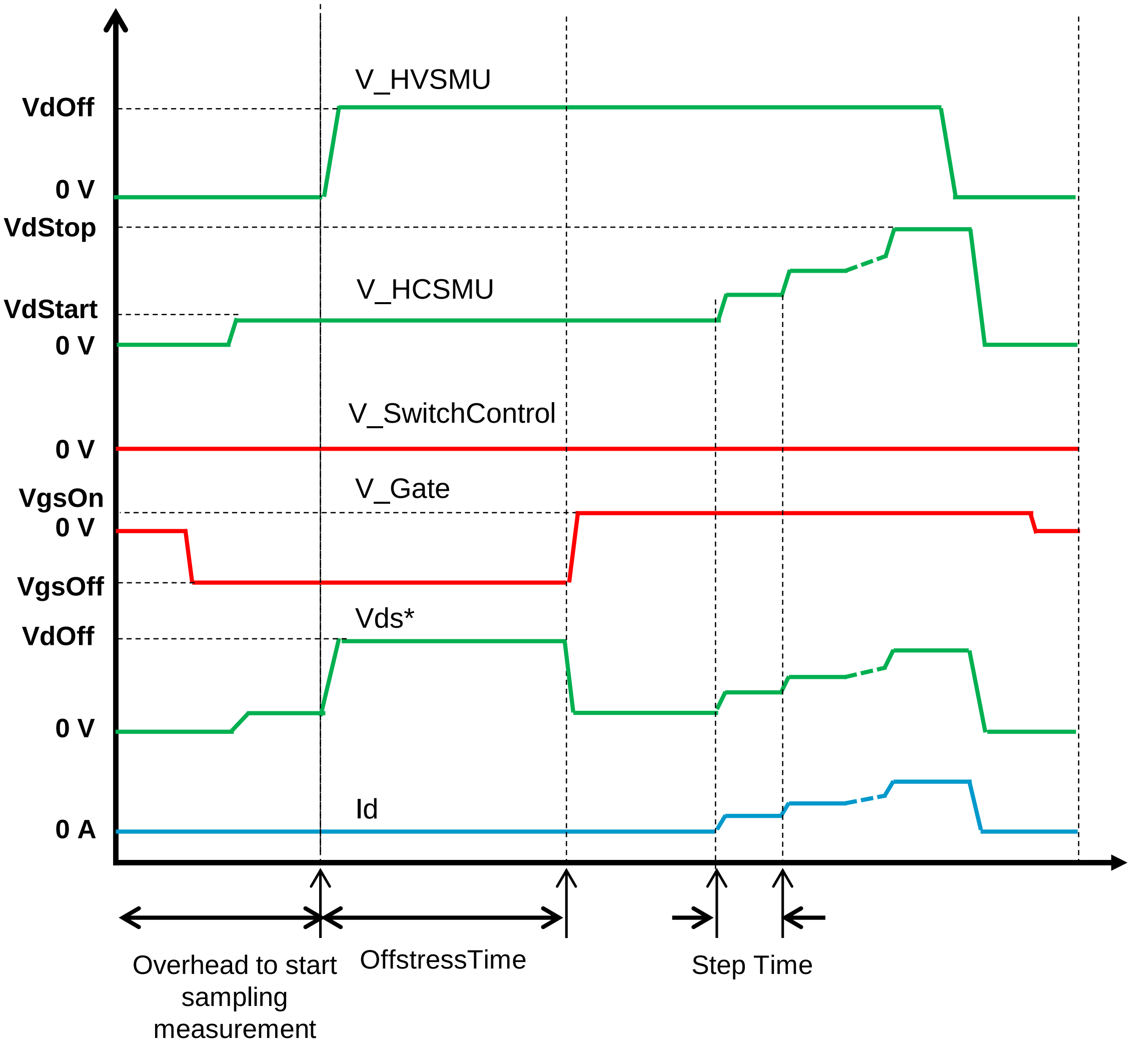
Id@OffState NaN A

Index	Vds	Id	Vgs	Ig	V_HCSMU	I_HCSMU
1/52	741.2000000 mV	274.8795700 mA	0 V	-200.0000000 nA	T 1.499928 V	T 266.879 mA
2/1	99.99960000 V	NaN A	-4.999940000 V	-6.400000000 uA	NaN V	NaN A

[Pulse Timing Chart]

Case 1: DischargeSwitchControl is "Off"

- When the drain on current is larger than 8 mA, the "DischargeSwitchControl" should be OFF.

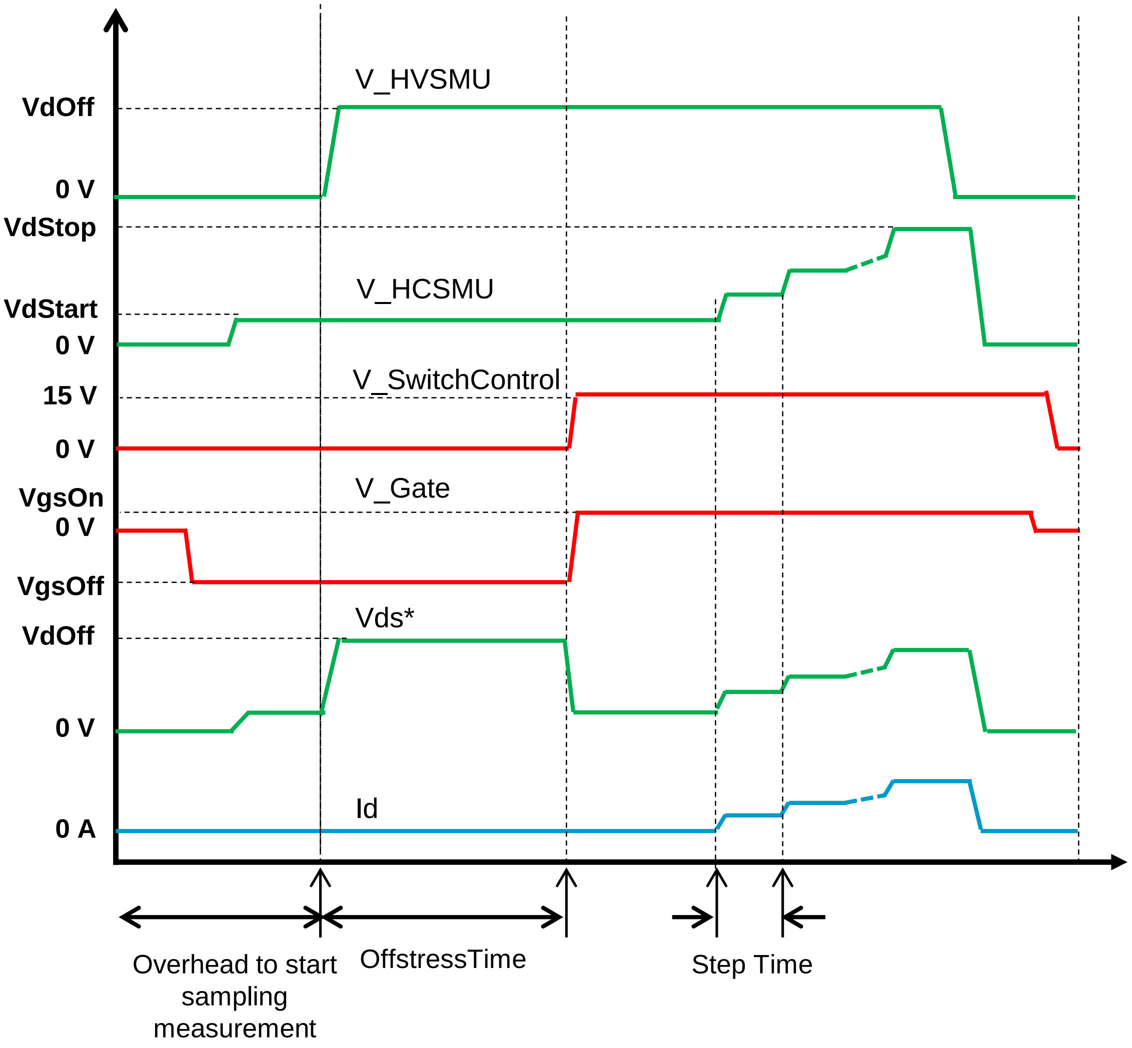


Order to output voltage: Substrate→Switch Control→ Gate→ HCSMU→HVSMU

*: The Vds at on-state is higher than the "VdOn" due to the voltage drop at the switch inside of the N1267A

Case 2: DischargeSwitchControl is "On"

- When the drain on current is smaller than 8 mA, "DischargeSwitchControl" should be On.



Order to output voltage: Substrate→Switch Control→ Gate→ HCSMU→HVSMU

*: The Vds at on-state is smaller than the "VdOn" due to the voltage drop at the switch inside of the N1267A

5-7. Diode Current Collapse IV-t Sampling

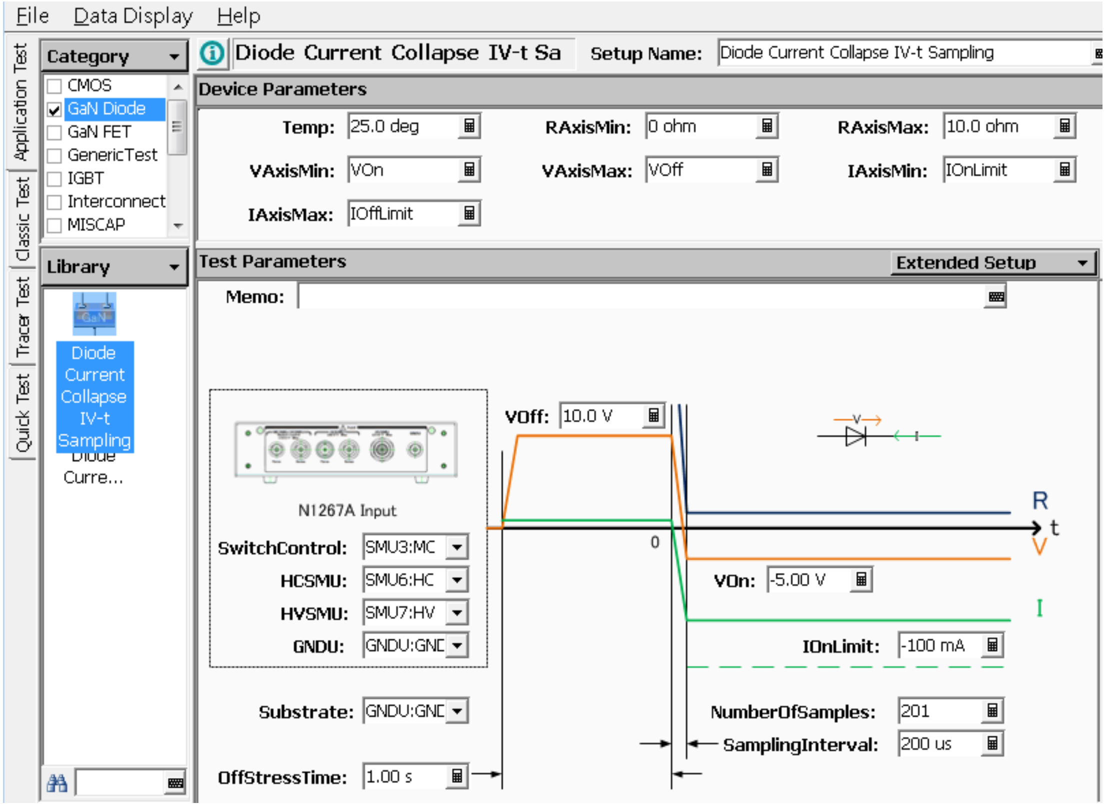
[Description]

Measures Current Collapse of GaN Diode.
On-state current, voltage and resistance after off-state are sampled using N1267A.

[Device Under Test]

GaN Diode, 3 terminals

[Input Parameters]



Diode Current Collapse IV-t Sa

Setup Name: Diode Current Collapse IV-t Sampling

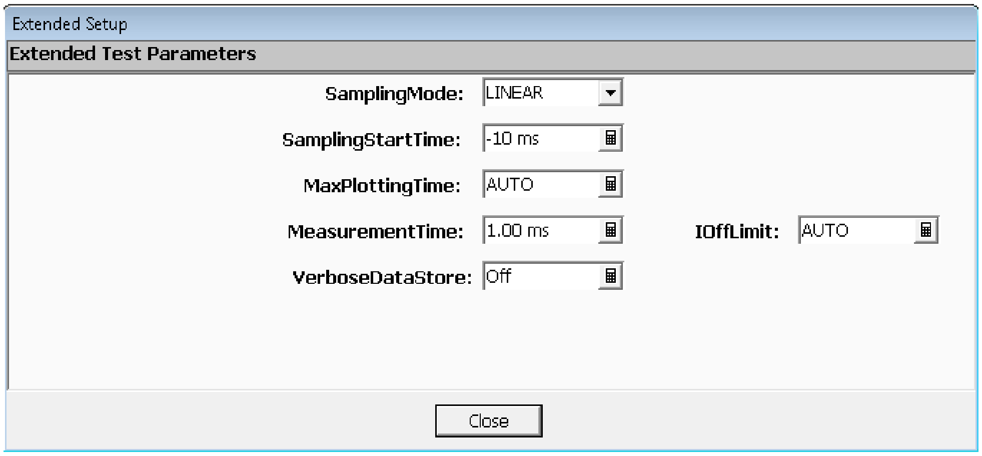
Device Parameters

Temp: 25.0 deg
RAxisMin: 0 ohm
RAxisMax: 10.0 ohm
VAxisMin: VOn
VAxisMax: VOff
IAxisMin: IOnLimit
IAxisMax: IOffLimit

Test Parameters

Memo:

SwitchControl: SMU3:MC
HCSMU: SMU6:HC
HVSMU: SMU7:HV
GNDU: GNDU:GND
Substrate: GNDU:GND
OffStressTime: 1.00 s
VOff: 10.0 V
VOn: -5.00 V
IOnLimit: -100 mA
NumberOfSamples: 201
SamplingInterval: 200 us



Extended Test Parameters

SamplingMode: LINEAR
SamplingStartTime: -10 ms
MaxPlottingTime: AUTO
MeasurementTime: 1.00 ms
IOffLimit: AUTO
VerboseDataStore: Off

Device Parameters							
Name	**Description**	**Default**	**Unit**	**Range**	**Digits**	**Resolution**	**Symbols**
Temp	Temperature	25	deg C	0	4	100 mdegC	N/A
RAxisMin	Y axis (R) minimum value	0	Ohm	-infinity to +infinity	3	1 mOhm	N/A
RAxisMax	Y axis (R) maximum value	10	Ohm	-infinity to +infinity	3	1 mOhm	N/A
VAxisMin	Y axis (V) minimum value	Von	V	-infinity to +infinity	3	1 mV	N/A
VAxisMax:	Y axis (V) maximum value	Voff	V	-infinity to +infinity	3	1 mV	N/A
IAxisMin	M Y axis (I) minimum value	IOnLimit	A	-infinity to +infinity	3	1 µA	N/A
IAxisMax:	Y axis (I) maximum value	IOffLimit	A	-infinity to +infinity	3	1 µA	N/A

Test Parameters							
Name	**Description**	**Default**	**Unit**	**Range**	**Digits**	**Resolution**	**Symbols**
Memo	Memorandum	N/A	N/A	N/A	N/A	N/A	N/A
GNDU	GNDU connected to N1267A GNDU input	GNDU	N/A	GNDU	N/A	N/A	N/A
HVSMU	HVSMU connected to N1267A HVSMU input	HVSMU	N/A	HVSMU	N/A	N/A	N/A
HCSMU	HCSMU connected to N1267A HCSMU input	HCSMU	N/A	HCSMU	N/A	N/A	N/A
SwitchControl	MCSMU connected to N1267A Switch Control	MCSMU	N/A	MCSMU	N/A	N/A	N/A
Substrate	SMU/GNDU connected to substrate	GNDU	N/A	SMU*, GNDU	N/A	N/A	N/A
VOff	Cathode voltage applied while off state	10 V	V	1 V to 3 kV	3	1 mV	N/A
VOn**	Cathode voltage applied while on state	5 V	V	-40 V to 1 V	3	1 mV	N/A
IOnLimit	Current compliance applied to DUT turned on	100 mA	A	-1 A to 0 A	4	1 mA	N/A
OffStressTime	DUT off-state stress time	1 s	s	0 s to 655.35 s	5	10 ms	N/A
SamplingInterval	Sampling interval	200 µs	S	200 us to 65.535 s	5	10 µs	N/A
NumberOfSamples	Number of samples	201	N/A	1 to 12500	6	1	N/A

*SMU: MPSMU, HPSMU, HVSMU, HCSMU, MCSMU

** The setting voltage of the HCMSU connected to the N1267A during the on-state measurement. The actual V is different from it due to the voltage drop at the switch in the N1267A.

Extended Parameters							
Name	**Description**	**Default**	**Unit**	**Range**	**Digits**	**Resolution**	**Symbols**
SamplingMode***	Options for linear or log sampling	Linear	N/A	Linear / Log	N/A	N/A	N/A
SamplngStartTime****	Time offset from turning DUT on to starting sampling	-10 ms	s	-90 ms to 655.35 s	5	10 ms	N/A
MaxPlottingTime	Max time of graph X axis for plotting	AUTO	S	0 to infinity	4	10 ms	Auto: Automatically determined by the SamplingInterval and NumberOfSamples
MeasurementTime	Measurement time (Aperture time, effective in case of 2 ms or above SamplingInterval)	200 µs	s	2 µs to 20 ms	3	2 µs	Minimum : 2 µs
IdOffLimit	Current compliance applied to DUT turned off	AUTO	A	0 A to 8 mA	3	1 nA	AUTO: Use the maximum current compliance of the HVSMU
VerboseDataStore	Option for verbose data store for embedded classic test setup	Off	N/A	0, 1	1	1	Off: 0 On: 1

***Log sampling is only valid when the SamplingInterval is equal to or longer than 2 ms.

****Negative value is only valid when the SamplingInterval is smaller than 2 ms.

[Measurement Parameters]

Name	Description	Unit
Time	On state time	s
V_HCSMU	Voltage measured by HCSMU	V
I_HCSMU	Current measured by HCSMU	A
V_HVSMU	Voltage measured by HVSMU	V
I_HVSMU	Current measured by HVSMU	A
V_SwitchControl	Voltage measured by SMU for switch control	V
I_SwitchControl	Current measured by SMU for switch control	A

[User Function]

Name	Description	Unit
V	Cathode Voltage (= V_HVSMU)	A
I	Current (= I_HCSMU + I_HVSMU)	V
R	Resistance (= V/ I)	Ohm
Ta	Temperature (= Temp)	degree C

[X-Y Plot]

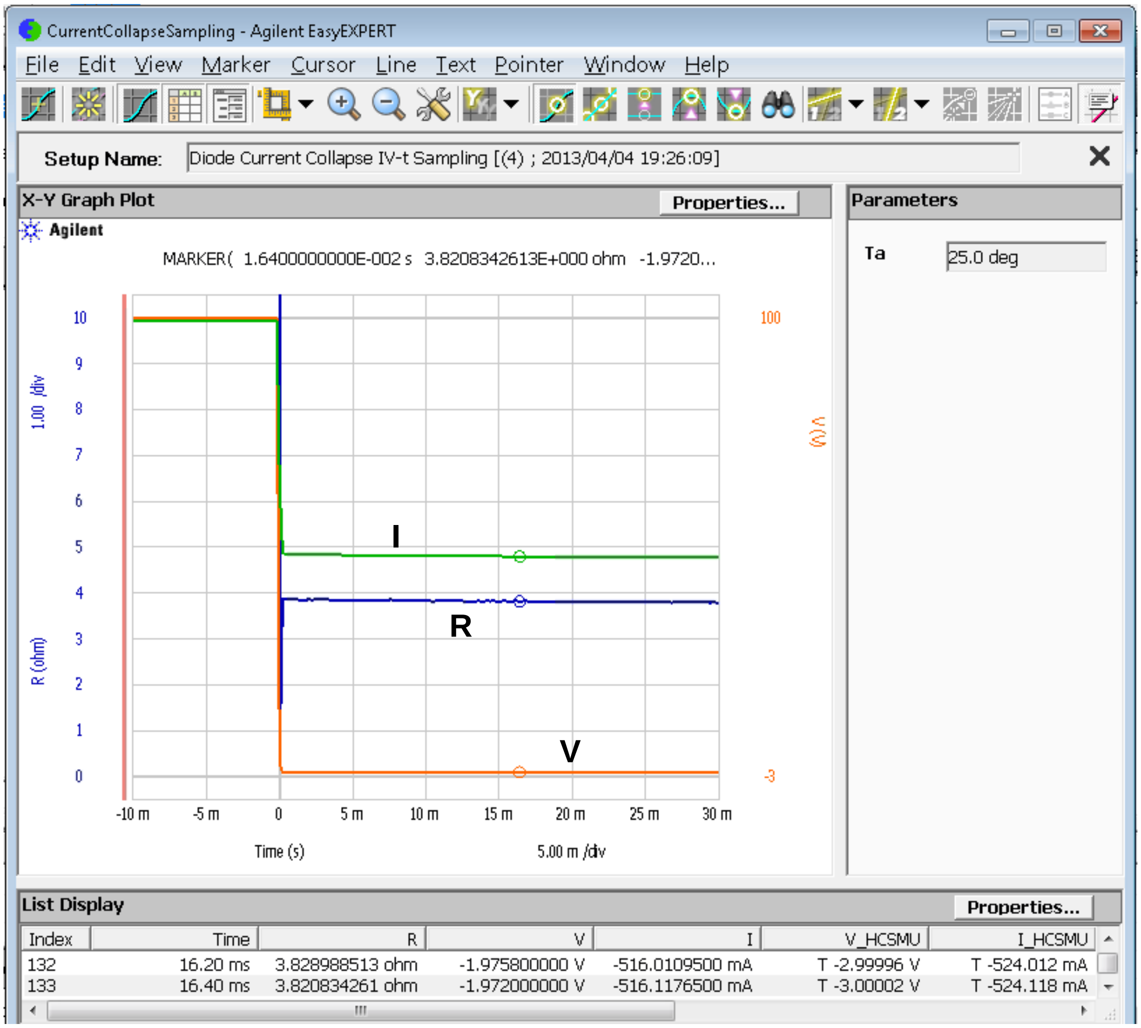
Axis	Item	Unit
X Axis	Time	s
Y1 Axis	R	Ohm
Y2 Axis	V	V
Y3 Axis	I	A

[List Display]

Name	Description	Unit
Time	On state time	S
R	Resistance (= Vds / Id)	Ohm
V	Cathode Voltage (= V_HVSMU)	V
I	Current (= I_HCSMU + I_HVSMU)	A
V_HCSMU	Voltage measured by HCSMU	V
I_HCSMU	Current measured by HCSMU	A
V_HVSMU	Current measured by HVSMU	V
I_HVSMU	Voltage measured by HVSMU	A
V_SwitchControl	Voltage measured by Switch Control	V
I_SwitchControl	Voltage measured by Switch Control	A

[Output Parameters]

Name	Description	Unit
Ta	Temperature (= Temp)	Degree C



Setup Name: Diode Current Collapse IV-t Sampling [(4) ; 2013/04/04 19:26:09]

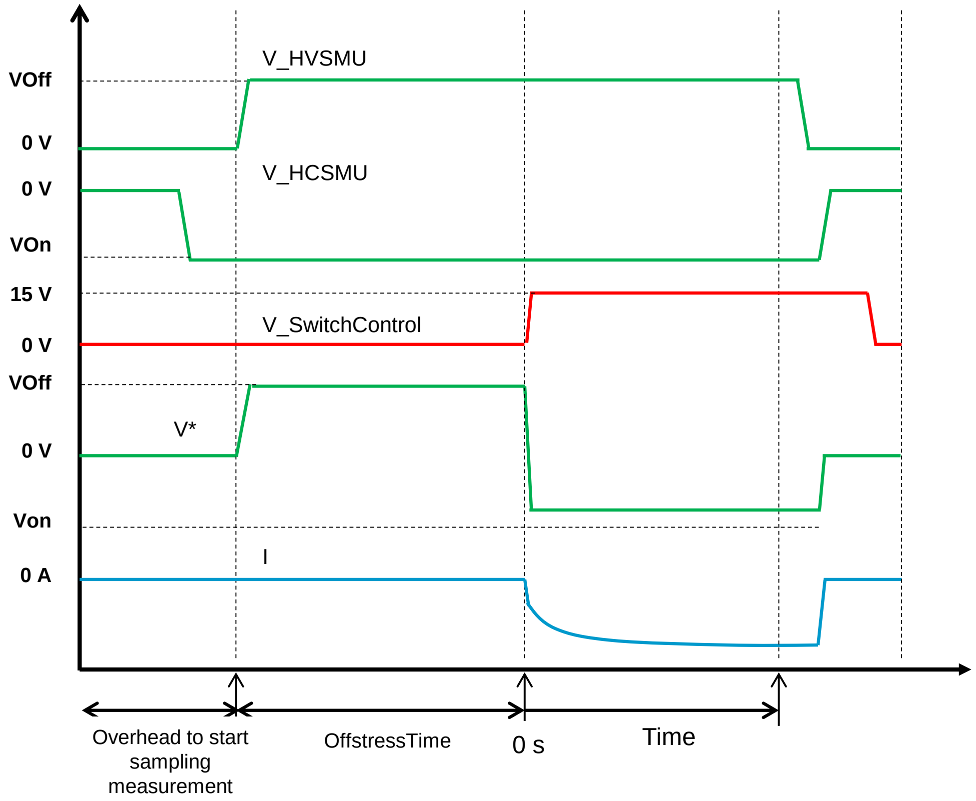
MARKER(1.6400000000E-002 s 3.8208342613E+000 ohm -1.9720...

Ta 25.0 deg

Index	Time	R	V	I	V_HCSMU	I_HCSMU
132	16.20 ms	3.828988513 ohm	-1.975800000 V	-516.0109500 mA	T -2.99996 V	T -524.012 mA
133	16.40 ms	3.820834261 ohm	-1.972000000 V	-516.1176500 mA	T -3.00002 V	T -524.118 mA

*This sample device is a Si diode and does not have any current collapse characteristics.

[Pulse Timing Chart]



Order to output voltage: Substrate→Switch Control→ HCSMU→HVSMU

*: The voltage at the on-state is higher than "Von" due to the voltage drop at the switch inside of the N1267A when I is larger than the current compliance of the HVSMU. If I is smaller than the current compliance of the HVSMU, V becomes larger than Von.

[Measurement Timing]

Same as the "FET Current Collapse IV-t Sampling".

3-8. Diode Current Collapse Signal Monitor

[Description]

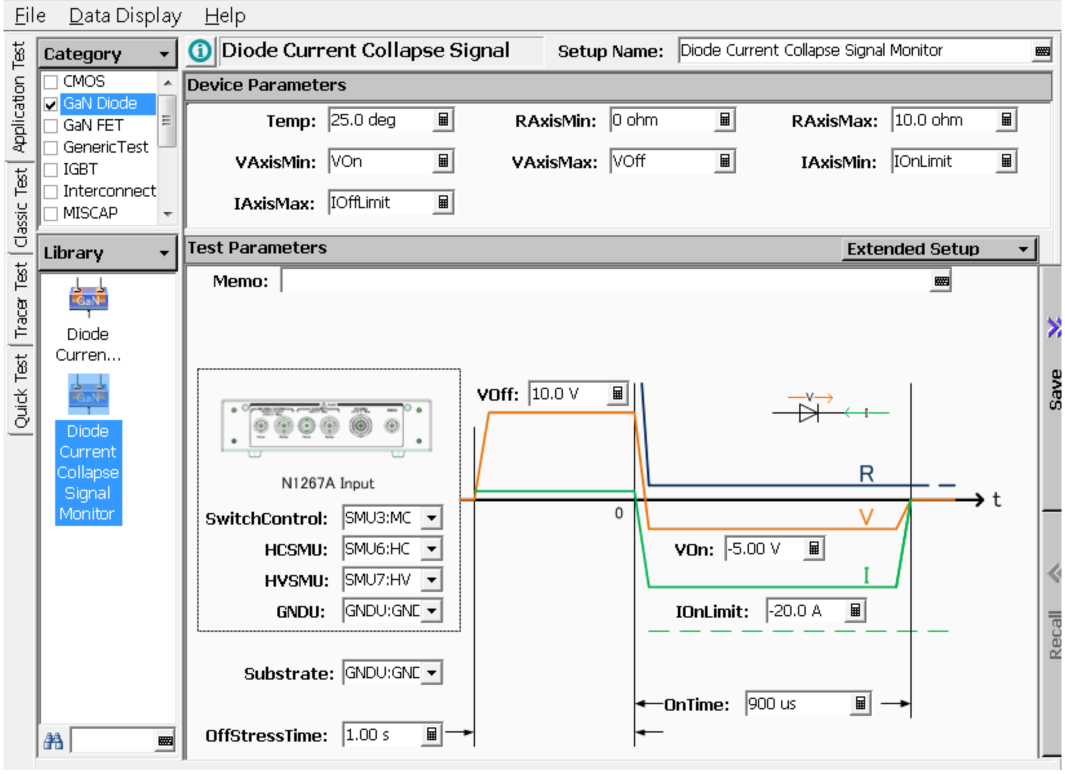
Measures Current Collapse of GaN Diode.

On-state current, voltage and resistance after off-state are measured by pulse and signal monitor using N1267A.

[Device Under Test]

GaN Diode, 3 terminals

[Input Parameters]



Category: ☐ CMOS ☑ GaN Diode ☐ GaN FET ☐ GenericTest ☐ IGBT ☐ Interconnect ☐ MISCAP

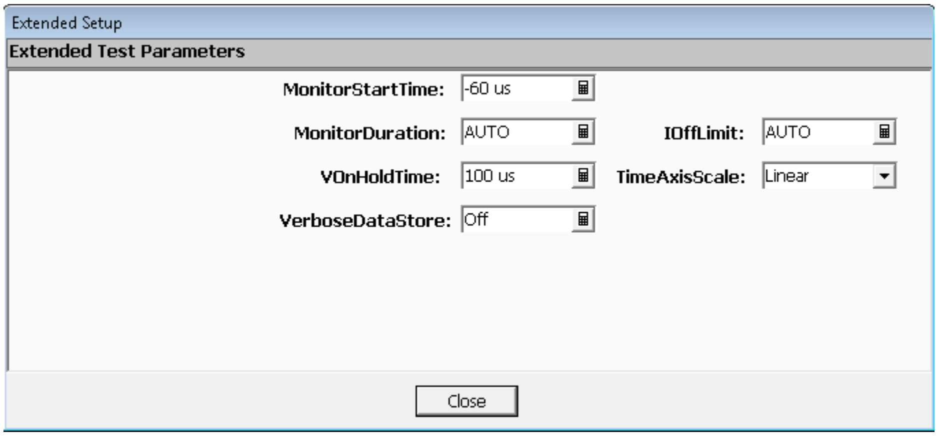
Diode Current Collapse Signal

Setup Name: Diode Current Collapse Signal Monitor

Temp: 25.0 deg
RAxisMin: 0 ohm
RAxisMax: 10.0 ohm
VAxisMin: VOn
VAxisMax: VOff
IAxisMin: IOnLimit
IAxisMax: IOffLimit

Memo:

SwitchControl: SMU3:MC
HCSMU: SMU6:HC
HVSMU: SMU7:HV
GNDU: GNDU:GN
Substrate: GNDU:GN
OffStressTime: 1.00 s
VOff: 10.0 V
VOn: -5.00 V
IOnLimit: -20.0 A
OnTime: 900 us



MonitorStartTime: -60 us
MonitorDuration: AUTO
IOffLimit: AUTO
VOnHoldTime: 100 us
TimeAxisScale: Linear
VerboseDataStore: Off

Device Parameters

Name	Description	Default	Unit	Range	Digits	Resolution	Symbols
Temp	Temperature	25	deg C	0	4	100 mdegC	N/A
RAxisMin	Y axis (R) minimum value	0	Ohm	-infinity to +infinity	3	1 mOhm	N/A
RAxisMax	Y axis (R) maximum value	10	Ohm	-infinity to +infinity	3	1 mOhm	N/A
VAxisMin	Y axis (V) minimum value	Von	V	-infinity to +infinity	3	1 mV	N/A
VAxisMax:	Y axis (V) maximum value	Voff	V	-infinity to +infinity	3	1 mV	N/A
IAxisMin	M Y axis (I) minimum value	IOnLimit	A	-infinity to +infinity	3	1 μA	N/A
IAxisMax:	Y axis (I) maximum value	IOffLimit	A	-infinity to +infinity	3	1 μA	N/A

Test Parameters

Name	Description	Default	Unit	Range	Digits	Resolution	Symbols
Memo	Memorandum	N/A	N/A	N/A	N/A	N/A	N/A
GNDU	GNDU connected to N1267A GNDU input	GNDU	N/A	GNDU	N/A	N/A	N/A
HVSMU	HVSMU connected to N1267A HVSMU input	HVSMU	N/A	HVSMU	N/A	N/A	N/A
HCSMU	HCSMU connected to N1267A HCSMU input	HCSMU	N/A	HCSMU	N/A	N/A	N/A
SwitchControl	MCSMU connected to N1267A Switch Control	MCSMU	N/A	MCSMU	N/A	N/A	N/A
Substrate	SMU/GNDU connected to substrate	GNDU	N/A	SMU*, GNDU	N/A	N/A	N/A
VOff	Cathode voltage applied while in off-state	10 V	V	1 V to 3 kV	3	1 mV	N/A
VOn**	Cathode voltage applied while in on-state	5 V	V	-40 V to 1 V	3	1 mV	N/A
IOnLimit	Current compliance applied to DUT turned on	100 mA	A	-20 A to 0 A	3	1 mA	N/A
OffStressTime	DUT off-state stress time	1 s	s	0 s to 655.35 s	5	10 ms	N/A
OnTime	Duration of VOn application	900 μs	S	50 μs to 24 ms	5	2 μs	N/A

*SMU: MPSMU, HPSMU, HVSMU, HCSMU, MCSMU

**The setting voltage of the HCMSU connected to the N1267A during the on-state measurement. The actual V is different from it due to the voltage drop at the switch in the N1267A.

Extended Parameters

Name	Description	Default	Unit	Range	Digits	Resolution	Symbols
MonitorStartTime	Signal Monitor start time	-60 µs	s	-120 µs to 0 s	4	6 µs	N/A
MonitorDuration:	Signal Monitor duration	AUTO	s	0 µs to 24 ms	4	6 µs	AUTO: Automatically determined by the "OnTime"
IOffLimit	Drain current compliance applied to DUT turned off	AUTO	A	0 A to 8 mA	3	1 nA	AUTO: Use the maximum current compliance of the HVSMU
VOnHoldTime:	Hold time of VdOn output by HCSMU before turning DUT on	100 µs	s	0 s to 4.99 s	6	2 µs	N/A
TimeAxisScale:	Option for scale of X axis (Time)	Linear	N/A	Linear, Log	N/A	N/A	N/A
VerboseDataStore	Option for verbose data store for embedded classic test setup	Off	N/A	0, 1	1	1	Off: 0 On: 1

[Measurement Parameters]

Name	Description	Unit
Time	On state time	s
V_HCSMU	Voltage measured by HCSMU	V
I_HCSMU	Current measured by HCSMU	A
V_HVSMU	Voltage measured by HVSMU	V
I_HVSMU	Current measured by HVSMU	A
Vsw	Voltage measured by Switch Control MCSMU	V
I_SwitchControl	Current measured by Switch Control MCSMU	A

[User Function]

Name	Description	Unit
V	Cathode Voltage (= V_HVSMU)	A
I	Current (= I_HCSMU + I_HVSMU)	V
R	Resistance (= Vds / Id)	Ohm
Ta	Temperature (= Temp)	degree C

[X-Y Plot]

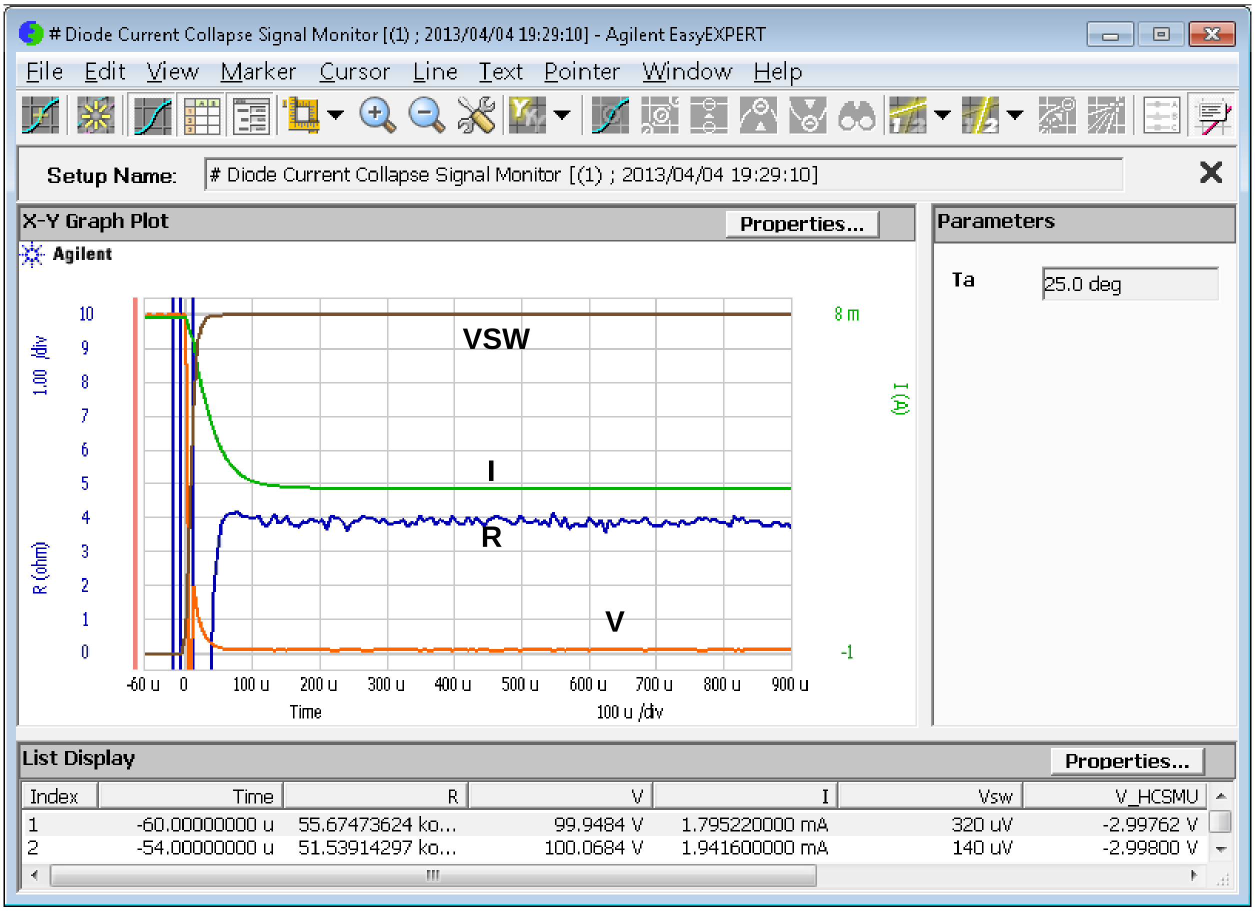
Axis	Item	Unit
X Axis	Time	s
Y1 Axis	R	Ohm
Y2 Axis	V	V
Y3 Axis	I	A
Y4 Axis	Vsw	V

[List Display]

Name	Description	Unit
Time	On state time	S
R	R (= V / I)	Ohm
V	Cathode Voltage (= V_HVSMU)	V
R	Current (= I_HCSMU + I_HVSMU)	A
V_HCSMU	Voltage measured by HCSMU	V
I_HCSMU	Current measured by HCSMU	A
V_HVSMU	Current measured by HVSMU	V
I_HVSMU	Voltage measured by HVSMU	A
Vsw	Voltage measured by SMU for switch control	V
I_SwitchControl	Current measured by SMU for switch control	A

[Output Parameters]

Name	Description	Unit
Ta	Temperature (= Temp)	Degree C



Diode Current Collapse Signal Monitor [(1) ; 2013/04/04 19:29:10] - Agilent EasyEXPERT

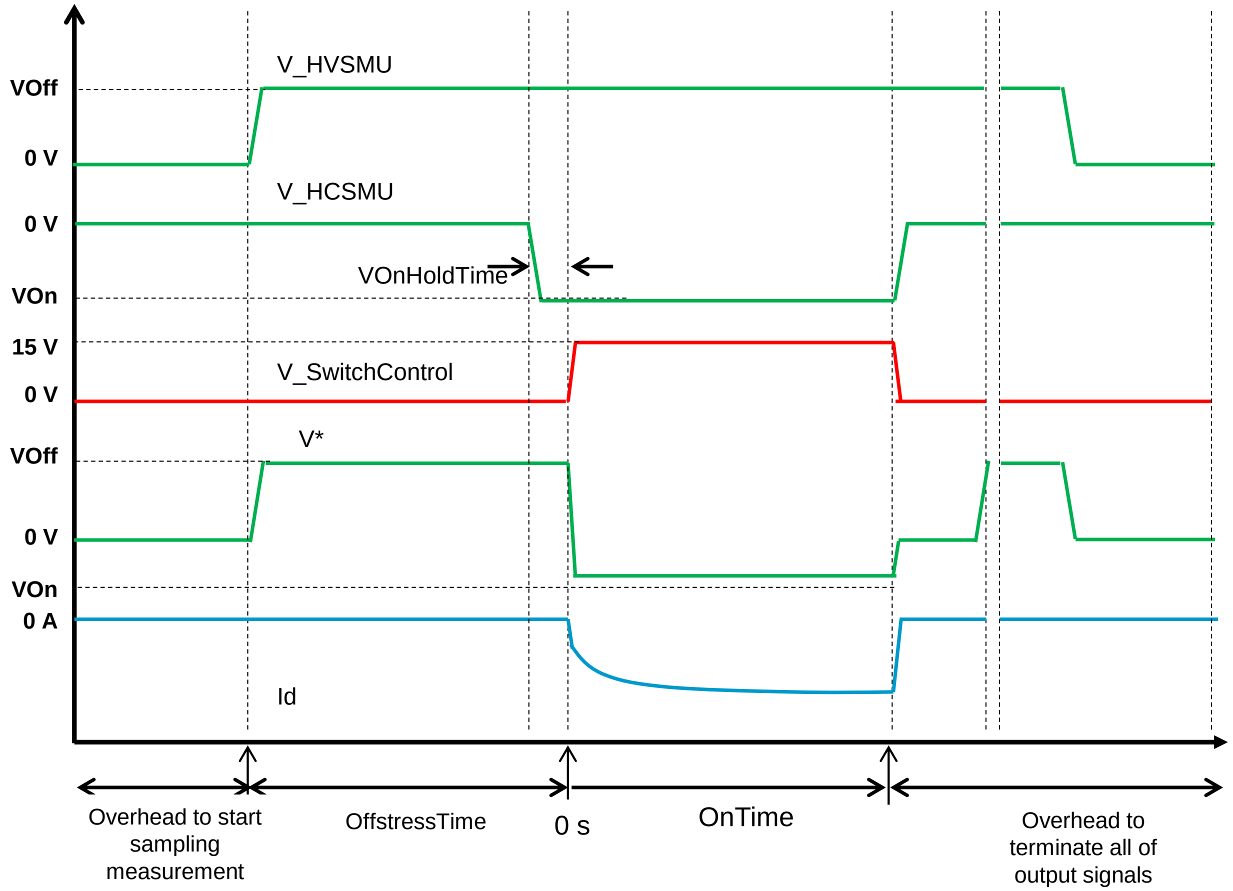
Setup Name: # Diode Current Collapse Signal Monitor [(1) ; 2013/04/04 19:29:10]

Ta 25.0 deg

Index	Time	R	V	I	Vsw	V_HCSMU
1	-60.00000000 u	55.67473624 ko...	99.9484 V	1.795220000 mA	320 uV	-2.99762 V
2	-54.00000000 u	51.53914297 ko...	100.0684 V	1.941600000 mA	140 uV	-2.99800 V

*: The voltage at the on-state is higher than “Von” due to the voltage drop at the switch inside of the N1267A when I is larger than the current compliance of the HVSMU. If I is smaller than the current compliance of the HVSMU, V becomes larger than Von.

[Pulse Timing Chart]



Order to output voltage: Substrate→Switch Control→ HCSMU→HVSMU

*: The voltage at the on-state is higher than “Von” due to the voltage drop at the switch inside of the N1267A

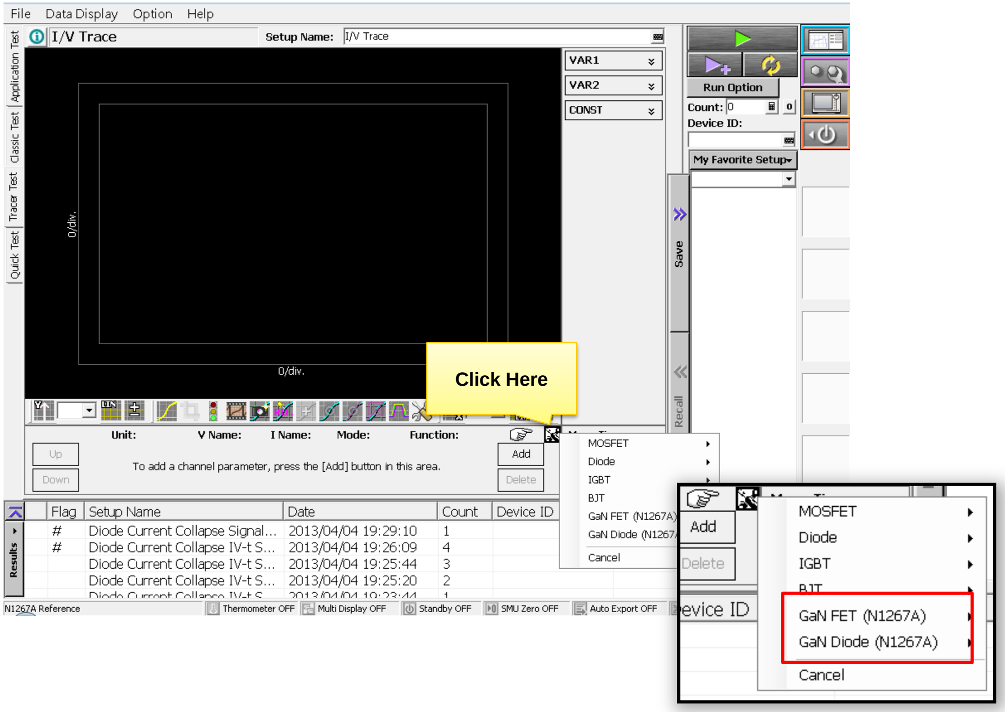
[Measurement Timing]

Same as the “FET Current Collapse Signal Monitor”.

6. GaN Current Collapse Tracer Test Preset Reference

6-1. Overview

In the Tracer Test mode, presets for current collapse measurement for GaN FET and GaN Diode are available.



To add a channel parameter, press the [Add] button in this area.

Flag	Setup Name	Date	Count	Device ID
#	Diode Current Collapse Signal...	2013/04/04 19:29:10	1	
#	Diode Current Collapse IV-t S...	2013/04/04 19:26:09	4	
	Diode Current Collapse IV-t S...	2013/04/04 19:25:44	3	
	Diode Current Collapse IV-t S...	2013/04/04 19:25:20	2	

In those preset groups, there are two categories of measurements, IV characteristic measurement to check the DUT adequateness and current collapse measurement.

The IV characteristics measurement includes following presets.

For GaN FET

- ✓ ID-VD
- ✓ ID(off)-VD

For GaN Diode

- ✓ IF-VF
- ✓ IR-VR

Those presets are performing standard IV measurements of FET and Diode while connecting them to the N1267A. After confirming that the DUT is adequate to do the current collapse test, you will be able to do them without changing cabling.

For current collapse measurement, the following presets are available.

For GaN FET

- ✓ ID-VDS Current Collapse
- ✓ FET Current Collapse Oscilloscope View

For GAN Diode

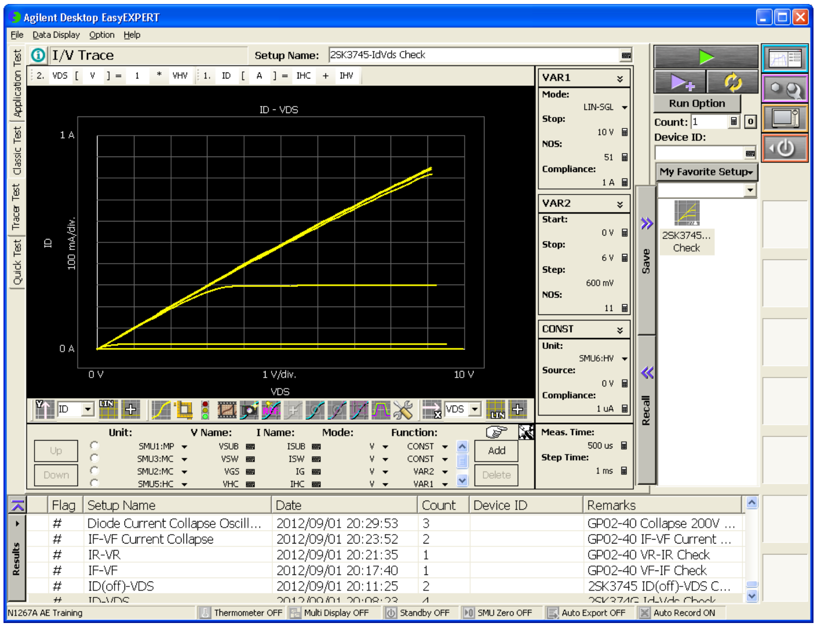
- ✓ IF-VF Current Collapse
- ✓ Diode Current Collapse Oscilloscope View

6-2. ID-VDS

[Description]

This preset is used to measure the ID-VDS characteristics of GaN FET while connecting it to the N1267A.

To use this preset, you have to specify the following parameters.



Agilent Desktop EasyEXPERT

I/V Trace — Setup Name: 2SK3745-IdVds Check

2. VDS [V] = 1 * VHV   1. ID [A] = IHC + IHV

VAR1 — Mode: LIN-SGL; Stop: 10 V; NOS: 51; Compliance: 1 A

VAR2 — Start: 0 V; Stop: 6 V; Step: 600 mV; NOS: 11

CONST — Unit: SMU6:HV; Source: 0 V; Compliance: 1 uA

Meas. Time: 500 us; Step Time: 1 ms

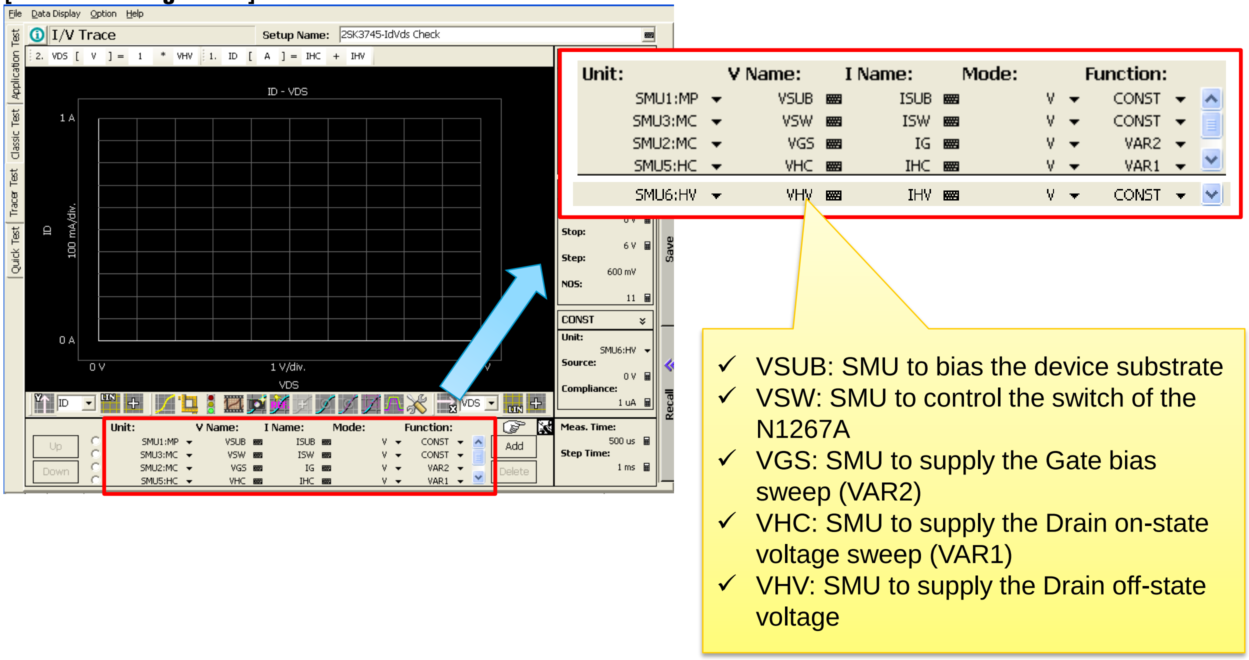
Count: 1

Unit:	V Name:	I Name:	Mode:	Function:
SMU1:MP	VSUB	ISUB	V	CONST
SMU3:MC	VSW	ISW	V	CONST
SMU2:MC	VGS	IG	V	VAR2
SMU5:HC	VHC	IHC	V	VAR1

Flag	Setup Name	Date	Count	Device ID	Remarks
#	Diode Current Collapse Oscill…	2012/09/01 20:29:53	3		GP02-40 Collapse 200V …
#	IF-VF Current Collapse	2012/09/01 20:23:52	2		GP02-40 IF-VF Current …
#	IR-VR	2012/09/01 20:21:35	1		GP02-40 VR-IR Check
#	IF-VF	2012/09/01 20:17:40	1		GP02-40 VF-IF Check
#	ID(off)-VDS	2012/09/01 20:11:25	2		2SK3745 ID(off)-VDS C…

N1267A AE Training | Thermometer OFF | Multi Display OFF | Standby OFF | SMU Zero OFF | Auto Export OFF | Auto Record ON

[Channel Assignment]

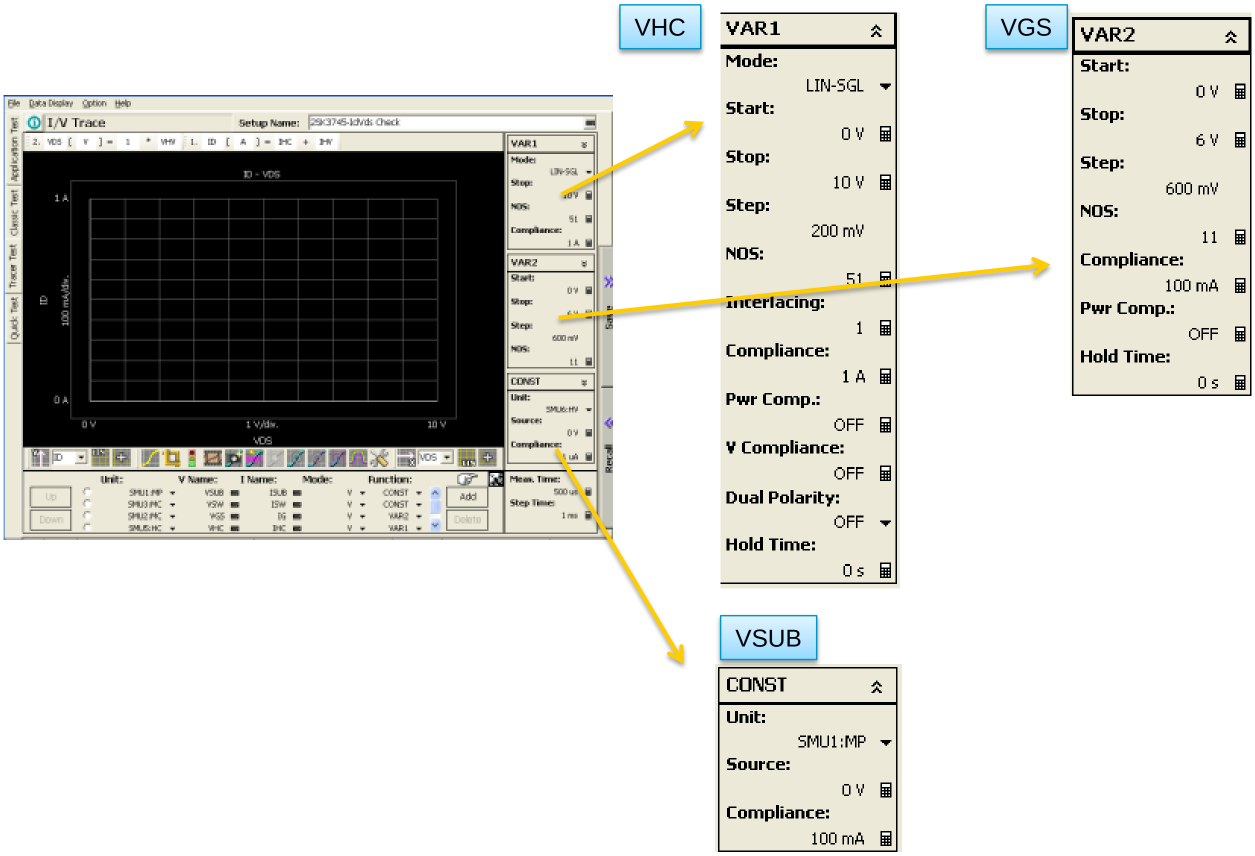


Unit:	V Name:	I Name:	Mode:	Function:
SMU1:MP	VSUB	ISUB	V	CONST
SMU3:MC	VSW	ISW	V	CONST
SMU2:MC	VGS	IG	V	VAR2
SMU5:HC	VHC	IHC	V	VAR1
SMU6:HV	VHV	IHV	V	CONST

- ✓ VSUB: SMU to bias the device substrate
- ✓ VSW: SMU to control the switch of the N1267A
- ✓ VGS: SMU to supply the Gate bias sweep (VAR2)
- ✓ VHC: SMU to supply the Drain on-state voltage sweep (VAR1)
- ✓ VHV: SMU to supply the Drain off-state voltage

[Measurement Parameters]

Specify the VHC sweep (VAR1) and the VGS sweep (VAR2) for ID-VDS measurement.
The VHV and VSW are not necessary to be changed.
Change the VSUB if you want to add a bias to the substrate of the device.



VAR1
Mode: LIN-SGL
Start: 0 V
Stop: 10 V
Step: 200 mV
NOS: 51
Interlacing: 1
Compliance: 1 A
Pwr Comp.: OFF
V Compliance: OFF
Dual Polarity: OFF
Hold Time: 0 s

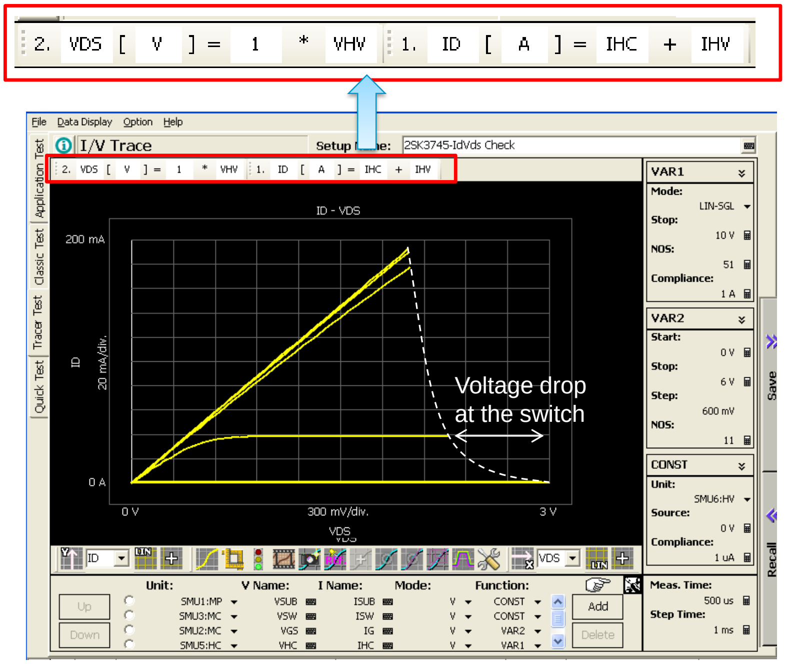
VAR2
Start: 0 V
Stop: 6 V
Step: 600 mV
NOS: 11
Compliance: 100 mA
Pwr Comp.: OFF
Hold Time: 0 s

CONST
Unit: SMU1:MP
Source: 0 V
Compliance: 100 mA

[Output Parameters]

The measured drain current (ID) versus drain voltage (VDS) curves are displayed in the chart area. The drain current is a summation of current measured by the HCSMU and HVSMU. The drain voltage is monitored by the HVSMU. Those calculations are defined in the arithmetic operation function of the Tracer Test mode as described in figure below. VHV is the measured voltage by the HVSMU. The IHC and IHV are the measured current by the HCSMU and HVSMU.

On the ID-VDS traces, the end points of each trace decrease with an increase of the drain current due to the voltage drop at the switch inside of the N1267A (Please refer to section 3-1).



2. VDS [V] = 1 * VHV

1. ID [A] = IHC + IHV

Setup Name: 2SK3745-IdVds Check

VAR1 Mode: LIN-SGL, Stop: 10 V, NOS: 51, Compliance: 1 A

VAR2 Start: 0 V, Stop: 6 V, Step: 600 mV, NOS: 11

CONST Unit: SMU6:HV, Source: 0 V, Compliance: 1 uA

Unit:	V Name:	I Name:	Mode:	Function:
SMU1:MP	VSUB	ISUB	V	CONST
SMU3:MC	VSW	ISW	V	CONST
SMU2:MC	VGS	IG	V	VAR2
SMU5:HC	VHC	IHC	V	VAR1

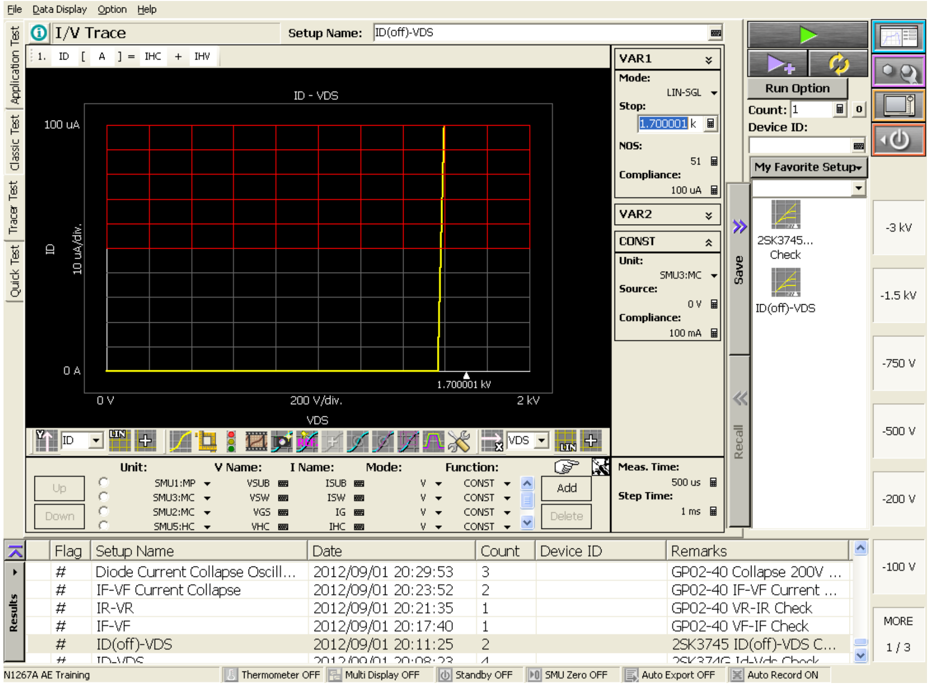
Meas. Time: 500 us

Step Time: 1 ms

6-3. ID(off)-VDS

[[Description]

This preset is used to measure the ID(off)-VDS characteristics of GaN FET while connecting it to the N1267A.



Setup Name: ID(off)-VDS

VAR1 — Mode: LIN-SGL; Stop: 1.700001 k; NOS: 51; Compliance: 100 uA

VAR2

CONST — Unit: SMU3:MC; Source: 0 V; Compliance: 100 mA

Count: 1

Device ID:

Unit:	V Name:	I Name:	Mode:	Function:
SMU1:MP	VSUB	ISUB	V	CONST
SMU3:MC	VSW	ISW	V	CONST
SMU2:MC	VGS	IG	V	CONST
SMU5:HC	VHC	IHC	V	CONST

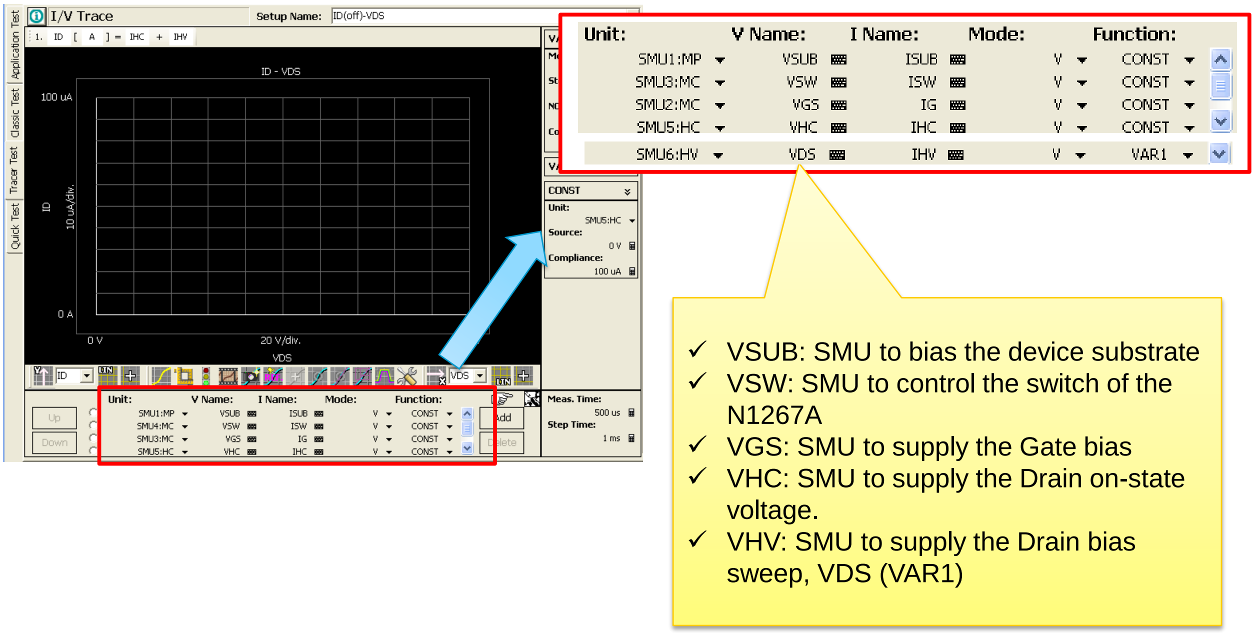
Meas. Time: 500 us

Step Time: 1 ms

Flag	Setup Name	Date	Count	Device ID	Remarks
#	Diode Current Collapse Oscill...	2012/09/01 20:29:53	3		GP02-40 Collapse 200V ...
#	IF-VF Current Collapse	2012/09/01 20:23:52	2		GP02-40 IF-VF Current ...
#	IR-VR	2012/09/01 20:21:35	1		GP02-40 VR-IR Check
#	IF-VF	2012/09/01 20:17:40	1		GP02-40 VF-IF Check
#	ID(off)-VDS	2012/09/01 20:11:25	2		2SK3745 ID(off)-VDS C...

N1267A AE Training | Thermometer OFF | Multi Display OFF | Standby OFF | SMU Zero OFF | Auto Export OFF | Auto Record ON

[Channel Assignment]

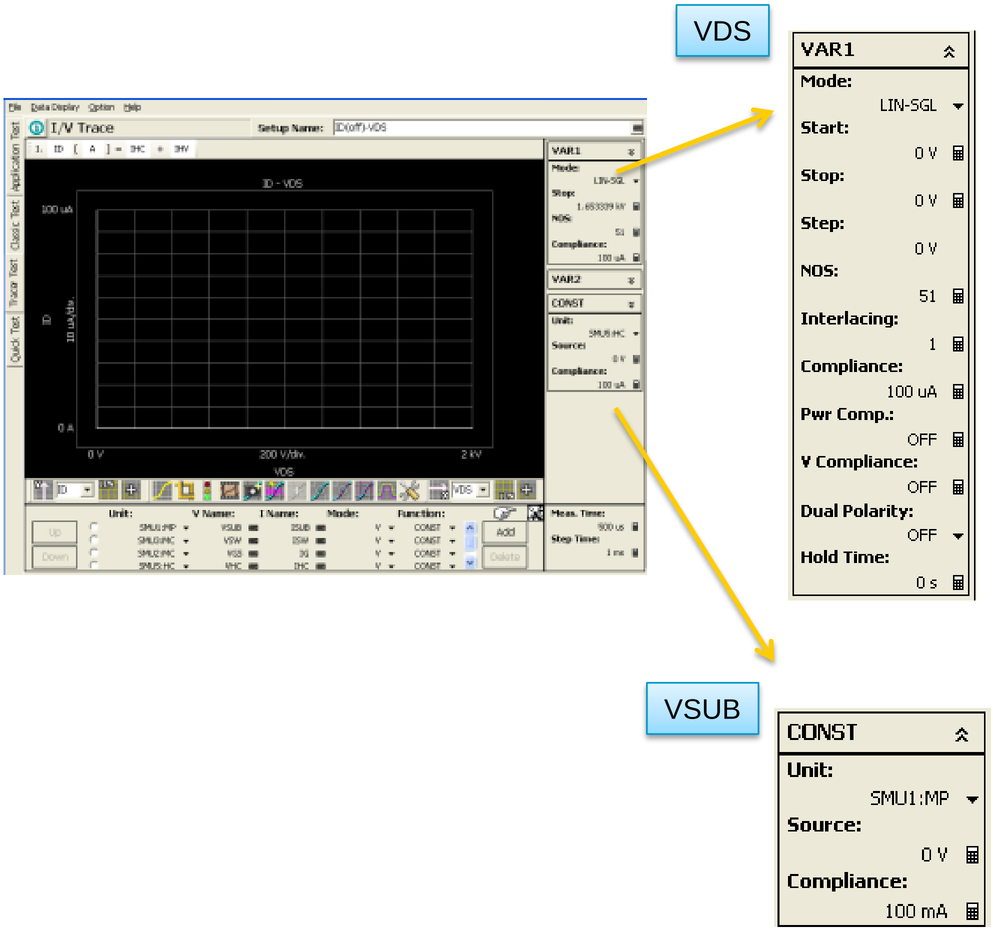


Unit:	V Name:	I Name:	Mode:	Function:
SMU1:MP	VSUB	ISUB	V	CONST
SMU3:MC	VSW	ISW	V	CONST
SMU2:MC	VGS	IG	V	CONST
SMU5:HC	VHC	IHC	V	CONST
SMU6:HV	VDS	IHV	V	VAR1

- ✓ VSUB: SMU to bias the device substrate
- ✓ VSW: SMU to control the switch of the N1267A
- ✓ VGS: SMU to supply the Gate bias
- ✓ VHC: SMU to supply the Drain on-state voltage.
- ✓ VHV: SMU to supply the Drain bias sweep, VDS (VAR1)

[Measurement Parameters]

Specify the VHV sweep (VAR1) for the ID(off)-VDS sweep.
The VHC, VGS and VSW are not necessary to be changed.
Change the VSUB if you want to add a bias to the substrate of the device.



VDS

VAR1

Mode: LIN-SGL
Start: 0 V
Stop: 0 V
Step: 0 V
NOS: 51
Interlacing: 1
Compliance: 100 uA
Pwr Comp.: OFF
V Compliance: OFF
Dual Polarity: OFF
Hold Time: 0 s

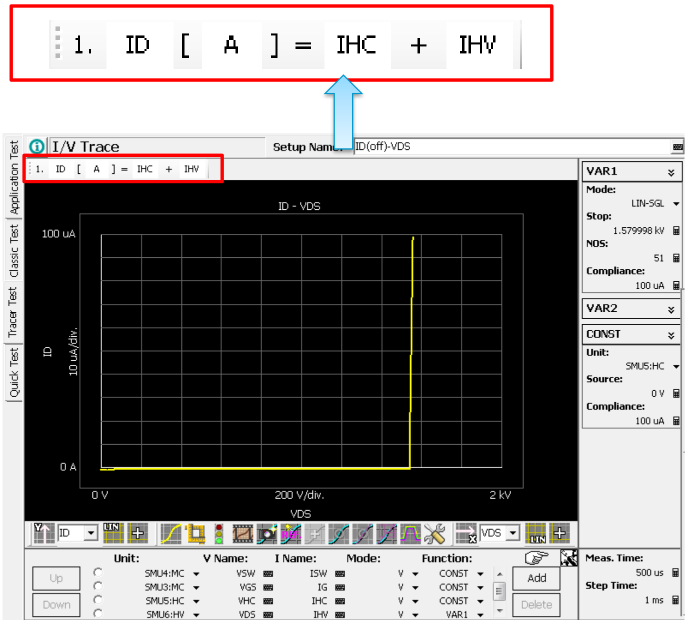
VSUB

CONST

Unit: SMU1:MP
Source: 0 V
Compliance: 100 mA

[Output Parameters]

The measured drain current (ID) versus drain voltage (VDS) curve is displayed in the chart area. The drain current is a summation of current measured by the HCSMU and HVSMU. The drain voltage is monitored by the HVSMU. Those calculations are defined in the arithmetic operation function of the Tracer Test mode as described in figure below. The IHC and IHV are the measured current by the HCSMU and HVSMU.



1. ID [A] = IHC + IHV

I/V Trace

Setup Name: ID(off)-VDS

VAR1
Mode: LIN-SGL
Stop: 1.579998 kV
NOS: 51
Compliance: 100 uA

VAR2

CONST
Unit: SMU5:HC
Source: 0 V
Compliance: 100 uA

Unit:	V Name:	I Name:	Mode:	Function:
SMU4:MC	VSW	ISW	V	CONST
SMU3:MC	VGS	IG	V	CONST
SMU5:HC	VHC	IHC	V	CONST
SMU6:HV	VDS	IHV	V	VAR1

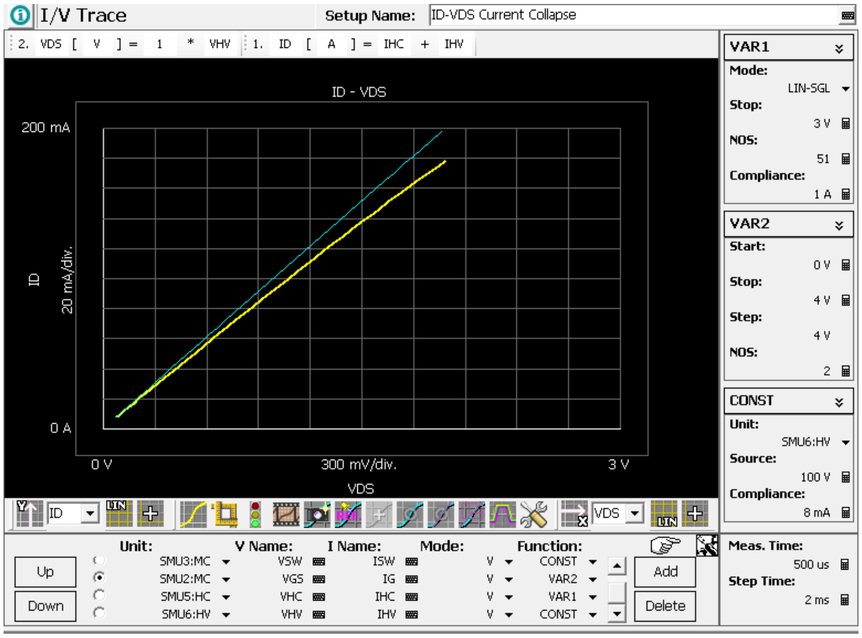
Meas. Time: 500 us
Step Time: 1 ms

6-4. ID-VDS Current Collapse

[Description]

The Id-Vds curve is measured after applying off-state stress bias voltage using N1267A. This preset is similar to the “GaN FET Id-Vds Current Collapse” application test (Please refer to section 5-6). The measurement sequence is implemented by turning on / off the device under test (DUT) by applying the gate bias as a secondary sweep value (VAR2).

Note: This setup is only useful for the DUT of which drain current is over 8 mA, because the discharge switch of the N1267A cannot be switched synchronized with the gate bias. For the DUT whose drain current is smaller than 8 mA, the “Id-Vds Current Collapse” application test has to be used.



Setup Name: ID-VDS Current Collapse

2. VDS [V] = 1 * VHV
1. ID [A] = IHC + IHV

VAR1
Mode: LIN-SGL
Stop: 3 V
NOS: 51
Compliance: 1 A

VAR2
Start: 0 V
Stop: 4 V
Step: 4 V
NOS: 2

CONST
Unit: SMU6:HV
Source: 100 V
Compliance: 8 mA

Meas. Time: 500 us
Step Time: 2 ms

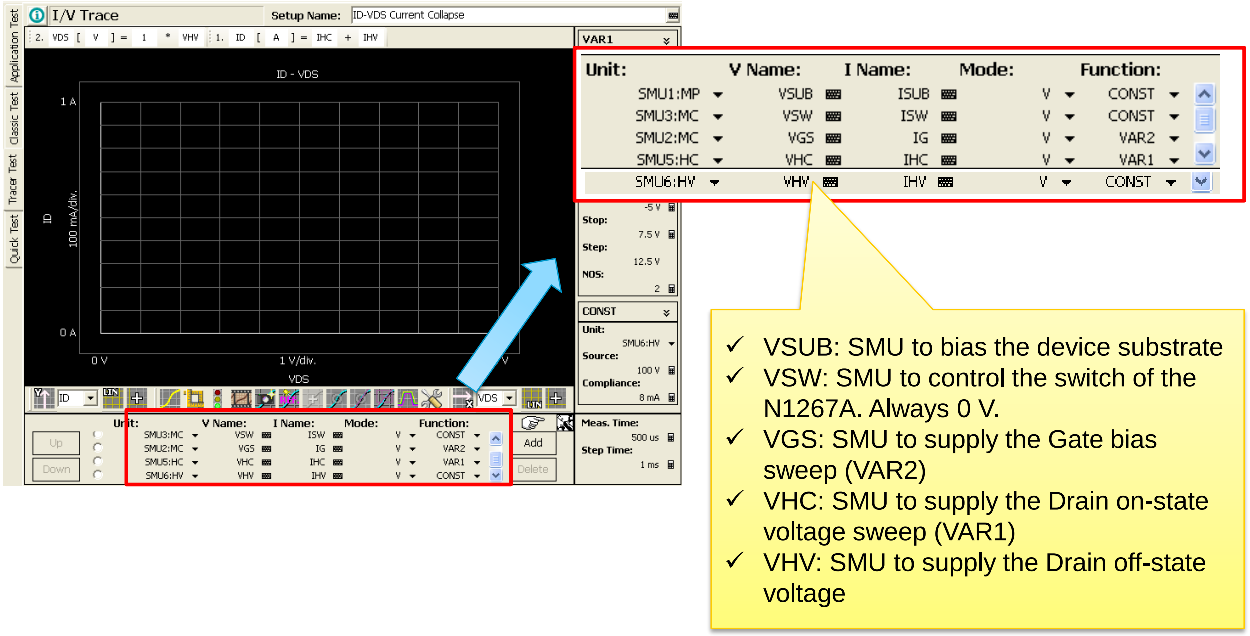
	Unit:	V Name:	I Name:	Mode:	Function:
○	SMU3:MC	VSW	ISW	V	CONST
●	SMU2:MC	VGS	IG	V	VAR2
○	SMU5:HC	VHC	IHC	V	VAR1
○	SMU6:HV	VHV	IHV	V	CONST

This setup measures the Id-Vds curve at the gate bias voltage specified as the Stop voltage of the VAR2 parameter. The Start voltage of the VAR2 sweep is the gate voltage to make FET turned off. Off-state stress voltage is specified as the Source voltage of the HVSMU.

At first, the Id-Vds curve without an off-state stress voltage is measured as a reference. This reference has to be measured by clicking the “Measure” button only once (single measurement). In this case, the Source voltage of the HVSMU is set at least 1 V larger than the Stop voltage of the drain voltage sweep (VAR1) to make the diode switch in the N1267A reverse-biased during the off-state of the DUT.

After saving the measured Id-Vds curve as a reference by clicking the capture button, change the off-state stress voltage and measure Id-Vds again to compare both curves. If the updated drain current becomes lower than the previous one, it shows that the current collapse phenomenon exists.

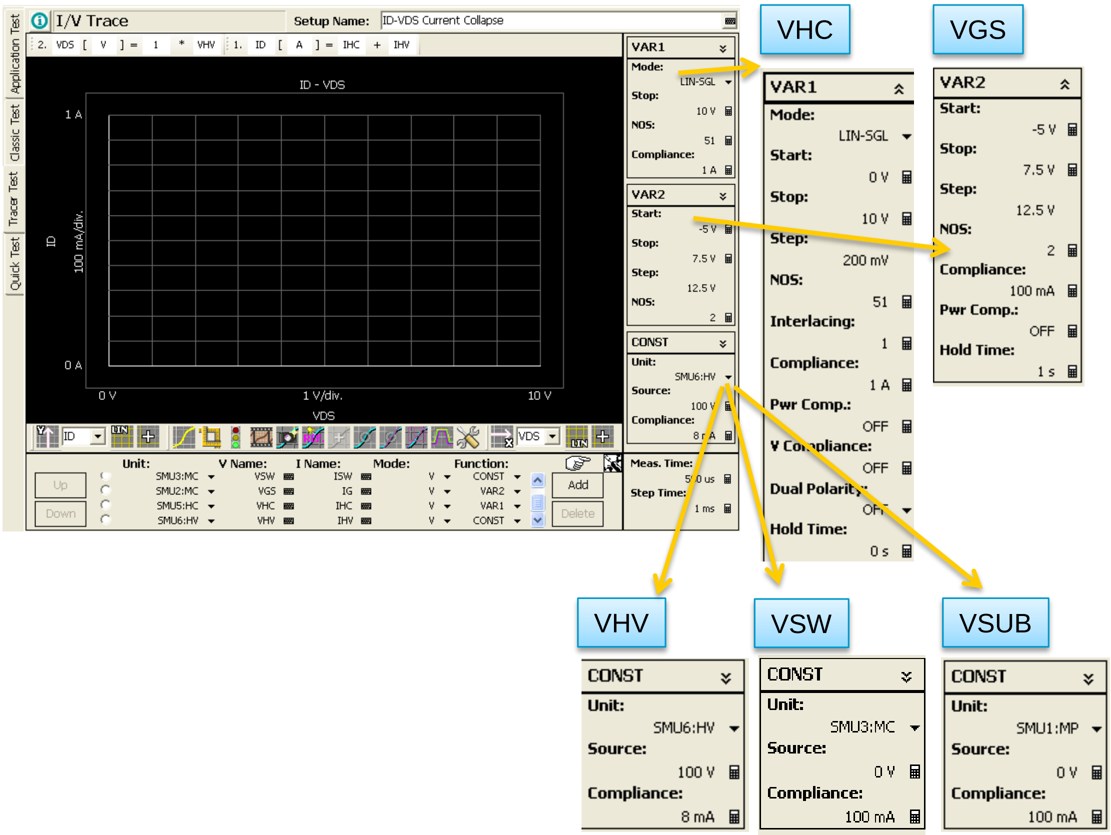
[Channel Assignment]



Unit:	V Name:	I Name:	Mode:	Function:
SMU1:MP	VSUB	ISUB	V	CONST
SMU3:MC	VSW	ISW	V	CONST
SMU2:MC	VGS	IG	V	VAR2
SMU5:HC	VHC	IHC	V	VAR1
SMU6:HV	VHV	IHV	V	CONST

- ✓ VSUB: SMU to bias the device substrate
- ✓ VSW: SMU to control the switch of the N1267A. Always 0 V.
- ✓ VGS: SMU to supply the Gate bias sweep (VAR2)
- ✓ VHC: SMU to supply the Drain on-state voltage sweep (VAR1)
- ✓ VHV: SMU to supply the Drain off-state voltage

[Measurement Parameters]



VHC

VAR1
Mode: LIN-SGL
Start: 0 V
Stop: 10 V
Step: 200 mV
NOS: 51
Interlacing: 1
Compliance: 1 A
Pwr Comp.: OFF
V Compliance: OFF
Dual Polarity: OFF
Hold Time: 0 s

VGS

VAR2
Start: -5 V
Stop: 7.5 V
Step: 12.5 V
NOS: 2
Compliance: 100 mA
Pwr Comp.: OFF
Hold Time: 1 s

VHV

CONST
Unit: SMU6:HV
Source: 100 V
Compliance: 8 mA

VSW

CONST
Unit: SMU3:MC
Source: 0 V
Compliance: 100 mA

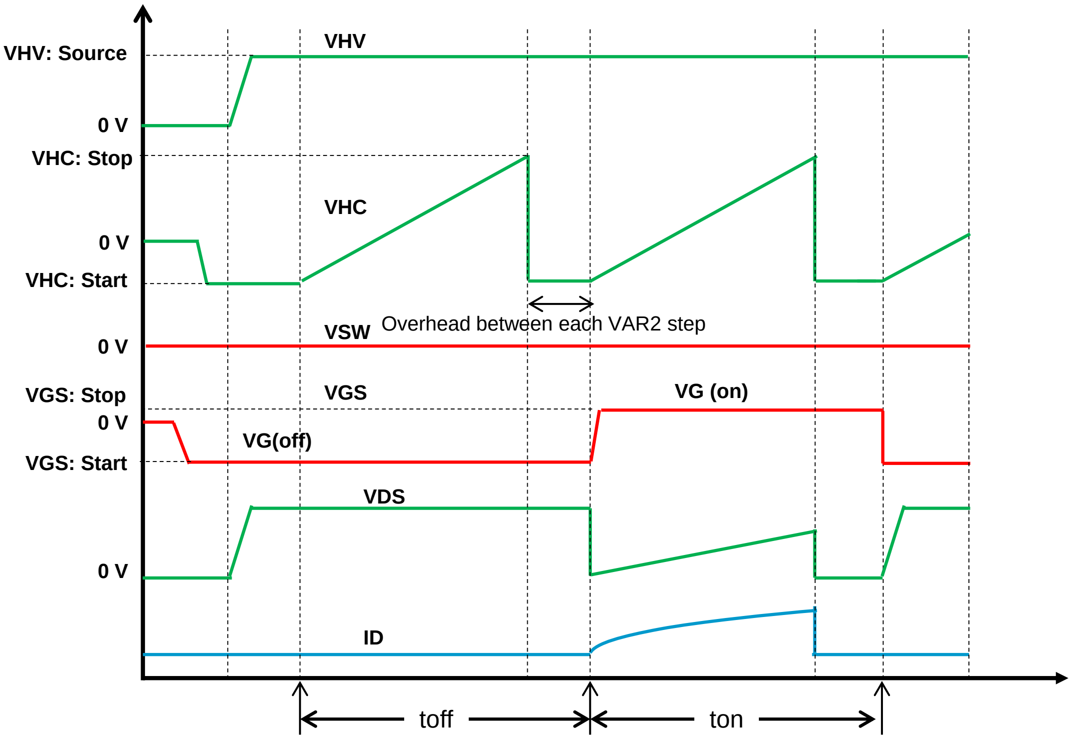
VSUB

CONST
Unit: SMU1:MP
Source: 0 V
Compliance: 100 mA

- VHV: Specify the off-state stress voltage as the Source voltage of the HVSMU (VHV). It should be at least 1 V higher than the Stop voltage of the HCSMU VAR1 sweep (VHC).
- VHC: Specify the Start and the Stop voltage to measure the Id-Vds curve at the on-state. The current compliance has to be larger than the expected amount of the drain current.
- VGS: Specify the Start voltage as the gate voltage which makes the DUT turned off. The Stop voltage is the gate voltage which makes the DUT turned on.
- VSW: Do not change it from the initial value.
- VSUB: Specify the Source voltage if want to add bias to the substrate of device.

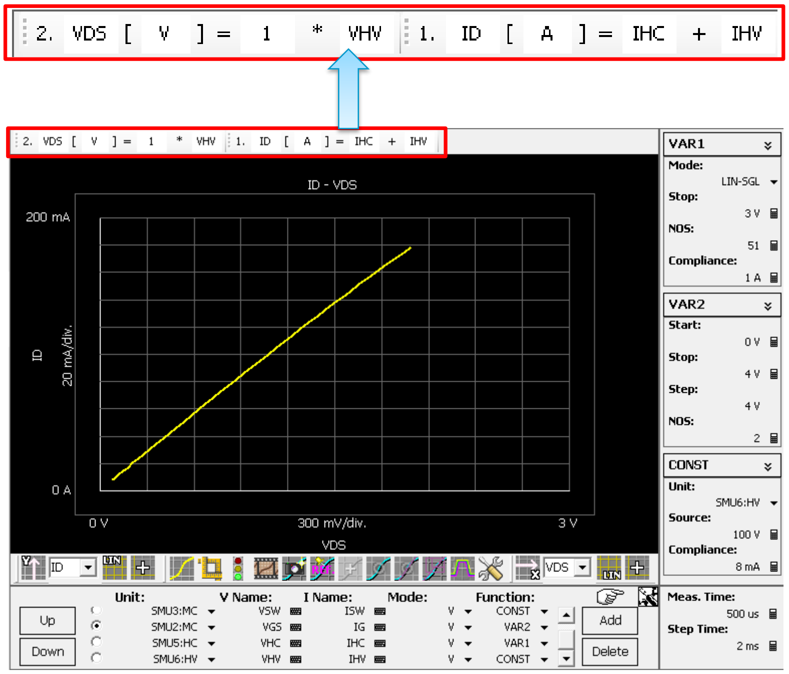
To increase the maximum current, use the “VPULSE” mode instead of the “V” mode for the HCSMU to measure the on-current. In the “VPULSE” mode, the maximum current of the HCMSU is extended to 20 A from 1 A in the “V” mode. The “VGS” has to be kept in “V” mode to keep the DUT turned on during the pulsed Id-Vds measurement.

[**Pulse Timing Chart]**



[Output Parameters]

The measured drain current (ID) versus drain voltage (VDS) curve is displayed in the chart area. The drain current is a summation of current measured by the HCSMU and HVSMU. The drain voltage is monitored by the HVSMU. Those calculations are defined in the arithmetic operation function of the Tracer Test mode as described in figure below. The IHC and IHV are the measured current by the HCSMU and HVSMU.



2. VDS [V] = 1 * VHV

1. ID [A] = IHC + IHV

VAR1
Mode: LIN-SGL
Stop: 3 V
NOS: 51
Compliance: 1 A

VAR2
Start: 0 V
Stop: 4 V
Step: 4 V
NOS: 2

CONST
Unit: SMU6:HV
Source: 100 V
Compliance: 8 mA

Meas. Time: 500 us
Step Time: 2 ms

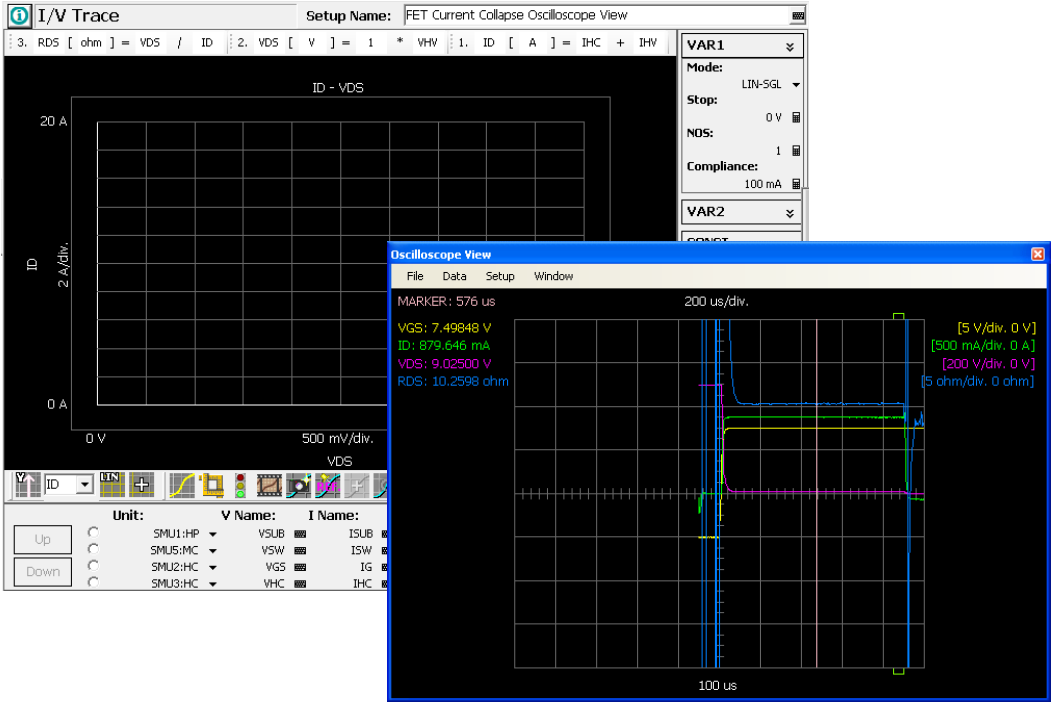
	Unit:	V Name:	I Name:	Mode:	Function:
○	SMU3:MC	VSW	ISW	V	CONST
●	SMU2:MC	VGS	IG	V	VAR2
○	SMU5:HC	VHC	IHC	V	VAR1
○	SMU6:HV	VHV	IHV	V	CONST

6-5. FET Current Collapse Oscilloscope View

[Description]

Transient behavior of the drain current or the on-resistance after switching from the off-state to the on-state is measured by using this preset. Operation of this preset is similar to the “FET Current Collapse Signal Monitor” application test (Please refer to section 5-3).
The key differences from the “FET Current Collapse Signal Monitor” are
-more flexibility
-higher timing resolution

Since bias and timing parameters of each SMU can be adjusted individually, it is possible to change the bias conditions more detailed than in the application test. Also, in the application test, the minimum sampling interval is rounded to 6 µs, the minimum sampling ratio of the HVSMU. In the Tracer Test, the minimum timing resolution of the HCMU and MCSMU are is their minimum resolution, 2 µs. The measured data by the HVSMU is divided into the 2 µs interval by interpolation.
This preset executes a single spot measurement and captures the voltage and current waveform at a transient from the off-state stress state to the on-state by using the Oscilloscope View function.



Setup Name: FET Current Collapse Oscilloscope View

3. RDS [ohm] = VDS / ID
2. VDS [V] = 1 * VHV
1. ID [A] = IHC + IHV

VAR1
Mode: LIN-SGL
Stop: 0 V
NOS: 1
Compliance: 100 mA

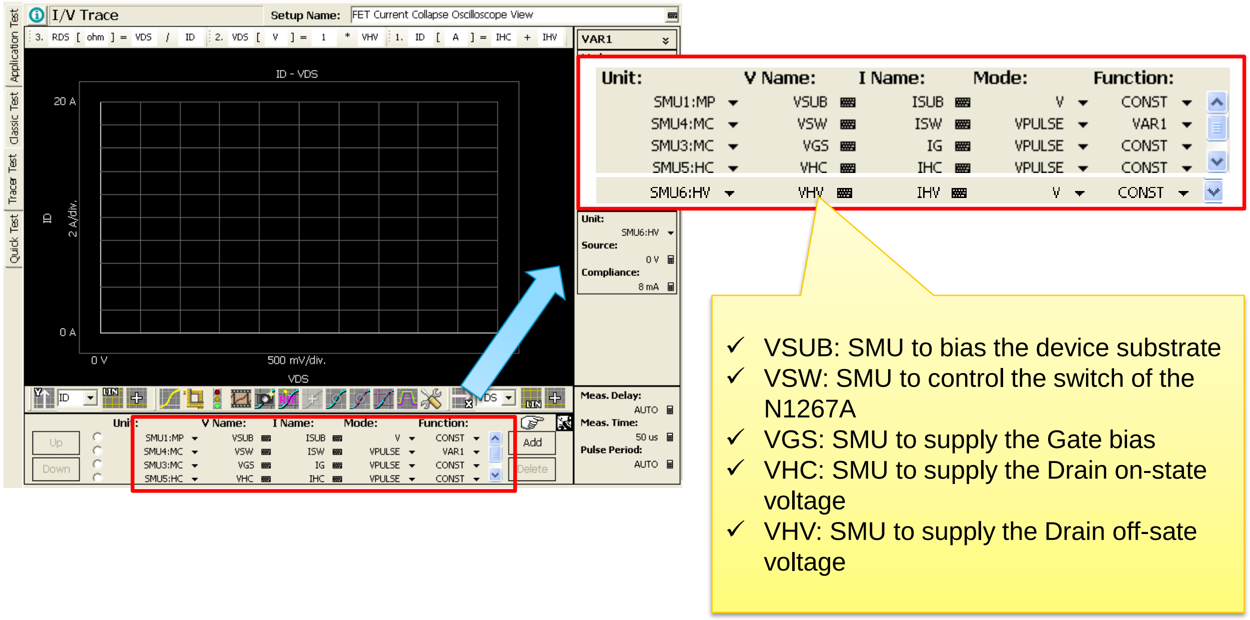
VAR2

Unit:	V Name:	I Name:
SMU1:HP	VSUB	ISUB
SMU5:MC	VSW	ISW
SMU2:HC	VGS	IG
SMU3:HC	VHC	IHC

MARKER: 576 us
VGS: 7.49848 V
ID: 879.646 mA
VDS: 9.02500 V
RDS: 10.2598 ohm

[5 V/div. 0 V]
[500 mA/div. 0 A]
[200 V/div. 0 V]
[5 ohm/div. 0 ohm]

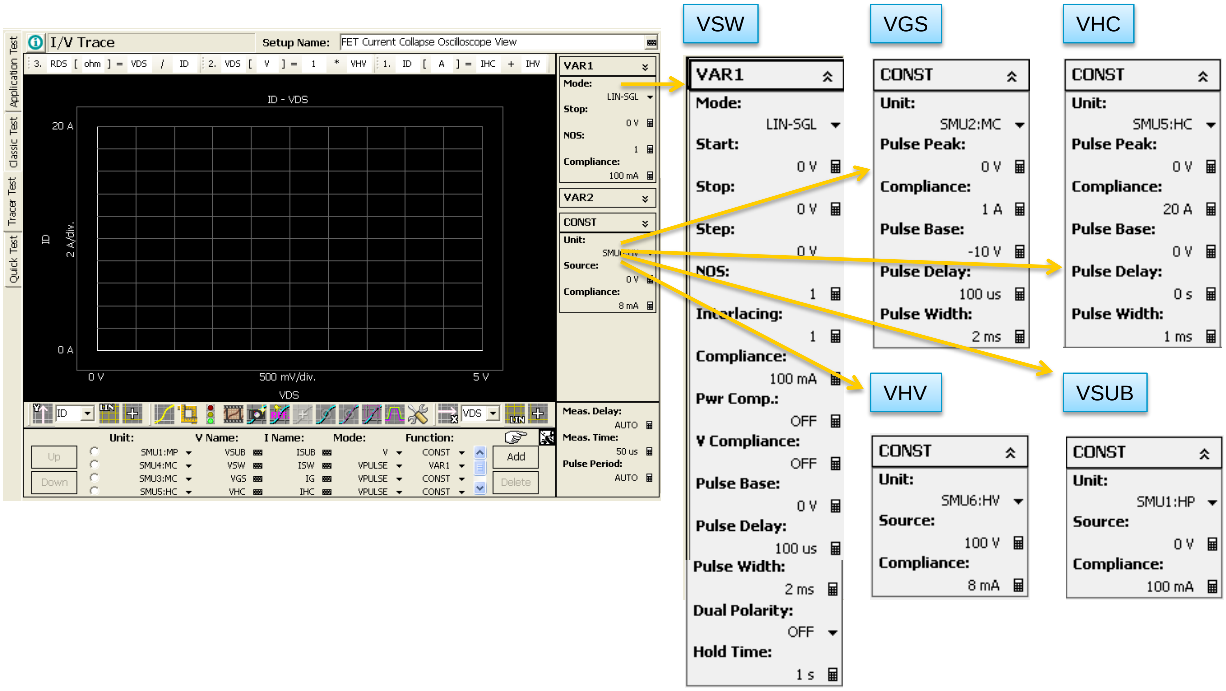
[Channel Assignment]



Unit:	V Name:	I Name:	Mode:	Function:
SMU1:MP	VSUB	ISUB	V	CONST
SMU4:MC	VSW	ISW	VPULSE	VAR1
SMU3:MC	VGS	IG	VPULSE	CONST
SMU5:HC	VHC	IHC	VPULSE	CONST
SMU6:HV	VHV	IHV	V	CONST

- ✓ VSUB: SMU to bias the device substrate
- ✓ VSW: SMU to control the switch of the N1267A
- ✓ VGS: SMU to supply the Gate bias
- ✓ VHC: SMU to supply the Drain on-state voltage
- ✓ VHV: SMU to supply the Drain off-sate voltage

[Measurement Parameters]



VSW

VAR1
Mode: LIN-SGL
Start: 0 V
Stop: 0 V
Step: 0 V
NOS: 1
Interlacing: 1
Compliance: 100 mA
Pwr Comp.: OFF
V Compliance: OFF
Pulse Base: 0 V
Pulse Delay: 100 us
Pulse Width: 2 ms
Dual Polarity: OFF
Hold Time: 1 s

VGS

CONST
Unit: SMU2:MC
Pulse Peak: 0 V
Compliance: 1 A
Pulse Base: -10 V
Pulse Delay: 100 us
Pulse Width: 2 ms

VHC

CONST
Unit: SMU5:HC
Pulse Peak: 0 V
Compliance: 20 A
Pulse Base: 0 V
Pulse Delay: 0 s
Pulse Width: 1 ms

VHV

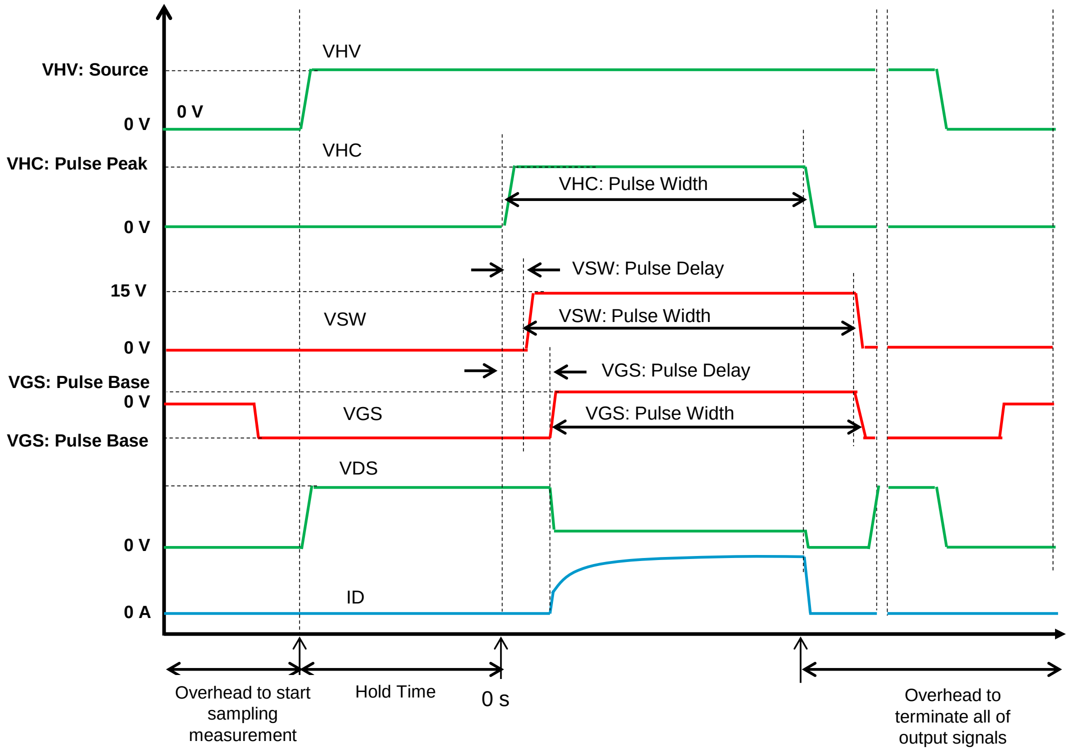
CONST
Unit: SMU6:HV
Source: 100 V
Compliance: 8 mA

VSUB

CONST
Unit: SMU1:HP
Source: 0 V
Compliance: 100 mA

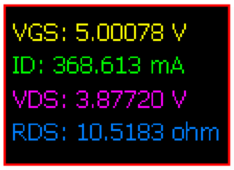
- VHV: Specify the off-state stress voltage as the Source voltage of the HVSMU. It should be at least 1 V higher than the Pulse Peak voltage of the VHC.
- VHC: Specify the voltage to measure the on-state current as the Pulse Peak voltage.
  The current compliance has to be larger than the expected drain current. For fast response, 1 A or larger current compliance is recommended.
  The Pulse delay is set as 0 s and it is used as a timing reference.
  The Pulse Width is specified as the duration to monitor the drain current waveform. If current compliance is larger than 1 A, the maximum pulse width is 1 ms. For the current compliance equal to or lower than 1 A, it is 24 ms. It is the maximum duration to be able to monitor by the Oscilloscope View.
- VGS: Specify the Pulse Peak voltage as the gate voltage to make the DUT turned on. The Pulse Base voltage is the gate voltage to make the device turned off.
  The current compliance has to be larger than100 mA to make the rising time of the gate pulse fast enough.
  The Pulse Delay is specified to start output of the HCSMU prior to the gate voltage. Initial delay time is 100 μs.
  The Pulse Width of the gate voltage pulse should be longer than the sum of the pulse width of the VHC and the pulse delay of the VGS. Its initial value is 2 ms.
- VSW: Specify the Start voltage as 0 V if the discharge switch of the N1267A is turned off. To make it turned on, specify 15 V.
  The Pulse Delay is specified to start output of the HCSMU prior to turning on the discharge switch. If it is necessary to discharge the cabling prior to turning on the DUT, specify a shorter delay time than the delay time of the VGS.
  The Pulse Width is specified to make the total duration of the pulse peak as identical with the pulse peak of the VGS to make the discharge switch turned off at the same time with the end of the peak voltage of the VGS.
  The Hold Time is used to adjust the duration of the off-state stress.
- VSUB: Specify the Source voltage, if you want to add a bias to the substrate of the device.

[Pulse Timing Chart]

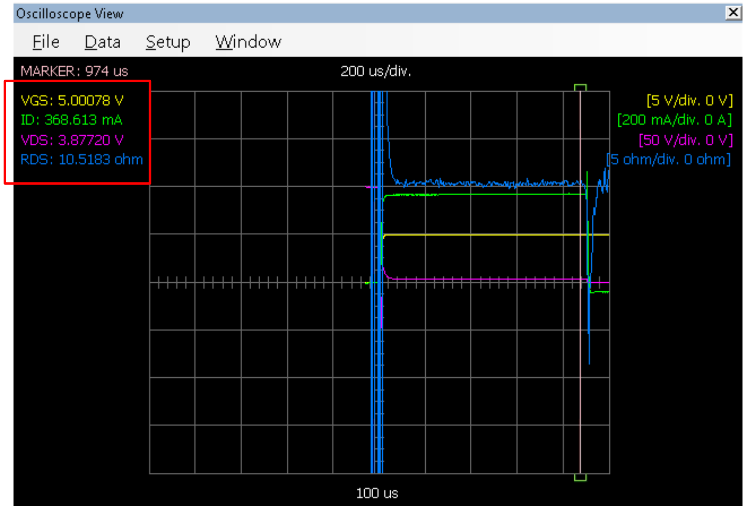


[Output Parameters]

Initially, the waveforms of VGS, ID, VDS and RDS are displayed.

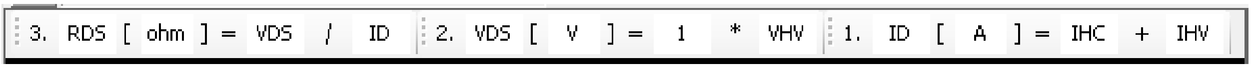


VGS: 5.00078 V
ID: 368.613 mA
VDS: 3.87720 V
RDS: 10.5183 ohm



MARKER: 974 us
200 us/div.
VGS: 5.00078 V
ID: 368.613 mA
VDS: 3.87720 V
RDS: 10.5183 ohm
[5 V/div. 0 V]
[200 mA/div. 0 A]
[50 V/div. 0 V]
[5 ohm/div. 0 ohm]
100 us

The ID is a combination of current measured by the HCSMU and HVSMU. The VDS is a measured voltage by the HVSMU. RDS is calculated from the measured VDS and ID.

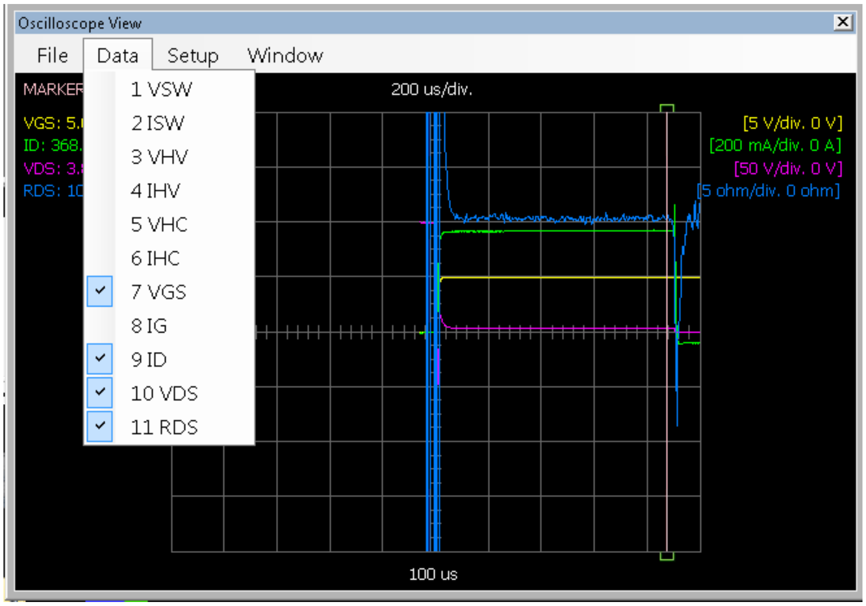


3. RDS [ohm] = VDS / ID

2. VDS [V] = 1 * VHV

1. ID [A] = IHC + IHV

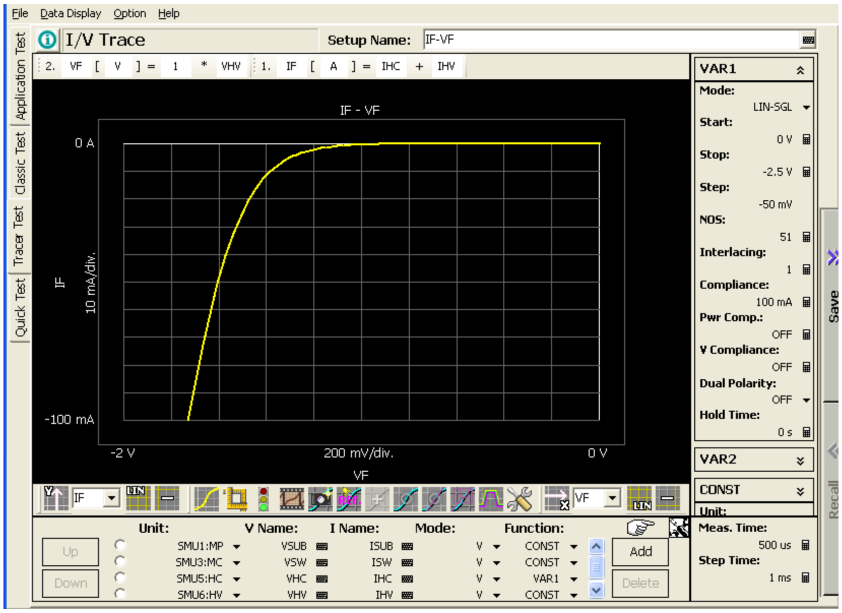
If you want to see the waveform of each module, it is possible to add it by selecting from the “Data” menu of the Oscilloscope view.



6-6. IF-VF

[Description]

This setup is used to check the forward characteristics of the diode while connecting it to the N1267A.



Setup Name: IF-VF

2. VF [V] = 1 * VHV 1. IF [A] = IHC + IHV

VAR1
Mode: LIN-SGL
Start: 0 V
Stop: -2.5 V
Step: -50 mV
NOS: 51
Interlacing: 1
Compliance: 100 mA
Pwr Comp.: OFF
V Compliance: OFF
Dual Polarity: OFF
Hold Time: 0 s

VAR2

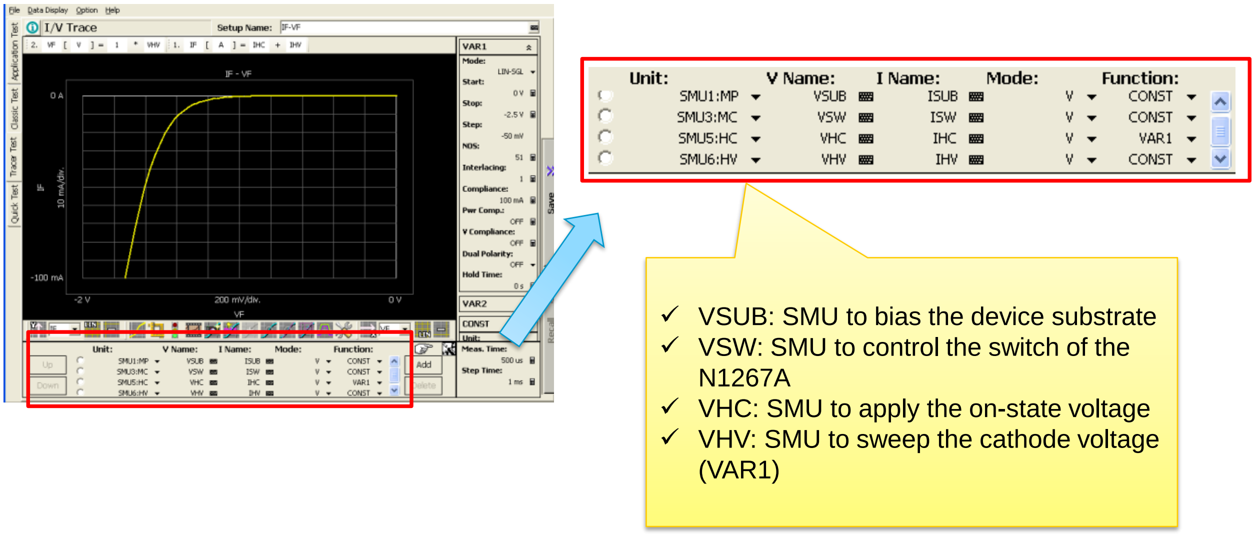
CONST

Meas. Time: 500 us
Step Time: 1 ms

Unit:	V Name:	I Name:	Mode:	Function:
SMU1:MP	VSUB	ISUB	V	CONST
SMU3:MC	VSW	ISW	V	CONST
SMU5:HC	VHC	IHC	V	VAR1
SMU6:HV	VHV	IHV	V	CONST

To use this preset, you have to specify the following parameters.

[Channel Assignment]



Unit:	V Name:	I Name:	Mode:	Function:
SMU1:MP	VSUB	ISUB	V	CONST
SMU3:MC	VSW	ISW	V	CONST
SMU5:HC	VHC	IHC	V	VAR1
SMU6:HV	VHV	IHV	V	CONST

- ✓ VSUB: SMU to bias the device substrate
- ✓ VSW: SMU to control the switch of the N1267A
- ✓ VHC: SMU to apply the on-state voltage
- ✓ VHV: SMU to sweep the cathode voltage (VAR1)

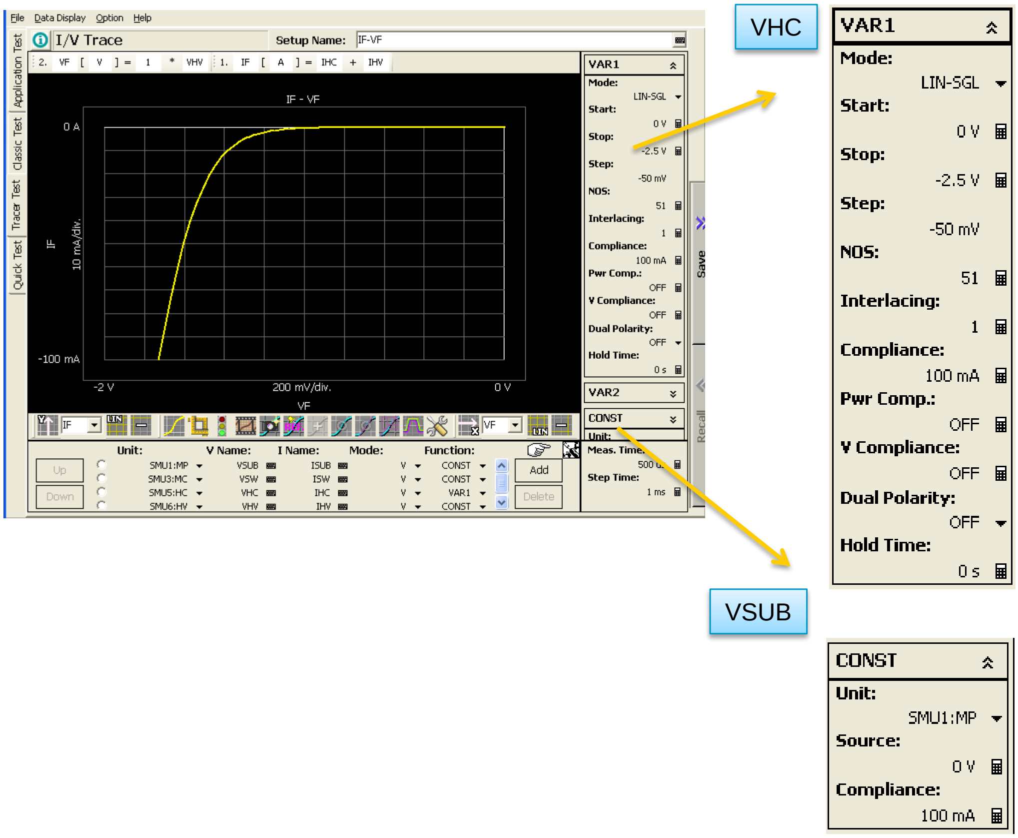
[Measurement Parameters]

Specify the VHC sweep (VAR1) in negative direction for the IF-VF (the HCSMU is connected to the cathode of diode in this case).

The VHV and VSW are not necessary to be changed.

Change the VSUB if you want to add a bias to the substrate of the device.

When using the N1267A, since the cathode of the diode is connected to the outputs of SMU, negative bias sweep is applied to measure the IF-VF characteristics.



Setup Name: IF-VF

2. VF [V] = 1 * VHV

1. IF [A] = IHC + IHV

Unit:	V Name:	I Name:	Mode:	Function:
SMU1:MP	VSUB	ISUB	V	CONST
SMU3:MC	VSW	ISW	V	CONST
SMU5:HC	VHC	IHC	V	VAR1
SMU6:HV	VHV	IHV	V	CONST

Meas. Time: 500 u

Step Time: 1 ms

VAR1

Mode: LIN-SGL

Start: 0 V

Stop: -2.5 V

Step: -50 mV

NOS: 51

Interlacing: 1

Compliance: 100 mA

Pwr Comp.: OFF

V Compliance: OFF

Dual Polarity: OFF

Hold Time: 0 s

CONST

Unit: SMU1:MP

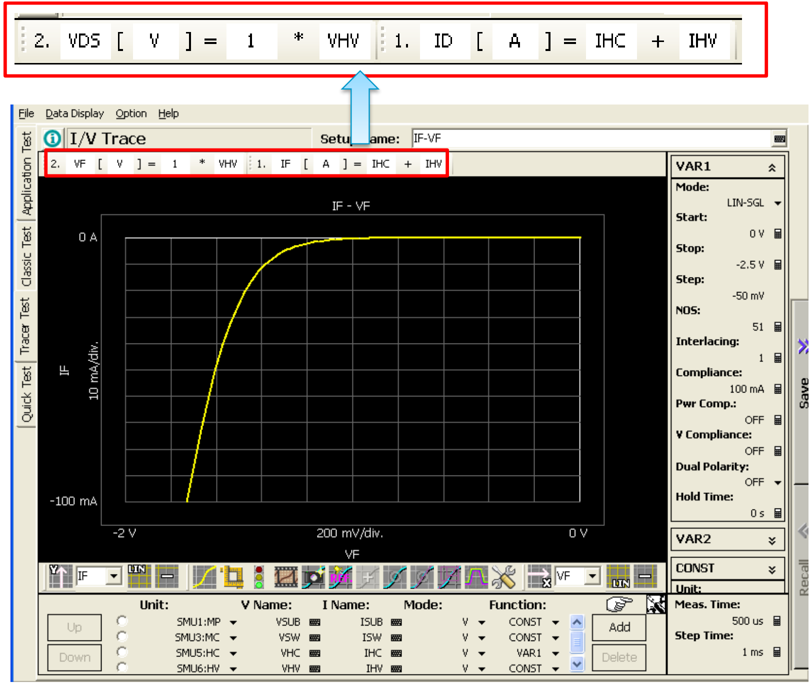
Source: 0 V

Compliance: 100 mA

[Output Parameters]

The measured forward current (IF) versus forward voltage (VF) curve is displayed in the chart area. The forward current is a summation of current measured by the HCSMU and HVSMU. The forward voltage is monitored by the HVSMU. Those calculations are defined in the arithmetic operation function of the Tracer Test mode as described in figure below. The IHC and IHV are the measured current by the HCSMU and HVSMU.

Since the cathode of the diode is connected to the output of SMUs, the measured forward current has a negative value as shown in figure below.



2. VDS [V] = 1 * VHV
1. ID [A] = IHC + IHV

2. VF [V] = 1 * VHV
1. IF [A] = IHC + IHV

Setup Name: IF-VF

Unit:	V Name:	I Name:	Mode:	Function:
SMU1:MP	VSUB	ISUB	V	CONST
SMU3:MC	VSW	ISW	V	CONST
SMU5:HC	VHC	IHC	V	VAR1
SMU6:HV	VHV	IHV	V	CONST

VAR1
Mode: LIN-SGL
Start: 0 V
Stop: -2.5 V
Step: -50 mV
NOS: 51
Interlacing: 1
Compliance: 100 mA
Pwr Comp.: OFF
V Compliance: OFF
Dual Polarity: OFF
Hold Time: 0 s

VAR2

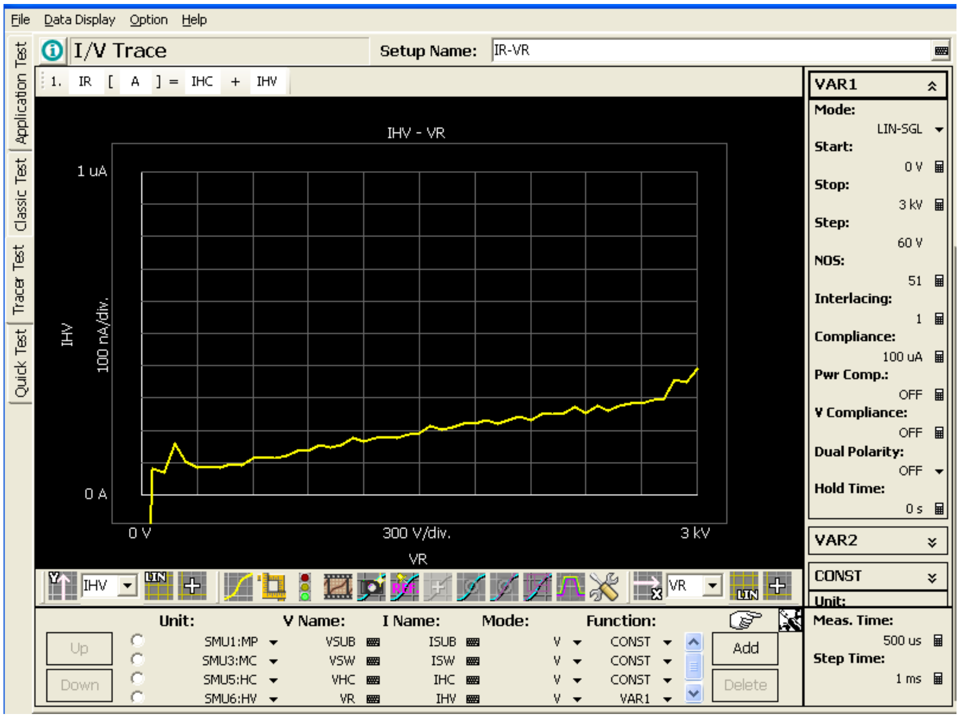
CONST

Meas. Time: 500 us
Step Time: 1 ms

6-7. IR-VR

[Description]

This setup is used to check the reverse leakage current of diode while connecting the DUT to the N1267A.



Setup Name: IR-VR

1. IR [A] = IHC + IHV

VAR1

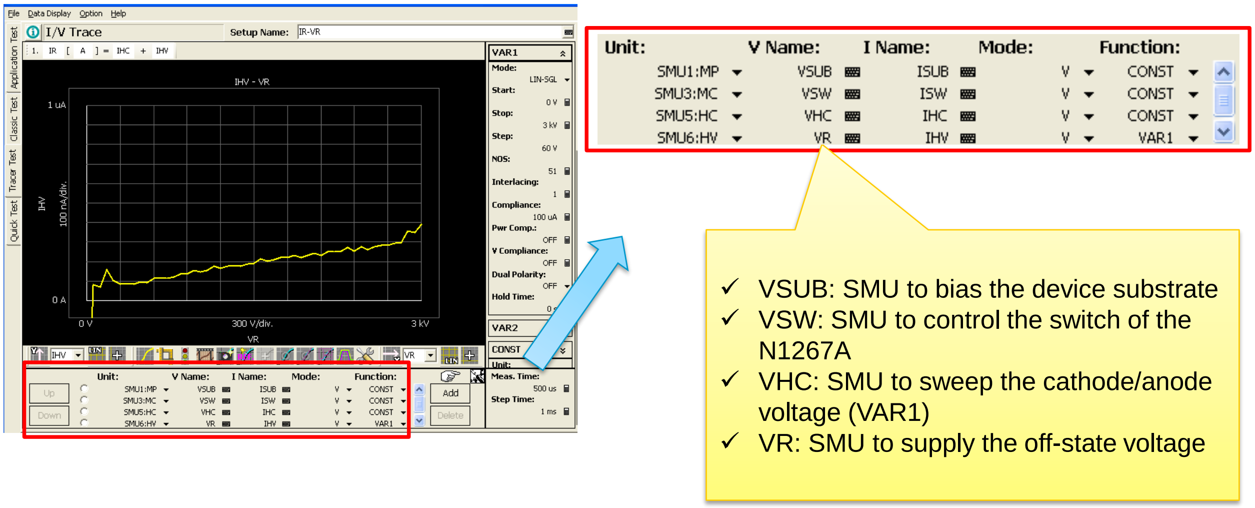
Mode: LIN-SGL
Start: 0 V
Stop: 3 kV
Step: 60 V
NOS: 51
Interlacing: 1
Compliance: 100 uA
Pwr Comp.: OFF
V Compliance: OFF
Dual Polarity: OFF
Hold Time: 0 s

Meas. Time: 500 us
Step Time: 1 ms

Unit:	V Name:	I Name:	Mode:	Function:
SMU1:MP	VSUB	ISUB	V	CONST
SMU3:MC	VSW	ISW	V	CONST
SMU5:HC	VHC	IHC	V	CONST
SMU6:HV	VR	IHV	V	VAR1

To use this preset, you have to specify the following parameters.

[Channel Assignment]



Unit:	V Name:	I Name:	Mode:	Function:
SMU1:MP	VSUB	ISUB	V	CONST
SMU3:MC	VSW	ISW	V	CONST
SMU5:HC	VHC	IHC	V	CONST
SMU6:HV	VR	IHV	V	VAR1

- ✓ VSUB: SMU to bias the device substrate
- ✓ VSW: SMU to control the switch of the N1267A
- ✓ VHC: SMU to sweep the cathode/anode voltage (VAR1)
- ✓ VR: SMU to supply the off-state voltage

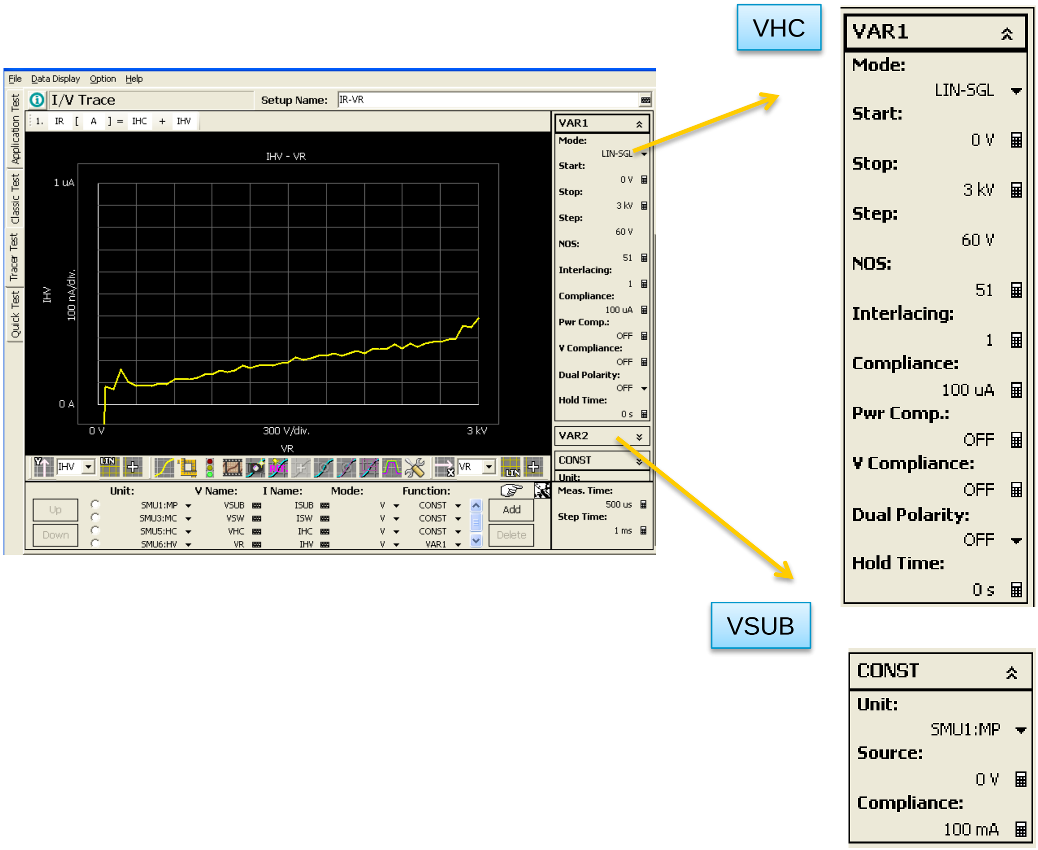
[Measurement Parameters]

Specify the VR sweep (VAR1) in positive direction for the IR-VR (the HCSMU is connected to the cathode of diode in this case).

The VHC and VSW are not necessary to be changed.

Change the VSUB if you want to add a bias to the substrate of the device.

When using the N1267A, since the cathode of the diode is connected to the outputs of SMU, a positive bias sweep is applied to measure the IR-VR characteristics.



Setup Name: IR-VR

Unit:	V Name:	I Name:	Mode:	Function:
SMU1:MP	VSUB	ISUB	V	CONST
SMU3:MC	VSW	ISW	V	CONST
SMU5:HC	VHC	IHC	V	CONST
SMU6:HV	VR	IHV	V	VAR1

Meas. Time: 500 us

Step Time: 1 ms

VAR1

Mode: LIN-SGL

Start: 0 V

Stop: 3 kV

Step: 60 V

NOS: 51

Interlacing: 1

Compliance: 100 uA

Pwr Comp.: OFF

V Compliance: OFF

Dual Polarity: OFF

Hold Time: 0 s

CONST

Unit: SMU1:MP

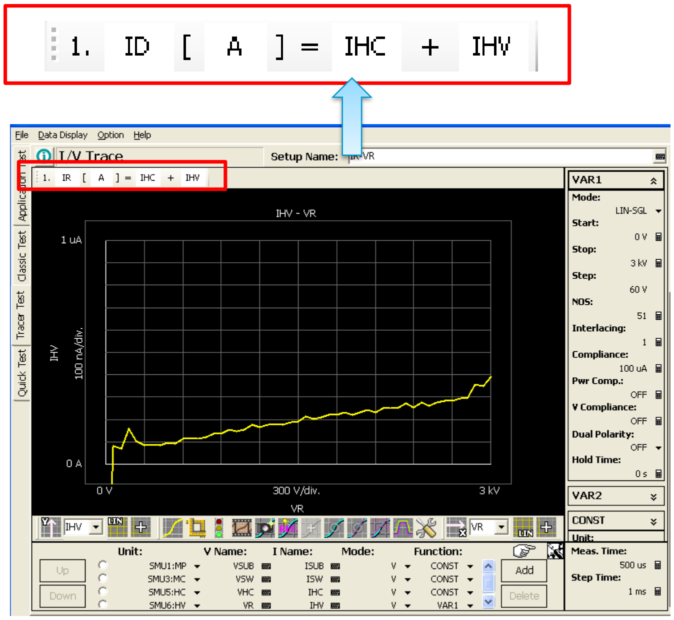
Source: 0 V

Compliance: 100 mA

[Output Parameters]

The measured reverse current (IR) versus reverse voltage (VR) curve is displayed in the chart area. The forward current is a summation of the current measured by the HCSMU and HVSMU. The forward voltage is monitored by the HVSMU. Those calculations are defined in the arithmetic operation function of the Tracer Test mode as described in figure below. The IHC and IHV are the measured current by the HCSMU and HVSMU.

Since the cathode of the diode is connected to the output of SMUs, the measured reverse current has a positive value as shown in figure below.



1. ID [A] = IHC + IHV

1. IR [A] = IHC + IHV

Setup Name: IR-VR

VAR1
Mode: LIN-SGL
Start: 0 V
Stop: 3 kV
Step: 60 V
NOS: 51
Interlacing: 1
Compliance: 100 uA
Pwr Comp.: OFF
V Compliance: OFF
Dual Polarity: OFF
Hold Time: 0 s

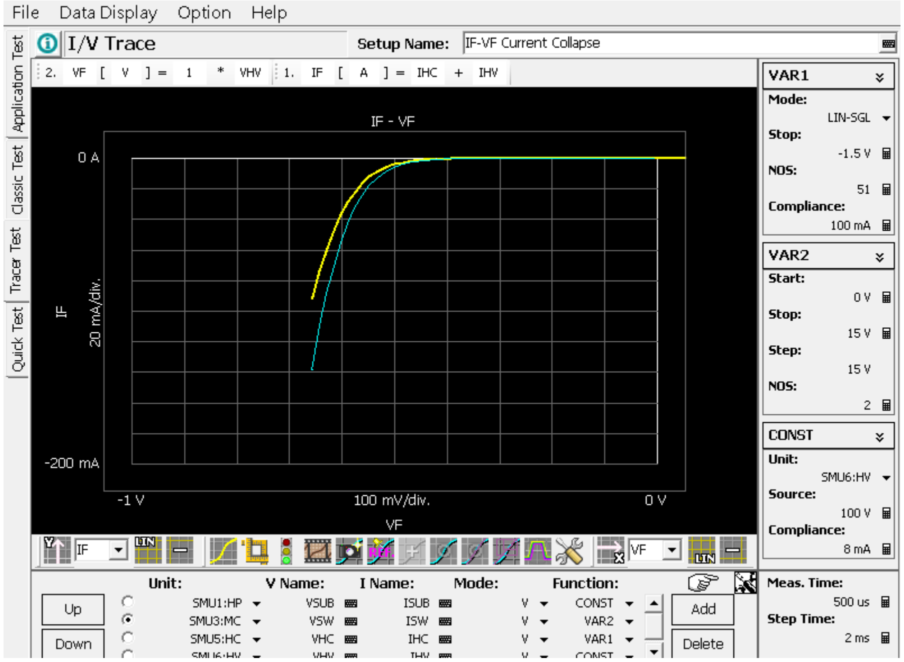
Unit:	V Name:	I Name:	Mode:	Function:
SMU1:MP	VSUB	ISUB	V	CONST
SMU3:MC	VSW	ISW	V	CONST
SMU5:HC	VHC	IHC	V	CONST
SMU6:HV	VR	IHV	V	VAR1

Meas. Time: 500 us
Step Time: 1 ms

6-8. IF-VF Current Collapse

[Description]

The IF-VF curve is measured after applying the off-state stress bias voltage using N1267A.



Setup Name: IF-VF Current Collapse

2. VF [V] = 1 * VHV

1. IF [A] = IHC + IHV

VAR1
Mode: LIN-SGL
Stop: -1.5 V
NOS: 51
Compliance: 100 mA

VAR2
Start: 0 V
Stop: 15 V
Step: 15 V
NOS: 2

CONST
Unit: SMU6:HV
Source: 100 V
Compliance: 8 mA

Meas. Time: 500 us
Step Time: 2 ms

	Unit:	V Name:	I Name:	Mode:	Function:
○	SMU1:HP	VSUB	ISUB	V	CONST
●	SMU3:MC	VSW	ISW	V	VAR2
○	SMU5:HC	VHC	IHC	V	VAR1
○	SMU6:HV	VHV	IHV	V	CONST

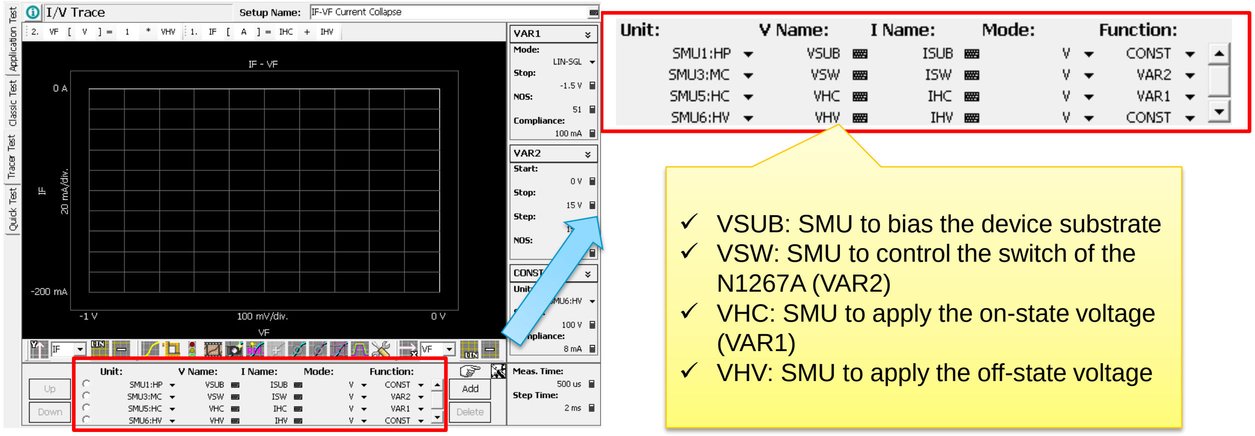
At first, the IF-VF curve without an off-state stress voltage is measured as a reference. This reference has to be measured by clicking the “Measure” button only once (single measurement). In this case, the Source voltage of the HVSMU is set at least 1 V larger than the Stop voltage of the drain voltage sweep (VAR1) to make the diode switch in the N1267A reverse-biased during the off-state of the DUT.

To make the diode switch off during the off-state, the cathode of the DUT is connected to the High port of the N1267A. And, the FET switch of the N1267A is turned on to measure the on-state current. It is controlled by the VAR2 sweep. The Start voltage of the VAR2 sweep is set to 0 V to make the FET switch turned off at the off-state, and the Stop voltage is set to 15 V to make it turned on at the on-state measurement.

Since the cathode of DUT is connected to the HVSMU and HCSMU, negative voltage is used as VAR1 sweep to measure the forward characteristics of the DUT, and measured current becomes negative, too.

After saving the measured IF-VF curve as a reference by clicking the capture button , change the off-state stress voltage and measure the IF-VF curve again to compare both curves. If the volume of the updated anode current becomes lower than the previous one, it shows that the current collapse phenomenon exists.

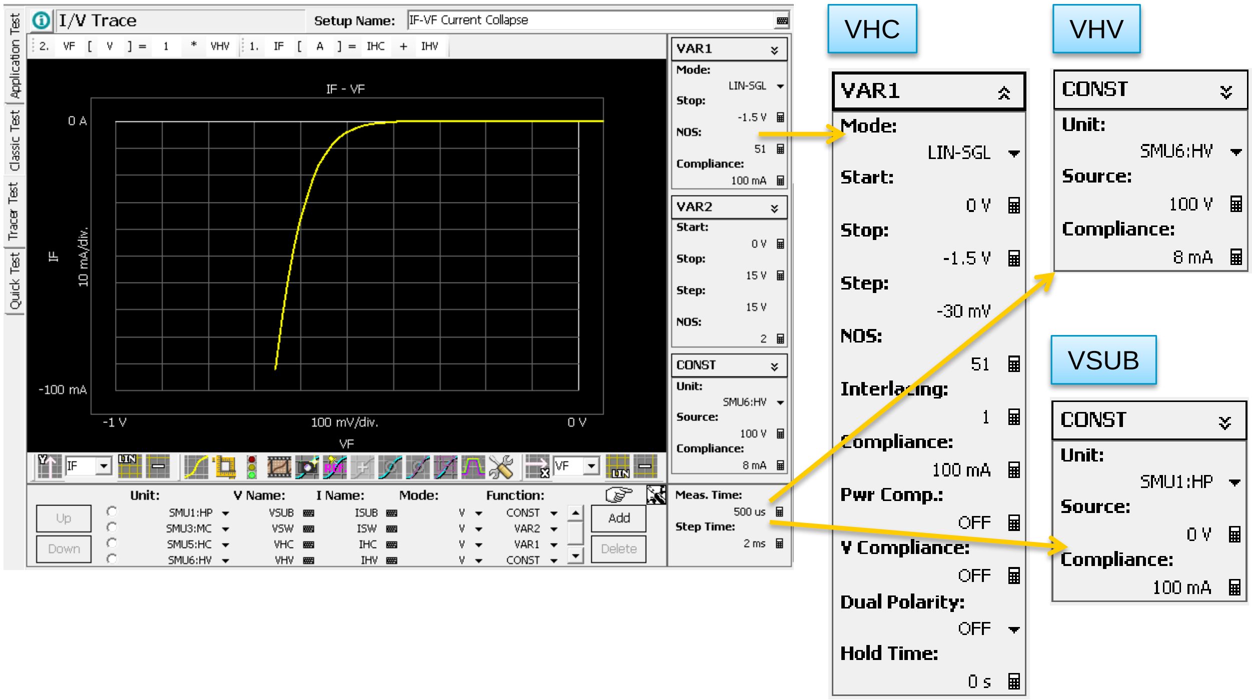
[Channel Assignment]



Unit:	V Name:	I Name:	Mode:	Function:
SMU1:HP	VSUB	ISUB	V	CONST
SMU3:MC	VSW	ISW	V	VAR2
SMU5:HC	VHC	IHC	V	VAR1
SMU6:HV	VHV	IHV	V	CONST

- ✓ VSUB: SMU to bias the device substrate
- ✓ VSW: SMU to control the switch of the N1267A (VAR2)
- ✓ VHC: SMU to apply the on-state voltage (VAR1)
- ✓ VHV: SMU to apply the off-state voltage

[Measurement Parameters]



VAR1
Mode: LIN-SGL
Start: 0 V
Stop: -1.5 V
Step: -30 mV
NOS: 51
Interlacing: 1
Compliance: 100 mA
Pwr Comp.: OFF
V Compliance: OFF
Dual Polarity: OFF
Hold Time: 0 s

VAR2
Start: 0 V
Stop: 15 V
Step: 15 V
NOS: 2

CONST (VHV)
Unit: SMU6:HV
Source: 100 V
Compliance: 8 mA

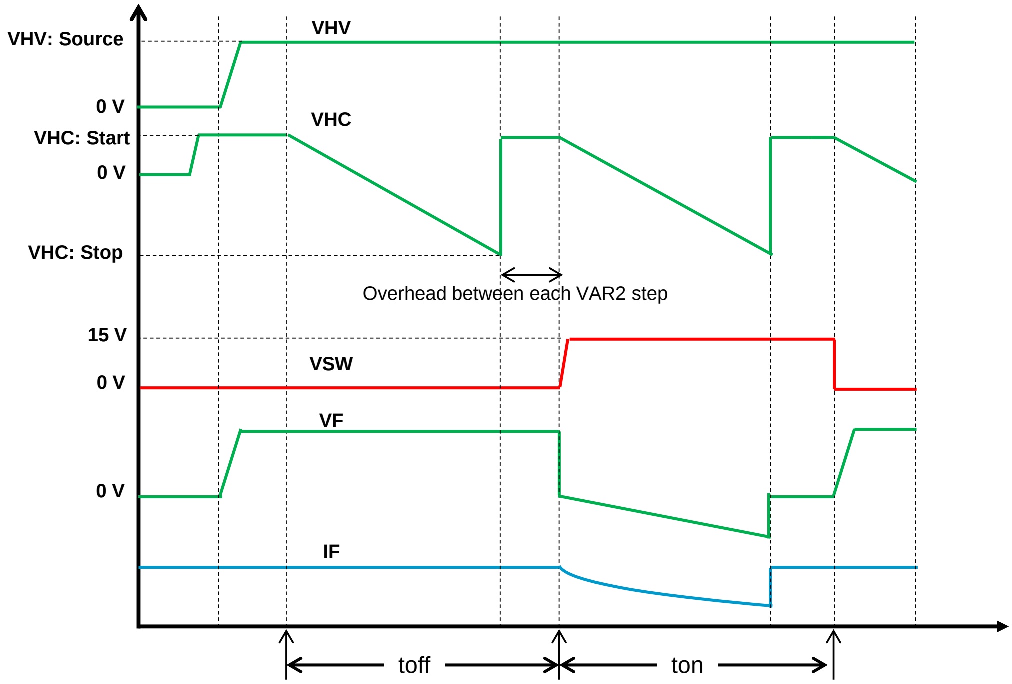
CONST (VSUB)
Unit: SMU1:HP
Source: 0 V
Compliance: 100 mA

Meas. Time: 500 us
Step Time: 2 ms

- VHV: Specify the off-state stress voltage as the Source voltage of the HVSMU (VHV). It should be at least 1 V higher than the stop voltage of the HCSMU VAR1 sweep (VHC).
- VHC: Specify the Start and the Stop voltage to measure the IF-VF curve at the on-state. The current compliance has to be larger than the expected amount of the drain current.
- VSW: Do not change it from the initial value.
- VSUB: Specify the Source voltage if you want to add a bias to the substrate of device.

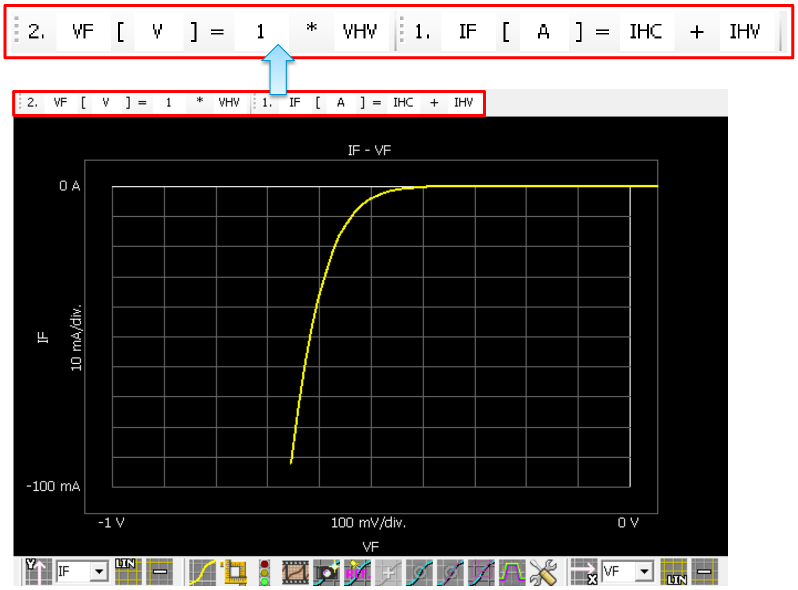
To increase the maximum current, use the “VPULSE” mode instead of the “V” mode for the HCSMU to measure the on-current. In the “VPULSE” mode, the maximum current of the HCMSU is extended to 20 A from 1 A in the “V” mode.

[Pulse Timing Chart]



[Output Parameters]

The measured drain current (IF) versus forward voltage (VF) curve is displayed in the chart area. The forward current is a summation of the current measured by the HCSMU and HVSMU. The forward voltage is monitored by the HVSMU. Those calculations are defined in the arithmetic operation function of the Tracer Test mode as described in figure below. The IHC and IHV are the measured current by the HCSMU and HVSMU.



2. VF [V] = 1 * VHV

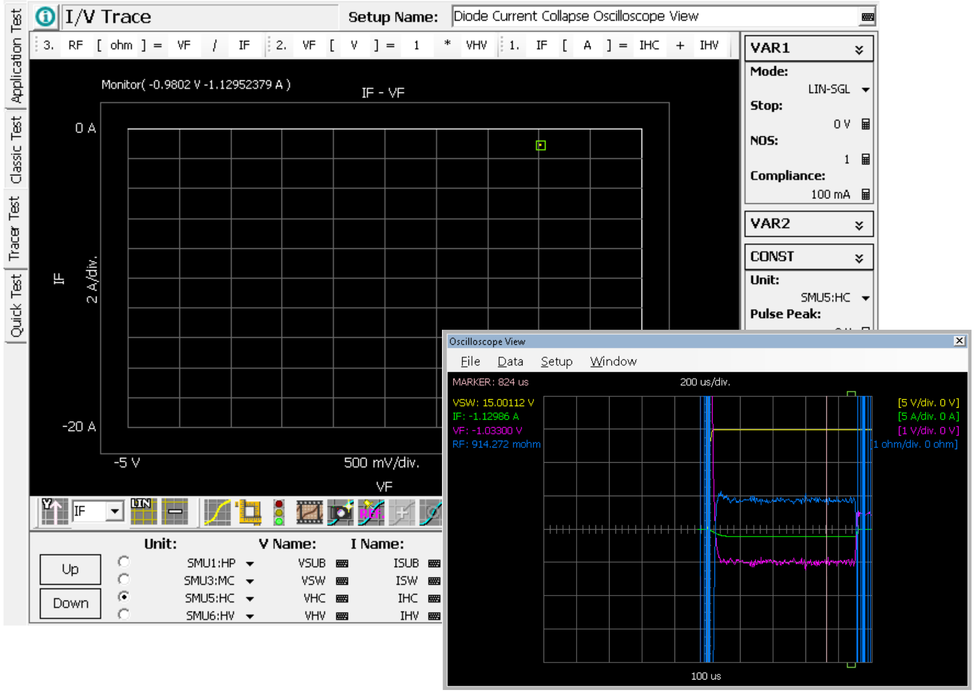
1. IF [A] = IHC + IHV

6-9. Diode Current Collapse Oscilloscope View

[Description]

The transient behavior of the forward current or the forward-resistance of the GaN diode after switching from the off-state to the on-state is measured by using this preset. The operation of this preset is similar to the “Diode Current Collapse Signal Monitor” application test (Please refer to section 5-7).
The key differences from the “Diode Current Collapse Signal Monitor” are
-more flexibility
-higher timing resolution

Since bias and timing parameters of each SMU can be adjusted individually, it is possible to change the bias conditions more detailed than in the application test. Also, in the application test, the minimum sampling interval is rounded to 6 μs, the minimum sampling ratio of the HVSMU. In the Tracer Test, the minimum timing resolutions of the HCMU and MCSMU are their minimum resolution, 2 μs. The measured data by HVSMU is divided into the 2-μs interval by interpolation.
This preset executes a single spot measurement and captures the voltage and current waveform at a transient from the off-state stress state to the on-state by using the Oscilloscope View function.



Setup Name: Diode Current Collapse Oscilloscope View

3. RF [ohm] = VF / IF
2. VF [V] = 1 * VHV
1. IF [A] = IHC + IHV

Monitor(-0.9802 V -1.12952379 A)

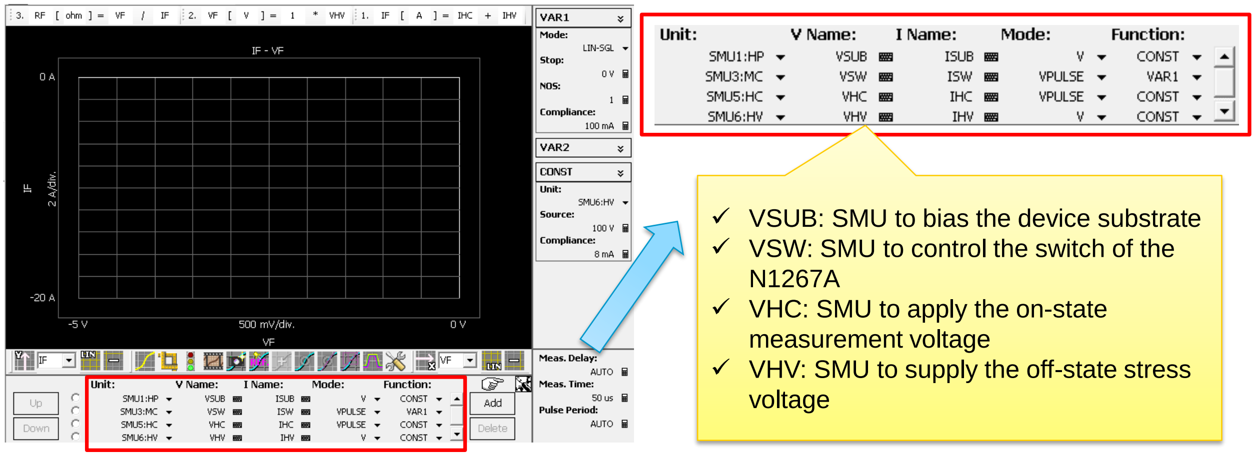
VAR1
Mode: LIN-SGL
Stop: 0 V
NOS: 1
Compliance: 100 mA

CONST
Unit: SMU5:HC

Unit:	V Name:	I Name:
○ SMU1:HP	VSUB	ISUB
○ SMU3:MC	VSW	ISW
● SMU5:HC	VHC	IHC
○ SMU6:HV	VHV	IHV

MARKER: 824 us
VSW: 15.00112 V
IF: -1.12986 A
VF: -1.03300 V
RF: 914.272 mohm

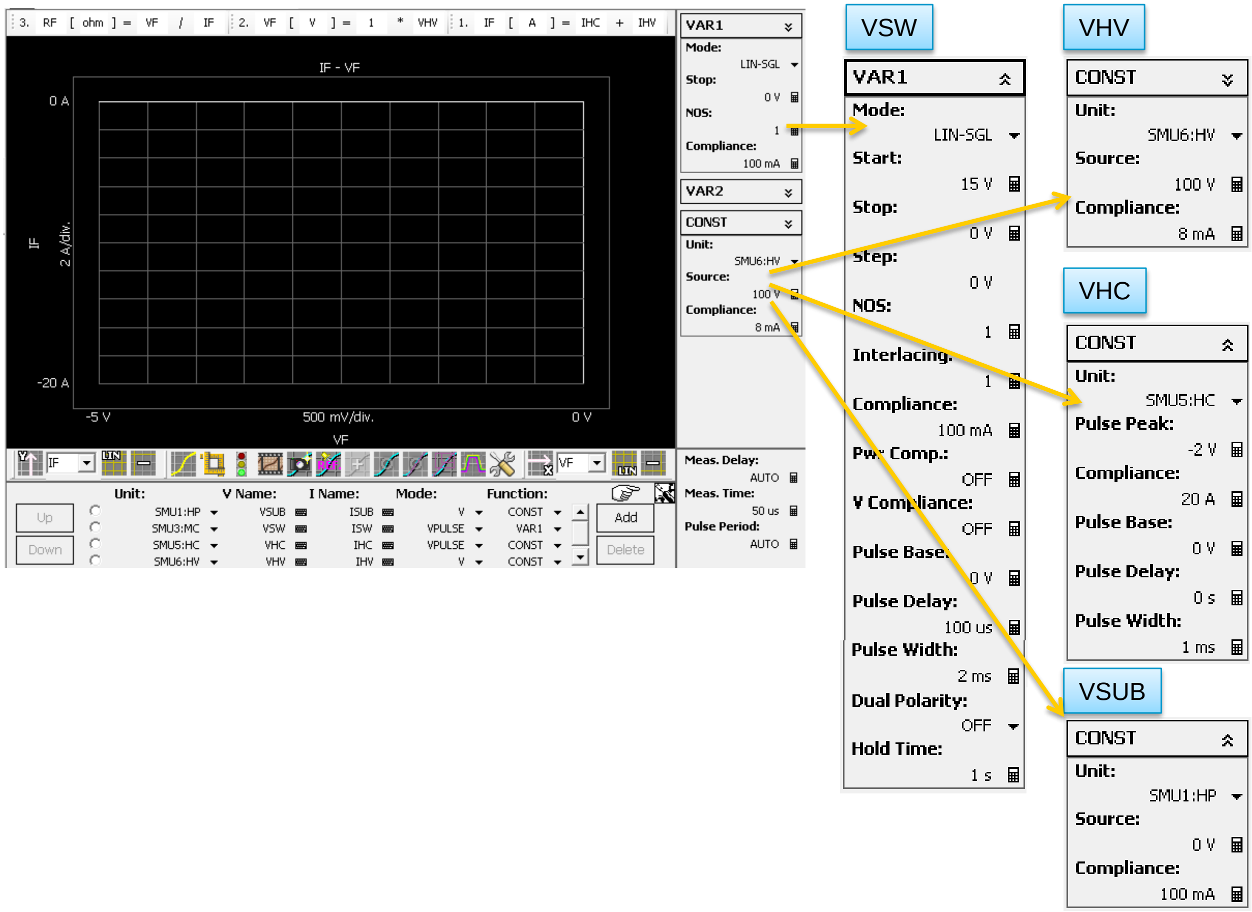
[Channel Assignment]



Unit:	V Name:	I Name:	Mode:	Function:
SMU1:HP	VSUB	ISUB	V	CONST
SMU3:MC	VSW	ISW	VPULSE	VAR1
SMU5:HC	VHC	IHC	VPULSE	CONST
SMU6:HV	VHV	IHV	V	CONST

- ✓ VSUB: SMU to bias the device substrate
- ✓ VSW: SMU to control the switch of the N1267A
- ✓ VHC: SMU to apply the on-state measurement voltage
- ✓ VHV: SMU to supply the off-state stress voltage

[Measurement Parameters]



3. RF [ohm] = VF / IF 2. VF [V] = 1 * VHV 1. IF [A] = IHC + IHV

VAR1
Mode: LIN-SGL
Stop: 0 V
NOS: 1
Compliance: 100 mA

VAR2

CONST
Unit: SMU6:HV
Source: 100 V
Compliance: 8 mA

Meas. Delay: AUTO
Meas. Time: 50 us
Pulse Period: AUTO

VSW

VAR1
Mode: LIN-SGL
Start: 15 V
Stop: 0 V
Step: 0 V
NOS: 1
Interlacing: 1
Compliance: 100 mA
Pwr Comp.: OFF
V Compliance: OFF
Pulse Base: 0 V
Pulse Delay: 100 us
Pulse Width: 2 ms
Dual Polarity: OFF
Hold Time: 1 s

VHV

CONST
Unit: SMU6:HV
Source: 100 V
Compliance: 8 mA

VHC

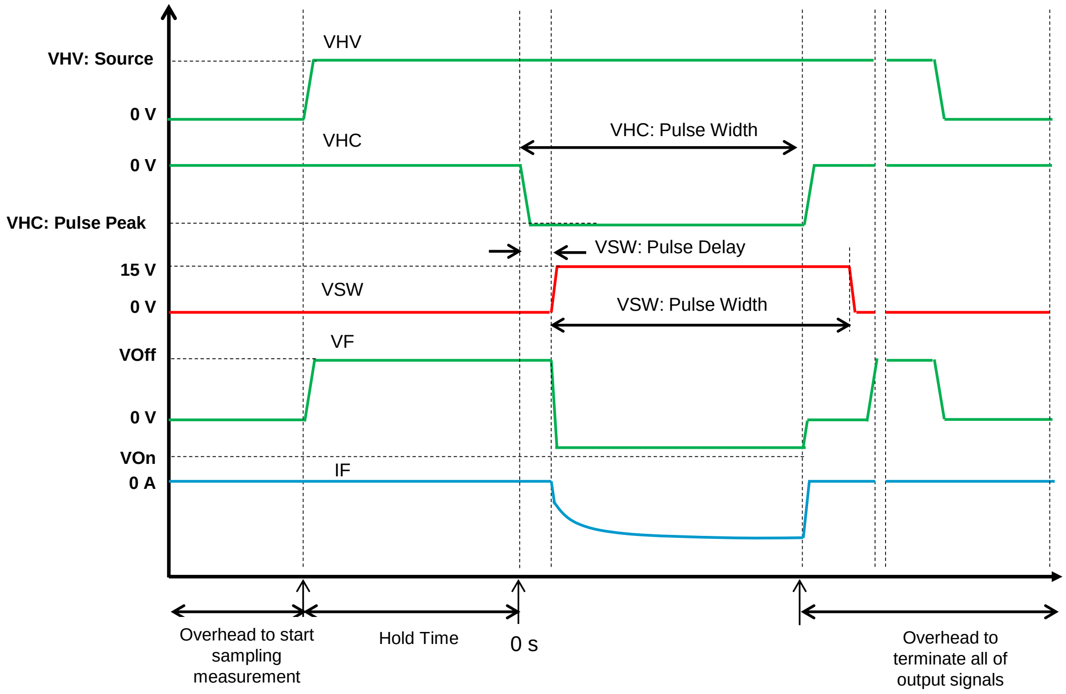
CONST
Unit: SMU5:HC
Pulse Peak: -2 V
Compliance: 20 A
Pulse Base: 0 V
Pulse Delay: 0 s
Pulse Width: 1 ms

VSUB

CONST
Unit: SMU1:HP
Source: 0 V
Compliance: 100 mA

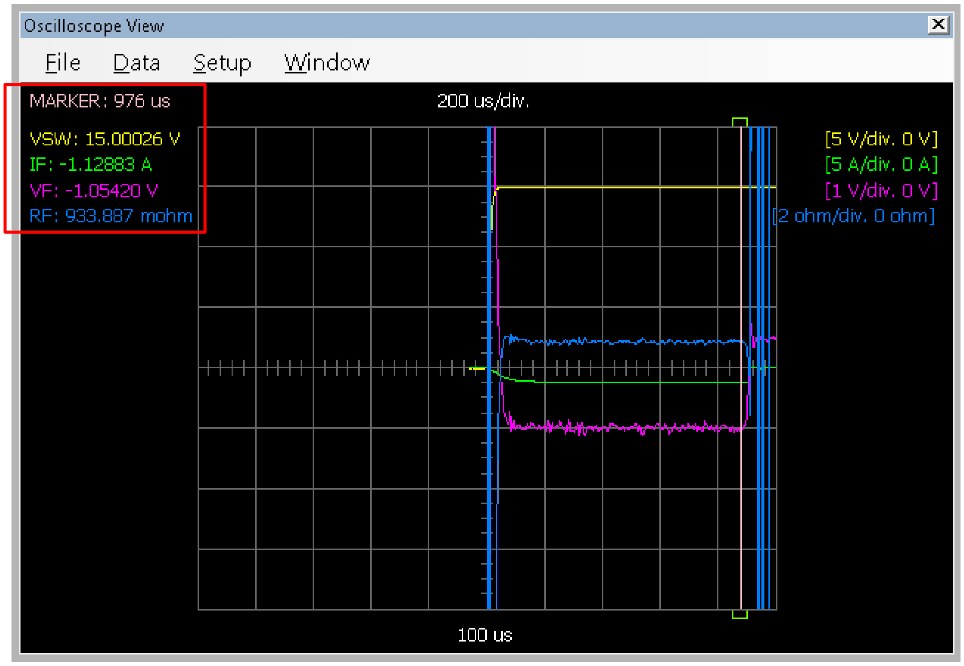
- VHV: Specify the off-state stress voltage as the Source voltage of the HVSMU. It should be at least 1 V higher than the Pulse Peak voltage of the VHCU.
- VHC: Specify the voltage to measure the on-state current as the Pulse Peak voltage.
  The current compliance has to be larger than the expected drain current. For fast response, 1 A or larger current compliance is recommended.
  The Pulse delay is set to 0 s, and it is used as a timing reference.
  The Pulse Width is specified as the duration to monitor the drain current waveform. If the current compliance is larger than 1 A, the maximum pulse width is 1 ms. For the current compliance equal to / lower than 1 A it is 24 ms. It is the maximum duration to be able to monitor by the Oscilloscope View.
- VSW: Set 15 V as the Start voltage to make the FET switch turned on.
  The Pulse Delay is specified to start output of the HCSMU prior to turning on the FET switch.
  The Pulse Width is specified to make the total duration of the pulse peak longer than the peak duration of the VHC pulse.
  The Hold Time is used to adjust the duration of the off-state stress.
- VSUB: Specify the Source voltage if you want to add a bias to the substrate of the device.

[Pulse Timing Chart]

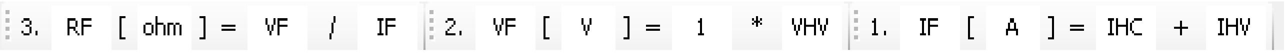


[Output Parameters]
Initially, the waveforms of VSW, VF, IF and RF are displayed.

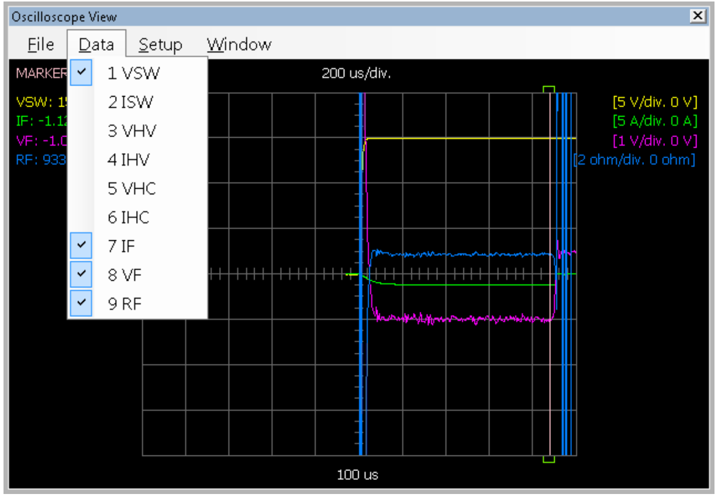

MARKER: 976 us
VSW: 15.00026 V
IF: -1.12883 A
VF: -1.05420 V
RF: 933.887 mohm


MARKER: 976 us
VSW: 15.00026 V
IF: -1.12883 A
VF: -1.05420 V
RF: 933.887 mohm

The IF is a combination of the current measured by the HCSMU and HVSMU. The VF is a measured voltage by the HVSMU. The RF is calculated from the measured VDS and ID.


3. RF [ohm] = VF / IF
2. VF [V] = 1 * VHV
1. IF [A] = IHC + IHV

If you want to see the waveform of each module, it is possible to add by selecting from the “Data” menu of the Oscilloscope view.



APPENDIX

A-1. Supported Module

- ✓ Supported Modules
- ✓ For the off-state stress biasing: B1513B HVSMU (B1513A HVSMU is not supported)
- ✓ For the on-state measurement: HCSMU
- ✓ For the switch control of the N1267A: MCSMU
- ✓ For the gate drive of the DUT: MCSMU or HCSMU*
- ✓ For the substrate biasing: MCSMU/HCSMU/MPSMU/HPSMU

(HSPMU / MPSMU are not supported as a gate drive, because those do not have the capability to modify the delay time to adjust the timing with output from other modules)

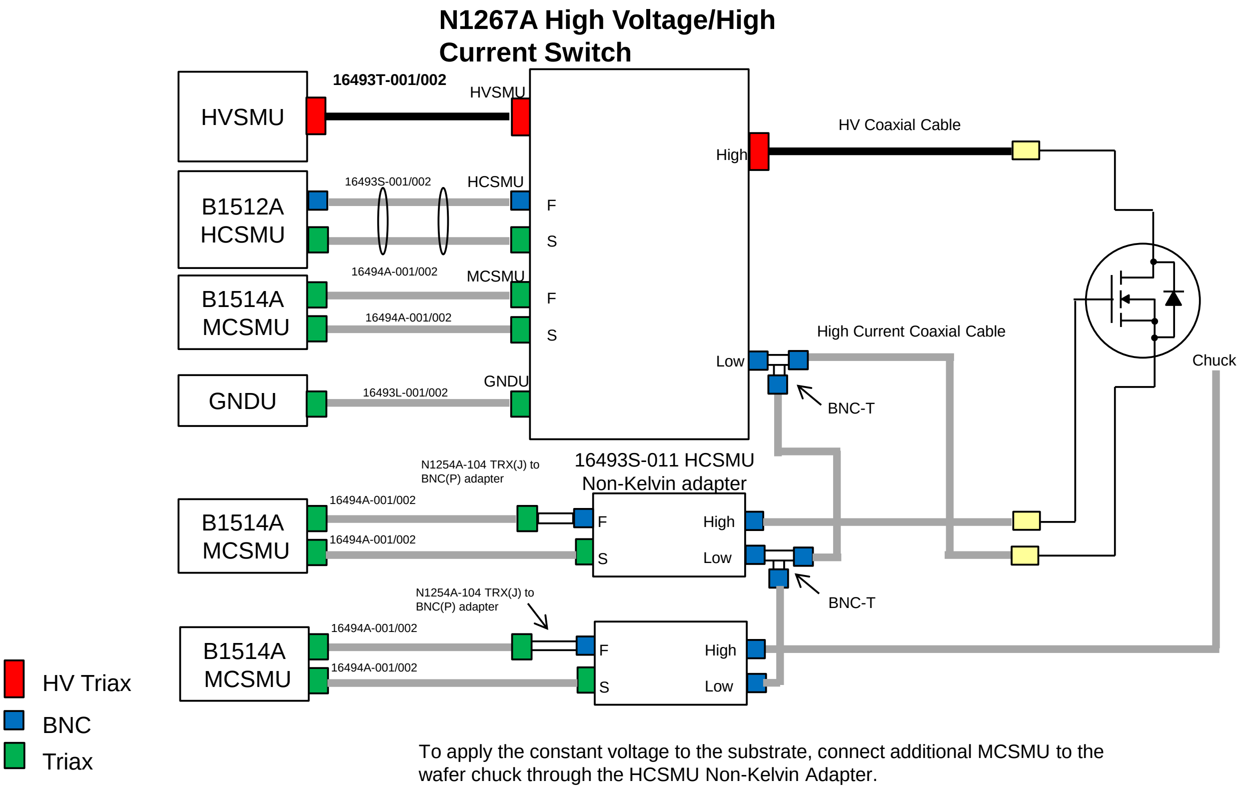
A-2. Supported Environment

- ✓ On-wafer measurement
- ✓ N1259A (Module selector option is required for Kelvin connection)
- ✓ N1265A*

*N1265A is not supported officially. In this document, the way to use N1265A as a fixture is introduced as an example usage. In a normal situation, we confirmed that it works fine.

A-3. Wiring Diagram for On-Wafer Measurement

A-3-1. Non-Kelvin Connection for On-wafer Measurement



To apply the constant voltage to the substrate, connect additional MCSMU to the wafer chuck through the HCSMU Non-Kelvin Adapter.

A-3-2. Kelvin Connection for On-wafer Measurement