

Measurement of Power Devices Using External DC Power Supply

Application Note 4156-5

- Maximum 500 W Output
 - 50 A / 8 V (Agilent 6651A)
 - 25 A / 20 V (Agilent 6652A)
 - 10 A / 50 V (Agilent 6654A-J05)
- Fast measurement speed
- Accurate Measurement for high power devices

Introduction

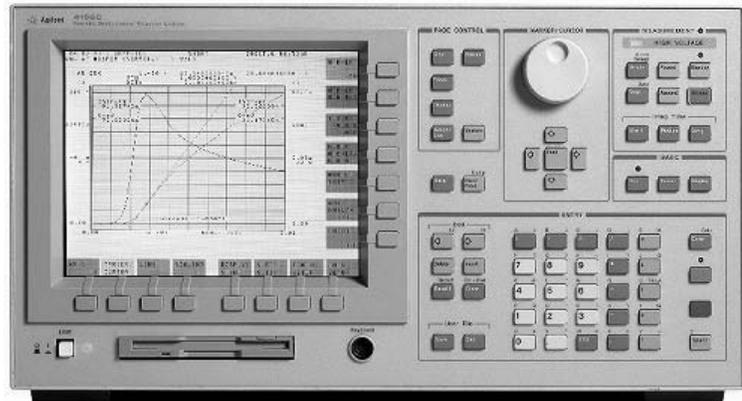
If used in combination with an external DC power supply, the Agilent 4155C/4156C semiconductor parameter analyzer can easily evaluate the DC characteristics of a power device that requires a current of fifty amperes maximum. This application note describes how to connect the Agilent 654X/664X/655X/665X series performance DC Power Supply (Figure 1) to the 4155C/4156C and to use the Agilent 4155/56C's automatic analysis functions to automatically calculate threshold voltage (Vth).

Power Transistor Measurement

Curve tracers are widely used for power transistor measurement, but have few analysis functions and have difficulties for extracting transistor parameters. They also have the disadvantage of being difficult to automate in order to improve productivity.

The 4155C/4156C offers a wide range of analysis functions including log sweep measurement functions,

Agilent 4155C / 4156C Semiconductor Parameter Analyzer



Agilent 4156C Precision Semiconductor Parameter Analyzer

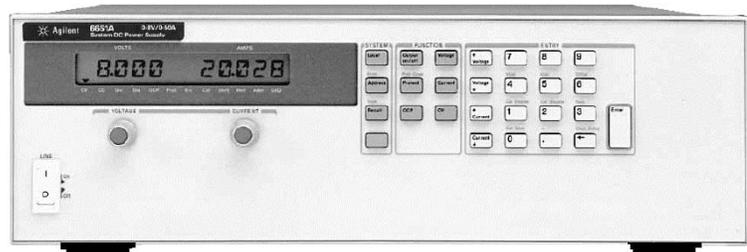


Figure 1. Agilent 6651A Performance DC Power Supply

tangent line, regression line, and marker Min/Max. It also has built-in Agilent Instrument BASIC, which enables the control and automation of all measurements without any external controller, and offers major improvements in

productivity from device development and design to incoming inspection. The dedicated expander (Agilent 41501B) gives a measurement range of up to 1 A/200 V, and using an external DC power supply that can be remotely

controlled, allows further expansion of the measurement range.

The Agilent 654X/664X/655X/665X series performance DC Power Supply shown in Figure 1 can be remotely controlled by applying a voltage to its control terminal, and current can be monitored remotely via its current monitor terminals. This paper describes how this function can be used to increase the output power and expand the current measurement range of the 4155C. Our example uses the Agilent 6654A-J05, which provides a maximum of 500 W and 10 A/50 V, but the other Agilent performance DC power supplies in the series are also suitable for semiconductor applications and the output range can be expanded as shown in Figure 2.¹

Key Techniques for Configuration

Connection

Figure 3 is the connection diagram of the Agilent 4156C, Agilent 6654A and the device under test (DUT) for positive voltage output.

SMU1 is connected to the modulation analog control terminal "VP" through the CR circuit to control the output voltage of the power supply. To obtain maximum performance and stability, SMU1 is used in current force mode; this current is converted to pseudo-floating voltage through the CR circuit.

The voltage measurement units (VMU1 and VMU2) are connected to the current

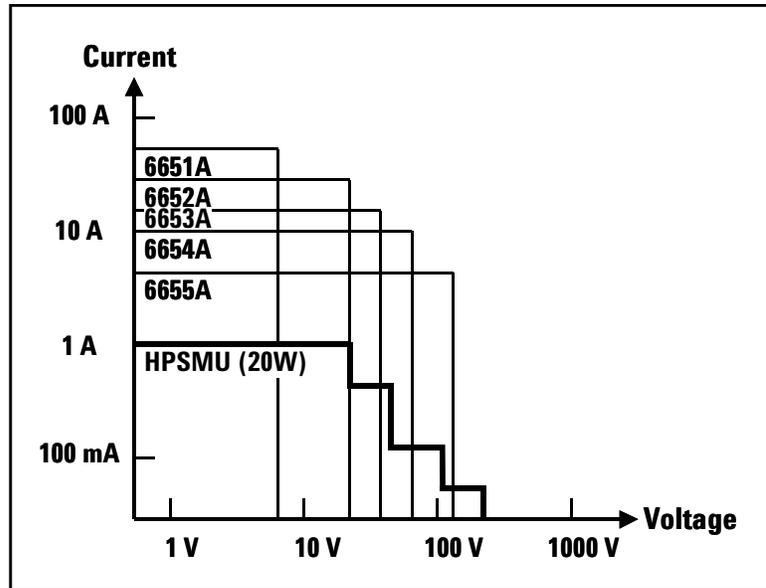


Figure 2. Expanding output power

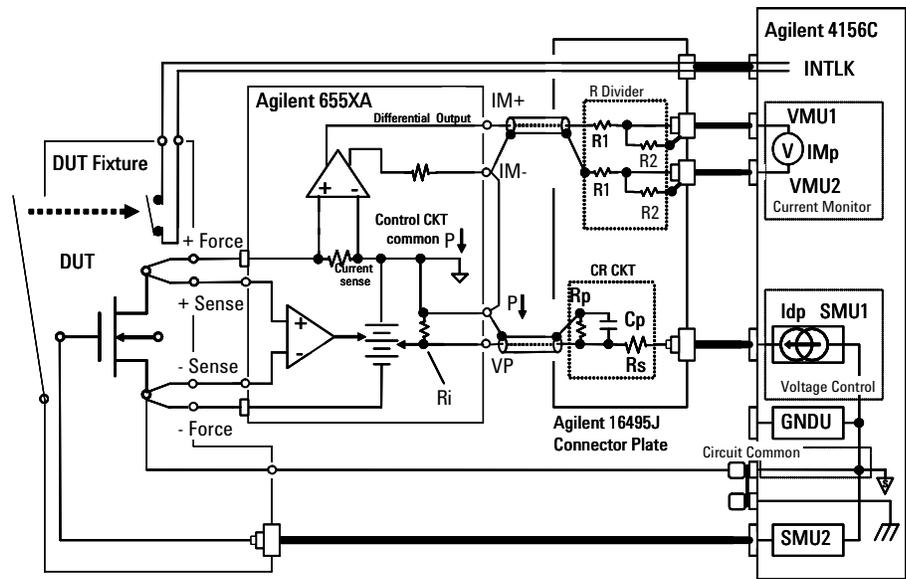


Figure 3. Diagram of Connections for N channel Power Transistor

monitor output IM+ and IM- of the power supply through the R divider to monitor the output current of the power supply. The differential R divider is used to reduce the -5 V output from the IM+ terminal that corresponds to the rated maximum current of the power supply to within the maximum input voltage of 2 V of the VMU

differential measurement mode, and to divide the power supply output voltage to within the VMS's 20V common mode input limit.

The power supply output is connected to the DUT using the Kelvin connection. To give the 6654A a circuit common potential, the common terminal

of the 4156C is connected to the Kelvin sense point at the DUT contact. By connecting the SMU circuit common to the Kelvin sense point of the DUT, accurate measurements that do not depend on the measurement current of the DUT become possible.

These connections can be made using the Agilent 16495J connector plate.

The CR circuit and shielded cables can be soldered to the unused connector terminal of the 16495J to fix the CR component firmly. (Figures 4a and 4b)

Figure 5 shows a wiring example of the connection terminal in the back panel of the power supply.

The CR circuit can be directly connected in the connection terminal instead of using the connector plate. In that case, the wiring must be secured to the plastic case or back panel of the power supply to ensure certain connection of the control signal between the 4156C.

Figure 6 is the connection diagram for negative voltage output for the DUT.

CR value

The CR value and the parameter conversion factor to control the power supply from the 4156C are provided.

Table 1 shows the parameter for positive output for each Agilent power supply model that can be used in this application.

Table 2 provides the parameters for negative output. Note that the force current

polarity of the SMU to set the power supply remains the same direction (always negative), but the actual voltage output polarity from the power supply is changed by the connection to the DUT. The compensation factor for current reading for negative voltage output is reversed to align the polarity of the SMU current reading.

Detailed technical information on these parameters and the theory of operation are provided in the technical note 5989-0920EN.² Further information about the publication is provided in the notes 2 at the end of this document.

Measurement parameter conversion

This technique controls the output voltage of the DC power supply using the analog signal from the SMU, and reads back the output current from the power supply as an analog voltage that is normalized to the maximum output current of the power supply; hence the parameters for these analog signals have to be converted properly.

1. Setting output voltage

When you set the output voltage of the power supply, -5 V at the VP input of the power supply corresponds to the maximum output voltage rating

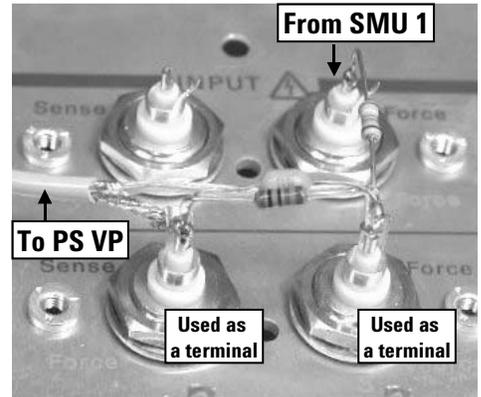


Figure 4a. CR circuit wiring for V control using the connector plate

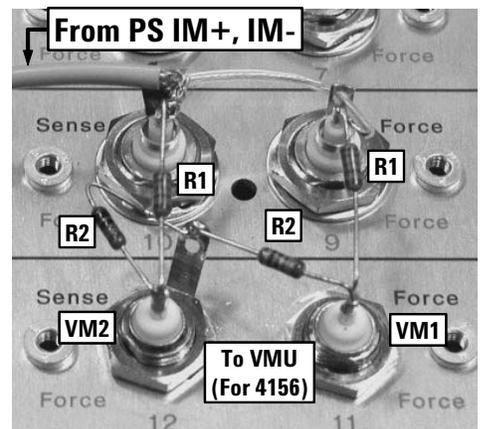


Figure 4b. CR circuit wiring for I monitor using the connector plate

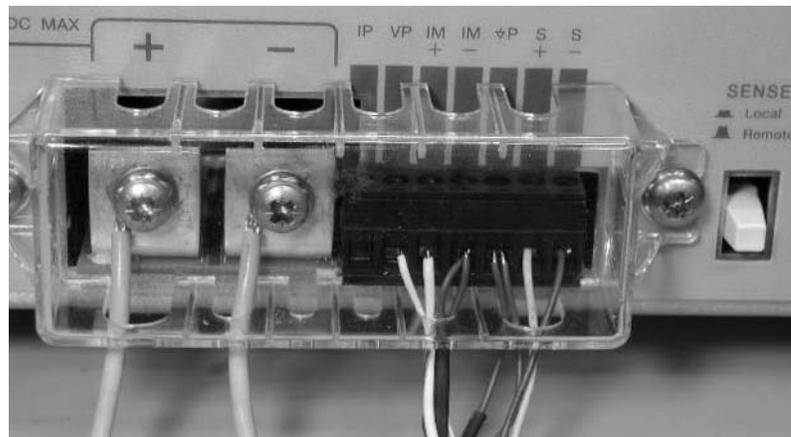


Figure 5. Power supply terminal connection

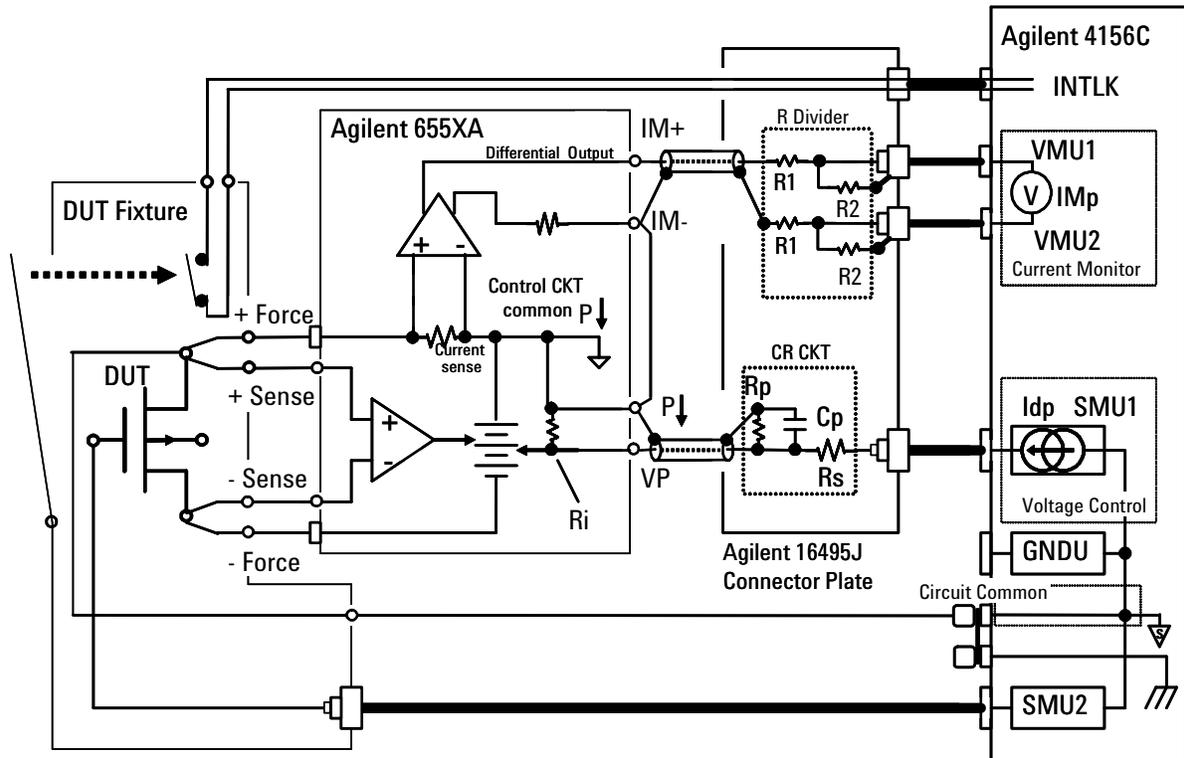


Figure 6. Diagram of Connections for P channel Power Transistor Measurement

Agilent Power Supply Model	Rp	Rs	R1	R2	I Force (SMU) / P.S V Output	V Force (SMU) / P.S V Output	P.S Max. Output V	P.S I Output (A) / P.S I Monitor (V)	P.S I Output (A) / P.S I Monitor x (R1+R2)/R2 (V)
6641A/6541A 8V-20A	1000	2150	21500	10000	-0.0006875	-1.1031	8	-4.0000	-12.600
6642A/6542A 20V-10A	1000	6810	21500	10000	-0.0002750	-1.1228	20	-2.0000	-6.300
6643A/6543A 35V-6A	1000	12100	21500	10000	-0.0001571	-1.0443	35	-1.2000	-3.780
6644A/6554A 60V-3.5A	1000	21500	21500	6810	-0.0000917	-1.0542	60	-0.7000	-2.910
6645A/6545A 120V-1.5A	1000	46400	21500	3320	-0.0000458	-1.1683	85 ^{*1}	-0.3000	-2.243
6651A/6551A 8V-50A	1000	2150	21500	10000	-0.0006875	-1.1031	8	-10.0000	-31.500
6652A/6552A 20V-25A	1000	6810	21500	10000	-0.0002750	-1.1228	20	-5.0000	-15.750
6653A/6553A 35V-15A	1000	12100	21500	10000	-0.0001571	-1.0443	35	-3.0000	-9.450
6654A/6654A-J05 50V-10A	1000	19600	21500	8250	-0.0001100	-1.2560	50	-2.0000	-7.212
6654A/6554A 60V-9A	1000	21500	21500	6810	-0.0000917	-1.0542	60	-1.8000	-7.483
6655A/6555A 120V-4A	1000	46400	21500	3320	-0.0000458	-1.1683	85 ^{*1}	-0.8000	-5.981

Note: Other parameters : Ri = 10 kohm (Input R), Cp = 0.1 uF. *1: Maximum output is limited to this voltage.

Table 1. CR CKT value (Positive output)

Agilent Power Supply Model	Rp	Rs	R1	R2	I Force (SMU) / P.S V Output ^{*1}	V Force (SMU) / P.S V Output ^{*1}	P.S Max. Output V	P.S I Output (A) / P.S I Monitor (V)	P.S I Output (A) / P.S I Monitor x (R1+R2)/R2 (V)
6641A/6541A 8V-20A	1000	2150	21500	10000	-0.0006875	-2.1031	-8	4.0000	12.600
6642A/6542A 20V-10A	1000	6810	21500	10000	-0.0002750	-2.1228	-20	2.0000	6.300
6643A/6543A 35V-6A	1000	12100	21500	10000	-0.0001571	-2.0443	-35	1.2000	3.780
6644A/6554A 60V-3.5A	1000	21500	21500	6810	-0.0000917	-2.0542	-60	0.7000	2.910
6645A/6545A 120V-1.5A	1000	46400	21500	3320	-0.0000458	-2.1683	-85 ^{*2}	0.3000	2.243
6651A/6551A 8V-50A	1000	2150	21500	10000	-0.0006875	-2.1031	-8	10.0000	31.500
6652A/6552A 20V-25A	1000	6810	21500	10000	-0.0002750	-2.1228	-20	5.0000	15.750
6653A/6553A 35V-15A	1000	12100	21500	10000	-0.0001571	-2.0443	-35	3.0000	9.450
6654A/6654A-J05 50V-10A	1000	19600	21500	8250	-0.0001100	-2.2560	-44 ^{*2}	2.0000	7.212
6654A/6554A 60V-9A	1000	21500	21500	6810	-0.0000917	-2.0542	-48 ^{*2}	1.8000	7.483
6655A/6555A 120V-4A	1000	46400	21500	3320	-0.0000458	-2.1683	-45 ^{*2}	0.8000	5.981

*1: The control signal polarity of the SMU to control the power supply is the same as the case for positive output. The polarity of the power supply output is referenced to the negative output terminal.

*2: Maximum output is limited to this voltage.

Table 2. CR CKT value (Negative output)

of the power supply; 0 V at VP is for 0 V output from the power supply. For correctly controlling the power supply from the SMU, the CR circuit is added and current source mode of the SMU is used. The current value that outputs 1 V from the power supply using the CR value in Table 1 is provided in the column "I Force (SMU) / P.S V output" as the V conversion factor. If Vo volts are output from the power supply, then the SMU is set to force current as Vo times the V conversion factor chosen from the appropriate power supply.

This V conversion factor should be tuned or calibrated so that the set value and the actual output from the power supply match precisely.

2. Setting voltage compliance

When the SMU drives the power supply in current force mode, the SMU must swing to an appropriate voltage that is determined by the CR circuit and the output voltage of the power supply. The voltage compliance of the SMU must be set larger than this voltage. This voltage can be determined by using the factor shown in the "V Force (SMU) / P.S V output" column, the ratio of the minimum required SMU force voltage and your power supply output voltage, Vo. Set the SMU voltage compliance larger than the Vo x "V Force (SMU) / P.S V output" value.

3. Current monitor

The current monitor voltage from the power supply is normalized to -5 V for its rated maximum output current. A

voltage divider consists of R1 and R2 is inserted for scaling down the -5 V to less than the maximum input for differential VMU of 2 V. The output current from the power supply can be converted using the current conversion factor; that is, the current monitor output voltage is multiplied by the current conversion factor shown in the column "P.S I output (A) / P.S I monitor x (R1+R2)/R2 (V)".

Here are two examples of parameter conversion, one for positive output and the other for negative output, for interfacing to the power supply.

Example 1. Positive V:

- Power supply : 6654A-J05 (10 A/50 V)
- Output voltage setting : 10 V (positive V connection)

1. The I force current of SMU1 to output 10 V:

From Table 1,
"I Force (SMU) / P.S V Output" = -0.000110 (A/V)

$$\begin{aligned} \text{"I force"} &= \\ &= -0.000110 \text{ (A/V)} \times 10 \text{ (V)} = \\ &= -0.0011 \text{ A} \end{aligned}$$

2. V compliance of SMU3:

From Table 1,
"V Force (SMU) / P.S V Output" = -1.256
V compliance >
10 (V) x -1.256 = -12.56V.

Considering a margin to cover the voltage drop of the force line of the power supply and the error of the CR circuit, a value greater than -15 V is advisable.

3. Current monitor conversion:

From Table 1, the current conversion factor is
"P.S I Output (A) / P.S I Monitor x (R1+R2)/R2 (V)" = -6.30

For example, if the voltage reading of the differential VMU is -0.7937 V, then the actual current output from the 6654A-J05 is 5 A
(= -0.7937 V x -6.3 A/V).

Example 2. Negative V:

- Power supply : 6652A (25 A/20 V)
- Output voltage setting : -10 V (negative V connection)

1. The I force current of SMU3 to program P.S V output 10V :

From Table 2, "I Force (SMU) / P.S V Output" = -0.0002750 (A/V)

$$\begin{aligned} \text{"I force"} &= \\ &= -0.000275 \text{ (A/V)} \times 10 \text{ (V)} = \\ &= -0.00275 \text{ A} \end{aligned}$$

2. V compliance of SMU3:

From Table 2, "V Force (SMU) / P.S V Output" = -2.1228
V compliance > 10 (V) x -2.1228 = -21.228V.

3. Current monitor conversion:

From Table 2, the current conversion factor is "P.S I Output (A) / P.S I Monitor x (R1+R2)/R2 (V)" = 15.75
For example, if the voltage reading of the differential VMU is -0.7937 V, then the actual current output from the negative output terminal of 6652A is -12.5 A
(= -0.7937 V x 15.75 A/V).

Results using Agilent 4156C and Agilent 6654A-J05

Agilent 4156C settings and results of measurements

Figures 7 to 9 show the 4155C setup screens for the drain characteristic measurements. On the CHANNEL DEFINITION page (Figure 7), SMU1, which drives the drain, is set to pulse output. Driving the drain using a pulse mode reduces the average output current, so thermal drift is reduced. VMU1 and VMU2 are set to differential mode and the potential difference (Vim) is measured.

The USER FUNCTION DEFINITION page (Figure 8) is used to calculate the Vd and Id variables. Vd is the SMU1 output current (Idp) divided by a factor depending on the DC power supply (-0.00011 for the 6654A-J05 as in the above example 1).

The current conversion factor is -6.3 for the 6654A-J05. Hence, set the user functions as follows:

$$V_d = V_{dp} / -0.00011 \text{ or } -V_{dp}/0.00011$$

$$I_d = I_{Mp} \times -6.3 \text{ or } -I_{Mp} \times 6.3$$

The SWEEP SETUP page (Figure 9) is used to set the sweep conditions for SMU1 and SMU2, and the pulse output for SMU1. In this example, to prevent heating, SMU1 is set to pulsed sweep.

Pulse width and pulse period are set so the pulse of SMU1 has a duty cycle of 2%.

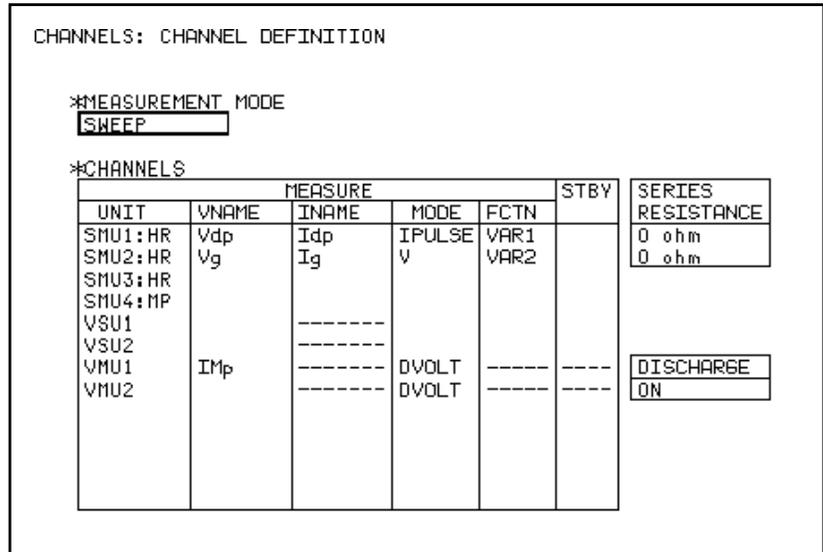


Figure 7. CHANNEL DEFINITION Page

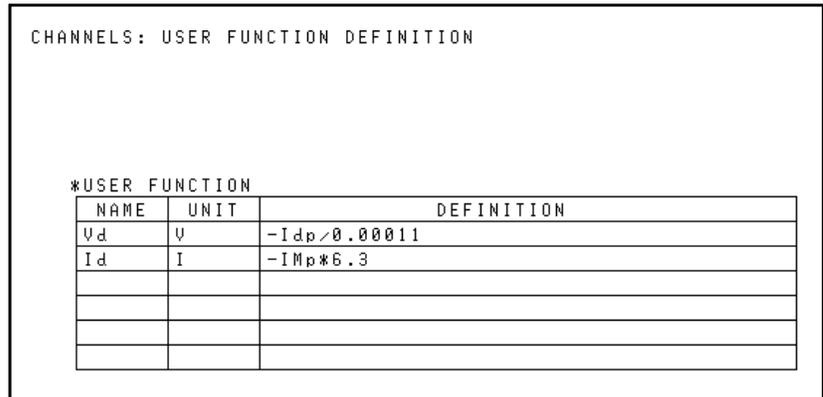


Figure 8. USER FUNCTION DEFINITION Page

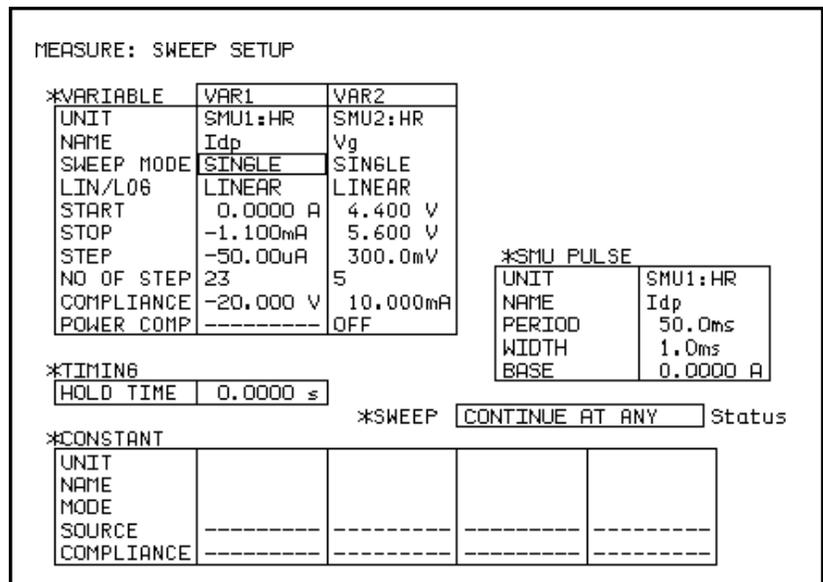


Figure 9. SWEEP SETUP Page

The measurement results of drain characteristics are shown in Figure 10.

Automatic extraction of Transistor Parameters

The 4155C/4156C parameter analyzer can automatically extract parameters after measurements.³ Figure 11 shows the automatic extraction of threshold voltage from the “drain current versus the gate voltage” characteristics graph. Before measurement, you can set up the ANALYSIS SETUP page to extract the desired parameters.

After measurement, 4155C/4156C automatically extracts the parameters.

In this example, the 4156C finds the maximum Gm, then draws the tangent to the Id curve of this point. The x-intercept of this tangent line is Vth, which is automatically displayed. Measurement productivity, repeatability, and speed are all significantly improved.

Conclusion

This application note describes how the Agilent 4155C/4156C can be used with the Agilent 654X/664X/655X/665X series performance DC Power Supply to extract power transistor parameters, which are difficult to extract using the conventional curve tracer method.

You can expand the measurement current to as much as fifty amperes, for example, with the Agilent 6651A power supply. There are several choices for the Agilent power supply

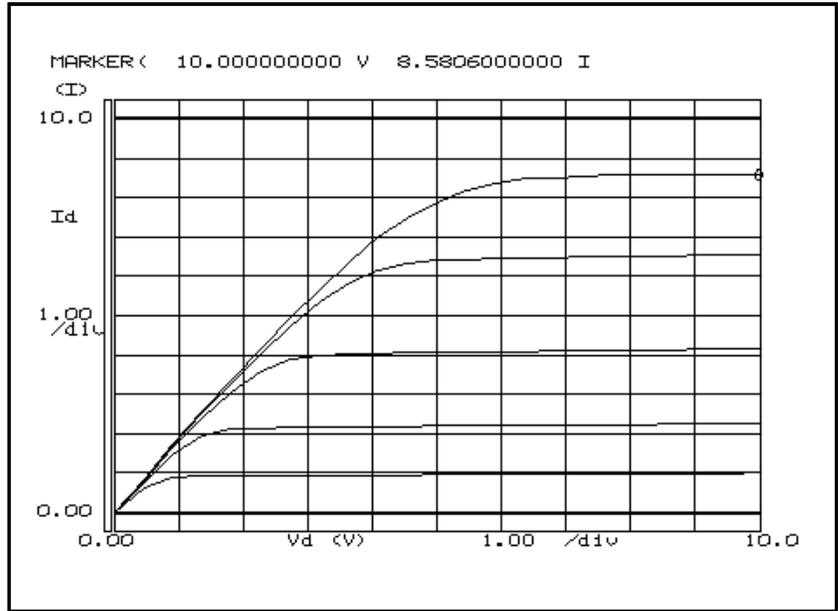


Figure 10. Examples of Drain Characteristic Measurements

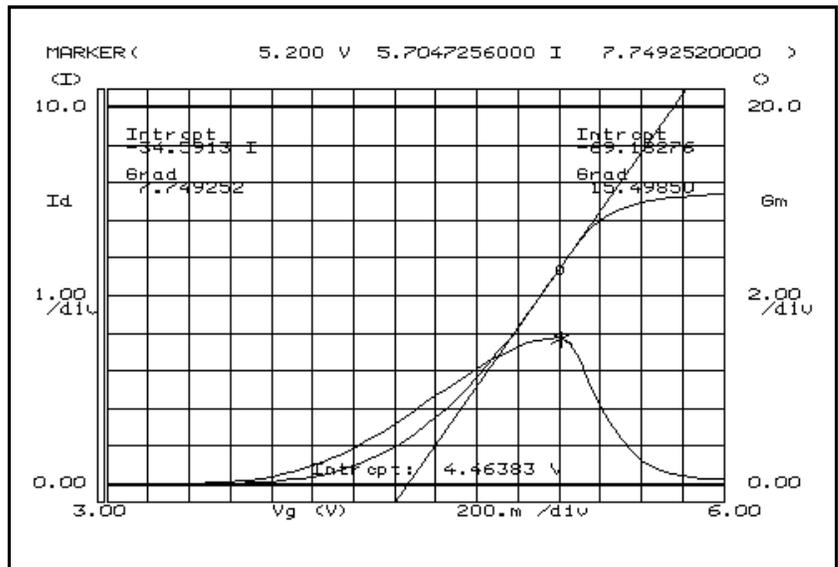


Figure 11. Drain Current versus Gate Voltage Characteristics to Obtain Vth

depending on your range of power requirements, and it can be implemented very easily.

The good accuracy in both voltage setting and current reading, together with the fast transient response, suits characterizing newly developing devices and technologies such as SiC power transistors for automotive use,

energy inverters for solar cells in home use and any precision characterization of power devices.

The 4155C/4156C’s automatic analysis functions and built-in Instrument BASIC environment also allow 4155C/4156C to become an automatic test station.

Notes:

1. Please observe the following safety precautions when using the Agilent 4156C.
 - Make sure that the wiring used with the connector plate and shield box has adequate capacity. The maximum output voltage and current of each external DC power supply are shown in Tables 1 and 2.
 - To protect yourself against electrical shocks when replacing the DUT, be sure to fit an INTLK switch and install the measurement system, including external DC power supply, in a shield box.
2. Refer to the Technical overview "Technique for controlling Agilent External DC Power Supply from SMU to expand SMU output power capability", Agilent publication number 5989-0920EN to learn more about the stable control of the power supply and measurement accuracy.
3. The minimum pulse width in the pulsed measurement depends on various factors and the minimum pulse width of the 4155C/4156C may not be applicable. Use wider pulse width in such a case.
4. For a detailed explanation of automatic analytical functions, see Application Note 4156-2, Automated Extraction of

Semiconductor Parameters Using the Agilent 4155C/4156C (Agilent publication number 5963-1249E).

5. The information contained in this application note also applies to the Agilent 4155A/4156A and Agilent 4155B/4156B.

Additional Information

For more information about Agilent Technologies parametric test products, please visit: www.agilent.com/see/parametric

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