HP 4155A / HP 4156A Semiconductor Parameter Analyzer

Sample Application Programs

HEWLETT
PACKARD

HP Part No. 04155-90130
Printed in Japan March 1995

Edition 1

1

About this manual

This manual describes some sample application programs and setup files,which will be helpful for creating your own applications.

All programs and setup files described in this chapter are stored on a DOS formatted 3.5-inch diskette that is provided with your HP 4155A/4156A.

The following examples are provided.

- V-RAMP
- J-RAMP
- SWEAT
- GO/NO-GO Test
- HCI Degradation Test

Caution These programs are only examples,so you may need to modify these programs and setup files for your own application before executing. If these example programs damage your devices,Hewlett-Packard is *NOT LIABLE* for the damage.

You should copy this diskette to a diskette that you will use as your working diskette. You can modify setup files by remote programming or interactively by front-panel keys.

HP 4155A/4156A Precision Semiconductor Parameter Analyzer

V-RAMP Sample Program Operation Manual

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Introduction

Voltage-Ramped (V-Ramp) test is one of the Wafer Level Reliability (WLR) tests, which is used to evaluate device reliability on a wafer. This test can provide quick evaluation data for estimating the overall reliability of thin oxides, and this data can be used to improve the thin oxide manufacturing process.

With the thickness of oxide shrinking along with device geometries, creating a reliable thin oxide has become an important issue. The integrity of the thin oxide in a MOS device is a dominant factor in determining the overall reliability of a micro-circuit. The V-Ramp test can promptly give useful feedback to the manufacturing process about oxide reliability.

This operation manual covers a sample V-Ramp program running on the HP 4155A/4156A, and how to use and customize the program. The program is written in HP Instrument BASIC (IBASIC), and is ready to run on the built-in IBASIC controller of the HP 4155A/4156A.

Note This is a sample program, so you may need to customize the program and setup files for your application before execution. If the sample program damages your device, Hewlett-Packard is *not liable* for the damages.

Contents of This Manual

Chapter 2 describes basic theory, procedure, and terminology of the V-Ramp test.

Chapter 3 describes the V-Ramp sample program. Included are V-Ramp methodology using the HP 4155A/4156A, how to execute the sample program, and program overview.

Chapter 4 describes how to customize the sample program. This is very helpful because you probably need to modify the sample program to suit your test device.

Appendix A shows HP 4155A/4156A page settings that are stored in the setup files.

2

Theory of V-Ramp Test Procedure

This chapter describes the Voltage-Ramped (V-Ramp) Test procedure. Included are basic theory, procedure, and terminology of V-Ramp test.

The V-Ramp test procedure is based on JEDEC standard No.35.

V-Ramp Test Overview

V-Ramp test measures the breakdown voltage (*Vbd*) and breakdown charge (*Qbd*) of thin oxide capacitors, which you designed as test structures on the wafer. These results are used to evaluate the oxide integrity. The higher the *Vbd* and *Qbd* measured by this test, the better the integrity of the oxide on wafer.

You extract these two parameters from a large amount of test structures and extracted parameters are used for standard process control to quickly evaluate oxide integrity.

In the V-Ramp test, an increasing voltage is forced to the oxide capacitor until the oxide layer is broken. Breakdown voltage (*Vbd*) is defined as the voltage at which breakdown occurs. And breakdown charge (*Qbd*) is the total charge forced through the oxide until the breakdown occurs.

Figure 2-1 shows a simplified flowchart of V-Ramp test.

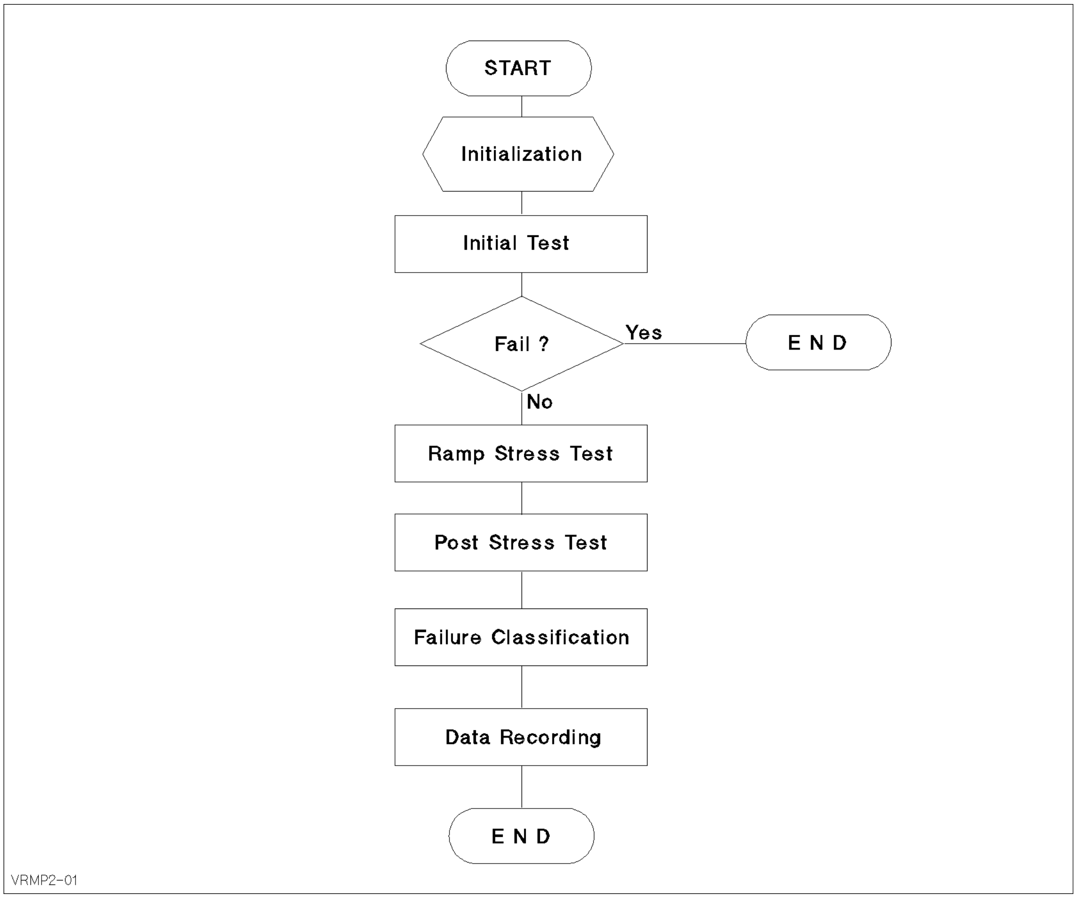


Figure 2-1. Simplified Flow Diagram of V-Ramp Test

The V-Ramp test consists of three tests: initial test, ramp stress test, and post stress test.

In the initial test, normal operating voltage is applied to the oxide capacitor, then leakage current through the capacitor is measured to check for initial failure.

In the ramp stress test, linear ramped voltage is applied to the capacitor, and the current is measured.

The post stress test is for confirming that failure occurred during the ramp stress test. The normal operating voltage is applied to the oxide capacitor again, and leakage current is measured under the same conditions as the initial test.

After the tests, the test results must be analyzed and saved (data recording).

Before performing the V-Ramp test, test conditions must satisfy the following:

- Gate bias polarity is in accumulated direction. That is, negative (minus) voltage is applied to gate conductor for P-type bulk, and positive (plus) voltage is applied for N-type bulk.
- Diffusions and wells (if any) must be connected to substrate.
- Temperature is in 25 ± 5 °C range.

Initial Test

Initial test is to confirm that the oxide capacitor is initially good. If leakage current of that capacitor exceeds 1 μA, it is categorized as **initial failure**.

For example, when you test a TTL-level oxide capacitor, constant voltage of -5 V is applied to that capacitor, and leakage current is measured. If the leakage current is more than 1 μA, that capacitor is an initial failure.

Ramp Stress Test

A linear ramped voltage or a linear stepped voltage, which is approximately ramped voltage, is applied to the oxide capacitor. While the ramped voltage is forced, the current through the oxide is measured.

The ramped voltage is stopped when one of the following conditions occurs:

- Current through the oxide exceeds ten times the expected current. The expected current is calculated from the applied voltage and structure of oxide capacitor. For example, the expected current density J for a 200 angstrom oxide capacitor is calculated from the equation for Fowler-Nordheim current as follows:

  $$J = A \cdot E^2 \exp\left(-\frac{B}{E}\right)$$

  Where, A and B are constants in terms of effective mass and barrier height.
  E is electric field.

- Current through the oxide exceeds the current compliance determined by the current density compliance limit of 20 A/cm^2.
- Electric field generated by the applied voltage exceeds 15 MV/cm. This typically indicates *faulty testing.*

Figure 2-2 shows the concept of *Vbd* and *Qbd*. In the graph, left vertical axis shows current through the oxide, right vertical axis shows voltage applied to the oxide capacitor, and horizontal axis shows time.

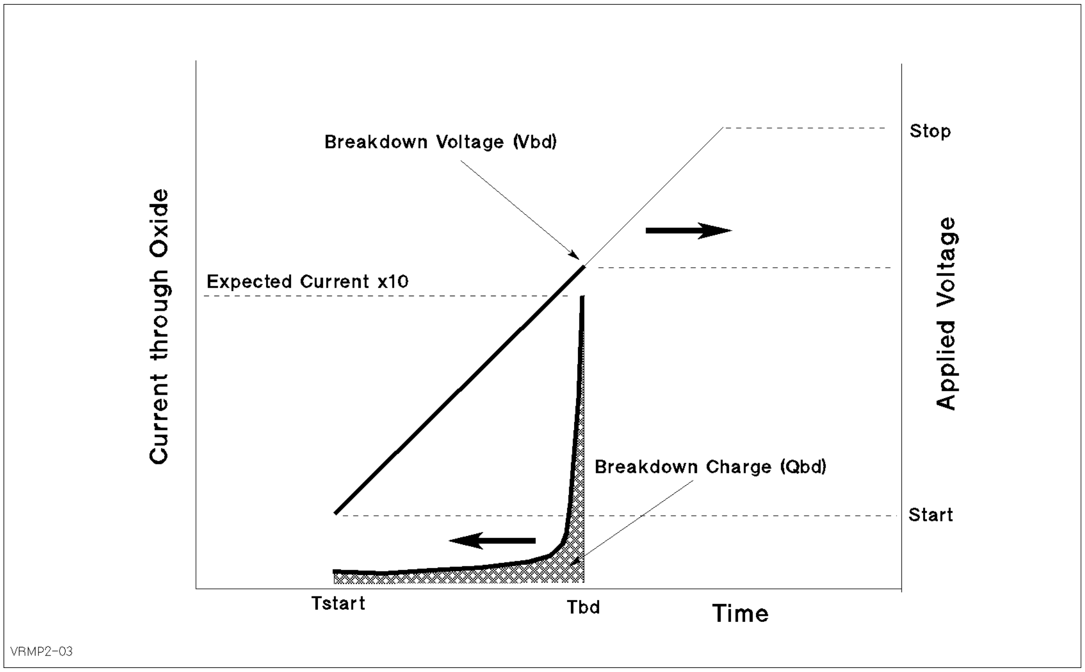


Figure 2-2. Concept of Breakdown Voltage and Charge

When the current through the oxide reaches 10 times the expected current, the ramped voltage is stopped, and the applied voltage at this point is the breakdown voltage (*Vbd*). Breakdown charge (*Qbd*) is calculated by integrating the current through the oxide:

$$Qbd = \int_{T_{start}}^{T_{bd}} I_{meas}(t) \cdot dt$$

Figure 2-3 shows the two ways to apply the voltage: linear ramped voltage or linear stepped voltage.

Note that the applied ramped voltage must satisfy the following conditions:

- Ramp rate is in range from 0.1 MV/cm·s to 1.0 MV/cm·s.
- Current measurement interval is 0.1 s or less.
- Ramped voltage starts at normal operating voltage or lower.
- Ramped voltage stops if electric field reaches 15 MV/cm.

If you use the linear stepped voltage, the following conditions must be satisfied also:

- Step value of ramped voltage is 0.1 MV/cm or less.
- Current measurement must be performed at least once for every step.

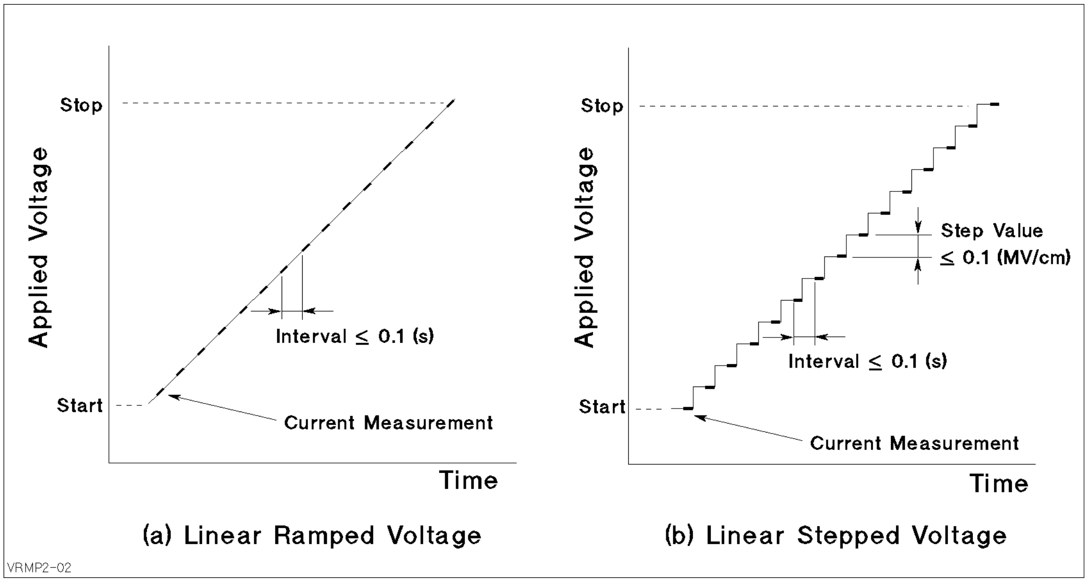


Figure 2-3. Linear Ramped and Linear Stepped Voltage

Post Stress Test

The post stress test checks the oxide status after the ramp stress test. If the oxide is broken, proper ramp stress was applied to the oxide capacitor. If not, maybe the ramp stress was not applied correctly.

To check the oxide status, the normal operating voltage is applied to the oxide capacitor (same as initial test), then leakage current is measured. The leakage current (I_{leak}) value indicates the following:

- If $I_{leak} > 1\ \mu A$:

  The oxide was broken by the applied ramped voltage.

- If $I_{leak} < 1\ \mu A$:

  The oxide was *not* broken by the applied ramped voltage.

  If the applied ramped voltage reached the maximum electric field, the testing was probably faulty: for example, the ramped voltage was not applied to the oxide due to an open circuit.

For example, if you test a TTL level oxide capacitor, constant voltage of -5 V is applied to that capacitor, then leakage current is measured. If the leakage current is more than 1 μA, the capacitor was properly broken.

Failure Categorization and Data Recording

According to the measurement results, the oxide status is categorized as follows and recorded:

Initial Failure:	Failed the initial test. Indicates initially defective oxide capacitor. Other tests should not be performed.
Catastrophic Failure:	Failed ramped and post stress tests. Indicates that oxide capacitor was properly broken by the ramped stress test.
Masked Catastrophic Failure:	Did not fail ramped stress test, but failed post stress test.
Non-catastrophic Failure:	Failed ramped stress test, but not post stress test.
Other	Did not fail ramped stress test or post stress test.

The failure category is recorded for each test device. If the catastrophic failure is observed, breakdown voltage (Vbd) and breakdown charge density ($q_{bd} = Qbd/Area$) are also recorded.

Table 2-1 shows the oxide failure categories.

Table 2-1. Oxide Failure Categories

Failure Category	Initial Test	Ramp Stress Test	Post Stress Test
Initial	Fail	n.a.	n.a.
Catastrophic[1]	Pass	Fail	Fail
Masked Catastrophic	Pass	Pass	Fail
Non-catastrophic	Pass	Fail	Pass
Other	Pass	Pass	Pass

1 Vbd and q_{bd} are also recorded.

3

Basic Operation

This chapter covers the following for using an HP 4155A/4156A to perform V-Ramp Test: required equipment, required files, methodology, how to execute the sample program, and sample program overview.

Methodology

The entire V-Ramp Test procedure can be performed by executing the VRAMP sample program on the built-in IBASIC controller of the HP 4155A/4156A.

As explained in Chapter 2, the V-Ramp test consists of three measurement parts and an analysis part. Each measurement part executes three steps as follows:

1. Loads the measurement setup file into the HP 4155A/4156A execution environment.
2. Changes some of the measurement or analysis parameters on the setup pages.
3. Executes the measurement.

The VRAMP program executes the above three steps for each test: initial test, ramp stress test, and post stress test. Using the measurement setups (step 1 above) loaded from a file reduces the length and complexity of the program. For details, see *HP 4155A/4156A Programmer's Guide*.

Measurement setups, which are loaded into the HP 4155A/4156A execution environment, were previously developed and saved to measurement setup files on the diskette. You can easily modify the measurement setup information in fill-in-the-blank manner in the HP 4155A/4156A execution environment. The VRAMP sample program is also saved to the diskette. You can easily modify the sample program by using the editor in the built-in IBASIC environment.

The VRAMP sample program assumes that the built-in IBASIC controller of the HP 4155A/4156A is used, but you can also use another controller, such as HP BASIC running on an external computer. To do so, you must modify the sample program for your environment. See Chapter 4 on how to modify the program to run on an external controller.

Initial Test

The initial test makes sure the oxide capacitor is initially good by applying the normal operating voltage (`Vuse`), then measuring the leakage current (I_{leak}) through the oxide. If I_{leak} exceeds 1 μA, the oxide capacitor is categorized as "initial failure".

The sample program assumes that SMU1 and SMU4 are connected to the oxide capacitor as shown in Figure 3-1.

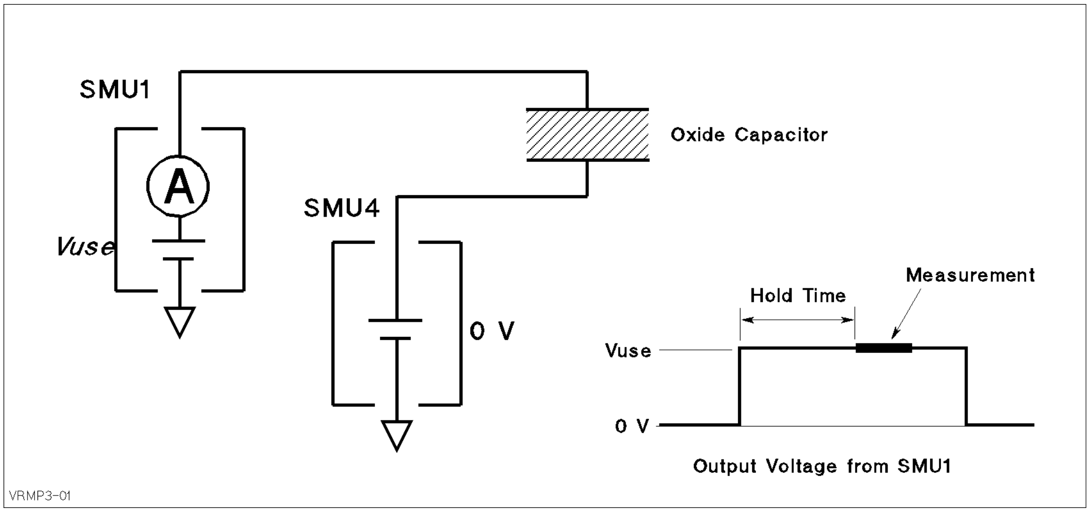


Figure 3-1. Simplified Measurement Circuit and Output Voltage of Initial Test

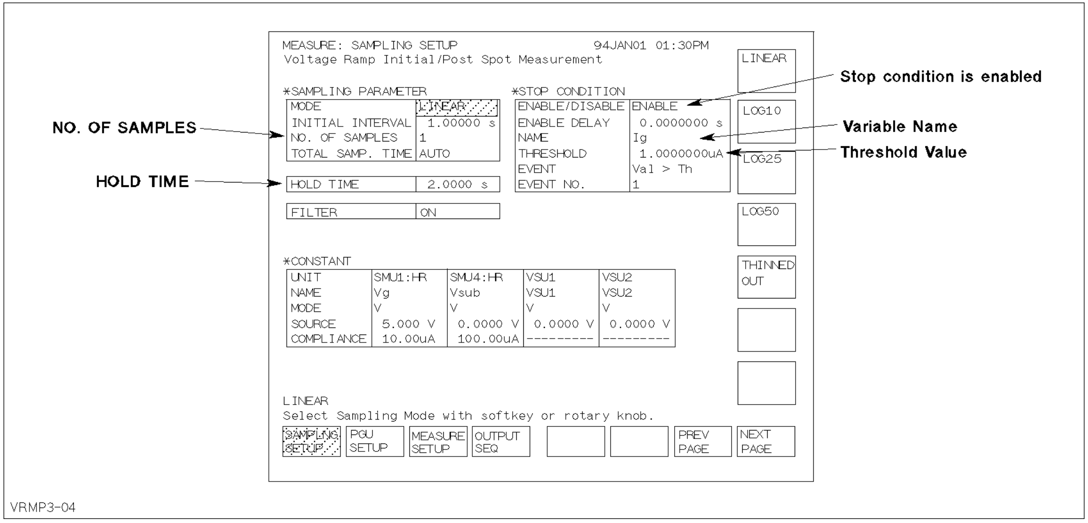
For the initial test, the sample program does as follows:

1. Sets up the HP 4155A/4156A according to the VRSPOT.MES setup file, which the sample program previously loaded from the diskette into internal memory MEM1.
2. Sets up SMU1 to constant voltage `Vuse` for PMOS device, or `-Vuse` for NMOS device. `Vuse` value is specified previously in the sample program, and reset on the MEASURE: SAMPLING SETUP page by OUTPUT statement (line 2550 of the sample program).
3. Forces voltage from SMU1, then measures current after the HOLD TIME, which was setup by VRSPOT.MES setup file described next.
4. Checks if current through the oxide `Ig` exceeds 1 μA. If so, the sample program aborts further testing.

The following are main points about the setup by the VRSPOT.MES setup file:

- On CHANNELS: CHANNEL DEFINITION page (see Figure A-1)
  - ☐ MEASUREMENT MODE is set to SAMPLING.
  - ☐ SMU1 and SMU4 are set to be constant voltage sources.
  - ☐ `Ig` is defined as name of current measured by SMU1.
- On MEASURE: SAMPLING SETUP page (see Figure 3-2)
  - ☐ NO. OF SAMPLES is set to 1 to execute the measurement once.
  - ☐ HOLD TIME is set to 2.00 s to allow the output voltage to stabilize.
  - ☐ SMU4 is set to force a constant 0 V.
  - ☐ STOP CONDITION is enabled, NAME is set to `Ig`, THRESHOLD is set to 1 μA, and EVENT is set to `Val > Th`.

  So, the measurement will stop if the current through the oxide (`Ig`) exceeds 1 μA. If so, the sample program will abort further testing.



```
MEASURE: SAMPLING SETUP                    94JAN01 01:30PM
Voltage Ramp Initial/Post Spot Measurement

*SAMPLING PARAMETER                *STOP CONDITION
MODE                LINEAR         ENABLE/DISABLE  ENABLE
INITIAL INTERVAL    1.00000 s      ENABLE DELAY    0.0000000 s
NO. OF SAMPLES      1              NAME            Ig
TOTAL SAMP. TIME    AUTO           THRESHOLD       1.0000000uA
                                   EVENT           Val > Th
HOLD TIME           2.0000 s       EVENT NO.       1

FILTER              ON

*CONSTANT
UNIT        SMU1:HR    SMU4:HR    VSU1       VSU2
NAME        Vg         Vsub       VSU1       VSU2
MODE        V          V          V          V
SOURCE      5.000 V    0.0000 V   0.0000 V   0.0000 V
COMPLIANCE  10.00uA    100.00uA   ---------  ---------

LINEAR
Select Sampling Mode with softkey or rotary knob.
```

Figure 3-2. MEASURE: SAMPLING SETUP Page for Initial Test

Ramp Stress Test

After the initial test, the sample program executes the ramp stress test. Linear stepped voltage is applied to the oxide.

The measurement setup for the ramp stress test is stored in the VRSWEP.MES setup file on the diskette. At the beginning of the sample program, this setup is loaded into internal memory (MEM2). Then, at the beginning of the ramp stress test, the sample program loads this setup into the HP 4155A/4156A.

To force proper stepped voltage, the sample program and VRSWEP.MES set the following:

- SMU channel definition (see Figure 3-3):

  SMU4 is set to force a constant 0 V, and SMU1 is set to voltage sweep mode.

- Constant step interval time (see Figure 3-5):

  Step interval time of output sweep voltage must be constant.

- Measurement stop mode:

  If the current through the oxide reaches the specified compliance, the voltage sweep and measurement stops.

- Auto-analysis and user functions:

  After the measurement, the HP 4155A/4156A executes analysis automatically to search for Vbd, and to calculate Qbd.

SMU Channel Definition.

The sample program assumes the connection between the SMUs and the oxide capacitor as shown in Figure 3-3. SMU4 is set to force a constant 0 V, and SMU1 is set to voltage sweep mode by the VRSWEP.MES setup as shown in Figure 3-4.

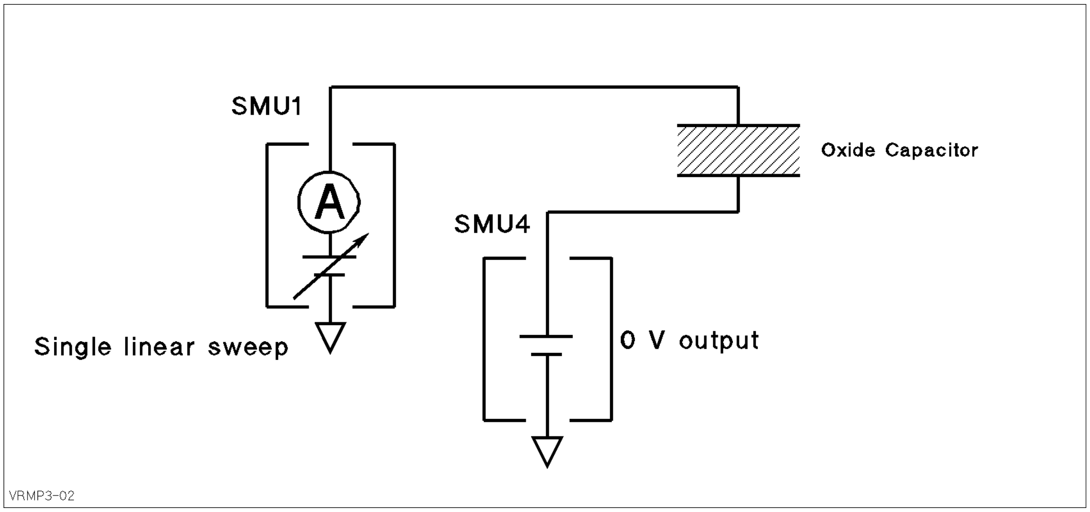
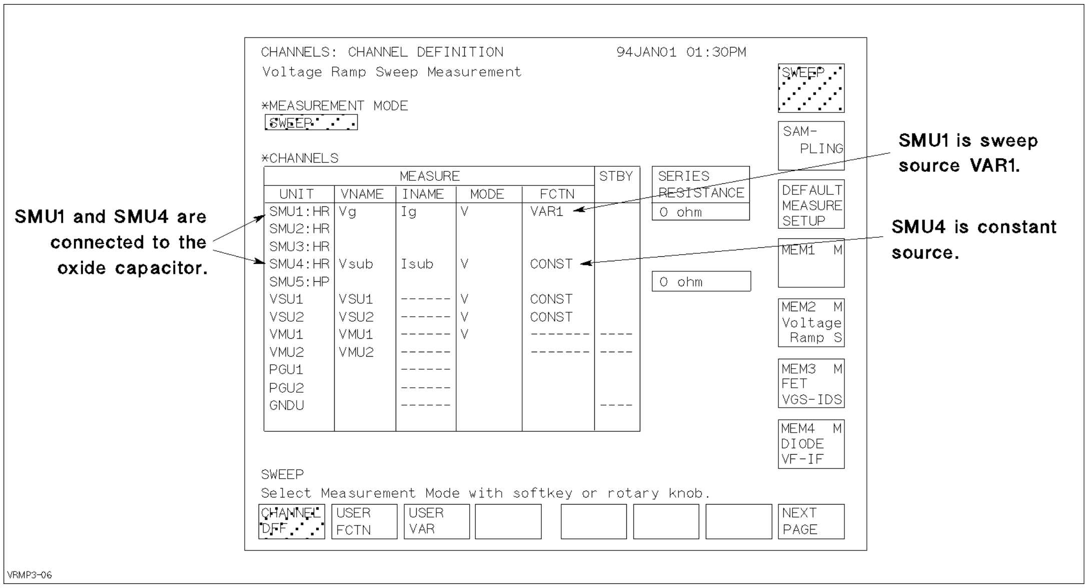


Figure 3-3. Simplified Measurement Circuit of Ramp Stress Test


CHANNELS: CHANNEL DEFINITION 94JAN01 01:30PM
Voltage Ramp Sweep Measurement

*MEASUREMENT MODE
SWEEP

*CHANNELS

MEASURE					STBY
UNIT	VNAME	INAME	MODE	FCTN	
SMU1:HR	Vg	Ig	V	VAR1	
SMU2:HR					
SMU3:HR					
SMU4:HR	Vsub	Isub	V	CONST	
SMU5:HP					
VSU1	VSU1	------	V	CONST	
VSU2	VSU2	------	V	CONST	
VMU1	VMU1	------	V	-------	----
VMU2	VMU2	------		-------	----
PGU1		------			
PGU2		------			
GNDU		------			----

SERIES RESISTANCE
0 ohm
0 ohm

SWEEP
Select Measurement Mode with softkey or rotary knob.

SMU1 and SMU4 are connected to the oxide capacitor.

SMU1 is sweep source VAR1.

SMU4 is constant source.

Figure 3-4. CHANNELS: CHANNEL DEFINITION Page for Ramp Stress Test

Constant step interval time.

To keep a constant step interval time for the voltage sweep and measurement, triggering and measurement ranging techniques are used. VRSWEP.MES sets the measurement ranging mode to FIXED, so the time between measurements does not vary due to range changing.

VRSWEP.MES enables the TRIG OUT function, and the sample program calculates and sets values so that the step interval time becomes constant as shown in Figure 3-5. The *step interval time* (`Step_time`) is the *delay time* (`Step_delay_t`) plus *step delay time* (`Step_keep_t`). Strictly speaking, the sample program calculates these as follows:

```
Step_time = Vstep/(Ramp_rate*Tox) - 1.2 ms + 0.1 ms
Step_delay_t = Step_time/2
Step_keep_t = Step_time - Step_delay_t
```

Where,

- 1.2 ms is overhead time associated with the *delay time* for voltage sweep measurement, when the WAIT TIME field is set to 0 (zero). So, do not set another value in this field.
- 0.1 ms is overhead time associated with the TRIG OUT function.
- Ramp rate (`Ramp_rate`), oxide thickness (`Tox`), and step voltage (`Vstep`) are specified in lines 1800 to 1840 of the sample program.

The start voltage (`Vstart`), stop voltage (`Vstop`), and step voltage (`Vstep`) are specified in sample program in lines 1830 to 1850. For NMOS devices, the ramp stress test subprogram actually sets the opposite polarity for these values by using the `Tp` variable.

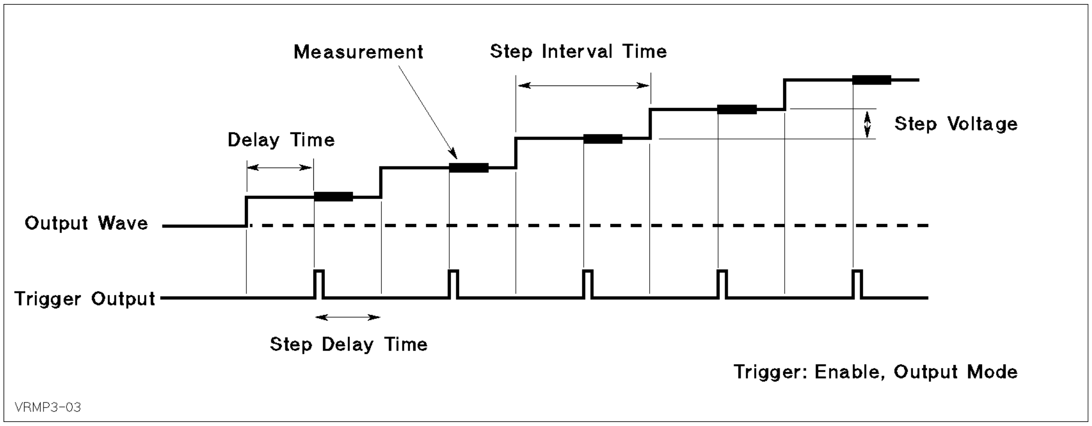
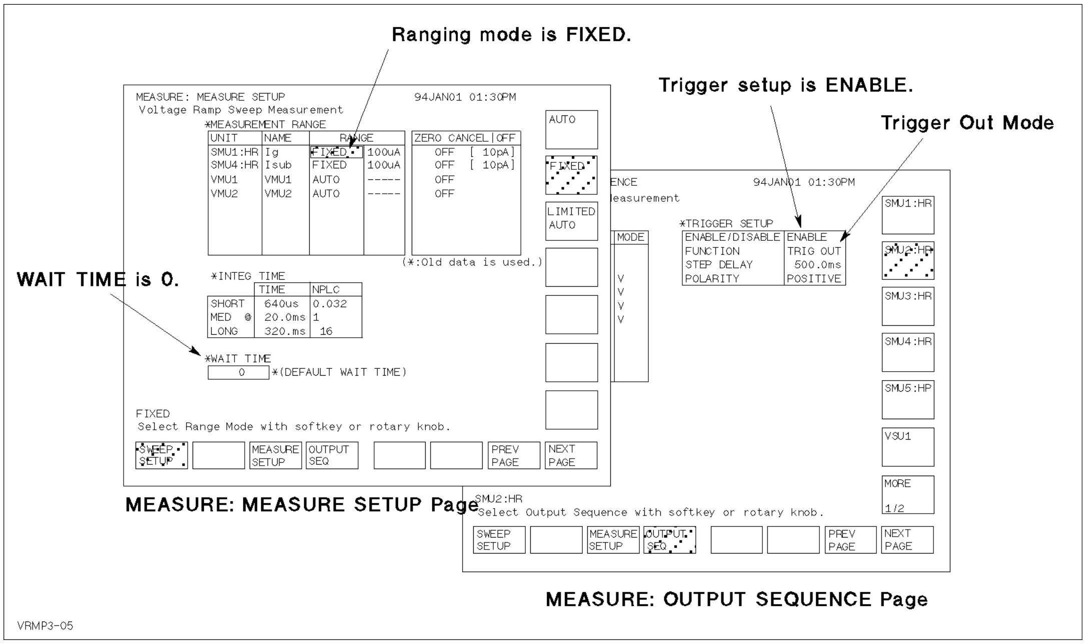


Figure 3-5. Output Sweep Voltage for Ramp Stress Test



MEASURE: MEASURE SETUP 94JAN01 01:30PM
Voltage Ramp Sweep Measurement

*MEASUREMENT RANGE

UNIT	NAME	RANGE		ZERO CANCEL|OFF
SMU1:HR	Ig	FIXED	100uA	OFF [10pA]
SMU4:HR	Isub	FIXED	100uA	OFF [10pA]
VMU1	VMU1	AUTO	-----	OFF
VMU2	VMU2	AUTO	-----	OFF

(*:Old data is used.)

*INTEG TIME

	TIME	NPLC
SHORT	640us	0.032
MED @	20.0ms	1
LONG	320.ms	16

*WAIT TIME
0 *(DEFAULT WAIT TIME)

FIXED
Select Range Mode with softkey or rotary knob.

ENCE 94JAN01 01:30PM
easurement

*TRIGGER SETUP

ENABLE/DISABLE	ENABLE
FUNCTION	TRIG OUT
STEP DELAY	500.0ms
POLARITY	POSITIVE

SMU2:HR
Select Output Sequence with softkey or rotary knob.

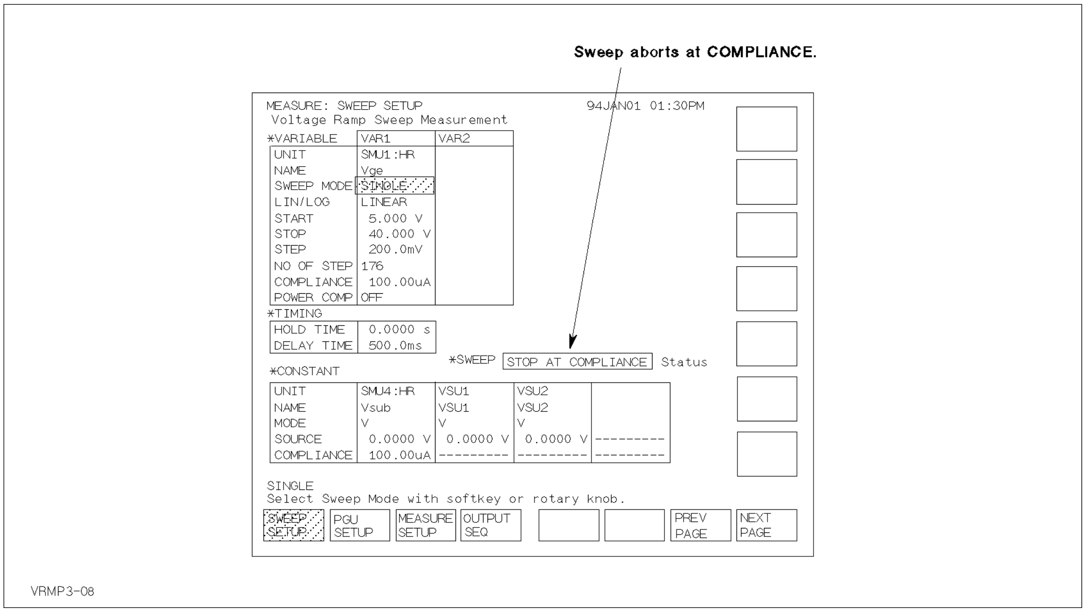
Figure 3-6. MEASURE: MEASURE SETUP and OUTPUT SEQUENCE Pages for Ramp Stress Test

Measurement stop mode.

Note

The JEDEC standard says that the ramp stress test should abort when the current through the oxide reaches 10 times the expected current (`Iexpect`). But this sample program aborts when the current reaches current compliance (`Igcomp`). The `Iexpect` and `Igcomp` values are specified in lines 1860 and 1870 of the sample program, and must meet the following condition: `Igcomp` ≥ `Iexpect` × 10.

VRSWEP.MES file sets the sweep stop condition to SWEEP STOP AT COMPLIANCE as shown in the Figure 3-7.



Sweep aborts at COMPLIANCE.

MEASURE: SWEEP SETUP 94JAN01 01:30PM
Voltage Ramp Sweep Measurement

*VARIABLE	VAR1	VAR2
UNIT	SMU1:HR	
NAME	Vge	
SWEEP MODE	SINGLE	
LIN/LOG	LINEAR	
START	5.000 V	
STOP	40.000 V	
STEP	200.0mV	
NO OF STEP	176	
COMPLIANCE	100.00uA	
POWER COMP	OFF	

*TIMING

HOLD TIME	0.0000 s
DELAY TIME	500.0ms

*SWEEP STOP AT COMPLIANCE Status

*CONSTANT

UNIT	SMU4:HR	VSU1	VSU2	
NAME	Vsub	VSU1	VSU2	
MODE	V	V	V	
SOURCE	0.0000 V	0.0000 V	0.0000 V	---------
COMPLIANCE	100.00uA	---------	---------	---------

SINGLE
Select Sweep Mode with softkey or rotary knob.

Figure 3-7. MEASURE: SWEEP SETUP Page for Ramp Stress Test

Auto-analysis and user functions.
The sample program does the following:

1. Sets up the maximum and minimum values for graph axes: X, Y1, and Y2. Lines 2940 to 2980.
2. Performs the measurement. Line 3020.
3. Moves marker to maximum `Ig`, and saves value to `Igmax`. Lines 3100 to 3170.
4. Moves marker to position where `Ig` = `Iexpect*10`. Line 3200.
5. If compliance was reached or if `Igmax` ≥ `Iexpect*10`, the sample program reads the value of `Vbd` and `Qbd` at present marker position. Lines 3250 to 3320. Where `Vdb` and `Qbd` are specified as described below.

The VRSWEP.MES setup file defines user functions on the CHANNELS: USER FUNCTION DEFINITION page (see Figure A-8) as follows:

Table 3-1. User Functions for Ramp Stress Test

Name	Units	Definition
Time	(sec)	@INDEX * 1[1]
Vbd	(V)	@MY2
Qbd	(Q)	INTEG(Ig,Time)

[1] This is a temporary value. Value of `Time` is redefined by line 2810 of the sample program.

The above user function calculates `Qbd` as follows:

$$Qbd = \int_{T_{start}}^{T_{bd}} Imeas(t)dt = \frac{1}{2}\sum_{i=2}^{N}(Imeas_i + Imeas_{i-1}) \times (T_i - T_{i-1})$$

Where, N is step number when the breakdown occurs.

Post Stress Test

Post stress test checks the oxide status after the ramp stress test.

The methodology of the post stress test is the same as for initial test. The normal operating voltage (`Vuse`) is applied to the oxide, then the leakage current (I_{leak}) is measured.

For the measurement circuit, connections, and measurement setups, see "Initial Test".

Failure Categorization

Table 3-2 shows the oxide failure categories that are determined by the sample program. The failure category is displayed for each device, and `Vbd`, `Qbd`, and `qbd` are also displayed.

The measured data and measurement settings are saved in a file.

Table 3-2. Oxide Failure Categories

Category	Initial Test	Ramp Stress Test	Post Stress Test
Initial	$I_{meas} > 1\ \mu A$	n.a.	n.a.
Catastrophic	$I_{meas} \leq 1\ \mu A$	$I_{meas} \geq I_{expect} \times 10$, or I compliance reached.	$I_{meas} > 1\ \mu A$
Masked Catastrophic	$I_{meas} \leq 1\ \mu A$	$I_{meas} < I_{expect} \times 10$, and I compliance not reached.	$I_{meas} > 1\ \mu A$
Non-catastrophic	$I_{meas} \leq 1\ \mu A$	$I_{meas} \geq I_{expect} \times 10$, or I compliance reached.	$I_{meas} \leq 1\ \mu A$
Other	$I_{meas} \leq 1\ \mu A$	$I_{meas} < I_{expect} \times 10$, and I compliance not reached.	$I_{meas} \leq 1\ \mu A$

Required Equipment

The following equipment is required to use the V-Ramp sample program:

- HP 4155A or HP 4156A Semiconductor Parameter Analyzer
- Two triaxial cables
- Probe station
- This operation manual
- Diskette that contains sample program file and two setup files

Files on the Diskette

The following files are stored in the sample diskette:

VRAMP	V-Ramp sample program. This is an IBASIC program file saved in ASCII format.
VRSPOT.MES	Measurement setup file for initial and post stress test.
VRSWEP.MES	Measurement setup file for ramp stress test.

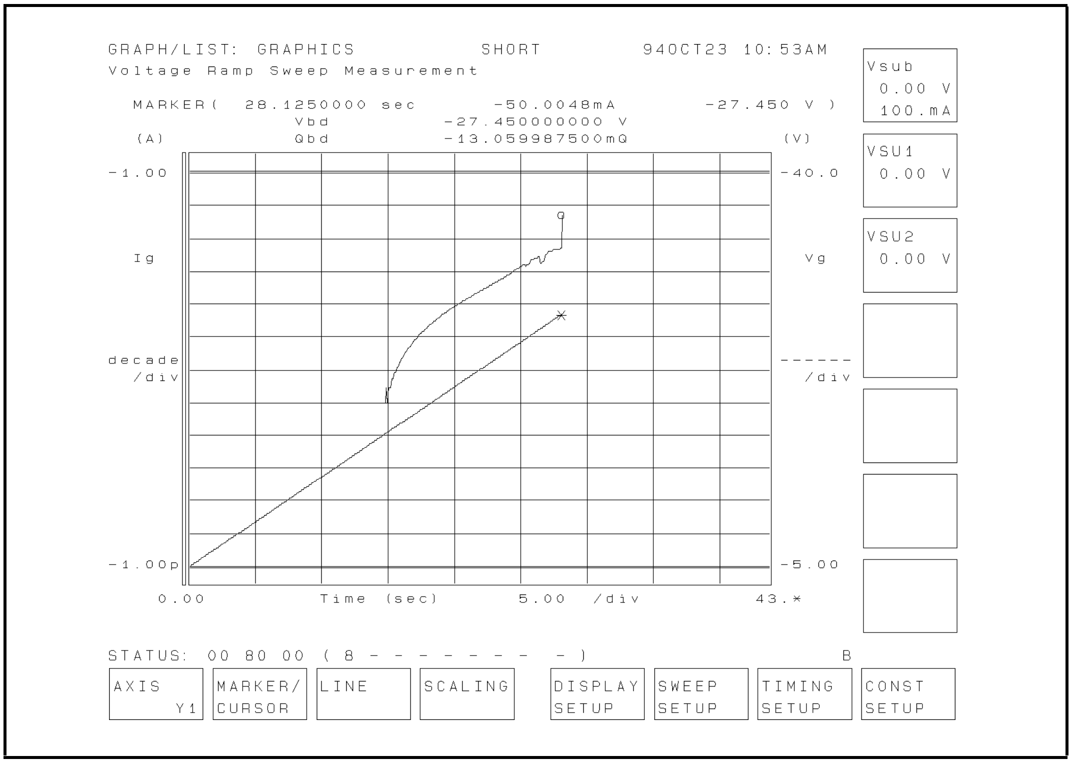
Executing the VRAMP Program

Before executing the program, you may need to customize the program to suit your test device. See Chapter 4.

To execute the sample program, use the following procedure:

1. Connect your HP 4155A/4156A to your test device. See Figure 3-1.
2. Turn on your HP 4155A/4156A.
3. Insert the diskette containing the VRAMP program into the built-in 3.5 inch flexible disk drive.
4. Press (Display) key in the IBASIC area of the front panel until All IBASIC screen is displayed.
5. Load the VRAMP program. Type: `GET "VRAMP"` (Enter).
6. Press (RUN) key in the IBASIC area of the front panel to start the program.

Measurement results similar to Figure 3-8 will be displayed on the GRAPHICS page of the HP 4155A/4156A.



```
GRAPH/LIST: GRAPHICS            SHORT          94OCT23 10:53AM
Voltage Ramp Sweep Measurement

  MARKER(  28.1250000 sec       -50.0048mA        -27.450  V )
               Vbd          -27.450000000 V
               Qbd          -13.059987500mQ

STATUS: 00 80 00 ( 8 - - - - - - -   - )                     B
```

Figure 3-8. An Example of Measurement Results

Note that this example is obtained when the maximum electric field is set to 50 MV/cm.

Flowchart of Sample VRAMP Program

Figure 3-9 shows flowchart of sample VRAMP program and corresponding subprogram names.

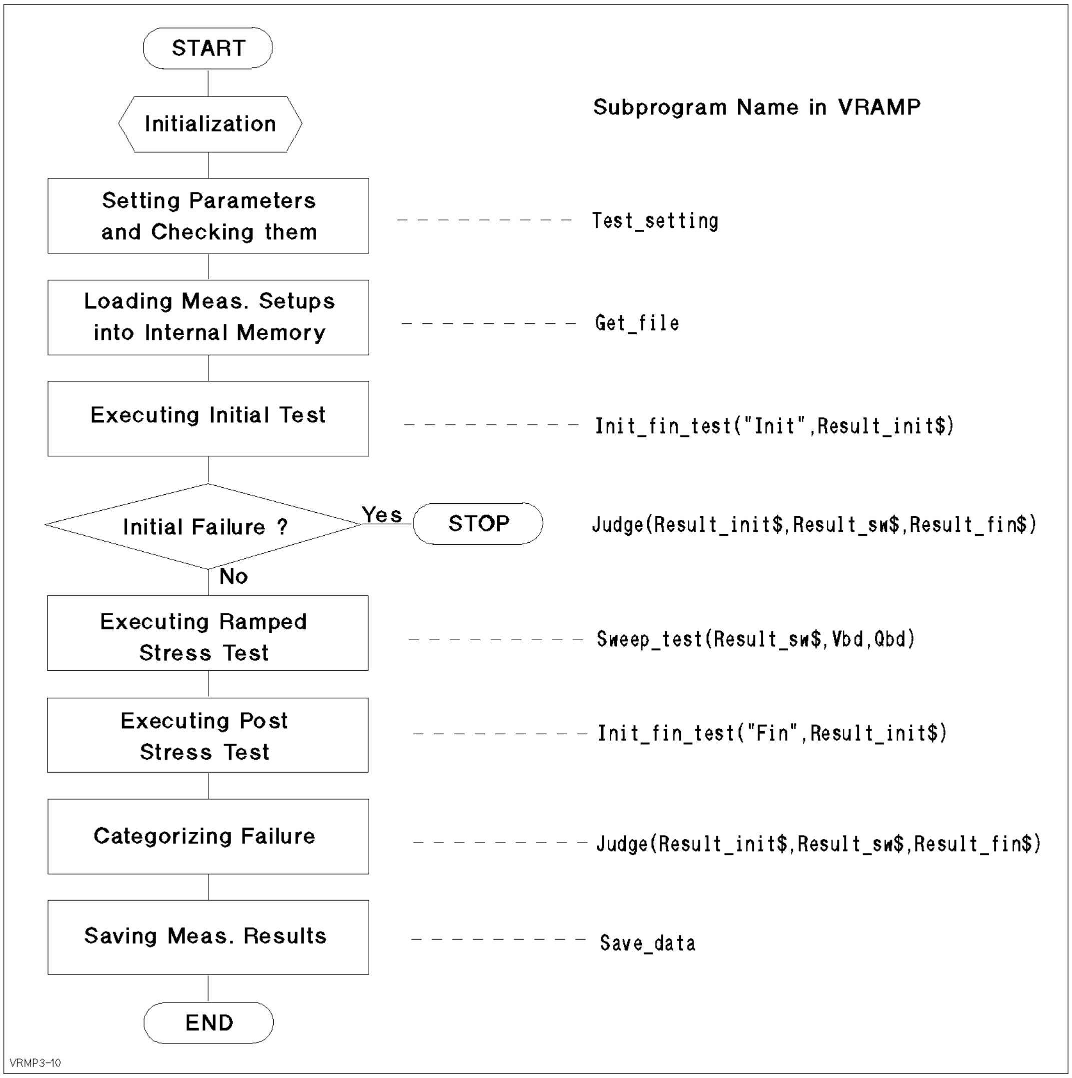


Figure 3-9. Flowchart of Sample VRAMP Program

The following provides a brief description for each subprogram.

`Test_setting`	Specifies and checks the parameter values. These are values that the program will set directly instead of some of the setup file values.
`Get_file`	Loads measurement setup files from the diskette into internal memory: spot measurement setup into MEM1, and sweep measurement setup into MEM2. Having the measurement setups in internal memory reduces the measurement time.
`Init_fin_test`	Executes the spot measurement for initial test or for post stress test. First parameter specifies the test: `Init` is for initial test, and `Fin` is for post stress test. The measurement results are returned to the second parameter.
`Judge`	Categorizes failure according to measurement results of initial, ramped stress, and post stress tests. If the failure is initial failure, this subprogram aborts the program.
`Sweep_test`	Executes sweep measurement for ramped stress test, then returns the result flag, `Vbd`, and `Qbd` to the three parameters. The measurement result data is temporarily stored in internal memory (MEM3).
`Save_data`	Saves measurement result data (that is in MEM3) to a file on the diskette.

4

Customization

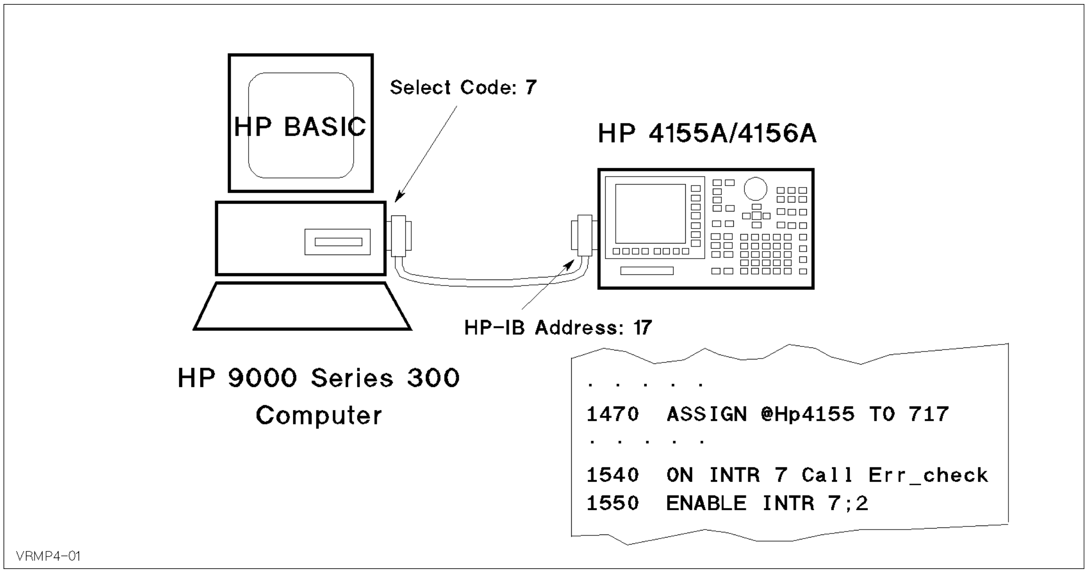
This chapter describes how to customize the sample program to suit your test device.

Using an External Computer

This sample program (VRAMP) is assumed to run on HP Instrument BASIC that is built into the HP 4155A/4156A. The HP 4155A/4156A is used as both the measurement instrument and the controller running IBASIC, so VRAMP sets device selector *800*. On the following three lines, the HP 4155A/4156A is assigned and interrupt from it is enabled as follows:

```
1470  ASSIGN @Hp4155 TO 800
   :
1540  ON INTR 8 CALL Err_check
1550  ENABLE INTR 8;2
```

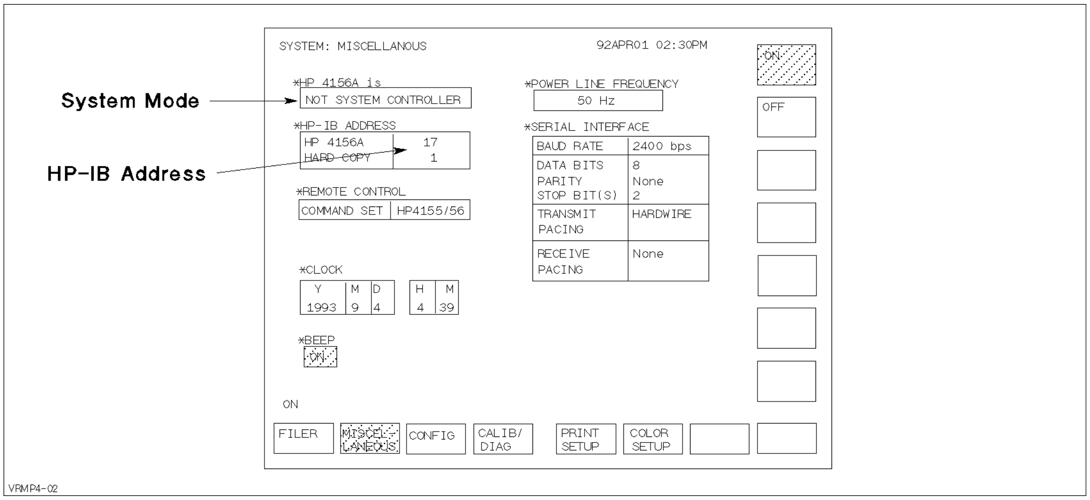
If you use an external controller (that can run HP BASIC environment) to control the HP 4155A/4156A, you need to modify a few lines of the sample program. For example, if you use HP BASIC/WS on an HP 9000 Series 300 computer, you only need to modify lines the above three lines as follows:



```
. . . . . .
1470  ASSIGN @Hp4155 TO 717
. . . . . .
1540  ON INTR 7 Call Err_check
1550  ENABLE INTR 7;2
```

In this case, the HP 4155A/4156A has HP-IB address 17 and is not used as the system controller, and is connected to the built-in HP-IB of the HP 9000 series 300 controller with an HP-IB cable. Use the following procedure to set the HP-IB address and system mode:

1. Turn on your HP 4155A/4156A.
2. Press (System) key.
3. Select `MISCELLANEOUS` softkey.
4. Move the field pointer to the "HP 415x is ` `" field, then select the `NOT CONTROLLER` softkey.
5. Move the field pointer to the "HP 415x" field in the HP-IB ADDRESS area, then enter: `17` (Enter).



SYSTEM: MISCELLANOUS 92APR01 02:30PM

*HP 4156A is
NOT SYSTEM CONTROLLER

*HP-IB ADDRESS

HP 4156A	17
HARD COPY	1

*REMOTE CONTROL

COMMAND SET	HP4155/56

*CLOCK

Y	M	D	H	M
1993	9	4	4	39

*BEEP
ON

*POWER LINE FREQUENCY
50 Hz

*SERIAL INTERFACE

BAUD RATE	2400 bps
DATA BITS	8
PARITY	None
STOP BIT(S)	2
TRANSMIT PACING	HARDWIRE
RECEIVE PACING	None

Specifying Setup File to Load

Two setup files are used to set up the HP 4155A/4156A for the V-Ramp test: one is used for initial and post stress tests, and the other is for ramp stress test.

Filenames of these setups are defined on the following lines:

```
1730    Init_file$="VRSPOT.MES"    ! Spot Measurement Setup File Name
1740    Sweep_file$="VRSWEP.MES"   ! Sweep Measurement Setup File Name
```

If you want to use other setup files, store the setup files on the diskette, then modify the filenames on the lines above.

File for Saving Measurement Results

The following lines specify the filename for the measurement results file. The filename starts with "`D`", then *HHMMS*, then ends with "`.DAT`". Where *HH* is hour, *MM* is minute, and *S* is second (tens digit only).

```
1750  Save_file$=TIME$(TIMEDATE) ! File Name for saving measurement results
1760  Save_file$="D"&Save_file$[1,2]&Save_file$[4,5]&Save_file$[7,7]&".DAT"
```

The following line commands the HP4155A/4156A to create the specified file on the diskette, then stores the result data in the file.

```
3860  OUTPUT @Hp4155;":MMEM:STOR:TRAC DEF,'"&Save_file$&"','DISK'"
```

For example, "`D09344.DAT`" file that contains measurement data is created on the diskette. This filename means the "data file created at 9:34 $4x$ seconds."

To change to your desired filename, you only need to edit line 1760.

Setting up Input Parameters

Input parameter values are specified on the following lines. These are values that the sample program will set directly instead of using some of the setup file values. You can easily modify the values by editing these program lines.

```
1780     Type$="NMOS"              ! Type  NMOS -- P bulk,  PMOS -- N bulk
1790     Vuse=5                    ! Vuse (V)
1800     Ramp_rate=.5*1.E+6        ! Ramp rate (MV/cm*s)
1810     Tox=160*1.E-8             ! Oxide Thickness  (cm)
1820     Area=.001                 ! Gate Area (cm^2)
1830     Vstart=5                  ! Start voltage (V)
1840     Vstop=24                  ! Stop voltage (V)
1850     Vstep=.05                 ! Step voltage (V)
1860     Iexpect=.003              ! Expected breakdown current (A)
1870     Igcomp=.05                ! Ig compliance (A)
```

Parameter	Default	Description
`Type$`	NMOS[1]	Bulk type: NMOS is for P bulk and PMOS is for N bulk
`Vuse`	5 (V)	Normal operating voltage for the device
`Ramp_rate`	5.0×10^5 (MV/cm·s)	Ramp rate of stepped voltage
`Tox`	1.60×10^{-6} (cm)	Thickness of oxide
`Area`	0.001 (cm^2)	Area of target oxide
`Vstart`	5 (V)	Start voltage
`Vstop`	24 (V)	Stop voltage
`Vstep`	50 (mV)	Step voltage
`Iexpect`	3 (mA)	Expected current through the oxide
`Igcomp`	50 (mA)	Current compliance through the oxide

1 If type is NMOS, opposite polarity values for the voltages are actually used later in the program by using the `tp` parameter, which is set to −1 in line 1880.

Searching for 10 × Iexpect

In the VRAMP program, `Iexpect` is set to 0.003 A in line 1860 of the program. However, this is a very simple method and might not give accurate results.

Iexpect is the expected current through the oxide, and is a function of the electric field E. So, the actual *Iexpect* depends on the applied voltage.

To get more accurate results, you can plot a graph of *Iexpect* versus Vg by using the Fowler-Nordheim equation:

$$J = A \cdot E^2 \exp\left(-\frac{B}{E}\right)$$

Where: A and B are constants in terms of effective mass and barrier height. E is electric field.

The oxide capacitor of MOS can be considered to be a parallel plate capacitance, so the oxide thickness (Tox) and its area ($Area$) results in the following:

$$\begin{aligned} Iexpect &= Area \cdot J \\ &= Area \cdot A \cdot \left(\frac{V}{Tox}\right)^2 \exp\left(-\frac{B \cdot Tox}{V}\right) \\ &= \frac{Area \cdot A}{Tox^2} V^2 \exp\left(-\frac{B \cdot Tox}{V}\right) \\ &= \alpha \cdot V^2 \exp\left(\frac{\beta}{V}\right) \end{aligned}$$

Where: V is applied voltage.

To draw the curve for the above equation, you can use a *user function*. For example, when α=100 and β=−415, you set the following user function on the CHANNELS: USER FUNCTION page:

NAME	UNIT	DESCRIPTION
Iexp	A	100*Vg^2*EXP(-415/Vg)

So, after the measurement finishes, you set up `Vg` for the X-Axis, `Ig` for the Y1 axis, and `Iexp` for the Y2 axis on the DISPLAY: DISPLAY SETUP page.

Also, set up analysis so that the marker will move automatically to the point on the curve where `Ig` is equal to `10*Iexp`. In the DISPLAY: ANALYSIS SETUP page, you would set as follows:

```
*MARKER: At a point where
 [Ig    ] = [10*Iexp                                ]
 [    ]
```

This method allows you to find more accurately the `Vbd`, which it the value of `Vg` where `Ig` is equal to `10*Iexp`.

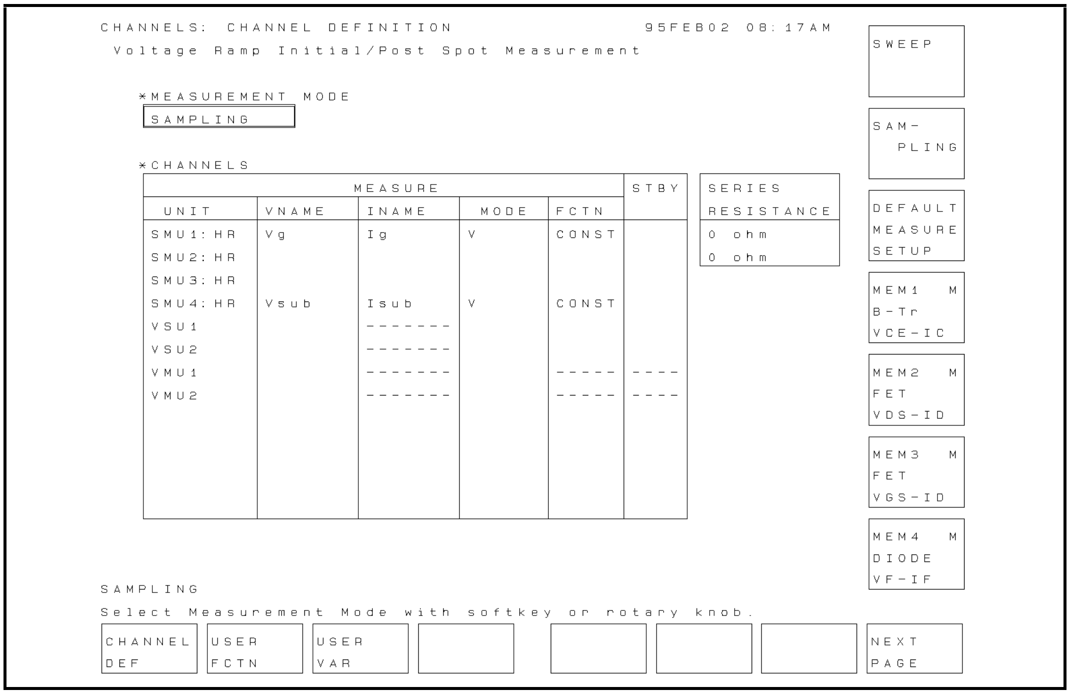
A

Measurement Setups

This appendix covers the measurement setups that are stored in the VRSPOT.MES and VRSWEP.MES files.

Setups for Initial and Post Stress Tests

The measurement setups stored in VRSPOT.MES are used for the initial and post stress tests. The following shows measurement setups of each page.



CHANNELS: CHANNEL DEFINITION 95FEB02 08:17AM

Voltage Ramp Initial/Post Spot Measurement

*MEASUREMENT MODE

SAMPLING

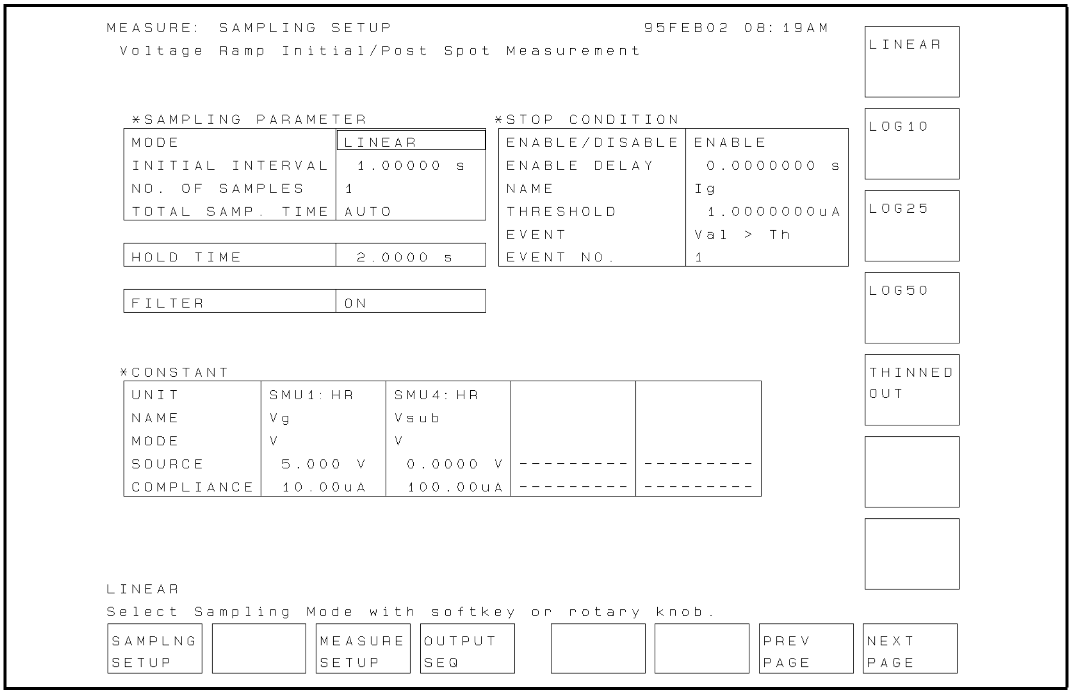
*CHANNELS

MEASURE					STBY	SERIES
UNIT	VNAME	INAME	MODE	FCTN		RESISTANCE
SMU1:HR	Vg	Ig	V	CONST		0 ohm
SMU2:HR						0 ohm
SMU3:HR						
SMU4:HR	Vsub	Isub	V	CONST		
VSU1		-------				
VSU2		-------				
VMU1		-------		-----	----	
VMU2		-------		-----	----	

SAMPLING

Select Measurement Mode with softkey or rotary knob.

Figure A-1. CHANNELS: CHANNEL DEFINITION Page



MEASURE: SAMPLING SETUP 95FEB02 08:19AM

Voltage Ramp Initial/Post Spot Measurement

*SAMPLING PARAMETER

MODE	LINEAR
INITIAL INTERVAL	1.00000 s
NO. OF SAMPLES	1
TOTAL SAMP. TIME	AUTO

HOLD TIME	2.0000 s

FILTER	ON

*STOP CONDITION

ENABLE/DISABLE	ENABLE
ENABLE DELAY	0.0000000 s
NAME	Ig
THRESHOLD	1.0000000uA
EVENT	Val > Th
EVENT NO.	1

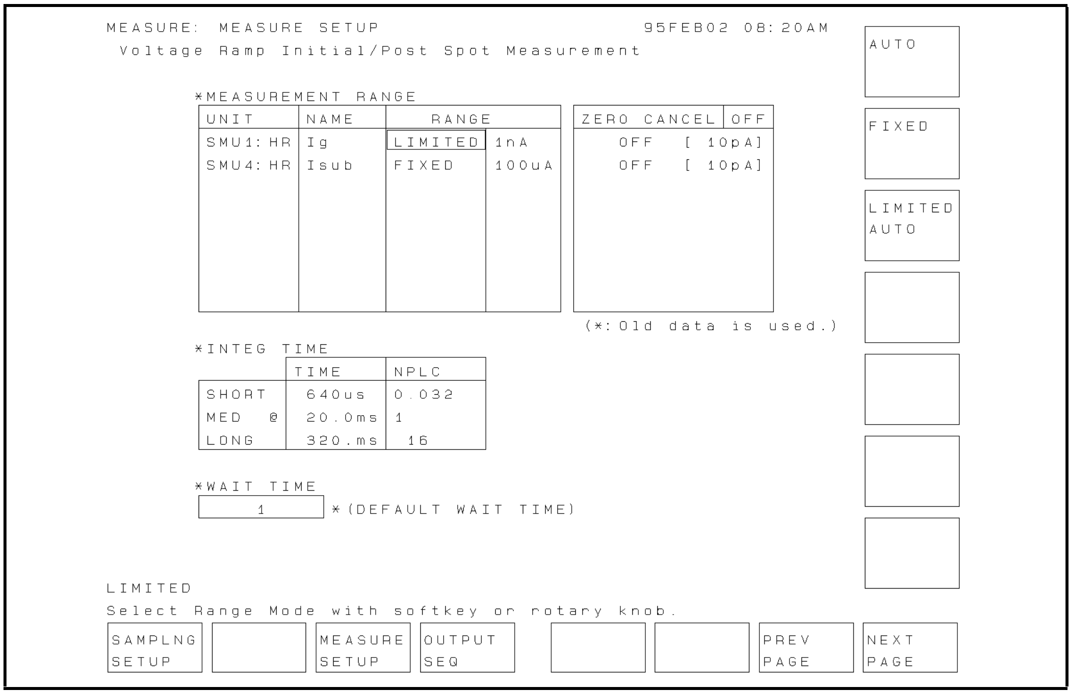
*CONSTANT

UNIT	SMU1:HR	SMU4:HR		
NAME	Vg	Vsub		
MODE	V	V		
SOURCE	5.000 V	0.0000 V	---------	---------
COMPLIANCE	10.00uA	100.00uA	---------	---------

LINEAR

Select Sampling Mode with softkey or rotary knob.

Figure A-2. MEASURE: SAMPLING SETUP Page



MEASURE: MEASURE SETUP 95FEB02 08:20AM

Voltage Ramp Initial/Post Spot Measurement

*MEASUREMENT RANGE

UNIT	NAME	RANGE		ZERO CANCEL	OFF
SMU1:HR	Ig	LIMITED	1nA	OFF	[10pA]
SMU4:HR	Isub	FIXED	100uA	OFF	[10pA]

(*:Old data is used.)

*INTEG TIME

	TIME	NPLC
SHORT	640us	0.032
MED @	20.0ms	1
LONG	320.ms	16

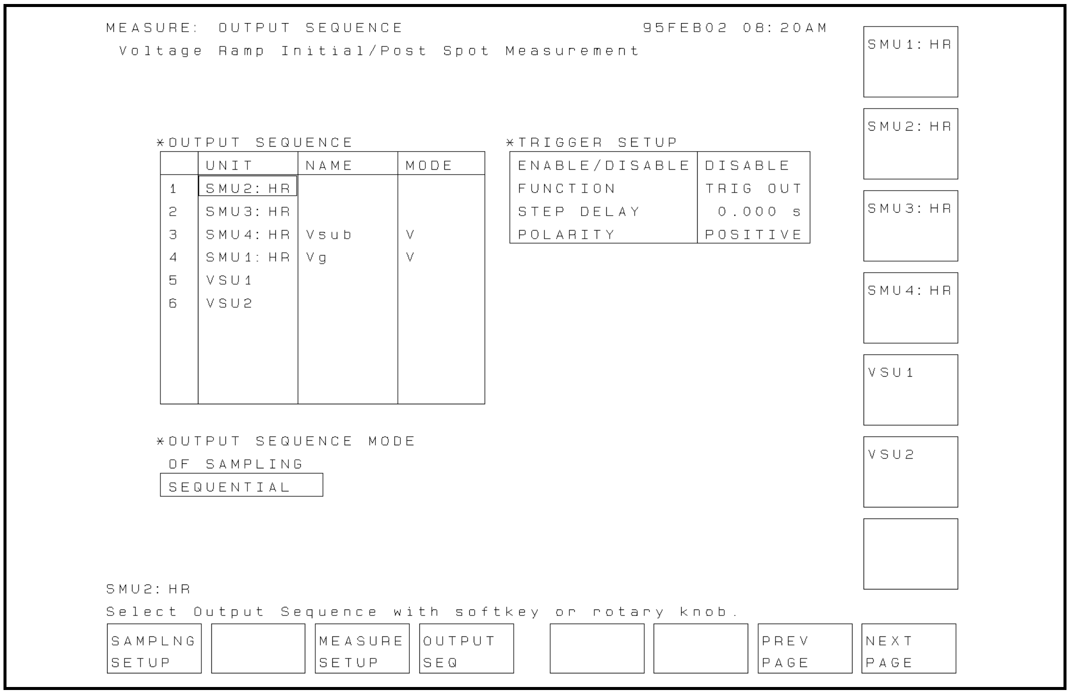
*WAIT TIME

1 *(DEFAULT WAIT TIME)

LIMITED

Select Range Mode with softkey or rotary knob.

Figure A-3. MEASURE: MEASURE SETUP Page



MEASURE: OUTPUT SEQUENCE 95FEB02 08:20AM
Voltage Ramp Initial/Post Spot Measurement

*OUTPUT SEQUENCE

	UNIT	NAME	MODE
1	SMU2:HR		
2	SMU3:HR		
3	SMU4:HR	Vsub	V
4	SMU1:HR	Vg	V
5	VSU1		
6	VSU2		

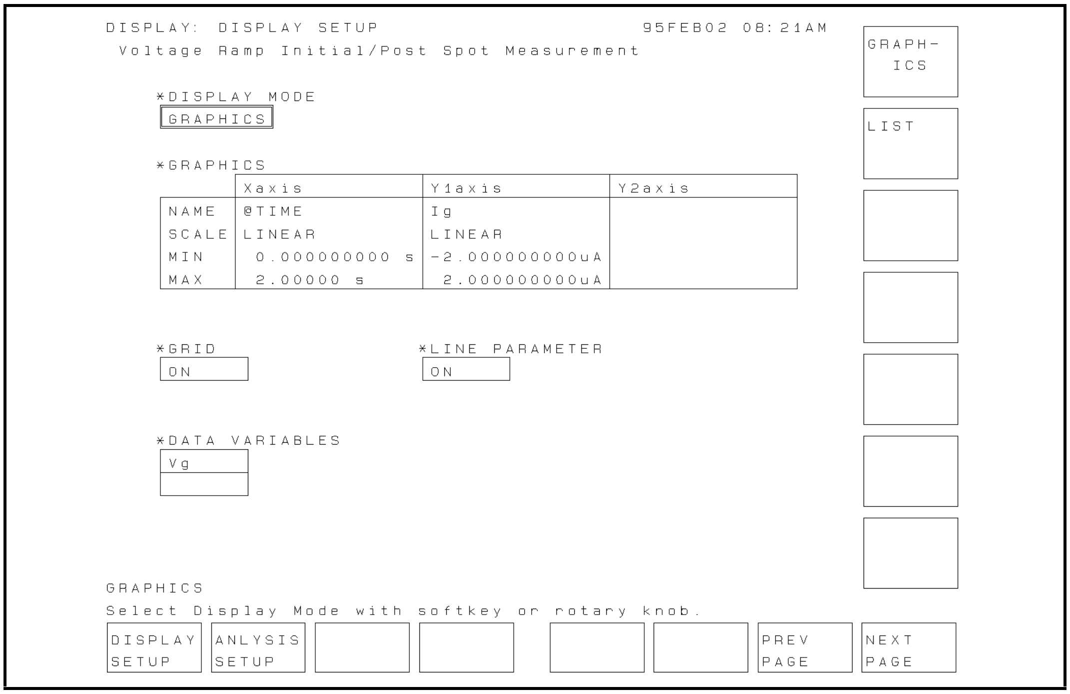
*TRIGGER SETUP

ENABLE/DISABLE	DISABLE
FUNCTION	TRIG OUT
STEP DELAY	0.000 s
POLARITY	POSITIVE

*OUTPUT SEQUENCE MODE
OF SAMPLING
SEQUENTIAL

SMU2:HR
Select Output Sequence with softkey or rotary knob.

Figure A-4. MEASURE: OUTPUT SEQUENCE Page



DISPLAY: DISPLAY SETUP 95FEB02 08:21AM
Voltage Ramp Initial/Post Spot Measurement

*DISPLAY MODE
GRAPHICS

*GRAPHICS

	Xaxis	Y1axis	Y2axis
NAME	@TIME	Ig	
SCALE	LINEAR	LINEAR	
MIN	0.000000000 s	-2.000000000uA	
MAX	2.00000 s	2.000000000uA	

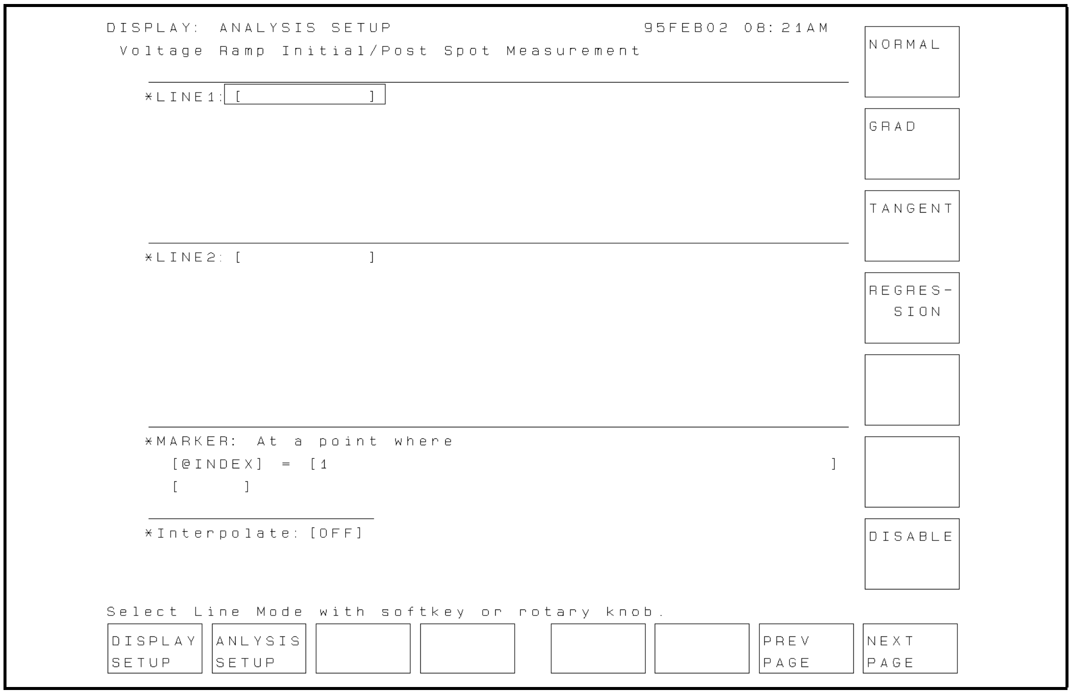
*GRID
ON

*LINE PARAMETER
ON

*DATA VARIABLES
Vg

GRAPHICS
Select Display Mode with softkey or rotary knob.

Figure A-5. DISPLAY: DISPLAY SETUP Page



DISPLAY: ANALYSIS SETUP 95FEB02 08:21AM

Voltage Ramp Initial/Post Spot Measurement

*LINE1: [ ]

*LINE2: [ ]

*MARKER: At a point where

[@INDEX] = [1]

[ ]

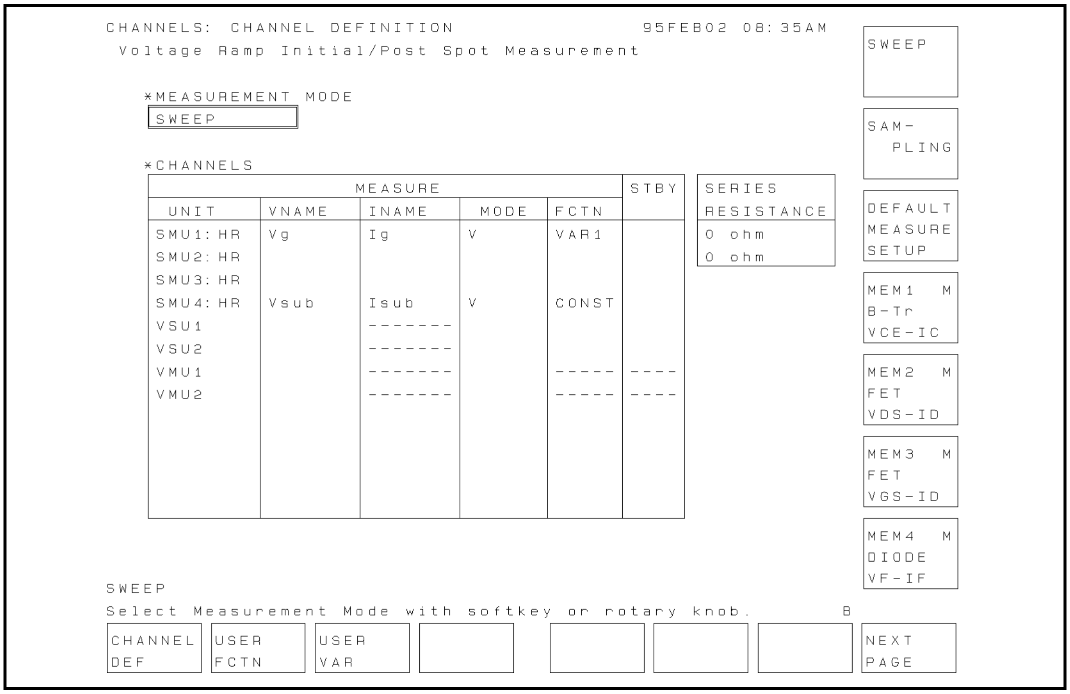
*Interpolate: [OFF]

Select Line Mode with softkey or rotary knob.

Figure A-6. DISPLAY: ANALYSIS SETUP Page

Setups for Ramped Stress Test

The measurement setups that are stored in VRSWEP.MES are used for the ramped stress test. The following shows the measurement setups of each page.



CHANNELS: CHANNEL DEFINITION 95FEB02 08:35AM
Voltage Ramp Initial/Post Spot Measurement

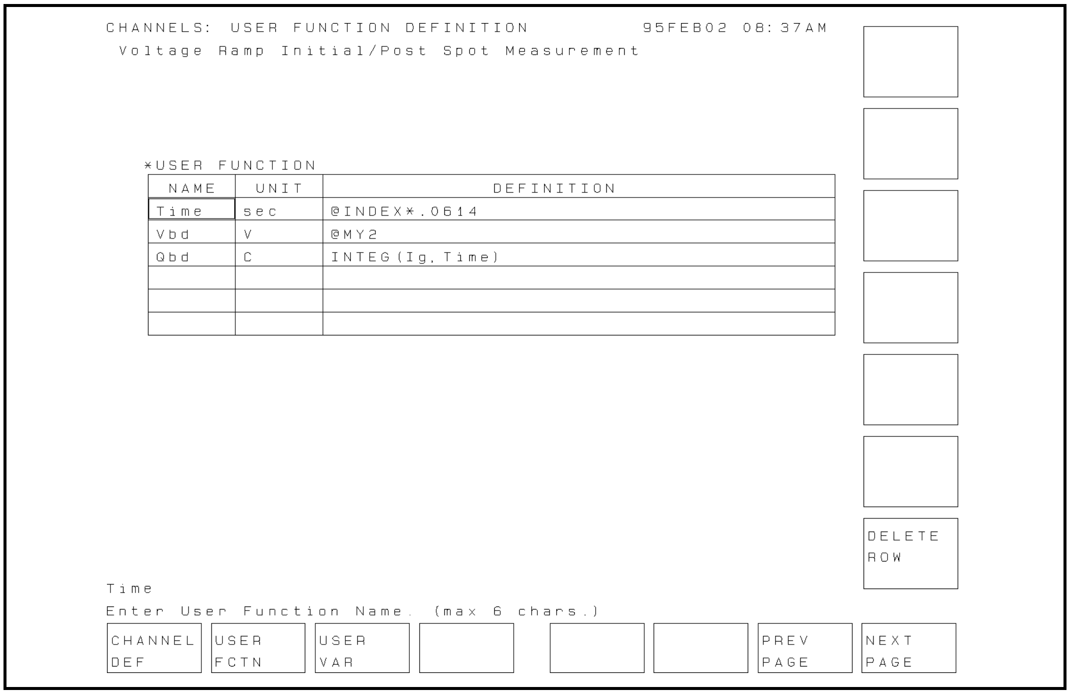
*MEASUREMENT MODE
SWEEP

*CHANNELS

MEASURE					STBY	SERIES
UNIT	VNAME	INAME	MODE	FCTN		RESISTANCE
SMU1:HR	Vg	Ig	V	VAR1		0 ohm
SMU2:HR						0 ohm
SMU3:HR						
SMU4:HR	Vsub	Isub	V	CONST		
VSU1		-------				
VSU2		-------				
VMU1		-------		-----	----	
VMU2		-------		-----	----	

SWEEP
Select Measurement Mode with softkey or rotary knob. B

Figure A-7. CHANNELS: CHANNEL DEFINITION Page



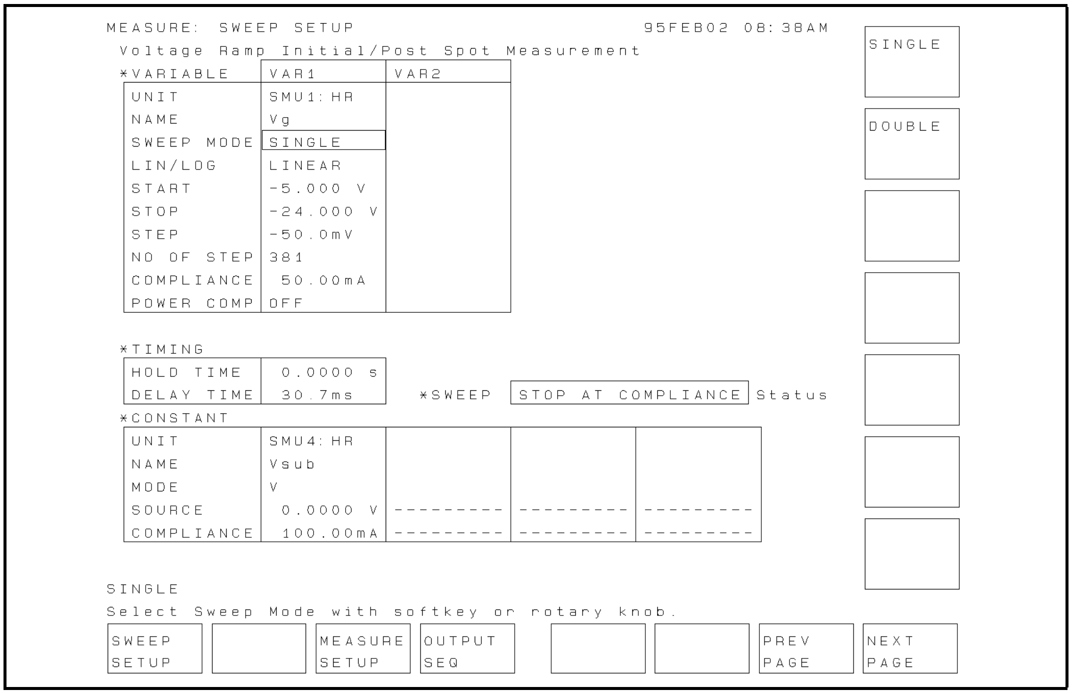
CHANNELS: USER FUNCTION DEFINITION 95FEB02 08:37AM
Voltage Ramp Initial/Post Spot Measurement

*USER FUNCTION

NAME	UNIT	DEFINITION
Time	sec	@INDEX*.0614
Vbd	V	@MY2
Qbd	C	INTEG(Ig,Time)

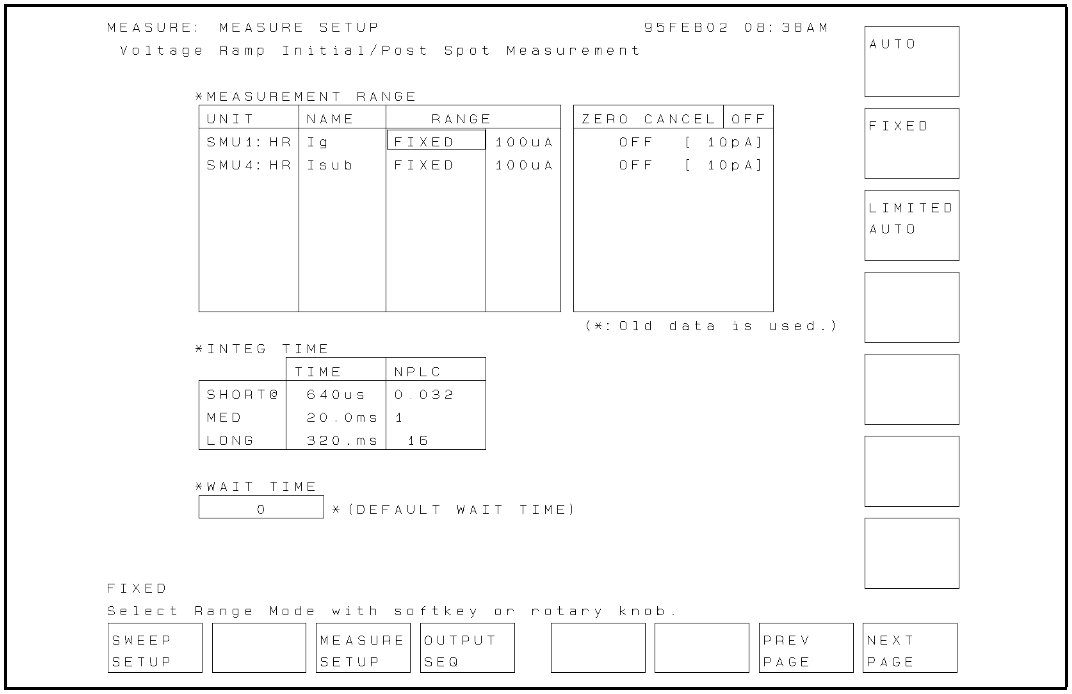
Time
Enter User Function Name. (max 6 chars.)

Figure A-8. CHANNELS: USER FUNCTION DEFINITION Page



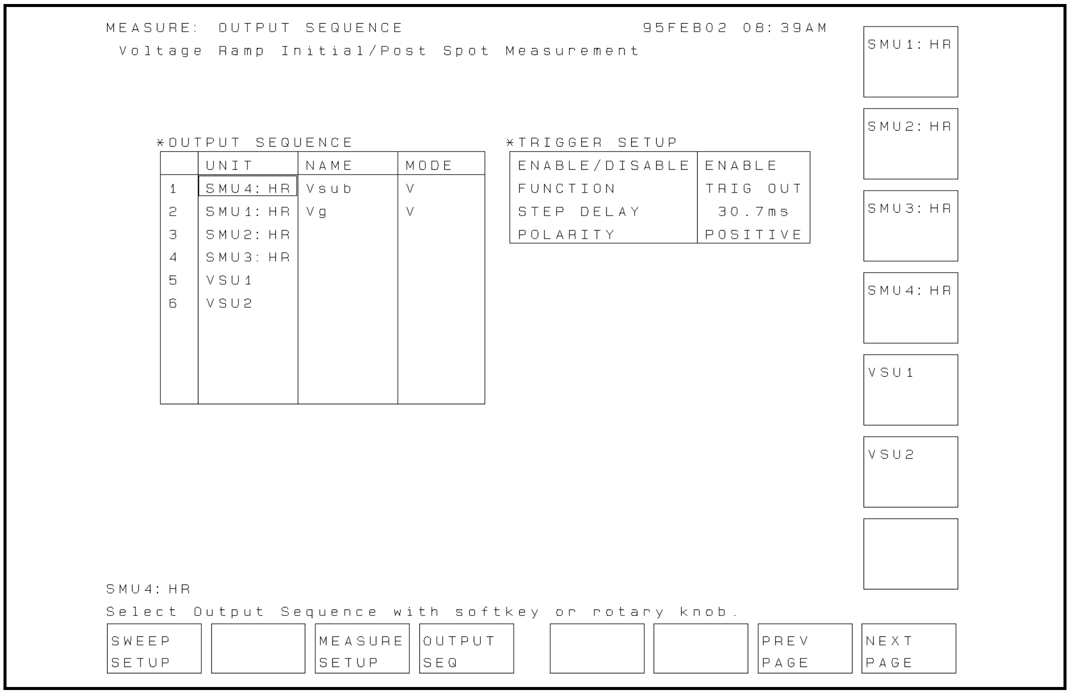
```
MEASURE: SWEEP SETUP                          95FEB02 08:38AM
 Voltage Ramp Initial/Post Spot Measurement
 *VARIABLE     VAR1        VAR2
  UNIT         SMU1:HR
  NAME         Vg
  SWEEP MODE   SINGLE
  LIN/LOG      LINEAR
  START        -5.000 V
  STOP         -24.000 V
  STEP         -50.0mV
  NO OF STEP   381
  COMPLIANCE    50.00mA
  POWER COMP   OFF

 *TIMING
  HOLD TIME     0.0000 s
  DELAY TIME    30.7ms      *SWEEP  STOP AT COMPLIANCE Status
 *CONSTANT
  UNIT         SMU4:HR
  NAME         Vsub
  MODE         V
  SOURCE        0.0000 V  ---------  ---------  ---------
  COMPLIANCE    100.00mA  ---------  ---------  ---------

SINGLE
Select Sweep Mode with softkey or rotary knob.
```

Figure A-9. MEASURE: SWEEP SETUP Page



```
MEASURE: MEASURE SETUP                        95FEB02 08:38AM
 Voltage Ramp Initial/Post Spot Measurement

           *MEASUREMENT RANGE
            UNIT     NAME       RANGE           ZERO CANCEL OFF
            SMU1:HR  Ig     FIXED    100uA        OFF  [ 10pA]
            SMU4:HR  Isub   FIXED    100uA        OFF  [ 10pA]

                                                (*:Old data is used.)
           *INTEG TIME
                      TIME     NPLC
            SHORT@    640us    0.032
            MED       20.0ms   1
            LONG      320.ms    16

           *WAIT TIME
                 0        *(DEFAULT WAIT TIME)

FIXED
Select Range Mode with softkey or rotary knob.
```

Figure A-10. MEASURE: MEASURE SETUP Page



MEASURE: OUTPUT SEQUENCE 95FEB02 08:39AM

Voltage Ramp Initial/Post Spot Measurement

*OUTPUT SEQUENCE

	UNIT	NAME	MODE
1	SMU4:HR	Vsub	V
2	SMU1:HR	Vg	V
3	SMU2:HR		
4	SMU3:HR		
5	VSU1		
6	VSU2		

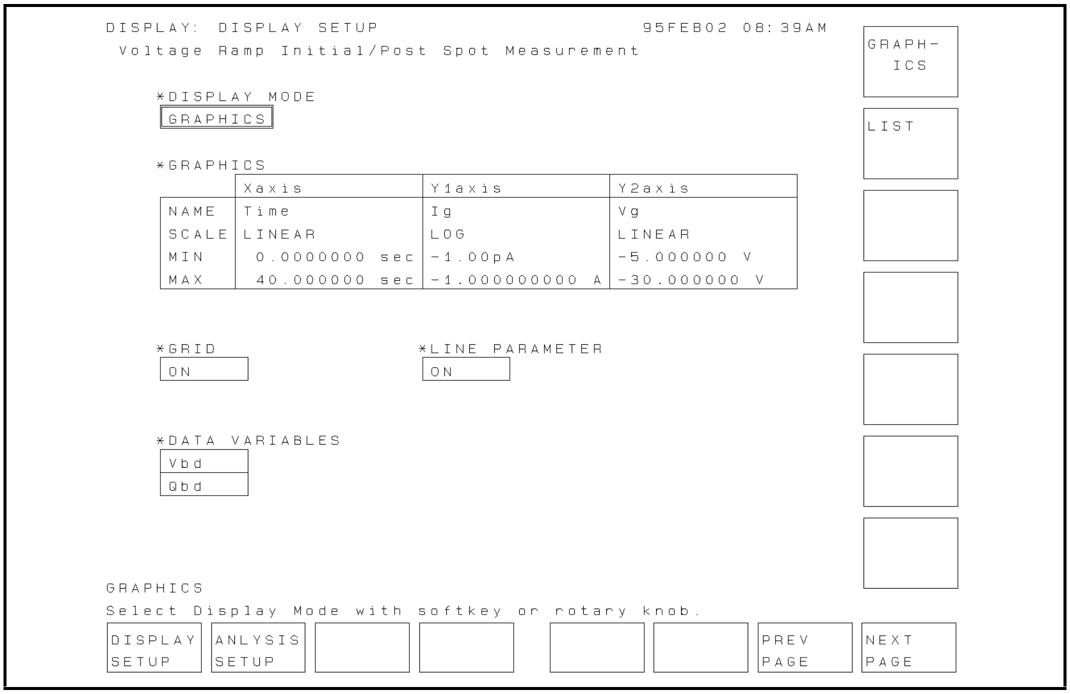
*TRIGGER SETUP

ENABLE/DISABLE	ENABLE
FUNCTION	TRIG OUT
STEP DELAY	30.7ms
POLARITY	POSITIVE

SMU4:HR

Select Output Sequence with softkey or rotary knob.

Figure A-11. MEASURE: OUTPUT SEQUENCE Page



DISPLAY: DISPLAY SETUP 95FEB02 08:39AM

Voltage Ramp Initial/Post Spot Measurement

*DISPLAY MODE

GRAPHICS

*GRAPHICS

	Xaxis	Y1axis	Y2axis
NAME	Time	Ig	Vg
SCALE	LINEAR	LOG	LINEAR
MIN	0.0000000 sec	-1.00pA	-5.000000 V
MAX	40.000000 sec	-1.000000000 A	-30.000000 V

*GRID

ON

*LINE PARAMETER

ON

*DATA VARIABLES

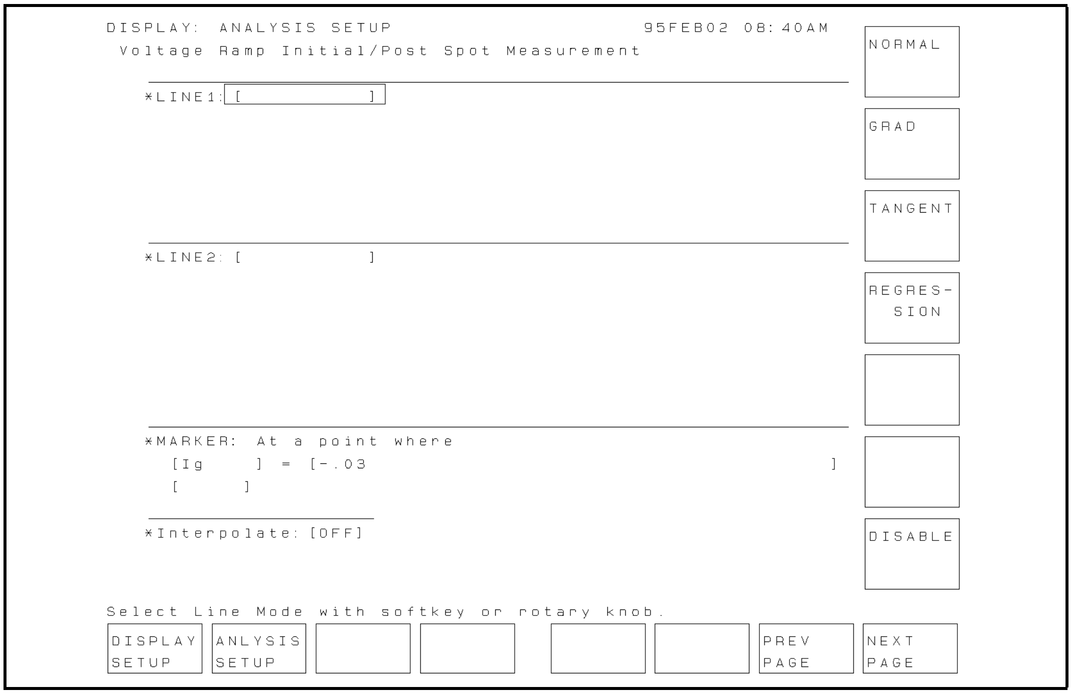
Vbd

Qbd

GRAPHICS

Select Display Mode with softkey or rotary knob.

Figure A-12. DISPLAY: DISPLAY SETUP Page



DISPLAY: ANALYSIS SETUP 95FEB02 08:40AM
Voltage Ramp Initial/Post Spot Measurement

*LINE1:[ ]

*LINE2:[ ]

*MARKER: At a point where
[Ig] = [-.03]
[ ]

*Interpolate:[OFF]

Select Line Mode with softkey or rotary knob.

Figure A-13. DISPLAY: ANALYSIS SETUP Page

HP 4155A/4156A Precision Semiconductor Parameter Analyzer

J-RAMP Sample Program Operation Manual

HEWLETT
PACKARD

HP Part No. 04155-90130
Printed in Japan March 1995

Edition 1

Contents

Figures

Tables

1

Introduction

Current-Ramped (J-Ramp) test is one of the Wafer Level Reliability (WLR) tests, which is used to evaluate device reliability on a wafer. This test can provide quick evaluation data for estimating the overall reliability of thin oxides, and this data can be used to improve the thin oxide manufacturing process.

With the thickness of oxide shrinking along with device geometries, creating a reliable thin oxide has become an important issue. The integrity of the thin oxide in a MOS device is a dominant factor in determining the overall reliability of a micro-circuit. The J-Ramp test can promptly give useful feedback to the manufacturing process about oxide reliability.

This operation manual covers a sample J-Ramp program running on the HP 4155A/4156A, and how to use and customize the program. The program is written in HP Instrument BASIC (IBASIC), and is ready to run on the built-in IBASIC controller of the HP 4155A/4156A.

Note

This is a sample program, so you may need to customize the program and setup files for your application before execution. If the sample program damages your device, Hewlett-Packard is *not liable* for the damages.

Contents of This Manual

Chapter 2 describes basic theory, procedure, and terminology of the J-Ramp test.

Chapter 3 describes the J-Ramp sample program. Included are J-Ramp methodology using the HP 4155A/4156A, how to execute the sample program, and program overview.

Chapter 4 describes how to customize the sample program. This is very helpful because you probably need to modify the sample program to suit your test device.

`***<xref PROGRAM-LIST>: undefined***` shows the sample program list.

Appendix A shows HP 4155A/4156A page settings that are stored in the setup files.

Appendix B shows how to solve equations described in chapter 3.

2

Theory of J-Ramp Test Procedure

This chapter covers Current Ramped (J-Ramp) Test procedure. Included are basic theory, procedure, and terminology of J-Ramp test.

The J-Ramp test procedure is based on the JEDEC standard No.35.

J-Ramp Test Overview

J-Ramp test searches for the breakdown voltage (*Vbd*), then calculates the breakdown charge (*Qbd*) of thin oxide capacitors, which you designed as test structures on the wafer. These results are used to evaluate the oxide integrity. The higher the *Vbd* and *Qbd* measured by this test, the better the integrity of the oxide on wafer.

You extract these two parameters from a large amount of test structures and usually plot the cumulative breakdown/breakdown charge distribution on a probability chart. The manufacturing process should be driven so that this distribution becomes closer to the ideal shape.

In the J-Ramp test, an increasing current is forced to the oxide capacitor. This charges up the capacitor so the voltage across the capacitor increases. When the oxide layer is broken by the high electric field in the oxide, the current can flow through, so the voltage across the oxide capacitor decreases (breakdown). Breakdown voltage (*Vbd*) is defined as the voltage at which breakdown occurs. And breakdown charge (*Qbd*) is the total charge forced through the oxide until breakdown occurs.

Figure 2-1 shows a simplified flowchart of J-Ramp test.

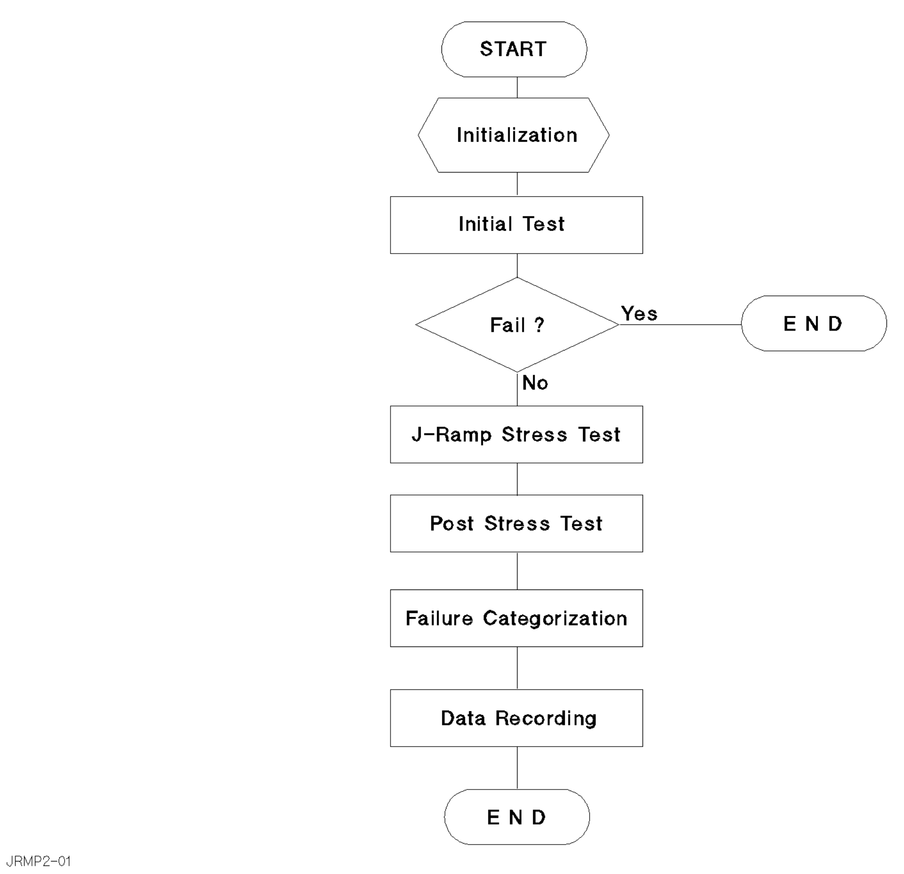


Figure 2-1. Simplified Flow Diagram of J-Ramp Test

The J-Ramp test consists of three tests: initial test, ramp stress test, and post stress test.

In the initial test, an initial current I_0 (typical value is 1 μA) is forced to the oxide capacitor, then voltage across the oxide is measured to check for initial failure.

In the ramp stress test, a stepped current is applied, and the voltage across the oxide is continuously measured.

The post stress test is for confirming that failure occurred during the ramp stress test. The initial current is forced again, then the voltage across the oxide is measured.

After the tests, the test results must be analyzed and saved (data recording).

Before performing the J-Ramp test, test conditions must satisfy the following:

- Gate bias polarity is in accumulated direction. That is, negative (minus) current is applied to gate conductor for P-type bulk, and positive (plus) current is applied for N-type bulk.
- Diffusions and wells (if any) must be connected to substrate.
- Temperature is in 25 ± 5 °C range.

Initial Test

Initial test is to confirm that the oxide capacitor is initially good. To do so, an initial current I_0 (typical value is 1 μA), which is low enough not to break the oxide, is forced to the oxide capacitor, and the voltage across the oxide is measured after a certain time $t_{initial}$. If the measured voltage does not reach the normal operating voltage, it is categorized as **initial failure**.

If an oxide capacitor is categorized as initial failure, test should not continue for the capacitor. If the capacitor passes the initial test, the J-ramp stress test may begin immediately.

The value of $t_{initial}$ is 50 ms or ten times the oxide time constant, whichever is greater. Initial current I_0 must be large enough to charge up the capacitor within a reasonably short time $t_{initial}$, but must be small enough not to break the oxide.

Typically, 10^{-6} C/cm^2 is the minimum breakdown current density q_{bd} that can be measured due to the system capacitance. The initial current I_0 varies depending on the area of the oxide capacitor (test structure), oxide thickness, and oxide defect levels.

J-Ramp Stress Test

A stepped current is applied to the oxide capacitor, and the voltage across the capacitor is continuously measured. Normally, applying the current to the oxide capacitor charges up the capacitor, so the voltage increases across the capacitor. When the electric field reaches a threshold, the oxide is broken, and current flows through the oxide.

Figure 2-2 shows the concept of *Vbd* and *Qbd* for the J-ramp stress test. The forced current is increased logarithmically, and the voltage across the capacitor is measured at a constant interval. When the *measured voltage* < *previously measured voltage* × 0.85, the breakdown is considered to have occurred in the oxide. The previously measured voltage is considered to be *Vbd*, and *Qbd* is calculated by integrating the current applied to the oxide.

If the measurement results indicate that breakdown occurred, the result of J-ramp stress test is defined as “fail”.

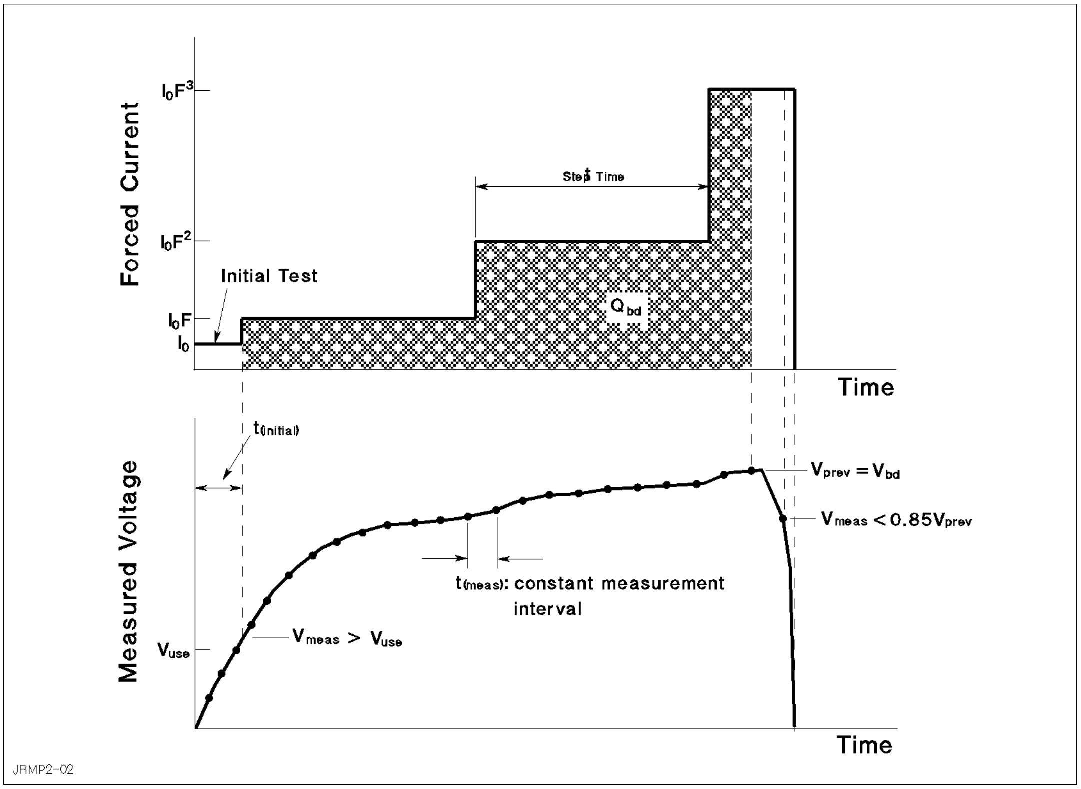


Figure 2-2. Concept of Breakdown Voltage and Charge

Step Increase Factor for Forced Current.
The current forced to the oxide capacitor is stepped in a logarithmic manner. The value of each step is related to the initial current I_0 by the step increase factor F as shown in the following equation:

$$I_n = I_0 \times F^n$$

Where n = 1, 2, 3, ...

That is,

$$\begin{aligned} I_1 &= I_0 \times F \\ I_2 &= I_0 \times F^2 \\ I_3 &= I_0 \times F^3 \\ &\vdots \\ I_n &= I_0 \times F^n \end{aligned}$$

J-Ramp Characteristics (Conditions for Forced Current).
The forced current must satisfy the following conditions:

- Current ramp rate: 1 decade/500 ms.
- Maximum time (t_{meas}) between voltage measurements: 50 ms or once per current step, whichever is less.
- Maximum charge density: 50 C/cm^2.
- Maximum electric field (voltage compliance limit): 15 MV/cm.
- Maximum current step increase factor F: $\sqrt{10}$, approximately 3.2.
- Step interval time of applied current: constant.

Indication of faulty J-ramp stress test.
If either of the following situations occurs during the J-ramp stress test, the test should be aborted. This indicates that the testing was faulty.

- Accumulated charge density (q) reaches the maximum allowed charge density. Charge density q is the accumulated charge Q divided by the oxide area $Area$.
- Maximum allowed electric field E is reached.

Post Stress Test

The post stress test checks the oxide status after the J-ramp stress test. If the oxide is broken, proper J-ramp stress was applied to the oxide capacitor, and the result of post stress test is defined as "fail".

To check the oxide status, the initial current (I_0) is applied to the oxide capacitor (same as initial test), then the voltage across the capacitor is measured. The measured voltage (V_{meas}) indicates the following:

- If $V_{meas} < V_{use}$:

  The oxide was broken by the J-ramp stress test. Forced current flows through the oxide, so the voltage across the capacitor does not increase enough.

- If $V_{meas} > V_{use}$:

  The oxide was not broken by the J-ramp stress test. Forced current does not flow through the oxide enough, so the voltage across the capacitor increases.

  One possible reason is that the testing was faulty as described in the previous section. For example, the current was not forced to the oxide due to an open circuit.

Failure Categorization and Data Recording

According to the measurement results, the oxide status is categorized as follows:

Initial Failure:	Failed the initial test. Indicates initially defective oxide capacitor. Other tests should not be performed.
Catastrophic Failure:	Failed during J-ramp and post stress tests. Indicates that oxide capacitor was properly broken by the J-ramp stress test.
Masked Catastrophic Failure:	Did *not* fail during J-ramp stress test, but failed post stress test.
Non-catastrophic Failure:	Failed during the J-ramp stress test, but *not* post stress test.
Others:	Did *not* fail during J-ramp stress test, *and* did *not* fail post stress test.

The failure category is recorded for each test device. If the catastrophic failure is observed, breakdown voltage (Vbd) and breakdown charge density ($q_{bd} = Qbd/Area$) are also recorded.

Table 2-1 shows the oxide failure categories.

Table 2-1. Oxide Failure Categories

Stress Failure Category	Initial Test	J-Ramp Stress Test	Post Stress Test
Initial	Fail	n.a.	n.a.
Catastrophic[1]	Pass	Fail	Fail
Masked Catastrophic	Pass	Pass	Fail
Non-catastrophic	Pass	Fail	Pass
Others	Pass	Pass	Pass

[1] Vbd and q_{bd} are also recorded.

3

Basic Operation

This chapter covers the following for using an HP 4155A/4156A to perform J-Ramp Test: required equipment, required files, methodology, how to execute the sample program, and sample program overview.

Methodology

The entire J-Ramp Test procedure can be performed by executing the JRAMP sample program on the built-in IBASIC controller of the HP 4155A/4156A.

As explained in Chapter 2, the J-ramp test consists of three measurement parts and an analysis part. Each measurement part executes three steps as follows:

1. Loads the measurement setup file into the HP 4155A/4156A execution environment.
2. Changes some of the measurement or analysis parameters on the setup pages.
3. Executes the measurement.

The JRAMP program executes the above three steps for each test: initial test, J-ramp stress test, and post stress test. Using the measurement setups (step 1 above) loaded from a file reduces the length and complexity of the program. For details, see the *HP 4155A/4156A Programmer's Guide*.

Measurement setups, which are loaded into the HP 4155A/4156A execution environment, were previously developed and saved to measurement setup files on the diskette. You can easily modify the measurement setup information in fill-in-the-blank manner in the HP 4155A/4156A execution environment. The JRAMP sample program is also saved to the diskette. You can easily modify the sample program by using the editor in the built-in IBASIC environment.

The JRAMP sample program assumes that the built-in IBASIC controller of the HP 4155A/4156A is used, but you can also use another controller such as HP BASIC running on an external computer. To do so, you must modify the sample program for your environment. See Chapter 4 on how to modify the program to run on an external controller.

Initial Test

The initial test makes sure the oxide capacitor is initially good by applying an initial current I_0 (`Iforce0` in the sample program), then measuring the voltage across the oxide capacitor. If the voltage does not reach the normal operating voltage, the oxide capacitor is categorized as "initial failure".

The sample program assumes that SMU1 and SMU4 are connected to the oxide capacitor as shown in Figure 3-1.

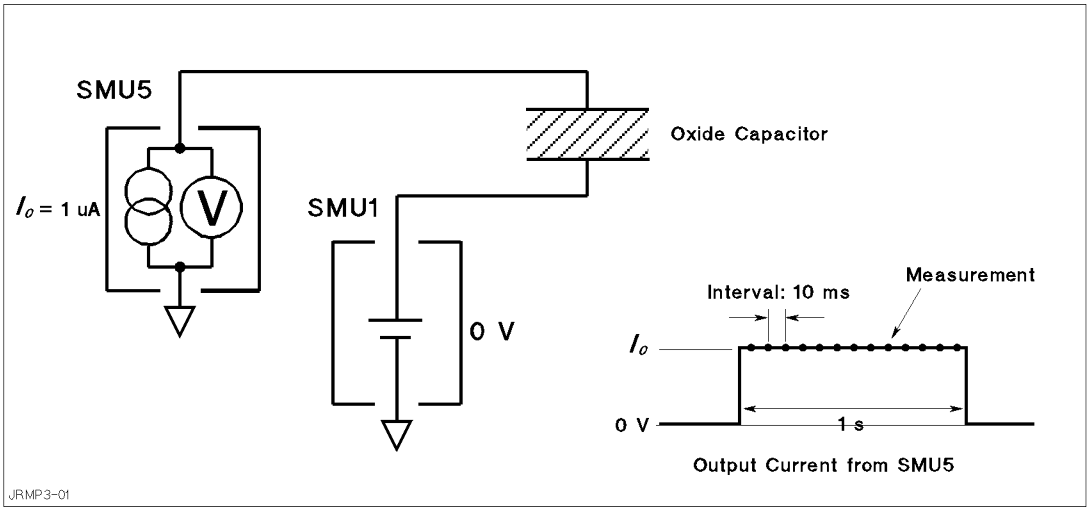


Figure 3-1. Simplified Measurement Circuit and Output Current of Initial Test

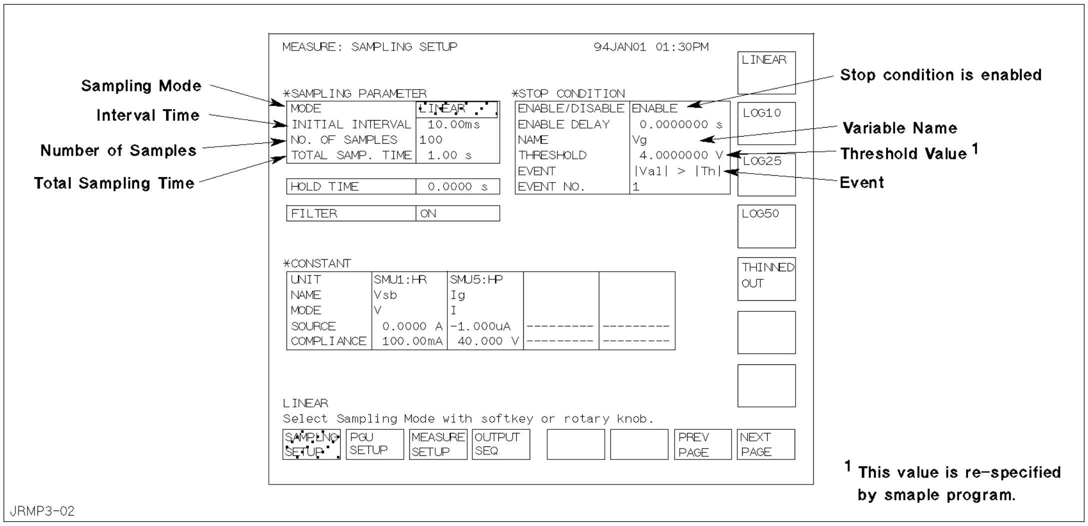
For the initial test, the sample program does as follows:

1. Sets up the HP 4155A/4156A according to the JINIT.MES setup file, which the sample program previously loaded from the diskette into internal memory (MEM1).
2. Sets up SMU1 to constant current `Iforce0` for PMOS device, or `-Iforce0` for NMOS device. `Iforce0` value is specified at beginning of the sample program, and reset in the MEASURE: SAMPLING SETUP page by OUTPUT statement (line 2520 of the sample program).
3. Sets the THRESHOLD value of the STOP CONDITION to `Vuse` or `-Vuse`, which is the normal operating voltage that was specified at beginning of the sample program.
4. Forces current `Iforce0` from SMU1, and measures as set up by the JINIT.MES file described next.
5. Checks if the maximum voltage reached `Vuse`. If not, the sample program aborts further testing.

The following are main points about the setup by the JINIT.MES setup file:

- On CHANNELS: CHANNEL DEFINITION page (see Figure A-1)
  - ☐ MEASUREMENT MODE is set to SAMPLING.
  - ☐ SMU4 is set to be a constant voltage source.
  - ☐ SMU1 is set to be a constant current source.
  - ☐ `Vg` is defined as name of voltage measured by SMU1.
- On MEASURE: SAMPLING SETUP page (see Figure 3-2)
  - ☐ Sample mode (MODE) is set to LINEAR.
  - ☐ Sampling measurement interval (INITIAL INTERVAL) is set to 10 ms.
  - ☐ NO. OF SAMPLES is set to 100.
  - ☐ TOTAL SAMP. TIME is set to 1 second ($t_{initial}$). So, for 1 second, the current `Iforce0` will be forced and sampling measurements will be performed.
  - ☐ SMU4 is set to force a constant 0 V.
  - ☐ SMU1 is set to force a constant 1 μA.
  - ☐ STOP CONDITION is enabled, NAME is set to `Vg`, and EVENT is set to `|Val| > |Th|`. Note that THRESHOLD is set to `Vuse` by the sample program as described previously.

  So, if the maximum `Vg` measured by SMU1 reaches `Vuse`, the sample program next performs the J-Ramp Stress test. If not, the measurement will abort further testing.



MEASURE: SAMPLING SETUP 94JAN01 01:30PM

*SAMPLING PARAMETER

MODE LINEAR
INITIAL INTERVAL 10.00ms
NO. OF SAMPLES 100
TOTAL SAMP. TIME 1.00 s

HOLD TIME 0.0000 s

FILTER ON

*STOP CONDITION

ENABLE/DISABLE ENABLE
ENABLE DELAY 0.0000000 s
NAME Vg
THRESHOLD 4.0000000 V
EVENT |Val| > |Th|
EVENT NO. 1

*CONSTANT

UNIT	SMU1:HR	SMU5:HP		
NAME	Vsb	Ig		
MODE	V	I		
SOURCE	0.0000 A	-1.000uA	---------	---------
COMPLIANCE	100.00mA	40.000 V	---------	---------

LINEAR
Select Sampling Mode with softkey or rotary knob.

[1] This value is re-specified by smaple program.

Figure 3-2. MEASURE: SAMPLING SETUP Page for Initial Test

J-Ramp Stress Test

After the initial test, the sample program executes the J-ramp stress test. Logarithmic stepped current is applied to the oxide, and voltage across the oxide is measured at least once for each step.

The measurement setup for the J-ramp stress test is stored in the JRMP.MES setup file on the diskette. At the beginning of the sample program, this setup is loaded into internal memory (MEM2). Then, at the beginning of the J-ramp stress test, the sample program loads this setup into the HP 4155A/4156A.

To force proper stepped current, the sample program and JRMP.MES set the following:

- SMU channel definition (see Figure 3-3):

  SMU4 is set to force a constant 0 V, and SMU1 is set to current sweep mode.

- Constant step interval time (see Figure 3-5):

  Step interval time of output sweep current must be constant.

- Stepped current to be forced:

  Stepped current forced to the oxide is increased logarithmically. This stepped current is defined in the sample program.

- Measurement stop condition:

  Current sweep continues until one of three conditions is satisfied.

- Searching for breakdown point and calculating Qbd:

  After the measurement, the JRAMP sample program gets the measured voltage values, and searches for the breakdown voltage (*Vbd*). Then, calculates the breakdown charge (*Qbd*) by using the user-defined functions.

SMU channel definition.

The sample program assumes the connection between the SMUs and the oxide capacitor as shown in Figure 3-3.

The JRMP.MES file sets the following (see Figure 3-4 and Figure 3-7):

- SMU4 is set to force a constant 0 V.
- SMU1 is set to current sweep mode.
- SMU4 is used prevent overcurrent by using its current compliance function. Compliance is set to 100 mA.

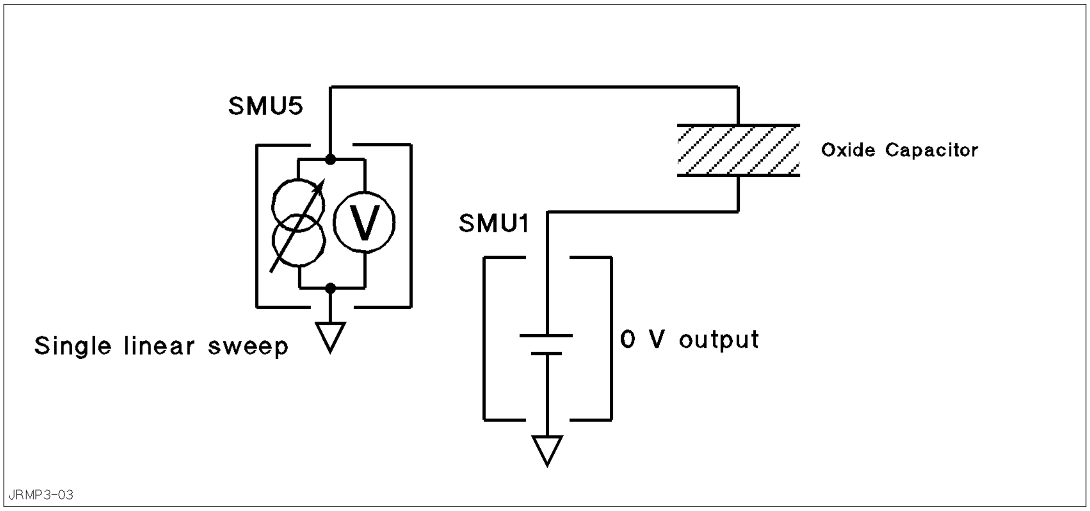
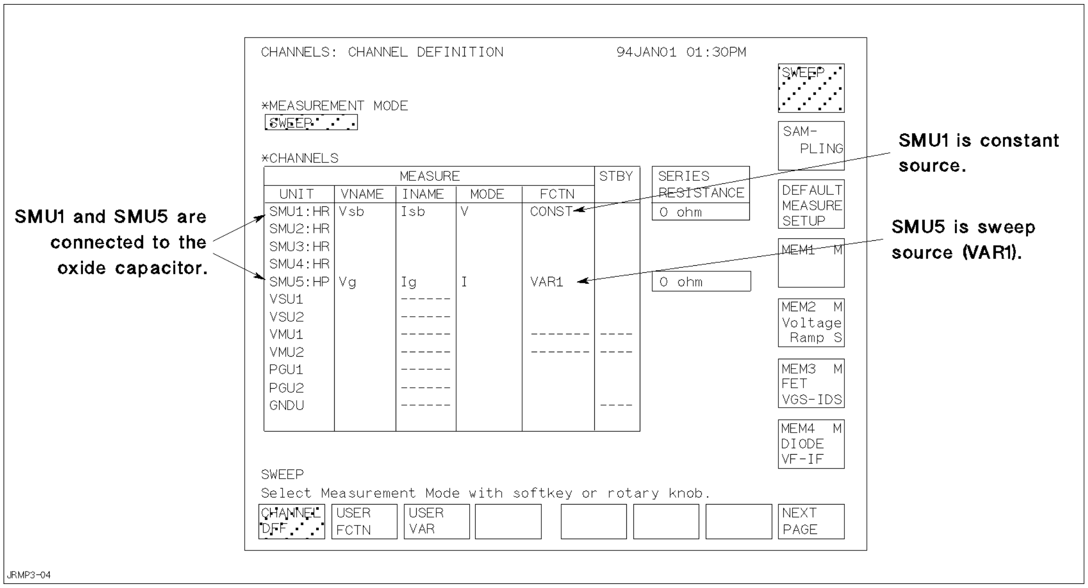


Figure 3-3. Simplified Measurement Circuit of J-Ramp Stress Test



CHANNELS: CHANNEL DEFINITION 94JAN01 01:30PM

*MEASUREMENT MODE
SWEEP

*CHANNELS

		MEASURE			STBY	SERIES RESISTANCE
UNIT	VNAME	INAME	MODE	FCTN		
SMU1:HR	Vsb	Isb	V	CONST		0 ohm
SMU2:HR						
SMU3:HR						
SMU4:HR						
SMU5:HP	Vg	Ig	I	VAR1		0 ohm
VSU1		------				
VSU2		------				
VMU1		------		-------	----	
VMU2		------		-------	----	
PGU1		------				
PGU2		------				
GNDU		------			----	

SWEEP
Select Measurement Mode with softkey or rotary knob.

SMU1 and SMU5 are connected to the oxide capacitor.

SMU1 is constant source.

SMU5 is sweep source (VAR1).

Figure 3-4. CHANNELS: CHANNEL DEFINITION Page for J-Ramp Stress Test

Constant step interval.
To keep a constant step interval time for the current sweep and measurement, triggering and measurement ranging techniques are used. JRMP.MES sets the measurement ranging mode to FIXED, so the time between measurements does not vary due to range changing.

JRMP.MES enables the TRIG OUT function, and the sample program calculates and sets values so that the *step interval time* becomes constant as shown in Figure 3-5. The *step interval time* (`Step_time`) is the *delay time* (`Step_delay_t`) plus *step delay time* (`Step_keep_t`). Strictly speaking, the sample program calculates these as follows:

```
Step_time = 0.5 * log10(Factor) - 1.5 ms + 0.1 ms
Step_delay_t = Step_time/2
Step_keep_t = Step_time - Step_delay_t
```

Where,

- 1.5 ms is overhead time associated with the *delay time* for current sweep measurement, when the WAIT TIME field is set to 0 (zero). So, do not set another value in this field.
- 0.1 ms is overhead time associated with the TRIG OUT function.
- `Factor` is the step increase factor. See later in this chapter and appendix C for details of this calculation.

The start current (`Iforce0` on line 1800) and stop current (`Istop` on line 4480) are specified in the sample program. For NMOS devices, the ramp stress test subprogram actually sets the opposite polarity for these values by using the `Tp` variable.

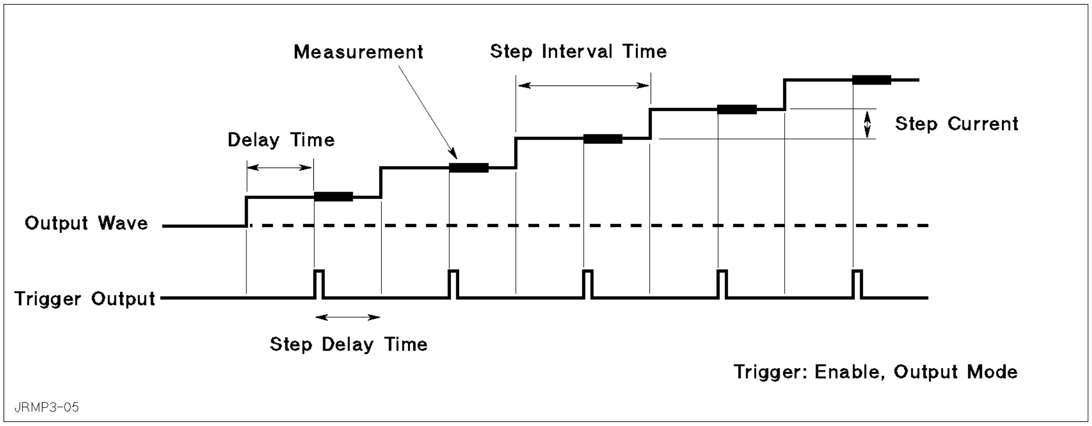
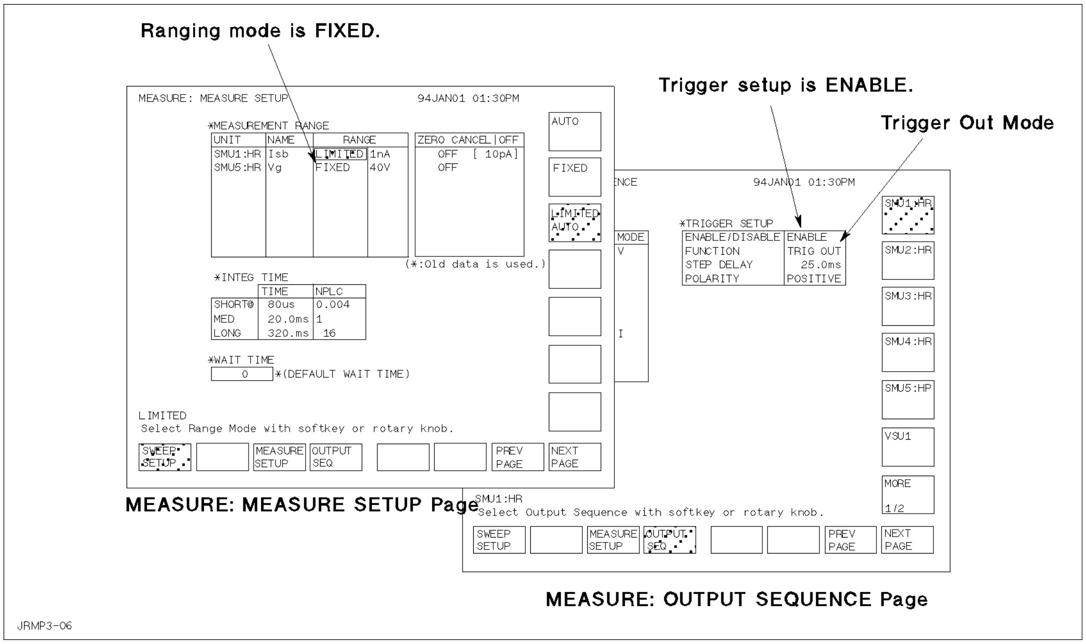


Figure 3-5. Output Sweep Current for J-Ramp Stress Test



MEASURE: MEASURE SETUP 94JAN01 01:30PM

*MEASUREMENT RANGE

UNIT	NAME	RANGE	
SMU1:HR	Isb	LIMITED	1nA
SMU5:HR	Vg	FIXED	40V

ZERO CANCEL|OFF
OFF [10pA]
OFF

(*:Old data is used.)

*INTEG TIME

	TIME	NPLC
SHORT@	80us	0.004
MED	20.0ms	1
LONG	320.ms	16

*WAIT TIME
0 *(DEFAULT WAIT TIME)

LIMITED
Select Range Mode with softkey or rotary knob.

NCE 94JAN01 01:30PM

MODE
V
I

*TRIGGER SETUP

ENABLE/DISABLE	ENABLE
FUNCTION	TRIG OUT
STEP DELAY	25.0ms
POLARITY	POSITIVE

SMU1:HR
Select Output Sequence with softkey or rotary knob.

Figure 3-6.
MEASURE: MEASURE SETUP and OUTPUT SEQUENCE Pages for J-Ramp Stress Test

Stepped current to be forced.
The sample program sets to force to the oxide a current that increases logarithmically according to the equation $I_n = I_0 \times F^n$, where n = 1, 2,.... n. See "J-Ramp Stress Test" in Chapter 2. In the JRAMP sample program, you specify the start current (`Iforce0`) and step increase factor F (`Factor`), then the step interval time (`Step_time`) and stop current (`Istop`) are calculated.

`Iforce0` is normally 1 μA, as mentioned in the Chapter 2. Three values ($10^{1/10}$, $10^{1/25}$, and $10^{1/50}$) are possible for step factor F (`Factor`) of the HP 4155A/4156A because you can use 10, 25, or 50 steps per decade for the logarithmic sweep.

The step interval time Ts (`Step_time` in program) of each step depends on the number of steps per decade, and must satisfy the condition that the ramp rate is 1 decade/500 ms. So, if N is the number of steps per decade, then $Ts = 0.5/N$. The following is the relationship of Ts to the step increase factor F:

$$Ts = 0.5 \times \log_{10} F$$

The current is stepped logarithmically until the charge density reaches the maximum allowed value, which is normally 50 C/cm^2, as follows:

$$\int_0^n I(t)dt = \int_0^n I_0 \cdot F^n \cdot Ts \cdot dn = q_{max} \cdot Area$$

> Where, $I(t) = I_0 \cdot F^n$, $t = n \cdot Ts$ (time), n is step number, Ts is the step interval time, q_{max} is the maximum allowed charge density, and $Area$ is the area of the oxide capacitor.

If you solve for n in the equation above, you get the following result:

$$n = \frac{1}{\log_{10} F} \cdot \log_{10}\left(\frac{\log_{10} F \cdot q_{max} \cdot Area}{I_0 \cdot Ts} + 1\right)$$

So, the current will be stepped n times to reach the maximum charge density, and the value of the current (`Istop`) at that step will be as follows:

$$Istop = I_0 \cdot F^n$$

So, the sample program calculates and sets Ts (`Step_time`) and `Istop` as described above.

For details about solving all the above equations above, see Appendix B.

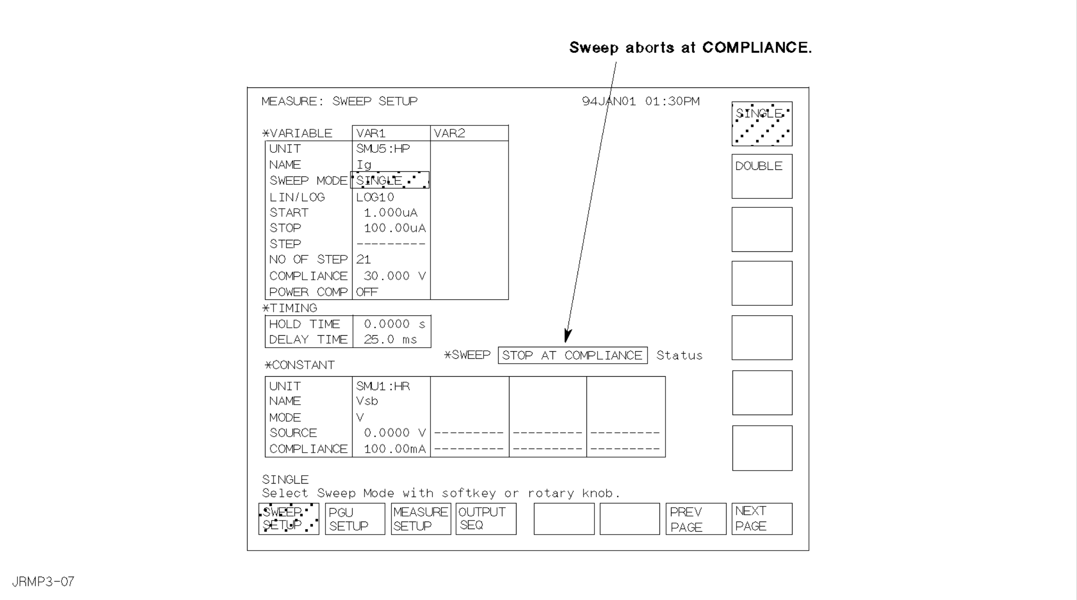
Measurement stop condition.

Note

JEDEC Standard No. 35 specifies that the current sweep should abort when breakdown occurs, but the JRAMP sample program continues the current sweep until one of the following three conditions is satisfied:

- Current sweep setting reaches current stop (`Istop`), which sample program calculates according to the maximum allowed charge density.
- SMU4 (which is set to force 0 V) reaches current compliance, which is set to 100 mA by the measurement setup file JRMP.MES.
- SMU1 (which is current sweep source) reaches voltage compliance (`Vgcomp`), which the sample program calculates as `Max_e*Tox`, where `Max_e` is the maximum allowed electric field, and `Tox` is the oxide thickness.

When the voltage across the oxide reaches the voltage compliance setting, the measurement must stop and current sweep must be aborted. So, SWEEP STOP AT COMPLIANCE must be set as shown in Figure 3-7.



Sweep aborts at COMPLIANCE.

```
MEASURE: SWEEP SETUP                          94JAN01 01:30PM

*VARIABLE      VAR1         VAR2
 UNIT          SMU5:HP
 NAME          Ig
 SWEEP MODE    SINGLE
 LIN/LOG       LOG10
 START          1.000uA
 STOP           100.00uA
 STEP          ---------
 NO OF STEP    21
 COMPLIANCE     30.000 V
 POWER COMP    OFF
*TIMING
 HOLD TIME      0.0000 s
 DELAY TIME     25.0 ms
                        *SWEEP  STOP AT COMPLIANCE  Status
*CONSTANT
 UNIT          SMU1:HR
 NAME          Vsb
 MODE          V
 SOURCE         0.0000 V  ---------  ---------  ---------
 COMPLIANCE     100.00mA  ---------  ---------  ---------

SINGLE
Select Sweep Mode with softkey or rotary knob.
```

Figure 3-7. MEASURE: SWEEP SETUP Page for J-Ramp Stress Test

Searching for breakdown point and calculating *Qbd*.
The sample program searches for the breakdown point as follows:

> When a *measured voltage* < *previous measured voltage* × 0.85, the previous measured voltage is defined as the breakdown voltage (*Vbd*).

To search for *Vbd*, the sample program stores all the measured voltage values in array variable `Vg`, then searches for the first TRUE case of the following, then sets `Vbd` as follows:

1. If `Vg(2)` < `Vg(1)*0.85`, then `Vbd` = `Vg(1)`.
2. If `Vg(3)` < `Vg(2)*0.85`, then `Vbd` = `Vg(2)`.
3. If `Vg(4)` < `Vg(3)*0.85`, then `Vbd` = `Vg(3)`.

⋮

99. If `Vg(100)` < `Vg(99)*0.85`, then `Vbd` = `Vg(99)`.

IBASIC programming can easily realize this algorithm. See lines 3250 to 3340 in the JRAMP sample program in `***<xref PROGRAM-LIST>: undefined***`.

After finding the breakdown point, the sample program performs analysis on the measured curve to get `Qbd` as follows:

1. Displays marker on the curve.
2. Moves the marker to the breakdown point.
3. Calculates `Qbd` by using a user function.
4. Saves value of `Qbd`.

The user-defined function calculates `Qbd` as follows:

$$Qbd = \int_{T_{start}}^{T_{bd}} Ig(t) \cdot dt = \frac{1}{2}\sum_{i=2}^{n}(Ig_i + Ig_{i-1}) \cdot (T_i - T_{i-1})$$

> Where, n is step number when the breakdown occurs.

The JRMP.MES setup file defines the user functions on the CHANNELS: USER FUNCTION DEFINITION page (see Figure A-9) as follows:

Table 3-1. User Functions for Ramp Stress Test

Name	Units	Definition
Time	(sec)	0.05 * @INDEX[1]
Vbd	(V)	@MY2
Qbd	(C)	INTEG(Ig,Time)

1 This is a temporary value. `Time` is redefined by line 2910 of the sample program.

Post Stress Test

Post stress test checks the oxide status after the ramp stress test.

The methodology of the post stress test is the same as for initial test. Initial current (`Iforce0`) is applied to the oxide, then the voltage across the oxide capacitor is measured.

For the measurement circuit, connections, and measurement setups, see “Initial Test”.

Failure Categorization

Table 3-2 shows the oxide failure categories that are determined by the sample program. The failure category is displayed for each device, and `Vbd`, `Qbd`, and `qbd` are also displayed.

The measured data and measurement settings are saved in a file.

Table 3-2. Oxide Failure Categories

Category	Initial Test	Ramp Stress Test	Post Stress Test
Initial	$V_{meas} < V_{use}$	n.a.	n.a.
Catastrophic	$V_{meas} \geq V_{use}$	$V_{meas} < 0.85 \times V_{prev}$ occurs.	$V_{meas} < V_{use}$
Masked Catastrophic	$V_{meas} \geq V_{use}$	$V_{meas} < 0.85 \times V_{prev}$ does not occur.	$V_{meas} < V_{use}$
Non-catastrophic	$V_{meas} \geq V_{use}$	$V_{meas} < 0.85 \times V_{prev}$ occurs.	$V_{meas} \geq V_{use}$
Other	$V_{meas} \geq V_{use}$	$V_{meas} < 0.85 \times V_{prev}$ does not occur.	$V_{meas} \geq V_{use}$

Required Equipment

The following equipment is required to use the J-Ramp sample program:

- HP 4155A or 4156A Semiconductor Parameter Analyzer
- Two triaxial cables
- Probe station
- This operation manual
- Diskette that contains sample program file and two setup files

Files on the Diskette

The following files are stored in the sample diskette:

JRAMP	J-Ramp sample program. This is an IBASIC program file saved in ASCII format.
JINIT.MES	Measurement setup file for initial and post stress test.
JRMP.MES	Measurement setup file for J-ramp stress test.
JRAMP1	J-Ramp sample program with HPSMU. This is an IBASIC program file saved in ASCII format.
JINIT1.MES	Measurement setup file for initial and post stress test with HPSMU.
JRMP1.MES	Measurement setup file for J-ramp stress test with HPSMU.

See “When SMU Lacks Power to Break Oxide” in Chapter 4 about more information on J-Ramp test with HPSMU.

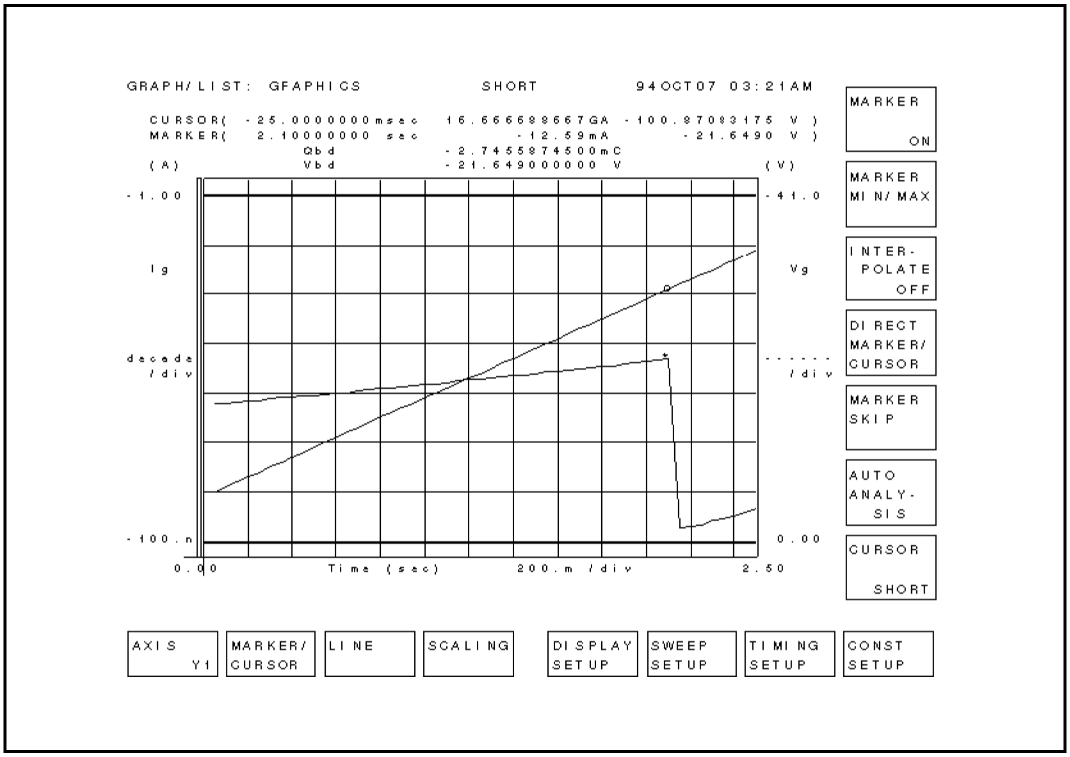
Executing the JRAMP Program

Before executing the program, you may need to customize the program to suit your test device. See Chapter 4.

To execute the sample program, use the following procedure:

1. Connect your HP 4155A/4156A to your test device. See Figure 3-1.
2. Turn on your HP 4155A/4156A.
3. Insert the diskette containing the JRAMP program into the built-in 3.5 inch flexible disk drive.
4. Press (Display) key in the IBASIC area of the front panel until All IBASIC screen is displayed.
5. Load the JRAMP program. Type: `GET "JRAMP"` (Enter).
6. Press (RUN) key in the IBASIC area of the front panel to start the program.

Measurement results similar to the Figure 3-8 will be displayed on the GRAPHICS page of the HP 4155A/4156A.



```
GRAPH/LIST: GFAPHICS          SHORT          94OCT07 03:21AM

  CURSOR( -25.0000000msec  16.666698667GA -100.97093175  V )
  MARKER(  2.10000000 sec         -12.59mA       -21.6490  V )
                 Qbd      -2.7455974500mC
                 Vbd      -21.649000000  V
```

Figure 3-8. An Example of Measurement Results

Flowchart of Sample JRAMP Program

Figure 3-9 shows flowchart of sample JRAMP program and corresponding subprogram names.

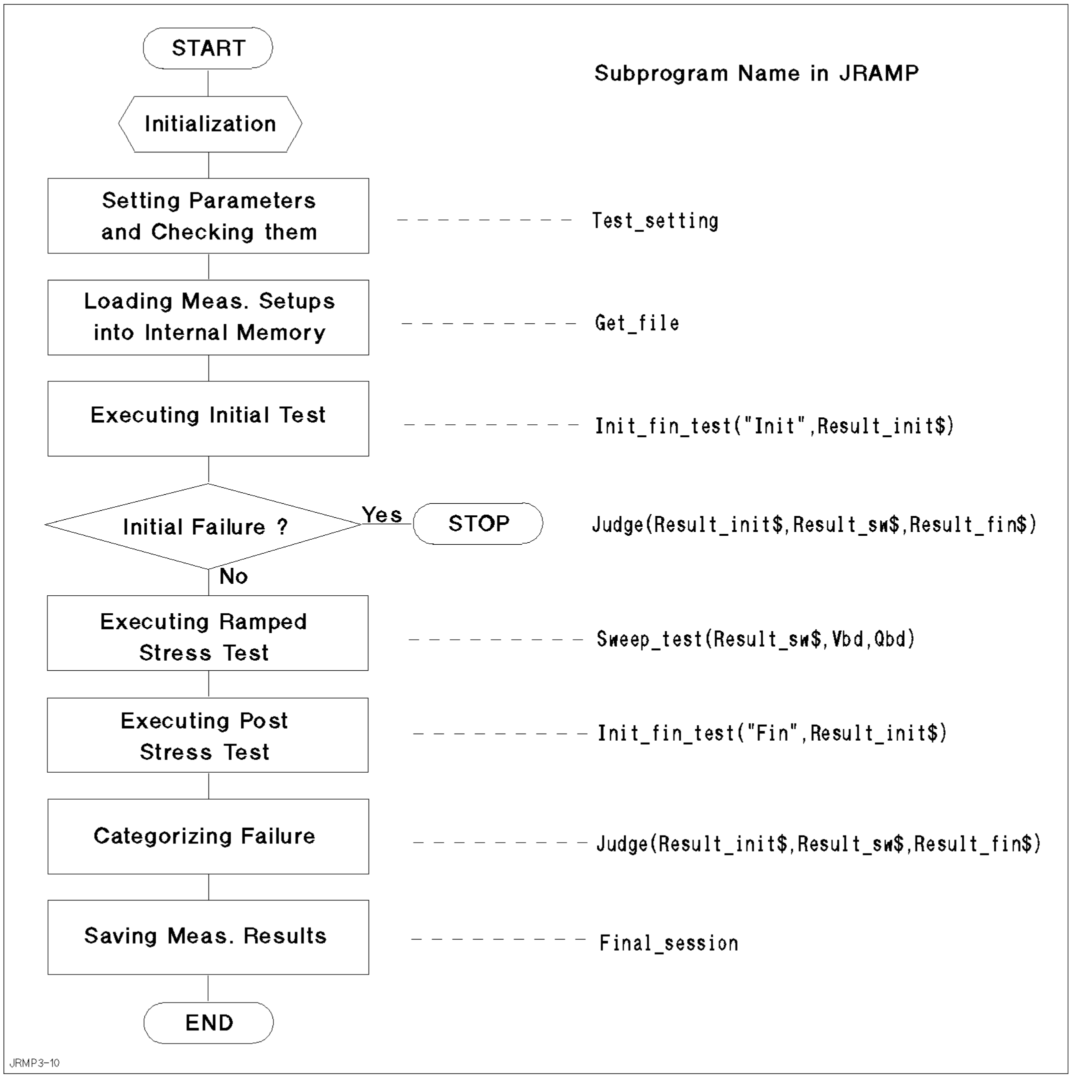


Figure 3-9. Flowchart of Sample JRAMP Program

The following provides a brief description for each subprogram.

`Test_setting`	Specifies and checks the parameter values. These are values that the program will set directly instead of some of the setup file values.
`Get_file`	Loads measurement setup files from the diskette into internal memory: initial/post measurement setup into MEM1, and sweep measurement setup into MEM2. Having the measurement setups in internal memory reduces the measurement time.
`Init_fin_test`	Executes the measurement for initial test or for post stress test. First parameter specifies the test: `Init` is for initial test, and `Fin` is for post stress test. The measurement results are returned to the second parameter.
`Judge`	Categorizes failure according to measurement results of initial, ramped stress, and post stress tests. If the failure is initial failure, this subprogram aborts the program.
`Sweep_test`	Executes sweep measurement for ramped stress test, then returns the result flag, `Vbd`, and `Qbd` to the three parameters. The measurement result data is temporarily stored in internal memory (MEM3).
`Save_data`	Saves measurement result data (in MEM3) to a file on the diskette.

4

Customization

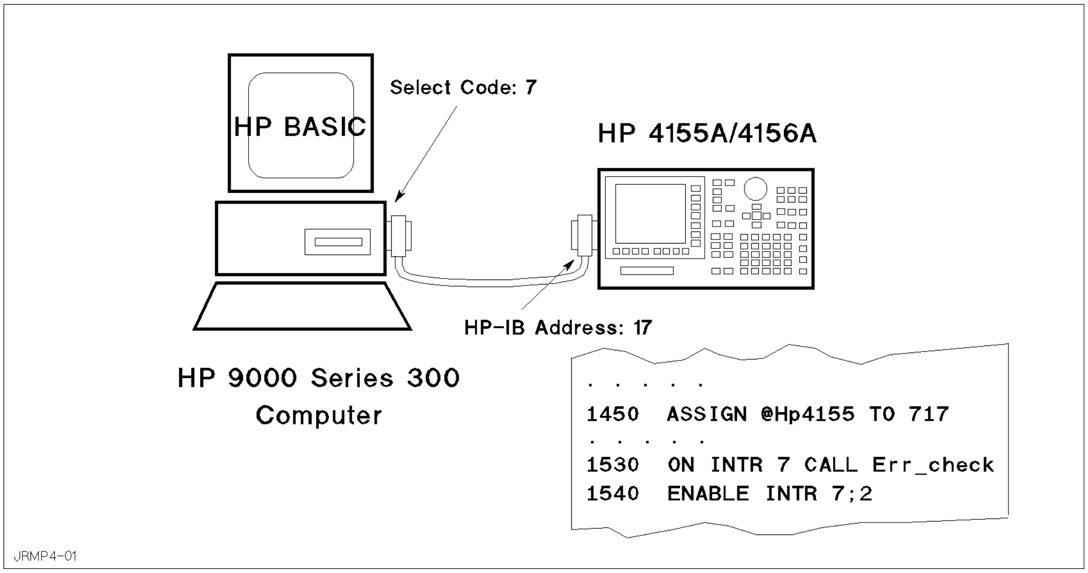
This chapter describes how to customize the sample program to suit your test device.

Using an External Computer

This sample program (JRAMP) is assumed to run on HP Instrument BASIC that is built into the HP 4155A/4156A. The HP 4155A/4156A is used as both the measurement instrument and the controller running IBASIC, so JRAMP sets device selector *800*. On the following three lines, the HP 4155A/4156A is assigned and interrupt from it is enabled as follows:

```
1450  ASSIGN @Hp4155 TO 800
    :
1530  ON INTR 8 CALL Err_check
1540  ENABLE INTR 8;2
```

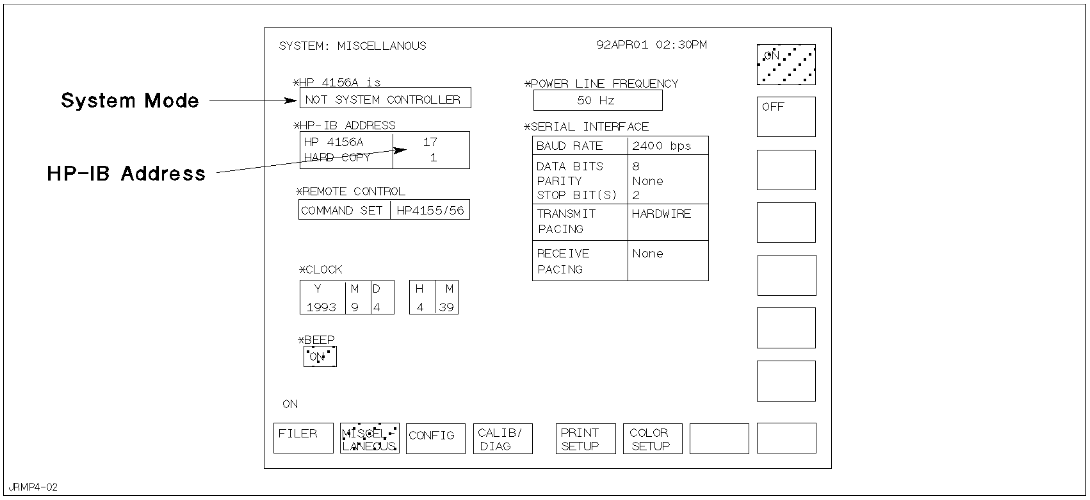
If you use an external controller (that can run HP BASIC environment) to control the HP 4155A/4156A, you need to modify a few lines of the sample program. For example, if you use HP BASIC/WS on an HP 9000 Series 300 computer, you only need to modify lines the above three lines as follows:



```
. . . . .
1450  ASSIGN @Hp4155 TO 717
. . . . .
1530  ON INTR 7 CALL Err_check
1540  ENABLE INTR 7;2
```

In this case, the HP 4155A/4156A has HP-IB address 17 and is not used as the system controller, and is connected to the built-in HP-IB of the HP 9000 series 300 controller with an HP-IB cable. Use the following procedure to set the HP-IB address and system mode:

1. Turn on your HP 4155A/4156A.
2. Press **System** key.
3. Select `MISCELLANEOUS` softkey.
4. Move the field pointer to the “HP 415x is ” field, then select `NOT CONTROLLER` softkey.
5. Move the field pointer to the “HP 415x” field in the HP-IB ADDRESS area, then enter: 17 **Enter**.



*HP 4156A is
NOT SYSTEM CONTROLLER

*HP-IB ADDRESS

HP 4156A	17
HARD COPY	1

*REMOTE CONTROL

COMMAND SET	HP4155/56

*CLOCK

Y	M	D	H	M
1993	9	4	4	39

*BEEP
ON

*POWER LINE FREQUENCY
50 Hz

*SERIAL INTERFACE

BAUD RATE	2400 bps
DATA BITS PARITY STOP BIT(S)	8 None 2
TRANSMIT PACING	HARDWIRE
RECEIVE PACING	None

Specifying Setup File to Load

Two setup files are used to set up the HP 4155A/4156A for the J-Ramp test: one is used for initial and post stress tests, and the other is for ramp stress test.

Filenames of these setups are defined on the following lines:

```
1740    Init_file$="JINIT.MES"    ! Init/Post Measurement Setup File Name
1750    Sweep_file$="JRMP.MES"    ! Ramp Setup File Name
```

If you want to use other setup files, store the setup files on the diskette, then modify the filenames on the lines above.

File for Saving Measurement Results

The following lines specify the filename for the measurement results file. The filename starts with "`D`", then *HHMMS*, then ends with "`.DAT`". Where *HH* is hour, *MM* is minute, and *S* is second (tens digit only).

```
1760  Save_file$=TIME$(TIMEDATE) ! File Name for saving measurement results
1770  Save_file$="D"&Save_file$[1,2]&Save_file$[4,5]&Save_file$[7,7]&".DAT"
```

The following line commands the HP4155A/4156A to create the specified file on the diskette, then stores the result data in the file.

```
4040  OUTPUT @Hp4155;":MMEM:STOR:TRAC DEF,'"&Save_file$&"','DISK'"
```

For example, "`D09344.DAT`" file that contains measurement data is created on the diskette. This filename means the "data file created at 9:34 4x seconds."

To change to your desired filename, you only need to edit line 1770.

Setting up Input Parameters

Input parameter values are specified on the following lines. These are values that the sample program will set directly instead of using some of the setup file values. You can easily modify the values by editing these program lines.

```
1790     Type$="NMOS"               ! Dev type NMOS - P bulk, PMOS -N bulk
1800     Iforce0=1.E-6              ! Initial current (A)
1810     Vuse=5                     ! Vuse (V) (Reference for Init/Post test)
1820    !---------------------------------------------------
1830    !  Allowable current factor :
1840    !      10^(1/10),   10^(1/25),  10^(1/50)
1850    !---------------------------------------------------
1860     Factor=10^(1/10)                             ! Current factor
1870     Step_time=.5/(1/LGT(Factor)) - .0014         ! Ramp step time
1880     Step_delay_t = Step_time/2                   ! Step delay time
1890     Step_keep_t = Step_time - Step_delay_t       ! Step keep time
1900    !
1910     Max_q=50                   ! Maximum charge (C/cm^2)
1920     Max_e=15*1.E+6             ! Maximum Field (V/cm)
1930    !
1940     Tox=130*1.E-8              ! Oxide Thickness  (cm)
1950     Area=.001                  ! Gate area (cm^2)
1960     Calc_istop                 ! Calculate Istop (A)
1970     Vgcomp=Max_e*Tox           ! Vg compliance (V)
1980     Igcomp=.1                  ! Ig compliance for SMU4
```

Parameter	Default	Description
`Type$`	NMOS[1]	Bulk type: NMOS is for P bulk and PMOS is for N bulk
`Iforce0`	1 (μA)	Initial current
`Vuse`	5 (V)	Normal operating voltage for the device
`Factor`	$10^{1/10}$	Ramp step increase factor F
`Max_q`	50 (C/cm^2)	Maximum charge density
`Max_e`	15 (MV/cm)	Maximum electric field
`Tox`	1.30×10^{-6} (cm)	Thickness of oxide
`Area`	0.001 (cm^2)	Area of oxide capacitor

1 If type is NMOS, opposite polarity values for some of the values are actually used later in the program by using the `Tp` parameter, which is set to -1 in line 2000.

When SMU Lacks Power to Break Oxide

You may encounter that the oxide does not break using MPSMU or HRSMU. Because voltage enough to break the oxide is not forced when relatively high current is forced. MPSMU or HRSMU can force maximum 20 V with the range of 40 mA through 100 mA.

To solve this problem, you can use HPSMU which is in the HP 41501A Expander. The HPSMU can force maximum 100 V with the range of 50 mA through 125 mA.

JRAMP1, JINIT1.MES, and JRMP1.MES assume to perform J-Ramp Test using an HPSMU and an SMU. Figure 4-1 shows the connections between SMUs and a DUT.

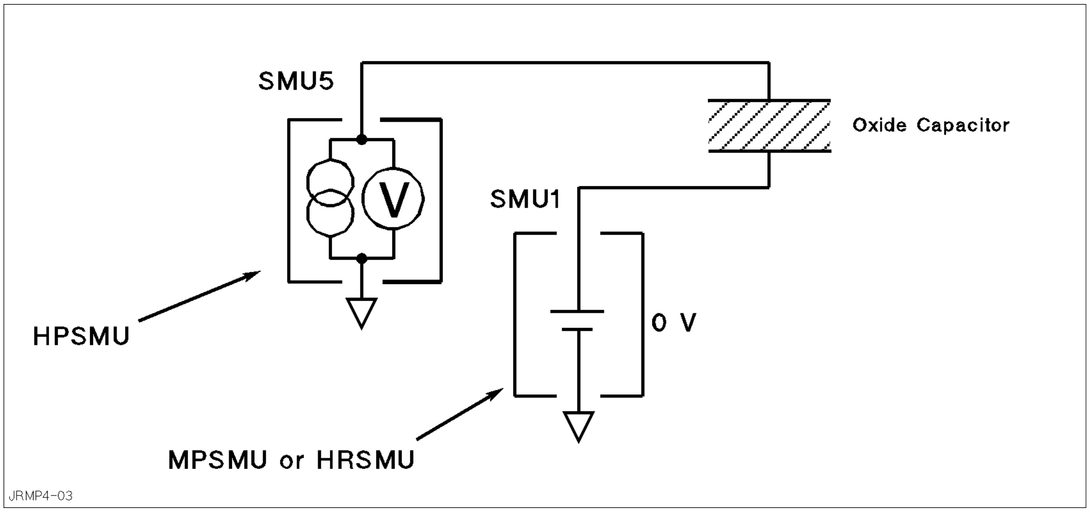


Figure 4-1. Simplified Measurement Circuit of J-Ramp Test With HPSMU

Note that you may need to customize the JRAMP1 program and JINIT1.MES and JRMP1.MES setup files for your application before execution.

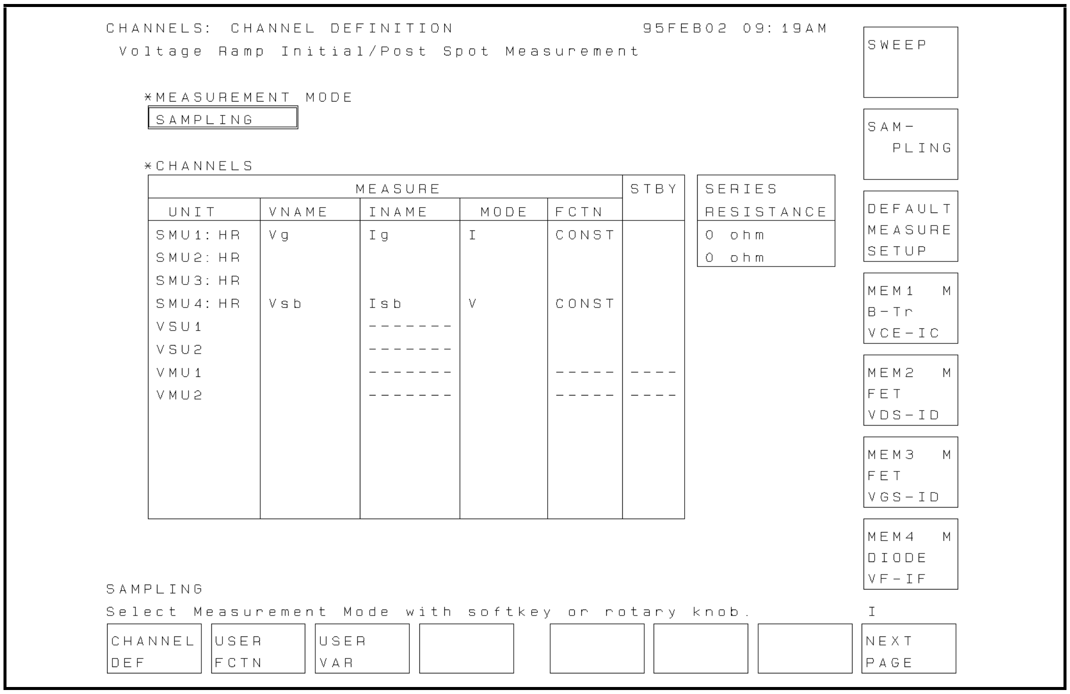
A

Measurement Setups

This appendix covers the measurement setups that are stored in the JINIT.MES and JRMP.MES files.

Setups for Initial and Post Stress Tests

The measurement setups stored in JINIT.MES are used for the initial and post stress tests. The following shows measurement setups of each page.



CHANNELS: CHANNEL DEFINITION 95FEB02 09:19AM
Voltage Ramp Initial/Post Spot Measurement

*MEASUREMENT MODE
SAMPLING

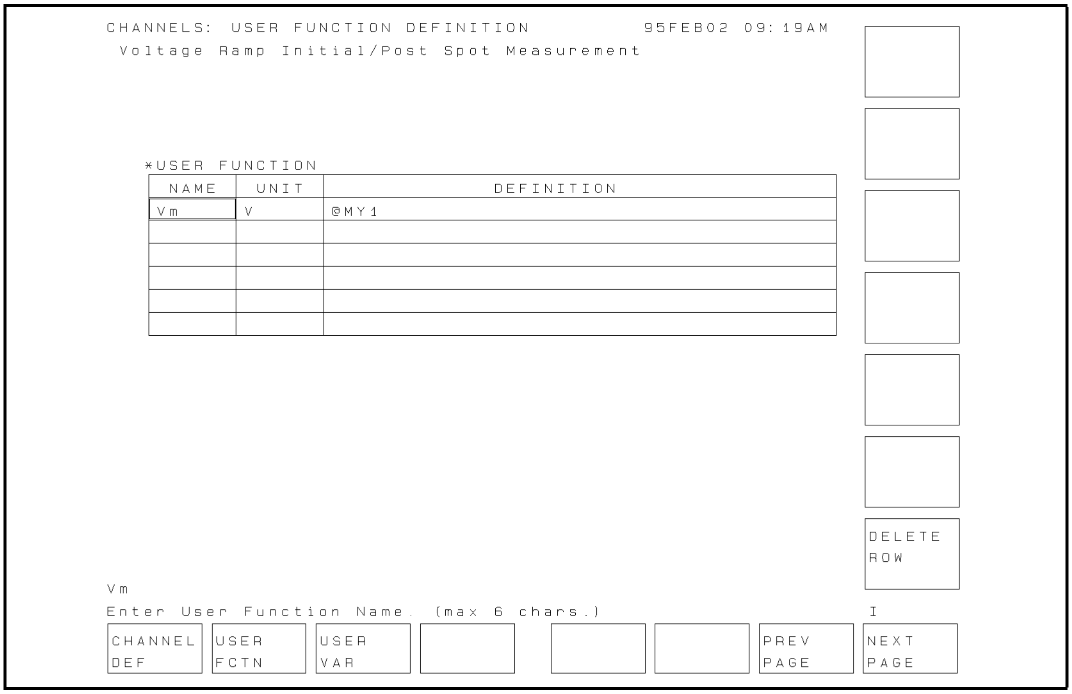
*CHANNELS

MEASURE					STBY
UNIT	VNAME	INAME	MODE	FCTN	
SMU1:HR	Vg	Ig	I	CONST	
SMU2:HR					
SMU3:HR					
SMU4:HR	Vsb	Isb	V	CONST	
VSU1		-------			
VSU2		-------			
VMU1		-------		-----	----
VMU2		-------		-----	----

SERIES RESISTANCE
0 ohm
0 ohm

SAMPLING
Select Measurement Mode with softkey or rotary knob. I

Figure A-1. CHANNELS: CHANNEL DEFINITION Page



CHANNELS: USER FUNCTION DEFINITION 95FEB02 09:19AM

Voltage Ramp Initial/Post Spot Measurement

*USER FUNCTION

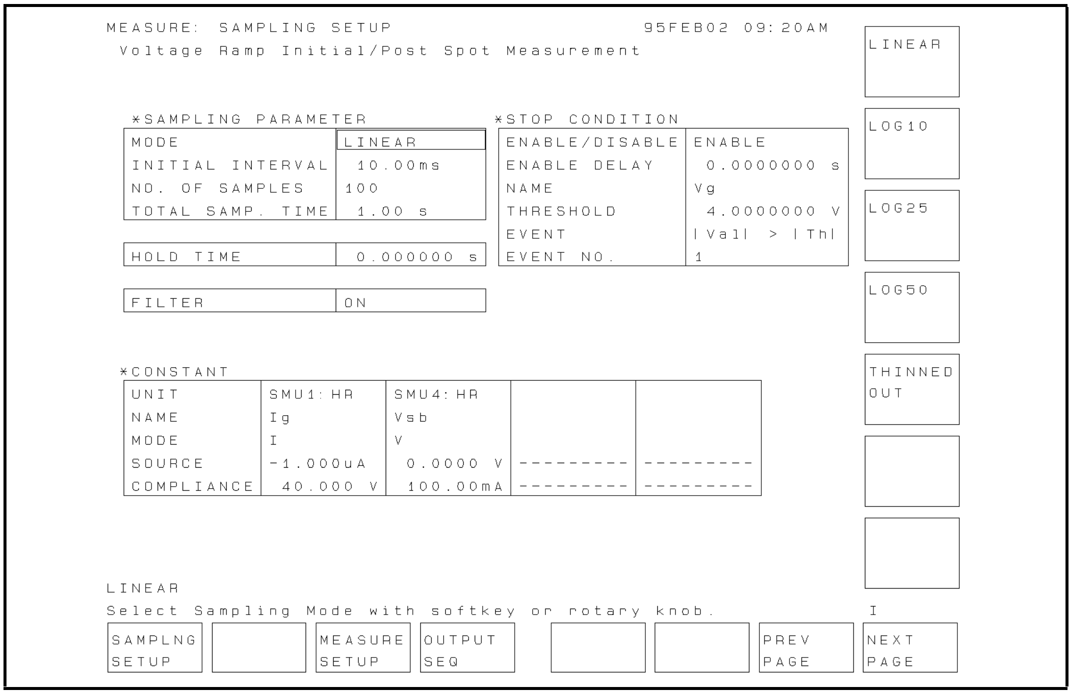
NAME	UNIT	DEFINITION
Vm	V	@MY1

Vm

Enter User Function Name. (max 6 chars.)

I

Figure A-2. CHANNELS: USER FUNCTION DEFINITION Page



MEASURE: SAMPLING SETUP 95FEB02 09:20AM

Voltage Ramp Initial/Post Spot Measurement

*SAMPLING PARAMETER

MODE	LINEAR
INITIAL INTERVAL	10.00ms
NO. OF SAMPLES	100
TOTAL SAMP. TIME	1.00 s

HOLD TIME	0.000000 s

FILTER	ON

*STOP CONDITION

ENABLE/DISABLE	ENABLE
ENABLE DELAY	0.0000000 s
NAME	Vg
THRESHOLD	4.0000000 V
EVENT	|Val| > |Th|
EVENT NO.	1

*CONSTANT

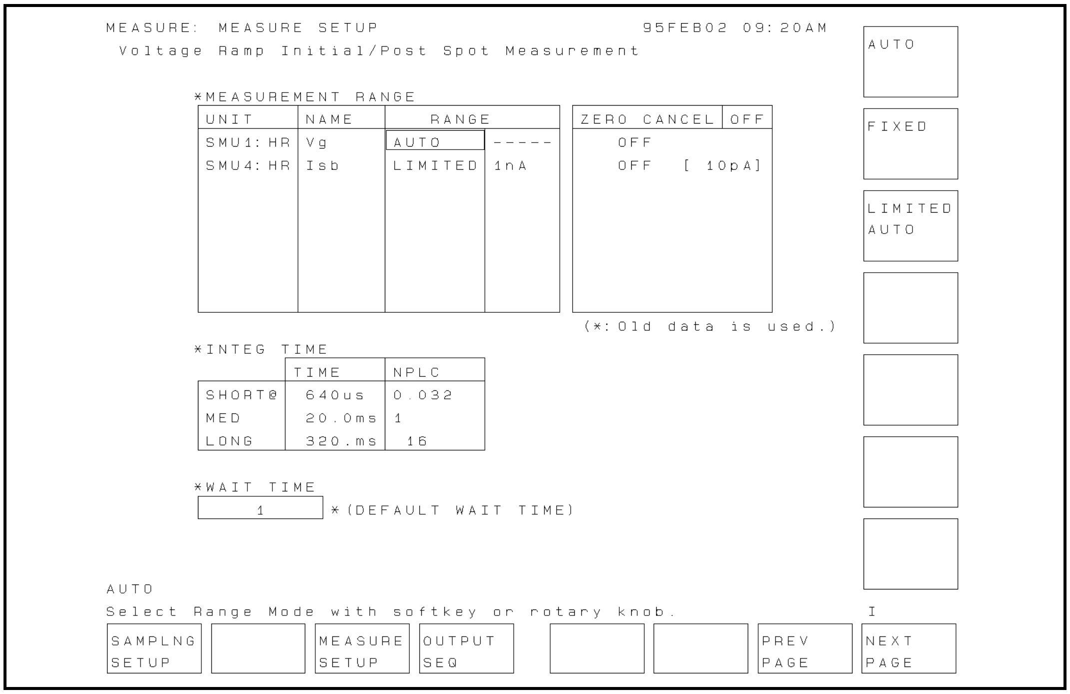
UNIT	SMU1:HR	SMU4:HR		
NAME	Ig	Vsb		
MODE	I	V		
SOURCE	-1.000uA	0.0000 V	---------	---------
COMPLIANCE	40.000 V	100.00mA	---------	---------

LINEAR

Select Sampling Mode with softkey or rotary knob.

I

Figure A-3. MEASURE: SAMPLING SETUP Page



MEASURE: MEASURE SETUP 95FEB02 09:20AM

Voltage Ramp Initial/Post Spot Measurement

*MEASUREMENT RANGE

UNIT	NAME	RANGE		ZERO CANCEL	OFF
SMU1:HR	Vg	AUTO	-----	OFF	
SMU4:HR	Isb	LIMITED	1nA	OFF [10pA]	

(*: Old data is used.)

*INTEG TIME

	TIME	NPLC
SHORT@	640us	0.032
MED	20.0ms	1
LONG	320.ms	16

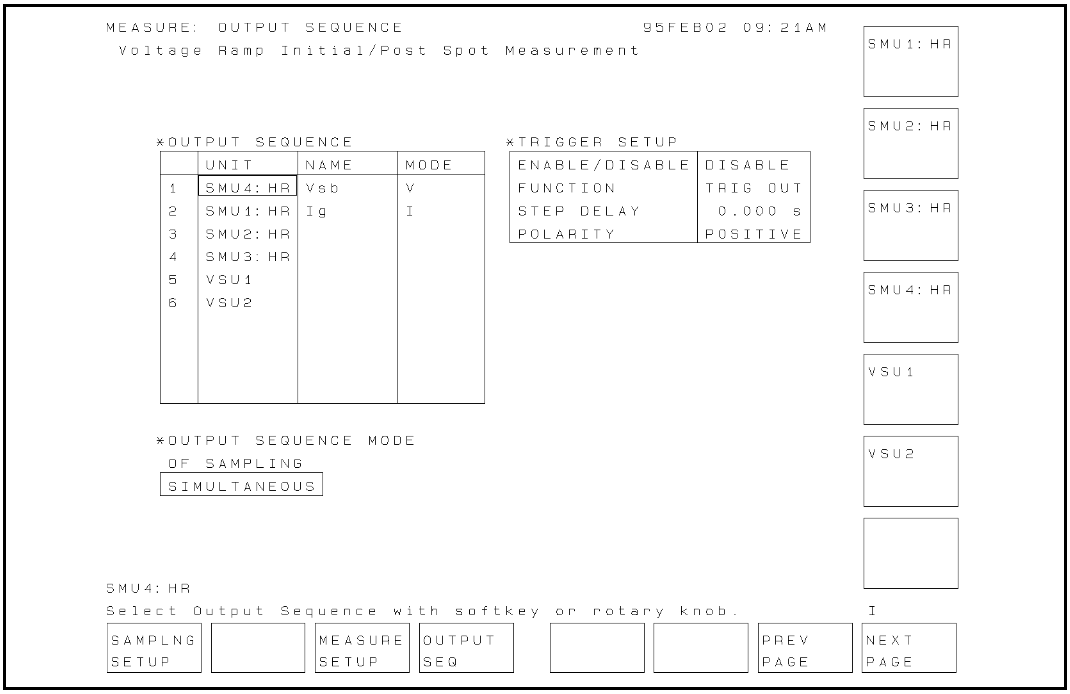
*WAIT TIME

1 *(DEFAULT WAIT TIME)

AUTO

Select Range Mode with softkey or rotary knob. I

Figure A-4. MEASURE: MEASURE SETUP Page



MEASURE: OUTPUT SEQUENCE 95FEB02 09:21AM

Voltage Ramp Initial/Post Spot Measurement

*OUTPUT SEQUENCE

	UNIT	NAME	MODE
1	SMU4:HR	Vsb	V
2	SMU1:HR	Ig	I
3	SMU2:HR		
4	SMU3:HR		
5	VSU1		
6	VSU2		

*TRIGGER SETUP

ENABLE/DISABLE	DISABLE
FUNCTION	TRIG OUT
STEP DELAY	0.000 s
POLARITY	POSITIVE

*OUTPUT SEQUENCE MODE

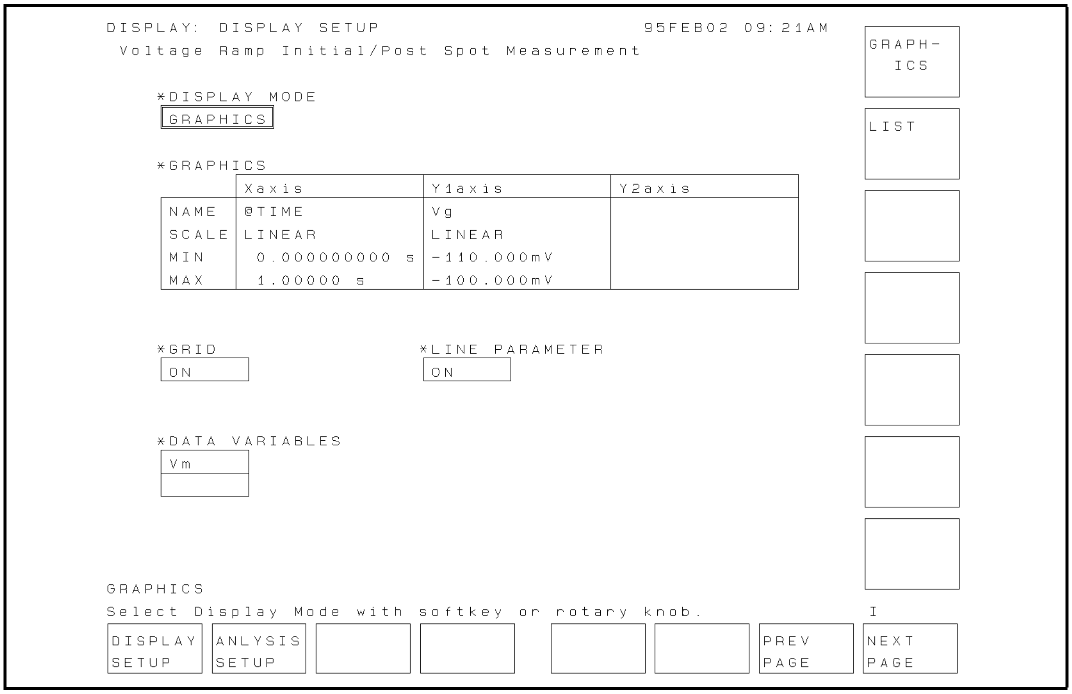
OF SAMPLING

SIMULTANEOUS

SMU4:HR

Select Output Sequence with softkey or rotary knob. I

Figure A-5. MEASURE: OUTPUT SEQUENCE Page


DISPLAY: DISPLAY SETUP 95FEB02 09:21AM
Voltage Ramp Initial/Post Spot Measurement

*DISPLAY MODE
GRAPHICS

*GRAPHICS

	Xaxis	Y1axis	Y2axis
NAME	@TIME	Vg	
SCALE	LINEAR	LINEAR	
MIN	0.000000000 s	-110.000mV	
MAX	1.00000 s	-100.000mV	

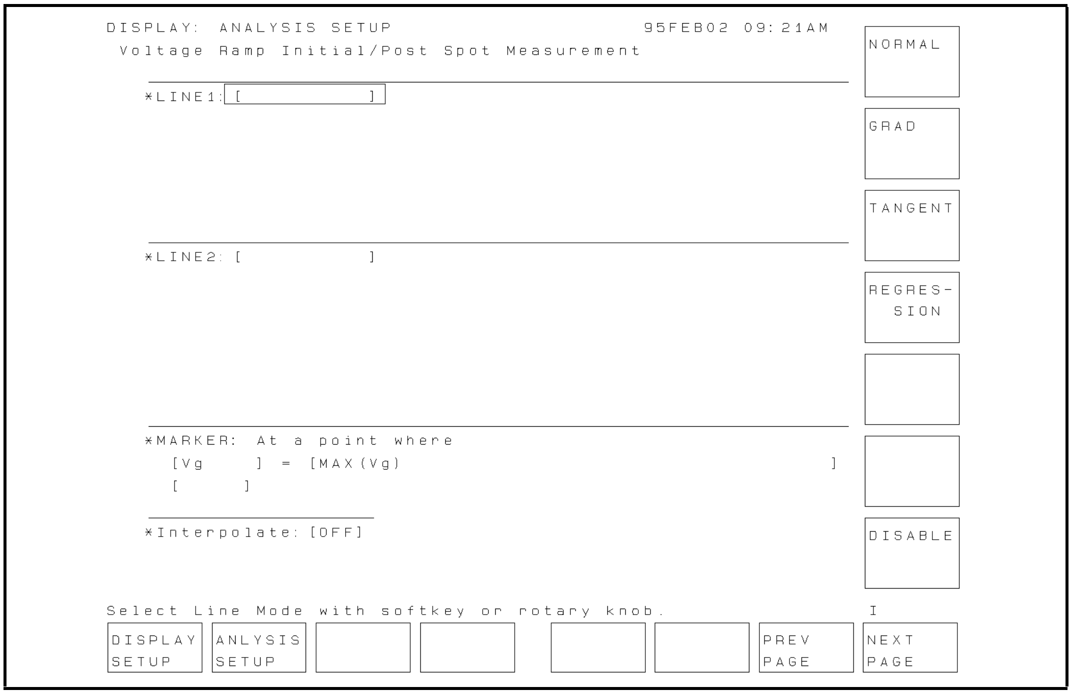
*GRID
ON

*LINE PARAMETER
ON

*DATA VARIABLES
Vm

GRAPHICS
Select Display Mode with softkey or rotary knob.

Figure A-6. DISPLAY: DISPLAY SETUP Page


DISPLAY: ANALYSIS SETUP 95FEB02 09:21AM
Voltage Ramp Initial/Post Spot Measurement

*LINE1: [ ]

*LINE2: [ ]

*MARKER: At a point where
[Vg] = [MAX(Vg)]
[ ]

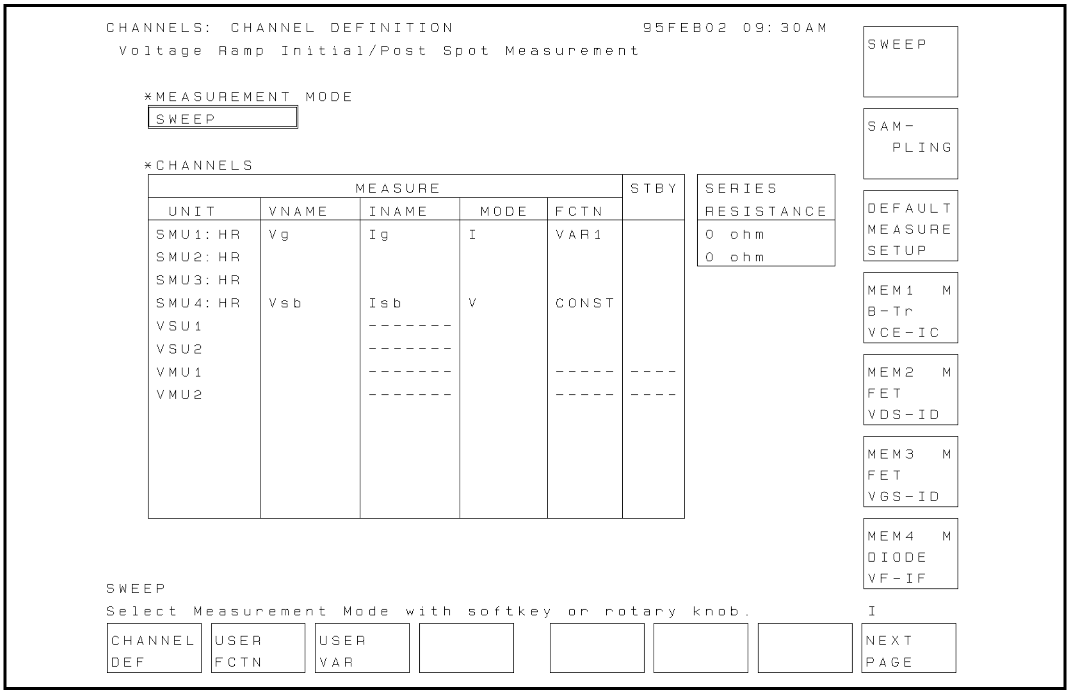
*Interpolate: [OFF]

Select Line Mode with softkey or rotary knob.

Figure A-7. DISPLAY: ANALYSIS SETUP Page

Setups for Ramped Stress Test

The measurement setups stored in JRMP.MES are used for the ramped stress test. The following shows measurement setups of each page.


CHANNELS: CHANNEL DEFINITION 95FEB02 09:30AM

Voltage Ramp Initial/Post Spot Measurement

*MEASUREMENT MODE

SWEEP

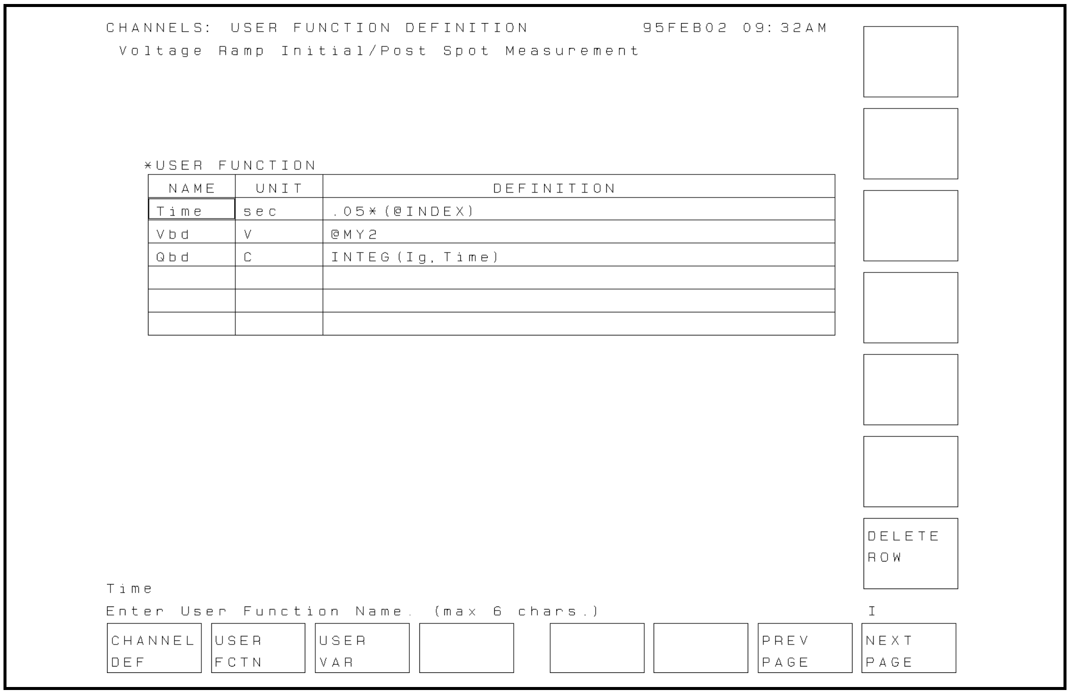
*CHANNELS

MEASURE					STBY	SERIES RESISTANCE
UNIT	VNAME	INAME	MODE	FCTN		
SMU1:HR	Vg	Ig	I	VAR1		0 ohm
SMU2:HR						0 ohm
SMU3:HR						
SMU4:HR	Vsb	Isb	V	CONST		
VSU1		-------				
VSU2		-------				
VMU1		-------		-----	----	
VMU2		-------		-----	----	

SWEEP

Select Measurement Mode with softkey or rotary knob. I

Figure A-8. CHANNELS: CHANNEL DEFINITION Page


CHANNELS: USER FUNCTION DEFINITION 95FEB02 09:32AM

Voltage Ramp Initial/Post Spot Measurement

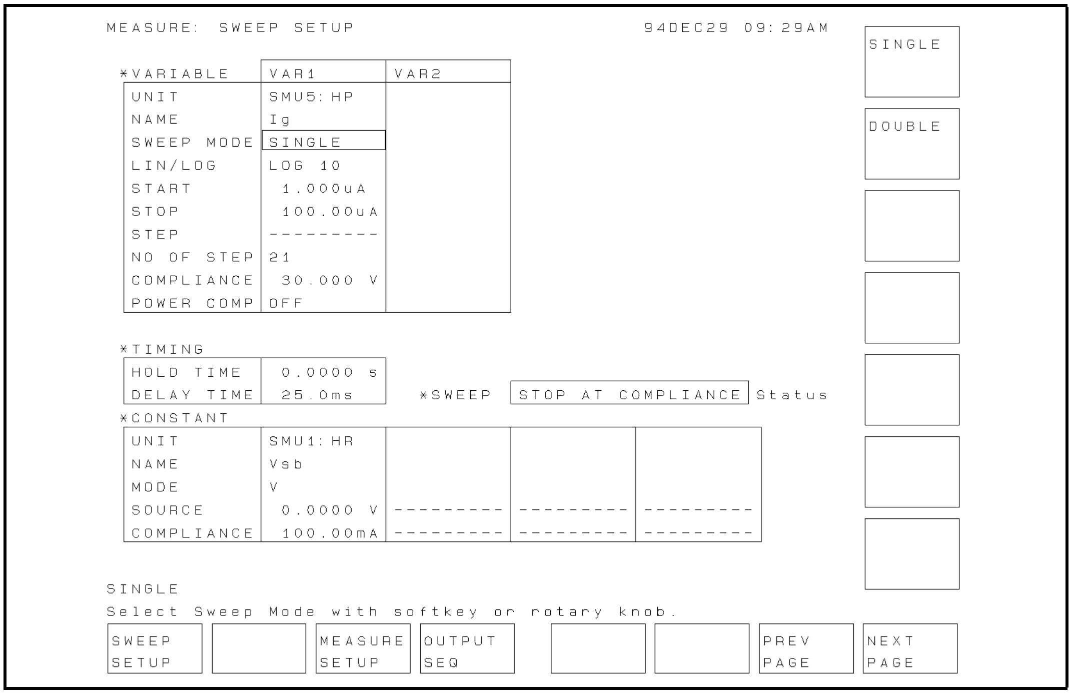
*USER FUNCTION

NAME	UNIT	DEFINITION
Time	sec	.05*(@INDEX)
Vbd	V	@MY2
Qbd	C	INTEG(Ig,Time)

Time

Enter User Function Name. (max 6 chars.) I

Figure A-9. CHANNELS: USER FUNCTION DEFINITION Page



MEASURE: SWEEP SETUP 94DEC29 09:29AM

*VARIABLE

	VAR1	VAR2
UNIT	SMU5:HP	
NAME	Ig	
SWEEP MODE	SINGLE	
LIN/LOG	LOG 10	
START	1.000uA	
STOP	100.00uA	
STEP	---------	
NO OF STEP	21	
COMPLIANCE	30.000 V	
POWER COMP	OFF	

*TIMING

HOLD TIME	0.0000 s
DELAY TIME	25.0ms

*SWEEP STOP AT COMPLIANCE Status

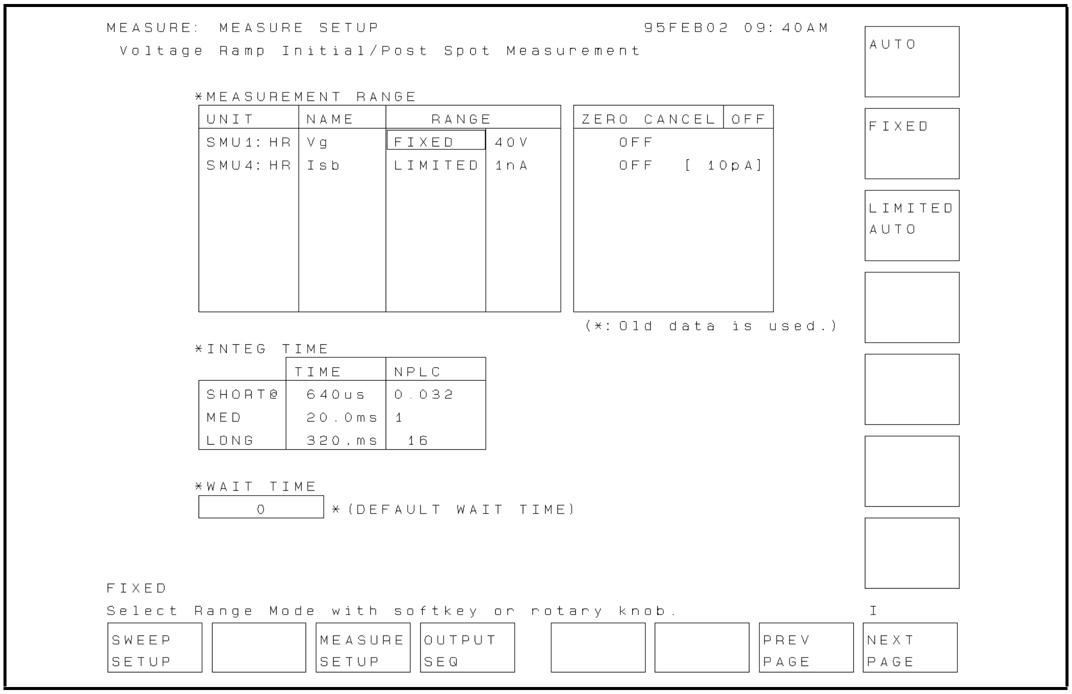
*CONSTANT

UNIT	SMU1:HR			
NAME	Vsb			
MODE	V			
SOURCE	0.0000 V	---------	---------	---------
COMPLIANCE	100.00mA	---------	---------	---------

SINGLE

Select Sweep Mode with softkey or rotary knob.

Figure A-10. MEASURE: SWEEP SETUP Page



MEASURE: MEASURE SETUP 95FEB02 09:40AM

Voltage Ramp Initial/Post Spot Measurement

*MEASUREMENT RANGE

UNIT	NAME	RANGE		ZERO CANCEL OFF
SMU1:HR	Vg	FIXED	40V	OFF
SMU4:HR	Isb	LIMITED	1nA	OFF [10pA]

(*: Old data is used.)

*INTEG TIME

	TIME	NPLC
SHORT@	640us	0.032
MED	20.0ms	1
LONG	320.ms	16

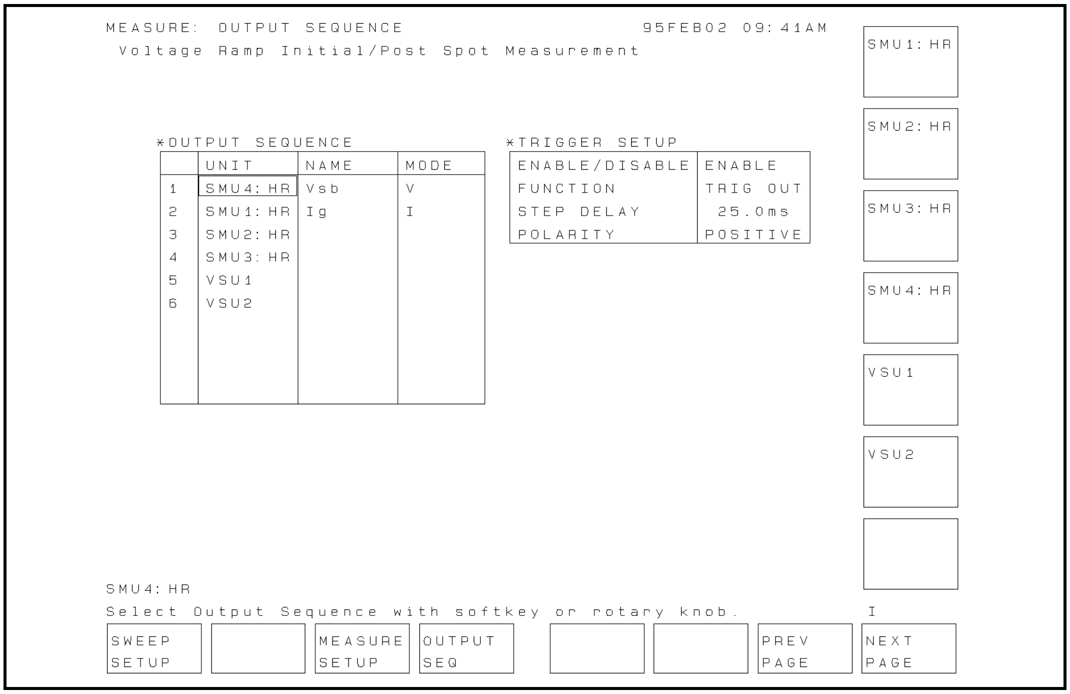
*WAIT TIME

0 *(DEFAULT WAIT TIME)

FIXED

Select Range Mode with softkey or rotary knob. I

Figure A-11. MEASURE: MEASURE SETUP Page



MEASURE: OUTPUT SEQUENCE 95FEB02 09:41AM

Voltage Ramp Initial/Post Spot Measurement

*OUTPUT SEQUENCE

	UNIT	NAME	MODE
1	SMU4:HR	Vsb	V
2	SMU1:HR	Ig	I
3	SMU2:HR		
4	SMU3:HR		
5	VSU1		
6	VSU2		

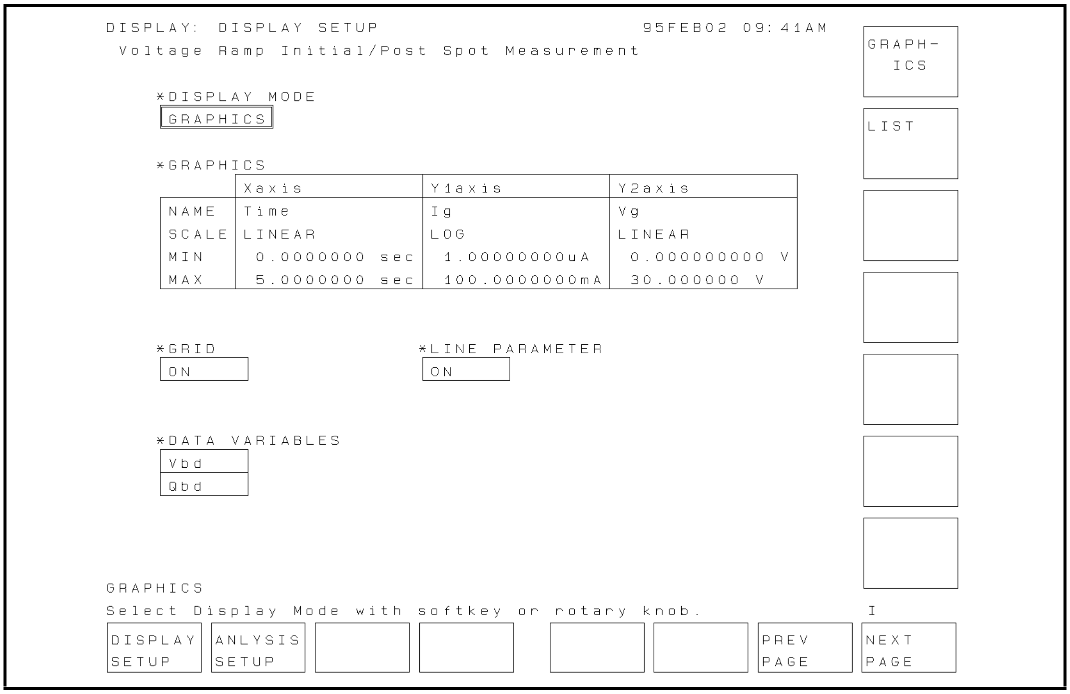
*TRIGGER SETUP

ENABLE/DISABLE	ENABLE
FUNCTION	TRIG OUT
STEP DELAY	25.0ms
POLARITY	POSITIVE

SMU4:HR

Select Output Sequence with softkey or rotary knob.

Figure A-12. MEASURE: OUTPUT SEQUENCE Page



DISPLAY: DISPLAY SETUP 95FEB02 09:41AM

Voltage Ramp Initial/Post Spot Measurement

*DISPLAY MODE

GRAPHICS

*GRAPHICS

	Xaxis	Y1axis	Y2axis
NAME	Time	Ig	Vg
SCALE	LINEAR	LOG	LINEAR
MIN	0.0000000 sec	1.00000000uA	0.000000000 V
MAX	5.0000000 sec	100.0000000mA	30.000000 V

*GRID

ON

*LINE PARAMETER

ON

*DATA VARIABLES

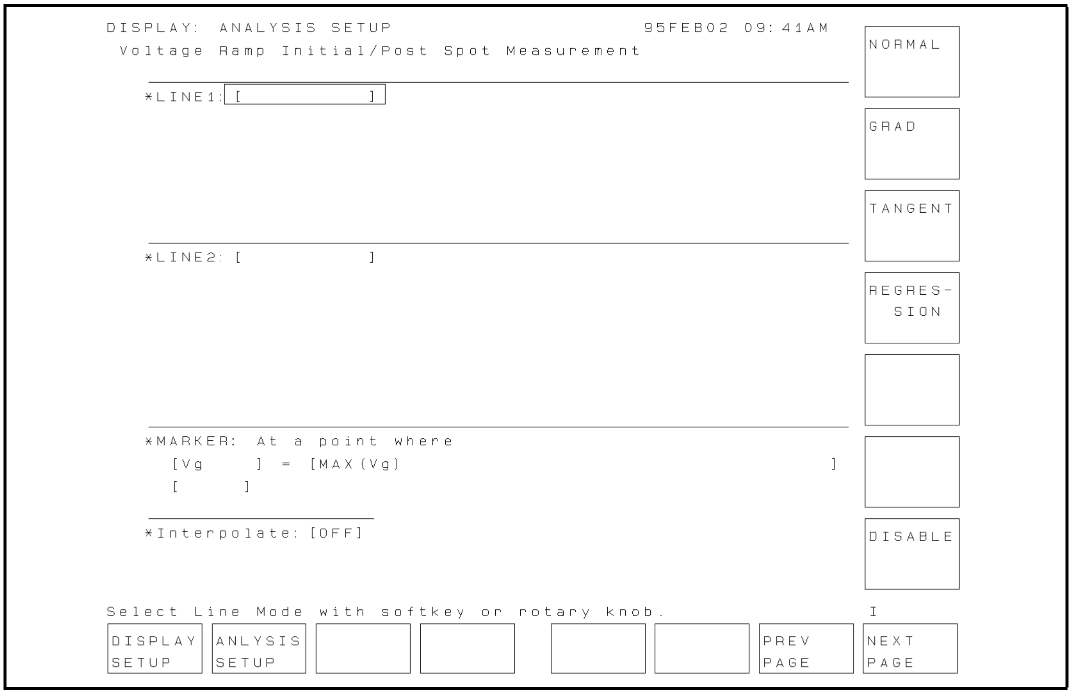
Vbd

Qbd

GRAPHICS

Select Display Mode with softkey or rotary knob.

Figure A-13. DISPLAY: DISPLAY SETUP Page



```
DISPLAY: ANALYSIS SETUP                        95FEB02 09:41AM
 Voltage Ramp Initial/Post Spot Measurement

   *LINE1:[            ]

   *LINE2: [            ]

   *MARKER: At a point where
     [Vg     ] = [MAX(Vg)                                   ]
     [      ]

   *Interpolate: [OFF]

Select Line Mode with softkey or rotary knob.
```

Figure A-14. DISPLAY: ANALYSIS SETUP Page

B

Proof of Equations

This appendix provides the information on how to solve the equations given in "J-Ramp Stress Test" in Chapter 3.

Step increase factor F

N steps per decade (N = 10, 25, or 50) gives the following equation:

$$10 \times I_0 = I_0 \times F^N$$

Solving for F gives the following:

$$\begin{aligned} 10 &= F^N \\ \log_{10} 10 &= \log_{10} F^N \\ 1 &= N \times \log_{10} F \\ \frac{1}{N} &= \log_{10} F \\ F &= 10^{\frac{1}{N}} \end{aligned}$$

So F can be one of the following: $10^{1/10}$, $10^{1/25}$, or $10^{1/50}$. In the JRAMP sample program, F is specified by the `Factor` variable.

$Step\_time$

Relation between N (steps per decade) and F (step increase factor) is:

$$10 = F^N$$

$$\begin{aligned} \log_{10} 10 &= \log_{10} F^N \\ 1 &= N \times \log_{10} F \\ N &= \frac{1}{\log_{10} F} \end{aligned}$$

So,

$$Step\_time = \frac{0.5}{N} = \frac{0.5}{\frac{1}{\log_{10} F}} = 0.5 \times \log_{10} F$$

The sample program sets N (`Fact$`) according to the F (`Factor`) that is set.

Current stop value ($Istop$)

The forced current I is a function of time t, so the accumulated charge to the oxide is:

$$\int_0^n I(t) \cdot dt = \int_0^n I_0 \cdot F^n \cdot Ts \cdot dn = q_{max} \cdot Area$$

Where, $I(t) = I_0 \cdot F^n$, $t = n \cdot Ts$ (time), n is step number, Ts is step time.

You want to solve to find the step number (n) of the step when the maximum allowed charge density is reached:

$$\begin{aligned}
\int_0^n I_0 \cdot F^n \cdot Ts \cdot dn &= q_{max} \cdot Area \\
I_0 \cdot Ts \cdot \int_0^n F^n \cdot dn &= q_{max} \cdot Area \\
I_0 \cdot Ts \cdot \frac{1}{\log_{10} F} \left[F^n\right]_0^n &= q_{max} \cdot Area \\
\frac{I_0 \cdot Ts}{\log_{10} F}(F^n - 1) &= q_{max} \cdot Area \\
(F^n - 1) &= \frac{q_{max} \cdot Area \cdot \log_{10} F}{I_0 \cdot Ts} \\
F^n &= \frac{q_{max} \cdot Area \cdot \log_{10} F}{I_0 \cdot Ts} + 1 \\
n \cdot \log_{10} F &= \log_{10}\left(\frac{q_{max} \cdot Area \cdot \log_{10} F}{I_0 \cdot Ts} + 1\right) \\
n &= \frac{1}{\log_{10} F} \cdot \log_{10}\left(\frac{q_{max} \cdot Area \cdot \log_{10} F}{I_0 \cdot Ts} + 1\right)
\end{aligned}$$

So, $Istop$ is as follows, where M is the minimum integer that satisfies $M \geq n$. In the JRAMP sample program, M is the `Step_n` variable:

$$Istop = I_0 \cdot F^M$$

Tip

Assuming "$y = a^x$, a: constant", you can get the following:

$$\begin{aligned}
\log y = \log a^x &= x \cdot \log a \\
(\log y)' &= \log a \\
\frac{1}{y} \cdot y' &= \log a \\
y' = \log a \cdot y &= (\log a) \cdot a^x
\end{aligned}$$

So, the integration of a^x is:

$$\int a^x = \int \frac{y'}{\log a} dx = \frac{1}{\log a} \int y' dx = \frac{1}{\log a} \cdot y = \frac{a^x}{\log a}$$

The result of this integration is used to go from 2nd to 3rd step of above solution (integration of F^n).

HP 4155A / HP 4156A Precision Semiconductor Parameter Analyzer

SWEAT Sample Program Operation Manual

HEWLETT
PACKARD

HP Part No. 04155-90130
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Edition 1

Contents

1. Introduction

2. SWEAT

3. Basic Operation

4. Customization

A. Setup files

Figures

1

Introduction

SWEAT means Standardized Wafer-level Electromigration Accelerated Test, which is an accelerated electromigration test for microelectronic metallization on the wafer.

This test can quickly provide data for monitoring metal reliability and process consistency.

This operation manual describes a sample SWEAT program running on the HP 4155A/4156A, and how to use and customize the program. The program is written in HP Instrument BASIC (IBASIC), and is ready to run on the built-in IBASIC controller of the HP 4155A/4156A.

Note

This is a sample program, so before execution, you may need to customize the program and the setup files for your application. If the sample program damages your device, Hewlett-Packard is *NOT LIABLE* for the damages.

Contents of this Manual

Chapter 2 describes the SWEAT procedure and terminology.

Chapter 3 describes the SWEAT methodology using the HP 4155A/4156A, how to execute the sample program, and program overview.

Chapter 4 describes the customization procedure. This procedure is very important because you probably need to modify the program to suit your test device.

Appendix A shows the HP 4155A/56A page settings that are stored in the setup files.

2

SWEAT

This chapter describes the SWEAT procedure (based on the proposed JEDEC 4-June-92 standard) and related terminology.

Overview

SWEAT evaluates sensitivity of metal lines to failure caused by electromigration.

Figure 2-1 shows the flow of the SWEAT test according to the JEDEC proceeding titled “A PROCEDURE FOR EXECUTING SWEAT” (4-Jun-92).

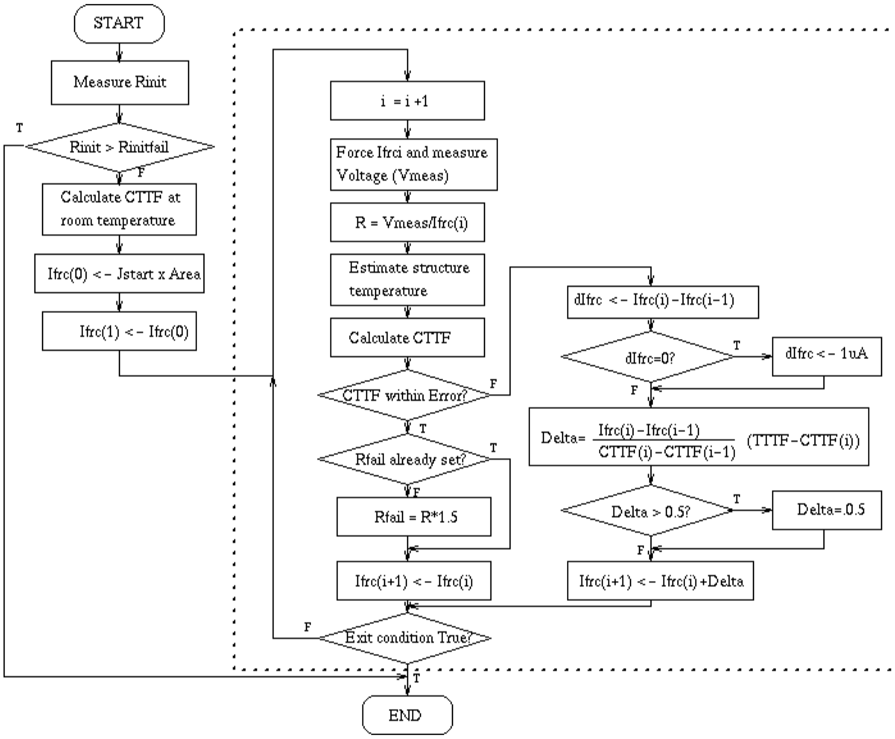


Figure 2-1. SWEAT Algorithm Flow

First, the initial structure resistance is measured. If it is too high, the program finishes.

If initial structure resistance is within limits, the stress/resistance measurement loop is performed, which is the part inside the dotted square in Figure 2-1. This loop is a feedback control loop that does the following:

1. An initial current is forced through the test structure, and the calculated time to failure (CTTF) is calculated by using Black's equation. The current is adjusted in a feedback loop until the CTTF is within a desired range (TTTF ± Errband), where TTTF is the target time-to-failure. This feedback period to reach the desired range is called the *settling period*. The structure resistance is measured when CTTF becomes within TTTF ± Errband. This is called the *settling resistance*.
2. After settling, the current is continuously forced to the test structure. By continuously adjusting the current, CTTF is forced to track TTTF. This period is called the hold period. This adjustment is performed by the same feedback control algorithm as used during the settling period. Gradually, the structure resistance increases due to electromigration voids (CTTF deviates from TTTF).

   The hold period continues until the structure resistance is *1.5* × *settling resistance*. This means the structure has ruptured (failed).

Input Parameters

Following table shows the input parameters required for the SWEAT procedure and the values used in the sample program. You can change these values to suit your device.

Input Parameter (Default Value)	**Description**
Tcr (2.E−3 °K^{-1})	Temperature coefficient of resistance (This value should be measured before performing the SWEAT evaluation.) See JEDEC No.33 *Standard Method for Measuring and Using the Temperature Coefficient of Resistance to Determine the Temperature of a Metallization Line* for how to measure TCR.
Rinitfail (1000 Ω)	Maximum allowable structure resistance during the initial resistance test.
Tttf (190 sec)	Target time to failure.
Ttt (1000 sec)	Total testing time. Testing stops if this time is reached.
Troom (298 °K)	Room temperature.
Vcomp (20 V)	Voltage compliance.
Isrc_max (1 A)	Maximum limit of current source.
Errband (2 sec)	Allowable difference between CTTF and TTTF during feedback control loop. If difference is greater than this value, forced current is adjusted.
Area (1E−8 cm^2)	Cross sectional area of the narrowest region of the structure.
Jstart (1.0E−2/Area A/cm^2)	Starting current density.
Acc (1.E+10 sA^2/cm^4)	Acceleration factor for Black's Equation.
Blk (2)	Current density factor (n) for Black's Equation.
Ea (0.6 eV)	Activation energy for the metallization for Black's Equation.

Initial Resistance (Rinit) Measurement

Rinit is the structure resistance at room temperature and low current density.

The algorithm assumes that the ambient temperature is 298°K and the current density is sufficiently low so that Joule heating is negligible. Actual Rinit is measured when voltage (small enough not to cause the Joule heating) is applied to the structure.

CTTF

CTTF is the Calculated Time to Failure of the structure based on Black's Equation:

$$CTTF = Acc * J^{-n} e^{Ea/kT}$$

Acc :	Acceleration factor
J :	Current density
Ea :	Activation energy for the metallization
n :	Current density factor
k :	Boltzman's constant
T :	Temperature in °K.

Rfail

Rfail is used to judge if the test structure fails during the stress/resistance measurement loop. Rfail is defined as 1.5 × *settling resistance*.

Exit Condition

SWEAT program ends if any of following occurs. The Ex_cond variable is set to indicate the exit condition and is saved to the result data file.

- Rinit is greater than Rinitfail (1000 Ω in sample program). Ex_cond = 10000.
- Rfail has been set and the structure resistance is greater than Rfail. This is the expected exit condition for the test. Rfail is defined as 1.5 × *settling resistance*. Ex_cond = 1.
- Total testing time has elapsed. Ex_cond = 2.
- New force current for feedback control is larger than the current limit. Ex_cond = 3.
- Voltage compliance of the current source has been reached. Ex_cond = 4.

Output Parameters

The SWEAT sample program stores the following results in the result data file when the test is exited:

- Exit Condition

  This is the number of the exit condition that caused the test to terminate.

- Time To Fail (TTF)

  TTF is the time (in seconds) at which the structure failed.

- Fail Resistance

  This is the resistance at TTF, which is the structure resistance value when structure resistance exceeds Rfail (1.5 × *settling resistance*).

- Fail J (Iforce/Area)

  This is the applied current density at TTF based on the area of the narrowest region of the test structure.

- Temperature at Fail

  This is the estimated temperature of the narrowest region of the test structure at TTF.

3

Basic Operation

This chapter describes the methodology for using HP 4155A/4156A to perform SWEAT, required equipment, required program and files, how to execute the sample program, and sample program overview.

Methodology

The entire SWEAT procedure can be performed by executing the SWEAT sample program.

The program loads measurement setups (into HP 4155A/56A) that were previously saved to the measurement setup files on diskette. These setup files are included on the diskette with the sample program. If you need to modify a setting, you can easily modify them in fill-in-the-blank manner from the HP 4155A/56A front panel, then resave to the file.

SWEAT test needs a controller to make complicated calculations (such as CTTF) and to control the forced current during the stress/resistance measurement loop. When using the HP 4155A/4156A, two controllers are available: an external computer or the built-in IBASIC controller of HP 4155A/4156A. The measurement data (CTTF versus Time) is displayed on the GRAPHICS page of the HP 4155A/4156A. Other result data is saved to a result data file.

The SWEAT sample program is created assuming that the HP 4155A/56A built-in IBASIC controller is used. The sample program can easily be modified to run on HP BASIC or IBASIC on an external computer. Refer to Chapter 4 on how to modify the program to run on an external computer.

If you use a high performance external computer, such as *HP 9000 S382* , you can speed up the feedback loop and reduce the settling period.

An HPSMU is necessary to force high current greater than 100mA, and must be connected to SMU5 port. Measurement mode is set to **Sampling mode**, and SMU5 is set to **Standby mode** so that current is continuously forced even when measurement is not being made, such as during calculation.

Initial Resistance (Rinit) Measurement

First, Rinit is measured while 0.1 V is applied to the test structure. Applied voltage value (0.1 V) is assumed to be low enough not to cause Joule heating. Rinit measurement circuit is shown in Figure 3-1.

This measurement setup is in the RINIT.MES file on the diskette, and the sample program loads this setup into the HP 4155A/56A at the beginning of the measurement. You can easily modify this measurement setup if desired. You just set the setup pages as desired from the front panel, then save the new setup to the RINIT.MES file.

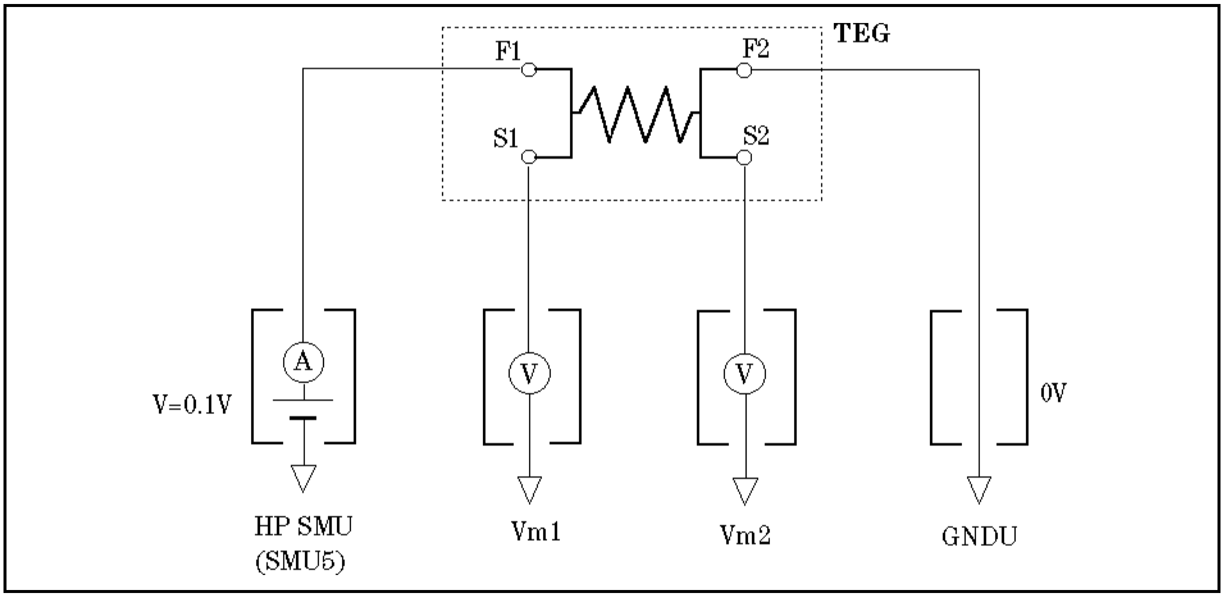


Figure 3-1. Rinit Measurement Circuit

Stress/Resistance Measurement Loop

After Rinit measurement, sample program loads a new setup into HP 4155A/56A, and a feedback loop is entered. Current (Iforce) is applied to the test structure. Iforce is controlled and adjusted until CTTF (computed using the measurement results) has settled close enough to TTTF (within ±Errband). HP 4155A/4156A is set to sampling mode to make a single spot measurement. SMU5 port is set to standby mode to keep the current continuously applied while measurements and calculations are performed.

Measurement circuit of this feedback loop is shown in Figure 3-2. Figure 3-3 and Figure 3-4 show an example CHANNEL DEFINITION and SAMPLING SETUP page. This measurement setup is stored in the IFVM.MES file on the diskette.

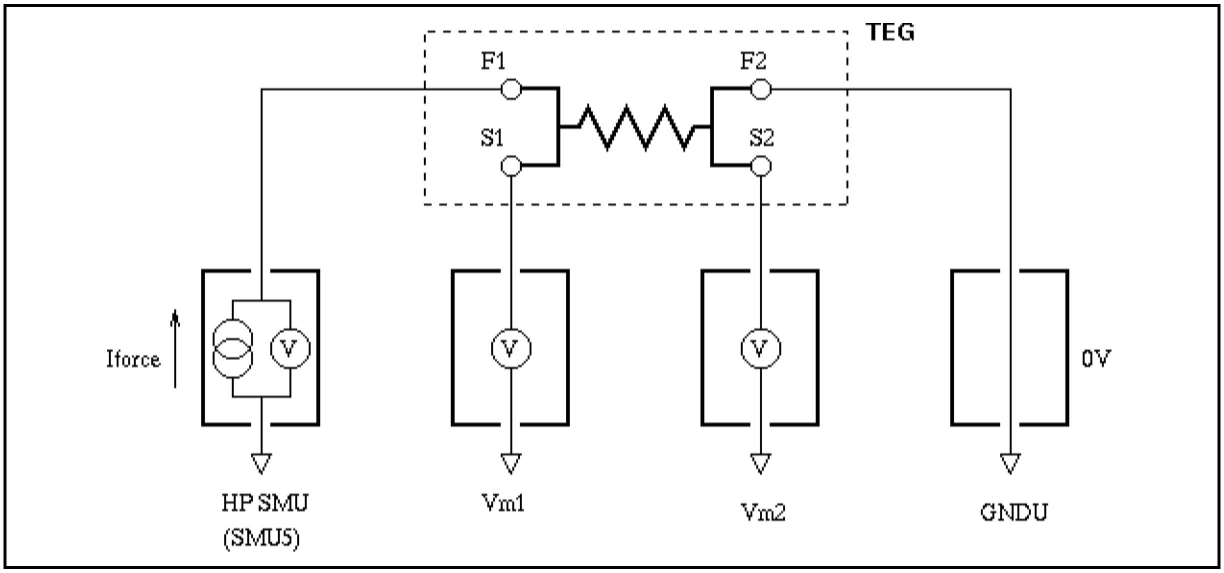
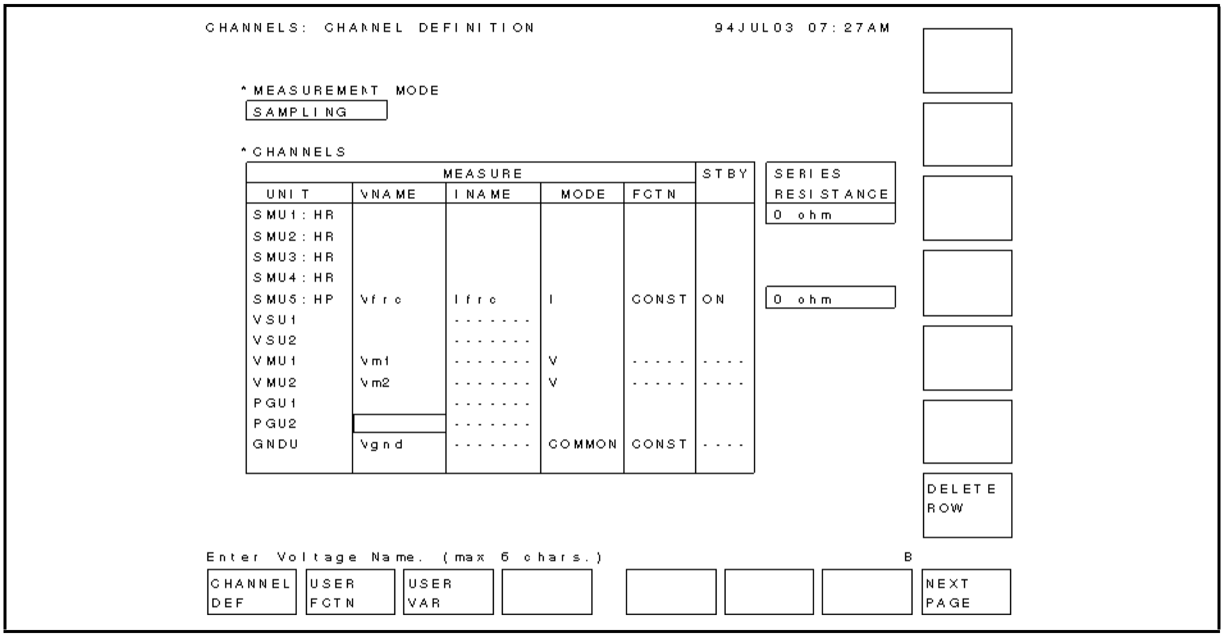


Figure 3-2. Stress/Resistance Measurement Circuit



CHANNELS: CHANNEL DEFINITION 94JUL03 07:27AM

*MEASUREMENT MODE

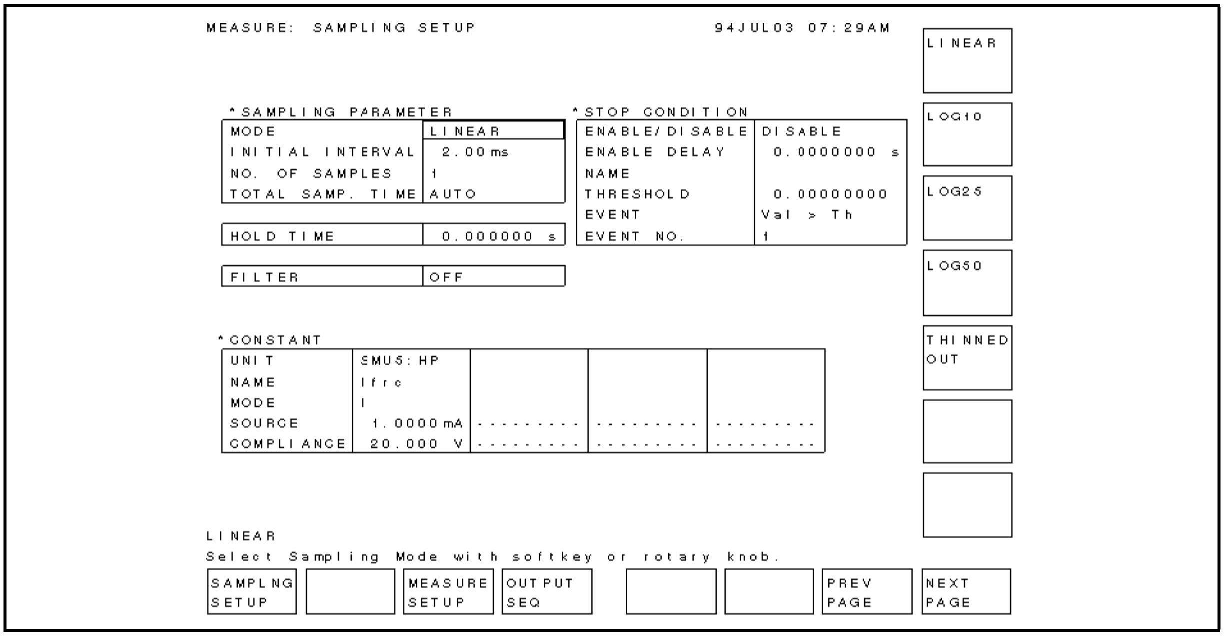
SAMPLING

*CHANNELS

MEASURE					STBY	SERIES RESISTANCE
UNIT	VNAME	INAME	MODE	FCTN		
SMU1:HR						0 ohm
SMU2:HR						
SMU3:HR						
SMU4:HR						
SMU5:HP	Vfrc	Ifrc	I	CONST	ON	0 ohm
VSU1		-------				
VSU2		-------				
VMU1	Vm1	-------	V	-----	----	
VMU2	Vm2	-------	V	-----	----	
PGU1		-------				
PGU2		-------				
GNDU	Vgnd	-------	COMMON	CONST	----	

Enter Voltage Name. (max 6 chars.) B

Figure 3-3. CHANNEL DEFINITION Page



MEASURE: SAMPLING SETUP 94JUL03 07:29AM

*SAMPLING PARAMETER

MODE	LINEAR
INITIAL INTERVAL	2.00ms
NO. OF SAMPLES	1
TOTAL SAMP. TIME	AUTO

HOLD TIME	0.000000 s

FILTER	OFF

*STOP CONDITION

ENABLE/DISABLE	DISABLE
ENABLE DELAY	0.0000000 s
NAME	
THRESHOLD	0.00000000
EVENT	Val > Th
EVENT NO.	1

*CONSTANT

UNIT	SMU5:HP			
NAME	Ifrc			
MODE	I			
SOURCE	1.0000mA	---------	---------	---------
COMPLIANCE	20.000 V	---------	---------	---------

LINEAR

Select Sampling Mode with softkey or rotary knob.

Figure 3-4. SAMPLING SETUP Page

After every measurement, the program updates only Iforce.

When CTTF becomes within specified range of TTTF, the structure resistance is measured. This is called the *settling resistance*.

Then, current continues to be forced and adjusted in the stress/resistance measurement loop until sufficient electromigration has occurred to change the structure resistance so that it is greater than Rfail (1.5 × *settling resistance*).

Required Equipment

The following are required to use the SWEAT sample program:

- HP 4155A or HP 4156A Semiconductor Parameter Analyzer
- HP 41501A SMU and Pulse Generator Expander furnished with HPSMU (Option 410 or 412)
- Four triaxial cables
- Probe station
- This operation manual
- Diskette that contains sample program and setup files.

Files on the Diskette

Make sure that following files are on the diskette:

- SWEAT

  SWEAT sample program.

- RINIT.MES

  File for setting up the HP 4155A/56A to measure initial resistance (Rinit).

- IFVM.MES

  File for setting up the HP 4155A/56A to measure resistance during stress/resistance measurement loop, and to plot CTTF versus Time.

Execution

Before executing the program, you may need to customize the program to suit your test device. If so, see Chapter 4.

1. Connect HP 4155A/4156A to your test device. Refer to Figure 3-1.
2. Insert diskette that contains SWEAT program into built-in drive of HP 4155A/4156A or drive of external controller.
   - To load the program into HP 4155A/56A, press the IBASIC (Display) key until All IBASIC screen is displayed. Then, type the following: `GET "SWEAT"` (Enter)
   - To load the program into an external controller, type the following on the command line of external controller display: `GET "SWEAT:,`*msus*`"` (Enter)

     Where *msus* is specifier of mass storage device that contains the SWEAT program. If default drive is used, just type `GET "SWEAT"` (Enter).

     Then, insert the diskette into the built-in drive of the HP 4155A/56A because HP 4155A/56A will need to load the measurement setup files.
3. Press the IBASIC (Display) key until All Instrument screen is displayed.
4. To run SWEAT program in HP 4155A/56A, press (RUN) front-panel key.

   To run SWEAT program in external controller, type `RUN` (Enter).

Measurement results will be displayed on GRAPHICS page of the HP 4155A/4156A.

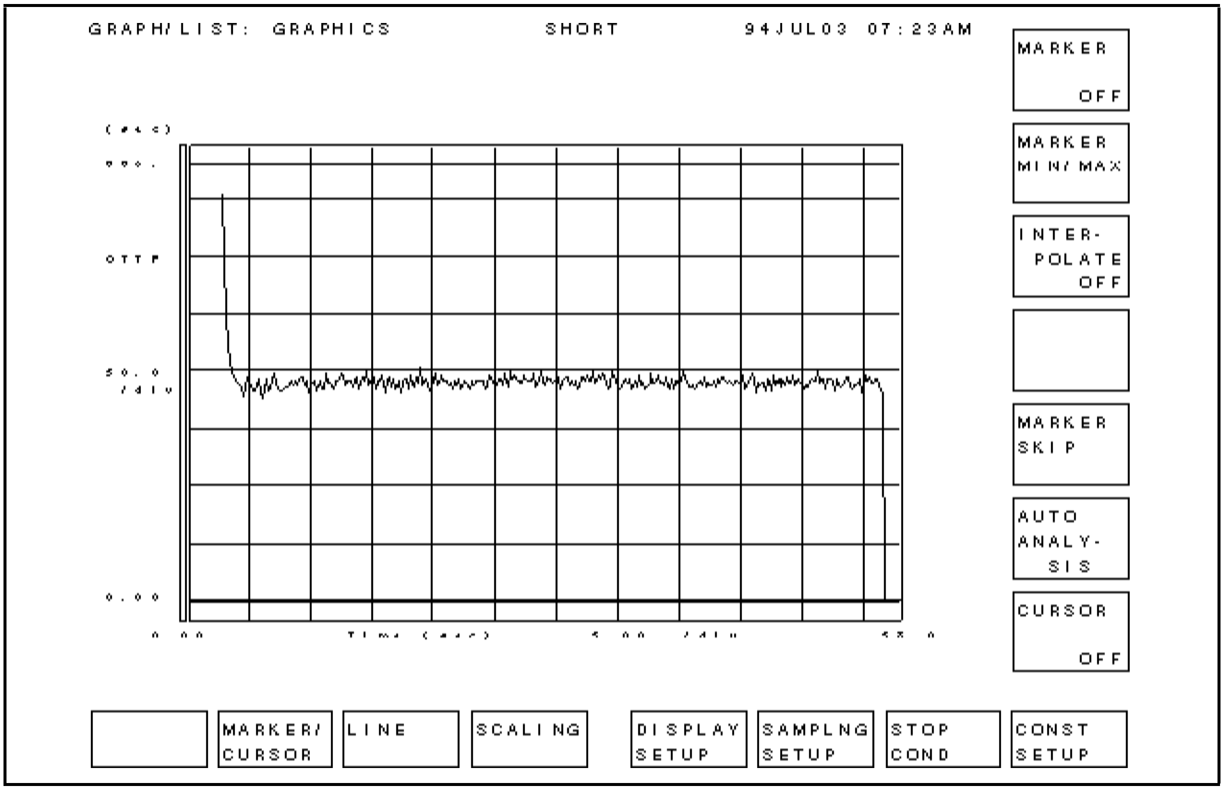


Figure 3-5. Measurement Result Example

Sample SWEAT Program Overview

For the actual program code, edit `SWEAT` program.

Line or Subprogram Name	Description
1510	Sets the HP 4155A/4156A's address. `800` means HP 4155A/4156A will be controlled by built-in IBASIC controller.
1530 - 1560	Creates data file for storing results.
1590 - 1600	Defines names for setup files that are on diskette.
1630 - 1750	Assigns input parameter values.
1800 - 1880	Loads Rinit measurement setup file, then measures Rinit.
1930	Loads setup file for stress/resistance measurement and displaying results.
1990	Sets standby mode.
2050 - 2400	Performs stress/resistance measurement loop.
2460 - 2500	Saves measured parameters into the result data file.
2520 - 2540	Displays "CTTF vs. Time" graph.
Init_hp415x	Subprogram for initializing HP 4155A/4156A.
Get_file	Subprogram for loading setup file from the diskette into HP 4155A/56A.
Rinit_meas	Subprogram for measuring Rinit.
Calc_cttf	Subprogram for calculating CTTF.
Calc_tmp	Subprogram for calculating structure temperature.
Sweat_graph	Subprogram for transferring measurement data from HP 4155A/56A user variable to program array variables, and setting up the "CTTF vs. Time" graph.

4

Customization

This chapter describes how to customize the sample program to suit your test device.

Using External Computer or Built-in Controller

Line 1510 specifies the address of HP 4155A/4156A:

```
1510  ASSIGN @Hp415x TO 800               !  Address setting
```

- If you will execute the SWEAT program using the HP 4155A/4156A's built-in IBASIC controller, use the above address (`800`).
- If you want to execute the SWEAT program on an external computer, use *XYZ* instead of `800`, where *X* is the HP-IB select code, and *YZ* is the HP-IB address of the HP 4155A/56A.

  For example, if the HP-IB select code is `7`, and the HP-IB address of HP 4155A/4156A is `17`, modify as follows:

  ```
  1510  ASSIGN @Hp415x TO 717               !  Address setting
  ```

  Also, set the HP 4155A/4156A to `NOT SYSTEM CONTROLLER` on SYSTEM: MISCELLANEOUS page.

Specifying Setup File to Load

Two setup files are required to set up the HP 4155A/56A for the SWEAT measurement: Rinit measurement setup file and stress/resistance measurement setup file.

These setup files are defined on lines 1590 and 1600.

```
1580  !----- File name setting -------------
1590  Ri_file$="RINIT.MES"       !  Rinit measurement setup file
1600  Ist_file$="IFVM.MES"       !  Istress measurement setup file
```

If you want to use other setup files instead, store the setup files on the diskette, then modify the file names on the above lines.

File for Saving Measurement Results

The following lines create an ASCII file for saving the extracted parameters:

```
1530  File$=TIME$(TIMEDATE)                  !
1540  File$=File$[1,2]&File$[4,5]            ! Creating
1550  CREATE File$,1                         !     Data
1560  ASSIGN @File1 TO File$;FORMAT ON       !       File
```

Lines 1530 and 1540 create a file with name that is the present time: *HHMM*, where *HH* = hour and *MM* = minute.

If you want to change the file name, modify line 1540, as shown in following example:

```
1540  File$="TESTDATA"
```

Line 1550 creates a DOS file, and `FORMAT ON` in line 1560 means ASCII file. So, extracted parameters will be stored in an ASCII-format DOS file.

In the sample program, the following result parameters will be stored in the file:

- Exit condition
- Time to failure
- Failure resistance
- Failure temperature
- Failure current density

You can add result parameters to be stored in the file by adding lines in the following format:

`OUTPUT @File1,"`*parameter*`"`

For example, if you want to store CTTF, structure temperature (`T_now`), time, and resistance (`R_now`) during the stress/resistance measurement loop, add the following two lines:

```
2172  OUTPUT @File1;"I=";I;" CTTF(I)=";Cttf(I);"(s) T_now=";T_now;"(K)"
2174  OUTPUT @File1;"Time =";Time(I);"(s) R_now=";R_now;"(ohm)"
```

Setting up Input Parameters

Input parameter values are assigned from line 1620 to 1720. Modify these values according to your test device.

Note

Input parameters for CTTF calculation are *not* defined here, but are defined in the Calc_cttf subprogram. See next section.

```
1620   !----- Parameter setting -------------
1630   Tcr=2.E-3                  ! Temperature Coefficient of R (1/K)
1640   Rinit_fail=1000            ! Unallowable initial resistance value (ohm)
1650   Tttf=190                   ! Target Time to Failure (sec)
1660   Ttt=1000                   ! Total Testing Time (sec)
1670   Troom=298                  ! Room Temperature (K)
1680   Vcomp=20                   ! Voltage compliance of every port
1690   Isrc_max=1                 ! Current Limit of HPSMU
1700   Errband=2                  ! Allowable Error Band (sec.)
1710   Area=1.E-8                 ! Narrowest cross section (cm^2)
1720   Jstart=1.0E-2/Area         ! Initial current density
```

Parameter	Description	Default
`Tcr`	Temperature coefficient of R	2.E-3 °K^{-1}
`Rinit_fail`	Maximum allowable initial resistance value	1000 Ω
`Tttf`	Target time to failure	190 sec
`Ttt`	Total allowed testing time	1000 sec
`Troom`	Room temperature	298 °K
`Vcomp`	Voltage compliance	20 V
`Isrc_max`	Current limit of HPSMU	1 A
`Errband`	Allowable error band	2 sec
`Area`	Narrowest cross section	1.E-8 cm^2
`Jstart`	Initial current density	1.0E-2/`Area` (A/cm^2)

Setting up Input Parameters Related to CTTF Calculation

The following input parameters are used in Black's Equation to calculate CTTF in the Calc_cttf subprogram. If you want to modify these values, change following lines.

```
2990    !----- parameter setting -------------
3000    Acc=1.E+10                       ! Acceleration factor (s*A^2/cm^4)
3010    Blk=2                            ! Dimensionless const for Black
3020    Ea=.6                            ! Activation Energy (eV)
```

Parameter	**Description**	**Default**
`Acc`	Acceleration factor	1.E+10 (sA^2/cm^4).
`Blk`	Exponent for current density (*n* in Black's equation)	2
`Ea`	Activation Energy for metallization	0.6 (eV)

How to Reduce the Settling Time of CTTF

If many operations are performed (such as displaying results) during the settling period, the intervals between stress current adjustments becomes long. As a result, it takes a long time for CTTF to settle close to TTTF. So, the test structure may become OPEN before the CTTF settles. This leads to unreliable measurement results.

The following are hints for reducing the settling time of CTTF.

Display the Results after Stress/Resistance Measurement Loop

The sample SWEAT program displays measurement results *after* the stress/resistance loop is exited. The following describes how to modify the SWEAT program so that measurement results are displayed *during* the stress/resistance measurement loop. If you make this modification, the CTTF settling period *becomes longer*.

The Sweat_graph subprogram is used to display the measurement results. In the SWEAT program, the Sweat_graph subprogram is called in line 2420, which is after the stress/resistance measurement loop is exited. The stress/resistance measurement loop is from line 2020 to 2410.

If you want to see the measurement results during the stress/resistance measurement loop, modify the SWEAT program to call the Sweat_graph subprogram after line 2170 as shown in the following, and add lines 3490 and 3500 to the Sweat_graph subprogram.

```
2170    Calc_cttf(Cttf(I),Iforce(I)/Area,T_now) ! CTTF calculation
2175    Sweat_graph(I,Time(*),Cttf(*))
2180    !
     ⋮
3500    OUTPUT @Hp415x;":PAGE:GLIS"     ! Display Graphic page
3510    OUTPUT @Hp415x;”:DISP ON”       ! Enable Display Update
3520    OUTPUT @Hp415x;”:DISP OFF”      ! Disable Display Update
```

The above modification displays the measurement results during the stress/resistance measurement loop, so the CTTF settling period becomes long.

Use a High Performance External Controller

If you use a high performance external controller (such as the HP 9000 S382 SPU), the calculation time is reduced.

Use Optimum J_{START}

If difference is too great between J_{START} and the stress current value when CTTF is settled, the CTTF settling time may become long. So, vary J_{START} value for first several measurements to find the optimum J_{START} value.

In the sample program, J_{START} is defined so that the first stress current is 1 mA.

Reducing Parameter Extractions during Measurement

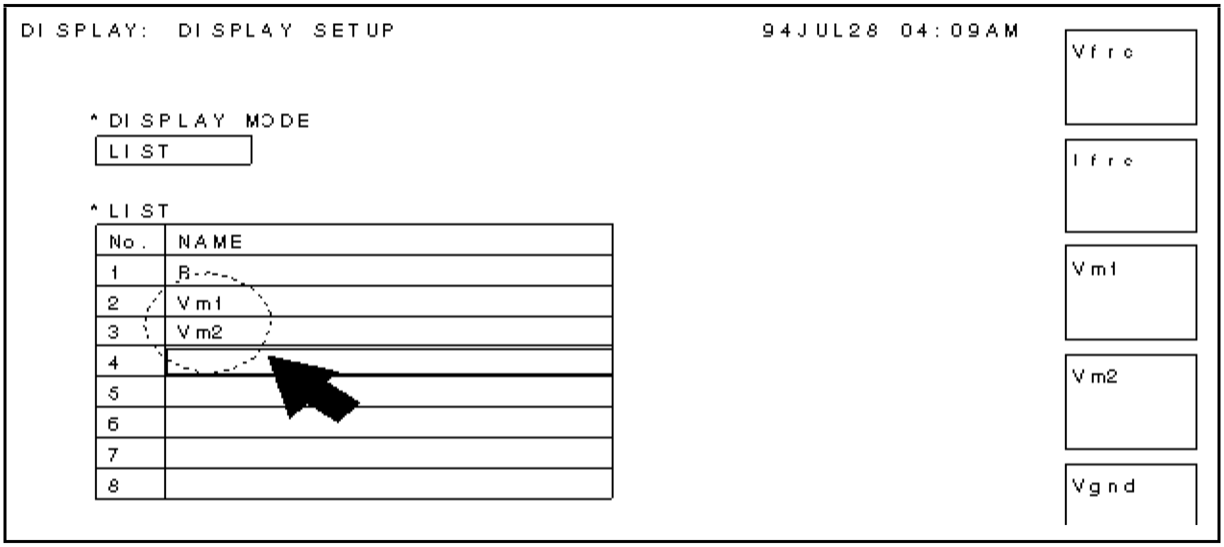
If many parameters are extracted during the stress/resistance measurement loop, especially when the stress current is being adjusted, the time interval between current adjustments becomes long. (Extract means to transfer the parameter from HP 4155A/56A to controller.)

So, do not extract parameters that are not important for the measurement results. In the sample program, only the resistance is extracted, which is required to calculate CTTF.

If you want to extract parameters other than resistance, you need to modify the setup file IFVM.MES and SWEAT program as described in the example below.

First, add parameter name to be extracted to the DISPLAY SETUP page shown in Figure 4-1. In this example, Vm1 and Vm2 monitored by VMUs are added.

You need to save the new setup to the IFVM.MES file.



DISPLAY: DISPLAY SETUP 94JUL28 04:09AM

*DISPLAY MODE

LIST

*LIST

No.	NAME
1	R
2	Vm1
3	Vm2
4	
5	
6	
7	
8	

Figure 4-1. Modification on DISPLAY SETUP Page

Then, add following lines to the SWEAT program:

```
2130    OUTPUT @Hp415x;"TRAC? 'R'"          ! Extract R_now
2140    ENTER @Hp415x;R_now                 !
2142    OUTPUT @Hp415x;”TRAC? ’Vm1’”        ! Extract Vm1
2144    ENTER @Hp415x;Vm1                   !
2146    OUTPUT @Hp415x;”TRAC? ’Vm2’”        ! Extract Vm2
2148    ENTER @Hp415x;Vm2                   !
2150    !
```

Note Adding parameters to be extracted *increases* the CTTF settling time.

Defining J_{START}

Test structure resistance is usually very small at first. So, the voltage drop across the test structure is very small if the start current is small. The voltage resolution of the VMU in sampling mode is 1 mV. It is very important for the current to be great enough to cause enough voltage drop to get an accurate resistance value. Modify following part if you need to change J_{start}.

```
1710  Area=1.E-8                  ! Narrowest cross section (cm^2)
1720  Jstart=1.0E-2/Area          ! Initial current density
```

Use the following equation to determine the best J_{START}:

$$J_{START} * Area * Rinit > 10mV$$

Current Adjustment Routine

The sample program is made based on the proposed JEDEC 4-June-92 standard, but the algorithm associated with the current adjustment routine in the stress/resistance measurement loop may not work for some test structures.

```
2190    IF Cttf(I)<Tttf-Errband OR Cttf(I)>Tttf+Errband THEN
2200      Delta_ifrc=Iforce(I)-Iforce(I-1)
2210      IF Delta_ifrc=0 THEN Delta_ifrc=1.E-6
2220      Delta=Delta_ifrc*(Tttf-Cttf(I))/Cttf(I)-Cttf(I-1)
2230      IF Delta>.05 THEN Delta=.05
2240      IF Delta<-.05 THEN Delta=-.05
2250      Iforce(I+1)=Iforce(I)+Delta
2260    ELSE
2270      IF Rf_set=0 THEN        !
2280        Rfail=R_now*1.5       ! Set Rfail value
2290        Rf_set=1              !
2300      END IF
2310      Iforce(I+1)=Iforce(I)
2320    END IF
```

This routine is slightly different from the proposed JEDEC 4-June-92 standard. In lines 2230 and 2240, Delta is set to 0.05A (or −0.05A) if calculated Delta exceeds 0.05A (or −0.05A). But in proposed JEDEC 4-June-92 standard, Delta is set to 0.5A (or −0.5A) if calculated Delta exceeds 0.5A (−0.5A).

This modification is made due to the maximum current limit (1A) of HPSMU.

If the sample program does not work properly, try modifying Delta definition, Jstart, or Errband until it works properly.

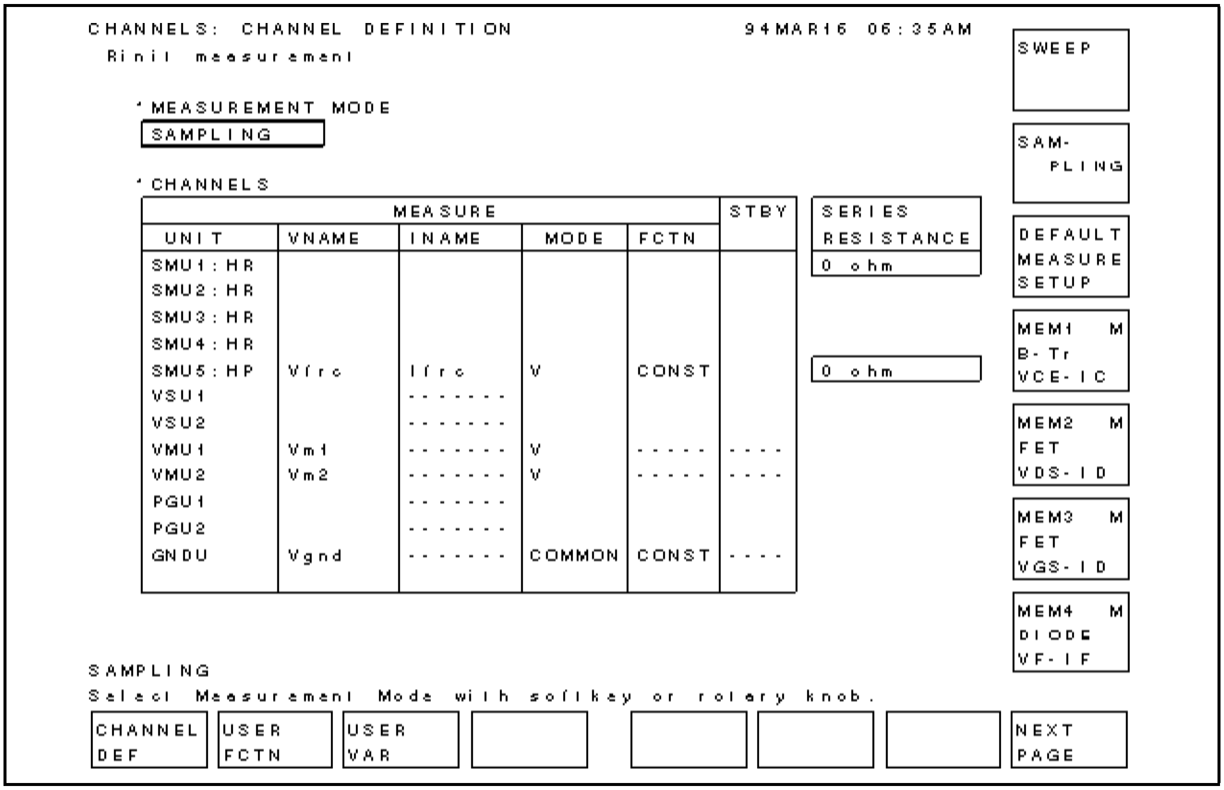
A

Setup files

This appendix describes the settings of the HP 4155A/56A setup pages that are stored in the RINIT.MES and IFVM.MES files. If you change the setup page settings, you need to save the settings to the files.

Setup File for Initial Resistance Measurement

The settings of the following setup pages are stored in the RINIT.MES file, which is used to set up HP 4155A/56A for initial resistance (Rinit) measurement.



CHANNELS: CHANNEL DEFINITION 94MAR16 06:35AM
Rinit measurement

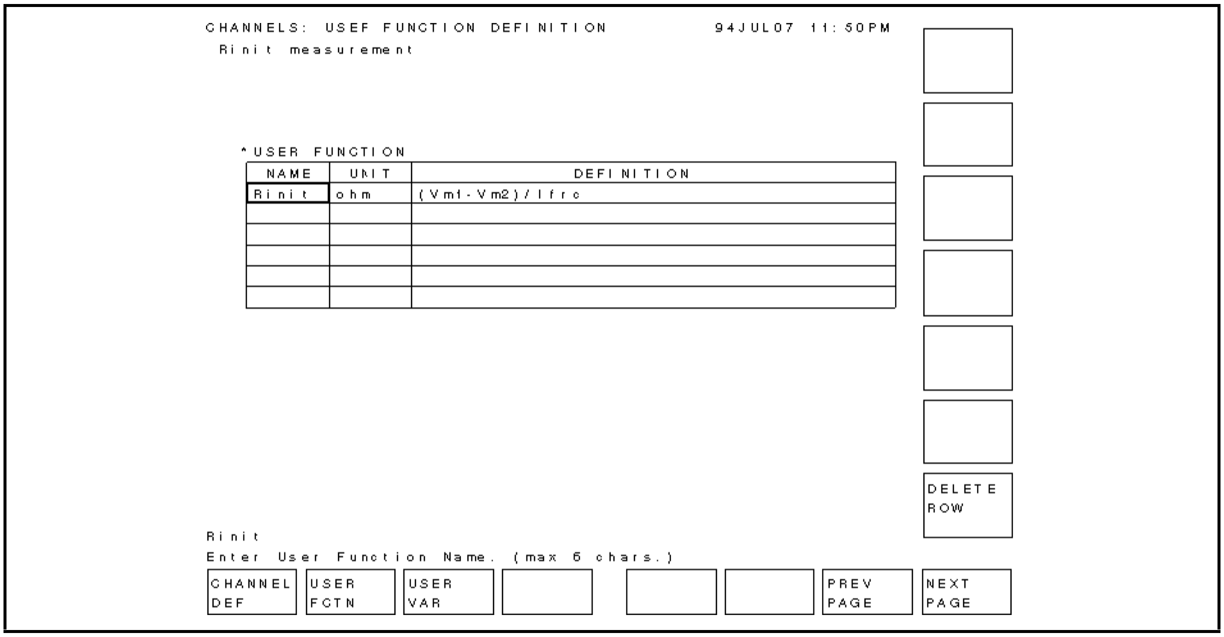
*MEASUREMENT MODE
SAMPLING

*CHANNELS

MEASURE					STBY	SERIES RESISTANCE
UNIT	VNAME	INAME	MODE	FCTN		
SMU1:HR						0 ohm
SMU2:HR						
SMU3:HR						
SMU4:HR						
SMU5:HP	Vfrc	Ifrc	V	CONST		0 ohm
VSU1		-------				
VSU2		-------				
VMU1	Vm1	-------	V	-----	----	
VMU2	Vm2	-------	V	-----	----	
PGU1		-------				
PGU2		-------				
GNDU	Vgnd	-------	COMMON	CONST	----	

SAMPLING
Select Measurement Mode with softkey or rotary knob.

Figure A-1. CHANNEL DEFINITION Page



CHANNELS: USEF FUNCTION DEFINITION 94JUL07 11:50PM

Rinit measurement

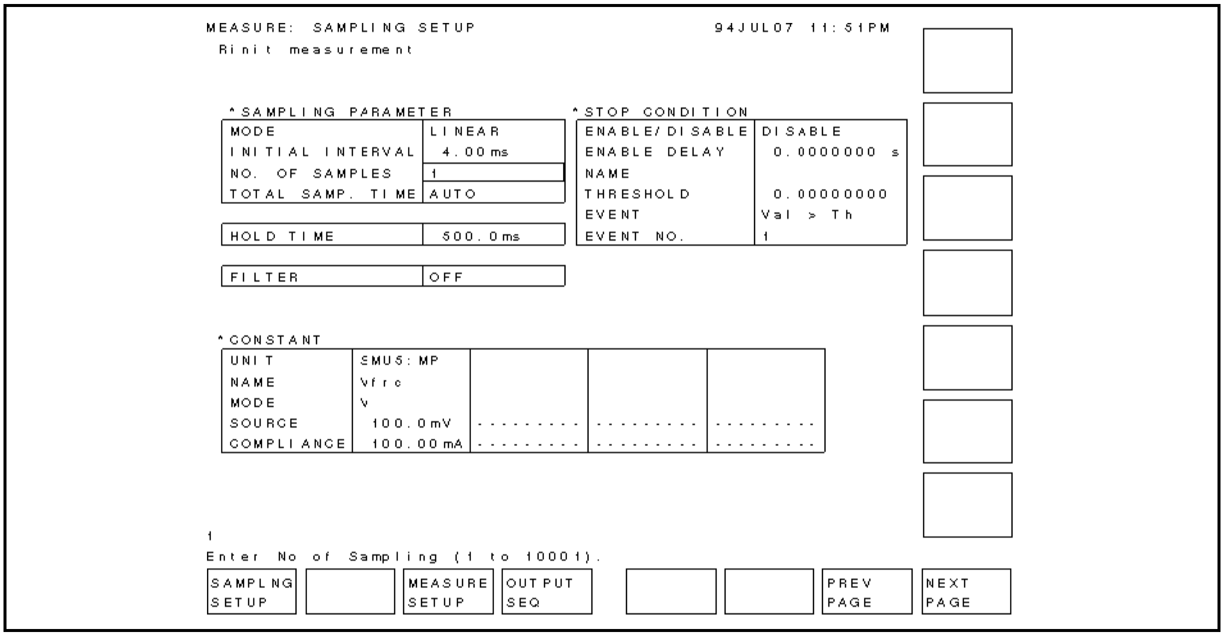
*USER FUNCTION

NAME	UNIT	DEFINITION
Rinit	ohm	(Vm1-Vm2)/Ifrc

Rinit

Enter User Function Name. (max 6 chars.)

Figure A-2. USER FUNCTION DEFINITION Page



MEASURE: SAMPLING SETUP 94JUL07 11:51PM

Rinit measurement

*SAMPLING PARAMETER

MODE	LINEAR
INITIAL INTERVAL	4.00ms
NO. OF SAMPLES	1
TOTAL SAMP. TIME	AUTO

HOLD TIME	500.0ms

FILTER	OFF

*STOP CONDITION

ENABLE/DISABLE	DISABLE
ENABLE DELAY	0.0000000 s
NAME	
THRESHOLD	0.00000000
EVENT	Val > Th
EVENT NO.	1

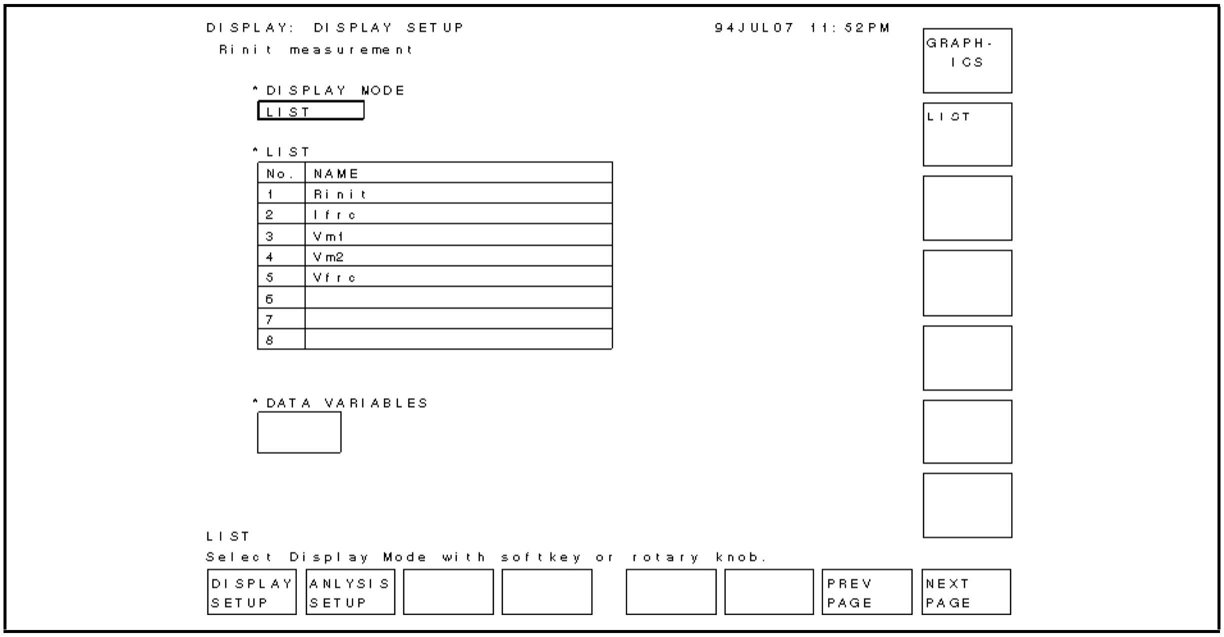
*CONSTANT

UNIT	SMU5:MP			
NAME	Vfrc			
MODE	V			
SOURCE	100.0mV	---------	---------	---------
COMPLIANCE	100.00mA	---------	---------	---------

1

Enter No of Sampling (1 to 10001).

Figure A-3. SAMPLING SETUP Page



DISPLAY: DISPLAY SETUP 94JUL07 11:52PM

Rinit measurement

*DISPLAY MODE

LIST

*LIST

No.	NAME
1	Rinit
2	Ifrc
3	Vm1
4	Vm2
5	Vfrc
6	
7	
8	

*DATA VARIABLES

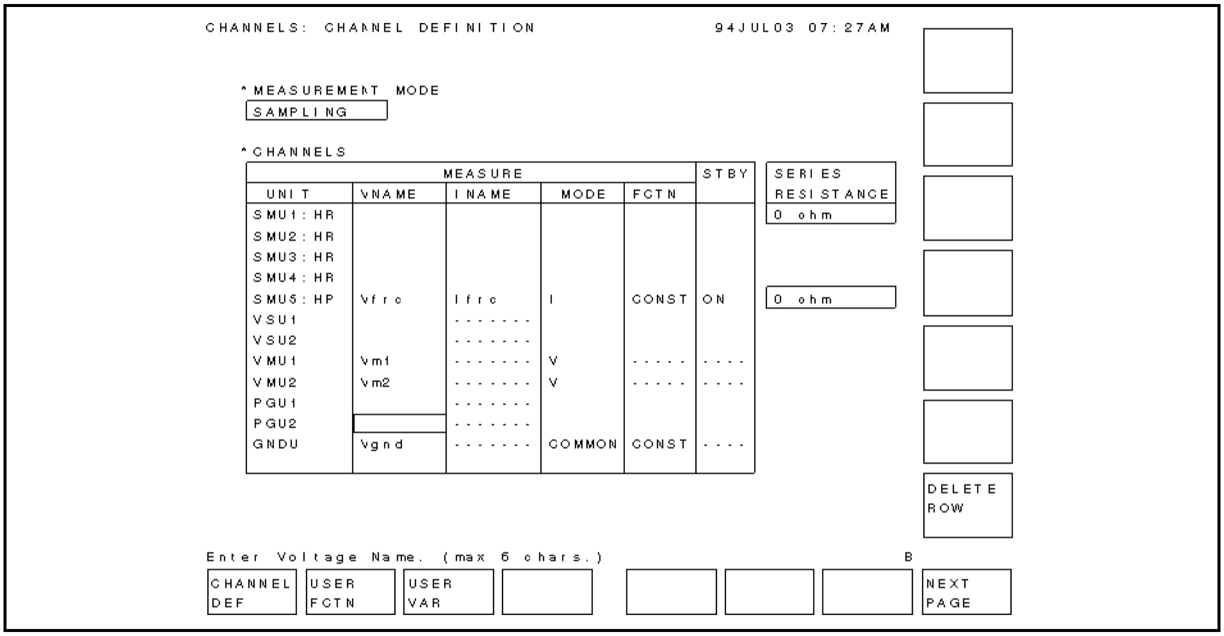
LIST

Select Display Mode with softkey or rotary knob.

Figure A-4. DISPLAY SETUP Page

Setup File for Stress/Resistance Measurement

Settings of following setup pages are stored in IFVM.MES file, which is used to set up HP 4155A/56A for stress/resistance measurement loop and for displaying results (CTTF versus Time) on graph.



CHANNELS: CHANNEL DEFINITION 94JUL03 07:27AM

*MEASUREMENT MODE

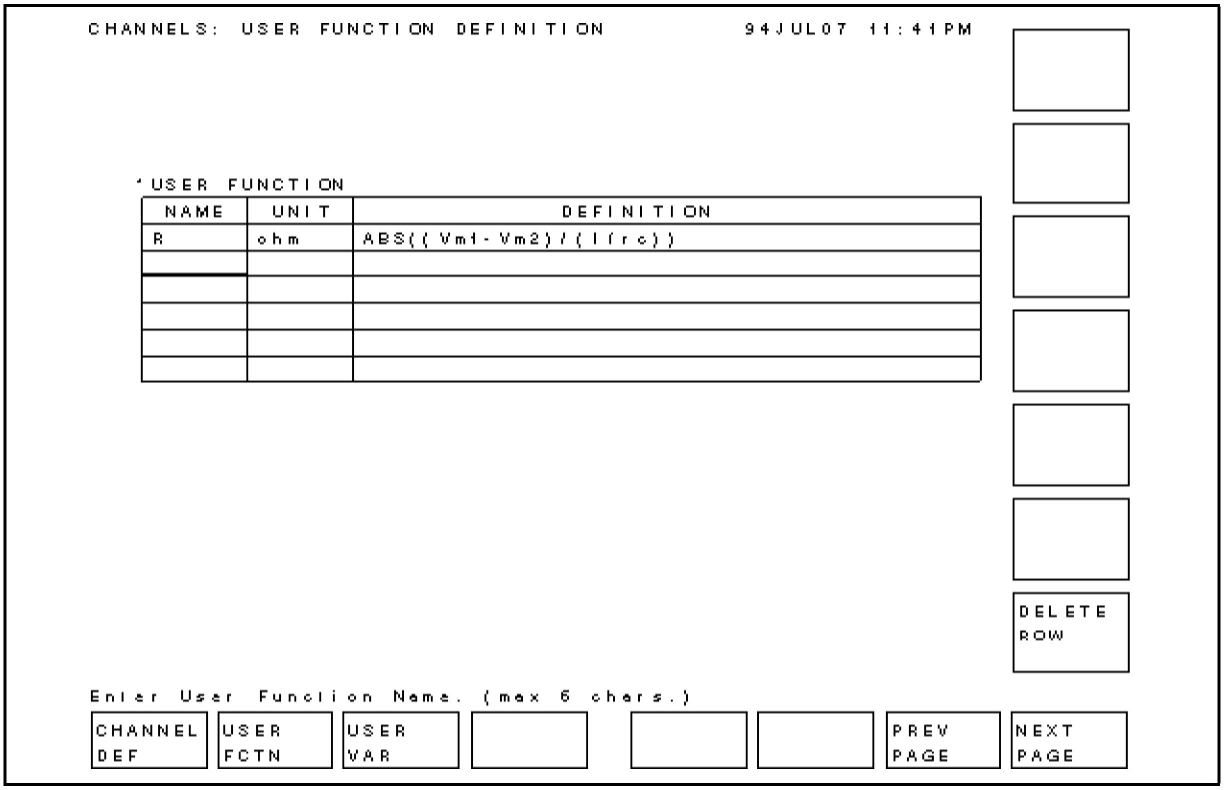
SAMPLING

*CHANNELS

MEASURE					STBY	SERIES RESISTANCE
UNIT	VNAME	INAME	MODE	FCTN		
SMU1:HR						0 ohm
SMU2:HR						
SMU3:HR						
SMU4:HR						
SMU5:HP	Vfrc	Ifrc	I	CONST	ON	0 ohm
VSU1		-------				
VSU2		-------				
VMU1	Vm1	-------	V	-----	----	
VMU2	Vm2	-------	V	-----	----	
PGU1		-------				
PGU2		-------				
GNDU	Vgnd	-------	COMMON	CONST	----	

Enter Voltage Name. (max 6 chars.) B

Figure A-5. CHANNEL DEFINITION Page



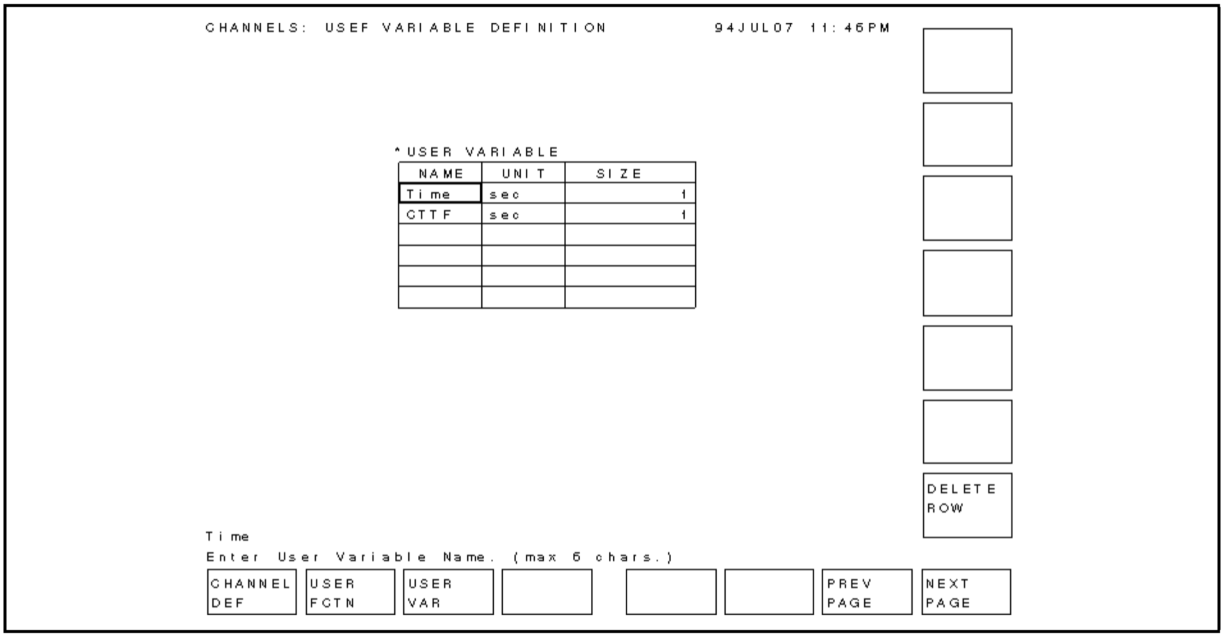
CHANNELS: USER FUNCTION DEFINITION 94JUL07 11:41PM

*USER FUNCTION

NAME	UNIT	DEFINITION
R	ohm	ABS((Vm1-Vm2)/(I(rc))

Enter User Function Name. (max 6 chars.)

Figure A-6. USER FUNCTION DEFINITION Page



CHANNELS: USEF VARIABLE DEFINITION 94JUL07 11:46PM

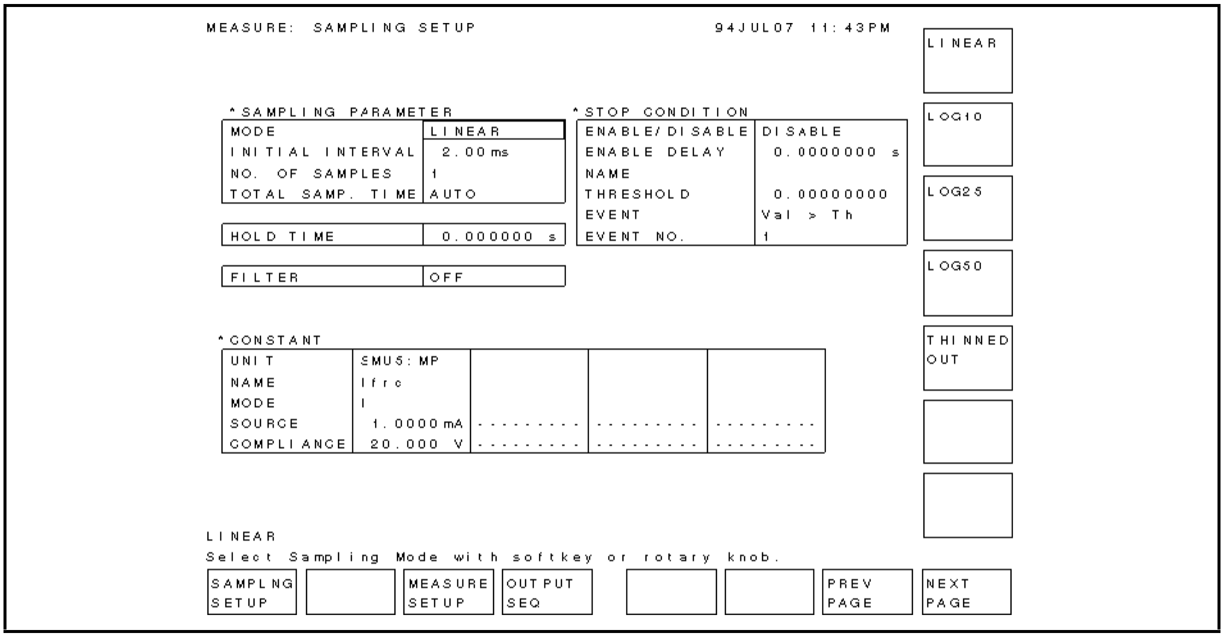
*USER VARIABLE

NAME	UNIT	SIZE
Time	sec	1
CTTF	sec	1

Time

Enter User Variable Name. (max 6 chars.)

Figure A-7. USER VARIABLE DEFINITION Page



MEASURE: SAMPLING SETUP 94JUL07 11:43PM

*SAMPLING PARAMETER

MODE	LINEAR
INITIAL INTERVAL	2.00ms
NO. OF SAMPLES	1
TOTAL SAMP. TIME	AUTO

HOLD TIME	0.000000 s

FILTER	OFF

*STOP CONDITION

ENABLE/DISABLE	DISABLE
ENABLE DELAY	0.0000000 s
NAME	
THRESHOLD	0.00000000
EVENT	Val > Th
EVENT NO.	1

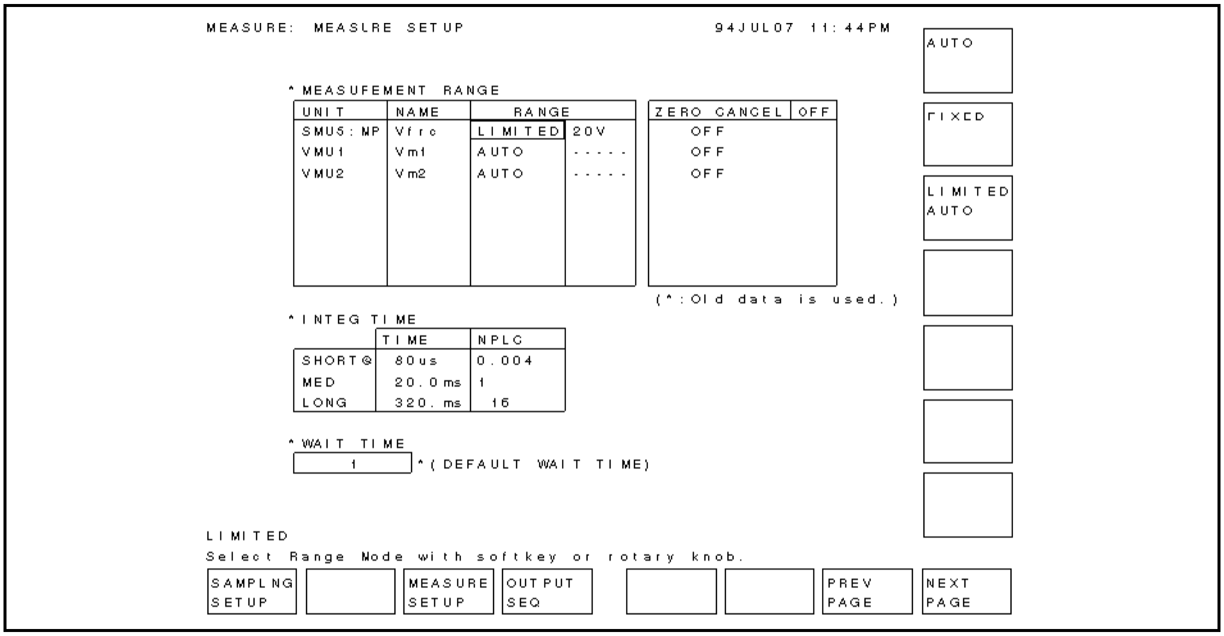
*CONSTANT

UNIT	SMU5:MP			
NAME	Ifrc			
MODE	I			
SOURCE	1.0000mA	---------	---------	---------
COMPLIANCE	20.000 V	---------	---------	---------

LINEAR

Select Sampling Mode with softkey or rotary knob.

Figure A-8. SAMPLING SETUP Page



MEASURE: MEASURE SETUP 94JUL07 11:44PM

*MEASUREMENT RANGE

UNIT	NAME	RANGE	
SMU5:MP	Vfrc	LIMITED	20V
VMU1	Vm1	AUTO	-----
VMU2	Vm2	AUTO	-----

ZERO CANCEL	OFF
OFF	
OFF	
OFF	

(*:Old data is used.)

*INTEG TIME

	TIME	NPLC
SHORT@	80us	0.004
MED	20.0ms	1
LONG	320. ms	16

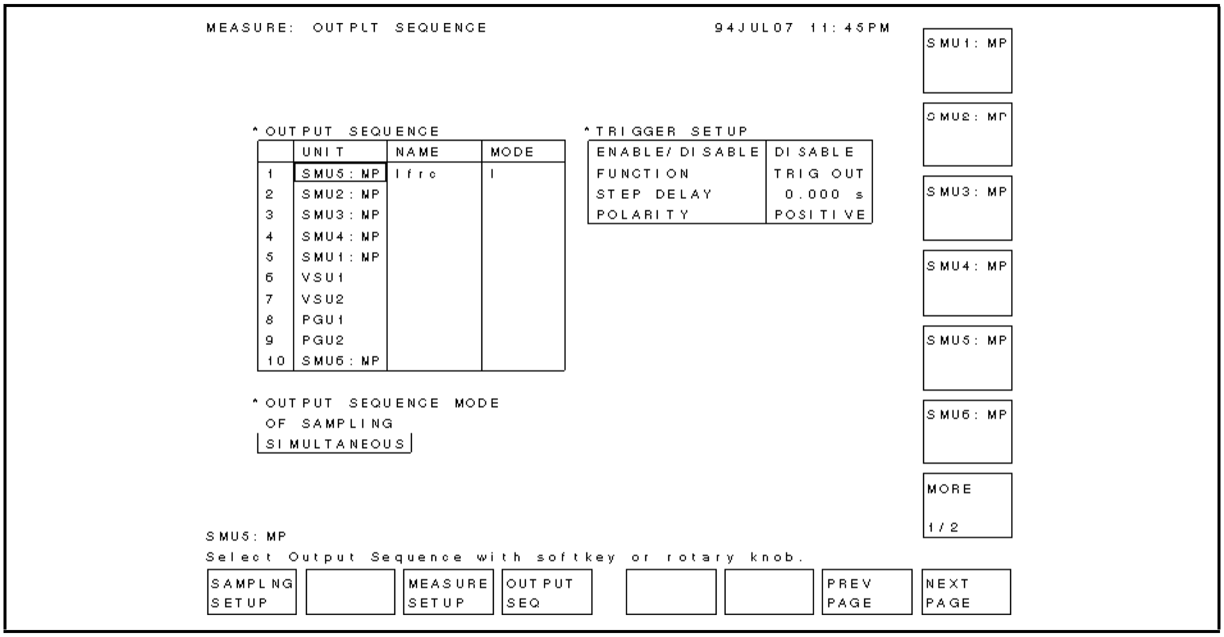
*WAIT TIME

1 *(DEFAULT WAIT TIME)

LIMITED

Select Range Mode with softkey or rotary knob.

Figure A-9. MEASURE SETUP Page



MEASURE: OUTPLT SEQUENCE 94JUL07 11:45PM

*OUTPUT SEQUENCE

	UNIT	NAME	MODE
1	SMU5:MP	Ifrc	I
2	SMU2:MP		
3	SMU3:MP		
4	SMU4:MP		
5	SMU1:MP		
6	VSU1		
7	VSU2		
8	PGU1		
9	PGU2		
10	SMU6:MP		

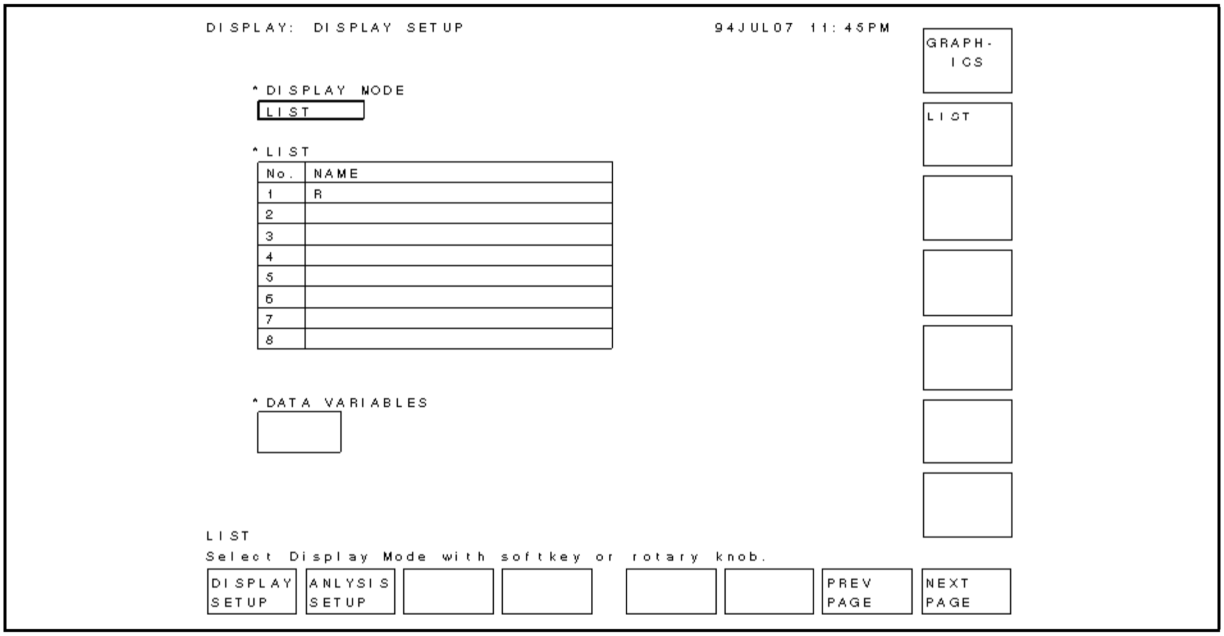
*TRIGGER SETUP

ENABLE/DISABLE	DISABLE
FUNCTION	TRIG OUT
STEP DELAY	0.000 s
POLARITY	POSITIVE

*OUTPUT SEQUENCE MODE
OF SAMPLING
SIMULTANEOUS

SMU5:MP
Select Output Sequence with softkey or rotary knob.

Figure A-10. OUTPUT SEQUENCE Page



DISPLAY: DISPLAY SETUP 94JUL07 11:45PM

*DISPLAY MODE
LIST

*LIST

No.	NAME
1	R
2	
3	
4	
5	
6	
7	
8	

*DATA VARIABLES

LIST
Select Display Mode with softkey or rotary knob.

Figure A-11. DISPLAY SETUP Page

HP 4155A / HP 4156A Semiconductor Parameter Analyzer

GO / NO-GO Test Sample Program Operation Manual

HEWLETT
PACKARD

HP Part No. 04155-90130
Printed in Japan March 1995

Edition 1

Contents

1. **Introduction**

2. **GONOGO Sample Program**

3. **Basic Operation**

4. **Customization**

Figures

1

Introduction

At present, incoming inspection and quality assurance inspection of semiconductor devices is extremely time-consuming due to the need to inspect a large number of different devices. It is important that the process be automated to save time. Also, the results are often different depending on the individual conducting the tests, and it is desirable that these differences be eliminated to raise the reliability of the results.

Using built-in Instrument BASIC (IBASIC) of the HP 4155A/56A, you can turn the HP 4155A/56A into a functional and easy-to-use automatic incoming/outgoing inspection tester.

This operation manual describes a sample incoming/outgoing inspection program that runs on the HP 4155A/56A, and describes how to use and customize the program. This sample program is stored on a diskette in the `GONOGO` file.

Contents of this Manual

Chapter 2 describes outline of GONOGO sample program.

Chapter 3 describes basic operation of the GONOGO sample program.

Chapter 4 describes procedure to customize the GONOGO sample program to suit your devices.

2

GONOGO Sample Program

This chapter gives an overview of the `GONOGO` sample program.

Overview

The GONOGO sample program has following functions.

- Menu driven operation

  The program can basically be operated by selecting a softkey. For example, after the device is connected, you need only press the `NEXT DEVICE` softkey. All measurement parameters will be extracted automatically using the Auto Analysis function, then the result values are displayed in the Result column.

- Automatic binning

  You can set upper and lower limits for the result values, which are judged automatically by the program.

- Viewing all measurement curves while measurement is in progress

  It is possible to view the measurement curves while the measurement is in progress. Or to only view the results.

- Viewing a particular measurement curve

  It is possible to view a particular measurement curve. This is useful for viewing the device characteristics when the measured result is judged to be out of specification.

- Changing limits

  You can change the upper or lower limit after the program is started.

- Showing statistics

  You can display statistical results (average, maximum, minimum, standard deviation) at any time.

- Downloading to spreadsheet

  After measurement for all devices is finished, all measurement data can be downloaded to an ASCII file. You can import this file into a spreadsheet, such as LOTUS 1-2-3 or Microsoft Excel.

Figure 2-1 shows the flowchart of the GONOGO sample program.

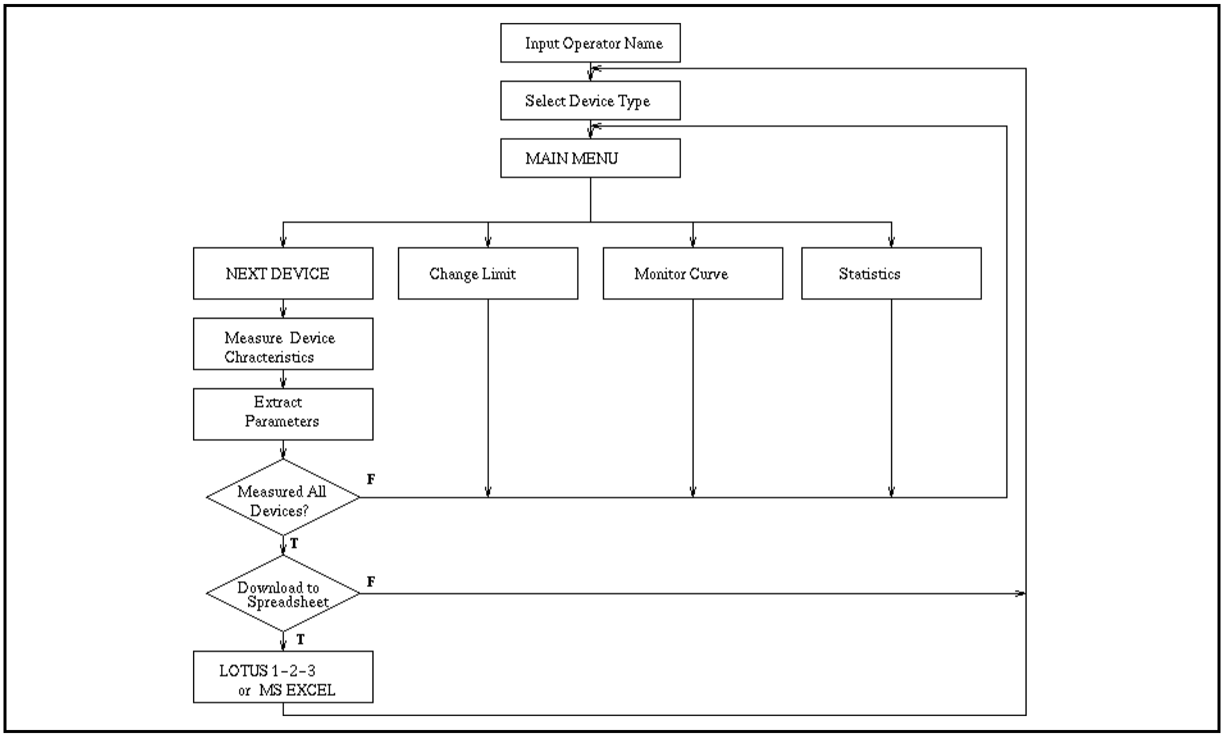


Figure 2-1. Flowchart of GONOGO Sample Program

3

Basic Operation

This chapter describes the required equipment, required program and files, connection, and how to execute the sample program.

Required Equipment

The following are required to use the GO/NO-GO test sample program:

- HP 4155A or HP 4156A
- HP 16442A test fixture
- Four triaxial cables
- This operation guide
- Diskette that contains sample program and HP 4155A/56A setup files.

Files on the Diskette

Following files are on the sample diskette:

- GONOGO

  GO/NO-GO sample program.

- VTH.MES

  File for setting up the HP 4155A/56A to measure Vth and beta.

- GM.MES

  File for setting up the HP 4155A/56A to measure gm.

- RDS.MES

  File for setting up the HP 4155A/56A to measure Rds(ON).

- BVCEO.MES

  File for setting up the HP 4155A/56A to measure BVceo.

- ICVC.MES

  File for setting up the HP 4155A/56A to measure Va and Rc.

- HFE.MES

  File for setting up the HP 4155A/56A to measure hFE.

- RE.MES

  File for setting up the HP 4155A/56A to measure Re.

Sample Devices

This sample program is for testing the following two devices:

- MOSFET (SD214DE): HP P/N 1855-0723
- Bipolar Transistor (2N3904): HP P/N 1854-0215

You can customize this sample program to suit your devices. Refer to Chapter 4 for details.

Connection

Connect HP 4155A/56A to HP 16442A as shown below:

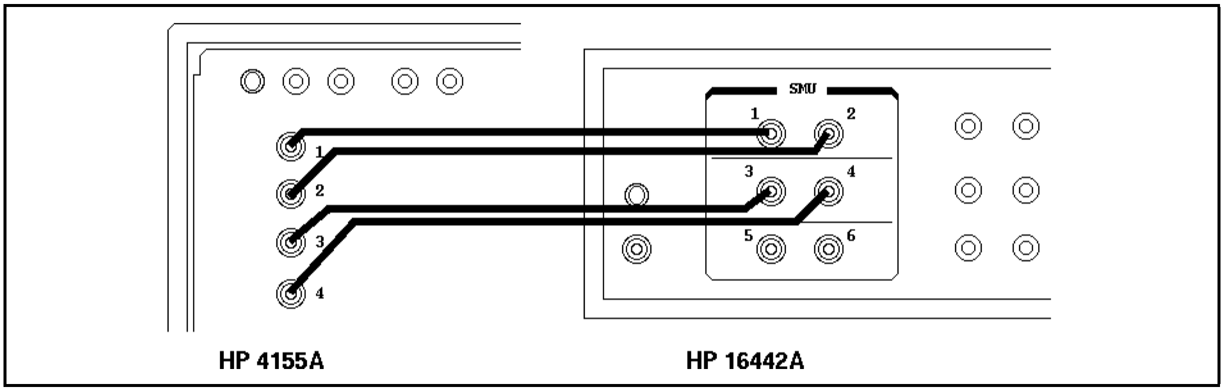


Figure 3-1. Connection between HP 4155A and HP 16442A

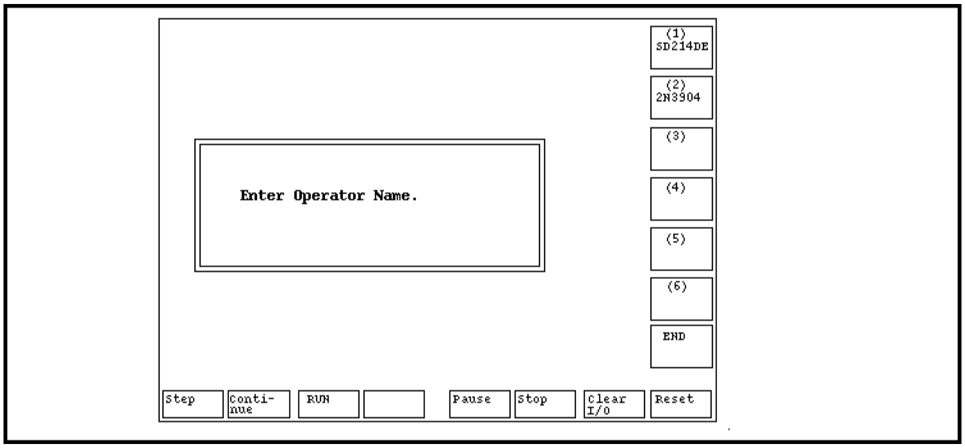
Execution

1. Insert diskette that contains GONOGO program into built-in drive of HP 4155A/4156A.
2. Press the IBASIC (Display) key until All IBASIC screen is displayed. Then, type the following:

   `GET "GONOGO"` (Enter)

3. To run GONOGO program, press (RUN) front-panel key.
4. You are required to enter supplemental information, such as "Operator name", as shown in Figure 3-2.

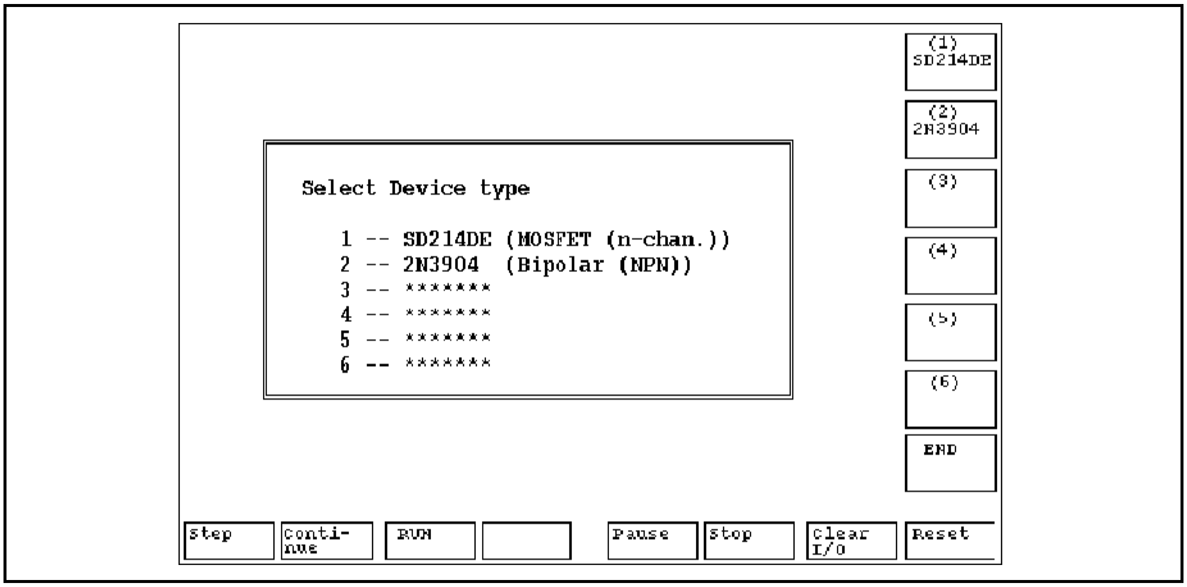
   Type in your name, then comment as requested.



Enter Operator Name.

Figure 3-2. Operator Name Input Screen

5. Program prompts you to select the device type from the selection menu as shown in Figure 3-3.

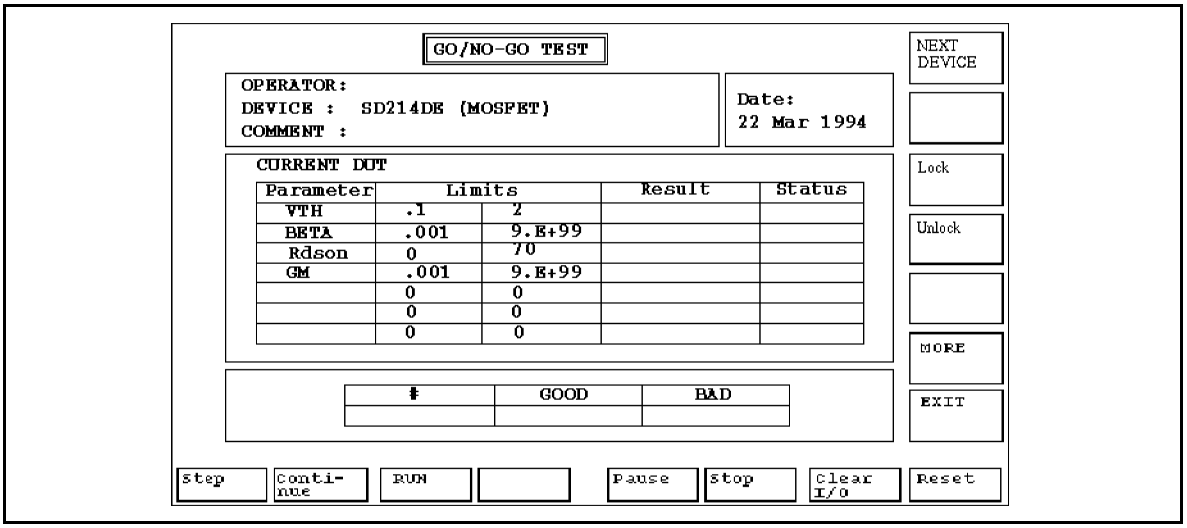


Select Device type

1 -- SD214DE (MOSFET (n-chan.))
2 -- 2N3904 (Bipolar (NPN))
3 -- *******
4 -- *******
5 -- *******
6 -- *******

Figure 3-3. Device Selection Menu

6. Select the softkey of desired device type. The following is displayed.



OPERATOR:
DEVICE : SD214DE (MOSFET)
COMMENT :

Date:
22 Mar 1994

CURRENT DUT

Parameter	Limits		Result	Status
VTH	.1	2		
BETA	.001	9.E+99		
Rdson	0	70		
GM	.001	9.E+99		
	0	0		
	0	0		
	0	0		

#	GOOD	BAD

Figure 3-4. Main Display

7. Connect (on HP 16442A test fixture) according to the device type you will use. See following figure.

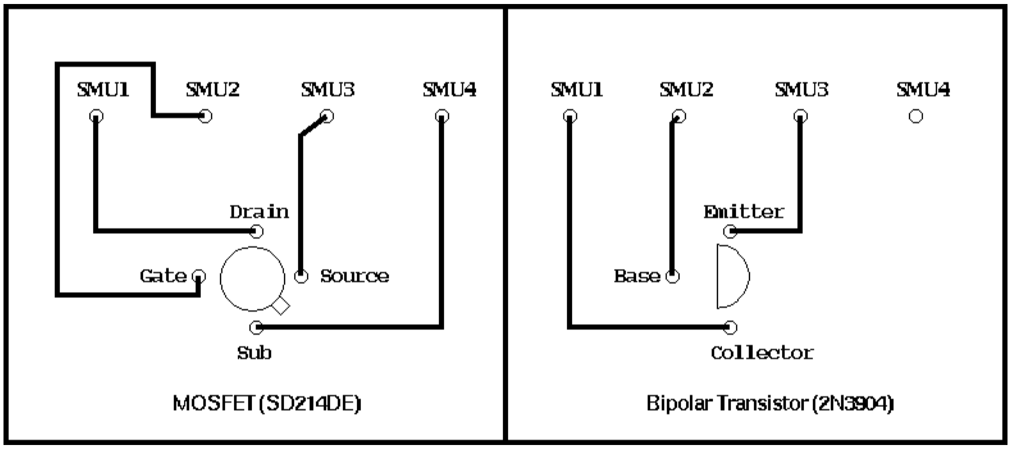


Figure 3-5. Connection of Device on Test Fixture (Top View)

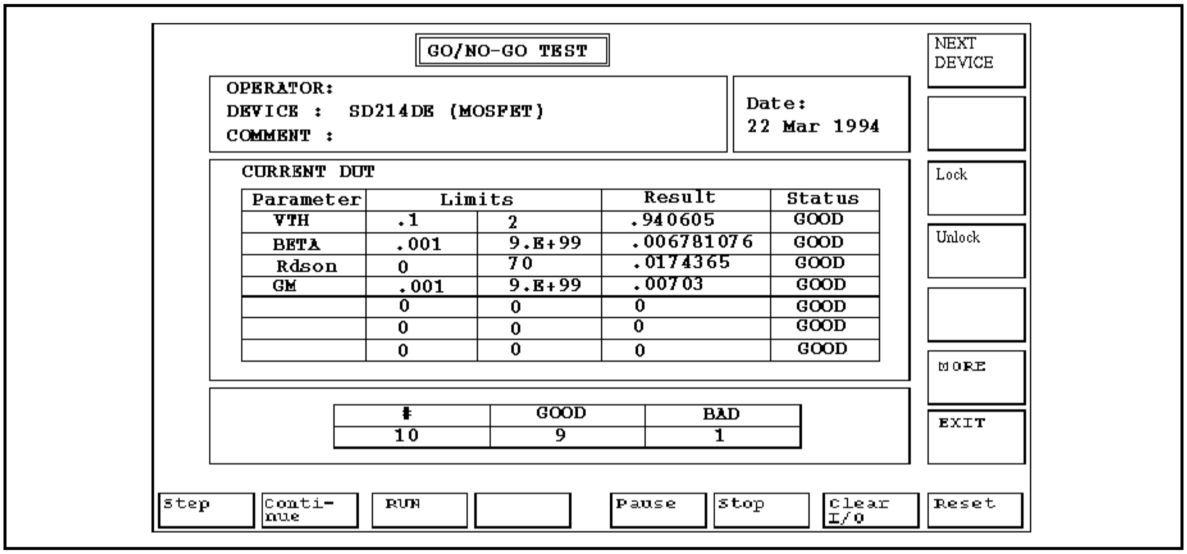
8. After putting the device on the fixture, press `NEXT DEVICE` softkey.

   The parameter extractions are performed one by one. After all the measurements are finished, results are displayed.

   Each measured parameter is compared to the upper and lower limits, and judged `GOOD` or `BAD`. If all parameters are within limits, the device is judged as `GOOD`, so the device is ready to be shipped or to be used. If `BAD`, the device has some defects.

9. Attach next device to the fixture, then select the `NEXT DEVICE` softkey.

   Figure 3-6 shows an example result screen after several devices are measured.



OPERATOR:
DEVICE : SD214DE (MOSFET)
COMMENT :

Date:
22 Mar 1994

CURRENT DUT

Parameter	Limits		Result	Status
VTH	.1	2	.940605	GOOD
BETA	.001	9.E+99	.006781076	GOOD
Rdson	0	70	.0174365	GOOD
GM	.001	9.E+99	.00703	GOOD
	0	0	0	GOOD
	0	0	0	GOOD
	0	0	0	GOOD

#	GOOD	BAD
10	9	1

Figure 3-6. Example Result Screen

Viewing All Curves while Measurement is in Progress

If you want to view all the measurement curves in real time while the test is in progress, select the `Unlock` softkey in the main display.

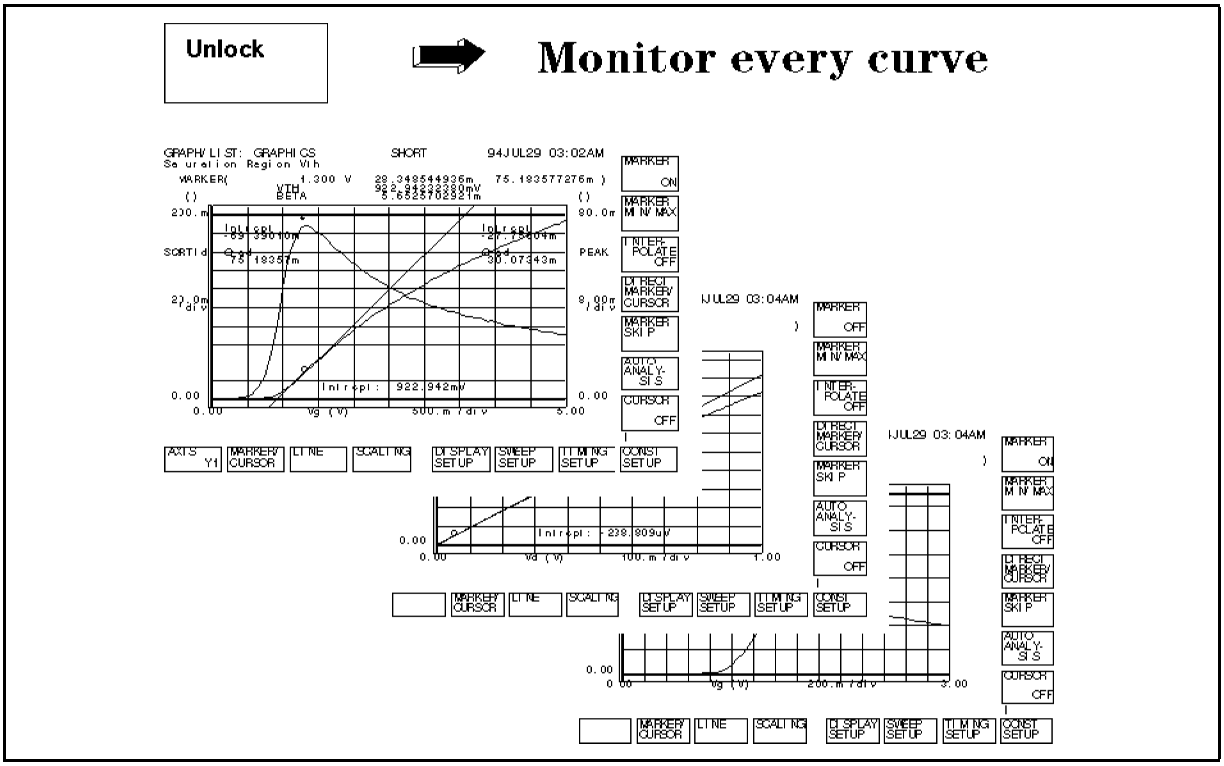
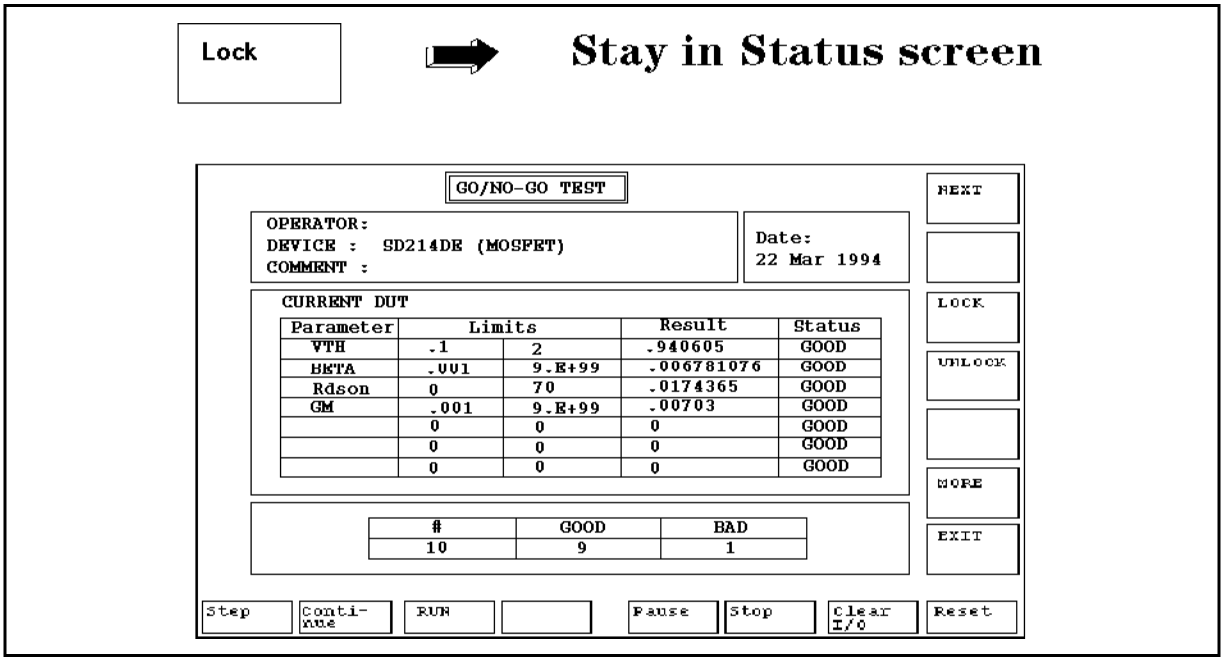


Figure 3-7. Unlock Function Shows Every Curve while Measurement is in Progress

Viewing Only Results while Measurement is in Progress

If you only want to see the measured parameter values, select `Lock` softkey in the main menu. Only the following screen will be displayed.



OPERATOR:
DEVICE : SD214DE (MOSFET)
COMMENT :

Date:
22 Mar 1994

CURRENT DUT

Parameter	Limits		Result	Status
VTH	.1	2	.940605	GOOD
BETA	.001	9.E+99	.006781076	GOOD
Rdson	0	70	.0174365	GOOD
GM	.001	9.E+99	.00703	GOOD
	0	0	0	GOOD
	0	0	0	GOOD
	0	0	0	GOOD

#	GOOD	BAD
10	9	1

Figure 3-8. Lock Function Displays only the Status Screen

Viewing a Particular Measurement Curve

If a device is judged **BAD**, you may want to remeasure, and display only a particular measurement curve. If so, press `MORE` softkey, then the `Monitor Curve` softkey.

The softkey labels are changed to `Curve curvename`, where *curvename* is the name of each curve. Select the softkey for the desired curve. The measurement is performed again, and only selected curve is displayed as shown in the following example.

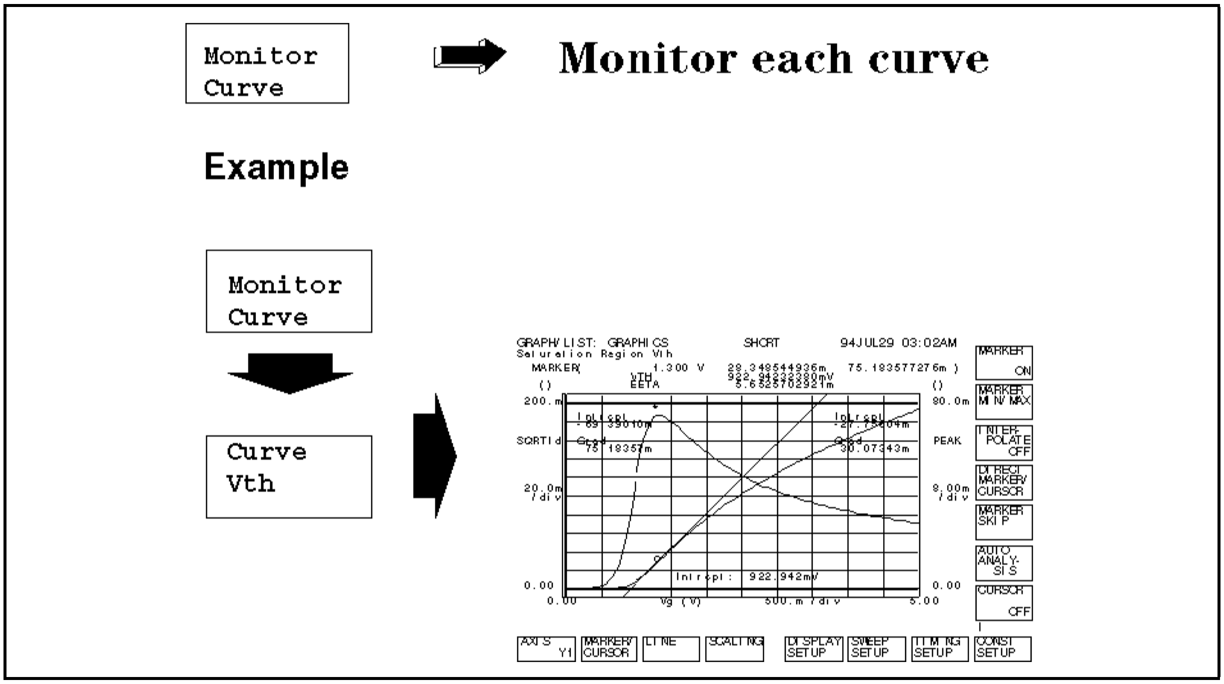
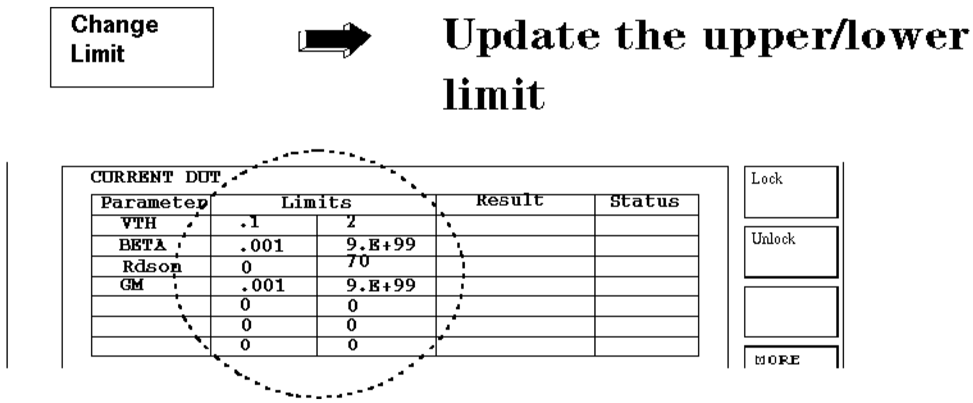


Figure 3-9. Monitor Curve Softkey

Changing Limits

If you want to change the limit values after the program is started, select the `MORE` softkey, then the `Change Limit` softkey.

Then, select the softkey for the limit value that you want to change. Type in the new value from the keyboard or front panel.



CURRENT DUT

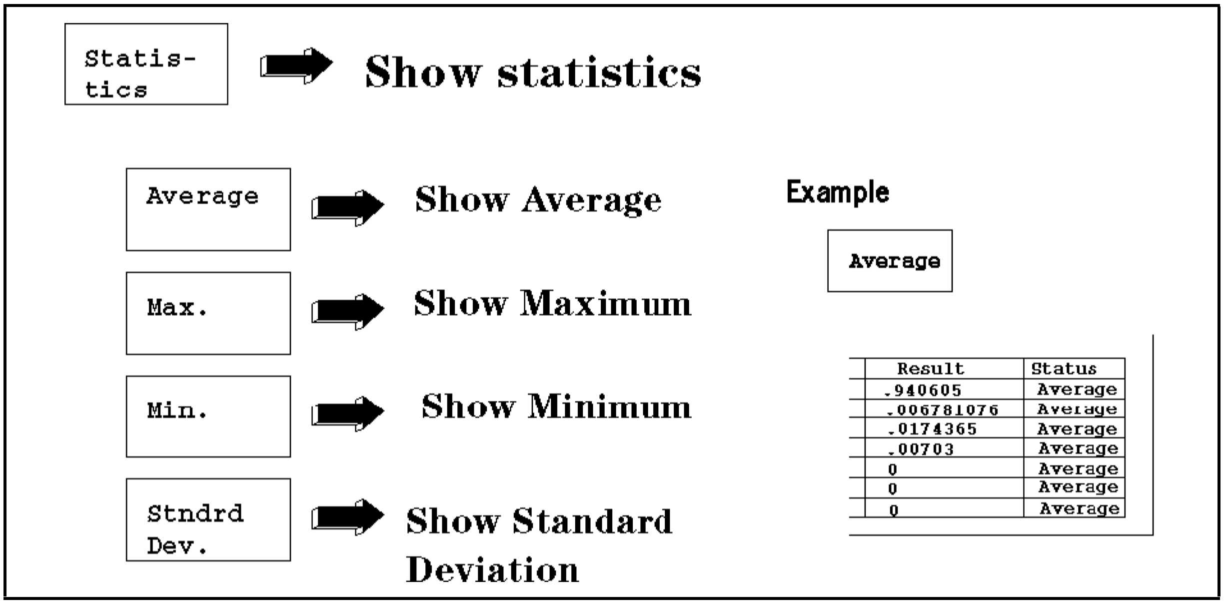
Parameter	Limits		Result	Status
VTH	.1	2		
BETA	.001	9.E+99		
Rdson	0	70		
GM	.001	9.E+99		
	0	0		
	0	0		
	0	0		

Figure 3-10. Change Limit Softkey

Displaying Statistical Data

To display statistical results, such as average or standard deviation, press `MORE` softkey, then `Statistics` softkey.

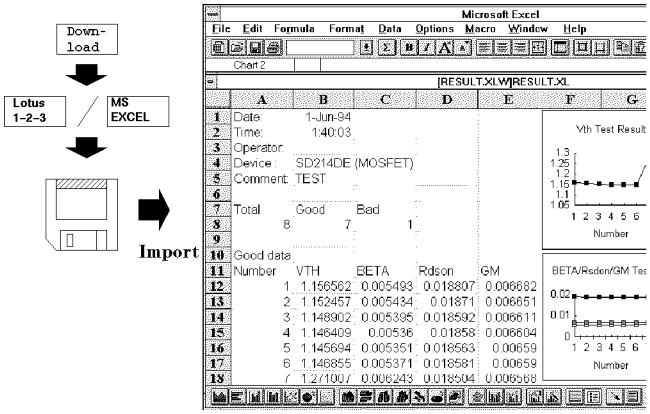
Then, select the softkey of the statistical data that you want to display. The statistical data of all devices that have been measured is displayed in the Result column, and the type of statistic is displayed in the Status column.



Result	Status
.940605	Average
.006781076	Average
.0174365	Average
.00703	Average
0	Average
0	Average
0	Average

Figure 3-11. Statistics Softkey

Exporting Data to Spreadsheet



	A	B	C	D	E
1	Date:	1-Jun-94			
2	Time:	1:40:03			
3	Operator:				
4	Device :	SD214DE (MOSFET)			
5	Comment:	TEST			
6					
7	Total	Good	Bad		
8	8	7	1		
9					
10	Good data				
11	Number	VTH	BETA	Rdson	GM
12	1	1.156562	0.005493	0.018807	0.006682
13	2	1.152457	0.005434	0.01871	0.006651
14	3	1.148902	0.005395	0.018592	0.006611
15	4	1.146409	0.00536	0.01858	0.006604
16	5	1.145694	0.005351	0.018563	0.00659
17	6	1.146855	0.005371	0.018581	0.00659
18	7	1.271007	0.006243	0.018504	0.006568

Figure 3-12. Exporting Result Data to a Spreadsheet

After finishing the test, you can export all the measured data to a spreadsheet as follows:

1. After all devices have been measured, select `EXIT` softkey on the main display.
2. Select `Download`, enter the desired file name, then select `LOTUS 1-2-3` or `MS EXCEL` softkey depending on which of these spreadsheets you have.

The result data is saved to a diskette in ASCII format, which can be imported into the spreadsheet.

The following data is saved to the file on diskette:

- Date
- Time
- Operator name
- Device type
- Comment
- Number of measured devices
- Number of good devices
- Number of bad devices
- Raw measurement data
- Average
- Maximum
- Minimum
- Standard deviation

4

Customization

This chapter describes how to customize the sample program to suit your test device.

Also, this chapter describes how to customize the sample program for use with a handler.

Overview

Customization procedure consists of following 5 steps:

1. Decide which parameters you want to measure.
2. Decide upper and lower limits of each parameter according to the device specifications.
3. Create a HP 4155A/56A measurement setup file for each parameter.
4. Edit the Select_dut subprogram in GONOGO program.
5. Edit the Dut_spec subprogram in GONOGO program.

The following describes each of these steps:

1. Decide Parameters to Measure

Decide which parameters you need to extract as shown in the following example for a MOSFET:

- Vth
- gm
- BVdss
- Rds(ON)

2. Decide Lower and Upper Limits for Each Parameter

Decide the upper and lower limits of each parameter as shown in following example for a MOSFET:

Parameter	Lower Limit	Upper Limit
Vth	0.2	2.5
Gm	0.001	90
BVdss	40	9.E+99
Rds(ON)	.001	9.E+99

Write down the values. You will enter these values in the program as described in step 5.

Note

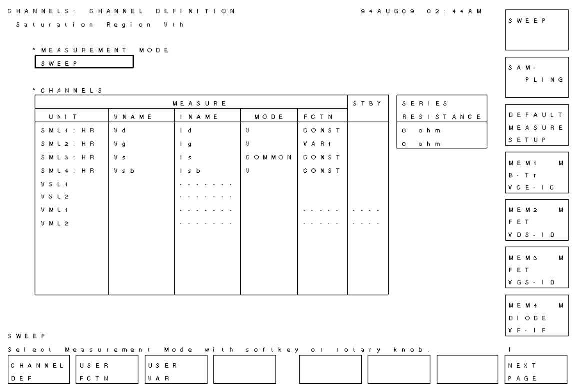
If you don't need to specify an upper limit or lower limit, assign a dummy value. For upper limit, the dummy value could be 9.E+99. For lower limit, it could be −9.E+99

3. Create the Measurement Setup Files

Create a file (*filename*`.MES`) for setting up the HP 4155A/56A for each parameter that you want to extract. For example, create the following measurement setup files for extracting the parameters.

Parameter	Setup file name
Vth	EXVTH.MES
gm	EXGM.MES
BVdss	EXBV.MES
Rds(ON)	EXRDS.MES

To extract the parameter, you can use the **USER FUNCTION** or **Auto Analysis Function** of the HP 4155A/56A. For example, to extract Vth, the following HP 4155A/56A settings should be saved to EXVTH.MES. In the USER FUNCTION, define the parameter name to be extracted. In this example, VTH is defined as `@L1X`, which is the X intercept of line 1.



CHANNELS: CHANNEL DEFINITION 94AUG09 02:44AM

Saturation Region Vth

*MEASUREMENT MODE

SWEEP

*CHANNELS

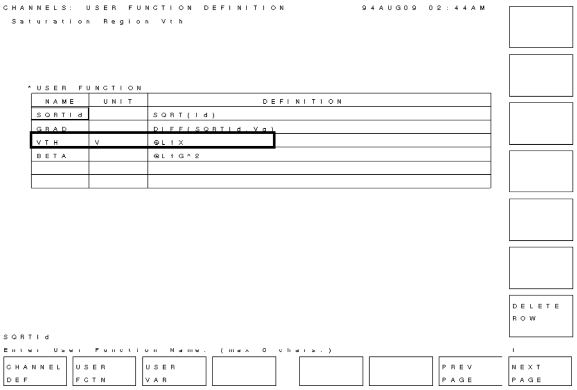
MEASURE					STBY
UNIT	VNAME	INAME	MODE	FCTN	
SMU1:HR	Vd	Id	V	CONST	
SMU2:HR	Vg	Ig	V	VAR1	
SMU3:HR	Vs	Is	COMMON	CONST	
SMU4:HR	Vsb	Isb	V	CONST	
VSU1		-------			
VSU2		-------			
VMU1		-------		-----	----
VMU2		-------		-----	----

SERIES RESISTANCE
0 ohm
0 ohm

SWEEP

Select Measurement Mode with softkey or rotary knob.

Figure 4-1. CHANNEL DEFINITION Page



CHANNELS: USER FUNCTION DEFINITION 94AUG09 02:44AM

Saturation Region Vth

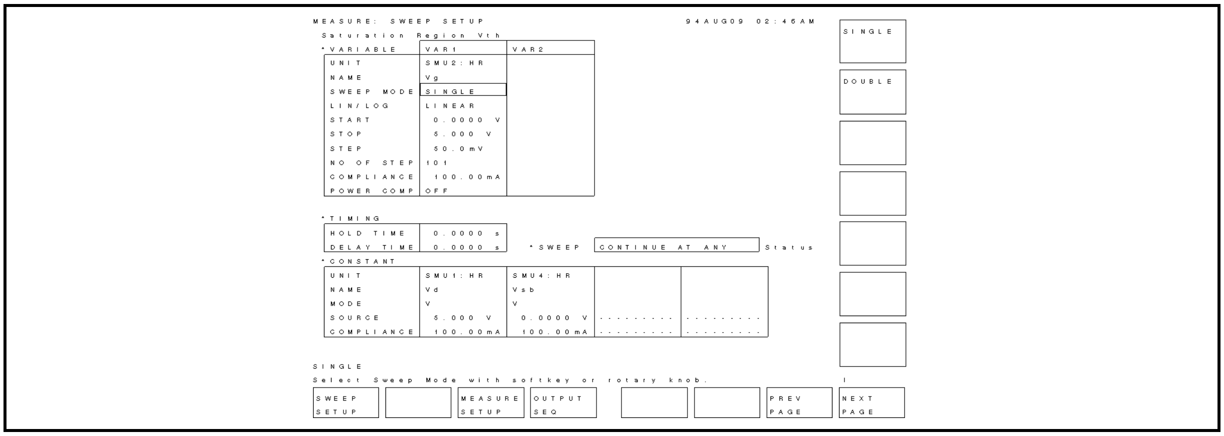
*USER FUNCTION

NAME	UNIT	DEFINITION
SQRTId		SQRT(Id)
GRAD		DIFF(SQRTId,Vg)
VTH	V	@L1X
BETA		@L1G^2

SQRTId

Enter User Function Name. (max 6 chars.)

Figure 4-2. USER FUNCTION DEFINITION Page



MEASURE: SWEEP SETUP 94AUG09 02:46AM

Saturation Region Vth

*VARIABLE

	VAR1	VAR2
UNIT	SMU2:HR	
NAME	Vg	
SWEEP MODE	SINGLE	
LIN/LOG	LINEAR	
START	0.0000 V	
STOP	5.000 V	
STEP	50.0mV	
NO OF STEP	101	
COMPLIANCE	100.00mA	
POWER COMP	OFF	

*TIMING

HOLD TIME	0.0000 s
DELAY TIME	0.0000 s

*SWEEP CONTINUE AT ANY Status

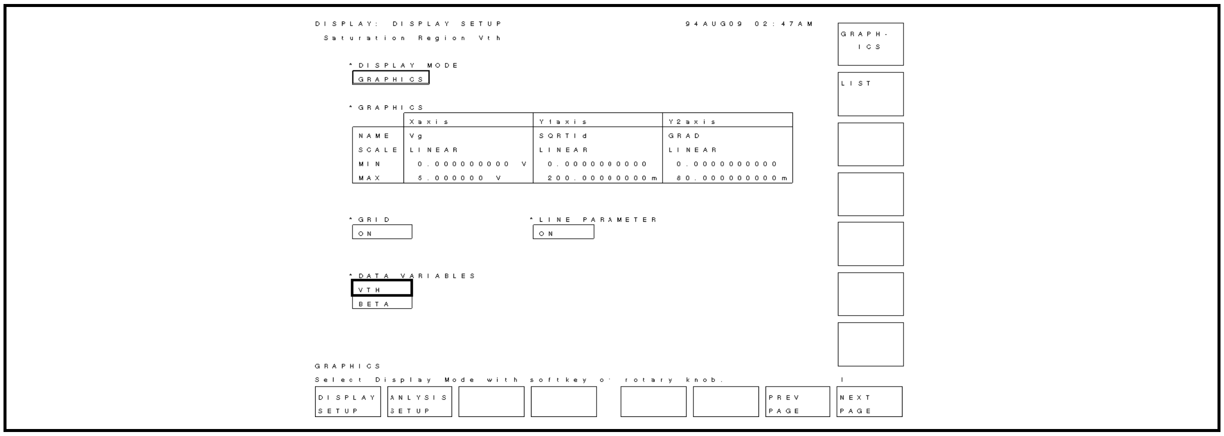
*CONSTANT

UNIT	SMU1:HR	SMU4:HR		
NAME	Vd	Vsb		
MODE	V	V		
SOURCE	5.000 V	0.0000 V	....	....
COMPLIANCE	100.00mA	100.00mA	....	....

SINGLE

Select Sweep Mode with softkey or rotary knob.

Figure 4-3. SWEEP SETUP Page



DISPLAY: DISPLAY SETUP 94AUG09 02:47AM

Saturation Region Vth

*DISPLAY MODE
GRAPHICS

*GRAPHICS

	Xaxis	Y1axis	Y2axis
NAME	Vg	SQRTId	GRAD
SCALE	LINEAR	LINEAR	LINEAR
MIN	0.000000000 V	0.0000000000	0.0000000000
MAX	5.000000 V	200.00000000m	80.000000000m

*GRID
ON

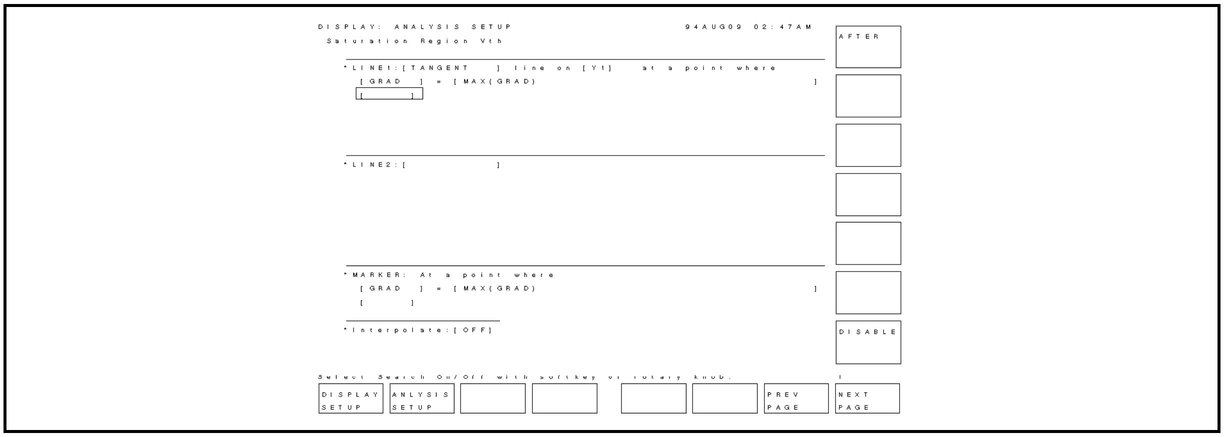
*LINE PARAMETER
ON

*DATA VARIABLES
VTH
BETA

GRAPHICS

Select Display Mode with softkey o· rotary knob.

Figure 4-4. DISPLAY SETUP Page



DISPLAY: ANALYSIS SETUP 94AUG09 02:47AM

Saturation Region Vth

*LINE1:[TANGENT] line on [Y1] at a point where
[GRAD] = [MAX(GRAD)]
[ ]

*LINE2:[ ]

*MARKER: At a point where
[GRAD] = [MAX(GRAD)]
[ ]

*Interpolate:[OFF]

Select Search On/Off with softkey or rotary knob.

Figure 4-5. ANALYSIS SETUP Page

4. Edit Select_dut Subprogram

Add the device type to the program by editing the `Select_dut` subprogram.

In the IBASIC editor, type in the following, then edit this subprogram.

```
EDIT Select_dut Enter
```

Adding Device Type to Selection Menu

To add the device type, you need to modify one of the following lines:

```
9990     PRINT TABXY(13,13);"2 -- 2N3904  (Bipolar (NPN))"
10000    PRINT TABXY(13,14);"3 -- *******"     ! for future enhancement ###
10010    PRINT TABXY(13,15);"4 -- *******"     ! for future enhancement ###
```

For example, modify line 9960 as follows:

```
9990     PRINT TABXY(13,13);"2 -- 2N3904  (Bipolar (NPN))"
10000    PRINT TABXY(13,14);"3 -- 2N4351 (MOSFET (npn))"
10010    PRINT TABXY(13,15);"4 -- *******"   ! for future enhancement ###
```

Setting the Device Type Flag

The device type you select is passed to the other subprograms via the `Dut_flag` flag.

You need to modify following part of the `Select_dut` subprogram. The following shows the original subprogram.

```
10080    ON KEY 2 LABEL " (2)   2N3904 " GOTO Dut2
10090    ON KEY 3 LABEL " (3)          " GOTO End
10100    ON KEY 4 LABEL " (4)          " GOTO End
      ⋮
10300 Dut3:  !
10310    Dut_flag=3
10320    Dname$=""
10330    GOTO Exit
```

In this example, we will modify lines 10040 and 10280 as follows:

```
10080    ON KEY 2 LABEL " (2)   2N3904 " GOTO Dut2
10090    ON KEY 3 LABEL " (3)   2N4351 " GOTO Dut3
10100    ON KEY 4 LABEL " (4)          " GOTO End
      ⋮
10300 Dut3:   !
10310    Dut_flag=3
10320    Dname$="2N4351 (MOSFET)"
10330    GOTO Exit
```

Parameter `Dname$` is passed to the other subprograms as the name of the device.

5. Edit Dut_spec Subprogram

The Dut_spec subprogram sets the following for your device: parameter names, limits of each parameter, the name of the HP 4155A/56 measurement setup file to extract the parameter, and unit of each parameter.

In the IBASIC editor, type in the following, then edit this subprogram:

`EDIT Dut_spec` Enter

This subprogram has a `SELECT Dut_flag` statement, which executes the CASE statement according to the `Dut_flag` flag value. The `Dut_flag` value was set by the Select_dut subprogram according to the device you selected by softkey.

You need to add a "CASE" statement for your device just before the "CASE ELSE" statement.

For example, insert "CASE 3" just before the "CASE ELSE" statement as follows:

```
3420       M_file$(7)=""
3430  !
3432     CASE 3
3440     CASE ELSE
```

The "3" corresponds to the "2N4351 (MOSFET)", which you set in the Select_dut subprogram as described in the previous section.

You set the parameter names in the `Par$(i)` variables (maximum 9 characters). You can set up to seven parameter names.

Note

This parameter name must correspond to the measurement setup file assigned to `M_file$(i)`. For example, if `Par$(1)="VTH"`, the setup file for measuring `VTH` must be specified for `M_file$(1)`. This measurement setup file was created as described in "3. Create the Measurement Setup Files".

The variable for the upper limit of the parameter is `Par_lmx(i)`.

The variable for the lower limit of the parameter is `Par_lmn(i)`.

The variable for the unit of the parameter is `Par_lu$(i)`, maximum 1 character.

The variable for the setup file name is `M_file$(i)`, maximum 10 characters.

Note

This file name must correspond to parameter assigned to `Par$(i)`. For example, if `Par$(1)="VTH"`, the setup file for measuring `VTH` must be specified for `M_file$(1)`. This measurement setup file was created as described in "3. Create the Measurement Setup Files".

Following is an example modification.

```
3420  !
3432     CASE 3
3434       Par$(1)="VTH"  ! parameter names
3440       Par$(2)="GM"
3450       Par$(3)="BVdss"
3460       Par$(4)="Rdson"
3470       Par$(5)=""
3480       Par$(6)=""
3490       Par$(7)=""
3500  !
3510       Par_lmx(1)=2.5    ! parameter spec max limit
3520       Par_lmx(2)=90
3530       Par_lmx(3)=9.E+99
3540       Par_lmx(4)=9.E+99
3550       Par_lmx(5)=0
3560       Par_lmx(6)=0
3570       Par_lmx(7)=0
3580      !
3590       Par_lmn(1)=.2     ! parameter spec min limit
3600       Par_lmn(2)=.001
3610       Par_lmn(3)=40
3620       Par_lmn(4)=.001
3630       Par_lmn(5)=0
3640       Par_lmn(6)=0
3650       Par_lmn(7)=0
3660  !
3670       Par_lu$(1)="V"
3680       Par_lu$(2)="S"
3690       Par_lu$(3)="V"
3700       Par_lu$(4)="o"
3710       Par_lu$(5)=" "
3720       Par_lu$(6)=" "
3730       Par_lu$(7)=" "
3740  !
3750       M_file$(1)="EXVTH.MES"
3760       M_file$(2)="EXGM.MES"
3770       M_file$(3)="EXBV.MES"
3780       M_file$(4)="EXRDS.MES"
3790       M_file$(5)=""
3800       M_file$(6)=""
3810       M_file$(7)=""
3820  !
3830     CASE ELSE
```

Hints to Use with Handler

If you want to use the sample program with a handler, insert the control routine for the handler as described in the following:

Mounting the DUT

When `NEXT DEVICE` softkey is selected in main screen, the program jumps to the `Next_device` label (line 4730).

Measurement parameter extraction starts from line 4820. Insert the handler control routine between lines 4810 and 4820.

Sorting the DUT

The measured data is compared to the upper and lower limits in the Check_data subprogram. The result is returned to the `Flag` parameter. If measured data is within specification, "0" is returned. If out of the specification, "1" is returned.

The Check_data subprogram is called at line 4910.

If you want to sort the device using handler, put the control routine for sorting just after line 4910 referring to the value of `Flag`.

HP 4155A / HP 4156A Precision Semiconductor Parameter Analyzer

HCI Degradation Test Sample Program Operation Manual

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PACKARD

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1

Introduction

Hot-carrier-induced (HCI) degradation of MOSFET parameters is an important reliability concern in modern microcircuits.

This operation manual describes a sample HCI degradation test program and data analysis program running on the HP 4155A/4156A, and how to use and customize the programs. The programs are written in HP Instrument BASIC (IBASIC), and are ready to run on the built-in IBASIC controller of the HP 4155A/4156A.

Note This is a sample program, so before execution, you may need to customize the program and the setup files for your application. If the sample program damages your device, Hewlett-Packard is *NOT LIABLE* for the damages.

Contents of this Manual

Chapter 2 describes basic theory, procedure, and terminology of the HCI degradation test.

Chapter 3 describes the HCI degradation test data analysis procedure.

Chapter 4 describes the HCI degradation test methodology using the HP 4155A/4156A, how to execute the sample programs, and program overview.

Chapter 5 describes the customization procedure. This procedure is very important because you probably need to modify the programs to suit your test device.

Appendix A shows the HP 4155A/4156A page settings that are stored in the setup files.

2

Hot-Carrier-Induced (HCI) Degradation Test

This chapter describes the Hot-Carrier-Induced Degradation measuring procedure (based on the proposed JEDEC 29-JULY-93 standard) and related terminology.

Hot-carriers are generated in the MOSFET by large electric fields in channel near the drain region. Hot-carriers break bonds at the Si/SiO_2 interface and can be also trapped in the SiO_2. The trapping or bond breaking creates interface traps and oxide charge that affect the channel carrier's mobility, and the effective channel potential. Interface traps and oxide charge affect transistor performance. The common method to identify performance degradation is to monitor parameters such as threshold voltage, transconductance, and drain current.

Generally n-channel MOSFETs have the greatest susceptibility. Therefore this manual describes an accelerated test for measuring the hot-carrier-induced degradation of an n-channel MOSFET under DC bias.

Overview

Figure 2-1 shows the flow of the HCI degradation test according to the JEDEC proceeding titled "A PROCEDURE FOR MEASURING HCI" (29-JULY-93).

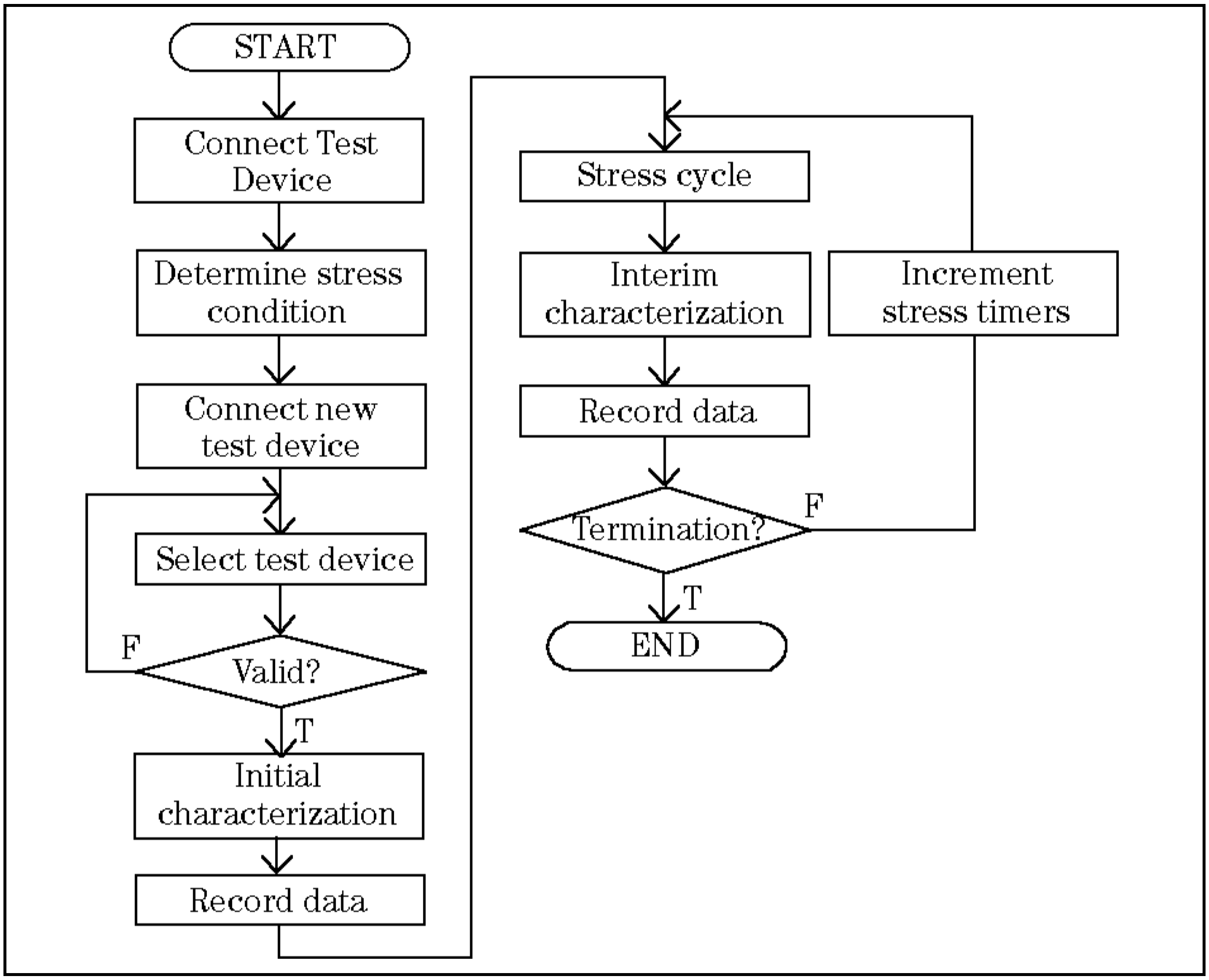


Figure 2-1. HCI Degradation Test Algorithm Flow

First, a test device is used to determine the stress bias conditions. After that, other test devices are connected and judged to be valid or not by measuring the gate, drain, and source leakage currents.

Note

The test device used to determine the stress bias conditions should not be used for hot-carrier stress testing.

For test devices that have all leakage currents within limits, initial characterization is performed, which measures and records the initial `Idlin`, `Gmmax`, `Vtext`, and `Vtci` parameters. Then, the stress/interim characterization loop is performed, which does the following:

1. During the stress cycle, the devices are biased using the previously determined stress bias conditions.
2. After each stress cycle, the device parameters are again measured, recorded and compared to the initial values.
3. If the parameter values have degraded past the limits, testing ends. Otherwise, another stress cycle is performed.

Determining Stress Bias Conditions

Hot-carrier stressing should be performed under constant voltage bias conditions as follows (you use a test device to determine the appropriate drain and gate bias voltages):

- Source voltage should be set to 0 V.
- Bulk voltage should be set to nominal bulk supply voltage of the technology(Vbb).
- (Recommended)Maximum drain stress bias voltage should be about 0.5 V below actual breakdown.
- For the selected drain bias condition, the corresponding gate bias should be set to induce the maximum possible bulk current. Peak Ib gate biasing typically results in the greatest rate of n-channel MOSFET degradation.

Selecting Test Devices

Before starting the stress cycle, select only devices that have gate, drain, and source leakage currents that are within desired limits. For the stress cycle, do not use the test device that was used to determine the stress bias conditions.

Initial Characterization

All parameters (`Idlin`, `Gmmax`, `Vtext`, and `Vtci`) are determined for the selected devices, and these parameter values are recorded as the initial parameter values.

Parameter Definitions

Following describes the parameters measured in the HCI degradation test program, and analyzed in the HCI degradation Data Analysis program.

Linear Drain Current (`Idlin`)

The linear drain current is measured under the following conditions:

Drain voltage Vd:	0.1 V
Gate voltage Vg:	Vdd
Source voltage Vs:	0 V
Bulk voltage Vb:	Vbb

Vdd and Vbb are nominal drain and bulk voltages for the technology.

Maximum Linear Transconductance (`Gmmax`)

The maximum linear transconductance is defined as the maximum slope of the Id-Vg curve. The Id-Vg characteristics are obtained by sweeping gate voltages under the following conditions:

Drain voltage Vd:	0.1 V
Source voltage Vs:	0 V
Bulk voltage Vb:	Vbb

The gate voltage is varied in increments of 20 mV or less, starting from below the turn-on voltage and increasing to a value that is large enough to ensure that the maximum slope point is reached.

Extrapolated Threshold Voltage (`Vtext`)

This parameter is obtained by measuring the drain current (Id) while sweeping the gate voltage (Vg). `Vtext` is calculated according the following equation

$$Vtext = Vg(Gmmax) - \frac{Id(Gmmax)}{Gmmax}$$

Vg(Gmmax) is the gate voltage at the point where the slope of the Id-Vg curve is maximum.

Id(Gmmax) is the drain current at the point of the maximum slope of the Id-Vg curve.

Vd is 0.1 V.

Constant Current Threshold Voltage (`Vtci`)

The constant current threshold voltage is defined as the gate voltage applied to the device during the Id-Vg measurement where the drain current is equal to 1 μA times the ratio of drawn gate width (W) to drawn gate length (L).

$$Vtci = Vg(@Id = 1\mu A * \frac{W}{L})$$

Stress Cycle

The transistor will be stressed with the voltages described previously in "Determining Stress Bias Conditions". The stress voltages should be applied in the following order:

1:Vs
2:Vb
3:Vg
4:Vd

Turning off the bias shall be done in the reverse order.
The minimum recommended stress intervals are *one-half* decade time-steps since the typical degradation follows a power-law with time.

Interim Characterization

All parameters (`Idlin`, `Gmmax`, `Vtext`, and `Vtci`) are determined for the selected devices, and these parameter values are recorded as the interim parameter values.

Stress Termination

Stress is terminated when one of following occurs:

- At least one parameter among `Idlin`, `Gmmax`, `Vtext`, or `Vtci` reaches the limit values described below in "Time to Target".
- Total stress time reaches 100,000 sec.

Time to Target (`Tdc`)

For `Idlin` or `Gmmax` parameter, `Tdc` is determined as the stress time at which the parameter has changed by 10% from its unstressed value.

For `Vtext` or `Vtci` parameter, `Tdc` is the stress time at which the parameter has changed by 20 mV from its unstressed value.

Precautions

Test Devices

Unstressed devices must be used in hot-carrier stress testing. Pre-stressed devices can have a `Tdc` that is much different from unstressed devices.

Interim Measurement

The devices under test may experience parameter recovery, so the parameter measurements should be made as soon as possible after each stress cycle.

Technical Requirements

Equipment Requirements

- The measurement system must be able to measure a minimum of 1 nA. The overshoot must not exceed 1% of applied voltage.
- To determine `Vtci`, the measurement system must have at least 2 mV resolution for Vg step. If the Vg step size is larger than 2 mV, an interpolation method may be used to achieve the 2 mV resolution.

Measurement Requirements

- The temperature of the wafer chuck or the temperature of the test fixture must be controlled to a temperature of 22°C ±3°C.
- The stress time interval should be known to an accuracy of ±3 %.

3

HCI Degradation Test Data Analysis

This chapter describes the Data Analysis procedure to determine Time to Target (`Tdc`) after Hot-Carrier-Induced Degradation test, which is based on the proposed JEDEC 29-JULY-93 standard.

Overview

Figure 3-1 shows the flow of the HCI degradation data analysis according to the JEDEC proceeding titled "A PROCEDURE FOR MEASURING HCI" (29-JULY-93).

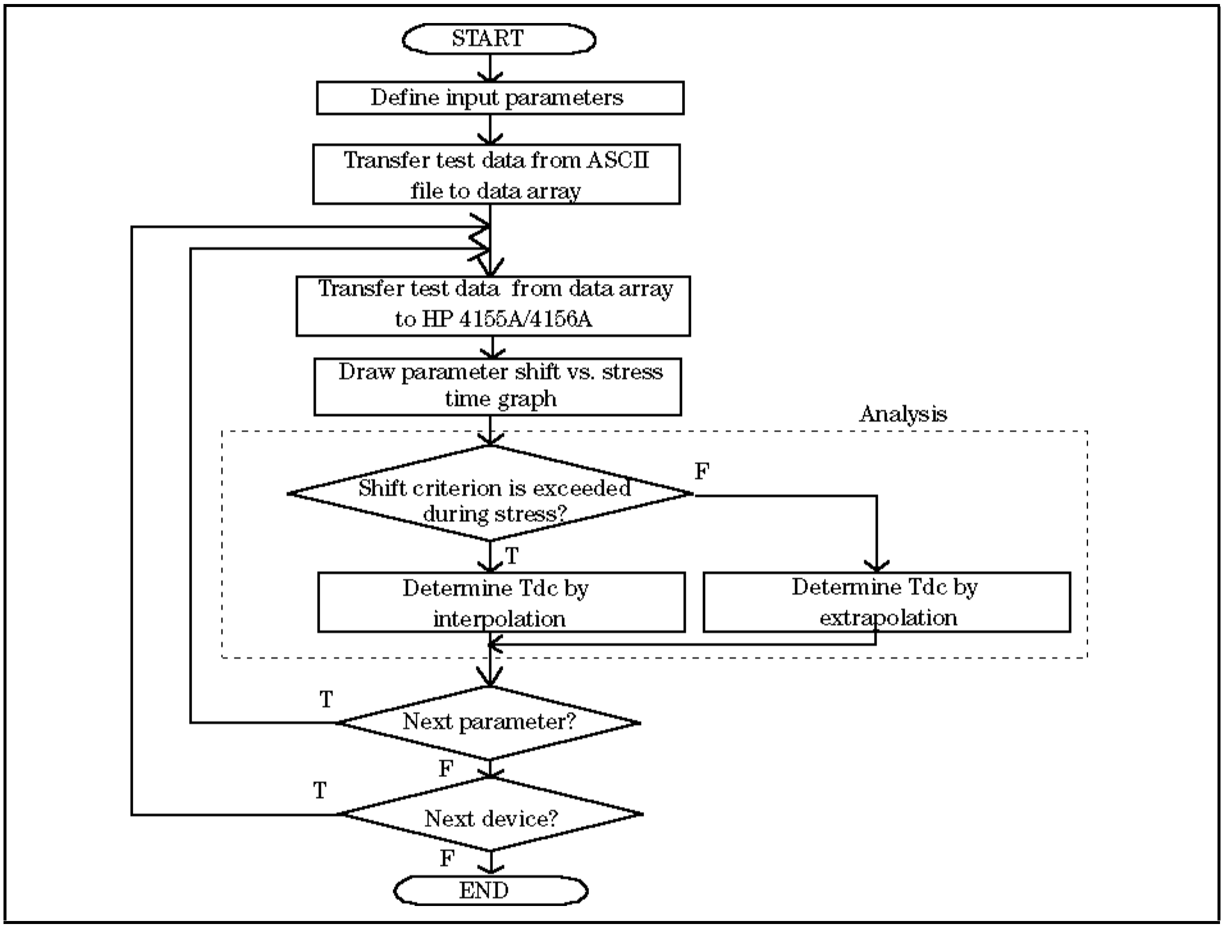


Figure 3-1. Data Analysis Algorithm Flow

- Percent change for `Idlin` and `Gmmax` is calculated as follows:

  Example for `Idlin`

  $$Idlinshift(t) = \frac{Idlin(t) - Idlin(init)}{Idlin(init)} * 100$$

  Idlinshift(t) is the percent change at stress time t

  Idlin(init) is the initial `Idlin` value

  Idlin(t) is the `Idlin` value at stress time t

- Relative shift for `Vtext` and `Vtci` is calculated as follows:

  Example of `Vtext`

  $$Vtextshift(t) = Vtext(t) - Vtext(init)$$

  Vtextshift(t) is the relative shift at stress time t

  Vtext(init) is the initial `Vtext` value

  Vtext(t) is the `Vtext` value at stress time t

The simple theory of hot-carrier degradation assumes that the degradation follows a power law with stress time. That is, the change in a parameter versus stress time is a straight line on a log-log plot.

The absolute value of change for each parameter should be fit to the following equation by using the least-squares fit:

Example for `Idlin`

$$|Idlinshift(t)| = Ct^n$$

where | Idlinshift(t) | is the absolute value of change in `Idlin` and t is the cumulative stress time. C is the absolute value of change in `Idlin` when t is 1, and n is the slope of the least-square fit line.

Tdc for each parameter should be *interpolated* or *extrapolated* from the data based on the C and n values from this least-squares fit. See the following two figures.

- If the shift criterion is *not* exceeded, *extrapolation* should be used based on the last two time decades as shown in following example.

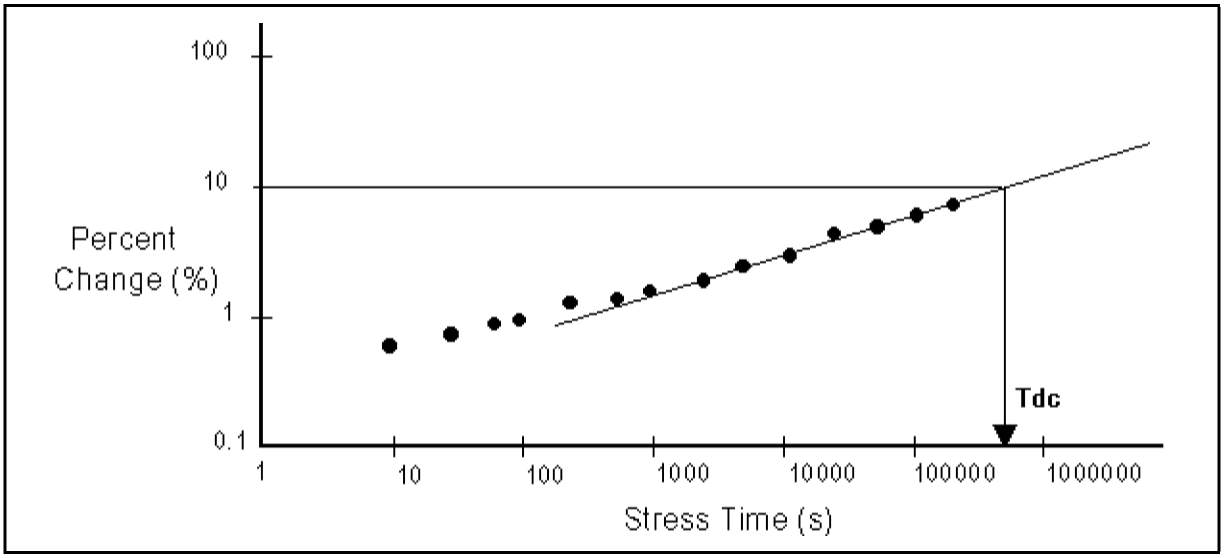


Figure 3-2. Example Extrapolation of HCI Degradation Data

- If the shift criterion is exceeded, `Tdc` should be determined by using a linear *interpolation* between the two data points as shown in following example.

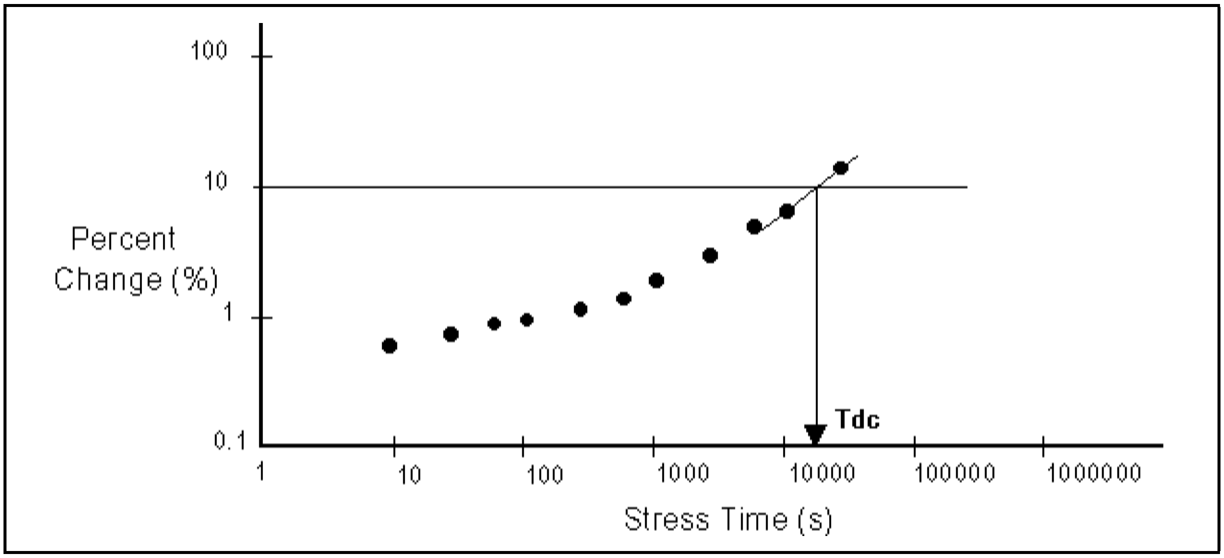


Figure 3-3. Example Interpolation of HCI Degradation Data

4

Basic Operation

This chapter describes how to use the HP 4155A/4156A to perform HCI degradation test and data analysis: methodology, input parameters, HCI degradation test, data analysis, required equipment, files on diskette, execution, and overview of sample programs.

Methodology

The HCI degradation can be evaluated by executing the HCI degradation test sample program (`DCDAHC`), then the data analysis sample program (`ANALYSIS`). These programs are included on the sample software diskette.

These programs can run on the built-in IBASIC controller of the HP 4155A/4156A. Or you can modify the sample program to run on an external controller that supports HP BASIC or HP Instrument BASIC. Refer to Chapter 5 on how to modify the program to run on an external controller.

The programs load measurement setup files into HP 4155A/4156A internal memory. The setups are previously saved in measurement setup files on the diskette. If you need to modify the setups, get them and modify them in fill-in-the-blank manner from the HP 4155A/4156A front panel, then re-save to the file.

The `DCDAHC` program displays the measurement data (Parameter shift versus Stress time) on the GRAPHICS page of HP 4155A/4156A, and stores data in ASCII files.

The `DCDAHC` program can perform multiple test device evaluation by using an HP 4085M switching matrix. Figure 4-1 shows the HCI degradation test flow for multiple device evaluation. To use another switching matrix or to not use any switching matrix, you need to modify the program as described in chapter 5.

The `ANALYSIS` program analyzes the measurement data (ASCII files that are saved by the `DCDAHC` program) to determine the time to target (Tdc).

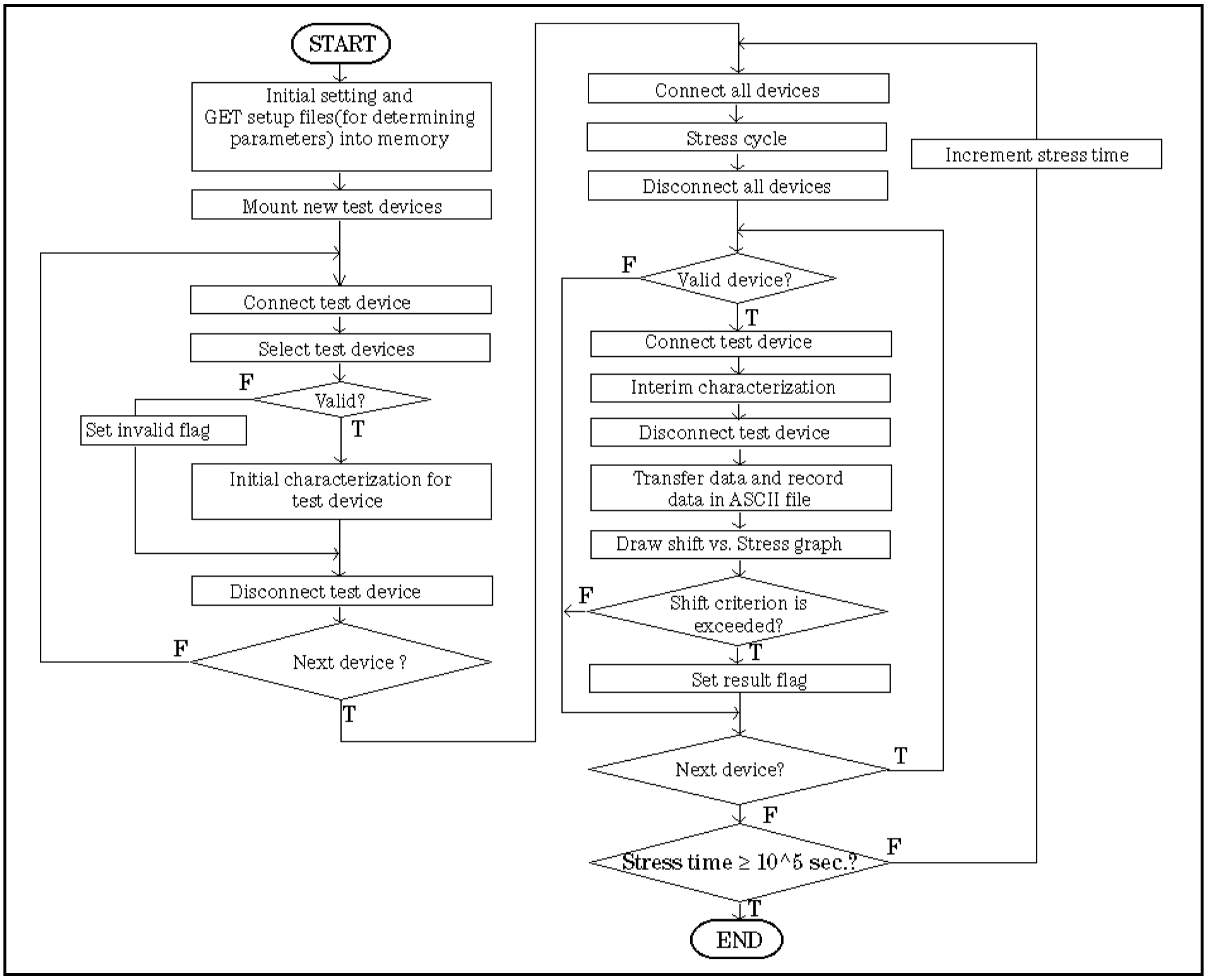


Figure 4-1. HCI Degradation Test Algorithm Flow for Multiple Devices

---

Input Parameters

Following table shows the input parameters required for the HCI degradation test program (`DCDAHC`) and the HCI degradation data analysis program (`ANALYSIS`). You can define these parameters by editing sample program in advance.

Input Parameters for HCI Degradation Test Program (DCDAHC)

Parameter Name	Description
Hpib_sc	HP-IB select code for controlling HP 415X
Hpib_addr	HP-IB address of HP 415X
Swm	HP-IB select code and address of switching matrix controller
No_of_devices	Total number of test devices
Meas_points	Total number of interim characterization points
Igleak_max	Upper limit of the gate leakage current
Idleak_max	Upper limit of the drain leakage current
Isleak_max	Upper limit of the source leakage current
Vdstr	Drain stress voltage
Vgstr	Gate stress voltage
Vdd	Nominal drain voltage
Vbb	Nominal bulk voltage
Gate_length	Drawn gate length
Gate_width	Drawn gate width
Source_str	Source pin assignment of device used to determine stress conditions
Gate_str	Gate pin assignment of device used to determine stress conditions
Drain_str	Drain pin assignment pin of device used to determine stress conditions
Bulk_str	Bulk pin assignment of device used to determine stress conditions
Source(*)[1]	Source pin assignment of device to stress/measure
Gate(*)[1]	Gate pin assignment of device to stress/measure
Drain(*)[1]	Drain pin assignment of device to stress/measure
Bulk(*)[1]	Bulk pin assignment of device to stress/measure
Ibvg_file$	Ib-Vg measurement setup file used to determine Vgstr
Igleak_file$	Ig-time measurement setup file to check gate leakage
Idleak_file$	Id-time measurement setup file to check drain leakage
Isleak_file$	Is-time measurement setup file to check source leakage
Str_file$	Stress setup file
Param_file$	Parameter measurement setup file
Idlin_data$	ASCII file of Idlin shift data
Gmmax_data$	ASCII file of Gmmax shift data
Vtext_data$	ASCII file of Vtext shift data
Vtci_data$	ASCII file of Vtci shift data
Meas_str_time	Stress duration data
Show_device	Flag to specify the devices for which you want to display parameter shift graphs (All=0 or Device No.)
Show_param	Flag to specify parameters for which you want to display parameter shift graphs (All=0, Idlin=1, Gmmax=2, Vtext=3, Vtci=4, −1=No graphs)
Save_at_last	Flag to specify when to save ASCII data files (Save after each interim test=0, Save all ASCII files after completing test=1)

---

[1] * is device number.

Input Parameters for HCI Degradation Data ANALYSIS Program

Parameter Name	Description
No_of_devices	Number of devices to analyze
Pause_to_save	Flag to specify whether to pause after drawing each "parameter shift vs stress time" graph so that you can save to a DAT file. (Pause: 1, No pause: 0)
Idlin_data$	ASCII file of Idlin shift data
Gmmax_data$	ASCII file of Gmmax shift data
Vtext_data$	ASCII file of Vtext shift data
Vtci_data$	ASCII file of Vtci shift data
Save_file$	ASCII file in which to save averaged Tdc data

HCI Degradation Test

Determining Stress Bias Conditions

Stress voltages should be forced to the devices under the following conditions with specified temperature:

Source stress voltage Vs:	0V
Bulk stress voltage Vb:	Vbb (= 0V)

Before executing the `DCDAHC` program, you should determine the drain stress voltage (`Vdstr`) by performing the Id-Vd measurement. The Id-Vd measurement setup is in the `IDVD.MES` file on the diskette. It is recommended that the maximum drain stress bias voltage is about 0.5V below actual breakdown. According to the measurement result, modify the value of `Vdstr` in the `DCDAHC` program before execution.

The `DCDAHC` program determines the gate stress voltage (`Vgstr`) by the Ib-Vg curve. The Ib-Vg setup is in the `IGVG.MES` file on the diskette. The sample program (`DCDAHC`) loads this setup into the HP 4155A/4156A at the beginning of the measurement, and sets the specified `Vdstr`. Ib-Vg measurement is performed and the gate stress voltage (`Vgstr`) is determined. Both `Vdstr` and `Vgstr` are saved to `DCDAHC.STR` file which is used for stress cycle.

Selecting Test Devices

Remove the test device that was used for determining the stress conditions. Then mount unstressed test devices on the switching matrix. After mounting, valid test devices are selected according to the gate, drain, and source leakage currents.

The following setup files are copied from the diskette to internal memory to be used for selecting valid devices:

IGLEAK.MES

IDLEAK.MES

ISLEAK.MES

If all leakage currents are within limits for a device, hot carrier stress testing will be performed for the device.

Note For hot-carrier stress testing, do not use the test device that was used to determine the stress conditions.

Initial Characterization

After selecting devices, one setup file is copied from the diskette to the HP 4155A/4156A internal memory:

PARAM.MES: setup file for determining Idlin, Gmmax, Vtext, and Vtci

`DCDAHC` program determines the *initial* Idlin, Gmmax, Vtext, and Vtci for the devices by using the above setup file. This setup file can easily be modified in fill-in-the-blank manner.

These initial measurement data (Idlin_init, Gmmax_init, Vtext_init and Vtci_init) are stored into IBASIC data arrays, and will be used to determine parameter shifts after each stress. These initial measurement data will be saved with parameter shift data into ASCII files on diskette after each interim measurement is performed.

Stress/Interim Characterization

Stress voltage is applied to all test devices simultaneously. The stress setup is in `DCDAHC.STR` file. The cumulative stress time is 10, 20, 50, 100, ... , 10000, 20000, 50000, 100000. After each of these cumulative times, the four parameters are measured for each device, then parameter shifts (Idlin_shift, Gmmax_shift, Vtext_shift, and Vtci_shift) are calculated and saved to ASCII files. This procedure is repeated until stress termination occurs for all test devices.

HCI Degradation Data Analysis

After hot carrier stress test, Tdc can be determined by executing `ANALYSIS` sample program. You can specify the values of following parameters:

- `No_of_devices`: Number of devices to be analyzed
- `Choice`: Analysis parameter (Idlin=1, Gmmax=2, Vtext=3, Vtci=4, All parameters=0).

After analysis, `ANALYSIS` program calculates average of `Tdc` for each parameter, then saves the calculated data to an ASCII data file on the diskette.

Required Equipment

The following are required to use the HCI degradation sample program:

- HP 4155A or HP 4156A Semiconductor Parameter Analyzer
- HP 4085M Switching Matrix (HP 4084B Switching Matrix Controller and HP 4085A Switching Matrix)
- Triaxial cable (4 cables)
- Test fixture for packaged device
- This operation manual
- Diskette that contains sample programs and setup files

Connect the required equipment and devices as shown in Figure 4-2 and Figure 4-3.

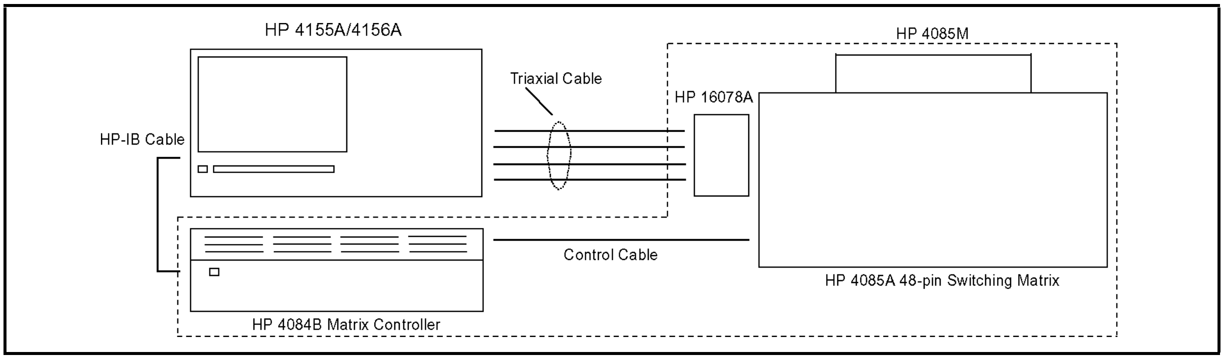


Figure 4-2. DC HCI Degradation Test Equipment Connections

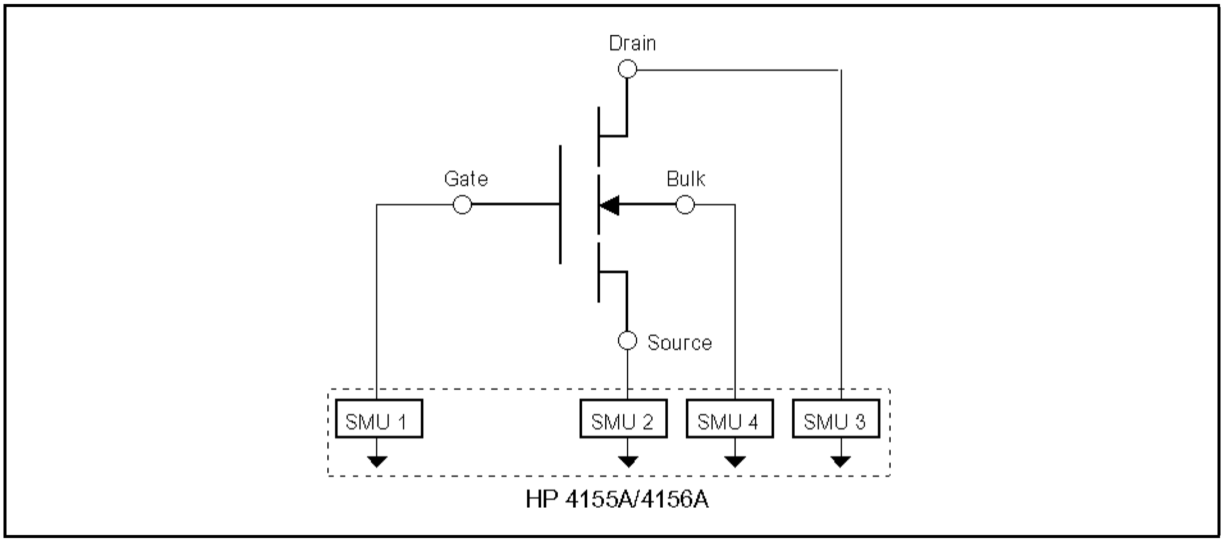


Figure 4-3. DC HCI Degradation Test Device Connections

Note

If you test on a wafer, you need to have HP 16077A Extension Cable Fixture to connect the matrix to a prober/probe card.

If you connect multiple devices for stress forcing, your device may oscillate due to the cable impedance and characteristics of your devices. In such a case, reduce the number of devices that are connected at the same time or use shorter measurement cables.

Note

If you test packaged devices, you need one of the following test fixtures:

- HP 16067A Low Leakage Fixture (24-pin DIP)
- HP 16068A Low Leakage Fixture (48-pin DIP)
- HP 16070A General Purpose DIP Fixture
- HP 16071A Universal Fixture

Warning

Maximum output voltage is limited to $40V$ if you use the HP 4085M to test on a wafer because the interlock terminal is not connected. However, you need to be careful that you don't touch the output terminals during the measurement.

AC Stress

If you execute AC HCI degradation test, the following are *also* required. Refer to "Performing HCI Degradation Test with AC Stress" in Chapter 5 for details.

- HP41501A SMU and Pulse Generator Expander furnished with 2 PGUs (Option 402, 412 or 422)
- HP16440A SMU/PG Selector

Files on the Diskette

Please make sure that following files are on the diskette.

File Name	Description
DCDAHC	DC Drain-Avalanche HCI degradation test sample program
IDVD.MES	File for setting up the HP 4155A/4156A to measure Id-Vd plot and determine Vdstr before running DCDAHC program.
IBVG.MES	File for setting up the HP 4155A/4156A to measure Ib-Vg plot and determine Vgstr
IGLEAK.MES	File for setting up the HP 4155A/4156A to measure gate leakage current for selecting test device
IDLEAK.MES	File for setting up the HP 4155A/4156A to measure drain leakage current for selecting test device
ISLEAK.MES	File for setting up the HP 4155A/4156A to measure source leakage current for selecting test device
DCDAHC.STR	File for setting up the HP 4155A/4156A to force DC stress to test device
PARAM.MES	File for setting up the HP 4155A/4156A to determine Idlin, Gmmax, Vtext, and Vtci after each stress
ACDAHC.STR	File for setting up the HP 4155A/4156A to force AC stress to test device
ANALYSIS	DC Drain-Avalanche HCI degradation test data analysis sample program

Execution

Before Executing HCI Degradation Test

Before executing the `DCDAHC` program, you must determine the drain stress voltage (`Vdstr`) by Id-Vd measurement:

1. Connect HP 4155A/4156A to HP 4085M switching matrix, then mount or probe the test device (that is used to determine stress conditions) on the HP 4085M.
2. Load the IDVD.MES setup file from the diskette into the HP 4155A/4156A, then perform the measurement. The Id-Vd measurement is displayed as shown in Figure 4-4.
3. Determine drain stress bias voltage (`Vdstr`) from the curve. Recommended maximum value is about 0.5 V below actual breakdown.
4. Enter value for `Vdstr` in line 1900 of `DCDAHC` program. See chapter 5 for details.

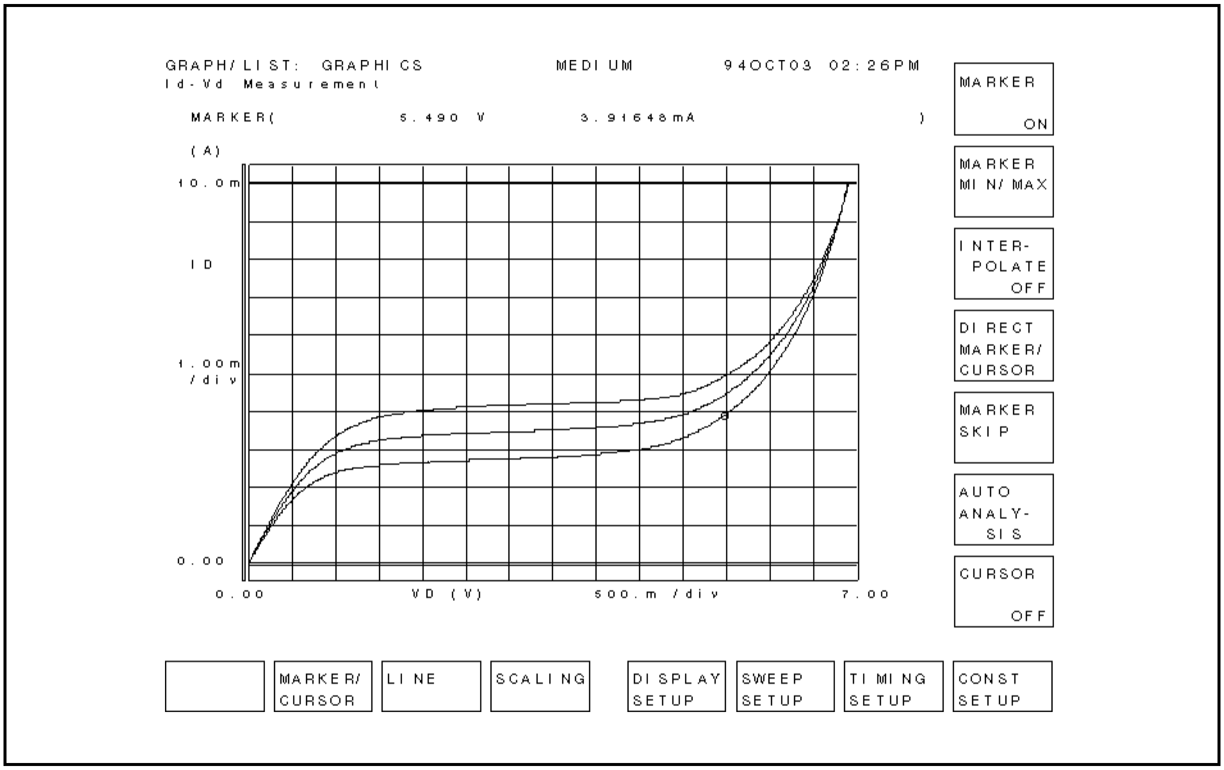


Figure 4-4. Id-Vd Measurement Example

HCI Degradation Test

1. Connect HP 4155A/4156A to HP 4085M switching matrix. If you test packaged devices, mount necessary test fixture on the switching matrix. If you test on wafer, mount the HP 16077A Extension Cable Fixture and connect measurement cables to a probe card or probes on the micro manipulators.
2. Mount or probe the test device (that is used to determine stress conditions) on the HP 4085M.

3. Insert diskette that contains HCI degradation test sample program into the built-in drive of HP 4155A/4156A or drive of external controller.

   - In case of using the built-in IBASIC of HP 4155A/4156A, press the IBASIC Display key until All IBASIC screen is displayed. Then, type as follows.

     `GET "DCDAHC"` Enter

   - If you use an external controller on which HP BASIC is working, type as follows.

     `GET "DCDAHC:,`*msus*`"` Enter

     Where *msus* is specifier of mass storage device that contains the DCDAHC program. If default *msus* is used, just type

     `GET "DCDAHC"` Enter.

     Then insert the diskette into the built-in disk drive of HP 4155A/4156A. The diskette is used when the measurement setup files are loaded.

4. To run DCDAHC program in HP 4155A/4156A, press RUN front-panel key.

   To run DCDAHC program in external controller, type `RUN` Enter.

   The Ib-Vg measurement is performed to determine the gate bias (`Vgstr`) that will be used in the stress testing, then this gate bias and drain bias (`Vdstr`) are saved to the DCDAHC.STR file. Ib-Vg curve is displayed on GRAPHICS page as shown in Figure 4-5.

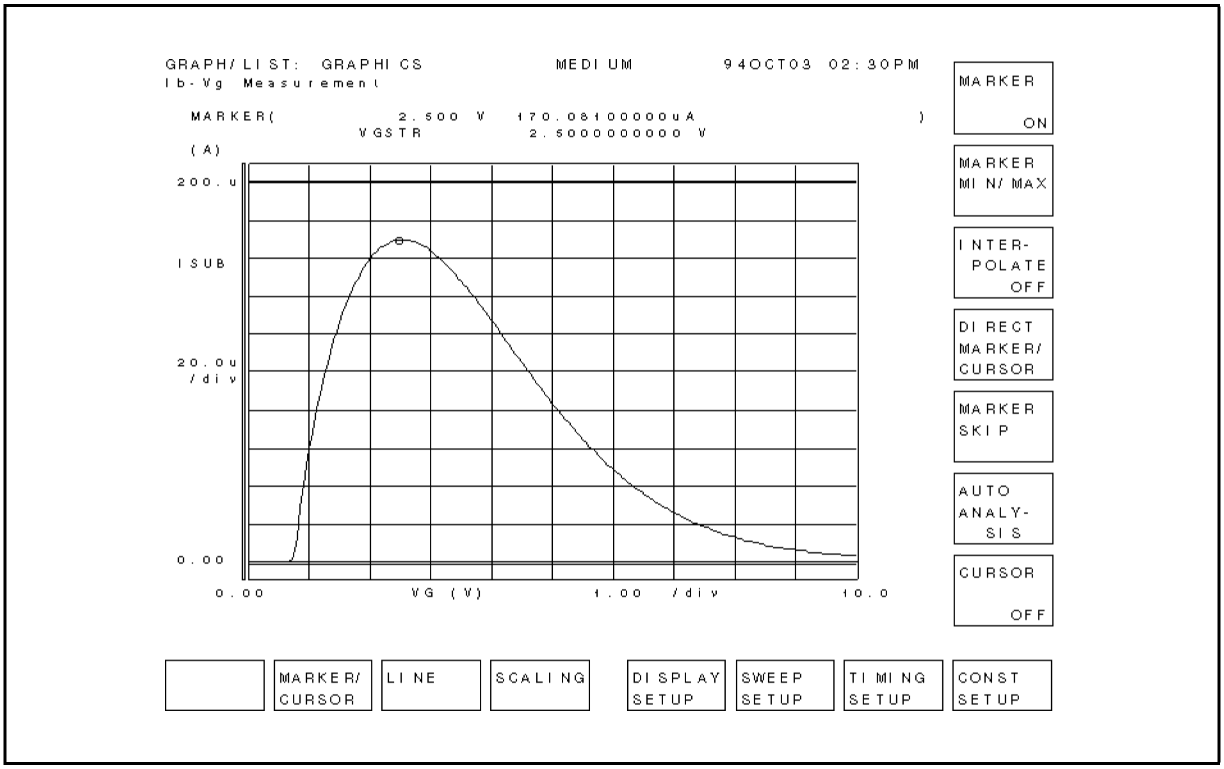
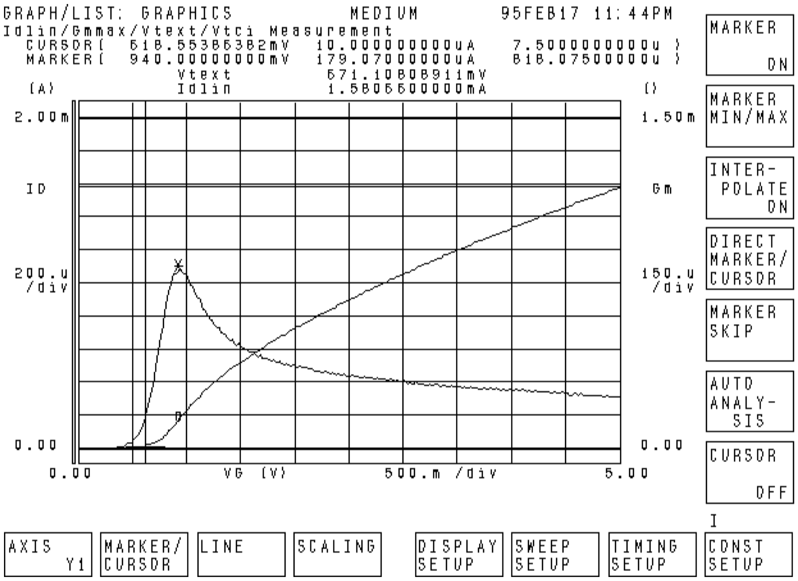


Figure 4-5. Ib-Vg Measurement Example

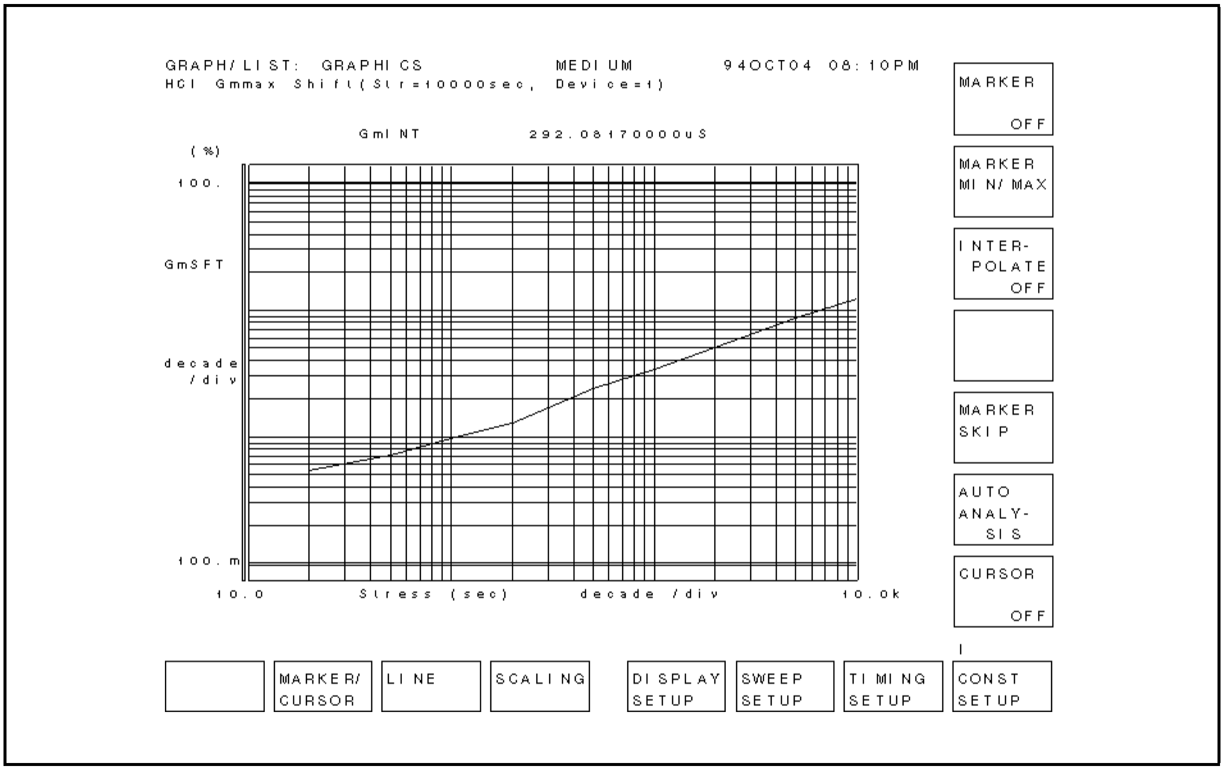
5. After `"Connect HCI degradation test devices"` is displayed, remove the device used to determine the stress conditions, then connect test devices for HCI degradation tests. Press `Continue` softkey to continue program. Leakage current tests are performed to select valid devices. If the device is valid, `"Device No. =` *XX* `can be used"` is displayed. If invalid, `"Device No. =` *XX* `shall not be used"` is displayed.
6. The initial characterization is performed for all *valid* devices. Then stress/interim characterization loop is executed until stress termination occurs. In each interim characterization, Idlin, Gmmax, Vtext and Vtci are determined. An example measurement is shown in Figure 4-6.



```
GRAPH/LIST: GRAPHICS            MEDIUM       95FEB17 11:44PM
Idlin/Gmmax/Vtext/Vtci Measurement
  CURSOR(  618.55386382mV  10.0000000000uA   7.5000000000u )
  MARKER(  940.00000000mV  179.0700000000uA  818.0750000000u )
                Vtext          671.10808911mV
                Idlin          1.5806600000mA
```

Figure 4-6. Initial/Interim Measurement Example

7. After each interim characterization, the fractional change in a parameter versus the stress time is displayed on GRAPHICS page of the HP 4155A/4156A as shown in Figure 4-7.



GRAPH/LIST: GRAPHICS MEDIUM 94OCT04 08:10PM
HCI Gmmax Shift(Str=10000sec, Device=1)

GmINT 292.08170000uS

Figure 4-7. HCI Degradation Test Result Example

8. After testing, `"HCI Degradation Test is Completed!!"` is displayed. All test data is saved to the following ASCII data files.

   - `ID`*XX*: Percent change data for Idlin
   - `GM`*XX*: Percent change data for Gmmax
   - `VTE`*XX*: Relative shift data for Vtext
   - `VTI`*XX*: Relative shift data for Vtci

     (where *XX* = Test device number)

   Each file contains following data:

   - If the device is judged as valid by the leakage current tests:
     - `Vdstr`, `Vgstr`, `Gate_length`, `Gate_width` values at stress termination
     - Number of interim characterization points until stress termination for the device, and initial measurement data of the device
     - Parameter shift data for each interim characterization points until stress termination

       In case of `ID`*XX* for example, `Idlin_shift`(*) are saved.
     - Cumulative stress time `Meas_str_time`(*) of interim characterization points until stress termination for the device.

     The following is an example of `VTE`*XX* data file.

     ```
     5, 1.95, 1.E-6, 1.E-5
     5, 1.094966
     .000921, .001106, .002565, .003549, .004747
     10, 20, 50, 100, 200
     ```

   - If the device is judged as invalid by the leakage current tests:
     - `Vdstr`, `Vgstr`, `Gate_length`, `Gate_width`
     - 0,0

Data Analysis

1. Insert diskette that contains `ANALYSIS` program and ASCII data files into built-in drive of HP 4155A/4156A or drive of external controller.
   - To load the program into HP 4155A/4156A, press the IBASIC (Display) key until All IBASIC screen is displayed. Then, type the following:

     `GET "ANALYSIS"` (Enter)
   - To load the program into an external controller, type the following on the command line of external controller display:

     `GET "ANALYSIS:,`*msus*`"` (Enter)

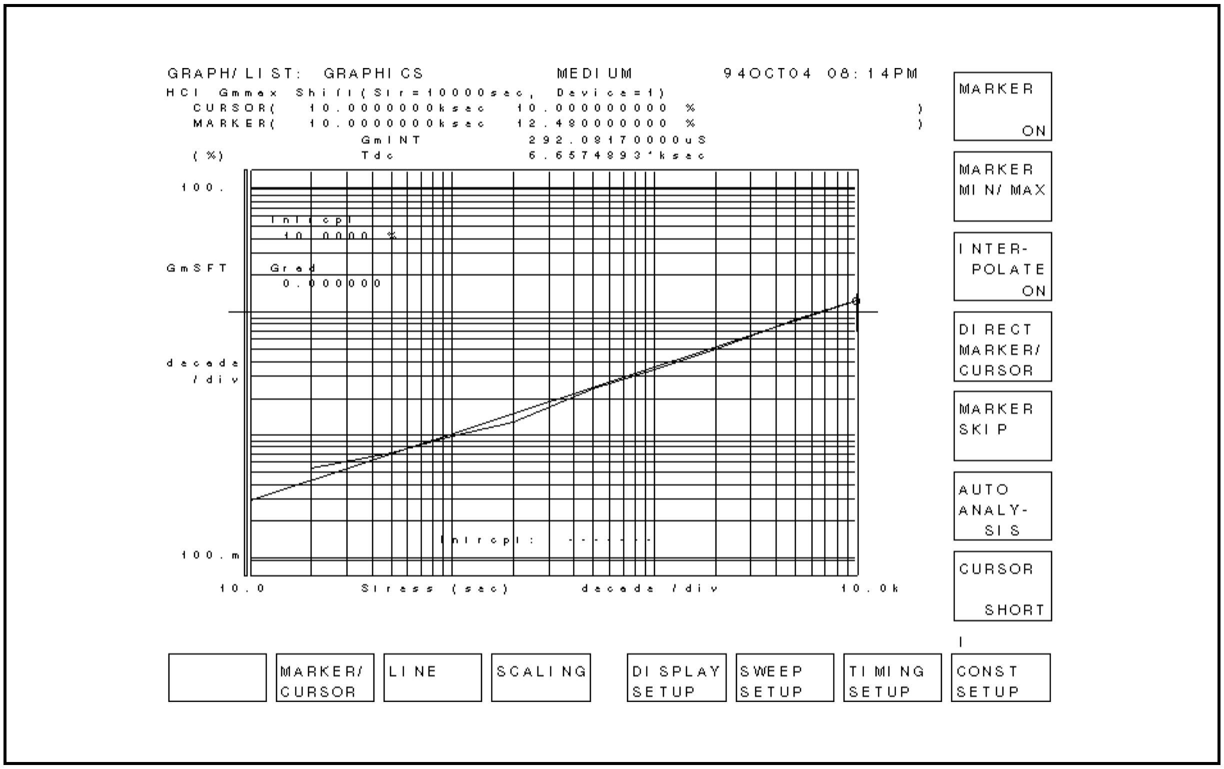
     Where *msus* is specifier of mass storage device that contains the ANALYSIS program. If default *msus* is used, just type

     `GET "ANALYSIS"` (Enter).

     Then insert the diskette into the built-in disk drive of HP 4155A/4156A. The diskette is used when the measurement result files are loaded.
2. To run ANALYSIS program on HP 4155A/4156A, press (RUN) front-panel key.

   To run ANALYSIS program on external controller, type `RUN` (Enter).
3. Enter number of devices to be analyzed. Default number is 4.
4. Select softkey of parameter for which you want to extract `Tdc`.
5. Analysis result and Tdc will be displayed on GRAPHICS page of the HP 4155A/4156A as shown in Figure 4-8. This step is repeated according to entered number of devices and selected parameters. After each graph is displayed, program pauses. During pause, you can save analyzed data to a DAT type file. To continue program, select `Continue` softkey.

   If you don't want program to pause, change line 1740 in ANALYSIS program to `Pause_to_save=0` before you run the ANALYSIS program.



```
GRAPH/LIST:  GRAPHICS               MEDIUM         94OCT04 08:14PM
HCI Gmmax Shift(Str=10000sec, Device=1)
  CURSOR(   10.0000000ksec   10.000000000  %                        )
  MARKER(   10.0000000ksec   12.480000000  %                        )
                GmINT             292.08170000uS
  (%)           Tdc               6.6574893'ksec
```

```
Intrcpt
 10.0000 %
Grad
 0.000000
Intrcpt: -------
```

Figure 4-8. HCI Degradation Test Data Analysis Example

6. All calculated data is saved to `ANAHCI`, which is an ASCII file. The data is also listed on IBASIC screen. After analyzing, saving, and listing the data, the HP 4155A/4156A is initialized.

   Following are contents of this file for the case that you selected `Idlin` parameter for the `Tdc` extraction:

   - *Number of devices*
   - *Vdstr*, *Vgstr*, *Gate width*, *Gate length*
   - `Idlin`
   - `Device ,Validity ,Tdc_idlin`
     - *First device number,* `0` or `1` (valid: `0`, invalid: `1`), *Extracted Tdc for the device*
     - ⋮
     - *Last device number*, `0` or `1`, *Extracted Tdc for the device*
   - `Averaged Tdc_idlin`
     - *Calculated average Tdc*

The following is an example of `ANAHCI` data file for the following case:

- *Number of devices* is 4
- *Vdstr* is 5 V
- *Vgstr* is 1.95 V
- *Gate width* is 1 μm
- *Gate length* is 10 μm
- All parameters are selected

```
 4
 5, 1.95, 1.E-6, 1.E-5
Idlin
Device Validity Tdc_idlin
 1, 0, 835.5786
 2, 0, 3401.432
 3, 0, 6269.047
 4, 0, 24366.79
Averaged Tdc_idlin
 8718.2119
Gmmax
Device  Validity Tdc_gmmax
 1, 0, 856.0696
 2, 0, 1089.116
 3, 0, 1963.261
 4, 0, 5580.226
Averaged Tdc_gmmax
 2372.16815
Vtext
Device Validity Tdc_vtext
 1, 0, 205.1144
 2, 0, 327.8407
 3, 0, 455.0903
 4, 0, 1506.441
Averaged Tdc_vtext
 623.6216
Vtci
Device Validity Tdc_vtci
 1, 0, 179.3154
 2, 0, 345.677
 3, 0, 557.895
 4, 0, 2956.594
Averaged Tdc_vtci
 1009.87035
```

Sample HCI Degradation Test Program (DCDAHC) Overview

For the program code, edit `DCDAHC`.

Line or Subprogram Name	Description
1640-1750	Sets the HP-IB interface select code and address for the HP 4155A/4156A and HP 4085M. `800` means HP 4155A/4156A will be controlled by built-in IBASIC controller. Also assigns the FORMAT OFF attribute to the I/O path name "@Form_off" without changing the file pointers. Default HP-IB interface select code and address for the HP 4085M are set to `722`.
1770-2700	Assigns input parameter values and file names
2730	Calls Initial_setting subprogram, which performs the initial settings.
2740	Calls Init_hp415x subprogram, which initializes HP 4155A/4156A
2750-2760	Enables service request from HP 4155A/4156A to interrupt program
2790	Calls Str_define subprogram, which determines DC stress condition
2860 - 2980	Calls subprograms that connect test devices (Swm_connect), select valid test devices (Device_check), execute initial characterization for valid devices (Param_meas), then disconnect devices (Swm_clear). If device is invalid, calls subprograms (Record_*parameter*) that save data and invalid flag to data file.
3020 - 3100	Calls subprograms that connect devices (Swm_connect), force stress to devices (Stress), then disconnect devices (Swm_clear).
3130	Calls Calibration subprogram, which performs calibration if required (Commented)
3220 - 3240	Calls subprograms that connect devices (Swm_connect), performs an interim characterization (Param_meas), then disconnects devices (Swm_clear).
3280 - 3330	Calls subprograms (Record_*parameter*) that save interim characterization data to ASCII files after each interim characterization
3340 - 3360	Calls Record_data subprogram, which saves interim characterization data to DAT type files after each interim characterization (Commented)
3400 - 3760	Calls subprograms (Stress_*parameter*) that draw "parameter shift vs stress time" graphs for specified devices and parameters.
3800 - 4000	Judges whether shift criterion is exceeded for each parameter
4050 - 4090	Judges whether test should be terminated
4080	Judges whether all devices exceed shift criterion
4090	Judges whether accumulated stress time exceeds 100,000 sec
4130 - 4210	Calls subprograms (Record_*parameter*) that save all interim characterization data to ASCII files after entire test is completed
4220	Calls Test_end subprogram, which initializes HP 4155A/4156A at the end of test
4230	Displays test completion message

Line or Subprogram Name	**Description**
Initial_setting (4280)	Defines the dimension of data arrays and initializes test result data variables
Init_hp415x (4650)	Initializes HP 4155A/4156A, loads PARAM.MES and DCDAHC.STR setup files into HP 4155A/4156A, and sets the input parameter values to the these setups, then resaves setups to disk.
Str_define (5070)	Loads IBVG.MES setup file, writes new `Vdstr` value for this setup, determines DC stress condition (`Vgstr`), then saves the determined `Vgstr` to the stress setup file (DCDAHC.STR).
Device_check (5440)	Selects valid test devices by measuring leakage currents
Param_meas (6350)	Determines Idlin, Gmmax, Vtext and Vtci, then calculates Idlin shift, Gmmax shift, Vtext shift, and Vtci shift
Stress (6790)	Forces stress
Record_iddata (7180)	Saves Idlin shift data to ASCII file
Record_gmdata (7810)	Saves Gmmax shift data to ASCII file
Record_vtedata (8450)	Saves Vtext shift data to ASCII file
Record_vtidata (9090)	Saves Vtci shift data to ASCII file
Stress_idgraph (9730)	Draws "Idlin shift vs stress time" graph
Stress_gmgraph (10430)	Draws "Gmmax shift vs stress time" graph
Stress_vtegraph (11120)	Draws "Vtext shift vs stress time" graph
Stress_vtigraph (11820)	Draws "Vtci shift vs stress time" graph
Calibration (12510)	Performs calibration of HP 4155A/4156A
Connect (12690)	Connects one SMU port to the specified pin of HP 4085M
Swm_connect (12850)	Connects four SMU ports to the specified different pins of HP 4085M
Swm_clear (12970)	Disconnects all SMU ports from connected pins
DEF FNSmu (13090)	Defines FNSmu used in "Connect", "Swm_connect" and "Swm_clear" subprograms
Err_check (13200)	Checks if HP 4155A/4156A error occurred during the test
Error_rep (13490)	Checks if HP 4085M error occurred during the test
Record_data (13600)	Saves interim characterization data to DAT type files
Test_end (13690)	Initializes HP 4155A/4156A at the end of test

Sample HCI Degradation Test Data Analysis Program (ANALYSIS) Overview

For the actual program code, edit `ANALYSIS`.

Line or Subprogram Name	Description
1600-1630	Sets the HP-IB interface select code and address for the HP 4155A/4156A. `800` means HP 4155A/4156A will be controlled by built-in IBASIC controller. Also assigns the FORMAT OFF attribute to the I/O path name "@Form_off" without changing the file pointers.
1650 - 1830	Assigns input parameter values and file names
1850 - 1890	Prompts you to specify input parameters.
1920 - 2160	Creates labels for softkeys that allow you to select which parameters to analyze
2200	Calls Init_setting subprogram, which sets HP 4155A/4156A display to be not updated, then transfers Idlin/Gmmax/Vtext/Vtci shift data from ASCII file to IBASIC data arrays
2260 - 2360	Calls subprograms to analyze the Idlin shift data as described in next three rows.
2280	Calls Trans_iddata subprogram, which Transfers Idlin shift data from IBASIC data arrays to HP 4155A/4156A
2290	Calls Stress_idgraph subprogram, which draws Idlin shift vs stress time graph
2300	Calls Analysis1 program, which determines Tdc from the Idlin shift vs stress time graph
2380 - 2480	Performs same operations for Gmmax shift data as was performed for Idlin shift data
2500 - 2600	Performs same operations for Vtext shift data as was performed for Idlin shift data
2620 - 2720	Performs same operations for Vtci shift data as was performed for Idlin shift data
2780	Calls Calculate subprogram, which calculates average Tdc
2790	Calls Save_calc_data subprogram, which saves calculated average Tdc to ASCII file
2800	Calls Print_calc_data subprogram, which prints calculated average Tdc on IBASIC screen
2830	Calls Test_end subprogram, which initializes HP 4155A/4156A at the end of program
2840	Displays analysis completion message

Line or Subprogram Name	Description
Init_setting (2880)	Sets HP 4155A/4156A display to be not updated. Then transfers Idlin/Gmmax/Vtext/Vtci shift data from ASCII file to IBASIC data arrays.
Trans_iddata (3940)	Transfers Idlin shift data from IBASIC data array to HP 4155A/4156A
Trans_gmdata (4440)	Transfers Gmmax shift data from IBASIC data array to HP 4155A/4156A
Trans_vtedata (4940)	Transfers Vtext shift data from IBASIC data array to HP 4155A/4156A
Trans_vtidata (5430)	Transfers Vtci shift data from IBASIC data array to HP 4155A/4156A
Stress_idgraph (5930)	Draws "Idlin shift vs stress time" graph
Stress_gmgraph (6310)	Draws "Gmmax shift vs stress time" graph
Stress_vtegraph (6690)	Draws "Vtext shift vs stress time" graph
Stress_vtigraph (7070)	Draws "Vtci shift vs stress time" graph
Analysis1 (7450)	Determines Tdc for Idlin/Gmmax by using a linear interpolation or a power law extrapolation
Analysis2 (8130)	Determines Tdc for Vtext/Vtci by using a linear interpolation or a power law extrapolation
Calculate (8800)	Calculates average of Tdc
Save_calc_data (9220)	Saves calculated average Tdc to ASCII file
Print_calc_data (9980)	Prints calculated average Tdc on IBASIC screen
Test_end (10500)	Initializes HP 4155A/4156A at the end of test

5

Customization

This chapter describes how to customize the sample program to suit your test device and requirements.

Using External Computer or Built-in Controller

The `DCDAHC` and `ANALYSIS` programs are created assuming that they will be run on the built-in IBASIC controller of the HP 4155A/4156A. However, you may be able to use an external computer, such as *HP 9000 S382* .

The following lines specify the HP-IB select code and address of HP 4155A/4156A:

```
1670  Hpib_sc=8           ! HP 415X HP-IB Select Code
1680  Hpib_addr=0         ! HP 415X HP-IB Address
```

- If you will execute the `DCDAHC` or `ANALYSIS` program using the HP 4155A/4156A built-in IBASIC controller, use the above HP-IB select code and address (`800`).
- If you want to execute the `DCDAHC` or `ANALYSIS` program on an external computer, modify above lines. For example, if the HP-IB select code is `7`, and the HP-IB address of HP 4155A/4156A is `17`, modify as follows:

  ```
  1670  Hpib_sc=7           ! HP 415X HP-IB Select Code
  1680  Hpib_addr=17        ! HP 415X HP-IB Address
  ```

  Also, set the HP 4155A/4156A to `NOT SYSTEM CONTROLLER` on SYSTEM: MISCELLANEOUS page.

  1. Press (System) key
  2. Select `MISCELLANEOUS` softkey.
  3. Move the field pointer to the `HP 415x is` field, then select `NOT CONTROLLER` softkey.
  4. Move the field pointer to the `HP 415x` field of the HP-IB ADDRESS area, then enter: `17`(Enter).

Modifying and Specifying Setup File to Load

The `DCDAHC` program loads six setup files to set up the HP 4155A/4156A for the HCI degradation test.

- Ib-Vg measurement setup file (`IBVG.MES`)
- Gate leakage current measurement setup file (`IGLEAK.MES`)
- Drain leakage current measurement setup file (`IDLEAK.MES`)
- Source leakage current measurement setup file (`ISLEAK.MES`)
- DC stress setup file (`DCDAHC.STR`)
- Parameter (Idlin, Gmmax, Vtext and Vtci) measurement setup file (`PARAM.MES`)

These setup files must be on the diskette and diskette must be in the flexible disk drive of the HP 4155A/4156A, even if you run the program from the external controller.

The setup pages of each setup file are shown in Appendix A.

Before testing, you can modify a setup and re-save it to a file on the diskette. For example, if you want to change the gate voltage in the gate leakage current measurement setup file IGLEAK.MES, which is used to select valid devices, use the following procedure:

1. Press (Get) key. In the Get dialogue, select `FILE CATALOG`, move the field pointer to `IGLEAK.MES`, then select the `SELECT` and `EXECUTE` softkeys.
2. Press (Meas) key in page control key group. On the MEASURE: SAMPLING SETUP page, move the field pointer to the SOURCE field of SMU1(VG).
3. For example, to change the gate voltage from 5 V to 6 V, type `6` then press (Enter).
4. Press (Save) key. In the Save dialogue, select `FILE CATALOG`, move the field pointer to `IGLEAK.MES`, then select the `SELECT` and `EXECUTE` softkeys.

The `DCDAHC` program file loads the above files into the HP 4155A/4156A. The file names are defined in the following lines of the program:

```
2360  ! --------- Definition of measurement and stress setup files -----------
2370  !
2380  Ibvg_file$="IBVG.MES"     ! Ib-Vg measurement to determine Vgstr
2390  Igleak_file$="IGLEAK.MES" ! Ig-time measurement to check gate leakage
2400  Idleak_file$="IDLEAK.MES" ! Id-time measurement to check drain leakage
2410  Isleak_file$="ISLEAK.MES" ! Is-time measurement to check source leakage
2420  !
2430  Str_file$="DCDAHC.STR"    ! DC stress setup file
2440  ! Str_file$="ACDAHC.STR"  ! AC stress setup file
2450  !
2460  Param_file$="PARAM.MES"   ! Idlin/Gmmax/Vtext/Vtci measurement setup file
2470  !
```

If you want to use other setup files instead, change the file names. For example, to use `INTRIM.MES` instead of `PARAM.MES`, change line 2460 as follows:

```
2460  Param_file$="INTRIM.MES"   ! Idlin/Gmmax/Vtext/Vtci measurement setup file
```

Be sure that the files you specified in above lines are on the diskette before running `DCDAHC` program.

Changing File for Saving Measurement Results

The `DCDAHC` sample program creates ASCII data files as shown in the following lines. The `ANALYSIS` sample program gets these files to analyze test data and determine Tdc. For the contents of these files, please refer to step 8 in “Execution” in Chapter 4.

```
2480  ! ---------- File name to save ASCII data --------------------------------
2490  Idlin_data$="ID"          ! Idlin shift data file name
2500  Gmmax_data$="GM"          ! Gmmax shift data file name
2510  Vtext_data$="VTE"         ! Vtext shift data file name
2520  Vtci_data$="VTI"          ! Vtci shift data file name

7270    Save_file$=Idlin_data$&VAL$(Device)
   ⋮
7910    Save_file$=Gmmax_data$&VAL$(Device)
   ⋮
8550    Save_file$=Vtext_data$&VAL$(Device)
   ⋮
9190    Save_file$=Vtci_data$&VAL$(Device)
```

So, the following files are created, where *XX* is test device number.

`ID`*XX*, `GM`*XX*, `VTE`*XX*, `VTI`*XX*

If you want to change the file names, modify above lines as in following example:

```
2480  ! ---------- File name to save ASCII data --------------------------------
2490  Idlin_data$="DTA"         ! Idlin shift data file name
2500  Gmmax_data$="DTB"         ! Gmmax shift data file name
2510  Vtext_data$="DTC"         ! Vtext shift data file name
2520  Vtci_data$="DTD"          ! Vtci shift data file name
```

The following files are created, where *XX* is the test device number:

`DTA`*XX*, `DTB`*XX*, `DTC`*XX*, `DTD`*XX*

Also, you need to modify corresponding lines in the `ANALYSIS` program:

```
1790  ! ---------- Get file name ----------------------------------------------
1800  Idlin_data$="DTA"          ! Idlin shift data file name
1810  Gmmax_data$="DTB"          ! Gmmax shift data file name
1820  Vtext_data$="DTC"          ! Vtext shift data file name
1830  Vtci_data$="DTD"           ! Vtci shift data file name
```

Note

We recommend not to change lines 7270, 7910, 8550, and 9190 of `DCDAHC` program. If so, you need to modify many lines in `ANALYSIS` program because device number is used to handle measurement data files.

Changing Input Parameters for HCI Degradation Test

Default parameter values for the test conditions are defined from line 1770 to 2350 in the `DCDAHC` program. Modify these values according to your test device and environment.

```
1770  ! ---------- Input Parameters --------------------------------------------
1780  !
1790  No_of_devices=4      ! Number of test devices
1800  Meas_points=13       ! Number of times to repeat measurements
1810  REDIM Meas_str_time(1:Meas_points)
1820  REDIM Last_test(No_of_devices)
1830  !
1840  ! ---------- Limits for leakage tests -----------------------------------
1850  Igleak_max=2.E-10    ! Maximum gate leakage current
1860  Idleak_max=1.E-8     ! Maximum drain leakage current
1870  Isleak_max=1.E-8     ! Maximum source leakage current
1880  !
1890  ! ----- Drain stress voltage should be determined by Id-Vd characteristics
1900  Vdstr=5              ! Drain stress voltage
1910  Vgstr=2.5            ! Gate stress voltage
1920  Vdd=5                ! Drain nominal voltage
1930  Vbb=0                ! Bulk nominal voltage
1940  !
1950  ! ---------- Device geometries -------------------------------------------
1960  Gate_length=1.E-6    ! Gate length
1970  Gate_width=1.E-5     ! Gate width
1980  !
1990  ! ---------- Pin assignment to determine stress bias condition -----------
2000  Source_str=1         ! Pin assignment of source (Stress)
2010  Drain_str=2          ! Pin assignment of drain (Stress)
2020  Gate_str=3           ! Pin assignment of gate (Stress)
2030  Bulk_str=4           ! Pin assignment of bulk (Stress)
2040  !
2050  ! ---------- Pin assignment for forcing stresses and interim measurements
2060  ! Pin assignment for Device No. = 1
2070  Source(1)=5
2080  Drain(1)=6
2090  Gate(1)=7
2100  Bulk(1)=8
2110  !
2120  ! Pin assignment for Device No. = 2
2130  Source(2)=9
2140  Drain(2)=10
2150  Gate(2)=11
2160  Bulk(2)=12
2170  !
2180  ! Pin assignment for Device No. = 3
2190  Source(3)=13
2200  Drain(3)=14
2210  Gate(3)=15
2220  Bulk(3)=16
2230  !
2240  ! Pin assignment for Device No. = 4
2250  Source(4)=17
2260  Drain(4)=18
2270  Gate(4)=19
2280  Bulk(4)=20
2290  !
2300  ! Pin assignment for Device No. = X
2310  ! Source(X)=XX
2320  ! Drain(X)=XX
2330  ! Gate(X)=XX
2340  ! Bulk(X)=XX
2350  !
```

Parameter	Description	Default
`No_of_devices`	Number of devices to be tested	4
`Meas_points`	Number of times to repeat stress/measurement cycles	13 times
`Igleak_max`	Maximum gate leakage current	200 pA
`Idleak_max`	Maximum drain leakage current	10 nA
`Isleak_max`	Maximum source leakage current	10 nA
`Vdstr`	Drain stress voltage. See note below.	5 V
`Vgstr`	Default gate stress voltage, used if you skip determination of gate stress bias condition	2.5 V
`Vdd`	Nominal drain voltage	5 V
`Vbb`	Nominal bulk voltage	0 V
`Gate_length`	Gate length	1 μm
`Gate_width`	Gate width	10 μm
`Source_str`	Source pin of switching matrix to determine gate stress voltage	1
`Drain_str`	Drain pin of switching matrix to determine gate stress voltage	2
`Gate_str`	Gate pin of switching matrix to determine gate stress voltage	3
`Bulk_str`	Bulk pin of switching matrix to determine gate stress voltage	4
`Source(*)`	Pin assignment of source terminal for stress/interim characterization loop. `Source`(*Device number*)	5,9,13,17
`Drain(*)`	Pin assignment of drain terminal for stress/interim characterization loop. `Drain`(*Device number*)	6,10,14,18
`Gate(*)`	Pin assignment of gate terminal for stress/interim characterization loop. `Gate`(*Device number*)	7,11,15,19
`Bulk(*)`	Pin assignment of bulk terminal for stress/interim characterization loop. `Bulk`(*Device number*)	8,12,16,20

Note

Before executing the `DCDAHC` program, you must determine `Vdstr` (drain stress voltage) by using `"IDVD.MES"` setup file stored on the diskette. Then, manually edit line 1900 of the DCDAHC program to enter the determined `Vdstr` value. Refer to "Execution" in Chapter 4.

To Change Pin Assignment

The switching matrix's pin assignment of source, gate, drain and bulk pins for each test device is defined in lines 1990 to 2280. To change pin assignment, change these lines. For example, to change the pin assignment of device 1 to following, change lines 2070 to 2100 as below:

Device Terminal	Default Pin Assignment	New Pin Assignment
Source	5	31
Drain	6	32
Gate	7	33
Bulk	8	34

```
2050  ! ---------- Pin assignment for forcing stresses and interim measurements
2060  ! Pin assignment for Device No. = 1
2070  Source(1)=31
2080  Drain(1)=32
2090  Gate(1)=33
2100  Bulk(1)=34
```

To Change Number of Test Devices

Number of devices to test is defined in line 1790. Default in `DCDAHC` program is 4 devices.

```
1790  No_of_devices=4       ! Number of test devices
```

You can change the number of test devices by manually editing this line. For example, to decrease number of devices from 4 to 3, change line 1790 as follows:

```
1790  No_of_devices=3       ! Number of test devices
```

For example, to increase number of devices from 4 to 5, change line 1790 as follows:

```
1790  No_of_devices=5       ! Number of test devices
```

If you increase the number of devices, you need to assign switching matrix pins for the extra devices. For example, for the fifth device, use template lines 2300 to 2340:

```
2300  ! Pin assignment for Device No. = 5
2310   Source(5)=21
2320   Drain(5)=22
2330   Gate(5)=23
2340   Bulk(5)=24
```

Note If you connect many devices, SMUs may oscillate during stress forcing due to larger stray capacitances and residual inductances.

Changing the Cumulative Stress Times

In the `DCDAHC` program, the cumulative stress times are set in the following lines:

```
2540  ! ---------- Stress duration setup ---------------------------------------
2550 Str_time: !                      ! Stress duration data
2560  DATA      10,     20,     50
2570  DATA     100,    200,    500
2580  DATA    1000,   2000,   5000
2590  DATA   10000,  20000,  50000
2600  DATA  100000
2610  RESTORE Str_time
2620  READ Meas_str_time(*)
```

To make interim characterizations more or less frequently, modify above DATA lines.

To Make Interim Characterizations More Frequently

Following is an example of more frequent interim characterization.

```
2540  ! ---------- Stress duration setup ---------------------------------------
2550 Str_time: !                      ! Stress duration data
2560  DATA     10,    20,    40,    70
2570  DATA    100,   200,   400,   700
2580  DATA   1000,  2000,  4000,  7000
2590  DATA  10000, 20000, 40000, 70000
2600  DATA 100000
2610  RESTORE Str_time
2620  READ Meas_str_time(*)
```

Also, change number of interim characterization points (`Meas_points`) from 13 to 17.

```
1800  Meas_points=17      ! Number of times to repeat measurements
```

To Make Interim Characterizations Less Frequently

Following is an example of less frequent interim characterization.

```
2540  ! ---------- Stress duration setup ---------------------------------------
2550 Str_time: !                      ! Stress duration data
2560  DATA     10,    30
2570  DATA    100,   300
2580  DATA   1000,  3000
2590  DATA  10000, 30000
2600  DATA 100000
2610  RESTORE Str_time
2620  READ Meas_str_time(*)
```

Also, change number of interim characterization points (`Meas_points`) from 13 to 9.

```
1800  Meas_points=9       ! Number of times to repeat measurements
```

Skipping Determination of Gate Stress Bias Condition

In `DCDAHC` program, gate stress bias condition is determined by the following line:

```
2780  ! --------- Determine Stress Bias Condition ---------
2790  CALL Str_define                ! Determine DC stress condition
2800  DISP "Connect HCI degradation test devices"
2810  PAUSE
```

To skip determination of gate stress bias condition and use the default gate stress voltage defined on line 1910, comment out lines 2790 to 2810 as follows.

```
2780  ! --------- Determine Stress Bias Condition ---------
2790  !CALL Str_define                ! Determine DC stress condition
2800  !DISP "Connect HCI degradation test devices"
2810  !PAUSE
```

Reducing the Interval between Stress and Interim Measurement

According to JEDEC proceeding, the parameter measurements should be made as soon as possible after each stress cycle has terminated. In the DCDAHC program, line 2680 specifies to re-save test data to the ASCII file after *each* interim measurement so that data is not lost if an unexpected accident occurs:

```
2680  Save_at_last=0    ! 0:Save ASCII data files after each interim test
2690                    ! 1:Save all ASCII data files after completing whole test
```

To shorten the interval, you can save test data in the ASCII file only after the termination criteria is exceeded by changing line 2680 as follows:

```
2680  Save_at_last=1    ! 0:Save ASCII data files after each interim test
2690                    ! 1:Save all ASCII data files after completing whole test
```

Selecting Parameter Shift Graphs to Draw

The `DCDAHC` program draws graphs of each parameter shift for each device after each interim characterization. The following lines set the flags to select device number and parameter type that you want to a graph.

```
2640  ! ---------- Setup for drawing / saving data in main menu ----------------
2650  Show_device=0       ! 0:Draw graphs of all devices, Specify device No.
2660  Show_param=0        ! 0:Draw graphs of all params
2670                      ! 1:Idlin, 2:Gmmax, 3:Vtext, 4:Vtci, -1:No graphs
```

The above sets that all parameter shift graphs will be drawn for all devices.

To Skip Drawing Graphs

To shorten the interval, you can skip drawing parameter shift graphs. Change line 2660.

```
2640  ! ---------- Setup for drawing / saving data in main menu ----------------
2650  Show_device=0       ! 0:Draw graphs of all devices, Specify device No.
2660  Show_param= -1     ! 0:Draw graphs of all params
2670                      ! 1:Idlin, 2:Gmmax, 3:Vtext, 4:Vtci, -1:No graphs
```

The above sets that no parameter shift graphs will be drawn.

To Draw Graphs of Specified Device Only

To draw parameter shift graphs for specified device only, change line 2650.

```
2640  ! ---------- Setup for drawing / saving data in main menu ----------------
2650  Show_device=3       ! 0:Draw graphs of all devices, Specify device No.
2660  Show_param=0        ! 0:Draw graphs of all params
2670                      ! 1:Idlin, 2:Gmmax, 3:Vtext, 4:Vtci, -1:No graphs
```

The above sets that all parameter shift graphs will be drawn, but only for device number 3.

To Draw Graphs of Specified Parameter Only

To draw specified parameter shift graph for specified device only, change lines 2650 and 2660.

```
2640  ! ---------- Setup for drawing / saving data in main menu ----------------
2650  Show_device=2       ! 0:Draw graphs of all devices, Specify device No.
2660  Show_param=4        ! 0:Draw graphs of all params
2670                      ! 1:Idlin, 2:Gmmax, 3:Vtext, 4:Vtci, -1:No graphs
```

The above sets that the only graph drawn will be Vtci shift graph for device number 2.

If You Don't Use Switching Matrix

If you directly connect SMUs of the HP 4155A/4156A to the test device and don't use a switching matrix, modify the DCDAHC program as follows:

Change the number of devices to 1.

```
1790  No_of_devices=1      ! Number of test devices
```

And comment out the following lines:

```
2870  !  CALL Swm_connect              ! Connect test device
2970  !  CALL Swm_clear                ! Disconnect test device
3040  !  CALL Swm_connect              ! Connect test devices in parallel
3100  !  CALL Swm_clear                ! Disconnect all test devices
3220  !  CALL Swm_connect              ! Connect test device
3240  !  CALL Swm_clear                ! Disconnect test device
5180  !  Connect(FNSmu(1),Gate_str)
5190  !  Connect(FNSmu(2),Source_str)
5200  !  Connect(FNSmu(3),Drain_str)
5210  !  Connect(FNSmu(4),Bulk_str)
5370  !  CALL Swm_clear
```

Using Another Switching Matrix

The `DCDAHC` program assumes that you use the HP 4085M switching matrix. If you want to use another switching matrix, modify the following subprograms by replacing with corresponding HP-IB control commands for your switching matrix.

- Connect
- Swm_connect
- Swm_clear

Subprogram	Input Parameter	Functionality
`Connect`	`Port` (Port number), `Pin` (Pin number), `Swm` (HP-IB select code and address of switching matrix)	Connects the specified port to the specified measurement pin
`Swm_connect`	`Device` (Device number), `Source(*)` (Pin assignment of source), `Gate(*)` (Pin assignment of gate), `Drain(*)` (Pin assignment of drain), `Bulk(*)` (Pin assignment of bulk)	Connects four terminals of specified device to SMU 1,2,3,4
`Swm_clear`	`Swm` (HP-IB select code and address of switching matrix)	Disconnects all measurement ports from the measurement pins

Note

For switching of the switching matrix relays, you must use **Dry Switching** method, which means switching occurs only after the object signal has been turned off or removed from the relay's terminal.

Do *not* use the wet switching method because it reduces the life of switching matrix relays. In the DCDAHC program, dry switching is executed by lines `12760`, `12900`, `13020` and `13250`.

```
12760   OUTPUT @Hp415x;":PAGE:SCON:STOP"
12900   OUTPUT @Hp415x;":PAGE:SCON:STOP"
13020   OUTPUT @Hp415x;":PAGE:SCON:STOP"
13250   OUTPUT @Hp415x;":PAGE:SCON:STOP"
```

Performing HCI Degradation Test with AC Stress

If desired, you can also perform HCI degradation test with AC stress. Figure 5-1 shows the setup for AC HCI degradation test. Figure 5-2 shows the measurement circuit.

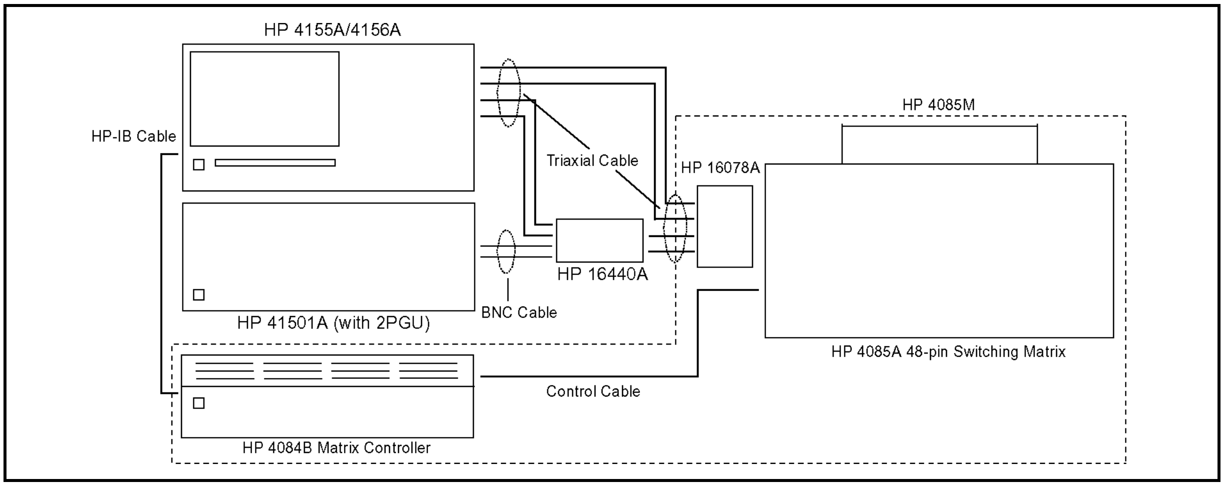


Figure 5-1. AC HCI Degradation Test Equipment Connections

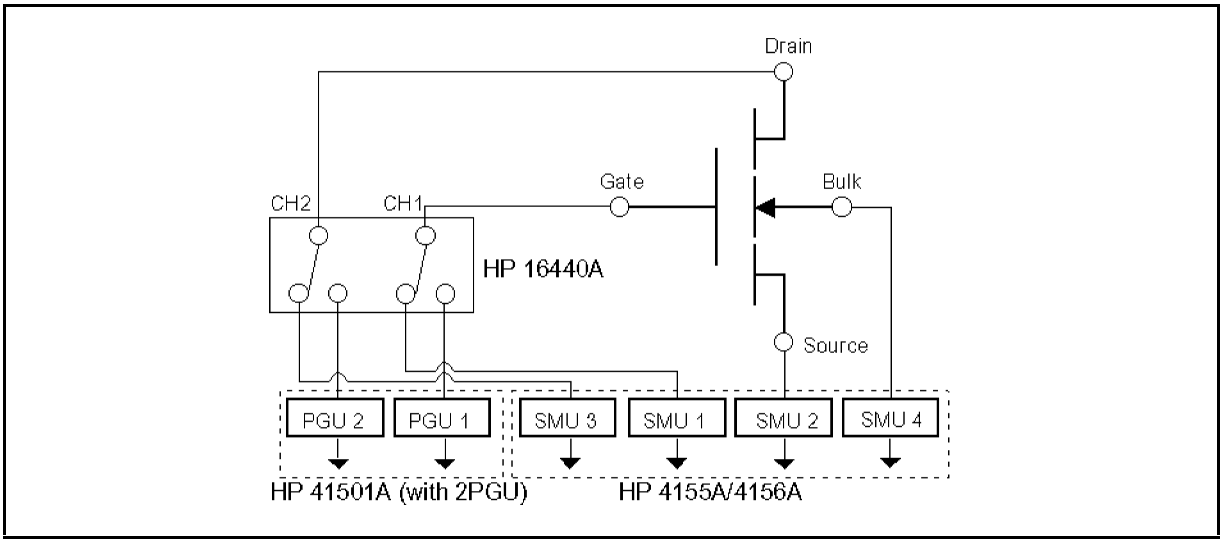


Figure 5-2. AC HCI Degradation Test Device Connections

ACDAHC.STR file must be used instead of DCDAHC.STR. This file sets up the HP 4155A/4156A as shown in Appendix A. Before testing, you must modify these settings according to your requirements, then re-save to the diskette.

In the DCDAHC sample program, stress setup file to be used is defined as follows:

```
2430  Str_file$="DCDAHC.STR"    ! DC stress setup file
2440  ! Str_file$="ACDAHC.STR"  ! AC stress setup file
```

To use `ACDAHC.STR`, exchange the comment mark (!) as follows:

```
2430  !Str_file$="DCDAHC.STR"    ! DC stress setup file
2440  Str_file$=”ACDAHC.STR”  ! AC stress setup file
```

The following lines set DC stress voltages of SMUs.

```
4990    OUTPUT @Hp415x;":PAGE:STR:SET:CONS:SMU3 ";Vdstr
5000    OUTPUT @Hp415x;":PAGE:STR:SET:CONS:SMU1 ";Vgstr

5390    OUTPUT @Hp415x;":PAGE:STR:SET:CONS:SMU1 ";Vgstr
```

Change these lines as follows so that these lines set AC stress voltages of PGU1 and PGU2.

```
4990    OUTPUT @Hp415x;”:PAGE:STR:SET:PULS:PGU2:PEAK ”;Vdstr
5000    OUTPUT @Hp415x;”:PAGE:STR:SET:PULS:PGU1:PEAK ”;Vgstr

5390    OUTPUT @Hp415x;”:PAGE:STR:SET:PULS:PGU1:PEAK ”;Vgstr
```

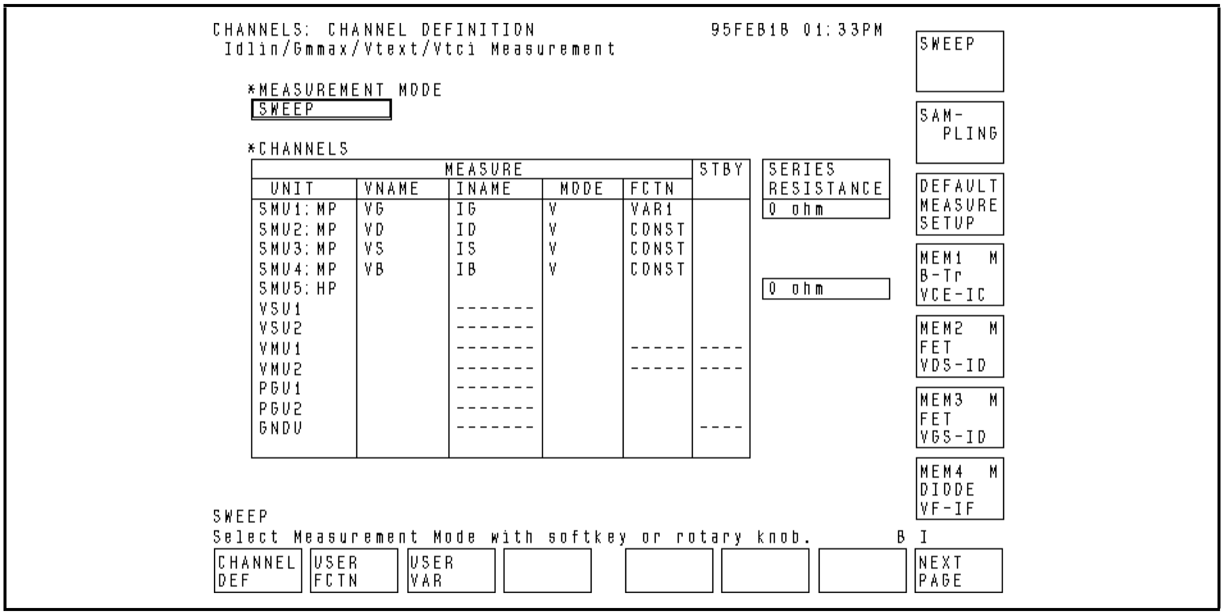
Note

Before starting AC stress test, you need to modify setup of `ACDAHC.STR` file. Set appropriate pulse period, width, leading time, and trailing time on STRESS: STRESS SETUP page.

Performing Reverse Mode Test

The `DCDAHC` program performs forward mode tests. In this mode, the polarity between drain and source during parameter measurement is the same as during stress. For reverse mode test, it is opposite.

If you want to perform reverse mode tests, switch assignments of SMUs for drain and source in `PARAM.MES` file for CHANNELS: CHANNEL DEFINITION page as in the following figure, then resave it before executing test.


CHANNELS: CHANNEL DEFINITION 95FEB18 01:33PM
Idlin/Gmmax/Vtext/Vtci Measurement

*MEASUREMENT MODE
SWEEP

*CHANNELS

MEASURE					STBY	SERIES RESISTANCE
UNIT	VNAME	INAME	MODE	FCTN		
SMU1: MP	VG	IG	V	VAR1		0 ohm
SMU2: MP	VD	ID	V	CONST		
SMU3: MP	VS	IS	V	CONST		
SMU4: MP	VB	IB	V	CONST		
SMU5: HP						0 ohm
VSU1		-------				
VSU2		-------				
VMU1		-------		-----	----	
VMU2		-------		-----	----	
PGU1		-------				
PGU2		-------				
GNDU		-------			----	

SWEEP
Select Measurement Mode with softkey or rotary knob. B I

Figure 5-3. Changing SMU Assignment in PARAM.MES for Reverse Mode Test

Changing Input Parameters for Test Data Analysis

In the ANALYSIS program, the input parameters are defined on the following lines:

```
1650  ! --------------- Input Parameters ---------------
1660  No_of_devices=4                          ! Number of devices to be evaluated
1670  !
1680  ! ---------- Flag to PAUSE program after each Tdc analysis --------------
1690  ! If the following flag is 1, this program is paused
1700  ! after drawing Shift parameter v.s. Stress time graph.
1710  ! During pause, you can manually save analyzed data to
1720  ! a DAT file. Then press continue. If you don't want to
1730  ! PAUSE program, change following flag to 0.
1740  Pause_to_save=1
1750  !
1760  ! ---------- Save ASCII file name ---------------------------------------
1770  Save_file$="ANAHCI"
1780  !
```

You can modify these values before executing ANALYSIS program.

Parameter	Description	Default
`No_of_devices`	Default number of devices for which to analyze data. This value is used if you do not enter a value when prompted at beginning of ANALYSIS program.	4
`Pause_to_save`	Flag to pause program after each Tdc extraction	`1` (pause)
`Save_file$`	ASCII file name in which to save calculated average Tdc	`ANAHCI`

Not to Pause Program after each Tdc Extraction

The `ANALYSIS` program extracts Tdc for all devices and all parameters specified. The program pauses after drawing each “shift parameter vs stress time” graph so that you can manually save analyzed data to a DAT file. If you don't want to pause program, change line 1740 as follows:

```
1740  Pause_to_save=0
```

Changing File Name to save Calculated Average Tdc

After analysis, averaged Tdc for each parameter is calculated and saved into an ASCII file. Refer to “Data Analysis” of Chapter 4. The file name is defined in line 1770. For example, if you want to change the file name to `TDCAVG`, change as follows:

```
1760  ! ---------- Save ASCII file name ---------------------------------------
1770  Save_file$="TDCAVG"
```

A

Setup Files

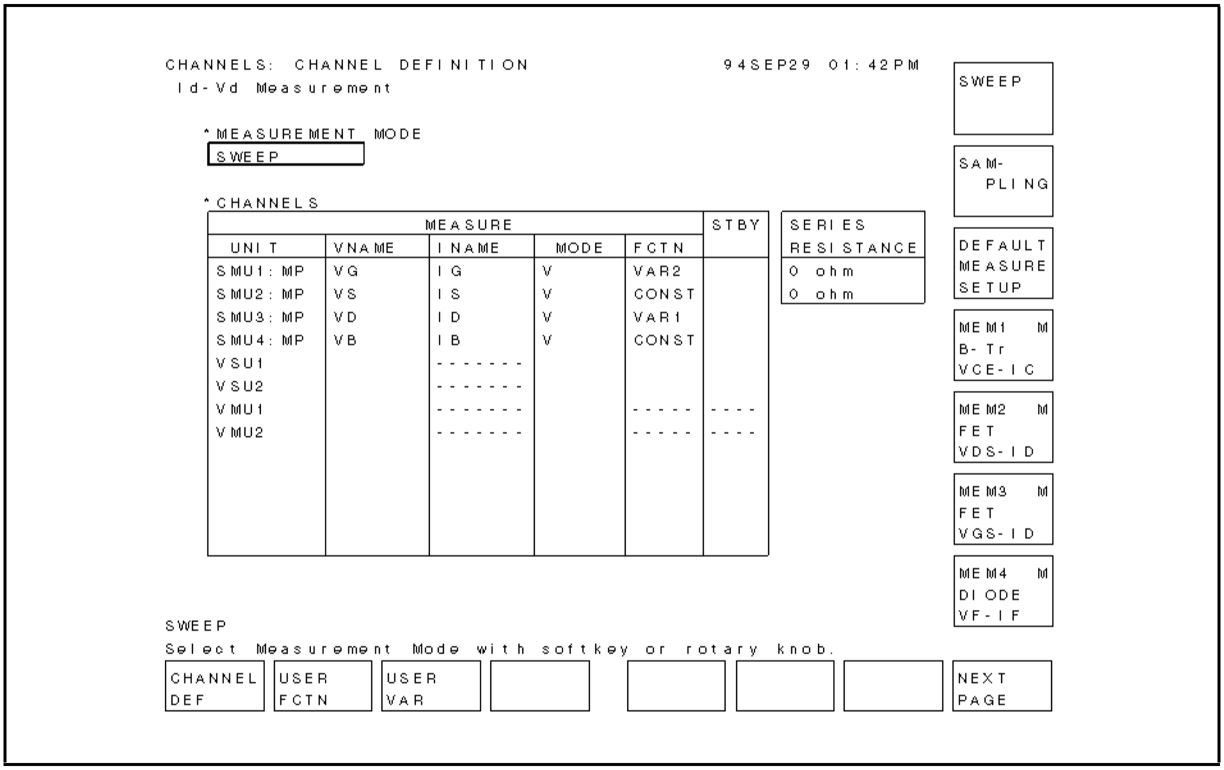
This appendix describes the settings of the HP 4155A/4156A setup pages that are stored in the setup files. If you change the setup page settings, you need to re-save the settings to the corresponding setup file. The DCDAHC program loads these files (except IDVD.MES) to perform the HCI degradation test.

Setup File for Id-Vd Measurement to Determine Drain Stress Voltage

Settings of following setup pages are stored in IDVD.MES file, which is used to set up HP 4155A/4156A to determine Vdstr.

Note

You need to use this setup to determine Vdstr manually before running the DCDAHC program. See "Execution" in Chapter 4 for details.



CHANNELS: CHANNEL DEFINITION 94SEP29 01:42PM
Id-Vd Measurement

*MEASUREMENT MODE
SWEEP

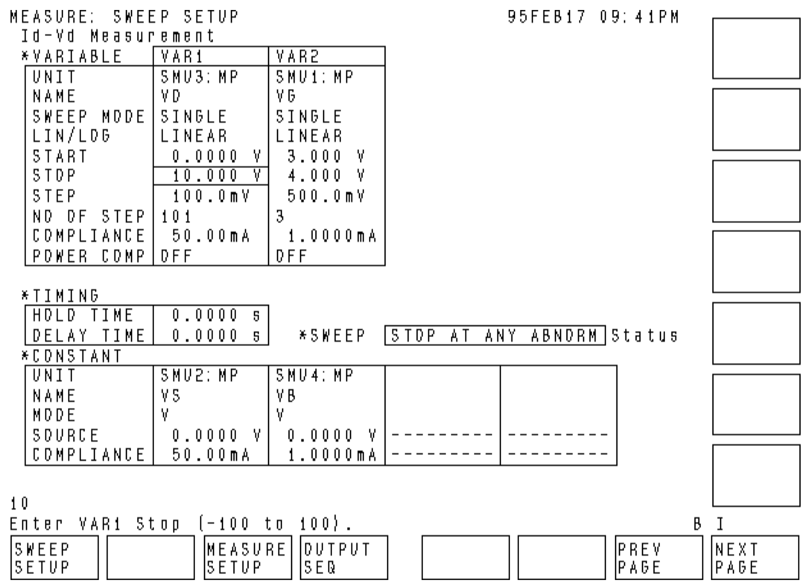
*CHANNELS

MEASURE					STBY
UNIT	VNAME	INAME	MODE	FCTN	
SMU1:MP	VG	IG	V	VAR2	
SMU2:MP	VS	IS	V	CONST	
SMU3:MP	VD	ID	V	VAR1	
SMU4:MP	VB	IB	V	CONST	
VSU1		-------			
VSU2		-------			
VMU1		-------		-----	----
VMU2		-------		-----	----

SERIES RESISTANCE
0 ohm
0 ohm

SWEEP
Select Measurement Mode with softkey or rotary knob.

Figure A-1. CHANNEL DEFINITION Page of IDVD.MES



MEASURE: SWEEP SETUP 95FEB17 09:41PM

Id-Vd Measurement

*VARIABLE	VAR1	VAR2
UNIT	SMU3:MP	SMU1:MP
NAME	VD	VG
SWEEP MODE	SINGLE	SINGLE
LIN/LOG	LINEAR	LINEAR
START	0.0000 V	3.000 V
STOP	10.000 V	4.000 V
STEP	100.0mV	500.0mV
NO OF STEP	101	3
COMPLIANCE	50.00mA	1.0000mA
POWER COMP	OFF	OFF

*TIMING

HOLD TIME	0.0000 s
DELAY TIME	0.0000 s

*SWEEP STOP AT ANY ABNORM Status

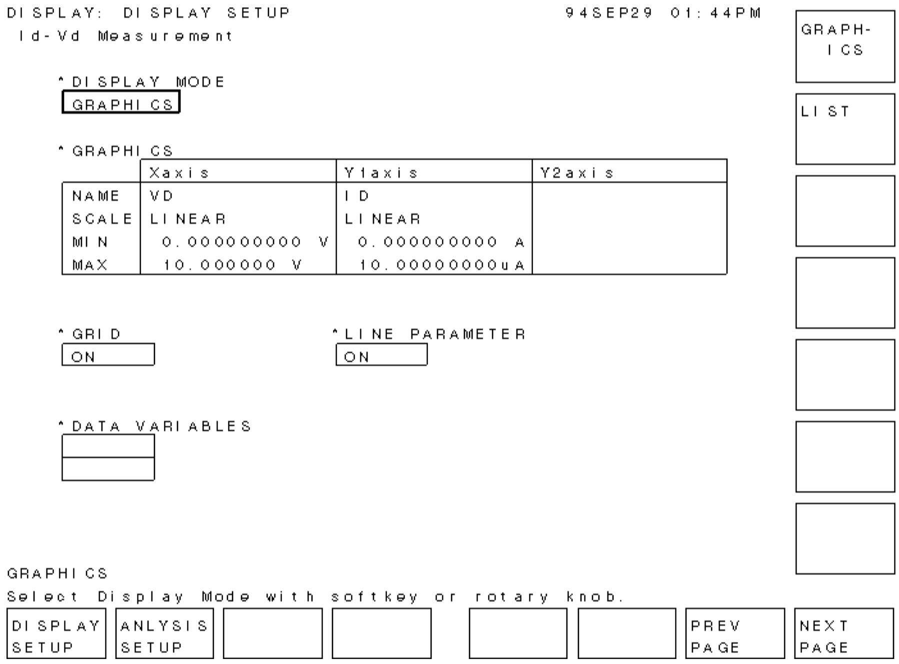
*CONSTANT

UNIT	SMU2:MP	SMU4:MP		
NAME	VS	VB		
MODE	V	V		
SOURCE	0.0000 V	0.0000 V	----------	----------
COMPLIANCE	50.00mA	1.0000mA	----------	----------

10

Enter VAR1 Stop (-100 to 100).

Figure A-2. SWEEP SETUP Page of IDVD.MES



DISPLAY: DISPLAY SETUP 94SEP29 01:44PM

Id-Vd Measurement

*DISPLAY MODE

GRAPHICS

*GRAPHICS

	Xaxis	Y1axis	Y2axis
NAME	VD	ID	
SCALE	LINEAR	LINEAR	
MIN	0.000000000 V	0.000000000 A	
MAX	10.000000 V	10.00000000uA	

*GRID

ON

*LINE PARAMETER

ON

*DATA VARIABLES

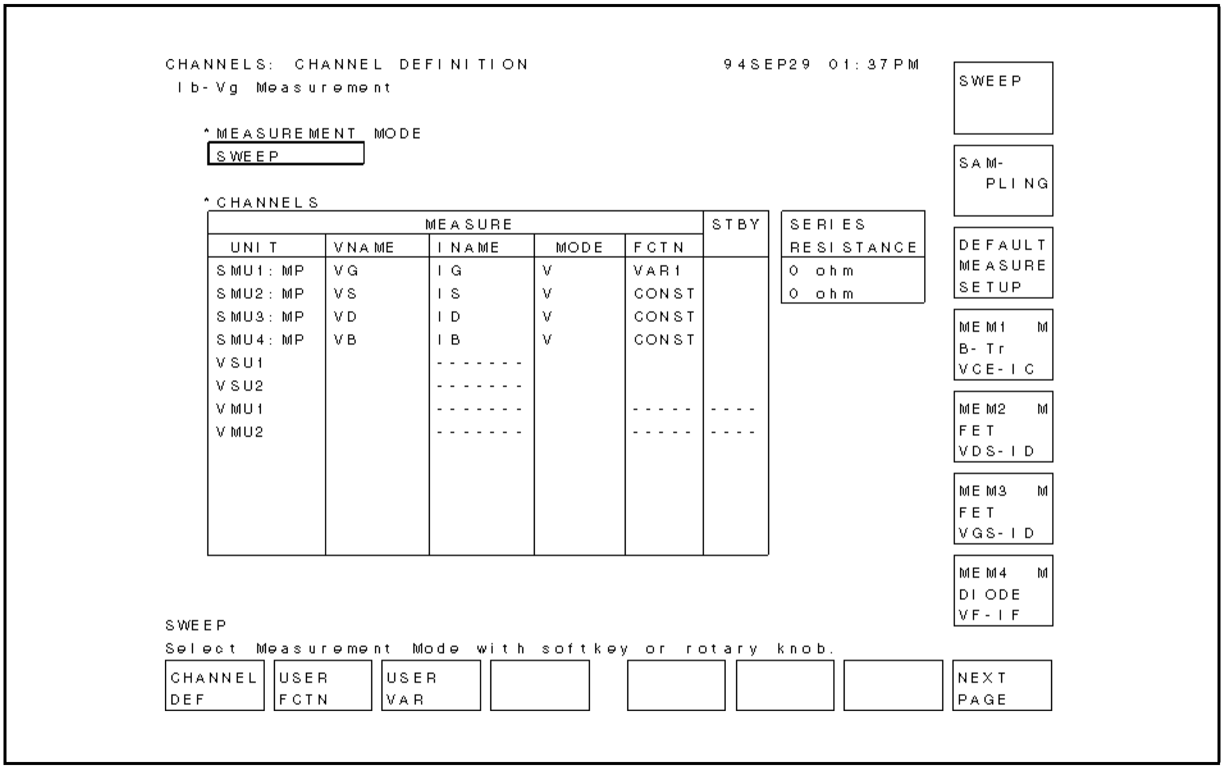
GRAPHICS

Select Display Mode with softkey or rotary knob.

Figure A-3. DISPLAY SETUP Page of IDVD.MES

Setup File for Ib-Vg Measurement to Determine Gate Stress Voltage

Settings of the following setup pages are stored in the IBVG.MES file, which is used to set up HP 4155A/4156A to determine Vgstr during DCDAHC program.


CHANNELS: CHANNEL DEFINITION 94SEP29 01:37PM
Ib-Vg Measurement

*MEASUREMENT MODE
SWEEP

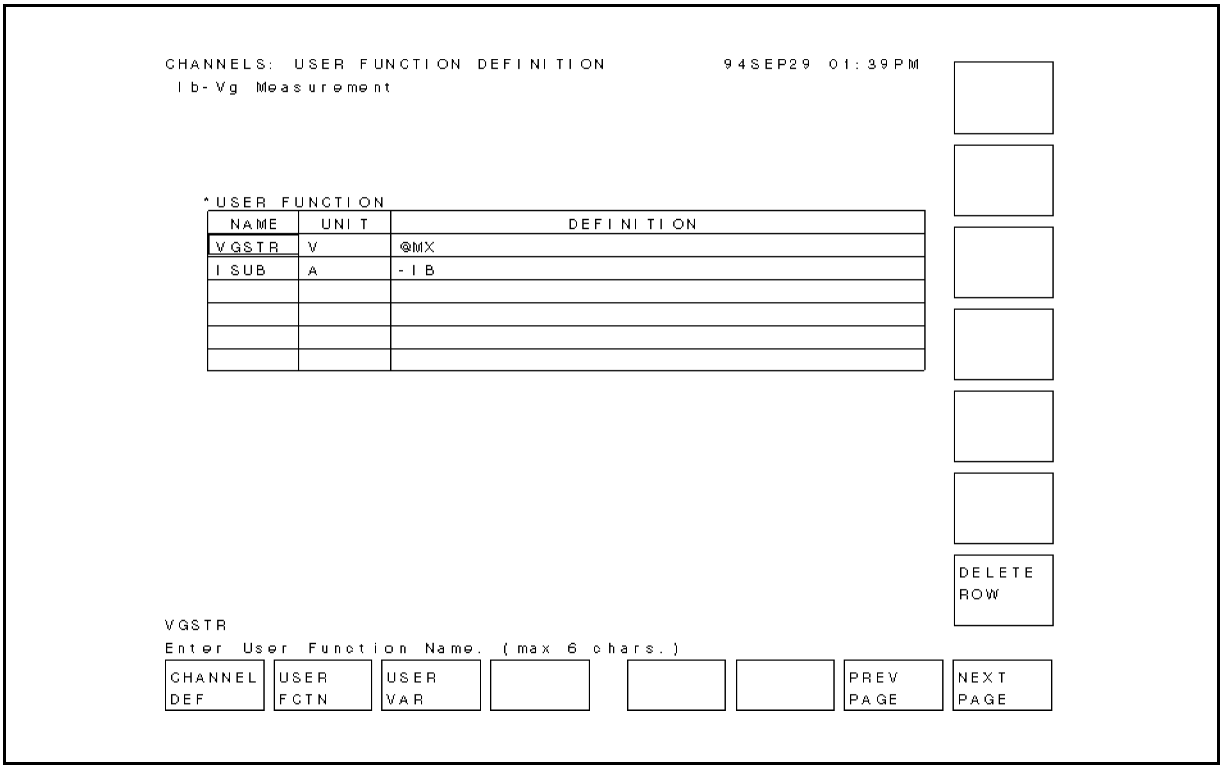
*CHANNELS

MEASURE					STBY
UNIT	VNAME	INAME	MODE	FCTN	
SMU1:MP	VG	IG	V	VAR1	
SMU2:MP	VS	IS	V	CONST	
SMU3:MP	VD	ID	V	CONST	
SMU4:MP	VB	IB	V	CONST	
VSU1		-------			
VSU2		-------			
VMU1		-------		-----	----
VMU2		-------		-----	----

SERIES RESISTANCE
0 ohm
0 ohm

SWEEP
Select Measurement Mode with softkey or rotary knob.

Figure A-4. CHANNEL DEFINITION Page of IBVG.MES



CHANNELS: USER FUNCTION DEFINITION 94SEP29 01:39PM

Ib-Vg Measurement

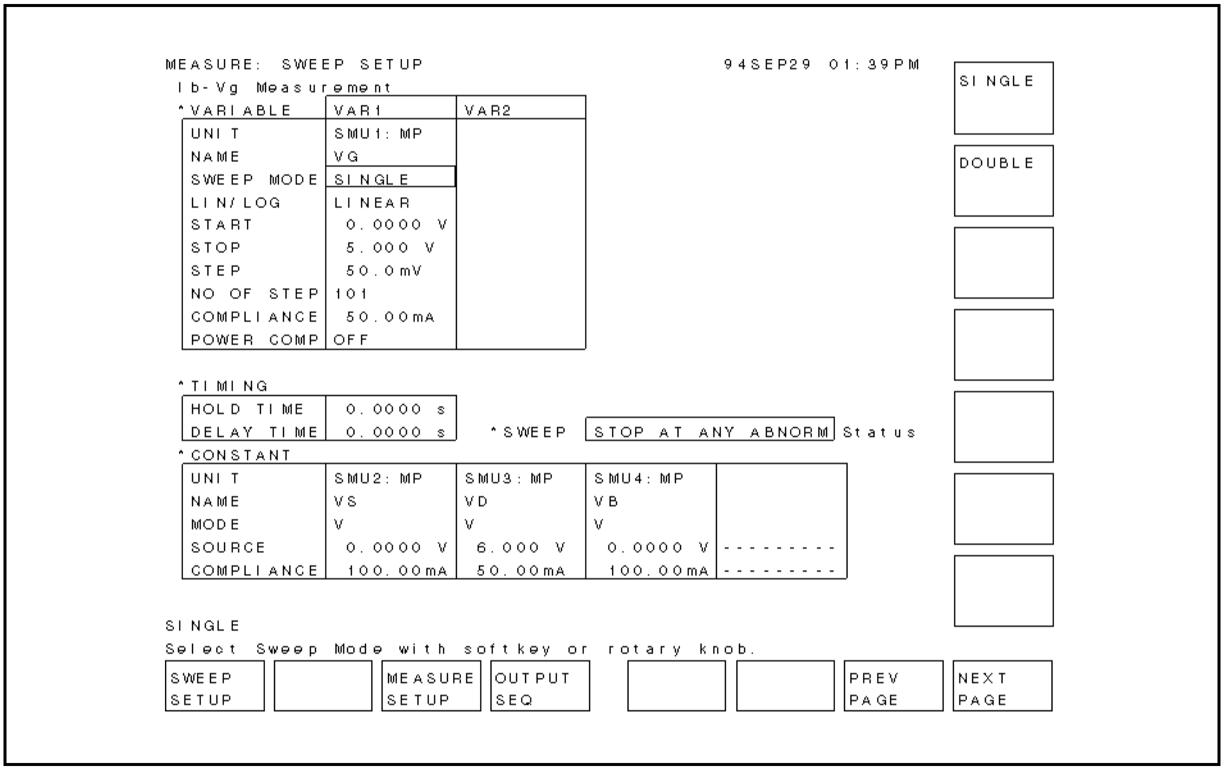
*USER FUNCTION

NAME	UNIT	DEFINITION
VGSTR	V	@MX
ISUB	A	-IB

VGSTR

Enter User Function Name. (max 6 chars.)

Figure A-5. USER FUNCTION DEFINITION Page of IBVG.MES



MEASURE: SWEEP SETUP 94SEP29 01:39PM

Ib-Vg Measurement

*VARIABLE	VAR1	VAR2
UNIT	SMU1:MP	
NAME	VG	
SWEEP MODE	SINGLE	
LIN/LOG	LINEAR	
START	0.0000 V	
STOP	5.000 V	
STEP	50.0mV	
NO OF STEP	101	
COMPLIANCE	50.00mA	
POWER COMP	OFF	

*TIMING

HOLD TIME	0.0000 s
DELAY TIME	0.0000 s

*SWEEP STOP AT ANY ABNORM Status

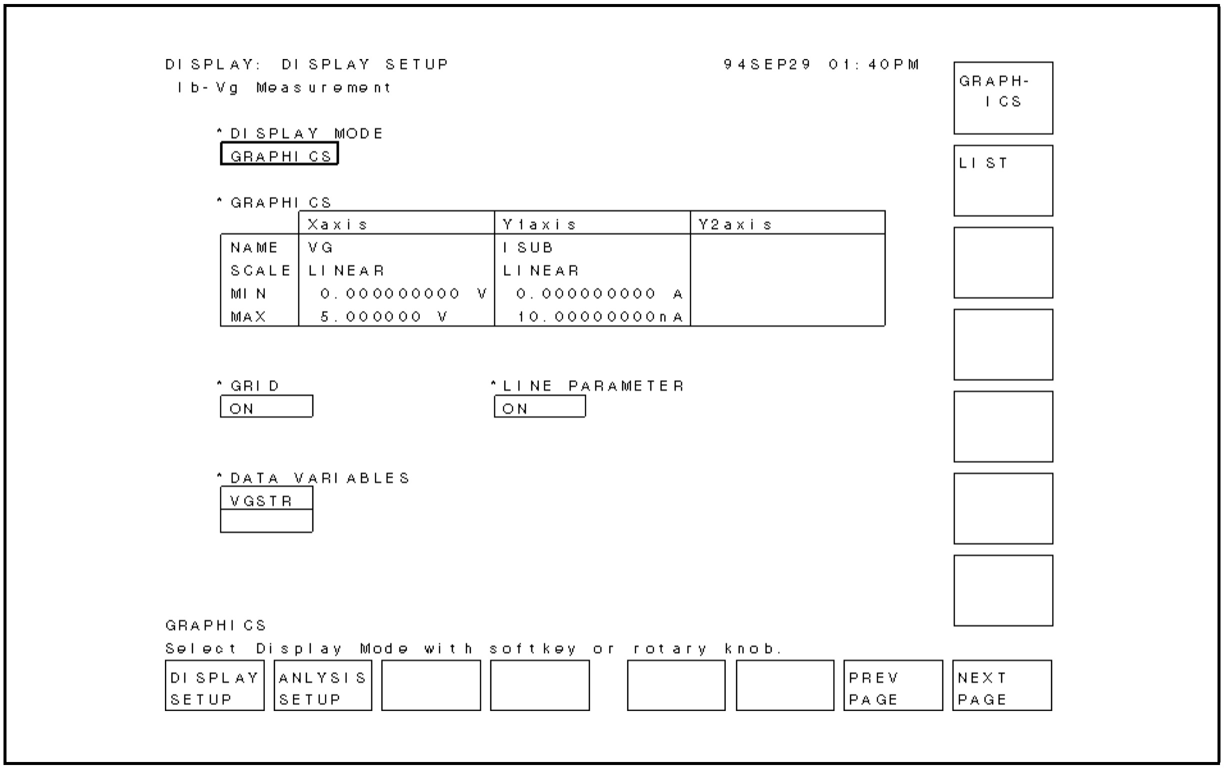
*CONSTANT

UNIT	SMU2:MP	SMU3:MP	SMU4:MP	
NAME	VS	VD	VB	
MODE	V	V	V	
SOURCE	0.0000 V	6.000 V	0.0000 V	---------
COMPLIANCE	100.00mA	50.00mA	100.00mA	---------

SINGLE

Select Sweep Mode with softkey or rotary knob.

Figure A-6. SWEEP SETUP Page of IBVG.MES



DISPLAY: DISPLAY SETUP 94SEP29 01:40PM
Ib-Vg Measurement

*DISPLAY MODE
GRAPHICS

*GRAPHICS

	Xaxis	Y1axis	Y2axis
NAME	VG	ISUB	
SCALE	LINEAR	LINEAR	
MIN	0.000000000 V	0.000000000 A	
MAX	5.000000 V	10.00000000nA	

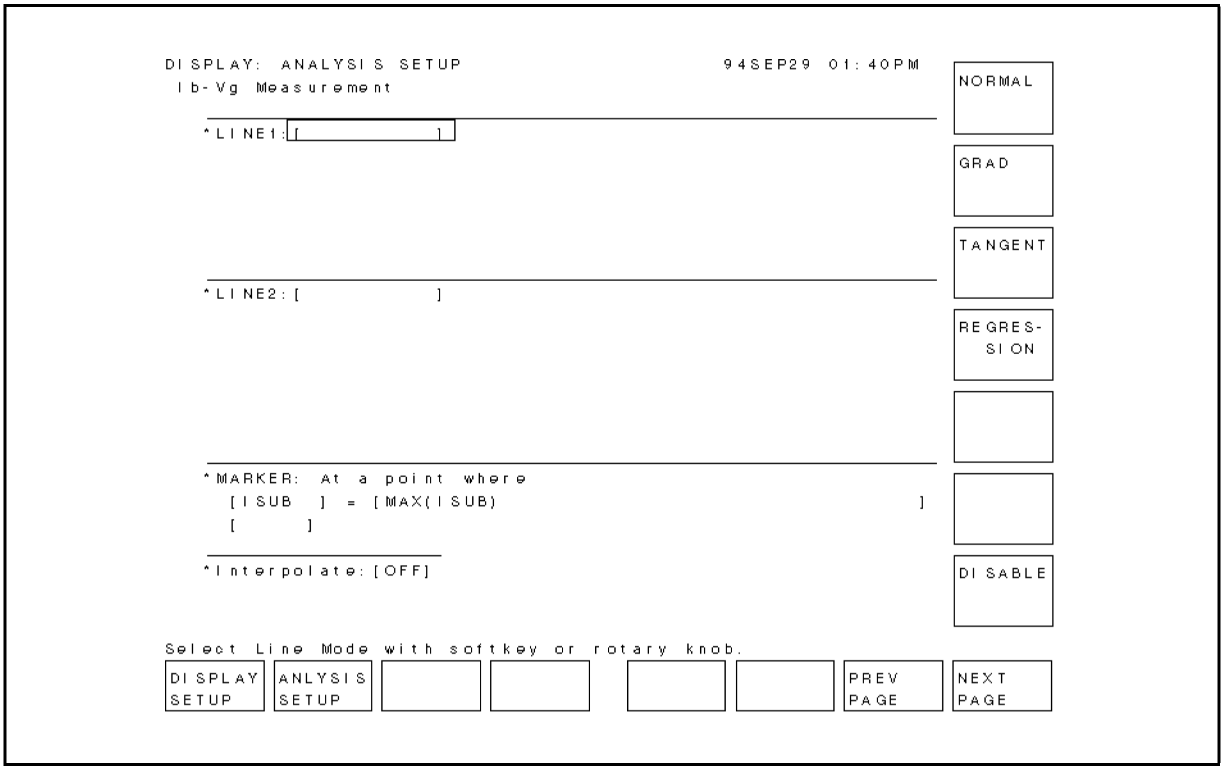
*GRID
ON

*LINE PARAMETER
ON

*DATA VARIABLES
VGSTR

GRAPHICS
Select Display Mode with softkey or rotary knob.

Figure A-7. DISPLAY SETUP Page of IBVG.MES



DISPLAY: ANALYSIS SETUP 94SEP29 01:40PM
Ib-Vg Measurement

*LINE1:[ ]

*LINE2:[ ]

*MARKER: At a point where
[ISUB] = [MAX(ISUB)]
[ ]

*Interpolate:[OFF]

Select Line Mode with softkey or rotary knob.

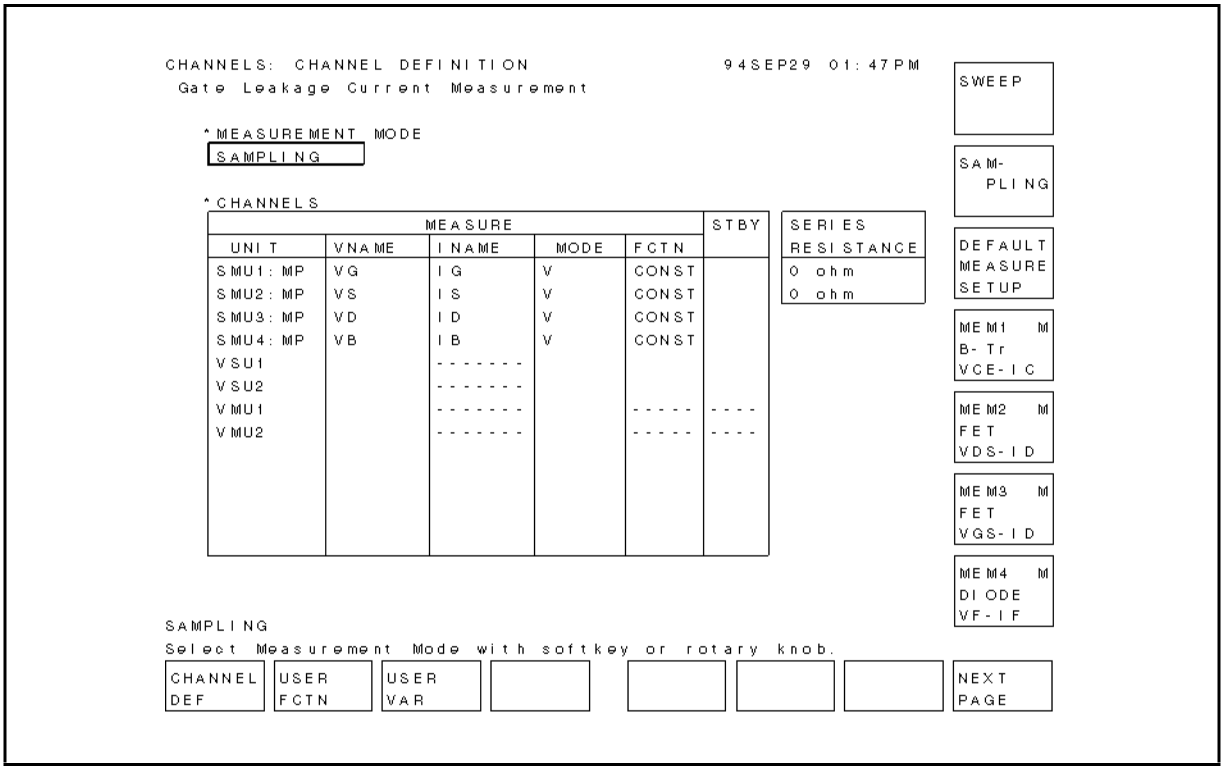
Figure A-8. ANALYSIS SETUP Page of IBVG.MES

Setup File for Gate Leakage Current Measurement

Settings of following setup pages are stored in IGLEAK.MES file, which is used to set up HP 4155A/4156A for gate leakage current measurement during DCDAHC program.

Note

This appendix does not show the setup pages for the IDLEAK.MES (drain leakage current) and ISLEAK.MES (source leakage current) setup files. These setup files are similar to the IGLEAK.MES setup file.



CHANNELS: CHANNEL DEFINITION 94SEP29 01:47PM
Gate Leakage Current Measurement

*MEASUREMENT MODE
SAMPLING

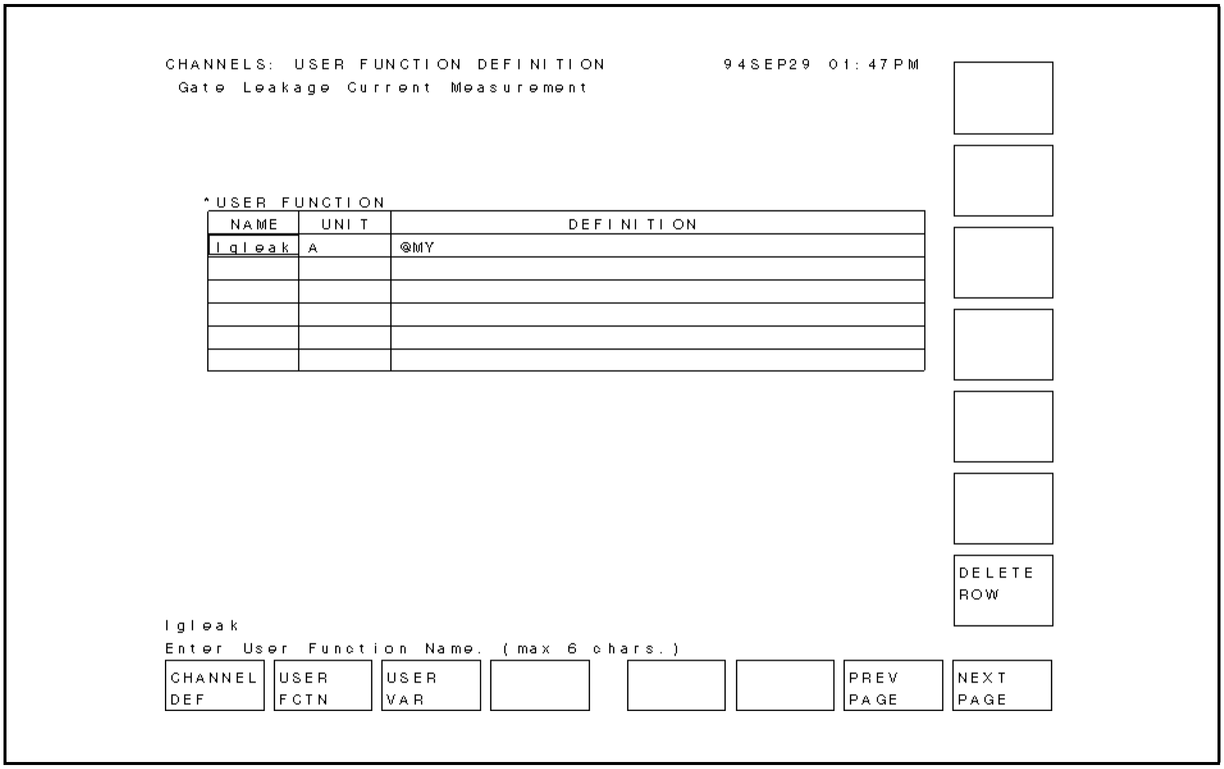
*CHANNELS

MEASURE					STBY
UNIT	VNAME	INAME	MODE	FCTN	
SMU1:MP	VG	IG	V	CONST	
SMU2:MP	VS	IS	V	CONST	
SMU3:MP	VD	ID	V	CONST	
SMU4:MP	VB	IB	V	CONST	
VSU1		-------			
VSU2		-------			
VMU1		-------		-----	----
VMU2		-------		-----	----

SERIES RESISTANCE
0 ohm
0 ohm

SAMPLING
Select Measurement Mode with softkey or rotary knob.

Figure A-9. CHANNEL DEFINITION Page of IGLEAK.MES



CHANNELS: USER FUNCTION DEFINITION 94SEP29 01:47PM

Gate Leakage Current Measurement

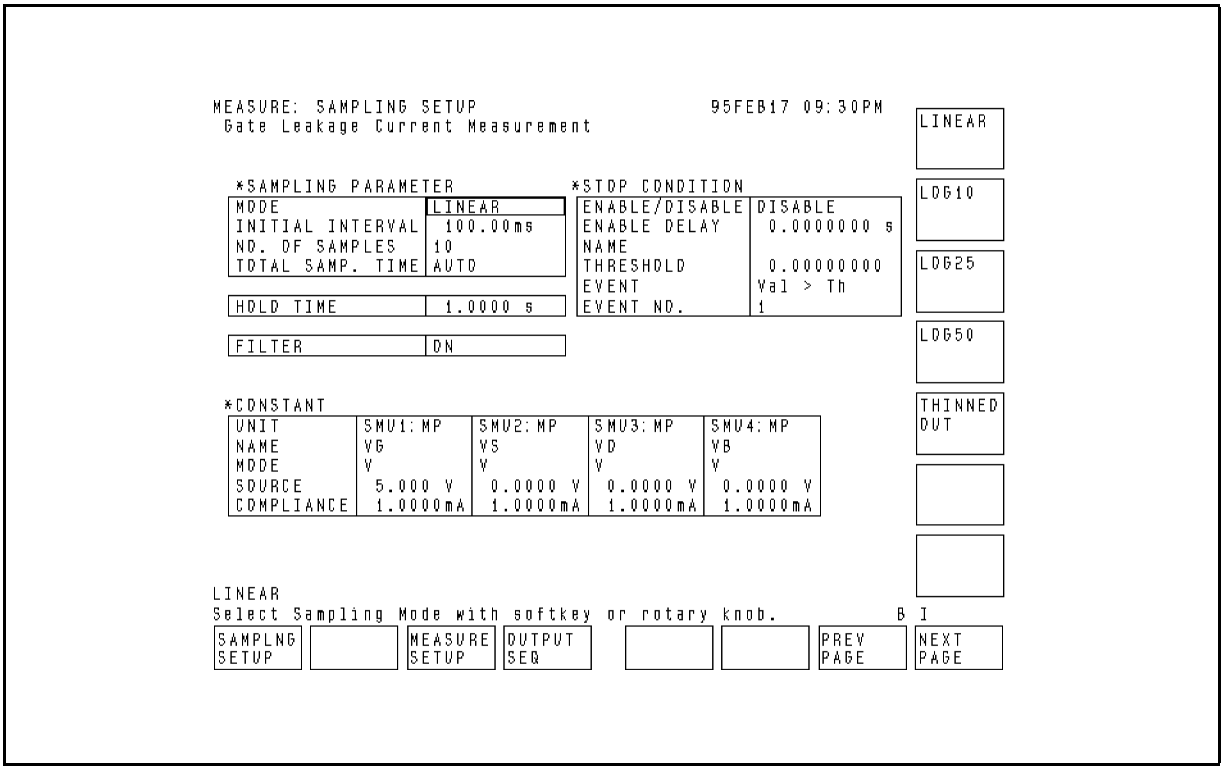
*USER FUNCTION

NAME	UNIT	DEFINITION
Igleak	A	@MY

Igleak

Enter User Function Name. (max 6 chars.)

Figure A-10. USER FUNCTION DEFINITION Page of IGLEAK.MES



MEASURE: SAMPLING SETUP 95FEB17 09:30PM

Gate Leakage Current Measurement

*SAMPLING PARAMETER

MODE	LINEAR
INITIAL INTERVAL	100.00ms
NO. OF SAMPLES	10
TOTAL SAMP. TIME	AUTO

HOLD TIME	1.0000 s

FILTER	ON

*STOP CONDITION

ENABLE/DISABLE	DISABLE
ENABLE DELAY	0.0000000 s
NAME	
THRESHOLD	0.00000000
EVENT	Val > Th
EVENT NO.	1

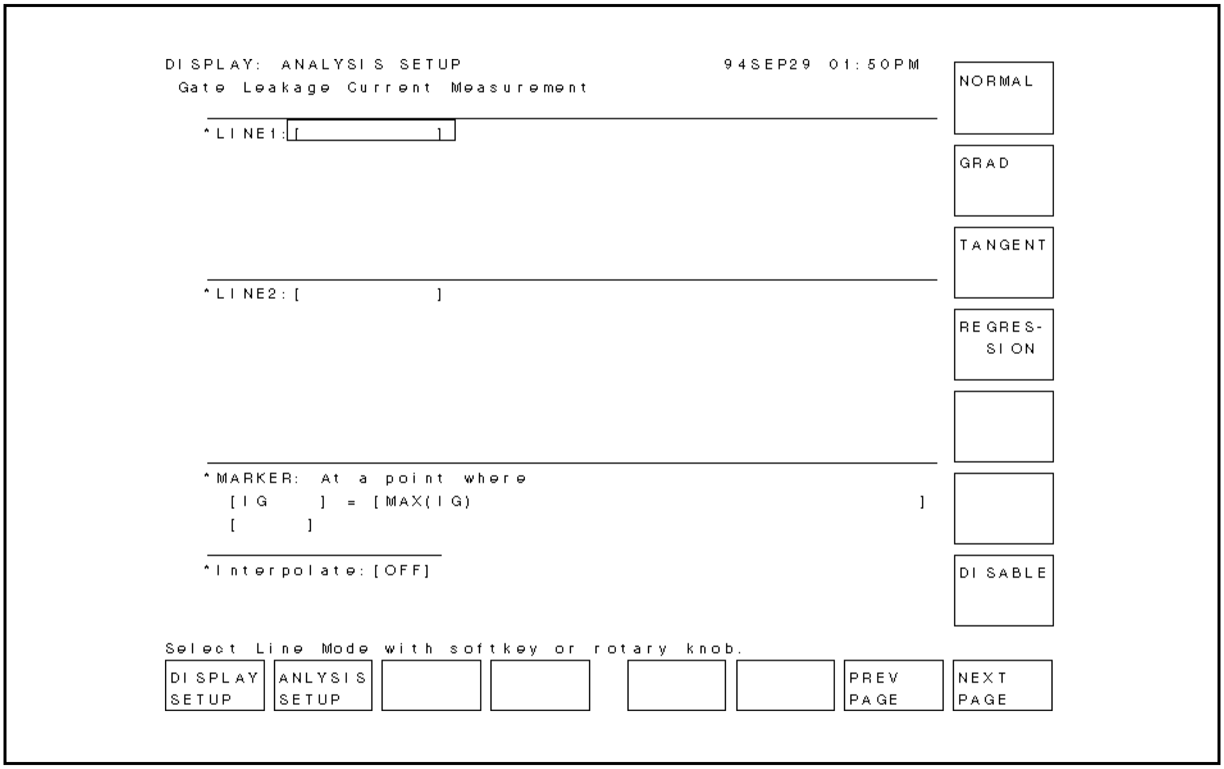
*CONSTANT

UNIT	SMU1:MP	SMU2:MP	SMU3:MP	SMU4:MP
NAME	VG	VS	VD	VB
MODE	V	V	V	V
SOURCE	5.000 V	0.0000 V	0.0000 V	0.0000 V
COMPLIANCE	1.0000mA	1.0000mA	1.0000mA	1.0000mA

LINEAR

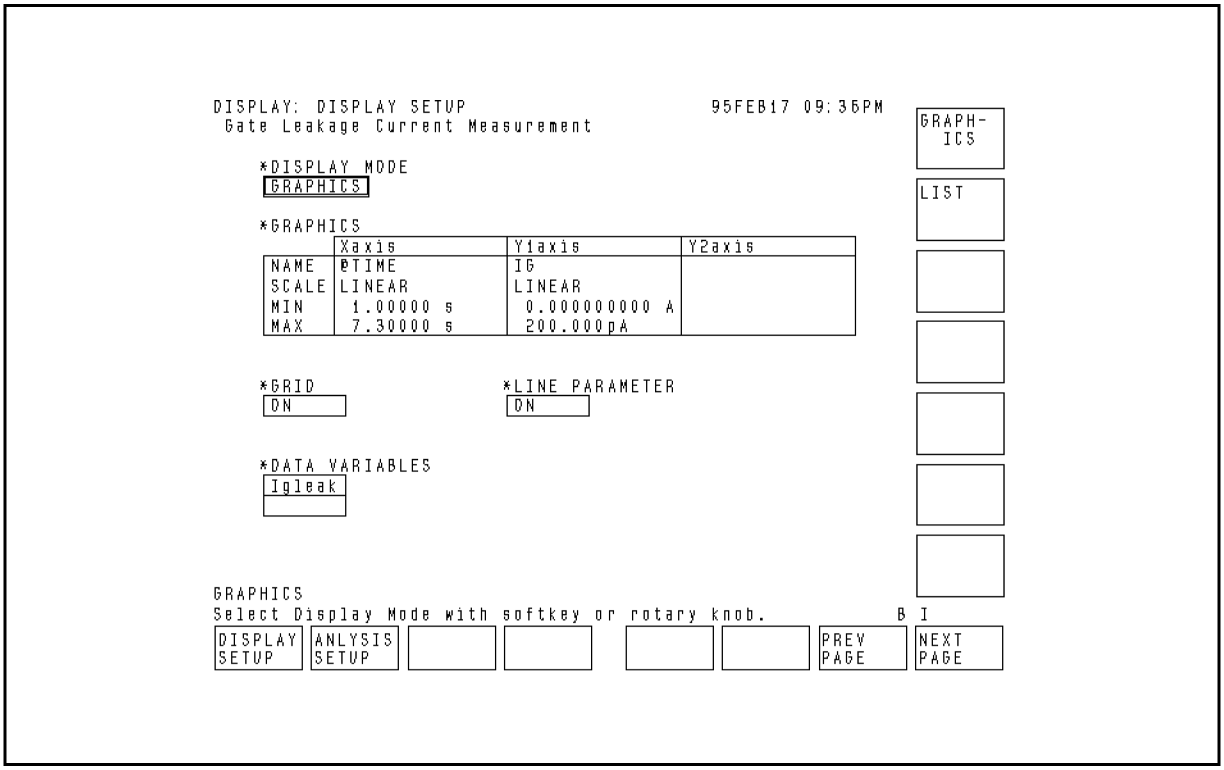
Select Sampling Mode with softkey or rotary knob. B I

Figure A-11. SAMPLING SETUP Page of IGLEAK.MES



```
DISPLAY: ANALYSIS SETUP                          94SEP29 01:50PM
 Gate Leakage Current Measurement

*LINE1:[            ]

*LINE2:[            ]

*MARKER: At a point where
  [IG      ] = [MAX(IG)                                        ]
  [      ]

*Interpolate:[OFF]

Select Line Mode with softkey or rotary knob.
```

Figure A-12. ANALYSIS SETUP Page of IGLEAK.MES



```
DISPLAY: DISPLAY SETUP                          95FEB17 09:36PM
 Gate Leakage Current Measurement

  *DISPLAY MODE
   GRAPHICS

  *GRAPHICS
```

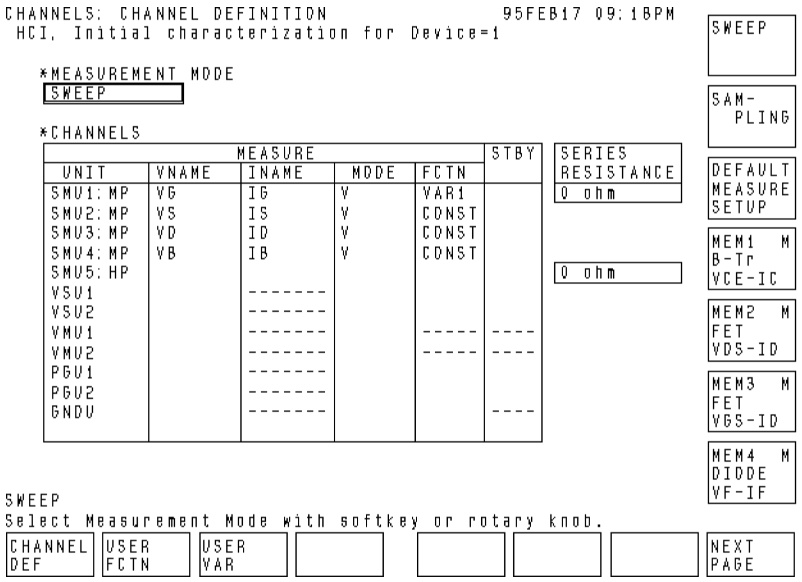
	Xaxis	Y1axis	Y2axis
NAME	@TIME	IG	
SCALE	LINEAR	LINEAR	
MIN	1.00000 s	0.000000000 A	
MAX	7.30000 s	200.000pA	

```
  *GRID                    *LINE PARAMETER
   ON                       ON

  *DATA VARIABLES
   Igleak

GRAPHICS
Select Display Mode with softkey or rotary knob.        B I
```

Figure A-13. DISPLAY SETUP Page of IGLEAK.MES

Setup File for Initial/Interim Characterization

Settings of following setup pages are stored in PARAM.MES file, which is used to set up HP 4155A/4156A for Idlin/Gmmax/Vtext/Vtci measurements during DCDAHC program.



CHANNELS: CHANNEL DEFINITION 95FEB17 09:18PM
HCI, Initial characterization for Device=1

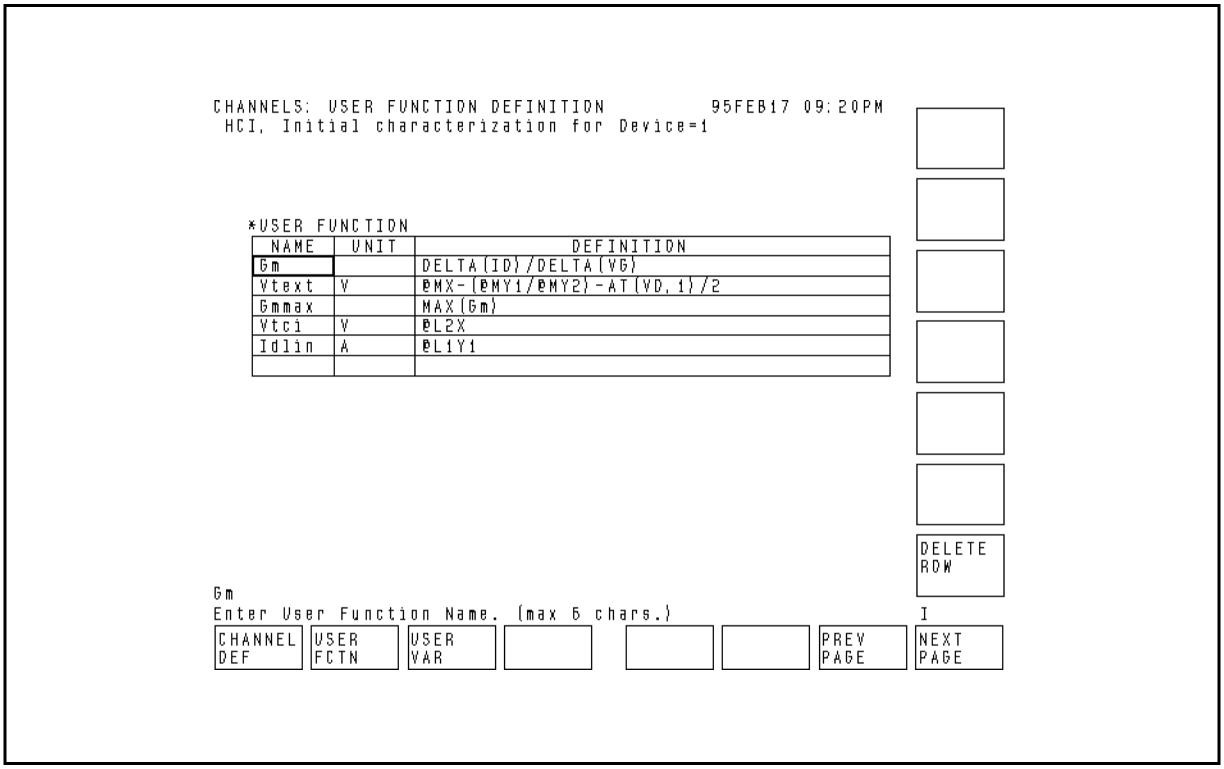
*MEASUREMENT MODE
SWEEP

*CHANNELS

MEASURE					STBY	SERIES RESISTANCE
UNIT	VNAME	INAME	MODE	FCTN		
SMU1:MP	VG	IG	V	VAR1		0 ohm
SMU2:MP	VS	IS	V	CONST		
SMU3:MP	VD	ID	V	CONST		
SMU4:MP	VB	IB	V	CONST		
SMU5:HP						0 ohm
VSU1		-------				
VSU2		-------				
VMU1		-------		-----	----	
VMU2		-------		-----	----	
PGU1		-------				
PGU2		-------				
GNDU		-------			----	

SWEEP
Select Measurement Mode with softkey or rotary knob.

Figure A-14. CHANNEL DEFINITION Page of PARAM.MES



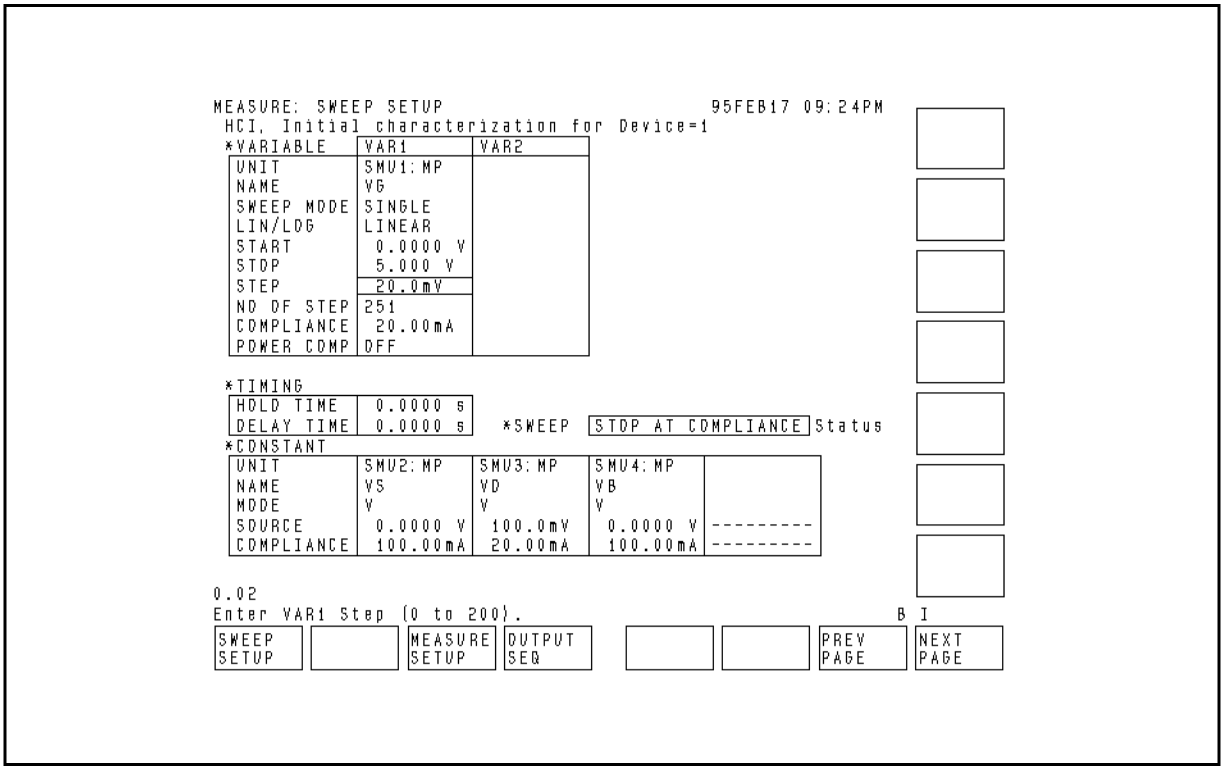
CHANNELS: USER FUNCTION DEFINITION 95FEB17 09:20PM
HCI, Initial characterization for Device=1

*USER FUNCTION

NAME	UNIT	DEFINITION
Gm		DELTA(ID)/DELTA(VG)
Vtext	V	@MX-(@MY1/@MY2)-AT(VD,1)/2
Gmmax		MAX(Gm)
Vtci	V	@L2X
Idlin	A	@L1Y1

Gm
Enter User Function Name. (max 6 chars.) I

Figure A-15. USER FUNCTION DEFINITION Page of PARAM.MES



MEASURE: SWEEP SETUP 95FEB17 09:24PM
HCI, Initial characterization for Device=1

*VARIABLE	VAR1	VAR2
UNIT	SMU1:MP	
NAME	VG	
SWEEP MODE	SINGLE	
LIN/LOG	LINEAR	
START	0.0000 V	
STOP	5.000 V	
STEP	20.0mV	
NO OF STEP	251	
COMPLIANCE	20.00mA	
POWER COMP	OFF	

*TIMING

HOLD TIME	0.0000 s
DELAY TIME	0.0000 s

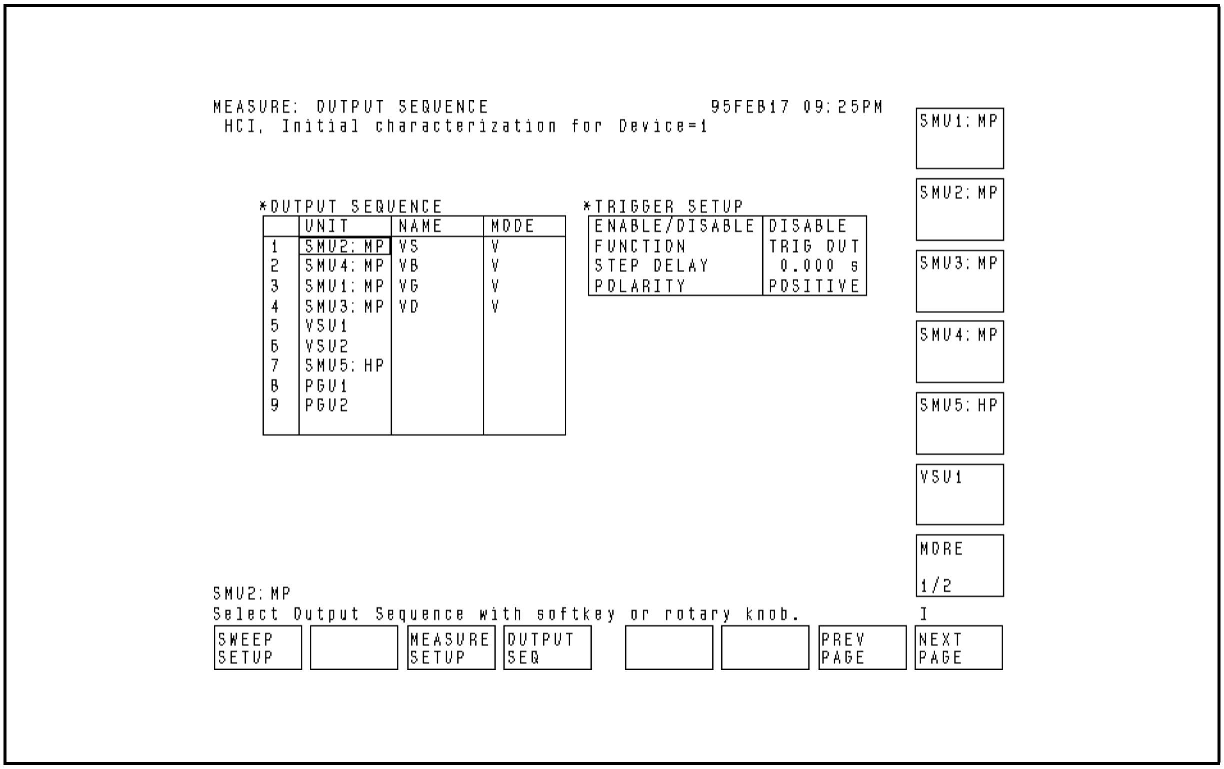
*SWEEP STOP AT COMPLIANCE Status

*CONSTANT

UNIT	SMU2:MP	SMU3:MP	SMU4:MP	
NAME	VS	VD	VB	
MODE	V	V	V	
SOURCE	0.0000 V	100.0mV	0.0000 V	---------
COMPLIANCE	100.00mA	20.00mA	100.00mA	---------

0.02
Enter VAR1 Step (0 to 200). B I

Figure A-16. SWEEP SETUP Page of PARAM.MES


MEASURE: OUTPUT SEQUENCE 95FEB17 09:25PM
HCI, Initial characterization for Device=1

*OUTPUT SEQUENCE

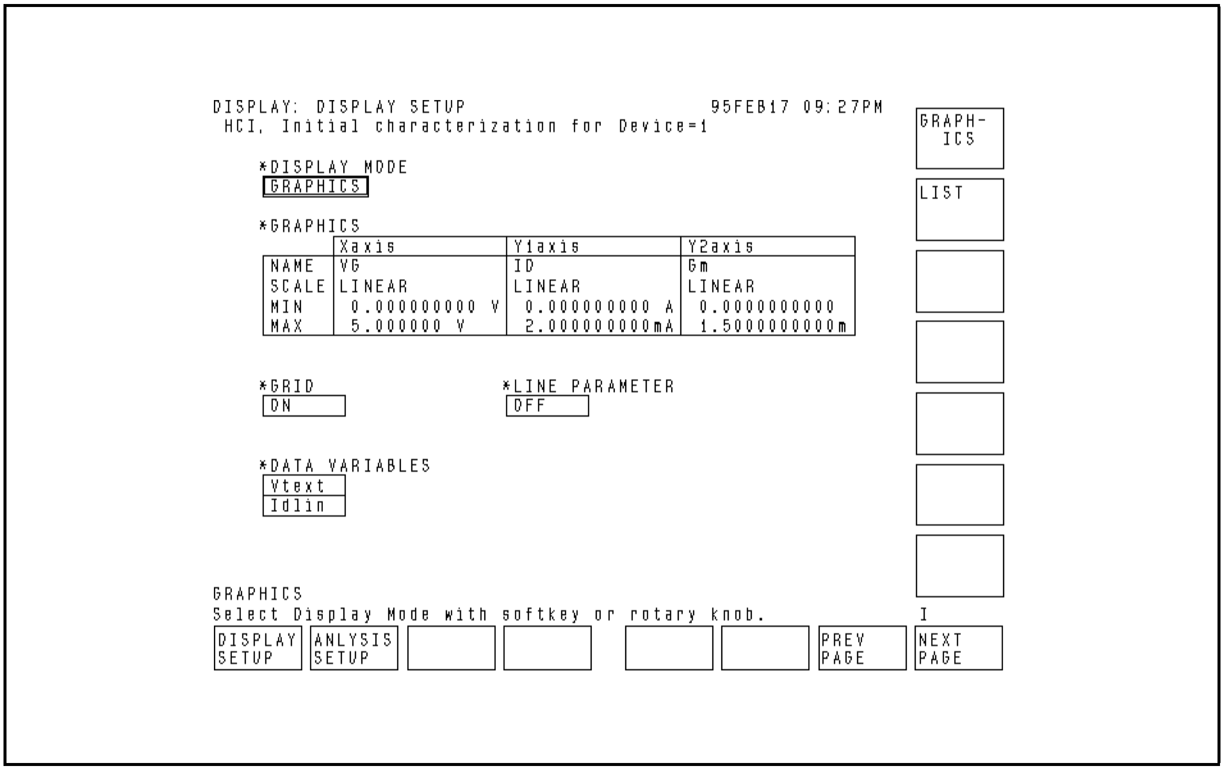
	UNIT	NAME	MODE
1	SMU2:MP	VS	V
2	SMU4:MP	VB	V
3	SMU1:MP	VG	V
4	SMU3:MP	VD	V
5	VSU1		
6	VSU2		
7	SMU5:HP		
8	PGU1		
9	PGU2		

*TRIGGER SETUP

ENABLE/DISABLE	DISABLE
FUNCTION	TRIG OUT
STEP DELAY	0.000 s
POLARITY	POSITIVE

SMU2:MP
Select Output Sequence with softkey or rotary knob.

Figure A-17. OUTPUT SEQUENCE Page of PARAM.MES


DISPLAY: DISPLAY SETUP 95FEB17 09:27PM
HCI, Initial characterization for Device=1

*DISPLAY MODE
GRAPHICS

*GRAPHICS

	Xaxis	Y1axis	Y2axis
NAME	VG	ID	Gm
SCALE	LINEAR	LINEAR	LINEAR
MIN	0.000000000 V	0.000000000 A	0.0000000000
MAX	5.000000 V	2.000000000mA	1.5000000000m

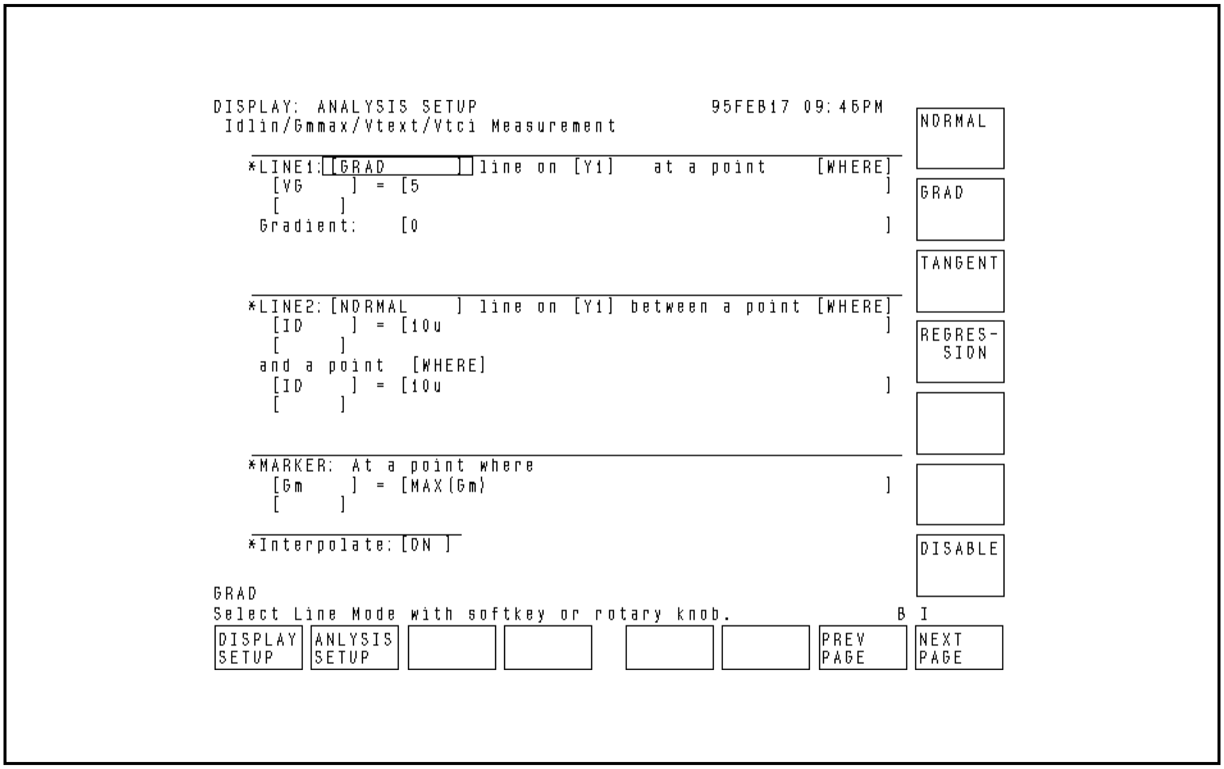
*GRID
ON

*LINE PARAMETER
OFF

*DATA VARIABLES
Vtext
Idlin

GRAPHICS
Select Display Mode with softkey or rotary knob.

Figure A-18. DISPLAY SETUP Page of PARAM.MES

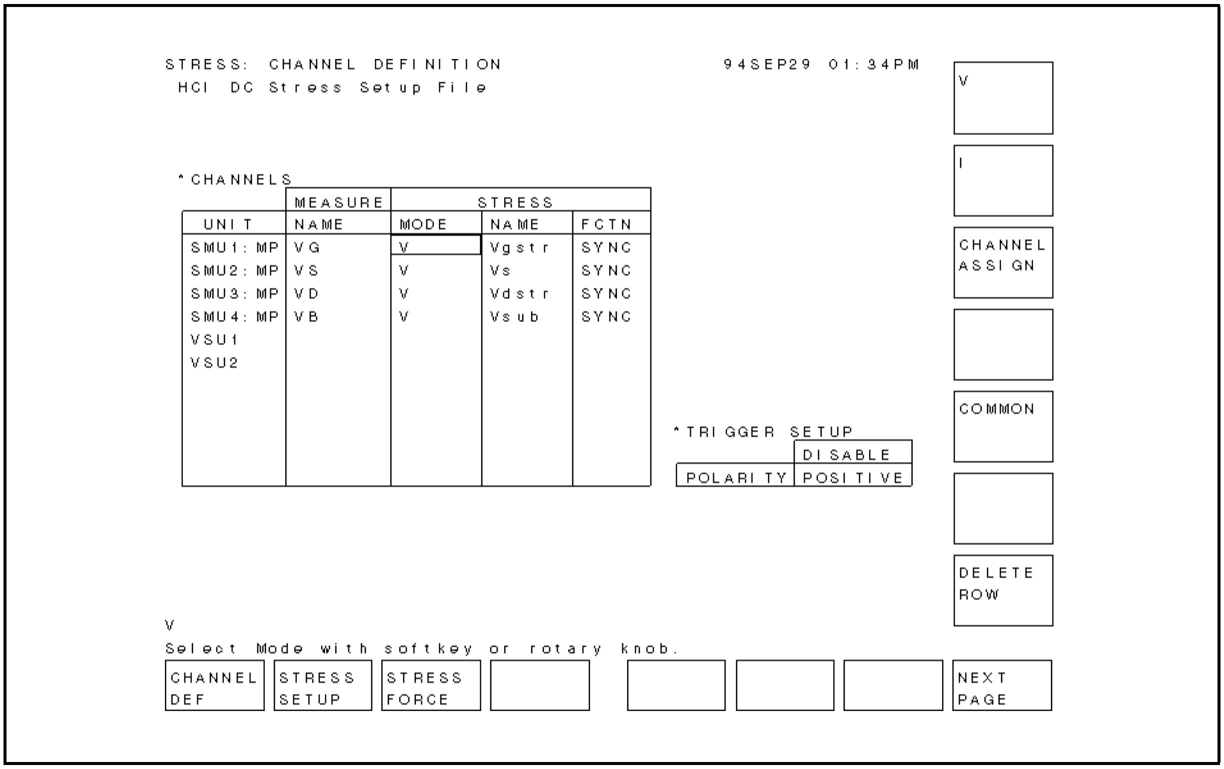


```
DISPLAY: ANALYSIS SETUP                          95FEB17 09:46PM
 Idlin/Gmmax/Vtext/Vtci Measurement

   *LINE1:[GRAD         ] line on [Y1]    at a point     [WHERE]
     [VG    ] = [5                                             ]
     [      ]
    Gradient:    [0                                            ]


   *LINE2:[NORMAL    ] line on [Y1] between a point [WHERE]
     [ID    ] = [10u                                           ]
     [      ]
    and a point  [WHERE]
     [ID    ] = [10u                                           ]
     [      ]


   *MARKER: At a point where
     [Gm    ] = [MAX(Gm)                                       ]
     [      ]

   *Interpolate:[ON ]

GRAD
Select Line Mode with softkey or rotary knob.              B I
```

Figure A-19. ANALYSIS SETUP Page of PARAM.MES

Setup File for DC Stress

Settings of following setup pages are stored in DCDAHC.STR file, which is used to set up HP 4155A/4156A for DC stress during the DCDAHC program.



STRESS: CHANNEL DEFINITION 94SEP29 01:34PM
HCI DC Stress Setup File

*CHANNELS

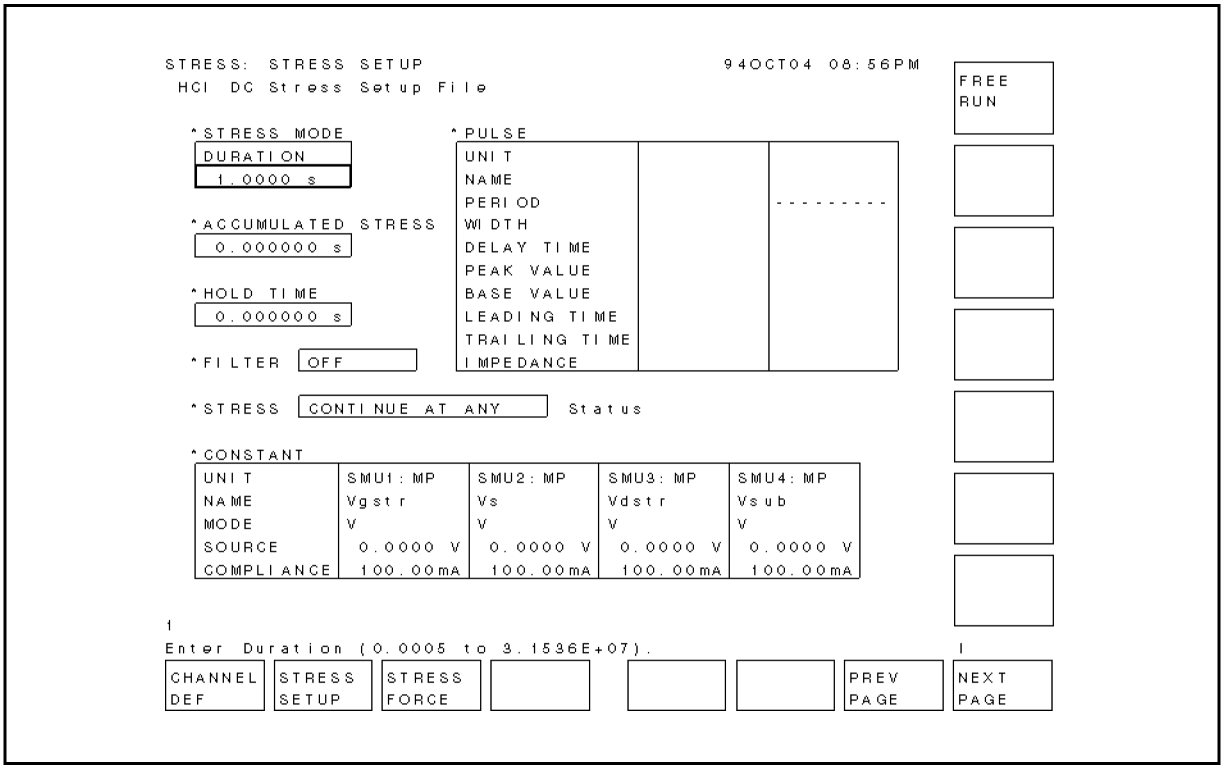
	MEASURE	STRESS		
UNIT	NAME	MODE	NAME	FCTN
SMU1:MP	VG	V	Vgstr	SYNC
SMU2:MP	VS	V	Vs	SYNC
SMU3:MP	VD	V	Vdstr	SYNC
SMU4:MP	VB	V	Vsub	SYNC
VSU1				
VSU2				

*TRIGGER SETUP

	DISABLE
POLARITY	POSITIVE

V
Select Mode with softkey or rotary knob.

Figure A-20. CHANNEL DEFINITION Page of DCDAHC.STR



STRESS: STRESS SETUP 94OCT04 08:56PM
HCI DC Stress Setup File

*STRESS MODE
DURATION
1.0000 s

*ACCUMULATED STRESS
0.000000 s

*HOLD TIME
0.000000 s

*FILTER OFF

*STRESS CONTINUE AT ANY Status

*PULSE

UNIT		
NAME		
PERIOD		---------
WIDTH		
DELAY TIME		
PEAK VALUE		
BASE VALUE		
LEADING TIME		
TRAILING TIME		
IMPEDANCE		

*CONSTANT

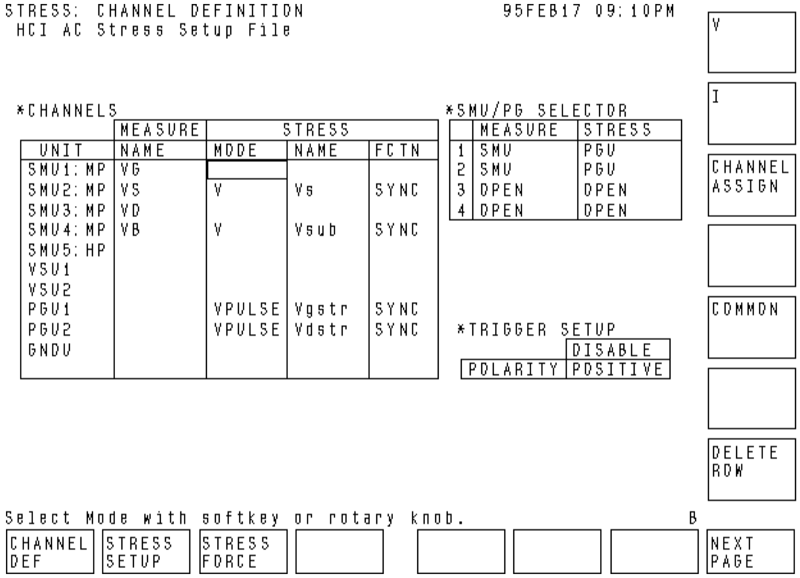
UNIT	SMU1:MP	SMU2:MP	SMU3:MP	SMU4:MP
NAME	Vgstr	Vs	Vdstr	Vsub
MODE	V	V	V	V
SOURCE	0.0000 V	0.0000 V	0.0000 V	0.0000 V
COMPLIANCE	100.00mA	100.00mA	100.00mA	100.00mA

1
Enter Duration (0.0005 to 3.1536E+07).

Figure A-21. STRESS SETUP Page of DCDAHC.STR

Setup File for AC Stress

Settings of following setup pages are stored in ACDAHC.STR file, which is used to set up HP 4155A/4156A for AC stress. You need to customize the DCDAHC program to perform AC stress. See "Performing HCI Degradation Test with AC Stress" in Chapter 5.



STRESS: CHANNEL DEFINITION 95FEB17 09:10PM
HCI AC Stress Setup File

*CHANNELS

	MEASURE	STRESS		
UNIT	NAME	MODE	NAME	FCTN
SMU1:MP	VG			
SMU2:MP	VS	V	Vs	SYNC
SMU3:MP	VD			
SMU4:MP	VB	V	Vsub	SYNC
SMU5:HP				
VSU1				
VSU2				
PGU1		VPULSE	Vgstr	SYNC
PGU2		VPULSE	Vdstr	SYNC
GNDU				

*SMU/PG SELECTOR

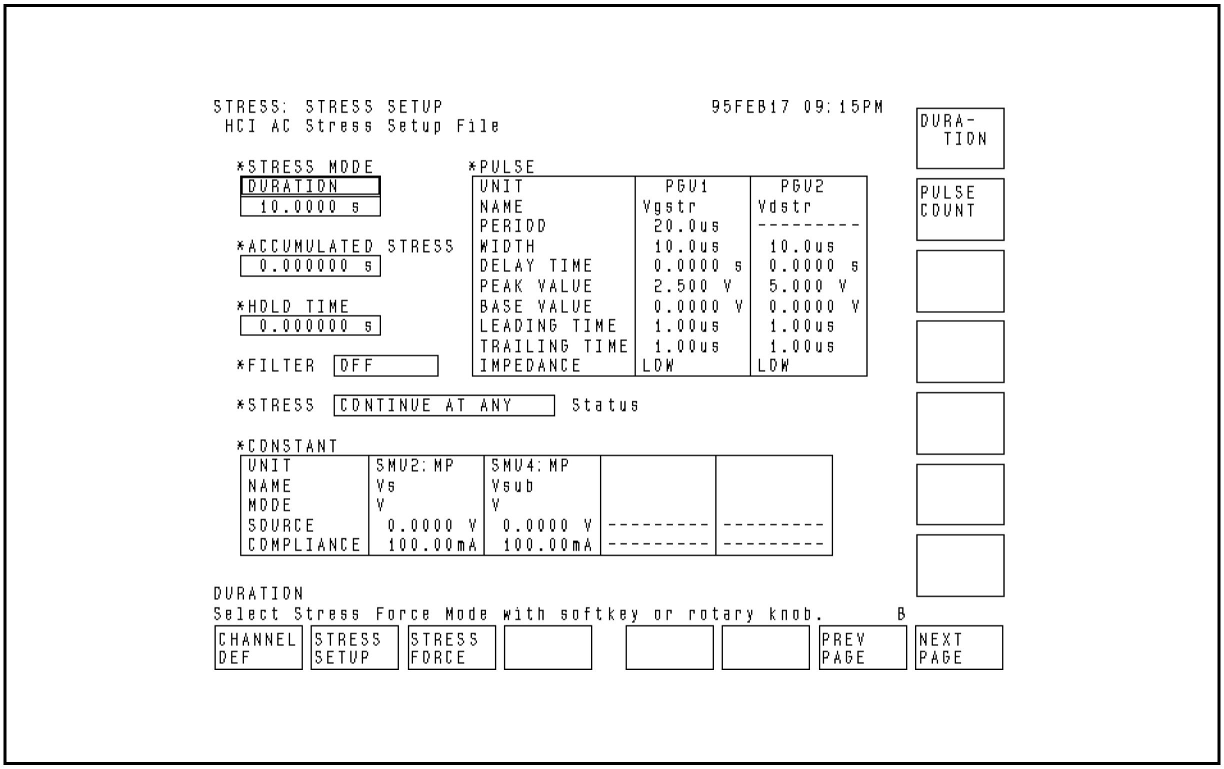
	MEASURE	STRESS
1	SMU	PGU
2	SMU	PGU
3	OPEN	OPEN
4	OPEN	OPEN

*TRIGGER SETUP

	DISABLE
POLARITY	POSITIVE

Select Mode with softkey or rotary knob. B

Figure A-22. CHANNEL DEFINITION Page of ACDAHC.STR



STRESS: STRESS SETUP 95FEB17 09:15PM

HCI AC Stress Setup File

*STRESS MODE

DURATION

10.0000 s

*ACCUMULATED STRESS

0.000000 s

*HOLD TIME

0.000000 s

*FILTER OFF

*STRESS CONTINUE AT ANY Status

*PULSE

UNIT	PGU1	PGU2
NAME	Vgstr	Vdstr
PERIOD	20.0us	---------
WIDTH	10.0us	10.0us
DELAY TIME	0.0000 s	0.0000 s
PEAK VALUE	2.500 V	5.000 V
BASE VALUE	0.0000 V	0.0000 V
LEADING TIME	1.00us	1.00us
TRAILING TIME	1.00us	1.00us
IMPEDANCE	LOW	LOW

*CONSTANT

UNIT	SMU2:MP	SMU4:MP		
NAME	Vs	Vsub		
MODE	V	V		
SOURCE	0.0000 V	0.0000 V	---------	---------
COMPLIANCE	100.00mA	100.00mA	---------	---------

DURATION

Select Stress Force Mode with softkey or rotary knob. B

Figure A-23. STRESS SETUP Page of ACDAHC.STR