Agilent 4155C

Semiconductor Parameter Analyzer

Agilent 4156C

Precision Semiconductor Parameter Analyzer

Sample Application Programs Guide Book

Agilent Technologies

Notices

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In This Manual

This manual describes some sample application programs and setup files, which will be helpful for creating your own applications using Agilent 4155C/4156C.

All programs and setup files described in this manual are stored on the Sample Application Program Disk (DOS formatted, 3.5-inch diskette) that is furnished with your 4155C/4156C. All programs are written in the Instrument BASIC, and ready to run in the 4155C/4156C's built-in Instrument BASIC environment.

This manual covers the following applications:

- V-RAMP
- J-RAMP
- SWEAT
- GO/NO-GO Test
- HCI Degradation Test
- Charge Pumping
- Flash EEPROM Test
- TDDB
- Electromigration

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, Agilent Technologies is *NOT LIABLE* for the damage.

NOTE

You should copy all files in the Sample Application Program Disk to a diskette that you will use as your working diskette, and keep the original diskette as backup.

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1 V-RAMP

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 Agilent 4155/4156, and how to use and customize the program. The program is written in the Instrument BASIC (IBASIC), and is ready to run on the built-in IBASIC controller of the 4155/4156.

"Theory of V-Ramp Test Procedure" describes basic theory, procedure, and terminology of the V-Ramp test.

"Basic Operation" describes the V-Ramp sample program. Included are V-Ramp methodology using the 4155/4156, how to execute the sample program, and program overview.

"Customization" 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.

"Measurement Setups" shows the 4155/4156 page settings that are stored in the setup files.

Theory of V-Ramp Test Procedure

This section 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

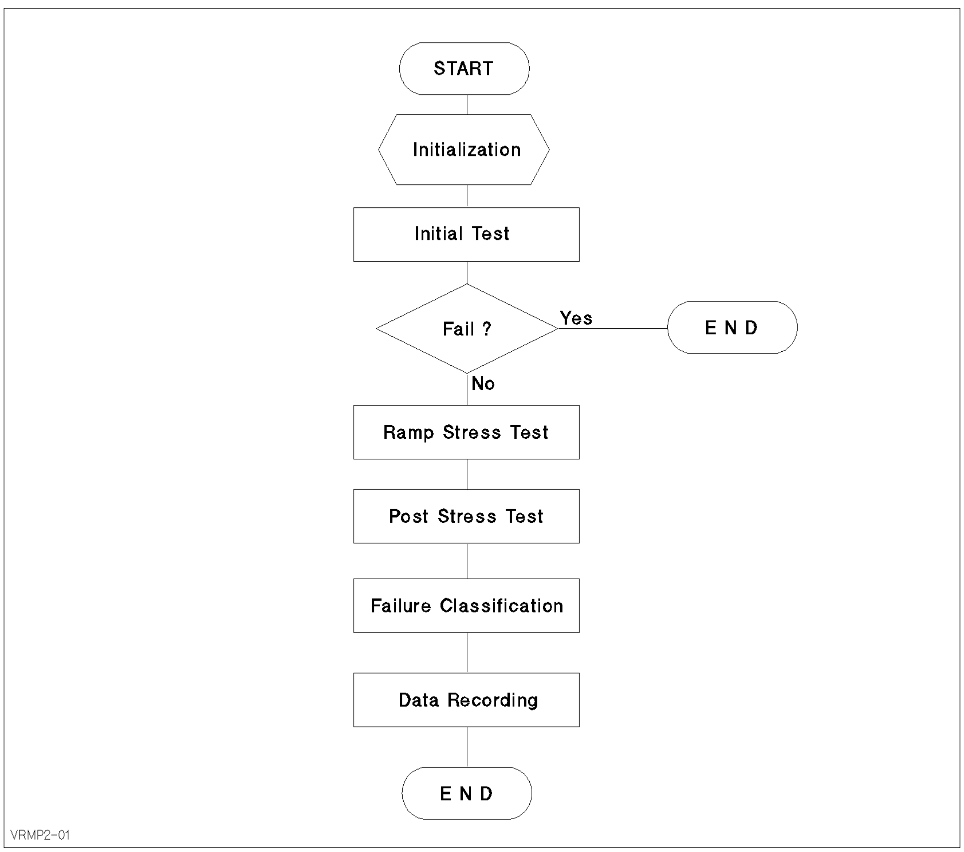
V-Ramp test measures the breakdown voltage (*Vbd*) and breakdown charge (*Qbd*) of thin oxide capacitors, which you designed as test structures on the wafer. These results are used to evaluate the oxide integrity. The higher the *Vbd* and *Qbd* measured by this test, the better the integrity of the oxide 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 1-1 shows a simplified flowchart of V-Ramp test.

Figure 1-1 **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.

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 μA:

  The oxide was broken by the applied ramped voltage.

- If I_{leak} < 1 μA:

  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.

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 1-2 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.

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:

$$Qbd = \int_{\mathrm{Tstart}}^{\mathrm{Tbd}} Imeas(t)dt$$

Figure 1-2 **Concept of Breakdown Voltage and Charge**

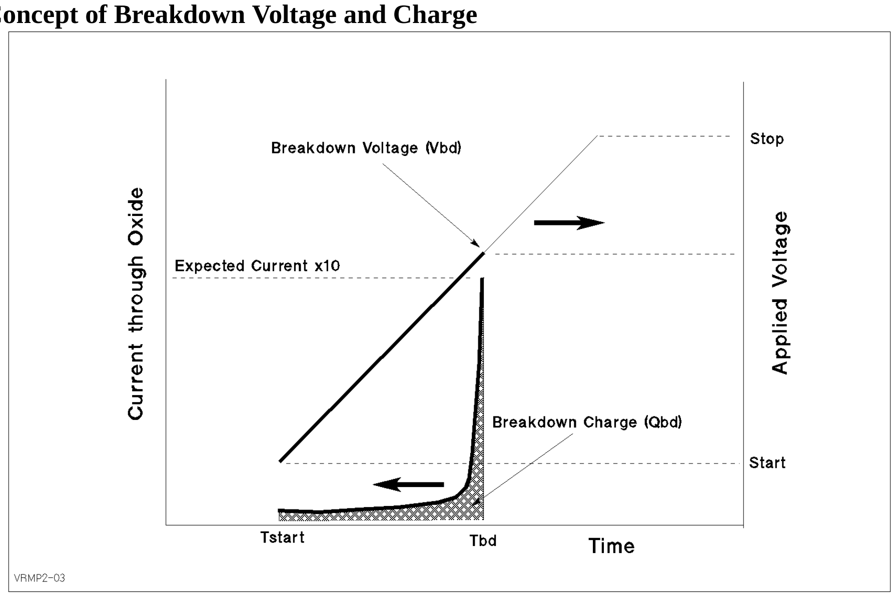


Figure 1-3 shows the two ways to apply the voltage: linear ramped voltage or linear stepped voltage.

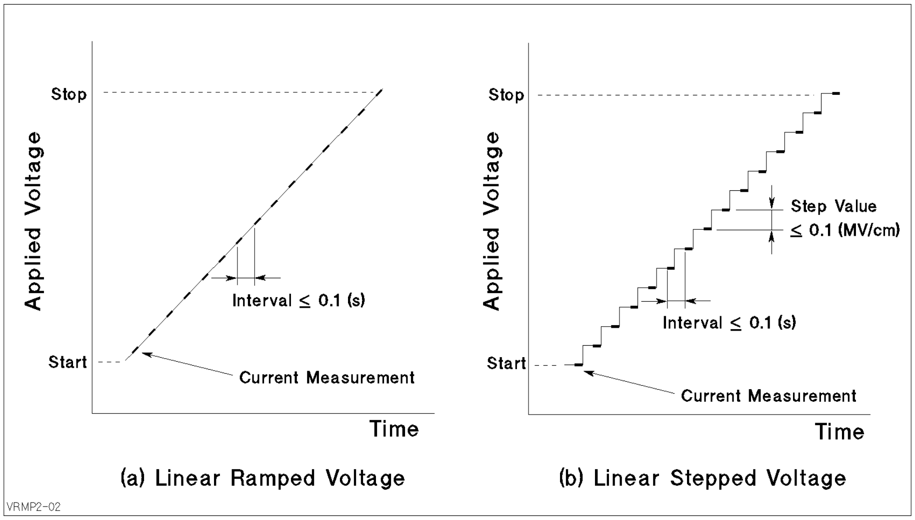
Note that the applied ramped voltage must satisfy the following conditions:

- 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 1-3 **Linear Ramped and Linear Stepped Voltage**



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 1-1 shows the oxide failure categories.

Table 1-1 Oxide Failure Categories

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

a. *Vbd* and q_{bd} are also recorded.

Basic Operation

This section covers the following for using an 4155/4156 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 4155/4156.

As explained in “Theory of V-Ramp Test Procedure”, 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 4155/4156 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 *Programmer's Guide*.

Measurement setups, which are loaded into the 4155/4156 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 4155/4156 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 4155/4156 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 “Customization” 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 1-4.

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

1. Sets up the 4155/4156 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 1-13)
  - 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 1-5)
  - 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.

Figure 1-4 **Simplified Measurement Circuit and Output Voltage of Initial Test**

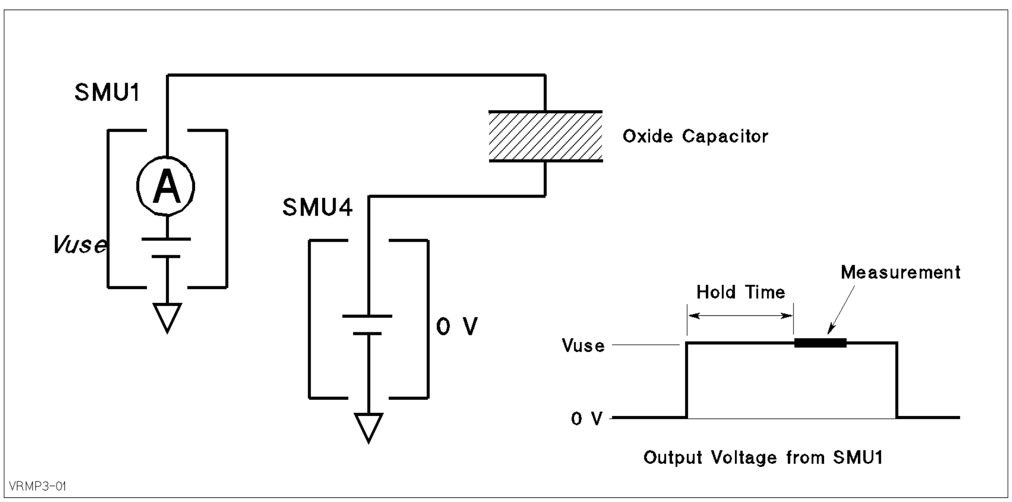
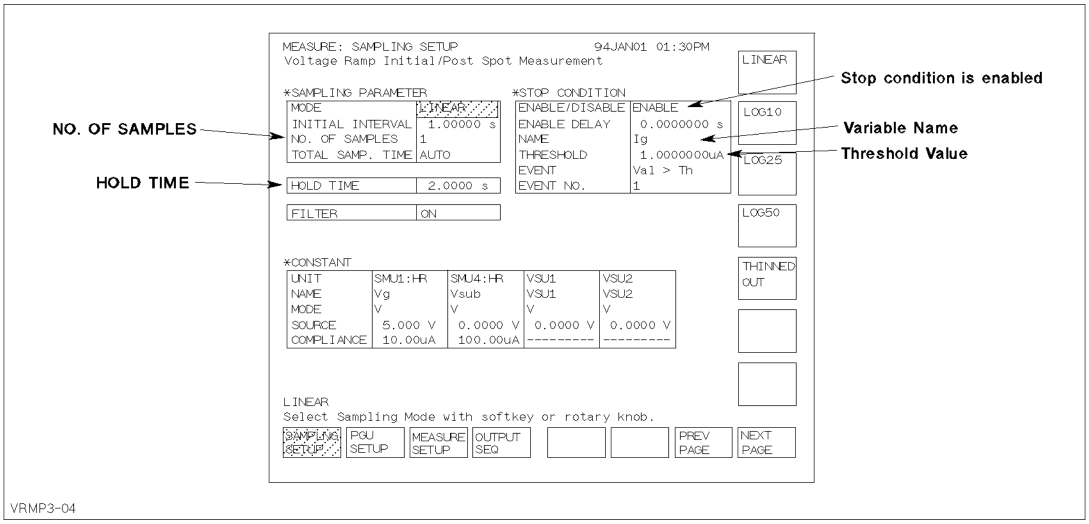


Figure 1-5 MEASURE: SAMPLING SETUP Page for Initial Test



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 4155/4156.

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

- SMU channel definition (see Figure 1-6):

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

- Constant step interval time (see Figure 1-8):

  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 4155/4156 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 1-6. 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 1-7.

Figure 1-6 **Simplified Measurement Circuit of Ramp Stress Test**

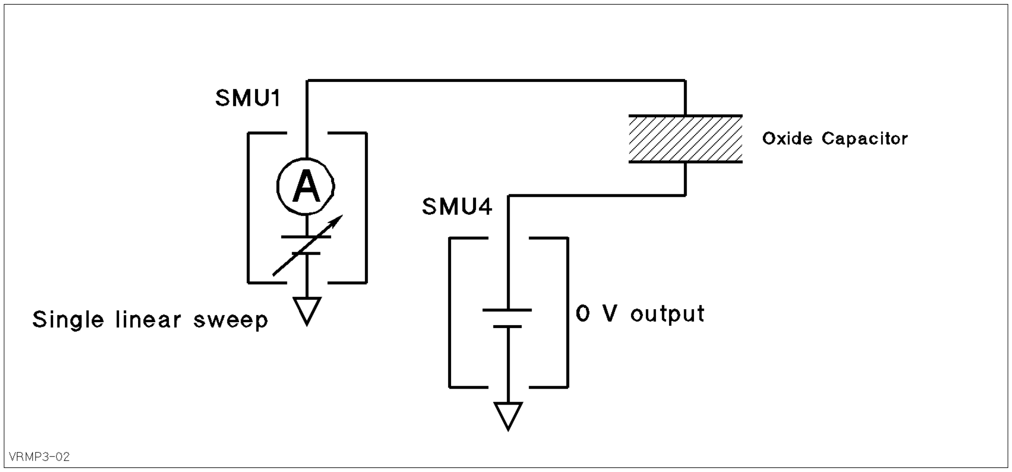
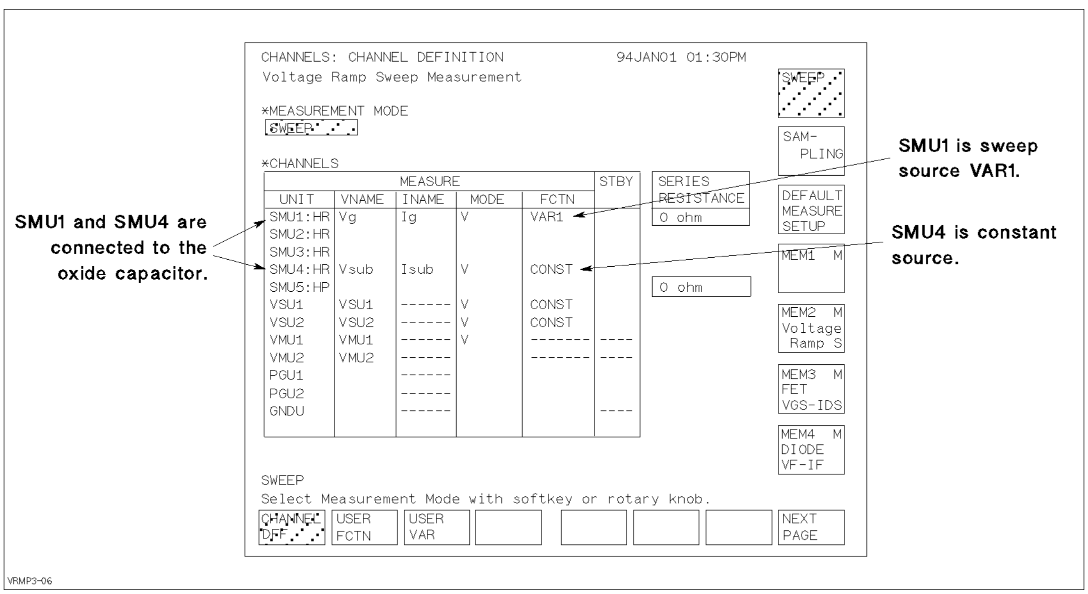


Figure 1-7 **CHANNELS: CHANNEL DEFINITION Page for Ramp Stress Test**



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 1-8. 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)-1.2ms+0.1ms
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.

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 1-10.

Figure 1-8 Output Sweep Voltage for Ramp Stress Test

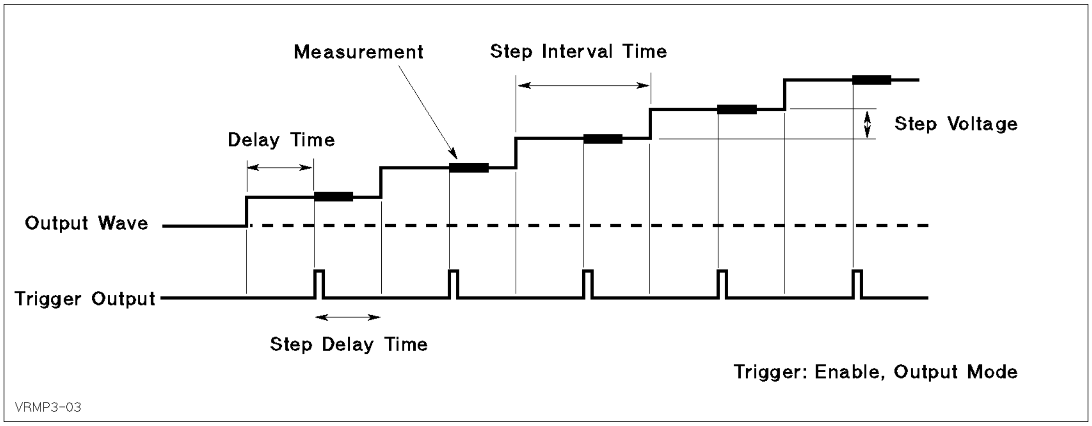


Figure 1-9 MEASURE: MEASURE SETUP and OUTPUT SEQUENCE Pages for Ramp Stress Test

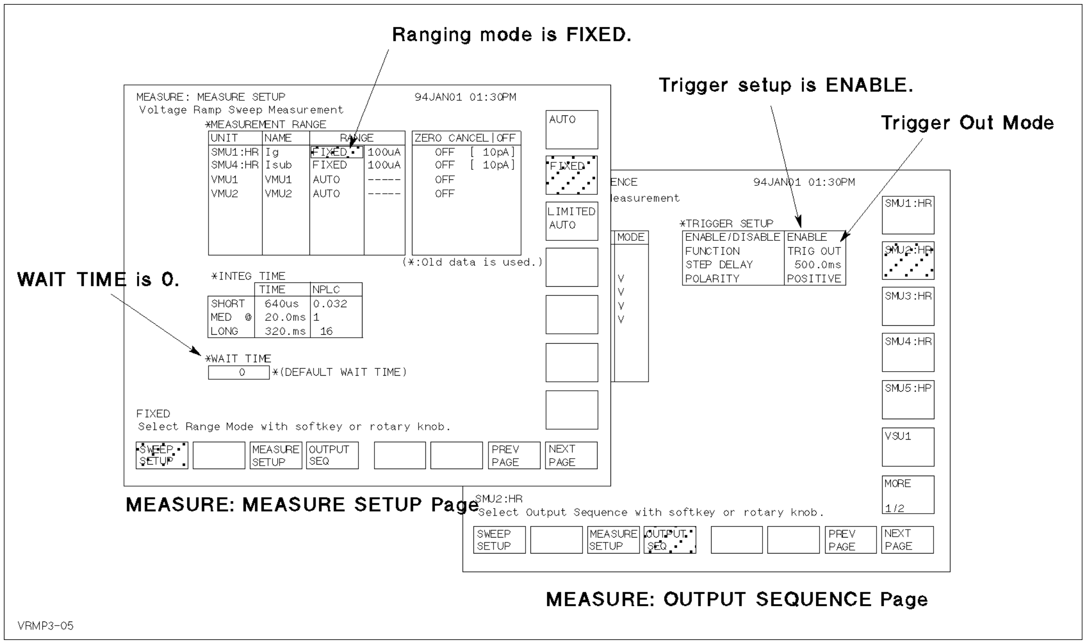
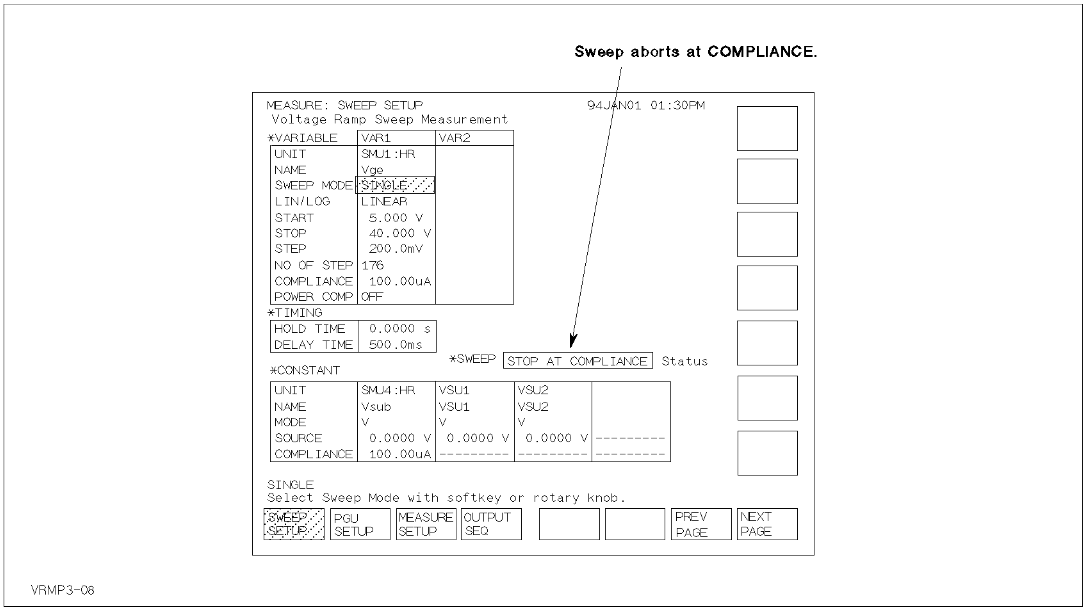


Figure 1-10 MEASURE: SWEEP SETUP Page for Ramp Stress Test



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 1-20) as follows:

Table 1-2 **User Functions for Ramp Stress Test**

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

a. 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:

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

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 1-3 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 1-3 **Oxide Failure Categories**

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

Required Equipment

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

- Agilent 4155 or Agilent 4156 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

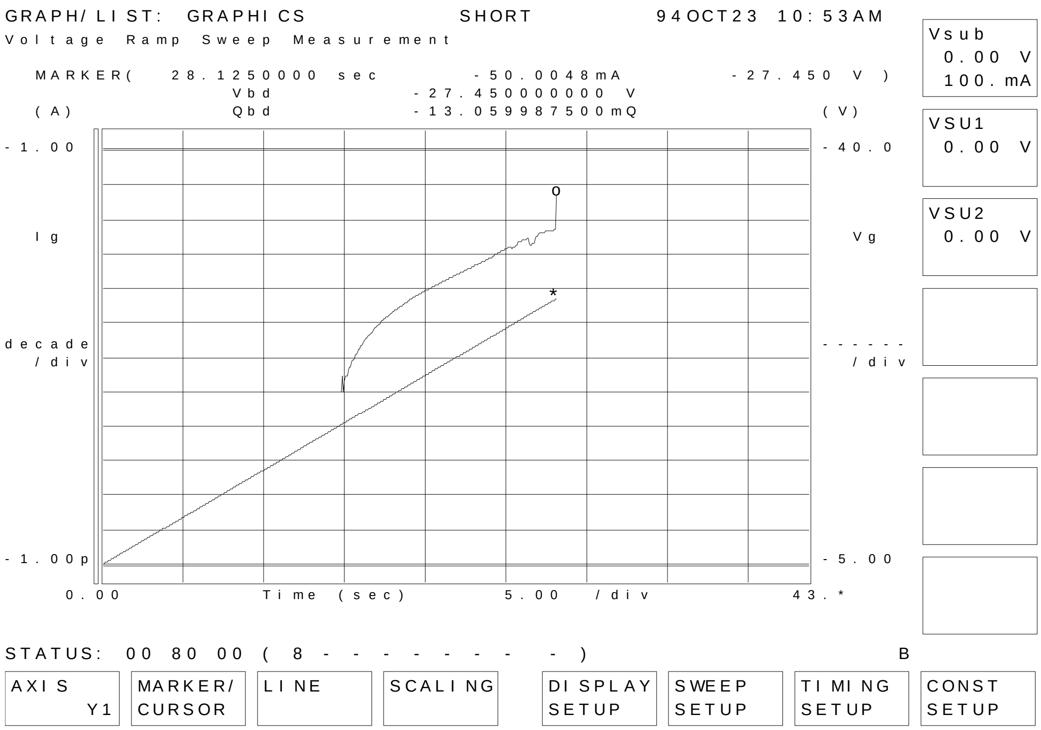
Before executing the program, you may need to customize the program to suit your test device. See “Customization”.

To execute the sample program, use the following procedure:

1. Connect your 4155/4156 to your test device. See Figure 1-4.
2. Turn on your 4155/4156.
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"` and press **Enter** key.
6. Press **RUN** key in the IBASIC area of the front panel to start the program.

Measurement results similar to Figure 1-11 will be displayed on the GRAPHICS page of the 4155/4156.

Figure 1-11 An Example of Measurement Results

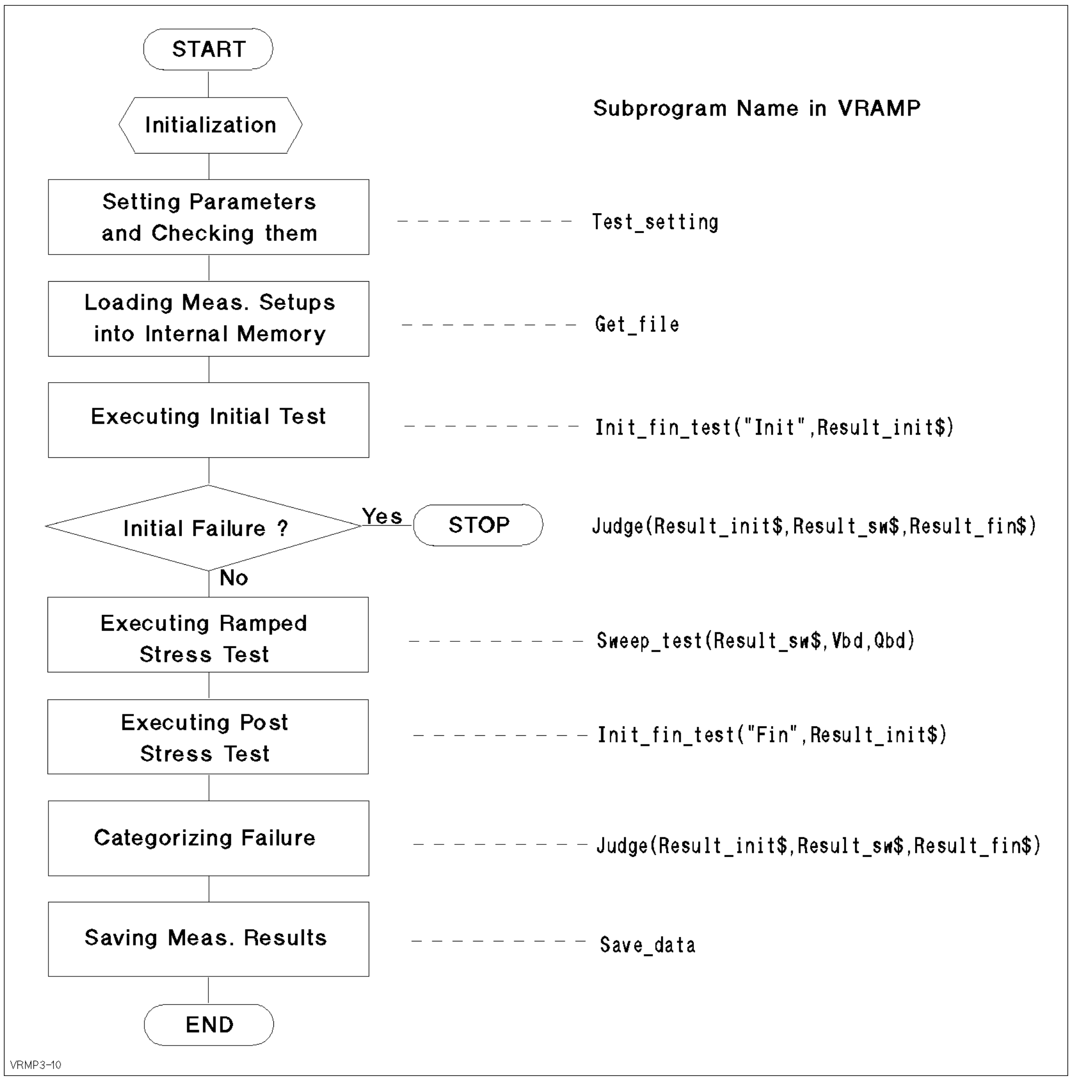


Note that this example is obtained when the maximum electric field is set to 50 MV/cm.

Flowchart of Sample VRAMP Program

Figure 1-12 shows flowchart of sample VRAMP program and corresponding subprogram names.

Figure 1-12 **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.

Customization

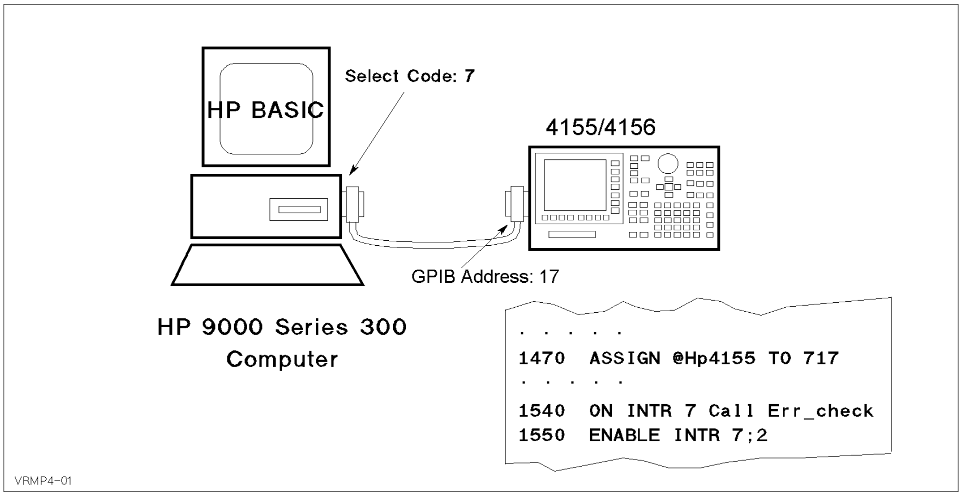
This section describes how to customize the sample program to suit your test device.

Using an External Computer

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

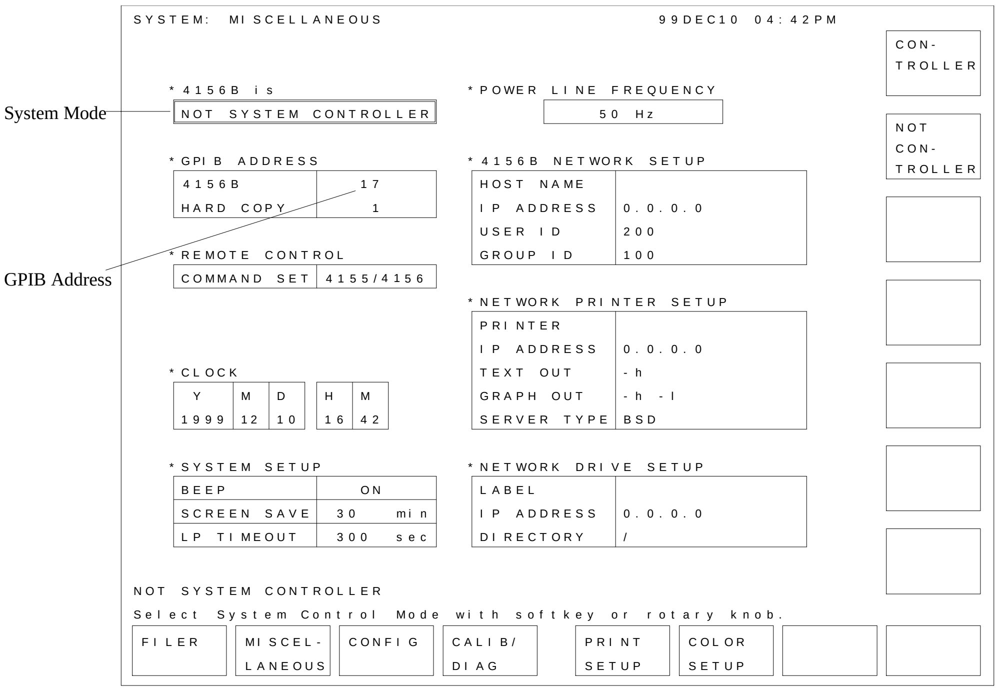
```
1470 ASSIGN @Hp4155 TO 800
    :
1540 ON INTR 8 CALL Err_check
1550 ENABLE INTR 8;2
```

If you use an external controller (that can run HP BASIC environment) to control the 4155/4156, 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:



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

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



Specifying Setup File to Load

Two setup files are used to set up the 4155/4156 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]&".D
AT"
```

The following line commands the 4155/4156 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 4*x* 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 -- Pbulk, PMOS -- Nbulk
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 [a]	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

a. 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:

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

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`.

Measurement Setups

This section 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 setups of each page are shown in Figure 1-13 to Figure 1-18.

Setups for Ramped Stress Test

The measurement setups that are stored in VRSWEP.MES are used for the ramped stress test. The setups of each page are shown in Figure 1-19 to Figure 1-25.

Figure 1-13 CHANNELS: CHANNEL DEFINITION Page for Initial/Post Stress

CHANNELS: CHANNEL DEFINITION 95FEB02 08:17AM
Voltage Ramp Initial/Post Spot Measurement

* MEASUREMENT MODE
SAMPLING

* CHANNELS

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

SERIES RESISTANCE
0 ohm
0 ohm

SWEEP | SAM-PLING | DEFAULT MEASURE SETUP | MEM1 M B-Tr VCE-IC | MEM2 M FET VDS-ID | MEM3 M FET VGS-ID | MEM4 M DIODE VF-IF

SAMPLING
Select Measurement Mode with softkey or rotary knob.

CHANNEL DEF | USER FCTN | USER VAR | | | | | NEXT PAGE

Figure 1-14 **MEASURE: SAMPLING SETUP Page for Initial/Post Stress**

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.

LINEAR	
LOG10	
LOG25	
LOG50	
THINNED OUT	

SAMPLNG SETUP | | MEASURE SETUP | OUTPUT SEQ | | | PREV PAGE | NEXT PAGE

Figure 1-15 **MEASURE: MEASURE SETUP Page for Initial/Post Stress**

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.

AUTO | FIXED | LIMITED AUTO

SAMPLNG SETUP | | MEASURE SETUP | OUTPUT SEQ | | | PREV PAGE | NEXT PAGE

Figure 1-16 **MEASURE: OUTPUT SEQUENCE Page for Initial/Post Stress**

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.

Side softkeys: SMU1:HR | SMU2:HR | SMU3:HR | SMU4:HR | VSU1 | VSU2

Bottom softkeys: SAMPLNG SETUP | MEASURE SETUP | OUTPUT SEQ | PREV PAGE | NEXT PAGE

Figure 1-17 **DISPLAY: DISPLAY SETUP Page for Initial/Post Stress**

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.

Side softkeys: GRAPH-ICS | LIST

Bottom softkeys: DISPLAY SETUP | ANLYSIS SETUP | PREV PAGE | NEXT PAGE

Figure 1-18 DISPLAY: ANALYSIS SETUP Page for Initial/Post Stress

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.

Side softkeys: NORMAL | GRAD | TANGENT | REGRES-SION | | | DISABLE

Bottom softkeys: DISPLAY SETUP | ANLYSIS SETUP | | | | | PREV PAGE | NEXT PAGE

Figure 1-19 CHANNELS: CHANNEL DEFINITION Page for Ramped Stress

CHANNELS: CHANNEL DEFINITION 95FEB02 08:35AM
Voltage Ramp Initial/Post Spot 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	
VSU1		-------			
VSU2		-------			
VMU1		-------		-----	----
VMU2		-------		-----	----

SERIES RESISTANCE
0 ohm
0 ohm

SWEEP
Select Measurement Mode with softkey or rotary knob. B

Side softkeys: SWEEP | SAM-PLING | DEFAULT MEASURE SETUP | MEM1 M B-Tr VCE-IC | MEM2 M FET VDS-ID | MEM3 M FET VGS-ID | MEM4 M DIODE VF-IF

Bottom softkeys: CHANNEL DEF | USER FCTN | USER VAR | | | | | NEXT PAGE

Figure 1-20 CHANNELS: USER FUNCTION DEFINITION Page for Ramped Stress

```
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)

DELETE ROW

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

CHANNEL DEF	USER FCTN	USER VAR				PREV PAGE	NEXT PAGE

Figure 1-21 MEASURE: SWEEP SETUP Page for Ramped Stress

```
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
DOUBLE

SINGLE
Select Sweep Mode with softkey or rotary knob.

SWEEP SETUP		MEASURE SETUP	OUTPUT SEQ			PREV PAGE	NEXT PAGE

Figure 1-22 **MEASURE: MEASURE SETUP Page for Ramped Stress**

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

*MEASUREMENT RANGE

UNIT	NAME	RANGE	
SMU1:HR	Ig	FIXED	100uA
SMU4:HR	Isub	FIXED	100uA

ZERO CANCEL	OFF
OFF	[10pA]
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.

Softkeys: AUTO | FIXED | LIMITED AUTO

SWEEP SETUP | | MEASURE SETUP | OUTPUT SEQ | | | PREV PAGE | NEXT PAGE

Figure 1-23 **MEASURE: OUTPUT SEQUENCE Page for Ramped Stress**

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.

Softkeys: SMU1:HR | SMU2:HR | SMU3:HR | SMU4:HR | VSU1 | VSU2

SWEEP SETUP | | MEASURE SETUP | OUTPUT SEQ | | | PREV PAGE | NEXT PAGE

Figure 1-24 **DISPLAY: DISPLAY SETUP Page for Ramped Stress**

```
DISPLAY:  DISPLAY SETUP                                95FEB02 08:39AM   [GRAPH-ICS]
 Voltage Ramp Initial/Post Spot Measurement
                                                                         [LIST]
   *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                  *LINE PARAMETER
   [ON]                   [ON]

   *DATA VARIABLES
   [Vbd]
   [Qbd]

GRAPHICS
Select Display Mode with softkey or rotary knob.
[DISPLAY SETUP] [ANLYSIS SETUP] [ ] [ ] [ ] [ ] [PREV PAGE] [NEXT PAGE]
```

Figure 1-25 **DISPLAY: ANALYSIS SETUP Page for Ramped Stress**

```
DISPLAY:  ANALYSIS SETUP                               95FEB02 08:40AM   [NORMAL]
 Voltage Ramp Initial/Post Spot Measurement
                                                                         [GRAD]
  *LINE1:[              ]
                                                                         [TANGENT]

  *LINE2:[              ]                                                [REGRES-SION]



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

  *Interpolate:[OFF]                                                     [DISABLE]

Select Line Mode with softkey or rotary knob.
[DISPLAY SETUP] [ANLYSIS SETUP] [ ] [ ] [ ] [ ] [PREV PAGE] [NEXT PAGE]
```

2 J-RAMP

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 4155/4156, and how to use and customize the program. The program is written in the Instrument BASIC (IBASIC), and is ready to run on the built-in IBASIC controller of the 4155/4156.

"Theory of J-Ramp Test Procedure" describes basic theory, procedure, and terminology of the J-Ramp test.

"Basic Operation" describes the J-Ramp sample program. Included are J-Ramp methodology using the 4155/4156, how to execute the sample program, and program overview.

"Customization" 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.

"Measurement Setups" shows the 4155/4156 page settings that are stored in the setup files.

"Proof of Equations" shows how to solve equations described in "Basic Operation".

Theory of J-Ramp Test Procedure

This section 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.

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.

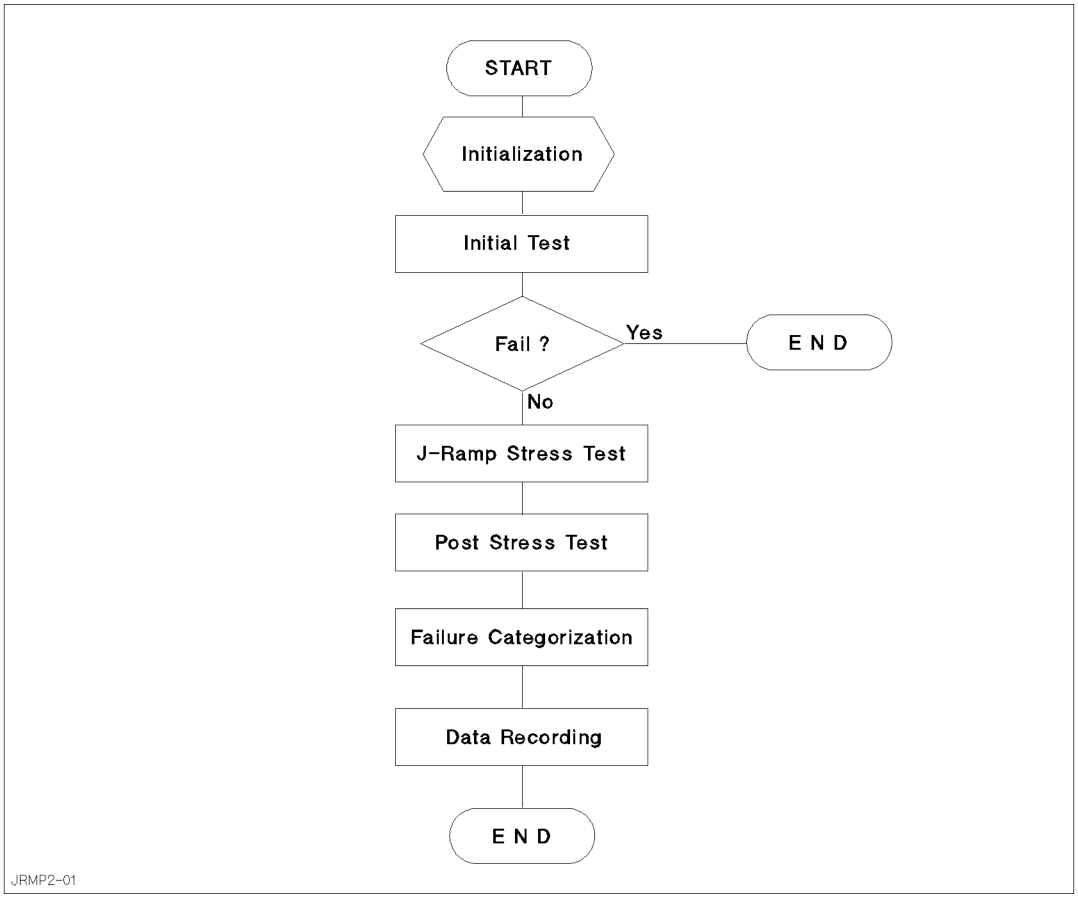
The post stress test is for confirming that failure occurred during the ramp stress test. The initial current is forced again, then the voltage across the oxide is measured.

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.

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



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.

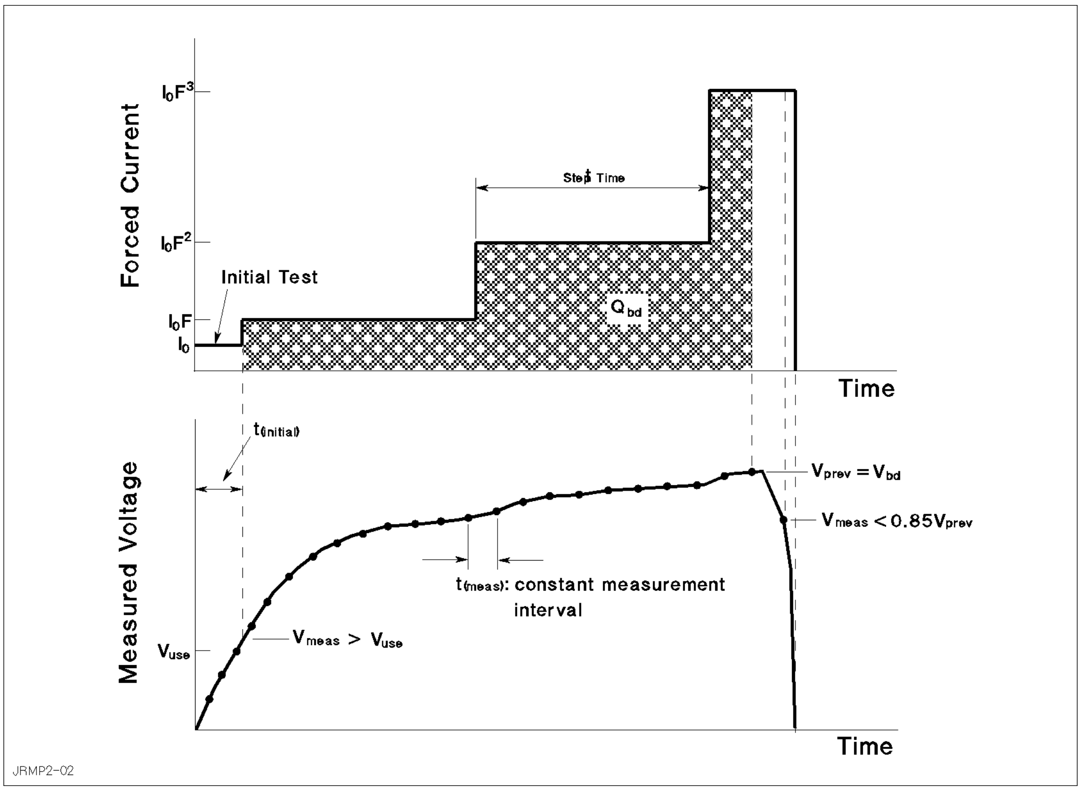
J-Ramp Stress Test

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,

$I_1 = I_0 \times F$

$I_2 = I_0 \times F^2$

$I_3 = I_0 \times F^3$

. . . .

$I_n = I_0 \times F^n$

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 [a]	Pass	Fail	Fail
Masked Catastrophic	Pass	Pass	Fail
Non-catastrophic	Pass	Fail	Pass
Others	Pass	Pass	Pass

a. *Vbd* and q_{bd} are also recorded.

Basic Operation

This section covers the following for using an 4155/4156 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 4155/4156.

As explained in “Theory of J-Ramp Test Procedure”, 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 4155/4156 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 *Programmer's Guide*.

Measurement setups, which are loaded into the 4155/4156 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 4155/4156 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.

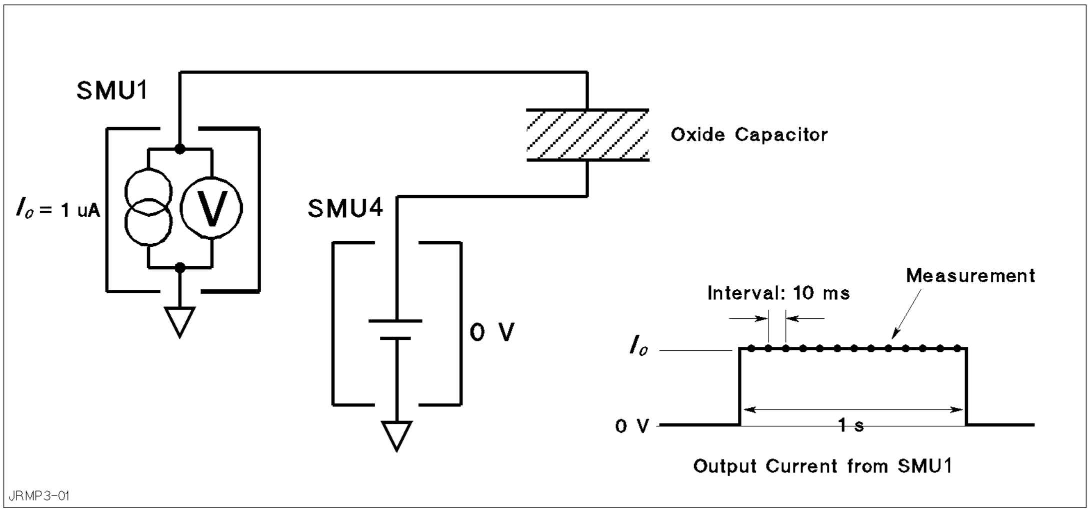
The JRAMP sample program assumes that the built-in IBASIC controller of the 4155/4156 is used, but you can also use another controller such as HP BASIC running on an external computer. To do so, you must modify the sample program for your environment. See “Customization” on how to modify the program 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 2-3.

Figure 2-3 Simplified Measurement Circuit and Output Current of Initial Test



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

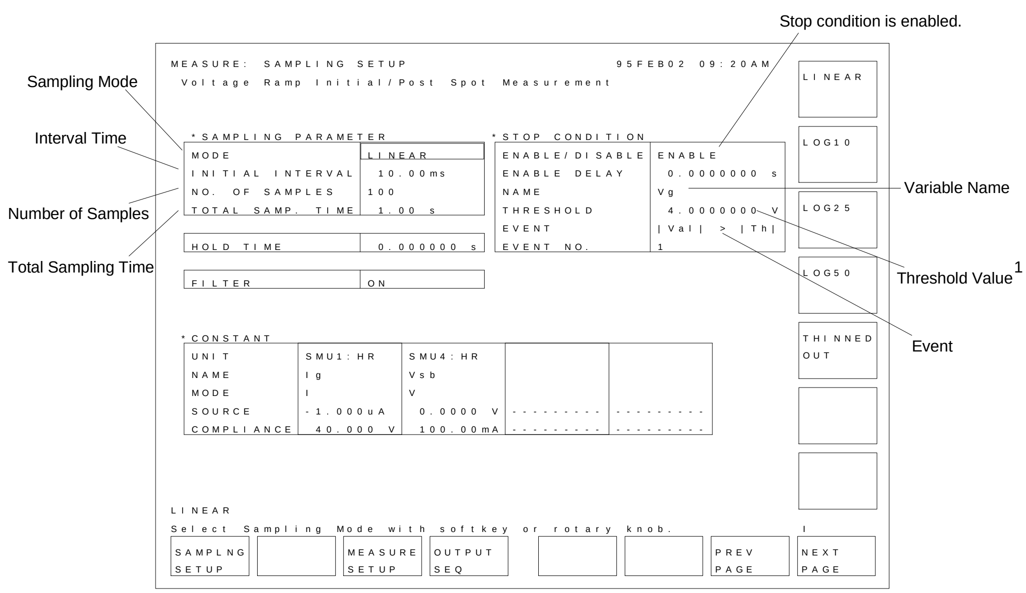
1. Sets up the 4155/4156 according to the JINIT.MES setup file, which the sample program previously loaded from the diskette into internal memory (MEM1).
2. Sets up SMU1 to constant current `Iforce0` for PMOS device, or `-Iforce0` for NMOS device. `Iforce0` value is specified at beginning of the sample program, and reset in the MEASURE: SAMPLING SETUP page by OUTPUT statement (line 2550 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 2-13)
    - 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 2-4)
    - Sampling 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.

Figure 2-4 MEASURE: SAMPLING SETUP Page for Initial Test



1 This value is re-specified by sample program.

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 4155/4156.

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

- SMU channel definition (see Figure 2-5):

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

- Constant step interval time (see Figure 2-7):

  Step interval time of output sweep current should be constant. The time can be constant by setting the *delay time* and *step delay time*. See Figure 2-7. However in the logarithmic sweep, if the sweep range extends to 1 decade or more (example; sweep range 1 μA to 100 μA), the step interval time varies due to the output range changing of sweep source. This interval time error will cause the calculation error of breakdown charge (*Qbd*). Then the JRAMP sample program does the error correction of *Qbd* after the measurement.

- 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 *Qbd* by using the user-defined functions. Finally, the program compensates the *Qbd* calculation error, and displays the *Qbd* value.

SMU channel definition.

The sample program assumes the connection between the SMUs and the oxide capacitor as shown in Figure 2-5.

The JRMP.MES file sets the following (see Figure 2-6 and Figure 2-9):

- 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 2-5 **Simplified Measurement Circuit of J-Ramp Stress Test**

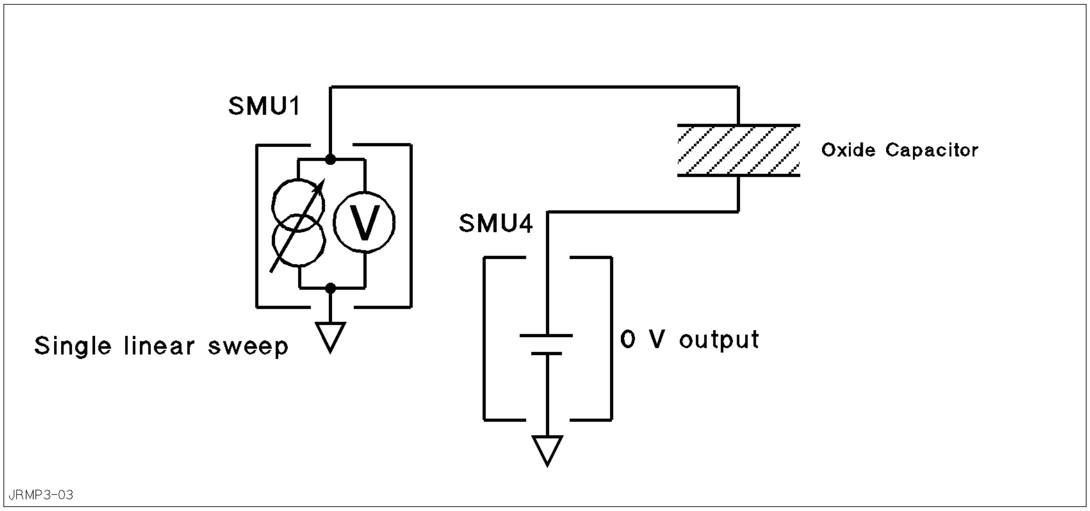
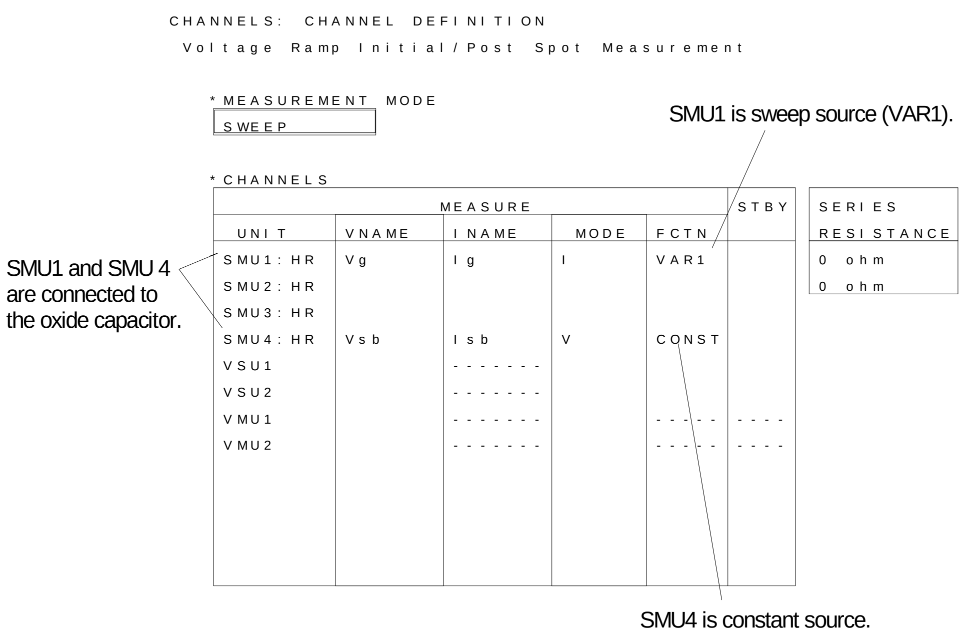


Figure 2-6 **CHANNELS: CHANNEL DEFINITION Page for J-Ramp Stress Test**



Constnt 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 measurement 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 2-7. 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` $= 0.5 \times \log_{10}($`Factor`$) - 3.7$ ms

`Step_delay_t = Step_time/2` (*delay time*)

`Step_keep_t = Step_time - Step_delay_t` (*step delay time*)

Where,

- 3.7 ms is overhead time associated with the current output logarithmic sweep mode. So, do not set another value in this field.
- `Factor` is the step increase factor. See later in this section and “Proof of Equations” for details of this calculation.

In the logarithmic sweep, if the sweep range extends to 1 decade or more, the *step interval time* (`Step_time`) varies due to the output range changing of sweep source. The output range changing adds the range changing time to the *step interval time*. This additional time depends on the range setting, but it is approximately 2 % of the time for 1 decade sweep. The output range changing will also cause the calculation error of *Qbd*. The JRAMP sample program can compensate this calculation error.

Figure 2-7 Output Sweep Current for J-Ramp Stress Test

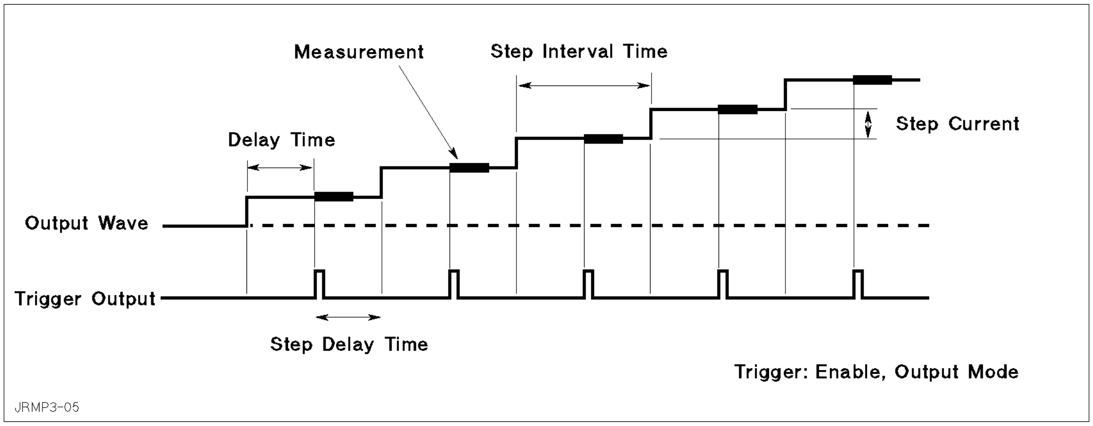
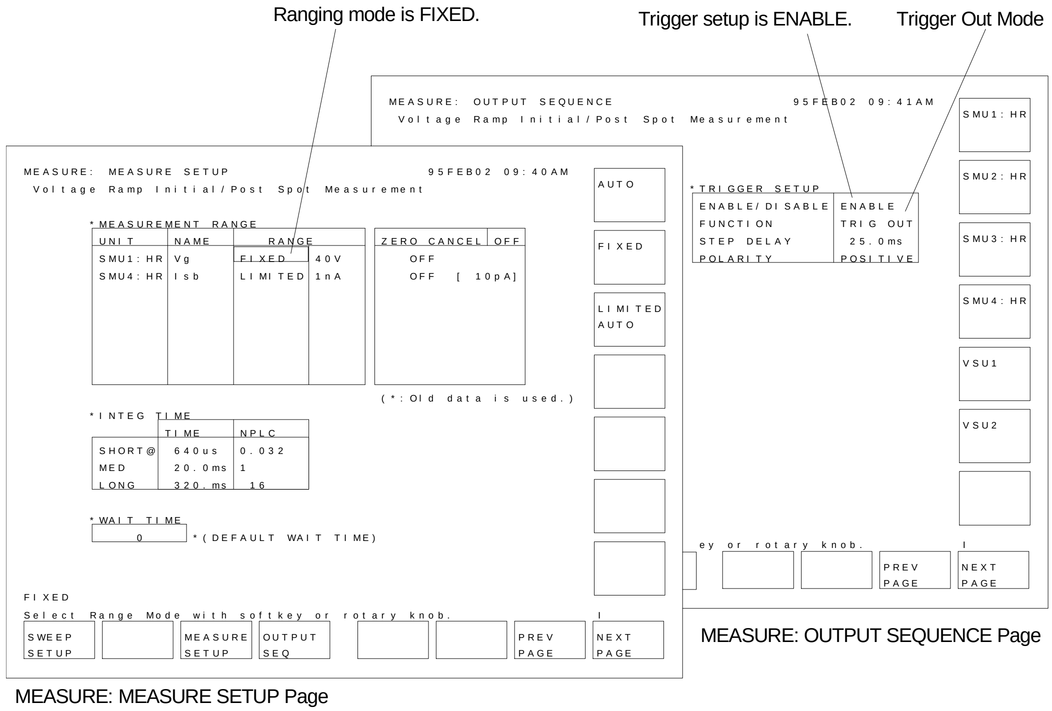


Figure 2-8 MEASURE: MEASURE SETUP and OUTPUT SEQUENCE Pages for J-Ramp Stress Test



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 the JRAMP sample program, you specify the start current (`Iforce0` on line 1800) and step increase factor F (`Factor` on line 1890), then the step interval time (`Step_time` on line 1900) and stop current (`Istop` on line 4560) are calculated. For NMOS devices, the ramp test subprogram actually sets the opposite polarity for these values by using the `Tp` variable (lines 2020 and 2030).

`Iforce0` is normally 1 μA, as mentioned in the “Theory of J-Ramp Test Procedure”. Three values ($10^{1/10}$, $10^{1/25}$, and $10^{1/50}$) are possible for step factor F (`Factor`) of the 4155/4156 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:

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

Where, $I(t) = I_0 \times F^n$, $t = n \times Ts$ (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:

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

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:

$$I_{stop} = I_0 \cdot F^n$$

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 “Proof of Equations”.

Measurement stop condition.

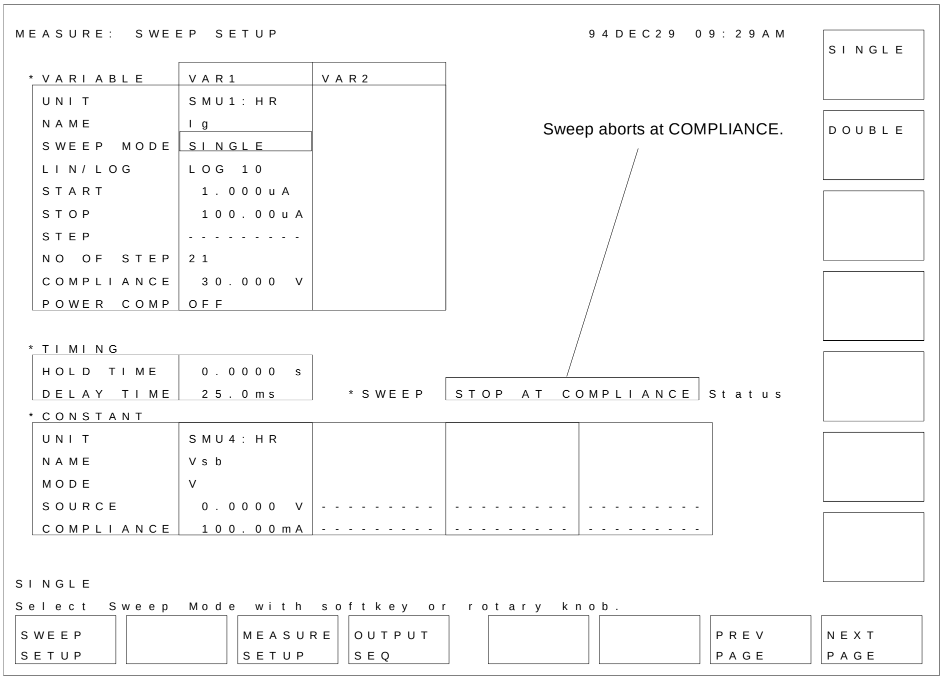
NOTE

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 2-9.

Figure 2-9 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.

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:

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

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 2-21) as follows:

Table 2-2 User Functions for Ramp Stress Test

Name	Units	Definition
Time	sec	0.05 * @INDEX [a]
Vbd	V	@MY2
Qbdo	C	INTEG(Ig,Time)
Qbd	C	0 [b]

a. This is a temporary definition. `Time` is redefined by line 2940 of the sample program.

b. This is a temporary value. `Qbd` value is entered by line 3590 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 2-3 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 2-3 **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:

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

Program Files Required

The following files are used for the J-Ramp test:

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.

Executing the JRAMP Program

Before executing the program, you may need to customize the program to suit your test device. See “Customization”.

This procedure describes how to execute the sample program.

1. Display the SYSTEM: MISCELLANEOUS screen, and set the REMOTE CONTROL COMMAND SET field to 4155/4156.
2. Display the All IBASIC screen by pressing the front-panel **Display** key twice.
3. Insert a diskette containing the JRAMP program and JRMP.MES file into the built-in 3.5 inch flexible disk drive.
4. Get the JRAMP sample program as follows:
   a. Select the GET "" softkey.
   b. Enter JRAMP as shown below.

      ```
      GET"JRAMP"
      ```
   c. Press the front-panel **Enter** key.
5. (Optional) Edit the program, and change the measurement conditions. See Table 2-4.
6. Connect test device to the 4155/4156. See Figure 2-3.
7. Press the front-panel **Run** key to execute the program.

Measurement results similar to the Figure 2-10 will be displayed on the GRAPHICS page of the 4155/4156.

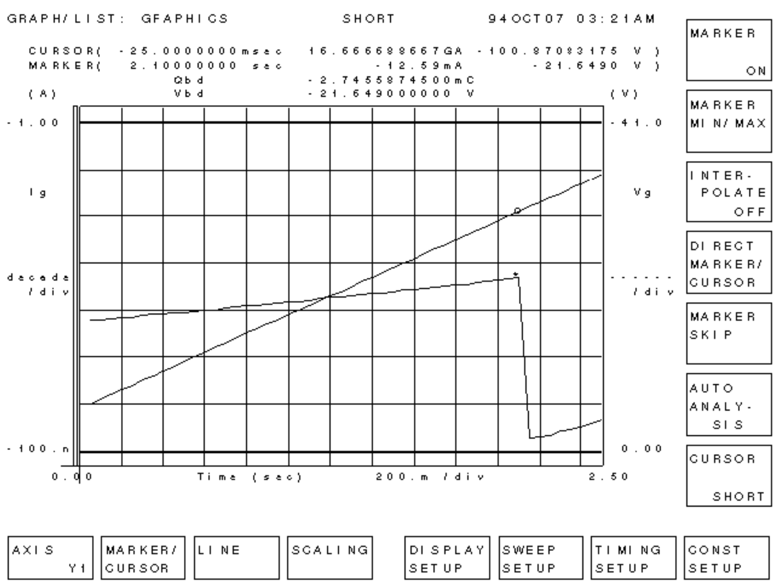
Table 2-4 JRAMP Sample Program Setup Parameters

Parameter	Line No.	Variable Name	Default Value
Device Type (NMOS or PMOS)	1790	`Type$` [a]	NMOS
Initial current or sweep start current (A)	1800	`Iforce0`	1.E-6
Normal operating voltage for the device (V) (threshold value used for Initial Test/Post Test)	1810	`Vuse`	5
Type of SMU used for current sweep source (1: HRSMU, 0: MPSMU or HPSMU)	1820	`Smu_type` [b]	1
Ramp step increase factor $10^{1/10}$, $10^{1/25}$, or $10^{1/50}$	1890	`Factor`	$10^{1/10}$
Maximum charge (C/cm^2)	1940	`Max_q`	50
Maximum electric field (V/cm)	1950	`Max_e`	15*1.E+6
Thickness of oxide (cm)	1970	`Tox`	130*1.E–8
Area of oxide capacitor (cm^2)	1980	`Area`	0.001

a. 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 2030.

b. If you use the 4155, or MPSMU in the 41501 Expander, change the value to 0. If you use the HPSMU in the 41501, use the JRAMP1 sample program. See “When SMU Lacks Power to Break Oxide”.

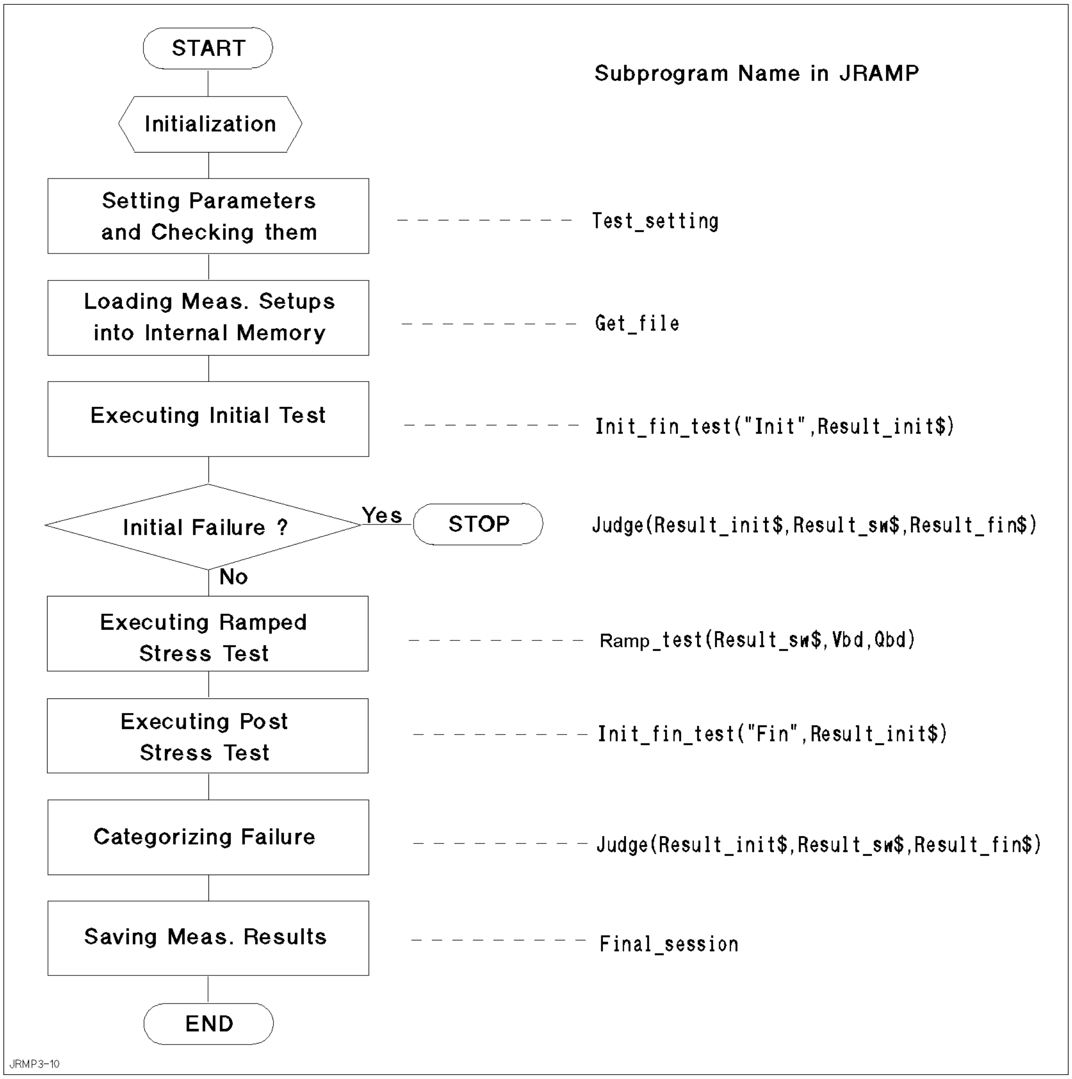
Figure 2-10 An Example of Measurement Results



Flowchart of Sample JRAMP Program

Figure 2-11 shows flowchart of sample JRAMP program and corresponding subprogram names.

Figure 2-11 **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. This subprogram calls the `Calc_istop` subprogram to calculate the sweep stop current value.

`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 initial test or 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.

`Ramp_test` Executes sweep measurement for ramped stress test. After the measurement, compensates the *Qbd* value using the `FNCompen` function, and displays `Vbd`, `Qbd`, and `qbd` values. 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.

`Calc_istop` Calculates the sweep stop current value from the start current (`Iforce0`) and ramp step increase factor (`Factor`).

`FNCompen` Compensates the *Qbd* calculation error caused by the sweep source output range changing.

Customization

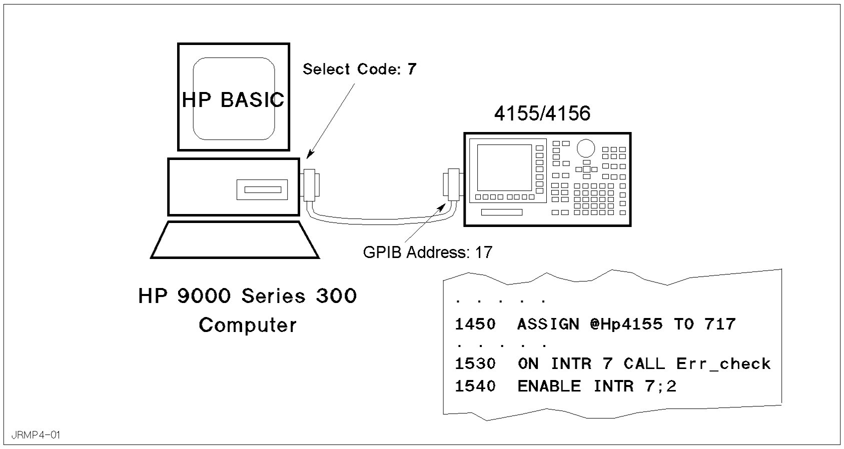
This section describes how to customize the sample program to suit your test device.

Using an External Computer

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

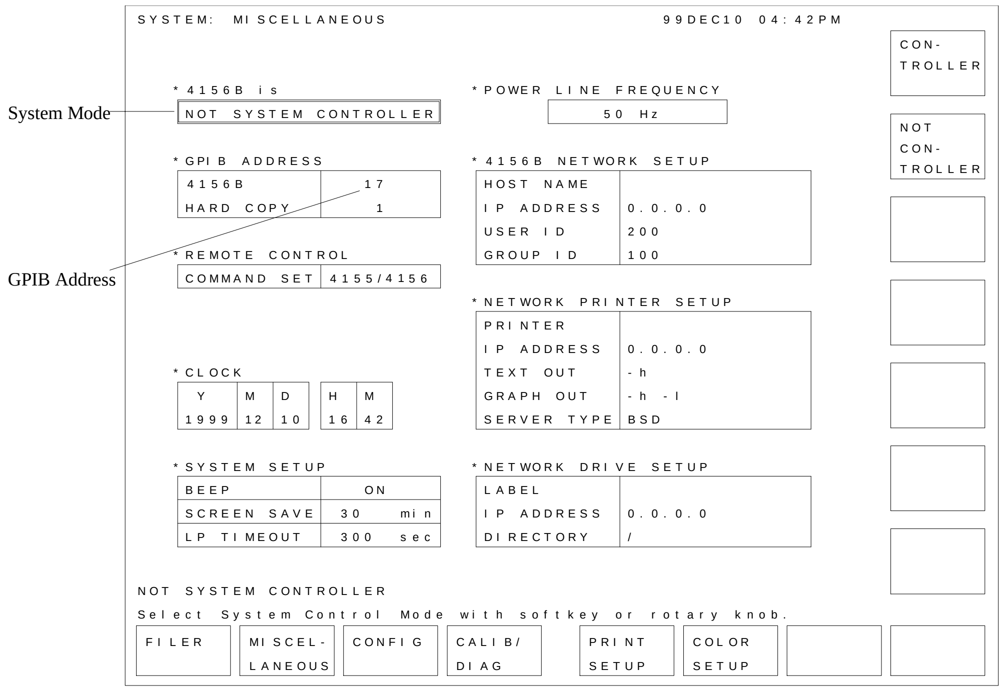
```
1450  ASSIGN @Hp4155 TO 800
              :
1530  ON INTR 8 CALL Err_check
1540  ENABLE INTR 8;2
```

If you use an external controller (that can run HP BASIC environment) to control the 4155/4156, 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:



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

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



Specifying Setup File to Load

Two setup files are used to set up the 4155/4156 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 4155/4156 to create the specified file on the diskette, then stores the result data in the file.

```
4120  OUTPUT @Hp4155;":MMEM:STOR:TRACDEF,'"&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 4*x* 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  Smu_type=1        !SMU type used
1830                    !0:MP/HPSMU
1840                    !1:HRSMU
1850  !---------------------------------------------------
1860  !Allowable current factor:
1870  !10^(1/10), 10^(1/25), 10^(1/50)
1880  !---------------------------------------------------
1890  Factor=10^(1/10) !Current factor
1900  Step_time=.5/(1/LGT(Factor))-.0037  !Ramp step time
1910  Step_delay_t=Step_time/2            !Step Delay time
1920  Step_keep_t=Step_time-Step_delay_t  !Step keep time
1930  !
1940  Max_q=50          !Maximum charge (C/cm^2)
1950  Max_e=15*1.E+6    !Maximum Field (V/cm)
1960  !
1970  Tox=130*1.E-8     !Oxide Thickness (cm)
1980  Area=.001         !Area of oxide capacitor (cm^2)
1990  Calc_istop        !Calculate Istop (A)
2000  Vgcomp=Max_e*Tox !Vg compliance (V)
2010  Igcomp=.1         !Ig compliance (A)
```

Parameter	Default	Description
`Type$` [a]	NMOS	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
`Smu_type` [b]	1	Type of SMU used for current sweep source (1: HRSMU, 0: MPSMU or HPSMU)
`Factor`	$10^{1/10}$	Ramp step increase factor *F* ($10^{1/10}$, $10^{1/25}$, or $10^{1/50}$)
`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

a. 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 2030.

b. If you use the 4155, or MPSMU in the 41501 Expander, change the value to 0. If you use the HPSMU in the 41501, use the JRAMP1 sample program. See “When SMU Lacks Power to Break Oxide”.

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 41501 Expander. The HPSMU can force maximum 100 V with the range of 50 mA through 125 mA.

The following program and setup files assume to perform J-Ramp Test using an HPSMU and an SMU. Figure 2-12 shows the connections between SMUs and a DUT.

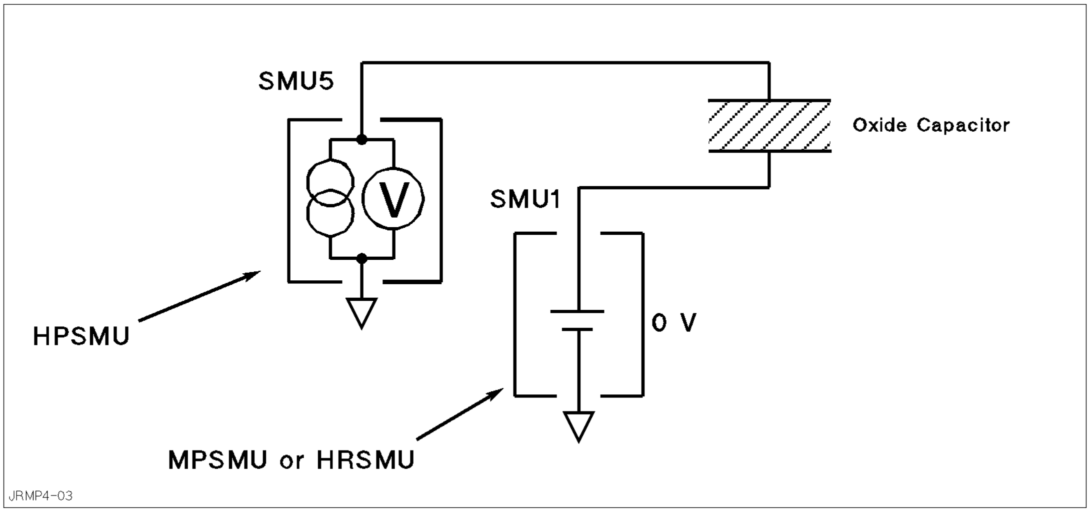
JRAMP1 J-Ramp sample program with HPSMU. This is an IBASIC program file saved in ASCII format.

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.

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

Figure 2-12 Simplified Measurement Circuit of J-Ramp Test With HPSMU



Measurement Setups

This section 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 setups of each page are shown in Figure 2-13 to Figure 2-19.

Setups for Ramped Stress Test

The measurement setups stored in JRMP.MES are used for the ramped stress test. The setups of each page are shown in Figure 2-20 to Figure 2-26.

Figure 2-13 **CHANNELS: CHANNEL DEFINITION Page for Initial/Post Stress**

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

SWEEP | SAM-PLING | DEFAULT MEASURE SETUP | MEM1 M B-Tr VCE-IC | MEM2 M FET VDS-ID | MEM3 M FET VGS-ID | MEM4 M DIODE VF-IF

SAMPLING
Select Measurement Mode with softkey or rotary knob. I

CHANNEL DEF | USER FCTN | USER VAR | | | | | NEXT PAGE

Figure 2-14 **CHANNELS: USER FUNCTION DEFINITION Page for Initial/Post Stress**

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

*USER FUNCTION

NAME	UNIT	DEFINITION
Vm	V	@MY1

DELETE ROW

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

CHANNEL DEF | USER FCTN | USER VAR | | | | PREV PAGE | NEXT PAGE

Figure 2-15 **MEASURE: SAMPLING SETUP Page for Initial/Post Stress**

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	---------	---------

Softkeys: LINEAR | LOG10 | LOG25 | LOG50 | THINNED OUT

LINEAR
Select Sampling Mode with softkey or rotary knob.

SAMPLNG SETUP		MEASURE SETUP	OUTPUT SEQ			PREV PAGE	NEXT PAGE

Figure 2-16 **MEASURE: MEASURE SETUP Page for Initial/Post Stress**

MEASURE: MEASURE SETUP 95FEB02 09:20AM
Voltage Ramp Initial/Post Spot Measurement

*MEASUREMENT RANGE

UNIT	NAME	RANGE	
SMU1:HR	Vg	AUTO	-----
SMU4:HR	Isb	LIMITED	1nA

ZERO CANCEL	OFF
OFF	
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)

Softkeys: AUTO | FIXED | LIMITED AUTO

AUTO
Select Range Mode with softkey or rotary knob.

SAMPLNG SETUP		MEASURE SETUP	OUTPUT SEQ			PREV PAGE	NEXT PAGE

Figure 2-17 MEASURE: OUTPUT SEQUENCE Page for Initial/Post Stress

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.

Softkeys (right): SMU1:HR | SMU2:HR | SMU3:HR | SMU4:HR | VSU1 | VSU2

Softkeys (bottom): SAMPLNG SETUP | | MEASURE SETUP | OUTPUT SEQ | | | PREV PAGE | NEXT PAGE

Figure 2-18 DISPLAY: DISPLAY SETUP Page for Initial/Post Stress

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.

Softkeys (right): GRAPH-ICS | LIST

Softkeys (bottom): DISPLAY SETUP | ANLYSIS SETUP | | | | | PREV PAGE | NEXT PAGE

Figure 2-19 **DISPLAY: ANALYSIS SETUP Page for Initial/Post Stress**

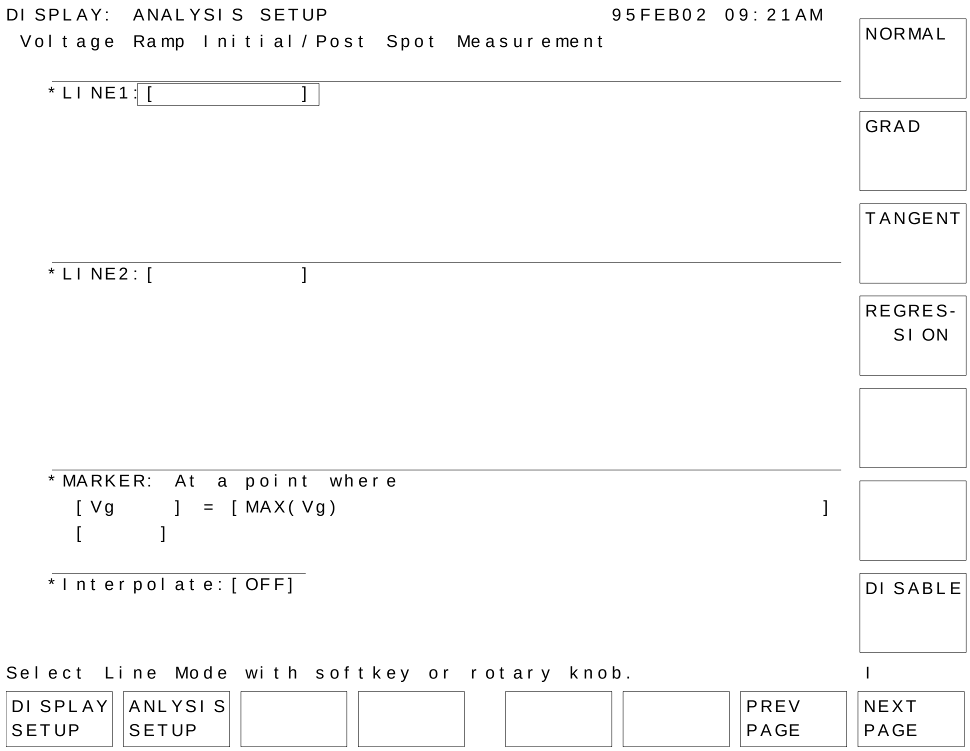


Figure 2-20 **CHANNELS: CHANNEL DEFINITION Page for Ramped Stress**

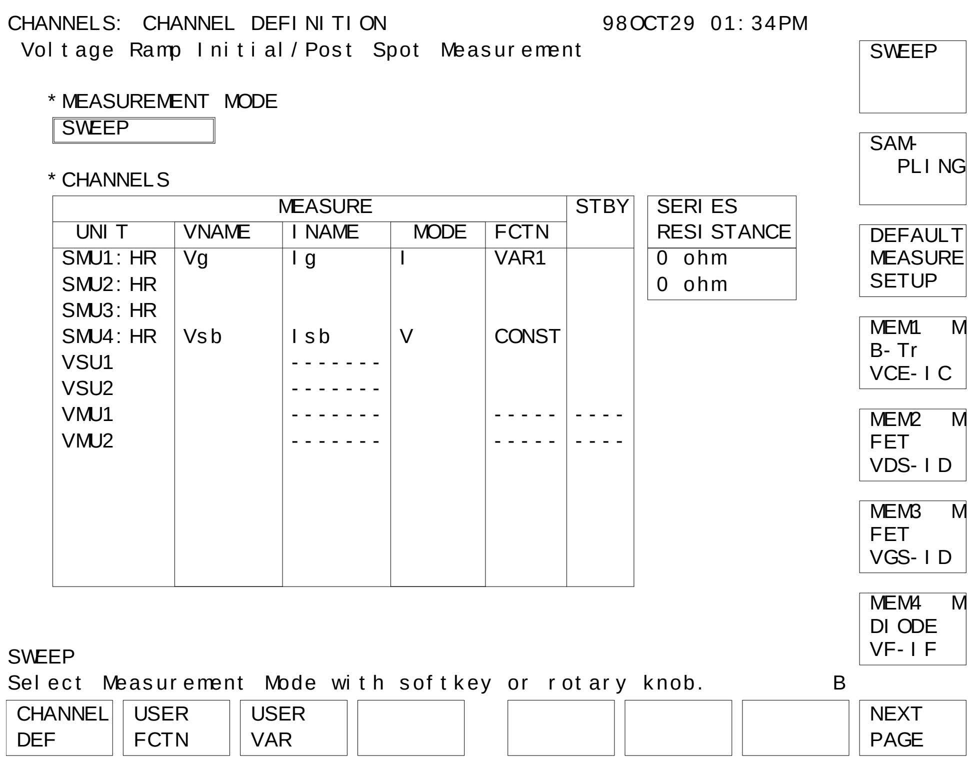


Figure 2-21 **CHANNELS: USER FUNCTION DEFINITION Page for Ramped Stress**

CHANNELS: USER FUNCTION DEFINITION 98OCT29 01:32PM
Voltage Ramp Initial/Post Spot Measurement

*USER FUNCTION

NAME	UNIT	DEFINITION
Time	sec	@INDEX*.0486
Vbd	V	@MY2
Qbdo	C	INTEG(Ig,Time)
Qbd	C	0

DELETE ROW

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

CHANNEL DEF | USER FCTN | USER VAR | PREV PAGE | NEXT PAGE

Figure 2-22 **MEASURE: SWEEP SETUP Page for Ramped Stress**

MEASURE: SWEEP SETUP 98OCT30 11:19AM
Voltage Ramp Initial/Post Spot Measurement

*VARIABLE	VAR1	VAR2
UNIT	SMU1:HR	
NAME	Ig	
SWEEP MODE	SINGLE	
LIN/LOG	LOG 10	
START	1.0000uA	
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	SMU4:HR			
NAME	Vsb			
MODE	V			
SOURCE	0.0000 V	---------	---------	---------
COMPLIANCE	100.00mA	---------	---------	---------

SINGLE | DOUBLE

SINGLE
Select Sweep Mode with softkey or rotary knob. B

SWEEP SETUP | MEASURE SETUP | OUTPUT SEQ | PREV PAGE | NEXT PAGE

Figure 2-23 MEASURE: MEASURE SETUP Page for Ramped Stress

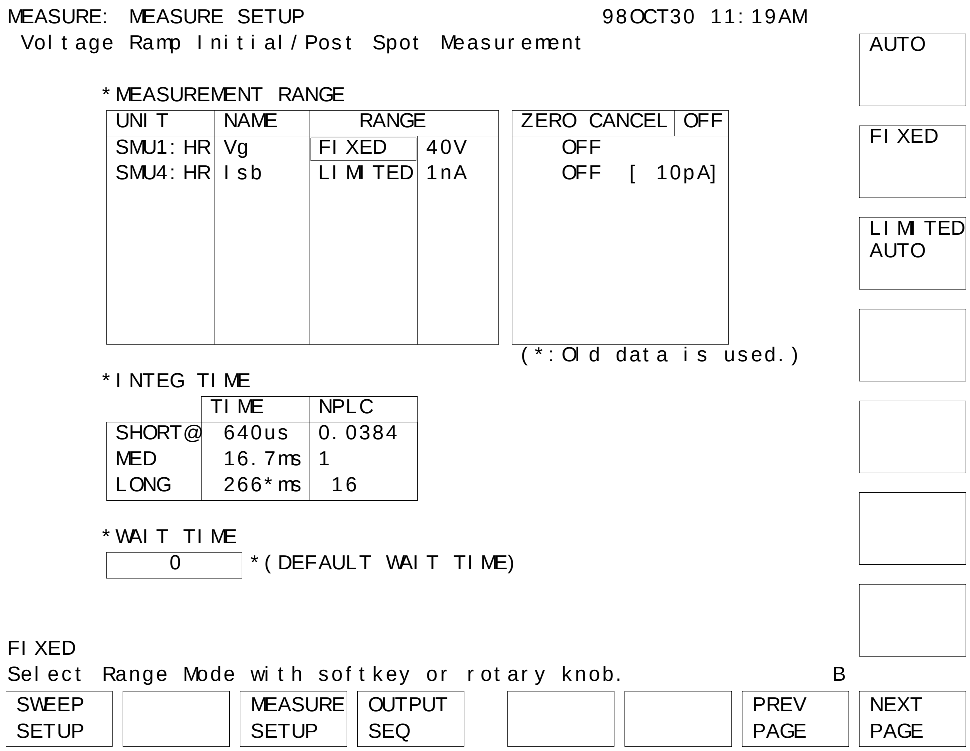


Figure 2-24 MEASURE: OUTPUT SEQUENCE Page for Ramped Stress

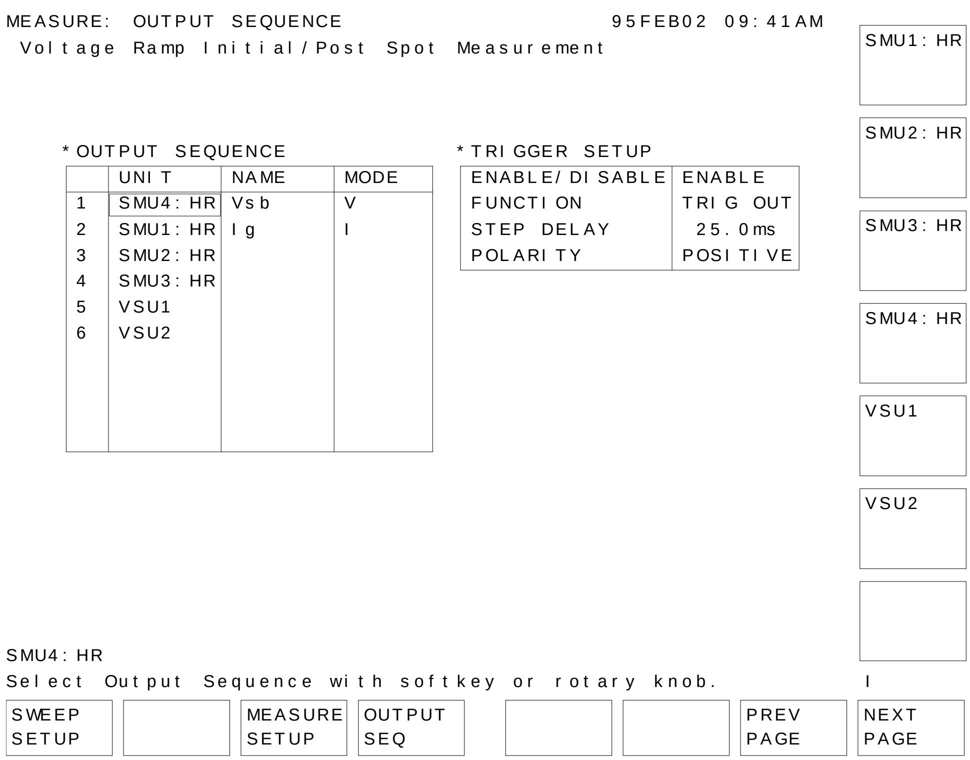


Figure 2-25 **DISPLAY: DISPLAY SETUP Page for Ramped Stress**

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.

Softkeys (right): GRAPH-ICS, LIST

Softkeys (bottom): DISPLAY SETUP, ANLYSIS SETUP, PREV PAGE, NEXT PAGE

Figure 2-26 **DISPLAY: ANALYSIS SETUP Page for Ramped Stress**

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.

Softkeys (right): NORMAL, GRAD, TANGENT, REGRES-SION, DISABLE

Softkeys (bottom): DISPLAY SETUP, ANLYSIS SETUP, PREV PAGE, NEXT PAGE

Proof of Equations

This section provides the information on how to solve the equations given in “J-Ramp Stress Test” on page 2-5.

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:

$10 = F^N$

$\log_{10}10 = \log_{10}F^N$

$1 = N \times \log_{10}F$

$1/N = \log_{10}F$

$F = 10^{1/N}$

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 (*Step_time*)

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

$10 = F^N$

$\log_{10}10 = \log_{10}F^N$

$1 = N \times \log_{10}F$

$N = 1 / \log_{10}F$

So,

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

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:

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

Where, $I(t) = I_0 \times F^n$, $t = n \times Ts$ (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:

$$\int_0^n I_0 \cdot F^n \cdot T_s \cdot dn = q_{max} \cdot Area$$

$$I_0 \cdot T_s \cdot \int_0^n F^n \cdot dn = q_{max} \cdot Area$$

$$I_0 \cdot T_s \cdot \frac{1}{\log_{10} F}[F^n]_0^n = q_{max} \cdot Area$$

$$\frac{I_0 \cdot T_s}{\log_{10} F}(F^n - 1) = q_{max} \cdot Area$$

$$F^n - 1 = \frac{q_{max} \cdot Area \cdot \log_{10} F}{I_0 \cdot T_s}$$

$$F^n = \frac{q_{max} \cdot Area \cdot \log_{10} F}{I_0 \cdot T_s} + 1$$

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

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

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:

$Istop = I_0 \times F^M$

NOTE

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

$\log y = \log a^x = x \times \log a$

$(\log y)' = \log a$

$y' \times 1/y = \log a$

$y' = (\log a) \times y = (\log a) \times a^x$

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).

3 SWEAT

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 4155/4156, and how to use and customize the program. The program is written in the Instrument BASIC (IBASIC), and is ready to run on the built-in IBASIC controller of the 4155/4156.

"SWEAT" describes the SWEAT procedure and terminology.

"Basic Operation" describes the SWEAT methodology using the 4155/4156, how to execute the sample program, and program overview.

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

"Setup files" shows the 4155/56 page settings that are stored in the setup files.

SWEAT

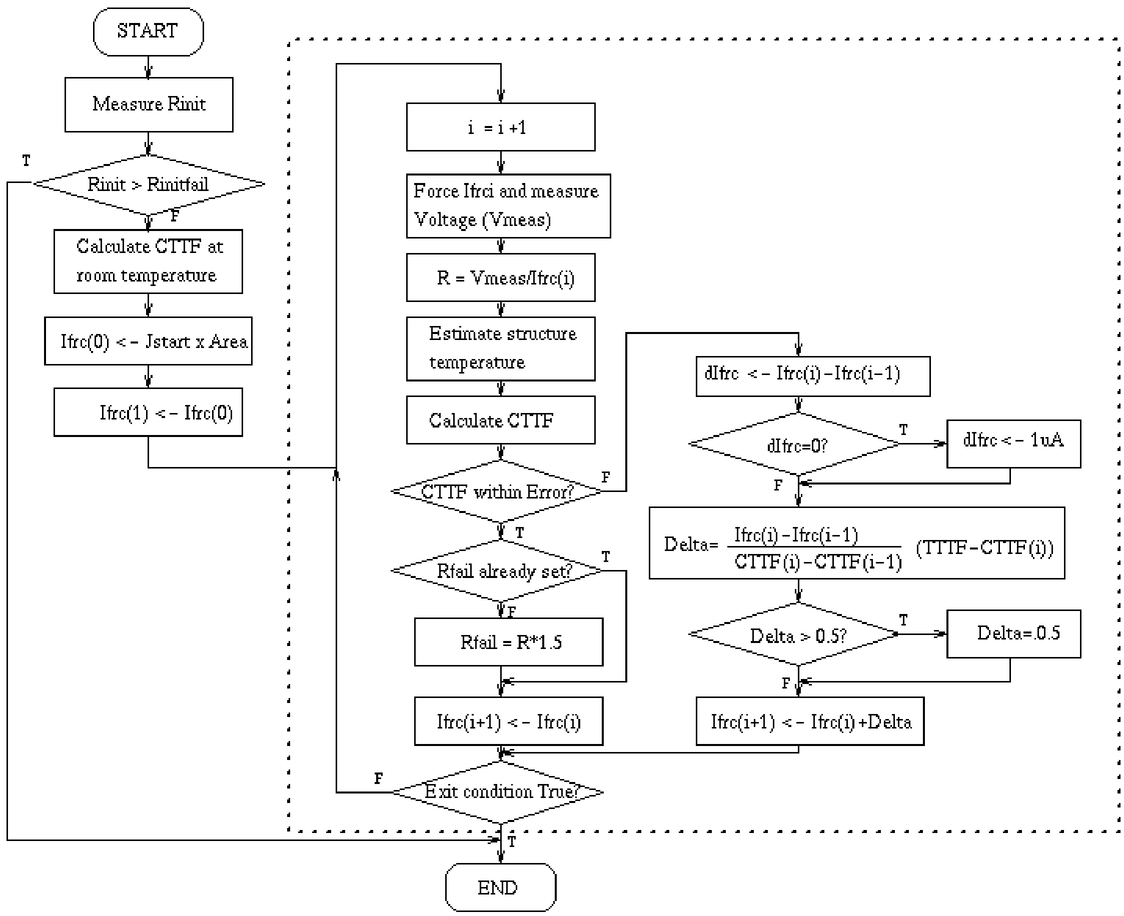
This section describes the SWEAT procedure (based on the proposed JEDEC 4-June-92 standard) and related terminology.

Overview

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

Figure 3-1 shows the flow of the SWEAT test according to the JEDEC proceeding titled "A PROCEDURE FOR EXECUTING SWEAT" (4-Jun-92).

Figure 3-1 **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 3-1. This loop is a feedback control loop that does the following:

SWEAT

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.

SWEAT

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.

SWEAT

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.

Basic Operation

This section describes the methodology for using the 4155/4156 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 the 4155/56) 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 4155/56 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 4155/4156, two controllers are available: an external computer or the built-in IBASIC controller of the 4155/4156. The measurement data (CTTF versus Time) is displayed on the GRAPHICS page of the 4155/4156. Other result data is saved to a result data file.

The SWEAT sample program is created assuming that the 4155/56 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 “Customization” 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.

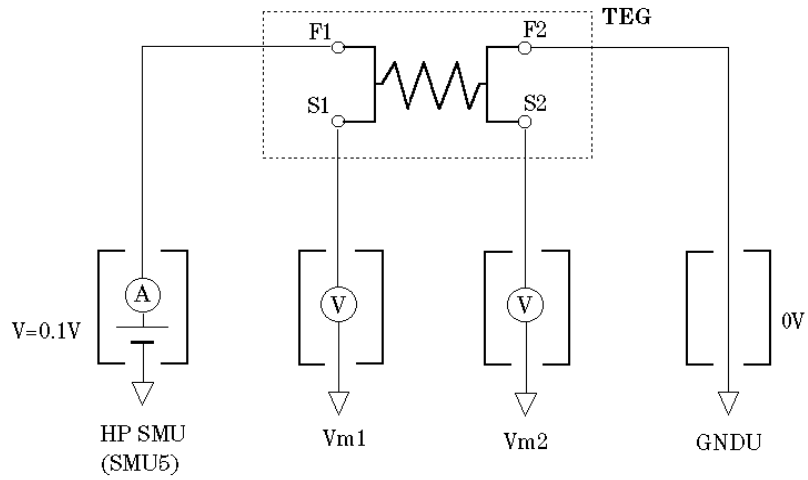
An HPSMU is necessary to force high current greater than 100mA, and must be connected to SMU5 port. Measurement mode is set to **Sampling mode** , and SMU5 is set to **Standby mode** so that current is continuously forced even when measurement is not being made, such as during calculation.

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 3-2.

This measurement setup is in the RINIT.MES file on the diskette, and the sample program loads this setup into the 4155/56 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 3-2 **Rinit Measurement Circuit**



Stress/Resistance Measurement Loop

After Rinit measurement, sample program loads a new setup into the 4155/56, 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). The 4155/4156 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 3-3. Figure 3-4 and Figure 3-5 show an example CHANNEL DEFINITION and SAMPLING SETUP page. This measurement setup is stored in the IFVM.MES file on the diskette.

Figure 3-3 **Stress/Resistance Measurement Circuit**

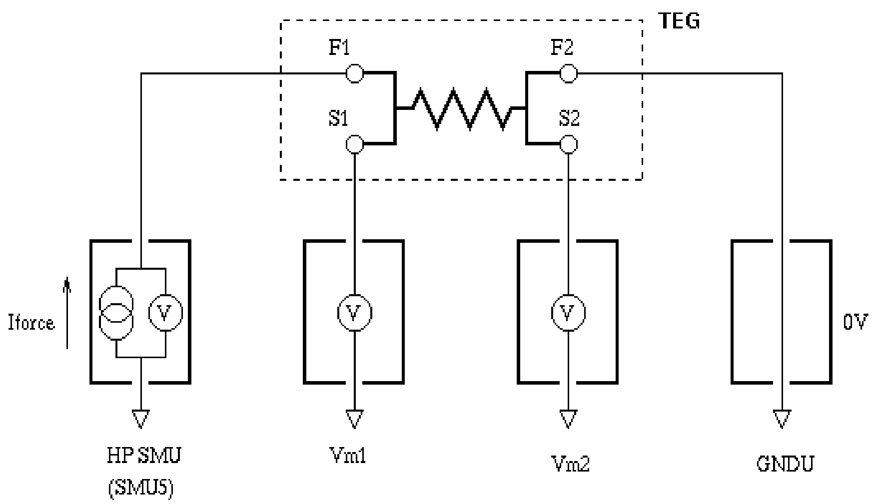


Figure 3-4 **CHANNEL DEFINITION Page**

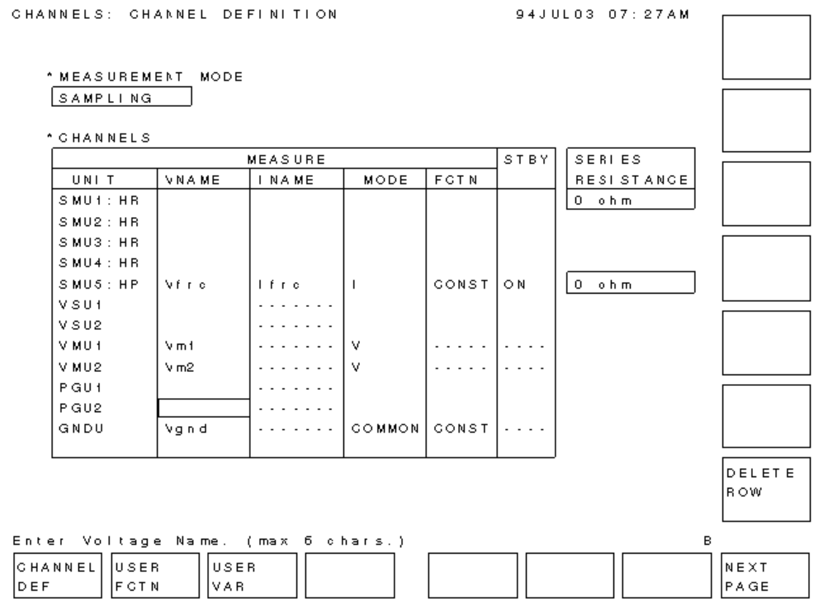
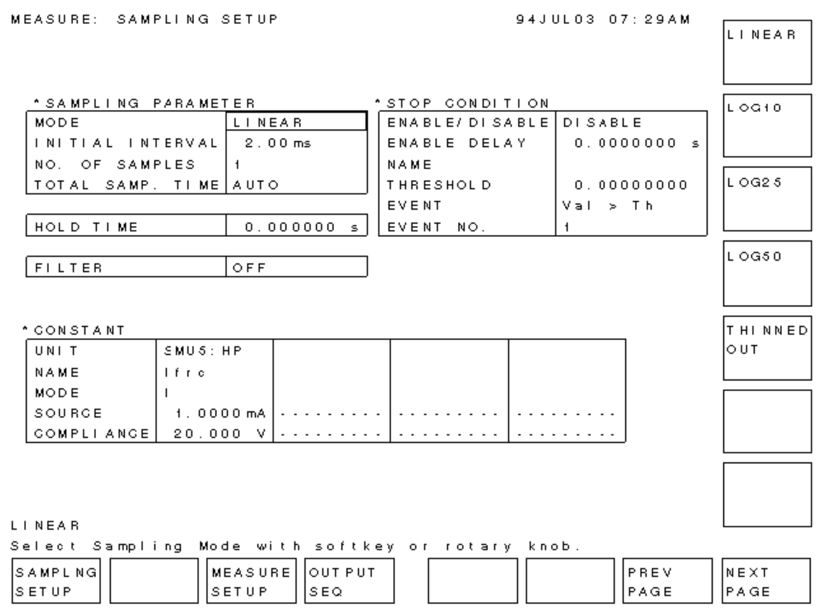


Figure 3-5 **SAMPLING SETUP Page**



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:

- Agilent 4155 or Agilent 4156 Semiconductor Parameter Analyzer
- Agilent 41501 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 4155/56 to measure initial resistance (Rinit).

- IFVM.MES

  File for setting up the 4155/56 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 “Customization”.

1. Connect the 4155/4156 to your test device. Refer to Figure 3-2.
2. Insert diskette that contains SWEAT program into built-in drive of the 4155/4156 or drive of external controller.
    - To load the program into the 4155/56, 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

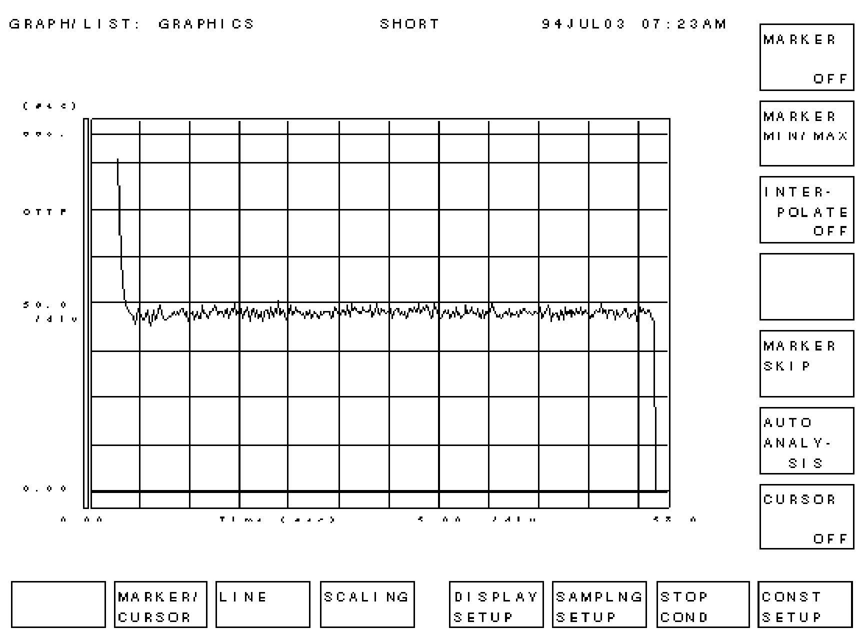
      Where *msus* is specifier of mass storage device that contains the SWEAT program. If default drive is used, just type `GET "SWEAT"` Enter.

      Then, insert the diskette into the built-in drive of the 4155/56 because the 4155/56 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 the 4155/56, 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 4155/4156.

Figure 3-6 **Measurement Result Example**



Sample SWEAT Program Overview

For the actual program code, edit SWEAT program.

Line or Subprogram Name	Description
1510	Sets the 4155/4156's address. 800 means the 4155/4156 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 the 4155/4156.
Get_file	Subprogram for loading setup file from the diskette into the 4155/56.
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 the 4155/56 user variable to program array variables, and setting up the "CTTF vs. Time" graph.

Customization

This section 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 the 4155/4156:

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

- If you will execute the SWEAT program using the 4155/4156'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 GPIB select code, and *YZ* is the GPIB address of the 4155/56.

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

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

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

Specifying Setup File to Load

Two setup files are required to set up the 4155/56 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 Timeto 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 the 4155/56 to controller.)

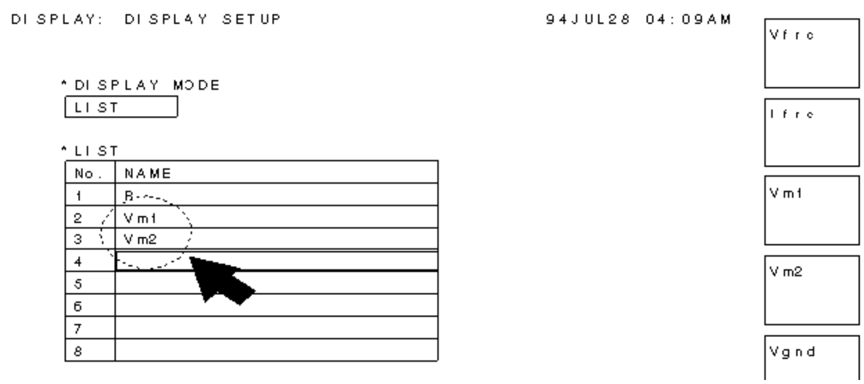
So, do not extract parameters that are not important for the measurement results. In the sample program, only the resistance is extracted, which is required to calculate CTTF.

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 3-7. In this example, Vm1 and Vm2 monitored by VMUs are added.

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

Figure 3-7 **Modification on DISPLAY SETUP Page**



Then, add following lines to the SWEAT program:

```
2130  OUTPUT @Hp415x;"TRAC? 'R'"    !ExtractR_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}:

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

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.

Setup files

This section describes the settings of the 4155/56 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 measurement setups stored in RINIT.MES file are used for the initial resistance (Rinit) measurement. The setups of each page are shown in Figure 3-8 to Figure 3-11.

Setup File for Stress/Resistance Measurement

The measurement setups stored in IFVM.MES file are used for the stress/resistance measurement loop and for displaying results (CTTF versus Time) on graph. The setups of each page are shown in Figure 3-12 to Figure 3-18.

Figure 3-8 **CHANNEL DEFINITION Page for Initial Resistance Measurement**

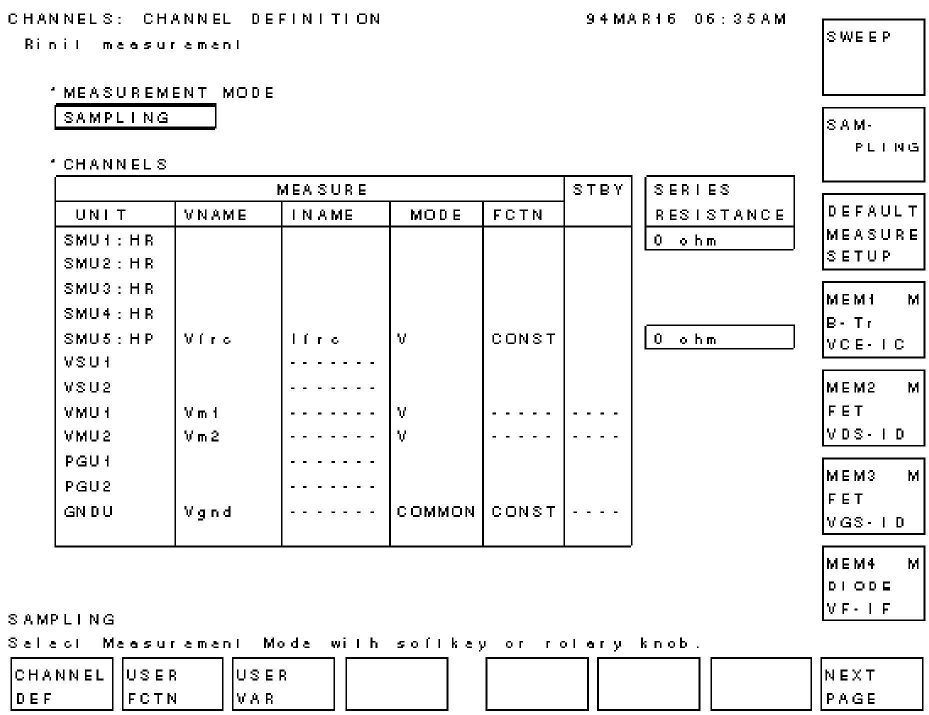


Figure 3-9 USER FUNCTION DEFINITION Page for Initial Resistance Measurement

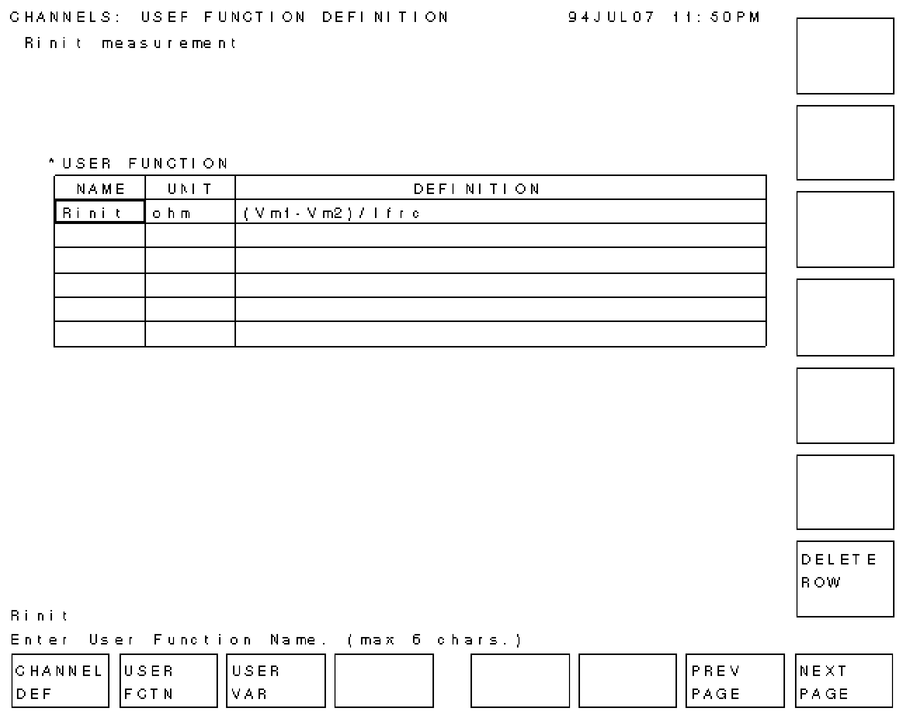


Figure 3-10 SAMPLING SETUP Page for Initial Resistance Measurement

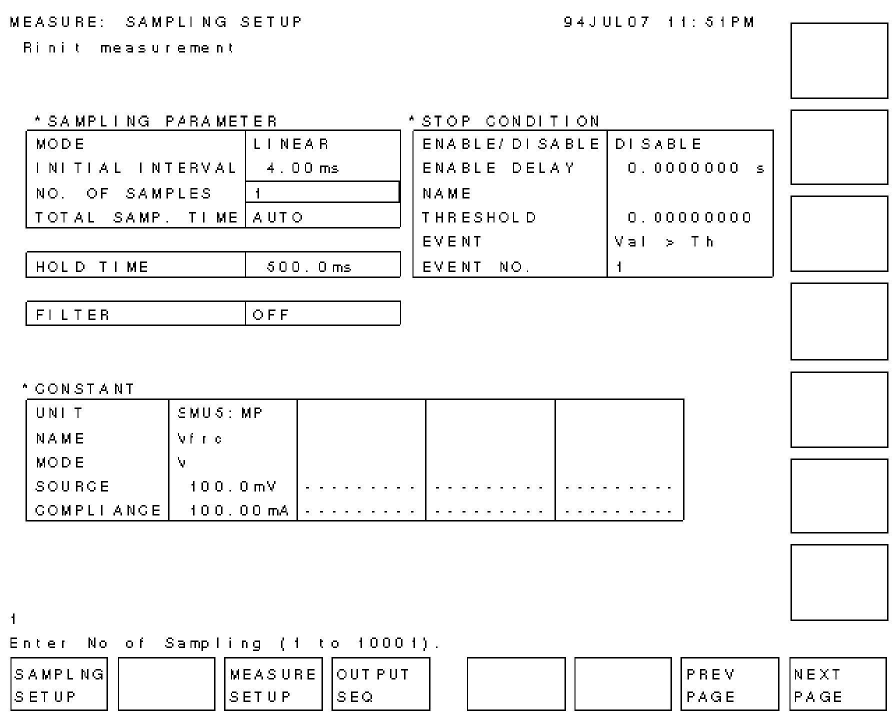


Figure 3-11 DISPLAY SETUP Page for Initial Resistance Measurement

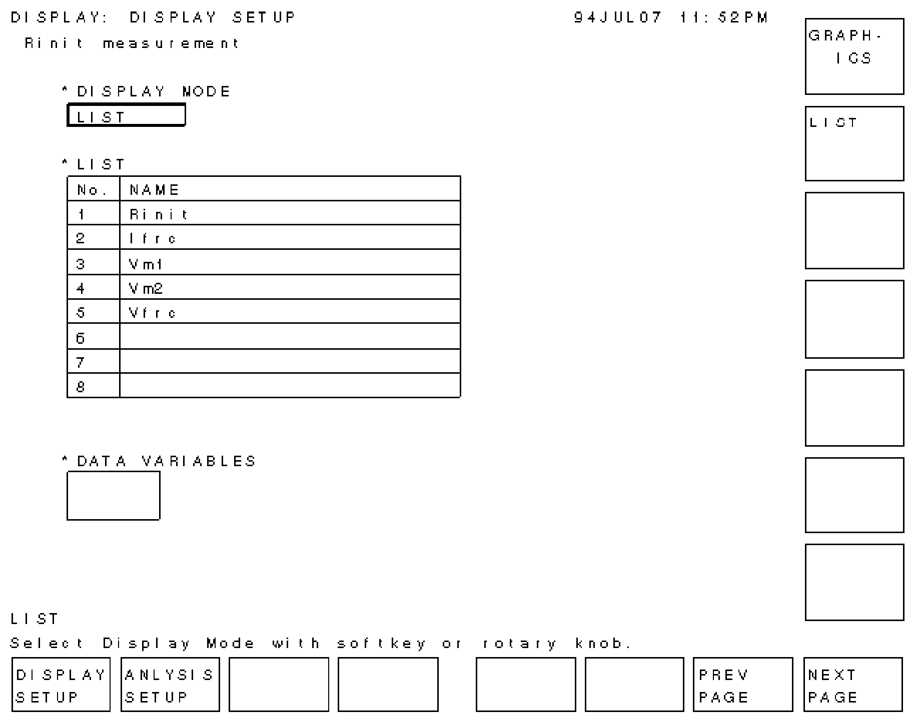


Figure 3-12 CHANNEL DEFINITION Page for Stress / Resistance Measurement

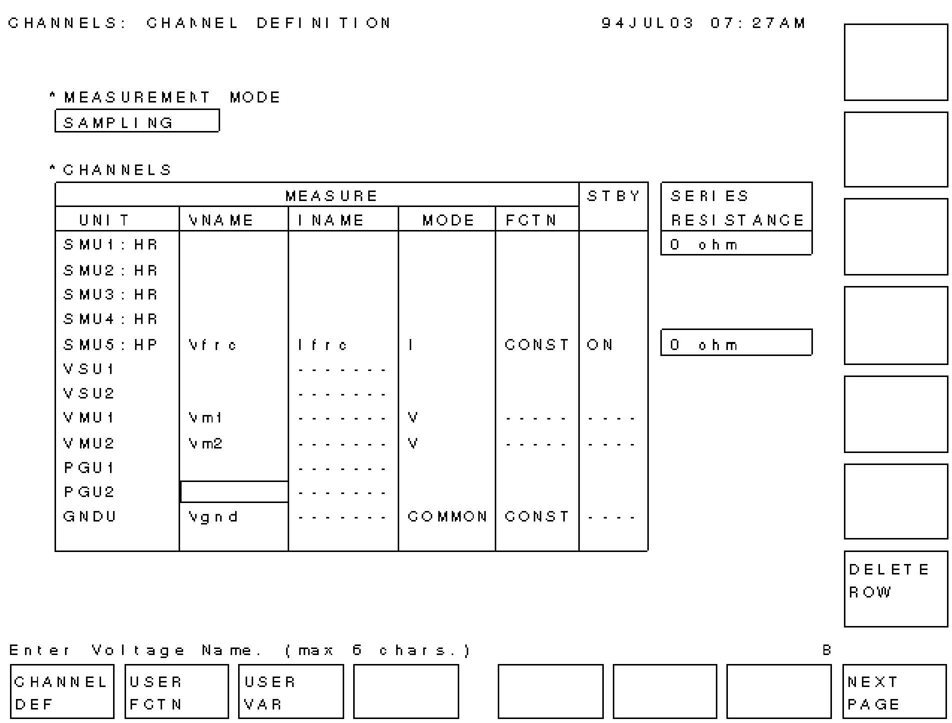


Figure 3-13 **USER FUNCTION DEFINITION Page for Stress / Resistance Measurement**

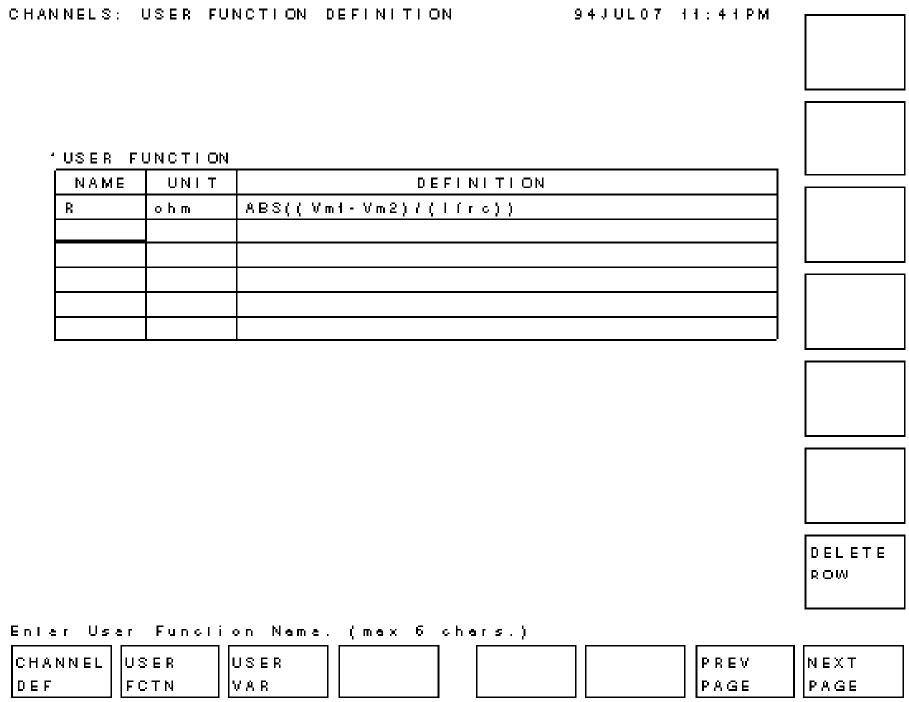


Figure 3-14 **USER VARIABLE DEFINITION Page for Stress / Resistance Measurement**

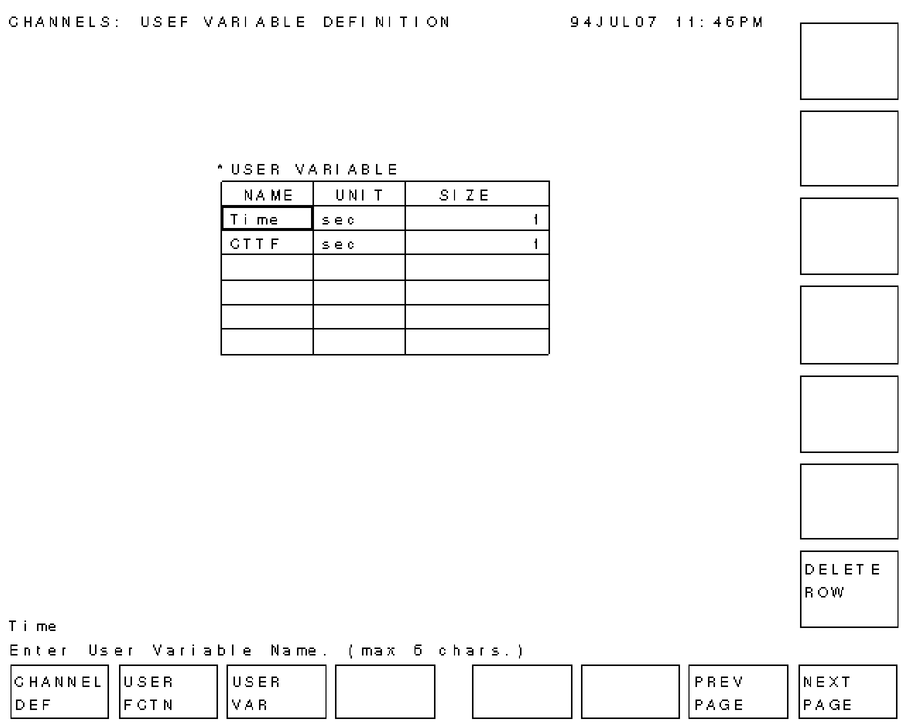


Figure 3-15 SAMPLING SETUP Page for Stress / Resistance Measurement

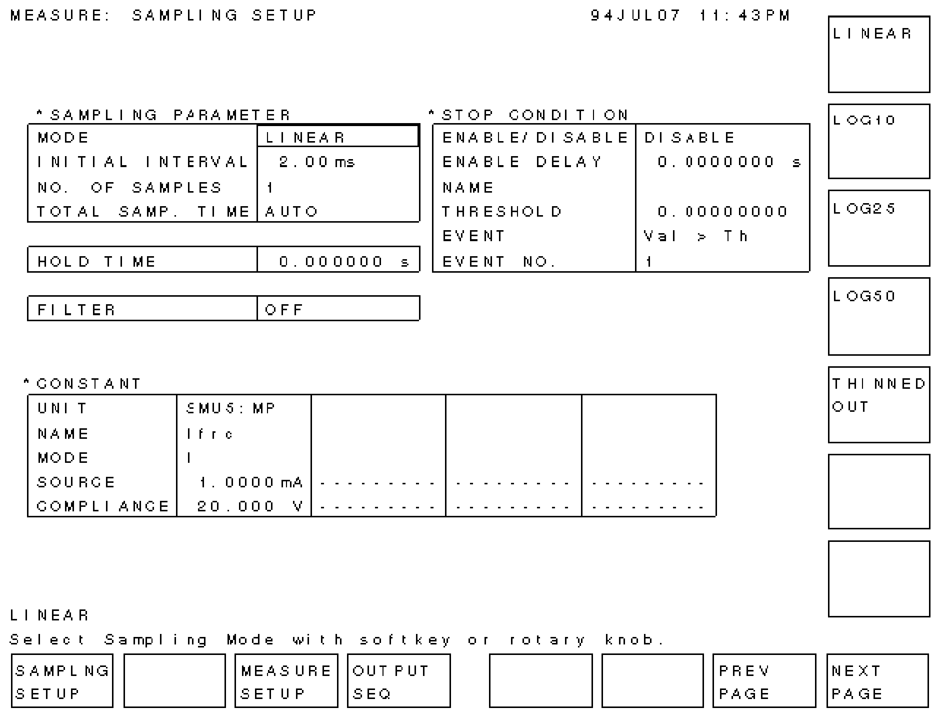


Figure 3-16 MEASURE SETUP Page for Stress / Resistance Measurement

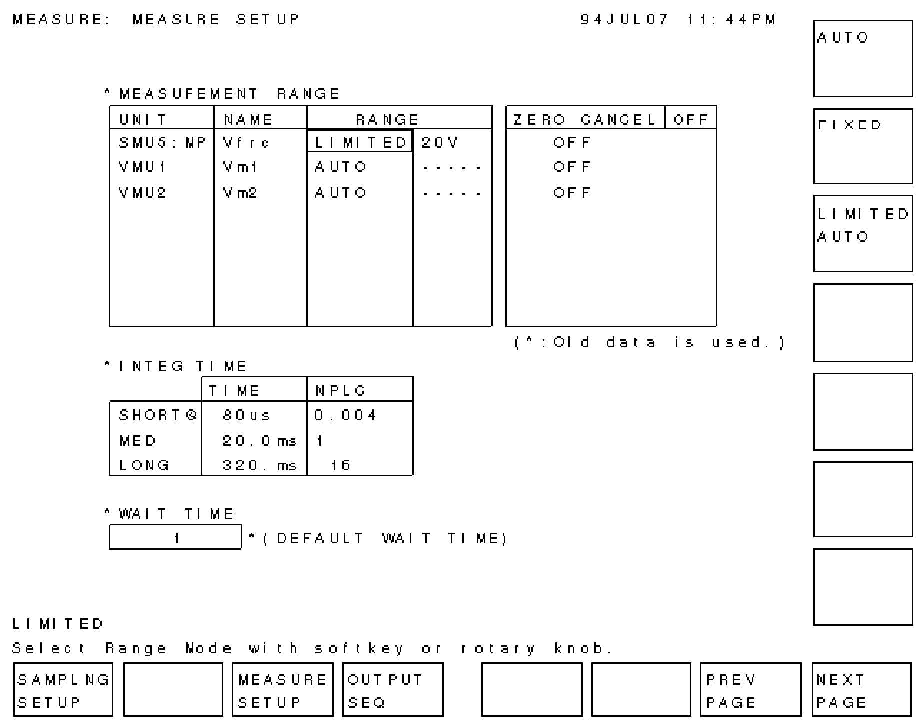


Figure 3-17 OUTPUT SEQUENCE Page for Stress / Resistance Measurement

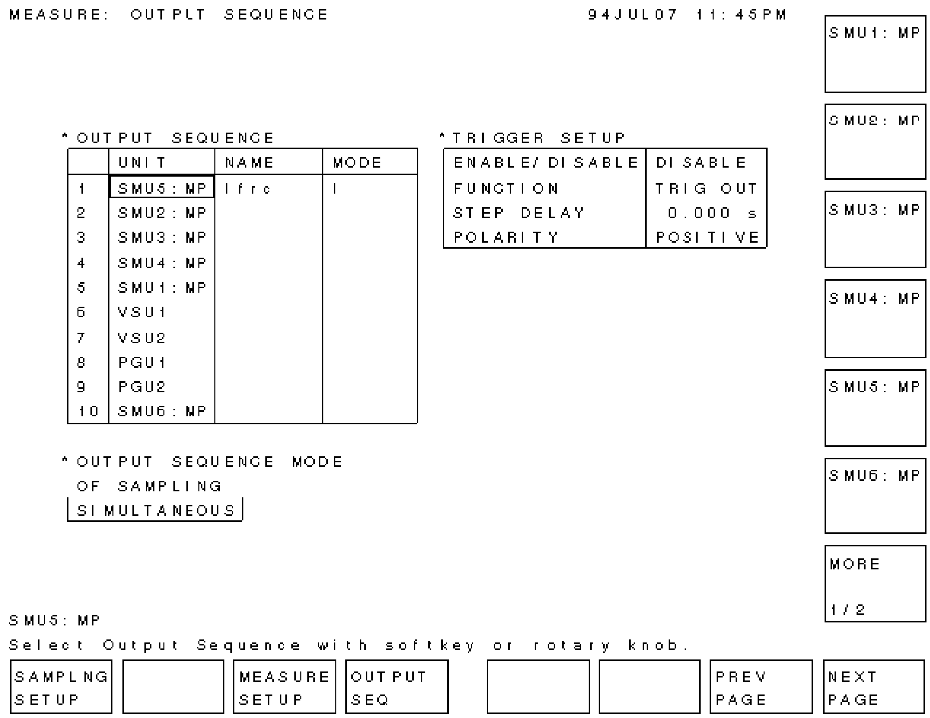
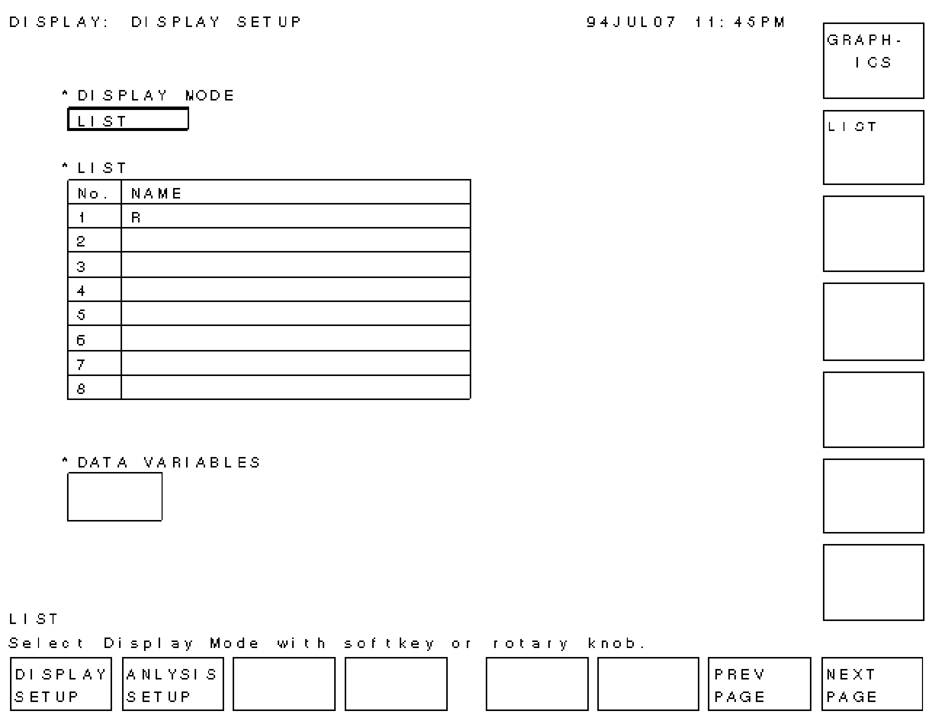


Figure 3-18 DISPLAY SETUP Page for Stress / Resistance Measurement



4 Go/NO-GO

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 4155/4156, you can turn the 4155/4156 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 4155/4156, and describes how to use and customize the program. This sample program is stored on a diskette in the `GONOGO` file.

“GONOGO Sample Program” describes outline of GONOGO sample program.

“Basic Operation” describes basic operation of the GONOGO sample program.

“Customization” describes procedure to customize the GONOGO sample program to suit your devices.

GONOGO Sample Program

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

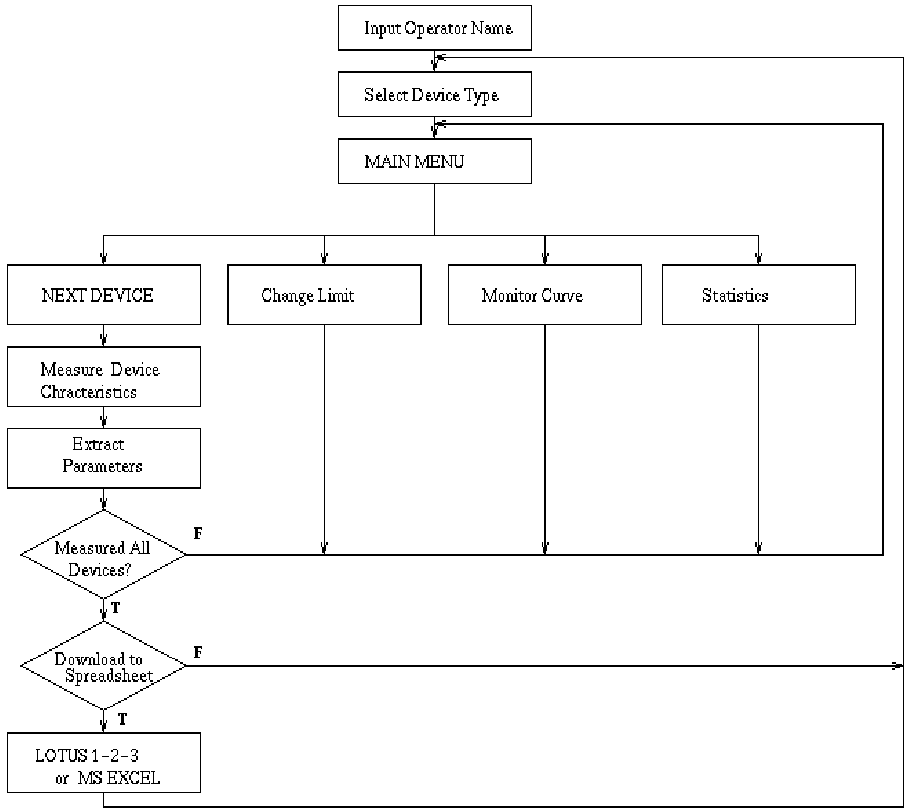
  You can display statistical results (average, maximum, minimum, standard deviation) at any time.

- 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 4-1 shows the flowchart of the GONOGO sample program.

Figure 4-1 Flowchart of GONOGO Sample Program



Basic Operation

This section 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:

- Agilent 4155 or Agilent 4156
- Agilent 16442A test fixture
- Four triaxial cables
- This operation guide
- Diskette that contains sample program and the 4155/4156 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 4155/4156 to measure Vth and beta.
- GM.MES

  File for setting up the 4155/4156 to measure gm.
- RDS.MES

  File for setting up the 4155/4156 to measure Rds(ON).
- BVCEO.MES

  File for setting up the 4155/4156 to measure BVceo.
- ICVC.MES

  File for setting up the 4155/4156 to measure Va and Rc.
- HFE.MES

  File for setting up the 4155/4156 to measure hFE.
- RE.MES

  File for setting up the 4155/4156 to measure Re.

Sample Devices

This sample program is for testing the following two devices:

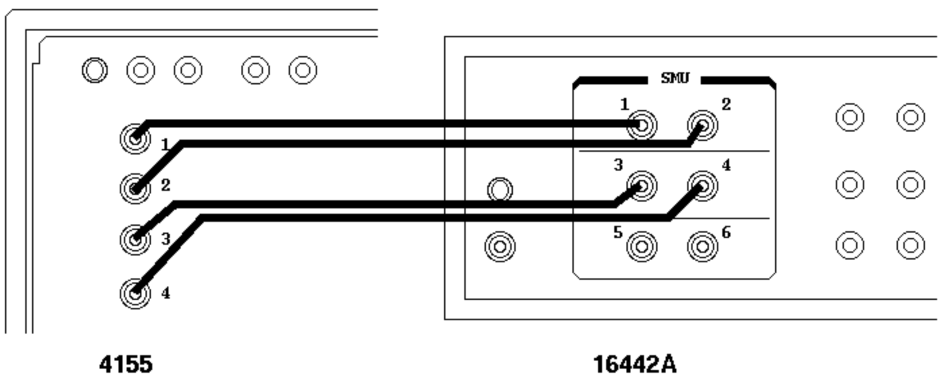
- MOSFET (SD214DE): Agilent P/N 1855-0723
- Bipolar Transistor (2N3904): Agilent P/N 1854-0215

You can customize this sample program to suit your devices. Refer to “Customization” for details.

Connection

Connect the 4155/4156 to the 16442A as shown below. If you use the 4156, connect triaxial cables to the Force terminals, and open the Sense terminals.

Figure 4-2 **Connection between 4155 and 16442A**



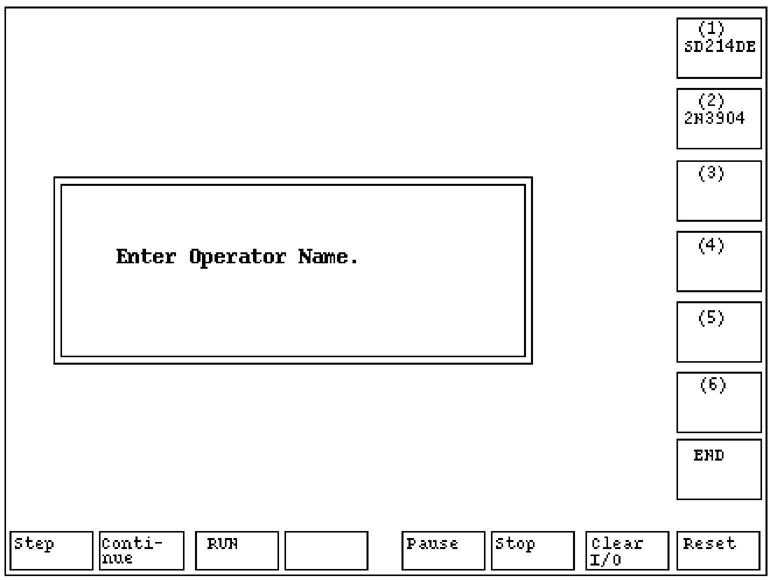
Execution

1. Insert diskette that contains GONOGO program into built-in flexible disk drive of the 4155/4156.
2. Press the IBASIC **Display** key until All IBASIC screen is displayed. And enter the following command to get the GONOGO program.

   `GET"GONOGO"`
3. Press **RUN** front-panel key to execute the program.
4. You need to enter supplemental information, such as "Operator name", as shown in Figure 4-3.

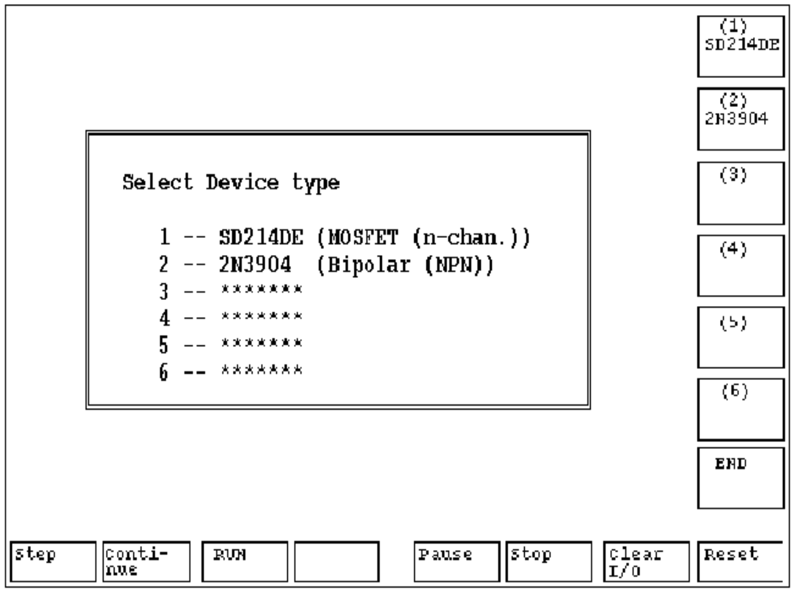
   Type in your name, then comment as requested.

Figure 4-3 **Operator Name Input Screen**



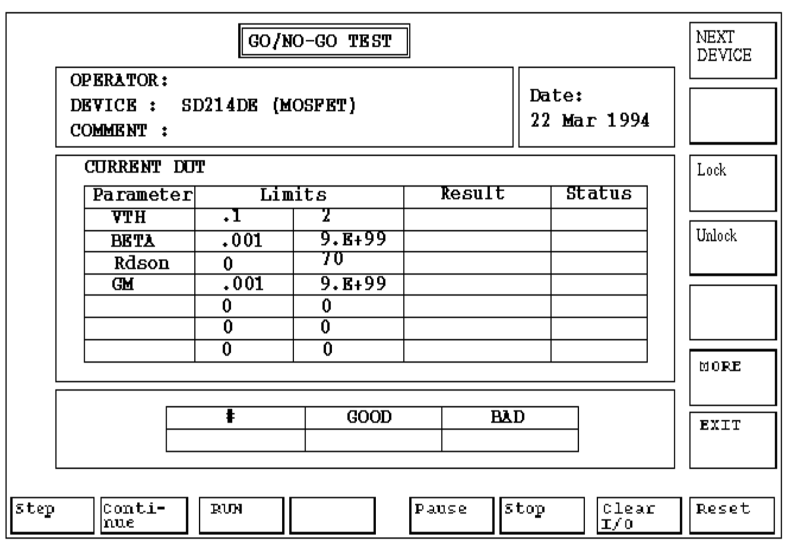
5. Program prompts you to select the device type from the selection menu as shown in Figure 4-4.

Figure 4-4 Device Selection Menu



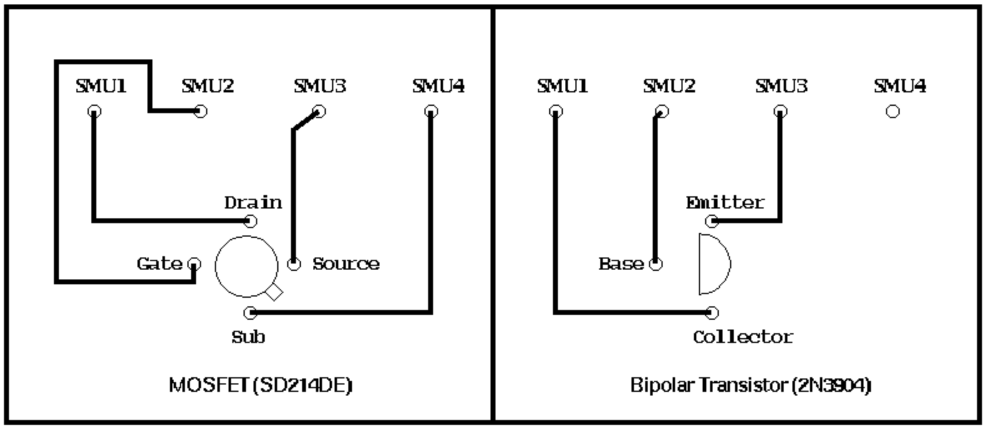
6. Select the softkey of desired device type. The following is displayed.

Figure 4-5 Main Display



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

Figure 4-6 Connection of Device on Test Fixture (Top View)



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

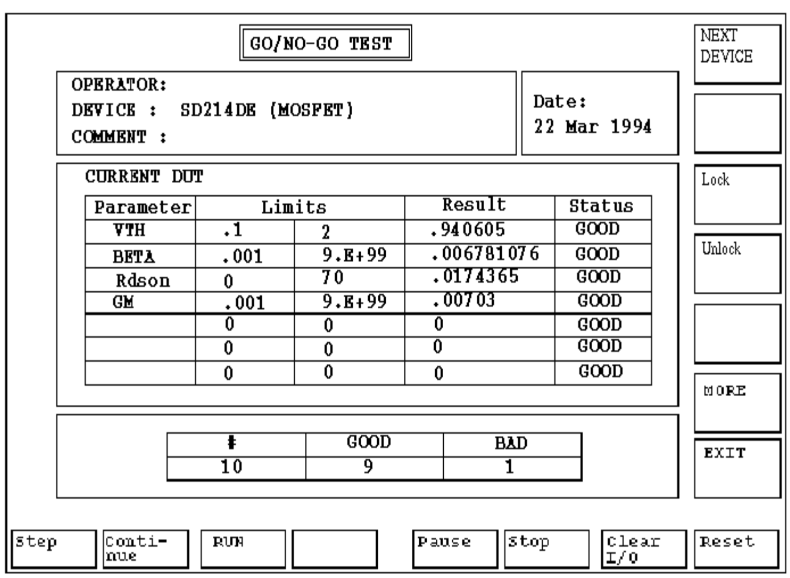
   The parameter extractions are performed one by one. After all the measurements are finished, results are displayed.

   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 4-7 shows an example result screen after several devices are measured.

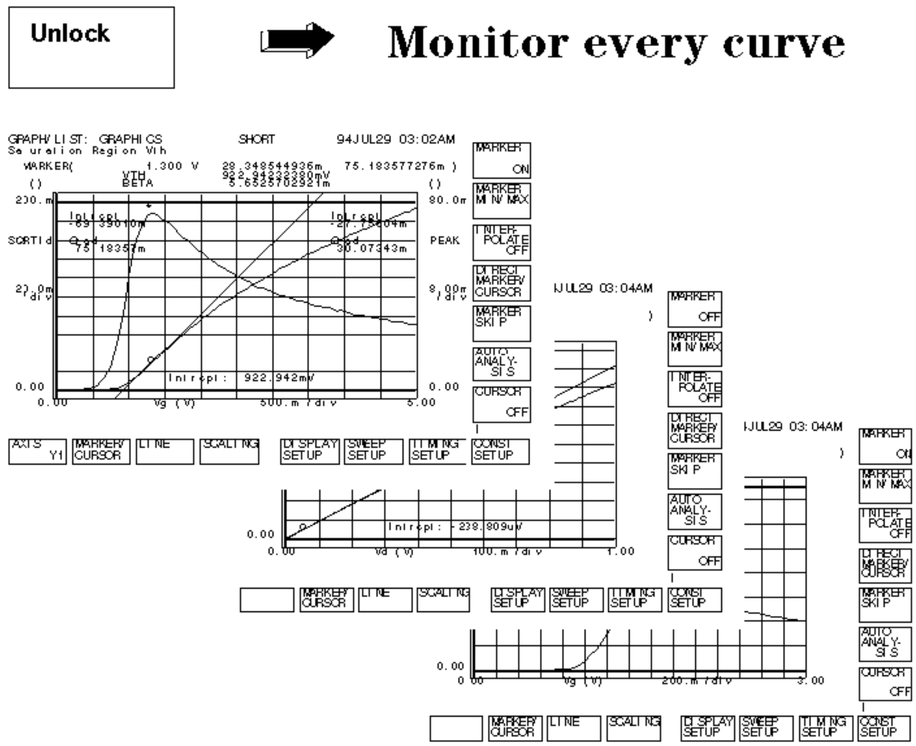
Figure 4-7 Example Result Screen



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.

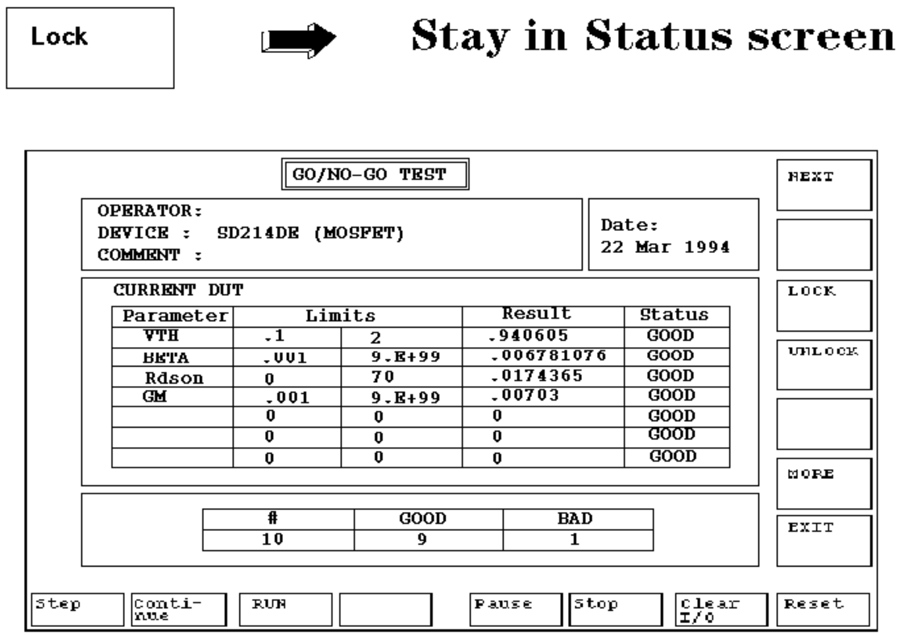
Figure 4-8 Unlock Function Shows Every Curve while Measurement is in Progress



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.

Figure 4-9 Lock Function Displays only the Status Screen

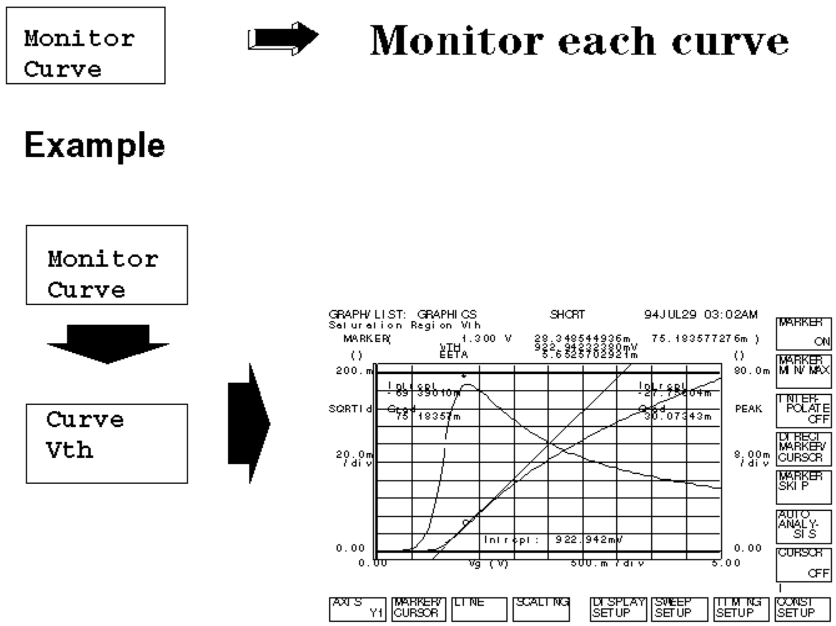


Viewing a Particular Measurement Curve

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.

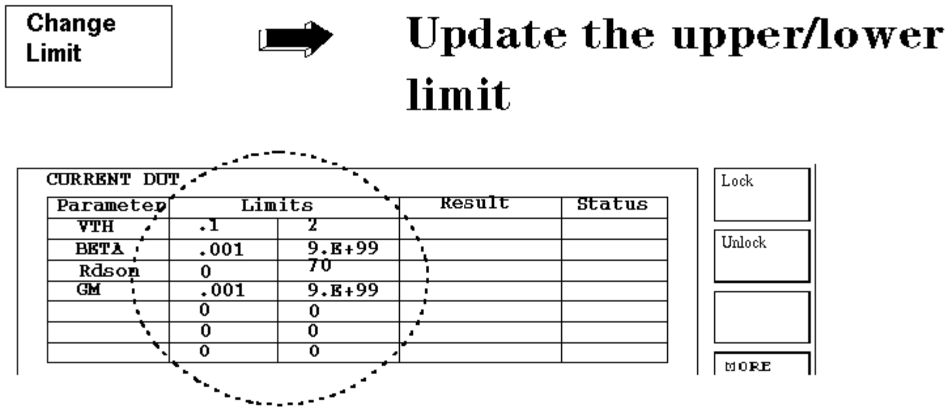
Figure 4-10 **Monitor Curve Softkey**



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.

Figure 4-11 **Change Limit Softkey**

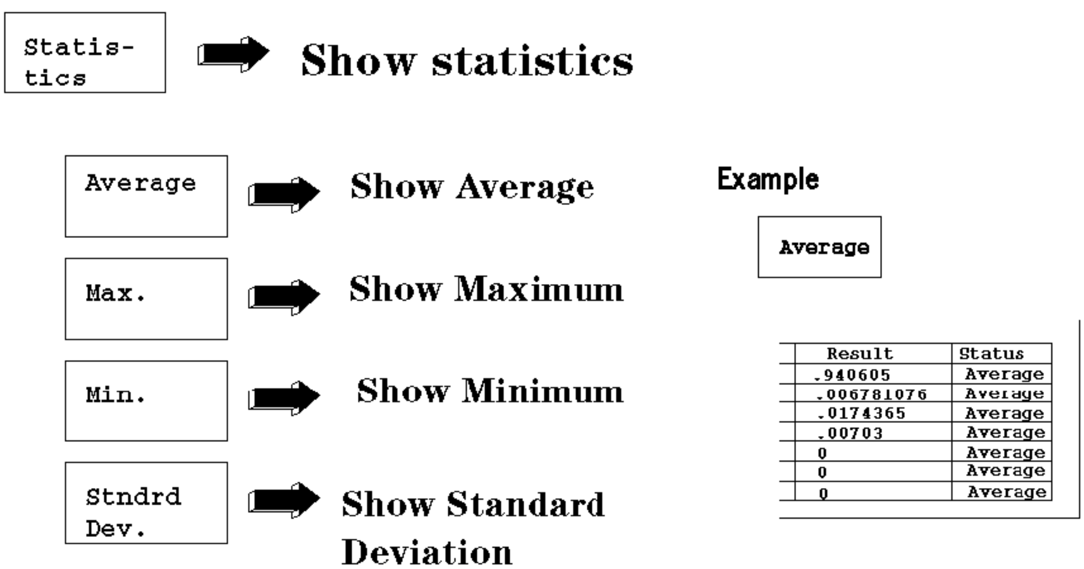


Displaying Statistical Data

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

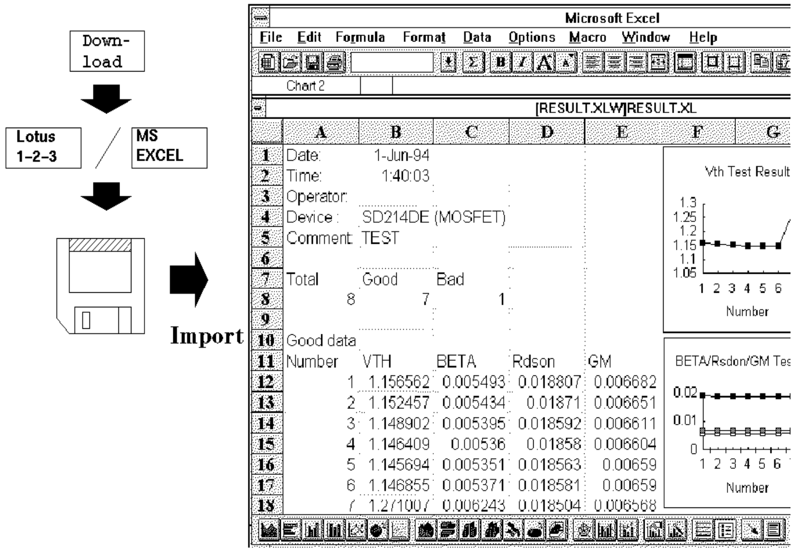
Then, select the softkey of the statistical data that you want to display. The statistical data of all devices that have been measured is displayed in the Result column, and the type of statistic is displayed in the Status column.

Figure 4-12 **Statistics Softkey**



Exporting Data to Spreadsheet

Figure 4-13 **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

Customization

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

Also, this section 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 4155/4156 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:

To 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)

To 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

To Create the Measurement Setup Files

Create a file (*filename*.MES) for setting up the 4155/4156 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 4155/4156. For example, to extract Vth, the following 4155/4156 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.

Figure 4-14 CHANNEL DEFINITION Page

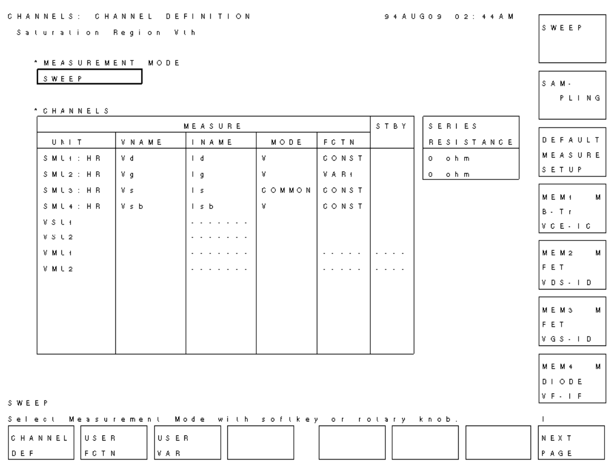


Figure 4-15 USER FUNCTION DEFINITION Page

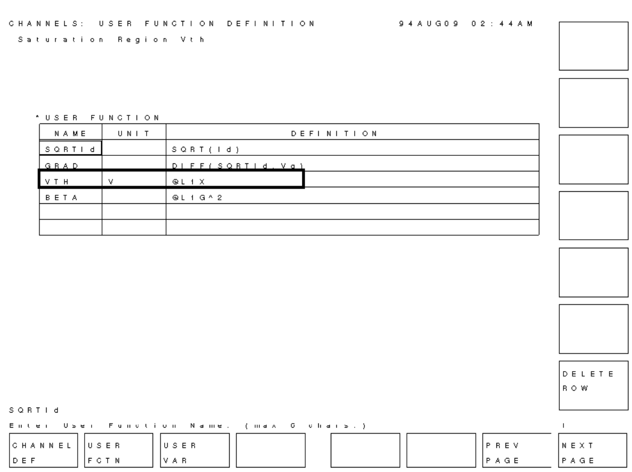


Figure 4-16 **SWEEP SETUP Page**

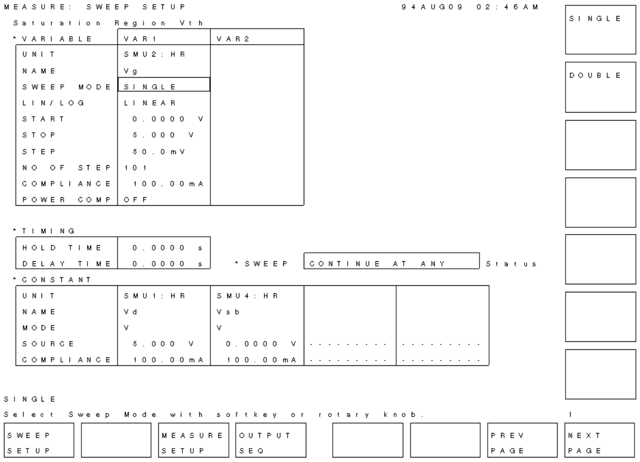


Figure 4-17 **DISPLAY SETUP Page**

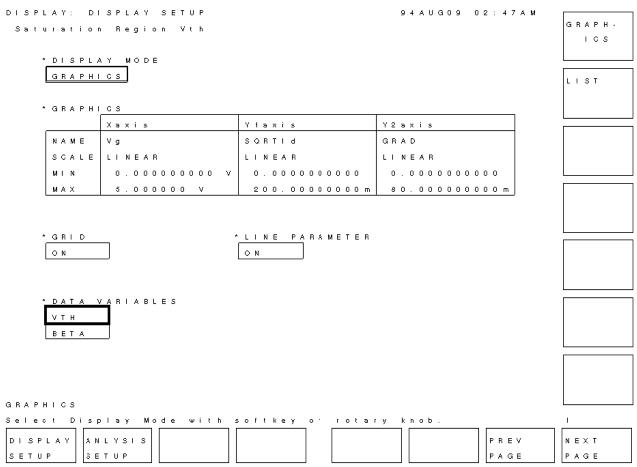


Figure 4-18 **ANALYSIS SETUP Page**

To Edit Select_dut Subprogram

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

In the IBASIC editor, enter the following command. And edit the subprogram.

```
EDIT Select_dut
```

Adding Device Type to Selection Menu.

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

```
9380  PRINT TABXY(13,13);"2 -- 2N3904  (Bipolar (NPN))"
9390  PRINT TABXY(13,14);"3 -- *******"  !for future enhancement###
9400  PRINT TABXY(13,15);"4 -- *******"  !for future enhancement###
```

For example, modify line 9390 as follows:

```
9380  PRINT TABXY(13,13);"2 -- 2N3904  (Bipolar (NPN))"
9390  PRINT TABXY(13,14);"3 -- 2N4351  (MOSFET (npn))"
9400  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.

```
9470  ON KEY 2 LABEL " (2)   2N3904 " GOTO Dut2
9480  ON KEY 3 LABEL " (3)          " GOTO End
9490  ON KEY 4 LABEL " (4)          " GOTO End
   :            :
9690  Dut3:    !
9700      Dut_flag=3
9710      Dname$=""
9720      GOTO Exit
```

In this example, we will modify lines 9480 and 9710 as follows:

```
9470  ON KEY 2 LABEL " (2)   2N3904 " GOTO Dut2
9480  ON KEY 3 LABEL " (3)   2N4351 " GOTO End
9490  ON KEY 4 LABEL " (4)          " GOTO End
   :            :
9690  Dut3:    !
9700      Dut_flag=3
9710      Dname$="2N4351 (MOSFET)"
9720      GOTO Exit
```

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

To Edit Dut_spec Subprogram

The Dut_spec subprogram sets the following for your device: parameter names, limits of each parameter, the name of the 4155/4156 measurement setup file to extract the parameter, and unit of each parameter.

In the IBASIC editor, enter the following command. And edit the subprogram:

```
EDIT Dut_spec
```

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:

```
2630      M_file$(7)=""
2640   !
2641      CASE 3
2650      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 “To 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 “To Create the Measurement Setup Files”.

Example Modification.

Following is an example modification. If you do this modification which inserts lines 2641 to 2681, program line numbers 2650, 2660, 2670, and 2680 of original program will automatically shift to 2683, 2684, 2685, and 2686, respectively.

```
2640  !
2641     CASE 3
2642       Par$(1)="VTH"    !parameter names
2643       Par$(2)="GM"
2644       Par$(3)="BVdss"
2645       Par$(4)="Rdson"
2646       Par$(5)=""
2647       Par$(6)=""
2648       Par$(7)=""
2649  !
2650       Par_lmx(1)=2.5   !parameter spec max limit
2651       Par_lmx(2)=90
2652       Par_lmx(3)=9.E+99
2653       Par_lmx(4)=9.E+99
2654       Par_lmx(5)=0
2655       Par_lmx(6)=0
2656       Par_lmx(7)=0
2657  !
2658       Par_lmn(1)=.2    !parameter spec min limit
2659       Par_lmn(2)=.001
2660       Par_lmn(3)=40
2661       Par_lmn(4)=.001
2662       Par_lmn(5)=0
2663       Par_lmn(6)=0
2664       Par_lmn(7)=0
2665  !
2666       Par_lu$(1)="V"
2667       Par_lu$(2)="S"
2668       Par_lu$(3)="V"
2669       Par_lu$(4)="o"
2670       Par_lu$(5)=""
2671       Par_lu$(6)=""
2672       Par_lu$(7)=""
2673  !
2674       M_file$(1)="EXVTH.MES"
2675       M_file$(2)="EXGM.MES"
2676       M_file$(3)="EXBV.MES"
2677       M_file$(4)="EXRDS.MES"
2678       M_file$(5)=""
2679       M_file$(6)=""
2680       M_file$(7)=""
2681  !
2683     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 4040).

Measurement parameter extraction starts from line 4130. Insert the handler control routine between lines 4120 and 4130.

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 4740.

If you want to sort the device using handler, put the control routine for sorting just after line 4740 referring to the value of `Flag`.

5 HCI Degradation Test

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 4155/4156, and how to use and customize the programs. The programs are written in the Instrument BASIC (IBASIC), and are ready to run on the built-in IBASIC controller of the 4155/4156.

"Hot-Carrier-Induced (HCI) Degradation Test" describes basic theory, procedure, and terminology of the HCI degradation test.

"HCI Degradation Test Data Analysis" describes the HCI degradation test data analysis procedure.

"Basic Operation" describes the HCI degradation test methodology using the 4155/4156, how to execute the sample programs, and program overview.

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

"Setup Files" shows the 4155/4156 page settings that are stored in the setup files.

Hot-Carrier-Induced (HCI) Degradation Test

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

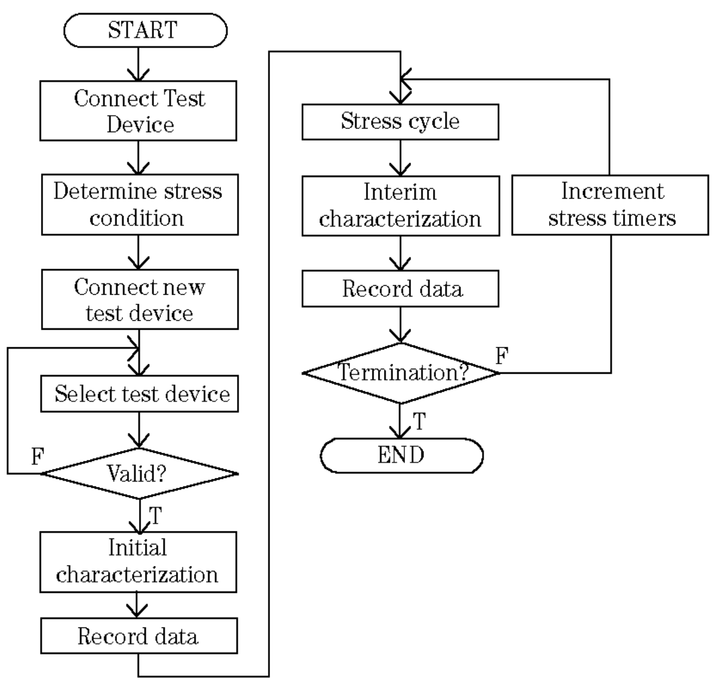
Hot-carriers are generated in the MOSFET by large electric fields in channel near the drain region. Hot-carriers break bonds at the Si/SiO_2 interface and can be also trapped in the SiO_2. The trapping or bond breaking creates interface traps and oxide charge that affect the channel carrier's mobility, 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 5-1 shows the flow of the HCI degradation test according to the JEDEC proceeding titled "A PROCEDURE FOR MEASURING HCI" (29-JULY-93).

Figure 5-1 **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*) – *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*=1µA*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 (Tdc)”.
- 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

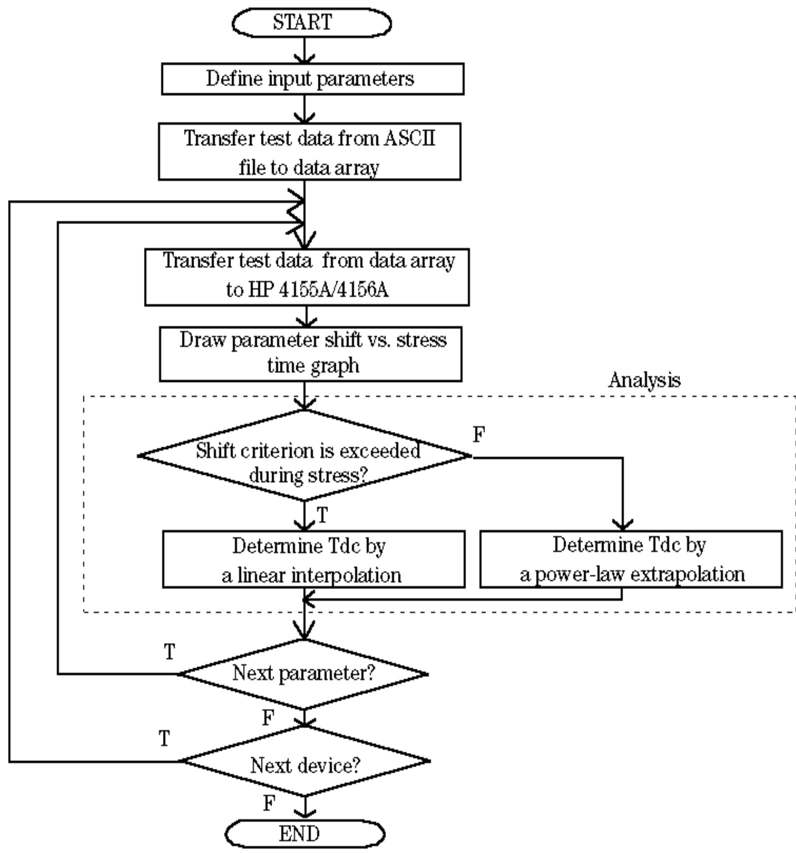
- The temperature of the wafer chuck or the temperature of the test fixture must be controlled to a temperature of 22 °C ± 3 °C.
- The stress time interval should be known to an accuracy of ± 3 %.

HCI Degradation Test Data Analysis

This section 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.

Figure 5-2 shows the flow of the HCI degradation data analysis according to the JEDEC proceeding titled "A PROCEDURE FOR MEASURING HCI" (29-JULY-93).

Figure 5-2 Data Analysis Algorithm Flow



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

  Example for *Idlin*

  Idlinshift(t) = (*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.

Figure 5-3 **Example Extrapolation of HCI Degradation Data**

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

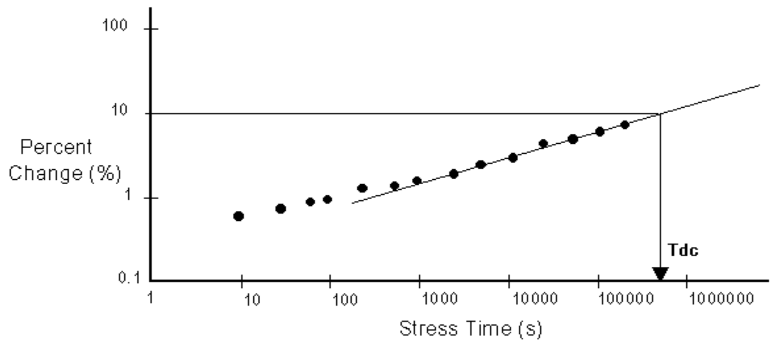
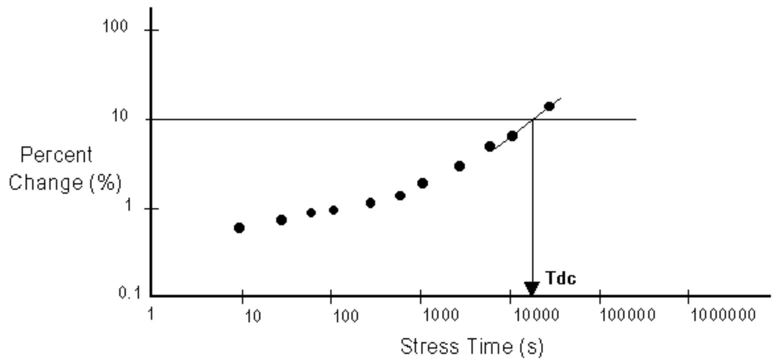


Figure 5-4 **Example Interpolation of HCI Degradation Data**

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.



Basic Operation

This section describes how to use the 4155/4156 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 4155/4156. Or you can modify the sample program to run on an external controller that supports HP BASIC or Instrument BASIC. Refer to “Customization” on how to modify the program to run on an external controller.

The programs load measurement setup files into the 4155/4156 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 4155/4156 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 the 4155/4156, and stores data in ASCII files.

The `DCDAHC` program can perform multiple test device evaluation by using Agilent 4085M switching matrix. Figure 5-5 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 “Customization”.

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

Input Parameters

Table 5-1and Table 5-2 show 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.

Figure 5-5 HCI Degradation Test Algorithm Flow for Multiple Devices

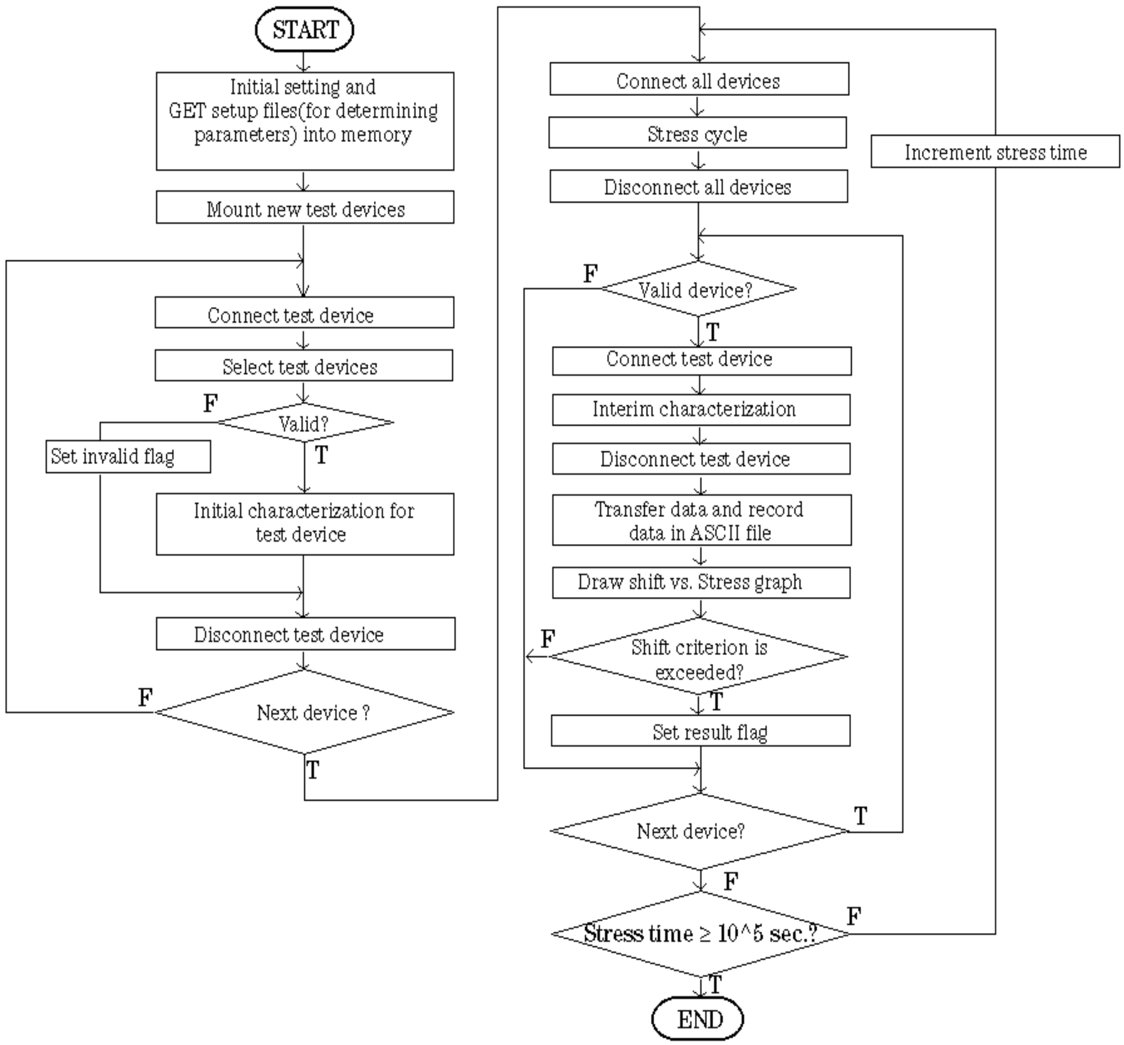


Table 5-1 Input Parameters for HCI Degradation Test Program (DCDAHC)

Parameter Name	Description
Hpib_sc	GPIB select code for controlling 415X
Hpib_addr	GPIB address of 415X
Swm	GPIB 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(*) [a]	Source pin assignment of device to stress/measure
Gate(*) [a]	Gate pin assignment of device to stress/measure
Drain(*) [a]	Drain pin assignment of device to stress/measure
Bulk(*) [a]	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

Parameter Name	Description
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)

a. * is device number.

Table 5-2 **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: 0 V

Bulk stress voltage Vb: Vbb (= 0 V)

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 4155/4156 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 4155/4156 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`	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:

- Agilent 4155 or Agilent 4156 Semiconductor Parameter Analyzer
- Agilent 4085M Switching Matrix (Agilent 4084B Switching Matrix Controller and Agilent 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 5-6 and Figure 5-7.

Figure 5-6 **DC HCI Degradation Test Equipment Connections**

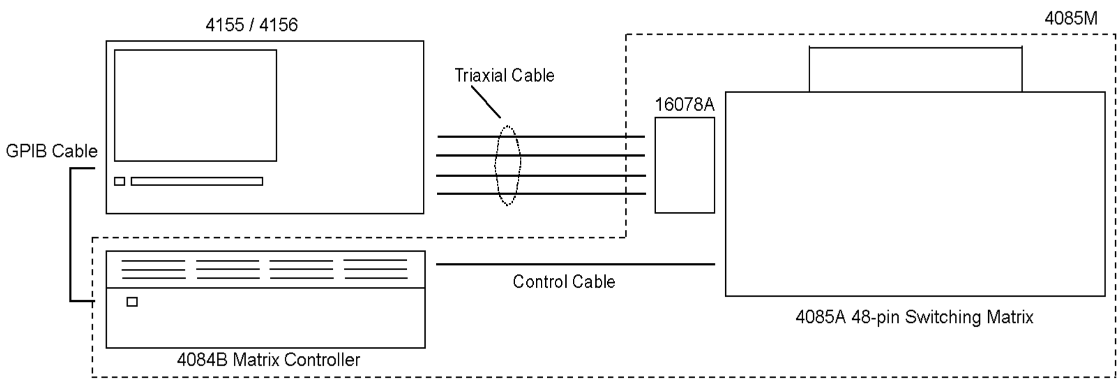
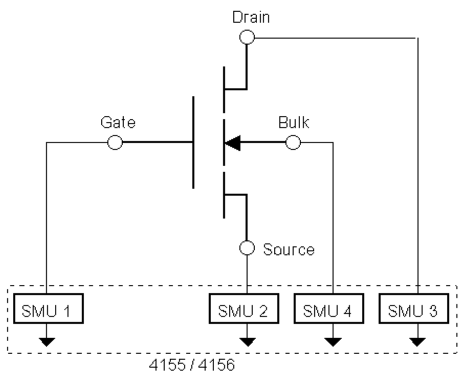


Figure 5-7 **DC HCI Degradation Test Device Connections**



NOTE

If you test on a wafer, you need to have Agilent 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:

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

WARNING

Maximum output voltage is limited to *40V* if you use Agilent 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” on page 5-41 for details.

- Agilent 41501 SMU and Pulse Generator Expander furnished with 2 PGUs (Option 402, 412 or 422)
- Agilent 16440A 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 4155/4156 to measure Id-Vd plot and determine Vdstr before running DCDAHC program.
IBVG.MES	File for setting up the 4155/4156 to measure Ib-Vg plot and determine Vgstr
IGLEAK.MES	File for setting up the 4155/4156 to measure gate leakage current for selecting test device
IDLEAK.MES	File for setting up the 4155/4156 to measure drain leakage current for selecting test device
ISLEAK.MES	File for setting up the 4155/4156 to measure source leakage current for selecting test device
DCDAHC.STR	File for setting up the 4155/4156 to force DC stress to test device
PARAM.MES	File for setting up the 4155/4156 to determine Idlin, Gmmax, Vtext, and Vtci after each stress
ACDAHC.STR	File for setting up the 4155/4156 to force AC stress to test device
ANALYSIS	DC Drain-Avalanche HCI degradation test data analysis sample program

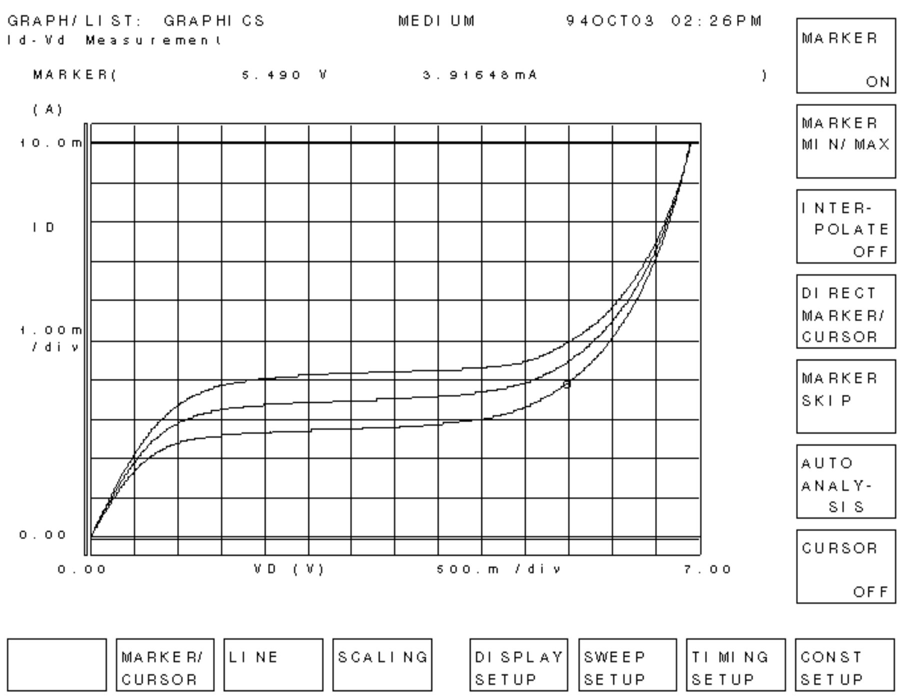
Execution

Before Executing HCI Degradation Test

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

1. Connect the 4155/4156 to the 4085M switching matrix, then mount or probe the test device (that is used to determine stress conditions) on the 4085M.
2. Load the IDVD.MES setup file from the diskette into the 4155/4156, then perform the measurement. The Id-Vd measurement is displayed as shown in Figure 5-8.
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 “Customization” for details.

Figure 5-8 **Id-Vd Measurement Example**



HCI Degradation Test

1. Connect the 4155/4156 to the 4085M switching matrix. If you test packaged devices, mount necessary test fixture on the switching matrix. If you test on wafer, mount the 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 4085M.

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

   - In case of using the built-in IBASIC of the 4155/4156, press the IBASIC **Display** key until All IBASIC screen is displayed. And enter the following command:

     `GET "DCDAHC"`

   - If you use an external controller on which HP BASIC is working, enter the following command:

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

     Where *msus* is specifier of mass storage device that contains the DCDAHC program. If default *msus* is used, enter the following command:

     `GET "DCDAHC"`

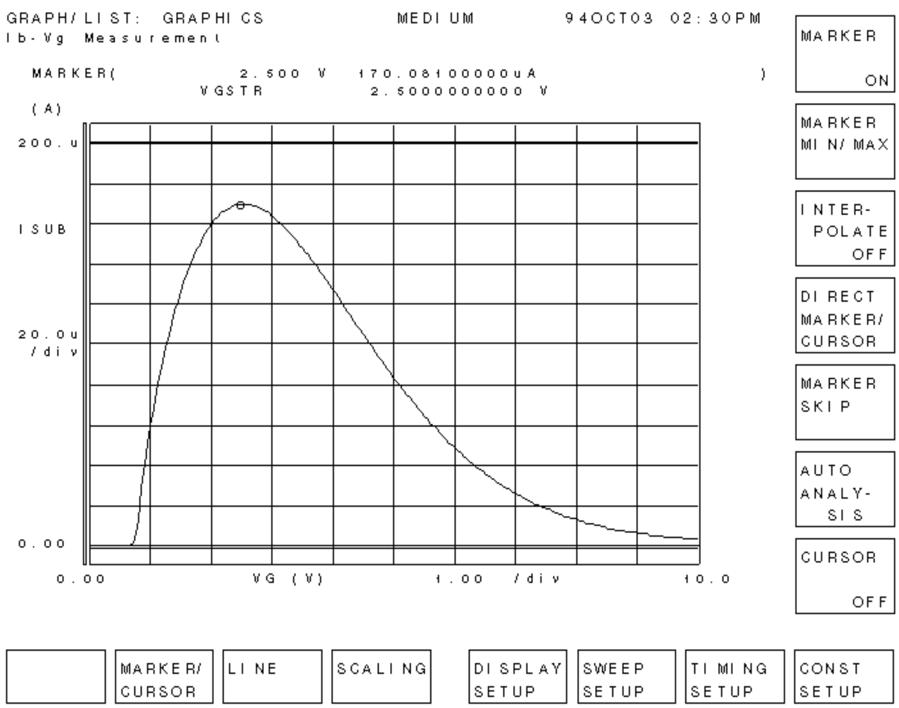
     Then insert the diskette into the built-in disk drive of the 4155/4156. The diskette is used when the measurement setup files are loaded.

4. Press **RUN** front-panel key to run DCDAHC program in the 4155/4156.

   To run DCDAHC program in external controller, type `RUN`, then press **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 5-9.

Figure 5-9 Ib-Vg Measurement Example



5. After the message shown below 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.

   `"Connect HCI degradation test devices"`

   If the device is valid, the following message is displayed.

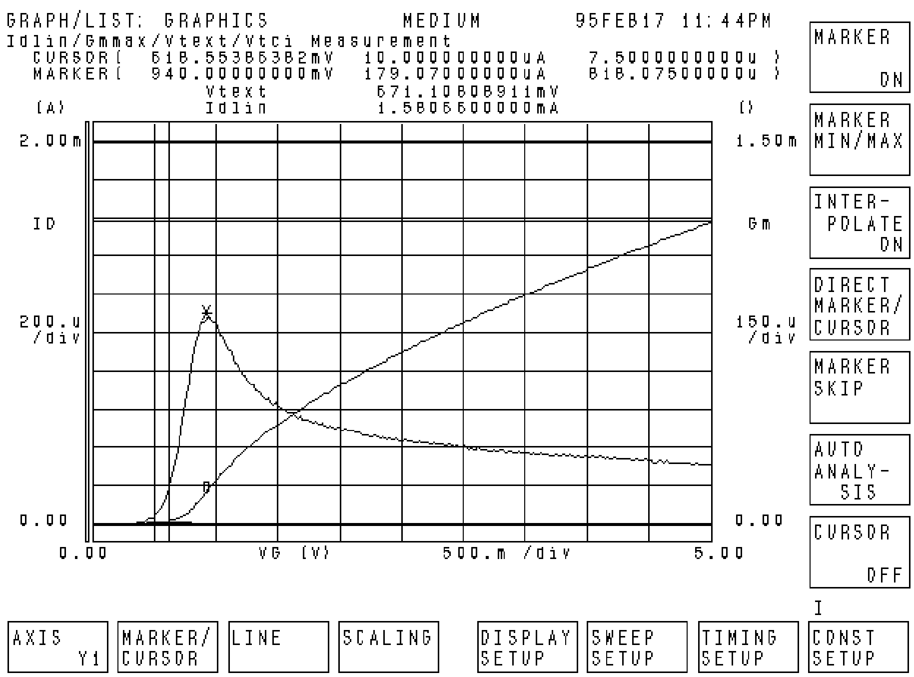
   `"Device No. = ` *`XX`* ` can be used"`

   If the device is invalid, the following message is displayed.

   `"Device No. = ` *`XX`* ` shall not be used"`

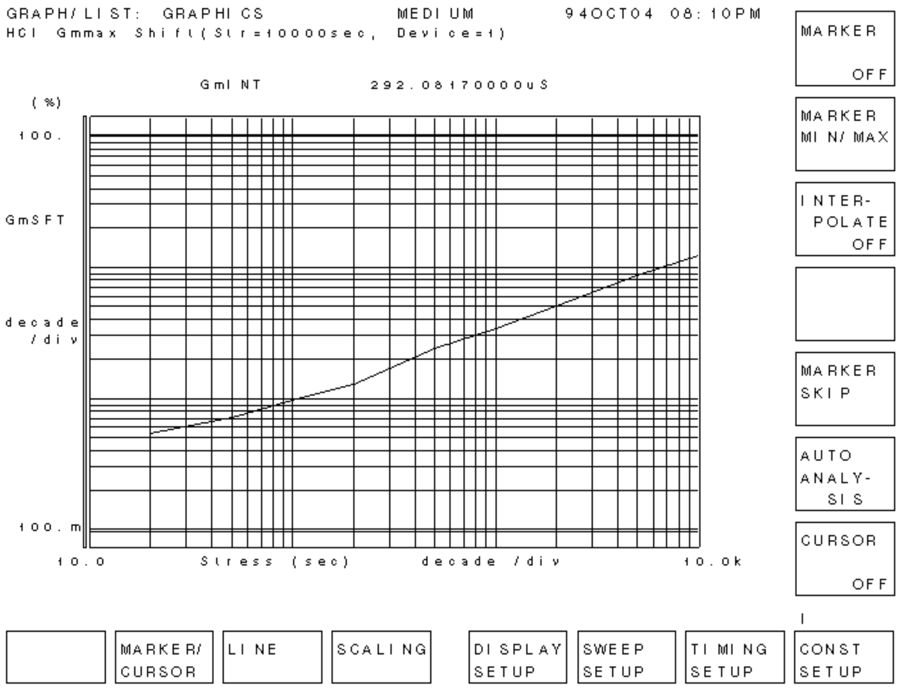
6. The initial characterization is performed for all *valid* devices. Then stress/interim characterization loop is executed until stress termination occurs. In each interim characterization, Idlin, Gmmax, Vtext and Vtci are determined. An example measurement is shown in Figure 5-10.

Figure 5-10 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 4155/4156 as shown in Figure 5-11.

Figure 5-11 HCI Degradation Test Result Example



8. After testing, the following message is displayed.

   `"HCI Degradation Test is Completed!!"`

   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:

     a. `Vdstr`, `Vgstr`, `Gate_length`, `Gate_width` values at stress termination

     b. Number of interim characterization points until stress termination for the device, and initial measurement data of the device

     c. Parameter shift data for each interim characterization points until stress termination

        In case of `ID`*XX* for example, `Idlin_shift`(*) are saved.

     d. 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:

     a. `Vdstr`, `Vgstr`, `Gate_length`, `Gate_width`

     b. 0,0

Data Analysis

1. Insert diskette that contains `ANALYSIS` program and ASCII data files into built-in drive of the 4155/4156 or drive of external controller.

   - To load the program into the 4155/4156, press the IBASIC **Display** key until All IBASIC screen is displayed. Then, enter the following command:

     ```
     GET "ANALYSIS"
     ```

   - To load the program into an external controller, enter the following command on the external controller:

     ```
     GET "ANALYSIS:,msus"
     ```

     Where *msus* is specifier of mass storage device that contains the ANALYSIS program. If default *msus* is used, enter the following command:

     ```
     GET "ANALYSIS"
     ```

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

2. Press **RUN** front-panel key to execute ANALYSIS program on the 4155/4156.

   To run ANALYSIS program on external controller, type `RUN`, then press **Enter**.

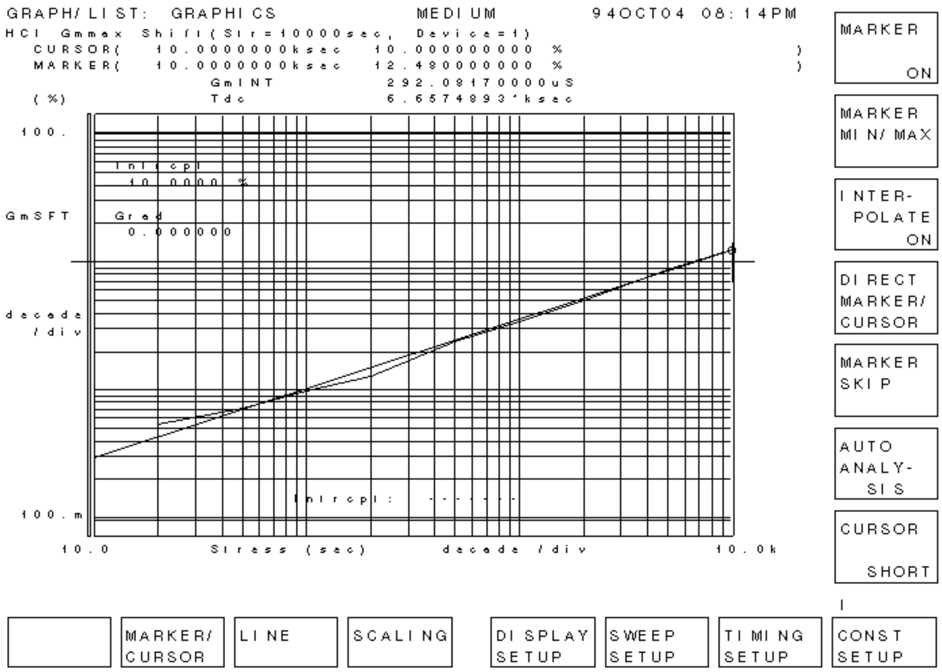
3. Enter number of devices to be analyzed. Default number is 4.

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 4155/4156 as shown in Figure 5-12. 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.

Figure 5-12 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 4155/4156 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.

Example of ANAHCI data file:

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

Example:

```
 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 program.

Line or Subprogram Name	Description
1640 to 1750	Sets the GPIB interface select code and address for the 4155/4156 and 4085M. `800` means the 4155/4156 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 GPIB interface select code and address for the 4085M are set to `722`.
1770 to 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 4155/4156
2750 to 2760	Enables service request from 4155/4156 to interrupt program
2790	Calls Str_define subprogram, which determines DC stress condition
2860 to 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 to 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 to 3240	Calls subprograms that connect devices (Swm_connect), performs an interim characterization (Param_meas), then disconnects devices (Swm_clear).
3280 to 3330	Calls subprograms (Record_*parameter*) that save interim characterization data to ASCII files after each interim characterization
3340 to 3360	Calls Record_data subprogram, which saves interim characterization data to DAT type files after each interim characterization (Commented)
3400 to 3760	Calls subprograms (Stress_*parameter*) that draw "parameter shift vs stress time" graphs for specified devices and parameters.
3800 to 4000	Judges whether shift criterion is exceeded for each parameter
4050 to 4090	Judges whether test should be terminated

Line or Subprogram Name	Description
4080	Judges whether all devices exceed shift criterion
4090	Judges whether accumulated stress time exceeds 100,000 sec
4130 to 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 4155/4156 at the end of test
4230	Displays test completion message
Initial_setting (4280)	Defines the dimension of data arrays and initializes test result data variables
Init_hp415x (4650)	Initializes 4155/4156, loads PARAM.MES and DCDAHC.STR setup files into the 4155/4156, 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

Line or Subprogram Name	Description
Stress_vtigraph (11820)	Draws "Vtci shift vs stress time" graph
Calibration (12510)	Performs calibration of the 4155/4156
Connect (12690)	Connects one SMU port to the specified pin of the 4085M
Swm_connect (12850)	Connects four SMU ports to the specified different pins of the 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 4155/4156 error occurred during the test
Error_rep (13490)	Checks if 4085M error occurred during the test
Record_data (13600)	Saves interim characterization data to DAT type files
Test_end (13690)	Initializes 4155/4156 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 to 1630	Sets the GPIB interface select code and address for the 4155/4156. `800` means the 4155/4156 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 to 1830	Assigns input parameter values and file names
1850 to 1890	Prompts you to specify input parameters.
1920 to 2160	Creates labels for softkeys that allow you to select which parameters to analyze
2200	Calls Init_setting subprogram, which sets the 4155/4156 display to be not updated, then transfers Idlin/Gmmax/Vtext/Vtci shift data from ASCII file to IBASIC data arrays
2260 to 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 the 4155/4156
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 to 2480	Performs same operations for Gmmax shift data as was performed for Idlin shift data
2500 to 2600	Performs same operations for Vtext shift data as was performed for Idlin shift data
2620 to 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 4155/4156 at the end of program

Line or Subprogram Name	Description
2840	Displays analysis completion message
Init_setting (2880)	Sets the 4155/4156 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 the 4155/4156
Trans_gmdata (4440)	Transfers Gmmax shift data from IBASIC data array to the 4155/4156
Trans_vtedata (4940)	Transfers Vtext shift data from IBASIC data array to the 4155/4156
Trans_vtidata (5430)	Transfers Vtci shift data from IBASIC data array to the 4155/4156
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 4155/4156 at the end of test

Customization

This section 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 4155/4156. However, you may be able to use an external computer, such as *HP 9000 S382* .

The following lines specify the GPIB select code and address of the 4155/4156:

```
1670  Hpib_sc=8      !415X GPIB Select Code
1680  Hpib_addr=0    !415X GPIB Address
```

- If you will execute the DCDAHC or ANALYSIS program using the 4155/4156 built-in IBASIC controller, use the above GPIB 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 GPIB select code is 7, and the GPIB address of the 4155/4156 is 17, modify as follows:

  ```
  1670  Hpib_sc=7      !415X GPIB Select Code
  1680  Hpib_addr=17   !415X GPIB Address
  ```

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

  1. Press **System** key.
  2. Select MISCELLANEOUS softkey.
  3. Move the field pointer to the 415x is field, then select NOT CONTROLLER softkey.
  4. Move the field pointer to the 415x field of the GPIB ADDRESS area, then enter 17.

Modifying and Specifying Setup File to Load

The DCDAHC program loads six setup files to set up the 4155/4156 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 4155/4156, even if you run the program from the external controller.

The setup pages of each setup file are shown in "Setup Files" on page 5-44.

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 dialog, 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 dialog, 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 4155/4156. The file names are defined in the following lines of the program:

```
2360 !-------Definition of measurement and stress setup files---------
2370 !
2380 Ibvg_file$="IBVG.MES"     !Ib-Vg meas. to determine Vgstr
2390 Igleak_file$="IGLEAK.MES" !Ig-time meas. to check gate leak
2400 Idleak_file$="IDLEAK.MES" !Id-time meas. to check drain leak
2410 Isleak_file$="ISLEAK.MES" !Is-time meas. to check source leak
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 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 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" on page 5-19.

```
2480 !------- File name to save ASCII data -------------------------
2490 Idlin_data$="ID"    !Idlinshift data file name
2500 Gmmax_data$="GM"    !Gmmaxshift data file name
2510 Vtext_data$="VTE"   !Vtextshift data file name
2520 Vtci_data$="VTI"    !Vtcishift 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 character
istics
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” on page 5-19.

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 4155/4156 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 4085M switching matrix. If you want to use another switching matrix, modify the following subprograms by replacing with corresponding GPIB control commands for your switching matrix.

Subprogram	Input Parameter	Functionality
`Connect`	`Port` (Port number), `Pin` (Pin number), `Swm` (GPIB 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` (GPIB 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 5-13 shows the setup for AC HCI degradation test. Figure 5-14 shows the measurement circuit.

Figure 5-13 AC HCI Degradation Test Equipment Connections

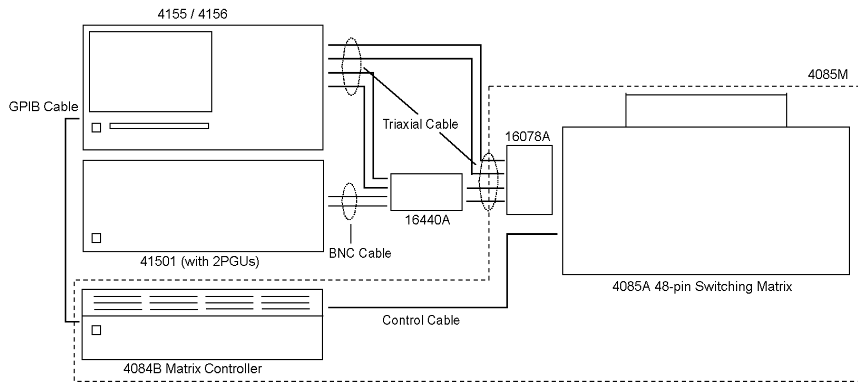
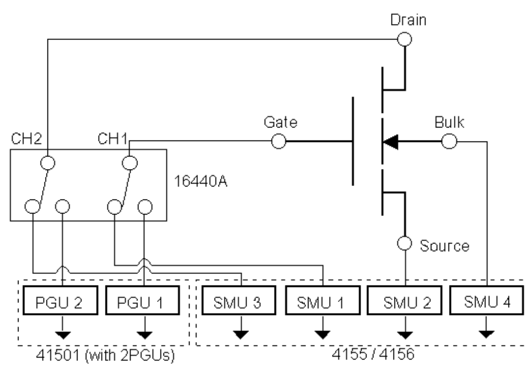


Figure 5-14 AC HCI Degradation Test Device Connections



ACDAHC.STR file must be used instead of DCDAHC.STR. This file sets up the 4155/4156 as shown in "Setup Files" on page 5-44. 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

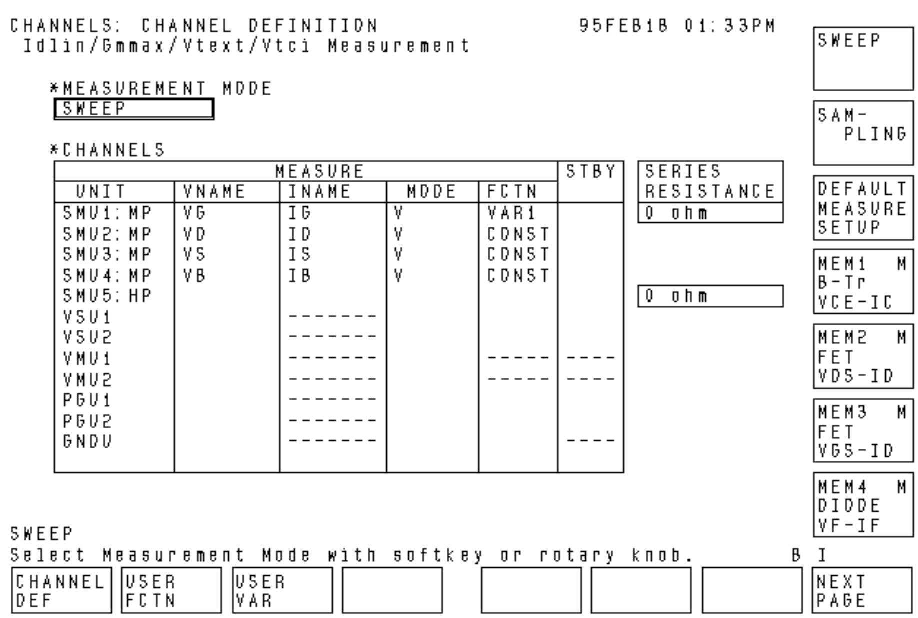
Before starting AC stress test, you need to modify setup of `ACDAHC.STR` file. Set appropriate pulse period, width, leading time, and trailing time on STRESS: STRESS SETUP page.

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.

Figure 5-15 **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  !---------------InputParameters---------------
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 “HCI Degradation Test Data Analysis” on page 5-8. 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"
```

Setup Files

This section describes the settings of the 4155/4156 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 the 4155/4156 to determine Vdstr.

NOTE

You need to use this setup to determine Vdstr manually before running the DCDAHC program. See “Execution” on page 5-19 for details.

Figure 5-16 **CHANNEL DEFINITION Page of IDVD.MES**

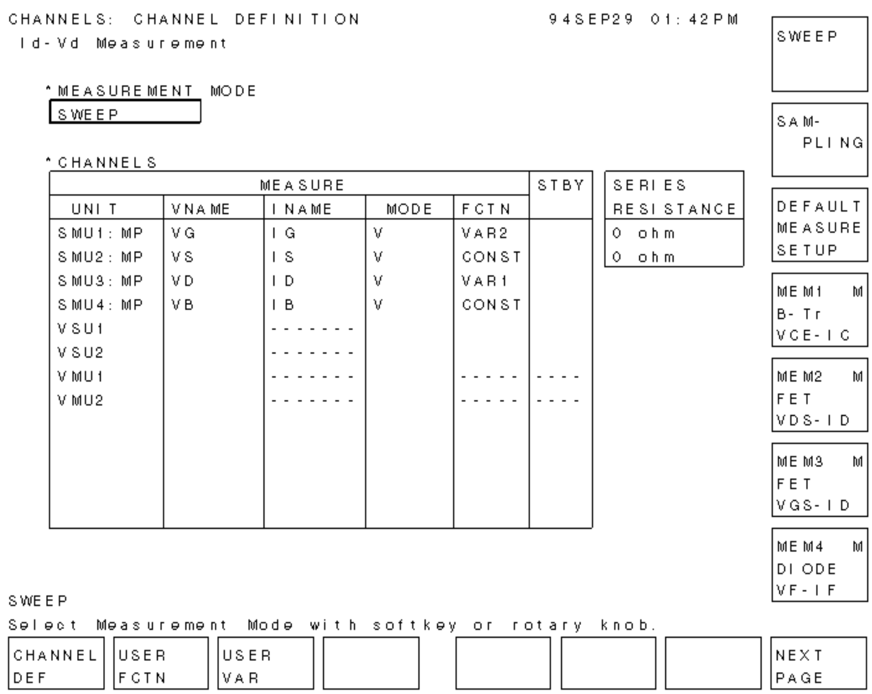


Figure 5-17 SWEEP SETUP Page of IDVD.MES

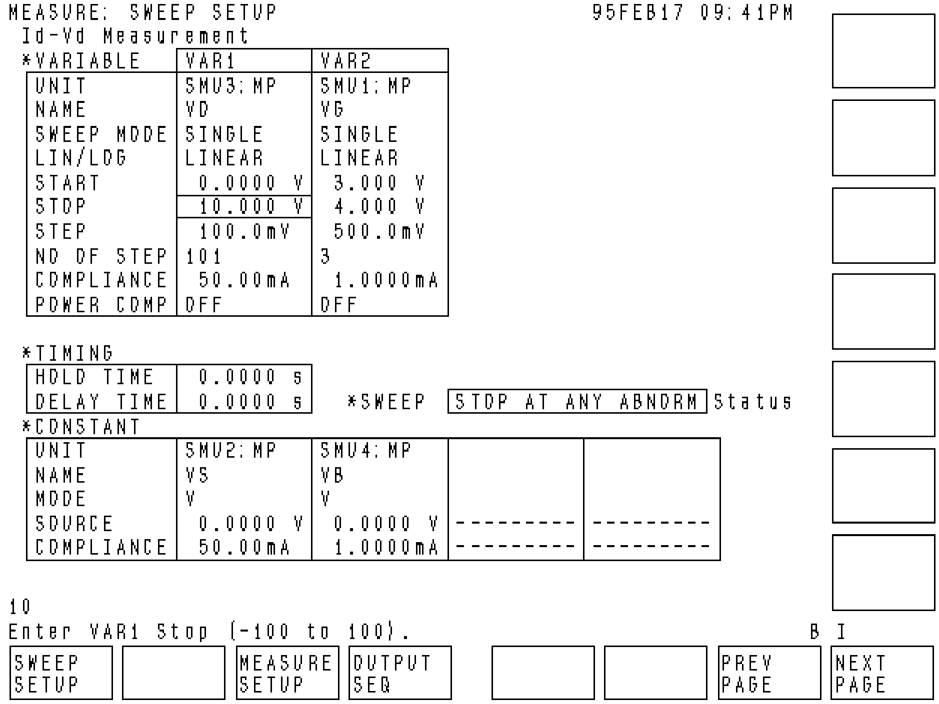
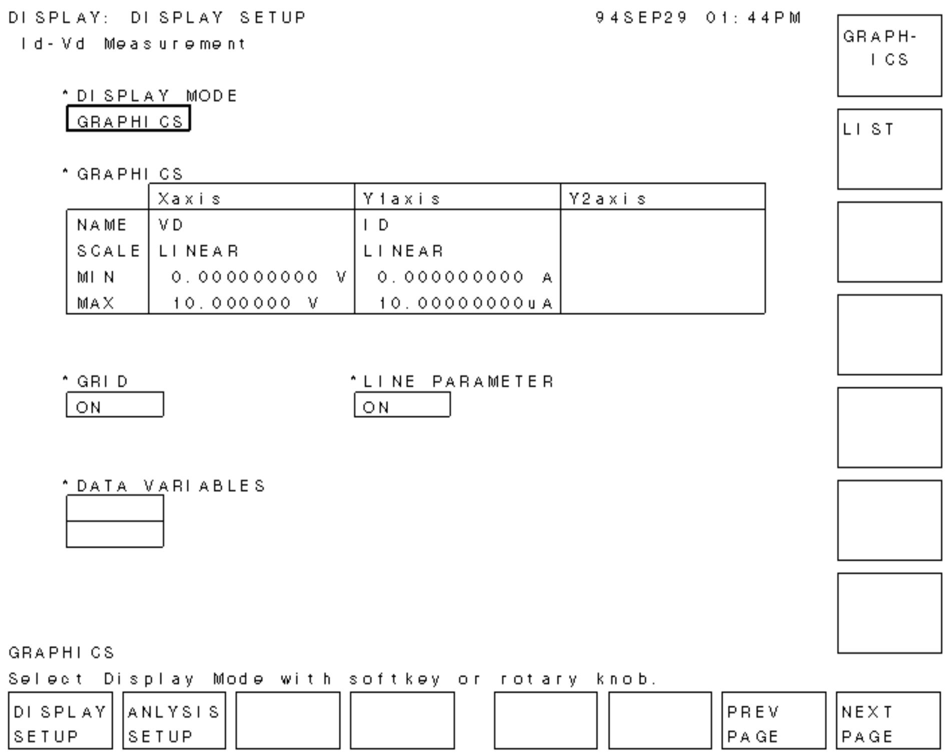


Figure 5-18 DISPLAY SETUP Page of IDVD.MES



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 the 4155/4156 to determine Vgstr during DCDAHC program.

Figure 5-19 CHANNEL DEFINITION Page of IBVG.MES

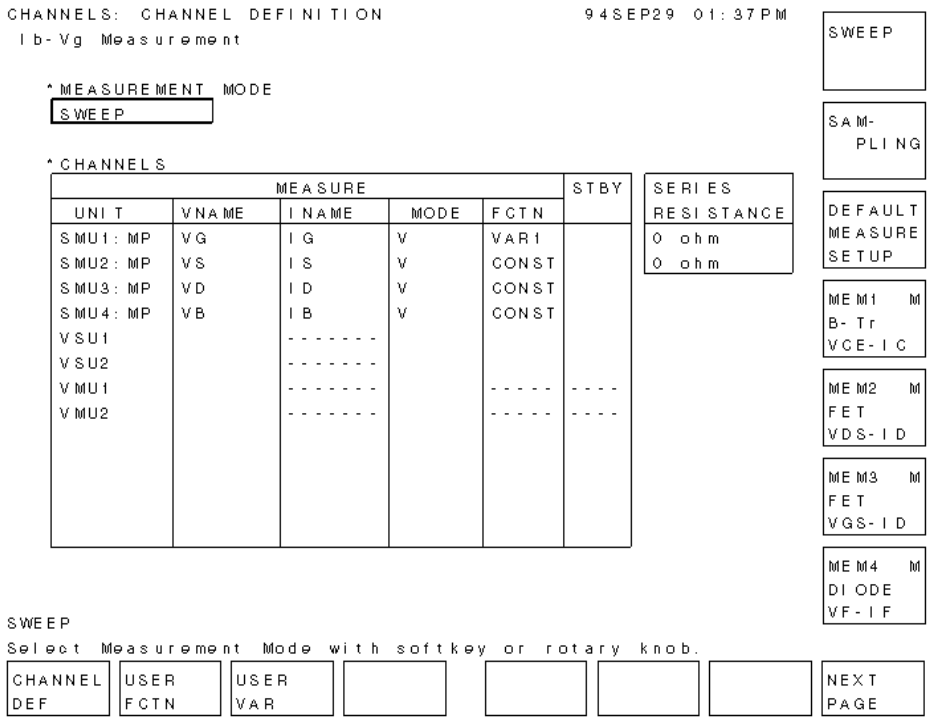


Figure 5-20 USER FUNCTION DEFINITION Page of IBVG.MES

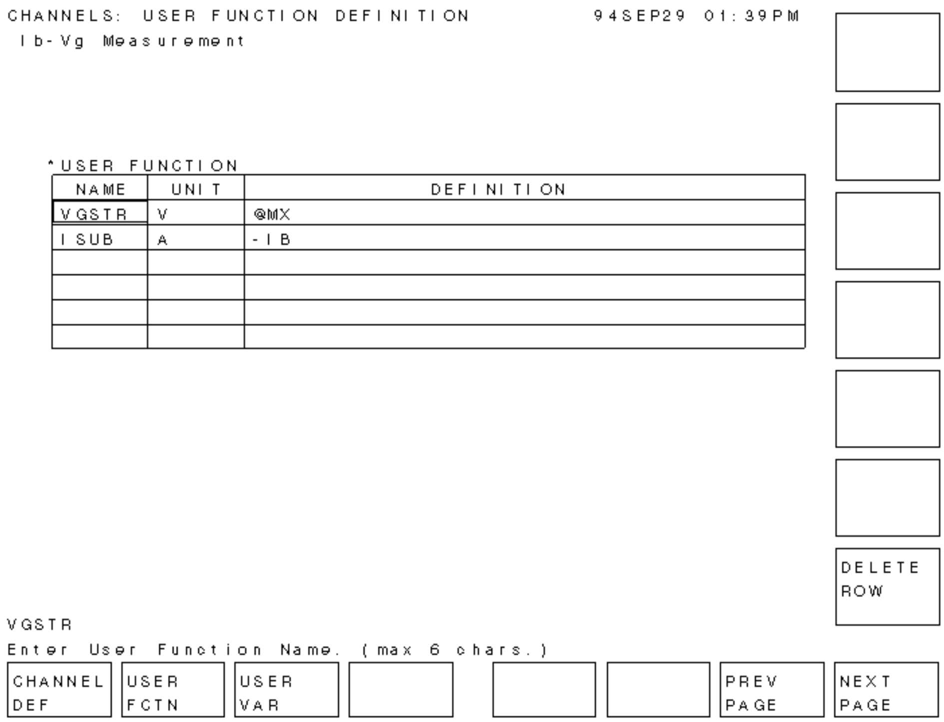


Figure 5-21 SWEEP SETUP Page of IBVG.MES

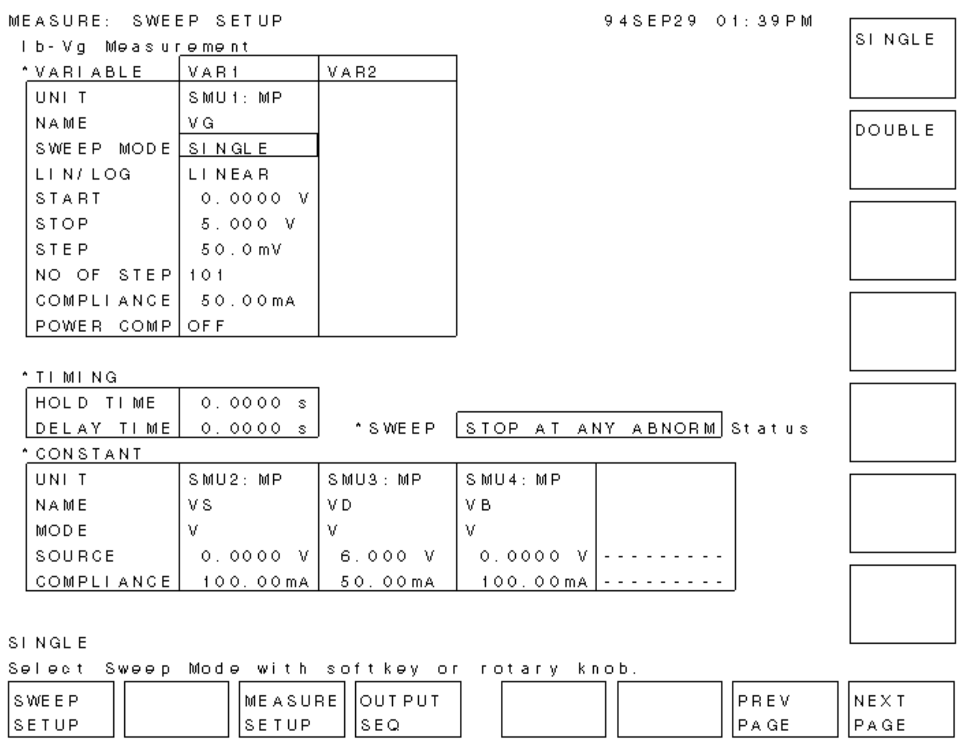


Figure 5-22 DISPLAY SETUP Page of IBVG.MES

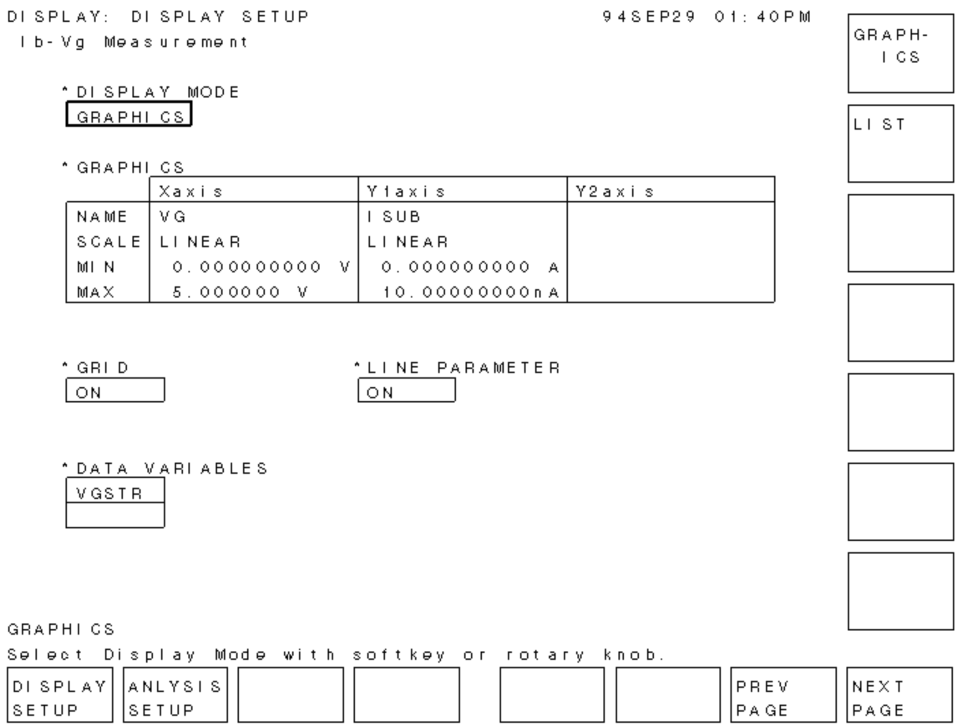
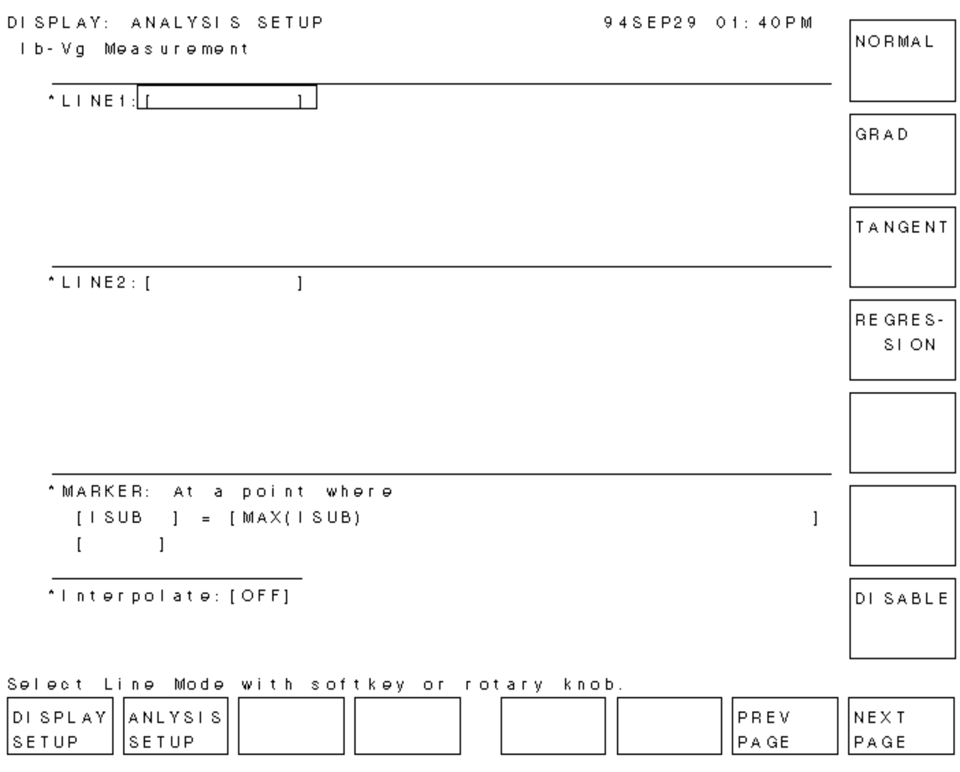


Figure 5-23 ANALYSIS SETUP Page of IBVG.MES



Setup File for Gate Leakage Current Measurement

Settings of following setup pages are stored in IGLEAK.MES file, which is used to set up the 4155/4156 for gate leakage current measurement during DCDAHC program.

NOTE

This section 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.

Figure 5-24 **CHANNEL DEFINITION Page of IGLEAK.MES**

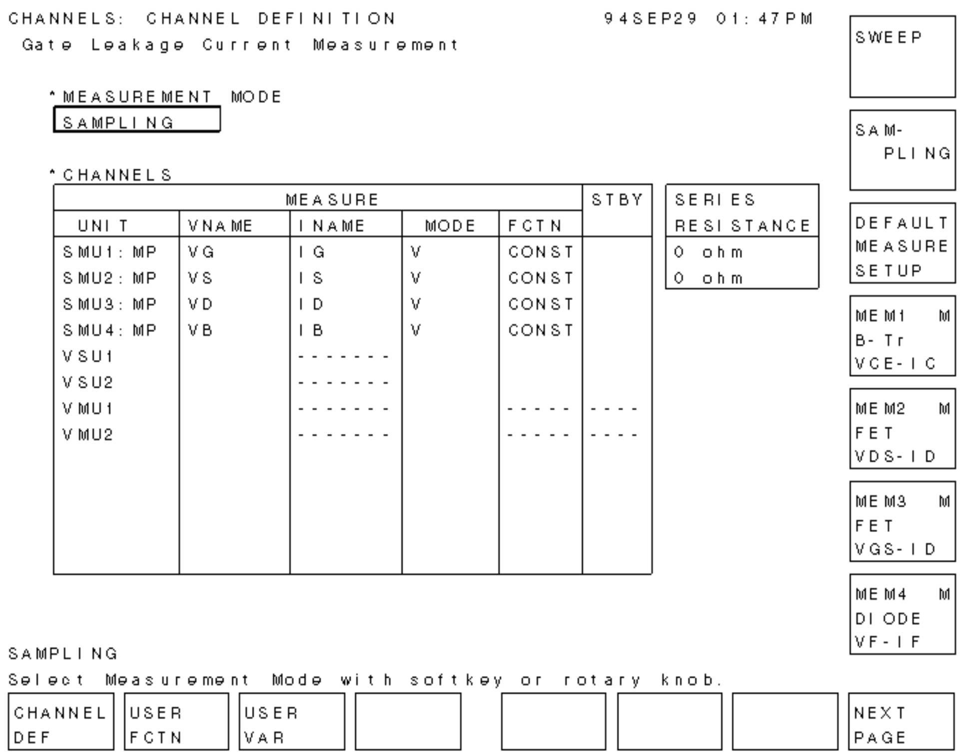


Figure 5-25 **USER FUNCTION DEFINITION Page of IGLEAK.MES**

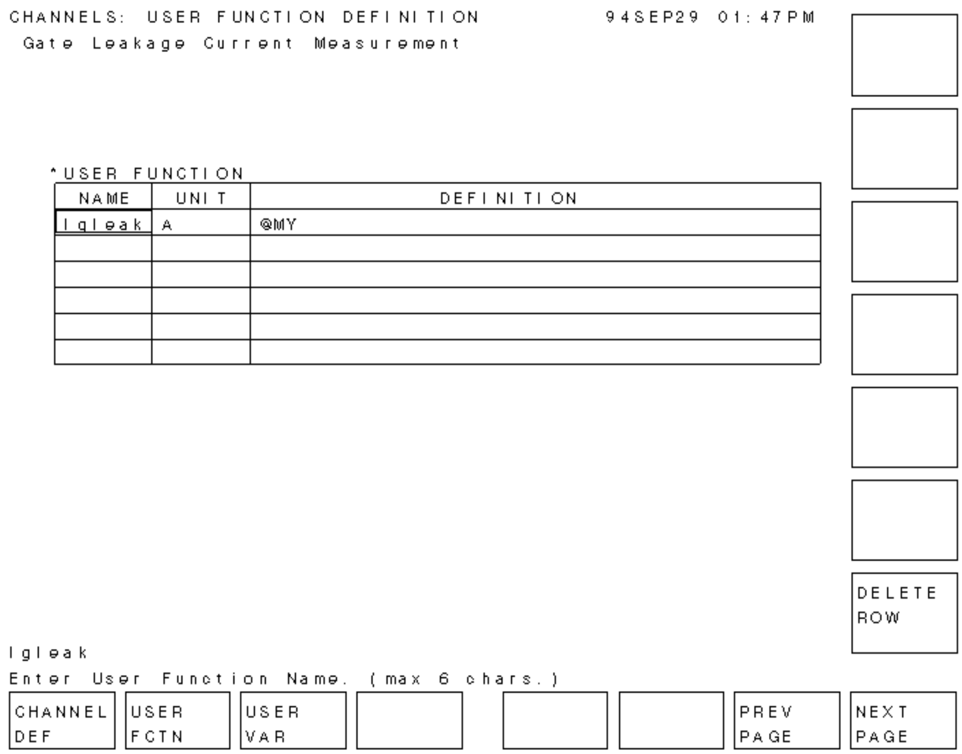


Figure 5-26 **SAMPLING SETUP Page of IGLEAK.MES**

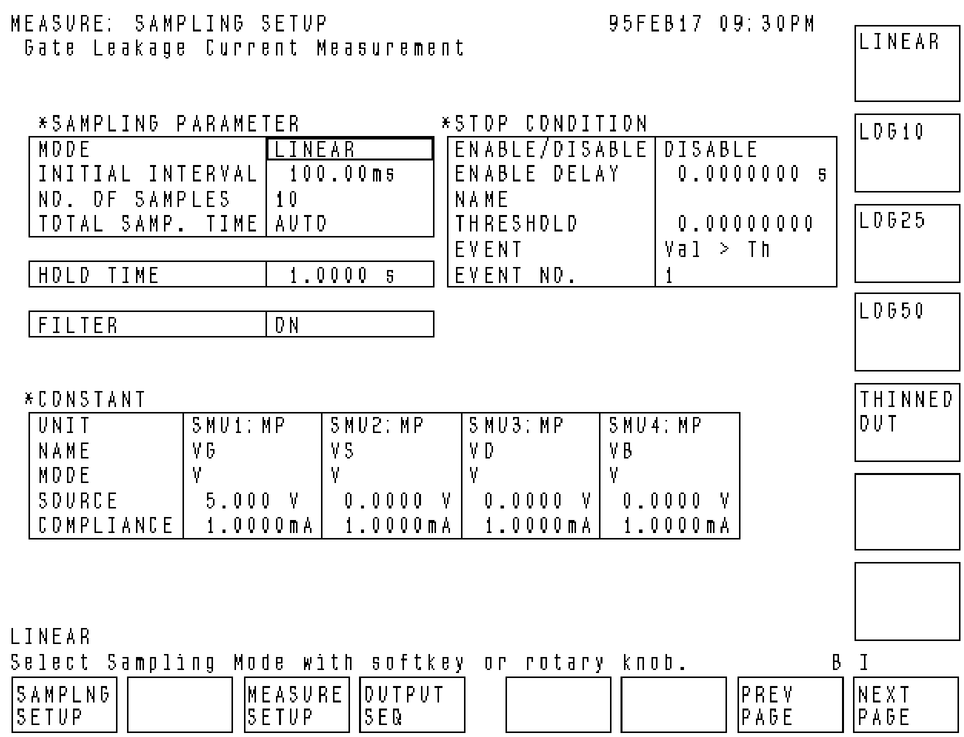


Figure 5-27 **ANALYSIS SETUP Page of IGLEAK.MES**

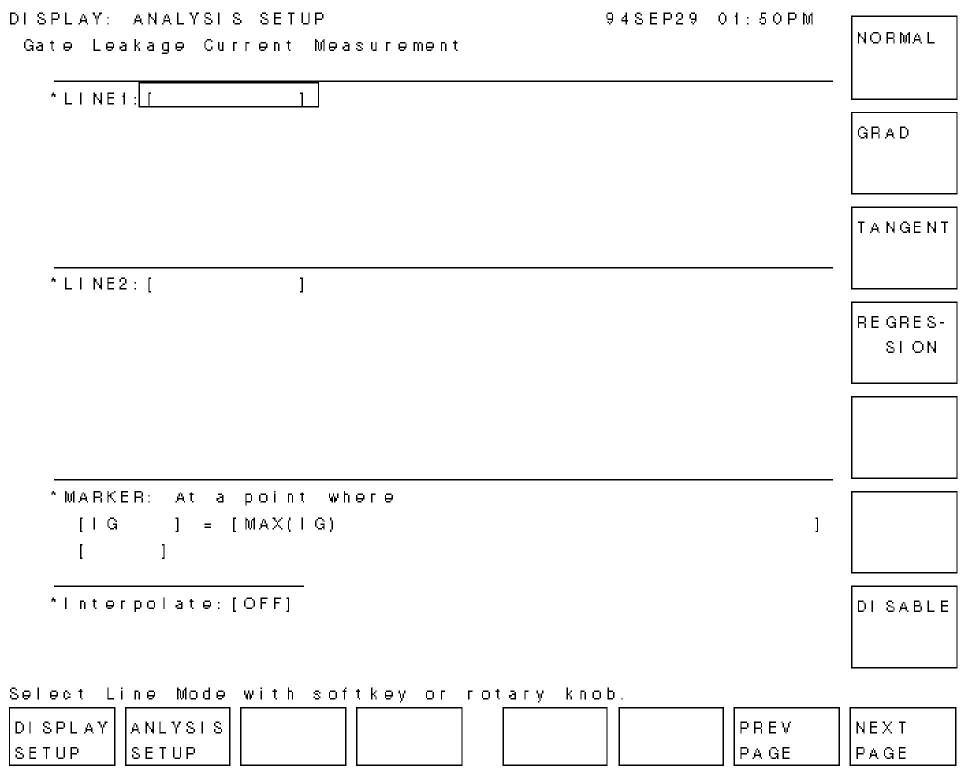
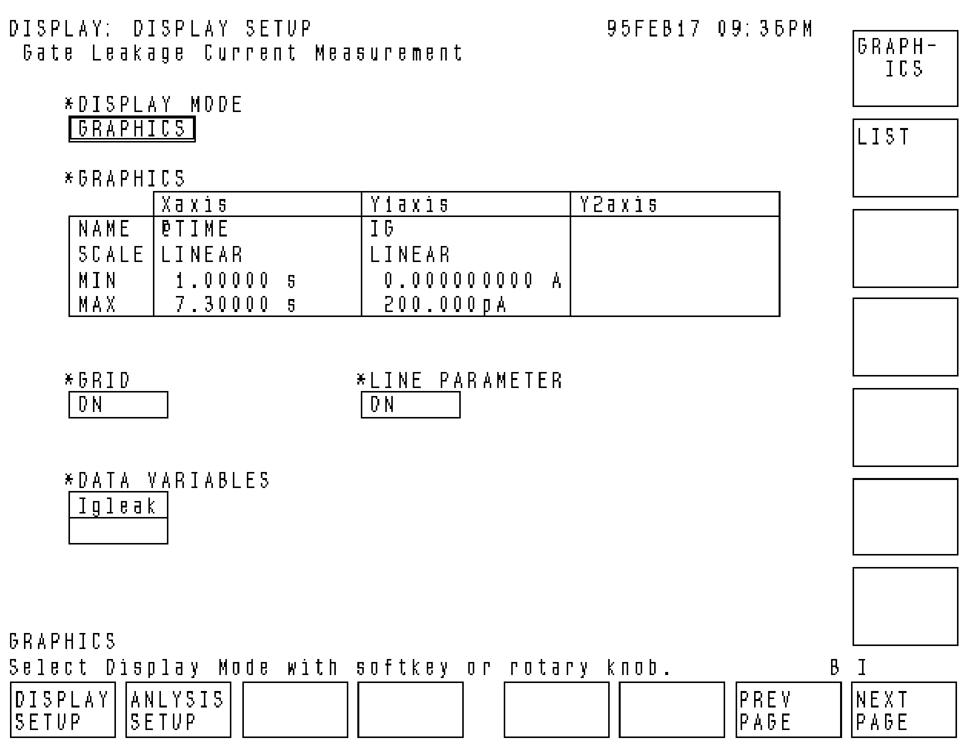


Figure 5-28 **DISPLAY SETUP Page of IGLEAK.MES**



Setup File for Initial/Interim Characterization

Settings of following setup pages are stored in PARAM.MES file, which is used to set up the 4155/4156 for Idlin/Gmmax/Vtext/Vtci measurements during DCDAHC program.

Figure 5-29 **CHANNEL DEFINITION Page of PARAM.MES**

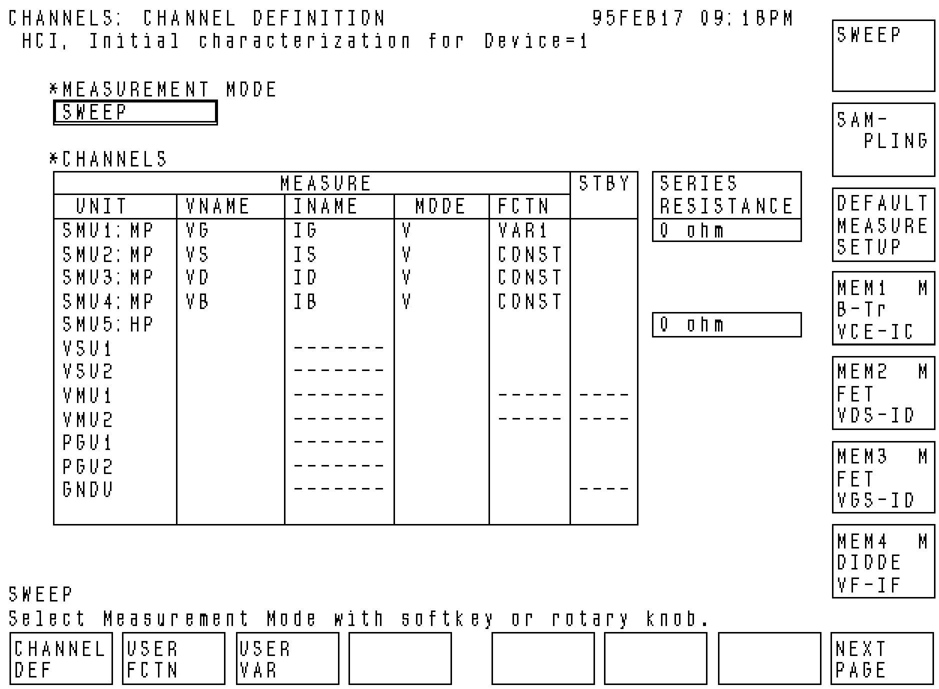


Figure 5-30 **USER FUNCTION DEFINITION Page of PARAM.MES**

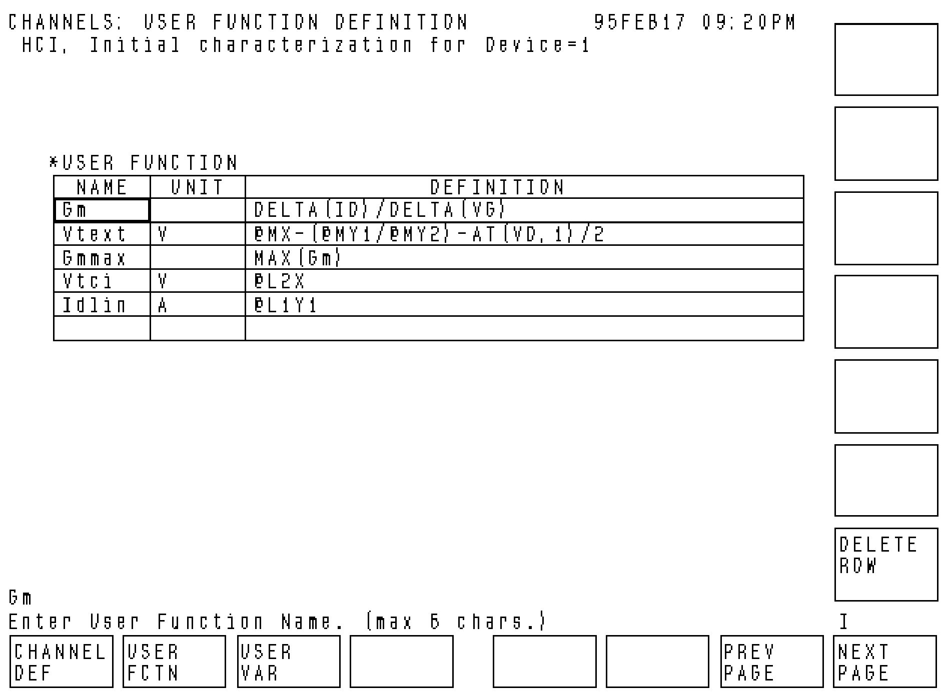


Figure 5-31 SWEEP SETUP Page of PARAM.MES

```
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
SWEEP  |        | MEASURE | OUTPUT |        |        | PREV | NEXT
SETUP  |        | SETUP   | SEQ    |        |        | PAGE | PAGE
```

Figure 5-32 OUTPUT SEQUENCE Page of PARAM.MES

```
MEASURE: OUTPUT SEQUENCE                                  95FEB17 09:25PM   SMU1:MP
 HCI, Initial characterization for Device=1
                                                                            SMU2:MP

   *OUTPUT SEQUENCE                    *TRIGGER SETUP                       SMU3:MP
      | UNIT    | NAME | MODE          ENABLE/DISABLE | DISABLE
    1 | SMU2:MP | VS   | V             FUNCTION       | TRIG OUT
    2 | SMU4:MP | VB   | V             STEP DELAY     |  0.000 s            SMU4:MP
    3 | SMU1:MP | VG   | V             POLARITY       | POSITIVE
    4 | SMU3:MP | VD   | V
    5 | VSU1    |      |                                                    SMU5:HP
    6 | VSU2    |      |
    7 | SMU5:HP |      |
    8 | PGU1    |      |                                                    VSU1
    9 | PGU2    |      |

                                                                            MORE
                                                                            1/2
SMU2:MP
Select Output Sequence with softkey or rotary knob.                          I
SWEEP  |        | MEASURE | OUTPUT |        |        | PREV | NEXT
SETUP  |        | SETUP   | SEQ    |        |        | PAGE | PAGE
```

Figure 5-33 **DISPLAY SETUP Page of PARAM.MES**

```
DISPLAY: DISPLAY SETUP                              95FEB17 09:27PM   GRAPH-
 HCI, Initial characterization for Device=1                            ICS

    *DISPLAY MODE                                                     LIST
    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                   *LINE PARAMETER
    ON                      OFF

    *DATA VARIABLES
    Vtext
    Idlin

GRAPHICS
Select Display Mode with softkey or rotary knob.                     I
DISPLAY  ANLYSIS                                  PREV    NEXT
SETUP    SETUP                                    PAGE    PAGE
```

Figure 5-34 **ANALYSIS SETUP Page of PARAM.MES**

```
DISPLAY: ANALYSIS SETUP                             95FEB17 09:46PM   NORMAL
 Idlin/Gmmax/Vtext/Vtci Measurement

   *LINE1:[GRAD       ] line on [Y1]   at a point      [WHERE]        GRAD
     [VG     ] = [5                                          ]
     [       ]
    Gradient:   [0                                           ]        TANGENT

                                                                      REGRES-
   *LINE2:[NORMAL     ] line on [Y1] between a point   [WHERE]         SION
     [ID     ] = [10u                                        ]
     [       ]
    and a point  [WHERE]
     [ID     ] = [10u                                        ]
     [       ]

   *MARKER: At a point where
     [Gm     ] = [MAX(Gm)                                    ]
     [       ]
                                                                      DISABLE
   *Interpolate:[ON ]

GRAD
Select Line Mode with softkey or rotary knob.                     B  I
DISPLAY  ANLYSIS                                  PREV    NEXT
SETUP    SETUP                                    PAGE    PAGE
```

Setup File for DC Stress

Settings of following setup pages are stored in DCDAHC.STR file, which is used to set up the 4155/4156 for DC stress during the DCDAHC program.

Figure 5-35 **CHANNEL DEFINITION Page of DCDAHC.STR**

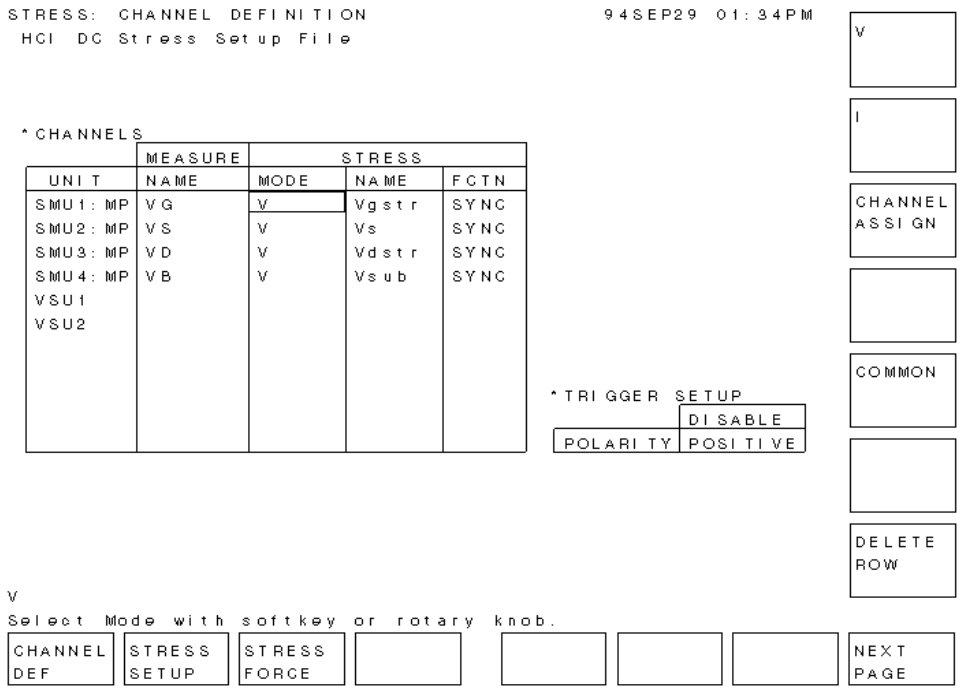
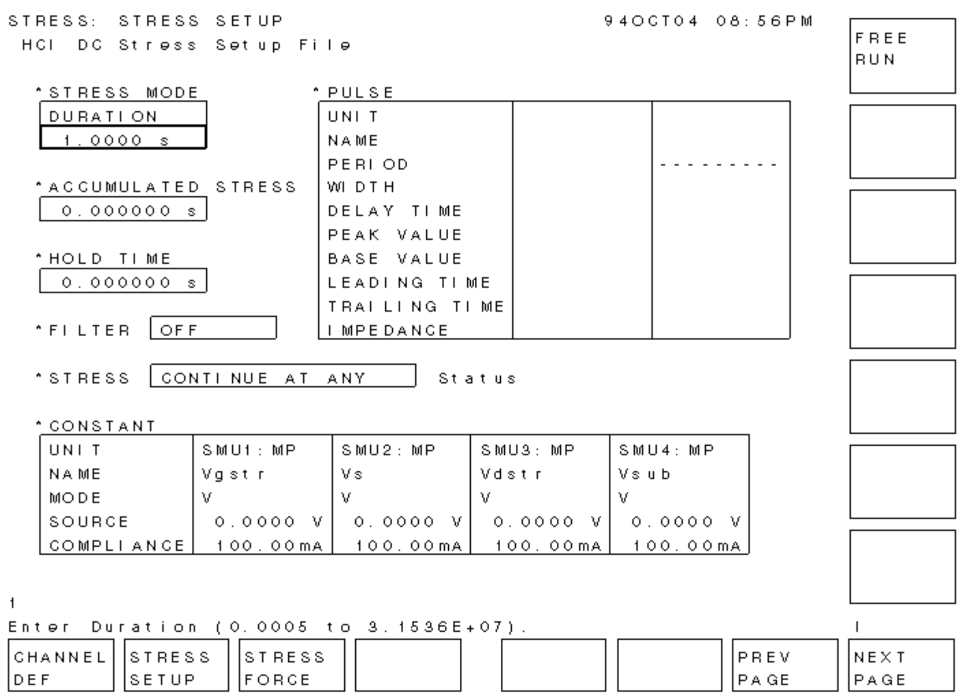


Figure 5-36 **STRESS SETUP Page of DCDAHC.STR**



Setup File for AC Stress

Settings of following setup pages are stored in ACDAHC.STR file, which is used to set up the 4155/4156 for AC stress. You need to customize the DCDAHC program to perform AC stress. See “Performing HCI Degradation Test with AC Stress” on page 5-41.

Figure 5-37 **CHANNEL DEFINITION Page of ACDAHC.STR**

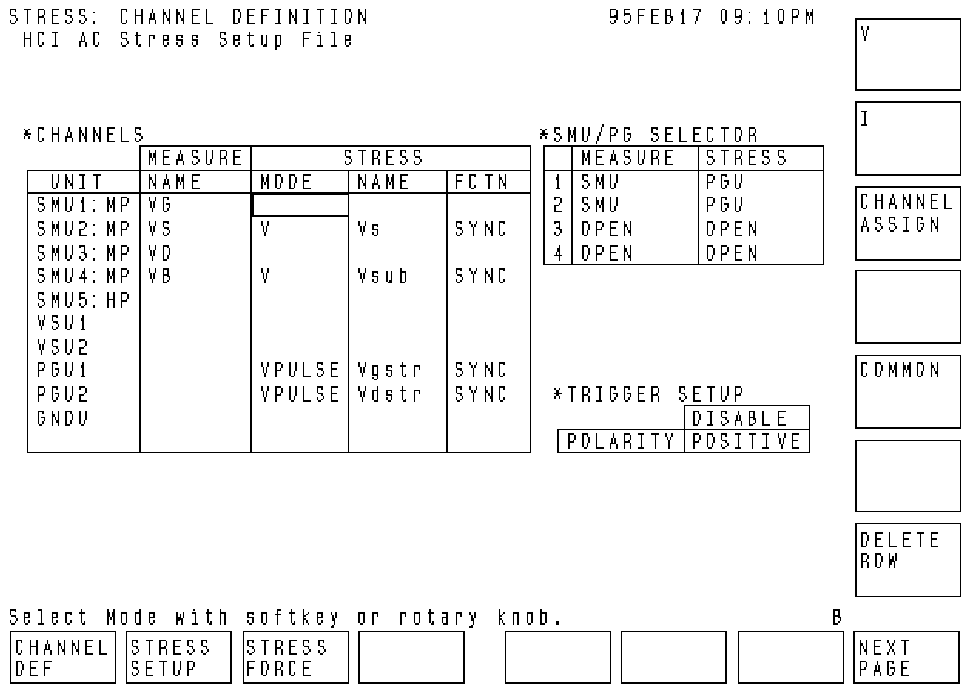
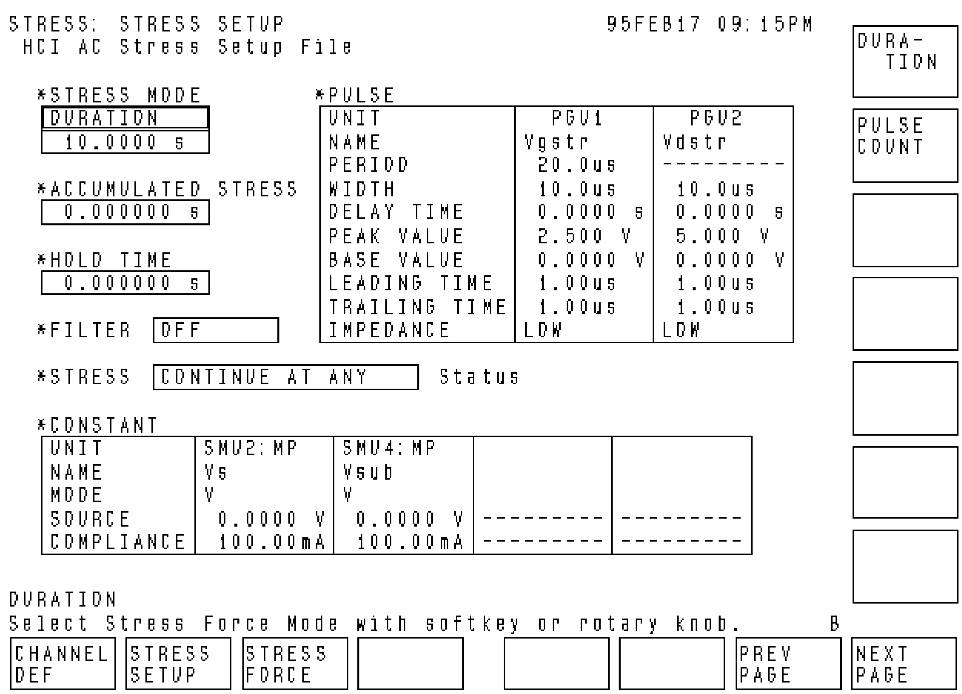


Figure 5-38 **STRESS SETUP Page of ACDAHC.STR**



6 Charge Pumping

The evolution of micro devices and ULSI technologies has created problems with device reliability. For example, hot carrier induced (HCI) degradation and short channel effects are important reliability issues for MOSFET devices. This manual discusses the evaluation of surface-states at the Si-SiO_2 interface of MOSFET devices which is one of these reliability issues.

Charge pumping is a measurement technique for evaluating the Si-SiO_2 interface-state of MOSFET devices. This technique is used to analyze the mechanics of hot carrier induced degradation.

This operation manual shows how to use the charge pumping method to evaluate the interface-state with the 4155/4156.

"Charge Pumping Methods" introduces three methods of charge pumping.

"Square Pulse Method" explains the theory of the square pulse method and how to perform the test using the sample program. An example measurement result is also shown.

"Square Pulse Method without Program" describes how to perform a square pulse method charge pumping test without using a program. An example measurement result is also shown.

"Triangular Pulse Method" explains the theory of the triangular pulse method and how to perform the test using the sample program. An example measurement result is also shown.

"Trapezoidal Pulse Method" explains the theory of the trapezoidal pulse method and how to perform the test using the sample program. An example measurement result is also shown.

"Program Modification Examples" describes examples of sample program modifications.

Charge Pumping Methods

Charge pumping is one of the measurement methods that extracts the Si-SiO_2 interface-state density and the capture cross-section of the MOSFET devices. Figure 6-1 shows the measurement circuit diagram of a charge pumping test. The gate of a MOSFET device is connected to a pulse generator, A reverse bias (Vr) is applied to the source and the drain, while the substrate current is measured. This current is caused by the repetitive recombination of minority carriers with majority carriers at the interface traps when the gate pulses the channel between inversion and accumulation. Three different charge pumping methods are described below:

Square Pulse Method

The square pulse method extracts the interface-state density from the charge pumping current versus the pulse base voltage curve. The curve is obtained by applying a fixed-shape square pulse to the gate, measuring the charge pumping current (substrate current), stepping up the pulse base voltage, and repeating the measurement.

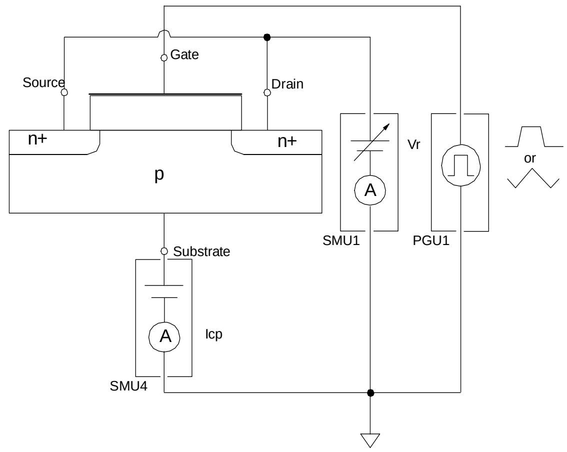
Triangular Pulse Method

The triangle pulse method extracts the mean interface-state density and capture cross-section from the recombined charge versus the pulse frequency curve. The curve is obtained by applying a constant height triangle wave to the gate, measuring the charge pumping current, stepping up the pulse frequency, repeating the measurement, and extracting the recombined charge.

Trapezoidal Pulse Method

The trapezoidal pulse method presents the energy distribution of interface-state (interface-state density versus energy curve). The characteristics are obtained by applying a fixed height trapezoidal pulse to the gate, measuring the charge pumping current, stepping up the pulse rise-time or pulse fall-time, repeating the measurement, and then extracting the interface-state density.

Figure 6-1 **Measurement Circuit Diagram**



Equipment Required

The sample programs explained here are the Instrument BASIC programs which run on the 4155/4156 built-in IBASIC controller. To execute a sample program, the following equipment is required.

- Agilent 4155 or Agilent 4156 Semiconductor Parameter Analyzer
- Agilent 41501 Expander equipped with Pulse Generator Units
- Two triaxial cables
- One coaxial cable
- Test fixture or probe station
- This operation manual
- Diskette that contains the sample program files and the 4155/4156 setup files

To perform the square pulse method test without using a program, as described in “Square Pulse Method without Program” on page 6-13, all the equipment listed above is required.

NOTE Program files and setup files are stored on the Sample Application Program Disk furnished with the 4155/4156. Before executing the program, copy the files to your working diskette. You should keep the original diskette as backup.

Square Pulse Method

The square pulse method extracts interface-state density ($\overline{Dit}$), as shown in Figure 6-2. This figure is a flowchart of the sample program described here. A square pulse should be applied to the gate, and the substrate leakage current should be measured at the point shown in Figure 6-3.

The amplitude of the square pulse is not changed, and the pulse base voltage (BaseV) is varied from well-below to well-above the threshold voltage. The substrate leakage current is measured for each pulse base voltage. For every sampling measurement, the maximum substrate current is defined as the charge pumping current (Icp). The pulse output, the sampling measurement, and the Icp extraction are performed using the setup information found in the 4155/4156 measurement setup file, not in the sample program.

The pulse base voltage is increased with each iteration of the measurement loop. Then the charge pumping current (Icp) versus pulse base voltage (BaseV) curve is drawn. $\overline{Dit}$ is extracted from the Icp versus BaseV curve.

To Extract Interface-state Density

The interface-state density ($\overline{Dit}$) is extracted using the equation shown below. The sample program uses the maximum Icp value for this calculation. The maximum Icp value is obtained from the charge pumping current (Icp) versus pulse base voltage (BaseV) curve.

$Icp = f \times Qss = f \times q \times Ag \times \overline{Dit}$

So,

$\overline{Dit} = Icp / (f \times q \times Ag)$

where,

Qss **:**	Recombined charge per pulse period
f **:**	Pulse frequency
q **:**	Electron charge
Ag **:**	Channel area of the transistor
$\boldsymbol{\overline{Dit}}$ **:**	Mean interface-state density, averaged over the energy levels swept through by the Fermi level ($cm^{-2}\ eV^{-1}$)

Figure 6-2 **Flowchart of Square Pulse Method**

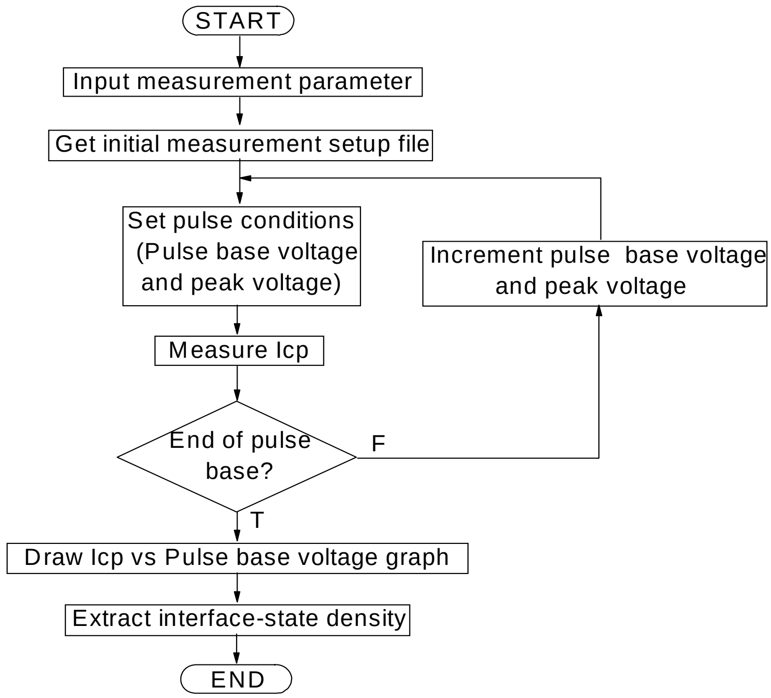
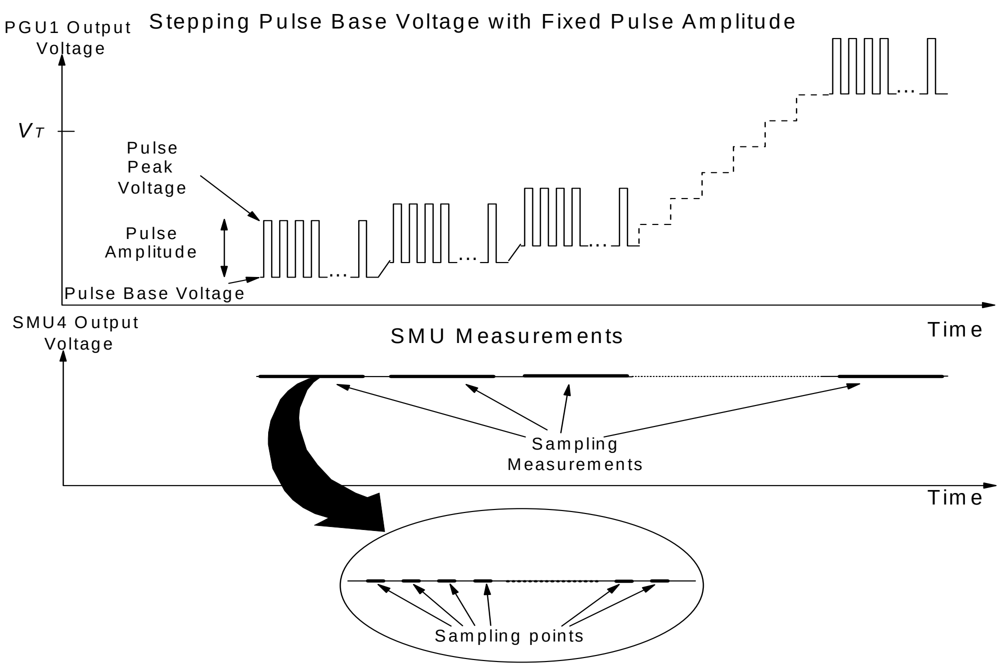


Figure 6-3 **Timing Chart of Square Pulse Method**



Program Files Required

The following files are used for the square pulse method test:

CPV	Square pulse method sample program. IBASIC program file. ASCII format.
CHP.MES	Sample setup file for the square pulse method. 4155/4156 setup file.

NOTE

The sample program file and the 4155/4156 setup file should be stored on your working diskette. The diskette must be inserted in the 4155/4156 built-in flexible disk drive during the program execution. The sample program loads the setup file and automatically saves the data files on the diskette.

Example Measurement Result Files

The following files save example data created after executing the CPV program. The files are stored on the Sample Application Program Disk.

CHP.DAT	4155/4156 setup and measurement data file.
CHP.ASC	ASCII format file.

Sample Setup File

The square pulse method sample program loads and uses the information in the 4155/4156 setup file for the measurement. For the actual setup information in the setup file you use, load the file using the 4155/4156 filer function, and then refer to the 4155/4156 setup screen.

The following table shows the key setup screens of the CHP.MES sample setup file.

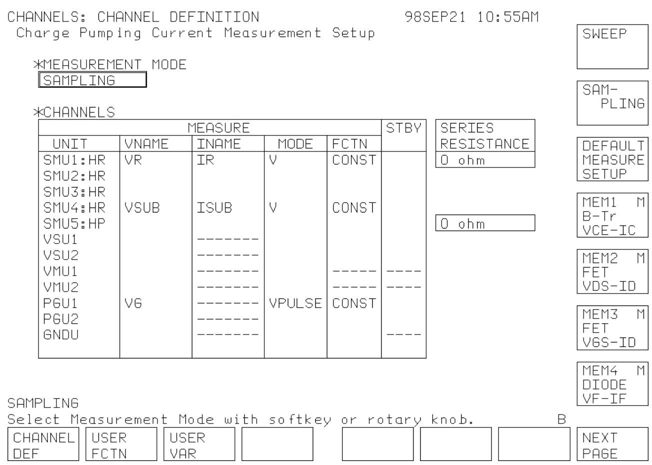
NOTE

If you change the setup information of the sample setup file for your application, load the sample setup file, change the setup, and save it as a new file.

To use the new file for the measurement, perform one of the following:

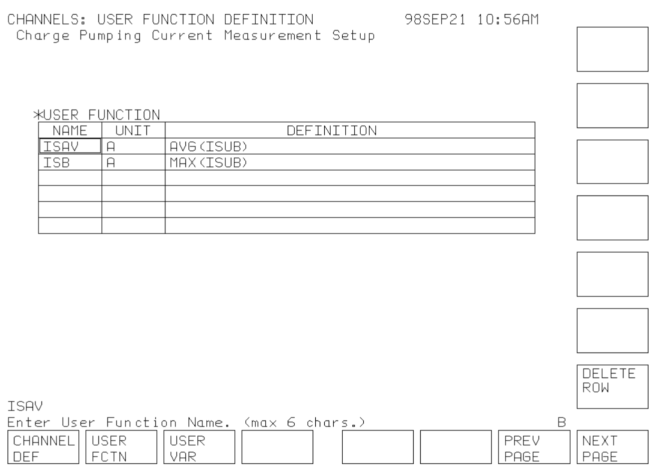
- Run the sample program, and select the File Name and Setup File softkeys, and enter the file name.
- Edit the sample program, and change the initial value for the setup file name. See “To Change the Initial Value of Input Parameters” on page 6-36.

CHANNEL DEFINITION screen



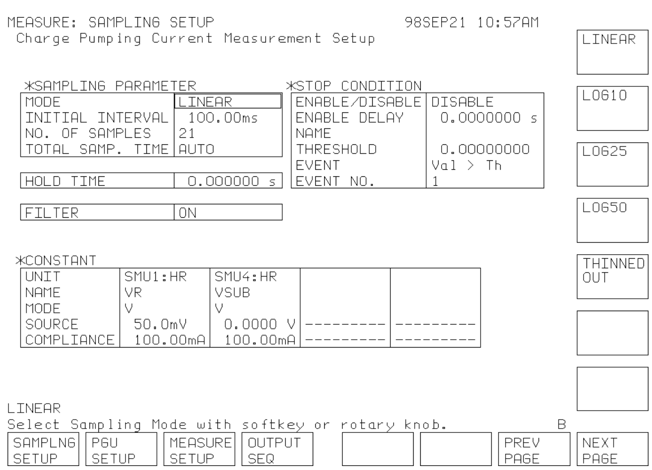
Use this screen to define the measurement units used to set the gate pulse, drain and source voltages, and to measure the substrate current (ISUB). The measurement circuit diagram shown in Figure 6-1 uses this definition.

USER FUNCTION DEFINITION screen



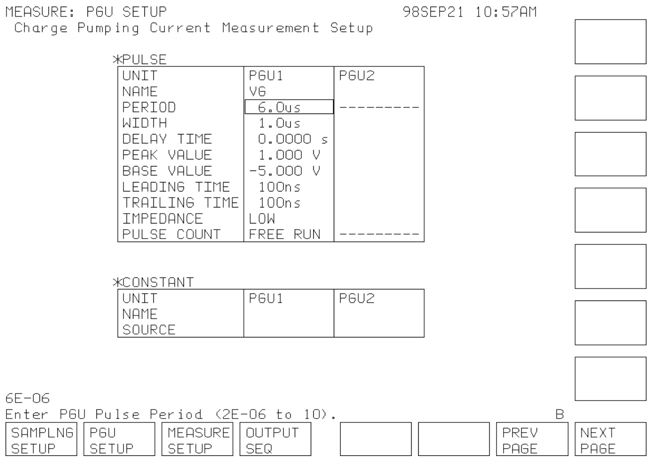
This setup screen is required to calculate the averaged ISUB value (ISAV) and to get the maximum ISUB value (ISB) automatically for each sampling measurement. During the execution of the sample program, the ISB value is collected and used to plot the charge pumping current (Icp) versus pulse base voltage (BaseV) curve.

SAMPLING SETUP screen

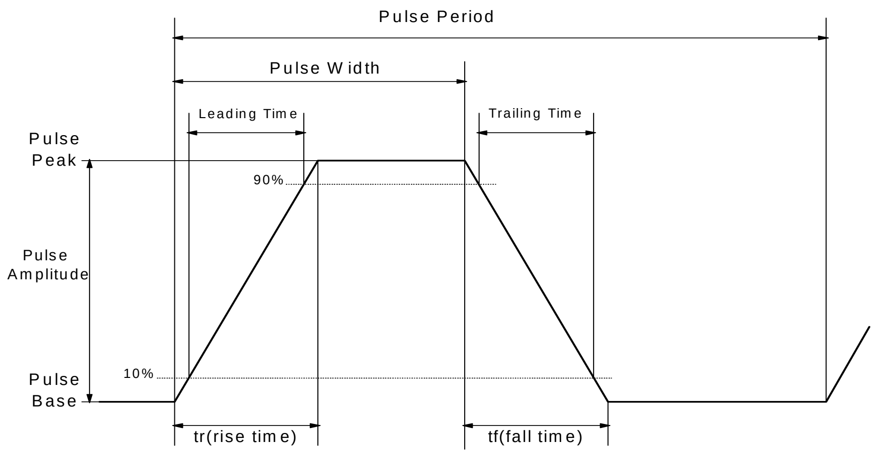


Use this screen to set the sampling measurement condition for the substrate current (ISUB) measurement.

PGU SETUP screen

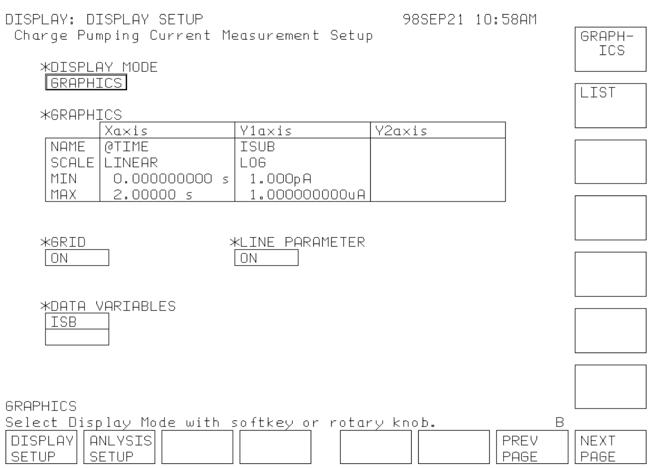


Use this screen to set the output condition used to pulse the gate. During the execution of the sample program PEAK VALUE and BASE VALUE are automatically changed by the program for each sampling measurement. For the definition of the pulse setup parameters, see the figure below.



f (Pulse Frequency) = 1 / Pulse Period

DISPLAY SETUP screen



Use this screen to set the measurement and display parameters. For the sampling measurement, the x-axis must be set to @TIME. To measure the substrate current, the y-axis must be set to ISUB. ISB must be set to the DATA VARIABLES field to display the ISB value on the GRAPH/LIST: GRAPHICS screen.

To Execute the Sample Program

This procedure describes how to execute the sample program.

1. Display the SYSTEM: MISCELLANEOUS screen, and set the REMOTE CONTROL COMMAND SET field to 4155/56.
2. Display the All IBASIC screen by pressing the front-panel **Display** key twice.
3. Insert a diskette containing the CPV program file and the setup file used for this test into the 4155/4156 built-in flexible disk drive.
4. Get the CPV sample program as follows:
   a. Select the GET "" softkey.
   b. Enter CPV as shown below.
      `GET"CPV"`
   c. Press the front-panel **Enter** key.
5. Press the front-panel **Run** key to execute the program.
6. To change the following measurement conditions, select the appropriate softkeys, and enter the new value:
   - File Name (select the File Name softkey)
     - Setup file name to get (enter the name of the setup file if it has been changed)
     - ASCII file name to save the result data (see Figure 6-5)
     - DAT file name to save the result data (see Figure 6-4)
   - Pulse Voltage (select the Pulse Voltage softkey)
     - Pulse Amplitude [V]
     - Start pulse base voltage [V]
     - Stop pulse base voltage [V]
     - Step pulse base voltage [V]
   - Pulse Time (select the Pulse Time softkey)
     - Pulse period [sec]
     - Pulse width [sec]
     - Pulse leading time [sec]
     - Pulse trailing time [sec]
   - SMU Bias (select the SMU BIAS softkey)
     - Drain and Source bias [V]
     - Substrate bias [V]
   - Device parameters (select the Device Parameter softkey)
     - Channel width [cm]
     - Channel length [cm]
7. Connect the device as shown in Figure 6-1.
8. To start the test, select the Measure softkey.

After the Measurement

After the measurement, the CPV program automatically performs the following functions:

- Displays a list of the pulse base voltage (BaseV) and the charge pumping current (Icp) on the All IBASIC screen.
- Changes the 4155/4156 setup information. This displays the Icp versus BaseV curve, and extracts and displays the interface-state density ($\overline{Dit}$). To review changes in the setup file, see the table on the next page.
- Displays the Icp versus BaseV curve on the GRAPH/LIST: GRAPHICS screen. See Figure 6-4.
- Saves the ASCII file to the diskette inserted in the 4155/4156 built-in flexible disk drive. See Figure 6-5.
- Saves the DAT file to the diskette inserted in the 4155/4156 built-in flexible disk drive.

Figure 6-4 **Square Pulse Method Measurement Result**

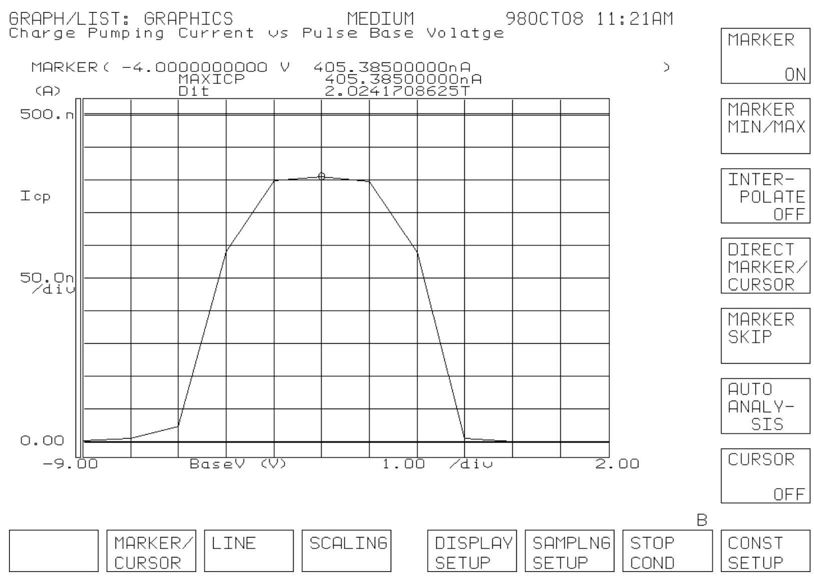


Figure 6-5 **Example Data of ASCII File**

```
 6,-9, 2, 1, 12
 2.E-6, 1.E-6, 1.E-7, 1.E-7
-9,-8,-7,-6,-5,-4,-3,-2,-1, 0, 1, 2
 8.8758E-9, 3.4555E-8, 2.1863E-7, 4.1005E-7, 4.5665E-7, 4.4278E-7, 3.5182E-7, . . . .
```

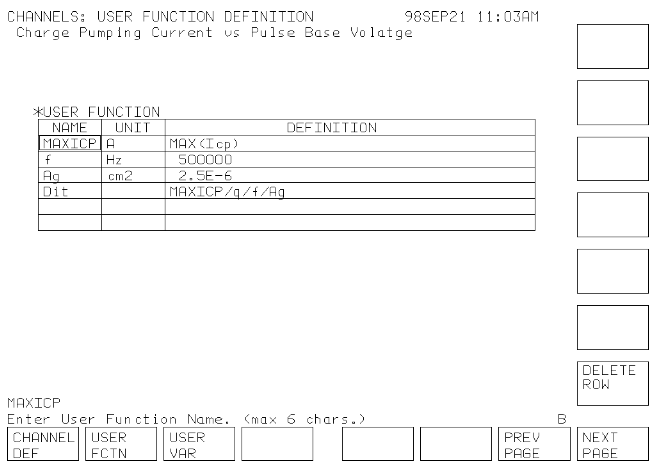
In Figure 6-5, the first line is the gate pulse amplitude [V], the gate pulse base start voltage [V], the base stop voltage [V], the base step voltage [V], and the number of steps in the gate pulse base voltage.

The Second line is the pulse period [sec], the pulse width [sec], the pulse leading time [sec], and the pulse trailing time [sec].

The third line is the pulse base voltage (BaseV value) [V].

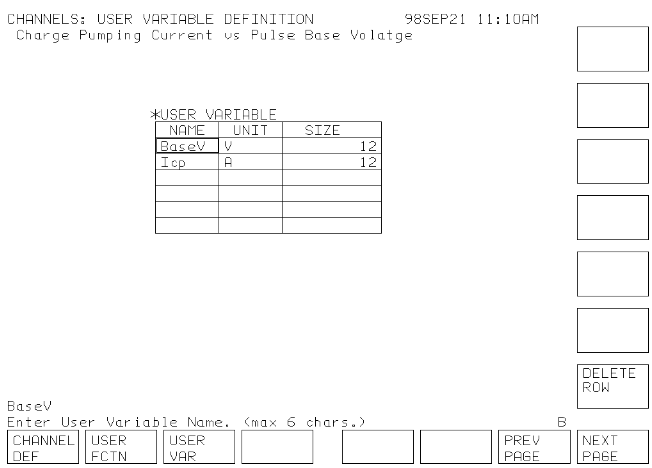
The last line is the charge pumping current (Icp value) [A].

USER FUNCTION DEFINITION screen



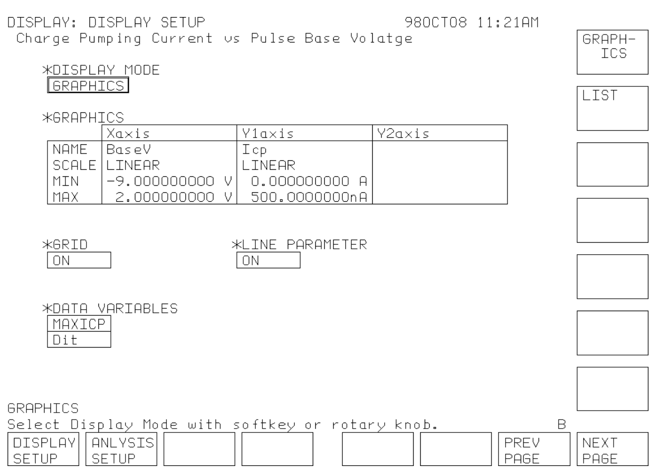
ISAV and ISB are deleted from the original setup. MAXICP, f, Ag, and Dit are added instead. MAXICP is the maximum Icp value, f is frequency of the gate pulse, Ag is the area of gate, and Dit is the interface-state density. The equation shown in “To Extract Interface-state Density” on page 6-5 is defined in the DEFINITION field of Dit, not in the sample program.

USER VARIABLE DEFINITION screen



User variables are newly defined. BaseV is the pulse base voltage. Icp is the charge pumping current. The number of data points for both BaseV and Icp are automatically calculated by the sample program using the start, stop, and step values of the pulse base voltage. In this example, the number of data points is 12, because the start value is –9 V, the stop value is 2 V, and step value is 1 V. The values of the variables are defined in the sample program.

DISPLAY SETUP screen



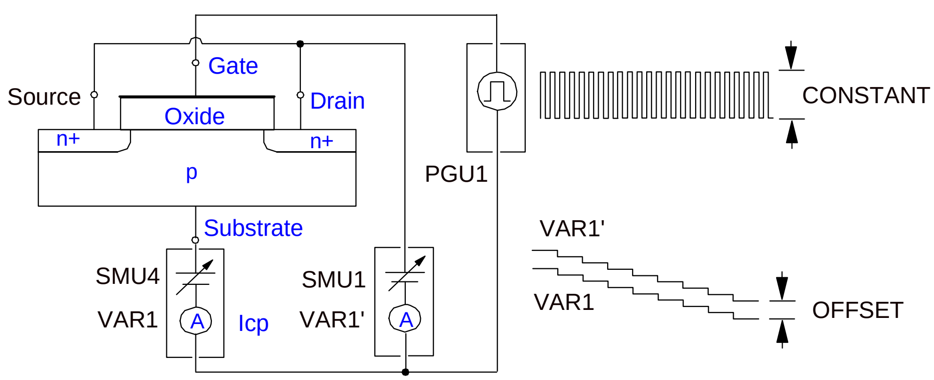
In the original setup, the x-axis was @TIME, and the y-axis was ISUB when measuring the substrate current. However, to display the Icp versus BaseV curve, BaseV and Icp are set to the x-axis and y-axis, respectively. Dit must be set to the DATA VARIABLES field to display the $\overline{Dit}$ value on the GRAPH/LIST: GRAPHICS screen.

Square Pulse Method without Program

The “Square Pulse Method” introduces the theory of the square pulse method and describes how to perform the test using the CPV sample program. This section describes how to perform the square pulse method test without using a program.

The measurement method described in this section uses the sweep measurement mode, not the sampling measurement mode used by the CPV sample program. The CPV sample program steps up the gate pulse base and peak voltage, while keeping the source, drain, and substrate voltages constant. This bias control can be replaced by keeping the gate pulse bias constant, and stepping down the voltage for the other terminals. The 4155/4156 forces a constant pulse to the gate, and forces the staircase sweep voltage to the source, drain, and substrate. Then the VAR1 function is used for the substrate voltage, and the VAR1' function is used for the source and drain voltage. See Figure 6-6. For the measurement setup, see “Sample Setup File” on page 6-13.

Figure 6-6 **Square Pulse Method Measurement Circuit**



Requirement

The following file is required for the test:

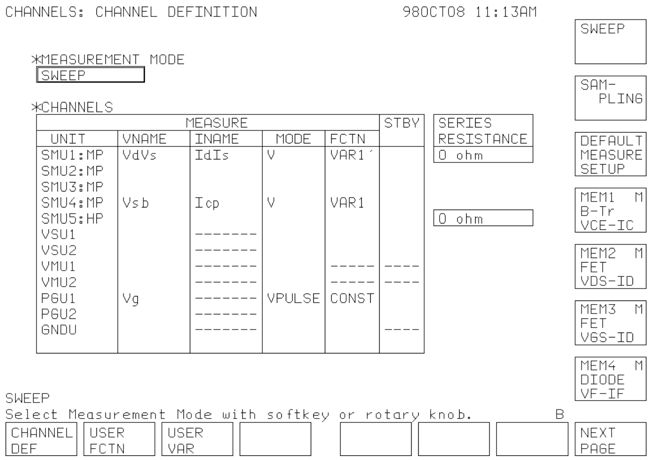
CPV.DAT 4155/4156 measurement setup and result data file. This file saves the measurement setup data and an example of the measurement result data.

NOTE You can change the measurement setup information of the CPV.DAT file to suit your device. Open and change the setup data on the 4155/4156. After the changes have been made, save the setup data file with a name other than CPV.DAT. You should keep the original file as a backup.

Sample Setup File

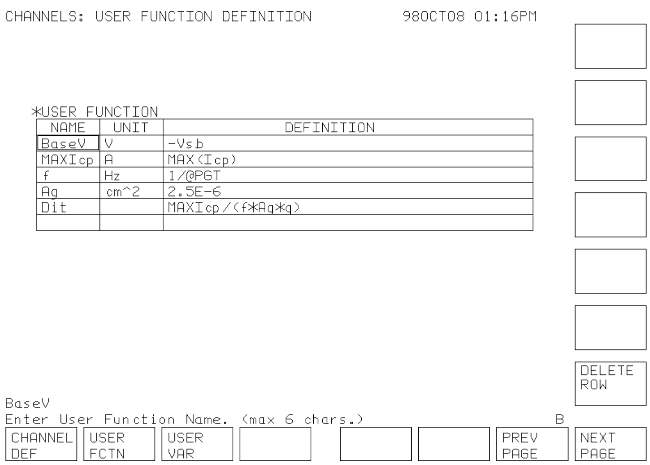
The key setup screens of the CPV.DAT file are shown in the following table.

CHANNEL DEFINITION screen



Use this screen to define the measurement units set the gate pulse, drain and source, and substrate voltages, and to measure the charge pumping current (Icp). The measurement circuit diagram shown in Figure 6-6 uses this definition.

USER FUNCTION DEFINITION screen



This setup screen calculates and defines the following parameters:

BaseV: Pulse base voltage

MAXIcp: Maximum charge pumping current

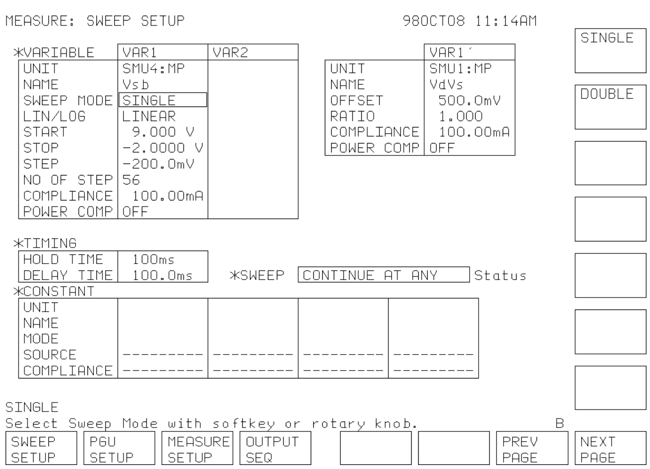
f: Pulse frequency

Ag: Channel area

Dit: Interface-state density ($\overline{Dit}$)

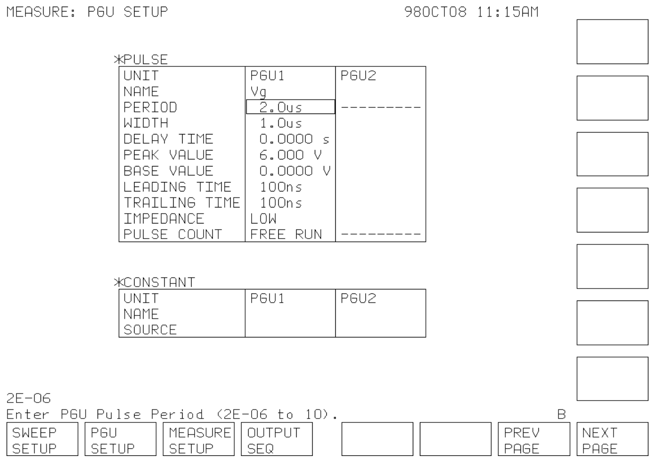
This definition is used to display the Icp versus BaseV curve, and the MAXIcp and $\overline{Dit}$ values.

MEASUREMENT SETUP screen

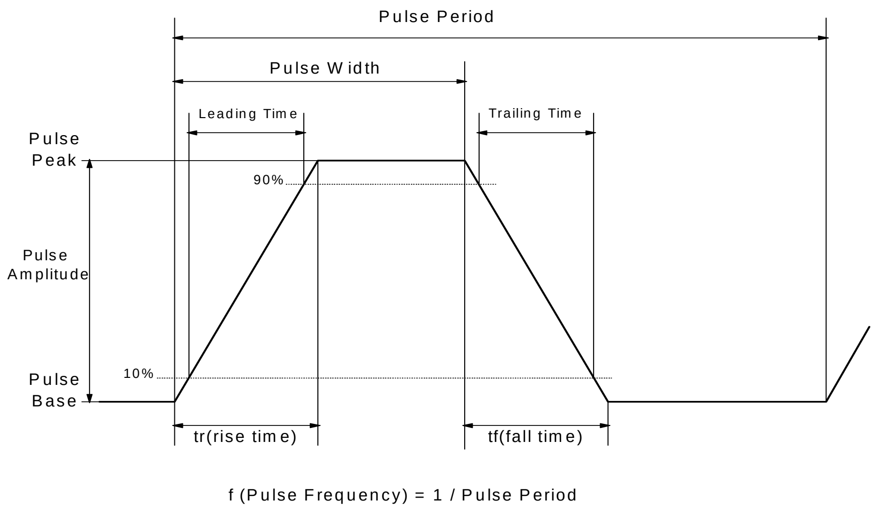


Use this screen to set the staircase sweep condition of the substrate voltage (VAR1) and the source and drain voltage (VAR1'). The source and drain voltage is 0.5 V more than the substrate voltage.

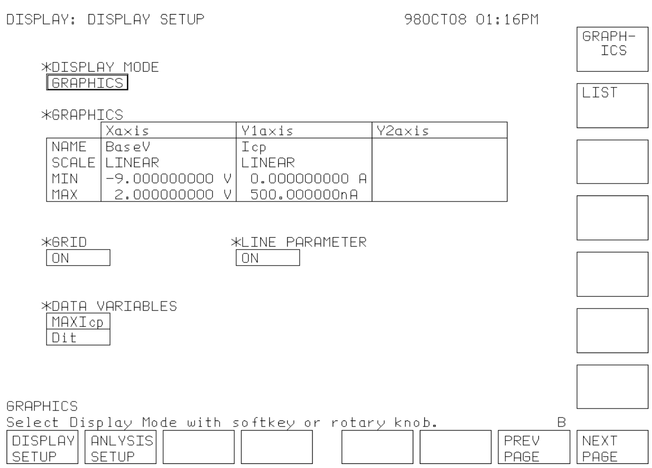
PGU SETUP screen



Use this screen to set the pulse output condition used to force the constant voltage pulse to the gate. For the definition of the pulse setup parameters, see the figure below.



DISPLAY SETUP screen



Use this screen to set the measurement parameters and display parameters. The GRAPH/LIST: GRAPHICS screen displays the Icp versus BaseV curve, the maximum charge pumping current (MAXIcp), and the interface-state density ($\overline{Dit}$).

To Execute the Measurement

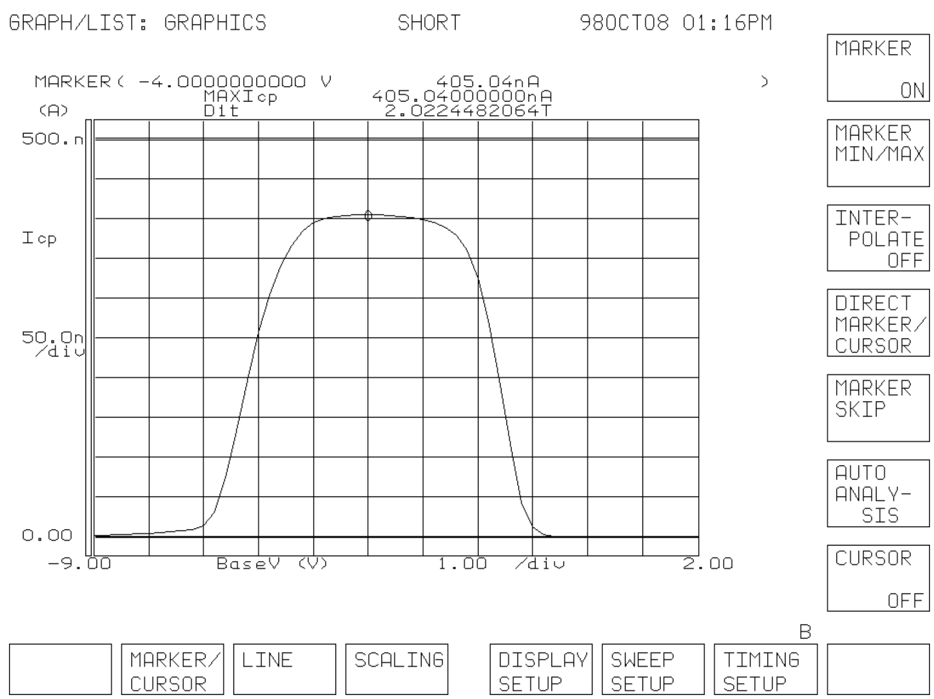
This procedure describes how to execute the measurement.

1. Insert a diskette containing the CPV.DAT file or the setup file you are using into the 4155/4156 built-in flexible disk drive.
2. Get the measurement setup file as follows:
   a. Press the front-panel **GET** key.
   b. Enter the file name, without an extension, in the NAME field. To get the CPV.DAT file, enter `CPV`.
   c. Select the MES or DAT softkey to set the file type in the TYPE field. To get the CPV.DAT file, select the DAT softkey.
   d. Press the front-panel **Enter** key.
3. (Optional) Change the measurement setup as desired.
4. Connect the device as shown in Figure 6-6.
5. Select the front-panel **Single** key to start a single sweep measurement.

After the Measurement

After the measurement, the charge pumping current (Icp) versus pulse base voltage (BaseV) curve is displayed on the GRAPH/LIST: GRAPHICS screen. The screen also displays the maximum Icp value (MAXIcp) and the interface-state density ($\overline{Dit}$). See Figure 6-7.

Figure 6-7 **Square Pulse Method Measurement Result**



Triangular Pulse Method

The triangle pulse method extracts the mean interface-state density ($\overline{Dit}$) and the capture cross section (σ) as shown in Figure 6-8. The triangle pulse should be applied to the gate, and the substrate leakage current measured at the point shown in Figure 6-9.

The amplitude of the triangle pulse is held constant while varying the frequency of the pulse. The substrate leakage current is measured by the sampling measurement mode for each frequency change. For every sampling measurement, the averaged substrate current is defined as the charge pumping current (Icp). The pulse output, the sampling measurement, and the Icp extraction are performed using the setup information in the 4155/4156 measurement setup file, not in the sample program.

The pulse frequency is increased with each iteration of the measurement loop. Then the recombined charge (Qss) versus pulse frequency (f) curve is drawn. Where, Qss is calculated by the program using the following equation. $\overline{Dit}$ and σ are extracted from the Qss versus pulse frequency curve.

$Qss = Icp / f$

Figure 6-8 **Flowchart of Triangle Pulse Method**

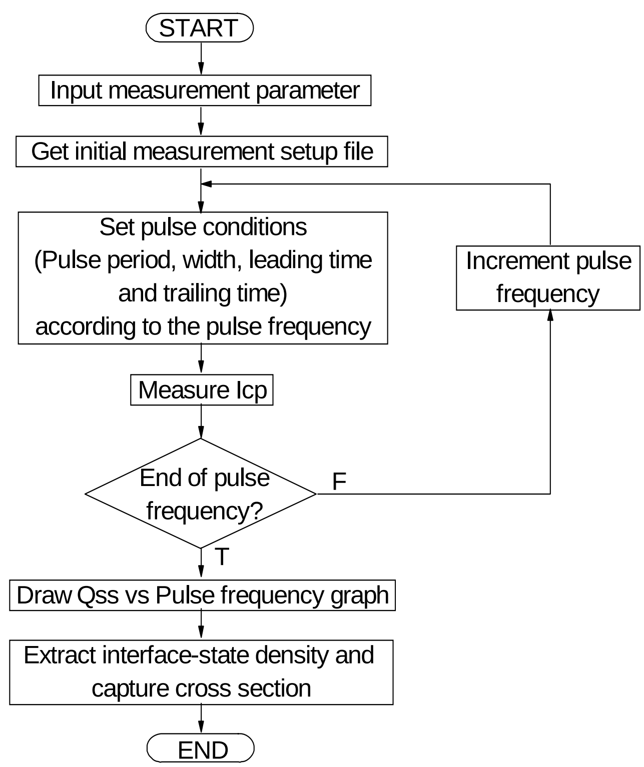
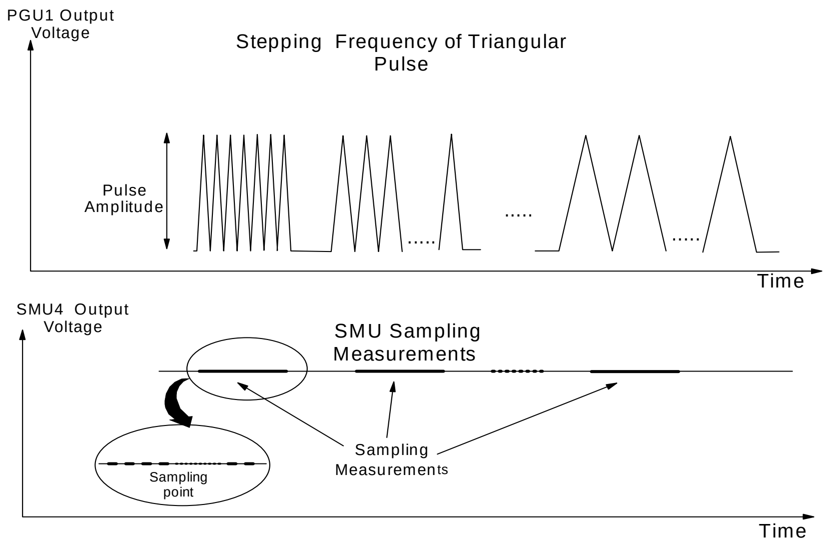


Figure 6-9 **Timing Chart of Triangle Pulse Method**



To Extract Interface-state Density

The mean interface-state density ($\overline{Dit}$) is extracted using the following equation, where, *Slope* is the slope of the regression line for the recombined charge (*Qss*) versus pulse frequency (*f*) curve on a linear-log graph. The slope value is obtained from the graph using the auto-analysis capability and the read-out function of the 4155/4156.

$$\frac{dQss}{d\log f} = \frac{2qkT\overline{Dit}}{\log e}Ag = Slope$$

So,

$$\overline{Dit} = \frac{\log e \cdot Slope}{2qkTAg}$$

where,

Qss : Recombined charge per pulse period

f : Pulse frequency

q : Electron charge

k : Boltzmann's constant

T : Temperature

Ag : Channel area of the transistor

$\overline{Dit}$: Mean interface-state density (cm^{-2} eV^{-1})

To Extract Capture Cross Section

When using triangular pulses, the recombined charge (*Qss*) can be calculated using the following equation.

$$Qss = 2q \cdot \overline{Dit} \cdot Ag \cdot k \cdot T \cdot \left[\ln(\nu_{th} \cdot n_i \cdot \sqrt{\sigma_n \cdot \sigma_p}) + \ln\left(\frac{\sqrt{\alpha \cdot (1 - \alpha)} \cdot |V_{FB} - V_T|}{f \cdot |V_{GH} - V_{GL}|} \right) \right]$$

The geometric mean of the capture cross section (σ) is extracted using the following equation, where f_0 is the frequency where the charge becomes zero. This means that f_0 is the x-axis intercept of the regression line for the *Qss* versus pulse frequency curve on a linear-log graph. The x-axis intercept is obtained from the graph using the auto-analysis capability and the read-out function of the 4155/4156.

$$\sigma = \sqrt{\sigma_n \cdot \sigma_p} = \frac{1}{\nu_{TH} \cdot n_i} \cdot \frac{|V_{GH} - V_{GL}|}{|V_{FB} - V_T|} \cdot \frac{f_0}{\sqrt{\alpha \cdot (1 - \alpha)}}$$

where,

$\sigma_{\mathbf{n}}$ **:**	Capture cross section of electrons
$\sigma_{\mathbf{p}}$ **:**	Capture cross section of holes
$\nu_{\mathbf{th}}$ **:**	Thermal velocity of the carriers
$\mathbf{n_i}$ **:**	Intrinsic carrier concentration
$\mathbf{V_{GH}}$ **:**	Pulse peak voltage
$\mathbf{V_{GL}}$ **:**	Pulse base voltage
$\mathbf{V_{FB}}$ **:**	Flat band voltage
$\mathbf{V_T}$ **:**	Threshold voltage of the transistor
α **:**	$t_r / (t_r + t_f)$
$\mathbf{t_r}$ **:**	Pulse rise-time
$\mathbf{t_f}$ **:**	Pulse fall-time

Program Files Required

The following files are used for the triangle pulse method test:

CPF	Triangle pulse method sample program. IBASIC program file. ASCII format.
SETUP.MES	Sample setup file for this application. 4155/4156 setup file.

NOTE The sample program file and 4155/4156 setup file should be stored on your working diskette. The diskette must be inserted in the 4155/4156 built-in flexible disk drive during the program execution. The sample program loads the setup file and saves the data files to the diskette automatically.

Example Measurement Result Files

The following files save example data created after executing the CPF program. The files are stored on the Sample Application Program Disk.

CPF.DAT	4155/4156 setup and measurement data file.
CPF.ASC	ASCII format file.

Sample Setup File

The triangle pulse method sample program loads and uses the 4155/4156 setup file for the measurement. For the actual setup information of the setup file you are using, load the file using the 4155/4156 filer function, and refer to the 4155/4156 setup screen.

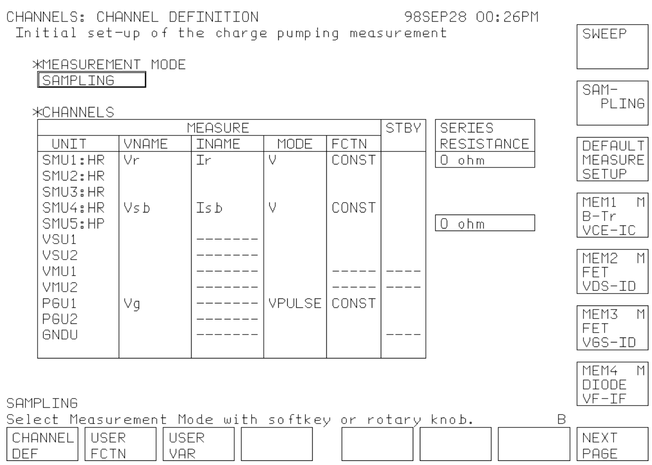
The following table shows the key setup screens of the SETUP.MES sample setup file.

NOTE If you change the setup information of the sample setup file for your application, load the sample setup file, change the setup, and save it as a new file.

To use the new file for the measurement, perform one of the following:

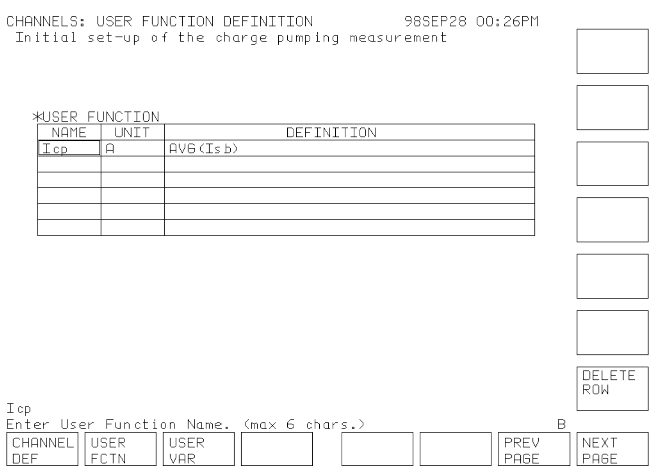
- Run the sample program, and select the File Name and Setup File softkeys, and enter the file name.
- Edit the sample program, and change the initial value for the setup file name. See “To Change the Initial Value of Input Parameters” on page 6-36.

CHANNEL DEFINITION screen



Use this screen to define the measurement units used to force the gate pulse, drain and source voltage, and to measure the substrate current (Isb). The measurement circuit diagram shown in Figure 6-1 uses this definition.

USER FUNCTION DEFINITION screen

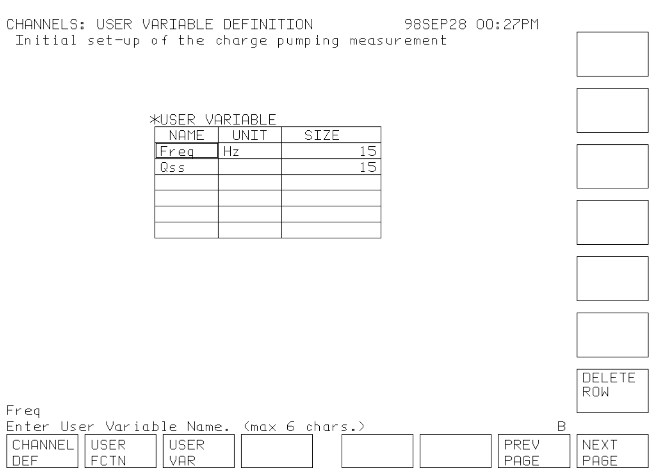


This setup screen is required to calculate the averaged Isb value (Icp) automatically. Icp value is used to calculate the recombined charge (Qss). Qss is calculated in the program using the following equation:

`Qss=Icp/Freq`

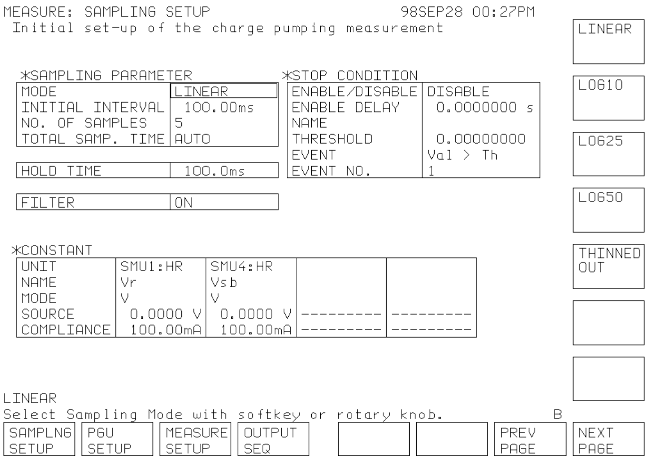
where Freq is the pulse repetition frequency [Hz].

USER VARIABLE DEFINITION screen



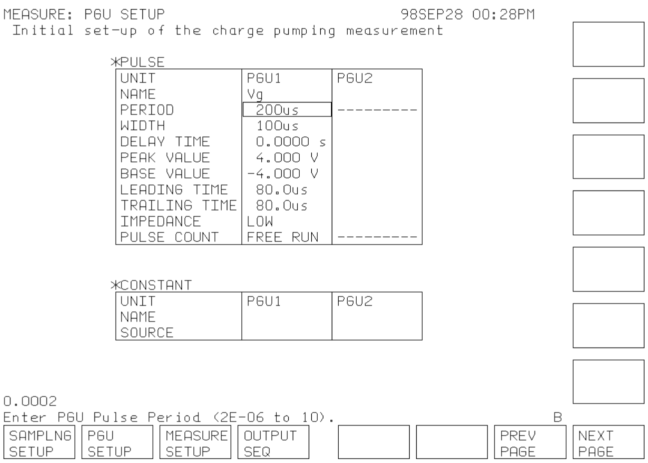
Freq and Qss are defined as the user variable. Freq is the pulse frequency. Qss is the recombined charge. The number of data points for both Freq and Qss is initially set to 15, but the number will be changed automatically during program execution. The sample program sets the SIZE to the value of the *Number of frequencies* parameter which you can define while running the program. You can also define the pulse frequency values.

SAMPLING SETUP screen



This setup screen sets the sampling measurement condition for the substrate current (Isb) measurement.

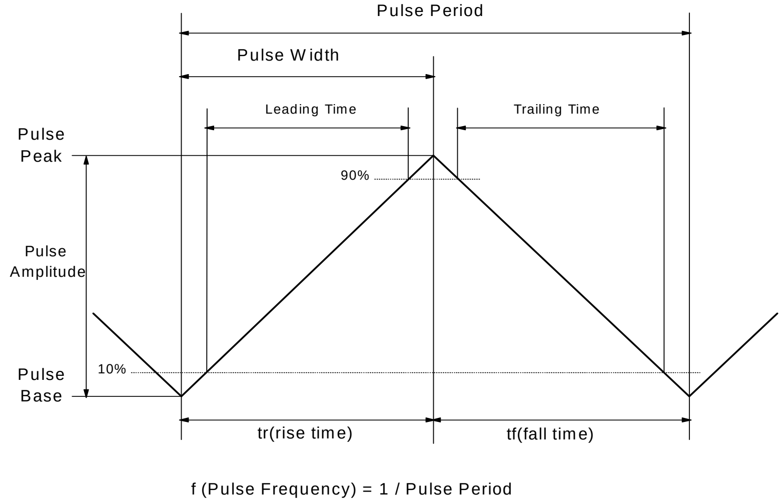
PGU SETUP screen



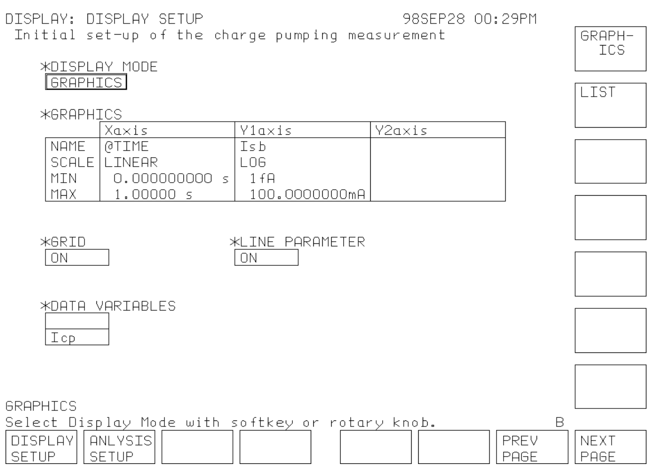
Use this screen to set the pulse output condition used to force the gate pulse. During the sample program execution, PERIOD, WIDTH, LEADING TIME, and TRAILING TIME are automatically calculated and changed by the program using the following equations:

```
PERIOD= 1/Freq
WIDTH= PERIOD × 0.5
LEADING TIME= WIDTH × 0.8
TRAILING TIME= WIDTH × 0.8
```

where Freq is the pulse frequency [Hz]. For the definition of the pulse setup parameters, see the figure below.

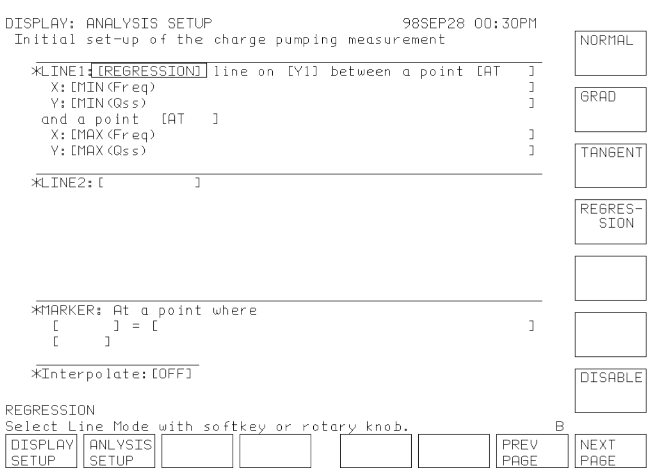


DISPLAY SETUP screen



Use this screen to set the measurement parameters and display parameters. For the sampling measurement, the x-axis must be set to @TIME. To measure the substrate current, the y-axis must be set to Isb. Icp must be set to the DATA VARIABLES field to display the Icp value on the GRAPH/LIST: GRAPHICS screen.

ANALYSIS SETUP screen



This setup screen is required to display the regression line for the Qss versus pulse frequency curve, and to calculate the slope and the x-axis intercept of the line. After the Isb measurement at all pulse frequencies, the GRAPHICS screen displays the Qss versus pulse frequency curve and this regression line. From the line parameters (slope and X-intercept), the mean interface-state density ($\overline{Dit}$) and the capture cross section (σ) are extracted automatically. The parameters can also be displayed on the screen.

To Execute the Sample Program

This procedure describes how to execute the sample program.

1. Display the SYSTEM: MISCELLANEOUS screen and set the REMOTE CONTROL COMMAND SET field to 4155/56.
2. Display the All IBASIC screen by pressing the front-panel **Display** key twice.
3. Insert a diskette containing the CPF program file and the setup file used for this test into the 4155/4156 built-in flexible disk drive.
4. Get the CPF sample program as follows:
   a. Select the GET "" softkey.
   b. Enter CPF as shown below.

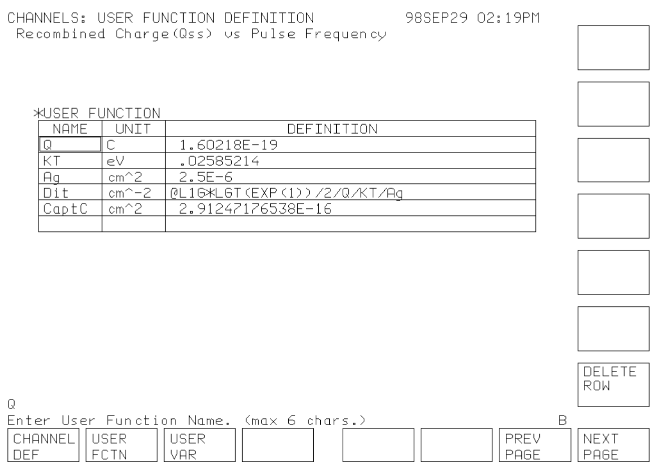
      `GET"CPF"`
   c. Press the front-panel **Enter** key.
5. Press the front-panel **Run** key to execute the program.
6. To change the following measurement conditions, select the appropriate softkeys, and enter the new value:
   - File Name (select the File Name softkey)
     - Setup file name to get (enter the name of setup file if you changed)
     - ASCII data file name to save the result data (see Figure 6-11)
     - DAT file name to save the result data (see Figure 6-10)
   - Pulse Voltage (select the Pulse Voltage softkey)
     - Pulse base voltage [V]
     - Pulse peak voltage [V]
   - Pulse Frequency (select the Pulse Frequency softkey)
     - Number of frequencies
     - Measurement frequency [Hz]
   - SMU Bias (select the SMU BIAS softkey)
     - Drain and Source bias [V]
     - Substrate bias [V]
   - Device geometry and Temperature (select the Device Geometry softkey)
     - Channel width [cm]
     - Channel length [cm]
     - Temperature [K]
     - Flat band voltage [V]
     - Threshold voltage [V]
7. Connect the device as shown in Figure 6-1.
8. Select the Measure softkey to start the test.

After the Measurement

After the measurement, the CPF program automatically does the following:

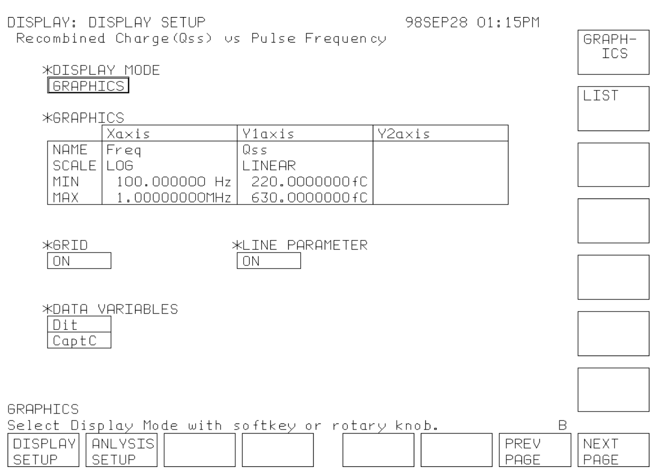
- Displays a list of the pulse frequency (*f*), charge pumping current (*Icp*), and recombined charge (*Qss*) on the All IBASIC screen.
- Changes the 4155/4156 setup information. This change is to display the Qss versus pulse frequency curve, and to extract and display the interface-state density ($\overline{Dit}$) and the capture cross section (σ). To review changes to the setup file, see the table below.
- Displays the Qss versus pulse frequency curve on the GRAPH/LIST: GRAPHICS screen. See Figure 6-10.
- Saves the ASCII file to the diskette inserted in the 4155/4156 built-in flexible disk drive. See Figure 6-11.
- Saves the DAT file to the diskette inserted in the 4155/4156 built-in flexible disk drive.

USER FUNCTION DEFINITION screen



Icp is deleted from the original setup, and Q, KT, Ag, Dit, and CaptC are added. Q is the electron charge, KT is $k \times T$ (*k*: Boltzmann's constant, *T*: Temperature), Ag is the area of gate, Dit is the interface-state density, and CaptC is the capture cross section. The equation shown in “To Extract Interface-state Density” on page 6-18 is defined in the DEFINITION field of Dit, not in the sample program. The values for other parameters are calculated in the sample program, and automatically entered in each DEFINITION field.

DISPLAY SETUP screen



In the original setup, the x-axis was @TIME. To measure the substrate leakage current, the y-axis was Isb. However, to display the Qss versus pulse frequency curve, Freq and Qss are set to the x-axis and y-axis respectively. Dit and CaptC must be set to the DATA VARIABLES fields to display the $\overline{Dit}$ and σ values on the GRAPH/LIST: GRAPHICS screen. The SCALE of the x-axis must be LOG to display a linear-log graph (linear for Qss, and log for Freq).

Figure 6-10 **Triangle Pulse Method Measurement Result**

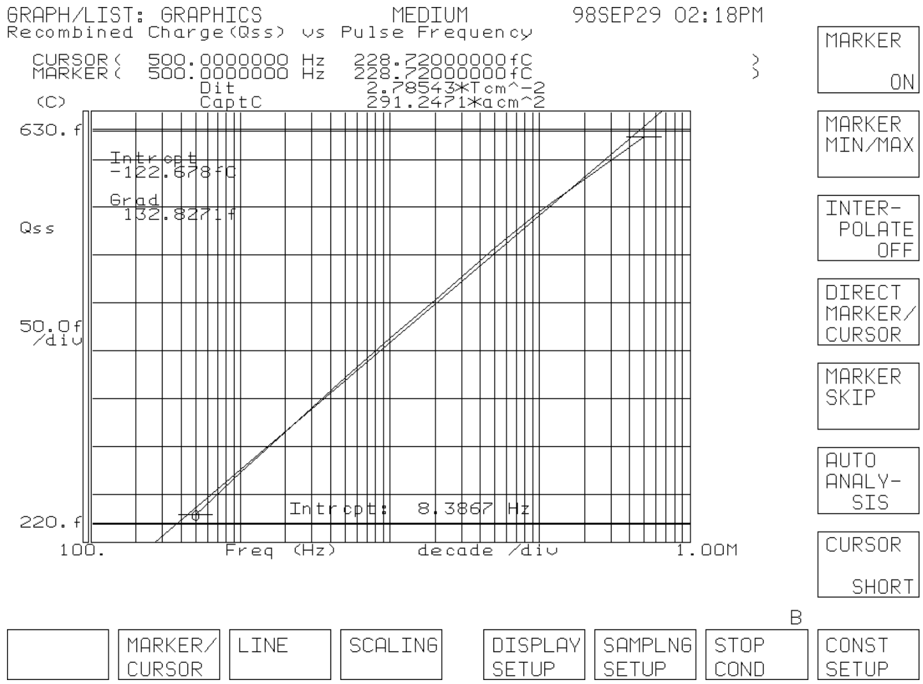


Figure 6-11 **Example Data of ASCII File**

```
 10
-4, 4
 .5, 0
 .005, .0005, 300,-1.3, .75
 500, 1000, 2000, 5000, 10000, 20000, 50000, 100000, 200000, 500000
 1.1436E-10, 2.726E-10, 6.3092E-10, 1.8625E-9, 4.13682E-9, 9.06936E-9,  . . . . . .
 2.2872E-13, 2.726E-13, 3.1546E-13, 3.725E-13, 4.13682E-13, 4.53468E-13, . . . . . .
 2.78543814996E+12, 2.91247176538E-16
```

In Figure 6-11, the first line is the number of frequencies.

The Second line is the pulse base voltage [V] and the pulse peak voltage [V].

The third line is the drain and source voltage [V] and the substrate voltage [V].

The fourth line is the channel width [cm], channel length [cm], temperature [K], flat band voltage [V], and the threshold voltage [V].

The fifth line and following two lines are the measurement result data; frequency (f) [Hz], charge pumping current (Icp) [A] and recombined charge (Qss) [C].

The last line is the mean interface-state density ($\overline{Dit}$) and the capture cross section (σ).

Trapezoidal Pulse Method

The trapezoidal pulse method presents the energy distribution of interface-states (interface-state density ($\overline{Dit}$) versus energy characteristics). This test is performed as shown in Figure 6-12. A trapezoidal pulse is applied to the gate and the substrate leakage current is measured at the point shown in Figure 6-13.

The amplitude of the trapezoidal pulse is held constant while the rise-time and the fall-time of the pulse are varied. The substrate leakage current is measured using the sampling measurement mode for each change of the pulse transient time (rise-time or fall-time). For each sampling measurement, the averaged substrate current is defined as the charge pumping current (Icp). First, Icp is measured while varying the fall-time of the pulse and keeping the rise-time of the pulse constant. Next, Icp is measured while varying the rise-time of the pulse and keeping the fall-time of the pulse constant. The pulse output, the sampling measurement, and the Icp extraction are performed using the setup information in the 4155/4156 measurement setup file, not in the sample program.

The pulse transient time is increased with each iteration of the measurement loop. Then the interface-state density $\overline{Dit}$ versus energy characteristics is drawn. The value of $\overline{Dit}$ and energy is calculated by the program.

To Extract Interface-state Density

The energy distribution of interface-states is obtained by the following equations.

$$E1 = E_i + k \cdot T \cdot \ln\left(\nu_{th} \cdot \sigma_p \cdot n_i \cdot \frac{|V_{FB} - V_T|}{|V_{GH} - V_{GL}|} \cdot t_r\right)$$

$$\overline{Dit1} = -\frac{t_r}{q \cdot Ag \cdot k \cdot T \cdot f} \cdot \frac{dI_{cp}}{dt_r}$$

$$E2 = E_i - k \cdot T \cdot \ln\left(\nu_{th} \cdot \sigma_n \cdot n_i \cdot \frac{|V_{FB} - V_T|}{|V_{GH} - V_{GL}|} \cdot t_f\right)$$

$$\overline{Dit2} = -\frac{t_f}{q \cdot Ag \cdot k \cdot T \cdot f} \cdot \frac{dI_{cp}}{dt_f}$$

where,

E1 :	Energy below the intrinsic level (eV)
E2 :	Energy over the intrinsic level (eV)
E_i :	Intrinsic level. Center level of the forbidden band. (eV)
k :	Boltzmann's constant
T :	Temperature
ν_{th} :	Thermal velocity of the carriers
σ_p :	Capture cross section of holes
σ_n :	Capture cross section of electrons
n_i :	Intrinsic carrier concentration
V_{FB} :	Flat band voltage
V_T :	Threshold voltage of the transistor
V_{GH} :	Pulse peak voltage
V_{GL} :	Pulse base voltage
t_r :	Pulse rise-time
t_f :	Pulse fall-time
$\overline{Dit1}$:	Interface-state density for E1 (cm^{-2} eV^{-1})
$\overline{Dit2}$:	Interface-state density for E2 (cm^{-2} eV^{-1})
q :	Electron charge
Ag :	Channel area of the transistor
f :	Pulse frequency
I_{cp} :	Charge pumping current

Figure 6-12 **Flowchart of Trapezoidal Pulse Method**

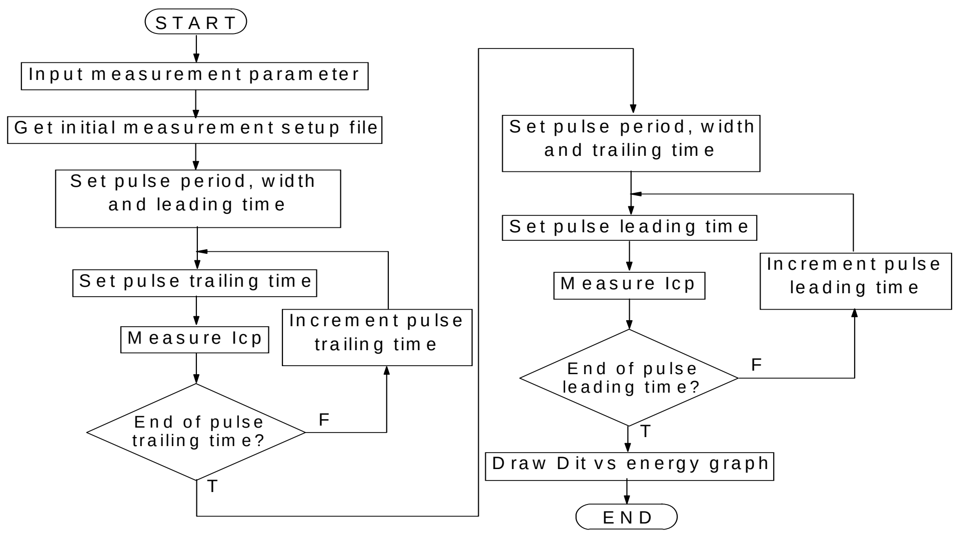
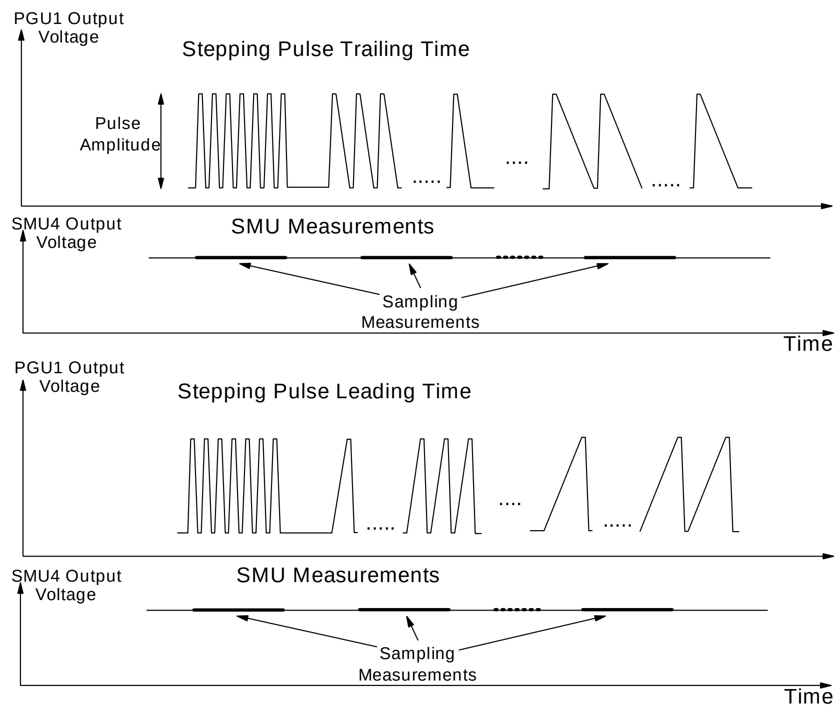


Figure 6-13 **Timing Chart of Trapezoidal Pulse Method**



Program Files Required

The following files are used for the trapezoidal pulse method test:

CPDIST	Trapezoidal pulse method sample program. IBASIC program file. ASCII format.
SETUP.MES	Sample setup file for this application. 4155/4156 setup file.

NOTE The sample program file and the 4155/4156 setup file should be stored on your working diskette. The diskette must be inserted in the 4155/4156 built-in flexible disk drive during program execution. The sample program loads the setup file and saves the data files on the diskette automatically.

Example Measurement Result Files

The following files save example data created after executing the CPDIST program. The files are stored on the Sample Application Program Disk.

CPFD.DAT	4155/4156 setup and measurement data file.
CPFD.ASC	ASCII format file.

Sample Setup File

The trapezoidal pulse method sample program loads and uses the 4155/4156 setup file for the measurement. Load the setup file using the 4155/4156 filer function, and refer to the 4155/4156 setup screen to view the actual setup information you are using.

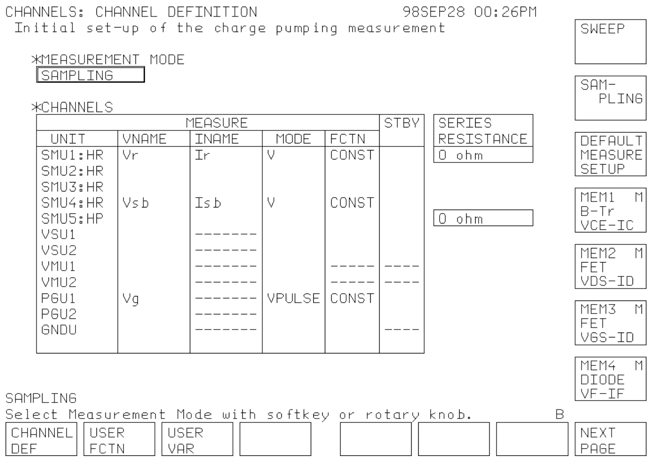
The following table shows the key setup screens of the SETUP.MES sample setup file.

NOTE If you change the setup information of the sample setup file for your application, load the sample setup file, change the setup, and save it as a new file.

To use the new file for the measurement, perform one of the following:

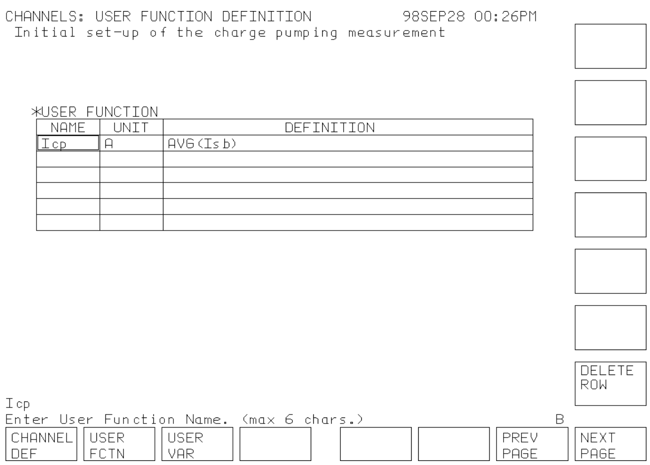
- Run the sample program, and select the File Name and Setup File softkeys, and enter the file name.
- Edit the sample program, and change the initial value for the setup file name. See “To Change the Initial Value of Input Parameters” on page 6-36.

CHANNEL DEFINITION screen



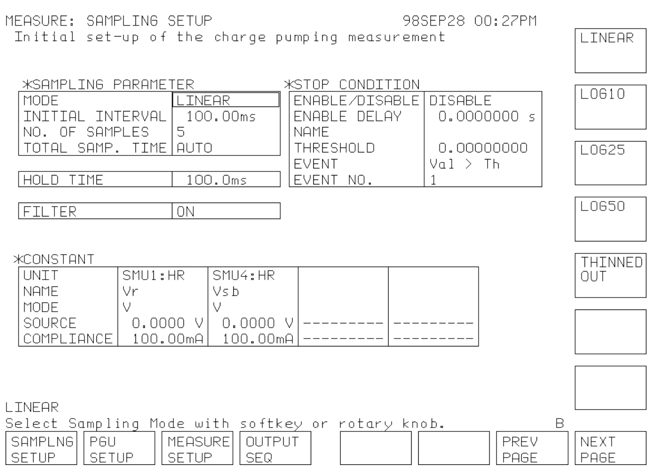
Use this screen to define the measurement units used to set the gate pulse, drain and source voltages, and to measure the substrate current (Isb). The measurement circuit diagram shown in Figure 6-1 uses this definition.

USER FUNCTION DEFINITION screen



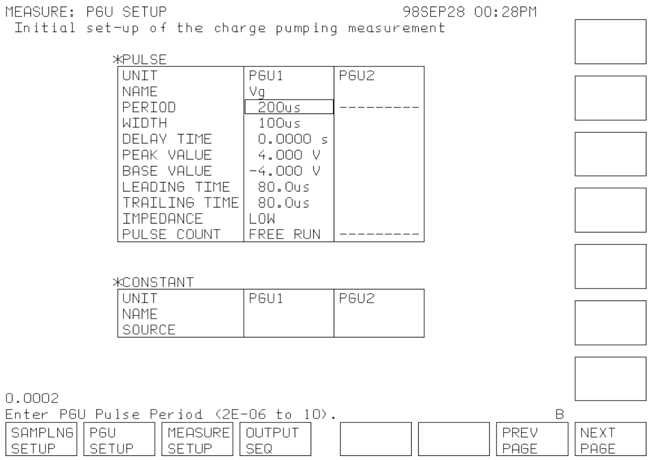
This screen is required to calculate the average Isb value (Icp). Icp value is used to calculate the interface-state density ($\overline{Dit}$) in the sample program.

SAMPLING SETUP screen



Use this screen to set the sampling measurement condition for the substrate current (Isb) measurement.

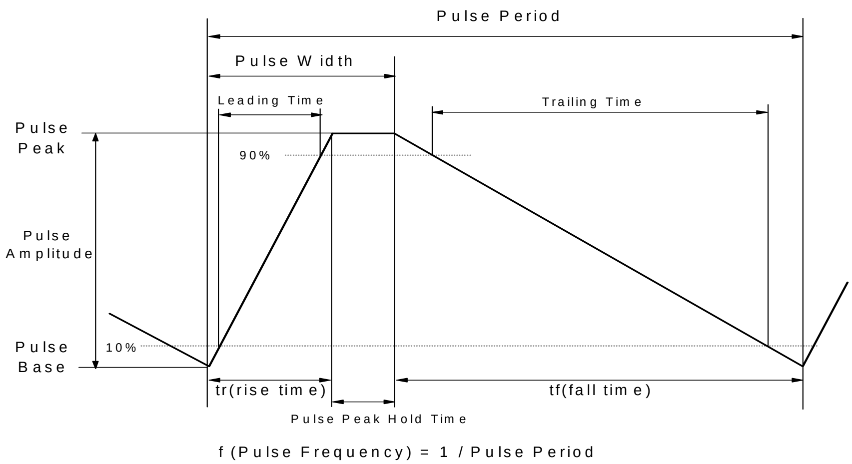
PGU SETUP screen



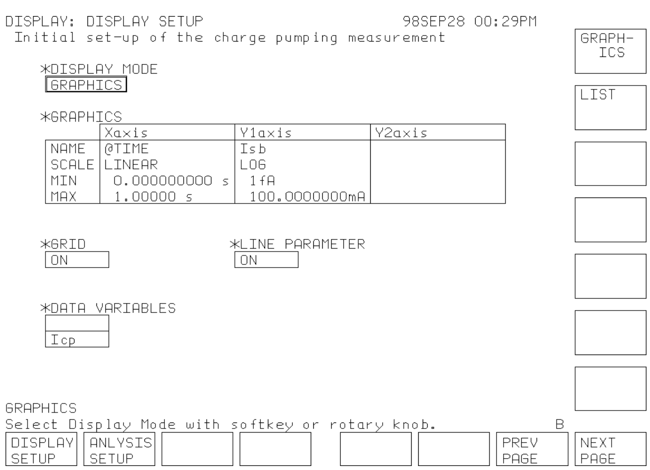
This setup screen sets the pulse output condition used to force the gate pulse. During the sample program execution, PERIOD, WIDTH, LEADING TIME, and TRAILING TIME are automatically calculated and changed by the program. PERIOD and WIDTH are calculated as shown below:

```
PERIOD= 1/Freq
WIDTH= Tpeak+Tlead/0.8
```

where Freq is the pulse frequency, T_{peak} is the pulse peak hold time, and T_{lead} is the pulse leading time. When the pulse rise-time is constant, T_{lead} is the constant transient time defined in the program. For the definition of the pulse setup parameters, see the figure below.



DISPLAY SETUP screen



This setup screen sets the measurement and display parameters. For the sampling measurement, the x-axis must be set to @TIME. To measure the substrate current, the y-axis must be set to Isb. Icp must be set to the DATA VARIABLES field to display the Icp value on the GRAPH/LIST: GRAPHICS screen.

To Execute the Sample Program

This procedure describes how to execute the sample program.

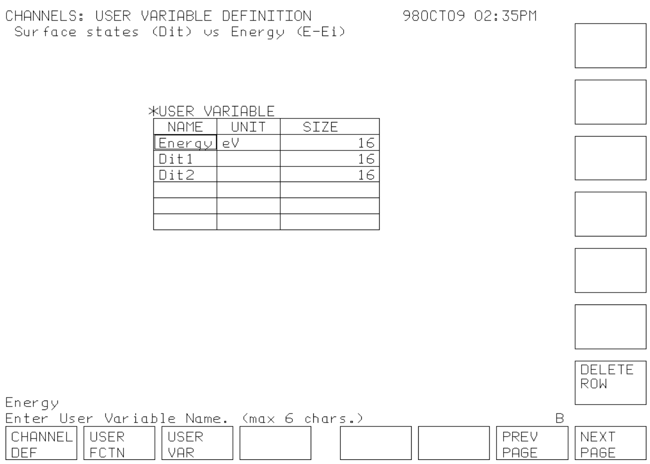
1. Display the SYSTEM: MISCELLANEOUS screen and set the REMOTE CONTROL COMMAND SET field to 4155/56.
2. Display the All IBASIC screen by pressing the front-panel **Display** key twice.
3. Insert a diskette containing the CPDIST program file and the setup file used for this test into the 4155/4156 built-in flexible disk drive.
4. Get the CPDIST sample program as follows:
   a. Select the GET "" softkey.
   b. Enter CPDIST as shown below.
      `GET"CPDIST"`
   c. Press the front-panel **Enter** key.
5. (Optional) To change the following measurement conditions, edit the program. See “To Change the Initial Value of Input Parameters” on page 6-36.
   - Pulse peak hold time [sec]
   - Pulse trailing time [sec]
   - Constant transient time [sec] used to set the constant rise/fall time
6. Press the front-panel **Run** key to execute the program.
7. To change the following measurement conditions, select the appropriate softkeys, and enter the new value:
   - File Name (select the File Name softkey)
     - Setup file name to get (enter the name of setup file if you changed)
     - ASCII data file name to save the result data (see Figure 6-15)
     - DAT file name to save the result data (see Figure 6-14)
   - Measurement Setup (select the Meas Setup softkey)
     - Pulse base voltage [V]
     - Pulse peak voltage [V]
     - Pulse frequency [Hz]
     - Drain and Source bias [V]
     - Substrate bias [V]
     - Number of measurement points
     - Pulse transient time (pulse leading time) [sec]
   - Device parameters and Temperature (select the Device Parameter softkey)
     - Channel width [cm]
     - Channel length [cm]
     - Temperature [K]
     - Flat band voltage [V]
     - Threshold voltage [V]
     - Capture cross section [cm^{-2}]
8. Connect device as shown in Figure 6-1.
9. Select the Measure softkey to start the test.

After the Measurement

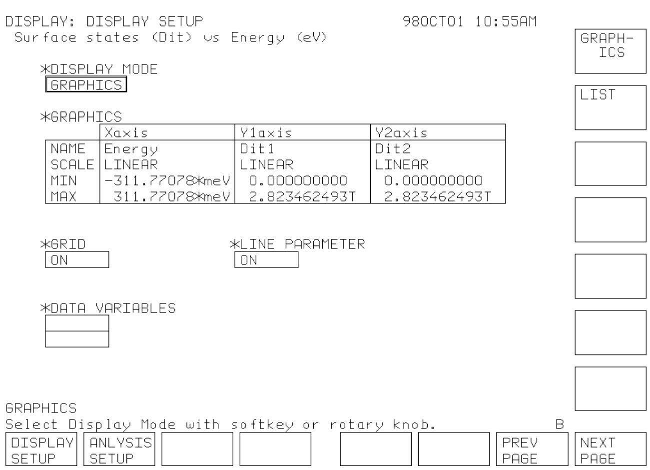
After the measurement, the CPDIST program automatically does the following:

- Changes the 4155/4156 setup information. This change displays the $\overline{Dit}$ (Dit1 and Dit2) versus energy curve. To review changes to the setup file, see the table below.
- Displays the energy distribution of interface-states ($\overline{Dit}$ versus energy curve) on the GRAPH/LIST: GRAPHICS screen. See Figure 6-14.
- Saves the ASCII file to the diskette inserted in the 4155/4156 built-in flexible disk drive. See Figure 6-15.
- Saves the DAT file to the diskette in the 4155/4156 built-in flexible disk drive.

<table>
<tr>
<td>
USER VARIABLE DEFINITION screen



</td>
<td>Energy, Dit1, and Dit2 are set to display the energy distribution of interface-states ($\overline{Dit}$ versus energy curve) on the GRAPH/LIST: GRAPHICS screen. The value of the Energy, Dit1, and Dit1 are calculated in the sample program.</td>
</tr>
<tr>
<td>
DISPLAY SETUP screen



</td>
<td>In the original setup, the x-axis was @TIME, and the y-axis was Isb. But Energy, Dit1, and Dit2 are set to x-axis, y1-axis, and y2-axis respectively to display the energy distribution of interface-states.</td>
</tr>
</table>

Figure 6-14 **Trapezoidal Pulse Method Measurement Result**

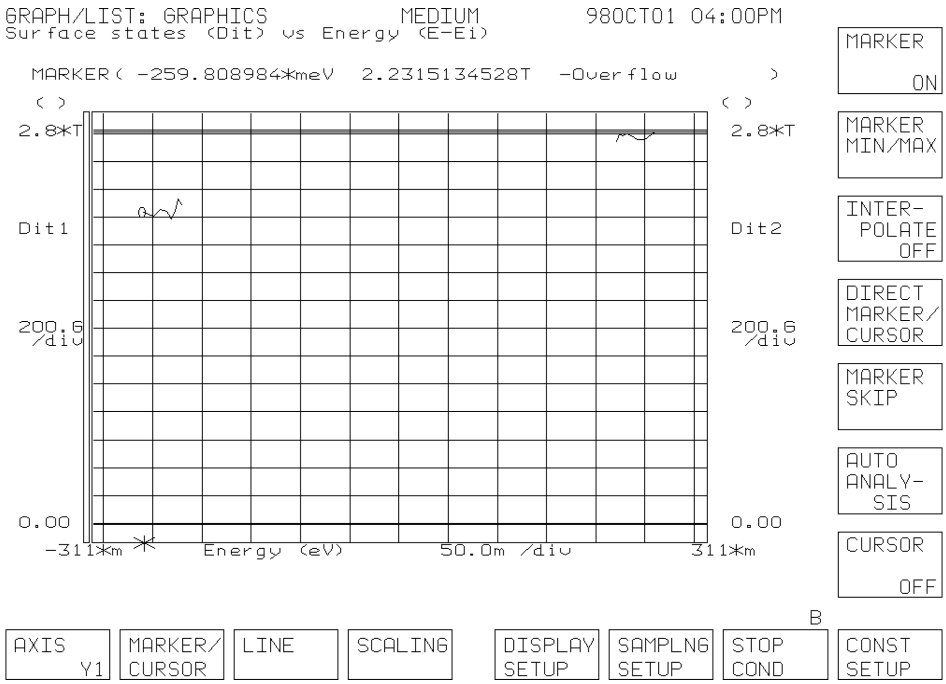


Figure 6-15 **Example Data of ASCII File**

```
 10
-4, 4, 10000, 1.E-5, 8.E-6
 .5, 0
 .005, .0005, 300,-1.3, .75, 3.E-16
 1.E-6, 2.E-6, 3.E-6, 4.E-6, 5.E-6, 6.E-6, 7.E-6, 8.E-6, . . . . .
 1.E-5, 9.E-6, 8.E-6, 7.E-6, 6.E-6, 5.E-6, 4.E-6, 3.E-6, . . . . .
 5.8114E-9, 5.6318E-9, 5.52214E-9, 5.44262E-9, . . . . .
 5.16922E-9, 5.20662E-9, 5.24964E-9, 5.29638E-9, . . . . .
 2.23475827E+12, 2.19234376E+12, 2.26550687E+12, . . . . .
 2.79588146E+12, 2.77386300E+12, 2.80352998E+12, . . . . .
-.259808984074,-.249326843334,-.241889646121, . . . . .
 .220925364642, .223970308169, .227422380425, . . . . .
```

In Figure 6-15, the first line is the number of measurement points. The second line is the pulse base voltage [V], pulse peak voltage [V], pulse frequency [Hz], pulse peak hold time [sec], and the constant transient time [sec]. The constant transient time is the pulse leading-time when the pulse rise-time is constant, and the pulse trailing-time when the pulse fall-time is constant.

The third line is the drain and source voltage [V] and the substrate voltage [V]. The fourth line is the channel width [cm], channel length [cm], temperature [K], flat band voltage [V], threshold voltage [V], and the capture cross section [cm^{-2}].

The fifth line is the pulse leading-time [sec] when the pulse rise-time is varied. The sixth line is the pulse trailing-time [sec] when the pulse fall-time is varied. The seventh line is the charge pumping current when pulse rise-time is varied. The eighth line is the charge pumping current when pulse fall-time is varied. The ninth is the $\overline{Dit}$. The tenth is the $\overline{Dit}$. The 11th is the energy (E1). The last line is the energy (E2).

Program Modification Examples

This section includes examples for modifying the sample program, and covers the following modification examples:

- "To Change the Initial Value of Input Parameters"
- "To Change the Measurement Unit"
- "To Change the Destination of the File Operation"

To Change the Initial Value of Input Parameters

If you want to change the initial value of the input parameters shown below, edit the program, and change the value.

CPV Sample Program Input Parameters

Input Parameter	Variable Name	Initial Value in original program	Program Line No.
Pulse Amplitude	Pulse_amp	6 V	640
Pulse Base Start Voltage	Pulse_start	–9 V	650
Pulse Base Stop Voltage	Pulse_stop	2 V	660
Pulse Base Step Voltage	Pulse_step	1 V	670
Pulse Period	Pulse_period	2.E–6 sec	740
Pulse Width	Pulse_width	1.E–6 sec	750
Pulse Leasing Time	Pulse_lead	1.E–7 sec	760
Pulse Trailing Time	Pulse_trail	1.E–7 sec	770
Drain and Source Voltage	Drain_source_v	0.5 V	800
Substrate Voltage	Sub_v	0 V	810
Channel Width	Weff	0.005 cm	840
Channel Length	Leff	0.0005 cm	850
Measurement Setup File	Setup_file$	"CHP.MES"	890
Measurement Result ASCII File	Save_ascii$	"CHP.ASC"	920
Measurement Result DAT File	Save_data$	"CHP.DAT"	950

Original program lines to set the initial value:

```
520  ! ---------- Input Parameters ----------------------------------
530  !
540  ! ---------- GPIB Setup ----------------------------------------
550  INTEGER Hpib_addr,Swm_sc,Swm_addr
560  !
570  Hpib_sc=8             ! 415X GPIB Select Code
580  Hpib_addr=0           ! 415X GPIB Address
590  !
600  ASSIGN @Hp415x TO Hpib_sc*100+Hpib_addr
610  ASSIGN @Form_off TO Hpib_sc*100+Hpib_addr;FORMAT OFF
620  !
630  ! ---------- Pulse Voltage Conditions --------------------------
640  Pulse_amp=6           ! Pulse Amplitude Voltage
650  Base_start=-9         ! Start Pulse Base Voltage
660  Base_stop=2           ! Stop Pulse Base Voltage
670  Base_step=1           ! Step Pulse Base Voltage
680  !
690  No_of_step=INT((Base_stop-Base_start)/Base_step)+1 !No.of steps
700  REDIM V_base(1:No_of_step)
710  REDIM Isb(1:No_of_step)
720  !
730  ! ---------- Pulse Timing Conditions ---------------------------
740  Pulse_period=2.E-6    ! Pulse Period
750  Pulse_width=1.E-6     ! Pulse Width
760  Pulse_lead=1.E-7      ! Pulse Leading Time
770  Pulse_trail=1.E-7     ! Pulse Trailing Time
780  !
790  ! ---------- Bias Conditions -----------------------------------
800  Drain_source_v=.5     ! Drain and Source Voltage
810  Sub_v=0               ! Substrate Voltage
820  !
830  ! ---------- Device geometry -----------------------------------
840  Weff=.005             ! Channel width [cm]
850  Leff=.0005            ! Channel length [cm]
860  !
870  ! ----- Definition of measurement and stress setup files -------
880  !
890  Setup_file$="CHP.MES"      ! Charge Pumping Test Setup file
900  !
910  ! ---------- File name to save ASCII data ----------------------
920  Save_ascii$="CHP.ASC"      ! Charge Pumping Test Data ASCII file
930  !
940  ! ---------- File name to save GRAPHICS data -------------------
950  Save_data$="CHP.DAT"       ! Charge Pumping Test Data file
960  !
```

CPF Sample Program Input Parameters

Input Parameter	Variable Name	Initial Value in original program	Program Line No.
Pulse Base Voltage	Pulse_base	–4 V	660
Pulse Peak Voltage	Pulse_peak	4 V	670
Number of Frequencies	No_of_freq	10	700
Pulse Frequency	Pulse_freq(*)	See below. [a]	710 to 780
Drain and Source Voltage	Drain_source_v	0.5 V	810
Substrate Voltage	Sub_v	0 V	820
Channel Width	Weff	0.005 cm	850
Channel Length	Leff	0.0005 cm	860
Temperature	T	300 K	870
Flat Band Voltage	Vfb	–1.3 V	880
Threshold Voltage	Vt	0.75 V	890
Measurement Setup File	Setup_file$	"SETUP.MES"	990
Measurement Result ASCII File	Save_ascii$	"CPF.ASC"	1020
Measurement Result DAT File	Save_data$	"CPF.DAT"	1050

a. 500, 1k, 2k, 5k, 10k, 20k, 50k, 100k, 200k, 500k [Hz]

Original program lines to set the initial value:

```
540   ! ---------- Input Parameters --------------------------------
550   !
560   ! ---------- GPIB Setup --------------------------------------
570    INTEGER Hpib_addr,Swm_sc,Swm_addr
580   !
590    Hpib_sc=8           ! 415X GPIB Select Code
600    Hpib_addr=0         ! 415X GPIB Address
610   !
620    ASSIGN @Hp415x TO Hpib_sc*100+Hpib_addr
630    ASSIGN @Form_off TO Hpib_sc*100+Hpib_addr;FORMAT OFF
640   !
650   ! ---------- Pulse Voltage Conditions -------------------------
660    Pulse_base=-4       ! Pulse Base Voltage
670    Pulse_peak=4        ! Pulse Peak Voltage
680   !
690   ! ---------- Pulse Frequency ----------------------------------
700    No_of_freq=10
710 Freq_data: !
720    DATA 5E2,1E3,2E3,5E3,1E4,2E4,5E4,1E5,2E5,5E5
730   !
740    REDIM Pulse_freq(1:No_of_freq)
750    REDIM Icp(1:No_of_freq),Qss(1:No_of_freq)
760    RESTORE Freq_data
770   !
780    READ Pulse_freq(*)
790   !
800   ! ---------- Bias Conditions ----------------------------------
810    Drain_source_v=.5   ! Drain and Source Voltage
820    Sub_v=0             ! Substrate Voltage
830   !
840   ! ---------- Device geometry and temperature -----------------
850    Weff=.005           ! Channel width [cm]
860    Leff=.0005          ! Channel length [cm]
870    T=300               ! Temperature [K]
880    Vfb=-1.3            ! Flat band voltage [V]
890    Vt=.75              ! Threshold voltage [V]
900   !
910   ! ---------- Constants ----------------------------------------
920    Q=1.60218E-19   ! Electronic charge [C]
930    K=8.61738E-5    ! Boltzmann's constant [ev/K]
940    Ni=1.45E+10     ! Intrinsic carrier concentration of Si at 300
K [cm^-3]
950    Nuth=1.55E+7    ! Thermal verocity of carriers
960   !
970   ! ---- Definition of measurement and stress setup files -------
980   !
990    Setup_file$="SETUP.MES"    ! Charge Pumping Test Setup file
1000  !
1010  ! ---------- File name to save ASCII data ---------------------
1020   Save_ascii$="CPF.ASC"    ! Charge Pumping Test Data ASCII file
1030  !
1040  ! ---------- File name to save GRAPHICS data ------------------
1050   Save_data$="CPF.DAT"     ! Charge Pumping Test Data file
1060  !
```

CPDIST Sample Program Input Parameters

Input Parameter	Variable Name	Initial Value in original program	Program Line No.
Pulse Base Voltage	Pulse_base	–4 V	670
Pulse Peak Voltage	Pulse_peak	4 V	680
Pulse Frequency	Pulse_freq	10 kHz	690
Pulse Peak Hold Time [a]	Peak_hold	10 μsec	700
Constant Transient Time [b]	Fix_trans	8 μsec	710
Number of Measurement Points	No_of_meas	10	740
Pulse Leading Time (Varied)	Pulse_lead(*)	See below. [c]	810
Pulse Trailing Time (Varied)	Pulse_trail(*)	See below. [d]	830
Drain and Source Voltage	Drain_source_v	0.5 V	920
Substrate Voltage	Sub_v	0 V	930
Channel Width	Weff	0.005 cm	960
Channel Length	Leff	0.0005 cm	970
Temperature	T	300 K	980
Flat Band Voltage	Vfb	–1.3 V	990
Threshold Voltage	Vt	0.75 V	1000
Capture Cross Section	Cap_cross	300a cm^{-2}	1010
Measurement Setup File	Setup_file$	"SETUP.MES"	1110
Measurement Result ASCII File	Save_ascii$	"CPFD.ASC"	1140
Measurement Result DAT File	Save_data$	"CPFD.DAT"	1170

a. Pulse peak hold time is the time which the pulse peak value continues.
b. Constant transient time (t_{const}) is used to calculate the constant pulse rise-time (t_{cr}) and constant pulse fall-time (t_{cf}) . $t_{cr} = t_{cf} = t_{const} / 0.8$
c. 1μ, 2μ, 3μ, 4μ, 5μ, 6μ, 7μ, 8μ, 9μ, 10μ [sec]
d. 10μ, 9μ, 8μ, 7μ, 6μ, 5μ, 4μ, 3μ, 2μ, 1μ [sec]

Original program lines to set the initial value:

```
550   ! ---------- Input Parameters -------------------------------
560   !
570   ! ---------- GPIB Setup ---------------------------------------
580    INTEGER Hpib_addr,Swm_sc,Swm_addr
590   !
600    Hpib_sc=8           ! 415X GPIB Select Code
610    Hpib_addr=0         ! 415X GPIB Address
620   !
630    ASSIGN @Hp415x TO Hpib_sc*100+Hpib_addr
640    ASSIGN @Form_off TO Hpib_sc*100+Hpib_addr;FORMAT OFF
650   !
660   ! ---------- Pulse Voltage Conditions ------------------------
670    Pulse_base=-4       ! Pulse Base Voltage
680    Pulse_peak=4        ! Pulse Peak Voltage
690    Pulse_freq=10000.   ! Pulse frequency : 10 kHz. Pulse period :
100 usec
700    Peak_hold=1.E-5     ! Pulse peak hold time 10 usec
710    Fix_trans=8.E-6     ! Fixed transient time (10% to 90%)
720   !
730   ! ---------- No. of Measurement -------------------------------
740    No_of_meas=10
750    REDIM Pulse_lead(1:No_of_meas),Pulse_trail(1:No_of_meas)
760    REDIM Icp_lead(1:No_of_meas),Icp_trail(1:No_of_meas)
770    REDIM Dit_lead(2:No_of_meas-1),Dit_trail(2:No_of_meas-1)
780    REDIM Energy_lead(2:No_of_meas-1),Energy_trail(2:No_of_meas-1)
790   !
800 Leading_data: !
810    DATA 1E-6,2E-6,3E-6,4E-6,5E-6,6E-6,7E-6,8E-6,9E-6,10E-6
820 Trailing_data: !
830    DATA 10E-6,9E-6,8E-6,7E-6,6E-6,5E-6,4E-6,3E-6,2E-6,1E-6
840   !
850    RESTORE Leading_data
860    READ Pulse_lead(*)
870   !
880    RESTORE Trailing_data
890    READ Pulse_trail(*)
900   !
910   ! ---------- Bias Conditions ---------------------------------
920    Drain_source_v=.5   ! Drain and Source Voltage
930    Sub_v=0             ! Substrate Voltage
940   !
950   ! ---------- Device geometry and temperature ------------------
960    Weff=.005           ! Channel width [cm]
970    Leff=.0005          ! Channel length [cm]
980    T=300               ! Temperature [K]
990    Vfb=-1.3            ! Flat band voltage [V]
1000   Vt=.75              ! Threshold voltage [V]
1010   Cap_cross=3.E-16    ! Capture cross section [cm^-2]
1020  !
1030  ! ---------- Constants ----------------------------------------
1040   Q=1.60218E-19   ! Electronic charge [C]
1050   K=8.61738E-5    ! Boltzmann's constant [ev/K]
1060   Ni=1.45E+10     ! Intrinsic carrier concentration of Si at 300
K [cm^-3]
1070   Nuth=1.55E+7    ! Thermal verocity of carriers
1080  !
1090  ! ----- Definition of measurement and stress setup files ------
1100  !
1110   Setup_file$="SETUP.MES"    ! Charge Pumping Test Setup file
1120  !
1130  ! ---------- File name to save ASCII data --------------------
1140   Save_ascii$="CPFD.ASC"    ! Charge Pumping Test Data ASCII file
1150  !
1160  ! ---------- File name to save GRAPHICS data ------------------
1170   Save_data$="CPFD.DAT"     ! Charge Pumping Test Data file
1180  !
```

To Change the Measurement Unit

The original code in the sample program uses SMU1, SMU4, and PGU1 for the measurement. Other combinations of measurement units can be used, such as a combination of SMU2, SMU3, and PGU2.

Modification example shown below uses:

- SMU2 instead of SMU1 (to force drain voltage and source voltage)
- SMU3 instead of SMU4 (to force substrate voltage and to measure current)
- PGU2 instead of PGU1 (to force gate pulse)

1. Change the setup file as follows:

   a. Get the original setup file (CPV.MES for CPV sample program, or SETUP.MES for CPF and CPDIST sample programs).

   b. Display the CHANNELS: CHANNEL DEFINITION screen.

   c. Move the field pointer to the SMU1 VNAME field, and select the CHANNEL ASSIGN softkey. Then the pointer moves to the SMU1 UNIT field.

   d. Select a softkey for every UNIT. See the table below:

UNIT name before change	Softkey	UNIT name after change
SMU1	SMU2	SMU2
SMU2	SMU1	SMU1
SMU3	SMU4	SMU4
SMU4	SMU3	SMU3
PGU1	PGU2	PGU2
PGU2	PGU1	PGU1

   e. Select the EXIT CHANNEL ASSIGN softkey.

   f. Save the MES data as a new file, for example, NEW.MES, when it is stored on your working diskette the sample program is saved also.

2. Change the program as follows:

   a. Edit the following program line to change the measurement setup file name. The modification example shown below changes the name to NEW.MES.

Program Name	Program Line No.
CPV	890
CPF	990
CPDIST	1110

   Example: Following example modifies the CPV program.

```
890   Setup_file$="NEW.MES"
```

   b. Edit the following program lines to change the SMU channels (SMU1 to SMU2, and SMU4 to SMU3).

Program Name	Program Line No.
CPV	3770 and 3780
CPF	3770 and 3780
CPDIST	4230 and 4240

   Example: Following example modifies the CPV program.

```
3770  OUTPUT @Hp415x;":PAGE:MEAS:SAMP:CONS:SMU2:SOUR ";Drain_
source_v
3780  OUTPUT @Hp415x;":PAGE:MEAS:SAMP:CONS:SMU3:SOUR ";Sub_v
```

c. Edit the following program lines to change the PGU channel (PGU1 to PGU2).

Program Name	Program Line No.
CPV	5830 to 5860, 5920 to 5930
CPF	6150 to 6180, 6250 to 6260
CPDIST	7160 to 7190, 7260 to 7270

Example: Program lines marked >> are modified. This modifies the CPV program.

```
   5790 Set_pulse_time:SUB Set_pulse_time
   5800    COM @Hp415x,@Form_off,INTEGER Hpib_sc
   5810    COM /Condition2/ REAL Pulse_period,Pulse_width,Puls
   e_lead,Pulse_trail
   5820    !
>> 5830    OUTPUT @Hp415x;":PAGE:MEAS:PGUS:PULS:PGU2:PER ";Pul
   se_period
>> 5840    OUTPUT @Hp415x;":PAGE:MEAS:PGUS:PULS:PGU2:WIDT ";Pu
   lse_width
>> 5850    OUTPUT @Hp415x;":PAGE:MEAS:PGUS:PULS:PGU2:LEAD ";Pu
   lse_lead
>> 5860    OUTPUT @Hp415x;":PAGE:MEAS:PGUS:PULS:PGU2:TRA ";Pul
   se_trail
   5870  SUBEND
   5880   !
   5890 Set_pulse_volt:SUB Set_pulse_volt(Pulse_base,Pulse_pea
   k)
   5900    COM @Hp415x,@Form_off,INTEGER Hpib_sc
   5910   !
>> 5920    OUTPUT @Hp415x;":PAGE:MEAS:PGUS:PULS:PGU2:BASE ";Pu
   lse_base
>> 5930    OUTPUT @Hp415x;":PAGE:MEAS:PGUS:PULS:PGU2:PEAK ";Pu
   lse_peak
   5940  SUBEND
```

To Change the Destination of the File Operation

The sample program loads the measurement setup file from the diskette in the 4155/4156 built-in flexible disk drive. After the measurement, the sample program also saves the measurement result DAT file and the ASCII measurement result data file on the diskette.

You can use an NFS mounted disk drive instead of the built-in flexible disk drive. To change the drive, modify the program as shown below. After the modification, the program loads the measurement setup file from the NET1 drive, saves the measurement result DAT file on the NET1 drive, and saves the ASCII measurement result data file onto both the diskette and the NET1 drive. NET1 is one of the network drives defined in the NETWORK DRIVE SETUP table on the SYSTEM: MISCELLANEOUS screen (you can define maximum 4 network drives using the table).

NOTE

To save the ASCII measurement result data file onto an NFS mounted drive, the ASCII data must be previously saved on the diskette.

The IBASIC program cannot write the ASCII data directly to the NFS mounted drive.

1. To change the drive used to load the measurement setup file, insert the following program lines.

Program Line (Command)	Program Name	Program Line No.
`OUTPUT @Hp415x;":MMEM:DEST NET1"`	CPV	3731
	CPF	3721
	CPDIST	4181
`OUTPUT @Hp415x;":MMEM:DEST INT"`	CPV	3741
	CPF	3731
	CPDIST	4191

Example: Program lines marked >> are inserted. This modifies the CPV program.

```
   3710    !
   3720    ! Load setup file, and set bias conditions
   3730    !
>> 3731    OUTPUT @Hp415x;":MMEM:DEST NET1"
   3740    OUTPUT @Hp415x;":MMEM:LOAD:STAT 0,'"&Setup_file$&"','D
   ISK'"
>> 3741    OUTPUT @Hp415x;":MMEM:DEST INT"
   3750    Comment$="Charge Pumping Current Measurement"
   3760    OUTPUT @Hp415x;":PAGE:CHAN:COMM '"&Comment$&"'"
   3770    OUTPUT @Hp415x;":PAGE:MEAS:SAMP:CONS:SMU1:SOUR ";Drain
   _source_v
   3780    OUTPUT @Hp415x;":PAGE:MEAS:SAMP:CONS:SMU4:SOUR ";Sub_v
   3790    CALL Set_pulse_time
   3800    !
```

2. To change the drive used to save the measurement result DAT file, insert the following lines.

Program Line (Command)	Program Name	Program Line No.
`OUTPUT @Hp415x;":MMEM:DEST NET1"`	CPV	5181
	CPF	5501
	CPDIST	6511
`OUTPUT @Hp415x;":MMEM:DEST INT"`	CPV	5191
	CPF	5511
	CPDIST	6521

Example: Program lines marked >> are inserted. This modifies the CPV program.

```
   5140 Save_data:SUB Save_data
   5150     COM @Hp415x,@Form_off,INTEGER Hpib_sc
   5160     COM /File_name1/ Setup_file$,Save_ascii$,Save_data$
   5170     ! ---- Save charge pumping data to DAT file -----------
   5180     ON ERROR GOSUB Error
>> 5181     OUTPUT @Hp415x;":MMEM:DEST NET1"
   5190     OUTPUT @Hp415x;":MMEM:STOR:TRAC DEF,'"&Save_data$&"','
   DISK'"
>> 5191     OUTPUT @Hp415x;":MMEM:DEST INT"
   5200     OFF ERROR
   5210     SUBEXIT
```

3. Follow the next steps to add a function which writes the measurement result data to an ASCII file on the NET1 network drive.

   a. Insert the following program line.

Program Line (Command)	Program Name	Program Line No.
`CALL Save_asc_net`	CPV	1081
	CPF	1181
	CPDIST	1311

   Example: Program lines marked >> are inserted. This modifies the CPV program.

```
   970   !///////////////// Main //////////////////////////////
   980   !
   990   ON INTR Hpib_sc CALL Err_check   ! Enables GPIB inter
   rupt
   1000  ENABLE INTR Hpib_sc;2
   1010  !
   1020  CALL Input_param                 ! Input Parameters
   1030  CALL Init_hp415x                 ! Initialize 415X
   1040  CALL Measure                     ! Measure Charge Pum
   ping Current
   1050  CALL Graph                       ! Draw Graph of Icp
   - Pulse Base Voltage
   1060  CALL Save_ascii                  ! Save ASCII file
   1070  CALL Save_data                   ! Save DAT file
   1080  CALL Test_end                    !
>> 1081  CALL Save_asc_net                ! Save ASCII file to
   network drive
   1090  DISP "HCI Degradation Test is Completed!!"
   1100  !
   1110  END
```

   b. Add the following program lines at the bottom of the program. This example writes the data to an ASCII file on the NET1 drive.

```
8000 Save_asc_net:SUB Save_asc_net
8010 ! USE FLEX MODE
8020    COM @Hp415x,@Form_off,INTEGER Hpib_sc
8030    COM /File_name1/ Setup_file$,Save_ascii$,Save_data$
8040    DIM Data$[250]
8050    OUTPUT @Hp415x;"US"
8060    OUTPUT @Hp415x;"SDSK 0"
8070    OUTPUT @Hp415x;"OPEN ";CHR$(39)&Save_ascii$&CHR$(39);",0"
8080    OUTPUT @Hp415x;"RD?"
8090    ENTER @Hp415x USING "-K";Data$
8100    OUTPUT @Hp415x;"CLOSE"
8110    !
8120    OUTPUT @Hp415x;"SDSK 1"
8130    OUTPUT @Hp415x;"OPEN ";CHR$(39)&Save_ascii$&CHR$(39);",1"
8140    OUTPUT @Hp415x;"WR ";Data$
8150    OUTPUT @Hp415x;"CLOSE"
8160    OUTPUT @Hp415x;":PAGE"
8170   SUBEND
```

Perform the following steps *before* executing the modified program.

1. Display the SYSTEM: MISCELLANEOUS screen, and perform the following steps:
   a. Define the 4155 NETWORK SETUP table or the 4156 NETWORK SETUP table properly.
   b. Move the field pointer to the NETWORK DRIVE SETUP table, and select the first softkey from the top. This softkey displays the definition for the NET1 network drive in the NETWORK DRIVE SETUP table.
   c. Confirm the definition in the NETWORK DRIVE SETUP table.

      If the definition is not completed, define the setup properly and select the ADD softkey.

      If you want to modify the definition, define the setup properly and select the UPDATE softkey.
2. Insert a diskette containing the program file and the measurement setup file used to the test into the built-in flexible disk drive.
3. Get the setup file from the diskette.
4. Display the SYSTEM: FILER screen, and save the setup file on the NET1 network drive as shown below:
   - Move the field pointer to the DISK field, and select the softkey for the NET1 drive (softkey label is same as the LABEL in the NETWORK DRIVE SETUP table). The 4155/4156 will mount the NET1 drive.
   - Save the setup file on the NET1 drive.
   - Move the field pointer to the DISK field, and select the FLOPPY softkey.
5. (Optional) If you do not want to save the measurement result ASCII data file on the diskette containing the program, perform the following steps:
   - Load the program from the diskette.
   - Remove the diskette.
   - Insert another diskette used to save the ASCII data file.

After the all steps shown above, you should perform the steps described in "To Execute the Sample Program". Then you can skip the step 3 which presses you to insert the diskette into the built-in flexible disk drive.

7 Flash EEPROM Test

This program forces write and erase pulses, then measures Vth shift.

	name
Program	NOR_TEST
Setup files	ROMVTH.MES, NORWRT.STR, NORERS.STR, NANWRT.STR, NANERS.STR

This program uses NORWRT.STR and NORERS.STR stress setup files for write and erase pulses. These setup files are for NOR type flash EEPROM.

To use this program for NAND type flash EEPROM, please modify as follows to use NANWRT.STR and NANERS.STR stress setup files:

- Modify the following two lines:

```
1990    Wrt_file$="NORWRT.STR"     ! Write Stress Setup File Name
2000    Ers_file$="NORERS.STR"     ! Erase Stress Setup File Name
```

  as follows:

```
1990    Wrt_file$="NANWRT.STR"     ! Write Stress Setup File Name
2000    Ers_file$="NANERS.STR"     ! Erase Stress Setup File Name
```

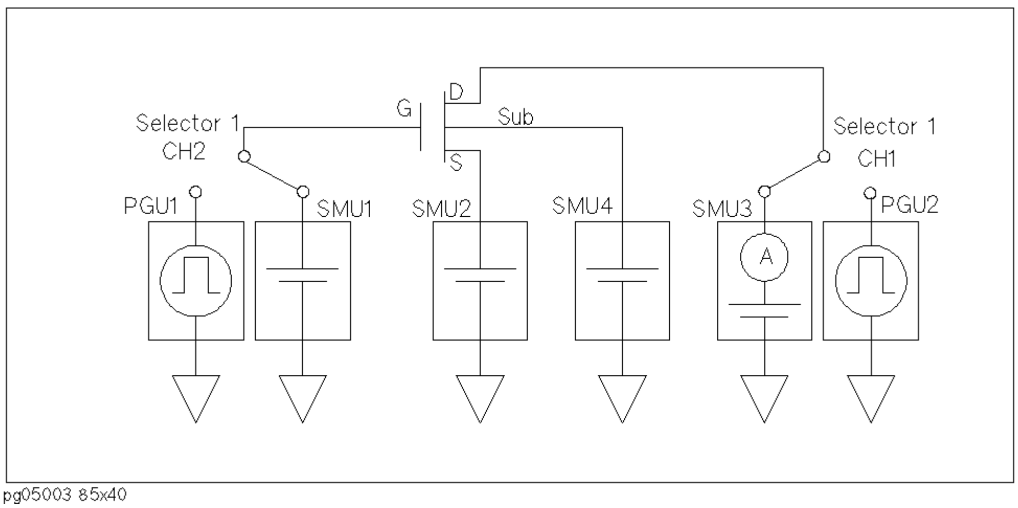
Program Overview

Device connections for NOR and NAND type flash EEPROM are different.

Device Connection for NOR type flash EEPROM

As shown in Figure 7-1, one 16440A SMU/Pulse Generator Selector is used to switch units for forcing write pulse and erase pulse, and measuring Vth.

Figure 7-1 **Device Connection (NOR Type)**



The following table shows the selector's state for each phase:

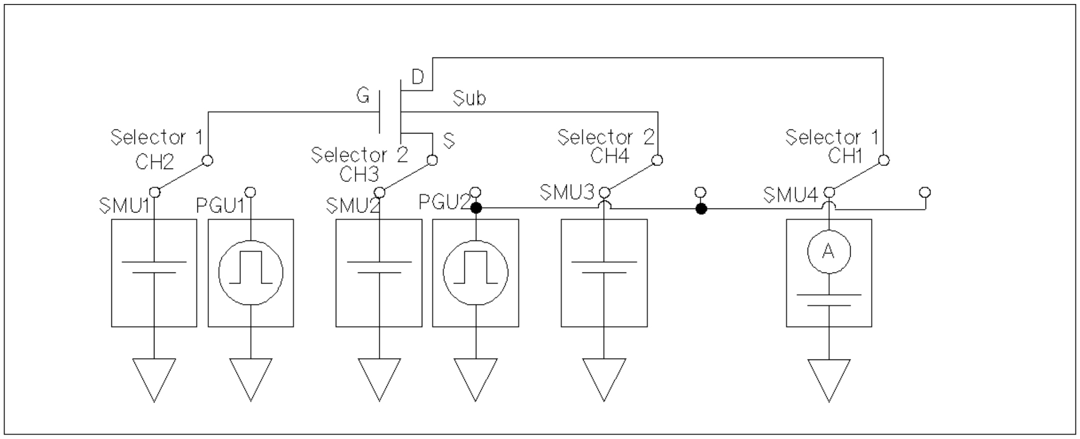
Table 7-1 **Selector's State in Each Phase**

Selector Channel	Write	Erase	Vth Measure
CH1 (Drain)	PGU	PGU OPEN	SMU
CH2 (Gate)	PGU	PGU	SMU

Device Connection for NAND type flash EEPROM

As shown in Figure 7-2, two 16440A SMU/Pulse Generator Selectors are used to switch units for forcing write pulse and erase pulse, and measuring Vth.

Figure 7-2 **Device Connection (NAND Type)**



pg05004 100x60

Table 7-2 shows the selector's state for each phase:

Table 7-2 **Selector's State in Each Phase**

Selector Channel	Write	Erase	Vth Measure
CH1 (Drain)	PGU	PGU	SMU
CH2 (Gate)	PGU	PGU	SMU
CH3 (Source)	PGU	PGU	SMU
CH4 (Substrate)	PGU	PGU	SMU

Main Program

The following is the main program:

```
1560  !/////////////// Main ///////////////////////////////////////////
1570  CALL Init_hp4155
1580  ON INTR 8 CALL Err_check
1590  ENABLE INTR 8;2
1600  !
1610  CALL Test_setting
1620  CALL Get_file
1630  !
1640  Str_num=1
1650  FOR I=1 TO Meas_points
1660    CALL Stress_loop(I)
1670    IF Meas_str_num(I)>4500 THEN CALL Calibration
1680    !
1690    OUTPUT @Hp4155;":MMEM:LOAD:STAT 0,’MEM2.STR’,’MEMORY’"
1700    OUTPUT @Hp4155;":MMEM:LOAD:STAT 0,’MEM1.MES’,’MEMORY’"
1710    CALL Vth_meas("Write",I)
1720    !
1730    OUTPUT @Hp4155;":MMEM:LOAD:STAT 0,’MEM3.STR’,’MEMORY’"
1740    CALL Vth_meas("Erase",I)
1750    !
1760    CALL Trans_data(I)
1770    CALL Stress_graph(I)
1780    !
1790    IF Vth_w(I)<.1 OR Vth_e(I)<.1 THEN
1800      PRINT "     ### The Device is broken. Test Aborted ###"
1810      PRINT "         Final Stress Times  : ";Str_num
1820      CALL Final_session
1830      STOP
1840    END IF
1850    Str_num=Str_num+1
1860  NEXT I
1870  !
1880  CALL Final_session
1890  !
1900  END
```

Line	Description
1570	initializes 4155/4156. enables the Service Request "Enable" Register for Command, Execution, Device-dependent, and Query errors to generate service requests.
1580 and 1590	enables service request from the 4155/4156 to interrupt program.
1610	defines names of measurement setup files for Vth measurement and stress setup files for write stress and erase stress, and other stress setup.
1620	loads measurement setup file for Vth measurement and stress setup files for write and erase into internal memories.

Line	Description
1650	*Meas_points* is specified in subprogram "Test_setting".
1660	forces write and erase pulses. Refer to "Stress_loop" for details.
1690 and 1700	loads measurement setup file for Vth measurement and stress setup file for write pulse from internal memories.
1710	forces last write pulse, then measures Vth. Refer to "Vth_meas".
1730	loads stress setup file for erase pulse from an internal memory.
1740	forces last erase pulse, then measures Vth. Refer to "Vth_meas".
1760	transfers measurement results (Vth shifts) to the 4155/4156.
1770	displays measurement results.
1880	stores measurement results onto the diskette.

Stress_loop

Subprogram "Stress_loop" to force write and erase stress is shown below:

```
2610 Stress_loop:SUB Stress_loop(INTEGER I)
2620    COM @Hp4155,@Form_off,Start_time,End_time
2630    COM /Meas_info/ INTEGER Meas_points,REAL Str,Str_num,Meas_st
r_num(*)
2640    INTEGER K
2650    REAL Str_end
2660    !
2670    OUTPUT @Hp4155;":STAT:MEAS:EVEN?"
2680    ENTER @Hp4155;K
2690    OUTPUT @Hp4155;":STAT:MEAS:ENAB 267"
2700    !
2710    OUTPUT @Hp4155;":PAGE:SCON:STAN ON"
2720    Str_end=Meas_str_num(I)-1
2730    FOR Str=Str_num TO Str_end
2740      DISP VAL$(Str);"/";VAL$(Meas_str_num(I))
2750      OUTPUT @Hp4155;"MMEM:LOAD:STAT 0,'MEM2','MEMORY';:PAGE:SCO
N:STR;*WAI"
2760      OUTPUT @Hp4155;"MMEM:LOAD:STAT 0,'MEM3','MEMORY';:PAGE:SCO
N:STR"
2770      OUTPUT @Hp4155;"*OPC?"
2780      ENTER @Hp4155;A
2790    NEXT Str
2800    !
2810    Str_num=Str
2820    OUTPUT @Hp4155;":PAGE:SCON:STAN OFF"
2830    OUTPUT @Hp4155;":STAT:MEAS:ENAB 0"
2840  SUBEND
```

Line	Description
2670 and 2680	clears the Measurement/Stress Status "Event" register.
2690	enables Bit 0 (A/D Overflow), 1 (Oscillation Status), 3 (Compliance Status), and 8 (PGU Status) of enable mask for the Measurement/Stress Status "Event" register.
2710	enables standby state so that state does *not* become idle between write and erase stress. If state becomes idle, the relay will switch after every write and erase stress, which will damage the relay.
2730 to 2790	repeats forcing write/erase pulses until one write/erase pulse before next Vth measurement.
2820	disables standby state.

Vth_meas

Subprogram "Vth_meas" to force last write and erase pulses, then measure Vth:

```
2860 Vth_meas:SUB Vth_meas(Str_type$,INTEGER I)
2870    COM @Hp4155,@Form_off,Start_time,End_time
2880    COM /Meas_info/ INTEGER Meas_points,REAL Str,Str_num,Meas_st
r_num(*)
2890    COM /Meas_data/ Vth_w(*),Vth_e(*)
2900    INTEGER K
2910    !
2920    OUTPUT @Hp4155;":PAGE:SCON:STR;*OPC?"
2930    ENTER @Hp4155;A
2940    DISP Str_type$;" Times = "&VAL$(Str_num)
2950    !
2960    OUTPUT @Hp4155;":PAGE:CHAN:COMM 'Flash ROM Vth Meas. @"&Str_
type$&" Times = "&VAL$(Str_num)&"'"
2970    OUTPUT @Hp4155;":PAGE:GLIS"
2980    OUTPUT @Hp4155;":DISP ON"
2990    OUTPUT @Hp4155;":PAGE:SCON:SING;*OPC?"
3000    ENTER @Hp4155;A
3010    OUTPUT @Hp4155;":DISP OFF"
3020    OUTPUT @Hp4155;":STAT:MEAS:EVEN?"
3030    ENTER @Hp4155;K
3040    OUTPUT @Hp4155;":TRAC? 'VTH'"
3050    SELECT Str_type$
3060    CASE "Write"
3070      ENTER @Hp4155;Vth_w(I)
3080      PRINT USING "#,4X,DESZ,10X,SD.DDD";Str_num,Vth_w(I)
3090    CASE "Erase"
3100      ENTER @Hp4155;Vth_e(I)
3110      PRINT USING "10X,SD.DDD,7X,SD.DDE";Vth_e(I),Vth_w(I)-Vth_e(I)
3120    END SELECT
3130  SUBEND
```

Line	Description
2990 and 3000	executes Vth measurement and waits until completion.
3040	gets measurement result.

Program Customization

This section describes how to customize program for your own application.

Subprogram “Test_setting”

In this subprogram, you may need to customize the following:

- Name of setup files.

  If you want to use your own measurement or stress setup files, store the files on diskette, then modify the file names on the following lines:

  - Measurement setup file name for Vth measurement.

    ```
    1980  Vth_file$="ROMVTH.MES"  !Vth Measurement Setup File Name
    ```

  - Stress setup file name for write pulse.

    ```
    1990  Wrt_file$="NORWRT.STR"  !Write Stress Setup File Name
    ```

  - Stress setup file name for erase pulse.

    ```
    2000  Ers_file$="NORERS.STR"  !Erase Stress Setup File Name
    ```

- File name for saving measurement results.

  Following two lines create following file name for saving measurement results: *time*`.DAT`. To change this file name, modify these lines:

  ```
  2010  Save_file$=TIME$(TIMEDATE)  !File Name for saving measurement results
  2020  Save_file$=Save_file$[1,2]&Save_file$[4,5]&Save_file$[7,7]&".DAT"
  ```

- Number of times to repeat measurement (FOR loop of Main Program) Following line specifies how many times to measure Vth during stress.

  ```
  2030  Meas_points=16  !Number of times to repeat Measurement
  ```

- Stress pulse count data.

  For example, if `Meas_points=4`, a total of ten write/erase pulses are forced, and Vth is measured after 1st, 2nd, 5th, and 10th pulse.

  ```
  2060 Str_num: !                    ! Stress Pulse Count data
  2070    DATA       1,       2,       5
  2080    DATA      10,      20,      50
  2090    DATA     100,     200,     500
  2100    DATA    1000,    2000,    5000
  2110    DATA   10000,   20000,   50000
  2120    DATA  100000,  200000,  500000
  2130    DATA 1000000
  ```

Measurement setup file for Vth measurement (for NOR type)

Measurement setup for Vth measurement is stored in "ROMVTH.MES" file on provided diskette. As described previously, if you use your own setup file with a different file name, change line 2000. In the ROMVTH.MES file, the following is set up. You can modify these settings in the ROMVTH.MES file or your own file:

- Gate voltage sweep setup (SMU1):

Start voltage	Stop voltage	Sweep step	Compliance
0 V	8 V	10 mV	1 nA

SMU1 is gate voltage source as shown in Figure 7-1 and Figure 7-2.

- Constant source setup:

Units	Output	Compliance
SMU2 (Source)	0 V	100 µA
SMU3 (Drain)	100 mV	2 µA
SMU4 (Substrate)	0 V	100 µA

- Analysis function for Vth extraction:

In this example, Vth is extracted by moving marker to the point where Id is 1 µA, then reading the voltage at that point. Refer to the following user function and auto-analysis setup.

User Function Definition:

Name	Unit	Definition
Vth	V	@MX

Analysis Setup:

Setup	Definition
Marker	Id = 1 µA
Interpolate	ON

Stress setup file for write pulse of NOR type

Stress setup for write pulse of NOR type is stored in "NORWRT.STR" file on provided diskette. As described previously, if you use your own setup file with a different file name, change line 2010. In the NORWRT.STR file, the following is set up. You can modify these settings in the NORWRT.STR file or your own file:

- PGU1 (Gate)

Period	Width	Delay Time	Peak Value	Base Value	Leading Time	Trailing Time	Impe-dance
1.03 ms	1.02 ms	0.0 s	14 V	0 V	1 μs	1 μs	50 ohm

- PGU2 (Drain)

Period	Width	Delay Time	Peak Value	Base Value	Leading Time	Trailing Time	Impe-dance
Same as PGU1	1.00 ms	10 μs	7 V	0 V	1 μs	1 μs	50 ohm

- Constant source setup

Unit	Source	Compliance
SMU2 (Source)	0 V	100 mA
SMU4 (Substrate)	0 V	100 mA

Stress setup file for erase pulse of NOR type

Stress setup for erase pulse is stored on "NORERS.STR" file on provided diskette. As described previously, if you use your own setup file with a different file name, change line 2020.

In the NORERS.STR file, the following is set up. You can modify these settings in the NORERS.STR file or your own file:

- Constant source setup

Unit	Source	Compliance
SMU2 (Source) [a]	11 V	100 mA
SMU4 (Substrate)	0 V	100 mA

a. Erase pulse source

- Erase pulse width

  Pulse width of erase pulse is specified as stress DURATION and set to 20ms.

Stress setup file for write pulse of NAND type

Stress setup for write pulse of NAND type is stored in "NANWRT.STR" file on provided diskette. As described previously, you must change line 2010 to "NANWRT.STR" or your own custom file name. In the NANWRT.STR file, the following is set up. You can modify these settings in the NANWRT.STR file or your own file:

- PGU1 (Gate)

Period	Width	Delay Time	Peak Valu e	Base Valu e	Leading Time	Trailing Time	Impe-dance
413 µs	400 µs	0.0 s	20 V	0 V	10 µs	10 µs	50 ohm

- PGU2 (connected to drain, source, and substrate, and set to constant source)

Source	Impedance
0 V	50 ohm

Stress setup file for erase pulse of NAND type

Stress setup for erase pulse of NAND type is stored in "NANERS.STR" file on provided diskette. As described previously, you must change line 2020 to "NANERS.STR" or your own custom file name. In the NANERS.STR file, the following is set up. You can modify these settings in the NANERS.STR file or your own file:

- PGU1 (connected to gate, and set to constant source)

Source	Impedance
0 V	50 ohm

- PGU2 (connected to drain, source, and substrate)

Period	Width	Delay Time	Peak Valu e	Base Valu e	Leading Time	Trailing Time	Impe-dance
5.02 ms	5.00 ms	0.0 s	20 V	0 V	10 µs	10 µs	50 ohm

Program Listing

```
1000 !****************************************************
1010 !*
1020 !* FILE:         NOR_TEST
1030 !* DESCRIPTION:  Program for NOR-FLASH ROM Stress Test.
1040 !*
1450 !****************************************************
1460  Start_time=TIMEDATE
1470  ASSIGN @Hp4155 TO 800
1480  ASSIGN @Form_off TO 800;FORMAT OFF
1490  COM @Hp4155,@Form_off,Start_time,End_time
1500  COM /File_name/ Vth_file$[12],Wrt_file$[12],Ers_file$[12],Save
_file$[12]
1510  COM /Meas_info/ INTEGER Meas_points,REAL Str,Str_num,Meas_str_n
um(1:55)
1520  COM /Meas_data/ Vth_w(1:55),Vth_e(1:55)
1530  COM /Err/ Err_num(1:6),Err_message$(1:6)[50]
1540  INTEGER I
1550  !
1560  !/////////////// Main /////////////////////////////////////////
1570  CALL Init_hp4155
1580  ON INTR 8 CALL Err_check
1590  ENABLE INTR 8;2
1600  !
1610  CALL Test_setting
1620  CALL Get_file
1630  !
1640  Str_num=1
1650  FOR I=1 TO Meas_points
1660    CALL Stress_loop(I)
1670    IF Meas_str_num(I)>4500 THEN CALL Calibration
1680    !
1690    OUTPUT @Hp4155;":MMEM:LOAD:STAT 0,'MEM2.STR','MEMORY'"
1700    OUTPUT @Hp4155;":MMEM:LOAD:STAT 0,'MEM1.MES','MEMORY'"
1710    CALL Vth_meas("Write",I)
1720    !
1730    OUTPUT @Hp4155;":MMEM:LOAD:STAT 0,'MEM3.STR','MEMORY'"
1740    CALL Vth_meas("Erase",I)
1750    !
1760    CALL Trans_data(I)
1770    CALL Stress_graph(I)
1780    !
1790    IF Vth_w(I)<.1 OR Vth_e(I)<.1 THEN
1800      PRINT "     ### The Device is broken. Test Aborted ###"
1810      PRINT "         Final Stress Times  : ";Str_num
1820      CALL Final_session
1830      STOP
1840    END IF
1850    Str_num=Str_num+1
1860  NEXT I
1870  !
1880  CALL Final_session
1890  !
1900  END
1910  !
1920  !/////////////// Sub //////////////////////////////////////////
1930 Test_setting:SUB Test_setting
1940    COM /File_name/ Vth_file$,Wrt_file$,Ers_file$,Save_file$
1950    COM /Meas_info/ INTEGER Meas_points,REAL Str,Str_num,Meas_str
_num(*)
1960    COM /Meas_data/ Vth_w(*),Vth_e(*)
1970    !
1980    Vth_file$="ROMVTH.MES"     ! Vth Measurement Setup File Name
1990    Wrt_file$="NORWRT.STR"     ! Write Stress Setup File Name
```

```
2000    Ers_file$="NORERS.STR"     ! Erase Stress Setup File Name
2010    Save_file$=TIME$(TIMEDATE) ! File Name for saving measurement
results
2020    Save_file$=Save_file$[1,2]&Save_file$[4,5]&Save_file$[7,7]&"
.DAT"
2030    Meas_points=16             ! Number of times to repeat Measur
ement
2040    REDIM Meas_str_num(1:Meas_points)
2050    REDIM Vth_w(1:Meas_points),Vth_e(1:Meas_points)
2060 Str_num: !                    ! Stress Pulse Count data
2070    DATA       1,       2,       5
2080    DATA      10,      20,      50
2090    DATA     100,     200,     500
2100    DATA    1000,    2000,    5000
2110    DATA   10000,   20000,   50000
2120    DATA  100000,  200000,  500000
2130    DATA 1000000
2140    RESTORE Str_num
2150    READ Meas_str_num(*)
2160  SUBEND
2170 !
2180 Init_hp4155:SUB Init_hp4155
2190    COM @Hp4155,@Form_off,Start_time,End_time
2200    !
2210    CLEAR SCREEN
2220    CLEAR @Hp4155
2230    OUTPUT @Hp4155;"*RST"
2240    OUTPUT @Hp4155;"*CLS"
2250    OUTPUT @Hp4155;":STAT:PRES"
2260    OUTPUT @Hp4155;"*ESE 60;*SRE 34;*OPC?"
2270    ENTER @Hp4155;A
2280    OUTPUT @Hp4155;":DISP:WIND:ALL BST"
2290    OUTPUT @Hp4155;":DISP OFF"
2300    PRINT "            <<< Flash ROM Stress Test >>>"
2310    PRINT "Stress Times   Vth Write [V]   Vth Erase [V]   Diff [V]"
2320  SUBEND
2330 !
2340 Get_file:SUB Get_file
2350    COM @Hp4155,@Form_off,Start_time,End_time
2360    COM /File_name/ Vth_file$,Wrt_file$,Ers_file$,Save_file$
2370    !
2380    OUTPUT @Hp4155;":MMEM:COPY '"&Vth_file$&"','DISK','MEM1.MES',
'MEMORY'"
2390    OUTPUT @Hp4155;":MMEM:COPY '"&Wrt_file$&"','DISK','MEM2.STR',
'MEMORY'"
2400    OUTPUT @Hp4155;":MMEM:COPY '"&Ers_file$&"','DISK','MEM3.STR',
'MEMORY'"
2410  SUBEND
2420  !
2430 Calibration:SUB Calibration
2440    COM @Hp4155,@Form_off,Start_time,End_time
2450    !
2460    OUTPUT @Hp4155;":PAGE:SYST:CDI"
2470    OUTPUT @Hp4155;":DISP ON"
2480    OUTPUT @Hp4155;":CAL:ALL?"
2490    ENTER @Hp4155;A
2500    SELECT A
2510    CASE 0
2520      OUTPUT @Hp4155;":PAGE:GLIS"
2530      OUTPUT @Hp4155;":DISP OFF"
2540    CASE ELSE
2550      PRINT "     #### Calibration FAIL ,Test Aborted ####"
2560      CALL Final_session
2570      STOP
2580    END SELECT
2590  SUBEND
2600  !
2610 Stress_loop:SUB Stress_loop(INTEGER I)
2620    COM @Hp4155,@Form_off,Start_time,End_time
2630    COM /Meas_info/ INTEGER Meas_points,REAL Str,Str_num,Meas_str
```

```
_num(*)
2640     INTEGER K
2650     REAL Str_end
2660     !
2670     OUTPUT @Hp4155;":STAT:MEAS:EVEN?"
2680     ENTER @Hp4155;K
2690     OUTPUT @Hp4155;":STAT:MEAS:ENAB 267"
2700     !
2710     OUTPUT @Hp4155;":PAGE:SCON:STAN ON"
2720     Str_end=Meas_str_num(I)-1
2730     FOR Str=Str_num TO Str_end
2740       DISP VAL$(Str);"/";VAL$(Meas_str_num(I))
2750       OUTPUT @Hp4155;"MMEM:LOAD:STAT 0,'MEM2','MEMORY';:PAGE:SCON
:STR;*WAI"
2760       OUTPUT @Hp4155;"MMEM:LOAD:STAT 0,'MEM3','MEMORY';:PAGE:SCON
:STR"
2770       OUTPUT @Hp4155;"*OPC?"
2780       ENTER @Hp4155;A
2790     NEXT Str
2800     !
2810     Str_num=Str
2820     OUTPUT @Hp4155;":PAGE:SCON:STAN OFF"
2830     OUTPUT @Hp4155;":STAT:MEAS:ENAB 0"
2840   SUBEND
2850   !
2860 Vth_meas:SUB Vth_meas(Str_type$,INTEGER I)
2870     COM @Hp4155,@Form_off,Start_time,End_time
2880     COM /Meas_info/ INTEGER Meas_points,REAL Str,Str_num,Meas_str
_num(*)
2890     COM /Meas_data/ Vth_w(*),Vth_e(*)
2900     INTEGER K
2910     !
2920     OUTPUT @Hp4155;":PAGE:SCON:STR;*OPC?"
2930     ENTER @Hp4155;A
2940     DISP Str_type$;" Times = "&VAL$(Str_num)
2950     !
2960     OUTPUT @Hp4155;":PAGE:CHAN:COMM 'Flash ROM Vth Meas. @"&Str_
type$&" Times = "&VAL$(Str_num)&"'"
2970     OUTPUT @Hp4155;":PAGE:GLIS"
2980     OUTPUT @Hp4155;":DISP ON"
2990     OUTPUT @Hp4155;":PAGE:SCON:SING;*OPC?"
3000     ENTER @Hp4155;A
3010     OUTPUT @Hp4155;":DISP OFF"
3020     OUTPUT @Hp4155;":STAT:MEAS:EVEN?"
3030     ENTER @Hp4155;K
3040     OUTPUT @Hp4155;":TRAC? 'VTH'"
3050     SELECT Str_type$
3060     CASE "Write"
3070       ENTER @Hp4155;Vth_w(I)
3080       PRINT USING "#,4X,DESZ,10X,SD.DDD";Str_num,Vth_w(I)
3090     CASE "Erase"
3100       ENTER @Hp4155;Vth_e(I)
3110       PRINT USING "10X,SD.DDD,7X,SD.DDE";Vth_e(I),Vth_w(I)-Vth_e(I)
3120     END SELECT
3130   SUBEND
3140   !
3150 Trans_data:SUB Trans_data(INTEGER I)
3160     COM @Hp4155,@Form_off,Start_time,End_time
3170     COM /Meas_info/ INTEGER Meas_points,REAL Str,Str_num,Meas_str
_num(*)
3180     COM /Meas_data/ Vth_w(*),Vth_e(*)
3190     !
3200     REDIM Meas_str_num(1:I),Vth_w(1:I),Vth_e(1:I)
3210     OUTPUT @Hp4155;":TRAC:DEL:ALL"
3220     OUTPUT @Hp4155;":TRAC:DEF 'Stress',"&VAL$(I)
3230     OUTPUT @Hp4155;":TRAC:DEF 'VthWRT',"&VAL$(I)
3240     OUTPUT @Hp4155;":TRAC:DEF 'VthERS',"&VAL$(I)
3250     OUTPUT @Hp4155;":TRAC:UNIT 'Stress','Times'"
3260     OUTPUT @Hp4155;":TRAC:UNIT 'VthWRT','V'"
3270     OUTPUT @Hp4155;":TRAC:UNIT 'VthERS','V'"
```

```
3280    !
3290    OUTPUT @Hp4155;":FORM:DATA REAL,64"
3300    OUTPUT @Hp4155;":FORM:BORD NORM"
3310    OUTPUT @Hp4155;":TRAC ’Stress’,#0";
3320    OUTPUT @Form_off;Meas_str_num(*),END
3330    OUTPUT @Hp4155;":TRAC ’VthWRT’,#0";
3340    OUTPUT @Form_off;Vth_w(*),END
3350    OUTPUT @Hp4155;":TRAC ’VthERS’,#0";
3360    OUTPUT @Form_off;Vth_e(*),END
3370    OUTPUT @Hp4155;":FORM:DATA ASCII"
3380    REDIM Meas_str_num(1:Meas_points),Vth_w(1:Meas_points),Vth_e
(1:Meas_points)
3390  SUBEND
3400  !
3410 Stress_graph:SUB Stress_graph(INTEGER I)
3420    COM @Hp4155,@Form_off,Start_time,End_time
3430    COM /Meas_info/ INTEGER Meas_points,REAL Str,Str_num,Meas_str
_num(*)
3440    !
3450    OUTPUT @Hp4155;":PAGE:CHAN:COMM ’Flash ROM Vth Shift(Stress="&
VAL$(Meas_str_num(I))&")’"
3460    OUTPUT @Hp4155;":PAGE:CHAN:UFUN:DEF ’Diff’,’V’,’VthWRT-VthERS’"
3470    !
3480    OUTPUT @Hp4155;":PAGE:DISP:GRAP:X:NAME ’Stress’"
3490    OUTPUT @Hp4155;":PAGE:DISP:GRAP:Y1:NAME ’VthWRT’"
3500    OUTPUT @Hp4155;":PAGE:DISP:GRAP:Y2:NAME ’VthERS’"
3510    OUTPUT @Hp4155;":PAGE:DISP:GRAP:X:SCAL LOG"
3520    OUTPUT @Hp4155;":PAGE:DISP:GRAP:X:MIN 1"
3530    OUTPUT @Hp4155;":PAGE:DISP:GRAP:X:MAX "&VAL$(MAX(Meas_str_num
(Meas_points),2))
3540    OUTPUT @Hp4155;":PAGE:DISP:GRAP:Y1:SCAL LIN"
3550    OUTPUT @Hp4155;":PAGE:DISP:GRAP:Y1:MIN 0"
3560    OUTPUT @Hp4155;":PAGE:DISP:GRAP:Y1:MAX 7"
3570    OUTPUT @Hp4155;":PAGE:DISP:GRAP:Y2:SCAL LIN"
3580    OUTPUT @Hp4155;":PAGE:DISP:GRAP:Y2:MIN 0"
3590    OUTPUT @Hp4155;":PAGE:DISP:GRAP:Y2:MAX 7"
3600    !
3610    OUTPUT @Hp4155;":PAGE:DISP:DVAR:DEL ’VTH’"
3620    OUTPUT @Hp4155;":PAGE:DISP:DVAR ’Diff’"
3630    !
3640    OUTPUT @Hp4155;":PAGE:DISP:ANAL:LINE1:MODE DIS"
3650    OUTPUT @Hp4155;":PAGE:DISP:ANAL:LINE2:MODE DIS"
3660    OUTPUT @Hp4155;":PAGE:DISP:ANAL:MARK:DIS"
3670    !
3680    OUTPUT @Hp4155;":PAGE:GLIS:INT OFF"
3690    OUTPUT @Hp4155;":PAGE:GLIS:LINE OFF"
3700    OUTPUT @Hp4155;":PAGE:GLIS:MARK ON"
3710    OUTPUT @Hp4155;":PAGE:GLIS:MARK:DIR:X MAX"
3720    !
3730    OUTPUT @Hp4155;":DISP ON;:DISP OFF"
3740  SUBEND
3750  !
3760 Final_session:SUB Final_session
3770    COM @Hp4155,@Form_off,Start_time,End_time
3780    COM /File_name/ Vth_file$,Wrt_file$,Ers_file$,Save_file$
3790    COM /Meas_info/ INTEGER Meas_points,REAL Str,Str_num,Meas_str
_num(*)
3800    COM /Err/ Err_num(*),Err_message$(*)
3810    !
3820    IF Str_num-1=Meas_str_num(Meas_points) THEN
3830      Save_file$="D"&Save_file$
3840      PRINT "=============== Measurement Completed !!! =========
========"
3850      PRINT "Final Stress Times  : ";Str_num-1
3860    ELSE
3870      Save_file$="F"&Save_file$
3880    END IF
3890    !
3900    PRINT "Save Data File Name : ";Save_file$
3910    PRINT "Test Duration : ";
```

```
3920    End_time=TIMEDATE
3930    PRINT DATE$(Start_time);",";TIME$(Start_time);" ~ ";DATE$(End
_time);",";TIME$(End_time)
3940    !
3950    DISABLE INTR 8
3960    OUTPUT @Hp4155;":MMEM:STOR:TRAC DEF,'"&Save_file$&"','DISK'"
3970    OUTPUT @Hp4155;"*OPC?"
3980    ENTER @Hp4155;A
3990    OUTPUT @Hp4155;":SYST:ERR?"
4000    ENTER @Hp4155;Err_num(1),Err_message$(1)
4010    IF Err_num(1)<>0 THEN PRINT "### ";Err_num(1);Err_message$(1)
;"###"
4020    !
4030    OUTPUT @Hp4155;":DISP:ALL INST"
4040    OUTPUT @Hp4155;":PAGE:GLIS"
4050    OUTPUT @Hp4155;":DISP ON"
4060  SUBEND
4070  !
4080 Err_check:SUB Err_check
4090    COM @Hp4155,@Form_off,Start_time,End_time
4100    COM /Err/ Err_num(*),Err_message$(*)
4110    INTEGER I,J
4120    !
4130    I=0
4140    REPEAT
4150      I=I+1
4160      OUTPUT @Hp4155;":SYST:ERR?"
4170      ENTER @Hp4155;Err_num(I),Err_message$(I)
4180    UNTIL Err_num(I)=0
4190    !
4200    IF I=1 THEN
4210      CALL Meas_stat_check
4220    ELSE
4230      FOR J=1 TO I-1
4240        PRINT "### ERROR Occurred ###:";Err_num(J);Err_message$(J)
4250        DISP "### ERROR Occurred ###:";Err_num(J);Err_message$(J)
4260      NEXT J
4270      CALL Meas_stat_check
4280      PRINT "              === Test Aborted ==="
4290      CALL Final_session
4300      STOP
4310    END IF
4320  SUBEND
4330  !
4340 Meas_stat_check:SUB Meas_stat_check
4350    COM @Hp4155,@Form_off,Start_time,End_time
4360    COM /Meas_info/ INTEGER Meas_points,REAL Str,Str_num,Meas_str
_num(*)
4370    INTEGER K
4380    !
4390    OUTPUT @Hp4155;":STAT:MEAS:EVEN?"
4400    ENTER @Hp4155;K
4410    !
4420    IF K<>0 THEN
4430      PRINT "### Abnormal Stress Status Event Occurred ###:";K
4440      PRINT "    at Stress Number = ";Str;"[Times]"
4450      PRINT "              === Test Aborted ==="
4460      CALL Final_session
4470      STOP
4480    END IF
4490  SUBEND
```

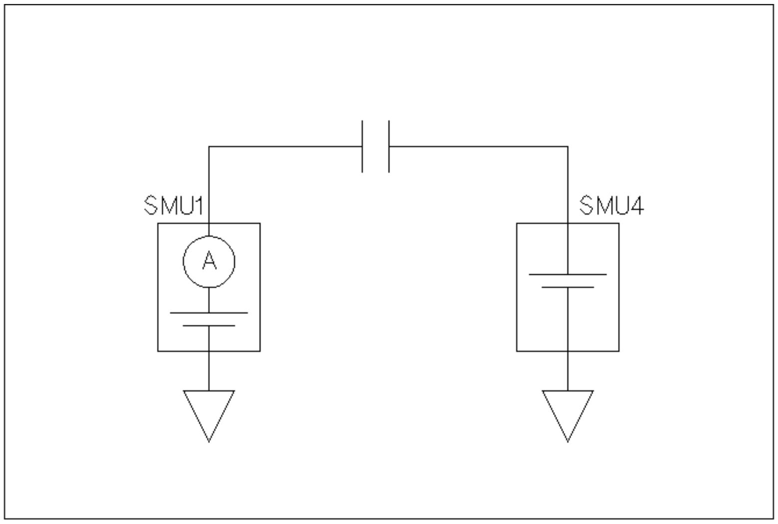
8 Time Dependent Dielectric Breakdown (TDDB)

This setup forces a constant voltage to the gate until the gate oxide breakdowns or a maximum time limit is reached, then calculates the total forced electric charge.

	name
Program	none
Setup file	TDDB.MES

Application Overview

Figure 8-1 **Device Connection**



pg05002 60x40

The measurement flow is as follows:

1. Forces a constant voltage to the gate.
2. Measures gate current by sampling measurement.
3. If gate current exceeds specified threshold, measurement is stopped.
4. Calculates total electric charge that was forced by using a user function with definition `INTEG(Ig,@TIME)`.

Customization

Measurement setup file is stored in "TDDB.MES" file on provided diskette. In the TDDB.MES file, the following is set up. You can modify these settings in the TDDB.MES file or your own file, then use the setup for your own application.

- Constant source setup

Units	Output	Compliance
SMU1 (Gate)	20 V	1.001 μA
SMU4 (Substrate)	0 V	100 μA

- Sampling Parameters

Mode	Initial interval	No. of samples	Total samp. time
Thinned-out	100 ms	1001	999.9 s

- Stop Condition

  This setup is used to judge the oxide breakdown. If gate current exceeds the specified threshold, measurement is stopped.

Enable Delay	Threshold
200 ms	1 μA

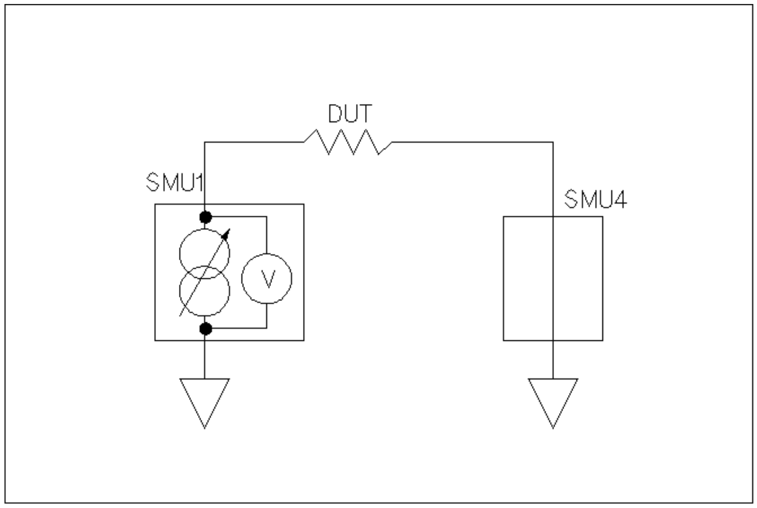
9 Electromigration

This setup forces a constant current to the DUT (metal), measures time-to-failure of DUT, then calculates the total forced electric charge.

	name
Program	none
Setup file	EM.MES

Application Overview

Figure 9-1 **Device Connection**



pg05005 60x40

The measurement flow is as follows:

1. Forces constant current.
2. Monitors DUT voltage by sampling measurement.
3. If the DUT voltage reaches specified threshold, the forcing stops.
4. Calculates total electric charge that was forced by using a user function with definition `INTEG(Idut1,@TIME)`.

Customization

Measurement setup file is stored in "EM.MES" file on provided diskette. In the EM.MES file, the following is set up. You can modify these settings in the EM.MES file or your own file, then use the setup for your own application.

- Constant source setup

Units	Output	Compliance
SMU1	50 mA	20.002 V

- Sampling Parameters

Mode	Initial interval	No. of samples	Total samp. time
Linear	1 s	10001	AUTO [a]

a. Initial interval No. of samples

- Stop Condition

  If the DUT voltage exceeds the specified threshold, measurement is stopped.

Enable Delay	Threshold
20 ms	20 V