Agilent Technologies
Innovating the HP Way

Agilent Technologies Hot Carrier Injection Test Solution

Author: Alan Wadsworth

Date: SEP-2000
Revision: 2.0

[This Page Intentionally Left Blank]

Table of Contents:

AGILENT TECHNOLOGIES HOT CARRIER INJECTION TEST SOLUTION 1

TABLE OF CONTENTS: 3

OVERVIEW 5

Major HCI Solution Components 6
Required Hardware List 7

CONFIGURING THE HARDWARE 8

GPIB Device Settings 8
4156A/B/C System Settings 9
E5250A Multiplexer Module Cards (E5255A) 10
Schematic Diagram 10
Internal Connections 11
E5255A Card Configuration 12
8 Device Configuration 12
Detailed Connections for Card 1 (Slot 1) 13
Detailed Connections for Card 2 (Slot 2) 14
Power Supply Settings 15
Choosing a Power Supply 15
Using the Power Supply as a Ground Unit 16
Connecting up the Cables 17
Agilent 4156A/B/C to E5250A Cable Connections: 17
Agilent 6624A/6626A to E5250A Cable Connections: 17
DUT to E5250A Cable Connections: 17
GPIB Cable Connections: 17
Cable Connection Illustration (8 DUTs) 18

SOFTWARE OPERATION 19

Starting the Program 19
Main Menu Screen 21
Main Menu Softkeys 22
CHAR DEVICE Screen 23
CHAR DEVICE Softkeys 24
Important points to keep in mind after pausing the program 24
CHANGE PARAMS Screens 25
CHANGE PARAMS Screen #1 25
CHANGE PARAMS Screen #2 26
CHANGE PARAMS Screen #3 27
CHANGE PARAMS Screen #4 28
Gate Voltage Stress Extraction 29
HCI Program Flow 30
Overview 30

Initial Characterization 31
Stress/Characterization 32
Stress Display 33
Saving Data to Disk 34

MODIFYING MEASUREMENT CONDITIONS 35

Parameter Definitions 35
User Functions 35
Display Setup 35
Auto Analysis Function 35
Idlin 36
Definition of Idlin 36
Modifying the Idlin Measurement 36
Gmmax 37
Definition of Gmmax 37
Vtext 37
Definition of Vtext 37
Vtci 37
Definition of Vtci 37
Modifying the Vtci Measurement 37

APPENDIX A – REVISION HISTORY 38

Revision 1.0 – March 2000 38
Revision 2.0 – May 2000 38

APPENDIX B – DATA FILE FORMATS 39

PARAMS.TXT Data Format 39
Invalid Device Data Format 39
Valid Device Data Format 40

APPENDIX C – MODIFYING THE PROGRAM 41

Changing Input Parameters 41
Changing Contact & Leakage Test Limits 41
Changing Drain & Gate Stress Voltages 41
Changing Other Stress Parameters 42
Changing Device Geometries 42
Changing MOS Device Type 42
Changing Measure Reverse Characteristics Switch 42
Changing .MES File Names Called by the Program 43
Changing Names of Files Saved by the Program 43
Changing the Stress Measurement Times 43

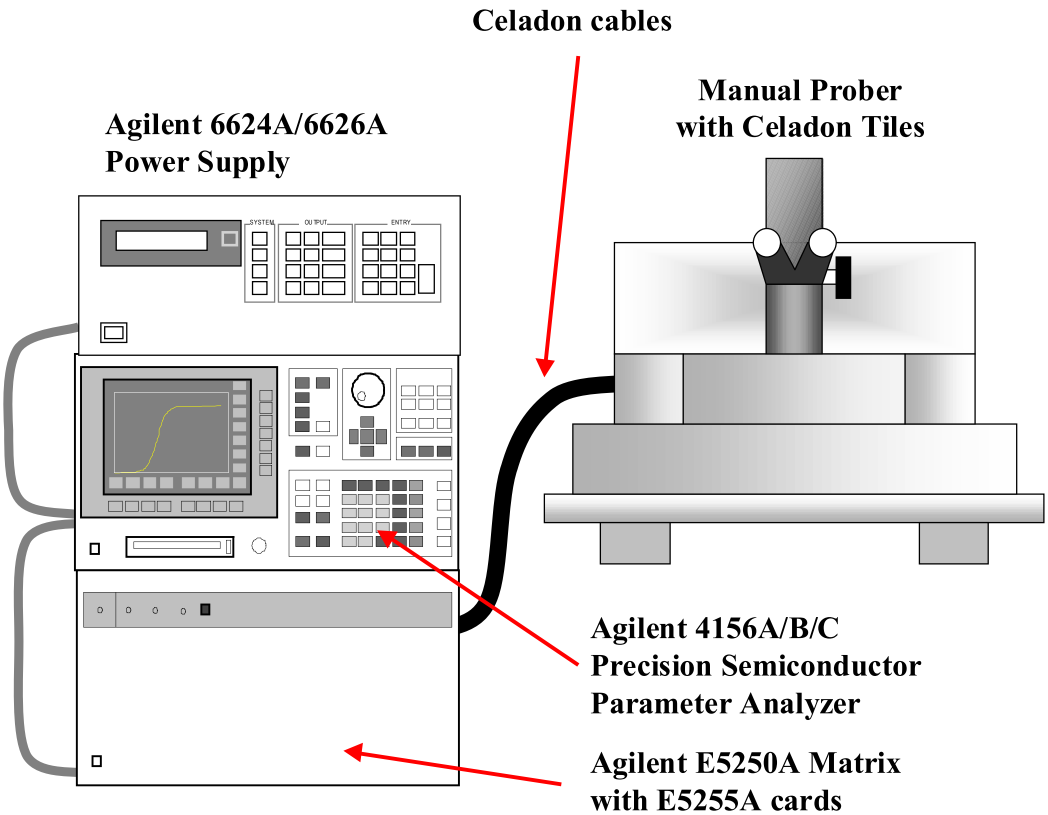
Overview

This PDF file documents how to use the hot carrier injection test solution provided by Agilent Technologies. This solution provides you with many benefits:

1. **Simplicity** - The entire system is controlled by the Agilent 4156A/B/C. This eliminates the need for external PC or workstation control.
2. **Ease of use** – Minimal or no IBASIC programming is required. Many of the test parameters can be changed by simply modifying the front-panel measurement (.MES) files called by the IBASIC program. In addition, most of the other program parameters can be changed interactively while running the program.
3. **Open source code** – You are fully free to modify the IBASIC code to suit your individual needs.
4. **Low cost** – A typical hot carrier test instrument solution is less than $100K (including probes and cables).

Major HCI Solution Components

The picture below shows the hardware components of the HCI solution:



Note #1: While this solution will work with the Agilent 4155A/B/C, it is not recommended since the 4155A/B/C does not have the low-current resolution capability of the 4156A/B/C.

Note #2: While this solution uses Celadon tiles and cables, your prober manufacturer may be able to offer other solutions as well.

Required Hardware List

The following is a complete list of all of the hardware required to run the HCI software for testing 8 devices in parallel:

Product	**Option**	**Description**	**Quantity**
4156	N/A	Precision Semiconductor Analyzer	1
	#10	Delete Kelvin cables.	1
	#60	60 Hz power supply	1
	ABA	English localization	1
E5250A	N/A	Low Leakage Switch Mainframe	1
	#501	24(8x3) Channel Multiplexer (E5255A)	2
6624A or 6626A	N/A	Quad Output Power Supply	1
16494A	#001	1.5m Triaxial Cables	4
10833A	N/A	GPIB Cable (1m)	2
	N/A	Celadon Probe Card	1
	N/A	Celadon 24-pin Triaxial Cable Bundle	2
	N/A	Celadon Test Fixture	1

Configuring the Hardware

This HCI test solution assumes certain device settings and hardware configurations. The following sections describe these in greater detail.

GPIB Device Settings

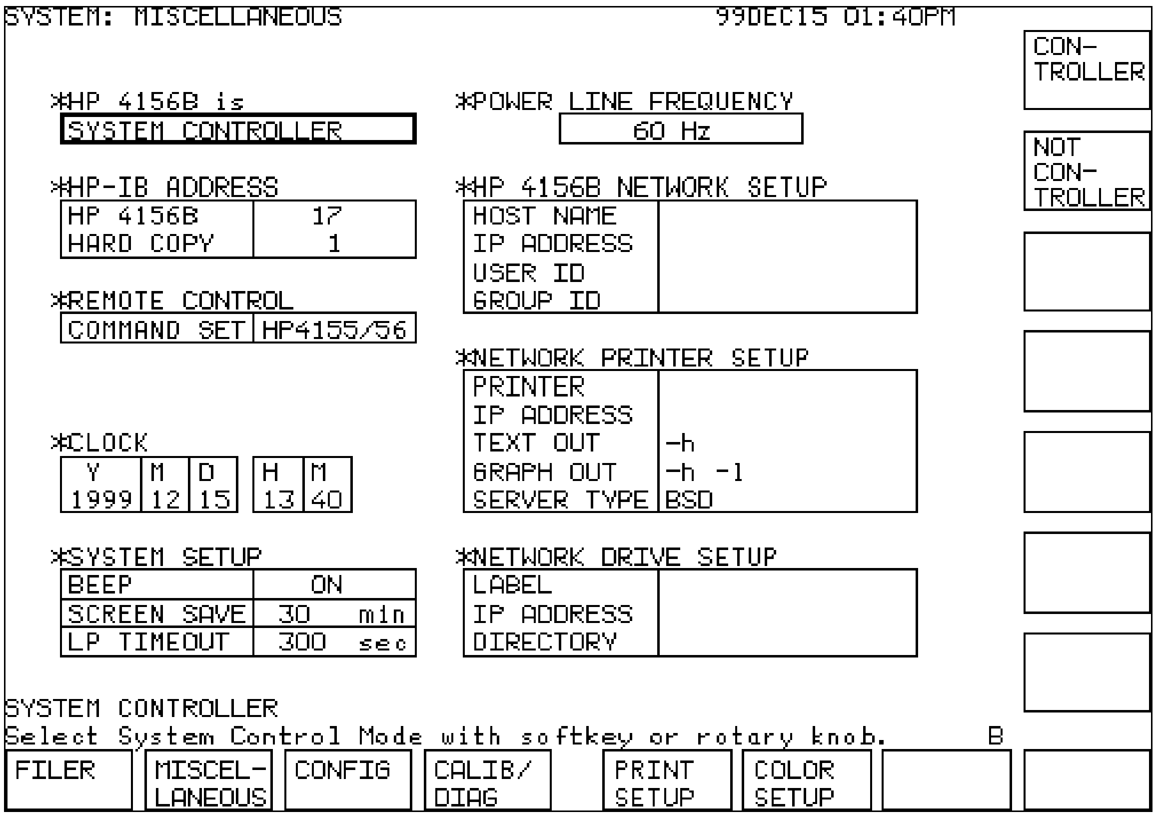
The following are the required GPIB instrument settings:

Instrument	GPIB Setting
4156A/B/C	17
E5250A	22
6624A/6626A	5

If the program is aborting at startup and giving error messages that one or more pieces of hardware are not present, then you should check the GPIB settings of all of the instruments to ensure that they match the above settings.

4156A/B/C System Settings

The 4156A/B/C must be configured as the system controller. To check this setting, press the "System" located under the "PAGE CONTROL" buttons on the front panel of the instrument (immediately to the right of the screen). Next, press the "Miscellaneous" softkey located at the lower left of the screen. You should now see the following screen:

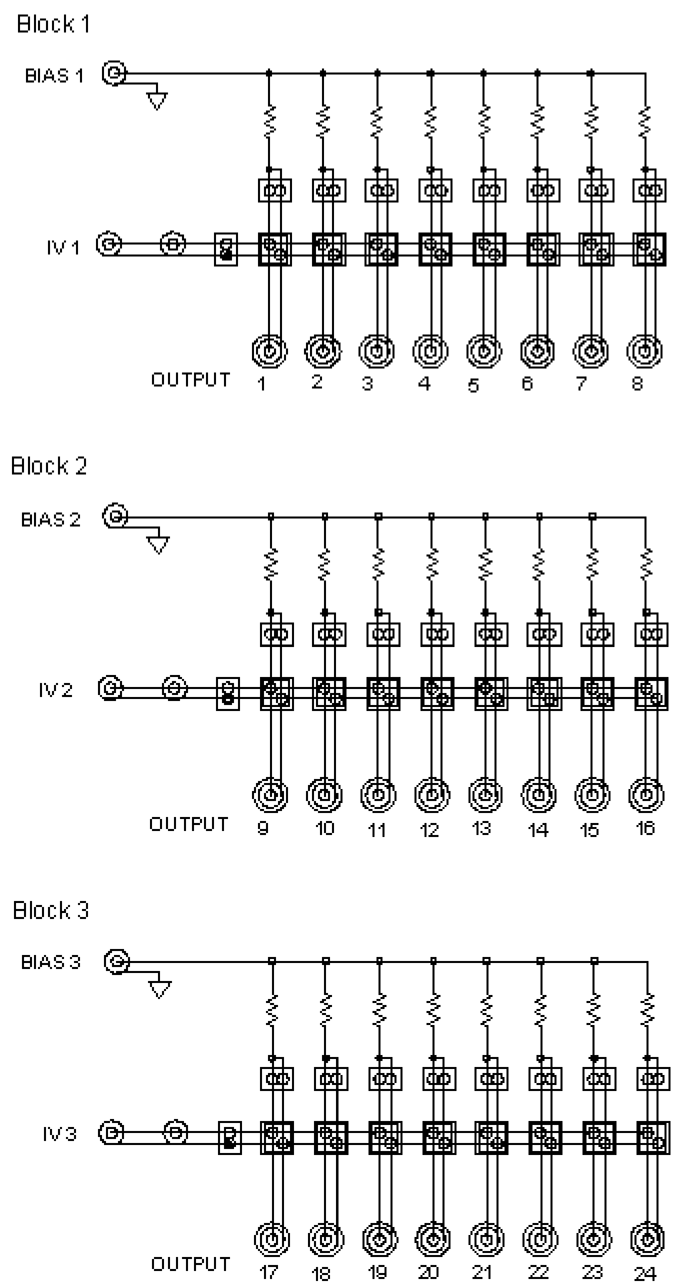


The "*HP 4156B is", "*HP-IB ADDRESS", and "*REMOTE CONTROL" settings should be exactly the same as shown on the above screen.

E5250A Multiplexer Module Cards (E5255A)

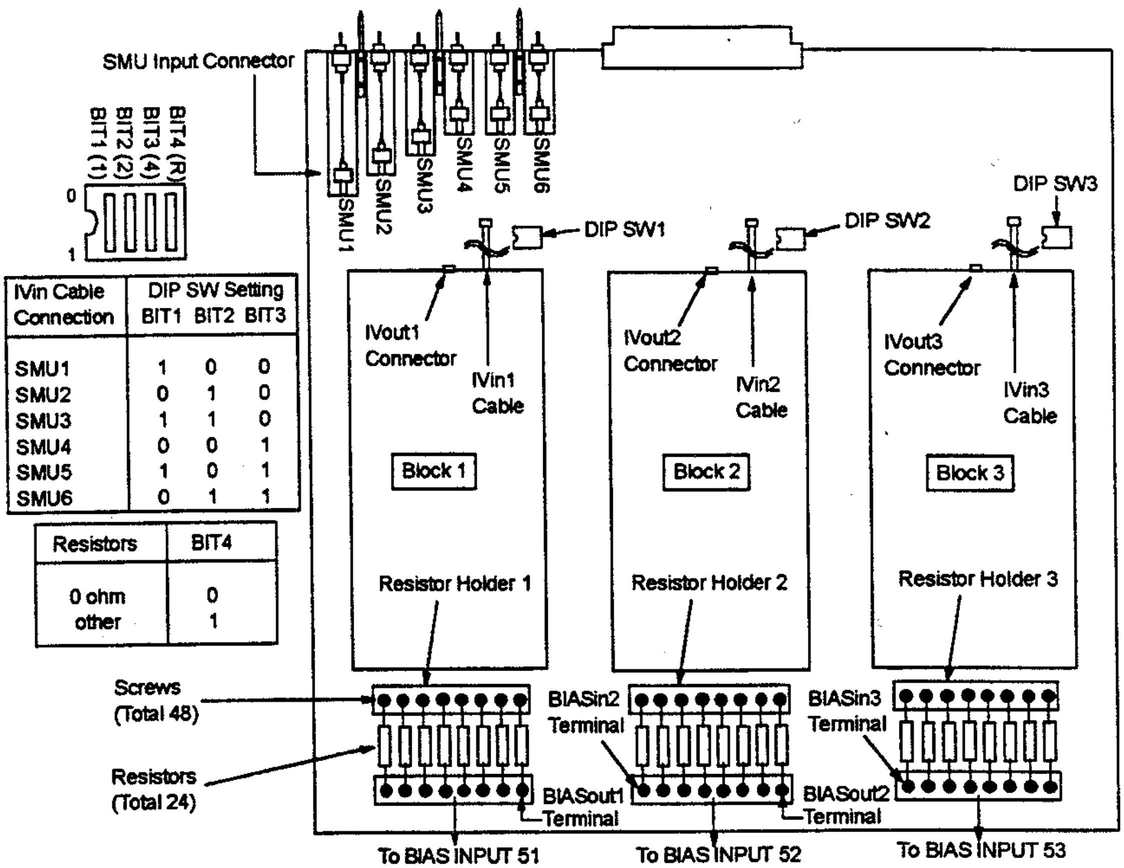
Schematic Diagram

Understanding the functionality of the E5250A low leakage switch mainframe's E5255A multiplexer module is key to understanding the functionality of the HCI program. These cards are designed for long-term reliability testing where external bias sources are to be applied to the DUT. A schematic of the E5255A card is shown below:



Internal Connections

Each card has 3 groups of 8 outputs. Each group of eight can be connected to a separate bias source and SMU. In addition, optional resistors can be placed between the bias source and the DUT (the default factory setting has 0 Ohm resistors in place). However, by modifying switch settings and cable hook-ups on the card you can also have any of the groups share bias sources and/or SMUs. The ability to have independent or shared resources gives a great deal of flexibility to the user. Please refer to the illustration shown below:



IVin Cable Connection	DIP SW Setting BIT1	BIT2	BIT3
SMU1	1	0	0
SMU2	0	1	0
SMU3	1	1	0
SMU4	0	0	1
SMU5	1	0	1
SMU6	0	1	1

Resistors	BIT4
0 ohm	0
other	1

EVEN IF YOU HAVE CORRECTLY CONNECTED EACH BLOCK TO THE APPROPRIATE SMU INPUT, THE MATRIX WILL NOT FUNCTION CORRECTLY UNLESS YOU ALSO SET THE DIP SWITCH TO THE CORRECT SETTINGS. PLEASE REFER TO THE FOLLOWING PHOTOS AND ILLUSTRATIONS.

E5255A Card Configuration

8 Device Configuration

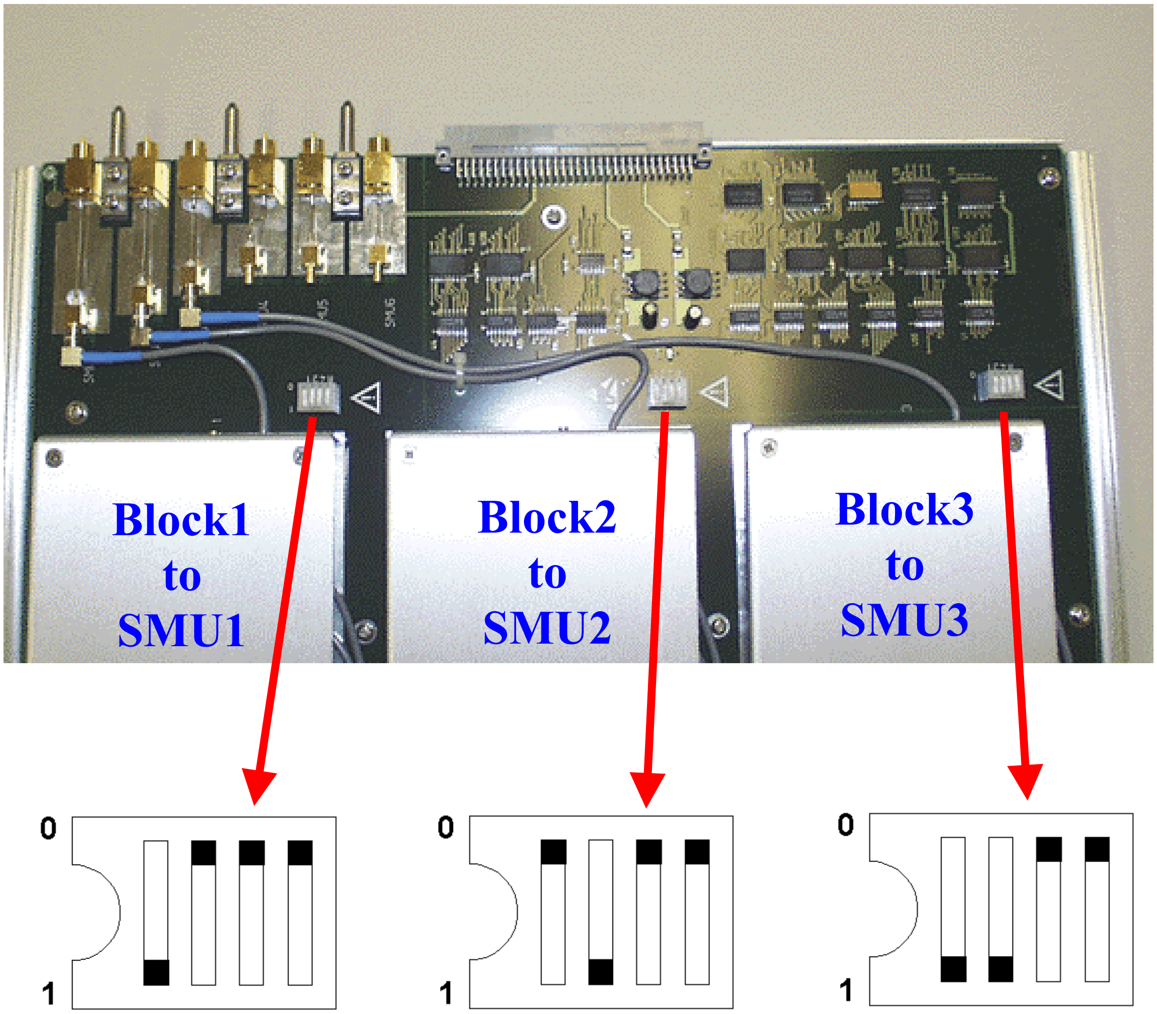
The matrix cards are controlled via software commands issued over the GPIB bus. The HCI program takes care of issuing the appropriate commands for you. During stress, all of the DUTs have their drain, gate, source, and substrate terminals connected to power supply outputs one, two, three, and four (respectively). During measurement, each DUT is individually connected to the 4156A/B/C for characterization (the other devices of course having their connection relays open). The following table summarizes this information:

Device Terminal	**During Stress Connected to:**		**During Measure Connected to:**
Drain	Card 1: Pins 1-8	PS* Output #1	SMU1
Gate	Card 1: Pins 9-16	PS* Output #2	SMU2
Source	Card 1: Pins 17-24	PS* Output #3	SMU3
Substrate	Card 2: Pins 1-8	PS* Output #4	SMU4

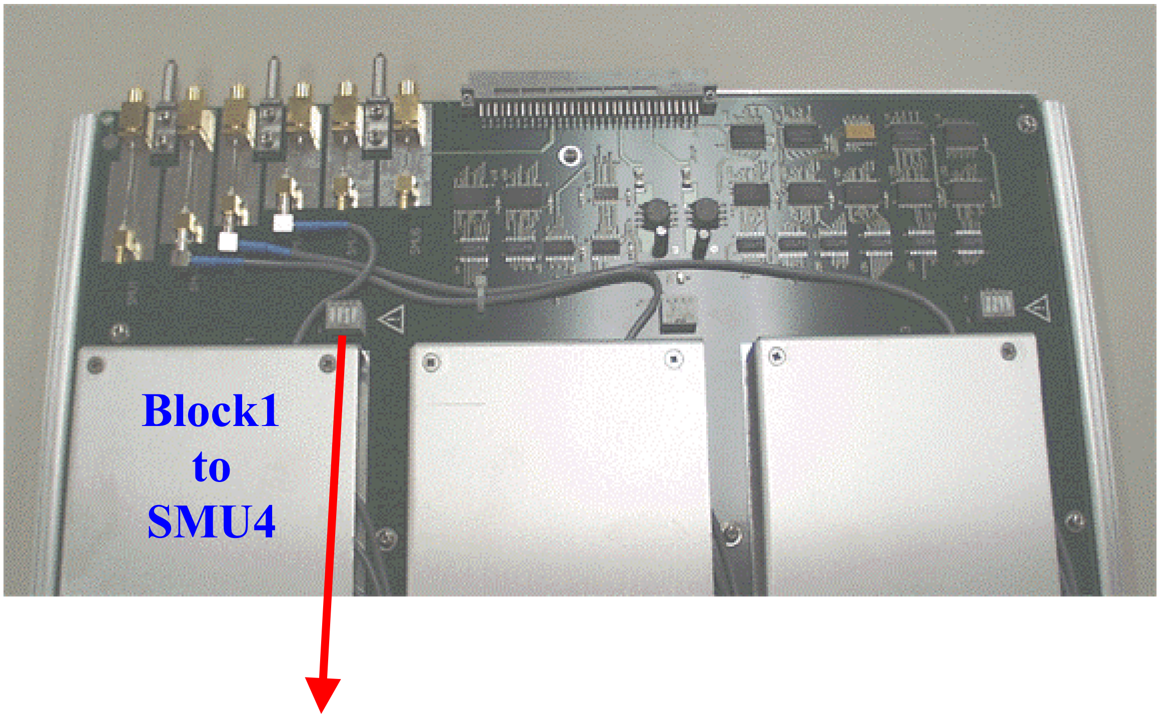
*PS = Power Supply

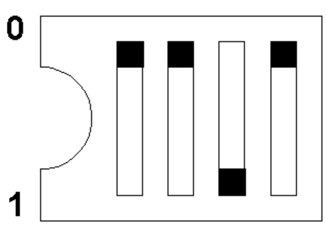
The following two pages show the correct internal connections for the E5255A multiplexer module cards.

Detailed Connections for Card 1 (Slot 1)



Detailed Connections for Card 2 (Slot 2)





Note: Blocks 2 & 3 are not used and their connections do not matter.

Power Supply Settings

You can use either of the following Agilent quad output power supplies: 6624A or 6626A. For either of these power supplies, you only need to insure that the GPIB address is set to “5” as specified in the above table.

Choosing a Power Supply

Note: The Agilent HCI solution uses the 6624A as the default standard because it is the lowest cost solution. In many cases, the increased accuracy of the 6626A is not needed. However, the following are some pertinent power supply specifications that you should keep in mind when deciding upon which power supply is best for you:

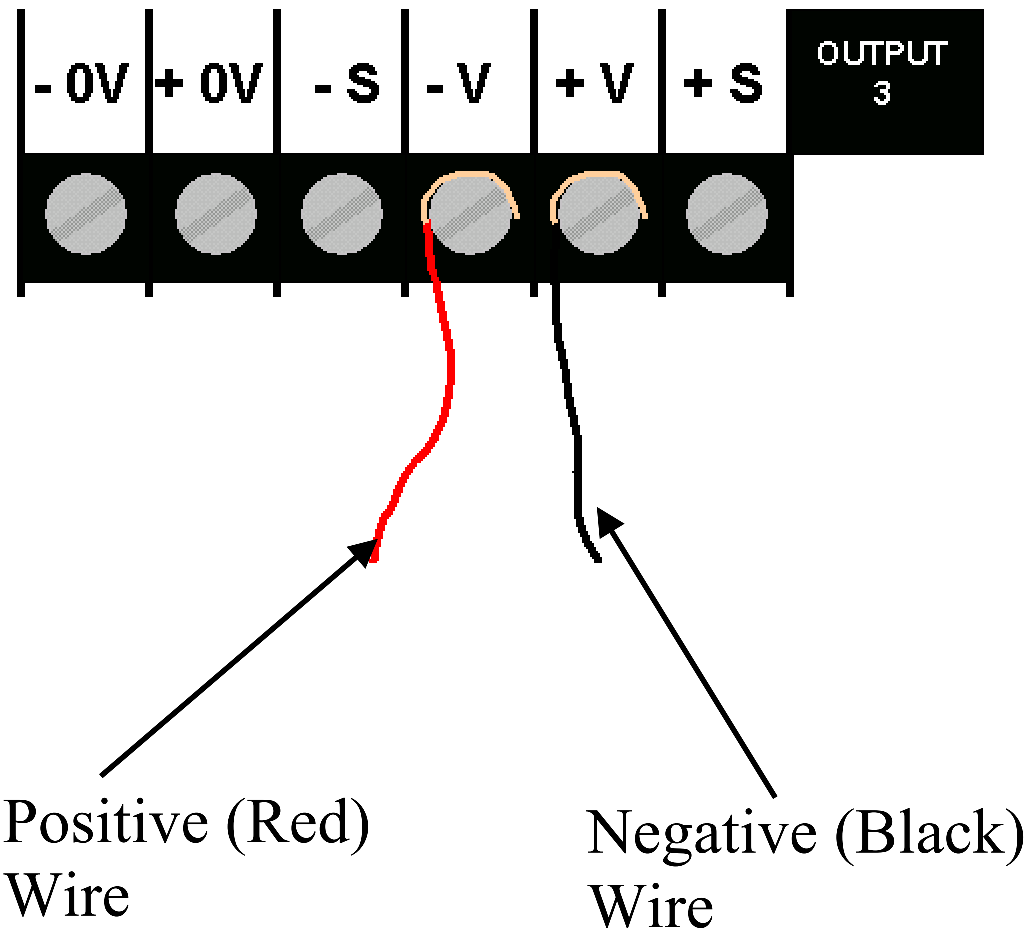
6624A Specifications		
Output Power (0 - 55 deg C)	40-watt output Low-range: 0 to 7 V, 0 to 5 A High-range: 0 to 20 V, 0 to 2 A	40-watt output Low-range: 0 to 20 V, 0 to 2 A High-range: 0 to 50 V, 0 to 0.8 A
Number of Outputs	2	2
Programming accuracy (at 25 deg C +/- 5 deg C)	Voltage: 0.06% + 19mV Current: 0.16% + 50 mA	Voltage: 0.06% + 50 mV Current: 0.16% + 20 mA
Load regulation	Constant Voltage (rms): 500 µV Constant Voltage (p-p): 3 mV Constant Current (rms): 1 mA	Constant Voltage (rms): 500 µV Constant Voltage (p-p): 3 mV Constant Current (rms): 1 mA
Load cross regulation	Voltage: 2 mV Current: 1 mA	Voltage: 2 mV Current: 0.5 mA
Line regulation	Voltage: 1 mV Current: 1 mA	Voltage: 2.5mV Current: 0.5 mA

6626A Specifications		
Output Power (0 - 55 deg C)	25-watt output Low-range: 0 to 7 V, 0 to 15 mA High-range: 0 to 50 V, 0 to 500 mA	50-watt output Low-range: 0 to 16 V, 0 to 200 mA High-range: 0 to 50 V, 0 to 1 A or: 0 to 16 V, 0 to 2 A
Number of Outputs	2	2
Programming accuracy (at 25 deg C +/- 5 deg C)	Voltage (low): 0.016% + 1.5 mV Voltage (high): 0.016% + 10 mV	Voltage (low): 0.016% + 3 mV Voltage (high): 0.016% + 10 mV
	Current (low): 0.04% + 15 µA Current (high): 0.04% + 100 µA	Current (low): 0.04% + 185 µA Current (high): 0.04% + 500 µA
Load regulation	Voltage: 0.5 mV Current: 0.005 mA	Voltage: 0.5 mV Current: 0.01 mA
Load cross regulation	Voltage: 0.25 mV Current: 0.005 mA	Voltage: 0.25 mV Current: 0.01 mA
Line regulation	Voltage: 0.5 mV Current: 0.005 mA	Voltage: 0.5 mV Current: 0.01 mA

If you feel that you need a more accurate power supply, then you should order the 6626A.

Using the Power Supply as a Ground Unit

To reduce costs, this HCI solution does not require you to purchase the Agilent 41501B expander box in order to have a ground unit. Instead, the 4156A/B/C SMUs are used for ground when making characterization measurements, and the 6624A/6626A quad power supply is used as a ground during stress. However, there is one very important detail that you must observe in order for this scheme to function correctly. **The terminals going to the power supply output used as the source ground (output 3 in this case) must be connected with the polarity reversed.** That is, for output 3 the positive (red) terminal should go to the power supply (-) output, and the negative (black) terminal should go to the power supply (+) output.



Connecting up the Cables

Agilent 4156A/B/C to E5250A Cable Connections:

	4156A/B/C		E5250A
Connect	SMU1 (Force)	to	SMU Input 1 (Blue)
Connect	SMU2 (Force)	to	SMU Input 2 (Blue)
Connect	SMU3 (Force)	to	SMU Input 3 (Blue)
Connect	SMU4 (Force)	to	SMU Input 4 (Blue)

Note: The 4156A/B/C and E5250A are designed to accept Kelvin SMU connections. You want to make sure that you connect up the SMUs in **non-Kelvin** mode. Make sure that you use the 4156A/B/C force outputs and that these are connected to the correct SMU inputs on the E5250A matrix (use the blue numbers).

Agilent 6624A/6626A to E5250A Cable Connections:

	6624A/6626A		E5250A
Connect	PS Output 1	to	Bias port input 1 of card 1
Connect	PS Output 2	to	Bias port input 2 of card 1
Connect	PS Output 3	to	Bias port input 3 of card 1
Connect	PS Output 4	to	Bias port input 1 of card 2

DUT to E5250A Cable Connections:

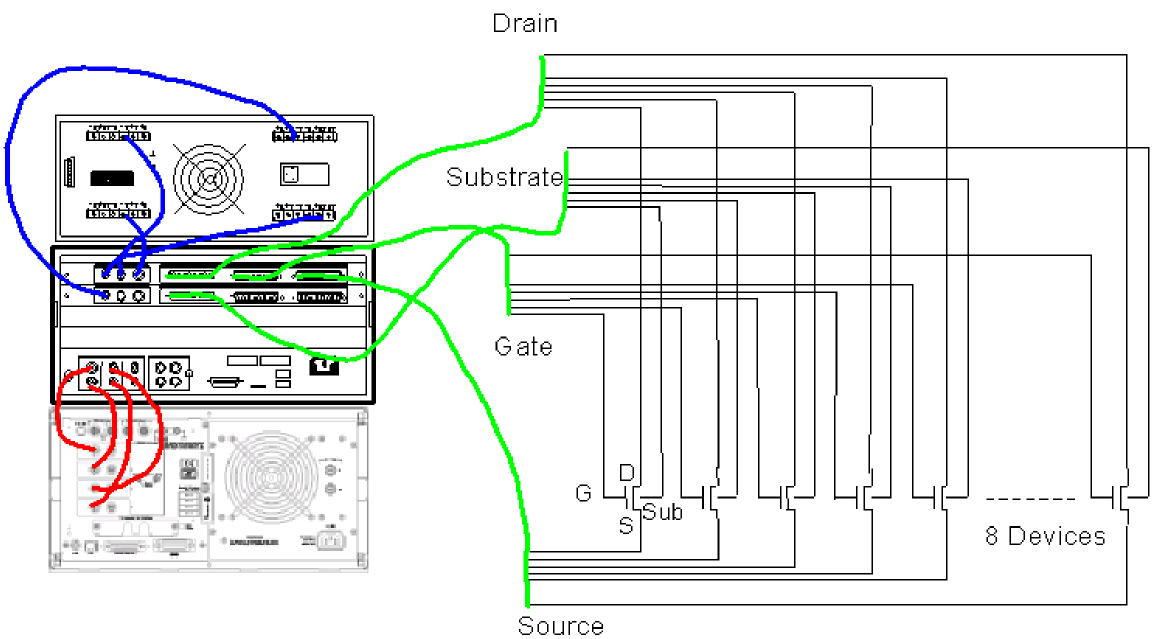
	DUT		E5250A
Connect	Drain	to	Card 1: Pins 1-8
Connect	Gate	to	Card 1: Pins 9-16
Connect	Source	to	Card 1: Pins 17-24
Connect	Substrate	to	Card 2: Pins 1-8

GPIB Cable Connections:

Make sure that you have GPIB cables connecting the 4156A/B/C, E5250A, and 6624A/6626A together (2 cables required).

Cable Connection Illustration (8 DUTs)

An illustration of the correct cable connections is shown below:

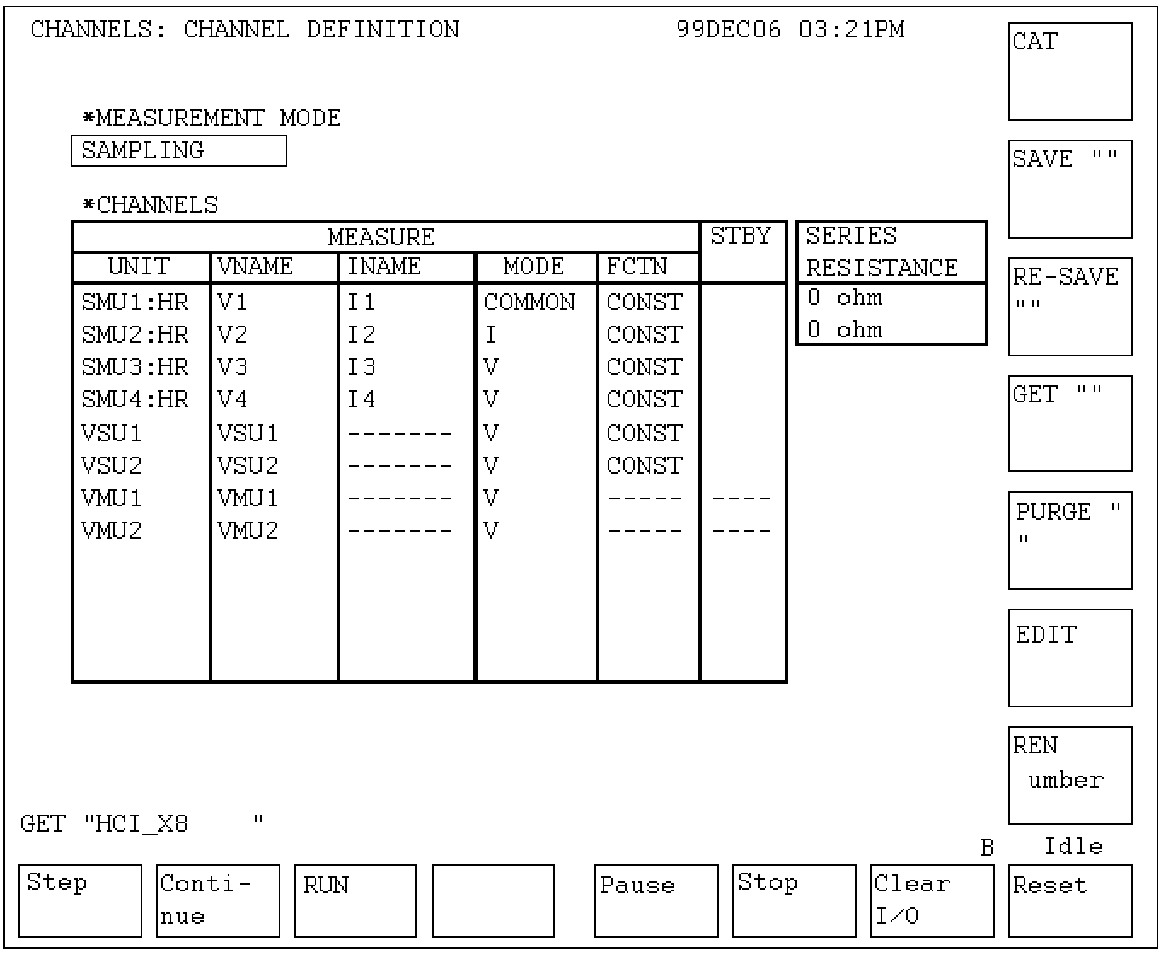


Note: The GPIB cables are not shown in this illustration, although the GPIB ports must be connected together.

Software Operation

Starting the Program

Insert the floppy disk into containing the HCI IBASIC program and associated measurement files (.MES) into your 4156A/B/C. Press the “Display” button located under the IBASIC keys until the IBASIC softkeys appear. Press the “GET” softkey and then type in the name of the IBASIC program that you want to load (“HCI_X8 in the example shown below).



You will need to wait a minute or two while the file loads. Do not press any more buttons until the light on the floppy disk drive turns off.

Once the program has finished loading, you can press the "Run" button located under the IBASIC keys. The software will proceed to initialize all of the instruments and check their functionality. The software performs the following operations:

1. Resets the Agilent 4156A/B/C Semiconductor Parameter Analyzer
2. Resets and initializes the Agilent 5250A Low Leakage Switch Mainframe
   - Configuration Mode: AUTO
   - Bias Mode: OFF
   - Connection Rule: FREE
   - Channel Status: All Relays Open
3. Resets and initializes the Agilent 6624A/6626A Quad Output Power Supply

If any of the above instruments are not detected, then an error message will be generated and the program will abort.

Main Menu Screen

Assuming everything initializes correctly, you should see the following main menu screen:

```
CURRENT HCI PROGRAM SETTINGS:                                        START
                                                                     HCI
Currently selected device number = 1
                                                                     CHAR
MOSFET device type to be tested = NMOS                               DEVICE

Number of Test Devices (8 max) = 8                                   CHANGE
Number of Measurement Points = 16                                    PARAMS
Number of Measurements Before Backup = 7
                                                                     EXTRACT
Drain Voltage During Stress = 5 V                                    Vg STR
Gate Voltage During Stress = 2.5 V
                                                                     CONTACT
Gate Length Used for Calculations = 1.E-6 M                          CHECK
Gate Width Used for Calculations =  1.E-5 M

Test Reverse Characteristics = NO

Minimum Value of Id for Continuity Test =    1.E-9 A
Maximum Value of Ig for Gate Leakage Test =  2.E-10 A
Maximum Value of Id for Drain Leakage Test = 1.E-8 A
                                                                     QUIT
Subdirectory where data files will be stored = TEST_D                PROGRAM

                                                                 B   Run
Step    Conti-   RUN            L  Pause    Stop     Clear   Reset
        nue                                          I/O
```

The main menu displays the status of all of the program parameters that can be modified interactively. Since they can be modified interactively, the values of these parameters are always written to a file in the data directory called “PARAMS.TXT” each time the HCI program executes a stress/measure procedure.

Main Menu Softkeys

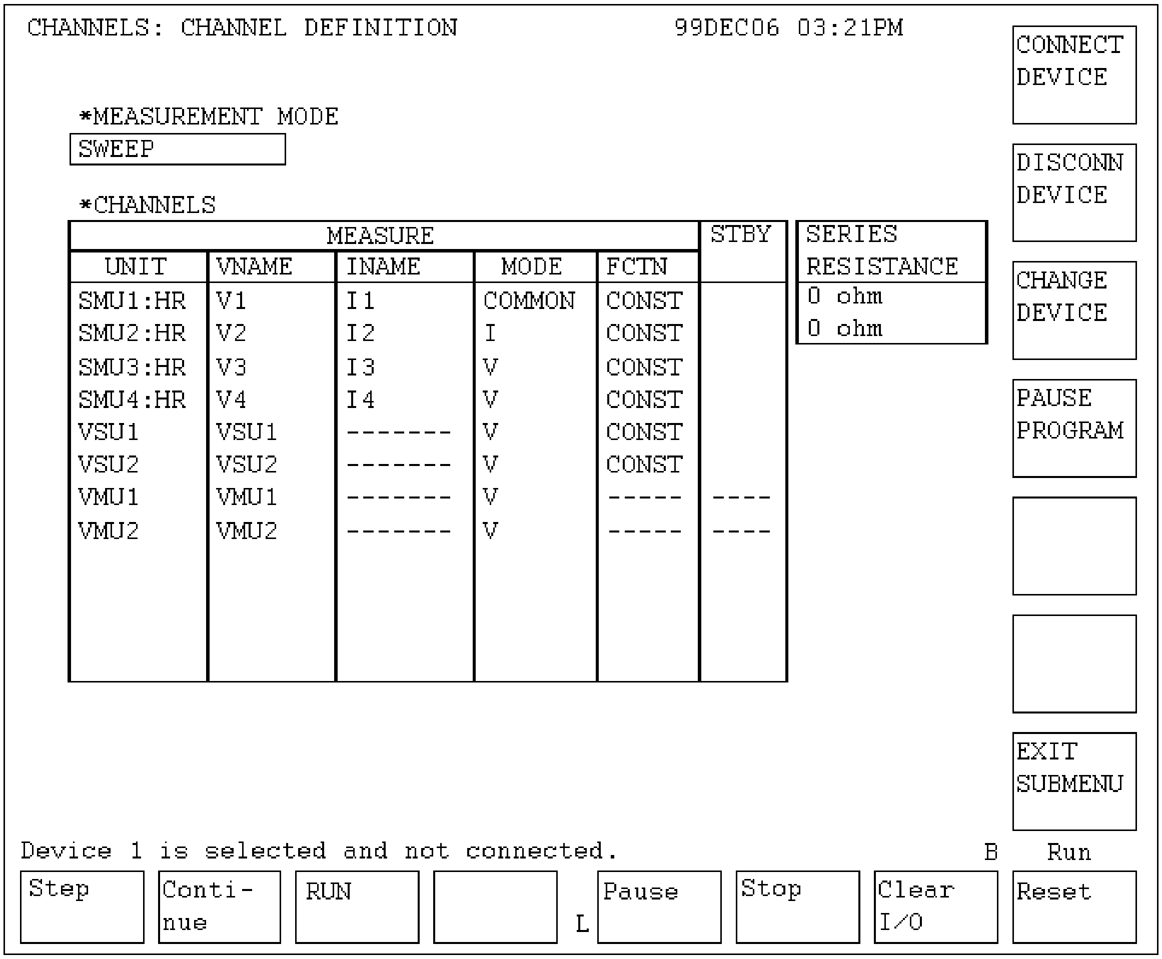
There are six main menu softkeys. The following table describes the function of each softkey:

Softkey Name	Function
START HCI	Starts the HCI program stress/measurement.
CHAR DEVICE	Takes you to a submenu that allows you to connect any of the DUTs directly to the 4156A/B/C, and then pause the program so that you can modify the measurement (.MES) files before proceeding with the HCI test.
CHANGE PARAMS	Takes you to a submenu that allows you to change any of the displayed parameters interactively, so that you do not have to edit the IBASIC code.
EXTRACT Vg STR	Runs the routine that extracts the optimum gate stress voltage by sweeping the gate voltage and determining where substrate current is at a maximum. The gate stress voltage on the main menu screen is automatically updated after running this routine to reflect the optimal value.
CONTACT CHECK	Performs a quick spot measurement on devices 1 through "No_of_devices." After performing the test, the results are displayed for 5 seconds. If any devices fail, then their device number will be shown.
QUIT PROGRAM	Exits the HCI program.

The following sections discuss the two submenus, the routine to extract the optimum value for the gate stress voltage, and the flow of the HCI test program.

CHAR DEVICE Screen

The CHAR DEVICE submenu has the following appearance:



Note: The instrument screen displayed will vary depending upon the previous state of the instrument and has no bearing on the softkey functionality.

Essentially, the function of this submenu is to allow you to connect up any of the devices being probed to the 4156A/B/C, and then pause the program operation so that you can use the 4156A/B/C to characterize the connected device in interactive mode. It is a debug/development feature.

CHAR DEVICE Softkeys

There are five CHAR DEVICE softkeys. The following table describes the function of each softkey:

Softkey Name	Function
CONNECT DEVICE	Connects the selected device through the E5250A to the 4156A/B/C
DISCONN DEVICE	Disconnects the selected device from the 4156A/B/C by opening the E5250A relays
CHANGE DEVICE	Changes the device number selected
PAUSE PROGRAM	Pauses program execution
EXIT SUBMENU	Exits the CHAR DEVICE submenu and returns you to the main menu

Important points to keep in mind after pausing the program

1. After pausing an IBASIC program, you may need to press the "System" button located under the "PAGE CONTROL" keys on the front panel of the instrument before you will be able to load a measurement (.MES) file from the floppy disk. Pressing the "Get" button located under the "User File" keys on the front panel of the instrument without first pressing the "System" button may not work.
2. The relay settings on the E5250A will remain in effect after program pause until you either change them via the HCI program or shut off power to the E5250A.
3. To return to the program, press the "Display" button located under the "IBASIC" keys on the front panel of the instrument until the "Continue" softkey appears at the lower left of the screen. Press the "Continue" softkey to resume program operation. DO NOT PRESS the "Run" softkey or the "Run" key located under the "IBASIC" keys on the front panel of the instrument, as this will start running the program from its very beginning.

CHANGE PARAMS Screens

CHANGE PARAMS Screen #1

The first page of the CHANGE PARAMS submenu has the following appearance:

```
CURRENT HCI PROGRAM SETTINGS:                                      [MOSFET TYPE]

Currently selected device number = 1

MOSFET device type to be tested = NMOS                             [NO. OF DEVICES]

Number of Test Devices (8 max) = 8
Number of Measurement Points = 16                                  [MEAS POINTS]
Number of Measurements Before Backup = 7

Drain Voltage During Stress = 5 V                                  [BACKUP POINTS]
Gate Voltage During Stress = 2.5 V

Gate Length Used for Calculations = 1.E-6 M                        [          ]
Gate Width Used for Calculations =  1.E-5 M

Test Reverse Characteristics = NO

Minimum Value of Id for Continuity Test =    1.E-9 A               [NEXT PAGE]
Maximum Value of Ig for Gate Leakage Test =  2.E-10 A
Maximum Value of Id for Drain Leakage Test = 1.E-8 A

Subdirectory where data files will be stored = TEST_D              [EXIT SUBMENU]

                                                                 B    Run
[Step] [Conti-nue] [RUN] [    ] L [Pause] [Stop] [Clear I/O] [Reset]
```

Softkey Name	**Function**
MOSFET TYPE	Allows you to change the type of MOSFET device that you want the HCI program to test (NMOS or PMOS).
NO. OF DEVICES	Allows you to change the number of devices that will be tested by the HCI program.
MEAS POINTS	Allows you to change the number of measurement points.
BACKUP POINTS	Allows you to change the number of measurement points to be taken before automatic backup occurs (i.e. the number of measurement points taken before data is always written to file after each measurement).

CHANGE PARAMS Screen #2

The second page of the CHANGE PARAMS submenu has the following appearance:

```
CURRENT HCI PROGRAM SETTINGS:                                      [VDSTR]

Currently selected device number = 1

MOSFET device type to be tested = NMOS                             [VGSTR]

Number of Test Devices (8 max) = 8
Number of Measurement Points = 16
Number of Measurements Before Backup = 7                           [GATE
                                                                    LENGTH]
Drain Voltage During Stress = 5 V
Gate Voltage During Stress = 2.5 V                                 [GATE
                                                                    WIDTH]
Gate Length Used for Calculations = 1.E-6 M
Gate Width Used for Calculations =  1.E-5 M
                                                                   [PREV
Test Reverse Characteristics = NO                                   PAGE]

Minimum Value of Id for Continuity Test =    1.E-9 A               [NEXT
Maximum Value of Ig for Gate Leakage Test =  2.E-10 A               PAGE]
Maximum Value of Id for Drain Leakage Test = 1.E-8 A

Subdirectory where data files will be stored = TEST_D              [EXIT
                                                                    SUBMENU]
                                                                 B  Run
[Step] [Conti-  [RUN] [    ] L [Pause] [Stop] [Clear  [Reset]
        nue]                                    I/O]
```

Softkey Name	Function
VDSTR	Allows you to change the voltage applied the drains of the MOSFETs during stress.
VGSTR	Allows you to change the voltage applied the gates of the MOSFETs during stress.
GATE LENGTH	Allows you to change the gate length in meters to be used by the HCI program when making calculations.
GATE WIDTH	Allows you to change the gate width in meters to be used by the HCI program when making calculations.

CHANGE PARAMS Screen #3

The third page of the CHANGE PARAMS submenu has the following appearance:

```
CURRENT HCI PROGRAM SETTINGS:                                      [REVERSE CHAR]

Currently selected device number = 1                               [IDTEST MIN]

MOSFET device type to be tested = NMOS                             [IGLEAK MAX]

Number of Test Devices (8 max) = 8                                 [IDLEAK MAX]
Number of Measurement Points = 16
Number of Measurements Before Backup = 7                           [PREV PAGE]

Drain Voltage During Stress = 5 V                                  [NEXT PAGE]
Gate Voltage During Stress = 2.5 V
                                                                   [EXIT SUBMENU]
Gate Length Used for Calculations = 1.E-6 M
Gate Width Used for Calculations =  1.E-5 M

Test Reverse Characteristics = NO

Minimum Value of Id for Continuity Test =    1.E-9 A
Maximum Value of Ig for Gate Leakage Test =  2.E-10 A
Maximum Value of Id for Drain Leakage Test = 1.E-8 A

Subdirectory where data files will be stored = TEST_D

                                                              B   Run
[Step] [Conti-nue] [RUN] [ ]  L [Pause] [Stop] [Clear I/O] [Reset]
```

Softkey Name	Function
REVERSE CHAR	Allows you to specify if you want the reverse transistor characteristics to be measured, tested, and recorded.
IDTEST MIN	Allows you to change the minimum value of drain current in Amps that must be detected in order to pass continuity.
IGLEAK MAX	Allows you to change the maximum value of gate current in Amps that is allowed in order to pass the gate leakage test.
IDLEAK MAX	Allows you to change the maximum value of drain current in Amps that is allowed in order to pass the drain leakage test.

CHANGE PARAMS Screen #4

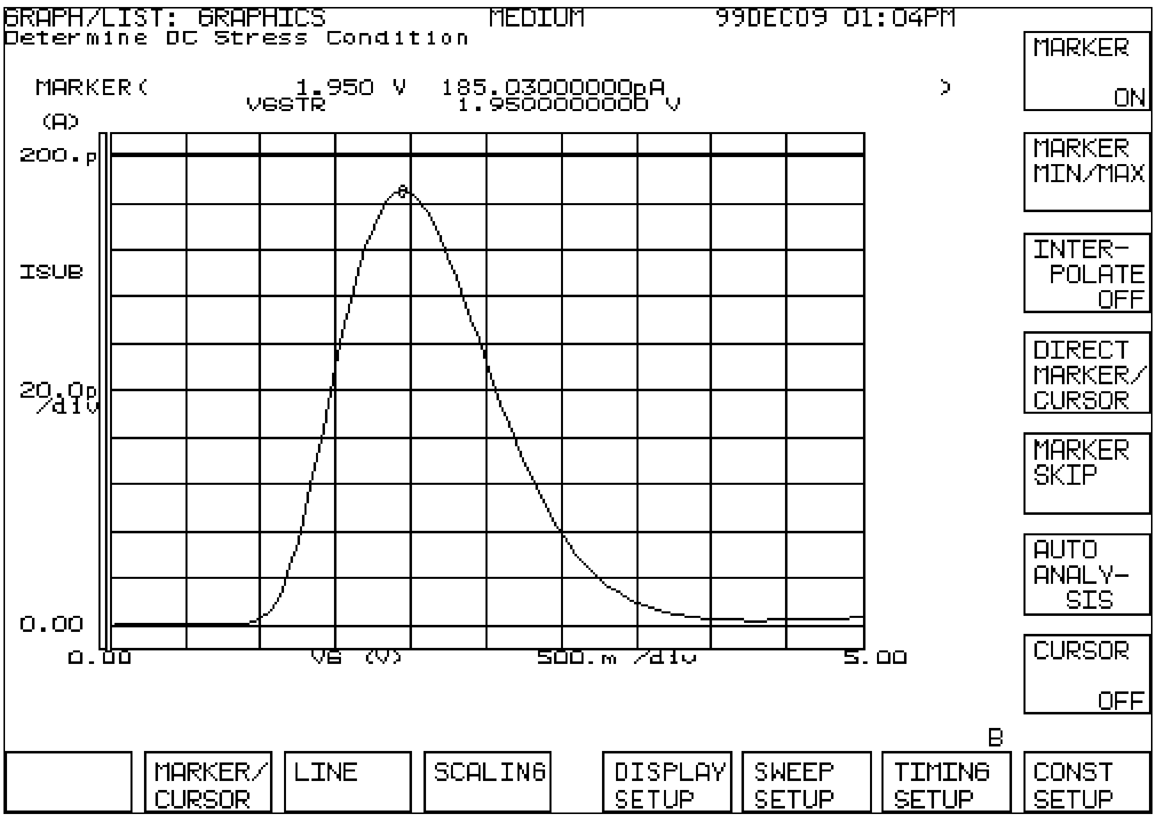
The fourth page of the CHANGE PARAMS submenu has the following appearance:

```
CURRENT HCI PROGRAM SETTINGS:                                        [DATA DIR]

Currently selected device number = 1

MOSFET device type to be tested = NMOS                               [        ]

Number of Test Devices (8 max) = 8
Number of Measurement Points = 16                                    [        ]
Number of Measurements Before Backup = 7

Drain Voltage During Stress = 5 V
Gate Voltage During Stress = 2.5 V                                   [        ]

Gate Length Used for Calculations = 1.E-6 M
Gate Width Used for Calculations =  1.E-5 M                          [PREV PAGE]

Test Reverse Characteristics = NO

Minimum Value of Id for Continuity Test =    1.E-9 A                 [        ]
Maximum Value of Ig for Gate Leakage Test =  2.E-10 A
Maximum Value of Id for Drain Leakage Test = 1.E-8 A

Subdirectory where data files will be stored = TEST_D                [EXIT SUBMENU]

                                                                   B    Run
[Step] [Conti-nue] [RUN] [    ] L [Pause] [Stop] [Clear I/O] [Reset]
```

Softkey Name	**Function**
DATA DIR	Allows you to change the name of the data directory where the HCI data will be stored.

Gate Voltage Stress Extraction

For optimal HCI testing, the voltage applied to the device gates during stress should be determined from actual device measurement. The "EXTRACT Vg STR" softkey on the main menu performs this function. This subroutine calls the 4156A/B/C measurement setup file "IBVG.MES", and connects device #1 to the 4156A/B/C through the E5250A. The IBVG.MES grounds the device source and substrate, sets the device drain to the drain stress voltage, and then sweeps the gate voltage from 0V to 5V. The substrate leakage current is measured, and the gate voltage value where the substrate leakage current is a maximum is determined. This gate voltage value is the optimum value at which to run the HCI program. A sample measurement result is shown below:



Note #1: It is obvious that the values used in this measurement setup file are probably not optimal for your devices. You should use the "CHAR DEVICE" submenu to connect up a device and modify the IBVG.MES file parameters to fit your device characteristics.

Note #2: To be completely rigorous, the device used to determine the optimal gate stress voltage should not be used for the HCI test program. However, the decision as to whether or not to use the device in the subsequent HCI testing is at your discretion.

HCI Program Flow

Overview

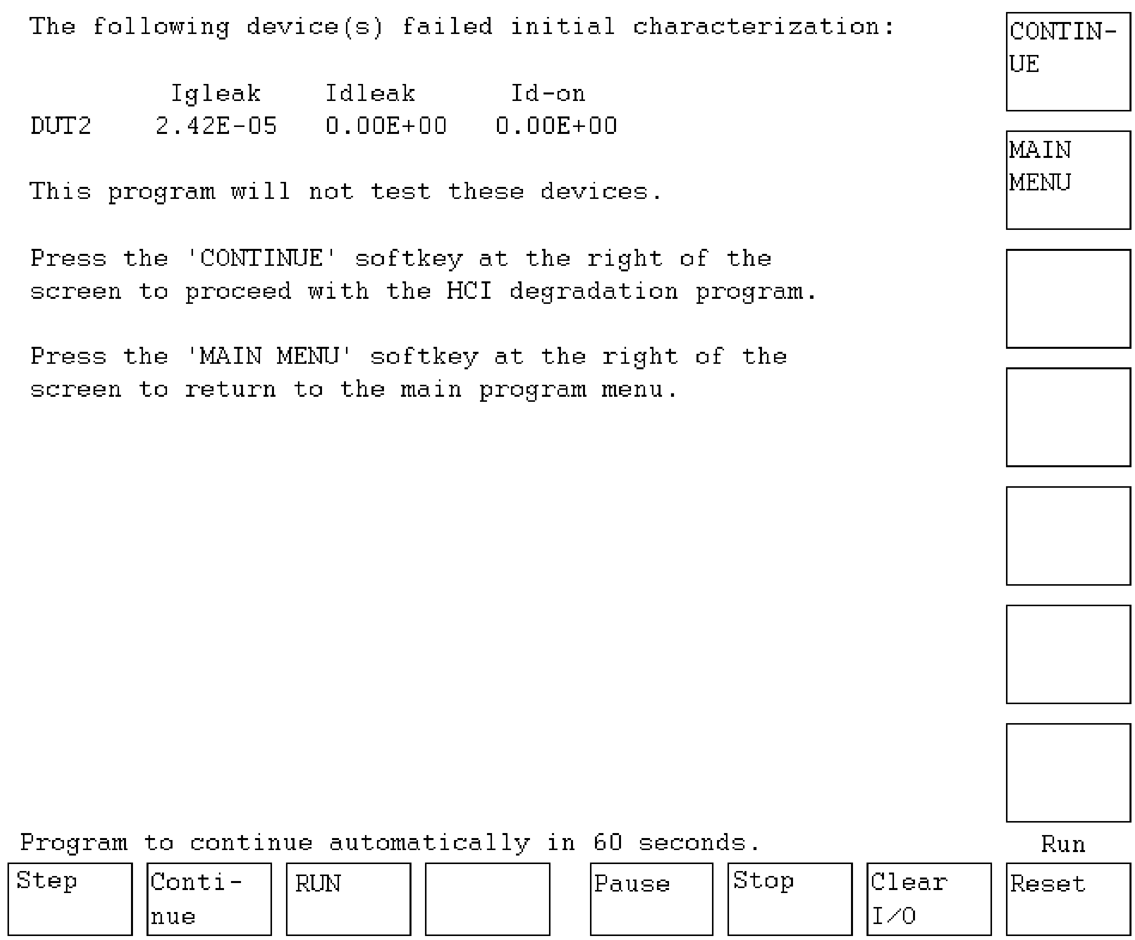
The HCI degradation program performs the following steps using the indicated 4156A/B/C measurement setup (.MES) files:

Step	Description	Setup File(s)
1	Determine if devices are valid and present for the HCI test.	IGLEAK.MES IDLEAK.MES CNTACT.MES
2	Characterize the initial parameters.	PARAM.MES
3	Apply stress and characterize the parameters.	PARAM.MES

These measurement setup files can be modified by the user as desired, as long as the variables defined under the user functions keep the same names as in the default files. In other words, you are free to use whatever methods you choose to derive the parameters used by the setup files, as long as your user variables keep the same names.

Initial Characterization

All devices are first checked for gate leakage, and drain leakage, and continuity (presence of an actual device). If the device fails, then default fail data is written to the data files for that device and no further testing on that device will occur. If the device passes, then the program performs an initial characterization of the device. After all of the devices are checked, the program pauses to display a summary of the initial characterization results:



You have 60 seconds to decide if you want to go back to the main menu and use the CHAR DEVICE menu to further characterize the bad device(s). After 60 seconds, the program will automatically proceed with the HCI device stress. If you do not want to wait 60 seconds, then you can proceed immediately to the HCI stress by pressing the "CONTINUE" softkey.

Stress/Characterization

The program then enters into the Stress/Characterization portion of the HCI test. The default program will stress and measure the devices at the following intervals:

Stress Cycle	Stress Time	Cumulative Stress Time
1	10 sec	10 sec
2	10 sec	20 sec
3	30 sec	50 sec
4	50 sec	100 sec
5	100 sec	200 sec
6	300 sec	500 sec
7	500 sec	1,000 sec
8	1,000 sec	2,000 sec
9	3,000 sec	5,000 sec
10	5,000 sec	10,000 sec
11	10,000 sec	20,000 sec
12	30,000 sec	50,000 sec
13	50,000 sec	100,000 sec
14	100,000 sec	200,000 sec
15	300,000 sec	500,000 sec
16	500,000 sec	1,000,000 sec

Each device is characterized at the end of each stress interval. Devices are continuously stressed and measured until all of the stress cycles have been completed, or until **one** of the following conditions is met:

1. The Idlin parameter has changed by 10% from its unstressed value.
2. The Gmmax parameter has changed by 10% from its unstressed value.
3. The Vtext parameter has changed by 20 mV from its unstressed value.
4. The Vtci parameter has changed by 20 mV from its unstressed value.

Note #1: Devices that have met one of the above conditions are no longer stressed or measured.

Note #2: If you have specified the program to measure reverse transistor characteristics, then all of the above parameters will be checked for change in reverse transistor characteristics as well. Change in the reverse parameters by the amounts specified above will also result in device failure.

You can change the above limits in the program by changing a single variable for each parameter limit in the program. Please see Appendix C.

Stress Display

During stress the initial parameter values and last measured parameter shift values for the forward characteristics of the device(s) under stress are displayed. Only devices currently under stress bias are displayed. Thus, no devices that failed initial device check or devices that have exceeded the specified parameter shift limits are displayed. A sample screen display is shown below:

STRESSING DEVICES: Next Measurement at 5000 sec.

Initial (forward) parameter values:

	Idlin	Gmmax	Vtext	Vtci
DUT1	1.83E-03	1.11E-03	1.01E+00	9.58E-01
DUT2	1.81E-03	1.10E-03	1.01E+00	9.57E-01
DUT3	1.80E-03	1.05E-03	1.00E+00	9.57E-01
DUT4	1.87E-03	0.98E-03	1.05E+00	9.60E-01
DUT5	1.84E-03	1.00E-03	1.01E+00	9.58E-01
DUT6	1.89E-03	1.02E-03	1.00E+00	9.58E-01
DUT7	1.88E-03	0.99E-03	0.99E+00	9.56E-01
DUT8	1.83E-03	1.07E-03	1.05E+00	9.59E-01

Parameter shift at last measurement point:

	Idlin(%)	Gmmax(%)	Vtext	Vtci
DUT1	0.77E-01	0.34E-01	5.62E-03	7.84E-03
DUT2	0.56E-01	0.38E-01	3.56E-03	6.77E-03
DUT3	0.98E-01	0.29E-01	5.89E-03	5.11E-03
DUT4	0.46E-01	0.43E-01	4.47E-03	7.99E-03
DUT5	0.74E-01	0.50E-01	6.72E-03	8.93E-03
DUT6	0.94E-01	0.83E-01	2.45E-03	4.56E-03
DUT7	0.82E-01	0.78E-01	4.56E-03	5.89E-03
DUT8	0.49E-01	0.25E-01	5.88E-03	8.01E-03

Accumulated Stress Time = 3288 sec.

B Run

Step	Conti-nue	RUN		L	Pause	Stop	Clear I/O	Reset

This screen allows you to check the progress of your HCI test. Note: If the screen goes blank (screen saver mode), simply press the space bar on the keyboard to recover the display.

Saving Data to Disk

Since writing data to floppy disk can take considerable time, interim characterization results are not necessarily stored to floppy disk after each measurement. The conditions under which data are written to floppy disk during stress/characterization are as follows:

1. The device has changed from its unstressed value for Idlin, Gmmax, Vtext, or Vtci by the amount specified previously.
2. The current measurement point has exceeded the value of the "Number of Measurements before Backup."
3. All stress/measurement cycles have been completed.

Note: The feature of having the measurement data always written to floppy disk only after a specified number of measurements have been made is done as a convenience to the user. This way, time is not wasted during the short initial stress/measurement intervals writing data to floppy disk, but the user is protected from catastrophic occurrences (i.e. power failures) of data loss after many hours of measurement.

The measurement data is saved to the appropriate directory on the floppy disk for each device as ASCII text (.TXT) files with the following file names:

- 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.

Note: If you are measuring reverse characteristics as well, then a second set of files for each device will be created. The file names (with .TXT extensions) will be as follows:

- ID*xx*_r: Percent change data for reverse Idlin
- GM*xx*_r: Percent change data for reverse Gmmax
- VTE*xx*_r: Relative shift data for reverse Vtext
- VTI*xx*_r: Relative shift data for reverse Vtci

Where *xx* = test device number.

Modifying Measurement Conditions

Parameter Definitions

User Functions

The “PARAM.MES” file uses the following user function equations:

Gm = DIFF(ID,VD)
Vtext = @MX-(@MY1/@MY2)-AT(VD,1)/2
Gmmax = MAX(Gm)
Vtci = @L2X
Idlin = @L1Y1

Display Setup

The “PARAM.MES” file uses the following display setup:

X-axis: VG
Y1-axis: ID
Y2-axis: Gm
Data Variables: Vtext and Idlin

Auto Analysis Function

The “PARAM.MES” file uses the following display setup:

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


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


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

*Interpolate:[ON ]
```

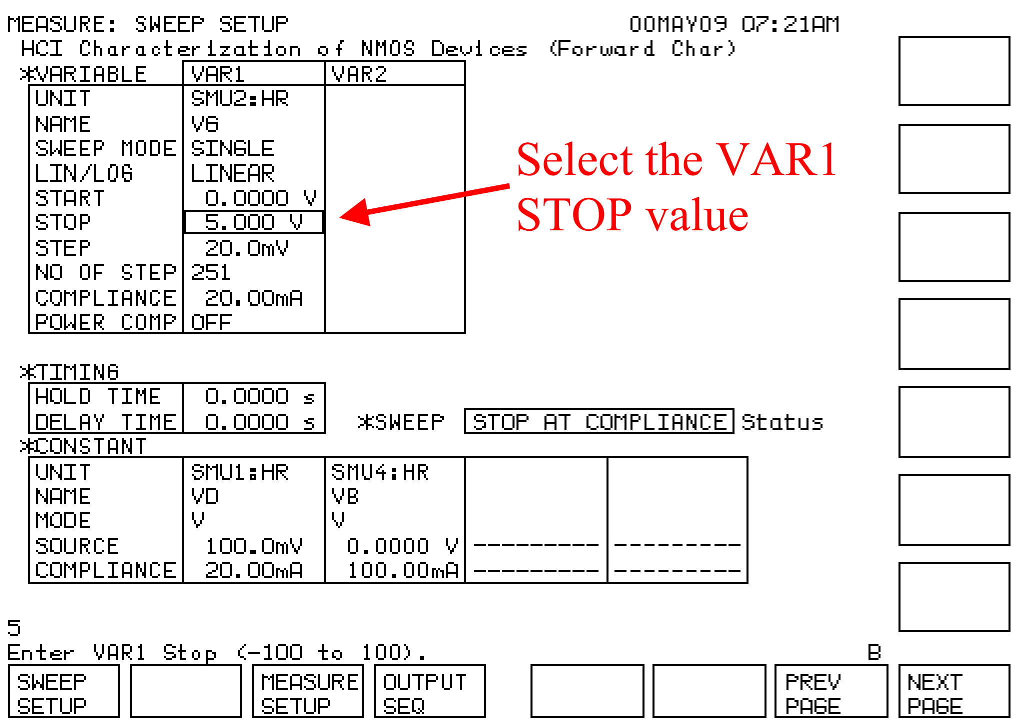
Idlin

Definition of Idlin

Idlin (drain current under linear conditions) is determined by evaluating the value of the drain current at the end of the gate voltage sweep. In the default measurement setup files, the gate voltage sweeps to 5V. Therefore, Idlin in the default program is the value of the drain current at 5V. If you want to use a different point to define Idlin, then you need to go in and modify the "PARAM.MES" file.

Modifying the Idlin Measurement

First, you need to load the "PARAM.MES" file into the 4156A/B/C. After doing this, press the "MEAS" front-panel key in the PAGE CONTROL key group. Using the cursor keys, move the highlight box until the VAR1 Stop value is selected.



Type in the new Stop value for VAR1. This will be the value of VG at which Idlin will be measured. Make sure that you save your changes and overwrite the existing version of "PARAM.MES".

Note: The reverse characteristic setup will automatically check the Stop value of VAR1 and use this value when computing the reverse Idlin.

Gmmax

Definition of Gmmax

Gmmax (maximum value of Gm) is defined as the point where Gm (the derivative of ID with respect to VD) is a maximum. Typically, you do not want or need to modify the definition of Gm.

Vtext

Definition of Vtext

Vtext (extracted voltage threshold) is obtained from the following equation:

$$I_d = k[(V_g - V_t)V_{ds} - V_{ds}^2/2]$$

Solving for Vt yields:

$$V_t = V_g - [I_d / (kV_{ds})] - V_{ds}/2$$

This is equivalent to saying that:

```
Vtext = Vg(Gmmax) - Id(Gmmax)/Gmmax - VD/2
```

Where Vg(Gmmax) and Id(Gmmax) represent the values of Vg and Id at the point where Gm is a maximum. Typically, you do not want or need to modify the definition of Vtext.

Vtci

Definition of Vtci

Vtci (voltage threshold at constant current) is defined as the point where the value of the drain current (ID) equals the W/L ratio (Gate Width/Gate Length ratio) in micro-Amps. Therefore, Vtci in the default program is the value of the gate voltage where Id equals 10µA (since the default W/L ratio is 10).

Modifying the Vtci Measurement

You can change the values of gate length and gate width programmatically at run time. The value of drain current used to define Vtci will automatically be updated for both the forward and reverse directions after you change either gate length or gate width.

Appendix A – Revision History

Revision 1.0 – March 2000

Original Document

Revision 2.0 – May 2000

Document revised to reflect changes and improvements to version 2.0 of the HCI software. Rev 2.0 of the HCI program has the following changes:

1. Reverse characteristic measurements added
2. PMOS measurement capability added
3. Number of measurement points increased to 16
4. Display during stress improved
5. Quick continuity test added

Appendix B – Data File Formats

PARAMS.TXT Data Format

The PARAMS.TXT file stores the following lines of data, where data on each line is separated by commas:

Line 1: No. of devices, Number of measurement points, Number of points before backup
Line 2: Id contact test minimum, Ig leakage test maximum, Id leakage test maximum
Line 3: Drain stress voltage, Gate stress voltage
Line 4: Gate length, Gate Width

Example PARAMS.TXT data is shown below:

```
8, 13, 7
1.E-9, 2.E-10, 1.E-8
5, 2.5
1.E-6, 1.E-5
```

Invalid Device Data Format

Device data files where the device was determined to be defective during initial characterization all have the same format, where data on each line is separated by commas:

Line 1: Drain stress voltage, Gate stress voltage, Gate length, Gate Width
Line 2: "0, 0"

Note: All invalid device data files have the same format.

Example data for a bad device is shown below:

```
5, 2.5, 1.E-6, 1.E-5
0, 0
```

Note: Here the drain stress voltage was 5 V, the gate stress voltage was 2.5 V, and the gate length and width used for calculations were 1E-6 M and 1E-5 M, respectively.

Valid Device Data Format

Valid device data files vary slightly in structure depending upon the parameter being measured.

The ID*xx*.TXT and GM*xx*.TXT files have the following data structure:

Line 1: Drain stress voltage, Gate stress voltage, Gate length, Gate Width
Line 2: No. of measurement points taken, Initial value of parameter
Line 3: Array of percent change in parameter at each measurement point
Line 4: Array of cumulative stress (in sec) at each measurement point

Example data for a GM*xx*.TXT data file after 4 measurement points is shown below:

5, 2.5, 1.E-6, 1.E-5
4, .001105725
1.53519, 2.60236, 4.61688, 5.91241
10, 20, 50, 100

The VTE*xx*.TXT and VTI*xx*.TXT files have the following data structure:

Line 1: Drain stress voltage, Gate stress voltage, Gate length, Gate Width
Line 2: No. of measurement points taken, Initial value of parameter
Line 3: Array of relative shift data for the parameter at each measurement point
Line 4: Array of cumulative stress (in sec) at each measurement point

Example data for a VTExx.TXT data file after 4 measurement points is shown below:

5, 2.5, 1.E-6, 1.E-5
4, 1.013433
.005348, .009176, .0162597, .0212953
10, 20, 50, 100

Appendix C – Modifying the Program

Program lines 1000 through 2190 contain the variable definition statements that you can modify if you want to manually change program parameters.

Changing Input Parameters

Search for the string 'Input Parameters'. You can change the following variables if you want to change the default values in the program (these values can also be changed programmatically).

Max_devices	=	Maximum number of test devices
Max_meas_pts	=	Maximum number of measurement points
Backup_save	=	Point after which data always saved

Note: Make sure that the maximum number of measurement points does not exceed the number of points contained in the 'Stress duration setup' DATA statements.

Changing Contact & Leakage Test Limits

Search for the string 'Limits for contact/leakage tests'. You can change the following variables if you want to change the default values in the program (these values can also be changed programmatically).

Idtest_min	=	Minimum value for Idmax (contact test)
Igleak_max	=	Maximum allowed gate leakage current
Idleak_max	=	Maximum allowed drain leakage current

Changing Drain & Gate Stress Voltages

Search for the string 'Drain/Gate Stress values'. You can change the following variables if you want to change the default values in the program (these values can also be changed programmatically).

Vdstr	=	Drain Voltage During Stress
Vgstr	=	Gate Voltage During Stress

Changing Other Stress Parameters

Search for the string 'Other Stress Parameters'. Normally, you should not need to change these parameters. If you do, make sure that you understand the capabilities and limitations of your power supply.

Vsstr	=	Source Stress Voltage
Vbstr	=	Bulk (substrate) Stress Voltage
Idstr_limit	=	Drain current stress current limit
Igstr_limit	=	Gate current stress current limit
Isstr_limit	=	Source stress current limit
Ibstr_limit	=	Bulk (substrate) stress current limit

Changing Device Geometries

Search for the string 'Device geometries'. You can change the following variables if you want to change the default values in the program (these values can also be changed programmatically).

Gate_length	=	Gate length (in meters)
Gate_width	=	Gate width (in meters)

Note: The ratio of Gate_width to Gate_length (W/L) determines where Vtci will be measured. Vtci is measured at the value of W/L in micro-Amps.

Changing MOS Device Type

Search for the string 'MOS Device Type'. You can change the following variable if you want to change the default value in the program (this value can also be changed programmatically).

Mos_type	=	(0=NMOS; 1=PMOS)

Changing Measure Reverse Characteristics Switch

Search for the string 'Measure Reverse Characteristics'. You can change the following variable if you want to change the default value in the program (this value can also be changed programmatically).

Rev_char	=	(0=Do not measure; 1=Measure)

Changing .MES File Names Called by the Program

Search for the string 'Definition of measurement and stress setup files'. Normally, you should not need to change these names.

Ibvg_file$	=	File used to determine Vgstr
Igleak_file$	=	File used to measure gate leakage
Idleak_file$	=	File used to measure drain leakage
Cntact_file$	=	File used for contact test
Param_file$	=	File used for Idlin/Gmmax/Vtext/Vtci

Changing Names of Files Saved by the Program

Search for the string 'File name to save ASCII data'. Normally, you should not need to change these names.

Dir$	=	Default directory to save data
Idlin_data$	=	Idlin shift data filename
Gmmax_data$	=	Gmmax shift data filename
Vtext_data$	=	Vtext shift data filename
Vtci_data$	=	Vtci shift data filename

Changing the Stress Measurement Times

Search for the string 'Stress duration setup'. To change the times at which measurement will occur, you need to modify the DATA statements. All times are in seconds.