

*Sample*

**KEITHLEY INSTRUMENTS**

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**Model 5958 C-V  
Software Utilities  
Instruction Manual**

*new*



Contains Operating Information

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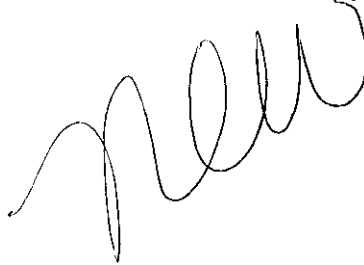
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**Instruction Manual  
Model 5958  
C-V Software Utilities**



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# MODEL 5958 C-V UTILITIES SOFTWARE

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## OVERVIEW

### INSTRUMENTS CONTROLLED:

**Required:** Model 590 C-V Analyzer.

**Optional:** Model 230-1 Voltage Source, Temptronic Hot Chuck (user supplied, for BTS only), GPIB switch or prober. Switch Control Files are provided for Keithley switching systems.

**TESTS:** Controls instruments to connect devices, acquire data, and stress the device under test.

**Capacitance vs. Voltage (C-V):** Controls the Model 590 to measure capacitance and conductance (or resistance) versus voltage.

**Capacitance vs. time (C-t):** Controls the Model 590 to measure capacitance versus time.

**Bias Temperature Stress (BTS) Cycle:** Cycles the hot chuck specified by the hot chuck control file. Stress temperature time and voltage are programmable.

**BTS Test Sequence:** Tests up to 99 devices using specified C-V Parameter, Stress Cycle, Switch Control, and Data Destination files.

**Sequence Type:** Sequential, Parallel, or No Stress.

**Stress Type:** + then -, - then +, + only or - only.

**Zerbst Test Sequence:** Tests up to 99 devices using specified C-V Parameter, C-t Parameter, Switch Control, and Data Destination files.

**Sequence Type:** Multiple C-V, One C-V, or No C-V.

**DATA DISPLAY:** Graphic or list display of data arrays. Tabular display of calculated parameters.

### FILES:

**C-V Parameter File (.CVP):** Contains all setup parameters for C-V Measurements.

**C-t Parameter File (.CTP):** Contains all setup parameters for C-t Measurements.

**Stress Cycle Parameter File (.SCP):** Contains all setup parameters for Bias Temperature Stress cycles.

**BTS Test Sequence File (.BTS):** Contains all setup parameters for BTS Test Sequences.

**Zerbst Test Sequence File (.ZTS):** Contains all setup parameters for Zerbst Test Sequences.

**Data Destination Files (.DAT, .CTD):** Each contains C-V or C-t curve data, user-input device parameters, and derived results. Model 5958 C-V data files (.DAT) are compatible with Model 5957V2.0.

**Configuration File (.CFG):** Specifies default paths and system configuration parameters.

**Switch Control File (.SWC):** User-defined ASCII file containing the necessary commands to make device connections with a GPIB device. Commands include INIT, PARALLEL, DEVICE n, and FINAL.

**Hot Chuck Control File (.HCC):** User-defined ASCII file containing the necessary commands to control a GPIB hot chuck. Commands include SENDWINDOW, SENDSETPPOINT, SENDSRQMASK, GETTEMP, NUMCHUCKS, CHUCKADDR, TERMINATOR, SPATTEMP, and SPNOTBUSY.

**Cable Calibration File (.CAL):** Contains reference capacitor values and calibration constants to be sent to the Model 590 to calibrate particular range and frequency combinations.

**Material Constants File (MATERIAL.CON):** Specifies material constants to be used in analysis such as insulator and semiconductor permittivity, bandgap energy, intrinsic carrier concentration, metal work function, and electron affinity.

### CAPACITANCE MEASUREMENT CAPABILITY:

**Test Signal Frequency:** 100kHz or 1MHz.

**100kHz Measurement Ranges:** 2pF/2uS, 20pF/20uS, 200pF/200uS, and 2nF/2mS.

**1MHz Measurement Ranges:** 20pF/200uS, 200pF/2mS, 2nF/20mS.

**Bias Voltage:**  $\pm 20V$  maximum using Model 590 internal voltage source.  $\pm 100V$  max using external Model 230-1 voltage source.

**Bias Voltage Waveform:** Stair and pulsed stair waveforms.

**Measurement Rates (readings/sec):** 1, 10, 18, and 75. 1000 reading/sec. available also for C-t measurement.

Selectable measurement filter and series or parallel device model.

**C-t Sample Time:** 1msec to 65 sec per sample, up to 450 samples (up to 1350 samples at the 1000/sec measurement rate).

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## ANALYSIS

**MIS Analysis Constants:** Oxide capacitance and thickness, gate area, series resistance, equilibrium minimum capacitance, average doping, bulk doping, device type, Debye length, flatband capacitance and voltage, work function difference, threshold voltage, effective oxide charge and charge concentration, best depth, and capacitance gain and offset.

**Doping Profile:** Depletion approximation doping versus depletion depth and depth versus gate voltage, Ziegler method Majority Carrier Corrected (MCC) doping profile.

**Bias Temperature Stress:** Mobile ionic charge, total fixed oxide charge ( $Q_{ss}$ ), oxide capacitance and thickness, gate area, series resistance, equilibrium minimum capacitance, average doping, bulk doping, device type, flatband capacitance and voltage, threshold voltage, and capacitance gain and offset.

**C-t/Zerbst:** Zerbst plot of C-t data to determine carrier generation lifetime, surface generation velocity.

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## SYSTEM REQUIREMENTS

**RECOMMENDED COMPUTER CONFIGURATION:** IBM compatible 80386 with 80287 or 80387 math coprocessor and disk cache, 640kB RAM, hard disk drive, 1.2MB 5¼-inch or 720kB 3½-inch floppy drive, EGA or VGA monitor, Microsoft or Logitech mouse.

**MINIMUM COMPUTER CONFIGURATION:** IBM AT, PS/2, or 100% compatible, 640kB RAM, hard disk drive, 1.2MB 5¼-inch or 720kB 3½-inch floppy drive.

**OPERATING SYSTEM:** MS-DOS or PC-DOS 3.2 (minimum).

**GRAPHICS ADAPTER:** CGA, EGA, VGA (EGA mode), or Hercules Graphics Adapter.

**MEMORY and DISK STORAGE REQUIREMENTS:** 4.5MB of hard disk space (prior to installation) and 400kB free conventional RAM.

### IEEE-488 (GPIB) INTERFACE CARDS SUPPORTED:

Using Iotech Driver 488 software V2.60 or earlier:

Capital Equipment PC-488, 4x488; IBM GPIB Adapter; Iotech GP488, GP488A, GP488B+, MP488, MP488CT; Keithley PC-488-CEC, 4-488-CEC-0M, 4-488-CEC-1M; Metrabyte KM488-DD, KM488-ROM; National Instruments PC-II, PC-IIA, PC-III.

Using Iotech Driver 488 software V2.61:

Iotech GP488B+, MP488, MP488CT.

**Iotech Personal 488/2 is required for PS/2 operation.**

**COMPATIBLE PRINTERS:** Cannon BJ80; C. Itoh Prowriter; C. Itoh 24LQ; Epson FX, RX, MX, LQ1500; HP Think Jet, Laser Jet+; IBM Graphic or Professional; NEC 8023, 8025; NEC Pinwriter P Series; Okidata 92, 93, 192+; Smith Corona D100; Tektronix 4695/6; Toshiba 24 pin.

**COMPATIBLE PLOTTERS:** Epson HI-80; Hewlett-Packard 7470, 7475, 7440; Houston DMP-XX; Roland DXY-800; Watanabe Digi-Plot.

**COMPATIBLE MOUSE:** Microsoft or Logitech mouse with MOUSE.SYS installed.

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## MATERIALS PROVIDED:

Instruction manual.

Diskettes containing installation, programs, source code, and sample data.

\*Note: Microsoft BASIC 7.1 required to modify source code.

Specifications subject to change without notice.

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*THIS IS A HOT HOT HOT*

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# SECTION 1

## General Information

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### 1.1 INTRODUCTION

This section contains overview information for the Model 5958 C-V Software Utilities and is organized as follows:

- 1.2 Features
- 1.3 Warranty Information
- 1.4 Manual Addenda
- 1.5 Safety Symbols and Terms
- 1.6 Specifications
- 1.7 Computer Requirements
- 1.8 Required Equipment
- 1.9 Optional Accessories

### 1.2 FEATURES

The Model 5958 C-V Utilities software package is designed to perform BTS (bias temperature stress) measurements and Zerbst analysis on semiconductors with the aid of a user-supplied Model 590 C-V Analyzer. A Tempronic Model TP0315B Hot Chuck (not supplied) is required for BTS measurements.

Model 5958 measurement and analysis capabilities include:

- C-V and C-t measurements
- Insulator thickness or gate area from high-frequency C-V measurements.
- Semiconductor average doping
- Insulator mobile ion charge density
- Effective surface charge
- Minority carrier lifetime
- Surface generation velocity
- Flatband voltage and capacitance
- Threshold voltage
- Metal semiconductor work function

### 1.3 WARRANTY INFORMATION

Warranty information is located on the inside front cover of this instruction manual. Should you require warranty service, contact your Keithley representative or the factory for further information.


### 1.4 MANUAL ADDENDA

Any improvements or changes concerning the Model 5958 will be explained on a separate addendum supplied with the manual. Please be sure to note these changes and incorporate them into the manual before using the software.

### 1.5 SAFETY SYMBOLS AND TERMS

The following safety symbols and terms may be found on one of the instruments or used in this manual:



The  symbol on an instrument indicates that you should consult the operating instructions in the associated manual.

The **WARNING** heading used in this and other manuals cautions against possible hazards that could lead to personal injury or death.

A **CAUTION** heading outlines dangers that could lead to instrument damage. Such damage may invalidate the warranty.

## 1.6 SPECIFICATIONS

Detailed specifications for the Model 5958 are located at the front of this instruction manual. Specifications for equipment used with the Model 5958 can be found in the respective instruction manuals.

## 1.7 COMPUTER REQUIREMENTS

The following paragraphs discuss minimum computer requirements, supported graphics and interface cards, supported plotters and printers, and required system software.

### 1.7.1 Computer Hardware Requirements

The Model 5958 software is intended to run on IBM AT, PS/2, or compatible computers. Table 1-1 summarizes the minimum required computer configuration.

#### NOTE

A coprocessor-equipped 386-based computer is recommended for best performance. Also, a smart extended memory manager such as SMARTDRV.SYS may speed up program operation if you have extended or expanded memory.

Table 1-1. Computer Hardware Requirements

Description	Requirements
Computer	IBM AT, PS/2, or 100% compatible*
Minimum RAM	640KB
Disk drives	Hard drive, one 1.2MB 5 1/4", or 720KB 3-1/2" floppy disk drive
Monitor/graphics card	Color or monochrome (see Table 1-2)
Instrument interface	IEEE-488 (see Table 1-3)
Plotter/printer interface	Serial, parallel, or IEEE-488 (see Tables 1-4, 1-5)

\* Compatible 386-based machines such as the Compaq 386 can also be used. NOTE: select IBM graphics mode; Compaq graphics is not supported.

### 1.7.2 Supported Graphics Cards

Table 1-2 lists the graphics card supported by the Model 5958.

**Table 1-2. Graphics Cards Supported by Model 5958**

Graphics Cards
IBM CGA or 100% compatible
IBM EGA or 100% compatible
IBM VGA or 100% compatible (EGA mode)
Hercules monochrome or 100% compatible
Tseng EVA
Tecmar Graphics Master
TeleVideo AT
TeleVideo HRCGB
Sigma Color 400
AT&T 6300
Corona PC
Corona PC400
Corona ATP
H.P Vectra
T.I. Professional
Genoa SuperEGA HiRes

### 1.7.3 Supported IEEE-488 Interfaces

Table 1-3 lists computer IEEE-488 interfaces supported by the Model 5958.

**Table 1-3. IEEE-488 Interfaces Supported by Model 5958**

Interface	Manufacturer
GP488/GP488A/Power488	IOtech
PC II, PC IIA, PC III	National Instruments
PC-488-CEC, 4-488-CEC	Keithley Instruments
PC-488, 4-488	Capitol Equipment Corp.
GPIB	IBM
GP488/2*	IOtech

\* This interface is required for PS/2 machines, the remainder are used with AT and compatibles.

### 1.7.4 Recommended Printers and Plotters

A user-supplied printer or plotter is required for hard copy graphs or data printouts. Table 1-4 summarizes recommended printers, and Table 1-5 lists plotters. Additional plotter and printer considerations are discussed in paragraph 2.3.

**Table 1-4. Recommended Printers**

Printer
NEC 8023, C. Itoh Prowriter
Cannon BJ80
Epson FX, MX, RX
Okidata 92, 93
Smith Corona D100
IBM Graphics
Tektronix 4695/6
C. Itoh 24LQ, Toshiba 24 pin
Epson LQ1500
HP Laser Jet+ (or compatible)
Okidata 192+
HP Think Jet
NEC Pinwriter

**Table 1-5. Recommended Plotters**

Plotter
Hewlett-Packard 7440, 7475, 7440
Watanabe Digiplot
Houston DMP-XX
Roland DXY-800
Epson HI-80

NOTE: Plotters must support HPGL graphics language.

### 1.7.5 Software Requirements

Table 1-6 summarizes the required computer software. Additional information on software installation is located in paragraph 2.3.

### 1.8 REQUIRED EQUIPMENT

Table 1-7 summarizes the minimum equipment required to use the Model 5958 software. Additional optional equipment may be added to enhance capabilities; see paragraph 1.9 for a summary of recommended optional equipment.

Table 1-6. Software Requirements

Software	Comments
MS-DOS or PC-DOS, version 3.2 or higher IOtech Driver488* Microsoft BASIC, version 7.1**	Operating system IEEE-488 interface driver Compile/link source code

\* Driver488 is supplied with the Model 5958.

\*\* BASIC is not supplied and is necessary only if you intend to modify the source code.

Table 1-7. Required Equipment

Description	Comments
Keithley Model 590 C-V Analyzer	Model 590/100k: 100kHz test frequency Model 590/1M: 1MHz test frequency Model 590/100k/1M: 100kHz and 1MHz test frequencies
Temptronic TP0315B Thermochuck equipped with SA4430 IEEE-488 interface*	Required for BTS tests
Keithley Model 7007 IEEE-488 cables (2)	Connects C-V analyzer and hot chuck to computer IEEE-488 interface
Keithley Model 7051 50Ω BNC cables (2 minimum, 3 minimum with Model 230-1 Voltage Source)	Connects C-V analyzer to prober, Model 230-1 trigger output to Model 590 trigger input.
Model 5905, 5906, 5907 or 5909 Calibration Sources**	Aid in performing cable correction (see paragraph 1.9.3)

\* Program can be user modified for use with other hot chucks. See Section 6 for details on modifying hot chuck driver file.

\*\* Calibration sources are recommended for performing the cable correction procedure, a requirement for optimizing high-frequency C-V measurement accuracy. Use Model 5905 Sources to calibrate 20pF, 200pF, and 2nF ranges. Use Model 5906 Sources to calibrate all Model 590 ranges. Use Model 5907 Sources to calibrate only the 2nF range. Use Model 5909 sources to calibrate only 200pF and 2nF ranges.

## 1.9 OPTIONAL ACCESSORIES

The optional accessories described below can be used to enhance Model 5958 capabilities and are available from Keithley Instruments or third-party sources as noted.

### 1.9.1 Voltage Source

**Model 230-1 Programmable Voltage Source:** Extends the normal  $\pm 20\text{V}$  DC bias range of a Model 5958 system to  $\pm 100\text{V}$  and also adds light-control capability using the digital I/O port. A Model 4851 BNC Shorting Plug and a BNC cable are also required for this application.

### 1.9.2 Connecting Cables

**Model 7007 Shielded IEEE-488 Cables:** Shielded IEEE-488 cables with a shielded connector on each end (metric). Available as Model 7007-1 (1m, 3.3 ft. long), and Model 7007-2 (2m, 6.6 ft. long).

**Model 7051 BNC to BNC Cables:**  $50\Omega$  (RG-58C) BNC to BNC coaxial cables, available as Model 7051-2 (0.6m, 2ft. long), Model 7051-5 (1.5m, 5 ft. long), and Model 7051-10 (3m, 10 ft. long).

### 1.9.3 Calibration Sources

**Model 5905 Calibration Sources:** Includes 4.7pF, 18pF, 47pF, 180pF, 470pF, and 1.8nF capacitance sources, 180 $\mu\text{S}$ , 1.8mS, and 18mS conductance sources and two female-to-female BNC barrels. These sources can be used to cable calibrate the 20pF, 200pF, and 2nF ranges, and they can also be used for standard instrument calibration of the 20pF through 2nF ranges.

**Model 5906 Calibration Sources:** Includes 0.5pF, 1.5pF, 4.7pF, 18pF, 47pF, 180pF, 470pF, 1.8nF, 4.7nF, and 18nF capacitance sources, 1.8 $\mu\text{S}$ , 18 $\mu\text{S}$ , 180 $\mu\text{S}$ , 1.8mS, and 18mS conductance sources and two female-to-female BNC barrels. These sources will cable calibrate all Model 590 ranges (2pF, 20pF, 200pF, and 2nF), and they can also be used for standard instrument calibration of the 2pF through 2nF ranges.

**Model 5907 Calibration Sources:** Includes 470pF and 1.8nF capacitance calibration sources and two female-to-

female BNC barrels. These sources will cable calibrate only the 2nF range.

**Model 5909 Calibration Sources:** Includes 47pF, 180pF, 470pF, and 1.8nF capacitance calibration sources and two female-to-female BNC barrels. These sources will cable calibrate the 200pF and 2nF ranges.

### 1.9.4 Rack Mount Kits

**Model 1019A-1 Fixed Rack Mount Kit:** Mounts the optional Model 230-1 Voltage Source in a standard 19-inch rack or equipment cabinet.

**Model 1019A-2 Fixed Rack Mount Kit:** Mounts the optional Model 230-1 Voltage Source and a second similar instrument side-by-side in a standard 19-inch rack or equipment cabinet.

**Model 2288 Fixed Rack Mount Kit:** Mounts one Model 590C-V Analyzer in a standard 19 inch rack or equipment cabinet.

**Model 8000-14 Equipment Cabinet:** A standard 14-inch high, 19-inch wide equipment cabinet, which can be used to enclose instruments used with the Model 5958. Rack mount kits (above) are also required.

### 1.9.5 Hot Chuck and Probe Station

Temptronic TP0315B ThermoChuck accessories:

- 4, 5, 6, or 8" hot chuck
- Extended temperature range option (300°C)

Manual or semi-automatic probe station equipped with:

- Microscope
- Micropositioners
- Coax probe tips
- IEEE-488 interface (for programmable positioning)

Contact the Keithley Instruments, Inc Applications Department for recommendations on these items.

## 1.9.6 Switching Equipment

Optional switching equipment is used for multiple device testing using BTS and Zerbst test sequences. The following paragraphs summarize recommended switching mainframes and cards. Table 1-8 summarizes recommended switching equipment and important specifications.

### Switching Mainframes

**Model 705/706 Scanners:** The Model 705 Scanner provides two-card switching capability with up to 20 channels or 40 crosspoints per mainframe, while the Model 706 can switch 100 channels or 200 matrix crosspoints per mainframe. Both the Models 705 and 706 have a standard IEEE-488 interface which allows automated control of switching functions associated with Model 5958 systems. Cards which can be used with the Models 705 and 706 include 705X and 715X cards discussed below.

**Model 707 Switching Matrix:** The Model 707 Switching Matrix can accommodate up to six compatible 707X or 717X cards (see below). The Model 707 has a standard IEEE-488 interface and can store up to 100 relay setups, simplifying system configuration. Separate analog backplanes assure that maximum signal integrity is maintained.

### Switching Cards

#### Model 705/706 Switching Cards

**Model 7062 RF Switch Card:** The Model 7062 has two independent 1 of 5 switches and provides an inexpensive

solution for high-frequency C-V switching of up to five DUTs.

**Model 7152 Low-Current 4 × 5 Matrix Card:** The Model 7152 Matrix Card is organized as a 4 row by 5 column matrix and provides 1-pole, low-current switching suitable for general-purpose I-V/C-V applications.

#### Model 707 Switching Cards

**Model 7072 Semiconductor Matrix Card:** Organized as an 8 × 12 matrix, the Model 7072 provides two paths for high-frequency C-V measurements, two paths for sub-picoamp I-V measurements, and has four general-purpose paths. The Model 7072 is recommended for general I-V/C-V applications. NOTE: optional Model 7078-TRX-BNC triax-to-BNC adapters (one per path) are required to connect BNC cables to the Model 7072.

**Model 7073 Coaxial Matrix Card:** The Model 7073 is organized as an 8 × 12 matrix and provides 1-pole, 50Ω switching on each path. The Model 7073 is recommended for BTS parallel switching.

**Model 7074D/7075 Multiplexer Cards:** Each Model 7074D/7075 has eight 1 × 12 multiplexer banks, which can be combined in several multiplexer configurations up to 1 × 96.

**Model 7173-50 Two-Pole High Frequency Matrix Card:** The Model 7173 provides 4 rows by 8 columns of 2-pole, 50Ω switching, and is ideal for high-frequency C-V applications except where parallel switching is required.

**Table 1-8. Switch Selection Table for Model 5958 Tests**

	7062	7152	7075	7056	7073	7173	7072*
Zerbst Sequence	X	X	X	X	X	X	X
BTS Sequential	X	X	X	X	X	X	X
BTS Parallel		X	X	X	X		X
Bandwidth	500MHz	60MHz	30MHz	10MHz	30MHz	300MHz	5-15MHz
Stray Capacitance	no spec	<1pF	<3pF	<20pF	0.3pF	<0.04pF	0.4-1pF
Shunt Capacitance	no spec	<100pF	<100pF	<50pF	220pF	150pF	no spec
Offset Current	no spec	<1pA	<100pA	—	10pA typ	<200pA	A, B, 1pA G, H 20pA
Maximum Voltage	24V	200V	110V	150V	200V	30V	200V HV:1.1kV
Maximum Current	50mA	1A	1A	250mA	1A	0.5A	1A
Connection Scheme	BNC	M-series/ BNC	Sub-D/ Dress Cable	Screw Terminal	BNC Common LO	BNC	3-lug Triax/ BNC
DUTs per Card	5	2-2.5	48	5	6	6	6
Mainframe	705/706	705/706	707	705/706	707	707	707

\*Rows A and B are low-current rows; rows G and H are high-frequency C-V rows.

# SECTION 2

## Getting Started

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### 2.1 INTRODUCTION

This section includes introductory information on getting your Model 5958 software up and running as quickly as possible. For details on test setup, measurement, and analysis, refer to Sections 3, 4, and 5 respectively.

Section 2 contains the following:

- 2.2 **IEEE-488 Bus Considerations:** Gives an overview of IEEE-488 interface installation, bus connections, and primary address.
- 2.3 **Software Installation:** Details software backup and installing the software on your hard drive.
- 2.4 **Test Connections:** Shows BTS and Zerbst test connections as well as connections for the optional Model 230-1 Voltage Source and matrix card.
- 2.5 **Cable Correction:** Covers the cable correction procedure necessary to optimize measurement accuracy.
- 2.6 **Running the Software:** Covers running the software, menus, as well as run time considerations.
- 2.7 **Test and Measurement Overview:** Provides an overall summary of how to perform C-V, C-t, and BTS tests and analyze the results.

### 2.2 IEEE-488 BUS CONSIDERATIONS

The following paragraphs discuss computer IEEE-488 interface card installation, bus connections, and primary address.

#### 2.2.1 Interface Card Installation

##### AT Interface Card Installation

Model 5958 can be used with AT and compatible computers and the following IEEE-488 interfaces:

- IOtech GP488, GP488A, and Power488
- National Instruments PCII, PCIIA, and PCIII
- Keithley Instruments PC-488-CEC and 4-488-CEC
- Capitol Equipment Corp. PC-488 and 4-488
- IBM GPIB

Before installation, note the following interface board settings so that you can properly configure the bus driver software during driver software installation:

- I/O port address
- DMA status
- Interrupts
- System controller

After noting these settings, install the interface card in the computer. Refer to the documentation supplied with the card for detailed installation procedures.

## PS/2 Interface Installation

Model 5958 supports PS/2 computers with the following IEEE-488 interface:

- IOtech GP488/2

The PS/2 compatible IEEE-488 interface card should be installed in the computer using the manufacturer's instructions. Refer to the interface card documentation for IEEE-488 bus driver installation instructions and information on using the IBM PS/2 computer reference diskette.

### 2.2.2 Bus Connections

For proper operation, the Model 590 C-V Analyzer, hot chuck, and Model 230-1 Voltage Source and switching mainframe (if used) must be connected to the computer IEEE-488 interface. Shielded IEEE-488 cables, such as the Model 7007, should be used for bus connections to minimize electrical noise, which could affect Model 5958 measurements.

Figure 2-1 shows typical IEEE-488 bus connections between the computer, the Model 590 C-V Analyzer, and

the optional Model 230-1 Voltage Source. Bus connections to the hot chuck and switching matrix interface are similar.

### 2.2.3 Default Primary Address Settings

The default primary address of each device associated with the Model 5958 is as follows:

- Model 590 C-V Analyzer: 15
- Temptronic 0315B ThermoChuck: 9
- Optional Model 230-1 Voltage Source: 13

You can select other addresses for the Models 590 and 230-1 during installation. The thermoChuck primary address is defined in the hot chuck control file (see Section 6).

If a switching mainframe is used, the primary address must be that same as specified in the user-defined switch control file (see Section 6). Also, any other devices connected to the same IEEE-488 bus must not use any of the primary addresses listed above. Each device on the bus must have a unique primary address.

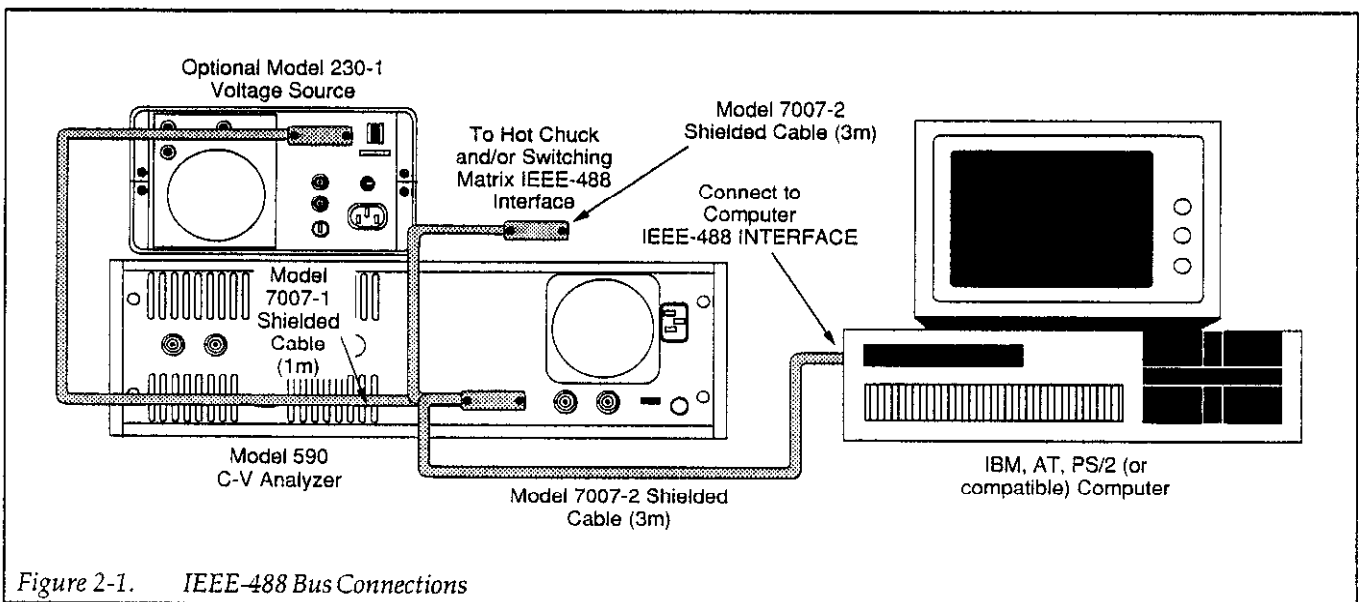


Figure 2-1. IEEE-488 Bus Connections



## 2.3 SOFTWARE INSTALLATION

### 2.3.1 Software Backup

Before installing the software on your hard disk, it is strongly recommended that you make backup copies of each of the disks supplied with the Model 5958. Use the DOS DISKCOPY command to make copies. For two-floppy disk systems, the general command syntax is:

```
DISKCOPY A: B: <Enter>
```

Here, the source disk is assumed to be in drive A, and the target (copy) disk is in drive B. (Note that DISK COPY can be used only for the same type of drives; use COPY \*.\* for dissimilar drives.)

Similarly, the command for single-floppy drive systems is:

```
DISKCOPY A: A: <Enter>
```

After copying all supplied disks, put the original disks away for safekeeping.

### 2.3.2 Installation Procedure

Follow the appropriate procedure below to install the Model 5958 software on your hard disk. The following paragraphs discuss using INSTALL.EXE to install the software.

#### NOTE

INSTALL.EXE can also be used to reconfigure the software after installation. Select the reconfigure option to change an existing software configuration. (You can also run EQUIP.EXE after installation to select graphics and printer/plotter configurations.) You should have at least 5MB of free disk space prior to installing the Model 5958. (You can save some disk space by choosing not to install source files during installation if they are not needed.)

1. Place the installation disk in drive A: or B:, then type:  
A: <Enter>  
or  
B: <Enter>
2. Type the following to start the installation process:  
INSTALL <Enter>
3. Follow the prompts on the screen to select the directories for the various files and programs. You can select installation defaults, which are summarized in Table 2-1, or your own directory names, as desired. You can also choose not to install source files if desired (source files are required only if you intend to modify the program).
4. Select whether or not you are using a Model 82 Simultaneous C-V System. NOTE: refer to Appendix H for further considerations when using a combined Model 82/5958 system.
5. Next select whether an option Model 230-1 Voltage Source, hot chuck, and switching mainframe are present in your system.
6. If you are using a Model 230-1, select whether or not you will be using a light to speed up equilibrium. (Refer to paragraph 2.4.4 for light connections.)
7. Indicate whether your Model 590 C-V Analyzer has 100kHz and/or 1MHz options.
8. Choose the line printer. Note: this selection affects only text print-outs. Graphics printer operation is selected separately (see below).
9. Be sure to select the correct Model 590 and Model 230-1 primary addresses (only if you are not using a Model 82 system).
10. Continue the installation process by selecting appropriate graphics cards, printers, and plotters at the appropriate prompts. Table 2-2 summarizes graphics cards, and Table 2-3 lists supported printers and plotters. Also, refer to paragraph 2.3.5 below for certain plotter and printer considerations.

#### NOTE

The Model 5958 will run properly on most VGA, Super VGA, and 8514 monitor computer systems in the EGA mode. To use the Model 5958 with any of these graphics systems, select the EGA graphics mode at the appropriate prompt.

Table 2-1. Default Directories

Sub-directory	Contents
C:\KTHLY_CV\MODEL58	KI5958CV.EXE, configuration file, CONFIG.GPC, .FNT or other files needed by KI5958CV.EXE, CABLECAL.EXE
C:\KTHLY_CV\MODEL58\CAL	Cable calibration data files, *.CAL
C:\KTHLY_CV\MODEL58\CTRL	Switch control and hot chuck control files, *.SWC and *.HCC
C:\KTHLY_CV\MODEL58\DAT	Data destination files, *.DAT and *.CTD
C:\KTHLY_CV\MODEL58\PAR	C-V, C-t, and stress cycle parameter files, *.CVP, *.CTP, and *.SCP
C:\KTHLY_CV\MODEL58\SEQ	BTS and Zerbst test sequence files, *.BTS and *.ZTS
C:\KTHLY_CV\MODEL58\SRC	Source code, library, and utilities to re-build.
C:\KTHLY_CV\MODEL58\TMP	Temporary files used for program communication.*
C:\IEEE488	IOtech Driver488 GPIB interface driver software*

\* NOTE: C:\IEEE488 is not created by Model 5958 INSTALL program.  
 \TMP directory is not user selectable.

Table 2-2. Supported Graphics Cards

Graphics Board	Mode	Resolution
IBM color board	monochrome	640 × 200
Tsent EVA		640 × 480
Tecmar Graphics Master	monochrome	720 × 700
	16 color	640 × 400
Hercules Monochrome	monochrome	720 × 348
Enhanced Graphics Adapter (EGA)	16 color	640 × 350
TeleVideo AT	monochrome	640 × 400
TeleVideo HRCGB	16 color	640 × 400
Sigma Color 400	16 color	640 × 400
AT&T 6300	native graphics	640 × 400
Corona PC	native graphics	640 × 325
Corona PC400	native graphics IBM emulation	640 × 400
Corona ATP	monochrome	640 × 400
H.P. Vectra	monochrome	640 × 400
T.I Professional	monochrome	720 × 300
Genoa SuperEGA HiRes	16 color	800 × 600
IBM VGA*	16 color	640 × 480
	monochrome	640 × 480

\* Select EGA mode

Table 2-3. Supported Printers and Plotters

Printer/Plotter
C. Itoh Prowriter; NEC 8023, 8025
Epson FX, RX; Cannon BJ80
Okidata 92, 93
IBM Graphic or Professional; Epson MX
Tektronix 4695 ink jet printer
Toshiba P321 and P351 (unidirectional printing)
Corona Laser Printer (requires extra 128K memory)
Houston DMP-XX plotters
Hewlett-Packard HP-GL plotters
C. Itoh 24LQ
Watanabe Digi-Plot plotter
Epson LQ-1500
Smith Corona D100
Epson HI-80 plotter
Hewlett-Packard LaserJet+ (or compatible)
Micro Peripherals 150, 180
Okidata 192+ (8-bit graphics)
CALCOMP ColorMaster
Toshiba 1340 (no unidirectional)
HP ThinkJet (SW5 up, 6.5 X 8.5 in.)
Roland DXY-800 plotter
Toshiba P351C with color ribbon
NEC Pinwriter P series
Quadram QuadLaser (with vector software)
NEC Pinwriter P series (with color ribbon)

### 2.3.3 IEEE-488 Driver Software Installation

The driver software for the IEEE-488 interface card should be installed per manufacturer's recommendations. Refer to the IEEE-488 driver software documentation for complete details.

### 2.3.4 CONFIG.SYS Modification

For most computer configurations, you should assign at least 20 buffers and files in CONFIG.SYS. Use a text editor to modify or add the following lines:

```
FILES = 20
BUFFERS = 20
```

#### NOTE

After modifying CONFIG.SYS, reboot the computer (press <Ctrl>-<Alt>-<Del>) to place the changes into effect.

## 2.3.5 Plotter and Printer Considerations

### Printer Hard Copy Resolution

Selecting a plotting option on the graphics menu generates a half-page plot with low resolution. To control the size and resolution of the plot from the graphics menu, type in one of the following letters:

"m" half page, low resolution  
 "M" half page, high resolution  
 "l" full page, low resolution  
 "L" full page, high resolution

Selecting one of these options automatically generates the corresponding plot.

### Plotter Support

Model 5958 supports Hewlett-Packard, Watanabe, Houston, and Epson pen plotters that use the HP-GL graphics language. For HP plotters not listed in the configuration menu, first try one of the listed plotters. For example, select 7475A for 7470A.

### Serial Printer and Plotter Support

Model 5958 will drive printers or plotters connected to either the serial or parallel port of your computer. If you are using the serial port, you must initialize the port by selecting the proper parameters for your particular serial connection during installation or reconfiguration. For Hewlett-Packard serial plotters, select eight data bits and one stop bit serial parameters.

The graphics routines use polling to send characters to the serial port. Polling means that a character is sent, and a check is made to see if the device is busy. If so, the routine waits until the device is ready to accept another character. However, if the serial port device sends back any character other than busy, the transmission sequence will be interrupted. For that reason, be sure to set your printer or plotter to its least intelligent mode (turn off handshaking and status reports). Also, be sure to use the proper serial cable, as the software requires that all serial signal lines be present.

### Laser Printer Support

Model 5958 supports a Hewlett-Packard LaserJet+ or compatible printer with full-page 300dpi resolution. However, the printer must be equipped with at least 1.5MB of memory to support this resolution. In addition, some computer configurations may not have enough memory to support the required large bit map. In those cases, an "m" (300dpi, 1/2 page) or "l" (150dpi, full page) plot can be performed.

### GPIB (IEEE-488 Bus Plotter Support)

A GPIB HP-GL plotter can be used with the Model 5958 by selecting the "output to Driver 488 plotter" option on the configuration menu. The plotter must be set for the addressable mode using a primary address of 5.

Note that a GPIB printer cannot be used.

### 2.3.6 Memory and Hard Disk Considerations

Your computer should have at least 400KB free base memory before running the software. Also, you should have at least 5MB of free hard disk space prior to installation.

## 2.4 TEST CONNECTIONS

### 2.4.1 C-V Analyzer Connections

Figure 2-2 shows typical connections between the Model 590 C-V Analyzer and a probe station. To minimize noise,

it is recommended that the entire probe station be mounted in a suitable metal enclosure which is electrically connected to C-V Analyzer OUTPUT and INPUT LO. (Mounting chassis-mount BNC connectors on the enclosure chassis will electrically connect the enclosure to LO.)

#### WARNING

**Connect the shielded enclosure to safety earth ground using #18AWG or larger wire before use.**

#### NOTE

Connections for the hot chuck, which is required for BTS measurements, are not shown in Figure 2-2. Refer to the instruction manual for the hot chuck equipment for operating details pertaining to that equipment. Note, however, that some hot chucks connect chassis ground to the chuck. In that case, setup the Model 590 for floating operation (set rear panel ANALOG COMMON GROUNDING switch to the ungrounded position.)

When making C-V analyzer connections, keep the following points in mind:

- Use only 50Ω coaxial cables of good quality.
- Keep cable lengths as short as possible.
- Use the minimum number of connectors possible.
- Perform cable correction before making measurements (paragraph 2.5).
- Connect INPUT to gate, OUTPUT to substrate to minimize noise.

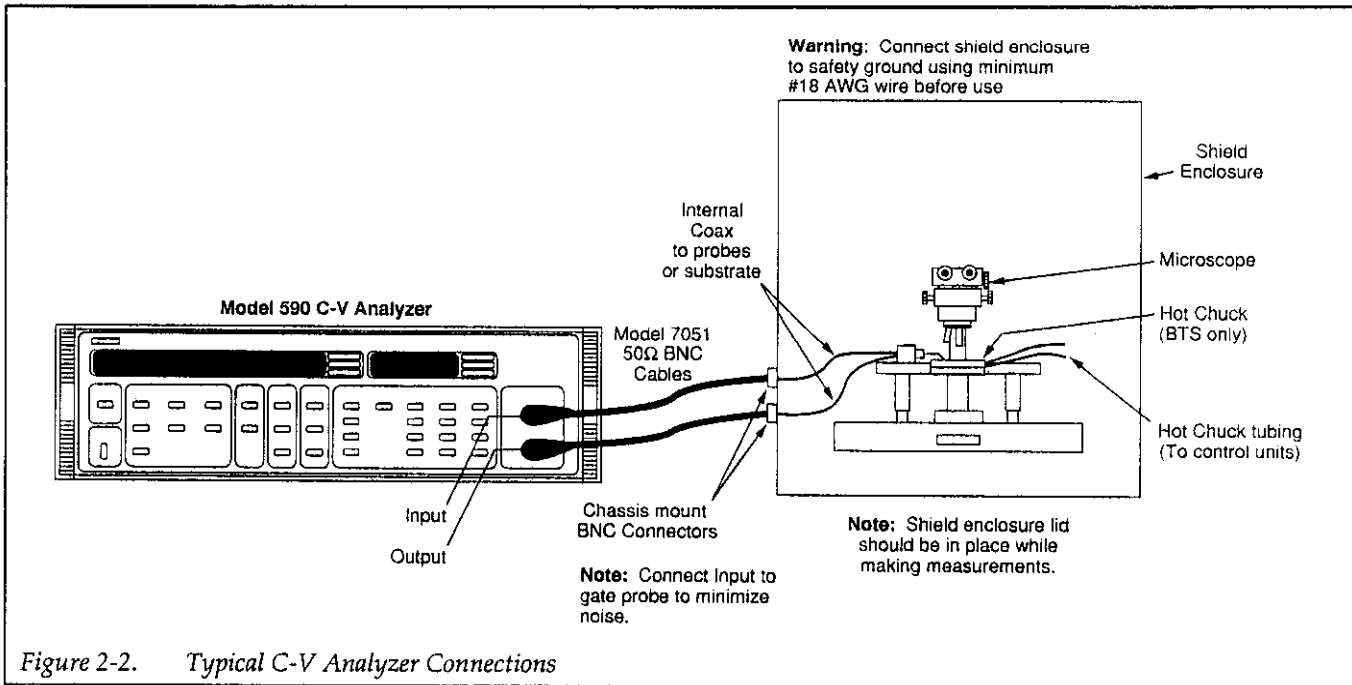


Figure 2-2. Typical C-V Analyzer Connections

### 2.4.2 Optional Voltage Source Connections

An optional Model 230-1 Voltage Source may be used with the Model 5958 system to extend the voltage range to  $\pm 100V$ . Figure 2-3 shows connections between the optional Model 230-1 Voltage Source and the C-V Analyzer. In addition to the source connecting cable, a BNC shorting cap (Model 4851) must be connected where indicated, and the external trigger cable must also be in place.

**WARNING**

**Hazardous voltage may be present on terminals when the Model 230-1 Voltage Source is connected to the system.**

### 2.4.3 Typical Switching Card Connections

A matrix card or scanner card and a switching mainframe can be added to a Model 5958 test system to perform automatic test sequencing. Figure 2-4 shows typical connections between the Model 590 and a Model 7062 RF switch card, which can be used to switch up to five DUTs. Figure 2-5 shows typical connections using a Model 7173-50 Two-Pole High Frequency Matrix Card installed in a Model 707 Switching Mainframe. See paragraph 4.5.1 for more details on switch connections.

**NOTE**

In order to use a switching mainframe, you must first configure an appropriate switch control file or use one of the supplied switch control files. Section 6 discusses switching control in detail. Appendix J covers default switch control files supplied with the Model 5958.

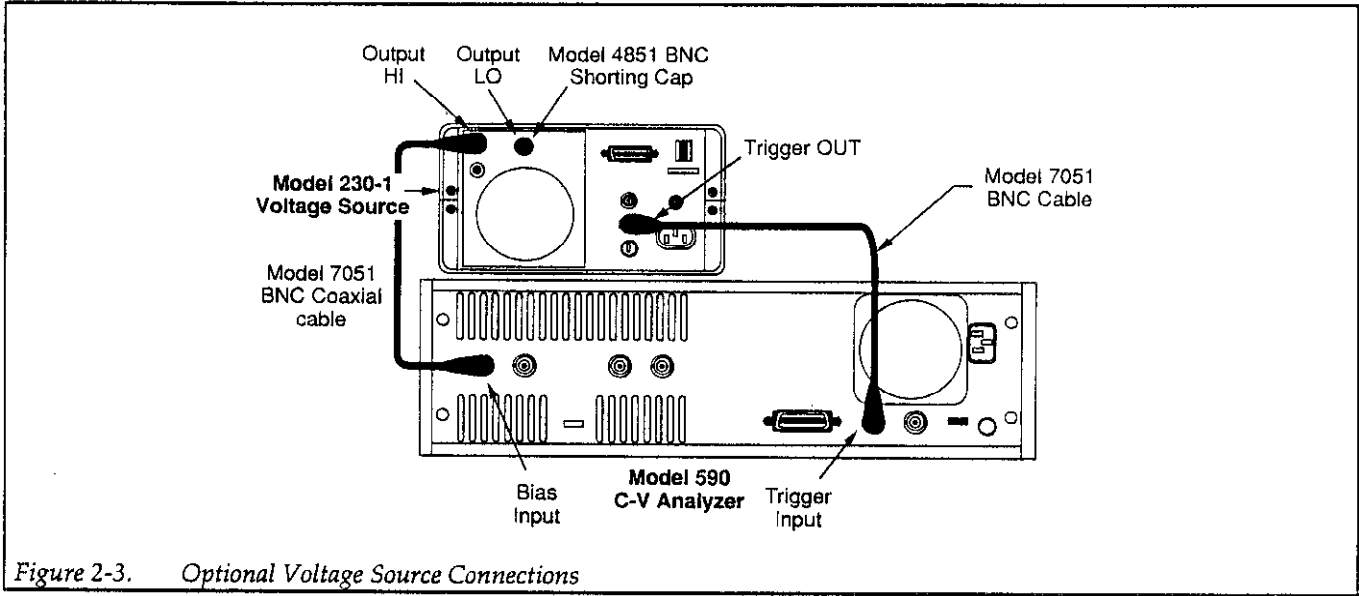


Figure 2-3. Optional Voltage Source Connections

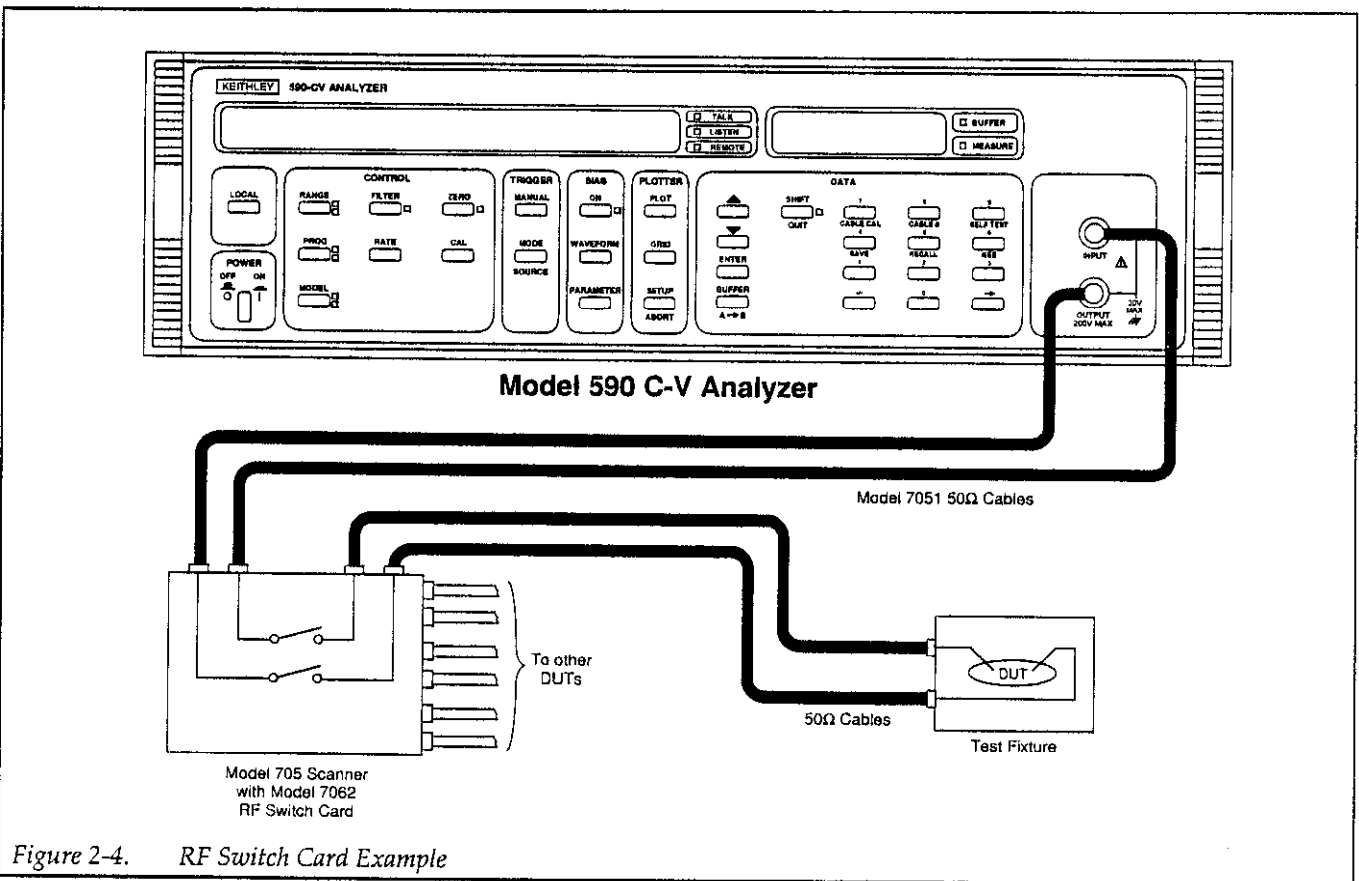


Figure 2-4. RF Switch Card Example

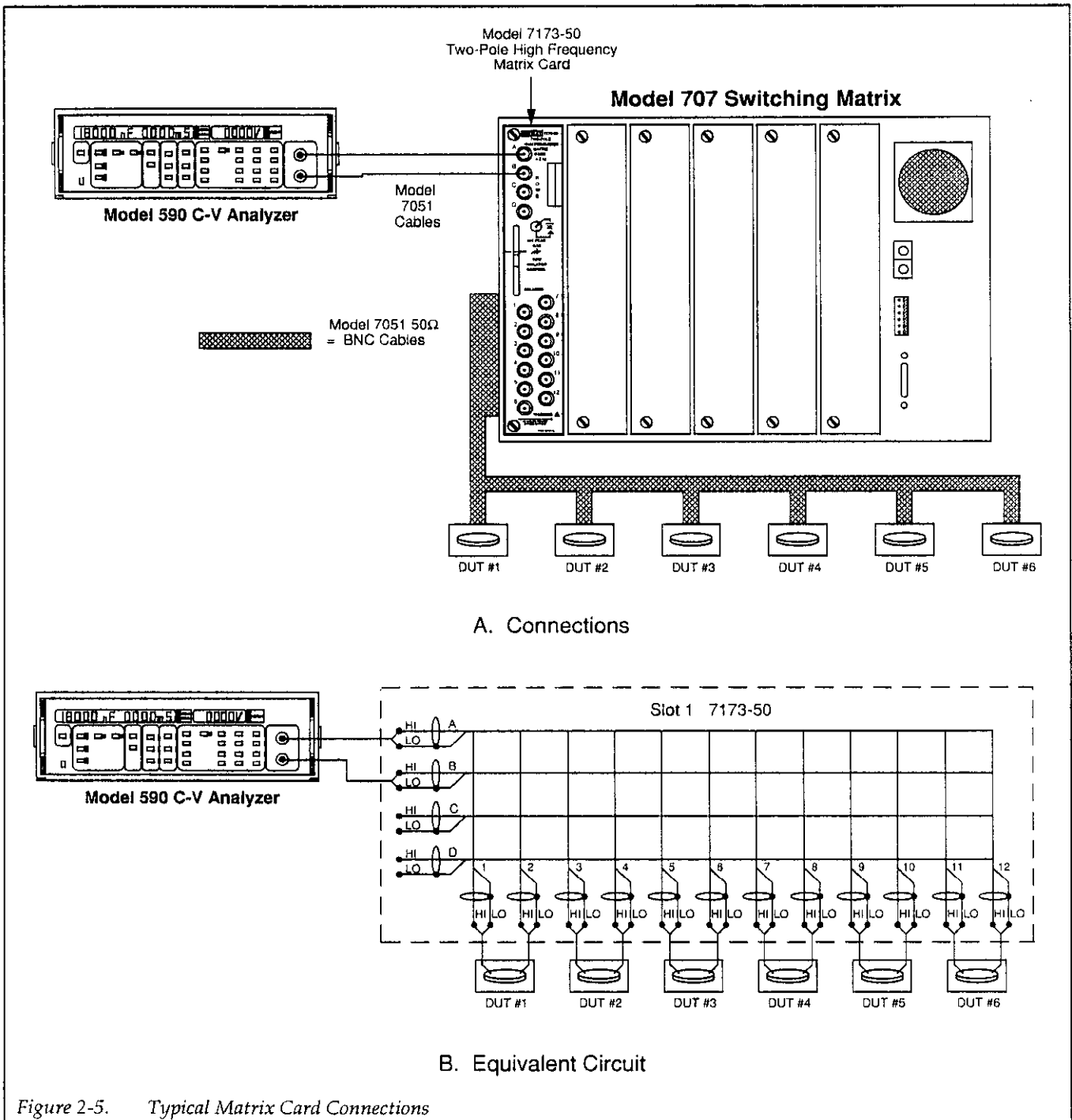


Figure 2-5. Typical Matrix Card Connections

### 2.4.4 Light Connections

A user-supplied light can be connected to a system equipped with an optional Model 230-1 Voltage Source to help attain device equilibrium in inversion more rapidly. This light is controlled through terminals on the Model 230-1 Digital I/O port. The following paragraphs discuss terminal assignments and typical light connections.

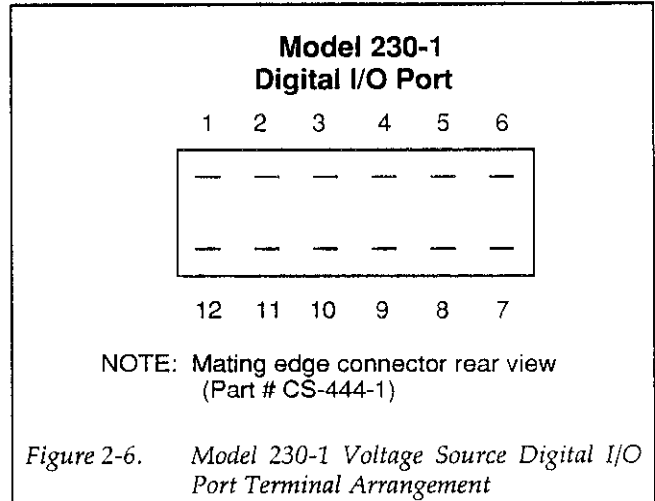
#### Digital I/O Port Terminals

Table 2-4 summarizes Model 230-1 Digital I/O Port Assignments, and Figure 2-6 shows the terminal arrangement for the mating edge connector (Keithley part number CS-444-1). Note that pin 10 is used for controlling an external light. This output is LS-TTL compatible and can sink a maximum of 8mA. Logic convention is such that the light is on when the output is LO, and the light is off when the output is HI.

**Table 2-4. Model 230-1 Digital I/O Port Terminal Assignments**

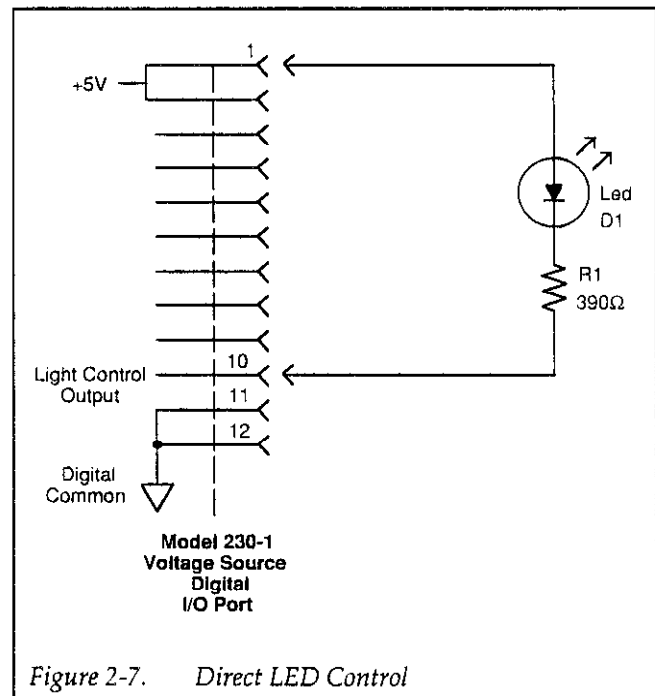
Terminal	Description
1	+5V
2	+5V
3	Input (Bit 3)
4	Input (Bit 2)
5	Input (Bit 1)
6	Input (Bit 0)
7	Output (Bit 0)
8	Output (Bit 1)
9	Output (Bit 2)
10	Output (Bit 3), Light Control Bit*
11	Digital Common
12	Digital Common

\* Pin 10 controls light: HI = OFF; LO = ON



#### LED Connections

The digital output has sufficient drive capability to directly drive LEDs that draw up to 8mA using the connecting method shown in Figure 2-7. The anode of the LED should be connected to +5V, and the cathode of the LED should be connected through a 390Ω current-limiting resistor to the light control bit (pin 10).





### Relay Light Control

For large LEDs, or for small incandescent lamps, an external relay control circuit can be used to switch the larger current. Figure 2-8 shows a typical circuit, which requires a normally closed relay contact. Note that an external power supply is necessary to supply the external circuitry.

The value of the base resistor will depend on the current gain of the transistor, the power supply voltage, and the

relay coil resistance. For example, with a supply voltage of 5V, a coil resistance of 500Ω, and a transistor current gain of 100, a base resistor value of 10kΩ should be low enough to drive the transistor well into saturation.

Note that the diode across the relay coil should be included to protect the transistor from switching transients.

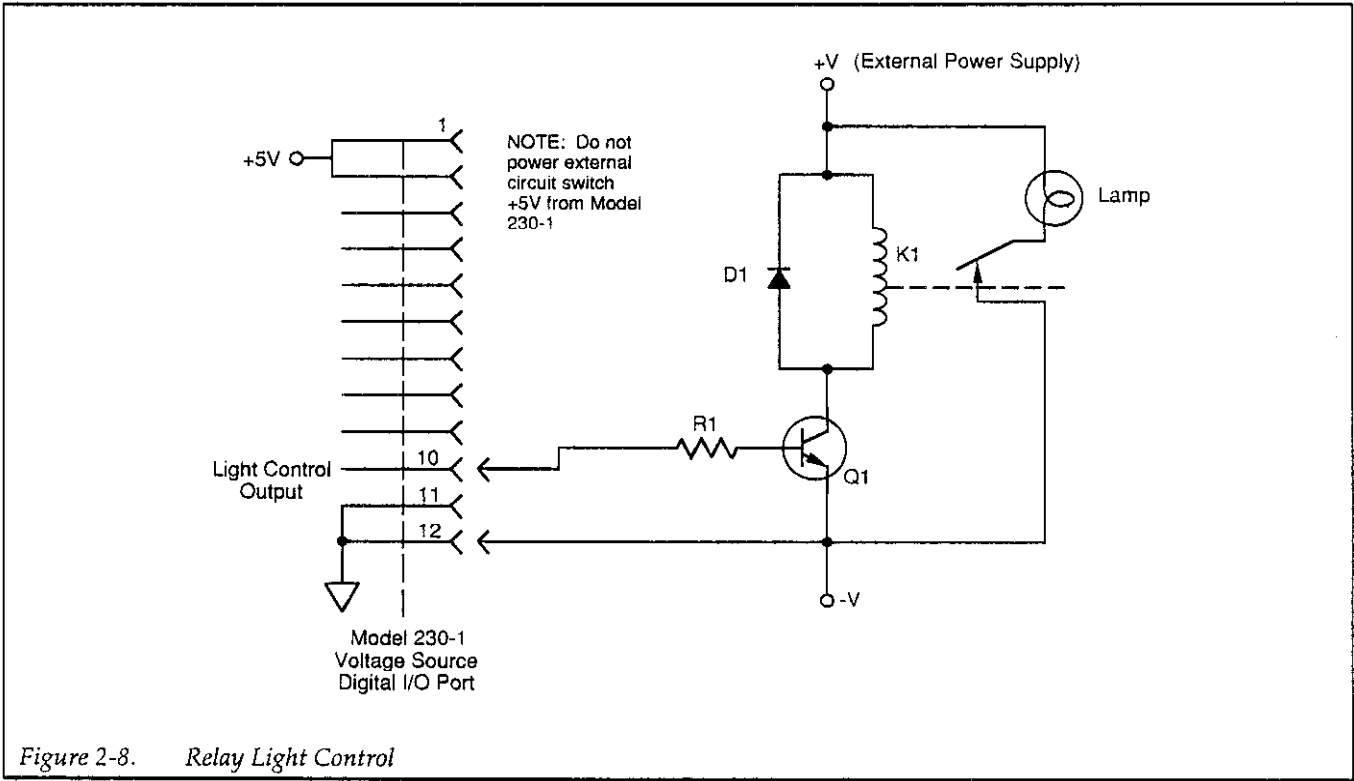


Figure 2-8. Relay Light Control

## 2.5 CABLE CORRECTION

Cable correction is necessary to optimize accuracy of high-frequency C-V measurements by compensating for cabling effects. Cable correction is especially important for accurate 1MHz measurements, but it can also be beneficial when making 100kHz measurements.

The process involves using the CABLECAL.EXE utility and connecting calibration capacitors with precisely known values in place of the test fixture or probe station. Once correction is complete, correction constants are written to a user-defined file and recalled when tests are performed.

### 2.5.1 When to Perform Cable Correction

Cable correction must be performed the first time you use your system. Thereafter, you should cable correct your system if the ambient temperature changes by more than  $\pm 5^{\circ}\text{C}$  from the previous correction temperature. You can cable correct your system daily, if desired, but doing so is not absolutely essential.

### 2.5.2 Recommended Correction Sources

Table 2-5 summarizes the recommended calibration sources, which are included in one of several optional calibration capacitor sets (see paragraph 1.9.3 for a description of recommended sources). The values shown are nominal; you should use the 100kHz and 1MHz values marked on the sources when performing correction.

### 2.5.3 Calibration Source Connections

In order to correct your system, it will be necessary for you to disconnect the Model 590 from the probe station or test fixture and connect the calibration capacitor in its place. Figure 2-9 shows typical connections. Use two female-to-female BNC barrels to connect each source to the cable ends.

When using the sources, be sure not to handle them excessively, as the resulting temperature rise will change the source values, degrading the accuracy of the correction process.

Table 2-5. Cable Correction Sources

Model 590 Range	Nominal Value*	100kHz Value**	1MHz Value**
2pF***	0.5pF 1.5pF	_____	_____
20pF	4.7pF 18pF	_____	_____
200pF	47pF 180pF	_____	_____
2nF	470pF 1.8nF	_____	_____

\* Nominal values included with calibration capacitor set. See paragraph 1.9.3 for a description of various calibration capacitors.

\*\* Enter values marked on sources where indicated. Use actual source values when performing cable correction using CABLECAL.EXE.

\*\*\* 100kHz test frequency only

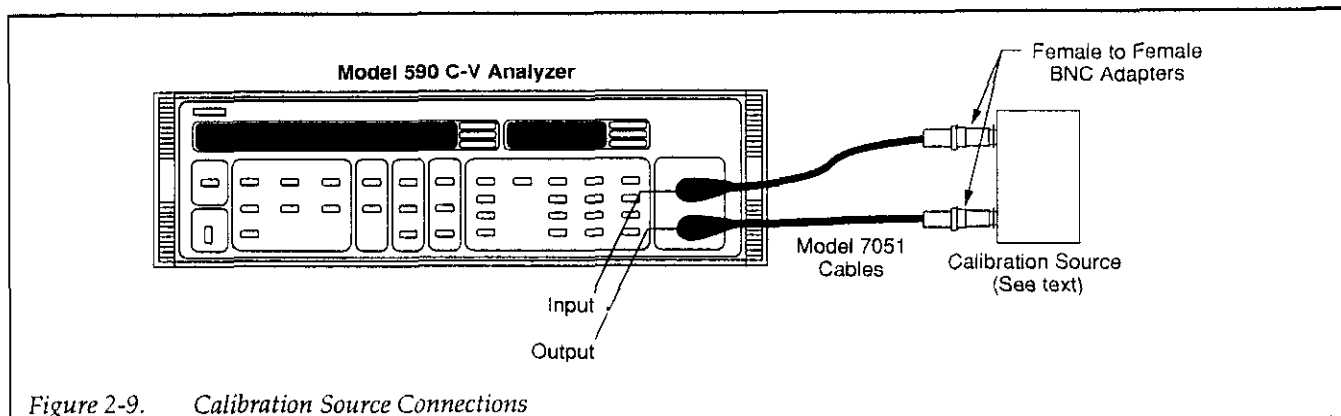


Figure 2-9. Calibration Source Connections

## 2.5.4 Correction Procedure

### NOTE

The procedure outlined below uses the CABLECAL.EXE utility, which is discussed in detail in Appendix E.

1. While in the C:\KTHLY\_CV\MODEL58 directory, type in the following to run the cable calibration utility:

```
CABLECAL <Enter>
```

2. To load an existing calibration constants file, press <Alt>-F, then select Load on the menu. Select an existing file, or type in the name of the file.
3. Press <Alt>-E, then select Cable Cal 590 and the desired range.
4. If you are cable correcting your system for the first time, enter the nominal, 100kHz, and 1MHz values where indicated (use the <Tab> key to move around selections). Capacitor #1 is the smaller of two values, and Capacitor #2 is the large capacitor value for a given range. Select OK after entering source values to begin the calibration process.
5. Choose the CALIBRATE selection to perform complete cable calibration.
6. Follow the prompts on the screen to complete the calibration process. During calibration, you will be prompted to connect calibration capacitors, or to leave the terminals open in some cases. If any errors occur, you will be notified by suitable messages on the screen.
7. Repeat steps 3 through 6 for all Model 590 ranges to be cable corrected.
8. After calibration is complete, you must save the new calibration constants. To do so, Press <Alt>-F, then

select Save or Save As as required. If you use Save As, be sure to use a filename with a .CAL extension. Use the same filename when specifying the cable correction filename while setting up your tests (refer to Sections 3 and 6).

### NOTE

Be sure to save cable calibration files in the C:\KTHLY\_CV\MODEL58\CAL directory.

## 2.5.5 Optimizing Correction Accuracy to Probe Tips

To correct as close as possible to the probe tips, construct two 50Ω coaxial cables equal in length to the probe station cables connected between the BNC connectors and the probe tips. Connect those cables in place of the probe station, and perform the cable correction procedure listed in paragraph 2.5.4.

## 2.5.6 Cable Correcting Switching Pathways

If you intend to use switching for multiple or sequential tests, you should cable correct the entire pathway through the switch and as close to the probe station or test fixture as possible. If multiple pathways are to be used, correction should be performed for each pathway individually, and each set of correction constants should be saved under its own filename. In some cases, a single calibration will suffice. Contact the Keithley Applications Department for details. Remember to close all channels or crosspoints in a given pathway when performing correction. Also, be sure to enter each cable correction filename in the switch control file (see Section 6).

## 2.6 RUNNING THE SOFTWARE

The following paragraphs discuss the basic procedures for running the Model 5958.

### 2.6.1 Starting the Program

To execute the program from the main menu, simply type in the program name (KI5958CV) while in the C:\KTHLY\_CV\MODEL58 subdirectory. For example, to load and run KI5958CV from the DOS prompt, simply type:

```
KI5958CV <Enter>
```

#### NOTE

The program to be executed must be located in the current default directory to run. Previous parameter setup and data files will be automatically loaded at run time.

### 2.6.2 Default Paths

Normally, the Model 5958 software uses the default paths specified during installation for parameter and data files. If you specify a new path when loading or saving files, the new path will become the default path for the current session.

### 2.6.3 Run Time Considerations

In order to use Model 5958 properly, it may be necessary to remove software drivers (such as GPIB print or mouse drivers) from your computer configuration to free up enough memory or to avoid conflicts. Use EDLIN or other text editor to remove the driver installation statements from CONFIG.SYS or AUTOEXEC.BAT as required. Reboot your computer after making modifications before running the Model 5958 software.

Also, be careful not to touch Model 590 front panel buttons while a program is running. Doing so may change instrument settings and lead to erroneous results.

### 2.6.4 Selecting Menu Items

#### Menu Title Bar

Major menu selections will appear in the menu title bar at the top of the screen. You can select one of these menu items using one of two methods:

- Hold down the <Alt> key, and press the highlighted letter, or use the left or right arrow keys to highlight the desired selection, then press <Enter>.
- If you are using a mouse, simply move the mouse to place the cursor on the desired selection, then click the appropriate mouse button. (Usually, the left mouse button selects an item, while the right mouse button performs the escape function.)

#### Using Keys to Move Around Menus

Use the following keys to move around a menu and make selections:

- Up/down arrow keys: Use these keys to move cursor vertically. Pressing up arrow or down arrow also enters a new numeric value if that value was changed.
- Left/right arrow keys: Use these keys to tab the cursor to another selection on a line that has multiple selections and to move the cursor within a numeric or file name field while entering parameters.
- <Tab>: Use the <Tab> key to tab to the right for multiple selections on a line. Press <Shift> <Tab> to tab to the left.
- <Enter> key: Press <Enter> to complete numeric parameter or file name entry.
- <Space> key: Press <Space> to toggle menu button selections on or off.
- <Esc>: Press <Esc> to close a window or pull-down menu.

#### Using a Mouse to Move Around Menus

Move the mouse to place the cursor on the desired item, then click the appropriate mouse button.

The Model 5958 may be used with a Microsoft mouse (or compatible) as long as memory or other conflicts do not occur.

## 2.6.5 Main Menu Description

### Setup

The Setup selections allow you to program parameters for the various tests. Setup selections include:

- C-V
- C-t
- BTS Cycle
- BTS Sequence
- Zerst Sequence

For complete details on setting up tests, refer to Section 3.

### Run

The Run selection allows you to choose the type of test to run. Note that you must use the corresponding Setup parameter menu to select measurement parameters before running each test.

Run menu selections include:

- C-V
- C-t
- BTS Cycle
- BTS Sequence
- Zerst Sequence

Refer to Section 4 for detailed information on using these selections to make measurements.

### Analyze

The Analyze selection allows you to perform analysis on data taken during measurements. Operations available under Analyze include file I/O, displaying data, printing data, as well as graphing data. The three general types of data analysis are:

- C-V
- C-t
- BTS

Analysis is covered in detail in Section 5.

### Exit

- Exit to DOS

Selecting this main menu item will return you to DOS.

## 2.6.6 File Types

The various file types for parameters, data, and control information are summarized in Table 2-6. Appendix D gives more detailed information on these files and their formats.

Table 2-6. File Types

File	Extension	Default Path*
BTS test sequence file	.BTS	\SEQ
Cable calibration file	.CAL	\CAL
C-V measurement parameters file	.CVP	\PAR
C-t measurement parameters file	.CTP	\PAR
C-t data destination file	.CTD	\DAT
C-V data destination file	.DAT	\DAT
Hot chuck control file	.HCC	\CTRL
Stress cycle parameters file	.SCP	\PAR
Switch control file	.SWC	\CTRL
Temporary file	.TMP	\TMP
Zerst test sequence file	.ZTS	\SEQ

\* All path names are preceded by C:\KTHLY\_CV\MODEL58 as the default path. You can select different path names during installation, if desired. Refer to paragraph 2.3 for installation details.

## 2.6.7 Running with Floppy-Based Test/ Data Files

Normally, test and data files are run from subdirectories summarized in Table 2-6. You can, however, load this information from suitable files stored on floppy disks simply by specifying the complete pathname at filename prompt for the load operation.

For example, assume that you wish to load a data file called "MYFILE.DAT" from drive A:. You would simply type in the following at the load file prompt:

```
A:\MYFILE <Enter>
```

## 2.6.8 Printing Screens

You can print out any screen that contains only text information simply by pressing the Print Screen key.

## 2.6.9 Default Material Constants

As shipped, the Model 5958 software is designed to work with devices with silicon substrate, silicon dioxide insulator, and aluminum gate material. Constants that define these and other parameters are stored in the MATERIAL.CON file, which can be modified for use with other types of materials. See Appendix A for details.

## 2.7 TEST SETUP, MEASUREMENT AND ANALYSIS OVERVIEW

The following paragraphs outline the basic procedures for performing tests and viewing the results. For complete details on test setup, measurement, and analysis, refer to Sections 3, 4, and 5.

Before attempting to make any measurements using the Model 5958, you should complete the following:

- Install the software, as described in paragraph 2.3.
- Connect the Model 590 to the computer and probe station (paragraph 2.4).
- For BTS measurements, install the hot chuck and connect it to the computer IEEE-488 interface (refer to hot chuck manual).
- Perform cable correction, as discussed in paragraph 2.5.

- Run the KI5958CV program, as covered in paragraph 2.6.

## 2.7.1 C-V Measurement Overview

### Step 1: Setup C-V Measurement Parameters

1. From the main menu, press <Alt>-S, and select C-V setup to display the C-V parameters menu.
2. Select the various measurement parameters such as range, frequency, model, and rate, as required. Use the up/down and left/right arrow keys to move around the parameter screen.
3. Choose the waveform type and various time/delay parameters. Remember to use a step time long enough so that the device remains in equilibrium throughout the sweep. Also, you should be certain to program a sufficiently long start delay time to allow the device to reach equilibrium before the sweep begins when sweeping from inversion to accumulation.

Briefly, time parameters are defined as follows:

**Start Delay:** An additional delay period at the beginning of the first bias step.

**Step Time:** The time period for each bias step for stair waveform.

**Pulse On:** The on period of each pulse for pulse stair waveform.

**Stop Delay:** An additional delay period at the end of the sweep.

**Pulse Off:** The time period between pulses for the pulse stair waveform.

4. Enter the bias voltage parameters necessary to bias the device into accumulation and inversion during the sweep. Briefly, bias voltage parameters are defined as follows:

**First Bias V:** The first DC bias voltage step value and the bias applied before the sweep.

**Bias Step V:** The incremental change in the bias voltage waveform.

**Last Bias V:** The last DC bias voltage step value.

**Default Bias V:** The DC bias voltage applied to the device after a sweep.

5. If you have a light connected to your system, program the desired light on time.
6. Enter the cable calibration filename where indicated (see paragraph 2.5 for cable calibration details).
7. After you have entered all your parameters, select Save, then enter the desired filename at the prompt.
8. Select OK to return to the main menu.

### Step 2: Perform a C-V Measurement

1. From the main menu, press <Alt>-R, then select C-V.
2. Make sure that the probes are up and that zero is turned off.
3. Allow the reading to settle, then select Enable Zero to null any offsets in the system.
4. Place the probes down on the test dots.
5. If you are using a light to speed up equilibrium, select Enable Light. Turn the light off after equilibrium is reached before starting the sweep.
6. Select Start Sweep to begin the sweep. During the sweep current measurement parameters will be displayed, and you can press any key to halt the sweep.
7. After the sweep is completed, return to the main menu.

### Step 3: Analyze C-V Data

1. From the main menu, press <Alt>-A, then select C-V.
2. Return to the C-V Analysis menu, then press <Alt>-D to display data arrays or constants. You can also use <Alt>-P to print array values or constants on your printer.
3. To graph C-V data, press <Alt>-G while in the C-V ANALYSIS menu. Typical C-V graphs include C vs. V and G vs. V.

## 2.7.2 C-t Measurement Overview

### Step 1: Setup C-t Measurement Parameters

1. From the main menu, press <Alt>-S, and select C-t setup to display the C-t parameters menu.
2. Select the various measurement parameters such as range, frequency, model, and rate, as required. Use the up/down and left/right arrow keys to move around the parameter screen.
3. Enter the number of samples to take for the C-t measurement.

4. Choose the various time/delay parameters. Briefly, time parameters are defined as follows:

**Start Delay:** An additional delay before the first sample in the C-t measurement is taken before the sweep begins and the voltage changes.

**Sample Time:** The time period between individual samples in the C-t measurement.

**Stop Delay:** An additional delay after the last sample before the end of the C-t measurement cycle.

5. Enter the bias voltage parameters necessary to bias the device as required both before and during the sweep. Briefly, bias voltage parameters are defined as follows:

**Default Bias V:** The DC bias voltage applied to the device both before and after the C-t measurement.

**Test Bias V:** The DC bias voltage applied to the device during the C-t measurement.

6. Enter the cable calibration filename where indicated (see paragraph 2.5 for cable calibration details).
7. After you have entered all your parameters, select Save, then enter the desired filename at the prompt.
8. Select OK to return to the main menu.

### Step 2: Perform a C-t Measurement

1. From the main menu, press <Alt>-R, then select C-t.
2. Make sure that the probes are up and that zero is turned off.
3. Allow the reading to settle, then select Enable Zero to null any offsets in the system.
4. Place the probes down on the test dots.
5. If you are using a light to speed up equilibrium, select Enable Light. Turn the light off after equilibrium is reached before starting the sweep.
6. Select Start Sweep to begin the sweep. During the sweep current measurement parameters will be displayed, and you can press any key to halt the sweep.
7. After the sweep is completed, return to the main menu.

### Step 3: Analyze C-t Data

1. From the main menu, press <Alt>-A, then select C-t.
2. Return to the C-t Analysis menu, then press <Alt>-D to display data arrays or constants. You can also use <Alt>-P to print array values or constants on your printer.

3. To graph C-t data, press <Alt-G> while in the C-t ANALYSIS menu. Typical C-t graphs include C vs. t and Zerst analysis.

### 2.7.3 BTS Measurement Overview

#### Step 1: Setup C-V Measurement Parameters

1. From the main menu, press <Alt>-S, and select C-V setup to display the C-V parameters menu.
2. Select the various measurement parameters such as range, frequency, model, and rate, as required. Use the up/down and left/right arrow keys to move around the parameter screen.
3. Choose the waveform type and various time/delay parameters. Remember to use a step time long enough so that the device remains in equilibrium throughout the sweep. Also, you should be certain to program a sufficiently long start delay time to allow the device to reach equilibrium before the sweep begins when sweeping from inversion to accumulation.

Briefly, time parameters are defined as follows:

**Start Delay:** An additional delay period at the beginning of the first bias step.

**Step Time:** The time period for each bias step for stair waveform.

**Pulse On:** The on period of each pulse for pulse stair waveform.

**Stop Delay:** An additional delay period at the end of the sweep.

**Pulse Off:** The time period between pulses for the pulse stair waveform.

4. Enter the bias voltage parameters necessary to bias the device into accumulation and inversion during the sweep. Briefly, bias voltage parameters are defined as follows:

**First Bias V:** The first DC bias voltage step value.

**Bias Step V:** The incremental change in the bias voltage waveform.

**Last Bias V:** The last DC bias voltage step value.

**Default Bias V:** The DC bias voltage applied to the device both before and after a sweep.

5. If you have a light connected to your system, program the desired light on time.

6. Enter the cable calibration filename where indicated (see paragraph 2.5 for cable calibration details).
7. After you have entered all your parameters, select Save, then enter the desired filename at the prompt.
8. Select OK to accept parameters and return to the main menu.

#### Step 2: Program BTS Stress Cycle Parameters

1. From the main menu, Press <Alt>-S, then select BTS Cycle.
2. Select the 590 Internal bias source if you are using only the Model 590, or select the 230-1 External bias source if you are using an optional Model 230-1 Voltage Source.
3. Program the + Stress V, - Stress V, and Stress OFF V parameters to the desired values. Briefly, these parameters are defined as follows:

**+ Stress V:** Voltage applied to device during the positive stress cycle.

**- Stress V:** Voltage applied to device during negative stress cycle.

**Stress OFF V:** Voltage applied to device during stress off cycle.

4. Enter the desired stress temperature and stress time parameters where indicated. These parameters are defined as follows:

**Stress Temp:** The temperature of the device during the stress cycle.

**Stress OFF Temp:** The temperature of the device at times other than during the stress cycle.

**Temp. Tolerance:** At temperature tolerance of Hot Chuck.

**Stress Time:** The time duration of the stress cycle.

5. Select Save, then enter the filename to save the BTS cycle parameters.
6. Select OK to return to the main menu.

#### Step 3: Program BTS Test Sequence Parameters

1. From the main menu, press <Alt>-S, then select BTS Sequence.
2. Choose the test sequence type: sequential, parallel, or no stress. The sequential test type runs through the entire stress-measurement sequence for each device in a sequential manner, while the parallel test sequence stresses a number of devices in parallel and



then measures C-V parameters for each device individually. The no stress option is used for C-V only measurements without stress.

3. Select the stress cycle type: + then -, - then +, + only, or - only. + then - applies the positive then negative stress voltages - then + applies negative then positive voltages, while + only and - only apply only the positive or negative stress voltages respectively during the stress cycle.
4. Select the type of  $C_{MIN}$  checking: manual, auto, or none. (to select auto, you must have a light connected to the optional Model 230-1 voltage source.)
5. Enter any comments in the indicated field.
6. Program the number of devices based on your test requirements. In order to test more than one device automatically, you must have a switching mainframe or probe sequencer that can connect to multiple test dots automatically. See Section 6 for information on setting up a control file for this equipment.
7. Enter the C-V, stress cycle parameter, and data destination filenames where indicated. These are the files set up in steps 1 and 2 above. The switch control filename should also be specified if you are using a switching mainframe. The data destination filename defines the storage location for data taken during a BTS test.
8. Select Save, then save the BTS stress sequence parameters under a convenient filename.
9. Select OK to return to the main menu.

#### Step 4: Run the BTS Test

1. From the main menu, Press <Alt>-R.
2. To run only the stress cycle without making C-V measurements, select BTS Cycle. To run the entire stress-measurement sequence, select BTS Sequence.
3. With the probes up, select Enable Zero to null any system offsets.
4. Place the probes down on the test dots, then select Start Test. During the test, pertinent test parameters will be displayed on the screen, and you can halt the test by pressing any key.
5. When the test is complete, return to the main menu.

#### Step 5: Analyze BTS Data

1. From the main menu, press <Alt>-A, then select BTS.
2. Select Display, Print, or Graph to display your data as required. For example, press <Alt>-G to select graphing options, then select the appropriate option.

## 2.7.4 Zerbst Measurement Overview

### Step 1: Setup C-V Measurement Parameters

1. From the main menu, press <Alt>-S, and select C-V setup to display the C-V parameters menu.
2. Select the various measurement parameters such as range, frequency, model, and rate, as required. Use the up/down and left/right arrow keys to move around the parameter screen.
3. Choose the waveform type and various time/delay parameters. Remember to use a step time long enough so that the device remains in equilibrium throughout the sweep. Also, you should be certain to program a sufficiently long start delay time to allow the device to reach equilibrium before the sweep begins when sweeping from inversion to accumulation.

Briefly, time parameters are defined as follows:

**Start Delay:** An additional delay period at the beginning of the first bias step.

**Step Time:** The time period for each bias step for stair waveform.

**Pulse On:** The on period of each pulse for pulse stair waveform.

**Stop Delay:** An additional delay period at the end of the sweep.

**Pulse Off:** The time period between pulses for the pulse stair waveform.

4. Enter the bias voltage parameters necessary to bias the device into accumulation and inversion during the sweep. Briefly, bias voltage parameters are defined as follows:

**First Bias V:** The first DC bias voltage step value.

**Bias Step V:** The incremental change in the bias voltage waveform.

**Last Bias V:** The last DC bias voltage step value.

**Default Bias V:** The DC bias voltage applied to the device both before and after a sweep.

5. If you have a light connected to your system, program the desired light on time. (After the inversion voltage has been applied, and the light has been turned off, this time period is used to allow capacitance to settle out to  $C_{MIN}$ .)
6. Enter the cable calibration filename where indicated (see paragraph 2.5 for cable calibration details).
7. After you have entered all your parameters, select Save, then enter the desired filename at the prompt.

8. Select OK to accept parameters and return to the main menu.

### Step 2: Setup C-t Measurement Parameters

1. From the main menu, press <Alt>-S, and select C-t setup to display the C-t parameters menu.
2. Select the various measurement parameters such as range, frequency, model, and rate, as required. Use the up/down and left/right arrow keys to move around the parameter screen.
3. Enter the number of samples to take for the C-t measurement.
4. Choose the various time/delay parameters. Briefly, time parameter are defined as follows:

Start Delay: An additional delay before the test bias is applied.

Sample Time: The time period between individual samples in the C-t measurement.

Stop Delay: An additional delay after the last sample before the end of the C-t measurement cycle.

5. Enter the bias voltage parameters necessary to bias the device as required both before and during the sweep. Briefly, bias voltage parameters are defined as follows:

Default Bias V: The DC bias voltage applied to the device both before and after the C-t measurement.

Test Bias V: The DC bias voltage applied to the device during the C-t measurement.

6. Enter the cable calibration filename where indicated (see paragraph 2.5 for cable calibration details).
7. After you have entered all your parameters, select Save, then enter the desired filename at the prompt.
8. Select OK to return to the main menu.

### Step 3: Program Zerbst Test Sequence Parameters

1. From the main menu, press <Alt>-S, then select Zerbst Sequence.
2. Choose the test sequence type: multiple C-V, one C-V, or no C-V. The multiple C-V option can be used to test a number of dissimilar devices where a sepa-

rate C-V data set is required for each device. The one C-V option can be used to test a number of similar devices where only one C-V data set is required for all the devices. The no C-V option should be used in cases where only C-t measurements are required.

3. Choose the type of C<sub>MIN</sub> checking: manual, auto, or none. (A light is required to use auto.)
4. Enter any comments in the indicated field.
5. Program the number of devices based on your test requirements. In order to test more than one device automatically, you must have a switching mainframe or probe sequencer that can connect to multiple sets of test dots automatically. See Section 6 for information on setting up a control file for this equipment.
6. Enter the C-V, C-t, and data destination filenames where indicated. These are the files set up in steps 1 and 2 above. The switch control filename should also be specified if you are using a switching mainframe. The data destination filename defines the storage location for data taken during a Zerbst test.
7. Select Save, then save the Zerbst sequence parameters under a convenient filename.
8. Select OK to return to the main menu.

### Step 4: Run the Zerbst Test

1. From the main menu, Press <Alt>-R.
2. Select Zerbst Sequence.
3. With the probes up, select Enable Zero to null any system offsets.
4. Place the probes down on the test dots, then select Start Test. During the test, pertinent test parameters will be displayed on the screen, and you can halt the test by pressing any key.
5. When the test is complete, return to the main menu.

### Step 5: Analyze Zerbst Data

1. From the main menu, press <Alt>-A, then select C-t.
2. To save measurement data, press <Alt>-F, then select Save C-t File and Save C-V File. Type in the desired filename at the prompt.
3. Press <Alt>-G to select the graphing option, then select the Zerbst Plot option to graph Zerbst data.
4. Select option 7 on the graphics control menu, then follow the prompts on the screen to determine generation velocity and lifetime.

# SECTION 3

## Test Setup

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### 3.1 INTRODUCTION

This section describes setup procedures for various Model 5958 tests:

#### 3.2 C-V Measurement Parameters

#### 3.3 C-t Measurement Parameters

#### 3.4 Stress Cycle Parameters

#### 3.5 BTS Test Sequence

#### 3.6 Zerst Test Sequence

To access one of these setup menus, select Setup on the main menu, then select the desired setup on the displayed pull-down menu.

#### NOTE

Refer to the Model 590 Instruction Manual for complete details on measurement parameters.

### 3.2 C-V MEASUREMENT PARAMETERS

C-V measurement parameters define how C-V sweeps are performed. C-V sweeps are used for stand-alone C-V tests, BTS test sequences, and Zerst test sequences when so indicated. The paragraphs below outline the C-V measurement parameter menu and also describe the purpose of each parameter.

#### 3.2.1 C-V Measurement Parameter Menu

Figure 3-1 shows the overall format of the C-V measurement parameter menu. In addition to selecting and programming parameters (described below), you can perform the following menu operations:

**OK:** Accepts any parameter changes and exits the menu.

**Load:** Loads an existing C-V measurement parameter file.

**Save:** Saves the current parameters to a designated file.

**Help:** Provides helpful information on setting parameters.

**Cancel:** Cancels any parameter changes and exits the C-V parameter menu.

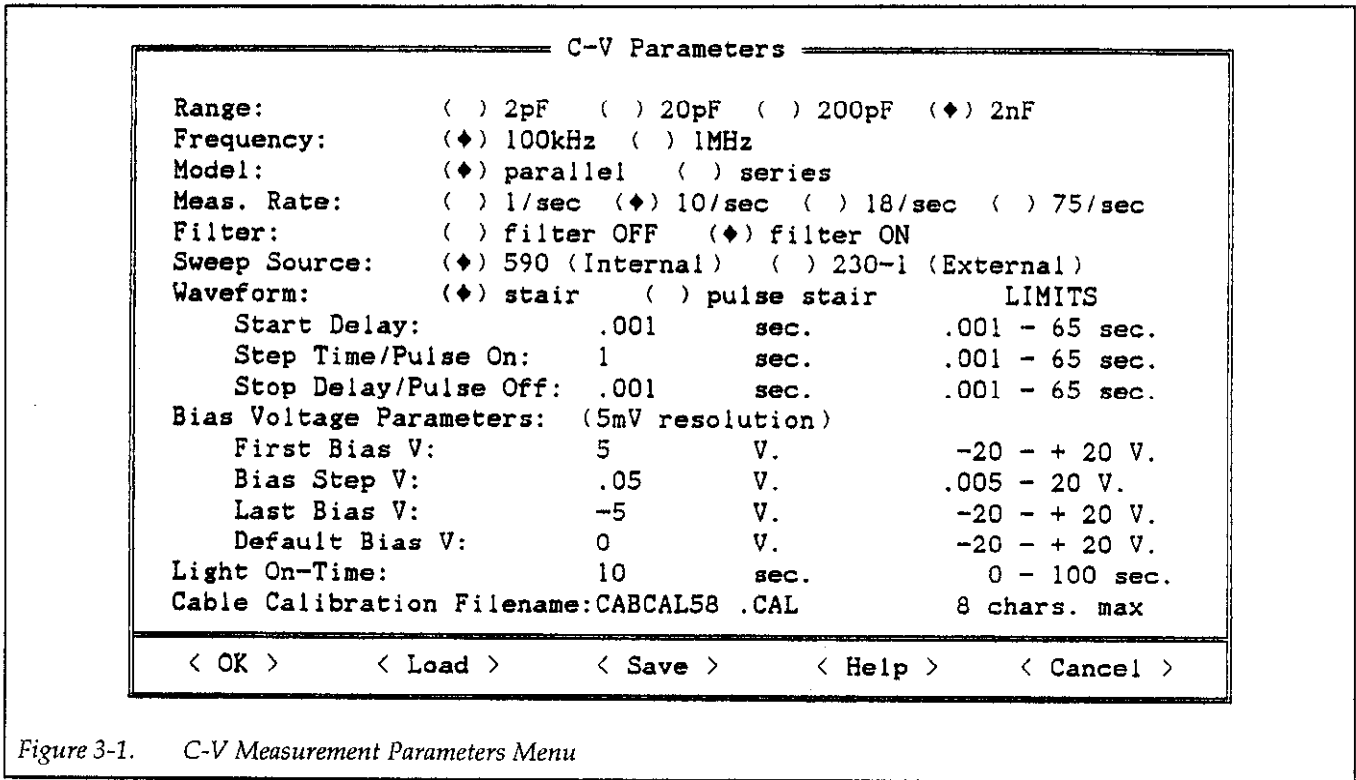


Figure 3-1. C-V Measurement Parameters Menu

### 3.2.2 C-V Measurement Parameters

**Range:** Selects 2pF (100kHz only), 20pF, 200pF, or 2nF measurement range. For best accuracy, choose the lowest range possible without overranging the Model 590.

**Frequency:** Selects 100kHz or 1MHz test frequency. Note that the Model 590 must be equipped with 100kHz and/or 1MHz modules in order to use the corresponding frequencies.

**Model:** Selects parallel or series measurement model. The Model 590 always measures the device using the parallel model, and series model capacitance and resistance are computed from the measured data. See paragraph 4.7 for details on parallel/series model.

**Meas. Rate:** Selects measurement rates of 1, 10, 18, or 75 readings per second. Note that the slower rates yield the best accuracy, resolution, and noise performance. Table 3-1 summarizes how the selected reading rate affects resolution and number of integrations averaged (the higher the number of readings averaged, the better the noise performance).

Table 3-1. Reading Rates

Measurement Rate	Reading Resolution	Integrations Averaged
1/sec	4-1/2 digits	4
10/sec	4-1/2 digits	2
18/sec	4-1/2 digits	1
75/sec	3-1/2 digits	1

**NOTE**

The maximum effective reading rate is about 7/sec when the optional Model 230-1 Voltage Source is used.

**Filter:** Allows you to turn the Model 590 filter on or off. Since using the filter can slow down the effective measurement rate, the filter should be left off unless reading noise is determined to be a problem. Inaccurate capacitance and conductance readings may result if the filter is used when measuring devices with rapidly changing bias waveforms.

**Sweep Source:** If you have no optional Model 230-1 Voltage Source connected to your system, select 590 (Internal) sweep source. To use the optional Model 230-1 Voltage Source, select 230-1 (External). In general, bias voltage values are limited to  $\pm 20V$  without the optional voltage source and  $\pm 100V$  with the optional voltage source.

### 3.2.3 Waveform Parameters

Figure 3-2 and Figure 3-3 show the basic waveform definitions for the waveform parameters described below.

**Waveform:** Selects stair or pulse stair waveform, as defined in Figure 3-2 and Figure 3-3.

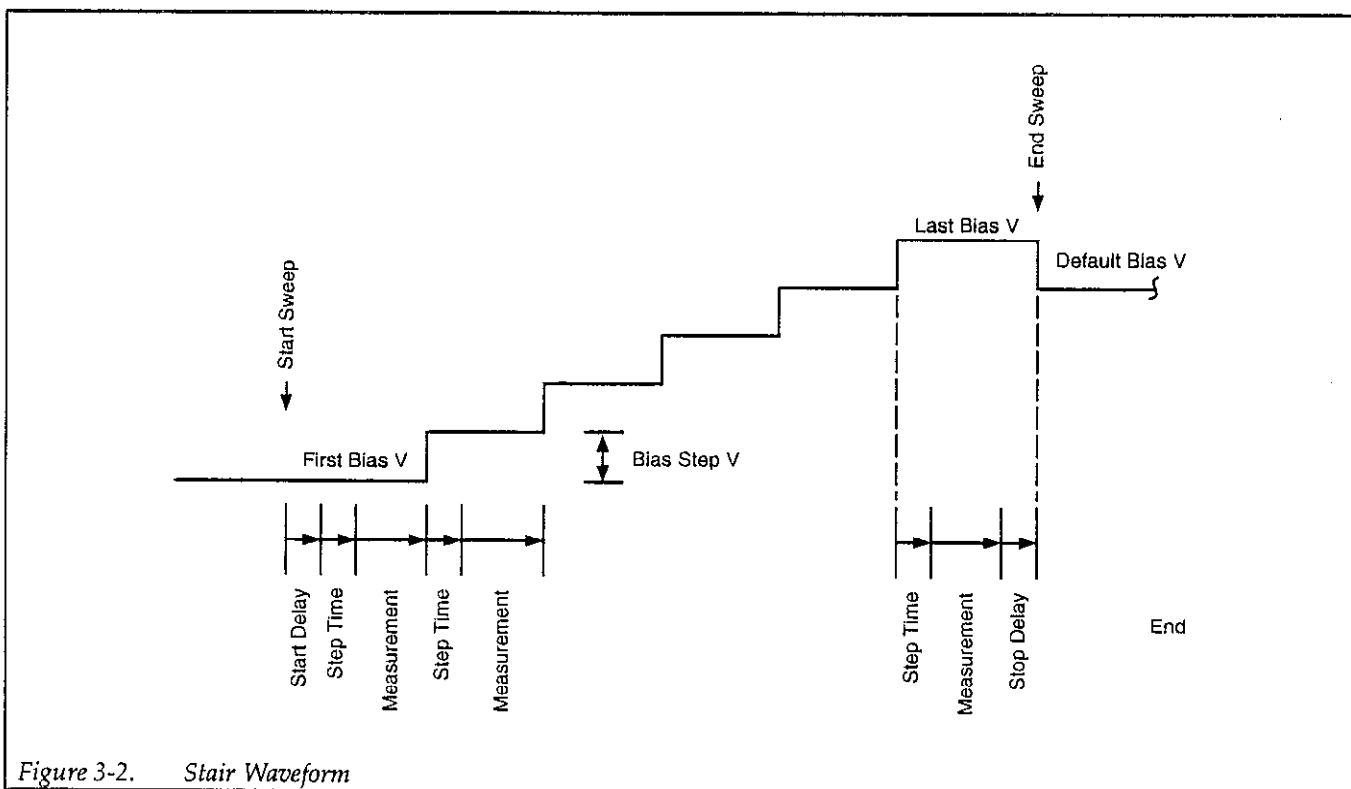
**NOTE**

All programmed time periods should be multiplied by a factor of 1.024 to obtain the actual time periods.

**Start Delay:** The time period on the first bias step from the start of the sweep until the first step time. The allowable range is from 0.001sec to 65sec.

**Step Time/Pulse On:** For the stair waveform, the step time is the time period after transition to a new bias step before the Model 590 begins a measurement. For the pulse stair waveform, the pulse on time is the length of the bias pulse. The allowable range is from 0.001sec to 65sec. NOTE: When using the optional Model 230-1, the actual minimum step time with 0.001sec programmed is 110msec.

**Stop Delay/Pulse Off:** For the stair waveform, the stop delay is the time period after the last measurement in the sweep before the Model 590 returns to the default bias voltage. For the pulse stair waveform, the pulse off time is the off time duration for each pulse. The range for this parameter is from 0.001sec to 65sec.



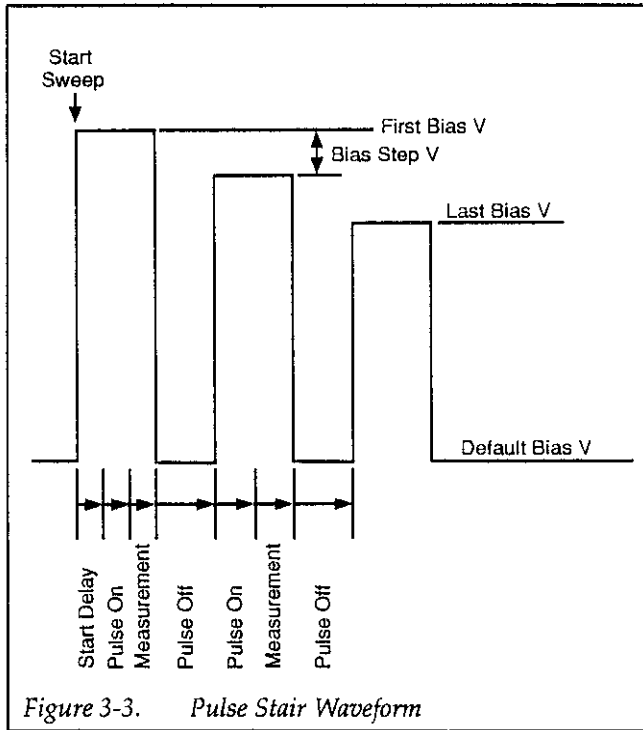


Figure 3-3. Pulse Stair Waveform

### 3.2.4 Bias Voltage Parameters

#### NOTE

All bias voltage parameters have a resolution of 5mV (internal bias source) or 10mV (external bias source). If an optional Model 230-1 Voltage Source is not being used, the maximum range for all voltage parameters is  $\pm 20V$ .

**First Bias V:** The initial voltage setting of the bias waveform. The range of this parameter is  $-20V$  to  $+20V$  without the optional Model 230-1 Voltage Source, or from  $-100V$  to  $+100V$  with the optional Model 230-1 Voltage Source.

**Bias Step V:** The incremental change in bias voltage of each step in the bias voltage waveform. The range for this parameter is from 5mV to 20V (10mV to 20V with the optional Model 230-1 Voltage Source).

**Last Bias V:** The final voltage setting of the bias waveform. The range of this parameter is  $-20V$  to  $+20V$  without the optional Model 230-1 Voltage Source, or from  $-100V$  to  $+100V$  with the optional Model 230-1 Voltage Source.

**Default Bias V:** The bias voltage setting after the sweep and between pulses for the pulse stair waveform. The range is from  $-20V$  to  $+20V$  without the optional Model 230-1 Voltage Source, or from  $-100V$  to  $+100V$  with the optional Model 230-1 Voltage Source.

### 3.2.5 Miscellaneous Parameters

**Light On-Time:** If you have a light connected to your system in order to attain equilibrium more rapidly, this parameter controls the length of time the light stays on when determining  $C_{MIN}$  automatically. The range for the light control parameter is from 0sec to 100sec. See paragraph 2.4.4 for information on connecting a light to your system.

**Cable Calibration Filename:** This parameter defines the name of the file that holds the cable correction parameters for basic C-V tests (see paragraph 2.5 for details on performing cable correction). The cable calibration constants stored in this file are used only for basic C-V measurements. Cable correction filenames for test sequences are defined in the switch control file (see Section 6).

### 3.2.6 C-V Parameter Programming Procedure

1. From the main menu, select Setup by pressing <Alt>-S.
2. Select C-V to display the C-V parameter menu.
3. If you are loading a set of C-V measurement parameters from an existing file, select Load, then select or enter the name of the C-V parameter file.
4. Program the Model 590 measurement parameters such as range, frequency, model, rate, and filter, and be sure to select internal or external voltage source as appropriate.
5. Select the waveform type as well as the desired start, step, and stop delay times. Keep in mind that programmed times must be multiplied by a factor of 1.024 to obtain actual times.
6. Select the first, step, last, and default bias voltage parameters as required.
7. If you are using a light with your system, program the desired light on time.
8. Enter the filename of the cable correction file.
9. To save the selected C-V parameters, select Save, then type in the desired filename.
10. Select OK to use the new parameters, or choose Cancel to cancel any changes made to the previously displayed parameters.

### 3.2.7 Saving/Loading C-V Measurement Parameters

#### Saving C-V Measurement Parameters

1. From the C-V measurement parameter menu, select Save.
2. Type in the desired filename at the prompt, or select an existing file.
3. C-V measurement parameters will be saved with the appropriate extension in the current directory unless otherwise specified.

#### Loading C-V Measurement Parameters

1. From the C-V measurement parameter menu, select Load.
2. Type in the desired filename, or select one of the displayed C-V measurement parameter files.
3. C-V parameters will be loaded, and the C-V measurement parameters menu will be updated with the new parameter values.

### 3.3 C-t MEASUREMENT PARAMETERS

C-t measurement parameters control the way a C vs. t sweep is performed. The following paragraphs describe the C-t measurement parameter menu and associated parameters.

#### 3.3.1 C-t Measurement Parameter Menu

Figure 3-4 shows the overall format of the C-t measurement parameter menu. In addition to selecting and programming parameters (described below), you can perform the following menu operations:

- OK:** Exits C-t parameter menu with parameter changes placed into effect.
- Load:** Loads an existing C-t menu parameter file.
- Save:** Saves the current C-t measurement parameters to a designated file.
- Help:** Provides helpful information on setting parameters.
- Cancel:** Cancels parameter changes and exits the C-t parameter menu.

C-t Parameters				
Range:	( ) 2pF	( ) 20pF	( ) 200pF	(♦) 2nF
Frequency:	(♦) 100kHz	( ) 1MHz		
Model:	(♦) parallel	( ) series		
Meas. Rate:	( ) 1/sec	(♦) 10/sec	( ) 18/sec	( ) 75/sec ( ) 1000/sec
Filter:	( ) filter OFF	(♦) filter ON		
Sweep Source:	(♦) 590 (Internal)	( ) 230-1 (External)		
				LIMITS
# Samples:	100			1 - 450
Waveform Time Parameters:				
Start Delay:	.001	sec.		.001 - 65 sec.
Sample Time:	1	sec.		.001 - 65 sec.
Stop Delay:	.001	sec.		.001 - 65 sec.
Bias Voltage Parameters:	(5mV resolution)			
Default Bias V:	5	V.		-20 - + 20 V.
Test Bias V:	-5	V.		-20 - + 20 V.
Cable Calibration Filename:	CABCAL58 .CAL			8 chars. max
<p>&lt; OK &gt;      &lt; Load &gt;      &lt; Save &gt;      &lt; Help &gt;      &lt; Cancel &gt;</p>				

Figure 3-4. C-t Measurement Parameters Menu

### 3.3.2 C-t Measurement Parameters

**Range:** Selects 2pF (100kHz only), 20pF, 200pF, or 2nF measurement range. For best accuracy, choose the lowest range possible without overranging the Model 590.

**Frequency:** Selects 100kHz or 1MHz test frequency. Note that the Model 590 must be equipped with 100kHz and/or 1MHz modules in order to use the corresponding frequencies.

**Model:** Selects parallel or series measurement model. Readings are always taken using parallel model and then converted to series C and R data if series model is selected. See paragraph 4.7 for details on parallel/series model.

**Meas. Rate:** Selects Model 590 measurement rates of 1, 10, 18, 75, or 1000 readings per second. Note that the slower rates yield the best accuracy, resolution, and noise performance (see Table 3-1), and that only capacitance data is taken at the 1000/sec rate.

**Filter:** Allows you to turn the Model 590 filter on or off. Normally the filter should be left off unless noise is determined to be a problem because inaccurate readings may result if the filter is turned on with rapid waveforms.

**Sweep Source:** Select 230-1 (External) sweep source only if your system is equipped with the optional Model 230-1 Voltage Source; otherwise, you should select 590 (Internal). Bias voltages are limited to  $\pm 20V$  without the optional voltage source and  $\pm 100V$  with the optional voltage source.

**# Samples:** Sets the number of samples for the C-t measurement. Limits are from 1 to 450 samples for all reading rates except 1000/sec, which has a 1,350 sample limitation.

### 3.3.3 Waveform Time Parameters

Figure 3-5 shows the basic waveform definitions for the waveform time parameters described below.

#### NOTE

All programmed time periods should be multiplied by a factor of 1.024 to obtain the actual time periods. See the Model 590 Instruction Manual for details.

**Start Delay:** The time period the default bias is applied at the start of the sweep. The allowable range is from 0.001sec to 65sec.

**Sample Time:** The sample time is the time interval between individual samples. The allowable range is from 0.001sec to 65sec. Note that the total reading interval per step ( $t_i$ ) is the sum of the step time ( $t_{\text{SAMPLE}}$ ) and the reciprocal of the reading rate ( $R$ ):  $t_i = t_{\text{SAMPLE}} + 1/R$

**Stop Delay:** The stop delay is the time period after the last measurement before the Model 590 returns to the default bias voltage. The range for this parameter is from 0.001sec to 65sec.

### 3.3.4 Bias Voltage Parameters

#### NOTE

All bias voltage parameters have a resolution of 5mV (internal bias source) or 10mV (external bias source). If an optional Model 230-1 Voltage Source is not being used, the maximum range for all voltage parameters is  $\pm 20V$ .

**Default Bias V:** The bias voltage value before and after a C vs. t sweep. The range of this parameter is  $-20V$  to  $+20V$  without the optional Model 230-1 Voltage Source, or from  $-100V$  to  $+100V$  with the optional Model 230-1 Voltage Source.

**Test Bias V:** The bias voltage setting during the C vs. t sweep. The range for this parameter is from  $-20V$  to  $+20V$  without the optional Model 230-1 Voltage Source, or from  $-100V$  to  $+100V$  with the optional Model 230-1 Voltage Source.

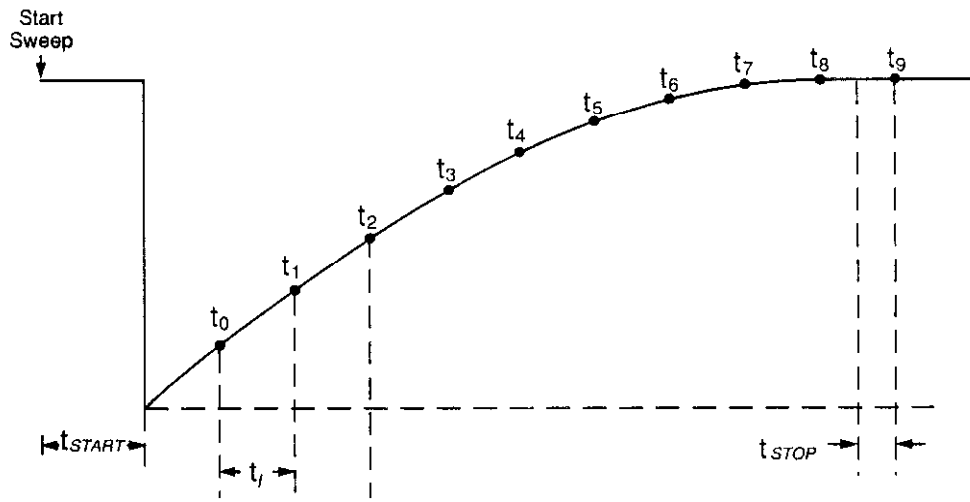
### 3.3.5 Cable Correction Filename

**Cable Calibration Filename:** Enter the cable correction filename where indicated (see paragraph 2.5 for cable correction details). The cable correction filename entered in this menu is used only for basic C-t tests. Cable correc-

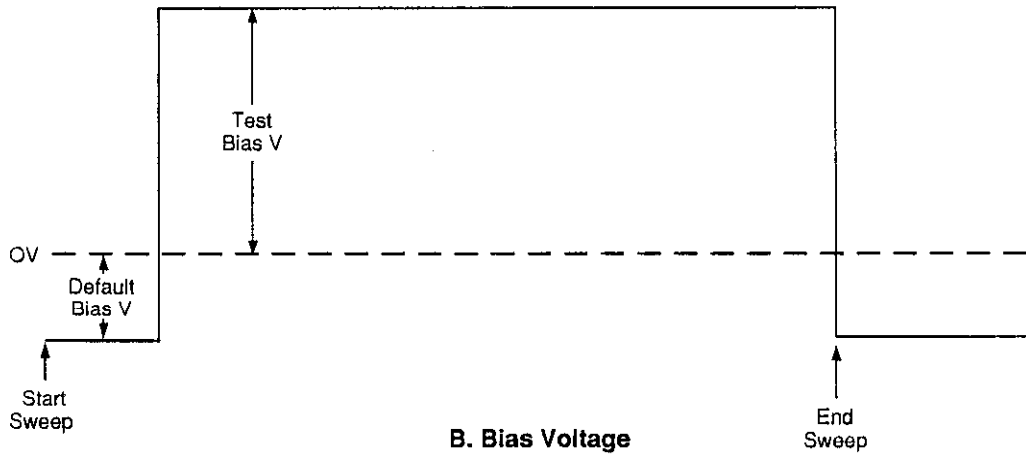


Definitions:  
 $t_{START}$  = Start Delay  
 $t_{STOP}$  = Stop Delay  
 $t_{SAMPLE}$  = Sample Time (Programmed)  
 $t_r$  = Reading Interval =  $t_{SAMPLE} + 1/R$   
 (R = Reading Rate)

Time Computation:  
 $t_s = t_{START} + (t_{SAMPLE} + 1/R) S$   
 Where: S = Sample #  
 $t_s$  = Time at Sample #



A. Capacitance



B. Bias Voltage

Figure 3-5. C-t Waveform

### 3.3.6 C-t Parameter Programming Procedure

1. From the main menu, select Setup by pressing <Alt>-S.
2. Select C-t to display the C-t parameter menu.
3. Program the Model 590 measurement parameters such as range, frequency, model, rate, and filter. Also be sure to select internal or external sweep source as appropriate.
4. Program the number of samples to be taken during the C-t measurement.
5. Select the desired start, step, and stop delay times. Keep in mind that programmed times must be multiplied by a factor of 1.024 to obtain actual times.
6. Select the first and test bias voltage parameters as required.
7. Enter the filename of the cable correction file.
8. To save the programmed C-t parameters, select Save, then type in the desired filename.
9. Select OK to use the new parameters, or choose Cancel to cancel any parameter changes made.

### 3.3.7 Saving/Loading C-t Measurement Parameters

#### Saving C-t Measurement Parameters

1. From the C-t measurement parameter menu, select Save.
2. Type in or select the desired filename at the prompt.
3. C-t measurement parameters will be saved with the appropriate extension in the current directory unless otherwise specified.

#### Loading C-t Measurement Parameters

1. From the C-t measurement parameter menu, select Load.
2. Type in the desired filename, or select one of the displayed C-t measurement parameter files.
3. C-t parameters will be loaded, and the C-t measurement parameters menu will be updated with the new parameter values.

## 3.4 STRESS CYCLE PARAMETERS

Stress cycle parameters control temperature, voltage, and time parameters associated with the BTS stress cycle.

The stress cycle menu and corresponding parameters are discussed below.

### 3.4.1 Stress Cycle Parameter Menu

Figure 3-6 shows the format of the stress cycle parameter menu. Note that you can perform the following menu operations in addition to programming parameters:

- OK:** Accepts stress cycle parameter changes and exits the menu.
- Load:** Loads an existing stress cycle menu parameter file.
- Save:** Saves the current stress cycle parameters to a designated file.
- Help:** Provides helpful information on setting stress cycle parameters.
- Cancel:** Cancels stress cycle parameter changes and exits the stress cycle parameter menu.

### 3.4.2 Stress Cycle Parameters

Stress cycle parameters are summarized below. See paragraph 3.4.5 below for a description of the complete stress cycle.

**Bias Source:** Select 230-1 (External) only if you are using an optional Model 230-1 Voltage Source, otherwise choose 590 (Internal) for the bias source. Voltage parameters are limited to  $\pm 20V$  without the optional voltage source or  $\pm 100V$  with the optional voltage source.

**+Stress V:** Sets the voltage value applied to the device during the positive stress cycle. Parameter limits are 0 to +20V (without the Model 230-1) or 0 to +100V (with the Model 230-1).

**-Stress V:** Programs the bias voltage value applied to the device during the negative stress cycle. Limits for this parameter are from 0 to -20V without the optional Model 230-1 Voltage Source, or from 0 to -100V with the optional Model 230-1 Voltage Source.

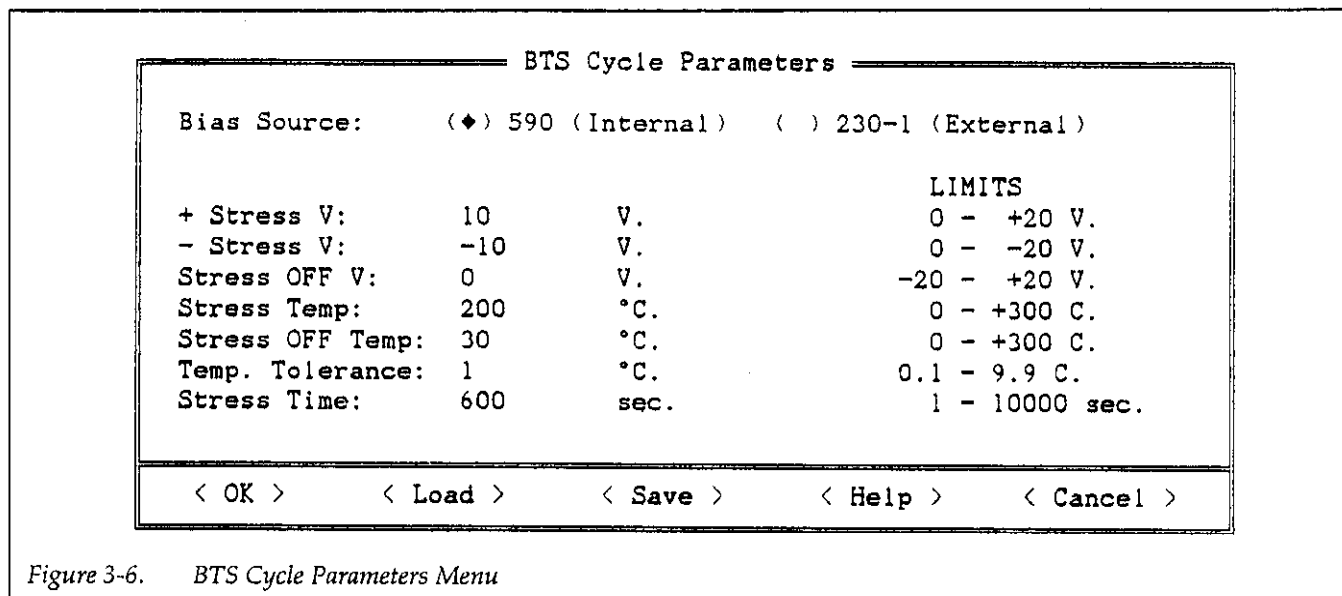


Figure 3-6. BTS Cycle Parameters Menu

**Stress OFF V:** Programs the bias voltage applied to the device during the off period of the stress cycle. Parameter limits are -20V to +20V with the optional Model 230-1 Voltage Source, or -100V to +100V with the optional Model 230-1 Voltage Source.

**Stress Temp:** Programs the hot chuck temperature during the stress on period of the stress cycle. Limits for this parameter are from 0°C to +300°C.

**Stress OFF Temp:** Sets the hot chuck temperature during the stress off period of the stress cycle. Parameter limits are from 0°C to +300°C.

**Temp. Tolerance:** This parameter programs the at temperature tolerance of the temperature cycle. The at temperature tolerance is the deviation from the programmed stress temperature at which timing for the stress on interval will begin. For example, if the stress on temperature is 300°C, and the at temperature tolerance is 2°C, the stress on interval will begin at a temperature of 298°C. The programmable range is from 0.1°C to 9.9°C tolerance.

**Stress Time:** Sets the time duration for the stress on period of the stress cycle, which begins when the at temperature tolerance setting has been satisfied. The stress time parameter range is from 1sec to 10000sec.

### 3.4.3 Programming Stress Cycle Parameters

1. From the main menu, press <Alt>-S, then select Stress Cycle.
2. Select internal or external sweep source as required.
3. Set the three stress voltages (+Stress V, -Stress V, and Stress OFF V) as desired.
4. Program the hot chuck temperature parameters (Stress Temp, Stress OFF Temp, and Temp Tolerance) to required values.
5. Set the Stress Time as needed.
6. Select Save, then type in or select the desired filename to save newly programmed stress cycle parameters.
7. Select OK to accept new parameters and return to the main menu.

### 3.4.4 Saving/Loading Stress Cycle Parameters

#### Saving Stress Cycle Parameters

1. From the stress cycle parameter menu, select Save
2. Type in the desired filename at the prompt.
3. Stress cycle parameters will be saved with the appropriate extension in the current directory unless otherwise specified.

### Loading Stress Cycle Parameters

1. From the stress cycle parameter menu, select Load.
2. Type in the desired filename, or select one of the displayed stress cycle parameter filenames.
3. Stress cycle parameters will be loaded, and the stress cycle parameters menu will be updated with the new parameter values.

### 3.4.5 Stress Cycle Description

The basic purpose of the stress cycle is to apply both a bias voltage and temperature stress to the DUT. The basic sequence for the stress cycle is summarized below. A flowchart for the stress cycle is shown in Figure 3-7.

1. When the stress cycle is first started, the bias voltage and temperature will be set to Stress OFF V and Stress OFF Temp. respectively.
2. The device is biased with the +Stress V or -Stress V value, depending on whether the stress cycle is positive or negative.
3. The hot chuck temperature is ramped up to the value determined by the Stress Temp. parameter.
4. Once the hot chuck temperature reaches the tolerance value determined by the Temp. Tolerance parameter, stress cycle timing begins.
5. The DUT remains at stress temperature and bias voltage for the time interval determined by the Stress Time parameter.
6. Once the required stress time has elapsed, the hot chuck is ramped down to a temperature determined by the Stress OFF Temp. parameter, and the bias voltage is set to the value determined by the Stress OFF V parameter.

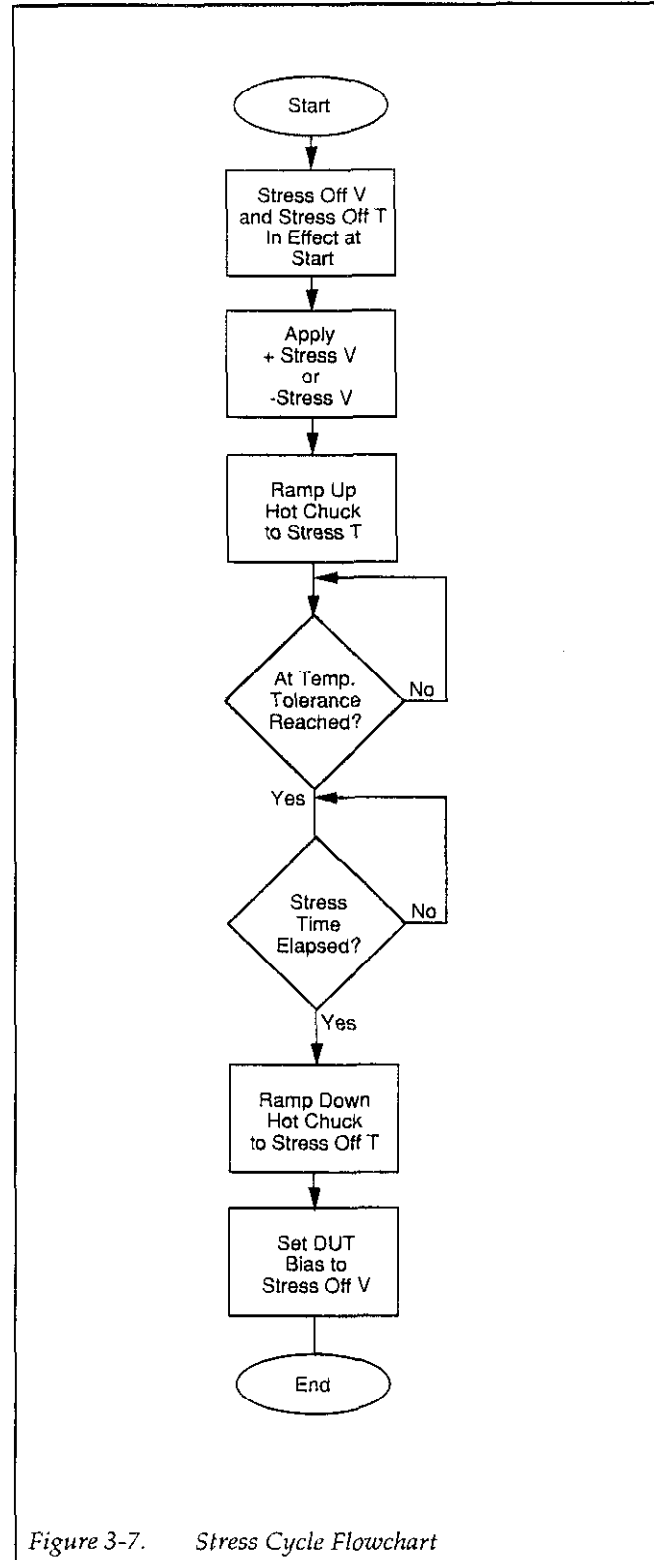


Figure 3-7. Stress Cycle Flowchart

### 3.5 BTS TEST SEQUENCE

BTS test sequence parameters define the test sequence type, number of devices to test, as well as the various control and parameter files associated with the BTS test.

#### 3.5.1 BTS Test Sequence Menu

Figure 3-8 shows the BTS test sequence menu. The various parameters defined in this menu are used when running a BTS test sequence, as described in paragraph 4.5. Use the selections at the bottom of the screen to perform the following:

- OK:** Accepts entered BTS test sequence parameters and exits the test sequence menu.
- Load:** Loads an existing BTS test sequence file.
- Save:** Saves the present BTS test sequence parameters in a user-defined file
- Help:** Provides useful help information on programming BTS test sequence parameters.
- Cancel:** Cancels parameter changes and exits the BTS test sequence menu.

#### 3.5.2 BTS Test Sequence Setup Parameters

**Test Sequence Type:** Selects sequential, parallel, or no stress, as required. See paragraph 3.5.5 below for a more detailed discussion of test sequence types.

**Stress Cycle Type:** Sets + then -, - then +, + only, or - only. With + then - or - then +, both positive and negative voltages (+Stress V and -Stress V) will be applied to the device in sequence during stress (+Stress V then -Stress V, or -Stress V then +Stress V). With + only and - only positive and negative voltages respectively will be applied to the device during stress. Flowcharts discussed in paragraph 3.5.5 show how the various stress cycles work with test sequences.

**Type of C<sub>MIN</sub> Checking:** If you have multiple devices, you may or may not want to determine true C<sub>MIN</sub> for each device. Choosing manual indicates the program will stop at the end of each sweep and prompt you for certain information (see paragraph 4.2.4). The auto selection, which appears only if you have an optional Model 230-1 voltage source, is completely automatic, and it requires that you have a light connected to the system (paragraph 2.4.4). Choosing none results in automatic program operation, but C<sub>MIN</sub> is not determined. (C<sub>MIN</sub> can also be entered under analysis, as discussed in paragraph 5.6.3 in Section 5.)

BTS Test Sequence

Test Sequence Type: ( ) sequential (♦) parallel ( ) no stress  
 Stress Cycle Type: (♦) +then- ( ) -then+ ( ) +only ( ) -only  
 Type of Cmin Checking: (♦) manual ( ) auto ( ) none

	LIMITS
Comments: (Enter on next line)	64 chars.
This is a sample BTS test sequence file distributed with 5958.	
Number of Devices: 1	99 max.
C-V Parameter Filename: SAMPLE .CVP	8 chars.
Stress Cycle Filename: SAMPLE .SCP	8 chars.
Switch Control Filename: ---- .SWC	8 chars.
Data Destination Filename: SAMP_ .DAT	5 chars.

Figure 3-8. BTS Test Sequence Setup Menu

**Comments:** Allows you to type in one line of up to 64 characters of comments for future reference.

**Number of Devices:** Sets the number of devices to test (1-99). In order to test more than one device, you must use a switching mainframe or probe sequencer and define a switch control file (see Section 6).

**C-V Parameter Filename:** Defines the filename that contains the C-V parameters for the C-V portion of the BTS test sequence. See paragraph 3.2 for information on programming these parameters.

**Stress Cycle Filename:** Defines the filename of the stress cycle parameters. Paragraph 3.4 describes how to program stress cycle parameters and save them in an appropriate file.

**Switch Control Filename:** Defines the switch control filename, which is required when using switching with the BTS system. See Section 6 for information on setting up the switch control file.

**Data Destination Filename:** Defines the file in which BTS test sequence data will be stored at run time.

**NOTE**

The maximum number of characters for each filename is indicated on the screen. Also, you should not type in filename extensions because the extensions are automatically added by the program.

### 3.5.3 Setting Up a BTS Test Sequence

1. Setup your C-V measurement parameters, as discussed in paragraph 3.2. Be sure to save the parameters using a convenient filename.
2. Program the stress cycle parameters, which are described in paragraph 3.4. Again, save the stress cycle parameters using the Save option on the menu.
3. From the main menu, press <Alt>-S, then select BTS Sequence.
4. Select your test sequence type, stress cycle type, and C<sub>MIN</sub> checking type.
5. Enter any comments for reference on the indicated line.

6. Select the number of devices to test (only one device can be tested if no switching or sequencing provisions are included in your system).
7. Enter your C-V parameter filename, as determined in step 1.
8. Type in the stress cycle parameter filename chosen in step 2.
9. If you are using a switch (or sequencer), enter the switch control filename (Section 6 describes setting up a switch control file).
10. Type in the data destination filename to define where data taken during the BTS test sequence will be stored.
11. Select Save, then type in the desired filename to save the defined test sequence.

### 3.5.4 Saving/Loading BTS Test Sequence Setups

#### Saving BTS Test Sequence Setups

1. From the BTS test sequence menu, select Save.
2. Type in or select the desired filename at the prompt.
3. The BTS test sequence setup will be saved with the appropriate extension in the current directory unless otherwise specified.

#### Loading BTS Test Sequence Setups

1. From the BTS test sequence setup menu, select Load.
2. Type in the desired filename, or select one of the displayed BTS test sequence setup files.
3. The BTS test sequence setup will be loaded, and the BTS test sequence setup menu will be updated accordingly.

### 3.5.5 BTS Test Sequence Description

**NOTE**

Test sequencing of multiple devices requires that you define a control file or use one of the default switch control files. See Section 6 and Appendix J for details.

#### Sequential Test

With a sequential test, the entire BTS sequence is performed on each device while it is connected to the system. The basic steps for the sequential test using a + then - stress cycle are summarized below. Figure 3-9 through Figure 3-12 show flowcharts for the sequential test se-

quence using the four available stress cycles (+ then -, - then +, + only, and - only).

1. If a switch or automatic probe sequencer is being used, a switch control string (from the switch control file) is sent to the switching mainframe or sequencer to select the device being tested. (With the switch, relay contacts are closed to select the DUT, while a positioning device selects a specific test dot with a probe sequencer.)
2. An initial, pre-stress C-V curve measurement is performed, and the resulting data is stored in a disk file.
3. The positive BTS stress cycle is applied to the device. This stress cycle includes the positive stress voltage and the programmed stress temperature.
4. A second C-V curve measurement is made, and the data is stored in a disk file.
5. The negative BTS stress cycle is applied to the device. The negative stress cycle includes the programmed negative stress voltage and the programmed temperature.
6. A third C-V measurement is made, and the results are stored in a disk file.
7. If a switch is being used, a switch control string is sent to the switching mainframe to open the contacts to the device being tested.
8. Steps 1 through 7 are repeated for all devices to be tested.
9. The bias voltage is turned off to allow for safe device removal.

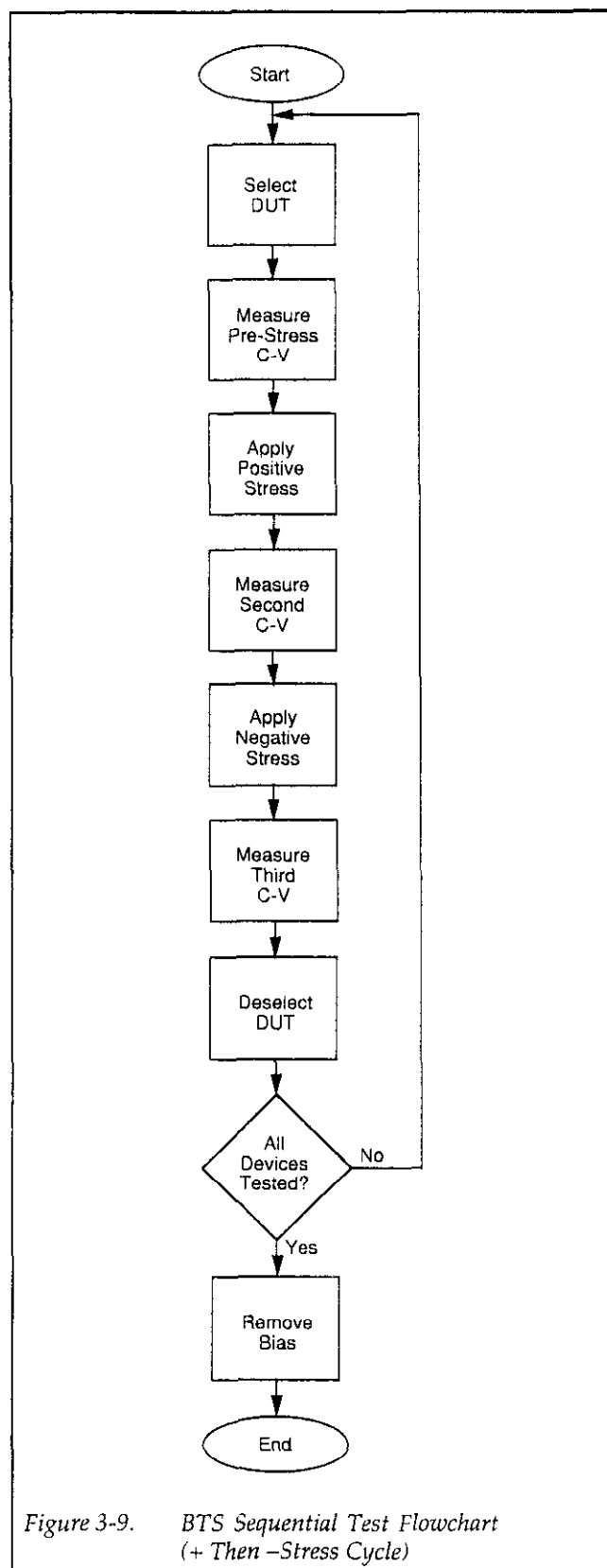
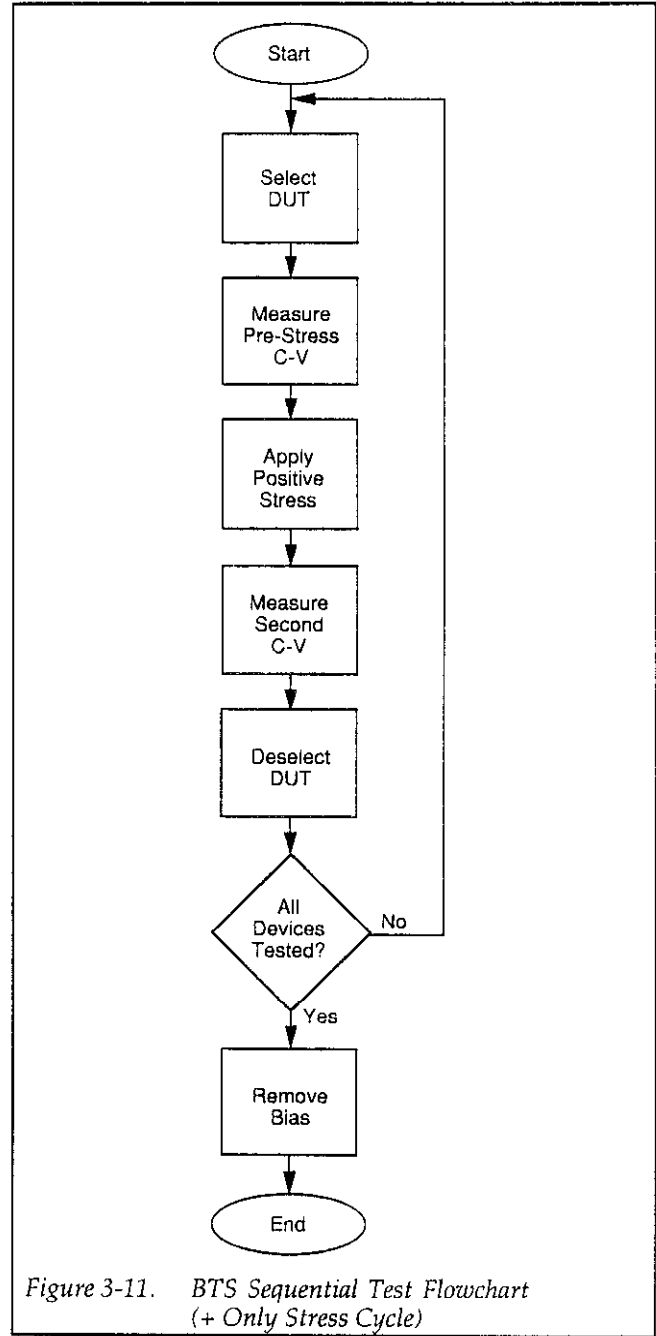
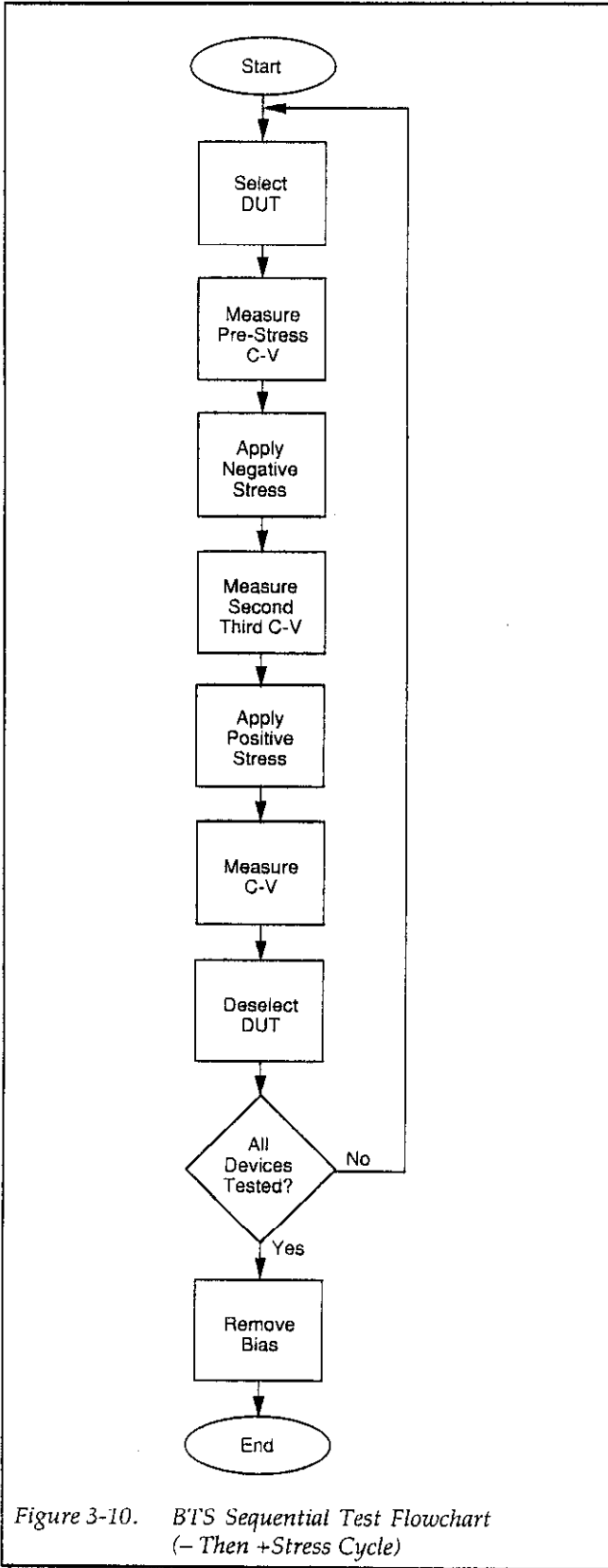
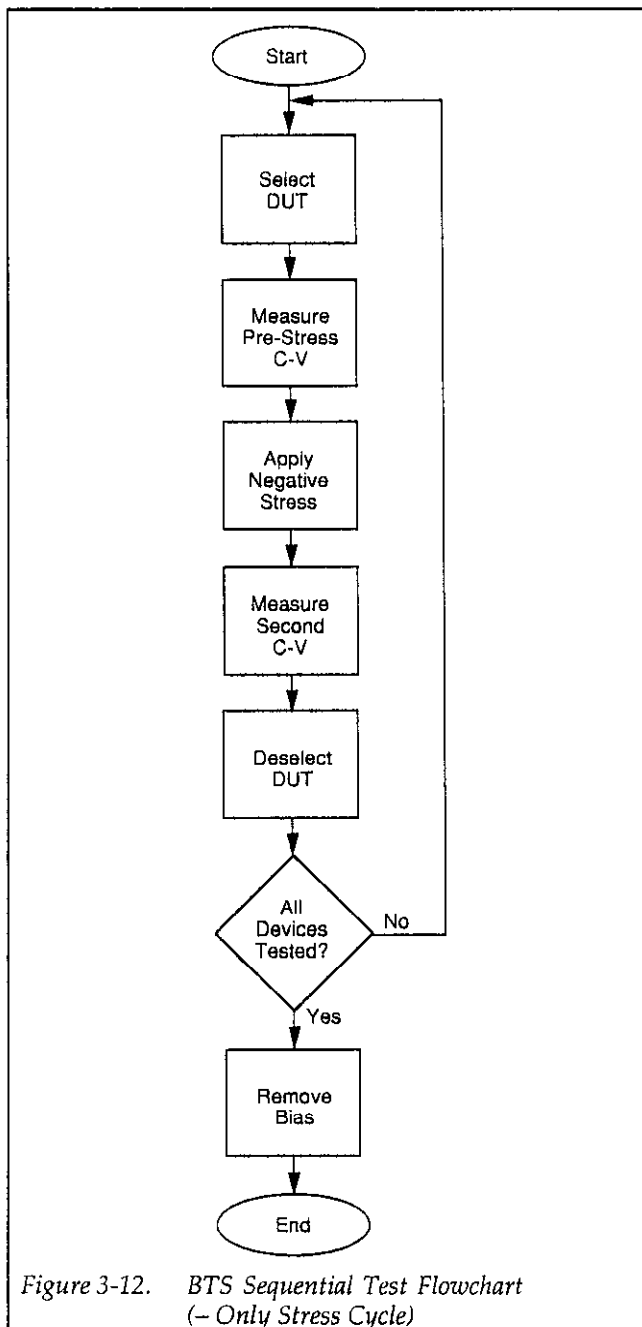


Figure 3-9. BTS Sequential Test Flowchart (+ Then - Stress Cycle)







### Parallel Test

The parallel sequence test has the advantage of speeding up BTS measurement of a number of devices by performing time-consuming stress operations in parallel. Basically, all devices are stressed in parallel and tested at each stage (pre-stress, positive stress, negative stress) before moving on to the next stage. Note that switching is required for this test because all devices must be connected in parallel during the stress cycle, a requirement that cannot be met by an automatic probe sequencer.

The steps below outline the overall parallel test sequence for the + then - stress cycle, which is shown in the flowchart of Figure 3-14. Figure 3-14 through Figure 3-16 show flowcharts for the parallel test with the remaining stress cycle types.

1. A switch control string is sent to the switching mainframe to close the contacts to connect the device to be tested.
2. A pre-stress C-V curve measurement is made, and the data is placed in a disk file.
3. A switch control string is sent to the switching mainframe to open the contacts connecting the current device.
4. Steps 1 through 3 are repeated for all devices to be tested.
5. A switch control string is sent to the switching mainframe to connect all devices in parallel.
6. The positive BTS stress cycle is applied to all devices simultaneously.
7. A switch control string is sent to the switching mainframe to disconnect parallel devices.
8. A switch control string is sent to the switching mainframe to close the contacts to connect the device to be tested.
9. A second C-V curve measurement is made, and the resulting data is stored in a data file.
10. A switch control string is sent to the switching mainframe to open the contacts connecting the current device.
11. Steps 8 through 10 are repeated for all devices to be tested.
12. A switch control string is sent to the switching mainframe to connect all devices in parallel.
13. The negative BTS stress cycle is applied to all devices simultaneously.
14. A control string is sent to the switching mainframe to disconnect all parallel devices.
15. A switch control string is sent to the switching mainframe to close the contacts to connect the device to be tested.
16. A third C-V curve measurement is made, and the resulting data is stored in a disk file.

17. A switch control string is sent to the switching mainframe to open the contacts connecting the current device.
18. Steps 15 through 17 are repeated for all devices to be tested.
19. The bias voltage is turned off to allow for safe device removal.

**No Stress Test**

The no stress test option performs only a basic C-V curve measurement without stress. This option can be used to verify for proper C-V measurement parameters and device connections, or for basic multiple-device C-V measurements. A switching mainframe or automatic probe sequencer can be controlled to test a number of devices automatically.

The basic steps included in the no stress test are summarized below. Figure 3-17 shows a flow chart of the BTS no stress test sequence.

1. A control string is sent to the switching mainframe or probe sequencer to select the device to be tested.
2. A C-V curve measurement is made, and the resulting data is stored in a disk file.
3. If switching is being used, a switch control string is sent to the switching mainframe to open contacts to the device being tested.
4. Steps 1 through 3 are repeated for each device being tested.
5. The bias voltage is turned off to allow for safe device removal.

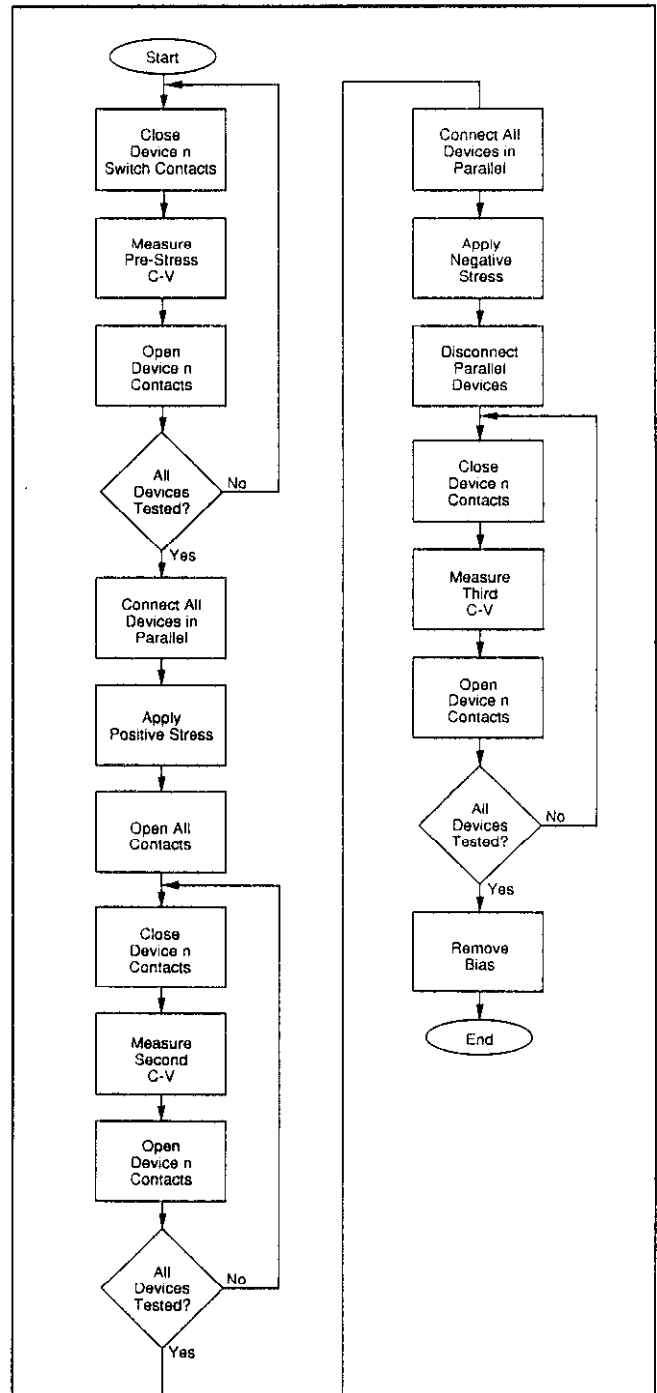
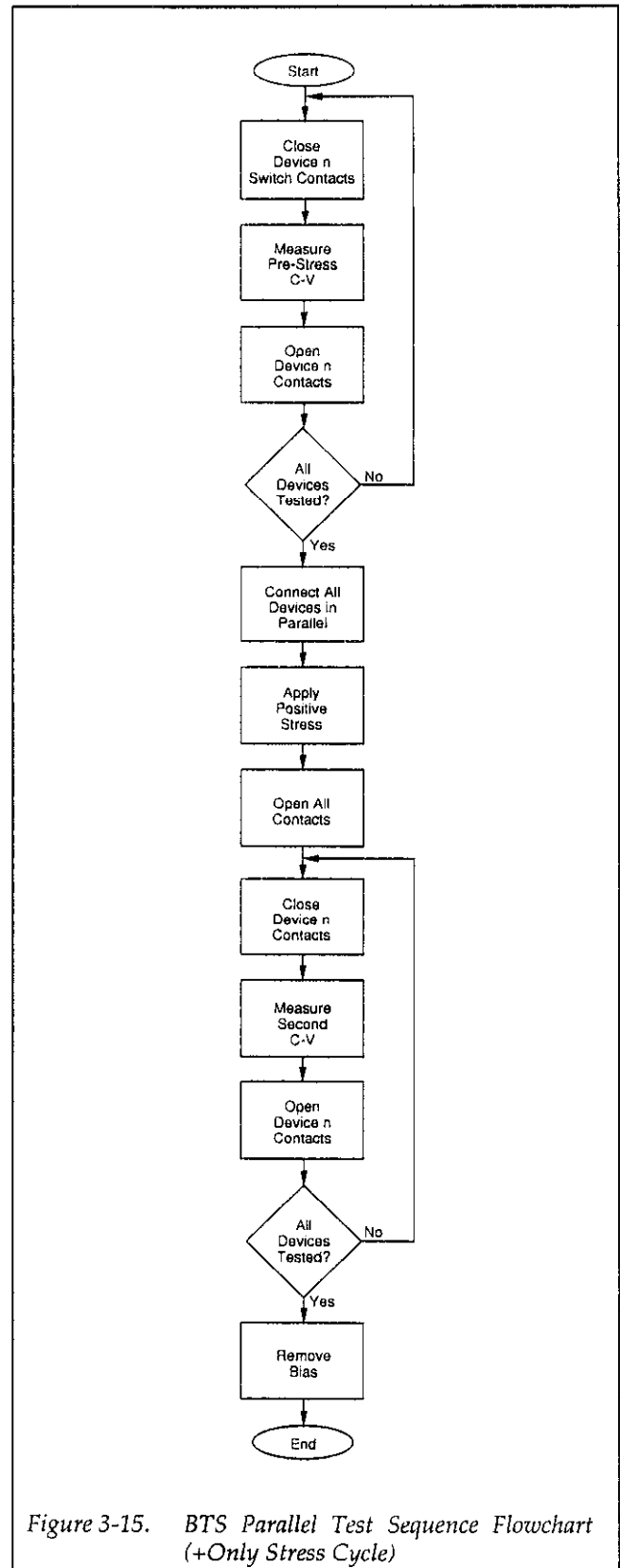
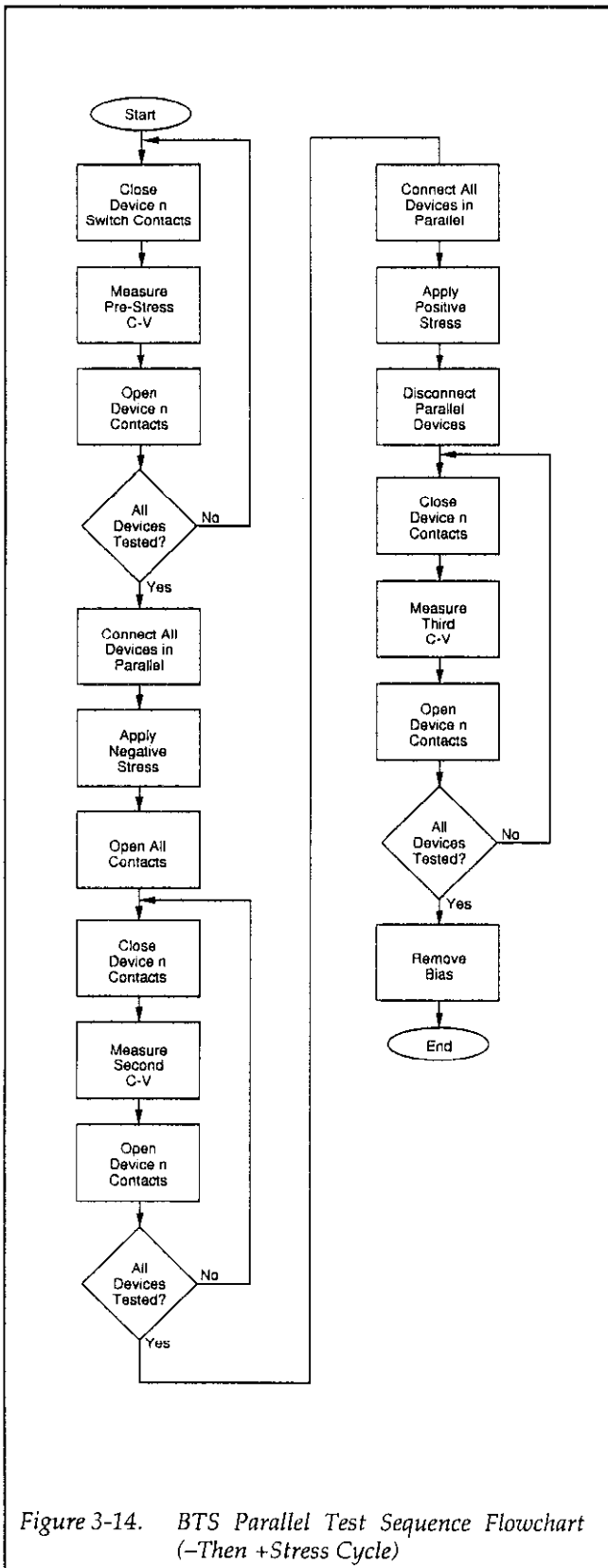


Figure 3-13. BTS Parallel Test Sequence Flowchart (+Then -Stress Cycle)



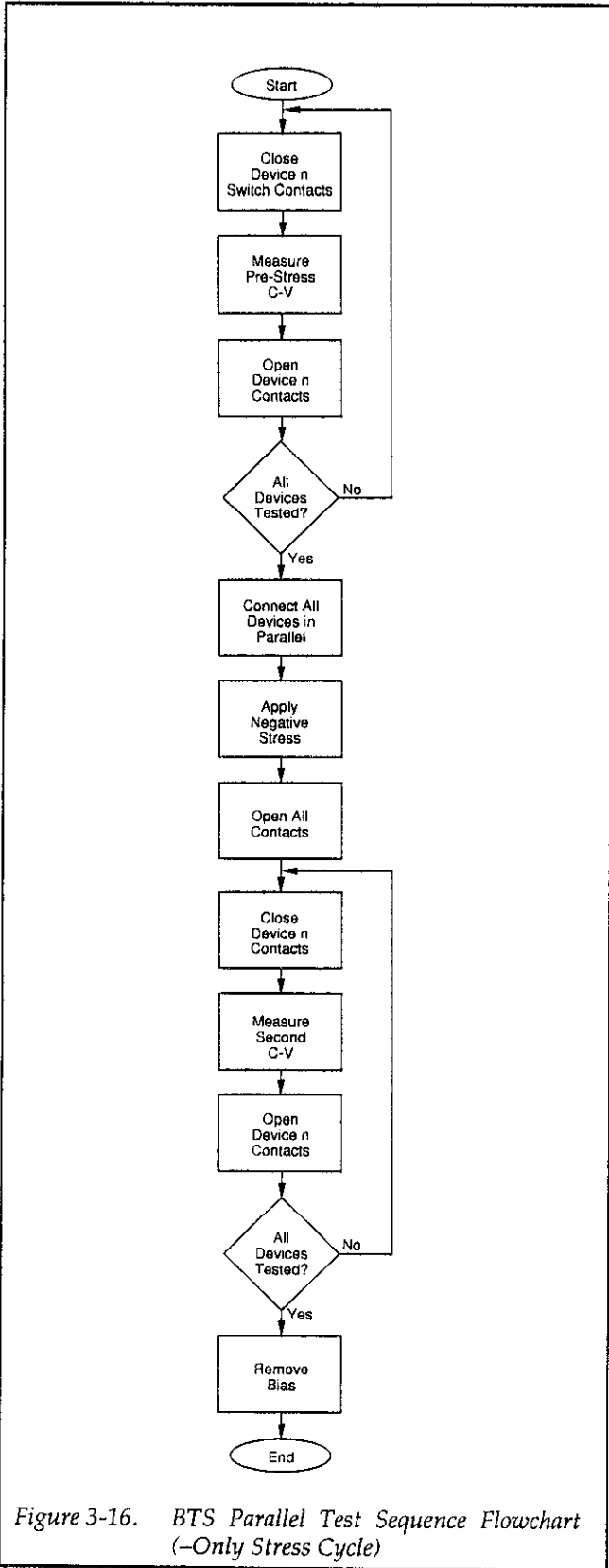


Figure 3-16. BTS Parallel Test Sequence Flowchart (-Only Stress Cycle)

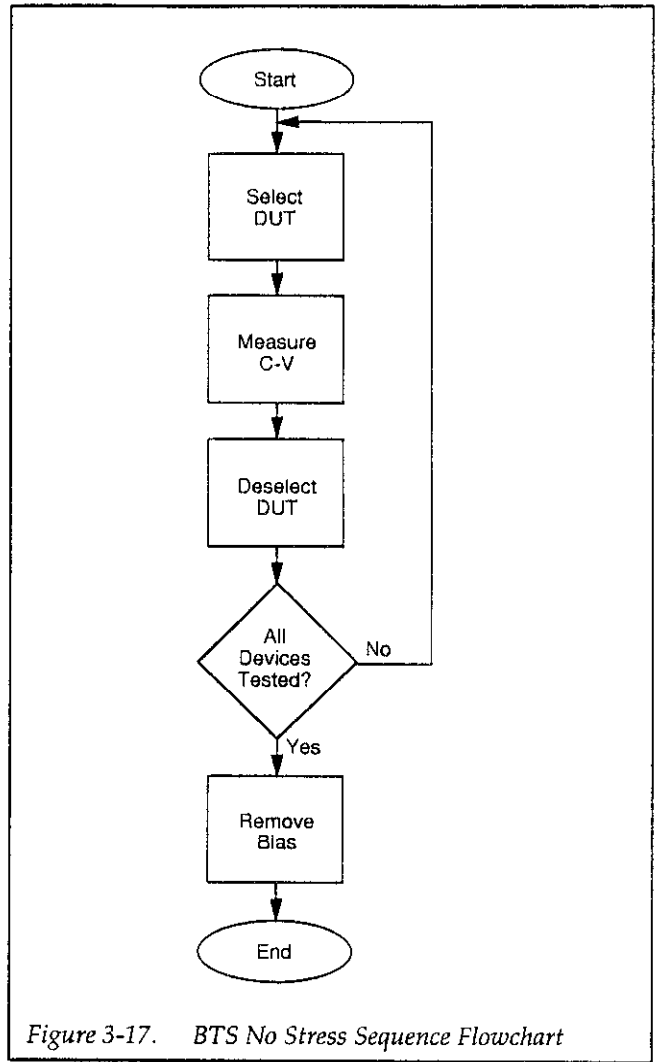


Figure 3-17. BTS No Stress Sequence Flowchart

## 3.6 ZERBST TEST SEQUENCE

Zerbst test sequence parameters define the test sequence type, number of devices to test, as well as the various control and measurement parameter files associated with the test.

### 3.6.1 Zerbst Test Sequence Setup Menu

Figure 3-18 shows the Zerbst test sequence setup menu. Parameters defined in this menu are used when running a Zerbst test sequence, which is covered in paragraph 4.6. Use the selections at the bottom of the screen to perform the following:

- OK:** Accepts entered Zerbst test sequence parameters and returns to the main menu.
- Load:** Loads an existing Zerbst test sequence setup file.
- Save:** Saves the present Zerbst test sequence setup in a user-defined file
- Help:** Provides useful help information on programming Zerbst test sequence setup parameters.
- Cancel:** Exits the Zerbst test sequence menu.

### 3.6.2 Zerbst Test Sequence Setup Parameters

**Test Sequence Type:** Select multiple C-V, one C-V, or no C-V, as required. See paragraph 3.6.5 below for a more detailed discussion of test sequence types.

**Type of  $C_{MIN}$  Checking:** Selects whether or not  $C_{MIN}$  will be determined (see paragraph 3.5.2).

**Comments:** Use this feature to type in one line of up to 64 characters as comments for future reference. Comment text is entered on the next line.

**Number of Devices:** Selects the number of devices to test (1-99). In order to test more than one device, you must use a switching mainframe or probe sequencer and define a switch control file (see Section 6).

**C-V Parameter Filename:** Defines the filename that contains the C-V measurement parameters. See paragraph 3.2 for information on programming these parameters.

**C-t Parameter Filename:** Defines the filename with C-t measurements parameters, as covered in paragraph 3.3.

**Switch Control Filename:** Defines the switch control filename, which is required when using switching or sequencing with the Zerbst system. See Section 6 for information on setting up the switch control file.

**Data Destination Filename:** Defines the files in which Zerbst test data will be stored.

#### NOTE

The maximum number of characters for each filename is indicated by the length of the field displayed on the screen. Also, you should not type in filename extensions because the extensions are automatically defined by the program.

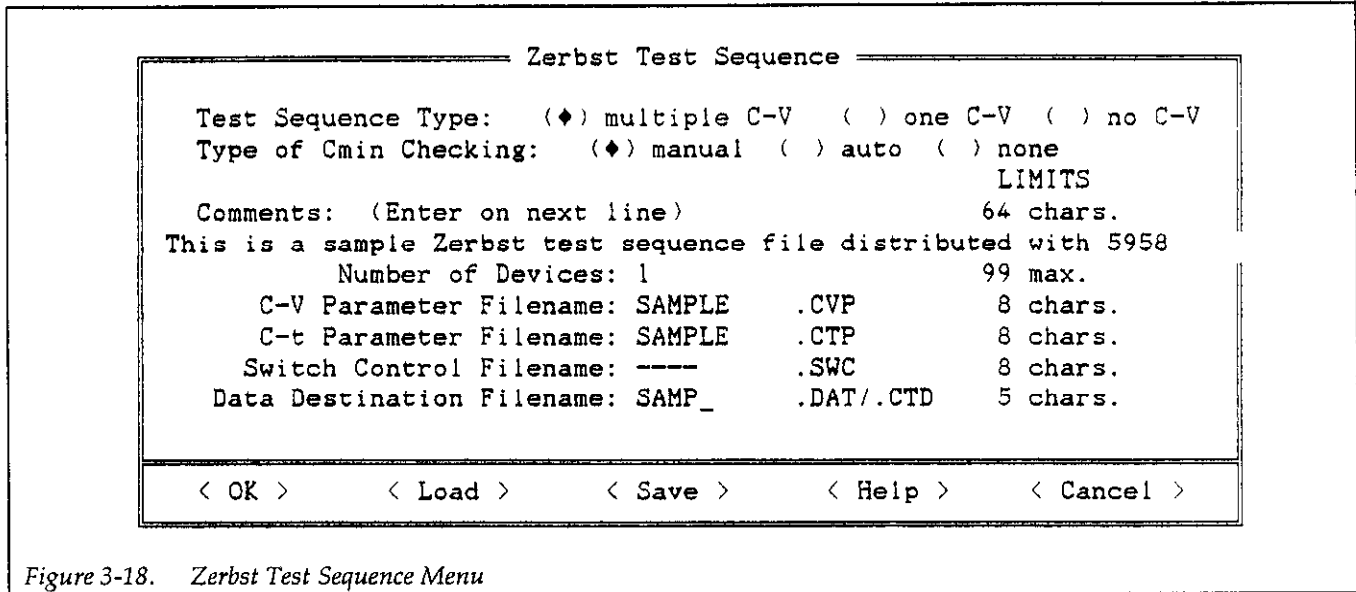


Figure 3-18. Zerbst Test Sequence Menu

### 3.6.3 Setting Up a Zerbst Test Sequence

1. Setup your C-V measurement parameters, as discussed in paragraph 3.2. Be sure to save the parameters using a convenient filename.
2. Program the C-t measurement parameters, which are described in paragraph 3.3. Again, save the C-t measurement parameters using the Save option on the menu.
3. From the main menu, press <Alt>-S, then select Zerbst Sequence.
4. Select your test sequence type and type of C<sub>MIN</sub> checking.
5. Enter any comments for reference on the indicated line.
6. Select the number of devices to test (only one device can be tested if no switching or sequencing provisions are included in your system).
7. Enter your C-V parameter filename, as determined in step 1.
8. Type in the C-t measurement parameter filename chosen in step 2.
9. If you are using a switch or sequencer, enter the switch control filename (Section 6 describes setting up a switch control file).
10. Type in the data destination filename to define where data taken during the Zerbst test sequence will be stored.

11. Select Save, then type in or select the desired filename to save the defined test sequence.

### 3.6.4 Saving/Loading Zerbst Test Sequence Setups

#### Saving Zerbst Test Sequence Setups

1. From the Zerbst test sequence setup menu, select Save.
2. Type in or select the desired filename at the prompt.
3. The Zerbst test sequence setup will be saved with the appropriate extension in the current directory unless otherwise specified.

#### Loading Zerbst Test Sequence Setups

1. From the Zerbst test sequence setup menu, select Load.
2. Type in the desired filename, or select one of the displayed Zerbst test sequence setup files.
3. The Zerbst test sequence setup file will be loaded, and the Zerbst test sequence setup menu will be updated accordingly.

### 3.6.5 Zerbst Test Sequence Types

#### NOTE

Test sequencing of multiple devices requires that you define a control file or use one of the default switch control files. See Section 6 and Appendix J for information.

#### Multiple C-V Test

The multiple C-V test is intended for use with dissimilar devices where both C-V and C-t tests are required for all devices. The basic steps included in the multiple C-V test are summarized below. Figure 3-19 shows a flowchart of the test sequence.

1. A switch control string from the switch control file is sent to the switching mainframe or automatic probe sequencer to select the device being tested.
2. A C-V curve measurement is made, and the C-V data is stored on disk.
3. A C-t measurement is made, and the C-t data is stored on disk.
4. If a switch is used, a switch control string is sent to the switching mainframe to open the contacts to the current device.
5. Steps 1 through 4 are repeated for all devices to be tested.
6. The bias voltage is removed to allow for safe device removal.

#### One C-V Test

The one C-V test can be used to test a group of similar devices. With this type of test, only one C-V measurement on a single device is performed, while C-t measurements are performed on all devices being tested. In order for this test to be valid, the first device tested in the sequence must be representative of all devices.

The steps for the test are outline below, and Figure 3-20 shows a flowchart of the test sequence.

1. A control string from the switch control file is sent to the switching mainframe or automatic probe sequencer to close the contacts for the device being tested.
2. For the first device tested only, a C-V curve measurement is made, and the C-V data is stored on disk.
3. A C-t measurement is made, and the C-t data is stored on disk.
4. If a switch is used, a switch control string is sent to the switching mainframe to open the contacts to the current device.
5. Steps 1 through 4 are repeated for all devices to be tested.
6. The bias voltage is removed to allow for safe device removal.

#### No C-V Test

As the name implies, the no C-V test type performs only C-t measurements. This test sequence is intended for performing automatic sequencing of multiple C-t tests. The basic steps in the procedure are outlined below, and Figure 3-21 shows a flowchart of the test sequence.

1. A control string from the switch control file is sent to the switching mainframe or automatic probe sequencer to select the device being tested.
2. A C-t measurement is made, and the C-t data is stored on disk.
3. If a switch is used, a switch control string is sent to the switching mainframe to open the contacts to the current device.
4. Steps 1 through 3 are repeated for all devices to be tested.
5. The bias voltage is removed to allow for safe device removal.

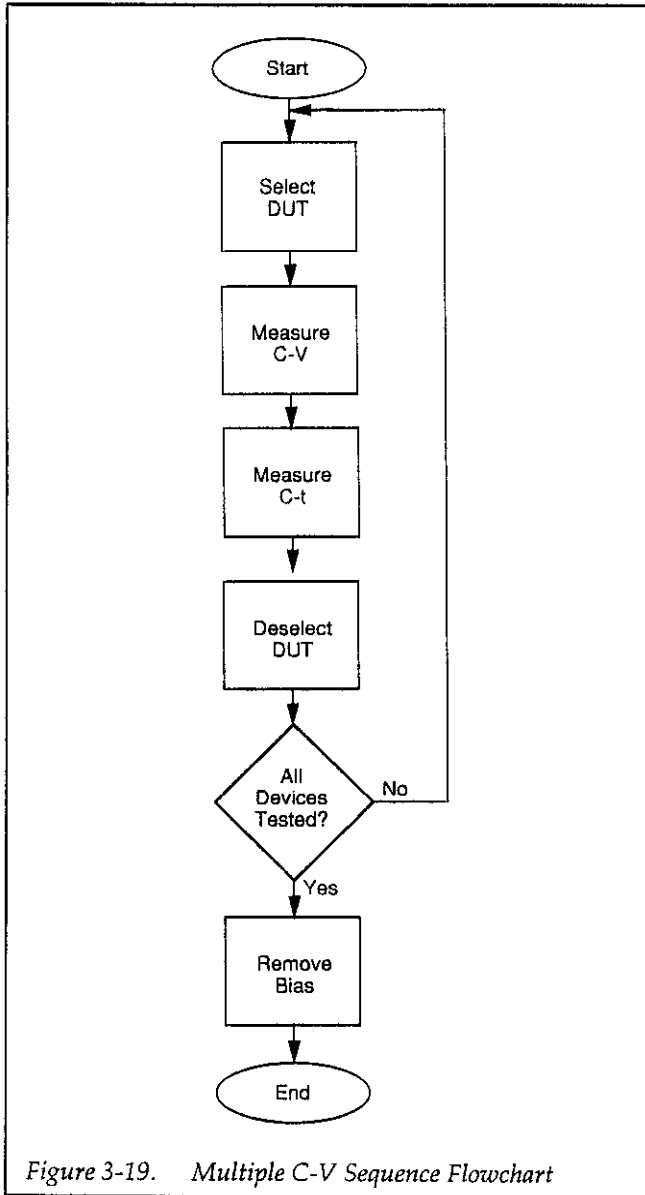


Figure 3-19. Multiple C-V Sequence Flowchart

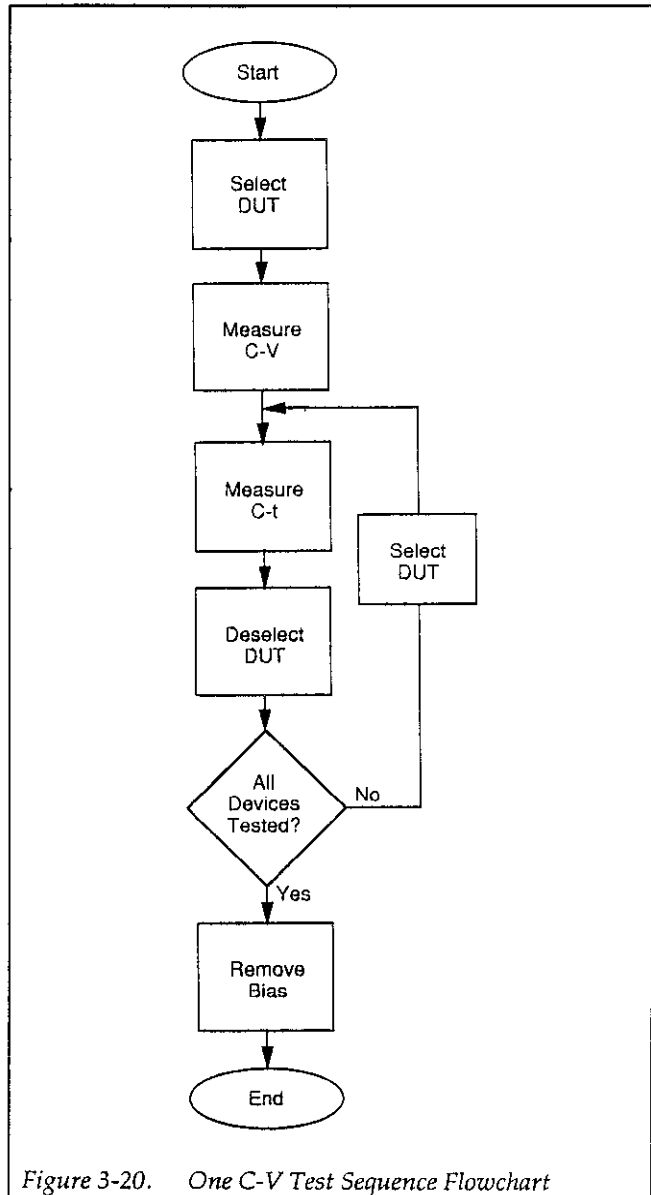


Figure 3-20. One C-V Test Sequence Flowchart



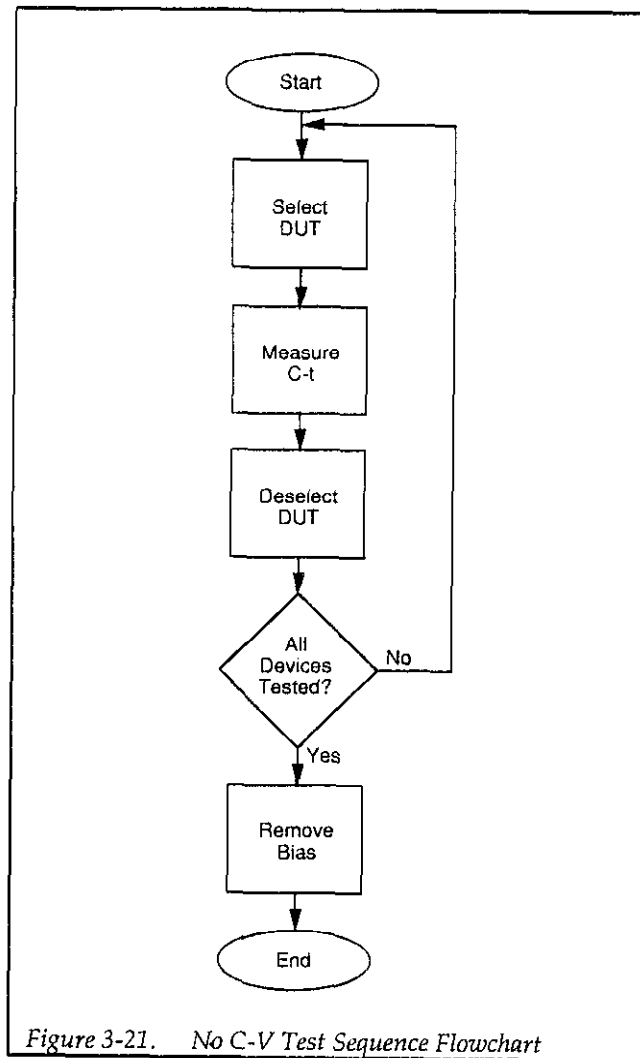


Figure 3-21. No C-V Test Sequence Flowchart

# SECTION 4

# Measurement

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## 4.1 INTRODUCTION

This section includes detailed information on performing various Model 5958 measurement procedures and is organized as follows:

- 4.2 **C-V Measurements:** Details test connections, C-V measurement procedures, and discusses selecting optimum parameters.
- 4.3 **C-t Measurements:** Covers test connections, typical C-t measurement procedures, and discusses optimum time selection.
- 4.4 **BTS Stress Cycle:** Briefly discusses hot chuck connections and outlines the basic procedure for performing a BTS stress cycle.
- 4.5 **BTS Test Sequence Measurements:** Covers connections to scanner and matrix card, basic BTS test sequence measurement procedure, and choosing the best test sequence.
- 4.6 **Zerbst Test Sequence Measurements:** Details connections to a switch card and Zerbst test sequence measurement procedure.
- 4.7 **Measurement Considerations:** Discusses a number of important considerations to keep in mind when performing measurements.

## 4.2 C-V MEASUREMENTS

Basic C-V measurements involve setting up your C-V measurement parameters, connecting the Model 590 to the DUT, and performing the test procedure outlined below.

### NOTE

The basic C-V test procedure cannot use switching or sequencing to test multiple DUTs. To perform C-V measurements on multiple DUTs, setup a BTS test sequence and select the no stress option. See paragraph 4.5 for details.

### 4.2.1 C-V Measurement Connections

Figure 4-1 shows typical test connections for C-V measurements. Since no switching or sequencing is used, connections are straightforward. When making connections, keep the following points in mind:

- Keep cable lengths as short as possible (five meters maximum).
- Use only 50 $\Omega$  (RG-58) cables such as the Model 7051.
- Match all instrument, cable, and adapter impedances to as close to 50 $\Omega$  as possible.
- Minimize the total number of connections to avoid losses caused by inevitable mismatch at connecting points.

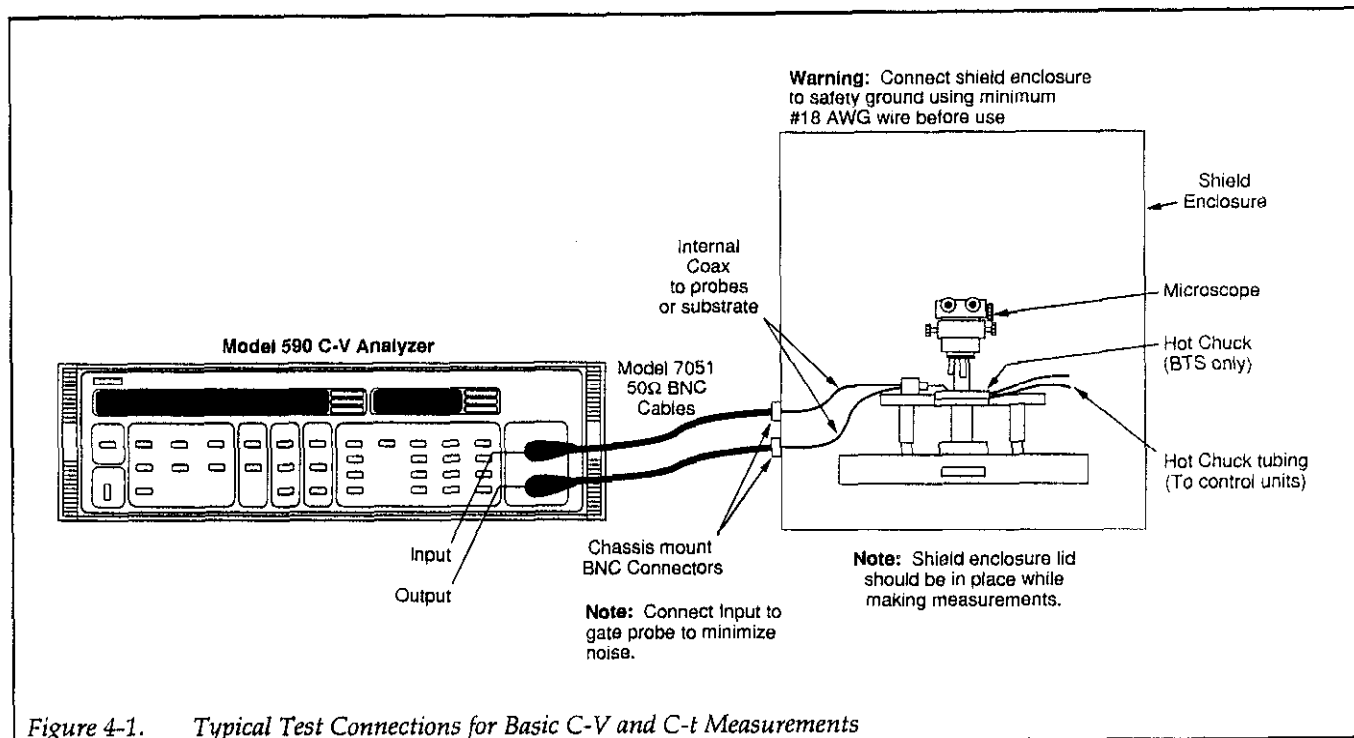


Figure 4-1. Typical Test Connections for Basic C-V and C-t Measurements

- Shield probes as close to wafer as possible, and shield wafer with Faraday shield.
- Perform cable correction before making measurements (paragraph 2.5).
- Connect INPUT to gate, OUTPUT to substrate to minimize noise.

#### 4.2.2 Selecting Optimum C-V Measurement Parameters

When programming C-V measurement parameters, keep the following points in mind. Refer to paragraph 4.7 for a more complete discussion of these and other considerations.

##### Choosing Optimum Start and Stop Voltages

Most C-V data is derived from the steep transition, or depletion region of the C-V curve (see Figure 4-2). For that reason, start and stop voltages should be chosen so that the depletion region makes up about 1/3 to 2/3 of the voltage range.

The upper flat, or accumulation region of the high-frequency C-V curve defines the oxide capacitance,  $C_{ox}$ .

Since much analysis relies on the ratio  $C/C_{ox}$ , it is important that you choose a start or stop voltage (depending on the sweep direction) to bias the device into strong accumulation at the start or end of the sweep.

The Model 5958 software will automatically recommend the maximum high-frequency capacitance as the value for  $C_{ox}$ , but you can enter your own value if you have reason to believe that the device would saturate at a higher value. See paragraph 5.6 for more information on changing  $C_{ox}$ .

##### Selecting the Number of Data Points

The relative values of the start, stop, and step voltages determine the number of data points in the sweep. When choosing these parameters, some compromise is in order between having too few data points in one situation, or too many data points in another.

The complete doping profile is derived from data taken in the depletion region of the curve by using a derivative calculation. As the data point spacing decreases, the vertical point spacing is increasingly caused by noise rather than changes in the desired signal. Consequently, choosing too many points in the sweep will result in increased

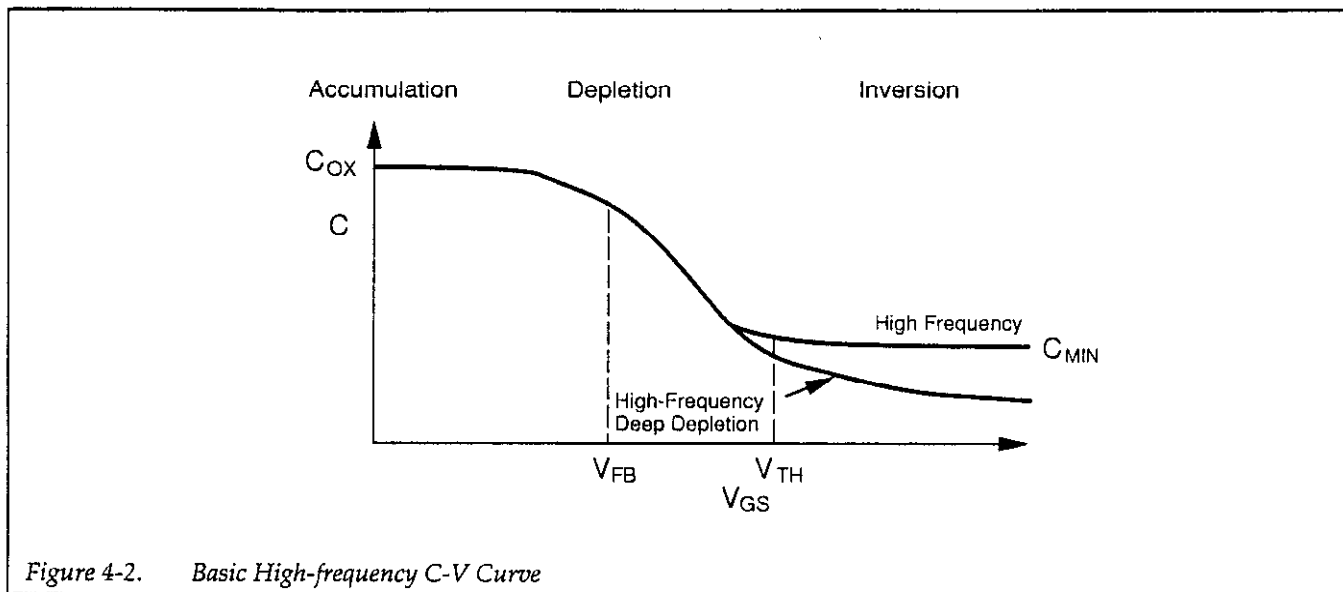


Figure 4-2. Basic High-frequency C-V Curve

noise rather than an increased resolution in measurement of the C-V waveform.

To minimize noise, choose parameters that will yield a capacitance change of approximately ten times the percentage error in the signal. For the Model 5958, the optimum step size is about 1% change in capacitance value per step.

### Sweep Direction

For high-frequency C-V sweeps, you can sweep either from accumulation to inversion, or from inversion to accumulation. Sweeping from accumulation to inversion will allow you to achieve deep depletion—profiling deeper into the semiconductor than you otherwise would obtain by maintaining equilibrium. When sweeping from inversion to accumulation, using a brief light pulse before the start of the sweep will yield near-equilibrium results.

## 4.2.3 C-V Measurement Procedure

The step-by-step procedure below, outlines the basic procedure for making C-V measurements. For more information on setting up C-V parameters, refer to paragraph 3.2, Section 3. Section 5 covers C-V analysis in more detail.

### Step 1: Connect the Test Equipment

Connect the Model 590 to the test fixture or probe station using the connections outlined in Figure 4-1.

### Step 2: Setup C-V Measurement Parameters

1. From the main menu, press <Alt>-S, and select C-V setup to display the C-V parameters menu.
2. Select the various measurement parameters such as range, frequency, model, and rate, as required. Use the up/down and left/right arrow keys to move around the parameter screen. See paragraph 4.2.2 for a discussion on choosing optimum parameters.
3. Choose the waveform type and various time/delay parameters. Remember to use a step time long enough so that the device remains in equilibrium throughout the sweep. Also, you should be certain to program a sufficiently long start delay time to allow the device to reach equilibrium before the sweep begins when sweeping from inversion to accumulation.

Briefly, time parameters are defined as follows:

**Start Delay:** An additional delay period at the beginning of the first bias step.

**Step Time:** The time period for each bias step for stair waveform.

**Pulse On:** The on period of each pulse for pulse stair waveform.

Stop Delay: An additional delay period at the end of the sweep.

Pulse Off: The time period between pulses for the pulse stair waveform.

4. Enter the bias voltage parameters necessary to bias the device into accumulation and inversion during the sweep. Briefly, bias voltage parameters are defined as follows:

First Bias V: The first DC bias voltage step value.

Bias Step V: The incremental change in the bias voltage waveform.

Last Bias V: The last DC bias voltage step value.

Default Bias V: The DC bias voltage applied to the device after a sweep, and during pulse off time.

5. If you have a light connected to your system, program the desired light on time.
6. Enter the cable calibration filename where indicated (see paragraph 2.5 for cable calibration details).
7. After you have entered all your parameters, select Save, then enter the desired filename at the prompt.
8. Select OK to return to the main menu.

### Step 3: Perform a C-V Measurement

1. From the main menu, press <Alt>-R, then select C-V. The window shown in Figure 4-3 will be displayed. Note that capacitance, conductance, and voltage bias

readings are continuously updated and displayed. At the bottom of the window, four selections allow you to perform the following:

Start Sweep: Starts the C-V sweep.

Enable/Disable Zero: Toggles Model 590 zero on or off.

Enable/Disable Light: Toggles the light on/off if you have a light connected to the Model 230-1 digital I/O port.

Cancel: Exits this window and returns you to the main menu.

2. Make sure that the probes are up and that zero is turned off (select Disable Zero).
3. Allow the reading to settle, then select Enable Zero to null any offsets in the system.
4. Place the probes down on the test dots.
5. If you are using a light, turn the light on until the device reaches equilibrium. Turn the light off before starting the sweep.
6. Select Start Sweep to begin the sweep. After a message that instruments are being configured, the window shown in Figure 4-4 will be displayed. Note that the sweep time, start voltage, and stop voltage are displayed during the sweep, and you can press any key to halt the sweep.
7. After the sweep is completed, a message indicating that data is being read from the Model 590 will be displayed, and you will be prompted as to whether or not you want to determine  $C_{MIN}$ .

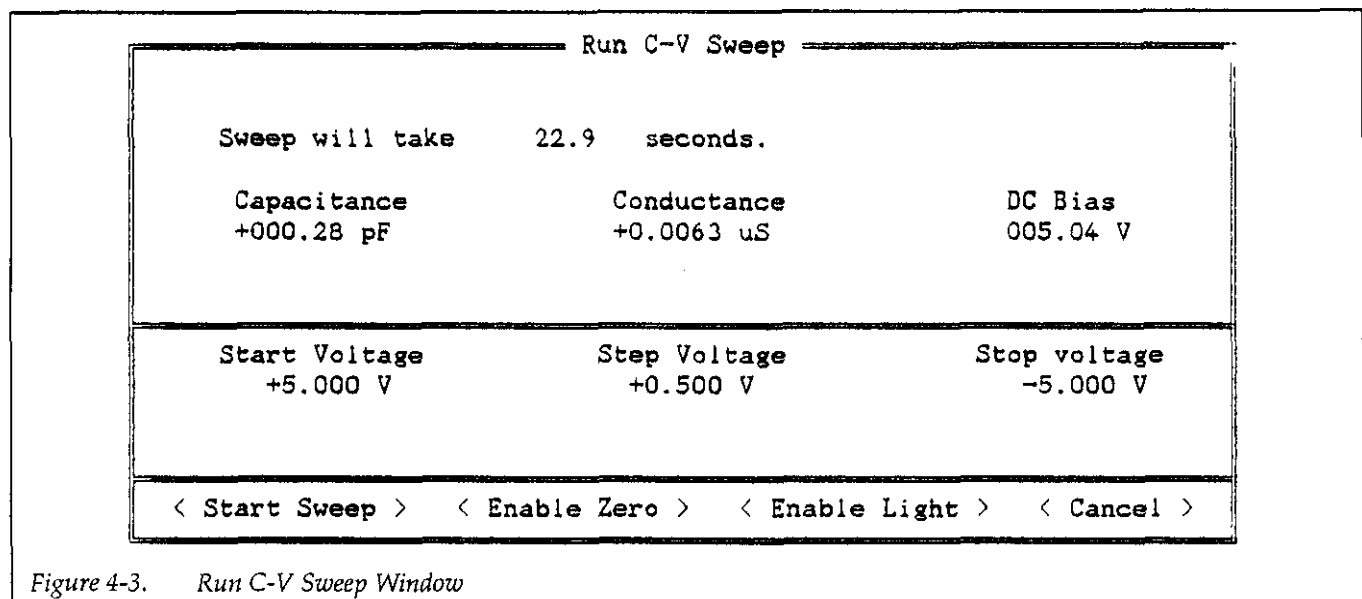


Figure 4-3. Run C-V Sweep Window

8. Select auto or manual on the displayed menu to determine  $C_{MIN}$ , then refer to paragraph 4.2.4 below. Select Cancel if you do not wish to determine  $C_{MIN}$ , and

the window shown in Figure 4-5 will be displayed.  
9. Select Sweep Done to return to the main menu.

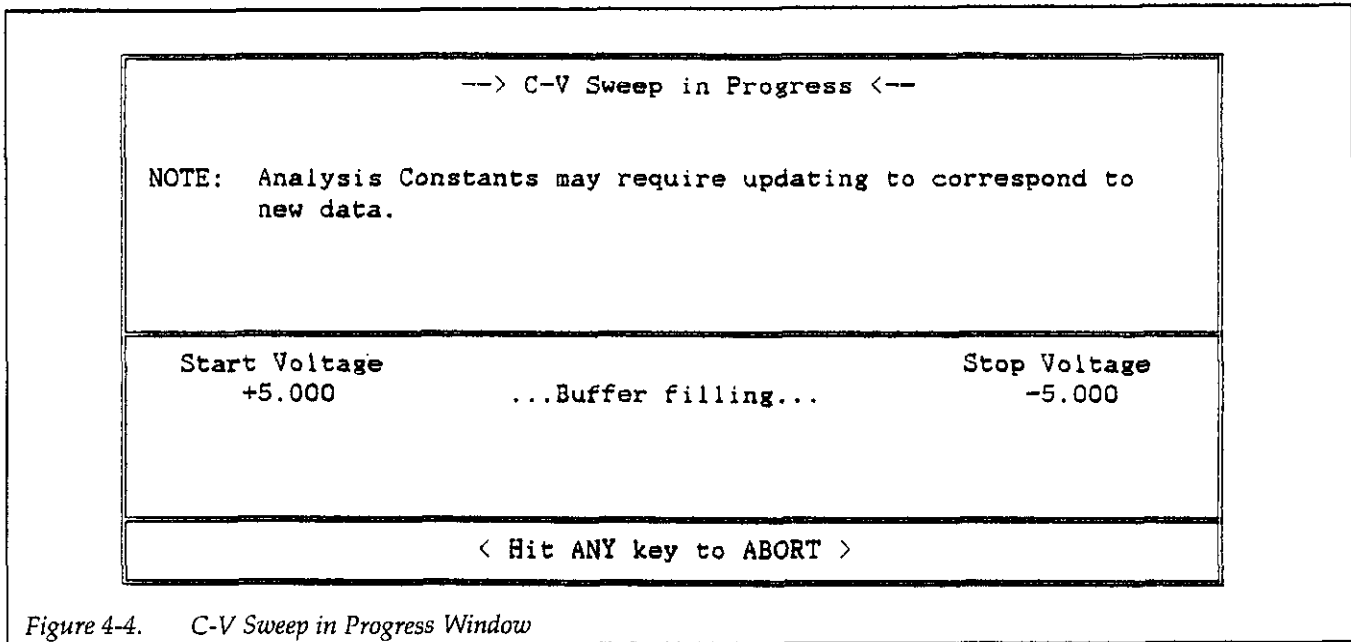


Figure 4-4. C-V Sweep in Progress Window

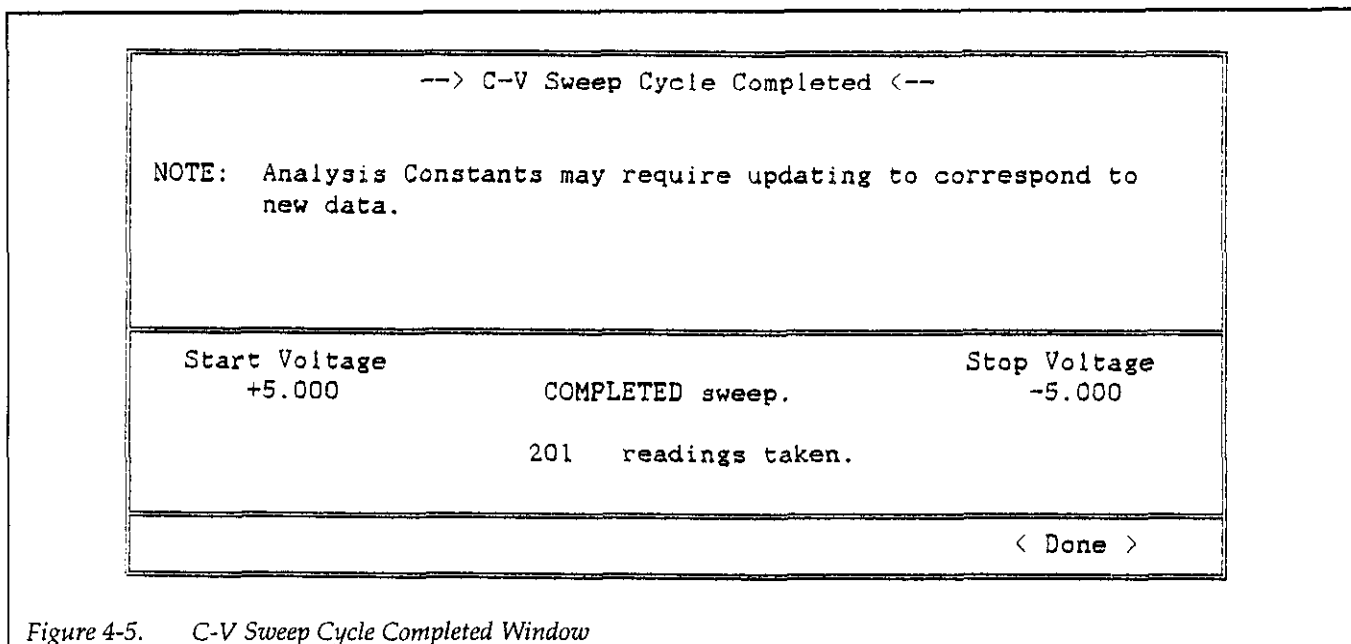


Figure 4-5. C-V Sweep Cycle Completed Window

#### Step 4: Save and Analyze C-V Data

1. From the main menu, press <Alt>-A, then select C-V.
2. To save your C-V data, press <Alt>-F to select file operations, then choose Save. Enter the desired filename to save the data.
3. Return to the C-V Analysis menu, then press <Alt>-D to display data arrays or constants. You can also use <Alt>-P to print array values or constants on your printer.
4. To graph C-V data, press <Alt>-G while in the C-V ANALYSIS menu. Typical C-V graphs include C vs. V and G vs. V.

#### 4.2.4 Determining $C_{MIN}$

$C_{MIN}$  is the minimum equilibrium high-frequency capacitance with the device biased in strong inversion. The correct value of  $C_{MIN}$  is important for calculating average doping,  $N_{AVG}$ , for determining optimum C-t measurement time, and for accurate Zerbst plots. You can determine  $C_{MIN}$  automatically or manually by using the appropriate procedure outlined below. Note that the  $C_{MIN}$  analysis constant (Section 5) is updated with the new  $C_{MIN}$  value determined by either of these methods.

##### Manual Method

The manual method requires that you manually select an appropriate inversion bias voltage. You can use the manual procedure either with or without a light, although the time to reach equilibrium will be much longer without a light.

Proceed as follows:

1. At the end of each C-V sweep, the window shown in Figure 4-6 will be displayed. To determine  $C_{MIN}$  manually, select Manual, or select Cancel to exit the window without determining  $C_{MIN}$ .
2. Note that inversion voltage window shown in Figure 4-7 is displayed. This window displays the current bias voltage and gives you the opportunity to change or apply the voltage.

##### WARNING

**Hazardous voltage may be applied to the device if an optional Model 230-1 Voltage Source is being used. Use caution when working with voltages greater than 30V.**

3. If you are satisfied with the displayed inversion voltage, select Apply Voltage, or choose New Voltage if you wish to program a new voltage.
4. If you choose to program a new inversion voltage, the window shown in Figure 4-8 will be displayed. Type in the desired voltage, press <Enter>, then select Apply Voltage when finished.

##### NOTE

When programming the voltage, be sure to choose a value that will bias the device in strong inversion.

5. The window shown in Figure 4-9 will be displayed. Turn on the light for a period sufficiently long for the device to reach equilibrium, then turn off the light before proceeding. Select OK after turning off the light; the program will then display the measured value of  $C_{MIN}$  (Figure 4-10) and the  $C_{MIN}$  value taken from C-V sweep data. Select OK to accept the value, or choose Repeat to repeat the procedure. Select Cancel to leave  $C_{MIN}$  unchanged. You can also use this manual procedure without a light, but the time to reach equilibrium will typically be much longer.

##### Auto Method

The auto method of determining  $C_{MIN}$  is fully automatic, with no operator intervention required.

##### NOTE

In order to use the auto method, you must have a light connected to the digital I/O port of the optional Model 230-1 Voltage Source. Refer to paragraph 2.4.4 for details on connections. Also, you must configure the software for light operation during installation or re-configuration.

The auto  $C_{MIN}$  method uses the cutoff method shown in Figure 4-11. The device is initially biased in accumulation with the light off, then biased in deep depletion, also with the light off. The device is then biased in inversion with the light on, and the capacitance is allowed to decay to  $C_{MIN}$  with the light off. Note that the light on and light off times are both determined by the programmed Light On-Time parameter, which can be set using the C-V parameters setup menu.

To use the auto method, simply select Auto at the Auto/Manual prompt.  $C_{MIN}$  will be automatically measured and updated.





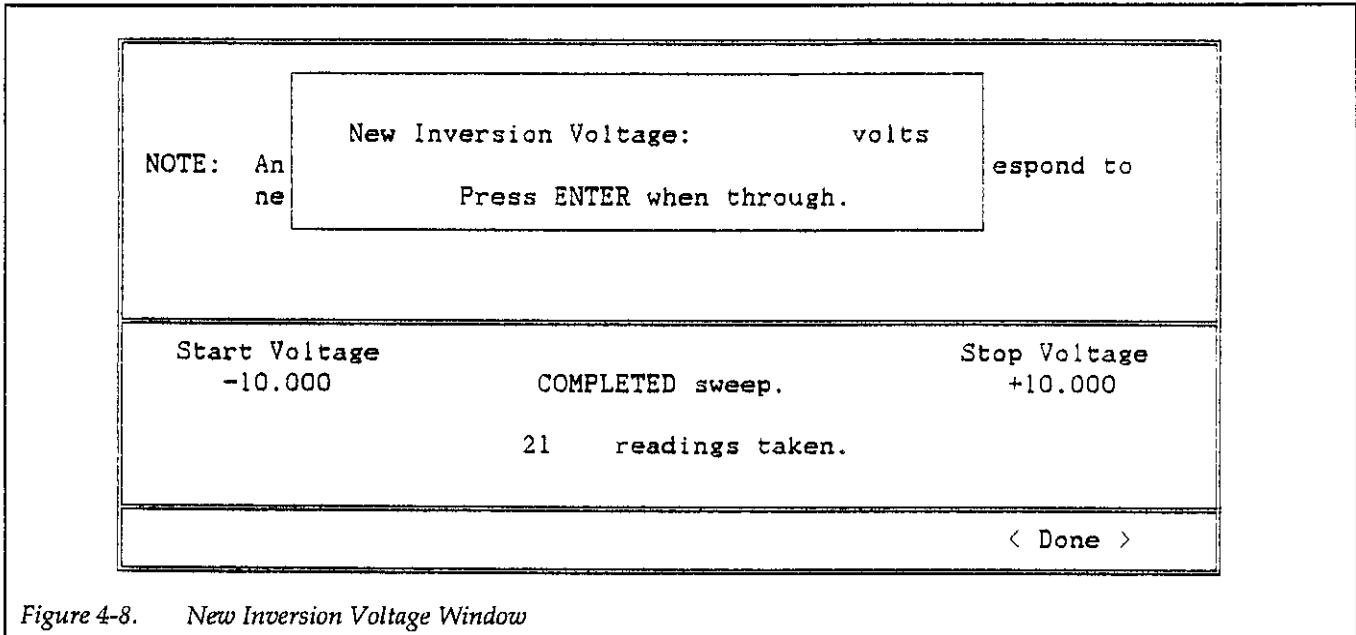


Figure 4-8. New Inversion Voltage Window

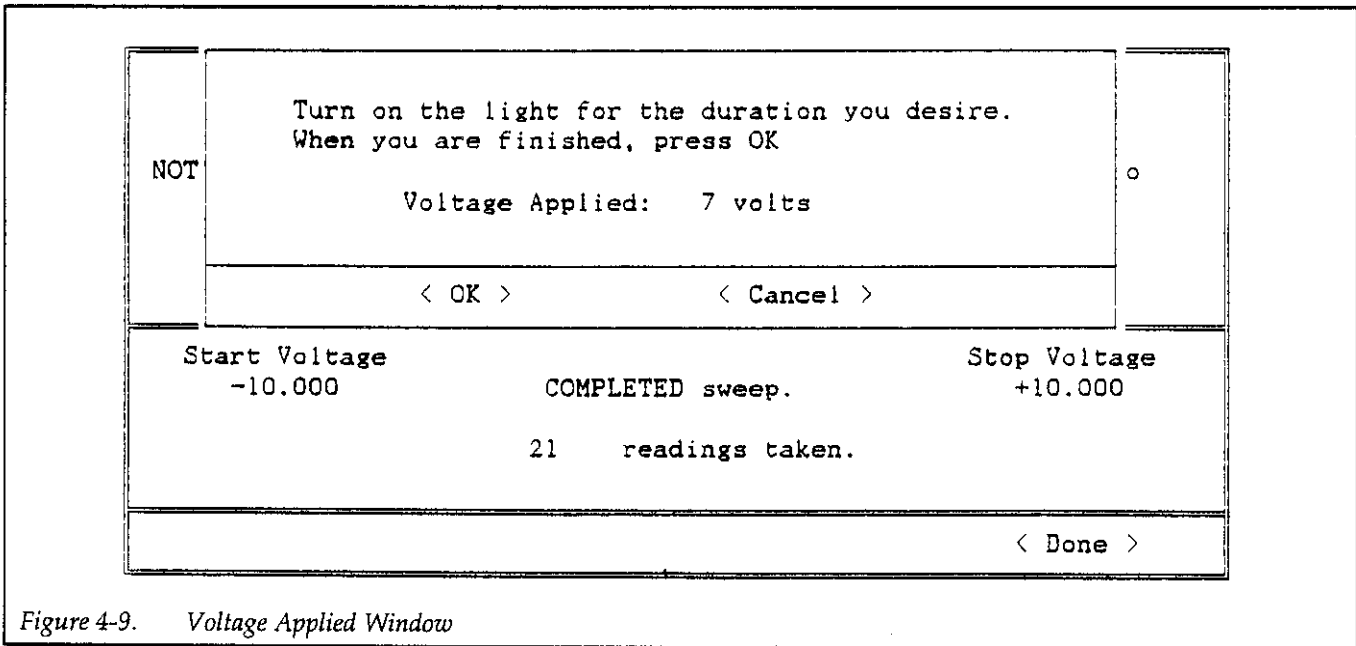


Figure 4-9. Voltage Applied Window

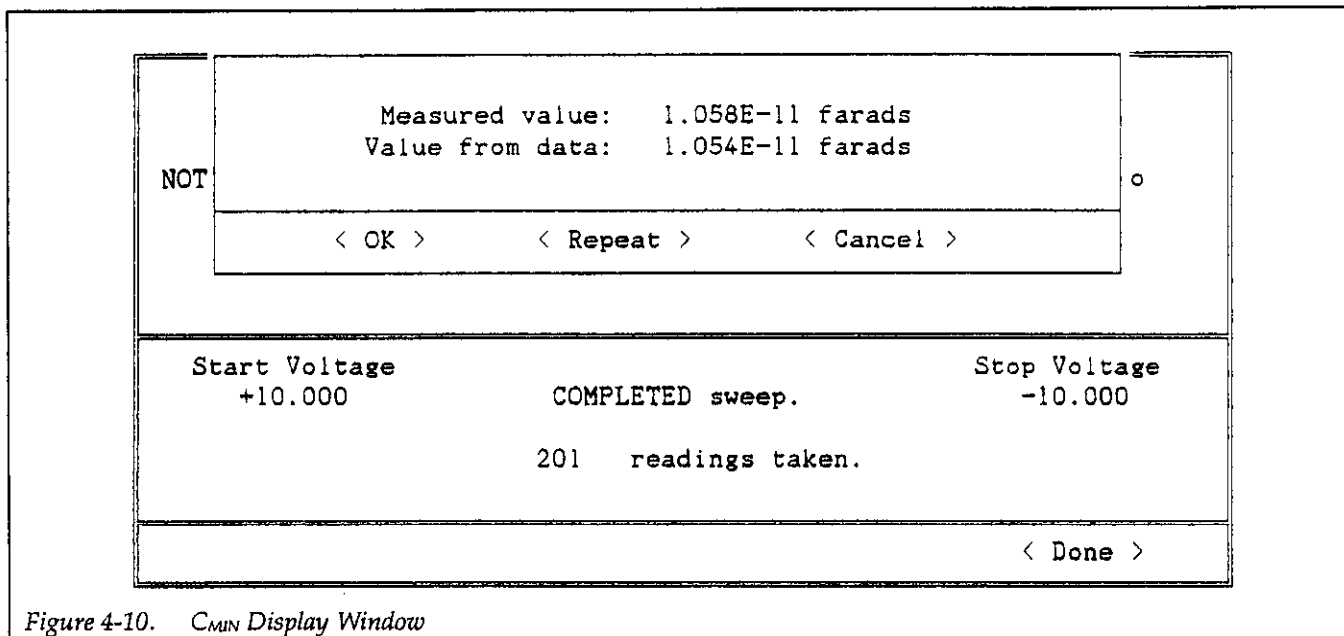


Figure 4-10.  $C_{MIN}$  Display Window

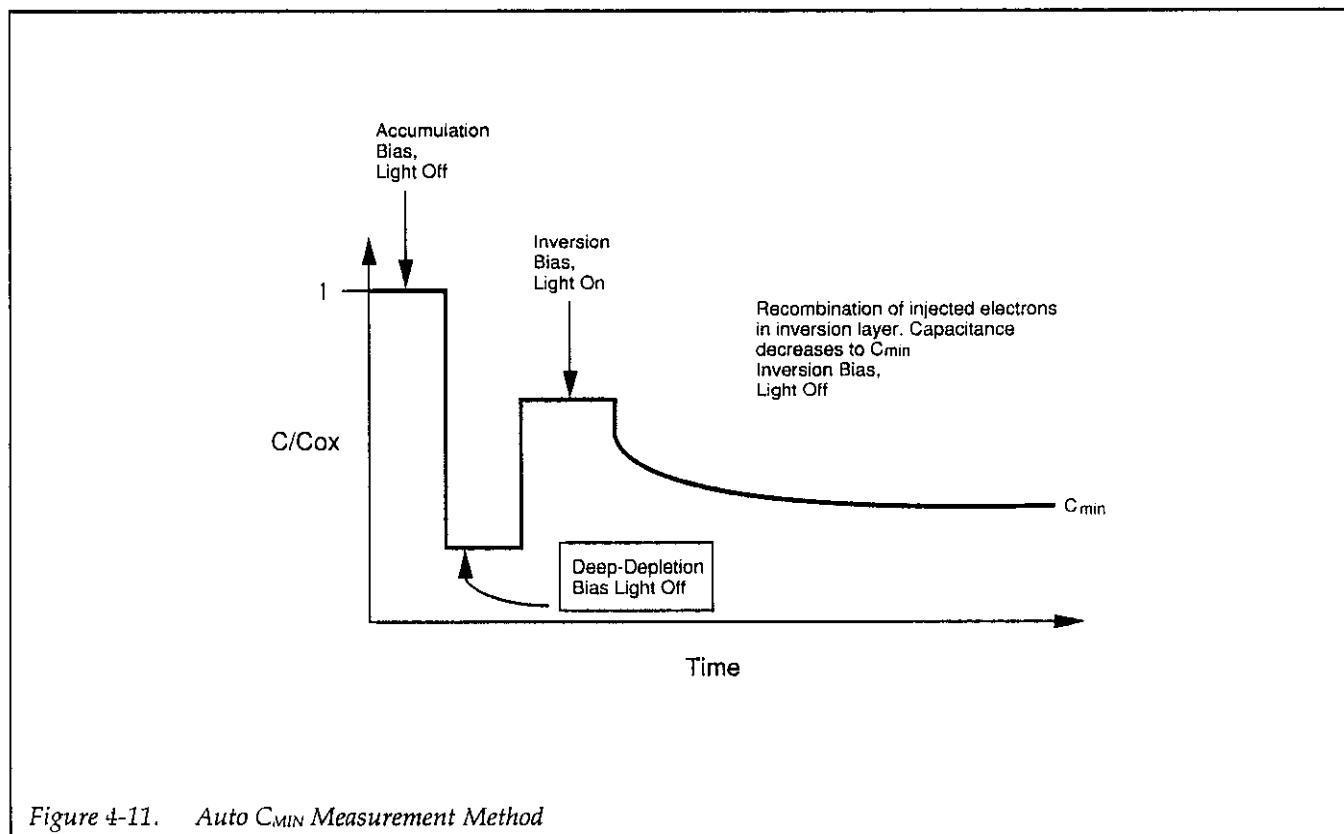


Figure 4-11. Auto  $C_{MIN}$  Measurement Method

### 4.3 C-t MEASUREMENTS

Basic C-t measurements involve setting up your C-t measurement parameters, connecting the Model 590 to the DUT, and performing the test procedure outlined below.

#### NOTE

The basic C-t test procedure cannot use switching or sequencing to test multiple DUTs. To perform C-t measurements on multiple DUTs, setup a Zerbst test sequence and select the no C-V option. See paragraph 4.6 for details.

#### 4.3.1 C-t Measurement Connections

Test connections used for basic C-t measurements are the same as those used for basic C-V measurement and are shown in Figure 4-1. Keep the following points in mind when making connections.

- Keep cable lengths as short as possible (five meters maximum).
- Use only 50Ω (RG-58) cables such as the Model 7051.
- Match all instrument, cable, and adapter impedances to as close to 50Ω as possible.
- Minimize the total number of connections to avoid losses caused by inevitable mismatch at connecting points.
- Shield probes as close to wafer as possible, and shield wafer with Faraday shield.
- Cable correct the system before making measurements (paragraph 2.5).
- Connect INPUT to gate, OUTPUT to substrate to minimize noise.

#### 4.3.2 Choosing Optimum C-t Measurement Parameters

##### Choosing Optimum Voltages

When setting up C-t measurement parameters, you can set the default bias and test bias voltages to step from accumulation to inversion, from depletion to inversion, or from inversion to strong inversion. Accumulation, depletion, and inversion boundaries can be determined by running a C-V measurement on the device, as discussed in paragraph 4.2. Note that the flatband voltage ( $V_{FB}$ ) re-

gion separates the accumulation and depletion regions, and the threshold voltage ( $V_{TH}$ ) separates depletion from inversion (see Figure 4-2).

##### Accumulation to Inversion

Stepping from accumulation to inversion provides the most active bias condition for interface traps. During accumulation, the surface is accumulated, and interface traps are filled. When inversion bias is applied, the surface is initially depleted, and the filled interface traps contribute to filling the inversion layer during the initial period of the transient voltage before shielding minimizes the effects of interface traps.

##### Depletion to Inversion

Stepping from depletion to inversion minimizes interface trap effects, but this method does not provide initial shielding. While the device is biased in depletion, the surface is depleted, and interface traps are partially filled. When the inversion bias is applied, only a small amount of the inversion layer charge is transferred from interface traps.

##### Inversion to Strong Inversion

Stepping from inversion to strong inversion provides bias conditions that result in the least amount of interface trap effects. During inversion, the inversion layer is populated, and interface traps are shielded. During strong inversion, the inversion layer shields interface traps from contributing to additional generation.

##### Choosing Optimum C-t Measurement Time

The total time period of a C-t measurement is determined by the sample time and the number of samples in the measurement. These two parameters should be carefully chosen to obtain the optimum C-t measurement time. If you choose a measurement time that is too short, only a portion of the transient capacitance waveform will be measured. If you program too many samples, only a few samples will be taken during the important transient portion of the waveform, with the majority of the samples being taken at the end point where the capacitance has reached its final value.

One recommended method for determining optimum C-t measurement time is to set parameters resulting in a

capacitance cutoff point of 95% of  $C_{MIN}$ . The basic procedure for this method is as follows:

1. Perform a C-V sweep on the device, as outlined in paragraph 4.2. Be sure to program start and stop voltages that bias the device well into accumulation and inversion during the sweep (see Figure 4-2). Also be sure that step time is sufficiently long so that the device remains in equilibrium throughout the sweep.
2. Determine  $C_{MIN}$ , as covered in paragraph 4.2.4.
3. Return to the Setup/Run main menu, then setup your preliminary C-t measurement parameters (refer to paragraphs 3.3 and 4.3.3 below).
4. From the main menu, press <Alt>-R, then select C-t to run the C-t measurement.
5. After the main measurement, return to the main menu, press <Alt>-A, then select C-t.
6. Press <Alt>-G, then choose a C vs. t plot to generate a plot of your C-t measurement.
7. Note the final capacitance value in the C-t measurement (if you require a more-precise value, use the Display menu selection to display C vs. t information in numerical form).
8. Repeats steps 3 through 7 until you obtain a final capacitance value equal to 95% of the value of  $C_{MIN}$  obtained in step 2. Parameters to adjust are the sample time and number of samples.

### 4.3.3 C-t Measurement Procedure

The step-by-step procedure below, outlines the basic procedure for making C-t measurements. For more information on setting up C-t parameters, refer to paragraph 3.3, Section 3. Section 5 covers C-t analysis in more detail.

#### Step 1: Connect the Test Equipment

Connect the Model 590 to the test fixture or probe station using the connections outlined in Figure 4-1.

#### Step 2: Setup C-t Measurement Parameters

1. From the main menu, press <Alt>-S, and select C-t setup to display the C-t parameters menu.
2. Select the various measurement parameters such as range, frequency, model, and rate, as required. Use the up/down and left/right arrow keys to move around the parameter screen.
3. Enter the number of samples to take for the C-t measurement. Be sure to review the recommendations discussed in paragraph 4.3.2 for optimum number of

samples and sample time, both of which determine measurement time.

4. Choose the various time/delay parameters. Briefly, time parameters are defined as follows:

**Start Delay:** An additional delay before the first sample in the C-t measurement is taken.

**Sample Time:** The time period between individual samples in the C-t measurement.

**Stop Delay:** An additional delay after the last sample before the end of the C-t measurement cycle.

5. Enter the bias voltage parameters necessary to bias the device as required both before and during the sweep. Briefly, bias voltage parameters are defined as follows:

**Default Bias V:** The DC bias voltage applied to the device both before and after the C-t measurement.

**Test Bias V:** The DC bias voltage applied to the device during the C-t measurement.

6. Enter the cable calibration filename where indicated (see paragraph 2.5 for cable calibration details).
7. After you have entered all your parameters, select Save, then enter the desired filename at the prompt.
8. Select OK to return to the main menu.

#### Step 3: Perform a C-t Measurement

1. From the main menu, press <Alt>-R, then select C-t. The window shown in Figure 4-12 will be displayed. Capacitance, conductance, and bias voltage readings are displayed as shown.

#### NOTE

Conductance and bias voltage readings are not available when the 1000/sec reading rate is used.

The selections at the bottom of the window allow you to perform the following:

**Start Sweep:** Starts the C-t sweep.

**Enable/Disable Zero:** Toggles Model 590 zero mode on or off.

**Enable/Disable Light:** Toggles the light on or off.

**Cancel:** Exits the window and returns to the main menu.

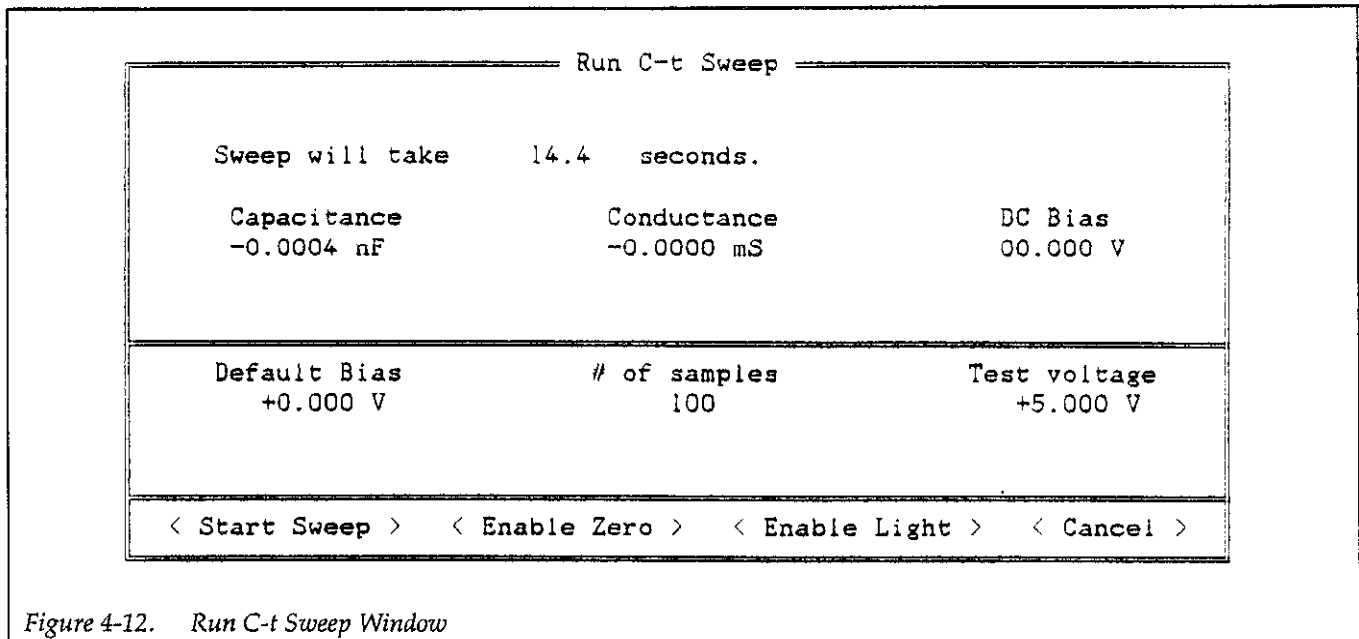


Figure 4-12. Run C-t Sweep Window

2. Make sure that the probes are up and that zero is turned off.
3. Allow the reading to settle, then select Enable Zero to null any offsets in the system.
4. Place the probes down on the test dots.
5. If you are using a light, turn the light on until the device reaches equilibrium. Turn the light off before starting the sweep.
6. Select Start Sweep to begin the sweep. After the instruments are initialized and configured, the window shown in Figure 4-13 will be displayed. Note that the sweep length, test voltage, and number of samples in the sweep are displayed, and you can press any key to abort the sweep.
7. After the sweep is completed, the window shown in Figure 4-14 will be displayed.

8. Select Done to return to the main menu.

#### Step 4: Save and Analyze C-t Data

1. From the main menu, press <Alt>-A, then select C-t.
2. To save your C-t data, press <Alt>-F to select file operations, then choose Save C-t Data. Enter the desired filename to save the data.
3. Return to the C-t Analysis menu, then press <Alt>-D to display data arrays or constants. You can also use <Alt>-P to print array values or constants on your printer.
4. To graph C-t data, press <Alt>-G while in the C-t ANALYSIS menu. Typical C-t graphs include C vs. t and Zerbst analysis.

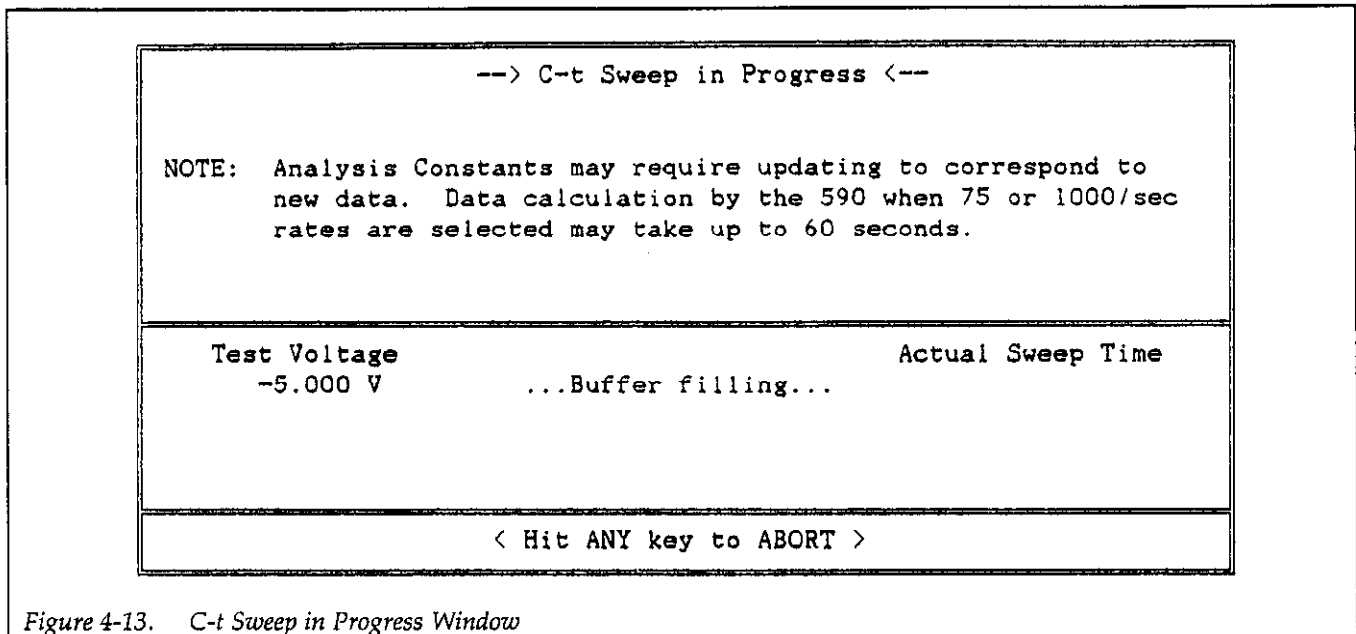


Figure 4-13. C-t Sweep in Progress Window

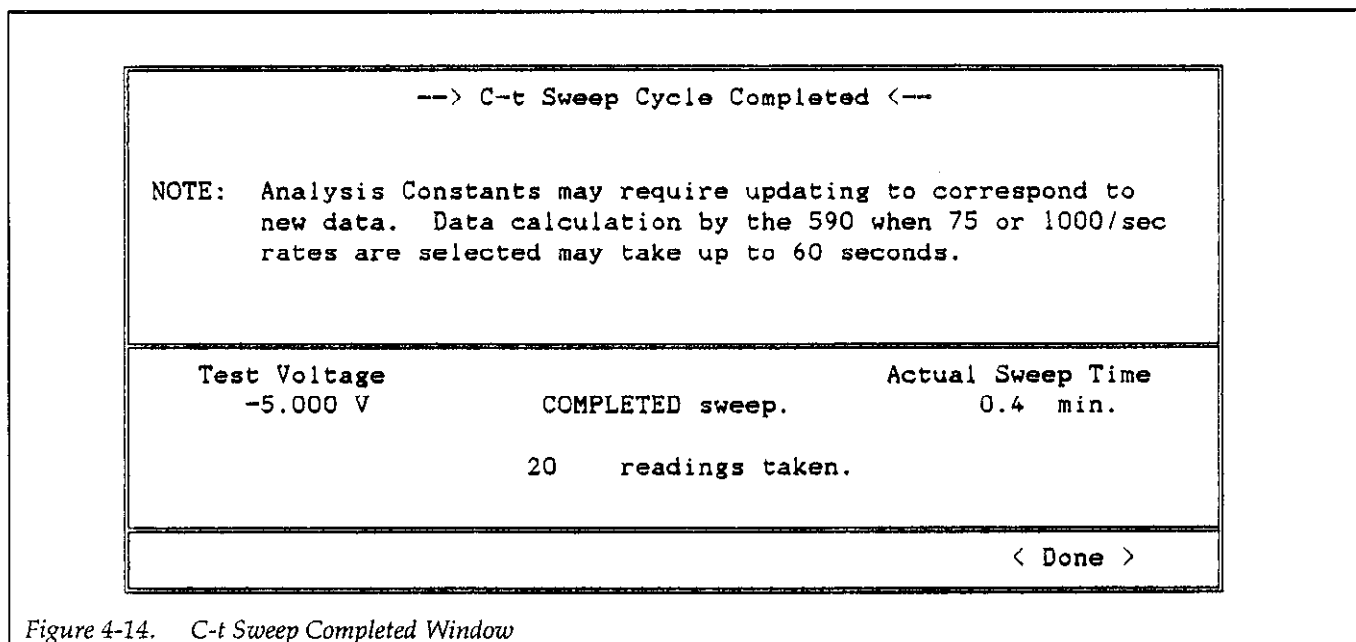


Figure 4-14. C-t Sweep Completed Window

## 4.4 BTS STRESS CYCLE

A BTS stress cycle can either be performed alone or as part of the BTS test sequence (paragraph 4.5). Basic stress cycle setup and measurement are covered in the following paragraphs. For more complete details on stress cycle parameters, refer to paragraph 3.4 in Section 3.

### 4.4.1 Hot Chuck Connections

Before performing a stress cycle, the hot chuck must be set up per the manufacturer's instructions. The Model 5958 software is designed to work with the Temptronic Model 0315B Thermochuck, but the hot chuck control file can be modified for use with other hot chucks, as described in Section 6.

#### NOTE

If the chuck is grounded, the Model 590 must be set up for floating operation. To do so, set the rear panel ANALOG COMMON GROUNDING switch to the ungrounded position

### 4.4.2 Selecting Optimum Voltage, Temperature, and Time Parameters

A bias temperature stress cycle is a combined stress of a bias voltage applied to a device while at a high temperature for specific period of time. The purpose of the stress cycle is to cause mobile ions to move across the oxide (insulator) of an MIS device. The transit time required for mobile ion drift varies inversely with the stress voltage and exponentially with  $1/T$ .

#### Stress Temperature

Practical limitations generally dictate the stress temperature. A minimum of 200°C is usually required to keep the stress time sufficiently short. The maximum temperature available from commercial hot chucks is usually in the neighborhood of 300°C to 350°C. At high temperatures, the device under test may undergo annealing, which must be taken into account.

#### Stress Voltage

The general rule of thumb for selecting a stress voltage is a value of about 10<sup>6</sup>V/cm of oxide thickness. Thinner ox-

ides require and tolerate lower voltages than do thicker oxides.

#### Stress Cycle Types

The most common method used is the positive then negative stress cycle. The positive stress cycle causes the positive charge to move from its initial position near the metal gate material across the insulator to the semiconductor. As a check, a negative stress cycle is then applied to force the charge back to the metal gate material. In some cases, only a positive stress cycle is used, but the additional negative stress cycle is recommended for maximum measurement reliability.

With a polysilicon gate material and some etching methods, the initial distribution of the ionic charge may not occur at the metal interface. Consequently, both positive and negative stressing is essential for these devices. If the initial charge distribution occurs at the semiconductor instead of at the metal, applying negative stress first is more desirable.

### 4.4.3 Performing a BTS Stress Cycle

#### Step 1: Program BTS Stress Cycle Parameters

1. From the main menu, Press <Alt>-S, then select BTS Cycle.
2. Select the 590 Internal sweep source if you are using only the Model 590, or select the 230-1 External sweep source if you are using an optional Model 230-1 Voltage Source.
3. Program the + Stress V, - Stress V, and Stress OFF V parameters to the desired values. Briefly, these parameters are defined as follows:

+ Stress V: Voltage applied to device during the positive stress cycle.

- Stress V: Voltage applied to device during negative stress cycle.

Stress OFF V: Voltage applied to device during stress off cycle.

4. Enter the desired stress temperature and stress time parameters where indicated. These parameters are defined as follows:

Stress Temp: The temperature of the device during the stress cycle.

Stress OFF Temp: The temperature of the device at times other than during the stress cycle.

Stress Time: The time duration of the stress cycle.

5. Select Save, then save your parameters using the desired filename.
6. Select OK to return to the main menu.

**Step 2: Perform the BTS Stress Cycle**

1. From the main menu, press <Alt>-R, then choose BTS Cycle. Select positive or negative cycle, and the window shown in Figure 4-15 will be displayed. Information shown includes stress time, capacitance, DC bias voltage, stress off temperature, present temperature, stress on temperature, and current elapsed

time. Selections at the bottom of the screen allow you to select the following:

Start Cycle: Starts the BTS stress cycle.

Cancel: Exits this window and returns you to the main menu.

2. Select Start Cycle, and note that the window shown in Figure 4-16 will be displayed. While the stress cycle is in progress, parameters that are changing, such as capacitance, stress time, and current temperature, will be continuously updated. You can choose to abort the cycle at any time, if desired.
3. When the cycle has been completed, the window shown in Figure 4-17 will be displayed, and you can select Done to return to the main menu.

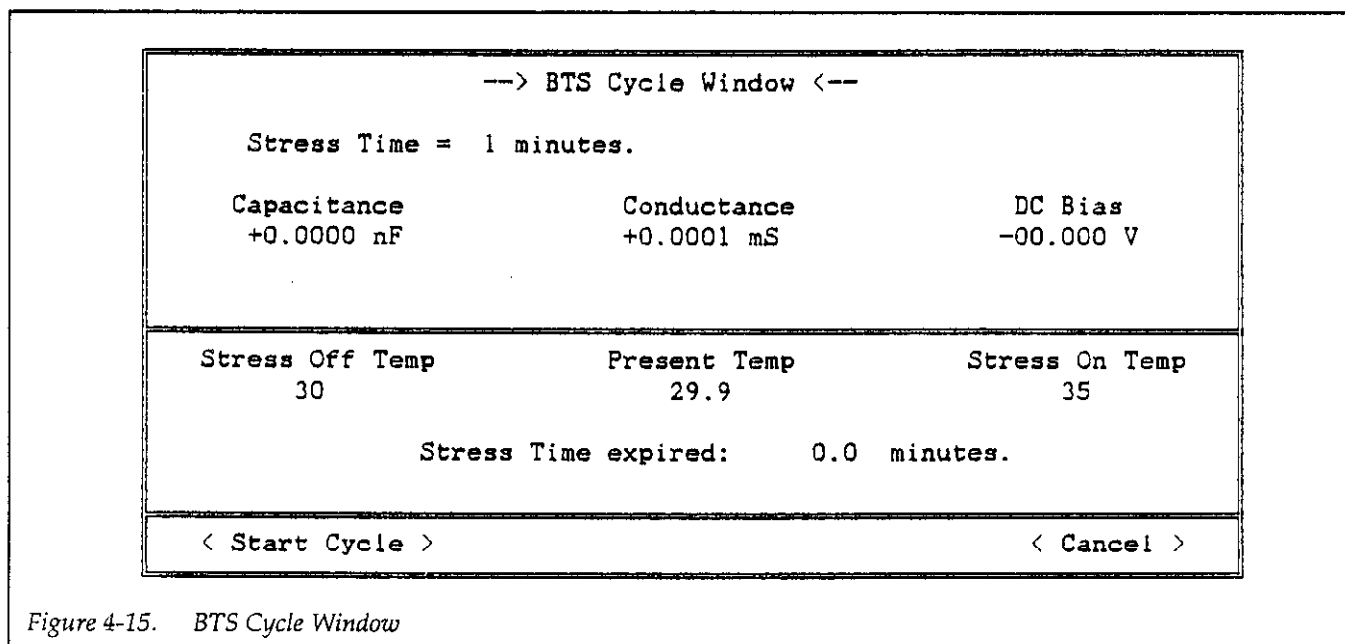


Figure 4-15. BTS Cycle Window



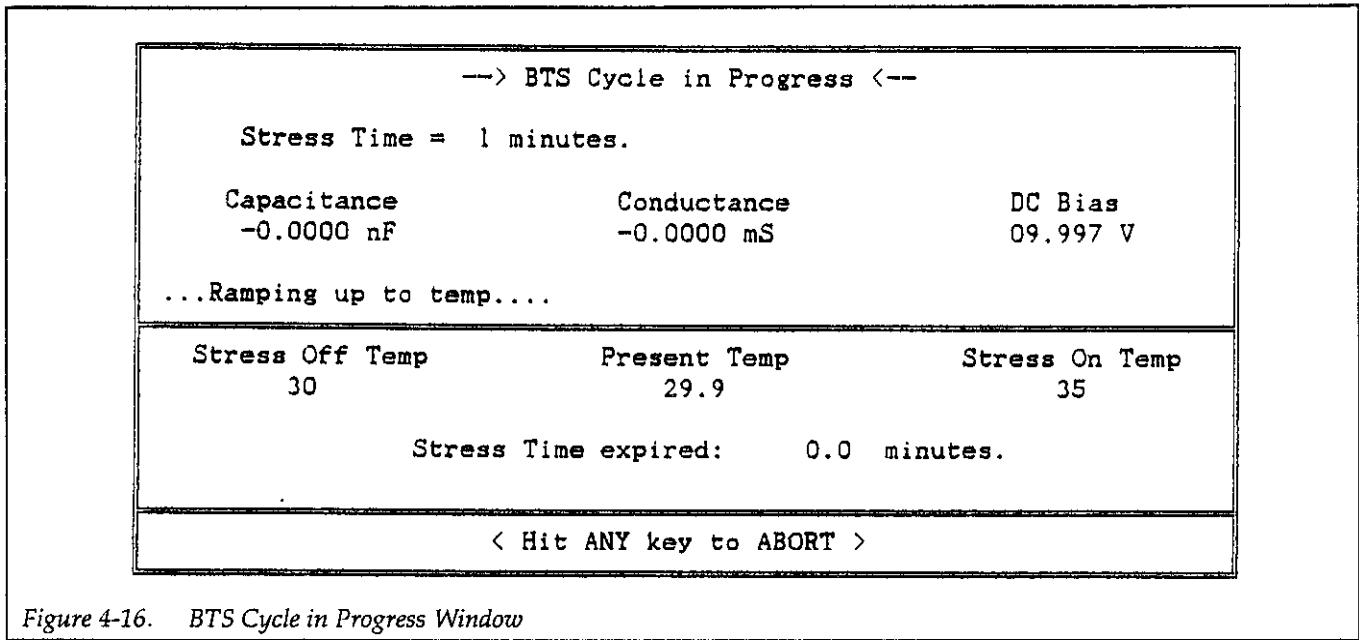


Figure 4-16. BTS Cycle in Progress Window

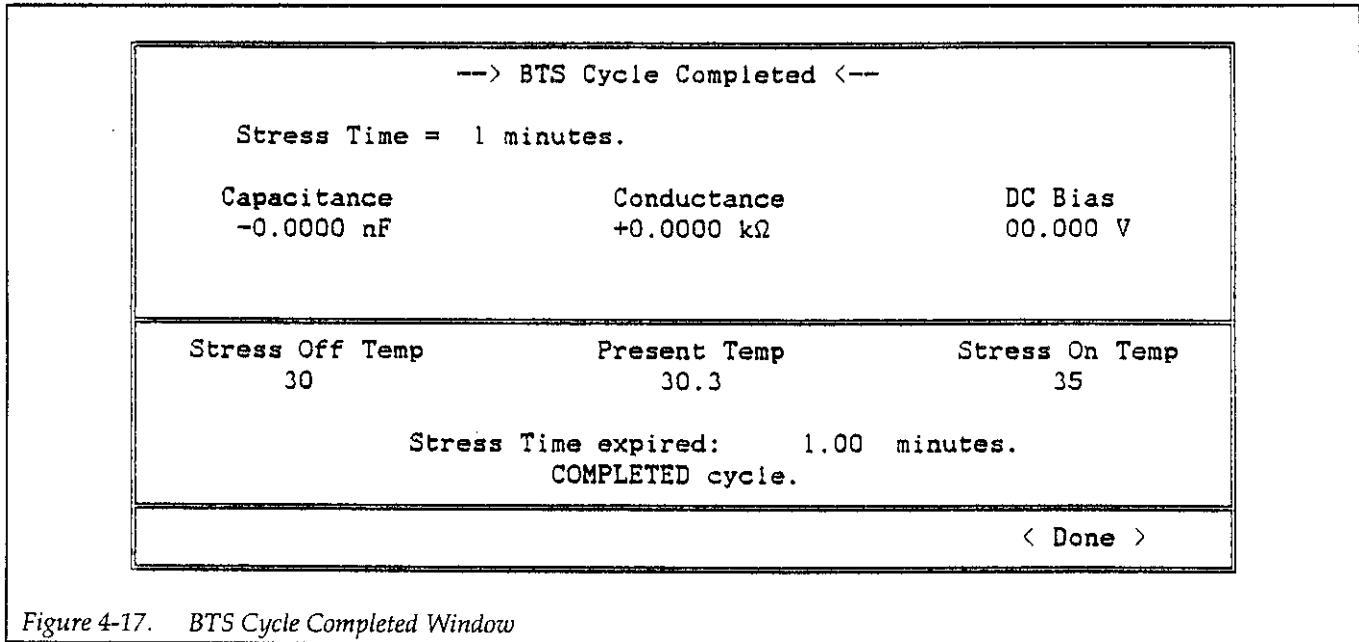


Figure 4-17. BTS Cycle Completed Window

## 4.5 BTS TEST SEQUENCE MEASUREMENTS

The following paragraphs discuss BTS test sequence connections and outline the basic BTS test sequence measurement procedure.

### 4.5.1 BTS Test Sequence Connections

In order to perform BTS or Zerst sequence tests on more than one device, you must either connect a suitable switching card to your system, or use an automatic probe sequencer (a probe sequencer cannot be used for BTS parallel tests, however). Connections for several switching methods are covered in the following paragraphs. When making connections, keep the following points in mind:

- Keep cable lengths as short as possible (five meters maximum).
- Use only 50 $\Omega$  (RG-58) cables such as the Model 7051.
- Match all instrument, cable, and adapter impedances to as close to 50 $\Omega$  as possible.
- Minimize the total number of connections to avoid losses caused by inevitable mismatch at connecting points.
- Shield probes as close to wafer as possible, and shield wafer with Faraday shield.
- Perform cable correction for each path before making measurements (paragraph 2.5).
- When possible, connect Model 590 output and input jacks to card paths as far apart as possible in order to maximize isolation and minimize stray capacitance.
- Use shortest pathways on card where possible.
- Select switching parameters so that INPUT is connected to gate and OUTPUT is connected to substrate.

#### Connections for Sequential Stress and No Stress Tests

Figure 4-18 shows typical connections using a Model 7062 RF switch card to switch among up to five devices. Two such cards can be installed in a single Model 705 Scanner to extend the test capability to ten devices. Ten switch cards can be installed in a Model 706 Scanner, allowing up to 50 devices to be switched with one mainframe. The Model 7062 maintains a nominal 50 $\Omega$  impedance to minimize test signal degradation.

Note that all test connections shown in Figure 4-18 are made using Model 7051 50 (RG-58) BNC cables. Devices are assumed to be housed in a shielded test fixture or probe station (not shown on the diagram). The test configuration shown can be used for all BTS sequence and

Zerst sequence tests except for BTS parallel test sequence, which requires parallel switching for the stress part of the test (see below).

#### Connections for All Test Sequences

The switch card connections discussed below can be used for all BTS test sequences (sequential, parallel, and no stress), as well as for all Zerst test sequences (paragraph 4.6).

#### Multiplexer Card Connections

A Model 7074D or Model 7075 Eight 1  $\times$  12 3-Pole Multiplexer Card can be used to provide switching for both parallel and sequential tests, as shown Figure 4-19. (For smaller systems with fewer devices to be tested, use Model 7056 cards.) Here, two of eight banks are used to multiplex or switch up to 12 DUTs, but multiplexer banks can be combined, allowing up to 48 devices to be switched from one card.

In this configuration, the Model 590 input and output jacks are connected to Row A and Row B, while the DUTs are connected to the bank inputs. Note that these cards are not equipped with standard BNC connectors, so custom-dressed cables must be constructed in order to use this configuration. Cable model numbers are shown on the diagram.

#### Matrix Card Connections

A Model 7073 Coaxial Matrix card can also be used to provide the necessary switching functions, as shown in Figure 4-20. Although only 12 DUTs per card can be switched with this configuration, the Model 7073 has two main advantages over the Model 7074D/7075 card discussed above:

- Matrix configuration allows greater switching flexibility, especially when adding additional measuring capabilities such as I-V testing.
- High-frequency design, resulting in lower crosstalk and better noise performance when making C-V measurements.

Since the Model 7073 is equipped with BNC connectors, all connections can be made using Model 7051 50 $\Omega$  (RG-58) cables. Again, DUTs are assumed to be located in a shielded test fixture or probe station equipped with BNC connectors.

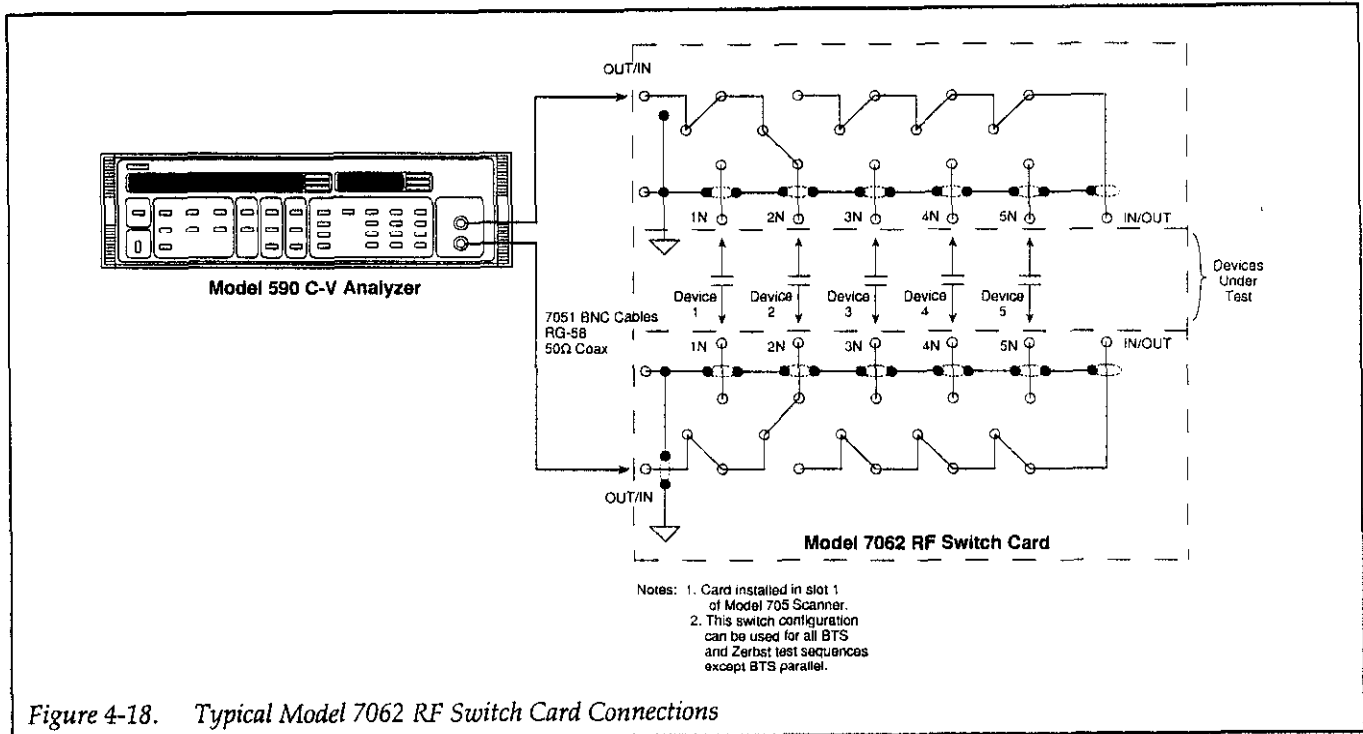


Figure 4-18. Typical Model 7062 RF Switch Card Connections

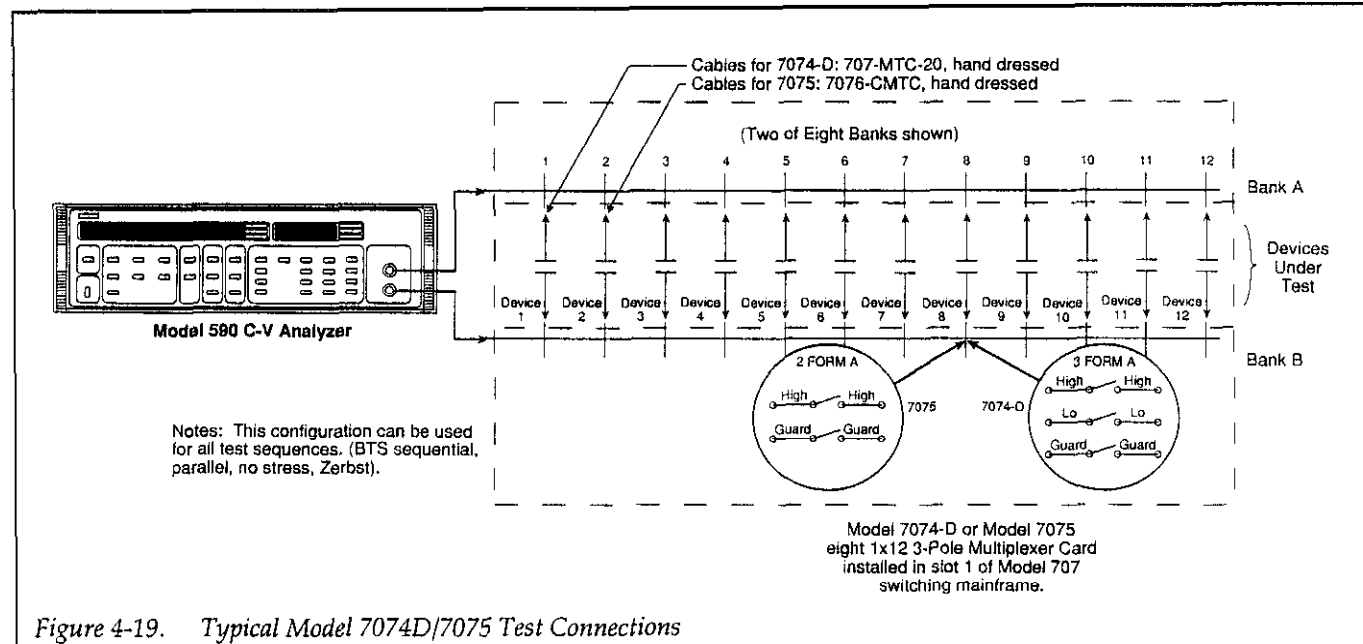


Figure 4-19. Typical Model 7074D/7075 Test Connections

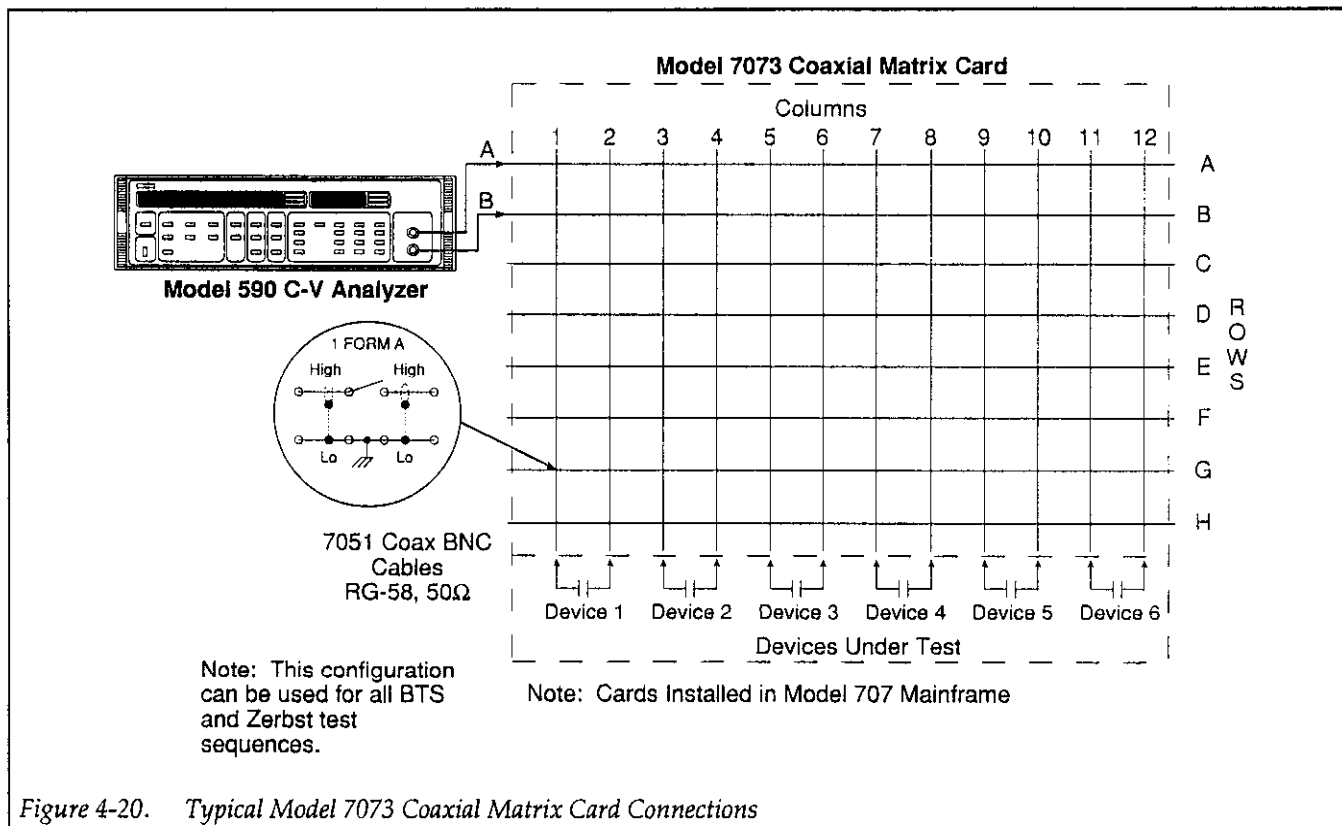


Figure 4-20. Typical Model 7073 Coaxial Matrix Card Connections

### Switch Control Files

The switch control files for the three connection examples above are summarized in Tables 4-1, 4-2, and 4-3. The basic procedure for creating these files is outlined below. (Refer to Section 6 for complete information on switch control files, and refer to Appendix J for information on default switch control files.) This procedure requires the use of a text editor or a word processor that can store files in pure ASCII format.

1. Run your text editor or word processor.
2. Enter each program code line as shown in the corresponding table. Be sure to enter only the program code; do not enter the line number or the comments. Be sure to enter the appropriate cable calibration filenames at the end of each DEVICE statement (see paragraph 4.5.2 for more information on cable calibration).

### NOTE

For the parallel BTS test sequence only, include the PARALLEL statement and associated parameters as shown. For all other test sequences (sequential, no stress, or Zerbst sequences), the PARALLEL statement is ignored.

3. Save the file in pure ASCII format using the .SWC extension. Be sure to save the file in the \CTRL subdirectory. An example might be:

```
C:\KTHLY_CV\MODEL58\CTRL\  
MODL7062.SWC
```

4. Enter this switch control filename in the BTS test sequence menu (see below).

Table 4-1. Switch Control File for Model 7062 RF Card Example

Line	Program Code	Comments
1	INIT @17,"R0XA2P0X"	Reset 705, 2-pole mode.
2	DEVICE 1 @17,"C1X","N1X",#CABLE1.CAL	Device 1 close, open commands.
3	DEVICE 2 @17,"C2X","N2X",#CABLE2.CAL	Device 2 close, open commands.
4	DEVICE 3 @17,"C3X","N3X",#CABLE3.CAL	Device 3 close, open commands.
5	DEVICE 4 @17,"C4X","N4X",#CABLE4.CAL	Device 4 close, open commands.
6	DEVICE 5 @17,"C5X","N5X",#CABLE5.CAL	Device 5 close, open commands.
7	FINAL @17,"R0X"	All relays open for safety.

NOTES:

1. Model 7062 assumed to be installed in slot 1 of Model 705.
2. Model 705 primary address = 17.
3. Cable calibration files, CABLEn.CAL assumed to be present in \CAL directory. See paragraph 4.5.2.

Table 4-2. Switch Control File for Model 7074D/7075 Card Example

Line	Program Code	Comments
1	INIT @18,"R0X"	Reset 707.
2	PARALLEL @18,"CA1,B1,A2,B2","NA1,B1,A2,B2X"	Parallel commands
3	PARALLEL @18,"CA3,B3,A4,B4X","NA3,B3,A4,B4X"	
4	PARALLEL @18,"CA5,B5,A6,B6X","NA5,B5,A6,B6X"	
5	PARALLEL @18,"CA7,B7,A8,B8X","NA7,B7,A8,B8X"	
6	PARALLEL @18,"CA9,B9,A10,B10X","NA9,B9,A10,B10X"	
7	PARALLEL @18,"CA11,B11,A12,B12X","NA11,B11,A12,B12X"	
8	DEVICE 1 @18,"CA1,B1X","NA1,B1X",#CABLE1.CAL	Device 1 commands.
9	DEVICE 2 @18,"CA2,B2X","NA2,B2X",#CABLE2.CAL	Device 2 commands.
10	DEVICE 3 @18,"CA3,B3X","NA3,B3X",#CABLE3.CAL	Device 3 commands.
11	DEVICE 4 @18,"CA4,B4X","NA4,B4X",#CABLE4.CAL	Device 4 commands.
12	DEVICE 5 @18,"CA5,B5X","NA5,B5X",#CABLE5.CAL	Device 5 commands.
13	DEVICE 6 @18,"CA6,B6X","NA6,B6X",#CABLE6.CAL	Device 6 commands.
14	DEVICE 7 @18,"CA7,B7X","NA7,B7X",#CABLE7.CAL	Device 7 commands.
15	DEVICE 8 @18,"CA8,B8X","NA8,B8X",#CABLE8.CAL	Device 8 commands.
16	DEVICE 9 @18,"CA9,B9X","NA9,B9X",#CABLE9.CAL	Device 9 commands.
17	DEVICE 10 @18,"CA10,B10X","NA10,B10X",#CABLE10.CAL	Device 10 commands.
18	DEVICE 11 @18,"CA11,B11X","NA11,B11X",#CABLE11.CAL	Device 11 commands.
19	DEVICE 12 @18,"CA12,B12X","NA12,B12X",#CABLE12.CAL	Device 12 commands.
20	FINAL @18,"R0X"	Reset 707.

NOTES:

1. Model 7074D/7075 assumed to be in slot 1 of Model 707.
2. Model 707 primary address = 18.
3. PARALLEL statements are ignored for all tests except BTS parallel tests.
4. Cable calibration files, CABLEn.CAL, assumed to be present in \CAL directory (see paragraph 4.5.2).

Table 4-3. Switch Control File for Model 7073 Card Example

Line	Program Code	Comments
1	INIT @18,"R0X"	Reset 707.
2	PARALLEL @18,"CA1,B2,A3,B4X","NA1,B2,A3,B4X"	Parallel commands.
3	PARALLEL @18,"CA5,B6,A7,B8X","NA5,B6,A7,B8X"	
4	PARALLEL @18,"CA9,B10,A11,B12X","NA9,B10,A11,B12X"	
5	DEVICE 1 @18,"CA1,B2X","NA1,B2X",#CABLE1.CAL	Device 1 commands.
6	DEVICE 2 @18,"CA3,B4X","NA3,B4X",#CABLE2.CAL	Device 2 commands.
7	DEVICE 3 @18,"CA5,B6X","NA5,B6X",#CABLE3.CAL	Device 3 commands.
8	DEVICE 4 @18,"CA7,B8X","NA7,B8X",#CABLE4.CAL	Device 4 commands.
9	DEVICE 5 @18,"CA9,B10X","NA9,B10X",#CABLE5.CAL	Device 5 commands.
10	DEVICE 6 @18,"CA11,B12X","NA11,B12X",#CABLE6.CAL	Device 6 commands.
11	FINAL @18,"R0X"	Reset 707.

## NOTES:

1. Model 7073 assumed to be in slot 1 of Model 707.
2. Model 707 primary address = 18.
3. PARALLEL statements are ignored for all tests except BTS parallel tests.
4. Cable calibration files, CABLEn.CAL assumed to be present in \CAL directory.

## 4.5.2 Cable Correcting Switching Pathways

Cable correction is particularly important when using switching because of the detrimental effects that long cables and switch paths can have on the C-V or C-t measurement. The procedure below outlines the basic procedure for cable correcting a switching system, and Figure 4-21 shows typical connections.

For more details on cable correction, refer to paragraph 2.5 and Appendix E.

**NOTE**

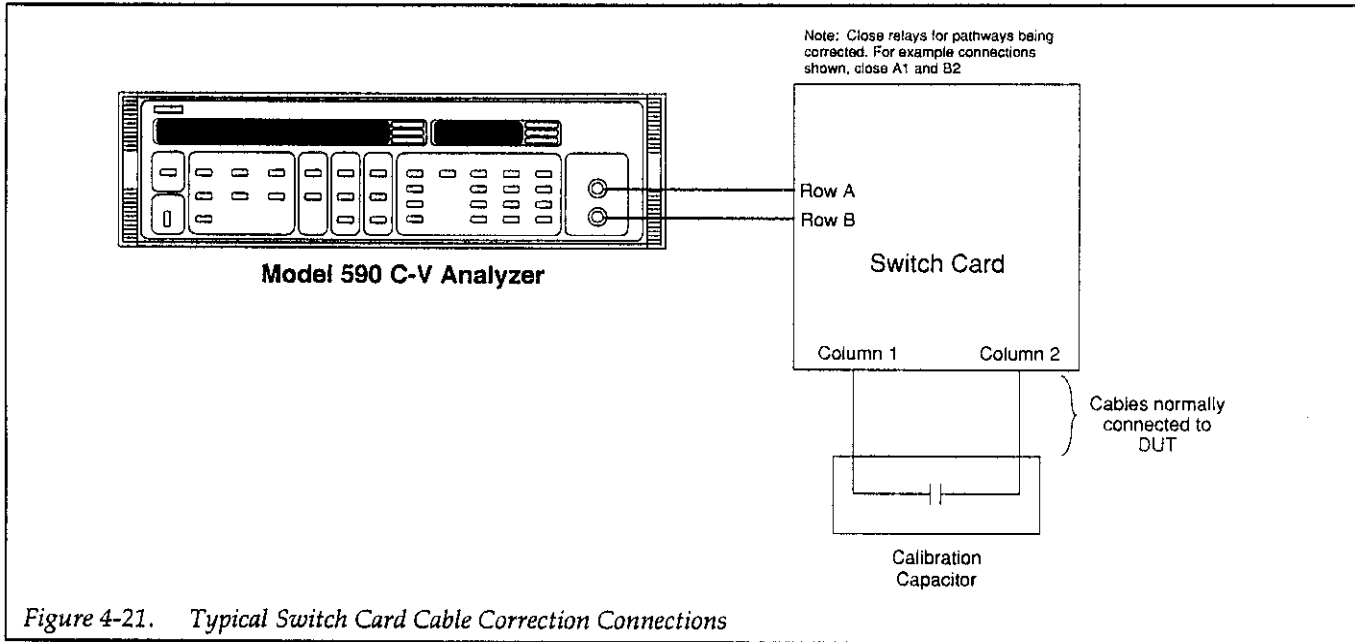
Each pathway to be used in the test should be cable corrected separately, and the resulting correction constants should be stored in a separate cable correction file. The cable correction filenames should be defined in the switch control file, as covered in paragraph 4.5.1 and Section 6.

1. From the C:\KTHLY\_CV\MODEL58 directory, type in the following to run the cable calibration utility:

```
CABLECAL <Enter>
```

2. Disconnect the cables for the pathway to be calibrated from the DUT.

3. Make sure that relays for the pathways to calibrated are closed (be sure that all other relays are open).
4. To load an existing calibration constants file, press <Alt>-F, then select Load on the menu. Select an existing file, or type in the name of the file.
5. Press <Alt>-E, then select Cable Cal 590 and the desired range.
6. If you are cable correcting your system for the first time, enter the nominal, 100kHz, and 1MHz values where indicated (use the <Tab> key to move around selections). Capacitor #1 is the smaller of two values, and Capacitor #2 is the large capacitor value for a given range. Select OK after entering source values to begin the calibration process.
7. Choose the CALIBRATE selection to perform complete cable calibration.
8. Follow the prompts on the screen to complete the calibration process. During calibration, you will be prompted to connect calibration capacitors, or to leave the terminals open in some cases. If any errors occur, you will be notified by suitable messages on the screen.
9. Repeat steps 3 through 8 for all Model 590 ranges to be cable corrected.
10. After calibration is complete, you must save the new calibration constants in the \CAL directory. To do so, Press <Alt>-F, then select Save or Save As as required. If you use Save As, be sure to use a filename with a .CAL extension.
11. Repeat steps 2 through 10 for all pathways to be corrected, and add the cable correction filenames to the switch control file where indicated.



### 4.5.3 Selecting Optimum BTS Test Sequence Parameters

C-V measurement and stress cycle parameters must be carefully chosen in order to obtain valid BTS test sequence results. Some important considerations on choosing C-V parameters are discussed in paragraph 4.2.2. Similarly, key points on selecting stress cycle voltage, temperature, and time parameters are discussed in paragraph 4.4.2.

Other points to keep in mind include:

- When using switching, program a C-V measurement start delay time sufficiently long to allow for relay settling time at the start of each C-V sweep. The settling time required will depend on the relay settling time of the switch card in question. A start delay time of 50msec should be sufficient for most applications.
- When using an automatic probe sequencer, program a C-V measurement start delay time long enough to allow for probe positioning. Refer to the probe sequencer specifications for recommended positioning times.

### 4.5.4 Parallel BTS Test Measurement Overload

During the stress portion of a parallel BTS test sequence, all devices are connected together in parallel, a condition

which could result in a Model 590 overload condition. In order to avoid a possible inadvertent Model 590 OVERLOAD error message, Model 590 triggers are disabled to disable measurement during the stress cycle. Doing so does not affect the C-V measurements because no measurements are made during device stress.

### 4.5.5 BTS Test Sequence Procedure

Follow the steps below to perform a BTS test sequence.

#### Step 1: Make Test Connections

Before performing the BTS test sequence, connect your system as outlined in paragraphs 4.5.1 and 4.5.2.

#### Step 2: Setup C-V Measurement Parameters

1. From the main menu, press <Alt>-S, and select C-V setup to display the C-V parameters menu.
2. Select the various measurement parameters such as range, frequency, model, and rate, as required. See paragraphs 3.2 and 4.2 for complete details.
3. After you have entered all your parameters, select Save, then enter the desired filename at the prompt.
4. Select OK to accept parameters and return to the main menu.

**Step 3: Program BTS Stress Cycle Parameters**

1. From the main menu, Press <Alt>-S, then select BTS Cycle.
2. Program the required BTS cycle parameters, as summarized in paragraphs 3.3 and 4.3. Be sure to specify the C-V filename you defined in Step 2.
3. After programming all your stress cycle parameters, select Save, then enter the filename to save the BTS cycle parameters.
4. Select OK to return to the main menu.

**Step 4: Program BTS Test Sequence Parameters**

1. From the main menu, press <Alt>-S, then select BTS Sequence.
2. Choose the test sequence type: sequential, parallel, or no stress. The sequential test type runs through the entire stress-measurement sequence for each device in a sequential manner, while the parallel test sequence stresses a number of devices in parallel and then measures C-V parameters for each device individually. The no stress option is used for C-V only measurements without stress.
3. Select the stress cycle type: + then -, - then +, + only, or - only. + then - applies the positive then negative stress voltages, - then + applies negative then positive stress, while + only and - only apply only the positive or negative stress voltages respectively during the stress cycle.
4. Select the type of  $C_{MIN}$  checking. Choose auto if you are using a light and wish to determine  $C_{MIN}$  automatically. Choose manual to stop after each C-V sweep and determine  $C_{MIN}$  manually. Select none to disable  $C_{MIN}$  checking.
5. Enter any comments in the indicated field.
6. Program the number of devices based on your test requirements. In order to test more than one device automatically, you must have a switching mainframe or automatic probe sequencer that can connect to multiple sets of test dots automatically (a probe sequencer cannot be used for the parallel stress test, however). See paragraph 4.5.1 and Section 6 for information on setting up a control file for this equipment.
7. Enter the C-V, stress cycle parameter, and data destination filenames where indicated. These are the files set up in steps 2 and 3 above. The switch control filename should also be specified if you are using switching. The data destination filename defines the storage location for data taken during a BTS test.
8. Select Save, then save the BTS stress sequence parameters under a convenient filename.
9. Select OK to return to the main menu.

**Step 5. Run the BTS Test**

1. From the main menu, Press <Alt>-R.
2. To run the entire stress-measurement sequence, select Stress Sequence. The window shown in Figure 4-22 will be displayed. Note that capacitance, conductance, and DC bias are displayed, and that you can select the following:

Start Test: Starts the BTS test sequence.

Enable/Disable Zero: Enables and disables the Model 590 zero feature.

Enable/Disable Light: Toggles the optional light on or off.

Cancel: Exits this window and returns to main menu.

3. With the probes up, select Enable Zero to null any system offsets.
4. Place the probes down on the test dots, then select Start Test. During the test, pertinent test parameters will be displayed on the screen shown in Figure 4-23. Parameters displayed in the top window segment include test sequence type (sequential, parallel, or no stress), number of devices being tested (1-99), the length of the test sequence, and which device is currently being tested. Parameters displayed in the bottom window segment include the start voltage, and the stop voltage.  
  
During the test sequence, you can press any key to abort, if desired.
5. When the test is complete, select Done to return to the main menu.

**Step 6: Analyze BTS Data**

1. From the main menu, press <Alt>-A, then select BTS.
2. Select Display, Print, or Graph to display your data as required. For example, press <Alt>-G to select graphing options, then select the appropriate option.

**4.6 ZERBST TEST SEQUENCE MEASUREMENTS****4.6.1 Zerbst Test Sequence Connections**

In order to perform a Zerbst test sequence on more than one device, you must use either an automatic probe sequencer or an appropriate switching system. Information on setting up a control file for use with a probe sequencer is located in Section 6. Paragraph 4.5.1 discusses typical switching systems that can be used for Zerbst test sequences. See also paragraph 4.5.2 for details on cable correcting switching systems.



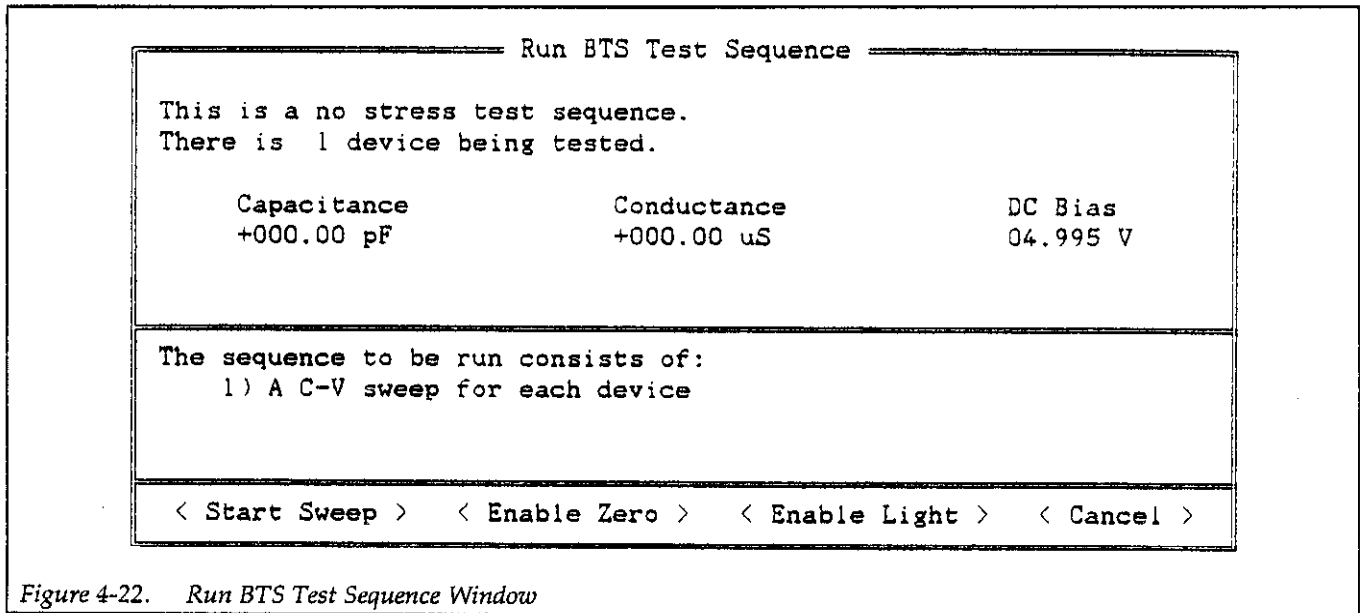


Figure 4-22. Run BTS Test Sequence Window

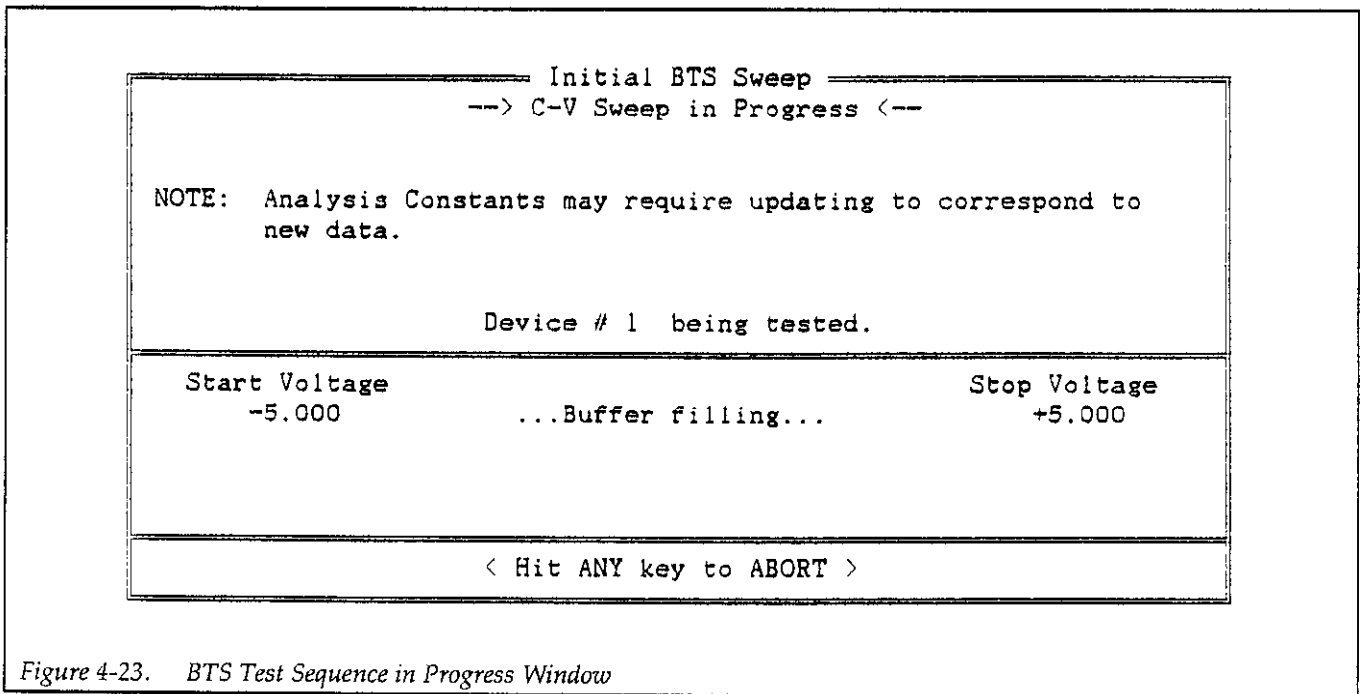


Figure 4-23. BTS Test Sequence in Progress Window

## 4.6.2 Selecting Optimum Zerbst Sequence Parameters

C-V and C-t measurement parameters should be carefully chosen in order to obtain good results from the Zerbst test sequence. Paragraph 4.2.2 discusses important considerations when setting up C-V parameters, and paragraph 4.3.2 covers methods for determining test voltages, sample time, and number of samples.

In addition, the following points should be kept in mind:

- When using switching, program C-V and C-t measurement start delay times sufficiently long to allow for relay settling time at the start of each C-V or C-t measurement. The settling time required will depend on the relay settling time of the switch card in question. A start delay time of 50msec should be sufficient for most applications.
- When using an automatic probe sequencer, program C-V and C-t measurement start delay times long enough to allow for probe positioning. Refer to the probe sequencer specifications for recommended positioning times.

## 4.6.3 Running a Zerbst Test Sequence

### Step 1: Make Test Connections

Connect your switch system, as discussed in paragraph 4.5.1.

### Step 2: Setup C-V Measurement Parameters

1. From the main menu, press <Alt>-S, and select C-V setup to display the C-V parameters menu.
2. Select the various measurement parameters such as range, frequency, model, and rate, as required. See paragraphs 3.2 and 4.2 for details.
3. After you have entered all your parameters, select Save, then enter the desired filename at the prompt.
4. Select OK to accept parameters and return to the main menu.

### Step 3: Setup C-t Measurement Parameters

1. From the main menu, press <Alt>-S, and select C-t setup to display the C-t parameters menu.

2. Select the various measurement parameters such as range, frequency, model, and rate, as required. Refer to paragraphs 3.3 and 4.3 for more information.
3. After you have entered all your parameters, select Save, then enter the desired filename at the prompt.
4. Select OK to return to the main menu.

### Step 4: Program Zerbst Test Sequence Parameters

1. From the main menu, press <Alt>-S, then select Zerbst Sequence.
2. Choose the test sequence type: multiple C-V, one C-V, or no C-V. The multiple C-V option can be used to test a number of dissimilar devices where a separate C-V data set is required for each device. The one C-V option can be used to test a number of similar devices where only one C-V data set is required for all the devices. The no C-V option should be used in cases where only C-t measurements are required.
3. Choose the desired type of  $C_{MIN}$  checking. (Auto determines  $C_{MIN}$  automatically only if you are using a light, while manual will cause the program to stop after each C-V sweep to manually determine  $C_{MIN}$ .)
4. Enter any comments in the indicated field.
5. Program the number of devices based on your test requirements. In order to test more than one device automatically, you must have a switching mainframe or automatic probe sequencer that can connect to multiple sets of test dots automatically. See paragraph 4.5.1 and Section 6 for information on setting up a control file for this equipment.
6. Enter the C-V, C-t, and data destination filenames where indicated. These are the files set up in steps 2 and 3 above. The switch control filename should also be specified if you are using a switching mainframe. The data destination filename defines the storage location for data taken during a Zerbst test.
7. Select Save, then save the Zerbst sequence parameters under a convenient filename.
8. Select OK to return to the main menu.

### Step 5: Run the Zerbst Test Sequence

1. From the main menu, Press <Alt>-R.
2. Select Zerbst Sequence. The window shown in Figure 4-24 will be displayed. Information displayed includes capacitance, conductance, and DC bias. Selections at the bottom of the window include:

Start Test: Starts the BTS test sequence.

Enable/Disable Zero: Toggles Model 590 zero on or off.

Enable/Disable Light: Turns the light on/off.

Cancel: Exits this window and returns to the main menu.

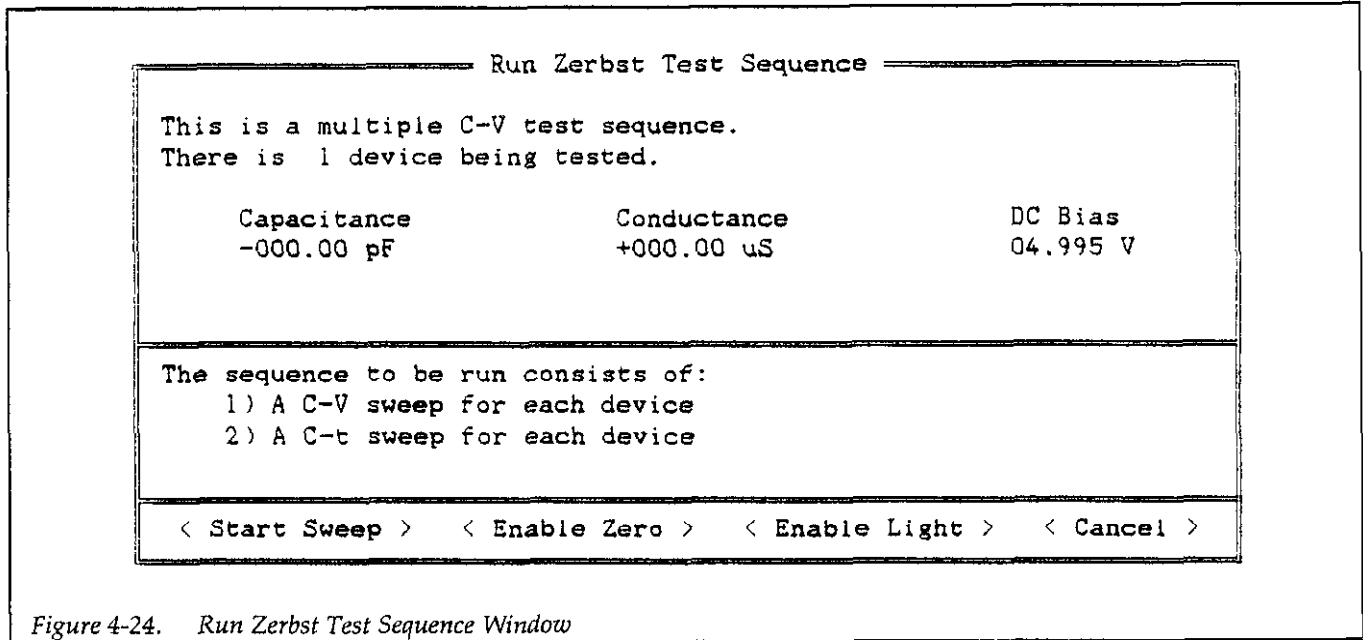


Figure 4-24. Run Zerbst Test Sequence Window

3. With the probes up, select Enable Zero to null any system offsets.
4. Place the probes down on the test dots, then select Start Test. During the test, pertinent test parameters will be displayed in the window shown in Figure 4-25. Parameters displayed in the top window segment include test sequence type (multiple C-V, one C-V, or no C-V), number of devices being tested (1-99), the time duration of the test sequence, and the current device being tested. The bottom window segment displays test voltage, time expired, and completion time.

During the test, you can choose to abort the sequence at any time, if desired.

5. When the test is complete, select Done to return to the main menu.

#### Step 5: Analyze Zerbst Data

1. From the main menu, press <Alt>-A, then select BTS.
2. Press <Alt>-G to select the graphing option, then select the Zerbst option to graph Zerbst data.
3. To display generation lifetime and generation velocity, select option 7 on the graphics menu. Follow the prompts on the screen to mark the beginning and end points of the linear region of the Zerbst plot.

Generation lifetime is displayed as  $\tau_g$  and is given in seconds. Generation velocity is displayed as  $s$  and is given in cm/sec.

## 4.7 MEASUREMENT CONSIDERATIONS

The importance of making careful C-V and C-t measurements is often underestimated. However, errors in the data will propagate through calculations, resulting in errors in device parameters derived from the curves. These errors can be amplified during calculations by a factor of 10 or more.

With careful attention, the effects of many common error sources can be minimized. In the following paragraphs, we will discuss some common error sources and provide suggested methods for avoiding them.

### 4.7.1 Potential Error Sources

Theoretically, a capacitance measurement using one of the common techniques would require only that two leads be used to connect the measuring instrument to the device under test (DUT)—the input and output. In practice, however, various parasitic or stray components complicate the measuring circuit.

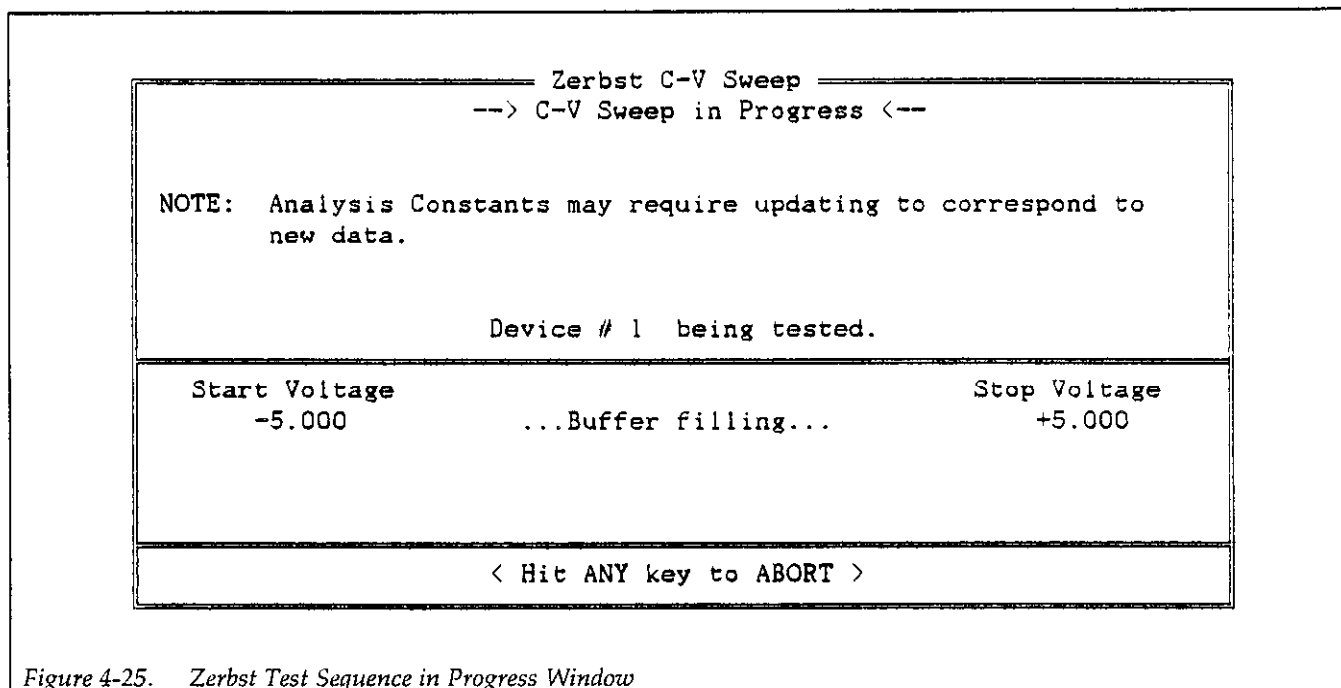


Figure 4-25. Zerbst Test Sequence in Progress Window

### Stray Capacitances

Regardless of the measurement frequency, stray capacitances present in the circuit are important to consider. Stray capacitances can cause offsets when they are in parallel with the device, can act as a shunt load on the input or output, or can cause coupling between the device and nearby AC signal sources.

When stray capacitance is in parallel with the DUT, it causes a capacitance offset, adding to the capacitance of the device under test ( $C_{DUT}$ ), as shown in Figure 4-26. Shunt capacitance, on the other hand, often increases the noise gain of the instrumentation amplifiers, increasing capacitance reading noise (Figure 4-27). Shunt capacitance also forms a capacitive divider with  $C_{DUT}$ , steering current away from the input to ground. This phenomenon results in capacitance gain error, with the C-V curve results shown in Figure 4-28.

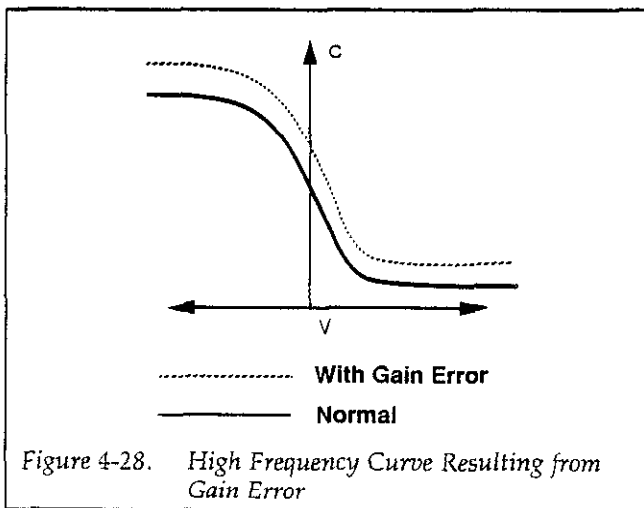
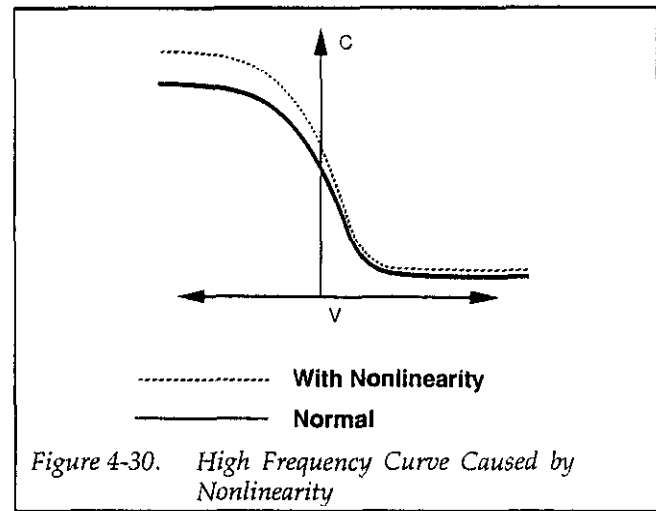
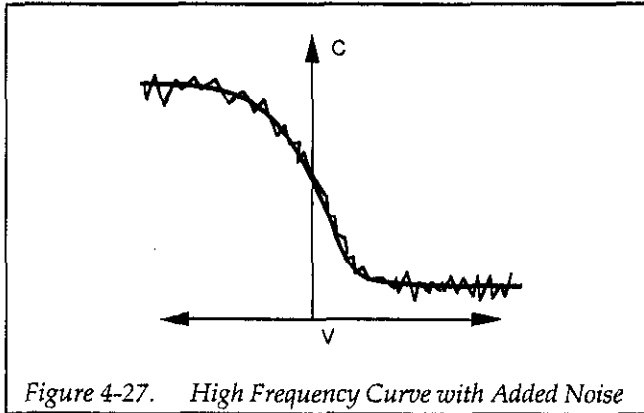
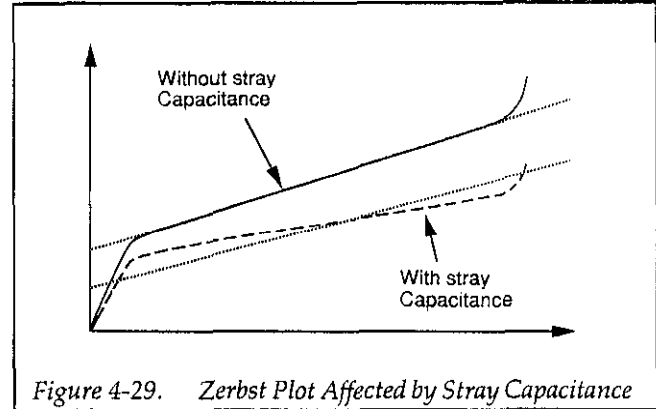
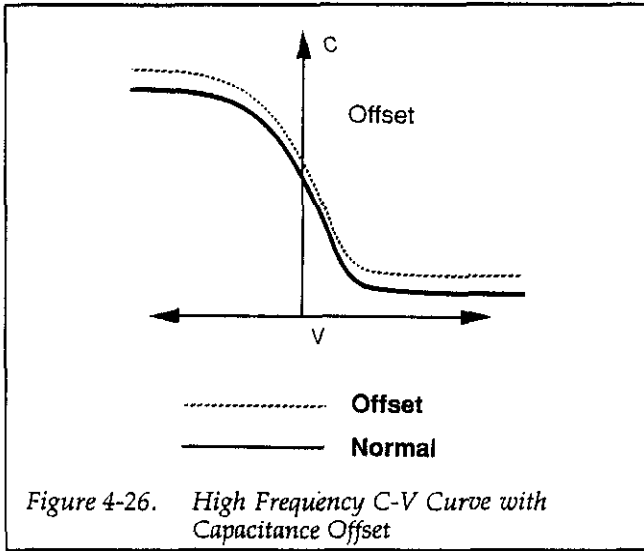
Stray capacitance may also couple current of charge from nearby AC signal sources into the input of the measuring instrument. This noise current adds to the device current and results in noisy, or unrepeatable measurements.

Digital and RF signals are the primary causes of noise induced in high-frequency C-V measurements. Stray capacitance can also affect C-t measurements. Figure 4-29 shows the effects of stray capacitance on a Zerbst plot.

### High-frequency Effects

At measurement frequencies of approximately 100kHz and higher, the impedance of  $C_{DUT}$  may be so small that any series impedance in the rest of the circuit may cause errors. Whether such series impedance is caused by inductance (such as from leads or probes), or from resistance (as with a high-resistivity substrate), this series impedance causes non-linearity in the measured capacitance. The resulting C-V curve is, of course, affected by such non-linearity, as shown in Figure 4-30.

Another high-frequency effect is caused by the AC network formed by the instrumentation, cables, switching circuits, and the test fixtures. Referred to as transmission line error sources, the network essentially transforms the impedance of  $C_{DUT}$  when it is referred to the input of the instrument, altering the measured value. Transmission line effects alter the gain and produce non-linearities.



## 4.7.2 Avoiding Capacitance Errors

The many possible error sources that can affect C-V and C-t measurements may seem like a great deal to handle. However, careful attention to a few key details will reduce errors to an acceptable level. Once most of the error sources have been minimized, any residual errors can be further reduced by using the zero feature.

Key details that require attention include use of proper cabling and effective shielding. These important aspects are discussed below.

### Cabling Considerations

Cables must be used to connect the instruments to the device under test. Ideally, these cables should supply the test voltage to the device unaltered in any way. The test voltage is converted into a current or charge in the DUT, and should be carried back to the instruments undisturbed. Along the way, potential error sources must be minimized.

Coaxial cable is usually used in order to eliminate stray capacitance between the measurement leads. The cable shield is connected to a low-impedance point (guard) that follows the meter input. This technique, known as the three-terminal capacitance measurement, is almost universally used in commercial instrumentation. The shield shunts current away from the input to the guard.

Coaxial cables also serve as smooth transmission lines to carry high-frequency signals without attenuation. For this reason, the cable's characteristic impedance should closely match that of the instrument input and output, which is usually 50Ω. Standard RG-58 cable is adequate for frequencies in the range of 1kHz to more than 10MHz. High-quality BNC connectors with gold-plated center conductors reduce errors from high series contact resistance.

One final point regarding cable precautions: Cables can only degrade the measurement, not improve it. Thus, cable lengths should be minimized where possible, without straining cables or connections.

### Device Connections

Care in properly protecting the signal path should not stop at the cable ends where the connection is made to the DUT fixture. In fact, the device connection is an extremely important aspect of the measurement. For the same reasons given for coaxial cables, it is best to continue the coaxial path as close to the DUT as possible by using coaxial probes. Also, it is important to minimize stray capacitance and maximum insulation resistance in the pathway from the end of the coaxial cable to the DUT.

Most devices have one terminal that is well insulated from other conductors, as in the gate of an MOS test dot. The input should be connected to the gate because it is more susceptible to stray signals than is the output. The output can better tolerate being connected to a terminal with high shunt capacitance, noise, or poor insulation resistance, although these characteristics should still be optimized for best results.

### Test Fixture Shielding

At the point where the coaxial cable shielding ends, the sensitive input node is exposed, inviting error sources to interfere. Proper device shielding need not end with the cables or probes, however, if a shielded test fixture is used.

A shielded fixture, sometimes known as a Faraday cage, consists of a metal enclosure that completely surrounds the DUT and leads. In order to be effective, the shield must be electrically connected to the coaxial shield. Typically, bulkhead connectors are mounted to the side of the cage to bring in the signals. Coaxial cables should be continued inside, if possible, or individual input and output leads should be widely spaced in order to maintain input/output isolation.

## 4.7.3 Correcting Residual Errors

Controlling errors at the source is the best way to optimize C-V measurements, but doing so is not always possible. Ways to deal with these error sources are discussed in the following paragraphs.

### Offsets

Offset capacitance and conductance caused by the test apparatus can be eliminated by enabling zero with the

probes in the up position. These offsets will then be nulled out when the measurement is made. Whenever the system configuration is changed, the zero procedure should be repeated.

#### Gain and Nonlinearity Errors

Gain errors are difficult to quantify. For that reason, gain correction is applied to every Model 5958 measurement. Gain constants are determined by measuring accurate calibration sources during the cable correction process.

Nonlinearity is normally more difficult to correct for than are gain or offset errors. The cable correction utility supplied with the Model 5958, however, provides nonlinearity compensation for high-frequency measurements, even for non-ideal configurations such as switching matrices.

#### Noise

Residual noise on the C-V curve can be minimized by using filtering when taking your data. Care must be taken, however, not to apply too much filtering, as doing so will distort the curve. Often, some experimentation may be necessary to optimize noise reduction and at the same time keep undesirable effects to a minimum.

#### 4.7.4 Interpreting C-V Curves

Even when all the precautions outlined here are followed, there are still some possible obstacles to successfully using C-V curves to analyze semiconductor devices. Semiconductor capacitances are far from ideal, so care must be taken to understand how the device operates. Also, the curves must be generated under well-controlled test conditions that ensure repeatable, analyzable results.

#### Maintaining Equilibrium

The condition of the device when all internal capacitances are fully charged is referred to as equilibrium. Most high-frequency C-V curve analysis is based on the simplifying assumption that the device is measured in equilibrium. Internal RC time constants limit the rate at which the device bias may be swept while maintaining equilibrium. They also determine the hold time required for device settling after setting the bias voltage to a new value before measuring  $C_{DUT}$ .

The two main parameters to be controlled, then, are the bias sweep rate and the hold time. When these parameters are set properly, the normal C-V curves shown in Figure 4-31 result. Once the proper sweep rate and hold time have been determined, it is important that all curves compared with one another be measured under the same test conditions; otherwise, it may be the parameters, not the devices themselves, that cause the compared curves to differ.

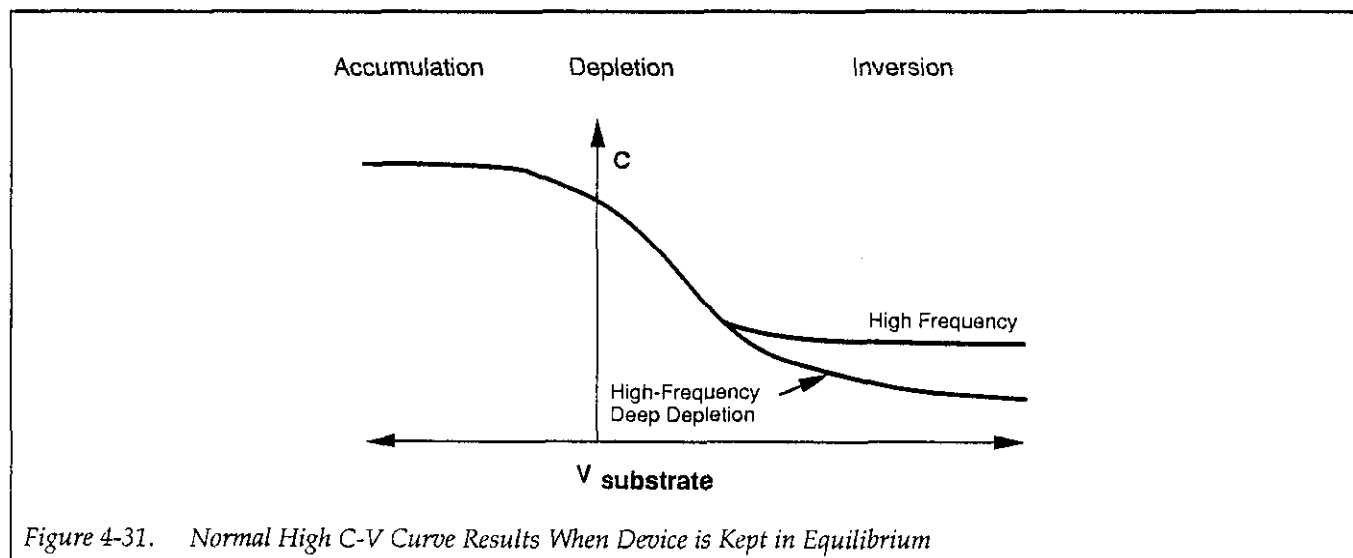


Figure 4-31. Normal High C-V Curve Results When Device is Kept in Equilibrium

### Analyzing Curves for Equilibrium

There are two primary indicators that can be used to determine whether a device has remained in equilibrium during high-frequency C-V testing. First, as long as a device is in equilibrium,  $C_{DUT}$  is settled at all points in the sweep. As a result, it makes no difference whether the sweep goes from accumulation to inversion, or from inversion to accumulation, nor does it matter how rapidly the sweep is performed. Therefore, curves made in both directions will be the same, exhibiting no hysteresis, and any curve made at a slower rate will be the same. Figure 4-32 shows the type of hysteresis that will occur if the sweep rate is too fast, and the device does not remain in equilibrium.

Secondly, the curves should exhibit the smooth equilibrium shape. Deviations from the ideal smooth shape indicate a non-equilibrium condition, as in the examples resulting from too short a hold time shown in Figure 4-33.

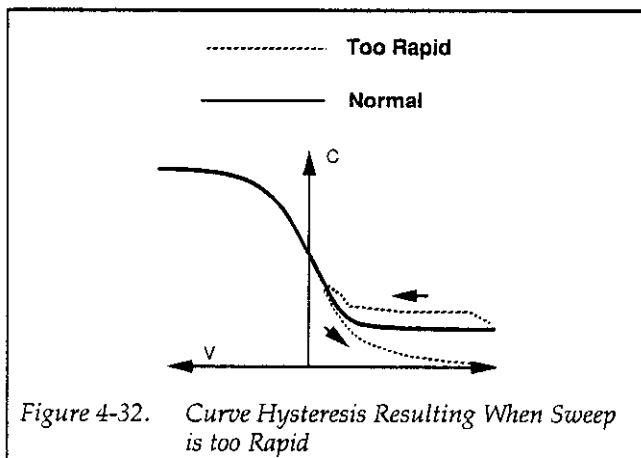


Figure 4-32. Curve Hysteresis Resulting When Sweep is too Rapid

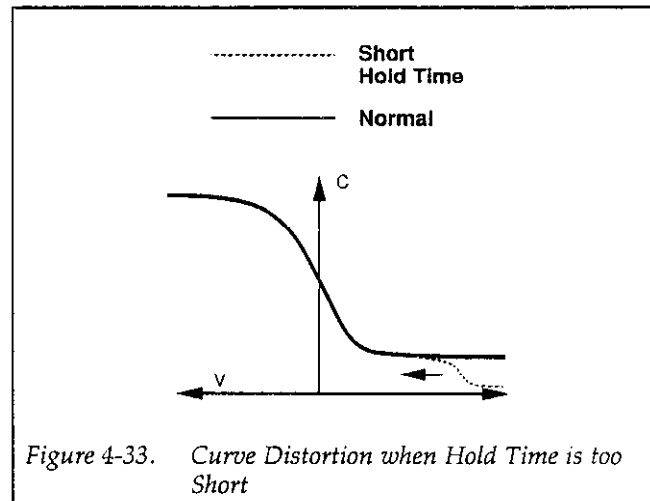


Figure 4-33. Curve Distortion when Hold Time is too Short

### Initial Equilibrium

Biasing the device to the starting voltage in the inversion region at the beginning of a C-V measurement creates a non-equilibrium condition that must be allowed to subside before the C-V sweep begins. This recovery to equilibrium can take seconds, minutes, or even tens of minutes to achieve. For that reason, it is generally advantageous to begin the sweep in the accumulation region of the curve whenever possible.

Still, it is often necessary to begin the sweep in the inversion region to check for curve hysteresis. In this case, a light pulse, shone on the device, can be used to quickly generate the minority carriers required by the forming inversion layer, thus speeding up equilibrium and shortening the hold time.

One way to ensure equilibrium is initially achieved is to monitor the capacitance level at the initial bias voltage and wait until it decays to its equilibrium level.



### 4.7.5 Dynamic Range Considerations

The dynamic range of a zeroed high-frequency measurement will be reduced by the amount of the zero value. For example, if, on the 200pF range, you were to suppress a value of 10pF, the dynamic range would be reduced by that amount. Under these conditions, the maximum value the instrument could measure without overflowing would be 190pF.

A similar situation exists because of cable correction. For example, the maximum measurable value on the 2nF range may be reduced to 1.8nF when using cable correction. The degree of reduction will depend on the amount of correction necessary for the particular test setup.

### 4.7.6 Series and Parallel Model Equivalent Circuits

A complex impedance can be represented by a simple series or parallel equivalent circuit made up of a single resistive element and a single reactive element, as shown in Figure 4-34. In the parallel form of (a), the resistive element is represented as the conductance,  $G$ , while the reactance is represented by the susceptance,  $B$ . The two together mathematically combine to give the admittance,  $Y$ , which is simply the reciprocal of the circuit impedance.

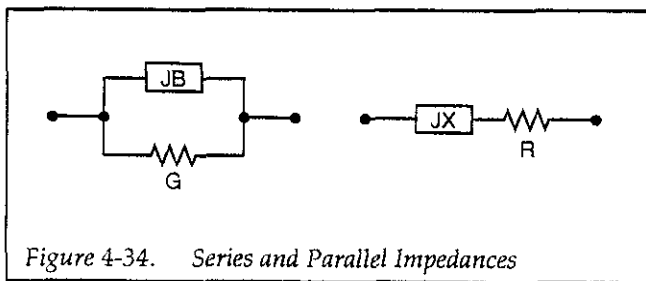


Figure 4-34. Series and Parallel Impedances

In a similar manner, the resistance and reactance of the series form of (b) are represented by  $R$  and  $X$ , respectively. The impedance of the series circuits is  $Z$ .

The net impedances of the equivalent series and parallel circuits at a given frequency are equal. However, the in-

dividual components are not. We can demonstrate this relationship mathematically as follows:

$$R + jX = \frac{1}{G + jB}$$

To eliminate the imaginary form in the denominator of the right-hand term, we can multiply both the denominator and numerator by the conjugate of the denominator as follows:

$$R + jX = \frac{1}{G + jB} \times \frac{G - jB}{G - jB}$$

Performing the multiplication and combining terms, we have:

$$R + jX = \frac{G - jB}{G^2 + B^2}$$

If we assume the reactance is capacitive, we can substitute  $-1/\omega C_s$  for the reactance and  $\omega C_p$  for the susceptance ( $C_s$  is the equivalent series capacitance, and  $C_p$  is the equivalent parallel capacitance). The above equation then becomes:

$$\frac{R - jX}{\omega C_s} = \frac{G - j\omega C_p}{G^2 + \omega^2 C_p^2}$$

In a lossless circuit ( $R$  and  $G$  both 0),  $C_p$  and  $C_s$  would be equal. A practical circuit, however, does have loss because of the finite values of  $R$  or  $G$ . Thus,  $C_s$  and  $C_p$  are not equal—the greater the circuit loss, the larger the disparity between these two values.

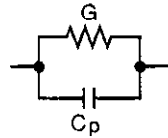
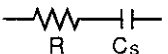
Series and parallel capacitance values can be converted to their equivalent forms by taking into account a dissipation factor,  $D$ .  $D$  is simply the reciprocal of the  $Q$  of the circuit. For a parallel circuit, the dissipation factor is:

$$D = \frac{1}{Q} = \frac{G}{\omega C_p}$$

For the series circuit, the dissipation factor is defined as:

$$D = \frac{1}{Q} = \omega C_s R$$

Table 4-4. Converting Series-parallel Equivalent Circuits

Model	Equivalent Circuit	Dissipation Factor	Capacitance Conversion	Resistance Conductance Conversion
Parallel, $C_p$ , $G$		$D = \frac{1}{Q} = \frac{G}{\omega C_p}$	$C_s = (1 + D^2) C_p$	$R = \frac{D^2}{(1 + D^2) G}$
Series $C_s$ , $R$		$D = \frac{1}{Q} = \omega C_s R$	$C_p = \frac{C_s}{1 + D^2}$	$G = \frac{D^2}{(1 + D^2) R}$

By using the dissipation factor along with the formulas summarized in Table 4-4, you can convert from one form to another. Note that  $C_s$  and  $C_p$  are virtually identical for very small values of  $D$ . For example, if  $D$  is 0.01  $C_s$  and  $C_p$  are within 0.01% of one another.

#### Example:

Assume that we make a 100kHz measurement on a parallel equivalent circuit and obtain values for  $C_p$  and  $G$  of 160pF and 30 $\mu$ S respectively. From these values, we can calculate the dissipation factor,  $D$ , as follows:

$$D = \frac{30 \times 10^{-6}}{2\pi(100 \times 10^3)(160 \times 10^{-12})}$$

$$D = 0.3$$

The equivalent series capacitance is then calculated as follows:

$$C_s = (1 + 0.09) 160\text{pF}$$

$$C_s = 174.4\text{pF}$$

### 4.7.7 Device Considerations

#### Series Resistance

Devices with high series resistance can cause measurement and analysis errors unless steps are taken to compensate for this error term. The high dissipation factor caused by series resistance can cause errors in  $C_{ox}$  measurement, resulting in errors in analysis functions (such as doping concentration) that use  $C_{ox}$  for calculations.

The Model 5958 software uses a three-element model (Figure 5-13) to compensate for series resistance. The series resistance,  $R_{SERIES}$ , is an analysis constant that can be entered using the Display Analysis Constants selection in the C-V Analysis menu (see paragraph 5.4). The default value for  $R_{SERIES}$  is 0, which means that data will be unaffected if the value is not changed.

The Model 5958 software determines the displayed value of  $R_{SERIES}$  by converting parallel model data from the Model 590 into series model data. The resistance value corresponding to the maximum high-frequency capacitance in accumulation is defined as  $R_{SERIES}$ . See paragraph 4.7.6 for a detailed discussion of parallel and series model.

#### Device Structure

The standard analysis used in the Model 5958 assumes a conventional MIS structure made up of silicon substrate, silicon dioxide insulator, and aluminum gate material. You can change the program for use with other types of materials by modifying the MATERIAL.CON file, as discussed in Appendix A. For compound materials, a weighted average of pertinent material constants is often used. Typical compound materials include silicon nitride and silicon dioxide in a two- or three-layer sandwich.

#### Device Integrity

In order for analysis to be valid, device integrity should be checked before measurement. Excessive leakage current through the oxide can bleed off the inversion layer, causing the device to remain in nonequilibrium indefinitely. In this situation, the inversion layer would never

form completely, and  $C_{MIN}$  and C-t measurements would be inaccurate.

### Charge Spreading

Most problems associated with C-t measurement reproducibility are caused by charge spreading. Basically, charge spreading occurs when the oxide surface beyond the gate edge becomes charged during measurement, causing inversion beyond the gate. The resulting extended inversion layer causes distorted C-t data, resulting in measurement and analysis errors.

The solution to the charge spreading problem is a guard ring capacitor which is concentrically located around the gate test dot. A DC bias voltage is applied to the guard ring to compensate for charge spreading. Since the gate is extremely sensitive to noise, the guard ring voltage must be very well filtered. One low-noise, low-cost solution is to use two 9V batteries and a switch to provide the guard ring voltage with appropriate polarity for the type of material being tested.

## 4.7.8 Test Equipment Considerations

### Light Leaks

High-quality MOS capacitors, which are the subject of C-V and C-t analysis are excellent light detectors. Consequently, care should be taken to ensure that no light leaks into the test fixtures or probe station. Typical areas to check include door edges and hinges, tubing entry points, and connectors or connector panels.

### Thermal Errors

Accurate temperature control is important for accurate C-V and C-t data. For example, the intrinsic carrier concentration,  $n_i$ , doubles for every 8°C increase in ambient temperature. In order to minimize the effects of thermal errors, keep the device at a constant temperature during measurement, and repeated measurements should all be made at the same temperature.

# SECTION 5

## Analysis

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### 5.1 INTRODUCTION

This section contains detailed information on data analysis features of the Model 5958 software, and it contains the following information:

- 5.2 **Default Constants and Symbols Used for Analysis:** Summarizes numerical constants and symbols discussed in this section and used by the Model 5958 software.
- 5.3 **Obtaining Basic Analysis Information from High-frequency C-V Curves:** Discusses how to determine device type; accumulation, depletion, and inversion regions; and  $C_{OX}$  and  $C_{MIN}$  from high-frequency C-V curves.
- 5.4 **Loading and Saving Data:** Discusses loading data, saving data, as well as importing data into other programs such as spreadsheets and word processors.
- 5.5 **Graphical Analysis:** Covers the graphics control menu, cursor operation, and overlaying curve data.
- 5.6 **C-V Data Analysis:** Details the various C-V analysis operations, including displaying and printing analysis constants and graphing C-V data.
- 5.7 **C-t Data Analysis:** Describes C-t analysis features such as displaying and printing analysis constants and graphing C-t and Zerbst Data.
- 5.8 **BTS Data Analysis:** Gives details on BTS analysis functions, including displaying, printing, and graphing data.
- 5.9 **References and Bibliography:** Summarizes works cited in this section and also lists recommended reading for C-V, Zerbst, and BTS analysis and related topics.

### 5.2 DEFAULT CONSTANTS AND SYMBOLS USED FOR ANALYSIS

#### 5.2.1 Default Constants

Constants used by the Model 5958 are defined for silicon substrate, silicon dioxide insulator, and aluminum gate material. These constants are defined in the MATERIAL.CON file, which can be modified for use with other material types (refer to Appendix A). Default material constants are summarized in Table 5-1.

#### 5.2.2 Calculated Data Symbols

Calculated data symbols used by the various analysis algorithms are summarized in Table 5-2.

Table 5-1. Default Material Constants

Symbol	Description	Default Value
q	Electron charge (Coul.)	$1.60219 \times 10^{-19}$ Coul.
k	Boltzmann's constant (J/°K)	$1.38066 \times 10^{-23}$ J/°K
T	Test temperature (°K)	293°K
$\epsilon_{OX}$	Permittivity of oxide (F/cm)	$3.4 \times 10^{-13}$ F/cm
$\epsilon_s$	Semiconductor permittivity (F/cm)	$1.04 \times 10^{-12}$ F/cm
$E_G$	Semiconductor energy gap (eV)	1.12eV
$n_i$	Intrinsic carrier concentration (1/cm <sup>3</sup> )	$1.45 \times 10^{10}$ cm <sup>-3</sup>
$W_{MS}$	Metal work function (V)	4.1V
*	Electron affinity (V)	4.15V

\*See MATERIAL.CON file for description (Appendix A).

Table 5-2. Calculated Data Symbols

Symbol	Description
A	Device gate area
$C_{FB}$	Flatband capacitance, corresponding to no band bending.
$C_{MIN}$	Minimum equilibrium capacitance in inversion
$C_{OX}$	Oxide capacitance, usually maximum capacitance in accumulation
$N_A$	Bulk doping for p-type (acceptors)
$N_D$	Bulk doping for n-type (donors)
$N_{AVG}$	Average doping concentration
$N_{BULK}$	Bulk doping concentration
$N_{EFF}$	Effective doping concentration
$N_{MI}$	Mobile oxide charge concentration
$N_{SS}$	Total oxide fixed charge concentration
$Q_{EFF}$	Effective oxide charge
$Q_{MI}$	Mobile oxide charge
$Q_{SS}$	Total oxide fixed charge
$R_{SERIES}$	Series resistance
$t_{OX}$	Oxide thickness
$V_{FB}$	Flatband voltage (gate voltage at accumulation-depletion boundary)
$V_{GS}$	Voltage at gate with respect to substrate
$V_{THRESH}$	Threshold voltage (gate voltage at inversion-depletion boundary)
w	Depletion depth or thickness
$\lambda$	Extrinsic Debye length

### 5.3 OBTAINING BASIC ANALYSIS INFORMATION FROM HIGH-FREQUENCY C-V CURVES

Much important information about the device under test can be obtained directly from a basic high-frequency C-V curve. Such information includes device type (p- or n-type material)  $C_{OX}$  (oxide capacitance), and  $C_{MIN}$ . These aspects are discussed in the following paragraphs.

#### 5.3.1 Basic High-frequency C-V Curves

Figure 5-1 and Figure 5-2 show fundamental high-frequency C-V curves for p-type and n-type materials respectively. Note that the high-frequency C-V curves are highly asymmetrical. Accumulation, depletion, and inversion regions are also shown on the curves along with  $C_{OX}$ ,  $C_{MIN}$ ,  $V_{FB}$ , and  $V_{THRESH}$ . The gate-biasing polarity and high-frequency curve shape can be used to determine device type, as discussed below.

#### 5.3.2 Determining Device Type

The semiconductor conductivity type (p or n dopant ions) can be determined from the relative shape of the

high-frequency C-V curves. The high-frequency curve gives a better indication than the quasistatic curve because of its highly asymmetrical nature. Note that the C-V curve moves from the accumulation to the inversion region as gate voltage,  $V_{GS}$ , becomes more positive for p-type materials, but the curve moves from accumulation to inversion as  $V_{GS}$  becomes more negative with n-type materials (Nicollan and Brews 372-374).

In order to determine the material type, use the following rules:

1. If  $C_H$  is greater when  $V_{GS}$  is negative than when  $V_{GS}$  is positive, the substrate material is p-type.
2. If, on the other hand,  $C_H$  is greater with positive  $V_{GS}$  than with negative  $V_{GS}$ , the substrate is n-type.
3. The end of the curve where  $C_H$  is greater is the accumulation region, while the opposite end of the curve is the inversion region. The transitional area between these two is the depletion region. These areas are marked on Figure 5-1 and Figure 5-2. Note that the Model 5958 will display the device type for you. See paragraph 5.6.3 for details.

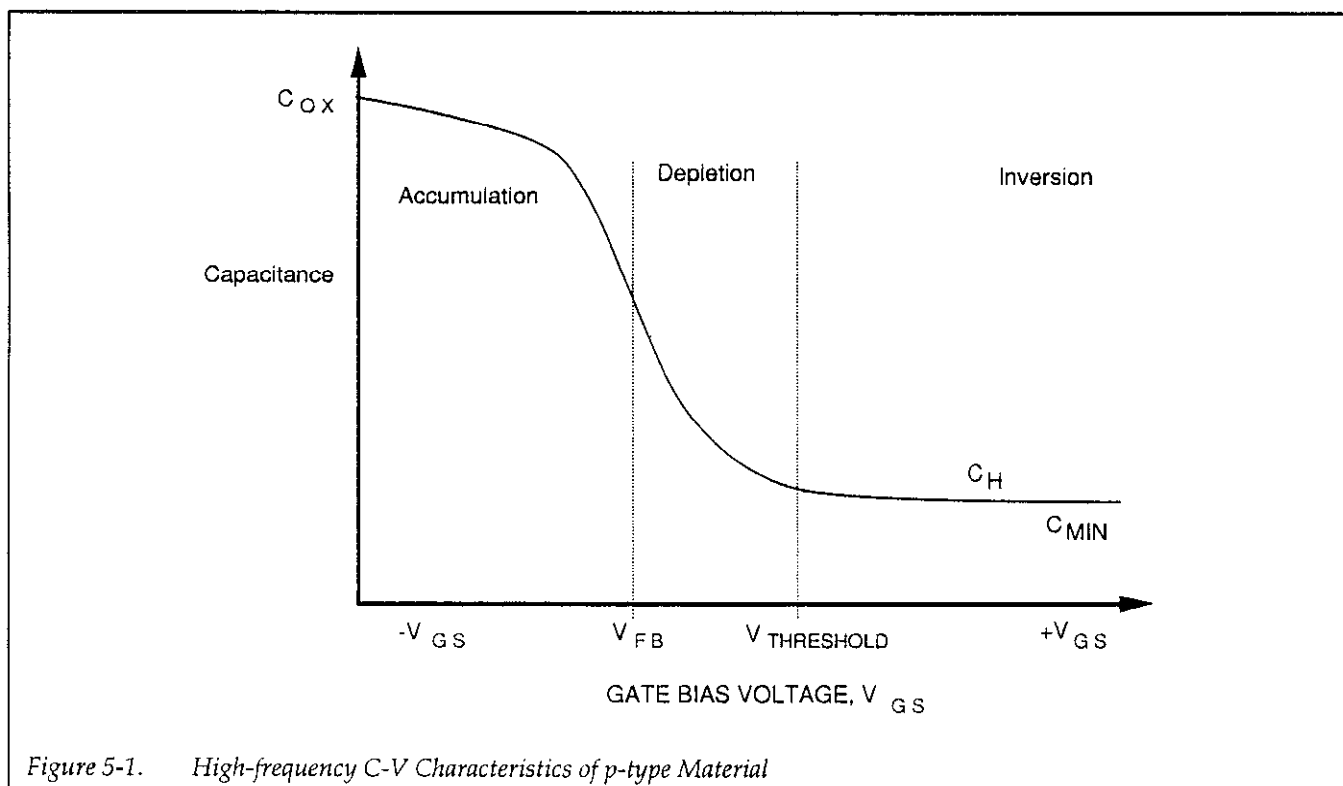


Figure 5-1. High-frequency C-V Characteristics of p-type Material

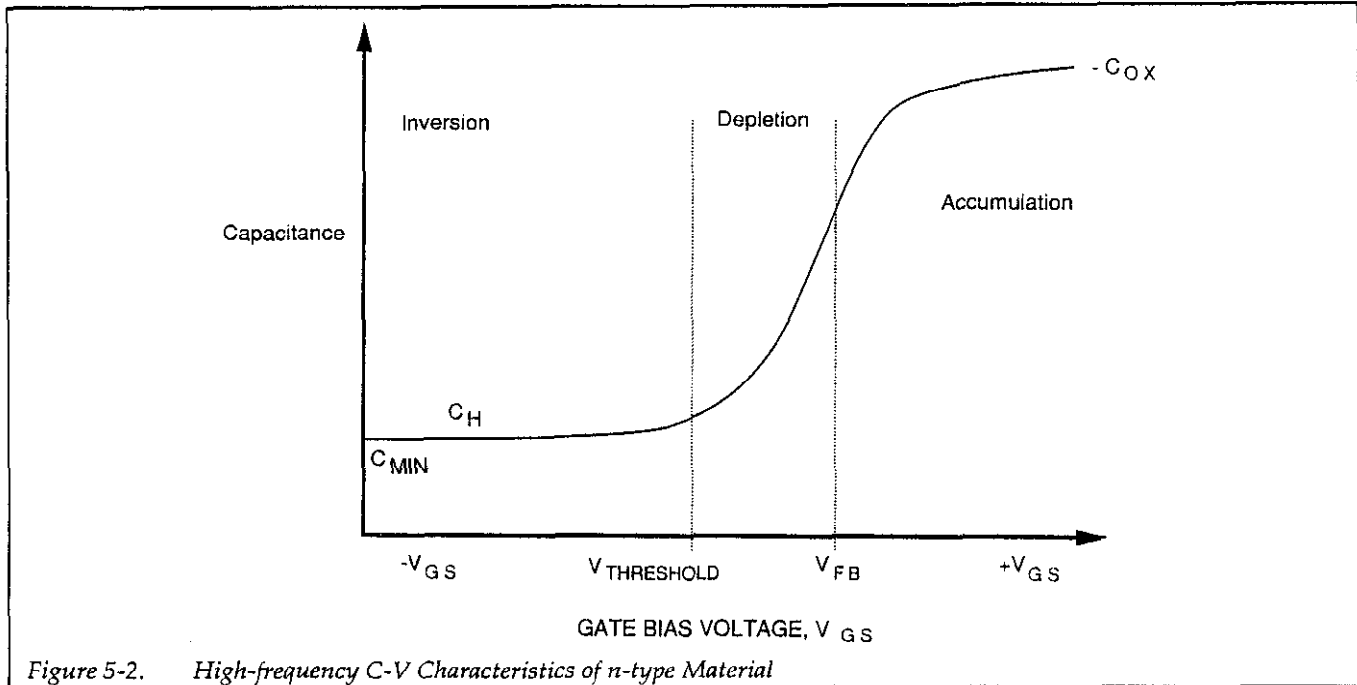


Figure 5-2. High-frequency C-V Characteristics of n-type Material

### 5.3.3 Oxide Capacitance and Minimum Capacitance

The oxide capacitance,  $C_{OX}$ , is usually defined as the maximum high-frequency capacitance, which occurs while the device is biased in strong accumulation. Similarly, the minimum capacitance,  $C_{MIN}$ , is the minimum high-frequency capacitance, and it occurs when the device is biased in strong inversion and has reached equilibrium.

The Model 5958 will recommend  $C_{OX}$  and  $C_{MIN}$  values based on the maximum and minimum capacitance values measured during a C-V sweep. You can display and change these values, as described in paragraph 5.6.3.

### 5.3.4 Flatband Voltage and Threshold Voltage

The flatband voltage,  $V_{FB}$ , marks the transition from accumulation to depletion, and the threshold voltage,  $V_{THRESHOLD}$  separates the depletion region from the inversion region. Flatband voltage and threshold voltage are marked as  $V_{fb}$  and  $V_{th}$  respectively on any graph that plots  $V_{GS}$  along the X axis. You can toggle the  $V_{fb}$ ,  $V_{th}$  display on or off by pressing the "V" key.

## 5.4 LOADING AND SAVING DATA

By selecting the File option on any of the main analysis menus, you can save current measurement and analysis data, or load previously stored data into memory.

A save/load operation, stores or recalls the following information:

- Measured capacitance, conductance, voltage, and time information.
- Calculated array data (for example, doping profile).
- Analysis constants (for example, flatband capacitance).

#### NOTE

See Appendix D for a description of the data file and its format.

#### NOTE

Data used for your last analysis session will be automatically loaded when the Model 5958 program is run.

### 5.4.1 Filename Formats for Data Files

The basic filename formats used by the Model 5958 differ among C-V, C-t, Zerst sequence, and BTS sequence

Table 5-3. Filename Formats for Data Files

File Type	Filename Format	Comments
Basic C-V	Filename.DAT	Eight characters maximum
Basic C-t	Filename.CTD	Eight characters maximum
Zerbst sequence	File_nnZ.DAT	C-V file, nn = device #
	File_nnZ.CTD	C-t file, nn = device #
BTS sequence	File_nnI.DAT	Pre-stress, nn = device #
	File_nnP.DAT	Positive stress, nn = device #
	File_nnN.DAT	Negative stress, nn = device #

tests. Formats are summarized in Table 5-3, and each of the filename formats is discussed below.

### C-V Data Files

Basic non-sequence C-V data files use a filename of up to eight characters and use a .DAT extension. Typical examples include:

```
MYFILE.DAT
WAFER_A.DAT
```

### C-t Data Files

Like basic C-V files, non-sequence C-t data files use a filename of up to eight characters. However, C-t data files use the .CTD extension, as in the examples below:

```
CAP_TEST.CTD
C_T_TEST.CTD
```

### Zerbst Sequence Data Files

Zerbst sequence data filenames include up to five characters for the name, followed by two characters representing the number of the device, and the letter "Z" to indicate Zerbst sequence data. Note that device numbers are automatically stored with the chosen filename when the test is run. If the no C-V test option is in effect, no C-V data will be taken. If the one C-V option is used, only one C-V data file will be created. For the multiple C-V option, multiple C-V files will be created.

**Example 1:** Assume a test assigning a data destination of WAFER has been performed. Typical filenames for device #7 include:

```
WAFER07Z.DAT (C-V data filename for device #7)
WAFER07Z.CTD (C-t data filename for device #7)
```

**Example 2:** A file called MYFILE is created for device #1. Filenames for the C-V and C-t files are:

```
MYFIL01Z.DAT (C-V file)
MYFIL 01Z.CTD (C-t file)
```

### BTS Sequence Data Files

BTS test sequence filenames can have up to five characters. The sixth and seventh characters define the device number, while the eighth character defines the stress type: "I" indicates initial, or pre-stress, while "P" and "N" represent positive and negative stress cycles respectively.

As an example, assume that a file called MYFILE has been defined in the BTS setup menu. The following three files would be created at test time for device #3:

```
MYFIL03I.DAT      (Device #3, pre-stress)
MYFIL03P.DAT      (Device #3, positive stress)
MYFIL03N.DAT      (Device #3, negative stress)
```

## 5.4.2 Loading Data

Use the following procedure to load a data file from disk into computer memory.

### NOTE

Loading data will overwrite any data currently stored in memory. Data analysis and graphing always carried out on data currently stored in memory.



1. From one of the analysis menus, press <Alt>-F, then select Load on the pull-down menu. The load file window shown in Figure 5-3 will be displayed along with any data (\*.DAT or \*.CTD) files stored in the current \DAT directory.
2. Select an existing file to load with the up arrow or down arrow key (or use a mouse, if available), then press <Enter>. You can also type in the complete name of the file, if desired (you must include the .DAT extension).
3. To load a file from different directory, change the path by typing in the complete path followed by \*.DAT. For example, to change to a directory called C:\DATA, type the following:

C:\DATA\\*.DAT <Enter>

The directory will be changed as specified, and the new directory will become the default for the current session until changed.

4. Once the filename is selected or entered, select OK to load it, or choose Cancel to exit the window without loading the data. If you choose to cancel, previous data loaded in memory will remain intact.

### 5.4.3 Saving Data

Follow the steps below to save data currently stored in computer memory in a designated disk file:

1. From one of the analysis menus, press <Alt>-F, then select Save on the pull-down menu. The save file window shown in Figure 5-4 will be displayed along with any data (\*.DAT or \*.CTD) files stored in the current \DAT directory.
2. To save data in memory to an existing filename, select the name using the up arrow or down arrow key (or use a mouse, if available). To save the data using a new filename, type in the name, including the .DAT extension (C-V files) or .CTD extension (C-t files). If you wish to save the file in a different directory, include the complete path (for example, A:MYFILE.DAT, or C:\DATA\MYFILE.DAT).
3. To change directories, type in the complete new path name followed by \*.DAT. For example, to change to a directory called C:\DATA, type the following:

C:\DATA\\*.DAT <Enter>

The directory will be changed as specified, and the new directory will become the default for the current session until changed.

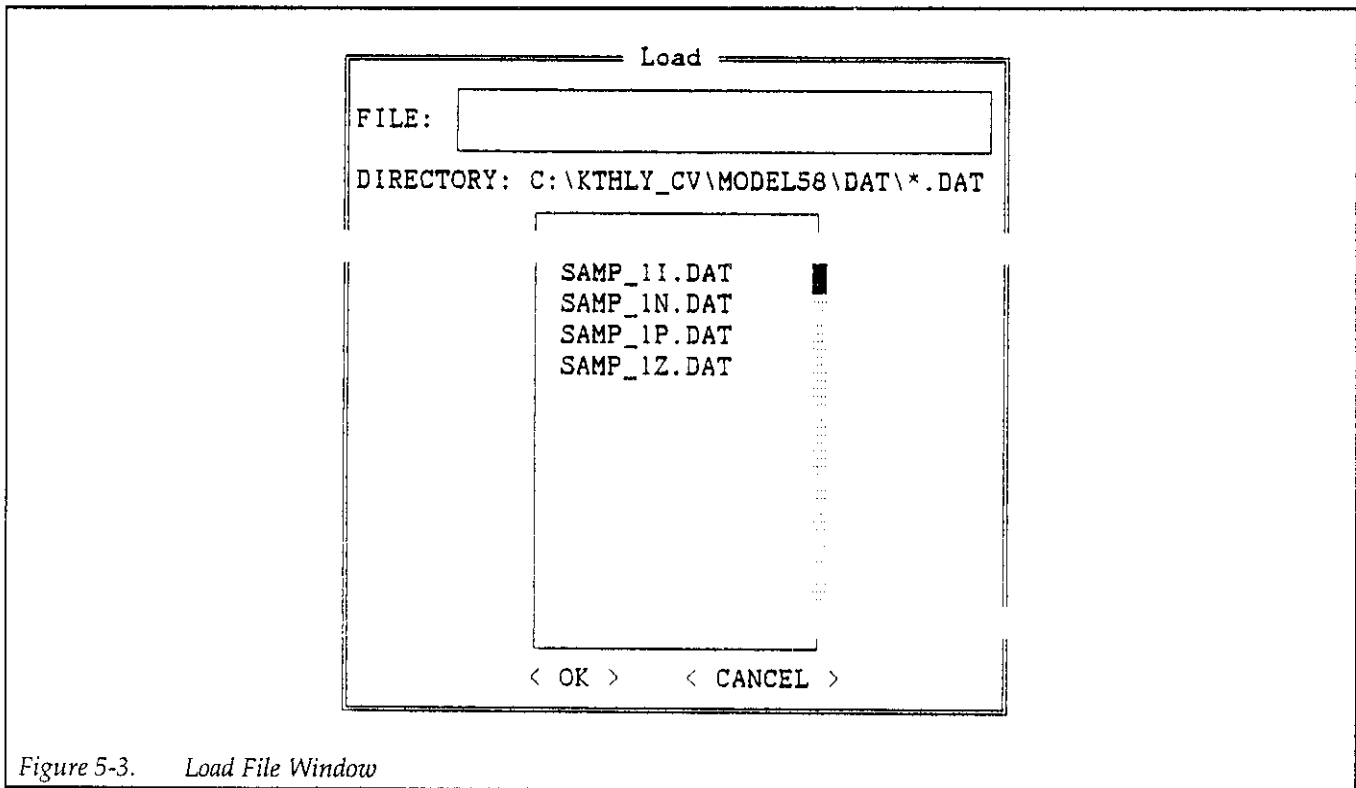


Figure 5-3. Load File Window

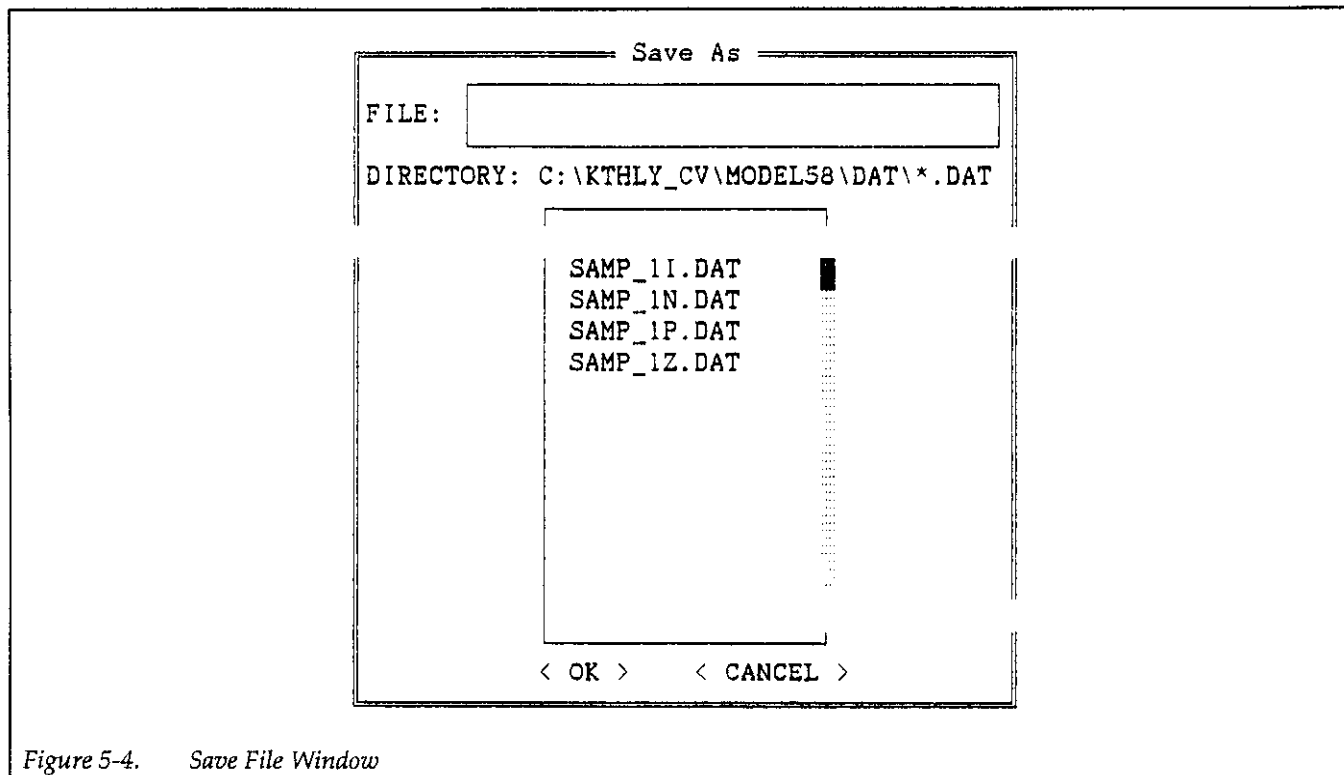


Figure 5-4. Save File Window

4. Once the filename is selected or entered, select OK to save it, or choose Cancel to exit the window without loading the data. If you choose to cancel, previous data loaded in memory will remain intact.
5. You will then be given the opportunity to choose one of three data delimiters: Tab, space, or comma. The delimiter choice is included to allow data to be imported into other programs (see paragraph 5.4.4), but any of the three delimiters can be used with Model 5958 files.
6. After the delimiter has been chosen, data will be saved using the selected filename.

#### 5.4.4 Importing Data into Other Programs

Since Model 5958 data files are stored in ASCII format, these files can be imported into many spreadsheet and word processing programs by choosing the proper data delimiter. Compatible delimiters for typical programs include:

Lotus 1-2-3: Tab, space, or comma  
 Microsoft Excel: Tab  
 Word processors: Tab or space

Typically, Model 5958 data can be imported into spreadsheets by using the retrieve numbers or import numbers option of the spreadsheet program. Data can be imported into word processors using the ASCII read option if one is available.

**Example:** Assume that you have a data file called WAFER1.DAT store in disk that you want to save in a compatible Lotus 1-2-3 format in the Lotus data directory called C:\LOTUS123\DATA. The following procedure demonstrates the process.

1. From an analysis menu, press <Alt>-F, then select Load on the pull-down menu.
2. Select the data file to load (WAFER1.DAT in this example), then select OK to load it.
3. Press <Alt>-F, then select Save.
4. Type in the complete path name, including the filename with the new extension. For our current example, the complete path would be:

C:\LOTUS123\DATA\WAFER1.DAT <Enter>

5. At the prompt, select a comma data delimiter.
6. After saving the file, exit the Model 5958 program, then run the Lotus 1-2-3 program.

7. Select the retrieve numbers option, then load the WAFER1.DAT file. Separate numbers and array elements will be placed into individual cells.

## 5.5 GRAPHICAL ANALYSIS

To generate an analysis graph, select the corresponding option from one of the three analysis menus, then use the graphics control menu discussed in paragraph 5.5.1 to tailor the graph as required.

### 5.5.1 Graphics Control Menu

Selecting a graphing option will cause a graph to be generated on the screen, along with the graphics control window.

#### NOTE

A particular graph retains its configuration until a new reading array is analyzed.

The graphics control menu is shown in Figure 5-5. Through this menu you can select the following:

1. Auto Scaling. When auto scaling is selected, the minimum and maximum values for the data will automatically be used as the limits for both X and Y axes.
2. Axes Limits. The option allows you to select the minimum and maximum limits for both X and Y axes, and it can be used to zoom in on a portion of the curve. At the prompts, type in Xmin, Xmax, Ymin, and Ymax (minimum must be less than maximum). To leave a parameter unchanged, simply press Enter. See also paragraph 5.5.6 for information on using the graphics range as an alternative.
3. Plot Graph. This option dumps the complete graph including the curve and axes to the printer or plotter (depending on the selected hard copy device). Note, however, that the graphics control menu will not appear on the hard copy plot. Plot resolution and size can be controlled, as discussed below.
4. Plot Curve. Use this option to generate the curve only with the external plotter. This feature is useful for drawing more than one curve on a graph.
5. Change Notes. You can type in two lines of notes that will appear at the top of the graph by using this option. The notes will also appear on any hard copy plot made of the graph. Each line is entered separately.
6.
  - A. Normalize to  $C_{OX}$ . This option is available only when plotting  $C_H$  vs. some other parameter such as gate voltage or band bending. When selected, the Y axis will show  $C/C_{OX}$ .
  - B. Lin/Log Graph. This option is available only for plots other than  $C_H$ . When log is selected, the Y axis is plotted logarithmically, but the X axis remains linear. Note that absolute values are plotted using the log option.
7. Gain/offset (some graphs). Allows you to change gain or offset applied to  $C_H$ .
7. Find  $t_g, s$  (Zerbst plot) allows you to find the generation lifetime,  $\tau_g$  (sec), and the generation velocity,  $s$  (cm/sec.)
7. or 8. Exit.

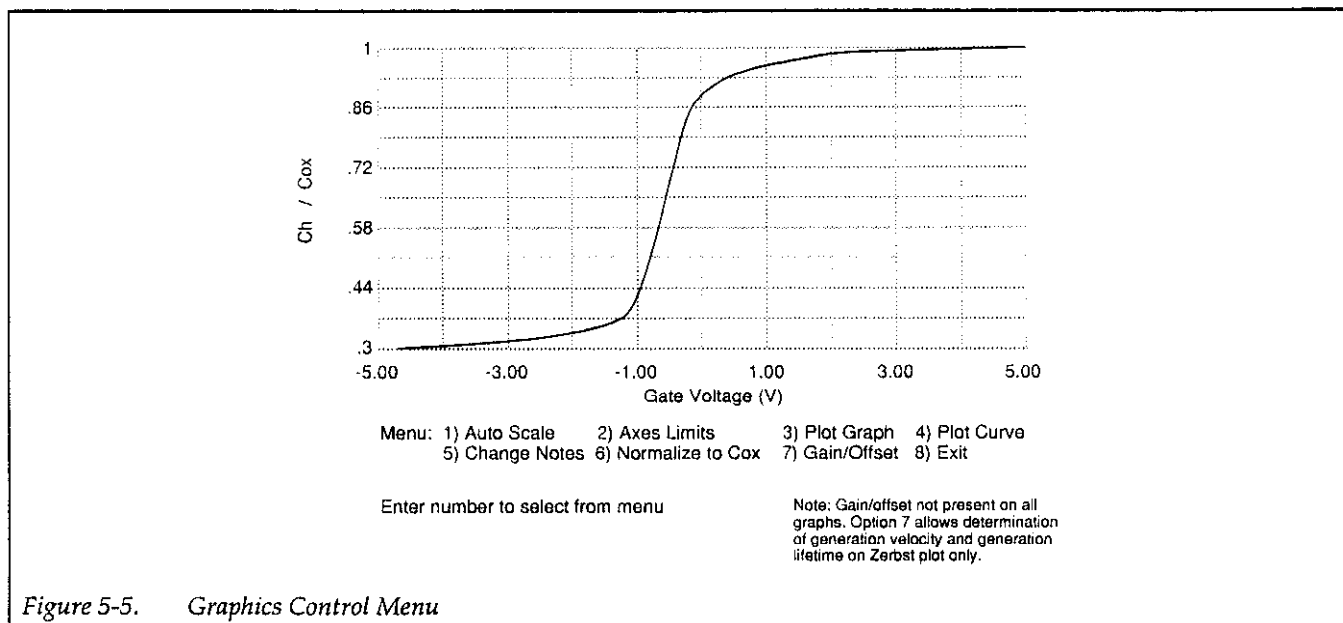


Figure 5-5. Graphics Control Menu

## 5.5.2 Controlling Hard Copy Size and Resolution

### Printer Size and Resolution

From the graphics menu, you can control the size and resolution of your hard copy graphs made on printer by pressing one of the following letters:

- m Half page, low-resolution plot
- M Half page, high-resolution plot
- l Full page, low-resolution plot
- L Full page, high-resolution plot
- Q Abort plot and return to graphics menu

Note that selecting option 3 or 4 on the graphics menu automatically generates a half-page, low-resolution curve or graph on the printer.

### Plot size

With a plotter, you can control the plot size. This selection will be displayed on the screen after you select the plotting option on the graphics menu. Type in the desired size, and press the <Enter> key to begin plotting.

## 5.5.3 Cursor Operation

To make it easier to change axes scales and gain and offset values, a cursor marker facility is included with Model 5958. To use this feature, type "C" or "c" from the graphics menu. Once enabled, a cursor will be displayed on the screen, and you can move that cursor around the screen using the arrow keys. The value corresponding to the present cursor location will be displayed at the bottom of the screen.

To mark a specific location, press the <Enter> key. The location will be marked with a set of crosshairs on the graph. Move the cursor to the second location with the cursor keys, and note that  $dy$  (change in  $y$ ) and  $ry$  (ratio between present  $y$  location and marked  $y$  location) are displayed on the bottom of the screen. To mark the second location, press <Enter> a second time, then press the <Esc> key to exit the cursor mode. Subsequently selecting the Axes Limits or Gain/Offset options will cause both markers to be displayed on the screen along with the differences between them. You can then use this information to set your new axes limits, or gain and offset values.

You can also use the <Insert> key to draw a line. To use this feature, move the cursor to the first location, then press <Enter>. Move the cursor to the second location, then press <Insert>.

### 5.5.4 Threshold Voltage and Flatband Voltage Display

Threshold voltage and flatband voltage are automatically marked as  $V_{th}$  and  $V_{fb}$  on any graph which displays  $V_{GS}$  along the X axis. You can toggle this display on or off by pressing the "V" key.

### 5.5.5 Overlaying Curves

When using a plotter, you can overlay a number of curves on the same graph. To use this feature, first plot the entire graph by selecting option 3 (plot graph) on the graphics control menu. Load your next data set, then generate the curve by selecting option 4 (plot curve). Repeat this process for as many curves as you wish to overlay.

Needless to say, the X and Y axis scaling factors for all sets of overlay data must be the same, or the resulting curve overlays will have minimal analytical value.

### 5.5.6 Selecting the Graphics Range

The graphics range defines the lower and upper limits of the arrays to be plotted. The graphics range can be used to select the range for best depth (the range over which N is accurate to within 5%). The graphics range feature can

also be used to zoom in on interesting sections of curves and to set lower and upper limits for data array printouts.

Procedure:

1. From an analysis menu, press <Alt>-F, then choose Select Graphics Range.
2. The window shown in Figure 5-6 will be displayed. Note that calculated best depth values are displayed along with current minimum and maximum graphics range valued.
3. Enter the desired minimum and maximum graphics range value where indicated, then select OK to place the changes into effect. You can also select Cancel to exit the window without changing the previous graphics range.

## 5.6 C-V ANALYSIS

The following paragraphs discuss the C-V analysis window, as well as displaying and printing analysis constants and array values, and graphing C-V data.

### 5.6.1 C-V Analysis Menu

The main selections on the C-V analysis menu are summarized below.

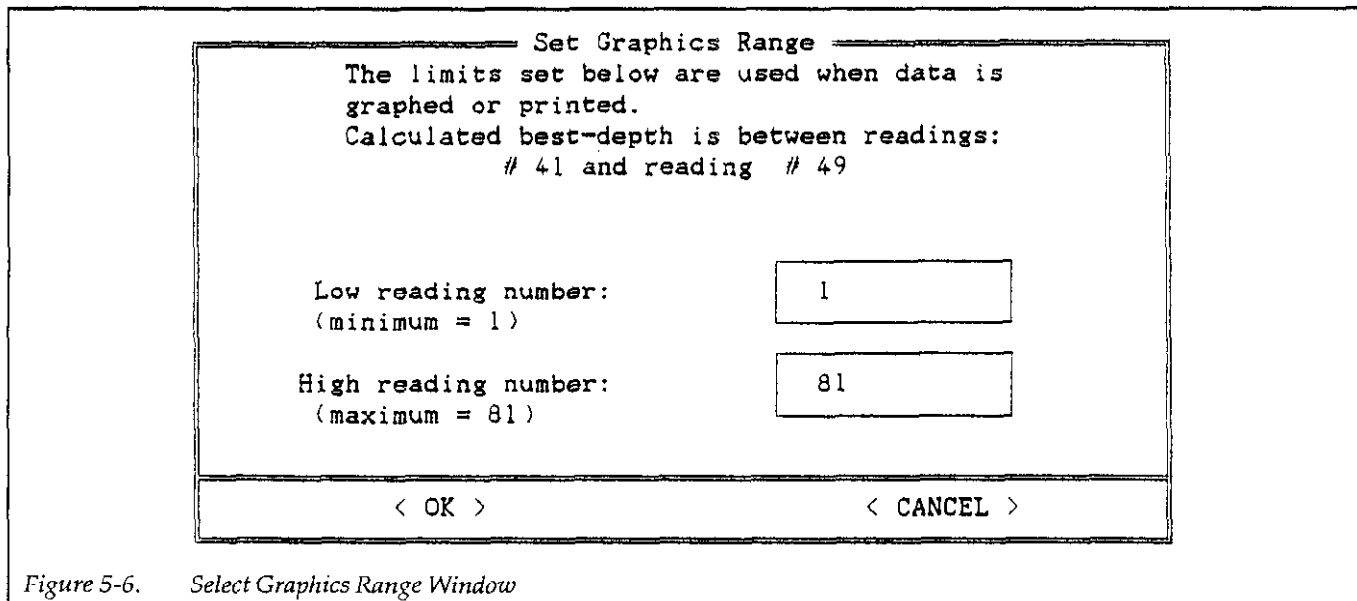


Figure 5-6. Select Graphics Range Window

**C-V ANALYSIS**

Setup/Run: Returns you to the setup/run menu.

Exit to Dos: Exits the Model 5958 program and returns you to DOS.

**File**

Save: Saves data in memory to a disk file.

Load: Loads a data file into memory.

Select Graphics Range: Allows you to select lower/upper limits for graphing and printing.

**Display**

C-V Analysis Constants: Displays analysis constants, best depth, and gain/offset, and allows user input of certain constants and gain/offset values.

C, G, V: Displays measured capacitance, conductance (resistance for series model), and voltage data.

w, N, Zw, ZN,  $1/C^2$ : Displays depth, doping, Ziegler depth, Ziegler doping, and  $1/C^2$  array data.

**Print**

C-V Analysis Constants: Prints analysis constants, best depth, and gain/offset values.

C, G, V: Prints measured capacitance, conductance (resistance for series model), and voltage data.

w, N, Zw, ZN,  $1/C^2$ : Prints depth, doping, Ziegler (MCC) depth, Ziegler doping, and  $1/C^2$  array data.

**Graph**

C vs. Vgs: Graphs capacitance vs. gate voltage.

G/R vs. Vgs: Graphs conductance vs. gate voltage (resistance vs. gate voltage for series model).

Depth vs. Vgs: Graphs depth vs. gate voltage.

Doping vs. Depth: Graphs doping concentration vs. depth.

Ziegler Doping vs. Depth: Graphs Ziegler doping concentration vs. Ziegler Depth.

**5.6.2 Loading and Saving C-V Data Files**

To load or save a C-V data files, press <Alt>-F, then select Load or Save as required. C-V filenames can have up to eight characters and use the .DAT extension. Refer to paragraph 5.4 for more details on file operations.

**5.6.3 Displaying Analysis Constants**

Select Display Analysis Constants on the Display menu to display the analysis constants shown in Figure 5-7. In addition to the analysis constants summarized in Table 5-4, selections at the bottom of this window allow you to perform the following operations:

Change Constants: Allows you change  $R_{SERIES}$ ,  $C_{OX}$  and  $tox$  or area, and  $C_{MIN}$ .

Gain/Offset: Allows you to program  $C_H$  gain and offset values.

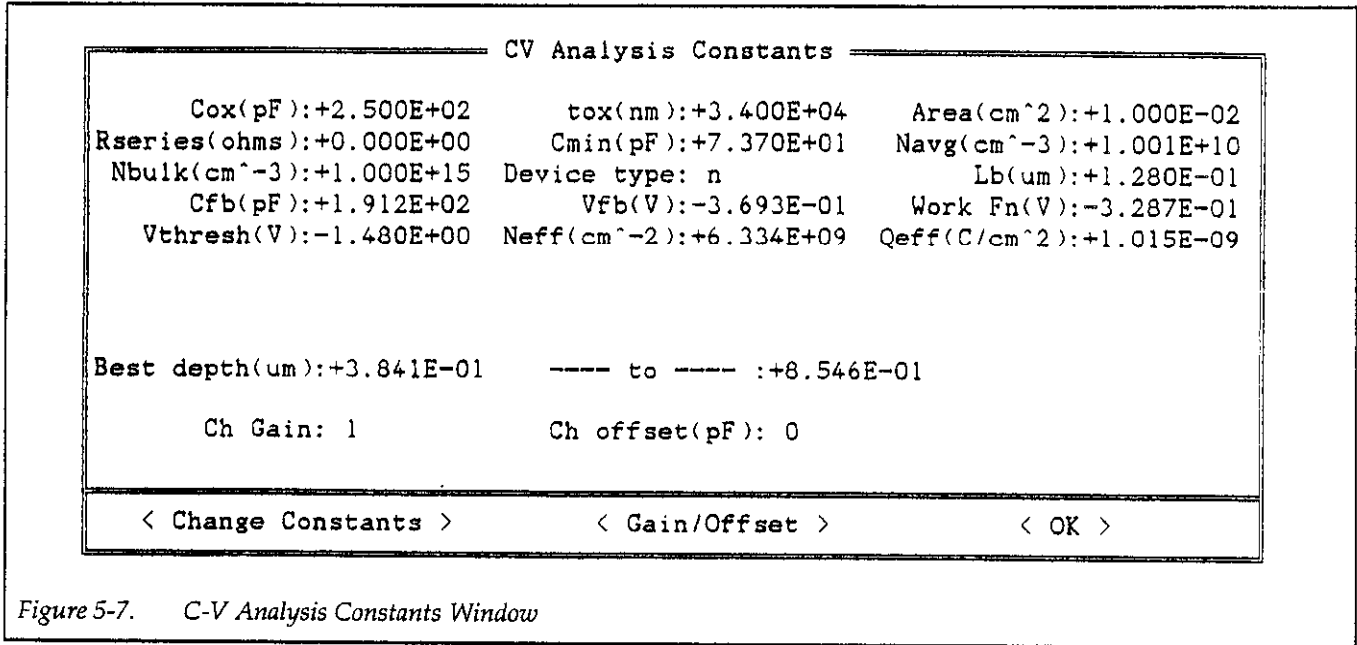


Figure 5-7. C-V Analysis Constants Window

Table 5-4. C-V Analysis Constants

Constants	Menu Term	Description	Units
C <sub>OX</sub>	Cox	Oxide capacitance	pF
R <sub>SERIES</sub>	R series	Series resistance	ohms
N <sub>BULK</sub>	Nbulk	Bulk doping concentration	cm <sup>-3</sup>
C <sub>FB</sub>	Cfb	Flatband capacitance	pF
V <sub>THRESHOLD</sub>	Vthresh	Threshold voltage	V
tox	tox	Oxide thickness	nm
C <sub>MIN</sub> *	Cmin	Minimum capacitance	pF
V <sub>FB</sub>	Vfb	Flatband voltage	V
N <sub>EFF</sub>	Neff	Effective oxide charge concentration	1/cm <sup>2</sup>
Area	Area	Gate area	cm <sup>-2</sup>
N <sub>AVG</sub>	Navg	Average doping concentration	cm <sup>-3</sup>
λ	Lb	Extrinsic debye length	μm
W <sub>MS</sub>	Work Fn	Work function difference	V
Q <sub>EFF</sub>	Qeff	Effective oxide charge	coul/cm <sup>2</sup>
	Device type	Device type	n or p
	Best depth	Best depth	μm

\*C<sub>MIN</sub> is determined using the procedure covered in paragraph 4.2.4.

## Changing Analysis Constants

Selecting Change Constants allows you enter new values for the following constants:

- R<sub>SERIES</sub>
- C<sub>OX</sub> and t<sub>OX</sub> or gate area
- C<sub>MIN</sub>
- N<sub>BULK</sub>

Follow the procedure outlined below to enter new values for these constants.

1. From the analysis constants window, select Display Constants. The R<sub>SERIES</sub> window shown in Figure 5-8 will be displayed along with the suggested value, current value, and new value. Note that the suggested value corresponds to the equivalent series resistance at the maximum high-frequency capacitance, which is the suggested value for C<sub>OX</sub>.
2. To enter a new value, use the <Tab> key to move to the New Value selection, then type in your series resistance value. (Press <Insert> to enable data entry.)

You can also <Tab> to ACCEPT SUGGESTED to use the suggested value.

3. Select OK or ACCEPT SUGGESTED to accept the new series resistance value, or choose CANCEL to leave the present value unchanged.
4. Next, the C<sub>OX</sub> window shown in Figure 5-9 will be displayed, along with the suggested value, current value, and new value. The suggested C<sub>OX</sub> value is the maximum high-frequency capacitance.
5. Next, you will be given a choice to either enter area and recalculate t<sub>OX</sub>, or to enter t<sub>OX</sub> and recalculate area. If you choose to enter area, the window shown in Figure 5-10 will be displayed; the window in Figure 5-11 will be displayed if you choose to enter t<sub>OX</sub>.
6. Enter area or t<sub>OX</sub> as appropriate, then select OK or ACCEPT SUGGESTED to accept the new value (or use CANCEL to leave the value unchanged).
7. The window shown in Figure 5-12 will be displayed. This window allows you to enter a new value for C<sub>MIN</sub>, if desired. C<sub>MIN</sub> is simply the minimum high-frequency capacitance value.
8. Enter a new value for C<sub>MIN</sub>, then select OK or ACCEPT SUGGESTED to accept the change.
9. Finally, the window in Figure 5-13 will be displayed. Enter or accept the value for N<sub>BULK</sub> as indicated.



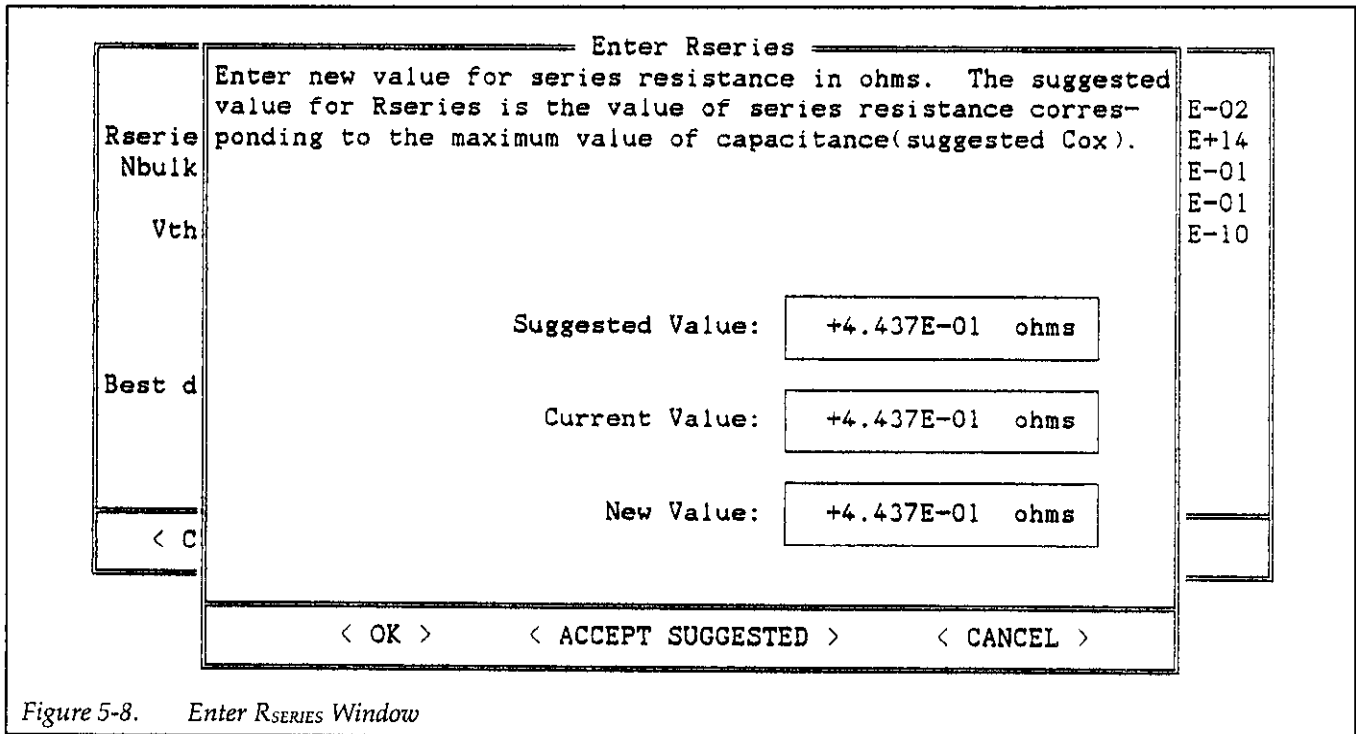


Figure 5-8. Enter R<sub>SERIES</sub> Window

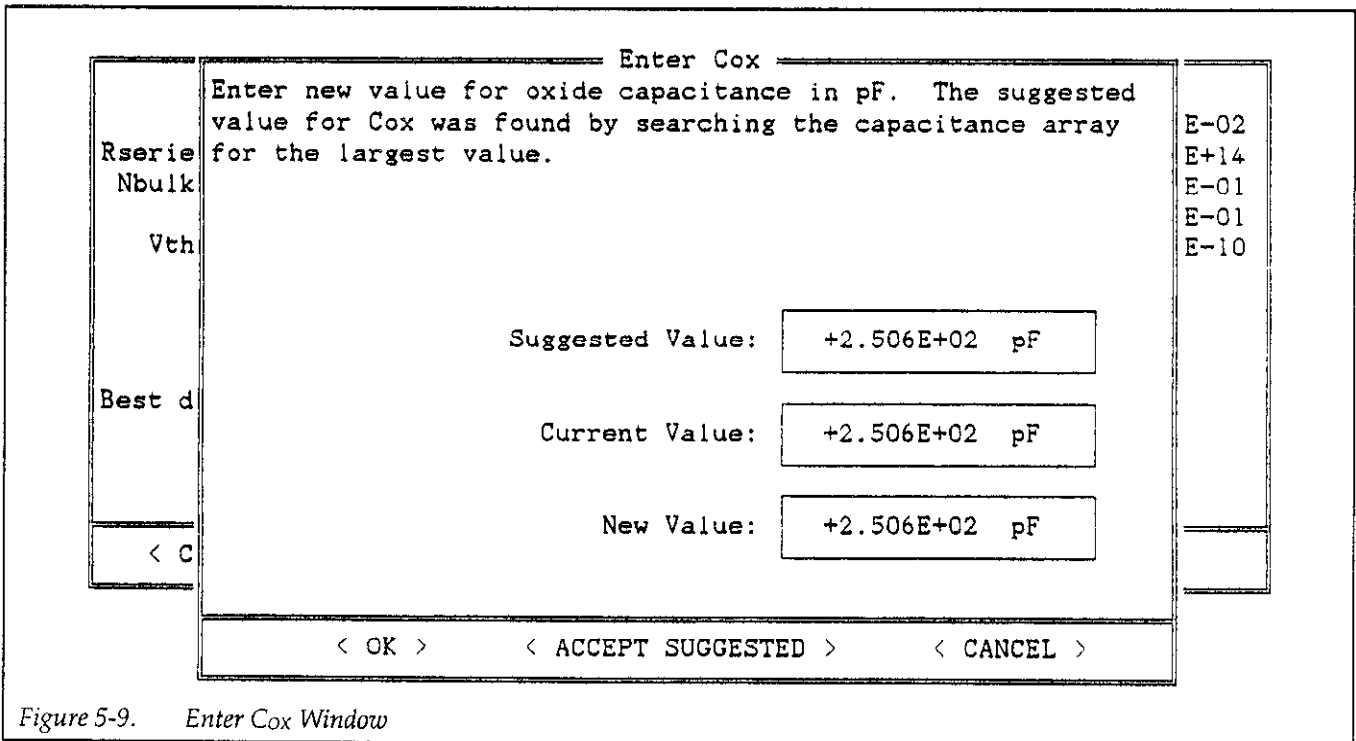


Figure 5-9. Enter Cox Window

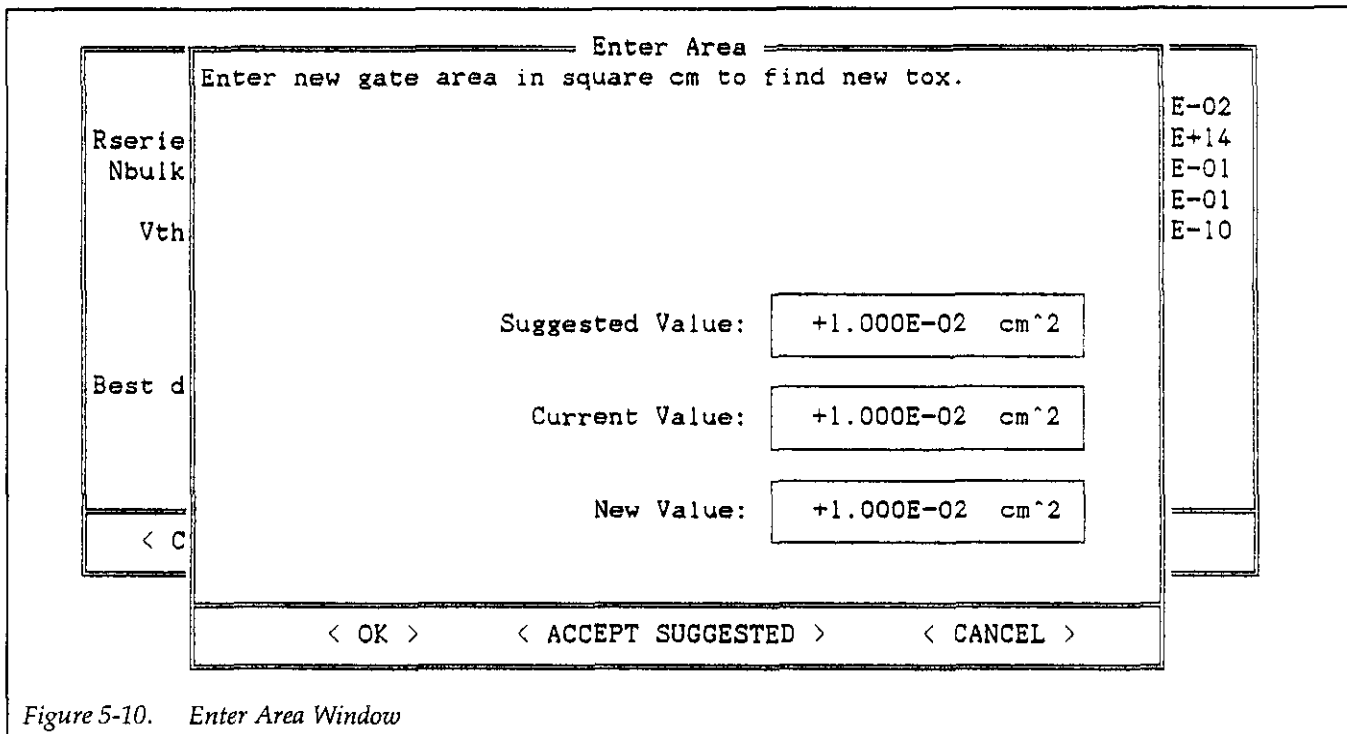


Figure 5-10. Enter Area Window

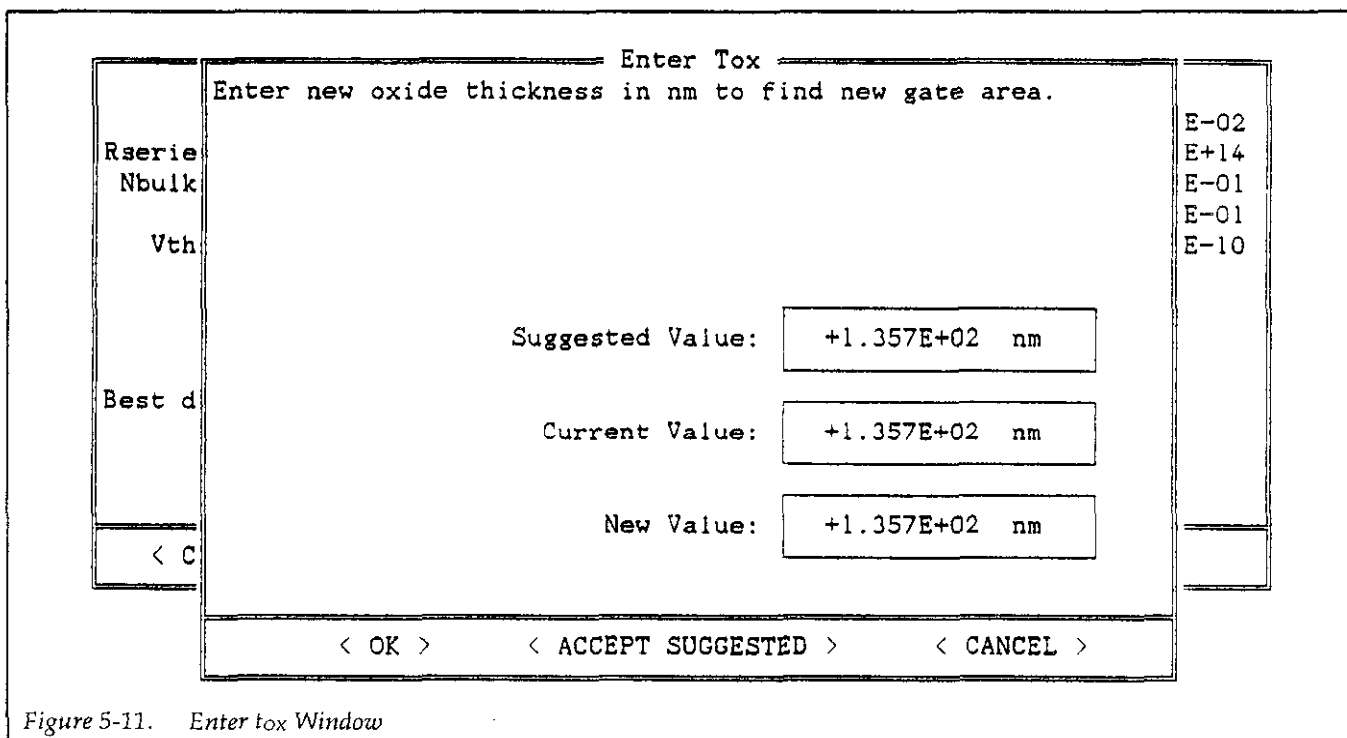


Figure 5-11. Enter tox Window

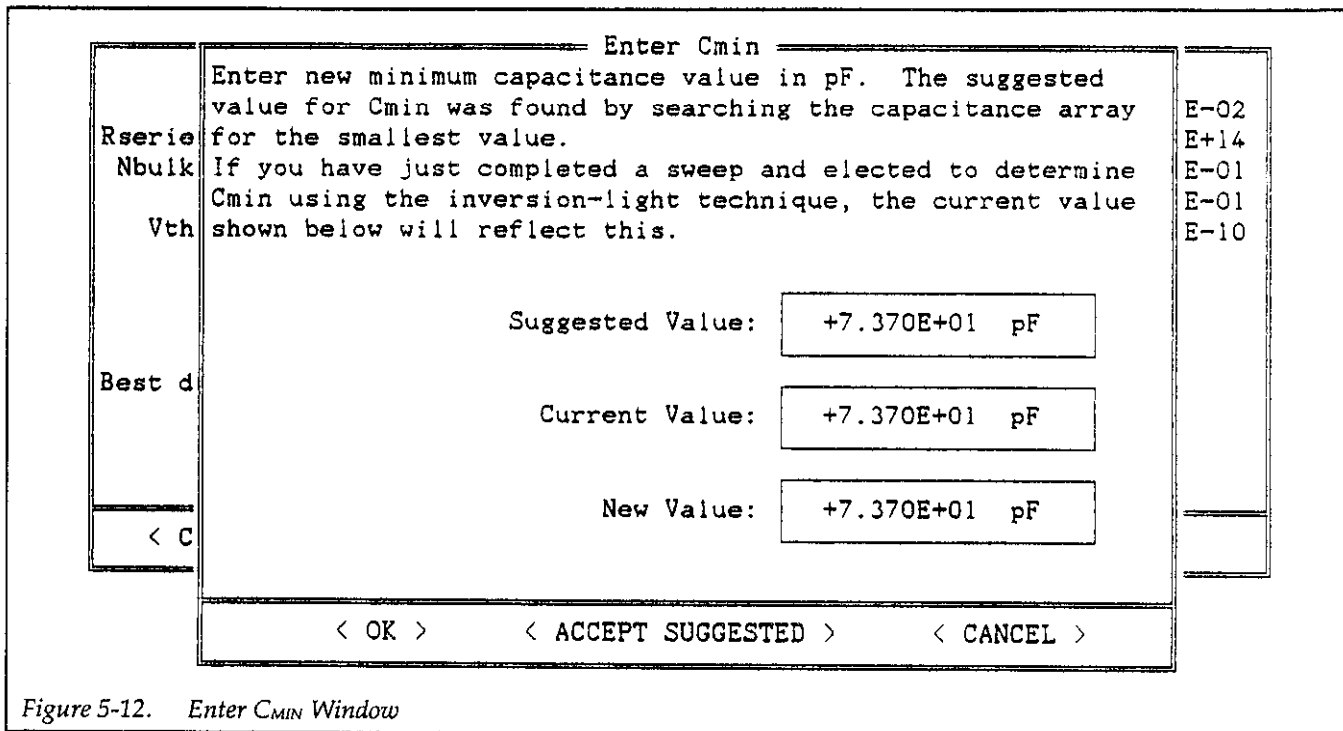


Figure 5-12. Enter  $C_{MIN}$  Window

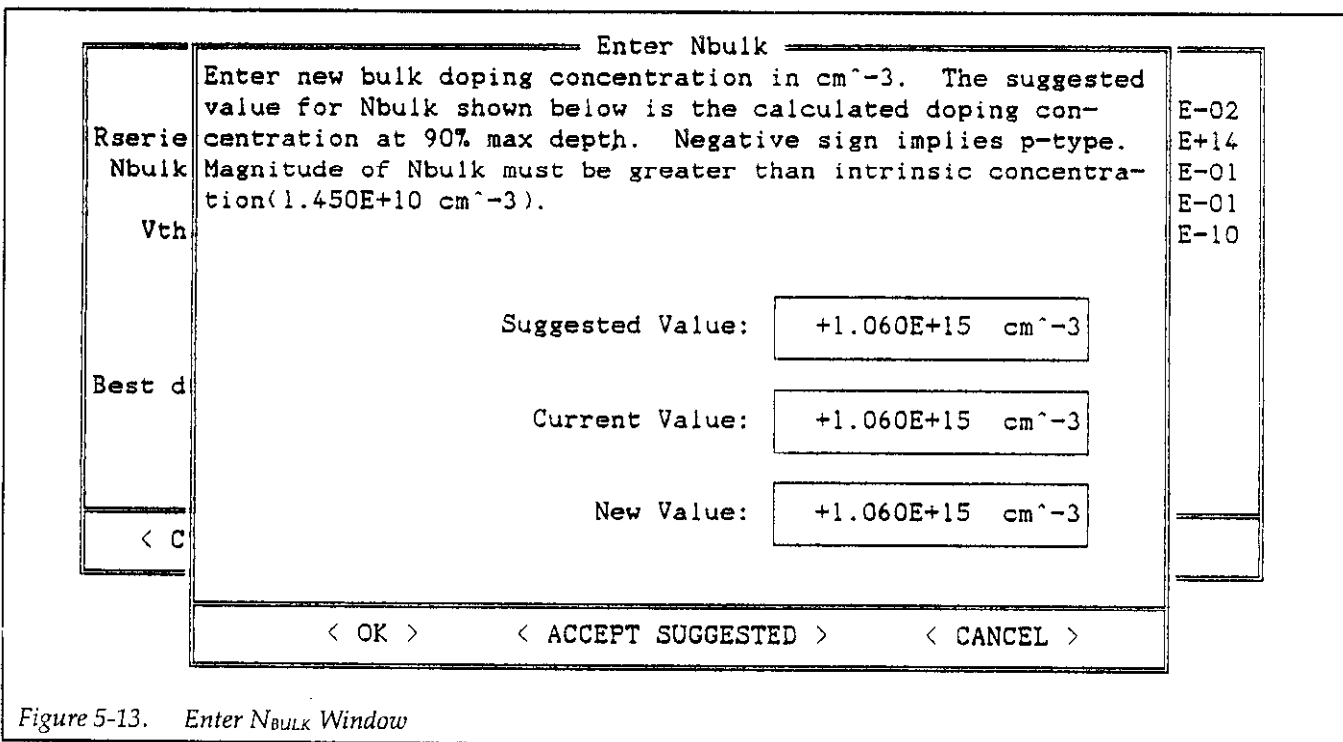


Figure 5-13. Enter  $N_{BULK}$  Window

### 5.6.4 Oxide Capacitance, Thickness, and Area Calculations

The oxide capacitance,  $C_{OX}$ , is the high-frequency capacitance with the device biased in strong accumulation.

Oxide thickness is calculated from  $C_{OX}$  and gate area as follows:

Eq. 1

$$t_{OX} = \frac{A \epsilon_{OX}}{(1 \times 10^{-19}) C_{OX}}$$

Where:  $t_{OX}$  = oxide thickness (nm)  
 $A$  = gate area (cm<sup>2</sup>)  
 $\epsilon_{OX}$  = permittivity of oxide material (F/cm)  
 $C_{OX}$  = oxide capacitance (pF)

The above equation can be easily rearranged to calculate to solve for gate area if the oxide thickness is known.

Note that  $\epsilon_{OX}$  and other constants are defined in the MATERIAL.CON file and are initialized for use with silicon substrate, silicon dioxide insulator, and aluminum gate material. See Appendix A for information on changing these constants for use with other materials.

### 5.6.5 Series Resistance Calculations

The series resistance,  $R_{SERIES}$ , is an error term that can cause measurement and analysis errors unless this series resistance error factor is taken into account.

The Model 5958 software compensates for series resistance using the simplified three-element model shown in Figure 5-14. In this model,  $C_{OX}$  is, of course, the oxide capacitance while  $C_A$  is the capacitance of the accumulation layer. The series resistance is represented by  $R_{SERIES}$ .

From Nicollian and Brews 224, the correction capacitance,  $C_C$ , and corrected conductance,  $C_G$ , are calculated as follows:

Eq. 2

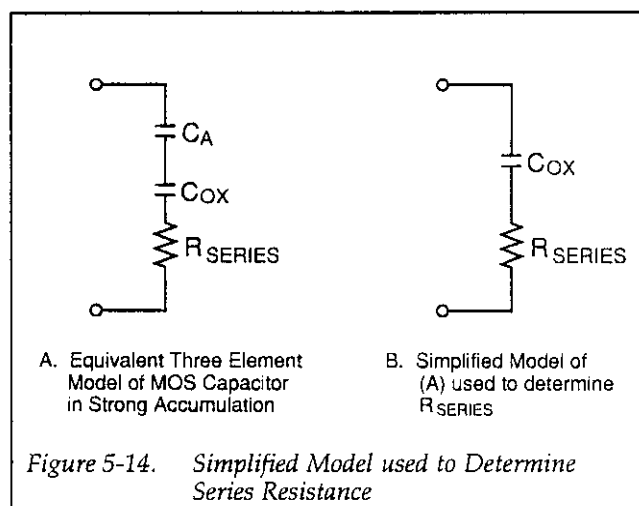
$$C_C = \frac{(G_M^2 + \omega^2 C_M^2) C_M}{a^2 + \omega^2 C_M^2}$$

and,

Eq. 3

$$G_C = \frac{(G_M^2 + \omega^2 C_M^2) a}{a^2 + \omega^2 C_M^2}$$

Where:  $a = G_M - (G_M^2 + \omega^2 C_M^2) R_{SERIES}$   
 $C_C$  = series resistance compensated parallel model capacitance  
 $C_M$  = measured parallel capacitance  
 $G_C$  = series resistance compensated conductance  
 $G_M$  = measured conductance  
 $R_{SERIES}$  = series resistance



### 5.6.6 Flatband Capacitance and Flatband Voltage

Model 5958 uses the flatband capacitance method of finding flatband voltage,  $V_{FB}$ . The Debye length is used to calculate the ideal value of flatband capacitance,  $C_{FB}$ . Once the value of  $C_{FB}$  is known, the value of  $V_{FB}$  is interpolated from the closest  $V_{GS}$  values (Nicollian and Brews 487-488).

The method used is invalid when interface trap density becomes very large ( $10^{12}$ – $10^{13}$  and greater). However, this algorithm should give satisfactory results for most users. Those who are dealing with high density values should consult the appropriate literature for a more appropriate method and modify the Model 5958 software accordingly.

Based on doping, the calculation of  $C_{FB}$  uses  $N$  at 90%  $W_{MAX}$ , or user-supplied  $N_A$  (bulk doping for p-type, acceptors) or  $N_D$  (bulk doping for n-type, donors).

$C_{FB}$  is calculated as follows:

Eq. 4

$$C_{FB} = \frac{C_{OX} \epsilon_s A / (1 \times 10^{-4})(\lambda)}{(1 \times 10^{12})(C_{OX}) + \epsilon_s A / (1 \times 10^{-4})(\lambda)}$$

Where:  $C_{FB}$  = flatband capacitance (pF)  
 $C_{OX}$  = oxide capacitance (pF)  
 $\epsilon_s$  = permittivity of substrate material (F/cm)  
 $A$  = gate area (cm<sup>2</sup>)  
 $1 \times 10^{-4}$  = units conversion for  $\lambda$   
 $1 \times 10^{-12}$  = units conversion for  $C_{OX}$

And  $\lambda$  = extrinsic Debye length =

Eq. 5

$$(1 \times 10^4) \left( \frac{\epsilon_s kT}{q^2 N_x} \right)^{1/2}$$

Where:  $kT$  = thermal energy at room temperature (4.046 × 10<sup>-21</sup>J)  
 $q$  = electron charge (1.60219 × 10<sup>-19</sup>coul.)  
 $N_x$  =  $N$  at 90%  $W_{MAX}$ , or  $N_A$  or  $N_D$ .

$N$  at 90%  $W_{MAX}$  is chosen to represent bulk doping,  $N_{BULK}$ .

## 5.6.7 Threshold Voltage

The threshold voltage,  $V_{THRESHOLD}$ , is the point on the C-V curve that corresponds to the onset of strong inversion (see Figures 5-1 and 5-2). For an enhancement mode MOSFET,  $V_{THRESHOLD}$  corresponds to the point where the device begins to conduct. Note that threshold voltage is displayed as  $V_t$  on graphs that plot  $V_{GS}$  on the X axis.

$V_{THRESHOLD}$  is calculated as follows:

Eq. 6

$$V_{THRESHOLD} = \left[ \pm \frac{\Lambda}{10^{12} C_{OX}} \sqrt{4 \epsilon_s q |N_{BULK}| |\phi_B|} + 2 |\phi_B| \right] + V_{FB}$$

Where:  $V_{THRESHOLD}$  = threshold voltage (V)  
 $A$  = gate area (cm<sup>2</sup>)  
 $C_{OX}$  = oxide capacitance (pF)  
 $10^{12}$  = units multiplier  
 $\epsilon_s$  = permittivity of substrate material  
 $q$  = electron charge (1.60219 × 10<sup>-19</sup> coul.)  
 $N_{BULK}$  = bulk doping (cm<sup>-3</sup>)  
 $\phi_B$  = bulk potential (V)  
 $V_{FB}$  = flatband voltage (V)

## 5.6.8 Metal Semiconductor Work Function Difference

The metal semiconductor work function difference,  $W_{MS}$ , is commonly referred to as the work function. It contributes to the shift in  $V_{FB}$  from the ideal zero value, along with the effective oxide charge (Nicollian and Brews 462-477, Sze 395-402). The work function represents the difference in work necessary to remove an electron from the gate and from the substrate, and it is derived as follows:

Eq. 7

$$W_{MS} = W_M - \left[ W_S + \frac{E_G}{2} - \phi_B \right]$$

Where:  $W_M$  = metal work function  
 $W_S$  = substrate material work function (electron affinity)  
 $E_G$  = substrate material bandgap  
 $\phi_B$  = bulk potential

For silicon, silicon dioxide and aluminum:

$$W_{MS} = 4.1 - \left[ 4.15 + \frac{1.12}{2} - \phi_B \right]$$

So that,

$$W_{MS} = -0.61 + \phi_B$$

$$W_{MS} = -0.61 - \left( \frac{kT}{q} \right) \ln \left( \frac{N_{BULK}}{n_i} \right) (\text{Dope Type})$$

Where, Dope Type is +1 for p-type materials, and -1 for n-type materials. For example, for an MOS capacitor with an aluminum gate and p-type silicon ( $N_{BULK} = 10^{16} \text{cm}^{-3}$ ),  $W_{MS} = -0.95 \text{V}$ . Also, for the same gate and n-type silicon ( $N_{BULK} = 10^{16} \text{cm}^{-3}$ ),  $W_{MS} = -0.27 \text{V}$ .

## NOTE

Model 5958 can be modified for use with materials other than silicon, silicon dioxide, and aluminum. See Appendix A for details.

## 5.6.9 Effective Oxide Charge

The effective oxide charge,  $Q_{\text{EFF}}$ , represents the sum of oxide fixed charge,  $Q_{\text{F}}$ , mobile ionic charge,  $Q_{\text{M}}$ , and oxide trapped charge,  $Q_{\text{OT}}$ .  $Q_{\text{EFF}}$  is distinguished from interface trapped charge,  $Q_{\text{IT}}$ , in that  $Q_{\text{IT}}$  varies with gate bias and  $Q_{\text{EFF}} = Q_{\text{F}} + Q_{\text{M}} + Q_{\text{OT}}$  does not (Nicollian and Brews 424-429, Sze 390-395). Simple measurements of oxide charge using C-V measurements do not distinguish the three components of  $Q_{\text{EFF}}$ . These three components can be distinguished from one another by temperature cycling, as discussed in Nicollian and Brews, 429, Fig. 10.2. Also, since the charge profile in the oxide is not known, the quantity,  $Q_{\text{EFF}}$  should be used as a relative, not absolute measure of charge. It assumes that the charge is located in a sheet at the semiconductor-insulator interface. From Nicollian and Brews, Eq. 10.10, we have:

$$V_{\text{FB}} - W_{\text{MS}} = -\frac{Q_{\text{EFF}}}{C_{\text{OX}}}$$

Note that  $C_{\text{OX}}$  here is per unit of area. So that,

$$Q_{\text{EFF}} = \frac{C_{\text{OX}}(W_{\text{MS}} - V_{\text{FB}})}{A}$$

However, since  $C_{\text{OX}}$  is in F, we must convert to pF by multiplying by  $10^{-12}$  as follows:

Eq. 8

$$Q_{\text{EFF}} = 10^{-12} \frac{C_{\text{OX}}(W_{\text{MS}} - V_{\text{FB}})}{A}$$

Where:  $Q_{\text{EFF}}$  = effective charge (coul/cm<sup>2</sup>)  
 $C_{\text{OX}}$  = oxide capacitance (pF)  
 $W_{\text{MS}}$  = metal semiconductor work function (V)  
 $A$  = gate area (cm<sup>2</sup>)

For example, assume a 0.01cm<sup>2</sup> 50pF capacitor with a flat-band voltage of -5.95V, and a p-type  $N_{\text{BULK}} = 10^{16}$  cm<sup>-3</sup> (resulting in  $W_{\text{MS}} = -0.95$ V). Such a capacitor would have a  $Q_{\text{EFF}} = 2.5 \times 10^{-8}$  coul/cm<sup>2</sup>.

## 5.6.10 Effective Oxide Charge Concentration

The effective oxide charge concentration,  $N_{\text{EFF}}$ , is computed from effective oxide charge and electron charge as follows:

Eq. 9

$$N_{\text{EFF}} = \frac{Q_{\text{EFF}}}{q}$$

Where:  $N_{\text{EFF}}$  = effective concentration of oxide charge (Units of charge/cm<sup>2</sup>)  
 $Q_{\text{EFF}}$  = effective oxide charge (coul./cm<sup>2</sup>)  
 $q$  = electron charge ( $1.60219 \times 10^{-19}$  coul.)

For example, with an effective oxide charge of  $2.5 \times 10^{-8}$  coul/cm<sup>2</sup>, the effective oxide charge concentration is:

$$N_{\text{EFF}} = \frac{2.5 \times 10^{-8}}{1.60219 \times 10^{-19}}$$

$$N_{\text{EFF}} = 1.56 \times 10^{11} \text{ units/cm}^2$$

## 5.6.11 Average Doping Concentration

The average doping concentration,  $N_{\text{AVG}}$ , is displayed on the analysis constants menu.  $N_{\text{AVG}}$  is calculated as follows:

Eq. 10

$$\frac{\ln(N_{\text{AVG}}/n_i)}{N_{\text{AVG}}} = \left[ \frac{q^2 \epsilon_s t_{\text{OX}}^2}{4kT \epsilon_{\text{OX}}^2} \left[ \frac{C_{\text{MAX}} - C_{\text{MIN}}}{C_{\text{MIN}}} \right]^2 \right]$$

Where:  $N_{\text{AVG}}$  = average doping concentration  
 $n_i$  = intrinsic carrier concentration of material used  
 $q$  = electron charge ( $1.60129 \times 10^{-19}$  coul.)  
 $\epsilon_s$  = permittivity of substrate material  
 $t_{\text{OX}}$  = oxide thickness (cm)  
 $k$  = Boltzmann's constant ( $1.38066 \times 10^{-23}$  J/°K)  
 $T$  = test temperature (°K)  
 $\epsilon_{\text{OX}}$  = permittivity of oxide material  
 $C_{\text{MAX}}$  = maximum measured high-frequency capacitance  
 $C_{\text{MIN}}$  = minimum high-frequency capacitance

The above equation cannot be explicitly solved, and its solution is only approximate. To obtain the approximate

solution, the Model 5958 software performs a binary search in the range of  $10^{10} < N < 10^{20}$ . The search begins at the end points and takes an average of the two results to determine a test value for N. The error is then calculated as follows:

$$\text{Error} = \left[ \frac{q^2 \epsilon_s t_{ox}^2}{4kT \epsilon_{ox}} \right] \left[ \frac{C_{MAX} - C_{MIN}}{C_{MIN}} \right]^2 \cdot N - \ln(N_{AVG} / n_i)$$

Since the average doping concentration equation above has no closed form solution for  $N_{AVG}$ , the equation is solved by minimizing the error in the interval from  $10^{10}$  to  $10^{20}$ .

### 5.6.12 Best Depth

The calculated values of N have nominal error of  $<\pm 5\%$  when the depletion depth, w, falls within the following limits:

Eq. 11

$$3\lambda \leq W \leq 2\lambda \sqrt{\ln(N_x/n_i)}$$

Where:  $\lambda$  = extrinsic Debye length  
 w = depletion depth ( $\mu\text{m}$ )  
 $N_x$  = N at 90%  $W_{MAX}$ ,  $N_A$ , or  $N_D$   
 $n_i$  = intrinsic carrier concentration

This accuracy range is displayed as best depth on the analysis constants menu. To set the graphics range to best depth, press <Alt>-F from the C-V analysis menu, then select Select Graphics Range. Type in the graphics range values equal to the displayed best depth values.

### 5.6.13 Gain and Offset

The Gain/Offset option on the analysis constants menu allows you to change gain and offset values applied to  $C_H$  data. Gain and offset can be applied to these data to compensate for measurement errors or other factors. A gain factor is a multiplier that is applied to all elements of  $C_H$

array data before plotting or graphics array calculation, and offset is a constant value added to or subtracted from all  $C_H$  data before plotting or array calculation.

Gain and offset values do not affect raw  $C_H$  values stored in the data file, but the gain and offset values will be stored in the data file so that compensated curves can easily be regenerated at a later date.

To disable gain, program a value of unity (1). Similarly, program a value of 0 to disable offset.

### 5.6.14 Displaying C-V Data Arrays

By choosing the appropriate display option, you can display numeric values stored in the measurement array (C, G, and V) or calculated data array (w, N, Ziegler w, Ziegler N, and  $1/C^2$ ). Figure 5-15 shows an example of a measurement array display, and Figure 5-16 is an example of a calculated data array display.

While displaying arrays, you can select the following:

JUMP: Allows you to jump to a specific reading number. Enter the reading number at the prompt, then press <Enter>.

Pg Up: Scrolls the display up.

Pg Dn: Scrolls the display down.

DONE: Exits the array display window.

### 5.6.15 Printing Analysis Constants and C-V Data Arrays

You can also print analysis constants or array contents on your printer simply by selecting the appropriate item on the Print menu. The basic format is the same as when displaying constants or arrays except that all array values will be printed continuously. To print out only part of an array, use the Select Graphics range selection on the File menu to set lower and upper array limits.

C, R, Vgs			
	C(pF)	R( $\Omega$ )	Vgs(V)
# 1	+157.3560	+50.9999	+ .9980
# 2	+157.1759	+51.9999	+ .9490
# 3	+157.0059	+52.0000	+ .8980
# 4	+156.8060	+50.9999	+ .8480
# 5	+156.6159	+51.9999	+ .7990
# 6	+156.3961	+50.9999	+ .7480
# 7	+156.1659	+51.9999	+ .6990
# 8	+155.9259	+51.9999	+ .6480
# 9	+155.6560	+51.9999	+ .5990
# 10	+155.3860	+51.9999	+ .5490
# 11	+155.0860	+51.9999	+ .4990
# 12	+154.7460	+51.9999	+ .4490
# 13	+154.4062	+50.9999	+ .3990
# 14	+154.0063	+50.9999	+ .3490
# 15	+153.5863	+50.9999	+ .2990

< JUMP >      < PgUp >      < PgDn >      < DONE >

Figure 5-15. Measurement Array Display Example

w, N, zw, zN, 1/C <sup>2</sup>					
	w( $\mu\text{m}$ )	N( $\text{cm}^{-3}$ )	zw( $\mu\text{m}$ )	zN( $\text{cm}^{-3}$ )	1/C <sup>2</sup> ( $\text{pF}^{-2}$ )
# 1	+8.3955E-06	+2.5404E+17	+1.3959E-04	+8.4680E+16	+4.0386E-05
# 2	+3.8705E-04	+2.7918E+17	+1.3315E-04	+9.3062E+16	+4.0479E-05
# 3	+7.4527E-04	+2.3194E+17	+1.4609E-04	+7.7313E+16	+4.0567E-05
# 4	+1.1675E-03	+2.3814E+17	+1.4417E-04	+7.9381E+16	+4.0670E-05
# 5	+1.5700E-03	+2.1352E+17	+1.5226E-04	+7.1174E+16	+4.0769E-05
# 6	+2.0366E-03	+1.9503E+17	+1.5931E-04	+6.5010E+16	+4.0884E-05
# 7	+2.5268E-03	+1.9384E+17	+1.5980E-04	+6.4614E+16	+4.1004E-05
# 8	+3.0393E-03	+1.6479E+17	+1.7331E-04	+5.4931E+16	+4.1130E-05
# 9	+3.6175E-03	+1.6722E+17	+1.7205E-04	+5.5739E+16	+4.1273E-05
# 10	+4.1980E-03	+1.4967E+17	+1.8186E-04	+4.9890E+16	+4.1417E-05
# 11	+4.8454E-03	+1.3125E+17	+1.9420E-04	+4.3750E+16	+4.1577E-05
# 12	+5.5821E-03	+1.3046E+17	+1.9478E-04	+4.3488E+16	+4.1760E-05
# 13	+6.3216E-03	+1.1006E+17	+2.1207E-04	+3.6687E+16	+4.1944E-05
# 14	+7.1961E-03	+1.0396E+17	+2.1820E-04	+3.4654E+16	+4.2162E-05
# 15	+8.1194E-03	+9.6187E+16	+2.2685E-04	+3.2062E+16	+4.2393E-05

< JUMP >      < PgUp >      < PgDn >      < DONE >

Figure 5-16. Calculated Data Array Display Example



### 5.6.16 Graphing C-V Data

To graph C-V data from the C-V analysis menu, simply press <Alt>-G to select the Graph option, then choose the desired option on the pull-down menu. C-V graphical analysis includes:

- C vs.  $V_{GS}$
- G vs.  $V_{GS}$
- Depletion depth vs.  $V_{GS}$
- Doping concentration vs. depth
- Ziegler (MCC) doping concentration vs. depth

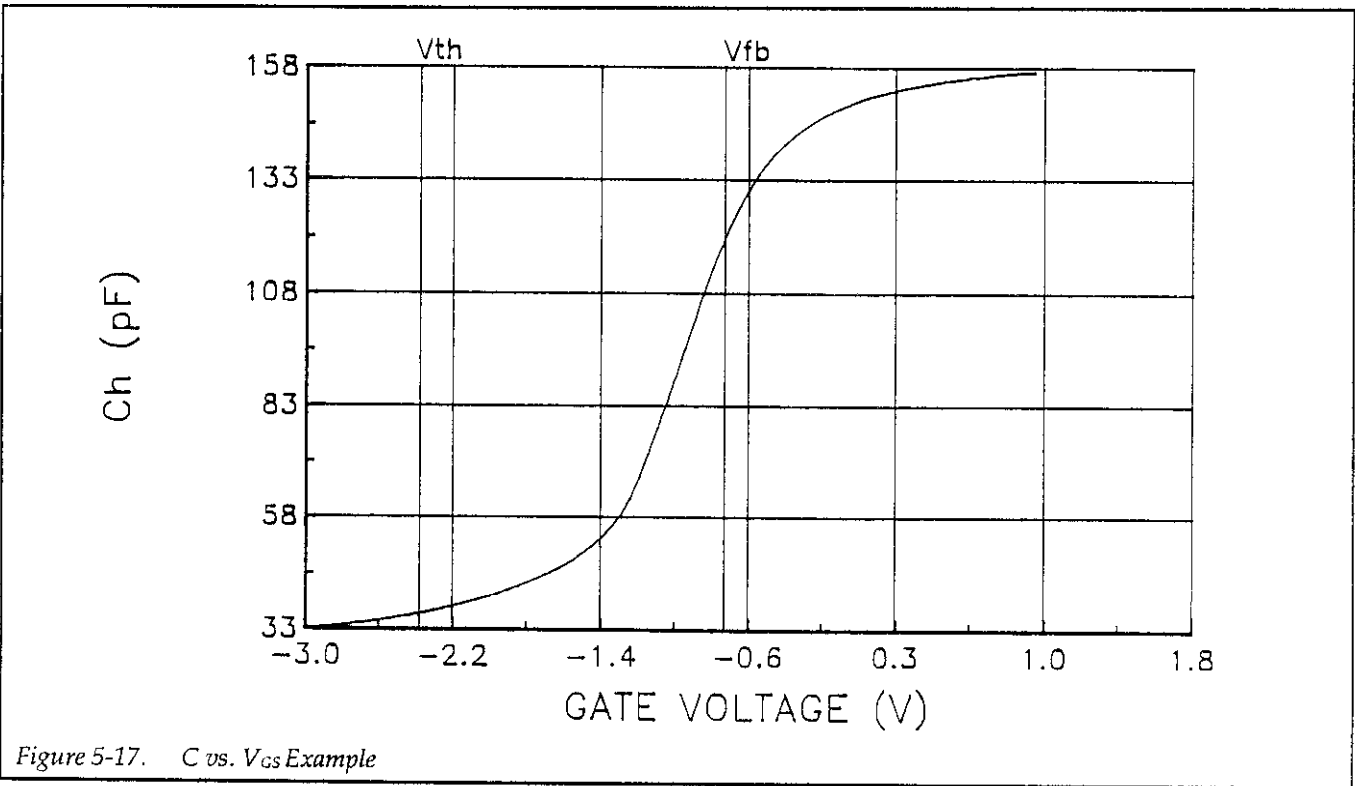
C-V graphing features are covered in the following paragraphs.

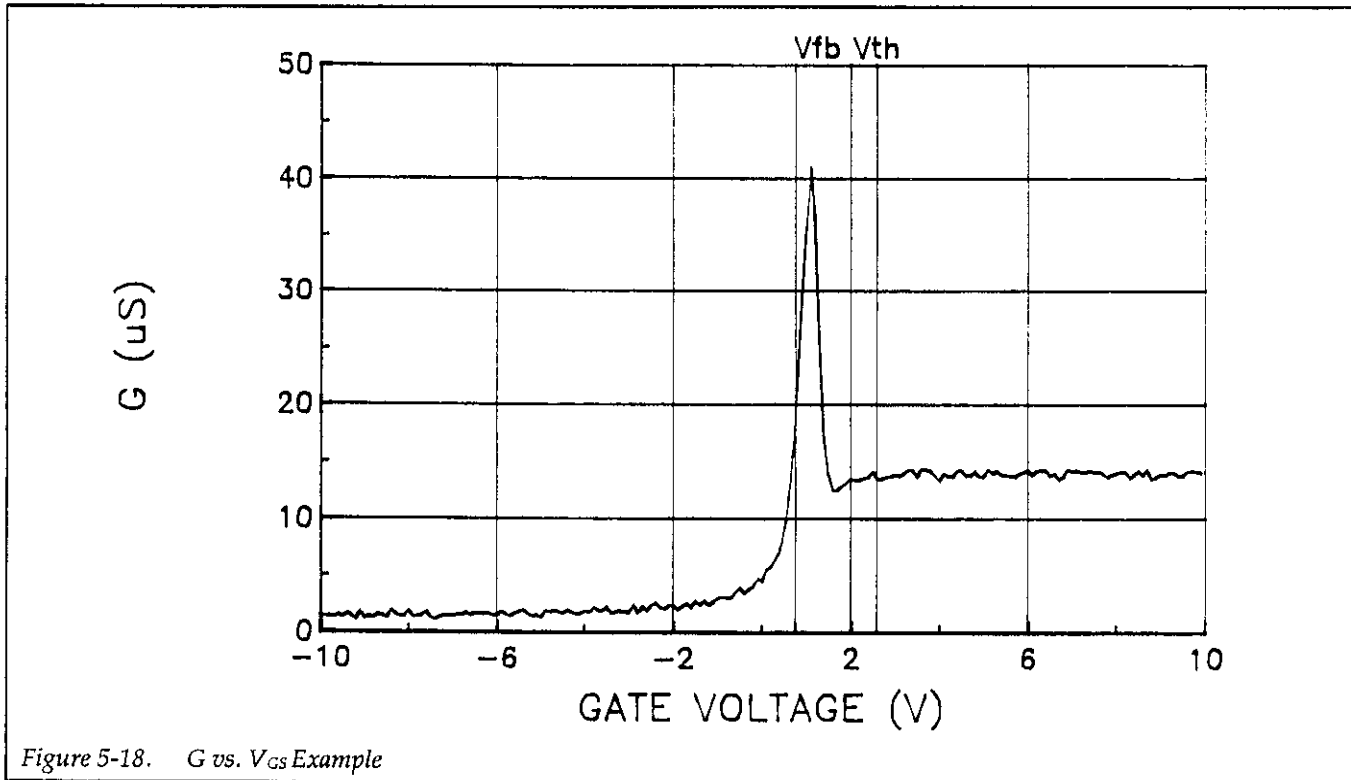
#### C vs. $V_{GS}$

The C vs.  $V_{GS}$  option graphs high-frequency capacitance vs. gate voltage, as in the example shown in Figure 5-17. Note that capacitance values are adjusted for gain and offset.

#### G vs. $V_{GS}$

G vs  $V_{GS}$  plots conductance vs. gate voltage, as shown in Figure 5-18. Note however, that R vs.  $V_{GS}$  will be plotted when series model is used.



Figure 5-18.  $G$  vs.  $V_{GS}$  Example

### Depletion Depth vs. Gate Voltage ( $w$ vs. $V_{GS}$ )

Model 5958 computes the depletion depth,  $w$ , from the high-frequency capacitance and oxide capacitance at each measured value of  $V_{GS}$  (Nicollian and Brews 386).

Depletion depth vs. gate voltage can be graphed by selecting the corresponding option on the analysis menu. In order to graph this function, the program computes each element of the  $w$  column of the calculated data array as shown below.

Eq. 12

$$w = A\epsilon_s \left( \frac{1}{C_H} - \frac{1}{C_{OX}} \right)$$

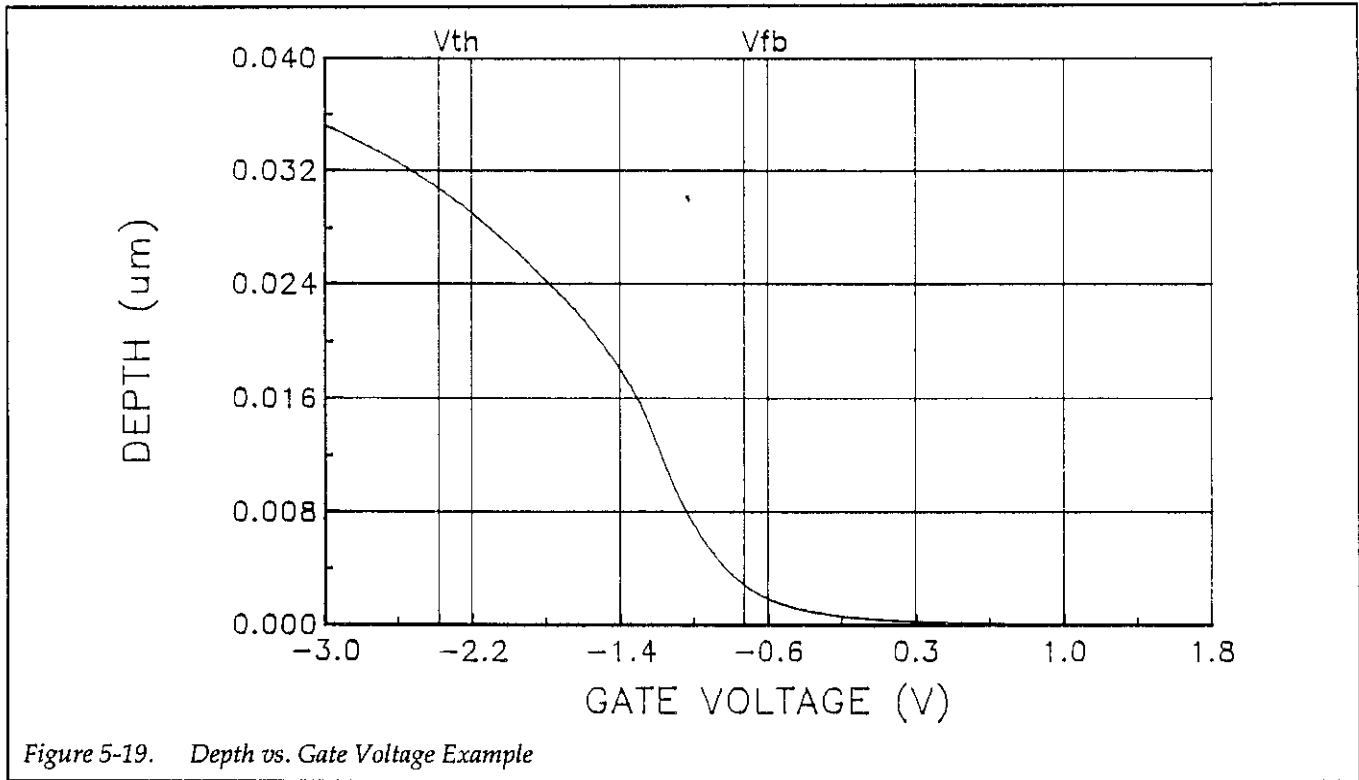
Where:  $w$  = depth ( $\mu\text{m}$ )  
 $\epsilon_s$  = permittivity of substrate material  
 $C_H$  = high-frequency capacitance (pF)  
 $C_{OX}$  = oxide capacitance (pF)  
 $A$  = gate area ( $\text{cm}^2$ )

Figure 5-19 shows a typical example of a  $w$  vs.  $V_{GS}$  plot.

### Doping Concentration vs. Depth ( $N$ vs. $w$ )

The doping profile of the device is derived from the  $C$ - $V$  curve based on the definition of the differential capacitance (measured by the Model 590) as the differential change in depletion region charge produced by a differential change in gate voltage (Nicollian and Brews 380-389).

The standard doping profile discussed here is valid only in depletion, and it becomes inaccurate when the depth is less than two Debye lengths. (See below for a discussion of Ziegler doping profile, which corrects for accumulation layer, and adjusts doping to be accurate to the surface). Note also that the Model 5958 doping calculation does not correct for interface trap stretchout and may yield artificially high doping profile results in some instances. The displayed best depth indicates the range over which doping profile is accurate to within 5%.



Doping profile is computed as follows:

Eq. 13

$$N = \frac{(-2 \times 10^{24})}{A^2 q \epsilon_s} \cdot \left[ \frac{d}{dV_{GS}} \left( \frac{1}{C_H^2} \right) \right]^{-1}$$

Where: N = doping concentration (cm<sup>-3</sup>)  
 C<sub>OX</sub> = oxide capacitance (pF)  
 C<sub>H</sub> = high-frequency capacitance (pF)  
 A = gate area (cm<sup>2</sup>)  
 q = electron charge (1.60219 × 10<sup>-19</sup> coul.)  
 ε<sub>s</sub> = permittivity of substrate material  
 1 × 10<sup>-24</sup> = units conversion factor

And:

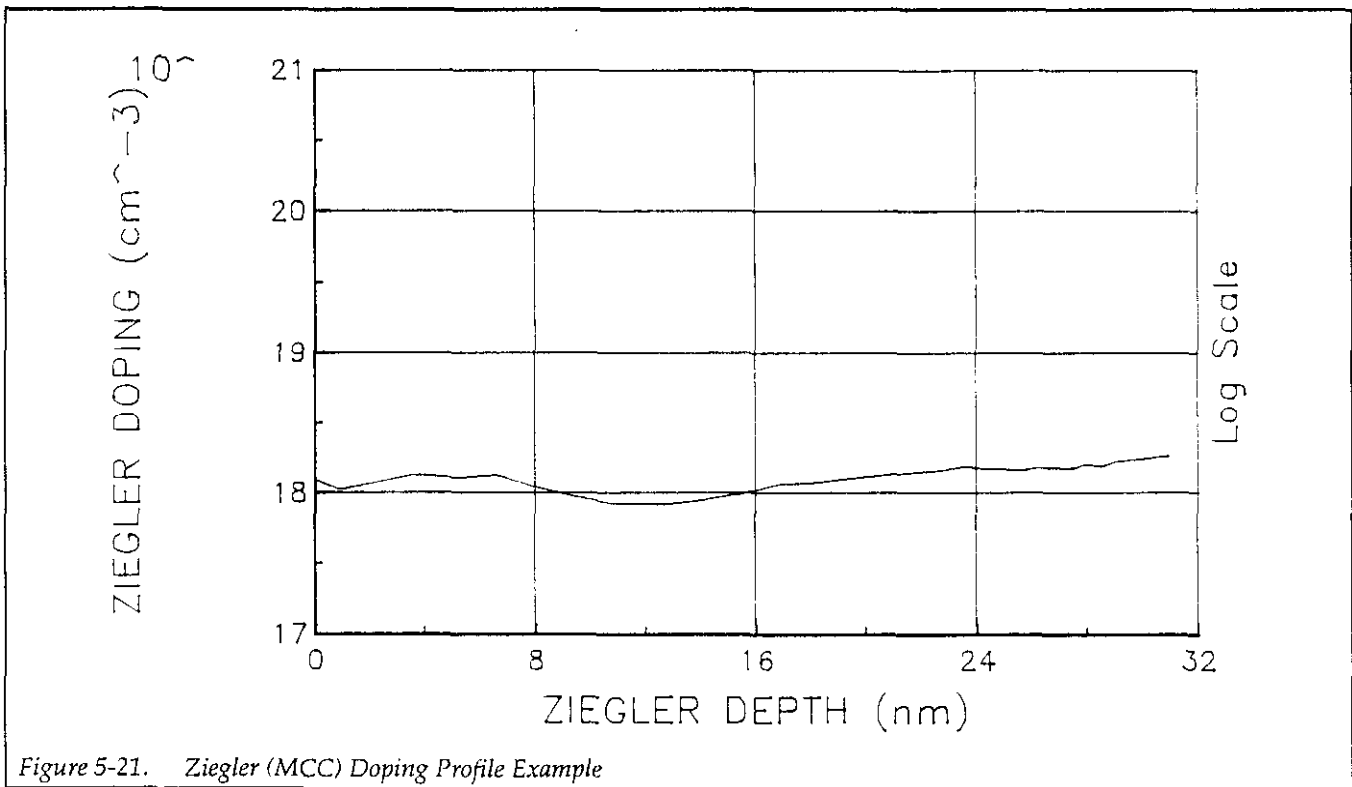
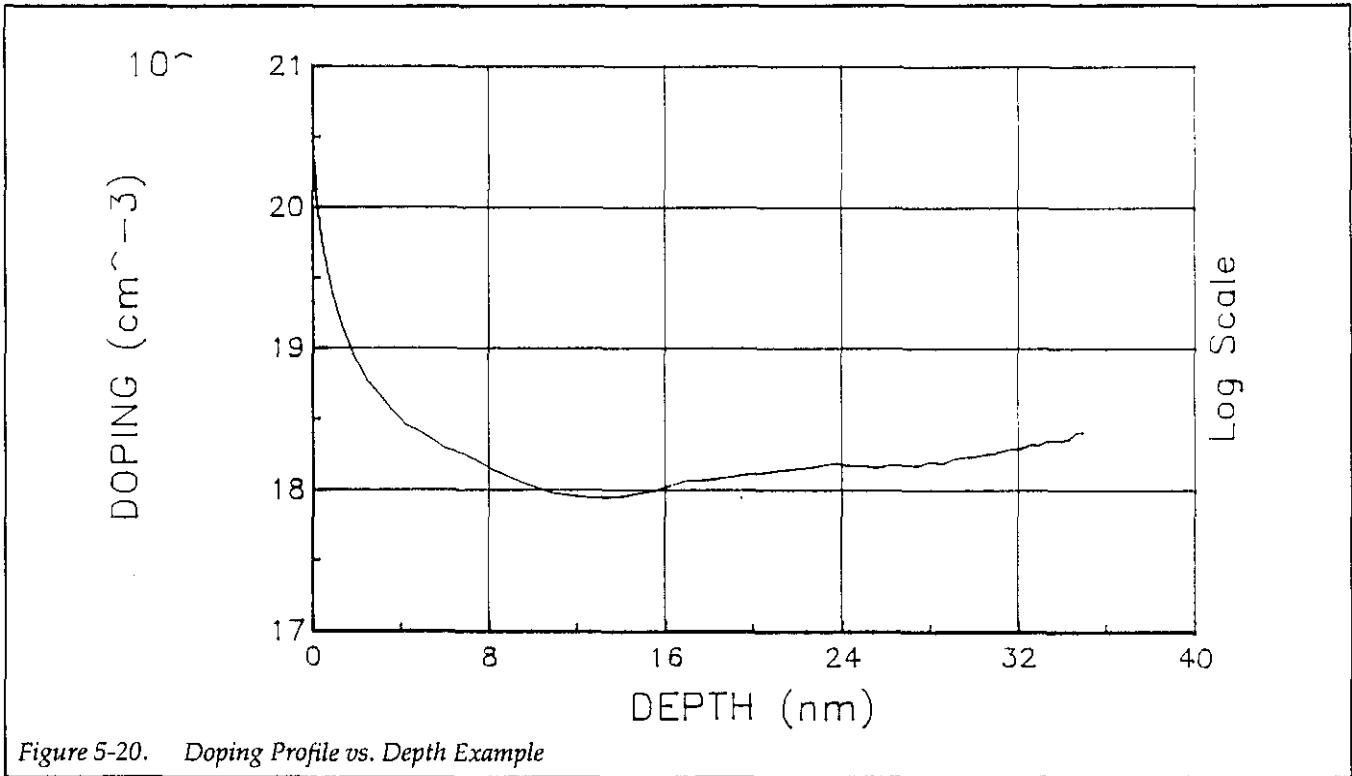
$$\frac{d}{dV_{GS}} \left( \frac{1}{C_H^2} \right) \cong \frac{1/C_{H^2}(i+1) - 1/C_{H^2}(i)}{V_{GS}(i+1) - V_{GS}(i)}$$

Figure 5-20 shows an example of an N vs. w graph.

### 5.6.17 Ziegler (MCC) Doping Profile

The Ziegler, or majority carrier corrected (MCC) doping profile method corrects for accumulation layer charge and compensates for errors in the doping profile calculation as the distance from the insulator becomes less than two Debye lengths. Like the standard doping profile, Ziegler doping calculations do not compensate for interface trap stretchout and may yield artificially high results in some cases. Figure 5-21 shows an example of a Ziegler N vs. w graph.

The basic algorithm used to compute the Ziegler compensated profile involves first computing a scaling factor to compensate the standard doping profile, and then calculating the new depth values based on the scaled doping profile (Ziegler et al).



The standard doping profile is scaled as follows:

Eq. 14

$$N(w) = \frac{(-2 \times 10^{24})}{A^2 q \epsilon_s} \cdot \left[ \frac{d}{dV_{GS}} \left( \frac{1}{C_H^2} \right) \right]^{-1} \cdot g_2 \left( \frac{w}{\lambda} \right)$$

Where:  $N(w)$  = scaled doping concentration ( $\text{cm}^{-3}$ )  
 $C_X$  = oxide capacitance (pF)  
 $C_H$  = high-frequency capacitance (pF)  
 $A$  = gate area ( $\text{cm}^2$ )  
 $q$  = electron charge ( $1.60129 \times 10^{-19}$  Coul.)  
 $\epsilon_s$  = permittivity of substrate material  
 $1 \times 10^{-24}$  = units conversion factor

In the above equation,  $g_2$  is parameter that is derived as outlined in the following steps:

1. A function,  $g_1$ , is computed from measured data as follows:

$$g_1 \left( \frac{w}{\lambda} \right) = \frac{2kT\epsilon_s}{q^2} \cdot \frac{1}{(w)^2 (N(w))}$$

where  $w$  and  $N(w)$  represent the uncompensated doping profile.

2. Once  $g_1$  is known, the equation below is solved for  $g$ :

$$g_1 \left( \frac{w}{\lambda} \right) = -2 \frac{g \left( \frac{w}{\lambda} \right)}{1 - g \left( \frac{w}{\lambda} \right)} + \frac{1 - g \left( \frac{w}{\lambda} \right)}{\frac{w^2}{\lambda^2}}$$

3.  $g_2$  can then be determined as follows:

$$g_2 \left( \frac{w}{\lambda} \right) = \frac{1}{1 - g \left( \frac{w}{\lambda} \right)} \left( 1 - 2 \frac{w^2}{\lambda^2} \cdot \frac{g \left( \frac{w}{\lambda} \right)}{\left[ 1 - g \left( \frac{w}{\lambda} \right) \right]^2} \right)$$

Once the  $g_2$  scaling factor is known, the compensated  $N$  values can then be computed. However, a compensated

depth,  $w$ , must also be computed for each  $N$  value. First, a new Debye length is computed as follows:

$$\lambda = \left( \frac{2kT\epsilon_s}{q^2 N(w)} \right)^{1/2}$$

Where:  $\lambda$  = extrinsic Debye length (cm)  
 $k$  = Boltzmann's constant ( $1.38066 \times 10^{-23}$  J/°K)  
 $T$  = Test temperature (°K)  
 $\epsilon_s$  = permittivity of substrate material  
 $q$  = electron charge ( $1.60219 \times 10^{-19}$  coul.)  
 $N(w)$  = compensated doping density ( $\text{cm}^{-3}$ )

Finally, the compensated depth is calculated from the new Debye length using the following relationship:

$$\frac{w}{\lambda} = (g - \ln g - 1)^{1/2}$$

## 5.7 C-t ANALYSIS

The following paragraphs discuss the C-t analysis window, as well as displaying and printing analysis constants and array values, and graphing C-t data.

### 5.7.1 C-t Analysis Menu

The main selections on the C-t analysis menu are summarized below.

#### C-t ANALYSIS

Setup/Run: Returns you to the setup/run menu.

Exit to Dos: Exits the Model 5958 program and returns you to DOS.

#### File

Load C-t file: Loads a C-t data file into memory (.CTD extension).

Save C-t file: Saves C-t data in memory to a designated file using a .CTD extension.

Load C-V file: Loads a C-V file into memory (.DAT extension)

Save C-V file: Saves C-V data in memory to a designated file using a .DAT extension.

Select Graphics Range: Allows you to select lower/upper limits for graphing and data array printing.

### Display

C-V Analysis Constants: Displays C-V analysis constants, best depth, and gain/offset, and allows user input of certain constants and gain/offset values.

C, t, G/N<sub>i</sub>, W-Wf: Displays capacitance and time information, as well as Zerbst array data.

C, G, V: Displays measured capacitance, conductance (resistance for series model), and voltage data.

### Print

C-V Analysis Constants: Prints C-V analysis constants, best depth, and gain/offset values.

C, t, G/N<sub>i</sub>, W-Wf: Prints capacitance and time information.

C, G, V: Prints measured capacitance, conductance (resistance for series model), and voltage data.

### Graph

C vs. t: Graphs capacitance vs. time information.

Zerbst Plot: Provides Zerbst analysis in graphical form.

C vs. V<sub>gs</sub>: Graphs capacitance vs. gate voltage.

G/R vs. V<sub>gs</sub>: Graphs conductance vs. gate voltage (resistance vs. gate voltage for series model).

## 5.7.2 Zerbst Analysis Data

Zerbst analysis requires that both C-V and C-t data be present in computer memory. You can either load C-V and/or C-t data sets from a data file (while in the C-t analysis menu), or you can perform C-V and/or C-t sweeps and perform your analysis on the current data set(s). If, for example, if you load a C-V data set from disk and then perform a C-t measurement, Zerbst analysis will be performed on the loaded C-V data and the most recently measured C-t data. Similarly, loading a C-t data set and measuring a C-V sweep will result in Zerbst

analysis on the loaded C-t data and the most recently measured C-V data.

## 5.7.3 Loading and Saving C-t and Zerbst Data

You can load or save C-t and C-V data by pressing <Alt>-F and then selecting Load C-t or C-V file, or Save C-t or C-V file. C-V data files use a .DAT extension, and C-t data files have a .CTD extension.

When accessing Zerbst sequence files, remember that the sixth and seventh characters of a Zerbst sequence file define the device number, and the eighth character is the letter "Z". You must load or save the individual C-t and C-V files for a particular device separately. Refer to paragraph 5.4 for more information on file operations.

## 5.7.4 Displaying Analysis Constants

Analysis constants available from the C-t menu are the same as those available from the C-V menu. Refer to paragraph 5.6.3 for complete details on analysis constants.

## 5.7.5 Displaying C-t Data Arrays

By choosing the appropriate display option, you can display C, t, G/N<sub>i</sub>, W-Wf or C, G, and V numeric values (C, R, and V for series model). Figure 5-22 shows an example of a C, t, G/N<sub>i</sub>, W-Wf array display.

The selections below allow you to perform the following operations:

JUMP: Allows you to jump to a specific reading number. Enter the reading number at the prompt, then press <Enter>.

Pg Up: Scrolls the display up.

Pg Dn: Scrolls the display down.

DONE: Exits the array display window.

## 5.7.6 Printing Analysis Constants and C-t Data Arrays

You can also print analysis constants or array contents on your printer simply by selecting the appropriate item on

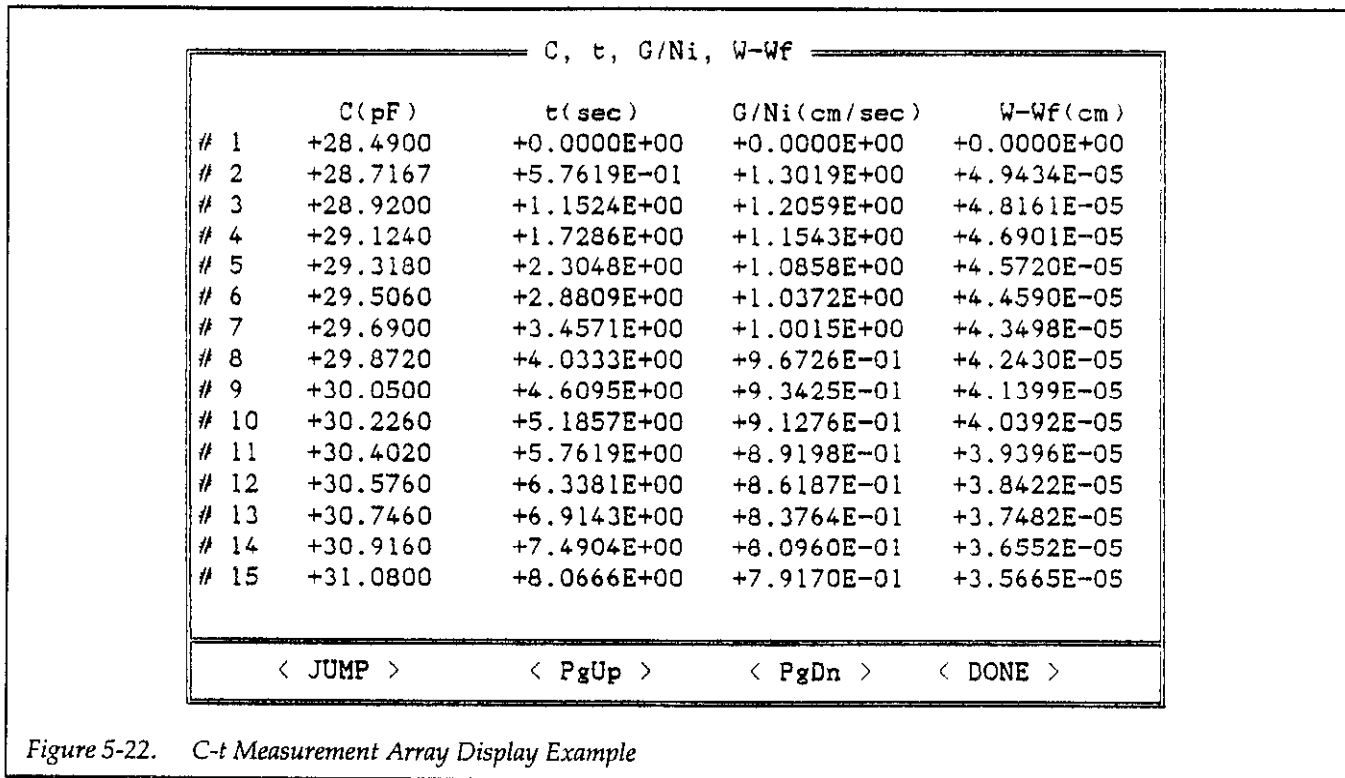


Figure 5-22. C-t Measurement Array Display Example

the Print menu. The basic format is the same as when displaying constants or arrays except that all array values will be printed continuously. To print out only part of an array, use the Select Graphics Range feature in the File menu to set upper and lower limits.

### 5.7.7 Graphing C-t Data

To graph C-t data from the C-t analysis menu, simply press <Alt>-G to select the Graph option, then choose the desired option on the pull-down menu:

- C vs. t
- Zerbst Plot
- C vs. V<sub>GS</sub>

- G/R vs. V<sub>GS</sub>

C-t graphing features are covered in the following paragraphs.

#### C vs. t

The C vs. t option plots capacitance vs. time information, as in the example shown in Figure 5-23. An important use for the C-t plot is to choose optimum sample time and number of samples. Typically, these parameters are chosen so that the last sample in the measured sequence reaches 95% of C<sub>MIN</sub>.

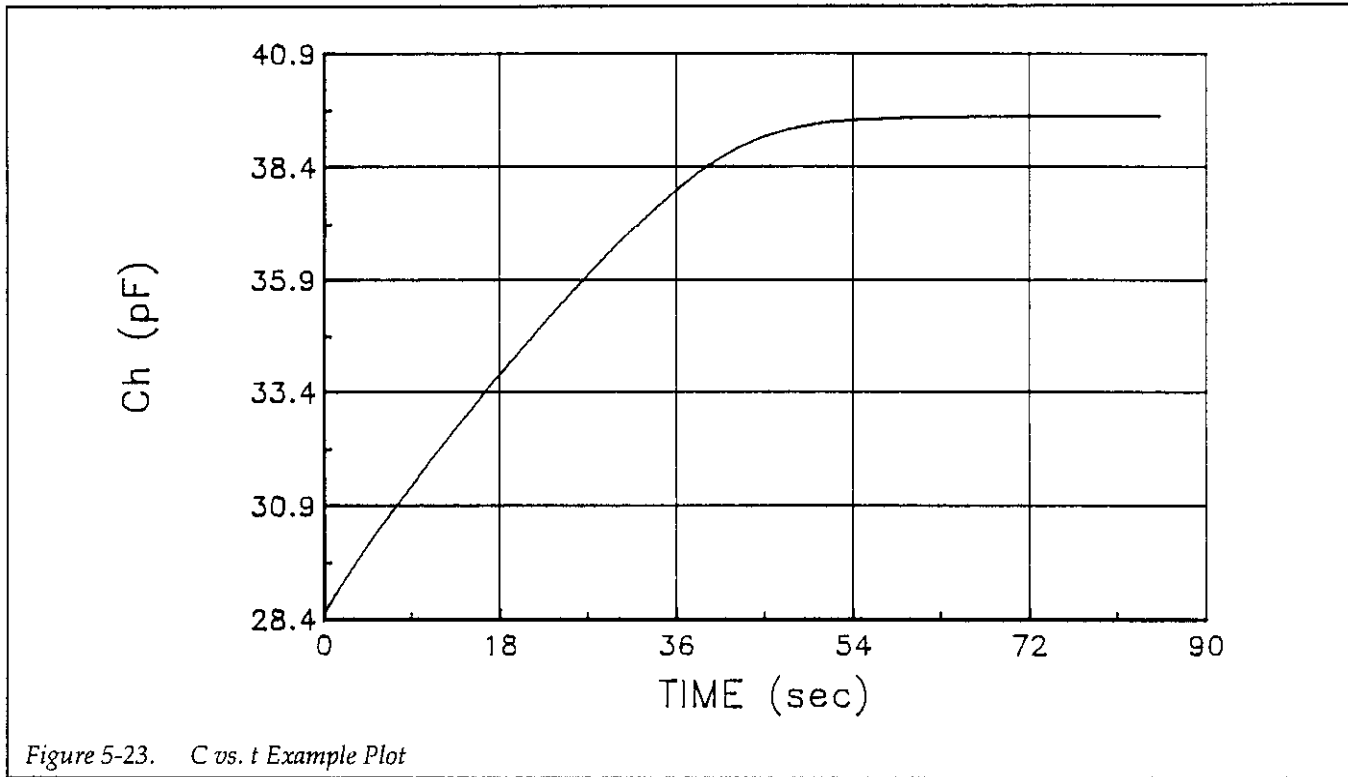


Figure 5-23. C vs. t Example Plot

### Zerbst Plot

Zerbst analysis requires two types of data: C-V, and C-t. Important data taken from the C-V measurement includes gate area,  $C_{OX}$ ,  $C_{MIN}$ , and doping concentration ( $N_{AVG}$  and  $N_{BULK}$ ). The results of the C-V analysis are integrated with data taken during a C-t measurement to compute generation velocity and generation lifetime of electron-hole pairs. These two parameters are computed from the slope and Y-axis intercept of the graph of  $G/n_i$  vs.  $w - w_F$ , and you can determine generation rate and generation lifetime, as outlined below.

The analysis method described here was developed simultaneously with an ASTM standard test method for C-t measurements, which is currently pending final approval. Every effort was made to ensure the validity of the analysis method.

Figure 5-24 shows an example of a Zerbst plot.

### $G/n_i$ Computation

Eq. 15

$$G/n_i = -\epsilon_s A N_{AVG} C_{OX} \cdot \left[ \frac{1}{C_{t(i+1)}^2} - \frac{1}{C_{t(i-1)}^2} \right] \cdot \left( \frac{1 \times 10^{12}}{2} \right)$$

- Where:
- $G$  = generation rate ( $s^{-1}$ )
  - $\epsilon_s$  = permittivity of semiconductor
  - $A$  = gate area ( $cm^2$ )
  - $N_{AVG}$  = average doping density ( $cm^{-3}$ )
  - $C_{OX}$  = oxide (maximum) capacitance (pF)
  - $C_{t(i+1)}$  = (i+1) value of C-t capacitance measured during C-t sweep (pF)
  - $C_{t(i-1)}$  = (i-1) value of C-t capacitance measured during C-t sweep (pF)
  - $n_i$  = intrinsic carrier concentration ( $cm^{-3}$ )
  - $t_{int}$  = time interval between C-t measurements(s)
  - $i = [2, \#Rdgs-1]$



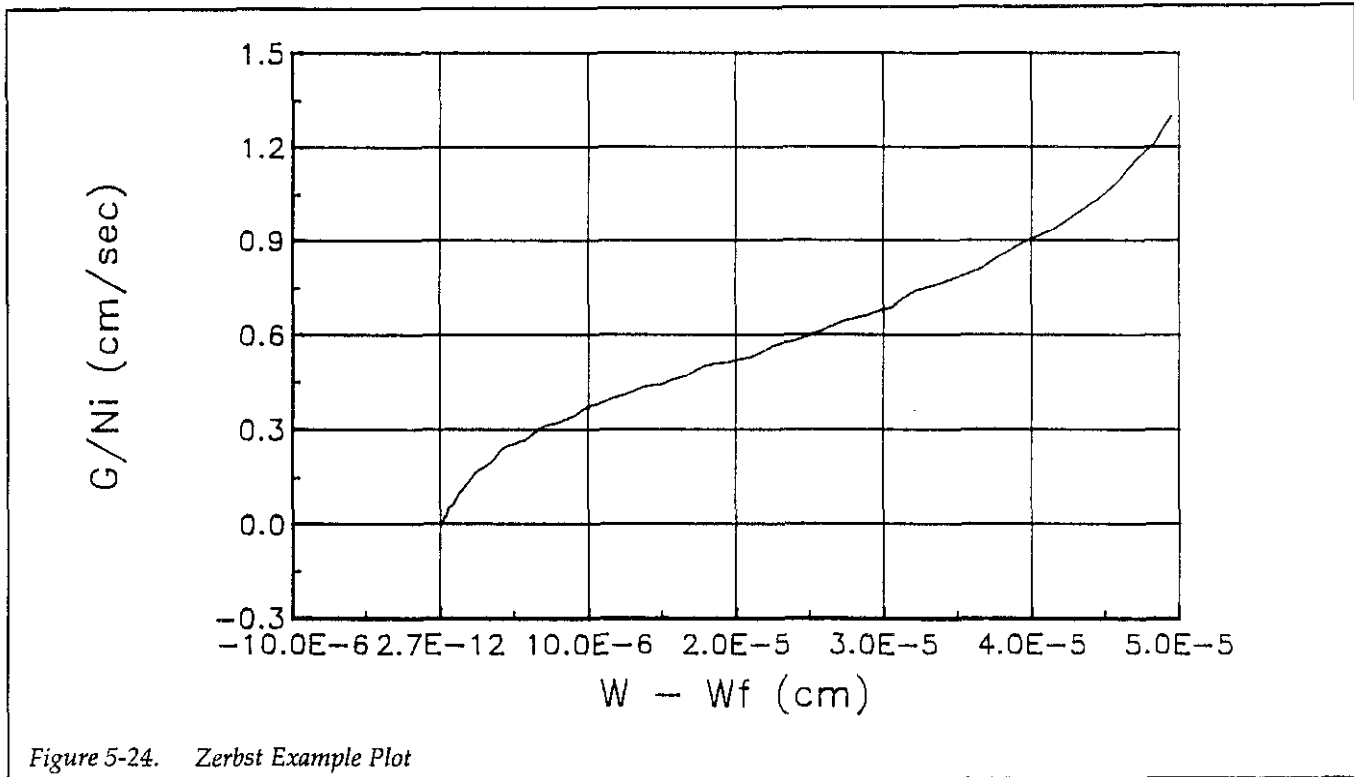


Figure 5-24. Zerst Example Plot

### w - w<sub>F</sub> Computation

Eq. 16

$$W - W_F = 1 \times 10^{12} \epsilon_s A \left( \frac{1}{C_{di}} - \frac{1}{C_{OX}} \right) - W_F$$

$$W_F = 1 \times 10^{12} \epsilon_s A \left( \frac{1}{C_{di}} - \frac{1}{C_{OX}} \right)$$

Where: w = depletion depth (cm)  
 w<sub>F</sub> = equilibrium inversion depth (cm)  
 ε<sub>s</sub> = permittivity of semiconductor  
 A = gate area (cm<sup>2</sup>)  
 C<sub>di</sub> = i(th) value of capacitance measured during C-t sweep (pF)  
 C<sub>MIN</sub> = equilibrium minimum capacitance

### Determining Generation Velocity and Generation Lifetime

The generation lifetime, τ<sub>g</sub>, is equal to the reciprocal of the slope of the linear portion of the Zerst plot, while the

generation velocity, s, is the Y-axis (G/n<sub>i</sub>) intercept of the same linear section of the Zerst plot.

You can determine generation lifetime and generation velocity from a Zerst plot as follows:

1. Display a Zerst plot of your data.
2. Select option 7, find t<sub>g</sub>, s on the graphics menu.
3. Using the arrow keys, move the cursor to the start of the linear region of the curve, then press <Enter>.
4. Move the cursor to the end of the linear portion of the curve, then press <Esc>.
5. The computer will then display τ<sub>g</sub> (sec) and S (cm/sec) below the X axis of the curve. Figure 5-25 shows an example of a Zerst plot with τ<sub>g</sub> and s displayed.

### C vs. V<sub>GS</sub> and G/R vs. V<sub>GS</sub>

Graphs of capacitance vs. gate voltage and conductance resistance vs. gate voltage can also be generated from the C-t analysis menu by selecting the corresponding options. Data for these graphs are obtained from C-V sweeps, and examples are shown in paragraph 5.6.

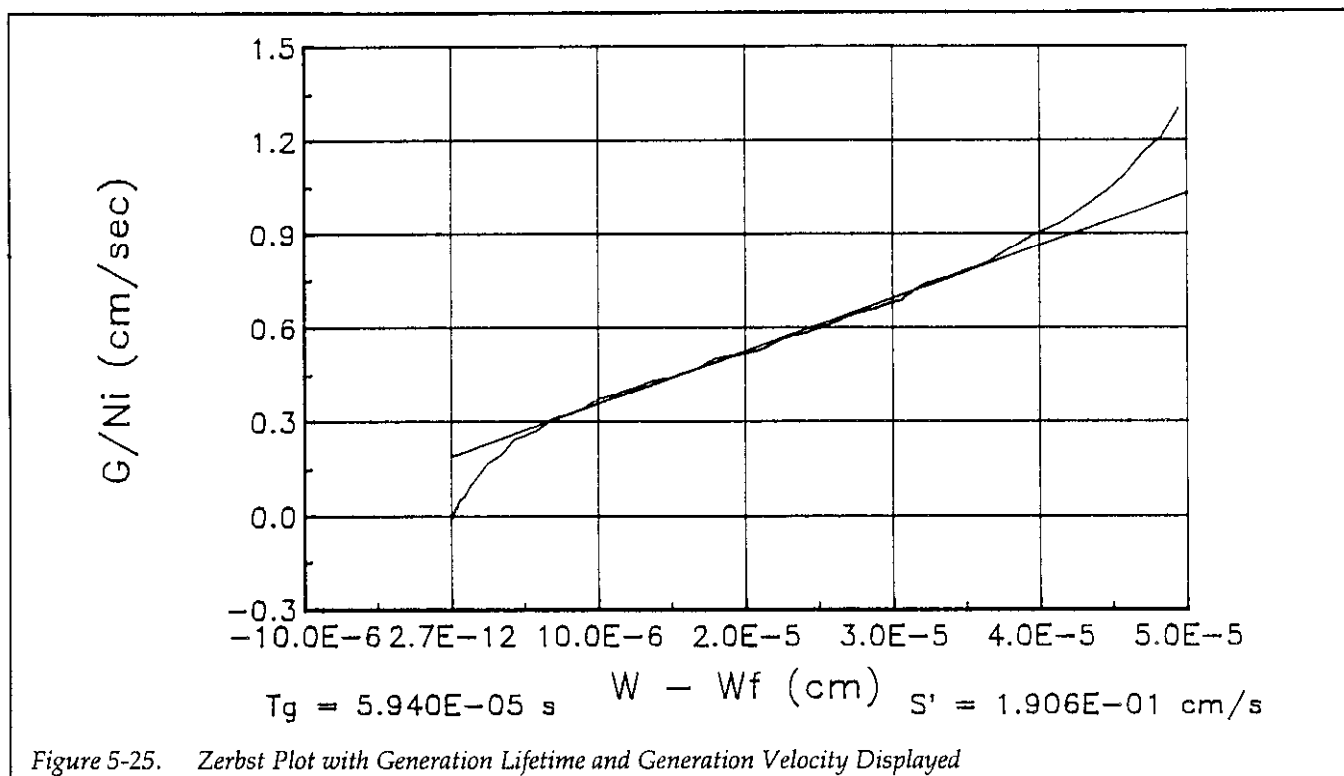


Figure 5-25. Zerst Plot with Generation Lifetime and Generation Velocity Displayed

## 5.8 BTS ANALYSIS

The following paragraphs discuss the BTS analysis window, as well as displaying and printing BTS analysis constants and array values.

### 5.8.1 BTS Analysis Menu

The main selections on the BTS analysis menu are summarized below.

#### BTS ANALYSIS

Setup/Run: Returns you to the setup/run menu.

Exit to Dos: Exits the Model 5958 program and returns you to DOS.

#### File

Load data set: Loads a BTS data set into memory. Note that a complete BTS data file set includes two or three files, as discussed in paragraph 5.8.2.

Save data set: Saves a BTS data set in memory to two or three disk files.

Select Graphics Range: Allows you to select lower/upper limits for graphing and data array printing.

#### Display

BTS Analysis Constants: Displays C-V analysis constants, pre-stress and post-stress flatband voltage and threshold voltage, mobile ion calculations, and allows user input of certain constants and gain/offset values.

C(0), C(+), C(-), Vgs: Displays pre-stress capacitance C(0), post positive-stress capacitance C(+), post negative-stress capacitance C(-), and gate voltage.

G(0), C(+), C(-), Vgs: Displays pre-stress conductance G(0), post positive-stress conductance G(+), post negative-stress conductance G(-), and gate voltage.

## Print

**BTS Analysis Constants:** Prints C-V analysis constants, pre-stress and post-stress flatband voltage and threshold voltage, mobile ion calculations, and allows user input of certain constants and gain/offset values.

**C(0), C(+), C(-), Vgs:** Prints pre-stress capacitance C(0), post positive-stress capacitance C(+), post negative-stress capacitance C(-), and gate voltage.

**G(0), C(+), C(-), Vgs:** Prints pre-stress conductance G(0), post positive-stress conductance G(+), post negative-stress conductance G(-), and gate voltage.

## Graph

**C vs. Vgs:** Graphs capacitance vs. gate voltage.

**G/R vs. Vgs:** Graphs conductance vs. gate voltage (resistance vs. gate voltage for series model).

Refer to paragraph 5.6 for examples.

## 5.8.2 Loading and Saving BTS Data

You can load or save BTS data by pressing <Alt>-F and then selecting Load data set or Save data set. All BTS data files are C-V files and use a .DAT extension.

Each BTS data file set includes two or three files, depending on the number of stress cycles used in the BTS test sequence. + then - and - then + sequences each have three files, while the + only and - only sequences store only two files. The last letter of the filename indicates the stress sequence: "I" means initial, or pre-stress, while "P" and "N" indicate post-positive and post-negative stress respectively. In addition, the fifth and sixth characters define the device number.

When loading or saving BTS data, you need only specify one of the two or three files associated with that particular BTS test. The Model 5958 will automatically load or save the other file(s) as appropriate. Refer to paragraph 5.4 for more information on file operations.

## 5.8.3 Displaying BTS Analysis Constants

To display BTS analysis constants from the BTS analysis menu, press <Alt>-D, then select BTS Analysis Constants. The BTS analysis constants window shown in Figure 5-26 will be displayed.

Constants displayed at the top of the curve are derived from the C-V sweep data and are discussed in detail in paragraph 5.6.3. You can also select Change Constants or Change Gain to enter new values, as discussed in that paragraph.

The middle portion of the window displays flatband voltage ( $V_{FB}$ ) and threshold voltage ( $V_{THRESH}$ ) for various stress conditions (see paragraph 5.8.6), while the bottom of the window displays mobile ion calculations ( $Q_{MI}$ ,  $N_{MI}$ ,  $Q_{SS}$ , and  $N_{SS}$ ), which are covered in detail in paragraph 5.8.7.

Note that you can change constants and gain/offset from this window, as discussed in paragraph 5.6.3.

## 5.8.4 Displaying BTS Data Arrays

By choosing the appropriate display option, you can display C(0), C(+), C(-), and  $V_{GS}$ , or G(0), G(+), G(-), and  $V_{GS}$  as numeric values. (0 indicates initial or pre-stress values, + identifies post positive-stress values, and - marks post negative-stress values).

Figure 5-27 shows an example of a capacitance array display.

The selections below allow you to perform the following operations:

**JUMP:** Allows you to jump to a specific reading number. Enter the reading number at the prompt, then press <Enter>.

**Pg Up:** Scrolls the display up.

**Pg Dn:** Scrolls the display down.

**DONE:** Exits the array display window.

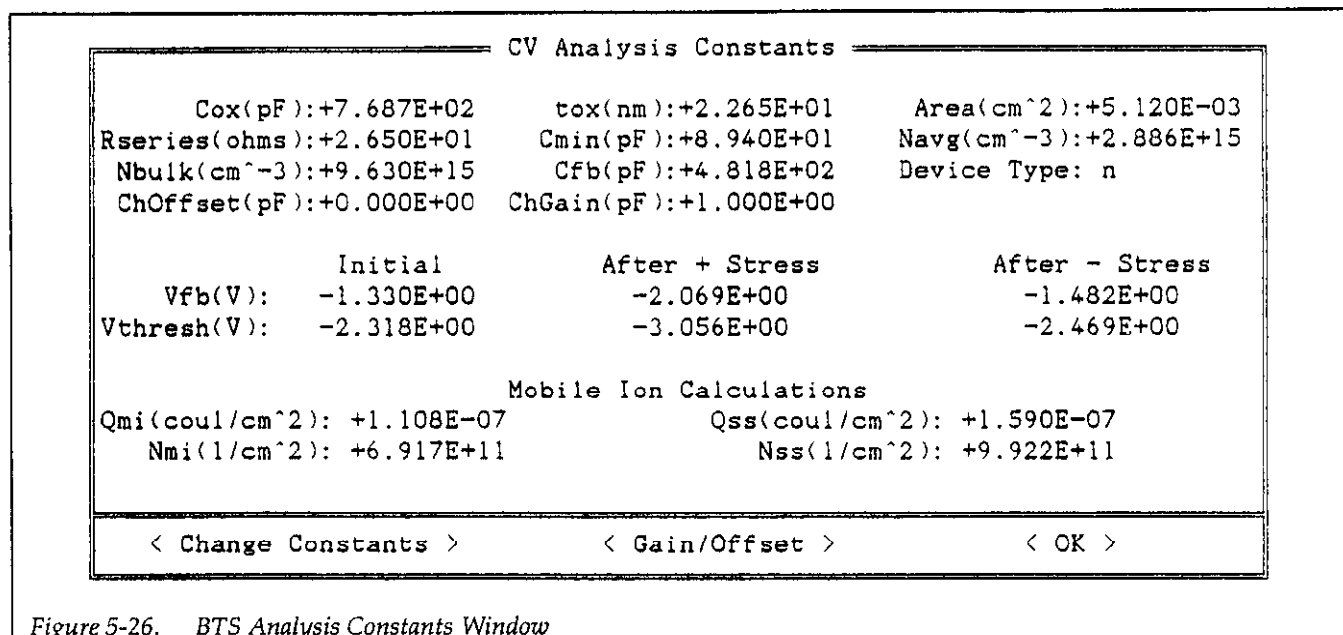


Figure 5-26. BTS Analysis Constants Window

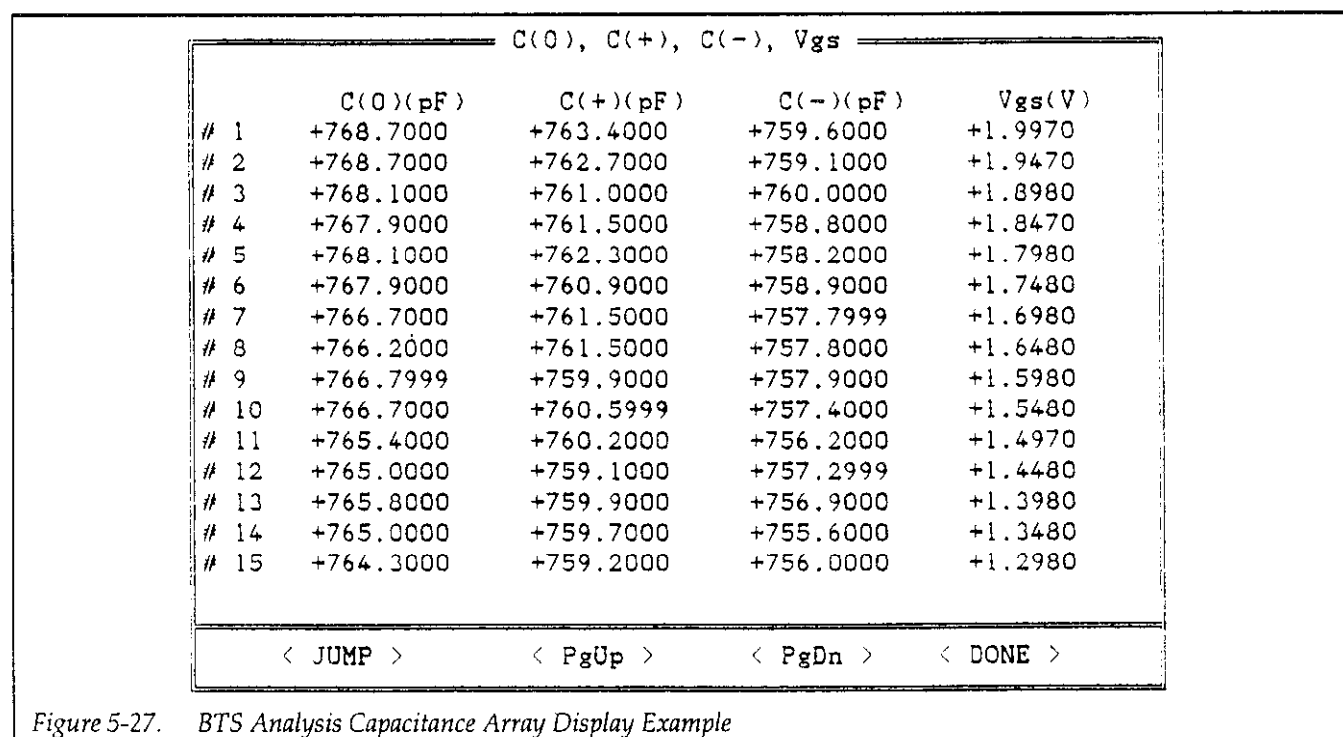


Figure 5-27. BTS Analysis Capacitance Array Display Example

### 5.8.5 Printing Analysis Constants and BTS Data Arrays

You can also print analysis constants or array contents on your printer simply by selecting the appropriate item on the Print menu. The basic format is the same as when displaying constants or arrays except that all array values will be printed continuously. To print out only part of an array, use the Select Graphics Range selection in the File menu.

### 5.8.6 Flatband Voltage and Threshold Voltage

Initial (pre-stress), after + stress, and after -stress values for flatband voltage and threshold voltage are displayed in the BTS analysis constants window as  $V_{FB}$  and  $V_{THRESH}$  respectively. Calculation methods for these two constants are discussed in paragraph 5.6.3.

### 5.8.7 Mobile Ion Calculations

Mobile ion calculation values, which are displayed in the BTS analysis constants window include:

- $Q_{MI}$  Mobile oxide charge (coul/cm<sup>2</sup>)
- $N_{MI}$  Mobile oxide charge concentration (1/cm<sup>2</sup>)
- $Q_{SS}$  Total oxide fixed charge (coul/cm<sup>2</sup>)
- $N_{SS}$  Total oxide fixed charge concentration (1/cm<sup>2</sup>)

The following paragraphs discuss how these values are calculated.

#### BTS Analysis Standard

Model 5958 BTS analysis is based on ASTM standard F1153-88. However, the ASTM equation for fixed oxide charge,  $N_{TF}$ , is incorrect because it has a sign error. The incorrect equation is shown below:

Eq. 17

$$N_{TF} = (6.2415 \times 10^6)(C_{MAX}/A)(-V_F + 4.7 + PM \pm PB)$$

where:  $V_F$  = most positive of  $V_{FB}$  (0),  $V_{FB}$  (+), and  $V_{FB}$  (-)(V)

- PM = vacuum work function of gate material (Aluminum  $\approx$  4.2V) (V)
- PB = Potential difference between fermi level and midgap (V) (add PB for n-type, subtract for p-type)
- $C_{MAX}$  = maximum (accumulation) capacitance (pF)
- A = gate area (cm<sup>2</sup>)

The corrected equation is shown below:

Eq. 18

$$N_{TF} = (6.2415 \times 10^6)(C_{MAX}/A)(-V_F - 4.7 + PM \pm PB)$$

Origin of the sign error and analysis equation derivations are discussed in the following paragraphs.

#### Oxide Charges

In general, there are three types of MOS oxide (insulator) charges. These three types are summarized below:

**Oxide Fixed Charge ( $Q_F$ ):**  $Q_F$  is the charge density remaining in the oxide after interface trap charge has been annealed out. This charge is typically located at or very near the semiconductor-insulator surface (typically within 30 angstroms). The concentration of  $Q_F$  is not very sensitive to oxide thickness, nor to semiconductor impurity concentration. It has been shown that a short-term annealing process in nitrogen or argon can decrease  $Q_F$ . Note that the  $Q_F$  charge is fixed and does not drift.

**Oxide Trapped Charge ( $Q_{OT}$ ):**  $Q_{OT}$  is the charge density usually located at an interface, (either the semiconductor-insulator interface, or the metal-insulator interface). An exception is when oxide traps are introduced by ion implantation. While ion implantation occurs,  $Q_{OT}$  can be distributed throughout the insulator. This charge is fixed in place and does not drift.

**Mobile Oxide Charge ( $Q_M$ ):**  $Q_M$  is a charge density which is almost always caused by the presence of ionized alkali metals such as sodium or potassium. This charge enters at the metal-insulator interface and often remains at that location. However, because this charge is mobile under normal operating conditions, it can drift to the semiconductor-insulator interface with an applied bias.  $Q_M$  almost always assumes a positive charge.

### Flatband Voltage Shift

When charge is located in the insulator, the C-V curve of the device will be offset or shifted because the flatband voltage ( $V_{FB}$ ) is not equal to zero. This flatband voltage shift becomes more prominent if the charge in the oxide is located very close to the semiconductor-insulator interface. In this situation, an "image" charge is formed, primarily in the semiconductor, resulting in a change in the charge stored in the semiconductor at thermal equilibrium. The larger the image charge, the larger the flatband shift becomes, an undesirable situation. If the oxide charge is located very close to the metal-insulator interface, the image charge will be formed almost entirely in the metal, and the flatband voltage shift will be minimal. From Nicollian and Brews (426), it can be shown that:

Eq. 19

$$Q_{TOT} = (Q_F + Q_{OT}) + Q_M = (W_{MS} - V_{FB}(0)) C_{OX}'$$

where:  $W_{MS}$  = metal-semiconductor work function difference (V)  
 $V_{FB}(0)$  = flatband voltage obtained from device prior to positive or negative stress. (V)  
 $C_{OX}'$  = maximum (accumulation) capacitance (pF/cm)

### Positive Stress Cycle

Since  $Q_M$  is almost always positive, the device is heated to give the mobile charge more thermal energy, and a positive gate voltage is applied to drive  $Q_M$  to the semiconductor-insulator interface. After the bias voltage and temperature stress have been maintained for an adequate time (to move all the mobile charge to the semiconductor-insulator interface) the sample is cooled while the bias is maintained. This in effect freezes  $Q_M$  at the semiconductor-insulator interface. This stress cycle is called the positive stress cycle.

Since the positive-stress cycle stores  $Q_M$  at the semiconductor-insulator interface, the flatband voltage obtained after the positive-stress cycle yields a better measure of  $Q_{TOT}$  because the maximum amount of image charge is formed in the semiconductor. Prior to the positive-stress cycle,  $Q_M$  was located in the insulator itself, and its full

impact on flatband voltage shift was not realized. The improved equation for  $Q_{TOT}$  is shown below:

Eq. 20

$$Q_{TOT} = (Q_F + Q_{OT}) + Q_M = (W_{MS} - V_{FB}(+)) C_{OX}'$$

### Negative Stress Cycle

Now that  $Q_{TOT}$  is accurately known,  $(Q_F + Q_{OT})$  is subtracted to obtain  $Q_M$ . The negative-stress cycle is used to obtain  $(Q_F + Q_{OT})$ . This procedure involves heating up the same sample while applying a negative-gate voltage. This stress cycle will draw  $Q_M$  to the metal-insulator interface (assuming  $Q_M$  is positively charged), and trap it there, where it will result in a negligible effect on flatband voltage shift. From Sze (395):

Eq. 21

$$\begin{aligned} (Q_F + Q_{OT}) &= (W_{MS} - V_{FB}(-)) C_{OX}' \\ &= [(W_M - [W_S + E_G/2 - \phi_B]) - V_{FB}(-)] C_{OX}' \\ &= [(W_M - W_S - E_G/2 + \phi_B) - V_{FB}(-)] C_{OX}' \end{aligned}$$

where:  $W_M$  = metal work function (V)  
 $W_S$  = semiconductor work function (electron affinity) (V)  
 $E_G$  = semiconductor band gap  
 $\phi_B$  = potential difference between fermi level and midgap (V):

$$\begin{aligned} &= -\frac{kT}{q} \ln\left(\frac{N_{BULK}}{n_i}\right) \text{(p-type)} \\ &= \frac{kT}{q} \ln\left(\frac{N_{BULK}}{n_i}\right) \text{(n-type)} \end{aligned}$$

$V_{FB}(-)$  = flatband voltage obtained from device after negative stress cycle

### Standard Equation Derivations

Equations 9 and 10 of the ASTM F1153-88 standard have been adapted for use with Al-SiO<sub>2</sub>-Si MOS devices. Equation 21 above is general and can be used with any type of MOS device (any gate metal, any semiconductor). In addition, ASTM Eq. 9 and 10 are intended for oxide charge concentration and not oxide charge. Shown below is a derivation of the ASTM standard equations, starting

with Eq. 21 above. This derivation identifies the sign error found in Eq. 9 and 10 of the ASTM standard.

Step 1:  $C_{OX}'$  in equation 21 above is in terms of  $F/cm^2$ . Actual measured  $C_{OX}(C_{MAX})$  is in farads. Therefore,  $C_{OX}'$  can be replaced by  $C_{OX}(C_{MAX})$  if  $C_{OX}(C_{MAX})$  is divided by area (A):

Eq. 22

$$(Q_F + Q_{OT}) = \frac{C_{OX}}{A} [(W_M - W_S - E_G/2 + \phi_B) - V_{FB}(-)]$$

Step 2: The desired equation is for oxide charge concentration. Therefore, we must divide Eq. 22 above by electron charge as follows:

Eq. 23

$$N_{SS} = \frac{C_{OX}}{qA} [(W_M - W_S - E_G/2 + \phi_B) - V_{FB}(-)]$$

Step 3: Divide Eq. 23 above by  $10^{12}$  to compensate for fact that  $C_{OX}(C_{MAX})$  is in pF:

Eq. 24

$$N_{SS} = \frac{C_{OX}}{qA(1 \times 10^{12})} [(W_M - W_S - E_G/2 + \phi_B) - V_{FB}(-)]$$

Step 4: Replace  $\phi_B$  with PB,  $V_{FB}(-)$  with  $V_F$ , and  $W_M$  with PM to adopt the ASTM symbol convention.

Eq. 25

$$N_{SS} = \frac{C_{OX}}{qA(1 \times 10^{12})} [PM - (W_S + E_G/2) \pm PB - V_F]$$

Step 5: The electron affinity ( $W_S$ ) for silicon is approximately 4.15V and the bandgap for silicon is approximately 1.12V. Therefore:

Eq. 26

$$W_S + E_G/2 = 4.15 + 1.12/2 \\ = 4.7V$$

Step 6: Substitute Eq. 26 into Eq. 25 to obtain:

Eq. 27

$$N_{SS} = \frac{C_{OX}}{qA(1 \times 10^{12})} [-V_F - 4.7 + PM \pm PB]$$

Note that the sum of electron affinity ( $W_S$ ) and 1/2 the bandgap ( $E_G$ ) is approximately 4.7V. This sum should not be added to  $V_F$  as in the ASTM standard equation, but it should be subtracted from  $V_F$  instead. This error in the ASTM standard has been confirmed by the author of the ASTM standard.

### N<sub>SS</sub> Computation

Equation 27 above is specifically designed for Al-SiO<sub>2</sub>-Si MOS devices. A more general form of this equation is found below (Sze 395). This equation is used by the Model 5958 software to compute the total fixed oxide charge concentration,  $N_{SS}$ . Many of the constants used in this equation are defined in the MATERIAL.CON file, which is discussed in Appendix A.

Eq. 28

$$N_{SS} = \frac{C_{OX}}{qA(1 \times 10^{12})} \bullet [W_{MS} - V_F]$$

where:  $W_{MS} = W_M - (W_S + E_G/2 + \phi_B)$   
 $W_M$  = metal work function (V)  
 $W_S$  = semiconductor electron affinity (V)  
 $E_G$  = semiconductor bandgap (V)  
 $\phi_B$  = potential difference between fermi level

and midgap (V):

$$= -\frac{kT}{q} \ln\left(\frac{N_{\text{BULK}}}{n_i}\right) (\text{p-type})$$

$$= \frac{kT}{q} \ln\left(\frac{N_{\text{BULK}}}{n_i}\right) (\text{n-type})$$

$V_F$  = most positive of  $V_{FB}(0)$ ,  $V_{FB}(-)$ , and  $V_{FB}(+)$

### Q<sub>SS</sub> Calculation

To find the total fixed oxide charge per unit area, ( $Q_{SS}$ ) Eq. 28 above is multiplied by the electron charge to obtain:

Eq. 29

$$Q_{SS} = \frac{C_{OX}}{A (1 \times 10^{12})} \cdot [W_{MS} - V_F]$$

### N<sub>MI</sub> Calculation

To find  $Q_M$ , one would normally subtract the sum of  $Q_F + Q_{OT}$  from the total oxide charge  $Q_F + Q_{OT} + Q_M$ . This calculation is equivalent to subtracting Eq. 20 and 21 discussed above. The derivation is not included, but it was confirmed that the ASTM standard equation for mobile oxide charge concentration is correct. Model 5958 uses a more general form, which is shown below.

Eq. 30

$$N_{MI} = \frac{1}{q(1 \times 10^{12})} \cdot \Delta V_{FB} \cdot \frac{C_{OX}}{A}$$

where:  $\Delta V_{FB}$  = larger of  $|V_{FB}(+) - V_{FB}(0)|$  and  $|V_{FB}(-) - V_{FB}(+)|$   
 $C_{OX}$  = maximum (accumulation) capacitance (pF)  
 $A$  = capacitor area (cm<sup>2</sup>)

### Q<sub>MI</sub> Calculation

Again, to obtain the mobile oxide charge per unit area simply multiply Eq. 30 above by the electron charge:

Eq. 31

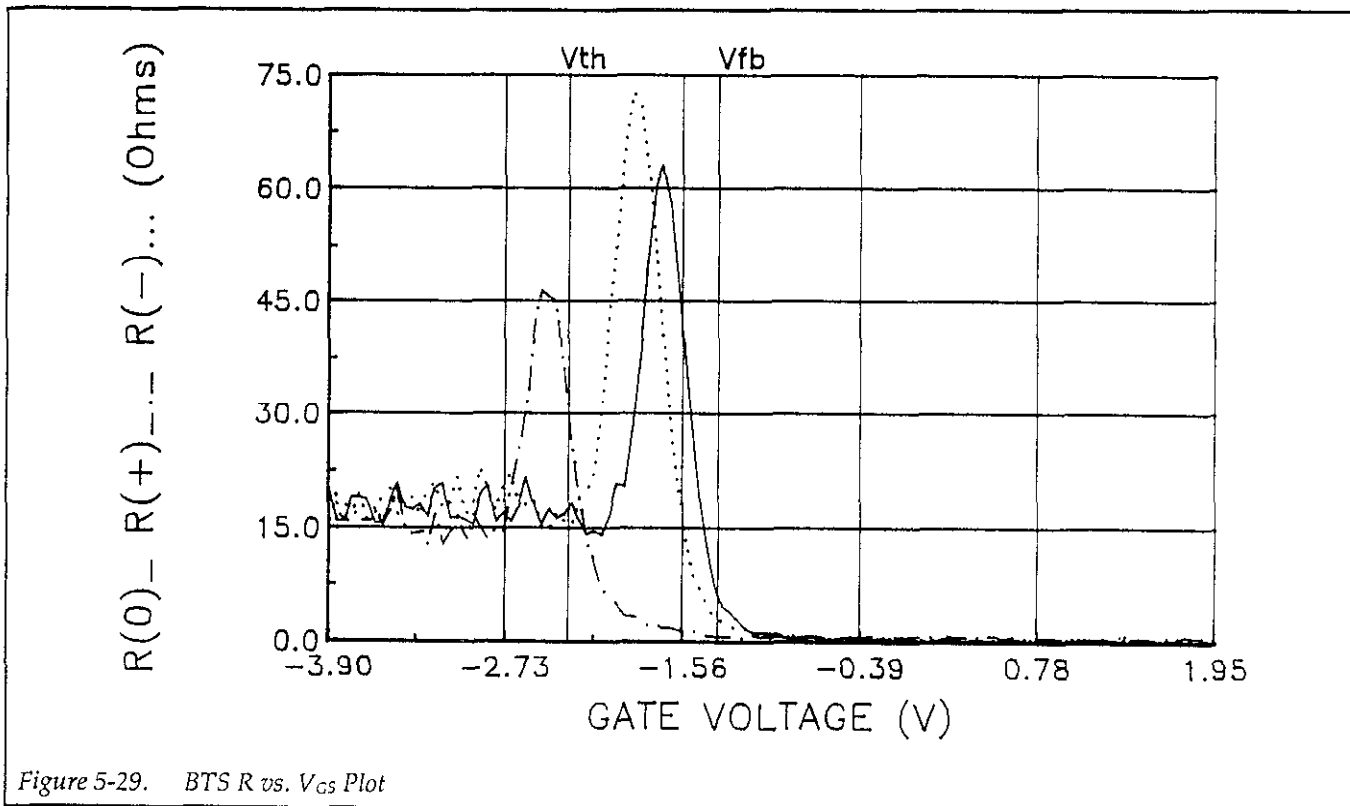
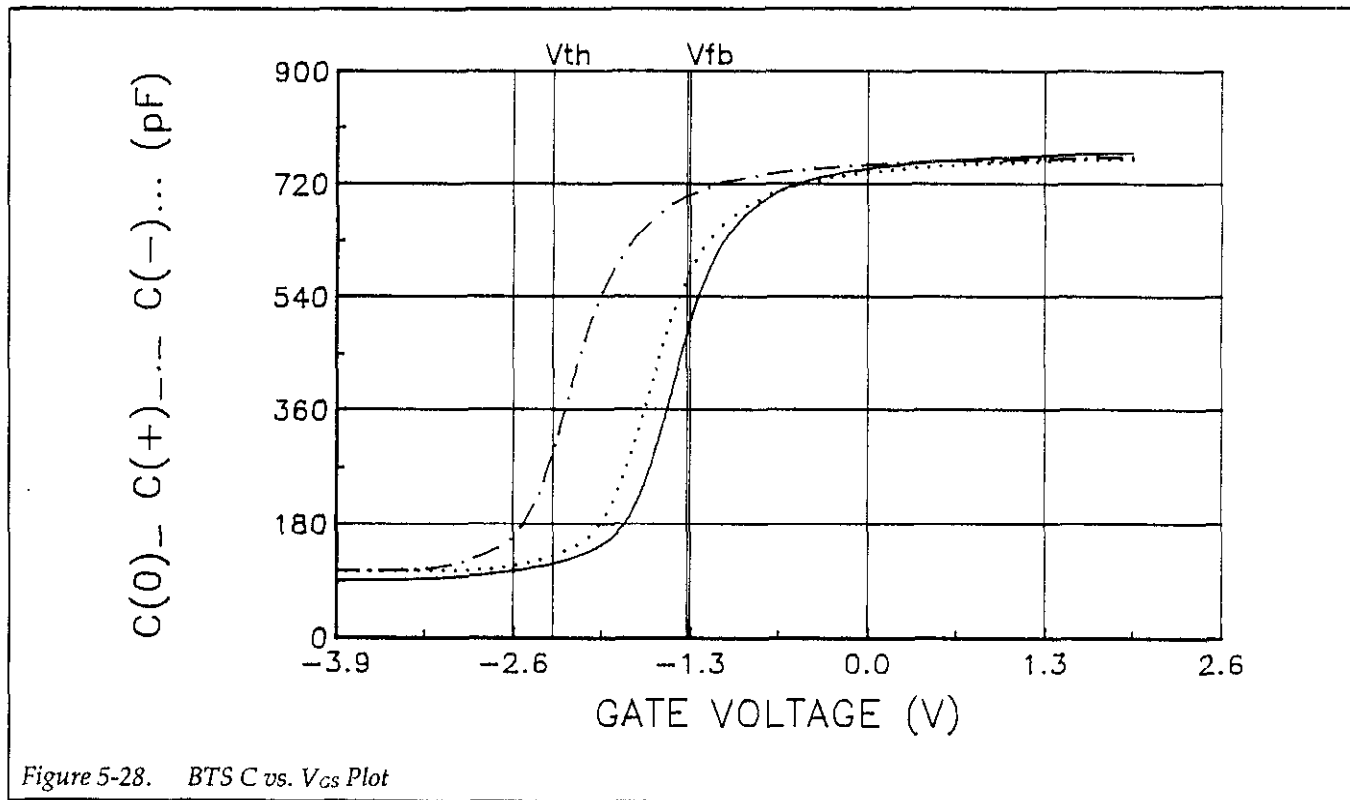
$$Q_{MI} = \frac{1}{(1 \times 10^{12})} \cdot \Delta V_{FB} \cdot \frac{C_{OX}}{A}$$

## 5.8.8 Graphing BTS Data

You can graph C vs.  $V_{GS}$  and G (R) vs.  $V_{GS}$  data by selecting appropriate options on the BTS analysis menu. Such graphs can demonstrate how the device parameters shift due to stress. Figure 5-28 shows a BTS C vs.  $V_{GS}$  plot, and Figure 5-29 shows a BTS R vs.  $V_{GS}$  plot. Note that all sets of pre-stress and post-stress data will be plotted.

C (0) and G (0) represent pre-stress data, C (+) and G (+) indicate post-positive stress data, and C (-) and G (-) show post-negative stress data.





## 5.9 REFERENCES AND BIBLIOGRAPHY

### 5.9.1 References

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### 5.9.2 Bibliography

The material below is recommended reading on C-V, C-t, and BTS measurements.

#### I. Texts:

- A. Grove, A.S., Physics and Technology of Semiconductor Devices. Wiley, New York (1967).
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  - C. Zerbst, M., "Relaxationseffekte an Halbleiter-Isolator-Grenzflaechen", *Z. Angew. Phys.* 22, 30 (1966).

# SECTION 6

## Bus Control File Setup

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### 6.1 INTRODUCTION

This section contains information on setting up files to control switching mainframes, hot chucks, and probe sequencers and is arranged as follows:

**6.2 Switch Control:** Discusses switch control file commands, control file examples, and using the switch control file to control probe sequencers.

**6.3 Probe Sequencer Control:** Describes methods for using the switch control file to control typical probe sequencers.

**6.4 Hot Chuck Control:** Covers hot chuck control commands and default hot chuck file format.

### 6.2 SWITCH CONTROL

#### 6.2.1 Switch Control File Description

Commands that control a switching mainframe are stored in an ASCII file called `Filename.SWC`, which must be located in the `\CTRL` directory. Note that you can specify the usual maximum of eight characters for `Filename`, and the standard DOS filename constraints apply. Some typical example filenames include:

```
SWITCH1.SWC  
CABLE2.SWC  
WAFER6_7.SWC
```

#### 6.2.2 Switch Control File Commands

Table 6-1 summarizes the commands and syntax for the switch control command keywords. Each of these keywords is discussed in detail in the following paragraphs. Note that commands are summarized and discussed in the general order they will appear in the control file.

Table 6-1. Switch Control File Commands

Command
INIT @<Device address (0-31)>,"<DDC>"
PARALLEL @<Device address (0-31)>,"<Pre-test DDC>","<Post-test DDC>"
DEVICE 1 @<Address (0-31)>,"<Pre-test DDC>","<Post-test DDC>"[#Cable_Cal_File]
DEVICE 2 @<Address (0-31)>,"<Pre-test DDC>","<Post-test DDC>"[#Cable_Cal_File]
.
.
.
DEVICE 99 @<Address (0-31)>,"<Pre-test DDC>","<Post-test DDC>"[#Cable_Cal_File]
FINAL @<Device address>,"<DDC>"

NOTES:

1. @ character must precede device primary address.
2. < > characters indicate parameter variable and must not be included in command string.
3. Brackets [] indicate parameter is optional.
4. Multiple lines per keyword are allowed.
5. DDC = device-dependent command (usually ASCII letters and number or words).
6. Quotes must be placed around DDCs in all command strings.
7. An exclamation point (!) can be placed on any line of the file in the first character position to add comments to the file.
8. Commands are executed in the order in which they appear in the control file.
9. Each control file line can have a maximum of 80 characters. A <CR><LF> sequence should terminate each line.
10. Leading spaces are allowed.
11. A maximum of 20 INIT, PARALLEL, and FINAL commands per control file are allowed. The maximum number of DEVICE commands per control file is 200 to allow control of up to 99 devices.

# INIT

## Purpose

To send initialization commands to the switching mainframe or probe sequencer.

## Format

```
INIT @<Address>,"<DDC>"
```

## Parameters

<Address> = primary address of instrument (0-30)  
<DDC> = device-dependent command string

## Description

The INIT command sends the <DDC> string to an instrument at primary <address> and should be the first active command in the switch control file. Typically, this command would be used to reset the switching mainframe and make sure all relays are open and to setup a particular switch configuration such as single-pole or double-pole mode. Up to 20 INIT commands may be placed in each file.

## Examples

```
INIT @18,"R0X"           (Reset unit at primary address 18.)  
INIT @17,"A1X"           (Select single-pole mode, address 17.)
```

## PARALLEL

### Purpose

To send commands to switching mainframe to simultaneously close then open relays for BTS stress cycle.

### Format

PARALLEL @<address>,"<Pre-test DDC>","<Post-test DDC>"

### Parameters

<address> = Primary address of instrument (0-31)  
<Pre-test DDC> = DDC to close all parallel relays  
<Post-test DDC> = DDC to open all parallel relays

### Description

The PARALLEL command sends DDCs to the switching mainframe to close all parallel relays before the stress cycle (pre-test DDC), and then open all parallel relays after the stress cycle. Note that the PARALLEL command is used only for the BTS parallel test sequence; PARALLEL will be ignored for all other test types (BTS sequential and no stress, and all Zerst test sequences). Up to 20 PARALLEL commands may be placed in each file.

### Programming Note

Double quote characters must be placed around the DDC command strings.

### Example

PARALLEL @18,"CA1,B2X","NA1,B2X" (Close/open A1,B2.)

## DEVICE

### Purpose

To send commands to the switching mainframe to close then open relay contacts before and after each device test, or to a probe sequencer to move to the next die position.

### Format

DEVICE <n> @<Address>,"<Pre-test DDC>","<Post-test DDC>" [,#Cable\_Cal\_File]

### Parameters

<n> = Device number (1-99)  
<Address> = Switching mainframe primary address  
<Pre-test DDC> = Command string to close relay(s)  
<Post-test DDC> = Command string to open relay(s)  
Cable\_Cal\_File = Filename of cable calibration file (optional)

### Description

The DEVICE command sends DDCs to the switching mainframe to close the necessary relay(s) prior to each device test, and then sends the commands necessary to open the relay(s) after each device test. An optional cable calibration filename can be specified to ensure optimum correction accuracy for each switching pathway. (Refer to paragraph 2.5 and paragraph 4.5.2 for more information on cable correction.) Up to 200 DEVICE commands may be placed in each file.

### Programming Notes

1. Double quote characters must be placed around the DDC command strings.
2. The # character must precede the cable correction filename. The filename must include a .CAL extension and must be located in the \CAL directory.
3. A space must be included between the DEVICE command and the device number.

### Examples

```
DEVICE 1 @18,"CA1,B2X","NA1,B2X"  
DEVICE 7 @18,"CA3,B4X","NA3,B4X",#CABLE1.CAL
```

## FINAL

### Purpose

To send the final, after-test command string to the switching mainframe or probe sequencer.

### Format

FINAL @<Address>,"<DDC>"

### Parameters

<Address> = Primary address of switching mainframe  
<DDC> = After-test command string

### Description

The FINAL command sends the last DDC string to the switching mainframe at the end of the test sequence. Typically, the switching mainframe would be programmed to ensure that all relays are open at the end of the test. Up to 20 FINAL commands may be placed in each file.

### Example

FINAL @18,"R0X"                   (Reset unit, open all relays.)



### 6.2.3 Switch Control Examples

Typical examples of switching configurations and the necessary switch control files are shown in Figure 6-1, through Figure 6-3. The configuration shown in Figure 6-1 uses a Model 7062 RF Switch Card installed in a Model 705 Scanner. This basic configuration can switch up to five devices per card, but it cannot be used for the parallel test sequences.

The Model 7074D/7075 Multiplexer system shown in Figure 6-2, and the Model 7073 configuration shown in Figure 6-3 can be used for both parallel and sequential test sequences. The Model 7074D/7075 system can switch up to 48 devices per card; the Model 7073 system can switch only six devices per card, but it will generally yield better noise performance, especially with small devices.

Refer to paragraph 4.5.1 for more details on these switching configurations and test connections in general.

### 6.2.4 Setting Up a Switch Control File

The basic procedure for creating switch control files is outlined below. This procedure requires the use of a text

editor or a word processor that can store files in pure ASCII format. Refer to Figure 6-1 through Figure 6-3 for examples.

1. Run your text editor or word processor.
2. Enter each program code line as described above. Be sure to enter the appropriate cable calibration file-names at the end of each DEVICE statement if you are using cable correction (see paragraph 4.5.2 for more information on cable calibration).

#### NOTE

For the parallel BTS test sequence only, include the PARALLEL statement and associated parameters as shown. For all other test sequences (sequential, no stress, or Zerbst sequences), omit the PARALLEL statement and associated parameters.

3. Save the file in pure ASCII format using the .SWC extension. Be sure to save the file in the \CTRL sub-directory. An example might be:

```
C:\KTHLY_CV\MODEL58\CTRL\MODL7062.SWC
```

4. Enter this switch control filename in the BTS test sequence menu (see Section 3).

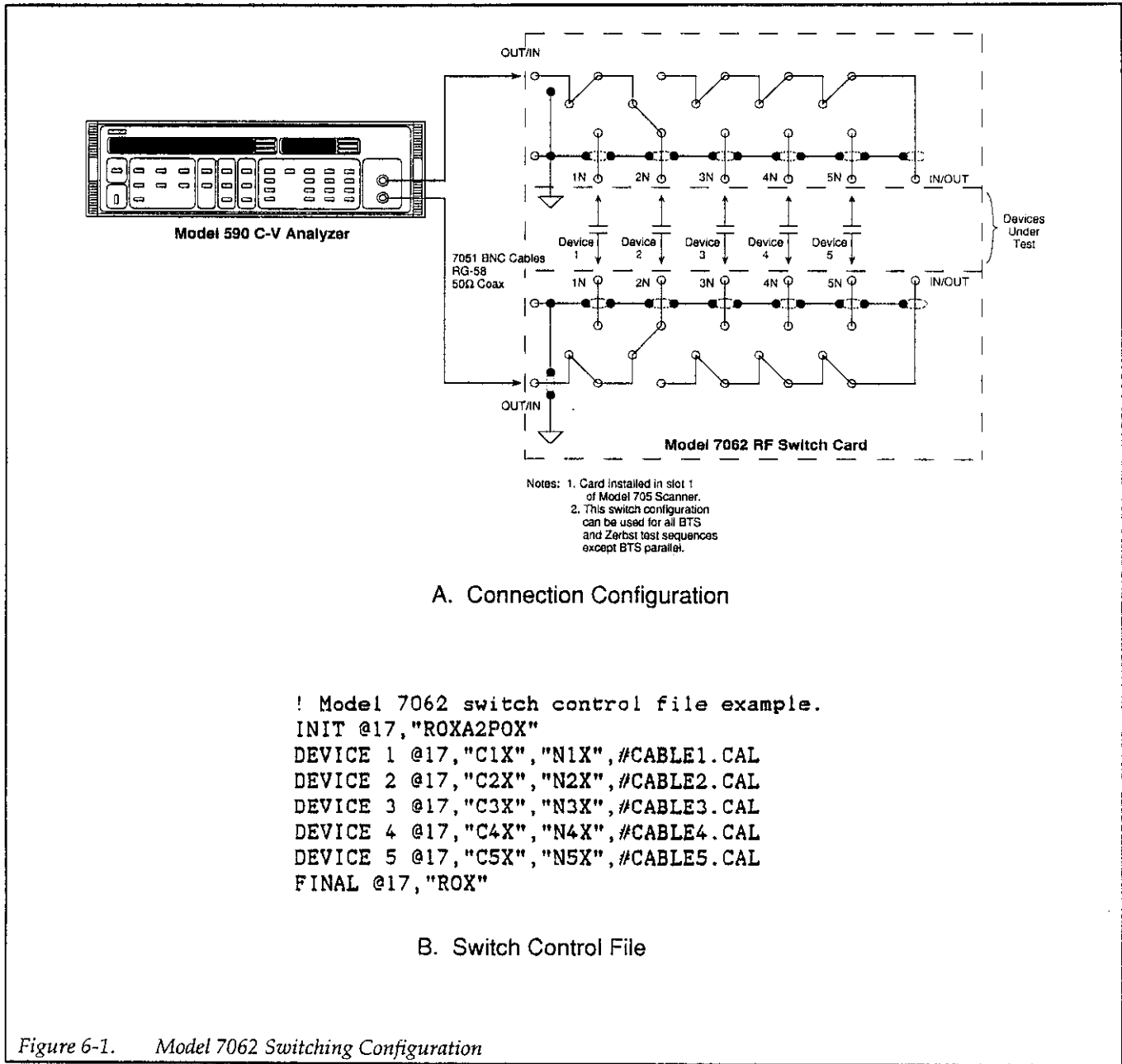
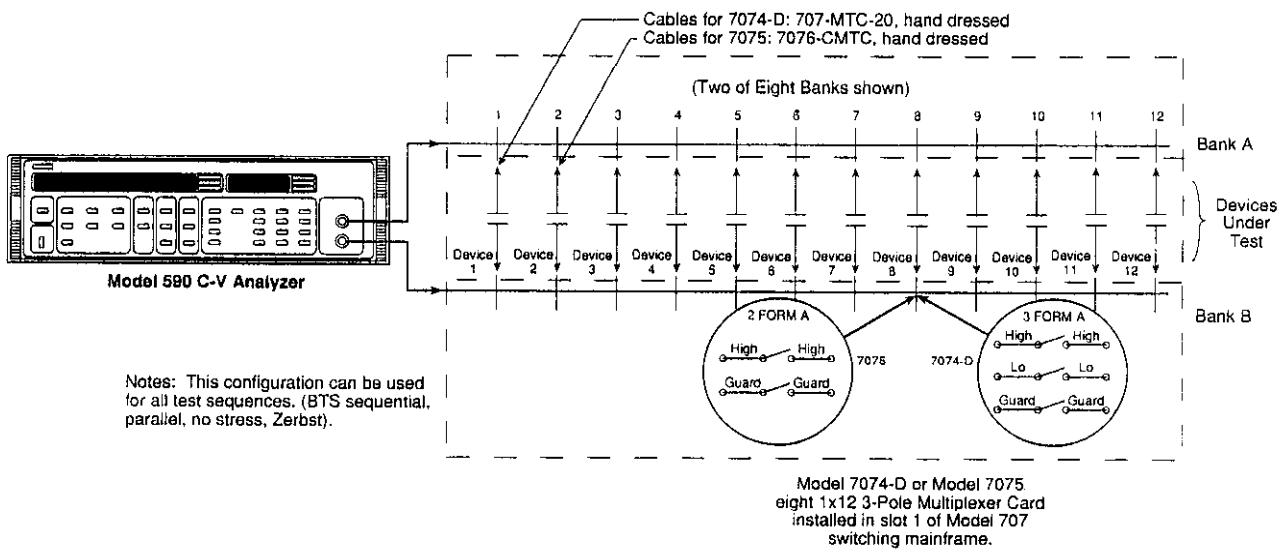


Figure 6-1. Model 7062 Switching Configuration



Notes: This configuration can be used for all test sequences. (BTS sequential, parallel, no stress, Zerst).

### A. Connection Configuration

```
! Model 7074D/7075 example switch control file.
INIT @18, "ROX"
PARALLEL @18, "CA1, B1, A2, B2, A3, B3, A4, B4X", "NA1, B1, A2, B2, A3, B3, A4, B4X"
PARALLEL @18, "CA5, B5, A6, B6, A7, B7, A8, B8X", "NA5, B5, A6, B6, A7, B7, A8, B8X"
PARALLEL @18, "CA9, B9, A10, B10, A11, B11X", "NA9, B9, A10, B10, A11, B11X"
PARALLEL @18, "CA12, B12X", "NA12, B12X"
DEVICE 1 @18, "CA1, B1X", "NA1, B1X", #CABLE1.CAL
DEVICE 2 @18, "CA2, B2X", "NA2, B2X", #CABLE2.CAL
DEVICE 3 @18, "CA3, B3X", "NA3, B3X", #CABLE3.CAL
DEVICE 4 @18, "CA4, B4X", "NA4, B4X", #CABLE4.CAL
DEVICE 5 @18, "CA5, B5X", "NA5, B5X", #CABLE5.CAL
DEVICE 6 @18, "CA6, B6X", "NA6, B6X", #CABLE6.CAL
DEVICE 7 @18, "CA7, B7X", "NA7, B7X", #CABLE7.CAL
DEVICE 8 @18, "CA8, B8X", "NA8, B8X", #CABLE8.CAL
DEVICE 9 @18, "CA9, B9X", "NA9, B9X", #CABLE9.CAL
DEVICE 10 @18, "CA10, B10X", "NA10, B10X", #CABLE10.CAL
DEVICE 11 @18, "CA11, B11X", "NA11, B11X", #CABLE11.CAL
DEVICE 12 @18, "CA12, B12X", "NA12, B12X", #CABLE12.CAL
FINAL @18, "ROX"
```

### B. Switch Control File

Figure 6-2. Model 7074D/7075 Switching Configuration

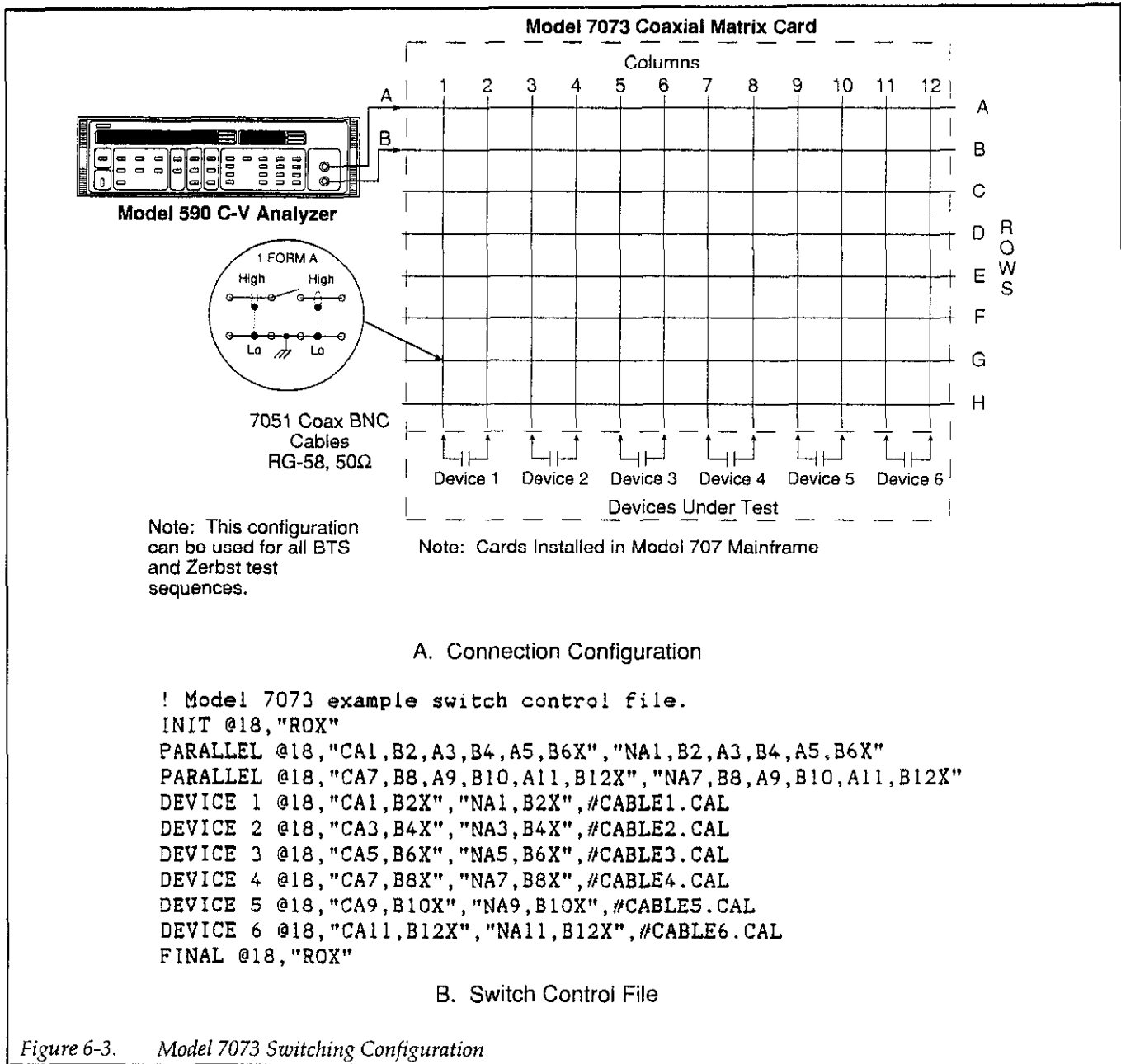


Figure 6-3. Model 7073 Switching Configuration

## 6.3 PROBE SEQUENCER CONTROL

The switch control file can also be used to program automatic and semi-automatic probe sequencers. Basic information on setting up a probe sequencer control file is presented in the following paragraphs.

### 6.3.1 Using Switch Control File Commands

#### INIT

INIT would typically be used to initialize the probe sequencer. Typical initialization commands could include those required to lower the probe platform, turn on vacuum, and perform any other necessary initialization routines.

#### PARALLEL

The PARALLEL command would probably never be used with a probe sequencer since the typical sequencer cannot perform parallel testing.

#### DEVICE

The DEVICE statement would typically be used to send a command to the probe sequencer to move to the next die position. Here it is assumed that the sequencer previously "learned" die positions, either through a learn mode, or from template data.

#### FINAL

The FINAL command can be used to send post-test commands to the probe sequencer. Typically, the commands would perform such tasks as raising the probe platform and turning off vacuum.

### 6.3.2 Programming Constraints

There are a couple of important constraints to keep in mind when using the switch control file to program probe sequencers, including:

1. Each DEVICE command string must include both the pre-test and post-test DDC strings. Since a typical probe sequencer will require only a pre-test command, you can either include a dummy command that will be ignored by the probe sequencer in the post-test DDC position, or simply repeat the pre-test command in the post-test DDC position. Note, however, that repeating commands may create conflicts; refer to your probe sequencer manual for details.
2. Since the switch control file has no provisions for reading back status information from the probe sequencer, there is no way to determine when the prober has completed stepping to the next position. Because it could take up to several seconds to step from die to die, you should allow for this delay period by programming a C-V and/or C-t test start delay time long enough to allow for stepping time. Some experimentation may be required to determine the best delay times.

### 6.3.3 Hypothetical Probe Sequencer Commands

Table 6-2 lists some hypothetical probe sequencer commands. Command names have been chosen to allow easy identification of command purposes and are presented only to demonstrate the basic procedure for using the switch control file to program a probe sequencer.

**Table 6-2 Hypothetical Probe Sequencer Commands**

Command	Description
INIT	Initializes probe sequencer, turns on vacuum.
LOWER	Lowers probe platform to test position.
MOVE <n>	Moves probes to test die <n>.*
RAISE	Raises probe platform from test position.

\*Die positions separately determined using learn mode or template.

### 6.3.4 Example Hypothetical Probe Sequencer Control File

Table 6-3 summarizes a simple switch control file using the hypothetical sequencer command language listed in Table 6-2. A total of five devices are tested, and the primary address of the probe sequencer is assumed to be 10.

**Table 6-3. Example Switch Control File for Hypothetical Probe Sequencer**

Command Line	Comments
INIT @10,"INIT"	Initialize probe sequencer.
INIT @10,"LOWER"	Lower probe platform to test position.
DEVICE 1 @10,"MOVE 1"	Step to device 1.
DEVICE 2 @10,"MOVE 2"	Step to device 2.
DEVICE 3 @10,"MOVE 3"	Step to device 3.
DEVICE 4 @10,"MOVE 4"	Step to device 4.
DEVICE 5 @10,"MOVE 5"	Step to device 5.
FINAL @10,"RAISE"	Raise probe platform.

## 6.4 HOT CHUCK CONTROL

### 6.4.1 Hot Chuck Control File Description

Commands that control the hot chuck are stored in an ASCII file called Filename.HCC, which must be located in the \CTRL directory. The hot chuck control filename is defined during software installation or reconfiguration, and the default name is TP0315B.HCC. The default file supplied with the Model 5958 is intended to control a Temptronic 0315B 300°C ThermoChuck.

Table 6-4 shows the commands in the default hot chuck control file.

### 6.4.2 Hot Chuck Control File Commands

Table 6-5 summarizes hot chuck control file commands. Commands are discussed in detail in the following paragraphs.

**Table 6-4. Default Hot Chuck Control File Commands**

Command	Description
SENDWINDOW "RW"	Define at temperature tolerance command.
SENDSETPOINT "RS"	Define set temperature command.
SENDSRQMASK "RM"	Define send SRQ mask command.
GETTEMP "ST"	Define get temperature command.
NUMCHUCKS #1	Define number of hot chucks.
CHUCKADDR @9	Define hot chuck primary address.
TERMINATOR " "	Define command terminator.
SPATTEMP B0	Define serial poll AT TEMP bit.
SPNOTBUSY B2	Define serial poll NOT BUSY bit.

**Table 6-5. Hot Chuck Control File Command Summary**

Command	Description
CHUCKADDR @<Addr1>,@<Addr2>,...,@<Addrn>	Define chuck addresses (1-10).
GETTEMP "<DDC>"	Define get temp. command.
NUMCHUCKS #<integer # of chucks>	Declare number of hot chucks used.
SENSETPOINT "<DDC>"	Define set temperature command.
SENDSRQMASK "<DDC>"	Define SRQ mask command.
SENDWINDOW "<DDC>"	Define at temp. command.
SPATTEMP B<0-7>	Define serial poll AT TEMP bit.
SPNOTBUSY B<0-7>	Define serial poll NOT BUSY bit.
TERMINATOR "<ASCII>"	Define command terminator.

NOTES:

1. < > characters indicate parameter variable and must not be included in command string.
2. DDC = device-dependent command (usually ASCII letters and number or words).
3. Quotes must be placed around DDCs in all command strings.
4. An exclamation point (!) can be placed on any line of the file in the first character position to add comments to the file.
5. Each control file line can have a maximum of 80 characters. A <CR><LF> sequence should terminate each line.
6. All commands are required for the software to run properly except the TERMINATOR command.

## CHUCKADDR

### Purpose

To define the primary address(es) of the hot chuck(s) used in the system.

### Format

CHUCKADDR @<Addr1>,@<Addr2>,....,<Addrn>

### Parameters

<Addrn> = Chuck primary address(es) (0-30)

### Description

The CHUCKADDR command defines the hot chuck primary addresses. Typically, you would have only one hot chuck, in which case only one address should be specified. However, you can have up to 10 hot chucks in the system, and the number of addresses you specify with this command must be the same as the number of chucks defined by the NUMCHUCKS command (described on page 6-16).

### Programming Notes

1. Each device on the IEEE-488 bus must have a unique primary address, so be sure not to specify a primary address used by some other device. The default Model 590 primary address is 15, and the default Model 230-1 primary address is 13. The default primary address for the recommended Temptronic ThermoChuck is 9.
2. The @ character must be included before each primary address number.
3. Multiple hot chuck capability is intended for use with parallel BTS test sequences. If you specify multiple hot chucks with a sequential BTS test, only the first hot chuck specified will be controlled.

### Examples

CHUCKADDR @9	(One hot chuck at address 9.)
CHUCKADDR @9,@16,@20	(Three hot chucks at addresses 9,16,20)



## GETTEMP

### Purpose

To define the command used to request a temperature reading from the hot chuck.

### Format

```
GETTEMP "<DDC>"
```

### Parameter

<DDC> = Command string to request temperature from chuck.

### Description

GETTEMP defines the command that will be used to request a temperature reading from the hot chuck during a BTS stress cycle. The temperature data is used to display real-time device temperature during a test.

### Example

```
GETTEMP "ST"
```

## NUMCHUCKS

### Purpose

To define the number of hot chucks used in the system.

### Format

NUMCHUCKS #<n>

### Parameter

<n> = Integer number of hot chucks (1-10)

### Description

The number of hot chucks used in the system is defined by the NUMCHUCKS command. The allowable range for <n> is from 1 to 10, and the value of <n> must be the same as the number of primary addresses specified with the CHUCKADDR command.

### Programming Notes

1. The # character must immediately precede the number of chucks parameter <n>.
2. Multiple-chucks should be used only with parallel BTS sequences. If you specify multiple hot chucks with sequential BTS tests, only the first defined hot chuck in the hot chuck control file will be used.

### Example

NUMCHUCKS #1                    (one hot chuck)

## SENDSETPOINT

### Purpose

To define the command used to send the hot chuck set temperature.

### Format

```
SENDSETPOINT "<DDC">
```

### Parameter

<DDC> = Command to program hot chuck set temperature

### Description

SENDSETPOINT defines the DDC used to set the temperature of the hot chuck. Note that only the set temperature command itself is defined in the control file. The temperature parameter value comes from the stress cycle parameter file, which is defined when you define and save a stress cycle setup via the BTS stress cycle parameter setup menu. (At different points in the stress cycle, the set temperature will be determined either by the stress temperature parameter or the stress off temperature parameter.)

### Example

```
SENDSETPOINT "RS"
```

## SENDSRQMASK

### Purpose

To define the hot chuck SRQ mask command.

### Format

```
SENDSRQMASK "<DDC>"
```

### Parameter

<DDC> = Command to set SRQ mask bits

### Description

SENDSRQMASK defines the command used to set specific hot chuck SRQ bits. The bits that are set by this command (0-7) are defined by the SPATTEMP and SPNOT-BUSY commands described below. SRQ (Service Request) conditions are used by the computer to determine when a particular hot chuck status is reached. For example, an SRQ is generated when the hot chuck reaches the programmed at temp. value.

### Example

```
SENDSRQMASK "RM"
```

## SENDWINDOW

### Purpose

To define the command that programs the hot chuck at temperature window tolerance.

### Format

```
SENDWINDOW "<DDC>"
```

### Parameter

<DDC> = Command necessary to program at temp. window tolerance.

### Description

The at temperature tolerance window command is defined by the SENDWINDOW command. Note that only the command is defined here; the at temperature parameter itself comes from the stress cycle parameter file, which is defined during stress cycle parameter setup (At Temp. parameter).

When the hot chuck reaches the at temperature tolerance defined by this command, it will signal the controller via the SRQ line that the programmed temperature tolerance has been reached.

### Example

```
SENDWINDOW "RW"
```

## SPATTEMP

### Purpose

To define the AT TEMP SRQ mask and serial poll bits.

### Format

SPATTEMP B<n>

### Parameter

<n> = Bit position number (0-7)

### Description

SPATTEMP defines the AT TEMP bit designation for the SRQ mask and serial poll bytes. The allowable range for the <n> parameter is from 0-7, with bit 0 the least significant bit, and bit 7 the most significant bit.

This bit definition is used in conjunction with the SENDSRQMASK command to enable SRQ when the at temperature window is reached. The Model 5958 software also uses this bit definition to define which hot chuck serial poll bit flags the AT TEMP condition.

The recommended Temptronic TP0315B Thermochuck uses bit 0 of the SRQ mask and serial poll byte as the AT TEMP bit.

### Programming Note

The B character must appear immediately before the bit designation number.

### Examples

SPATTEMP B0	(Bit 0)
SPATTEMP B3	(Bit 3)

## SPNOTBUSY

### Purpose

To define the NOT BUSY SRQ mask and serial poll bits.

### Format

SPNOTBUSY B<n>

### Parameter

<n> = Bit position number (0-7)

### Description

SPNOTBUSY defines the NOT BUSY bit designation for the SRQ mask and serial poll bytes. The allowable range for the <n> parameter is from 0-7.

This bit definition is used with the SENDSRQMASK command to enable SRQ when a not busy condition is present. The Model 5958 software also uses this bit definition to define which hot chuck serial poll bit flags the NOT BUSY condition.

The recommended Temptronic TP0315B ThermoChuck uses bit 2 of the SRQ mask and serial poll byte as the NOT BUSY bit.

### Programming Note

The B character must appear immediately before the bit designation number.

### Examples

SPNOTBUSY B2	(Bit 2)
SPNOTBUSY B4	(Bit 4)

## TERMINATOR

### Purpose

To define the terminator character(s) sent at the end of the hot chuck command string.

### Format

TERMINATOR "<ASCII>"

### Parameters

<ASCII> = One or more ASCII characters

### Description

TERMINATOR defines one or more ASCII terminator characters which will be appended to the end of each command string sent to the hot chuck. Typically, the terminator is an execute character such as an "X". Note, however, that many units (including the Temptronic ThermoChuck) require no terminator. When no terminator is required, include null quotes with the TERMINATOR command ("").

### Examples

TERMINATOR "X"	("X" is the terminator).
TERMINATOR ""	(No terminator).



### 6.4.3 Setting Up a Hot Chuck Control File

The basic procedure for creating a hot chuck control file is outlined below. This procedure requires the use of a text editor or a word processor that can store files in pure ASCII format.

This procedure assumes that you will modify the existing hot chuck control file and save the modified file under the default filename (TP0315B.HCC). You can also save the new control file under a different name (the .HCC extension is still required, however). If you use a different filename, you will have to run the INSTALL program and change the hot chuck control filename.

Procedure:

1. Change to the \CTRL directory by typing the following:

```
CD \KTHLY_CV\MODEL58\CTRL <Enter>
```

2. Make a backup copy of the default control file by typing the following:

```
COPY TP0315B.HCC BACKUP.HCC
```

3. Run your text editor or word processor. If the program directory is not defined in the current path, you will have to specify the complete path when running the program.
4. Load the TP0315B.HCC file. Figure 6-4 shows the contents of this file.
5. Modify each program code line as required, using your hot chuck manual as a guide. In addition to command changes, be sure to specify the primary address, terminator, and serial poll bit positions.
6. Save the file in pure ASCII format using the TP0315B.HCC filename. Be sure to save the file in the \CTRL subdirectory. The complete default path and filename is:

```
C:\KTHLY_CV\MODEL58\CTRL\TP0315B.HCC
```

7. To restore the original hot chuck control file, rename your new file to some convenient name, then rename the BACKUP.HCC file to TP0315B.HCC.

```
!This is a Temptronic TP0315B Hot Chuck control file
SENDWINDOW "RW"
SENDSETPPOINT "RS"
SENDSRQMASK "RM"
GETTEMP "ST"
NUMCHUCKS #1
CHUCKADDR @9
TERMINATOR ""
SPATTEMP B0
SPNOTBUSY B2
```

Figure 6-4. Default Contents of TP0315B.HCC File



# APPENDIX A

## Material Constants File Modification

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As shipped, the Model 5958 is intended to work with devices with a silicon substrate, a silicon dioxide insulator, and aluminum gate material. Constants that define these and other parameters are stored in a file called MATERIAL.CON, which is automatically loaded by the Model 5958 software at run time. (Figure A-1 shows the general format and factory default values stored in MATERIAL.CON, and Table A-1 summarizes default constant values.) Since this file is in ASCII format, you can modify these values by editing the file using a text editor or a word processor that can handle straight ASCII files.

Before making changes, you should create a backup version of the file under a similar filename (for example MATERIAL.DEF). Also, be careful not to alter the overall file format in any way.

### NOTE

The Model 5958 software may not run properly if you change the format of MATERIAL.CON from that shown in Figure A-1. Also, changing constants to improper values will probably lead to erroneous results in analysis.

Table A-1. Default Material Constants File (MATERIAL.CON)

Symbol	Description	Default Value
q	Electron charge (Coul.)	$1.60219 \times 10^{-19}$ Coul.
k	Boltzmann's constant (J/°K)	$1.38066 \times 10^{-23}$ J/°K
T	Test temperature (°K)	293°K
$\epsilon_{ox}$	Permittivity of oxide (F/cm)	$3.4 \times 10^{-13}$ F/cm
$\epsilon_s$	Semiconductor permittivity (F/cm)	$1.04 \times 10^{-12}$ F/cm
$E_G$	Semiconductor energy gap (eV)	1.12eV
$n_i$	Intrinsic carrier concentration (1/cm <sup>3</sup> )	$1.45 \times 10^{10}$ cm <sup>-3</sup>
$W_{MS}$	Metal work function (V)	4.1V
X	Electron affinity (V)	4.15V

**Procedure:**

1. From DOS, select the directory in which MATERIAL.CON is located (default= C:\KTHLY\_CV \MODEL58).
2. Make a backup copy of MATERIAL.CON by typing the following:

```
COPY MATERIAL.CON MATERIAL.DEF <Enter>
```

3. Load the MATERIAL.CON file into your text editor or word processor. A typical command might be:

```
ED MATERIAL.CON <Enter>
```

4. Using Figure A-1 as guide, make the desired value changes, but be sure that the != symbols appear before each value.
5. Save the file using the name MATERIAL.CON after all changes have been made. Remember that the file must be saved in straight ASCII format. (Most text editors automatically save in ASCII format, and many word processors have an ASCII format save option.) Also, remember to save this file in the default \MODEL58 directory so the program can locate it at run time.
6. Run the Model 5958 software in the usual manner. The new constants will be used by the program for analysis.

FILE: MATERIAL.CON  
DESCRIPTION: This file is used to initialize the physical constants associated with a particular type of MIS device. This file contains physical constants for the following device type at room temperature:

Silicon - Silicon Dioxide - Aluminum

substrate material \_\_\_ | insulator | \_\_\_ gate material

VARIABLE	DESCRIPTION	VALUE
KQ	Charge of an electron(Coul)	!= 1.60219E-19
Kk	Boltzmann's constant(J/K)	!= 1.38066E-23
Kt	Test temperature(K)	!= 293
KEox	Permittivity of oxide(F/cm)	!= 3.40000E-13
KEs	Permittivity of semiconductor(F/cm)	!= 1.04000E-12
KEg	Energy gap of semiconductor(eV)	!= 1.12
KNi	Intrinsic carrier concentration(1/cm <sup>3</sup> )	!= 1.45000E+10
KPhim	Metal work function(V)	!= 4.1
*KX	Semiconductor electron affinity(V)	!= 4.15
	( see note )	

In modern integrated-circuit processing, heavily doped polysilicon is often used as the gate material instead of aluminum. If this is the case, the work function constants are computed as follows(as per Sze's book "Physics of Semiconductor Devices").

p - type polysilicon gate

KPhim = Semiconductor electron affinity + Energy gap of semiconductor

n - type polysilicon gate

KPhim = Semiconductor electron affinity

Figure A-1. Default Material Constants File (MATERIAL.CON)

Below you will find a table of electron affinities for various semiconductors. This table was taken from page 438 of Helmut F. Wolf's book entitled "Semiconductors".

<u>semiconductor</u>	<u>electron affinity(V)</u>
Si	4.05
Ge	4.13
GaAs	4.07
GaP	3.21
GaSb	4.06
InAs	4.90
InSb	4.59
CdS	3.90

Below you will find a table of metal work functions for various metals at 300K. This table was taken from page 424 of Wolf's book.

<u>metal</u>	<u>work function(V)</u>
Ag	4.3-5.1
Al	4.1-4.3
Au	4.7-5.0
Ba	2.4-2.6
Ce	1.9-2.0
Cr	4.5-4.6
Cu	4.3-4.7
Mg	3.2-3.7
Mo	4.3-4.5
Ni	4.5-4.7
Pt	5.2-5.3
Si	5.1-5.2
W	4.5-4.6

\*\*\*\*\*NOTE\*\*\*\*\*

Version A2 of the 5957 software used a silicon electron affinity of 4.15 Volts. This number was taken from page 397 of Sze's book. After closer inspection, a discrepancy was found in Sze's book. On Sze page 850 you will find a table of electron affinities. In this table, silicon's electron affinity is 4.05 Volts which is consistent with other sources; more specifically Wolf.

Default Material Constants File (MATERIAL.CON) (Cont.)

## BIBLIOGRAPHY FOR MATERIAL.CON

1. Sze, S.M. Physics of Semiconductor Devices. 2nd Edition. New York: John Wiley & Sons, 1981.
2. Wolf, H.F. Semiconductors. New York: John Wiley & Sons, 1971.

NOTE: See paragraph 5.9 at the end of Section 5 for additional references.





# APPENDIX B

## Summary of Analysis Equations

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Analysis Function	Computation
Doping Profile	$w = A\epsilon_s \left( \frac{1}{C_H} - \frac{1}{C_{Ox}} \right)$ $N = \frac{(-2 \times 10^{24})}{A^2 q \epsilon_s} \cdot \left[ \frac{d}{dV_{GS}} \left( \frac{1}{C_H^2} \right) \right]^{-1}$ <p style="margin-left: 20px;">where: <math>\frac{d}{dV_{GS}} \left( \frac{1}{C_H^2} \right) \cong \frac{\frac{1}{C_H^2(i)} - \frac{1}{C_H^2(i+1)}}{V_{GS}(i+1) - V_{GS}(i)}</math></p>
Flatbands	$C_{FB} = \frac{C_{Ox} A \epsilon_s / \lambda (1 \times 10^{-4})}{(1 \times 10^{-12}) C_{Ox} + A \epsilon_s / \lambda (1 \times 10^{-4})}$ <p style="margin-left: 20px;">where: <math>\lambda = (1 \times 10^4) \sqrt{\frac{\epsilon_s k T}{q^2 N_x}}</math></p> <p style="margin-left: 20px;">Where: <math>N_x = N</math> at 90% <math>W_{MAX}</math>, <math>N_A</math> or <math>N_D</math></p>

Analysis Function	Computation
Oxide Thickness /Gate Area	$t_{OX} = \frac{A \epsilon_{OX}}{(1 \times 10^{-19}) C_{OX}}$
Series Resistance Compensation	$C_C = \frac{(G_M^2 + \omega^2 G_M^2) C_M}{a^2 + \omega^2 C_M^2}$ $G_C = \frac{(G_M^2 + \omega^2 G_M^2) a}{a^2 + \omega^2 C_M^2}$ $a = G_M - (G_M^2 + \omega^2 C_M^2) R_{SERIES}$
Threshold Voltage  Work Function	$V_{THRESHOLD} = \left[ \pm \frac{A}{10^{12} C_{OX}} \sqrt{4 \epsilon_s q  N_{BULK}   \phi_B } + 2  \phi_B  \right] + V_{FB}$ $W_{MS} = W_M - \left[ W_s + \frac{E_G}{2} - \phi_B \right]$
Effective Oxide Charge and Effective Charge Concentration	$Q_{EFF} = \frac{C_{OX}(W_{MS} - V_{FB})}{A}$ $N_{EFF} = \frac{Q_{EFF}}{q}$
Average Doping Concentration	$\frac{\ln(N_{AVG} / n_i)}{N_{AVG}} = \left[ \frac{q^2 \epsilon_s t_{OX}^2}{4kT \epsilon_{OX}^2} \left[ \frac{C_{MAX} - C_{MIN}}{C_{MIN}} \right]^2 \right]$

Analysis Function	Computation
Ziegler (MCC) Doping Profile	$N(w) = \frac{(-2 \times 10^{24})}{A^2 q \epsilon_s} \cdot \left[ \frac{d}{dV_{GS}} \left( \frac{1}{C_{H^2}} \right) \right]^{-1} \cdot g_2 \left( \frac{w}{\lambda} \right)$ <p>where,</p> $\frac{d}{dV_{GS}} \left( \frac{1}{C_{H^2}} \right) \cong \frac{\frac{1}{C_{H^2}(i)} - \frac{1}{C_{H^2}(i+1)}}{V_{GS}(i+1) - V_{GS}(i)}$ $g_1 \left( \frac{w}{\lambda} \right) = \frac{2kT\epsilon_s}{q^2} \cdot \frac{1}{(w)^2 (N(w))}$ $g_1 \left( \frac{w}{\lambda} \right) = -2 \frac{g \left( \frac{w}{\lambda} \right)}{1 - g \left( \frac{w}{\lambda} \right)} + \frac{1 - g \left( \frac{w}{\lambda} \right)}{\frac{w^2}{\lambda^2}}$ $g_2 \left( \frac{w}{\lambda} \right) = \frac{1}{1 - g \left( \frac{w}{\lambda} \right)} \left\{ 2 \frac{w^2}{\lambda^2} \frac{g \left( \frac{w}{\lambda} \right)}{\left[ 1 - g \left( \frac{w}{\lambda} \right) \right]^2} \right\}$ $\lambda = \left( \frac{2kT\epsilon_s}{q^2 N} \right)^{1/2}$ $\frac{w}{\lambda} = (g - \ln g - 1)^{1/2}$
Zerbst Plot	$G/n_t = -\epsilon_s A N_{AVG} C_{OX} \cdot \left[ \frac{\frac{1}{C_{i+1}^2} - \frac{1}{C_{i-1}^2}}{n_t t_{int}} \right] \cdot \left( \frac{1 \times 10^{12}}{2} \right)$ $W - W_F = 1 \times 10^{12} \epsilon_s A \left( \frac{1}{C_{i-1}} - \frac{1}{C_{OX}} \right) - W_F$
BTS Analysis	$N_{SS} = \frac{C_{OX}}{qA (1 \times 10^{12})} \cdot [W_{MS} - V_F]$ $Q_{SS} = \frac{C_{OX}}{A (1 \times 10^{12})} \cdot [W_{MS} - V_F]$ $N_{MI} = \frac{1}{q(1 \times 10^{12})} \cdot \Delta V_{FB} \cdot C_{OX}/A$ $Q_{MI} = \frac{1}{(1 \times 10^{12})} \cdot \Delta V_{FB} \cdot \frac{C_{OX}}{A}$



# APPENDIX C

## C-V Analysis Constants

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Constant	Menu Term	Description	Units
C <sub>OX</sub>	Cox	Oxide capacitance	pF
R <sub>SERIES</sub>	Rseries	Series resistance	ohms
N <sub>BULK</sub>	Nbulk	Bulk doping concentration	cm <sup>-3</sup>
C <sub>FB</sub>	Cfb	Flatband capacitance	pF
V <sub>THRESHOLD</sub>	Vthresh	Threshold voltage	V
tox	tox	Oxide thickness	nm
C <sub>MIN</sub>	Cmin	Minimum capacitance	pF
V <sub>FB</sub>	Vfb	Flatband voltage	V
N <sub>EFF</sub>	Neff	Effective oxide charge concentration	1/cm <sup>2</sup>
Area	Area	Gate area	cm <sup>2</sup>
N <sub>AVG</sub>	Navg	Average doping concentration	cm <sup>-3</sup>
λ	Lb	Extrinsic Debye length	μm
W <sub>MS</sub>	Work Fn	Work function	V
Q <sub>EFF</sub>	Qeff	Effective oxide charge	coul/cm <sup>2</sup>
	Device Type	Device type	n or p
	Best depth	Best depth	μm



# APPENDIX D

## Disk File Formats

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### INTRODUCTION

Formats of the various disk files are described in the following paragraphs. Table D-1 summarizes file types, extensions, and default paths for the various files.

#### BTS Test Sequence File

Filename: Eight characters  
Extension: .BTS  
Example: TEST23.BTS  
File Type: ASCII  
Default Path: C:\KTHLY\_CV\MODEL58\SEQ

This file defines parameters for the BTS test sequence. Its format is shown in Table D-2.

#### Cable Calibration File

Filename: Eight characters  
Extension: .CAL  
Example: CABLECAL.CAL  
File Type: ASCII  
Default Path: C:\KTHLY\_CV\MODEL58\CAL

Cable calibration files are created by the CABLECAL.EXE utility (see Appendix E). These files contain ca-

ble calibration constants that are sent to the Model 590 C-V analyzer to compensate for cabling effects during measurement. Each pathway in the system should have a separate cable calibration file.

Cable Calibration filenames have the form:

CALNAME.CAL

#### Configuration File

Filename: MODEL58  
Extension: .CFG  
Example: MODEL58.CFG  
File Type: ASCII  
Default Path: C:\KTHLY\_CV\MODEL58

The configuration file is created by the INSTALL program, and it is used by the Model 5958 software at run time to determine default paths and equipment parameters. If desired, you can edit this file to make quick and easy changes to your system configuration without running the INSTALL program. Be careful when doing so, however, because inappropriate changes may cause the Model 5958 to run improperly or not at all. For this reason, we recommend that you make a backup copy of MODEL58.CFG before making modifications.

The basic format of the configuration file is shown in Table D-3.

Table D-1. Model 5958 File Summary

File Type	Extension	Default Path*
BTS Test Sequence	.BTS	\SEQ
Cable Calibration	.CAL	\CAL
Configuration	.CFG	\MODEL58
C-t Data Destination	.CTD	\DAT
C-V Data Destination	.DAT	\DAT
C-t Measurement Parameters	.CTP	\PAR
C-V Measurement Parameters	.CVP	\PAR
Hot Chuck Control	.HCC	\CTRL
Source	.BAS	\SRC
Stress Cycle Parameters	.SCP	\PAR
Switch Control	.SWC	\CTRL
Temporary**	.TMP	\TMP
Zerbst Test Sequence	.ZTS	\SEQ

\* All pathnames except \MODEL58 are preceded by C:\KTHLY\_CV\MODEL58 as the default. Path names are chosen during installation.

\*\*Temporary files are for program inter-communication only, and serve as memory between executable programs.

NOTE: MATERIAL.CON (Appendix A) is not shown.

Table D-2. BTS Test Sequence File Format

File Contents	Description
1   2   3	1 = sequential test sequence 2 = parallel test sequence 3 = no stress test sequence
1   2   3   4	1 = + then - stress cycle 2 = - then + stress cycle 3 = + only stress cycle 4 = - only stress cycle
1   2   3	1 = manual C <sub>MIN</sub> checking 2 = auto C <sub>MIN</sub> checking 3 = no C <sub>MIN</sub> checking
64 characters	Comment field
1-99	Number of devices
8 characters	C-V Parameter Filename
8 characters	Stress Cycle Parameter Filename
8 characters	Switch Control Filename
5 characters	Data Destination Filename



Table D-3. Configuration File Format

File Contents	Description
Model 5958 configuration file	Comment
-----	Comment
C:\pathname\DAT	Data file directory
C:\pathname\PAR	Parameter files directory
C:\pathname\SEQ	Test sequence files directory
C:\pathname\CAL	Cable calibration files directory
C:\pathname\CTRL	Switch and chuck control files directory
C:\pathname\TMP	Temporary files directory
-1   0	-1 = Model 82 present; 0 = no Model 82
-1   0	-1 = Use light; 0 = no light
-1   0	-1 = 230-1 present; 0 = no 230-1
-1   0	-1 = Hot chuck in system; 0 = no chuck
-1   0	-1 = Switch in system; 0 = no switch
-1   0, -1   0	100kHz/1M 590 option present; -1=yes,0=no
Filename.HCC	Hot chuck control filename
LPTn:	n = parallel printer port
nn	590 primary address
nn	230-1 primary address

**C-t Data Destination File**

Filename: Eight characters  
 Extension: .CTD  
 Example: MYDATA.CTD  
 File Type: ASCII  
 Default Path: C:\KTHLY\_CV\MODEL58\DAT

C-t data destination filenames have the form:

MYDATA.CTD

Zerbst sequence C-t data destination filenames are of the form: MYDATnnZ.CTD, where nn represents the number of the device tested, and "Z" indicates Zerbst sequence. Note that device numbers are automatically assigned at test time.

Figure D-1 shows the general format of the C-t data file. The first one or two lines contain the comments (these lines may print out as one or two lines, depending on the method used to print them out). The next two lines identify the file type and data delimiter. Subsequent lines indicate various operating parameters, while the remaining lines contain C-t measurement array data in columnar form.

```

"Line 1"
 59581
"SPACE"
"Rdgcnt=" 100
"Tint=" 1.976563E-03
"Frequency=" 100000
"Model=" 1
"Ch" "t" "Gni" "WWF"
67.33999 0 0 0
67.33999 1.976563E-03 0 0
67.33999 3.953125E-03 0 0
67.33999 5.929688E-03 0 0
67.33999 7.906251E-03 0 0
67.33999 9.882812E-03 0 0
67.33999 1.185938E-02 0 0
67.33999 1.383594E-02 0 0
67.33999 .0158125 0 0
67.33999 1.778906E-02 0 0
67.33999 1.976562E-02 0 0
67.33999 2.174219E-02 0 0
67.33999 2.371875E-02 0 0
67.33999 2.569531E-02 0 0
67.18999 2.767188E-02 0 0
67.33999 2.964844E-02 0 0
67.18999 .031625 0 0
  
```

Figure D-1. C-t Data File Format

### C-V Data Destination File

Filename: Eight characters  
Extension: .DAT  
Example: MYDATA.DAT  
File Type: ASCII  
Default Path: C:\KTHLY\_CV\MODEL58\DAT

C-V data destination filenames have the form:

MYDATA.DAT.

Zerbst sequence C-V data destination filenames are of the form: MYDATnnZ.DAT, where nn represents the number of the device tested, and "Z" indicates Zerbst sequence. Note that device numbers are automatically assigned at test time.

BTS sequence data destination filenames have the form: MYDATnnX.DAT, where nn represents the device number, which is automatically assigned at test time. X defines the stress type: "I" means initial, or pre-stress, "P" indicates post-positive stress, and "N" shows the data was taken after negative stress.

Figure D-2 shows the general format of the C-V data file. The first one or two lines contain the comments (these lines may print out as one or two lines, depending on the method used to print them out). The next two lines identify the file type and data delimiter. Subsequent lines indicate various operating parameters and constants, while the remaining lines contain C-V measurement array data in columnar form.

### C-t Measurement Parameters File

Filename: Eight characters  
Extension: .CTP

Example: WAFER21.CTP  
File Type: ASCII  
Default Path: C:\KTHLY\_CV\MODEL58\PAR

The C-t measurement parameters file contains parameters defined for given C-t measurement. All devices in a given test sequence use one file. The file format is summarized in Table D-4.

### C-V Measurement Parameters File

Filename: Eight characters  
Extension: .CVP  
Example: CVWAFER.CVP  
File Type: ASCII  
Default Path: C:\KTHLY\_CV\MODEL58\PAR

The C-V measurement parameters file contains parameters to be used for a given C-V sweep. All devices in a given test sequence use the same file to define measurement parameters. The file format is shown in Table D-5.

### Hot Chuck Control File

Filename: Eight characters  
Extension: .HCC  
Example: TP0315B.HCC  
File Type: ASCII  
Default Path: C:\KTHLY\_CV\MODEL58\CTRL

The hot chuck control file defines the commands necessary to control the hot chuck. The default hot chuck supported is the Temptronic TP0315B 300xC Thermochuck. Refer to Section 6 for details on setting up a hot chuck control file.

The commands supported are summarized in Table D-6.

```

"Line 1"
59580
"SPACE"
"Rdgcnt=" 114
"Frequency=" 1000000
"Model=" 1
"GStepv=" 50
"Rseries=" .44
"Cox=" 250.6
"Tox=" 135.6744
"Area=" .01
"Nbulk=" 8.4E+14
"Cmin=" 73.7
"CqGain=" 0
"CqOffset=" 0
"ChGain=" 1
"ChOffset=" 0
"Cfb=" 0
"Vfb=" 0
"Lb=" 0
"Qeff=" 0
"Neff=" 0
"Vth=" 0
"Navg=" 0
"WorkFn=" 0
"PhiB=" 0
"Qmi=" 0
"Qss=" 0
"Nmi=" 0
"Nss=" 0
"Vfb+=" 0
"Vfb-=" 0
"Vth+=" 0
"Vth-=" 0
"DevType=" ""
"Cq" "Iq" "Ch" "Gh" "Vh" "W" "N" "ZW" "ZN" "Psis" "Et" "Dit" "InvSqCh" "ACq" "ACh"
0 0 250.6 1.1 5.84 0 0 0 0 0 0 0 0 0 0
0 0 250.5 1.1 5.74 0 0 0 0 0 0 0 0 0 0
0 0 250.5 1.1 5.64 0 0 0 0 0 0 0 0 0 0
0 0 250.4 1.1 5.54 0 0 0 0 0 0 0 0 0 0
0 0 250.4 1.1 5.44 0 0 0 0 0 0 0 0 0 0
0 0 250.3 1.1 5.34 0 0 0 0 0 0 0 0 0 0
0 0 250.4 1.1 5.23 0 0 0 0 0 0 0 0 0 0
0 0 250.2 1.1 5.14 0 0 0 0 0 0 0 0 0 0
0 0 250.1 1.1 5.03 0 0 0 0 0 0 0 0 0 0
0 0 250.2 1.1 4.93 0 0 0 0 0 0 0 0 0 0
0 0 250.1 1.1 4.83 0 0 0 0 0 0 0 0 0 0

```

Figure D-2. C-V Data File Format

Table D-4. C-t Measurement Parameters File Format

File Contents	Description
1   2   3   4	Range 2pF, 20pF, 20pF 200pF only (1-4)
0   1	Frequency 0 = 100kHz, 1 = 1MHz
0   1	Model 0 = parallel, 1 = serial
0   1   2   3   4	Rate 0 = 1000, 1 = 75, 2 = 18, 3 = 10, 4 = 1
0   1	Filter 0 = off, 1 = on
0   1	Sweep Source 0 = 590; 1 = 230-1
1 - 1350	# of samples 1-450 for 1/10/18/75/sec rate 1-1350 for 1000/sec rate
.001 - 65	Start Delay time in seconds, 1msec resolution
.001 - 65	Sample Time time in seconds, 1msec resolution
.001 - 65	Stop Delay time in seconds, 1msec resolution
-200 - +200	Default Bias V floating point voltage, 5mV resolution
-200 - +200	Test Bias V floating point voltage, 5mV resolution
8 characters	Cable Cal Filename

Table D-5. C-V Measurement Parameter File Format

File Contents	Description
1   2   3   4	Range 2pF, 20pF, 20pF 200pF only (1-4)
0   1	Frequency 0 = 100kHz, 1 = 1MHz
0   1	Model 0 = parallel, 1 = serial
1   2   3   4	Rate 1 = 75, 2 = 18, 3 = 10, 4 = 1
0   1	Filter 0 = off, 1 = on
0   1	Sweep Source 0 = 590; 1 = 230-1
1   3	Waveform 1 = stair, 3 = pulsed stair
.001 - 65	Start Delay time in seconds, 1msec resolution
.001 - 65	Step Delay time in seconds, 1msec resolution
.001 - 65	Stop Delay time in seconds, 1msec resolution
-200 - +200	First Bias V floating point voltage, 5mV resolution
-200 - +200	Bias Step V floating point voltage, 5mV resolution
-200 - +200	Last Bias V floating point voltage, 5mV resolution
-200 - +200	Default Bias floating point voltage, 5mV resolution
0 - 1000	Light On Time 0 = light off, time in seconds
8 characters	Cable Cal Filename

Table D-6. Hot Chuck Control File Commands

Command	Description
GETTEMP "<DDC>"	Define get temperature command
SENDWINDOW "<DDC>"	Define at temperature command
SENDSETPOINT "<DDC>"	Define temperature setting command
SENDSRQMASK "<DDC>"	Define SRQ mask command.
NUMCHUCKS #<n>	Define <n> number of chucks (<n> = integer)
CHUCKADDR @<Addr1>, @<Addr2>, ..., @<Addrn>	Define chuck addresses (1-10)
SPATTEMP B<0-7>	Define serial poll AT TEMP bit
SPNOTBUSY B<0-7>	Define serial poll NOT BUSY bit
TERMINATOR "<DDC>"	Command terminator

NOTES:

1. Number of addresses defined in CHUCKADDR must be the same as the number of chucks defined with NUMCHUCKS.
2. A line beginning with ! is considered to be a comment line.
3. To omit terminator, use null quotes ("").

**Stress Cycle Parameter File**

Filename: Eight characters  
 Extension: .SCP  
 Example: CHUCK1.SCP  
 File Type: ASCII  
 Default Path: C:\KTHLY\_CV\MODEL58\PAR

The stress cycle parameter file contains defined voltage and temperature parameters for the BTS stress cycle. The basic format is shown in Table D-7.

Table D-7. Stress cycle Parameter File Format

File Contents	Description
0 to +200	+ Stress V, in volts
0 to -200	- Stress V, in volts
-200 to +200	Stress Off V, in volts
0.0 to 300.0	Stress Temp, in degrees C
0.0 to 300.0	Stress Off Temp, in degrees C
0.1 to 9.9	Temp Tolerance, in degrees C
1 - 10000	Stress Time, in seconds

**Switch Control File**

Filename: Eight characters  
 Extension: .SWC  
 Example: CONTRL705.SWC  
 File Type: ASCII  
 Default Path: C:\KTHLY\_CV\MODEL58\CTRL

The switch control file is a user-defined file containing the necessary commands to control a switch to be used by the given test sequence (Zerbst or BTS). See Section 6 for information on setting up a switch control file.

The switch control file commands are summarized in Table D-8.

Table D-8. Switch Control File Commands

File Contents
<pre>! A line beginning with a ! character is comment. INIT @&lt;Device address(0-31)&gt;, "&lt;Device command (DDC)&gt;" PARALLEL @&lt;Device address(0-31)&gt;, "&lt;Pre-test DDC&gt;", "&lt;Post-test DDC&gt;" DEVICE 1 @&lt;add(0-31)&gt;,"&lt;Pre-test DDC&gt;", "&lt;Post-test DDC&gt;"[#Cable_Cal_Filename] DEVICE 2 @&lt;add(0-31)&gt;,"&lt;Pre-test DDC&gt;", "&lt;Post-test DDC&gt;"[#Cable_Cal_Filename] .. .. .. DEVICE 99 @&lt;add(0-31)&gt;,"&lt;Pre-test DDC&gt;", "&lt;Post-test DDC&gt;"[#Cable_Cal_Filename] FINAL @&lt;Device address(0-31)&gt;,"&lt;Device command (DDC)&gt;"</pre>

Multiple commands can be used to define multiple devices, or in cases where the command line length exceeds the maximum allowed 80 characters.

Table D-9. Temporary Files

Temporary File Names	Description
CVPAR.TMP	Interfaces between KSETUP and KIRUN
CTPAR.TMP	Interfaces between KSETUP and KIRUN
CYCLEPAR.TMP	Interfaces between KSETUP and KIRUN
BTSPAR.TMP	Interfaces between KSETUP and KIRUN
ZERPAR.TMP	Interfaces between KSETUP and KIRUN
CVDAT.TMP	Interfaces between KIRUN and KICVA
CTDAT.TMP	Interfaces between KIRUN and KICTA
BTSDAT.TMP	Interfaces between KIBTSA and KIBTSG
MENUPTR.TMP	Interfaces between KSETUP and KIRUN

Temporary Files

Filename: Eight characters  
 Extension: .TMP  
 Example: CVPAR.TMP  
 Default Path: C:\KTHLY\_CV\MODEL58\TMP

Temporary files are used to retain memory between executable programs. They are used between setup and run programs and between run and analysis programs, as well as between analysis and graphics programs. Table D-9 summarizes temporary files.

NOTE

Do not attempt to modify or delete temporary files.

Zerbst Test Sequence File

Filename: Eight characters  
 Extension: .ZTS  
 Example: TEST6.ZTS  
 File Type: ASCII  
 Default Path: C:\KTHLY\_CV\MODEL58\SEQ

This file stores parameters associated with the Zerbst test sequence, and its format is defined in Table D-10.

Table D-10. Zerbst Test Sequence File Format

File Contents	Description
1   2   3	1 = multiple C-V test sequence 2 = one C-V test sequence 3 = no C-V test sequence
1   2   3	1 = manual C <sub>MIN</sub> checking 2 = auto C <sub>MIN</sub> checking 3 = no C <sub>MIN</sub> checking
64 characters	Comment field
1-99	Number of devices
8 characters	C-V Parameter Filename
8 characters	C-t Parameter Filename
8 characters	Switch Control Filename
5 characters	Data Destination Filename





# APPENDIX E

## Cable Calibration Utility

---

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### DESCRIPTION

The CABLECAL.EXE utility performs cable calibration for the Model 5958. (This utility can also be used to perform cable calibration for the Model 82 Simultaneous C-V System, as discussed in the Model 82 Instruction Manual.) Refer to paragraph 2.5 of this instruction manual for details on required calibration source capacitors.

### STARTING CABLECAL.EXE

To start the cable calibration program, simply type in the following while in the C:\KTHLY\_CV\MODEL58 directory:

```
CABLECAL
```

The main menu and startup banner shown in Figure E-1 will appear on the screen.

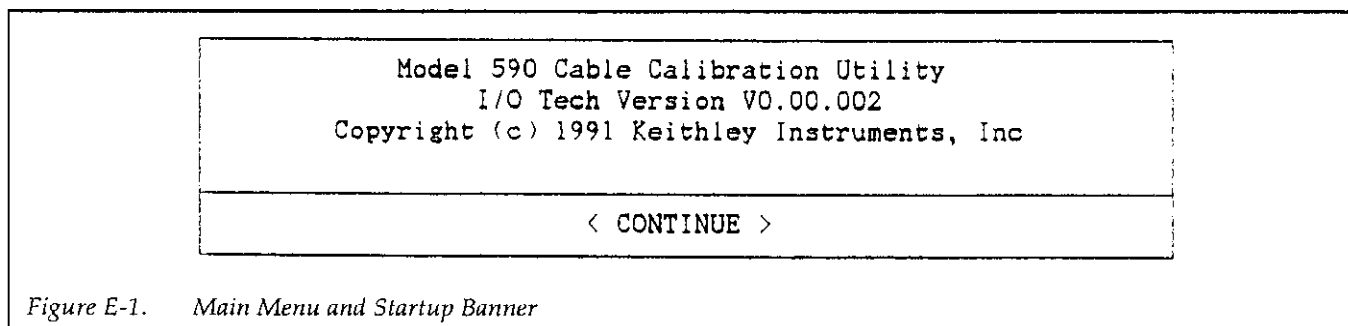


Figure E-1. Main Menu and Startup Banner

## MAIN MENU SELECTIONS

A menu of selections will appear at the top of the screen. To select a main menu item, hold down the <Alt> key, and press the first letter of that selection, or use the left/right arrow keys to highlight the selection, then press <Enter>.

Use the <Tab> key to move the cursor around the screen. To enter numeric values, simply type in the desired value. Selecting OK will accept changes, and selecting Cancel will of course cancel those changes. You can also use the <Esc> key to close windows.

If your system has a compatible mouse, you can use the mouse to select various menu items. Simply move the cursor into position with the mouse, then click the appropriate mouse button.

### File

#### Save

This selection saves the cable calibration constants to the existing filename. If a Model 82 calibration was performed, the file will be saved in a format compatible with the Model 82 software. If a Model 590 range calibration was performed, the file will be saved in a Model 5958 format (see later topic in this appendix for format description). Note that you cannot perform a Model 590 range calibration and then save it using the PKG82CAL.CAL filename as that name is reserved for Model 82 cable calibration.

#### Save As

This selection saves the cable calibration constants as above except that it saves to a user-defined filename.

#### Load

Selecting the Load option displays the Load window shown in Figure E-2. You can scroll through displayed

filenames by using the scroll bar, up/down arrow keys, or by clicking on the box area. You can also type in the complete filename including a new path, if desired (the path will become the default for subsequent load/save operations). You can also specify the \* character for the filename, and the default directory will be changed.

### NOTE

All cable correction constants files must have a .CAL extension.

#### DOS Shell

This selection suspends program operation (without losing data), allowing you to execute DOS commands or to run other programs (memory permitting). Type EXIT <Enter> to return to CABLECAL.EXE from the DOS shell.

#### Exit

Exits to the DOS prompt. Note that you will be warned if data has not been saved.

#### Execute

##### Set IEEE Address

Selecting this item displays the window shown in Figure E-3 and allows you to set the IEEE-488 primary addresses for the Models 230-1, 590, and 595 (the Models 230-1 and 595 are not used by the Model 5958). Each instrument must have a unique address, which must be in the range of 0-30. Selecting OK accepts the changes, and Cancel exits the window without changing previous addresses.

#### Send DDC

The Send DDC selection allows you to send a DDC (device dependent command) to a device with the specified primary address (Figure E-4). To use this feature, first select the primary address, enter your DDC, then select OK. Selecting Cancel closes the window.

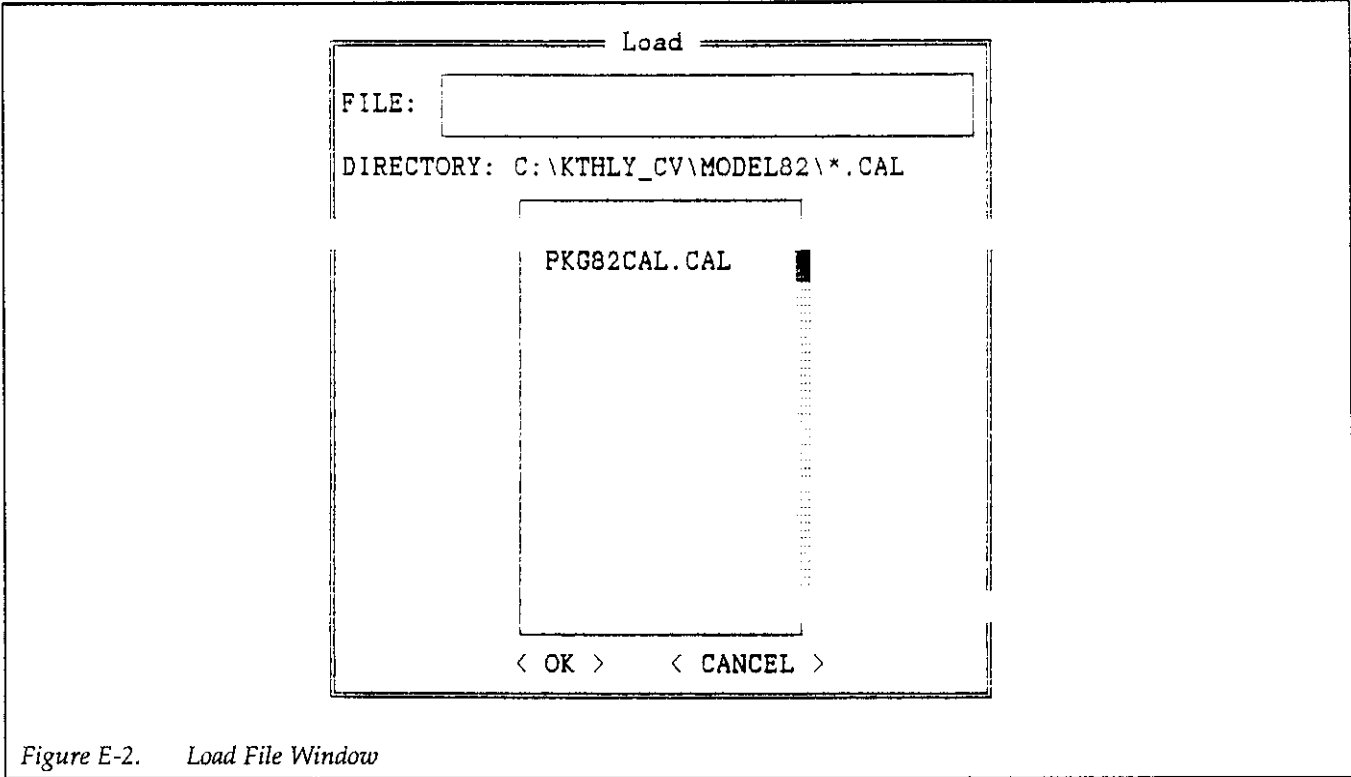


Figure E-2. Load File Window

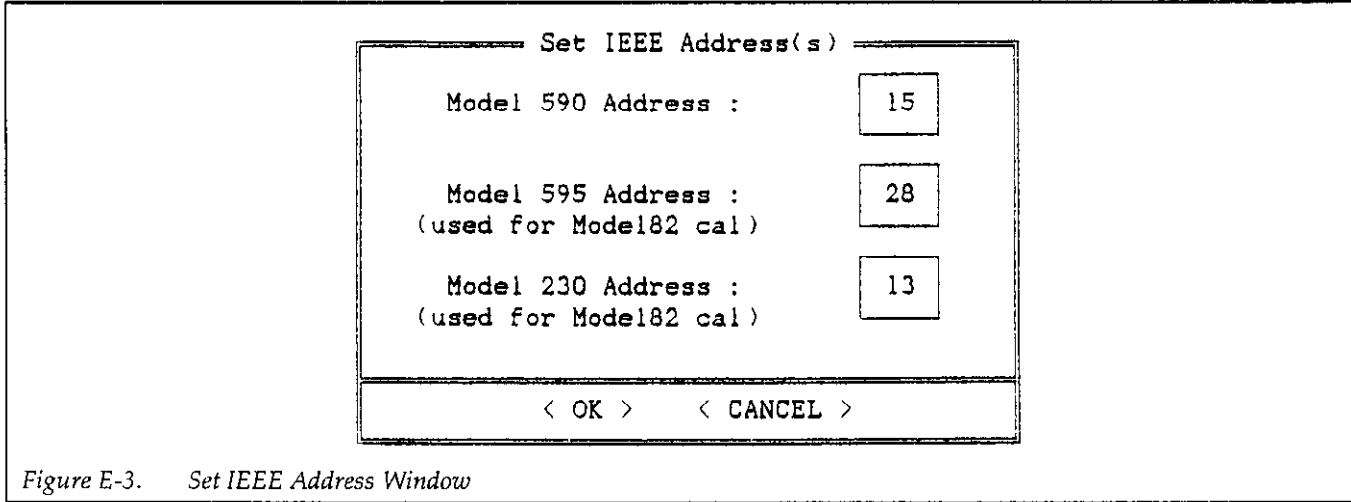


Figure E-3. Set IEEE Address Window

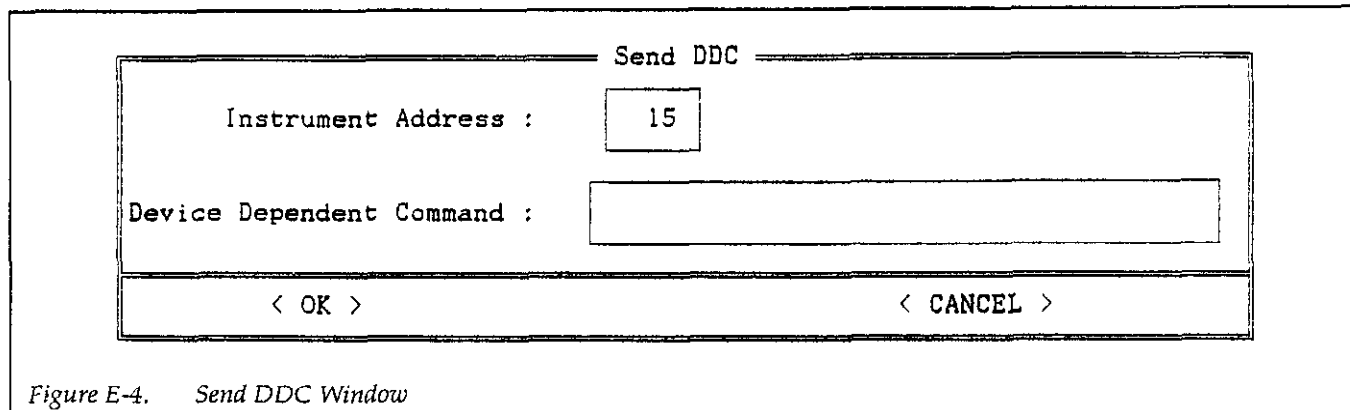


Figure E-4. Send DDC Window

#### Cable Cal 590: 2pF (20pF, 200pF, 2nF) Range

These four selections allow you to individually calibrate the 2pF, 20pF, 200pF, and 2nF ranges of the Model 590. In order to calibrate the Model 590, you will need the appropriate calibration capacitor set (see paragraph 2.6).

At the start of the calibration process, a window similar to the one shown in Figure E-5 will be displayed. Enter the two capacitor values for each range where indicated. Note that 1kHz values are not required for Model 590 and the corresponding fields are disabled. Also, no 2pF, 1MHz range calibration is required because the Model 590 has no such range.

After entering your values, select OK to complete the entry process. Error checking will be performed to make sure the entered values are within the required limits, and that Capacitor #1 values are less than Capacitor #2 values.

If all values are within required limits, the window shown in Figure E-6 will be displayed. If you wish to perform cable calibration, select the CALIBRATE option, then follow the prompts on the screen. If, on the other hand you wish to simply send existing calibration constants in memory to the Model 590, select SEND CONSTANTS. If no constants are in memory, an error message will be displayed.

#### Cable Cal Model 82

This selection performs cable calibration of the Model 82 system and does not apply to the Model 5958.

#### Help

The Help menu selections provides online instructions for using the cable calibration program. Use Page Up and Page Down to scroll through help information.

2 pF Range

CAPACITOR #1

Nominal	1 kHz	100 kHz	1 MHz
<input type="text"/> pF	<not needed>	<input type="text"/> pF	<not needed>

CAPACITOR #2

Nominal	1 kHz	100 kHz	1 MHz
<input type="text"/> pF	<not needed>	<input type="text"/> pF	<not needed>

< OK >                      < CANCEL >

Figure E-5. Model 590 Calibration Source Value Entry Window

How do you wish to proceed ?

< CALIBRATE >      < SEND CONSTANTS >      < CANCEL >

Figure E-6. Calibration/Send Constants Window



## MODEL 590 CABLE CALIBRATION PROCEDURE

1. While in the \MODEL58 directory, type in the following to run the cable calibration utility:

CABLECAL <Enter>

2. To Load the existing calibration constants file, press <Alt>-F, then select Load on the menu. Select an existing file, or type in the name of the file.
3. Press <Alt>-E, then select Cable Cal 590 and the desired range.
4. If you are cable correcting your system for the first time, enter the nominal, 100kHz, and 1MHz values where indicated (use the Tab key to move around selections). Capacitor #1 is the smaller of two values, and Capacitor #2 is the large capacitor value for a given range. Select OK after entering source values to begin the calibration process.
5. Choose the CALIBRATE selection to perform complete cable calibration.
6. Follow the prompts on the screen to complete the calibration process. During calibration, you will be prompted to connect calibration capacitors, or to leave the terminals open in some cases. If any errors occur, you will be notified by suitable messages on the screen.
7. Repeat steps 3 through 6 for each range to be cable calibrated.
8. After calibration is complete, you must save the new calibration constants. To do so, Press <Alt>-F, then select Save or Save As as required. If you use Save As, be sure to use a filename with a .CAL extension.

## SENDING EXISTING CONSTANTS TO THE MODEL 590

1. From the \MODEL58 directory, type in the following:

CABLECAL <Enter>

2. Press <Alt>-F, then select Load.
3. Load the file that contains the constants to be sent.
4. Press <Alt>-E, then select Cable Cal 590 .
5. If all source values are acceptable, select OK.
6. Select SEND CONSTANTS to send the constants in memory to the Model 590.

## CABLE CALIBRATION FILE FORMAT

Figure E-7 shows the calibration file generated by any of the Cable cal 590 menu selections and Table E-1 summarizes each field. (The format for the Cable Cal Model 82 selection is different and is not presented here.) This format is compatible with the Model 5958 CV Utilities software and is presented here for those who wish to customize their own calibration files. Note that "UNCAL" appears in a field for a range that has not been calibrated.

Table E-1. Calibration File Format Description

Line	Field Contents
1	"2 pF Range"
2	"-----"
3	(cap #1 nominal value)
4	(cap #1 100kHz value)
5	(cap #2 nominal value)
6	(cap #2 100kHz value)
7	(2pF/100kHz calibration DDC)
8	"20pF Range"
9	"-----"
10	(cap #1 nominal value)
11	(cap #1 100kHz value)
12	(cap #1 1MHz value)
13	(cap #2 nominal value)
14	(cap #2 100kHz value)
15	(cap #2 1MHz value)
16	(20pF/100kHz DDC)
17	(20pF/1MHz DDC)
18	"200pF Range"
19	"-----"
20	(cap #1 nominal value)
22	(cap #1 100kHz value)
23	(cap #1 1MHz value)
24	(cap #2 nominal value)
25	(cap #2 100kHz value)
26	(cap #2 1MHz value)
27	(200pF/100kHz DDC)
28	(200pF/1MHz DDC)
29	"2nF Range"
30	"-----"
31	(cap #1 nominal value)
32	(cap #1 100kHz value)
33	(cap #1 1MHz value)
34	(cap #2 nominal value)
35	(cap #2 100kHz value)
36	(cap #2 1MHz value)
37	(2nF/100kHz DDC)
38	(2nF/1MHz DDC)

\*Note: "UNCAL" appears in calibration DDC position for uncalibrated ranges.



```

"2 pf Range"
"-----"
"0.0E-12"
"0.0E-12"
"0.0E-12"
"0.0E-12"
"UNCAL"
"20 pf Range"
"-----"
"0.0E-12"
"0.0E-12"
"0.0E-12"
"0.0E-12"
"0.0E-12"
"0.0E-12"
"UNCAL"
"UNCAL"
"200 pf Range"
"-----"
"47E-12"
"46.381E-12"
"46.385E-12"
"180E-12"
"182.71E-12"
"182.77E-12"
"CCP 0 4.1974E-04 9.9903E-01 5.5781E+00 -1.3368E+00"
"CCP 0 2.2992E-03 9.9398E-01 4.3320E+00 -3.3043E-01"
"2 nf Range"
"-----"
"470E-12"
"465.24E-12"
"465.66E-12"
"1800E-12"
"1802.9E-12"
"1808.8E-12"
"CCP 0 1.1666E-04 9.9944E-01 3.3691E-01 1.3413E-01"
"CCP 0 4.7381E-03 9.9430E-01 4.5266E+00 2.1559E-01"

```

Figure E-7. Calibration File Format (Compatible with Model 5958)





# APPENDIX F

## Graphic 4.0 Functions Used by Model 5958

---

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## **bgnplot(monitor, screentype, "filename")**

---

<b>int monitor</b>	1 if picture is to be plotted on the screen and stored in Tektronix format. 0 if the picture is to be stored and not plotted.
<b>int screentype</b>	't' if only text is to be displayed on the screen. 'g' or 'G' if only graphics is to be displayed on the screen. 'G' selects the EGA 800x600 mode. 'b' if both text and graphics are to be displayed. Only Corona PCs support this mode. The single quotes around the characters are required.
<b>char "filename"</b>	The name given to the output Tektronix-type file. It must be enclosed in double quotes, and be sure to specify the correct drive. If you want to suppress the TKF file, use the name "notek".

**bgnplot()** is the first call that you should make to GraphiC. It opens an output file to receive the Tektronix formatted data, initializes the defaults for many parameters, and puts the computer into graphic mode if called for. **bgnplot()** should only be called one time, at the beginning of the plotting session.

## **putsg**

---

<b>STRING</b>	string of text to be displayed
<b>INTEGER</b>	X position for the display
<b>INTEGER</b>	Y position for the display

This routine is used to display a string of text on the current graph using the matrix font. The X and Y position arguments are in lines and columns rather than pixels.

## **fontsetup**

---

This routine is used to initialize the special matrix font. This font is used for drawing the menus and other labels on the completed graph. It is also used when drawing the cursor display.

## roundq

---

<b>INTEGER</b>	number of divisions for the axis
<b>FLOAT</b>	minimum value
<b>FLOAT</b>	value to increment by
<b>FLOAT</b>	maximum value
<b>STRING</b>	format returned by this function

This function accepts a specification of the max and min values for the axis, along with the value to increment by and the number of divisions to use, and returns a format string that can be passed to the grid routine to draw the axis.

## hardcopy(type)

---

<b>char type</b>	The type of hardcopy desired. type = 'l', 'm', 'L', 'M' for printer dump type = 0 to return GraphiC to normal interactive mode type = 'n' to continue through the remaining pictures without hard copies and without user intervention
------------------	---

**hardcopy()** allows GraphiC to make unattended hard copies of each GraphiC plot. To keep your plots from crossing the page boundary, remember that one 'L' (or 'l') plot or two 'M' (or 'm') plots use an entire page. **hardcopy()** should be called before the **endplot()** associated with the desired picture. This routine will not work with plotters.

## font(nfont, "font1", 'esc1', "font2", 'esc2', "font3", 'esc3', "font4", 'esc4')

---

<b>int nfont</b>	The number of fonts selected, where 1 ≤ nfont ≤ 4
<b>char *font#</b>	The name of the font(s) to be selected must be in double quotes. The presently available fonts are: <b>simplex.fnt</b> , <b>simgrma.fnt</b> , <b>complex.fnt</b> , <b>compital.fnt</b> , <b>compgrma.fnt</b> , <b>engoth.fnt</b> , <b>triplex.fnt</b> , <b>tripital.fnt</b> , <b>duplex.fnt</b> , <b>russian.fnt</b> , <b>simscr.fnt</b> , <b>comscr.fnt</b> , <b>microg.fnt</b> , <b>microb.fnt</b> . The filled font is called <b>block1.fnt</b> . Be sure to specify the disk drive and path of each font.

## page(width, height)

---

<b>float width</b>	The width of the picture in inches (or cm) as measured on the high resolution printer dump.
<b>float height</b>	The height of the picture in inches (or cm) as measured on the high resolution printer dump.

`page()` sets the size of the picture on the output page. Here, "width" and "height" refer to the shape of the picture viewed upright. The maximum picture size is 9.00" x 6.855" (unrotated) or 6.855" x 9.00" (rotated) corresponding to the size of the output page itself. If a smaller size is called for, it will be centered within this area unless `pgshift()` is used to offset it.

## pgshift(xshift, yshift)

---

<b>float xshift</b>	The x-distance in inches (or cm) on an output page of the lower left corner of the picture from the corresponding corner of the output page, viewed with the picture upright.
<b>float yshift</b>	The y-distance in inches (or cm) on an output page of the lower left corner of the picture from the corresponding corner of the output page, viewed with the picture upright.

If `pgshift()` is not called, GraphiC will center the picture on the output page. `pgshift()` is used, for example, to put several pictures on a single output page. It must be called after `page()` and before `area2d()`. If `rotate(1)` has been called, the shifts are with respect to the upper left corner of the monitor screen. If not, they are with respect to the lower left corner. See D2TEST.C for an example of how to do multiple plots page.

## physor(xphysor, yphysor)

---

<b>float xphysor</b>	x distance of physical origin from lower left corner of drawing page in inches (or cm).
<b>float yphysor</b>	y distance of physical origin from lower left corner of drawing page in inches (or cm).

`physor()` allows you to move the plot on the drawing page.

### **area2d(xinch, yinch)**

---

<b>float xinch</b>	The length of the x-axis in inches (or cm), viewed with the picture upright, as measured on the high resolution printer dump.
<b>float yinch</b>	The length of the y-axis in inches (or cm), viewed with the picture upright, as measured on the high resolution printer dump.

**area2d()** defines the lengths of the x and y axes. The size and positioning of the plot are determined by this call.

### **tmargin(marginch)**

---

<b>float marginch</b>	Size of top margin of text plot in inches (or cm) from the edge of the high-resolution printer plot.
-----------------------	--

**tmargin()** *must be called every time you start a new page of text plot.* It determines the top position of any text on the page. It must be called *before* **ctline()** or **ltline()**. The first line of text will be placed below this by a distance `height*ratio`. To get text as near to the top of the page as possible, you might want to call **linesp(1.1)** before your first line of text.

### **lmargin(marginch)**

---

<b>float marginch</b>	Size of left-hand margin of text plot in inches (or cm) from the edge of a full page printer plot.
-----------------------	--

Although there is a small margin around the plots produced by GraphiC, you may wish to increase it. This routine only works with **ctline()** and **ltline()**.

### **numht(inch)**

---

<b>float inch</b>	The height of the characters used to label the plot. The height is given in inches (or cm) on a full page output.
-------------------	---

### **axnamht(inch)**

---

<b>float inch</b>	The height of the characters used to label the axes. The height is given in inches (or cm) on a full page output.
-------------------	---

### **rtline("string", height)**

---

<b>char *string</b>	The line of text you wish plotted. You must determine whether it fits within your page size. The string must be enclosed in double quotes, and the first letter should be a font selection character.
<b>float height</b>	The height of your characters in inches (or cm) on the full page printer plot.

**rtline()** puts a line of text on the page flush against the right margin. The first line is at the location determined by **tmargin()**, and each succeeding line is placed below the previous one by a distance  $\text{height} \times \text{ratio}$ , where **ratio** is the argument of **linesp()**. The default ratio is 1.6.

### **ltline("string", height)**

---

<b>char *string</b>	The line of text you wish plotted. You must determine whether it fits within your page size. The string must be enclosed in double quotes, and the first letter should be a font selection character.
<b>float height</b>	The height of your characters in inches (or cm) on the full page printer plot.

**ltline()** puts a line of text on the page flush against the left margin. The first line is at the location determined by **tmargin()**, and each succeeding line is placed below the previous one by a distance  $\text{height} \times \text{ratio}$ , where **ratio** is the argument of **linesp()**. The default ratio is 1.6. Indentation may be obtained by inserting tabs (`\t`) into the text, or by a call to **lmargin()**.

### **ctline("string", height)**

---

<b>char *string</b>	The line of text you wish plotted. You must determine whether it fits within your page size. The string must be enclosed in double quotes. The first character in the string should be a font selection character.
<b>float height</b>	The height of your characters in inches (or cm) on the full page printer plot.

**ctline()** centers a line of text on the page between the left margin and the right margin. The first line is at the location determined by **tmargin()**, and each succeeding line is placed below the previous one by a distance **height\*ratio**, where **ratio** is the argument of **linesp()**. The default ratio is 1.6.

### **prtfnt(x, y, "string", height, angle)**

---

<b>float x</b>	x location of lower left corner of the string from the left hand edge of the drawing page -- measured in inches (or cm) on the full page printer plot.
<b>float y</b>	y location of lower left corner of the string from the bottom of the drawing page -- measured in inches (or cm) on the full page printer output.
<b>char *string</b>	String to be plotted.
<b>float height</b>	Height of the characters in inches (or cm) on the full page output.
<b>Int angle</b>	Angle at which the string is to be plotted. The angle is defined to increase in the counterclockwise direction, and is measured in degrees from the positive x axis. Any integer degree from -180 to +180 is allowed.

**prtfnt()** can be used for making text slides and view-graphs since it doesn't require any plotting commands other than those in levels 0 and 1. Ordinarily, the paper is oriented with the long direction horizontal. The orientation may be changed by calling **rotate()**. Using **lmargin()**, **tmargin()**, **linesp()**, **ctline()**, and **ltline()** makes the production of text slides easy. You must still call **page()**. All the size and location parameters are absolute unless **setscale(1)** is called.

## grid(isgrid)

---

**Int isgrid**               = 0 if no grid is desired.  
                              = 1 if dotted grid is desired.  
                              = 2 if fine dot grid lines are desired.  
                              = 3 if solid grid lines are desired.

**grid()** draws dotted lines through the tick marks. It must be called before the axis-creating routines.

## fgrid(isgrid, nxdiv, nydiv)

---

**Int isgrid**               = 0 if no grid subdivisions are desired.  
                              = 1 if dotted grid lines on subdivision marks are desired.  
                              = 2 if only tick marks at subdivisions are desired.

**Int nxdiv**                The number of desired subdivisions between main grid lines on the x axis.

**Int nydiv**                The number of desired subdivisions between main grid lines on the y axis.

**fgrid()** allows you to draw one or more grid lines between adjacent axis tick marks. This feature prevents overlapping of axis labels. To use **fgrid()**, you must

also call **grid()**. With logarithmic axes, the requested number of divisions is ignored, and 10 grid lines per decade are plotted. **fgrid()** also allows you to put small tick marks at subdivision spaces without drawing grid lines.

## upright(uplab)

---

**Int uplab**                = 1 to turn on upright y-axis labels.  
                              = 0 to turn off upright y-axis labels.

When **upright()** is called with a 1, it sets a flag that causes the y axis labels to be upright. This mode will stay in effect until **upright()** is called with a 0.



### scales(nxdiv, nydiv, x, y, npts)

---

<b>int nxdiv</b>	The number of x axis divisions.
<b>int nydiv</b>	The number of y axis divisions.
<b>float *x</b>	The vector of x data. Be sure to dimension it in your calling routine.
<b>float *y</b>	The vector of y data.
<b>int npts</b>	The number of data points in the x and y vectors.

**scales()** is the self-scaling routine for linear plots. It calculates the maximum and minimum values of x and y, and chooses the appropriate set of round numbers to use as axis labels and then calls **graf()**. The data must be calculated before **scales()** is called.

### graf("xformat", xori, xste, xmax, "yformat", yori, yste, ymax)

---

<b>char *xformat</b>	The x-axis format. Use a floating point conversion specification (see p146 in K&R). Since it is a character string, it must be enclosed in double quotes. For example: "%-3.2f". Use "%-1.0f" for integer labels. Because C automatically expands the format to accommodate the required number of characters, it is best to use a width (number to the left of the decimal point) that is too small. This ensures that the labels will be centered. %e and %g formats may also be used.
<b>float xori</b>	The value of x at the left-hand end of the x axis.
<b>float xste</b>	The change in x between each two tick marks on the x axis.
<b>float xmax</b>	The value of x at the right-hand end of the x axis.
<b>char *yformat</b>	The y axis format (see above).
<b>float yori</b>	The value of y at the bottom of the y axis.
<b>float yste</b>	The change in y between each two tick marks on the y axis.
<b>float ymax</b>	The value of y at the top of the y axis.

**graf()** is the primary axis setup routine for x-y plots. Because the maximum and minimum values of the variables are supplied by you, **graf()** may be called either before or after the data are calculated. Any values of x and y which lie beyond the page boundaries will be scissored.

## heading("title")

---

**char \*title**            The title for the plot. It must be less than 30 characters long. It is centered at the top of the picture. The first character may be a font selection character, otherwise, the currently active font is used.

`heading()` must be called if you want to caption a 2-D plot.

## xname("xlabel")

---

**char \*xlabel**            The name of the x axis. It must be less than 30 characters long. The double quotes are required. The first character may be a font selection character. Super- and subscripts may be used.

`xname()` must be called if you want the x axis of a 2-D plot to have a name.

## yname("ylabel")

---

**char \*ylabel**            The name of the y axis. It must be less than 30 characters long. The double quotes are required. The first character may be a font selection character. Super- and subscripts may be used.

`yname()` must be called if you want the y axis of a 2-D plot to have a name.

## Color

The color default for supported color boards is white lines on a blue background. Curve colors may be changed by calls to `color()` as described below.

## rightax(yright)

---

**int yright**                = 1 turns on right hand y-axis.  
                              = 0 turns off right hand y-axis.

`rightax()` is a parameter setting routine which will cause GraphiC to draw a right-hand y-axis. When this flag is set, the first time `scales()` is called the left-hand y-axis and the x-axis will be drawn. With a second call to `scales()` the program will rescale and draw the y-axis on the right side of the x-axis. This is done without recalculating or redrawing the x-axis.

## axesoff(noaxes)

---

**Int noaxes**                   = 0 (default) if labeled axes are desired.  
                                  = 1 if no axes or axis labels are desired.

**axesoff()** allows you to draw plots with no axes or axis labels. Either **scales()** or **graf()** must still be called so that GraphiC can calculate the limits for the plot. **axesoff()** cannot be used with contour plots. It must be called before any routines which draw the axes, i.e., **graf()** or **scales()**. **axesoff()** can also be used with 3-D routines. Note that **axesoff()** only turns off the axes. Grid lines (and fine grid lines) will still be drawn if the options are active.

## startplot(color)

---

**Int color**                    The IBM color number to be used for the background of the plot. See **color()** for a list of available colors.

**startplot()** initializes each plot by putting necessary information into the file containing the plot data. It also raises the program to Level 1

## setcolor

---

### INTEGER

This routine sets the current color that GraphiC will draw on the screen. It uses the IBM numbering system.

0 - Black	7 - White
1 - Blue	8 - Dark Grey
2 - Green	9 - Light Blue
3 - Cyan	10 - Light Green
4 - Red	11 - Light Cyan
5 - Magents	12 - Light Red
6 - Brown	

## endplot()

---

**endplot()** is called after each page of plots is completed. It stores all of the remaining data for the plot and returns GraphiC to Level 1. **endplot()** resets the page rotation to its upright position. After the last page is completed, **stopplot()** must also be called.

## stopplot()

---

**stopplot()** is called at the very end of the plotting session. It empties the buffers and closes the plot and error files. It returns the screen to text mode, and GraphiC to Level 0.

## curson()

---

A call to **curson()** turns on all of the cross hairs functions. Type an *Esc* to exit this mode. The axis drawing routines must be called before **curson()**.

When the program gets to the call to **curson()** the cross hairs will appear in the center of the plot area. To the left of the screen will be displayed a readout of the cross hairs position.

Movement of the cross hairs is controlled by the arrow keys or a supported mouse.

The readout will be in plot units by default. To change to inch units, type an *Alt-I*. An *Alt-U* will return the readout to plot units.

To draw lines, mark a point by typing *Enter*; move the cross hairs to the next point and type *Ins*. This line can be continued by moving the cross hairs to the next point and typing *Ins* again. Typing *Enter* will start a new line.

To erase a line, simply draw over it. You must start and end the erasure on the exact vector ends or it will not completely erase the line.

Every time *Enter* is typed, the x and y values of the cross hairs are entered in the global arrays `xgq[indq]` and `ygq[indq]` which are in user units and `cxq[cntq]` and `cyq[cntq]` which are in pixel units.

The cross hairs have three speeds which can be changed by typing *Alt-Y* successively.

When using a three-button Mouse, the left button is the same as *Enter*, the center button is the same as *Ins*, and the right button is the same as *Esc*. With a two-button mouse, the left button is the same as *Enter*, the right button is the same as *Ins*, and both buttons together are the same as *Esc*.

## solid()

---

After **solid()** is called, all lines will be returned to their original unbroken manner until some other line style is activated

## chndsh()

---

After `chndsh()` is called, all lines will be drawn as alternating dots and dashes until some other line style is called for.

## curve(x, y, npts, sym)

---

<b>float *x</b>	The x vector to be plotted.
<b>float *y</b>	The y vector to be plotted.
<b>int npts</b>	The dimension of x and y.
<b>int sym</b>	sym = 0 draw curve only. sym > 0 draw curve and symbols every sym points. sym < 0 draw symbols only every sym points.

Each time `curve()` is called, a curve is drawn on the plot. Eight different symbols, for use as curve markers, and six different line styles are available. The line and symbol styles can be changed automatically by using the legend feature or manually by calling the appropriate routine (see pages 40, 49, and 50). `curve()` is used for any of the linear or logarithmic plots.

Scatter plots may be drawn by calling `scatplot()` with a 1 before calling `curve()`. You can still draw symbols every `sym` points.

## scalexq

---

### INTEGER

This routine is used to scale a value from GraphiC pixels to actual screen pixels. GraphiC uses a pixel array of 4096 by 3120 and scales this to the actual screen resolution.

## scaleyq

---

### INTEGER

This routine is used to scale a value from GraphiC pixels to actual screen pixels. GraphiC uses a pixel array of 4096 by 3120 and scales this to the actual screen resolution.

## intopixq

---

### FLOAT

This routine converts from inches on the GraphiC page into pixels on the GraphiC bitmap (4096 by 3120).

## pixtoinq

---

### FLOAT

This routine converts from pixels on the GraphiC bitmap to inches on the GraphiC page (9 by 11 inches).

## lclr

---

<b>INTEGER</b>	line number to clear
<b>INTEGER</b>	starting column to clear
<b>INTEGER</b>	ending column to clear

This routine is used to clear a line in preparation for writing some text on the line with the matrix font.

## passstr

---

<b>STRING</b>	standard BASIC string
---------------	-----------------------

Converts a BASIC string to C format and copies it into a special buffer. Each of the functions listed above has its own internal buffer. The function returns a 32 bit pointer to its internal buffer which can then be passed to any of the GraphiC functions requiring a string as an argument (such as Font).

### passstr1

---

**STRING**                      standard BASIC string

Converts a BASIC string to C format and copies it into a special buffer. Each of the functions listed above has its own internal buffer. The function returns a 32 bit pointer to its internal buffer which can then be passed to any of the GraphiC functions requiring a string as an argument (such as Font).

### passstr2

---

**STRING**                      standard BASIC string

Converts a BASIC string to C format and copies it into a special buffer. Each of the functions listed above has its own internal buffer. The function returns a 32 bit pointer to its internal buffer which can then be passed to any of the GraphiC functions requiring a string as an argument (such as Font).

### passstr3

---

**STRING**                      standard BASIC string

Converts a BASIC string to C format and copies it into a special buffer. Each of the functions listed above has its own internal buffer. The function returns a 32 bit pointer to its internal buffer which can then be passed to any of the GraphiC functions requiring a string as an argument (such as Font).

### passarr

---

**Pointer**                      Hex number identifying offset within the 64 k segment.

**Segment**                      Hex number identifying which 64k segment the array resides.

Converts the pointer to an array from BASIC format, consisting of a 16-bit segment and a 16-bit offset; to C format, consisting of one 32-bit pointer.

## **getstr**

---

**STRING**                    standard BASIC string

Copies the contents of the internal buffer used by passstr (not passstr1, 2, or 3) into the BASIC string variable identified as the argument.

## **getxy**

---

**X pointer**                    32-bit pointer (C format) to array of X values

**Y pointer**                    32-bit pointer (C format) to array of y values

Returns the X and Y values of markers selected using the graphics cursor.



# APPENDIX G

## Software Modification

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### INTRODUCTION

The Model 5958 program needs no modifications to run. However, in some cases, you may desire to make changes to the software to customize it for your specific needs. For example, you may wish to change analysis formulas.

### COMPILING SOURCE CODE

Since the programs were compiled under Microsoft BASIC 7.1, it will be necessary for you to edit, recompile, and relink the program using BASIC 7.1 if any changes are required. Source code for the programs are broken up into numerous files, each of which has the .BAS extension. These files are stored in the C:\KTHLY\_CV\MODEL58\SRC directory.

The general procedure below should be followed to modify the software.

1. Use the supplied BASIC SETUP utility to install BASIC 7.1 on your hard disk.
2. With the C:\KBC7\BIN subdirectory selected, type in the following to enter the BASIC editor:

QBX <Enter>

3. LOAD the desired source module into the editor, then save it as a backup file.
4. Edit the source file as required. The FIND option under the Search menu will be helpful in locating specific code.
5. After you modified the module to your satisfaction, SAVE it under the same filename (note that doing so will overwrite the previous version of that particular module).
6. Repeat steps 3 through 5 for all modules you intend to modify.
7. After all modules have been modified, exit BASIC, and return to DOS.
8. From DOS, type in the following to compile and link a new executable program:

MAKE <program name> <Enter>

Here <program name> is the name of the module name you are making (see Table G-1). All the separate modules will be separately compiled, and then linked. The time required for this option will depend on the speed of your computer. Once the process has been completed, you can run the modified program in the usual manner.

Table G-1. Executables and Corresponding Files

Executable	Description	Make File to Use
CABLECAL.EXE	Cable calibration utility	MAKECAL.BAT
KIBTSA.EXE	BTS analysis program	MAKEKIBA.BAT
KIBTSG.EXE	BTS graph program	MAKEKIBG.BAT
KICTA.EXE	C-t analysis program	MAKEKITA.BAT
KICTG.EXE	C-t graph program	MAKEKITG.BAT
KICVA.EXE	C-V analysis program	MAKEKIVA.BAT
KICVG.EXE	C-V graph program	MAKEKIVG.BAT
KIRUN.EXE	Run program	MAKEKIRN.BAT
KISETUP.EXE	Setup program	MAKEKIST.BAT

# APPENDIX H

## Using the Model 5958 with Other Programs

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### INTRODUCTION

This appendix discusses using the Model 5958 with other programs and equipment and includes the following:

- Using the Model 5958 with a Model 82 Simultaneous C-V system.
- Using the Model 5958 with the Model 251 I-V Test Software.
- Calling Model 5958 programs from other programs.

### Using the Model 5958 with a Model 82 Simultaneous C-V System

The Model 5958 can be used with a Model 82 Simultaneous C-V system to add quasistatic C-V capabilities to your system since both systems use a Model 590 C-V Analyzer and can use the same computer. The following paragraphs discuss software and hardware considerations and also give a typical switching example.

#### NOTE

You must indicate that you will be using a Model 82 system during installation. See paragraph 2.3.

### Software Considerations

Model 82 and Model 5958 systems share a common directory (C:\KTHLY\_CV) and use the same IEEE-488 bus driver software. Cable correction for both systems is performed by the CABLECAL.EXE utility. Note, however, that Model 82 cable correction constants files and Model 590 cable correction constants files have different formats and are not interchangeable.

The Model 82 and 5958 software both use the same data file format for C-V data. Thus, you can take high-frequency C-V data using either the Model 82 or the Model 5958 and analyze that data using the other software. Of course, the Model 82 cannot analyze C-t or BTS data, and the Model 5958 cannot analyze quasistatic C-V data. You can, however, merge quasistatic C-V data with high-frequency C-V data using the file merge utility supplied with the Model 82.

### Hardware Considerations

Model 82 system connections can be used for Model 5958 operation with the exception of external trigger connections. Although the Model 595 Quasistatic C-V Meter is not used for Model 5958 measurements, it should still be turned on and connected to the system. Combined system connections are shown in Figures H-1 through H-3.

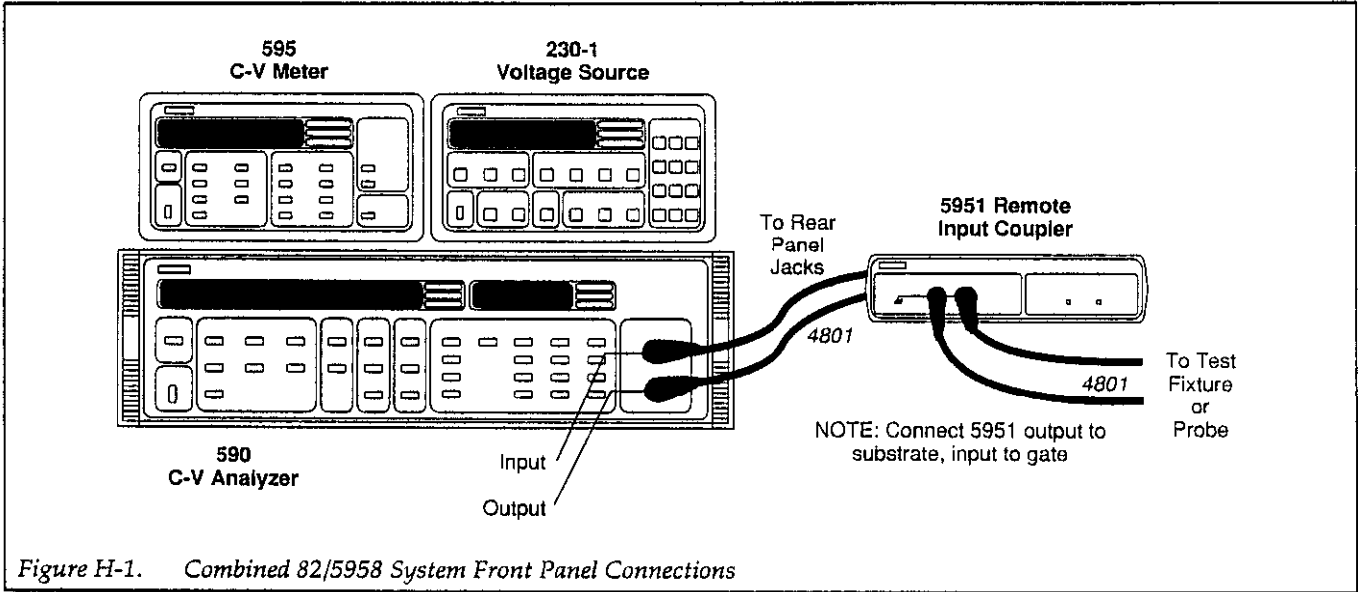


Figure H-1. Combined 82/5958 System Front Panel Connections

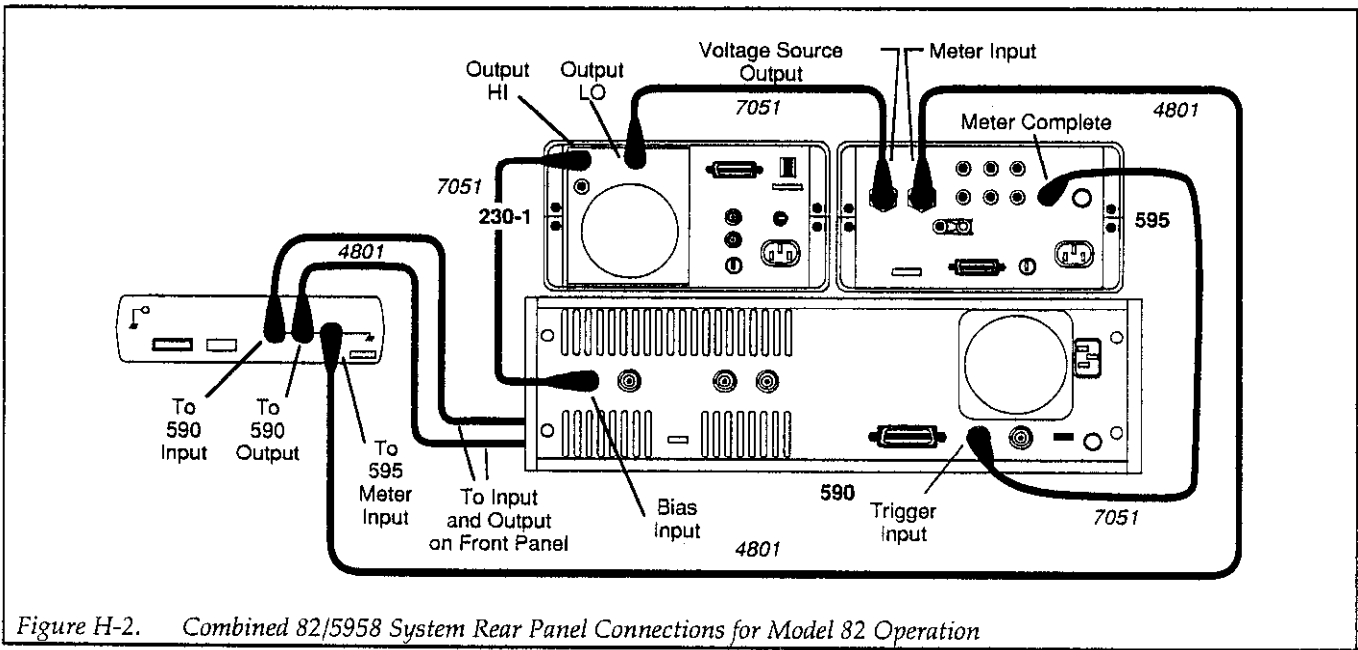


Figure H-2. Combined 82/5958 System Rear Panel Connections for Model 82 Operation

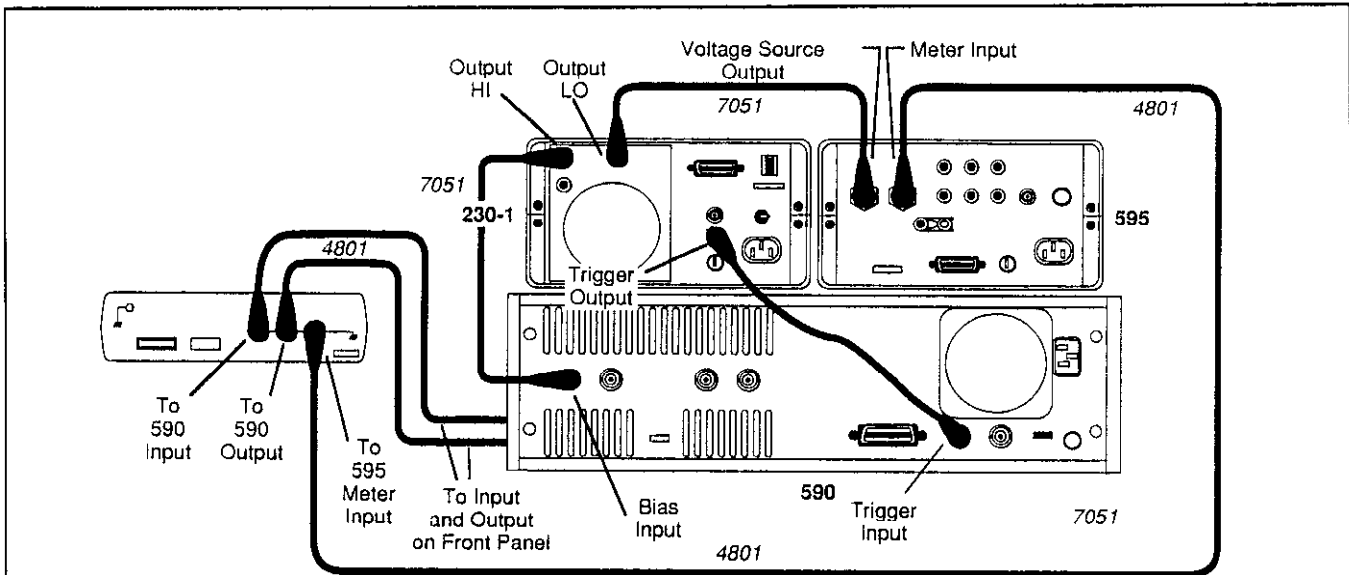


Figure H-3. Combined 82/5958 System Rear Panel Connections for Model 5958 Operation

External trigger connections for the two systems are as follows:

- Model 82 operation: Connect the Model 595 METER COMPLETE OUTPUT to the Model 590 EXTERNAL TRIGGER INPUT jack.
- Model 5958 operation: Connect the Model 230-1 Voltage Source EXTERNAL TRIGGER OUTPUT jack to the Model 590 EXTERNAL TRIGGER INPUT jack.

You can either make these connections manually, or add some form of switching method to route the trigger signals as required (see below).

### Primary Addresses

When using a combined Model 82/5958 system, the instrument primary addresses must be set as follows:

- Model 230-1 Voltage Source: 13
- Model 590 C-V Analyzer: 15
- Model 595 C-V Meter: 28

### Automatic Trigger Signal Switching

Figure H-4 shows a switching configuration that can be used to automatically switch the trigger signals for Model 82 and Model 5958 operation. This particular configuration uses a Model 7062 RF Switch Card installed in a Model 705 Scanner. The Model 7062 includes BNC connectors to simplify connections. General purpose scanner cards such as the Model 7056 could also be used, although cable cutting and dressing is necessary to make connections.

### Model 82/Model 5958 Selection Program

Program H-1 is a QuickBASIC program that provides for selection between the Model 82 and Model 5958 programs and includes control of the scanner for the configuration shown in Figure H-4. Keep the following points in mind when using this program:

- Compile the program using the run-time library option to leave enough free memory for the Model 82 and Model 5958 programs to run.
- Be sure to connect the Model 705 scanner to the IEEE-488 bus of the system; set the primary address of the Model 705 to 17.

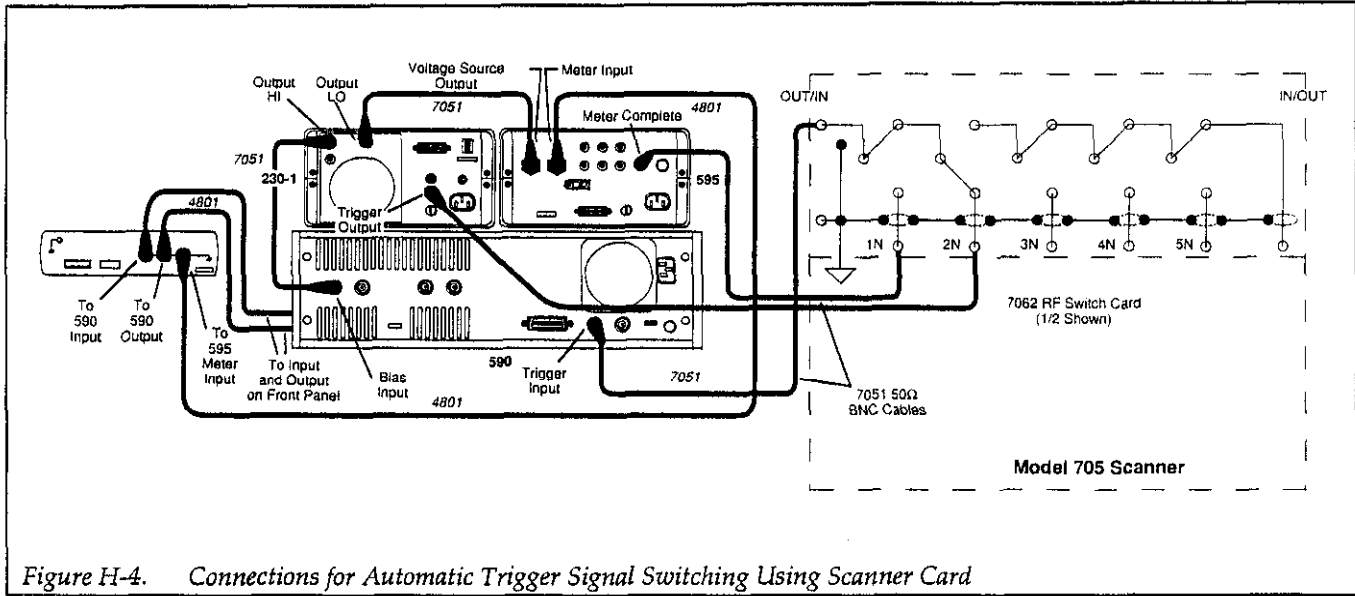


Figure H-4. Connections for Automatic Trigger Signal Switching Using Scanner Card

### Using the Model 5958 with the Model 251 I-V Test Software

The Model 5958 can be combined with Model 251 I-V Test Software to form a comprehensive C-V/I-V semiconductor test system. The following paragraphs discuss software and hardware considerations when combining these software packages.

#### Software Considerations

Both the Model 5958 and the Model 251 can use the same computer. However, unlike the Model 5958, the Model 251 requires expanded memory. Also, be sure not to load the IEEE-488 bus driver when running the Model 251 program, and you may have to reduce the number of

FILES and BUFFERS assigned in the CONFIG.SYS file to 10 each in order to free up enough memory.

#### Hardware Considerations

Switching is essential to putting together a comprehensive I-V/C-V test system. Figure H-5 shows a typical system configuration, and Figure H-6 shows connections. The system includes three SMUs (Source Measure Units) for I-V testing and a Model 590 C-V Analyzer for C-V testing. Note that Model 236, 237, or 238 Source Measure Units can be used depending on voltage and current requirements.

Appropriate switching functions can be controlled from both the Model 5958 and Model 251 Version 2 by setting up appropriate control files.

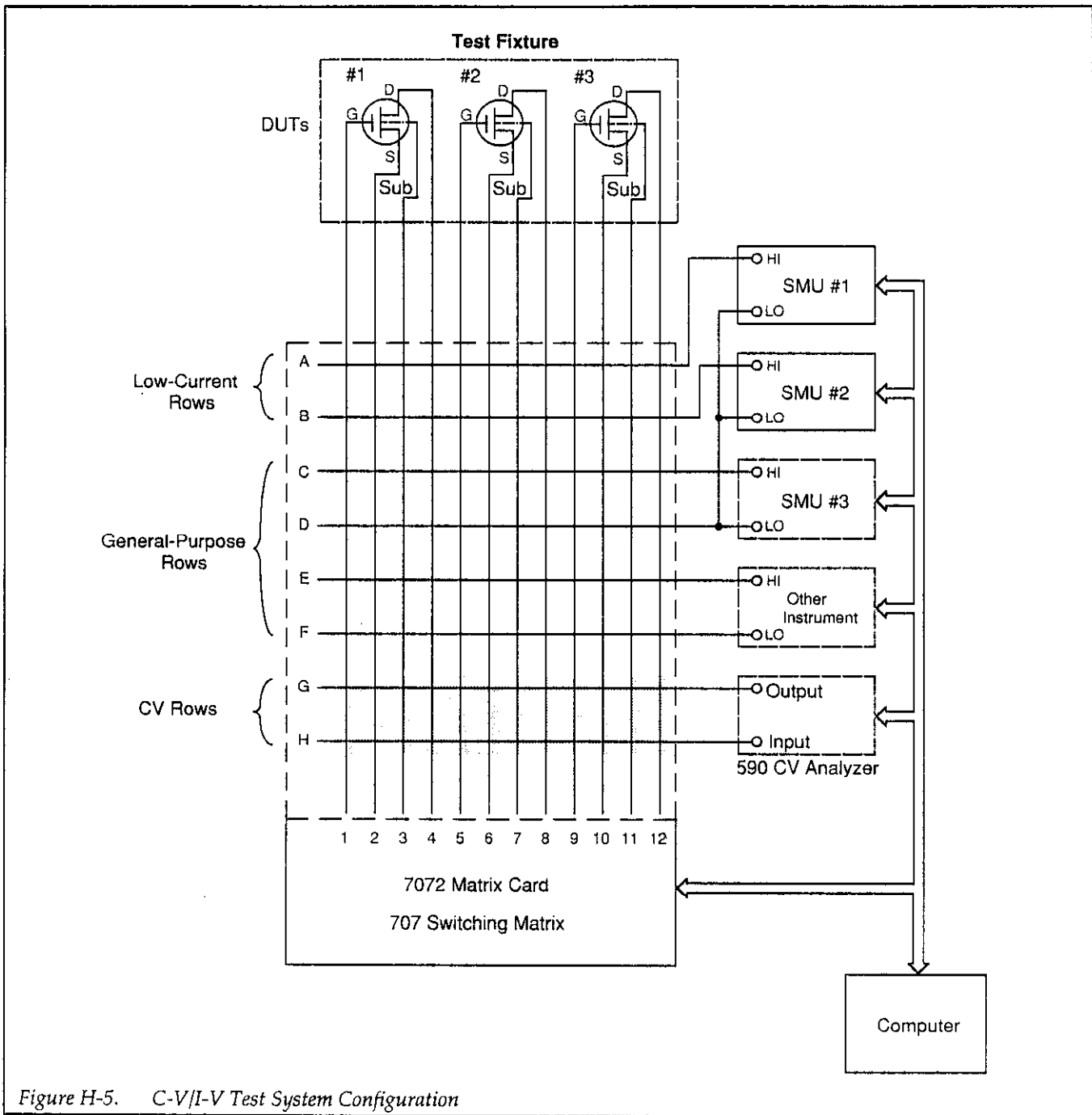
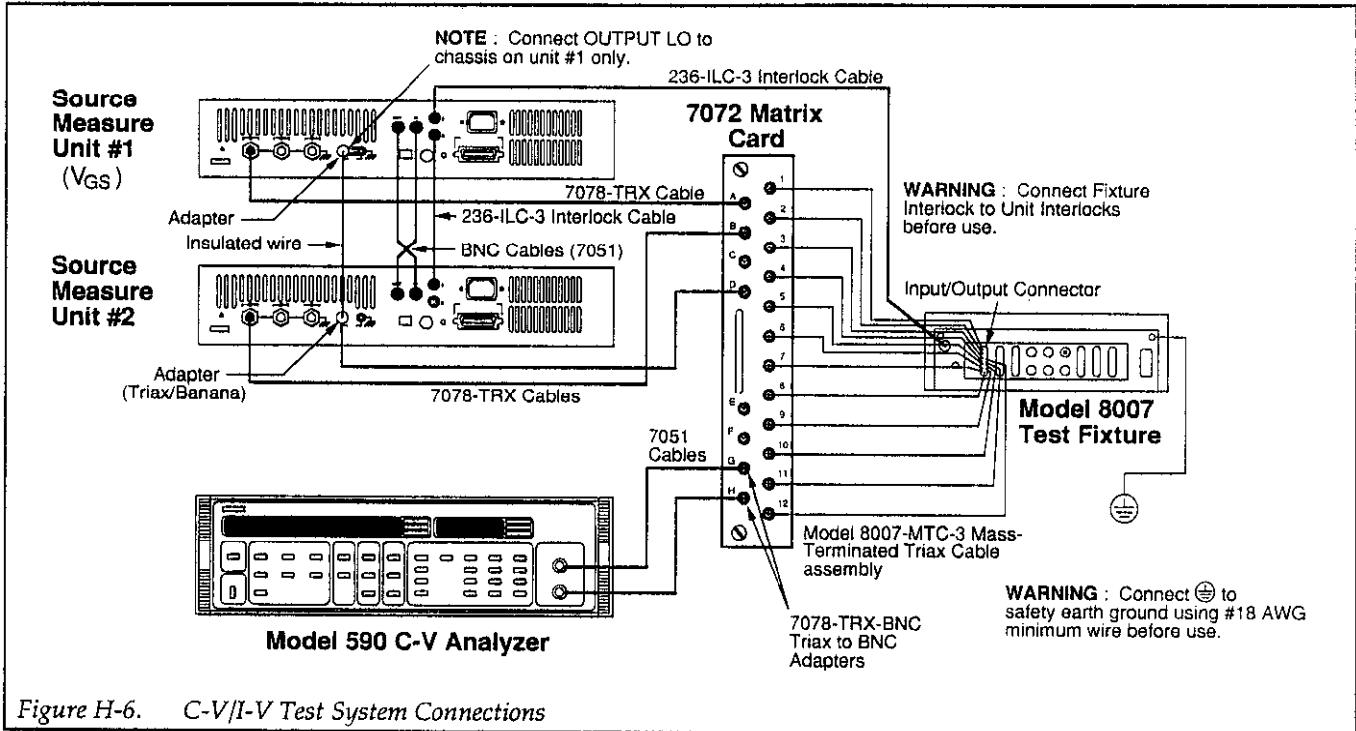


Figure H-5. C-V/I-V Test System Configuration



### Calling Model 5958 Programs from Other Programs

As summarized in Table H-1, the Model 5958 software is actually made up of a number of separate executable programs. In some cases, you may be able to call one of these programs from another program by using the DOS SHELL function if available from that program.

Program H-2 is a simple QuickBASIC program, which demonstrates the SHELL technique to select among the analysis programs. Since memory seems to be at a premium in many MS-DOS applications, the amount of memory taken up by the calling program should be fairly small. Also, you may see unpredictable results in some cases depending on the order the various programs are

called. For example, you cannot run setup or run programs from a called analysis program.

Table H-1. Model 5958 Executable Programs

Executable	Description
CABLECAL.EXE	Cable calibration utility
KIBTSA.EXE	BTS analysis program
KIBTSG.EXE	BTS graph program
KICTA.EXE	C-t analysis program
KICTG.EXE	C-t graph program
KICVA.EXE	C-V analysis program
KICVG.EXE	C-V graph program
KIRUN.EXE	Run program
KISETUP.EXE	Setup program



Program H-1. Example Program to Switch Between Model 82 and Model 5958

```

' This program switches 705 and selects 82/5958 program (see text).
' Be sure Model 705 is set to primary address 17.
OPEN "\DEV\IEEEOUT" FOR OUTPUT AS #1      ' Open IEEE-488 output path.
IOCTL #1, "BREAK"                        ' Reset interface.
PRINT #1, "RESET"                         ' Warm start interface.
CLS                                       ' Clear CRT.
PRINT #1, "OUTPUT 18;ROXA1X"             ' Reset 705, 1-pole mode.
PRINT "Choose C-V Program:"              ' Input program selection.
PRINT "1 - Model 5958 C-V Utilities"
PRINT "2 - Model 82 Simultaneous C-V"
INPUT "Choice"; A
IF A = 1 THEN
    PRINT #1, "OUTPUT 17;C2X"             ' Close channel 2.
    CHDIR "\KTHLY_CV\MODEL58"             ' Change to 5958 directory.
    SHELL "KI5958CV"                      ' SHELL to 5958 program.
ELSE
    PRINT #1, "OUTPUT 17;C1X"             ' Close channel 1.
    CHDIR "\KTHLY_CV\MODEL82"             ' Change to 82 directory.
    SHELL "KI82CV"                        ' SHELL to 82 program.
END IF
PRINT #1, "OUTPUT 17;ROX"                 ' Open all relays.
CLOSE 1
END

```

Program H-2. Demonstrating SHELL Calling of Model 5958 Programs

```

REM This program demonstrates calling 5958 programs using BASIC SHELL.
CLS                                       ' Clear CRT.
PRINT "Select program to run:"          ' Choose program.
PRINT "1 - C-V Analysis"
PRINT "2 - C-t Analysis"
PRINT "3 - BTS Analysis"
INPUT "Enter Program Number:"; N
CHDIR "\KTHLY_CV\MODEL58"               ' Change to 5958 directory.
SELECT CASE N                            ' Select program to run.
    CASE 1                               ' C-V analysis program.
        SHELL "KICVA"
    CASE 2                               ' C-t analysis program.
        SHELL "KICTA"
    CASE 3                               ' BTS analysis program.
        SHELL "KIBTSA"
END SELECT
END

```



# APPENDIX I

## Error Messages

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---

### Error Log File

The error log file ERRORS.LOG, which is located in the C:\KTHLY\MODEL58 directory, logs only cable cali-

bration errors. This file is in ASCII format, and its contents can be viewed with the DOS PRINT or TYPE command.

Table I-1. Switch Control File Errors

Error Message
NOT FOUND: <switch control filename>
ERROR: line length is > 80 characters in LINE <line number>
WARNING: extra INIT keyword ignored in LINE <line number>
WARNING: extra PARALLEL keyword ignored in LINE <line number>
ERROR: there is no pretest DDC string in LINE <line number>
ERROR: there is no post-test DDC string in LINE <line number>
WARNING: extra FINAL keyword ignored in LINE <line number>
ERROR: invalid keyword in LINE <line number>
ERROR: The number of DEVICE commands is less than the number of devices in the test sequence.
ERROR: invalid address format in LINE <line number>
ERROR: no comma in string in LINE <line number>
ERROR: invalid device address format in LINE <line number>
ERROR: invalid device address in LINE <line number>
ERROR: invalid format, quote or comma missing in LINE <line number>
ERROR: invalid format, quote missing in LINE <line number>
ERROR: invalid cable cal filename in LINE <line number>
ERROR: Device number must be >0 and <=99
ERROR: There is no DEVICE command.
ERROR: Non-numeric device address in LINE <line number>
ERROR: Device address is <0 or >30 in LINE <line number>
ERROR: Cable cal file not found in LINE <line number>

Table I-2. Hot Chuck Control File Errors

Error Message
NOT FOUND: <hot chuck control filename>
ERROR: line length is > 80 characters in LINE <line number>
ERROR: there is no SENDWINDOW command
ERROR: there is no SENDSETPOINT command.
ERROR: there is no SENDSRQMASK command.
ERROR: there is not GETTEMP command
ERROR: there is not NUMCHUCKS command
ERROR: there is no CHUCKADDR command
ERROR: there is no SPATTEMP command
ERROR: there is no SPNOTBUSY command
ERROR: < 1 Hot Chucks not allowed.
ERROR: > 10 Hot Chucks not allowed.
ERROR: invalid number after # in LINE <line number>
ERROR: missing 'B' in SPATTEMP command in LINE <line number>
ERROR: missing 'B' in SPNOTBUSY command in LINE <line number>
ERROR: invalid keyword in LINE <line number>
ERROR: invalid address format in LINE <line number>
ERROR: invalid character after @ in LINE <line number>
ERROR: invalid device address format in LINE <line number>
ERROR: invalid device address in LINE <line number>
WARNING: No more than 10 hot chucks are allowed. CHUCKADDR ignored.
ERROR: invalid format, quote missing in LINE <line number>
ERROR: there is no argument for SENDWINDOW in LINE <line number>
ERROR: there is no argument for SENDSETPOINT in LINE <line number>
ERROR: there is no argument for SENDSRQMASK in LINE <line number>
ERROR: there is no argument for GETTEMP in LINE <line number>

Table I-3. Summary of Possible File or Device Errors

Error Message
DEVICE TIMEOUT
DEVICE FAULT
BAD FILENAME OR NUMBER
FILE NOT FOUND
BAD FILE MODE
FILE ALREADY OPEN
DEVICE I/O ERROR
FILE ALREADY EXISTS
BAD RECORD LENGTH
DISK FULL
INPUT PAST END OF FILE
BAD RECORD NUMBER
BAD FILENAME
TOO MANY FILES
DEVICE UNAVAILABLE
PERMISSION DENIED
DISK NOT READY
DISK-MEDIA ERROR
PATH/FILE ACCESS ERROR
PATH NOT FOUND
INVALID NAME
UNKNOWN ERROR

Table I-4. Run-Time Errors

Type	Error Message
Hot Chuck Errors	There is no Hot Chuck in this system! At install time no hot chuck was reported. BTS Cycle Not Possible
Switch Errors	There is no switch in this system! You cannot run a parallel stress test without a switch. Test Sequence Not Possible
Voltage Source Errors (C-t measurement)	There is no 230-1 in this system! At install time no 230-1 was reported. C-t Sweep Aborted
Voltage Source Errors (C-V Measurement)	There is no 230-1 in this system! At install time no 230-1 was reported. C-V Sweep Aborted

**Table I-5. Temporary File Errors at Read Time**

Error Message
WARNING: Missing temporary BTS parameter file! SETUP must be run to have valid BTS parameters.
WARNING: Missing temporary C-t parameter file! SETUP must be run to have valid C-t parameters.
WARNING: Missing temporary C-V parameter file! SETUP must be run to have valid C-V parameters.
WARNING: Missing temporary cycle parameter file! SETUP must be run to have valid cycle parameters.
WARNING: Missing temporary Zerbst parameter file! SETUP must be run to have valid Zerbst parameters.

**Table I-6. Configuration File Errors at Read Time**

Error Message
ERROR: File MODEL58.CFG not found! No file was created at install time, or file was moved or deleted.
MODEL58.CFG File Read Error ERROR: Invalid device address. PROGRAM ABORTED

Table I-7. Input Errors for Setup Parameters

Error Message
<p>*** BTS Test Sequence Input Errors ***</p> <p>ERROR: You can only have 1 device without a switch.            ERROR: Number of devices must be &gt; 0 and &lt; 99.            ERROR: There must be a C-V parameter filename.            ERROR: There must be a stress cycle filename.            ERROR: There must be a data destination filename.            ERROR: Invalid character in C-V parameter filename.            ERROR: Invalid character in stress cycle parameter filename.            ERROR: Invalid character in data destination filename.            ERROR: Invalid character in switch control filename.</p> <p>*** C-t Parameters Input Errors ***</p> <p>ERROR: Number of samples must be &gt; 0 and &lt; [either 450 or 1350]            ERROR: Start delay must be <math>\geq .001</math> and <math>\leq 65</math> seconds.            ERROR: Sample time must be <math>\geq .001</math> and <math>\leq 65</math> seconds.            ERROR: Stop delay must be <math>\geq .001</math> and <math>\leq 65</math> seconds.            ERROR: Default bias voltage cannot be &gt; [either 20V or 100V]            ERROR: Test bias voltage cannot be &gt; [either 20V or 100V]            ERROR: Invalid character in cable cal filename.</p> <p>*** C-V Parameters Input Errors ***</p> <p>ERROR: Step size is too small for given voltages.            ERROR: Start delay must be <math>\geq .001</math> and <math>\leq 65</math> seconds.            ERROR: Sample time must be <math>\geq .001</math> and <math>\leq 65</math> seconds.            ERROR: Stop delay must be <math>\geq .001</math> and <math>\leq 65</math> seconds.            ERROR: First bias voltage cannot be &gt; [either 20V or 100V]            ERROR: Bias step voltage cannot be &gt; [either .005V or .01V]            ERROR: Last bias voltage cannot be &gt; [either 20V or 100V]            ERROR: Default bias voltage cannot be &gt; [either 20V or 100V]            ERROR: Light-on time must be &lt; 100 seconds.            ERROR: Invalid character in cable cal filename.</p> <p>*** Stress Cycle Input Errors ***</p> <p>ERROR: + Stress voltage cannot be &gt; [either 20V or 100V]            ERROR: - Stress voltage cannot be &gt; [either 20V or 100V]            ERROR: Stress off voltage cannot be &gt; [either 20V or 100V]            ERROR: Stress temperature cannot be &gt; 300C or &lt; 0C.            ERROR: Stress off temperature cannot be &gt; 300C or &lt; 0C.            ERROR: Temperature tolerance must be &gt; 0 and &lt; 10.            ERROR: Stress time must be &lt; 10000 seconds and &gt; 1 second.</p>

Input Errors for Setup Parameters (Cont.)

Error Message
*** Zerbst Test Sequence Input Errors ***
ERROR: You can only have 1 device without a switch
ERROR: Number of devices must be > 0 and < 99.
ERROR: There must be a C-V parameter filename.
ERROR: There must be a C-t parameter filename.
ERROR: There must be a data destination filename.
ERROR: Invalid character in C-V parameter filename.
ERROR: Invalid character in C-t parameter filename.
ERROR: Invalid character in data destination filename.
ERROR: Invalid character in switch control filename.



# APPENDIX J

## Default Switch Control Files

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### INTRODUCTION

This appendix summarizes information on the supplied default switch control files. You can view these files on the computer screen by using the DOS TYPE command, or you can print them on your printer with the DOS PRINT command.

Refer to Section 6 for details on creating your own switch control files.

#### Model 7056 General Purpose Card Control File

Filename: 7056.SWC  
 Default Directory: C:\KTHLY\_CV\MODEL58\  
 CTRL  
 Mainframe: 705/706

Primary Address: 18  
 System Configuration: Figure J-1

#### Model 7072 Semiconductor Matrix Card Control File

Filename: 7072.SWC  
 Default Directory: C:\KTHLY\_CV\MODEL58\  
 CTRL  
 Mainframe: 705/706  
 Primary Address: 18  
 System Configuration: Figure J-2

#### Model 7152 Matrix Card Control File

Filename: 7152.SWC  
 Default Directory: C:\KTHLY\_CV\MODEL58\  
 CTRL  
 Mainframe: 705/706  
 Primary Address: 18  
 System Configuration: Figure J-3

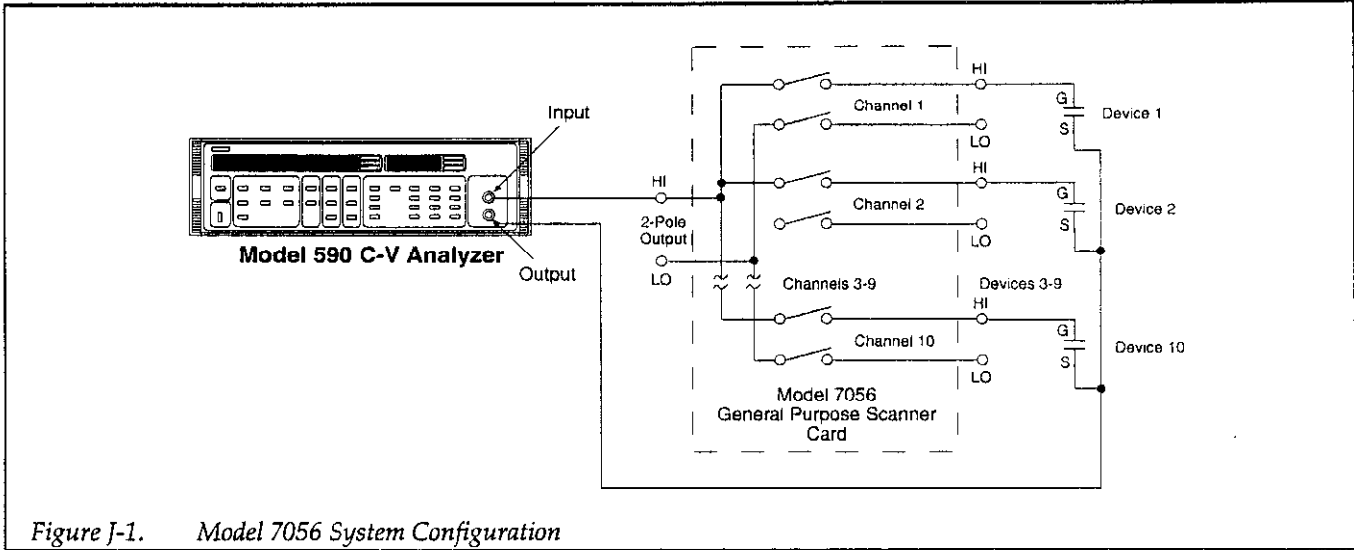


Figure J-1. Model 7056 System Configuration

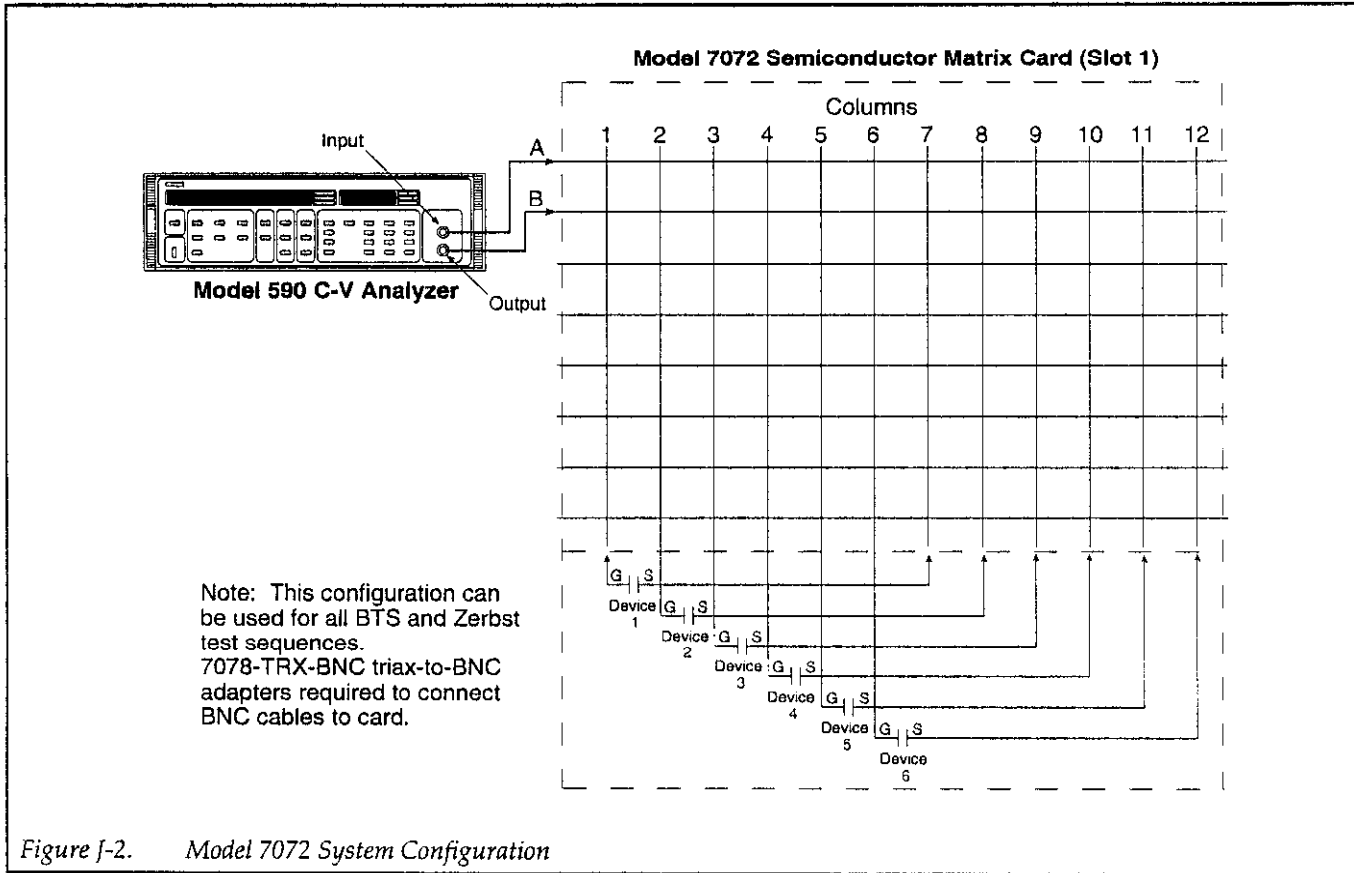


Figure J-2. Model 7072 System Configuration



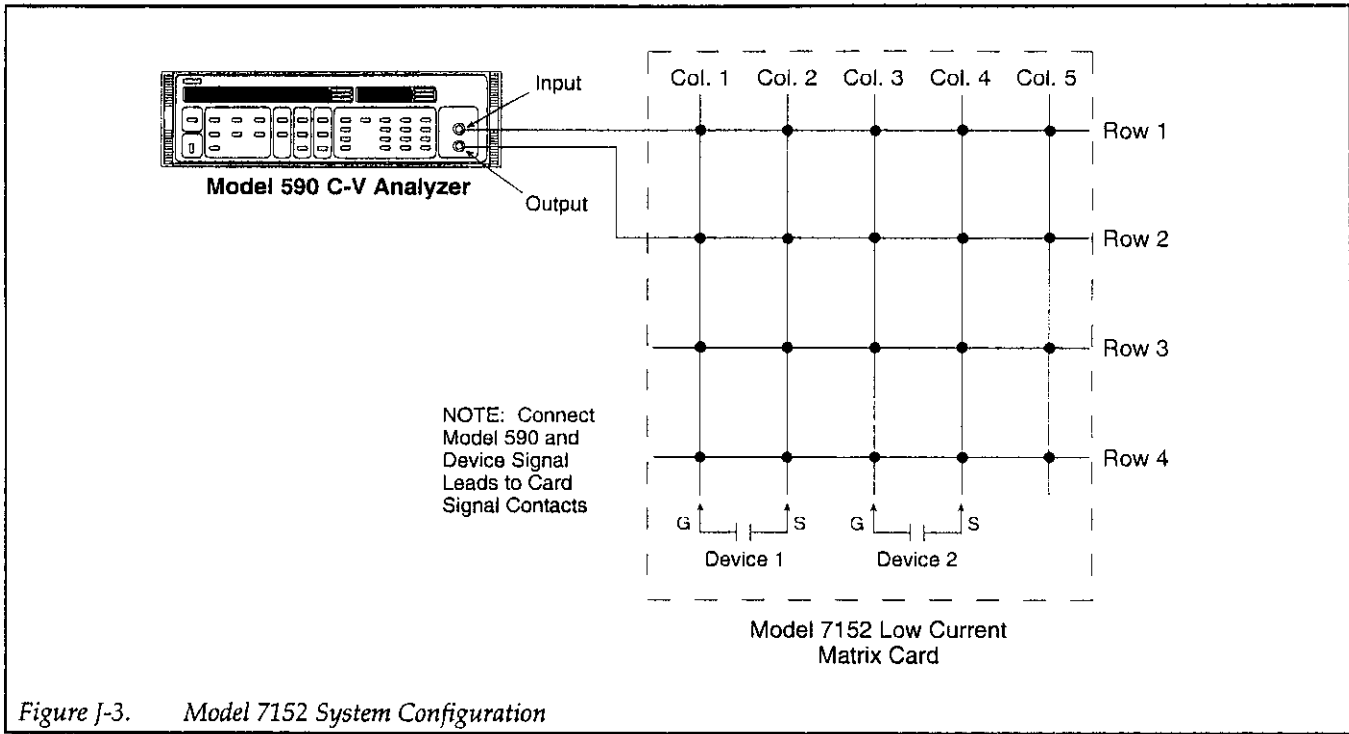


Figure J-3. Model 7152 System Configuration



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