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SIGMA SYSTEMS
MODELS C4 & CC-3.5
PROGRAMMABLE TEMPERATURE CONTROLLER

OPERATING & PROGRAMMING MANUAL

Firmware Version 8.6.3

Manual Revision 4

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1. INTRODUCTION & Quick Start

This manual describes the operating procedures for the Sigma Systems Models C4 & CC-3.5 Controllers, microprocessor based controllers and control communications interfaces for the family of Sigma Systems temperature chambers and thermal platforms. These controllers are complex in nature and require a minimum level of understanding to operate successfully. **There is no Quick Start section in this manual.** It is important that some basic features of the controller be understood before the first operation. Here's the suggested reading course for those in a hurry:

1. Skim Chapter 1 (this chapter) for information that is pertinent to you.

2. Read Chapter 2 (physical description) & Chapter 3 (general operation and error conditions) thoroughly. They contain vital information that affects all modes of operation. There is no doubt that if you do not read these chapters, you will experience error and shutdown conditions which will be both frustrating and time costly and you'll probably end up reading these chapters anyway.

3. Read Chapter 4 (improving productivity) if you want to take advantage of any of the special features of the controller that can speed your processes. If you're just going to do simple control, you can skip this chapter.

4. Skip to Chapter 8 (setup) to setup your controller. If your controller was supplied with a Sigma Systems temperature chamber or thermal platform, most of the setup has been done for you. However, items like communication parameters, DUT temperature limits, etc. will still need your attention. Even if you don't need to set anything, you should review Chapter 8 to gain an understanding of the environment in which the controller operates and the control you have over that environment.

5. Now you're ready to start controlling with the controller. Chapter 5 details "Local Mode"... the "set it and let it run" mode. Chapter 6 tells how to write simple to sophisticated temperature control programs from the controller front panel keypad. Chapter 7 details the commands available for remote control via the EIA-232 port and/or the IEEE-488 GPIB (General Purpose Instrument Bus). We suggest that you at least experiment with Local Mode before using either Program Mode or Remote Mode.

1.1 Models C4 & CC-3$^{.5}$ Explained

The models C4 & CC-3$^{.5}$ controllers are successors to the model CC-3.

> The model **C4** is a completely redesigned controller that uses a completely different and more modern set of internal components with a new processor and completely new firmware. Model C4 controllers are only available as new products from Sigma Systems.
>
> The model **CC-3$^{.5}$** is a hybrid upgrade controller that uses only the digital circuitry of the model C4. It is made by substituting the C4 digital p.c. board (known within Sigma Systems as the "CPU board", or the "A" board) for the CC-3's "A" board. The upgrade from CC-3 to CC-3$^{.5}$ also includes a few small modifications to other internal components. The power supply, power switching, analog, and front panel components of the CC-3 remain. Model CC-3$^{.5}$ controllers are only available as the product of upgrading a CC-3 controller.

From a functional perspective, models C4 & CC-3$^{.5}$ are identical because all of the functionality of the controllers is defined by the processor, bus interface components, and firmware... all of which are integral with the C4 "A" board. The C4 analog and front panel components that remain unique to the C4 (not included in the CC-3$^{.5}$ upgrade from CC-3) provide slightly better accuracy and substantially better noise and static immunity.

For the balance of this manual, the term C4 will mean to include both the model C4 controller and the model CC-3$^{.5}$ controller. In the event that there is a difference between the two models, that difference will be explicitly detailed.

1.2 General Description

Using the model C4, temperature control is available manually from the front panel, by use of user entered programs, or via remote control via either a EIA-232 or IEEE-488 GPIB. The controller has a precision temperature reading capability with a digital read-out. Two temperature probes can be connected to the controller allowing either probe or both probes to be the control probe(s) while either probe can be used to take measurements.

Two additional controlled device ports are available. They are intended for on/off control of a refrigeration compressor and an external load such as a device under test, or a main chamber or platform power relay. These ports normally are supplied as TTL level (low voltage) ports but are optionally available with solid state relays to control line voltage as is the case of units with mechanical refrigeration. The Refer Port may be toggled from the front panel at any time in the manual (LOCAL) mode. The compressor is designed to not cycle on and off with the temperature control function.

The controller operates in each of four modes:

Local Mode	Single Setpoint control from the front panel. Simple Start/Stop functionality.
Program Mode	Programmed control using programs entered, stored, and run from the front panel. 100 Temperature/Duration Program steps available. Multiple programs may be stored and called as needed.
Remote Mode	Control via EIA-232 or IEEE-488 GPIB. The IEEE-488 interface implementation is a TALKER/LISTENER with serial poll. Extended addressing and parallel poll capabilities are not supported. The EIA-232 interface is fully configurable for baud rate, data bits, stop bits and parity.
Setup Mode	Used to define and store operation and environment variables that control how the C-4 behaves.

1.3 Custom Features / Interchangeability WARNING

Each Sigma Systems C4 Controller has been custom configured for the chamber or platform with which it was supplied or for which it was specified. Many units include special wiring for custom control applications, precision fail-safe additions, non-standard voltages, external unit power control, etc. **Units that may appear to be identical may be internally quite different. Do not interchange controllers between controlled devices (chambers and/or platforms) unless you are certain that the controllers have been identically constructed.**

Failure to heed this warning voids your warranty, may cause unpredictable controlled device behavior that could cause damage to persons or property, pose a risk of fire, or cause other problems. If you must move controllers between controlled devices, please contact the Sigma technical support department for assistance and advice.

1.4 Release 8.6.3 Firmware

This manual is specifically written to cover the features of Release 8.6.3 firmware for the Sigma Systems Model C4 controller. All commands from the CC-3, CC-3.5, and earlier C4 releases are maintained in this release and are compatible with this release.

However, this release redefines the Error Byte and Status Byte, makes changes to the Error/Status String, adds Adjustable Settling Bands, Minimum Ramp Rate Timeout, T-Drive thermal over driving, communications flow control and many other features. The setup parameter table has been modified to condense the EIA-232 settings to two parameters so that parameters to set the default state of the Refer Compressor Port, the Aux Power Port, and the bumpless transfer function could be added. Also, the PID control algorithm has been completely rewritten. Although the same setup parameters are still used for the PID routine, they may need to be set to different values for proper operation. See §1.6.

1.5 C4 vs. CC-3 Differences

1.5.1 Hardware & Stability Improvements

The new C4 introduces a number of improvements to make the controller faster and more reliable than its CC-3 predecessor.

The C4 has a completely new digital processing board. The new board has a much faster processor, more memory, and a much faster IEEE-488 GPIB controller. Interrupts have been completely restructured to improve stability. The multilayer design is far more tolerant of both static and power line interference. There is now a watchdog timer to detect system lockups in the event that something does interfere with the system. The battery backed RAM has been replaced by an EEPROM. The Vactrol type isolation device in the failsafe circuit has been replaced. The C4 contains no components that have a time based failure mode.

The new firmware also monitors the state and integrity of internal memory. Critical system information is stored in multiple places so that minor errors due to uncontrollable transients or other causes can be repaired on the fly with no disruption in process control. Likewise, both the front panel display and the GPIB interface are monitored constantly to assure that their operation has not been compromised by static discharge or line transient. In the event of a problem, either device can be reset on the fly to allow operations to continue normally.

System integrity is further enhanced by a series of successive shutdown processes that monitor the integrity of the data coming from the sensor probes. In the event that any probe reports a temperature more than 20°C beyond the limits set in the controller, the controller will shut down all heating and cooling and display a warning message. Likewise, in the event that a sensor probe reports an extreme temperature, either hot or cold, the system will assume that a probe has become compromised by an open or shorted circuit and stop applying heat and cooling, shut down the system, and display an appropriate warning message..

1.5.2 Hardware Change (EEPROM replaces BBSRAM)

All C4 controllers and CC-3.5 controllers converted after January 1998 have the battery backed static RAM (BBSRAM) replaced with an EEPROM. This change was implemented to reduce the possibility that the controller will require service. Although changing the BBSRAM when the battery died (about every 5-12 years) was a fairly simple matter, the necessity for doing so was found to be a nuisance as was diagnosing the need for the change. The BBSRAM or EEPROM provides the non-volatile memory where the C4 stores both the setup parameter information and the user programs.

1.5.3 Firmware Uploads

When new firmware is available for your C4, you can easily upload most releases into the controller using the controller's serial port. The procedure requires only a diskette bootable PC and a serial cable and takes only about ten minutes. Firmware updates, when available, may be obtained on diskette for a fee from Sigma Systems or for free by download from www.SigmaSystems.Com. See §3.2.2

1.5.4 Forced Start from EPROM Firmware

The controller can be started from the original firmware version that is stored in the EPROM. Uploaded versions are stored in flash memory. If a firmware upload session should go astray somehow, this feature allows the controller to still operate. See §9.3.8.a.

1.5.5 Front Panel Information Display at Startup

The controller model is displayed at startup - See §3.1.1
The firmware version number is displayed at startup - See §3.1.1
The operating range may be displayed at startup - See §3.1.2
The controller serial number may be displayed - See §3.1.3

1.5.6 Temperature Out of Range Shutdown

The controller now stores the operational limits for itself, the controlled device (Sigma chamber or platform), and the unit under test (DUT). The operating temperature is checked against these limits, if it is too far outside these limits,. the system is shutdown with an appropriate error message displayed. See §3.6.

1.5.7 Internal Error Shutdown Conditions

The C4 monitors system health by keeping track of three additional areas;
they are:

Processor health . . . . . Tracked by watchdog timer
Memory condition . . . . . Checked at startup
Setup parameter table . . . . . Checked continuously as used

Some detected internal errors can be repaired on the fly. If this is possible, the C4 will recover from the error and you will not know the error existed. If, however, the error is not repairable and the system must be shut down, an error message will be displayed to help you understand what happened and how to prevent or cope with it. See §3.7.

1.5.8 Fahrenheit Temperature Scale Supported

The controller will now operate in either Celsius °C or Fahrenheit °F mode. See §3.4.

1.5.9 Temperature Probe Correction (Calibration)

The C4 will allow you to enter data via the Setup Mode that will correct anomalies in the temperature readings and control. Such adjustments are sometimes necessary to optimize accuracy at a particular temperature, or to compensate for differences between raw probe temperature data and actual temperatures. These differences can be the result of probe placement, effects of the unit under test on the temperature data, or other causes. See §3.8

1.5.10 "Bumpless" Temperature Control

When the setpoint is changed, the PID control algorithm begins a new "search" for the right amount of heat and/or cooling to maintain the new setpoint. Normally, for each new setpoint, the PID routines begin the search anew... behaving as if the controller was just turned on. The controller will quickly determine that heat or cooling is called for, and while the chamber or platform advances toward the new Setpoint, the PID routine adjusts for the response to heat and cool and methodically settles the chamber or platform at the new setpoint temperature. For most setpoint changes, where the new and old setpoints are quite different, this is a fast, accurate and appropriate method of control.

However, when the change in the Setpoint is very small, this "start from the beginning" search routine can search over such a wide range that it will introduce a "bump" in the platform or chamber temperature that can exceed the amount of the Setpoint change. The C4 includes an intelligent PID routine that constrains the search appropriately for the change in Setpoint and thus eliminates the "PID bump". See §3.13.

1.5.11 Adjustable Settling Band

The C4 Adjustable Settling Band feature allows the user to define the standards that must be met to satisfy a "go to setpoint" command. The Adjustable Settling Band feature does not change the accuracy or method of control. It simply changes the standard that is internally applied for deciding when a setpoint has been achieved.

Users with very high precision requirements can set rigorous standards that must be met before the C4 will signal that it has achieved the setpoint temperature. Conversely, users with less demanding needs can set less rigorous standards. When less rigorous standards are set, the C4 can meet those standards more quickly and process the next program step sooner, thus substantially reducing test and conditioning time. See §4.1.

1.5.12 Touch 'n Go

Touch 'n Go is designed to allow very fast cycle testing by eliminating the need to completely "settle" on the setpoint temperature at each excursion. Fast cycling tests can often be completed in substantially less than ½ of the time that would normally be required. Touch 'n Go is a special case of Adjustable Settling Band. See §4.1.3.

1.5.13 T-Drive Thermal Overdriving

T-Drive is a thermal overdrive algorithm than can dramatically reduce process times for thermal conditioning and testing of large mass or thermally slow objects. T-Drive requires two temperature sensing probes, the second of which must be located in the DUT or a DUT imposter. Unlike other thermal overdriving schemes, T-Drive can respect both absolute temperature exposure limits and thermal stress limits. As a result, T-Drive can often cut test times by more than 50% and reduce thermal stress at the same time. See §4.2.

1.5.14 Default Setup Parameters Restore

There is a procedure for erasing the current setup parameter table data and restoring it basic default values. See §3.3

1.5.15 Program Mode Step Insert & Delete

Program steps may now be deleted from or inserted into programs.
See §6.3.4 & §6.3.5.

1.5.16 Program Mode Any Step Points to Step 100

Any program step may now point to step 100 (program end) as the next step to execute.

1.5.17 Program Mode Safer Program Clear

Some deliberate delays have been added to the key sequence to completely clear the program memory to lessen the likelihood that all of program memory will be erased by accident. See §6.3.1.

1.5.18 Program Mode Run Time Program Pre-check

When a program is run in Program Mode, the C4 pre-reads the program to look for run-time errors that it can report to you before starting. By pre-checking your program, errors are dealt with immediately rather than after the program has partially completed. The following items are checked:

Calls for probe 2 when only one probe is defined for the system
Calls for setpoints that are not within the system operating range
Loop counter numbers not within the range of 1 to 999 integer

See §6.3.8 for a full explanation.

1.5.19 Remote Mode EIA-232 Baud Rate Improvement

EIA-232 communications are now supported at 19,200 and 38,400 bps.
See §8.

1.5.20 Remote Mode EIA-232 Port Initialization

The CC-3 required that to use the EIA-232 port, the port had to be initialized by switching the mode switch to SETUP before switching to Remote Mode. The C4 eliminates this requirement. The EIA-232 port is initialized each time the remote switch is switched to Remote Mode.

1.5.21 Remote Mode Fault Tolerant Parser

The C4 uses a fault tolerant parser. Command strings received over either the EIA-232 or GPIB ports are converted to upper case, extra spaces and tabs are removed, commas are converted to spaces and line terminators are corrected if necessary. For this reason, programs that work properly with the C4 and not with a CC-3, that use only CC-3 commands, probably have syntax errors that the C4 parser corrects. See §7.3.3.c.

1.5.22 Remote Mode New Commands

1.5.22.a Controller Environment Information Queries		See Section:
QV	Query Firmware Version	7.4.1
QN	Query Controller Serial Number	7.4.2
QR	Query Controller Temperature Range	7.4.3

1.5.22.b Controller Information Queries & Commands		See Section:
RSA	Request Status Byte (ASCII hex)	7.5.1
REA	Request Error Byte (ASCII hex)	7.5.2
QE	Query Error/Status String (binary	7.5.3
QEA	Query Error/Status String (ASCII hex)	7.5.3
QC	Query Last Command String	7.5.4

1.5.22.c Controller Setup Commands		See Section:
SC	Set Correction for Probe *n*	7.6.1
WP	Set PID Constants	7.6.2
RP	Read PID Constants	7.6.3
BF	Blowers off (Enable Blower Shut-Off Mode)	7.6.4
BO	Blowers on (Disable Blower Shut-Off Mode)	7.6.4
SL	Set DUT Temperature Limits	7.6.5
SD	Set DUT Temperature Differential Limits	7.6.6
SB	Set Settling Band Parameters	7.6.7
TD	Set T-Drive™ Parameters	7.6.8
QF	Query Setup Parameter (binary)	7.6.9
QFA	Query Setup Parameter (ASCII hex)	7.6.9
UP	Write Current Parameters to NV Memory	7.6.10

1.5.22.d System Operation Commands		See Section:
GTF	Go to Temperature - Fahrenheit	7.7.4
RAF	Ramp to Temperature - Fahrenheit	7.7.5
QS	Query Setpoint & Control Probe Number	7.7.7
QU	Quit Controlling (return to idle state)	7.7.10
DC	Device Clear (reset controller)	7.7.11
TE	Text Echo	7.7.12

1.5.23 Remote Mode IEEE-488 (GPIB) Monitoring

The IEEE-488 bus controller is automatically reset if a problem is detected. No message to the user is generated as no data is typically lost in the process.

1.5.24 Setup Mode Easier Parameter Access

Setup parameters may now be accessed directly by number rather than having to scroll the entire list. If scrolling is used, there is now a backup key so the list can be scrolled in either direction. Likewise, for parameters that are chosen from a list, the list can be scrolled in either direction or the parameters can be keyed in directly without scrolling the list. See §8.1.

1.5.25 Setup Parameters changed for EIA-232 settings

The function of setup parameters F4-F7 (serial port data bits, stop bits, parity enable, and parity type) have been consolidated into parameter F4. Parameters F5-F7 are now used for other purposes.

1.5.26 Setup Parameter for Aux/Power Port Default State

Setup parameter F5 now sets the default state of the Aux/Power Port. This port previously defaulted to ON. As it is now used for other purposes, including control of cryogenic boost cooling of refrigerated systems, control of the default state is helpful.

1.5.27 Setup Parameter for Refer Port default State

Setup parameter F6 now sets the default state of the Refer compressor port. This port typicically defaults OFF and rarely needs to be changed, but as it has some other uses in custom applications, the default state can now be user set.

1.5.28 Setup Parameter for Bumpless PID Default State

The new Bumpless PID routine can greatly improve stability for very small temperature setpoint transitions. However, the effects of the Bumpless routine can be annoying for normal control situations. F7 sets the default state of the Bumpless feature and is normally OFF.

1.5.29 Power Sharing feature added

The C4 can now share available power between the refrigeration system and the boost heating system. This feature allows much higher performance mechanically refrigerated systems for a given input power current. See §8.3.6.a.

1.6 Version 8.0.0 and later Compatibility Issues

All C4 firmware after version 8.0.0 contains changes that solve a number of long standing issues, but which create some incompatibilities with earlier versions. Earlier C4 firmware was largely backward compatible with CC-3 firmware. That is, programs that were designed to run on the CC-3 would run on the C4. Likewise, programs that were designed to run on the C4, but that used only CC-3 commands, and which followed the more rigorous CC-3 syntax rules, would run on the CC-3.

Version 8.0.0 and later firmware contains changes that may require changes in early programs before they will run. The areas that changed are:

Error Byte	Bit definitions changed, clearing behavior changed, RE returned string changed. See §7.8
Status Byte	Bit definitions changed, clearing behavior changed, RS returned string changed. See §7.8.
Error/Status String	Bit definitions changed, clearing behavior changed QE returned string changed. See §7.8.
Communications Flow Control	No previous flow control, but Error Byte flags now used differently. Flow control enabled. See §7.9.
PID Control	The PID routine has been rewritten. As a result, PID constants may need to be changed. A Cooling/Heating gain factor has been added that needs to be set correctly to optimize mid range control. See §9.4.
Remote Program Mode Command Queuing	In Remote Program Mode (SP), some commands are immediately executed when received by the C4, others are placed in a queue and are executed sequentially. Some commands have been changed from Queued to Immediate, or from Immediate to Queued. See §7.2.
Timeout	The go to temperature timeout feature has been replaced with the Ramp Timeout Function. See §3.11.
Aux/Power Port	The behavior of the Aux/Power Port has been changed such that the port is no longer returned to its default state of ON (high) when controlling ends, but is returned to that state if a reset is issued. See §2.2.2, §7.7.9, §7.10 & §8. The default state of the Aux/Power Port is now set by setup parameter F5. Programs that depend on the start

up state of the Aux/Power Port may need to have explicit steps added to control the port.

Refer Port The Refer Port is no longer turned off when temperature controlling is finished. See §2.2.2, §7.7.8, §7.10 & §8.

The default state of the Refer compressor port is now set by setup parameter F6. Programs that depend on the start up state of the Refer Port may need to have explicit steps added to control the port.

2. PHYSICAL DESCRIPTION

The C4 Controller fits into an area 3.5" x 5.5" x 9.5" long. Connection to the chamber or platform is made through an umbilical cable with a 12 pin connector that is standard for all SIGMA chambers and thermal platforms. Controllers destined for use with SIGMA thermal platforms, or which are not housed in a cabinet that is not attached to the chamber cabinet, have an additional 6 pin connector used for the sensor probe circuits. Controllers with a 6 pin connector may also have a 2 pin connector if they were supplied with a Sigma Precision Fail-safe. All C4 controllers have a 3 pin connector at the back of the controller for control of refrigeration and auxiliary devices via TTL output and solid state relay(s). This feature was optional on CC-3 controllers and is thus not a consistent feature of CC-3.5 controllers.

2.1 Front Panel

The front panel consists of four major parts: the LED digit display, the LED indicators, the mode switch and the keypad. The numbers in circles on the front panel guide the user through the steps for changing the temperature setting in the LOCAL (manual) mode of operation. See § 5.

2.1.1 Digital LED Display

The Digital LED Display is a 7 digit display arranged in the following configuration:

8.8.8.-8.8.8.8.

The display is used for showing probe temperatures, setpoints, program steps, fail-safe status and setup information.

2.1.2 LED Indicators

Below the Digital LED Display are four discrete LED Indicators. These indicators are arranged in the following order:

REFER	**COOL**	**HEAT**	**RUN**

REFER indicator lights if power is applied to the refrigeration Refer Port (not all units are equipped with compressors).

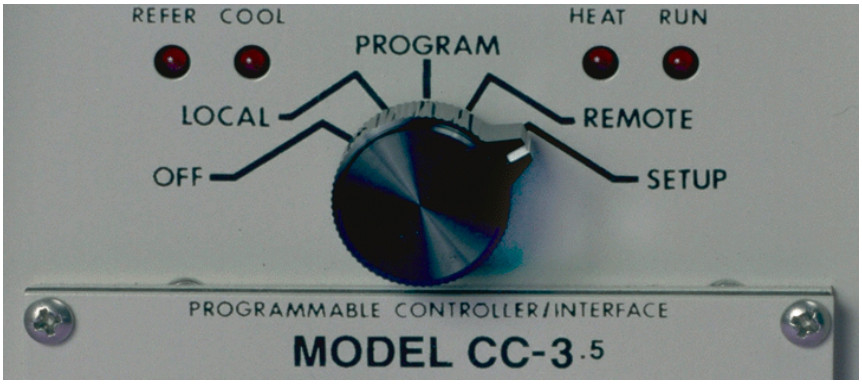
COOL indicator lights when cooling is active, typically during the time the cryogenic valve is open on cryogenically cooled units.

HEAT indicator is pulsed along with the on and off function of the heaters. These indicators are active in all modes of operation.

RUN indicator shows whether the chamber temperature is being controlled.

2.1.3 Mode Switch

The Mode Switch is used to apply power to the chamber and to select the mode of operation. It is a 5 position rotary switch arranged as follows:



The OFF position removes the power from heating and cooling and compressor control circuits of both the controller and the chamber or thermal platform.

> **CAUTION: Placing the mode switch in the OFF position does <u>not</u> remove all power from either the controller or the chamber or thermal platform. Only the heating, cooling, and compressor control circuits are turned off. Full line voltage potential is still available in many places in both the controller and the chamber or platform. See servicing warnings and instructions in the appendix of this manual.**

Moving the rotary switch changes the mode of operation of the chamber. The different modes are described in detail in separate sections of this manual. When the rotary mode switch is moved to a new position, other than OFF, the temperature control loop, if running, is turned off, heating and cooling are disabled but the chamber blowers will continue to run unless disabled via setup parameter F15. Likewise, at the end of a local or remotely controlled program, chamber blowers will continue to run, but heating and cooling will be disabled. Note that a chamber in this condition, with blowers running, will exhibit some heating due to blower air friction. This effect is exaggerated in units equipped with high velocity blowers. Moving the rotary switch between OFF and LOCAL will maintain the last used setpoint for the next operation of the controller. See 8.3.2 for description of auto-start function.

2.1.4 Keyboard

The keyboard consists of 20 momentary contact keys. Certain keys are functional only in some of the modes of operation. With some keys, such as the Display Control, the function is different depending on the mode of operation. The Keyboard is arranged in the following configuration:

1	2	3	CLEAR PROG	START STOP
4	5	6	REFER	ENTER
7	8	9	ADV	DISP TEMP
.	0	+ -	CLEAR ENTRY	DISP CNTL

CLEAR PROG	Clear program from memory
START STOP	Start/Stop temperature control
REFER	Toggle refrigeration compressor port on or off *
ENTER	Enter/finalize current keyboard entry
ADV	Advance to next program step or next value
DISP TEMP	Display temperature
CLEAR ENTRY	Clear current keyboard/display entry
DISP CNTL	Display control setpoint

* = Local Mode ONLY.

2.2 Rear Panel Connections

2.2.1 Probe and Fail-safe terminal strip (J1)

At the rear panel of the controller, a cable is provided to connect to the power, cooling solenoid, mechanical refrigeration and heaters of the chamber. In addition, a six lug screw terminal block (J1) is provided for eyelet terminal connection of the temperature probes and for connection of one additional optional device such as the Sigma PFS-2 Precision Fail Safe.

J1 TOP

ì	Probe 1 (Black lead)
í	Probe 2 (Black lead)
î	Chassis Ground (Probe shield) (Chamber or platform ground, etc.)
ï	Probe 1 & 2 return (Red or White lead)
ð	Auxiliary device ground
ñ	12 VDC for Fail-Safe

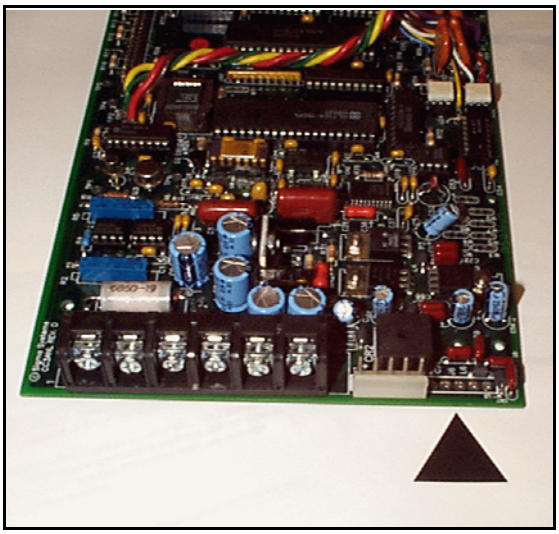
Please observe all standard anti-static procedures when making connections to these points!

There is also an IEEE-488 (GPIB) connector, series 57 (metric threads), and an EIA-232 connector, female DB-25, for the Remote Modes of operation. To maintain compliance with EMI emission standards, only shielded cables may be used for connection to either of these ports. The C4 is configured as DCE (Data Communications Equipment). Therefore, do NOT use a "null modem" type serial cable that has pins 2 & 3 crossed.

Warning: The probe 1 ground MUST ALWAYS be connected to terminal 3 of J1. Failure to maintain this ground will void the C4 warranty and may result in fire, or injury to operators.

2.2.2 TTL Outputs and Input

The C4 has incorporated in it the ability to receive one TTL ground signal and send two TTL signals. Throughout the manual, the TTL outputs are referred to as AUX/POWER CONTROL PORT and REFRIGERATION COMPRESSOR PORT. The input is referred to as the AUX INPUT (previously known as the DOOR SWITCH INPUT). These signals are available on the "B" circuit board (the board with the 6 lug screw terminal strip (J1) on the back). The TTL connections are available on pins 6-10 of J6 at the back of the board. Look for the 5 pin connector just below the 6 lug terminal strip. The 5 pin header uses pins 1-5 of J6 and the 5 through hole solder pads just below it are pins 6-10.



The J6 pin-outs are as follows:

PIN 6	+5v
PIN 7	Aux Input
PIN 8	Ground
PIN 9	Aux/Power Control
PIN 10	Compressor Control

Pin 6 (+5v) is not used. The Aux Input (Pin 7) senses the presence of a ground (Pin 8). The Aux input can be used to sense the opening or closing of any non powered circuit that is connected between Pins 7 & 8. When Pin 7 is connected to ground, bit 7 of byte 35 of the Error/Status String (See §7.8.4) is set (1). When Pin 7 is not connected to ground, that bit is reset (0). Each time the state of Pin 7 changes (connected or disconnected from ground), bit 0 of the Error Byte (See §7.8.2) is set. Because this "toggle indicator" is available in the Error Byte, programs can easily be notified (via the SRQ function, see §7.5.5 & §7.5.6).

Pins 9 and 10 supply +5v when the port is "on". The state of both ports is reported by byte 35 of the Error/Status String (See §7.8.4). The reporting Error/Status String bits are set (1) if the port is "on" (+5v) and reset (0) if the port is off.

These ports are TTL level and will require proper isolation and drive capability considerations when interfacing to other devices. **Damage to the C4 from improper connection or use of these board level facilities is not covered under your Sigma Systems warranty.**

If the controller is equipped with internal solid state relay to control the compressor, the output of the solid state relay is through pin 8 of P1, the 12 pin power cable to the controller. Internal solid state relays were optionally fitted to some CC-3 controllers for refrigerated systems. C4 controllers purchased to replace such CC-3 controllers can be custom fitted in this manner on request.

Most C4 controllers also have a 3 pin connector wired to the B board J6 pins 8, 9 & 10. This connector brings the Refer compressor, Aux/Power Port, and ground connections from J6 to a convenient connector. If a connected refrigeration system does not function, try reversing the polarity of the connection to this plug. Reversing the connection will not cause harm, but it will disable the refrigeration system and the Aux/Power Port. The 3 pin connector that plugs onto this header typically will have a violet&white wire at the bottom (pin 10) and a black&white wire at the top (pin 8).

The Aux/Power and Refer Ports are returned to their default conditions as determined by Setup parameters F5 and F6 upon power up of the C4 and when a reset is processed. See §8.3.6. On the next page is a table showing how the Refer and Aux/Power Ports are controlled and affected by C4 operations.

C4 Aux/Power Port and Refer Port Behavior			
	Local Mode	**Program Mode**	**Remote Mode**
State of Refer and Aux ports upon entering mode	According to value of F5 & F6 unless Autostart enabled (F14=1) then, if last mode was Off and prior mode was Local, Refer Port to be same as when last in Local Mode.	According to value of F5 & F6	According to value of F5 & F6
How Aux port is controlled	Not controlled. Remains in mode according to F5	Controlled by program steps	Controlled by TO and TF
How Refer Port is controlled	Using REFER button if F13=1. REFER button toggles Refer Port state regardless of whether or not C4 is controlling temperature.	Controlled by program steps REFER button not active	Controlled by CO & CF REFER button not active
Effect of Start/Stop button on ports	Does not affect either port when starting or stopping control	Does not affect either port when starting or stopping/pausing control	Start/Stop button not active
Program/control end effects on ports	N/A	Step 100 stops temp control but does not change port status	QU stops temp control but does not change port status
Reset effects on ports	N/A	N/A	DC, & GPIB Device Clear, Selected Device Clear, Interface Clear reset ports to F5 & F6 defined states
Fail-safe effect on ports	Reset ports to F5 & F6 defined states	Reset ports to F5 & F6 defined states	Reset ports to F5 & F6 defined states

Note: Even though the C4 may reset a port to "on" in a failsafe mode, the chamber or platform will likely be wired to disable power to the port's controlled device, such as cryogenic boost system, or a mechanical refrigeration compressor.

3. GENERAL OPERATION & ERROR CONDITIONS

3.1 Startup Displays

3.1.1 Model Number and Firmware Version Number Display

The C4 identifies itself upon power up. It will display the model number for 1 second, then the firmware version number for 2½ seconds as follows:

C3-S rEL 8.6.3.

C4 rEL 8.6.3.

3.1.2 Temperature Range Display

Each C4 controller is set at the factory for use with a specific device (chamber or platform). Because the controlled device was made to specific thermal limit specifications, and because constraining the operating range of the controller improves it's accuracy, the controller to be used with each device is set to operate only within the range appropriate for that device. The setting of an operating range involves a number of internal adjustments and calibrations and the loading of specific control tables for that range. This setting can only be changed by Sigma Systems service personnel. We recommend that each controller be kept with the device for which it was originally configured.

However, if you find that it is necessary to move a controller to another device, it is important that you check to be sure that the controller that is moved is configured to operate in the appropriate range for the device it is to control. As of this firmware release, controllers are supplied for six ranges as follows:

0	-100°C to 200°C	-148°F to 392°F	1	-100°C to 300°C	-148°F to 572°F
2	-100°C to 350°C	-148°F to 662°F	3	-175°C to 400°C	-283°F to 752°F
4	-195°C to 300°C	-319°F to 572°F	5	-195°C to 500°C	-319°F to 932°F

To check the internal range setting of your C4 controller, turn the mode switch from OFF to any other position. During the 2½ seconds that the firmware release number is shown on the display, rapidly press **<DISP/TEMP>** three times. The internal range setting will be displayed for 5 seconds following the version display. An example:

200 - 100C (Celsius mode)

392 - 148F (Fahrenheit mode)

The C4 controller uses different hardware settings as well as software settings to maximize accuracy and take full advantage of the range of the A/D converter and other internal components. The range of the controller can only be changed by factory personnel. **Note that any range that includes 500°C also requires**

operation with a specially built 425 ohm RTD temperature sensor specifically designed for this use.

3.1.3 Serial Number Display

The controller serial number can be displayed at startup by pressing **<DISP/CTRL>**

while the model number (C3-5 or C4) is displayed. The serial number will be displayed in the format:

4-0 3276

The first digit (either a 3 or 4) indicates whether the controller is a CC-3-5 or C4, and the 5 digits to the right of the dash is the sequential part of the number. There is no significance to the leftmost of the 5 sequential digits being separated from the other 4 digits. The separation is a limitation of the display. When recording or reporting serial numbers, please always use the 7 digit string, including the leftmost digit and the dash in this format: 4-03276.

When the serial number is displayed, the controller is not controlling. The number will remain on the display until the controller is turned off.

3.2 Updating Firmware

There are two methods of updating the firmware in the C4.

1. Physically replace the EPROM that contains the firmware.
   (There is usually a charge for firmware EPROMs)

.

2. Use a PC to upload the firmware through the C4 serial port.
   Firmware and upload software are currently free from Sigma System's web site: www.SigmaSystems.com

Note: All firmware updates are available on EPROM chips for physical installation. Not all updates are available as downloads from the Sigma Systems web site. Some firmware updates make changes in the basic data structures inside the C4. Because firmware loaded into the C4 through the serial port is stored separately, and in addition to, the EPROM firmware, and because the C4 can be started from either resident version, the two versions should use compatible data structures. Thus, versions that will modify the data structures in the C4 should typically be installed by changing the firmware EPROM.

Caution: If you use the serial port to upload new firmware that has a different data structure than the EPROM resident version, the new firmware will convert the data structure in order to run properly. If you subsequently attempt to start the C4 from the EPROM based firmware (see §9.3.8.a), it will likely crash.

Important: Write down all setup parameter values before upgrading firmware. Some upgrades erase the setup parameters. You will need to know the values to re-enter them. **Check the new version firmware manual to see if there are changes in the use and the values associated with the setup parameters.** You may need to make changes to some of the values before re-entering them.

3.2.1 Upgrading Firmware by EPROM Replacement

Before starting, be certain that you have a properly grounded antistatic surface, and a grounding strap, to prevent damaging the C4 components during disassembly and reassembly.

Remove the C4 from its cabinet or rack, then remove the EPROM chip that contains the firmware and replace it with a new one containing the updated firmware. Firmware EPROMs are available from Sigma Systems. There is a charge for firmware EPROMs.

The firmware EPROM is located on the digital or "A" board, the same board that has the EIA-232 and GPIB connectors on the end. The EPROM socket is labeled U16. Make certain that the end of the EPROM with the notch or notch mark is toward the inside, or center, of the board.

Note that it is possible to remove and replace the firmware EPROM without disassembling the C4. If you lay the controller upside down, and look at the digital board from the bottom, the firmware EPROM is the first large chip from the front of the controller. You will not be able to see the U16 label, but you can see the C36 label on the small capacitor located next to the firmware EPROM socket. Using a small flat bladed screwdriver or chip removal tool, carefully pry the old EPROM from it's socket. Try to keep the chip as flat as possible while removing it to prevent damage to the pins or socket. When replacing, keep the replacement EPROM flat to the socket, make sure all pins are started in their respective receivers in the socket, then press the chip firmly into place.

3.2.2 Upgrading Firmware by Uploading through C4 Serial Port

Note: CC-3.5 controllers with version 7.0.0 firmware or earlier have battery backed RAMS for non volatile storage. These units MUST have the BBRAM replaced with an EEPROM before newer firmware is installed.

Note: Firmware versions starting with a 7, other than the released version 7.5.2, were beta firmware. Those beta versions may not be upgraded by serial port upload. Version 7.5.2 requires a special two step upload procedure. That procedure is explained in detail in the README.TXT file contained in the ZIP'd upload file set available from the Sigma Systems web site.

Use a DOS bootable diskette and a PC type computer to load the new firmware through the C4's serial port. You can obtain the required diskette from Sigma Systems for a fee, or you can provide your own DOS bootable diskette and obtain the necessary files for the upload process from the Sigma Systems site on the Internet. The Internet address for the site is:

www.SigmaSystems.com

The download file, SSUPxxxx.EXE, may contain specific instructions that replace the instructions in the next paragraph. After downloading the file, copy it to an otherwise empty DOS bootable diskette and run SSUPxxxx.EXE. This file is a self extracting ZIP archive that will install all the files you need onto the diskette. Check for the presence of a README.TXT file on the diskette for instructions that supplement or supercede these instructions.

3.2.2.a Making the physical connection for upload

To upload firmware to your C4, you will need to connect the C4 to a DOS bootable PC compatible computer using a straight-through, or modem type serial cable. The C4 is configured as DCE (Data Communications Equipment). Therefore, do NOT use a "null modem" type serial cable that has pins 2 & 3 crossed. Connect the cable to either COM1 or COM2 on the PC and to the female DB25 connector on the back of the C4.

3.2.2.b Running the upload software on the PC

After you run the SSUPxxxx.EXE file on your DOS bootable diskette you are ready to run the software. Place the floppy in the "A" drive of the PC and turn on or reset the PC to allow it to boot from the floppy. Follow the instructions on the screen. Note that the menu will allow you to do successive uploads without restarting and will allow you to change serial ports as you do so. Users who will be uploading to a number of controllers in one session will find that this feature saves some time.

If the uploads are being done on a bench (as opposed to leaving the controller in it's chamber or platform housing), be certain to follow all precautions about removing all power before removing the controller and about taking care to use proper anti-static procedures when handling the controller. Be certain that the bench has a properly grounded anti-static surface.

If you are going to upload firmware into many controllers successively in a bench environment, you can use a PC with two serial ports (COM1 and COM2) and two serial cables. You can then have the upload program alternate serial ports for the uploads so that you can upload to one controller while connecting and disconnecting the other.

3.2.2.c Starting the upload on the C4

When the PC is ready, turn the C4 controller on. During the 1 second display of the model number, rapidly press <CLEAR/PROG> three times. The display will read:

rS LOAd

The firmware upload should begin immediately. The PC will indicate when the load is complete.

If you have difficulties, see the trouble shooting information in §9.3.8.

3.3 Restoring Setup Parameters to Default Values

Note: The default values are very generic. They are not the values that were likely in the controller when it was shipped from the factory. After completing this procedure, please check each value to make certain that it is appropriate.

To restore the default values to the setup parameter table, turn the controller off, then back on. During the 1 second in which the controller model is displayed, press **<CLEAR/ENTRY>** very quickly 3 times. The display should then read

Su rES

Press **<ENTER>** to confirm that you want restore the default values. (Any other key will abort the process). The display should then read

EE buSY and then Su dOnE

Turn the controller off, then on again to resume operation with the new values. If the EEPROM is new, the first time the controller is turned back on after restoring the default setup parameters, the display will show ALL rES. The mode switch must then be turned to SETUP. (You may see an EE buSY display and model number and/or firmware version number at this time.) The controller forces you to Setup Mode before it will function as a reminder that the default values have been loaded and that the parameters needed for your operation have not yet been set. When you have set the necessary parameters for your needs, you are ready to go to LOCAL, PROGRAM, or Remote Mode.

3.4 Fahrenheit Operation

The C4 can use either Celsius or Fahrenheit temperature scales. Celsius is the default mode. When the controller is operating in Celsius mode it's behavior is identical to the model CC-3 controller. When the controller is operating in

Fahrenheit mode, both the displays and the bus communications are different. These differences are intentional and designed to prevent errors that might arise from a user using setpoints in one scale while the controller is operating in the other scale. Note, however, that there is no difference in the Program Mode programming operation of the C4 when operating in either Fahrenheit or Celsius mode. It is incumbent upon the user to notice the differences in the temperature displays and program accordingly.

To change the temperature scale, use Setup Mode (See §8) to access setup parameter F16. Select either of these field values:

0	Celsius
1	Fahrenheit

When in Fahrenheit mode, temperature displays have an "F" following the probe identifier on the left side of the display. Example:

P1F 102.4

Likewise, temperature inquires over the bus (PT command - See §7.5.7) will return a string with an "F" as the third byte in the string. The string will therefore be 1 byte longer than the string returned in Celsius mode. This difference was intentional as it requires a modification of the parsing routine that will assure that Celsius and Fahrenheit data are recognized properly. Thus, if the current probe 1 temperature is 86.7°F, the result of a Fahrenheit mode get temperature query for probe 1 (query command = PT1) would be

T1F 86.7<CR><LF>

If the temperature at probe 1 was 55.4°C, the same command in Celsius mode would return

T1 55.4<CR><LF>

During Remote Mode operation, the C4 may be queried to determine the current temperature scale by using the QS, Query Setpoint, command. See §7.7.7.

3.5 System Operating (Temperature) Range

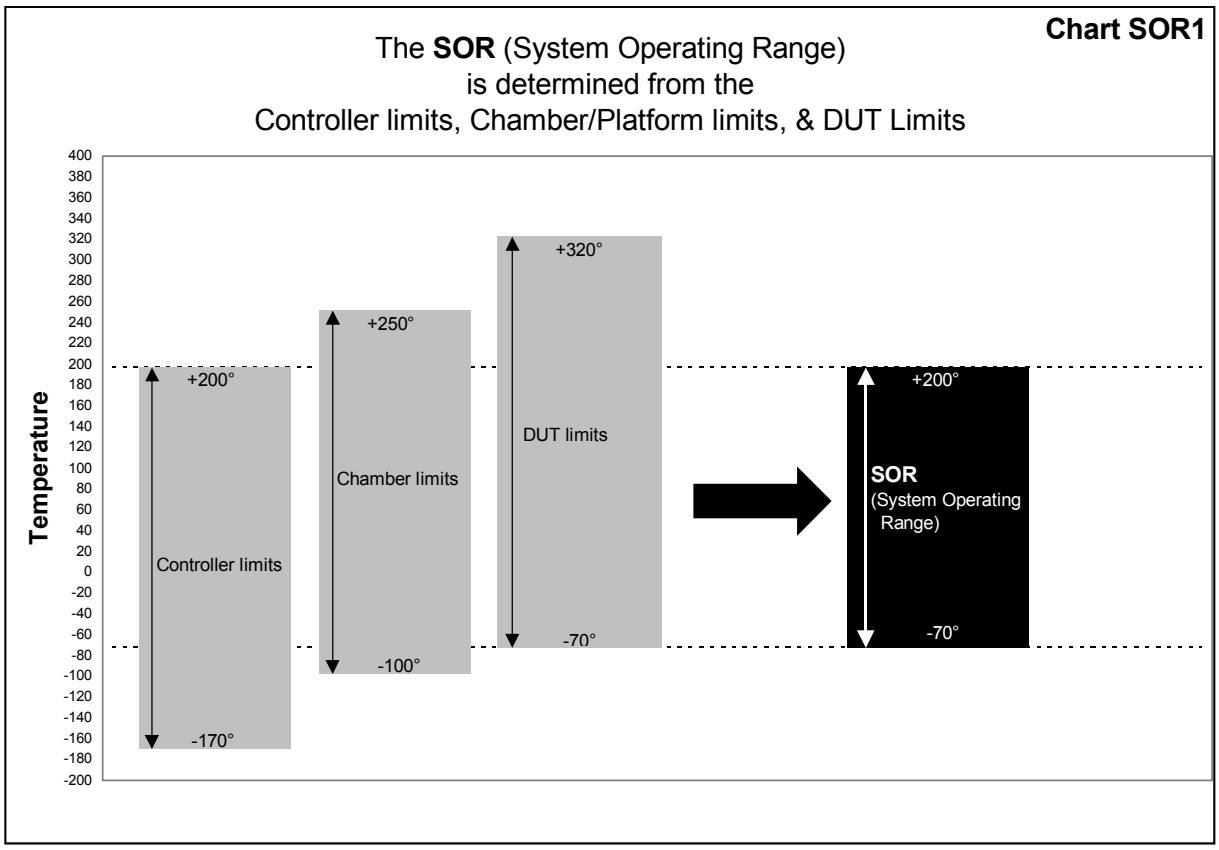
The C4 controller operates within the limits of the system devices and the DUT (Device Under Test). There are 3 pairs (low-high) of temperature limits that constrain the range of operations:

1. The range of the C4 as it is set at the factory

2 The range of the controlled device (chamber or platform) as described by setup parameters F25 & F26.

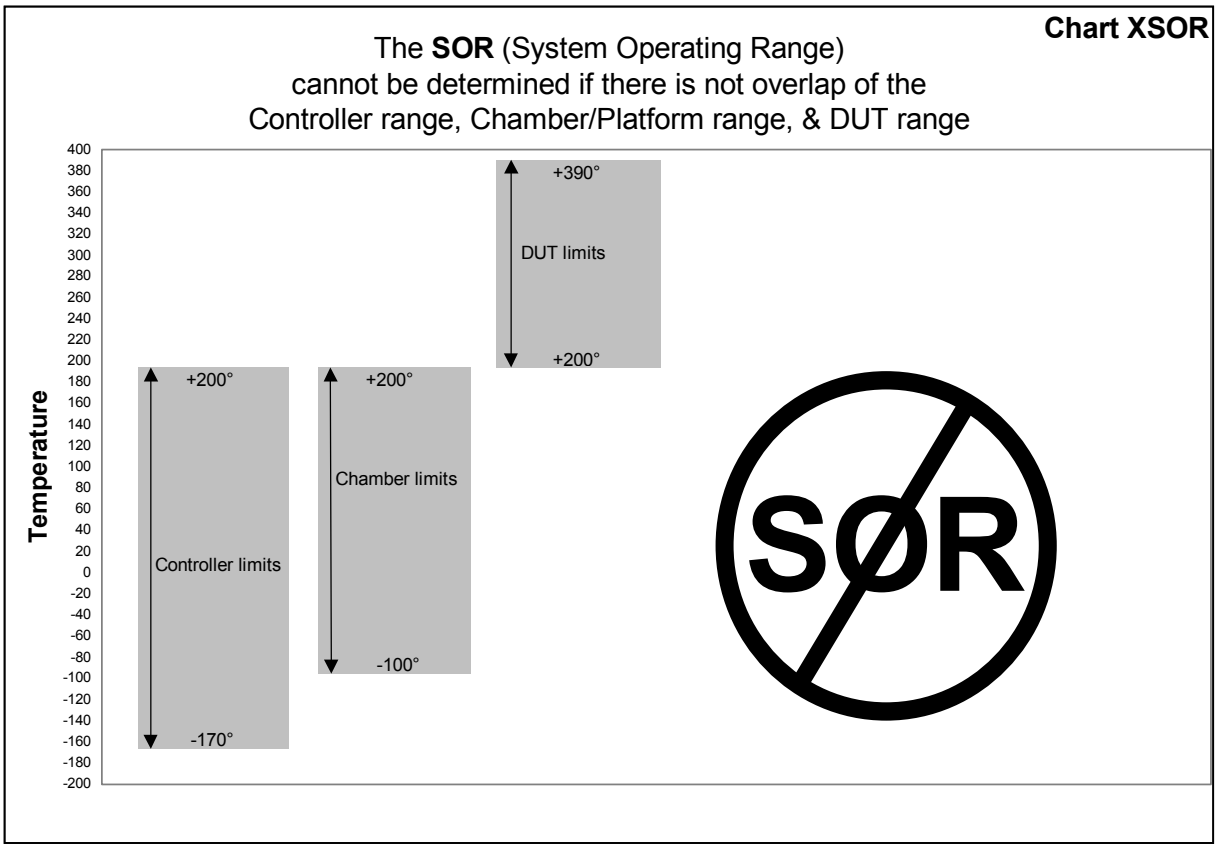
3 The range of the DUT (device under test) as described by setup parameters F27 & F28.

Each of these ranges is characterized by a low limit and a high limit. The highest of the 3 low limits is the System Operating Range Lower Limit. The lowest of the 3 high limits is the System Operating Range Upper Limit. In other words, the controller will respect the most restrictive limits that are described by the combination of the 3 ranges listed above. See the chart below.



The **System Operating Range** is the range where all three sets of limits overlap. The controller will not accept setpoints outside the System Operating Range and will report error conditions and stop controlling if the controlling probe(s) report a temperature too far outside that range.

There must be some overlap of the ranges of the controller, chamber or platform, and DUT for a valid SOR to be defined. If the controller range plus the ranges defined by F25, F26, F27, & F28 do not have any overlapping range, then a valid SOR cannot be determined.



In this case, the controller will display

SOr Err

and will set Byte 2, bit 5, of the Error/Status String. This error will also be generated if either the chamber/platform limits or the DUT limits are entered backward, that is if F25>F26 or if F27>F28. When this error is displayed, only Setup Mode will be active so the problem can be corrected before continuing.

3.6 Probe Out of Range Shutdown

When the C4 is actively controlling the temperature of a chamber or platform, it frequently checks to be certain that the control temperature, as reported by any active control probe, is within the System Operating Range.

In the event that the temperature reported by the active control probe is more than 20°C, and less than 50°C, outside the controller's System Operating Range, then the

controller will presume that a “run away” condition exists. The controller will turn off all heating and cooling and stop controlling. Blowers will be left in the condition determined by setup parameter F15 (Blower shut-off mode). The controller display will show

P1 LO P1 HI

“LO” indicates that the reported temperature was 20-50°C below the System Operating Range. “HI” indicates that the reported temperature was 20-50°C above the System Operating Range. The number following the P is the number of the probe that reported the excessive temperature.

In the event that the control temperature reported by the active control probe is more than 50°C beyond the System Operating Range, the controller will presume that the operation of the probe has been compromised by an open or shorted circuit. The controller will turn off all heating and cooling and stop controlling. Blowers will be left in the condition determined by setup parameter F15 (Blower shut-off mode). The controller display will show

P1 Err P1 -Err

The minus sign in the display indicates that the reported temperature was below the System Operating Range and the absence of the minus sign indicates that it was above the System Operating Range.

Note that because the C4 will report a HI or LO condition and stop controlling for an error of 20-50°C, the only events that will typically trigger an Err or -Err condition is an instantaneous failure of the sensing circuit, most likely an open circuit (Err) or short (-Err).

3.6.1 Effect of Probe Correction on Out of Range Shutdown

Any adjustments to the probe readings made by the Software Probe Correction feature (See §3.8) will not affect system over/under temperature shutdown operations. The raw (uncorrected) probe readings for the current active control probe(s) are used for the system health monitoring.

3.6.2 Probe Out of Range Shutdown Reported in Error/Status String

Any Probe Out of Range Shutdown will set a bit in Byte 03 of the Error/Status String. See §7.8.4.b for specific bit assignments.

3.6.3 Clearing a Probe Out of Range Shutdown

The Probe Out of Range Shutdown condition can be cleared by pressing **<START/STOP>** in Local or Program Mode, by rotation the mode switch on the front panel to a different position, or by issuing a Device Clear in Remote Mode.

3.7 Internal Error Shutdown Conditions

The C4 monitors system health by keeping track of four internal areas; they are:

Processor health . . . . . Tracked by watchdog timer
Memory condition . . . . . Checked at startup
Setup parameter integrity . . . . . Checked continuously
IEEE-488 bus integrity . . . . . Checked continuously

The first three items, above, are discussed in sub sections below. The IEEE-488 bus controller is automatically reset if a problem is detected. No message to the user is generated as no data is typically lost in the process.

3.7.1 Watchdog Timer

Should the system become locked due to corruption that causes the processor to continuously malfunction, an independent watchdog timer will cause a full system reset. After a watchdog reset, the display will show

rES Err

When this occurs, the mode switch must be turned to the OFF position, then back to the desired mode to clear the reset message and continue operation. Internal memory will be the same as it was when the shutdown condition occurred.

3.7.2 Memory Signature Checking

Each time the C4 is powered up, the system checks a series of memory signature bytes to test the integrity of system memory. If the signature bytes are not correct, the system assumes that memory has been compromised. If this should occur (a normal event any time a memory chip is replaced) all of system memory is reinitialized. All program steps for Program Mode are reset to their default values, and all setup parameters are reset to their default values. The display will show

ALL rES

The mode switch must be subsequently turned to the SETUP position to clear the display and resume normal operations. Be sure you remember to restore any setup parameters that have been changed by the system reset.

3.7.3 Setup parameter integrity checking

Each time the system must rely on a system setup parameter the condition of the setup parameter table is checked against a replica that the system stores in another place in memory. If there is any difference between the two copies of the parameter table, the system will try to determine which table is correct and restore the correct copy. If restoration is not possible, the system will turn off all heating and cooling, reinitialize the setup parameters to their defaults, and display

Su Err

The mode switch must be subsequently turned to the SETUP position to clear the display and resume normal operations. Be sure you remember to restore any setup parameters that have been changed by the system reset.

3.8 Software Probe Correction (Calibration)

The C4 will allow you to enter data via Setup or Remote Mode that will correct any anomalies in the temperature readings and control at two points. Such adjustments are sometimes necessary to optimize accuracy at a particular temperature, or to compensate for differences between raw probe temperature data and actual temperatures.

Note: The purpose of Software Probe Correction is to allow precise calibration at two points near the critical points of the user's testing scheme. It does not replace the hardware calibration process, nor should it. A number of system health checks as well as process limits are based upon the raw, or uncorrected, temperatures reported by the probes. It is important to optimize the hardware level calibration before using this software calibration method.

Software probe correction is achieved by entering four temperatures, U1, C1, U2, & C2, for each probe into the setup parameter table. U1 & U2 are the uncorrected, or displayed, temperatures at two points. C1 & C2 are the corrected, or actual, temperature at those same two points. Thus to make a correction using ice water (0°C) and boiling water (100°C) when the display shows 2.3°C for the ice water and 99°C for the boiling water, the user would enter the following:

U1	2.3
C1	0
U2	99
C2	100

The C4 will then calculate a new slope and offset for the entire probe curve. All temperatures reported by the corrected probe will be adjusted by applying this new slope and offset to the raw temperature data reported by the probe.

Note: Software probe correction is done separately for each probe. The following table shows the U1, C1, U2, C2 setup parameter assignments:

	Probe 1	Probe 2
U1	F17	F21
C1	F18	F22
U2	F19	F23
C2	F20	F24

Entering these parameters via Setup Mode is discussed in §8.3.5.
Changing these parameters "on the fly" in Remote Mode is discussed in §7.6.1

3.9 Status and Error Reporting

In Local Mode and Program Mode, the only source of error and status data is the front panel display. A list of all possible displays with section references for detailed information is contained in §9.5. Remote Mode also provides information via the error status system consisting of the following:

The Status Byte

The Error Byte

The Error/Status String (64 bytes)

Note that beginning with C4 firmware version 8.0.0, all three of these sources have been substantially changed. Routines that accessed this information from previous versions of the firmware will have to be rewritten to accommodate the new bit definitions and behavior. See §7.8 for detailed information.

3.10 Fail-safe System

The C4 is designed to sense the loss of control circuit power due to opening of a "fail-safe" thermal limit switch such as those supplied with all Sigma chambers and thermal platforms. If the controller is in the RUN mode and the fail-safe is tripped,

the controller will stop controlling and display FL SAFE on the digital LED display. It will also report the fail-safe tripped condition over the computer bus interface if in use. In order to re- establish normal operation, the failsafe system on Sigma chambers and thermal platforms requires that power be cycled off, then on, in addition to the out of range temperature condition subsiding. Turn the rotary mode switch to OFF to clear the fail-safe condition.

If the controller is to be used independently of a Sigma Systems temperature chamber or thermal platform, connect pins 10 & 11 of the 12-pin power plug to pin 3 for 120 volt operation. In the case of 208-240 volt operation connect pins 10 & 11 to pin 6 through a pair of 56kS ½ watt resistors in parallel. Opening this connection will cause the above described failsafe condition.

3.11 Ramp Timeout Function

The temperature chamber or thermal platform connected to the C4 has the ability to transition a test environment from one temperature to another. Commands are given to the C4 to control these temperature transitions and there is often an expectation, based upon the heating and cooling capabilities of the platform or chamber, that these temperature transitions can and will take place at some acceptable rate. The Ramp Timeout Function allows the user to set the minimum acceptable level of performance (ramp rate) for temperature transitions. If, during a temperature transition, the chamber or platform fails to maintain, for two successive minutes, a ramp rate at least equal to the minimum rate specified, a timeout notice is generated.

The Ramp Timeout Function is useful for two purposes:

For repetitive testing or conditioning, a ramp rate can be set that is a minor percentage below the chamber or platform's known rate. If a malfunction should occur such as a heater failing or cryogenic coolant becoming depleted, that degrades the performance of the chamber or platform, the Ramp Timeout Function may notify the user of a problem.

For precision ramping using the C4's ramping commands, the Ramp Timeout Function will notify the user if the chamber or platform is not able to maintain the specified ramp rate. With the Ramp Timeout Function, a user specifying a ramp rate for a temperature transition needn't constantly monitor the process temperature to know if the specified ramp is actually being maintained. The failure to meet the specified ramp rate could be because the chamber or platform is not capable of the rate requested, or because of a chamber or platform component failure, or for other reasons. The issue may later be to determine why a ramp rate is not being maintained. The purpose of the Ramp Timeout Function is to inform the user that the requested ramp rate is not being maintained.

Note: Because the C4 slows the ramp rate as it approaches the setpoint to avoid overshoot, it also disables the ramp timeout function as the setpoint is approached.

For some applications, performance is not as critical. If the C4 is being used in Remote Mode, the GT (go to temperature) and RA (ramp to temperature) commands can pass a Ramp Timeout parameter along with the setpoint temperature and ramp rate data. When a Ramp Timeout parameter is passed with the GT, GTF, RA, or RAF command, the passed value is used for the Ramp Timeout Function comparison. By using this feature, the number of unwanted Ramp Timeout notices can be reduced while still monitoring system performance.

3.11.1 Ramp Timeout Notice

When the Ramp Timeout Function determines that the chamber or platform has failed to maintain the minimum specified ramp rate for two successive minutes, a Ramp Timeout Notice is generated. The nature of the timeout notice depends on the mode of C4 operation.

In Local Mode, the display will show:

-rA-

In Program Mode, the display will include the program step number that was being executed when the ramp timeout occurred. Example:

04 -rA-

(Timeout occurred while executing program step 4)

To clear the error notice and return the display to normal, press **<DISP/TEMP>** **<DISP/PROG>**, or **<ADV>** (ADV key available only in Program Mode).

In Remote Mode, the notice is sent by setting bit 7 of the Error Byte. See §7.8.2 on Error Byte handling.

The notice is information only. The ramp timeout notice does not change the function of the controller or modify the temperature control process in any way. When the notice is posted to the display or the Error Byte, it will remain there until it is cleared (Local or Program Modes), or read (Remote Mode) by the user. This is true even if the C4 has gone on to execute additional commands or program steps.

3.11.2 Ramp temperature comparison value sources

During a temperature transition, the Ramp Timeout Function operates by comparing the actual ramp rate being achieved by the chamber or platform with a comparison value obtained from one of three sources. The source used depends on the mode and the command used to request the temperature transition.

C4 controller mode of operation and command used	Notes	Source of timeout comparison ramp rate
Local Mode	1	Setup parameter F33
Program Mode ramp step that does not specify a ramp time in substep 1	1	Setup parameter F33
Program Mode ramp step that does specify a ramp time in substep 1	1	The ramp rate specified (the degrees to be transitioned divided by the time in minutes)
Remote Mode GT or GTF command	1	Setup parameter F33
Remote Mode RA or RAF command	1	The ramp rate specified (the degrees to be transitioned divided by the time in minutes)

Remote Mode GT, GTF, RA, or RAF command with optional Ramp Timeout comparison value passed as optional command parameter	2	Value passed as optional parameter

Note 1: If setup parameter F33 is set to 0, the Ramp Timeout Function is disabled for all temperature transitions except Remote Mode commands that pass the optional Ramp Timeout comparison value with the command.

Note 2: The Ramp Timeout comparison value passed as an optional parameter with a GT, GTF, RA, or RAF command is used for the Ramp Timeout Function for that one instance of the command only. In this mode, the Ramp Timeout Function will operate for that one instance of the command even if setup parameter F33 is set to 0.

3.11.3 Using & Disabling the Ramp Timeout Function

If you do not wish to use the Ramp Timeout Function, set setup parameter F33 to 0, it's default state.

To use the Ramp Timeout Function for all temperature transitions, set the minimum ramp rate that makes sense for your chamber or platform. For example, if you have a platform that can ramp up at 40°C/minute and ramp down at 60°C per minute, you might want to set F33=30. If you need to be sure that each of your ramps is at least 40°C/minute, set F33=40 and the Ramp Timeout Function will notify you if the platform fails to maintain that ramp rate. The legal values for F33 are 0 (disabled) or .1 to 100 (°C/minute). See §8 for setup parameter information.

Note, however, that setting the rate very close to the performance limits of the chamber or platform will increase the likelihood of a Ramp Timeout Notice. There is a trade off between close monitoring and overhead required to process incessant notices.

Once F33 is set, the Ramp Timeout Function is automatic. In Local, Program, or Remote Mode, each temperature transition is checked against the specified ramp rate, or the value in F33 per the table in §3.11.2.

To use the Ramp Timeout Function for a single instance of a GT, GTF, RA, or RAF command in Remote Mode, simply pass the optional Ramp Timeout comparison parameter with the command. See §7.7.4 through §7.7.5 for the syntax for these commands.

3.12 Component Fault Sensing System

If your chamber or platform is constructed with a Sigma Component Fault Sensing System, and that system detects a reportable fault, the system fault indicator will light, and bit 1 of the Error Byte will be set. The state of the fault sensing input to the C4 can be checked in bit 6 of byte 33 of the Error/Status String. See §7.8.2.c.

3.13 Bumpless PID Transitions

When the setpoint is changed, the PID control algorithm begins a new “search” for the right amount of heat and/or cooling to maintain the new setpoint. Normally, for each new setpoint, the PID routines begin the search anew... behaving as if the controller was just turned on. The controller will quickly determine that heat or cooling is called for, and while the chamber or platform advances toward the new setpoint, the PID routine adjusts for the response to heat and cool and methodically settles the chamber or platform in on the new setpoint. For most setpoint changes, where the new and old setpoints are quite different, this is a fast, accurate and appropriate method of control.

However, when the change in the Setpoint is very small, this “start from the beginning” search routine can search over such a wide range that it will introduce a “bump” in the platform or chamber temperature that can exceed the amount of the setpoint change. The C4 includes an intelligent “bumpless” PID routine that constrains the search appropriately for any change in setpoint where the new setpoint is within 5°C (9°F) of the current temperature. As a result of this bumpless routine, the minimum time required to achieve the new setpoint will be no less than 1 minute for each 1°C (1.8°F) of temperature change requested. Bumpless transitions are only used for Local Mode, Program Mode "9900" steps, and Remote Mode GT commands.

The bumpless control routine is not active by default. If you want to use the bumpless routine, you need to set Setup Parameter F7 = 1 (enabled). See §8.

3.14 Controlling with Probe 2

The C4 can use either temperature probe for control. Typically the probe 1 inputs on the controller are connected to the probe which is located in the temperature chamber air stream or in the thermal platform surface. Probe 2 can be located anywhere the user chooses. Probe 2 can then be read via the C4 and/or it can be used for control. Using probe 2 for control can occasionally provide some benefits, but it also presents significant risks.

3.14.1 Benefits of Probe 2 Control

The benefits of using probe 2 for control derive from placing probe 2 in or near the thermally critical area of the DUT (Device Under Test). There is almost always some gradient within a chamber or platform and it’s test mass. As probe 1 is located at the back of the chamber or deep within the thermal platform surface, the temperature that is measured by that probe will be slightly different from the DUT temperature. It is often quite satisfactory to “calibrate out” that difference using the probe correction feature (see §3.8 & §8.3.5), or compensate in some other way if the difference is not within the required tolerance. However placing probe 2 at, within, or near the critical DUT mass can allow the C4 to more accurately control the temperature at that position.

Warning: Using probe 2 for control without the establishing the proper safe operating limits and/or setting the proper PID constants can cause "run-away" conditions that can potentially ruin test loads and subject operators to unexpected temperatures.

3.14.2 Risks of Probe 2 Control

The risks of using probe 2 for control center around two issues:

(1) Maintaining the integrity of the probe location, and

(2) Adjusting the PID settings to reflect the thermal characteristics of the load at the probe 2 position.

3.14.2.a Maintaining the integrity of the probe location

The C4 uses the information from the controlling probe to determine whether to add or subtract heat from the system. As the probe that is built into the chamber or platform is normally connected to the probe 1 input of the controller, and as that probe is typically well protected and permanently positioned, using probe 1 for control is both reliable and safe. However, as probe 2 can be located anywhere, it is incumbent upon the user to be certain that probe 2 is located properly within a chamber or attached securely to a mass thermally connected to a platform.

If the controlling probe become compromised, or is not within the area controlled by the controller, the temperature reported by that probe will not accurately reflect the operating conditions within the test environment. As a result, the C4 will determine that heat should be added or removed from the test environment based upon this erroneous data. Catastrophic over or under heating ("run-away") can easily result. As an example:

The ambient air temperature is 22°C
The setpoint for the C4 is set to 70°C using probe 2
Temperature control is started
Probe 2 is accidentally left outside the chamber

The C4 obtains the temperature of 22° from probe 2 and determines that some heat needs to be added to achieve the 70° setpoint. The chamber temperature rises to 30°, 40°, 50°, 60°, 70°, etc. However, probe 2 has been left outside the chamber, so it continues to report 22° to the C4. As the C4 does not "see" the increasing temperature inside the chamber, it continues to apply more heat to get the temperature at probe 2 to achieve the 70° setpoint. No matter how hot the chamber gets, probe 2 continues to report 22° and the C4 continues to call for more heat. The chamber will continue to heat until some limit is reached that will stop the process.

If probe 1 is properly located in the chamber air stream, and the system operating limit (SOR) is properly set (see §3.5), the C4 will stop controlling when the SOR limit

is reached. If an external fail-safe is available and properly set, that device may bring the process to a stop. Users using probe 2 for control should always make certain that all of these safeguards are properly implemented.

3.14.2.b Adjusting PID for Probe 2 Control

The PID settings used for "normal" probe 1 control are a reflection of the thermal characteristics of the chamber or platform and load at the position of probe 1. If probe 2 is used for control, the thermal characteristics at the position of that probe may be quite different. For instance, if probe 1 is located inside a chamber, but probe 2 is located within a thermally slow DUT located inside the chamber, the response of each probe to a heat input will be quite different.

Example:

> Probe 1 is located within the chamber air stream in the normal position
> Probe 2 is located at the center of a DUT that is placed inside the chamber. The DUT core, where probe 2 is located, is somewhat isolated from the DUT shell by a layer of silicone rubber.

When additional heat is applied to the chamber air stream, probe 1 will see that heat almost immediately. However, due to the longer thermal path, and the silicone rubber barrier within the DUT, probe 2 will not see the increased heat for some time. The thermal response over time (the time constant) for each probe is not the same. The PID parameters for proper control will very likely be quite different for probe 1control as compared to those for probe 2 control.

If all control is done using probe 2, then the PID settings can be adjusted to work properly with probe 2. However, if probe 1 control is used (including T-Drive - see §4.2) for part of the control process and then control is switched to probe 2, the PID settings may need to be changed "on the fly".

To change the PID terms during program execution in Program Mode, use the special PID specification step detailed in §6.2.8.

To change the PID terms while in Remote Mode, use the WP command as detailed in §7.3.1.c & §7.6.2. The changes will take effect immediately.

3.15 Output Port Use, Configuration, & Control

There are six controlled output ports on the C4. They are:

Cooling
Heating 1
Heating 2 (boost)
Blower
Refer
Aux/Power

The **cooling port** is a line voltage, high current, pulse width modulated output used to control a solenoid coolant metering valve. This valve controls the flow of coolant, either refrigerant from a closed loop compressor based system, and/or an expendable cryogenic coolant such as liquid Carbon Dioxide or liquid Nitrogen. The cooling port is under the exclusive control of the PID temperature control routine. There is no direct control of this port available to the user.

The **heating ports** are line voltage, high current, pulse width modulated outputs used to control two sets of resistance heating elements. They are called Control Heat and Boost Heat. Functionally, the two ports are identical and are typically used in unison. There are two ports for heating as the current loads can be substantial for some chambers or platforms. Dividing the load between two circuits allows lower current on each. The two circuits are turned on and off in identical patterns but are a few cycles apart in operation to reduce inrush spikes and noise. If Power Sharing (See §8.3.6.a) is enabled, the Boost Heat port is disabled when the refrigeration compressor port is on.

The **blower port** is a line voltage, high current, switched output used to control the air circulation blowers in temperature chambers. There is limited user control over this port when the chamber is in idle mode (not controlling temperature). The blower port control feature is Blower Shut-off Mode. Blower shut-off mode is set by setup parameter F15 (see §8 and §8.3.3) and can be controlled in Remote Mode with the BO and BF commands (see §7.6.4).

The refrigeration Refer Port, the "**Refer Port**", is a TTL level output used to control a power switching device such as an SSR that powers the compressor and other components of a mechanical refrigeration system in a chamber or platform. The Refer Port is under direct user control. The C4 does <u>not</u> automatically turn the refrigeration system on or off based upon cooling demand. The Refer Port is set to its default condition as determined by setup parameter F6 (see §8 and §8.3.6) upon power up or reset (see exception for Autostart mode, §8.3.2). The behavior of the port is directly controlled by special program steps in Program Mode (see §6.2.2-3), or by the CO and CF commands (see §7.7.8) in Remote Mode. A complete description of the Refer Port control operation can be found in §7.7.8. The general behavior of the port is detailed in §2.2.2.

The **Aux/Power Port** is a TTL level output used to control a power switching device such as an SSR that powers a user load, or to enable and disable the cryogenic boost system that was optionally supplied with a mechanically refrigerated unit, or some other special purpose. The Aux/Power Port is under direct user control. The Aux/Power Port is set to its default condition as determined by setup parameter F5 (see §8 and §8.3.6) upon power up or reset. The behavior of the port is directly controlled by special program steps in Program Mode (see §6.2.4-5), or by the TO and TF commands (see §7.7.9) in Remote Mode. The general behavior of the port is detailed in §2.2.2.

4. IMPROVING PRODUCTIVITY

Note: All the Sigma Systems Productivity Improving features described in this section are the subject of a variety of U.S. and foreign patents pending.

This section will show you how to use the special features of the C4 controller designed to reduce the time required for a thermal testing or conditioning process using a temperature chamber or thermal platform.

Thermal testing and conditioning involves moving heat. Moving heat takes time. Time spent waiting for the process determines productive output. When you use a temperature chamber or thermal platform, you wait upon two events:

> First, you set the temperature of the chamber or platform containing your DUT (Device Under Test) to the desired temperature, and you wait for the system to stabilize at that temperature.
>
> Then you wait for the heat to move into or out of the DUT.

While we can't change the fact that it takes time to move heat into or out of your DUT, we can use the advanced features of the C4 controller to change the traditional approach to thermal processing to a more sophisticated one and substantially reduce the time required for your process.

The three features that can shorten your process and save you time are:

> Adjustable Settling Band
> "Touch 'n Go"
> T-Drive (thermal overdrive)

Adjustable Settling Band is important to you if use more than one temperature in a testing or conditioning profile. Adjustable Settling Band does not change the way the C4 controls the setpoint temperature. However, when you have multiple steps in your thermal profile, the controller needs to finish one step (example: going to a setpoint temperature), before going on to the next step. Adjustable Settling Band lets you specify how close the chamber or platform needs to get to the setpoint and how stable the temperature must be before the next command can be processed. If you need extreme accuracy and stability, you can ask the controller to meet your standard exactly. If, on the other hand, you can tolerate less rigid standards, you can specify that too and save a lot of test or conditioning time. For details, see §4.1.

Touch 'n Go is a special case of the Adjustable Settling Band feature. Touch 'n Go is designed to allow very fast cycling when you don't need to settle on a setpoint, but just need to "touch" the setpoint and then go immediately to the next step or setpoint. Touch 'n Go can cut rapid cycle times to a fraction of their normal time. For details, see §4.1.3.

T-Drive will bring the core of high mass or thermally slow objects to temperature much more quickly than the normal "just let it soak" method. If your DUT has high

mass and/or is a poor thermal conductor, the time required for the DUT core to come to the setpoint temperature can be substantial. T-Drive will apply a very controlled convergent thermal overdrive to force the DUT core to temperature quickly. T-Drive can do this while reducing or controlling the thermal stress on the DUT. For details, see §4.2.

4.1 Adjustable Settling Band

The Adjustable Settling Band feature is designed to only affect those conditions that must be satisfied for the controller to assert that a "go to temperature" command is complete. It does not affect the accuracy of temperature control. If you continue to request control at the same temperature (or simply have no command next in the buffer or program) the C4 will continue to try to stabilize ever closer to the setpoint, without regard to the settling band parameters.

Note: There is a low level interaction between the PID control routine and the settling band temperature range value (F31). The larger the value of F31, the larger the potential oscillations of the chamber/platform temperature as it settles upon the setpoint. However, this effect is normally trivial and inconsequential.

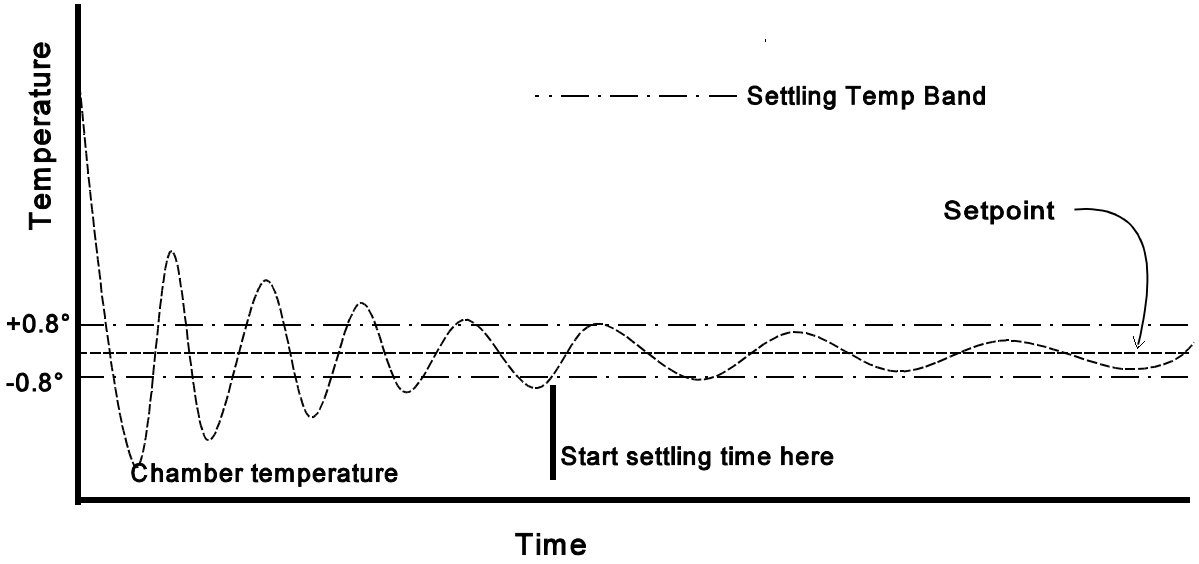
As the setpoint temperature is approached by the chamber or platform, the controller begins the process of determining how much heating and/or cooling is required to precisely maintain the setpoint. The controller uses a PID algorithm that measures thermal responses to inputs of heat and cooling. The controller uses an iterative process of applying heat or cooling, measuring the temperature response over time, applying a modified amount of heat or cooling based upon the previous responses, etc. As the dynamics of the load, coolant availability, etc. begin to stabilize, and as the controller "learns" more about the load response characteristics, the temperature "settles in" toward the setpoint. As this process progresses, there is typically an ever decreasing oscillation of the temperature about the setpoint. At some point in time, the deviations from the setpoint have been small enough for a long enough period of time that the controller will assert that the setpoint has been achieved. The command to control the temperature to that setpoint has been "satisfied".

When the controller has satisfied a "go to temperature" command, it can process the next command. If the next command is a "hold" or "dwell" command, then the controller will begin that hold interval. If the next command is another "go to temperature" command, then the controller will begin the process of going to the new temperature. <u>The critical issue here is that the current command must be "satisfied", before the next command can be processed</u>. Settling band parameters determine when a "go to temperature" command is satisfied.

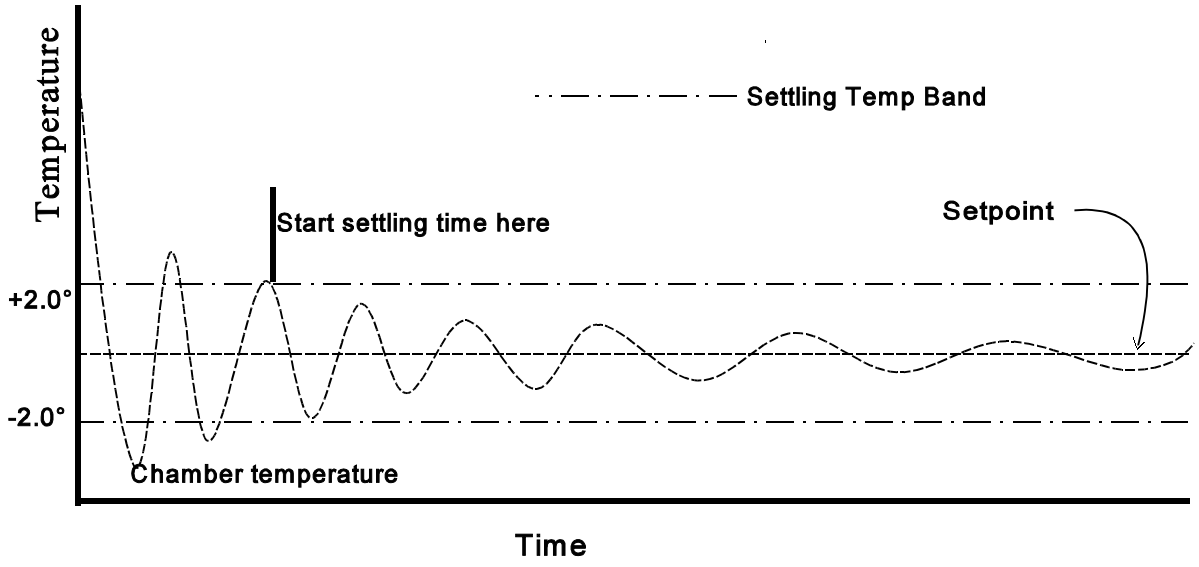
The default parameters for the settling band in the C4 are 0.8°C and 15 seconds. The C4 will consider that a "go to temperature" command has been satisfied if the chamber or platform temperature, as reported by the controlling probe (usually probe 1), remains within ±0.8°C of the setpoint continuously for 15 seconds.

4.1.1 Adjustable Settling Band Temperature Range (F31)

The chart below is an example of typical chamber or platform temperature oscillation as the setpoint is approached. Note the dashed lines above and below the setpoint. These lines indicate the settling band temperature range. Note also the heavy vertical line at the point in time where the chamber temperature begins remaining within the settling band temperature.



Note that if the settling band was wider (example ±2° instead of ±0.8°), the time period in which the chamber temperature is within the band would begin sooner and conditioning/test time would be shortened. An example:



Conversely, if you require extremely tight tolerance temperature control before moving on the the next program step or beginning a test, you could set the settling temperature band to be much narrower, but you would have to wait longer for the temperature to "settle down" within that range.

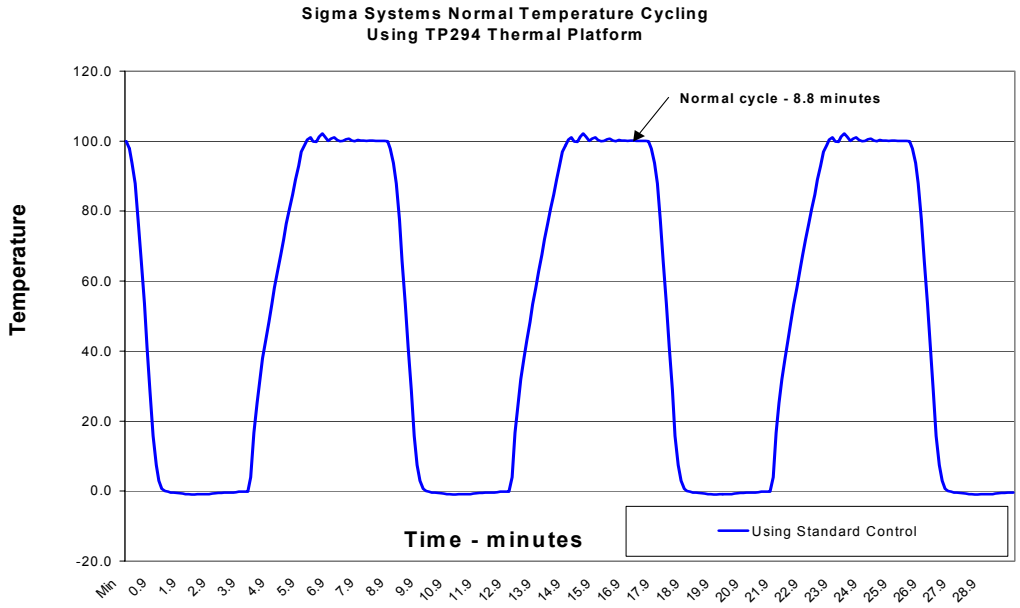
You can often save substantial time by setting the settling band parameters to the largest value (lowest tolerance) that is appropriate for your process. The valid range for F31 is 0.1°C to 10.0°C (0.2°F to 18°F).

4.1.2 Adjustable Settling Band Minimum Stable Time (F32)

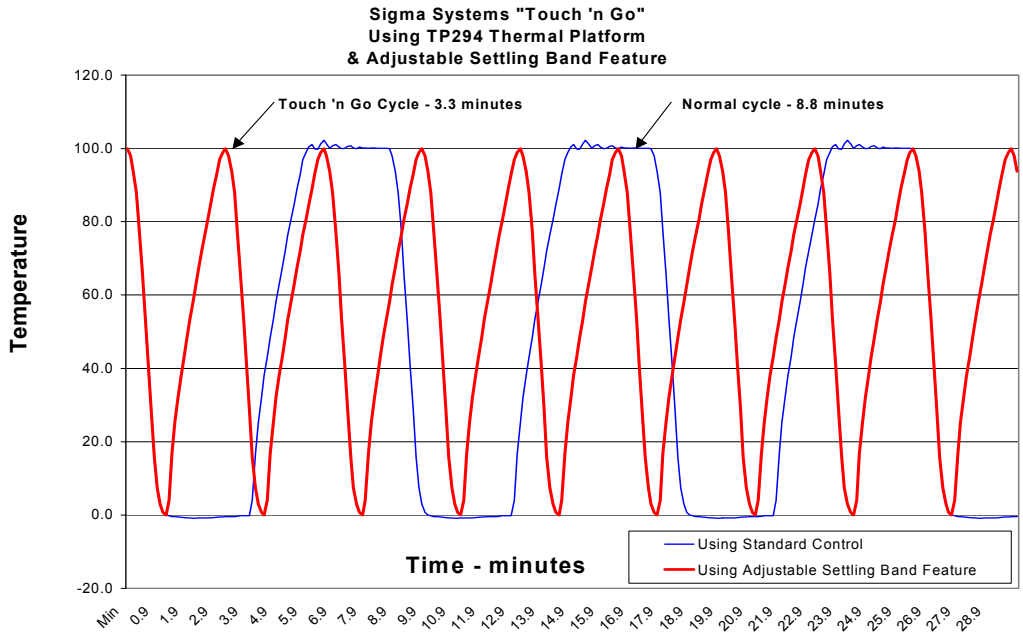
You can also set the length of time that the chamber or platform must continuously remain within the temperature band to satisfy a "go to temperature" command. The 15 second default is probably appropriate for most uses. If you are conditioning a very large thermal mass, the period of the temperature settling oscillations about the setpoint may be more than 15 seconds. The minimum settling band settling time (F32) should be at least equal to the period of the DUT settling oscillations so that the chamber or platform temperature will not move outside the settling band after the minimum stable time has expired. The valid range for F32 is 0 seconds(Touch 'n Go), or 0.1 second to 59 seconds.

4.1.3 Touch 'n Go fast cycling

If you need to run a fast cycling program between two (or more) temperatures, but you do not need precise settling at each temperature, you can use the C4's Touch 'n Go feature. Below is an example of a normal hot/cold cycle using the normal controller settling algorithm:



Touch 'n go allows extremely fast turn around for multi cycle or multi temperature profiles where it is only important to instantaneously reach a temperature before moving on to the next setpoint. Whereas most controllers require the full settling process for each temperature, the C4, with this feature enabled, will simply "touch" a temperature and then move on to the next step. Following is an example of the same hot/cold cycling using Touch 'n Go:



If you set the settling band minimum stable time to 0, the controller will consider a "go to temperature" command satisfied at the next instance that the chamber or platform temperature falls inside the settling band temperature (setpoint ± the settling band allowable temperature variance). Thus, instead of waiting for the temperature to stabilize within the settling band temperature range, the controller instead goes immediately to the next command. The C4 just "touches" the setpoint temperature, then "goes" to the next command.

4.1.4 Using Adjustable Settling Band to Increase Precision

If your application requires especially fine precision, you can use the adjustable settling band feature to be certain that you have achieved the objective by adjusting the settling band temperature range to a very small number and/or increasing the settling band minimum stable time. Increased precision will come at the expense of longer test/conditioning time. Note that if you demand exceptional precision, 0.1°C for instance, that even changes in the room air conditioning flow patterns can affect the ability of the system to stabilize to that tolerance. Ultra precise tolerance testing requires an ultra stable operating environment. If you are cooling using cryogenic coolants, ultra precise tolerance testing may also require that you make special efforts to assure a consistent delivery of liquid refrigerant to the chamber or platform cooling control valve. This can be a non-trivial matter. Sigma suggests that you

always test with the most tolerant settings that will do a proper job. While specifying increased precision may seem like extra insurance, it will often cost more than is expected in increased test/conditioning time and facilities problems.

4.1.5 Using Adjustable Settling Band

The settling band feature is always active in Program Mode and Remote Mode. As Local Mode has no ability to either report the satisfaction of the temperature request or to move on to another command, there is no effect in Local Mode.

If you choose to not use this feature, simply leave the default settings. The default settings are time proven values that have been in use in Sigma controllers for over 20 years. If you choose to use this feature, remember that there are two settling band parameters that you can set. They are:

F31	Adjustable settling band allowable temperature variance from setpoint (in degrees)
F32	Adjustable settling band minimum stable time

The values are stored in the Setup Parameter Table (see §8) as parameter fields F31 and F32. If you change the values in the Setup Parameter Table, the changes will be stored in non-volatile memory and are permanent until you change them again. The Setup Parameter Table values will be used for all further commands unless overridden by run time commands.

4.1.5.a Run-time settling band adjustment

Both Program Mode and Remote Mode offer commands to change the settling band parameters “on the fly”. In both cases, changes to the settling band parameters are made only to the working copy of the setup parameter table that is created when the mode is entered (using the front panel rotary switch). The changed values are used for all subsequent “go to temperature” commands unless changed again. In Program Mode there is no method for permanently storing the changes to the permanent Setup Parameter Table. Remote Mode allows the parameters to be permanently stored by use of the UP command. For more information on commands to change the settling band parameters in Program Mode see §6.2.6 or in Remote Mode see §7.6.7.

4.2 T-Drive (Thermal Overdrive)

Read the entire section on T-Drive before using it. T-Drive is a very powerful tool that does not lend itself to "Quick Start" use. It is extremely important that you have a thorough understanding of T-Drive and it's power and capabilities before use. Improperly used, T-Drive is quite capable of damaging your DUT and wasting a lot of your time. Used properly, it can save vast amounts of time and substantially improve thermal conditioning and testing throughput.

Common single probe control strives to maintain the setpoint temperature in either the chamber airstream, or at the platform surface. The DUT is then left in the chamber, or on the thermal platform, long enough to allow heat to transfer in or out so the DUT will assume the same temperature. If the DUT is massive, or is a poor thermal conductor, the internal temperature of the DUT can lag the chamber or platform temperature considerably for a long period of time.

If, while waiting for the DUT to "come to temperature", the conditioning is terminated too quickly, the DUT may not have actually achieved the desired setpoint test temperature. Therefore, most users of this traditional approach elect to "soak" the DUT at the setpoint for more time than it takes to get the DUT core to the required temperature. The typical and appropriate rationale is that it is better to waste some time in over soaking than it is to run a substandard test. As a result, test times are long and productivity is low.

Another approach is to use a second temperature sensor probe, buried inside the DUT (or a thermal imposter), to control the temperature. This may achieve better DUT interior temperature control, but it will do so at the risk of extreme temperatures in the chamber or on the platform and thus at the DUT surface as well. This method is so fraught with risks and control problems that it is seldom used after initial trials reveal the difficulties created.

T-Drive is designed to quickly and measurably achieve the setpoint temperature inside the DUT either as quickly as possible, or at a controlled ramp rate, while always respecting the limits of the controller, chamber or platform, and DUT. The user may specify not only the absolute limits of the DUT, but limit thermal shock as well by specifying a proportionally applied maximum temperature differential for the DUT skin to core temperature. T-Drive will maximize speed in achieving internal DUT setpoint temperatures, while, at the same time, controlling the thermal stress on the DUT.

T-Drive requires the internal temperature of the DUT (or a thermal imposter) to be used in the temperature control algorithm. Both the primary temperature probe, located in the chamber airstream or in the platform, and the secondary probe, typically located inside the DUT/imposter, are used to provide a chamber or platform response that can accelerate testing or conditioning while respecting the absolute and relative limits of all the affected components.

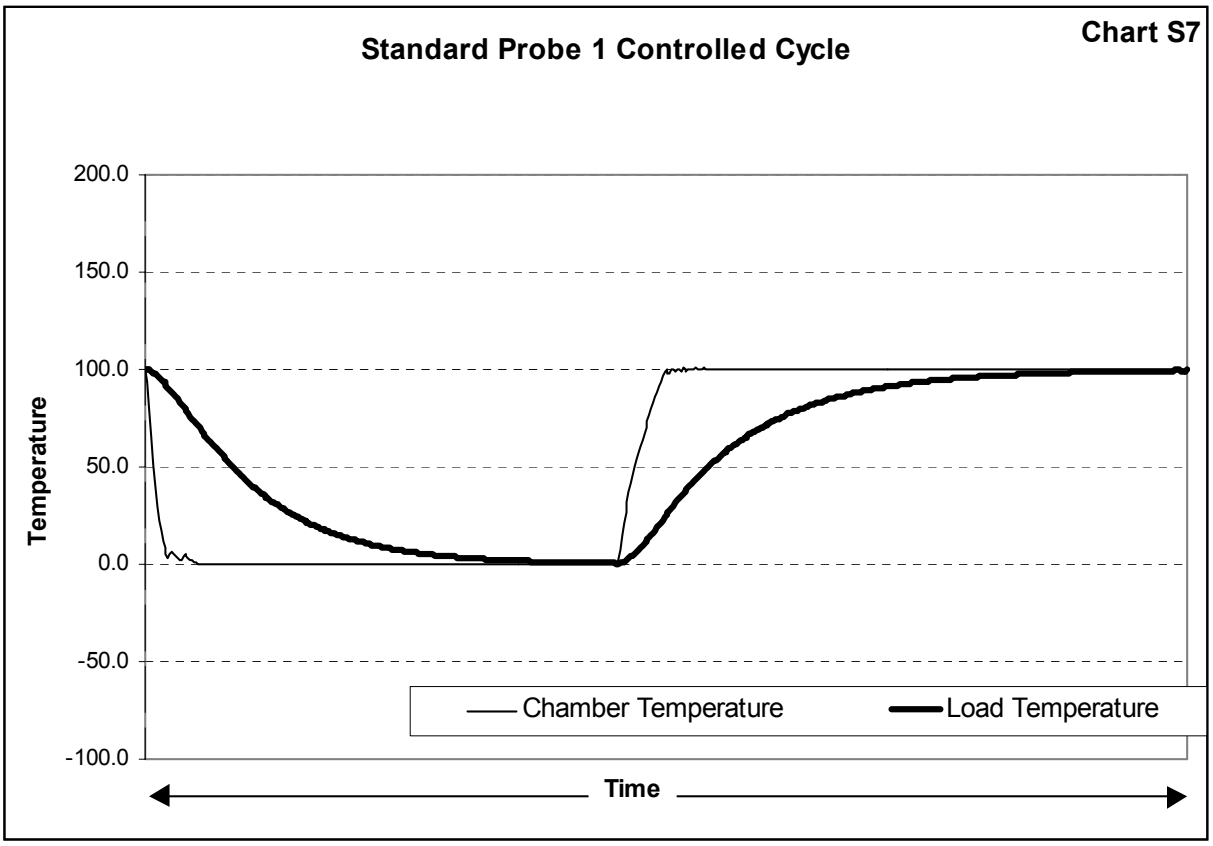
The Problem T-Drive Solves

T-Drive takes advantage of the fact that increasing the temperature differential between two objects increases the rate of heat transfer between them. For instance, if a thick and heavy object is to be heated from 0° to 100°, and the object is placed in a temperature chamber with a 100° internal air stream temperature, the temperature of the object will rise quickly at first because of the large temperature differential between the chamber air stream and the object.

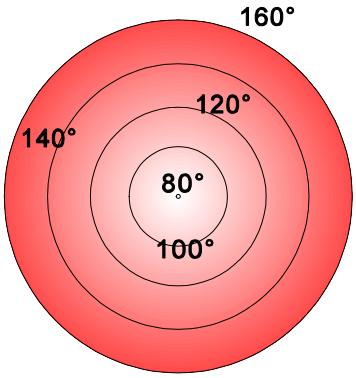
However, as the object continues to absorb heat, its temperature rises, the temperature differential with the constant 100° chamber air decreases, and the rate of heat transfer decreases. The closer the object's temperature approaches the air stream temperature, the more slowly the object absorbs heat.

Think of the problem as though you were trying to travel 100 miles by going ½ of the remaining distance each hour. The first hour you travel 50 miles, the second hour you travel only 25 miles, etc. You eventually get close, but never there, and your progress gets painfully slow after a short time. Transferring heat has the same problem. Because the rate of heat transfer is determined, in part, by the difference in temperature, as the difference is halved, the transfer rate is halved. Obviously, the normal method of just soaking at the setpoint temperature can be a tedious process.

Chart S7 shows a typical example of a cold-hot thermal cycle using standard single probe control and the method of setting a setpoint and letting the DUT soak until it reaches the setpoint temperature.



Let's review the second half, or heating part, of the cycle shown in Chart S7. Note that the rate of DUT heating slows substantially as the DUT temperature approaches the chamber temperature. To maintain the thermal transfer efficiency that existed early in the heating process (when the differential was, for example, 80°), the air stream would have to continually get warmer as the object heated. When the object was 20°, the air would have to be 100°, when the object was 50°, the air would have to be 130°, when the object was 80°, the air would have to be 160°, etc. The heating rate could be maintained by keeping the chamber air constantly the same amount warmer than the DUT temperature. In more appropriate terms, the heat transfer rate to the DUT could be maintained by maintaining a constant temperature differential between the chamber air and the DUT.



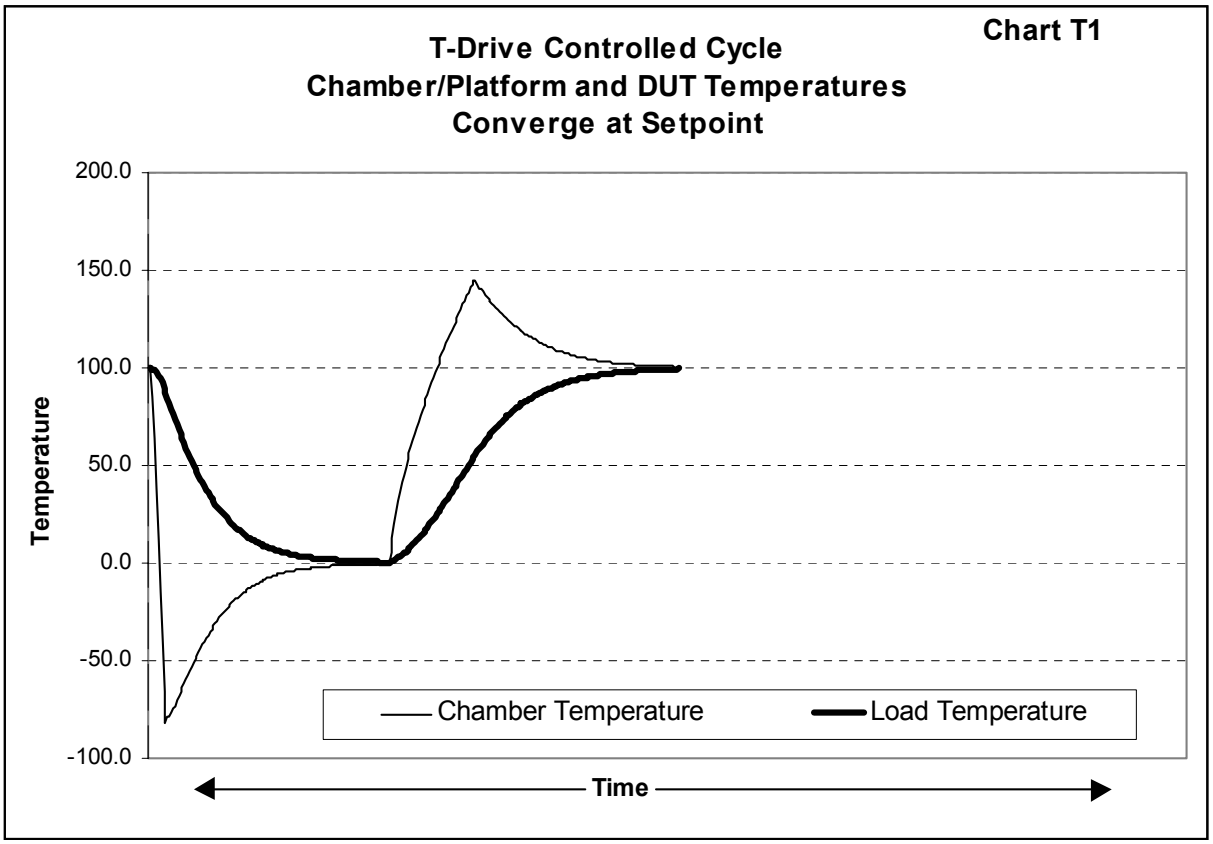
However, because our object is thick and heavy, there likely is a large temperature differential between the surface temperature of the object and the core temperature that we are measuring. Even though the object's core is only 80° at this point in this accelerated heating process, the object's surface temperature, exposed to 160° air, may well be at a much higher temperature. In fact, if the object is a poor thermal conductor like the example cross section to the left, the surface temperature may approach the air

temperature... in this example, 160°. As shown, a substantial part of the object's mass may become significantly overheated even though the core has not yet reached the setpoint.

Already, our example is sufficiently overheated throughout most of it's mass that if no more heat is applied the entire object will be well over the setpoint temperature when it soaks long enough to become thermally homogenous. In this example, most of the object will be at about 135° when it reaches a stable temperature. If the now 135° object were in a chamber with 100° air inside, the air would be cooling the object. Clearly, we need a more sophisticated method of overdriving the temperature that does not significantly overshoot the objective. T-Drive addresses all these issues.

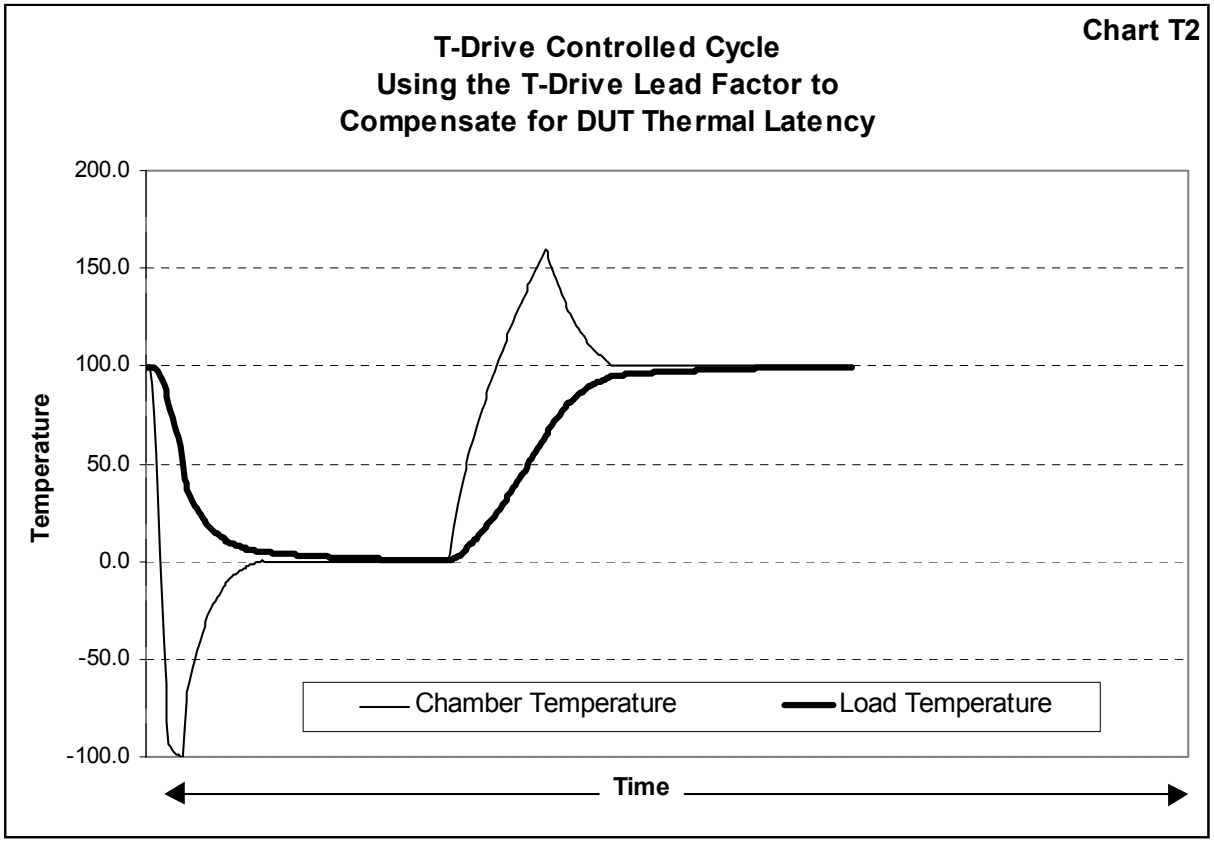
4.2.1.a T-Drive converges on the setpoint

As the object's core temperature approaches the setpoint, T-Drive reduces the amount of over heating of the platform surface or chamber air and thus the object's surface. Chart T1 shows that the closer the object's core temperature gets to the setpoint, the less overheating T-Drive applies. Eventually, just as the object's core temperature reaches the setpoint, the amount of overheating reaches zero.



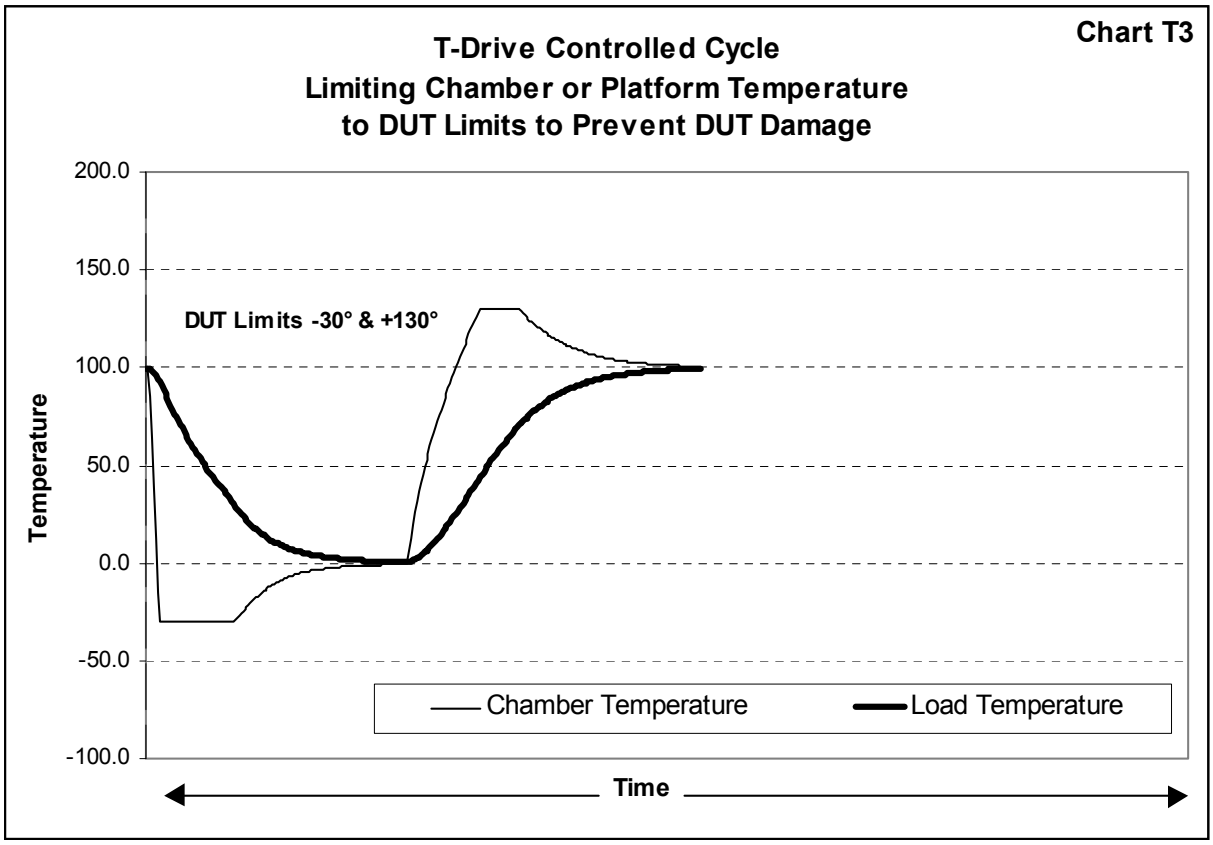
4.2.1.b T-Drive Thermal Latency Compensation

If the object, like our example, has substantial thermal latency, T-Drive can be told to undershoot the setpoint by a fixed amount so that the chamber or platform will stop overdriving the temperature and return to the setpoint temperature early enough to allow the objective to homogeneously stabilize at or near the setpoint. The ramp rate of the core of the object is thus maximized without significant "overshoot". Chart T2 shows how T-Drive can move the chamber air or platform temperature past the setpoint and then return it to the setpoint before the DUT reaches setpoint temperature so that remaining internal DUT heat can be distributed to achieve the setpoint objective.



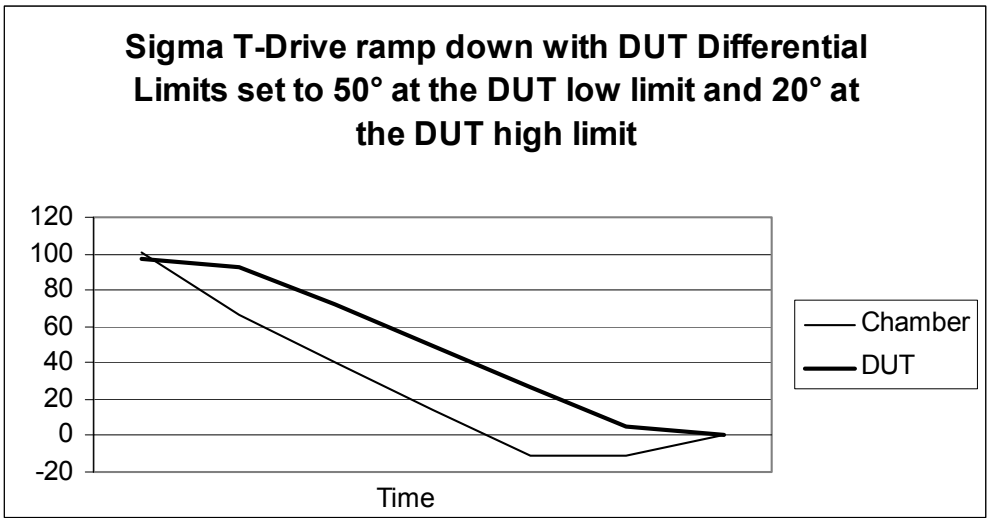
4.2.1.c T-Drive Respects DUT Thermal Limits

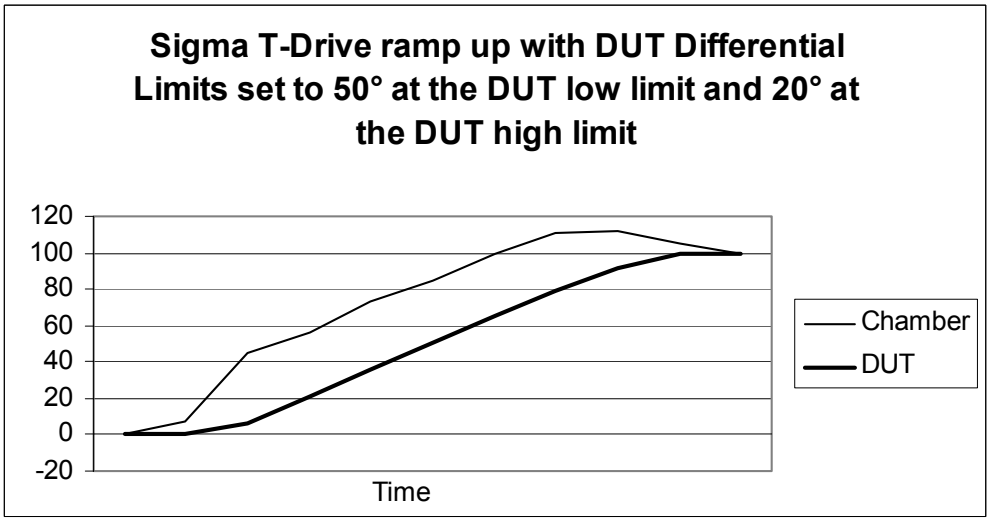
There's another problem with thermal overdriving. While we would like to have our object's core temperature increase as quickly as possible, inducing a surface temperature that is 60° over the setpoint may be more than the object can tolerate. If we knew, however, that the object's surface could tolerate 130°, then we could use a chamber air stream or platform temperature of 130° - but no more - to speed the transfer of heat into the object. T-Drive will restrict the over heating to the limits specified for the object.



4.2.1.d T-Drive Manages DUT Thermal Stress

There is one more consideration. You may want to achieve an object core temperature as quickly as possible using T-drive thermal overdriving to improve production testing efficiency, but you may need to limit the thermal stress during the process. The object may have more tolerance for thermal differentials when hot than cold, or visa versa. To properly protect your object you need to be able to constrain the air temperature in the chamber, or the temperature of a thermal platform surface, and thus the surface temperature of the object, such that the difference between the object's surface temperature and it's core temperature does not exceed the thermal differential the object can tolerate. It would be useful to be able to specify such a differential tolerance for both the high and low thermal limits of the object. T-Drive let's you specify these differential limits and still use thermal overdriving to improve your productivity. Here's how it looks in practice.





4.2.2 Preparing for T-Drive

Preparing to use T-Drive is not difficult. There are three steps:

1. Set the temperature & differential limits for the DUT
2. Set the T-Drive Acceleration and Lead constants
3. Change the controlling probe to probe 0

Then, you use the normal commands or operations, in Local Mode, Program Mode, or Remote Mode, to go to temperatures, and hold temperatures, etc.

4.2.2.a Setting DUT Absolute and Differential Limits

The limits for the DUT temperature extremes are set in Setup parameter fields F27 (lower limit) and F28 (upper limit). The values of F27 and F28 are the absolute minimum and maximum temperatures to which the DUT can be exposed. These values are part of the SOR (System Operating Range) calculations. See §3.5. These values can be set in Setup Mode as described in Section 8, or by using the SL (Set DUT Temperature Limits) command from Remote Mode as described in Section 7.6.5.

You can also set limits for the amount of thermal stress the DUT can tolerate. These limits are expressed as a maximum temperature differential between the chamber/platform temperature (probe 1) and the DUT core temperature (probe 2). The values are set in degrees and can be different for low temperatures than for high temperatures. The low temperature differential limit is stored in setup parameter F29 and the high temperature differential limit is stored in setup parameter F30. The two limits you can set are the allowable differential at the DUT's extreme cold limit and the allowable differential at the DUT's extreme high limit. That is:

> The allowable differential stored in F29 is the amount of thermal stress the DUT will tolerate at the low limit temperature stored in F27.
>
> The allowable differential stored in F30 is the amount of thermal stress the DUT will tolerate at the high limit temperature stored in F28.

These values can be set in Setup Mode as described in Section 8, or by using the SD (Set DUT Temperature Differential Limits) command from Remote Mode as described in Section 7.6.6.

For example:

> If the lower DUT limit (F27) is set to -50° and
> the lower differential limit (F29) is set to 40°, and
> the setpoint is set to 80°
> while the DUT is at -50°, then
>
> T-Drive will be constrained to not heat the chamber air temperature above -10° until the DUT starts to warm. Thus, at it's low limit, the DUT will not be exposed to a temperature stress (the difference between the temperature of it's

surface in contact with the chamber air, and it's core as measured by probe 2) in excess of 40° (-10° = -50° +40° (lower differential limit)).

The same rules hold true for the high limit of the DUT range except that the high differential limit (F30) is applied at the high limit of the DUT range (F28). For example:

If the upper DUT limit (F28) is set to +280° and
the upper differential limit (F30) is set to 100°, and
the setpoint is set to 80°
while the DUT is at +280°, then

T-Drive will be constrained to not cool the chamber air temperature below +180° until the DUT starts to cool. Thus, at it's high limit, the DUT will not be exposed to a temperature stress (the difference between the temperature of it's surface in contact with the chamber air, and it's core as measured by probe 2) in excess of 100° (180° = 280° -100° (upper differential limit)).

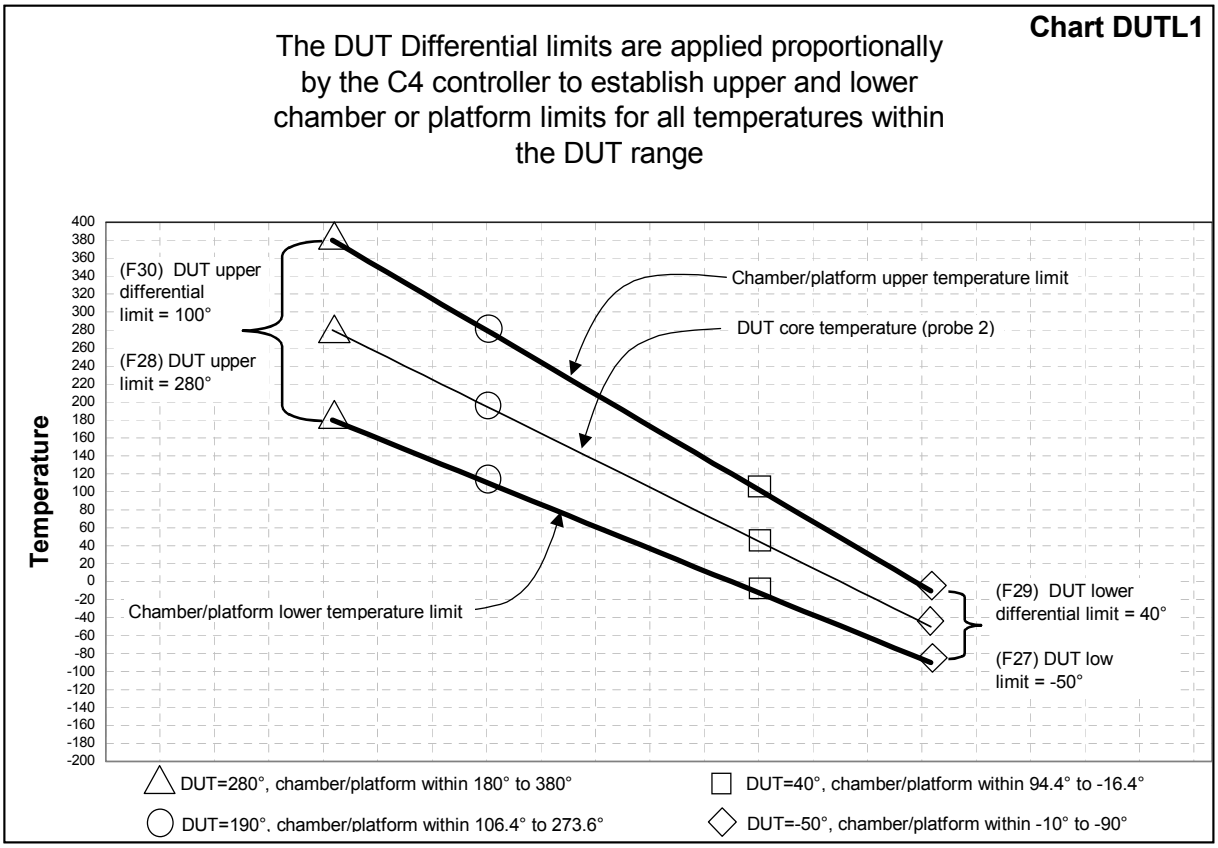
For DUT core temperatures between those limits, a proportional differential limit is calculated by the C4 based upon the limits specified at the extremes. For Example:

If the lower DUT limit (F27) is set to -50° and
the upper DUT limit (F28) is set to +280° and
the lower differential limit (F29) is set to 40° and
the upper differential limit (F30) is set to 100°,

the differential limit calculated for a DUT core (probe 2) temperature of 190° would be 83.6°. (Don't worry about the math... the C4 does it for you.)

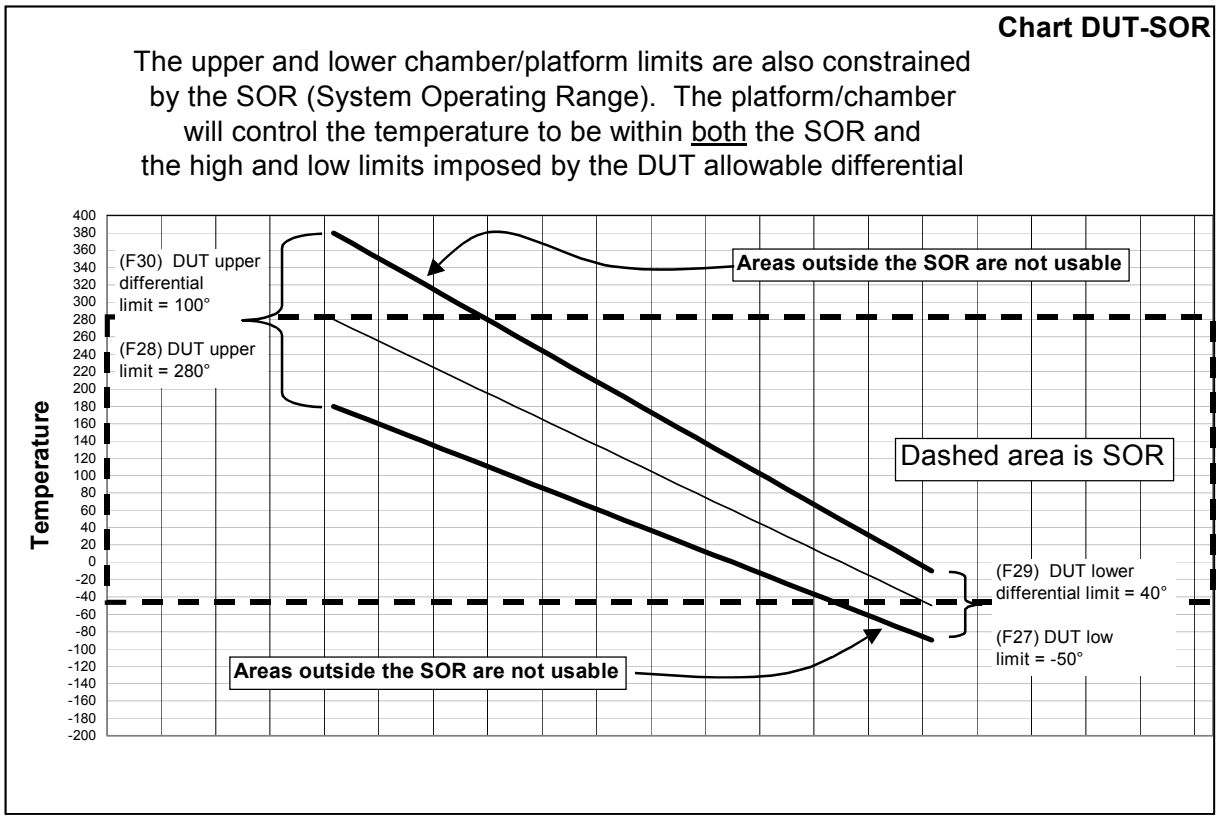
This means that if the DUT core was at 190°, a chamber being used to heat the DUT would be constrained to a maximum air temperature of +273.6° (190° + 83.6°) until the core temperature increased. Conversely, a chamber being used to cool the DUT would be constrained to a minimum air temperature of 106.4° (190° - 83.6°) until the DUT core temperature decreased.

Chart DUTL1 shows how the C4 uses proportioning to calculate a high and low differential limit for all DUT core temperatures between the high and low limits of the DUT.



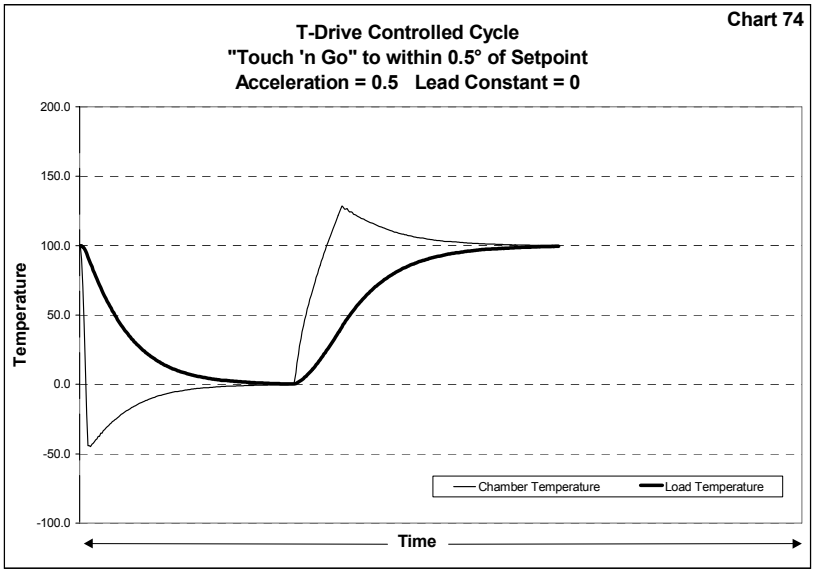
Important: T-Drive, like normal control using probe 1 or probe 2, is constrained by the limits of the SOR (system operating range) - see §3.5. As you can see in Chart DUT-SOR, below, the extreme upper and lower differential limits define temperature limits that are outside of the SOR. As the C4 will not allow control to temperatures outside the SOR, the SOR will be the limiting factor at the extremes of the DUT temperature range.

Caution: If probe correction has been implemented for either or both probes (F17 - F24), those adjustments will be used as well. It is incumbent upon the user to be certain that they are aware of these settings and their potential for interaction.



4.2.2.b Setting T-Drive Acceleration Factor

Chart 71 shows the effects of using T-Drive. Note that Chart 71 indicates "Acceleration =1.0". Acceleration factors begin at 0 (no overdrive) and extend to 5 (very extreme overdrive). See Charts 74, 71, 72, 73. The default value is 2.0. The normal range is 0.5 to 3.0. Lower values will cause T-Drive to gently overdrive the DUT, while higher values will cause more radical overdriving if your system is capable.

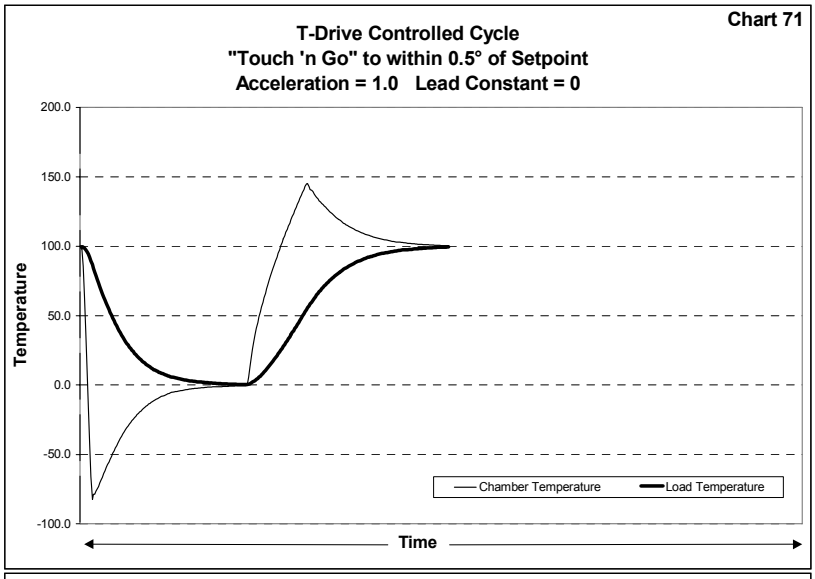


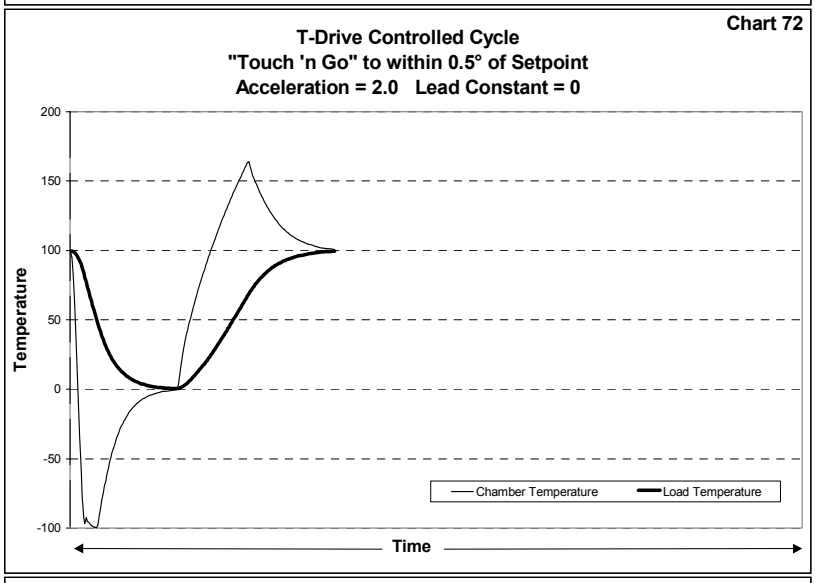
Keep in mind that the heating or cooling capacity of your chamber or platform may be more of a restraint to thermal overdriving than the acceleration factor you specify. Telling T-Drive that you want to use an acceleration factor of 5 to very rapidly and extremely overdrive your DUT for a cooling ramp is pointless if you are using a chamber with a small refrigeration

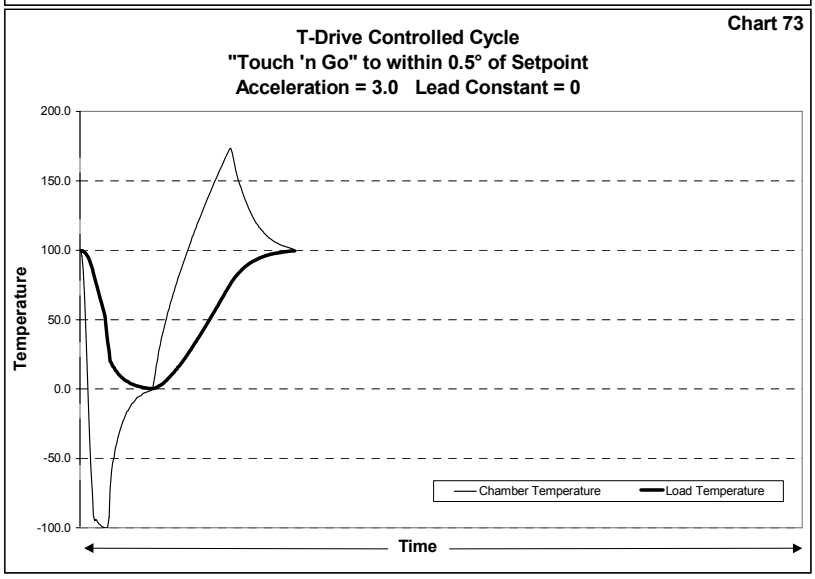
compressor. The chamber is simply not capable of achieving the ramp speeds and overdrive temperatures that T-Drive is likely to request.

On the other hand, if you are using a chamber with high capacity "shock" valves metering in copious quantities of liquid Nitrogen, you may well be able to let T-Drive have it's way. There is no harm in asking for more performance than the chamber or platform is capable of. The chamber or platform will do it's best and the process will likely still be an improvement over non T-Drive control. Study the four charts on the right to see the affects of using differing T-Drive acceleration factors.

The T-Drive acceleration factor is stored in the setup parameter table as parameter F34. See §8. The minimum value is 0 (no T-Drive overdrive) and the maximum is 5. The T-Drive lead constant is stored in the setup parameter table as parameter F35. See §8. The minimum value is -10.0 and the maximum is 10.0. The value is a one decimal place number. The default value is 5. The value can also be set "on the fly" in Remote Mode using the TD command. See §7.6.8. The value set using the TD command







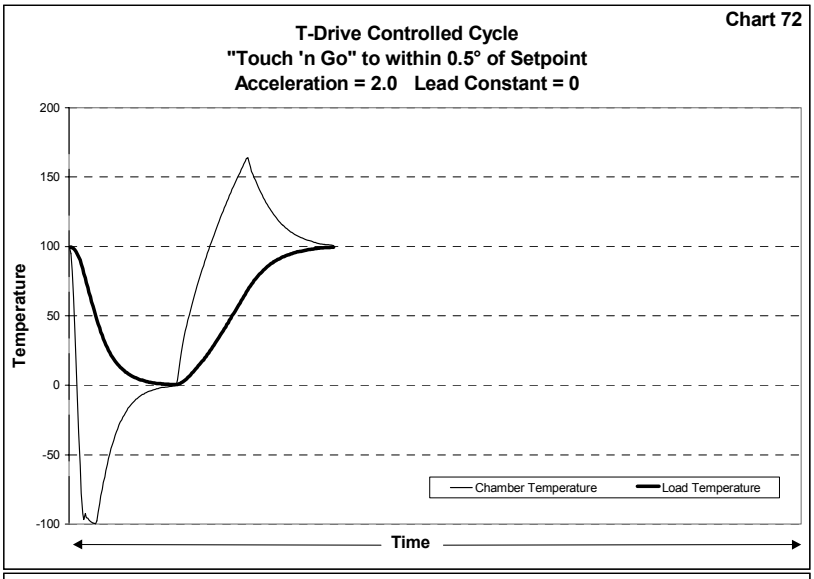
affects only the temporary working copy of the setup parameter table unless a subsequent UP command is used. See §7.6.10.

4.2.2.c Setting T-Drive Lead Constant

The T-Drive lead constant is used to tell T-Drive to make the chamber or platform temperature converge upon the setpoint either before or after the DUT core does so.

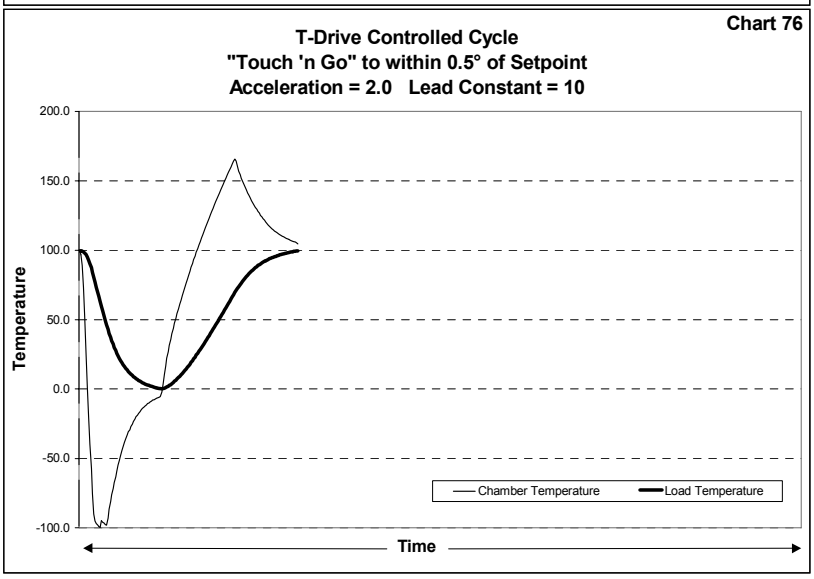
A negative lead constant is very useful for "turning off" T-Drive early enough to allow large mass, thermally slow objects to "coast" to the setpoint using internal heat so that overshoot is minimized. An example would be a large phenolic composite DUT. See Chart 75. Note that this type of DUT is difficult to condition quickly. T-Drive can substantially improve conditioning time, but it cannot do anything about the fact that the DUT moves heat very slowly internally and must be given time to stabilize.

Conversely, a positive lead constant can force a larger thermal differential as the DUT approaches the setpoint. If the DUT is thermally fast and a bit of overshoot is not a problem for your application, applying a small positive lead constant can substantially speed your process. See Chart 76. Note, however, that your chamber or platform must be capable of rapidly returning to the setpoint when the DUT gets there or substantial overshoot will occur.

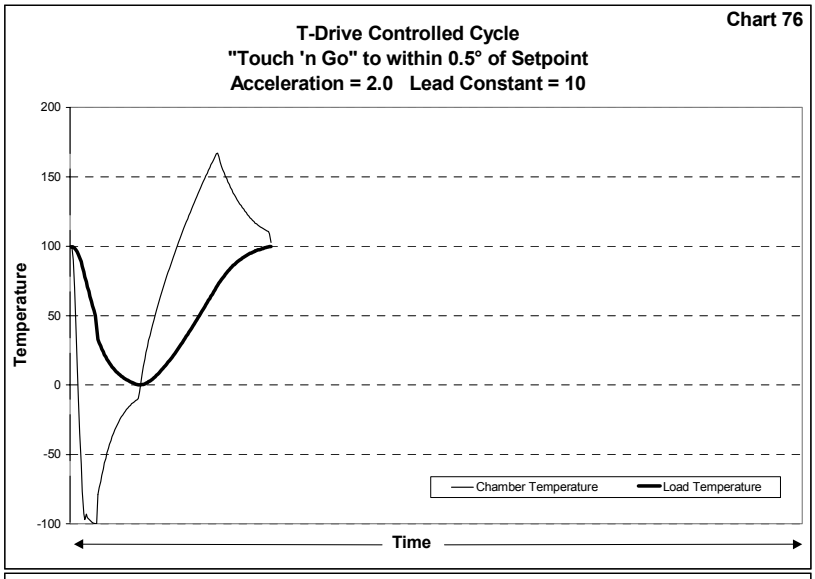


When the lead constant is negative, T-Drive will converge upon the setpoint when the DUT is that number of degrees away from the setpoint.

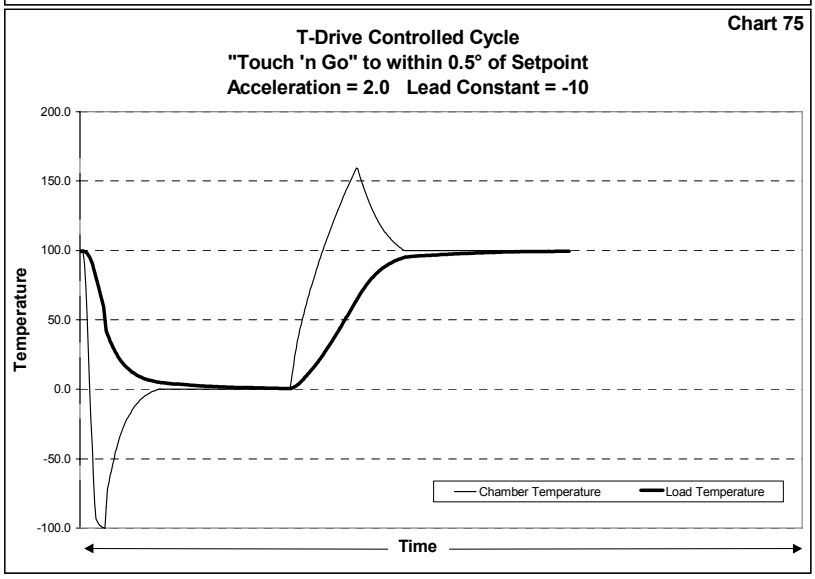
When the lead constant is positive, T-Drive will control as though it will converge on the setpoint when the DUT has gone that number of degrees



past the setpoint. However, when the DUT reaches the setpoint, T-Drive will be dropped and the chamber or platform will immediately try to maintain the temperature at the setpoint using the fastest possible ramp to get there. See Chart 76.



The charts just above show examples of various lead/lag constant affects.



The T-Drive lead constant is stored in the setup parameter table as parameter F35. See §8. The minimum value is -10.0 and the maximum is 10.0. The value is a one decimal place number. The default value is 5. The value can also be set "on the fly" in Program Mode (see § 6.2.7) or in Remote Mode using the TD command (see §7.6.8). The value set using the TD command affects only the temporary working copy of the setup parameter table unless a subsequent UP command is used. See §7.6.10.

4.2.2.d Using T-Drive to Limit Thermal Stress Without Overdrive

T-Drive can be used to limit thermal stress while ramping normally (no overdrive). If you set the upper and lower differential limits (see §4.2.2.a) for your DUT and set the T-Drive acceleration factor to 0 (see §4.2.2.b) and set the T-Drive lead constant to 0 (see §4.2.2.c), T-Drive will perform the fastest possible normal ramp, without any overdrive, that your DUT can accept based upon the differential limits you set. This allows you to make the fastest possible non-overdrive DUT temperature ramp that does not stress the DUT beyond the differential limits specified. This type of ramp can save substantial time when compared to time based ramps as the time based ramp must have some safety factor included to be certain that that DUT does not

become stressed. Because T-Drive measures the stress directly, it can ramp right at the limit of the DUT's tolerance.

4.3 Using T-Drive

Before you use T-Drive, please read all of §4. It is very important that all the necessary limits, plus the T-Drive acceleration and lead constants are properly set before T-Drive is used. Then perform a trial test to see if you need to optimize T-Drive with a few adjustments. T-Drive may be a bit intimidating when you first read this manual and start using it. However, it won't take long before you'll have a good "feel" for what will work.

4.3.1 Two Probes Required

T-Drive requires the use of two temperature sensing probes. Remember to enable both probes by using Setup Mode to set setup parameter F1 = 2. See §8.3.1.

Probe 1 is expected to be in the chamber airstream or buried in the thermal platform and is the standard control probe. Probe 2 should be located at the point inside the DUT that is of concern to you. Sigma has a variety of C4 compatible probes available to suit or fit most any DUT.

4.3.2 Control DUT Required

In many cases it is not practical to put a probe inside the DUT because to do so would destroy the DUT. In this case, you will need to substitute an imposter that can be included with the DUT(s) in the chamber or on the platform. The imposter should be as close a thermal replica of the DUT as possible. Often, for production environments, one sample DUT is permanently sacrificed for this purpose and a probe is buried in this unit. Whether the object with the probe inside is the real DUT, a sacrificed DUT, or an imposter, we will call it the "control DUT". To use T-Drive, the control DUT must be inside the chamber or on the platform with the DUT's to be conditioned. It is the probe inside the control DUT that tells T-Drive what the DUT core temperature is. To be certain that all the DUT's in each load to be tested/conditioned are properly brought to temperature, place the control DUT in the most remote corner of the normal DUT testing/conditioning area.

4.3.3 Invoking T-Drive

To use T-Drive, set the probe number to zero (0). In Local Mode this is done when the setpoint is entered. In Program Mode, the probe is selected with each program step. In Remote Mode the probe is selected with the PN command. See §7.7.3. Starting T-Drive sets Error/Status string state byte 46, bit 0. See §7.8.4.b If the active, or controlling probe is set to 0, T-Drive will be active for the next setpoint. Use the GT or GTF commands to begin controlling to a setpoint in the same manner

as you would using probe 1 for normal control. PN 0 is always required before a GT command if T-Drive control is to be invoked. Note that the RA & RAF commands are not valid when used with PN 0 and will be ignored if sent and return an error in Bit 6 of Byte 2 of the Error/Status String. Likewise, in Program Mode, a "9900" step is required to use T-Drive. T-Drive cannot be invoked with a command that specfies a ramp to temperature over time as the objective of T-Drive is to achieve the setpoint temperature within the DUT as quickly as possible. When you start controlling with T-Drive, the display will show

P0 ----

Pressing **<DISP/TEMP>** will result in the above display being sequenced as part of the probe 1 and probe 2 temperature displays. If **<DISP/CNTL>** is pressed, the display will show the current T-Drive setpoint in the format

Example:

S0	TTT.T	S0 -80.5	Celsius mode
S0F	TTT.T	S0F -80.5	Fahrenheit mode

PT commands in Remote Mode will return normal probe 1 and probe 2 temperatures for PT 1 and PT 2 commands respectively. <u>However, PT 0 commands will return the current T-Drive internal control setpoint</u>. This is the setpoint that T-Drive is using to tell the controller what the temperature of the chamber or platform should be for proper thermal overdriving. This information is not normally of much use, but can be helpful in understanding how T-Drive behaves when you are trying to optimize a process.

4.3.4 PN 0 Required for Each T-Drive Remote Mode Setpoint

In Remote Mode it is possible for T-Drive to be active when a new GT command is received for processing in Remote Immediate Mode (See §7.2). If this happens, T-Drive will change the active probe to probe 1 when the first command is abandoned to process the new command. Thus, the new command will NOT be a T-Drive command unless an intervening PN 0 command is used. In Remote Program Mode (See §7.2), a T-Drive command must complete or time-out for the next command to be processed. Either exit path resets the active probe to probe 1, so PN 0 is always required before a GT command if T-Drive control is to be invoked.

4.3.5 T-Drive DUT Out of Range Error

The C4 will only control temperatures within the SOR (system operating range - See §3.5). In addition, during T-Drive control, the DUT differential limits (See §4.2.2.a) also restrict the temperatures available for control to a range defined by the current DUT core temperature ± the DUT differential limit. Because T-Drive must respect

both limits, it is not possible for T-Drive to function if there are no temperatures that lie within both sets of limits.

Example #1 (not an error condition):

System Operating Limit:	-100° +200°
DUT Lower Differential Limit	30°
DUT Upper Differential Limit	30°
DUT core temperature (probe 2)	210°
Setpoint	40°

T-Drive will try to cool the DUT, but because of the differential limit of 30°, the chamber/platform temperature will be constrained to 180° (210° DUT temperature - 30° allowable differential) until the DUT cools down from it's 210° starting point. This scenario will work satisfactorily because the temperature that T-Drive is requesting is within the SOR.

However, let's presume that our example DUT has internal heating and is continuing to gain heat. By the time we are ready to start our test from the above example, the DUT temperature has risen substantially:

Example #2 (an error condition):

System Operating Limit:	-100° +200°
DUT Lower Differential Limit	5°
DUT Upper Differential Limit	5°
DUT core temperature (probe 2)	215°
Setpoint	40°

T-Drive will generate an error because the DUT is so warm that the current DUT core temperature, less the allowable differential, is outside the SOR. (215° - 5° = 210°) T-Drive cannot set a temperature which is both within the 5° allowable differential from the DUT core temperature and which is within the SOR.

This type of error is normally associated with excessive live loads that have been left on before the start of a test. If T-Drive encounters this problem, it will display

LL Err

in all modes and will set Bit 3 of Byte 02 of the Error/Status String if in Remote Mode. The controller will ignore the command that precipitated the error display and remain in the same state as before the command was received. The error display will remain until an active key is pressed.

4.3.6 Stopping T-Drive

T-Drive normally exits and returns the controller to "normal" probe 1 control if the DUT core temperature, as reported by probe 2, either (a) reaches or passes through the setpoint settling band (See §4.1.1) or (b) has not moved at least 0.1°C closer to the setpoint in the last 10 minutes. When T-Drive exits and probe 1 control resumes, the controller will change to the normal probe 1 control and display. In Remote Mode, Error/Status String byte 46, bit 0 (T-Drive state) will be reset, and byte 06, bit 0, (T-Drive exit event) will be set. See §7.8.4.b.

The setting of the T-Drive event bit (byte 06, bit 0) will result in the setting of the Error/Status string bit in the Error Byte, which will set the Error bit of the Status Byte, which will set the SRQ, if it is enabled. All of which means that you can easily know when T-Drive exits. This information can be very useful should you want to switch to probe 2 control (see §3.14), or take some other action.

PT 0 commands issued when T-Drive is not active will result in a "bad parameter" error being set in the Error Byte. See §7.8.2.d.

T-Drive will also be stopped by any of the normal commands that stop temperature controlling: QU, DC, Fail-Safe condition, etc.

Important post T-Drive control note: When T-Drive exits, control is always returned to probe 1 as probe 1 is the permanently mounted control probe in the chamber or platform, and is thus a more reliable control temperature source than probe 2. In temperature chambers containing DUTs that do not have heating/cooling influences other than the chamber, probe 1 control will likely be ideal.

However, if the DUT is on a thermal platform, or has heating/cooling influences such as live heat loads, circulating fluids from an outside source, etc., then there will likely be a temperature difference between the platform/chamber temperature as seen by probe 1 and the DUT temperature as seen by probe 2. Simple logic, then, would suggest that T-Drive would be most convenient if it transferred control to probe 2, rather than probe 1 when it exited, so that the chamber or platform would keep the DUT at the setpoint temperature.

You need to be aware that there are risks in using probe 2 for primary chamber or platform control. These risks are discussed in §3.14. Please read that section thoroughly before using probe 2 control. With that said, it is likely that when T-Drive exits, you may want to change to probe 2 control so that the chamber or platform will control your DUT to the setpoint, rather than controlling the chamber or platform to the setpoint.

5. Local Mode (Basic Operation)

The C4 Local Mode of operation provides simple control of the chamber or platform through the front panel controls. In this mode, a single setpoint is entered from the front panel and the controller will attempt to have the chamber or platform reach and hold that temperature. In Local Mode the compressor of mechanically refrigerated units can be turned on or off using the **<REFER>** button on the front panel.

The controller can be set to automatically start controlling at the last used temperature upon startup by setting the controller to the AutoStart mode. See AutoStart mode description, §8.3.2.

The circled numbers on the front panel guide the user through the sequence for the basic operation of changing the setpoint. The reasoning for each keystroke is as follows:

1. Display control setpoint temperature.

2. Clear the existing setpoint value.

3. Key-in control probe number (only if 2 probes defined in setup parameter F1) & new setpoint.

4. Commit new setpoint entry.

5. Display current chamber temperature.

If controller RUN LED is not ON press **<START/STOP>** to begin controlling at set temperature.

5.1 Displaying Temperature

The temperature may be displayed at any time by pressing the **<DISP/TEMP>** key. The format of the display is

Pn TTT.T	Example:	P1 - 102.6	(Celsius)
PnF-TTT.T	Example:	P1F- 102.6	(Fahrenheit)

where ***n*** indicates from which probe the reading originates and the **-TTT.T** indicates the numeric temperature. In single probe mode, ***n*** is always 1. In two probe mode, ***n*** can be 1 or 2 as the temperature display toggles between probe 1 and probe 2 with each press of the Display Temperature **<DISP/TEMP>** key. If T-Drive is implemented (probe number set to 0), the display will rotate from probe 1 to probe 2 to probe 0 (-----), then back to probe 1, etc. with each press of **<DISP/TEMP>**. The temperature is displayed to the nearest tenth of a degree C. although internal temperature values are kept at a much higher precision. The value is rounded so that a display of 30.2

means a temperature between 30.15 and 30.24. Fahrenheit values display an F after the probe number.

5.2 Displaying and Changing the Setpoint

The setpoint may be displayed by pressing the Display Control key **<DISP/CNTL>**. The format of the display is

Sn TTT.T	Example:	S1 - 102.6	(Celsius)
SnF-TTT.T	Example:	S1F- 102.6	(Fahrenheit)

where ***n*** is the probe used for control. Upon entering the Local Mode from the PROGRAM REMOTE or Setup Mode, the control probe defaults to 1 and the setpoint is erased. If the setpoint has been erased, the "no setpoint" message displays in lieu of the setpoint temperature. Example:

S1 nSP S1F nSP

To change either the setpoint temperature or the control probe (of a 2 probe configuration only), use the following procedure:

1. First display the setpoint using **<DISP/CNTL>.**

2. Press **<CLEAR/ENTRY>** to clear the current value from the display. If single probe mode is in effect, S1 or S1F will appear at the left of the display indicating the control probe must be 1. If two probe mode is in effect, the probe number is also cleared.

3. If the probe number is erased, (in two probe mode) enter the controlling probe desired, either 1 or 2 for control by probe 1 or probe 2, or enter 0 for T-Drive. See §4.2. If in single probe mode, ignore this step.

4. Enter a setpoint temperature using the numeric, decimal point and sign keys. Numbers may be entered with a maximum of 1 decimal place. Pressing the sign **<+/->** key will toggle the value between positive and negative. Positive values will have no indication, negative values will show a minus (-) sign to the left of the temperature display.

5. Errors may be corrected by simply pressing **<CLEAR/ENTRY>** and re-keying the entry prior to pressing **<ENTER>**.

6. After the number is keyed in, press **<ENTER>** to commit the entry and store it as the new setpoint.

7. The controller will remain in the RUN mode if the rotary switch has not been changed and **<START/STOP>** has not been pressed.

Note: If the setpoint entered is not within the System Operating Range (See §3.5), an error message will be displayed and the setpoint will not be stored. If the requested setpoint is below the System Operating Range, the error will be preceded by a minus sign (-). Examples:

50r -50r

When this message is displayed, press **<CLEAR/ENTRY>** to return to setpoint entry mode.

TIP: It is not necessary to stop the controller from controlling the chamber or platform to change the setpoint. The setpoint may be changed at any time, even while the chamber or platform is being actively controlled.

5.3 Controlling to a Setpoint

The controller will start to control to the specified setpoint when **<START/STOP>** is pressed. The RUN LED will light to indicate the control process is active. A subsequent press of **<START/STOP>** will cause the controller to stop controlling and the RUN LED will be extinguished. Unless disabled through setup parameter F15, Blower Shut-off Mode (See §8.3.3), the chamber blowers will continue to run regardless of RUN status. If **<START/STOP>** is pressed before a setpoint has been set, the following error will be displayed:

SP Err

5.4 Compressor Control (mechanically refrigerated unit control only)

The compressor of a system employing mechanical refrigeration can be manually toggled at any time during Local Mode controlling operation by pressing the **<REFER>** button. The REFER LED on the front panel indicates the state of the refrigeration Refer Port. The port is shut off when controlling action is stopped by pressing the **<START/STOP>** button and restarted if **<START/STOP>** is pressed again before the rotary switch is moved to a mode other than Local or Off.

The controller can be configured to not respond to front panel **<REFER>** (compressor) ON/OFF commands. See Setup Mode, §8 - setup parameter F13.

5.5 AutoStart Mode

The C4 can be set to start controlling to a temperature immediately when the mode switch is moved from Off to Local. To learn more about AutoStart, see §8.3.2.

6. Program Mode

The Program Mode allows more complicated front panel control than the Local Mode. The Program Mode allows a temperature control program to be entered into the controller memory for subsequent execution as required. Up to 100 program steps may be entered. Multiple programs may be entered and executed as long as the total number of steps in all programs does not exceed 100. Programs are stored in non-volatile EEPROM memory. See §6.5 for Sample Programs.

6.1 Description of a Temperature Program Step

Each program step has five data parameters, called substeps. The program substeps are numbered 0-4. For temperature setpoint setting steps, each substep has a dedicated function as follows:

Substep **0** is a setpoint temperature.

Substep **1** is the ramp time.

Substep **2** is the hold time.

Substep **3** is the next step to be executed. If this substep is specified as 100, the program will terminate after execution and the display will show "End".

Substep **4** is the probe used for control. It can be specified as 0, 1, or 2 to select the probe or mode to be used for temperature control.

When displaying program steps on the LED display, the program step.substep is displayed at the left side of the display and the data associated with that program step.substep is displayed on the right as follows:

The example above shows step 6, substep 0 contains the temperature data -30.5

Each program step contains all five substeps, regardless of whether or not each step is used. Therefore, a complete program step is as follows:

6.1.1 Format of a Temperature Program Step

FORMAT OF A STEP

```
substep  ))))))
   step  )))0, *   -----------data-----------
            ** *
           00.0  -TTT.T      - temp (setpoint)
           00.1   HH.MM      - ramp time
           00.2   HH.MM      - hold time
           00.3     NNN      - next step
           00.4       P      - control probe
```

where: step is the current program step number (00 - 99)
substep is the current program substep (0-4)

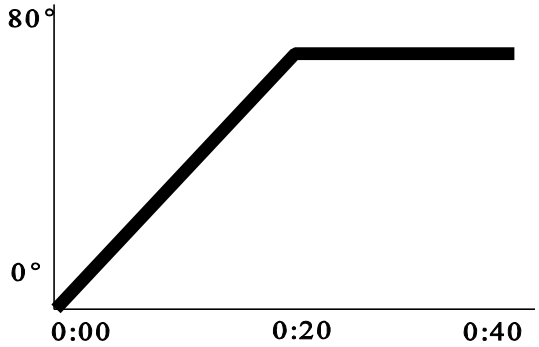
TTT.Tis the setpoint temperature displayed to the nearest .1EC

HH is hour(s) (00 - 99) for ramp or hold
MM is minute(s) (00 - 59) for ramp or hold

NNN is the next program step number (00 - 100) to execute

P is the number of the probe (0, 1 or 2) to use for control or...
P is the special command indicator (values of 3 thru 10)
(See 6.2 for details)

The simple graph at the right shows a typical ramp & hold scenario. In this example the user wants to ramp from 0E to 78E in 20 minutes and then hold 78E for the next 20 minutes. A single program step will accomplish both tasks.



The sample program step below will pass control to program step 6 when it has completed.

Program step.substep	Data	Effect/Purpose
05.0	78.0	Sets temp setpoint to 78E
05.1	00.20	Sets ramp time to 20 minutes
05.2	00.20	Sets hold time to 20 minutes
05.3	6	Sets step 6 as next step to execute
05.4	1	Selects probe 1 for active control

6.1.2 Ramp Time and Hold Time Considerations

When a ramp time is specified in a program step, the controller attempts, within the limits of system capability, to achieve a linear temperature change rate such that the setpoint is achieved precisely at the end of the ramp period. If an insufficient ramp time is specified, some of the hold time will be "borrowed" to allow the ramp to setpoint to complete. In this event, and if the Ramp 'Timeout Function is enabled, a timeout message will be displayed (see §3.11).

6.1.3 Maximizing Ramp Speed ("9900" Steps)

To achieve the maximum ramp rate, set the ramp time (substep 1) to 00.00 and the hold time (substep 2) to 99.00. A program step with a ramp time of 00.00 and a hold time (substep 2) of 99.00 will cause the controller to achieve the setpoint as quickly as possible then immediately execute the next step. Example:

04.0	50.0	setpoint of 50°
04.1	00.00	} maximum speed ramping
04.2	99.00	} maximum speed ramping
04.3	5	next step to execute
04.4	1	use probe 1

If a specific hold time following ramping at maximum ramp rate is required, then use two steps. Both steps should specify the same setpoint. The first step should have a ramp time of 00.00 and a hold time of 99.00. The second step should have a ramp time of 00.00 and the desired hold time.

Note & Warning: A program step with specified ramp and hold times will terminate at the end of the specified time (ramp time + hold time), regardless of whether the controller was able to achieve the setpoint. On the other hand, a maximum speed ramp step (substep 1 = 00.00 & substep 2 = 99.00) will not advance to the next step until the setpoint is achieved. If the unit under test generates or absorbs heat in a manner that prevents the test environment from ever becoming stable at the setpoint, the program will "hang" on such a step as it will not advance to the next step unless it can stabilize the platform or chamber at the setpoint.

6.1.4 Null Program Steps

A program step with a ramp time of 00.00, a hold time of 00.00, and a probe number of either 0, 1 or 2 is a null program step. A null program step has no effect on the temperature setpoint of the chamber. It is used to fill an unneeded step in an existing program. Example:

04.0	50.0	setpoint of 50° (not used)
04.1	00.00	} = null program step
04.2	00.00	
04.3	5	next step to execute
04.4	1	use probe 1 (not used)

6.1.5 Invoking T-Drive

To achieve the maximum ramp rate using T-Drive thermal overdriving (see §4.2), set the ramp time (substep 1) to 00.00 the hold time (substep 2) to 99.00 and the probe (substep 4) to 0. A program step with a ramp time of 00.00, a hold time (substep 2) of 99.00, and a probe number of 0, will cause the controller to achieve the setpoint as quickly as possible using T-Drive thermal overdriving, then immediately execute the next step. Example:

04.0	-50.0	setpoint of -50°
04.1	00.00	} maximum speed ramping
04.2	99.00	
04.3	5	next step to execute
04.4	0	use T-Drive

If a specific hold time following ramping at maximum ramp rate is required, then use two steps. Both steps should specify the same setpoint. The first step should have a ramp time of 00.00 and a hold time of 99.00. The second step should have a ramp time of 00.00 and the desired hold time.

Note: A T-Drive invocation step (substep 4 = 0) which does not have the ramp time set to 00 and the hold time set to 99.00 will result in a T-Drive Invocation Error at run time. See §6.3.8.g

6.2 Special Command Steps

There are special commands that use the substep data within a step for different purposes than a temperature step. These commands are:

Sub-step	Section	Description
0,1,2	§6.1	Temperature program step
3	§6.2.1	Creating controlled loops
4,5	§6.2.2 - 6.2.3	Refer Port control on/off
6,7	§6.2.4 - 6.2.5	Aux/Power (cryo boost) port control on/off
8	§6.2.6	Settling Band parameter specification
9	§6.2.7	T-Drive factor specification
10	§6.2.8	PID-R specification

In each case only some of the substeps may be used. To enhance program readability, we suggest that you set any unused substep values to zero.

6.2.1 Program Looping

The program may be placed into a controlled loop by the use of the PROGRAM LOOP command. When the substep 4 = 3, the C4 interprets the step as a loop step.

Substep	**Loop Step**
0	Specifies the number of loops. Value must be in the range 0 - 999
1	Specifies the number of thousands of loops (k-loops). The substep 0 and substep 1 values must be specified as integers and be in the range 0 - 999. The total number of loops that will execute is the value in substep 1 x 1000 plus the value in substep 0.
2	Not used
3	Specifies the step number for the beginning of the loop
4	Set to 3 to define this step as a loop step

Example of a loop step for 15 loops:

Step.substep	Value	Description
13.0	15	loop 15 times
13.1	0	loop 0 thousands of times
13.2	0	not used
13.3	4	begin loop execution at step 4
13.4	3	defines this as a loop step

Example of a loop step for 3050 loops:

Step.substep	Value	Description
13.0	50	loop 50 times
13.1	3	loop 3 thousands of times
13.2	0	not used
13.3	4	begin loop execution at step 4
13.4	3	defines this as a loop step

Example of a loop step for 9000 loops:

Step.substep	Value	Description
13.0	0	loop 0 times
13.1	9	loop 9 thousands of times
13.2	0	not used
13.3	4	begin loop execution at step 4
13.4	3	defines this as a loop step

When the loop command is first encountered in program execution, a loop counter is set up that is equal to the sum of substep 0 + 1000 x substep 1. Each time the Loop

Command is again reached in the program, the loop counter is decremented by one. As long as the loop counter is greater than zero, the program will execute the step indicated in substep 3 of the Program Loop step. When the loop counter finally becomes zero, the step following the Program Loop step is executed.

The examples listed above are for loop steps defined in step 13. Because substep 3 = 4 in all examples, each will cause the program to return to step 4 to begin the loop execution. It is important that the steps that begin at step 4 process in a sequence that eventually processes step 13. The steps in the loop do not have to be sequential, but execution must return to the loop step (13 in our examples) so the loop counter can be decremented and the loop process restarted. When the loop counter is zero, our examples will then continue processing at step 14 (the step following the loop step).

6.2.1.a Program Loop Processing Notes

Nested program loops are not supported. They may appear to work if you try to use them, but the loop will never complete, and further results are not predictable.

A loop count of 5 (example) will cause the program to execute the loop 5 times. If the program loop refers to a previously executed step as the loop start step, then that step will be executed once originally, plus the 5 times for the loop, for a total of 6 times.

6.2.1.b Displaying the Loop Count During Execution

You can display the current loop count when executing a loop sequence by pressing **<ADV>**. The display will show the k-loops on the left and the loops on the right.

Example:

LOOP	Word LOOP alternates with count as below
002 981	(Program is executing the 2,981st loop)

Note that the loop counter display counts up and shows the number of loops already executed, including the currently executing loop. It does not show the number of loops remaining to be executed.

If no loop is currently being executed, the display will show:

nO LOOP

6.2.2 Refrigeration Compressor Port On

When substep 4 = 4, the program step turns the refrigeration Refer Port on. Setup parameter F6 defines the default mode for this port upon power up or upon changing the position of the rotary mode switch. The REFER LED on the front panel will indicate when this port is on or off. The behavior of this port is fully documented in §2.2.2.

Substep	**Refrigeration Compressor Port ON Step**
0	Not used
1	Not used
2	Not used
3	Specifies the step number of the next step to execute
4	Set to 4 to define this step as a Refrigeration Compressor Port ON step

Note: The compressor port is not automatically turned off at the end of a program. If you want the compressor (port) off when a program ends, you must explicitly use a program step to turn it off.

6.2.3 Refrigeration Compressor Port Off

When substep 4= 5, the program step turns the refrigeration Refer Port off. Setup parameter F6 defines the default mode for this port upon power up or upon changing the position of the rotary mode switch. The REFER LED on the front panel will indicate when this port is on or off. The behavior of this port is fully documented in §2.2.2.

Substep	**Refrigeration Compressor Port OFF Step**
0	Not used
1	Not used
2	Not used
3	Specifies the step number of the next step to execute
4	Set to 5 to define this step as a Refrigeration Compressor Port OFF step

6.2.4 Aux/Power Control Port On

When substep 4= 6, the program step turns the Aux/Power control port on. Setup parameter F5 defines the default mode for this port upon power up or upon changing the position of the rotary mode switch. The port is NOT automatically turned off at the end of program execution. There is no indicator on the front panel to indicate when this port is on or off. The behavior of this port is fully documented in §2.2.2.

Substep	**Aux/Power Control Port ON Step**
0	Not used
1	Not used
2	Not used
3	Specifies the step number of the next step to execute
4	Set to 6 to define this step as a Aux/Power Control Port ON step

For special order chambers or platforms equipped with an optional solid state relay to control main power, this command may need be used once at the beginning of a program in order to turn the chamber or platform on. Note that because this control will disable all power to a chamber with solid state relay chamber power control, the normal continuous running of the air circulation fans is disabled, regardless of the state of the Blower Shutoff Mode setup parameter.

Note that mechanically refrigerated chambers or platforms with cryogenic coolant boost use the Aux/Power Port to control the availability of the cryogenic boost system.

6.2.5 Aux/Power Control Port Off

When substep 4 = 7, the program step turns the Aux/Power load control port off. On is the default mode for this port upon power up, start of program, and changing the rotary switch. The port is NOT automatically turned off at the end of program execution. There is no indicator on the front panel to indicate when this port is on or off.

Substep	**Aux/Power Control Port OFF Step**
0	Not used
1	Not used
2	Not used
3	Specifies the step number of the next step to execute
4	Set to 7 to define this step as a Aux/Power Control Port OFF step

6.2.6 Settling Band Specification Step

You can change the settling band range and minimum stable time by using a program step that has substep 4 = 8.

Substep	**Settling Band Specification Step**
0	Temperature tolerance (replaces value from F31)
1	Minimum stable time (replaces value from F32)
2	Not used
3	Specifies the step number of the next step to execute
4	Set to 8 to define this step as a Settling Band Specification step

The settling band values set with this command will remain in effect for the currently executing program unless replaced by a subsequent settling band specification step. The permanent setup parameter table values for F31 and F32 are not affected by this command. The permanent copy values of F31 and F32 will again be used at the start of the next executed program.

See §4.1 to learn more about the Adjustable Settling Band feature, or read §8 to learn more about setup parameters.

6.2.7 T-Drive Specification Step

You can change the T-Drive acceleration factor and lead constant by using a program step that has substep 4 = 9.

Substep	**T-Drive Specification Step**
0	T-Drive acceleration factor (replaces value from F34)
1	T-Drive lead constant (replaces value from F35)
2	Not used
3	Specifies the step number of the next step to execute
4	Set to 9 to define this step as a T-Drive Specification step

The T-Drive factors set with this command will remain in effect for the currently executing program unless replaced by a subsequent T-Drive specification step. The permanent setup parameter table values for F34 and F35 are not affected by this command. The permanent copy values of F34 and F35 will again be used at the start of the next executed program.

See §4.2 to learn more about the T-Drive feature, or §8 to learn more about setup parameters.

6.2.8 PID-R Specification Step

You can change the PID & R terms by using a program step that has substep 4 = 10.

Substep	**PID Specification Step**
0	R factor (-9999 to +9999) (replaces value from F12)
1	P term value (replaces value from F0) (uses only the two characters to the right of the decimal point.) Thus 00.06 would be the entry for a P term of 6
2	I term value (replaces value from F10) (uses the two characters to the left of the decimal point) D term value (replaces value from F11) (uses the two characters to the right of the decimal point) Thus, 04.06 would be the entry for an I term of 4 with a D term of 6
3	Specifies the step number of the next step to execute
4	Set to 10 to define this step as a PID-R Specification step

All four of the PID-R constants must be set with this command at one time. All 4 items must be specified. The PID terms and R factor set with this command will remain in effect for the currently executing program unless replaced by a subsequent PID-R specification step. The permanent setup parameter table values for F0, F10, F11, and F12 are not affected by this command. The permanent copy values of F0, F10, F11, and F12 will again be used at the start of the next executed program.

See §9.4 to learn more about the PID terms, or §8 to learn more about setup parameters.

6.3 Programming Tasks

6.3.1 Clearing Program Memory (Reinitializing program steps)

When the controller is shipped from the factory, all program steps are initialized to their default values as shown below. To create a usable program for the controller to run, the user enters replacement values in those program steps to be used. All program steps are retained in memory even during power down of the controller. When it becomes necessary to clear all of the user programmed steps from memory, use the CLEAR PROGRAM **<CLEAR/PROG>** key on the keyboard. All program steps will be reinitialized to their default values. The procedure below will reinitialize all program steps to their default values.

To reinitialize all program steps to their default values, press **<CLEAR/PROG>** to display the CLr warning message on the display, then press **<CLEAR/PROG>** again to return all program steps to their default values as shown below. If ever you

accidentally press **<CLEAR/PROG>** and see the CLr warning on the display, you may press any key <u>except</u> the **<CLEAR/PROG>** key to abort the memory clearing process.

Note: The two presses of **<CLEAR/PROG>** must be at least ½ second apart. This assures that the two presses were intentional and prevents accidental program erasure. Once program memory has been erased, it cannot be restored.

When the program memory is reinitialized, each of the 100 program steps is initialized to the following default values (null program steps):

Substep 0	30.0	(30 degrees C.)
Substep 1	00.00	(Ramp time zero)
Substep 2	00.00	(Hold time zero)
Substep 3	NNN	(Next sequential step= current step +1)
Substep 4	1	(Control = Probe one)

6.3.2 Displaying Program Steps (not during execution)

To display the program steps, press **<DISP/CNTL>**. Unless you are already in Program Mode and have just displayed a different program step, step 0, substep 0 (the setpoint for step zero) will be displayed. Each subsequent press of **<DISP/CNTL>** will cause the display to increment to the next program substep.

To display a specific program step, enter a one or two digit step number directly after any press of **<DISP/CNTL>** and then press **<DISP/CNTL>** again to display the entered step.substep 0.

6.3.3 Entering or Changing a Program Step

There is no difference between entering a program step and modifying an existing one.

To change any part of the program, first display the current step by pressing **<DISP/CNTL>**. If you wish to make changes to a step other than the current step, enter the 1 or 2 digits for the step number (0-99) and press **<DISP/CNTL>** again. Substep 0 of the desired step will now be displayed.

For each substep displayed, you may change the current value or accept the current value. To accept the current value and display the next substep, press **<DISP/CNTL>**.

To change the current value, press **<CLEAR/ENTRY>** to clear the old value then enter the desired new value. Pressing the **<ENTER>** key stores the new substep value and advances the display to the next substep. Only valid changes are allowed. Subsequent steps and substeps may be altered in the same manner by pressing **<DISP/CNTL>** until the desired step is displayed.

Note: The program may only be changed when the program is not executing (run LED is off) and the controller is in the Program Mode (Mode switch set to PROGRAM).

§6.7 contains a template form for writing programs.

6.3.4 Insert Program Step

To insert a step before an existing step:

1. Enter the step number to be moved up and press **<DISP/CNTL>**
2. Press **<CLEAR/ENTRY>**
3. Press **<ADV>**

The display shows "InS nn", where nn is the new incremented step number for the current step.

4. Press **<ENTER>** to move the current and all higher steps up 1 step and insert a new step at the current step number.

The current step will then be the new step with default values. New step.substep 0 will be displayed so you can enter your data for that step.

Note that inserting a step pushes old step 99 out of memory.

6.3.5 Delete Program step

1. Enter the step number to be deleted and press **<DISP/CNTL>**
2. Press **<CLEAR/ENTRY>**.
3. Press **<CLEAR/ENTRY>** again.

The display shows "dEL nn", where nn = step number to be deleted.

4, Press **<ENTER>** to delete the step and move all higher steps down one step.

6.3.6 Run (Execute) a Program

To start program execution, the beginning program step of the program to be run must be displayed. Displaying a specific program step is covered in Section 6.3.

With any step of a program displayed, pressing **<START/STOP>** will begin program execution at that step. The program will continue to execute until it reaches program step 100 where it will display End and wait for action from the operator.

Running programs may also be stopped at any time by pressing **<START/STOP>**. After a program has been stopped in this manner, pressing **<START/STOP>** again will cause the program to continue executing from the <u>beginning</u> of the step it was

executing when it was stopped. Important: When a program is paused, the Refer and Aux/Power Ports are not affected. Likewise, program end with step 100 also has no effect on the state of the Refer and Aux/Power Ports. It is incumbent upon the user to include program steps at the end of the program to set the ports to the correct state for program termination.

At the end of a program, the controller will not turn on further heat or cool, however, the chamber blowers will remain on unless blower shutoff mode has been enabled. See §8.3.3. The blowers can be turned off manually by an operator using the front panel mode switch. Set the switch to OFF to turn off the blowers.

CAUTION: Chamber temperatures can exceed 70EC, without heaters energized, if high velocity blowers have been installed. If this presents a problem, be sure the test load is removed promptly at the end of the program run, or enable blower shutoff mode (see §8.3.3) to have blowers not run on at the end of a program execution.

6.3.7 Program Run Time Information/Considerations

When a program is running, the display shows the currently executing program step number on the left, and the total amount of remaining run time for that step on the right. The time displayed is the sum of any remaining ramp time and/or hold time. The temperature may be displayed by pressing **<DISP/TEMP>** while the program is running. Pressing **<DISP/CNTL>** will restore the display of the current step number and the time left in the step.

Programs may be designed to run continuously by specifying the next step to be any previous step of the program. In this way, step 100, the end, is never reached. The program must then be stopped by the operator by pressing the **<START/STOP>** key. Controlled looping is also possible. See §6.2.1.

Multiple programs may be stored in memory since a program may be started from any step and terminates with any step specifying 100 as its next program step. It is the operator's responsibility to keep a record of the beginning program step number for each program in memory.

6.3.8 Run Time Pre-read Errors

When a program is started by pressing **<START/STOP>** with the first step of the program displayed, the C4 will pre-read all the program's steps in the run time execution sequence. During the pre-read, the C4 checks all steps for errors so that the user can solve any problems immediately rather than having them occur later, during program execution. The pre-read makes certain that the program to be run does not call for probe 2 use when only one probe is defined by setup parameter F1, that all loop commands contain valid loop counters, and that all setpoints requested are within the System Operating Range. The pre-read also checks to be sure all ramp requests, settling band parameters, and T-Drive parameters are valid. In each case, if an error is found, the display will show the step number that contains the error on the left side of the display, and the error message on the right side.

Note that the pre-read will display the first error it finds. If there is more than one error, each successive error will be shown on the display after the last displayed error is corrected and a program start is again attempted.

6.3.8.a No Probe 0 Error

If a program step calls for control by probe 0 (T-Drive) when setup parameter F1 = 1 (number of probes) the C4 will generate a No Probe 0 Error. Example

07 noP0

You must either remove the step that calls for probe 2 or enable probe 2 with setup parameter F1 (See §8) before the program will run. See §8.3.

6.3.8.b No Probe 2 Error

If a program step calls for control by probe 2 when setup parameter F1 = 1 (number of probes) the C4 will generate a No Probe 2 Error. Example

07 noP2

You must either remove the step that calls for probe 2 or enable probe 2 with setup parameter F1 (See §8) before the program will run. See §8.3.

6.3.8.c Invalid Loop Count Error

If a program step is a loop start step (substep 4, probe value = 3), then the loop counts (substep 0, loop count; substep 1, k-loop count) must be in the range 0 - 999 integer (no decimal value) with either substep 0 or substep 1 being greater than zero. If the number is either not an integer, or is outside the range 0 - 999, or if both substeps 0 and 1 are zero, the C4 will generate an Invalid Loop Count Error. Example:

09 LErr

The invalid loop count must be corrected before the program will run. See §6.2.1.

6.3.8.d Setpoint Out of Range Error

If a program step requests a setpoint outside the System Operating Range (See Section 3.5), the C4 will generate a Setpoint Out of Range Error. The error message will be preceded by a minus sign (-) if the setpoint requested is lower than the System Operating Range and will not show a minus sign if the requested setpoint is above the System Operating Range. Example:

05 SOr 05 -SOr

Either the setpoint request or one of the temperature ranges that defines the System Operating Range will have to be changed before the program will run.

Note: If the last used program step does not explicitly point to step 100, but instead allows execution of intermediate steps that contain default 30°C setpoints, then the SOR must not have an upper limit of less than 30° or this error will be triggered.

6.3.8.e Settling Band Out of Range Error

If an Adjustable Settling Band specification program step (substep 4 = 8)specifies either a settling band range (substep 0), or a minimum stable time (substep 1) that is outside the valid range (see §4.1.1 & §4.1.2), the C4 will generate a Settling Band Error. Example:

04 SErr

The invalid parameter(s) must be corrected before the program will run. See §4.1.

6.3.8.f T-Drive Parameter Specification Error

If a T-Drive specification program step (substep 4 = 9)specifies either an acceleration factor (substep 0), or a lead constant (substep 1) that is outside the valid range (see §4.2.2.b & §4.2.2.c), the C4 will generate a T-Drive Error. Example:

06 CErr

The invalid parameter(s) must be corrected before the program will run. See §4.2.

6.3.8.g T-Drive Invocation Error

If a T-Drive program step (substep 4 = 0) specifies either a ramp time other than 0 (substep 1 … 00.00) or a hold time other than 99 (substep 2 … 99.00), the C4 will generate a T-Drive Error. Example:

06 tErr

The invalid parameter(s) must be corrected before the program will run. See §6.1.5.

6.3.8.h Ramp Error

The minutes time specified in substep 1 or substep 2 of the temperature control step is outside the range 00-59, or the value was negative.

Example:

06 rErr

The invalid parameter(s) must be corrected before the program will run. See §6.1.

6.3.8.i PIDR Specification Error

At least one of the values specified in a PID specification step are invalid.

Example:

04 PErr

The invalid parameter(s) must be corrected before the program will run. See §6.1, §8, and §9.4.

6.4 Common Programming Issues

6.4.1 Step Numbering

Remember that the first step or substep is 0 instead of 1.

6.4.2 Changing Substep Values

When changing a substep value on the right half of the display, you must use the **<CLEAR/ENTRY>** key to clear the previous entry from the display before entering a new value. Then enter the new value by keying on the keypad, then press **<ENTER>** to store that new value.

6.4.3 Control Ports

The Aux/power and Refrigeration Refer Ports will return to their default values as specified by Setup parameters F5 & F6 respectively upon changing the setting of the rotary switch. At the end of program execution, the ports will remain in the state last used by the terminating program. See §2.2.2.

6.4.4 Displaying Temperature

The temperature may be displayed at any time by pressing the **<DISP/TEMP>** key. The format of the display is:

Pn TTT.T	Example:	P1 - 102.6	(Celsius)
PnF-TTT.T	Example:	P1F- 102.6	(Fahrenheit)

where ***n*** indicates from which probe the reading originates, and the **-TTT.T** indicates the numeric temperature. In single probe mode, ***n*** is always 1. In two probe mode, ***n*** can be 1 or 2 as the temperature display toggles between probe 1 and probe 2 with each press of the Display Temperature **<DISP/TEMP>** key. If T-Drive is implemented (probe number set to 0), the display will sequence from probe 1 to probe 2 to probe 0 (-----), then back to probe 1, etc. with each press of **<DISP/TEMP>**. The temperature is displayed to the nearest tenth of a degree C. although internal temperature values are kept at a much higher precision. The value is rounded so that a display of 30.2 means a temperature between 30.15 and 30.24. Fahrenheit values display an F after the probe number.

6.5 Programming Examples & Notes

6.5.1 Simple Program Mode Example

The following temperature test routine uses basic temperature control commands including controlled and maximum rate ramping and temperature hold (dwell):

Using Probe 1 for control...
Use 5 minutes to ramp from ambient to 45.2°C
Hold 45.2 for 2 minutes
Use 2 minutes to ramp to 32.3°C
Hold 32.3°C for 6 minutes
Go to 50.1°C as quickly as possible
Go to -10°C as quickly as possible
Hold -10°C for 3 minutes
End program

The following is the exact key sequence for entering this routine as a program into C4 program memory:

Set the C4 to Program Mode by setting the rotary MODE switch to the PROGRAM position.

If you wish to erase any programs already in memory and start with "clear" reinitialized program memory, press **<CLEAR/PROG><CLEAR/PROG>**

The table which follows shows how to enter all of the data for this program. There are shortcuts that can be used to save some time when entering program data. The shortcuts are shown in the next table. If you are not familiar with C4 programming,

be sure your understand all of the entries in the first table before attempting to use the shortcut method.

Step Number	Displayed Step . Substep	Keys to press	Description of entry
0	00.0	CLEAR/ENTRY 45.2 ENTER	Go to 45.2°C
	00.1	CLEAR/ENTRY 5 ENTER	Use 5 minute ramp time
	00.2	CLEAR/ENTRY 2 ENTER	Hold temperature for 2 minutes
	00.3	CLEAR/ENTRY 1 ENTER	Execute step 1 next
	00.4	CLEAR/ENTRY 1 ENTER	Use probe 1
1	01.0	CLEAR/ENTRY 32.3 ENTER	Go to 32.3°C
	01.1	CLEAR/ENTRY 2 ENTER	Use 2 minute ramp time
	01.2	CLEAR/ENTRY 6 ENTER	Hold 32.3°C for 6 minutes
	01.3	CLEAR/ENTRY 2 ENTER	Execute step 2 next
	01.4	CLEAR/ENTRY 1 ENTER	Use probe 1
2	02.0	CLEAR/ENTRY 50.1 ENTER	Go to 50.1°C
	02.1	CLEAR/ENTRY 0 ENTER	Ramp as quickly as possible
	02.2	CLEAR/ENTRY 9900 ENTER	Do not hold at this temperature Execute next step immediately
	02.3	CLEAR/ENTRY 3 ENTER	Execute step 3 next
	02.4	CLEAR/ENTRY 1 ENTER	Use probe 1
3	03.0	CLEAR/ENTRY -10.0 ENTER	Go to -10°C
	03.1	CLEAR/ENTRY 0 ENTER	Ramp as quickly as possible
	03.2	CLEAR/ENTRY 3 ENTER	Hold -10°C for 3 minutes
	03.3	CLEAR/ENTRY 100 ENTER	End program Turn off heat & cool
	03.4	CLEAR/ENTRY 1 ENTER	Use probe 1

6.5.2 Using shortcuts to shorten program entry time

Shortcuts can make program entry easier and faster if the program step memory to be used for the new program contains the values that you need. Default reinitialization values are stored in every program step when program memory is "cleared" by pressing **<CLEAR/PROG>** **<CLEAR/PROG>** to reinitialize program memory. These default values are often what you need.

If a program is already in memory, a new program can be entered into either the steps that the existing program occupies or into steps that remain unused since the last reinitialization. In either case, some of the existing data in the steps to be used may be the same as the new program data. If the is the case, the old data can be retained more easily than it can be re-entered.

The "shortcut" is simply a one keystroke method of retaining the existing value in a step when that value is the value you need. For instance, a reinitialized program step always has a substep 4 (probe #) value of 1. If you are going to use probe 1 in a step in your program, you can simply retain that value instead of rekeying the value.

When entering a program, you display substeps sequentially by pressing **<DISP/CNTL>**. When you have displayed a substep that contains and displays a value that is the same as the value you need for that substep, you can simply retain that value. To retain an existing value in a substep and go on to the next substep, press **<DISP/CNTL>** when the step.substep and value are displayed.

Thus the program entry sequence from the table above could be changed to the following, more efficient, entry sequence. (This sequence presumes that you have just reinitialized program memory by pressing **<CLEAR/PROG><CLEAR/PROG>**)

Step	Displayed	Keys to press	Description of entry
0	00.0	CLEAR/ENTRY 45.2 ENTER	Go to 45.2°C
	00.1	CLEAR/ENTRY 5 ENTER	Use 5 minute ramp time
	00.2	CLEAR/ENTRY 2 ENTER	Hold temperature for 2 minutes
	00.3	DISP/CNTL	Accept default value of 1 Execute step 1 next
	00.4	DISP/CNTL	Accept default value of 1 Use probe 1
1	01.0	CLEAR/ENTRY 32.3 ENTER	Go to 32.3°C
	01.1	CLEAR/ENTRY 2 ENTER	Use 2 minute ramp time
	01.2	CLEAR/ENTRY 6 ENTER	Hold 32.3°C for 6 minutes
	01.3	DISP/CNTL	Accept default value of 2 Execute step 2 next
	01.4	DISP/CNTL	Accept default value of 1 Use probe 1
2	02.0	CLEAR/ENTRY 50.1 ENTER	Go to 50.1°C
	02.1	DISP/CNTL	Accept default value of 0 Ramp as quickly as possible
	02.2	CLEAR/ENTRY 9900 ENTER	Do not hold at this temperature Execute next step immediately
	02.3	DISP/CNTL	Accept default value of 3 Execute step 3 next
	02.4	DISP/CNTL	Accept default value of 1
3	03.0	CLEAR/ENTRY -10.0 ENTER	Go to -10°C
	03.1	DISP/CNTL	Accept default value of 0 Ramp as quickly as possible
	03.2	CLEAR/ENTRY 3 ENTER	Hold -10°C for 3 minutes
	03.3	CLEAR/ENTRY 100 ENTER	End program Turn off heat & cool
	03.4	DISP/CNTL	Accept default value of 1 Use probe 1

To run this program, set the program pointer to the first program step (00) and then start the program using the following key sequence:

00 <DISP/CNTL><START/STOP>

6.5.3 Program Mode Example Using the Special Commands

The following temperature test routine uses program looping commands and the special port control commands:

Turn chamber or platform (or auxiliary load) on
Do the following loop 5 times
    Using probe 2 for control...
    Turn compressor on
    Use 15 minutes to ramp from ambient to 11.5°C
    Hold 11.5 for 20 minutes
    Use 1 hour to ramp to -32.3°C
    Hold -32.3°C for 1 hour
    Turn compressor off
    Go to 50°C as quickly as possible
    Hold 50°C for 2 ½ hours
Turn chamber or platform (or auxiliary load) off
End program

The following is the exact key sequence for entering this program into the C4 program step memory:

Set the C4 to Program Mode by setting the rotary MODE switch to the PROGRAM position. Press **<DISP/CNTL>**, then:

Step Number	Displayed Step . Substep	Keys to press	Description of entry
0	00.0	DISP/CNTL	Accept default value Value not used
	00.1	DISP/CNTL	Accept default value Value not used
	00.2	DISP/CNTL	Accept default value Value not used
	00.3	DISP/CNTL	Accept default value of 1 Execute step 1 next
	00.4	CLEAR/ENTRY 6 ENTER	Turn aux/power control port on

Step Number	Displayed Step . Substep	Keys to press	Description of entry
1	01.0	DISP/CNTL	Accept default value Value not used
	01.1	DISP/CNTL	Accept default value Value not used
	01.2	DISP/CNTL	Accept default value Value not used
	01.3	DISP/CNTL	Accept default value of 2 Execute step 2 next
	01.4	CLEAR/ENTRY 4 ENTER	Turn compressor port on
2	02.0	CLEAR/ENTRY 11.5 ENTER	Go to 11.5°C
	02.1	CLEAR/ENTRY 15 ENTER	Use 15 minute ramp time
	02.2	CLEAR/ENTRY 20 ENTER	Hold temperature for 20 minutes
	02.3	DISP/CNTL	Accept default value of 3 Execute step 3 next
	02.4	CLEAR/ENTRY 2 ENTER	Use probe 2
3	03.0	CLEAR/ENTRY -32.3 ENTER	Go to 32.3°C
	03.1	CLEAR/ENTRY 100 ENTER	Use 1 hour ramp time
	03.2	CLEAR/ENTRY 100 ENTER	Hold -32.3°C for 1 hour
	03.3	DISP/CNTL	Accept default value of 4 Execute step 4 next
	03.4	CLEAR/ENTRY 2 ENTER	Use probe 2
4	04.0	DISP/CNTL	Go to 50.1°C
	04.1	DISP/CNTL	Accept default value of 0 Ramp as quickly as possible
	04.2	CLEAR/ENTRY 9900 ENTER	Do not hold at this temperature Execute next step immediately
	04.3	DISP/CNTL	Accept default value of 3 Execute step 3 next
	04.4	CLEAR/ENTRY 5 ENTER	Turn compressor port off

Step Number	Displayed Step . Substep	Keys to press	Description of entry
5	05.0	CLEAR/ENTRY 50.0 ENTER	Go to 50°C
	05.1	DISP/CNTL	Accept default value of 0 Ramp as quickly as possible
	05.2	CLEAR/ENTRY 230 ENTER	Hold 50°C for 2 hours & 30 minutes
	05.3	DISP/CNTL	Accept default value of 6 Execute step 6 next
	05.4	CLEAR/ENTRY 2 ENTER	Use probe 2
6	06.0	CLEAR/ENTRY 5 ENTER	Set loop count to 5
	06.1	DISP/CNTL	Accept default value Value not used
	06.2	DISP/CNTL	Accept default value Value not used
	06.3	DISP/CNTL 1 ENTER	Step number of first step in loop routine
	06.4	CLEAR/ENTRY 3 ENTER	Loop command
7	07.0	DISP/CNTL	Accept default value Value not used
	07.1	DISP/CNTL	Accept default value Value not used
	07.2	DISP/CNTL	Accept default value Value not used
	07.3	DISP/CNTL	Accept default value of 8 Execute step 8 next
	07.4	CLEAR/ENTRY 7 ENTER	Turn aux/power control port off
8	08.0	DISP/CNTL	Accept default value Value not used
	08.1	DISP/CNTL	Accept default value Value not used - Null step
	08.2	DISP/CNTL	Accept default value Value not used - Null step
	08.3	CLEAR/ENTRY 100 ENTER	End program Turn off heat and cool
	08.4	DISP/CNTL	Accept default value Value not used (must be 1 or 2)

Sample program notes:

AUX/POWER CONTROL PORT ON/OFF commands are only necessary when using special order options such as an external relay to control chamber or platform power or an active load under test. COMPRESSOR PORT ON/OFF commands similarly depend on the equipment being controlled having a refrigeration compressor. If the chamber or platform being controlled does not require their use, either of these ports can be configured to control user equipment. Call our technical support department for information.

Step 8 is required only to maintain CC-3 compatibility because End of Program (substep 3 (next step) = 100) must be in a step my itself in the CC-3.

6.6 Keeping More than One Program in Memory

Programs can be installed and run anywhere there is room within the 100 step (00-99) memory allocation. To install programs at step number **xx**, press

<DISP/CNTL> xx <DISP/CNTL>.

Example: **<DISP/CNTL> 18 <DISP/CNTL>** will set the program pointer to step 18, substep 0.

Once you have set the program pointer to a step, you can enter new program information by following the procedure in Section 6.3.3 or run a program that begins at that step as detailed in Section 6.3.6.

IMPORTANT: When placing more than one program in memory, all programs except the last one must end with SUBSTEP 3 = 100, or a non terminating loop, in order to prevent separate successive programs from automatically running successively. It is good programming practice to place an End of Program (SUBSTEP 3 = 100) command at the end of every program. This will assure that program data that may be entered into higher step numbers at a later time will not have unexpected results when the initial program is run.

6.7 Sigma Systems C4 Programming Worksheet

(O.K. to copy)

Date:	Program Name:	Page _____of _____

Step	Sub-Step	Substep Data	Notes/Comments
	.0		
	.1		
	.2		
	.3		
	.4		

Step	Sub-Step	Substep Data	Notes/Comments
	.0		
	.1		
	.2		
	.3		
	.4		

	.0		
	.1		
	.2		
	.3		
	.4		

	.0		
	.1		
	.2		
	.3		
	.4		

	.0		
	.1		
	.2		
	.3		
	.4		

	.0		
	.1		
	.2		
	.3		
	.4		

	.0		
	.1		
	.2		
	.3		
	.4		

	.0		
	.1		
	.2		
	.3		
	.4		

7. Remote Mode

7.1 Bus & User Interfaces

Remote Mode provides for control of the C4 from a remote computer or terminal using either standard EIA-232 serial communication or Instrumentation Standard IEEE-488 (GPIB) communication. Selection of the type of interface is made from the Setup Mode, parameter F2, see §8.

NOTE: The IEEE-488.2 requirement for lockout of front panel control during IEEE-488 control is not enabled in this controller. The front panel mode switch remains active during remote control.

In Remote Mode, the C4 is controlled or programmed externally by sending, over the bus, a 2 or 3 character ASCII command, often followed by arguments and ending with a terminator. See §7.3.3 for programming syntax.

7.1.1 EIA-232 Interface

The controller may communicate remotely through an EIA-232 interface. To use EIA-232 communication, setup parameter F2 must be set to 0, see §8. Additionally, the interface must be software selected for proper baud rate, parity, data bits and stop bits. These are also set through the keypad in Setup Mode and become stored in the non- volatile memory. See §8, Setup Mode. To maintain compliance with EMI emission standards, only shielded cables may be used for connection to this port.

A female DB-25 connector is provided on the rear panel. The interface is set up as a DCE with DTR and CTS set always true.

7.1.2 IEEE-488 Interface

The IEEE-488 interface is implemented as a Talker/Listener without extended addressing or parallel poll capability. This is the default bus through which the C4 communicates. It is selected using setup parameter F2, see §8. The primary address is selected through the keypad in Setup Mode. A standard IEEE-488 connector is provided on the rear panel. To maintain compliance with EMI emission standards, only shielded cables may be used for connection to this port.

7.1.3 Displaying Temperature

The temperature may be displayed at any time by pressing the **<DISP/TEMP>** key. The format of the display is

Pn TTT.T	Example:	P1 - 102.6	(Celsius)
PnF-TTT.T	Example:	P1F- 102.6	(Fahrenheit)

where ***n*** indicates from which probe the reading originates and the **-TTT.T** indicates the numeric temperature. In single probe mode, ***n*** is always 1. In two probe mode, ***n*** can be 1 or 2 as the temperature display toggles between probe 1 and probe 2 with each press of the Display Temperature **<DISP/TEMP>** key. If T-Drive is implemented (probe number set to 0), the display will rotate from probe 1 to probe 2 to probe 0 (-----), then back to probe 1, etc. with each press of **<DISP/TEMP>**. The temperature is displayed to the nearest tenth of a degree C. although internal temperature values are kept at a much higher precision. The value is rounded so that a display of 30.2 means a temperature between 30.15 and 30.24. Fahrenheit values display an F after the probe number.

7.1.4 Displaying Setpoint Temperature

The setpoint temperature may be displayed at any time by pressing **<DISP/CNTL>**. The format of the display is

Sn TTT.T	Example:	S1 - 100.0	(Celsius)
SnF-TTT.T	Example:	S1F- 100.0	(Fahrenheit)

where ***n*** indicates from which probe the reading originates and the **-TTT.T** indicates the numeric temperature. In single probe mode, ***n*** is always 1. In two probe mode, ***n*** can be 0, 1 or 2, 0 indicating a T-Drive setpoint.

7.2 Remote Immediate and Remote Program Modes

The C4 can process commands either immediately upon receipt or in the sequence received.

In Remote Immediate Mode all operational commands (go to temperature, hold at temperature, etc.) and all setup commands are processed when received. Any previous command that was being processed is canceled and discarded. Query commands are also processed upon receipt, but do not cancel the underlying operational command that may be in process. This mode relies on the controlling computer to keep track of events, and provide commands as needed on a real-time basis. This mode is selected by the SI command - see §7.7.1.

In Remote Program Mode (not related to the Program Mode that can be selected using the front panel mode switch), operational and setup commands are queued or "stacked" in a command buffer. Each command is executed to completion before the next command in the queue is retrieved and executed. Query commands are processed upon receipt and do not interrupt the processing of queued commands. This mode relies on the C4 to keep track of events and can use the TE command (see §7.7.12) to notify the controlling computer when a certain place in the command queue has been reached. This mode is selected by the SP command - see §7.7.2.

7.3 Command Summary & Programming Syntax

7.3.1 Command Summary (by functional group)

7.3.1.a Controller Environment Information Queries		SP Mode Behavior	See Section:
QV	Query Firmware Version	Immediate	7.4.1
QN	Query Controller Serial Number	Immediate	7.4.2
QR	Query Controller Temperature Range	Immediate	7.4.3

7.3.1.b Controller Information Queries & Commands		SP Mode Behavior	See Section:
RS	Request Status Byte (binary)	Immediate	7.5.1
RSA	Request Status Byte (ASCII hex)	Immediate	7.5.1
RE	Request Error Byte (binary)	Immediate	7.5.2
REA	Request Error Byte (ASCII hex)	Immediate	7.5.2
QE	Query Error/Status String (binary	Immediate	7.5.3
QEA	Query Error/Status String (ASCII hex)	Immediate	7.5.3
QC	Query Last Command String	Immediate	7.5.4
ES	Enable SRQ	Queued	7.5.5
DS	Disable SRQ (Default)	Queued	7.5.6
PT	Read Probe *n* Temperature	Immediate	7.5.7

7.3.1.c Controller Setup Commands		SP Mode Behavior	See Section:
SC	Set Correction for Probe *n*	Queued	7.6.1
WP	Set PID Constants	Queued	7.6.2
RP	Read PID Constants	Immediate	7.6.3
BF	Blowers off (Enable Blower Shut-Off Mode)	Queued	7.6.4
BO	Blowers on (Disable Blower Shut-Off Mode)	Queued	7.6.4
SL	Set DUT Temperature Limits	Queued	7.6.5
SD	Set DUT Temp. Differential Limits	Queued	7.6.6
SB	Set Settling Band Parameters for Celsius mode	Queued	7.6.7
SBF	Set Settling Band Parameters for Fahrenheit mode	Queued	7.6.7
TD	Set T-Drive™ Parameters in Celsius mode	Queued	7.6.8
TDF	Set T-Drive™ Parameters in Fahrenheit mode	Queued	7.6.8
QF	Query Setup Parameter (binary)	Immediate	7.6.9
QFA	Query Setup Parameter (ASCII hex)	Immediate	7.6.9
UP	Write Current Parameters to NV Memory	Queued	7.6.10

7.3.1.d System Operation Commands		SP Mode Behavior	See Section:
SI	Select Immediate Execution Mode	Immediate	7.7.1
SP	Select Program Mode (Default)	Immediate	7.7.2
PN	Select Probe *n* for Control	Queued	7.7.3
GT,GTF	Go to Temperature	Queued	7.7.4
RA, RAF	Ramp to Temperature	Queued	7.7.5
DL	Delay (hold) for Interval	Queued	7.7.6
QS	Query Setpoint & Control Probe Number	Immediate	7.7.7
CO	Turn Refrigeration Compressor On	Queued	7.7.8
CF	Turn Refrigeration Compressor Off	Queued	7.7.8
TO	Turn Aux/Power Port On	Queued	7.7.9
TF	Turn Aux/Power Port Off	Queued	7.7.9
QU	Quit Controlling (return to idle state)	Queued	7.7.10
DC	Device Clear (reset controller)	Immediate	7.7.11
TE	Text Echo	Queued	7.7.12

7.3.2 Command Summary (alphabetical)

Command	Description	SP Mode Behavior	See Section:
BF	Blowers off (Enable Blower Shut-Off Mode)	Queued	7.6.4
BO	Blowers on (Disable Blower Shut-Off Mode)	Queued	7.6.4
CF	Turn Refrigeration Compressor Off	Queued	7.7.8
CO	Turn Refrigeration Compressor On	Queued	7.78
DC	Device Clear (reset controller)	Immediate	7.7.11
DL	Delay (hold) for Interval	Queued	7.7.6
DS	Disable SRQ (Default)	Queued	7.5.6
ES	Enable SRQ	Queued	7.5.5
GT,GTF	Go to Temperature	Queued	7.7.4
PN	Select Probe *n* for Control	Queued	7.7.3
PT	Read Probe *n* Temperature	Immediate	7.5.7
QC	Query Last Command String	Immediate	7.5.4
QE	Query Error/Status String (binary	Immediate	7.5.3
QEA	Query Error/Status String (ASCII hex)	Immediate	7.5.3
QF	Query Setup Parameter (binary)	Immediate	7.6.9
QFA	Query Setup Parameter (ASCII hex)	Immediate	7.6.9
QN	Query Controller Serial Number	Immediate	7.4.2
QR	Query Controller Temperature Range	Immediate	7.4.3
QS	Query Setpoint & Control Probe Number	Immediate	7.7.7
QU	Quit Controlling (return to idle state)	Queued	7.7.10
QV	Query Firmware Version	Immediate	7.4.1
RA, RAF	Ramp to Temperature	Queued	7.7.5
RE	Request Error Byte (binary)	Immediate	7.5.2
REA	Request Error Byte (ASCII hex)	Immediate	7.5.2
RP	Read PID Constants	Immediate	7.6.3
RS	Request Status Byte (binary)	Immediate	7.5.1
RSA	Request Status Byte (ASCII hex)	Immediate	7.5.1
SB, SBF	Set Settling Band Parameters	Queued	7.6.7
SC	Set Correction for Probe *n*	Queued	7.6.1
SD	Set DUT Temp. Differential Limits	Queued	7.6.6
SI	Select Immediate Execution Mode	Immediate	7.7.1
SL	Set DUT Temperature Limits	Queued	7.6.5
SP	Select Program Mode (Default)	Immediate	7.7.2
TD, TDF	Set T-Drive™ Parameters	Queued	7.6.8
TE	Text Echo	Queued	7.7.12
TF	Turn Aux/Power Port Off	Queued	7.7.9
TO	Turn Aux/Power Port On	Queued	7.7.9
UP	Write Current Parameters to NV Memory	Queued	7.6.10
WP	Set PID Constants	Queued	7.6.2

7.3.3 Programming Syntax

All C4 commands are either 2 or 3 letters. Some commands require arguments (parameters) and some also allow optional arguments. All commands are sent with a line terminator sequence. Commands are separated from arguments by a "delimiter". Likewise, multiple arguments are separated from each other by delimiters. The line terminator sequence follows the last argument (or the command if there are no arguments). No delimiter needs to precede the line terminator sequence. Acceptable delimiters are <space>, <comma>, or <tab> characters. The line terminator sequence is <CR><LF> to maintain CC-3 compatibility. If CC-3 compatibility is not an issue, any one of <CR>, <LF>, or GPIB EOI are acceptable line terminators.

7.3.3.a Manual conventions

The following conventions are used to specify commands:

QN	Commands are shown in UPPER CASE in this font
<error byte>	Single entities that are not characters are described by < > symbols. The < > are not part of the command.
<comma>	Indicates a comma character (ASCII 44, h2C), but is only used when needed for clarity. In most instances a comma is shown in the text.
<space>	Indicates a space character (ASCII 32, h20), but is only used when needed for clarity. In most instances a space is shown in the text.
<tab>	Indicates a tab character (ASCII 09, h09), but is only used when needed for clarity. In most instances the text is shown tabbed.
[ ]	Brackets contain optional items. The brackets are not part of the command sequence.
{ }	Braces indicate repeating items. A sequence of items that repeats will be shown inside braces with ellipsis ... following.
|	Vertical bars separate mutually exclusive choices.
nnn.n	Lower case characters in *italics* denote replaceable arguments and are always explained in the entry.
<CR>	Is a carriage return, ASCII 13, h0D.
<LF>	Is a line feed, ASCII 10, h0A

7.3.3.b CC-3 Compatibility

Programs that ran on the Sigma CC-3 controller will, with the exception of some Status Byte and Error Byte operations, run on the C4. However, because the C4 is far more lenient with command syntax, programs that run on the C4 may not run on the CC-3, even if they contain only compatible commands. This is because the C4 features a "fault tolerant" command parser that "fixes" the incoming command strings.

7.3.3.c Fault Tolerant Command Parser

The C4 fault tolerant parser "fixes" incoming command strings before storing them in the command queue. The following "fixes" are applied:

Backspace characters are acted upon. The backspace character and the character immediately preceding it are discarded.

Lower case commands are converted to upper case.

Tabs are converted to space characters

Commas are converted to space characters

Sequential multiple space characters are reduced to a single space character.

<CR> without <LF> or <LF> without <CR> are converted to <CR><LF>

GPIB EOI is converted to <CR><LF>

Extra line terminators (<CR>, <LF>, EOI) are discarded

Because the fault tolerant parser makes these changes internally, you are free to use multiple spaces, tabs, or commas as delimiters to make your programs easier to read. If you prefer to write programs in lower case, the C4 will not care.

7.3.3.d Strings without quotes or delimiters

The C4 accepts literal strings for some command arguments. Strings may never include any of the delimiter characters... spaces, commas, or tabs. Strings may also not include semicolons or colons. Quotes are not allowed as a container for strings that contain these characters. Quotes will be treated as string characters. Strings with imbedded delimiters will be seen as multiple arguments and will likely cause an argument error.

7.4 Controller Environment Information Queries

7.4.1 QV Query Firmware Version

This command returns the current internal firmware release number in ASCII text in the following format:

QV *nnn.nnn.nnn*<CR><LF>

Where *nnn* is the number of each part of the release number, padded on the left with leading zeros if necessary.

Returned data example:

QV 007.003.001<CR><LF> Returning version 7.3.1

The syntax for the command is:

QV<CR><LF>

7.4.2 QN Query Controller Serial Number

This command returns the controller serial number in ASCII text in the following format:

QN *n-nnnnn*<CR><LF>

Where the first number *n* is the number designating the model group (3 for CC-3.5, or 4 for C4) and the five digits *nnnnn* following the dash comprise the sequential part of the serial number.

Example:

QN 4-03376<CR><LF> Returning serial number 4-03376 (4-3376)

Note: When recording or reporting the serial number, always use all 7 characters in the string..

The syntax for the command is:

QN<CR><LF>

7.4.3 QR Query Controller Temperature Range

This command returns the controller temperature range in ASCII text in the following format:

QR *thhh-lll*<CR><LF>

where *t* = F (if Fahrenheit mode)
hhh = high limit
lll = low limit

Returned data examples:

For standard range controller in Celsius mode:

QR 200-100<CR><LF>

For standard range controller in Fahrenheit mode:

QR F200-100<CR><LF>

The syntax for the command is:

QR<CR><LF>

7.5 Controller Information Queries & Commands

7.5.1 RS, RSA Request Status Byte

These commands retrieve the Status Byte. Reading the Status Byte will clear some of the bits. See §7.8.3.

If RS is used, the Status Byte is returned as a one byte binary value imbedded in an ASCII text string as follows:

RS<binary status byte><CR><LF>

If RSA is used, the Status Byte is returned as a two byte ASCII hex string imbedded in an ASCII text string as follows:

RSA<space><2 character ASCII hex string><CR><LF>

Returned data example for RSA:

RSA 47<CR><LF>

The syntax for the command is:

RS<CR><LF>	Request 1 byte binary value
RSA<CR><LF>	Request 2 byte ASCII hex value

7.5.2 RE, REA Request Error Byte

These commands retrieve the Error Byte. Reading the Error Byte will clear some of the bits. See §7.8.2.

If RE is used, the error byte is returned as a one byte binary value imbedded in an ASCII text string as follows:

RE<error byte><CR><LF>

If REA is used, the error byte is returned as a two byte ASCII hex string imbedded in an ASCII text string as follows:

REA<space><2 character ASCII hex string><CR><LF>

Returned data example for REA:

REA 40<CR><LF>

The syntax for the command is:

RE<CR><LF>	Request 1 byte binary value
REA<CR><LF>	Request 2 byte ASCII hex value

7.5.3 QE, QEA Query Error/Status String

These commands return the 64 byte (512 bit) Error/Status String which includes the Error Byte and Status Byte. Each bit in the string represents an error or status condition. If the bit is set (1), the condition is true, if the bit is reset (0), the condition is false. The Error/Status String is divided into three parts. Reading the Error/Status String will clear some of the bits. See §7.8.4 for a complete explanation of the Error/Status String.

The syntax for the command is:

QE<CR><LF>	Request binary value
QEA<CR><LF>	Request ASCII hex value

The QE command will return:

QE<a fixed length 64 byte binary string><CR><LF>.
Total return string length=68 bytes, including terminators.

The QEA command will return the 64 bytes of error/status data in 2 character per byte ASCII hex in 4 lines of 16 error/status bytes each formatted as follows:

For each line:
QEA<space><first byte number in two ASCII digits><triple space><then 16 bytes of error/status data as ASCII hex with 1 space between bytes 0-7, three spaces between bytes 7-8, one space between bytes 8-15><CR><LF> as follows:

```
QEA 00   00 00 00 00 00 00 00 00   00 00 00 00 00 00 00 00<CR><LF>
QEA 16   00 00 00 00 00 00 00 00   00 00 00 00 00 00 00 00<CR><LF>
QEA 32   00 00 00 00 00 00 00 00   00 00 00 00 00 00 00 00<CR><LF>
QEA 48   00 00 00 00 00 00 00 00   00 00 00 00 00 00 00 00<CR><LF>
```

Programmer's note: Each of the 4 lines of text is terminated with a <CR><LF> pair. Programs that put up read commands that are satisfied by <CR><LF> will need to put up 4 reads to obtain all the data returned by QEA. The primary use of QEA is for debugging using a dumb terminal or terminal program. The line terminators are necessary in this use to format the screen output correctly.

7.5.4 QC Query Last Command

This command returns the last non-null command string sent to the controller. The returned string is the string that was delivered to the controller after the internal parser did any "fixing". It does not have to be a valid command. The string is ASCII text and is terminated with <CR><LF>. Null strings are discarded by the parser.

Example:

Previous command sent:	QC returns:
Ra, -55 2,11<CR><LF>	RA -55 2 11<CR><LF>

The syntax for the command is:

QC<CR><LF>

7.5.5 ES Enable SRQ (Status Request Mode)

For the IEEE-488 interface, SRQ is sent with the binary status. The status is not cleared until read with an RS command.

This command enables the SRQ function. Format of the command is:

ES<CR><LF>

SRQ is sent on the event of a change in state of some bits in the Status Byte. See §7.8.3 for details. For the EIA-232 interface, SRQ is sent as the ASCII string:

SQ "binary status byte" <CR> <LF>

The SRQ is a simple method for obtaining timely information from the C4 about your process. Because the SRQ is event driven, continuous polling of the C4 is not necessary. GPIB general purpose programming is beyond the scope of this manual. However, if you are not familiar with the workings and advantages of this powerful feature, we suggest that you obtain a GPIB tutorial and learn more.

7.5.6 DS Disable the SRQ

This command disables the SRQ function (default is DS - disabled). Format of the command is:

DS<CR><LF>

7.5.7 PT Read Temperature (or CSP)

This command is used to read the specified probe temperature or the T-Drive™ Control Setpoint (CSP). The format of the command is:

PT *n*<CR><LF>

where *n* is the number (0, 1 or 2) of the probe to be read. Probe 2 is only available if enabled by Setup Parameter F1 (See Section 8). Specifying probe 0 will return the Control Setpoint if the current control probe number is 0 (T-Drive™ is active). See §4.3.3. If T-Drive™ is not active, PT 0 will return a parameter error. If two probes are not enabled in setup parameter F1 (see §8.3.1), PT 2 or PT 0 will return a parameter error.

Example:

PT 2<CR><LF>

reads the temperature reported by probe 2

The response is ASCII text with temperature as a one decimal place number. Negative temperatures are preceded by a minus sign. Temperatures read in Fahrenheit mode have an "F" character inserted after the probe number:

T*n* -*ttt.t*<CR><LF>	for Celsius mode
T*n*F -*ttt.t*<CR><LF>	for Fahrenheit mode

where *n* is the probe number (0, 1 or 2) and *ttt.t* is the temperature. The *ttt.t* value is not fixed length, but always includes one decimal place. A minus sign precedes negative values.

Response examples:

T1 102.0<CR><LF>	Probe 1 reports a temperature of 102.0°C
T1F -74.3<CR><LF>	Probe 1 reports a temperature of -74.3°F
T0 96.2<CR><LF>	The T-Drive™ Control Setpoint (CSP) is 96.2°C

7.6 Controller Setup Commands

Each time Remote Mode is entered (by turning the Mode switch on the front panel of the controller) a new copy of the permanent setup parameter values is read into a working copy that is used during the Remote Mode session. If any of these working copy values have been modified by Remote Mode setup commands in this section, they will not be the same as the permanent setup parameter table values, unless an UP command (see §7.6.10) is subsequently used to replace the permanent copy values with the temporary copy values. Upon exiting Remote Mode, including by power loss or fail-safe event, the temporary copy values are discarded.

The commands listed in this section change only the temporary working copy of the setup parameters. To save these values in the non-volatile permanent setup parameter table, use the UP command. See §7.6.10.

7.6.1 SC Set Probe Correction

A complete discussion of the probe correction entries is in Section 8.3.5. Read that section carefully before using this command.

WARNING: Incorrect usage of this command may cause temperature control to be effected by invalid data and may result in unexpected temperature excursions that can cause harm to personnel and damage to equipment.

The SC command writes the data for either probe 1, or probe 2, to setup parameter fields F17-F20 or F21-F24 respectively. The data for all 4 parameters used to correct one probe must be sent with the command.

Software probe correction is achieved by entering four temperatures, U1, C1, U2, & C2, for each probe into the setup parameter table. U1 & U2 are the uncorrected, or displayed, temperatures at two points. C1 & C2 are the corrected, or actual, temperatures at those same two points.

Values for probe correction should be entered in the current scale, °C or °F, as set in setup parameter F16. There is no difference in the command syntax for Fahrenheit operation, so it is incumbent upon the user to use the correct values.

Note: Software probe correction is done separately for each probe. The following table shows the U1, C1, U2, C2 setup parameter assignments:

	Probe 1	Probe 2
U1	F17	F21
C1	F18	F22
U2	F19	F23
C2	F20	F24

The syntax for the SC command is ASCII text as follows:

SC*n* U1 C1 U2 C2<CR><LF>

where *n* = number of probe to correct
U1, C1, U2, and C2 are floating point numbers to one decimal place.

Example:

SC1 0 2.3 100 101.3

In the event the correction parameters do not conform to the restrictions detailed in §8.3.5, the controller will discard the correction and set the appropriate bit in Byte 04 of the Error/Status String.

7.6.2 WP Set PID Constants

A complete discussion of the PID terms entries is in Setup §8.3.4. A discussion of how to use the terms to improve control is in the Appendix in Section 9.4. Read both sections carefully before using this command.

WARNING: Incorrect usage of this command may cause temperature control to be adversely effected and may result in unexpected temperature excursions that can cause harm to personnel and damage to equipment if the appropriate system operating limits are not properly set.

The WP command writes the P, I, D & R data to setup parameter fields F0, F10, F11, & F12 respectively. The data for all 3 PID parameters used for PID control must be sent with the command. The R parameter is optional. The syntax for the WP command is ASCII text as follows:

WP *p i d* [*r*]<CR><LF>

where *p* = proportional term constant
i = integral term constant
d = differential term constant
r = relative cooling system/heating system gain

format all four values are integer numbers

Example:

WP 6 5 5 30<CR><LF> (with optional R parameter)
WP 6 5 5<CR><LF> (without optional R parameter)

7.6.3 RP Read PID&R Constants

A complete discussion of the PID terms entries is in Setup §8.3.4. A discussion of how to use the terms to improve control is in the Appendix in §9.4.

The RP command reads the P, I, D & R data from setup parameter fields F0, F10, F11, & F12 respectively. The data for all 4 parameters used for PID control is returned by this command. The syntax for the RP command is ASCII text as follows:

RP<CR><LF>

Example:

RP<CR><LF>

The response from this command is ASCII text as follows:

RP<space>*p*<space>*i*<space>*d*<*space*>*r*<CR><LF>

where *p* = proportional term constant
i = integral term constant
d = differential term constant
r = relative cooling system/heating system gain

format all four values are integer numbers

Example:

RP 6 5 5 30<CR><LF>

7.6.4 BF & BO Blower Off & Blower On Commands

The BF and BO commands affect the state of setup parameter F15, (Blower Shut-off Mode). See §8.3.3 for a detailed explanation. Note that these commands change the current temporary copy of the setup parameter table. The changes made to F15 with these commands will not be preserved in permanent memory unless an UP command is subsequently issued.

Because the Blower Shut-off Mode only affects the behavior of the blowers when the controller is in idle state (not controlling) after running a program, the BF and BO commands only affect that state. However, the C4 monitors the state of Blower Shut-off Mode while idling, so that using BO or BF at that time can change the state of the blowers during controller idle time. BO and BF received while the C4 is controlling a temperature will change the state of setup parameter F15, but will not affect the state of the blowers at that time as F15 only affects blower operation while the controller is in idle mode (not controlling).

The BF command will turn the blowers off in idle mode. This command sets setup parameter F15 to 1.

The BO command will turn the blowers on in idle mode. This command sets setup parameter F15 to 0.

The syntax of the command is:

BF<CR><LF>	Turn blowers off (enables Blower Shut-off Mode)
BO<CR><LF>	Turn blowers on (disables Blower Shut-off Mode)

Note for systems with refrigeration compressors: Turning the blowers off using the BF command disables the main power to the chamber or platform and thus will also turn off the refrigeration compressors. To prevent short cycling of the compressors, do not use the BF command with mechanically refrigerated systems.

7.6.5 SL Set DUT Temperature Limits

The SL command sets the lower DUT limit (setup parameter F27) and the upper DUT limit (setup parameter F28). For a detailed explanation of the effect of these parameters, see §3.5 and 4.2.2.a. The command sets the lower and upper temperature limits at the same time. The syntax of the command is:

SL lll.l uuu.u<CR><LF>

where: lll.l is the lower limit (F27)
uuu.u is the upper limit (F28)
lll.l & uuu.u are one decimal place numbers

Example:

SL -75 130<CR><LF> Sets DUT limits to -75° & +130°

7.6.6 SD Set DUT Temperature Differential Limits

The SD command sets the lower DUT temperature differential limit (setup parameter F29) and the upper DUT temperature differential limit (setup parameter F30). For a detailed explanation of the effect of these parameters, see §4.2.2.a. The command sets the lower and upper temperature differential limits at the same time. The syntax of the command is:

SD lll.l uuu.u<CR><LF>

where lll.l is the lower differential limit (F29)
uuu.u is the upper differential limit (F30)
lll.l & uuu.u are one decimal place floating point numbers

Example:

SD 50 30<CR><LF>

7.6.7 SB, SBF Set Settling Band Parameters

The SB & SBF commands set the setpoint temperature bandwidth and minimum stable time requirements for "satisfying" a go to temperature request (setup parameters F31 & F32). For a detailed description of this feature, please see §4.1. The command sets the setpoint temperature bandwidth and stable time at the same time. The syntax of the command is:

SB tt.t ss<CR><LF> Celsius mode
SBF tt.t ss<CR><LF> Fahrenheit mode

where tt.t is degrees of temperature bandwidth (± from setpoint) allowed to "satisfy" a go to temperature request). The valid range of this parameter is .1°C (.2°F) to 10°C (18°F). Default = 0.8°C

ss is seconds of stable temperature (within above bandwidth) required to "satisfy" a go to temperature request. The valid range is 0 to 59 seconds. Zero has the special meaning that the setpoint will be considered "satisfied" the first time the controlling probe temperature reaches or passes through the setpoint (± the allowable bandwidth as above). Default = 15 seconds

Example:

SB .8 15<CR><LF>
SBF 1.3 20<CR><LF>

Sets the settling band parameters to the °C mode default values of 0.8° and 15 seconds or 1.3°F and 20 seconds in Fahrenheit mode..

Note: If the second parameter is omitted, it is assumed to be 0 (Touch 'n Go - see §4.1.3)

If the parameters passed with this command are invalid, Bit 2 of the Error Byte will be set.

7.6.8 TD, TDF Set T-Drive Factors

The TD and TDF commands set the T-Drive™ acceleration factor and lead constant (setup parameters F34 & F35). For a detailed description of this feature, please see §4.2. The command sets the T-Drive™ acceleration factor and lead constant at the same time. The syntax of the command is:

TD s.s dd.d<CR><LF> Celsius mode
TDF s.s dd.d<CR><LF> Fahrenheit mode

where s.s is the thermal overdrive slope factor (F34). The valid range of this parameter is 0 to 5.0. Default = 2.0

dd.d is degrees of thermal overdrive lead(+) or lag(-) (F35). Default = 5.0°C (9.0°F)

Example:

TD 2 5<CR><LF>	Celsius mode
TDF 2 9<CR><LF>	Fahrenheit mode

Sets the T-Drive™ acceleration factor and lead/lag constant to the °C mode default values of 2 and 5 respectively or °F mode default values of 2 and 9 respectively.

If the parameters passed with this command are invalid, Bit 2 of the Error Byte will be set.

7.6.9 QF, QFA Query Setup Parameter Value

This command returns the current value of a setup parameter field from the temporary working copy of the setup parameter table. QF requests the data to be returned in binary form, QFA requests the data to be returned in ASCII text form. The syntax of the command is:

QF*nn*<CR><LF>	QFA*nn*<CR><LF>
(Query for binary)	(Query for ASCII text)

Where *nn* is a one or two byte ASCII text decimal number of the setup parameter field to be returned.

For parameters numbered 0 through 16:

If QF is used, the value stored for that parameter is returned as a one byte binary value in an ASCII string as follows:

QF*nn* <binary byte><CR><LF>

Where *nn* is the setup parameter number in 2 bytes of ASCII text decimal (leading zero if required).

If QFA is used, the value is returned in two bytes of ASCII hex in the format 00 in an ASCII string followed by CR/LF as follows:

QFA*nn* *hh*<CR><LF>

Where *nn* is the setup parameter number in 2 bytes of ASCII text decimal (leading zero if required) and *hh* is the ASCII hex value.

For parameters numbered 17 through 35:

The values returned for parameters numbered 17 through 35 are expressed as ASCII decimal numbers. All except F33 are expressed with one decimal place. F32 is expressed as an integer. Negative values will have a leading minus sign. If the value is a Fahrenheit value, the character "F" will be appended to the end of the string. CR/LF terminates the string. QF and QFA return the same strings for parameters 17 through 35. Format of the returned data is::

QF*nn* -123.4F<CR><LF>
QFA*nn* -123.4F<CR><LF>

Note: The values returned by QF and QFA are the temporary working values. These values are originally obtained for Remote Mode from the permanent values used by Local, Program, and Setup Modes. Each time Remote Mode is entered (by turning the Mode switch on the front panel of the controller) a new copy of the permanent setup parameter values is read into a working copy that is used during the Remote Mode session. If any of these working copy values have been modified by Remote Mode setup commands (See §7.6 & §7.6.10) they will not be the same as the permanent copy values unless an UP command was subsequently used to replace the permanently copy values with the temporary copy values. Upon exiting Remote Mode, including by power loss or fail-safe event, the temporary copy values are discarded.

7.6.10 UP Write Temporary Setup Parameters to Permanent Table

UP writes the current working copy setup parameters to the permanent setup parameter table. See §7.6 for explanation. This command uses no arguments. The command writes all parameters at one time. The syntax of the command is:

UP<CR><LF>

There is no response from the controller to this command.

7.7 System Operation Commands

7.7.1 SI Select Immediate Mode

This command selects the immediate mode of operation. In immediate mode, a command is executed immediately when it is received over the interface. If a previous command is executing, it is canceled. Query or status commands do not cancel executing operating commands. §7.3 lists all Remote Mode commands. Commands shown as "immediate" in that table are executed without interrupting the currently executing command. Command syntax is:

SI<CR><LF>

The controller does not respond when receiving this command.

7.7.2 SP Select Remote Program Mode

This command selects the remote Program Mode of operation. This is not the same "Program Mode" that can be selected from the front panel. This is a Remote Mode feature. In remote Program Mode, process commands are stored in a command buffer until such time as the controller can execute them in the order in which they were received. Query, and a few other commands, are executed immediate upon receipt and do not interrupt the executing command sequence. §7.3 lists which commands are immediately executed and which are queued for sequential execution. Remote Program Mode (SP) is the default upon entering the Remote Mode of operation.

Note that the command buffer is limited in size. The buffer can hold at least 32 queued commands. If your program does not use more than 32 queued commands, you do not need to check the buffer control bits in the Status Byte. However, if you have 33 or more queued commands in your program sequence, you should use the Status Byte for flow control. For a more complete description of flow control, see §7.9. Command syntax is:

SP<CR><LF>

7.7.3 PN Select Active (control) Probe

This command selects the probe that will be used for control of the chamber. The default when entering the Remote Mode of operation is probe 1. For single probe systems, this command is never used although all units are sold capable of utilizing two probes. Valid probe numbers here are 0, 1 and 2 only. Selecting probe 0 will initiate T-Drive™ Control. See §4.2. Specifying Probe 0 or Probe 2 when only one probe has been defined for the system in setup parameter F1 will cause a "bad parameter error" to be set in the Error Byte. Command syntax is:

PN *n*<CR><LF> Where *n* is probe number to use for control

Example:

PN 1<CR><LF> Selects probe 1 (default) for control.

Warning: Probe 1 should always be the probe in the platform or in the chamber airstream. Using probe 2 for control when that probe is inside a thermally latent or isolated mass can easily result in a "run-away" condition that can cause risk to both equipment and operators. The controller always presumes that the probe attached to the probe 1 input is located in the platform or chamber airstream so that the controller can check for conformance with the System Operating Limits. See §3.5.

7.7.4 GT, GTF Go To Temperature

This command instructs the controller to control to the setpoint specified in the command. The arguments for the command include a setpoint temperature, and optionally, a ramp timeout value. Bit 4 (setpoint reached) of the Status Byte is set when the chamber or platform has stabilized within the settling band as described in §4.1 as defined by setup parameters F31 and F32. The default settling requirement is within 0.8°C of the setpoint for 15 seconds. The chamber or platform will attempt to reach the specified setpoint as quickly as possible. The command syntax is:

GT<space>[-]*ttt.t* [*rrr.r*]<CR><LF> Celsius mode
GTF<space>[-]*ttt.t* [*rrr.r*]<CR><LF> Fahrenheit mode

Where *ttt.t* is the final setpoint temperature
rrr.r is the minimum ramp rate value for the Ramp Timeout Function in °/minute

See §3.11 for a complete discussion of the Ramp Timeout feature.

Examples:

GT 125<CR><LF> Celsius mode - go to 125°C
GTF 180<CR><LF> Fahrenheit mode - go to 180°F

GT 125 5<CR><LF> Go to 125°C and set warning if ramp rate falls below 5°C/minute

7.7.5 RA, RAF Ramp to Temperature

This command executes a ramping function. The arguments for the command include a ramp temperature and a ramp time, and optionally, a minimum ramp rate value. The controller will execute a linear ramp from the current temperature to the specified temperature over the specified time period. Bit 3 (interval complete) of the

Status Byte is set when the chamber or platform has completed the ramp. The command syntax is:

RA [-]*ttt.t hh mm* [*rrr.r*]<CR><LF>	Celsius mode
RAF [-]*ttt.t hh mm* [*rrr.r*]<CR><LF>	Fahrenheit mode

Where *ttt.t* is the final setpoint temperature
hh are the hours to be used for the ramp (range is 0-99 hrs)
mm are the minutes to be used for the ramp (range is 0-59 mins)
rrr.r is the minimum ramp rate value for the Ramp Timeout Function

See §3.11 for a complete discussion of the Ramp Timeout feature to have the C4 monitor the success of the ramp command.

Examples:

RA -55 2 15<CR><LF>	Celsius mode
RAF -55 2 15<CR><LF>	Fahrenheit mode Ramps to -55° over 2 hours and 15 minutes
RA -55 2 15 1<CR><LF>	Ramps to -55°C over 2 hours and 15 minutes and sets minimum ramp warning if unable to maintain at least 1°C/minute ramp rate.

Note: The RA & RAF (ramp) commands may not be used with T-Drive. If an RA or RAF command is received by the C4 when the active probe is 0 (PN=0), the command will be ignored and Bit 6 of Byte 2 in the Error/Status String will be set. See §7.8.4.b.

T-Drive has it's own ramping capability based upon temperature differential limits. For many applications, the T-Drive ramp method using these limits and the GT & GTF commands will be a superior solution offering better DUT protection and higher testing process speed. See §4.2.2.a.

7.7.6 DL Delay (Dwell Interval)

The DL command causes the controller to maintain the setpoint temperature for a specified interval of time before executing the next command. The Interval Complete bit of the Status Byte is set when the chamber or platform has completed the requested delay interval. The command syntax is:

DL *hh mm*<CR><LF>

Where *hh* are hours to be used for the delay interval
mm are the minutes to be used for the delay interval

Example:

DL 1 20<CR><LF>

Will hold the current setpoint for 1 hour and 20 minutes

Note: The DL command can also be used at the beginning of a program, or after a QU command to insert a "wait" interval before the next command will execute (in Remote Program (SP) mode - see §7.7.2).

7.7.7 QS Query Setpoint & Control Probe Number

This command returns the current setpoint and control probe number as follows:

S*p* [-]*nnn*<CR><LF> For Celsius mode
S*p*F [-]*nnn*<CR><LF> For Fahrenheit mode

Where *p* is the number of the controlling probe and
Where *nnn* is the current setpoint with leading minus sign if needed.

Returned data example: Control with probe 1 to -85°F

S1F -85.0<CR><LF>

Note: If probe number returned = 0, then T-Drive™ is active.

The syntax for the command is:

QS<CR><LF>

7.7.8 CO & CF Turn Refrigeration Compressor On & Off

The CO command turns the refrigeration compressor port on. The CF command turns it off. The default port setting upon entering Remote Mode is determined by setup parameter F6. The behavior of this port is fully documented in §2.2.2. If setup parameter F6 is set to 0, you will need to use CO to turn the compressor port on before a GT (go to temperature) or RA (ramp to temperature) command is sent. To turn the compressor on or off, send a CF command.

Note: The compressor port is not automatically turned off at the end of a program. If you want the compressor (port) off when a program ends, you must explicitly use a CF command to turn it off

You may easily check the state of the compressor port by using the QE or QEA command to read the Error/Status String. The state of the port is reported by Byte 35, Bit 4. See §7.8.4.b.

The REFER LED on the front panel will display the status of the refrigeration compressor port.

The command syntax is:

CO<CR><LF>	Set (turn on) the compressor port
CF<CR><LF>	Reset (turn off) the compressor port

7.7.9 TO & TF Turn Aux/Power/Boost Coolant Control Port On & Off

The TO command turns on the Auxiliary/Power port. The TF command turns the port off. The default setting upon entering Remote Mode is determined by setup parameter F5. The current state of the Aux/Power Port is reported by Byte 35, Bit 4 of the Error Status String which can be accessed using the QE or QEA commands. See §7.8.4.b. The behavior of this port is fully documented in §2.2.2.

The Auxiliary/Power port is standardly implemented as a TTL output available at back of the C4 B circuit board. The port is typically used to control an optional remote (chamber or platform) power switch or to enable or disable a cyrogenic boost coolant circuit for mechanically refrigerated chambers.

The command syntax is:

TO<CR><LF>	Turn the Aux/Power Port on
TF<CR><LF>	Turn the Aux/Power Port off

7.7.10 QU Quit Controlling

The QU command stops the C4 from controlling temperature. All heating and cooling is turned off, the blowers are set to the mode determined by setup parameter F15 (Blower Shut-off Mode), the Refer Port and Aux/Power Ports are not affected. The command syntax is:

QU<CR><LF>

After a QU command, the display will show:

uIC 65.0	(Celsius mode with current temperature display)
uIF 102.6	(Fahrenheit mode with current temperature display)

Note: The C4 can also be commanded to STOP controlling the temperature by issuing a DC command or IEEE-488 standard I/O statements ABORTIO, Device Clear, or Selected Device Clear. The primary functional difference is that the QU commands simply returns the system to the "idle" state. The DC and GPIB commands Device Clear and Selected Device Clear, but not the GPIB function Interface Clear, result in a system reset. See §7.10.

7.7.11 DC Device Clear

The DC command executes the same routines as a GPIB Device Clear or Selected Device Clear. See §7.10. The command returns the C4 nearly to it's power on state with a new copy of the permanent setup parameters in the working setup parameter table. The communications and command buffers are cleared and all working copy setup parameters are lost.

The syntax of the command is:

DC<CR><LF>

7.7.12 TE Text Echo

TE is a queued (Remote Program Mode) command that returns the argument text when processed. The purpose of the command is to allow a text string to be imbedded in a command sequence. When the command is executed, the string supplied as the command's argument is returned to the user. The text string can be any ASCII text up to 8 bytes in length.

Use example:

> The objective is to go to 120°, hold for 30 minutes, then run a test that takes 10 minutes, then go to -50°, hold for 30 minutes then run a second test that takes 10 minutes. There are two ways to accomplish the goal.
>
> One way is to run the controller in Remote Immediate Mode (SI command) and let the controlling computer do the timing work and keep track of events in the following manner:
>
> Send **SI** Set controller to Remote Immediate Mode
> Send **GT 120** Go to 120°
> Watch for "setpoint reached" (bit 4) in the Status Byte
> Send **DL 0 30** Hold for 30 minutes
> Watch for "interval complete" (bit 3) in the Status Byte
> Run test (controller will continue to hold 120°)
> Send **GT -50** Go to -50°
> Watch for "setpoint reached" (bit 4) in the Status Byte
> Send **DL 0 30** Hold for 30 minutes
> Watch for "interval complete" (bit 3) in the Status Byte
> Run test (controller will continue to hold 120°)
> Send **QU** Quit controlling

The other way is to run the controller in Remote Program Mode (SP command - see §7.2) and let the controller do the timing work and keep track of events, notifying the controlling computer when it is time to run the tests. The sequence uses the TE command to let the controlling computer know when it is time to run the tests. Example:

Send **SP**	Set controller to Remote Program Mode
Send **GT 120**	Go to 120°
Send **DL 0 30**	Hold for 30 minutes
Send **TE Begin1**	Echo “Begin1" when 30 minute hold is finished
Send **DL 0 11**	Hold for 11 minutes (10 min for test + 1 min for starting and stopping the test)
Send **GT -50**	Go to -50°
Send **DL 0 30**	Hold for 30 minutes
Send **TE Begin2**	Echo “Begin2" when 30 minute hold is finished
Wait for “TE Begin1" then run test 1	
Wait for “TE Begin2" then run test 2	
Send **QU**	Quit controlling

7.8 Error and Status Reporting - Overview

There are three sources for error and status information:

The Error Byte

The Status Byte

The Error/Status String
(64 bytes)

Important note: Versions of C4 firmware through 7.9.9 were backward compatible with Sigma CC-3 controllers. Versions 8.0.0 and later use redefined bit meanings for the Status Byte, Error Byte, and Error/Status String. Some bits have been moved, others serve new purposes. Unlike prior versions, versions 8.0.0 and later use only one Status Byte bit definition for both EIA-232 and IEEE-488 GPIB. Users planning on using control programs written for firmware versions earlier than 8.0.0 should refer to §1.6 for a list of differences that must be considered.

7.8.1 Relationship of Error Byte, Status Byte, and Error/Status String

CC-3 controller firmware contained only two bytes of information that were user accessible - the Error Byte and the Status Byte. Early CC-3.5 and C4 firmware added the Error/Status String with the Error Byte and Status Byte replicated in the first two bytes. However, the definition of the Status Byte changed when the communications port (EIA-232 or IEEE-488 GPIB) changed and handling of the Error/Status String replicas of the Error Byte and Status Byte was not consistent.

Beginning with version 8.0.0 of C4 firmware, byte 00 of the Error/Status String <u>is</u> the Error Byte (not a replica) and byte 01 of the Error/Status String <u>is</u> the Status Byte (again, not a replica). Thus, there cannot be inconsistencies in the behavior of the separately accessible Error Byte and Status Byte as compared to their Error/Status String counterparts as they are now the same C4 internal data.

Because the Error Byte and Status Byte can be read either directly or as part of the Error/Status String, the user is free to decide if the additional information available in the Error/Status String is needed. If the additional information is needed, then reading the Error/Status String will provide both the Error Byte and Status Byte information as well as the additional Error/Status String data in a single read. However, if the additional information is not required, the user can use the simpler single byte read commands to read the Error Byte and the Status Byte without incurring the overhead of having to parse the 64 byte Error Status String. The behavior of the Error Byte and Status Byte bits is the same regardless of the method used to read them.

7.8.2 Error Byte

The Error Byte is a one byte block of data in which each of the eight bits reports the status of an item. Each bit can be either 0 or 1. A bit with a value of 0 is "reset" and is equivalent to logical false. A bit with a value of 1 is "set" and is equivalent to logical true. The bits in the Error Byte report the status of the following items:

Bit	Definition - Error Byte	Type
0	Aux Input toggled (typically optional door switch open/closed)	Event
1	System Fault Alert	Event
2	Illegal argument string. A valid command was received but the accompanying argument(s) was/were not valid	Event
3	Fail-safe tripped	Event
4	Data in bytes 02-31 of the Error/Status String changed	State
5	Undefined command. A command string was received that is not recognized by the controller	Event
6	Command buffer overrun. Commands were sent to the controller when the command buffer was full and commands were permanently lost.	Event
7	Time-out error. Chamber or platform did not maintain minimum ramp rate	Event

Seven of the Error Byte bits are "event" bits and one is a "state" bits. State bits reflect the state of the item they report at the time the Status Byte was read. Event bits indicate that an event took place since the last time the Status Byte was read. Bits 0, 1, 2, 3, 5, 6, and 7 are event bits. Bit 4 is a state bit..

State bits are set and reset by the condition they report. Thus, if any of the bits in bytes 02-31 of the Error/Status String are set, bit 1 will be set. If all of the bits in bytes 02-31 of the Error/Status String are reset, bit 4 of the Error Byte will be reset. Reading the Error Byte does not affect the state of bit 4.

Event bits are set by the condition they report. However, they are only reset when the Error Byte is read or the controller receives a Device Clear, or is powered off. Thus, an event bit tells you if an event took place since the last time you read the Error Byte. There are a number of methods to "read" the Error Byte. The RE and REA commands read the Error Byte directly. The QE and QEA commands read the Error Byte as part of the Error/Status String.

Except for bit 4, the Error Byte is "event" information. Each time the state of an event item that is reported in the Error Byte becomes true, the associated event bit in the Error Byte is set. If the condition of the reported event item subsequently becomes false, the associated event bit is <u>not</u> reset. The entire Error Byte, except bit 4, is cleared (reset) after it is read with the RE, REA, QE, or QEA commands. As the

Error Byte is byte 00 of the Error/Status String, byte 00 of the Error/Status String is cleared when the Error Byte is read.

7.8.2.a Effect of the Error Byte on Bit 7 of the Status Byte

The bits of the Error Byte are "ORed" to set the state of bit 7, the Error Bit, in the Status Byte. That is, if any of the bits in the Error Byte are set, then bit 7 of the Status Byte will be set. Conversely, when the bits of the Error Byte are reset (cleared) by the Error Byte being read, bit 7 of the Status Byte will also be reset (provided that Error Byte bit 4 is not set by the Error/Status String).

Following is an explanation of the function and behavior of each of the bits in the Error Byte:

7.8.2.b Bit 0, Aux Input Toggled

Each time the state of the TTL Aux Input (See §2.2.2) changes, from open to closed, or from closed to open, bit 0 will be set. Note: The current state of the Aux Input can be read from the Error/Status String, byte 35, bit 7.

7.8.2.c Bit 1, System Fault Alert

If the chamber or platform is equipped with the optional Sigma Component Fault Sensing System, and that system detects a monitored component failure, bit 1 will be set. Because this bit represents the "ORing" of the various component fault signals of the Component Fault Monitoring System, bit 1 will not be set again until the system has run without a fault condition. That is, if the Error Byte is read after a fault indication, bit 1 will be reset. If system operation is continued without resolving the condition that caused the fault indication, neither the continuing fault, nor any additional faults will be reported. The Component Fault Monitoring System expects faults to be cured and the system to operate from a fault-free (logical 0) base condition.

7.8.2.d Bit 2, Illegal Argument String

This bit is set when a command is received from the host controller that is a valid command but which is accompanied by an argument (parameter) that is not in the specified format or that is not within the legal range. The command and the argument data will be discarded.

7.8.2.e Bit 3, Fail-safe Tripped

Bit 3 is set when the fail-safe system (either bi-metal or precision) shuts down the system due to an over or under temperature condition. See §3.10 for a detailed discussion of fail-safe operation.

7.8.2.f Bit 4, Error/Status String Data

Bit 4 is set when any of the "event" bits (bytes 02-31) in the Error/Status String are set. It is incumbent upon the user to read the Error/Status String after reading the Error Byte to ascertain the nature of the reported event, and to clear the event section of the Error/Status String. It is important to recognize that bit 4 of the Error Byte is the "ORed" sum of bytes 02-31 of the Error/Status String and is thus cleared (reset) only when all bits in bytes 02-31 of the Error/Status String are reset.

7.8.2.g Bit 5, Undefined Command

Bit 5 is set when the controller receives a command from the host computer that it does not recognize. The C4 features a "fault tolerant" parser that will try to fix syntax errors, line termination, etc. However, if the parser cannot find a known command at the beginning of a string of received data, bit 5 will be set and the data received will be discarded.

7.8.2.h Bit 6, Command Buffer Overrun

Bit 6 is set when the C4 receives commands it cannot store because the command buffer is full. The data received will be discarded. Note: Bits 1 & 2 of the Status Byte provide for a method of flow control to prevent this problem. See §7.9 on communications flow control.

7.8.2.i Bit 7, Time-out Error

Bit 7 is set when the device being controlled (chamber or platform) fails to achieve temperature transitions at the minimum rate specified in Setup Parameter F33. See §3.11 for a complete discussion of this feature.

7.8.3 Status Byte

The Status Byte is a one byte block of data in which each of the eight bits reports the status of an item. Each bit can be either 0 or 1. A bit with a value of 0 is "reset" and is equivalent to logical false. A bit with a value of 1 is "set" and is equivalent to logical true. The bits in the Status Byte report the status of the following items:

Bit	Definition - Status Byte	Type	Sets SRQ
0	SRQ enabled (1), disabled (0)	State	No
1	Buffer over at least 75% full - stop sending	State	No
2	Buffer not more than 50% full - resume sending	State	No
3	Interval complete	Event	Yes
4	Setpoint reached	Event	Yes
5	Not Used	---	---
6	SRQ set	Event	---
7	Error	State	Yes

Some of the Status Byte bits are "state" bits and others are "event" bits. State bits reflect the state of the item they report at the time the Status Byte was read. Event bits indicate that an event took place since the last time the Status Byte was read. Bits 0, 1, 2, and 7 are state bits. Bits 3, 4, & 6 are event bits.

State bits are set and reset by the condition they report. Thus, if the buffer is at least 75% full, bit 1 will be set. If the buffer is not at least 75% full, the bit will be reset. Reading the Status Byte does not affect the state bits.

Event bits are set by the condition they report. However, they are only reset when the Status Byte is read or the controller receives a Device Clear, or is powered off. Thus, an event bit tells you if an event took place since the last time you read the Status Byte. There are a number of methods to "read" the Status Byte. The RS and RSA commands and the GPIB serial poll (spoll) command read the Status Byte directly. The QE and QEA commands read the Status Byte as part of the Error/Status String. The Status Byte is also deemed read when it is sent in EIA-232 mode as a result of having SRQ enabled (see below).

SRQ is a special function of the Status Byte. Setting of bit 6, the SRQ bit, indicates that the Status Byte has new information and needs to be read and processed. If the SRQ function has been enabled by the ES command, then the SRQ will be "asserted". If the communication bus is IEEE-488, the SRQ line will be set high to signal to the bus controller that the Status Byte needs to be read. If the communication bus is EIA-232, the Status Byte will automatically be sent. See §7.8.1 for a complete discussion on reading the Status Byte.

The Status Byte is contained in byte 01 of the Error/Status String.

Following is an explanation of the function and behavior of each of the bits in the Status Byte:

7.8.3.a Bit 0, SRQ Enabled

Bit 0 is set when the SRQ function is enabled by ES command. Bit 0 is reset when the SRQ function is disabled at power on or by the DS command. See §7.8.3 for a discussion of the SRQ Function. Bit 0 is not reset when the Status Byte is read. Setting bit 0 does not assert the SRQ, it simply sets the C4 in the mode to assert the SRQ when bit 6 is set.

7.8.3.b Bit 1, Buffer at least 75% full
7.8.3.b Bit 2, Buffer no more than 50% full

If you have used the SP command to select Remote Mode programming of the C4, the controller can receive and store commands to be executed. If the buffer that stores the commands becomes 75% full, bit 1 will be set indicating that transmissions to the C4 should pause. When enough commands have been taken from the buffer that the buffer is less than 50% full, bit 2 will be set indicating that there is now enough room in the C4 buffer for command transmission to resume. See §7.9 for a discussion of communications flow control. Bits 1 & 2 are not reset when the Status Byte is read. Bit 1 is reset when the buffer is less than 75% full. Bit 2 is reset when the buffer is more than 50% full. Setting either bit 1 or bit 2 sets the SRQ, bit 6, as well.

7.8.3.c Bit 3, Interval Complete

Bit 3 is set when a timed delay (DL command) or ramping interval (RA, RAF commands) is completed. Bit 3 is reset when the Status Byte is read. Setting bit 3 sets the SRQ, bit 6, as well.

7.8.3.d Bit 4, Setpoint Reached

Bit 4 is set when a go to setpoint (GT, GTF commands) is satisfied. A setpoint is satisfied when the chamber or platform temperature has remained stable about the setpoint within the limits prescribed by settling band parameters. See §4.1(F31 & F32), and §7.6.7 (SB). Bit 4 is reset when the Status Byte is read. Setting bit 4 sets the SRQ, bit 6, as well.

7.8.3.e Bit 5, Not Used

7.8.3.f Bit 6, SRQ Set

Bit 6 is set whenever bits 1, 2, 3, 4, or 7 are set. Bit 6 is reset when the Status Byte is read. If the SRQ is enabled (see bit 0), the host controller will be notified as follows that the SRQ (bit 6) is set:

Communication Mode	SRQ Action
IEEE-488 GPIB	SRQ line asserted
EIA-232	Status Byte sent Bits 3, 4, & 6 reset

7.8.3.g Bit 7, Error

Bit 7 is set when any bit is set in the Error Byte. Every function that sets a bit in the Error Byte, also sets bit 7 and bit 6 of the Status Byte. Bits 7 is reset only when the Error Byte is read and thus cleared.

7.8.4 Error/Status String

The Error/Status String is a string of 64 bytes (512 bits) that can be obtained from the controller. Not all of the bytes in the Error/Status String are currently defined. Although the information contained in the Error/Status String is at the bit level, related information is grouped by bytes. Specific information can then be obtained by selecting the needed information group byte by offset. The bit level information can then be used or extracted.

7.8.4.a String Organization

The bytes of the Error/Status String are arranged in three groups:

Bytes	Purpose
00-01	Error Byte & Status Byte
02-31	Event Information
32-63	Status Information

Some of the Error/Status String bits are “state” bits and others are “event” bits. Event bits indicate that an event took place since the last time the Error/Status String was read. State bits reflect the state of the item they report at the time the Error/Status String was read. Bits in bytes 02-31 are event bits. Bits in bytes 32-63 are state bits.

Event bits are set by the condition they report. However, they are only reset when the Error/Status String is read or the controller receives a Device Clear, or is powered off. Thus, an event bit tells you if an event took place since the last time you read the Error/Status String.

State bits are set and reset by the condition they report. Thus, if the refrigeration compressor is turned on, byte 35, bit 3 will be set. If the compressor is turned off, the bit will be reset. Reading the Error/Status String does not affect the state bits.

If a bit is set (1), the condition is true, if a bit is reset (0), the condition is false.

Note: Byte 00 of the Error/Status String is the Error Byte that is available using RE and REA commands. Byte 00 is cleared (all bits reset) each time a QE or QEA command is issued. This byte is also cleared anytime the RE or REA commands are issued to read the Error Byte. This byte is maintained in the Error/Status String so that it is not necessary to use two commands to obtain the Error Byte and the extended error information contained in the Error/Status String.

> Byte 01 of the Error/Status String is the Status Byte that is available using the RS, RSA, and serial poll commands. Bits 3, 4, & 6 are cleared (reset) when the Status Byte or the Error/Status String (containing the Status Byte) is read.

Many of the bits in the Error/Status String have no current definition and will always be reset (0). Successive releases of Sigma Systems C4 controller firmware may implement additional bit definitions. The length of the Error/Status String will remain at 64 bytes.

7.8.4.b Error/Status String Bit Definitions

Error Byte & Status Byte

	Byte 00 - Error Byte
00:0	Aux input toggled (typically optional door switch open/closed)
00:1	Fault system alert
00:2	Illegal parameter (A valid command was received with an illegal parameter)
00:3	Fail-safe tripped
00:4	Event set in bytes 02-31 of Error/Status String
00:5	Unrecognized command (the controller received data that it did not recognize)
00:6	Command buffer overrun (data was received and lost because the buffer was full)
00:7	Time-out error (specified minimum ramp rate was not maintained)

	Byte 01 - Status Byte
00:0	SRQ enabled
00:1	Buffer at least 75% full - stop sending commands
00:2	Buffer not more than 50% full - resume sending commands
00:3	Interval complete
00:4	Setpoint reached
00:5	Not used
00:6	SRQ set
00:7	Error (bit set in Error Byte)

Event Bytes

Byte 02 - Setpoint, Probe & Command Errors

02:0 Setpoint submitted exceeds SOR upper operating limit
02:1 Setpoint submitted exceeds SOR lower operating limit
02:2 Probe requested is not defined in F1
02:3 T-Drive DUT core out of control range
02:4 PT 0 received when T-Drive not active
02:6 RA command received while PN=0 (T-Drive active)

Byte 03 - Probe Temperature Value Errors

03:0 Probe 1 more than 20EC and less than 50EC exceeding high temp operation limit
03:1 Probe 1 more than 20EC and less than 50EC exceeding low temp operation limit
03:2 Probe 2 more than 20EC and less than 50EC exceeding high temp operation limit
03:3 Probe 2 more than 20EC and less than 50EC exceeding low temp operation limit
03:4 Probe 1 more than 50EC exceeding high temp operation limit
03:5 Probe 1 more than 50EC exceeding low temp operation limit
03:6 Probe 2 more than 50EC exceeding high temp operation limit
03:7 Probe 2 more than 50EC exceeding low temp operation limit

Byte 04 - Correction Value Errors

04:0 Correction temperatures submitted less than 50°C apart
04:1 Correction temperatures submitted resulted in a correction greater than 10% of the controller range at the limits of that range
04:2 Correction temperatures submitted were outside the System Operating Range, per §3.5

Byte 05 - Hardware & Setup Errors

05:0 EEPROM write failed
05:1 FLASH memory write failed
05:2 F25 >26 or F27>F28 or lower SOR limit > upper SOR limit

Byte 06 - Control Events

06:0 T-Drive exited

31.x **Internal system errors**
(if any bit in byte 31 gets set, notify Sigma Systems technical support)

State Bytes

Byte 35 - Port status (set=on, reset=off)

35:0 Blower port on
35:1 Main heater port (control heat) on
35:2 Boost heater port on
35:3 Refer (compressor) port on
35:4 Aux output (power) port on
35:5 Coolant port on
33:6 Fault alert
35:7 Aux input port on (connected to ground)

Byte 45 - Port Control Flags

45:0 Blower enabled (when controller idle - not controlling temperature)

Byte 46 - Control States

46:0 T-Drive enabled (active probe = 0)

7.9 Communication Flow Control

Remote Mode operates in either of two sub-modes:

Remote sub-mode	Command	See §	
Remote Program Mode	SP	7.7.2	default
Remote Immediate Mode	SI	7.7.1	

In Remote Immediate Mode all commands sent to the controller are acted on immediately. As commands are not queued, there are no issues relating to command buffering or flow control. Therefore, the balance of this section relates to flow control when the controller is operating in the Remote Program Mode.

In Remote Program Mode, some commands, such as queries, are acted upon immediately and are thus not stored in a command queue. However, all operational and some other commands are stored in an internal command buffer (queued). Each command in the queue is executed in the order in which it was placed in the queue (FIFO). Each command executes until it completes, regardless of the number of commands stacked behind it in the queue. When a command completes execution, such as a GT (go to temperature) command achieving the desired setpoint temperature, the next command in the queue is retrieved and executed.

The table in §7.3 details which commands are queued in Remote Program (SP) Mode.

The command queue (buffer) is limited in size. The buffer can hold at least 32 queued commands. If your program does not use more than 32 queued commands, you do not need to check the buffer control bits in the Status Byte. However, if you have 33 or more queued commands in your program sequence, you should use the Status Byte for flow control. Bits 1 & 2 in the Status Byte are flow control bits. See §7.8.3.

If you have SRQ enabled, the setting of either of the flow control bits in the Status Byte will trigger the SRQ. With SRQ enabled, your flow control routine does not need to constantly poll the Status Byte, it can wait for an SRQ event. If however, you do not have SRQ enabled, you will need to poll the Status Byte at appropriate intervals to maintain flow control. The balance of this section assumes that the SRQ function has been enabled.

The C4 constantly monitors the available space in the command queue. When the available space in the queue is less than 25% of the total queue space, the C4 sets bit 1 of the Status Byte. When bit 1 has been set, you should stop sending commands to the C4 until the queue has been emptied (by command processing in the C4) sufficiently. Note that after bit 1 of the Status Byte has been set, the C4 will accept at least 8 more commands. However, there are other buffers in the command communication chain, including send buffers at the sending side, raw receiving buffer at the C4 end, a parser buffer in the C4, and other possible buffers that could hold commands that your program thinks are sent, but that the C4 has not yet stored in

the command queue. To be certain that all these latent transmissions are received without error, your program should stop sending commands as soon as bit 1 of the Status Byte has been set.

When the command buffer becomes 75% or less full, bit 1 of the Status Byte will be reset (cleared). If you are polling the Status Byte, you can again transmit anytime that bit 1 is not set. However, if you are using the SRQ system, there is an easier method that can reduce programming and bus traffic.

When the command buffer becomes not more that 50% full, bit 2 of the Status Byte is set and the SRQ is triggered. The setting of bit 2 is the signal to resume sending commands to the C4 until bit 1 is again set and the SRQ is again triggered.

Thus, the C4 will set bit 2 of the Status Byte and the SRQ when commands should be sent, and will set bit 1 of the Status Byte and the SRQ when commands should not be sent.

7.10 Reset Commands

The C4 uses one common reset routine to reset the system. The multiple reset levels required by SCPI and IEEE-488.2 are not supported. *RST is not supported. The C4 command DC, the GPIB commands Device Clear and Selected Device Clear all cause the common reset routine to be executed. The reset routine performs the following functions:

Flush the communications input & ring buffers
Flush the command buffer
Clear the GT/RA command timeout flag
Turn the refrigeration compressor port to its default state per setup parameter F6
Turn the Aux/Power Port to its default state per setup parameter F5
Clear the Aux input flag
Clear the Component Fault input flag
Clear the event bits in the Error Byte, Status Byte, and Error/Status string
Setup the Serial Poll register
Reset the SRQ enable bit
Turn controller off (stop all heating and cooling, turn off blowers)
Return the setpoint to 30°C
Replaces any temporary setup parameters with the values from the permanent table

Note: Unlike all previous versions of CC-3, CC-3.5 and C-4 firmware, this, and subsequent versions do/will not trigger the reset routine upon receipt of a GPIB Interface Clear.

8. Setup Mode

Setup Mode is entered by placing the mode switch in the right most position. Setup Mode is used to modify operational parameters of the C4 controller. When first entering Setup Mode, the front panel should display:

F-0 **n**(n = 1 to 20)

This first display indicates the setting for parameter (field) F0. There are thirty six parameters, which can be modified, numbered F0 through F35. Table 8.1 shows the meaning of each parameter, the values each parameter can be assigned, the default values, the Remote Mode command to modify the parameter, and the manual sections that explain further the use of the parameter.

TABLE 8.1

Parameter #	Parameter Purpose	Permitted Values	Default Setting	See Section(s):	Remote Mode Command to Modify
F0	PID controller, Proportional term	1 - 20	4	9.4	WP
F1	Number of Probes installed	1 - 2	1	8.3.1	none
F2	Remote communication port select 0 = EIA-232 1 = IEEE-488	0 - 1	1	7.1	none
F3	EIA-232 port baud rate 1=300 2=600 3=1200 4=2400 5=4800 6=9600 7=19,200 8=38,400	1 - 8	6	---	none
F4	EIA-232 communications setting for data bits, parity enable, stop bits 7=7E1 8=8N1	7 - 8	8	---	none
F5	Aux/Power Port default state 0=disabled 1=enabled	0 - 1	0	8.3.6	none
F6	Refer Port default state Power sharing state	0 - 3	0	8.3.6	none
F7	Bumpless PID transfer default state 0=disabled 1=enabled	0 - 1	0	3.13	none
F8	EIA-232 port echo 0=disabled 1=enabled	0 - 1	1	---	none
F9	IEEE-488 port primary address	0 - 30	1	---	none

Param-eter #	Parameter Purpose	Permitted Values	Default Setting	See Section(s):	Remote Mode Command to Modify
F10	PID controller, Integral term	1 - 20	5	9.4	WP
F11	PID controller, Differential term	1 - 20	5		
F12	PID controller, Relative cooling vs. heating gain factor	-9999 to 9999	4		
F13	Refrigeration compressor front panel control for Local Mode 1=yes 0=no	0 - 1	1	9.3.6.e	none
F14	Autostart in Local Mode 1=yes 0=no	0 - 1	0	8.3.2	none
F15	Blower shut-off mode 0=disable 1=enable	0 - 1	0	3.15 8.3.3	BO BF
F16	Temperature Scale 0=Celsius 1=Fahrenheit	0 - 1	0	3.4	none
F17	Probe 1 Correction Uncorrected first value (U1)	See Section 8.3.5	0.0	8.3.5	SC
F18	Probe 1 Correction Corrected first value (C1)		0.0		
F19	Probe 1 Correction Uncorrected second value (U2)		100.0		
F20	Probe 1 Correction Corrected second value (C2)		100.0		
F21	Probe 2 Correction Uncorrected first value (U1)		0.0		
F22	Probe 2 Correction Corrected first value (C1)		0.0		
F23	Probe 2 Correction Uncorrected second value (U2)		100.0		
F24	Probe 2 Correction Corrected second value (C2)		100.0		

Param-eter #	Parameter Purpose	Permitted Values	Default Setting	See Section(s):	Remote Mode Command to Modify
F25	Chamber/Platform Lower Operating Temperature Limit	-200°C -328°F	As required Default = -100.0	3.5	none
F26	Chamber/Platform Upper Operating Temperature Limit	500°C 932°F	As required Default = 200.0		
F27	Device Under Test (DUT) Lower Operating Temperature Limit	-200°C -328°F	As required Default = -100.0		SL
F28	Device Under Test (DUT) Upper Operating Temperature Limit	500°C 932°F	As required Default = 200.0		
F29	Device Under Test (DUT) Lower Operating Temperature Differential Limit	From 0.1 to full controller range (ie.: 300 for a -100 to +200 controller) (see note, below)	Full controller range (ie.: 300.0 for a -100 to +200 controller)	4.2.2.a	SD
F30	Device Under Test (DUT) Upper Operating Temperature Differential Limit				
F31	Settling Band Allowable Variance from Setpoint	.1°C - 10°C .2°F - 18°F	.8°C 1.4°F	4.1.1	SB
F32	Settling Band Minimum Stable Time (in seconds)	0 (Touch 'n Go) 1 - 59	15	4.1.2	
F33	Minimum Acceptable Temperature Transition Rate (°/Min)	.1 - 500°C .2 - 900°F 0 = Disabled	0.0	3.11	GT, RA
F34	T-Drive™ Acceleration Factor	0 - 5.0	2.0	4.2.2.b	TD
F35	T-Drive™ Lead constant	-20.0°C to +20.0°C -36.0°F to +36°F	5.0°C 9.0°F	4.2.2.c	

Note: The setup parameters are stored in non-volatile memory that is retained even during power down. There is a 4 digit display limitation due to the controller design. F29 and F30 can have values that exceed this limit. In this case, only the integer portion will display, but normal precision is retained internally.

8.1 Displaying the Parameter Values

The contents of parameter F0 is displayed upon entering the Setup Mode. To display the next parameter value, press **<DISP/CNTL>**. Pressing **<DISP/CNTL>** after parameter F35 will cause parameter F0 to be re-displayed. Pressing **<DISP/TEMP>** will scroll backward. Entering a 2 digit number and pressing **<ENTER>** will display the entered parameter without having to scroll through the list.

8.2 Changing the Value of a Setup Parameter

A parameter may be changed with the following procedure:

1. Display the parameter to be changed using the **<DISP/CNTL>** key as detailed in §8.1.

2. Press **<CLEAR/ENTRY>** to clear the current value.

3. Enter the new value

Note: For setup parameters F0-F16, the valid choices may be scrolled by using **<ADV>** and/or **<+/->** until the desired parameter value appears on the display. If you wish to use this method, do not press **<CLEAR/ENTRY>** first.

4. Press **<ENTER>** to replace the old value with the new value.

The old value is not replaced until **<ENTER>** is pressed. Therefore, a change may be canceled simply by pressing **<DISP/CNTL>** before **<ENTER>** has been pressed. The new parameters go into effect upon leaving the Setup Mode.

The Local Mode setpoint is erased upon leaving the Setup Mode and the controller will be in the idle (not controlling) mode.

8.3 Setup Parameter Notes

8.3.1 Two Probe Mode (Setup parameter F1)

This controller will control or display from either probe input. The behavior of the controller, and selection of the probe which controls it, is by program command in both Program Mode and Remote Mode. In Local Mode, the setup parameter F1(# of active probes) must be set to 2 before the two probe mode (See §5.2) or T-Drive (See Section 4.2) in can be used.

It is very important to use only 500S platinum RTD probes from Sigma. Sigma probes are specially calibrated and matched to the internal controller data sets of the C4. Use of other probes will likely cause significant loss of accuracy.

8.3.2 Auto-start Mode (Setup parameter F14)

The controller may be set up to automatically begin controlling at the last used Local Mode temperature by setting the Auto-start setup parameter (F14) to 1. When Autostart is enabled, moving the mode switch from OFF to LOCAL will cause the controller to begin controlling to the last set Local Mode setpoint without the necessity of pressing **<START/STOP>**. If the system includes mechanical refrigeration, and the last Local Mode control session had the compressor turned on, it will be turned on for the Autostart session as well. Note that AutoStart is not compatible with T-Drive. Upon moving the mode switch from Local to Off, the probe number is changed to 1 and the controller is returned to idle state.

8.3.3 Blower Shut-off Mode (Setup parameter F15)

Normally at the end of a program execution, or in the event of a Fail-Safe shutdown condition, the blowers in an chamber will continue to run. If this is not desired, the blowers can be set to shut off under these conditions by enabling the Blower Shut-off mode. To enable Blower Shut-off Mode, set setup parameter F15 to 1. Blower Shut-off mode does not apply to Local Mode.

Note for systems with refrigeration compressors: Turning the blowers off using the BF command disables the main power to the chamber or platform and thus will also turn off the refrigeration compressors. To prevent short cycling of the compressors, do not use the BF command with mechanically refrigerated systems.

8.3.4 Temperature Control Terms (PID) (Setup parameters 0, 10, 11, 12)

The PID control terms that the C4 uses for temperature control are available in setup parameters F0, F10, and F11. Parameter F12 sets the relative gain between the heating and cooling systems in the chamber or platform. This value will not need to be changed unless you have a system that has both cryogenic cooling, and mechanical refrigeration, and you change which is in use. If you are not familiar with PID terms and their effects, a non-theoretical discussion can be found in §9.4 in the troubleshooting appendix of this manual. **Note that the PID algorithm in the C4 was completely rewritten for firmware versions 8.0.0 & later. PID settings used with previous versions may need to be changed for optimum performance.**

8.3.5 Software Probe Correction (Calibration)

The C4 will allow you to enter data via Setup or Remote Mode that will correct any anomalies in the temperature readings and control at two points. Such adjustments are sometimes necessary to optimize accuracy at a particular temperature, or to compensate for differences between raw probe temperature data and actual temperatures.

Note: The purpose of this feature is to allow precise calibration at two points near the critical points of the user's testing scheme. It does not replace the hardware calibration process, nor should it. A number of system health checks as well as process limits are based upon the raw, or uncorrected, temperatures reported by the probes. **It is important to optimize the hardware level calibration before using this software calibration method.**

Software probe correction is achieved by entering four temperatures, U1, C1, U2, & C2, for each probe into the setup parameter table. U1 & U2 are the uncorrected, or displayed, temperatures at two points. C1 & C2 are the corrected, or actual, temperature at those same two points. Thus to make a correction using ice water (0°C) and boiling water (100°C) when the display shows 2.3°C for the ice water and 99°C for the boiling water, the user would enter the following:

U1	2.3
C1	0
U2	99
C2	100

The C4 will then calculate a new slope and offset for the probe curve. All temperatures reported by the corrected probe will be adjusted by applying this new slope and offset to the raw temperature data reported by the probe.

Note: Software probe correction is done separately for each probe. The following table shows the U1, C1, U2, C2 setup parameter assignments:

	Probe 1	Probe 2
U1	F17	F21
C1	F18	F22
U2	F19	F23
C2	F20	F24

Changing these parameters "on the fly" in Remote Mode is discussed in §7.6.1.

It is the responsibility of the user to be certain that this feature is used properly. Improper use of this feature can result in the C4 reporting very inaccurate temperature data and then using that data for temperature control. To minimize the risk from such errors, the following rules have been adopted.

1. U1 & U2 as well as C1 &C2 must be at least 50°C apart.

2. All correction temperatures must be within the System Operating Range. See §3.5.

3. The correction values entered must be so constrained that when the internally calculated slope and offset are applied to the raw probe temperatures at the extremes of the C4 current operating range, the maximum calculated temperature difference (correction) is no more than 10% of the range.

Examples:

C4 Operating Temperature Range Limits	Approximate Range	Max Calculated Probe Correction at Range Limits
-100°C to +200°C	300°C	±30°C
-100°C to +300°C	400°C	±40°C
-100°C to +350°C	450°C	±45°C
-175°C to +400°C	575°C	±57.5°C
-195°C to +300°C	495°C	±49.5°C
-195°C to +500°C	695°C	±69.5°C

8.3.5.a Entering probe correction setup data

When entering probe correction data, the data for all four parameters associated with one probe must be entered successively in one session. Start the entry session by displaying the first parameter, either F17 or F21. Enter the data for that parameter and the next 3 parameters in succession. If the data entered is within bounds prescribed by the rules above, they will be stored.

If the values entered do not comply with the rules as defined above, the display will show Cor Err. None of the data will have been stored in this case and the process must be begun again with data that complies with the rules.

8.3.6 Aux/Power and Refer Port defaults (F5 & F6)

The Aux/Power and Refer Ports (see §2.2.2 and §3.15) will be set to their default conditions upon power up of the C4, upon any change of modes by the Mode switch (except with Autostart, see §8.3.2), or upon any event that stops the controller controlling the temperature such as:

Device Clear
Selected Device Clear
QU command
DC command
Step 100 processing the Program Mode
Stop from the **<START/STOP>** button in Program or Local Mode

The factory defaults for these ports are OFF for both the Aux/Power Port and the Refer Port. It is important to be sure that the Refer port setting (F6) remains OFF if there is a mechanical refrigeration system to prevent the compressor from starting unnecessarily or cooling without control when the C4 is powered up. See §8.3.6.a, below, for more information of the use of Setup parameter F6.

8.3.6.a Refer/Boost Heat Power Sharing

Note: This feature is no longer used. It will be removed in the next firmware release. Power Sharing is now enabled in the chamber or platform hardware, rather than as a C4 software feature.

The C4 has the ability to share some of its input power between the refrigeration system and the boost heat system. If Power Sharing is enabled, the boost heater output is disabled when the compressor port is on. This allows the C4 to use the control heater output to provide small amounts of heat for stable control when the refrigeration system is operating and still allow fast heating rates by enabling the boost heater output when the compressor port is off.

To enable the Power Sharing feature, use the F6 setup parameter, the same parameter that sets the default state of the refrigeration compressor port. The acceptable values for F6 are 0 - 3. The table below shows the effect of each value.

F6 Value	Default State of Refrigeration Compressor Port	Power Sharing
0	Off	Disabled
1	On	Disabled
2	Off	Enabled
3	On	Enabled

Caution: If your chamber or platform was designed for Power Sharing, make certain that F6 is NEVER set to 0 or 1. Disabling Power Sharing in the C4 when controlling a chamber or platform that requires it will result in overloading the input power line and will trip circuit breakers, blow fuses, etc.

9. APPENDIX

9.1 Cryogenic Boost for Mechanically Refrigerated Systems

Note: This section does not apply to controllers used with chambers or platforms that use a "heat bucking" control system. Those systems have only on/off control of the mechanical refrigeration system and use the more powerful heating system to provide temperature control. Heat bucking systems have sufficient heating available to overcome the effects of the cooling systems when high temperatures are required. The C4 is perfectly suited to control heat bucking systems, but the balance of this section describes a control mechanism that is not applicable to those systems. To use the C4 with a heat bucking system, the refrigeration compressor must be turned on to control at any temperature below the normal idle temperature (blowers running). This temperature is normally between 50°C and 80°C, depending on chamber construction and blowers fitted.

9.1.1 Cryogenic Boost Overview

The C4 can control temperature chambers or platforms with cryogenic (typically L-N_2 or L-CO_2) cooling and/or mechanical refrigeration (using a compressor). Systems that use both systems are referred to as "cryogenically boosted mechanically refrigerated" systems, or, for ease of use, "boosted " systems. Boosted systems require special attention for proper use. Because the boost is used for differing purposes, some user intervention in control is required.

There are two reasons to use a boost on a refrigerated system:

1. Improve cooling speed
2. Achieve cold temperatures below the limits of the refrigeration system.

Using cryogenic cooling to improve cooling speed within the normal temperature range available from the refrigeration system is simply a matter of adding the cryogenic cooling to the refrigeration cooling. The cryogenic cooling will most always cool the system much faster than the mechanical refrigeration system. Under most circumstances, there is no harm in allowing the mechanical refrigeration system to continue to function during a cooling cycle. The boost cryogenic cooling is simply added to the process. When the desired temperature is achieved, the boost system is turned off, and the mechanical refrigeration system is left running to maintain the setpoint temperature.

Using cryogenic cooling to take the chamber or platform to a temperature below the limits of the mechanical refrigeration system poses special risks. Unless the system has a special return gas temperature control system with an auxiliary heater in the mechanical refrigeration system, there is the very real possibility that an over chilled system will return refrigerant liquid, instead of the required gas, to the compressor when the system is at very low temperatures. Should this happen even one time, for only a second or two, catastrophic damage can be done to the compressor that will require immediate and expensive service. To preclude this event, **the user must**

make certain that the mechanical refrigeration system is turned off anytime the chamber or platform is operating with cryogenic coolants at temperatures below the normal limits of the system's mechanical refrigeration system.

9.1.2 Controlling the Chamber or Platform Cooling

9.1.1.a Controlling the Mechanical Refrigeration System

The mechanical refrigeration system is connected to the the Refrigeration Compressor Port (see §2.2.2). Control of this port is different for each controller mode as selected by the front panel mode switch.

Mode	**Refrigeration controlled by**
Local Mode	Refer switch on front panel
Program Mode	Refer compressor steps (see §6.2.2 & 6.2.3)
Remote Mode	CO & CF commands (see §7.7.8)

9.1.1.b Controlling the Cryogenic Boost Cooling System

The cryogenic boost cooling system is connected to the Aux/Power Port (see §2.2.2). Control of this port is different for each controller mode as selected by the front panel mode switch.

Mode	**Cryogenic boost system controlled by**
Local Mode	There is no C4 control of the Aux/Power Port in Local Mode. If control of the cryogenic boost system is required in Local Mode, use an external manual selection switch.
Program Mode	Aux/Power Port steps (see §6.2.4 & §6.2.5)
Remote Mode	TO & TF commands (see §7.7.9)

9.1.1.c Controlling Cryogenic Boost and Mechanical Refrigeration Together

The flow into the chamber or platform of both the refrigerant that circulates in the mechanical refrigeration system and the expendable cryogenic coolant are controlled by a single "cooling" output that is regulated by the PID control routine in the C4. This is the output that is "on" when the COOL indicator on the front of the C4 is lit.

If the refrigeration system is "on", refrigerant will be introduced into the evaporator space of the chamber or platform when the cooling output is on. If the cryogenic cooling system is enabled, cryogenic coolant will be introduced into the chamber or platform for cooling. If both the refrigeration system and the cryogenic system are enabled, both systems will operate simultaneously.

It is rare that both systems need to be on at the same time for extended periods. To use the boost to achieve a fast cooling ramp, turn on both systems or only the boost system, then run the rapid ramp. If a hold at the setpoint is desired, turn on the refrigeration system, if not already on, then disable the boost system to economically hold the low temperature. Using either Program or Remote Modes, this process can be made a bit more efficient by using the Adjustable settling band feature of the C4 (see §4.1) to trigger a "setpoint reached" condition near the setpoint. The boost cooling system can then be turned off by the program, a tighter settling band can be specified, and the same setpoint can be specified again for the final approach by the mechanical refrigeration system alone.

9.1.1.d Adjusting the PID Constants for Boosted Cooling

§9.4 of this appendix details the use of the PID & R constants to adjust the C4 to the equipment and load to be controlled. The thermal behavior of a mechanically refrigerated system will likely be quite different when the cryogenic boost is enabled. In fact, the behavior of the boosted system, when the boost is enabled, will be nearly identical to the behavior of a pure cryogenically cooled system. To get the best performance from your system, you may need to change the PID-R parameters when enabling and disabling the cryogenic boost. These parameters can be changed "on the fly" by your program in Program Mode by using a PIDR Specification Step (see §6.2.8), or in Remote Mode by using the WP command (see §7.6.2).

9.2 Field Calibration of Model C4 Controller

WARNING: Sigma Systems C4 Controllers obtain power from the chamber or platform to which they are connected. The controllers do not have protective side covers on the chassis. It is imperative to disconnect the power to both the chamber or platform and the controller (if separate) from the power source before removing the controller. Look for an optional separate power cord going to the controller. If the controller is equipped with a separate power cord, disconnect that cord also before removing the controller. FAILURE TO HEED THIS WARNING WILL LIKELY RESULT IN SEVERE DAMAGE TO THE CONTROLLER AND DANGER OF HIGH VOLTAGE ELECTRICAL SHOCK TO THE USER.

Equipment Required:

Digital volt meter capable of four digits accuracy.
Decade resistance box capable of 0.1 ohm resolution.

IMPORTANT: Before beginning the calibration process, the software probe correction must be set to default values (no correction). If this is not done, calibration may not be possible due to range limitations of the calibration potentiometers. In addition, the temperatures reported by the probe(s) will be incorrect. Incorrect calibration can result in extreme and/or unexpected temperatures that will likely result in damage to equipment and test specimens, and harm to personnel.

Procedure:

Be certain that the probe correction parameter fields are set to default (no correction) values. With the temperature scale (setup parameter F16=0) set to °C, setup parameters F17, F18, F21, & F22 should be set to 0 and setup parameters F19, F20, F23, & F24 should be set to 100.

2. Remove power from the unit. Access the controller chassis by removing the screws at the four corners of the controller front panel.

3. Remove probe connections at the controller's rear terminal strip, J1-1 and J1-4.

4. Locate test points TP1 and TP6 (TP2 on CC-3-5) and adjustments R5 (R29 on CC-3-5) and R2 (R32 on CC-3-5) in the upper rear area of the right hand circuit board (B- board see fig.).

5. Apply power to unit and turn power switch on.

6. * With nothing hooked to the probe inputs of the controller, adjust R5 (R29) until the voltage at TP1 reads 7.100 volts +\- 0.005 . and adjust R2 (R32) until the voltage at TP6 (TP2) reads 1.70 volts +\- 0.05 for controllers that operate in the standard range of -100 to 200. For controllers configured for other ranges, adjust R2 (R32) until the voltage at TP6 (TP2) reads 2.00 volts +\- 0.05

7. Securely connect the resistance box across the probe-1 inputs, (J1-1 and J1-4) set the resistance box to 500.0 ohms. Adjust R2 (R32) slightly until the controller front panel reads exactly P1 0.0 (no minus sign). Value should already be within +/- 5 degrees C.

8. With the resistance box still across the probe-1 inputs, (J1-1 and J1-4) set the resistance box to 695.0 ohms. Adjust R5 (R29) slightly until the controller front panel reads exactly P1 100.0.

9. Recheck that the controller still reads 0.0 with 500.0 ohms at input. If it takes more than 3 iterations of these adjustments to calibrate the controller, the controller is in need of repair work.

10. Remove power from unit, reinstall controller into unit.

11. Controller response rate can be adjusted as follows. With the rotary switch in the Setup Mode, press ADV until F0 = 4 to 6, then press ENTER. Higher numbers represent larger proportional term and thus a slower controller response (lower gain) and lower numbers represent faster response (higher gain). See §9.4.2.

* This step may be omitted if calibration error is less than +/- 5.0 degrees C.

9.3 Troubleshooting

9.31 Servicing Considerations - Service WARNINGS

WARNING: Sigma Systems C4 Controllers obtain power from the chamber or platform to which they are connected. The controllers do not have protective side covers on the chassis. It is imperative to disconnect the power to both the chamber or platform and the controller (if separate) from the power source before removing the controller. Look for an optional separate power cord going to the controller. If the controller is equipped with a separate power cord, disconnect that cord also before removing the controller. FAILURE TO HEED THIS WARNING WILL LIKELY RESULT IN SEVERE DAMAGE TO THE CONTROLLER AND DANGER OF HIGH VOLTAGE ELECTRICAL SHOCK TO THE USER.

9.3.2 Before you go any further...

Make sure you have the most recent firmware for your C4. A number of problems for each of the areas discussed in this troubleshooting section have been addressed with firmware upgrades over the years. To check the firmware version number, simply turn the controller off and back on. The version number will be displayed for 2.5 seconds (See §3.1.1).

As of the date of this manual, the current firmware version is 8.6.3. Any other version is older, including versions 10 and 12. If you have other than the current firmware, see §3.2.

9.3.3 Diagnosing and Solving Hardware Problems

Most hardware related problems are best left to the technicians at Sigma Systems.

If you are having problems with the controller stopping or locking up at unexpected times, check the ground connections for the power source. Also review §9.3.4 in this manual for some tips on noise immunity. If the problem persists, you may be able to obtain a noise suppression kit from Sigma that will help. If your controller uses power from the chamber or platform, it is possible to install an optional separate power cord for the controller so that it may have it's own clean power source.

If the problem relates to the display getting scrambled, the cause is likely static discharges in or near the front panel. Especially if the environment is carpeted, train your users to use their finger to discharge the static potential they may have accumulated on something other than the C4 front panel.

9.3.4 Noise Immunity

Noise can show up as lost or incorrect data sent over the bus. In extreme cases this noise can disrupt controller operation regardless of whether the computer bus is in control or not. The following modification has been found to solve many computer bus related noise problems. It will provide static ground to the backshell of the IEEE 488 bus connector as well as pin 1 of the EIA-232 connector, bypassing any path through the digital circuitry. It is not done at the factory because, in some cases, it actually degrades noise immunity by creating a ground loop.

Bus static ground connection is made as follows: Solder a short green 22g. wire to the A-Board static ground eyelet located below the IEEE-488 connector. Hook the other end of the wire to a horseshoe lug and connect it to the main terminal strip J1, lug #3. (green).

9.3.5 Diagnosing and Solving Local Mode Problems

9.3.5.a Controller starts immediately in Local Mode

If the system improperly begins controlling to the setpoint when you turn the controller from OFF to Local Mode, before you press **<START/STOP>**, the Autostart setup parameter (F14) is set to enable Autostart. Resetting this setup parameter to 0 will disable the automatic starting feature.

9.3.6 Diagnosing and Solving Program Mode Problems

9.3.6.a Hard Loops

Also note that hard loops will execute forever. Standard loops, using the loop command, do not allow nesting. Only one loop may be active at a time. If you have a nested loop, it may appear to function properly, but it will probably never complete.

9.3.6.b Explicit Program End

If you are observing behavior that indicates that the controller is continuing to control beyond the end of the steps you have in your program, check to be certain that you have a step at the end of your program that points to step 100 to end the process. Otherwise, if there are some unused steps further up in program memory, they may be getting executed in error. Be sure that any unused steps that are in the middle of your program have been changed to null steps (ramp and hold time both = 0, probe = 1 or 2).

9.3.6.c Blowers Misbehaving

If the blowers seem to behave differently than you expect, check the Blower Shutoff Mode setup parameter (F15).

9.3.6.d Program hangs on “Ramp as Quickly as Possible” (9900) step

Note that a program step with specified ramp and hold times will terminate at the end of the specified time (ramp time + hold time), regardless of whether the controller was able to achieve the setpoint. On the other hand, a maximum speed ramp step (substep 1 = 00.00 & substep 2 = 99.00) will not advance to the next step until and unless the setpoint is achieved. If the unit under test generates or absorbs heat in a manner that prevents the test environment from ever becoming stable at the setpoint, the program will “hang” on such a step as it will not advance to the next step unless it can stabilize the platform or chamber at the setpoint.

9.3.6.e Refer button on front panel does not work

Check the state of setup parameter F13, refer front panel control. This parameter must be set to 1 (default) to enable the front panel refrigeration compressor control.

9.3.7 Diagnosing and Solving Remote Mode Problems

9.3.7.a General Considerations & CC-3 Compatibility

Bus communication problems often involve command syntax errors. The Sigma C4 is NOT case sensitive. The command “GT” is satisfied by “Gt”, “gT”, or “gt”. Each command line should be properly terminated with both a CR (ODh) and LF (10h), but the C4 can fix the problem if one of the termination characters is present. The C4 fixes up extra spaces, tabs, and commas. The model CC-3 controller does not have a fault tolerant parser. If programs that use only CC-3 compatible commands run properly on the C4, but not on the CC-3, the problem is likely a command syntax problem that the C4's fault tolerant parser corrects.

If you are having no success with bus communications, check to be certain that the correct bus (EIA-232 or GPIB IEEE-488) is selected using setup parameter F2.

SI (Immediate Mode) or the default SP (Program Mode) are typically issued at the beginning of a program sequence. However they may be issued at any point. If the C4 receives a SI command and there is a command executing and/or commands in the command buffer, the executing command is interrupted and the command buffer is cleared.

The Aux/Power ON (TO) and Aux/Power OFF (TF) commands control the auxiliary power control port. This port is normally used to control power to the chamber or platform or an optional device. It is not necessary to use these commands to enable and disable temperature control.

9.3.7.b EIA-232 Problems

EIA-232 issues are usually communications interface related. The C4 is configured as DCE (Data Communications Equipment). Therefore, it is not appropriate to use a crossover or "null modem" cable. Use a straight-through cable that does not have pins 2 and 3 reversed. The C4 does no hardware or software handshaking. DTR and CTS are constantly asserted by the C4 for compatibility with devices that need these signals. Hardware handshaking from the controlling device is ignored. Software handshaking will be parsed as data by the C4 and will reliably result in failure.

9.3.7.c GPIB IEEE-488 Problems

C4 status requests are available either via the manual RS (read status) command or by enabling SRQ with the ES command and then using serial poll to obtain the status byte. The serial poll method will only return the status byte after SRQ is enabled with an ES command.

9.3.8 Firmware Upload Problems

Firmware upload is very straight forward and has no options except for the user to select a COM port on the PC. If the upload never starts after the PC program is started, try turning the controller off, and then back on, and reinvoking rS LOAd mode. Depending on the behavior of the COM ports on the two devices, some experimentation may be in order as to which device needs to be brought up first.

If your uploads appear to run properly, and the upload software indicates a successful result, yet the system will not run, you should try the load again. It is unlikely that a problem will cause a bad load, but it is possible and it's the easiest problem to fix, so try reloading first.

9.3.8.a Starting the C4 from EPROM based firmware

If reloading doesn't work, you can try starting the controller from the older firmware that permanently resides on the EPROM in the controller. To initiate a EPROM based startup, press **<START/STOP>** rapidly three times while the model number is displayed (very first display upon power up). This will cause the controller to bypass the newly installed firmware and run from the older version.

9.3.8.b COM port issues

If the update software on the PC won't start due to communication problems, the difficulty is likely either a bad/wrong cable, non standard COM port settings, or a non standard UART. Check to be certain that you are using a standard modem cable (straight through) and not a "null modem" cable (pins 2 & 3 crossed). If the cable is not the problem, use a utility program such as Microsoft's MSD or Norton Utilities'

NDIAGS to test the PC's COM ports and check the addresses, interrupt, and UART number. COM1 should be located at address 3F8 with IRQ4, and COM2 should be at address 2F8 with IRQ3. The UART should be an 8250 or a number that starts with 16. Some early PCs used non standard UARTs and address assignments and relied on the very slow system BIOS to keep all this straight. The Sigma upload software bypasses the BIOS to achieve better performance (19,200 baud) and cannot tolerate non standard COM ports.

If you've done all the above, and still have a problem, check the Sigma web site at www.SigmaSystems.Com for service bulletins. If you still don't have a solution, your controller will likely need to be returned to Sigma for service.

9.4 Temperature Control (PID) Tuning & Problems

The Sigma C4 controller uses a classic PID control algorithm. Users who are familiar with PID control will find this section somewhat simplistic and generalized as it is written for use by support personnel who are competent installers and mechanics, but who may not know, or need to know, the theory and intricacies of PID control.

There are four user adjustable control "terms" that the C4 uses to control temperature. They are:

Proportional term	Setup parameter F0
Integral term	Setup parameter F10
Differential term	Setup parameter F11
Cooling/Heating Gain factor	Setup parameter F12

The Cooling/Heating Gain factor (F12) is unique to Sigma controllers. Some PID controllers use different PID settings for heating and cooling. This is typically because the heating and cooling capability of most platforms or chambers is not "in balance". That is, applying 100% of available cooling capacity will yield a different ramp rate than applying 100% of heating capacity. PID control routines automatically adjust controller output based upon the response to previous output. You can use the P, I, & D terms to adjust the way the PID routine responds so that it will settle upon the setpoint quickly without unacceptable oscillation or overshoot. The best "terms" for the PID routine will be dependent upon factors such as cooling and/or heating capacity, load characteristics, your needs, etc. Note that the heating and/or cooling capacity is part of the consideration.

Because the cooling capacity is probably different than the heating capacity, improved results can often be obtained by having one set of PID terms for heating and another set for cooling. A number of controller manufacturers take this approach. However, the dual terms approach has two drawbacks.

The first drawback is seen where the heating and cooling are alternately applied. When controlling very near to ambient temperatures with dual terms PID routines, there is often a "step" function that results from the controller switching from the heating terms to the cooling terms, or visa versa. This can cause instability and

oscillation that can only be cured by some transitional algorithm that may induce more odd behavior.

The second drawback is seen in systems where the heating or cooling capacity can instantaneously change. A Sigma Systems temperature chamber with both cryogenic cooling (very high cooling capacity) and mechanical refrigeration (typically low cooling capacity) is a perfect example. As both the cryogenic cooling and the mechanical cooling can be switched into or out of the process at any time, a PID routine with only one set of cooling PID terms would be insufficient to tune the system optimally.

The Sigma solution for this problem is the Cooling/Heating Gain Factor (F12). This number sets the relationship between the performance of the cooling system vs. the heating system in a chamber or platform. Once this relationship is defined, a single set of PID terms will work properly for both heating and cooling. Because there is only one set of terms, and because the relationship between the cooling and heating capacity is defined for the controller, the step function effects at the transition between heating and cooling are minimized. Furthermore, if the cooling capacity changes by, for example, enabling a cryogenic boost on a mechanically cooled system, the user need only set a new Cooling/Heating Gain Factor (F12) to optimize the PID control routine to the new cooling capabilities.

9.4.1 Adjusting for changing needs.

When your C4 was shipped from the factory, it was optimized, or "tuned", for normal operation of the chamber or platform to which it was attached, or for which it was intended. It was presumed that the load that you would test would not have great mass, that some overshoot of the setpoint was acceptable when going to a new temperature, and that the cryogenic coolant available (if used) would be delivered from a supply source that indeed delivered liquid, not just compressed gas.

Your needs may not match the original settings, or your controller may have had it's settings changed for other reasons. If the controller is settling a little short of the setpoint, or is oscillating, you can probably make a few changes in the PID settings and improve things considerably.

You need to be aware that very precise control requires a stable environment. The C4 is an excellent and accurate controller. However, it is not magic. For example, if you tune your C4 to provide fast ramps with conservative approaches to setpoints with liquid nitrogen cooling a static load, and then run the unit using a nitrogen source that delivers gas instead of liquid a good part of the time, and then you add a substantial live load as well, your system performance will not be what you expected. Before you start the tuning process, we suggest that you do what you can to be sure that you are tuning for the actual loads that you will be testing, using the coolant that will be available at test time.

If you are using cryogenic coolant, be certain that the coolant delivery is consistent. It is not possible to provide a stable environment in your chamber or on your platform if the supplied coolant's ability to absorb heat keeps drastically changing as the

supply vacillates between liquid and gas. Likewise, if you will have live loads that turn on and off during the test, optimize the performance of the system with the load at the point that is most critical to you. If the live loading is small, it should make little difference. However, if the live load is substantial, the performance of the system will be adversely affected when it is operating with a load substantially different than the load for which it was tuned. If you will be operating with more than one set of conditions, and those conditions are sufficiently different from one another to warrant separate PID terms, then you can use the Remote Mode WP command to modify the PID terms when the conditions change.

Before you change any of the PID terms in your C4, write down the existing values. It is not hard for inexperienced users to make enough changes that things get much worse. If this happens to you, you will want to have a list of the original settings so you can at least go easily back to what you had. If you forget to write the setting down, or if your controller was way off to begin with, we suggest that you start with the default settings as shown in Section 8, Setup Mode.

9.4.2 The Proportional Term

The Proportional term (Setup field 0) is the most often adjusted term. It is the system gain control. It determines, or proportions, the amount of heating/cooling response generated for a given difference between the active probe temperature and the setpoint temperature. The proportional term is inversely related to the gain. That is, the lower the proportional term, the higher the gain.

The proportional term determines the number of degrees from the setpoint at which the C4 will begin to decrease the applied heating or cooling. If the proportional term = 10, then the heating or cooling will start being reduced when the probe temperature is some distance from the setpoint. If the proportional term = 5, then heating or cooling will continue at full rate until the probe temperature is nearer to the setpoint. A setting of 20 would cause the heating and cooling to be reduced substantially before the setpoint is reached.

Decreasing the proportional term value will cause the C4 to apply full heating or cooling to the chamber or platform for a longer time (slows closer to the setpoint). Increasing the proportional term will begin the ramp slowdown sooner.

Decreased proportional term value will allow faster ramping at the expense of more overshoot. Increasing the value will reduce overshoot at the expense of a long settle time.

The proportional term sets the base gain of both the integral term and the differential term. As a result, once those terms are set, small adjustment of the proportional term may often be made without need for adjustment of the others.

The proportional term is very necessary to slow the heating or cooling to prevent wild overshoot of the setpoint. However, because the slowing increases as the setpoint is approached, there is a point at which the applied heating or cooling is not sufficient

to continue the progress to achieve the setpoint. The Integral term compensates for this shortcoming of the proportional term effect.

9.4.3 The Integral Term

The Integral term (Setup parameter F10) adds heating or cooling based upon time. The longer the active control probe temperature remains away from the setpoint temperature, the more heating/cooling the integral term adds. Thus, if the output of the proportional term results in the system controlling to a temperature short of the setpoint, the integral term will, over time, continually increase the output until the setpoint temperature is reached. If the integral term is too small, the setpoint may never be reached. If it is too large, there will be an oscillation of the temperature about the setpoint. Increase the integral term value if the temperature never quite gets to the setpoint. Lower this value if the temperature oscillates about the setpoint.

There will always be some oscillation, but a proper setting of the integral term will keep these oscillations very minor and within the range of established control accuracy. When the C4 is shipped from the factory, the integral term is set such that it will work well for most applications. Small adjustments to the proportional term rarely require adjustment of the integral term. Change this setting in small amounts only after careful demonstration of the need.

The integral term has an inverse relationship with the output. Integral term gain is increased as the integral term is decreased.

9.4.4 The Differential Term

The Differential term (Setup parameter F11) adds, or subtracts, heating or cooling based upon the magnitude of the <u>change</u> of the difference between the active control probe temperature and the setpoint temperature. In other words, the differential term determines if the system temperature is getting closer to the setpoint temperature or if it is getting further away, and by what amount. If the active control probe temperature is moving further away from the setpoint temperature, the differential term will add to heating/cooling output to help it along. If the active probe temperature is moving toward the setpoint temperature, the differential term will reduce the heating/cooling output to try to keep the system from moving too fast and grossly overshooting the setpoint.

The differential term responds to the <u>rate</u> at which the active control probe temperature is moving toward or away from the setpoint temperature. Thus if the difference between active control probe temperature and the setpoint temperature is not changing, there will be no effect from the differential term.

The differential term can be of significant use for fast responding systems such as cryogenic cooling and high power heating. Because its output is a function of the system rate of temperature change, it has little impact on slow systems.

The differential term, unlike the proportional and integral terms, has a direct relationship to the output. Differential gain is increased by increasing the differential term (F11).

9.4.5 The Cooling/Heating Gain Factor

The heating/cooling gain factor (F12) is used to define the relationship between the chamber or platform's heating capacity and it's cooling capacity. The number entered into F12 is generated from heating and cooling ramp rate information. Sigma uses and supplies an algorithm for calculating the value for F12. However, you may never need to use the algorithm as every C4 controller ships with F12 properly set for the intended use. If you move your C4 controller to a different model chamber or platform, you may need to change F12. Sigma Systems publishes a list of standard model equipment and the proper F12 setting for each. This list is available on the Sigma web site. See §9.6. Also available on the Sigma web site is a Microsoft Excel spreadsheet that you can download to do the calculations for you. If all that fails, or is unavailable, you can use the worksheet on the next page to do the calculations by hand.

9.4.6 Changing the PID&R "on the fly" for Changing Loads

The PID & R constants are a reflection of behavior of your system. They tell the C4 a bit of what to expect from your load and the heating and cooling systems. If you have loads that change dramatically during the test/conditioning process, or if you have a special chamber or platform that has cryogenic boost for a refrigerated system or has other facilities that allow the system behavior to change significantly, you may need to modify the PID & R constants to keep the system optimized. These parameters can be changed "on the fly", while your program is running. In Program Mode by use a PIDR Specification Step (see §6.2.8), or in Remote Mode by using the WP command (see §7.6.2) to make changes.

There will likely be a small "bump" in the temperature as the system must be reset when new constants are received. It may take a minute or two for the C4 to again settle in on an effective control strategy.

Sigma Systems C4 Controller

(O.K. to copy)

Worksheet for calculating the value for C4 Controller Setup Parameter F12

To calculate the value of F12 for your chamber or platform, you will need to know the cooling ramp rate and the heating ramp rate for full-on (100%) cooling and heating. The rate should be in Celsius degrees per minute at 25°C. To get these rates, set the chamber or platform setpoint to 50°C. When the chamber or platform has stabilized at 50°C, set a new setpoint of 0°C. Make sure you then have the probe 1 temperature displayed. Using a stop watch, watch the display on the controller. As the chamber or platform passes through 40°C, start the stopwatch. Stop the stopwatch when the temperature passes through 10°C. Divide 30 by the time (in minutes). The result is the cooling ramp rate at 25°C (actually for the range of 25°C ± 15°C).

When the chamber or platform has stabilized at 0°C, set the setpoint to 50°C. Using the same approach as you used for the cooling rate, time the transition from 10°C to 40°C. Divide 30 by the time (in minutes, again) to get the heating ramp rate.

Enter the heating ramp rate in Box 1

1	

Enter the cooling ramp rate in Box 2

2	

If the rate in Box 1 is equal to the rate in Box 2,
enter 0 in Box 7. You are finished.

If the rate in Box 1 is **greater** than the rate in Box 2,
divide the rate in Box 1 by the rate in Box 2,
put the result, rounded to one decimal place, in Box 3

If the rate in Box 1 is **less** than the rate in Box 2,
put a minus sign (-) in Box 6 and...
divide the rate in Box 2 by the rate in Box 1,
put the result, rounded to one decimal place, in Box 3

3	

Subtract 1 from the number in Box 3 and enter result in Box 4 -1

4	

Multiply the number in Box 4 by 10 and enter the integer result in Box 5 X 10

5	

If the number in Box 5 is less than 10,000 (probably a lot less),
enter that same number in Box 7.

If the number in Box 5 is greater than 9999, enter 9999 in Box 7

6	

7	

Enter the number in Box 7 as Setup Parameter F12.
If there is a minus sign in Box 6, enter the value as a negative number.

9.5 Displayed Messages and Errors Table

indicates a step number is displayed

Display	Description	Manual Section
06.0 -30.5	Program step display	6.1
200 - 100C	Controller range - Celsius mode	3.1.2
392 - 148F	Controller range - Fahrenheit mode	3.1.2
4-0 3276	Controller serial number	3.1.3
ALL rES	Full memory reset	3.7.2
C3-S or C4	Model number	3.1.1
## CErr	T-Drive specification step parameter error	6.3.8.f
CLr	Clearing program steps	6.3.1
Cor Err	Probe correction data entry error	8.3.5.a
dEL	Deleting program step	6.3.5
EE buSY	Busy system, writing to EEPROM	3.3
End	Program finished executing - idle mode	6.3.6
F-0 through F35	Setup parameter display	8, 8.1
FL SAFE	Fail-Safe tripped	3.10
InS	Inserting program step	6.3.4
## LErr	Loop count error	6.3.8.c
LL Err	T-Drive DUT out of range error	4.3.5
LOOP	Indicates alternating display is loop counter	6.2.1.b

## noP0	Program step probe 0 error	6.3.8.a
## noP2	Program step probe 2 error	6.3.8.b
nSP	No setpoint	5.2
## PErr	PIDR Specification error	6.3.8.i
P0 ---- P0F ----	T-Drive™ control active	4.3.3
P1 102.4	Temperature for probe 1 in °C	5.1
P1 Err or P1 -Err	Probe out of range	3.6
P1 LO or P1 HI	Probe out of range	3.6
P2F 165.9	Temperature for probe 2 in °F	3.4, 5.1
-rA-	Ramp timeout error	3.11.1
rEL 8.6.3	Controller firmware version	3.1.1
## rErr	Ramp step error	6.3.8.h
rES Err	Watchdog timer reset	3.7.1
rS LOAd	Ready to upload firmware	3.2.2.c
S1 -77.7	Setpoint for probe 1 control	5.2
## SErr	Adjustable Settling Band specification step parameter error	6.3.8.e
SOr or -SOr	Setpoint out of System Operating Range error	5.2
SOr Err	System Operating Range cannot be determined - parameter error	3.5

## -SOr ## SOr	Setpoint out of range error	6.3.8.d
SP Err	Setpoint error	5.3
Su rES	Setup parameter default value restore	3.3
Su Err	Setup parameter table error	3.7.3
Su dOnE	Finished writing to EEPROM	3.3
## tErr	T-Drive specification step parameter error	6.3.8.g
uOC ---- or uOF ---- u1C 65.3 or u1F 102.7 u2C 65.3 or u2F 102.7	Idle after QU command (second character on display is probe number that was active at time the QU command was processed)	7.7.10

9.6 Technical Support, Repairs & Returns

Sigma's Technical Support department can be reached by email, fax, or telephone:

Email:	TechSupport@SigmaSystems.com
Fax:	*1.619.283.6526*
Telephone:	1.619.283.3193

Normal business hours are 8:00 AM to 5:00 PM, normal business weekdays, Pacific time.

Also you can access our Web site at:

www.SigmaSystems.com

If you wish to send us a controller for repair or updating, please contact technical support before shipping to obtain a return authorization number. When contacting technical support, it is often very helpful if you know the serial number of the unit under discussion. Out of warranty repairs can be charged on either VISA or Mastercard, or can be billed if you have an account with us. Please obtain purchase authorization from your buying department before returning items to us for servicing. Pre-authorized and credit card based repairs are typically returned to you much faster than repairs that must wait for purchase authorizations during the time, or after, repairs are made.

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