Model 263A
Potentiostat/Galvanostat

Command Set Handbook

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Advanced Measurement Technology, Inc.

a/k/a Princeton Applied Research, a subsidiary of AMETEK®, Inc.

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Safety Instructions and Symbols

This manual contains up to three levels of safety instructions that must be observed in order to avoid personal injury and/or damage to equipment or other property. These are:

DANGER	Indicates a hazard that could result in death or serious bodily harm if the safety instruction is not observed.
WARNING	Indicates a hazard that could result in bodily harm if the safety instruction is not observed.
CAUTION	Indicates a hazard that could result in property damage if the safety instruction is not observed.

Please read all safety instructions carefully and make sure you understand them fully before attempting to use this product.

Cleaning Instructions

WARNING	Using this instrument in a manner not specified by the manufacturer may impair the protection provided by the instrument.

To clean the instrument exterior:

- Unplug the instrument from all voltage sources.
- Remove loose dust on the outside of the instrument with a lint-free cloth.
- Remove remaining dirt with a lint-free cloth dampened in a general-purpose detergent and water solution. Do not use abrasive cleaners.

CAUTION	To prevent moisture inside of the instrument during external cleaning, use only enough liquid to dampen the cloth or applicator.

- Allow the instrument to dry before reconnecting the power cord.

1. INTRODUCTION

1.1. Controlling the Model 263A

The Model 263A Potentiostat/Galvanostat can be operated either directly from its front panel or remotely from a personal computer. This *Command Set Handbook* explains how to operate the Model 263A remotely from the computer of your choice via either the RS-232 or GPIB (IEEE-488) interface port.

By interfacing the Model 263A to a host computer, complete remote control of the instrument is readily accomplished using the Princeton Applied Research Electrochemical Command Set, a group of over 100 mnemonic software statements specifically developed for electrochemical measurements. These commands place unprecedented flexibility in the hands of the electrochemist. They provide:

- Access to most front-panel functions.
- Control of all timing functions.
- Application of pulse and staircase waveforms.
- Automatic acquisition of data with or without current auto-ranging.
- Data averaging in real-time.
- Internal storage and arithmetic data manipulation.

Instructions for operating the Model 263A as a stand-alone instrument controlled from the front panel are given in the separately bound *Model 263A User's Guide*. The *User's Guide* also shows how to set the GPIB and RS-232 communications parameters necessary for controlling the instrument from a host computer.

1.2. About this Manual

This *Command Set Handbook* is organized into two chapters and four appendixes. Chapter 1 explains how the Model 263A can be controlled remotely from your computer via either the RS-232 or GPIB data link, and discusses the different kinds of commands that can be used. Chapter 2 describes each command in detail.

The quickest way to find information about any command, however, is by first referring to the condensed command descriptions in the Alphabetical Command Index, which follows the appendixes at the end of the manual. Then, if you need more detailed information, go to the complete discussion of the command in Chapter 2. The summary of each command in the Alphabetical Command Index ends in a reference to the page in Chapter 2 that gives more complete information about the command.

Detailed explanations of GPIB and RS-232 communications, such as pinouts, communications protocols, and some useful communications routines, are located in the appendixes.

Appendix A discusses interfacing and communications protocols for both RS-232 and GPIB (IEEE-488) data links. It describes the nature and format of the signals passing between the Model 263A and the computer controlling it.

Appendix B contains a detailed discussion of the GPIB bus standard and its use on the Model 263A. It describes each signal and explains the GPIB address settings (which are made from the front panel). It also includes a section on troubleshooting GPIB communications problems.

The RS-232 computer interface is described in detail in Appendix C. This appendix explains the differences between the GPIB and RS-232 interfaces, describes the RS-232 signals, and shows how to set RS-232 parameters from the front panel. It also includes a section on troubleshooting RS-232 communications problems.

Appendix D comprises an application note on waveform programming, one of the most useful functions of the Model 263A but perhaps the most complex to understand.

1.3. LCD Display

The voltage and current measurements taken during your experiment are shown on the liquid crystal display on the front panel of the Model 263A. This display provides continuous information on the experiment in progress.

Pressing the F5 key beneath the display panel returns control of your experiment from the computer to the front panel. Chapter 5 of the *Model 263A User's Guide* describes the functions of the LCD display, pushbuttons, and VALUE knob when you are controlling the Model 263A from its front panel.

Note: Many of the parameters set from a remote computer via the GPIB or RS-232 bus are stored in memory locations shared with similar parameters set from the front panel. In some circumstances this can cause unpredictable interactions between remote parameters and front-panel parameters. We recommend that you do not mix front-panel and remote operations.

The third line of the four-line LCD display is normally blank in remote operation, but you may display a message there of up to 40 characters with the TYPE command.

1.4. Error Messages

In the event of a problem with your system, the fourth line of the LCD panel may display an error message. The message will say:

COMM ERROR *xx*

with *xx* being a hexadecimal error code. If this message appears at power-up, it indicates a hardware problem in your instrument. Call the Princeton Applied Research Service Department (609-530-1000) and report the error code displayed. The service technician will diagnose the problem and advise you as to what action to take.

If an error message is displayed while you are running in remote-control operation via the GPIB (IEEE-488) bus, also call Princeton Applied Research. If a message is displayed while you are controlling the instrument via the RS-232 bus, check that the following communications parameters are set to the same values on both the Model 263A and the software with which you are controlling it:

- Terminator (CR or CRLF)
- Parity bits
- Baud rate
- Data bits
- Stop bits

If the error message persists after you check these parameters, call the Princeton Applied Research Service Department and report the error code displayed.

Note: Error messages displayed on the LCD panel are hardware error messages and are not related to error messages displayed on the host computer with the ERR command. For an explanation of hardware error messages, refer to the *Model 263A User's Guide*, Chapter 5, Section 5.10.

1.5. Polarity Convention

The Model 263A follows the American polarity convention, and its display indications are consistent with that convention. Positive current is cathodic, that is, a current is defined as positive if reduction is taking place at the working electrode. Negative current is anodic, that is, a current is defined as negative if oxidation is taking place at the working electrode. If the working electrode is driven positive with respect to the equilibrium potential, the resulting current is anodic. If the electrode is driven negative with respect to the equilibrium potential, the resulting current is cathodic.

In complex electrochemical systems, there may be more than one equilibrium system. Where this is the case, either polarity with respect to the equilibrium potential could give rise to anodic or cathodic current, according to the system's characteristics.

1.6. Command Categories

There are three classes of commands used in controlling the Model 263A with an external computer:

1. *Communications commands*: Communications commands are used to pass information between the host computer and the Model 263A. For example, the IEEE-488 (GPIB) port requires the use of a set of standard communication messages to accomplish certain control actions. Appendixes B and C provide GPIB and RS-232 communications information in detail.

2. *Programming commands*: Programming commands are the programming language commands used to instruct the computer to perform the desired action.

3. *Model 263A commands*: These commands are sent to the Model 263A from the host computer. When the Model 263A receives one of these commands, it performs the function defined for it. The Model 263A recognizes more than one hundred different commands, allowing highly sophisticated experiments to be programmed. All are explained in Chapter 2. There are six kinds of Model 263A commands:

ACTION: A command that directly causes an event to happen. An example is DCL, which restores the default parameter values.

READ: A command that causes one or more values to be read and reported to the host computer. An example is VER, which requests the Model 263A to report its software version to the host computer.

SET: A command that sets a parameter value. An example is VERTEX n1 n2, which sets a vertex location and the modulation level at that vertex.

SET/READ: A command that, if sent with an operand, sets a parameter value, and if sent without an operand, requests the Model 263A to report the parameter value in effect to the host computer. An example is FLT n, which sets or reads the filter status.

CONTROL: A command used to set up loops and user-defined operations. An example is

DO 10;READE;LOOP

which executes READE ten times.

ACTION READ: A command that initiates some action and then takes a reading. An example is AS n, which initiates a single auto-range followed by reporting the resulting range value to the host computer.

The *Instructional Command Set* listed in Table 1-1 is a subset of the Model 263A commands. These commands permit simple experiments to be readily conducted. They are particularly useful for gaining an understanding of how the Model 263A works, and for getting some operating experience.

Note that the utility of these commands in complex measurements is limited. Do not attempt to use them solely from the information in Table 1-1. Instead, look up the full description of a command to learn how it works before using it.

Some of these commands interfere with one another, or with other commands in the general command set. These interactions must be understood and avoided for successful measurements.

1.7. Notation Conventions

The following conventions are used in the command descriptions:

"n" is used to denote a numeric parameter or response.

"n1...nx" is used to denote multiple parameters or responses (x is an integer larger than 1).

Default parameter values are enclosed by brackets, [ ].

Table 1-1. Instructional Command Set

Command	Function
SETE	Set Appl. Potential (CONTROL E MODE)
SETI	SET Appl. Current (CONTROL I MODE)
READE	Read Cell Potential
READI	Read Cell Current
I/E	I/E Converter Range
CELL	Cell Switch ON/OFF
FLT	Filter IN/OUT
OVER	Read Overload Status
MODE	Sets Operating Mode
ID	Read Identification Number
VER	Read Firmware Version Number
ERR	Rear Error Status

2. MODEL 263A COMMANDS

2.1. How this Chapter is Organized

The quickest way to find information about a command is by first referring to the condensed command descriptions in the Alphabetical Command Index at the end of the book. Then, if you need more detailed information, go to the complete discussion of that command in this chapter. The summary of each command in the Alphabetical Command Index includes a reference to the page in this chapter that gives more complete information about the command.

Commands in this chapter are organized in the following groups. In many cases, more detailed discussions of the functions of each group of commands are presented at the beginning of each section describing a group.

Setting commands (Section 2.2) set or report the setting of parameters used internally by the instrument, such as current range.

Memory Partitioning commands (Section 2.3) are used to optimally partition available memory to fit the number and length of the curves. This section also includes *Curve Designation commands* that designate which curves are to be used.

Bias commands (Section 2.4) set the level of the fixed bias added to the potential or current applied to the cell.

Modulation commands (Section 2.5) are used to modulate the potential applied to the cell during each sweep. For example, ramp modulation can be used so that a different potential is calculated and applied for each data point. Other waveforms can be applied; a detailed discussion is presented in Section 2.5.

Data Acquisition Control commands (Section 2.6) are used to initialize and control curve acquisition.

Sampling and Sweep Control commands (Section 2.7) are used to control how data are collected. They also control the number of sweeps in an acquisition and the kind of sweep averaging, if any, to be used.

Uncompensated Resistance commands (Section 2.8) set or control the measurement of the uncompensated resistance.

Current Integration commands (Section 2.9) are used to control the gated integrator of the Model 263A.

Electrochemical Impedance Interface commands (Section 2.10) are additional commands intended for use with the AC Impedance software.

Data Acquisition Monitoring commands (Section 2.11) are used to report the status of a curve in progress or the current value of a sampled parameter.

Curve Processing and Curve Data Transfer commands (Section 2.12) are used to transfer curve data between the Model 263A and the host computer, and for copying data from one curve to another. They also perform various kinds of processing on stored curves.

Communications Control and Status commands (Section 2.13). The Communications Control commands specify the delimiter to be used between two numbers in a transmission, and explain how to cause a service request. Status commands request the Model 263A to report errors, overload, and whether operations have been completed.

Control Structure commands (Section 2.14) are used to set up multiple commands, set up USR functions, and interrupt command execution.

Auxiliary Interface commands (Section 2.15) control signals placed on the rear-panel AUXILIARY INTERFACE connector, including those that control the Model 303A Static Mercury Drop Electrode.

System Identification, Option, and Display commands (Section 2.16) cause the Model 263A to report its firmware version, model number, and whether a particular optional feature is installed. The TYPE command allows you to print a customized message on the third line of the LCD display.

A Word About Delimiters: When a command is applied with operands, use a space as the delimiter. If a command is applied that evokes response values (Read commands or any Set/Read command sent without operands), the responses are separated by the character defined by the **DD** command. The default delimiter as defined by the **DD** command is the comma. In the discussions that follow, all operands are shown separated simply by a space.

2.2. Setting Commands

I/E n [-4]: A Set/Read command, I/E (CURRENT TO VOLTAGE CONVERTER) sets the full-scale current range. If "n" is omitted, I/E requests that the Model 263A report the selected current range. The codes are:

n	CURRENT RANGE
0	1 A (94 option)
-1	100 mA
-2	10 mA
-3	1 mA
-4	100 µA
-5	10 µA
-6	1 µA
-7	100 nA

Notes: A cell current equal to the selected range will give 1 V at the output of the I/E converter and at the I OUTPUT connector.

The I/E command will be accepted only if current auto-ranging is OFF (see discussion of AR command). If current auto-ranging is active, a Mode Error (Error 11) will be returned.

AS n: An Action Read command, AS (AUTO-SENSITIVITY) causes the Model 263A to seek that current range which will result in an output between 15% and 190% of full scale, and to respond with the number that indicates that range. This is done immediately upon receipt of the command. The codes signifying the current range are the same as those listed above for the I/E command. If the signal is too large to achieve this objective, the Sensitivity will be set to the highest range of the instrument and "n" will be 1000. If the signal is too small to achieve this objective, the 100 nA range is selected and, again, "n" is 1000. "1000" will also be returned and no auto-ranging will occur if:

1. A Curve Acquisition is in progress.

2. The Model 263A is in the Galvanostatic mode. (The Autosensitivity function can be activated in the Potentiostat mode only.)

3. Only the "E" signal is being sampled.

Example: The Model 263A is set to the 100 µA range with a current of 5 µA when the AS command is applied. On receipt of this command, the Model 263A selects the 10 µA range, on which the 5 µA current represents 50%. In addition, the number "-5" is sent to the computer to indicate that the 10 µA range has been selected.

Note: Full scale at the output of the analog-to-digital converter is 2000. In terms of the converter output range, the Model 263A seeks to set the converter to a range that will give an output between 150 and 1900 counts.

AR n [2]: A Set/Read command, AR (AUTO-RANGE) turns the auto-ranging function ON or OFF for the parameters, CURRENT, POTENTIAL or AUX. If "n" is omitted, the command requests the Model 263A to report its autoranging status. AR differs from AS in that, whereas AS causes a single current auto-range to take place, AR establishes a continuously active mode. The codes are:

n	I AUTO-RNG	E AUTO-RNG	AUX AUTO-RNG (98 option)
0	OFF	OFF	OFF
1	ON	OFF	OFF
2	OFF	ON	OFF
3	ON	ON	OFF
4	OFF	OFF	ON
5	ON	OFF	ON
6	OFF	ON	ON
7	ON	ON	ON

Current Auto-ranging causes the Model 263A to automatically seek that current range which puts the output between 15% and 190% of full scale. It does not affect the IGAIN, however. Up auto-ranging decisions occur on a sample-by-sample basis, while down auto-ranging decisions take place on a point-by-point basis.

Auto-ranging will yield meaningless results if the time base is less than 1000 µs, or if "I" is not being sampled. Data can also be lost if the data amplitude is changing faster than the auto-ranging function can track.

Current auto-ranging can only be performed in potentiostatic operation. If it is attempted in the galvanostatic mode, a Command Error 11 (wrong mode) will be generated. Also, current auto-ranging should not be enabled when doing sweep averaging (SAM command operand 1 or 2). If it is, meaningless data will result.

When I auto-ranging is enabled, the data are packed with the range data in the top four bits and the current data in the bottom twelve bits. See the description of the DC command for information on unpacking this type of data.

E Auto-ranging causes the Model 263A to adjust the gain of the voltage sensed by the Reference Electrode as required to maintain the highest possible resolution (consistent with limit constraints) in reported readings of that potential. The thresholds are as follows.

|E|	Gain
|E| > 1900 mV	x5 to x1
|E| > 190 mV	x50 to x10
|E| < 1800 mV	x1 to x5
|E| < 180 mV	x10 to x50

Note that the number of counts stored remains the same. The gain never switchs between ×5 and ×10.

The EGAIN command also affects the E auto-range function. If EGAIN is set to 1 or 5, E auto-ranging behaves as described in the preceding paragraph. If, however, EGAIN is set to 10 or 50, an additional factor of ten gain increase occurs, and the auto-ranging decision points become 180 mV and 190 mV, giving resolutions of 100 µV (gain of X1 and X10 in effect) and 500 µV (gain of X5 and X10 in effect), respectively. See the discussion of the EGAIN command for a description of the relationship between reported "counts" and potential.

No auto-ranging will take place in NO FRILLS data acquisition. See the TMB command.

AUX auto-ranging (only available in units equipped with the 98 Option) causes the Model 263A to adjust the gain of the voltage applied to the rear-panel AUX A/D INPUT connector as required to maintain the highest possible resolution (consistent with limit constraints) in reported readings of that potential. The gain, decision points, and resolution are the same as for E auto-ranging, previously discussed.

Note: The use of user-generated auto-range routines is not recommended. Complex problems stemming from the internal signal-processing architecture of the Model 263A makes the successful function of user routines in high-noise situations problematical.

AL n [-7]: A Set/Read command, AL (AUTO-LIMIT) sets the most sensitive current range to which the Model 263A can automatically range in response to the AS or AR 1 command. If I auto-ranging is enabled when this command is received and the present current range is below n, the current range will immediately be set to n. If n is omitted, the AL command requests that the Model 263A report the limit sensitivity setting. The codes are:

n	**CURRENT RANGE**
0	1 A (94 option)
-1	100 mA
-2	10 mA
-3	1 mA
-4	100 µA
-5	10 µA
-6	1 µA
-7	100 nA

Example: If the computer sends the command AL -5, the highest sensitivity to which the Model 263A can auto range in response to an AS or AR 1 command will be 10 µA.

EGAIN n [1]: A Set/Read command, EGAIN (POTENTIAL GAIN) sets the potential measurement gain ahead of the Analog-to-Digital Converter to either X1, X5, X10, or X50. The gain determines the value sent to the host computer as the potential reading. If the gain is X1 or X10, the number of counts (number read) is multiplied by 5 to produce a reading in millivolts or tenths of millivolts, respectively. If the gain is X5 or X50, the A/D value (number of counts) is reported directly in millivolts or tenths of millivolts, respectively. An example follows.

E	**EGAIN**	**READING**
100 mV	X1	100
100 mV	X5	100
100 mV	X10	1000
100 mV	X50	1000

Note: In NO FRILLS data acquisition, the foregoing data manipulation does not occur. See the TMB command.

Note that the AR command, described earlier, also controls EGAIN. As explained in the description of the AR command, AR can switch the potential gain between X1 and X5 as required to achieve the best resolution in reported potential readings. However, AR does not affect the additional X10 gain multiplier. If the X10 multiplier was previously activated by the commands

EGAIN 10 or EGAIN 50, AR will switch the net gain between X10 and X50. If the X10 multiplier is not active (EGAIN 1 or EGAIN 5), AR will switch the net gain between X1 and X5.

You may note that the READE command also affects EGAIN in that it automatically deactivates the additional X10 gain multiplier whenever it is applied.

For highest accuracy, the gain should be as high as possible consistent with keeping the amplified voltage below 10. If the gain is too high, the range of the internal circuitry will be exceeded. If the gain is too low, resolution will be lost. A listing of recommended gain versus monitored potential follows.

|E|	**RECOMMENDED EGAIN**
<200 mV	X50
between 200 mV and 1 V	X10
between 1 V and 2 V	X5
>2 V	X1

The codes for "n" are:

n	**EXPAND STATUS**
1	X1
5	X5
10	X10
50	X50

Note: The READE command automatically sets EGAIN to X1 or X5, whichever gives the most accurate READE measurement. If the X10 additional gain multiplier is active when READE is applied, READE immediately deactivates it. Thus, an operator-set value of EGAIN X10 or EGAIN X50 can be lost. Recall that the reported value is direct reading in mV when the net EGAIN is X1 or X5.

Caution: The EGAIN command remains in effect if you switch to local control from the front panel. In some circumstances this can cause unpredictable interactions with experiment parameters set from the front panel. We recommend that you do not mix front-panel and remote operations.

ESUP n [0]: A Set/Read command, ESUP (POTENTIAL SUPPRESSION) allows the E potential signal (only; not ΔE) to be suppressed ahead of the Analog to Digital Converter. If applied without an operand, ESUP requests the Model 263A to report the suppression value. Suppression is in units of 2 mV/count with a range of ±5000 for a full-scale range of ±10 V. Positive values are added to the cell signal.

By allowing the static potential value to be suppressed, ESUP allows small fluctuations with respect to the static value to be readily examined. Note that ESUP is effective whether the unit is running a curve or doing a scan.

n range: 5000...-5000

Example: An experiment yields a steady signal of 9 V. ESUP -4500 will suppress this signal. With this level of suppression applied, EGAIN can then be set to X10 or X50 for increased sensitivity in fluctuation measurements. For example, if the EGAIN operand is 10 or 50, the E readings of the fluctuations will read true in tenths of mV.

Note: This command has meaning only in FULL FRILLS data acquisition. In SOME FRILLS and NO FRILLS operation, use the SUPDAC command. See the SUPDAC and TMB commands.

IGAIN n [1]: A Set/Read command, IGAIN (CURRENT GAIN) sets the current measurement gain ahead of the Analog-to-Digital Converter and thus the number of counts (current reading) provided for any given cell current. If "n" is omitted, the IGAIN command requests that the Model 263A report the IGAIN setting. Gains of X1, X5, X10, and X50 are available. A full-scale current (IGAIN set to 1) gives a reading of 1000 counts. Readings as high as 2000 counts can be accommodated. The following example shows how the current reading in counts varies with IGAIN for a given current level.

I	IGAIN	READING (COUNTS)
4% of f.s.	50	2000
4% of f.s.	10	400
4% of f.s.	5	200
4% of f.s.	1	40

For best accuracy, the IGAIN should be as high as possible consistent with avoiding current overload. The recommended IGAIN as a function of the current level is as follows.

I	RECOMMENDED IGAIN
<4% of f.s.	X50
Between 4% and 20% of f.s.	X10
Between 20% and 40% of f.s.	X5
>40% of f.s.	X1

The codes are:

n	EXPAND STATUS
1	X1
5	X5
10	X10
50	X50

Note: The READI command automatically sets IGAIN to X1 or X5, whichever gives the most accurate READI measurement. If the X10 additional gain multiplier is active when READI is applied, READI immediately deactivates it. Thus, an operator-set value of IGAIN X10 or IGAIN X50 can be lost. Recall that the value is reported in mV when the IGAIN is X1 or X5.

ISUP n [0]: A Set/Read command, ISUP (CURRENT SUPPRESS) allows the I/E current signal to be suppressed ahead of the Analog-to-Digital Converter. If applied without an operand, ISUP requests the Model 263A to report the suppression value. Maximum suppression is two times the present current range. By allowing the static current value to be suppressed, ISUP allows small fluctuations with respect to the static value to be readily examined.

Since n ranges from ±8000, and full scale is two times the current range, one count corresponds to 2/8000 or 0.25×10^{-3} times the current range. For example, on the 1 mA current range 1 count corresponds to 0.25 µA of current. Note that ISUP cannot be used when auto-ranging.

n range: 8000...-8000

Example: An experiment yields a steady signal of 90% of the selected current range. ISUP -3600 will suppress this signal, giving a net input to the A/D input of "0". With this level of suppression applied, IGAIN can then be adjusted to obtain the desired level of fluctuation sensitivity. For example, if the IGAIN operand is 50, a current of 2 mA on the 100 mA scale will yield 8000 counts.

Note: This command has meaning only in FULL FRILLS data acquisition. In SOME FRILLS and NO FRILLS operation, use the SUPDAC command. See the SUPDAC and TMB commands.

SUPDAC n [0]: A Set/Read command that suppresses the I or E signal ahead of the A/D converter. The allowed range of -8000 to +8000 represents ±8 V for E or ±2 × full scale on the selected current range for I. This command will be executed in all timebases. Any subsequent SUPDAC command will overwrite the DAC value.

This command is provided to allow suppression in SOME FRILLS and NO FRILLS data acquisition. Be aware that if both E and I are being sampled in SOME FRILLS acquisition, the same value will be used for both.

AUXSEL n [0]: (Units with 98 Option only), AUXSEL is a SET/READ command that selects the AUX channel to read. The parameter range is 0 to 7.

AUXGAIN n [1]: (Units with 98 option only), AUXGAIN (AUXILIARY GAIN) is a SET/READ that sets the gain of the rear-panel Auxiliary A/D Input. If "n" is omitted, the command requests that the Model 263A send the AUXGAIN setting. The codes are:

n	**GAIN**
1	X1
5	X5
10	X10
50	X50

Auxiliary input potential readings are always in units of mV and "read true" for all gains. For example, an input potential of 2 V will result in a reading of 2000 with a gain setting of either X1 or X5. However, for best accuracy, the higher gain should be used whenever possible. Since the product of the gain times the input voltage cannot exceed 10 V, this means using a gain of X5 if the auxiliary potential is less than 2 V, and a gain of X1 if the auxiliary potential is between 2 V and 10 V.

MODE n [2]: A Set/Read command. If MODE is applied with an operand, it sets the Model 263A operating mode. If applied without an operand, it causes the mode to be reported.

The codes are:

n	**MODE**
1	Galvanostat
2	Potentiostat

Note: If Mode is set to 1 (Galvanostatic), I auto-ranging and iR compensation will be turned off.

FLT n [0]: A Set/Read command that controls the filters. To use it as a Set command, apply the command with the appropriate operand, as indicated in the following table for the filter conditions you wish to establish.

	E FILTER		
I FILTER	**None**	**5.3**	**590**
None	0	16	48
5.3	65	81	113
590	73	89	121
I/E + 5.3	1	17	49
I/E + 590	9	25	57
I/E Only	8	24	56
I/E Only	8	24	56

You may select either a 5.3 Hz or a 590 Hz low-pass filter for either I or E signals. In addition, you may reduce the bandwidth of the I/E converter by switching in a roll-off capacitor. The effect of this capacitor on bandwidth depends on the current range selected. On the 1 mA current range and up, the rise time is approximately 50 µs. The rise time goes up about a decade for each decade of current range decrease.

Note that the table lists all possible filter selections, with a different operand value for each possible E Filter and I Filter combination. I/E indicates that the roll-off capacitor is switched in and active.

Examples:

1. FLT 0 would select **No Filtering**.
2. FLT 121 would select **E Filter 590 Hz**, **I Filter 590 Hz**, and **I/E Filter OFF**.
3. FLT 17 would select **E Filter 5.3 Hz, I Filter 5.3 Hz**, and **I/E Filter ON.**
4. FLT 56 would select **E Filter 590 Hz**, **I Filter OFF**, and **I/E Filter ON.**
5. FLT 8 would select **E Filter OFF**, **I Filter OFF**, and **I/E Filter ON.**

To use FLT as a READ command. Simply omit the operand value. This will cause the potentiostat to respond with the operand value that defines its filter status.

FS n [0]: A Set/Read command, FS (FILTER SELECT) sets or clears FLT bit 3. To use it as a Set command, enter the operand value shown in the following table. To use it as a Read command, omit the operand value. The command then requests that the potentiostat report the status of FLT bit 3.

This command exists primarily to make the Model 263A compatible with software that supports the older Model 273 firmware when enabling the 590 Hz low-pass filter.

n	**FLT BIT 3 STATUS**
0	Cleared
1	Set

BW n [0]: A Set/Read command, BW (BANDWIDTH) sets the bandwidth/stability parameter. If "n" is omitted, it is a request for the Model 263A to report this information. The codes are:

n	MODE
0	High Stability
1	High Speed

CELL n [0]: A Set/Read command, CELL controls the internal cell relay and active FET switch. If "n" is omitted, the command is a request that the Model 263A report the relay/switch status. The codes are:

n	CELL STATUS
0	Off
1	On

Note: Also see the description of the DUMMY Command, which causes the Model 263A to report the cell type (real or dummy).

EXT n [0]: A Set/Read command, EXT determines whether the front-panel EXT INPUT is ON or OFF. If "n" is omitted, it is a request for the Model 263A to report the External Input status to the host computer. The codes are:

n	STATUS
0	Off
1	On, with unity gain

Note: This command shares the same input BNC with the OSCIN command. If OSCIN is set to on and an attempt is made to turn on EXT IN, a Command Error 11 (Wrong Mode) will be generated.

Use OSCIN when you want to amplify or attenuate a signal applied at the EXT IN connector. Use EXT when the applied signal does not require amplification or attenuation.

DCL: An Action command, DCL (DEVICE CLEAR) restores the default parameter values with two exceptions: the MSK and DD operands do not change.

CAL: An Action command, CAL (CALIBRATE) is used to calibrate the Model 263A. CAL has the same effect as pressing F1 from the [System Interface] menu screen on the front panel of the Model 263A (refer to the *Model 263A User's Guide*, Chapter 5, Section 5.8).

Before calibrating the instrument, allow it to warm up for at least one half hour.

2.3. Memory Partitioning and Curve Designation Commands

The Model 263A has memory enough to store 6144 data values in as many as six curves (Curve 0 through Curve 5). The maximum number of curves depends on their length, up to the maximum of six curves. If a curve is short (1024 or fewer points), the 6144-point memory is large enough to allow the maximum of six curves. At the other extreme, if a curve is longer than 3072 points, the 6144-point memory will only be large enough for one curve. Unused memory capacity is simply unavailable. For example, a 5000-point curve would leave 1144 points unused and unavailable.

For purposes of memory partitioning, the curve length is defined as LP + 1, where LP is the operand of the LP (LAST POINT) command. For example, if the last point as designated by the LP command is 1024, the curve length would be considered to be 1025 points. As indicated in the table that follows, there would only be room for three curves of this length in memory. If the curve length were reduced by a single point, the number of curves that could be stored would increase from three to six, the maximum.

Curves are identified by numbers, and each curve always begins at a specific point in memory. The numbers range from 0 to 5, that is, six numbers to designate as many as the maximum of six curves. The point at which each curve begins is:

CURVE 0	0
CURVE 1	1024
CURVE 2	2048
CURVE 3	3072
CURVE 4	4096
CURVE 5	5120

In other words, the starting location of each curve in memory is always the same. (Knowing these locations is critical when doing data dumps from the Model 263A to the host computer.) For a given curve length, as determined by the LP command, only specific curves will be available, as indicated in the following list. For example, if the curve length were such as to allow six curves, all six curves, 0 through 5, would be available. On the other hand, if the curve length were such as to allow three curves, the available curves would be 0, 2, 4, and the starting location of each would be as listed above. Curves 1, 3, and 5 would not be available and could not be designated.

Optional Memory: When equipped with the 91 Option, the Model 263A has up to 96 curves (0 through 95). These curves follow the same partitioning rules as do the basic six curves.

LENGTH	CURVES AVAIL.	NUMBER(S)
3073 to 6144	1	0
2049 to 3072	2	0 & 3
1025 to 2048	3	0, 2, & 4
1 to 1024	6	0, 1, 2, 3, 4, & 5

With 91 Option:

LENGTH	CURVES AVAIL.	NUMBER(S)
3073 to 6144	16	0, 6, 12 ... 90
2049 to 3072	32	0, 3, 6, 9, 12 ... 93
1025 to 2048	48	0, 2, 4, 6, 8 ... 94
1 to 1024	96	0, 1, 2, 3, 4, 5 ... 95

Each point is a 16-bit signed integer (-32768 to +32767). By making the capacity of the memory locations (nominally 32000) much larger than the full-scale output of the analog-to-digital converter (nominally 2000), room is provided for sweep averaging. In the linear averaging mode, 16 sweeps containing full-scale values could be averaged without overflowing the memory. In the exponential averaging mode, a very large number of sweeps could be averaged since the value at convergence won't exceed the value at the output of the analog-to-digital converter for that point.

Functionally, there are five kinds of curves. They are:

1. SOURCE CURVE: Data stored in the Source Curve define a modulation waveform. If the MM 2 command has been executed, the modulation waveform stored in the SOURCE CURVE will be applied during subsequent curve acquisitions.

2. DESTINATION CURVE: This is the curve into which data will be placed during curve acquisitions. I, E, AUX, and ΔE (the current-interrupt compensation potential) could all be stored in successive curves as determined by the SIE command. The first curve is the

Destination Curve. The other or others, according to the data designations made with the SIE command, are NEXT CURVES.

3. NEXT CURVE: This is the curve into which E, AUX, or ΔE data are placed during curve acquisitions. There can be up to three Next Curves according to the SIE selection. NEXT CURVE(s), if present, always immediately follow the DESTINATION CURVE.

4. ALTERNATE CURVE: During a run comprising many sweeps, it is possible to store the measurement results obtained on some number of sweeps in one curve, and the measurement results obtained on the remainder of the sweeps in another curve. The first set of results is stored in the DESTINATION CURVE. The curve in which the results for the remainder are stored is the ALTERNATE CURVE.

5. PROCESSING CURVE: A curve on which post-acquisition processing (see descriptions of Curve Processing Commands, ADD, SUB, EX, MIN, IMIN, MAX, IMAX, INT, IINT, and ILOG) is performed is the PROCESSING CURVE. A given curve can be a PROCESSING CURVE as well as one of the other previously described kinds of curves. For example, you could designate Curve 1 as both the DESTINATION CURVE and the PROCESSING CURVE.

Six commands, DCV, ACV, SCV, PCV, CRVMEM, and AVAIL control curve functions. In using these commands, it is essential that the constraints on the number of allowable curves, and on the available curve-designation numbers, be observed, as discussed in the first few paragraphs of this section. A discussion of these commands follows.

DCV n [0]: A Set/Read command, DCV designates the DESTINATION CURVE: the starting curve number where measured data are stored. The number of curves used depends on the SIE selected. The order in which data are stored is I, E, AUX (98 Option only), and ΔE.

n range: -1...5 (*-1...95 with 91 Option*)

If n = -1, no data will be stored in any curve. This allows data from preliminary sweeps to be discarded, useful when the ACV command is used. If n is omitted, this command requests that the Model 263A report the Destination Curve number.

DCV also designates the NEXT CURVE (or curves), which will be the next one(s) available.

Example: DCV is set to "0," and SIE is set to "3" (I and E). The I values will be stored in curve 0 and the E values will be stored in curve 1.

Notes: If the user misprograms the Model 263A with the DCV command so that, if the curve were run, data would be written past the end of the memory, the curve will not be run.

For example, if the user sets DCV to "0", SCV to "1", and LP to 1023, there is no problem, since Curve 0 can hold up to 1024 points. If LP is set to 1024 or higher, data would be written onto the source curve. To prevent this, the Model 263A will not run the curve.

If the DCV command is received while a curve is in progress, Command Error 12 (Acquisition Error) will be generated.

ACV n1 n2 [0 0]: A Set/Read command, ACV (Alternate Curve) switches the destination curve or curves to n1 at sweep n2. If n1 = -1 or n2 = 0, or the present sweep is beyond n2 when this command is received, no destination curve switch will occur. If n1 and n2 are omitted, it is a request for the Model 263A to report this information.

The ranges are:

n1 range: -1...5 (*-1...95 with 91 Option*)
n2 range: 0...32767

Example: The command ACV 1 5 would designate Curve 1 the Alternate Curve. Beginning with sweep 5, acquired data will be stored in this curve. The sweep number counts up from one to the number specified by the SWPS operand. For example, if 10 sweeps were specified, the first would be number 1, the second number 2, etc. For prior sweeps, the Destination Curve would be located as specified by the DCV command.

When the next NC (NEW CURVE) command is applied, the original location set by DCV will be restored.

Notes:

1. If the user misprograms the Model 263A with the ACV command so as to cause data to be written past the end of the memory, no data for that curve will be stored.

   For example, if the user sets ACV to "0", SCV to "1", and LP to 1023, there is no problem, since Curve 0 can hold up to 1024 points. If LP is set to 1024 or higher, data would be written onto the source curve. To prevent this, no data would be stored for the curve at all.

2. When the 91 Option is installed, multiple alternate curves are available by stacking the ACV command. For example, the following sequence:

   ACV 90,5
   ACV 91,6
   ACV 92,7

   will cause the 263A to store data from sweeps 5, 6, & 7 in curves 90, 91, & 92. To clear stacked ACV commands, set n1 = -1.

SCV n [3]: A Set/Read command, SCV (SOURCE CURVE) designates the Source Curve. This curve contains the point-by-point source data when Modulation Mode 2 (random waveform) is selected. If "n" is omitted, the command is a request for the Model 263A to transmit this information.

n range: 0...5 (*0...95 with 91 Option*)

A curve may be designated as both the Source Curve and Destination Curve. This would be done, for example, if it were necessary to acquire a 6144-point curve using the random waveform modulation mode. The Source Curve data would be replaced by the acquired data as each point is taken. Therefore, only one sweep can be done. Since the NC command clears the Destination Curve buffer, the Source Curve should be loaded into the Model 263A after NC but before TC.

An alternative method is to load the Source Curve into the potentiostat and then use the RC command instead of the NC command.

Note: If this command is received while a curve is in progress, Command Error 12 (Acquisition Error) will be generated.

PCV n [0]: A Set/Read command, PCV (Processing Curve) designates the Processing Curve. If "n" is omitted, the command is a request for the Model 263A to send this information.

n range: 0...5 (*0...95 with 91 Option*)

All curve data manipulation and processing commmands except the BL and BD commands operate on points relative to the Processing Curve.

Example: If the following commands were received:

PCV 2;DC 0 1000

the actual points dumped from curve memory would be 2048 to 3047 (assuming LP - FP < 1025).

CRVMEM: A READ command, CRVMEM (Curve Memory) returns the amount of curve memory in kilopoints installed in the instrument.

Example: In a standard 263A, CRVMEM will return **6**, which means that the instrument has 6144 points of storage.

AVAIL: A READ command, AVAIL (Available) returns the logical number of each curve that is available.

Example: Suppose your 263A has the 91 Option installed with **LP** (see discussion of LP command on page 22) set to 6000. AVAIL would respond with:

0,6,12,18,24,30,36,42,48,54,60,66,72,78,84,90

If DCV, SC, or ACV is set to a curve number that is not in this list (i.e., **not** available), a command error will be generated when the **NC** or **RC** command is received. In addition, if **PCV** is set to a curve that is not available, a command error will be generated when any command that acts on the Processing Curve is applied.

2.4. Bias Commands

The potential (or current, in galvanostatic operation) applied to the cell is the sum of several sources. When controlling the Model 263A from the front panel, the cell potential or current set with the VALUE knob, together with any potential applied to the EXT INPUT connector, determines the cell potential (or current). When controlling the Model 263A from an external computer, the front-panel controls are no longer active, and the cell potential (current) is set by the modulation and bias commands, together with any potential applied to the EXT INPUT connector (see the discussion of the EXT command).

As previously explained, the Modulation DAC allows a cell excitation that changes over the course of a curve acquisition to be applied. The function of the Bias DAC is similar except that its output is fixed at the programmed level. A detailed discussion of the BIAS, SETE, and SETI commands follows.

BIAS n [0]: A Set/Read command, BIAS sets the bias potential to be applied as soon as the cell is on. The bias level is specified with a resolution of 1 mV per count. If n is omitted, it is a request for the Model 263A to report the bias setting.

n range: -8000...8000

Note that the polarity of the applied bias depends on the Model 263A operating mode. In Galvanostatic operation, BIAS 8000 causes a bias current of -2 * full scale. In Potentiostatic operation, BIAS 8000 causes a bias potential of +8 V.

The Model 263A follows the American polarity convention and the Model 263A display indications are consistent with that convention. Positive current is cathodic, that is, a current is defined as positive if reduction is taking place. Negative current is anodic, that is, a current is defined as negative if oxidation is taking place. If the working electrode is driven positive with respect to the equilibrium potential, the resulting current is anodic. If the electrode is driven negative with respect to the equilibrium potential, the resulting current is cathodic.

In complex electrochemical systems, there may be more than one equilibrium system. Where this is the case, either polarity with respect to the equilibrium potential could give rise to anodic or cathodic current, according to the system's characteristics.

SETE n [0]: A Set/Read command, SETE (SET POTENTIAL) sets the number of millivolts to be applied in the Potentiostat mode. If SETE is applied when the Model 263A is in the Galvanostat mode, Command Error 11 (Wrong Mode) will be generated. If "n" is omitted, it is a request for the Model 263A to report the SETE operand.

n range: -10000...10000

Note: This command is similar to the BIAS command, except that SETE sets the output of the Modulation DAC to zero. Because it sets MOD to zero, it interferes with the action of the MOD command.

SETI n1 n2 [0, -7]: A Set/Read command, SETI (SET CURRENT) sets the cell current in the Galvanostat mode. The ranges are:

n1 range: -2000...2000
n2 range: -4 to -10 (*-3 to -10 with 94 Option*)

n1 is the percent of full scale on the range selected by n2, where ±2000 = ±200%. BIAS is set to zero and MOD is set to 4 × n1. n2 is the current range, where:

n2	RANGE
-3	1 A (*94 Option only*)
-4	100 mA
-5	10 mA
-6	1 mA
-7	100 µA
-8	10 µA
-9	1 µA
-10	100 nA

These settings conflict with those used in the I/E command, but allow easy reading of the current level.

If SETI is applied when the Model 263A is in the Potentiostat mode, Command Error 11 (Wrong Mode) will be generated. If n1 and n2 are omitted, it is a request for the Model 263A to report the SETI operands.

Example: The command SETI 1000 -6 will set the current to 1000 × 10^{-6} A, that is, to 1 mA.

Notes: Although a given current can be programmed with different combinations of n1 and n2, resolution and precision considerations will generally make it desirable that n2 be as small as possible. This is because n2 sets the current range and n1 sets the fraction of that range to be programmed. The error on any range is a percentage of the range (plus other components). If a current is set by making n2 large and n1 small, the error, a fixed percentage of the n2 range, could well be an appreciable portion of desired setting.

For example, both SETI 10 -4 and SETI 1000 -6 will set the current to 1 mA. If the command is SETI 10 -4 the setting is .01 of the 100 mA range, that is, 1 mA. However, the error is a percentage of the 100 mA, and will be large relative to the 1 mA being set. If the command is SETI 1000 -6, the setting is one times the 1 mA range, and the error, a percentage of the 1 mA range, will be as small as possible.

2.5. Modulation Commands

The Model 263A is capable of applying a modulation program during each sweep such that a different potential is applied to the cell for each point. In many applications, the applied modulation will be a ramp that progresses as programmed. However, there is provision for specifying and applying any arbitrary waveform, if desired. The modulation applied depends on the operating mode. Although full-scale modulation is always ±8000 counts (*±32000 with 91 Option*), the available potential or current modulation range depends on the MR command and the actual modulation is easily expressed in units of potential or current (see descriptions of individual modulation commands).

In Control E operation, the full-scale count range of ±8000 corresponds to potentials of ±20 mV, ±200 mV, or ±2 V, as established by the MR (MOD RANGE) command operand. In the Galvanostat mode, +8000 counts is anodic full scale and -8000 counts is cathodic full scale. The available ranges as determined by the MR command are ±200%, ±20%, and ±2% of full scale.

There are several constraints that must be observed in defining a ramp program. If any are violated, a parameter error is generated and the erroneous ramp-program step is ignored. The constraints are:

1. For the INITIAL command, n1 must be the point number of the first point of the curve and n2 must be a valid modulation DAC value, that is, between -8000 and 8000.

2. For the VERTEX command, n1 must be greater than n1 of the previous step and n2 must be a valid modulation DAC value. Also, n1 of the last VERTEX command should equal the memory address of the last point of the curve. Otherwise the ramp program is not specified for the entire curve.

Consider the following example:

INITIAL 0 -8000;VERTEX 999 8000

which generates a ramp from negative full scale to positive full scale. This default ramp program specifies that the modulation change by 16000 counts over 1000 steps with a data point taken at each step. The first data value is stored in point 0 and the last data value is stored in point 999. Therefore, the modulation will advance 16 counts per step.

In some cases, the step size will not be constant. For example, the ramp program:

INITIAL 0 0;VERTEX 999 1001

requires that the modulation change by 1001 counts over 1000 steps. To accomplish this, 999 steps would each be one count, but one step would be two counts.

Note: If the 91 option is present, the full-scale modulation is extended to ±16000 counts for Modulation Mode 1 (see MM command) and to ±32000 counts for Modulation Mode 2. The actual current depends on the **MR** command.

A discussion of the individual modulation commands follows.

MR n [2]: A Set/Read command, MR (MODULATION RESOLUTION) sets the resolution of the modulation DAC. If "n" is omitted, MR is a request for the Model 263A to report the resolution in effect.

The codes are:

MODULATION RESOLUTION

n	**POTENTIOSTATIC**	**GALVANOSTATIC**
0	2.5 µV per count	I f.s./400,000
1	25 µV per count	I f.s./40,000
2	250 µV per count	I f.s./4,000

Example: In potentiostatic operation, MR 1 sets the resolution of the modulation DAC to 25 µV per count. In the galvanostatic mode, the resolution set by MR depends on the f.s. current range (selected with the I/E command). For example, if the current range is set to 1 mA (I/E = -3), MR 2 would set the resolution to 0.25 µA.

MM n [0]: A Set/Read command, MM (Modulation Mode) sets the Model 263A Modulation Mode. When "n" is omitted, MM requests that the Model 263A report the Modulation Mode. The codes are:

MODULATION MODE

0 No modulation.

1 Ramp program modulation on. Each MOD DAC value is calculated from the initial potential and vertices. (See the INITIAL and VERTEX commands.)

2 Random waveform modulation. Each MOD DAC value is specified in the Source Curve.

In the Ramp Program mode (n = 1), the modulation is a ramp specified by the INITIAL n1 n2 and VERTEX n1 n2 commands. As the experiment progresses, this ramp develops point by point and is applied to the cell. If desired, the ASM command can be used to load the ramp program into the Source Curve for convenient transfer to the host computer.

In the Random Waveform mode (n = 2), the modulation is a waveform specified point-by-point by the computer and stored in the Model 263A as the "Source Curve" by the LC (LOAD CURVE) or BL (BINARY LOAD) commands. If the instrument is in the random waveform mode and option 91 is installed, modulation ranges of ±32000 are obtainable.

Note: If the MM command is received while a curve is in progress, Command Error 12 (Acquisition Error) will be generated.

INITIAL n1 n2 [0 -8000]: A Set command, INITIAL (Initial Point and Potential) tells the Model 263A the point number where the first data value of a ramp program will be stored, and the modulation value at that point. The point specified by "n1" must be the same as that specified by the Curve Acquisition FP command.

When Ramp Program Modulation (MM 1) is being used, n2 is the modulation value of the first point. As explained in the discussion of the MR command, the actual modulation corresponding to the value of "n2" depends on the MR command. The ramp will progress point by point to the first vertex. The step size will depend on the number of points and the potential difference between the initial point and the first vertex point. The actual curve modulation/acquisition process begins when the TC (TAKE CURVE) command is applied.

The ranges are:

n1: 0...6143 (must equal FP)
n2: -8000...8000 (-16000...16000 with 91 option)

Example: Suppose one wished the modulation ramp to begin at point 0 with a value of 50 mV, where the MR 1 command had set the full-scale modulation level to 200 mV. The appropriate command would be:

INITIAL 0 2000

"0" specifies point 0. "2000" specifies 50 mV (50 mV/200 mV f.s. modulation output × 8000 counts f.s. for the DAC = 2000 counts).

Notes: The INITIAL command must be the first Ramp Program command executed because it erases any Ramp Program in the Model 263A memory.

The INITIAL command must always be followed by at least one VERTEX command, as it causes the removal of all VERTEX commands.

If the INITIAL command is received while a curve is in progress, Command Error 12 (Acquisition Error) will be generated.

VERTEX n1 n2 [999 8000]: A Set command, VERTEX (VERTEX MODULATION & POINT) specifies the end point of the ramp and the modulation level at that point. At least one VERTEX command is required if an INITIAL command has been applied. However, more than one VERTEX command up to a maximum of 50 can be specified, allowing very complex modulation programs to be generated. The program begins at the point specified by the INITIAL command, advances to the point specified by the first VERTEX command, and from there advances to the point specified by the second VERTEX command. From there the ramp modulation sequence advances in similar fashion until the entire program has been executed.

The actual ramp begins when the TC (TAKE CURVE) command is applied.

"n1", the point operand, must be larger than the FP (FIRST POINT) operand but less than or equal to the LP (LAST POINT) operand. Otherwise, a parameter error (Error 3) will be generated. The allowable range is 1 to 6143.

"n1" of the last VERTEX command of a ramp program should equal the last point. Otherwise, the ramp values for all points would not be fully specified and results for unspecified points would be unpredictable.

As explained in the discussion of the MR command, the actual modulation corresponding to the value of "n2" depends on the MR command. The ranges are:

-8000...8000 *(-16000...16000 with 91 option)*

Example: A modulation waveform could be specified by the following program:

INITIAL 0 0;VERTEX 400 4000;VERTEX 600 4000

Assuming that MM 1 had been sent to select the ramp program mode, during the subsequent curve acquisition, the modulation would begin with the acquisition of point 0 and the initial modulation value would be 0 counts. The ramp would proceed in steps to point 400, where it would have a value of 50% of full scale (50% of 8000 is 4000). It would remain at this level to the end of the program (point 600).

Notes: INITIAL n1 n2 must be sent before any VERTEX commands. Sending another INITIAL command reinitializes the function, erasing any previous vertices. If you wish to modify a previously entered vertex, you must first use the INITIAL command.

The power-up default values for these commands are INITIAL 0 -8000;VERTEX 999 8000, which generates a 1000-point ramp from minus full scale to plus full scale.

The step size will depend on the specified number of points and on the specified modulation levels. For example, in the default case there are 16,000 counts and 1,000 points. The step size in counts per point will be 16. If the user specifies values which do not divide evenly, the Model 263A will vary the step size up and down as the scan progresses to maintain as close to a linear ramp as possible.

You cannot enter two VERTEX commands with the same point operand. An attempt to enter a second with the same point will generate a Command Error 3 (Out of Bounds).

If the VERTEX command is received while a curve is in progress, Command Error 12 (Acquisition Error) will be generated.

PROG n1 n2 n3 n4....nx: A Read command, PROG (PROGRAM) is a request for the Model 263A to send the ramp program (INITIAL operands and all VERTEX operands) to the host computer.

n1 range: 0...6143
n2 range: -8000...8000 (*±16000 with 91 Option*)
n3 range: 1...6143
n4 range: -8000...8000 (*±16000 with 91 Option*)

Example: Assuming the default ramp program values were in place, the PROG command would result in the following numbers being sent to the host computer.

0 -8000
999 8000

n1, the INITIAL Point, is 0, and n2, the INITIAL Modulation, is -8000. n3, the VERTEX Point, is 999, and n4, the VERTEX Modulation, is 8000.

ASM: An Action command, ASM (ASSEMBLE) causes the Ramp program, defined by the INITIAL and VERTEX commands, to be assembled into a sequence of values that are stored in the Source Curve. Once assembled and stored, the data in the Source Curve can be transferred to the host computer (for graphing) using the DC or BD commands. The Source Curve also makes the Ramp program available for Modulation Mode 2.

Notes: If this command is received while a curve is in progress, Command Error 12 (acquisition error) will be generated.

If no vertices have been specified, Command Error 32 (no vertices) will be generated.

MOD n [0]: A Set/Read command, MOD (MODULATION) allows the user to immediately program a constant modulation output level. The MOD command is used to set the MOD DAC output when the MM operand is 0. If n is omitted, the Model 263A is requested to report the MOD setting. Setting the modulation via this command will result in a conflict if the MM operand is 1 or 2 and data acquisition is underway.

n range: -8000...8000 *(-32000...+32000 with 91 option)*

The resolution of this value depends on the value of the MR command (see the MR command).

INTRP n [0]: A Set/Read command, INTRP (INTERPOLATE) sets the interpolation function status. If n is omitted, the Model 263A is requested to report the ON/OFF status of this function. The codes are:

n	**STATUS**
0	Off
1	On

Interpolation of a ramp means to use the smallest possible potential steps between points. Therefore, this command only has meaning if Modulation Mode 1 (Ramp Program Modulation) or Modulation Mode 2 (Random Waveform Modulation) is selected and there is more than one sample per point.

In understanding the interpolation function, it is important to distinguish between a point and a sample. A sample is taken every time the potential or current is measured and an analog-to-digital conversion done on the measured value. Values placed in memory are points. A point could be a single sample value, or the average of many sample values (see the discussion of PAM and S/P commands).

The INTRP command determines how often the Modulation DAC, and hence the modulation level, is updated. If the Interpolation Function is OFF, the MOD DAC output is updated once per *point*. If the Interpolation Function is ON, the MOD DAC output is updated once per *sample*. If the number of samples per point is greater than one, this will result in a smoother modulation waveform. In other words, the INTRP command allows the modulation to advance in smaller steps in situations where there are many samples per point.

Example: Assume the "Arbitrary Waveform" Modulation Mode (MM 2), the "Store Average of N Samples" Point Averaging Mode (PAM 2), and 10 samples per point (S/P 10). Further assume that Point 0 of the Source Curve has a value of 0 and that Point 1 of the Source Curve has a value of 20. If the Interpolation Function were OFF, the MOD DAC output would remain at 0 throughout the 10 samples of Point 0, and would jump to 20 after the last sample of Point 0 to prepare for Point 1. If the Interpolation Function were ON, the MOD DAC output would be interpolated between 0 and 20. Its output would start at 0. After Sample 1, which is the first sample taken for the point (up-counting is used), it would be set to 2 in preparation for Sample 2. After Sample 2, it would be set to 4 in preparation for Sample 3. This process would continue through Sample Number 10, at which point the MOD DAC output would be set to 20 in preparation for Sample Number 1 of Point Number 1.

Notes: If the INTRP command is received while a curve is in progress, Command Error 12 (Acquisition Error) will be generated.

The setting of INTRP will be ignored in NO FRILLS data acquisition. See the TMB command.

2.6. Data Acquisition Control Commands

FP n [0]: A Set/Read command, FP (FIRST POINT) sets the location of the start of the stored curve. If "n" is omitted, the location is reported. FP defines a point number in the DCV, not direct memory addresses. If DCV is 0, then FP 0 means to start storing data in point 0 of Curve 0. If DCV is 2, FP 0 means to start storing data in point 0 of Curve 2 (really point 2048 in the memory). For maximum data space, FP is usually set to 0. The same relative addressing applies to LP.

The Curve Length, with respect to the maximum number of data values, is simply (LP - FP) +1. However, with respect to memory partitioning considerations, it is LP + 1. Values which would overwrite the end of a curve will result in no data being stored.

"n" range: 0...6143

Notes: If modulation is being applied using the ramp-program commands, the point designated by the INITIAL n1 operand must be the same as that designated by the FP operand (FP predominates).

If the FP command is received while a curve is in progress, Command Error 12 (Acquisition Error) will be generated.

HC: An Action command, HC (HALT CURVE) causes the curve acquisition in process to stop. Curve acquisition can be restarted with a TC command. If this is done, data acquisition will begin with the next active point (all points between FP and LP are active points). If the TC command is preceded by NC, curve acquisition will begin with the point designated by the FP operand.

If a curve is not in progress, the HC command will be ignored.

LP n [0]: A Set/Read command, LP (LAST POINT) sets the last data storage location. Together with FP, LP sets the curve length, which is simply (LP - FP) + 1. However, with respect to memory partitioning, the curve length is defined simply as LP + 1. If "n" is omitted, the value of LP in effect is reported. Like FP, LP is relative addressed with respect to the designated curve.

n range: 1...6143

"n" must be larger than the FP operand.

Notes: Data points between the first point and the last point inclusive are referred to as Active Points.

If the LP command is received while a curve is in progress, Command Error 12 (Acquisition Error) will be generated.

NC: An Action command, NC (NEW CURVE) causes the Model 263A to be initialized for curve acquisition. NC must be executed before TC (TAKE CURVE). If NC is received while a curve is in progress, that curve is immediately aborted.

Specific actions of the NC command are:

1. Performs extensive error checking to ensure that all of the curve parameters that were set prior to the NC command are legal.

2. Clears (sets to zero) all active points in the Destination Curve and Next Curve. It also clears Alternate Curve if the ACV command is activated.

   Note: The Next Curve or Curves will be cleared only if data were stored in them. See discussions in Section 2.3, Memory Partitioning and Curve Designation Commands, and the description of the SIE command.

3. Makes the point designated by the FP operand the currently accessed point.

4. If a modulation ramp is to be applied (MM operand = "1" or "2"), NC sets the modulation level to its starting value.

5. Halts curve acquisition if curve acquisition is in progress.

6. Calculates the locations at which the first data values (I, E, ΔE) are to be stored in the Destination Curve.

7. Calculates the locations at which the first data values (I, E, ΔE) are to be stored in the Alternate Curve if the ACV command is in effect.

8. Sets the Sweep Number to "1".

9. Calculates the address from which the first modulation value is to be taken if the arbitrary waveform mode is selected.

10. Sets up variables used for interpolating the modulation waveform if INTERPOLATION is enabled.

11. Determines the divisor to be used to average samples as determined by the Point Averaging Mode.

Note: Once NC is applied, do not apply any command that will change what the data acquisition routines do. Specifically, the following setting commands will not be accepted after NC is invoked, and will generate Command Error 12 (Acquisition Error).

TMB	MM	INITIAL	VERTEX	INTRP
SCV	SAM	SHF	PAM	S/P
SEL	DCV	ACV	SIE	FP LP

The following command errors may be generated by NC:

ERROR CODE	MEANING
7	TIME BASE (TMB) TOO SHORT. This error will occur if the accumulated time penalties for enabled features exceeds the selected time base in NO FRILLS or SOME FRILLS operation. See the TMB command for a table of time penalties.
25	FP GREATER THAN LP. This error will occur if First Point is not less than or equal to Last Point.
26	CURVE NOT AVAILABLE. This error will occur if a selected curve is not available due to curve size and partitioning.
27	NOT ENOUGH CURVES. This error will occur if there are not enough curves available due to curve size to support the SIE selection.
28	INITIAL POINT NOT EQUAL FP. This error will occur if Modulation Mode (MM) is set to 1 and the Initial Point does not equal the First Point.
31	SCV WITHIN DCV. This error will occur if the selected source curve is the same as one of the destination curves or alternate curves, and MM is set to 2. As NC clears all the destination curves, this would destroy the source curve.
32	NO VERTICES. This error will occur if MM is set to 1 and no vertices have been specified.
33	SEL NOT WITHIN S/P. This error will occur if the point-averaging mode (PAM) is set to 2 or 6 and the selected samples (SEL) lie outside the samples per point (S/P).

RC: An Action command, RC (RESET CURVE) initializes the Model 263A for curve acquisition. It works like the New Curve (NC) command with the following two exceptions:

- The Destination Curves (DCV) and the Alternate Curves (ACV) are not cleared to 0.

- If the selected source curve is the same as one of the destination curves, Command Error 31 (SCV Within DCV) is not generated. The source curve is overwritten point by point.

Note: If multiple sweeps are in effect, the source curve has been replaced by the measured data after the first sweep.

TC: An Action command, TC (TAKE CURVE) causes the curve acquisition to begin (if a curve is not currently in progress). A data set will be acquired and stored in accordance with the conditions established by the other commands.

If a curve has been halted with the HC (HALT CURVE) command, TC will resume the curve. If this command is received while a curve is in progress, it will be ignored.

WCD: An Action command, WCD (WAIT TILL CURVE DONE), if used in a multiple command, suspends the command's interpretation and execution until the curve is done. This command is meaningful only if curve acquisition is in progress.

Example: Without WCD, the multiple command:

NC;TC;MIN;MAX

would not work properly because the MIN and MAX operations would be carried out before curve acquisition was completed. However, if WCD were included in the multiple command ahead of MIN and MAX, giving the command:

NC;TC;WCD;MIN;MAX

there would be no problem because WCD would cause execution of the multiple command to pause until curve acquisition was complete.

Note: If a running curve has been halted with the HC (HALT CURVE) command, WCD will be ignored.

WAIT n: An Action command, WAIT causes curve acquisition to halt for "n" time-base intervals (as set by the TMB command).

n range: 0...65535

Note: This command is meaningful only if curve acquisition (initiated by the TC command) is in progress. If curve acquisition is not in progress, Command Error 12 (Aquisition Error) will be generated.

DISCARD n: An Action command, DISCARD causes data acquisition to pause for "n" points. This command is meaningful only if curve acquisition (initiated by the TC command) is in progress. If curve acquisition is not in progress, an Aquisition Error (Error 12) will occur.

n range: 0...65535

WFL: An Action command, WFL (WAIT FOR LINE) suspends command interpretation and execution until the next power line trigger.

2.7. Sampling and Sweep Control Commands

Sampling Control Commands

In understanding the following discussions, it is important to distinguish between a point and a sample. A sample is taken every time the potential or current is measured and an analog-to-digital conversion is performed on the measured value. Values placed in memory are points. A point could be a single sample value, or the average of many sample values (see discussions of PAM and S/P commands).

In the simplest case of Curve Acquisition, one sample of "E" or "I" is taken at each point. In other words, the number of samples required to fill a curve will equal the number of points in it. However, a wide range of sampling control and averaging is provided for improved flexibility. For example, the programmer may wish to take some number of samples at each point, discard all but the "N"th sample, and store its value. If "N" were "5", 5120 samples would be required to fill a

1024-point curve. Alternatively, the programmer might wish to take "N" samples at each point and to store their average value as the value for that point. Again, if "N" were "5", 5120 samples would be required to fill a 1024-point curve.

PAM n [0]: A Set/Read command, PAM (POINT AVERAGING MODE) determines whether the Model 263A will store each sample, select a group of samples, or average the samples taken at each point. If "n" is omitted, the command is a request for the Model 263A to send this information. The codes are:

n	**POINT AVERAGING MODE**
0	No point averaging.
1	Point averaging. All samples within a point are averaged.
2	Selected point averaging. Only samples within the selected range are averaged. See the SEL command.
5	Point integration. All samples within a point are integrated.
6	Selected point integration. Only samples within the selected range are integrated. See the SEL command.

Note that averaging will provide an improvement in the signal-to-noise ratio proportional to the square root of the number of samples averaged. If the PAM operand is 1, the number of samples to be averaged is set with the S/P command. If the PAM operand is 2, use SEL n1 n2 to select the samples.

Note: If the PAM command is received while a curve is in progress, Command Error 12 (Acquisition Error) will be generated.

S/P n [1]: A Set/Read command, S/P (SAMPLES PER POINT) sets "n", the number of samples to take for each data point. If "n" is omitted, the command is a request for the Model 263A to report this information. If the PAM operand is "0", all but the last sample for a given point will be discarded. If the PAM operand is "1", the sum of "n" samples is divided by "n". If the PAM operand is "2", a selected range out of the "n" samples, as determined by the SEL command, is averaged for each point. In each case, the result is stored in the Destination Curve.

n range: 1...32767

Note: If this command is received while a curve is in progress, Command Error 12 (Acquisition Error) will be generated.

SEL n1 n2 [1 1]: A Set/Read command, SEL (SELECT) selects the samples to be averaged when PAM 2 or PAM 6 is enabled. The samples in the range n1–n2 will be averaged and the average value stored. If "n1" and "n2" are omitted, the values in effect for these operands will be reported. The ranges are:

n1 range: 1...32767
n2 range: n1...32767

n2 must be larger than, or equal to, n1.

For example, if the S/P operand is "10", and the SEL operands are "2" and "7", 10 samples would be taken at each point. Of these, samples 2, 3, 4, 5, 6, and 7 would be averaged (added and divided by six) and the average stored as the value for the point. Sample 1 would be discarded, as would be samples 8, 9, and 10.

Note: If this command is received while a curve is in progress, Command Error 12 (Acquisition Error) will be generated.

SIE n [1]: A Set/Read command, SIE (SAMPLE I/E) determines whether the sampled parameter will be current (I), the Electrometer Monitor potential (E), the potential applied to the rear-panel AUX A/D INPUT (98 Option only), the Current Interrupt iR Compensation Potential (ΔE), or any combination of these parameters. If "n" is omitted, this command is a request for the Model 263A to report the SIE setting. The codes are:

n	I	E	AU (98 option)	ΔE
0	OFF	OFF	OFF	OFF
1	ON	OFF	OFF	OFF
2	OFF	ON	OFF	OFF
3	ON	ON	OFF	OFF
4	OFF	OFF	ON	OFF
5	ON	OFF	ON	OFF
6	OFF	ON	ON	OFF
7	ON	ON	ON	OFF
8	OFF	OFF	OFF	ON
9	ON	OFF	OFF	ON
10	OFF	ON	OFF	ON
11	ON	ON	OFF	ON
12	OFF	OFF	ON	ON
13	ON	OFF	ON	ON
14	OFF	ON	ON	ON
15	ON	ON	ON	ON

Note that if IRMODE is not set to 2 or 3, ΔE will not be sampled.

Data acquisition may be TURBO, NO FRILLS, SOME FRILLS, or FULL FRILLS. Although each mode is described in detail in the following paragraph, one important difference is that the sampled-data selections differ for each, as follows.

Mode	Data That Can Be Sampled
TURBO	I only
NO FRILLS	I **or** E **or** AUX
SOME FRILLS	I **and** E **and** AUX
FULL FRILLS	I **and** E **and** AUX **and** ΔE

Although FULL FRILLS acquisition allows any combination of I, E, AUX, and ΔE to be sampled, keep in mind that in galvanostat operation, IRMODE is set to zero and ΔE will not be sampled.

Note: If this command is received while a curve is in progress, Command Error 12 (Acquisition Error) will be generated.

TMB n [4000]: A Set/Read command, TMB (Timebase) sets the sample time, in microseconds, during curve acquisition. The time per point is equal to the time base times the number of samples per point. When "n" is omitted, the command is a request for the Model 263A to report this information. TMB is a curve acquisition parameter; it doesn't affect the front-panel scan timing. The range is:

n range: 100...50000

When a curve acquisition is initiated with the sequence "NC;TC", the Model 263A begins by checking the time base as established by the last TMB command. Depending on the value in effect, one of four different data acquisition modes will be selected. These four modes, TURBO, NO FRILLS, SOME FRILLS, and FULL FRILLS are described in the following paragraphs. ***Note:*** *Line-synchronized operation overrides the TMB selection in FULL FRILLS operation. In TURBO, NO FRILLS, and SOME FRILLS, it does not and TMB timing remains in effect.*

TURBO: If the 91 option is installed, data acquisition is possible between 30 µs and 100 µs. However, during data acquisition at these speeds, no communication with the instrument is possible until the curve is complete. TURBO mode permits only SIE=1 and MM2 or MM0 modulation. All other features are ignored.

NO FRILLS: **NO FRILLS** is established when TMB is less than 350 µs. In NO FRILLS operation, the following restrictions apply:

1. Only I, E, or AUX (not more than one of these) may be sampled.

2. Only one sample per point is allowed.

3. Point averaging (PAM), if selected, will be ignored.

4. Auto-ranging, if selected, will be ignored.

5. Only linear sweep averaging (SAM 1) is allowed.

6. Only random (arbitrary) waveform modulation (MM 2) is allowed.

7. Ramp interpolation (INTRP 1), if selected, will be ignored.

8. Only positive feedback iR compensation (IRMODE 1) is allowed. Current interrupt iR compensation (IRMODE 2 or 3), if selected, will be ignored.

9. The E signal will not be corrected for EGAIN. The raw A/D converter counts are reported with ±2000 being full scale.

10. The A/D converter overload bits will not be updated.

11. Line sync, if selected, will be ignored.

12. Front-panel display of I or E will not be updated.

13. Q (coulombs) will not be calculated or updated.

In addition, the minimum time base of 100 µs cannot be achieved if all of the allowable features are turned on. The actual basic NO FRILLS handler with SIE set to 0 takes 45 µs ±3 µs. As additional features are turned on, this time gets longer. The time penalties for each additional feature are as follows:

SIE 1	39 µs	(Sample I)
SIE 2	39 µs	(Sample E)
SIE 4	40 µs	(Sample AUX)
SWPS>1	36 µs	(Number of Sweeps)
SAM 1	1 µs	(Linear Sweep Averaging)
MM 2	17 µs	(Random Waveform Modulation)

If the accumulated penalties for enabled features exceed the selected time base, Command Error 7 (TMB Too Short) will be generated when the NC command is received.

SOME FRILLS: Data acquisition is considered to be in the SOME FRILLS mode when TMB is greater than or equal to 350 µs and less than 4 ms. In SOME FRILLS operation, the following restrictions apply:

1. I, E, and AUX may be sampled. If ΔE is selected, it will be ignored.

2. Only PAM 1 or 2 are allowed. PAM 5 or 6, if selected, will be ignored.

3. Only I auto-ranging is allowed. E and AUX auto-ranging, if selected, will be ignored.

4. Only positive feedback iR compensation (IRMODE 1) is allowed. Current interrupt iR compensation (IRMODE 2 or 3), if selected, will be ignored.

5. The A/D converter overload bits will not be updated.

6. Line sync, if selected, will be ignored.

7. Q (coulombs) will not be calculated or updated.

In addition, the minimum time base of 350 µs cannot be achieved if all of the allowable features are turned on. The actual basic SOME FRILLS handler with SIE set to 0 takes 90 µs ±3 µs. As additional features are turned on, this time gets longer. The time penalties for each additional feature are as follows:

SIE 1	160 µs	(Sample I)
SIE 2	60 µs	(Sample E)
SIE 3	220 µs	(Sample I and E)
SIE 4	60 µs	(Sample AUX)
SIE 5	233 µs	(Sample I, AUX)
SIE 6	210 µs	(Sample E, AUX)
SIE 7	320 µs	(Sample I, E, AUX)
S/P>1	28 µs	(Samples per Point)
SWPS>1	70 µs	(Number of Sweeps)
PAM 1	30 µs per SIE Item	(Point Averaging)
PAM 2	45 µs per SIE Item	(Point Averaging)
SAM 1	8 µs per SIE Item	(Lin. Sweep Avg.)
SAM 2	14 µs per SIE Item	(Exp. Sweep Avg.)
MM 1	50 µs	(Ramp Prog. Mod.)
MM 2	18 µs	(Random Waveform)
INTRP	150 µs	(Interpolation Status)
AR 1	320 µs	(I Autoranging)

If the accumulated penalties for enabled features exceed the selected time base, Command Error 7 (TMB Too Short) will be generated when the NC command is received.

Note: Although I auto-ranging is allowed all the way down to 350 µs, it is not recommended below 1 ms due to the settling time of the current range relays.

FULL FRILLS: Data acquisition is considered to be in the FULL FRILLS mode when TMB is greater than or equal to 4000 µs. In FULL FRILLS operation, enough time is available to perform all of the enabled features at the minimum time base of 4000 µs. Therefore, there are no restrictions in this mode.

Note: If the TMB command is received while a curve is in progress, Command Error 12 (acquisition errror) will be generated.

LS n [0]: A Set/Read command, LS (LINE SYNC) determines whether data acquisition will be synchronized with the power-line frequency. If LS is applied without "n", it is a request for the Model 263A to report this information. The codes are:

n	**STATUS**
0	Line sync disabled
1	Line sync enabled

When line sync is enabled, a sample is taken once each line cycle and the value of TMB is ignored. ***Note: This is only true for a FULL FRILLS acquisitions. In TURBO, NO FRILLS, and SOME FRILLS operation LS does NOT override TMB.***

Line synchronized operation also limits the speed of reliable serial communications; the selected baud rate should be 9600 baud or slower.

Note: If this command is received while a curve is in progress, Command Error 12 (acquisition errror) will be generated.

Sweep Control Commands
It is possible to make multiple sweeps, using sample selection or averaging, and to average the data resulting from the sweeps, either linearly or exponentially, to obtain the values stored in the curve. Descriptions of the sampling and sweep averaging commands follow.

SWPS n [1]: A Set/Read command, SWPS (SWEEPS) sets the number of sweeps in an acquisition. If "n" is omitted, the command is a request for the Model 263A to report the SWPS setting.

n range: 1...32767

SAM n [0]: A Set/Read command, SAM (SWEEP AVERAGING MODE) determines whether sweeps will be averaged, and, if averaged, whether the averaging will be linear or exponential. If "n" is omitted, the command is a request for the Model 263A to provide this information. The codes are:

n	**MODE**
0	No Sweep Averaging
1	Linear Sweep Averaging
2	Exponential Sweep Averaging

In linear sweep averaging, the results of each sweep are added point by point, with equal weighting applied to the data from all sweeps. (Note that this is not really averaging at all.) It is essential that the sum of the sweep results does not exceed the memory capacity (-32768 to +32767 at each point), as no overflow checking is done. Linear averaging yields an improvement in signal-to-noise ratio proportional to the square root of the number of sweeps averaged. If data values approach full scale, a maximum of 16 sweeps can be averaged.

In exponential sweep averaging, the data from the current sweep are added to the data from the previous sweeps in such a way that the value stored at each point asymptotically approaches a final value. The average is weighted such that the most recent sweep has the greatest influence. The formula used is:

$$A = A_0 + \{[1/(2^S)] \times (P - A_0)\}$$

where
- A = new average
- A_0 = previous average
- P = present point value
- S = value of the SHF command

Notes: Sweep averaging, either linear or exponential, should not be used with auto-ranging (AR command) enabled. If it is, meaningless data will result.

If this command is received while a curve is in progress, Command Error 12 (acquisition errror) will be generated.

SHF n [1]: A Set/Read command, SHF (SHIFTS) sets the number of times the data are to be shifted before being added to the old data when doing exponential sweep averaging. "n" can take all values from 1 to 15 (n = 0 is not allowed). If "n" is omitted, the command is a request for the Model 263A to report the SHF setting.

This command sets the "S" term in the exponential sweep averaging formula, given in the discussion to the SAM command, Mode 2.

The averaged function reaches 63% of its final value in 2^n sweeps. The function converges in 6 x 2^n sweeps. The signal-to-noise improvement ratio, at convergence, improves 6 dB for each 2n, as indicated in the following table.

n	**SWEEPS TO REACH 63%**	**SWEEPS TO CONVERGE**	**SNIR**	**SNI (dB)**
2	4	24	2	6 dB
4	16	96	4	12 dB
6	64	384	8	18 dB
8	256	1536	16	24 dB
10	1024	6144	32	30 dB
12	4096	24576	64	36 dB
14	16384	98304	128	42 dB

where SNIR is the Signal-to-Noise Improvement Ratio and SNI is the Signal-to-Noise Improvement in dB.

In a typical application, it may prove impractical to use large values of n because of the long experiment times required.

Note: If this command is received while a curve is in progress, Command Error 12 (acquisition errror) will be generated.

DT n [0]: A Set/Read command, DT (DEAD TIME) sets the time between sweeps (dead time) in milliseconds. If "n" is omitted, the command is a request for the Model 263A to report the DT setting. "n" can take values from 0 to 32767.

Notes: This command only has meaning while a curve is in progress. It does not affect front-panel operation.

2.8. IR Compensation Commands

IRMODE n [0]: A Set/Read command, IRMODE (IR COMPENSATION MODE) sets the iR Compensation mode. If "n" is omitted, the command requests the Model 263A to report this information.

The codes are:

n	**COMPENSATION MODE**
0	*No Compensation*.
1	*Positive Feedback*. Activates Positive Feedback iR Compensation and sets the iR compensation resistance to the value specified by the SETIR command. See discussion of SETIR command before applying IRMODE 1.
2	*Current Interrupts with Correction Applied*. Activates periodic current interrupt with correction potential measured and applied to cell. (If single interrupts via DORUPT command are wanted, use IRMODE 4).
3	*Current Interrupts with No Correction*. Periodic current interrupts performed and correction potential measured, but not applied. (Required to store the error values, if desired, as specified with the SIE command.)
4	*Prepare for Current Interrupt* but don't do it (necessary preliminary to using DORUPT command).

Notes: This command is legal only in potentiostat mode. If it is received while the instrument is in a galvanostatic mode, Command Error 11 (Wrong Mode) will be generated.

IRMODE 2 and 3 can only be used in FULL FRILLS data acquisition and in front-panel operation. In SOME FRILLS and NO FRILLS operation, these modes will be ignored if selected. See the TMB command.

SETIR n1 n2 [0 -2]: A Set/Read command, SETIR specifies the value of uncompensated resistance (R_u) in ohms, where n1 is the mantissa and n2 the exponent. For example, a mantissa of 436 and an exponent of -1 could be used to specify a resistance of 43.6 Ω. This command is used for doing Positive Feedback iR Compensation. If the operand is omitted, the command requests that the Model 263A report this information.

The operand ranges are:

n1 range: 0 to 2000
n2 range: -2 to 4 (*-3 to 4 with 94 Option*)

If the specified value is too low, R_U will not be adequately compensated. If it is too high, the system will be unstable and may even oscillate.

Resistance values specified have a resolution limit and a range limit determined by the size of the current measuring resistor associated with a given current range. The changing resolution can affect the value applied if the current range changes. The resolution limits and the maximum compensation level as a function of current range are given below.

CURRENT RANGE	MAXIMUM COMPENSATION	RESOLUTION LIMIT
1 A	2 Ω	1 mΩ (94 option only)
100 mA	20 Ω	10 mΩ
10 mA	200 Ω	100 mΩ
1 mA	2 kΩ	1 Ω
100 µA	20 kΩ	10 Ω
10 µA	200 kΩ	100 Ω
1 µA	2 MΩ	1 kΩ
100 nA	20 MΩ	10 kΩ

Consider how the resolution limit affects the accuracy of the programmed value. For example, assume a resistance of 1.234 kΩ is specified on the 100 µA range. On that range the resistance resolution is 10 Ω, giving an actual programmed resistance of 1230 Ω. In other words, the programmed resistance differs from the specified resistance by 4 Ω.

Let us continue with this example to see how error due to the resolution limit can occur when the current range changes. If, during the experiment, the current range changes to 1 mA, where the resistance resolution is 1 Ω, the actual programmed resistance will change to 1234 Ω. The improved resolution allows the actual programmed value to be identically that originally specified. Although this change could be a problem in some situations, it will usually be relatively minor.

The real problem occurs when shifting to a more sensitive range. For instance, if, in the example, the current range were to shift to 10 µA, where the resolution limit is 100 Ω, the actual programmed resistance will become 1200 ohms because the value can only be represented to the nearest 100 Ω.

In other words, the error will now total 34 Ω. Similarly, a further shift to 1 µA would give a resistance of 1000 Ω (234 Ω error), and a shift to 100 nA would give a resistance of 0 Ω (1234 Ω error).

Note: Should one later shift to less sensitive ranges, the error will be successively reduced with each current range step.

Clearly, operators need to be mindful of the resolution limit for the "setup" current range and should specify a resistance appropriate to that limit. Also, if more sensitive ranges are used during the experiment, users will have to be mindful of the impact the changing resolution will have on the programmed resistance and of the possible consequences of large resistance errors.

If SETIR is applied without an operand, the previously specified value will be reported. The COMP command can be used to read the actual compensation resistance, which, as discussed in the previous paragraphs, can differ from that specified.

In some situations, the value of uncompensated resistance is not known in advance, but must be determined experimentally. A suitable procedure is provided under "Positive Feedback iR Compensation (PFIR)" in Chapter 8 of the *Model 263A User's Guide*.

COMP n1 n2: A Read command, COMP causes the Model 263A to report the actual compensation resistance applied (in ohms) when Positive Feedback iR Compensation (IRMODE 1) is selected. This may differ from that set with the SETIR command because of iR Compensation DAC resolution. "n1" is the mantissa and "n2" the exponent. Their ranges are:

n1 range: 0...2000
n2 range: -2...4 (*-3...4 with 94 Option*)

Example: A response of 400 0 indicates that the actual resistance compensated is 400 Ω.

IRPC n [100]: A Set/Read command, IRPC (IR PERCENT) establishes the percentage of the measured correction to be applied when IRMODE is set to 2. If n is omitted, it is a request for the Model 263A to report the set percentage factor. *This command applies to current interrupt operation only.*

n range: 0 to 200

Example: To set a correction factor of 100%, apply:

IRPC 100

IRX n1 n2 n3: A Set/Read command, IRX (IR EXTRAPOLATION) allows the user to specify the times at which cell potential will be sampled in determining the Current Interrupt iR Compensation correction factor. The actual correction value is developed by extrapolation back to the interrupt time. The extrapolation times *can be set independently for each current range.*

The command takes three operands. n1 selects the current range. n2 and n3 select the sample points in time along the exponential decay of potential in the cell after current is interrupted (n3 represents the time elapsed since n2). The default values for n2 and n3 are 10 µs on the 100 mA current range (and 1 A range if installed) and 75 µs on all other current ranges. To request present settings, the command must include n1. A command error will be generated if IRX is sent by itself. The codes are:

OPERAND	RANGE
n1	-1 to -7 (0 to -7 with 94 option)
n2	10 to 2000 - n3
n3	10 to 2000 - n2

A positive-going pulse is provided at the TRIG OUT pin (pin 4) of the Auxiliary Interface connector when the current is interrupted. You can measure the cell potential at the time of interruption by triggering your oscilloscope with this signal. This will aid in selecting times for n1 and n2. The actual time that the current is off is n2 + n3 + 23 µs.

Examples:

1. To request the extrapolation times for the 100 µA range, apply the command:

   IRX -4

2. To set the extrapolation times to 60 µs and 100 µs on the 1 mA range, apply the command:

   IRX -3 60 40

Notes: n2 + n3 must be no greater than 2000. Both times have a resolution of 5 µs. Values are always rounded up to the next nearest multiple of 5 µs.

DORUPT n: An Action/Read command, DORUPT (DO CURRENT INTERRUPT) performs a single current-interrupt iR compensation cycle and reports the value (in mV), but does not correct the applied E.

Notes: If this command is received while a curve is in progress, Command Error 12 (Acquisition Error) will be generated.

IRMODE 4 must be invoked prior to doing a DORUPT. If IRMODE is not set to 4 or MODE is not set to 2, Command Error 11 (Wrong Mode) will be generated.

IRUPT n [5]: A Set/Read command, IRUPT (INTERMITTENT CURRENT INTERRUPT) establishes periodic Current Interrupt iR Compensation cycling. IRUPT sets the time between current interrupts in number of points based on the present TMB setting. If "n" is omitted, it is a request for the Model 263A to report "n". Current-interrupt cycling begins when IRMODE 2 is applied.

n range: 1 to 32767.

Example: If IRUPT 10 were applied (followed by IRMODE 2), an interrupt would be performed after every ten points. If TMB is 4000 and S/P is 1, this would be every 40,000 µs or 40 ms.

RUERR n: A Read command, RUERR (Uncompensated Resistance Error) causes the compensation potential value, in mV, obtained from a current interrupt to be reported. It would normally be used when IRUPT cycling is in effect (DORUPT causes the compensation potential, in mV, for the initiated interrupt to be reported immediately).

n range: -10000...10000

Note: This command only applies to Current Interrupt iR Compensation. It will return 0 if IRMODE is not set to 2 or 3.

2.9. Current Integration Commands

COUL n1 n2: A Read command that causes the Model 263A to report the accumulated charge in coulombs. "n1" is the mantissa and "n2" the exponent; that is:

$Q = n1 \times 10^{n2}$ coulombs

Their ranges are:

n1 range: 0...9999
n2 range: -16...+3

Example: A response of 1000 0 indicates that the accumulated charge is 1000 C.

Note: Coulombs are only updated in front-panel operation and in FULL FRILLS curve acquisition. Note that reported number is valid when a curve is *not* in progress.

Q n1 n2: A Read command, Q (CHARGE) is an alias for the COUL command (see above).

QRST: An Action command, QRST (Q RESET) resets the coulombs to 0.

GIGAIN n [1]: A Set or Read command that sets or reads the gated integrator gain "n."

n = 1, 5, 10, 50, 100, 500

Gain distribution is as follows. For gains of 1, 5, 10, or 50, the gain ahead of the gated integrator is unity and the gain after the integrator is ×1, ×5, ×10, or ×50, respectively. For gains of 100 and 500, the gain ahead of the gated integrator is ×10 and the gain after the integrator is ×10 and ×50, respectively.

Notes: If the GIGAIN command is received while a curve is in progress, Command Error 12 (Acquisition Error) will be generated.

Increasing GIGAIN decreases the full-scale charge and the effective time constant for the experiment. See the ITC command description for more information.

INTEG n [0]: A Set or Read command, INTEG controls the gated integrator. The setting codes are:

n	**MEANING**
0	Reset Integrator
1	Start Integrator
2	Hold Integrator

Note that the TC command starts data collection but does not enable the integrator. If you have not entered the PAM command, an INTEG 1 command should precede the TC command in order for useful data to be acquired. (See the PAM command for details.)

ITC n [-1]: ITC is a Set/Read command that controls the time constant for the gated integrator.

The time constant combines with the gain factors and the current range to determine the full-scale range of the integrator. The table below relates n to the RC values involved, the resulting RC time constants, and the full-scale charge, assuming GIGAIN = 1 and a current range of 1 mA.

n	R X C	TIME CONSTANT	FULL-SCALE CHARGE*
-1	4 MΩ × 10 nF	40 ms	40 µC
-2	400 kΩ × 10 nF	4 ms	4 µC
-3	40 kΩ × 10 nF	400 µs	400 nC
-4	4 kΩ × 10 nF	40 µs	40 nC

*Assumes current range is 1 mA (I/E = -3).

Note that the GIGAIN setting will reduce the effective time constant and full-scale charge value. For example, for ITC = -1 and GIGAIN = 10, the effective time constant is 4 ms and 4 µC on the 1 mA current range.

The effective time constant determines how long a full-scale current must persist to produce a full-scale charge value. A full-scale current that lasts one effective time constant will generate a full-scale charge at the A/D Converter. That is, for ITC = -1, GIGAIN = 1 and I/E = -3, a 1 mA current that lasts 40 ms (= 40 µC) will produce a full-scale A/D count (1000 counts). The Model 263A just stores the A/D counts which can be converted to charge using the following general equation:

Q = (A/D Counts/Full-Scale A/D Counts) × Charge Full Scale / GIGAIN

Charge Full Scale = (RC Time Constant × Current Range)

Combining:

Q = [(A/D Counts/1000) × RC × Current Range] / GIGAIN

Substituting 2 × 10^{ITC} for RC and $10^{I/E}$ for the current range, and simplifying, yields

$$Q = [(A/D\ Counts/1000) \times 10^{ITC} \times 10^{I/E}] / GIGAIN$$

Note: If this command is received while a curve is in progress, Command Error 12 (acquisition error) will be generated.

2.10. Electrochemical Impedance Interface Commands

The Model 263A firmware can process a number of commands that facilitate communication between the potentiostat and other devices using the Electrochemical Impedance Interface. The commands are described below.

OSCIN n [0]: This is a Set/Read command. When the operand is 1, an oscillator signal applied to the EXT IN connector will modulate the signal sent by the Model 263A to the cell. The gain of the applied signal is controlled by the OSCGAIN command. If the operand is 0, the EXT IN connector is off and no modulation can occur.

Notes: This command shares the same input BNC with the EXT command. If EXT is set to 1 (on) and an attempt is made to set OSCIN to 1, a Command Error 11 (Wrong Mode) will be generated.

Use OSCIN when you want to amplify or attenuate a signal applied at the EXT IN connector. Use EXT when the applied signal does not require amplification or attenuation.

OSCGAIN n [0]: When OSCIN is set to 1, this Set/Read command sets the gain applied to an external signal at the EXT INPUT connector. OSCGAIN 2 sets the gain to 2 times the external input voltage. OSCGAIN 1 sets the gain to 0.2 times input voltage, and OSCGAIN 0 sets the gain to 0.02 times input voltage.

Example: For a 5 V rms input, OSCGAIN 2 amplifies the applied signal to 10 V rms. OSCGAIN 1 attenuates it to 1 V rms.

MIE n [1]: A Set/Read command, MIE (MONITOR I/E) determines whether an ac-coupled E or I signal will be provided at the front-panel OUTPUT connector. This command and the MULTIPLEXED OUTPUT function are intended for use with Princeton Applied Research ac impedance measurement systems. Multiplexing is accomplished by alternating the operand between "1" and "2" on successive measurements. The codes are:

n	SIGNAL MONITORED AT OUTPUT CONNECTOR
1	Output current
2	Output voltage

EOUTSUP n [0]: (*Units with 98 Option only*) This is a SET/READ command used to change the dc bias at the front-panel E OUTPUT connector. Be careful not to confuse EOUTSUP with ESUP. These two commands function independently of each other. EOUTSUP controls the dc bias on the *analog* output available at the E OUTPUT connector, while ESUP affects the dc bias applied to the *digital* output.

EOUTSUP can supply ±10 V of suppression. The range for the number of counts, n, is ±5000, with each count corresponding to 2 mV of suppression.

IOUTSUP n [0]: (*Units with 98 Option only*) This SET/READ command determines the level of dc suppression applied to the front-panel I OUTPUT connector. Note that this dc bias is applied independently of the IOUTDC setting. Also, be careful not to confuse IOUTSUP with ISUP. IOUTSUP affects the *analog* output of the instrument while ISUP affects the *digital* output. See the description of the ISUP command for more information.

IOUTSUP can produce an offset equivalent to ±4 times full-scale current of the selected current range. Since *n*, the number of counts, ranges from ±8000, each count corresponds to 0.5×10^{-3} times full-scale current. For example, on the 1 mA current scale, maximum suppression is ±4 mA and 1 count is 0.5 µA. Be aware that changing the current range will change the level of suppression.

2.11. Data Acquisition Monitoring Commands

A/D n: A Read command, A/D (ANALOG TO DIGITAL CONVERSION) bypasses the normal timing and control cycling and causes an immediate A/D conversion. The resulting reading is transmitted to the host computer. This command is *not* used in normal data acquisition. The range is:

n range: -2048...2047

EGAIN and IGAIN must be taken into account (see EGAIN and IGAIN discussions).

PARAMETER	CONVERSION FORMULA
I	I = (n/1000 * f.s.)/IGAIN
E	E = (n mV) / EGAIN

Current readings are in current relative to full scale (Current Range in effect). Potential readings are in mV (gain of 1 or 5) or tenths of mV (gain of 10 or 50).

The parameter selection (I or E as selected by the SIE command) should be made before applying the A/D command.

Note: If this command is received while a curve is in progress, Command Error 12 (acquisition error) will be generated.

TP n1 n2 n3: An Action Read command, TP (TAKE POINT) causes a single reading to be taken, with the reading value to be reported to the host computer. This command functions the same as the SP command, except that the data are sent back to the host computer instead of being stored in the destination curve or curves.

If TP is executed while a curve is running, it reports the most recent I and E sample values without doing any extra sampling. If TP is executed when a curve is not running, it does a sample and then reports. The point will be taken according to the set SAMPLING CONTROL, MODULATION, and BIAS operands. The Model 263A responds by reporting:

- n1, the number of the accessed point (0 to 6143).
- n2, the value of the "I" data (-2048 to +2047). If I is not being sampled, this value will be reported as a "0". The expression relating I to the reported number is:

  I = (#R/1000 * f.s.) / IGAIN

  where f.s. is the selected current range, and assuming IGAIN is 1.

- n3, the value of the "E" data (-2048 to +2047). If E is not being sampled, this value will be reported as a "0". The expression relating E to the reported number is:

  E = (#R mV) / EGAIN

Example: In response to a TP command, the Model 263A might respond:

734,789,0250

signifying that the accessed point was 734, that the I data value is 789 (.789 of current range), and that the E data value is 250 (250 mV).

Note that both TP and SP increment PNT automatically, but TP does not store the data collected. For this reason, TP and SP commands should not be mixed in an experimental run.

SP: An Action command, SP (STORE POINT) takes a single-point curve using the point number specified by the PNT command (and increments PNT if its value is below LP). All selected legal curve acquisition features are in effect and subject to the same error-checking rules as the RC command.

SP functions the same as the TP (TAKE POINT) command except that the resulting data are not reported to the host computer but simply stored in a curve. SP can be used in conjunction with PNT (POINT) to allow custom data acquisition routines to be created, as illustrated in the following discussion of the PNT command.

Note that both TP and SP increment PNT automatically, but TP does not store the data collected. For this reason, TP and SP commands should not be mixed in an experimental run.

PNT n: A Set/Read command, PNT (POINT) sets the address of the next point to be accessed with the TP or SP command. If "n" is omitted, PNT causes the Model 263A to report this information. The point in question is called the current point and determines where the I, E, or ΔE data will be stored, as well as from what location the Modulation DAC data will be fetched if the random waveform mode of modulation (MM 2) is selected.

Both TP and SP increment the PNT value automatically. SP stores its data at the present PNT. Thus SP may be combined with the PNT command to cause data to be stored in noncontiguous sections of memory. PNT may be used at any time to read the number of the current point but may be used to set the number of the current point only if curve acquisition is not in progress. The range is:

n range: FP...LP

The following example shows how SP and PNT can be combined with some other commands to do custom curve acquisition.

NC	(initialize curve acquisition)
BIAS 1000	(set initial desired bias)
SP	(take first data value and store it)

PNT 10	(advance to a different point)
BIAS 1010	(set bias desired for second point)
SP	(take second data value and store it)

Note: If the PNT command is received while a curve is in progress, Command Error 12 (Acquisition Error) will be generated.

MON n1 n2 n3 n4 n5 n6: A Read command, MON (MONITOR) causes the Model 263A to report the curve acquisition status. There are six items in the response, as follows.

1. "n", Curve Acquisition in Progress: 1 if YES. 0 if NO.

2. "n2", Number of Current Sweep (1...32767).

3. "n3", Currently Accessed Point (0 to 6193).

4. "n4", Value of the Modulation Output (-8000...8000; ±*32000 with 91 Option)*.

5. "n5", Last "I" Value Acquired. If I is not being sampled, a 0 will be sent (-2048...2047).

6. "n6", Last "E" Value Acquired. If E is not being sampled, a 0 will be sent (-10240...10235).

Example: In response to an MON command, the Model 263A might send the following to the host computer.

1,3,253,2000,1000,0

This response would indicate that a curve acquisition is in progress, that sweep number three is underway, that point 253 is currently being accessed, that the modulation output is 2000 counts (25% of full scale), and that the last "I" value acquired was 1000. The final 0 indicates that "I" data only are being acquired ("E" value reported as 0) or that "E" is being sampled and that its value is "0".

M n1 n2 n3 n4 n5 n6: A Read command, M (MONITOR) is an alias for the MON command (see above).

READI n1 n2: An Action Read command, READI (READ CURRENT) causes the Model 263A to take ten I samples and report their average. The report is in two parts. "n1" is the mantissa and "n2" the exponent. For example, a response of "1000 -6" would indicate a current of 1000 * 10^{-6} A, that is, 1 mA.

I auto-ranging will be performed regardless of the AR setting. READI autoranges the I/E converter and automatically adjusts IGAIN to optimize data resolution. As a result, the IGAIN and I/E settings may change as a result of this command. Note that IGAIN settings of X10 and X50 are always reset, as they are not used by READI. The READI response always "reads true," that is, it is adjusted for the IGAIN value as appropriate.

Note: If this command is received while a curve is in progress, Command Error 12 (Acquisition Error) will be generated.

READAUX n: (*Units with 98 Option only*) An ACTION command, READAUX (READ AUXILIARY A/D INPUT) causes the Model 263A to take ten samples of the AUX A/D Input potential and report their average value to the computer.

n range: -10000...10000 (corresponds to -10 V to +10 V)

Note: *The AUXGAIN setting affects the AUX readings. See the description of that command for details.*

READE n: An Action Read command, READE (READ POTENTIAL) causes the Model 263A to take ten E samples and report the average of these values.

n range: -10000...10000 (corresponds to -10 V to +10 V)

E auto-ranging will be performed regardless of the AR setting. However, READE will only switch gain between ×1 and ×5. Thus, if EGAIN was previously set to ×10 or ×50, that setting will be lost. Note that the value reported by READE will "read true", in mV. No conversion from counts to mV is required.

Note: If this command is received while a curve is in progress, Command Error 12 (Acquisition Error) will be generated.

2.12. Processing and Data Transfer

Curve Processing Commands
Various kinds of processing can be performed on stored curves, as described in the following discussions of these commands. In cases where the operand curve is not explicitly identified in the command, the Processing Curve is the operand curve.

Note that the MIN, MAX, and INT commands work on any integer data, including I and E. They do *not* work on packed data, that is, data taken with AUTORANGING enabled. The related commands IMIN, IMAX, IINT, and ILOG work on packed current data only, that is, current data taken with Autoranging enabled.

ADD n: An Action command, ADD causes a constant defined by "n" to be added to all active points in the Processing Curve. The only constraint on n other than range is that it not be so large as to cause overflow.

n range: -32768...32767

The ADD command is influenced by the PCV and LP commands. The actual memory location changed is determined by which of the six curves is assigned as the Processing Curve. The LP command determines how much of the Processing Curve is actually added to.

Example:

FP 0;LP 50;ADD 50

will add 50 points points to the first 51 points of the Processing Curve.

Notes: If LP is less than FP, Command Error 25 (FP more than LP) will be generated. If the selected PCV is not available due to curve size, Command Error 26 (Curve Not Available) will be generated.

SUB n1 n2: An Action command, SUB (SUBTRACT) causes a point-by-point subtraction of one curve from another. "n1" specifies the subtrahend curve. "n2" specifies the minuend curve. The result is stored in the minuend curve.

n1 range: 0...5 (*0...95 with 91 Option*)
n2 range: 0...5 (*0...95 with 91 Option*)

Example: The command SUB 2,1 would cause each point in Memory 2 to be subtracted from each point in Memory 1 and the result stored in Memory 1.

Notes: This command`s effect is not limited to the processing curve. The only other commands not limited to the processing curve are CLEAR and COPY.

If LP is less than FP, Command Error 25 (FP more than LP) will be generated. If either selected curve is not available due to curve size, Command Error 26 (Curve Not Available) will be generated.

EX n1 n2: An Action command, EX (EXPAND) causes all points in the Processing Curve (designated by the PCV command) to be multiplied by "n1" and divided by "n2". The only constraint on "n1" and "n2", other than range, is that they not cause memory overflow. Note that n = 0 is permitted but will result in setting all points to zero.

n1 range: -32767...32767
n2 range: -32767...32767

Example: The command: EX 1,3 would cause all points in the processing curve to be multiplied by one and divided by three, in effect reducing the size of each value in the curve by a factor of three.

Note that this process proceeds via integer division, so values of 6, 7, and 8 result in a value of 2 when using EX 1,3.

MIN n1 n2: An Action Read command, MIN is a request for the Model 263A to scan the Processing Curve from FP to LP (as designated by the PCV command), find the point number where the minimum occurs, and report the point number and the value stored there. This command must be applied only to unpacked I data (Auto-ranging disabled when data were taken) or E data, or meaningless data will result. "n1" is the location and "n2" the value.

n1 range: 0...6143
n2 range: -32767...32767

Example: In response to the MIN command, the Model 263A might respond:

782,-1983

indicating that the minimum is located at point 782 and that the value stored in that point is -1983.

Notes: If LP is less than FP, Command Error 25 (FP More Than LP) will be generated. If the selected PCV is not available due to curve size, Command Error 26 (Curve Not Available) will be generated.

IMIN n1 n2 n3: An Action Read command, IMIN causes the Model 263A to scan the Processing Curve from FP to LP as designated by the PCV command, find the point where the minimum current value occurs, and report the current at that point. Three numbers are reported. The first is the point number, the second is the mantissa of the current value, and the third is the exponent of the current value.

For example, if the IGAIN was 1 when the data were taken, a response of "300 1000 -6" would indicate a current of 1000 * 10^{-6} A, that is, 1 mA, at point 300. With higher values of IGAIN, the stored values will read "proportionally higher." The necessary corrections will have to be supplied by the host computer.

IMIN only works on packed data (Auto-Ranging enabled when data were taken), or meaningless data will result.

n1 range: 0...6143
n2 range: -2000...2000
n3 range: -4...-10 *(-3...-10 with 94 Option)*

Notes: If LP is less than FP, Command Error 25 (FP More Than LP) will be generated. If the selected PCV is not available due to curve size, Command Error 26 (Curve Not Available) will be generated.

MAX n1 n2: An Action Read command, the MAX command causes the Model 263A to scan the Processing Curve fron FP to LP (as designated by the PCV command), find the point number where the maximum occurs, and report the point number and the value stored there. This command must be applied only to unpacked I data (Auto-ranging disabled when data were taken) or E data, or meaningless data will result. "n1" is the location and "n2" the value.

n1 range: 0...6143
n2 range: -32767...32767

Example: In response to the MAX command, the Model 263A might respond:

491,2036

indicating that the maximum is located at point 491 and that the value stored at that point is 2036.

Notes: If LP is less than FP, Command Error 25 (FP More Than LP) will be generated. If the selected PCV is not available due to curve size, Command Error 26 (Curve Not Available) will be generated.

IMAX n1 n2 n3: An Action Read command, IMAX requests the Model 263A to scan the Processing Curve (I values only) as designated by the PCV command, find the point where the maximum occurs, and report the current at that point. Three numbers are reported. The first is the point number, the second is the mantissa of the current value, and the third is the exponent of the current value. For example, a response of "500 1000 -5" would indicate a current of 1000 * 10^{-5} A, that is, 10 mA, at point 500.

The reported value only "reads true" with IGAIN = 1. With higher IGAIN's, corrections will have to be supplied by the host computer. Note that IMAX only works with packed data, that is, data taken with Auto-Ranging enabled, or meaningless data will result.

n1 range: 0...6143
n2 range: -2000...2000
n3 range: -4...-10 (*-3...-10 with 94 Option*)

Notes: If LP is less than FP, Command Error 25 (FP More Than LP) will be generated. If the selected PCV is not available due to curve size, Command Error 26 (Curve Not Available) will be generated.

INT n1 n2: An Action Read command, INT (Integrate) reports the integral of all data points from FP to LP in the processing curve. The number is reported in two parts, "n1" and "n2". Response "n1" is the sum of all the data divided by 10,000. Response "n2" is the remainder of this division. The two must be combined by the host computer to determine the actual sum.

INT only works on packed I data (I Auto-Ranging enabled when data were taken), or meaningless data will result.

The expression is:

$$SUM = n2 + (n1 * 10000)$$

$$Q = (SUM/1000) * (10^{I/E}/IGAIN) * TMB * (10^{-6}\ s/\mu s) * S/P$$

Notes: If LP is less than FP, Command Error 25 (FP More Than LP) will be generated. If the selected PCV is not available due to curve size, Command Error 26 (Curve Not Available) will be generated.

IINT n1 n2: An Action Read command, IINT (Current Integrate) reports the *sum* of all data points from FP to LP of the processing curve (current only). Two numbers, n1 the mantissa and n2 the exponent, are reported. For example, a response of "1000 -6" would indicate a current of 1000 * 10^{-6} A (current + current = current). Coulombs can be computed from the formula:

$$Q = 10^{-6}\ (S/P * TMB/IGAIN) * n1 \times 10^{n2}$$

where:

Q = charge in coulombs
S/P = samples per point as set by S/P command
TMB = timebase in microseconds as set by TMB command
n1 and n2 are the responses to the IINT command

IINT works with packed I data only, that is, data taken with Auto-ranging enabled. Do not use IINT with unpacked data, or meaningless data will result.

Notes: If LP is less than FP, Command Error 25 (FP More Than LP) will be generated. If the selected PCV is not available due to curve size, Command Error 26 (Curve Not Available) will be generated.

ILOG: An Action command, ILOG (CURRENT LOG) requests that the Model 263A compute the log (base 10) of every point in the Processing Curve (I data values only), replace the PCV with the log data, and report the log data to the computer. Each current value is stored as 1000 times the log of that value. For example, if the log of the current is -3.794, the number stored in the memory will be 3794. ILOG only works on packed data, that is, data taken with Auto-Ranging enabled, or meaningless data will result.

Notes: If LP is beyond FP, Command Error 25 (FP Greater Than LP) will be generated. If the processing curve selected is not available due to curve size, Command Error 26 (Curve Not Available) will be generated. Also, note that ILOG does not take into account IGAIN.

Data Transfer Commands
Once curves have been acquired and processing done on them, the user may wish to transmit the resulting data to the host computer. There may also be times when it is desirable to transmit curves from the computer to the Model 263A, such as to place an arbitrary modulation waveform in the Source Curve. Provision is also made for copying data from one Model 263A curve to another, and for clearing one or all curves, as desired. Both ASCII and binary transfer capabilities are provided, as defined by the following commands.

BD n1 n2: An Action command, BD (BINARY DUMP) is used to dump data to the host computer in binary format. This command can be used where it is necessary to execute dumps at the fastest possible speed.

"n1" specifies the address of the first point to be dumped and "n2" the number of points to be dumped. *In the standard unit the address range is 0 to 6143 and the range for the number of points is 1 to (6144 - n1). In units having the 91 Option, the address range is 0 to 98,303 and the range for the number of points is 1 to (98,304 - n1).* Since there are two bytes per point, the number of bytes sent will be twice n2. The high-order byte of a given point is sent first, followed by the low-order byte. There is no separator between points. Every byte is a data byte.

Note that binary dumps are more vulnerable to operator error than are ASCII dumps. Success is most likely to be achieved if use of this routine is limited to those who are very familiar with computers and with general digital interface operations. You must supply your own transfer routine.

In this type of transfer, bytes of data are moved from the Model 263A to the computer without processing of the bytes as they are transferred. As a result, the user must accommodate the following constraints.

1. "n1" must indicate the starting point number for the curve being transferred as follows.

CURVE #	STARTING POINT NUMBER
0	0
1	1024
2	2048
3	3072
4	4096
5	5120

2. Exactly the number of points defined by "n2" must be sent. No terminator will follow the last byte of binary data. However, $\overline{EOI}$ will be asserted with the last byte and only with the last byte.

3. Data are transmitted exactly as it is stored in the Model 263A memory. Therefore, if autoranging is used, the user will have to unpack the data in the host computer. See the discussion of the DC command for details of the packing method and a suggested deconvolution routine.

4. There are two ways of aborting a binary transfer. They are to cycle the Model 263A power or to assert $\overline{IFC}$.

BL n1 n2: The BL (BINARY LOAD) command allows data to be transferred from the host computer to the Model 263A. As with the BD command, "n1" specifies the first memory address where data are to be stored (note that this is not relative to the processing curve). "n2" specifies the number of points to be loaded. In the standard unit the address range is 0 to 6143 and the range for the number of points is 1 to (6144 - n1). In units having the 91 Option, the address range is 0 to 98,303 and the range for the number of points is 1 to (98,304 - n1). Since there are two bytes per point, the number of bytes sent will be twice n2. The high-order byte of a given point is sent first, followed by the low-order byte. There is no separator between points.

The Model 263A expects exactly the number of points specified by n2, and will hang until at least n2 points have been received. If more data are received than specified by n2, the Model 263A will try to interpret this extra data as a command and a command error will probably be generated.

If this command is included inside a loop or a USR function, Command Error 34 or 35 (Not in Loop or Not in USR) will be generated.

CLR: An Action command, CLR (CLEAR) clears (sets to zero) all active points of the Processing Curve.

Notes: Points from the first point to the last point inclusive are referred to as active points.

If LP is beyond FP, Command Error 25 (FP Greater Than LP) will be generated. If the curve selected for the PCV is not available due to curve size, Command Error 26 (Curve Not Available) will be generated.

CLEAR: An Action command, CLEAR (CLEAR ALL) clears all active points of all selected curves to 0. If LP is beyond FP, Command Error 25 (FP Greater Than LP) will be generated.

Note: This command`s effect is not limited to the processing curve. Other commands not limited to the processing curve are "SUB" and "COPY".

COPY n1 n2: An Action command, COPY directs the Model 263A to copy the data in one curve into another curve. "n1" specifies the curve to copy from (0 to 5) and "n2" specifies the curve to copy to (0 to 5). All points from FP to LP are copied.

n1 range: 0...5 (*0...95 with 91 Option*)
n2 range: 0...5 (*0...95 with 91 Option*)

Example: The command COPY 0,1 would cause the data in CURVE 0 to be copied into CURVE 1.

Notes: If LP is beyond FP, Command Error 25 (FP Greater Than LP) will be generated. If either curve selected is not available due to curve size, Command Error 26 (Curve Not Available) will be generated.

This command`s effect is not limited to the processing curve. The only other commands not limited to the processing curve are "SUB" and "CLEAR".

DC n1 n2: An Action command, DC (DUMP CURVE) specifies the points to be transmitted to the host computer. "n1" specifies the number of the first point to be dumped (0 to 6143). "n2" specifies the number of points to be dumped (1 to 6144 - n1). Data are dumped for the Processing Curve only. Each value is followed by the value of the DD command. In GPIB communications, $\overline{EOI}$ is asserted with the terminator (carriage return or carriage return, line feed) after the very last character of the very last value only.

Note: The limitation of 80 characters in the Model 263A output buffer applies to all commands except DC and BD, which do not have the output buffer constraint.

n1 range: 0...6143
n2 range: 1...6144 - n1

Example: The command DC 0 6 might elicit the response:

1473 1480 1485 1491 1494 1497

indicating that the value at point 0 is 1473, the value at point 1 is 1480, the value at point 2 is 1485, the value at point 3 is 1491, the value at point 4 is 1494, and the value at point 5 is 1497.

Notes:

1. When the BD and BL commands are used, there can be a maximum of six curves (0 through 5). The starting point of each curve is fixed. Consequently, to transfer a specific curve, "n1" must specify the appropriate curve starting point, as follows.

CURVE #	STARTING POINT NUMBER
0	0
1	1024
2	2048
3	3072
4	4096
5	5120

2. Current values are acquired by the Model 263A with 12 bits (0.025%) precision. If autoranging is not used, the data are represented as a signed integer with each data value occupying two eight-bit bytes in memory. Data values between -2048 and +2047 are possible in this system.

   Current-reading data acquired with the autorange function active are packed so that the range setting for any acquired point is stored with the value stored at that point. The word width is 16 bits (D0 through D15; D0 is the LSB and D15 is the MSB.) The data value is stored as a 12-bit number in bits D0 through D11, with D11 acting as the sign bit. The code signifying the current range (codes are the same as listed for the I/E command) is stored in bits D12, D13, D14, and D15. D15 is the sign bit for the I/E Range.

0 or 1	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Bit	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
	I/E Range				A/D Value											

   Example: 1110 110101010101 = ED55 hex

   Data plotting or interpretation requires that these data be converted to a real number, where the I/E range is the exponent and the A/D value is the current measured at that I/E range. The procedure in Quick BASIC to deconvolute the data is:

```
'C = A/D Counts
'E = Exponent or I/E Range
'P = Packed Integer Value
'N = Real Number Value
 E = Int (P/4096)
 C = P - (E * 4096)
 If C ≥ 2048 then C = C - 4096

 N = (C/1000) * 10 ^ E
```

   Example: P = ED55 hex as above. This corresponds to -4779 as a signed integer (the QB integer format).

E = Int (-4779/4096) = Int (-1.167) = -2 (not -1!)
C = -4779 - (-2) * 4096 = 3415
If C(=3415) ≥ 2048 then C = C - 24096 = 3415 - 4096
N = (-683/1000) * 10^{-2} = -0.683 * 10^{-2}

DP n: An Action command, DP (DUMP POINT) causes a single point in the Processing Curve to be dumped to the host computer in ASCII format. "n" is the point number.

n range: 0...6143

If DP is applied at a time when data are not being actively taken, the value at the specified point is reported immediately. If DP is applied when the curve is running (TAKE CURVE command was applied and the resulting data acquisition is in progress), the response does not occur until the
specified point has been taken. The data value is then dumped. This feature is particularly useful in experiments where the data are to be displayed as they are acquired.

LC n1 n2: An Action command, LC (LOAD CURVE) directs the Model 263A to accept the subsequent data stream from the host computer and to load it into the Processing Curve at the points specified by "n1" and "n2. "n1" specifies the first storage location (the absolute starting point relative to the processing curve). "n2" specifies the number of points to be loaded. The data must be transmitted as a string of ASCII decimal numbers separated by at least one space.

n1 range: 0...6143
n2 range: 1...6144 - n1

Because the Model 263A input buffer holds 80 characters, no more than 80 characters should be sent on any one line. More than one line can be used, if necessary, to meet this constraint.

Example: After sending the command LC 0 8, the computer might then send the following data:

1234 2345 3456 5432 6543 0123 9834 9876

These data would be loaded into the Processing Curve starting at point 0.

If only a few points are to be loaded, the data can be on the same line as the command.

Example: LC 0 5 1234 2345 3456 4567 5678 <CR>

Notes: The Model 263A expects exactly the number of points specified by n2, and will hang until at least n2 points have been received. If more data are received than specified by n2, the Model 263A will try to interpret these extra data as a command and a command error will probably be generated.

If this command is included inside a loop or a USR function, Command Error 34 or 35 (Not in Loop or Not in USR) will be generated.

2.13. Communications Control and Status Commands

Communications Control Commands

MSK n [0]: A Set/Read command, MSK (SRQ MASK) determines which events must take place to cause a service request. If "n" is omitted, MSK is a request for the Model 263A to report the decimal value of the mask byte. The range is 0 to 255.

"n" is a binary bit weighted parameter. Each bit enables or masks a bit in the serial poll byte. When the serial poll bit is set and the mask bit is set, an SRQ (Service Request) will be sent to the host computer over the IEEE-488 bus. The serial poll bit will be cleared when the SRQ is serviced.

The serial poll bits reflect the following conditions:

Bit 0 Command done. Set when a complete command line has been processed.

Bit 1 Command error. Set when a command causes an error condition. The ERR command may be used to determine the specific error.

Bit 2 Curve done. Set at the completion of a curve. Cleared by the NC command.

Bit 3 Not used.

Bit 4 Overload. Set whenever an I overload, E overload, or A/D converter overload occurs. **Note:** When this condition is serviced, the MSK bit is also cleared, making it necessary to set this bit again to detect further overloads. This is to avoid the condition where the Model 263A becomes SRQ-bound until the overload goes away.

Bit 5 Sweep done. Set at the end of a sweep and cleared at the start of the next sweep.

Bit 6 $\overline{SRQ}$ bit. This is the only bit in the serial poll byte that is specified by the IEEE-488 standard and cannot be masked.

Bit 7 Output ready. Set when the Model 263A has data to transmit.

Example: If the Mask Byte operand is such as to give a Mask Byte of:

10000001 (=129 decimal)

a service request will be generated anytime bit 0 or bit 7 of the Status Byte is a "1". Service requests will not occur for any of the other bits of the Status Byte status.

Note: If the mask is coded to assert $\overline{SRQ}$ on detecting an overload state, and an overload in fact occurs, $\overline{SRQ}$ will be asserted *and* the Overload Bit (only) in the SRQ Mask byte *will be cleared*. This ensures that the overload condition will cause *one* service request to be generated, and not a continual stream of service requests. When the overload has been corrected, it will be necessary to restore the SRQ Mask.

DD n [44]: A Set command, DD (DATA DELIMITER) specifies the ASCII character to be sent by the Model 263A as the delimiter between two numbers in a multiple-response Read command. The default or power-up delimiter is the comma. Any other ASCII character can be specified by "n" in the range of 0 to 255.

Note that this command governs only the delimiter for transmitted characters. The Model 263A will accept only spaces as delimiters.

Example: DD 59 specifies the semicolon (decimal equivalent of ASCII code for a semicolon is 59) as the delimiter to be sent by the Model 263A.

Note: This command is not affected by the DCL command. The default value is set only at power-up with a dead battery.

Status Commands

ST n: The ST (DEVICE STATUS) command is a request for the Model 263A to report its serial poll status. The response is an ASCII number that is the sum of the individual bits in the status byte (unlike the serial poll response, which is an eight-bit binary number). The range is 0...255. This command is provided for RS-232 communications to simulate the IEEE-488 serial poll.

The weighting function of each bit, with a value of 1 indicating true, is:

ITEM	BIT NO.	BIT LOGIC STATE	DECIMAL VALUE
Command Done	0	0/1	1
Command Error	1	0/1	2

Curve Done	2	0/1	4
Unused	3	0	0
Overload	4	0/1	16
Sweep Done	5	0/1	32
Service Requested	6	0/1	64
Output Ready	7	0/1	128

See the the MSK command for a description of the serial poll bits.

Example: Suppose the status were:

ITEM	TRUE/FALSE	NUMERIC VALUE
Command Done	FALSE	0
Command Error	FALSE	0
Curve Done	TRUE	4
Overload	FALSE	0
Sweep Done	TRUE	32
Service Requested	TRUE	64
Output Ready	TRUE	128
	Total	228

In response to the ST command, the Model 263A would return the decimal number 228.

ERR n: A Read command, ERR (Error Status) requests the Model 263A to report its error status. The error code returned reflects the error status at the completion of the previous command, that is, at the end of the command preceding the ERR command. The codes are:

ERROR CODE **MEANING**

0 NO ERROR HAS OCCURRED.

1 OPTION NOT INSTALLED. Command cannot be executed without option.

2 COMMAND NOT UNDERSTOOD. This error will occur if:

- The command mnemonic is incorrectly spelled.
- One or more parameters are present with a command that requires no parameters.
- No parameters are present with a command that requires one or more parameters.

Corrective action is to send the proper command.

3 PARAMETER OUT OF BOUNDS. This error will occur if any parameter is not within allowable upper and lower limits. The Model 263A is designed to accept signed integers from -32768 to 32767 (for example, the ADD n command) or unsigned numbers from 0 to 32767 (for example, the DT n command). Corrective action is to send the valid parameter.

5 NOTHING TO SAY. This error will occur in operation via the GPIB port if the Model 263A is made a talker when there is no output to be sent. For example, if the user wanted the Model 263A to report its sensitivity, the I/E command would have to be sent prior to the TALK message. One error that is easily made is that of sending a parameter set command instead of the corresponding information-request command. For example, should the user send the command I/E -3, the Model 263A would range to the corresponding sensitivity, instead of preparing the sensitivity setting information for transmission on receipt of the subsequent TALK message.

An Error 5 will also be generated during a serial poll if the host computer sends the TALK message before sending the SERIAL POLL ENABLE message, or if the host computer does not send the UNTALK message before sending the SERIAL POLL DISABLE message.

6 PARAMETER WRONG TYPE. This error will occur if:

- Any non-numeric characters are present in a decimal parameter.
- Any non-hexadecimal characters are present in a hex parameter.

7 TIME BASE (TMB) TOO SHORT. This error will occur at NC or RC if the accumulated time penalties for enabled features exceeds the selected time base in NO FRILLS or SOME FRILLS operation. See the TMB command for a table of time penalties.

11 WRONG MODE. This error will occur if:

- In galvanostat mode, a command is sent that is only legal in potentiostat mode.
- In potentiostat mode, a command is sent that is only legal in galvanostat mode.
- A DORUPT command is sent and IRMODE is not set to 4.
- An attempt is made to change current range while I auto-ranging is enabled.

12 ACQUISITION ERROR. This error will occur if:

- Any of the following commands are sent while a curve is in progress: DORUPT, READE, READI, or ASM.
- The DISCARD or WAIT command is sent while a curve is *not* in progress.
- An attempt is made to change any of the following parameters while a curve is in progress: DCV, FP, GIGAIN, INITIAL, INTRP, ITC, LP, MM, FAM, SAM, S/P, SCV, SEL, SHF, SIE, TMB, or VERTEX.

20 COMMAND HEAP FULL. This error will occur if:

- An attempt is made to include more than 38 commands between DO and LOOP.
- An attempt is made to include more than 38 commands between BEGIN and AGAIN.
- An attempt is made to include more than 38 commands in a user function.

21 MISSING BEGIN OR DO. This error will occur if:

- A LOOP command is received without a preceding DO command.
- An AGAIN command is received without a preceding BEGIN command.

22 NESTING VIOLATION. This error will occur if:

- A user function attempts to call itself.
- An attempt is made to nest a BEGIN-AGAIN loop within another BEGIN-AGAIN loop.
- An attempt is made to nest a DO-LOOP loop within another DO-LOOP loop.

23 NOT ENOUGH PARAMETERS. This error will occur if fewer than the required number of parameters are sent with the command mnemonic.

24 TOO MANY PARAMETERS. This error will occur if more than the required number of parameters are sent with the command mnemonic.

25 FP GREATER THAN LP. This error will occur with the following commands if First Point is not less than or equal to Last Point: ADD, CLEAR, CLR, COPY, EX, IINT, ILOG, IMAX, IMIN, INT, MAX, MIN, NC, RC, SUB.

26 CURVE NOT AVAILABLE. This error will occur if:

- Any of the following commands are sent and the processing curve selected is not available due to curve size: ADD, CLR, EX, IINT, ILOG, IMAX, IMIN, INT, MAX, MIN.
- The COPY or SUB command is sent and the source or destination curve specified is not available due to curve size.
- The NC or RC command is sent and any of the curves required to run the curve are not available due to curve size.

27 NOT ENOUGH CURVES. This error will occur if the NC or RC command is sent and there are not enough curves available due to curve size to support the SIE selection.

28 INITIAL POINT NOT EQUAL FP. This error will occur if:

- The Initial command is sent and the first parameter does not equal the specified First Point.
- The NC or RC command is sent with MM set to 1 and the Initial Point does not equal the First Point.

29 VERTEX NOT GREATER THAN INITIAL. This error will occur if a Vertex command is sent and its first parameter is not greater than the initial point.

30 VERTICES FULL. This error will occur if more than 50 vertices are received.

31 SCV WITHIN DCV. This error will occur if the NC (not RC) command is sent with MM set to 2 and the SCV selected is within any of the DCVs or ACVs required to run the curve. The NC command clears all DCVs which would destroy the SCV.

32 NO VERTICES. This error will occur if:

- The NC or RC command is sent with MM set to 1 and no vertices have been received.
- The ASM command is sent and no vertices have been received.

33 SEL NOT WITHIN S/P. This error will occur if the NC or RC command is sent with PAM set to 2 or 6 and the SEL parameter is not within samples per point.

34 COMMAND ILLEGAL IN LOOP. This error will occur if an attempt is made to include BL, LC, or any USR definition in a DO-LOOP or a BEGIN-AGAIN loop.

35 COMMAND ILLEGAL IN USR. This error will occur if an attempt is made to include any of the following commands in a USR function: AGAIN, BEGIN, BL, DCL, DO, LC, LOOP.

36 COMMUNICATIONS ERROR. This error will occur in GPIB or RS-232 communications if an error code is found in the device status register. The code will be displayed on the front panel of the Model 263A until the error is cleared by a successful communication or by switching to local mode.

37 CALIBRATION ERROR. This error will occur if a calibration is performed and the values generated are outside the calibration limits. The display of this error code means that the instrument needs manual calibration or repair. This should be done only by an authorized Princeton Applied Research service technician.

OVER n1 n2 n3: A Read command, OVER (OVERLOAD) is a request for the Model 263A to report its overload status. The Model 263A responds with three numbers. "n1" gives the overload status at the time the command is executed. "n2" reports on the status during the interval since the last time an OVER command was applied. If an overload occurred at any time during that interval, it will be reported in the second response number, independent of whether the unit is in overload when the OVER command is applied. "n3" reports the cumulative overload status at the input to the A/D Converter (the A/D Converter reading is +2047 or -2048).

Note that "n3" is maintained only in FULL FRILLS data acquisition and in front-panel (local) operation. It is not maintained in SOME FRILLS or NO FRILLS operation. For a detailed discussion of the meaning of FULL FRILLS, SOME FRILLS, and NO FRILLS, see the description of the TMB command. The codes for all three responses are:

n1,n2,n3	MEANING
0	No Overload
1	I Overload
2	E Overload
3	I and E Overloads
4	AUX Overload*
5	AUX & I Overload*
6	AUX & E Overload*
7	AUX, I, & E Overload*

* only if 98 option is present

Note that "n2 and "n3 are cleared on completing the execution of each "OVER" command. As a result, they reflect the cumulative overload status since the previous time an OVER command was invoked.

CS n: A Read command, CS (CELL SWITCH) requests that the Model 263A report the on/off status of the mechanical cell switch. The response to this command will always be 1 (On), as there is no mechanical cell switch in the Model 263A. This command is provided only for compatibility with the Model 273A Potentiostat/Galvanostat.

DUMMY n: A Set/Read command, DUMMY requests the Model 263A to select or report the cell type (real or dummy). The codes are:

n	STATUS
0	Real cell selected; dummy cell off
1	Dummy cell (10.0 kΩ) selected

FF n: A Read command, FF (Find Frequency) requests that the Model 263A report the power-line frequency. A response of "0" indicates 60 Hz; "1" indicates 50 Hz.

FLOAT n: A Read command, FLOAT reports the status of the 99 Option and is only valid with the 99 Option installed. A response of 1 indicates that the cell is floating (rear-panel switch set to FLOAT) A response of 0 indicates that the cell is not floating (rear-panel switch set to NORMAL). Note that the FLOAT command is only valid when the 99 Option is installed.

2.14. Control Structure Commands

BEGIN: A Control command, BEGIN is used to mark the beginning of an infinite loop in a multiple command. The program will loop continuously between BEGIN and the AGAIN command. This capability is useful in program development, where it allows the user to put the Model 263A in an endless loop to facilitate observing its behavior. For example, the command:

BEGIN;BIAS;MOD;AGAIN

would cause the BIAS and MODULATION DAC values to be sent continually from the Model 263A to the host computer. Such a loop must be terminated with "AGAIN". Once such a loop has been initiated, it can only be terminated by sending a Ctrl-B to the serial port, sending an IFC signal to the GPIB port, or turning off the power.

Notes: Loop nesting is not allowed. If an attempt is made to nest a loop within another loop, Command Error 22 (no nesting) will be generated. In addition, if any of the following commands are included with a loop, Command Error 34 (illegal in loop) will be generated:

BL
LC
any USR macro

AGAIN: A Control command, AGAIN is used to mark the end of an endless loop started with the BEGIN command, as described above.

DO n: A Control command, DO marks the beginning of a finite loop and specifies the number of times the loop is to be performed. The end of the loop must be marked by the LOOP command. For example, the multiple command:

DO 1000;BIAS;MOD;LOOP

would cause the Model 263A to report the Bias and Modulation DAC values 1000 times. Sending a Ctrl-B to the serial port or an IFC signal to the GPIB port will abort the loop.

n range: 1...32767

Notes: Loop nesting is not allowed. If an attempt is made to nest a loop within another loop, Command Error 22 (No Nesting) will be generated. In addition, if the BL or LC command, or any USR macro, is included within a loop, Command Error 34 (Illegal in Loop) will be generated.

LOOP: A Control command, LOOP is used to mark the end of a finite loop that was started with the DO command.

Notes: Neither BEGIN/AGAIN nor DO/LOOP commands may be nested. Also, if the command generates any output, that output will be dumped when the words AGAIN or LOOP are interpreted,

so the Model 263A output buffer won't overflow. Loop execution will pause each time until the dump is completed.

USR1, USR2, USR3, USR4: These Control commands (USER FUNCTION 1 through 4) define or execute user-defined macros. For example, the command string

USR1 NC;CELL 1;TC;WCD;CELL 0

defines USR1 as the command string which follows it. Simply sending USR1 would cause those commands to be executed. Note that there must be a space between the name of the user function and the command string that defines it. A user function executes approximately ten times faster than the command string it replaces.

User functions may be part of a multiple command. The command string USR1;NC;TC would execute properly. However, the DC, LC, BD, and BL commands will not function properly in a user function and so should not be used with one.

If the USR macro is specified with legal commands followed by spaces, the commands are compiled as a list of addresses and parameters in memory. If USR is not specified with a list of commands, the previous list of compiled commands will be executed. At power-up, all USR macros are empty.

Notes: A USR function can call other USR functions, but may not call itself. Furthermore, a USR macro cannot be defined within another USR macro. If either of these disallowed operations are attempted, or if the DC, LC, BD, or BL command is included when a USR macro is defined, Command Error 35 (Illegal in USR) will be generated when the macro is executed.

P n: An Action command, P (PAUSE) causes command interpretation to pause for approximately "n" seconds. "n" can take values from 1 to 32767. For example, the sequence:

BIAS 1000;P 3;BIAS 0

would cause the Bias DAC to be set to 1000 for three seconds, and then reset to zero.

2.15. Auxiliary Interface Commands

General Commands

TRIG n [0]: An Action command, TRIG (TRIGGER) is used to place a pulse on the Trigger Output line (pin 4) of the rear-panel AUXILIARY INTERFACE connector. The Trig Out baseline is either a logic 0 or a logic 1 (default is logic 0), according to the operand of the last applied TRIG command. The TRIG operands have the following effects:

TRIG 0: If the Trig Out signal is currently high (logic 1), a 10 ms to 20 ms TTL low (logic 0) pulse will be generated. If the Trig Out signal is currently low, a TTL high baseline will be established and subsequent TRIG 0 commands will produce a 10 ms to 20 ms TTL low pulse.

TRIG 1: If the Trig Out signal is currently low (logic 0), a 10 ms to 20 ms TTL high (logic 1) pulse will be generated. If the Trig Out signal is currently high, a TTL low baseline will be established and subsequent TRIG 1 commands will produce a 10 ms to 20 ms TTL high pulse.

WFT n: An Action command, WFT (WAIT FOR TRIGGER) suspends command interpretation and execution until the rear-panel AUXILIARY INTERFACE EXT TRIG (pin 2) TTL level matches that of "n". If WFT 0 is applied, operation will resume when a logic 0 is applied to the EXT TRIG line. If WFT 1 is applied, operation resumes when a logic 1 is applied to the EXT TRIG line. The control level applied to EXT TRIG line must remain at the required state for at least 10 ms.

The WFT command can be used to synchronize command execution with an external event if the external event can generate the pulse required at the EXT TRIG line of the AUXILIARY INTERFACE connector. For example, suppose data acquisition isn't to begin until a specific external event occurs. One might apply the sequence:

NC;WFT 1;TC

NC prepares the Model 263A to take the data. WFT 1 prevents data acquisition from beginning when the following TC command is applied. When the external event occurs, a TTL logic 1 is applied to the EXT TRIG line. At that point, the previously applied TC command becomes effective and data acquisition begins.

Note: The level applied to the EXT TRIG line is not continuously sensed. Instead, the line is polled periodically. The interval between polls depends on how "busy" the Model 263A is at the time, and can vary over a wide range. In other words, there can be considerable jitter in the EXT TRIG sense timing.

BIT n1 n2: A Set/Read command, BIT sets the level of the BIT 0 OUT line (pin 7) of the rear-panel AUXILIARY INTERFACE connector. "n1" is always 0 (there is only one output bit). "n2" is either 0 or 1. If n2 is not entered, the Model 263A reports the status of the BIT 0 OUT line. (See the description of the AUXILIARY INTERFACE connector in the appendix of the *Model 263A User's Guide* for additional information.)

Note: This command will not control the BIT 0 OUT line if Current Interrupt iR Compensation (IRMODE 2) has been selected.

The "n2" and response codes are:

n2 OR RESPONSE	BIT 0 OUT
0	TTL logic 0
1	TTL logic 1

OUT n [4]: A SET/READ command, OUT sets the Output DAC mode. When applied without an operand, this command requests the Model 263A to read the mode and report it to the computer. The codes are:

n	MODE
0	NONE
4	VALUE IN SETOUT

Note: Applies for 98 option only.

SETOUT n [0]: Active only in units equipped with the 98 Option, SETOUT is a SET/READ command that makes a voltage available at the OUTPUT 1 BNC connector if OUT 4 is set. The range is +2047...-2047.

Example: SETOUT 1000 causes a 1 V level to be present at the OUTPUT 1 BNC connector if OUT 4 is set.

SETOUT2 n [0]: Active only in units equipped with the 98 Option, SETOUT 2 is a SET/READ command that makes a voltage available at the OUTPUT 2 BNC connector if OUT 4 is set. The range is +2047...-2047.

Example: SETOUT2 1000 causes a 1 V level to be present at the OUTPUT 2 BNC connector if OUT 4 is set.

OUTRES n [0]: Active only in units equipped with the 98 Option, OUTRES is a SET/READ command that determines the resolution at the OUTPUT 2 BNC connector, as follows.

n	RESOLUTION
0	1 mV/count for a FS output of +2.047 V to -2.048 V
1	5 mV/count for a FS output of +10.235 to -10.24 V

Model 303A Interface Commands

In remote control from a host computer, the Model 263A can control the Model 303A Static Mercury Drop Electrode via the Model 507 Interface. The Model 507 Interface is a universal power supply and control interface for the Model 303A SMDE. It can relay DISPENSE, PURGE, and STIR signals from the Model 263A AUXILIARY INTERFACE connector to the Model 303A. The Model 507 is provided with all cables required to make the necessary connections. Refer to the *Model 507 Interface Installation Guide*, Princeton Applied Research Part Number 222556, for installation instructions.

DISP: An Action command, DISP (DISPENSE) initiates a Model 303A Dispense/Dislodge operation by transmitting a pulse (60 µs, TTL logic 0) at pin 3 of the rear- panel AUXILIARY INTERFACE connector.

PURGE n [0]: A Set/Read command, PURGE controls the Model 303A's purge function via pin 8 of the rear-panel AUXILIARY INTERFACE connector. It allows a Model 303A purge to be turned on or off (operand applied) or the purge status to be reported (command applied without operand). The codes are:

n	PURGE STATUS
0 (applies TTL high)	Off
1 (applies TTL low)	On

STIR n [0]: A Set/Read command, STIR allows the Model 263A to control a Model 305 Stirrer via the Model 303A. If applied with an operand, the Stirrer is turned on or off. If applied without an operand, the Model 263A reads the status of the Stirrer Control message being generated by the Model 303A. The control signal is provided on the STIR line (pin 9) of the rear-panel AUXILIARY INTERFACE connector. The codes are:

n	STIRRER
0 (applies TTL low)	Off
1 (applies TTL high)	On

2.16. System Identification, Option, and Display Commands

ID n [2631]: A Read command, ID (IDENTIFICATION) requests the Model 263A to report its model number (2631 representing 263A).

BID n1 n2: A Read command, BID (BOARD IDENTIFICATION) reports which PC boards are installed in the Model 263A. The range of n1 is 90 to 99, with the following meanings:

If n1 = 90, n2 = the number of a basic system board, where:

0 = main board
1 = analog board
2 = display board

If n1 = 91 to 99:

n1 = the option number of an installed option.
n2 = 0 for single-board options, or the board number for multi-board options.

When the BID command is received, six responses will be returned. They have the following meanings:

r1 = 1 if the board is present, -1 if the board is absent.
r2,r3,r4 = the unique board ID values if the board in question is present, and -1 if it is not. Some options do not require a unique board.
r5 = CRC value of responses 1 to 4.
r6 = board revision level.

VER n: A Read command, VER (FIRMWARE VERSION) causes the Model 263A to report its firmware version code.

OPTION n: A Read command, OPTION reports whether a particular optional feature for the Model 263A is installed. The range of n is 90 to 99, corresponding to Options 90 through 99. Note that most of these option numbers are not assigned, as they are reserved for possible future enhancements to the instrument. Currently assigned option numbers are:

91	Memory
94	2 A
98	AUX + OUTPUT
99	FLOAT

The response codes are:

RESPONSE	**STATUS**
0	Option not installed
1	Option installed

TYPE: The TYPE command is an Action command that allows you to print a customized message on line 3 of the front-panel LCD display. The message string may consist of up to 40 characters. If more than 40 characters are sent, the string is truncated. If the command is sent without a string, line 3 of the display is cleared.

For example, the command line

TYPE my experiment is running

would cause the text "my experiment is running" to appear on the third line of the LCD display (without the quotation marks).

Note that quotes are not required and will be printed if included in the string. The only requirements are:

- There must be at least one space between the TYPE command and the string to be printed.
- The string cannot contain an ASCII character lower than 32 (decimal).

APPENDIX A. COMMUNICATIONS PROTOCOL AND INTERFACING

A.1. Introduction

This appendix discusses the Model 263A communications protocol and the general requirements for establishing successful communications. Unless otherwise indicated, this information applies equally to both GPIB and RS-232 communications.

A.2. Communications Protocol

Introduction
A transmission to the Model 263A consists of a command followed by a space, a number or numbers if necessary, and a terminator. If a command is followed by one or more parameters, it is taken to be a request to set the associated function according to the parameters. If the command is *not* followed by one or more parameters, it is interpreted as a request to read the associated setting or status.

Each command consists of one or more upper-case letters. The letters used to form the command suggest the associated function. Where necessary, the letters are followed by one or more decimal numbers to complete the command. In the case of ON/OFF functions, "1" is used to denote ON and "0" to denote OFF. In the case of commands used to choose between E (potential) and I (current), "1" is used to denote I and "2" to denote E.

If a command has parameters associated with it, a space must separate the command from the parameters. Parameters of a command will be integer numbers separated by a delimiter, which must be a space. The Model 263A *sends* a comma as the delimiter unless the DD command is used to specify some other character. Note that the DD command has no effect on the characters recognized as a delimiter by the Model 263A. As a final note on delimiters, bear in mind that many BASIC language implementations will not accept the comma as a delimiter in input statements.

Numbers are transmitted as ASCII decimal with the most significant digit transmitted first.

Terminator
The terminator that follows each command message can be either a Carriage Return (CR) or a Carriage Return followed by a Line Feed (CRLF), as selected from the System Parameters menu with the VALUE knob. In communications with a computer, *the terminator must be set according to the requirements of the host computer*. If the computer is expecting a line feed and "CR" has been selected, the system will "hang" as the computer waits forever for the missing line feed. If the computer expects "CR" and "CRLF" is selected, the computer will respond to the carriage return in the CRLF sequence all right, but then will make the line feed the first character of the next command, probably with unexpected and undesired results.

Compound Commands
Several commands can be sent on one line by separating them with a semicolon. For example, the sequence:

AL -5 <CR>
AR 1 <CR>
AS <CR>

could be transmitted as a single compound command with the sequence:

AL -5;AR 1;AS <CR>

However, if an error is detected at any point in the line, the rest of the command will be ignored. The size of the Model 263A's input buffer is 80 characters. Commands longer than 80 characters will be truncated at 80 characters. Similarly, the size of the output buffer is also 80 characters. Any compound command that generates more than 80 characters of output will cause data to be lost.

Note: The 80 output character limit does not apply to Curve Dump commands.

Control Characters
Table A-1 lists the control characters to which the Model 263A responds and describes the instrument's response. All other control characters are ignored. A control character such as Control B must be sent by the host computer as a single byte without any terminator. The EOI line on the GPIB may be in either state when a control character is sent.

Communications Control
Commands cannot be transmitted to the Model 263A while it is busy executing a previous command. Should a command be sent when the Model 263A is busy, it will be ignored and a Command Overrun error will be generated.

In GPIB communications, the Serial Poll function can be used to maintain orderly bus control. The Output Ready and Command Complete bits of the Serial Poll Status byte are provided for this purpose. In RS-232 communications, the Model 263A sends a prompt to the host computer at power-up and after executing each command. This prompt can be used by the host computer to prevent command overruns. Use of the Serial Poll Status byte to control GPIB communications is discussed in Appendix B. Use of the RS-232 prompt is discussed in Appendix C.

Table A-1. CONTROL CHARACTERS RECOGNIZED BY MODEL 263A

ASCII CODE	NAME	ACTION
13	<CR>	Starts interpretation of the command if <CR> has been selected as the terminator.
10	<LF>	Starts interpretation of the command if <CRLF> has been selected as the terminator. If <CRLF> has not been selected, the Model 263A reconfigures itself to accept <CRLF> and interpretation of the command begins anyway.
2	CTRL B	ABORT: Terminates the execution of a multiple command on completion of the individual command currently being carried out. Also terminates any command in its output phase.
19	CTRL S	X-OFF: Prevents instrument from transmitting via the RS-232 port (only). The host computer must be ready to accept a couple of characters after it transmits X-OFF. Does not prevent characters from being echoed if the ECHO mode is ON. Transmission resumes when X-ON (Control Q) is applied.
17	CTRL Q	X-ON: Once RS-232 transmission has been halted by X-OFF, transmission can be resumed by applying Control Q (X-ON).

A.3. Interfacing to a Host Computer

Introduction
Successful interfacing between the Model 263A and an external computer requires detailed knowledge of a number of areas, including:

1. The response of the instrument to incoming commands.

2. The protocol required by the instrument to enable an orderly flow of commands and responses.

3. The protocol required by the host computer.

4. The capability and requirements of the language in which the host computer is programmed.

Additionally, the user must be aware of interactions between these various factors. In the event that the system does not function as expected, there is ample room for uncertainty as to the cause of the malfunction. By taking a methodical approach, the user can eliminate much of this uncertainty.

A suggested approach to establishing successful communications follows.

1A. GPIB INTERFACE:

   a. Assert the REN line on the GPIB and send the Model 263A LISTEN address. The LCD display on the front panel of the Model 263A should change to the Remote menu. If it doesn't, either the address is wrong or there is a problem with the Model 263A, computer, or interconnecting cable.

   b. Execute a GPIB serial poll of the Model 263A from the host computer and see if the expected response is sent. A serial poll is the simplest possible data transfer and does not involve the Model 263A's microprocessor. If the serial poll status byte can be read successfully, it indicates that the Model 263A's GPIB address is configured properly and that the 263A is able to transmit and receive bytes.

1B. RS-232 INTERFACE: Determine whether the computer receives the RS-232 prompt when the Model 263A is first turned on. Assuming the baud rate, number of stop bits, and parity-bit configuration of the Model 263A and the host computer are compatible, the 263A will transmit a prompt (an asterisk) when it is ready to receive a command. The prompt is transmitted after power-up, and after completion of any command. It is provided to facilitate orderly data and command flow. If the command generates an error condition, the prompt is a question mark.

2. Send the instrument a simple command that requires a number response. The ID command, for example, should cause the Model 263A to respond with "2631". This test demonstrates whether bidirectional data transfer is possible.

   If this step is successful, it confirms that the terminator character has been properly specified. If it is not successful, the cause may be that the instrument is configured for a <CR> terminator and the host computer expects a <CRLF>. This is a common problem when interfacing to Hewlett-Packard equipment, which generally expects a <CRLF> terminator.

3. At this point it is often useful to know whether the host computer can receive a response consisting of more than one number. The M command, for example, should cause six numbers to be returned.

If the interface passes the test in (2) but fails the test in (3), it is possible that the host computer will not accept the comma as a delimiter between numbers (some BASICs will not accept a comma delimiter on input statements). This delimiter can be changed to an acceptable character, such as a space, with the DD command.

4. The host computer must pace the flow of commands so that the instrument completes the previous command before it receives a new one. For this reason, a single subroutine is recommended for sending all commands to the instrument. A string containing the commands can be passed to this subroutine. We also recommend that a single subroutine be used to receive responses from the instrument.

   It is essential that the host computer only send a command to the Model 263A when the 263A has finished processing the previous command. In GPIB communications this is done by checking the COMMAND DONE bit of the Model 263A's Serial Poll byte as described in Section B.4 of Appendix B. In RS-232 communications, it is accomplished by always waiting for the prompt (asterisk) that the Model 263A transmits when it is ready for a command.

Note: If the Model 263A detects an error condition, the prompt is a question mark. See Section C.2 of Appendix C.

5. A useful exercise at this point is to write a simple program that displays and updates the status of the Model 263A. Once this is accomplished, the resulting program structure can be used for reliable sequencing and monitoring of the instrument.

6. A final recommendation is that the controlling program be as modular and structured as possible to permit quick and logical tracing if a problem occurs.

The important point of this sequential process of bringing the Model 263A up on a host computer is that, if a problem occurs at any step, the user can go back to the previous step and figure out what caused the new problem to occur.

APPENDIX B. GPIB INTERFACE

B.1. Introduction

The IEEE 488-1978 Instrument Bus Standard defines a bit-parallel, byte-serial bus structure designed to allow communications between intelligent instruments. Using this standard, many instruments may be interconnected and remotely controlled or programmed. Data can be taken from, sent to, or transferred between instruments via one connector or port. The standard defines all voltage and current levels, pinouts, connector specifications, timing, and handshake requirements. As a result, it should be possible to take two or more devices equipped with a GPIB port, remove them from their shipping cartons, connect them to the bus, and expect that they will be able to communicate on the bus.

However, to operate the Model 263A from a remote computer, it is necessary to know and use both standard GPIB and device-dependent commands as required to accomplish the intended measurement. This appendix contains detailed information about the GPIB as implemented in the Model 263A, together with a more detailed general description of the GPIB (Section B.7).

B.2. Address Settings

Introduction

When the controller communicates with a device on the bus, it begins by placing the address of that device on the bus with $\overline{ATN}$ asserted. Naturally, each device must "know" its own TALK and LISTEN address. In the case of the Model 263A, these addresses are set from the System menu on the front panel with the VALUE knob. The normal address setting for use with Princeton Applied Research software is 14. See your software manual for its individual requirements.

The decimal address value set in with the VALUE knob is translated to a binary number. Each address is seven bits long. A listen address begins with binary "01", and a talk address with "10", with the controller supplying the "01" or "10" as required. Thus, even though we speak of a device's GPIB address, the address setting at any time defines not one address, but two. It is common practice to refer to the decimal equivalent of the binary address sequence as the device's GPIB address.

To determine the actual hexadecimal LISTEN and TALK addresses, simply precede the binary sequence by "01" or "10" as appropriate, and convert the resulting sequence to hex. An alternative technique for determining the hex LISTEN address is to begin with the decimal equivalent of the five-bit sequence, add 32, and convert to hex. Similarly, the hex TALK address can be determined by adding 64 to the decimal address and then converting to hex. Table B-1 shows the available addresses.

Table B-1. ADDRESS CODING

BINARY BIT SEQUENCE	DECIMAL SETTING	HEX LISTEN ADDRESS	HEX TALK ADDRESS
00000	0	20	40
00001	1	21	41
00010	2	22	42
00011	3	23	43
00100	4	24	44
00101	5	25	45
00110	6	26	46
00111	7	27	47
01000	8	28	48
01001	9	29	49
01010	10	2A	4A
01011	11	2B	4B
01100	12	2C	4C
01101	13	2D	4D

01110	14	2E	4E
01111	15	2F	4F
10000	16	30	50
10001	17	31	51
10010	18	32	52
10011	19	33	53
10100	20	34	54
10101	21	35	55
10110	22	36	56
10111	23	37	57
11000	24	38	58
11001	25	39	59
11010	26	3A	5A
11011	27	3B	5B
11100	28	3C	5C
11101	29	3D	5D
11110	30	3E	5E

ON selects logic "1"; OFF selects logic "0".

Test Echo
A special GPIB TEST ECHO mode can be established by switching to the System menu and using the VALUE knob to set GPIB Echo = ON. When the Test Echo function is ON, every character transmitted or received via the GPIB port will be echoed to the RS-232 Interface Connector. This feature is particularly useful when developing programs. If a "dumb" CRT terminal is connected to the RS-232 Interface, the programmer will see all communications on the CRT. Such a terminal will allow direct interaction, thereby facilitating the programmer's understanding of the commands and responses. In addition, the programmer will be able to monitor the program data and intervene if necessary. The RS-232 baud rate should be high to prevent slowing down the GPIB. During normal operation, GPIB Echo should be set to OFF.

Terminator
The terminator is the character that marks the end of each transmission from the Model 263A to the host computer or from the host computer to the Model 263A. It is set from the System menu using the VALUE knob. When the Terminator is set to "CR", the terminator is a Carriage Return. When the Terminator is set to "CRLF", it is a Carriage Return followed by a Line Feed.

The terminator *must be selected according to the requirements of the host computer, sometimes in conjunction with the software it is running.* Failure to satisfy this requirement is one of the most common causes of problems in establishing communications via the GPIB. Note that, no matter what the terminator setting, the Model 263A accepts $\overline{EOI}$ asserted as a terminator, and will itself assert $\overline{EOI}$ with the last character in each message. The terminator required for Apple computers and IBM PC-compatible computers running Princeton Applied Research software is CR.

B.3. General Interface Management Lines

There are five general interface lines. Their function is defined by the standard and briefly discussed in Section B.7. Some additional comment is appropriate for them as they apply to the Model 263A.

First, the instrument recognizes $\overline{ATN}$ and $\overline{IFC}$ as defined in the standard.

$\overline{REN}$ (Remote Enable) transfers the Model 263A from local (front-panel controlled) to remote (GPIB or RS-232C port) operation. The instrument powers up in the local mode. When $\overline{REN}$ is asserted and the proper LISTEN address applied, it transfers to the remote mode, in which the front-panel controls are locked out. Return to local can be accomplished either by deasserting $\overline{REN}$, by applying the multi-line GTL (GO TO LOCAL) message, or by pressing F5 on the front panel of the Model 263A. Note, however, that if the LLO (LOCAL LOCKOUT) multi-line message is applied, transfer to local via F5 will be inhibited.

A command sent via the GPIB bus when the Model 263A is in the local mode (under front-panel control) places the Model 263A in the remote mode. The Model 263A accepts $\overline{EOI}$ as a terminator for a multi-byte message and asserts $\overline{EOI}$ with the last byte of each response. The instrument asserts SRQ when the conditions established by the MSK (MASK) command are satisfied.

B.4. Remote Messages

IEEE-488 defines a large number of multiline messages the controller can place on the bus when $\overline{ATN}$ is asserted. Of these, the Model 263A recognizes TALK, UNTALK, LISTEN, UNLISTEN, GTL (GO TO LOCAL), LLO (LOCAL LOCK OUT), DCL (DEVICE CLEAR), SPE (SERIAL POLL ENABLE), and SPD (SERIAL POLL DISABLE). Each is discussed in the following paragraphs.

1. TALK, UNTALK, LISTEN, and UNLISTEN: The TALK and LISTEN messages direct the Model 263A to assume the talker and listener states, respectively. Similarly, the UNTALK and UNLISTEN commands direct the Model 263A to assume the talker-idle and listener-idle states, respectively.

2. GTL (GO TO LOCAL) returns the instrument to local control. Other ways of restoring local (front- panel) control are to cycle the power, deassert $\overline{REN}$, or to assert $\overline{IFC}$.

   If GTL is used to return to local control, it is only necessary to place the Model 263A's listen address on the bus to reestablish control via the bus.

3. LLO (LOCAL LOCK OUT) inhibits returning the Model 263A to the local mode with the front-panel F5 button.

4. DEVICE CLEAR: The DEVICE CLEAR (DCL) message restores the default values of all Model 263A parameters.

5. SERIAL POLL ENABLE and SERIAL POLL DISABLE: These messages control the serial polling process. The SERIAL POLL ENABLE message tells the Model 263A to prepare to place its status byte (eight-bit binary) on the bus. This actually occurs when the talk address is applied. The SERIAL POLL DISABLE message directs the Model 263A to take its Serial Poll Status byte off of the bus. In making a serial poll, the correct sequence is:

   a. The host computer sends the SERIAL POLL ENABLE message ($\overline{ATN}$ asserted).

   b. The host computer sends the TALK message ($\overline{ATN}$ asserted).

   c. The host computer deasserts $\overline{ATN}$.

   d. The Model 263A sends the Serial Poll Status byte to the host computer.

   e. After reading the Serial Poll Status byte, the host computer reasserts $\overline{ATN}$.

   f. The host computer sends the UNTALK message ($\overline{ATN}$ asserted).

   g. The host computer sends the SERIAL POLL DISABLE message ($\overline{ATN}$ asserted).

When the host computer reads the Serial Poll Status byte, it must transmit the UNTALK and SERIAL POLL DISABLE messages and go on to its next operation. Table B-2 indicates the meaning of each bit of the serial-poll status byte.

By monitoring the COMMAND DONE and OUTPUT READY bits of the Serial Poll Response byte, the computer can obtain the information it needs to pace the flow of commands so as to proceed as rapidly as possible without interfering with the Model 263A. The polling response is handled entirely by the Model 263A's GPIB Interface chip, and does not involve the microprocessor. When the Model 263A has finished carrying out the previous command, Bit 0 will be set. Whenever it has output of any kind ready to send to the computer, Bit 7 will be set.

By polling frequently, the computer will know as soon as possible that there is data available for processing, and/or that the Model 263A is free to accept another command.

The question of when to perform the poll is important. If the computer is dedicated solely to the Model 263A, simply have the computer continually poll the 263A whenever it isn't busy performing another function.

Two approaches can be taken in a multitasking system. The first is to have the computer poll the Model 263A from time to time as part of its basic operating routine. The second is to have the 263A make a service request (assert $\overline{SRQ}$) to generate an interrupt that causes the computer to do a serial poll. The MSK (MASK) command provides the means for determining which events must occur to cause a service request.

The MASK byte and SERIAL POLL STATUS byte are AND'ed in the Model 263A. When any corresponding bits of both the MASK and STATUS bytes are a logic 1, $\overline{SRQ}$ is asserted. This is the mechanism by which the 263A makes a service request. The computer's response should be to do a serial poll, that is, to read the Serial Poll Status byte of every device on the bus. In so doing, the computer will determine which instrument requires service and take the appropriate action. The serial poll clears $\overline{SRQ}$.

Note: It is not necessary that the Model 263A make a service request (assert $\overline{SRQ}$) for the computer to do a serial poll. The computer can do a serial poll at any time. The service request is simply one means of initiating a serial poll, one best suited to use in complex systems where the computer is controlling many devices.

B.5. Troubleshooting GPIB Communications Problems

1. Check the address as set on the System menu with the VALUE knob.

2. Check the Controller's Timeout function. Many controllers (early PET's, HP, etc.) will only wait a short time for an instrument to respond on the bus.

   However, some Model 263A commands could take some time to execute.

Table B-2. SERIAL POLL STATUS BYTE BIT WEIGHTING

BIT	MEANING	COMMENT
BIT 0 (LSB)	COMMAND DONE	Bit 0 is cleared when Model 263A is busy executing a command. It is set when execution of previous command is completed and the Model 263A is ready for a new command.
BIT 1	COMMAND ERROR	Bit 1 is cleared if previous command did not contain an error. It is set if the previous command did contain an error.
BIT 2	CURVE DONE	Bit 2 is cleared if a data acquisition is in progress. It is set if data acquisition is complete.
BIT 3	NOT USED	
BIT 4	OVERLOAD	Bit 4 is cleared if no OVERLOAD is detected. It is set if a Potentiostat overload condition is detected.
BIT 5	SWEEP DONE	Bit 5 is cleared if a data acquisition sweep is in progress. It is set if the previous sweep is complete and next one hasn't started yet.
BIT 6	SRQ	Bit 6 is cleared if service is not being requested. It is set if service is being requested.

BIT 7	OUTPUT READY	Bit 7 is cleared if the Model 263A has no output to dump to the host computer. It is set if the Model 263A does have output to dump to the computer.

3. Check that each command executes fully before sending another one. Some commands take time to execute and must not be interrupted while in execution. Characters received while another command is executing will cause a Error Condition (Error 4; Command Overrun). As discussed in B.4, the OUTPUT READY and COMMAND COMPLETE bits of the Serial Poll Status byte provide a convenient means for maintaining orderly, efficient communications between the Model 263A and the host computer.

4. Check the terminator options on both the controller and the Model 263A. The terminator selected at the Model 263A must be that of the host computer.

B.6. GPIB (IEEE 488, 1978): An Overview

Introduction
It is not necessary to understand the material in the following paragraphs to use the GPIB interface. This information is provided for background only. You may find it helpful in the sense that any background information gives insights useful in problem solving.

Table B-3. GPIB PINOUT

PIN #	FUNCTION
1	$\overline{DIO1}$
2	$\overline{DIO2}$
3	$\overline{DIO3}$
4	$\overline{DIO4}$
5	$\overline{EOI}$
6	$\overline{DAV}$
7	$\overline{NRFD}$
8	$\overline{NDAC}$
9	$\overline{IFC}$
10	$\overline{SRQ}$
11	$\overline{ATN}$
12	SHIELD
13	$\overline{DIO5}$
14	$\overline{DIO6}$
15	$\overline{DIO7}$
16	$\overline{DIO8}$
17	$\overline{REN}$
18	GND 6
19	GND 7
20	GND 8
21	GND 9

22	GND 10
23	GND 11
24	LOGIC GROUND

Description
The IEEE 488-1978 Instrument Bus Standard defines a bit-parallel, byte-serial bus structure designed to allow communications between intelligent instruments. Using this standard, many instruments may be interconnected and remotely controlled or programmed. Data can be taken from, sent to, or transferred between instruments via one connector or port. The standard defines all voltage and current levels, pinouts, connector specifications, timing, and handshake requirements. As a result, it should be possible to take two or more devices equipped with a GPIB port, remove them from their shipping cartons, connect them to the bus, and expect that they will be able to communicate on the bus. However, the standard cannot guarantee that they will necessarily understand one another.

Operating States
With respect to a device (Model 263A) operating on the bus, there are only three operating states, CONTROLLER, TALKER, and LISTENER. The controller (computer) coordinates communications on the bus by commanding the other devices connected to it. Talkers can put information on the bus. Listeners accept messages that have been placed on the bus. The controller generally both talks and listens.

Some devices can operate in only one state. For example, systems could exist where a voltmeter connected to the bus would function as a talker only. A printer on the same bus, by way of contrast, might function as a listener only, providing a permanent record of the voltage readings when commanded to do so by the controller.

Some devices can support more than one of these states. The Model 263A, for example, can act as both a talker and listener, as commanded by the controller.

Although a system could contain more than one controller, only one can be active at a time. Similarly, only one talker at a time can be active. Since listening is a passive activity, more than one device is allowed to listen.

Devices are assigned addresses for identification. The controller activates each device at the proper time by placing its address on the bus. Once the instrument has been "alerted" in this manner, the appropriate command can be transmitted to it. There is provision for commands that will be recognized by all devices, or by only those designated via the addressing technique.

Number and Kinds of Lines
The bus operates with sixteen signal lines. Of these, eight are data lines. The data lines are bidirectional and carry both data and commands. Table B-3 shows the names of the signals by connector pin.

Of the remaining eight lines, three are designated the byte transfer control group. Their function is to implement the handshake required to transmit a data byte or command.

Last is the general interface management group of five lines. These are for single-line commands and status messages. They function independent of the handshake requirement. TTL levels with negative true logic are used throughout.

The Handshake
As mentioned in the preceding paragraph, the handshake is implemented on the three byte-transfer control lines, designated $\overline{DAV}$ (data valid), $\overline{NRFD}$ (not ready for data), and $\overline{NDAC}$ (no data accepted). The following sequence occurs each time a data word or command is transferred. Figure B-1 illustrates a data transfer.

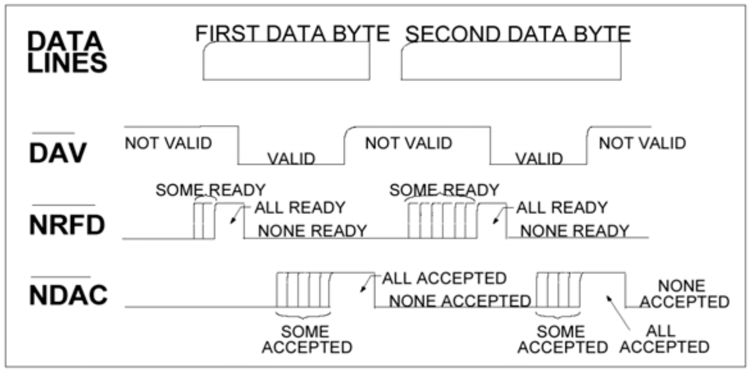

Figure B-1. GPIB DATA TRANSFER

1. In the quiescent state (when data are not being transferred), the talker may or may not have meaningful data on the bus. As far as the upcoming transfer is concerned, it doesn't matter.

2. The talker continuously monitors the $\overline{NRFD}$ line. This line is controlled by all active listeners in such a way that it can change state (low to high) only if every active listener is ready to accept data. As long as any active listener is not ready to accept data, $\overline{NRFD}$ will be low. Once all active listeners are ready, $\overline{NRFD}$ goes high, initiating the transfer.

3. On sensing that $\overline{NRFD}$ has gone high, the talker is free to put data on the bus and pull $\overline{DAV}$ down. If the data are already on the bus (it may have been there for some time), $\overline{DAV}$ goes low immediately. If there are no data on the bus, the byte to be transmitted is placed on the bus first. Then, at least 2 µs later, $\overline{DAV}$ is pulled down, signaling the active listeners that they can read the data byte.

4. On sensing that $\overline{DAV}$ is low, the active listeners know that there is a valid data word on the bus and that they are to read it. In so doing, they become "busy" and $\overline{NRFD}$ returns to the low state, where it remains until every active listener is ready to receive data again.

5. The active listeners also control the $\overline{NDAC}$ line. It is held low during the quiescent state and while the data are being accepted. The active talker monitors the $\overline{NDAC}$ line. Only when every listener has accepted the data byte does this line go high, notifying the talker that the data byte has been transmitted.

6. On sensing the positive transition of $\overline{NDAC}$, the talker releases $\overline{DAV}$, allowing it to return to the high state. The listeners sense this and respond by again pulling down $\overline{NDAC}$, thereby restoring the quiescent conditions in preparation for the next data transfer.

This sequence repeats with the transmission of every data or command byte.

General Interface Management Group

1. $\overline{ATN}$ (Attention): This is a critically important line. When asserted (low), it causes the active talker to relinquish control of the $\overline{DAV}$ line. The controller takes the place of the active talker, and both talkers and listeners alike accept the specific control information transmitted when $\overline{ATN}$ is asserted.

   Note: Some of the codes transmitted when $\overline{ATN}$ is asserted will have different but equally valid meanings if transmitted when $\overline{ATN}$ isn't asserted. The commands that can be transmitted when $\overline{ATN}$ is asserted, Remote Message commands, are defined by the standard. $\overline{ATN}$ is also asserted when transmitting an address. A device becomes an active talker when its talk address is placed on the bus. It becomes an active listener when its listen address is placed on the bus. Commands asserted when $\overline{ATN}$ is not asserted are device dependent.

A given device connected to the bus needn't understand all of the standard commands. Individual device manufacturers can select the commands their device will recognize. Should the others appear on the bus, they will simply be ignored.

2. $\overline{IFC}$ (Interface Clear): This line is asserted (pulled low) to override all bus activity and return the bus to a known "clear" state. Ordinarily, it is not used, but is reserved for system initialization or for situations where something has gone wrong. Any data on the bus may be lost when $\overline{IFC}$ is asserted.

3. $\overline{REN}$ (Remote Enable): This line is asserted to enable transfer of devices on the bus from local to remote control. The device does not actually go from the local control to remote control until it is addressed to listen while $\overline{REN}$ is asserted.

4. $\overline{EOI}$ (End or Identify): This line may be asserted by the talker to designate the last byte of a multi-byte message. This is referred to as the END message.

   Note: The Model 263A does not support parallel polling.

5. $\overline{SRQ}$ (Service Request): All devices on the bus share this line. Any device on the bus can assert the line, indicating to the controller that some device requires attention. For example, a voltmeter might assert $\overline{SRQ}$ after it has taken a reading to tell the controller it's ready to place the reading on the bus for transfer and further processing. All service requests look alike. The controller must use serial polling to identify the devices requiring service.

   In polling, the SERIAL POLL ENABLE message is transmitted by the controller to put all devices into the serial-poll mode. Then, every device on the bus is successively queried as to its status by the controller. In each case, the device answers with an eight-bit status byte that carries the necessary information. The controller then transmits a SERIAL POLL DISABLE message to return the device to the data mode. Assuming the devices on the bus support serial polling, by the time the controller has queried each device, it will "know" which one required the service, and will act accordingly.

Addressing
Addressing is an essential GPIB concept. Each device on the bus is assigned a listen address and a talk address (assuming both are relevant to the device in question). These addresses are set at the device. When the controller wishes to communicate with a specific device on the bus, it places the listen address of the device on the bus. Only the device having the corresponding address will respond to the subsequent message. Similarly, if the controller wants a device to talk, it sends the talk address of the device in question. The addressed device will transmit only until a different talker is designated.

Summary
The preceding discussion of how the GPIB functions is by no means complete. A great deal of additional detail has to be considered by device designers. The principal responsibility of the user is to provide the controller program that coordinates all the bus activity necessary to accomplish the task at hand. For more detailed information concerning IEEE 488.1, 1987, the reader is advised to purchase a copy of the standard from:

IEEE
345 East 47th St.
New York, New York 10010

APPENDIX C. RS-232C INTERFACE

C.1. Introduction

RS-232 is an industry standard *serial* data communications interface. It is widely used for communications between digital devices such as computers, terminals, printers, and telephone links. RS-232 is capable of bidirectional data transfer between digital devices.

Both devices must be equipped with an RS-232 interface for data transfer. Virtually every modern computer has RS-232 capability as standard or optional equipment. RS-232 interfacing specifies data transfer as a stream of serial characters. Usually ASCII (American Standard Code for Information Interchange) coding, which defines each character as a specific set of seven bits, is used. For example, the character sequence "-0.200V" is seven characters long. The RS-232 circuit translates each of the seven characters into the proper bit sequence and transmits each character sequentially to the receiving device.

The RS-232 Standard specifies many parameters, such as voltage (logic) levels and transfer rates, for data transfer. However, some parameters have optional values that are user selectable. *The user must be aware of these parameters, since all parameters must be the same on both devices for proper communication.*

The user-selectable RS-232 parameters are baud rate, data word length, parity, and stop-bit configuration. These four parameters must be selected to be exactly the same on both devices. Some of the parameters may be fixed by one of the devices, in which case the other device must be configured to match the fixed parameters.

If the devices are transferring data back and forth, some method of determining the readiness of the receiving device is needed, especially for rapid data transfer. "Handshaking" is a term used to describe this function. As explained in Section C.4, a more detailed general discussion of RS-232, the RS-232 handshake system was designed for a specific limited application, and is not well suited to general interface use. As a result, RS-232 communications are particularly prone to handshake problems.

C.2. RS-232 in the Model 263A

Introduction
A key difference between GPIB and RS-232 communications as implemented in the Model 263A has to do with the concept of LOCAL versus REMOTE, that is, control via a front panel or by remote messages applied to an interface port, neither of which can be simultaneously active. The RS-232 port is always active. In principle, if GPIB REN is asserted, one could use both the GPIB and RS-232 ports simultaneously (not recommended). There is no logic in the Model 263A to arbitrate between RS-232 and GPIB communications.

Before the Serial Interface can be used, several factors have to be considered. Included are the details of the pinout, construction of the interconnecting cable, the handshake, and several user-controlled serial interface parameters, all discussed in the following paragraphs.

RS-232 Parameter Settings
The Baud rate, number of data bits, parity, and number of stop bits must be the same for both the Model 263A and the device with which it is communicating via the RS-232 bus. These parameters are set with the VALUE knob on the front panel of the Model 263A. The parameters appear on the third line of the System menu on the front-panel LCD display. To set an RS-232 parameter:

1. If the [System Interface] menu is not displayed on the LCD panel, press the SYSTEM pushbutton as many times as necessary to bring it up. Pressing this pushbutton cycles through three menus: FUNCTION, one of the potentiostatic or galvanostatic experiment menus, and SYSTEM.

2. Press the PARAMETER pushbuttons (PREV and NEXT) as many times as necessary to bring up the desired parameter on the third line of the display. Pressing these pushbuttons cycle through the user-selectable parameters.

3. Set the parameter to the desired value by turning the VALUE knob.

Each of the user-selectable RS-232 parameters is discussed in the following paragraphs.

Serial Stop Bits: Either one or two stop bits can be selected. Two stop bits give more reliable communications at high baud rates.

Serial Echo: Gives the user the choice of echo or no-echo operation. If echo is selected, each character received via the RS-232 port will be echoed back to the character source. The RS-232 echo is normally used only when the Model 263A is connected to a CRT terminal. **Note:** Do not confuse this function with the GPIB ECHO.

Serial Parity: The user has the choice of PARITY ODD, PARITY EVEN, or PARITY NONE. Parity maintenance involves keeping the total number of "1's" in the data (START and STOP bits don't count) either even or odd, as desired. If odd parity is selected, the parity bit will be "1" when that is necessary to have the total number of data bits, including the parity bit, odd. For example, if the data word in question is 0010010, the parity bit would be "1" so that there would be three "1's" in all. If the number of "1's" in the word is already odd, such as in the word 0010110, the parity bit would be a "0". Even parity is similar except that the parity bit is made "1" or "0" as necessary to keep the total number of "1's", including the parity bit, even.

The utility of parity maintenance is that it provides a direct way of detecting garbled data if the computer is programmed to only accept words having the selected parity. If a word having incorrect parity is read, it is a message to the computer that data loss is occurring.

Serial Baud Rate: This setting allows baud rates from 110 to 19.2 k baud to be selected. Note that at baud rates of 9.6 k and 19.2 k, the recommended parameters are a character length of eight bits, no parity, and two stop bits. When **Line Sync** is enabled, baud rates above 9.6k are not recommended.

Character Length: A character length of either seven bits or eight bits can be selected. Most communications are in ASCII, a seven-bit code. However, eight-bit coding, convenient for byte-oriented I/O, is provided. If "8" is selected, the Model 263A will always send a "0" as the eighth (MSB) bit when transmitting ASCII codes. Eight data bits are required for binary data transfers, with bit 7 the sign bit.

Word Construction

Between transmissions, the transmit data line rests at the low-voltage level. Each transmission begins with a START bit, the leading edge of which is marked by the transmit line going to the positive voltage level. The START bit is then followed by the seven data bits that define the character being transmitted. Bit 8, if transmitted, is a logic 0 for ASCII characters.

Negative true logic is used for data. A logic 1 is represented by -12 V. A logic 0 is represented by +12 V. (In no case apply voltages higher than 12 V to the RS-232 port.)

The ASCII Character code is used and the most significant bit is sent first. If the user has elected to include a parity bit, it directly follows the bits that define the character.

The parity bit is followed by either one or two STOP bits, as selected. The STOP bits are at the negative-voltage level, returning the line to the quiescent state. If the user has selected "Parity = NONE", the parity bit time slot will be deleted, and the time slot immediately following the last data bit will be allocated to a STOP bit.

Prompts and Command Overruns

In RS-232 communications, command overruns (sending a command while the Model 263A is still busy executing the previous command) are prevented by using the prompt function provided. Assuming all RS-232 parameters have been set properly, the host computer will receive a prompt character from the Model 263A when it is ready for a new command. If the previously executed command generated no errors in the Model 263A (such as Invalid

Command), the prompt character will be an asterisk (*). If the previously executed command did generate an error in the Model 263A, the prompt is a question mark (?). The prompt is transmitted after power up and after completion of any command. By waiting for the prompt character, Command Overrun errors will be avoided.

Terminator
When two RS-232 compatible devices are communicating, their protocol requirements may well be such as to require no special terminator considerations. More frequently, however, one device or the other will have specific terminator requirements that will have to be observed for proper operation.

If the Model 263A is communicating with an external computer via the RS-232 port, the choice of terminator is critical. The terminator is the character that marks the end of each transmission from the Model 263A to the external computer or from the external computer to the 263A. It is set from the System menu using the VALUE knob. When the terminator is set to "CR", the terminator is a Carriage Return. When the terminator is set to "CRLF", it is a Carriage Return followed by a Line Feed.

The terminator *must be selected according to the requirements of the host computer.* Failure to satisfy this requirement is one of the most common causes of problems in establishing communications with an external computer via the RS-232 port.

Cable and Pinout
No serial interface cable is supplied with the Model 263A. Suitable cables and connectors are readily available from commercial sources. A standard null-modem cable will work with most microcomputers whose RS-232 port is configured as Data Terminal Equipment (DTE). The RS-232 port pinout is provided in the appendix of the *Model 263A User's Guide*.

RS-232 Summary
The preceding paragraphs contain all the information a user needs to know about the Serial Interface. To actually use the interface to control the Model 263A, the user will additionally have to understand and implement the appropriate user commands applied according to the requirements of the Model 263A Interface Communications Protocol. The protocol is discussed in Appendix A. The device-dependent commands recognized by the Model 263A are discussed in Chapter 5 of the *Model 263A User's Guide*.

C.3. Troubleshooting RS-232 Communications Problems

1. Check the wiring of the RS-232 connector. The Transmit Data line of one device must be connected to the Receive Data line of the other.

   The Clear to Send Input line of each device must be connected to the other's Request to Send or to a voltage in the range of +5 V to +12 V. The Model 263A's Clear to Send is internally pulled up to +12 V and so may be left unconnected.

2. Check that the following settings agree on both the Model 263A and host computer:

   - Baud rate.
   - Number of character bits in the serial data word.
   - Logic state of the eighth character bit, if selected.
   - Parity settings.
   - Number of stop bits.

3. Check that the host computer and Model 263A agree on the terminator character, either <CR> or <CRLF>. The terminator set at the Model 263A should be that of the host computer (normally <CR>).

4. Avoid command overruns; make the host computer wait for the RS-232 prompt character before sending a new command.

5. Check that there are no timing problems. Two different timing problems are commonly encountered when RS-232 is used to interface a host computer to a device. Both are associated with responses from the device to the host.

   First, when the host sends a command to the device, the host must be ready to accept the response from the device before the device sends the first character of the response. There are three methods for solving this problem. The host's program can be written to have a fast turnaround from the portion that sends the command to the portion that receives the response. This is not always possible with a slow, high-level language. It may work at low baud rates, but it is not a guaranteed solution. Alternatively, the host can use its Request to Send line to inhibit the device's Clear to Send line until the host is ready to receive the device's output. Finally, the host can be programmed to accept the device's output stream under interrupt control. This is a reliable method, but it requires intimate knowledge of the host computer's hardware and assembly language.

   Second, once the device's output stream starts, the host must be able to accept characters as fast as the device can send them. This can be assured by selecting a very low baud rate. To allow data transfer at high baud rates, it may be necessary to code the host's input routine in assembly language. Whether in high-level or assembly language, the host's program should accept the entire output stream of the device in a tight loop.

   It is advisable to start out at a very low baud rate such as 300 baud. Once the host's program is seen to be working, the baud rate can be raised as high as the host's software will allow.

   The data stream can be cut off by making the Clear-to-Send line negative or by applying X-OFF (CONTROL S). If this is done, the Model 263A will finish transmitting the character being processed at that instant, and possibly one more besides. Data transmission can be resumed by setting Clear to Send positive or by sending X-ON. As long as the computer's software anticipates that one or two more characters will be forthcoming, this is a perfectly legitimate means of controlling the data flow with a Model 263A. However, since this is definitely not in accordance with the RS-232 Standard, users should not infer that RS-232 communications with other devices can be controlled in this way.

6. In the case of intractable problems, it might prove helpful to monitor the controller's output line with an oscilloscope. One effective approach to doing this is to program the controller to transmit the letter "U" (alternate 1's and 0's) in a repeating loop. If the scope is adjusted to trigger about ground on a positive transition and the X-axis display is calibrated so that the time per division equals one bit period, the serial data can be easily examined and decoded. Any RS-232 parameter discrepancies can then be determined and corrected. The output of the Model 263A can be similarly checked by setting Serial Echo = ON and observing the Model 263A echo the "U" from the host computer.

   A logic bus analyzer, such as those manufactured by Hewlett Packard, Tektronix, or Interface Technology, may also prove useful.

One final note. If you find it necessary to change from the default settings of the computer to make it work with the Model 263A, be sure to bypass the computer's I/O re-initialization routines. They may restore the default values and so cause messages to be garbled.

C.4. History and Problems of RS-232

The remainder of this appendix consists of general discussion of the history and problems of RS-232. An understanding of this material is in no way essential to using the RS-232 Interface. It is simply provided as a source of additional background for those who may be interested.

RS-232 is a standard serial communications protocol that defines signal and mechanical requirements for communications between a DTE (Data Terminal Equipment), typically a computer or a video terminal, and a DCE (Data Communications Equipment), a modem.

This standard has served well and is the basis for almost all long-distance data transmission. However, its very success has led to its adoption in applications for which it was not intended. Today there are countless communications links that use the RS-232 standard, even though the standard is not intended to apply to them. Computers, printers, terminals, measuring instruments, etc., are frequently provided with "RS-232 compatible" serial data links. However, since many of these devices are neither terminals nor modems, they cannot, by definition, comply strictly with RS-232. Although users may expect that two pieces of equipment having RS-232 ports should successfully communicate as soon as they are connected, it frequently happens that they do not.

There are several possible reasons why successful communications may be thwarted. The first stems from the direction of the data flow as a function of the assigned interconnecting wire. The standard specifies that data transmitted from a terminal to a modem be routed via pin 2 of the terminal connector. Data received from the modem must enter the terminal via pin 3 of its interface connector. Where the device in question is neither a terminal nor a modem, the manufacturer has to arbitrarily select which pin is used to output data and which to receive data. As a result, it sometimes happens that users have to cross-wire from pin 2 to pin 3 for two pieces of "RS-232 Standard" equipment to communicate.

Handshake compatibility is another problem, sometimes a serious one. RS-232 has limited handshake requirements. The standard is concerned solely with terminal-modem communications, and the Request-to-Send and Clear-to-Send lines (pins 4 and 5 respectively) fill that requirement. They do not necessarily satisfy the handshake requirements for other equipment. According to the standard, the DTE is supposed to assert Request-to-Send when it has data to send. Having asserted Request-to-Send, it is then supposed to wait for Clear-to-Send to be asserted by the DCE. Thus far no problem.

Once data transfer begins, however, the DCE is not allowed to drop Clear-to-Send until the DTE drops Request-to-Send. Clearly there is a potential for the DCE being asked to take a longer drink than it can handle. If the Clear-to-Send line is arbitrarily used as a spigot to turn the data flow on and off (definitely not according to the standard), there is the question of determining just when it should switch. If it changes state when its buffer is full, it might stop in the middle of a character and garble the data. If it waits, the buffer will overflow and data will be lost. The problem is simply that RS-232 was not designed for the job it is often asked to do, even though it can generally be made to work.

Note: As stated in C.3, RS-232 data flow from the Model 263A can be cut off by bringing Clear-to-Send to its negative state, or by applying X-OFF (CONTROL S). The Model 263A will finish sending the character being processed, and possibly one more as well. If the host computer's software is prepared to handle these one or two additional characters, this is a perfectly legitimate way of controlling the data flow. Bear in mind, however, that controlling in this manner is not in accordance with the standard, and may not work for other RS-232 compatible devices.

Another problem has its origin in the RS-232 voltage levels. Because TTL is so ubiquitous in modern electronic designs, it is all too easy to assume that TTL devices and levels apply everywhere. However, RS-232 was around long before TTL, and its voltage levels differ from those of TTL. Negative true logic is used for data communications; positive true logic is used for commands. The levels are +3 V to +25 V for the positive logic level, and -3 V to -25 V for the negative logic level. The region between ±3 V is undefined. As a result, designers cannot use TTL devices in implementing RS-232 communications.

Note: The actual levels used in the Model 263A are ±12 V. Do not apply voltages higher than ±12 V to the Model 263A's RS-232 port.

Users also must take care to ascertain that both pieces of equipment operate at the same data-transmission rate (baud rate), agree on parity, have the same number of stop bits, and use the same character code (usually ASCII). A mismatch in any one of these parameters will cause data to be garbled or lost.

Between data transmissions, the data lines idle at the negative logic level. As shown in Figure C-1, each transmission begins with a start bit, the leading edge of which is defined by the data line going positive (logic 0). The start bit lasts for one bit time (the duration of each bit is set by the baud rate), and acts as a signal to the receiving device to begin sampling the level on the line at the center of each bit time interval in the sequence. Clearly, both devices must agree as to the number of bits to follow if they are to communicate successfully.

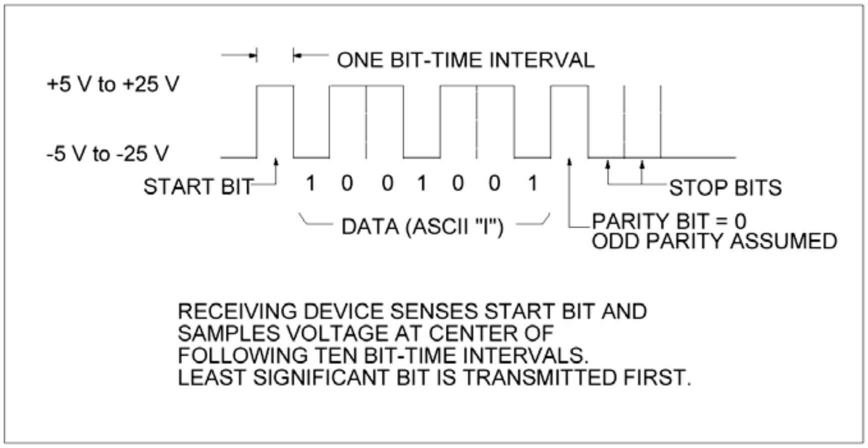

Figure C-1. TYPICAL RS-232 DATA WORD

The start bit is followed by the data bits, seven for ASCII, that define the character transmitted. Next is the parity bit. RS-232 allows even parity, odd parity, or no parity (no parity-bit time interval included in the sequence). However, both instruments have to be set the same with respect to the parity bit. The parity bit is then followed by either one or two stop bits. The line comes back to the negative logic level for the duration of the stop bits and continues idling at the negative level until another start bit is transmitted to mark the beginning of the subsequent communication.

Most RS-232 compatible devices have provision for user selection and control of the parity bit, the number of stop bits, and the baud rate. Most use the ASCII code. Sometimes eight bits are used instead of seven, convenient for byte-oriented I/O. Successful communications can usually be established. It's just not so straightforward as expected.

Serial interfacing is popular and reliable. However, when two pieces of equipment are to communicate serially, the communications link must be established with care and attention to detail, even though both devices have serial ports implemented "in accordance with the RS-232 Standard." Users who wish to have more detailed information about the RS-232 standard can purchase a copy of the standard from:

Electronic Industries Association
Engineering Department
2001 I Street, N.W.
Washington, DC

APPENDIX D. WAVEFORM PROGRAMMING

D.1. Introduction

The Model 263A Potentiostat/Galvanostat is a powerful and versatile instrument for computer-assisted electrochemistry. Its internal command set allows a wide variety of electrochemical experiments. Two 14-bit Digital-to-Analog Converters (DACs) provide flexible and precise control of the controlled potential or current for electrochemical techniques. A 12-bit Analog-to-Digital Converter (ADC) allows rapid and convenient data acquisition.

The Model 263A's functions can be divided into the following categories:

- Waveform Generation
- Data Acquisition
- Data Manipulation
- Data Transfer

Of these functions, waveform generation is the most complex to understand, due to the great variety of techniques that can be employed to achieve the experimental goal. Some of the capabilities of data acquisition, data manipulation, and data transfer will be discussed, since all of these functions can be used in waveform generation. However, this appendix will deal primarily with waveform programming techniques.

D.2. Model 263A Memory Usage

The Model 263A has memory enough to store 6144 data values in as many as six curves (Curve 0 through Curve 5). The maximum number of curves depends on their length, up to the maximum of six curves. If a curve is short (1024 or fewer points), the 6144-point memory is large enough to allow the maximum of six curves. At the other extreme, if a curve is longer than 3072 points, the 6144-point memory will only be large enough for one curve. Unused memory capacity is simply unavailable. For example, a 5000-point curve would leave 1144 points unused and unavailable.

For purposes of memory partitioning, the curve length is defined as LP + 1, where LP is the operand of the LP (LAST POINT) command. For example, if the last point as designated by the LP command is 1024, the curve length would be considered to be 1025 points. As indicated in the table that follows, there would only be room for three curves of this length in memory. If the curve length were reduced by a single point, the number of curves that could be stored would increase from three to six, the maximum.

Curves are identified by numbers, and each curve always begins at a specific point in memory. The numbers range from 0 to 5, that is, six numbers to designate as many as the maximum of six curves. The point at which each curve begins is given in Figure D-1.

CURVE 0	0
CURVE 1	1024
CURVE 2	2048
CURVE 3	3072
CURVE 4	4096
CURVE 5	5120

Figure D-1. STARTING MEMORY ADDRESS FOR EACH CURVE.

In other words, the starting location of each curve in memory is always the same. (Knowing these locations is critical when doing data dumps from the Model 263A to the host computer.) For a given curve length, as determined by the LP command, only specific curves will be available, as indicated in the list that follows. For example, if the curve length were such as to allow six curves, all six curves, 0 through 5, would be available. On the other hand, if the curve length were such as to allow three curves, the available curves would be 0, 2, and 4, and the starting location of each would be as listed in Figure D-1. Curves 1, 3, and 5 would not be available and could not be designated.

CURVE LENGTH	# AVAIL.	NUMBER(S)
3073 to 6144	1	0
2049 to 3072	2	0 & 3
1025 to 2048	3	0, 2, & 4
1 to 1024	6	0, 1, 2, 3, 4, & 5

Each point is a 16-bit signed integer (-32767 to +32767). By making the capacity of the memory locations (nominally 32000) much larger than the full-scale output of the analog-to-digital converter (nominally 2000), room is provided for sweep averaging. In the linear averaging mode, sixteen sweeps containing full-scale values could be averaged without overflowing the memory. In the exponential averaging mode, a very large number of sweeps could be averaged since the value at convergence won't exceed the value at the output of the analog-to-digital converter for that point.

Functionally, there are five kinds of curves. They are:

1. SOURCE CURVE: Data stored in the Source Curve define a modulation waveform. If the MM 2 command has been executed, the modulation waveform stored in the SOURCE CURVE will be applied during subsequent curve acquisitions.

2. DESTINATION CURVE: This is the curve into which data will be placed during curve acquisitions. I, E, and ΔE (the current-interrupt compensation potential) could all be stored in successive curves as determined by the SIE command. The first curve is the Destination Curve. The other or others, according to the data designations made with the SIE command, are NEXT CURVES.

3. NEXT CURVE: This is the curve into which E or ΔE data are placed during curve acquisitions. There can be zero, one, two, or five Next Curves according to the SIE selection. NEXT CURVES, if present, always immediately follow the DESTINATION CURVE.

4. ALTERNATE CURVE: During a run comprising many sweeps, it is possible to store the measurement results obtained on some number of sweeps in one curve, and the measurement results obtained on the remainder of the sweeps in another curve. The first set of results is stored in the DESTINATION CURVE. The curve in which the results for the remainder are stored is the ALTERNATE CURVE.

   The Alternate Curve capability facilitates collecting two data sets in one experiment. For example, in cyclic voltammetry, the two sweeps of most interest are the first sweep and the Nth (or steady state sweep). The Model 263A can be used to collect data for the first sweep in the Destination Curve, then collect the steady state data in the Alternate Curve.

5. PROCESSING CURVE: A curve on which postacquisition processing (see descriptions of Processing Commands, ADD, SUB, EX, MIN, IMIN, MAX, IMAX, INT, IINT, and ILOG) is performed is the PROCESSING CURVE. A given curve can be a PROCESSING CURVE as well as one of the other previously described kinds of curves. For example, you could designate Curve 1 as both the DESTINATION CURVE and as the PROCESSING CURVE.

As discussed in Chapter 2, commands are provided that allow the operator to designate curve functions. In using these commands, it is essential that the constraints on the number of allowable curves, and on the available curve-designation numbers be observed.

Using these curve names, the Model 263A memory can be used with great efficiency to perform a wide variety of experiments. Since data acquisition is the desired end of producing a waveform with this system, you will note the commands FP (First Point) and LP (Last Point) used with every experiment in this appendix. FP and LP instruct the Model 263A on the number of data points to collect. FP and LP define point numbers in the Destination Curve memory, not direct memory addresses. If DCV is 0, then FP 0 means to start storing data in point 0 of Curve 0. If DCV is 2, FP 0 means to start storing data in point 0 of Curve 2, which is really point 2048 in the Model 263A memory. FP is usually set to 0. The same relative addressing applies to LP. For all examples given here, DCV will always be 0 for consistency.

D.3. DAC Descriptions

One DAC is called the Bias DAC. The Bias DAC has a range of ±8000 mV in controlled potential mode or two times the full-scale setting of the I/E converter in controlled current mode.

The second DAC is the Modulation DAC. This DAC can be used to apply waveforms of virtually any shape to the cell. The Modulation DAC can be used to apply complex waveforms far beyond the capabilities of an analog waveform programmer. Since the Modulation DAC is the heart of waveform generation using the Model 263A Potentiostat/Galvanostat, it will be discussed in detail.

The Modulation DAC, unlike the Bias DAC, has three full scale ranges selected by the MR command (Modulation Range). The modulation range covers a minimum of ±8000 counts. If the 91 option has been installed, this range is increased to ±16000 counts in Modulation Modes 0 and 1. If the 91 option has been installed and Modulation Mode 2 is selected, an arbitrary waveform between ±32000 counts can be downloaded. The ranges and resolution for each scale are shown below:

CMD	FS (mV)	CNTL E CNTS/mV	RESOLUTION (mV)
MR 0	±20	400	0.0025
MR 1	±200	40	0.025
MR 2	±2000	4	0.25

The available resolution of the Modulation DAC is dependent on the full scale setting for the DAC. In all cases, however, the percent precision for any range is 0.012% of full scale.

In the Control I mode, the Modulation DAC has the same range as the Bias DAC, 2 times full scale of the I/E converter. The range and resolution as a function of the MR command are as shown below.

CMD	RANGE (% F.S.)	RESOLUTION (% f.s.)
MR 0	2 % f.s.	0.00025
MR 1	20 % f.s.	0.0025
MR 2	200 % f.s.	0.025

The Modulation DAC can be programmed by the Ramp Program Commands (INITIAL and VERTEX) or point-by-point in a mode called the Arbitrary Waveform Mode. The method selected depends on the complexity of the desired waveform and/or on the degree of control over the experiment desired by the chemist.

D.4. Modulation Modes

There are three modulation modes available in the Model 263A. The desired mode is selected by the Modulation Mode Command, MM. The types of modulation are defined as:

MM 0 No Modulation
MM 1 Ramp Program Modulation
MM 2 Arbitrary Waveform Modulation

The Modulation Mode determines the source of modulation information for the Model 263A. Modulation Mode 0 has no modulation at all; the Modulation DAC is not updated during the experiment (it is not automatically zeroed in this mode, simply not changed. The command MOD 0 can be used to zero the Modulation DAC). Modulation Mode 1 uses the Ramp Program commands to generate the Modulation DAC values during the experiment. Modulation Mode 2 requires that the user specify the modulation waveform point-by-point and store the waveform in the Model 263A memory before the experiment begins.

D.5. Experiment Timing

The primary topic of this application note is to discuss methods of generating waveforms with the Model 263A. However, there is some overlap between the data-acquisition commands and the waveform-programming commands. This overlap deals with the timing of the experiment.

Experiment timing can be referred to as "scan rate" or "step time" when dealing with waveform generation or "data acquisition rate" when discussing data acquisition. It's obvious that the two functions must be related. Otherwise, synchronization between the modulation waveform and the data would be difficult to determine.

The commands to control this timing are TMB (Timebase) and S/P (Samples per Point). In most cases, the time to acquire one data point or to update the Modulation DAC according to the programmed waveform is equal to the product of the two parameters:

Rate = TMB (microseconds) * S/P

D.6. Waveform Constraints

The design of the Model 263A requires that the Modulation DAC be updated at least once for each data point collected and stored by the instrument. This is an important consideration in designing waveforms on the Model 263A, since it is not possible to program in varying "dead times" between data points. The time between data points is the timebase multiplied by the samples/point.

If the timebase is less than 500 µs, the Model 263A uses a special high-speed data-acquisition mode, in which most of the instrument's special functions are bypassed. The only waveform mode available is the Arbitrary Waveform Mode. Samples per point (S/P), point averaging (PAM), overload checking (OVER), and experiment monitoring functions are ignored.

In the Arbitrary Waveform Mode, the waveform is usually (*but not always*) sent point-by-point from the host computer to the Model 263A, then stored in the Source Curve memory (defined by the SCV command). Point- by-point definition provides maximum flexibility in waveform shape. In this mode, the Model 263A can acquire data as rapidly as 104 µs/point (10000 points/second). The penalty is memory; the Source Curve does occupy a portion of the data memory. If the waveform is to only be applied once, the data can overlay the waveform, allowing use of the full 6144-point memory (one parameter stored; see D.2, MODEL 263A MEMORY USAGE). **Note:** This overlay technique cannot be used if doing Sweep Averaging (SAM 1 or 2). SCV and DCV must be separate curves, limiting the maximum curve length to 3072 points.

In the Ramp Program Mode, the waveform is calculated "on the fly" by the Model 263A during the experiment. The waveform does not occupy any of the 6144 data point memory of the instrument during the experiment. The penalty for this feature is time.

An important command in the Model 263A is INTRP (Interpolate Modulation). This command can have two values, "1" for on and "0" for off. When on, the INTRP command instructs the Model 263A to update the Modulation DAC once per sample, rather than once per point. If samples per point (S/P) is greater than one, the Model 263A will automatically calculate the smallest step size that it can apply to the cell while maintaining the experiment timing. This feature aids in approximating an analog waveform by applying small steps. There will be occasions where this function is not desired. For example, if a discreet step is required, such as in square-wave voltammetry, the INTRP function must be turned off.

D.7. No Modulation Mode - “MM 0"

Some experiments require no modulation. Chronoamperometry is often performed by applying a constant potential to the working electrode, then monitoring current as a function of time.

Chronopotentiometry involves the application of a constant current, monitoring the potential as a function of time. A third type of experiment requiring no modulation is one in which the open-circuit potential of the cell is monitored as a function of time.

In these experiments, Modulation Mode 0 is used. Any applied potential or current is set using one of the following commands:

BIAS	Set Bias DAC (Control I or E Mode)
SETE	Set Cell Potential (Control E Mode)
SETI	Set Cell Current (Control I Mode)

D.8. Ramp Program Mode - “MM 1"

The Ramp Program Mode is selected by the command MM 1 (Modulation Mode 1). The Model 263A is instructed to generate a waveform defined by the vertices of the waveform. Up to 50 vertices can be

defined, allowing a great degree of flexibility. This flexibility is the result of using a digital waveform programmer.

The use of the Ramp Program Mode requires that the vertices of the waveform be defined in terms of data-point numbers and Modulation DAC values. DAC values are used in place of real units, such as mV, since the modulation may be either current or potential, thus providing the greatest flexibility. The INITIAL command is always used to define the first vertex. The INITIAL command instructs the Model 263A that a new waveform program is starting, plus it defines the first data point to be used during the acquisition. Subsequent vertices are defined by a VERTEX command. Each vertex of the waveform must be defined in the same sequence as their appearance in the experiment.

For example, suppose we wished to perform a linear sweep voltammetry experiment starting at 0 V and ending at +1.000 V (all potentials will be versus the reference electrode). Since the potential range is 1000 mV, we must use the ±2000 mV range (MR 2) of the Modulation DAC. There are two vertices in the waveform, one being the Initial Potential and the other the Final Potential. Since the potentials are 0 and 1000 mV, the Modulation DAC values at the vertices are 0 and 4000, respectively (4 counts/mV * 1000 mV).

The next parameter to decide is the resolution of the data points. If we wish to collect one data point/mV, we would collect 1000 data points. Thus the commands to define our waveform are:

FP 0	(First Data Point Number)
LP 999	(Last Data Point Number)
INITIAL 0 0	(start at point zero, MOD DAC 0 counts)
VERTEX 999 4000	(ramp to point 999, MOD DAC 4000 counts)

Note that we have only defined the shape of the waveform, not the scan rate. If we wished to perform this experiment at a scan rate of 100 mV/second, the following commands must be added:

TMB 10000	(Timebase 10000 µs)
S/P 1	(Collect 1 Sample/Point)

Note that any combination of TMB and S/P equal to 10000 would result in the same scan rate.

Figure D-2 depicts the ramp waveform in this example, indicating the commands to define each vertex. If we change the data density to collect one data point for each 2 mV of the scan, the second command would become VERTEX 499 4000, and we would change the Last Point command to LP 499. To maintain the same scan rate, we would have to slow the timebase by a factor of two, to 20000. Otherwise, collecting half the data points would require only half the time, doubling the scan rate.

FP 0	(First Data Point Number)
LP 999	(Last Data Point Number)
INITIAL 0 0	(start at point zero, MOD DAC 0 counts)

VERTEX 999 4000	(ramp to point 999, MOD DAC 4000 counts)
TMB 10000	(Timebase 10000 µs)
S/P 1	(Collect 1 Sample/Point)

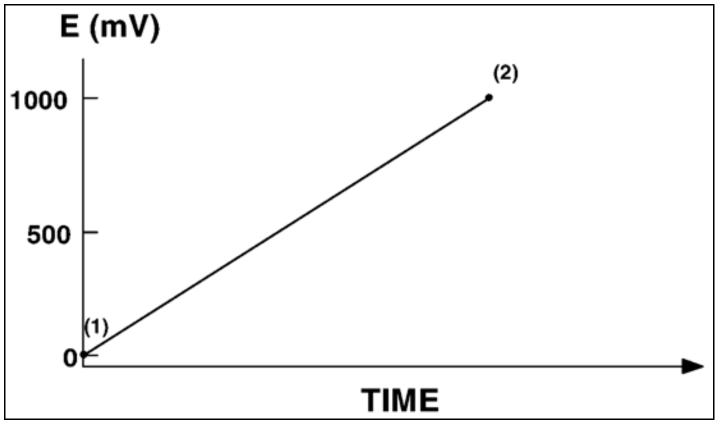

Figure D-2. RAMP WAVEFORM FOR LINEAR SWEEP EXPERIMENT.

Consider another experiment, one in which we wish to apply the waveform shown in Figure D-3. The Initial Potential is -0.2 V, ramping to +1.2 V, then ramping to -0.6 V, and finally ramping to 0.0 V. There are four vertices in this waveform as shown in Figure D-3. We wish to scan at 20 mV/second. In addition, we wish to maximize data resolution, i.e., we want to collect as many data points as possible. The absolute maximum is 6144 in the Model 263A memory.

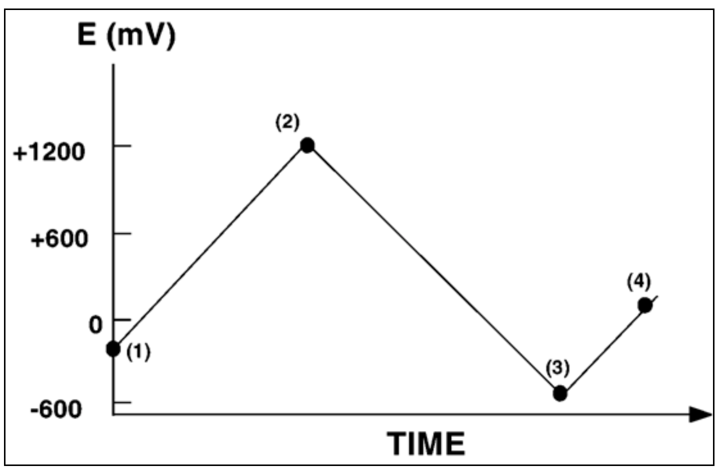

Figure D-3. WAVEFORM FOR RAMP PROGRAM EXPERIMENT.

Since the greatest potential range is 1800 mV (-0.6 to +1.2 V), we must use the 2000 mV range on the Modulation DAC (MR 2). If we number our vertices one through four, the Modulation DAC will have the following values at each vertex:

VERTEX	POTENTIAL	MODULATION DAC
1	-200 mV	-800
2	+1200 mV	+4800
3	-600 mV	-2400
4	0 mV	0

The next step is to calculate the resolution we can achieve for the experiment. This is done by adding up the total mV scanned by each ramp of the waveform:

	FROM	TO	RANGE
	-200 mV	+1200 mV	1400 mV
plus	+1200 mV	-600 mV	1800 mV
plus	-600 mV	0 mV	600 mV
TOTAL RANGE			3800 mV

The best resolution we can achieve is 1 mV/point, for a total of 3800 data points. Since 10 mV/second is equal to 1 mV every 100 ms, the TMB * S/P must be equal to 100000. The maximum value for TMB is 50000, so one acceptable pair of values would be TMB 50000 and S/P 2. The complete series of commands to define the waveform are:

```
FP 0
LP 3799
TMB 50000
S/P 2
INITIAL 0 -800
VERTEX 1399 4800
VERTEX 3199 -2400
VERTEX 3799  0
```

Though the INITIAL and VERTEX commands are called Ramp Program Mode Commands, they can be used to define the waveform of a step-pulse experiment. For example, the step-pulse experiment shown in Figure D-4 can easily be performed using the Model 263A in the Ramp Program Mode. The Initial Potential is -0.2 V, which is then stepped to -0.5 V, and then to -1.0 V.

As shown in Figure D-4, there are six vertices in this experiment. The time at each potential can be varied simply by varying the number of data points collected at each potential. There should always be only one point separating the vertices of the potential step, i.e., vertex pairs 2 and 3, 4 and 5. In our example, we will spend an equal period of time, collecting 1000 data points, at each potential, collecting one data point every 500 µs.

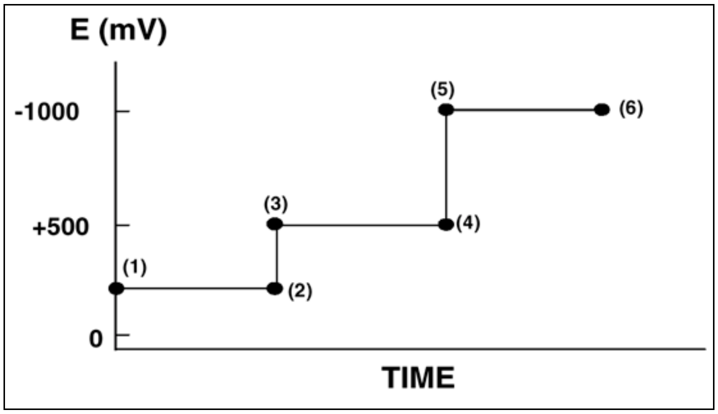

Figure D-4. STEP PULSE EXPERIMENT WITH RAMP PROGRAM MODE.

The command set to perform this experiment is:

```
FP 0
LP 2999
TMB 500
S/P 1
INITIAL  0 -800
VERTEX 999 -800
VERTEX 1000 -2000
VERTEX 1999 -2000
```

```
VERTEX 2000 -4000
VERTEX 2999 -4000
```

Note that since we can define up to 50 vertices and that each potential step requires two, we can define a pulse experiment with up to 24 potential steps (don't forget one vertex at the beginning and one at the end).

Staircase ramps and pulses can be combined in any combination desired, provided that the maximum of 50 vertices is not exceeded.

Though the greatest range of the Modulation DAC is ±2000 mV, we can perform a linear sweep or cyclic experiment over a 4-volt range by using the Bias DAC to offset the Initial Potential. For example, if we wish to perform a cyclic voltammogram from 0 V to +4.0 V, then back to 0 V, we could use the command set below:

```
FP 0
LP 3999
BIAS 2000
INITIAL 0 -8000
VERTEX 1999 8000
VERTEX 3999 -8000
```

Note that the values of the Bias DAC and the Modulation DAC are additive. At the Initial Potential we are applying +2000 mV from the Bias DAC and -2000 mV from the Modulation DAC for a net applied potential of zero.

D.9. Arbitrary Waveform Mode - “MM 2"

The Arbitrary Waveform mode is selected by the command MM 2 (Modulation Mode 2). This mode gains it name from the fact that the user defines the modulation waveform point-by-point in the host computer, then sends the waveform to the Model 263A, which will then apply the waveform to the cell. Since the waveform is defined point-by-point, it may have any shape desired as long as the DAC values defined by the waveform are valid, i.e., ±8000 DAC counts (±32000 counts with 91 option). Please note that there are often several ways to define a particular waveform, some using the Ramp commands, some using the Load Curve command, and some using both. Complex waveforms can often be divided into components for easier programming.

The Arbitrary Waveform mode must be used in all cases where the waveform is too complex to define using Ramp commands or in cases where the Ramp functions slow the experiment execution speed to unacceptable rates.

A major use of the Arbitrary Waveform mode is for experiments which require a data acquisition rate faster than that possible with the Ramp Modulation mode. (See the description of the TMB command in Chapter 2 for a discussion of the various factors that influence the maximum sampling speed.) For experiments where the waveform can be defined by the Ramp commands but require the Arbitrary mode for speed, a command called ASM is available. ASM instructs the Model 263A to assemble the waveform defined by the Ramp commands point-by-point in the Source Curve (defined by the command SCV) memory. ASM allows the facility of Ramp commands to be used in the Arbitrary waveform mode.

Many electrochemical experiments require complex waveforms that cannot be defined using the Ramp Program Commands in spite of their flexibility. For example, in Princeton Applied Research's Model 398 AC Impedance System, ac frequencies from 0.0001 Hz to 10 Hz are generated using an FFT method in which 20 frequencies are combined into a single, complex waveform by the computer (Figure D-5), then applied to the cell by the Model 263A. The Arbitrary Waveform Mode must be used to apply this waveform. For additional information, request Application Note AC-1, Basics of AC Impedance Measurements.

Any waveform that can be produced using the Ramp Program commands can also be generated using the Arbitrary Waveform Mode. One of our examples for Ramp Program Mode was a step-pulse experiment. Let's start with a simple step-pulse experiment.

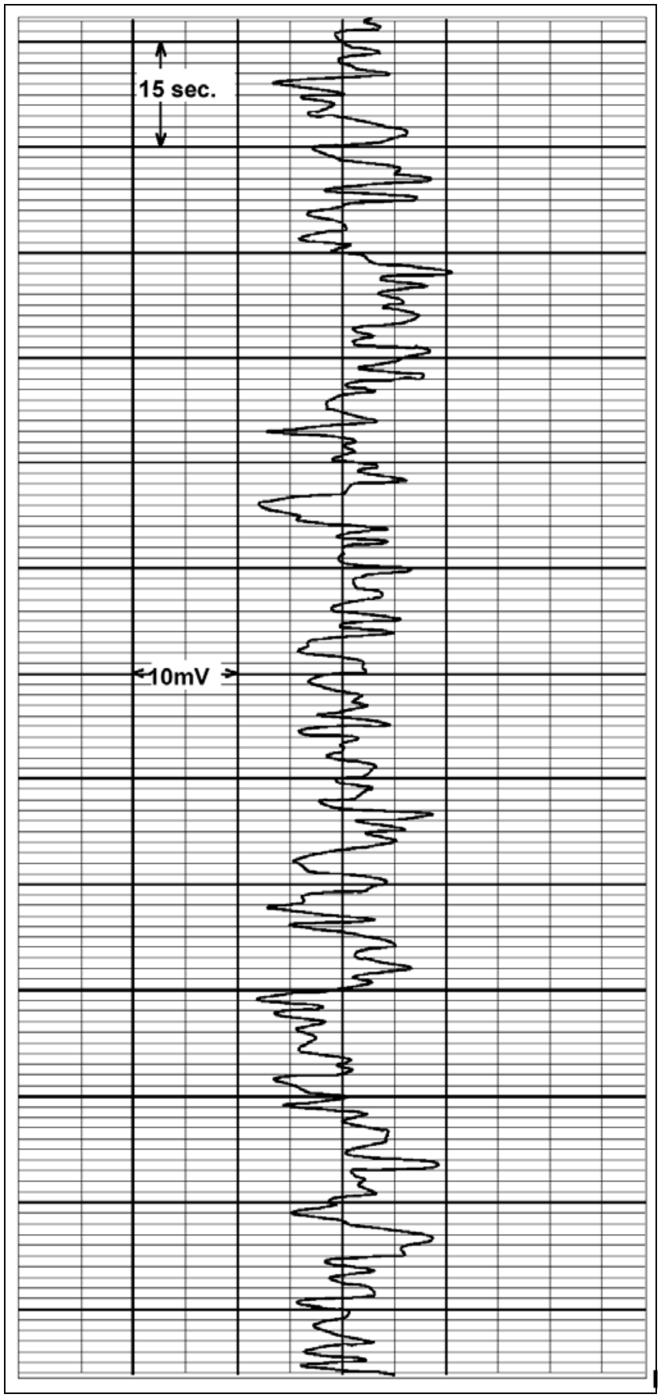

Figure D-5. AN FFT WAVEFORM FOR A BASE FREQUENCY OF 50 MHz AND MAXIMUM AMPLITUDE OF 10mV.

In this experiment, we wish to start at -0.1 V, then step to -0.9 V. The purpose of the experiment is to record the transient current in a short period of time after the application of the pulse. The Arbitrary Waveform Mode allows us to sample the current as rapidly as 104 µs per point to collect data during the transient period. In our example, we will collect a total of 2000 data points, with 5 points at -0.1 V and the balance at -0.9 V.

We can use the fact that the Model 263A has two DACs to perform this experiment simply. The command set for this experiment is:

FP 0	First Point is 0
LP 1999	Last Point is 1999
MM 2	Arbitrary Waveform Mode
MR 2	Modulation Range ±2000 mV
TMB 104	104 µs/point
BIAS -900	Set Bias DAC to -900 mV
DCV 0	Destination Curve 0
SCV 2	Source Curve 2
PCV 2	Processing Curve 2
CLR	Clear Points in PCV
LC 0 5 3200 3200 3200 3200 3200	
NC	New Curve
CELL 1	Cell On
TC	Take Curve

This experiment shows a technique for simplifying waveform programming in the Arbitrary Waveform Mode. Instead of defining the Modulation DAC value at each point for 2000 points, we used the CLR command to set each point in the PCV (identically the SCV) to zero. We then defined the first five points of the SCV to be +800 mV (3200 DAC counts) and set the Bias DAC to -900 mV. Since the two DACs are additive, the applied potential for the first five points will be -900 + 800 = -100 mV, and the applied potential for the last 1995 points will be -900 + 0 = -900 mV.

D.10. Square-Wave Voltammetry Using the Arbitrary Waveform Mode

Square-wave voltammetry is an example of an experiment that requires a waveform not definable by the Ramp commands. This waveform is the sum of a staircase ramp and a symmetrical square wave, as shown in Figure D-6. For more information on the theory of square-wave voltammetry, request Princeton Applied Research Application Note S-7, Basics of Square-Wave Voltammetry.

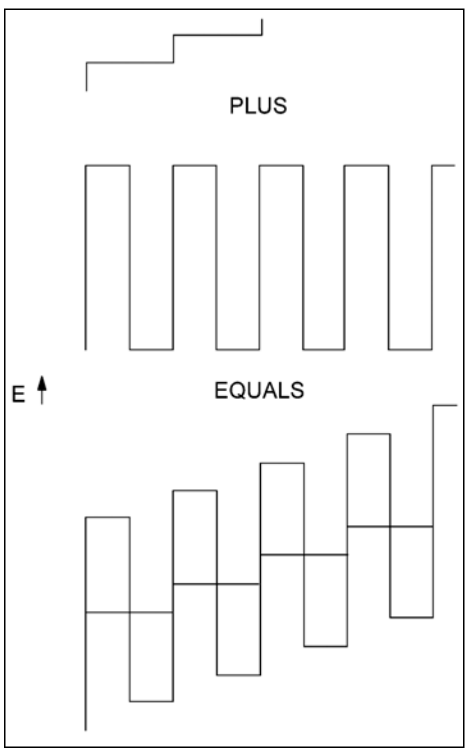

Figure D-6. WAVEFORM USED FOR SQUARE-WAVE VOLTAMMETRY.

The scan rate for square-wave voltammetry is defined as the frequency (units inverse seconds) multiplied by the potential step in mV. Two data points are required per square-wave cycle, one during the forward pulse and one during the reverse pulse. Since the time for a single data point is equal to the Timebase multiplied by the Samples per Point (TMB * S/P), the frequency for square-wave voltammetry can be related to the TMB and S/P by the equation:

$$\text{Frequency (Hz)} = 1{,}000{,}000/(\text{TMB} * \text{S/P} * 2)$$

If S/P is 1, the TMB can be used to define frequencies between 5000 Hz at TMB = 100 (the theoretical maximum for the Model 263A, though in reality it is considerably lower) and 10 Hz at TMB = 50000. Lower frequencies can be achieved by increasing S/P.

There are at least two methods that can be used to define a square-wave voltammetry waveform. In the first method, the host computer defines the entire waveform point by point, then uses the LC (Load Curve) command to transfer the waveform to the Model 263A. Let's set up a square- wave voltammetry experiment using this technique.

1. DEFINE EXPERIMENT: We wish to perform square-wave voltammetry on a solution containing lead and cadmium. The Initial Potential will be -0.2 V and the Final Potential will be -0.8 V. We will collect a data point every 2 mV, i.e., E_{STEP} = 2 mV. Since a square-wave voltammogram requires two measurements per step, one on the forward pulse and one on the reverse pulse, we must use 1 mV/point. For our example, the pulse height, E_{SW} will be 10 mV, corresponding to a 20 mV peak-to-peak square wave.

2. CALCULATE WAVEFORM: We will use the Bias DAC to set the Initial Potential with the BIAS -200 command, so the first point of our waveform will be 0. The second point will be the sum of our potential step of -2 mV (-8 Modulation DAC counts) and the forward pulse, -10 mV (-40 Modulation DAC counts). The third point will have the same potential step, but with the reverse pulse added (+18 mV or +40 Modulation DAC counts). At the fourth point, we will apply a staircase step with the forward pulse added, and so on. Figure D-7 shows a QuickBASIC (Ver. 4.5) program to calculate the square wave waveform.

```
' Square Wave Calculation Routine
'
' **Entry Conditions:
'     I = Initial Mod DAC Value (0)
'     S = Potential Step in DAC counts (8)
'     P = Pulse Height in DAC counts (40)
'     N = Number of Points (600)
'
DIM A(N)
A(0) = I + P
A(1) = I - P
A(2) = I + S + P
FOR X = 3 TO N
A(X) = A(X-2) + S
NEXT X
```

Figure D-7. CALCULATE SQUARE WAVE IN COMPUTER.

3. SET UP MODEL 263A FOR EXPERIMENT:

COMMANDS TO SEND

```
MM 0
DCV 0
SCV 1
PCV 1
FP 0
LP 600
BIAS -200
LC 0 601
```

4. START THE EXPERIMENT: The experiment is now set up and ready to run. The commands to start the experiment are:

```
CELL 1
NC
TC
```

The second method is an excellent example of a useful programming technique for the Model 263A. In this technique, the Ramp commands are used to produce one part of the waveform and the host computer constructs the rest. Referring to Figure D-7, we see that a square-wave voltammetry waveform is the sum of a square wave and a staircase. The Model 263A can be used to create a staircase to which we simply add a square wave.

We will use the same cadmium and lead solution from the first square-wave voltammetry example. The Initial Potential will be - 0.2 V and the Final Potential will be -0.8 V. We will collect a data point every 2 mV, i.e., E_{STEP} = 2 mV. Since a square-wave voltammogram requires two measurements per step, one on the forward pulse and one on the reverse pulse, we must use 1 mV/point (we really want 2 mV steps every two points, but we can't program it directly; we have to use trickery). In addition, we need one point at the initial potential, which we obtain with an extra VERTEX command. The staircase ramp will thus be defined as:

INITIAL	0	-800
VERTEX	1	-800
VERTEX	600	-3200

If we define the Source Curve memory as 2 with the SCV 2 command, we can instruct the Model 263A to assemble the waveform defined by the Ramp commands into the Source Curve by sending the command ASM.

Next, we program the host computer to generate a square wave. If we want E_{SW} to be 10 mV (which corresponds to a 20 mV pk-pk square wave), the computer would fill an array with alternating -40's and +44's, totalling 601 elements, with the first element equal to 0 to coincide with our first point in the staircase.

0 -40 44 -40 44 -40 44 -40 44...

This may seem strange, since square-wave voltammetry usually is performed with the forward pulse in the same direction as the staircase step, plus the fact that one step is -10 mV while the other is +11 mV.

The apparent polarity reversal of the square wave can be explained by the commands available in the Model 263A. You may have guessed by now that we will add two waveforms in the Model 263A to form our final square wave signal. The Model 263A does not have a command to add two curves, but does have a command to subtract one curve from another. This command will be used. By starting with reversed polarity on the square wave generated by the computer and then subtracting the square wave curve from the staircase curve, we will obtain the correct polarity in the final waveform.

The reason for using different amplitudes for the forward and reverse pulses is to compensate for the form of the staircase generated by the Ramp commands. As shown in Figure D-8, the staircase generated is not exactly the one required. In staircase voltammetry, the time for each potential step is equal to one square-wave cycle. The staircase obtained with the Ramp commands causes a step of 1 mV halfway through the square-wave cycle. By making the original square wave reverse pulse 1 mV larger in amplitude, the resultant waveform is corrected.

The Model 263A commands needed to load the square wave into memory 0 are:

```
FP 0
LP 600
PCV 0
LC 0 601
```

The LC, or Load Curve, command always loads into the Processing Curve, specified by the PCV command. More information on using the Load Curve command is provided further on.

Let's summarize the steps in generating the square wave voltammetry waveform for our example:

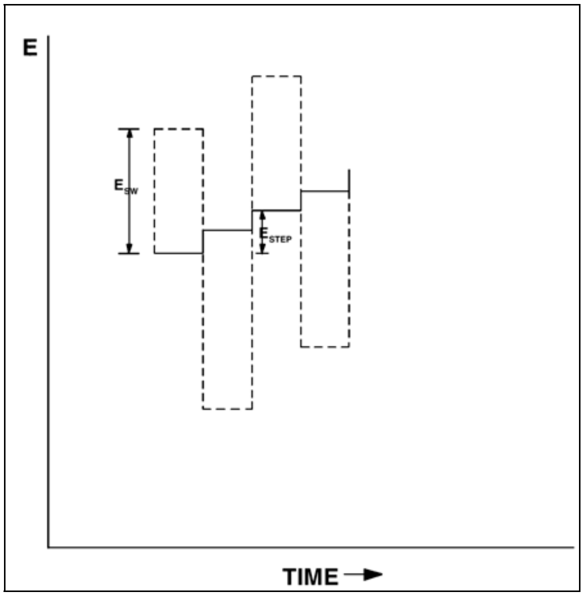

Figure D-8. STAIRCASE GENERATED BY MODEL 263A RAMP COMMANDS WITH SQUARE WAVE SUPERIMPOSED.

1. CREATE STAIRCASE

```
FP 0
LP 600
INITIAL 0 -800
VERTEX  1 -800
VERTEX 600 -3200
SCV 2
ASM
```

   The staircase is now in memory 2 of the Model 263A.

2. CREATE SQUARE WAVE IN COMPUTER

```
DIM A%(600)
A%(0) = 0
FOR X = 1 TO 600 STEP 2
A%(X) = 44

A%(X+1) = -40
NEXT X
```

3. SEND SQUARE WAVE TO THE MODEL 263A MEMORY 0

```
PCV 0
FP 0
LP 600
LC 0 601 ...
```

4. PRODUCE COMPOSITE WAVEFORM

SUB 0

D.11. Asymmetrical Waveforms

Asymmetric waveforms all require use of the Arbitrary Waveform mode in the Model 263A. The Model 263A is not as useful for experiments involving asymmetric waveforms, such as normal pulse or differential pulse voltammetry, as it is for symmetric waveforms. This is due to the timing of the experiment. The timebase of the experiment cannot be smaller than the time of the shortest event of the waveform. In the case of differential pulse voltammetry, the shortest timed event is the duration of the pulse. For such an experiment, if the pulse duration is one-tenth the step time for the staircase, ten points must be defined for every step. As shown in Figure D-9, this results in the Model 263A collecting eight data points that are not required for the experiment, i.e., eighty percent of the Model 263A's memory is necessarily wasted to maintain the timing. Because of the asymmetry and the method used by the Model 263A to update the Modulation DAC, waveforms of this type must be generated point-by-point in the host computer, then transferred to the Model 263A for execution.

Let's set up a differential-pulse voltammetry experiment. We have a solution containing cadmium and lead again. We wish to perform a differential pulse voltammetry experiment from -0.2 V to -0.8 V with a step time of 0.5 seconds, a step potential of 2 mV, a pulse time of 0.05 seconds, and a pulse height of 50 mV.

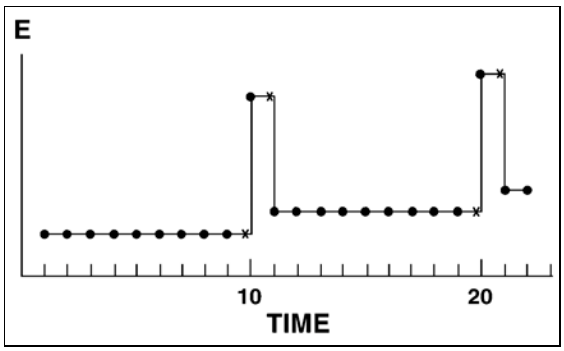

Figure D-9. WAVEFORM TIMING FOR DIFFERENTIAL PULSE POLAROGRAPHY.

The shortest event in this experiment is the pulse duration, which is 50 msec. Since the pulse duration is one-tenth of the step time, we must collect 10 points per step, nine at the step potential and one during the pulse. There are 300 steps in the experiment, so we have to collect a total of 3000 data points. A computer routine to calculate the waveform for this experiment is shown in Figure D-10.

```
' Routine to Calculate Waveform for
' Differential Pulse Voltammetry Experiment.
'       Entry Conditions:
'       I = Initial Mod DAC counts
'       S = Step Size in DAC counts
'       P = Pulse Height in DAC counts
'       N = Total Points
'
DIM C(N)
FOR X = 0 TO N STEP 10
     FOR Y = 1 TO 9
         C(X+Y) = I
     NEXT Y
     C(X+10) = I + P
     I = I + S
NEXT X
```

Figure D-10. ROUTINE TO CALCULATE DIFFERENTIAL PULSE WAVEFORM.

The following commands can be used to set up the experiment:

```
FP 0
LP 2999
PCV 0
DCV 0
SCV 0
BIAS -200
MM 2
MR 2
INTRP 0
TMB 10000
S/P 10
NC
LC 0 3000 ...
CELL 1
TC
```

Note that the New Curve command (NC) is executed before the Source Curve is loaded with the waveform. This is important because one function of the NC command is to clear all points in DCV. Since DCV and SCV are the same in this experiment, the NC command would erase the waveform if sent after the execution of the LC command.

D.12. Load Curve Command

The Load Curve command (LC) is used to load data from the computer into the Model 263A memory. The data will be loaded into the curve memory defined by the PCV (Processing Curve) command, not the SCV (Source Curve). Normally, the PCV is set to be equal to the SCV before the LC command is executed to ensure that the data are loaded into the correct area of memory.

The Load Curve (LC) command requires special handling in a program. It cannot be used to transfer a large number of data points from the computer to the Model 263A using the GPIB routines found in the Simple Static Interface Routines. GPIB protocol causes each number sent on the bus to be translated into a string of ASCII characters. For example, the number 1234 would be translated into a string of five characters, the first character for the sign followed by the ASCII representation of 1, 2, 3, and 4. This string would then be followed by one more character, called a delimiter, to separate it from the next number in a series, or a terminator if it is the last number sent. This translation is performed automatically by the GPIB driver of the computer.

The Model 263A input buffer is limited to a maximum of 80 ASCII characters. It's obvious that a few numbers can occupy the full input buffer. If the input buffer is overfilled, an error results.

The solution to this problem is to first send the LC command to set up the transfer and then transmit each point by itself on one line. Below is a QuickBASIC program fragment to accomplish this.

```
' N = NUMBER OF POINTS
' C$ = COMMAND STRING
' SENDCOMMAND = SUBROUTINE TO SEND
' GPIB COMMANDS
C$ = "LC 0 " + VAL$(N)
CALL SENDCOMMAND(C$)
FOR I = I TON
    C$ = VAL$(A(I))
    CALL SENDCOMMAND(C$)
NEXT I
```

D.13. Conclusion

The Model 263A has very flexible waveform programming capabilities. As the waveform becomes more complex, the need for thorough understanding on the part of the programmer becomes more and more important. There may be several ways to achieve a selected goal. Practicing various waveform programming techniques can result in the ability to quickly and easily program the Model 263A for new experiments.

APPENDIX E. ABBREVIATED COMMAND DESCRIPTIONS: ALPHABETICAL INDEX

E.1. Introduction

The table beginning on page 90 uses the following codes:

COMMAND TYPE CODES

A	=	ACTION command
R	=	READ only command
S	=	SET only command
S/R	=	SET or READ (omit parameters to read)
AR	=	ACTION-READ command
C	=	CONTROL command

PARAMETER CODES

n	=	numeric parameter
n1...nx	=	multiple-parameters (x is integer greater than 1)
1...x	=	integer numbers from 1 to x inclusive (x is integer)
na	=	not applicable

	Type	Function	Def. Value	Parameter	Range	Pg
A/D n		R	Reads and reports A/D output.	na	-2048...2047	36
ACV	n1 n2		Set/Read Alternate Curve. Set/Read number of sweeps with which ACV storage begins.	0 0	-1...5 (*-1...95 with 91 Option*) 0...32767	15
ADD n		A	Add "n" to every PC point to LP.	na	-32768...32767	39
AGAIN		C	Mark end of endless loop.	na	na	51
AL n		S/R	Set/Read Max. Auto-Range Sens.	-7	-7...-1 (*-7...0 with 94 Option*)	8
AR n		S/R	Set/Read Auto-Range Status.	2	0...7	7
AS n		A/R	One Auto Range with Response.	na	na	6
ASM		A	Stores Ramp Program in SCV.	na	na	21
AUXGAIN n		S/R	Set or read pre A/D Aux Gain (98 option only)	1	1,5,10,50	11
AUXSEL n		S/R	Set or read the AUX channel (98 option only)	0	0...7	11
AVAIL		R	Returns logical # of each available curve.	na	0...5 (*0...95 with 91 Option*)	17
BEGIN		C	Put 263A in endless loop.	na	na	50
BD	n1 n2	A	Sets first binary dump point. Sets # of points to binary dump.	na na	0...6143 (*0...98,303 with 91 Option*) 1...6144 - n1 (*0...98,304 - n1 with 91 Option*)	42
BIAS n		S/R	Set/Read bias level.	0	-8000...8000	17
BID	n1 n2	R	Board identification.	na na	90...99 0...2	54
BIT	n1 n2	S/R	Must Always be "0". Sets level on Bit 0 OUT Line.	na na	0 0...1	52
BL	n1 n2	A	Sets first binary load location. Sets # of points to binary dump.	na na	0...6143 (*0...98,303 with 91 Option*) 0...6144 - n1 (*0...98,304 - n1 with 91 Option*)	43
BW n		S/R	Set/Read Bandwidth/Stability.	0	0...1	13
CAL		A	Calibrate Model 263A	na	na	13

	Type	Function	Def. Value	Parameter	Range	Pg
CELL n		S/R	Set/Read Cell Relay Status.	0	0...1	13
CLEAR		A	Sets all active pts of selected curve to "0".	na	na	43
CLR		A	Sets all active PCV points to "0".	na	na	43
COMP	n1 n2	R	Read actual compen. resis. mant. Read actual compen. resis. exp.	na na	0...2000 -2...4 (*-3...4 with 94 Option*)	32
COPY	n1 n2	A	Curve to copy from. Curve to copy to. This command is used to copy data from one curve to another.	na	0...5 (*0...95 with 91 Option*) 0...5 (*0...95 with 91 Option*)	43
COUL	n1 n2	R	Report coulombs. n1 is mantissa, n2 is exponent.	na na	0...9999 -16...3	34
CRVMEM		R	Returns curve memory in kpoints.	na	6 (*96 with 91 Option*)	16
CS n		R	Read Cell Enable key status.	na	1	50
DC	n1 n2	A	Sets # of 1st point of PCV to dump. Sets number of points to dump. This command is used to dump a data set.	na na	0...6143 1...6144 - n1	43
DCL		A	Restores Default Parameters.	na	na	13
DCV n		S/R	Set/Read Destination Curve.	0	-1...5 (*-1...95 with 91 Option*)	15
DD n		S	Set Delimiter.	44	0...255	46
DISCARD n		A	Pauses data acq. for "n" points.	na	0...32767	25
DISP		A	Dispense/Dislodge cmd. to 303A.	na	na	53
DO n		C	Sets # times to repeat loop.	na	1...3276	51
DORUPT n	AR		Initiates single cur. interrupt.	na	-10000...10000	33
DP n		A	Sets # of point to dump. This command is used dump a point.	na	0...6143	45
DT n		S/R	Set/Read time between sweeps.	0	0...32767	31
DUMMY n		S/R	Set/read Elec. Mode switch status.	na	0...1	50
EGAIN n		S/R	Set/Read pre. A/D Potential Gain.	1	1,5,10,50	8
EOUTSUP n		S/R	E DC suppression (1 bit = 2 mV) (98 option only)	0	+5000...-5000	36

	Type	Function	Def. Value	Parameter	Range	Pg
ERR n		R	Read Error Status 0 = No Error 1 = Option Not Installed 2 = Command Not Understood 3 = Parameter Out of Bounds 5 = Nothing to Say 6 = Parameter Wrong Type 7 = Time Base (TMB) Too Short 11 = Wrong Mode 12 = Acquisition Error 20 = Command Heap Full 21 = Missing Begin or Do 22 = Nesting Violation 23 = Not Enough Parameters 24 = Too Many Parameters 25 = FP Greater Than LP 26 = Curve Not Available 27 = Not Enough Curves 28 = Initial Point Does Not Equal FP 29 = Vertex Not Greater Than Initial 30 = Vertices Full 31 = SCV Within DCV 32 = No Vertices 33 = SEL Not Within S/P 34 = Command Illegal in Loop 35 = Command Illegal in USR 36 = Communications Error 37 = Calibration Error	na	0...37	47
ESUP n		S/R	Set/Read potential suppression.	0	5000...-5000	9
EX	n1 n2	A	PCV points multiplied by n1. PCV points divided by n2.	na na	-32768...32767 -32768...32767	39
EXT n		S/R	Set/Read External Input Status.	0	0...1	13
FF n		R	Read power frequency. 0 = 60 Hz 1 = 50 Hz	na	0...1	50
FLOAT		R	Read status of float switch (99 option only)	na	0 or 1	50
FLT n		S/R	Set/Read Filter Status.	0	0...121	11

	Type	Function	Def. Value	Parameter	Range	Pg
FP n		S/R	Set/Read first point location.	0	0...6143	22
FS n		S/R	Sets or clears FLT bit 3.	0	0...1	12
GIGAIN		S/R	Gated Integrator Gain **Note**: The counts stored in the 263A memory and the charge that flowed through the cell are related as follows: Q = 1/500 * (counts * 10^{ITC} * $10^{I/E}$)/GIGAIN	1	1,5,10,50,100,500	34
HC		A	Halts Curve Acquisition until TC is applied.	na	na	23
I/E n		S/R	Set/Read Current Range.	-4	-1...-7 (*0...-7 with 94 Option*)	6
ID		R	Read model number.	na	2631	54
IGAIN n		S/R	Set/Read pre. A/D current Gain.	1	1,5,10,50	10
IINT	n1 n2	AR	Mantissa of sum of all I data. Exponent of sum of all I data.	na na	na na	41
ILOG		A	Replace PCV with log of PCV.	na	na	42
IMAX	n1 n2	AR	Report current maximum mantissa. Report current maximum exponent.	na na	-2048...2047 -4...-10 (*-3...-10 with 94 Option*)	41
IMIN	n1 n2	AR	Report current minimum mantissa. Report current minimum exponent.	na na	-2048...2047 -4...-10 (*-3...-10 with 94 Option*)	40
INITIAL	n1 n2	S	Set mod. first point location. Set first point mod. level.	0 -8000	0...6143 -8000...8000 (*±16000 with 91 Option*)	20
INT	n1 n2	AR	Sum all data in PCV. SUM = n2 + (10000 * n1).	na na	na na	41
INTEG n		S/R	Controls Integrator	0	0 = Reset Integ. 1 = Start Integ. 2 = Hold Integ.	34
INTRP n		S/R	Set/Read Interpolation function status.	0	0...1	22
IOUTSUP n		S/R	DC suppression (1 bit = 0.5 x 10^{-3} x I range) (98 option only)	0	+8000...-8000	36
IRMODE n		S/R	Set/Read iR Compensation mode.	0	0...4	31
IRPC n		S/R	Set/Read % correction (IRUPT)	100	0...200	33

	Type	Function	Def. Value	Parameter	Range	Pg
IRUPT n		S/R	Sets # points per cur. interrupt.	5	1...32767	33
IRX	n1 n2 n3	S/R	Sets I range for extrap. points Set/Read 1st IRUPT extrap. point. Set/Read 2nd IRUPT extrap. point.	na 10 or 75 10 or 75	-1...-7 (*0...-7 with 94 Option*) 10...2000 - n3 10...2000 - n2	33
ISUP n		S/R	Set/Read current suppression.	0	8000...-8000	10
ITC n		S/R	Integrator Time Constant 4 MΩ x 10 nF 400 kΩ x 10 nF 40 kΩ x 10 nF 4 kΩ x 10 nF **Note:** The Effective Integrator Time Constant = Integrator Time Constant/(GIGAIN)	-1	Effective Time Constants: -1 = 40 ms -2 = 4 ms -3 = 400 µs -4 = 40 µs	34
LC	n1 n2	A	Sets first storage location. Sets number of points to store. This command is used to store data from host computer in 263A Processing Curve.	na na	0...6143 1...6144 - n1	45
LOOP		C	Mark end of loop to be repeated specific number of times.	na	na	51
LP n		S/R	Set/Read last point location.	999	1...6143	23
LS n		S/R	Set/Read Line Sync Status	0	0...1	29
M	n1 n2 n3 n4 n5 n6	R	Report Curve Acquisition Status. Report Number of Current Sweep. Report Number of Curr. Acc. Pt. Report Modulation Level. Report last I value. Report last E value.	na na na na na na	0...1 1...65535 0...6143 -8000...8000 (±*32000 with 91 Option*) 0,-2048...2047 0,-10240...10235	38
MAX	n1 n2	AR	Point number of maximum. Data value at maximum.	na na	0...6143 -32767...32768	40
MIE n		S/R	Measure I/E 1 = output current at OUTPUT 2 = output voltage at OUTPUT	1	1, 2	36
MIN	n1 n2	AR	Point number of minimum. Data value at minimum.	na na	0...6143 -32768...32767	40

	Type	Function	Def. Value	Parameter	Range	Pg
MM n		S/R	Set/Read Modulation Mode	0	0...2	19
MOD n		S/R	Set/Read constant mod. level.	0	-8000...8000 (*±32000 with 91 Option*)	22
MODE n		S/R	Set/Read operating mode.	2	1, 2	11
MON		R	Alias for the M command.	na		38
MR n		S/R	Set/Read full-scale mod. poten.	2	0...2	19
MSK n		S/R	Set/Read the mask byte.	0	0...255	45
NC		A	Init. 263A for Curve Acquisition.	na	na	23
OPTION n		R	Reports if a particular option is installed.	na	90...99	54
OSCGAIN n		S/R	Full-scale (FS) range select 0 = 0.02 x input voltage 1 = 0.2 x input voltage 2 = 2 x input voltage	0	0, 1, 2	35
OSCIN n		S/R	Attenuator enable	0	0, 1	35
OUT n		S/R	Set or read output 1 mode 0: Output 1 always set to 0 4: Output 1 set to SETOUT value (98 option only)	4	0 or 4	53
OUTRES n		S/R	Set or read the resolution at Output 2 (98 option only)	0	0 to 1	53
OVER	n1 n2 n3	R	Read Ovl. Status at Exec. Time. Read Ovl. Stat. since last OVER. Read cumulative Ovl. Status.	na na na	0...3 (*0...7 with 98 Option*) 0...3 0...7	50
P n		A	Causes pause in cmd. exec.	na	0...32767	52
PAM n		S/R	Set/Read Point Averaging Mode.	0	0...6 (but not 3 or 4)	26
PCV n		S/R	Set/Read Processing Curve.	0	0...5 (*0 to 95 with 91 Option*)	16
PNT n		S/R	Set/Read next point to be read.	na	0...6143	37

	Type	Function	Def. Value	Parameter	Range	Pg
PROG	n1 n2 n3 n4	R	Reads mod. first point location. Reads first point mod. level. Reads vertex point location. Reads modulation at vertex. (Additional vertices, if in program, will be similarly reported).	na na na na	0...6143 -8000...8000 (*±16000 with 91 Option*) 1...6143 -8000...8000 (*±16000 with 91 Option*)	21
PURGE n		S/R	Purge to 303A.	0	0...1	53
Q	n1 n2	R	Reports coulombs (mantissa). Coulombs exponent.	na na	-9 999...9999 -16...3	34
QRST		A	Resets coulombs to 0.	na	na	34
RC		A	Init. 263A for Curve Acquisition. (Unlike NC, RC doesn't clear the Destination Curve, Next Curve, or Alternate Curve)	na	na	24
READAUX n		AR	Take 10 AUX samples; report avg. (98 option only)	na	na	38
READE n		AR	Take 10 E samp. Report average.	na	-10240...10235	38
READI	n1 n2	AR	Mantissa of aver. of 10 I samp. Exponent of aver. of 10 I samp.	na na	-2048...2047 -4...-10 (*-3...-10 with 94 Option*)	38
RUERR n		R	Reports uncompensated iR potential.	na	-10240...10235	34
S/P n		S/R	Set/Read Samples Per Point.	1	1...32767	26
SAM n		S/R	Set/Read Sweep Aver. Mode.	0	0...2	30
SCV n		S/R	Set/Read Source Curve.	3	0...5 (*0...95 with 91 Option*)	16
SEL	n1 n2	S/R	Set/Read first samp. to be avgd. Set/read last samp. to be avgd.	1 1	1...32767 1...32767	26
SETE n		S/R	Set/Read App. Potential.	0	-10000...10000	17
SETI	n1 n2	S/R	Set/Read App. Current mantissa. Set/Read App. Current exponent.	0 -7	-2000...2000 -4...-10 (*-3...-10 with 94 Option*)	18
SETIR	n1 n2	S/R	Set/Read uncomp. resis. mantissa. Set/Read uncomp. resis. exponent.	0 0	0...2000 -2...4 (*-3...4 with 94 Option*)	31

	Type	Function	Def. Value	Parameter	Range	Pg
SETOUT n		S/R	Set or read the value sent to Output 1 (98 option only)	0	-2048...+2047	53
SETOUT2 n		S/R	Set or read the value sent to Output 2 (98 option only)	0	-2048...-2047	53
SHF n		S/R	Set/Read number of Exp. Avg.shifts.	1	1...15	30
SIE n		S/R	Set/Read sampled parameter.	1	0...15	27
SP		A	Store Point.	na	na	37
ST		R	Status Byte (same as Ser. Poll). Bit / Decimal = Meaning 0 / 1 = Command Done 1 / 2 = Command Error 2 / 4 = Curve Done 3 / 8 = Unused 4 / 16 = Overload 5 / 32 = Sweep Done 6 / 64 = Service Requested 7 / 128 = Output Ready For each bit, 0 = NO, 1 = YES	na	0...255	46
STIR n		S/R	Stir to 305 via 303A.	0	0...1	53
SUB	n1 n2	A	"n1" Specifies subtrahend curve. "n2" Specifies minuend curve. Note: Command causes point-by-point subtraction of subtrahend curve from minuend curve with result stored in minuend curve.	na na	0...5 (*0...95 with 91 Option*) 0...5 (*0...95 with 91 Option*)	39
SUPDAC n		S/R	Set/Read value in suppression DAC.	0	-8000...+8000	11
SWPS n		S/R	Set/Read Number of Sweeps.	1	1...32767	29
TC		A	Starts Curve Acquisition.	na	na	25
TMB n		S/R	Set/Read Timebase.	4000	100...50000 (*30...50000 with 91 Option*)	27
TP	n1 n2 n3	AR	Point # read and reported. Read and report I data value. Read and report E data value.	na na na	0...6143 -2048...2047 -10240...10235	36
TRIG n		A	Puts pulse on TRIG OUT line.	0	0...1	52

	Type	Function	Def. Value	Parameter	Range	Pg
TYPE nnnn...n		A	Prints msg. on LCD display.	na	ASCII (40 chars. max.)	54
USR1, 2, 3, 4		C	Allows user-defined commands.	na	na	51
VER n		R	Read software version.	na	na	54
VERTEX	n1 n2	S	Sets vertex point location. Sets modulation at vertex. (As many as fifty vertices can be specified.)	999 8000	1...6143 -8000...8000 (±*16000 with 91 Option*)	20
WAIT n		A	Halts Curve Acq. for "n" tmb.	na	0...32767	25
WCD		A	Postpones next cmd. in sequence until curve acquis. is complete.	na	na	25
WFL		A	Wait for Line.	na	na	25
WFT n		A	Wait For Trigger.	na	0...1	52

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