

**21X MICROLOGGER
OPERATOR'S MANUAL**

REVISION: 3/96

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SELECTED OPERATING DETAILS

1. Storing Data - Data is stored in Final Storage only by Output Processing Instructions and only when the Output Flag is set. (Sections OV2 and OV3.3)
2. Storing Date and Time Date and time are stored in Final Storage ONLY if the Real Time Instruction 77 is used. (Section 11)
3. Data Transfer - On-line data transfer from Final Storage to peripherals (tape, printer, Storage Module, etc.) occurs only if enabled with Instruction 96 in the datalogger program or in the *4 Mode. (Section 4.1)
4. Final Storage Resolution - All Input Storage values are displayed (*6 mode) as high resolution with a maximum value of 99999. However, the default resolution for data stored in Final Storage is low resolution, maximum value of 6999. Results exceeding 6999 are stored as 6999 unless Instruction 78 is used to store the values in Final Storage as high resolution values. (Sections 2.2.1 and 11)
5. Floating Point Format - The computations performed in the 21X use floating point arithmetic. CSI's 4 byte floating point numbers contain a 23 bit binary mantissa and a 6 bit binary exponent. The largest and smallest numbers that can be stored and processed are 9×10^{18} and 1×10^{-19} , respectively. (Section 2.2.2)
6. Erasing Final Storage Data in Final Storage can be erased without altering the program by repartitioning memory in the *A Mode. (Section 1.5.2)
7. ALL memory can be erased and the 21X completely reset by entering 978 for the number of bytes left in Program Memory. (Section 1.5.2)
8. The set of instructions available in the 21X is determined by the PROM (Programmable Read Only Memory) that it is equipped with.

PROMs are available which have different combinations of instructions. Appendix B describes the options available and gives the signatures of the current PROMS.

9. Significant changes in the current PROM release (OSX-0.1, OSX-1.1, and OSX-2.1) include:

INSTRUCTIONS

Case Statement (83 & 93, Section 12)

Arc Tangent (66 Section 10)

Wind Vector (69 replaces 76, Section 11)

Serial Output has an option to send a file mark to a Storage Module (96, Section 12)

Low Pass Filter: on the first execution after compiling, the input value is used for the filtered result

Commands to set, toggle and pulse ports are now available for Program Control Instructions (Section 12)

Revision 3 of the above PROMS includes the capability to sense status(0 V low, 5 V high) on the high side of a differential channel (Instruction 91, Section 12).

FEATURES

Ports can now be manually toggled from the keyboard or TERM (PC208 software)

The *B Mode now displays PROM version and revision, execution overruns, and accumulated error 8s in addition to signatures.

The capability of transferring *programs* via cassette tape is no longer supported in the standard PROM options.

CAUTIONARY NOTES

1. Damage will occur to the analog input circuitry if voltages in excess of ± 16 V are applied for a sustained period. Voltages in excess of ± 8 V will cause errors and possible overranging on other analog input channels.
2. There are frequent references in this manual to Storage Modules. The Storage Modules referred to are the SM192 and SM716. The old SM16 and SM64 Storage Modules cannot perform many of the functions available with the SM192 and SM716.
3. The sealed lead acid batteries used with the 21XL are permanently damaged if discharged below 11.76 V. The cells are rated at a 2.5 Ahr capacity but experience a slow discharge even in storage. It is advisable to maintain a continuous charge on the 21XL battery pack, whether in operation or storage (Section 14).

21X MICROLOGGER OVERVIEW

The 21X Micrologger combines precision measurement with processing and control capability in a single battery operated system.

Campbell Scientific, Inc. provides three documents to aid in understanding and operating the 21X:

1. This Overview
2. The 21X Operator's Manual
3. The 21X Prompt Sheet

This Overview introduces the concepts required to take advantage of the 21X's capabilities. Hands-on programming examples start in Section OV4. Working with a 21X will help the learning process, so don't just read the examples, turn on the 21X and do them. If you want to start this minute, go ahead and try the examples, then come back and read the rest of the Overview.

The sections of the Operator's Manual which should be read to complete a basic understanding of the 21X operation are the Programming Sections 1-3, the portions of the data retrieval Sections 4 and 5 appropriate to the method(s) you are using (see OV5), and Section 14 which covers installation and maintenance.

Section 6 covers details of serial communications. Sections 7 and 8 contain programming examples. Sections 9-12 have detailed descriptions of the programming instructions, and Section 13 goes into detail on the 21X measurement procedures.

The Prompt Sheet is an abbreviated description of the programming instructions. Once familiar with the 21X, it is possible to program it using only the Prompt Sheet as a reference, consulting the manual if further detail is needed.

Read the Selected Operating Details and Cautionary Notes at the front of the Manual before using the 21X.

OV1. PHYSICAL DESCRIPTION

The 21X Micrologger is shown in Figure OV1-1. The 21X is powered with 8 alkaline "D" cells and has only the power switch on the base. The 21XL is powered with rechargeable lead acid cells and, in addition to the power switch, has a charger input plug and an LED which lights when the charging circuit is active. The 21XL should always be connected to a solar panel or AC charger. The lead acid batteries provide backup in event of a power failure but are permanently damaged if their voltage drops below 11.76 volts. Campbell Scientific does not warrant batteries. The battery base is the only difference between the 21X and the 21XL.

The 16 character keyboard is used to enter programs, commands and data; these can be viewed on the 8 digit display (LCD).

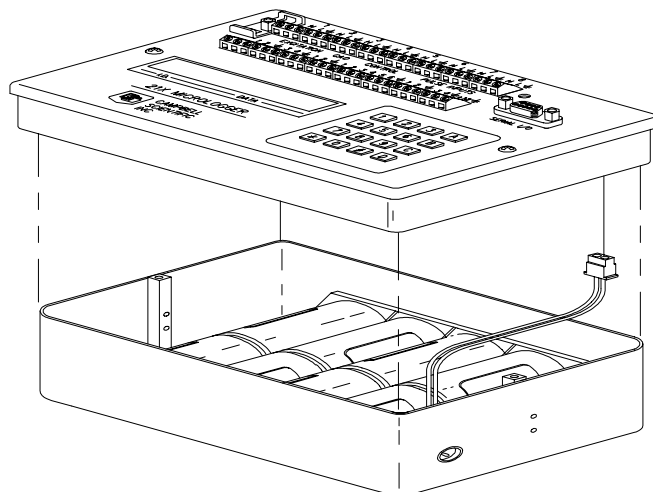


FIGURE OV1-1. 21X Micrologger

21X MICROLOGGER OVERVIEW

The 9-pin serial I/O port provides connection to data storage peripherals, such as the SM192/716 Storage Module or RC35 Cassette Recorder, and provides serial communication to computer or modem devices for data transfer or remote programming (Section 6). *This 9 pin port does NOT have the same pin configuration as the 9 pin serial ports currently used on many personal computers.* An SC32A is required to

interface the 21X to a RS232 serial port (Section 6).

The panel also contains two terminal strips which are used for sensor inputs, excitation, control outputs, etc. Figure OV1-2 shows the 21X panel and the associated programming instructions.

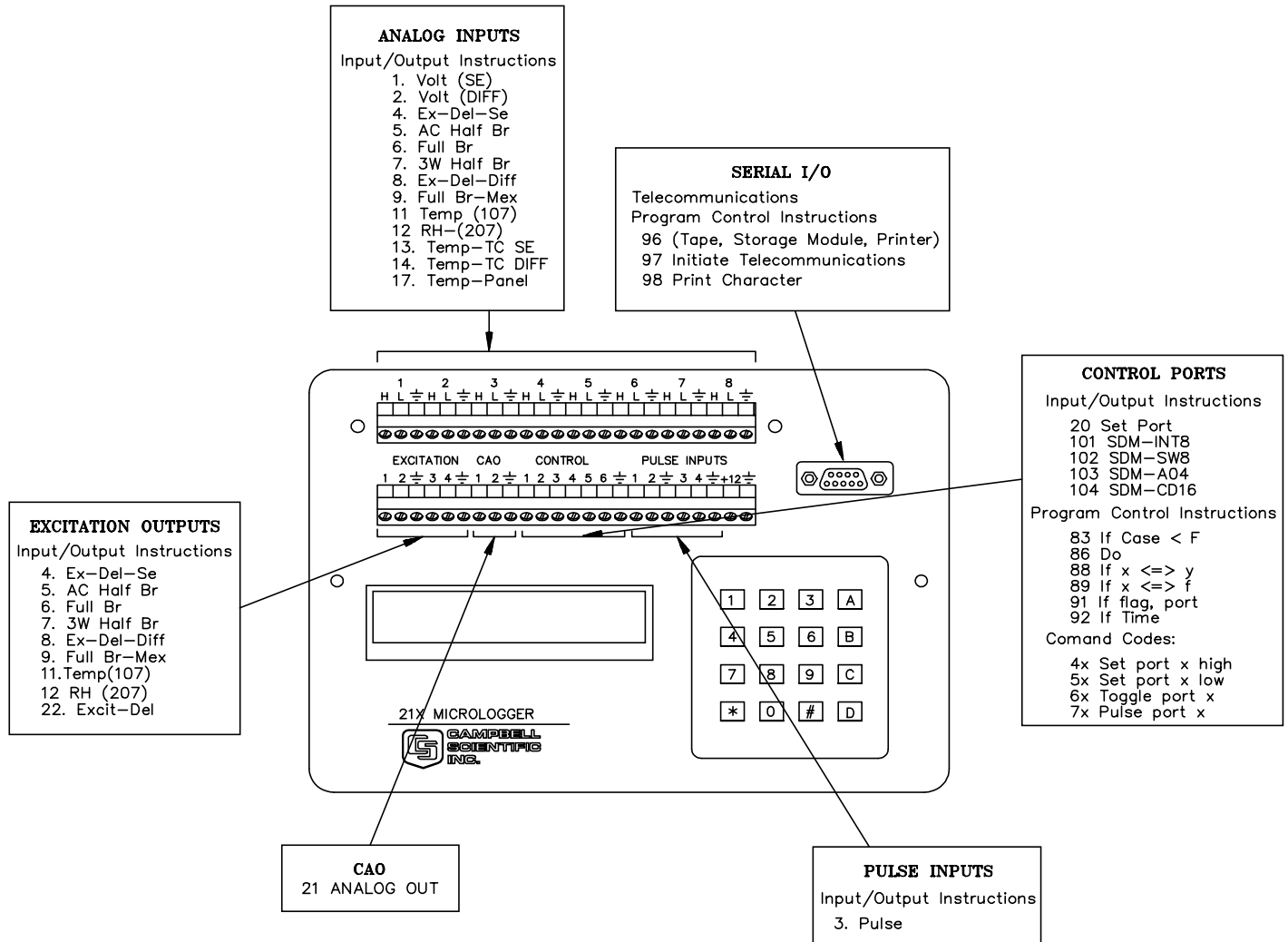


FIGURE OV1-2. 21X Wiring Panel and Associated Programming Instructions

OV1.1 ANALOG INPUTS

The terminals in the upper strip are for analog inputs. The numbering on the terminals refers to the differential channels; i.e., the voltage on the HI input is measured with respect to the voltage on the LOW input. When making single-ended measurements either the HI or the LOW channel may be used independently to measure the voltage with respect to the 21X ground. Single-

ended channels are numbered sequentially, e.g. the HI and LOW sides of differential channel 2 are single-ended channels 3 and 4, respectively (Section 13.2).

The analog input terminal strip has an insulated cover to reduce temperature gradients across the input terminals. The cover is required for accurate thermocouple measurements (Section 13.4).

OV1.2 SWITCHED EXCITATION OUTPUTS

The first four numbered terminals on the lower terminal strip are the SWITCHED EXCITATION channels. These supply programmable excitation voltages for resistive bridge measurements. The excitation channels are only switched on during the measurement.

OV1.3 CONTINUOUS ANALOG OUTPUTS

The two Continuous Analog Output (CAO) channels supply continuous output voltages, under program control, for use with strip charts, X-Y plotters, or proportional controllers.

OV1.4 DIGITAL CONTROL PORTS

The six DIGITAL CONTROL PORTS (0 or 5 volt states) allow on-off control of external devices. These control ports have a very limited current output (5 mA) and are used to switch solid state devices which in turn provide power to relay coils (Section 14.4).

OV1.5 PULSE COUNT INPUTS

The four PULSE COUNT INPUTS measure contact closure, low level AC, or high frequency pulse signals.

OV1.6 12 VOLTS AND GROUND

The +12 volt terminal provides a direct connection to the 21X power supply. The +12 and ground terminals can be used to connect an external 12 volt battery to the 21X to maintain system power while changing internal batteries or to provide power for extended periods in the field.

OV2. MEMORY AND PROGRAMMING CONCEPTS

The 21X must be programmed before it will make any measurements. A program consists of a group of instructions entered into a program

table. The program table is given an execution interval which determines how frequently that table is executed. When the table is executed, the instructions are executed in sequence from beginning to end. After executing the table, the 21X waits the remainder of the execution interval and then executes the table again starting at the beginning.

The interval at which the table is executed will generally determine the interval at which the sensors are measured. The interval at which data are stored is separate and may range from samples every execution interval to processed summaries output hourly, daily, or on longer or irregular intervals.

Figure OV2-1 represents the measurement, processing, and data storage sequence in the 21X and shows the types of instructions used to accomplish these tasks.

OV2.1 INTERNAL MEMORY

The 21X has 40,960 bytes of Random Access Memory (RAM), divided into five areas. The five areas of RAM are:

1. **Input Storage** - Input Storage holds the results of measurements or calculations. The *6 Mode is used to view Input Storage locations to check current sensor readings or calculated values. Input Storage defaults to 28 locations. Additional locations can be assigned using the *A Mode.
2. **Intermediate Storage** - Certain Processing Instructions and most of the Output Processing Instructions maintain intermediate results in Intermediate Storage. Intermediate storage is automatically accessed by the Instructions and cannot be accessed by the user. The default allocation is 64 locations. The number of locations can be changed using the *A Mode.

21X MICROLOGGER OVERVIEW

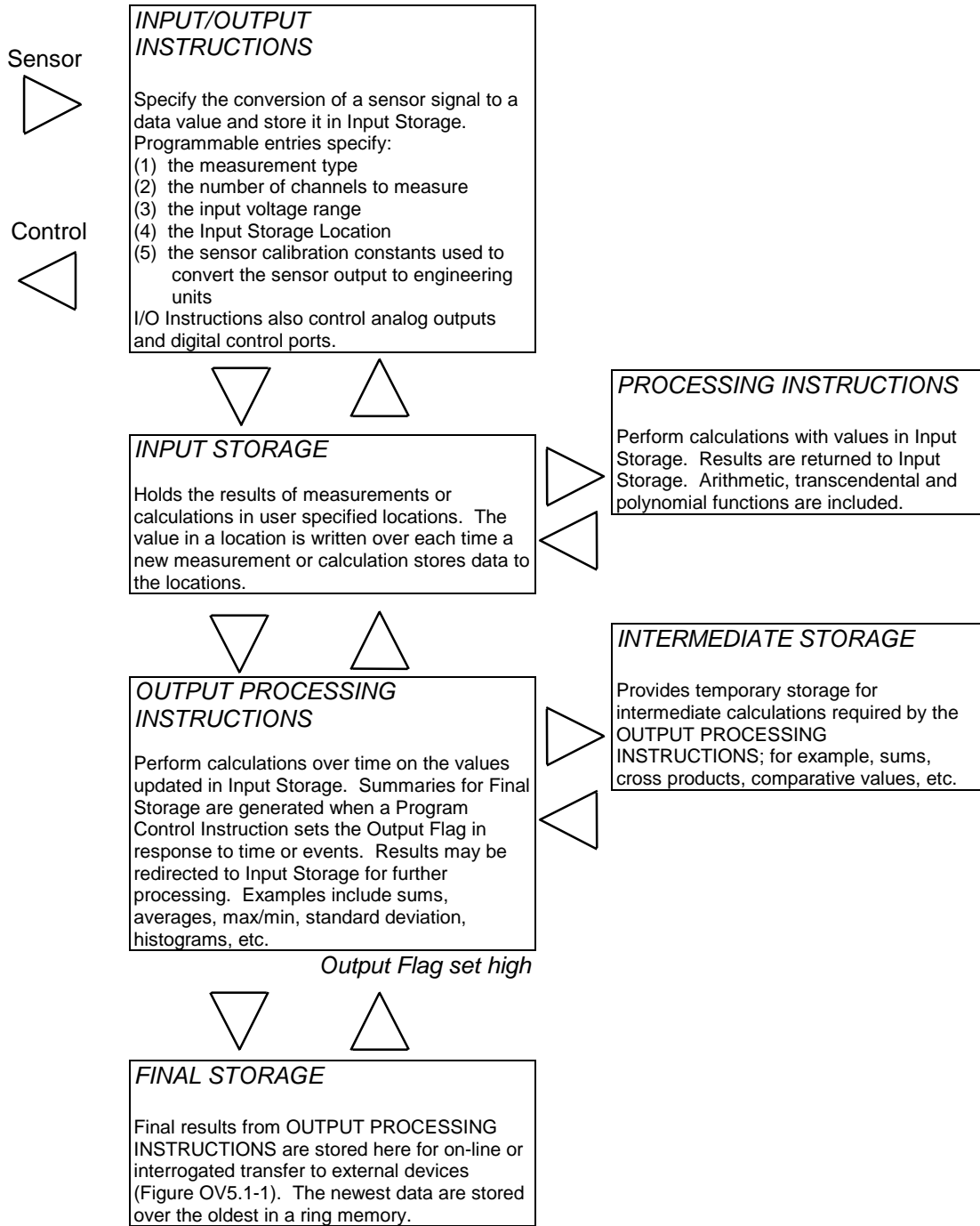


FIGURE OV2-1. Instruction Types and Storage Areas

3. **Final Storage** - Final, processed values are stored here for transfer to printer, tape, solid state Storage Module or for retrieval via telecommunication links. Values are stored in Final Storage only by the Output Processing Instructions and only when the Output Flag is set in the users program. The 19,296 locations allocated to Final Storage at power up is reduced if Input or Intermediate Storage is increased.
4. **System Memory** - used for overhead tasks such as compiling programs, transferring data, etc. The user cannot access this memory.
5. **Program Memory** - available for user programs entered in Program Tables 1 and 2, and Subroutine Table 3. (Sections OV3, 1.1)

The use of the Input, Intermediate, and Final Storage in the measurement and data processing sequence is shown in Figure OV2-1. While the total size of these three areas remains constant, memory may be reallocated between the areas to accommodate different measurement and processing needs (*A Mode, Section 1.5). The size of system and program memory, are fixed.

OV2.2 21X INSTRUCTION TYPES

Figure OV2.1 illustrates the use of the three different instruction types which act on data. The fourth type, Program Control, is used to control output times and vary program execution. Instructions are identified by numbers.

1. **INPUT/OUTPUT INSTRUCTIONS** (1-26,101-104, Section 9) control the terminal strip inputs and outputs (the sensor is the source, Figure OV1-2), storing the results in Input Storage (destination). Multiplier and offset parameters allow conversion of linear signals into engineering units. The Control Ports and Continuous Analog Outputs are also addressed with I/O Instructions.
2. **PROCESSING INSTRUCTIONS** (30-66, Section 10) perform numerical operations on values located in Input Storage (source) and store the results back in Input Storage (destination). These instructions can be

used to develop high level algorithms to process measurements prior to Output Processing (Section 10).

3. **OUTPUT PROCESSING INSTRUCTIONS** (69-82, Section 11) are the only instructions which store data in Final Storage (destination). Input Storage (source) values are processed over time to obtain averages, maxima, minima, etc. There are two types of processing done by Output Instructions: Intermediate and Final.

Intermediate processing normally takes place each time the instruction is executed. For example, when the Average Instruction is executed, it adds the values from the input locations being averaged to running totals in Intermediate Storage. It also keeps track of the number of samples.

Final processing occurs only when the Output Flag is high. The Output Processing Instructions check the Output Flag. If the flag is high, final values are calculated and output. With the Average, accumulated totals are divided by the number of samples and the resulting averages sent to Final Storage. Intermediate locations are zeroed and the process starts over. The Output Flag, Flag 0, is set high by a Program Control Instruction which must precede the Output Processing Instructions in the user entered program.

4. **PROGRAM CONTROL INSTRUCTIONS** (85-98, Section 12) are used for logic decisions and conditional statements. They can set flags, compare values or times, execute loops, call subroutines, conditionally execute portions of the program, etc.

OV2.3 PROGRAM TABLES AND THE EXECUTION AND OUTPUT INTERVALS

Programs are entered in Tables 1 and 2. Subroutines, called from Tables 1 and 2, are entered in Subroutine Table 3. The size of each table is flexible, limited only by the total amount of program memory. If Table 1 is the only table programmed, the entire program memory is available for Table 1.

Table 1 and Table 2 have independent execution intervals, entered in units of seconds

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<p>Table 1. Execute every x sec. $0.0125 \leq x \leq 6553$</p> <p><i>Instructions are executed sequentially in the order they are entered in the table. One complete pass through the table is made each execution interval unless program control instructions are used to loop or branch execution.</i></p> <p>Normal Order: MEASURE PROCESS CHECK OUTPUT COND. OUTPUT PROCESSING</p>	<p>Table 2. Execute every y sec. $0.1 \leq y \leq 6553$</p> <p><i>Table 2 is used if there is a need to measure and process data on a separate interval from that in Table 1.</i></p>	<p>Table 3. Subroutines</p> <p><i>A subroutine is executed only when called from Table 1 or 2.</i></p> <p>Subroutine Label Instructions End</p> <p>Subroutine Label Instructions End</p> <p>Subroutine Label Instructions End</p>
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FIGURE OV2-2. Program and Subroutine Tables

with an allowable range of 0.0125 to 6553 seconds. Intervals shorter than 0.1 seconds are allowed only in Table 1. Subroutine Table 3 has no execution interval; subroutines are only executed when called from Table 1 or 2.

OV2.3.1 THE EXECUTION INTERVAL

The execution interval specifies how often the program in the table is executed, which is usually determined by how often the sensors are to be measured. Unless two different measurement rates are needed, use only one table. A program table is executed sequentially starting with the first instruction in the table and proceeding to the end of the table.

Each instruction in the table requires a finite time to execute. If the execution interval is less than the time required to process the table, the 21X overruns the execution interval, finishes processing the table and waits for the next execution interval before initiating the table. When an overrun occurs, decimal points are shown on either side of the G on the display in the LOG mode (*0). Overruns and table priority are discussed in Section 1.1.

OV2.3.2 THE OUTPUT INTERVAL

The interval at which output occurs is independent from the execution interval, other than the fact that it must occur when the table is executed (i.e., a table cannot have a 10 minute execution interval and output every 15 minutes).

A single program table can have many different output intervals and conditions, each with a unique data set (output array). Program Control Instructions are used to set the Output Flag which determines when output occurs. The Output Processing Instructions which follow the instruction setting the Output Flag determine the data output and its sequence. Each additional output array is created by another Program Control Instruction setting the Output Flag high in response to an output condition, followed by Output Processing Instructions defining the data set to output.

OV3. PROGRAMMING THE 21X

A program is created by keying it directly into the datalogger or on a PC using the PC208 Datalogger Support Software program EDLOG. This manual describes direct interaction with the

21X. Work through the direct programming examples in this overview before using EDLOG and you will have the basics of 21X operation as well as an appreciation for the help provided by the software. Section OV3.5 describes options for loading the program into the 21X.

OV3.1 FUNCTIONAL MODES

User interaction with the 21X is broken into different functional MODES, (e.g., programming the measurements and output, setting time, manually initiating a block data transfer to Storage Module, etc.). The modes are referred to as Star (*) Modes since they are accessed by first keying *, then the mode number or letter. Table OV3-1 lists the 21X Modes.

TABLE OV3-1. * Mode Summary

Key	Mode
*0	LOG data and indicate active Tables
*1	Program Table 1
*2	Program Table 2
*3	Program Table 3, subroutines only
*4	Enable/disable tape and/or printer output
*5	Display/set real time clock
*6	Display/alter Input Storage data, toggle flags
*7	Display Final Storage data
*8	Final Storage data transfer to cassette tape
*9	Final Storage data transfer to printer
*A	Memory allocation/reset
*B	Signature test/PROM version
*C	Security
*D	Save/load Program

OV3.2 KEY DEFINITION

Keys and key sequences have specific functions when using the 21X keyboard or a terminal/computer in the remote keyboard state (Section 5). Table OV3-2 lists these functions. In some cases, the exact action of a key depends on the mode the 21X is in and is described with the mode in the manual.

TABLE OV3-2. Key Description/Editing Functions

Key	Action
0-9	Key numeric entries into display
*	Enter Mode (followed by Mode Number)
A	Enter/Advance
B	Back up
C	Change the sign of a number or index an input location to loop counter
D	Enter the decimal point
#	Clear the rightmost digit keyed into the display
#A	Advance to next instruction in program table (*1, *2, *3) or to next output array in Final Storage (*7)
#B	Back up to previous instruction in program table or to previous output array in Final Storage
#D	Delete entire instruction

OV3.3 PROGRAMMING SEQUENCE

In routine applications, sensor signals are measured, processed over some time interval, and the results are stored in Final Storage. A generalized programming sequence is:

1. Enter the execution interval, determined by the desired sensor scan rate.
2. Enter the Input/Output Instructions required to measure the sensors.
3. Enter any Processing Instructions required to get the data ready for Output Processing.
4. Enter a Program Control Instruction to test the output condition and Set the Output Flag when the condition is met. For example, use Instruction 92 to output based on time, 86 to output each time the table is executed, and 88 or 89 to compare input values. This instruction must precede the Output Processing Instructions.
5. Enter the Output Processing Instructions to store processed data in Final Storage. The order in which the data are stored is determined by the order of the Output Processing Instructions in the table.
6. Repeat steps 4 and 5 for output on different intervals or conditions.

21X MICROLOGGER OVERVIEW

OV3.4 INSTRUCTION FORMAT

Instructions are identified by an instruction number. Each instruction has a number of parameters that give the 21X the information it needs to execute the instruction.

The 21X Prompt Sheet has the instruction numbers in red, with the parameters briefly listed in columns following the description. Some parameters are footnoted with further description under the "Instruction Option Codes" heading.

For example, Instruction 73 stores the maximum value that occurred in an Input Storage Location over the output interval. The instruction has three parameters (1) REPetitionS, the number of sequential Input Storage locations on which to find maxima, (2) TIME, an option of storing the time of occurrence with the maximum value, and (3) LOC the first Input Storage Location operated on by the Maximum Instruction. The codes for the TIME parameter are listed in the "Instruction Option Codes".

The repetitions parameter specifies how many times an instruction's function is to be repeated. For example, four 107 thermistor probes, wired to single-ended channels 1 through 4, are measured using a single Instruction 11, Temp-107, with four repetitions. Parameter 2 specifies the input channel of the first thermistor (channel 1) and parameter 4 specifies the Input Storage Location in which to store measurements from the first thermistor. If Location 5 were used, the temperature of the thermistor on channel 1 would be stored in Input Location 5, the temperature from channel 2 in Input Location 6, etc.

Detailed descriptions of the instructions are given in Sections 9-12.

OV3.5 ENTERING A PROGRAM

Programs are entered into the 21X in one of four ways:

1. Keyed in using the 21X keyboard.
2. Loaded from a pre-recorded listing using the *D Mode. There are 2 types of storage/input:

- a. Stored on disk/sent from computer (PC208 software TERM and EDLOG).
- b. Stored/loaded from SM192/716 Storage Module

3. Loaded from Storage Module or internal PROM (special software) upon power-up.

A program is created by keying it directly into the datalogger as described in the following Section, or on a PC using the PC208 Datalogger Support Software.

EDLOG and TERM are PC208 Software programs used to develop and send programs to the 21X. EDLOG is a prompting editor for writing and documenting programs for Campbell Scientific dataloggers. Program files developed with EDLOG can be downloaded directly to the 21X using TERM. TERM supports communication via direct wire, telephone, or Radio Frequency (RF).

Programs on disk can be copied to a Storage Module with SMCOM. Using the *D Mode to save or load a program from a Storage Module is described in Section 1.8.

If the SM192/716 Storage Module is connected when the 21X is powered-up the 21X will automatically load program number 8, provided that a program 8 is loaded in the Storage Module (Section 1.8).

It is also possible (with special software) to create a PROM (Programmable Read Only Memory) that contains a datalogger program. With this PROM installed in the datalogger, the program will automatically be loaded and run when the datalogger is powered-up, requiring only that the clock be set.

OV4. PROGRAMMING EXAMPLES

We will start with a simple programming example. There is a brief explanation of each step to help you follow the logic. When the example uses an instruction, find it on the Prompt Sheet and follow through the description of the parameters. Using the Prompt Sheet while going through these examples will help you become familiar with its format. Sections 9-12 have more detailed descriptions of the instructions.

OV4.1 SAMPLE PROGRAM 1

The 21X has a thermistor built into the input panel that measures the panel temperature and provides a reference for thermocouple temperature measurements. In this example

the 21X is programmed to read the panel temperature every 5 seconds and send the results directly to Final Storage.

TURN ON THE POWER SWITCH AND PROCEED AS INDICATED

Key	Display Shows (ID:Data)	Explanation
--	HELLO	On power-up, the 21X displays "hello" while it checks the memory.
		<i>after a few seconds delay</i>
--	11:111111	The result of the memory check. Each digit represents a memory socket on the CPU board. 1's indicate good memory, 0's bad memory (Section 1.5).
*	00:00	Select mode.
1	01:00	Enter Program Table 1.
A	01:0.0000	Advance to execution interval (seconds).
5	01:5	Key 5 second execution interval.
A	01:P00	Enter the 5 second execution interval and advance to the first program instruction location. The 21X prompts with a P when it is time to enter an instruction number.
17	01:P17	Key in I/O Instruction 17, measure the panel temperature in degrees C.
A	01:0000	Enter Instruction 17 and advance to the first parameter.
1	01:1	Key in the Input Storage location in which to store the measurement; location 1.
A	02:P00	Enter the location number. Note that the 21X knows how many parameters are associated with an instruction and will prompt for a new instruction number when parameter entry is completed.

The 21X is now programmed to read the panel temperature every five seconds and place the reading in Input Storage location 1. Before adding any more instructions, we will start the program and display the measurement in Input Storage.

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Key	Display Shows (ID:Data)	Explanation
*0	:LOG 1	Exit Table 1, enter *0 mode to compile table and begin measurements.
*6	06:0000	Enter *6 mode to view Input Storage.
A	01:21.234	Advance to Input Storage location 1. Panel temperature is 21.234°C.

Wait a few seconds:

01:21.423	The measurement will be updated every 5 seconds when a new measurement is made.
-----------	---

At this point the 21X is measuring the temperature every 5 seconds and sending the value to Input Storage. No data are being saved. The next step is to have the 21X send each reading to Final Storage. (Remember the Output Flag must be set first.)

Key	Display Shows (ID:Data)	Explanation
*1	01:00	Exit *6 mode. Enter Program Table 1.
2A	02:P00	Advance to 2nd instruction location; this is where we left off. Note how we jumped to the 2nd instruction instead of just advancing by keying A.
86	02:P86	86 is the DO instruction; a Program Control Instruction which unconditionally executes a command.
A	01:00	Enter instruction and advance to the first parameter specifying the command.
10	01:10	10 is the command to set Flag 0, the Output Flag. The command codes are listed in the Instruction Option Codes for Instructions 86-92 on the Prompt Sheet and in Table 12.1-2.
A	03:P00	Enter the command and advance to third program instruction location.
70	03:P70	The Output Processing Instruction, SAMPLE, transfers values from Input Storage to Final Storage when the Output Flag is set.
A	01:00	Enter 70 and advance to first parameter specifying the repetitions.
1	01:1	There is only one value to sample so only one repetition is entered.

Key	Display Shows (ID:Data)	Explanation
A	02:0000	Enter repetition and advance to the second parameter which specifies the first Input Storage location to sample.
1	02:1	Input Storage location 1, where the panel temperature is stored.
A	04:P00	Enter location and advance to fourth instruction location. Note that a value is not entered into memory until A is keyed. If *0 was keyed after the 1 in the previous step, the location would not be entered and would remain 0.
*0	:LOG 1	Exit Table 1, enter *0 mode, compile program, and log data.

*The 21X is now programmed to measure the panel temperature every 5 seconds and send each reading to Final Storage. Values in Final Storage can be viewed using the *7 Mode (Section 2.3):*

Key	Display Shows (ID:Data)	Explanation
*7	07: 13.000	Enter *7 Mode. The Data Storage Pointer (DSP) is displayed showing the next available Final Storage Location (location 13 in this example).
A	01: 0102	Advance to the first value, the output array Identifier (ID). The ID indicates the Output Flag was set in Table 1 by the second instruction (Section 2.1).
A	02: 21.23	Advance to the first temperature stored. Note that there are only 4 digits displayed (low resolution) while the readings in Input Storage displayed 5 digits (Section 2.2 and Inst. 78).
A	01: 0102	Advance to the next output array. Same output array ID.
A	02: 21.42	Advance to 2nd stored temp.
*0	:LOG 1	Change to *0 Mode.

In the above example, no time information is stored with the data. In the second example, Instruction 77 is used to save the time of the measurements.

OV4.2 EDITING AN EXISTING PROGRAM

When editing an existing program in the 21X, entering a new instruction inserts the instruction; entering a new value for an instruction parameter replaces the previous value.

To insert an instruction, enter the program table and advance to the position where the instruction is to be inserted (i.e., P in the data portion of the display) key in the instruction number, and then key A. The new instruction

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will be inserted at that point in the table, advance through and enter the parameters. The Instruction that was at that point and all instructions following it will be pushed down to follow the inserted instruction.

An instruction is deleted by advancing to the instruction number (P in display) and keying #D (Table OV3-2).

To change the value entered for a parameter, advance to parameter and key in the correct

value then key A. Note that the new value is not entered until A is keyed.

The next example program uses the panel temperature measurement but uses timed intervals for output instead of every execution. To get ready for the example, we will delete Instructions 86 and 70.

Key	Display Shows (ID:Data)	Explanation
	: LOG1	21X is in *0 Mode
*1	01:00	Enter Program Table 1.
2A	02:P86	Jump to 2nd instruction in table; Instruction 86, DO.
#D	02:P70	Delete Instruction 86. Second instruction is now 70.
#D	02:P00	Delete Instruction 70. Second instruction is now vacant.
*0	:LOG1	Return to *0 Mode

OV4.3 SAMPLE PROGRAM 2

Our second example is more representative of a data collection situation. This time the panel temperature will be used as the reference temperature for a type T (copper-constantan) thermocouple (TC). Thermocouples measure the temperature relative to their reference junction temperature. To obtain the absolute temperature, the reference junction temperature must be known.

The 21X is shipped with a short thermocouple wired to differential channel 5. The copper lead is connected to the high input (H) and the constantan lead is connected to the low input (L). We'll read the sensor every 5 seconds, and store one hour average temperatures along with a daily maximum and minimum temperature and the times at which they occur. The date and time will also be stored with the data.

Instruction 14 measures TC temperature with a differential voltage measurement. The first parameter is the number of times to repeat the measurement. There is only one thermocouple, so we enter a 1. If there were several TCs, they could be wired to sequential input channels and the number of TCs would be entered in Parameter 1. The 21X would measure all of the TCs.

Parameter 2 is the full scale voltage input range to use when making the measurement. Type T TC signals are very small, approximately $40\mu\text{V}/^\circ\text{C}$ difference in temperature between the measurement and reference junction. If we use a range code of 1 (± 5 mV full scale, slow integration), the TC voltage will not exceed the input range as long as the measurement junction is within 125°C of the panel temperature.

Parameter 3 specifies the channel on which to make the first measurement. Parameter 6 specifies the Input Storage location in which to store the first channel measurement. If multiple repetitions are specified, measurements from sequential channels are stored in adjacent input locations beginning with the location specified in Parameter 6. For Example, if there are 5 repetitions and the first measurement is stored in location 3, the final measurement will be stored in location 7.

Parameter 5 specifies the Input Storage location in which to find the reference temperature in this case location 1 where the panel temperature is stored. Parameters 7 and 8 are the multiplier and offset which convert the measurement to engineering units. The TC instructions return the measurement in units of

°C when a multiplier of 1 and an offset of 0 are used.

The first example was explained one keystroke at a time. Instead of listing each keystroke, the following format shows the display after a value is keyed in; the use of the A key to advance to the next entry is not shown. This format is similar to that used in the PC208 EDLOG program.

If you have followed through sample program 1 and edited the program in OV4.2, your 21X now has a 5 second execution interval and Instruction 17 in Table 1. To continue with this example you can simply advance (key A) through the execution interval and Instruction 17 and check the entries against the following listing. The new entry starts with the second instruction in the table.

Sample Program 2

Instruction (Loc.:Entry)	Parameter (Par.#:Entry)	Description
*1		Enter Program Table 1
01:5		5 second execution interval
01:P17	01:1	Measure panel temperature Store temp. in location 1
02:P14	01:1	Measure thermocouple temp. (differential). 1 repetition.
	02:1	Range code (5mV, slow).
	03:5	Input channel of TC.
	04:1	TC type: copper-constantan.
	05:1	Reference temp is stored in location 1.
	06:2	Store TC temp in location 2.
	07:1	Multiplier of 1 (degrees C)
	08:0	Offset of 0.
03:P92		If Time
	01:0	0 minutes into the interval.
	02:60	60 minute interval.
	03:10	Set Output Flag (Flag 0).

The 21X is programmed to measure the thermocouple temperature every 5 seconds. The If Time Instruction, 92, sets the Output Flag at the beginning of each hour. Next, the instructions for time and average are added.

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Instruction (Loc.:Entry)	Parameter (Par.#:Entry)	Description
04:P77	01:10	Output Time Store hour and minute.
05:P71	01:1 02:2	Average One repetition. Source of TC temps to be averaged, Input Storage location 2.

To obtain daily output, the If Time instruction is again used to set the Output Flag and is followed by the Output Instructions to store time and the daily maximum and minimum temperatures and the time each occurs.

Any Program Control Instruction which is used to set the Output Flag high will set it low if the conditions are not met for setting it high. Instruction 92 above sets the Output Flag high

every hour. The Output Instructions which follow do not output every hour because they are preceded by another Instruction 92 which sets the Output Flag high at midnight (and sets it low at any other time). This is a unique feature of Flag 0. The Output Flag is set low at the start of each table (Section 3.7).

Instruction (Loc.:Entry)	Parameter (Par.#:Entry)	Description
06:P92	01:0 02:1440 03:10	If Time 0 minutes into the interval. 1440 minute interval. Set Output Flag (Flag 0).
07: P77	01:110	Output Time Store day, hour and minute.
08: P73	01:1 02:10 03:2	Maximize instruction. One repetition. Output the time at which the maximum occurs, in hours and minutes. Location to maximize, TC temp.
09: P74	01:1 02:10 03:2	Minimize instruction. One repetition. Output the time at which the minimum occurs, in hours and minutes. Location to minimize, TC temp.

*On power-up the year and day are initialized to the date the 21X PROMs were assembled, the clock must be set to the current date and time. This is done in the *5 Mode (Section 1.2).*

Key	Display Shows (ID:Data)	Explanation
*5	00:21:32	Enter *5 mode. Clock running but not set correctly.
A	05:89	Advance to YEAR location.
90	05:90	Key in current year (1990).
A	05:0076	Enter and advance to day of year.
197	05:197	Key in day of year. The 21X Prompt Sheet has a day of year calendar.
A	05:00:21	Enter and advance to hour and minute.
1324	05:1324	Key in hrs:min (1:24 PM in this example).
A	:13:24:01	Clock set and running. (:HR:MIN:SEC)

*Now that the clock is set, we will erase Final Storage so that any data from the first example will not be confused with this data. The *A Mode is used to repartition memory between Input, Intermediate, and Final Storage. Final Storage is erased when memory is repartitioned, even if the same sizes are retained (Section 1.5).*

Key	Display Shows (ID:Data)	Explanation
*A	01:0028	There are 28 Input Storage locations.
28	01:28	"Change" to 28 locations
A	02:0064	Enter 28, display no. of Intermediate loc.
*0	:LOG 1	Exit *A, enter *0, compile Table 1 and commence logging data.

The 21X is now programmed to measure the panel and TC temperatures every 5 seconds. Every hour there will be 3 values output: 1) the output array ID, 103 (3rd instruction in Table 1 set the Output Flag), 2) time, and 3) average of the thermocouple readings that occurred in the previous hour.

Every day there will be 7 values output: 1) output array ID, 106 (6th instruction in Table 1 set the Output Flag), 2) day, 3) time, 4) maximum TC temperature that occurred in the previous day, 5) time at which the maximum occurred, 6) minimum TC temperature, and 7) the time at which the minimum occurred.

OV5. DATA RETRIEVAL OPTIONS

There are several options for data storage and retrieval. These options are covered in detail in Sections 2, 4, and 5. Figure OV5-1 summarizes the various possible methods.

Regardless of the method used, there are three general approaches to retrieving data from a datalogger.

1. On-line output of Final Storage data to a peripheral storage device. On a regular schedule, that storage device is brought back to the office/lab where the data is transferred to the computer. Another storage device is usually taken into the field

21X MICROLOGGER OVERVIEW

and exchanged for the one which is retrieved so that data collection can continue uninterrupted.

2. Bring a storage device to the datalogger and transfer all the data that has accumulated in Final Storage since the last visit.
3. Retrieve the data over some form of telecommunications link, that is, Radio Frequency (RF), telephone, short haul modem, multi-drop interface, or satellite. The PC208 TELCOM program automates

this process for IBM PC/XT/AT/PS-2's and compatibles.

Regardless of which method is used, the retrieval of data from the datalogger does NOT erase those data from Final Storage. The data remain in the ring memory until:

- they are written over by new data (Section 2.1)
- memory is reallocated (Section 1.5)
- the power to the datalogger is turned off.

Table OV5-1 lists the instructions used with the various methods of data retrieval.

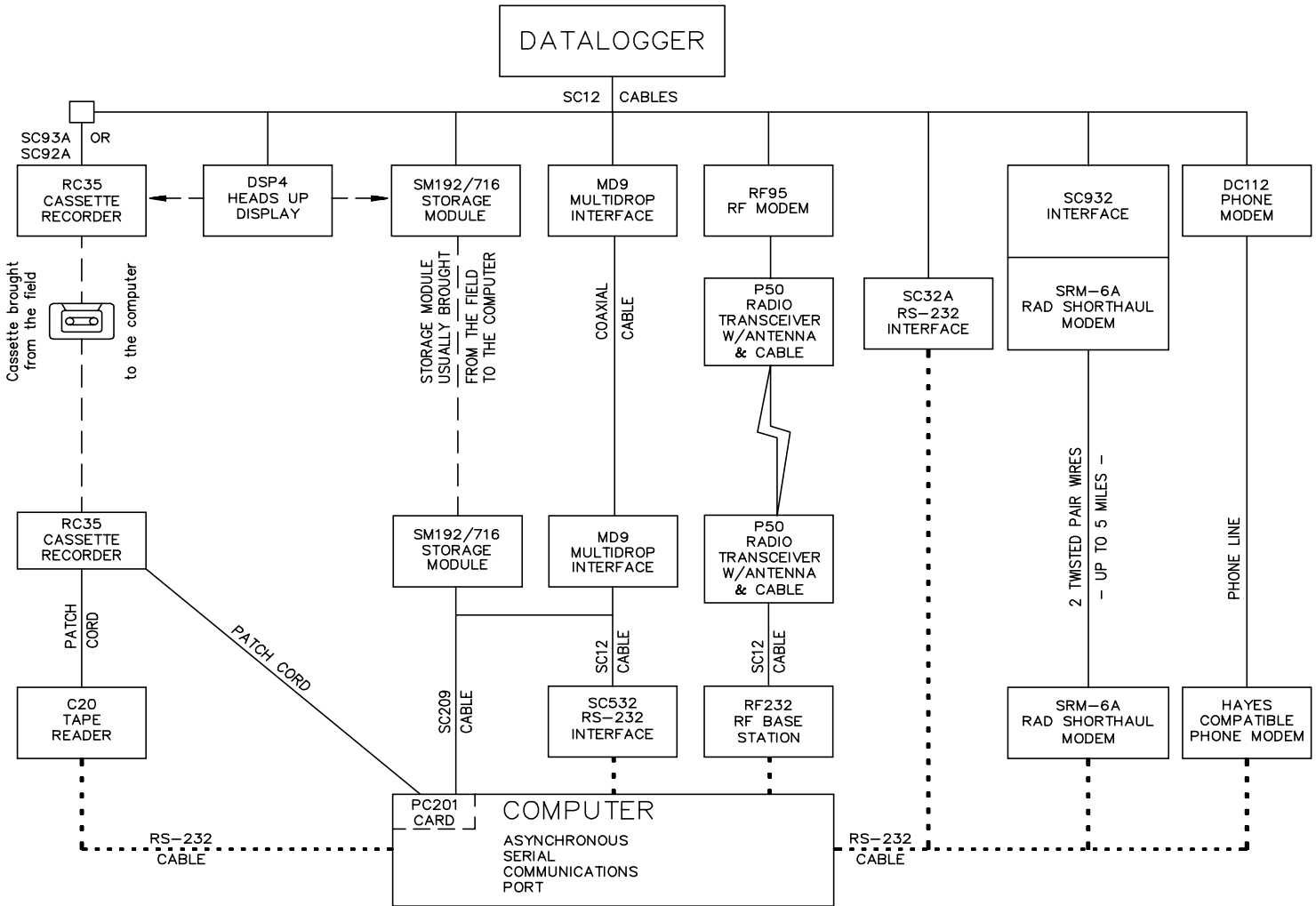
TABLE OV5-1. Data Retrieval Methods and Related Instructions

<u>Cassette Tape</u>	<u>Storage Module</u>	<u>Printer, other Serial Device</u>	<u>Telecommunications (RF, Phone, Short Haul, SC32A)</u>
Inst. 96	Inst. 96,	Inst. 96, 98	Inst. 97
*4	*4	*4	
*8	*9	*9	(Telecommunications Commands)
	*D	*D	

TABLE OV5-2. Data Retrieval Sections in Manual

<u>Topic</u>	<u>Section in Manual</u>
Instr. 96	4.1, 12
Instr. 97	12
*4	4.1
*8	4.2
*9	4.2
*D	1.8
Cassette Tape	4.3
Storage Module	4.4
Telecommunications	5

DATA RETRIEVAL



- NOTES:**
1. ADDITIONAL METHODS OF DATA RETREIVAL ARE:
 - A. SATELLITE TRANSMISSION
 - B. DIRECT DUMP TO PRINTER
 2. THE DSP4 HEADS UP DISPLAY ALLOWS THE USER TO VIEW DATA IN INPUT STORAGE. ALSO BUFFERS FINAL STORAGE DATA AND WRITES IT TO CASSETTE TAPE, PRINTER OR STORAGE MODULE.
 3. ALL CAMPBELL SCIENTIFIC RS-232 INTERFACES HAVE A FEMALE 25 PIN RS-232 CONNECTOR.

FIGURE OV5-1. Data Retrieval Hardware Options

OV6. SPECIFICATIONS

SECTION 1. FUNCTIONAL MODES

1.1 PROGRAM TABLES - *1, *2, AND *3 MODES

Data acquisition and processing functions are controlled by instructions contained in program tables. Programming can be separated into 2 tables, each having its own programmable execution interval. A third table is available for programming subroutines which may be called by instructions in Tables 1 or 2 or by a special interrupt. The *1 and *2 Modes are used to access Tables 1 and 2. The *3 Mode is used to access Subroutine Table 3.

When a program table is first entered, the display shows the table number in the ID Field and 00 in the Data Field. Press A and the 21X will advance to the execution interval. If there is an existing program in the table, enter an instruction location number prior to A and the 21X will advance directly to the instruction (e.g., 5 will advance to the fifth instruction in the table).

1.1.1 EXECUTION INTERVAL

The execution interval is entered in units of seconds as follows:

0.0125 0.1 seconds, in multiples of 0.0125

0.16553 seconds, in multiples of 0.1 second

Intervals less than 0.1 second are allowed in Table 1 only. Execution of the table is repeated at the rate determined by this entry. The table will not be executed if 0 is entered. Values less than 0.1 are rounded to the nearest even multiple of 0.0125. If the Interval is 0.1 or greater, the 21X will not allow entry of digits beyond 0.1.

The sample rate for a 21X measurement is the rate at which the measurement instruction can be executed (i.e., the measurement made, scaled with the instruction's multiplier and offset, and the result placed in Input Storage). Additional processing requires extra time. The throughput rate is the rate at which a measurement can be made and the resulting value stored in Final Storage. The maximum throughput rate for fast single ended measurements (other than with the burst

measurement) is 256 measurements per second (16 measurements repeated 16 times per second).

If the specified execution interval for a table is less than the time required to process that table, the 21X overruns the execution interval, finishes processing the table and waits for the next occurrence of the execution interval before again initiating the table (i.e., when the execution interval is up and the table is still executing, that execution is skipped). Since no advantage is gained in the rate of execution with this situation, it should be avoided by specifying an execution interval adequate for the table processing time.

NOTE: Whenever an overrun occurs, decimal points are displayed on both sides of the sixth digit of the 21X display (e.g., L O.G. in the *0 Mode).

When the Output Flag is set high, extra time is consumed by final output processing. The execution interval may be exceeded at this time only, which may be acceptable. For example, suppose it is desired to measure every 0.1 seconds and output processed data every ten minutes. The processing time of the table is less than 0.1 seconds except when output occurs (every 10 minutes). With final output processing the time required is 1 second. With the execution interval set at 0.1 seconds, and a one second lag between samples once every 10 minutes, 10 measurements out of 6000 (.17%) are missed: an acceptable statistical error for most populations.

1.1.2 SUBROUTINES

Table 3 is used to enter subroutines which may be called with Program Control Instructions in Tables 1 and 2 or other subroutines. The group of instructions which form a subroutine starts with Instruction 85, Label Subroutine, and ends with Instruction 95, End. (Section 12)

SECTION 1. FUNCTIONAL MODES

1.1.3 TABLE PRIORITY/INTERRUPTS

Table 1 execution has priority over Table 2. If Table 2 is being executed when it is time to execute Table 1, Table 2 will be interrupted. After Table 1 is completed, Table 2 resumes at the point of interruption. If the execution interval of Table 2 coincides with Table 1, Table 1 will be executed first, followed by Table 2.

Interrupts by Table 1 are not allowed in the middle of a measurement or while output to Final Storage is in process (the Output Flag, flag 0, is set high). The interrupt occurs as soon as the measurement is completed or flag 0 is set low.

1.1.4 COMPILING A PROGRAM

When a program is first entered, or if any changes are made in the *1, *2, *3, *4, *A, or *C Modes, the program must be compiled before it starts running. The compile function checks for programming errors and optimizes program information for execution. If errors are detected, the appropriate error codes are indicated on the Display (Section 3.10). The compile function is executed when the *0, *6, or *B Modes are entered and prior to saving a program listing in the *D Mode. The compile function is only executed after a program change has been made; any subsequent use of any of these Modes does not cause compiling.

When the *0, *B, or *D Mode is used to compile, all output ports and flags are set low, the timer (Instruction 26) is reset, and data values contained in Input and Intermediate Storage are RESET TO ZERO.

When the *6 Mode is used to compile data values contained in Input Storage, the state of flags, control ports, and the timer are UNALTERED. Compiling always zeros Intermediate Storage.

1.2 SETTING AND DISPLAYING THE CLOCK - *5 MODE

The *5 Mode is used to display time or change the year, day of year, or time. When *5 is pressed, the current time is displayed. The time parameters displayed in the *5 Mode are given in Table 1.2-1.

The 21X powers-up with hours and minutes set to 0 and the day and year set for the date that the PROMs were first released by Campbell Scientific. To set the year, day, or time, enter the *5 Mode and advance to display the appropriate value. Key in the desired number and enter the value by pressing **A**. When a new value for hours and minutes is entered, the seconds are set to zero and current time is again displayed. To exit the *5 Mode, press *. When the time is changed, a partial recompile is done automatically to resynchronize program execution with real time. The resynchronization process can change the interval of a pulse rate measurements for one execution interval as explained in the PULSE COUNT Instruction 3 in Section 9.

TABLE 1.2-1. Sequence of Time Parameters in *5 Mode

Key	Display ID:DATA	Description
*5	:HH:MM:SS	Display current time
A	05:XX	Display/enter year
A	05:XXXX	Display/enter day of year
A	05:HH:MM:	Display/enter hours:minutes

1.3 DISPLAYING AND ALTERING INPUT MEMORY OR FLAGS - *6 MODE

The *6 Mode is used to display or change Input Storage values and to toggle and display user flags. If the *6 Mode is entered immediately following any changes in program tables or the *4 Mode, the programs will be compiled and execution will begin.

When the *6 Mode is used to compile data values contained in Input Storage, the state of flags, control ports, and the timer are UNALTERED. Compiling always zeros Intermediate Storage.

TABLE 1.3-1. *6 Mode Commands

Key	Action
A	Advance to next location or enter new value
B	Back-up to previous location
C	Change value in displayed location(Key C, then value, then A)
D	Display/alter user flags
#	Display current location and allow a location no. to be keyed in, followed by A to jump to that location
*	Exit *6 Mode

1.3.1 DISPLAYING AND ALTERING INPUT STORAGE

When *6 is keyed, the display will read "06:0000". One can advance to view the value stored in Input Storage location 1 by pressing **A**. To go directly to a specific location, key in the location number before keying **A**. For example, to view the value contained in Input Storage location 20, key in *6 20 **A**. The ID portion of the display shows the last 2 digits of the location number. If the value stored in the location being monitored is the result of a program instruction, the value will be updated each time the instruction is executed.

Values may be entered into input locations using the change command, **C**. While viewing the contents of the input location in which the value is to be entered, key **C**; the location number in the ID field will disappear. Key in the desired value and then enter it by pressing **A**.

If an algorithm requires parameters to be manually modified during execution of the program WITHOUT INTERRUPTION of the Table execution process, the parameters can be loaded in Input Storage locations and the *6 Mode can be used to change the values. If values must be in place before program execution commences, use Instruction 91 at the beginning of the program table to prevent execution until a flag is set high (see next section). The initial values can be entered into input locations using the *6 Mode after compiling the table. The flag can then be set high to enable the table(s).

If any program tables *1, *2, *3, or *4 output options are altered and compiled in the *0 Mode, values in Input Storage will be set to 0. To preserve values entered in Input Storage, compile with *6.

1.3.2 DISPLAYING AND TOGGLING USER FLAGS

If D is keyed while the 21X is displaying a location value, the current status of the user flags will be displayed in the following format: "00:01:00:10". The characters represent the flags, the left-most digit represents Flag 1 and right most Flag 8. A "0" indicates the flag is low and a "1" indicates the flag is high. In the above example, Flags 4 and 7 are set high. To toggle a flag, simply key the corresponding number. To return to displaying the input location, press **A**.

Entering appropriate flag tests into the program allows manual control of program execution. For example: It is desired to be able to manually start the execution of Table 2. Instruction 91 is the first instruction entered in Table 2:

```
01:    P91      If Flag
      01:   25      5 is set low
      02:    0      Go to end of program table
```

If Flag 5 is low, all subsequent instructions in Table 2 will be skipped. Flag 5 can be toggled from the *6 Mode, effectively starting and stopping the execution of Table 2.

1.3.3 DISPLAYING AND TOGGLING PORTS

The current status of the user's ports can be displayed by hitting "0" while looking at an input location (e.g., *6A0). Ports are displayed left to right as 0, 0, C6, C5, ..., C1 (exactly opposite to the flags). A port can be toggled by pressing its number on the keypad while in the port display mode.

1.4 COMPILING AND LOGGING DATA - *0 MODE

When the *0 Mode is entered after programming the 21X, the program is compiled (Section 1.1.4) and the display shows "LOG" and the numbers of the program tables that were enabled at

SECTION 1. FUNCTIONAL MODES

compilation. The display is not updated after entering *0.

When the *0, *B, or *D Mode is used to compile, all output ports and flags are set low, the timer (Instruction 26) is reset, and data values contained in Input and Intermediate Storage are RESET TO ZERO.

The 21X should normally be left in the *0 Mode when logging data. This Mode requires slightly less power than Modes which frequently update the display.

1.5 MEMORY ALLOCATION - *A

1.5.1 INTERNAL MEMORY

There are 8 sockets on the 21X CPU board which are used for Read Only Memory (ROM) or Random Access Memory (RAM). The basic 21X is provided with 64K of memory: three 8K Programmable Read Only Memory (PROM) chips for a total of 24K ROM and five 8K RAM chips. Appendix E describes how to change RAM and ROM chips.

When powered-up, the 21X displays HELLO while performing a self check; the result of the check is then displayed. The 8 characters in the display represent the 8 memory sockets numbered from left to right: 1 means a good chip is in the corresponding socket; 0 means the socket is empty or an error was detected in the chip. For example, when equipped with standard memory, the display will read "11:111111"; the five 1s on the left represent the 8K RAM chips; the three 1s on the right, the three 8K PROMs.

There are 978 bytes allotted to program memory. This memory may be used for 1 program table or shared among all program tables. Tables 3.9-1 to 3.9-4 list the amount of memory used by each program instruction.

Input Storage is used to store the results of Input/Output and Processing Instructions. The values stored in input locations may be displayed using the *6 Mode (Section 1.3).

Intermediate Storage is used by Output Processing Instructions to store the results of intermediate calculations necessary for averages, standard deviations, histograms, etc.

Final Storage holds output data, the results of Output Processing Instructions which are stored when the Output Flag is set high (Section 3.7). The data in Final Storage can be displayed using the *7 Mode (Section 2.3).

Figure OV2-1 illustrates the use of Input, Intermediate, and Final Storage.

Each Input or Intermediate Storage location requires 4 bytes of memory. Each Final Storage location requires 2 bytes of memory. Low resolution data points require 1 Final Storage location and high resolution data points require 2. Section 2 describes Final Storage and data retrieval in detail.

Table 1.5-1 lists the basic memory areas and the amount of memory allotted to them in the standard 21X.

**TABLE 1.5-1. Memory Allocation in Standard 21X
(24K ROM, 40K RAM)**

	PROM	Program Memory	System Memory	Input Storage*	Intermediate Storage*	Final Storage*]
Avail. bytes	24K	978	1022	112	256	38,592
Avail. Loc.	---	---	---	28	64	19,296

**Default allocation on power-up*

1.5.2 *A MODE

The *A Mode is used to 1) determine the number of locations allocated to Input, Intermediate, and Final Storage; 2) repartition this memory; 3) check the number of bytes remaining in program memory; 4) erase Final Storage; and 5) to completely reset the datalogger. When *A is keyed, the first value displayed is the number of memory locations allocated to Input Storage. Press A to advance through the memory values. Table 1.5-2 describes what the values seen in the *A Mode represent.

TABLE 1.5-2. Description of *A Mode Data

Key Entry	Display ID: Data	Description of Data
*A	01: XXXX	The number of memory locations currently allocated to Input Storage. This value can be changed by keying in the desired number (minimum of 28, maximum limited by available memory).
A	02: XXXX	The number of memory locations currently allocated to Intermediate Storage. This value can be changed by keying in the desired number (limited by available memory).
A	03: XXXXX	The number of memory locations currently allocated to Final Storage. This number is automatically altered when the number of memory locations in Input and/or Intermediate Storage is changed. A minimum of 768 locations are always retained in Final Storage.
A	04:XXXX	The number of bytes remaining in Program memory (978 bytes total). Entering 978 will ERASE ALL MEMORY and put the 21X through the initial power-up routine.

The numbers of memory locations allocated to Input, Intermediate and Final Storage default at power-up to the values in Table 1.5-1.

The sizes of Input and Intermediate Storage may be altered by keying in the desired value and entering it by keying A. The size of Final Storage will be adjusted automatically.

When Input Storage is increased beyond 28 locations, all of Input Storage comes out of Final Storage and the memory previously allocated to Input Storage (112 bytes) goes unused. This is because memory allocated to minimum Input Storage is bounded by write protected program memory. When more Input Storage is required, Input Storage must be moved to where a contiguous block of memory is available.

One Input or Intermediate Storage location can be exchanged for two Final Storage locations and vice-versa. A minimum 28 Input and 768 Final Storage locations will ALWAYS be retained. The size of Intermediate Storage may be reduced to 0.

All data in Intermediate and Final Storage are erased when memory is repartitioned. This feature may be used to clear memory without altering programming. The number of locations does not actually need to be changed; the same value can be keyed in and entered. After repartitioning memory, the Tables must be recompiled. Recompiling erases Intermediate Storage. Recompiling with *0 erases Input Storage; recompiling with *6 leaves Input Storage unaltered.

If Intermediate Storage size is too small to accommodate the programs or instructions entered, the program will not compile and the "E:04" ERROR CODE will be displayed; the size of Intermediate Storage must be increased before the program will compile. Final Storage size can be maximized by limiting Intermediate Storage size to the minimum number of memory locations necessary to accommodate the programs entered. The number of Final Storage locations and the rate at which data are stored determines how long it will take for Final Storage to fill, at which point new data will write over old.

SECTION 1. FUNCTIONAL MODES

1.6 MEMORY TESTING AND SYSTEM STATUS - *B

The *B Mode is used to 1) read the signature of the program memory and the software PROMs, 2) display the power-up memory status, 3) display the number of E08 occurrences (Section 3.10), 4) display the number of overrun occurrences (Section 1.1.1), and 5) display PROM version and revision number. Table 1.6-1 describes what the values seen in the *B Mode represent. The correct signatures of the 21X PROMs are listed in Appendix B.

A signature is a number which is a function of the data and the sequence of data in memory. It is derived using an algorithm which assures a 99.998% probability that if either the data or its sequence changes, the signature changes. The signature of the program memory is used to determine if the program tables have been altered. During the self check on power-up, the signature computed for a PROM is compared with a signature stored in the PROM to determine if a failure has occurred. The algorithm used to calculate the signature is described in Appendix C.

The contents of windows 8 and 9, PROM version and version revision, are helpful in determining what PROM is in the datalogger. Over the years, several different PROM versions have been released, each with operational differences. When calling Campbell Scientific for datalogger assistance, please have these two numbers available.

TABLE 1.6-1. Description of *B Mode Data

Key Entry	Display ID: Data	Description of Data
*B	01: XXXXX	Program memory Signature. The value is dependent upon the programming entered and memory allotment. If the Tables have not been previously compiled, they will be compiled and run.
A	02: XXXXX	First PROM Signature
	03: XXXXX	Second PROM Signature

	04: XXXXX	Third PROM Signature
A	05: XXXXX	Memory status, decimal equivalent to the 1s and 0s shown on power-up (Section 1.5.1 e.g., 11111111=255)
A	06: XXXXX	No. of E08 occurrences (Key in 88 to reset)
A	07: XXXXX	No. of overrun occurrences (Key in 88 to reset)
A	08: X.XXXX	PROM version number
A	09: XXXX.	Version revision number

1.7 *C MODE -- SECURITY

The *C Mode is used to secure the user's program information. If security is activated, then the 21X will block keyboard access to the *1, *2, *3, *4, and *A Modes. Activated security will also block Telecommunications access to the *1, *2, *3, *4, *5, and *D Modes and the Telecommunications C command. A four digit password allows entry to the *C Mode and becomes part of the program memory, affecting the program signature. If security is enabled when *C is keyed, the password must be keyed in before one can advance to window 1. If security is disabled, keying *C brings up window 1 immediately. In window 1 a command can be entered to either enter a new password (1), or temporarily disable security (00) in order to check or alter the programming. The password on power-up is 0000 (unless *D was used to create a custom PROM with the password built in), which disables security. When security is temporarily disabled, it is possible to enter all modes and to alter programming. Keying *0 or *6 will automatically re-enable security, unless the password is 0000.

Entering the 4 digit password as an indexed value (i.e. xxxx--, entered by keying C after entering the four digits) blocks access to the *1, *2, *3, *4, and *A Modes, but it will allow the user to view and change the password.

TABLE 1.7-1. *C Mode Entries and Codes

Key Entry	Display ID: Data	Description
*C	12:0000	Enter current password. If correct, then advance, else exit *C Mode. 12:00 indicates *C Mode is not in PROMs. If security is disabled, *C advances directly to window 1.
A	01:00	Window 1, enter command: 00 = disable security and advance to window 2; subsequent *0 or *6 enables security. 01 = security remains enabled, but it advances to window 2 and allows entry of a new password.
A	02:XXXX	Set new password (XXXX is current password).
A		Returns to window 1. Entering 0000 disables security (window 1 must be set to 0).

1.8 *D MODE -- SAVE OR LOAD PROGRAM

The *D Mode allows the user's program information in the *1, *2, *3, *4, *A, *C (if OSX-0), and *B Modes to be output to or loaded from printer/computer (ASCII), tape, or SM192/716 Storage Module. Table execution and on-line tape and printer outputs are suspended while in the *D Mode. When *D is keyed, the 21X will display "13:00".

TABLE 1.8-1. *D Mode Commands

Command	Description
1	Save ASCII Program
2	Load ASCII Program
71	Save/Load/Clear Program from Storage Module

A command is entered by keying the command number and **A**. When Command 1, 2, or 71 is entered, the command number is displayed in the ID field. The user must then key in a baud rate code for command 1 or 2 or the command code for the Storage Module (Table 1.8-2). After the code is keyed in, key **A** to execute the command. After a command is executed, "13:0000" is displayed; *D must be entered again before another command can be given.

If the 21X program has not been compiled when a command to save the program is entered, it will be compiled before the command is executed.

TABLE 1.8-2. *D Mode Baud Rate and Storage Module Codes

BAUD RATE CODES	STORAGE MODULE COMMAND CODES
0 - 300 baud	1X Save Program X to Storage Module (X=1-8)
1 - 1200	
2 - 9600	2X Load Program X from Storage Module (X=1-8)
3 - 76,800	3X Erase Program X from Storage Module (X=1-8)

All data in Input, Intermediate and Final Storage are erased when a command to load a program is executed or when a program is written to tape. If nothing is received within 30-40 seconds after giving the command to load a program the command will be aborted and an error code displayed (E99 for Storage Module or ASCII). Commands 1, 2, and 71 are the only commands that can be executed via telecommunications (Section 5). For commands 1 and 2, the 21X will use the baud rate already established in telecommunications and will be ready to receive or send the file as soon as the command is received.

TABLE 1.8-3. Program Load Error Codes

E 98	Uncorrectable errors detected
E 99	Wrong type of file or no data received

SECTION 1. FUNCTIONAL MODES

1.8.1 TRANSFER TO COMPUTER/PRINTER

This section describes commands 1 and 2 (Table 1.8-1). TERM (PC208 Software) automatically uses these commands for uploading and downloading programs.

SENDING ASCII PROGRAM INFORMATION

Command 1 is to send the program listing in ASCII. At the end of the listing, the 21X sends control E (5 hex or decimal) twice. Except when in telecommunications, the baud rate code must be entered after command 1.

Table 1.8-4 is an example of the program listing sent in response to command 1 (the actual listing is in one column but is printed in two columns to save space). Note that the listing uses numbers for each mode: The numbers for *A, *B, and *C modes are 10, 11, and 12, respectively.

TABLE 1.8-4. Example Program Listing From *D Command 1

```

MODE 1
SCAN RATE 2
1:P17
1:1
1:P0

2:P14
1:1
2:1
3:5
4:1
5:1
6:2
7:1
8:0

3:P92
1:0
2:5
3:10

MODE 1
SCAN RATE 2

4:P71
1:2
2:1
    
```

```

5:P0

MODE 2
SCAN RATE 0

MODE 3

MODE 4
1:0
2:0

MODE 10
1:28
2:64
3:19328
4:934

MODE 12
1:0
2:0

MODE 2
SCAN RATE 0
    
```

LOAD PROGRAM FROM ASCII FILE

Command 2 sets up the 21X to load a serial ASCII program. The format is the same as sent in response to command 1 (Table 1.8.4). Except when in telecommunications, the baud rate code must be entered after command 2.

A download file need not follow exactly the same format that is used when listing a program (i.e., some of the characters sent in the listing are not really used when a program is loaded). Some rules which must be followed are:

1. **"M"** must be the first character other than a carriage return (CR) or line feed (LF). The **"M"** serves the same function as **"*** does from the keyboard. The order that the Modes are sent in does not matter (i.e., the information for Mode 4 could be sent before that for Mode 1).
2. **"S"** is necessary prior to the execution interval (Scan rate).
3. The colons (:) are used to mark the start of actual data.

SECTION 1. FUNCTIONAL MODES

4. A semicolon (;) tells the 21X to ignore the rest of the line and can be used after an entry so that a comment can be added.

There are 4 two-character control codes which may be used to verify that the 21X receives a file correctly:

^B ^B	(2hex, 2hex)	Discard current buffer and reset signature
^C ^C	(3hex, 3hex)	Send signature for current buffer
^D ^D	(4hex, 4hex)	Load current buffer and reset signature
^E ^E	(5hex, 5hex)	Exit and compile program

As a download file is received, the 21X buffers the data in memory; the data is not loaded into the editor or compiled until the 21X receives a command to do so. The minimum file that could be sent is the program listing, then **^E^E**. **^C^C** tells the 21X to send the signature (Section C.3) for the current buffer of data. If this signature does not match that calculated by the sending

device, **^B^B** can be sent to discard the current buffer and reset the signature. If the signature is correct, **^D^D** can be sent to tell the 21X to load the buffer into the editor and reset the signature. Once the complete file has been sent and verified, send **^E^E** to compile the program and exit the load command.

1.8.2 PROGRAM TRANSFER WITH STORAGE MODULE

The SM192/716 Storage Module must be connected to the 21X. Key ***D**, then enter command 71. The command to save, load, or clear a program and the program number (Table 1.8-2) is entered. After the operation is finished "13:0000" is displayed.

The datalogger can be programmed on power-up using a Storage Module. Storage Modules can store up to eight separate programs. If a program is stored as program number 8, and if the Storage Module is connected to the datalogger serial port at power-up, program number 8 is downloaded to the datalogger and compiled.

SECTION 1. FUNCTIONAL MODES

SECTION 2. INTERNAL DATA STORAGE

2.1 FINAL STORAGE AREAS, OUTPUT ARRAYS, AND MEMORY POINTERS

Final Storage is that portion of memory where final, processed data are stored. Data must be sent to Final Storage before they can be transferred to a computer or external storage peripheral.

The size of Final Storage is expressed in terms of memory locations or bytes. A low resolution data point (4 decimal characters) occupies one memory location (2 bytes), whereas a high resolution data point (5 decimal characters) requires two memory locations (4 bytes). Table 1.5-1 shows the default allocation of memory locations to Input, Intermediate, and Final Storage. The *A Mode is used to reallocate memory or erase Final Storage (Section 1.5). A minimum of 768 memory locations will ALWAYS be retained in Final Storage.

Final Storage can be represented as ring memory (Figure 2.1-1) on which the newest data are written over the oldest data.

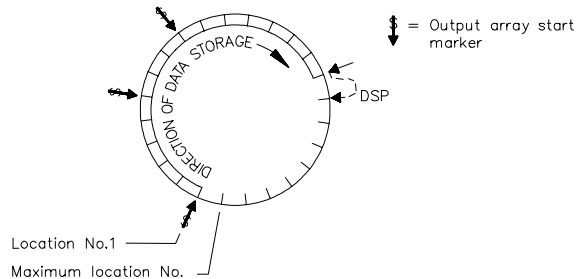


FIGURE 2.1-1. Ring Memory Representation of Final Data Storage

Output Processing Instructions store data into Final Storage only when the Output Flag is set high. The string of data stored each time the Output Flag is set high is called an **output array**. The first data point in the output array is a 4 digit **Output Array ID**. This ID number is set in one of two ways:

- 1) In the default condition, the ID consists of the program table number and the Instruction Location Number of the instruction which set the Output Flag for that

output array. For example, the ID of 118 in Figure 2.1-2 indicates that the 18th instruction in Table 1 set the Output Flag high.

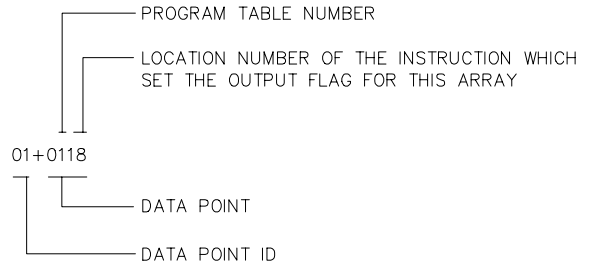


FIGURE 2.1-2. Output Array ID

- 2) The output array ID can be set by the user with the second parameter of Instruction 80 (Section 11). The ID can be set to any positive integer up to 511. Instruction 80 must follow the instruction which set the Output Flag high. This option allows the user to make the output array ID independent of the programming. The program can be changed (instructions added or deleted) without changing the output array ID. This avoids confusion during data reduction, especially on long term projects where program changes or updates are likely.

NOTE: If Instruction 80 is used to designate Final Storage and parameter 2 is 0, the output array ID is determined by the position of Instruction 80 or by the position of the instruction setting the Output Flag, whichever occurs last.

Data are stored in Final Storage before being transmitted to an external device. There are 5 pointers which are used to keep track of data transmission. These pointers are:

1. Data Storage Pointer (**DSP**)
2. Display Pointer (**DPTR**)
3. Tape Pointer (**TPTR**)
4. Printer Pointer (**PPTR**)
5. Telecommunications (Modem) Pointer (**MPTR**)

SECTION 2. INTERNAL DATA STORAGE

The **Data Storage Pointer (DSP)** is used to determine where to store each new data point in the Final Storage area. The DSP advances to the next available memory location after each new data point is stored.

The **DPTR** is used to recall data to the LCD display. The positioning of this pointer and data recall are controlled from the keyboard (*7 Mode).

The **TPTR** is used to control data transmission to a cassette tape recorder. When on-line tape transfer is activated (*4 Mode or Instruction 96, option 00), data is transmitted to tape whenever the DSP is a minimum of 512 memory locations ahead of the TPTR. The TPTR may also be positioned via the keyboard for manually initiated data transfer to tape (*8 Mode).

The **PPTR** is used to control data transmission to a printer, Storage Module, or other serial device. Whenever on-line printer transfer is activated (*4 Mode or Instruction 96), data between the PPTR and DSP are transmitted.

When on-line transfer to a SM192/716 Storage Module is activated by Instruction 96 with output code 30, data is transmitted each time an output array is stored in Final Storage IF THE STORAGE MODULE IS CONNECTED TO THE 21X. If the Storage Module is not connected, the 21X does not transmit the data nor does it advance the PPTR to the new DSP location. It saves the data until the Storage Module is connected. Then, during the next execution of Instruction 96, the 21X outputs all of the data between the PPTR and the DSP and updates the PPTR to the DSP location (Section 4.1)

The **MPTR** is used in transmitting data over a telecommunications interface. When Telecommunications is first entered, the MPTR is set to the same location as the DSP. Positioning of the MPTR is then controlled by commands from the external calling device (Section 5.1).

NOTE: All memory pointers are set to the DSP location when the datalogger compiles a program. For this reason, ALWAYS RETRIEVE UNCOLLECTED DATA BEFORE MAKING PROGRAM CHANGES. For example, assume the TPTR lags the DSP by less than 512 data points when the datalogger program is altered. On compiling, the TPTR is positioned with the DSP, losing reference to the data that was intended to be transferred to tape. The data is not automatically transferred and appears as a discontinuity in the data file. Until the ring memory wraps around and data overwrite occurs, the data may be recovered using the *8 Mode. This scenario is also true for the PPTR and data intended for a Storage Module.

2.2 DATA OUTPUT FORMAT AND RANGE LIMITS

Data are stored internally in Campbell Scientific's Final Storage Format (Appendix C.2). Data may be sent to Final Storage in either LOW RESOLUTION or HIGH RESOLUTION format. Low resolution is the default. To change the resolution, Instruction 78 (Section 11) must precede the Output Instructions in the program table.

2.2.1 RESOLUTION AND RANGE LIMITS

Low resolution data is a 2 byte format with 3 or 4 significant digits and a maximum magnitude of ± 6999 . High resolution data is a 4 byte format with 5 significant digits and a maximum possible output value of ± 99999 (see Table 2.2-1 below).

TABLE 2.2-1. Resolution Range Limits of 21X Data

Resolution	Zero	Minimum Magnitude	Maximum Magnitude
Low	0.000	± 0.001	± 6999 .
High	0.0000	± 0.00001	± 99999 .

The resolution of the low resolution format is reduced to 3 significant digits when the first (left most) digit is 7 or greater (Table 2.2-2). Thus, it may be necessary to use high resolution output or an offset to maintain the desired resolution of a measurement. For example, if water level is to be measured and output to the nearest 0.01 foot, the level must be less than 70 feet for low resolution output to display the 0.01 foot increment. If the water level is expected to range from 50 to 80 feet the data could either be output in high resolution or could be offset by 20 feet. (transforming the range to 30 to 60 feet.).

TABLE 2.2-2. Decimal Location in Low Resolution Format

Absolute Value	Decimal Location
0 - 6.999	X.XXX
7 - 69.99	XX.XX
70 - 699.9	XXX.X
700 - 6999.	XXXX.

While output data have the limits described above, the computations performed in the 21X are done in floating point arithmetic. Values are rounded when converting to Final Storage Format.

2.2.2 INPUT AND INTERMEDIATE STORAGE DATA FORMAT

In Input and Intermediate Storage, numbers are stored and processed in a binary format with a 23 bit binary mantissa and a 6 bit binary exponent. The largest and smallest numbers that can be stored and processed are 9×10^{18} and 1×10^{-19} , respectively. The size of the number determines the resolution of the arithmetic. A rough approximation of the resolution is that it is better than 1 in the seventh digit. For example, the resolution of 97,386,924 is better than 10. The resolution of 0.0086731924 is better than 0.000000001.

A precise calculation of the resolution of a number may be determined by representing the number as a mantissa between .5 and 1 multiplied by 2 raised to some integer power. The resolution is the product of that power of 2 and 2^{-24} . For example, representing 478 as $.9336 \times 2^9$, the resolution is $2^9 \times 2^{-24} = 2^{-15} =$

0.0000305. A description of Campbell Scientific's floating point format may be found in the description of the J and K telecommunications commands in Appendix C.

2.3 DISPLAYING STORED DATA ON KEYBOARD/DISPLAY - *7 MODE

The *7 Mode is used to display Final Storage data. Enter the Mode by keying *7. The display will show "07:XXXXX", where XXXXX is the Final Storage location (DSP) where the next data will be stored. Two options are available:

1. Press **A** to advance and display the output array ID of the oldest array in Final Storage.
2. Enter a Final Storage location number. When **A** is pressed, the DPTR will jump to the location entered and, if it is not at the start of an array, advance to the first start of array. The display will show the Array ID.

Repeated use of the **A** key advances through the output array, while use of the **B** key backs the DPTR through memory.

The Final Storage location of the data point being viewed may be displayed by keying #. At this point, another location may be entered, followed by **A** to jump to the start of the output array equal to or just ahead of the location entered. Whenever a location number is displayed by keying #, the corresponding data point can be displayed by keying **C**. To advance to the start of the next output array, key **#A**. To back up one output array key **#B**.

TABLE 2.3-1. *7 Mode Command Summary

Key	Action
A	Advance to next data point
B	Back-up to previous data point
#	Display location number of currently displayed data point value
C	Display value of current location
#A	Advance to start of next output array
#B	Back-up to previous output array

SECTION 2. INTERNAL DATA STORAGE

SECTION 3. INSTRUCTION SET BASICS

The instructions used to program the 21X are divided into 4 types: Input/Output (I/O), Processing, Output Processing, and Program Control. I/O Instructions are used to make measurements and store the readings in input locations or to initiate analog or digital port output. Processing Instructions perform numerical operations using data from Input Storage locations and place the results back into specified Input Storage locations. Output Processing Instructions provide a method for generating time or event dependent data summaries from processed sensor readings residing in specified Input Storage locations. Program Control Instructions are used to direct program execution based on time and/or conditional tests on input data and to direct output to external devices.

Instructions are identified by a number. Each instruction has a number of parameters which give the 21X the information it needs to execute the instruction.

The set of instructions available in the 21X is determined by the Programmable Read Only Memory chips (PROMS) that are installed. Appendix B lists the software options available.

3.1 PARAMETER DATA TYPES

There are 3 different data types used for Instruction parameters: Floating Point (FP), 4 digit integers (4), and 2 digit integers (2). In the listings of the instruction parameters (Sections 9-12), the parameter data type is identified by its abbreviation. Different data types are used to allow the 21X to make the most efficient use of its memory.

Floating Point parameters are used to enter numeric constants for calibrations or arithmetic operations. While it is only possible to enter 5 digits (magnitude ± 0.00001 to ± 99999), the internal format has a much greater range (1×10^{-19} to 9×10^{18} , Section 2.2.1).

3.2 REPETITIONS

The repetitions parameter on many of the I/O, Processing, and Output Processing Instructions is used to repeat the instruction on a number of sequential Input Channels or Input Storage locations. For example, if you have 4 differential voltage measurements to make on the same voltage range, wire the inputs to sequential channels and instead of entering the Differential Voltage Measurement Instruction 4 times, enter it once with 4 repetitions. The instruction will make 4 measurements starting on the specified channel number and continuing through the 3 succeeding differential channels, with the results being stored in the specified input location and the 3 succeeding input locations. Averages for all 4 measurements can be calculated by

entering the Average Instruction with 4 repetitions.

When several of the same type of measurements are to be made but the calibrations of the sensors are different, it requires less time to use a single measurement instruction with repetitions and then apply the calibrations with Instruction 53 than it does to enter the instruction several times in order to use different multipliers and offsets. This is due to the set up and calibration time for each measurement instruction. However, if time is not a constraint, separate instructions may make the program easier to follow.

3.3 ENTERING NEGATIVE NUMBERS

After keying in a number, press **C** or "-" to change the number's sign. On floating point numbers a minus sign (-) will appear to the left of the number.

Excitation voltages in millivolts for I/O Instructions are 4 digit integers; when **C** is pressed, minus signs (-) will appear to the right of the number indicating a negative excitation. Even though this display is the same as that indicating an indexed input location, (Section 3.4) there is no indexing effect on excitation voltage.

3.4 INDEXING INPUT LOCATIONS

When used within a Loop, the parameters for input locations can be Indexed to the loop

SECTION 3. INSTRUCTION SET BASICS

counter. The loop counter is added to the indexed value to determine the actual input location the instruction acts on. Normally the loop counter is incremented by 1 after each pass through the loop. Instruction 90, Step Loop Index, allows the increment step to be changed. See Instructions 87 and 90, Section 12, for more details.

To index an input location (4 digit integer) key C after keying the value but before entering the parameter. Two minus signs (-) will be displayed to the right of the parameter.

3.5 VOLTAGE RANGE AND OVERRANGE DETECTION

The RANGE code parameter on Input/Output Instructions is used to specify the full scale voltage range of the measurement and the integration period for the measurement (Table 3.5-1).

Select the smallest full scale range that is greater than or equal to the full scale output of

the sensor being measured. Using the smallest possible range will result in the best resolution for the measurement.

Two different integration sequences are possible. The slow integration, 16.67 milliseconds, is one 60 Hz cycle and rejects noise from 60 Hz AC line power as well as having better rejection of random noise than the fast integration. A PROM with 50Hz rejection is available for countries whose electric utilities operate at 50Hz (Appendix B).

When a voltage input exceeds the range programmed, the value stored is the maximum negative number, displayed in the *6 Mode as -99999. In output data from Final Storage this becomes -6999 in low resolution or -99999. in high resolution.

An input voltage greater than +8 volts on one of the analog inputs will result in errors and possible overranging on the other analog inputs. Voltages greater than 16 volts may permanently damage the 21X.

TABLE 3.5-1. Input Voltage Ranges and Codes

<u>Range Code</u>		<u>Full Scale Range</u>	<u>Resolution*</u>
Slow 16.67ms Integ.	Fast 250µs Integ.		
1	11	±5 millivolts	0.33 microvolts
2	12	±15 millivolts	1. microvolts
3	13	±50 millivolts	3.33 microvolts
4	14	±500 millivolts	33.3 microvolts
5	15	±5000 millivolts	333. microvolts

**Differential measurement, resolution for single-ended measurement is twice value shown.*

3.6 OUTPUT PROCESSING

Most Output Processing Instructions require both an intermediate processing operation and a final processing operation. For example, when the Average Instruction, 71, is executed, the intermediate processing operation increments a sample count and adds each new Input Storage value to a cumulative total residing in Intermediate Storage. When the Output Flag is set, the final processing operation divides the total by the number of sample counts, stores the resulting average in Final Storage and zeros the

value in Intermediate Storage so that the process starts over with the next execution.

Final Storage is the default destination of data output by Output Processing Instructions (Sections OV1.2, 1.5, 2.1). Instruction 80 may be used to direct output to Input Storage or to Final Storage.

Output Processing Instructions requiring intermediate processing sample the specified input location(s) each time the Output Instruction is executed, NOT necessarily each time the

location value is updated by an I/O Instruction. For example: Suppose a temperature measurement is initiated by Table 1 which has an execution interval of 1 second. The instructions to output the average temperature every 10 minutes are in Table 2 which has an execution interval of 10 seconds. The temperature will be measured 600 times in the 10 minute period, but the average will be the result of only 60 of those measurements because the instruction to average is executed only one tenth as often as the instruction to make the measurement.

Final processing occurs only when the Output Flag is set (Section 3.7.1). The Output Flag, Flag 0, is set at desired intervals or in response to specified conditions by using an appropriate Program Control Instruction (Section 11).

3.7 USE OF FLAGS: OUTPUT AND PROGRAM CONTROL

There are 10 flags which may be used in 21X programs. Two of the flags have functions with Output Processing Instructions: Flag 0 controls final processing and data storage, and Flag 9 can disable intermediate processing. Flags 1-8 may be used as desired in programming the 21X. Flags 0 and 9 are automatically set low at the beginning of the program table. Flags 1-8 remain unchanged until acted on by a Program Control Instruction or until manually toggled from the *6 Mode.

TABLE 3.7-1. Flag Description

Flag 0	-	Output Flag
Flag 1 to 8	-	User Flags
Flag 9	-	Intermediate Processing Disable Flag

Flags are set with Program Control Instructions. The Output Flag, Flag 0, and the intermediate processing disable flag, Flag 9, will always be set low if the set high condition is not met. The status of flags 1-8 are not changed if a conditional test is false.

3.7.1 THE OUTPUT FLAG

A set of processed data values is placed in Final Storage by Output Processing Instructions when the Output Flag, Flag 0, is set high. This set of

data is called an output array. The Output Flag is set according to time or event dependent intervals using Program Control Instructions specified by the user. The Output Flag is set low at the beginning of each table.

Each group of Output Processing Instructions creating an output array must be preceded by a Program Control Instruction that sets the Output Flag.

Output is most often desired at fixed intervals; this is accomplished with Instruction 92, If Time, which checks the clock to see if it is X minutes into a Y minute interval. If the time condition is met, a command is executed. Output at the beginning of the interval by making Parameter 1, time into the interval, 0. Parameter 2, the time interval in minutes, is how often output will occur; i.e., the Output Interval. Enter 10 for parameter 3, the command code, to set Flag 0 high. Instruction 92 is followed in the program table by the Output Instructions which define the output array desired.

The time interval is synchronized to 24 hour time; output will occur on each integer multiple of the Output Interval starting from midnight (0 minutes). If the Output Interval is not an even divisor of 1440 minutes (24 hours), the last output interval of the day will be less than the specified time interval. Output will occur at midnight and will resume synchronized to the new day.

NOTE: If the Output Flag is already set high and the test condition of a subsequent Program Control Instruction acting on the flag fails, the flag is set low. This feature eliminates having to enter another instruction to specifically reset the Output Flag at the end of an output array before proceeding to another group of Output Instructions with a different output interval (see example in OV4.3).

3.7.2 THE INTERMEDIATE PROCESSING DISABLE FLAG

The Intermediate Processing Disable Flag, Flag 9, suspends intermediate processing when it is

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set high. This flag is used to restrict sampling for averages, totals, maxima, minima, etc., to times when certain criteria are met. The flag is automatically set low at the beginning of the program table.

As an example, suppose it is desired to obtain a wind speed rose incorporating only wind speeds greater than or equal to 4.5 m/s. The wind speed rose is computed using the Histogram Instruction 75, and wind speed is stored in Input location 14, in m/s. Instruction 89 is placed just before Instruction 75 and is used to set Flag 9 high if the wind speed is less than 4.5 m/s:

TABLE 3.7-2. Example of the Use of Flag 9

Inst. Loc.	Param. No.	Entry	Description
X	P	89	If wind speed < 4.5 m/s
	1	14	Wind speed location
	2	4	Comparison: <
	3	4.5	Minimum wind speed for histogram
	4	19	Set Flag 9 high
X+1	P	75	Histogram
X+2	P	86	Do
	1	29	Set Flag 9 Low

NOTE: Flag 9 is automatically reset the same as Flag 0. If the intermediate processing disable flag is already set high and the test condition of a subsequent Program Control Instruction acting on Flag 9 fails, the flag is set low. This feature eliminates having to enter another instruction to specifically reset Flag 9 before proceeding to another group of test conditions.

3.7.3 USER FLAGS

Flags 1-8 are not dedicated to a specific purpose and are available to the user for general programming needs. The user flags can be manually toggled from the keyboard in the *6 Mode (Section 1.3) or from a computer using TERM's monitor feature. By inserting flag tests (Instruction 91) at appropriate points in the program, the user can manually set flags to direct program execution.

3.8 PROGRAM CONTROL LOGICAL CONSTRUCTIONS

Most of the Program Control Instructions have a command code parameter which is used to specify the action to be taken if the condition tested in the instruction is true. Table 3.8-1 lists these codes.

TABLE 3.8-1. Command Codes

0	-	Go to end of program table
1-9, 77-99	-	Call Subroutine 1-9, 77-99
10-19	-	Set Flag 0-9 high
20-29	-	Set Flag 0-9 low
30	-	Then Do
31	-	Exit loop if true
32	-	Exit loop if false
41-46	-	Set port 1 - 6 high
51-56	-	Set port 1 - 6 low
61-66	-	Toggle port 1 - 6
71-76	-	Pulse port 1 - 6 100 ms

3.8.1 IF THEN/ELSE COMPARISONS

When Command 30, THEN DO, is used with one of the IF Instructions, 88-92, the instruction is followed immediately by instructions to execute if the comparison is true. The Else Instruction, 94, is optional and is followed by the instructions to execute if the comparison is false. The End Instruction, 95, marks the end of the branching started by the IF Instruction. Subsequent instructions are executed regardless of the outcome of the comparison (Figure 3.8-1).

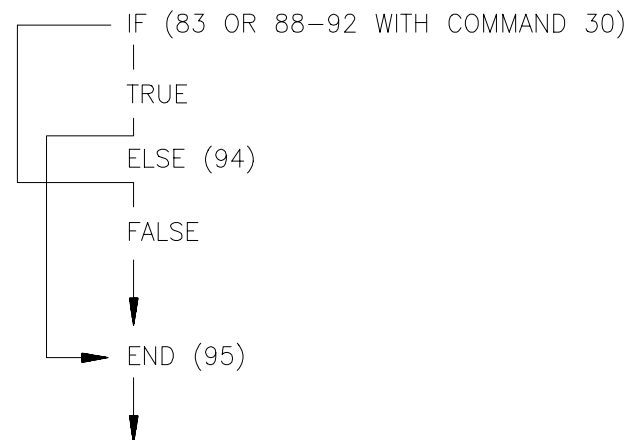


FIGURE 3.8-1. If Then/Else Execution Sequence

If Then/Else comparisons may be nested to form logical AND or OR branching. Figure 3.8-2 illustrates an AND construction. If conditions A and B are true, the instructions included between IF B and the first End Instruction will be executed. If either of the conditions is false, execution will jump to the corresponding End Instruction, skipping the instructions between.

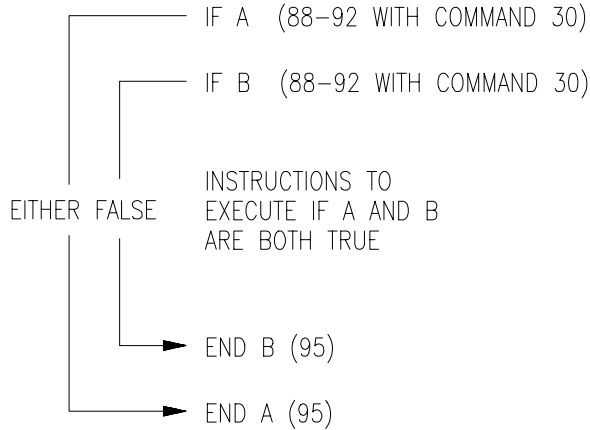


FIGURE 3.8-2. Logical AND Construction

Figure 3.8-3 illustrates the instruction sequence that will result in subroutine X being executed if either A or B is true.

```

IF A (88-92 with command 30)
Call subroutine X (86, command=X)
ELSE (94)
IF B (88-92 with command 30)
Call subroutine X (86, command=X)
END B (95)
END A (95)
    
```

FIGURE 3.8-3. Logical OR Construction

A logical OR can also be constructed by setting a flag if a comparison is true. (The flag is cleared before making the comparisons.) After all comparisons have been made, execute the desired instructions if the flag is set.

The Begin Case Instruction 93 and If Case Instruction 83 allow a series of tests on the value in an input location. The case test is started with Instruction 93 which specifies the location to test. A series of Instructions 83 are then used to compare the value in the location with fixed values. When the value in the input location is less than the fixed value specified in Instruction 83 the command in that Instruction 83 is executed; when the next Instruction 83 is

encountered, execution branches to the END Instruction 95 which closes the case test (see Instruction 93).

3.8.2 END, INSTRUCTION 95

END, Instruction 95, is required to mark the end of:

1. A Subroutine (starts with Instruction 87)
2. A Loop (starts with Instruction 85)
3. An IF ... THEN DO sequence (starts with one of Instructions 89-93 with the THEN DO command 30).
4. A case statement (starts with Instruction 93)

The IF instructions 89-93 require Instruction 95 only when the THEN DO command 30 is used.

If one of the above instructions is used without the corresponding END, the 21X will display error 22 when compiling the program. Error 21 is displayed if END is used without being preceded by one of these instructions (Section 3.10).

An END instruction is always paired with the most recent instruction that requires an END and does not already have one. A way of visualizing this is to draw lines between each instruction requiring an END and the END paired with it (as in Figure 3.8-2). The lines must not cross. To debug logic or find a missing or extra END error, list the program and draw the lines.

Subroutines can be called from other subroutines; they cannot be embedded within other subroutines. A subroutine must end before another subroutine begins (Error 20). Any loops or IF...THEN DO sequences started within a subroutine must end before the subroutine.

3.8.3 NESTING

A branching or loop instruction which occurs before a previous branch or loop has been closed with the END instruction is nested. The maximum nesting level is 9 deep. Error 30 is displayed when attempting to compile a program which is nested too deep.

The Loop Instruction, 87, counts as 1 level. Instructions 86, 88, 89, 91, and 92 each count as one level when used with the THEN DO command 30. Use of Else, Instruction 94, also counts as one nesting level each time it is used. For example, the AND construction above is

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nested 2 deep while the OR construction is nested 3 deep. Branching and loop nesting starts at zero within each subroutine and then returns to the previous level after returning from the subroutine.

Subroutine calls do not count as nesting with the above instructions. They have a separate nesting limit of seven (Instruction 85, Section 12).

Any number of groups of nested instructions may be used in any of the three Programming

Tables. The number of groups is only restricted by the program memory available.

3.9 INSTRUCTION MEMORY AND EXECUTION TIME

The standard 21X has 978 bytes of program memory available for the programs entered in the *1, *2, and *3 program tables. Each instruction also makes use of varying numbers of Input, Intermediate, and Final Storage locations. The following tables list the memory used by each instruction and the approximate time required to execute the instruction.

TABLE 3.9-1. Input/Output Instruction Memory

R = No. of Reps.
D = Delay

INSTRUCTION	INPUT LOC.	MEMORY PROG. BYTES	EXECUTION TIME (ms)		
			1-4 or NA	5.*	11-14
1 VOLT (SE)	R	15	38.0 + 19.2R	8.4 + 3.7R	5.5 + 2.4R
2 VOLT (DIFF)	R	15	36.9 + 38.0R	7.8 + 6.9R	5.5 + 3.7R
3 PULSE	R	15	0.2 + 1.2R		
4 EX-DEL-SE	R	20	38.0 + (19.2 + D)R	8.1 + (4.4 + D)R	5.3 + (2.8 + D)R
5 AC HALF BR	R	18	38.8 + 40R	10.7 + 7.5R	7.5 + 5.1R
6 FULL BR	R	18	41.8 + 73.0R	10.5 + 13.1R	7.6 + 7.4R
7 3W HALF BR	R	18	41.2 + 76.8R	10.6 + 16.2R	7.1 + 11.0R
8 EX-DEL-DIFF	R	20	38.1 + (19.2 + D)2R	8.1 + (4.2 + D)2R	5.3 + (2.8 + D)2R
9 FULL BR-MEX	R	19	76.7 + 149.6R	15.7 + 28.2R	9.9 + 16.7R
10 BATT. VOLT	1	4	7.6		
11 TEMP (107)	R	15	5.0 + 8.4R		
12 RH (207)	R	17	7.9 + 7.0R		
13 TEMP-TC SE	R	18	40.8 + 23.2R		7.9 + 6.7R
14 TEMP-TC DIF	R	18	39.2 + 42.7R		7.8 + 8.5R
16 TEMP-RTD	R	15	0.4 + 2.7R		
17 TEMP-INTERNAL	1	4	14.0		
18 TIME	1	7	1.4		
19 SIGNATURE	1	4	1200		
20 PORT SET	1	4	0.3		
21 ANALOG OUT	1	5	10.5		
22 EXCIT-DEL	1	11	1.0 + D		
23 BURST MODE	R				
26 TIMER	1 or 0	4	0.54 to reset, 0.25 to load into location		
101 SDM-INT8	25				
102 SDM-SW8	16				
103 SDM-AO4	0	6			
104 SDM-CD16	6				

* Range 5 uses a 1.67ms integration time; the other "slow integration" ranges (1-4) use 16.67ms integrations. Range 15 uses a 25µs integration (ranges 11 - 14 use 250µs). The execution times for instructions using range 15 are faster than those given for ranges 11 - 14 by approximately 225µs per rep for single-ended measurements, and 450µs per rep for differential.

TABLE 3.9-2. Processing Instruction Memory and Execution Times
R = No. of Reprs.

INSTRUCTION		INPUT LOC.	MEMORY INTER. LOC.	PROG. BYTES	EXECUTION TIME (ms)
30	Z=F	1	0	8	0.3
31	Z=X	1	0	6	0.5
32	Z=Z+1	1	0	4	0.6
33	Z=X+Y	1	0	8	1.1
34	Z=X+F	1	0	10	0.9
35	Z=X-Y	1	0	8	1.1
36	Z=X*Y	1	0	8	1.2
37	Z=X*F	1	0	10	0.9
38	Z=X/Y	1	0	8	2.7
39	Z=SQRT(X)	1	0	6	12.0
40	Z=LN(X)	1	0	6	7.4
41	Z=EXP(X)	1	0	6	5.9
42	Z=1/X	1	0	6	2.6
43	Z=ABS(X)	1	0	6	0.7
44	Z=FRAC(X)	1	0	6	0.3
45	Z=INT(X)	1	0	6	1.0
46	Z=X MOD F	1	0	10	3.2
47	Z=XY	1	0	8	13.3
48	Z=SIN(X)	1	0	6	6.5
49	SPA MAX	1 or 2	0	7	1.5 + 0.9 (swath-1)
50	SPA MIN	1 or 2	0	7	1.7 + 0.9 (swath-1)
51	SPA AVG	1	0	7	3.3 + 0.6 (swath-1)
53	A*X+B	4	0	36	2.5 + 0.4 scaling pair
54	BLOCK MOVE	R	0	10	0.18 + 0.17R
55	POLYNOMIAL	R	0	31	1.2 + R(2.0 + 0.4 * order)
56	SAT VP	1	0	6	4.2
57	WDT-VP	1	0	10	8.1
58	LP FILTER	R	R	13	0.5 + 2.2R
59	X/(1-X)	1	0	9	0.4 + 3.0R
60	FFT	See Instruction Description Section 10			
61	INDIR MOVE	1	0	6	0.35 neither indexed 0.54 one location indexed 0.73 both locations indexed
62	COV/COR	See Instruction Description Section 10			
66	ARC TAN	1	0	8	6.7

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TABLE 3.9-3. Output Instruction Memory and Execution Times
R = No. of Reprs.

INSTRUCTION	MEMORY			EXECUTION TIME (ms)	
	INTER. LOC.	FINAL VALUES ¹	PROG. BYTES	FLAG 0 LOW	FLAG 0 HIGH
69 WIND VECTOR	2+9R	(2, 3, or 4)R <i>Options 00, 01, 02</i> <i>Options 10, 11, 12</i>	12	3.5 + 17.5R 3.5 + 16R	3.5 + 75R 3.5 + 30R
70 SAMPLE	0	R	5	0.1	0.4+ 0.6R
71 AVERAGE	1+R	R	7	0.9+ 0.5R	2.1+ 3.0R
72 TOTALIZE	R	R	7	0.6+ 0.5R	1.1+ 1.0R
73 MAXIMIZE	(1 or 2)R	(1,2,or3)R	8	0.9+ 1.7R	1.3+ 2.8R
74 MINIMIZE	(1 or 2)R	(1,2,or3)R	8	0.9+ 1.7R	1.3+ 2.8R
75 HISTOGRAM	1+bins*R	bins*R	24	0.4+ 3.1R	0.9+ R(3.3+2.8*bins)
77 REAL TIME	0	1 to 4	4	0.1	1.0
78 RESOLUTION	0	0	3	0.4	0.4
79 SMPL ON MM	R	R	7	0.3	1.1
80 STORE AREA	0	0	5		
81 RAINFLOW HISTOGRAM	See Instruction Description Section 11				
82 STD. DEV.	1+2R	R	7		

¹Output values may be sent to either Final Storage or Input Storage with Instruction 80.

TABLE 3.9-4. Program Control Instruction Memory and Execution Times

INSTRUCTION	MEMORY		EXECUTION TIME (ms)
	INTER. LOC.	PROG. BYTES	
83 IF CASE <F	0	9	0.5
85 LABEL SUBR	0	3	0.0
86 DO	0	5	0.1
87 LOOP	1	9	0.2
88 IF X<=>Y	0	10	0.6
89 IF X<=>F	0	12	0.4
90 LOOP INDEX	0	3	0.5
91 IF FLAG	0	6	0.2
92 IF TIME	1	11	0.3
93 BEGIN CASE	1	8	0.2
94 ELSE	0	4	0.2
95 END	0	4	0.2
96 SERIAL OUT	0	3	
97 INIT. TELE.	7	23	
98 SEND CHAR.	0	4	

3.10 ERROR CODES

There are four types of errors flagged by the 21X: Compile, Run Time, Editor, and *D Mode. When an error is detected an E is displayed followed by the 2 digit error code.

Compile errors are errors in programming which are detected once the program is keyed in and compiled for the first time (*0, *6, or *B Mode entered).

Run Time errors are detected while the program is running. Error 31 is the result of a programming error. Error 8 is the result of a hardware and software "watchdog" that checks the processor state, software timers, and program related counters. The watchdog will attempt to reset the processor and program execution if it finds that the processor has bombed or is neglecting standard system

updates, or if the counters are out of allowable limits. Error code 08 is flagged when the watchdog performs this reset.

Error 8 is occasionally caused by voltage surges or transients. Frequent repetitions of E08 are indicative of a hardware problem or a software bug and should be reported to Campbell Scientific. The 21X keeps track of the number of times (up to 99) that E08 has occurred. The number can be displayed and reset with the Telecommunications A command (Section 5.1).

Editor errors are detected as soon as an incorrect value is entered and are displayed immediately.

***D Mode errors** indicate problems with saving or loading a program. Only the error code is displayed.

TABLE 3.10-1. Error Codes

Code	Type	Description
03	Editor	Program table full
04	Compile	Intermediate Storage full
08	Run Time	21X reset by watchdog timer
09	Run Time	Data sent to unallocated Input Storage
11	Editor	Attempt to allocate more Input or Intermediate Storage than is available
20	Compile	SUBROUTINE encountered before END of previous subroutine
21	Compile	END without IF, LOOP or SUBROUTINE
22	Compile	Missing END, nonexistent SUBROUTINE
24	Compile	ELSE in SUBROUTINE without IF
25	Compile	ELSE without IF
26	Compile	EXIT LOOP without LOOP
30	Compile	IF and/or LOOP nested too deep
31	Run Time	SUBROUTINES nested too deep
40	Compile	Table 2 Execution interval too short
40	Editor	Instruction not in PROM
60	Compile	Inadequate Input Storage for FFT
61	Compile	Burst Mode Scan Rate too short
97	*D MODE	Tape data not received within 30 seconds
98	*D MODE	Uncorrectable errors detected
99	*D MODE	Wrong file type, editor error or program not received

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SECTION 4. EXTERNAL STORAGE PERIPHERALS

External data storage devices are used to provide a data transfer medium that the user can carry from the test site to the lab and to supplement the internal storage capacity of the 21X, allowing longer periods between visits to the site. The standard data storage peripherals for the 21X are the cassette tape (Section 4.3) and the Storage Module (Section 4.4). Output to a printer or related device is also possible (Section 4.5). These peripherals are connected to the 21X through the 9 pin serial connector.

*Data output to a peripheral device can take place ON-LINE (automatically, as part of the 21X's routine operation) or it can be MANUALLY INITIATED. On-line data transfer is accomplished with Instruction 96 or with the *4 Mode (Section 4.1). Manual initiation is done in the *8 or *9 Modes (Section 4.2). Regardless of the method, the source of any data transferred is Final Storage.*

A modem is another type of peripheral that can be connected to the 21X. Communication via a modem (Telecommunications) is discussed in Section 5.

The 21X can output data to multiple peripherals (i.e., a tape recorder, modem, and Storage Module could all be connected at the same time). However, only one cassette recorder and only one modem may be connected to the 21X at any one time. It is possible to connect two Storage Modules, although it is seldom necessary.

*The 21X can tell whether or not a SM192 or SM716 Storage Module is present. When Instruction 96 or *9 is used to send data to one of these Storage Modules, the 21X will not send data if the Storage Module is not connected (Section 4.4.2).*

4.1 ON-LINE DATA TRANSFER - INSTRUCTION 96, *4 MODE

On-line data transfer is accomplished with Instruction 96 entered in the datalogger program. The *4 Mode is retained from earlier software to maintain compatibility with existing programs. Use only one method to enable output. If using Instruction 96, do not enable output in the *4 Mode.

4. Enter Instruction 96 to enable the on-line transfer of Final Storage data to the specified device. If outputting to both tape and a Storage Module or printer option, Instruction 96 must be entered twice.

Instruction 96 has a single parameter which specifies the peripheral to enable. Table 4.1-1 lists the output device codes.

4.1.1 INSTRUCTION 96

Instruction 96 enables output to external storage peripherals under program control. This instruction must be included in the datalogger program for on-line data transfer to take place. Instruction 96 needs to be included only once in the program tables, and should follow the Output Processing Instructions. The suggested programming sequence is:

1. Set the Output Flag.
2. If you wish to set the output array ID, enter Instruction 80 (Section 11).
3. Enter the appropriate Output Processing Instructions.

TABLE 4.1-1. Output Device Codes for Instruction 96

CODE	DEVICE
00	Tape. Data transferred in blocks of 512 Final Storage Locations
1x	Printer, Printable ASCII
2x	Printer, Binary
30	SM192/716 Storage Module
31	Send filemark to SM192/716
x = BAUD RATE CODE	
0	300
1	1200
2	9600
3	76,800

SECTION 4. EXTERNAL STORAGE PERIPHERALS

Only one of the options 1x, 2x, or 30 may be used in a program. If using a SM64 Storage Module, output code 21 should be used. Use of the SM192/716 is discussed further in Section 4.4, print output formats are discussed in Section 4.5.

Section 4.3 contains specifics on the cassette recorder. Note that tape operation is for above freezing temperatures only.

4.1.2 *4 MODE

The *4 Mode may be used in place of Instruction 96 to enable or disable printer and/or cassette tape output and to set the printer baud rate. The first parameter is a two digit number determining the tape and printer status. The second is the baud rate code. To enter a different status, key in the appropriate code from Table 4.1-2, followed by "A". **Printer data is sent in the printable ASCII format only (Section 4.5).** If tape or printer status is changed during execution of the program tables, execution stops until the programs are recompiled. Instruction 96 should be used to send data to the SM192/716 Storage Modules. Do not use *4 if Instruction 96 is used in the program.

TABLE 4.1-2. *4 Mode Parameters and Codes

Key	Display ID:DATA	Description
*4	04:00	
A	01:XX	Output Enable Code (e.g., "10" means tape enabled, printer disabled)
A	02:XX	Baud Rate Code

Output Enable Codes

Code	Description
X0	printer disabled
X1	printer enabled, ASCII
0X	tape disabled
1X	tape enabled

Baud Rate Codes

Code	Baud Rate
00	300
01	1200
02	9600
03	76,800

4.2 MANUALLY INITIATED DATA OUTPUT - *8 AND *9 MODES

Data may be transferred to tape using the *8 Mode and to printer or Storage Module using the *9 Mode. These Modes allow the user to retrieve a specific block of data, on demand, regardless of whether or not the 21X is programmed for on-line data output.

If external storage peripherals (cassette, Storage Module, etc.) are not left on-line, the maximum allowable time between visiting the site to retrieve data must be calculated to insure that data placed in Final Storage are not written over before they are collected. In order to make this calculation, users must determine: (1) the size of Final Storage, (2) the number of output arrays being generated, (3) the number of low and/or high resolution data points included in each output array, and (4) the rate at which output arrays are stored in Final Storage. When calculating the number of data points per output array, remember to add 1 overhead data point (2 bytes) per array for the output array ID.

For example, assume that 19,296 locations are assigned to Final Storage (*A Mode), and that 1 output array, containing the Array ID (1 memory location), 9 low resolution data points (9 memory locations) and 5 high resolution data points (10 memory locations) is stored each hour. In addition, an output array with the Array ID and 5 high resolution data points (11 memory locations) is stored daily. This is a total of 491 memory locations per day ((20 x 24) + 11). 19,296 divided by 491 = 39.3 days. Therefore, the 21X would have to be visited every 39 days to retrieve data, because write-over would begin in the 40th day.

4.2.1 MANUAL TAPE DUMP *8 MODE

If on-line tape storage is enabled, entering the *8 Mode will suspend it. If left in the *8 Mode, on-line storage will be re-enabled if no key entries are made for 3.4 minutes. Setting up the tape recorder is discussed in Section 4.3.4.

TABLE 4.2-1. *8 Mode Entries

Key	Display ID:DATA	Description
*8	08:00	Enter *8 Mode, key A to advance to first window.
A	01:XXXXX	Start of Dump location, initially the TPTR location, a different location may be keyed in if desired.
A	02:XXXXX	End of Dump location, initially the DSP location, a different location may be keyed in if desired.
A	03:00	Ready to Dump, to initiate dump, key any number then A. While dumping, "08:" will be displayed in the ID field and the location number in the Data field. The location number will stop incrementing when the dump is complete.

If the TPTR is at the same location as the DSP, then a block of 512 "dummy" values are transferred. This provides a means of checking the 21X/cassette connections and the cassette operation. During data playback, the PC201 and C20 Cassette Interfaces recognize dummy values and do not transmit them.

When on-line tape transfer is not enabled and the *8 Mode is used to dump new data, the start of dump pointer (TPTR) will remain where it was when the dump was completed or aborted until the next time the *8 Mode is entered. If the End of Dump location (window 2) is changed while in the *8 Mode, the TPTR will be set to its previous value when the *8 Mode is exited. Changing the program and compiling moves the TPTR to the current DSP location.

When on-line, the 21X dumps data to tape in blocks of 512 Final Storage locations. Residual data is data which has accumulated since the last full block. When picking up a data tape from

a field site, dump the residual data before removing the tape.

To dump the residual data enter the *8 Mode, advance directly to window 3 and initiate a dump. Because data are written to tape in fixed blocks of 512 locations, the TPTR may be in the middle of an output array. Entering a location for the TPTR, even the location originally displayed, will result in the TPTR being moved to the first output array start marker following the location entered. Thus, the portion of the array following the original TPTR location would not be written to tape.

To use the ***8 Mode to transfer all data** from Final Storage to tape, enter a start of dump location number which is 1 greater than the end of dump location, advance to ready to dump (03:) and key any number and A. Data transfer occurs immediately and is completed when the display shows "08:" and the current DSP location.

To dump a portion of the data in Final Storage, key in the start and end locations before initiating the dump. The locations can be determined by viewing the contents of Final Storage in the *7 Mode. By saving the current location of the DSP and using it for the starting location on the next visit to the site, only the data stored between visits are transferred to tape.

NOTE: A tape dump can be aborted by keying #. However, since it cannot be aborted in the middle of a 512 data point block, up to 5 seconds may elapse before the tape stops.

4.2.2 MANUAL STORAGE MODULE OR PRINTER DUMP - *9 MODE

Using the *9 Mode, data in Final Storage can be transmitted as ASCII or binary data out the serial port by manually initiating a dump. If on-line printing is enabled with Instruction 96 or the *4 Mode, entering *9 will stop it. On-line printing will be re-enabled if no keyboard entries are made for 3.4 minutes. Return to the *0 Mode when the dump is completed.

SECTION 4. EXTERNAL STORAGE PERIPHERALS

When on-line Storage Module or printer transfer is not enabled and the *9 Mode is used to dump new data, the start of dump pointer (PPTR) will remain where it was when the dump was completed or aborted until the next time the *9 Mode is entered. If the End of Dump location (window 2) is changed while in the *9 Mode, the TPTR will be set to its previous value when the *9 Mode is exited. Changing the program and compiling moves the PPTR to the current DSP location.

NOTE: A printer dump is aborted by keying #.

TABLE 4.2-2. *9 Mode Entries

Key	Display ID:DATA	Description
*9	09:00	Output Code 1X Printable ASCII 2X Final Storage Format 30 SM192/716 Storage Module 31 Send filemark to SM192/716
		x = Baud Rate Code
		0 300
		1 1200
		2 9600
		3 76800
A	01:XXXXX	Start of Dump location, initially the PPTR location, a different location may be keyed in if desired. To dump all data in Final Storage, enter into window #1 a number 1 greater than the End of Dump location.
A	02:XXXXX	End of Dump location, initially the DSP location, a different location may be keyed in if desired.
A	03:00	Ready to Dump, to initiate dump, key any number then A. While dumping, "09:" will be displayed in the ID field and the location number in the Data field. The location

number will stop incrementing when the dump is complete.

4.3 CASSETTE TAPE OPTION

The Model RC35 Cassette Tape Recorder or equivalent can be left attached to the 21X for continuous on-line data recording or it can be periodically taken to the 21X site for the manually initiated retrieval of the data accumulated in Final Storage. The *8 Mode is used to manually initiate tape transfer.

4.3.1 CASSETTE RECORDER

The RC35 Cassette Recorder offered by Campbell Scientific is an inexpensive recorder for use with the 21X (also compatible with the CR10 and CR7 dataloggers). The record/playback function of each RC35 is tested by Campbell Scientific along with a head alignment procedure prior to shipment. 21X/RC35 connections are made with the SC92A Cassette Write Only Interface or the SC93A Cassette Read/Write Interface. The 21X turns the RC35 on and off by switching power through the DC power input.

TABLE 4.3-1 Cassette Recorder Specifications

Power	6VDC (provided by 21X through SC92A or SC93A); 4 AA size batteries; 120VAC/6VDC adapter
Current Drain while Recording	200mA typ./5 sec., 300 max.
Tape Length	C-60 recommended
Tape Quality	Normal bias, high quality (e.g., TDK, Maxell)
External Inputs	Mic., DC In, Monitor, and Remote
Operating Temperature	0° to +40°C

POWER SUPPLY

The 21X's internal power supply will power the recorder during periods of data transfer, but will NOT be available to play, advance, or back-up tapes. In order to perform these functions during setup and check-out operations, the recorder requires 4 alkaline AA batteries or the 120 VAC adapter.

OPERATING TEMPERATURE LIMITATIONS

The cassette recorder is recommended for use in an environmental operating temperature range of 0° to +40°C. Temperatures below 0°C may cause tape speed variation in excess of that which can be tolerated during playback. Data Recorded with the RC35 outside the 0°C to 40°C range may be unreadable.

VOLUME CONTROL

When recording data, the RC35's volume setting does not matter. The recorder is equipped with an automatic gain control which controls the recorded signal level. For playback, a mid range volume setting is normally required.

CASSETTE TAPES

Normal bias, high quality cassette tapes are recommended for use with the recorder. The more expensive high bias chromium oxide tapes will NOT perform satisfactorily. Although the use of C-90 tapes is generally successful, Campbell Scientific recommends the use of C-60 (30 minutes per side) cassettes. TDK, Maxell, and equivalent quality cassette tapes perform well and are readily available. Bargain-priced tapes have often performed poorly and are not recommended.

New tapes are often tightly wound, creating enough drag or pressure to cause the tape recorder to "pop" out of the record mode. This potential loss of data may be overcome by fast-forward/rewinding the entire tape before placing it in service.

4.3.2 CASSETTE CONNECTOR INTERFACE CABLES

A Cassette Interface Cable is required to connect the cassette recorder to the 21X. Two models are available. The SC92A is a WRITE ONLY interface. The SC93A READ/WRITE

interface is only necessary if the 21X has special software for transferring programs via tape (Appendix B).

The SC92A and SC93A have a combination backshell circuit card and 9-pin connector which attaches to the serial I/O connector on the 21X. The SC92A has two plugs which connect to the POWER and MIC jacks on the recorder. The SC93A has three plugs which connect to the POWER, MIC and EAR (or MONITOR) jacks on the recorder. Both cables transform 12V from the 21X to 6V to power the recorder during periods of data transfer. Additional circuitry shapes the data signal waveform.

4.3.3 TAPE FORMAT

Data tapes generated by the 21X are read by the PC201 tape read card for the IBM PC/XT/AT or by the C20 Cassette Interface. The C20 decodes the tape and transmits the data in ASCII via a standard RS232 interface.

TABLE 4.3-2. Format 2 Specifications

Data	Binary
Low Resolution	2 bytes/data point
High Resolution	4 bytes/data point
C-60 Capacity (Lo Res.)	180,000 data points (1 side only)
Data Transfer Rate (Lo Res.)	100 data points/sec.
Block Size	512 Final Storage locations

4.3.4 CONNECTING TAPE RECORDER TO 21X

The procedure for setting up the 21X and cassette recorder for transfer to tape is as follows:

1. Load a cassette in the recorder and advance the tape forward until the tape leader is past the recording head. (Internal batteries or AC power required.)
2. Connect the SC92A or SC93A to the 9-pin serial I/O port.

SECTION 4. EXTERNAL STORAGE PERIPHERALS

3. Insert the plugs on the free end of the SC92A or SC93A into the DC-IN and MIC (and Ear if SC93A) jacks on the recorder.
4. Simultaneously press the RECORD and PLAY buttons on the recorder to set it for recording. With the DC-IN Jack plugged in, the tape will not move until the dump occurs.
5. To test connections manually initiate transfer by keying in the *8 commands as listed in Table 4.2-1. The tape should advance as data is transferred. If the Start of dump location is equal to the End of dump location, the 21X will write a "dummy" block of data to tape.

If you are leaving the recorder on-line (tape enabled with Instruction 96) it is a good idea to write a dummy block of data to tape (5 above) to ensure that the recorder is correctly connected. Leave the 21X in the *0 Mode.

4.4 STORAGE MODULE (SM192/716)

The Storage Module stores data in battery backed RAM. Backup is provided by an internal lithium battery. Operating power is supplied by the 21X over pin 1 of the 9 pin connector. When power is applied to the Storage Module, a File Mark is placed in the data (if a File Mark is not the last data point already in storage).

The File Mark separates data. For example, if you retrieve data from one 21X, disconnect the Storage Module and connect it to a second 21X, a File Mark is placed in the data. This mark follows the data from the first 21X but precedes the data from the second.

The SM192 has 192K bytes of RAM storage; the SM716 has 716K bytes. Both can be configured as either ring or fill and stop memory.

4.4.1 USE OF TWO STORAGE MODULES

It is possible to connect two Storage Modules to the 21X for on-line storage. One module must be configured as fill and stop and the other as ring memory (see Storage Module operator's manual for configuring information). Data is written to both modules simultaneously. The module configured as fill and stop quits accepting data once it is full while that with the ring memory continues to store new data over

old. The Storage Modules must be retrieved before the module configured as ring memory wraps around memory a second time.

4.4.2 STORAGE MODULE USE WITH INSTRUCTION 96

When output to the Storage Module is enabled with Instruction 96, the Storage Module(s) may be either left with the 21X for on-line data transfer and periodically exchanged, or brought to the site for data transfer.

USE OF STORAGE MODULE TO PICK UP DATA

The 21X can tell when the Storage Module is connected. Each time Instruction 96 is executed and there is data to output, the 21X checks for the presence of the Storage Module. If a Storage Module is not connected no data are sent and the Printer Pointer (PPTR, Section 2.1) is not advanced.

When a Storage Module is connected, two things happen:

1. Immediately upon connection, a File Mark is placed in the Storage Module Memory following the last data stored.
2. During the next execution of Instruction 96, the 21X detects the Storage Module and outputs all data between the PPTR and the DSP location.

The File Mark allows the operator to distinguish blocks of data from different dataloggers or from different visits to the field.

If the SM is just brought to the site to pick-up data, the SC90 Serial Line Monitor can be used to visually confirm that data were transferred. The SC90 contains an LED which lights during data transmission. When the light goes OFF data transfer is complete and the SM can be disconnected from the 21X.

4.4.3 *9 DUMP TO STORAGE MODULE

In addition to the on-line data output procedures described above, output from 21X Final Storage to the SM192 and SM716 can be manually initiated in the *9 Mode. The procedure for setting up and transferring data is as follows:

SECTION 4. EXTERNAL STORAGE PERIPHERALS

1. Connect the Storage Module to the 21X using the SC12 cable.
2. Enter the appropriate commands as listed in Table 4.2-2.

4.5 PRINTER OUTPUT FORMATS

Printer output can be sent in the binary Final Storage Format (Appendix C.2) or Printable ASCII. If using the *4 Mode to enable on-line output, Printable ASCII is the only format available.

In the Printable ASCII format each data point is preceded by a 2 digit data point ID and a + or - sign. The ID and fixed spacing of the data points make particular points easy to find on a printed output. This format requires 10 bytes per data point to store on disk.

Figure 4.5-1 shows both high and low resolution data points in a 12 data point output array. The example data contains Day, Hour-Minute, and Seconds in the 2nd - 4th data points. The output array ID and time values (year, day, hour-minute, and seconds) are always 4 character numbers, even when high resolution output is specified.

Each full line of data contains 8 data points (79 characters including spaces), plus a carriage return (CR) and line feed (LF). If the last data point in a full line is high resolution, it is followed immediately with a CR and LF. If it is low resolution, the line is terminated with a space, CR and LF. Lines of data containing less than 8 data points are terminated similarly after the last data point.

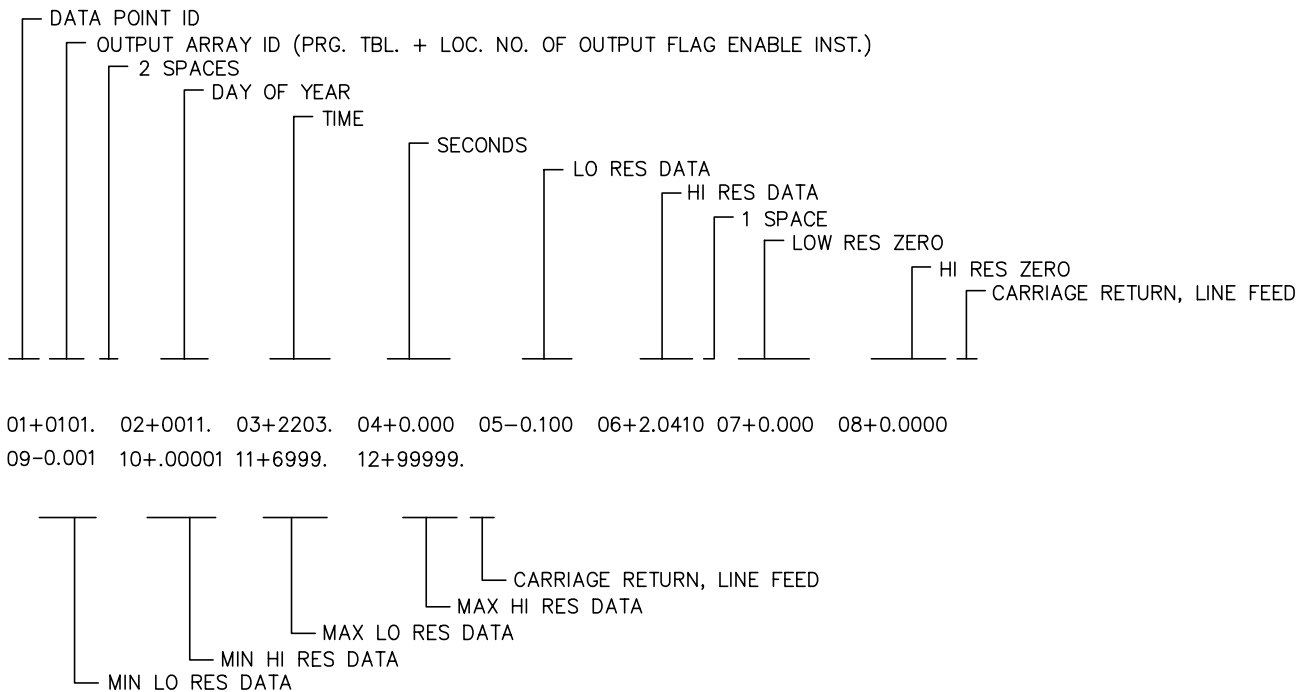


FIGURE 4.5-1. Example of 21X Printable ASCII Output Format

SECTION 4. EXTERNAL STORAGE PERIPHERALS

SECTION 5. TELECOMMUNICATIONS

Telecommunications allows a computer to retrieve data directly from Final Storage and may be used to program the 21X and monitor sensor readings in real time. Any user communication with the 21X that makes use of a computer or terminal instead of the 21X keyboard is through Telecommunications.

Telecommunications can take place over a variety of links including:

- *telephone*
- *radio frequency*
- *short haul modem*
- *SC32A and ribbon cable*
- *multi-drop interface and coax cable*

This section does not cover the technical interface details for any of these links. Those details are covered in Section 6 and in the individual manuals for the devices.

Data retrieval can take place in either ASCII or BINARY. The BINARY format is five times more compact than ASCII. The shorter transmission times for binary result in lower long distance telephone charges and more reliable data transfer. On "noisy" links shorter blocks of data are more likely to get through without interruption.

In addition to more efficient data transfer, binary data retrieval makes use of a signature for error detection. The signature algorithm assures a 99.998% probability that if either the data or its sequence changes, the signature changes.

The PC208 Datalogger Support Software for PCs and compatibles contains the program TELCOM which automates data retrieval and TERM which will upload and download programs and monitor Input Storage. The PC208 package has been designed to meet the most common needs in datalogger support and telecommunications. This section is not intended to furnish sufficient detail to write Telecommunications software. Appendix C contains some details of binary data transfer and Campbell Scientific's binary data format.

This section emphasizes the commands that a person would use when manually (i.e., entered by hand) interrogating or programming the 21X via a computer/terminal. These commands and the responses to them are sent in the American Standard Code for Information Interchange (ASCII). The Remote Keyboard State (Section 5.2) allows the user with a computer/terminal to use the same commands as the 21X keyboard.

5.1 TELECOMMUNICATIONS COMMANDS

When the 21X is rung by a modem, it answers (enables the modem) almost immediately. Several carriage returns (CR) must be sent from the computer to allow the 21X to set its baud rate to that of the modem/terminal (300, 1200, 9600, or 76,800). Once the baud rate is set, the 21X sends the prompt, *, signaling that it is ready to receive a command.

GENERAL RULES governing the telecommunications commands are:

1. * from datalogger means "ready for command".
2. All commands are of the form: [no.]letter, where the number may or may not be optional.
3. Valid characters are the numbers **0-9**, the capital letters **A-L**, the colon (:), and the carriage return (CR).
4. An illegal character increments a counter and zeros the command buffer, returning *.

SECTION 5. TELECOMMUNICATIONS

5. **CR** to datalogger means "execute".
6. **CRLF** from datalogger means "executing command".
7. ANY character besides a **CR** sent to the datalogger with a legal command in its buffer causes the datalogger to abort the command sequence with **CRLF*** and to zero the command buffer.
8. All commands return a response code, usually at least a checksum.
9. The checksum includes all characters sent by the datalogger since the last *, including the echoed command sequence, excluding only the checksum itself. The checksum is formed by summing the ASCII values, without parity, of the transmitted characters. The largest possible checksum value is 8191. Each time 8191 is exceeded, the 21X starts the count over; e.g., if the sum of the ASCII values is 8192, the checksum is 0.
10. Commands that return Campbell Scientific binary format data (F and K commands) return a signature (Appendix C).

The 21X sends ASCII data with 8 data bits, no parity, plus one start bit and one stop bit.

After answering a ring, or completing a command, the 21X waits about 40 seconds (147 seconds in the Remote Keyboard State) for a

valid character to arrive. If a valid character is not received, the 21X "hangs up". Some modems are quite noisy when not on line; it is possible for valid characters to appear in the noise pattern. To insure that this situation does not keep the 21X in telecommunications, the 21X counts all the invalid characters it receives from the time it answers a ring, and terminates communication after receiving 150 invalid characters.

The 21X continues to execute its measurement and processing tasks while servicing the telecommunication requests. If the processing overhead is large (short execution interval), the processing tasks will slow the telecommunication functions. In a worst case situation, the 21X interrupts the processing tasks to transmit a data point every 0.1 second.

The best way to become familiar with the Telecommunication Commands is to try them from a terminal connected to the 21X via the SC32A or other modem interface (Section 6.5). Telecommunications Commands are described in the following Table. The Data Storage Pointer (DSP) and Telecommunications Modem Pointer (MPTR) referred to in the table are described in Section 2.1.

TABLE 5.1-1. Telecommunications Commands

<u>Command</u>	<u>Description</u>
A	STATUS - Datalogger returns Reference , the DSP location; the number of filled Final Storage locations; Version of datalogger; Errors #1 and #2 where #1 is the number of E08 and #2 is the number of overrun that have occurred (cleared by entering 8888A); Memory status , the decimal number (in ASCII characters) that is the equivalent of the 8 bit binary number shown as the result of the memory check on power-up; Location of MPTR; and Checksum. All in the following format: R+xxxxx F+xxxxx Vx Exx xx Mxxxx L+xxxxx Cxxxx If data are stored while in telecommunications, the A command must be issued to update the Reference to the new DSP.
[no. of arrays] B	BACK-UP - MPTR is backed-up the specified number of output arrays (no number defaults to 1) and advanced to the nearest start of array. 21X sends the MPTR Location and Checksum: L+xxxxx Cxxxx

[YR:DAY:HR:MM:SS] C	RESET/SEND TIME - If time is entered the time is reset. If only 2 colons are in the time string, HR:MM:SS is assumed; 3 colons means DAY:HR:MM:SS. If only the C is entered, time is unaltered. 21X returns year, Julian day, hr:min:sec, and Checksum: Y:xx Dxxxx Txx:xx:xx Cxxxx
[no. of arrays] D	ASCII DUMP - If necessary, the MPTR is advanced to the next start of array. 21X sends the number of arrays specified (no number defaults to 1) or the number of arrays between MPTR and Reference, whichever is smaller, CRLF, Location, Checksum.
E	End call. Datalogger sends CRLF only.
[no. of loc.] F	BINARY DUMP - Used in TELCOM (PC208). See Appendix C.
[F.S. loc. no.] G	MOVE MPTR - MPTR is moved to specified Final Storage location. The location number must be entered. 21X sends Location and Checksum: L+xxxxx Cxxxx
2718H	REMOTE KEYBOARD - 21X sends the prompt ">" and is ready to execute standard keyboard commands (Section 5.2).
[loc. no.] I	Display/change value at Input Storage location. 21X sends the value stored at the location. A new value and CR may then be sent. 21X sends checksum. If no new value is sent (CR only) the location value will remain the same.
3142J	TOGGLE FLAGS AND SET UP FOR K COMMAND - Used in the Monitor Mode and with the Heads Up Display. See Appendix C for details.
K	CURRENT INFORMATION - In response to the K command, the 21X sends datalogger time, user flag status, the data at the input locations requested in the J command, and Final Storage Data if requested by the J command. Used in the Monitor Mode and with Heads Up Display. See Appendix C.
[Password] L	Unlocks security (See *C Mode, Section 1.7). 21X sends ON or OFF and checksum: OFF Cxxxx

5.2 REMOTE PROGRAMMING OF THE 21X

The 21X can be programmed via telecommunications using the PC208 software or manually through the Remote Keyboard State.

The PC208 Datalogger Support Software was developed for use with IBM or compatible PC's. Datalogger programs are developed on the computer using the program editor EDLOG and downloaded to the datalogger with the terminal emulator program TERM.

The 21X is placed in the Remote Keyboard State by sending "2718H" and a carriage return

(CR). The 21X responds by sending a CR, line feed (LF), and the prompt ">". The 21X is then ready to receive the standard keyboard commands (Section OV3); it recognizes all the standard 21X keyboard characters plus the decimal point. While in the Remote Keyboard State, the 21X sends the ASCII character control Q (17 decimal) after each user entry. Entering *0 returns the 21X to the telecommunications command state.

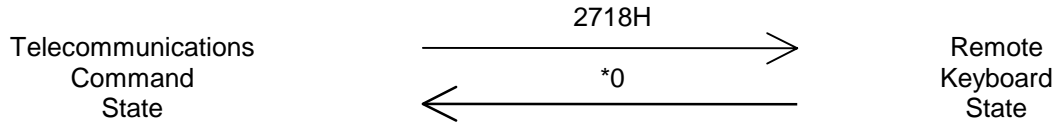
It is important to remember that the Remote Keyboard State is still within Telecommunications. Entering *0 exits the Remote Keyboard and returns the datalogger to the Telecommunications Command State,

SECTION 5. TELECOMMUNICATIONS

awaiting another command. So the user can step back and forth between the Telecommunications Command State and the Remote Keyboard State.

Keying *0 will compile and run the 21X program if program changes have been made. To compile and run the program without leaving the

Remote Keyboard State, use *6 (Section 1.1.4). The 21X display will show "LOG" when *0 is executed via telecommunications. It will not indicate active tables (enter *0 via the keyboard and the display will show the tables).



SECTION 6. 9 PIN SERIAL INPUT/OUTPUT

6.1 PIN DESCRIPTION

All external communication peripherals connect to the 21X through the 9-pin serial I/O connector (Figure 6.1-1). Table 6.1-1 gives a brief description of each pin's function.

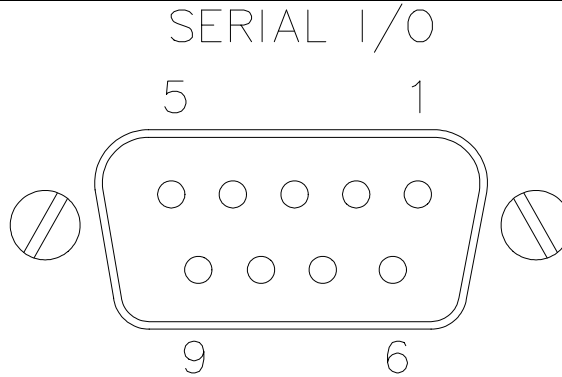


FIGURE 6.1-1. 9 Pin Connector

TABLE 6.1-1. Pin Description

ABR = Abbreviation for the function name.
 PIN = Pin number.
 O = Signal Out of the 21X to a peripheral.
 I = Signal Into the 21X from a peripheral.

PIN	ABR	I/O	Description	PIN	ABR	I/O	Description
1	5V	O	5V: Sources 5V DC, used to power peripherals.	6	PE	O	Printer Enable: Raised to enable Storage Module or other print device.
2	G		Ground: Provides a power return for pin 1 (5V), and is used as a reference for voltage levels.	7	G	I/O	Ground, common with pin 2.
3	RING	I	Ring: When raised by a peripheral the 21X enters telecommunications.	8	TE	O	Tape Enable: Powers the cassette recorder during data transfer to tape.
4	RXD	I	Receive Data: Serial data transmitted by a peripheral are received on pin 4.	9	TXD	O	Transmit Data: Serial data are transmitted from the 21X to peripherals on pin 9; logic low marking (0V) logic high spacing (5V) standard asynchronous ASCII, 8 data bits, no parity, 1 start bit, 1 stop bit, 300, 1200, 9600, 76,800 baud (user selectable).
5	ME	O	Modem Enable: Raised by the 21X after the ring line has been raised.				

SECTION 6. 9 PIN SERIAL INPUT/OUTPUT

6.2 ENABLING PERIPHERALS

Several peripherals may be connected in parallel to the 9-pin port. The 21X directs data to a particular peripheral by raising the voltage on a specific pin dedicated to the peripheral; the peripheral is enabled when the pin goes high. Three pins are dedicated to specific devices, Tape Enable pin 8, Modem Enable pin 5, and Print Enable pin 6.

Tape Enable (**TE**), pin 8, is raised to 12 volts to power the tape recorder. The SC92A or SC93A Cassette Interface regulates the 12 volts to 6 volts to power the RC35 recorder. *Only one tape interface and recorder may be connected to the 21X.*

Modem Enable (**ME**), pin 5, is raised to enable a modem that has raised the ring line. *Only one modem/terminal may be connected to the 21X.*

Print Enable (**PE**), pin 6, is raised to enable a Storage Module or other print peripheral. Print peripherals are defined as peripherals which have an asynchronous serial communications port used to RECEIVE data transferred by the 21X. In most cases the peripheral is a printer, but could also be an on-line computer or other device. It is possible to have more than one print peripheral connected to the 21X at one time, as long as they don't load down the TXD line (e.g., two Storage Modules, Section 4.4.1); all connected receive the same data.

6.3 INTERRUPTING DATA TRANSFER TO STORAGE PERIPHERALS

Instruction 96 is used for on-line data transfer to peripherals (Section 4.1). Data transfer is aborted when a modem raises the Ring line and the 21X then enters Telecommunications (Section 5, 6.4). After the 21X exits Telecommunications, data transfer to the peripheral is resumed the next time Instruction 96 is executed, or, if activated by the *4 Mode, at the completion of the next active table.

The *8 and *9 Modes are used to position the Memory Pointers, and to manually initiate data transfer from Final Storage to a peripheral. If the # key is pressed during data transfer, the transfer is stopped and the display shows the Final Storage location where the pointer stopped.

Data transfer can be stopped as follows:

1. Printable ASCII - after every output array.
2. Binary - after every Final Storage location.
3. Tape - after every block (512 Final Storage locations).

6.4 TELECOMMUNICATIONS - MODEM PERIPHERALS

Any serial communication device which raises the Ring line and holds it high until the ME line is raised is a modem. The DC112 phone modem, RF95 RF modem, MD9 Multi-Drop Interface, and the SC32A RS232 interface used with computers or terminals are modems.

When a modem raises the Ring line, the 21X responds by raising the ME line. The 21X must be sent carriage returns until it sets the baud rate. When the baud rate is set, the 21X sends a carriage return, line feed, *.

The ME line is held high until the 21X receives an E to exit telecommunications. The ME is also lowered if a character is not received after 40 seconds in the Telecommunications Command State or 147 seconds in the Remote Keyboard State. The colon in 21X display is not shown while the 21X is in telecommunications.

Some modems are quite noisy when not on line; it is possible for valid characters to appear in the noise pattern. For this reason, the 21X counts all the invalid characters it receives from the time it answers a ring and terminates communication (lowers the ME line and returns to the *0 Mode) after receiving 150 invalid characters.

6.5 INTERFACING WITH COMPUTERS, TERMINALS, AND PRINTERS

This section deals with some of the basics of serial communication between the 21X and common computer equipment. If you have an IBM compatible PC, the PC208 Datalogger Support Software takes care of the software protocol required in communicating with the 21X. This section does not discuss modem interfaces other than the SC32A. Please refer to the PC208 and modem operator's manuals for interfacing details on other modems.

6.5.1 SC32A INTERFACE

Most computers, terminals, and printers require the SC32A Optically Isolated RS232 Interface for a "direct" connection to the 21X. The SC32A raises the 21X's ring line when it receives characters from the computer or terminal, and converts the 21X's logic levels (0V logic low, 5V logic high) to RS232 logic levels.

The SC32A 25 pin port is configured as Data Communications Equipment (DCE) which allows direct connection to Data Terminal Equipment (DTE), which includes most PCs and printers. For connection to DCE devices such as modems and some computers, a null modem cable is required.

When the SC32A receives a character from the computer or terminal (pin 2), 5V is applied to the datalogger Ring line (pin 3) for one second or until the Modem Enable line (ME) goes high. The 21X waits approximately 40 seconds to receive carriage returns, which it uses to establish baud rate. After the baud rate is set the 21X transmits a carriage return, line feed, *, and enters the Telecommunications Command State (Section 5). If the carriage returns are not received within the 40 seconds, the 21X "hangs up".

NOTE: The SC32A has a jumper. With the jumper in place the SC32A blocks printer data and passes data only when the 21X is in Telecommunications.

6.5.2 COMPUTER/TERMINAL REQUIREMENTS

Computers, terminals and printers are usually configured as Data Terminal Equipment (DTE). Pins 4 and 20 are used as handshake lines, which are set high when the serial port is enabled. Power for the SC32A is taken from these pins. For equipment configured as DTE a direct ribbon cable connects the modem/terminal to the SC32A. Clear to Send (CTS) pin 5, Data Set Ready (DSR) pin 6, and Received Line Signal Detect (RLSD) pin 8 are held high by the SC32A (when the RS232 section is powered) which should satisfy hardware handshake requirements of the modem/terminal.

Table 6.5-1 lists the most common RS232 configuration for Data Terminal Equipment.

TABLE 6.5-1. DTE Pin Configuration

PIN = 25-pin connector number
 ABR = Abbreviation for the function name
 O = Signal Out of the terminal to another device
 I = Signal Into the terminal from another device

PIN	ABR	I/O	FUNCTION
2	TD	O	Transmitted Data: Data is transmitted from the terminal on this line.
3	RD	I	Received Data: Data is received by the terminal on this line.
4	RTS	O	Request to Send: The terminal raises this line to ask a receiving device if the terminal can transmit data.
5	CTS	I	Clear to Send: The receiving device raises this line to let the terminal know that the receiving device is ready to accept data.
20	DTR	O	Data Terminal Ready: The terminal raises this line to tell the modem to connect itself to the telephone line.
6	DSR	I	Data Set Ready: The modem raises this line to tell the terminal that the modem is connected to the phone line.
8	DCD	I	Data Carrier Detect: The modem raises this line to tell the terminal that the modem is receiving a valid carrier signal from the phone line.
22	RI	I	Ring Indicator: The modem raises this line to tell the terminal that the phone is ringing.
7	SG		Signal Ground: Voltages are measured relative to this point.

SECTION 6. 9 PIN SERIAL INPUT/OUTPUT

If the computer is configured as DCE equipment (pin 2 is an input for RD), a null modem cable is required. See the SC32A manual for details.

6.5.3 COMMUNICATION PROTOCOL/TROUBLE SHOOTING

The ASCII standard defines an alphabet consisting of 128 different characters where each character corresponds to a number, letter, symbol, or control code.

An ASCII character is a binary digital code composed of a combination of seven "bits", each bit having a binary state of 1 or more. For example, the binary equivalent for the ASCII character "1" is 0110001 (decimal 49).

ASCII characters are transmitted one bit at a time, starting with the first (least significant) bit. During data transmission the marking condition is used to denote the binary state 1, and the spacing condition for the binary state 0. The signal is considered marking when the voltage is more negative than minus three volts with respect to ground, and spacing when the voltage is more positive than plus three volts.

Most computers use 8-bits (1 byte) for data communications. The eighth bit is sometimes used for a type of error checking called parity-checking. Even parity binary numbers have an even number of 1's, odd-parity characters have an odd number of 1's. When parity checking is used, the eighth bit is set to either a 1 or a 0 to make the parity of the character correct. The 21X ignores the eighth bit of a character that it receives, and transmits the eighth bit as a binary 0. This method is generally described as "no parity".

To separate ASCII characters a Start bit is sent before the first data bit, and a Stop bit is sent after the eighth data bit. The start bit is always a space, and the stop bit is always a mark. Between characters the signal is in the marking condition.

Figure 6.5-1 shows how the ASCII character "1" is transmitted. The SC32A interface transmits spacing and marking voltages which are positive and negative, as shown. Signal voltages at the 21X I/O port are 5 volts in the spacing condition, and 0 volts in the marking condition.

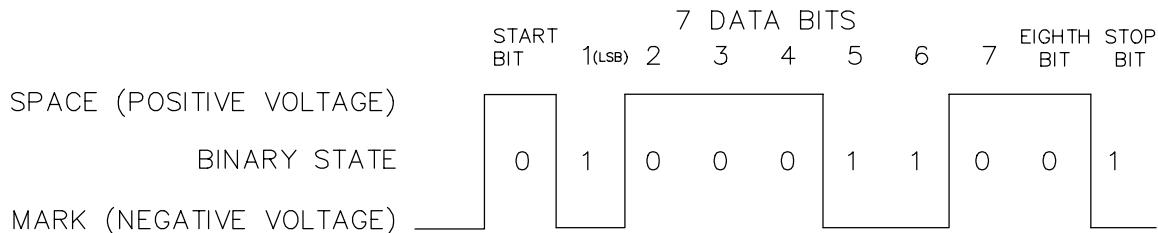


FIGURE 6.5-1. Transmitting the ASCII Character 1

BAUD RATE

BAUD RATE is the number of bits transmitted per second. The 21X can communicate at 300, 1200, 9600, and 76,800 baud. In the Telecommunications State, the 21X will set its baud rate to match the baud rate of the modem.

The baud rate of the modem or computer is usually set with dip switches or programmed from the keyboard. The instrument's instruction manual should explain how to set it.

DUPLEX

Full duplex means that two devices can communicate in both directions simultaneously. Half duplex means that the two devices must send and receive alternately. Full duplex should always be specified when communicating with Campbell Scientific peripherals and modems. However, communication between some Campbell Scientific modems (such as the RF95 RF modem) is carried out in a half duplex fashion. This can affect the way commands should be sent to and received from such a

SECTION 6. 9 PIN SERIAL INPUT/OUTPUT

modem, especially when implemented by computer software.

To overcome the limitations of half duplex, some communications links expect a terminal sending data to also write the data to the screen. This saves the remote device having to echo that data back. If, when communicating with a Campbell Scientific device, characters are displayed twice (in pairs), it is likely that the terminal is set to half duplex rather than the correct setting of full duplex.

IF NOTHING HAPPENS

If the 21X is connected via the SC32A interface to a terminal or computer and * is not received after sending carriage returns:

1. Verify that the 21X has power and that the cables connecting the devices are securely connected.
2. Verify that the port of the computer or terminal is an asynchronous serial communications port configured as DTE (see Table 6.5-2). The most common problems occur when the user tries to use a parallel port, or doesn't know the port address (i.e. COM1 or COM2). IBM, and most compatibles come with a Diagnostic disk which can be used to identify ports, and their addresses. If the serial port is standard equipment, then the operators manual should give you this information. Some serial ports such as the Super Serial Card for Apple computers, can be

configured as DTE or DCE with a jumper block. Pin functions must match with Table 6.5-1.

If you are using a computer, then a program or communication software must be used to enable the serial port, and to make the computer function as a terminal. The port should be enabled for 300, 1200, or 9600 baud, 8 data bits, 1 stop bit, and no parity. TERM (PC208 Software) provides this function for IBM PC/XT/AT/PS-2's and compatibles.

If you are not sure that your computer or terminal is sending or receiving characters, there is a simple way to verify it. Set the duplex to full. Next, take a paper clip and connect one end to pin 2, and the other end to pin 3 of the serial port. Each character typed on the keyboard will be displayed only if transmitted from the terminal on pin 2, and received on pin 3 (with half duplex the character will be displayed once if it is not transmitted, or twice if it is transmitted).

IF GARBAGE APPEARS

If garbage characters appear on the modem/terminal, check that the modem/terminal's baud rate is supported by the 21X. If the baud rate is correct, verify that the modem/terminal is set for 8 Data bits, and no Parity. Garbage will appear if 7 Data bits and no Parity are used. If the modem/terminal is set to 8 Data bits and even or odd Parity, communication cannot be established.

SECTION 6. 9 PIN SERIAL INPUT/OUTPUT

SECTION 7. MEASUREMENT PROGRAMMING EXAMPLES

This section gives some examples of Input Programming for common sensors used with the 21X. These examples detail only the connections, Input, Program Control, and Processing Instructions necessary to perform measurements and store the data in engineering units in Input Storage. Output Processing Instructions are omitted. It is left for the user to program the necessary instructions to obtain the final data in the form desired. NO OUTPUT TO FINAL STORAGE WILL TAKE PLACE WITHOUT ADDITIONAL PROGRAMMING.

The examples given in this section would likely be only fragments of larger programs. In general, the examples are written with the measurements made by the lowest numbered channels, the instructions at the beginning of the program table, and low number Input Storage locations used to store the data. It is unlikely that an application and 21X configuration exactly duplicates that assumed in an example. THESE EXAMPLES ARE NOT MEANT TO BE USED VERBATIM; SENSOR CALIBRATION AND INPUT LOCATIONS SELECTED MUST BE ADJUSTED FOR THE ACTUAL CIRCUMSTANCES. UNLESS OTHERWISE NOTED, ALL EXCITATION CHANNELS ARE SWITCHED ANALOG OUTPUT.

7.1 DIFFERENTIAL VOLTAGE - LI200S SILICON PYRANOMETER

The silicon pyranometer puts out a current which is dependent upon the solar radiation incident upon the sensor. The current is measured as the voltage drop across a fixed resistor. The Campbell Scientific LI200S uses a 100 ohm resistor. The calibration supplied by LI-COR, the manufacturers of the pyranometer, is given in $\mu\text{A}/\text{kW}/\text{m}^2$. The calibration in terms of volts is determined by multiplying the μA calibration by the resistance of the fixed resistor.

The calibration of the pyranometer used in this example is assumed to be $76.9\mu\text{A}/\text{kW}/\text{m}^2$, which when multiplied by 100 ohms equals $7.69\text{mV}/\text{kW}/\text{m}^2$. The multiplier used to convert the voltage reading to kW/m^2 is $1/7.69\text{mV}/\text{kW}/\text{m}^2 = 0.13004$.

Most LI-COR calibrations run between 60 and $90\mu\text{A}/\text{kW}/\text{m}^2$, which correspond to calibrations of 6.0 to $9.0\text{mV}/\text{kW}/\text{m}^2$. Above the earth's atmosphere, the flux density through a surface normal to the solar beam is $1.36\text{kW}/\text{m}^2$; radiation on earth will be less than this. Thus, the 15mV scale provides an adequate range ($9.0\text{mV}/\text{kW}/\text{m}^2 \times 1.36 \text{ kW}/\text{m}^2 < 15\text{mV}$).

CONNECTIONS

The pyranometer output is measured with a differential voltage measurement on channel 3. The low side of signal is jumpered to datalogger

ground to hold the signal within common mode range (Section 14.3-2).

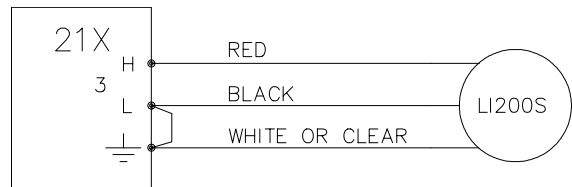


FIGURE 7.1-1. Wiring Diagram for LI200S

PROGRAM

01:	P2	Volt (DIFF)
01:	1	Rep
02:	2	15 mV slow Range
03:	3	IN Chan
04:	1	Loc [:RAD kW/m2]
05:	.13004	Mult
06:	0	Offset

7.2 DATALOGGER AND SENSOR WITH A COMMON EXTERNAL POWER SUPPLY

Some sensors either contain or require active signal conditioning circuitry to provide an easily measured analog voltage output. Generally, the output is referenced to the sensor ground. The associated current drain usually requires a power source external to the 21X. A typical connection scheme where AC power is not available and both the 21X and sensor are powered by an external battery is shown in

SECTION 7. MEASUREMENT PROGRAMMING EXAMPLES

Figure 7.2-1. Since a single-ended measurement is referenced to the 21X ground, any voltage difference between the sensor ground and 21X ground becomes a measurement error. A differential measurement avoids this error by measuring the signal between the two leads without reference to ground.

This example analyzes the ground potential error of a single-ended measurement of pH using a Martek Mark V water quality analyzer.

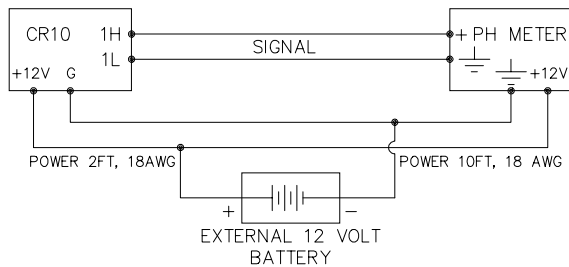


FIGURE 7.2-1. Typical Connection for Active Sensor with External Battery

The wire used to supply power from the external battery is 18 AWG with an average resistance of 6.5 ohms/1000 feet. The power runs to the 21X and pH meter are 2 feet and 10 feet, respectively. Typical current drain for the pH meter is 300mA. When making measurements, the 21X draws about 60mA. Since voltage is equal to current times resistance ($V=IR$), ground voltages at the pH meter and the 21X relative to battery ground are:

$$\begin{aligned} \text{pH meter ground} &= \\ 0.3\text{A} \times 10/1000 \times 6.5\text{ohms} &= +0.0195\text{V} \end{aligned}$$

$$\begin{aligned} \text{21X ground} &= \\ 0.060\text{A} \times 2/1000 \times 6.5\text{ohms} &= +0.0008\text{V} \end{aligned}$$

Ground at the pH meter is 0.0187V higher than ground at the 21X. The meter output is 0-1 volt referenced to meter ground, for the full range of 14 pH units, or 0.0714V/pH. Thus, if the output is measured with a single-ended voltage measurement, it is 0.0187V or 0.26 pH units too high. If this offset remained constant, it could be

corrected in programming. However, it is better to use a differential voltage measurement which does not rely on the current drain remaining constant. The program that follows illustrates the use of Instruction 2 to make the measurement. A multiplier of 0.014 is used to convert the millivolt output into pH units.

PROGRAM

```
01: P2 Volt (DIFF)
02: 1 Rep
03: 5 5000 mV slow Range
04: 1 IN Chan
05: 1 Loc [:pH ]
06: .014 Mult
07: 0 Offset
```

7.3 THERMOCOUPLE TEMPERATURES USING 21X REFERENCE

The use of the built in 21X thermocouple reference thermistor is described in the introductory programming example (Section OV4).

7.4 THERMOCOUPLE TEMPERATURES USING AN EXTERNAL REFERENCE JUNCTION

When a number of thermocouple measurements are made at some distance from the 21X, it is often better to use a reference junction box located at the site rather than using the 21X panel for the reference junction. This reduces the required length of expensive thermocouple wire as regular copper wire can be used between the junction box (J-box) and 21X. In addition, if the temperature gradient between the J-box and the thermocouple measurement junction is smaller than the gradient between the 21X and the measurement junction, thermocouple accuracy is improved. In the following example, an external reference junction is used on 5 thermocouple measurements. A Campbell Scientific 107 Temperature Probe is used to measure the reference temperature. The connection scheme is shown in Figure 7.4-1.

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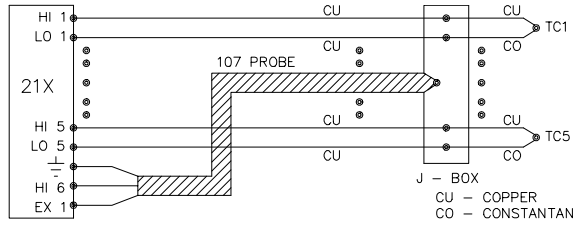


FIGURE 7.4-1. Thermocouples with External Reference Junction

The temperature of the 107 Probe is stored in input location 1 and the thermocouple temperatures in Locations 2-6.

PROGRAM

```

01:  P11      Temp 107 Probe
01:    1      Rep
02:   11      IN Chan
03:    1      Excite all reps w/EXchan 1
04:    1      Loc [:REF TEMP ]
05:    1      Mult
06:    0      Offset

02:  P14      Thermocouple Temp (DIFF)
01:    5      Reps
02:    2      15 mV slow Range
03:    1      IN Chan
04:    1      Type T (Copper-Constantan)
05:    1      Ref Temp Loc REF TEMP
06:    2      Loc [:TC TEMP#1]
07:    1      Mult
08:    0      Offset
    
```

7.5 107 TEMPERATURE PROBE

Instruction 11 is designed to excite and measure the Campbell Scientific 107 Thermistor Probe (or the thermistor portion of the 207 temperature and relative humidity probe) and convert the measurement into temperature (°C). In this example, the temperatures are obtained from three 107 probes. The measurements are made on single-ended channels 1-3, and the temperatures are stored in input locations 1-3.

CONNECTIONS

The black leads from the probes go to excitation channel 1, the white leads go to ground, and the red leads go to single-ended channels 1, 2, and

3 (high and low sides of differential channel 1 and high side of 2).

PROGRAM

```

01:  P11      Temp 107 Probe
01:    3      Reps
02:    1      IN Chan
03:    1      Excite all reps w/EXchan 1
04:    1      Loc [:TEMP #1 ]
05:    1      Mult
06:    0      Offset
    
```

7.6 207 TEMPERATURE AND RH PROBE

Instruction 12 excites and measures the RH portion of the Campbell Scientific 207 Temperature and Relative Humidity Probe. This instruction relies on a previously measured temperature for temperature compensation when computing RH. In this example, three probes are measured. Instruction 11 is used to obtain the temperatures of the three probes which are stored in input locations 1-3; the RH values are stored in input locations 4-6. The temperature measurements are made on single-ended input channels 1-3, just as in Example 7.5. The program listed below is a continuation of the program given in Example 7.5.

CONNECTIONS

The black leads from the probes are connected to excitation channel 1; the clear leads are connected to ground. The red leads are from the thermistor circuit and are connected to single-ended channels 1-3. The white leads are from the RH circuit and are connected to single-ended channels 4-6. The correct order must be maintained when connecting the red and white leads; i.e., the red lead from the first probe is connected to single-ended channel 1 and the white lead from that probe is connected to single-ended channel 4, etc.

PROGRAM

```

02:  P12      RH 207 Probe
01:    3      Reps
02:    4      IN Chan
03:    1      Excite all reps w/EXchan 1
04:    1      Temperature Loc TEMP #1
05:    4      Loc [:RH #1 ]
06:    1      Mult
07:    0      Offset
    
```

SECTION 7. MEASUREMENT PROGRAMMING EXAMPLES

7.7 ANEMOMETER WITH PHOTOCOPPER OUTPUT

An anemometer with a photochopper transducer produces a pulsed output which is monitored with the Pulse Count Instruction, configured for High Frequency Pulses. The anemometer used in this example is the R.M. Young Model No. 12102D Cup Anemometer which has a 10 window chopper wheel. The photochopper circuitry is powered from the 21X or 21XL 12V supply. Supplemental charging, AC or solar, should be used with the 21XL. If a charging source is not practical, back-up batteries should be used to compensate for the increased current drain.

Wind speed is desired in meters per second. There is a pulse each time a window in the chopper wheel, which revolves with the cups, allows light to pass from the source to the photoreceptor. Because there are 10 windows in the chopper wheel, there are 10 pulses per revolution. Thus, 1 rpm is equal to 10 pulses per 60 seconds (1 minute) or 6 rpm = 1 pulse per second. The manufacturer's calibration for relating wind speed to rpm is:

$$\text{Wind speed (m/s)} = 0.01632 \text{ m/s/rpm} \times \text{rpm} + 0.2 \text{ m/s}$$

Pulse count instruction has the option of converting counts to frequency in Hz (counts/second). The multiplier and offset to convert Hz to meters per second are:

$$\begin{aligned} \text{m/s} &= 0.01632 \text{ m/s/rpm} \times 6 \text{ rpm/Hz} \times \text{XHz} + 0.2 \text{ m/s} \\ &= 0.0979 \text{ m/s/Hz} \times \text{XHz} + 0.2 \text{ m/s} \end{aligned}$$

There are times when the 21X is not able to reset the pulse counters at the exact time interval programmed. If the artificially large wind speed that results from a long interval is used, it causes a false average or maximum value. To avoid this, the 21X is instructed to discard values resulting from long intervals and use the previous value instead.

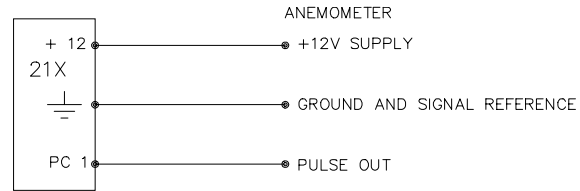


FIGURE 7.7-1. Wiring Diagram for Anemometer

PROGRAM

01:	P3	Pulse
01:	1	Rep
02:	1	Pulse Input Chan
03:	20	High frequency; Output Hz.
04:	10	Loc [:WS m/s]
05:	.0979	Mult
06:	.2	Offset

7.8 TIPPING BUCKET RAIN GAUGE WITH LONG LEADS

A tipping bucket rain gauge is measured with the Pulse Count Instruction configured for Switch Closure. Counts from long intervals will be used (an option in Parameter 3), as the final output desired is total rainfall (obtained with Instruction 72, Totalize). If counts from long intervals were discarded, less rainfall would be recorded than was actually measured by the gauge (assuming there were counts in the long intervals). Output is desired in millimeters of precipitation. The gauge is calibrated for a 0.01 inch tip; a multiplier of 0.254 is used.

CONNECTIONS

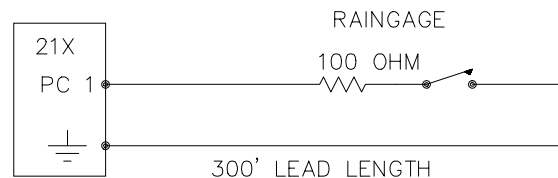


FIGURE 7.8-1. Wiring Diagram for Rain Gauge with Long Leads

In a long cable there is appreciable capacitance between the lines, which is discharged across the switch when it closes. In addition to

SECTION 7. MEASUREMENT PROGRAMMING EXAMPLES

shortening switch life, a transient may be induced in other wires, packaged with the rain gauge leads, each time the switch closes. The 100 ohm resistor protects the switch from arcing and the associated transient from occurring, and should be included any time leads longer than 100 feet are used with a switch closure.

PROGRAM

1	P	3	Count pulses from rain gauge
		1	1 rep
		2	Pulse channel #1
		3	Switch closure, all pulses counted
		4	Location to store count
		5	0.254 Multiplier
		6	0 Offset

7.9 100 OHM PRT IN 4 WIRE HALF BRIDGE

Instruction 9 is the best choice for accuracy where the Platinum Resistance Thermometer (PRT) is separated from other bridge completion resistors by a lead length having more than a few thousandths of an ohm resistance. In this example, it is desired to measure a temperature in the range of -10 to 40°C. The length of the cable from the 21X to the PRT is 500 feet.

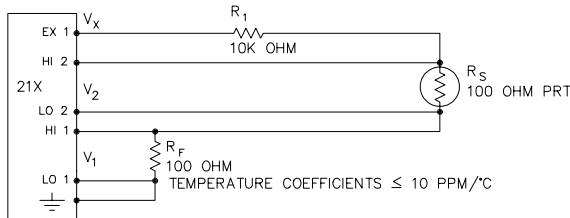


FIGURE 7.9-1. Wiring Diagram for PRT in 4 Wire Half Bridge

Figure 7.9-1 diagrams the circuit used to measure the PRT. The 10 kohm resistor allows the use of a high excitation voltage and a low input range. This insures that noise in the excitation does not have an effect on signal noise. Because the fixed resistor (R_f) and the PRT (R_s) have approximately the same resistance, the differential measurement of the voltage drop across the PRT can be made on the same range as the differential measurement of the voltage drop across R_f . The use of the

same range eliminates any range translation error that might arise from the 0.01% tolerance of the range translation resistors in the 21X.

If the voltage drop across the PRT (V_2) is kept on the 50mV range, self heating of the PRT should be less than 0.001°C in still air. The resolution of the measurement is increased as the excitation voltage (V_x) is increased as long as the Input Range is not exceeded. The voltage drop across the PRT is equal to V_x multiplied by the ratio of R_s to the total resistance, and is greatest when R_s is greatest ($R_s=115.54$ ohms at 40°C). To find the maximum excitation voltage that can be used, we assume V_2 equal to 50mV and use Ohm's Law to solve for the resulting current, I .

$$I = 50\text{mV}/R_s = 50\text{mV}/115.54 \text{ ohms} = 0.433\text{mA}$$

Next solve for V_x :

$$V_x = I(R_1 + R_s + R_f) = 4.42\text{V}$$

If the actual resistances were the nominal values, the 21X would not overrange with $V_x = 4.4\text{V}$. To allow for the tolerances in the actual resistances, it is decided to set V_x equal to 4.2 volts (e.g., if the 10 kohms resistor is 5% low, $R_s/(R_1 + R_s + R_f) = 115.54/9715.54$, and V_x must be 4.204V to keep V_s less than 50mV).

The result of Instruction 9 when the first differential measurement (V_1) is not made on the 5V range is equivalent to R_s/R_f . Instruction 16 computes the temperature (°C) for a DIN 43760 standard PRT from the ratio of the PRT resistance to its resistance at 0°C (R_s/R_0). Thus, a multiplier of R_f/R_0 is used in Instruction 9 to obtain the desired intermediate, R_s/R_0 ($=R_s/R_f \times R_f/R_0$). If R_s and R_0 were each exactly 100 ohms, the multiplier would be 1. However, neither resistance is likely to be exact. The correct multiplier is found by connecting the PRT to the 21X and entering Instruction 9 with a multiplier of 1. The PRT is then placed in an ice bath (0°C; $R_s=R_0$), and the result of the bridge measurement is read using the *6 Mode. The reading is R_s/R_f , which is equal to R_0/R_f since $R_s=R_0$. The correct value of the multiplier, R_f/R_0 , is the reciprocal of this reading. The initial reading assumed for this example was 0.9890. The correct multiplier is: $R_f/R_0 = 1/0.9890 = 1.0111$.

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The fixed 100 ohm resistor must be thermally stable. Its precision is not important because the exact resistance is incorporated, along with that of the PRT, into the calibrated multiplier. The 10 ppm/°C temperature coefficient of the fixed resistor will limit the error due to its change in resistance with temperature to less than 0.15°C over the -10 to 40°C temperature range. Because the measurement is ratiometric (R_s/R_f), the properties of the 10 kohm resistor do not affect the result.

PROGRAM

```

01:    P9      Full BR w/Compensation
01:    1       Rep
02:    3       50 mV slow EX Range
03:    3       50 mV slow BR Range
04:    1       IN Chan
05:    1       Excite all reps w/EXchan 1
06:    4200    mV Excitation
07:    1       Loc [:Rs/R0 ]
08:    1.0111  Mult
09:    0       Offset

02:    P16     Temperature RTD
01:    1       Rep
02:    1       R/Ro Loc Rs/R0
03:    2       Loc [:TEMP degC]
04:    1       Mult
05:    0       Offset
    
```

7.10 100 OHM PRT IN 3 WIRE HALF BRIDGE

The temperature measurement requirements in this example are the same as in Section 7.9. In this case, a three wire half bridge, Instruction 7, is used to measure the resistance of the PRT. The diagram of the PRT circuit is shown in Figure 7.10-1.

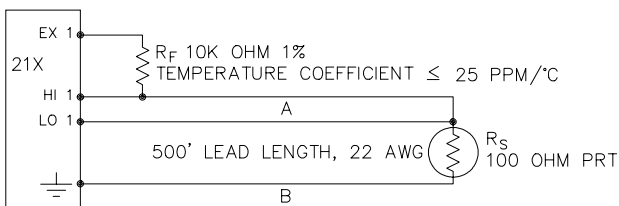


FIGURE 7.10-1. 3 Wire Half Bridge Used to Measure 100 ohm PRT

As in the example in Section 7.9, the excitation voltage is calculated to be the maximum possible, yet allow the +50mV measurement range. The 10 kohm resistor has a tolerance of $\pm 1\%$; thus, the lowest resistance to expect from it is 9.9 kohms. We calculate the maximum excitation voltage (V_x) to keep the voltage drop across the PRT less than 50mV:

$$0.050V > V_x \cdot 115.54 / (9900 + 115.54); \quad V_x < 4.33V$$

The excitation voltage used is 4.3V.

The multiplier used in Instruction 7 is determined in the same manner as in Section 7.9. In this example, the multiplier (R_f/R_0) is assumed to be 100.93.

The 3 wire half bridge compensates for lead wire resistance by assuming that the resistance of wire A is the same as the resistance of wire B. The maximum difference expected in wire resistance is 2%, but is more likely to be on the order of 1%. The resistance of R_s calculated with Instruction 7, is actually R_s plus the difference in resistance of wires A and B. The average resistance of 22 AWG wire is 16.5 ohms per 1000 feet, which would give each 500 foot lead wire a nominal resistance of 8.3 ohms. Two percent of 8.3 ohms is 0.17 ohms.

Assuming that the greater resistance is in wire B, the resistance measured for the PRT ($R_0 = 100$ ohms) in the ice bath would be 100.17 ohms, and the resistance at 40°C would be 115.71. The measured ratio R_s/R_0 is 1.1551; the actual ratio is $115.54/100 = 1.1554$. The temperature computed by Instruction 16 from the measured ratio would be about 0.1°C lower than the actual temperature of the PRT. This source of error does not exist in the example in Section 7.9, where a 4 wire half bridge is used to measure PRT resistance.

The advantages of the 3 wire half bridge are that it only requires 3 lead wires going to the sensor and takes 2 single-ended input channels, whereas the 4 wire half bridge requires 4 wires and 2 differential channels.

PROGRAM

```

01:    P7      3 Wire Half Bridge
01:    1      Rep
02:    3      50 mV slow Range
03:    1      IN Chan
04:    1      Excite all reps w/EXchan 1
05:    4300   mV Excitation
06:    1      Loc [:Rs/R0 ]
07:    100.93 Mult
08:    0      Offset

02:    P16    Temperature RTD
01:    1      Rep
02:    1      R/Ro Loc Rs/R0
03:    2      Loc [:TEMP degC]
04:    1      Mult
05:    0      Offset
    
```

7.11 100 OHM PRT IN 4 WIRE FULL BRIDGE

This example describes obtaining the temperature from a 100 ohm PRT in a 4 wire full bridge (Instruction 6). The temperature being measured is in a constant temperature bath and is to be used as the input for a control algorithm. The PRT in this case does not adhere to the DIN standard (alpha = 0.00385) used in the temperature calculating Instruction 16. Alpha is defined as $(R_{100}/R_0 - 1)/100$, where R_{100} and R_0 are the resistances of the PRT at 100°C and 0°C, respectively. In this PRT, alpha is equal to 0.00392.

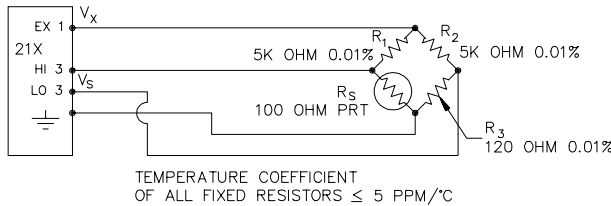


FIGURE 7.11-1. Full Bridge Schematic for 100 ohm PRT

The result (X) given by Instruction 6 is $1000 V_s/V_x$ (where V_s is the measured bridge output voltage, and V_x is the excitation voltage) which is:

$$X = 1000 (R_s/(R_s+R_1) - R_3/(R_2+R_3))$$

The resistance of the PRT (R_s) is calculated with the Bridge Transform Instruction 59:

$$R_s = R_1 X'/(1-X')$$

Where

$$X' = X/1000 + R_3/(R_2+R_3)$$

Thus, to obtain the value R_s/R_0 , ($R_0 = R_s @ 0^\circ\text{C}$) for the temperature calculating Instruction 16, the multiplier and offset used in Instruction 6 are 0.001 and $R_3/(R_2+R_3)$, respectively. The multiplier used in Instruction 59 to obtain R_s/R_0 is R_1/R_0 ($5000/100 = 50$).

It is desired to control the temperature bath at 50°C with as little variation as possible. High resolution is desired so the control algorithm will be able to respond to minute changes in temperature. The highest resolution is obtained when the temperature range results in an output voltage (V_s) range which fills the measurement range selected in Instruction 6. The full bridge configuration allows the bridge to be balanced ($V_s = 0\text{V}$) at or near the control temperature. Thus, the output voltage can go both positive and negative as the bath temperature changes, allowing the full use of the measurement range.

The resistance of the PRT is approximately 119.7 ohms at 50°C. The 120 ohm fixed resistor balances the bridge at approximately 51°C. The output voltage is:

$$\begin{aligned}
 V_s &= V_x [R_s/(R_s+R_1) - R_3/(R_2+R_3)] \\
 &= V_x [R_s/(R_s+5000) - 0.023438]
 \end{aligned}$$

The temperature range to be covered is $50 \pm 10^\circ\text{C}$. At 40°C R_s is approximately 115.8 ohms, or:

$$V_s = -802.24 \times 10^{-6} V_x$$

even with an excitation voltage (V_x) equal to 5000mV, V_s can be measured on the $\pm 5\text{mV}$ scale ($40^\circ\text{C} = 115.8 \Omega = -4.01\text{mV}$, $60^\circ\text{C} = 123.6 \Omega = 3.428\text{mV}$). There is a change of approximately 4mV from the output at 40°C to the output at 51°C, or $364 \mu\text{V}/^\circ\text{C}$. With a resolution of $0.33 \mu\text{V}$ on the 5mV range, this means that the temperature resolution is 0.0009°C .

The 5 ppm per °C temperature coefficient of the fixed resistors was chosen so that their 0.01% accuracy tolerance would hold over the desired temperature range.

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The relationship between temperature and PRT resistance is a slightly nonlinear one. Instruction 16 computes this relationship for a DIN standard PRT where the nominal temperature coefficient is 0.00385/°C. The change in nonlinearity of a PRT with the temperature coefficient of 0.00392/°C is minute compared with the slope change. Entering a slope correction factor of $0.00385/0.00392 = 0.98214$ as the multiplier in Instruction 16 results in a calculated temperature which is well within the accuracy specifications of the PRT.

PROGRAM

```

01:    P6      Full Bridge
      01:    1      Rep
      02:    1      5 mV slow Range
      03:    3      IN Chan
      04:    1      Excite all reps w/EXchan 1
      05: 5000      mV Excitation
      06:    11     Loc [:Rs/R0 ]
      07:    .001    Mult
      08:    .02344  Offset

02:    P59     BR Transform Rf[X/(1-X)]
      01:    1      Rep
      02:    11     Loc [:Rs/R0 ]
      03:    50     Multiplier (Rf)

03:    P16     Temperature RTD
      01:    1      Rep
      02:    11     R/Ro Loc Rs/R0
      03:    12     Loc [:TEMP degC]
      04:    .98214  Mult
      05:    0      Offset
  
```

7.12 PRESSURE TRANSDUCER - 4 WIRE FULL BRIDGE

This example describes a measurement made with a Druck PDCR 10/D depth measurement pressure transducer. The pressure transducer was ordered with passive temperature compensation for use with positive or negative excitation and has a range of 5 psi or about 3.5 meters of water. The transducer is used to measure the depth of water in a stilling well.

Instruction 6, 4 Wire Full Bridge, is used to measure the pressure transducer. The high output of the semiconductor strain gauge necessitates the use of the 50mV input range. The sensor is calibrated by connecting it to the

21X and using Instruction 6 with a multiplier of 1 and an offset of 0, noting the readings (*6 Mode) with 10 cm of water above the sensor and with 334.6 cm of water above the sensor. The output of Instruction 6 is $1000 V_s/V_x$ or millivolts per volt excitation. At 10 cm the reading is 0.19963mV/V and at 334.6 cm the reading is 6.6485mV/V. The multiplier to yield output in cm is:

$$(334.6 - 10)/(6.6485 - 0.19963) = 50.334 \text{ cm/mV/V}$$

The offset is determined after the pressure transducer is installed in the stilling well. The sensor is installed 65 cm below the water level at the time of installation. The depth of water at this time is determined to be 72.6 cm relative to the desired reference. When programmed with the multiplier determined above and an offset of 0, a reading of 65.12 is obtained. The offset for the actual measurements is thus determined to be $72.6 - 65.12 = 7.48$ cm.

The lead length is approximately 10 feet, so there is no appreciable error due to lead wire resistance. Example 7.13 shows a means of compensating for long lead lengths.

CONNECTIONS

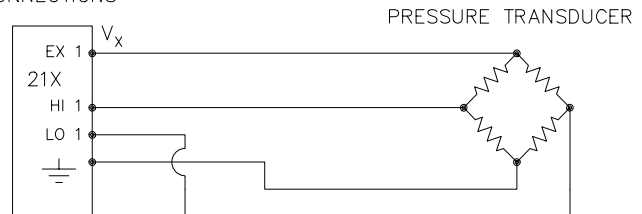


FIGURE 7.12-1. Wiring Diagram for Full Bridge Pressure Transducer

PROGRAM

```

01:    P6      Full Bridge
      01:    1      Rep
      02:    3      50 mV slow Range
      03:    1      IN Chan
      04:    1      Excite all reps w/EXchan 1
      05: 5000      mV Excitation
      06:    1      Loc [:WATER cm ]
      07: 50.334    Mult
      08:    7.48   Offset
  
```


7.13 LYSIMETER - 6 WIRE FULL BRIDGE

When a long cable is required between a load cell and the 21X, the resistance of the wire can create a substantial error in the measurement if the 4 wire full bridge (Instruction 6) is used to excite and measure the load cell. This error arises because the excitation voltage is lower at the load cell than at the 21X due to voltage drop in the cable. The 6 wire full bridge (Instruction 9) avoids this problem by measuring the excitation voltage at the load cell. This example shows the errors one would encounter if the actual excitation voltage was not measured and shows the use of a 6 wire full bridge to measure a load cell on a weighing lysimeter (a container buried in the ground, filled with plants and soil, used for measuring evapotranspiration).

The lysimeter is 2 meters in diameter and 1.5 meters deep. The total weight of the lysimeter with its container is approximately 8000 kg. The lysimeter has a mechanically adjustable counterbalance, and changes in weight are measured with a 250 pound (113.6 kg) capacity Sensotec Model 41 tension/compression load cell. The load cell has a 4:1 mechanical advantage on the lysimeter (i.e., a change of 4 kg in the mass of the lysimeter will change the force on the load cell by 1 kg-force or 980 N).

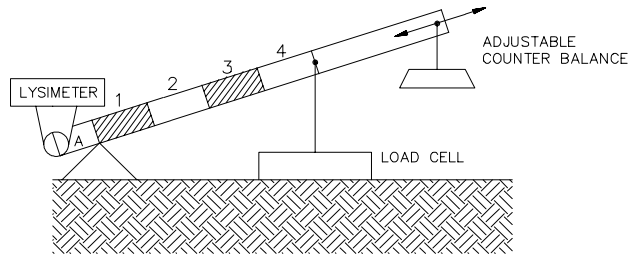


FIGURE 7.13-1. Lysimeter Weighing Mechanism

The surface area of the lysimeter is 3.1416 m² or 31,416 cm², so 1 cm of rainfall or evaporation results in a 31.416 kg change in mass. The load cell can measure ±113.6 kg, a 227 kg range. This represents a maximum change of 909 kg (28 cm of water) in the lysimeter before the counterbalance would have to be readjusted.

There is 1000 feet of 22 AWG cable between the 21X and the load cell. The output of the load cell is directly proportional to the excitation

voltage. When Instruction 6 (4 wire half bridge) is used, the assumption is that the voltage drop in the connecting cable is negligible. The average resistance of 22 AWG wire is 16.5 ohms per 1000 feet. Thus, the resistance in the excitation lead going out to the load cell added to that in the lead coming back to ground is 33 ohms. The resistance of the bridge in the load cell is 350 ohms. The voltage drop across the load cell is equal to the voltage at the 21X multiplied by the ratio of the load cell resistance, R_S, to the total resistance, R_T, of the circuit. If Instruction 6 were used to measure the load cell, the excitation voltage actually applied to the load cell, V₁ would be:

$$V_1 = V_x R_S / R_T = V_x 350 / (350 + 33) = 0.91 V_x$$

Where V_x is the excitation voltage. This means that the voltage output by the load cell would only be 91% of that expected. If recording of the lysimeter data was initiated with the load cell output at 0 volts, and 100mm of evapotranspiration had occurred, calculation of the change with Instruction 6 would indicate that only 91mm of water had been lost. Because the error is a fixed percentage of the output, the actual magnitude of the error increases with the force applied to the load cell. If the resistance of the wire was constant, one could correct for the voltage drop with a fixed multiplier. However, the resistance of copper changes 0.4% per degree C change in temperature. Assume that the cable between the load cell and the 21X lays on the soil surface and undergoes a 25°C diurnal temperature fluctuation. If the resistance is 33 ohms at the maximum temperature, then at the minimum temperature, the resistance is:

$$(1 - 25 \times 0.004) 33 \text{ ohms} = 29.7 \text{ ohms}$$

The actual excitation voltage at the load cell is:

$$V_1 = 350 / (350 + 29.7) V_x = .92 V_x$$

The excitation voltage has increased by 1%, relative to the voltage applied at the 21X. In this case, where we were recording a 91mm change in water content, there would be a 1mm diurnal change in the recorded water content that would actually be due to the change in temperature. Instruction 9 solves this problem by actually measuring the voltage drop across the load cell bridge. The drawbacks to using Instruction 9

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are that it requires an extra differential channel and the added expense of a 6 wire cable. In this case, the benefits are worth the expense.

The load cell has a nominal full scale output of 3 millivolts per volt excitation. If the excitation is 5 volts, the full scale output is 15 millivolts; thus, the ± 15 millivolt range is selected. The calibrated output of the load cell is 3.106mV/V_1 at a load of 250 pounds. Output is desired in millimeters of water with respect to a fixed point. The calibration in $\text{mV/V}_1/\text{mm}$ is:

$$3.106\text{mV/V}_1 / 250\text{lb} \times 2.2\text{lb/kg} \times 3.1416\text{kg/mm} / 4 =$$

$$0.02147\text{mV/V}_1/\text{mm}$$

The reciprocal of this gives the multiplier to convert mV/V_1 into millimeters. (The result of Instruction 9 is the ratio of the output voltage to the actual excitation voltage multiplied by 1000, which is mV/V_1):

$$1/0.02147\text{mV/V}_1/\text{mm} = 46.583\text{mm/mV/V}_1$$

The output from the load cell is connected so that the voltage increases as the mass of the lysimeter increases. (If the actual mechanical linkage was as diagrammed in Figure 7.13-1, the output voltage would be positive when the load cell was under tension.)

When the experiment is started, the water content of the soil in the lysimeter is approximately 25% on a volume basis. It is decided to use this as the reference, (i.e., $0.25 \times 1500\text{mm} = 375\text{mm}$). The experiment is started at the beginning of what is expected to be a period during which evapotranspiration exceeds precipitation. Instruction 9 is programmed with the correct multiplier and no offset. After hooking everything up, the counterbalance is adjusted so that the load cell is near the top of its range; this will allow a longer period before readjustment is necessary. The result of Instruction 9 (monitored with the *6 Mode) is 109. The offset needed to give the desired initial value of 375mm is 266. However, it is decided to add this offset in a separate instruction so that the result of Instruction 9 can be used as a ready reminder of the strain on the load cell (range = $\pm 140\text{mm}$). When the strain on the load cell nears its rated limits, the

counterbalance is readjusted and the offset recalculated to provide a continuous record of the water budget.

The program table has an execution interval of 10 seconds. The average value in millimeters is output to Final Storage (not shown in Table) every hour. The average is used, instead of a sample, in order to cancel out the effects of wind loading on the lysimeter.

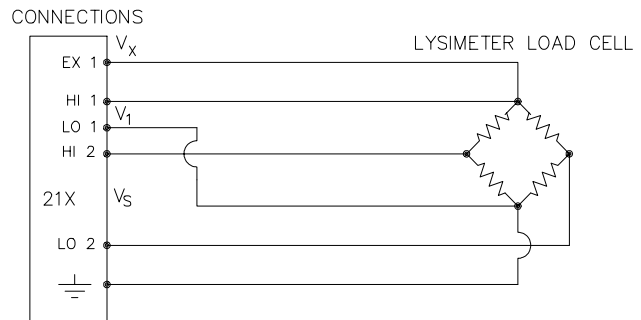


FIGURE 7.13-2. 6 Wire Full Bridge Connection for Load Cell

PROGRAM

01:	P9	Full BR w/Compensation
01:	1	Rep
02:	5	5000 mV slow EX Range
03:	2	15 mV slow BR Range
04:	1	IN Chan
05:	1	Excite all reps w/EXchan 1
06:	5000	mV Excitation
07:	1	Loc [:RAW MEAS.]
08:	46.583	Mult
09:	0	Offset
02:	P34	Z=X+F
01:	1	X Loc RAW MEAS.
02:	266	F
03:	2	Z Loc [:MEAS+OFFS]

7.14 227 GYPSUM SOIL MOISTURE BLOCK

Soil moisture is measured with a gypsum block by relating the change in moisture to the change in resistance of the block. An AC Half Bridge (Instruction 5) is used to determine the resistance of the gypsum block. Rapid reversal of the excitation voltage inhibits polarization of the sensor. Polarization creates an error in the output so the fast integration time is used. The output of Instruction 5 is the ratio of the output

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voltage to the excitation voltage; this output is converted to gypsum block resistance with Instruction 59, Bridge Transform.

The Campbell Scientific 227 Soil Moisture Block uses a Delmhorst gypsum block with a 1 kohm bridge completion resistor (there are also series capacitors to block DC current and degradation due to electrolysis. Using data supplied by Delmhorst, Campbell Scientific has computed coefficients for a 5th order polynomial to convert block resistance to water potential in bars. There are two polynomials: one to optimize the range from -0.1 to -2 bars, and one to cover the range from -0.1 to -10 bars (the minus sign is omitted in the output). The -0.1 to -2 bar polynomial requires a multiplier of 1 in the Bridge Transform Instruction (result in kohms) and the -0.1 to -10 bar polynomial requires a multiplier of 0.1 (result in 10,000s of ohms). The multiplier is a scaling factor to maintain the maximum number of significant digits in the coefficients of the polynomial.

In this example, we wish to make measurements on 6 gypsum blocks and output the final data in bars. The soil where the moisture measurements are to be made is quite wet at the time the data logging is initiated, but is expected to dry beyond the -2 bar limit of the wet range polynomial. The dry range polynomial is used, so a multiplier of 0.1 is entered in the bridge transform instruction.

When the water potential is computed, it is written over the resistance value. The potentials are stored in input locations 1-6 where they may be accessed for output to Final Storage. If it was desired to retain the resistance values, the potential measurements could be stored in Locations 7-12 by changing Parameter 3 in Instruction 55 to 7.

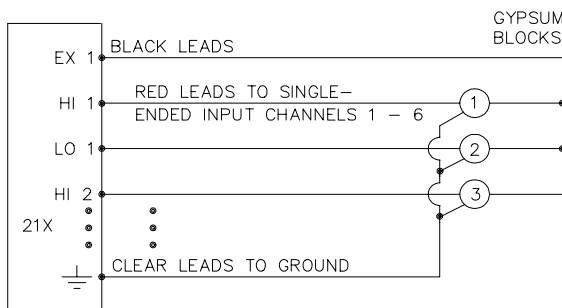


FIGURE 7.14-1. 6 Gypsum Blocks Connected to the 21X

PROGRAM

```

01:    P5      AC Half Bridge
      01:    6      Reprs
      02:   14      500 mV fast Range
      03:    1      IN Chan
      04:    1      Excite all reps w/EXchan 1
      05:   500     mV Excitation
      06:    1      Loc :
      07:    1      Mult
      08:    0      Offset

02:    P59     BR Transform Rf[X/(1-X)]
      01:    6      Reprs
      02:    1      Loc :
      03:    .1    Multiplier (Rf)

03:    P55     Polynomial
      01:    6      Reprs
      02:    1      X Loc
      03:    1      F(X) Loc :
      04:   .15836 C0
      05:   6.1445 C1
      06:  -8.4189 C2
      07:   9.2493 C3
      08:  -3.1685 C4
      09:   .33392 C5
    
```

7.15 NONLINEAR THERMISTOR IN HALF BRIDGE (CAMPBELL SCIENTIFIC MODEL 101)

Instruction 11, 107 Thermistor Probe, automatically calculates temperature by transforming the millivolt reading with a 5th order polynomial. Instruction 55, Polynomial, can be used to calculate temperature of any nonlinear thermistor, provided the correlation between temperature and probe output is known, and an appropriate polynomial fit has been determined. In this example, the 21X is used to measure the temperature of 5 Campbell Scientific 101 Probes (used with the CR21). Instruction 4, Excite, Delay, and Measure, is used because the high source resistance of the probe requires a long input settling time (see Section 13.3.1). The excitation voltage is 2000mV, the same as used in the CR21. The signal voltage is then transformed to temperature using the Polynomial Instruction.

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The manual for the 101 Probe gives the coefficients of the 5th order polynomial used to convert the output in millivolts to temperature (E denotes the power of 10 by which the mantissa is multiplied):

C0	-53.7842
C1	0.147974
C2	-2.18755E-4
C3	2.19046E-7
C4	-1.11341E-10
C5	2.33651E-14

The 21X will only allow 5 significant digits to the right or left of the decimal point to be entered from the keyboard. The polynomial cannot be applied exactly as given in the 101 manual. The initial millivolt reading must be scaled if the coefficients of the higher order terms are to be entered with the maximum number of significant digits. If 0.001 is used as a multiplier on the millivolt output, the coefficients are divided by 0.001 raised to the appropriate power (i.e., $C0=C0$, $C1=C1/0.001$, $C2=C2/0.000001$, etc.). With this adjustment, the coefficients entered in Parameters 4-9 of Instruction 55 become:

C0	-53.784
C1	147.97
C2	-218.76
C3	219.05
C4	-111.34
C5	23.365

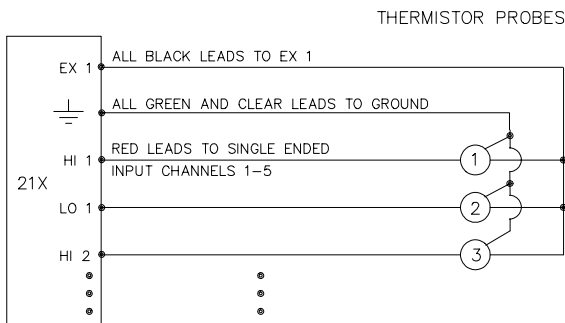


FIGURE 7.15-1. 101 Thermistor Probes Connected to 21X

PROGRAM

01:	P4	Excite,Delay,Volt(SE)
01:	5	Reps
02:	5	5000 mV slow Range
03:	1	IN Chan
04:	1	Excite all reps w/EXchan 1
05:	10	Delay (units .01 sec)
06:	2000	mV Excitation
07:	1	Loc :
08:	.001	Mult
09:	0	Offset
02:	P55	Polynomial
01:	5	Reps
02:	1	X Loc
03:	1	F(X) Loc :
04:	-53.784	C0
05:	147.97	C1
06:	-218.76	C2
07:	219.05	C3
08:	-111.34	C4
09:	23.365	C5

7.16 MEASURING 107 TEMPERATURE PROBE WITH 60 HZ REJECTION

The 107 temperature probe is normally measured with Instruction 11 which uses the same measurement sequence as Instruction 5 with a fast integration voltage measurement. The fast integration does not reject 60 Hz noise. In environments where 60 Hz is a problem, the 107 probe can be measured with Instruction 5 using the slow integration time.

A multiplier of 800 in Instruction 5 is used to scale the voltage measurement for the polynomial Instruction 55 which is used to convert the voltage measurement to °C.

SECTION 7. MEASUREMENT PROGRAMMING EXAMPLES

This measurement sequence should not be used to measure temperature on the 207 temperature and RH probe. The longer excitation/integration time could cause polarization of the RH element, shifting its calibration.

The connections for this example are the same as for Example 7.5, where instruction 11 is used to measure three 107 Temperature Probes.

PROGRAM

```
01:    P5      AC Half Bridge
  01:    3      Reps
  02:    2      15 mV slow Range
  03:    1      IN Chan
  04:    1      Excite all reps w/EXchan 1
  05:  4000     mV Excitation
  06:    1      Loc [:107 T #1 ]
  07:   800     Mult
  08:    0      Offset

02:    P      55 Polynomial
  01:    3      Reps
  02:    1      X Loc 107 T #1
  03:    1      F(X) Loc [:107 T #1 ]
  04:  -53.46   C0
  05:   90.807  C1
  06:  -83.257  C2
  07:   52.283  C3
  08:  -16.723  C4
  09:    2.211  C5
```

SECTION 7. MEASUREMENT PROGRAMMING EXAMPLES

SECTION 8. PROCESSING AND PROGRAM CONTROL EXAMPLES

The following examples are intended to illustrate the use of Processing and Program Control Instructions, flags, and the capability to direct the results of Output Processing Instructions to Input Storage.

The specific examples may not be as important as some of the techniques employed, for example:

Directing Output Processing to Input Storage is used in the Running Average and Rainfall Intensity examples (8.1 and 8.2).

Flags tests are used in the Running Average, Interrupt Subroutine, and Converting Wind Direction examples (8.1, 8.5, and 8.7)

Control ports and the Loop are illustrated in the AM416 example (8.3).

These examples are not complete programs to be taken verbatim. They need to be altered to fit specific needs.

8.1 COMPUTATION OF RUNNING AVERAGE

It is sometimes necessary to compute a running average (i.e., the average includes a fixed number of samples and is continuously updated as new samples are taken). Because the output interval is shorter than the averaging period, Instruction 71 cannot be used; the algorithm for computing this average must be programmed by the user. The following example demonstrates a program for computing a running average.

In this example, each time a new measurement is made (in this case a thermocouple temperature) an average is computed for the 10 most recent samples. This is done by saving all 10 temperatures in contiguous input locations and using the Spatial Average Instruction (51) to compute the average. The temperatures are stored in locations 11 through 20. Each time the table is executed, the new measurement is stored in location 20 and the average is stored in location 2. The Block Move Instruction (54) is then used to move the temperatures from locations 12 through 20 down by one location; the oldest measurement (in location 11) is lost when the temperature from location 12 is written over it.

Input Location Labels:

1:Panl Temp	15:Temp i-5
2:10smp av	16:Temp i-4
11:Temp i-9	17:Temp i-3
12:Temp i-8	18:Temp i-2
13:Temp i-7	19:Temp i-1
14:Temp i-6	20:Temp i

*Where i is current reading,
i-1 is previous reading, etc.*

*	1	Table 1 Programs
01:	10	Sec. Execution Interval
01:	P17	Panel Temperature
01:	1	Loc [:Panl Temp]
02:	P14	Thermocouple Temp (DIFF)
01:	1	Rep
02:	1	5 mV slow Range
03:	1	IN Chan
04:	1	Type T (Copper-Constantan)
05:	1	Ref Temp Loc Panl Temp
06:	20	Loc [:Temp i]
07:	1	Mult
08:	0	Offset
03:	P51	Spatial Average
01:	10	Swath
02:	11	First Loc Temp i-9
03:	2	Avg Loc [:10smp av]

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```

04:   P54   Block Move
01:    9   No. of Values
02:   12   First Source Loc Temp i-8
03:    1   Source Step
04:   11   First Destin. Loc [:Temp i-9 ]
05:    1   Destination Step
  
```

```

05:   P86   Do
01:   10   Set high Flag 0 (output)
  
```

```

06:   P70   Sample
01:    1   Rep
02:    2   Loc 10smpl av
  
```

```

07:    P    End Table 1
  
```

In the above example, all samples for the average are stored in input locations. This is necessary when an average must be output with each new sample. In most cases, averages are desired less frequently than sampling. For example, it may be necessary to sample some parameter every 5 seconds and output every hour an average of the previous three hours readings. If all samples were saved, this would require 2160 input locations. The same value can be obtained by computing an hourly average and averaging the hourly averages for the past three hours. To do this requires that hourly averages be stored in input locations.

Instruction 80 is used to send the 1 hour average to Input Storage and again to send the 3 hour average to Final Storage.

Input Location Labels:

```

1:AVG i-2
2:AVG i-1
3:AVG i
4:3 HR AVG
5:XX mg/M3
  
```

```

*      1   Table 1 Programs
01:    5   Sec. Execution Interval
  
```

```

01:   P2   Volt (DIFF)
01:    1   Rep
02:    5   5000 mV slow Range
03:    3   IN Chan
04:    5   Loc [:XX mg/M3 ]
05:   10   Mult
06:    0   Offset
  
```

```

02:   P92   If time is
01:    0   minutes into a
02:   60   minute interval
03:   10   Set high Flag 0 (output)
  
```

```

03:   P80   Set Active Storage Area
01:    3   Input Storage Area
02:    3   Array ID or location
  
```

```

04:   P71   Average
01:    1   Rep
02:    5   Loc XX mg/M3
  
```

```

05:   P51   Spatial Average
01:    3   Swath
02:    1   First Loc AVG i-2
03:    4   Avg Loc [:3 HR AVG ]
  
```

```

06:   P80   Set Active Storage Area
01:    1   Final Storage Area
02:   25   Array ID or location
  
```

```

07:   P77   Real Time
01:  220   Day,Hour-Minute
  
```

```

08:   P70   Sample
01:    1   Rep
02:    4   Loc 3 HR AVG
  
```

```

09:   P91   If Flag
01:   10   0 (output) is set
02:   30   Then Do
  
```

```

10:   P54   Block Move
01:    2   No. of Values
02:    2   First Source Loc AVG i-1
03:    1   Source Step
04:    1   First Destin. Loc [:AVG i-2 ]
05:    1   Destination Step
  
```

```

11:   P95   End
  
```

```

12:    P    End Table 1
  
```

8.2 RAINFALL INTENSITY

In this example, the total rain for the last 15 minutes is output only if any rain has occurred. The program makes use of the capability to direct the output of Output Processing Instructions to Input Storage.

Every 15 minutes, the total rain is sent to Input Storage. If the total is not equal to 0, output is

SECTION 8. PROCESSING AND PROGRAM CONTROL EXAMPLES

redirected to Final Storage Area 1, the time is output and the total is sampled.

Input Location Labels:

1:Rain (mm)
2:15min tot

*	1	Table 1 Programs
01:	60	Sec. Execution Interval
01:	P3	Pulse
01:	1	Rep
02:	1	Pulse Input Chan
03:	2	Switch closure
04:	1	Loc [:Rain (mm)]
05:	.254	Mult
06:	0	Offset
02:	P92	If time is
01:	0	minutes into a
02:	15	minute interval
03:	10	Set high Flag 0 (output)
03:	P80	Set Active Storage Area
01:	3	Input Storage Area
02:	2	Array ID or location
04:	P72	Totalize
01:	1	Rep
02:	1	Loc Rain (mm)
05:	P89	If X<=>F
01:	2	X Loc 15min tot
02:	2	<>
03:	0	F
04:	30	Then Do
06:	P80	Set Active Storage Area
01:	1	Final Storage Area
02:	25	Array ID or location
07:	P77	Real Time
01:	220	Day,Hour-Minute
08:	P70	Sample
01:	1	Rep
02:	2	Loc 15min tot
09:	P95	End
10:	P	End Table 1

8.3 USING CONTROL PORTS AND LOOP TO RUN AM416 MULTIPLEXER

This example uses an AM416 to measure 16 copper-constantan thermocouples and 16 Model 223 soil moisture blocks. The sensors are read every ten minutes and the average value output once an hour. The multiplexer is housed in an AM-ENCT enclosure to minimize thermocouple errors created by thermal gradients. Thermocouple Wire is run from the 21X to the AM416 common used for the TC measurements and the 21X panel temperature is used for the reference temperature.

The AM416 switches the 223 moisture block out of the circuit when it is not being measured. This eliminates the need for the blocking capacitors used in the model 227 soil moisture block. The 223 blocks are about one fifth the cost of the 227 blocks.

Control ports are used to reset the AM416 and clock it through its channels. The sequence of the program is:

- Measure the 21X panel temperature for TC temperature reference.
- 21X sets the port high which resets the AM416.
- A loop is entered; within each pass:
 - The port clocking the AM416 is pulsed.
 - The connected TCs and moisture blocks are measured.
- 21X sets the port controlling AM416 reset low.
- Soil moisture measurements are converted to block resistances.

The input location in which the temperature and soil moisture measurements are stored is indexed to the loop counter (Instruction 87, Section 12). An indexed location is incremented by one with each pass through the loop. For example, on the first pass temperature is stored in Location 2, and soil moisture in Location 18. On the second pass temperature is stored in Location 3, and soil moisture in Location 18. After 16 loop passes, temperature and soil moisture measurements occupy Locations 2 through 17 and 18 through 33, respectively.

Connections are shown in Figure 8.3-1.

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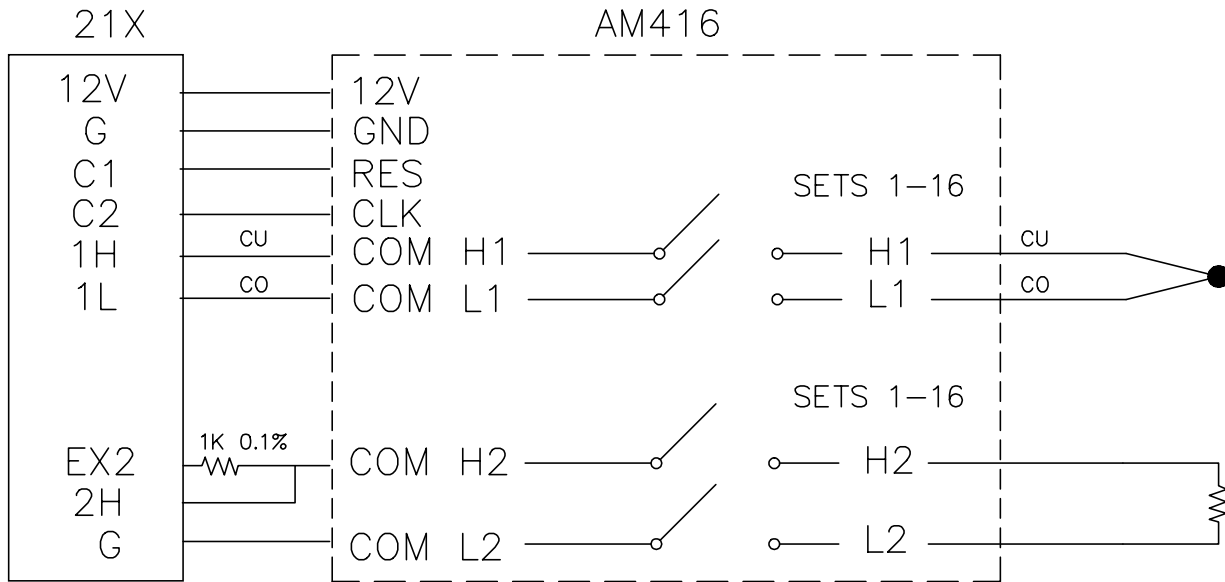


FIGURE 8.3-1. AM416 Wiring Diagram For Thermocouple and Soil Moisture Block Measurements

EXAMPLE PROGRAM MULTIPLEXING THERMOCOUPLES AND SOIL MOISTURE BLOCK			06:	P5	AC Half Bridge
			01:	1	Rep
			02:	14	500 mV fast Range
			03:	3	IN Chan
*	1	Table 1 Programs	04:	2	Excite all reps w/EXchan 2
01:	600	Sec. Execution Interval	05:	500	mV Excitation
01:	P17	Panel Temperature	06:	18--	Loc [:SOIL M#1]
01:	1	Loc [:REF TEMP]	07:	1	Mult
			08:	0	Offset
02:	P86	Do	07:	P95	End
01:	41	Set high Port 1			
03:	P87	Beginning of Loop	08:	P86	Do
01:	0	Delay	01:	51	Set low Port 1
02:	16	Loop Count	09:	P59	BR Transform $Rf[X/(1-X)]$
04:	P86	Do	01:	16	Reps
01:	72	Pulse Port 2	02:	18	Loc [:SOIL M#1]
			03:	.1	Multiplier (Rf)
05:	P14	Thermocouple Temp (DIFF)	10:	P92	If time is
01:	1	Rep	01:	0	minutes into a
02:	1	5 mV slow Range	02:	60	minute interval
03:	1	IN Chan	03:	10	Set high Flag 0 (output)
04:	1	Type T (Copper-Constantan)			
05:	1	Ref Temp Loc REF TEMP	11:	P77	Real Time
06:	2--	Loc [:TC TEMP#1]	01:	110	Day,Hour-Minute
07:	1	Mult			
08:	0	Offset	12:	P71	Average
			01:	33	Reps
			02:	1	Loc REF TEMP

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```

13:      P      End Table 1
*
      A      Mode 10 Memory Allocation
01:    35      Input Locations
02:    64      Intermediate Locations
    
```

8.4 SUB 1 MINUTE OUTPUT INTERVAL SYNCHED TO REAL TIME

Instruction 92 has 1 minute resolution. If processed output is required on an interval less than 1 minute, Instructions 18 and 89 can be used to set the Output Flag on a shorter interval.

Instruction 18 takes time (tenths of seconds into minute, minutes into day, or hours into year), performs a modulo divide by a user specified value and loads it into an input location.

When the modulo divisor divides evenly into the interval, one gets a counter in an input location that goes to 0 on a periodic interval. In this example, tenths of seconds into the minute is modulo divided by 300. The counter counts up to 295 then goes to 0 (i.e., every 30 seconds; tenths of seconds into minute has a resolution of 0.1 seconds.)

Instruction 89 is used to set the Output Flag when the tenths of seconds counter is less than 5 (the execution interval, 0.5 seconds). With this short program the Output Flag could be set when the seconds counter equaled 0. However, if Instruction 18 followed a series of instructions that took longer than 0.1 seconds to execute or was in Table 2, executed at the same interval as an extensive Table 1, the time at which Instruction 18 was executed might be 0.1 seconds or more beyond the modulo divisor. The value output would not equal 0. Setting the Output Flag when the seconds counter is less than the execution interval avoids this problem.

Using Instruction 18 keeps the output interval synchronized with real time. If a counter incremented within the program was used to determine when to set the Output Flag, output would depend on the number of times the table was executed. The actual time of output would depend on when the program was actually compiled and started running. If the table overran its execution interval (Section 1.1.1), the output interval would not be the count multiplied

by the execution interval, but some longer interval.

In this example a temperature (type E thermocouple) is measured every 0.5 seconds and the average output every 30 seconds.

Input Location Assignments:

```

1:TEMP DEG C
10:30 SEC 0

*      1      Table 1 Programs
01:    .5     Sec. Execution Interval

01:    P18    Time
01:    0      Tenths of seconds into
              minute (maximum 600)
02:    300    Mod/by
03:    10     Loc [:30 SEC 0 ]

02:    P17    Panel Temperature
01:    1      Loc [:REF TEMP ]

03:    P14    Thermocouple Temp (DIFF)
01:    1      Rep
02:    11     5 mV fast Range
03:    2      IN Chan
04:    2      Type E (Chromel-Constantan)
05:    1      Ref Temp Loc REF TEMP
06:    2      Loc [:TC TEMP ]
07:    1      Mult
08:    0      Offset

04:    P89    If X<=>F
01:    10     X Loc 30 SEC 0
02:    4      <
03:    .5     F
04:    10     Set high Flag 0 (output)

05:    P71    Average
01:    1      Rep
02:    2      Loc TC TEMP

06:      P      End Table 1
    
```

8.5 SDM-A04 ANALOG OUTPUT MULTIPLEXER TO STRIP CHART

This example illustrates the use of the SDM-A04 4 Channel Analog Output Multiplexer to output 4 analog voltages to strip chart.

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While of questionable value because of current requirements and strip chart reliability, some archaic regulations require strip chart backup on weather data. The SDM-A04 may be used with the 21X to provide an additional four continuous analog outputs for strip charts. The output values in this example are wind speed, wind direction, air temperature, and solar radiation.

Instruction 103 is used to activate the SDM-A04. The 4 millivolt values to output must be stored in adjacent Input Storage locations, the first of which is referenced in Instruction 103.

The following program measures the sensors every 5 seconds. The readings are moved to another 4 locations and scaled to a 0 to 1000 millivolt output for the SDM-A04. Wind direction is changed from a 0-360 degree input to output representing 0 to 540 degrees. This conversion is done in a subroutine which is described in the next example.

The example also includes instructions to output wind vector and average temperature and solar radiation every hour.

Input location Assignments:

1:WS
2:0-360 WD
3:Ta
4:SR
5:WS output
6:0-540 out
7:Ta output
8:SR output
10:0-540 WD

* 1 Table 1 Programs
01: 5 Sec. Execution Interval
01: P3 Pulse
01: 1 Rep
02: 1 Pulse Input Chan
03: 22 Switch closure; Output Hz.
04: 1 Loc [:WS]
05: 1.789 Mult
06: 1 Offset

02: P4 Excite,Delay,Volt(SE)
01: 1 Rep
02: 14 500 mV fast Range
03: 1 IN Chan
04: 1 Excite all reps w/EXchan 1
05: 2 Delay (units .01sec)

06: 1000 mV Excitation
07: 2 Loc [:0-360 WD]
08: .72 Mult
09: 0 Offset

03: P11 Temp 107 Probe
01: 1 Rep
02: 2 IN Chan
03: 2 Excite all reps w/EXchan 2
04: 3 Loc [:Ta]
05: 1.8 Mult
06: 32 Offset

04: P2 Volt (DIFF)
01: 1 Rep
02: 2 15 mV slow Range
03: 3 IN Chan
04: 4 Loc [:SR]
05: .14493 Mult
06: 0 Offset

05: P92 If time is
01: 0 minutes into a
02: 60 minute interval
03: 10 Set high Flag 0 (output)

06: P54 Block Move
01: 4 No. of Values
02: 1 First Source Loc WS
03: 1 Source Step
04: 5 First Destination Loc [:WS output]
05: 1 Destination Step

07: P86 Do
01: 1 Call Subroutine 1

08: P53 Scaling Array (A*loc +B)
01: 5 Start Loc [:WS output]
02: 10 A1
03: 0 B1
04: 1.8519 A2
05: 0 B2
06: 8 A3
07: 25 B3
08: 1000 A4
09: 0 B4

09: P103 SDM-A04 (OSX-0,-1)
01: 4 Reps
02: 30 Address
03: 5 Loc WS output

10: P92 If time is
01: 0 minutes into a

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```

02: 60      minute interval
03: 10      Set high Flag 0 (output)

11: P69      Wind Vector
01: 1        Rep
02: 180      Samples per sub-interval
03: 00       US, DV, SD (Polar Sensor)
04: 1        Wind Speed/East Loc WS
05: 2        Wind Direction/North Loc
              0-360 WD

12: P71      Average
01: 2        Reps
02: 3        Loc Ta

13: P        End Table 1
    
```

```

3:Ta
4:SR
5:WS output
6:0-540 out
7:Ta output
8:SR output
10:0-540 WD
*      3
01: P85
01: 1

02: P89
01: 10
02: 3
03: 270
04: 30
    
```

Table 3 Subroutines

```

01: P85      Beginning of Subroutine
01: 1        Subroutine Number

02: P89      If X<=>F
01: 10       X Loc 0-540 WD
02: 3        >=
03: 270      F
04: 30       Then Do
    
```

8.6 CONVERTING 0-360 WIND DIRECTION OUTPUT TO 0-540 FOR STRIP CHART

If 0-360 degree wind direction is output to a strip chart, the discontinuity at 0/360 will cause the pen to jump back and forth full scale when the winds are varying from the north. In the days of strip charts this was solved with a 0-540 degree pot on the wind vane (direction changes from 540 to 180 and from 0 to 360 so the pen only jumps once when the wind is out of the north or south).

When faced with the necessity of strip chart output (see previous example), the following algorithm can be used to change a 0-360 degree input to 0-540. (If you have a 0-540 pot, it can be used with the 21X since the Wind Vector Instruction, 69, will work with this output.)

To change 0-360 degrees to the 0-540 degrees, 360 degrees must sometimes be added to the reading when it is in the range of 0 to 180. The following algorithm does this by assuming that if the previous reading was less than 270, the vane has shifted through 180 degrees and does not need to be altered. If the previous 0-540 reading was greater than 270, 360 degrees is added.

This example is written as a subroutine which is used by the previous example to output an analog voltage to a strip chart.

Input Location Labels:

```

1:WS
2:0-360 WD
    
```

```

03: P86      Do
01: 11       Set high Flag 1

04: P94      Else

05: P86      Do
01: 21       Set low Flag 1

06: P95      End

07: P31      Z=X
01: 2        X Loc 0-360 WD
02: 10       Z Loc [:0-540 WD]

08: P89      If X<=>F
01: 10       X Loc 0-540 WD
02: 4        <
03: 180      F
04: 30       Then Do

09: P91      If Flag
01: 11       1 is set
02: 30       Then Do

10: P34      Z=X+F
01: 10       X Loc 0-540 WD
02: 360      F
03: 10       Z Loc [:0-540 WD]

11: P31      Z=X
01: 10       X Loc 0-540 WD
02: 6        Z Loc [:0-540 out]

12: P        95 End

13: P        95 End
    
```

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14: P95 End

15: P End Table 3

The props can all be measured as single-ended voltages, but the vertical wind prop calibration differs from the U and V prop calibration. The fastest input sequence is to measure both levels (6 props) with a single instruction using the U and V calibration and correct the W measurements with the Fixed Multiply, Instruction 37.

8.7 COVARIANCE CORRELATION PROGRAMMING EXAMPLE

The example is a 2 level meteorological tower with 5 sensors at each level. The three components of the wind are measured using prop anemometers. Two thermocouples (TC) are used to measure ambient and wet-bulb temperatures and calculate water vapor pressure on-line. All sensors are scanned once per second (1 Hz) and a 5 minute averaging period with a 30 minute Output Interval is specified. The example optimizes the input measurement sequence for speed and shows the instructions necessary to provide calibrated inputs, properly ordered to produce the desired outputs from the Covariance Correlation (CV/CR) Instruction. Table 8.7-1 groups the sensors according to measurement type and gives the 21X multiplier and offset.

The type E thermocouples are measured on the most sensitive input range, 5mV, accommodating a ±80°C range between the measurement and 21X reference junction. The resolution is (.33µV/(60µV/°C) or about 0.006°C. Measuring absolute temperature with TCs requires a reference junction temperature measurement. This is measured with Instruction 17.

The specified outputs determine the input order required by the CV/CR Instruction. Table 8.7-2 lists the desired outputs from the two levels along with the Input Storage locations for the processed results.

TABLE 8.7-1. Example Sensor Description and 21X Multiplier and Offset

DESCRIPTION	SYMBOL	SENSOR	CALIB	MEAS TYPE	MULT	OFFSET
Horiz. Wind	U	prop	18m/s/V	S.E.V.	.018m/s/mV	0.0
Horiz. Wind	V	prop	18m/s/V	S.E.V.	.018	0.0
Vert. Wind	W	prop	22m/s/V	S.E.V.	.022	0.0
Air Temp.	Ta	TC	-	TC DIFF.	1.0oC	0.0
Wet-bulb Temp.	Tw	TC	-	TC DIFF.	1.0oC	0.0
Vap. Pressure	e	derived	-	-	-	-

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TABLE 8.7-2. Example Outputs and Input Storage Locations

LEVEL 1 OUTPUTS							
<u>MEANS LOC</u>		<u>VARIANCES LOC</u>		<u>COVARIANCES LOC</u>		<u>CORRELATIONS LOC</u>	
M(W1)	20	V(W1)	25	CV(W1,U1)	30	CR(W1,U1)	34
M(U1)	21	V(U1)	26	CV(W1,V1)	31	CR(W1,V1)	35
M(V1)	22	V(V1)	27	CV(W1,Ta1)	32		
M(Ta1)	23	V(Ta1)	28	CV(W1,e1)	33		
M(e1)	24	V(e1)	29				

LEVEL 2 OUTPUTS					
<u>MEANS LOC</u>		<u>VARIANCES LOC</u>		<u>COVARIANCES LOC</u>	
M(W2)	36	V(W2)	41	CV(W2,U2)	46
M(U2)	37	V(U2)	42	CV(W2,V2)	47
M(V2)	38	V(V2)	43	CV(W2,Ta2)	48
M(Ta2)	39	V(Ta2)	44	CV(W2,e2)	49
M(e2)	40	V(e2)	45	CV(U2,V2)	50
				CV(U2,Ta2)	51
				CV(U2,e2)	52
				CV(V2,Ta2)	53
				CV(V2,e2)	54

Table 8.7-3 lists the input channel configuration and Input Storage allocation for the measured values. After reading the new input samples, the Level 2 measurements are relocated using the Block Move Instruction 54, then Ta1 is relocated through a separate move and e1 is positioned by specifying the destination location in the Wet/Dry-Bulb Instruction. The CV/CR Instruction must be entered twice, once for each level.

In addition to ordering Level 1 and Level 2 in locations 1-5 and 11-15 respectively, 2 more

locations are required. Converting the wet-/dry-bulb measurements to vapor pressure using Instruction 57 requires atmospheric pressure. We'll use the standard atmosphere for the site elevation and key the value into Location 17 using the C command in the *6 Mode. The reference junction temperature obtained by Instruction 17 is stored in Location 16.

This example requires that 54 locations be allotted to Input Storage and 79 to Intermediate Storage (35 for the 1st CV/CR Instruction, 43 for the second, and 1 for Instruction 92).

TABLE 8.7-3. Example Input Channel and Location Assignments

PARAM	INPUT CHAN	INPUT LOC		PARAM	INPUT LOC		PARAM	INPUT LOC
W1	1	1		W1	1		W1	1
U1	2	2		U1	2		U1	2
V1	3	3		V1	3		V1	3
W2	4	4		Ta1	9	-----	Ta1	4
U2	5	5		Tw1	10	Separate moves	e1	5
V2	6	6		W2	11		W2	11
Ta2	7	7	->Block->	U2	12		U2	12
Tw2	8	8	move	V2	13		V2	13
Ta1	9	9		Ta2	14		Ta2	14
Tw1	10	10		Tw2	15		e2	15

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*	1	Table 1 Programs	09:	P57	Wet/Dry Bulb Temp to VP
01:	1	Sec. Execution Interval	01:	17	Pressure Loc
			02:	14	Dry Bulb Temp Loc Ta2
01:	P17	Panel Temperature	03:	15	Wet Bulb Temp Loc Tw2
01:	16	Loc [:PANL TEMP]	04:	15	Loc [:Tw2]
02:	P1	Volt (SE)	10:	P92	If time is
01:	6	Reps	01:	0	minutes into a
02:	5	5000 mV slow Range	02:	30	minute interval
03:	1	IN Chan	03:	10	Set high Flag 0 (output)
04:	1	Loc [:W1]			
05:	.018	Mult	11:	P62	CV/CR (OSX-0)
06:	0	Offset	01:	5	No. of Input Values
			02:	5	No. of Means
03:	P14	Thermocouple Temp (DIFF)	03:	5	No. of Variances
01:	4	Reps	04:	0	No. of Std. Dev.
02:	11	5 mV fast Range	05:	4	No. of Covariances
03:	7	IN Chan	06:	2	No. of Correlations
04:	2	Type E (Chromel-Constantan)	07:	300	Samples per Average
05:	16	Ref Temp Loc PANL TEMP	08:	1	First Sample Loc W1
06:	7	Loc [:Ta2]	09:	20	Loc [:MEAN (W1)]
07:	1	Mult			
08:	0	Offset	12:	P62	CV/CR (OSX-0)
			01:	5	No. of Input Values
04:	P37	Z=X*F	02:	5	No. of Means
01:	1	X Loc W1	03:	5	No. of Variances
02:	1.2222	F	04:	0	No. of Std. Dev.
03:	1	Z Loc [:W1]	05:	4	No. of Covariances
			06:	2	No. of Correlations
05:	P37	Z=X*F	07:	300	Samples per Average
01:	4	X Loc W2	08:	11	First Sample Loc W2
02:	1.2222	F	09:	36	Loc [:MEAN (W2)]
03:	4	Z Loc [:W2]			
			13:	P77	Real Time
06:	P54	Block Move	01:	110	Day,Hour-Minute
01:	5	No. of Values			
02:	4	First Source Loc W2	14:	P70	Sample
03:	1	Source Step	01:	35	Reps
04:	11	First Destination Loc [:W2]	02:	20	Loc MEAN (W1)
05:	1	Destination Step			
			15:	P	End Table 1
07:	P31	Z=X	*	A	Mode 10 Memory Allocation
01:	9	X Loc Ta1	01:	54	Input Locations
02:	4	Z Loc [:W2]	02:	79	Intermediate Locations
08:	P57	Wet/Dry Bulb Temp to VP			
01:	17	Pressure Loc			
02:	9	Dry Bulb Temp Loc Ta1			
03:	10	Wet Bulb Temp Loc Tw1			
04:	5	Loc [:U2]			

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TABLE 8.7-4. Thirty Minute Output From Example

01 110	02 DAY	03 HRMIN	04 M(W1)	05 M(U1)	06 M(V1)	07 M(Tai)	08 M(e1)
09 V(W1)	10 V(U1)	11 V(V1)	12 V(Ta1)	13 V(e1)	14 CV(W1,U1)	15 CV(W1,V1)	16 CV(W1,Ta1)
17 CV(W1,e1)	18 CR(W1,U1)	19 CR(W1,V1)	20 M(W2)	21 M(U2)	22 M(V2)	23 M(Ta2)	24 M(e2)
25 V(W2)	26 V(U2)	27 V(V2)	28 V(Ta2)	29 V(e2)	30 CV(W2,U2)	31 CV(W2,V2)	32 CV(W2,Ta2)
33 CV(W2,e2)	34 CV(U2,V2)	35 CV(U2,Ta2)	36 CV(U2,e2)	37 CV(V2,Ta2)	38 CV(V2,e2)		

8.8 FAST FOURIER TRANSFORM EXAMPLES

8.8.1. EXAMPLE WITHOUT BIN AVERAGING

The 21X was used to generate data representing two superimposed sine wave signals, one at 1.25 Hz (amplitude = 1) and the other at 0.25 Hz (amplitude = 2). The 1024 generated samples simulate a sampling rate of 10 Hz or a 0.1 second scan rate. Figure 8.8-1 shows a plot of the simulated signal. The FFT was applied to the data and the real and imaginary, phase and magnitude, and the power spectra results are shown in Tables 8.8-1, 8.8-2,

and 8.8-3 respectively. A portion of the power spectra results are illustrated in Figure 8.8-2.

The phase of the cosine wave that describes the signal at the *beginning* of the first interval and the *end* of the last interval can be determined by looking at the 21X program (Table 5) that generated the "original time series data". The 1.25 Hz signal began and ended at 270 degrees. [$\cos 270 = \cos(0 - 90) = \sin 0$]. The 0.25 Hz signal began at 270 degrees and ended at 126 degrees. The phases of the 1.25 and 0.25 signals are 270 and 198 respectively (Table 8.8-2).

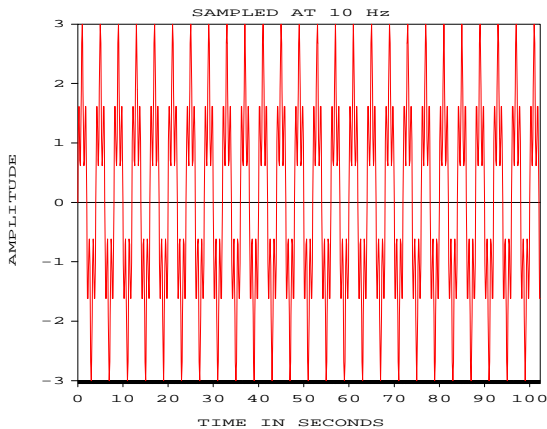


FIGURE 8.8-1. Simulated 1.25 and 0.25 Hz Signals

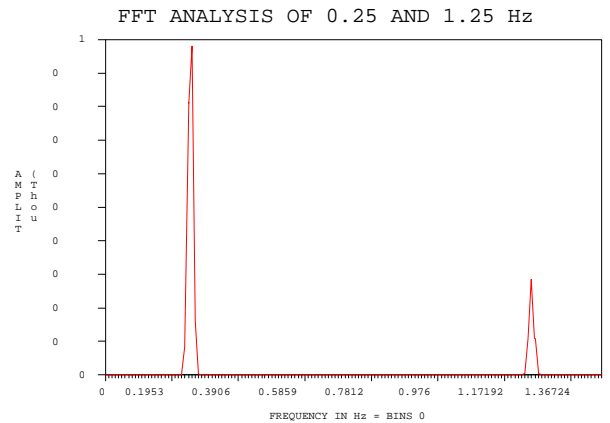


FIGURE 8.8-2. FFT Power Spectra Analysis of 0.25 and 1.25 Hz Signal

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TABLE 8.8-1. FFT Real and Imaginary Results 0.25 and 1.25 Hz Signal

BIN #	Hz	FFT Ri	FFT li
0	0	0.02303	0
1	0.009766	0.01036	0
2	0.019532	-0.00206	0
3	0.029298	0	0
.	.	.	.
22	0.214852	-0.00086	-0.00009
23	0.224618	0.01096	0.0036
24	0.234384	-0.19328	-0.06277
25	0.24415	0.59858	0.19439
26	0.253916	-0.65827*	-0.21391*
27	0.263682	0.26778	0.08709
28	0.273448	-0.02466	-0.00796
29	0.283214	0.00086	0.00034
.	.	.	.
125	1.22075	0	0.00069
126	1.230516	0.00009	-0.04342
127	1.240282	0.00009	0.23044
128	1.250048	0*	-0.37302*
129	1.259814	0	0.23053
130	1.26958	-0.00009	-0.0435
131	1.279346	0.00009	0.0006
.	.	.	.
511	4.990426	-0.00009	0

TABLE 8.8-2. FFT Magnitude and Phase Results 0.25 and 1.25 Hz Signal

BIN #	Hz	FFT Mi	FFT Pi
0	0	0.02303	0
1	0.009766	0.01036	0
2	0.019532	0.00206	180
3	0.029298	0	-99999
.	.	.	.
22	0.214852	0.00086	185.58
23	0.224618	0.01154	17.952
24	0.234384	0.20321	197.78
25	0.24415	0.62935	17.776
26	0.253916	0.69215*	197.79*
27	0.263682	0.28158	17.801
28	0.273448	0.02592	197.68
29	0.283214	0.00092	21.646
.	.	.	.
125	1.22075	0.00069	90
126	1.230516	0.04342	270.11
127	1.240282	0.23044	89.979
128	1.250048	0.37302*	270*
129	1.259814	0.23053	90
130	1.26958	0.0435	269.89
131	1.279346	0.00061	82.042
.	.	.	.
511	4.990426	0.00009	180

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**TABLE 8.8-3. FFT Power Spectra Results
0.25 and 1.25 Hz Signal**

BIN #	Hz	FFT P <i>S</i> i
0	0	1.0859
22	0.214852	0
23	0.224618	0.49212
24	0.234384	84.152
25	0.24415	811.01
26	0.253916	980.79*
27	0.263682	162.4
28	0.273448	1.4764
29	0.283214	0
125	1.22075	0
126	1.230516	3.9369
127	1.240282	108.76
128	1.250048	284.94*
129	1.259814	108.76
130	1.26958	3.9369
131	1.279346	0
511	4.990426	0

Program: *The first part of this program generates a dummy data set that represents two signals superimposed on top of each other. One signal has a frequency of 1.25 Hz and a zero to peak amplitude of 1 while the other signal has a frequency of .25 Hz and a zero to peak amplitude of 2. The data simulates a sampling rate of 10 Hz or a .1 sec scan rate.*

This program generates power spectra FFT results with out bin averaging.

Flag Usage: *Flag 1 is automatically set once the inst. have been executed once.*

* 1 Table 1 Programs
01: 1 Sec. Execution Interval

01: P91 If Flag
01: 11 1 is set
02: 0 Go to end of Program Table

The 2nd through 11th instructions are used to generate and combine the 1.25 and 0.25 Hz signals for the FFT.

```

02:    P30        Z=F
01:        0        F
02:    1025       Z Loc :

03:    P30        Z=F
01:        0        F
02:    1026       Z Loc :

04:    P87        Beginning of Loop
01:        0        Delay
02:    1024       Loop Count

05:    P48        Z=SIN(X)
01:    1025       X Loc
02:    1027       Z Loc :

06:    P48        Z=SIN(X)
01:    1026       X Loc
02:    1028       Z Loc :

07:    P37        Z=X*F
01:    1028       X Loc
02:        2        F
03:    1028       Z Loc :

08:    P33        Z=X+Y
01:    1027       X Loc
02:    1028       Y Loc
03:        1--      Z Loc :

09:    P34        Z=X+F
01:    1025       X Loc
02:        45       F
03:    1025       Z Loc :

10:    P34        Z=X+F
01:    1026       X Loc
02:        9        F
03:    1026       Z Loc :

11:    P95        End

The FFT is now computed and the power spectra results sent to Final Storage.

12:    P60        FFT (OSX-2)
01:        10       Log(base 2) of Samples
02:        1        Power Spectra/Taper
03:        0        Log(base 2) of Bins
04:        1        First Sample Loc
05:        1        Multiplier
    
```

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```

13:  P87      Beginning of Loop
    01:  0      Delay
    02:  512     Loop Count

14:  P86      Do
    01:  10     Set high Flag 0 (output)

15:  P78      Resolution
    01:  1      High Resolution

16:  P70      Sample
    01:  1      Rep
    02:  1--    Loc

17:  P95      End

18:  P86      Do
    01:  11     Set high Flag 1

19:  P        End Table 1

*    A        Mode 10 Memory Allocation
    01: 1030   Input Locations
    02:  260   Intermediate Locations
  
```

8.8.2 EXAMPLE WITH BIN AVERAGING

The 21X was used to generate data simulating wave data from an ocean buoy with four superimposed sine wave signals, 0.1, 0.125, 0.14, and 0.2 Hz. The 2048 generated samples simulate a sampling rate of 0.5 Hz or a 2.0 second scan rate. Figure 8.8-3 shows a plot of part of the simulated signal. A FFT with 8 bin averaging was performed on the data. A multiplier of 0.1 was used to keep the FFT results smaller than the +6999 upper limit of low resolution Final Storage. The results of the FFT are shown Table 8.8-4 and are illustrated in Figure 8.8-4.

In the example program, a multiplier of 0.1 is used in the FFT Instruction. By reducing the FFT results by a factor of 10, the Low Resolution output format can be used, thus maximizing the Final Storage capacity. A Low Resolution data point requires 2 bytes of Final Storage memory, while a High Resolution data point requires 4 bytes. When memory is a limiting factor, the data should be scaled to be less than 6999, so the Low Resolution format can be used.

SIMULATED OCEAN WAVE BUOY DATA

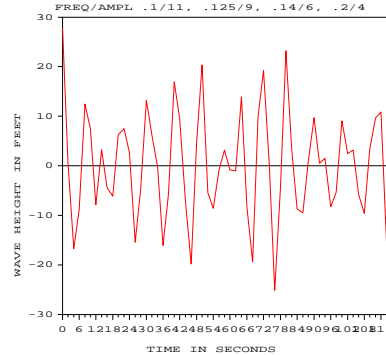


FIGURE 8.8-3. Simulated Ocean Buoy Wave Data

SIMULATED OCEAN WAVE BUOY FFT RESULTS

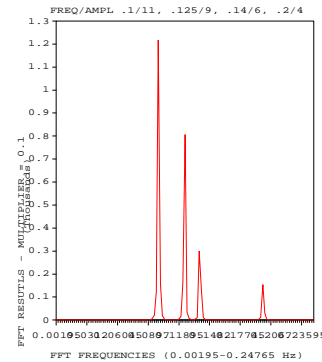


FIGURE 8.8-4. Simulated Ocean Buoy FFT Results

SECTION 8. PROCESSING AND PROGRAM CONTROL EXAMPLES

TABLE 8.8-4. FFT Bin Averaging Results from Simulated Ocean Buoy Wave Data

BIN #	FREQUENCY	FFT*0.1	BIN #	FREQUENCY	FFT*0.1
1	0.00195	0	26	0.0507	0
2	0.0039	0	27	0.05265	0
3	0.00585	0	28	0.0546	0
4	0.0078	0	29	0.05655	0
5	0.00975	0	30	0.0585	0
6	0.0117	0	31	0.06045	0
7	0.01365	0	32	0.0624	0
8	0.0156	0	33	0.06435	0
9	0.01755	0	34	0.0663	0
10	0.0195	0	35	0.06825	0
11	0.02145	0	36	0.0702	0
12	0.0234	0	37	0.07215	0
13	0.02535	0	38	0.0741	0
14	0.0273	0	39	0.07605	0
15	0.02925	0	40	0.078	0
16	0.0312	0	41	0.07995	0
17	0.03315	0	42	0.0819	0
18	0.0351	0	43	0.08385	0
19	0.03705	0	44	0.0858	0
20	0.039	0	45	0.08775	0
21	0.04095	0	46	0.0897	0.226
22	0.0429	0	47	0.09165	0.527
23	0.04485	0	48	0.0936	6.246
24	0.0468	0	49	0.09555	21.52
25	0.04875	0	50	0.0975	123.1

Program: *Simulate ocean wave data with 4 super imposed sine wave signals (Hz/zero to peak amplitude: .1/11, .125/9,*

Flag Usage: *Flag 1 high = generate and store "original time series data". Flag 2 high = calculate and store FFT results.*

Output Array Definitions:

104 = "ORIGINAL TIME SERIES DATA"

113= FFT POWER SPECTRA RESULTS

* 1 Table 1 Programs
01: 2 Sec. Execution Interval

If flag 1 is set, the simulated ocean wave data is calculated and sent to Final Storage.

01: P91 If Flag
01: 11 1 is set
02: 30 Then Do

02: P86 Do
01: 1 Call Subroutine 1

03: P87 Beginning of Loop
01: 0 Delay
02: 2048 Loop Count

04: P86 Do
01: 10 Set high Flag 0 (output)

05: P77 Real Time
01: 1 Seconds

06: P70 Sample
01: 1 Rep
02: 284-- Loc

07: P95 End

08: P95 End

09: P86 Do
01: 21 Set low Flag 1

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When flag 2 is set the FFT is computed and the results are sent to Final Storage.

10:	P91	If Flag
01:	12	2 is set
02:	30	Then Do
11:	P60	FFT (OSX-2)
01:	11	Log(base 2) of Samples
02:	1	Power Spectra/Taper
03:	3	Log(base 2) of Bins
04:	284	First Sample Loc
05:	0.1	Multiplier
12:	P87	Beginning of Loop
01:	0	Delay
02:	127	Loop Count
13:	P86	Do
01:	10	Set high Flag 0 (output)
14:	P70	Sample
01:	1	Rep
02:	284--	Loc
15:	P95	End
16:	P95	End
17:	P86	Do
01:	22	Set low Flag 2
18:	P	End Table 1
*	3	Table 3 Subroutines

Subroutine 1 creates the simulated ocean wave data. The 3rd through 7th instructions are used to slightly randomize the wave signal.

01:	P85	Beginning of Subroutine
01:	1	Subroutine Number
02:	P87	Beginning of Loop
01:	0	Delay
02:	2048	Loop Count

03:	P55	Polynomial
01:	1	Rep
02:	1	X Loc
03:	1	F(X) Loc :
04:	0.1	C0
05:	99	C1
06:	0	C2
07:	0	C3
08:	0	C4
09:	0	C5
04:	P44	Z=FRAC(X)
01:	1	X Loc
02:	1	Z Loc :
05:	P34	Z=X+F
01:	1	X Loc
02:	-0.5	F
03:	2	Z Loc :
06:	P37	Z=X*F
01:	2	X Loc
02:	30	F
03:	2	Z Loc :
07:	P58	Low Pass Filter
01:	1	Rep
02:	2	Sample Loc
03:	3	Loc :
04:	0.02	Weighting Factor
08:	P53	Scaling Array (A*loc +B)
01:	4	Start Loc :
02:	1	A1
03:	144	B1
04:	1	A2
05:	100.77	B2
06:	1	A3
07:	90	B3
08:	1	A4
09:	72	B4
09:	P87	Beginning of Loop
01:	0	Delay
02:	4	Loop Count
10:	P33	Z=X+Y
01:	3	X Loc
02:	4--	Y Loc
03:	4--	Z Loc :

SECTION 8. PROCESSING AND PROGRAM CONTROL EXAMPLES

11:	P46	Z=X MOD F
01:	4--	X Loc
02:	360	F
03:	4--	Z Loc :
12:	P48	Z=SIN(X)
01:	4--	X Loc
02:	8--	Z Loc :
13:	P95	End
14:	P53	Scaling Array (A*loc +B)
01:	8	Start Loc :
02:	4	A1
03:	0	B1
04:	6	A2
05:	0	B2
06:	9	A3
07:	0	B3
08:	11	A4
09:	0	B4
15:	P30	Z=F
01:	0	F
02:	12	Z Loc :
16:	P87	Beginning of Loop
01:	0	Delay
02:	4	Loop Count
17:	P33	Z=X+Y
01:	8--	X Loc
02:	12	Y Loc
03:	12	Z Loc :
18:	P95	End
19:	P37	Z=X*F
01:	12	X Loc
02:	1	F
03:	284--	Z Loc :
20:	P95	End
21:	P95	End
22:	P	End Table 3
*	A	Mode 10 Memory Allocation
01:	2500	Input Locations
02:	270	Intermediate Locations

SECTION 8. PROCESSING AND PROGRAM CONTROL EXAMPLES

SECTION 9. INPUT/OUTPUT INSTRUCTIONS

TABLE 9-1. Input Voltage Ranges and Codes

<u>Range Code</u>		<u>Full Scale Range</u>	<u>Resolution*</u>
Slow	Fast		
16.67ms	250µs		
Integ.	Integ.		
1	11	±5 millivolts	0.33 microvolts
2	12	±15 millivolts	1. microvolts
3	13	±50 millivolts	3.33 microvolts
4	14	±500 millivolts	33.3 microvolts
5**	15**	±5000 millivolts	333. microvolts

* Differential measurement; resolution for single-ended measurement is twice value shown.

** The Integration times for ranges 5 and 15 are 1.67ms and 25µs respectively.

NOTE: When a voltage input exceeds the range programmed, the value which is stored is set to the maximum negative number and displayed as -99999 in high resolution or -6999 in low resolution.

*** 1 SINGLE-ENDED VOLTS ***

FUNCTION

This instruction is used to measure voltage at a single-ended input with respect to ground. Standard Output (multiplier = 1, offset = 0) is in millivolts.

PARAM. NUMBER	DATA TYPE	DESCRIPTION
01:	2	Repetitions
02:	2	Range code
03:	2	Channel number for first measurement
04:	4	Input location for first measurement
05:	FP	Multiplier
06:	FP	Offset

Input locations altered: 1 per measurement

*** 2 DIFFERENTIAL VOLTS ***

FUNCTION

This instruction reads the voltage difference between the high and low inputs of a differential channel. Table 9-1 contains all valid voltage ranges and their codes. Both the high and low inputs must be within ±5V of the 21X's ground (see Common Mode Range in Section 13.2).

Pyranometer and thermopile sensors require a jumper between LOW and GROUND to keep them in Common Mode Range. Standard Output (multiplier =1, offset =0) is in millivolts.

PARAM. NUMBER	DATA TYPE	DESCRIPTION
01:	2	Repetitions
02:	2	Range code
03:	2	Channel number for first measurement
04:	4	Input location for first measurement
05:	FP	Multiplier
06:	FP	Offset

Input locations altered: 1 per measurement

*** 3 PULSE COUNT ***

There are three pulse input types which may be measured with the Pulse Count Instruction.

HIGH FREQUENCY PULSE

In this configuration, the minimum detectable pulse width is 2 microseconds i.e. the maximum frequency is 250 kHz with a 50% duty cycle. The 8 bit counter has a maximum input frequency of 2550 Hz and the 16 bit option a maximum of 250 kHz.

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The count is incremented when the input voltage changes from below 1.5 volts to above 3.5 volts. The maximum input voltage is ± 20 volts.

LOW LEVEL AC

This mode is used for counting frequency of AC signals from magnetic pulse flow transducers or other low voltage, sine wave outputs.

MINIMUM AC INPUT VOLTAGE: 6 millivolts RMS

INPUT HYSTERESIS: 11 millivolts

MAXIMUM AC INPUT VOLTAGE: 20 volts RMS

FREQUENCY RANGE:

AC Input Voltage (RMS)	Range
20 millivolts	1 Hz to 100 Hz
50 millivolts	0.5 Hz to 400 Hz
150 millivolts to 20 volts	0.3 Hz to 1000 Hz

(consult the factory if higher frequencies are desired)

SWITCH CLOSURE

In this configuration, the minimum switch closed time is 3 milliseconds. The minimum switch open time is 4 milliseconds. The maximum bounce time is 1 millisecond open without being counted.

The 4 pulse count input channels each have eight bit counters. Input frequencies greater than 2550 Hz (the limit of the eight bit counter, 255 counts at the reset interval of 0.1 second) can be counted by combining two counters on one input channel. When this option is selected, channel 1 or 3 is specified in parameter 2 and the input is connected to either channel 1 or 3. In this case, either channel 2 or 4 or both are not used. One may use 2 sixteen bit pulse count channels or a combination of 1 sixteen bit counter and 2 eight bit counters. (Campbell Scientific has a hardware and software modification that changes the reset interval to 0.0125 seconds allowing greater input frequency with the 8 bit counters ($255/.0125=20.4$ kHz). Pulse measurements with this modification will not work when voltage measurements are made with the "slow" integration. Consult the factory for additional information.)

Every 0.1 seconds, the 21X processor transfers the values from the 8 bit pulse counters into 16 bit accumulators (maximum count is 65,535) and the 8 bit counters are hardware reset to zero. The pulses accumulate in these 16 bit accumulators until the program table containing the Pulse Count instruction is executed. At the beginning of the execution of the Table containing the Pulse Count instruction, the total in the 16 bit accumulator is transferred to a temporary RAM buffer. The 16 bit accumulator is then zeroed. When the table execution reaches the Pulse Count instruction, the value in the RAM buffer is multiplied by the multiplier and added to the offset and placed into the designated Input Memory location. The RAM buffer does NOT accumulate counts; it is zeroed each time the table is executed regardless of whether or not the pulse instruction is executed. If all counts are necessary, it is imperative that the Pulse Count instruction be executed (not branched around) every time its table is executed.

If a table execution was skipped because the processor was executing the previous table (Section 2.1), the value in the 16 bit accumulator is the result of a longer than normal interval. This value can either be used or it can be discarded. If pulse counts are being totalized, a missing count could be significant and the value from the erroneously long interval should NOT be discarded. If the pulse count is being processed in a way in which the resultant value is dependent upon the sampling interval, the value from the excessive interval should be discarded. If the value is discarded the value in the RAM buffer from the previous measurement will be used.

There is also an option to output the count as a frequency (i.e., counts/execution interval in seconds = Hz) as well as discard the result from an excessive interval. This allows the use of a conversion factor that is independent of the execution interval.

When datalogger time is changed, whether through the keyboard or with a telecommunications program, a partial recompile is automatically done to resynchronize program execution with real time. The resynchronization process resets the pulse accumulation interval resulting in an interval whose length can be

SECTION 9. INPUT/OUTPUT INSTRUCTIONS

anywhere between one second too short to almost twice as long. Pulses are not lost during resynchronization so totalized values are correct but pulse rate information such as wind speed can be almost twice the correct value. The discard counts from excessive intervals option mentioned in the previous paragraph does not correct this problem in 21Xs with PROMs 391B/392D and earlier.

The options of discarding counts from long intervals, pulse input type, outputting frequency, and using a sixteen bit counter are selected by the code entered for the fourth parameter (Table 9-2).

NOTE: All pulse count instructions must be kept in the same table. If the pulse count instruction is contained within a subroutine, that subroutine must be called from Table 2.

TABLE 9-2. Pulse Count Configuration Codes

Code	Configuration
0	High frequency pulse
1	Low level AC
2	Switch closure
3	High frequency pulse, sixteen bit counter
4	Low level AC, sixteen bit counter
1X	Long interval data discarded, where X is configuration code
2X	Long interval data discarded, frequency (Hz) output

PARAM. NUMBER	DATA TYPE	DESCRIPTION
01:	2	Repetitions
02:	2	Channel number for first measurement
03:	2	Configuration code (from above table)
04:	4	Input location for first measurement
05:	FP	Multiplier
06:	FP	Offset

Input locations altered: 1 per measurement

***** 4 EXCITE, DELAY, AND MEASURE *****

FUNCTION

This instruction is used to apply an excitation voltage, delay a specified time, and then make a single-ended voltage measurement. A 1 before the excitation channel number (1X) causes the channel to be incremented with each repetition.

PARAM. NUMBER	DATA TYPE	DESCRIPTION
01:	2	Repetitions
02:	2	Range code
03:	2	Input channel number for first measurement
04:	2	Excitation channel number
05:	4	Delay in hundredths of a second
06:	4	Excitation voltage (millivolts)
07:	4	Input location number for first measurement
08:	FP	Multiplier
09:	FP	Offset

Input locations altered: 1 per measurement

***** 5 AC HALF BRIDGE *****

FUNCTION

This instruction is used to apply an excitation voltage to a half bridge (Figure 13.5-1), make a single-ended voltage measurement of the bridge output, reverse the excitation voltage, then repeat the measurement. The result of Instruction 5 is the ratio of the measurement to the excitation voltage. A 1 before the excitation channel number (1X) causes the channel to be incremented with each repetition.

The excitation "on time" for each polarity is exactly the same to insure that ionic sensors do not polarize with repetitive measurements. The range should be selected to be a fast measurement (range 11-15), limiting the excitation on time to 800 microseconds at each polarity. A slow integration time should not be used with ionic sensors because of polarization error.

SECTION 9. INPUT/OUTPUT INSTRUCTIONS

PARAM. NUMBER	DATA TYPE	DESCRIPTION
01:	2	Repetitions
02:	2	Range code
03:	2	Input channel number for first measurement
04:	2	Excitation channel number
05:	4	Excitation voltage (millivolts)
06:	4	Input location number for first measurement
07:	FP	Multiplier
08:	FP	Offset

Input locations altered: 1 per measurement

*** 6 FULL BRIDGE ***

FUNCTION

This instruction is used to apply an excitation voltage to a full bridge (Figure 13.5-1), make a differential voltage measurement of the bridge output, reverse the excitation voltage, then repeat the measurement. The result is 1000 times the ratio of the measurement to the excitation voltage. A 1 before the excitation channel number (1X) causes the channel to be incremented with each repetition.

PARAM. NUMBER	DATA TYPE	DESCRIPTION
01:	2	Repetitions
02:	2	Range code
03:	2	Input channel number for first measurement
04:	2	Excitation channel number
05:	4	Excitation voltage (millivolts)
06:	4	Input location number for first measurement
07:	FP	Multiplier
08:	FP	Offset

Input locations altered: 1 per measurement

*** 7 THREE WIRE HALF BRIDGE ***

FUNCTION

This instruction is used to determine the ratio of the sensor resistance to a known resistance using a separate voltage sensing wire from the sensor to compensate for lead wire resistance.

The measurement sequence is to apply an excitation voltage, make two voltage measurements on two adjacent single-ended channels, the first on the reference resistor and the second on the voltage sensing wire from the sensor (Figure 13.5-1), then reverse the excitation voltage and repeat the measurements. The two measurements are used to calculate the resulting value, which is the ratio of the voltage across the sensor to the voltage across the reference resistor. A 1 before the excitation channel number (1X) causes the channel to be incremented with each repetition.

PARAM. NUMBER	DATA TYPE	DESCRIPTION
01:	2	Repetitions
02:	2	Range code for both measurements
03:	2	Input channel number for first measurement
04:	2	Excitation channel
05:	4	Excitation voltage (millivolts)
06:	4	Input location number for first measurement
07:	FP	Multiplier
08:	FP	Offset

Input locations altered: 1 per measurement

*** 8 DIFFERENTIAL VOLTAGE WITH EXCITATION AND DELAY ***

FUNCTION

This measurement consists of applying a single excitation voltage, delaying a specified time, and making a differential voltage measurement. If a 0 delay is specified, the inputs are not switched for a second integration as is normally the case with a differential measurement (Section 13.2). The result stored is the voltage measured. With a delay of 0 Instruction 8 does not have as good resolution or common mode rejection as the ratiometric bridge measurement instructions. It does provide a very rapid means of making bridge measurements as well as supplying excitation to circuitry requiring differential measurements. This instruction does not reverse excitation.

SECTION 9. INPUT/OUTPUT INSTRUCTIONS

PARAM. NUMBER	DATA TYPE	DESCRIPTION
01:	2	Repetitions
02:	2	Range code
03:	2	Input channel number for first measurement
04:	2	Excitation channel number
05:	4	Delay (0.01s)
06:	4	Excitation voltage (millivolts)
07:	4	Input location number for first measurement
08:	FP	Multiplier
09:	FP	Offset

Input locations altered: 1 per measurement

*** 9 FULL BRIDGE WITH EXCITATION COMPENSATION ***

FUNCTION

This instruction is used to apply an excitation voltage and make two differential voltage measurements, then reverse the polarity of the excitation and repeat the measurements. The measurements are made on sequential channels. The result is the voltage measured on the second channel (V_2) divided by the voltage measured on the first (V_1). If V_1 is measured on the 5V range (code 5 or 15 in Parameter 2), then the result is 1000 times V_2/V_1 . A 1 before the excitation channel number (1X) causes the channel to be incremented with each repetition.

When used as a 6 wire full bridge (Figure 13.5-1), the connections are made so that V_1 is the measurement of the voltage drop across the full bridge, and V_2 is the measurement of the bridge output. Because the excitation voltage for a full bridge measurement is usually in the 5V range, the output is usually 1000 V_2/V_1 or millivolts output per volt excitation.

When used to measure a 4 wire half bridge, the connections are made so that V_1 is the voltage drop across the fixed resistor (R_f), and V_2 is the drop across the sensor (R_s). As long as V_1 is not measured on the 5V range, the result is V_2/V_1 which equals R_s/R_f .

PARAM. NUMBER	DATA TYPE	DESCRIPTION
01:	2	Repetitions
02:	2	Range code for V1
03:	2	Range code for V2
04:	2	Input channel number for first measurement
05:	2	Excitation channel number
06:	4	Excitation voltage (millivolts)
07:	4	Input location number for first measurement
08:	FP	Multiplier
09:	FP	Offset

Input locations altered: 1 per measurement

*** 10 BATTERY VOLTAGE ***

FUNCTION

This instruction reads the battery voltage and writes it to an input location. Battery voltage is stored in volts.

PARAM. NUMBER	DATA TYPE	DESCRIPTION
01:	4	Input location

Input locations altered: 1

*** 11 107 THERMISTOR PROBE ***

FUNCTION

This instruction applies a 4 VAC excitation voltage to Campbell Scientific's Model 107 Thermistor Probe, makes a fast, single-ended voltage measurement on the 15mV range and then calculates the temperature in degrees C with a polynomial. The maximum polynomial error from -40°C to +55°C is given below:

Curve Fit Error --

Range (°C)	Error (°C)
-40 to +55	+1.0
-35 to +48	+0.1

The fast integration time used in Instruction 11 does not provide rejection of 60 Hz noise. See example 7.16 for a method of measuring the 107 thermistor where 60 Hz noise is a problem.

SECTION 9. INPUT/OUTPUT INSTRUCTIONS

PARAM. NUMBER	DATA TYPE	DESCRIPTION	Range (%RH)	Error (%RH)
01:	2	Repetitions	10 - 100	±4
02:	2	Input channel number of first measurement	15 - 94	±1
03:	2	Excitation channel number		
04:	4	Input location for first measurement		
05:	FP	Multiplier		
06:	FP	Offset		

Input locations altered: 1 for each thermistor channel

*** 12 207 RELATIVE HUMIDITY PROBE ***

FUNCTION

This instruction applies a 3 VAC excitation across Campbell Scientific's Model 207 Temperature and RH Probe, makes a fast single-ended measurement across a series resistor on the 150mV range, calculates the result with a fifth order polynomial, and performs the required temperature compensation before outputting the result in % RH.

When measuring several probes, all the RH elements should be connected sequentially. The temperature values used to correct the RH measurements should also be stored sequentially to make use of the REP feature in Instruction 11.

NOTE: The temperature value used in compensating the RH value (Parameter 5) must be obtained (see Instruction 11) prior to executing Instruction 12.

The RH results are placed sequentially into the input locations beginning with the first RH value.

In the 207 probe, the RH and temperature elements use a common excitation line. NEVER EXCITE THE 207 PROBE WITH DC EXCITATION (this includes ohm meters) as the RH chip will be damaged.

The maximum error from the polynomial used for calculating RH is given here:

PARAM. NUMBER	DATA TYPE	DESCRIPTION
01:	2	Repetitions
02:	2	First channel for RH measurement
03:	2	Excitation channel number
04:	4	Input location for first compensating temperature measurement
05:	4	Input location for first RH measurement
06:	FP	Multiplier
07:	FP	Offset

Input locations altered: 1 for each RH measurement

*** 13 THERMOCOUPLE TEMPERATURE, *** SINGLE-ENDED

FUNCTION

This instruction uses the selected thermocouple calibration to calculate the thermocouple output voltage at the reference temperature, then it makes a SINGLE-ENDED VOLTAGE MEASUREMENT (Section 13.2) on the thermocouple and adds the measured voltage to the calculated reference voltage, then converts the voltage to temperature in °C. Select the smallest voltage range that will accommodate the temperatures being measured (Table 9-4).

PARAM. NUMBER	DATA TYPE	DESCRIPTION
01:	2	Repetitions
02:	2	Range code
03:	2	First TC channel
04:	2	Thermocouple type code
05:	4	Reference temperature location
06:	4	Destination input location
07:	FP	Multiplier
08:	FP	Offset

Input locations altered: 1 for each thermocouple channel

TABLE 9-3. Thermocouple Type Codes

Code	Thermocouple Type	
X1	T (copper - constantan)	X = 0 Normal Measurement
X2	E (chromel - constantan)	X = 8 TC input from A5B40 isolation (use 5 V range)
X3	K (chromel - alumel)	X = 9 Output -99999 if out of common mode (Inst. 14 only)
X4	J (iron - constantan)	

TABLE 9-4. Voltage and Temperature Ranges for Thermocouples if Reference Junction is 20°C

Voltage Range	Temperature Range °C			
	Type T	Type E	Type K	Type J
±5 mV	-131 to 131	-70 to 98	-122 to 141	-84 to 113
±15 mV	-270 to 316	-270 to 237	-270 to 386	-210 to 294
±50 mV	-270 to 400	-270 to 676	-270 to 1254	-210 to 760
±500 mV		-270 to 1000	-270 to 1372	

***** 14 THERMOCOUPLE TEMPERATURE, ***
DIFFERENTIAL MEASUREMENT**

FUNCTION

This instruction calculates the thermocouple temperature for the thermocouple type selected. The instruction specifies a DIFFERENTIAL VOLTAGE MEASUREMENT (Section 13.2) on the thermocouple, adds the measured voltage to the voltage calculated for the reference temperature relative to 0°C, and converts the combined voltage to temperature in °C. The differential inputs are briefly shorted to ground prior to making the voltage measurement to insure that they are within the common mode range. Table 9-3 gives the thermocouple type codes for Parameter 4. Select the smallest voltage range that will accommodate the temperatures being measured (Table 9-4).

PARAM. NUMBER	DATA TYPE	DESCRIPTION
01:	2	Repetitions
02:	2	Range code
03:	2	First TC channel
04:	2	Thermocouple type code
05:	4	Reference temperature location
06:	4	Destination input location
07:	FP	Multiplier
08:	FP	Offset

Input locations altered: 1 for each thermocouple channel

***** 16 TEMPERATURE FROM ***
PLATINUM R.T.D.**

FUNCTION

This instruction uses the result of a previous RTD bridge measurement to calculate the temperature according to the DIN 43760 specification adjusted (1980) to conform to the pending International Electrotechnical Commission standard. The polynomial range is -200°C to 850°C. The error is less than 0.001°C between -100 and +300°C, and is less than 0.003°C between -180°C and +830°C. The error (T calculated - T standard) is +0.006°C at -200°C and -0.006°C at +850°C. The input must be the ratio R_s/R_0 , where R_s is the RTD resistance and R_0 the resistance of the RTD at 0°C (Sections 7.9 and 7.10).

PARAM. NUMBER	DATA TYPE	DESCRIPTION
01:	2	Repetitions
02:	4	Input location of R_s/R_0
03:	4	Input location of result
04:	FP	Multiplier
05:	FP	Offset

Input locations altered: 1 for each RTD

SECTION 9. INPUT/OUTPUT INSTRUCTIONS

*** 17 TEMPERATURE OF INPUT PANEL ***

FUNCTION

This instruction measures the temperature in degrees Celsius of the input panel.

PARAM. NUMBER	DATA TYPE	DESCRIPTION
01:	4	Input location number for temperature

Input locations altered: 1

*** 18 MOVE TIME TO INPUT LOCATION ***

FUNCTION

This instruction takes the current time in tenths of seconds into the minute, minutes into the day, or hours into the year and does a modulo divide (see Instruction 46) on the time value with the number specified in the second parameter. The result is stored in the specified input location. Entering 0 or a number which is greater than the maximum value of the time for the modulo divide will result in the actual time value being stored.

PARAMETER 1 CODES

Code	Time Units
0	Tenths of seconds into minute (maximum 600)
1	Minutes into current day (maximum 1440)
2	Hours into current year (maximum 8784)

PARAM. NUMBER	DATA TYPE	DESCRIPTION
01:	2	Time Code
02:	4	Number to modulo divide by
03:	4	Input location number

Input locations altered: 1

*** 19 MOVE SIGNATURE INTO INPUT LOCATION ***

FUNCTION

This instruction stores the signature of the Read Only Memory (ROM) and user program memory (RAM) into an input location. This signature is

not the same as the signatures given in the *B Mode. Recording the signature allows detection of any program change or ROM failure.

PARAM. NUMBER	DATA TYPE	DESCRIPTION
01:	4	Input location number

Input locations altered: 1

*** 20 PORT SET ***

FUNCTION

This instruction sets a specified Digital Control output port either as specified by a flag or unconditionally.

PARAMETER 1 CODE OPTIONS

Code	Function
00	SET LOW (0V)
01	SET HIGH (5V)
1X	SET PORT ACCORDING TO FLAG X
2X	SET OPPOSITE TO FLAG X

PARAM. NUMBER	DATA TYPE	DESCRIPTION
01:	2	Option code
02:	2	Control Port number (1-6)

Input locations altered: 0

*** 21 ANALOG OUTPUT ***

FUNCTION

This instruction sets a Continuous Analog Output to a voltage level specified in an input location. The analog output degrades approximately 0.17mV every 7 seconds requiring the instruction to be periodically repeated to maintain a given output accuracy.

PARAM. NUMBER	DATA TYPE	DESCRIPTION
01:	2	CAO channel number
02:	4	Input location no. of analog output magnitude in millivolts

Input locations altered: 0

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*** 22 EXCITATION WITH DELAY ***

FUNCTION

This instruction is used in conjunction with others for measuring a response to a timed excitation using the switched analog outputs. It sets the selected excitation output to a specific value, waits for the specified time, then turns off the excitation and waits an additional specified time before continuing on to the next instruction in the program table. The excitation on time can be set to zero and the off time delay can be used if the only requirement is the delay of program execution.

PARAM. NUMBER	DATA TYPE	DESCRIPTION
01:	2	Excitation channel number
02:	4	Delay time in hundredths of a second that excitation is on
03:	4	Delay time in hundredths of a second after excitation is turned off
04:	FP	Excitation voltage in millivolts

Input locations altered: 0

*** 23 BURST MEASUREMENT ***

FUNCTION

Instruction 23 will repeatedly make a voltage measurement on a series of single-ended or differential channels, applying excitation if desired. The measurement units are millivolts prior to scaling. The measurements saved can be those made immediately upon execution of the instruction or grouped around a specified trigger condition. The results of the measurements may be stored in Input Storage or the raw A/D data can be sent out the serial port. The minimum sample time per channel is 970 μ s (i.e., one channel can be sampled at a maximum rate of 1030 Hz).

MEASUREMENT

The voltage measurement must use the fast integration time of 250 μ s. Differential measurements are made with a single integration. The noise level on a fast single-ended or a differential measurement with 1 integration is 3 μ V RMS. Thus, only the 50mV

and greater voltage ranges are practical (range codes 13-15).

Excitation is always supplied from excitation channel 1. The excitation voltage in millivolts is entered in Parameter 9. If excitation is not needed, enter 0 for Parameter 9.

TRIGGER

Measurements may be triggered either by the value of the measurement on the first channel being measured or by an external digital trigger. Three options are available. Only one trigger can be used.

Three options are available for the first digit in Parameter 4.

- 0 - Trigger on the first measurement channel.
- 1 - Digital trigger on single-ended channel one (1H).
- 2 - Trigger on the first measurement channel, set Digital control port high when trigger is met and low when measurements have finished.

When triggering on options 0 or 2, the measurement on the first specified channel (Parameter 3) is compared to the limit specified in Parameter 8.

The user's multiplier and offset are not applied before the comparison: the limit must be entered in millivolts. If a digital trigger (CMOS levels, low < 1.5V, high > 3.5V) is used, it must be input into single-ended Channel 1 (1H). The digital trigger condition is checked at the start of each scan.

Five trigger options are available and are selected by the number entered as the second digit in Parameter 4: 0 - trigger immediately, start saving or sending data with the first measurement made; 1 - trigger if the measurement is greater than the limit entered or if the digital trigger is high; 2 - trigger if the measurement is less than the limit or if the digital trigger is low; 3 - trigger on rising edge; i.e., when the measurement goes from below to above the limit or when the digital trigger goes from low to high; 4 - trigger on falling edge; i.e.,

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trigger when measurement goes from above the limit to below it or when the digital trigger goes from high to low. When triggering on the rising or falling edge, the input must make the specified transition to trigger. For example, when triggering on the rising edge, if the input starts out high, it must go low and then high again to trigger.

DATA SENT TO INPUT STORAGE

When the measurements are sent to Input Storage, Parameter 6 is used to specify the number of scans made on the channels being measured (the 21X multiplies the number entered by 1000). The measurements from each channel are stored contiguously. For example: Parameter 1 specifies 4 channels are to be measured, Parameter 6 specifies 250 scans (0.250 entered), and Parameter 10 specifies 1 as the first input location in which to store data. The measurements from the first channel will be stored in Input locations 1-250, those from the second channel in locations 251-500, etc. If insufficient locations are allocated to Input Storage (*A) to accommodate the number of locations called for by Parameter 6 multiplied by Parameter 1 (e.g., $250 \times 4 = 1000$), an error code, E 60, will be displayed when the program is compiled.

The number of scans determines how many samples will be saved, and hence, when Instruction 23 will be completed and execution will pass on to the next instruction. Measurements before and/or after the trigger can be saved. Parameter 7 determines how many scans that occurred prior to the trigger are saved. For example, if 250 scans are specified, and an offset of 20 is entered for Parameter 7, then the trigger measurement will be stored in Location 21. Locations 1-20 will contain the measurements that preceded the trigger and 22-250 will contain the measurements following the trigger. If only 10 measurements are made before the trigger, then they will be stored in locations 11-20 while the value -99999. will be stored in locations 1-10 for which no measurements were made.

DATA SENT TO SERIAL PORT

When the raw A/D data is sent out the serial port, the measurement data is not buffered and hence, only the trigger and subsequent measurements can be sent. The number of

measurements is determined by Parameters 1 and 6. Because the total number of measurements are limited only by the storage of the receiving computer, this can be a very large number. Parameter 6 is the number of measurements per channel to send in units of 1000 (e.g., 0.001 represents 1 measurement). If 0 is entered for Parameter 6, the 21X will continue to send data until the instruction is aborted with the # key.

Raw A/D data may be sent to up to 2 SM192 or SM716 Solid State Storage Modules (SM) at 76.9K baud (parameter 4, Destination Option C=2). One SM should be set as Fill and Stop memory and the other SM set as Ring memory. Data sent will be stored in both SM's (in parallel) until the Fill and Stop SM is full. The Fill and Stop SM will store no more data. The Ring SM will continuously store data, overwriting the oldest data when full, until Burst measurements end. When the Burst measurements end the Fill and Stop SM will contain the oldest data generated while the Ring SM will contain the newest. If the amount of data generated exceeds the capacity of both SM's only the oldest and newest data will be saved. If the amount of Burst data generated is less than the total capacity of both SM's, part of the data stored will be stored in both SM's. If the data is retrieved from the SM's using SMCOM.COM, a Storage Module communications program contained in the PC208 Datalogger Support Software, the data collection format must be "A as stored 8 bit". This will transfer the raw A/D data to a computer file. The raw A/D data can be converted to ASCII using SPLIT.COM, a general purpose data reduction program also contained in PC208.

If SPLIT is not available for converting the raw A/D, the following A/D format information is provided for decoding purposes. At the start and end of the series of measurements, the 21X makes a self-calibration measurement. The calibration data is sent at the start and end of the measurement data. The serial data is sent as a series of signed 2 byte integers (most significant byte sent first; i.e., Integer = $256 * \text{byte 1} + \text{byte 2}$): $I_1 \dots I_n$. The first integer, I_1 , is a start of output identifier, FCxx (hex), where the first byte is always FC (never seen in the data), and the second byte is a number less than 100 (decimal, 64 hex), which is the instruction

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location number of Instruction 23 in the program table. I_2 divided by I_3 is the multiplier and I_4 the offset (to the raw data) determined by the first calibration. I_2 is a fixed value determined by the input range selected. I_5 through I_{n-2} are the raw measurement data. Thus, the value of the first measurement sent (M_1) in millivolts is:

$$M_1 = I_2/I_3 (I_5 - I_4)$$

The measurement data are sent in the order that the measurements are made (i.e., the first measurement for each channel, then the second measurement for each channel, etc.). The last 2 integers sent, I_{n-1} and I_n correspond to I_3 and I_4 and are the results of the final calibration.

NOTE: When the raw serial data option is selected, the CALIBRATION VALUES are for CONVERSION TO MILLIVOLTS ONLY. Parameters 11 and 12 are ignored.

SCAN INTERVAL

Instruction 23 has its own scan interval independent of the execution interval of the program table in which it resides. The resolution of the clock timing the execution interval is 813 nanoseconds. This scan interval, entered in Parameter 5 (in milliseconds), is the time between each scan of the specified channels (i.e., if 4 channels are specified in Parameter 1, and the scan interval is 5ms, then the 4 measurements will be repeated every 5ms). The minimum time that is allowed per measurement is 0.97ms. The maximum time that is allowed per measurement is 50ms. If the scan interval entered does not allow this much time per measurement (e.g., if with 4 reps, an interval less than 3.88ms is entered), an error code, E 61, will be displayed when the program is compiled. When sending data to the serial port, the rate at which the data can be transferred may limit the scan interval (e.g., at 9600 baud the minimum time per measurement is 2.2ms).

NOTE: Instruction 23 can be aborted by keying #.

Burst/Telecommunications Considerations

The 21X will not respond to attempts to enter telecommunications while Burst measurements are in progress.

If the Burst Measurement instruction is encountered while telecommunications is in progress, the destination of the data determines whether or not the instruction is executed:

Burst data sent to input locations- If the Burst instruction specifies that Burst data be sent to input locations, all telecommunication activity will be suspended. After the Burst trigger condition is met and all Burst measurements made, Telecommunications can resume.

Burst data sent to Serial I/O Port- If the Burst instruction specifies that Burst data be sent to the serial port (i.e., Storage module), 21X program execution will pause until telecommunications is exited. During this pause telecommunications (i.e., view input locations, Monitor Mode with Term, etc.) can continue. No Burst measurements are made while in telecommunications and no Burst data is sent to the serial port. After telecommunication has ended, datalogger program execution will resume as if the Burst instruction were just executed.

PARAM. NUMBER	DATA TYPE	DESCRIPTION
01:	2	Repetitions (no. of channels)
02:	2	Range code (12-15)
03:	2	1st channel for analog measurements
04:	4	Option, 4 digit code ABCD
	A	Trigger
	0	Trigger on 1st analog channel
	1	Digital trigger on single-ended Channel 1 (1H)
	2	Same as 0, but set Digital Control Port #1 high when trigger is met, Low

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		when done measuring.
	B	Trigger option
		0 - Trigger immediately
		1 - Trigger if above limit (high)
		2 - Trigger if below limit (low)
		3 - Trigger on rising edge
		4 - Trigger on falling edge
	C	Destination
		0 - Input Storage
		1 - Serial port 9600 baud
		2 - Serial port 76,800 baud
	D	Measurement
		0 - Differential measurement
		1 - Single-ended measurement
05:	FP	Scan interval (ms, minimum 0.97 x reps, limited to 0.97-50ms)
06:	FP	Number of scans (units of 1000)
07:	4	Trigger offset; the number of samples saved before trigger (not used with serial output)
08:	FP	Trigger limit (mV, unscaled measurement)
09:	4	Excitation voltage (mV)
10:	4	1st input location in which to store data
11:	FP	Multiplier (not used with serial output)
12:	FP	Offset (not used with serial output)

*** 26 TIMER ***

FUNCTION

This instruction will reset a timer or store the elapsed time registered by the timer in an Input Storage location. Instruction 26 can be used with Program Control instructions to measure the elapsed time between specific input conditions. There is only one timer and it is common to all tables (e.g., if the timer is reset in Table 1 and later in Table 2, a subsequent

instruction in Table 1 to read the timer will store the elapsed time since the timer was reset in Table 2).

Elapsed time is tracked in 0.1 second increments but displayed as an integer. For example, a 20 second elapsed time is displayed as "200". The time starts over after reaching a maximum value of 65,536 - about 109 minutes.

The timer is also reset in response to certain keyboard entries:

1. When tables are changed and compiled with the *0 Mode, the timer is reset automatically.
2. When tables are changed and then compiled in the *B Mode, the timer is automatically reset and Tables 1 and 2 are disabled. Entering "*0" at this point enables both tables and resets the timer.
3. Entering "*6" after changing the tables compiles the programs, but does NOT reset the timer.

PARAM. NUMBER	DATA TYPE	DESCRIPTION
01:	4	Input location no. of elapsed time (or enter 0 to reset)

Input locations altered: 1 (0 if timer is being reset)

*** 101 SDM-INT8 ***

The 8 channel Interval Timer (INT8) is a measurement module which provides processed timing information to the datalogger. Each of the 8 input channels may be independently configured to detect either rising or falling edges of either high level or a low level signal. Each channel may be independently programmed. See the SDM-INT8 manual for detailed instructions and examples. This instruction is not in all PROM options.

PARAM. NUMBER	DATA TYPE	DESCRIPTION
01:	2	Address of INT8

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02:	4	*Input configuration; channels 8,7,6,5
03:	4	*Input configuration; channels 4,3,2,1
04:	4	**Function; channels 8,7,6,5
05:	4	**Function; channels 4,3,2,1
06:	4	***Output option
07:	4	Loc
08:	FP	Mult
09:	FP	Offset

- * Input configurations:
 0 = high level, rising edge
 1 = high level, falling edge
 2 = low level, rising edge
 3 = low level, falling edge

- ** Functions:
 0 = no value returned
 1 = period in ms
 2 = frequency in kHz
 3 = time since previous channel's edge
 in ms
 4 = time since channel 1 in ms
 5 = counts on channel 2 since channel
 1, linear interpolation
 6 = frequency in kHz (low resolution)
 7 = counts
 8 = counts on Channel 2 since Channel
 1, no interpolation

- *** Output option:
 0 Average over execution interval
 0-- Continuous averaging
 XXXX Averaging interval in msec,
 XXXX>0
 XXXX-- Capture all events until
 XXXX edges of channel 1
 (0<XXXX,9999)
 9999-- Test memory

*** 102 SDM-SW8A ***

The 8 channel SDM-SW8A Switch Closure Input Module is a peripheral for measuring up to 8 channels of switch closure or voltage pulse inputs. Each channel may be configured to read single-pole double-throw (SPDT) switch closure, or single-pole single-throw (SPST) switch closure, or voltage pulse. Output options include counts, duty cycle, and state. This instruction is not in all PROM options.

The SW8A is addressed by the datalogger, allowing multiple SW8A's to be connected to one datalogger. 16 addresses are available.

If more channels are requested than exist in one module, the datalogger automatically increments the address and continues to the next SW8A. The address settings for multiple SW8A's must sequentially increase. For example, assume 2 SW8A's addressed as 22 and 23 are connected, and 12 Reps are requested. 8 channels from the first SW8A and the first 4 channels from the next will be read.

Only one Function Option (**Parameter 3**) may be specified per Instruction 102. If all 4 functions are desired, the instruction must be entered 4 times.

Function Option 0 provides the state of the signal at the time P102 is executed. A 1 or 0 corresponds to high or low states, respectively.

Function Option 1 provides signal duty cycle. The result is the percentage of time the signal is high during the sample interval.

Function Option 2 provides a count of the number of positive transitions of the signal.

Function Option 3 provides the signature of the SW8A PROM. A positive number (signature) indicates the PROM and RAM are good, a zero (0) indicates bad PROM, and a negative number indicates bad RAM. Function Option 3 is not used routinely, but is helpful in "debugging". Only one Rep is required for Option 3.

Parameter 4 specifies the first SW8A channel to be read (1..8). One or more sequential channels are read depending on the Reps. To optimize program efficiency, the sensors should be wired sequentially.

Data are stored in sequential datalogger input locations, starting at the location specified in **Parameter 5**. The number of input locations consumed is equal to the number of Reps.

The scaling multiplier and offset (**Parameters 6 and 7**) are applied to all readings. If a multiplier is not entered, all readings are set to 0.

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If the SW8A does not respond, -99999 will be loaded into input locations. Modules which do not respond when addressed by the datalogger may be wired or addressed incorrectly. Verify that the address specified in Parameter 2 corresponds to the jumper setting and that all connections are correct and secure. See the SDM-SW8A Manual for examples.

PARAM. NUMBER	DATA TYPE	DESCRIPTION
01:	2	Number of Channels
02:	2	Module Address (00..33)
03:	2	Function Option (0=State, 1=Duty 2=Counts, 3=Signature)
04:	2	SDM-SW8A Starting Channel (1..8)
05:	4	Starting input location for results
06:	FP	Mult
07:	FP	Offset

*** 103 SDM-AO4 ***

Instruction 103 is used to activate a SDM-AO4 4 Channel Continuous Analog Output Module connected to ports C1, C2, and C3. This instruction is not in all PROM options.

There are 4 analog voltage outputs per SDM-AO4. The output voltages in millivolts must be stored in 4 adjacent input locations starting with the location entered in parameter 4. Four reps are required for each SDM-AO4. Every 4 reps another device at the next higher address is selected.

PARAM. NUMBER	DATA TYPE	DESCRIPTION
01	2	Reps (# of outputs) 1 = SDM-AO4
02	2	Address (Base 4)
03	4	Starting input location

C1 is Data line
C2 is Clk/Hand Shake line
C3 is SDE (Enable) line

*** 104 SDM-CD16 ***

The SDM-CD16 Control Port Expansion Module has 16 digital control ports with drivers. Each port can be controlled by a datalogger or controlled manually with an override toggle switch. Each port can be thought of as a switch to ground; closed when active, open when inactive. The primary function is to activate DC powered external relays, solenoids, or resistive loads under datalogger control. This instruction is not in all PROM options.

The SDM-CD16 is a synchronously addressed datalogger peripheral. Datalogger control ports 1, 2 and 3 are used to address the SDM-CD16 then clock out the desired state of each of the 16 control ports. Up to 16 SDM-CD16's may be addressed, making it possible to control a maximum of 256 ports from the first three datalogger control ports.

For each Rep, the 16 ports of the addressed SDM-CD16 are set according to 16 sequential input locations starting at the input location specified in parameter 3. Any non-zero value stored in an input location activates (connects to ground) the associated SDM-CD16 port. A value of zero (0) deactivates the port (open circuit). For example, assuming 2 Reps and a starting input location of 33, OUTPUT 1 through 16 of the first SDM-CD16 are set according to Input Locations 33 through 48, and OUTPUT 1 through 16 of the second SDM-CD16 are set according to Input Location 49 through 64. See the SDM-CD16 manual for detailed instructions and examples.

PARAM. NUMBER	DATA TYPE	DESCRIPTION
1	2	Reps (# of CD16 modules sequentially addressed)
2	2	Starting Address (base 4: 00..33)
3	4	Starting input location

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To facilitate cross referencing, parameter descriptions are keyed [] to the values given on the PROMPT SHEET. These values are defined as follows:

[Z] = User specified input location number destination
 [X] = Input location no. of source X
 [Y] = Input location no. of source Y
 [F] = Fixed Data (user specified, entered via the keyboard)

***** 30 LOAD FIXED DATA, Z = F *****

FUNCTION
 Store a fixed value into input location Z.

PAR. DATA
 NO. TYPE DESCRIPTION

01:	FP	Fixed data	[F]
02:	4	Destination for input location	[Z]

Input locations altered: 1

***** 31 MOVE INPUT DATA, Z = X *****

FUNCTION
 Move data from one input location to another.

PAR. DATA
 NO. TYPE DESCRIPTION

01:	4	Input location no. of source	[X]
02:	4	Destination for input location	[Z]

Input locations altered: 1

***** 32 INCREMENT INPUT LOCATION, *****
Z = Z+1

FUNCTION
 Add 1 to the current value in input location Z.

PAR. DATA
 NO. TYPE DESCRIPTION

01:	4	Destination for input location	[Z]
-----	---	--------------------------------	-----

Input locations altered: 1

***** 33 X + Y *****

FUNCTION
 Add the value in Input location X to the value in location Y and place the result in location Z.

PAR. DATA
 NO. TYPE DESCRIPTION

01:	4	Input location of X	[X]
02:	4	Input location of Y	[Y]
03:	4	Dest. input location of X + Y	[Z]

Input locations altered: 1

***** 34 X + F *****

FUNCTION
 Add the fixed number F to the value in location X and place the result in location Z.

PAR. DATA
 NO. TYPE DESCRIPTION

01:	4	Input location of X	[X]
02:	FP	Value to add	[F]
03:	4	Dest. input location of X + F	[Z]

Input locations altered: 1

***** 35 X - Y *****

FUNCTION
 Subtract the value in location Y from the value in location X and place the result in location Z.

PAR. DATA
 NO. TYPE DESCRIPTION

01:	4	Input location of X	[X]
02:	4	Input location of Y	[Y]
03:	4	Dest. input location for X - Y	[Z]

Input locations altered: 1

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***** 36 X * Y *****

FUNCTION

Multiply the value in location X by the value in location Y and place the result in location Z.

PAR. DATA

NO.	TYPE	DESCRIPTION
-----	------	-------------

01:	4	Input location of X [X]
02:	4	Input location of Y [Y]
03:	4	Dest. input location for X * Y [Z]

Input locations altered: 1

***** 37 X * F *****

FUNCTION

Multiply the value in location X by the fixed number F and place the result in location Z.

PAR. DATA

NO.	TYPE	DESCRIPTION
-----	------	-------------

01:	4	Input location of X [X]
02:	FP	Fixed multiplier [F]
03:	4	Dest. input location for X * F [Z]

Input locations altered: 1

***** 38 X / Y *****

FUNCTION

Divide the value in location X by the value in location Y and place the result in location Z. Division by 0 will cause the result to be set to the maximum 21X number (+99999 if positive, -99999 negative).

PAR. DATA

NO.	TYPE	DESCRIPTION
-----	------	-------------

01:	4	Input location of X [X]
02:	4	Input location of Y [Y]
03:	4	Dest. input location for X / Y [Z]

Input locations altered: 1

***** 39 SQUARE ROOT *****

FUNCTION

Take the square root of the value in location X and place the result in location Z. If the value in X is negative, 0 will be stored as the result.

PAR. DATA

NO.	TYPE	DESCRIPTION
-----	------	-------------

01:	4	Input location of X [X]
02:	4	Dest. input location for X1/2 [Z]

Input locations altered: 1

***** 40 LN(X) *****

FUNCTION

Take the natural logarithm of the value in location X and place the result in location Z. If the value in X is 0 or negative, -99999 will be stored as the result.

PAR. DATA

NO.	TYPE	DESCRIPTION
-----	------	-------------

01:	4	Input location of X [X]
02:	4	Dest. input location for LN(X) [Z]

Input locations altered: 1

***** 41 EXP(X) *****

FUNCTION

Raise the exponential base e to the value in location X power and place the result in location Z.

PAR. DATA

NO.	TYPE	DESCRIPTION
-----	------	-------------

01:	4	Input location of X [X]
02:	4	Dest. input location for EXP(X) [Z]

Input locations altered: 1

***** 42 1/X *****

FUNCTION

Take the inverse of the value in location X and place the result in location Z. If X=0, 99999 will be stored as the result.

PAR. DATA

NO.	TYPE	DESCRIPTION
-----	------	-------------

01:	4	Input location of X [X]
02:	4	Dest. input location for 1/X [Z]

Input locations altered: 1

SECTION 10. PROCESSING INSTRUCTIONS

*** 43 ABS(X) ***

FUNCTION

Take the absolute value of the value in location X and place the result in location Z.

PAR. DATA

NO.	TYPE	DESCRIPTION
01:	4	Input location of X [X]
02:	4	Dest. input location for ABS(X) [Z]
Input locations altered: 1		

*** 44 FRACTIONAL VALUE ***

FUNCTION

Take the fractional value (i.e., the non-integer portion) of the value in location X and place the result in location Z.

PAR. DATA

NO.	TYPE	DESCRIPTION
01:	4	Input location of X [X]
02:	4	Dest. input location for FRAC(X) [Z]
Input locations altered: 1		

*** 45 INTEGER VALUE ***

FUNCTION

Take the integer portion of the value in location X and place the result in location Z.

PAR. DATA

NO.	TYPE	DESCRIPTION
01:	4	Input location of X [X]
02:	4	Dest. input location for INT(X) [Z]
Input locations altered: 1		

*** 46 X MOD F ***

FUNCTION

Do a modulo divide of the value in location X by the fixed value F and place the result in location Z. X MOD F is defined as the REMAINDER obtained when X is divided by F (e.g., 3 MOD 2 = 1). X MOD 0 returns X.

PAR. DATA

NO.	TYPE	DESCRIPTION
01:	4	Input location of X [X]
02:	FP	Fixed divisor [F]
03:	4	Dest. input location for X MOD F [Z]
Input locations altered: 1		

*** 47 X^Y ***

FUNCTION

Raise the value in location X to the value in location Y power and place the result in location Z.

PAR. DATA

NO.	TYPE	DESCRIPTION
01:	4	Input location of X [X]
02:	4	Input location of Y [Y]
03:	4	Dest. input location for XY [Z]
Input locations altered: 1		

*** 48 SIN(X) ****

FUNCTION

Calculate the sine of the value in location X (assumed to be in degrees) and place the result in location Z. The cosine of a number can be obtained by adding 90 to the number and taking the sine (COSX = SIN (X + 90)).

PAR. DATA

NO.	TYPE	DESCRIPTION
01:	4	Input location of X [X]
02:	4	Dest. input location for SIN(X) [Z]
Input locations altered: 1		

*** 49 SPATIAL MAXIMUM ***

FUNCTION

Find the maximum value in the given set or SWATH of contiguous input locations and place the result in location Z. To find the input location where the maximum value occurs, enter 1000 + the input location number (1000 + Z) as Parameter 03. The input location of the maximum value observed will then be stored in destination [Z] plus 1.

SECTION 10. PROCESSING INSTRUCTIONS

Parameter 3 cannot be entered as an indexed location within a loop (Instruction 87). To use Instruction 49 within a loop, enter Parameter 3 as a fixed location and follow 49 with Instruction 31 (Move Data). In Instruction 31, enter the location in which 49 stores its result as the source (fixed) and enter the destination as an indexed location.

PAR. DATA
NO. TYPE DESCRIPTION

01:	2	Swath	[SWATH]
02:	4	Starting input location	[1ST LOC]
03:	4	Dest. input location for maximum	[MAX or Z]

Input locations altered: 1 or 2

*** 50 SPATIAL MINIMUM ***

FUNCTION

Find the minimum value in the given set or SWATH of contiguous input locations and place the result in location Z. To find the input location where the minimum value occurs, follow the instructions given above for SPATIAL MAXIMUM.

Parameter 3 cannot be entered as an indexed location in a loop. Within a loop, Instruction 50 must be used in conjunction with Instruction 31 as described for Instruction 49.

PAR. DATA
NO. TYPE DESCRIPTION

01:	2	Swath	[SWATH]
02:	4	Starting input location	[1ST LOC]
03:	4	Dest. input location for minimum	[MIN or Z]

Input locations altered: 1 or 2

*** 51 SPATIAL AVERAGE ***

FUNCTION

Calculate the average of the values in the given set or SWATH of contiguous input locations and place the result in location Z.

PAR. DATA
NO. TYPE DESCRIPTION

01:	2	Swath	[SWATH]
02:	4	Starting input location	[1ST LOC]
03:	4	Dest. input location for average	[AVG or Z]

Input locations altered: 1

*** 53 SCALING ARRAY WITH MULTIPLIER AND OFFSET ***

FUNCTION

Take 4 input location values, multiply each by a floating point constant, then add another floating point constant to the resulting products and place the results back into each of the original 4 input locations.

PAR. DATA
NO. TYPE DESCRIPTION

01:	4	First input location	[STRT LOC]
02:	FP	Multiplier 1	[A1]
03:	FP	Offset 1	[B1]
04:	FP	Multiplier 2	[A2]
05:	FP	Offset 2	[B2]
06:	FP	Multiplier 3	[A3]
07:	FP	Offset 3	[B3]
08:	FP	Multiplier 4	[A4]
09:	FP	Offset 4	[B4]

Input locations altered: 4

*** 54 BLOCK MOVE ***

FUNCTION

Moves a block of data from one set of input locations to another. Parameters specify the number of values to move, the source, source step, destination, and destination step. The "step" parameters designate the increment of the source and destination Input locations for each value that is moved. For example, a "source step" of 2 and a "destination step" of 1 will move data from every other Input location to a contiguous block of Input locations.

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PAR. DATA
NO. TYPE DESCRIPTION

- 01: 4 Number of values to move
- 02: 4 1st source location
- 03: 2 Step of source
- 04: 4 1st destination location
- 05: 2 Step of destination

***** 55 5TH ORDER POLYNOMIAL *****

FUNCTION

Evaluate a 5th order polynomial of the form.

$$F(X)=C0+C1X+C2X^2+C3X^3+C4X^4+C5X^5$$

where C0 through C5 are the coefficients for the argument X raised to the zero through fifth power, respectively. The magnitude of the user entered coefficient is limited to a range of +99999 to -99999. Polynomials with coefficients outside this range can be modified by pre-scaling the X value by an appropriate factor to place the coefficients within the entry range. Pre-scaling can also be used to modify coefficients which are very close to 0 in order to increase the number of significant digits.

PAR. DATA
NO. TYPE DESCRIPTION

- 01: 2 Repetitions [REPS]
- 02: 4 Starting input location for X [X]
- 03: 4 Dest. input location for F(X) [F(X) or Z]
- 04: FP C0 coefficient [C0]
- 05: FP C1 coefficient [C1]
- 06: FP C2 coefficient [C2]
- 07: FP C3 coefficient [C3]
- 08: FP C4 coefficient [C4]
- 09: FP C5 coefficient [C5]

Input locations altered: 1* Reps

***** 56 SATURATION VAPOR PRESSURE *****

FUNCTION

Calculate saturation vapor pressure over water (SVPW) in kilopascals from the air temperature (°C) and place it in an input location. The algorithm for obtaining SVPW from air temperature (°C) is taken from: Lowe, Paul R., 1976: An Approximating Polynomial for

Computation of Saturation Vapor Pressure. J. Appl. Meteor. 16, 100-103.

Saturation vapor pressure over ice (SVPI) in kilopascals for a 0°C to -50°C range can be obtained using Instruction 55 and the relationship

$$SVPI = -.00486 + .85471 X + .2441 X^2$$

where X is the SVPW derived by Instruction 56. This relationship was derived by Campbell Scientific from the equations for the SVPW and the SVPI given in Lowe's paper.

PAR. DATA
NO. TYPE DESCRIPTION

- 01: 4 Input location of air temperature oC [TEMP.]
- 02: 4 Dest. input location for saturated vapor pressure [VP or Z]

Input locations altered: 1

***** 57 VAPOR PRESSURE FROM WET-/DRY-BULB TEMPERATURES *****

FUNCTION

This instruction calculates vapor pressure in kilopascals from wet- and dry-bulb temperatures in °C. The algorithm is of the type used by the National Weather Service:

$$VP = VPW - A(1 + B \cdot TW)(TA - TW) P$$

VP = ambient vapor pressure in kilopascals

VPW = saturation vapor pressure at the wet-bulb temperature in kilopascals

- TW = wet-bulb temperature, deg. C
- TA = ambient air temperature, deg. C
- P = air pressure in kilopascals
- A = 0.000660
- B = 0.00115

Although the algorithm requires an air pressure entry, the daily fluctuations are small enough that for most applications a fixed entry of the standard pressure at the site elevation will suffice. If a pressure sensor is employed, the current pressure can be used.

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PAR. DATA

NO.	TYPE	DESCRIPTION
01:	4	Input location no. of atmospheric pressure in kilopascals [PRESSURE]
02:	4	Input location no. of dry-bulb temp. [DB TEMP.]
03:	4	Input location no. of wet-bulb temp. [WB TEMP.]
04:	4	Dest. input location for vapor pressure [VP or Z]

Input locations altered: 1

*** 58 LOW PASS FILTER ***

FUNCTION

Apply a numerical approximation to an analog resistor capacitor (RC) low pass (LP) filter using the following algorithm.

$$F(X_i) = W * X_i + F(X_{i-1}) * (1-W)$$

Where, X = input sample,
 W = user entered weighting function,
 0 < W < 1
 If W=0, F(X_i)=X_i; if W=1, F(X_i)=X,
 F(X_{i-1}) = output calculated for previous sample.

The equivalent RC time constant is given by T/W, where T is the sampling time in seconds. For values of W less than 0.25, the analogous "cut off" frequency (the frequency where the ratio of output to input is .707) is accurately represented by W/(2[T]). For larger values of W, this "analog" estimate of the cutoff frequency becomes less representative.

On the first execution after compiling, F(x) is set equal to X.

PAR. DATA

NO.	TYPE	DESCRIPTION
01:	2	Repetitions [REPS]
02:	4	First input location for input data [X]
03:	4	Dest. input location for filtered data [F(X) or Z]
04:	FP	Weighting function, W [W]

Input locations altered: 1 for each repetition

*** 59 BRIDGE TRANSFORM ***

FUNCTION

This instruction is used to aid in the conversion of a ratiometric Bridge measurement by obtaining the value for R_s which is equivalent to R_f[X/(1-X)], where X is the value derived by the standard 21X Bridge Measurement Programs (with appropriate multiplier and offset, Section 13.5) and R_f represents the MULTIPLIER value. The result of Instruction 59 is stored in the same location that X was.

PAR. DATA

NO.	TYPE	DESCRIPTION
01:	2	Repetitions [REPS]
02:	4	Starting input location and destination [X]
03:	FP	Multiplier (Rf) [MULT.]

Input locations altered: 1 for each repetition

*** 60 FAST FOURIER TRANSFORM ***

THEORY

Instruction 60 performs a Fast Fourier Transform (FFT) on a set of data contained in contiguous locations in Input Storage. The FFT is used to obtain information on the relative magnitudes and phases of the various frequency components in a time varying signal. FFT theory requires that the signal be sampled at a frequency that is at least two times faster than the highest frequency component in the signal. For example, a signal representing ocean waves with a maximum frequency of 0.125 Hz would need to be sampled at a rate of 0.25 Hz or greater. The measurements must be made at the appropriate sampling rate and stored in contiguous input locations before the FFT can be applied. The measured data stored in sequential input locations is also referred to as the "original time series data".

The results of the FFT can be expressed as: 1) the real and imaginary components, 2) the magnitude and phase components, or 3) the power spectra. The real and imaginary results are analogous to the orthogonal (east and north) representation of a wind vector. The magnitude and phase results are analogous to the polar (speed and direction) representation of a wind vector. The power spectra results indicate the

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amount of power at the different frequencies but do not contain any phase information.

If desired, the original time varying signal can be reconstructed by taking the Inverse Fourier Transform of either the real and imaginary or the magnitude and phase results.

PROGRAMMING

The FFT Instruction is a Processing Instruction and will not output data to final memory or any data storage device. FFT results are transferred to Final Memory by setting the Output Flag and sampling the input locations which contain the FFT results. Referring to Table 5, the thirteenth through the seventeenth instructions illustrate one method of transferring the data from input memory to final memory.

PAR. DATA

NO.	TYPE	DESCRIPTION
01:	2	Log base 2 of N, where N is the number of samples in the original data; e.g., this parameter is 11 for 2048 samples or 12 for 4096 samples. Maximum is 13 or 8192.
02:	2	FFT Option X0 = No Taper 0X = Power Spectra X1 = Taper 1X = Real & Imaginary 2X = Magnitude & Phase
03:	2	Log base 2 of the number of adjacent bins to average; e.g., this parameter is 3 for averaging 8 adjacent bins.
04:	4	Input location containing the first value in the original time series. After this program has executed, this location will contain the first spectral bin or bin average of the result.
05:	FP	Multiplier for scaling FFT results.

Input storage locations: Greater than or equal to the number of values in the original time series data.

Intermediate storage locations: $2 + (.125 * N)$

Execution time in seconds:

- REAL AND IMAGINARY
= $.00065 * N * \text{LOG}_2$ of N + .58
- MAGNITUDE AND PHASE
= $.00077 * N * \text{LOG}_2$ of N + 1.66
- POWER SPECTRA
= $.00066 * N * \text{LOG}_2$ of N + .45

PARAMETER 1 is an integer from 1 to 13. The number 2, raised to the power of Parameter 1, is equal to the number of data values in the original time series data, N. For example, if Parameter 1=13, then N=8192. Maximum value for Parameter 1 is 13 (8192).

PARAMETER 2, the FFT Option, is a two digit parameter. The first digit specifies which results are to be generated and the second digit specifies whether or not a "taper" is applied.

First Digit: A "0" in the first digit specifies that the FFT result be expressed as the power spectra. Bin averaging is allowed with this option. A "1" in the first digit specifies that the FFT result be expressed as the real and imaginary components. Bin averaging is not allowed with this option. A "2" in the first digit specifies that the FFT result be expressed as the magnitude and phase components. Bin averaging is not allowed with this option.

Second Digit: A "0" in the second digit specifies that no taper be applied, whereas a "1" specifies that a taper be applied. If the original data set is not known to be periodic with an integral number of periods in the data set, then it is necessary to apply a taper to the beginning and end of the data. The taper that is applied is a four term Blackman-Harris as specified by Fredric J. Harris, Proceedings of the IEEE, Vol. 66, No. 1, January 1978. When the taper is used, the 21X applies a correction by multiplying the results by the ratio of the variance before the taper to the variance after the taper.

The variance ratio is saved only when the power spectra option is selected. The variance ratio is saved in input location $(N/2)+B$, where B is the location (Parameter 4) that contained the first value of the original time series data.

PARAMETER 3 specifies how many of the resulting spectral bins (if any) are to be averaged. Bin averaging is only allowed when

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power spectral is output. Parameter 3 is equal to the log base 2 of A where A is the number of bins to be averaged. For example, if there are 1024 samples in the original time series data and the resulting 512 spectral bins are averaged in groups of 8 (Parameter 3 = 3 = log base 2 of 8) then 63 (=N/2A - 1) averaged bins will be produced.

PARAMETER 4 defines which input location will contain the first value at the original time series data. Once the FFT program has executed, this location will contain the first resulting value.

PARAMETER 5 is a scaling multiplier that is applied to the FFT results (i.e., after the FFT computation has been done). The multiplier is not applied to the DC component.

MEMORY REQUIREMENTS

The number of Input Memory Locations allocated must be enough to accommodate the N sampled values, where N is defined under Parameter 1. The number of Intermediate Memory Locations allocated must be greater than or equal to (N/8 + 2). If insufficient Input or Intermediate Memory Locations have been allocated, the datalogger will flag an E60 or E04, respectively.

NOTE: The 21X has 1 Intermediate Location that is not available for use by Processing or Output Instructions so the number of Intermediate Locations allocated must exceed the indicated total requirement by at least 1.

FFT RESULTS WITHOUT BIN AVERAGING

When no bin averaging is specified, the FFT results may be calculated in terms of the real/imaginary components, the magnitude/phase components, or the power spectra. The rest of this section deals with the DC component, bin frequency, and the FFT results just mentioned. An example showing each of the possible results is given in Section 8.8.1.

DC COMPONENT

Before the FFT is applied, the average of the original time series data is subtracted from each

value. This is done to maintain the resolution of the math in the rest of the FFT calculations.

If the real and imaginary or the magnitude and phase results are specified by Parameter 2 the DC component is the average of the original time series data. If power spectra results are specified, the DC component is equal to the square of the average of the original time series data times 2N.

The DC component is stored in the first input location specified by Parameter 4 which corresponds with the frequency at 0 Hz (bin 0).

BIN FREQUENCY

The band width or the frequency covered by each bin is equal to F/N where F is the sample frequency in Hz (1/scan interval in seconds).

The frequency (f_i) of any given bin i where i ranges from 0 to (N/2)-1 is given by the following equation:

$$(i-1 * F) / N < f_i < (i * F) / N \quad [1]$$

For example, given that the power spectra result shows that the energy peak of a signal falls in bin 128 when it is sampled at a frequency of 10 Hz for 1024 samples, the frequency of the signal is:

$$127 * 10 / 1024 < f_i < 128 * 10 / 1024$$

$$1.24 \text{ Hz} < f_i < 1.25 \text{ Hz}$$

REAL AND IMAGINARY COMPONENTS

The result of the FFT when the real and imaginary option is selected is N/2 input locations containing the real components (R_i) followed by N/2 input locations containing the imaginary components (I_i). There is a real and an imaginary component for each bin. The value of i varies from 1 to N/2. The real and imaginary results at each frequency i , are related to the magnitude (M_i) and phase (P_i) as shown below:

$$R_i = M_i * \cos P_i \quad [2]$$

$$I_i = M_i * \sin P_i \quad [3]$$

where M_i is the magnitude and P_i is the phase of the signal in degrees. Magnitude is half of the

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zero to peak amplitude or one quarter of the peak to peak value of the sinusoidal signal.

MAGNITUDE AND PHASE COMPONENTS

The result of the FFT when the magnitude and phase option is selected is N/2 input locations containing the magnitude components (M_i) followed by N/2 input locations containing the phase components (P_i). Magnitude is half of the zero to peak amplitude or one quarter of the peak to peak value of the sinusoidal signal. There is a magnitude and a phase component for each bin. The value of i varies from 1 to N/2. The magnitude and phase components are related to the real (R_i) and imaginary (I_i) components as shown below:

$$M_i = \text{SQRT}[(R_i * R_i) + (I_i * I_i)] \quad [4]$$

$$P_i = \arctan (I_i/R_i) \quad [5]$$

To calculate the magnitude and phase the 21X's FFT algorithm must first compute the real and imaginary components. Conversion from real and imaginary to the magnitude and phase requires quite a bit more datalogger execution time and no new information is gained. If datalogger execution time is limiting, program the datalogger to store the real and imaginary results and have a computer do the conversion to magnitude and phase during the data reduction phase. The FFT assumes the signal was sampled at the beginning of each of N intervals. Since the FFT assumes the signal is periodic with a period equal to the total sampling period, the result of its phase calculation at each frequency component is the average of the phase at the *beginning* of the first interval with the phase at the *end* of the last interval. The phase is the angle (0 360 degrees) of the cosine wave that describes the signal at a particular point in time.

POWER SPECTRA

The result of the FFT when the power spectra option is selected is N/2 bins of spectral energy (PS_i) representing frequencies from 0 Hz to 1/2 the sampling frequency. The value of i varies from 1 to N/2. The result in each bin i , is related to the magnitude (M_i) of the wave in the following manner:

$$PS_i = 2 * N * (M_i * M_i) \quad [6]$$

where the magnitude is half of the zero to peak amplitude or one quarter of the peak to peak value of the sinusoidal signal.

The power spectra can also be expressed as either of the following:

$$PS_i = N * (U_i * U_i) \quad [7]$$

$$PS_i = F * T * (U_i * U_i) \quad [8]$$

U_i is defined as the root mean square (RMS) value of the sine component of frequency i (f_i) ($U_i = \text{magnitude } (M_i) \text{ of the sine wave multiplied by the square root of 2}$) in units of the input signal multiplied by the scaling multiplier. In equation 8, F is the sampling frequency (Hz) and T is the duration of the original time series data (seconds).

When the FFT results are expressed in terms of the power spectra, a multiplier of 1 will cause the average of all the bins to be very nearly equal to twice the variance of the original data.

FFT RESULTS WITH BIN AVERAGING

When bin averaging is specified, the FFT results can only be calculated in terms of the power spectra. The rest of this section deals with the DC component, bin frequency, and the power spectra results. An example showing bin averaging FFT results is given in Section 8.8.2.

DC COMPONENT

Before the FFT is applied, the average of the original time series data is subtracted from each value. This is done to maintain the resolution of the math in the rest of the FFT calculations. When bin averaging is specified then the DC component is not output.

BIN FREQUENCY

The band width or the frequency covered by each averaged bin is equal to FA/N where F is the sample frequency in Hz (1/scan interval in seconds) and A is the number of bins being averaged.

The frequency (f_i) of any given averaged bin i where i ranges from 1 to $(N/2A)-1$ is given by the following equation:

$$i-1 * F * A / N < f_i < i * F * A / N \quad [9]$$

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For example, given that the power spectra result shows that the energy peak of a signal falls in bin 32 when it is sampled at a frequency of 10 Hz for 1024 samples and that the bin averaging specified is 4, the frequency of the signal in bin i is:

$$31 * 10 * 4 / 1024 < f_i < 32 * 10 * 4 / 1024$$

$$1.21 \text{ Hz} < f_i < 1.25 \text{ Hz}$$

POWER SPECTRA

The result of the FFT with A bins averaged, are (N/2A)-1 bins of average spectral energy (APSn) representing frequencies from 0 Hz to 1/2 the sampling frequency. The value of i varies from 1 to (N/2A)-1. The results are found in consecutive input locations starting with the first one specified by Parameter 4. The value for average bin n (APSn) is related to the spectral bin values (PS_i see previous section) by the following equation:

$$APSn = (\sum PS_i + 0.5(PS_{nA-A/2} + PS_{nA+A/2})) / A \quad [10]$$

where i goes from nA-(A/2-1) to nA+(A/2-1)

The following table illustrates how bin averaging is done given a time series of 1024 values taken at one per second with the resulting 512 spectral bins averaged in groups of 4 (Parameter 3 = log base 2 of 4 = 2) to produce 127 averaged bins.

In the following example, averaging produces bins with representative frequencies that are the same as if 256 samples had been used with no averaging. Note that when averaging is done, information from the first few and last few bins is not included so that the averages can better represent frequencies that correspond to results of fewer original samples.

Examples of the use of the FFT are given in Section 8.

TABLE 10-1. Example of FFT Power Spectra Bin Averaging (Assuming 1024 time series values starting in Location 1)

No Bin Averaging			Averaged in Groups of 4		
BIN NO.	LOC.	REPRESENTATIVE FREQUENCY	AVERAGED BIN NO.	LOC. FREQUENCY	REPRESENTATIVE FREQUENCY
0	1	DC			
1	2	1/1024			
2	3	2/1024			
3	4	3/1024			
4	5	4/1024	----- 1	1	4/1024 or 1/256
5	6	5/1024			
6	7	6/1024			
7	8	7/1024			
8	9	8/1024	----- 2	2	8/1024 or 2/256
9	10	9/1024			
10	11	10/1024			
11	12	11/1024			
		. . .			
502		502/1024			
503		503/1024			
504		504/1024	----- 126	126	504/1024 or 126/256
505		505/1024			
506		506/1024			
507		507/1024			
508		508/1024	----- 127	127	508/1024 or 127/256
509		509/1024			
510		510/1024			
511		511/1024			

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***** 61 INDIRECT INDEXED MOVE *****

FUNCTION

Moves input data from location X to location Y, where X and Y are indirectly addressed. The values of the location numbers X and Y are stored in the locations specified by Parameters 1 and 2. The 21X looks in the locations specified in the parameters to find the locations to use as the source and destination of the data. When used within a LOOP, a location parameter can be specified as "indexed" (xxxx-), then the actual Input location referenced is calculated by adding the current index counter to the value in the specified Input location.

PAR. DATA

NO.	TYPE	DESCRIPTION
01:	4	Input location in which Source Input location is stored
02:	4	Input location in which Destination input location is stored

***** 62 COVARIANCE/CORRELATION *****

FUNCTION

The special Covariance/Correlation Instruction (CV/CR) for the 21X calculates: 1) means (M), 2) variances (V), 3) standard deviations (SD), 4) covariances (CV), and 5) correlations (CR) for a set of input values and stores the results in Input Storage. The instruction requires the set of input values to be located contiguously in Input Storage. The user specifies the location of the first value and how many total values exist. The number of input values processed by each type of calculation (means, variances, etc.) is independently specified for each type. The order of the input values determines which inputs are processed for each type of calculation.

The instruction does not conform to the 21X's four instruction types. Data located in Input Storage is processed, and the results returned to Input Storage whenever an averaging period is completed (Parameter 7) or the Output Flag is set. The instruction controlling the Output Flag must precede the CV/CR Instruction. The reason the calculated results are returned to Input Storage is to allow the user access for additional processing before storing the values in Final Storage. Sample Instruction 70 must be

used to transfer final results from Input to Final Storage.

To accommodate cases where it is desirable to calculate the statistical quantities over time periods shorter than the Output Interval, an averaging period shorter than the Output Interval may be specified. The final values obtained at the Output Interval are the properly weighted average of the values calculated at the subinterval averaging periods. This feature allows the recording of statistical data over longer time periods by removing the effect of longer period frequencies in the input signals; i.e., it provides a high pass filter. For example, assume the variance of an input is desired. It is determined that the averaging period should not exceed 5 minutes due to variation in the mean over longer time intervals. One approach is to calculate and record the variance every 5 minutes. By specifying the subinterval averaging period as 5 minutes and the Output Interval as 1 hour, however, the average of the 5 minute variances are recorded every hour. The averaging period is entered as the number of input samples in Parameter 7 of the CV/CR Instruction. The number of samples for a given period is given by:

$$\text{Number of Samples} = \frac{\text{Averaging period in seconds}}{\text{Table execution interval in seconds}}$$

PAR. DATA

NO.	TYPE	DESCRIPTION
01:	2	Number of input values located sequentially in input memory
02:	2	Number of means desired
03:	2	Number of variances desired
04:	2	Number of standard deviations desired
05:	2	Number of covariances desired
06:	2	Number of correlations desired
07:	FP	Number of input samples in averaging period
08:	4	Input storage location of first value in sequential input string
09:	4	First Input Storage location to store string of final results

If the specified number of samples in the averaging period (Parameter 7) exceeds the actual number of samples occurring in the Output Interval, the Output Interval becomes the averaging period.

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TABLE 10-2. Maximum Number of Outputs and Output Order for K Input Values.
(The output order flows from left to right and from top to bottom)

INPUTS:		X1	X2	X3	X4	.....	XK
<u>TYPE</u>	<u>MAX NO. OUTPUTS</u>	<u>(1st)</u>	<u>(2nd)</u>	<u>(3rd)</u>	<u>OUTPUTS (4th)</u>		<u>(Kth)</u>
Means	K	M(X1)	M(X2)	M(X3)	M(X4)	.....	M(XK)
Variations	K	V(X1)	V(X2)	V(X3)	V(X4)	.....	V(XK)
Std. Deviation	K	SD(X1)	SD(X2)	SD(X3)	SD(X4)	.....	SD(XK)
Covariance	(K/2)(K-1)		CV(X1,X2)	CV(X1,X3) CV(X2,X3)	CV(X1,X4) CV(X2,X4) CV(X3,X4)	..... ..... .....	CV(X1,XK) CV(X2,XK) CV(X3,XK)
					
					
					
					
					
					
					
Correlation	(K/2)(K-1)		CR(X1,X2)	CR(X1,X3) CR(X2,X3)	CR(X1,X4) CR(X2,X4) CR(X3,X4)	..... ..... .....	CR(X1,XK) CR(X2,XK) CR(X3,XK)
					
					
					
					
					

<u>SYMBOL</u>	<u>DEFINITION</u>
M(XK)	Mean of Kth value
V(XK)	Variance of Kth value
SD(XK)	Standard deviation of Kth value
CV(XK,X1)	Covariance of Kth and 1th value
CR(XK,X1)	Correlation of Kth and 1th value

MAXIMUM NUMBER OF POSSIBLE OUTPUTS

No limitation exists on the number of inputs that can be processed by the CV/CR Instruction, but the processing time and Intermediate Storage requirements increase rapidly. The instruction requires that the input values reside sequentially in Input Storage. Since the number of outputs is specified for each type of statistical calculation, the instruction starts with the first value, working sequentially through the input values. For this reason, the order of the input values determines which values are processed.

Table 10-8 shows the maximum number of outputs which can be generated and the output order for K input values located sequentially in Input Storage. The output order shown in Table 10-2 flows from left to right and top to bottom.

INSTRUCTION PROCESSING

The CV/CR Instruction contains 3 separate processing phases:

1. Input Processing
2. Averaging Period Processing
3. Output Processing

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The Input Processing phase is where new input values are received, the necessary squares or cross products formed, and the appropriate summations calculated as required by the desired final output. The rate at which the measurements can be made, the input values ordered, and the input processing phase completed without interruption determines the maximum rate of execution (see Execution Time).

The Averaging Period Processing occurs whenever the number of input samples entered in Parameter 7 is satisfied or whenever an Output Interval occurs (i.e., whenever the Output Flag is set). Results from these calculations are stored sequentially in Input Storage locations starting with the location specified in Parameter 9. The calculations performed are shown below, where N is the number of input samples in the averaging period:

1. Means:
 $M(X) = \Sigma X/N$
2. Variances:
 $V(X) = \Sigma X^2/N - (\Sigma X/N)^2$
3. Standard Deviations:
 $SD(X) = V(X)^{1/2}$
4. Covariances:
 $CV(X,Y) = \Sigma XY/N - \Sigma X \Sigma Y/N^2$
5. Correlations:
 $CR(X) = CV(X,Y)/(SD(X)SD(Y))$

NOTES: 1. The square root algorithm in the 21X returns a result of 0 for negative arguments.

2. The divide algorithm returns the largest floating point number possible ($\pm 10^{18}$ displayed as ± 99999) for a divide by 0.

3. When computing the variance of a constant signal, round off error produces a small negative result. The 21X returns a 0 for the square root of a negative number; therefore, the standard deviation is set to 0. If the signal is also used in a correlation calculation, division by 0 returns an overrange value for the correlation result.

If a fast execution interval is specified, it is possible that the combined execution times of the input and averaging period processing may exceed the program table execution interval. The occurrence of an execution interval Overrun (see Section 2.1 of 21X Operator's Manual) is noted by decimal points on either side of the G in LOG (*0 MODE). This results in the omission of one input sample. The calculations are not affected, however, since the number of input samples is incremented only when valid input processing occurs. Averaging period processing occurs only when the number of input samples specified in Parameter 7 is accumulated.

Regardless of whether all of the input samples for the averaging period (specified in Parameter 7) have occurred or not, averaging period processing occurs whenever the Output Flag is set. This accommodates situations where the Output Interval may not be an integer multiple of the averaging period. If for example a 30 minute Output Interval is set by Instruction 92 and an 8 minute averaging period is specified by Parameter 7, then three 8 minute and one 6 minute calculations will occur. The proper weighting of these values in producing the final output is described below.

The Output Processing occurs only at the Output Interval and involves averaging the statistical results obtained at the averaging periods. These final results are then stored sequentially in Input Storage beginning with the location specified in Parameter 9. The Sample Instruction 70 must be used to transfer the data to Final Storage. All but the last averaging period in the Output Interval will contain the same number of input scans as specified by Parameter 7. To insure that results from the averaging periods contribute to the final result proportional to their averaging periods, the output processing uses the following equation:

$$RF = (NR1 + NR2 + \dots + N'RL)/NT$$

RF is the final result
R1 R2, etc., are the results from the averaging period processing
RL is the result from the last averaging period in the Output Interval
N is the number of input samples in the specified averaging period (Parameter 7)

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N' is the number of input scans in the last averaging period

NT is the total number of input samples processed in the Output Interval

INTERMEDIATE STORAGE REQUIREMENTS

The number of Intermediate locations will depend upon the number of input values and outputs desired:

1. Define K as the number of input values.
2. Define S as the maximum of either the variances, standard deviations, or C , where $C = K$ if $K <$ the number of correlations requested, or $C =$ number of correlations + 1 if $K >$ the number of correlations requested.
3. Define Q as the maximum of either the covariances or correlations desired.
4. Define P as the total number of outputs desired.

The amount of intermediate memory locations (IML) required, is then given by:

$$IML = K + S + Q + P + 2$$

EXECUTION TIME

If K , S , and Q are defined as in the previous section, the execution time of the CV/CR Instruction in milliseconds can be approximated by:

$$T(\text{ms}) = 1.1K + 0.5S + 0.9Q + 1.8$$

When evaluating how frequently input samples can be processed by the CV/CR Instruction (i.e., determining the minimum program table execution interval), the time required to make the measurements and order the input values must be added to the CV/CR execution time. Two alternatives exist for the measurement portion of the programming. The fastest method is to group as many sensors as possible into the fewest measurement instructions, ignoring the Input location order required by the CV/CR Instruction. After the measurements are made, use "move" instructions (i.e., 31 and 54) to obtain the proper input order. The slower alternative is to order separate measurement instructions directly as required by the CV/CR Instruction. While avoiding "move" instructions, this approach uses more measurement

instructions. The reason the first method is in general faster is that less overhead time is required in going from one measurement to another within a single instruction (using the "repetitions" feature) than in going from one measurement instruction to another.

In many situations, the 21X must perform measurement and processing tasks in addition to those associated with the CV/CR Instruction. Uninterrupted operation of the CV/CR Instruction is assured by entering it in Program Table 1 (highest priority) and placing the additional tasks in Program Table 2.

A covariance correlation example is given in Section 8.

*** 66 ARCTAN ***

FUNCTION

Calculate the angle in degrees whose tangent is X/Y . The polarity of X and Y must be known to determine the quadrant of the angle, as shown here. If 0 is entered for Parameter 2, the Arctangent of X is the result (limits of the function are $-90^\circ < \text{ARCTAN} < 90^\circ$).

Quadrant	Sign of X	Sign of Y
I	+	+
II	+	-
III	-	-
IV	-	+

PAR. DATA

NO.	TYPE	DESCRIPTION	
01:	4	Input location of X	[X]
02:	4	Input location of Y	[Y]
03:	4	Destination input location for ARCTAN(X/Y)	

Input locations altered: 1

SECTION 11. OUTPUT PROCESSING INSTRUCTIONS

*** 69 WIND VECTOR ***

FUNCTION

Instruction 69 processes the primary variables of wind speed and direction from either polar (wind speed and direction) or orthogonal (fixed East and North propellers) sensors. It uses the raw data to generate the mean wind speed, the mean wind vector magnitude, and the mean wind vector direction over an output interval.

Two different calculations of wind vector direction (and standard deviation of wind vector direction) are available, one of which is weighted for wind speed.

When used with polar sensors, the instruction does a modulo divide by 360 on wind direction, which allows the wind direction (in degrees) to be 0 to 360, 0 to 540, less than 0, or greater than 540. The ability to handle a negative reading is useful in an example where a difficult to reach wind vane is improperly oriented and outputs 0 degrees at a true reading of 340 degrees. The simplest solution is to enter an offset of -20 in the instruction measuring the wind vane, which results in the correct output following processing.

When a wind speed sample is 0, the instruction uses 0 to process scalar or resultant vector wind speed and standard deviation, but the sample is not used in the computation of wind direction. The user may not want a sample less than the sensor threshold used in the standard deviation. If this is the case instruction 89 can be used to check wind speed, and if less than the threshold, Instruction 30 can set the input location equal to 0.

Standard deviation can be processed one of two ways: 1) using every sample taken during the output period (enter 0 for parameter 2), or 2) by averaging standard deviations processed from shorter sub-intervals of the output period (enter the number of scans in the sub-interval for parameter 2). Averaging sub-interval standard deviations minimizes the effects of meander under light wind conditions, and it provides more complete information for periods of transition¹.

Standard deviation of horizontal wind fluctuations from sub-intervals is calculated as follows:

$$\sigma(\Theta)=[((\sigma_{\Theta_1})^2+(\sigma_{\Theta_2})^2 \dots+(\sigma_{\Theta_M})^2)/M]^{1/2}$$

where $\sigma(\Theta)$ is the standard deviation over the output interval, and $\sigma_{\Theta_1} \dots \sigma_{\Theta_M}$ are sub-interval standard deviations.

PARAM. NUMBER	DATA TYPE	DESCRIPTION
01:	2	Repetitions
02:	4	Samples per sub-interval (number of scans)
03:	2	Sensor/Output 2 digits: AB A Sensor type: 0 = Speed and Direction 1 = East and North B Output option: 0 S, Θ1, $\sigma(\Theta)$ 1 S, Θ1 2 S, U, Θu, $\sigma(\Theta$u)
04:	4	First wind speed input location no. (East wind speed)
05:	4	First wind direction input location no. (North wind speed)

Outputs Generated: 2-4 (depending on output option) for each repetition

A sub-interval is specified as a number of scans. The number of scans for a sub-interval is given by:

$$\text{Desired sub-interval (secs) / scan rate (secs)}$$

In an example where the scan rate is 1 second and the Output Flag is set every 60 minutes, the standard deviation is calculated from all 3600 scans when the sub-interval is 0. With a sub-interval of 900 scans (15 minutes) the standard deviation is the average of the four sub-interval standard deviations. The last sub-interval is weighted if it does not contain the specified number of scans.

¹ EPA On-site Meteorological Program Guidance for Regulatory Modeling Applications.

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There are three Output Options, which specify the values calculated.

Option 0:

Mean horizontal wind speed, **S**.
Unit vector mean wind direction, **Θ1**.
Standard deviation of wind direction, **σ(Θ1)**.

Standard deviation is calculated using the Yamartino algorithm. This option complies with EPA guidelines for use with straight-line Gaussian dispersion models to model plume transport.

Option 1:

Mean horizontal wind speed, **S**.
Unit vector mean wind direction, **Θ1**.

Option 2:

Mean horizontal wind speed, **S**.
Resultant mean wind speed, **U**.
Resultant mean wind direction, **Θu**.
Standard deviation of wind direction, **σ(Θu)**.

This standard deviation is calculated using Campbell Scientific's wind speed weighted algorithm.

Use of the Resultant mean horizontal wind direction is not recommended for straight-line Gaussian dispersion models, but may be used to model transport direction in a variable-trajectory model.

Measured raw data:

S_i = horizontal wind speed
 Θ_i = horizontal wind direction
 U_{e_i} = east-west component of wind
 U_{n_i} = north-south component of wind
 N = number of samples

Calculations:

Scalar mean horizontal wind speed, S:

$$S = (\sum S_i) / N$$

where in the case of orthogonal sensors:

$$S_i = (U_{e_i}^2 + U_{n_i}^2)^{1/2}$$

Unit vector mean wind direction, Θ1:

$$\Theta 1 = \text{Arctan} (U_x / U_y)$$

where

$$U_x = (\sum \sin \Theta_i) / N$$

$$U_y = (\sum \cos \Theta_i) / N$$

or, in the case of orthogonal sensors

$$U_x = (\sum (U_{e_i} / U_i)) / N$$

$$U_y = (\sum (U_{n_i} / U_i)) / N$$

$$\text{where } U_i = (U_{e_i}^2 + U_{n_i}^2)^{1/2}$$

Standard deviation of wind direction, σ(Θ1), using Yamartino algorithm:

$$\sigma(\Theta 1) = \text{arc sin}(\epsilon) [1 + 0.1547 \epsilon^3]$$

where ,

$$\epsilon = [1 - ((U_x)^2 + (U_y)^2)]^{1/2}$$

and U_x and U_y are as defined above.

Resultant mean horizontal wind speed, U:

$$U = (U_e^2 + U_n^2)^{1/2}$$

where for polar sensors:

$$U_e = (\sum S_i \sin \Theta_i) / N$$

$$U_n = (\sum S_i \cos \Theta_i) / N$$

or, in the case of orthogonal sensors:

$$U_e = (\sum U_{e_i}) / N$$

$$U_n = (\sum U_{n_i}) / N$$

Resultant mean wind direction, Θu:

$$\Theta u = \text{Arctan} (U_e / U_n)$$

Standard deviation of wind direction, σ(Θu), using Campbell Scientific algorithm:

$$\sigma(\Theta u) = 81(1 - U/S)^{1/2}$$

*** 70 SAMPLE ***

FUNCTION

This instruction stores the value from each specified input location.

PAR. DATA

NO.	TYPE	DESCRIPTION
01:	2	Repetitions
02:	4	Starting input location no.

Outputs generated: 1 for each sample

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***** 71 AVERAGE *****

FUNCTION

This instruction stores the average value over the given output interval for each input location specified.

PAR. DATA

NO. TYPE DESCRIPTION

01: 2 Repetitions
02: 4 Starting input location no.

Outputs generated: 1 for each input location

***** 72 TOTALIZE *****

FUNCTION

This instruction stores the totalized value over the given output interval for each input location specified.

PAR. DATA

NO. TYPE DESCRIPTION

01: 2 Repetitions
02: 4 Starting input location no.

Outputs generated: 1 for each input location

***** 73 MAXIMUM *****

FUNCTION

This instruction stores the MAXIMUM value taken (for each input location specified) over a given output interval. An internal FLAG is set whenever a new maximum value is seen. This FLAG may be tested by Instruction 79. Time of maximum value(s) is OPTIONAL output

information, which is selected by entering the appropriate code for Parameter 2.

PAR. DATA

NO. TYPE DESCRIPTION

01: 2 Repetitions
02: 2 Time of maximum (optional)
03: 4 Starting input location no.

Outputs generated: 1 for each input location (plus 1 or 2 with time of max. option)

CODE OPTIONS

00 Output the maximum (or minimum) value ONLY
01 Output the max. (or min.) value with SECONDS information
10 Output the max. (or min.) value with HOUR-MINUTE information
11 Output the max. (or min.) value with HR-MIN,SEC information

***** 74 MINIMUM *****

FUNCTION

Operating in the same manner as Instruction 73, this instruction is used for storing the MINIMUM value sensed (for each input location specified) over a given output interval.

PAR. DATA

NO. TYPE DESCRIPTION

01: 2 Repetitions
02: 2 Time of minimum (optional)
03: 4 Starting input location no.

Outputs generated: 1 for each input location (plus 1 or 2 with time of min. option)

***** 75 STANDARD AND WEIGHTED VALUE HISTOGRAM *****

FUNCTION

Processes input data as either a standard histogram (frequency distribution) or a weighted value histogram.

The standard histogram outputs the fraction of time that the value in a specified input location

SECTION 11. OUTPUT PROCESSING INSTRUCTIONS

(defined as the bin select value) is within a particular subrange of the total specified range. The count in the bin associated with each subrange is incremented whenever the value falls within that subrange. The value which is output to Final Storage for each bin is computed by dividing the accumulated total in each bin by the total number of scans. This form of output is also referred to as a frequency distribution.

The weighted value histogram uses data from 2 input locations. One location contains the bin select value; the other contains the weighted value. Each time the instruction is executed, the weighted value is added to a bin. The subrange that the bin select value is in determines the bin to which the weighted value is added. When the Output Flag is set, the value accumulated in each bin is divided by the TOTAL number of input scans to obtain the values that are output to Final Storage. These values are the contributions of the sub-ranges to the overall weighted value. To obtain the average of the weighted values that occurred while the bin select value was within a particular sub-range, the value output to Final Storage must be divided by the fraction of time that the bin select value was within that particular sub-range (i.e., a standard histogram of the bin select value must also be output).

For either histogram, the user must specify: 1) the number of repetitions, 2) the number of bins, 3) a form code specifying whether a closed or open form histogram is desired (see below), 4) the bin select value input location, 5) the weighted value input location (see below), 6) the lower range limit, 7) the upper range limit.

The standard histogram (frequency distribution) is specified by entering "0" in the weighted value input location parameter. Otherwise, this parameter specifies the input location of the weighted value. With more than one repetition the bin select value location will be incremented each repetition and the weighted value location will remain the same (same weighted value sorted on the basis of different bin select values). The weighted value location will be incremented if it is entered as an indexed location (key "C" at some point while keying in Parameter 5; two dashes, --, will appear on the right of the display).

At the user's option, the histogram may be either closed or open. The open form includes all values below the lower range limit in the first bin and all values above the upper range limit in the last bin. The closed form excludes any values falling outside of the histogram range.

The difference between the closed and open form is shown in the following example for temperature values:

Lower range limit	10°C		
Upper range limit	30°C		
Number of bins	10		
		Closed Form	Open Form
Range of first bin	10 to 11.99°		<12°
Range of last bin	28 to 29.99°		>28°

A common use of a closed form weighted value histogram is the wind speed rose. Wind speed values (the weighted value input) are accumulated into corresponding direction sectors (bin select input).

PAR. NO.	DATA TYPE	DESCRIPTION
01:	2	Repetitions
02:	4	Number of bins
03:	2	Form code (0=open form, 1=closed form)
04:	4	Bin select value input location no.
05:	4	Weighted value input location no. (0 = frequency distribution option)
06:	FP	Lower limit of range
07:	FP	Upper limit of range

Outputs generated: number of bins * repetitions

*** 77 RECORD REAL TIME ***

FUNCTION

This instruction stores the current time in Final Storage. At midnight the clock rolls over from 23:59 to 00:00. The day also changes.

If hourly or daily summary data is output, it may be desirable to have the previous day specified with the output, since that is when the measurements were made. Entering a 2 for the day code causes the previous day to be output if

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it is the first minute of the day. Similarly, entering 2 for the hour-minute code causes 2400 instead of 0000 to be output (the next minute is still 0001). When day and hour-minute are both output, a 2 for either code results in the previous day at 2400.

The year is output as 19xx if xx is greater than 85, otherwise it will be output as 20xx. The 21X will require a PROM update in the year 2085. If year is output along with a 2 option in day or hour-minute, the previous year will be output during the first minute of the new year.

CODE RESULTS

xxx1	SECONDS (with a resolution of 0.1 sec.)
xx1x	HOUR-MINUTE
xx2x	HOUR-MINUTE, 2400 instead of 0000
x1xx	DAY OF YEAR
x2xx	DAY OF YEAR, previous day during first minute of new day
1xxx	YEAR

Any combination of Year, Day, HR-MIN, and seconds is possible (e.g., 1011: YEAR, HR-MIN, SEC).

PAR. DATA
NO. TYPE DESCRIPTION

01: 4 Enter appropriate TIME option code

Outputs generated: 1 for each time parameter selected

*** 78 SET HIGH OR LOW RESOLUTION *** FINAL STORAGE FORMAT

FUNCTION

This instruction sets the Final Storage Format to high resolution (5 character) or low resolution (4 character, Section 2.2). Instruction 78 should be entered ahead of the output instructions for which the specified resolution is desired. The default format is low resolution. At the beginning of each program table execution, the low resolution format is automatically enabled.

PAR. DATA
NO. TYPE DESCRIPTION

01: 2 0 = low resolution;
1 = high resolution

Outputs generated: 0

*** 79 SAMPLE ON MAXIMUM *** OR MINIMUM

FUNCTION

Instruction 79 samples specified input location values at the time a new maximum or minimum value is detected by a previous Maximize (73) or Minimize (74) Instruction. When the Output Flag is set, the values copied to Intermediate Storage are transferred to Final Storage.

Instruction 79 must directly follow the maximum or minimum Instruction to which it refers. If the previous Instruction 73 or 74 has more than 1 repetition, Instruction 79 samples whenever a new maximum or minimum is detected in any of the locations. If sampling is to occur only when a specific input location shows a new maximum or minimum, the previous Maximize or Minimize Instruction should have one rep referring to that input location.

PAR. DATA
NO. TYPE DESCRIPTION

01: 2 Repetitions (number of sequential locations to sample)

02: 4 Starting input location no.

Outputs generated: 1 for each repetition

*** 80 SET ACTIVE OUTPUT AREA ***

Instruction 80 is inserted prior to a series of Output Processing Instructions to set the output array ID recorded with the data in Final Storage or to direct the results to Input Storage. The first parameter selects either Final or Input Storage. When data are sent to Input Storage, no ID is sent.

At the start of each pass through a program table, the active output area is Final Storage. If Instruction 80 is not used in the program, output data are sent to Final Storage and the array ID is determined by the location of the instruction that sets the output flag (Section 2.1).

SECTION 11. OUTPUT PROCESSING INSTRUCTIONS

The output flag must be set each time Instruction 80 is used. Instruction 80 must directly follow the instruction that sets the output flag.

PAR. DATA

NO.	TYPE	DESCRIPTION
01:	2	Storage area option 01 = Final Storage (00 and 02 also default to Final Storage) 03 = Input Storage Area
02:	4	Starting input location destination if option 03 Output Array ID if options 0-2 (1-511 are valid IDs)

*** 81 RAINFLOW HISTOGRAM ***

The Rainflow Instruction implements the rainflow counting algorithm, essential to estimating cumulative damage fatigue to components undergoing stress/strain cycles. Data can be provided by making measurements in either the standard or the burst mode. The Rainflow Instruction can process either a swath of data following the burst mode, or it can process "on line" similar to other processing instructions.

The output is a two dimensional Rainflow Histogram for each sensor or repetition. One dimension is the amplitude of the closed loop cycle (i.e., the distance between peak and valley); the other dimension is the mean of the cycle (i.e., [peak value + valley value]/2). The value of each element (bin) of the histogram can be either the actual number of closed loop cycles that had the amplitude and average value associated with that bin or the fraction of the total number of cycles counted that were associated with that bin (i.e., number of cycles in bin divided by total number of cycles counted).

The user enters the number of mean bins, the number of amplitude bins, and the upper and lower limits of the input data.

The values for the amplitude bins are determined by difference between the upper and lower limits on the input data and by the number of bins. For example, if the lower limit is 100 and the upper limit is 150, and there are 5 amplitude bins, the maximum amplitude is 150 -

100 = 50. The amplitude change between bins and the upper limit of the smallest amplitude bin is $50/5 = 10$. Cycles with an amplitude, A , less than 10 will be counted in the first bin. The second bin is for $10 \leq A < 20$, the third for $20 \leq A < 30$, etc.

In determining the ranges for mean bins, the actual values of the limits as well as their difference are important. The lower limit of the input data is also the lower limit of the first mean bin. Assume once again that the lower limit is 100, the upper limit 150, and that there are 5 mean bins. In this case the first bin is for cycles which have a mean value, M , $100 \leq M < 110$, the second bin $110 \leq M < 120$, etc.

If C_{ma} is the count for mean range m and amplitude range a , and M and N are the number of mean and amplitude bins respectively; then the output of one repetition is arranged sequentially as $(C_{1,1}, C_{1,2}, \dots, C_{1,N}, C_{2,1}, C_{2,2}, \dots, C_{M,N})$. Multiple repetitions are sequential in memory. Shown in two dimensions, the output is:

$C_{1,1}$	$C_{1,2}$	...	$C_{1,N}$
$C_{2,1}$	$C_{2,2}$	...	$C_{2,N}$
.	.	.	.
.	.	.	.
.	.	.	.
$C_{M,1}$	$C_{M,2}$	...	$C_{M,N}$

The histogram can have either open or closed form. In the open form, a cycle that has an amplitude larger than the maximum bin is counted in the maximum bin; a cycle that has a mean value less than the lower limit or greater than the upper limit is counted in the minimum or maximum mean bin. In the closed form, a cycle that is beyond the amplitude or mean limits is not counted.

The minimum distance between peak and valley, Parameter 8, determines the smallest amplitude cycle that will be counted. The distance should be less than the amplitude bin width ($[\text{high limit} - \text{low limit}] / \text{no. amplitude bins}$) or cycles with the amplitude of the first bin will not be counted. However, if the value is too small, processing time will be consumed counting "cycles" which are in reality just noise.

SECTION 11. OUTPUT PROCESSING INSTRUCTIONS

More than one Rainflow Histogram can be calculated using the Repetitions parameter. The swath of input data, the size of the mean and amplitude dimensions, the low and high limits of the input data, and minimum distance between peaks and valley are all selectable by the user with parameters.

Data are output to Final Storage or to Input Storage for further processing when the datalogger's Output Flag is set. Partial accumulations are kept in Intermediate Storage.

PAR. DATA		
NO.	TYPE	DESCRIPTION
01:	2	Repetitions
02:	4	Input location of input data
03:	4	Swath (per rep) of data at input location; 1 = on line processing
04:	4	No. of Mean bins
05:	4	No. of Amplitude bins
06:	FP	Low limit of input data
07:	FP	High limit of input data
08:	FP	Minimum distance between peak and valley
09:	2	Option (AB) A: Form 0 = closed, 1 = open form B: Output 0 = fraction, 1 = counts
10:	4	Input location to start storing histogram. Enter 0 to send output directly to Final Storage.

Execution time: 6.5 - 7.0 msec, with 60 Amplitude Bins and 1 Mean Bin.

Intermediate Storage locations required: $\text{Reps} \times (\text{Bins} + 2 \times (\text{No. Amplitude Bins}) + 4)$, where Bins = No. Means Bins \times No. Amplitude Bins.

*** 82 STANDARD DEVIATION IN TIME ***

FUNCTION

Calculate the standard deviation (STD DEV) of a given input location. The standard deviation is calculated using the formula:

$$S = ((\sum X_i^2 - (\sum X_i)^2/N)/N)^{1/2}$$

where X_i is the i th measurement and N is the number of samples.

PAR. DATA		
NO.	TYPE	DESCRIPTION

01:	2	Repetitions
02:	4	Starting input location no.

Outputs generated: 1 for each repetition

SECTION 11. OUTPUT PROCESSING INSTRUCTIONS

SECTION 12. PROGRAM CONTROL INSTRUCTIONS

TABLE 12-1. Flag Description

Flag 0	Output Flag
Flag 1 to 8	User Flags
Flag 9	Intermediate Processing Disable Flag

TABLE 12-2. Command Codes

0	-	Go to end of program table
1-9, 77-99	-	Call Subroutine 1-9, 77-99
10-19	-	Set Flag 0-9 high
20-29	-	Set Flag 0-9 low
30	-	Then Do
31	-	Exit loop if true
32	-	Exit loop if false
41-46	-	Set port 1 - 6 high
51-56	-	Set port 1 - 6 low
61-66	-	Toggle port 1 - 6
71-76	-	Pulse port 1 - 6 100 ms

***** 83 IF CASE X < F *****

FUNCTION

Instruction 83 tests the value in an input location specified in the Begin Case Instruction 93. A series of Instructions 83 are used to compare the value in the input location to ever increasing fixed values. If the value in the location is less than the fixed value entered as Parameter 1, then the command in Parameter 2 is executed and when the next Instruction 83 is encountered execution branches to the end of the case statement. If the fixed value is less, the next Instruction 83 is executed. See Instruction 93 for an example.

PARAM. NUMBER	DATA TYPE	DESCRIPTION
01:	FP	Fixed value
02:	2	Command

***** 85 LABEL SUBROUTINE *****

FUNCTION

This instruction marks the start of a subroutine. A subroutine is a series of instructions beginning with Instruction 85 and terminated with

Instruction 95, END. All subroutines must be placed in Table 3 (Subroutine Table). When a subroutine is called by a command in a Program Control Instruction, the subroutine is executed, then program flow continues with the instruction following that which called the subroutine.

Subroutines cannot be embedded within other subroutines; a subroutine must end before the next one begins. Subroutines may be called from within other subroutines (nested). The maximum nesting level for subroutines is 7 deep. Attempts to nest more than 7 deep will not be detected at compilation, but will result in a run time error. When the seventh subroutine attempts to call the eighth, error 31 will be displayed. Execution will not branch to the eighth subroutine; it will continue with the Instruction following that calling the subroutine.

PAR. NO.	DATA TYPE	DESCRIPTION
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01: 2 Subroutine number (1-9, 77-99)

***** 86 DO *****

FUNCTION

This instruction unconditionally executes the specified command.

PAR. NO.	DATA TYPE	DESCRIPTION
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01: 2 Command (Table 12-2)

***** 87 LOOP *****

FUNCTION

Instructions included between the Loop Instruction and the End Instruction (95) are repeated the number of times specified by the iteration count (Parameter 2), or until an Exit Loop command (31, 32) is executed by a Program Control Instruction within the Loop. If 0 is entered for the count, the loop is repeated until an Exit Loop command is executed.

The first parameter, delay, controls how frequently passes through the loop are made. The delay unit is the table execution interval:

SECTION 12. PROGRAM CONTROL INSTRUCTIONS

A delay of 0 means that there is no delay between passes through the loop. Each time the table is executed all iterations of the loop will be completed and execution will pass on to the following instructions.

If the delay is 5, every fifth time that the execution interval comes up, one pass through the loop is made; only those instructions in the loop will be executed and other portions of the table are not executed in the interim. When the loop is executed, execution starts at the loop, skipping over any previous instructions in the table.

When a fixed number of iterations are executed, the time spent in the loop is equal to the product of the execution interval, delay, and the number of iterations. For example, a loop with a delay of 1 and a count of 5 will take 5 seconds if the execution interval is 1 second. When the loop is first entered, one pass through the loop is made, then the 21X delays until the next execution interval and makes the second pass through the loop. After making the fifth pass through the loop, there is the fifth delay, after which execution passes to the instruction following the END instruction which goes with the loop.

While in a loop with delay, the table will not be initiated at each execution interval. (However, the overrun decimals will not be displayed.) Some consequences of this are: The Output Flag will not be automatically cleared between passes through the loop. Because Table 2 cannot interrupt Table 1, Table 2 will not be executed while Table 1 is in a loop with delay. Table 1 will not interrupt Table 2 in the middle of an output array. Thus, if the Output Flag is set in Table 2 prior to entering the loop or within the loop, the flag must be specifically cleared before the end of the pass or Table 1 will not be able to interrupt.

Input locations for Processing Instructions within a loop can be entered as Indexed locations. An Indexed location causes the input location to be incremented by 1 with each pass through the loop. (The Index counter is added to the location number in the program table.) Input locations which are not indexed will remain constant.

To specify an Indexed location, depress the C key at some point while keying in the digits for the input location and before entering the location with the A key. Two dashes, --, appear in the two right most characters of the display, indicating the entry is Indexed.

When the same output processing is required on values in sequential input locations, it must be accomplished by using the repetitions parameter of the Output Instruction, not by indexing the input location within a loop.

An Output Instruction within a loop is allotted the same number of Intermediate Storage locations as it would receive if it were not in the loop. For example, the Average instruction with a single repetition is allotted only two Intermediate locations: one for the number of samples and one for the running total. Each time through the loop the sample counter is incremented and the value in the referenced input location is added to the total. If the input location is indexed, the values from all input locations are added to the same total. If the Average instruction with 1 repetition and location 1 indexed is placed within a loop of 10 and the Output Flag set high prior to entering the loop, 10 values will be output. These will not be the averages for locations 1-10. The first will be the average of all the readings in locations 1-10 since the previous output. Because the Intermediate locations are zeroed each time an output occurs, the next nine values will be the current values (samples at the time of output) of Locations 2-10.

Loops can be nested. Indexed locations within nested loops are indexed to the inner most loop that they are within. The maximum nesting level in the 21X is 9 deep. This applies to If Then/Else comparisons and Loops or any combination thereof. An If Then/Else comparison which uses the Else Instruction, 94 counts as being nested 2 deep.

PAR.	DATA	
NO.	TYPE	DESCRIPTION
01:	2	Delay
02:	4	Iteration count

The following example involves the use of the Loop Instruction, without a delay, to perform a block data transformation.

SECTION 12. PROGRAM CONTROL INSTRUCTIONS

The user wants 1 hour averages of the vapor pressure calculated from the wet- and dry-bulb temperatures of 5 psychrometers. One pressure transducer measurement is also available for use in the vapor pressure calculation.

1. The input locations are assigned as follows:
 - a) pressure - location 10
 - b) dry-bulb temperatures - location 11-15
 - c) wet-bulb temperatures - location 16-20
 - d) calculated vapor pressure - location 16-20 (vapor pressure is written over the wet-bulb temperatures.)

2. The program flow is as follows:
 - a) Enter the Loop Instruction 87 with delay=0 and iteration count=5.
 - b) Calculate the vapor pressure with Instruction 57 using a normal location entry of 10 for atmospheric pressure and Indexed locations of 11, 16 and 16 for the dry-bulb, wet-bulb and calculated vapor pressure, respectively.
 - c) End loop with Instruction 95.
 - d) Use the If Time Instruction 92 to set the Output Flag every hour.
 - e) Use the Average Instruction 71 with 5 repetitions starting at Input Location 16 to average the vapor pressure over the hour.

The actual keyboard entries for the examples are shown below with the first example Instruction location equal to 10. The Input Instructions to make the pressure and temperature measurements are assumed.

TABLE 12-3. Loop Example: Block Data Transform

10:	P87	Beginning of Loop
01:	0	Delay
02:	5	Loop Count
11:	P57	Wet/Dry Bulb Temp to VP
01:	10	Pressure Loc
02:	11--	Dry Bulb Temp Loc DRY BLB#1
03:	16--	Wet Bulb Temp Loc VP #1
04:	16--	Loc [:VP #1]
12:	P95	End
13:	P92	If time is
01:	0	minutes into a
02:	60	minute interval
03:	10	Set high Flag 0 (output)
14:	P71	Average
01:	5	Reps
02:	16	Loc VP #1

The Loop with a delay may be used so that only those instructions within the Loop are executed while certain conditions are met. As a simple example, suppose it is desired to execute one set of instructions from midnight until 6 AM, another set between 6 AM and 4 PM, and a third set between 4 PM and midnight. Between 6 AM and 4 PM, samples are desired every 10 seconds; the rest of the time one minute between samples is sufficient. The execution interval is set to 10 seconds; when a one minute sample rate is desired, a delay of 6 (6 x 10s = 60s) is used in the loop.

TABLE 12-4. Example: Loop with Delay Execution Interval = 10 seconds

*	1	Table 1 Programs
01:	10	Sec. Execution Interval
01:	P87	Beginning of Loop
01:	6	Delay
02:	0	Loop Count
11:	P86	Do
01:	1	Call Subroutine 1

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```

12:  P89      If X<=>F
    01:  25      X Loc DAY
    02:  3       >=
    03:  6       F
    04:  31      Exit Loop if true

13:  P95      End

14:  P87      Beginning of Loop
    01:  1       Delay
    02:  0       Loop Count

27:  P86      Do
    01:  1       Call Subroutine 1

28:  P89      If X<=>F
    01:  25      X Loc DAY
    02:  3       >=
    03:  16      F
    04:  31      Exit Loop if true

29:  P95      End

30:  P87      Beginning of Loop
    01:  6       Delay
    02:  0       Loop Count

36:  P86      Do
    01:  1       Call Subroutine 1

37:  P89      If X<=>F
    01:  25      X Loc DAY
    02:  3       >=
    03:  5       F
    04:  32      Exit Loop if false

38:  P95      End

39:  P        End Table 1

*    3        Table 3 Subroutines

01:  P85      Beginning of Subroutine
    01:  1       Subroutine Number

02:  P18      Time
    01:  2       Hours into current year
                (maximum 8784)
    02:  24      Mod/by
    03:  25      Loc [:DAY  ]

03:  P95      End

```

*** 88 IF X COMPARED TO Y ***

FUNCTION

This instruction compares two input locations and, if the result is true, executes the specified Command. The comparison codes are given in Table 12-5.

PAR. DATA
NO. TYPE DESCRIPTION

01: 4 Input location for X
02: 2 Comparison code (Table 12-5)
03: 4 Input location for Y
04: 2 Command

Input locations altered: 0
Execution time: 0.6ms

TABLE 12-5. Comparison Codes

Parameter 1	Function
1	IF X = Y
2	IF X ≠ Y
3	IF X > Y
4	IF X < Y

*** 89 IF X COMPARED TO F ***

FUNCTION

This instruction compares an input location to a fixed value and, if the result is true, performs the specified Command. The comparison codes are given in Table 12-5.

PAR. DATA
NO. TYPE DESCRIPTION

01: 4 Input location for X
02: 2 Comparison code (Table 12-5)
03: FP Fixed value
04: 2 Command

*** 90 STEP LOOP INDEX ***

FUNCTION

When used within a Loop (Instruction 87), Instruction 90 will increment the index counter by a specified amount after the first time through the loop, thus affecting all indexed input location parameters in subsequent instructions within the loop. For example, if 4 is specified, the index counter will count up by 4 (0, 4, 8, 12,...) inside

SECTION 12. PROGRAM CONTROL INSTRUCTIONS

the loop. Instruction 90 does not affect the loop counter which still counts by 1.

PAR. DATA
NO. TYPE DESCRIPTION

01: 2 Increment for the loop index counter

***** 91 IF FLAG, PORT *****

FUNCTION

This instruction checks one of the ten flags or 8 ports and conditionally performs the specified command.

The high input of any differential channel may be used to sense the status of a logic signal (3 V < high < 5.5 V; -0.5 V < low < 0.8 V). This option only exists with 21X PROMS released after July 1993 (OSX-X.1 revision 3 and greater).

The first parameter specifies the flag or port to check and the state (high or low) on which to execute the command.

- 1X = execute Command if Flag X is high
- 2X = execute if Flag X is low
- 4X = execute if Port X is high
- 5X = execute if Port X is low

PAR. DATA
NO. TYPE DESCRIPTION

01: 2 Flag/status
02: 2 Command

***** 92 IF TIME *****

FUNCTION

The user specifies the number of minutes into an interval, the duration of the interval, and a command. The command is executed each time the real time is the specified number of minutes into the interval.

The time interval is synchronized with real time; if a 60 minute time interval is specified with 0 minutes into the interval, the Command will be executed each hour on the hour. The time interval is automatically synchronized by making a modulo divide of the number of minutes since midnight by the specified real time interval. If the result is 0, the interval is up. Thus, the first interval of the day always starts at midnight (0 minutes). Only one execution is allowed in any minute (e.g., if the command is to set the Output Flag, and the execution interval of the table is 10 seconds, there will only be one output generated by this instruction, not six.)

The Output Flag (Flag 0) is a special case in that it will automatically be set low if it is not time to set it high.

PAR. DATA
NO. TYPE DESCRIPTION

01: 4 Time into interval (minutes)
02: 4 Time interval (minutes)
03: 2 Command

***** 93 BEGIN CASE STATEMENT *****

Instruction 93 specifies an input location for comparison with fixed values in subsequent If Case instructions (83). When a comparison is true, the command in the If Case instruction is executed and at the next Instruction 83 execution jumps to the End Instruction 95 associated with the Begin Case Instruction.

PAR. DATA
NO. TYPE DESCRIPTION

01: 4 Input location for subsequent comparisons

EXAMPLE:

01: P93 Case
01: 2 Case Loc

02: P83 If Case Location < F
01: 69.4 F
02: 3 Call Subroutine 3
else

03: P83 If Case Location < F
01: 72 F
02: 10 Set high Flag 0 (output)
else

04: P83 If Case Location < F
01: 77.3 F
02: 30 Then Do

05: P30 Z=F
01: 0 F
02: 0 Exponent of 10
03: 25 Z Loc :

06: P95 End *Then Do*

07: P95 End *of Case Statement*

***** 94 ELSE *****

FUNCTION

When Command 30 (Then/Else) is used with If Instruction, the Else Instruction is used to mark

SECTION 12. PROGRAM CONTROL INSTRUCTIONS

the start of the instructions to execute if the test condition is false (Figure 3.8-1). The Else Instruction is optional; when it is omitted, a false comparison will result in execution branching directly to the End Instruction. Instruction 94 has no parameters.

***** 95 END *****

FUNCTION

Instruction 95 is used to indicate the end/return of a subroutine (Instruction 85), the end of a loop (Instruction 87), the end of an If Then/Else sequence, or the end of the Case statement (Instructions 88-93 when used with command 30). The End Instruction has no parameters.

***** 96 ACTIVATE SERIAL DATA OUTPUT *****

FUNCTION

Instruction 96 is used instead to activate the tape, Storage Module, or serial port output. By using Program Control Instructions to allow execution of Instruction 96 only at certain times, the user can control when the output is active.

When used to send data to the SM192 or SM716 Storage Module, the 21X can determine whether or not the Storage Module is connected. If the Storage Module is not connected, the data will not be sent until it is connected. Instruction 96 also allows for faster data output via the serial port with the Binary Option, which outputs FINAL STORAGE FORMAT (2 bytes per low resolution data point) instead of ASCII (10 bytes per data point, Section 4.5). Appendix C describes FINAL STORAGE FORMAT. Section 4.3 describes Tape output.

A single parameter is used to select whether the instruction is to control the tape, Storage Module, or the printer output, and if the printer is selected, the format and baud rate. Instruction 96 must be entered separately for each output device used.

Instruction 96 uses the same Tape and Printer pointers as the *8 and *9 modes which can be used to get a residual or partial dump of Final Storage (Section 4). Note that the Tape output will not activate until at least 512 Final Storage Locations have been stored.

Do not use *4 to activate a device that is activated by Instruction 96.

PAR. DATA
NO. TYPE DESCRIPTION

01: 2 The left digit specifies the Option and the right digit specifies the baud rate for the printer. The code for tape must be 00, and for Storage Module it is 30.

Option	X = Baud Rate
00 -- TAPE	0 -- 300
1X -- PRINTER, ASCII	1 -- 1200
2X -- PRINTER, Binary	2 -- 9600
30 -- SM192 or SM716	3 -- 76,800
31 -- Send filemark to SM192/716	

***** 97 INITIATE *****
TELECOMMUNICATIONS

Instruction 97 is used to have the 21X initiate telecommunications in response to certain conditions. When the instruction is executed with the interrupt disable flag set low, the 21X will make a call and send the ID number specified in Parameter 8 (in ASCII at the specified baud rate). The ID number will be sent every 4 seconds until the 21X receives a response or the time specified in Parameter 3 expires. The expected response is to have the ID sent back to the 21X, at which time the 21X will go into telecommunications and the normal telecommunications time limit will take effect (Section 5.1). The 21X will not send any data without first receiving a command to do so. The TELCOM program in Campbell Scientific's PC208 datalogger support software enables IBM PC/XT/AT/PS2 and compatible computers to automatically answer calls and retrieve data.

When the 21X receives a correct digit for the ID, it restarts the 4 second timer. There are then 4 seconds in which the next digit must be received before the 21X again sends the ID. When the 21X sends the ID, it expects the response to start from the beginning. If an incorrect character is detected, the 21X will immediately send the correct ID. If a correct response is not received within the time allotted in Parameter 3, the 21X will hang up.

SECTION 12. PROGRAM CONTROL INSTRUCTIONS

When either the DC112 or RF modem options are specified, the time limit on the call (without a correct response) specified in Parameter 3 is timed from the start of the instruction and must include the dialing time.

If the correct response is not received within the time specified in Parameter 3, the 21X will continue to make calls. The 21X will repeat the calls at the fast interval specified by Parameter 4 for the number of retries specified in Parameter 5, after which the calls will be attempted at the slow interval specified in Parameter 6. Parameter 4 and 6 are timed from the start of the Instruction. The actual delay between retries for both the fast and slow attempts has a random factor built in, which is added as an offset to the delay specified. The random factor prevents calls from different stations from occurring at the same time. This offset will range between 0 and one half of the delay specified. The resolution of the timer for these delays is the execution interval of the table in which the alarm call is initiated.

Parameter 2 specifies which user flag (1-8) is to be used as the interrupt disable flag. If this flag is set high, Instruction 97 will not initiate an alarm call. If the 21X is in the process of trying to get through with an alarm call, setting the interrupt disable flag high will abort further attempts. Instruction 97 sets this flag high when an alarm call has received the correct response. Instruction 97 does not set the flag low; the flag will remain high until set low by the program or external command. When the flag is set low, Instruction 97 is reinitialized.

Instruction 97 is unique in having a variable number of parameters. Parameter 9 is the number of stations, if any, in a RF link to the base station. A non-zero entry (N) for Parameter 9 will result in N parameters, numbered 10 to N+9, in which the RF station IDs are keyed. The RF station IDs are the IDs of the RF Modems in the path from the initiating datalogger to the base station. This excludes the ID of the initiating datalogger's RF Modem. Parameter 10+N (10 if 0 RF stations are specified) is the number of digits, if any, in the phone number. There are then as many additional parameters as the number of digits entered. The phone number is entered 1 digit per parameter.

If the call is to go through a RF link to a phone, then the RF Modem is specified in Parameter 1. A RF Modem must be used between the DC95 and the phone line. See the PC208 manual for additional interfacing notes.

When the DC112 Modem (Hayes compatible commands) is specified, the following commands are sent to the modem before the phone number: ATV0, ATS7=180, and ATDT. The first command causes the modem to respond with digits rather than words. The second command causes the modem to wait for the carrier 180 seconds after calling or answering. The third command causes the Hayes to dial the number that follows the command in "Touch Tones". The 21X will not accept the line feed found in some Hayes "compatible" modems.

PAR. NO.	DATA TYPE	DESCRIPTION										
01:	2	Modem option and baud rate code. The left digit specifies the modem being used and the right, the baud rate. <table border="1" style="margin-left: 20px;"> <thead> <tr> <th>Modem</th> <th>Baud Rate</th> </tr> </thead> <tbody> <tr> <td>0 - RF Modem</td> <td>0 - 300</td> </tr> <tr> <td>1 - Direct</td> <td>1 - 1200</td> </tr> <tr> <td>2 - DC112</td> <td>2 - 9600</td> </tr> <tr> <td></td> <td>3 - 76,800</td> </tr> </tbody> </table>	Modem	Baud Rate	0 - RF Modem	0 - 300	1 - Direct	1 - 1200	2 - DC112	2 - 9600		3 - 76,800
Modem	Baud Rate											
0 - RF Modem	0 - 300											
1 - Direct	1 - 1200											
2 - DC112	2 - 9600											
	3 - 76,800											
02:	2	Interrupt disable flag (0-8)										
03:	4	Time limit on call, 1 sec. units										
04:	4	Delay between fast retries, 1 sec. units										
05:	2	Number of retries at fast rate										
06:	4	Delay between slow retries, 1 min. units										
07:	4	Input location to store no. of tries										
08:	4	ID to send										
09:	2	Number of RF Stations (N)										
10 to N+9:	4	Station IDs										
10+N:	2	Number of Digits (D) in phone number										
N+11 to D+N+10	2	Telephone number by single digits										

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*** 98 SEND CHARACTER ***

Instruction 98 is used to send a character to the printer. The single parameter sets the baud rate and gives the decimal equivalent of the 7 bit character (sent as 8 bits, no parity). For example, to send the ASCII character control R at 9600 baud, 2018 would be entered for Parameter 1. This instruction can be used to send a control character to activate some device. The specified character is sent at the time Instruction 98 is executed; this will cause it to precede any output arrays generated in the same table, since the output data is sent to the printer at the completion of the table.

PAR. DATA

NO. TYPE DESCRIPTION

01: 4 Decimal Value of ASCII character:
yxxx xxx=ASCII value (1-127)
y=Baud rate code
0 300 baud
1 1200 baud
2 9600 baud
3 76,800 baud

SECTION 13. 21X MEASUREMENTS

13.1 FAST AND SLOW MEASUREMENT SEQUENCE

The 21X makes voltage measurements by integrating the input signal for a fixed time and then holding the integrated value for the analog to digital (A/D) conversion. The A/D conversion is made with a 14 bit successive approximation technique which resolves the signal voltage to approximately one part in 15,000 of the full scale range on a differential measurement (e.g., $1/15,000 \times 5V = 333\mu V$). The resolution of a single-ended measurement is one part in 7500.

Integrating the signal removes noise that could create an error if the signal were instantaneously sampled and held for the A/D conversion. The slow integration time provides a more noise-free reading than the fast integration time. One of the most common sources of noise is 60 Hz from AC power lines. The slow integration time of 16.67 milliseconds (1.67ms on the 5V range) is equal to one 60 Hz cycle. During the integration time, the AC noise will integrate to 0. With different software and a hardware modification, the slow integration time can be lengthened to 20 ms for countries that have 50 Hz power.

There are several situations where the fast integration time of 250 microseconds ($25\mu s$ on the 5V range) is preferred. The fast integration time minimizes time skew between measurements and increases the throughput rate. The current drain on the 21X batteries is lower when fast integration time is used. The fast integration time should ALWAYS be used with the AC half bridge (Instruction 5) when measuring AC resistance or the output of an LVDT. An AC resistive sensor will polarize if a DC voltage is applied, causing erroneous readings and sensor decay. The induced voltage in an LVDT decays with time as current in the primary coil shifts from the inductor to the series resistance; a long integration time would result in most of the integration taking place after the signal had disappeared.

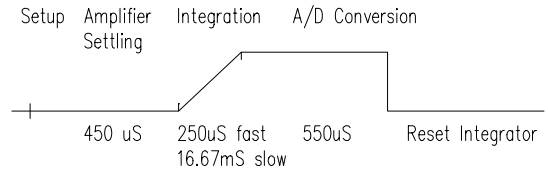


FIGURE 13.1-1. Timing of Single-Ended Measurement

Before making a series of measurements prescribed by an Input Instruction, the 21X makes a calibration measurement. The calibration is accomplished by measuring two known voltages which are sent through the same amplifier circuit that will be used for the measurements. The calibration for a single-ended measurement consists of measuring a voltage which is 4/5ths of full scale and then making a measurement with the input grounded. A differential measurement is made once with the inputs as connected and a second time with the inputs reversed (Section 13.2); calibration for differential measurements uses voltages at $\pm 4/5$ ths of full scale.

13.2 SINGLE-ENDED AND DIFFERENTIAL VOLTAGE MEASUREMENTS

NOTE: The channel numbering on the 21X panel refers to differential channels. Either the high or low side of a differential channel can be used for single ended measurements. Each side must be counted when numbering single-ended channels; e.g., the high and low sides of differential channel 8 are single-ended channels 15 and 16, respectively.

The timing and sequence of a single-ended measurement is shown in Figure 13.1-1. A single-ended measurement is made on a single input which is referenced to ground. A single integration is performed for each measurement. A differential measurement measures the difference in voltage between two inputs. The measurement sequence on a differential measurement involves two integrations: First with the high input referenced to the low, then with the inputs reversed (Figure 13.2-1). The 21X computes the differential voltage by

SECTION 13. 21X MEASUREMENTS

averaging the magnitude of the results from the two integrations and using the polarity from the first. An exception to this is the differential measurement in Instruction 8 which makes only one integration.

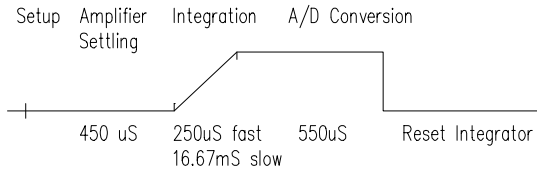


FIGURE 13.2-1. Differential Voltage Measurement Sequence

Because a single-ended measurement is referenced to 21X ground, any difference in ground potential between the sensor and the 21X will result in an error in the measurement. For example, if the measuring junction of a copper-constantan thermocouple, being used to measure soil temperature, is not insulated and the potential of earth ground is 1mV greater at the sensor than at the point where the 21X is grounded, the measured voltage would be 1mV greater than the thermocouple output or approximately 25°C high. Another instance where a ground potential difference creates a problem is in a case such as described in Section 7.2, where external signal conditioning circuitry is powered from the same source as the 21X. Despite being tied to the same ground, differences in current drain and lead resistance result in different ground potential at the two instruments. For this reason a differential measurement should be made on an analog output from the external signal conditioner. Differential measurements MUST be used where the inputs are known to be different from ground, such as is the case with the output from a full bridge.

In order to make a differential measurement, the inputs must be within the 21X common mode range of $\pm 5V$. The common mode range is the voltage range, relative to 21X ground, within which both inputs of a differential measurement must lie in order for the differential measurement to be made. For example, if the high side of a differential input is at 4V and the low side is at 3V relative to 21X ground, there is no problem; a measurement made on the $\pm 5V$ range would indicate a signal of 1V. However, if the high input is at 5.8V and the low input is at 4.8V, the measurement

cannot be made because the high input is outside of the common mode range. (The 21X will indicate the overrange with the maximum negative number, see Section 3.5.)

Problems with exceeding common mode range may be encountered when the 21X is used to read the output of external signal conditioning circuitry if a good ground connection does not exist between the external circuitry and the 21X. When operating where AC power is available, it is not always safe to assume that a good ground connection exists through the AC wiring. If a 21X is used to measure the output from a laboratory instrument (both plugged into AC power and referencing ground to outlet ground), it is best to run a ground wire between the 21X and the external circuitry. Even with this ground connection, the ground potential of the two instruments may not be at exactly the same level, which is why a differential measurement is desired.

A differential measurement has better noise rejection than a single-ended measurement. Integrating the signal in both directions also reduces input offset voltage due to thermal effects in the amplifier section of the 21X. Input offset voltage on a single-ended measurement is less than 5 microvolts; the input offset voltage on a differential measurement is less than 1 microvolt.

A single-ended measurement is quite satisfactory in cases where noise is not a problem and care is taken to avoid ground potential problems. Channels are available for twice as many single-ended measurements. A single-ended measurement takes about half the time of a differential measurement, which is valuable in cases where rapid sampling is a requirement.

NOTE: Sustained voltages in excess of ± 16 VDC applied to the analog inputs will damage the 21X input circuitry.

13.3 THE EFFECT OF SENSOR LEAD LENGTH ON THE SIGNAL SETTling TIME

Whenever an analog input is switched into the 21X measurement circuitry prior to making a measurement, a finite amount of time is required for the signal to stabilize at its correct value. The rate at which the signal settles is determined by the input settling time constant which is a function of both the source resistance, and input capacitance (explained below). The 21X allows a 450µs settling time before initiating the measurement. In most applications this settling time is adequate, but the additional wire capacitance associated with long sensor leads can increase the settling time constant to the point that measurement errors may occur. There are three potential sources of error which must settle before the measurement is made:

1. The signal must rise to its correct value.
2. A small transient (5mV) caused by switching the analog input into the measurement circuitry must settle.
3. A larger transient, usually about 40mV/V, caused by the switched, precision excitation voltage used in resistive bridge measurements must settle.

The purpose of this section is to bring attention to potential measurement errors caused when the input settling time constant gets too large and to discuss procedures whereby the effects of lead length on the measurement can be estimated. In addition, physical values are given for three types of wire used in Campbell Scientific sensors, and error estimates for given lead lengths are provided. Finally, techniques are discussed for minimizing input settling error when long leads are mandatory.

13.3.1 THE INPUT SETTling TIME CONSTANT

The rate at which an input voltage rises to its full value or that a transient decays to the correct input level are both determined by the input settling time constant. In both cases the waveform is an exponential. Figure 13.3-1 shows both a rising and decaying waveform settling to the signal level, V_{so}. The rising input voltage is described by Equation 13.3-1 and the decaying input voltage by Equation 13.3-2,

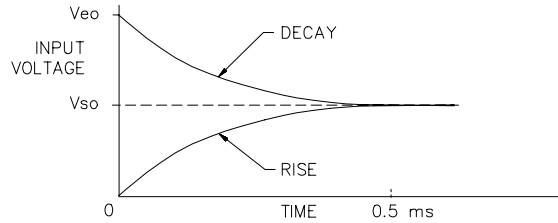


FIGURE 13.3-1. Input Voltage Rise and Transient Decay

$$V_s = V_{so} \left(1 - e^{-t/R_o C_T} \right) \text{ rise} \quad [13.3-1]$$

$$V_s = V_{so} + (V_{eo} - V_{so}) e^{-t/R_o C_T}, \text{ decay} \quad [13.3-2]$$

where V_s is the input voltage, V_{so} the true signal voltage, V_{eo} the peak transient voltage, t is time in seconds, R_o the source resistance in ohms, and C_T is the total capacitance between the signal lead and ground (or some other fixed reference value) in farads.

The settling time constant in seconds, τ, and the capacitance relationships are given in Equations 13.3-3 through 13.3-5,

$$\tau = R_o C_T \quad [13.3-3]$$

$$C_T = C_f + C_w L \quad [13.3-4]$$

$$C_f = 3.3 \text{ nfd} \quad [13.3-5]$$

where C_f is the fixed 21X input capacitance in farads, C_w is the wire capacitance in farads/foot, and L is the wire length in feet.

Equations 13.3-1 and 13.3-2 can be used to estimate the input settling error, V_e, directly. For the rising case, V_s = V_{so} - V_e, whereas for the decaying transient, V_s = V_{so} + V_e. Substituting these relationships for V_s in Equations 13.3-1 and 13.3-2, respectively, yields expressions in V_e, the input settling error:

$$V_e = V_{so} e^{-t/R_o C_T}, \text{ rise} \quad [13.3-6]$$

$$V_e = V'_{eo} e^{-t/R_o C_T}, \text{ decay} \quad [13.3-7]$$

Where V'_{eo} = V_{eo} - V_{so}, the difference between the peak transient voltage and the true signal voltage.

SECTION 13. 21X MEASUREMENTS

NOTE: Since the peak transient, V_{eo} , causes significant error only if it is several times larger than the signal, V_{so} , error calculations made in this section approximate V'_{eo} by V_{eo} ; i.e., $V'_{eo} \approx V_{eo}$.

If the input settling time constant, τ , is known, a quick estimation of the settling error as a percentage of the maximum error (V_{so} for rising, V'_{eo} for decaying) is obtained by knowing how many time constants (t/τ) are contained in the $450\mu s$ 21X input settling interval (t). The familiar exponential decay relationship is given in Table 13.3-1 for reference.

TABLE 13.3-1. Exponential Decay, Percent of Maximum Error vs. Time in Units of τ

Time Constants	% Max. Error	Time Constants	% Max. Error
0	100.0	5	0.7
1	36.8	7	0.1
3	5.0	10	0.004

Before proceeding with examples of the effect of long lead lengths on the measurement, a discussion on obtaining the source resistance, R_o , and lead capacitance, C_wL , is necessary.

DETERMINING SOURCE RESISTANCE

The source resistance used to estimate the settling time constant is the resistance the 21X input "sees" looking out at the sensor. For our purposes the source resistance can be defined as the resistance from the 21X input through all external paths back to the 21X. Figure 13.3-2 shows a typical resistive sensor, (e.g., a thermistor) configured as a half bridge. Figure 13.3-3 shows Figure 13.3-2 redrawn in terms of the resistive paths determining the source resistance R_o , is given by the parallel resistance of R_s and R_f , as shown in Equation 13.3-8.

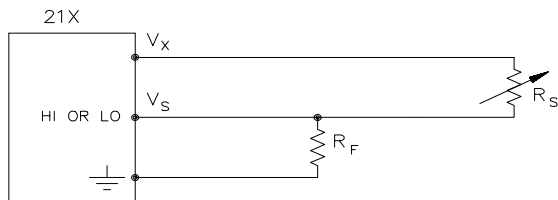


FIGURE 13.3-2. Typical Resistive Half Bridge

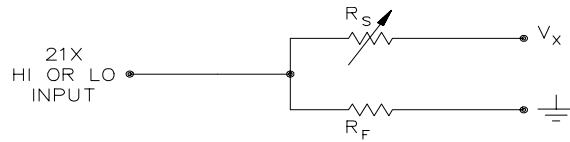


FIGURE 13.3-3. Source Resistance Model for Half Bridge Connected to the 21X

$$R_o = R_s R_f / (R_s + R_f) \quad [13.3-8]$$

If R_f is much smaller, equal to or much greater than R_s , the source resistance can be approximated by Equations 13.3-9 through 13.3-11, respectively.

$$R_o \approx R_f, R_f \ll R_s \quad [13.3-9]$$

$$R_o = R_f / 2, R_f = R_s \quad [13.3-10]$$

$$R_o \approx R_s, R_f \gg R_s \quad [13.3-11]$$

The source resistance for several Campbell Scientific sensors are given in column 3 of Table 13.3-5.

DETERMINING LEAD CAPACITANCE

Wire manufacturers typically provide two capacitance specifications: 1) the capacitance between the two leads with the shield floating, and 2) the capacitance between the two leads with the shield tied to one lead. Since the input lead and the shield are tied to ground (often through a bridge resistor, R_f) in single-ended measurements such as Figure 13.3-2, the second specification is used in determining lead capacitance. Figure 13.3-4 is a representation of this capacitance, C_w , usually specified as pfd/ft. C_w is actually the sum of capacitance between the two conductors and the capacitance between the top conductor and the shield. Capacitance for 3 Belden lead wires used in Campbell Scientific sensors is shown in column 6 of Table 13.3-2.

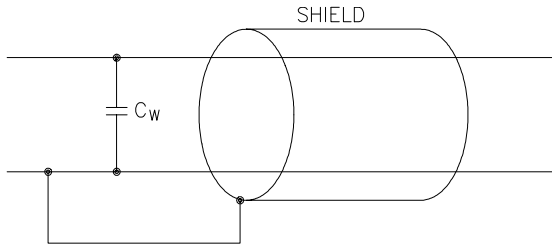


FIGURE 13.3-4. Wire Manufacturers Capacitance Specifications, C_w

DIELECTRIC ABSORPTION

The dielectric absorption of insulation surrounding individual conductors can seriously affect the settling waveform by increasing the time required to settle as compared to a simple exponential. Dielectric absorption is difficult to quantify, but it can have a serious effect on low level measurements (i.e., 50mV or less). The primary rule to follow in minimizing dielectric absorption is: **AVOID PVC INSULATION** around conductors. PVC cable jackets are permissible since the jackets don't contribute to the lead capacitance because the jacket is outside the shield. Campbell Scientific uses only polyethylene and polypropylene insulated conductors in 21X sensors (see Table 13.3-2) since these materials have negligible dielectric absorption. Teflon insulation is also very good but quite expensive.

TABLE 13.3-2. Properties of Three Belden Lead Wires Used by Campbell Scientific

Belden Wire #	Conductors	Insulation	AWG	RI (ohms/1000ft.)	C_w (pfd/ft.)
8641	1 shld. pair	polyethylene	24	23	42
8771	1 shld. 3 cond.	polyethylene	22	15	41
8723	2 shld. pair	polypropylene	22	15	62

13.3.2 EFFECT OF LEAD LENGTH ON SIGNAL RISE TIME

In the 024A Windvane, a potentiometer sensor, the peak transient voltage is much less than the true signal voltage (Table 13.3-5). This means the signal rise time is the major source of error and the time constant is the same as if C_w were between the signal lead and ground as represented below.

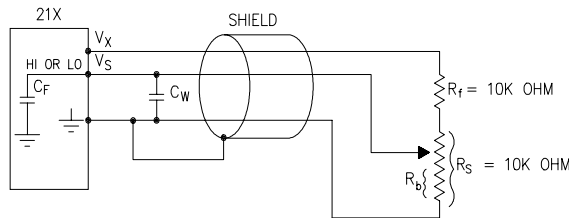


FIGURE 13.3-5. Model 024A Wind Direction Sensor

R_o , the source resistance, is not constant because R_b varies from 0 to 10 kohms over the

0 to 360 degree wind direction range. The source resistance is given by:

$$R_o = R_b(R_s - R_b + R_f) / (R_s + R_f) = R_b(20k - R_b) / 20k \quad [13.3-12]$$

Note that at 360 degrees, R_o is at a maximum of 5k ($R_b = 10k$) and at 0 degrees, R_o is 0 ($R_b = 0$). It follows that settling errors are less at lower direction values.

The value of R_b for any direction D (degrees) is given by:

$$R_b(\text{kohms}) = (10k)(D) / 360 \quad [13.3-13]$$

Equation 13.3-6 can be rewritten to yield the settling error of a rising signal directly in units of degrees.

$$\text{Error (degrees)} = De^{-t / (-t(R_o(C_f + C_wL)))} \quad [13.3-14]$$

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Equation 13.3-12, -13 and -14 can be combined to estimate the error directly in degrees at various directions and lead lengths (Table 13.3-3). Constants used in the calculations are given below:

$$C_f = 3.3\text{ nfd}$$

$$C_w = 41\text{ pfd/ft.}, \text{ Belden \#8771 wire}$$

$$t = 450\mu\text{s}$$

TABLE 13.3-3. Settling Error (Degrees) for 024A Wind Direction Sensor vs. Lead Length

Wind Direction	----- Error -----	
	L=1000 ft.	L=500 ft.
360°	47°	8°
270°	31°	5°
180°	12°	1°
90°	1°	0°

The values in Table 13.3-3 show that significant error occurs at large direction values for leads in excess of 500 feet. Instruction 4, Excite, Delay, and Measure, should be used to eliminate errors in these types of situations. Using a 10ms delay, settling errors are eliminated up to lengths that exceed the drive capability of the excitation channel (≈ 2000 ft.).

13.3.3 TRANSIENTS INDUCED BY SWITCHED EXCITATION

Figure 13.3-6 shows a typical half bridge resistive sensor, such as Campbell Scientific's Model 107 Temperature Probe, connected to

the 21X. The lead wire is a single-shielded pair, used for conducting the excitation (V_x) and signal (V_s) voltages. When V_x is switched on, a transient is capacitively induced in V_s , the signal voltage. If the peak transient level, V_{eo} , is less than the true signal, V_{so} , the transient has no effect on the measurement. If V_{eo} is greater than V_{so} , it must settle to the correct signal voltage to avoid errors.

NOTE: Excitation transients are eliminated if an option exists to contain excitation leads in a shield independent from the signal leads.

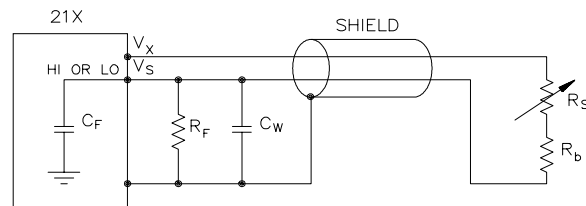


FIGURE 13.3-6. Resistive Half Bridge Connected to Single-Ended 21X Input

The size of the peak transient is linearly related to the excitation voltage and increases as the bridge resistor, R_f , increases. Table 13.3-4 shows measured levels of V_{eo} for 1000 foot lengths of three Belden wires used in Campbell Scientific sensors. Values are given for R_f equal to 1 kohm and 10 kohm. Table 13.3-4 is meant only to provide estimates of the excitation transients encountered; the exact magnitude will depend upon the specific sensor configuration.

TABLE 13.3-4. Measured Peak Excitation Transients for 1000 Foot Lengths of Three Belden Lead Wires Used by Campbell Scientific

Vx(mV)	----- V_{eo} (mV) -----					
	$R_f=1$ kohm			$R_f=10$ kohm		
	#	#	#	#	#	#
	8641	8771	8723	8641	8771	8723
5000	125	200	130	215	320	180
4000	100	165	110	180	260	150
3000	75	130	90	140	200	110
2000	50	100	60	100	140	80
1000	25	65	40	60	90	40

Equation 13.3-7 can be solved for the maximum lead length, L, permitted to maintain a specified error limit. Combining Equations 13.3-7 and 13.3-4 and solving for L gives:

$$L = -(R_o C_f + (t/\ln(V_e/V_{eo}))) / R_o C_w \quad [13.3-15]$$

where V_e is the measurement error limit.

EXAMPLE LEAD LENGTH CALCULATION FOR CAMPBELL SCIENTIFIC 107 TEMPERATURE SENSOR

Assume a limit of 0.05°C over a 0°C to +40°C range is established for the transient settling error. This limit is a reasonable choice since it approximates the polynomial error over that range. The output signal from the thermistor bridge varies nonlinearly with temperature (refer to 107 Operator's Manual), ranging from about 200µV/°C at 0°C to 100µV/°C at 40°C. Taking the most conservative figure yields an error limit of $V_e = 5\mu V$. The other values needed to calculate the maximum lead length are summarized in Table 13.3-5 and listed below:

- 1) $V_{eo} \approx 100mV$, peak transient at 4V excitation
- 2) $V_e \approx 5\mu V$, allowable measurement error
- 3) $t = 450\mu s$, 21X input settling time
- 4) $R_o = 1kohm$, 107 probe source resistance
- 5) $C_f = 3.3nfd$, 21X input capacitance
- 6) $C_w = 42pfd/ft.$, lead wire capacitance

Solving Equation 13.3-15 gives a maximum lead length of:

$$L \approx 1003 \text{ ft.}, \text{ error} \approx 0.05^\circ C$$

Setting the allowable error at 0.1°C or approximately 10µV, the maximum lead length increases to:

$$L \approx 1085 \text{ ft.}, \text{ error} \approx 0.1^\circ C$$

TABLE 13.3-5. Summary of Input Settling Data For Campbell Scientific Resistive Sensors

Sensor Model #	Belden Wire #	Ro (kohms)	Cw (pfd/ft.)	τ^* (us)	Input Range(mV)	Vx(mV)	$V_{eo}(mV)^{**}$
107	8641	1	42	45	15	4000	100
207(RH)	8771	1	41	44	150	3000	130
WVU-7	8723	1	62	65	15	4000	0
227	8641	0.1-1	42	5-45	500	500	0
237	8641	1	42	45	50	5000	125
024A	8771	0-5	41	1-222	500	1000	0-90

* Estimated time constants are for 1000 foot lead lengths and include 3.3nfd 21X input capacitance.
 ** Measured peak transients for 1000 foot lead lengths at corresponding excitation, V_x .

13.3.4 SUMMARY OF SETTLING ERRORS FOR CAMPBELL SCIENTIFIC RESISTIVE SENSORS

Table 13.3-5 summarizes the data required to estimate the effect of lead length on settling errors for Campbell Scientific's resistive sensors. Comparing the transient level, V_{eo} , to the input range, one suspects that transient errors are the most likely limitation for the 107 sensor. The sensors in the WVU-7 are the same as in the Model 107 (the lead wire is different), but the signal leads for the WVU-7 wet and dry-bulbs are not subject to excitation

transients because they are shielded independently from the excitation.

The comparatively small transient yet large source resistance of the 024A sensor indicates that signal rise time may be the most important limitation. The analysis in Section 13.3.2 confirms this.

The Model 227 Soil Moisture Block has a relatively short time constant and essentially no transient. Lead lengths in excess of 2000 feet produce less than a 0.1 bar (0-10 bar range) input settling error. With this sensor, the drive capability of the excitation channel limits the

SECTION 13. 21X MEASUREMENTS

lead length. If the capacitive load exceeds 0.1 μf and the resistive load is negligible, V_x will oscillate about its control point. If the capacitive load is 0.1 μf or less, V_x will settle to within 0.1% of its correct value in 150 μs . A lead length of 2000 feet is permitted for the Model 227 before approaching the drive limitation.

Table 13.3-6 summarizes maximum lead lengths for corresponding error limits in six Campbell Scientific sensors. Since the first three sensors are nonlinear, the voltage error, V_e , is the most conservative value corresponding to the error over the range shown.

TABLE 13.3-6. Maximum Lead Length vs. Error for Campbell Scientific Resistive Sensors

Sensor Model #	Error	Range	$V_e(\mu\text{V})$	Maximum Length(ft.)
107	0.05°C	0°C to 40°C	5	1000 ¹
207(RH)	1%RH	20% to 90%	500	1890 ³
WVU-7	0.05°C	0°C to 40°C	5	865 ²
024A	3°	@ 360°	1390	430 ²
227	-	-	-	2000 ³
237	10 kohm	20k to 300k	500	1860 ³

¹ based on transient settling

² based on signal rise time

³ limit of excitation drive

MINIMIZING SETTling ERRORS IN NON-CAMPBELL SCIENTIFIC SENSORS

When long lead lengths are mandatory in sensors configured by the user, the following general practices can be used to minimize or measure settling errors:

1. When measurement speed is not a prime consideration, Instruction 4, Excite, Delay, and Measure, can be used to insure ample settling time for half bridge, single-ended sensors.
2. An additional low value bridge resistor can be added to decrease the source resistance, R_o . For example, assume a YSI nonlinear thermistor such as the model 44032 is used with a 30 kohm bridge resistor, R_f' . A typical configuration is shown in Figure 13.3-7A. The disadvantage with this configuration is the high source resistance shown in column 3 of Table 13.3-7. Adding another 1K resistor, R_f , as shown in Figure 13.3-7B, lowers the source resistance of the 21X input. This offers no improvement over configuration A because R_f' still combines with the lead capacitance to slow the signal response at point P. The source resistance at point P (column 5) is essentially the

same as the input source resistance of configuration A. Moving R_f' out to the thermistor as shown in Figure 13.3-7C optimizes the signal settling time because it becomes a function of R_f and C_w only.

Columns 4 and 7 list the signal voltages as a function of temperature using a 5V excitation for configurations A and C, respectively. Although configuration A has a higher output signal (5V input range), it does not yield any higher resolution than configuration C which uses the $\pm 500\text{mV}$ input range.

NOTE: Since R_f' attenuates the signal in configuration B and C, one might consider eliminating it altogether. However, its inclusion "flattens" the non-linearity of the thermistor, allowing more accurate curve fitting over a broader temperature range.

3. Where possible, run excitation leads and signal leads in separate shields to minimize transients.
4. AVOID PVC INSULATED CONDUCTORS to minimize the effect of dielectric absorption on input settling time.

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5. Use the 21X to measure the input settling error associated with a given configuration. For example, assume long leads are required but the lead capacitance, C_w , is unknown. Configure R_f on a length of cable similar to the measurement. Leave the sensor end open as shown in Figure 13.3-8 and measure the result using the same instruction parameters to be used with the sensor. The measured deviation from 0V is the input settling error.
6. Most Campbell Scientific sensors are configured with a small bridge resistor, R_f , (typically 1 kohm) to minimize the source resistance. If the lead length of a Campbell Scientific sensor is extended by connecting to the pigtails directly, the effect of the lead resistance, R_l , on the signal must be considered. Figure 13.3-9 shows a Campbell Scientific Model 107 sensor with 500 feet of extension lead connected directly to the pigtails. Normally the signal

voltage is proportional to $R_f/(R_s+R_b+R_f)$, but when the pigtails are extended, the signal is proportional to $(R_f+R_l)/(R_s+R_b+R_f+R_l)$. R_l is much smaller than the other terms in the denominator and can be discarded. The effect on the signal can be analyzed by taking the ratio of the signal with extended leads, V_{sl} to the normal signal, V_s :

$$V_{sl}/V_s = (R_f+R_l)/R_f$$

Plugging in values of $R_f=1k$ and $R_l=.012k$ (500' at 23 ohms/1000', Table 13.3-2) gives an approximate 1% error in the signal with extended leads. Converting the error to °C gives approximately a 0.3°C error at 0°C, 0.6°C error at 20°C, and a 1.5°C error at 40°C. The error can be avoided by maintaining the pigtails on the 21X end of the extended leads because R_l does not add to the bridge completion resistor, R_f , and its influence on the thermistor resistance is negligible.

TABLE 13.3-7. Source Resistances and Signal Levels for YSI #44032 Thermistor Configurations Shown in Figure 13.3-7 (2V Excitation)

T	Rs (kohms)	--- A ---		- B -	--- C ---	
		Ro (kohms)	Vs(mV)	Ro@P (kohms)	Ro (kohms)	Vs(mV)
-40	884.6	29.0	164	30.0	1	5.5
-20	271.2	27	498	27.8	1	16.5
0	94.98	22.8	1200	23.4	1	39.5
+25	30.00	15.0	2500	15.2	1	82.0
+40	16.15	10.5	3250	10.6	1	106.0
+60	7.60	6.1	3989	6.1	1	129.5

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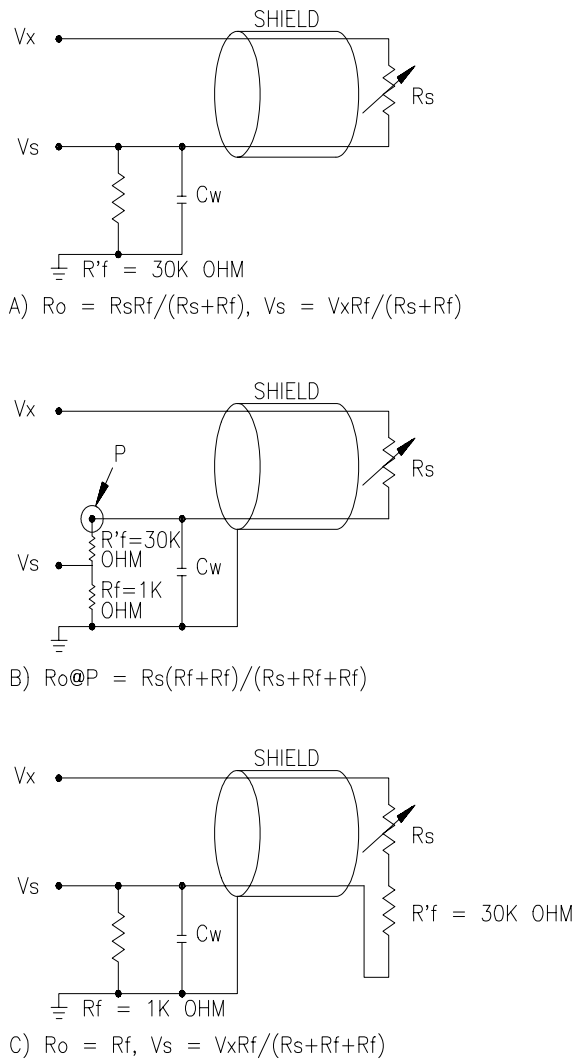


FIGURE 13.3-7. Half Bridge Configuration for YSI #44032 Thermistor Connected to 21X

Showing: A) Large source resistance, B) large source resistance at point P, and C) configuration optimized for input settling

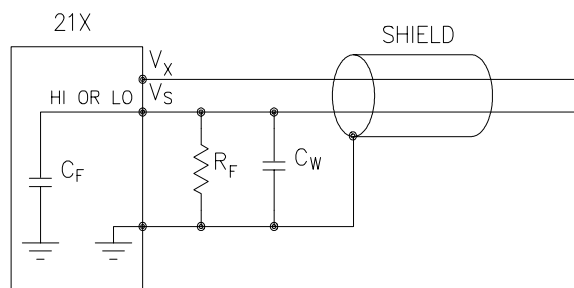


FIGURE 13.3-8. Measuring Input Settling Error with the 21X

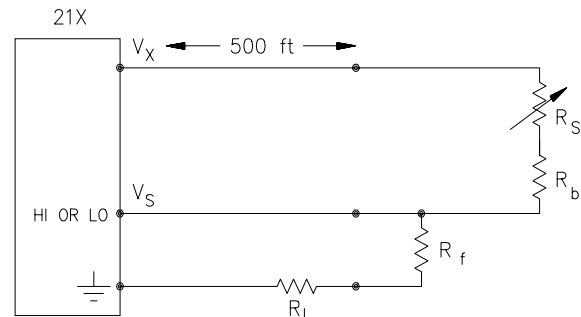


FIGURE 13.3-9. Incorrect Lead Wire Extension on Model 107 Temperature Sensor

13.4 THERMOCOUPLE MEASUREMENTS

A thermocouple consists of two wires, each of a different metal or alloy, which are joined together at each end. If the two junctions are at different temperatures, a voltage proportional to the difference in temperatures is induced in the wires. When a thermocouple is used for temperature measurement, the wires are soldered or welded together at the measuring junction. The second junction, which becomes the reference junction, is formed where the other ends of the wires are connected to the measuring device. (With the connectors at the same temperature, the chemical dissimilarity between the thermocouple wire and the connector does not induce any voltage.) When the temperature of the reference junction is known, the temperature of the measuring junction can be determined by measuring the thermocouple voltage and adding the corresponding temperature difference to the reference temperature.

The 21X determines thermocouple temperatures using the following sequence. First, the temperature of the reference junction is measured. If the reference junction is the 21X panel, the temperature is measured with the built-in thermistor (Instruction 17). The reference junction temperature in °C is stored in an input location which is accessed by the thermocouple measurement instruction (Instruction 13 or 14). The 21X calculates the voltage that a thermocouple of the type specified would output at the reference junction temperature if its reference junction were at 0°C, and adds this voltage to the measured thermocouple voltage. The temperature of the measuring junction is then calculated from a

polynomial approximation of the NBS TC calibrations.

13.4.1 ERROR ANALYSIS

The error in the measurement of a thermocouple temperature is the sum of the errors in the reference junction temperature, the thermocouple output (deviation from standards published in NBS Monograph 125), the thermocouple voltage measurement, and the polynomial error (difference between NBS standard and 21X polynomial approximations). The discussion of errors which follows is limited to these errors in calibration and measurement and does not include errors in installation or matching the sensor to the environment being measured.

REFERENCE JUNCTION TEMPERATURE WITH 21X PANEL

The 21X panel temperature is measured with a Fenwal Electronics UUT51J1 thermistor mounted in the center of the analog input terminal strip. The accuracy of this measurement is a combination of Fenwal's interchangeability specification, the precision of the bridge resistors, and the polynomial error. In a "worst case" example, all errors add to yield a $\pm 0.3^{\circ}\text{C}$ error in the range of -35°C to $+50^{\circ}\text{C}$. It

is emphasized that this is the worst case. In Campbell Scientific's experience, the overall accuracy is typically better than $\pm 0.2^{\circ}\text{C}$. The major error component in the -35°C to $+50^{\circ}\text{C}$ range is the $\pm 0.2^{\circ}\text{C}$ thermistor specification. When a 21X is outside of this temperature range, the polynomial error becomes much worse (Figure 13.4-1), and may necessitate the use of an external reference junction to improve the accuracy.

Any difference in temperature between the thermistor and the actual reference junction (the channel to which the thermocouple is attached) will become an error in the measurement. The terminal strip cover is designed to reduce the gradient from one end of the terminal strip to the other. In a test the 21X was subjected to the severe thermal gradient caused by bringing the 21X from equilibrium at -25°C into an ambient temperature of approximately 20°C . After 100 minutes the gradient between the batteries and air temperature was still 15°C . The time rate of change of temperature in a natural environment would seldom cause even this great a gradient. The maximum error at this time, approximately 0.3°C , is used as an estimate of the error which could occur in a field situation with proper radiation shielding. The error is lowest on channel 4 because it is directly over the thermistor.

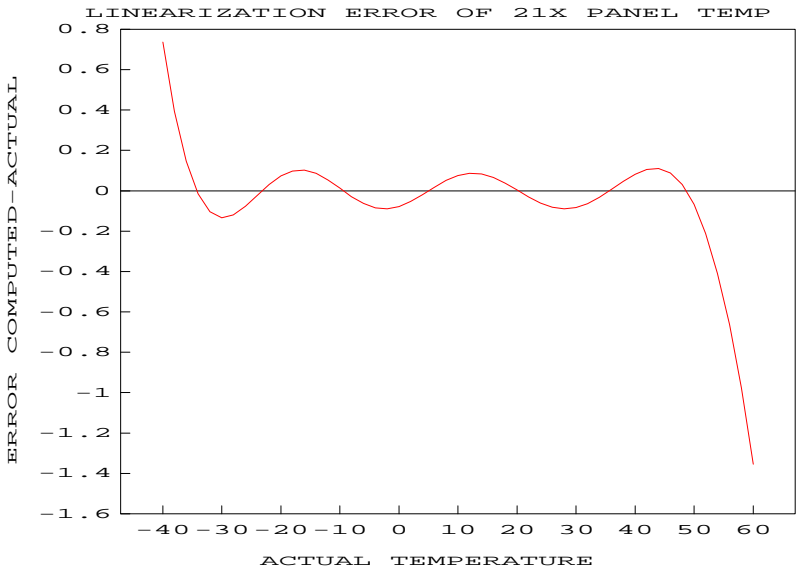


FIGURE 13.4-1. Thermistor Polynomial Error

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THERMOCOUPLE LIMITS OF ERROR

The standard reference which lists thermocouple output voltage as a function of temperature (reference junction at 0°C) is the National Bureau of Standards Monograph 125

(1974). The American National Standards Institute has established limits of error on thermocouple wire which is accepted as an industry standard (ANSI MC 96.1, 1975). Table 13.4-1 gives the ANSI limits of error for standard and special grade thermocouple wire of the types accommodated by the 21X.

TABLE 13.4-1. Limits of Error for Thermocouple Wire (Reference Junction at 0°C)

Thermocouple Type	Temperature Range oC	Limits of Error (Whichever is greater)	
		Standard	Special
T	-200 to 0	± 1.0°C or 1.5%	± 0.5°C or 0.4%
	0 to 350	± 1.0°C or 0.75%	
J	0 to 750	± 2.2°C or 0.75%	± 1.1°C or 0.4%
E	-200 to 0	± 1.7°C or 1.0%	± 1.0°C or 0.4%
	0 to 900	± 1.7°C or 0.5%	
K	-200 to 0	± 2.2°C or 2.0%	± 1.1°C or 0.4%
	0 to 1250	± 2.2°C or 0.75%	

When both junctions of a thermocouple are at the same temperature, there is no voltage produced (law of intermediate metals). A consequence of this is that a thermocouple cannot have an offset error; any deviation from a standard (assuming the wires are each homogeneous and no secondary junctions exist) is due to a deviation in slope. In light of this, the fixed temperature limits of error (e.g., ±1.0°C for type T as opposed to the slope error of 0.75% of the temperature) in the table above are probably greater than one would experience when considering temperatures in the environmental range. In other words, the reference junction, at 0°C, is relatively close to the temperature being measured, so the absolute error (the product of the temperature difference and the slope error) should be closer to the percentage error than the fixed error. Likewise, because thermocouple calibration error is a slope error, accuracy can be increased when the reference junction temperature is close to the measurement temperature. For the same reason, differential temperature measurements, over a small temperature gradient, can be extremely accurate.

In order to quantitatively evaluate thermocouple error when the reference junction is not fixed at 0°C, one needs limits of error for the Seebeck coefficient (slope of thermocouple voltage vs. temperature curve) for the various thermocouples. Lacking this information, a reasonable approach is to apply the percentage errors, with perhaps 0.25% added on, to the difference in temperature being measured by the thermocouple.

ACCURACY OF THE THERMOCOUPLE VOLTAGE MEASUREMENT

The accuracy of a 21X voltage measurement is specified as 0.1% (0.05% 0 to 40°C) of the full scale range being used to make the measurement. The actual accuracy may be better than this as it involves a slope error (the error is proportional to the measurement being made though limited by the resolution). The error in the temperature due to inaccuracy in the measurement of the thermocouple voltage is worst at temperature extremes, where a relatively large scale is necessary to read the thermocouple output. For example, assume type K (chromel-alumel) thermocouples are used to measure temperatures at 1000°C. The TC output is on the order of 40mV, requiring the ±50mV input range. The accuracy specification of 0.05% FSR is 25µV which is a temperature

error of about 0.6°C. In the environmental temperature range with voltage measured on an appropriate scale, error in temperature due to the voltage measurements is a few hundredths of a degree.

THERMOCOUPLE POLYNOMIALS: Voltage to Temperature

NBS Monograph 125 gives high order polynomials for computing the output voltage of a given thermocouple type over a broad range of temperatures. In order to speed processing and accommodate the 21X's math and storage capabilities, 4 separate 6th order polynomials are used to convert from volts to temperature over the range covered by each thermocouple type. Table 13.4-2 gives error limits for the thermocouple polynomials.

TABLE 13.4-2. Limits of Error on 21X Thermocouple Polynomials (Relative to NBS Standards)

TC Type	Range °C	Limits of Error °C
T	-270 to 400	
	-270 to -200	+18 @ -270
	-200 to -100	±0.08
	-100 to 100	±0.001
	100 to 400	±0.015
J	-150 to 760	±0.008
	-100 to 300	±0.002
E	-240 to 1000	
	-240 to -130	±0.4
	-130 to 200	±0.005
	200 to 1000	±0.02
K	-50 to 1372	
	-50 to 950	±0.01
	950 to 1372	±0.04

REFERENCE JUNCTION COMPENSATION: Temperature to Voltage

The polynomials used for reference junction compensation (converting reference temperature to equivalent TC output voltage) do not cover the entire thermocouple range. Substantial errors will result if the reference junction temperature is outside of the

polynomial range. The ranges covered by these polynomials include the 21X environmental operating range, so there is no problem when the 21X is used as the reference junction. External reference junction boxes, however, must also be within these temperature ranges. Temperature difference measurements made outside of the reference temperature range should be made by obtaining the actual temperatures referenced to a junction within the reference temperature range and subtracting. Table 13.4-3 gives the reference temperature ranges covered and the limits of error in the polynomials within these ranges.

Two sources of error arise when the reference temperature is out of range. The most significant error is in the calculated compensation voltage; however, error is also created in the temperature difference calculated from the thermocouple output. For example, suppose the reference temperature for a measurement on a type T thermocouple is 300°C. The compensation voltage calculated by the 21X corresponds to a temperature of 272.6°C, a -27.4°C error. The type T thermocouple with the measuring junction at 290°C and reference at 300°C would output -578.7µV; using the reference temperature of 272.6°C, the 21X calculates a temperature difference of -10.2°C, a -0.2°C error. The temperature calculated by the 21X would be 262.4°C, 27.6°C low.

TABLE 13.4-3. Reference Temperature Compensation Range and Polynomial Error Relative to NBS Standards

TC Type	Range °C	Limits of Error °C
T	-100 to 100	± 0.001
J	-150 to 296	± 0.005
E	-150 to 206	± 0.005
K	-50 to 100	± 0.01

ERROR SUMMARY

The magnitude of the errors described in the previous sections illustrate that the greatest sources of error in a thermocouple temperature measurement are likely to be due to the limits of error on the thermocouple wire and in the reference temperature determined with the built-in thermistor. Errors in the thermocouple

SECTION 13. 21X MEASUREMENTS

and reference temperature polynomials are extremely small, and error in the voltage measurement is negligible.

To illustrate the relative magnitude of these errors in the environmental range, we will take a worst case situation where all errors are maximum and additive. A temperature of 45°C is measured with a type T (copper-constantan) thermocouple, using the ±5mV range. The nominal accuracy on this range is 2.5μV (0.05% of 5mV), which at 45°C changes the temperature by 0.06°C. The RTD is 25°C but is indicating 25.3°C, and the terminal that the thermocouple is connected to is 0.3°C cooler than the RTD.

TABLE 13.4-4. Example of Errors in Thermocouple Temperature

Source	Error °C	% of Total Error	
		1°C Error	1% Slope Error
Reference Temp.	0.6	36.1	69.6
TC Output ANSI	1.0	60.1	
0.01 x 20°C	0.2		23.2
Voltage Measurement	0.06	3.6	7.0
Reference Linearization	0.001	0.1	0.1
Output Linearization	0.001	0.1	0.1
<hr/>			
Total Error With ANSI error	1.662	100	
Assuming 1% slope error	0.862		100

13.4.2 USE OF EXTERNAL REFERENCE JUNCTION OR JUNCTION BOX

An external junction box is often used to facilitate connections and to reduce the expense of thermocouple wire when the temperature measurements are to be made at a distance from the 21X. In most situations, it is preferable to make the box the reference junction, in which case its temperature is measured and used as the reference for the thermocouples; copper wires are run from the box to the 21X (Section 7.4). Alternatively, the junction box can be used to couple extension grade thermocouple wire to the thermocouples being used for measurement, and the 21X panel used as the reference junction.

Extension grade thermocouple wire has a smaller temperature range than standard thermocouple wire, but meets the same limits of error within that range. The only situation where it would be necessary to use extension grade wire instead of an external measuring junction is where the junction box temperature is outside the range of reference junction compensation provided by the 21X. This is only a factor when using type K thermocouples, where the upper limit of the reference compensation linearization is 100°C and the upper limit of the extension grade wire is 200°C. With the other types of thermocouples, the reference compensation range equals or is greater than the extension wire range. In any case, errors can arise if temperature gradients exist within the junction box.

Figure 13.4-3 illustrates a typical junction box. Terminal strips will be a different metal than the thermocouple wire. Thus, if a temperature gradient exists between A and A' or B and B', the junction box will act as another thermocouple in series, creating an error in the voltage measured by the 21X. This thermoelectric offset voltage is a factor whether or not the junction box is used for the reference. It can be minimized by making the thermal conduction between the two points large and the distance small. The best solution in the case where extension grade wire is being connected to thermocouple wire would be to use connectors which clamped the two wires in contact with each other.

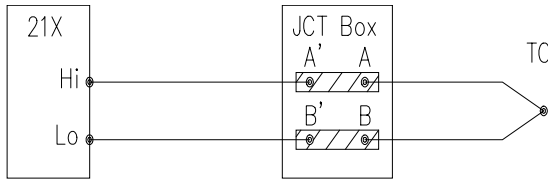


FIGURE 13.4-2. Diagram of Junction Box

An external reference junction box must be constructed so that the entire terminal area is very close to the same temperature. This is necessary so that a valid reference temperature can be measured, and to avoid a thermoelectric offset voltage which will be induced if the terminals at which the thermocouple leads are connected (points A and B in Figure 13.4-3) are at different temperatures. The box should contain elements of high thermal conductivity, which will act to rapidly remove any thermal gradients to which the box is subjected. It is not necessary to design a constant temperature box; it is desirable that the box respond slowly to external temperature fluctuations. Radiation shielding must be provided when a junction box is installed in the field. Care must also be taken that a thermal gradient is not induced by conduction through the incoming wires. The 21X can be used to measure the temperature gradients within the junction box.

13.5 BRIDGE RESISTANCE MEASUREMENTS

There are 6 bridge measurement instructions included in the standard 21X software. Figure 13.5-1 shows the circuits that would typically be measured with these instructions. In the diagrams, the resistors labeled R_s would normally be the sensors and those labeled R_f would normally be fixed resistors. Circuits other than those diagrammed could be measured, provided the excitation and type of measurements were appropriate.

With the exception of Instructions 4 and 8, which apply an excitation voltage then wait a specified time before making a measurement,

all of the bridge measurements make one set of measurements with the excitation as programmed and another set of measurements with the excitation polarity reversed. The error in the two measurements due to thermal emfs is then accounted for in the processing of the measurement instruction. The excitation is switched on $450\mu s$ before the integration portion of the measurement starts and is grounded as soon as the integration is completed. Figure 13.5-2 shows the excitation and measurement sequence for Instruction 6, a 4 wire full bridge. When more than one measurement per sensor is necessary (Instructions 7 and 9), excitation is applied separately for each measurement. (For example, in Instruction 9 (6 wire full bridge), the differential measurement of the voltage drop across the sensor is made with the excitation at both polarities; excitation is again applied and reversed for the measurement of the output voltage.)

Instruction 8 applies an excitation voltage, delays a specified time, and makes a differential voltage measurement. If a delay of 0 is specified, the inputs for the differential measurement are not switched for a second integration as is normally the case (Section 13.2). The result stored is the voltage measured. Instruction 8 does not have as good resolution or common mode rejection as the ratiometric bridge measurement instructions. It does provide a very rapid means of making bridge measurements as well as supplying excitation to circuitry requiring differential measurements. This instruction does not reverse excitation. A 1 before the excitation channel number (1X) causes the channel to be incremented with each repetition. The output of Instruction 8 is simply the voltage measurement. When 8 is used to measure a full bridge (same connections as Instruction 6 in Figure 13.5-1), the result is V_1 which equals

$$V_x (R_3/(R_3+R_4) - R_2/(R_1+R_2)).$$

(In other words, to make the output the same as Instruction 6, use a factor of $1000/V_x$ in the multiplier.)

SECTION 13. 21X MEASUREMENTS

INSTR. #	DIAGRAM	DESCRIPTION	RESULT = X
4		DC HALF BRIDGE WITH USER ENTERED SETTLING TIME	$X = V_1 = V_x \frac{R_s}{R_s + R_f}$
5		AC HALF BRIDGE EXCITATION ALTERNATES POLARITY FOR ION DEPOLARIZATION	$X = \frac{V_1}{V_x} = \frac{R_s}{R_s + R_f}$
6		4 WIRE FULL BRIDGE	$X = 1000 \frac{V_1}{V_x} = 1000 \left(\frac{R_3}{R_3 + R_4} - \frac{R_2}{R_1 + R_2} \right)$
7		3 WIRE HALF BRIDGE	$X = \frac{2V_2 - V_1}{V_x - V_1} = \frac{R_s}{R_f}$
9		6 WIRE FULL BRIDGE WITH EXCITATION LEAD COMPENSATION	$X = 1000 \frac{V_2}{V_1} = 1000 \left(\frac{R_3}{R_3 + R_4} - \frac{R_2}{R_1 + R_2} \right)$ (V1 ON 5 V RANGE)
9		4 WIRE HALF BRIDGE	$X = \frac{V_2}{V_1} = \frac{R_s}{R_f}$ (V1 NOT ON 5 V RANGE)

FIGURE 13.5-1. Circuits Used with Instructions 4-9

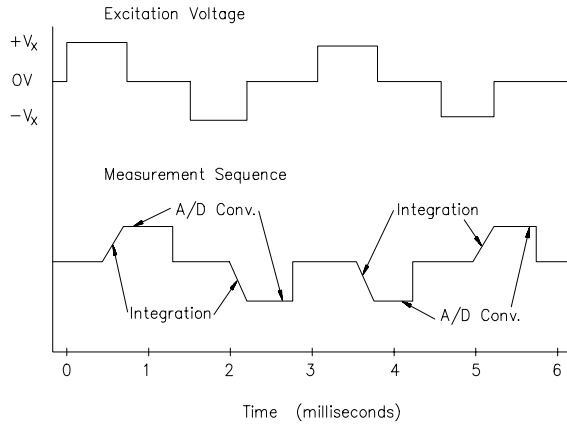


FIGURE 13.5-2. Excitation and Measurement Sequence for 4 Wire Full Bridge

TABLE 13.5-1. Comparison of Bridge Measurement Instructions

Instr.	Circuit	Description
4	DC Half Bridge	User entered settling time allows compensation for capacitance in long lead lengths. No polarity reversal. One single-ended measurement. Measured voltage output.
5	AC Half Bridge	Rapid reversal of excitation polarity for ion depolarization. One single-ended measurement at each excitation polarity. Ratiometric output.
6	4 Wire Full Bridge	Slightly lower noise than 9. One differential measurement at each excitation polarity. Ratiometric output.
7	3 Wire Half Bridge	Compensates for lead wire resistance, assuming resistance is same in both wires. Two single-ended measurements at each excitation polarity. Ratiometric output.
8	Differential Measurement with Excitation	Makes a differential measurement without reversing excitation polarity or switching inputs. Used for fast measurements on load cells, PRTs etc. Resolution and common mode rejection worse than 6 if used with delay=0. Measured voltage output.
9	6 Wire Full Bridge or 4 Wire Half Bridge	Compensates for lead wire resistance. Two differential measurements at each excitation polarity. Ratiometric output.

Calculating the actual resistance of a sensor which is one of the legs of a resistive bridge usually requires the use of one or two Processing Instructions in addition to the bridge measurement instruction. Instruction 59 takes a value, X, in a specified input location and computes the value $MX/(1-X)$, where M is the multiplier and stores the result in the original location. Instruction 42 computes the reciprocal of a value in an input location. Table 13.5-2 lists the instructions used to compute the resistance of any single resistor shown in the diagrams in Figure 13.5-1, provided the values of the other resistors in the bridge circuit are known.

SECTION 13. 21X MEASUREMENTS

TABLE 13.5-2. Calculating Resistance Values from Bridge Measurement

Instr. Result	Instr. Multiplier and Offset
<p>4 $X = V_x(R_s / (R_s + R_f))$</p> <p>$R_s = R_f \frac{X / V_x}{1 - X / V_x}$</p> <p>$R_f = \frac{1}{((X / V_x) / (1 - X / V_x)) / R_s}$</p>	<p>4. Mult. = $1/V_x$; ofs. = 0</p> <p>59. Mult. = R_f</p> <p>4. Mult. = $1/V_x$; ofs. = 0</p> <p>59. Mult. = $1/R_s$</p> <p>42.</p>
<p>5 $X = R_s / (R_s + R_f)$</p> <p>$R_s = R_f \frac{X}{1 - X}$</p> <p>$R_f = \frac{1}{(x / (1 - X)) / R_s}$</p>	<p>5. Mult. = 1; ofs. = 0</p> <p>59. mult. = R_f</p> <p>5. Mult. = 1; ofs. = 0</p> <p>59. Mult. = $1/R_s$; ofs. = 0</p> <p>42.</p>
<p>6,8,9* $X - 1000[R_3 / (R_3 + R_4) - R_2 / (R_1 + R_2)]$</p> <p>$R_1 = \frac{1}{(X_1 / (1 - X_1)) / R_2}$</p> <p>where $X_1 = -X / 1000 + R_3 / (R_3 + R_4)$</p> <p>$R_2 = R_1(X_2 / (1 - X_2))$</p> <p>where $X_2 = X_1$</p> <p>$R_3 = R_4(X_3 / (1 - X_3))$</p> <p>where $X_3 = X / 1000 + R_2 / (R_1 + R_2)$</p> <p>$R_4 = \frac{1}{(X_4 / (1 - X_4)) / R_3}$</p> <p>where $X_4 = X_3$</p>	<p><i>*used for full bridge</i></p> <p>6 or 9. Mult. = -0.001; ofs. = $R_3 / (R_3 + R_4)$</p> <p>8. Mult. = $1/V_x$; ofs. = $R_3 / (R_3 + R_4)$</p> <p>59. Mult. = $1/R_2$</p> <p>42.</p> <p>6 or 9. Mult. = -0.001; ofs. = $R_3 / (R_3 + R_4)$</p> <p>59. Mult. = R_1</p> <p>6 or 9. Mult. = 0.001; ofs. = $R_2 / (R_1 + R_2)$</p> <p>59. Mult. = R_4</p> <p>6 or 9. Mult. = 0.001; ofs. = $R_2 / (R_1 + R_2)$</p> <p>59. Mult. = $1/R_3$</p> <p>42.</p>
<p>7&9* $X = R_s / R_f$</p> <p>$R_s = R_f X$</p> <p>$R_f = R_s / X$</p>	<p><i>*used as half bridge</i></p> <p>7 or 9. Mult. = R_f; ofs. = 0</p> <p>7 or 9. Mult. = $1/R_s$; ofs. = 0</p> <p>42.</p>

13.6 RESISTANCE MEASUREMENTS REQUIRING AC EXCITATION

Some resistive sensors require AC excitation. These include the 207 relative humidity probe, soil moisture blocks, water conductivity sensors, and wetness sensing grids. The use of DC excitation with these sensors can result in polarization, which will cause an erroneous measurement, and may shift the calibration of the sensor and/or lead to its rapid decay.

The AC half bridge Instruction 5 (incorporated into the 207 relative humidity measurement Instruction 12) reverses excitation polarity to provide ion depolarization and, in order to minimize the time excitation is on, grounds the excitation as soon as the signal is integrated (Figure 13.6-1). The slow integration time should never be used with a sensor requiring AC excitation because it results in the excitation lasting about 20 times as long, allowing polarization to affect the measurement.

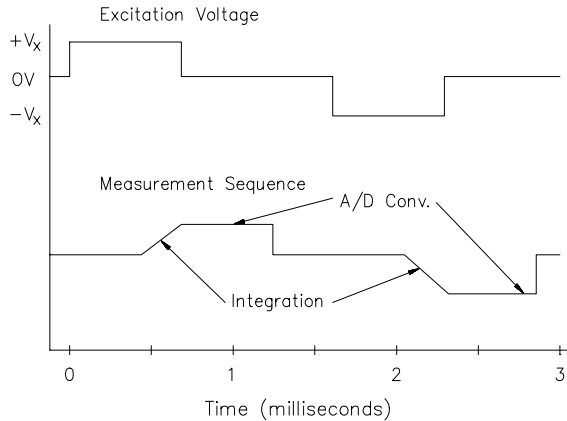


FIGURE 13.6-1. AC Excitation and Measurement Sequence for AC Half Bridge

INFLUENCE OF GROUND LOOP ON MEASUREMENTS

When measuring soil moisture blocks or water conductivity, the potential exists for a ground loop which can adversely affect the measurement. This ground loop arises because the soil and water provide an alternate path for the excitation to return to 21X ground, and can be represented by the model diagrammed in Figure 13.6-2.

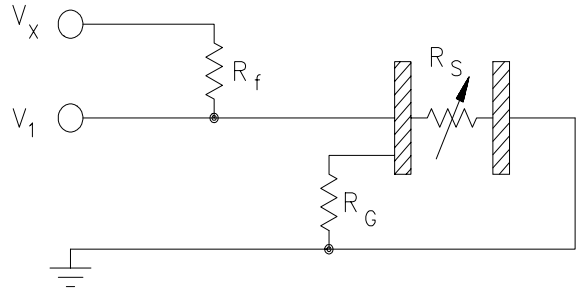


FIGURE 13.6-2. Model of Resistive Sensor with Ground Loop

In Figure 13.6-2, V_x is the excitation voltage, R_f is a fixed resistor, R_s is the sensor resistance, and R_G is the resistance between the excited electrode and 21X earth ground. With R_G in the network, the measured signal is:

$$V_1 = V_x \frac{R_s}{(R_s + R_f) + R_s R_f / R_G} \quad [13.6-1]$$

R_sR_f/R_G is the source of error due to the ground loop. When R_G is large the equation reduces to the ideal. The geometry of the electrodes has a great effect on the magnitude of this error. The Delmhorst gypsum block used in the 227 probe has two concentric cylindrical electrodes. The center electrode is used for excitation; because it is encircled by the ground electrode, the path for a ground loop through the soil is greatly reduced. Moisture blocks which consist of two parallel plate electrodes are particularly susceptible to ground loop problems. Similar considerations apply to the geometry of the electrodes in water conductivity sensors.

The ground electrode of the conductivity or soil moisture probe and the 21X earth ground form a galvanic cell, with the water/soil solution acting as the electrolyte. If current was allowed to flow, the resulting oxidation or reduction would soon damage the electrode, just as if DC excitation was used to make the measurement. Campbell Scientific probes are built with series capacitors in the leads to block this DC current. In addition to preventing sensor deterioration, the capacitors block any DC component from affecting the measurement.

SECTION 13. 21X MEASUREMENTS

SECTION 14. INSTALLATION AND MAINTENANCE

14.1 PROTECTION FROM THE ENVIRONMENT

The normal environmental variables of concern are temperature and moisture. The standard 21X is designed to operate reliably from -25 to +50°C (-55 to +80°C, optional) in noncondensing humidity. When humidity tolerances are exceeded, damage to IC chips, microprocessor failure, and/or measurement inaccuracies due to condensation on the various PC board runners may result. Effective humidity control is the responsibility of the user.

The 21X is not hermetically sealed. Two half unit packets of DESI PAK desiccant are located by the batteries. This desiccant should, in most cases, keep the interior components dry between battery changes. A dry package weighs approximately 19 grams and will absorb a maximum of six grams of water at 40% humidity and 11 grams at 80%. Desiccant packets can be dried out by placing the packets in an oven at 120°C for 16 hours (desiccant only, not the 21X).

Campbell Scientific offers two enclosures for housing a 21X and peripherals. The fiberglass enclosures are classified as NEMA 4X (water-tight, dust-tight, corrosion-resistant, indoor and outdoor use). A 1.25" diameter entry/exit port is located at the bottom of the enclosure for routing cables and wires. The enclosure door can be fastened with the hasp for easy access, or with the two supplied screws for more permanent applications. The white plastic inserts at the corners of the enclosure must be removed to insert the screws. Both enclosures are white for reflecting solar radiation, thus reducing the internal enclosure temperature.

The Model ENC 10/12 fiberglass enclosure houses the 21X and one peripheral such as a Storage Module. Inside dimensions of the ENC 10/12 are 12"x10"x4.5", outside dimensions are 16"x11.5"x7" (with brackets); weight is 8.5 lbs.

The Model ENC 12/14 fiberglass enclosure houses the 21X and one or more peripherals. Inside dimensions of the ENC 12/14 are 14"x12"x5.5", outside dimensions are 18"x13.5"x8.13" (with brackets); weight is 11.16 lbs.

TABLE 14.2-1. Typical Current Drain for Common 21X Peripherals

Peripheral	Typical Current Drain (mA)	
	Quiescent	Active
RC35 Cassette	0	300
P50-VHF 5 Watt Radio	18	1350
P50-UHF 4 Watt Radio	15	1100
RF95 RF Modem	1.4	30
SM192/SM716 Storage Module	0.25	3
MD9	1.2	80
RAD Modem and SC932 Interface	2.2	10-15
DC112 Phone Modem	0.002	45
SDM-A04	10.5	--
SDM-CD16	6.0	11/LED lit
SDM-INT8	0.4	6.5
SDM-SW8A	3	6

SECTION 14. INSTALLATION AND MAINTENANCE

14.2 POWER REQUIREMENTS

The 21X operates at a nominal 12V DC. Below 9.6 or above 16 volts the 21X does not operate properly.

The 21X is diode protected against accidental reversal of the positive and ground leads from the battery. Input voltages in excess of 18V may damage the 21X and/or power supply. A transorb provides transient protection by limiting voltage at approximately 20V.

System operating time for the batteries can be determined by dividing the battery capacity (amp-hours) by the average system current drain. The 21X draws 1.0 mA in the quiescent state, 25 mA while processing, and 60 mA during an analog measurement; the length of operating time for each datalogger instruction is listed in Section 3. Typical current requirements for common 21X peripherals are given in Table 14.2-1.

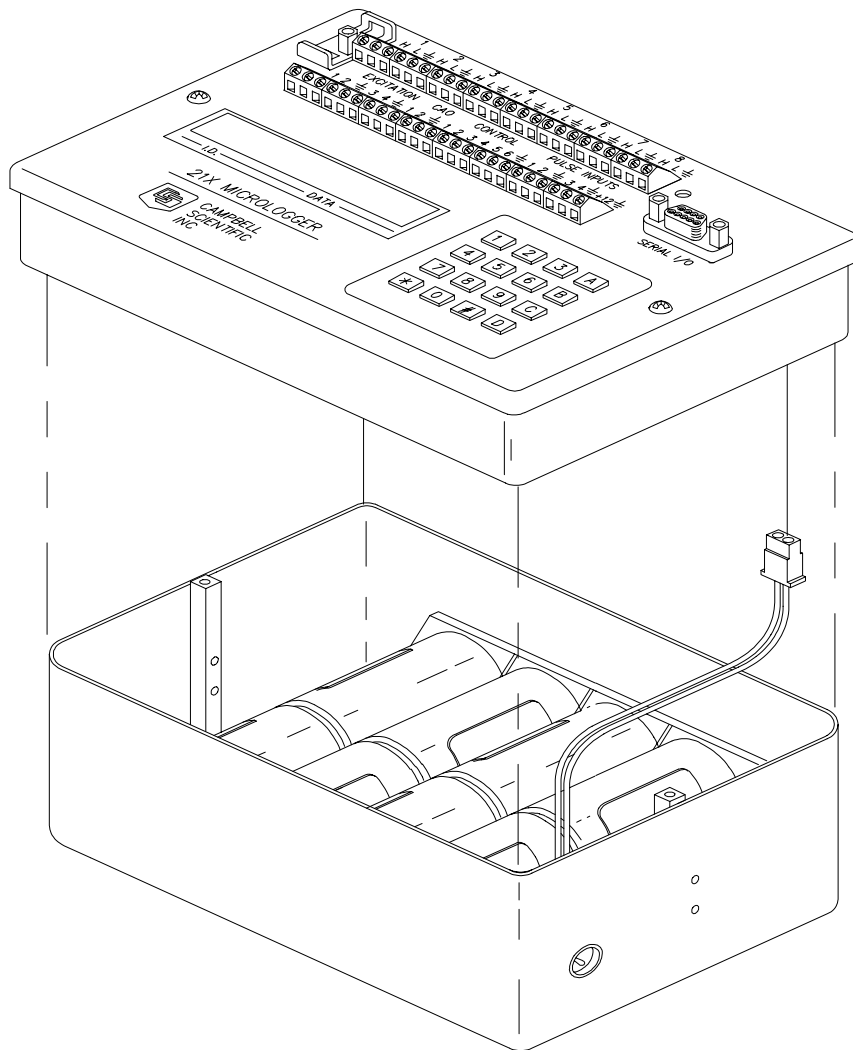


FIGURE 14.3-1. 21X Battery Pack and Panel

14.3 21X POWER SUPPLIES

The 21X is available with both alkaline batteries (21X) and lead acid batteries (21XL). The difference between the 21X and 21XL is the power supply base. Converting from a 21X to 21XL or vice versa can be done by simply purchasing the appropriate base.

14.3.1 21X ALKALINE POWER SUPPLY

The 21X utilizes 8 alkaline D cells. Two screws must be removed from the front panel to install the batteries, see Figure 14.3-1. After battery installation, the power switch on the side of the 21X will turn the datalogger on and off.

To replace the batteries without losing the datalogger program and data: 1) do not turn the power switch off, 2) connect an external battery to the 12 volt, 3) remove the old batteries, 4) replace with new alkaline D cell batteries, and 5) remove the external battery.

A fresh set of eight alkaline D cells has 12.4 volts and a nominal rating of 7.5 amp-hours at 20°C. The amp-hour rating decreases with temperature as shown in Table 14.3-1. Datalogger Instruction 10 can be used to monitor battery voltage. Replace the alkaline cells before the 21X battery voltage drops below 9.6 V.

TABLE 14.3-1. Typical Alkaline Battery Service and Temperature

Temperature (°C)	% of 20°C Service
20 - 50	100
15	98
10	94
5	90
0	86
-10	70
-20	50
-30	30

NOTE: This data is based on one "D" cell under conditions of 50 mA current drain with a 30 ohm load. As the current drain decreases, the percent service improves for a given temperature.

14.3.2 21XL LEAD ACID BATTERY POWER SUPPLY

The 21XL includes a 12V, 2.5 amp-hour lead acid battery, a AC transformer (20V DC), and a temperature compensated charging circuit with a charge indicating diode. An AC transformer or solar panel should be connected to the 21XL at all times. The charging source powers the 21X while float charging the lead acid batteries. The internal lead acid battery powers the datalogger if the charging source is interrupted. The 21XL lead acid battery specifications are given in Table 14.3-2.

The connector from the charging source can be inserted into the receptacle on the side of the 21XL. A transzorb provides transient protection to the charging circuit. A sustained input voltage in excess of 40V will cause the transzorb to limit voltage.

Solar panels and AC transformers should be supplied with a connector. If trying to use a charging source which has only two bare leads (no connector), contact Campbell Scientific for identification of the proper connector.

The red light (LED) on the 21XL is on during charging. The switch turns power on and off, battery charging still occurs when the switch is off.

If the voltage of the lead acid batteries drops below 11.76 volts before recharging, permanent damage to the lead acid cells may result. Campbell Scientific does not warrant batteries.

Monitor the power supply using datalogger Instruction 10. Users are strongly advised to incorporate this instruction into their data acquisition programs to keep track of the state of the power supply. If the system voltage level consistently decreases through time, some element(s) of the charging system has failed. Instruction 10 measures the voltage at the 12V port, not the voltage of the lead acid battery. External power sources must be disconnected from the 21XL in order to measure the actual lead acid battery voltage.

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TABLE 14.3-2. 21XL Battery and AC Transformer Specifications

Lead Acid Battery	
Battery Type	Gates #810-0011X
Float Life @ 25°C	8 years minimum
Capacity	2.5 amp-hour
Shelf Life, full charge	Check twice yearly
Charge Time (AC Source)	40 hr full charge, 20 hr 95% charge
AC Transformer	
Input:	120V AC, 60 Hz
Isolated Output:	20V DC @ 350 mA max.

There are inherent hazards associated with the use of sealed lead acid batteries. Under normal operation, lead acid batteries generate a small amount of hydrogen gas. This gaseous by-product is generally insignificant because the hydrogen dissipates naturally before build-up to an explosive level (4%) occurs. However, if the batteries are shorted or overcharging takes place, hydrogen gas may be generated at a rate sufficient to create a hazard. Campbell Scientific makes the following recommendations:

1. A 21X equipped with standard lead acid batteries should NEVER be used in applications requiring INTRINSICALLY SAFE equipment.
2. A lead acid battery should not be housed in a gas-tight enclosure.

14.4 SOLAR PANELS

Auxiliary photovoltaic power sources, such as Solarex Models MSX5, MSX10, and MSX18 Solar Panels may be used to maintain charge on lead acid batteries.

TABLE 14.4-1. MSX5 and MSX10 Solar Panel Specifications

	MSX5	MSX10	MSX18
Typical Peak Power (Watts)	4.2	8.9	18.6
Current @ Peak (Amps)	.27	.59	1.06
Amp Hrs/week	6.4	14.4	26.4

NOTE: Specifications assume 1 kW/m² illumination at a panel cell temperature of 25°C. Individual panel performance may vary as much as 10%.

When selecting a solar panel, a rule-of-thumb is that on a stormy overcast day the panel should provide enough charge to meet the system current drain (assume 10% of average annual global radiation, kW/m²). Specific site information, if available, could strongly influence the solar panel selection. For example, local effects such as mountain shadows, fog from valley inversion, snow, ice, leaves, birds, etc. shading the panel should be considered.

Guidelines are available from the Solarex Corporation for solar panel selection called "DESIGN AIDS FOR SMALL PV POWER SYSTEMS". It provides a method for calculating solar panel size based on general site location and system power requirements. If you need help in determining your system power requirements contact Campbell Scientific's Marketing Department.

14.5 DIRECT BATTERY CONNECTION TO THE 21X

Any 10 to 13V DC supply may be connected to the 12V and ground terminals on the 21X. Be careful not to short the leads together when connecting them to the datalogger.

A blocking diode prevents the external battery from charging the internal alkaline batteries.

14.6 VEHICLE POWER SUPPLY CONNECTIONS

When a vehicle's starting motor is engaged, the supply voltage drops considerably below the nominal 12 volts. If the 21X is connected directly to the vehicle's power supply, the 21X's batteries are also pulled down causing an E08 error each time the vehicle is started. Avoid this problem by placing a diode (1N4001) and a 3 ohm, 5 watt resistor in series with the positive lead going to the +12V terminal (Figure 14.6-1). The diode allows the vehicle to power the 21X without the datalogger attempting to charge the vehicle. The ground lead should be 16 AWG or larger to reduce the potential for ground reference errors in the measurements.

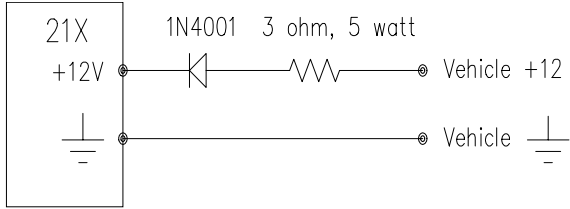


FIGURE 14.6-1. Connecting Vehicle Power Supply

14.7 USE OF DIGITAL CONTROL PORTS FOR SWITCHING RELAYS

Each of the six digital control ports can be set low or high (0V low, 5V high) using I/O Instruction 20, Port Set, or commands 41 - 78 associated with Program Control Instructions 83 through 93. A digital output port is normally used to operate an external relay driver circuit because the port itself has a limited drive capability (1.5mA at 3.5V). Figure 14.7-1 shows a typical relay driver circuit in conjunction with a coil driven relay which may be used to switch external power to some device. In this example, when the control port is set high, 12V from the datalogger passes through the relay coil, closing the relay which completes the power circuit to a fan, turning the fan on. Campbell Scientific offers the A21REL-12 Four Channel Relay Driver (12V coil) and the A6REL-12 Six Channel Relay Driver with manual override (12V coil) for use with the 21X.

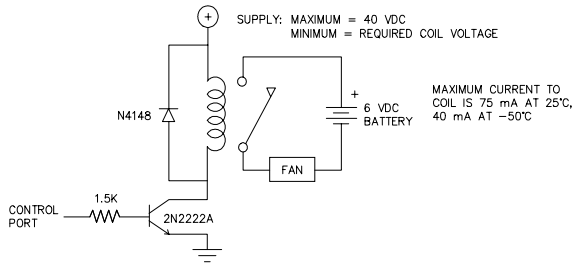


FIGURE 14.7-1. Relay Driver Circuit with Relay

In other applications it may be desirable to simply switch power to a device without going through a relay. Figure 14.7-2 illustrates a circuit for switching external power to a device without going through a relay. If the peripheral to be powered draws in excess of 75 mA at room temperature (limit of the 2N2907A

medium power transistor), the use of a relay (Figure 14.7-1) would be required.

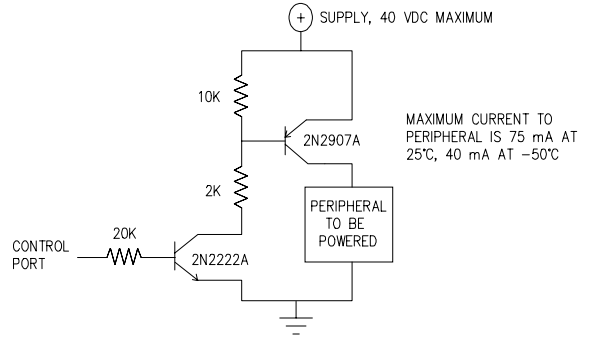


FIGURE 14.7-2. Power Switching without Relay

Other control port activated circuits are possible for applications with greater current/voltage demands than shown in Figures 14.7-1 and 14.7-2. For more information contact Campbell Scientific's Marketing Department.

14.8 GROUNDING

14.8.1 PROTECTION FROM LIGHTNING

Primary lightning strikes are those where lightning hits the datalogger or sensors directly. Secondary strikes occur when the lightning strikes somewhere near the system and induces a voltage in the wires. The purpose of an earth ground is to minimize damage to the system by providing a low resistance path around the system to a point of low potential. **ANY DATALOGGER IN A FIELD INSTALLATION MUST BE EARTH GROUNDED.** All components of the system (datalogger, sensors, external power supplies, mounts, housings, etc.) should be referenced to one common earth ground.

All input and output terminals on the 21X are transient protected with spark gaps. The 21X must have a good earth ground for the transient protection to work.

The spark gaps consist of a thin air gap between the conductor and a heavy copper bar tied to ground. Depending on the conductivity of the air, current will be diverted to ground at roughly 400 to 600V.

A modem/phone line connected to the 21X provides another path for transients to enter and

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damage the datalogger. Campbell Scientific's DC112 phone modem has spark gaps on the phone lines. A 12 AWG wire should be run from the modem ground terminal to earth ground.

In laboratory applications, locating a stable earth ground is not always obvious. In older buildings, new cover plates on old AC sockets may indicate that a safety ground exists when in fact the socket is not grounded. If a safety ground does exist, it is good practice to verify that it carries no current. If the integrity of the AC power ground cannot be verified, it is better to ground the system to a massive metal object such as a steel water pipe.

In the field, an earth ground may be created through a grounding rod. A 12 AWG or larger wire should be run between the 21X terminal and the earth ground. Campbell Scientific's CM10 and CM6 Tripods come complete with ground and lightning rods, grounding wires, and appropriate ground wire clamps.

14.8.2 EFFECT OF GROUNDING ON MEASUREMENTS: COMMON MODE RANGE

The common mode range is the voltage range, relative to the 21X ground, within which both inputs of a differential measurement must lie in order for the differential measurement to be made. Common mode range for the 21X is $\pm 5.0V$. For example, if the high side of a differential input is at 4V and the low side is at 3V relative to 21X ground, a measurement made on the $\pm 5.0V$ range would indicate a signal of 1V. However, if the high input changed to 6V, the common mode range is exceeded and the measurement cannot be made.

Common mode range may be exceeded when the 21X is measuring the output from a sensor which has its own grounded power supply and the low side of the signal is referenced to power ground. If the 21X ground and the sensor ground are at sufficiently different potentials, the signal will exceed the common mode range. To solve this problem, the sensor power ground and the 21X ground should be connected, creating one ground for the system.

In a laboratory application, where more than one AC socket may be used to power various sensors, it is not always safe to assume that the

power grounds are at the same potential. To be safe, the ground of all the AC sockets in use should be tied together with a 12 AWG wire.

14.9 MAINTENANCE

The 21X requires a minimum of routine maintenance. A few preventative maintenance steps will optimize battery life and decrease the chances of datalogger failure.

The 21X alkaline supply should not drop below 9.6V before replacement. When not in use, remove the eight cells to eliminate potential corrosion of contact points and store in a cool dry place.

When not in use, the 21XL lead acid battery should be stored in a cool, dry environment with the AC charging circuit activated. Discharging the 21XL lead acid batteries below 11.76V causes permanent damage, or at least drastically diminishes the batteries' normal life expectancy.

When connecting an external battery to the 21X, use care to avoid shorting the +12V and ground from the battery.

Four packets of active desiccant are provided with each 21X. Two packets are located in the battery base and two spare packets are sealed in a plastic bag. Used desiccant may be reactivated by oven drying for about 16 hours at 120°C. Routine desiccant replacement is required for reliable datalogger service.

14.10 CALIBRATION PROCEDURES

The 21X requires little maintenance or calibration. Measurements are made in such a way that small errors in the calibration are automatically removed. Measurements can be made to determine whether the accuracy of the 21X is within the specifications given at the front of this manual. If needed, the calibration procedures described in this section can be performed by an experienced technician having the suggested equipment.

NOTE: The precision of the 21X exceeds that of most standard electronic equipment. These procedures require that the test equipment have a precision and accuracy equal to or better than the 21X.

SECTION 14. INSTALLATION AND MAINTENANCE

The following procedures are for calibrating the voltage reference and the clock. Other factors such as range ratios, DAC non-linearity, and offset in either the switched excitation or the CAO voltage require that the 21X be returned to the factory for repair. Please call the factory to obtain authorization before sending in the unit.

14.10.1 VOLTAGE REFERENCE CALIBRATION PROCEDURE

SUGGESTED INSTRUMENTS

Five and one half digit digital volt meter (DVM) with 10 microvolt resolution. The accuracy of the DVM needs to be equal to that of the 21X which is ± 1 mV at 5 V DC.

PROCEDURE

1. Remove the 21X battery base and unplug the battery from the 21X. Remove the four screws holding the aluminum cover plate and remove the cover plate. Lay the 21X, panel down, on a padded flat surface with the circuit cards up and exposed as shown in Figure 14.6-1. Plug the battery back into the 21X. Turn on the 21X.
2. Set the DAC to output 0.000 volts DC by programming the 21X as follows:

*	1	Table 1 Programs
01:	1	Sec. Execution Interval
01:	P4	Excite,Delay,Volt(SE)
01:	1	Rep
02:	5	5000 mV slow Range
03:	1	IN Chan
04:	1	Excite all reps w/EXchan 1
05:	900	Delay (units .01sec)
06:	0000	mV Excitation
		<i>Change as instructed</i>
07:	1	Loc [:MEAS. mV]
08:	1	Mult
09:	0	Offset

3. Monitor the Digital to Analog Converter (DAC) output by connecting the positive lead of the DVM to the DAC OUTPUT TEST POINT which is the left side of the 3.3 K resistor shown in Figure 14.10-1. Connect the negative lead of the DVM to any ground on the front panel. Set the DVM to read on its most sensitive DC Volt scale.
4. Adjust the DAC OFFSET POTENTIOMETER (see Figure 14.10-1) for a DVM reading of 0.0000 V ± 0.0001 .
5. Change the 21X's program, so that Instruction 4, parameter 6 reads 4000 to change the DAC output to 4 V. Set up the DVM to read 4 V DC.
6. Adjust the VOLTAGE REFERENCE GAIN POTENTIOMETER (see Figure 14.10-1) until a DVM reading of 4.0000 V ± 0.0001 is obtained.
7. Change the 21X's program, step 2, so that Instruction 4, parameter 6 reads -4000 to change the DAC output to -4 V.
8. A DVM reading of -4.000 V ± 0.0025 verifies the linearity. If this reading is off, the 21X needs to be sent in for repair.
9. Lock both potentiometers into position with a dab of finger nail polish.

14.10.2 CLOCK CALIBRATION PROCEDURE

The clock circuitry resides on the CPU card (the card farthest from the front panel). The frequency of the clock crystal exhibits a parabolic response to temperature. The frequency maximum occurs at room temperature and drops off slowly at hotter or colder temperatures. When the 21X leaves the factory it is calibrated to be 20 ppm fast. If the 21X is placed in a controlled environment with the temperature close to room temperature, it would be better to set the crystal frequency exactly on.

SUGGESTED INSTRUMENTS

Digital frequency counter

PROCEDURE

SECTION 14. INSTALLATION AND MAINTENANCE

1. Remove the 21X battery base and unplug the battery from the 21X. Remove the four screws holding the aluminum cover plate and remove the cover plate. Lay the 21X, panel down, on a padded flat surface with the circuit cards up and exposed as shown in Figure 14.10-1. Plug the battery back into the 21X. Turn on the 21X.
2. Connect positive lead of the frequency counter to pin 3 of the integrated circuit
3. Lock the variable capacitor into position with a dab of fingernail polish.

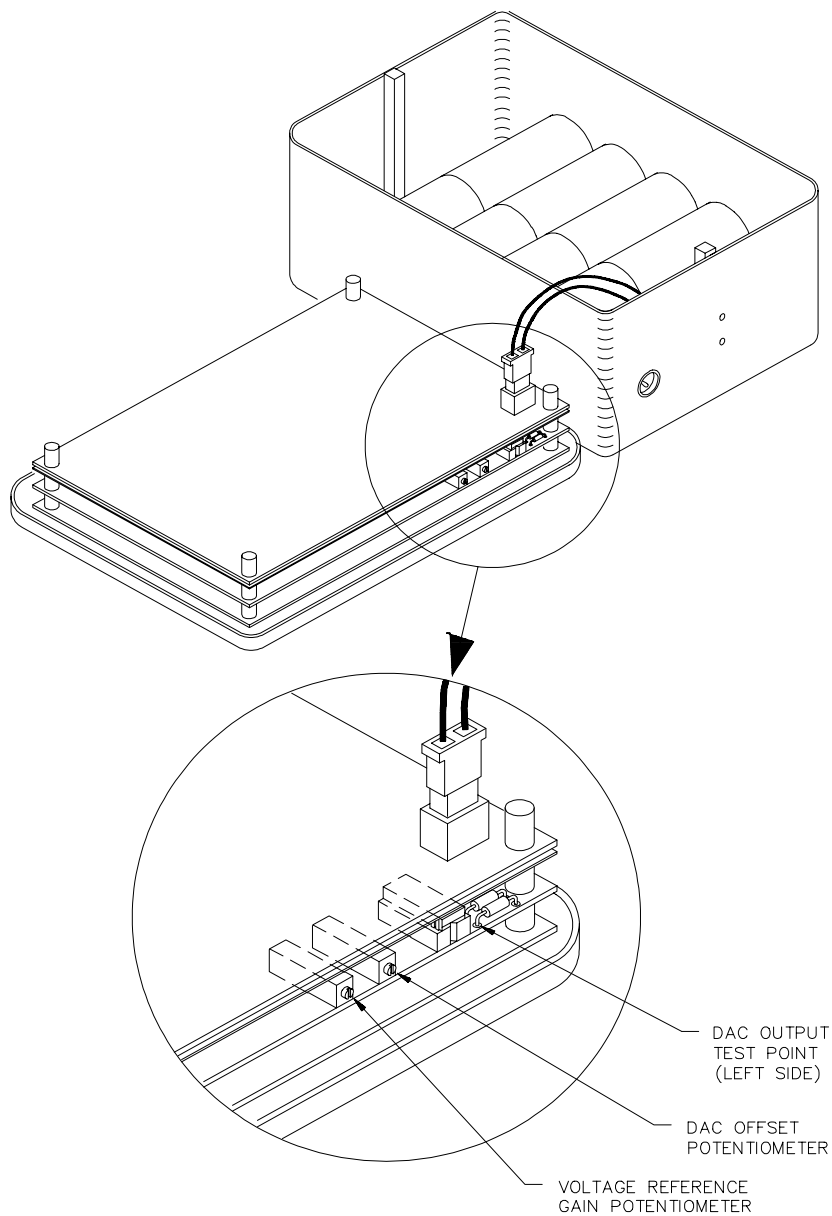


FIGURE 14.10-1. Calibration Points for the 21X

FIGURE 14.10-2. 21X CPU Board

SECTION 14. INSTALLATION AND MAINTENANCE

APPENDIX A. GLOSSARY

ASCII: Abbreviation for American Standard Code for Information Interchange (pronounced "askee"). A specific binary code of 128 characters represented by 7 bit binary numbers.

BAUD RATE: The speed of transmission of information across a serial interface, expressed in units of bits per second. For example, 9600 baud refers to bits being transmitted (or received) from one piece of equipment to another at a rate of 9600 bits per second. Thus, a 7 bit ASCII character plus parity bit plus 1 stop bit (total 9 bits) would be transmitted in $9/9600 \text{ sec.} = .94\text{ms}$ or about 1000 characters/sec. When communicating via a serial interface, the baud rate settings of two pieces of equipment must match each other.

DATA POINT: A data value which is sent to Final Storage as the result of an Output Instruction. Strings of data points output at the same time make up Output Arrays.

EXECUTION INTERVAL: The time interval between initiating each execution of a program table. The execution interval will be synchronized with the current 24 hour time assuming that the table is executed at midnight and every execution interval thereafter. The table will be executed for the first time at the first occurrence of the execution interval after compilation. Any time the clock is reset the execution interval is resynchronized. See Section 1.1 for information on the choice of an execution interval.

EXECUTION TIME: The time that it actually takes the 21X to execute an instruction or group of instructions. If the execution time of a program table exceeds the table's execution interval, the program table will be executed less frequently than programmed.

FINAL STORAGE: That portion of memory allocated for storing Output Arrays. Final Storage may be viewed as a ring memory, with the newest data being written over the oldest. Data in Final Storage may be displayed using the *7 Mode or sent to various peripherals (Section 2).

HIGH RESOLUTION: A high resolution data value has 5 significant digits and may range in magnitude from $\pm.00001$ to ± 99999 . A high resolution data value requires 2 Final Storage locations (4 bytes). All Input and Intermediate Storage locations are high resolution. Output to Final Storage defaults to low resolution; high resolution output must be specified by Instruction 78.

INDEXED INPUT LOCATION: An input location entered as an instruction parameter may be indexed by keying "C" before entering by keying "A"; two dashes (--) will appear at the right of the display. Within a loop (Instruction 87, Section 7), this will cause the location to be incremented each pass through the loop. Indexing is also used with Instruction 75 to cause an input location, which normally remains constant, to be incremented with each repetition.

INPUT/OUTPUT INSTRUCTIONS: Input/Output instructions are used to initiate measurements and store the results in Input Storage or to set Digital Control Ports or Continuous Analog Output channels.

INPUT STORAGE: That portion of memory allocated for storing the results of Input and Processing instructions. The values in Input Storage can be displayed and altered from the *6 Mode.

INSTRUCTION LOCATION NUMBER: As instructions are entered in a program table, they are numbered sequentially. The instruction location number is the number giving an instruction's order in the program table. When programming a table, the instruction location number and a P (e.g., 04: P00) prompts the user when it is time to enter an instruction.

APPENDIX A. GLOSSARY

INTERMEDIATE STORAGE: That portion of memory allocated for storing the results of intermediate calculations necessary for operations, such as averages or standard deviations. Intermediate storage is not accessible to the user.

LOW RESOLUTION: This is the default output resolution. A low resolution data value has 4 significant decimal digits and may range in magnitude from ± 0.001 to ± 6999 . A low resolution data value requires 1 Final Storage location (Section 2.2).

OUTPUT ARRAY: A string of data points output to Final Storage. Output occurs only when the Output Flag is set. The first point of an Output Array is the Output Array ID, which gives the table and the Instruction Location Number of the instruction which sets the Output Flag. The data points which complete the Array are the result of the Output Processing Instructions which are executed while the Output Flag is set. The Array ends when the Output Flag is reset at the end of the table or when another instruction acts upon the Output Flag. Output occurs only when the Output Flag is set.

OUTPUT INTERVAL: The time interval between initiation of a particular Output Array. Output occurs only when the Output Flag is set. The flag may be set at fixed intervals or in response to certain conditions (Section 3.7).

OUTPUT PROCESSING INSTRUCTIONS: These instructions process data values and generate Output Arrays. Examples of Output Processing Instructions include Totalize, Maximize, Minimize, Average, etc. The data sources for these instructions are values in Input Storage. The results of intermediate calculations are stored in Intermediate Storage. The destination of data generated by Output Processing Instructions is Final Storage. The transfer of processed summaries to Final Storage takes place when the Output Flag is set by a Program Control Instruction.

PARAMETER: When used in conjunction with 21X instructions, parameters are numbers or codes which are entered when programming the 21X to specify exactly what the instruction is to do. Once the instruction number has been entered in a program table, the 21X will prompt for the parameters by displaying the parameter number in the ID Field of the display.

PROCESSING INSTRUCTIONS: These instructions allow the user to further process input data values and return the result to Input Storage where it can be accessed for output processing. Arithmetic and transcendental functions are included in these instructions.

PROGRAM CONTROL INSTRUCTIONS: These instructions are used to modify the sequence of execution of instructions contained in program tables, and to set or clear flags.

PROGRAM TABLE: That portion of memory allocated for storing programs consisting of a sequence of user instructions which control data acquisition and processing. Programming can be separated into 2 tables, each having its own execution interval. A third table is available for subroutines which may be called by instructions in Tables 1 or 2. The *1 and *2 Modes are used to access Tables 1 and 2. The *3 Mode is used to access Subroutine Table 3. The length of the tables is constrained by the total memory available for programming (Section 1.1). Table 1 execution has the higher priority; it may interrupt Table 2.

SAMPLE RATE: The rate at which measurements are made. The measurement sample rate is primarily of interest when considering the effect of time skew (i.e., how close in time are a series of measurements). The maximum sample rates are the rates at which measurements are made when initiated by a single instruction with multiple repetitions.

SIGNATURE: A number which is a function of the data and the sequence of data in memory. It is derived using an algorithm which assures a 99.998% probability that if either the data or its sequence changes, the signature changes.

THROUGHPUT: The throughput rate is the rate at which a measurement can be made, scaled to engineering units, and the reading stored in Final Storage. The 21X has the ability to scan sensors at a rate exceeding the throughput rate (see SAMPLE RATE). The primary factor affecting throughput rate is the amount of processing specified by the user. In normal operation, all processing called for by an instruction must be completed before moving on the next instruction. The *maximum* throughput rate for a fast single-ended measurement is 256 measurements per second (16 measurements, 16 times per second).

APPENDIX A. GLOSSARY

APPENDIX B. PROM SIGNATURES AND SOFTWARE OPTIONS

The 21X PROM signatures are viewed by entering the *B Mode and advancing to the appropriate window (Section 2.4.3.). The 21X uses three PROMs. The third PROM determines the PROM option. The current PROM signatures are given in Table B-1.

TABLE B-1. 21X PROM SIGNATURES

OPTION	SIGNATURE	PROM VERSION	REVISION
--	02:14441.		
--	03:14436. or 03:5872.0*		
OSX-0.1	04:50721.	08:.10000	09:0005
OSX-1.1	04:866.00	08:1.1000	09:0004
OSX-2.1	04:44109.	08:2.1000	09:0005

** With this PROM and a hardware modification the slow integration time is 20 ms (one 50 Hz cycle). This option is available for countries where 50 Hz Ac power is used.*

When purchasing a new 21X, the user may select 1 of 3 combinations of software. If no option is specified, the default (OSX0) will be shipped. The differences between the options are listed in the following table. If an instruction or feature described in this manual is not listed in the table, it is in all PROM options.

DIFFERENCES BETWEEN PROM OPTIONS

		SOFTWARE VERSION		
		OSX-0 (default)	OSX-1	OSX-2
Instructions				
23	BURST MEASUREMENT		*	*
60	FFT			*
62	COVARIANCE/CORRELATION	*		
97	INITIATE TELECOMMUNICATIONS	*		
98	SEND CHARACTER	*		
101-104	SDM INSTRUCTIONS	*	*	
81	RAINFLOW HISTOGRAM		*	
Modes				
	*C MODE - SECURITY	*		
Telecommunications Commands				
	L -- SECURITY DISABLE/ENABLE	*		

APPENDIX C. BINARY TELECOMMUNICATIONS

C.1 TELECOMMUNICATIONS COMMAND WITH BINARY RESPONSES

Command	Description
[no. of loc.][F	BINARY DUMP - 21X sends, in Final Storage Format (binary, the number of Final Storage locations specified (from current MPTR locations), then Signature (no prompt).

DATALOGGER J AND K COMMANDS

3142J The 3142J command is used to toggle datalogger user flags, request Final Storage data, and to establish the input locations returned by the K command. The format of the command is as follows:

3142J<CR>abcd...nNULL

where

- 1) "3142J<CR>" is the command.
- 2) "a" is a 1 byte value representing the user flags to be toggled. The most significant bit (MSB), if set, will toggle datalogger user flag 8. Likewise, the 2nd most significant bit, if set, will toggle user flag 7, and so on to the least significant bit which, if set, toggles user flag 1. Toggle means that if a flag is set, it will be then reset, or if it is reset, it will be set.
- 3) "b" is a 1 byte value whose MSB will determine whether Final Storage Data is returned after the K command. If the bit is set, Final Storage Data, if any, will be returned after the next K command. The datalogger initially has this bit reset upon entering telecommunications, but once set by a J command, it will remain set until reset by another J command or telecommunications is terminated.

The 2nd MSB set means a port toggle byte will follow and port status is to be returned with the K command. Like the MSB, this bit is reset upon entering telecommunications,

but remains set once set until reset by another J command or telecommunications is terminated.

The remaining bits are reserved.

- 4) If the 2nd MSB in "b" was set then "c" is a port toggle byte, otherwise "c,d,...,n" are each 1 byte binary values each representing a datalogger Input Storage location. The data at those locations will be returned after the next K command. ASCII code 1 (0000001 binary) represents input location 1. ASCII codes 2 (0000010 binary) represents input location 2, and so on. The order of the location requests is not important. The list is limited, however, to 62 total location requests.
- 5) "Null" or ASCII code 0 (00000000 binary) terminates the J command. Alternately, 11111111 binary aborts the J command. If aborted, flags will not be toggled and location requests will not be saved.

User Enters	Datalogger Echo
3	3
1	1
4	4
2	2
J	J
CR	CR
	LF
	<
a	a
b	b
c	c
d	d
n	n
Null	Null

K The K command returns datalogger time, user flag status, port status if requested, the data at the input locations requested in the J command, and Final Storage Data if requested by the J command. The format of the command is K<CR> (K Return). The datalogger will echo the K and Return and send a Line Feed. The amount of data that follows depends on the J command

APPENDIX C. BINARY TELECOMMUNICATIONS

previously executed; four time bytes, a user flags byte, four bytes for each input location requested in the J command, Final Storage data in Campbell Scientific's binary format if requested by the J command, and terminating in 7F 00 HEX and two signature bytes.

User Enters	Datalogger Echo
K	K
CR	CR
	LF
	Time Minutes byte 1
	Time Minutes byte 2
	Time Tenths byte 1
	Time Tenths byte 2
	Flags byte
	Ports byte (if requested)
	Data1 byte 1
	Data1 byte 2
	Data1 byte 3
	Data1 byte 4
	Data2 byte 1
	Data2 byte 2
	Data2 byte 3
	Data2 byte 4
	DataN byte 1
	DataN byte 2
	DataN byte 3
	DataN byte 4
	Final Storage Data bytes
	01111111 binary byte
	00000000 binary byte
	Signature byte 1
	Signature byte 2

Time Minutes byte 1 is most significant. Convert from binary to decimal. Divide by 60 to get hours, the remainder is minutes. For example, 00000001 01011001 (01 59 HEX) is 345 decimal minutes or 5:45.

Time Tenths byte 1 is most significant. Convert from binary to decimal. Divide by 10 to get seconds and tenths of seconds. For example, 00000001 11000110 (01 C6 HEX) is 454 decimal or 45.4 seconds. Thus the datalogger time for 01 59 01 C6 HEX is 5:45:45.4.

The Flags byte expresses datalogger user flag status. The most significant bit represents Flag 8, and so on to the least significant bit which represents Flag 1. If a bit is set, the user flag is set in the datalogger.

The optional ports byte expresses the datalogger port status. The most significant bit represents Port 8, and so on to the least significant bit which represents Port 1.

For each input location requested by the J command, four bytes of data are returned. The bytes are coded in Campbell Scientific, Inc. Floating Point Format. The format is decoded to the following:

$$\text{Sign}(\text{Mantissa} * 2^{(\text{Exponent})})$$

Data byte 1 contains the Sign and the Exponent. The most significant bit represents the Sign; if zero, the Sign is positive, if one, the Sign is negative. The signed exponent is obtained by subtracting 40 HEX (or 64 decimal) from the 7 remaining least significant bits.

Data bytes 2 to 4 are a binary representation of the mantissa with byte 2 the most significant and 4 the least. The mantissa ranges in value from 80 00 00 hex (0.5 decimal) to FF FF FF HEX ($1-2^{-24}$ decimal). The one exception is for zero which is 00 00 00 00 HEX.

The Mantissa is calculated by converting Data bytes 2 to 4 into binary. Each bit represents some fractional value which is summed for all 24 bits. The bits are arranged from MSB to LSB with the most significant as bit₂₃ and least significant as bit₀. The value that each bit represents = 2^{n-24} , where n=bit location. For example, if there was a 1 at bit₂₀, it's value would be $2^{(20-24)}$ or 2^{-4} .

A simple method for programming this is as follows:

Set Mantissa = 0.

Set Bit Value = 0.5.

For loop count = 1 to 24 do the following:

If the MSB is one, then add Bit Value to the Mantissa.

Shift the 24 bit binary value obtained from Data bytes 2 to 4 one bit to the left.

Multiply Bit Value by 0.5.

End of loop.

Another method that can be used as an estimate is to convert Data bytes 2 to 4 from a long integer to floating point and dividing this value by 16777216.

As an example of a negative value, the datalogger returns BF 82 0C 49 HEX.

Data byte 1 = BF HEX.

Data byte 2 to 4 = 82 0C 49 HEX (or 8522825 decimal).

Data byte 1 is converted to binary to find the Sign. BF HEX = 10111111 BINARY.

The most significant bit is 1 so the Sign is NEGATIVE.

The exponent is found by subtracting 40 HEX from the remaining least significant bits. Converting the binary to hexadecimal, 111111 BINARY = 3F HEX (or 63 decimal).

3F - 40 HEX = FF FF FF FF FF HEX. Or in decimal: 63 - 64 = -1.

Exponent is -1 decimal.

The binary representation of Data bytes 2 to 4 is: 10000010 00001100 01001001.

Summing all the fractional values: $2^{-1} + 2^{-7} + 2^{-13} + 2^{-14} + 2^{-18} + 2^{-21} + 2^{-24} = 0.50800$.

Using the estimate method to find the Mantissa = 82 0C 49 HEX / 1 00 00 00 HEX (or 8522825 / 16777216) which is 0.50800 decimal.

The value is then $(-)0.508 \cdot 2^{-1}$ which equals -0.254.

As an example of a positive value, the datalogger returns 44 D9 99 9A HEX.

Data byte 1 = 44 HEX.

Data byte 2 to 4 = D9 99 9A HEX (or 891290 decimal).

Data byte 1 is converted to binary to find the Sign. 44 HEX = 01000100 BINARY.

NOTE: Don't lose the leading zero!

The most significant bit is 0 so the Sign is POSITIVE.

The exponent is found by subtracting 40 HEX from the remaining least significant bits. Converting the binary to hexadecimal, 1000100 BINARY = 44 HEX (or 68 decimal).

44 - 40 HEX = 4 HEX. Or in decimal: 68 - 64 = 4.

Exponent is 4 decimal.

The binary equivalent of Data bytes 2 to 4 is: 11011001 10011001 10011010.

Summing all the fractional values:

$2^{-1} + 2^{-2} + 2^{-4} + 2^{-5} + 2^{-8} + 2^{-9} + 2^{-12} + 2^{-13} + 2^{-16} + 2^{-17} + 2^{-20} + 2^{-21} + 2^{-23} = 0.85000$.

Using the estimate method to find the Mantissa = D9 99 9A HEX / 1 00 00 00 HEX (or 14260634 / 16777216) which is 0.85000 decimal.

The value is then $(+)0.85 \cdot 2^4$ which equals 13.60.

If appropriately requested by a J command, Final Storage data, if any, will immediately follow the input location data. Refer to the datalogger manual for a description of how to decode Final Storage data in Campbell Scientific's binary data format. Final Storage data will be limited to not more than 1024 bytes per K command.

The K command data is terminated with 7F 00 HEX (a unique binary format code) followed by two signature bytes. Refer to the datalogger manual for the meaning and calculation of the signature bytes. The signature in this case is a function of the first time byte through the 7F 00 HEX bytes. Calculate the signature of the bytes received and compare with the signature received to determine the validity of the transmission.

C.2 FINAL STORAGE FORMAT

21X data is formatted as either 2 byte LO Resolution or 4 byte HI Resolution values. The first two bytes of an output array contain a code noting the start of the output array and the output array ID, followed by the 2 or 4 byte data values. At the end of the data sent in response

APPENDIX C. BINARY TELECOMMUNICATIONS

to the telecommunications F command a 2 byte signature is sent (see below).

Representing the bits in the first byte of each two byte pair as ABCD EFGH (A is the most significant bit, MSB), the byte pairs are described below.

LO RESOLUTION FORMAT - D,E,F, NOT ALL ONES

BITS	DESCRIPTION
A	Polarity, 0 = +, 1 = -.
B, C	Decimal locators as defined below.
D-H plus second byte	13 bit binary value (D=MSB). Largest possible number without D, E, and F all 1 is 7167, but CAMPBELL SCIENTIFIC defines the largest allowable range as 6999.

The decimal locators can be viewed as a negative base 10 exponent with decimal locations as follows:

B	C	Decimal Location
0	0	XXXX.
0	1	XXX.X
1	0	XX.XX
1	1	X.XXX

DATA TYPE WHEN D,E,F, ALL EQUAL ONE

If D, E, and F are all ones, the data type is determined by the other bits as shown below. X implies a "don't care" condition; i.e., the bit can be either 1 or 0 and is not used in the decode decision.

A	B	C	D	E	F	G	H	DATA TYPE AND SECOND BYTE FORMAT
1	1	1	1	1	1	0	X	A,B,C, = 1 - Start of output array, G=0. H is the most significant bit of the output array ID. All 8 bits of the 2nd byte are also included in the ID.
X	X	0	1	1	1	X	X	C = 0 - First byte of a 4 byte value.
0	0	1	1	1	1	X	X	A,B = 0; C = 1 - Third byte of a 4 byte value.
0	1	1	1	1	1	1	1	A = 0; remaining bits = 1 - First byte of a 2 byte "dummy" word. The CR10 always transmits a 0 for the 2nd byte, but the word can be decoded on the basis of the 1st byte only.

HI RESOLUTION FORMAT

Continuing to use the A-H bit representation, the four byte number is shown below as two two byte pairs.

AB0111GH	XXXXXXXX	001111GH	XXXXXXXX
----------	----------	----------	----------

BITS, 1ST BYTE, 1ST PAIR	DESCRIPTION
CDEF = 0111	Code designating 1st byte pair of four byte number.
B	Polarity , 0 = +, 1 = -.
G,H,A,	Decimal locator as defined below.
2nd byte	16th - 9th bit (left to right) of 17 bit binary value.
ABCDEF = 001111	Code designating 2nd byte pair of four byte number.
G	Unused bit.
H	17th and MSB of 17 bit binary value.
2nd byte	8th - 1st bit (left to right) of 17 bit binary value.

CAMPBELL SCIENTIFIC defines the largest allowable range of a high resolution number to be 99999.

Interpretation of the decimal locator for a 4 byte data value is given below. The decimal equivalent of bits GH is the negative exponent to the base 10.

BITS G H A	DECIMAL FORMAT 5 digits
0 0 0	XXXXX.
0 0 1	XXXX.X
0 1 0	XXX.XX
0 1 1	XX.XXX
1 0 0	X.XXXX
1 0 1	.XXXXX

C.3 GENERATION OF SIGNATURE

At the end of a binary transmission, a signature is sent. The signature is a 2 byte integer value which is a function of the data and the sequence of data in the output array. It is derived with an algorithm that assures a 99.998% probability of detecting a change in the data or its sequence. The 21X calculates the signature using each transmitted byte except the 2 byte signature itself. By calculating the signature of the received data and comparing it to the transmitted signature, it can be determined whether the data was received correctly.

SIGNATURE ALGORITHM

- S1,S0 represent the high and low bytes of the signature, respectively

- M represents a transmitted data byte
- n represents the existing byte
- n+1 represents the new byte
- T represents a temporary location
- C represents the carry bit from a shift operation

1. The signature is initialized with both bytes set to hexadecimal AA.

$$S_1(n) = S_0(n) = AA$$

2. When a transmitted byte, M(n+1), is received, form a new high signature byte by setting it equal to the existing low byte. Save the old high byte for later use.

$$T_1 = S_1(n)$$

$$S_1(n+1) = S_0(n)$$

3. Form a temporary byte by shifting the old low signature byte one bit to the left and adding any carry bit which results from the shift operation. A "shift left" is identical to a multiply by 2. Ignore any carry bit resulting from the add.

$$T_2 = \text{shift left } (S_0(n)) + \text{carry}$$

4. Form the new low signature byte by adding the results of operation 3 to the old high signature byte and the transmitted byte. Ignore any carry bits resulting from these add operations.

$$S_0(n+1) = T_2 + S_1(n) + M(n+1)$$

As each new transmitted byte is received, the procedure is repeated.

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APPENDIX D. ASCII TABLE

*American Standard Code for Information Interchange
Decimal Values and Characters*

(X3.4-1968)

Dec.	Char.	Dec.	Char.	Dec.	Char.	Dec.	Char.
0	CONTROL @	32	SPACE	64	@	96	`
1	CONTROL A	33	!	65	A	97	a
2	CONTROL B	34	"	66	B	98	b
3	CONTROL C	35	#	67	C	99	c
4	CONTROL D	36	\$	68	D	100	d
5	CONTROL E	37	%	69	E	101	e
6	CONTROL F	38	&	70	F	102	f
7	CONTROL G	39	'	71	G	103	g
8	CONTROL H	40	(	72	H	104	h
9	CONTROL I	41	)	73	I	105	i
10	CONTROL J	42	*	74	J	106	j
11	CONTROL K	43	+	75	K	107	k
12	CONTROL L	44	,	76	L	108	l
13	CONTROL M	45	-	77	M	109	m
14	CONTROL N	46	.	78	N	110	n
15	CONTROL O	47	/	79	O	111	o
16	CONTROL P	48	0	80	P	112	p
17	CONTROL Q	49	1	81	Q	113	q
18	CONTROL R	50	2	82	R	114	r
19	CONTROL S	51	3	83	S	115	s
20	CONTROL T	52	4	84	T	116	t
21	CONTROL U	53	5	85	U	117	u
22	CONTROL V	54	6	86	V	118	v
23	CONTROL W	55	7	87	W	119	w
24	CONTROL X	56	8	88	X	120	x
25	CONTROL Y	57	9	89	Y	121	y
26	CONTROL Z	58	:	90	Z	122	z
27	CONTROL [	59	;	91	[	123	{
28	CONTROL \	60	<	92	\	124	|
29	CONTROL]	61	=	93	]	125	}
30	CONTROL ^	62	>	94	^	126	~
31	CONTROL _	63	?	95	_	127	DEL

APPENDIX E. CHANGING RAM OR PROM CHIPS

The 21X has 8 sockets for memory chips. Five sockets hold 8K Random Access Memory (RAM) chips and three hold Programmable Read Only Memory (PROM) chips. Older 21Xs may have two PROM chips and as few as two RAM chips.

E.1 DISASSEMBLY OF 21X

1. Turn power off, remove the two Phillips head screws located near the edges of the front panel of the micrologger. Carefully lift the micrologger up and away from the battery pack and disconnect the plastic power connector.
2. Lay the micrologger face down on a padded surface. Remove the four Phillips head screws from the corners of the aluminum back plate. Lift the back plate up and away to expose the 21X CPU board. Figure E-1 shows the CPU card; the memory chips are in the lower right hand corner. The locations numbered 1-5 hold RAM chips. Locations 8, 7, and 6 hold PROM chips.

FIGURE E-1. Memory Sockets on CPU Card

E.2 INSTALLING NEW RAM CHIPS

The standard 21X has the maximum memory allowable. In the unlikely event that a RAM chip fails, the 21X can detect the bad chip during its power-up memory check (Section 1.5). As a result of this check the 21X displays the status of the memory chips as a sequence of 1s and 0s, each representing a chip with the status of chip 1 on the left and 8 on the right; 0 indicates a bad chip. For example, 11011111 indicates that chip 3 (Figure E-1) is bad.

To replace a RAM chip carefully pry the old chip with a small flat blade screwdriver, start at one end and then loosen the other, alternating until the chip is free. The new chip should be installed with the notched end in the same direction as the other chips, to the right side of the card in Figure E-1. Before pushing the chips into the socket, make certain that all pins are correctly seated. After installing the chip, check for pins that may be bent or not firmly seated in the socket. If there is a bent pin, remove the chip, carefully straighten the pin and reinstall the chip.

APPENDIX E. CHANGING RAM OR PROM CHIPS

The earliest 21Xs were shipped with only two 4K RAM chips. Current software does not check for this condition; if an old 21X is being upgraded to new software PROMS, five 8K RAM chips (CSI Model number EMX8) should also be installed.

The older 21X has jumpers at locations M15, W20, and W27 (Figure E-1). With 8K RAM chips installed, M15 should be jumpered on the right set of pins and W20 and W27 should be jumpered on the left set of pins.

After changing RAM chips reassemble the 21X, turn on the power and confirm that the power-up check shows all good RAM.

In general, the PROM chip with the lowest number is inserted in socket 8 and the PROM with the highest number in socket 6, but check the documentation received with the PROM update to be sure.

After changing PROMS, reassemble the 21X and turn on the power. Confirm that the power-up check indicates that all PROMS and RAM are good. Then check the signature in the *B Mode to be certain that they match those sent with the documentation for the PROMS.

E.3 CHANGING PROM CHIPS

PROMs are installed at locations 6, 7, and 8 in Figure E-1. The procedure for changing a PROM is the same as for a RAM chip, carefully pry out the old chip and insert the new one, being certain that the notch on the chip is toward the close edge of the card and that all pins are correctly seated in the sockets.

APPENDIX F. DOCUMENTATION FOR SPECIAL SOFTWARE

15 SERIAL INPUT

1. FUNCTION

Instruction 15 for the 21X is used to read data from an "intelligent" sensor that outputs serial ASCII data.

- Serial input must consist of one start bit, eight data bits (eighth bit ignored), no parity, and 1 or more stop bits.
- 1200 baud is the ONLY rate at which the 21X will accept serial data.
- When Instruction 15 is executed a digital control port is asserted, signaling the sensor to send the data. The control port is reset and the Program Table execution proceeds to the next instruction when
 - the 21X receives a carriage return or
 - the number of characters specified in Parameter 4 are received, or
 - the delay time expires (Parameter 5).
- The data line from the sensor to the datalogger is connected to the high side of a differential channel (the low side may still be used as a single ended input).
- Multiple data points can be received per sensor output. The data point delimiter can be any character other than a numeric character, a + or - sign, or decimal. The delimiter causes data to be stored in the next consecutive Input location.

2. INSTRUCTION 15 AND PARAMETER DESCRIPTION

PARAMETER NUMBER	DATA TYPE	DESCRIPTION
01:	2	Repetitions
02:	2	Input Channel (differential)
03:	2	Digital Control Port/Logic Level X = Port X, TTL logic 1X = Port X, RS232 logic
04:		Number of characters per input
05:	4	Delay time (multiplies of 0.012 sec.)
06:	4	Input location
07:	FP	Multiplier
08:	FP	Offset

PARAMETER 1 Repetitions

"Repetitions" specifies the number of sensors to be read using the same Instruction 15 parameter configuration. For example, a REP of 3 is used for 3 identical sensors or sensors that are satisfied by the same parameter configuration. Instruction 15 must be entered separately for each sensor or group of sensors requiring a different configuration.

For each repetition specified, the 21X advances to the high side of the next differential channel (parameter 2) and increments to the next Control Port (parameter 3). The delay (parameter 5) and number of characters (Parameter 4) are repeated for each repetition.

PARAMETER 2 Input Channel

The sensor output line is connected to the high side of the differential channel specified in Parameter 2.

Standard RS232 logic levels range from 3 to 25 volts and -3 to -25 volts. Voltages in excess of +8 volts will cause errors and possible overranging on other analog input channels. The circuit shown in Figure 1 limits the input voltage range to 0 to 5 volts. Each input signal that is out of the +5 volt range requires one of these circuits or equivalent.

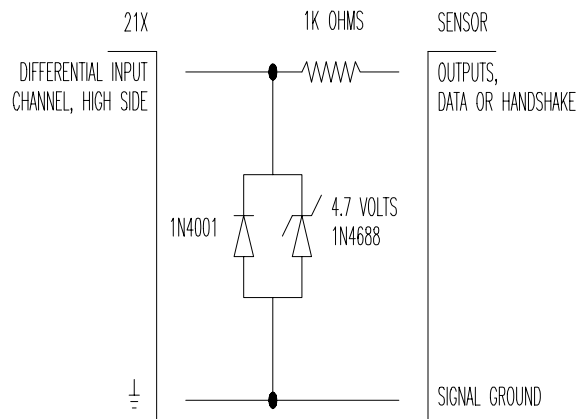


FIGURE 1. Circuit to Limit Input to 0 to 5 volts

15 SERIAL INPUT

PARAMETER 3 Digital Control Port/Logic Level

This parameter specifies which digital control port is used and what the input logic level is (TTL or RS232).

Digital Control Port The digital control port specified in Parameter 3 is asserted during the instruction, but is not asserted before or after the instruction. "Asserted" is 0 volts for TTL and 5 volts for RS232. "Not asserted" is the opposite; 5 volts for TTL and 0 for RS232. The control port stays asserted until all data are received.

NOTE: When the datalogger program is compiled, all digital control ports are set to 0 volts. Thus, when programmed to read a TTL input, the control port is asserted from the time the datalogger compiles until after the first execution of Instruction 15.

Logic Level If the input is RS232 logic levels, enter a 1 before entering the control port number. If the input to be received is TTL logic levels, specify only the control port. RS232 logical 1 is low voltage and TTL is high voltage.

PARAMETER 4 Number of Characters

Parameter 4 specifies the number of characters per repetition to expect including polarity, spaces, decimal, alpha, numeric, and carriage return characters. When the specified number of characters are received, the 21X advances to the next repetition or program instruction. Characters sent after the specified number of characters are received are ignored. If less are sent, and a carriage return is received, the value is stored and the program advances. If less are sent and a carriage return is not received and the specified delay expires, -99999 is stored in the Input location.

PARAMETER 5 Delay

Parameter 5 specifies a time limit for the 21X to receive characters from the sensor. Units are 0.012 seconds (e.g. entering a delay of 3 causes the 21X to receive characters for a maximum of 0.036 seconds). When the delay time expires, the 21X advances to the next repetition or program instruction. If the delay expires, -99999 is stored in the Input location (parameter 6).

PARAMETER 6 Input Location

The Input Location in which the first datapoint is stored is specified by parameter 6. If more than one value is received they are placed in consecutive Input Locations starting with the specified location.

3. EXAMPLE: INSTRUCTION 15 AND THE AIR-DB-1A BAROMETER

This example shows how to use a 21X with Instruction 15 to read the AIR-DB-1A Barometer. Various barometer functions (mode, units of output, baud rate, etc.) are determined by jumpers internal to the barometer. A summary of the jumper configurations is found in Appendix A. Please refer to the AIR barometer manual for jumper configuration details.

3.1 21X/BAROMETER CONFIGURATION LIMITATIONS

The 21X is limited to reading only certain barometer jumper configurations as described below:

- **MODES of OPERATION** The 21X reads all barometer "Modes of Operation" that have serial output except the Serial ID and Signature Analysis portion of the Test Mode. The 21X will NOT read a parallel input.
- **UNITS of OUTPUT** The 21X reads all "Units of Output".
- **NUMBER of MEASUREMENTS AVERAGED** Any "measurements averaged" barometer option may be read by the 21X. Keep in mind that the greater the number of measurements used to compute an average, the longer it takes for Instruction 15 to execute, resulting in a greater current drain (25 mA).
- **BAUD RATE** 1200 baud is the ONLY rate at which the 21X accepts serial data.
- **RS232 JUMPERS** For typical field use where power is limited, the RS232 jumpers should be removed to enable a TTL (0-5v) level output.

3.2 21X/BAROMETER HOOK-UP

Barometer lead wires are provided for two general types of connections: TTL level output to the 21X and an RS232 level output to a terminal or printer. Of the TTL output connections, two versions are available for the 21X. Table 1 contains hook-up information for two 21X configurations and one RS232 terminal/printer configuration. As indicated in Table 1, the barometer data line must connect to the HI side of a differential channel. Each hook-up configuration has specific advantages as described below.

CAUTION: To avoid damage to the barometer CMOS chips, make ground connections first and +12 volts last. All sensor leads not used in a particular hook-up configuration should be insulated to avoid possible shorting.

HOOK-UP CONFIGURATION #1 This hook-up demands the least power consumption (typically 1.0 mA quiescent, 6.0 mA active). If the barometer is jumpered to output the average of one measurement, the execution time of Instruction 15 is 0.5 to 0.6 seconds.

HOOK-UP CONFIGURATION #2 This hook-up demands greater power than Configuration #1 (typically 5.5 mA quiescent, 6.0 mA active), yet results in a faster measurement. If the barometer is jumpered to output the average of one measurement, Instruction 15 execution time is 0.2 to 0.3 seconds.

HOOK-UP CONFIGURATION #3 The purpose of this hook-up is to read the barometer on a standard RS232 device, such as a printer or terminal instead of the 21X. If failure occurs, this hook-up allows using a third device to check if the problem is with the barometer or with the CR10.

3.3 21X/BAROMETER PARAMETER CONSIDERATIONS

PARAMETER 3 This parameter specifies which Digital Control Port is controlling the barometer, and what type of serial input the 21X will receive. If only the Port number is entered, a TTL input is implied. A one (1) before the Port number implies an RS232 input. When Hook-up Configuration #1 or #2 are used, only the Port number should be entered.

For multiple repetitions (parameter 1), the Digital Control Port is sequentially incremented with each repetition. Thus, each barometer must connect to a separate adjacent Port.

PARAMETER 4 This parameter defines the total number of characters to expect per repetition.

Instruction 15 requires the use of Intermediate and Input locations. One Input location is required per data point. The number of Intermediate locations consumed is dependent on the value of Parameter 4. To optimize on Intermediate locations, Parameter 4 should be exactly equal to the number of characters per barometer output (refer to Table 2).

15 SERIAL INPUT

TABLE 1. 21X/Barometer Connection Details

	HOOK-UP #1	HOOK-UP #2	HOOK-UP #3	BAROMETER CONDUCTORS
CONNECTIONS	DIFFERENTIAL CHANNEL HI	DIFFERENTIAL CHANNEL HI	INSULATE	BLK DATA (TTL)
	INSULATE	INSULATE	PIN 3	BRN DATA (RS232)
	$\frac{\perp}{\equiv}$	DIGITAL CONTROL PORT	$\frac{\perp}{\equiv}$	RED DTR (TTL)
	INSULATE	INSULATE	PIN 20	ORG DTR (RS232)
	DIGITAL CONTROL PORT	$\frac{\perp}{\equiv}$	INSULATE	GRN SHUT DOWN
	$\frac{\perp}{\equiv}$	$\frac{\perp}{\equiv}$	PIN 7	YEL $\frac{\perp}{\equiv}$
	+12VDC	+12VDC	+12VDC	BLU +12VDC
	INSULATE	INSULATE	-12VDC	PRP -12VDC
DEVICE	CR10	CR10	TERMINAL/PRINTER	
POWER SUPPLY	+12VDC	+12VDC	+12VDC	
SECONDS/ MEASUREMENT	0.5 TO 0.6	0.1 TO 0.2		
TYPICAL SYSTEM CURRENT DRAIN ACTIVE QUIESCENT	6.0mA 1.0mA	6.0mA 5.5mA		
BAROMETER OUTPUT	LSTTL	LSTTL	RS232	
RS232 DRIVER CHIP	DISABLE	DISABLE	ENABLE	

TABLE 2. Number of Characters/Output and Memory Requirements for Various Barometer Output Modes

SERIAL OUTPUT MODE	CHARACTERS PER OUTPUT	DATA POINTS PER OUTPUT	INPUT LOC. REQUIRED	INTERM. LOC. REQUIRED
BAROMETER	8	1	1	3
ALTIMETER				
1 DATA POINT	8	1	1	3
2 DATA POINTS	22	2	2	6
ALTIMETER SETTING	22	2	2	6
TEST				
RAW/PRESS	41	5	5	11
RAW	33	4	4	9

PARAMETER 5 The purpose of this parameter is to limit the amount of time that Instruction 15 waits to receive a barometer output. If the barometer fails to output, Instruction 15 advances to the next repetition or instruction when the specified delay time expires. If a barometer output is received, Instruction 15 advances upon receipt of the data, regardless of any remaining delay time. Thus, the delay may be overestimated without slowing instruction execution. If the delay is underestimated, or the barometer fails to output, a default value of -99999 is placed in the specified input location (PARAMETER 6).

One delay unit is approximately equal to 0.012 seconds. The required delay may be estimated by dividing 0.012 into Instruction 15's execution time. Execution time is dependent on both the hook-up configuration and the barometer jumper configuration. Exact execution time must be verified, but an initial estimate may be calculated as follows:

HOOK-UP CONFIGURATION #1:
 $ET = 0.1 \times MA + .9$

HOOK-UP CONFIGURATION #2:
 $ET = 0.1 \times MA + .6$

WHERE:

ET = Execution time in seconds
 MA = Number of measurements averaged

The above equations overestimate the execution time. When execution speed is critical, the exact minimum execution time must be determined through trial and error.

Parameter 5 Delay is estimated by:

$Delay = ET/0.012$

3.4 PROGRAM

The following example program assumes the barometer is jumpered for TTL output and the average of one measurement. The following considerations are accounted for in the program.

- To preserve the barometer measurement resolution, barometer data must be output to the 21X Final Storage in high resolution (Instruction 78).
- A communication failure shows up as a partial value or -99999. It is generally desirable to exclude this value from subsequent processing instructions and log the incidence of failure. A failure may be detected by comparing it to expected limits. A bad value may be excluded from processing by temporarily setting the Intermediate Processing Disable flag (flag 9).

15 SERIAL INPUT

01:	P	15	Serial Input	
01:		1	Repetitions	
02:		1	Diff Input Chnl	
03:		1	Dig Ctrl Prt X=TTL/1X=RS232	
04:		9	Number Characters/Input	
05:		83	Delay (1=0.012 sec)	
06:		1	Input Loc	
07:		1	Multiplier	
08:		0	Offset	
02:	P	89	If X<=>F	<i>START: Limit testing</i>
01:		1	X Loc AIR mb	
02:		3	>=	
03:		1300	F	
04:		11	Set high Flag 1	<i>then set Flag 1 high</i>
03:	P	89	If X<=>F	
01:		1	X Loc AIR mb	
02:		4	<	<i>If reading is < 800 mb</i>
03:		800	F	
04:		30	Then Do	<i>then set Flag 1</i>
04:	P	91	If Flag	<i>If Flag 1 is set,</i>
01:		11	1 is set	
02:		30	Then Do	<i>do the following.</i>
05:	P	86	Do	<i>Output time of failure</i>
01:		10	Set high Flag 0 (output)	
06:	P	77	Real Time	
01:		110	Day,Hour-Minute	
07:	P	70	Sample	<i>Output out of range reading</i>
01:		1	Rep	
02:		1	Loc AIR mb	
08:	P	86	Do	<i>Set Intermediate Processing</i>
01:		19	Set high Flag 9	<i>Disable Flag</i>
09:	P	86	Do	<i>Set Flag 1 low</i>
01:		21	Set low Flag 1	
10:	P	95	End	<i>End of Flag Then Do</i>
11:	P	92	If time is	<i>Output mb twice/day</i>
01:		0	minutes into a	
02:		770	minute interval	
03:		10	Set high Flag 0 (output)	
12:	P	77	Real Time	
01:		110	Day,Hour-Minute	
13:	P	71	Average	
01:		1	Rep	
02:		1	Loc AIR mb	

*D TAPE UPLOAD AND DOWNLOAD

FUNCTION

This library option adds additional *D mode commands that allow datalogger programs to be saved to and loaded from a cassette tape.

INSTRUCTIONS

Command	Description
3	Save Program on Tape
4	Load Program from Tape

SAVING PROGRAM ON TAPE

Use Command 3 to save a program on tape. Connect the RC35 Cassette Recorder to the datalogger via the SC92A Cassette Write Only Interface or the SC93A Cassette Read/Write Interface. The SC93A has three plugs which plug into the microphone, monitor, and DC-Input jacks on the recorder. Enter *D Mode, switch the recorder to RECORD, and key in 3A to initiate the program dump. When the recording is completed, "13:0000" is displayed.

Command 3 writes an ASCII listing of the datalogger program to tape. The information saved on tape is the same as the printer listing

(Command 1). The C20, with the format switches in the "II, Decode" position, will read the file. The PC201 will read the file if the TAPE.COM program is run and the File Data Format is specified as either Printable ASCII or Comma Delineated ASCII.

LOADING PROGRAM FROM TAPE

Use Command 4 to load a program from tape to the datalogger. Connect the RC35 Cassette Recorder to the datalogger via the SC93A Cassette Read/Write Interface. The recorder's volume setting should be near mid-range. Position the tape at the start of the recorded program before plugging in the SC93A. Enter *D Mode, press the play button, and key in 4A to initiate the load.

When loading a program from tape, the datalogger suspends all other tasks, including updating the real-time clock. An "L" is displayed when a block of data is detected on the tape. A tape read error will be signaled by an "E". If data is not read within 30 seconds, the datalogger displays E97. If there are no correctable errors (E98), the datalogger will display "13:0000" after the tape read is complete. The new program will be in memory and running.

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