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HEWLETT PACKARD

OPERATING, PROGRAMMING AND CONFIGURATION MANUAL

MODEL 3421A
DATA ACQUISITION/CONTROL UNIT

IMPORTANT NOTICE

Most -hp- service offices in the United States are NOT authorized to service and repair 3421A DA/C Unit. Notify your local -hp- sales office for specific information on where to send the instrument for repair.

Any changes made in instruments manufactured after this printing will be found in a "Manual Changes" supplement supplied with this manual. Be sure to examine this supplement, if one exists for this manual, for any changes which apply to your instrument and record these changes in the manual.

WARNING

The 3421A uses latching relays on the multiplexer assembly (option 020, 021 or 022) and on the mainframe. The state of these relays can only be altered under program control. This is an advantage in the sense that, under most conditions of failure, the relays will remain in whatever state your program has set them. However, in case of power or equipment failure, any application requiring a failsafe method of insuring that the circuits under control are in a known state must be provided by the installer.

WARNING

In case of a component failure or programming error, any voltage that is input to a multiplexer assembly may be present on any other terminal of any installed multiplexer assembly as well as the 3421A front panel terminals. Likewise, any voltage that is input to the 3421A front panel terminals may be present on any other terminal of any installed multiplexer assembly.

Manual Part No. 03421-90010

Microfiche Part No. 03421-90060

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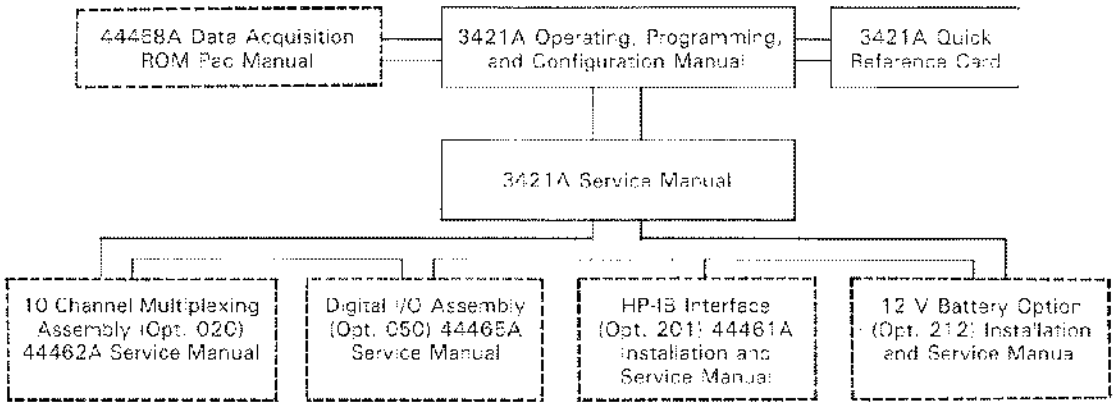
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3421A Manual Reference

The following block diagram shows the 3421A manual documentation scheme. Dashed line borders indicate those manuals that are shipped with the order of specific options; solid borders indicate those manuals that are shipped with every instrument.



3421A Operating, Programming, and Configuration Manual (03421-90010) for all users. All features and options of the 3421A are discussed in this manual.

3421A Quick reference Card (03421-90002) for all users. This card is a quick reference to all of the 3421A commands.

3421A Service Manual (03421-90008) for the service technician. Theory of operating, calibration, and troubleshooting are discussed.

44462A Service Manual (44462-90000) for the service technician. This manual covers installation and troubleshooting for the option assembly.

44465A Service Manual (44465-90000) for the service technician. This manual covers installation and troubleshooting for the option assembly.

44461A HP-IB Interface Installation and Service Manual (44461-90001) for the service technician. This manual covers installation and troubleshooting for the HP-IB option assembly.

12V Battery Option (Opt. 212) Installation and Service Manual (03421-90009) for the service technician. This manual explains how to connect the 12V Battery Option to an external 12V source and how to troubleshoot the option assembly.

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Herstellerbescheinigung

Hiermit wird bescheinigt, daß das Gerät/System HP 3421A in Übereinstimmung mit den Bestimmungen von Postverfügung 1046/84 funkentstört ist.

Der Deutschen Bundespost wurde das Inverkehrbringen dieses Gerätes/Systems angezeigt und die Berechtigung zur Überprüfung der Serie auf Einhaltung der Bestimmungen eingeräumt.

Zusatzinformation für Meß- und Testgeräte

Werden Meß- und Testgeräte mit ungeschirmten Kabeln und/oder in offenen Meßaufbauten verwendet, so ist vom Betreiber sicherzustellen, daß die Funk-Entstörbestimmungen unter Betriebsbedingungen an seiner Grundstücksgrenze eingehalten werden.

Manufacturer's declaration

This is to certify that the equipment HP 3421A is in accordance with the Radio Interference Requirements of Directive FTZ 1046/84. The German Bundespost was notified that this equipment was put into circulation, the right to check the series for compliance with the requirements was granted.

Additional Information for Test- and Measurement Equipment

If Test- and Measurement Equipment is operated with unscreened cables and/or used for measurements on open set-ups, the user has to assure that under operating conditions the Radio Interference Limits are still met at the border of his premises.

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Chapter 1
Meet The 3421A

Introduction

Welcome to the world of high performance, low cost data acquisition and control. Your new -hp- Model 3421A is a fully programmable unit combining precision measurement capability with process monitoring and control functions. When interfaced to an -hp- computer (such as the HP-85) or handheld calculator (such as the HP-41C/CV), the 3421A forms a versatile, easy to use data acquisition and control system.

The standard 3421A consists of a mainframe, a built in 5 1/2 digit voltmeter, a 10 kHz counter, and an HP-IL controller interface. Compensated temperature conversion using T-type thermocouples is also built in. The mainframe can hold up to three option assemblies. Available options include a 10 Channel Multiplexing Assembly, an 8-bit Digital I/O Assembly, and a Breadboard Assembly for custom circuit design. In addition, an optional HP-IB* interface or a 12V Battery Option is available.

Typically, at least one Multiplexing Assembly (44462A or option 020, 021, or 022) is used in the 3421A. This assembly provides 10 channels for signal input. A temperature reference junction is built in to each assembly for thermocouple compensation. In addition, two of the channels can be configured as actuators for controlling motors, alarms, etc.

The 8-bit Digital I/O Assembly (44465A or option 050) provides an 8-bit input port and an 8-bit output port. Typical uses for this assembly include monitoring limit or position switches, and low voltage actuating. The 3421A command set provides for individual bit control as well as 8-bit word control.

If neither of these assemblies meet your needs, Option 040, the Breadboard Assembly is available. This option permits you to custom design and build your own measurement or control assembly.

All of the 3421A features are completely programmable. A powerful instruction set means that the 3421A is very easy to use in a wide variety of applications. The major features are:

* HP IB (Hewlett Packard Interface Bus) is Hewlett-Packard's implementation of IEEE Standard 488-1978 and ANSI MC1.1.

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- HP-IL interface for connecting to the HP-41C/CV calculator or computers such as the HP-85. An optional HP-IB interface is available for interfacing to other computers.

- The 3421A may be combined with the HP-41C/CV handheld calculator, HP-82162A thermal printer/plotter, and HP-82161A digital cassette drive for a complete battery operated data acquisition system.

- Fully programmable 5½ digit voltmeter for measuring DC voltage, AC voltage, and 2- wire and 4- wire resistance measurements.

- Programmable power down, standby mode to conserve battery power in remote location usage.

- Memory storage for 30 readings allows fast data acquisition for later manipulation.

- Programmable counter for frequency measurements up to 10kHz or totalizing up to 65535 counts.

- Low thermal offset switching with built-in reference junction.

- Digital I/O for process control and monitoring.

Introduction to Data Acquisition and Control

As the core of a data acquisition and control system, the 3421A is capable of being used in many application areas where data received from various transducers needs processing.

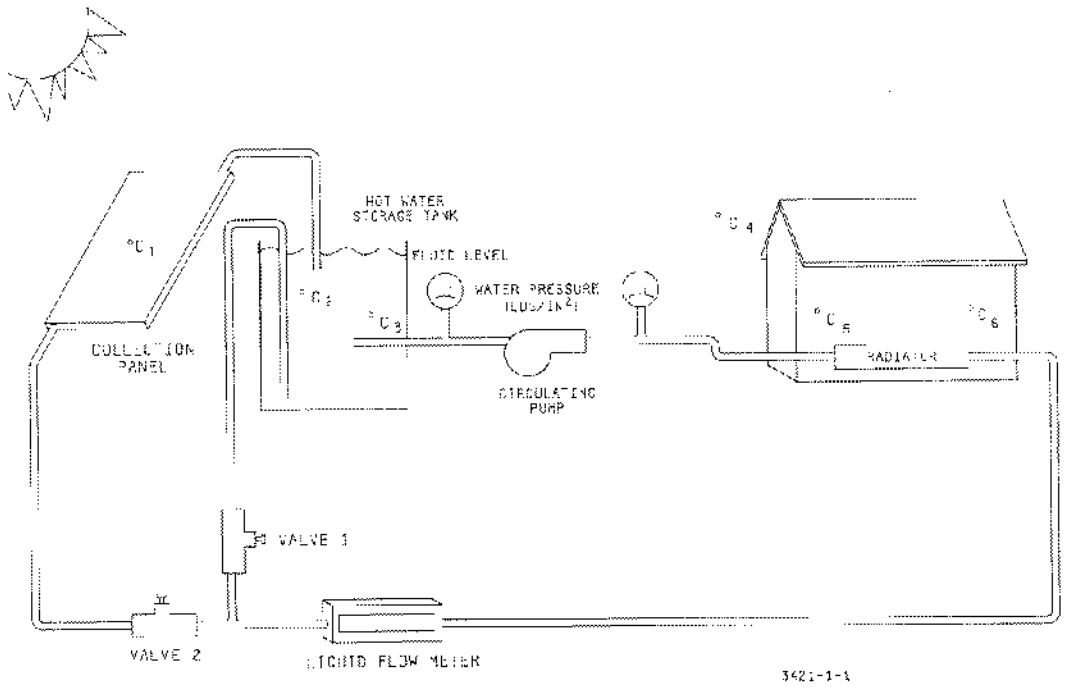
For example, in the areas of production control, quality assurance, and final test, the 3421A provides uniform and precise measurements. Using the 3421A to test and monitor prototypes can mean better knowledge of the product and therefore shorter development times in the R&D lab. Battery operation and the 3421A's light weight allow you to transport the system to out-of-the-way locations.

All of this is made possible because of the 3421A's ability to perform several measurement tasks under computer control. Tests can easily be altered to fit other applications. Instrument cost and setup time is greatly reduced since the measurement system is contained in one package.

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A simple solar heating demonstration will help you to visualize where the 3421A fits into a data acquisiton/control system. This illustration shows the power and flexability of the 3421A under computer control. In the following illustration, several parameters are to be measured including the temperature at different locations, fluid pressure on both sides of a pump, fluid flow and fluid level. Furthermore, the pump and two valves must be controlled, i.e., turned on or off.

The 3421A, under computer control, measures the various temperatures and transducer outputs and sends the data to the computer. The computer analyzes, records, and plots the data. But more than that, the computer makes certain decisions based upon the measured data and instructs the 3421A to actuate (turn on) the pump or valves. Several other functions may be included such as sounding an alarm if the pump pressure drops sharply or the liquid level in the tank is below normal.



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How To Use This Manual

This Operating, Programming, and Configuration Manual has been designed for you to serve as a complete reference document for using the 3421A. It covers both programming information and configuration/installation/connection information for the option assemblies. Information on Operator Maintenance, such as power requirements and specifications, are placed later in the manual, in Chapter 7. If you have just received your 3421A you will want to read this information. Chapters 8 and 9 discuss installing the option assemblies and the breadboard option (Opt. 040), respectively, and are intended for use only by qualified service trained personnel. A separate service manual for the 3421A contains information on calibration, performance testing and service.

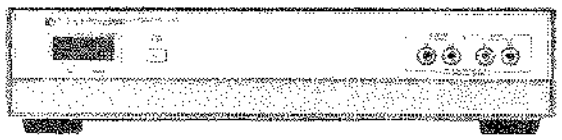
Familiarize yourself with the 3421A by looking through this manual. The best way to feel at ease with the instrument is to sit down with this manual, the 3421A, and your calculator and perform the examples shown. It won't take long to become familiar with the instrument and its many features.

The following paragraphs will serve as a guide to direct you to the remaining chapters in this manual. Acquaint yourself with the manual by reading through these descriptions.

Section I, Operating and Programming

Getting Started
Chapter 2

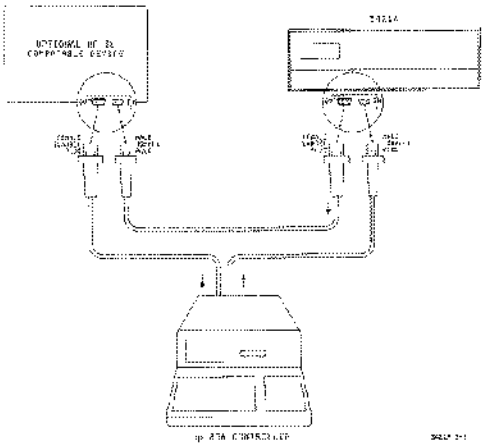
Chapter 2 discusses each function and feature of the 3421A. Major sections are devoted to the voltmeter, counter, and temperature measurements. Other topics include the power-down "sleep" mode, battery operation, and optimizing reading rates. This chapter should be read before you begin programming the 3421A as it sets a foundation for the remainder of the manual.





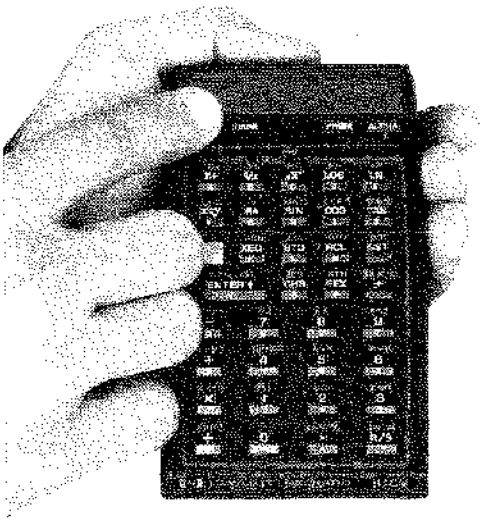
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BASIC Language Programming Chapter 3



Desktop computers with HP-IL or HP-IB capability, such as the -hp- Model 85, may be used to program the 3421A. Chapter 3 covers this subject and provides examples to enhance the discussion. Several application programs are provided throughout the chapter. Immediately following this chapter are several blue pages called a Command Directory. This directory explains each command the 3421A responds to and provides simple program examples.

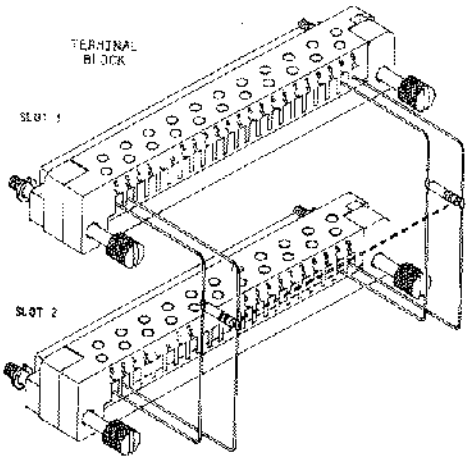
Programming With the -hp- Model 41C/CV Calculator Chapter 4



The -hp- Model 41C family of hand-held calculators can be used to program your 3421A. This chapter teaches you how to execute simple, one-line commands from the calculator and then shows you how to write simple programs for controlling the 3421A. At the end of the chapter are several application programs. Note that the assumption is made in this chapter that you do not have the HP-44468A Data Acquisition Pac ROM for the 41C/CV (option 541 for the 3421A). If you do have the 44468A, refer to its manual.

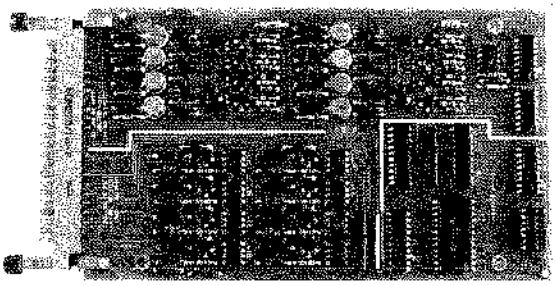
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44462A
10 Channel Multiplexing Assembly
Chapter 5



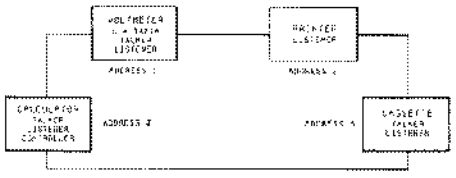
This chapter describes the features of the 44462A (opt. 020, 021, or 022) assembly and the many ways it can be used. Topics include voltage measurements, resistance measurements (both 2- and 4- wire), temperature measurements, and actuators. Several examples are provided to aid you in understanding and using the assembly.

44465A
8-Bit Digital I/O Assembly
Chapter 6



The 8-bit Digital I/O assembly (opt. 050) can be used in a wide variety of applications where on/off, present/not present, etc. conditions occur. This chapter shows how the assembly can be used to sense position or limit switches and control relays. Examples are scattered throughout the chapter.

Operators Maintenance
Chapter 7



This chapter addresses 3421A installation procedures (option installation is discussed in chapter 8). It also contains a complete table of specifications, what to do if you suspect a malfunction, and many other items of special interest to the operator.

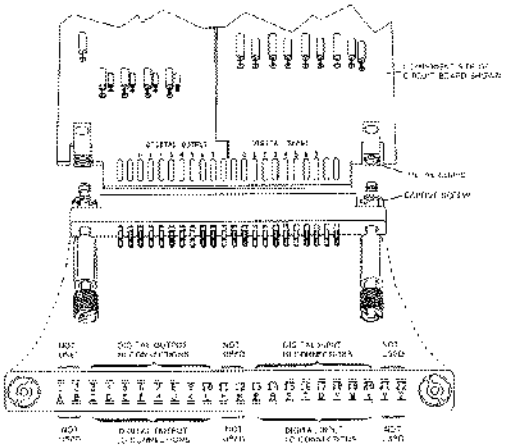
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Section II, Option Assembly Installation and Configuration

CAUTION

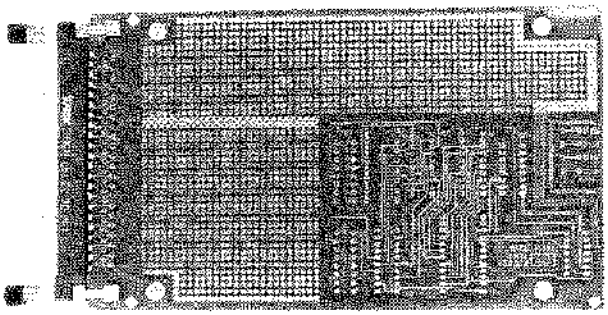
Only service trained personnel with an understanding of electronic circuitry and the hazards involved should install or reconfigure the option assemblies. The two chapters described below contain installation and configuration information.

Installation
Chapter 8



This chapter details the installation procedures for the option assemblies. Also included are discussions of jumper configurations and connections to the device under test.

44464A
Breadboard Assembly
Chapter 9

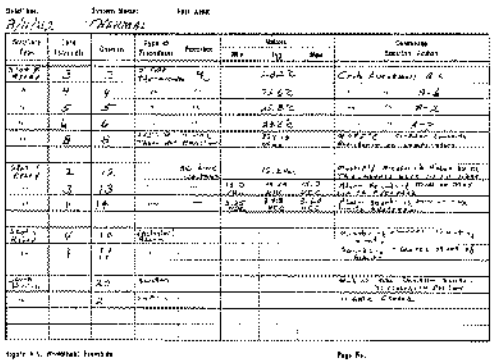


The Breadboard option (opt. 040) is discussed in this chapter. Details are provided for using the assembly for custom designed circuits. Specifications include component height, power dissipation, and power supply requirements.

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Documentation Worksheet
Appendix A

All too often it is discovered that documentation has been totally forgotten until the hardware and setup work have been done. Frequently this results in considerable effort and in documentation that does not accurately reflect the work that has been done. This appendix helps to alleviate the problem by providing a simple worksheet which can be completed simultaneously with the hardware and programming tasks.



HP-IL/HP-IB Summary
Appendix B

Appendix B provides a more detailed explanation of the two interfaces than provided in the rest of the manual. Refer to it for technical information on the HP-IL and HP-IB interfaces.





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Section I
Operating and Programming

WARNING

The 3421A uses latching relays on the multiplexer assembly (option 020, 021, or 022) and on the mainframe. The state of these relays can only be altered under program control. This is an advantage in the sense that , under most conditions of failure, the relays will remain in whatever state your program has set them. However, in case of power or equipment failure, any application requiring a failsafe method of insuring that the circuits under control are in a known state must be provided by the installer.

WARNING

In case of a component failure or programming error, any voltage that is input to a multiplexer assembly may be present on any other terminal of any installed multiplexer assembly as well as the 3421A front panel terminals. Likewise, any voltage that is input to the 3421A front panel terminals may be present on any other terminal of any installed multiplexer assembly.

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Chapter 2
Getting Started

Introduction

As a data acquisiton/control unit, the -hp- model 3421A is a self contained measurement system. A computer and of course your transducers are the only other devices required for data gathering and analysis. In the first chapter you saw the very basics of a data acquisition system. With this chapter you will begin learning how the features of the 3421A can solve many of your measurement needs. The information in this chapter represents a comprehensive description of the 3421A and its many features. For information on the three option assemblies, refer to Chapters 5, 6, and 9. Chapter 5 covers the 44462A 10 Channel Multiplexing Assembly and Chapter 6 covers the 44465A Digital I/O Assembly. The option 44463A Breadboard Assembly is discussed in detail in Chapter 9.

Operating Characteristics

The main operating characteristics of the 3421A are detailed in the table below. This table is an abbreviated set of 3421A specifications. You will probably find that this table answers most of your questions about the capabilities of the 3421A without laboring over several pages of specifications. The complete Table of Specifications for the 3421A can be found in Chapter 7 of this manual.

DC Volts:

1μV sensitivity (.3V range) to 300V full scale
R_{in}: $>10^{10}$, .3 and 3 V ranges
10MΩ ±1%, 30 and 300V ranges

AC Volts:

100μV sensitivity (3V range) to 30V full scale
Bandwidth: 30 Hz to 2kHz
Average responding converter

Resistance:

1mΩ sensitivity (300 Ω range) to 30MΩ full scale
Maximum open circuit voltage: 6.5 volts
Current through unknown resistance:

300,3kΩ ranges	— 1 mA
30kΩ range	— 100μA
300kΩ range	— 10μA
3MΩ range	— 1μA
30MΩ range	— 0.1μA

Counter:

Frequency response—1Hz to 10kHz (×1.5mS risetime)
Sensitivity: 600mVp-p
Minimum pulse width: 50μS
Input impedance: 10MΩ +1,-10%

Totalize:

Maximum count = 65535
Minimum pulse width (5V) = 50μS
Minimum pulse period = 100μS

Temperature (Type T thermocouple):

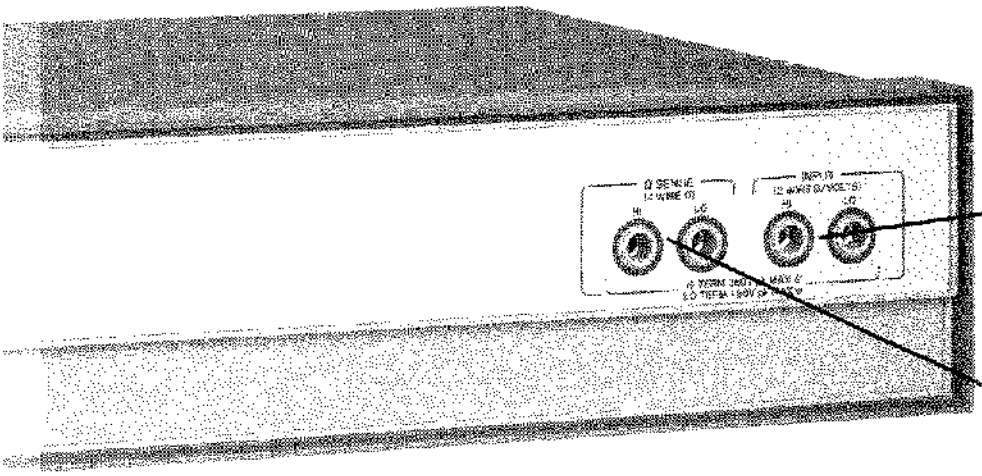
Temperature Range = -200°C to +400°C

Internal reference junction for software compensation.

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N OVERVIEW OF THE 3421A



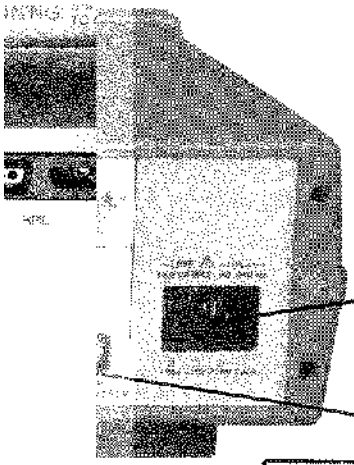
Input

These are the voltmeter and counter input terminals.

Ω Sense

These terminals are used for the voltmeter sense leads when making 4-wire ohms measurements.

IB Rear Panel

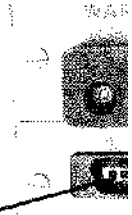


AC Line Cord and Fuse

Reset Switch

This reset switch is provided to completely remove operating power (as long as the switch is held in) from the 3421A. This is to be used only in case of failure.

HP-



HP-IL Connector

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The 3421A in Detail

Because the goal of this chapter is to provide the most comprehensive description of the 3421A and its features, this chapter is divided into 14 major subject headings. Each subject details a particular feature or function of the 3421A. At the end of most subjects will be a short list of Standard programming commands relating to that subject. The subject headings are:

Subject	Page
Turn-on	17
Battery Operation	19
Calibration	20
Channels	21
Commands	22
Counter	24
Display	27
HP-IL Power Down/Power Up	29
Optimizing Reading Rates	30
Rear Panel	33
Resistance Measurements	35
Temperature Measurements	37
Test/Reset	39
Voltmeter	41

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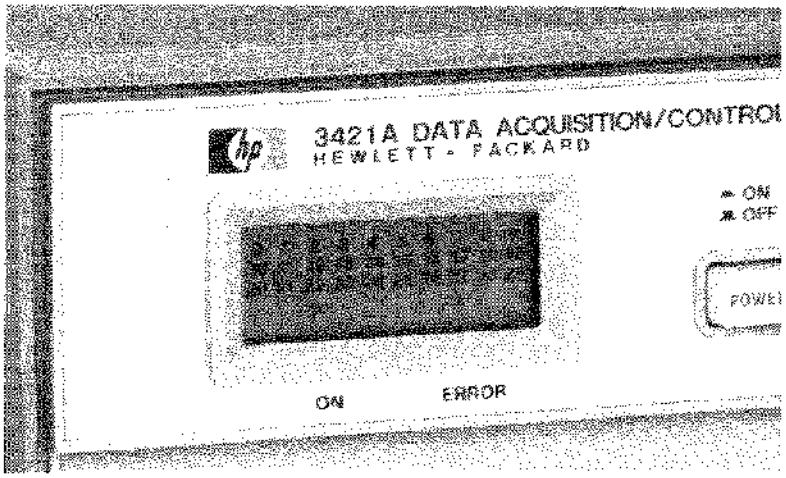
TURN-ON

Before applying AC Power to the 3421A, check the rear panel line voltage option label to be certain the instrument is set for the nominal line voltage in your area. If necesary, refer to the installation information in Chapter 7 of this manual. As you press the POWER switch, very carefully watch the display as the 3421A goes through its turn-on sequence and self test.

What Happens at Turn-on

At turn-on, the 3421A performs a series of 8 internal self tests. If any of them fail, the ERROR indicator is turned on in the display and the 3421A attempts to interrupt the computer (see SPOLL in chapter 3). A complete description of the self test will be given later in this chapter.

Next, you will hear a relay 'click' inside of the 3421A as all numbers in the display light up (see photo). These numbers will be on for about 1 second. Afterwards, if a failure is detected by any of the self tests, one or more numbers will light up in the display (for 1 second) indicating which test(s) failed. These numbers are assigned as follows.



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TURN-ON (Cont'd)

Number lit	Self Test Failed
0*	Calibration RAM checksum error
1	ROM 1 bad
2	ROM 2 bad
3	A/D Slope error
4	Microprocessor RAM bad
5	Internal RAM 1 bad
6	Internal RAM 2 bad
7**	Failed 10 Mohm test (not within ± 20%)
27	Low Battery. See section on Battery Operation.

* Error #0 will also occur if an option 44462A 10 channel multiplexer is added or moved to a different slot after the 3421A was calibrated. This is because the temperature reference was not calibrated.

** Error #7 will also occur if there is anything connected to the front panel input terminals or HCOM and LCOM on an installed 44462A 10 channel multiplexer assembly during the self test.

After the self test, you will hear the relay 'click' again. At this time, if the HP-IB add-on option is installed (option 201) **and** if the HP-IB/HP-IL switch is 'in' (for HP-IB), the 3421A will indicate the HP-IB address. This address will be displayed for about 1 second. After this, the 3421A will go to the following states:

- All 44462A option board(s) relays are open.
- All 44465A Digital output bits are cleared (high impedance state).
- Mainframe input relays are open.
- DC Volts function, Autorange on (starts on 300V range), Autozero on, 5 1/2 digits of resolution asserted.
- Counter set to 1 second gate time.
- Monitors rear panel switches and responds accordingly.
- The channel list (see chapters 3—6) set to all available multiplexer channels from lowest channel number to highest channel number.
- Request service from the computer if self test failed or Power-on SRQ enabled (rear panel switch).

The entire turn-on sequence takes only 2 to 3 seconds to complete.

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BATTERY OPERATION

Before operating the 3421A from its internal battery, ensure that the battery is fully charged. Connect the instrument to an appropriate AC power source and allow 16 hours for a full recharge with the POWER switch OFF (out). A fully charged battery will provide a minimum operating time of 12 hours. Operating the 3421A with the proper AC power source and the POWER switch ON (in) will provide a complete battery recharge in 21 hours. If the HP-IB option is being used, operating time is reduced to 6 hours.

Low Battery

CASE 1. If the battery becomes discharged (low battery) while the 3421A is in operation, the error indicator will light and the 3421A will require service from the computer (see REQUIRE SERVICE in Chapter 3). After 3 minutes, all relays, including those on the 44462A Multiplexer Assemblies, will be opened and the 3421A will power down. This is done to prevent the battery from becoming discharged. The HP-IL wakeup (see PWRUP in Chapter 4) is disabled when low battery occurs and will not be re-enabled until the battery is charged (or AC power applied) and the 3421A front panel POWER switch is cycled on and off.

During the three minute period after low battery occurs, most 3421A commands (i.e. DCV, FRQ, etc., see the blue pages at the end of Chapter 3.) as well as interface commands (i.e. TRIGGER, CLEAR, etc.) can be executed. This includes the loop power down (see PWRDN in Chapter 4) but remember that the 3421A cannot wake up (loop power up) until the battery is recharged or AC power connected to the rear panel. The 3421A commands that cannot be executed during this three minute period are: ML, MN, TOT, and DT.

Any commands executed during this three minute period will reduce the time before the 3421A powers down.

If a CLEAR, Reset (RS), SPOLL, etc. is executed, the 3421A will cease to require service from the computer but will still power down after the three minute period.

CASE 2. If a low battery is detected as the 3421A is turned on, the number 27 will appear in the display. The 3421A waits 3 seconds and then powers down. It will not go through self test or respond to any commands.

NOTE

If a low battery occurs, connect the 3421A to an AC power source and cycle the front panel LINE switch. If this is not done, the HP-IL wake-up circuitry will not work properly.

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CALIBRATION

What is Electronic Calibration?

One of the many features of the 3421A is electronic calibration. Although it is beyond the scope of this manual to present the entire calibration procedure, there are some points of interest the operator should be aware of. For complete calibration information, refer to the 3421A Service Manual.

Briefly, electronic calibration is performed by applying a known stimulus (voltage, resistance, etc.) to the 3421A. The 3421A is then told the exact value of that stimulus. Ten readings are taken by the 3421A and the average is compared to the exact value sent to the 3421A. A "CALIBRATION CONSTANT" is calculated to correct the averaged value to the known value. This Calibration constant is stored in the 3421A's calibration memory. Calibration constants are generated for each measurement function and range of the instrument. All subsequent measurements are corrected by the calibration constants. The calibration constant memory is backed-up by a long life battery to maintain the constants even when power is turned off.

Temperature Calibration

If you are using thermocouples with the 3421A to measure temperature, each 44462A Multiplexing Assembly must have its reference junction calibrated. Refer to the 3421A Service Manual. Ideally, temperature calibration should be done with the 3421A in the same physical position as it will be used. This is to eliminate any thermal gradients inside the case. Furthermore, 44462A assemblies must not be moved around inside the case, or plugged into a different slot, after calibration has been performed. If you send the 3421A to an -hp- service center for calibration, leave all option assemblies installed in the instrument case.

Calibration Enable

On the rear panel of the 3421A is a bank of eight small switches. Three of the eight switches are accessible without opening the 3421A case. Switch number 8, the rightmost switch, is the CALibration Enable switch and when set to the down position enables the 3421A to be calibrated. This switch should not be set (down position) except when qualified service trained personnel are to perform the calibration procedures. Enabling the CAL switch may result in loss of calibration if proper procedures are not followed.

3421A COMMANDS

Cx—Calibrate to value "x"
(see the 3421A and Service Manual)

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CHANNELS

What is a Channel?

Throughout this chapter, and indeed this manual, the words 'channel' and 'channel address' will be used. The word channel is used two ways. First, it represents one relay on a 44462A multiplexer assembly. In other words, since the multiplexer assembly has 10 relays, we can refer to it as a 10 channel multiplexing assembly. The relays are numbered 0 through 9. Therefore, when we speak of channel 5 we are talking about relay number 5 on a specific 44462A assembly.

The second way the word channel is used is when we are referring to either an output bit or an input bit on an option 44465A Digital I/O Assembly. Generally though, the word "switch" will be used to indicate a digital output channel and the word "bit" to indicate an input channel.

Channel Numbering and Addressing

Channel numbers are repeated on each 44462A (numbers 0-9) and 44465A (numbers 0-7) assemblies. Channel addresses, however, are determined by which slot the option assembly is plugged into plus the channel number. For an assembly in slot 1, channel 7 would be addressed as channel 17. The first digit stands for the slot number, and the second digit is the channel number. Channel 7 for an assembly in slot 2 would be addressed as 27. The following table shows the addressing scheme for the three different slots.

Channel Number*	Channel Address if Assembly is in Slot #:		
	Slot 0	Slot 1	Slot 2
0	00	10	20
1	01	11	21
2	02	12	22
3	03	13	23
4	04	14	24
5	05	15	25
6	06	16	26
7	07	17	27
8	08	18	28
9	09	19	29

* The digital I/O assembly uses only channel numbers 0 through 7.

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COMMANDS

The blue pages at the end of Chapter 3 list all of the commands the 3421A acknowledges. These commands are of two types: Standard and Advanced. The Standard commands provide the simplest method of programming the 3421A. Each command peforms a complete measurement task. An example of a Standard command is DCV2-17. This command sets up a channel list of channels 2 through 17, takes a DC voltage measurement from each channel, and stores the readings for future use.

Standard Commands

The Standard commands are broken down into 5 groups: Voltmeter, Temperature, Counter, Channel, and Digital. Many of the commands allow you to specify one or more channels to make the measurement(s) from. This is called a channel list. In the following discussion, brackets—[]—are used to indicate the optional channel list. Letters x, y, and z represent the channel addresses. If a command shows the letter 'x' without brackets, it means that a channel must be specified with the command or an error will result. When the letter 'i' is used, it indicates a slot number; 0, 1, or 2.

- Voltmeter Standard Commands ([x,y,...z] is optional channel list)

  DCV[x,y,...z] — DC Voltage measurements on optional channel list.
  ACV[x,y,...z] — AC Voltage measurements on optional channel list.
  TWO[x,y,...z] — 2-Wire Ohms measurements on optional channel list.
  FWO[x,y,...z] — 4-Wire Ohms measurements on optional channel list.

- Temperature Standard Commands

  TEM[x,y,...z] — Temperature Measurements (for T-type thermocouples only) on optional channel list.
  REF[x] — A temperature measurement on the 44462A reference junction.

- Counter Standard Commands

  FRQ[x,y,...z] — Frequency measurements on optional channel list.
  TOT[x] — Totalize events from optional channel.

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- Channel (multiplexer, actuator, or digital) Standard Commands

CLSx	—	Close specified channel, whether multiplexer, actuator or digital output switch.
CLPx	—	Close pairs (x and x + 10 or if x† = 20 then x and x-20)
OPN[x]	—	Open channel x,or if x is not sent then open all channels.

- Digital Standard Commands

REDi	—	Read the digital inputs from slot 'i'.
WRTi,abc		Write the decimal value [abc] to digital outputs in slot 'i'.
BIT x[y,...z]	—	Read the digital input bit values from bits x,y,... and z.

Advanced Commands

The Advanced Commands provide more programming flexibility than the Standard Commands but they do not perform a complete measurement task. The Advanced Commands are generally used in groups to complete the task. For example, F1RA1Z1N5LS2-17;T3 would be used to perform the same task as the DCV2-17 Standard Command. Though too numerous to list here, the Advanced Commands are discussed in detail in the blue pages at the end of Chapter 3.

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COUNTER

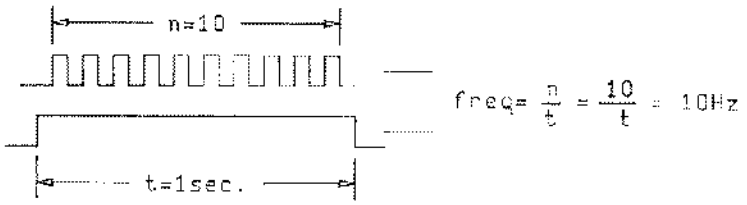
The 3421A internal counter is used to measure frequency to 10kHz or totalize events to 65535 counts. Signal inputs to the counter are through the 44462A multiplexer assembly or via the front panel INPUT terminals. Since the counter inputs are multiplexed through the same circuitry as voltage inputs, no other measurements can be made while the 3421A is measuring frequency or totalizing events. Once the measurement is complete, the 3421A is free to make other measurements.

Frequency

The operation of the frequency counter is best understood by describing how the counter takes a measurement. If 'n' is the number of cycles of a signal that occurs during a known time period 't', then the frequency 'f' is determined by:

$$f = \frac{n}{t}$$

The counter measures the frequency of a signal by counting the number of complete cycles, n, that occur during a specified time period t. This is demonstrated in the following figure.



The time period 't' is known as the Gate time. It represents the time period that the counter spends counting the input signal. The longer the gate time, the greater the resolution of the measurement. Three gate times are available with the 3421A Advanced commands. These three gate times and their respective resolution are shown in the following chart.

Advanced Command	Gate Time	Resolution (5 digits)
G-1	.1 Sec	10 Hz
G0	1 Sec	1 Hz
G1	10 Sec	.1 Hz

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As a general rule, use the shortest gate time, G-1, for the highest frequencies. Use the longest gate time, G1, for the lowest frequencies.

The Standard command FRQ sets the 3421A to the frequency mode (F7) and 1 second gate time (G0). As with most Standard commands, the FRQ command can be associated with a Channel List, for example: FRQ[x,y,...z]. If a channel list is sent, the 3421A makes the measurements on the channels specified and stores the readings. All the readings will be sent to the computer in the order the readings were made.

If no channel list is sent, no channels will change and only one measurement will be made. If no channel relays are closed, the signal can be input through the 3421A front panel.

3421A COMMANDS:

Standard	Advanced
FRQ[x,y,...z]	F7 Frequency G-1 .1 Sec. Gate Time G0 1 Sec. Gate Time G1 10 Sec. Gate Time

Totalize

The totalize mode is used to simply count events. Each event is represented by a pulse sent to the 3421A. The maximum number of events that the 3421A can count is 65,535. The Standard command TOT is used to set the 3421A to the TOTalize mode.

Upon receipt of TOT, the 3421A clears its counter and begins counting. Keep in mind that once the 3421A is in the TOTalize mode, it will continue to count until the 3421A receives another command. If a TRIGGER command is sent to the 3421A, the TOTalize mode will be aborted and the 3421A will take a frequency measurement. While the 3421A is TOTalizing, the 3421A can be addressed to talk (see ENTER statement in chapter 3 or IND in Chapter 4) and it will send the current subtotal without resetting the counter.

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The 44462A Multiplexing Assembly (option 020) is used to connect the signal to the Counter. Only one channel can be specified with the TOTx command. If 'x' is sent, and that channel is not a multiplexer channel, an error will be generated. Channel 'x' will remain closed until another command opens it.

3421A COMMANDS

Standard	Advanced
TOT[x]	

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DISPLAY

How It Is Used

The 3421A display serves two main functions. First, at turn-on or reset (RS command) the display provides the result of the internal Self Test and the HP-IB address (if the HP-IB option is present and switched in). Second, the display is used to indicate any channels or digital output switches that are closed.

Turn-on/Reset

At turn-on you will hear an internal relay 'click' as the all numbers in the 3421A turn on. This display will be on for about 1 second. Then, if any of the self tests fail, a number will light up in the display for about 1 second and the error indicator will turn on. Following this, a second relay 'click' is heard indicating that the self test has finished. If the HP-IB option (option 201) is installed **and** the HP-IB switch is 'in', the HP-IB address will be displayed next. After all of this, the 3421A will go to its turn-on state. The following chart shows the possible self test failures and the display number lit:

Number Lit	Self Test Failed
0*	Calibration RAM Checksum Error
1	ROM 1 Bad
2	ROM 2 Bad
3	A/D Slope Error
4	MicroprocessorRAM Bad
5	Internal RAM 1 Bad
6	Internal RAM 2 Bad
7**	Failed 10MΩ test (not within ± 20%)
27	Low Battery, the 3421A will shut itself off in three seconds.

* Error 0 will occur if an option 44462A, 10 channel multiplexer is added or moved to a different slot after the 3421A was calibrated. This is because the temperature reference was not calibrated.

** Error 7 will occur if there is anything connected to the front panel input terminals or HCOM and LCOM on an installed 10 channel multiplexer assembly during self test.

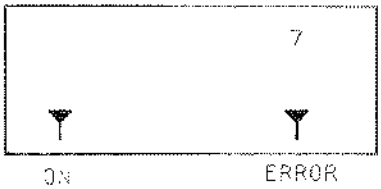
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DISPLAY (Cont'd)

When the 3421A is reset by the RS command, it goes through its self test routine just as if it were turned on. The display will light up all numbers for one second, followed by an error indication if any self test failed. The HP-IB address, however, will not be displayed.

Do This:

Simulate an error by shorting the front panel input terminals on the 3421A and either cycling the LINE switch off and on or sending the RS command.



After all numbers light up on the display, the number 7 should appear for one second and the error indication should light.

3421A COMMANDS:

Standard	Advanced
	RS Reset

Channel Display

Aside from the display being used to indicate errors during the self test, the display is used to indicate channel closures. The numbers lit on the display indicate channels or digital output switches that are closed. For example, if a 44465A Digital I/O Assembly is located in slot 01 and has output switches 2, 5, and 7 closed, the numbers 2, 5, and 7 will appear on the display. Furthermore, if a 44462A Multiplexer Assembly is located in slot 1, and DCV19 is executed, then channel numbers 2, 5, 7, and 19 will be displayed. This is because all these channels are closed.

3421A COMMANDS:

Standard	Advanced
All but REF, OPN, and REDi	DN, UC, SI1, SI0

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HP-IL POWER DOWN/POWER UP

Power Down

HP-IL Power Down can only be executed from the HP-41C/CV handheld calculator. Power down is used to put the 3421A in a low power standby mode. When the power down command is received by the 3421A, the complete status of the instrument is stored away in internal memory. The multiplexer and actuator (but not digital output switches) are left in the same state they were in previous to the command. In other words, a channel that was closed prior to Power Down will remain closed after Power Down. Digital Output Switches go to a high impedance (open) state.

Power Up

When any information is sent through the HP-IL loop, the 3421A will power back up, assuming that a low battery condition did not occur. If any Multiplexer or Digital I/O assemblies are changed or reconfigured, or if the data stored is no longer valid, the 3421A goes through its turn-on routine. If nothing has changed since the 3421A powered down, it remains in the same state except for:

1. TOT, if it was on, will now be off.
2. All digital output channels will be cleared (high impedance).

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OPTIMIZING READING RATES

Why Optimize

There are several reasons why you may want to optimize the rate at which readings are taken by the 3421A. Perhaps your system is being used to monitor a large number of points where a faster reading rate means a better picture of what is happening at a single point in time. Maybe you need to read quickly and not waste valuable computer time waiting for a measurement result. Whatever your reason for optimizing reading rates, the 3421A can solve many measurement requirements.

The maximum reading rate with the 3421A is influenced by many factors. These include the signal environment (line related and broadband noise, thermal gradients, etc.), the desired accuracy, and the type of measurement to be made. AC voltage measurements have a built-in 600mS settling delay. Resistance measurements can be made as fast as DC voltage measurements except on the 3 Mohm and 30 Mohm ranges where a settling time (20mS and 200mS respectively) is built in.

The speed and timing of the measurement process is dependent upon a number of factors. These include the number of digits of resolution selected (N commands), whether or not the autozero feature is enabled (Z command), and the selected function—DC volts, resistance, etc.

Your Signal Environment

The signal that you are attempting to measure may be subject to power line frequency related noise and broadband noise which can interfere with your measurement. The 3421A works to minimize or reject this kind of noise by using a form of Analog-to-Digital (A/D) conversion called integration. Integration is a process where line related noise is averaged to zero over the time period of an integer number of power line cycles.

The measure of the ability of the voltmeter to measure a DC voltage in the presence of AC voltages (at power line frequencies) is called Normal Mode Rejection (NMR). The NMR of the 3421A is dependent upon the number of digits of resolution selected (N3, N4, N5). Greatest NMR (80db) is provided with 5½ digits of resolution but this also has the slowest reading rate. The 4½ digit mode provides 59 db of NMR while the 3½ digit mode provides virtually no noise rejection. Another important part of this process is to make certain that the 50/60 Hz switch on the rear panel is set properly: down for 50 Hz line frequency and up for 60 Hz.

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OPTIMIZING READING RATES (Cont'd)

Autozero

The thermal stability of the measurement environment is also a very important consideration. If the 3421A is in a stable temperature environment, disabling the autozero function substantially increases the reading rate. There is very little loss of accuracy. Any range or function change results in an automatic autozero update which removes any accumulated offsets.

The Fastest Reading Rate

The maximum possible reading rate on one channel occurs when 3½ digits of resolution is selected (N3), autozero off (Z0), any DC voltage function (F1, F3, or F4), 60Hz line frequency set on the rear panel switch, manual ranging (not autoranging), and a positive voltage measured. This assumes that the channel list is loaded with that one channel; for example: LS5-5.

The following tables show the 3421A reading speeds assuming the readings are stored in internal memory.

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OPTIMIZING READING RATES (Cont'd)

READINGS/SECOND

Repeat on one channel:

	Z1F1	Z0F1	Z1F2*	Z0F2*	Z1F3/F4**	Z0F3/F4**	F6
N5	2.26	4.08	---	---	2.26	4.12	1.05
N4	15.85	23.92	0.4	0.4	15.85	24.31	1.05
N3	30.96	38.56	0.4	0.4	30.93	38.31	1.05

Random Channel

	Z1F1	Z0F1	Z1F2*	Z0F2*	Z1F3/F4**	Z0F3/F4**	F6
N5	2.19	3.98	---	---	2.19	3.99	.98
N4	13.18	18.34	0.4	0.4	13.20	18.61	.98
N3	22.22	25.99	0.4	0.4	22.19	26.01	.98

N5, N4, N3 = 5½, 4½, 3½ digit mode (respectively)
Z0, Z1 = Autozero off, on
F1 = DC Volts, F2 = AC Volts, F3 = 2-Wire Ohms, F4 = 4-Wire Ohms, F6 = Temperature Measurements.

* There is a 1.8 second delay between AC voltage readings. Consequently, the reading rate can be stated as 2.5 seconds per reading.

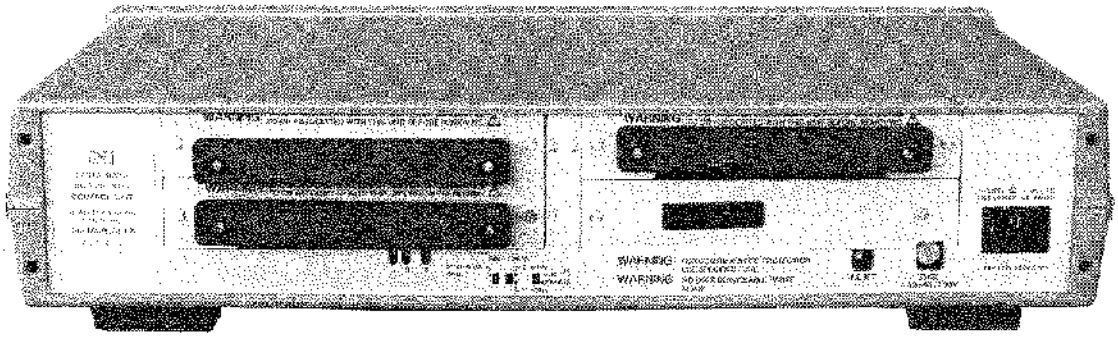
** Because of internal delays, the 3 MΩ and 30 MΩ ranges have reading rates of 2.1 Readings/Sec. and 1.5 readings/Sec., respectively.

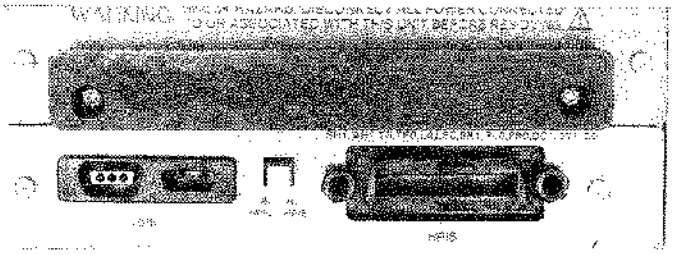
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REAR PANEL

What is on the Rear Panel?

The photo below is of the 3421A rear panel. The insert shows the 3421A with the optional HP-IB interface. Notice especially the line voltage option sticker, the HP-IL and/or HP-IB connector, and the rear panel control switches. Before plugging the 3421A into an AC power source, make certain that the option marked on the label coincides with the nominal line voltage in your area. The line voltage option for the 3421A may be changed only by qualified service trained personnel.





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REAR PANEL (Cont'd)

The Reset Switch

The Reset switch on the rear panel is used to completely reset the 3421A. In the event of a failure where the front panel POWER switch cannot turn the instument off, this reset switch is used to remove all power to the instrument for as long as you hold in the switch. As soon as you release the switch, power will be reapplied to the instrument.

The Rear Panel Control Switches

Of the eight rear panel switches, three are accessible from the rear panel. These switches are described below. Two of the switches that are not accessible are used for troubleshooting and the remaining three are not used. The switches are numbered from left to right.

Switches 2, 4, and 7 are not used.

Switch 3 is used to set the Power-on SRQ feature. When this feature is enabled, i.e. the switch is up, the 3421A will generate a service request to the system computer when the front panel LINE switch or rear panel Reset switch is cycled. Refer to REQUIRE SERVICE and SPOLL in Chapter 3 for more information.

Switches 1 and 6, at turn-on, forces the 3421A into Digital Signature Analysis routines for troubleshooting. Refer to 3421A Service Manual for troubleshooting procedures. These switches are not accessable from the rear panel.

Switch 5 is the 50/60Hz line frequency switch. This switch should be in the down position if a power line with 50Hz frequency is being used. The switch should be up for 60Hz line frequency. This switch changes the integration period (see optimizing reading rates) of the A/D convertor so as to obtain the greatest NMR. The reading rate is slightly lower (~ 17%) when 50Hz is selected.

Switch 8 is the Calibration Enable switch. When placed in the down position, calibration is enabled. Enabling the Calibration may result the loss of calibration of the 3421A. This switch should remain in the up position except when the 3421A is being calibrated by qualified service personnel.

NOTE

On instruments with a serial number prefix of 2247A or lower, switches 1, 2, and 7 are not used and switches 4 and 6 are used for Digital Signature Analysis.

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RESISTANCE MEASUREMENTS

Measuring Resistance

The 3421A is capable of measuring resistances from 1 milli-ohm to 30 Mohms in six ranges. Resistance measurements may be made in either 2- or 4- wire ohms configuration. The illustrations below show how resistance measurements are made. A known current is supplied by the 3421A and flows through the unknown resistance. The DC voltmeter measures the resulting voltage across the resistor and calculates the resistance. The table shows the nominal current through the unknown resistance for the individual resistance ranges.

Range	Current Through Unknown Resistance	Maximum Open Circuit Voltage
300 Ω	1 mA	6.5 V
3 kΩ	1 mA	6.5 V
30 kΩ	100 μA	6.5 V
300 kΩ	10 μA	5.5 V
3 MΩ	1μA	4.5 V
30 MΩ	0.1 μA	4.5 V

Nominal Current Through Unknown Resistance

The 3421A is factory calibrated in the 4-Wire ohms mode. If most or all of your resistance measurements will be made in the 2-Wire ohms mode, the 3421A can be recalibrated for best accuracy in the 2-Wire mode. See the 3421A Service Manual.

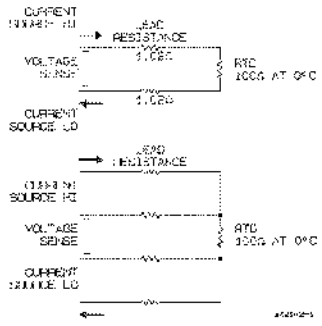
There are two situations in which the 3421A may indicate a negative resistance: either a small voltage exists on the circuit under test or the 4-Wire SENSE and the INPUT leads are inverted from each other in the 4-Wire ohms mode.

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RESISTANCE MEASUREMENTS (Cont'd)

2-Wire Resistance Measurements

2-wire resistance (or ohms) measurements can be used when the resistance of the test leads is not critical. Generally, the larger the resistance being measured, the less you have to be concerned about the lead resistance. For example, if the lead resistance of each lead is 5 ohms (10 ohms total), and you are measuring a fixed resistance of 10k ohms, the introduced error is small (10/10000 = .001 = .1%). However, a lead resistance of 10 ohms becomes quite significant when measuring small resistances. Suppose you are using leads with a resistance of 10 ohms and attempt to measure the resistance of a temperature dependent resistor (RTD) that is rated at 100 ohms at 0 °C. Here we have two problems. First, the lead resistance will add a significant error to the reading, even at 0 °C. (10/100 = .1 = 10%). The temperature coefficient for this type of device is typically about .385 ohms/°C. This means that if the RTD is being used to determine the temperature of some environment, the 10 ohm lead resistance would cause an approximate 26 °C error in the measurement. The second problem that arises is that if the temperature of the RTD environment changes, we cannot accurately track the change. Such an application would be better suited to 4-wire ohms.



4-Wire Resistance Measurements

The use of 4-wire ohms measurements virtually eliminates the error caused by the test lead resistance. The current through the unknown resistance is the same regardless of the lead resistance but the voltmeter measures only the voltage across the resistance, not across the combined test lead and resistance. The 4-wire ohms mode is essential when the highest accuracy is desired.

3421A COMMANDS:

Standard		Advanced
TWO[x,y,...z]	for 2-wire ohms —	F3 (use LS for channel list)
FWO[x,y,...z]	— for 4-wire ohms —	F4 (use LP for channel list)

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TEMPERATURE MEASUREMENTS

Using Thermocouples to Measure Temperature

Because thermocouples are useful over a wider range of temperatures than RTD's or themistors, they are frequently used in temperature measurements. The 3421A and its 44462A multiplexer option assembly are ideally suited for temperature measurement using thermocouples.

The 44462A multiplexer assembly for the 3421A utilizes an integrated circuit temperature sensor to determine the temperature of the isothermal terminal block. In performing a software compensated thermocouple measurement, the following steps must occur:

1. The voltage from the temperature sensor on the multiplexer assembly is measured. This voltage is used to compute the temperature of the terminal block which is known as the Reference Temperature. This step is performed automatically by the REF command.

2. Convert the terminal block temperature to a thermocouple Reference Voltage. The actual implementation of this step will depend on the type of thermocouple being compensated. It allows the use of several types of thermocouples to be used on the same 44462A assembly.

3. Measure the voltage produced by the thermocouple.

4. Add the Reference Voltage (computed in step 2) to the voltage produced by the thermocouple (step 3). This step produces the icepoint compensation.

5. Convert the sum voltage (step 4) to a temperature.

Although these five steps may seem cumbersome they are actually very easy to perform under computer control. Complete examples, including conversion coefficients for all thermocouples, are provided in Chapters 3 and 4.

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To simplify the matter even further, the 3421A was designed to automatically perform all of these steps for a T-type thermocouple. The answer returned will be in degrees C. With other thermocouple types, the 3421A can perform steps 1 and 3 but the system computer must do steps 2, 4, and 5.

Measuring the Reference Temperature

The Reference Temperature can be measured with the REF command. A single channel should be specified with the REF command. For example, if you will be measuring the thermocouple voltage from channel 5, you will need to also execute the command REF5. This will give the Reference temperature of the terminal block in slot 0 which is where channel 5 is located. If no channel is specified, then the REF command will simply default to the 44462A assembly where a multiplexer channel is closed. If there are no multiplexer channels closed, the REF command defaults to the 44462A assembly with the lowest slot number. If there are no 44462A assemblies in the 3421A, an error will be generated. See Require Service in Chapter 3 for error information.

Using T-type Thermocouples to Measure Temperatures

The TEM command is used to automatically perform a software reference junction compensated conversion for T-type thermocouples. As with most Standard commands, TEM can be used with a channel list. The TEM command makes use of the REF command to obtain the Reference Temperature. The Reference temperature will be taken on the same option board as the specified channel, if a channel is given with TEM. If no channels are specified, then the Reference Temperature measurement will be made on the 44462A multiplexer assembly where a multiplexer channel is already closed. If no multiplexer channels are closed, the Reference measurement will be made on the 44462A assembly in the lowest numbered slot. If there are no 44462A assemblies, an error will be generated.

3421A COMMANDS

	Standard	Advanced
Temperature	TEM[x,y,...z]	F6
Reference	REF[x]	

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TEST/RESET

What it Does

At power on or Reset (RS command), the 3421A performs a series of 8 checks on the digital logic and A/D converter. If any of these checks fail, the ERROR indicator will turn on in the display and the 3421A will attempt to interrupt the computer (see Require Service in chapter 3). The sequence of self tests are as follows:

1. Microprocessor internal RAM check. The microprocessor has internal Random Access Memory that is tested.

2. ROM Checksum. Both ROM's (Read Only Memory) are tested for proper checksums.

3. Calibration RAM Checksum*. The calibration RAM is tested for proper checksums.

4. Analog-to-Digital (A/D) Slope test. This test is for the A/D converter.

5. External RAM Tests. The two RAMs, external to the microprocessor, are tested.

6. 10 MΩ Test. This checks the 100:1 divider inside of the A/D input hybrid.

After the self tests have been performed, the 3421A will light all channel numbers in the display for about 1 second. After this, if any failures occurred during the self tests, a number will light up to indicate the failed self test. These numbers are as follows:

Number lit	Self Test Failed
0*	Calibration RAM checksum error. The calibration of the 3421A is suspect.
1	ROM 1 bad.
2	ROM 2 bad
3	A/D Slope error. This would indicate some error in the A/D converter circuitry.
4	Microprocessor RAM bad. Replace the microprocessor.
5	External RAM 1 is bad. This is one of the RAM's external to the microprocessor.
6	External RAM 2 is bad. This is the second RAM external to the microprocessor.
7**	Failed the 10 MΩ self test (it is not within ± 20%)

* Error #0 will also occur if a 44462A 10 channel multiplexer assembly is added or moved to another slot that is not calibrated for the temperature function.

** Error #7 will occur if there is anything connected to the front panel input terminals or to HCOM and LCOM on an installed multiplexer assembly during the self test.

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TEST/RESET (Cont'd)

After the self test, the 3421A will go to the following states:

- All 44462A option board relays are open.
- All 44465A digital output bits are cleared (high impedance state).
- DC volts function, Autorange on, Autozero on, 5½ digits of resolution.
- Counter set to 1 second gate time.
- The 3421A monitors the rear panel switches and acts accordingly.
- The channel list is set to all available multiplexer channels from the lowest number to the highest number.
- Request service from the computer if self test failed or Power-on SRQ enabled (rear panel switch).

3421A COMMANDS:

	Standard	Advanced
Reset		RS

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VOLTMETER

The Internal Voltmeter

The 3421A internal voltmeter provides many features not commonly found in a data acquisition voltmeter. The voltmeter provides 3½ to 5½ digit resolution for DC voltage and 2- or 4- wire resistance measurements, and 3½ to 4½ digit resolution for AC voltage measurements. Of course the voltmeter is used in making temperature measurements. The voltmeter offers DC voltage measuring performance of 1uV sensitivity to 300 volts maximum. AC voltage measurements can be made with 100uV sensitivity to 30 volts maximum with a bandwidth of 30Hz to 1kHz. Optional divider resistors are available for measuring AC voltages up to 300 volts peak. Resistance measurements are from 1mΩ sensitivity to 30MΩ (full scale).

By selecting the number of digits of resolution and using the autozero feature (discussed later), the voltmeter allows you great flexibility in measurement speed and accuracy. Up to 30 readings per second (one channel only with a 10 channel multiplexer assembly installed) can be made with the voltmeter in the 3½ digit mode. The autorange feature of the voltmeter allows fast measurements over a wide dynamic range.

To lower your cost of ownership, the voltmeter is calibrated electronically. There are no internal adjustments and the calibration of all functions is accomplished without removing any covers. The self test function verifies most of the internal circuitry of the 3421A indicating proper operation of the voltmeter.

Autozero

Autozero is a function that allows you to enable or disable the internal zero-correction circuitry of the voltmeter. Autozero on, which is the default condition, insures that any offset errors generated internal to the voltmeter are continuously nulled with each reading. This renders the most accuracy. Turning autozero off will substantially increase the reading rate but with a tradeoff of long term stability and accuracy.

With the autozero function enabled, the voltmeter takes two measurements per reading: a "zero" measurement and a measurement of the input signal. The internal processor takes the algebraic difference of the two readings and this is the value that is sent to the computer. The voltmeter makes the zero measurement by disconnecting the input relay and then shorting the internal input circuitry to circuit common. It then switches back for the input signal measurement.

With autozero turned off, whenever a new function or range is selected, the voltmeter immediately takes one zero measurement and stores the result in internal memory. Subsequent measurements of the input signal use this stored zero reading for correction. Since only the input signal is measured, the reading rate nearly doubles.

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There are some applications where disabling autozero is advantageous. With autozero off, the reading rate increases. This would be important in applications where measurement speed is critical. Furthermore, the voltmeter input circuitry remains in a completely static state with autozero off. This is useful when making measurements in extremely high impedance circuitry where the internal switching of the voltmeter might affect the reading accuracy.

Since the input circuitry for AC voltage measurements is capacitor coupled, it is not necessary to correct for DC offsets. Therefore, the autozero function is only used to null offsets in the A/D converter. Turning the autozero off for AC volts eliminates the zero reading of the A/D converter and results in a faster reading rate.

Calibration

It is beyond the scope of this section to provide the complete calibration procedures for the 3421A. Refer to the 3421A Service Manual for detailed information.

Briefly, Calibration is accomplished by simply applying a stimulus, i.e., voltage, resistance, etc., and informing the 3421A of the absolute value of that stimulus. Let's call this known value "A". The 3421A then takes ten readings of the input and averages them together. The average is subsequently compared to "A". The 3421A then computes a "Calibration Constant" which is stored in its internal memory. This "Calibration Constant" is used to correct all subsequent readings.

Measurement Functions

The 3421A internal voltmeter is capable of measuring DC voltages, AC voltages, and resistances in either 2- or 4- wire mode. If you have special requirements in making voltage or resistance measurements, be sure to read the sections elsewhere in this chapter on Optimizing Reading Rates, Autozero, Number of Digits of Resolution, and Triggering Modes.

DC Voltage Measurements

DC Voltage measurements with the 3421A internal voltmeter are simple and straightforward. The Standard Command "DCV" can be used to take DC voltage measurements from the front panel if no channel relays are closed. With the optional channel list, DC voltage measurements can be made from the specified channels.

Of course the Advanced command F1 with associated ranging and triggering commands can also be used. When using the Advanced commands, you can have more

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flexibility in your measurements. For example, you can turn autozero off to increase the reading rate. Similarly, you can select the number of digits of resolution (3½, 4½, or 5½). Read the section in this chapter on Optimizing Reading rates before attempting to use the Advanced commands.

AC Voltage Measurements

Like DC voltage measurements, AC voltage measurements are straightforward. Use the ACV Standard Command with the optional channel list. The Advanced Command for AC voltage is F2. The number of digits of resolution can be either 3½ or 4½.

The 3421A uses an Average responding AC to DC converter for AC voltage measurements. This means that the voltmeter measures the average value of the positive portion of the input and returns it as an RMS equivalent for a pure sine wave. Inputs that are non-sinusoidal, such as rectangular waves, will result in measurement errors.

Resistance Measurements

An entire section is devoted to resistance measurements earlier in this chapter. Please refer to it for information on resistance measurements.

Number of Digits Of Resolution

With the 3421A internal voltmeter you have a choice in the number of digits of resolution. This choice provides several alternatives and tradeoffs. For example, 3½ digits of resolution provides the fastest reading rate but it also has the least amount of noise rejection. At 5½ digits of resolution, the noise rejection is the greatest but the reading rate is much slower.

Changing the number of digits of resolution actually changes the "Integration Time" which determines the reading rate. Integration is a method of Analog-to-Digital (A/D) conversion where the effects of power line related noise averaged to zero over a period of an integral number of power line cycles (PLC's). The integration time is not the same as the time required for one measurement. Rather, the integration time is the time, in PLC's during which the input signal is sampled by the voltmeter. For DC Voltage measurements at 4½ digits of resolution, the time required for one integration cycle is one PLC: 16.66 mS at 60Hz line frequency or 20 mS at 50Hz. In the 3½ digit mode, the integration time is 0.1 PLC.

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Normal Mode Rejection (NMR) is the measure of the ability of a voltmeter to accurately measure DC voltages in the presence of AC voltages at power line frequencies. The 3421A voltmeter has much better NMR at 4½ digits of resolution than it does at 3½ digits (59db vs. 0dB). The greatest amount of NMR is available with 5½ digits of resolution: 80 dB. In this mode, ten (10) readings are taken at 1 PLC integration time and averaged together.

Ranging

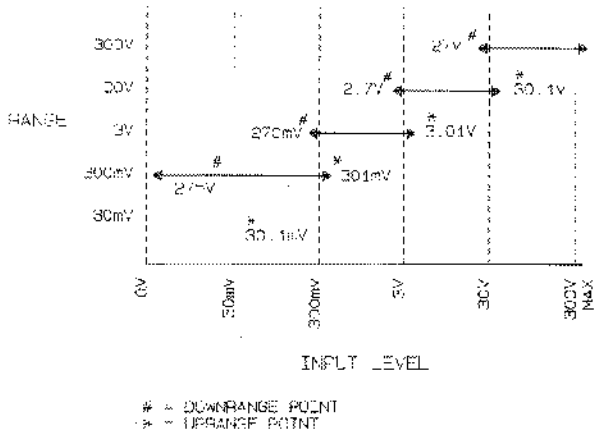
Selecting the proper range on the 3421A voltmeter may be done either automatically - called autoranging - or manually. All of the Standard Commands utilize autoranging. The fast autoranging in the voltmeter means that signals with a wide dynamic range, such as from channel to channel, are made quickly.

Autoranging

Autoranging in the 3421A voltmeter is done by taking readings in the 4½ digit mode. Measurements are made on successive ranges until one range is found where the reading is between full scale (30100 counts) and approximately 9% of full scale (02700 counts).

Autorange Hysteresis

In the autorange mode, the voltmeter will uprange (go to the next higher range) when the reading exceeds (±) 30100 counts. Conversely, it will downrange (go to the next lower range) if the reading decreases below (±) 02700 counts. These figures assume a 5½ digit mode. These numerical autorange points are irrespective of decimal point placement. The difference between the two points is called the autorange hysteresis. This is illustrated in the following figure for DC volts. Autorange hysteresis for other functions is similar.



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Manual Ranging

The 3421A is placed in the manual range mode by executing any of the manual range commands or the RA0 command. It can be returned to autorange with the RA1 command.

Valid 3421A Voltmeter Ranges

The following chart shows the various ranges available in the voltmeter.

Function	Ranges	Programming Code For Manual Ranging
DC Volts	.3V,3V,30V,300V	R-1,R0,R1,R2 (respectively)
AC Volts	3V,30V	R0,R1
Resistance	300Ω,3kΩ,30kΩ 300kΩ,3MΩ,30MΩ	R2,R3,R4,R5,R6,R7

If the voltmeter is in the manual range mode, the result returned to the computer will be +9.99999E+9 (5 1/2 digit mode) when the input is greater than the particular range can measure.

Triggering

To trigger the voltmeter simply means that you instruct it to take a measurement. Of course, this assumes that you have previously set up the voltmeter for the type of measurement with other commands. There are several methods of triggering the 3421A voltmeter. The Standard Commands trigger the voltmeter automatically. However, the advanced commands allow you to trigger the voltmeter in four (4) different ways. These are explained below.

Standard Commands

The Standard Commands DCV, ACV, TWO, FWO, TEM, REF, FRQ, and TOT program the respective measurements and then execute a software trigger (see T3 under Advanced commands). The software trigger causes the voltmeter or counter to take one reading from each channel specified in the channel list. If no channel list is sent with the command, one reading will be taken from a previously closed channel. If no channels are closed, the command can be used to make measurements from the front panel input terminals.

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Advanced Commands

The set of Advanced Trigger Commands include: T0, T1,T2, T3, DTia.

T0 — T0 is for hold (don't trigger) but enable the channel list scan and reading storage. In other words, when T0 is asserted, the voltmeter will not take any readings but will prepare the 3421A for readings from the channel list. To initiate the measurements, execute an interface TRIGGER command (see Chapters 3 and 4).

T1 — T1 sets the voltmeter for internal trigger. This means that the voltmeter will trigger any time you ask for a reading, such as using the ENTER command (see Chapter 3) or IND command (see Chapter 4). T1 will not open or close any relays.

T2 — T2 is a software trigger and causes the 3421A voltmeter to take one measurement only. T2 will not open or close any channels.

T3 — Trigger command T3 is used to initiate the measurements on the channel list and store those readings. Note that if F0 (no measurement function) is asserted when T3 is executed, an error will occur since the 3421A was not told what type of measurement was to be made.

DTix — The Digital Trigger command is used to implement an external trigger. DT will cause a T3 trigger when digital input bit 'x' on the digital I/O option assembly in slot 'i' goes LOW.

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Chapter 3
BASIC Language Programming

Introduction

The speed and data handling capabilities of todays desktop computers support the 3421A in a Data Acquisition/Control system. In this chapter you will learn how to use those powerful desktop computers to program and control the 3421A. Be sure that you have read through Chapter 2 of this manual before starting this chapter. You will need to understand the operating characteristics of the 3421A before you begin programming it.

Scope

The descriptions presented in this chapter are in general terms to optimize the flow of information regardless of the type of computer you are using. This means that both the inexperienced user as well as the experienced programmer will be programming the 3421A efficiently and productively with minimum instruction time. There are, however, many example programs given to enhance the discussion, all of which are given in the enhanced BASIC programming language such as the -hp- Model 85 Desktop computer uses.

Trying Out a Command

Before we actually begin the programming discussion, let's look at some simple examples that demonstrate how easy it is to program the 3421A. First, make certain that your 3421A is connected to a computer through either the HP-IL interface or the HP-IB interface. Chapter 7 of this manual gives interface connection instructions. Don't forget to turn on both the 3421A and the computer.

If you don't have one of the computers specifed in the following example, read through this section anyway as it provides a basis for later discussions. Consult the I/O programming manual for the computer you are using for information on sending and receiving information through the interface.

Now, have the 3421A display a number. Using the chart below as a guide, enter the command exactly as shown, replacing "x" with a number from 0 to 29 (i.e., DN5). After you execute the command, the number should appear on the 3421A's display.

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Interface/Computer	Type the Message	Press
HP-IL, HP-85	OUTPUT 901;''DNx''	[END LINE]
HP-IB, HP-85, 9845, 9826 (BASIC)	OUTPUT 709;''DNx''	[EXECUTE] (on the -hp- 85 press, [END LINE])

In the OUTPUT statements, the letters DN are called a command code and represent the message: **D**isplay **N**umber x. The numbers in the 3421A display represent channel numbers. We will learn more about this later. At the end of this chapter are several blue pages that describe each of the command codes the 3421A will respond to, and how they are used. The following program will sequentially display each number from 0 to 29.

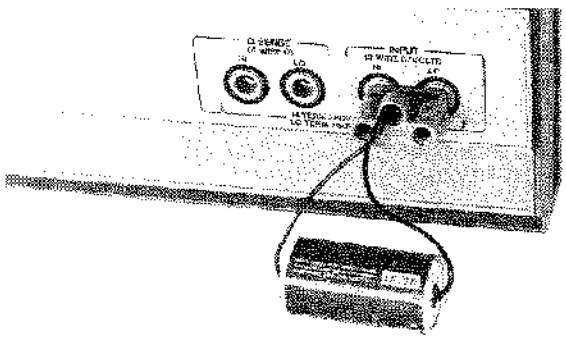
```
10 ! -HP- 85 version
20 ! HP-IL Example
30 ! 3421A at address 901
40 FOR X=0 TO 29 STEP 1 ! This line sets up the loop counter
50 OUTPUT 901 ;"DN";X ! 'DN' is sent followed by value 'X'
60 WAIT 500 ! Wait to see the number
70 NEXT X
80 END
```

Let's try another example. Connect a battery to the 3421A front panel INPUT terminals. Since a battery is a DC voltage, tell the 3421A to make a DC voltage measurement. This is done with a DCV command:

Interface/Computer	Type the Message	Press
HP-IL, HP-85	OUTPUT 901;''DCV''	[END LINE]
	ENTER 901; A	[END LINE]
	DISP A	[END LINE]
HP-IB, HP-85, 9845, 9826 (BASIC)	OUTPUT 709;''DCV''	[EXECUTE] or [END LINE]
	ENTER 709; A	[EXECUTE] or [END LINE]
	DISP A	[EXECUTE] or [END LINE]

Note. In the examples above, the 901 and 709 are the HP-IL address and HP-IB address, respectively. Addresses will be discussed in detail later. For now, simply perform the exercise.

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The value displayed is the measured battery voltage. The command DCV is called a Standard Command and performs a specific measurement task.

HP-IL vs. HP-IB

With the 3421A you have a choice of computer interfaces. The Hewlett-Packard Interface Loop (HP-IL) is standard with the 3421A and is ideal in low cost, low power, and medium distance applications. An optional HP-IB* interface is also available for the 3421A. From the programmers viewpoint these two interfaces are very similar and differ mainly in the instrument addressing.

Appendix B in this manual gives a brief description of the HP-IL and HP-IB interfaces. Chapter 7 of this manual gives interface connection instructions.

When the computer tells a particular instrument to send data over the interface, we say that the instrument has been "Addressed to Talk". Likewise, when the computer tells an instrument to receive data or instructions, the instrument is said to be "Addressed to Listen". The 3421A is capable of both "Talking" and "Listening". These terms are used throughout this chapter to describe various operations. There can be only one instrument addressed to talk at any one time.

Information Transfer

When operating with the HP-IL interface, most 3421A commands will "Hold-up" the computer until all readings have been taken. This feature makes Data Ready SRQ unnecessary for most measurements (Data Ready SRQ is described later in this chapter). In other words, suppose you have a 3421A, with three 44462A 10 channel multiplexer assemblies, programmed to take 30 readings; one reading from each channel. With a reading rate of approximately 2 readings per second, 15 seconds

*HP-IB (Hewlett-Packard Interface Bus) is Hewlett-Packard's implementation of IEEE Standard 488-1975 and ANSI MC1.1.

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are required to take all 30 readings. The computer will not be able to perform ANY task during this 15 second period while the 3421A is making the measurements. This is demonstrated in the following program.

```
10 ! EXAMPLE
20 OUTPUT 901 ;"DCV0-29"
30 FOR I=0 TO 29
40 ENTER 901; A(I)
50 DISP A(I)
60 NEXT I
70 END
```

After line 20 is executed, the 3421A will hold-up the computer while it takes the 30 readings.

The 3421A commands that do not hold-up the computer are: digital monitor commands MN, MH, and ML; TOTalize function; and Digital Trigger (DT). An example will be given later in this chapter demonstrating the DT command and interrupting the computer.

The advantage of this feature comes when you are using other devices with the 3421A. For example, let's say you are using the 3421A as a scanner - not using the internal voltmeter - with some measuring device such as a power meter. You would first close a channel on the 3421A and then trigger the power meter. Triggering cannot occur though, until the 3421A has closed the channel and freed the computer. In other words, the power meter is prevented from triggering until the 3421A relay is known to be closed, thus preventing false measurements.

With the HP-IB option and HP-IB selected, this computer hold-up feature is switch selectable. Access to the switch, however, is gained by removing the HP-IB option cover and should be done by service trained personnel only. With Buffered Transfer disabled (switch up, normal position) the 3421A acts much the same as the HP-IL interface, holding up the computer until all measurements are taken. Buffered transfer disabled (switch up) is the factory setting of this switch. With the switch in the DOWN position (buffered transfer enabled) the computer is released while the 3421A takes its measurements. This mode provides the fastest transfer of information between the computer and the 3421A.

You should be aware however, that if any of the digital monitor modes (MN, MH, ML, or DT) are in effect in the 3421A, any communication through the interface will cause the mode to be aborted. That is to say, if the 3421A is waiting for a Digital Trigger (DT) and the computer or another instrument sends any commands or data through the interface, the 3421A will abort the Digital Monitor and will no longer respond. It will need to be reprogrammed for that mode.

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Moreover, when you have the HP-IB option in the 3421A and are using the 3421A in one of the Digital Monitor modes, i.e., MH, ML, MN or DT, the 3421A MUST be set to unlisten. This is in order for the 3421A to interrupt the computer via the SRQ interrupt. For the -hp- 85 and 9826A (BASIC) this would take the form:

```
SEND 7 ; UNL
```

Other computers will use a different command syntax. Two examples using this command are shown in the Require Service section later in this chapter.

Buffered Transfers

Buffered transfers are enabled and disabled by HP-IB switch segment #6. This switch is accessed by removing the rear panel HP-IB option cover and should be done by qualified service trained personnel. When the switch is up (toward the pc board), buffered transfers are disabled (factory preset). When the switch is down, buffered transfers are enabled.

When is it appropriate to enable buffered transfers? Perhaps this question is best answered by a discussion of what buffered transfers are, and a limitation that they have. When buffered transfers are NOT enabled, and several commands are sent to the 3421A, each command is executed as it is received. The computer waits for the 3421A to execute the command that was just sent before sending the next command. Thus, the computer is not able to perform any other task until the 3421A executes the last command in the string. The 3421A holds up the computer by delaying the HP-IB handshake (i.e., the 3421A does not assert the NDAC handshake line until it has executed a command). Furthermore, the more commands sent, the longer the computer will be held-up.

When buffered transfers are enabled, the 3421A stores commands it receives in a buffer (up to 39 bytes). The computer is released to perform other program tasks as soon as the buffer storing is complete. The commands are then executed one after the other from the buffer. Hence, the computer does not wait for the 3421A to execute the buffer contents. As the 3421A executes the commands from the buffer, results are stored and then transferred to the computer when requested. Typically, this would be done using a Data Ready SRQ programming technique.

A limitation of buffered transfers is that different types of readings cannot be combined in the buffer. For example, do not specify a voltage and temperature measurement in the same command string. Furthermore, once a measurement is taken in the buffered transfer mode, the results should be retrieved before another measurement is taken.

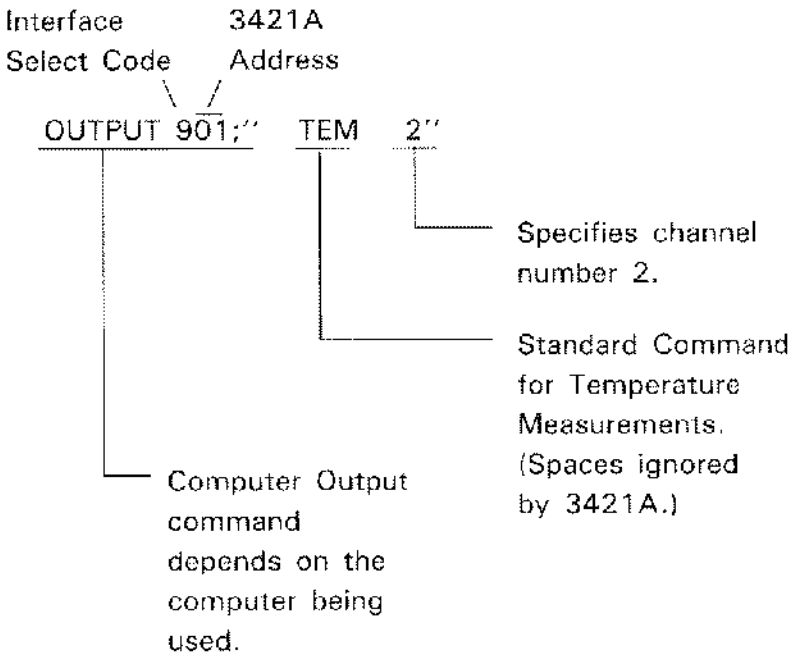
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The buffer size of 39 bytes should be more than adequate for the vast majority of applications. However, in instances where a string of commands exceeds 39 bytes, the buffered transfer mode is not recommended. If it is used, the computer will again be held-up once the buffer is full. In other words, it will defeat the benefits derived from using the buffered transfer mode.

Addressing

Each instrument that you connect to the interface, whether it be HP-IL or HP-IB, has a unique "address". The address provides a convenient way for the computer to send or receive data from a particular instrument even when there are several connected together.

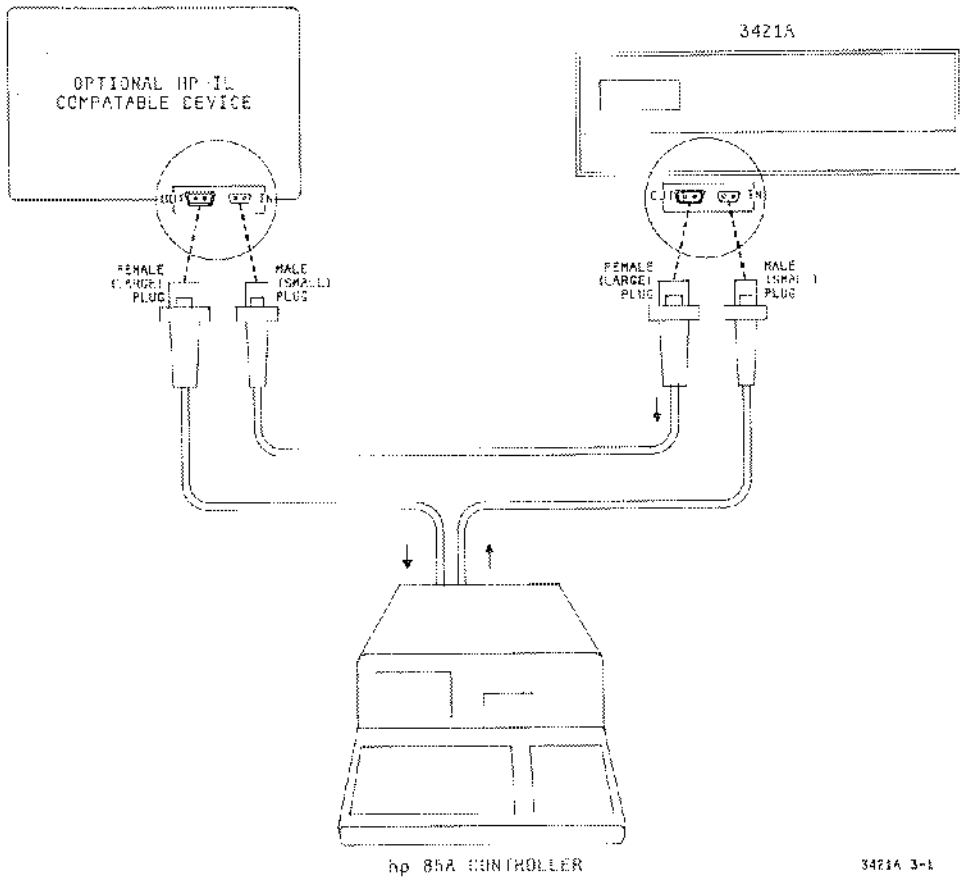
In earlier examples, an instruction such as OUTPUT 901 (HP-IL) or OUTPUT 709 (HP-IB) was used to send a message to the 3421A. The three digit number, 901 or 709, is used to specify the address of the 3421A. The first digit (9 or 7) is called the interface select code (isc). The isc for the HP-IB interface is 7; for the HP-IL interface it is 9. The remaining two digits, called the instrument address, are used to specify the 3421A - or any other instrument - connected to the same computer interface.



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HP-IL Addressing

The computer automatically reassigns addresses to each instrument connected in the loop. This is called ''Autoaddressing''. Addresses are assigned sequentially to instruments in the loop in the direction of information flow. Refer to the HP-IL diagram below. The first device in the loop after the controller has an address of ''1''. The second device will have an address of ''2'', the third device an address of ''3'', and so on through the loop. A maximum of 30 devices, including the computer, may be connected in the loop. The 3421A may be connected anywhere in the loop and will be autoaddressed accordingly.



All examples in this chapter assume the 3421A is the only device connected to the computer HP-IL interface. Therefore, when autoaddressed, the 3421A will have an address of 1. Also, the -hp- 85 desktop computer with an 82938A HP-IL interface is assumed to be the computer used in the examples. The 82938A HP-IL interface has an interface select code of ''9'', therefore, the 3421A will be addressed at 901.

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HP-IB Addressing

The 3421A with HP-IB option (Option 201) has a switch selectable HP-IB/HP-IL interface.

The HP-IB address for the 3421A is determined by switch settings on the HP-IB option board. The 3421A has a factory preset address of 09. If the address needs to be changed, a qualified service trained technician will find the necessary information in Chapter 8 of this manual. In the examples where HP-IB addressing is demonstrated, the address will be 709. This refers to the computer HP-IB interface select code "7" and the 3421A address of 09. Note however, that if the rear panel switch is set for HP-IL, the addressing will follow the Autoaddressing constraints of HP-IL and will ignore the setting of the HP-IB address switches.

Sending Instructions to the 3421A

Command codes are used to instruct the 3421A to perform a specific measurement or task. At the end of this chapter are several blue pages that provide a description of all of the commands the 3421A recognizes and responds to. Two categories of commands are provided.

A. Standard Commands set up the 3421A and then complete a measurement task. For example, the command DCV2,7-9 causes the 3421A to take DC Voltage measurements on channels 2, 7, 8, and 9, and store the readings in its internal memory. One command causes a complete measurement task to be performed. The Standard Commands make programming easy.

B. Advanced Commands provide more flexibility than the Standard commands but they do not perform a complete measurement task. Individual commands are used to perform only one aspect of a measurement.

The Standard Commands are conveniently provided for the 3421A to ease the task of programming. As a result, most of the examples in this chapter will use the Standard Commands. The Advanced Commands are available to those users who wish to tailor their system for particular requirements.

Procedure

Decide what task or measurement you want the 3421A to perform and determine the appropriate command. For example, if you are making temperature measurements (using T-type thermocouples) use the TEM command. If the thermocouple is connected to channel 2 in the 3421A, execute the command TEM2. The following message would be sent:

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```
OUTPUT 901;"TEM2"
```

Sample Problem

The previous illustration shows how to send the command to take a temperature measurement from channel 2. Suppose though, as will probably be the case, you have more than one measurement to make. They don't have to be temperature measurements, they could be voltage, resistance, or frequency measurements. The 3421A Standard Commands allow you to specify a group of channels, called a channel list, for the command.

To illustrate, assume you have T-type thermocouples connected to channels 2 through 8 and channel 14. The one command:

```
TEM2-8,14
```

will cause the 3421A to take temperature measurements from those eight channels and store the measurements internally. The complete command, along with the OUTPUT statement is:

```
OUTPUT 901;"TEM2-8,14"
```

Later in this chapter, you will learn to read back those eight temperature readings. For now, just remember that they are stored in the 3421A's internal memory. Up to 30 readings could be stored in this manner.

Programming Hints

Make certain that you have read the paragraphs under HP-IL vs. HP-IB. Those paragraphs deal with addressing and certain practices and exceptions that you will need to understand when programming.

When using the channel list the measurements are taken sequentially and stored. In other words, as in the previous example, channel 2 is measured first and the reading stored. Next, channel 3 is measured and its reading stored. This pattern continues for each channel until finally, channel 14 is measured and that reading stored.

Later, when you want to read back those measurements, the temperature from channel 2 will be returned first, followed by the temperature from channel 3, then 4,... and finally 14.

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The series of channels specified in a channel list must follow these rules.

a. The default channel list (asserted at power on or reset) consists of all multiplexer channels in numerical sequence. The channel list can be loaded with multiplexer channels by the DCV, ACV, TWO, FWO, TEM, FRQ, LS or LP commands. It can also be loaded with digital input bit numbers by the BIT command. See chapters 5 and 6 for more information on the channel list.

b. Channel addresses are separated by commas. However, a dash may be used to signify a contiguous set of channels. When using Advanced Commands, any command that specifies a channel must be separated from subsequent commands by either a colon (:) or a semicolon (;) but not a comma. For example: F1RA1Z1N5LS5-9;T3. If the last character in the command string is a comma, an error will be generated.

c. No more than 30 channels are accepted into the channel list. Legal channel numbers are 00 through 29.

d. The mnemonic determines what type of channel can be loaded into the channel list. In other words, if channel 1 is configured as an actuator channel, it should not be specified for any type of measurement (i.e., DCV1 or BIT1). If an attempt is made to load the channel list with an improper type of channel, a syntax error is generated (see SPOLL) and the command is aborted. If channels x-y are received and some channels in between and including x and y are the wrong type of channels for the command, they are not loaded into the list and the error message is not sent. The remainder of the channels are loaded into the list.

e. Leading zeros are ignored, that is, DCV00019 means DCV19.

f. All syntax following a decimal point is ignored except for commas, dash, semicolon, colon, Carriage Return (cr), or Line Feed (lf). DCV2.3 means DCV2.

g. Exponents are not allowed and cause a syntax error. The command is aborted.

h. All lower case letters are interpreted as upper case. Blanks and the plus (+) sign are ignored. Commas (,), colons (:), and semicolons (;) are used as terminators. All other punctuation give a syntax error. In other words, Dc V 21 is the same as DCV21.

i. Terminators are required after any command (Standard or Advanced) that either specifies a channel or a decimal value, when that command is to be followed by another command. For example, the 'Mx' command is used to set the SRQ mask. This command can have a decimal value 'x' of between 0 and 255. Therefore, this command must be followed by a terminator if another command is to follow it; e.g.,

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OUTPUT 901; "M1;T0". Valid terminators are a colon (:), a semicolon (;), a Carriage Return or Line Feed; but not a comma (,).

Receiving Data From The 3421A

The 3421A has the ability to talk to the computer or other instruments, giving the results of measurements or status information. The computer must tell or "address" the 3421A to talk in order for it to send information.

Example. In the last section we saw how to send a command for a temperature measurement on channel 2. Now we want to read back the measured temperature. The ENTER statement is used.

```
10 OUTPUT 901 ;"TEM2" ! From a previous section
20 ENTER 901 ; A
30 DISP A
40 END
```

The 3421A is addressed to talk by the ENTER 901 command. The measured temperature is stored in the variable A and displayed on the computer's display. Remember that the actual computer syntax used (i.e. ENTER, OUTPUT, DISP, etc.) is dependent on the computer you are using and may be different than the the examples given in this manual. You should refer to your computer's I/O manual for specific information.

You also learned in the last section how measurements could be made on several channels using the channel list with a command. To read back those measurements, you will need one variable for each channel. Two sample programs are provided to illustrate how that can be done.

```
10 OUTPUT 901 ;"TEM2-8,14" ! From previous section
20 ENTER 901 ; A,B,C,D,E,F,G,H
30 DISP A,B,C,D,E,F,G,H
40 END
```

OR

```
10 OUTPUT 901 ;"TEM2-8,14" ! From previous section
20 FOR I=1 TO 8
30 ENTER 901 ; B(I)
40 DISP B(I)
50 NEXT I
60 END
```

In the first example, each reading is stored in a separate variable. An array is used to store the readings in the second example. Remember that in some computers you

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may have to dimension the array.

Output Format

Measurement data is sent by the 3421A as 13 bytes in the following format (5 ½ digit mode):

Measurement:	±d.dddddE±d CR LF
Error:	-8.88888E+8 CR LF
Overload:	−9.99999E+9 CR LF

Digital data is sent as:

Digital:	ddd CR LF (where 0≤ddd≤255 decimal)
Digital Error:	888 CR LF

The character "d" represents a single digit. CR and LF are Carriage Return and Line Feed, respectively.

Readings Output Format

Readings are sent as indicated above. The exponent is the same as the voltmeter range (unless the measurement is temperature or frequency). In other words, the reading +1.23456E-1 means the measurement was taken on range R-1 (.3 volt) and the measured value is .123456 volts. If the measurement is entered into a numeric variable the measurement will be adjusted to eliminate the exponent. Refer to the Advanced Commands for more information on range codes. The number of digits following the decimal point is the same as the number of digits of resolution asserted. This means that if you have 3 digits of resolution asserted (N3), the reading will be output as: +d.dddE+d. This change of output digits is also true for errors.

Error Format. The -8.88888E+8 indicates an error and will be sent in place of the first reading after the error occurs. Bit 5 of the Status Register will also be set, see SPOLL later in this chapter. Conditions which will cause the error message are:

1. Hardware error
2. Calibration error
3. Command syntax not understood
4. Can't execute command
5. Low battery
6. Self Test failed

The error message will not be sent if the status byte is read (SPOLL or SR commands) before the 3421A is addressed to talk. In this case the reading, if available,

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will be sent. This is shown in the following two examples. The first example shows the typical command and data read sequence. The second example shows how to read the status byte prior to requesting data.

```
10 OUTPUT 901 ;"DCV3-7"
20 FOR I=1 TO 5
30 ENTER 901 ; A(I)
40 NEXT I
50 END
```

OR

```
10 OUTPUT 901 ;"DCV3-7"
20 P=SPOLL(901)
30 FOR I=1 TO 5
40 ENTER 901 ; A(I)
50 NEXT I
60 END
```

If an error exists, the first program would return the error message instead of the first reading for A(1). In the second program the actual measurement, if it were possible to make the measurement, would be returned to A(1) instead of the error message.

The reading will not be available if;

1. No measurement has been taken.
2. Function FO is asserted and the 3421A is triggered.
3. If the channel list is empty and the 3421A is triggered by T3, DT, or TRIGGER.

If an error occurred during a digital read, the error message is: 888.

Overload Format. Three conditions will cause the overload message (+9.99999E+9) to be sent. These are:

1. Voltmeter overload
2. Counter overflowed in TOTalize mode (greater than 65535 counts).
3. REFerence temperature out of range. That is,the REFerence junction temperature is not between 0 and 60 degrees C or the measured thermocouple voltage is not between 6 and 20 mV.

Simple Programming

We have seen how to send simple commands to the 3421A and how to get measurements from it. Now lets go one step further and look at a simple program. This program takes DC voltage measurements on channels 1, 2, and 3 and

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temperature measurements on channels 4 through 9. It is important to notice that the DC voltage readings are read back to the computer (lines 30-50) before the temperature measurements were made. This is because the TEM4-9 command sets up a new channel list and the temperature measurements would over write the DC voltage measurements in the 3421A reading storage.

```
10 ! Sample program
20 OUTPUT 901 ;"DCV1-3"
30 FOR I=1 TO 3
40 ENTER 901 ; B(I)
50 NEXT I
60 OUTPUT 901 ;"TEM4-9"
70 FOR I=4 TO 9
80 ENTER 901 ; B(I)
90 NEXT I
100 FOR I=1 TO 9
110 DISP B(I)
120 NEXT I
130 END
```

3421A Interface Capabilities

The following topics, arranged in alphabetical order, deal with HP-IL and HP-IB interface commands and the way the 3421A responds to them. Refer to the I/O programming section of your computer's I/O programming manual for specific information on syntax and actions taken by the interface when sending the message. The examples given apply to the -hp- 80 series desktop computers for HP-IL and HP-IB and the -hp- 9845, and 9826 (BASIC) for HP-IB.

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CLEAR

Example

HP-IL		HP-IB
CLEAR 9	(device clear)	CLEAR 7
CLEAR 901	(selected device clear)	CLEAR 709

Comments

Upon receiving the CLEAR message, the 3421A goes through its power-on/reset routine. The power-on/reset routine includes:

1. Self Test.
2. Opens all multiplexer and actuator channels.
3. Clears bits of the digital output ports (high impedance state).
4. Voltmeter set to: DC Volts, autorange on, autozero on, 5 ½ digit resolution, internal trigger on.
5. Counter set to 1 second gate time.
6. HP-IL address is not changed.
7. Checks rear panel switches (50/60 Hz, Power-on SRQ, etc.).
8. Channel list set to all available multiplexer channels, addressed sequentially
9. Request Service (SRQ) if self test failed.
10. Reading storage is cleared.

LOCAL
LOCAL LOCKOUT
REMOTE

Comments

The 3421A does not respond to these commands. This is because the 3421A has no front panel and must be controlled by a computer through an interface. The 3421A is always in remote state.

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REQUIRE SERVICE (SRQ)

Comments

One important feature of the 3421A is its ability to interrupt the computer when certain conditions occur. Of course the computer must be programmed to respond to the interrupt. The Require Service message (SRQ) is used to implement an interrupt and is independent of all other activity. The 3421A MUST BE PROGRAMMED to request service before the interrupt will take place. Several examples are included in this section to explain interrupt programming.

There are many conditions which can cause an interrupt. The following is a list of those conditions that can cause an interrupt.

1. Power-on/Reset. The 3421A can interrupt the computer when the 3421A power is turned on, receives a Device CLEAR or Selected Device CLEAR, or reset via the rear panel reset switch. The 3421A rear panel switch number 3 must be set to the up position for this interrupt to occur.

2. Data Ready.The 3421A can interrupt the computer after each completed measurement or, if a channel list is measured, the interrupt can occur after all readings are taken. The following commands will set the data read bit: DCV, ACV, TWO, FWO, FRQ, TEM, REF, TOT, RED, BIT, T1, T2, T3, DT, MH, ML, MN, and GET. An example of this, using the DT command, will be shown later in this section.

3. Self Test Error. If any of the seven self tests fail, an interrupt will occur.

4. Event Occurred. The 3421A can monitor the digital input ports and if a specified bit or 8-bit word occurs, it will interrupt the controller. This provides flexibility in timing events. An example of this will be shown later in this section.

5. Low Battery. If the 3421A is being powered by its internal battery, it will generate an interrupt when the battery voltage drops too low. After approximately three minutes, it will open all channels and power down. The following instructions cannot be executed after a low battery is detected: TOT, MH, ML, MN, DT.

6. Abnormal Condition. Abnormal conditions include:

   a. Hardware error
   b. Calibration Error
   c. Command not understood; e.g., the command FR3 is not a legitimate 3421A command
   d. Can't execute the command; e.g., the command DCV25 is sent but channel 25 is a digital channel

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e. Self Test failed
f. Low Battery
g. Attempt to load channel list with more than 30 channels
h. Attempt to increment channel list and trigger (T3) but channel list was empty
i. Requested a reading when no data was available
j. Triggered internal voltmeter while function F0 was asserted

How to use SRQ

When the Require Service message (SRQ) is sent, the computer must first determine which instrument, if more than one is connected to the interface, is requesting service. This is done by conducting a SERIAL POLL (SPOLL) of the devices connected to the interface that are capable of requesting service. When an instrument is serially polled, it responds by sending its "STATUS BYTE" which indicates whether or not it requested service. If it has, bit 6 will be set along with one or more of the other bits to indicate the nature of the request. If the Status Byte for the instrument polled indicates that it was not requesting service, the computer continues to poll the other instruments until the proper one is located. All of these actions assume that the computer has been programmed to respond to the SRQ interrupt as shown in the examples given later.

Status Register and Status Byte

The Status Register monitors several different 3421A operating conditions and is updated as events occur. If the 3421A SRQ mask is set (set being a "1") for a particular condition and that condition occurs, the 3421A will send an interrupt message to the computer. However, two bits of the 3421A SRQ mask (bit 2 and bit 4) cannot be masked. These two bits correspond to self test error and low battery. If either of these conditions occur, the 3421A will always send the interrupt message. For the remaining conditions, the SRQ mask must be set for the 3421A to send the interrupt message. Anytime the 3421A sends the interrupt message, regardless of whether it is a masked or non-masked condition that caused it to be sent, bit 6 of the Status Register will set. Bit 6 corresponds to "Require Service" and is used by the computer to identify the device that needs attention, assuming the computer is programmed to respond to the interrupt message. The remaining bits can be used by the computer to identify the reason that the interrupt occurred.

The Status Byte is an 8-bit byte that is sent from the 3421A to the computer in response to the SPOLL message. The Status Byte comes from the Status Register and is used to determine the current status of the 3421A.

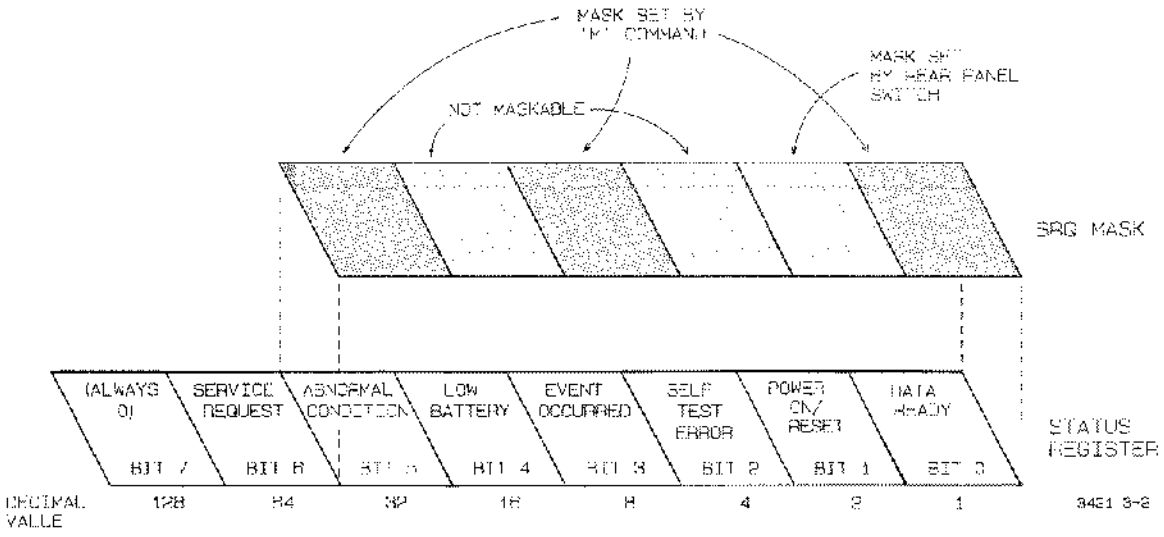
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Bit 7 N/A (always zero)	Bit 6 Require Service (no mask)	Bit 5 Abnormal Condition (see earlier)	Bit 4 Low Batt. (not maskable)	Bit 3 Event Occurred	Bit 2 Self Test Error (not maskable)	Bit 1 Power on Reset Occurred (switch mask only)	Bit 0 Data Ready

Status Register

Setting the SRQ Mask

Think of the SRQ mask as a cover hiding three bits of the Status Register. To "set" the mask you effectively poke holes in the cover. First, determine which conditions you want to interrupt the computer, e.g., data ready, abnormal conditions, etc. Refer to the figure below. Add together the decimal values for the bits that you want to interrupt the controller. Then, output the "M" command followed by the decimal value, that is, "Mx" where x is the decimal value. The following diagram shows the Status Register and the SRQ mask.



To set the SRQ mask for Event Occurred, for example, execute the command: OUTPUT 701;"M8". For either Event Occurred or Data Ready to interrupt the computer, execute: OUTPUT 701;"M9".

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NOTE

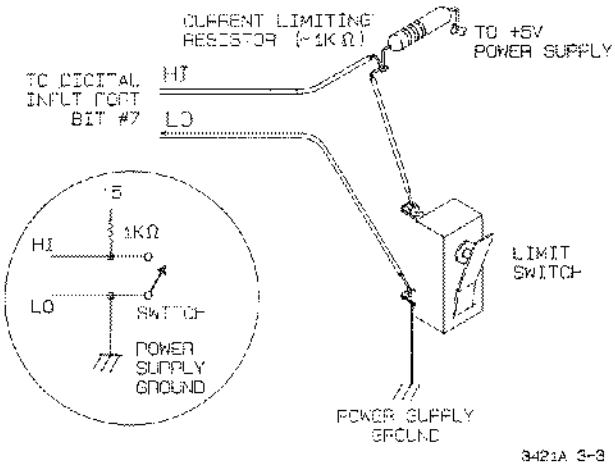
When you are doing interrupt programming; especially with the digital monitor commands MN, MH, ML, and DT, the end of line sequence should be suppressed. With most -hp- desktop computers this is done with the OUTPUT USING "#,K" command. The last character in the command string must be either a colon (:), a semicolon (;), a carriage return, or a linefeed. The following program examples show how this is done.

If you are using the 3421A with its HP-IB interface, the 3421A must be placed in an 'UNLISTEN' mode before it can interrupt the controller. With most -hp- desktop computers, this is done with the SEND 7,UNL command. These lines are shown in the following examples and may be deleted if you are using the HP-IL interface.

Example 1. Event Occurred

This is a simple example that demonstrates the usefulness of the SRQ interrupt. In this example, we will use Event Occurred to monitor one bit, bit 17, of a 44465A Digital I/O assembly. When that bit goes low, the 3421A will signal the computer that the event has occurred. Event occurred, as in this example, might be used to monitor limit or position switches.

The associated illustration shows the external connections that will need to be made. Remember that the Digital I/O assembly must be in slot 1 for the program to work. Type in the program and run it. After the computer displays "READY", close the switch. Notice that the program jumps down to the interrupt subroutine.



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SRQ (Cont'd)

HP-IL Example

```
 10 ! Event occurred example
 20 ! -HP- 85 version
 30 ! 3421A at address 901
 40 CLR
 50 CLEAR 9
 60 OUTPUT 901;"M8.ML17"
 70 ON INTR 9 GOSUB 1000
 80 ENABLE INTR 9;8
 90 DISP "READY"
100 ! Main program goes here
980 GOTO 100
990 END
1000 ! Serial poll subroutine
1010 P=SPOLL(901)
1020 STATUS 9,1;A
1030 IF P=73 THEN DISP "EVENT OC
     CURRED"
1040 RETURN
```

Line	Description
40	Clears the display.
50	Clears the Status Register.
60	Sets the 3421A for SRQ when event occurs (M8) and for monitor when bit 17 goes low (ML17).
70	This line tells the computer where to go when the interrupt occurs (line 1000).
80	ENABLE INTR 9;8 enables the computer to respond to the interrupt.
100-990	The main body of the program goes here. Line 980 will keep the main programming running indefinitely.
1000	This is the start of the interrupt subroutine.
1010	SPOLL returns the value of the Status Register (the Status Byte) to variable P. It also resets bit 6 of the Status Register.
1030	P is tested to determine what caused the interrupt. Bit 6 of the Status Register should be set since an interrupt occurred. This bit has a value of 64. Bit 3 should also be set for Event Occurred. This bit has a value of 8. Also, bit 0 will be set. Combined, these bits have a value of 73.
1040	End of subroutine.

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SRQ (Cont'd)

HP-IB Example

```
 10 ! Event occurred example
 20 ! -HP- 85 version
 30 ! 3421A at address 709
 40 CLEAR
 50 CLEAR 7 @ WAIT 5000
 60 OUTPUT 709 ;"M8;ML17"
 70 SEND 7 ; UNL
 80 ON INTR 7 GOSUB 1000
 90 ENABLE INTR 7;8
100 DISP "READY"
110 ! Main program goes here
980 GOTO 110
990 END
1000 ! Serial poll subroutine
1010 P=SPOLL(709)
1020 STATUS 7,1 ; A
1030 IF P=73 THEN DISP "EVENT OC
          CURRED"
1040 RETURN
```

Line	Description
40	Clears the display.
50	Clears the Status Register; wait 5 seconds or system error results.
60	Sets the 3421A for SRQ when event occurs (M8) and for monitor when bit 17 goes low (ML17).
70	The UNListen command permits the 3421A to interrupt the computer. Note, this line is not necessary if you are using HP-IL.
80	This line tells the computer where to go when the interrupt occurs (line 1000).
90	ENABLE INTR 7;8 enables the computer to respond to the interrupt.
110-990	The main body of the program goes here. Line 980 will keep the main programming running indefinitely.
1000	This is the start of the interrupt subroutine.
1010	SPOLL returns the value of the Status Register (the Status Byte) to variable P. It also resets bit 6 of the Status Register.
1030	P is tested to determine what caused the interrupt. Bit 6 of the Status Register should be set since an interrupt occurred. This bit has a value of 64. Bit 3 should also be set for Event Occurred. This bit has a value of 8. Also, bit 0 will be set. Combined, these bits have a value of 73.
1040	End of subroutine.

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Example 2. Abnormal Condition

There are several conditions which can cause bit 5 (abnormal condition) in State Register 1 (Status Register) to set. If any bit in State Registers 2, 3, or 4 is set, then bit 5 of the Status Register is set. The abnormal condition bit is also set if bit 2 or bit 4 of the Status Register is set. Abnormal conditions include:

1. Hardware Error
2. Calibration Error
3. Command not understood; e.g., the command FR3 is not a legitimate 3421A command
4. Can't execute the command; e.g., the command DCV25 is sent but channel 25 is a digital channel
5. Self Test failed
6. Low Battery
7. Attempt to load channel list with more than 30 channels
8. Attempt to increment channel list and trigger (T3) but channel list was empty
9. Requested a reading when no data was available
10. Triggered internal voltmeter while function F0 was asserted

The question arises then as to which one actually caused the interrupt. The following example shows a program which will allow you to determine the exact nature of the "Abnormal Condition." The program makes use of the SR command. This command sends 24 bytes which can tell you the exact status of the 3421A. However, we are only interested in the first 4 bytes as they contain the error information. The remaining 20 bytes are described in the blue pages at the end of this chapter.

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SRQ (Cont'd)

```
10 ! Abnormal condition example
20 ! -hp- 85 version
30 ! 3421A at address 901
40 OUTPUT 901 ;"M32"
50 ON INTR 9 GOSUB 1000
60 ENABLE INTR 9;8
70 OUTPUT 901 ;"DCV"
80 GOTO 80
90 END
1000 OUTPUT 901 ;"SR"
1010 ENTER 901 ; A,B,C,D
1020 DISP "STATUS REGISTER VALUE: ";A
1030 DISP "ERROR BYTE VALUE: ";B
1040 DISP "HARDWARE ERROR BYTE: ";C
1050 DISP "CALIBRATION ERROR VALUE: ";D
1060 RETURN
```

Line	Description
40	This line outputs the SRQ mask for abnormal condition.
50	Line 50 is used to tell the computer where to go when an interrupt occurs (line 1000).
60	ENABLE INTR 9;8 enables the computer to respond to interrupts.
70	DCV is a legitimate 3421A command. Therefore there will be no interrupt. Replace this command with FR3 and rerun the program.
80-90	The body of the program goes here.
1000	This is the first line of the interrupt subprogram. The "SR" command is used to tell the 3421A to send it status information.
1010	The values of the first 4 registers are entered into the computer and stored into variables A, B, C, D.
1020-1050	The values for the registers are displayed along with the register name.
1060	This line causes the program control to return to where it was interrupted.

Line 70 in the program contains the command "DCV". This is a legitimate 3421A command. Therefore, since there is no abnormal condition the interrupt will not occur. Now replace the DCV command with the command "FR3" and rerun the program. FR is not a legitimate command so an abnormal condition will exist. However, the 3421A will assume the R3 range. Compare the 4 values returned by the program to the charts below. Remember that the value returned is the sum of the values of the individual bits that are set.

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Example 3. Advanced SRQ Interrupt Programming Using The Digital Trigger Command

Data Ready is a feature of the 3421A that allows it to interrupt the controller after each completed measurement or, when used with a channel list, each group of measurements. Typically, the Data Ready feature is used only with the Digital Trigger command while utilizing SRQ interrupts. Digital Triggering allows the voltmeter to begin taking readings when a digital input goes low. A digital input is considered to go low when no current is passing through the digital port.

Abnormal conditions were previously explained under example 2.

To enable the Data Ready and Abnormal Condition features on the 3421A, you must set bit 0 and bit 5 in the SRQ mask. Remember that bit 0 in the status register will be true (a "1") anytime data is ready and that bit 5 will be true anytime there is an abnormal condition. However, neither condition will cause the 3421A to interrupt the computer unless the SRQ mask is set accordingly. The pattern for the SRQ mask for these conditions would look like:

Bit #:	7	6	5	4	3	2	1	0	
Value:	0	0	1	0	0	0	0	1	sum = 33

Therefore, use the command "M33" to set the SRQ mask for data ready and abnormal condition.

Now, whenever the 3421A has completed its measurement task it will interrupt the computer via the SRQ data ready interrupt. Likewise, it will interrupt the computer whenever there is an abnormal condition. Looking at this from another perspective, the computer will only be interrupted if bit 0 or bit 5 (or an unmaskable bit) in the Status Register is true. Bits 1 and 3 cannot cause the interrupt because the mask was not set for those bits.

The following programming example demonstrates the handling of Data Ready, Abnormal Condition, and all non-maskable interrupts. This programming example, as with most SRQ programming, requires a knowledge of advanced programming practices. This program exhibits many of the considerations necessary when creating interrupt driven programs, including:

Digital Trigger initiation of channel list measurements;
detecting and displaying all interrupt conditions;
and for abnormal (error) conditions, interrogates the
3421A to find out why the error occurred.

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SRQ (Cont'd)

It is recommended that the basic framework of this program be used when performing advanced interrupt programming. It will be necessary, however, to modify the main body, the latter part of subroutine #1 and all of subroutine #3 to meet the specific application.

```
10 !
20 ! ==========================
30 ! HP3421A SRQ interrupt dri-
40 ! ven channel list measure-
50 ! ment programming example.
60 ! ==========================
70 !
80 DIM A(30),M(1),L(1)
90 L=7 ! 85 HPIB INTERFACE SELE
   CT CODE
100 M=701 ! HP3421A HPIB ADDRESS
110 CLEAR ! SCREEN
120 !
130 ! ========================
140 ! Initialize entire system
150 ! for an interrupt program
160 ! ========================
170 !
180 STATUS L,1 ; S ! ASSURES SRQ
     RECEIVED FLAG IS CLEARED IN
     85
190 ON INTR L GOSUB 580 ! INTERR
   UPT HANDLING SUBROUTINE
200 ENABLE INTR L;8 ! GET READY
   TO RECEIVE SRQ INTERRUPTS FR
   OM HP3421A
210 CLEAR L ! RESET HPIB INSTRUM
   ENTS
220 WAIT 5000 ! ALLOW TIME FOR I
   NSTUMENTS TO RESET
230 OUTPUT M ;"F0T0" ! DISABLE 3
   421A POWER UP FUNCTIONS AND
240 ! AUTO TRIGGER SO DATA IS NO
   T ALWAYS READY
250 ! UPON ENABLING OF DATA READ
   Y INTERRUPT (COMMAND M1 OR M
   33)
260 S=SPOLL(M) ! ASSURE THE CLEA
   RING OF ALL STATUS BITS IN 3
   421A (ESPECIALLY DATA READY
   BIT)
270 !
280 ! ========================
290 ! Main program body
300 ! ========================
310 !
320 ! THE FOLLOWING LINES HAVE B
   EEN INTENTIONALLY COMMENTED
   OUT
330 ! THEIR EQUIVALENT FUNCTION
   CAN BE SENT AS ONE COMMAND A
   S INLINE 460
340 ! OUTPUT M ;"T0" ! ENBL CH L
   ST, DATA STORAGE, WAIT FOR T
   2 OR T3 TRIGGER
350 ! OUTPUT M ;"F1R1" ! TAKE DC
   V MEASUREMENTS IN 30V RANGE
360 ! OUTPUT M ;"Z0" ! DO NOT US
   E AUTO ZERO (FASTER CHANNEL
   LIST SEQUENCING)
370 ! OUTPUT M ;"N4" ! 4.5 DIGIT
    MEASUREMENTS
380 ! OUTPUT M ;"LS13-19,13-19,1
   3-19,13-19,13,14" ! LOAD SIN
   GLE CHANNEL CLOSURE LIST WIT
   H
390 ! THIS SEQUENCE
400 ! OUTPUT M ;"M33" ! INTERRUP
   T 85 WHEN MEASUREMENTS COMPL
   ETED (DATA READY) OR UPON
410 ! ABNORMAL CONDITION (ERROR)
420 ! OUTPUT M ;"DT7" ! INITIATE
    A T3 TRIGGER WHEN DIGITAL P
   ORT GOES LOW (IE. HIGH NOT C
   ONNECTED
430 ! TO 5V, LOW NOT CONNECTED T
   O GROUND OR THE TWO SHORTED,
440 ! (IE. NO CURRENT THROUGH PO
   RT)
450 ! THE PREVIOUSE COMMAND SEQU
   ENCE MAY BE SENT ALL AT ONCE
    AS IN
460 OUTPUT M ;"T0F1R1Z0N4LS13-19
   ,13-19,13-19,13-19,13,14;M33
   ;DT7"
470 N=30 ! SET READ-BACK COUNTER
    EQUAL TO NUMBER OF CHANNELS
    LOADED INTO CHAN LIST ABOVE
480 SEND L ; UNL ! NECESSARY OR
   HP3421A WILL NOT INTERRUPT T
   HE 85
490 F=0 ! PROGRAM FLAG INDICATIN
   G THAT THE 3421A IS ALL SET
   FOR MEASUREMENT TRIGGER
500 DISP "READY"
510 CLEAR ! SCREEN
520 IF F=1 THEN GOTO 460 ! SET U
   P FOR NEW TRIGGER OF MEASURE
   MENTS490
530 GOTO 500 ! CAUSE READY TO BL
   INK UNTIL INTERRUPT IS RECEI
   VED (DIGITAL TRIG RCVD)
540 END
550 !
560 ! ========================
570 !        SUBROUTINE #1
580 ! Interupt subroutine to
590 ! print type of interrupt
600 ! received and if data
610 ! ready read the stored
620 ! values from the HP3421A
630 ! internal buffer
640 ! ========================
```


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SRQ (Cont'd)

```
650 !
660 STATUS L,1 ; S ! CLEARS SRQ
     RECEIVED FLAG IN 85
670 DISP " "
680 DISP "INTERRUPT RECEIVED"
690 DISP "==================="
700 S=SPOLL(M) ! POLL (QUERY) IN
    STRUMENT TO DETERMINE REASON
     FOR SRQ
710 IF BIT(S,6)=1 THEN DISP "SRQ
     INTERRUPT"
720 IF BIT(S,0)=1 THEN DISP "DAT
    A READY"
730 IF BIT(S,1)=1 THEN DISP "POW
    ER ON RESET"
740 IF BIT(S,2)=1 THEN DISP "SEL
    F TEST ERROR"
750 IF BIT(S,3)=1 THEN DISP "EVE
    NT OCCURRED"
760 IF BIT(S,4)=1 THEN DISP "LOW
     BATTERY"
770 IF NOT BIT(S,5)=1 THEN GOTO
    800
780 DISP "ABNORMAL CONDITION"
790 GOSUB 920
800 DISP "==================="
810 WAIT 2000 ! ALLOW USER TIME
    TO VIEW ERROR
820 F=1 ! TELL PROGRAM ABOVE NOT
     TO CONTINUE TO LOOP
830 ! BUT RATHER TO GO UP AND SE
    T UP FOR NEW TRIGGER FIRST
840 ENABLE INTR L;8 ! MUST REENA
    BLE SRQ INTERRUPT
850 IF BIT(S,1)=1 THEN GOTO 910
    ! POWER ON RESET (ALSO CAUSE
    S DATA READY BIT TO BE SET D
    UE
860 ! TO DEFAULT AUTO TRIG, OCV
    STATE OF HP3421A, IN THIS MO
    DE DATA IS ALWAYS READY!)
870 IF BIT(S,2)=1 THEN GOTO 910
    ! SELF TEST ERROR
880 ! (DID A PWR-ON OR DEVICE CL
    EAR WHICH ALSO CAUSES DATA R
    EADY BIT TO BE SET DUE
890 ! TO DEFAULT AUTO TRIG, OCV
    STATE OF HP3421A, IN THIS MO
    DE DATA IS ALWAYS READY!)
900 IF BIT(S,0)=1 THEN GOSUB 121
    0 ! VALID DATA IS READY, REA
    D IT
910 RETURN
920 !
930 ! ========================
940 !       SUBROUTINE #2
950 ! Subroutine for reading
960 ! error type from HP3421A
970 ! and displaying
980 ! ========================
990 !
1000 OUTPUT M ;"SR" ! QUERY INST
     RUMENT TO DETERM WHAT ERROR
      IS
1010 ENTER M ; S1,S2,S3 ! GET 2N
     D AND 3RD STATUS REGISTERS
     TO DETERMINE ERROR
1020 FOR K=4 TO 24
1030 ENTER M ; S0 ! EXTRA READS
     OF OTHER STATUS BYTES (ALSO
      CLEARS INDICATOR ON HP3421
     A DISPLAY)
1040 NEXT K
1050 IF BIT(S2,0)=1 THEN DISP "
      TRIGGERED IN F0 MODE"
1060 IF BIT(S2,1)=1 THEN DISP "
      REQUESTED DATA UNAVAILABLE
     "
1070 IF BIT(S2,2)=1 THEN DISP "
      INVALID SYNTAX"
1080 IF BIT(S2,3)=1 THEN DISP "
      INVALID OPTION LOCATION"
1090 IF BIT(S2,4)=1 THEN DISP "
      BATT LOW, NO TOT,MH,ML,MN,
     OT"
1100 IF BIT(S2,5)=1 THEN DISP "
      T3 TRIG WHEN CHAN LIST EMP
     TY"
1110 IF BIT(S2,6)=1 THEN DISP "
      EXCEEDED CHAN LIST LIMIT O
     F 30"
1120 IF BIT(S3,0)=1 THEN DISP "
      INVALID CAL RAM CHECK SUM"
1130 IF BIT(S3,1)=1 THEN DISP "
      INVALID ROM 1 CHECKSUM"
1140 IF BIT(S3,2)=1 THEN DISP "
      INVALID ROM 0 CHECKSUM"
1150 IF BIT(S3,3)=1 THEN DISP "
      A/D FAILED SLOPE TEST"
1160 IF BIT(S3,4)=1 THEN DISP "
      PROCESSOR RAM FAILED TEST"
1170 IF BIT(S3,5)=1 THEN DISP "
      RAM U504 FAILED TEST"
1180 IF BIT(S3,6)=1 THEN DISP "
      RAM U503 FAILED TEST"
1190 IF BIT(S3,7)=1 THEN DISP "
      10M, 100:1 DIVIDER TEST FA
     ILED"
1200 RETURN
1210 !
1220 ! ========================
1230 !       SUBROUTINE #3
1240 ! Subroutine for reading
1250 ! measurement values from
1260 ! the HP3421A.
1270 ! ========================
1280 !
1290 CLEAR ! SCREEN
1300 DISP "READING MEASUREMENTS"
1310 PRINT "  HP-3421A MEASUREME
     NTS"
1320 PRINT "====================
     ======"
1330 FOR I=1 TO N STEP 1
1340 ENTER M ; A(I)
1350 PRINT "MEASUREMENT #";I;" =
     ";A(I)
1360 NEXT I
1370 FOR H=1 TO 5
1380 PRINT ! FORM FEED
1390 NEXT H
1400 RETURN
```


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SRQ (Cont'd)

The four registers will be cleared after all four have been read by the ENTER command. The following chart shows the meaning of each bit in the registers and its value. Remember that the decimal value returned is the sum of the values of the individual bits that are set within that register. There are actually 24 registers that can be read with the SR command, the remaining 20 are 3421A status registers. These can be used to report what option assemblies are available in the 3421A, which channels are closed, the setting of the SRQ, XOR, and AND masks, etc. Refer to the blue pages at the end of this chapter.

Register	Bit Number							
	7	6	5	4	3	2	1	0
1 Status Register	Always 0	SRQ	Abnormal Condition	Low Battery	Event Occurred	Self Test Error	Power-on Reset	Data Ready
2 Error Register	Undefined. May be 1 or 0	Tried to load channel list with more than 30 channels	Channel list is empty but tried to execute a T3	Battery is low but tried to do TOT,MN, MH, ML	Wrong type of option for command	Invalid Syntax	No Data ready but Addressed to talk	Func. F0 asserted but triggered
3 Hardware Error	10 MΩ test error	RAM Error	RAM Error	μP RAM Error	A/D Error	ROM 0 Error	ROM 1 Error	Cal. RAM Checksum Error
4 Cal Error	Undefined. may be 1 or 0	A/D Error	CAL RAM Bad	CAL attempted but not enabled	Invalid CAL Zero	Invalid CAL Signal	Invalid CAL Number	Invalid CAL Function or Range
Bit Value	128	64	32	16	8	4	2	1

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SPOLL
(Serial POLL)

Example

HP-IL	HP-IB	
P=SPOLL (901)	P=SPOLL (709)	(-hp- 85,9826A)
	STATUS 709;P	(-hp- 9835,9845A/B)

Comments

Serial Poll allows you to determine the current status of the 3421A even if no SRQ mask has been established. When the 3421A receives the Serial Poll message, it returns its Status Byte (from the Status Register). The value returned is the sum of the individual bits that are set. For example, if bits 6 and 1 are set the value would be 66 (64+2=66). The 8 bits of the Status Byte and their respective values are shown in the following figure. All of these bits were described in the previous section, Require Service.

	Bit 7 N/A Always 0	Bit 6 SRQ	Bit 5 Abnormal Condition	Bit 4 Low Battery	Bit 3 Event Occurred	Bit 2 Self Test Error	Bit 1 Power/on Reset	Bit 0 Data Ready
Decimal Value	128	64	32	16	8	4	2	1

Status Byte (Register)

Reading the status byte clears all bits except for the data ready bit (bit 0) and the low battery bit (bit 4). The low battery bit is cleared only by cycling the front panel on/off switch when the battery has been recharged. The data ready bit is cleared when the reading is read or no longer available.

All Status Register bits are reset by a Device Clear message. Bits 1, 2, 3, and 5 are cleared by a SPOLL if bit 6 was set. If bit 6 was a 0, indicating that the 3421A was not generating the interrupt, no bits are changed. Bit 4 is cleared only by turning the line switch off and back on again. Bit 1 is cleared by entering the current reading to the computer.

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TRIGGER

Example

HP-IL	HP-IB
TRIGGER 9	TRIGGER 7
TRIGGER 901	TRIGGER 709

Comments

If the 3421A is an addressed listener, the TRIGGER statement will cause the voltmeter to take one or more readings. For example, if scan trigger (T3) or hold/enable scan trigger (T0) is asserted, the TRIGGER command will initiate measurements sequentially from the channel list.

If internal trigger T1 is asserted, no measurements will be taken by the voltmeter until either the TRIGGER command is executed, a reading is asked for (i.e., ENTER901;A) or T2 is asserted.

The software trigger T2 will cause one reading to be taken. Subsequent readings can be initiated by either TRIGGER or sending T2.

Neither T1 or T2 will open or close a channel before taking the reading.

Topics In Advance Programming

The following two programs illustrate the flexibility and measurement power of the 3421A. The programs include temperature measurements using either thermistors or thermocouples. Although the programs were developed on an -hp- 85 desktop computer with an HP-IL interface, they can easily be modified to run on other computers. In some cases, suggestions are made for modifying the programs to suit your individual needs.

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TEMPERATURE MEASUREMENTS

Thermistor

This first program computes the temperature, in °C, corresponding to the resistance of a thermistor. The program is designed to work with thermistors exhibiting a resistance of 5.000 kOhms at 25 °C, such as a type 44007 (-hp- part number 0837-0164) or equivalent.

The program gives you the option of selecting either 2- or 4-wire ohms measurements to be made on the thermistor. As it stands, the program sets the 3421A for a 2-wire measurement. This will give suitable results if the thermistor is used at a temperature where its resistance is much greater than the resistance of the connecting leads. For greatest accuracy from a thermistor, a 4-wire measurement should be used. To convert the program to a 4-wire measurement, delete the exclamation mark from line 80 and make line 70 a comment statement.

The program will prompt for a channel number (lines 60 and 70), type in one channel number and press [END LINE]. The program will continually make measurements on that one channel, convert the reading to °C and display the temperature.

```
10 ! Temperature measurements
20 ! with a type 44007 thermistor
30 ! -HP- 85 version
40 ! 3421A at address 901
50 DISP "CHANNEL NUMBER?"
60 INPUT C
70 OUTPUT 901 ;"TWO";C
80 ! OUTPUT901;"FWO";C
90 Q3=.0000000941
100 Q2=.00023595
110 Q1=.001286
120 ENTER 901 ; B
130 Q4=LOG(B)
140 P=1/(Q1+Q4*(Q2+Q4*Q4*Q3))-273.15
150 DISP P
160 GOTO 70
170 END
```

Lines	Description
50-60	These two lines get the channel number.
70-80	Line 70 sets the 3421A up for a 2-wire resistance measurement on the thermistor. Line 80 can be used for 4-wire resistance measurements.
90-110	These three lines contain the conversion coefficients for the 44007 thermistor.
120	Line 120 enters the measured resistance from the 3421A.
130-140	These two lines convert the measured resistance to the corresponding temperature.
150	The calculated temperature is displayed.
160	The GOTO70 statement returns the program to line 70 for another measurement.

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Thermocouple

The TEM command can be used for temperature measurements as long as you use T-type thermocouples. But what if you want to use other types of thermocouples? This next program example demonstrates the procedure for making thermocouple temperature measurements. Although the program was written specifically for J-type thermocouples, it can easily be adapted for other types simply by changing the conversion coefficients. A chart is provided listing the coefficients for several thermocouples. In this example program, the J-type thermocouple is connected to channel 17.

There are five steps that must be performed in making accurate temperature measurements from thermocouples. The following explanation of these steps are referenced to line numbers in the program.

1. Lines 190 and 200. Measure the temperature of the 44462A assembly terminal block. This is done with the REF command and is known as the REFerence Temperature. The Reference Temperature is used to effect icepoint compensation of the thermocouple measurement.

2. Line 210. Convert the Reference Temperature to a thermocouple reference voltage. The coefficients used in this step are determined by the type of thermocouple being compensated. The equation used is: $V = R0 + (Tref * R1) + (Tref^2 * R2)$. In this equation, Tref is the Reference temperature and R0, R1, and R2 are the conversion coefficients. Later in this section, a chart is provided listing the coefficients for various thermocouples.

3. Lines 230 and 240. Measure the thermocouple voltage.

4. Line 250. Add the Reference voltage to the measured thermocouple voltage.

5. Line 260. Convert the sum voltage (step 4) to its corressponding temperature (Degrees C). Line 270 is used to round the computed temperature to 2 decimal places. The equation used in line 260 is:

$$\text{Temperature} = P0 + (V * P1) + V^2 * P2) + (V^3 * P3) + (V^4 * P4) + \ldots + (V^9 * P9)$$

In this equaton, V is the voltage computed in step 4. The coefficients P0 through P9 are listed in the chart for various thermocouples.

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TEMPERATURE MEASUREMENTS (Cont'd)

```
10 ! J-type thermocouple program
20 ! -HP- 85 version
30 ! 3421A at address 901
40 ! conversion coefficients
50 R0=-.00000075
60 R1=.00005053
70 R2=.000000023
80 P0=-.36
90 P1=19750.9
100 P2= 175117
110 P3=1.821297E7
120 P4=-2831128000
130 P5=271508380000
140 P6=-1.38014121E13
150 P7=3.79243843E14
160 P8=-5.3719255E15
170 P9=3.0840254E16
180 ! Measure and convert reference
190 OUTPUT 901 ;"REF17"
200 ENTER 901 ; R
210 V1=R0+R*(R1+R*R2)
220 ! Measure and convert thermocouple voltage
230 OUTPUT 901 ;"DCV17"
240 ENTER 901 ; V
250 V=V+V1
260 T1=P0+V*(P1+V*(P2+V*(P3+V*(P4+V*(P5+V*(P6+V*(P7+V*(P8+V*P9)))))))
270 T=INT(T1*100+.5)/100
280 DISP "TEMPERATURE = ";T
290 GOTO 190
300 END
```

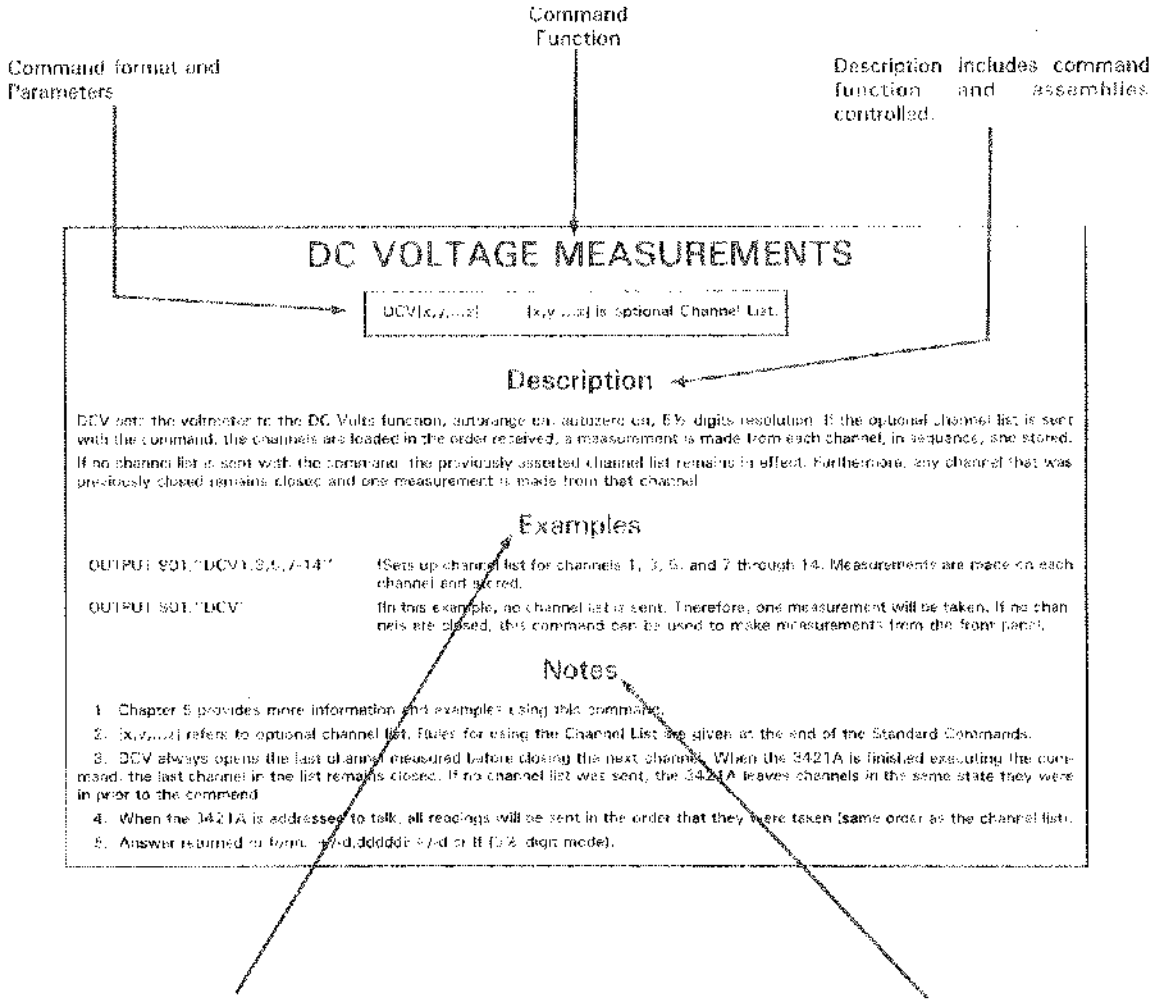
Thermocouple Type

Line Number	J	E	R	K	S
50	-7.5E-7	1.2E-7	-2.1E-7	-8.2E-7	-2.0E-7
60	5.053E-5	5.868E-5	5.334E-6	3.964E-5	5.442E-6
70	2.3E-8	4.5E-8	1.2E-8	1.6E 8	1.1E 8
80	-3.6E-1	2.1E-1	-1.5E0	-5.1E-2	-1.4E0
90	1.97509E4	1.61299E4	1.726456E5	2.48503E4	1.73545E5
100	-1.75117E5	-2.05411E5	-3.27669E7	-3.82662E5	-3.26257E7
110	1.821297E7	3.049432E7	7.787787E9	9.9661C57E7	8.477336E9
120	-2.83112E9	-2.9690242E9	1.13982593E12	1.0820624E10	-1.327040E12
130	2.7150838E11	1.4284958E11	1.01396299E14	6.0382855E11	1.2361123E14
140	1.38014121E13	-3.7221944E12	-5.4842602E15	-1.9109E13	-6.79267949E15
150	3.79243843E14	5.3981272E13	1.7414495E17	3.4782347E14	2.0689294E17
160	-5.3719255E15	-4.1055295E14	-2.9235505E18	-3.3991C28E15	-2.8874849E18
170	3.0840254E16	1.2777466E15	1.9280744E19	1.3828514E16	8.2683728E18

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COMMAND DIRECTORY

This command table for the 3421A is divided into two groups, first the Standard Commands and second the Advanced Commands. The Standard Commands are arranged by command group: VOLTMETER, TEMPERATURE, COUNTER, DIGITAL, and CHANNEL. Refer to chapters 5 and 6 in this manual for more information on channel addressing, etc. The Advanced Commands are also arranged by function: A/D (voltmeter, counter), DIGITAL, CHANNEL, and INSTRUMENT. The following format is used to describe the commands.



Examples are typical BASIC language statements with 3421A at HP-IL address 901.

Notes include power on state, where to look for more information, and special operating notes.

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DC VOLTAGE MEASUREMENTS

DCV[x,y,...z] [x,y,...z] is optional Channel List.

Description

DCV sets the voltmeter to the DC Volts function, autorange on, autozero on, 5½ digits resolution. If the optional channel list is sent with the command, the channels are loaded in the order received, a measurement is made from each channel, in sequence, and stored.

If no channel list is sent with the command, the previously asserted channel list remains in effect. Furthermore, any channel that was previously closed remains closed and one measurement is made from that channel.

Examples

OUTPUT 901;"DCV1,3,5,7-14"	!Sets up channel list for channels 1, 3, 5, and 7 through 14. Measurements are made on each channel and stored.
OUTPUT 901;"DCV"	!In this example, no channel list is sent. Therefore, one measurement will be taken. If no channels are closed, this command can be used to make measurements from the front panel.

Notes

1. Chapter 5 provides more information and examples using this command.
2. [x,y,...z] refers to optional channel list. Rules for using the Channel List are given at the end of the Standard Commands.
3. DCV always opens the last channel measured before closing the next channel. When the 3421A is finished executing the command, the last channel in the list remains closed. If no channel list was sent, the 3421A leaves channels in the same state they were in prior to the command.
4. When the 3421A is addressed to talk, all readings will be sent in the order that they were taken (same order as the channel list).
5. Answer returned in form: +/-d.ddddE+/-d or if (5½ digit mode).
6. If no parameters are sent, then T2 (software single trigger) is executed. If parameters are sent, then T3 is executed.

AC VOLTAGE MEASUREMENTS

ACV[x,y,...z] [x,y,...z] is optional channel list.

Description

ACV sets the voltmeter to the AC Volts function, autorange on, autozero on, 4½ digits resolution. If the optional channel list is sent with the command, the channels are loaded in the order received, a measurement is made from each channel, in sequence, and stored.

If no channel list is sent with the command, the previously asserted channel list remains in effect. Furthermore, any channel that was previously closed remains closed and one measurement is made from that channel.

Examples

OUTPUT 901;"ACV5,1,3,21,22"	!Sets up channel list as: 5, 1, 2, 3, 21, and 22. Measurements are made on each channel and stored.
OUTPUT 901;"ACV"	!In this example, no channel list is sent. Therefore, one measurement will be taken. If no channels are closed, this command can be used to make measurements from the front panel.

Notes

1. Chapter 5 provides more information and examples using this command.
2. [x,y,...z] refers to optional channel list. Rules for using the Channel List are given at the end of the Standard Commands.
3. ACV always opens the last channel measured before closing the next channel. When the 3421A is finished executing the command, the last channel in the list remains closed. If no channel list was sent, the 3421A leaves channels in the same state they were in prior to the command.
4. When the 3421A is addressed to talk, all readings will be sent in the order that they were taken (same order as the channel list).
5. Answer returned in form: +/-d.ddddE+/-d or if
6. If no parameters are sent, then T2 (software single trigger) is executed. If parameters are sent, then T3 is executed.

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2-WIRE RESISTANCE MEASUREMENTS

TWO[x,y,...z]	[x,y . . .z] is optional channel list.

Description

TWO sets the voltmeter to the 2-wire resistance function, autorange on, autozero on, 5½ digits resolution. If the optional channel list is sent with the command, the channels are loaded in the order received, a measurement is made from each channel, in sequence, and stored. Refer to T3 in Advanced Commands.

If no channel list is sent with the command, the previously asserted channel list remains in effect. Furthermore, any channel that was previously closed remains closed and one measurement is made from that channel. Refer to T2 in the Advanced commands.

Examples

OUTPUT 901;"TWO1,3,5,7-14"	!Sets up channel list for channels 1, 3, 5, and 7 through 14. Measurements are made on each channel and stored.
OUTPUT 901;"TWO"	!In this example, no channel list is sent. Therefore, one measurement will be taken. If no channels are closed, this command can be used to make measurements from the front panel.

Notes

1. Refer to Chapter 5 for more information and examples.
2. [x,y, ...z] refers to optional channel list. Rules for using the Channel List are given at the end of the Standard Commands.
3. TWO always opens the last channel measured before closing the next channel. When the 3421A is finished executing the command, the last channel in the list remains closed. If no channel list was sent, the 3421A leaves channels in the same state they were in prior to the command.
4. When the 3421A is addressed to talk, all readings will be sent in the order that they were taken (same order as the channel list).
5. Answer returned in form: +/-d.dddddE+/-d cr lf
6. If no parameters are sent, then T2 (software single trigger) is executed. If parameters are sent, then T3 is executed.

4-WIRE RESISTANCE MEASUREMENTS

FWO[x,y,...z]	[x,y,...z] is optional channel list.

Description

FWO sets the voltmeter to the 4-wire resistance function, autorange on, autozero on, 5½ digits resolution. If the optional channel list is sent with the command, the channels are loaded in the order received, a measurement is made from each channel, in sequence, and stored.

If no channel list is sent with the command, the previously asserted channel list remains in effect. Furthermore, any channel that was previously closed remains closed and one measurement is made from that channel.

Examples

OUTPUT 901;"FWO0-9"	!Sets up channel list of channels 0 through 9. Channels 10 through 19 will also be used. Measurements are made on channel pairs and stored.
OUTPUT 901;"FWO"	!In this example no channel list is sent. Therefore, one measurement will be taken. If no channels are closed, this command can be used to make measurements from the front panel.

Notes

1. Refer to Chapter 5 for more information and examples.
2. [x,y,...z] refers to optional channel list. Rules for using the Channel List are given at the end of the Standard Commands.
3. Ideally [x,y,...z] should be on the same slot; i.e. addresses 0-9, 10-19, or 20-29. Each channel in the channel list is automatically paired with [x+10,y+10,...z+10] unless [x,y,...z] are between 20 and 29. In this case they are paired with [x-20,y-20,...z-20]. Channel pairs are closed simultaneously. Use caution therefore and know which channels you will be closing.
4. FWO always opens the last channel or pair of channels measured before closing the next two channels. When the 3421A is finished executing the command, the last channel in the list remains closed. If no channel list was sent, the 3421A leaves channels in the same state they were in prior to the command.
5. When the 3421A is addressed to talk, all readings will be sent in the order that they were taken (same order as the channel list).
6. Answer returned in form: +/-d.dddddE+/-d cr lf
7. If no parameters are sent, then T2 (software single trigger) is executed. If parameters are sent, then T3 is executed.

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TEMPERATURE MEASUREMENTS

TEM[x,y,...z]	[x,y,...z] is optional channel list.

Description

TEM is used to take temperature measurements from T-type thermocouples only. A software reference junction compensated conversion is made. The answer returned to the calculator is in degrees C with 5½ digit resolution.

If no channel list is sent with the command, the previously asserted channel list remains in effect. Furthermore, any channel that was previously closed remains closed and one measurement is made from that channel.

Examples

OUTPUT 901;"TEM1,3,5,7-14"	!Sets up channel list for channels 1, 3, 5, and 7 through 14. Measurements are made on each channel and stored.
OUTPUT 901;"TEM"	!In this example, no channel number is sent. Therefore, the measurement will be made from whatever multiplexer channel is closed. If no channels are closed, the command can be used to make measurements from the front panel.

Notes

1. Refer to Chapter 5 for more information and examples.
2. [x,y,...z] refers to optional channel list. Rules for using the Channel List are given at the end of the Standard Commands.
3. The REFerence temperature will be taken on the same option board as the channel specified. If no channels are specified, the REFerence temperature measurement will be made on the 44462A assembly that has a multiplexer channel closed. If there are no multiplexer channels closed, the REF measurement will be made from the 44462A assembly in the lowest numbered slot. If there are no 44462A assemblies, an error will be generated.
4. TEM always opens the last channel measured before closing the next channel. When the 3421A is finished executing the command, the last channel in the list remains closed. If no channel list was sent, the 3421A leaves channels in the same state they were in prior to the command.
5. When the 3421A is addressed to talk, all readings will be sent in the order that they were taken (same order as channel list).
6. Answer in degrees C is returned in form: ±d.ddddE±d or if
7. If no parameters are sent, then T2 (software single trigger) is executed. If parameters are sent, then T3 is executed.

REFERENCE MEASUREMENT

REF[x]	[x] is optional channel number.

Description

REF is used to determine the temperature of the reference junction on the 44462A assembly where channel [x] is located. The measurement is performed by executing a software single trigger, T2. If channel [x] is not sent, the measurement will be taken from any 44462A assembly where a multiplexer channel is closed. If there are no 44462A assemblies with a closed channel, the REF measurement will be made from the 44462A assembly with the lowest slot number. If there are no 44462A assemblies, an error will result. The answer returned by REF is in degrees C. Refer to chapter 5 for more information.

Examples

```
10 OUTPUT 901;"REF1"      !Makes a reference junction temperature measurement on 44462A assembly in slot 0.
20 ENTER 901;A            !Answer returned is in degrees C.
```

Notes

1. Refer to Chapter 5 for more information on REFerence and TEMperature measurements. Also, there are examples in Chapters 3 and 4 using the REF command for thermocouple measurements.
2. [x] is an optional channel number.
3. The state of the 3421A changes to REFerence function (F5), autozero on, software trigger (T2) and 4½ digit resolution.

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FREQUENCY MEASUREMENTS

FRQ[x,y....z]	[x,y....z] is optional channel list.

Description

FRQ is used to set the 3421A for frequency measurements with a 1 second gate time and 5 digit resolution. The measurement is performed by executing a software single trigger, T2. If the optional channel list is sent, the channels are loaded in the order received, a measurement is made on each channel in sequence, and stored.

If no channel list is sent with the command, the previously asserted channel list remains in effect. Furthermore, any channel that was previously closed remains closed and one measurement is made from that channel.

Examples

OUTPUT 901;"FRQ1,3,5,7-14"	!Sets up channel list for channels 1, 3, 5, and 7 through 14. Measurements are made on each channel and stored.
OUTPUT 301;"FRQ"	!In this example, no channel list is sent. Therefore, the measurement will be made from any multiplexer channel that is closed. If no channels are closed, the command can be used to make measurements from the front panel.

Notes

1. Refer to chapter 5 for more information and examples.
2. [x,y,...z] refers to optional channel list. Rules for using the Channel List are given at the end of the Standard Commands.
3. FRQ always opens the last channel measured before closing the next channel. When the 3421A is finished executing the command, the last channel in the list remains closed. If no channel list was sent, the 3421A leaves channels in the same state they were in prior to the command.
4. When the 3421A is addressed to talk, all readings will be sent in the order that they were taken (same order as the channel list).

TOTALIZE COUNTER

TOT[x]	[x] is optional channel number.

Description

The TOTalize function is used to count events (totalize). The measurement is performed by executing a software single trigger, T2. If a channel is sent, the 3421A opens all other multiplexer channels, closes the specified channel, zeros the counter and starts counting. Maximum count is 65,535. If a channel is not specified, then no channels are changed. If the 3421A is addressed to talk, it will send the current subtotal without interrupting the totalizer. IMPORTANT: The TOT command remains in effect until another command is received by the 3421A causing it to change states.

Example

```
10 OUTPUT 901;"TOT3"        ! The TOTalize function is commenced on channel 3.
20 WAIT 1000
30 ENTER 901,A              ! The current subtotal is entered into variable A.
```

Notes

1. Refer to Chapter 5 for more information and examples.
2. [x] is an optional channel number, if no channel is specified, the TOT function is executed with no channels changing state.
3. If [x] is not a multiplexer channel, an error will occur.

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READ DIGITAL INPUTS (8-bit word)

REDi	"i" specifies the slot number to read from.

Description

REDi is used to read the digital input word (8-bits) from the 44465A Digital I/O assembly in slot "i". The answer returned by the 3421A is a decimal number (0 to 255) which is equal to the sum of the values of the individual bits that are set. Refer to the bit value chart and to Chapter 6.

Bit #	7	6	5	4	3	2	1	0
Value	128	64	32	16	8	4	2	1

Bit Value Chart

Examples

```
OUTPUT 901;"RED1"     ! Read the digital word from the 44465A assembly in slot number 1.
ENTER 901;A           ! The value A is the sum of the values of the set bits.
```

For example, if A = 173 then bits 7, 5, 3, 2, and 0 were set (128 + 32 + 8 + 4 + 1 = 173). This means that the input port looks like:

1 0 1 0 1 1 0 1

Notes

1. Refer to Chapter 6 for more information and examples.

DIGITAL WRITE

WRTi,abc	"i" specifies the slot number to write to. abc is a decimal value (0 to 255) to be sent to board.

Description

The WRT command is used to write a digital word ([abc]) to the 44465A Digital I/O assembly output port in slot "i". The value [abc] is the sum of the values of the bits to be set. Refer to the bit value chart.

Bit #	7	6	5	4	3	2	1	0
Value	128	64	32	16	8	4	2	1

Bit Value Chart

Examples

```
OUTPUT 901;"WRT0,7"   ! This command would result in turning on switches 0, 1  and 2 on the 44465A assembly in slot 0.
```

Notes

1. Refer to Chapter 6 for more information and examples.

READ DIGITAL INPUT BIT

BITx[,y,...z]	x is a mandatory bit, [,y,...z] is optional bit list.

Description

The BITx command reads the digital input bit specified by x. The 3421A will return a value of +0.000E+0 if the bit value is low, or a +1.000E+0 if the bit value is high. A bit list, similar to a channel list can be set up. Refer to Chapter 6 for more information.

Example

```
OUTPUT 901;"BIT15"    ! The 6th bit in slot 1 is read. Bits are numbered from 0 to 7.
ENTER 901;A           ! The variable A contains the value the bit, either 0 or 1.
```

Notes

1. Digital bits are numbered: 0-7, 10-17, 20-27. Numbers 08, 09, 18, 19, 28, and 29 are not valid digital bit numbers.
2. Refer to Chapter 6 for more information and examples.
3. Errors are sent as: -8.888E+8
4. Do not use T1 or T2 with the BIT command.

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CLOSE SINGLE CHANNEL, RELAY, OR BIT

CLSx x is mandatory

Description

Upon receipt of the CLSx command, the 3421A will determine the type of channel located at address "x". The following chart describes what will transpire, depending on the type of channel at the specified address:

Actuator—Closes actuator relay at address "x". Legal actuator channel numbers are (if so configured): 00, 01, 10, 11, 20, and 21.

Multiplexer—Opens all multiplexer channels then closes channel "x".

Digital—Sets bit "x". Legal Bit addresses are: 00-07, 10-17, and 20-27.

Non-existent—Cannot comply error asserted (see SPOLL) and no channels change.

Example

```
OUTPUT 901;"CLS05"      !This command would close channel or set bit 5 depending on what type of option assembly
                        is plugged into slot 0.
```

Notes

1. Refer to Chapter 5 and 6 for more information and examples.
2. CLS5 is the same as CLS05.

CLOSE CHANNEL PAIRS

CLPx x is a mandatory value.

Description

The CLPx command first causes all multiplexer channels to be opened and then closes channels x and x+10. If channel x is between 20 and 29, then channels x and x-20 will be closed. If either x or its pair is not a multiplexer channel, the cannot comply error will be asserted (see SPOLL) and no channels change state.

Example

```
OUTPUT 901;"CLP3"       ! Channels 3 and 13 will be closed.
OUTPUT 901;"CLP23"      ! Channels 23 and 3 will be closed.
```

Notes

1. Refer to Chapter 5 for more information and examples.

OPEN CHANNEL

OPN[x] x is an optional value.

Description

Upon receipt of the OPN command, the 3421A first determines what type of channel is specified by "x" and then performs the following:

"x" not sent—All channels (multiplexer, actuator, switches (see UC command) opened and all digital output bits cleared.

Actuator—opens relay.

Multiplexer—Opens channel. If that channel had been closed with a pair (CLP command) its pair would also be opened. For example, if you sent CLP3, then channels 3 and 13 would be closed. If you then sent OPN 3 or OPN 13 then both channels 3 and 13 would be opened.

Digital—Clears bit "x".

Switch—(those relays closed by the UC command), opens relay "x".

"x" non-existent—No channels change, cannot comply error asserted (see SPOLL).

Example

```
OUTPUT 901;"OPN3"       ! Opens channels 3 (or clears bit 3). If Channel 3 was closed with a pair (either channel 13 or
                        23), that channel would also be opened.
```

Notes

1. Refer to Chapters 5 and 6 for more information and examples.

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CHANNEL LIST

The series of channels specified in a channel list must follow these rules:

1. The default channel list (asserted at power on or reset) is all multiplexer channels in numerical sequence. The channel list can be loaded with multiplexer channels by the DCV, ACV, FWO, FWO, TEM, FRQ, LS or LP commands. It can also be loaded with digital input bit numbers by the BIT command. See chapters 5 and 6 for more information.

2. Channel numbers are separated by commas. However, a dash may be used to signify a contiguous set of channels (i.e., DCV2-9). Any command that specifies a channel must be seperated from subsequent commands by either a colon (:), a semicolon (;), or a Carriage Return/Line Feed but not a comma. If the last character in the command string is a comma, an error will be generated.

3. To take a burst of 30 readings on one channel, load the channel list with the channel number. For example, DCV5-5 will take 30 DC Voltage readings on channel 5.

4. The mnemonic determines what type of channel can be loaded into the channel list. In other words, if channel 1 is configured as an actuator channel, it should not be specified for any type of measurement (i.e., DCV1 or BIT1). If an attempt is made to load the channel list with an improper type of channel, a syntax error is generated (see SPOLL) and the command is aborted. If channels x y is received and some channels in between and including x and y are the wrong type of channels for the command, they are not loaded into the list and the error message is not generated. The remainder of the channels are loaded into the list.

5. Leading zeros are ignored, that is, DCV00019 means DCV19.

6. All syntax following a decimal point is ignored except for commas, dash, semicolon, colon, Carriage Return (cr), or Line Feed (lf). DCV2.3 means DCV2.

7. Exponents are not allowed and cause a syntax error. The command is aborted.

8. No more than 30 channels are accepted into the channel list. Legal channel numbers are 00 through 29.

9. All lower case letters are interpreted as upper case. ASCII characters, other than ", ; :" result in an error. In other words, Dc V 21 is the same as DCV21.

10. Terminators are required after any command (Standard or Advanced) that either specifies a channel or a decimal value, when that command is to be followed by another command. For example, the 'Mx' command is used to set the SRQ mask. This command can have a decimal value 'x' of between 0 and 255. Therefore, this command must be followed by a terminator if another command is to follow it; e.g., OUTPUT 901; "M1;T0" Valid terminators are a colon (:), a semicolon (;), a Carriage Return or Line Feed; but not a comma (,).

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Advanced Commands

A/D (Voltmeter, Counter)

RA1 = Auto Range ON
RA0 = Auto Range OFF

Function, Command	Range Codes R-1	R0	R1	R2	R3	R4	R5	R6	R7
All functions off, F0	*	*	*	*	*	*	*	*	*
DC Volts, F1	.3V	3V	30V	300V	*	*	*	*	*
AC Volts, F2	*	3V	30V	*	*	*	*	*	*
2-Wire Ohms, F3	*	*	*	300Ω	3KΩ	30KΩ	300KΩ	3MΩ	30MΩ
4-Wire Ohms, F4	*	*	*	300Ω	3KΩ	30KΩ	300KΩ	3MΩ	30MΩ
REFerence, F5 (See Standard command REF)	The Range is automatically set by the REF command								
TEMperature, F6 (Using T type Thermocouples. See Standard Command TEM.)	The Range is automatically set by the TEM command								
Frequency, F7	Gate Times: G-1 = .1 sec. G0 = 1 sec., G1 = 10 secs.								

* Indicates an invalid combination of function and range codes

Voltmeter Autozero:

Z0 = Auto zero OFF
Z1 = Auto zero ON

Number of Digits of Resolution:

N3 = 3½ digits
N4 = 4½ digits
N5 = 5½ digits

Trigger:

T0 = Enable channel list measurements and reading storage but do not take readings. Will trigger on either T3, DT, or HP-IB/HP-IL TRIGGER command. (With a 41C/CV, the TRIGGER command causes a timeout after 10 seconds. The T3 command is recommended as an alternative.)

T1 Internal trigger for readings initiated by a read command, i.e., ENTER 901. (Triggers only on read)

T2 = Software trigger. Takes one measurement on current channel.

T3 Triggers (makes measurements) with channel list and reading storage.

Note: if F0 is asserted and the 3421A receives either T1, T2 or T3, an error will be generated and -8.88888E+8 will be sent.

DTix = Executes T3 if bit "x" on Digital input port (slot) "i" goes low (i.e., no current is passing through the port). Note: If any information is passed through the interface prior to the event (trigger) the digital trigger function will be aborted.

Example

To set the 3421A to AC Volts function, 3½ digit resolution, trigger hold, execute the following command:

```
OUTPUT 901;"F2N3T0"
```


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Digital Control Commands

Monitor High (bit)

MHx (x = digital bit address)

Description

Sets bit 3 (event occurred) in Status Register when the specified bit equals a "1" (high). Therefore, an SRQ interrupt will be sent to the computer. When the 3421A is addressed to talk, it will send the status of the digital input word (8-bits) at the time the bit went high.

Example

```
OUTPUT 901;"M8"                          ! Set SRQ Mask for EVENT OCCURRED.
OUTPUT 901 USING "#,K" ; "MH15"          ! This command monitors bit 5 in slot 1 (Digital I/O)
```

Notes

1. After setting the 3421A for the monitor command, no further communication should be allowed on the interface (HP-IL or HP-IB). The monitor command may be aborted if any communication occurs.

2. If you are using the 3421A with the HP-IB interface, you will need to execute the command: SEND 7; UNL (or its equivalent) to "unlisten" the 3421A. If this is not done, the 3421A will not interrupt the computer.

Monitor Low (bit)

MLx (x = digital bit address)

Description

Sets bit 3 (event occurred) in Status Register when the specified bit equals a "0" (low). Therefore, an SRQ interrupt will be sent to the computer. When the 3421A is addressed to talk, it will send the status of the digital input word (8-bits) at the time the bit went low.

Example

```
OUTPUT 901;"M8"                          ! Set SRQ mask for EVENT OCCURRED.
OUTPUT 901 USING "#,K" ; "ML02"          ! Monitor bit 2 on slot 0 (Digital I/O)
```

Notes

1. After setting the 3421A for the monitor command, no further communication should be allowed on the interface (HP-IL or HP-IB). The monitor command may be aborted if any communication occurs.

2. If you are using the 3421A with the HP-IB interface, you will need to execute the command: SEND 7; UNL (or its equivalent) to "unlisten" the 3421A. If this is not done, the 3421A will not interrupt the computer.

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Monitor Slot (word)

MNi	Monitor Slot "i"

Description

This instruction reads digital input port on slot "i", Exclusive OR's it with the XOR mask (see XR[abc] command), ANDS the result with the AND mask (see AN[abc]) and if the final result equals zero it sets bit 3 in the Status Register. This command does not automatically set the SRQ Mask. An SRQ interrupt will be generated if bit 3 in the SRQ Mask is set, see "M" in the Advanced Commands.

Example

```
OUTPUT 901;"M8"                          ! Set SRQ mask for EVENT OCCURRED.
OUTPUT 901 USING "#,K" ; "MN2"           ! Monitor slot 2
```

Notes

1. After setting the 3421A for the monitor command, no further communication should be allowed on the interface (HP-IL or HP-IB). The monitor command may be aborted if any communication occurrs.

2. If you are using the 3421A with the HP-IB interface, you will need to execute the command: SEND 7; UNL (or its equivalent) to "unlisten" the 3421A. If this is not done, the 3421A will not interrupt the computer.

Exclusive OR Mask (for MN command)

XR[abc]	Exclusive OR mask, abc] represents a decimal number 0-255.

Description

The value [abc] is the sum of the values of the individual bits you want set in the mask. As a general rule, the XR mask is set to the bits you want to interrupt on when they go true (1). If no number is received, the mask is set to all zeros. See Bit value chart in chapter 6.

Example

```
OUTPUT 901;"XR53"     !Sets the Exclusive-OR mask to bits 5, 4, 2, and 0. (32+16+4+1 = 53)
```

AND Mask (for MN command)

AN[abc]	AND Mask, [abc] represents a decimal number 0-255.

Description

The value [abc] is the sum of the values of the bit you want to set in the mask. As a general rule, the AN mask is set to the bits you want to monitor to cause the interrupt. If no number is received with the AN command, the mask is set to all zeros. See bit value chart in Chapter 6.

Example

```
OUTPUT 901;"AN135"     ! Set the AND mask to bits 7, 2, 1, and 0. (128 + 4 + 2 + 1 = 135)
```


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Digital Set (word)

DSi,[abc]	"i" is the slot number for the Digital I/O option [abc] is a decimal value you wish to set the word to.

Description

This command "sets" the digital output port switches of the option card in slot "i" to the value [abc]. All switches not specified by [abc] remain unchanged. [abc] is the sum of the values of the individual bits you want set.

Example

```
10 OUTPUT 901;"DS1 53"      ! Set the word "53" (bits 5, 4, 2, and 0) in slot 1.
```

DIGITAL CLEAR

DCi,[abc]	"i" is the slot number for the Digital I/O option. [abc] is the decimal value you want to set the word to.

Description

This command "clears" the digital output port switches of the option card in slot "i" to the value [abc]. All switches not specified by [abc] remain unchanged. [abc] is the sum of the values of the individual bits you want cleared.

Example

```
10 OUTPUT 901;"DC2,17"      ! Clear bits 4 and 0 in slot 2.
```


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Channel Control Commands

READ CHANNEL LIST

RL	Read channel List

Description

This command allows you to read back to the computer the current channel list of the 3421A. The channel list is read back in the same order it was assigned. If a place in the list is empty, the place will be marked by "99".

Example

```
10 OUTPUT 901;"LS1 7"      !Set up channels 1 through 7 as channel list
20 OUTPUT 901;"RL"         ! Read channel list
30 FOR I 1 TO 30
40 ENTER A(I)              ! Enter and display the channel list.
50 DISP A(I)
60 NEXT I
```

The Channel List would be read back as: 1, 2, 3, 4, 5, 6, 7, 99, 99, 99, ... until 30 numbers are read back.

LOAD SINGLE CHANNELS (into channel list)

LS[x,y,...z]	Load channels [x,y,...z] into the channel list

Description

Use the LS command to load the channel list with single channels (see also LP command). If the voltmeter or counter is also set up, a TS command will open all multiplexer channels, close the first channel in the list, and initiate readings on the channel list and store them. The channels may be in any order.

Example

```
10 OUTPUT 901;"LS1-5,7"    ! Load channels 1,2,3 4,5, and 7 into the channel list.
```

LOAD CHANNEL PAIRS (into channel list)

LP[x,y,...z]	Load channels [x,x;10,y,y+10, ...z,z+10] into channel list.

Description

Use the LP command to load the channel list with channel pairs. Channels x and x+10 are closed simultaneously. If a channel number (e.g., x=24) is greater than 20, then its paired channel will be x-20 (e.g., 4).

Example

```
10 OUTPUT 901,"LP12-15"    ! Channel pairs 12&22, 13&23, 14&24, 15&25 are loaded into the
                           channel list.
```


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CHANNEL LIST POINTER

SI1 = Scanner increment

Description

Opens the currently closed multiplexer channel and closes the next channel in the list. No measurements are taken.

SI0 = Reset Pointer

Description

Resets channel list pointer to beginning of channel list. No channels are opened or closed and no measurements are taken.

Example

```
10 OUTPUT 901;"SI1"        ! increments multiplexer
```

UNCONDITIONALLY CLOSE CHANNEL

UCx = Unconditionally Close channel x.

Description

The channel specified by "x" is closed without opening any other channels. Also, if "x" is a digital output bit, the bit will be set.

WARNING

USE EXTREME CARE WITH THIS COMMAND. IT IS POSSIBLE TO HAVE TWO OR MORE CHANNELS CLOSED SIMULTANEOUSLY WITH THIS COMMAND. DAMAGE TO THE INSTRUMENT OR CUSTOMER TRANSDUCERS OR OTHER INSTRUMENTATION MAY OCCUR.

Example

```
10 OUTPUT 901;"UC12"       ! close channel 12 regardless of what type it is.
```


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Instrument Control Commands

RESET

RS	Reset

Description

This command is used to reset the 3421A. The 3421A goes through its internal self test and goes to the following states:

1. All multiplexer and actuator channels are opened.
2. All digital output bits are cleared.
3. Voltmeter is set to: DC Volts, Autorange on, Autozero on, 5½ digits resolution, internal trigger.
4. Counter is set to 1 second gate time.
5. Reads rear panel switches and responds accordingly.
6. Channel list is initialized to all available multiplexer channels from lowest number to highest number.
7. SRQ interrupt generated if self test failed.
8. The HP-IL address is not changed.
9. Reading storage buffer is empty.

Example

```
10 OUTPUT 901;"RS"          ! Reset the 3421A
```

DISPLAY NUMBER

DNx	x is optional numbers 0-29

Description

The number "x" (0 to 29) will be displayed on the 3421A display. No channels are changed and no measurements will be made. However, any channel numbers previously displayed will disappear.

Example

```
10 OUTPUT 901;"DN5"          ! This will display the number 5 on the 3421A display.
```

Notes

1 Sending DN without x returns the 3421A to normal display mode.

SET SRQ MASK

M[n]	Set SRQ Mask to value "n"

Description

This command is used to set the SRQ mask inside the 3421A. Only bits 0, 3, and 5 can be masked. Bit 1 is masked by the Power-on SRQ switch on the rear panel of the 3421A. The value "n" is a decimal value equal to the sum of the values of the bits you want to set. When a 1-to-1 correspondence of set bits in the Status Register and set bits in the SRQ mask occurs, an SRQ interrupt will be sent to the computer.

Bit 7	Bit 6	Bit 5	Bit 4	Bit 3	Bit 2	Bit 1	Bit 0
N/A	SRQ	Abnormal Condition	Low Batt	Event Occurred	Self Test Error	PWR-on Reset	Data Ready

Example

```
10 OUTPUT 901;"M1"          !Sets SRQ mask for Data Ready
```


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READ STATE REGISTERS

SR read State Registers

Description

When the 3421A receives this command, 24 decimal numbers will be sent to the computer. Each decimal number (0 to 255) represents one state register. The state registers are used to determine the exact status of the 3421A. The first four registers are error registers and are used to determine the exact nature of errors. These error registers are cleared after all four are read. For HP-IB, register 5 must also be read using an additional ENTER statement. The remaining registers are used to determine the current state of the 3421A, i.e., which option assemblies are available in the 3421A, the current measurement function (whether DC Volts, ohms, etc.), measurement range, which multiplexer and actuator channels are closed, and the setting of the various masks. These registers are not cleared after reading. If the 3421A receives another command before it has sent all of the 24 registers, it will stop sending them.

Example

```
10 DIM A(24)
20 OUTPUT 801; "SR"      ! This line sends the Status Register command.
30 FOR I=1 TO 24
40 ENTER 801; A(I)       ! These three lines read back the 24 registers.
50 DISP A(I)
60 NEXT I
```

The following describes each of the registers. The value returned from each register is the sum of the values of the bits that are set. Chapter 3 has a short BASIC language program that will read all 24 registers and decode them on a bit by bit basis.

Register 1: Status Register (see SPOLL, Chapter 3)

Bit 7	Bit 6	Bit 5	Bit 4	Bit 3	Bit 2	Bit 1	Bit 0
Always zero	SRQ	Abnormal Condition	Low Battery	Event Occured (MN,ML, MH)	Self Test Error	Power-on Reset	Data Ready

Register 2: Error

Bit 7	Bit 6	Bit 5	Bit 4	Bit 3	Bit 2	Bit 1	Bit 0
Not Defined	Tried to load channel list with more than 30 channels	Can't do T3 since channel list is empty	Can't do TOT,MH, ML,MN, OT while Battery is low	Option specified in command does not exist in that slot	invalid syntax.	Addressed to talk but no data ready	Triggered but EO asserted

Register 3: Hardware Error (see 3421A Service Manual)

Bit 7	Bit 6	Bit 5	Bit 4	Bit 3	Bit 2	Bit 1	Bit 0
10 MΩ test failed	RAM U503 failed	RAM U504 failed	µP RAM failed	A/D Slope Error	ROM 0 checksum error	ROM 1 checksum error	Cal RAM checksum error

Register 4: Calibration error (see 3421A Service Manual)

Bit 7	Bit 6	Bit 5	Bit 4	Bit 3	Bit 2	Bit 1	Bit 0
Not Defined	A/D error	Cal RAM bad	Cal attempted Cal RAM not enabled	Invalid CAL zero	Invalid Cal signal	Invalid Cal number	Invalid Cal function or range

NOTE: Those bits specified as Not Defined may be either a "1" or a "0".

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Register 5: Status of the SRQ Mask (see SPOLL in Chapter 3)

Bit 7	Bit 6*	Bit 5	Bit 4*	Bit 3	Bit 2*	Bit 1**	Bit 0
Not Defined	SRQ (always 1)	1 = SRQ if abnormal condition occurs	Low battery (always 1)	1 = SRQ if event occurs (MN,ML,MH DT)	Self Test failed (always 1)	1 = SRQ if Power on reset occurs	1 = SRQ if data ready

* The bits labeled as "always 1" are not maskable. When the event occurs, the SRQ internal message will be sent to the controller.

** This bit or feature is enabled/disabled by the POWER-ON SRQ switch on the rear panel of the 3421A.

Register 6: Option Boards Available

Bit 7	Bit 6	Bit 5	Bit 4	Bit 3	Bit 2	Bit 1	Bit 0
Not Defined	Slot 2 is digital option	Slot 1 is Digital option	Slot 0 is Digital option	always zero	Slot 2 is mux option	Slot 1 is mux option	Slot 0 is mux option

Register 7: Actuator Channels Available

Bit 7	Bit 6	Bit 5	Bit 4	Bit 3	Bit 2	Bit 1	Bit 0
Not Defined	Not Defined	1 = actuator channel 21	1 = channel 20	1 = channel 11	1 = channel 10	1 = channel 1	1 = channel 0

Register 8: Actuator Channels Closed

Bit 7	Bit 6	Bit 5	Bit 4	Bit 3	Bit 2	Bit 1	Bit 0
Not Defined	Not Defined	1 = actuator channel 21 closed	1 = actuator channel 20 closed	1 = actuator channel 11 closed	1 = actuator channel 10 closed	1 = acutator channel 01 closed	1 = actuator channel 00 closed

Registers 9 and 10:

Register 9 contains the channel address when a multiplexer channel is closed. If channel pairs were closed, Register 10 contains the paired channel.

Bit 7 Bit 6 Not Defined	Bit 5	Bit 4	Bit 3	Bit 2	Bit 1	Bit 0	
Slot 0:	0	0	0	0	0	0	:Channel 0
Slot 1:	0	1	0	0	0	1	:Channel 1
Slot 2:	1	0	0	0	1	0	:Channel 2
			0	0	1	1	:Channel 3
			0	1	0	0	:Channel 4
			0	1	0	1	:Channel 5
			0	1	1	0	:Channel 6
			0	1	1	1	:Channel 7
			1	0	0	0	:Channel 8
			1	0	0	0	:Channel 9
	X	X	1	1	1	1	:no channel closed

Bit definition for Registers 9 and 10 are the same.

NOTE. Those bits specified as Not Defined may be either a "1" or a "0".

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Registers 11 through 16: Indicates which relay channels were closed by the UC command.

Register 11

Bit 7	Bit 6	Bit 5	Bit 4	Bit 3	Bit 2	Bit 1	Bit 0
Not Defined	Not Defined	Not Defined	1 = chan 4 closed	1 = chan 3 closed	1 = chan 2 closed	1 = chan 1 closed	1 chan 0 closed

Register 12

Bit 7	Bit 6	Bit 5	Bit 4	Bit 3	Bit 2	Bit 1	Bit 0
Not Defined	Not Defined	Not Defined	1 = chan 9 closed	1 = chan 8 closed	1 = chan 7 closed	1 = chan 6 closed	1 = chan 5 closed

Register 13

Bit 7	Bit 6	Bit 5	Bit 4	Bit 3	Bit 2	Bit 1	Bit 0
Not Defined	Not Defined	Not Defined	1 = chan 14 closed	1 = chan 13 closed	1 = chan 12 closed	1 = chan 11 closed	1 = chan 10 closed

Register 14

Bit 7	Bit 6	Bit 5	Bit 4	Bit 3	Bit 2	Bit 1	Bit 0
Not Defined	Not Defined	Not Defined	1 = chan 19 closed	1 = chan 18 losed	1 = chan 17 closed	1 = chan 16 closed	1 = chan 15 closed

Register 15

Bit 7	Bit 6	Bit 5	Bit 4	Bit 3	Bit 2	Bit 1	Bit 0
Not Defined	Not Defined	Not Defined	1 = chan 24 closed	1 = chan 23 closed	1 = chan 22 closed	1 = chan 21 closed	1 = chan 20 closed

Register 16

Bit 7	Bit 6	Bit 5	Bit 4	Bit 3	Bit 2	Bit 1	Bit 0
Not Defined	Not Defined	Not Defined	1 = chan 29 closed	1 = chan 28 closed	1 = chan 27 closed	1 = chan 26 closed	1 = chan 25 closed

Register 17: Functions

Bit 7	Bit 6	Bit 5	Bit 4	Bit 3	Bit 2	Bit 1	Bit 0
Not Defined	Not Defined	Not Defined	Not Defined	Not Defined			
					No functions asserted. 0	0	0
					DC Volts 0	0	1
					AC Volts 0	1	0
					2-Wire Ohms: 0	1	1
					4-Wire Ohms: 1	0	0
					Reference Temperature: 1	0	1
					Tempererature (T-type thermocouple): 1	1	0
					Frequency: 1	1	1

NOTE. Those bits specified as Not Defined may be either a "1" or a "0".

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Register 18: Ranges

Bit 7	Bit 6	Bit 5	Bit 4	Bit 3	Bit 2	Bit 1	Bit 0	
Not Defined	Not Defined							
Counter Gate Time Codes	1 Second	0	0	0	0	0	0 - NOT USED	
	1 Second	0	0	0	0	0	1 - R-1	
	10 Second	1	1	0	0	1	0 R0	
				0	0	1	1 R1	Voltmeter
				0	1	0	0 - R2	Rnge
				0	1	0	1 - R3	Codes
				0	1	1	0 - R4	
				0	1	1	1 R5	
				1	0	0	0 - R6	
				1	0	0	1 - R7	

Register 19: Voltmeter status

Bit 7	Bit 6	Bit 5	Bit 4	Bit 3	Bit 2	Bit 1	Bit 0
1 = Cal enabled	Not Defined			1 = 50Hz 0 = 60Hz integration time	1 = auto-zero on 0 = auto zero off	1 = auto-range on 0 = auto range off	1 internal trigger

0	0 - T0 (Trigger hold)
0	1 - T1
1	0 - T2
1	1 T3

Register 20: Number of Digits of Resolution

Bit 7	Bit 6	Bit 5	Bit 4	Bit 3	Bit 2	Bit 1	Bit 0
Not Defined	Not Defined	Not Defined	Not Defined	Not Defined	Not Defined		
					invalid	0	0
					5½ digit res.:	0	1
					4½ digit res.:	1	0
					3½ digit res.:	1	1

Register 21: Channel List

Bit 7	Bit 6	Bit 5	Bit 4	Bit 3	Bit 2	Bit 1	Bit 0
1 = channel list is digital bits. 0 = channel list is mux channels	Not Defined	Not Defined	Not Defined	Not Defined	1 = TCT function on.	Not Defined	Not Defined

Register 22: Display Mode

Bit 7	Bit 6	Bit 5	Bit 4	Bit 3	Bit 2	Bit 1	Bit 0
Not Defined	Not Defined	Not Defined	Not Defined	Not Defined	1 = DN mode on 0 = DN mode off.	Not Defined	Not Defined

Register 23: AND mask (set by AN[abc] command)

Register 24: Exclusive-OR Mask (set by XR[abc] command)

NOTE. Those bits specified as Not Defined may be either a "1" or a "0".

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CHAPTER 4
Programming With the -hp- Model 41C/CV Calculator

Introduction

Your -hp- Model 3421A was designed to interface with a wide variety of calculators and computers over the Hewlett-Packard Interface Loop (HP-IL). In the last chapter we saw how to use the 3421A with BASIC language controllers. This chapter discusses the remote operation and programming of the 3421A from the -hp- 41C/41CV family of handheld calculators. The many features of the 3421A combined with the computational power of the 41C/CV calculator provides for a low cost, flexible measurement and control system. In addition, plotter/printers, cassette mass storage drives and other HP-IL instruments can easily be added to the loop.

This chapter shows you how to execute simple, one command instructions from the calculator to control the 3421A and then read the measurement data back. Later in the chapter, we'll discuss interface control and the development of powerful programs to solve your measurement needs. Last, you'll look at several application programs including a simple data logger with a printer and cassette drive.

Before beginning this chapter you will want to have read Chapters 1 and 2 of this manual. Those chapters will familiarize you with the many features of the 3421A and its command set. You will also find it helpful to read the -hp- Model 41C/41CV Owners Handbook and Programming Guide (-hp- part number 00041-90313) and the -hp- Model 82160A HP-IL Module Owners Manual (-hp- part number 82160-90001).

Special Note. The Data Acquisition Control Pac ROM (-hp- part number 44468A) for the 41C/CV provides friendliness for controlling the 3421A not afforded by the calculator alone. Therefore, if you have the DA/C Pac it may not be necessary to read this chapter. Read the manual provided with the ROM Pac instead. If you decide to write your own custom programs using the subprograms provided with the ROM Pac, this chapter provides a basis for program writing.

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Examples Format

The many examples in this chapter are designed to enhance your understanding of programming the 41C/CV to control the 3421A. The examples show the keystrokes used in entering a command or program line from the calculator keyboard. Also shown is the calculator display for each line as it has been entered. Enter the programs as shown. If you make a mistake when entering a command you can generally use the correction key (back arrow) to edit the line. If you are entering a program line, use the Back Step key [BST] or the Single Step key [SST]. Refer to the Owner's Handbook and Programming Guide for more operating and programming information for the 41C/CV.

Sending Instructions to the 3421A.

Using a programmable calculator to control the 3421A allows for greater flexability and control than afforded by a front panel. The calculator effectively becomes the 3421A's front panel. Of course this involves both sending instructions to the 3421A and receiving data from it. Let's begin by seeing how a simple instruction is sent .

Do This *

Connect only the 3421A in the loop with the 41C/CV.

Keystrokes	Comments	41C/CV Display
[ALPHA] DN5 [ALPHA]	You can replace '5' with any number between 0 and 29, e.g., DN27. Note that the shift key is required to enter numbers into the Alpha Register.	DN5
[XEQ] [ALPHA] OUTA [ALPHA]		OUTA

* If this example doesn't work, turn off both the 3421A and the calculator. Make certain that the HP-IL connections have been made. Turn the 3421A on first and wait until the display clears then turn the 41C/CV on. Try running the initialization program shown later in this chapter.

Let's take a closer look at what you did. First, the message DN5 was stored into the alpha register. DN (**D**isplay **N**umber) is called a command code and tells the 3421A to display the number 5. Second, the command OUTA (**OUT**put **A**lpha register) was executed (**XEQ**). Since the 3421A is the only device in the loop, it received the instruction and displayed the number. Try the command again using a different number.

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You should now execute the DN command without a number to clear the 3421A from the display number (DN) mode. That is:

[ALPHA] DN [ALPHA]

[XEQ] [ALPHA] OUTA [ALPHA]

There are several command codes that the 3421A recognizes. The blue pages at the end of the previous chapter describe the codes and give a brief example of how they are used.

Sample Problem

Suppose you need to make an AC voltage measurement from channel 12. The easiest way to do this would be to use the Standard command, ACV12. The sequence would look like:

[ALPHA] ACV12 [ALPHA]

[XEQ] [ALPHA] OUTA [ALPHA]

The command ACV12 means that an **AC** Voltage measurement is to be taken on channel 12. OUTA (**OUT**put **A**lpha register) is an instruction causing the contents of the Alpha register, in this case ACV12, to be sent through the interface to the 3421A. When the 3421A receives the command, the measurement is made.

Programming Hints

If the same type of measurement is to be made on several channels, all the channels can be specified in one command. In other words, ACV12,13,15-19 specifies an AC Voltage measurement on channels 12, 13, 15, 16, 17, 18, and 19. Channel 12 is measured first and the measured value is stored in the 3421A's reading storage. Then channel 13 is measured and the measured value stored. Finally, channel 19 is measured and that value is stored.

Later, when you want to read back the measured voltages (see the IND command later in this chapter), the voltage from channel 12 will be read back first, then from channel 13, and so on until the voltage from channel 19 is read back.

Instructions for the 3421A are sent as a series of 7-bit ASCII characters. If more than one instruction or piece of data is sent at one time, they must be separated

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by a colon (:). Characters that are ignored are blanks and plus (+). All other punctuation and character sequences that are not recognized by the 3421A will result in a syntax error. In other words, Dc V 21 is interpreted exactly the same as DCV21.

The series of channels specified in this way defines a "Channel List". The following rules apply to the channel list:

a. The default channel list (asserted at power on or reset) becomes all available multiplexer channels is numerical sequence. The DCV, ACV, TWO, FWO, TEM, FRQ, LS and LP commands can be used to alter or load the channel list. It can also be loaded with digital input bit numbers by the BIT command. See chapters 5 and 6 for more information.

b. Channel numbers are separated by commas. If the last character sent is a comma an error will be generated. A dash may be used to signify a contiguous set of channels (i.e. x-y). When using the Advanced Commands, any command that specifies a channel must be separated from subsequent command by a valid terminator. For example, F1RA1LS5-9;T3. If the last character in any command string is a comma, an error will be generated.

c. No more than 30 channels are accepted. Valid channel numbers are 0 through 29.

d. To take a burst of 30 readings from one channel, load the channel list with that one channel number. For example, to take DC voltage readings from channel 5, execute: DCV5-5.

e. The mnemonic determines what type of channels are loaded into the list. In other words, if channel 1 is configured as an actuator channel, it should not be specified for any type of measurement (i.e. DC Voltage or bit 1, etc.). If an attempt is made to load the list with an improper type of channel, a syntax error is sent (see INSTAT) and the command is aborted. If x-y is received where channels between and including x and y are of the wrong type, they are not loaded into the channel list and the error message is not sent. The remainder of the channels are loaded into the list

f. Leading zeros and spaces are ignored; i.e., 00019 is channel 19.

g. Generally, all syntax following a decimal point is ignored except for comma, dash, semicolon, colon, Carriage Return (cr), and Line Feed (lf). i.e.LS2.345 loads channel 2.

h. Exponents are not allowed and cause a syntax error; i.e., DCV2.345E+1 would cause an error and no channel list is accepted.

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Receiving Data From the 3421A

Not only can the 3421A be controlled by the 41C/CV calculator, but it can also talk to the calculator. The 3421A can send measurement data and status information about the mainframe and the digital option cards. The calculator can then process the measurement data or status information as necessary.

From the last section we saw how to program the 3421A to take an AC voltage measurement from channel 12. Now let's see how to transfer the measurement data from the 3421A to the calculator.

Keystrokes	Comments	41C/CV Display
[ALPHA] ACV12 [ALPHA]	AC Voltage measurement on channel 12.	ACV12
[XEQ] [ALPHA] OUTA [ALPHA]	**OUT**put Alpha Register.	OUTA
[XEQ] [ALPHA] IND [ALPHA]	**IN**put Decimal number.	IND
		(Measured Value)

IND (INput Decimal) is an instruction that causes the 3421A to talk to the calculator, giving measurement or status information. The measurement will appear in the calculator's display as well as in the X-register. Since the reading is in the X-register it is ready to be operated on by the calculator. For example, you could take the log of the reading by simply pressing the **LOG** key.

If a channel list were sent out with the command, e.g. ACV12,13,15-19, the reading from the first channel is sent the first time IND is executed, The second execution of IND causes the reading from the second channel to be sent. Subsequent executions of IND cause the readings from the remaining channels to be sent to the calculator. The error message, -8.88888E+8, will be sent if an error occurs—such as if IND is executed after the last channel has been read.

Looking closely at what we have done so far, we can see the beginnings of a very simple program. A program instructs the 3421A to do something (either make a measurement or read the status, etc.) and then enter the result into the calculator.

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The program will need to be completed by adding a label and an **END** statement. Look at the program listing below and compare it to the earlier example for reading the AC voltage on channel 12.

```
01*LBL "ACVOLTS"    — Label
02 "ACV12"          — Load the command into the Alpha register
03 XEQ "OUTA"       — OUTput Alpha register command
04 XEQ "IND"        — INput Decimal value from channel 12
05 END              — END of program
```

HP-IL Interface Control

Before pursuing further the subject of program writing, let's look at some special HP-IL commands. In the examples we've looked at so far, commands like IND, OUTA, and INA have been used. These commands are called Interface Control commands. Now, you'll learn what these and other commands mean and how they are used. The control commands allow you to directly specify a device to perform a function, send or receive information, or control the interface loop. These control commands also allow you to use more than one 3421A in the interface loop.

The eleven Interface Control Commands are listed below with a very brief explanation of what they do. After the list, we'll look at each one individually to see how it is used and to see more of what it does. You may also want to read the -hp-Model 82160A HP-IL Module Owners Manual.

SELECT	Select a particular device or instrument
OUTA	Output the Alpha register to the selected device
IND	Input decimal number from selected device
INA	Input from selected device to Alpha register
TRIGGER	Triggers all devices previously set to Listen mode plus the selected device
INSTAT	Input the status byte from selected device
PWRDN	The Power-Down command sets all devices to the standby power condition
PWRUP	The Power-Up command returns all devices to full operating power conditions
FINDID	Find the HP-IL address of a particular device
AUTOIO	Set the HP-IL interface to the Auto mode (default)
MANIO	Set the HP-IL interface to the Manual mode
REMOTE	Set the selected device to Remote mode (Not needed for 3421A, it is always in remote)
LOCAL	Set selected device to Local mode (Local not implemented on the 3421A)
LISTEN	Set selected device to Listen mode

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SELECT

Example

[XEQ] [ALPHA] SELECT [ALPHA]

Comments

The SELECT command is used to determine which HP-IL device will receive commands from the calculator—that is, become the "selected" device. You must put the HP-IL address of the device into the X-register prior to executing the SELECT command.

OUTA

Example

[ALPHA] DCV12,13,15-19 [ALPHA]

[XEQ] [ALPHA] OUTA [ALPHA]

Comments

The command OUTA (**OUT**put **A**lpha register) causes the contents of the Alpha register to be output to the selected device. In the example shown above, the alpha register is loaded with the command string: ACV12,13,15-19.

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IND

Example

XEQ ALPHA IND ALPHA

Comments

The IND (INput Decimal) command retrieves an ASCII-coded numeric value from the selected device and places it into the X-register of the calculator. If the 3421A has been given a measurement command (such as DCV) and then receives the IND command, the 3421A becomes a talker and outputs one measurement value in the form:

+/-d.ddddd E +/-d CR LF (5½ digit mode)

where d represents a single digit. The calculator automatically places the decimal point to remove the exponent. If the 3421A is in the 4½ digit mode, only the 4½ digits will be sent, i.e., +/-d.dddd E +/-d CR LF. In the 3½ digit mode, only the 3 1/2 digits will be sent. CR is Carriage Return and LF is Line Feed. CR LF is a standard end-of-line terminator and does not show in the display.

The message: +9.99999E+9 (5½ digit mode) indicates one of the following conditions:

a. Voltmeter overload
b. Counter overflowed in TOT mode
c. Temperature out of range, i.e., reference not between 0 and 60 degrees C or thermocouple voltage not between 6 and 20 millivolts.

Error conditions caused by the voltmeter, channel list, etc. are indicated by: -8.88888E+8 (5½ digit mode) The error message for digital I/O errors is: 888. Essentially there are 10 error conditions:

a. Function F0 is asserted and the 3421A received a trigger command.

b. A hardware error such as the calibration RAM checksum error or A/D slope error.

c. The 3421A is addressed to talk but it has nothing to send (i.e., it was not told to take a measurement).

d. A syntax error occurred.

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e. A command was given but the appropriate option board does not exist in the slot specified.

f. An attempt was made to load the channel list with more than 30 channels.

g. An attempt is made to increment the channel list and take a reading (T3) but the channel list is empty.

h. The 3421A internal battery is low but an attempt was made to execute TOT, MH, ML, or MN.

i. A calibration error (see the 3421A Installation and Service manual).

j. Failed Self Test.

An example is given with the INSTAT command on using the SR command to read the status bytes to determine which condition caused the error.

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INA

Example

[XEQ] [ALPHA] INA [ALPHA]

Comments

The INA (**IN**put **A**lpha register) command inputs data from the selected device and stores the data in the calculator's Alpha register but not in the X register.

TRIGGER

Example

[XEQ] [ALPHA] TRIGGER [ALPHA]

Comments

The TRIGGER command will frequently be used in conjunction with the T0 Advanced Command. Consider the following program:

```
01    LBL "TRIG"        10    TRIGGER
02    AUTOIO            11    2.00901
03    CF 17             12    STO 01
04    "HP3421A"         13 ◆  LBL "ENTER"
05    FINDID            14    IND
06    SELECT            15    PSE
07    "LS2-9:F1T0"      16    ISG 01
08    OUTA              17    GTO "ENTER"
09    PSE               18    END
```

Line 02 sets-up the 3421A with a channel list of channels 0 through 9, and for DC voltage measurements (F1). The T0 command prevents the 3421A from triggering but enables the scan through the channel list and reading storage. Therefore, when the TRIGGER command is executed, the 3421A reads each channel and stores the measurement results. The readings are input to the calculator in line 06.

NOTE

With the HP-41C/CV, the TRIGGER command sets up an interface timeout that occurs in 10 seconds. If the 3421A has not completed its measurements in 10 seconds, a TRANSMIT ERROR results (for example, when storing 30 readings into the 3421A internal buffer). For this reason, we recommend that the 3421A T3 trigger command be used instead of the HP-IL TRIGGER command in order to ensure proper operation.

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INSTAT

Example

XEQ ALPHA INSTAT ALPHA

Comments

The INSTAT (**IN**put **STAT**us) command causes the 3421A (or selected device) to output its 8-bit Status Byte. The entire eight bits are transferred to 41C/CV user flags 00 through 07. Status Byte bit 0 is placed in flag 00, bit 01 is placed in flag 01, etc. This allows testing of individual bits (flags). Also, a decimal value is placed into the X-register of the calculator. This decimal value is equal to the sum of the values of the least significant six bits that are set (a '1' or logic high).

Status Register

The Status Register in the 3421A is used to continuously monitor six conditions within the instrument. The Status Byte is an 8-bit byte sent from the Status Register in response to the INSTAT command. The figure below illustrates the Status Register and defines each bit. The bits are set (logic 1) when the indicated condition occurs and will be cleared when the INSTAT message is received, except as noted.

	Bit 7	Bit 6	Bit 5	Bit 4	Bit 3	Bit 2	Bit 1	Bit 0
	Always Zero	Require Service (RQS)	Abnormal Condition See Below	Low Battery	Event Occurred	Self Test Failed	Power-on Reset Occurred	Data Ready
Bit Value:	128	64	32	16	8	4	2	1

Bit 6 Bit 6 of the register will be set (a "1") when there is any one-to-one correspondence of bits in the Service Request (SRQ) Mask and the lower 6 bits of the Status Register. The bit will be cleared (a "0") when the one-to-one correspondence no longer exists or, in the case of bits 0, 1, 2, 3, and 5, with the execution of INSTAT.

Although the Require Service Message will be sent by the 3421A to the calculator when this bit is set, the 41C/CV is not capable of responding to the message. For this reason, the SRQ Mask and the Require Service Message will not be discussed further in this chapter. BASIC language controllers, see Chapter 3, are capable of responding and the SRQ mask is discussed under the topic of SPOLL. This means that the digital monitor commands MN, MH, and ML cannot be used to interrupt the 41C/CV.

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INSTAT (Cont'd)

Bit 6 Bit 6 of the register will be set (a "1") when there is any one-to-one correspondence of bits in the Service Request (SRQ) Mask and the lower 6 bits of the Status Register. The bit will be cleared (a "0") when the one-to-one correspondence no longer exists or, in the case of bits 0, 1, 2, 3, and 5, with the execution of INSTAT.

Although the Require Service Message will be sent by the 3421A to the calculator when this bit is set, the 41C/CV is not capable of responding to the message. For this reason, the SRQ Mask and the Require Service Message will not be discussed further in this chapter. BASIC language controllers, see Chapter 3, are capable of responding and the SRQ mask is discussed under the topic of SPOLL. This means that the digital monitor commands MN, MH, and ML cannot be used to interrupt the 41C/CV.

Bit 5 This bit will be set if any one of the following conditions are met. This bit will be cleared by the INSTAT command.

1. Hardware Error, such as an A/D converter error.

2. Calibration Error. This generally means a bad checksum was found in the calibration RAM. The calibration of the instrument is suspect.

3. Syntax Not Understood. An invalid command code was sent to the 3421A.

4. Can't Execute Syntax, e.g., the 3421A doesn't have an option board in slot 2 but was told to close a channel in that slot.

5. Low battery condition exists but an attempt was made to execute TOT, MH, ML, or MN.

6. An attempt was made to load the channel list with more than 30 channels.

7. An attempt was made to increment the channel list and trigger (T3) but the channel list was empty.

8. The 3421A was told to send its latest reading, but no reading was available.

9. The internal voltmeter received a trigger command but function F0 was asserted.

10. Self test failed.

Bit 4 This bit indicates a low battery condition. The bit will be cleared only when the 3421A is switched off and back on. This bit is not maskable with the SRQ mask.

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INSTAT (Cont'd)

Bit 3 Bit 3 indicates that an event has occurred as sensed by either of the three monitor functions; MN, ML, MH. Bit 3 is automatically enabled by the MH and MI commands and is cleared by the INSTAT command. The MN, ML, and MH commands are described in chapter 6.

Bit 2 This bit indicates a failure in the 3421A self test. Note that it is not maskable (see the M command). Refer to Chapter 2 for more information on Self Test.

Bit 1 Bit 1 will be set whenever a power-on reset has occurred. The bit will be cleared when the INSTAT command is sent to the 3421A. Although this bit may be true, an SRQ is not generated unless it is enabled by the Power ON SRQ switch on the rear panel.

Bit 0 When set to a "1", this bit can show that the 3421A has taken a reading (voltmeter, counter, bit, etc.) and is waiting to output it to the calculator. The following commands will set the data ready bit: DCV, ACV, TWO, FWO, FRQ, TEM, REF, TOT, RED, BIT, T1, T2, T3, DT, MH, ML, MN, and GET. This bit will be cleared if the reading is sent to the calculator (IND command) or the reading is no longer available.

Let's look at two examples of how INSTAT may be used. The first of these examples will be used in later programs.

Example 1. Data Ready

The data ready bit (bit 0 in the Status Register) of the 3421A allows the calculator to determine when new measurement data is ready. Since the data ready bit is bit 0, it will be placed into the calculator's Flag 00 when the INSTAT command is executed. Therefore, we can test Flag 00 to see if data is ready.

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INSTAT (Cont'd)

Keystrokes	Comments	41C/CV Display
ALPHA DCV12 ALPHA	Instructions for a DC voltage reading on channel 12	DCV12
XEQ ALPHA OUTA ALPHA	Output the instruction to the 3421A.	
XEQ ALPHA INSTAT ALPHA	Bit 0 is set indicating data is ready. The value of this bit is '1'.	1.0000
■ FS? 00	The test to see if Flag 00 is set returns a YES answer.	YES
XEQ ALPHA IND ALPHA	The display will show the 3421A reading.	(measured reading)
XEQ ALPHA INSTAT ALPHA	The data is no longer available. It was read into the calculator by IND. Bit 0 is cleared and INSTAT returns a '0'.	0.0000
■ FS? 00	The Flag 00 test now shows that bit 0 in the Status Register is clear.	NO

The DCV12 command caused the 3421A to take one reading. When the first INSTAT command was executed, the calculator display showed a "1". This is because bit 0 in the Status Register was set due to the reading being ready. When Flag 00 was tested (FS? 00), it was set and the calculator displayed "YES".

With the IND command , the measurement was sent to the calculator and no new measurements were taken. Therefore, no new readings became available and bit 0 in the Status Register is clear. This is evident by the second INSTAT command returning a "0" and the Flag 00 test answering NO.

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INSTAT (Cont'd)

The FS? and FC? tests may be used in programs to branch to subroutines if data is or is not ready.

Please note that the value returned after the first INSTAT command may be 3. This would indicate that a power-on reset of the 3421A has occurred; see Bit 2 in the Status Register. This bit will be cleared with the INSTAT command. Therefore, running through the example again should produce the results shown.

Example 2. Abnormal Condition

As stated earlier, there are several things that can cause an error. One example of an error condition is when the 3421A receives a command that it doesn't understand or cannot comply with. The following program shows how the INSTAT command and flag tests may be used in a program to detect errors.

```
01*LBL "FLAG"
02*LBL 01
03 "DCV12"
04 OUTA
05 INSTAT
06 FS? 05
07 TONE 5
08 FS? 00
09 IND
10 GTO 01
11 END
```

Line 3 should be changed to reflect some channel that you do have in your 3421A. If an error does occur, bit 5 in the Status Register will be true. When Flag 05 is tested the tone will sound. If the bit were not true (no error), the program would skip over the TONE 5 instruction. Try it by replacing line 3 with the command DCV35. This would cause an syntax error.

To find out exactly what caused the error, execute the SR command followed by four IND commands. SR is the command to send the Status Byte plus the three error registers. Execute the following instructions.

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INSTAT (Cont'd)

Keystrokes	Comments	41C/CV Display
[ALPHA] DCV35 [ALPHA]	A DC Voltage measurement on channel 35 is illegal. An error will occur.	
[XEQ] [ALPHA] OUTA [ALPHA]	Output the command DCV35	
[ALPHA] SR [ALPHA]	SR is the Status Register command.	
[XEQ] [ALPHA] OUTA [ALPHA]	Output the command SR	
[XEQ] [ALPHA] IND [ALPHA]	Input the first register which is the same as the Status Byte The Status Byte will will be cleared after this. The value 32 (bit 5) means an abnormal condition.	32
[XEQ] [ALPHA] IND [ALPHA]	Input the second Register which is the error register. The value 4 (bit 2) means invalid syntax.	4
[XEQ] [ALPHA] IND [ALPHA]	Input the third Register which is the hardware error register. The value 0 indicates no hardware error.	0
[XEQ] [ALPHA] IND [ALPHA]	Input the fourth Register which is the calibration error register. The value 0 means no calibration error.	0

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INSTAT (Cont'd)

The four error registers will be cleared after all four have been read by the IND command. The following chart shows the meaning of each bit in the registers and its value. Remember that the decimal value returned is the sum of the values of the individual bits that are set within that register. There are actually 24 registers that can be read with the SR command, the remaining 20 are 3421A status registers. These can be used to report what option assemblies are available in the 3421A, which channels are closed, the setting of the SRQ, XOR, and AND masks, etc. Refer to the blue pages at the end of the preceeding chapter.

Register	Bit Number							
	7	6	5	4	3	2	1	0
1 Status Register	Always 0	SRQ	Abnormal Condition	Low Battery	Event Occurred	Self Test Error	Power-on Reset	Data Ready
2 Error Register	*	Tried to load channel list with more than 30 channels	Channel list is empty but tried to execute a T3	Battery is low but tried to do TOT.MN, MH, ML	Wrong type of option for command	Invalid Syntax	No Data ready but Addressed to talk	Func. F0 asserted but triggered
3 Hardware Error	10 MΩ test failed	RAM Error	RAM Error	uP RAM Error	A/D Error	ROM 0 Error	ROM 1 Error	Cal. RAM Checksum Error
4 Cal Error	*	A/D Error	CAL RAM Bad	CAL attempted but not enabled	Invalid CAL Zero	Invalid CAL Signal	Invalid CAL Number	Invalid CAL Function or Range
Bit Value	128	64	32	16	8	4	2	1

* These bits are undefined and may be either a 1 or a 0.

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PWRDN
(POWER-DOWN)

Example

XEQ ALPHA PWRDN ALPHA

Comments

The Power-down command is used to put the 3421A and all other devices capable of power-down into their lowest, standby power condition. When the 3421A receives this command, it first stores its channel status in RAM before powering down. All multiplexer and actuator channels remain in the state they were in before the PWRDN command was received. All digital output ports are returned to a high impedance (switch opened) state. Also, the totalize mode is turned off.

The channel status information that is stored in RAM is used to remember which slots had 44462A multiplexer assemblies or 44465A Digital I/O assemblies. The status information also remembers which channels were actuators and which were multiplexers. During power-up, the 3421A will check to determine if any of this information has changed. If not, the 3421A will go to its turn on conditions. If something has changed, such as reconfiguring an actuator to a multiplexer channel, etc., the 3421A will go through its self test and reset state.

The 3421A will return to its full power-on state when there is any communication through the HP-IL interface. Refer to the PWRUP command for more information on power-up.

SPECIAL NOTE ON LOW BATTERY. Since the 3421A is a battery powered instrument, certain safeguards have been included to prolong the life of the battery. When the battery voltage drops below a predetermined point, the 3421A sets bits 6, 5, and 4 in the Status Byte (see INSTAT). The error indicator also lights up on the display. After approximately three minutes the 3421A will open all relays and power down. The Power-up (PWRUP) command will not cause the 3421A to power-up. The 3421A LINE switch must be cycled and the battery must be charged.

SPECIAL NOTE TO OPTION 040, 44464A BREADBOARD ASSEMBLY USERS. During power down, the breadboard assembly will lose all power supplies. Therefore, you may want to use latching relays if you need a relay closed during power-down.

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PWRUP
(POWER-UP)

Example

XEQ ALPHA PWRUP ALPHA

Comments

The PWRUP command is used to return all powered-down instruments to their full operating power conditions. Actually, the 3421A will return to normal operation when there is any communication through the HP-IL interface. When the 3421A powers-up, it first checks its status to see if any multiplexer boards were changed. If any changes have been made, the 3421A will go through its normal power-on reset and self test routine. If nothing has been changed, the 3421A remains in the same state that it was in prior to power-down. That is to say that all multiplexer or actuator relays that were closed prior to power-down will remain closed after power-up. Note that the power up command has no effect on instruments manually turned off.

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FINDID

Example

[ALPHA] HP3421A [ALPHA]

[XEQ] [ALPHA] FINDID [ALPHA]

Comments

The FINDID (**FIND IDentity**) command searches for a device with a specific identity and returns with the HP-IL address of that device. The device identity must be placed in the Alpha register of the calculator before FINDID is executed. The identity of the 3421A is: HP3421A. The address is returned to the X-register of the calculator.

In the AUTOIO mode the calculator searches the entire loop starting at the "selected" device. In the MANIO mode, the calculator checks only the "selected" device for the identity.

What happens if there are two or more 3421A's in the loop? If the interface is in the AUTOIO mode when FINDID is executed, the address of the first 3421A (starting with the selected device) is returned and the search ends. If we then "select" the device after the first 3421A (next address) and execute FINDID again. The calculator will return the address of the second 3421A. By selecting the device after the 3421A, we can find the address of the next 3421A.

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AUTOIO

Example

XEQ ALPHA AUTOIO ALPHA

Comments

The 82160A HP-IL interface module for the calculator controls the interface loop according to the module's operating mode—either Auto or Manual. The AUTOIO mode is the easiest to use with all HP-IL devices including the 3421A. This is especially true if you have a printer and/or cassette drive in the loop.

In the AUTOIO (**AUTO I/O**) mode, when you execute a printer or cassette drive operation, the interface automatically searches through the loop for the proper device to carry out the operation. Hence the name AUTOIO. For example, if you execute the PRA (PRint Alpha register) command when the 3421A is the selected device, the printer in the loop automatically performs the operation. In the Manual mode, the printer would have to be selected before the PRA command could be executed.

MANIO

Example

XEQ ALPHA MANIO ALPHA

Comments

The MANIO (**MAN**ual **I/O**) mode, means that device such as printers and cassette drives, must be "selected" before used. When MANIO is asserted, flag 32 is set in the 41C/CV calculator showing that the interface is in the MANIO mode.

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REMOTE

Example

XEQ ALPHA REMOTE ALPHA

Comments

The REMOTE command is used to cause the selected device to switch from local front panel control to remote program control. The remote mode of the 3421A is always asserted since it does not have a keyboard front panel. For this reason, it is not necessary to execute the REMOTE command if the 3421A is the only device in the loop. The 3421A ignores the REMOTE command.

LOCAL

Example

XEQ ALPHA LOCAL ALPHA

Comments

The LOCAL command is used to clear the selected device from the Remote mode and restore front panel operation. Since the 3421A does not have a front panel keyboard for control and must remain in the Remote mode, the LOCAL command is ignored.

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LISTEN

Example

XEQ ALPHA LISTEN ALPHA

Comments

The LISTEN command makes the selected device a dedicated listener, that is, the device is enabled to recieve information. A number must be placed into the X-register, representing the address of the selected device, prior to executing the LISTEN command. The address in the X-register should be between 1 and 30. However, if the number is 31 and the LISTEN command is executed, all devices in the loop are removed from the Listen mode.

This command allows more than one listener to be setup by executing the LISTEN command for each device. For example, suppose you have two 3421A's in the loop. You need them to trigger simultaneously. Individually, both instruments should be made listeners. When the TRIGGER command is executed, both voltmeters are triggered almost simultaneously. The time differential is the time required for the TRIGGER message to travel from one device to the next. The alternative is to select and trigger each voltmeter individually.

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SAMPLE APPLICATION PROGRAMS

Writing Programs

Earlier in this chapter we looked at a simple ac voltage measurement and developed a simple program for the 41C/CV calculator. That program illustrates the essentials of programming, namely: 1. a Label, 2. setting up the 3421A for the particular measurement(s), 3. triggering or executing the command, and 4. inputting the results. Of course, the program must also have an END statement. For more specific information on programming the 41C/CV, refer to the Owner's Handbook and Programming Guide.

Initialization

The following program locates the 3421A in the HP-IL loop (finds its address) and selects it to receive information. This is especially important if more than one device is in the loop. This program is used by the rest of the example programs in this chapter. The initialization program should be run before any other command or program is executed. This program need only be executed once unless an instrument is turned off or the loop is broken to remove or insert an instrument. The 82160A HP-IL Module should be inserted in the calculator before entering the program.

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SAMPLE APPLICATION PROGRAMS (Cont'd)

Initialization Program

Keystrokes	Comments	Display
PRGM		
■ GTO . .		
■ LBL ALPHA INI3421 ALPHA	INI3421 is the program name.	01 LBL INI3421
XEQ ALPHA AUTOIO ALPHA	Sets interface to AUTO mode.	02 AUTOIO
■ CF 17	Specifies normal end-of-line operation.	03 CF17
ALPHA HP3421A ALPHA	3421A identity.	04 HP3421A
XEQ ALPHA FINDID ALPHA	Searches for HP3421A.	05 FINDID
XEQ ALPHA SELECT ALPHA	Selects 3421A	06 SELECT
■ RTN	Returns to mainline program.	07 RTN
■ GTO . .		PACKING
PRGM		

The initialization program has now been entered. If you have not yet connected your 3421A into the loop, do so now. Remember to turn the calculator off before connecting any instrument to the loop. The initialization program will not be lost in the calculator with power turned off.

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SAMPLE APPLICATION PROGRAMS (Cont'd)

Running the Program

To run the initialization program, execute the following command:

[XEQ] [ALPHA] INI3421 [ALPHA]

The calculator will return with the HP-IL address of the 3421A. Now, let's go one step further and assign this program to the calculator **TAN** key. This will make execution easier in the future.

■ [ASN] [ALPHA] INI3421 [ALPHA] [TAN]

Now, when you want to execute the program, put the calculator in the USER mode and press the **TAN** key. The following is the -hp-Model 82153A Wand bar code for the initialization program.

```
01◆LBL "INI3421"
02 AUTOIO
03 CF 17
04 "HP3421A"
05 FINDID
06 SELECT
07 RTN
08 .END.
```

INITIALIZE

PROGRAM REGISTERS NEEDED: 5

ROW 1 (1 : 2)



ROW 2 (3 : 6)



ROW 3 (6 : 8)





[GTO] [.] [.]

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SAMPLE APPLICATION PROGRAMS (Cont'd)

3421A Front Panel

This 41C/CV program allows the calculator to serve as a remote front panel for the 3421A. The top two rows of keys and the shifted keys of the top row are defined by the program as the 15 main functions of the 3421A. The key assignments are shown in the keyboard overlay below. The functions are automatically assigned 41C/CV Local Labels A through J and a through e (shifted A through E). This is an excellent program when used to setup and test your system.

Operation of the program is simple. Load the program, either manually by the keyboard or using the -hp- 82153A Wand and Bar Code, and assign "FP" to the shifted R/S key. Make sure that all key assignments from the top two rows of keys are cleared. Put the calculator into the USER mode and press shift R/S to start the program. Remember to duplicate the keyboard overlay because many of the keys in the following examples are from the overlay.

Now if you want to make a DC Voltage measurement on channel 5, simply press: 5 [DCV]

To read the temperature on channel 9, press: 9 [TEM]

To write the value 32 to the digital I/O card in slot 1, press:

32 [ENTER↑] 1 [WRT RED]

To reset the 3421A, press: [R/S]

There are a few things to keep in mind when using this program. First, only one channel can be specified, no channel lists. Second, entries are only accepted while the 41C/CV is PAUSED. This means that the first key entry in the sequence may need to be held down until the calculator responds by displaying the key pressed. Other things to be aware of are:

1. Make certain that the INI3421 program is in the calculator.

2. Display format is fixed at ENG 5.

3. If "------" is displayed, it means no readings are available yet.

4. Repeated readings are made by the program on the channel specified. Flag 19 is used in the program to indicate repeated sending of the command and reading of data.

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SAMPLE APPLICATION PROGRAMS (Cont'd)

```
01*LBL "FP"
02 XEQ "INI3421"
03 INSTAT
04 CF 19
05 GTO 01
06*LBL A
07 "DCV"
08 XEQ "AX"
09 SF 19
10 GTO 02
11*LBL B
12 "TEM"
13 XEQ "AX"
14 SF 19
15 GTO 02
16*LBL C
17 "TWO"
18 XEQ "AX"
19 SF 19
20 GTO 02
21*LBL D
22 "FRQ"
23 XEQ "AX"
24 SF 19
25 GTO 02
26*LBL E
27 "RED"
28 XEQ "AX"
29 SF 19
30 GTO 02
31*LBL F
32 "CLS"
33 XEQ "AX"
34 CF 19
35 GTO 02
36*LBL G
37 "CLP"
38 XEQ "AX"
39 CF 19
40 GTO 02
41*LBL H
42 "OPN"
43 XEQ "AX"
44 CF 19
45 GTO 02
46*LBL I
47 "BIT"
48 XEQ "AX"
49 SF 19
50 GTO 02
51*LBL J
52 "RS"
53 OUTA
54 CF 19
55 GTO 02
56*LBL a
57 "ACV"
58 XEQ "AX"
59 SF 19
60 GTO 02
61*LBL b
62 "REF"
63 XEQ "AX"
64 SF 19
65 GTO 02
66*LBL c
67 "FWD"
68 XEQ "AX"
69 SF 19
70 GTO 02
71*LBL d
72 "TOT"
73 XEQ "AX"
74 CF 19
75 GTO 02
76*LBL e
77 "WRT"
78 XEQ "AY"
79 CF 19
80 GTO 02
81*LBL 01
82 " ------"
83 AVIEW
84 SF 28
85 SF 29
86*LBL 02
87 ENG 5
88 PSE
89 INSTAT
90 FS? 05
91 TONE 5
92 FC? 00
93 GTO 02
94 IND
95 VIEW X
96 FS? 19
97 TRIGGER
98 GTO 02
99*LBL "AX"
100 FIX 0
101 CF 28
102 CF 29
103 FS?C 22
104 ARCL X
105 OUTA
106 RTN
107*LBL "AY"
108 FIX 0
109 CF 28
110 CF 29
111 ARCL X
112 "+"
113 ARCL Y
114 OUTA
115 RTN
116 .END.
```

FRONT PANEL

PROGRAM REGISTERS NEEDED: 45

ROW 1 (1 : 2)

ROW 2 (2 : 7)

ROW 3 (7 : 12)

ROW 4 (12 : 17)

ROW 5 (17 : 21)

ROW 6 (22 : 26)

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ROW 7 (26 : 30)



ROW 8 (31 : 35)



ROW 9 (35 : 39)



ROW 10 (40 : 44)



ROW 11 (44 : 48)



ROW 12 (49 : 54)



ROW 13 (55 : 59)



ROW 14 (59 : 63)



ROW 15 (64 : 68)



ROW 16 (68 : 73)



ROW 17 (73 : 78)



ROW 18 (78 : 82)



ROW 19 (82 : 89)



ROW 20 (89 : 95)



ROW 21 (96 : 100)



ROW 22 (100 : 107)



ROW 23 (107 : 111)



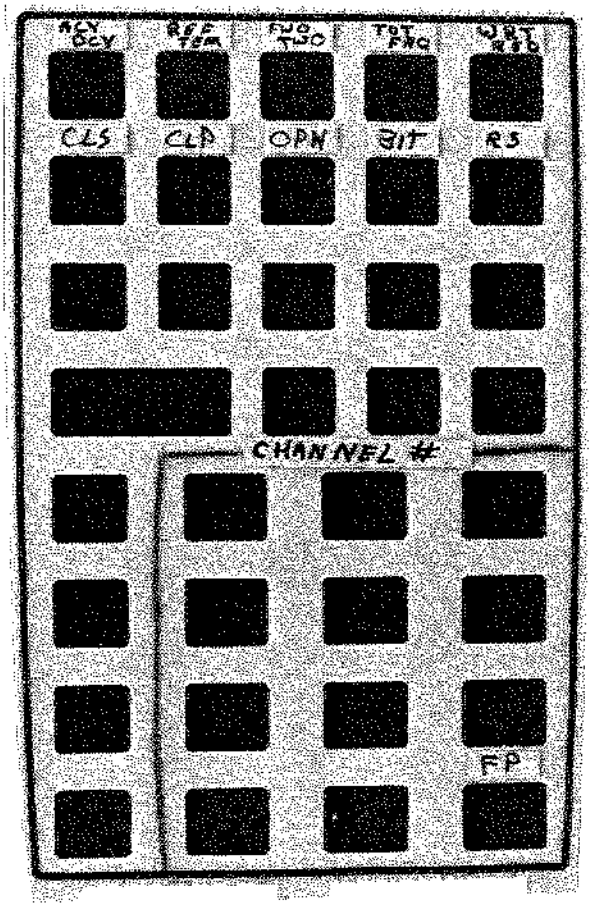
ROW 24 (112 : 116)





GTO

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Sample Programs

The following three examples illustrate program writing with the -hp- 41C/CV. They also demonstrate the flexibility and programming power of the 3421A and 41C/CV combination. All three programs use the Initialization Program to set up the 3421A. In addition to the program listings, bar codes are also provided for use with the -hp- 82153A Wand.

Remember that these programs, or any programs, can be assigned to individual keys in the calculator. Also, with simple modifications, the programs can be incorporated as subprograms into other mainline programs.

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TEMPERATURE MEASUREMENTS
(using a thermistor)

The thermistor temperature program computes the temperature, in degrees C, corresponding to the resistance of a thermistor. The program has been designed to work with thermistors exhibiting a 5.000 kOhm resistance at 25°C, such as a type 44007 (-hp- part number 0837-0164) or equivalent.

The program was written for a 2-wire resistance measurement on the specified channel. This will provide accurate results in most cases. For greater accuracy at high temperatures, a 4-wire resistance measurement should be made. Change line 06 to read: "FWO". This program is useful over a range of -80°C to +150°C.

The equation used to convert the measured resistance to a temperature is:

$$\text{Temperature} = \frac{1}{A + B(\text{LOG}(R)) + C(\text{LOG}(R))^3} - 273.15$$

where R is the measured resistance and A, B, and C are the conversion coefficients found in lines 24, 20, and 15, respectively. To use this program with a 2252 Ohm thermistor (25°C) change the coefficients to: 1.4709 E-3 (line 24), 2.3779 E-4 (line 20), and 1.0326 E-7 (line 15).

```
01*LBL "THERMIS"
02 XEQ "INI3421"
03 "CHANNEL ?"
04 PROMPT
05 FIX 0
06 "TWO"
07 "F"
08 ARCL X
09 OUTA
10*LBL "MEAS"
11 TRIGGER
12 IND
13 LN
14 STO 00
15 9.3244 E-6
16 RCL 00
17 3
18 Y↑X
19 *
20 2.361 E-4
21 RCL 00
22 *
23 +
24 1.2855 E-3
25 +
26 1/X
27 273.15
28 -
29 FIX 2
30 CLA
31 ARCL X
32 "+ DEG C"
33 AVIEW
34 GTO "MEAS"
35 .END.
```


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TEMPERATURE MEASUREMENTS (Cont'd)

THERMISTOR

PROGRAM REGISTERS NEEDED: 18

ROW 1 (1 : 2)



ROW 2 (2 : 3)



ROW 3 (3 : 7)



ROW 4 (8 : 11)



ROW 5 (11 : 15)



ROW 6 (15 : 20)



ROW 7 (21 : 25)



ROW 8 (26 : 31)



ROW 9 (32 : 34)



ROW 10 (34 : 35)





GTO . .

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TEMPERATURE MEASUREMENTS (using thermocouples)

There are two versions of the thermocouple temperature program. The first assumes that only type T thermocouples are used. Since the 3421A already has the conversion coefficients designed into it for type T thermocouples, this makes the programming task much easier.

The program is labeled TTEMP. It will prompt you for a channel number and then proceed to measure the thermocouple and display the temperature (in degrees C) on the calculator display.

The second version allows type J, E, K, R and S thermocouples. The program, THERMO, was written for J type thermocouples. If you will be using other types of thermocouples, the coefficients in lines 17, 19, 27, 29, 32, 35, 38, 41, 44, 47, 50, and 53 must be changed as per the table below.

Lines 11 through 23 provide the software compensation for the reference junction temperature. The equation for the compensation voltage is: V=P0+T*(P1+(T*P2)). In this equation, T is the measured reference temperature and V_c is the compensation voltage. This voltage is added to the measured thermocouple voltage V_t (line 23) to compensate for the reference junction. Lines 24 through 54 in the program convert this compensated voltage (V_c + V_t) to a temperature in degrees C. The equation used is a ninth order polynomial of the form:

Temperature = P0 + VP1 + V^2P2 + V^3P3 + ... + V^9P9.

Here, V is the compensated voltage and P0 through P9 are the conversion coefficients.

Thermocouple Type

Line Number	J	E	R	K	S
17	2.3E-8	4.5E-8	1.2E-8	1.6E-8	1.1E-8
19	5.053E-5	5.868E-5	5.334E-6	3.964E-5	5.442E-6
27	3.0840254E16	1.2777466E15	1.9280744E19	1.3828514E16	8.2663728E18
29	-5.3719255E15	-4.1055295E14	-2.9235505E18	3.3991028E15	-2.8874849E18
32	3.79243843E14	5.3981272E13	1.7414495E17	3.4782347E14	2.0689294E17
35	-1.38014121E13	-3.7221944E12	-5.4842602E15	-1.9109E13	6.79267949E15
38	2.7150838E11	1.4284958E11	1.01396299E12	6.0392855E11	1.2361123E14
41	2.831128E9	-2.9690242E9	-1.13982593E12	-1.0820624E10	-1.327040E12
44	1.821297E7	3.049432E7	7.787787E9	9.9661057E7	8.477335E9
47	-1.75117E5	2.05411E5	-3.27669E7	-3.82662E5	-3.26257E7
50	1.97509E4	1.61299E4	1.726456E5	2.48503E4	1.73545E5
53	-3.6E1	2.1E-1	-1.5E0	-5.1E-2	-1.4E0

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