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Agilent Technologies E1476A 64-Channel, 3-Wire Multiplexer Module User's Manual

Agilent Technologies

Manual Part Number: E1476-90005
Printed in U.S.A. E1100

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Edition 5
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Documentation History

All Editions and Updates of this manual and their creation date are listed below. The first Edition of the manual is Edition 1. The Edition number increments by 1 whenever the manual is revised. Updates, which are issued between Editions, contain replacement pages to correct or add additional information to the current Edition of the manual. Whenever a new Edition is created, it will contain all of the Update information for the previous Edition. Each new Edition or Update also includes a revised copy of this documentation history page.

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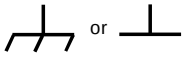
Safety Symbols



Instruction manual symbol affixed to product. Indicates that the user must refer to the manual for specific WARNING or CAUTION information to avoid personal injury or damage to the product.



Indicates the field wiring terminal that must be connected to earth ground before operating the equipment — protects against electrical shock in case of fault.



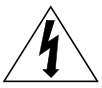
Frame or chassis ground terminal—typically connects to the equipment's metal frame.



Alternating current (AC)



Direct current (DC).



Warning. Risk of electrical shock.

WARNING Calls attention to a procedure, practice, or condition that could cause bodily injury or death.

CAUTION Calls attention to a procedure, practice, or condition that could possibly cause damage to equipment or permanent loss of data.

WARNINGS

The following general safety precautions must be observed during all phases of operation, service, and repair of this product. Failure to comply with these precautions or with specific warnings elsewhere in this manual violates safety standards of design, manufacture, and intended use of the product. Agilent Technologies assumes no liability for the customer's failure to comply with these requirements.

Ground the equipment: For Safety Class 1 equipment (equipment having a protective earth terminal), an uninterruptible safety earth ground must be provided from the mains power source to the product input wiring terminals or supplied power cable.

DO NOT operate the product in an explosive atmosphere or in the presence of flammable gases or fumes.

For continued protection against fire, replace the line fuse(s) only with fuse(s) of the same voltage and current rating and type. DO NOT use repaired fuses or short-circuited fuse holders.

Keep away from live circuits: Operating personnel must not remove equipment covers or shields. Procedures involving the removal of covers or shields are for use by service-trained personnel only. Under certain conditions, dangerous voltages may exist even with the equipment switched off. To avoid dangerous electrical shock, DO NOT perform procedures involving cover or shield removal unless you are qualified to do so.

DO NOT operate damaged equipment: Whenever it is possible that the safety protection features built into this product have been impaired, either through physical damage, excessive moisture, or any other reason, REMOVE POWER and do not use the product until safe operation can be verified by service-trained personnel. If necessary, return the product to Agilent for service and repair to ensure that safety features are maintained.

DO NOT service or adjust alone: Do not attempt internal service or adjustment unless another person, capable of rendering first aid and resuscitation, is present.

DO NOT substitute parts or modify equipment: Because of the danger of introducing additional hazards, do not install substitute parts or perform any unauthorized modification to the product. Return the product to Agilent for service and repair to ensure that safety features are maintained.

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Manufacturer's Name: Agilent Technologies, Inc.
Manufacturer's Address: *Measurement Products Unit*
815 14th Street S.W.
Loveland, CO 80537 USA

Declares, that the product

Product Name: 64-Channel, 3-Wire Multiplexer Module
Model Number: E1476A
Product Options: *This declaration includes all options of the above product(s).*

Conforms with the following European Directives:

The product herewith complies with the requirements of the Low Voltage Directive 73/23/EEC and the EMC Directive 89/336/EEC and carries the CE Marking accordingly.

Conforms with the following product standards:

	Standard	**Limit**
EMC	*IEC 61326-1:1997 + A1:1998 / EN 61326-1:1997 + A1:1998*	
	CISPR 11:1997 + A1:1997 / EN 55011-1991	*Group 1, Class A [1]*
	IEC 61000-4-2:1995+A1998 / EN 61000-4-2:1995	*4 kV CD, 8 kV AD*
	IEC 61000-4-3:1995 / EN 61000-4-3:1995	*3 V/m, 80-1000 MHz*
	IEC 61000-4-4:1995 / EN 61000-4-4:1995	*0.5 kV signal lines, 1 kV power lines*
	IEC 61000-4-5:1995 / EN 61000-4-5:1995	*0.5 kV line-line, 1 kV line-ground*
	IEC 61000-4-6:1996 / EN 61000-4-6:1996	*3 V, 0.15-80 MHz*
	IEC 61000-4-11:1994 / EN 61000-4-11:1994	*1 cycle, 100%*
	Canada: ICES-001:1998	
	Australia/New Zealand: AS/NZS 2064.1	
Safety	*IEC 61010-1:1990+A1:1992+A2:1995 / EN 61010-1:1993+A2:1995*	
	Canada: CSA C22.2 No. 1010.1:1992	
	UL 3111-1	

Supplemental Information:

[1] The product was tested in a typical configuration with Agilent Technologies test systems.

September 5, 2000
Date

Jim White
Name

Quality Manager
Title

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Chapter 1
Getting Started

Using This Chapter

This chapter gives guidelines to get started using the E1476A 64-Channel, 3-Wire Multiplexer module (multiplexer), including:

- Multiplexer Description 11
- Configuring the Multiplexer Module 15
- Configuring the Terminal Module 19
- Configuring the E1586A Rack Mount Terminal Panel. 26
- Programming the Multiplexer 31

Multiplexer Description

The E1476A 64-Channel, 3-Wire Multiplexer module is a VXIbus C-size register-based slave device. The multiplexer can operate in a C-size VXIbus mainframe or a VMEbus mainframe.

The multiplexer “instrument” is the firmware running in the Command Module (E1406, for example). This firmware is the instrument driver providing Standard Commands for Programmable Instruments (SCPI) programming capability. The term “switchbox” is used to refer to an “instrument” made up of one or more switch modules.

Programming the E1476A can be via a command module using SCPI commands, through an embedded controller using Compiled SCPI (C-SCPI), or Standard Instrument Control Language (SICL) or via direct register access (see Appendix B).

Reed relays are used for each channel and tree relay. Maximum voltage is 120VDC/RMS or 170V peak. Maximum current is 35 mA (non-inductive). Thermal offset is <4 µV per channel (<2 mV using maximum integration time with 10 samples averaged).

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Multiplexer Block Diagram

Figure 1-1 shows a simplified block diagram of the E1476A multiplexer with typical connections to external multimeters.

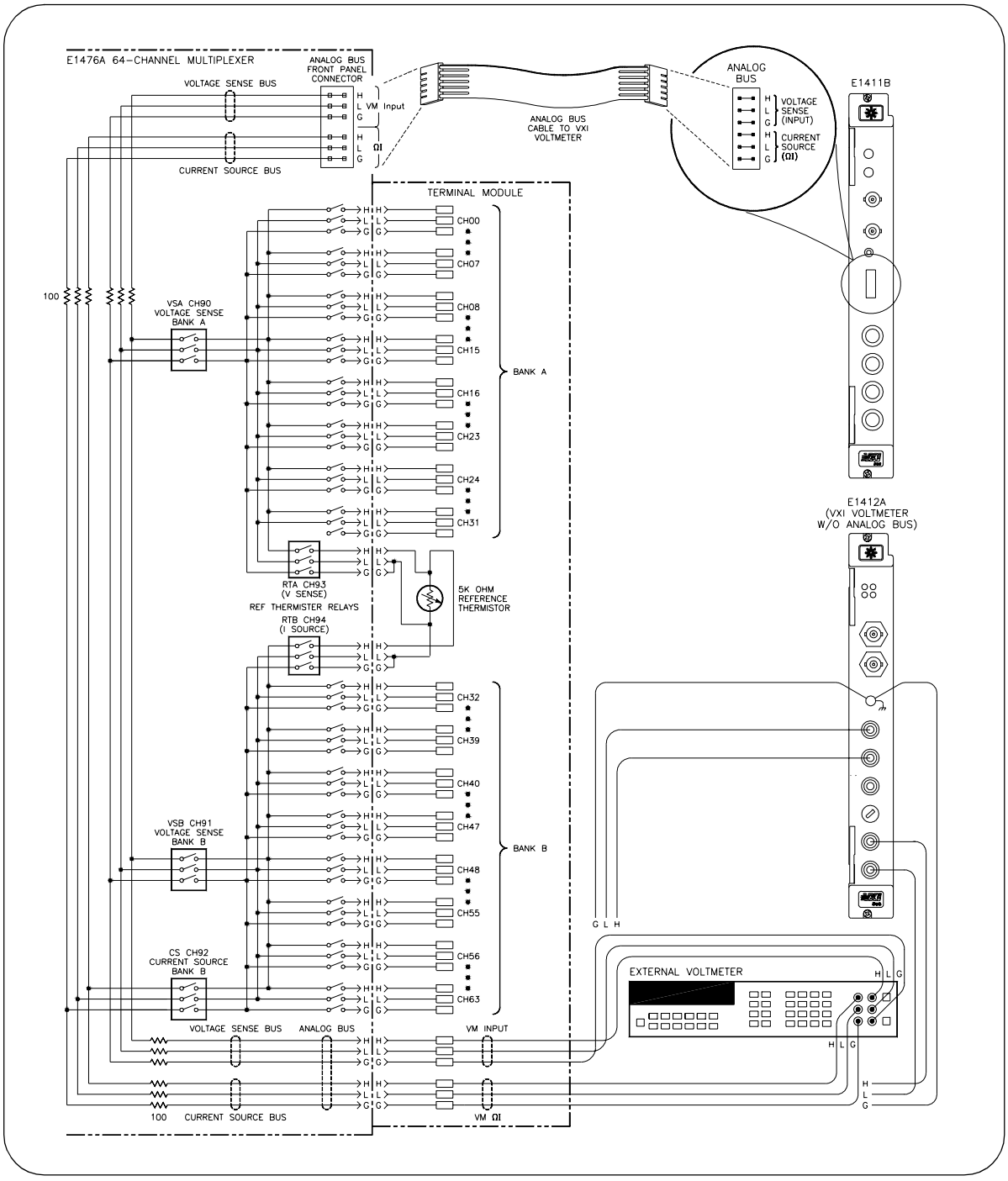


Figure 1-1. E1476A Simplified Block Diagram

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Multiplexer Front Panel

The E1476A multiplexer consists of a switch module and a terminal module. User inputs are connected to the multiplexer H, L, and G terminal connections on the terminal module. Figure 1-2 shows the multiplexer front panel and pin-out descriptions.

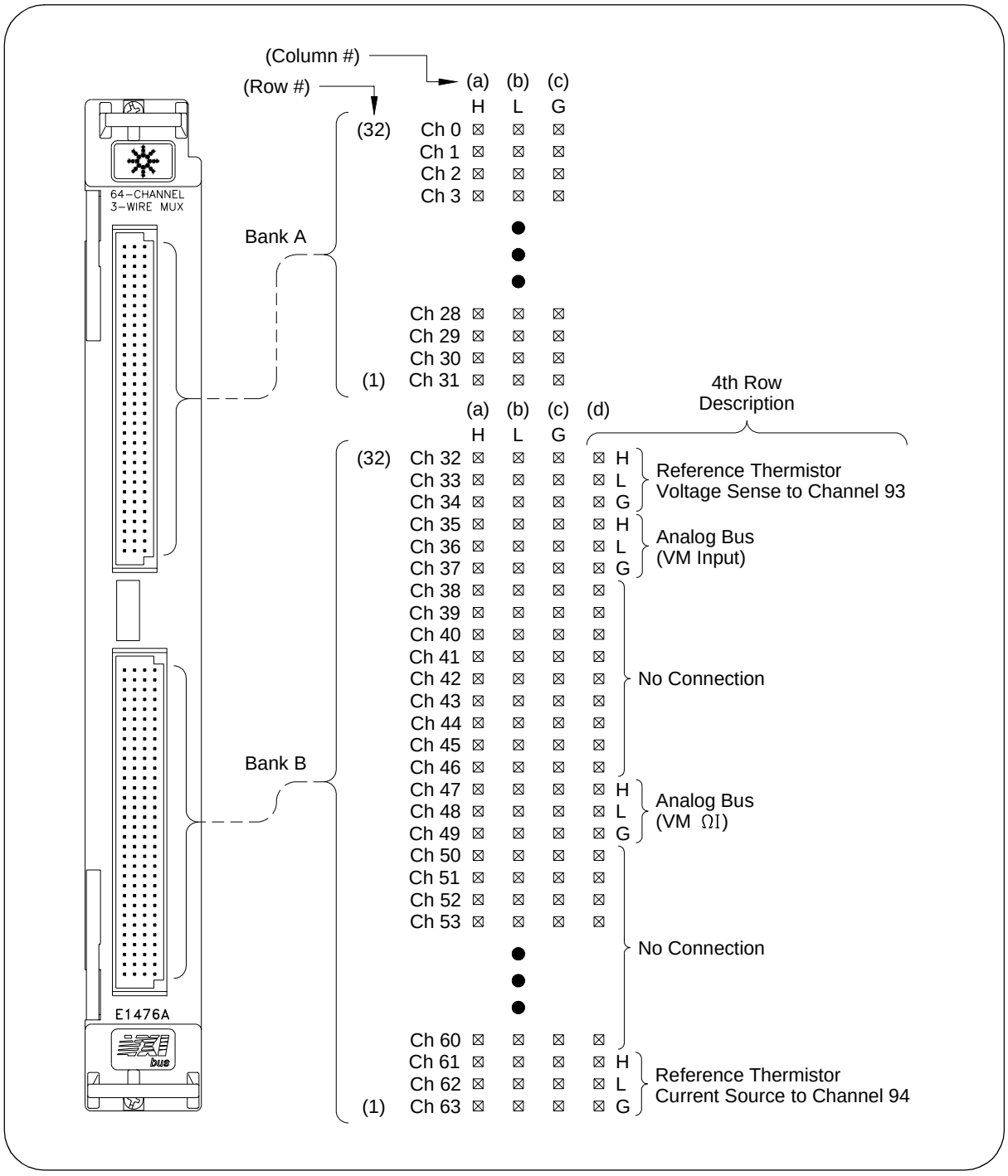


Figure 1-2. E1476A Multiplexer Front Panel and Pinouts

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Multiplexer Configurations

The E1476A multiplexer can be configured as a **switchbox** (single-module or multiple-module) or as a **scanning voltmeter** with the E1411B or E1326B 5-Digit Multimeter.

Switchbox

A switchbox configuration uses the "SWITCH" instrument driver and uses the commands in Chapter 4. For a single-module switchbox, the channel address (*channel_list*) has the form (@*nn*), where *nn* = channel number.

For a multiple-module switchbox, the channel address (*channel_list*) has the form (@*ccnn*) where *cc* = card number and *nn* = channel number. See Chapter 2 for switchbox applications. See Figure 1-3 for a typical multiple-module switchbox configuration.

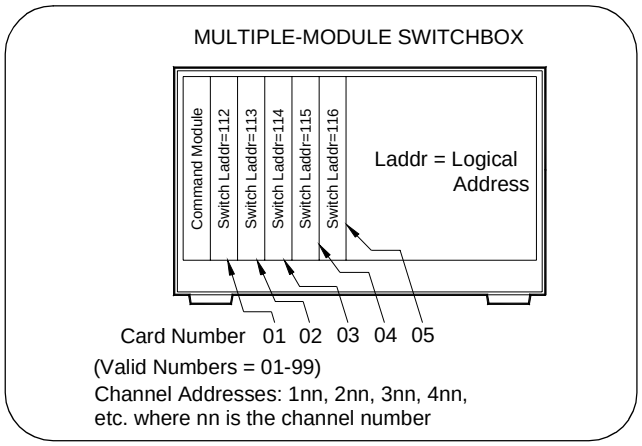


Figure 1-3. Typical Multiple-Module Switchbox

Scanning Voltmeter

A scanning voltmeter configuration uses the voltmeter instrument driver “VOLTMTR”. The scanning voltmeter commands are different from the switchbox commands listed in Chapter 4. A scanning voltmeter uses the commands in the *E1326B/E1411B 5-Digit Multimeter User’s Manual* to control the switches and make measurements. See Chapter 3 for scanning voltmeter applications. See Figure 1-4 for a typical scanning voltmeter configuration.

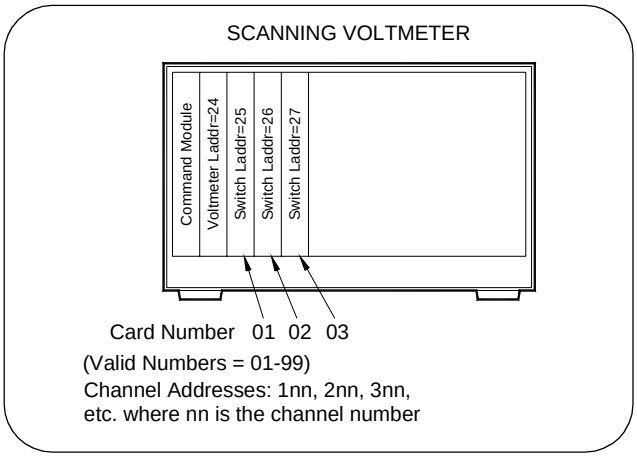


Figure 1-4. Typical Scanning Voltmeter

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Configuring the Multiplexer

This section gives guidelines to configure the switch module. See "Configuring the Terminal Modules" for guidelines to configure the terminal modules and to connect the E1586A Rack Mount Terminal Panel. This section includes:

- Warnings and Cautions
- Setting the Logical Address Switch
- Setting the Interrupt Priority
- Installing the Multiplexer in a Mainframe
- Connecting the Analog Bus

Warnings and Cautions



WARNING **SHOCK HAZARD. Only qualified, service-trained personnel who are aware of the hazards involved should install, configure, or remove the multiplexer module. Disconnect all power sources from the mainframe, the terminal modules, and installed modules before installing or removing a module.**



WARNING **When handling user wiring connected to a terminal module, consider the highest voltage present accessible on any terminal. Use only wire with an insulation rating greater than the highest voltage which will be present on the terminal module. Do not touch any circuit element connected to the terminal module if any other connector to the terminal module is energized to more than 30 VAC rms or 60 VDC.**



CAUTION **MAXIMUM VOLTAGE/CURRENT.** Maximum allowable voltage per channel, terminal-to-terminal or terminal-to-chassis for the multiplexer is 120 Vdc or 120 Vac rms (170 Vac peak). Maximum current per channel is 35 mA (non-inductive). Maximum transient voltage is 1300 V peak. Exceeding any limit may damage the Multiplexer Module.



CAUTION **WIRING THE TERMINAL MODULE.** When wiring to the terminal connectors on the E1476A terminal module, do not exceed a 5 mm strip back of insulation to prevent the possibility of shorting to other wiring on adjacent terminals.

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CAUTION

STATIC ELECTRICITY. Static electricity is a major cause of component failure. To prevent damage to the electrical components in the multiplexer, observe anti-static techniques whenever removing, configuring, and installing a module. The multiplexer is susceptible to static discharges. Do not install the multiplexer module without its metal shield attached.

Setting the Logical Address Switch

The logical address for the E1476A multiplexer is set with the Logical Address Switch on the module. The logical address switch factory setting for the E1476A is 112. Valid addresses are from 1 to 254 for static configuration (the address you set on the switch) and address 255 for dynamic configuration.

The E1476A supports dynamic configuration of the address. This means the address is set programmatically by the resource manager when it encounters a module with address 255 that supports dynamic configuration. See Figure 1-5 for switch position information.

NOTE *When using the E1406 Command Module, the address switch value must be a multiple of 8 if the module is the first module in a switchbox used with a VXIbus command module using SCPI commands. When in the scanning voltmeter configuration, the address switch value must be sequential to the voltmeter address.*

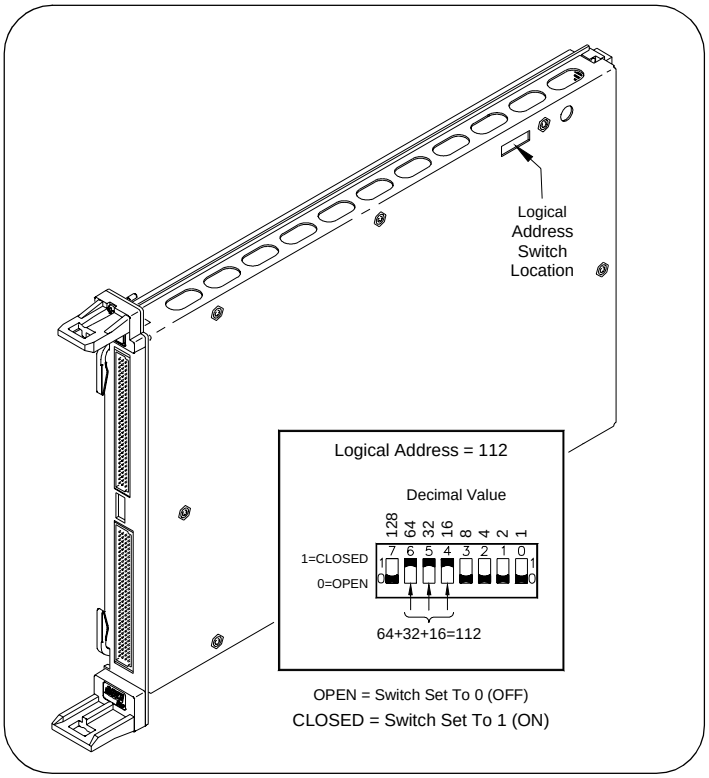


Figure 1-5. Setting the Logical Address Switch

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Setting the Interrupt Priority

For most applications, the interrupt priority level should not need to be changed. Interrupts are enabled at power-up, after a SYSRESET or after resetting the module via the Control Register. An interrupt is generated after any relay Control Register is accessed when interrupts are enabled. The interrupt is generated approximately 1.3ms after one of the registers is accessed.

The Interrupt Request Level switch selects the priority level to be asserted. The Interrupt Request Level switch is set in position 1 when shipped from the factory. The interrupts are disabled when set to level 0. Be careful when deciding to disable the interrupts, as both the "VOLTMTR" and "SWITCH" drivers require that interrupts be enabled.

To change the setting, rotate the switch so the arrow points to the interrupt priority level desired. Interrupts can also be disabled using the E1476A Status/Control Register. See Figure 1-6 for the Interrupt Request Level switch.

NOTE *Some mainframes may require that backplane jumpers be set correctly for each slot used. See the appropriate mainframe manual for details.*

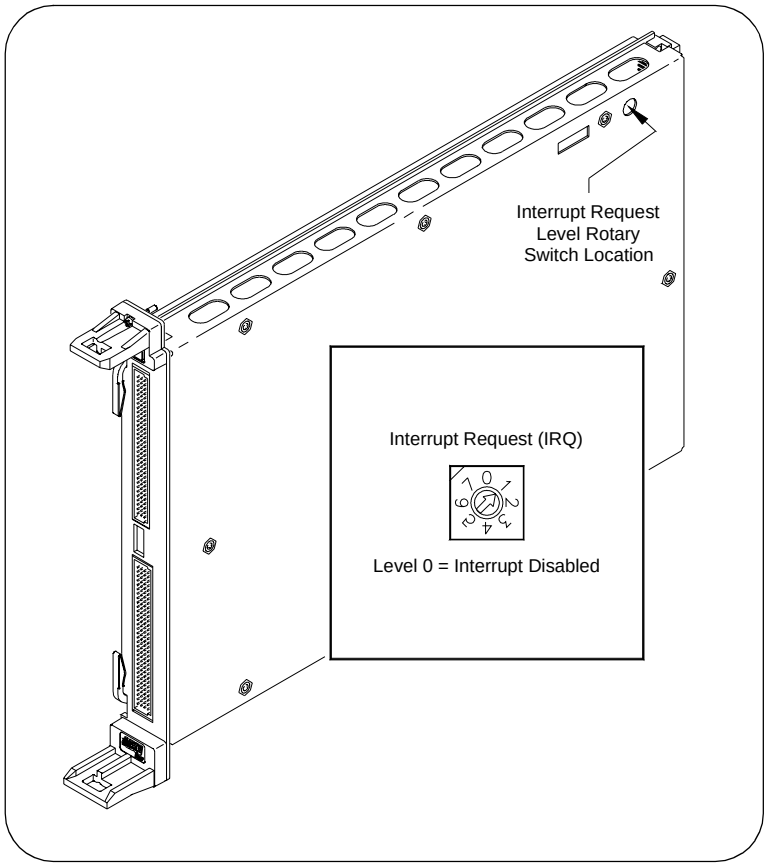


Figure 1-6. Setting Interrupt Request (IRQ) Priority

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Installing the Multiplexer in a Mainframe

The E1476A can be installed in any slot (except slot 0) in a C-Size VXIbus mainframe. See Figure 1-7 for steps to install the multiplexer in a mainframe.

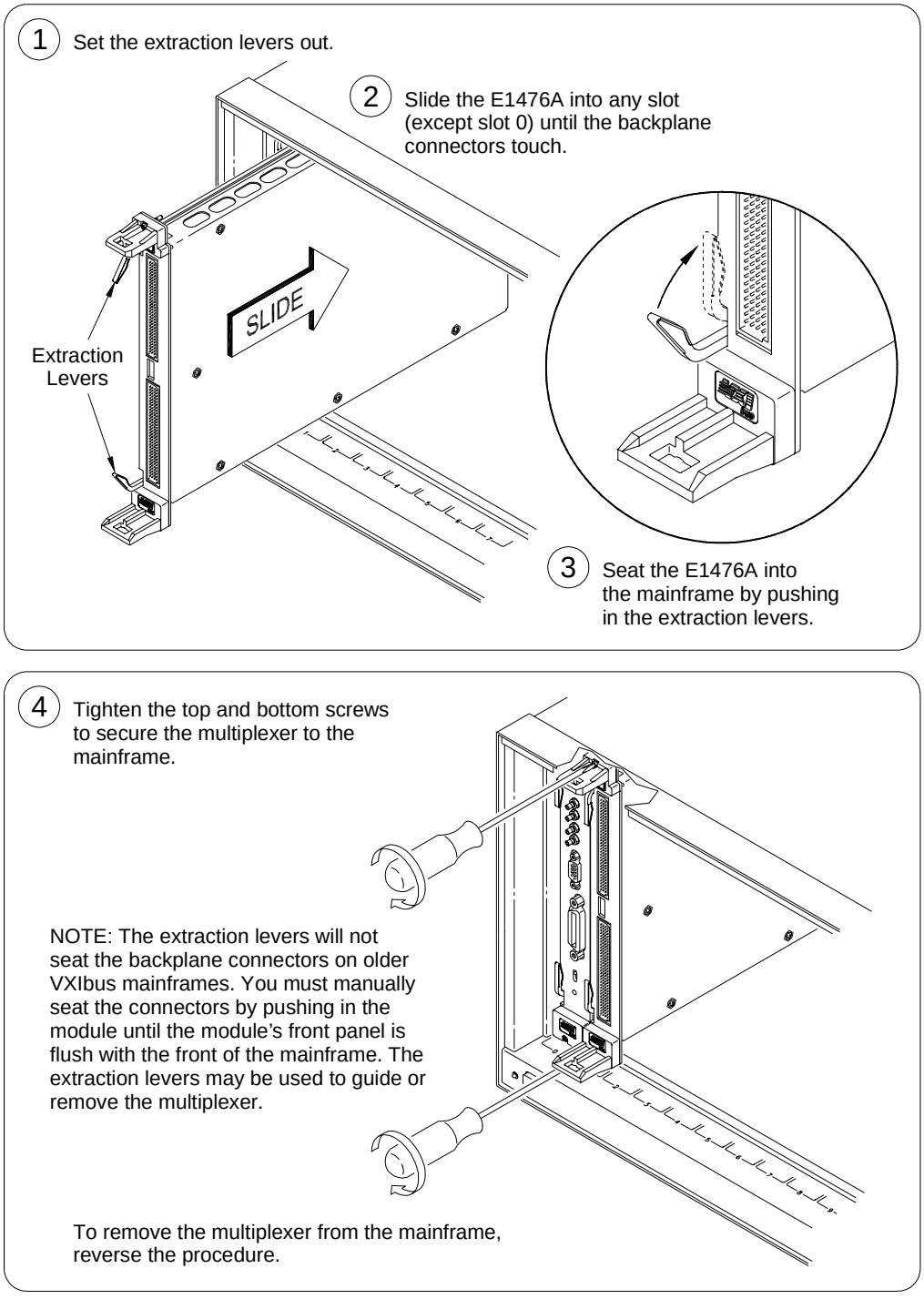


Figure 1-7. Installing the Multiplexer Module in a VXIbus Mainframe

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Configuring the Terminal Module

This section gives guidelines to configure the terminal module, including:

- Terminal Module Descriptions
- Wiring Terminal Modules
- Attaching a Terminal Module to the Multiplexer
- Connecting the Analog Bus

Terminal Module Descriptions

The E1476A 64-Channel, 3-Wire Multiplexer module consists of a multiplexer switch card and a spring clamp type terminal module. The screwless terminals use a spring clamp terminal for connecting solid or stranded wire. Connection is made with a push of a three-pronged insertion tool (part number 8710-2127) that is shipped with the multiplexer.

If the spring clamp type terminal module is not desired, a crimp-and-insert terminal module (Option A3E) and an interface to rack mount terminal panel (Option A3F) are available. See "Configuring the E1586A Rack Mount Terminal Panel" for details on using Option A3F.

Standard Terminal Module

Figure 1-8 shows the E1476A spring clamp standard terminal module connectors and associated channel numbers. See "Multiplexer Front Panel" for the connector pin-outs that mate to to terminal module.

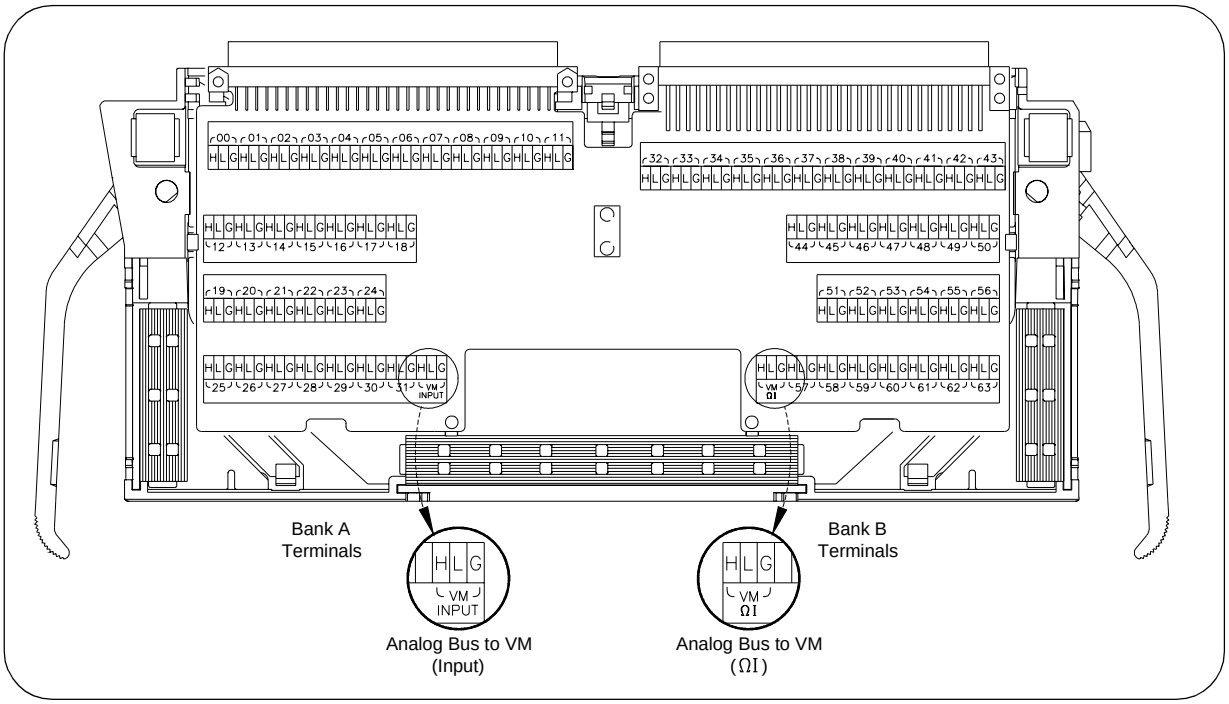


Figure 1-8. E1476A Standard Terminal Module

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Terminal Module Option A3E

Terminal module Option A3E (see Figure 1-9) provides a crimp-and-insert terminal module that allows you to crimp connectors onto wires which are then inserted directly into the multiplexer's mating connector. See the pin-out diagram (Figure 1-2) to make the connections. Table 1-1 shows the accessories that can be used with crimp-and-insert Option A3E.

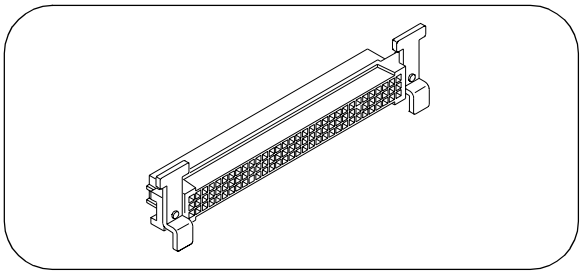
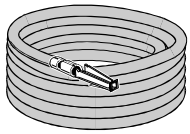
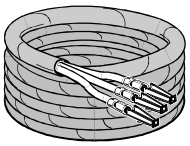
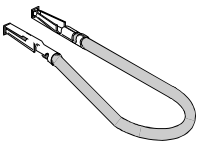
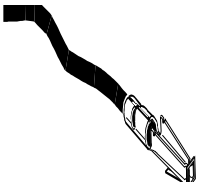


Figure 1-9. Option A3E Crimp-and-Insert Connector

Table 1-1. Option A3E Terminal Module Accessories

Accessory	Description	Picture	Specifications
Single-Conductor and Contact	A crimp-and-insert contact is crimped onto one end of a wire. The other end is not terminated. Order 91510A.		Length: 2 meters Wire Gauge: 24 AWG Quantity: 50 each Insulation Rating: 105°C max Voltage: 300 V
Shielded-Twisted-Pair and Contacts	A crimp-and-insert contact is crimped onto each conductor at one end of a shielded-twisted-pair cable. The other end is not terminated. Order 91511A.		Length: 2 meters Wire Gauge: 24 AWG Outside Diameter: 0.1 inches Quantity: 25 each Insulation Rating: 250°C max Voltage: 600 V
Jumper Wire and Contacts	A crimp-and-insert contact is crimped onto each end of a single conductor jumper wire. This jumper is typically used to tie two pins together in a single crimp-and-insert connector. Order 91512A.		Length: 10 cm Wire Gauge: 24 AWG Quantity: 10 each Insulation Rating: 105°C max Voltage: 300 V
Crimp-and-Insert Contacts	These contacts may be crimped onto a conductor and then inserted into a crimp-and-insert connector. The crimp tool kit is required to crimp the contacts onto a conductor and remove the contact from the connector. Order 91515A.		Wire Gauge Range: 20-26 AWG Quantity: 250 each Plating: Gold Plated Contact Maximum Current: 2A at 70°C
Crimp-and-Insert Tools	The hand crimp tool (part number 91518A) is used for crimping contacts onto a conductor. The pin extractor tool (part number 91519A) is required for removing contacts from the crimp-and-insert connector. *These products are not included with Option A3E or with the terminal option accessories listed earlier.*		
Extra Crimp-and-Insert Connectors	The crimp-and-insert connector is normally supplied with Option A3E. Contact Agilent if additional connectors are needed. Order 91484B.		

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Wiring a Terminal Module

Figure 1-10 gives guidelines to connect user (field) wiring to the spring clamp and to the crimp-and-insert terminal modules.

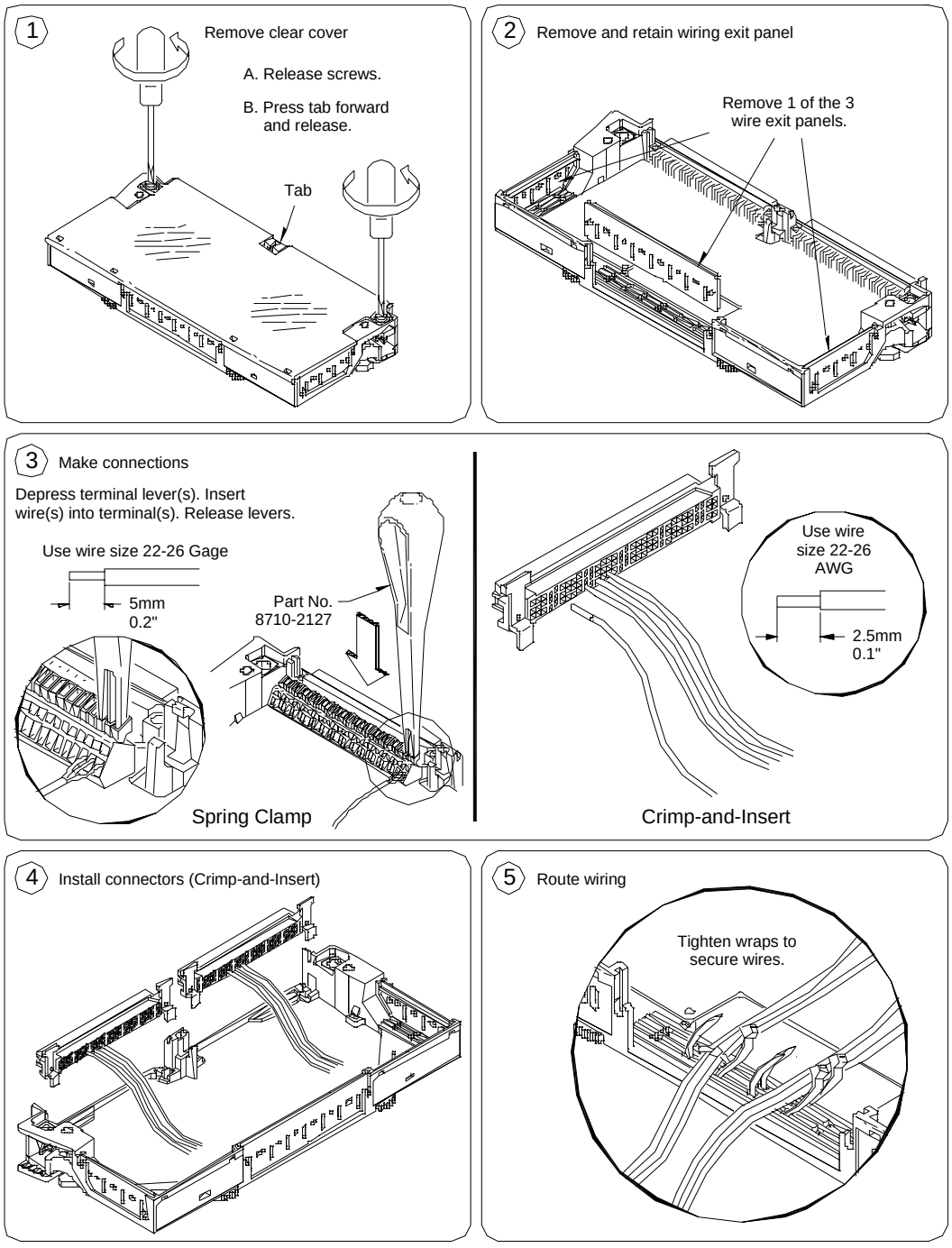


Figure 1-10. Steps to Connect User Wiring to a Terminal Module (cont'd on next page)

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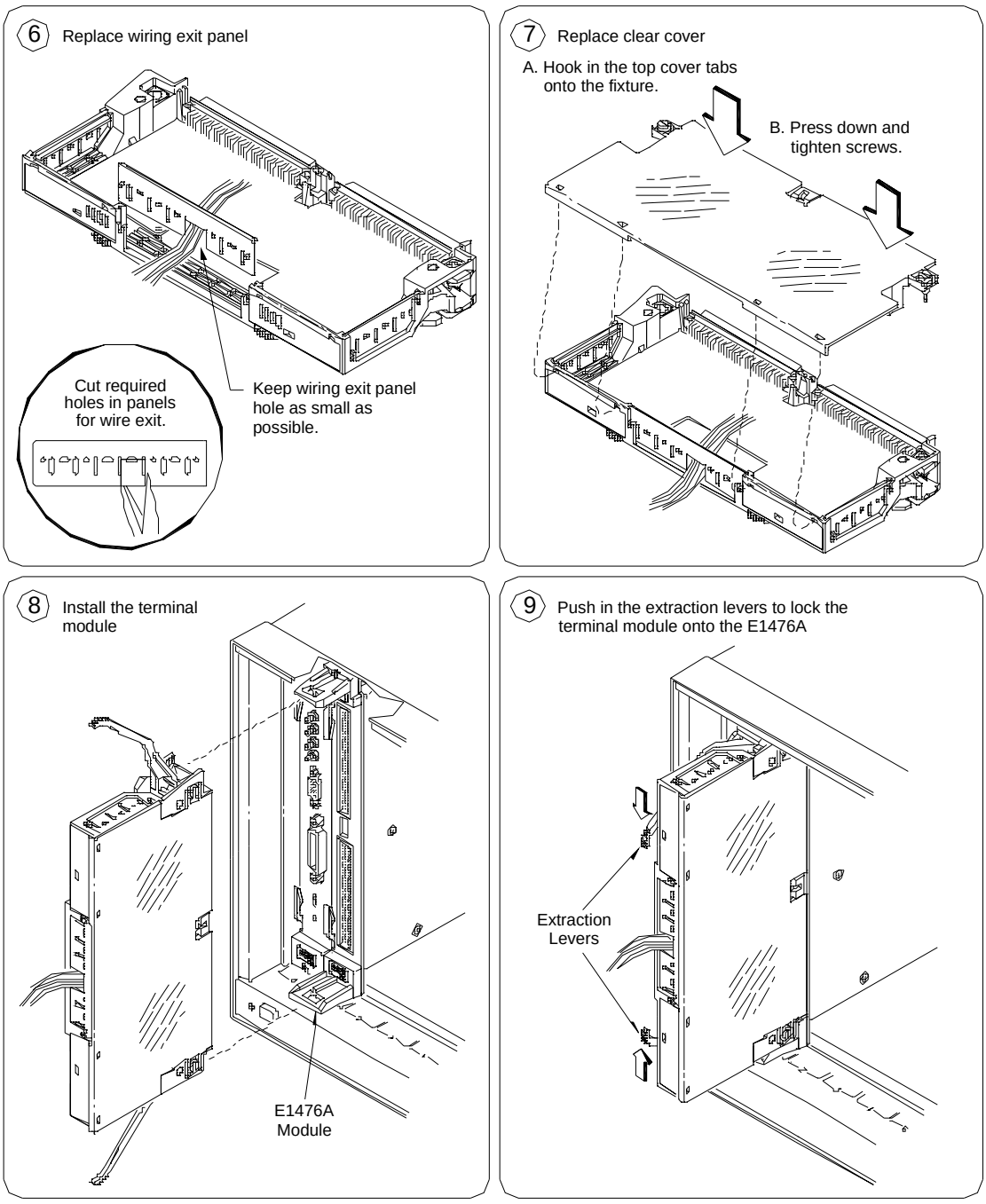


Figure 1-10. Steps to Connect User Wiring to a Terminal Module (cont'd)

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Attaching a Terminal Module to the Multiplexer

Figure 1-11 gives guidelines to attach a terminal module to the multiplexer.

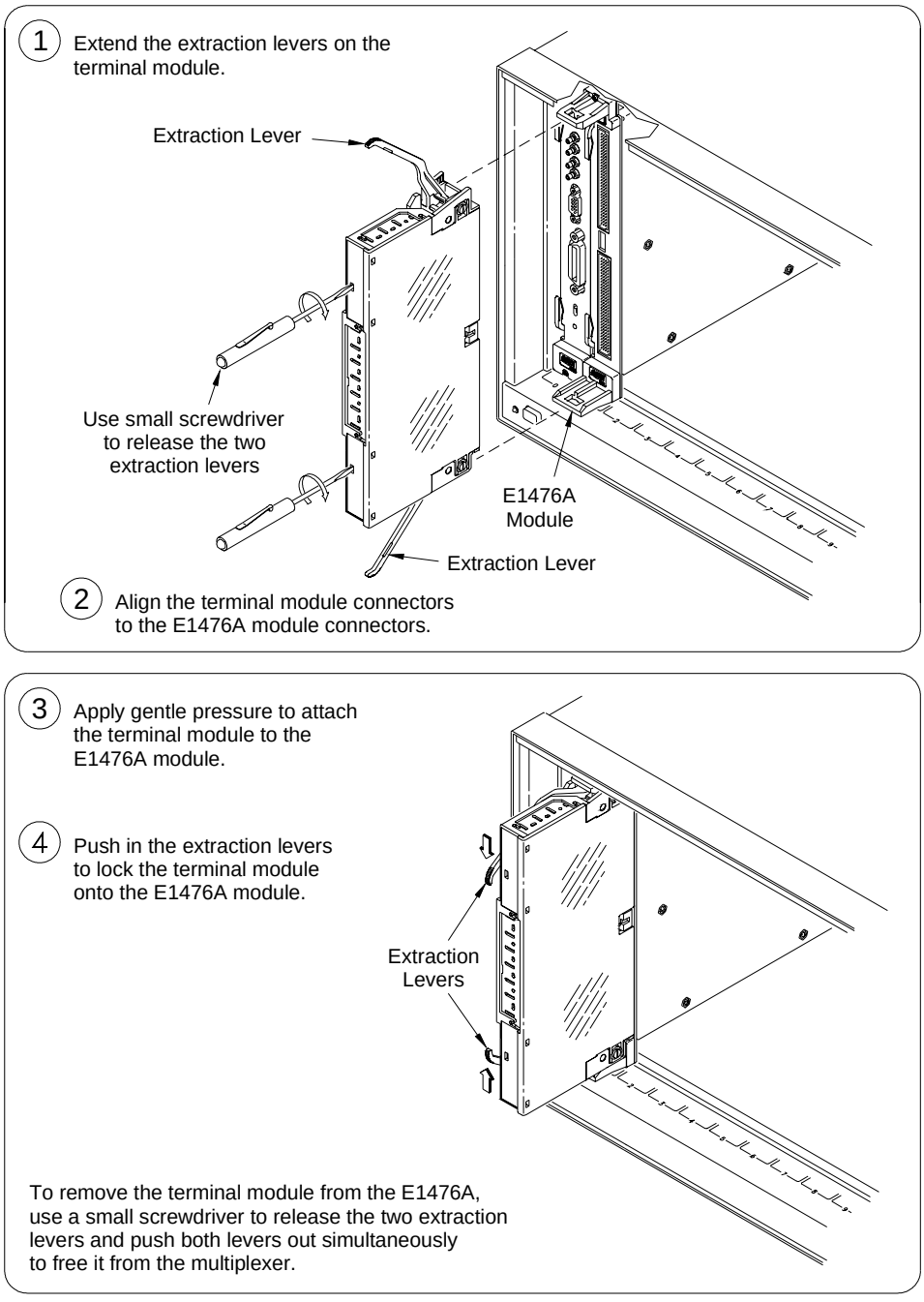


Figure 1-11. Steps to Attach a Terminal Module to the Multiplexer

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Connecting the Analog Bus

The analog bus provides a common bus to all switch modules in a switchbox or scanning voltmeter to which a single voltmeter can be connected. You must connect the flat ribbon analog bus cables between multiplexers and other VXI modules that have an analog bus (both C-size modules or B-size modules in a C-size adapter).

Connecting to a Multimeter

E1411B 5-Digit Multimeter users (and E1326B in a C-size adapter) must continue the analog bus connection between multiplexers and switch modules to the multimeter to use the scanning and measurement capability of the multimeter. These cables provide the input to the multimeter from the multiplexer/switch channels. See Figure 1-12 for connection details.

NOTE *Use the 19.5 inch analog bus cable (part number E1326-61611) for analog bus connection between an E1326B and the E1476A.*

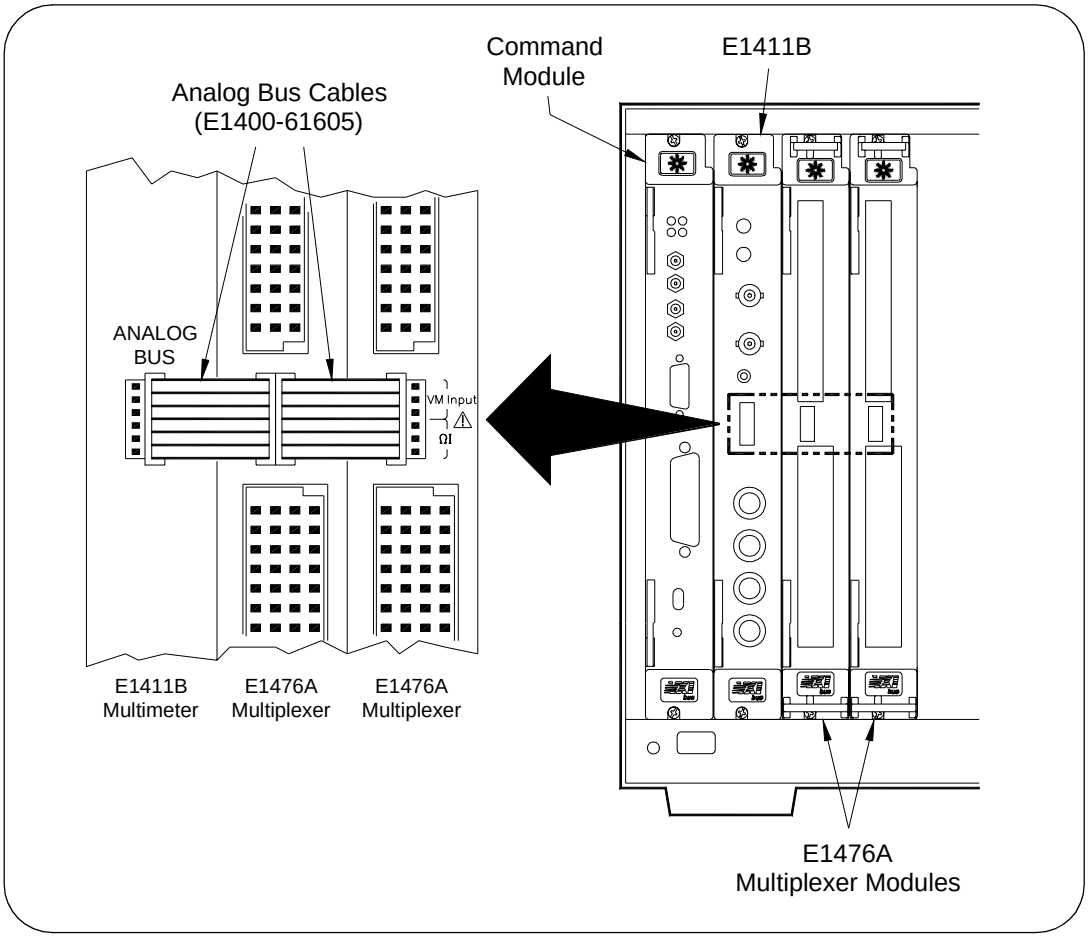


Figure 1-12. E1411B Connections to the Analog Bus

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Connecting to an External Measurement Device

An external measurement device can be connected to the analog bus by using the terminal module's “VM Input” and “VM ΩI” terminals. See Figure 1-13 for connection information.

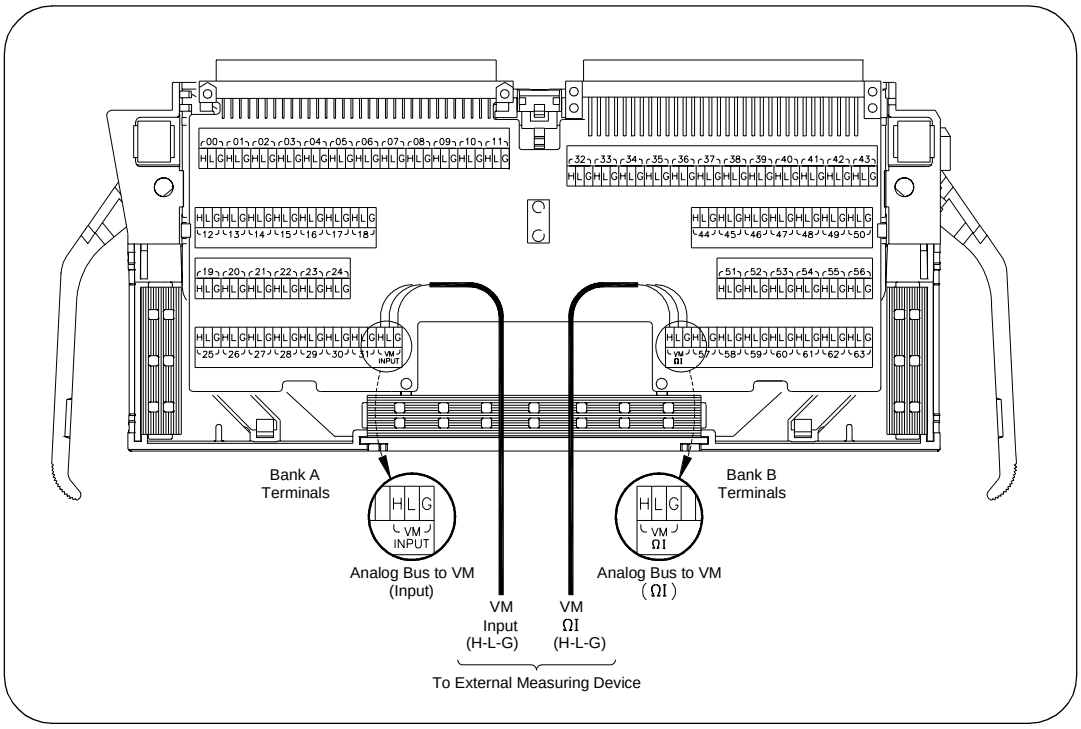


Figure 1-13. Externally Connecting to the Analog Bus

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Configuring the E1586A Rack Mount Terminal Panel

This section gives guidelines to connect and configure the E1586A Rack Mount Terminal Panel (Terminal Panel), including:

- Connecting the Terminal Panel
- Configuring the Terminal Panel

Connecting the Terminal Panel

The E1586A Rack Mount Terminal Panel provides extended connections to the E1476A multiplexer module. The Terminal Panel is recommended if the E1476A is located some distance from the measurement connections. The Terminal Panel provides up to 32 (3-wire) connections to allow 32 channel connections to the E1476A multiplexer module via the Option A3F terminal module. See Figure 1-14 for connection details.

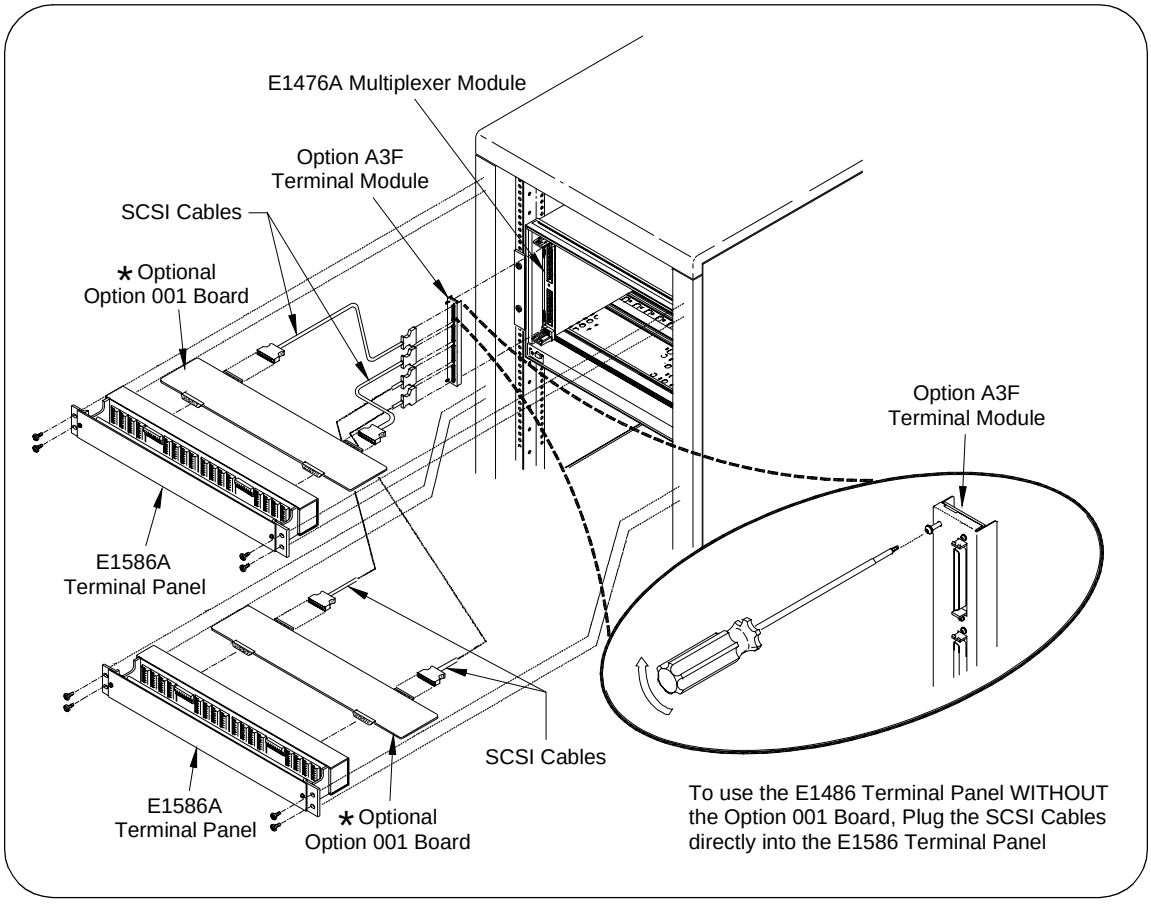


Figure 1-14. Connecting the E1586A Rack Mount Terminal Panel

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Option A3F Terminal Module

As shown in Figure 1-14, E1476A Terminal Module Option A3F allows an E1476A multiplexer module to be connected to an E1586A Rack Mount Terminal Panel. This option provides four SCSI plugs on a terminal module to enable connection to a rack-mount terminal panel using four terminal modules. See Figure 1-15 for the front panel view and connector pinouts of the Option A3F Terminal Module.

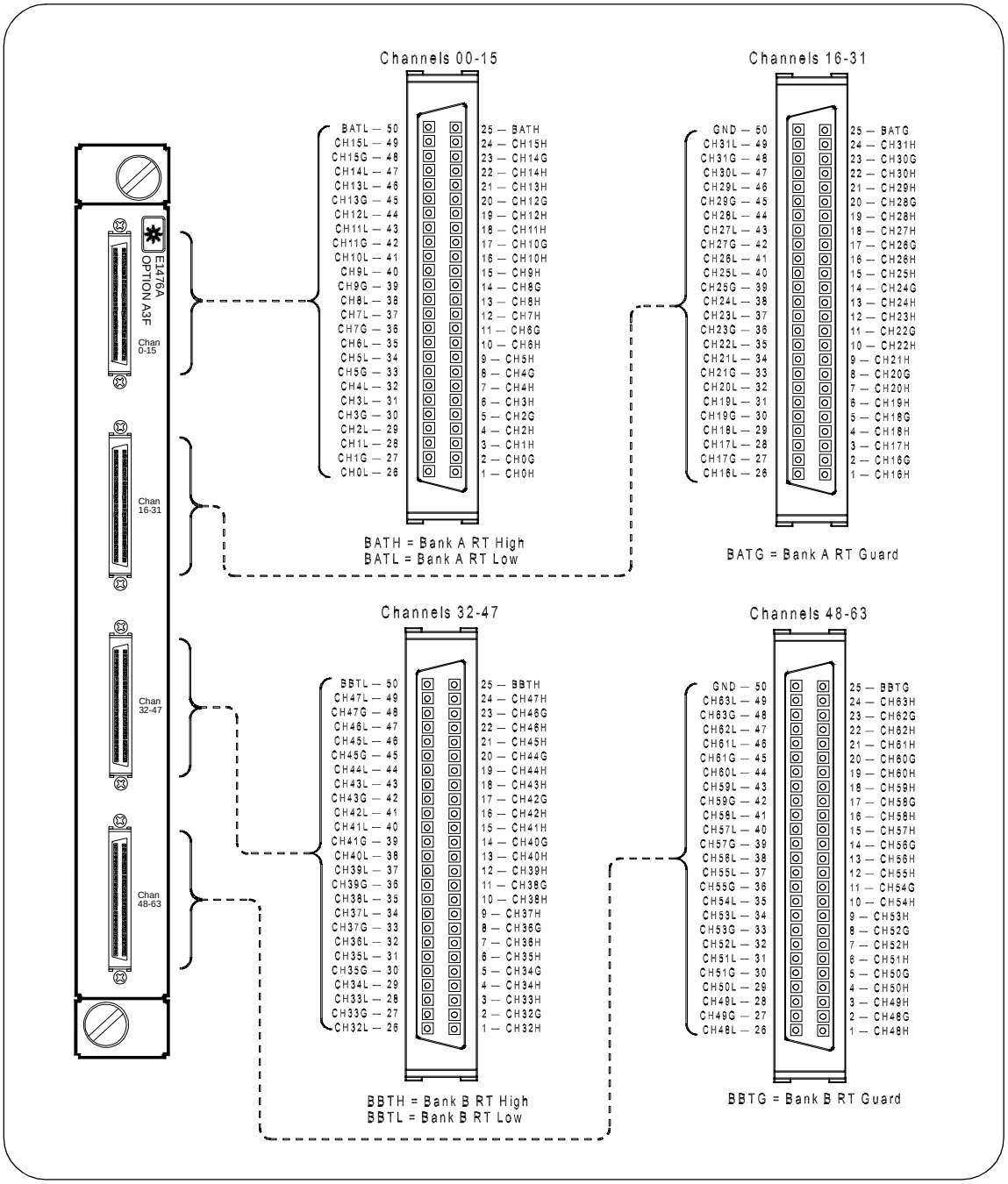


Figure 1-15. Terminal Module Option A3F Pinouts

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Terminal Panel Cables

There are two different SCSI cables available for connecting the E1586A Rack Mount Terminal Panel to the E1476A Option A3F Terminal Module. In both cases, four cables are required if all 64 channels are needed. This also requires two E1586A Rack Mount Terminal Panels since a single terminal panel only connects 32 channels. *The cables do not come with the E1476A Option A3F and must be ordered separately.* The cables are:

- **Standard Cable.** This cable (E1588A) is a 16-channel twisted pair cable with an outer shield and is suitable for relatively short cable runs.
- **Custom Length Cable.** This cable (Z2220A Option 050) is available in custom lengths. It is a 16-channel twisted pair cable with each twisted pair individually shielded to provide better quality shielding for longer cable runs.

HF Common Mode Filters

Optional high frequency common mode filters are available for the E1586A Rack Mount Terminal Panel input channels. These filters filter AC common mode signals in the cable that connects the terminal panel and the device under test. These filters are useful for filtering small common mode signals below 5Vp-p. To order these filters, order E1586A Option 001.

Connecting the Terminal Panel

The E1586A Terminal Panel can be mounted in a standard size instrument rack. To minimize temperature gradients across the panel, the panel should be mounted in the rack such that it is away from the other heat sources. The bottom of the rack is usually the preferred location.

Take particular care to minimize the temperature differences across the horizontal width of the Terminal Panel, since it is most susceptible to horizontal temperature gradients across its longest dimension. See Figure 1-13 for guidelines to connect the E1586A Terminal Panel to the E1476A Option A3F terminal modules.

Configuring the Terminal Panel

The E1586A Rack Mount Terminal Panel (Terminal Panel) provides extended connections to the E1476A multiplexer module. Since the Terminal Panel is used in place of the standard E1476A terminal module, all operations in Chapter 2 (except temperature measurements) apply to the Terminal Panel. However, since the Terminal Panel has three thermistors to make reference temperature measurements, reference temperature measurements are different than for the standard E1476A terminal module.

All channel and Analog Bus connections to make measurements have corresponding connections on the Terminal Panel. The following sections describe channel and analog bus connections to the Terminal Panel and connections for reference temperature measurements.

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Channel Connections

Channels on the Terminal Panel correspond directly to channels on the E1476A terminal module. For example, the channel 2 H, L, and G connections on the E1476A multiplexer have corresponding channel 2 H, L, and G connections on the Terminal Panel.

Since a single Terminal Panel has a total of 32 channels, two Terminal Panels are required to make connections to all channels of the E1476A multiplexer. The Bank A channels (00-31) connect to channels 0-31 on the first Terminal Panel and the Bank B channels (32-63) connect to channels 32-63 (shown in parentheses) of the second Terminal Panel. Figure 1-16 shows channel numbering for the E1586A Rack Mount Terminal Panel.

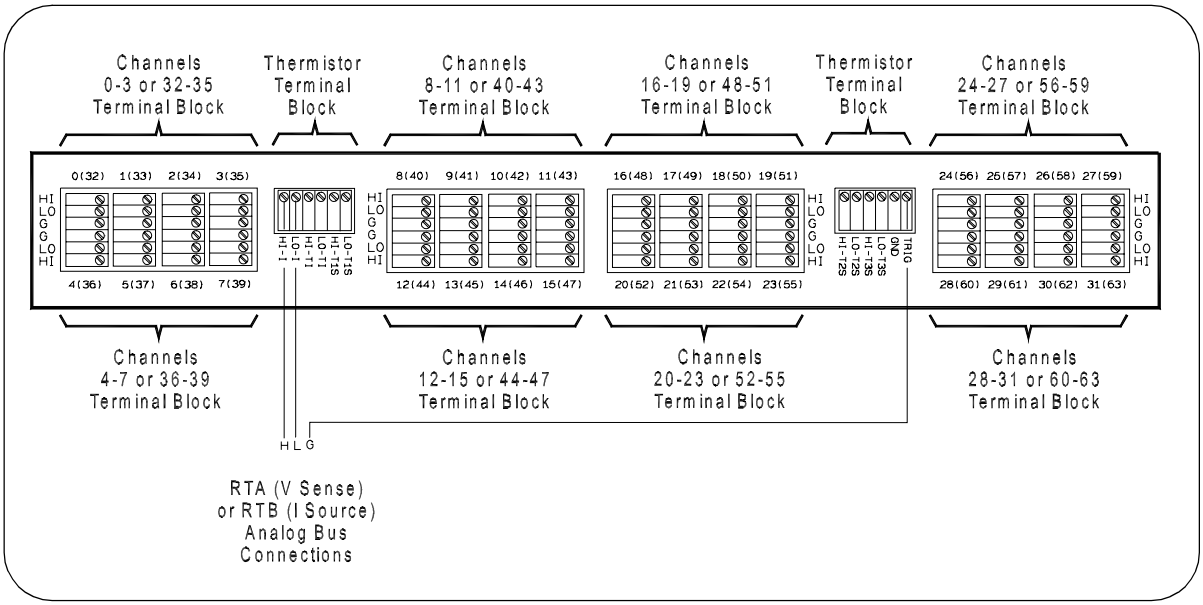


Figure 1-16. E1586A Rack Mount Terminal Panel Connections

Analog Bus Connections

The Terminal Panel also provides Analog Bus connections to the multiplexer module. However, since the terminal module is used with other modules, the Analog Bus connections are labeled differently on the Terminal Panel. Figure 1-16 shows the Analog Bus connections to the Terminal Panel.

Reference Thermistor Connections and Operations

The E1586 Terminal Panel's three thermistors are located next to the channel 3 terminal block, between channels 11 and 16 and next to channel 24 (see Figure 1-16).

The thermistor excitation source is usually supplied by an externally connected multimeter or voltmeter, such as the E1326/E1411 multimeter. When using an E1326/E1411, the excitation is available on the Terminal Panel terminals labeled HI-I and LO-I. The E1326/E1411 generates this excitation using the 2-wire or 4-wire Ohms measurement functions.

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CAUTION **DO NOT EXCEED COMPLIANCE VOLTAGE.** If using a single E1326/E1411 multimeter to supply the excitation for multiple E1586A Terminal Panels, the resultant voltage sum of the voltages developed across the thermistors could exceed the compliance voltage of the multimeter. This is especially true if attempting to excite all three thermistors on the Terminal Panels.

Connecting One Terminal Panel for Reference Temperature Measurements

In this configuration, a single Terminal Panel is used to provide up to 32 channels for temperature measurements. This provides the excitation current to all three on-board thermistors on the Terminal Panel. Figure 1-17 shows connections for a single Terminal Panel.

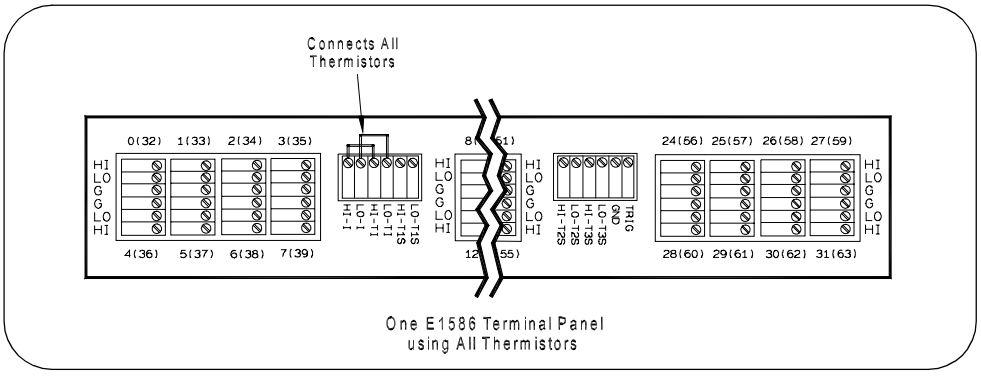


Figure 1-17. Connecting Three Thermistors on a Single Panel

Connecting Two Terminal Panels for Reference Temperature Measurements

In this configuration, two Terminal Panels are used to provide up to 64 channels for temperature measurements. This provides the excitation current to all six on-board thermistors on the Terminal Panels. Figure 1-18 shows the connection for two Terminal Panels.

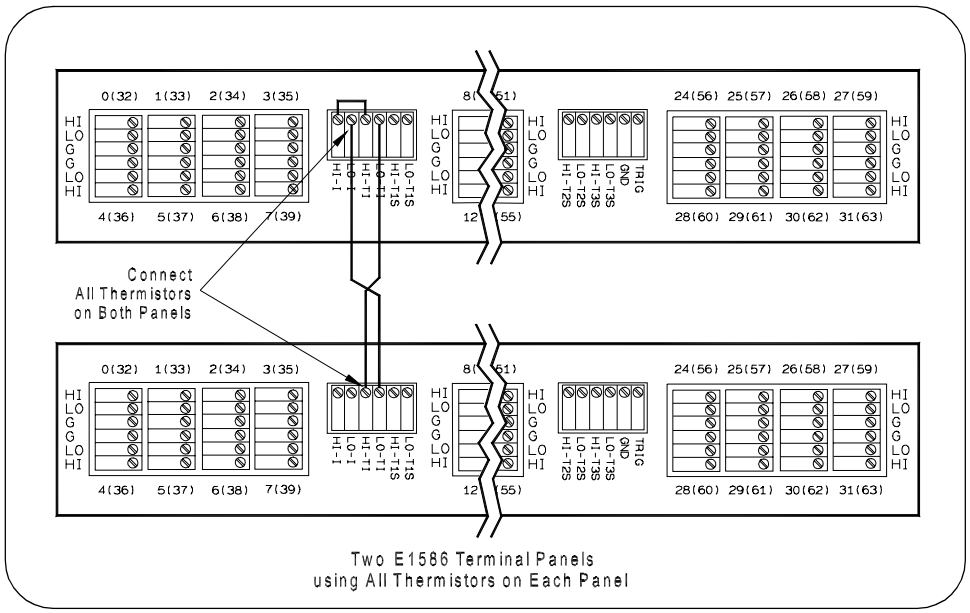


Figure 1-18. Connecting Six Thermistors on Two Panels

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Programming the Multiplexer

To program the E1476A multiplexer using Standard Commands for Programmable Instruments (SCPI), you must select the interface address and SCPI commands used. This section gives guidelines to program the multiplexer, including:

- Addressing the Multiplexer
- Default Conditions
- Start-Up Exercises

Addressing the Multiplexer

To program the E1476A multiplexer using SCPI, you must select the computer language, interface address, and SCPI commands to be used. Guidelines to select SCPI commands for the multiplexer follow.

NOTE *This discussion applies only to SCPI programming. See Appendix B for information on register-based programming of multiplexer registers.*

To address specific channels within a multiplexer, you must specify the SCPI command and multiplexer channel address. For the multiplexer, use CLOSe <*channel_list*> to close the channels specified. Use OPEN <*channel_list*> to open the channels specified. Use SCAN <*channel_list*> to close and open the set of channels specified, one channel at a time.

Card Numbers

The multiplexer card number depends on the switchbox configuration (single-module or multiple-module) set for the multiplexers. Leading zeroes can be ignored for the card number. See "Setting the Logical Address Switch" in this chapter for more information on setting logical addresses and switchbox configurations.

For a **single-module switchbox**, the card number is always 01. For a **multiple-module switchbox**, the card numbers are 01, 02,...,nn. The module with the lowest logical address is card number 01, the module with the next lowest logical address is card number 02, etc.

For example, assume three multiplexers are configured to form a multiple-module switchbox instrument with logical addresses of 112, 113, and 114 as shown in Figure 1-19. Since card number 01 is assigned to the module with the lowest logical address, card number 01 is assigned to the card at logical address 112. Card number 02 is assigned to the card at address 113 and card number 03 is assigned to the card at address 114.

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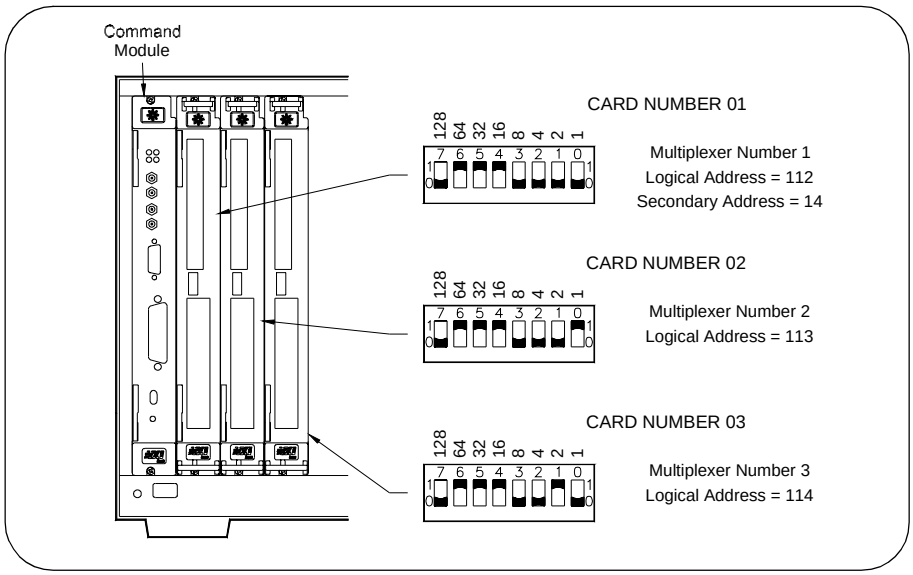


Figure 1-19. Card Numbers in a Multiple-Module Switchbox

Channel Addresses

Channel addresses (*channel_list*) have the form (@*ccnn*) where *cc* = multiplexer card number (01-99) and *nn* = channel numbers (00-63 and 90-94). Channels 90 through 94 are tree relays related to the analog bus and the reference thermistor used for thermocouple measurements.

You can address single channels (@*ccnn*), multiple channels (@*ccnn*,*ccnn*,...), sequential channels (@*ccnn*:*ccnn*), groups of sequential channels (@*ccnn*:*ccnn*,*ccnn*:*ccnn*) or any combination.

Multiplexer channels can be addressed using channel numbers or channel ranges. For a single-module switchbox, channel ranges can span across the channels. For multiple-module switchboxes, channel ranges can span across the channels of all modules.

Use commas (,) to form a channel list or use a colon (:) to form a channel range. Only valid channels can be accessed in a channel list or channel range. The channel list or channel range must be from a lower channel number to a higher channel number. For example, CLOS (@100:215) is acceptable, but CLOS (@215:100) generates an error.

Using the channel range (@*n*00:*n*99) with the SCAN command causes all channels to be scanned except the tree relays (channels 90 through 94). These are not typical scan channels and are not included in a scan list.

You can however, include channel 93 in a scan list (e.g., (@100:193)) when making a four-wire resistance measurement. The only restriction is that SCAN:MODE must be FRES (four-wire resistance) for channel 93 (the voltage sense). The current source channel is 94 and is automatically switched. Some example channel lists/ranges follow.

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Channel Lists:

```
CLOS(@100,112)          ! Close channels 00 and 12 on card 01
OPEN(@203,210)          ! Open channels 03 and 10 on card 02
```

Channel Ranges:

```
OPEN(@100:163)          ! Open all channels on card 01
SCAN(@100:163)          ! Scan all channels on card 01
SCAN(@100:199)          ! Scan all channels on card 01
SCAN(@100:223)          ! Scan all channels on card 01 and
                        ! channels 00 through 23 on card 02
SCAN(@100:104,200:204,300)  ! Scan channels 0 through 4 on card 1,
                            ! scan channels 0 through 4 on card 2,
                            ! and scan channel 0 on card 3
```

Default Conditions

If you want to use the E1476A as a switchbox or scanning voltmeter instrument using SCPI commands, you must first install the appropriate device driver into the E1406 Command Module. For switchbox applications, install “SWITCH” driver Rev A.08.00 or later. For scanning voltmeter applications, install “VOLTMTR” driver Rev A.06.00 or later. See "Start-Up Exercises" for procedures to install device drivers.

At power-on or following a reset of the module (*RST command), all channels are open. A *RST command invalidates the current scan list and you must specify a new scan list. Command parameters are set to the default conditions in Table 1-2.

Table 1-2. E1476A Default Conditions

Parameter	Default	Description
ARM:COUNt	1	Number of scanning cycles is one.
TRIGger:SOURce	IMM	Advances through a scanning list automatically.
INITiate:CONTinuous	OFF	Number of scanning cycles is set by ARM:COUNt
OUTPut[:STATe]	OFF	Trigger output from EXT, TTL, or ECL sources is disabled.
[ROUTe:]SCAN:MODE	NONE	Channel list is set up for volts measurement.
[ROUTe:]SCAN:PORT	NONE	Analog bus connections are disabled from channels.

Execute SCAN:PORT ABUS to enable use of the analog bus for the SCAN command. A CLOSe command requires that you also close the appropriate tree relay to make connection to the analog bus.

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Start-Up Exercises

This section provides five start-up exercises you can use to get the E1476A 64-Channel, 3-Wire Multiplexer module operational, including:

- Exercise 1: Check Device Driver (E1406 only)
- Exercise 2: Query Module Identity
- Exercise 3: Perform Open, Close, and Scan Operations
- Exercise 4: Check for System Errors
- Exercise 5: Make Scanning Voltmeter Measurements

NOTE *We recommend you do not make user connections to the multiplexer until you have verified correct multiplexer operation. If you have already connected user inputs to the terminal module, you may want to remove the terminal module from the switch module while doing these exercises.*

Exercise 1: Check Device Driver (E1406 Only)

If you use an E1406 Command Module, you can check the command module for the correct version of the "SWITCH" device driver for the E1476A. Skip this step and go to Exercise 2 if you do not use an E1406 Command Module.

Power-up the mainframe with the command module installed. The command module is the resource manager at logical address 0 and is typically addressed in the mainframe by 70900. Input this BASIC program into your computer.

```
10  DIM A$[256]
20  OUTPUT 70900;"DIAG:DRIV:LIST?"
30  ENTER 70900;A$
40  PRINT A$
50  END
```

RUN the program and look for the device driver "SWITCH,SWITCHBOX,A.08.00,RAM". RAM could be FLASH (flash ROM) depending on where the device driver is loaded. DIAGnostic:DRIVer:LIST? queries the command module at address 70900 for a list of the device drivers loaded in the command module. A typical response should be similar to the following and will depend on the specific drivers that were previously loaded in the command module.

```
SYSTEM,E1406A,A.08.00,ROM;A.04.02,ROM;VOLTMTR,E1326A,
A.06.00,ROM;SWITCH,SWITCHBOX,A.08.00,RAM;COUNTER,
E1332A,A.04.02,ROM;E1333A,A.04.02,ROM;DIG_I/O,E1330A,
A.04.03,ROM;D/A,E1328A,A.04.02,ROM
```

If you are using an E1411B or E1326B multimeter with E1476A multiplexer(s) configured as a scanning voltmeter, you will need the "VOLTMTR" device driver version A.06.00 (or later). For all non-scanning voltmeter applications, you will need the "SWITCH" driver version A.08.00 (or later). To load a new SWITCH or VOLTMTR device driver, use the *VXI Installation Consultant (VIC)* on the *Agilent Technologies Universal Instrument Drivers* CD.

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NOTE *For the latest information on instrument drivers, see http://www.agilent.com/find/inst_drivers.*

Exercise 2: Query Module Identity

Turn mainframe power OFF. If you want to set a logical address other than the factory-set address of 112, see "Setting the Logical Address Switch" to set a different logical address for the multiplexer. Install the multiplexer module in the mainframe. See "Installing the Multiplexer in a Mainframe" for steps to install the multiplexer.

NOTE *If you have already connected user inputs to the terminal module, you may want to disconnect the terminal module from the switch module for this exercise. See "Attaching a Terminal Module to the Multiplexer" to disconnect the terminal module.*

Turn mainframe power ON and enter the following BASIC program into your computer. For this program, the GPIB Select Code = 7, primary address = 09, and logical address = 112. The logical address divided by 8 = the secondary address (112/8 = 14). Thus, the instrument address is 70914.

```
10 DIM A$[256]
20 OUTPUT 70914;"*IDN?"
30 ENTER 70914;A$
40 PRINT A$
50 END
```

RUN the program. The response should be as follows. The device driver revision must be A.08.00 or later.

```
"HEWLETT PACKARD,SWITCHBOX,0,A.08.00"
```

Exercise 3: Perform Open, Close, and Scan Operations

This exercise performs close, open and scanning operations and queries the status byte. Now that communication with the module has been established, you can perform some close, open and scan operations and use the "SCAN COMPLETE" bit in the Status Operation Event register (bit 8).

Operation Event Register bit 8 designates scan complete when high. Reading this register clears the register (all bits to zero). This bit is monitored by serial polling (SPOLL) the status byte register (bit 7) in line 70. You may want to look at the STATUS command in Chapter 4 which graphically shows the relationship of these two bits and all status registers relating to this module.

Input this BASIC program into your computer. Do not input the comments preceeded by " ! ".

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```
10   DIM A$[256]                                  !Dimension array to hold data entered
20   OUTPUT 70914;"CLOSE (@100, 101, 102:163)"    !Close all channels
30   OUTPUT 70914;"*RST"                          !Open all channels by resetting module
40   OUTPUT 70914;"STAT:OPER:ENAB 256"            !Enable bit 8 of status operation event register
50   OUTPUT 70914;"SCAN (@100:163)"               !Scan all channels
60   OUTPUT 70914;"INIT"                          !Initiate the scan using the default TRIG[:IMM]
70   WHILE NOT BIT (SPOLL(70914),7)               !Serial poll bit 7 of the status byte until it is high
80      PRINT "WAITING FOR SCAN COMPLETE"
90   END WHILE
100  OUTPUT 70914;"STAT:OPER?"                    !Query the status operation event register
110  ENTER 70914;A$                               !Bit 8 reported high (status byte bit 7 was high)
120  PRINT "STAT:OPER:EVENT BIT 8 = ",A$          !Print response to the STAT:OPER query
130  END
```

RUN the program. You should hear channel relays opening and closing, especially when a large channel list is scanned.

Exercise 4: Check for System Errors

You can add the following lines to the program in Exercise 3 to verify that no system errors were generated. It is always a good idea to check if your program causes the instrument to report any errors during program development (such as command strings that are invalid and cause an error to be sent to the instrument's error queue). You can read the instrument's error queue by inserting the following four program lines (all errors are read until the error queue is "+0, No errors").

```
121  REPEAT
122     OUTPUT 70914;"SYST:ERR?"
123     ENTER 70914; A,A$                    !A gets the error number, A$ gets the
                                             !error message
124     PRINT A,A$
125  UNTIL A=0
```

See "Using Interrupts With Error Checking" in Chapter 2 for detecting errors with interrupts. For example, inserting the following (incorrect) program line:

```
51 OUTPUT 70914;"TRIG:SOURC BUS"
```

will cause an error to be sent to the error queue because TRIG:SOURC BUS is an incorrect command header (must be TRIG:SOUR BUS). The instrument still functions using the default value TRIG:IMMediate. To know that an error was reported and your instrument is doing what you intended it to do, you must read the error register with a SYSTem:ERRor? command.

You can insert this program segment at different places in your program to see where the error is generated when debugging your program if it cannot be determined from the error message or by examining the program lines. In this case, the error is returned as -113, "Undefined header" which means the command header was incorrectly specified. This error is generated by the instrument driver while trying to parse the command (the error -113 is documented in the command module manual).

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Exercise 5: Make Scanning Voltmeter Measurements

This exercise allows you to close multiplexer channels and make voltage measurements using a scanning voltmeter configuration. To do this exercise, you will need the following items. See Figure 1-20 for equipment configuration.

- E1411B multimeter
- E1476A multiplexer
- 2.5 inch Analog Bus cable (E1400-61605)
- Zero Ohm jumpers (such as paper clips)
- Resistors (any value)

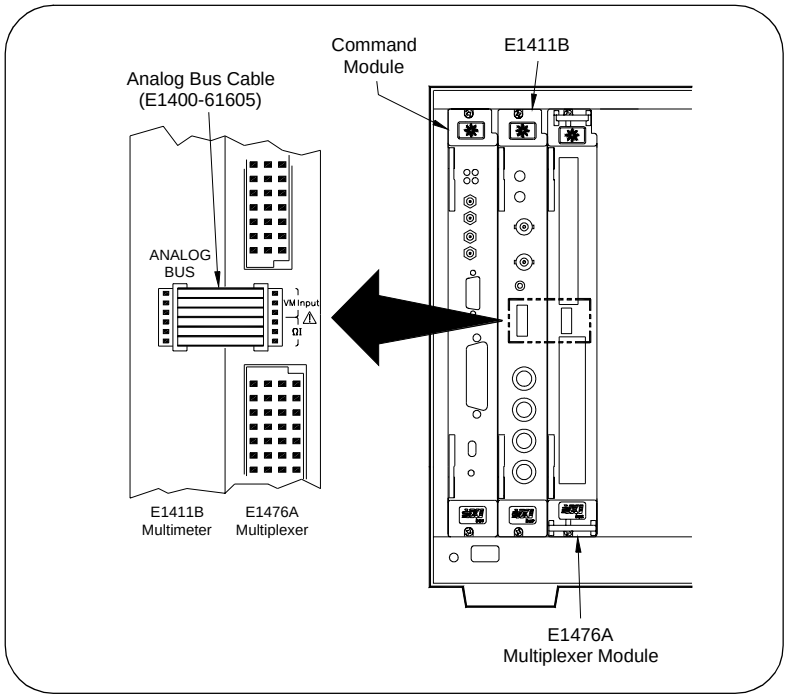


Figure 1-20. Exercise 5: Equipment Configuration

Since the E1411B multimeter and E1476A multiplexer form a scanning voltmeter configuration, the E1476A must have a logical address that is sequential to the E1411B. Also, the E1411B must be at an instrument address (logical address divisible by 8). Set the E1411B to logical address 24 (secondary address is 24/8 = 03) and the E1476A to logical address 25.

The modules must be installed in adjacent slots with the multiplexer to the right of the multimeter. The scanning voltmeter is addressed from GPIB interface 7 (or the interface you use instead of 7), primary address 09 and secondary address 03. The scanning voltmeter address is 70903 and the multimeter controls the multiplexer module.

As required, set the E1411B multimeter to logical address 24 and the E1476A multiplexer to logical address 25. Next, install the instruments in the mainframe and connect the Analog Bus cable between the E1411B multimeter and the E1476A multiplexer. Then, connect resistors and/or Zero Ohm jumpers to desired channels (between 0 and 31) on the terminal module.

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When the configuration is complete, turn mainframe power ON and verify that the "VOLTMETR" driver version A.06.00 is installed in the E1406 Command Module (see Exercise 1). If the appropriate "VOLTMETR" driver is installed, run the following program.

This program scans channels 0 through 31 of the multiplexer and makes a voltage measurement on each channel. The measured readings are entered into the computer and displayed after the scan. You can then check the measured readings with the values of the resistor(s) you installed on the channels.

```
10 DIM Rdgs(1:32)                                ! Dimension array to store readings
20 CLEAR 70903                                   ! Clear the scanning voltmeter
30 OUTPUT 70903;"*RST"                           ! Reset the scanning voltmeter
40 OUTPUT 70903;"MEAS:VOLT:DC?(@100:131)"        ! Configure the multimeter for DC voltage
                                                 ! measurements and specify channel list
                                                 ! to scan (channels 00 through 31)
50  ENTER 70903;Rdgs(*)                          ! Enter measured readings
60 PRINT Rdgs(*)                                 ! Display measured readings
70  END
```


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Chapter 2
Switchbox Applications

Using This Chapter

This chapter gives application information to use the E1476A multiplexer in the “switchbox” configuration, including:

- Switchbox Definition 39
- Switching Applications 41
- Scanning Applications 48
- Recalling and Saving States 55
- Detecting Error Conditions 56

Switchbox Definition

A “switchbox” can be a single multiplexer module or multiple multiplexer modules. It can also include other switch modules that are controlled by the same “switchbox” device driver. See Figure 2-1 for a typical multiple-module switchbox.

NOTE *A switchbox configuration does not include a multimeter (such as the E1411B) installed in the mainframe, and measurements must be made using an external multimeter. In contrast, a "scanning voltmeter" configuration does include a multimeter installed in the mainframe. See Chapter 3 for scanning voltmeter applications.*

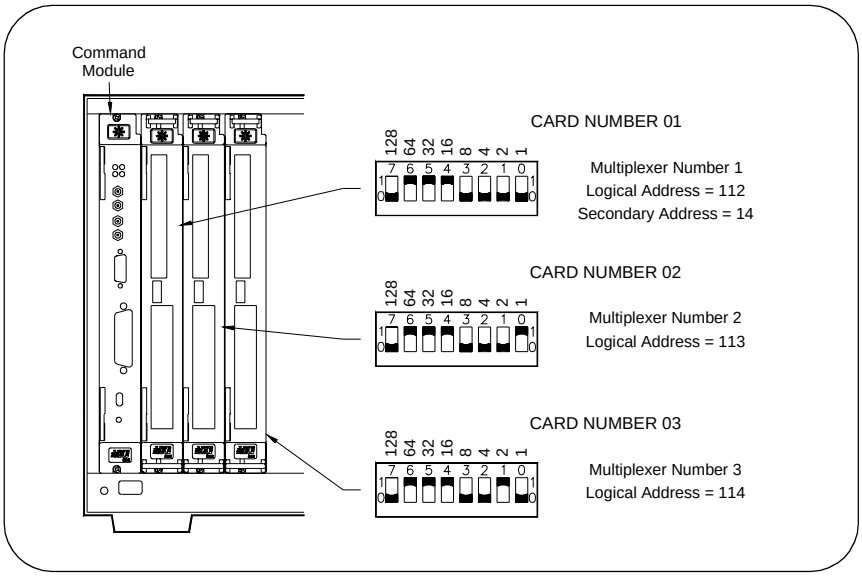


Figure 2-1. Typical Switchbox Configuration

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Switchbox Measurements

The multiplexer can be configured in switchbox configuration to perform voltage, 2-wire ohms, 4-wire ohms or temperature measurements via the internal analog bus. Measurements can be made using switching or scanning methods.

- **Switching.** All measurements can be made by individually switching the channels with CLOSe and OPEN commands. Individually switching the channels requires that you also close appropriate tree relay(s) to connect channels to the analog bus.
- **Scanning.** All measurements can be made by scanning a list of channels. The advantage of scanning is that the appropriate tree relays are closed automatically when you scan a channel list with the SCAN command and set SCAN:PORT ABUS.

NOTE *See "Switching Applications" for examples of measurements using switching methods. See "Scanning Applications" for examples of measurements using scanning methods.*

Multiplexer Reset Conditions

At power-on or following the reset of the multiplexer (*RST command), all 64 channels and the tree relays are open. In addition, after a *RST command, the current scan channel list is invalidated. Table 2-1 lists the parameters and default values for the functions following turn-on or reset.

Table 2-1. E1476A Default Conditions for Power-on and Reset

Parameter	Default	Description
ARM:COUNt	1	Number of scanning cycles is one.
TRIGger:SOURce	IMM	Advances through a scanning list automatically.
INITiate:CONTinuous	OFF	Number of scanning cycles is set by ARM:COUNt
OUTPut[:STATe]	OFF	Trigger output from EXT, TTL, or ECL sources is disabled.
[ROUTe:]SCAN:MODE	NONE	Channel list is set for volts measurement.
[ROUTe:]SCAN:PORT	NONE	Analog bus connections are disabled from channels.
Channel state	All 64 channels are open (channels 00 - 63)	
Tree relay state	All tree relays are open (channels 90 - 94)	
Channel list from SCAN command (after *RST)	Current channel list is invalidated following a reset of the module with *RST command.	

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Switching Applications

This section provides some example applications to make measurements using the switching method, including:

- Switching Channels to the Analog Bus
- Example: Connecting a Channel to the Analog Bus
- Example: 2-Wire Resistance Measurements
- Example: 4-Wire Resistance Measurements
- Example: Temperature Measurements

Switching Channels to the Analog Bus

For the switching method, when OPEN and CLOSe are use to individually switch channels, the appropriate tree relay (VSA, VSB or CS) must also be closed to connect channels to the analog bus to make measurements from the analog bus.

Once closed, a tree relay remains closed until specifically opened (OPEN command, remove power from the module or reset the module with a *RST command). Table 2-2 provides a description of each tree relay function.

Table 2-2. Tree Relay Descriptions

Tree Relay Channel	Designation	Functional Description
90	VSA	Connects the Voltage Sense H-L-G terminals of the Analog Bus to the Bank A channels (channels 00 to 31)
91	VSB	Connects the Voltage Sense H-L-G terminals of the Analog Bus to the Bank B channels (channels 32 to 63)
92	CS	Connects the Current Source H-L-G terminals of the Analog Bus to the Bank B channels (channels 32 to 63)
93	RTA	Connects the Reference Thermistor to Bank A for voltage sense (4-wire resistance measurement of the thermistor)
94	RTB	Connects the Reference Thermistor to Bank B for current source (4-wire resistance measurement of the thermistor)

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Example: Connecting a Channel to the Analog Bus

Use CLOSe *<channel_list>* command to close a channel (channel 00 - 63) or tree relay (channel 90 - 94). A channel or tree relay remains closed until an OPEN is sent or the module is reset using *RST. Removing power will open all channels and tree relays because the relays are non-latching.

You must close a tree relay to connect a channel to the analog bus. For example, close channel 23 on module number 1 and connect it to the analog bus by closing the voltage sense bank A tree relay (channel 90). See Figure 2-2.

```
CLOS(@123, 190)
Make measurement
OPEN(@123, 190)        !Channel 90 can be left closed and other
                       !bank A channels closed for measurement
```

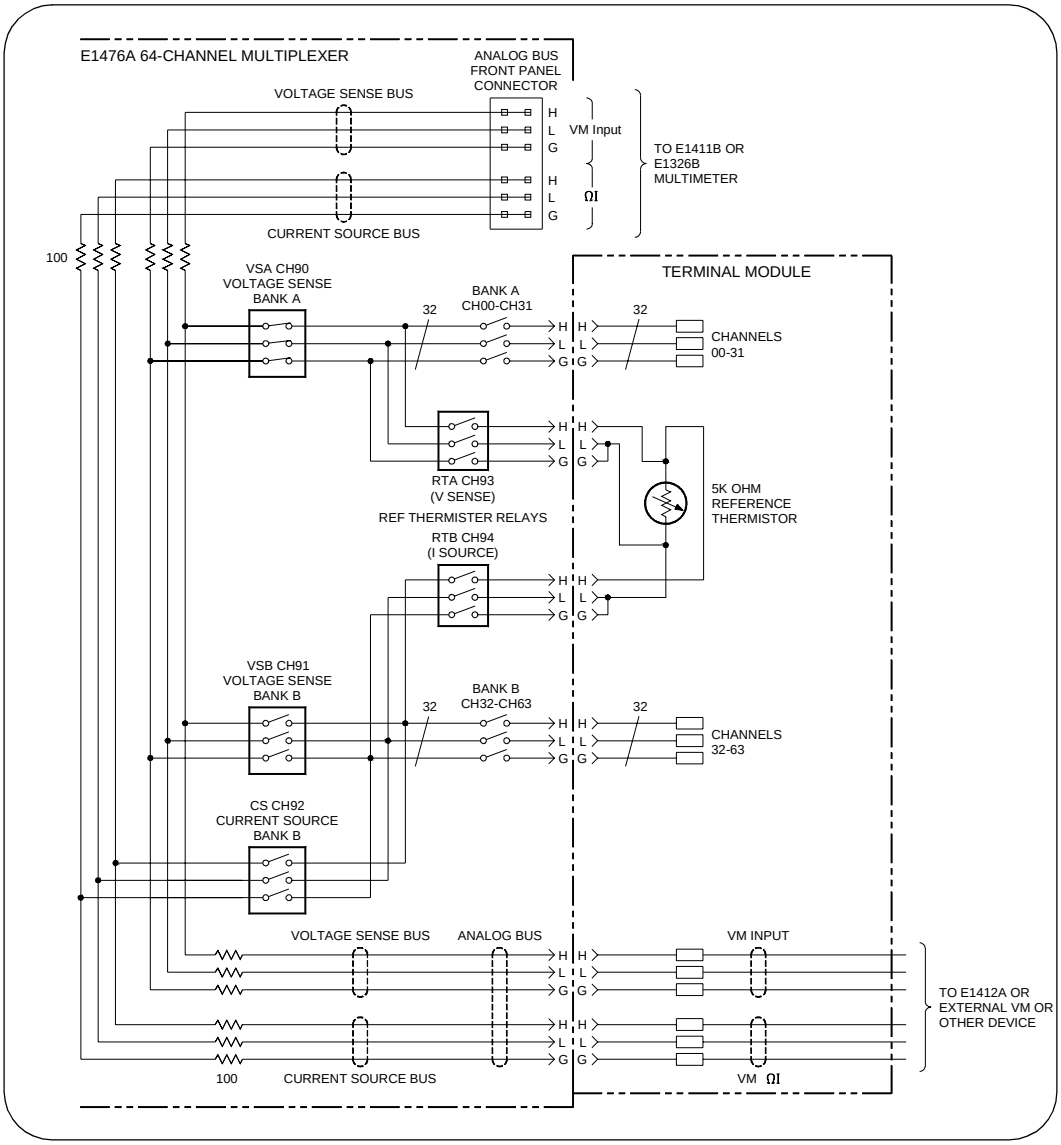


Figure 2-2. Example: Connecting a Channel to the Analog Bus

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Example: Two-Wire Resistance Measurements

This example illustrates three-wire switching and a method for making accurate 2-wire resistance measurements. The E1476A analog bus contains current-limiting protection resistors that can introduce measurement error if the measuring instrument does not have a suitable high impedance. This example describes a method to make measurements that avoids the protection resistors.

Making two-wire measurements from the analog bus requires the internal bus protection resistors which will introduce about 100 Ω per lead to the resistance measurement. Use Channel 00 as the common terminals to make two-wire measurements from channels 01 through 31 on bank A.

Close tree relays VSA and VSB (channels 90 and 91) to connect bank B channels (32 through 63) to channel 00 through the bank A bus. You can now make two-wire measurements from 63 channels using channel 00 as the common. No current-limiting resistors are in the path. See Figure 2-3 for a circuit diagram. A typical program sequence is:

```
CLOS(@190, 191, 100)      !Closes all paths through channel 00
CLOS(@1cc)                !"cc" = channel to be measured (01 to 63)
Make measurement
OPEN(@1cc)                !Open channel cc after measurement is made
```

Example: Four-Wire Resistance Measurements

To make four-wire resistance measurements when switching (not scanning), you must use a channel from bank A for the voltage sense and close the voltage sense bank A tree relay (VSA). Also, you must use a channel from bank B for the current source and you must close the current source relay (CS) on bank B.

The VSA and CS relays connect the device under test to the analog bus. Typically you pair the first channel of bank A with the first channel of bank B (e.g. channels 00 and 32, 01 and 33, 02 and 34, etc.). See Figure 2-4 for a circuit diagram. A typical program sequence follows.

NOTE *Using the* SCAN *command automatically pairs channels 00 and 32, 01 and 33, 02 and 34, etc. for four-wire measurements. See "Scanning Applications".*

```
CLOS(@100, 190, 132, 192) !Channels 100 and 132 are a 4-wire pair
Make measurement in four-wire mode
OPEN(@100, 132)           !Open measurement channels except tree
                          !relays
```


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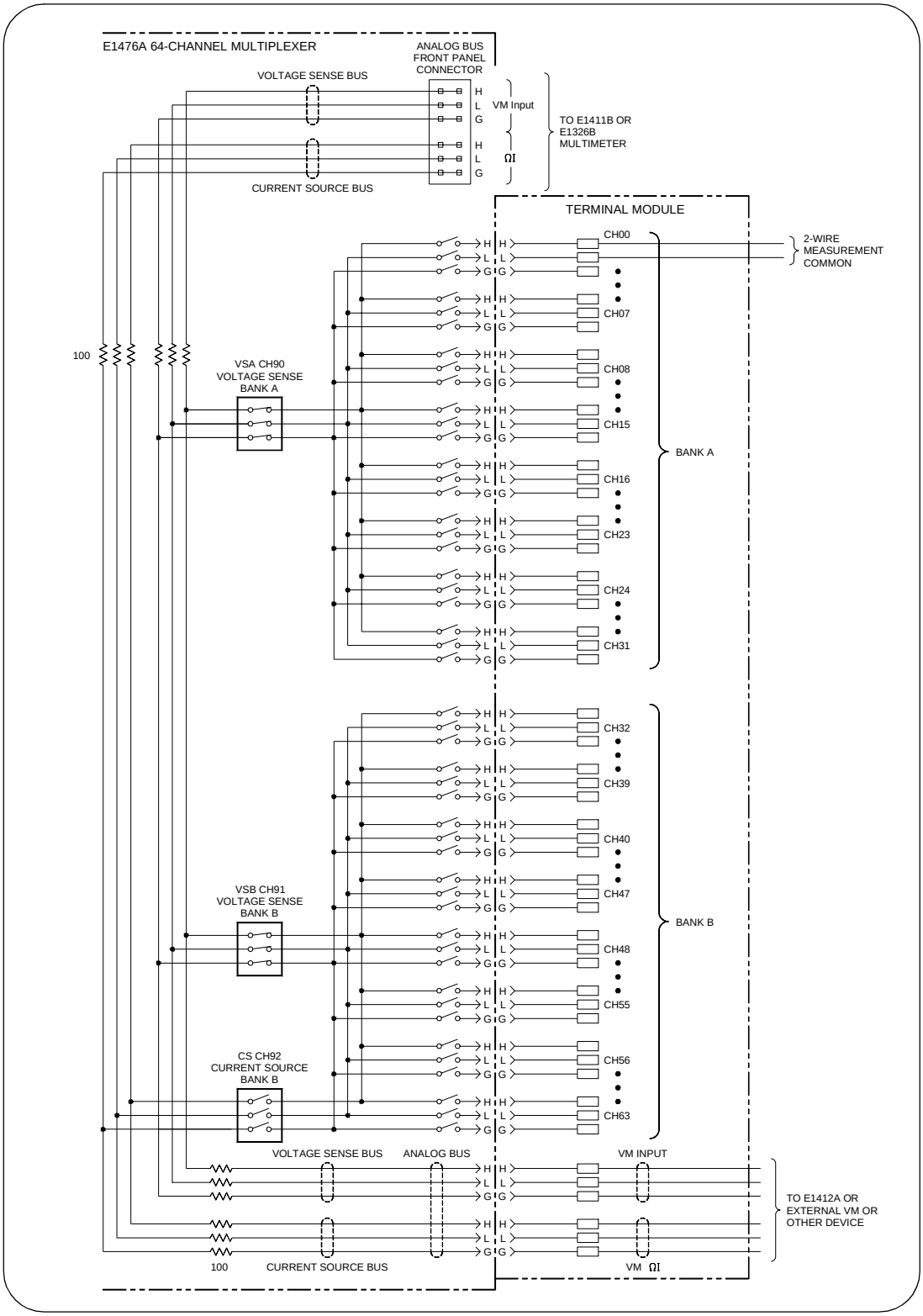


Figure 2-3. Example: Two-Wire Resistance Measurements

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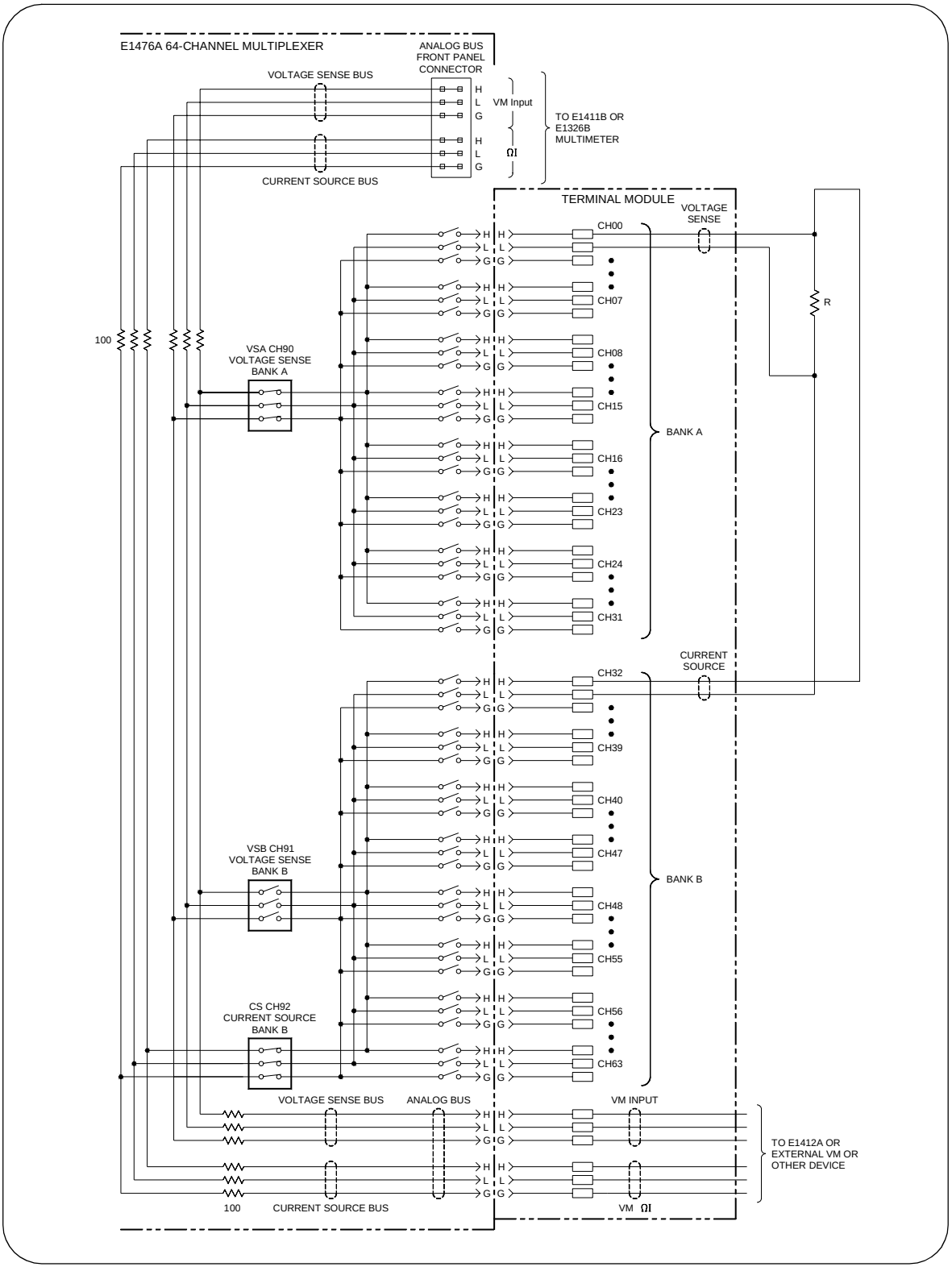


Figure 2-4. Example: Four-Wire Resistance Measurements

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Example: Temperature Measurements

The E1476A allows you to make temperature measurements from any channel of the multiplexer. A 5 KΩ reference thermistor is provided on the E1476A terminal module. You measure the resistance of this reference thermistor to calculate the temperature of the thermocouple junctions within the terminal module to compensate thermocouple temperature measurements.

Temperature measurements using thermistors consist of 2-wire or 4-wire ohms measurements.Thermocouple measurements are compensated by the thermistor on the E1476A terminal module. The temperature of the thermocouple lead junctions inside the terminal module affects the temperature reading taken from a thermocouple. Use the thermistor on the terminal module to determine the temperature inside the terminal module and to compensate the thermocouple temperature measurements.

This example shows one way to make temperature measurements using an E1412A or equivalent multimeter. See Figure 2-5 for typical connections. See Chapter 3 to make temperature measurements with the E1326 or E1411 multimeters.

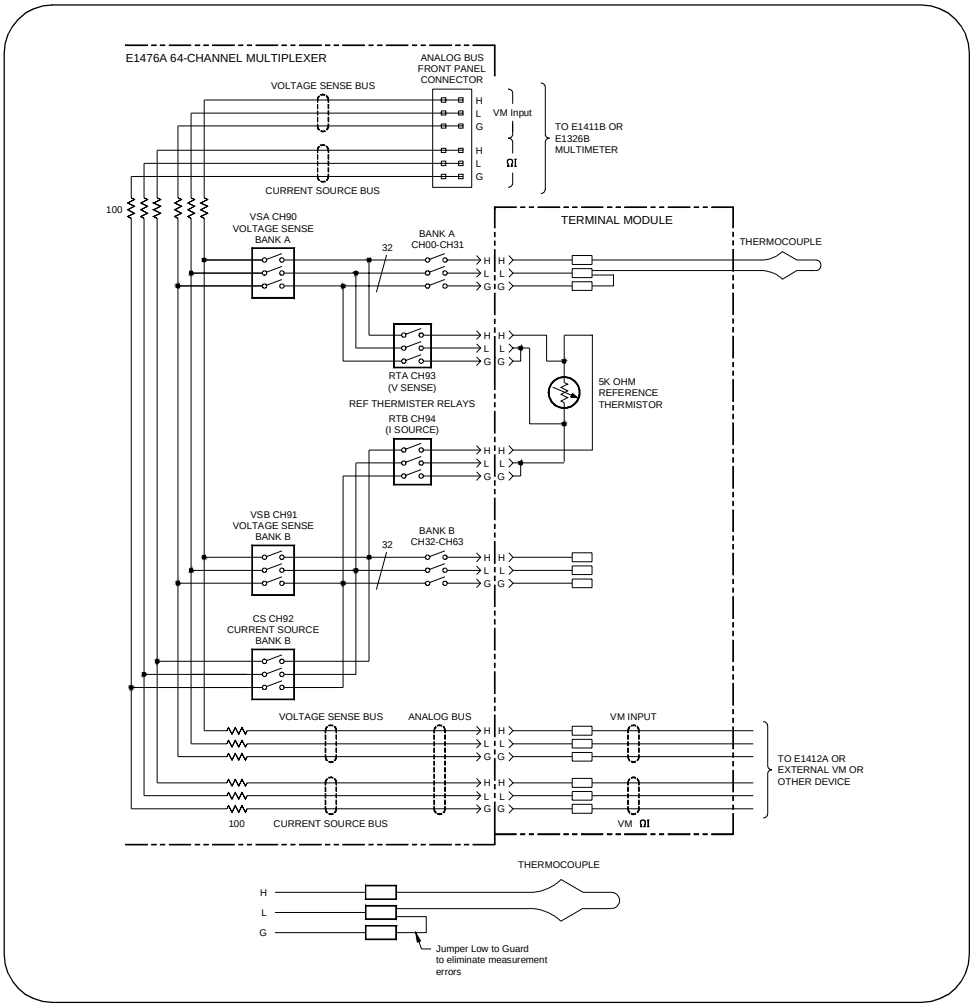


Figure 2-5. Example: Temperature Measurements

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The procedure to make temperature measurements is:

1 Measure the resistance of the 5 KΩ thermistor on the terminal module (Thr_ohms). A 4-wire ohms measurement should be made to avoid measurement errors by the 100Ω protection resistors (see "Example: Four-Wire Resistance Measurements").

2 Compute the temperature of the terminal module (Tref) from the reading (Thr_ohms). For values of resistance between 92.7 Ω to 3.685E6 Ω, use the following equation to calculate the temperature of the terminal module, where Tref = temperature in degrees C and Thr_ohms = the resistance of the 5 KΩ thermistor, W = ln (Thr_ohms), A = 1.28463E-3, B = 0.23625E-3, and C = 9.2697E-8.

$$Tref = \{ 1/(A + W * (B + C * W * W)) \} - 273.15$$

3 Measure voltage on the thermocouple connected to a channel (Vt).

4 Compute the effective temperature at the external thermocouple junction by doing the following two steps:

- Compute the actual voltage across the external thermocouple junction using $Vtc_{Texternal} = V_{meter} - Vtc_{Tref}$ where V_{meter} is the actual voltmeter reading and Vtc_{Tref} is the voltage across the selected thermocouple type at the terminal module temperature (Tref). This voltage must be evaluated from tabular data for the selected thermocouple.

- Evaluate the actual thermocouple temperature using the $Vtc_{Texternal}$ value and the tabular data for the selected thermocouple.

5 Compute the compensated voltage (V) by the formula: V = (Vt-Vref).

6 Convert the compensated voltage (V) calculated in Step 4 to temperature. This is the actual temperature measured by the thermocouple.

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Scanning Applications

This section provides some example applications to make measurements using the scanning method, including:

- Scanning Channels Using the Analog Bus
- Example: Scanning Using TTL VXIbus Triggers
- Example: Scanning Using BUS Trigger
- Example: Using the Scan Complete Bit

Scanning Channels Using the Analog Bus

Scanning a multiplexer channel consists of closing the channel and its associated bank analog bus tree relay. You can make a single scan through the channel list or scan a multiple number of times. You also can scan the channel list continuously until the scan is aborted. Figure 2-6 shows the commands in the scan sequence.

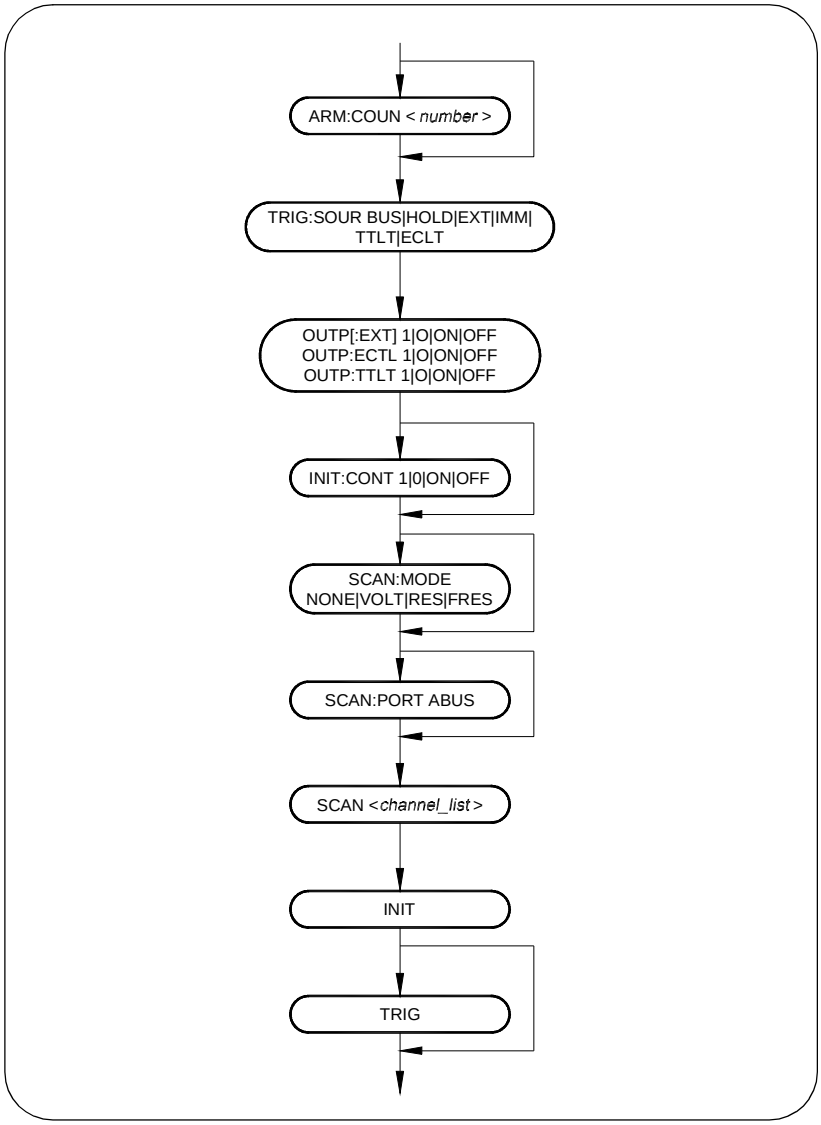


Figure 2-6. Command Sequence to Scan Channels

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The TRIGger:SOURce command specifies the source to advance the scan. The OUTPut command can be used to enable the E1406 Command Module's “Trig Out” port, TTL Trigger bus line (0-7) or ECL Trigger bus lines (0-1).

You can scan a channel or a list of channels using the SCAN command. The tree relays listed in Table 2-2 are automatically switched when you specify the command SCAN:PORT ABUS. This command is required for the tree relays to function during the scan through the channel list. The default value is SCAN:PORT NONE which does not allow these relays to operate and connect channels to the analog bus.

At power-on or after resetting the module with the *RST command, connection to the analog bus is disabled for scan operations. You must execute SCAN:PORT ABUS to enable analog bus tree relay (channels 90, 91 and 92) operation.

The analog bus provides access to all three wires of the channel (High, Low and Guard). Access is through the front panel analog bus connector (usually connected to other multiplexers or to the E1411B multimeter) or through the terminal module “VM Input” and “VM ΩI” terminals.

NOTE *To scan modules in a switchbox, you must first form a valid "SWITCHBOX" instrument. See Figure 2-1 for a typical switchbox configuration.*

For multiple-module switchbox configurations, channels to be scanned can extend across switch modules. For example, for a two-module switchbox instrument, SCAN (@100:263) scans all channels of both multiplexer modules.

Use ARM:COUNt *<number>* to set from 1 to 32767 scans. Use INITiate:CONTinuous ON to set continuous scanning. Tree relays (channels 90 through 94) are controlled automatically by the “SWITCH” driver SCAN command when used in conjunction with SCAN:MODE or SCAN:PORT ABUS.

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Example: Scanning Using TTL VXIbus Triggers

This example uses the TTL VXIbus triggers (TTLT 0-7) to synchronize channel closures with the E1412A 6-Digit Multimeter. A 2-wire ohms measurement is performed. Measurement synchronization is attained by using the following E1406 and E1412A signals.

- **E1406 TTL Trig In** is used by the multimeter to trigger the multiplexer to change channels
- **E1406 TTL Trig Out** is used by the multiplexer to trigger the multimeter for a measurement.
- **E1412A TTL Ext Trig** is used by the multiplexer to signal the multimeter to initiate a measurement.
- **E1412A TTL VM Complete** used the multimeter to signal the multiplexer that measurement is complete and the multiplexer should change channels.

The E1412A multimeter GPIB select code = 7, primary address = 09 and secondary address = 03 (addressed at 70903). The E1476A GPIB select code = 7, primary address = 09 and secondary address = 14 (addressed at 70914). Figure 2-7 shows connections for this example. A BASIC language example program follows Figure 2-7.

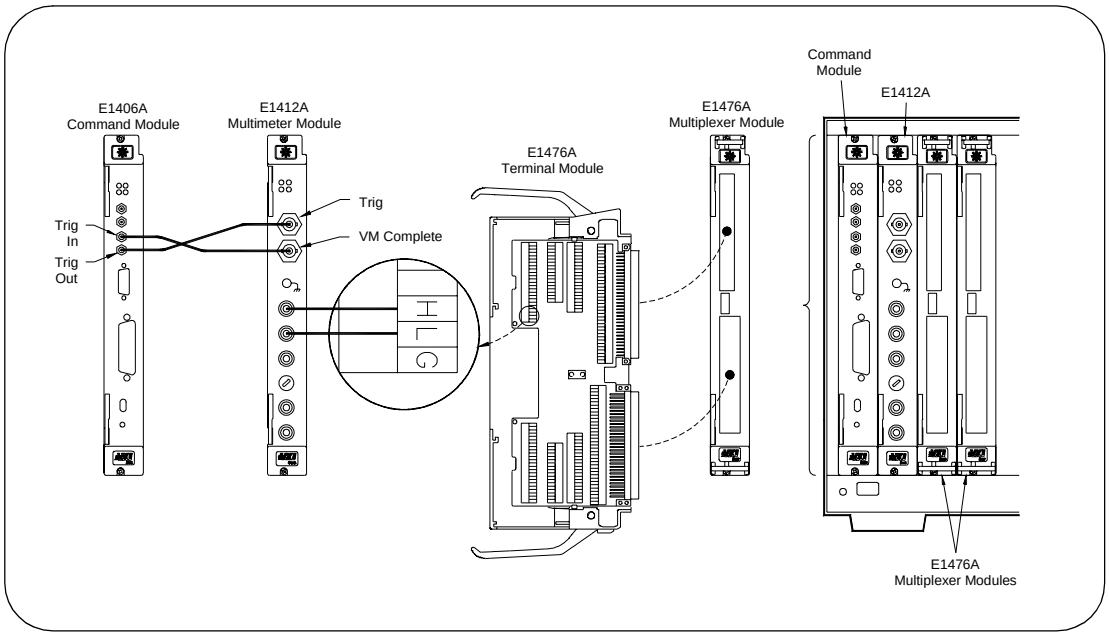


Figure 2-7. Example: Scanning Using TTL VXIbus Triggers

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```
10   ASSIGN @Switchbox TO 70914                !Assign switchbox logical address
20   ASSIGN @Voltmeter TO 70903                !Assign multimeter logical address
30   DIM Results(1:64)                         !Dimension array for readings
40   INTEGER Opc_value
50   OUTPUT @Voltmeter;"*RST;*CLS"             !Reset multimeter, clear status system
60   OUTPUT @Voltmeter;"CONF:RES"              !Configure for 2-wire Ohms
70   OUTPUT @Voltmeter;"TRIG:SOUR TTLT2"       !Set multimeter to receive trigger from TTLT2
80   OUTPUT @Voltmeter;"OUTP:TTLT1 ON"         !Output VM Complete on TTLT1 line
90   OUTPUT @Voltmeter;"TRIG:COUN 64"          !Accept 64 triggers
100  OUTPUT @Voltmeter;"*OPC?"                 !Pause until multimeter is ready
110  ENTER @Voltmeter;Opc_value                !Fetch the *OPC? response
120  OUTPUT @Voltmeter;"INIT"                  !Initialize multimeter; ser "wait-for-trigger"
130  OUTPUT @Switchbox;"*RST;*CLS"             !Reset switchbox, clear status system
140  OUTPUT @Switchbox;"OUTP:TTLT2 ON"         !Enable switchbox trigger output TTLT2
150  OUTPUT @Switchbox;"TRIG:SOUR TTLT1"       !Set for TTLT1 trigger input
160  OUTPUT @Switchbox;"SCAN:MODE RES"         !Set multiplexer for 2-wire Ohms
170  OUTPUT @Switchbox;"SCAN:PORT ABUS"        !Enable analog bus tree relay control
                                               !during scan
180  OUTPUT @Switchbox;"SCAN(@100:163)"        !Set 64-channel scan list
190  OUTPUT @Switchbox;"*OPC?"                 !Pause until switch is ready
200  ENTER @Switchbox;Opc_value                !Fetch the *OPC? response
210  OUTPUT @Switchbox;"INIT"                  !Initialize multiplexer scan
220  OUTPUT @Voltmeter;"FETC?"                 !Transfer readings to output buffer
230  ENTER @Voltmeter;Results(*)               !Read all 64 readings from multimeter
240  PRINT Results(*)                          !Print the Results array (all 64 readings)
250  OUTPUT @Switchbox;"*RST"                  !Reset multiplexer to open all channels
260  END
```


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Example: Scanning Using BUS Trigger

This example uses the BUS trigger (GET or *TRG) to synchronize channel closures with a 3457A voltmeter. A DC voltage measurement is performed. Measurement synchronization is attained by using the following E1406 and 3457A signals.

- **E1406 TTL Trig Out** is used by the multiplexer to trigger the voltmeter for a measurement.
- **3457A TTL Ext Trig** is used by the voltmeter to know when to initiate a measurement.

The 3457 voltmeter GPIB select code = 7 and primary address = 22 (addressed at 722). The E1476A GPIB select code = 7, primary address = 09 and secondary address = 14 (addressed at 70914). Figure 2-8 shows connections for this example. A BASIC language example program follows Figure 2-8.

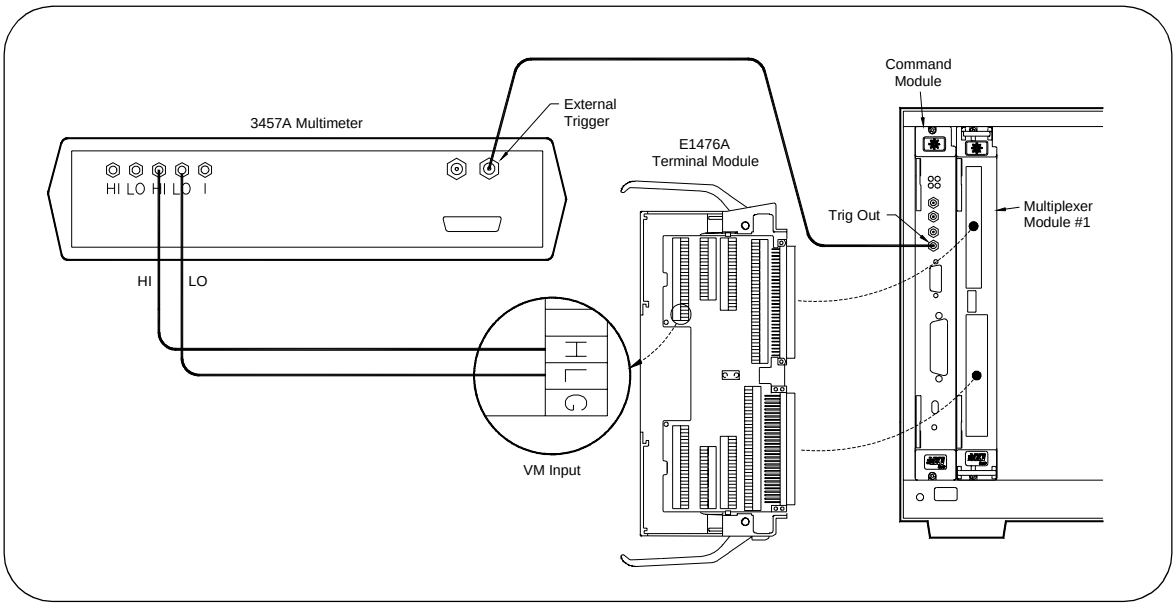


Figure 2-8. Example: Scanning Using BUS Trigger

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```
10   ASSIGN @Switchbox TO 70914          !Assign switchbox logical address
20   ASSIGN @VM3457 TO 722               !Assign voltmeter logical address
30   INTEGER Opc_value
40   OUTPUT @VM3457;"*RESET"             !Reset voltmeter
50   OUTPUT @VM3457;"TRIG EXT"           !Set voltmeter for external trigger
60   OUTPUT @VM3457;"DCV"                !Set voltmeter measurement mode
70   OUTPUT @VM3457;"MEM FIFO"           !Enable voltmeter reading memory mode
80   OUTPUT @Switchbox;"*RST;*CLS"       !Reset the multiplexer
90   OUTPUT @Switchbox;"OUTP ON"         !Enable the switchbox trigger output
100  OUTPUT @Switchbox;"TRIG:SOUR BUS"   !Set switchbox to be triggered by the bus
110  OUTPUT @Switchbox;"SCAN:MODE VOLT"  !Set switchbox to scan in voltage mode
120  OUTPUT @Switchbox;"SCAN:PORT ABUS"  !Enable ABUS tree switch control during scan
130  OUTPUT @Switchbox;"SCAN(@100:163)"  !Set scan list for all 64 channels
140  OUTPUT @Switchbox;"INIT"            !Start the scan
150  OUTPUT @Switchbox;"*OPC?"           !Pause until switchbox is set up
160  ENTER @Switchbox;Opc_value          !Read response to *OPC? command
170  ENTER @VM3457;Results               !Read the first voltmeter reading
180  PRINT "Channel 0",Results           !Print first reading
190  FOR Chan = 1 TO 63                  !Set up loop for other 63 channels
200    OUTPUT @Switchbox;"*TRG"          !Trigger switchbox to change channels
210    ENTER @VM3457;Results             !Enter voltmeter measurement result
220    PRINT "Channel",Chan,Results      !Print results
230  NEXT Chan                           !Loop back for next channel
240  OUTPUT @Switchbox;"*RST"            !Reset the switchbox to open all channels
250  END
```


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Example: Using the Scan Complete Bit

The scan complete bit (bit 8) can be used in the Operation Status Register of the “SWITCHBOX” driver to determine when a scanning cycle completes. Bit 8 has a decimal value of 256 and can be read directly with STAT:OPER? command (see STATus:OPERation[:EVENt]? for an example).

The scan complete bit will be reported as bit 7 of the Status Register when it is enabled by the STAT:OPER:ENAB 256 command. Use the GPIB Serial Poll or the IEEE 488.2 Common Command *STB? to read the Status Register.

This example monitors bit 7 in the Status Register to determine when the scanning cycle completes. The example uses GPIB select code 7, primary address 09 and secondary address 14 for the multiplexer (addressed at 70914).

```
10  OUTPUT 70914;"*CLS"                    !Clear to talk to the switch
20  OUTPUT 70914;"STAT:OPER:ENAB 256"      !Set so scan complete causes an event
30  OUTPUT 70914;"TRIG:SOUR EXT"           !Set to external trigger mode
40  OUTPUT 70914;"SCAN(@100:163)"          !Set scan list for 64 channels
50  OUTPUT 70914;"INIT"                    !Start scanning cycle
60  WHILE NOT BIT(SPOLL(70914),7)          !Loop unit bit 7 is set
70     PRINT "Do other operations here"    !Do other operations until bit 7 is set
80  END WHILE
90  END
```


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Recalling and Saving States

This section contains information about saving and recalling multiplexer states. The "SWITCHBOX" driver can store up to 10 states.

Saving States

The *SAV *<numeric_state>* command saves the current instrument state. The state number (0-9) is specified in the *numeric_state* parameter. The following settings are saved:

- Channel Relay State (channels 00 through 63 open or closed)
- Control Relay States (channels 90 through 94 open or closed)
- ARM:COUNt
- TRIGger:SOURce
- OUTPut[:STATe]
- INITiate:CONTinuous
- [ROUTe:]SCAN:MODE
- [ROUTe:]SCAN:PORT

Recalling States

The *RCL *<numeric_state>* command recalls a previously saved state. Enter the number (0-9) in the *numeric_state* parameter of the desired saved state. If *SAV was not previously executed using the selected number, the multiplexer will configure to the reset values (see Table 2-1).

NOTE *Scan lists are not saved when a state is saved. You must re-enter the scan list after recalling a state.*

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Detecting Error Conditions

There are two general approaches to error checking: polling and using interrupts.

Using Polling

The simplest, but most time consuming, is to ask the instrument whether there are errors at every step of the switching process. This is called “polling” and is illustrated in the following example.

```
10  DIM Err$[256]                          !Close channel 1
20  OUTPUT 70914;"CLOS(@101)"              !Query for error
30 OUTPUT 70914;"SYST:ERR?"                !Read response
40  ENTER 70914;Err$                       !If an error is found (Err$ not 0)
50  IF VAL (Err$) > 0 THEN                 !Print the error
60     PRINT "Error";Err$                  !Quit if error encountered
70     STOP
80  END IF
90  ... (PROGRAM CONTINUES)
```

Using Interrupts

The second approach to error checking involves the use of interrupts. The following program is a method of checking for errors using interrupts as you program the multiplexer. The program monitors the multiplexer's Standard Event Status Register for an error condition. If no errors occur, the multiplexer functions as programmed. If errors do occur, the multiplexer interrupts the computer, and the error codes and messages are read from the error queue.

```
10  !Add your application’s code here
  .
100  ON INTR 7 CALL Errmsg                 !Call to print out error message
110  ENABLE INTR7:2                        !Add your application’s code here
210  OUTPUT 70914;"*SRE 32"                !Enable the standard event summary bit SRE
220  OUTPUT 70914;"*ESE 60"                !Enable all parser-generated errors
230  !Add your application’s code here
  .
300 END
310  !Define interrupt service routine
320  SUB Errmsg
330    DIM A$[256]                         !Declare response string
340    CLEAR 70914                         !Clear the multiplexer
350    B = SPOLL(70914)                    !Fetch status byte
360    REPEAT                              !Repeat
370       OUTPUT 70914;"SYST:ERR?"         !Query for error
380       ENTER 70914;Code,A$              !Read response
390       PRINT Code,A$                    !Print error
400    UNTIL Code=0                        !Query for an error until error code = 0
410    OUTPUT 70914;"*CLS"                 !Clear status registers and error queue
420    STOP
430  SUBEND
```


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Chapter 3
Scanning Voltmeter Applications

Using This Chapter

This chapter provides application information and examples to use the E1476A 64-Channel, 3-Wire Multiplexer module (multiplexer) in a "scanning voltmeter" configuration, including:

- Scanning Voltmeter Description 57
- Scanning Voltmeter Measurements 60
- Scanning Voltmeter Commands Quick Reference 62

NOTE *The commands to use the E1476A in scanning voltmeter configuration are different than the commands to use the E1476A in switchbox configuration. See Chapter 4 for switchbox configuration commands. See "Scanning Voltmeter Commands Quick Reference" in this chapter for scanning voltmeter configuration commands.*

Scanning Voltmeter Description

A **scanning voltmeter** configuration uses the voltmeter instrument driver “VOLTMTR”. The scanning voltmeter commands are different from the switchbox commands listed in Chapter 4. A scanning voltmeter uses the commands in the *E1326B/E1411B 5-Digit Multimeter User’s Manual* to control the switches and make measurements. See Figure 3-1 for a typical scanning voltmeter configuration.

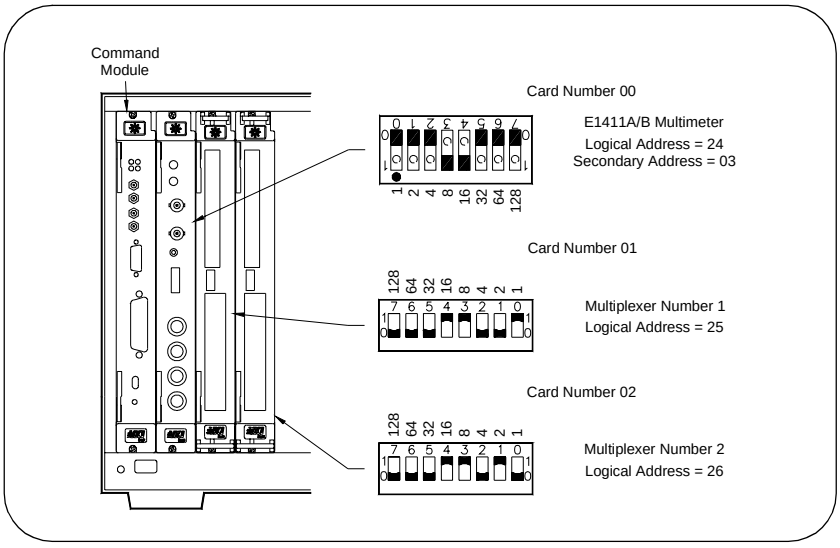


Figure 3-1. Typical Scanning Voltmeter Configuration

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Measurement Types

For scanning voltmeter configuration, you can make measurements with the E1411 (or E1326 used with a C-size adapter installed in the C-size mainframe) 5½-Digit Multimeter. The E1476A can be used with the multimeter to measure voltage, resistance or temperature. The multimeter used must be an E1411 (or E1326 used with a C-size adapter installed in the C-size mainframe). The device driver for these two multimeters controls switches in the scan mode.

Tree Relays

The scanning voltmeter can be configured to perform voltage, 2-wire ohms, 4-wire ohms or temperature measurements via the multiplexer internal analog bus. The E1326/E1411 multimeter automatically controls the channels and tree relays when you use the MEASure or CONFigure commands. See Table 3-1 for tree relays.

Table 3-1. Tree Relay Descriptions

Function	Channel	Designation	Description
Analog Bus Relays	90	VSA	Connects the Voltage Sense H-L-G terminals of the Analog Bus to Bank A.
	91	VSB	Connects the Voltage Sense H-L-G terminals of the Analog Bus to Bank B.
	92	CS	Connects the Current Source H-L-G terminals of the Analog Bus to Bank B.
Reference Thermistor Relays	93	RTA	Connects the Reference Thermistor to Bank A for voltage sense.
	94	RTB	Connects the Reference Thermistor to Bank B for current source.

Device Drivers

The scanning voltmeter configuration does not use the “SWITCH” switchbox device driver so you cannot use the switchbox command reference in Chapter 4. Instead, you use the “VOLTMTR” device driver and the E1411B multimeter command reference. The multimeter's command quick reference from the *E1326/E1411 5½-Digit Multimeter User's Manual* is provided at the end of this chapter for your convenience. See the multimeter manual for detailed descriptions of the commands.

The Analog Bus

The analog bus provides access to all three wires of the channel (High, Low and Guard). Access is through the front panel analog bus connector which is used to connect to other multiplexers and to the E1411 (or E1326) multimeter. See Figure 1-1 in Chapter 1 for a schematic representation of the scanning voltmeter using the E1411B multimeter with an E1476A multiplexer. The analog bus is connected from multiplexer to multiplexer in multiple-module scanning voltmeter instruments to provide a continuous bus for the instrument.

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Reset Conditions

This section describes the power-on and reset condition the E1476A multiplexer module is in when a “scanning voltmeter” reset occurs. The “VOLTMTR” device driver controls both the voltmeter and any switch module configured with it in a scanning voltmeter configuration.

At power-on or following the reset of a scanning voltmeter (*RST command sent to the voltmeter address), all 64 channels and all tree relays are open. In addition, after a *RST command, the current scan channel list is invalidated. See the *E1326/E1411 User’s Manual* for the reset conditions of the multimeter.

Table 3-2 lists the parameters and default values for the multiplexer module functions following power-on or reset. These are not accessible to you via the “VOLTMTR” driver, but are provided so you will know the multiplexer module condition after power-on or following a reset.

Table 3-2. E1476A Default Conditions for Power-on and Reset

Parameter	Default	Description
ARM:COUNt	1	Number of scanning cycles is one.
TRIGger:SOURce	IMM	Advances through a scanning list automatically.
INITiate:CONTinuous	OFF	Number of scanning cycles is set by ARM:COUNt
OUTPut[:STATe]	OFF	Trigger output from EXT, TTL, or ECL sources is disabled.
[ROUTe:]SCAN:MODE	NONE	Channel list is set for volts measurement.
[ROUTe:]SCAN:PORT	NONE	Analog bus connections are disabled from channels.
Channel state	All 64 channels are open (channels 00 - 63)	
Tree relay state	All tree relays are open (channels 90 - 94)	
Channel list from SCAN command (after *RST)	Current channel list is invalidated following a reset of the module with *RST command.	

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Scanning Voltmeter Measurements

This section provides an example program for making voltage, 2-wire ohms, 4-wire ohms and thermocouple or thermistor temperature measurements with a scanning voltmeter configuraton. The multimeter (E1326/E1411) MEASure command is used to specify the channel list to scan and to make measurements.

Configuring the Scanning Voltmeter

To do this example, you will need the following items. See Figure 3-2 for equipment configuration.

- E1411B multimeter
- E1476A multiplexer
- 2.5 inch Analog Bus cable (E1400-61605)
- Zero Ohm jumpers (such as paper clips)
- Resistors (any value)

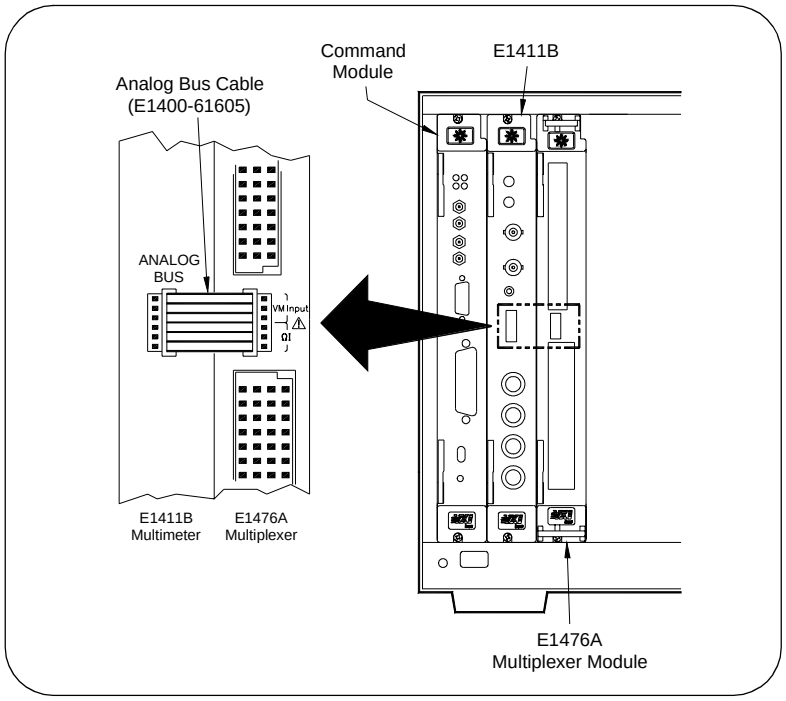


Figure 3-2. Scanning Voltmeter Equipment Configuration

Since the E1411B multimeter and E1476A multiplexer form a scanning voltmeter configuration, the E1476A must have a logical address that is sequential to the E1411B. Also, the E1411B must be at an instrument address (logical address divisible by 8). Set the E1411B to logical address 24 (secondary address is 24/8 = 03) and the E1476A to logical address 25.

The modules must be installed in adjacent slots with the multiplexer to the right of the multimeter. The scanning voltmeter is addressed from GPIB interface 7 (or the interface you use instead of 7), primary address 09 and secondary address 03. The scanning voltmeter address is 70903 and the multimeter controls the multiplexer module.

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As required, set the E1411B multimeter to logical address 24 and the E1476A multiplexer to logical address 25. Next, install the instruments in the mainframe and connect the Analog Bus cable between the E1411B multimeter and the E1476A multiplexer. Then, connect resistors and/or Zero Ohm jumpers to desired channels (between 0 and 31) on the terminal module.

Programming the Scanning Voltmeter

When the configuration is complete, turn mainframe power ON and verify that the "VOLTMETR" driver version A.06.00 is installed in the E1406 Command Module (see Exercise 1 in Chapter 1). If the appropriate "VOLTMETR" driver is installed, run the following program.

This example scans 32 multiplexer channels and makes a measurement on each channel. The measured readings are entered into the computer and displayed after the scan. Table 3-3 shows how to modify the program to make voltage, 2-Wire Ohms, 4-Wire Ohms, Thermocouple, and Thermistor measurements.

NOTE *For the example program, when the multimeter buffer fills, measurements are suspended until readings are read from the buffer (by the computer) to make space available.*

```
10 DIM Rdgs(1:32)                                  ! Dimension array to store readings
20 CLEAR 70903                                     ! Clear the scanning voltmeter
30 OUTPUT 70903;"*RST"                             ! Reset the scanning voltmeter
40 OUTPUT 70903;"MEAS:VOLT:DC?(@100:131)"          ! Configure the multimeter for DC voltage
                                                   ! measurements and specify channel list
                                                   ! to scan (channels 00 through 31)
50  ENTER 70903;Rdgs(*)                            ! Enter measured readings
60 PRINT Rdgs(*)                                   ! Display measured readings
70  END
```

Table 3-3. Changes to Example Program

For This Measurement:	Change Line 40 to:	Comments
Voltage	N/A	Line 40 performs a DCV measurement
2-Wire Ohms	40 OUTPUT 70903;"MEAS:RES? (@100:131)"	
4-Wire Ohms	40 OUTPUT 70903;"MEAS:FRES? (@100:131)"	Channels 32 - 63 are automatically paired with channels 00 - 31 for 4-wire measurements.
Thermocouple Temperature	40 OUTPUT 70903; "MEAS:TEMP? TC,K,(@100:131)"	Type K thermocouple temperature measurements.
Thermistor Temperature	40 OUTPUT 70903;"MEAS:TEMP? FTH,5000,(@100:131)"	4-wire, 5000Ω thermistor temperature measurements.

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Scanning Voltmeter Command Quick Reference

The following tables summarize SCPI commands for the E1326/E1411 multimeters. See the *E1326/E1411 User's Guide* for details.

Command		Description
ABORt		Place multimeter in idle state
CALibration	:LFRequency 50 | 60 | MIN | MAX :LFRequency? [MIN | MAX] :ZERO:AUTO OFF | 0 | ON | 1 :ZERO:AUTO?	Change line reference frequency Query line reference frequency Enable/disable autozero mode Query autozero mode.
CONFigure	:FRESistance [<*range*>[,<*resolution*>]] [,<*channel_list*>] :RESistance [<*range*>[,<*resolution*>]] , <*channel_list*> :TEMPerature <*transducer*>,<*type*>,<*channel_list*> :VOLTage:AC [<*range*> [,<*resolution*>]] [,<*channel_list*>] :VOLTage[:DC] [<*range*> [,<*resolution*>]] [,<*channel_list*>]	Configure multimeter for 4-wire ohms Configure multimeter for 2-wire ohms Configure multimeter for temperature Configure multimeter for AC voltage Configure multimeter for DC voltage
CONFigure?		Query multimeter configuration
DIAGnostic	:FETS <*mode*> :FETS?	Selects control of FET multiplexers Query mode of operation
DISPlay	:MONitor:CHANnel <*channel*> | AUTO :MONitor:CHANnel? :MONitor[:STATe] OFF | 0 | ON | 1 :MONitor[:STATe]?	Monitor multiplexer channel Query monitor channel Enable/disable monitor mode Query monitor mode
FETCh?		Place stored readings in output buffer
FORMat	[:DATA] <*type*>[,<*length*>]	Select output data format and length
FORMat?		Query format
INITiate	[:IMMediate]	Place multimeter in wait-for trigger state
MEASure	:FRESistance? [<*range*>[,<*resolution*>]] [,<*channel_list*>] :RESistance? [<*range*>[,<*resolution*>]], <*channel_list*> :TEMPerature? <*transducer*>,<*type*> [,<*channel_list*>] :VOLTage:AC? [<*range*> [,<*resolution*>]] [,<*channel_list*>] :VOLTage[:DC]? [<*range*> [,<*resolution*>]] [,<*channel_list*>]	Make 4-wire ohms measurements Make 2-wire ohms measurements Make temperature measurements Make AC voltage measurements Make DC voltage measurements
MEMory	:VME:ADDRess <*address*> :VME:ADDRess? [MIN | MAX] :VME:SIZE <*bytes*> :VME:SIZE? [MIN | MAX] :VME:STATe <*mode*> :VME:STATe?	Set address of memory on VME card. Query VME memory location (address) .Amount of memory used on VME card Query amount of VME memory used Direct readings to VME memory card Query VME memory mode
OUTPut	TTLTrg0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 [:STATe] OFF | 0 | ON | 1 :TTLTrg0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 [:STATe]?	Send VM compl to VXIbus trigger lines Query voltmeter complete destination
READ?		Place multimeter in wait-for trigger state Place readings in output buffer

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Command		Description
SAMPle	:COUNt 1-16777215 | MIN | MAX :COUNt? [MIN | MAX] :SOURce IMM | TIM :SOURce? :TIMer 76 ms - 65,534 ms | MIN | MAX :TIMer? [MIN | MAX]	Set number of readings per trigger Query number of readings per trigger Set pacing source Query pacing source Define period between readings Query period between readings
[SENSe:]	FUNCtion[:<*function*>] FUNCtion? RESistance:APERture <*time*> | MIN | MAX RESistance:APERture? [MIN | MAX] RESistance:NPLC <*number*> | MIN | MAX RESistance:NPLC? [MIN | MAX] RESistance:OCOMpensated OFF | 0 | ON | 1 RESistance:OCOMpensated? RESistance:RANGe <*range*> | MIN | MAX RESistance:RANGe? [MIN | MAX] RESistance:RANGe:AUTO OFF | 0 | ON | 1 RESistance:RANGe:AUTO? RESistance:RESolution <*resolution*> | MIN | MAX RESistance:RESolution? [MIN | MAX]VOLTage:AC: RANGe <range> | MIN | MAX VOLTage:AC:RANGe? [MIN | MAX] VOLTage:APERture <*time*> | MIN | MAX VOLTage:APERture? [MIN | MAX] VOLTage[:DC]:RANGe <*range*> | MIN | MAX VOLTage[:DC]:RANGe? [MIN | MAX] VOLTage:NPLC <*number*> | MIN | MAX VOLTage:NPLC? [MIN | MAX] VOLTage:RANGe:AUTO OFF | 0 | ON | 1VOLTage:RANGe:AUTO? VOLTage:RESolution <*resolution*> VOLTage:RESolution? [MIN | MAX]	Select measurement function Query measurement function Set aperture (integration) time in sec Query aperture (integration) time Set integration time in PLCs Query integration time Enable/disable offset compensation Query offset compensation mode Select range Query range Enable/disable autorange function Query autorange mode Specify resolution Query resolution Select measurement range Query range Set aperture (integration) time in sec Query aperture (integration) time Select range Query range Set integration time in PLCs Query integration time Enable/disable autoranging Query autorange mode Specify resolution Query resolution
SYSTem	:CDEScription? <*card_number*> :CTYPe? <*card_number*> :ERRor?	Return description of multiplexer in scanning multimeter Return card type of multiplexer in scanning multimeter Return error number/message from error queue
TRIGger	:COUNt 1-16777215 | MIN | MAX :COUNt? [MIN | MAX] :DELay 0-16.777215 | MIN | MAX :DELay? [MIN | MAX] :DELay:AUTO OFF | 0 | ON | 1 :DELay:AUTO? [:IMMediate] :SOURce BUS | EXT | HOLD | IMM | TTLTrg0-TTLTrg7 :SOURce?	Set number of triggers or scans Query trigger count Set delay between trigger and start of measurement Query trigger delay Enable/disable automatic trigger delay Query automatic trigger delay mode Trigger immediately Specify trigger source Query trigger source

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Command	Title	Description
*RST	Reset	Sets the multimeter and associated multiplexers. Sets: FUNC:VOLT:DC APER 16.7 ms|20 ms CAL:ZERO:AUTO ON NPLC 1 VOLT:RANG 8V VOLT:RES 7.629 mV RANGE:AUTO ON RES:RANG 16384 W RES:RES 15.6m W RES:COMP OFF TRIG:COUN 1 TRIG:DELAY:AUTO ON TRIG:SOUR IMM SAMP:COUN 1 SAMP:SOUR IMM SAMP:TIM 200 ms
*TRG	Bus Trigger	When the multimeter is in the wait-for-trigger state and the trigger source is TRIGger:SOURce BUS, use the *TRG command to trigger the multimeter.
TST	Self-Test	Should return 0. If code 1, 2, 3, or 4 occurs, return the multimeter to Agilent Technologies for repair.

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Chapter 4
Switchbox Command Reference

Using This Chapter

This chapter describes Standard Commands for Programmable Instruments (SCPI) and summarizes IEEE 488.2 Common (*) commands applicable to the E1476A 64-Channel 3-Wire Relay Multiplexer module when used in the switchbox configuration, including:

- Command Types 65
- SCPI Command Reference 67
- SCPI Command Quick Reference 96
- IEEE 488.2 Common Command Reference 97

Command Types

Commands are separated into two types: IEEE 488.2 Common Commands and SCPI Commands.

Common Commands Format

The IEEE 488.2 standard defines the common commands that perform functions such as reset, self-test, status byte query, and so on. Common commands are four or five characters in length, always begin with the asterisk character (*), and may include one or more parameters. The command keyword is separated from the first parameter by a space character. Some examples of common commands are shown below:

```
*RST  *ESR 32  *STB?
```

SCPI Command Format

The SCPI commands perform functions like closing switches, making measurements, and querying instrument states or retrieving data. A subsystem command structure is a hierarchical structure that usually consists of a top level (or root) command, one or more lower level commands, and their parameters. The following example shows part of a typical subsystem:

```
[ROUTe:]
   CLOSe <channel_list>
   SCAN <channel_list>
      :MODE?
```

[ROUTe:] is the root command, CLOSe and SCAN are second level commands with parameters, and :MODE? is a third level command.

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Command Separator

A colon (:) always separates one command from the next lower level command as shown below:

```
ROUTe:SCAN:MODE?
```

Colons separate the root command from the second level command (ROUTe:SCAN) and the second level from the third level (SCAN:MODE?).

Abbreviated Commands

The command syntax shows most commands as a mixture of upper and lower case letters. The upper case letters indicate the abbreviated spelling for the command. For shorter program lines, send the abbreviated form. For better program readability, you may send the entire command. The instrument will accept either the abbreviated form or the entire command.

For example, if the command syntax shows MEASure, then MEAS and MEASURE are both acceptable forms. Other forms of MEASure, such as MEASU or MEASUR will generate an error. You may use upper or lower case letters. Therefore, MEASURE, measure, and MeAsUrE are all acceptable.

Implied Commands

Implied commands are those which appear in square brackets ([ ]) in the command syntax. (The brackets are not part of the command and are not sent to the instrument.) Suppose you send a second level command but do not send the preceding implied command. In this case, the instrument assumes you intend to use the implied command and it responds as if you had sent it. Examine the partial [ROUTe:] subsystem shown below:

```
[ROUTe:]CLOSe <channel_list>
    CLOSe? <channel_list>
    OPEN <channel_list>
    OPEN? <channel_list>
    SCAN <channel_list>
        :MODE <mode>
        :MODE?
```

The root command [ROUTe:] is an implied command. To close relays in a <*channel_list*>, you can send either of the following command statements:

```
ROUT:CLOS (@100:107, 201, 225)   or   CLOS (@100:107, 201, 225)
```

These commands function the same closing channels 00 through 07 on card 1 and channels 01 and 25 on card 2.

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Parameters

Parameter Types. The following table contains explanations and examples of parameter types you might see later in this chapter.

Table 4-1.

Parameter Type	Explanations and Examples
Numeric	Accepts all commonly used decimal representations of number including optional signs, decimal points, and scientific notation. 123, 123E2, -123, -1.23E2, .123, 1.23E-2, 1.23000E-01. Special cases include MINimum, MAXimum, and DEFault.
Boolean	Represents a single binary condition that is either true or false (ON, OFF, 1, 0)
Discrete	Selects from a finite number of values. These parameters use mnemonics to represent each valid setting. An example is the TRIGger:SOURce <*source*> command where source can be BUS, EXT, HOLD, or IMM.

Optional Parameters. Parameters shown within square brackets ([ ]) are optional parameters. (the brackets are not part of the command and are not sent to the instrument.) If you do not specify a value for an optional parameter, the instrument chooses a default value. For example, consider the ARM:COUNt?[<MIN | MAX>] command.

If you send the command without specifying a parameter, the present ARM:COUNt setting is returned. If you send the MIN parameter, the command returns the minimum count available. If you send the MAX parameter, the command returns the maximum count available. Be sure to place a space between the command and the parameter.

Linking Commands

Linking IEEE 488.2 Common Commands with SCPI Commands. Use a semicolon between the commands. For example, *RST;OUTP ON or TRIG:SOUR HOLD;*TRG.

Linking Multiple SCPI Commands. Use both a semicolon and a colon between the commands. For example, ARM:COUN1;:TRIG:SOUR EXT.

SCPI Command Reference

This section describes the Standard Commands for Programmable Instruments (SCPI) commands for the E1476A Multiplexer module. Commands are listed alphabetically by subsystem and within each subsystem.

There are two ways to send commands to the instrument. The most often used way is from a controller over the GPIB interface. This method is called the “GPIB interface” in the command reference. The second way is to send commands is from a terminal connected to the E1406 command module (RS-232). Commands sent this way are referred to as “from the terminal” in the command reference.

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ABORt

The **ABORt** command stops a scan in progress when the trigger sources are either TRIGger:SOURce BUS or TRIGger:SOURce HOLD. See the comments to stop a scan if trigger source is not BUS or HOLD.

Subsystem Syntax

ABORt

Comments

- **Channel Status After an** ABORt**:** Aborting a scan will leave the last channel it closed in the closed position.
- **Effect on Scan Complete Status Bit:** Aborting a scan will not set the “scan complete” status bit.

Stopping Scans Enabled from GPIB Interface: When a scan is enabled from the GPIB interface, and the trigger source is not HOLD or BUS, you can clear the interface to stop the scan. In the BASIC programming language, this is done by executing the CLEAR command for your interface (CLEAR 7, for example).

When the scan is enabled from the GPIB interface and the trigger source is TRIGger:SOURce BUS or TRIGger:SOURce HOLD, send the ABORt command over the GPIB bus.

Note *Clearing the GPIB interface during a scan leaves the last channel the scan closed in the closed position and does not set the “scan complete” status bit.*

Stopping Scans by using the terminal: You may use a terminal connected to the E1406 Command Module to stop any scan.

If the scan was started from the terminal, and the trigger source is HOLD or BUS, send the ABORt command to halt the scan. If the scan was started from the terminal and some other trigger source is being used, **Ctrl+c** will send an interface CLEAR to the instrument and abort the scan. Sending **Ctrl+r** also sends an interface CLEAR to the instrument and additionally performs a reset (*RST) on the instrument. (See the *E1406 Command Reference* for details on the terminal interface.)

If the scan was started from the GPIB interface, but you want to stop it by using the terminal, first make sure that the correct instrument (e.g., SWITCH at desired logical address) is selected by using the terminal soft keys. Then send a **Ctrl+r**. This will send an interface CLEAR to the GPIB task, but will not place the instrument in the reset state with respect to the GPIB task. These actions will occur regardless of the trigger source setting.

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Note *Clearing the interface using a **Ctrl+c** from the terminal during a scan leaves the last channel it closed in the closed position and does not set the "scan complete" status bit.*

Related Commands: ARM, INITiate:CONTinuous, [ROUTe:]SCAN, TRIGger

Example

Stopping a Scan with ABORt

```
TRIG:SOUR  BUS                  Bus is trigger source
INIT:CONT  ON                   Set continuous scanning
SCAN  (@100:115)                Set channel list
INIT                            Start scanning cycle
 .
 .
ABOR                            Abort scan in progress
```


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ARM

The ARM subsystem allows a scan list to be scanned multiple times (1 through 32,767) with one INITiate command.

Subsystem Syntax

ARM
:COUNt <*number*> MIN|MAX
:COUNt? [<MIN|MAX>]

ARM:COUNt

ARM:COUNt <*number*> MIN|MAX allows scanning cycles to occur a multiple of times (1 to 32,767) with one INITiate command when INITiate:CONTinuous OFF|0 is set. MIN sets 1 cycle and MAX sets 32,767 cycles.

Parameters

Name	Type	Range of Values	Default Value
<*number*>	numeric	1 - 32,767 | MIN | MAX	1

Comments

Number of Scans: Use only values between 1 (MIN) to 32767 (MAX) for the number of scanning cycles.

Related Commands: ABORt, INITiate[:IMMediate], INITiate:CONTinuous

***RST Condition:** ARM:COUNt1

Example

Setting Ten Scanning Cycles

```
ARM:COUN 10          Set 10 scanning cycles
SCAN (@100:115)      Set channel list
INIT                 Start scanning cycle
```

ARM:COUNt?

ARM:COUNt? [<MIN|MAX>] returns the current number of scanning cycles set by ARM:COUNt. If a value between MIN and MAX is set, that value for ARM:COUNt is returned.

The optional parameters MIN and MAX allow you to query the module for these values instead of looking them up in the command reference. “1” is returned for the MIN parameter. “32767” is returned for the MAX parameter, regardless of the ARM:COUNt value set.

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Parameters

Name	Type	Range of Values	Default Value
<*MIN* | *MAX*>	numeric	MIN = 1, MAX = 32,767	current cycles

Comments

Related Commands: INITiate[:IMMediate]

Example

Query Number of Scanning Cycles

```
ARM:COUN  55          Set 10 scanning cycles
ARM:COUN?             Query number of scanning cycles;
                      returned value is 55
```


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DISPlay

The DISPlay subsystem monitors the channel state of a selected module (or card) in a switchbox. The DISPlay command subsystem only operates with a RS-232 terminal connected to an E1406 Command Module RS-232 port. These commands control the display on the terminal and would, in most cases, be typed directly from the terminal keyboard.

However, it is possible to send these commands over the GPIB interface, and control the terminal's display. In this case, care must be taken that the instrument receiving the DISPlay command is the same one that is currently selected on the terminal. Otherwise, the GPIB command will have no visible affect.

Subsystem Syntax

```
DISPlay
    :MONitor
        :CARD  <number> | AUTO
        :CARD?
        [:STATe]  <mode>
        [:STATe]?
```

DISPLay:MONitor:CARD

DISPlay:MONitor:CARD *<number>* | AUTO selects the module in a switchbox to be monitored. You must use DISP:MON:STAT ON to actually display the monitored module state to the RS-232 terminal.

Parameters

Name	Type	Range of Values	Default Value
<*number*> | AUTO	numeric	1 - 99	AUTO

Comments

Selecting a Specific Module to be Monitored: Send the card number in a switchbox with the DISPlay:MONitor:CARD command.

Selecting the Present Module to be Monitored: Use the DISPlay:MONitor:CARD AUTO command to select the last module addressed by a switching command ([ROUTe:]CLOSe, for example).

***RST Conditions:** DISPlay:MONitor:CARD AUTO

Example

Select Module #2 in a Switchbox for Monitoring

```
DISP:MON:CARD 2          Select module #2 in a switchbox
```


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DISPLay:MONitor:CARD?

DISPlay:MONitor:CARD? queries the setting of the DISPlay:MONitor:CARD command and returns the module in a switchbox to be monitored.

DISPLay:MONitor[:STATe]

DISPlay:MONitor[:STATe] ***<mode>*** turns the monitor mode ON or OFF. When monitor mode is on, the RS-232 terminal display presents an array of values indicating the open/close state of every switch on the module. This display is dynamically updated each time a switch is opened or closed.

Parameters

Name	Type	Range of Values	Default Value
<*mode*>	boolean	ON | OFF | 1 | 0	OFF | 0

Comments

Monitoring Switchbox Channels: DISPlay:MONitor:STATe ON or DISPlay:MONitor:STATe 1 turns the monitor mode ON to show the channel state of the selected module. DISPlay:MONitor:STATe OFF or DISPlay:MONitor:STATe 0 turns the channel monitor OFF.

Typing in another command on the terminal will cause the DISPlay:MONitor[:STATe] to automatically be set to OFF (0).

Note *Use of the* OFF *parameter is useful only if the command is issued across the GPIB interface.*

Selecting the Module to be Monitored: Use DISPlay:MONitor:CARD <*number*> AUTO to select the module.

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Monitor Mode on an E1406 Command Module Display: A typical display for the E1476A 64-Channel Multiplexer with all channels (all relays) closed follows. The "#H" indicates data is in hexadecimal format. Each channel is represented as a bit in the hex value. The channels are grouped into four blocks of 16 channels each. The tree relays (channels 90 - 94) are in the fifth group. For example, closing only channel 3 would appear as 15-0: #H0008.

15-0 #HFFFF 31-16 #HFFFF 47-32 #HFFFF 63-48 #HFFFF 94-90 #H1F

***RST Condition:** DISPlay:MONitor[:STATe] OFF|0. A *RST also opens all switches on the card. A DISP:MON ON command following a *RST will display the following:

15-0 #H0000 31-16 #H0000 47-32 #H0000 63-48 #H0000 94-90 #H00

Example **Enabling the Monitor Mode**

```
DISP:MON:CARD 2      Select module #2 in a switchbox
DISP:MON 1           Turn the monitor mode on
```

DISPLay:MONitor[:STATe]?

DISPlay:MONitor[:STATe]? queries the monitor mode. The command returns a "1" if monitor mode is on or a "0" if monitor mode is off.

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INITiate

The INITiate command subsystem selects continuous scanning cycles and starts the scanning cycle.

Subsystem Syntax

```
INITiate
    :CONTinuous  <mode>
    :CONTinuous?
    [:IMMediate]
```

INITiate:CONTinuous

INITiate:CONTinuous *<mode>* enables or disables continuous scanning cycles for the switchbox.

Parameters

Name	Type	Range of Values	Default Value
<*mode*>	boolean	ON | OFF | 1 | 0	OFF | 0

Comments

Continuous Scanning Operation: Continuous scanning is enabled with the INITiate:CONTinuous ON or INITiate:CONTinuous 1 command. Sending the INITiate:IMMediate command closes the first channel in the channel list. Each trigger from the trigger source specified by the TRIGger:SOURce command advances the scan through the channel list. A trigger at the end of the channel list closes the first channel in the channel list and the scan cycle repeats.

Noncontinuous Scanning Operation: Noncontinuous scanning is enabled with the INITiate:CONTinuous OFF or INITiate:CONTinuous 0 command. Sending the INITiate:IMMediate command closes the first channel in the channel list. Each trigger from the trigger source specified by the TRIGger:SOURce command advances the scan through the channel list.
A trigger at the end of the channel list opens the last channel in the list and the scanning cycle stops.

Note *The* INITiate:CONTinuous *command does not start a scanning cycle (see* INITiate[:IMMediate]*).*

Stopping Continuous Scan: See the ABORt command.

Related Commands: ABORt, ARM:COUNt, INITiate[:IMMediate], TRIGger:SOURce

***RST Condition:** INITiate:CONTinuous OFF|0

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Example **Enabling Continuous Scans**

```
INIT:CONT  ON          Enable continuous scanning
SCAN  (@100:163)       Set channel list
INIT                   Start scanning cycle
```

INITiate:CONTinuous?

INITiate:CONTinuous? queries the scanning state. With continuous scanning enabled, the command returns “1” (ON). With continuous scanning disabled, the command returns “0” (OFF).

Example **Query Continuous Scanning State**

```
INIT:CONT  ON          Enable continuous scanning
INIT:CONT?             Query continuous scanning state
```

INITiate[:IMMediate]

INITiate[:IMMediate] starts the scanning process and closes the first channel in the channel list. Successive triggers from the source specified by the TRIGger:SOURce command advances the scan through the channel list.

Comments **Starting the Scanning Cycle:** The INITiate:IMMediate command starts scanning by closing the first channel in the channel list. Each trigger received advances the scan to the next channel in the channel list. An invalid channel list generates an error (see [ROUTe:]SCAN).

Stopping Scanning Cycles: See the ABORt command.

Related Commands: ABORt, ARM:COUNt, INITiate:CONTinuous, TRIGger, TRIGger:SOURce

***RST Condition:** None

Example **Starting a Single Scan**

```
SCAN  (@100:163)       Set channel list
INIT                   Start scanning cycle by closing channel 00
                       and proceeding
```


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OUTPut

The OUTPut command subsystem enables one trigger line of the E1406 Command Module. It also can disable the active line.

Subsystem Syntax

OUTPut
:ECLTrg*n* (:ECLTrg0 or :ECLTrg1)
[:STATe] *<mode>*
[:STATe]?
[:EXTernal
[:STATe] *<mode>*
[:STATe]?
:TTLTrg*n* (:TTLTrg0 through :TTLTrg7
[:STATe] *<mode>*
[:STATe]?

OUTPut:ECLTrg*n*[:STATe]

OUTPut:ECLTrg*n*[:STATe] *<mode>* enables (ON or 1) or disables (OFF or 0) the ECL trigger bus pulse on the VXI bus line specified by n. There are two ECL trigger lines on the VXI bus allowing valid values for n to be 0 and 1. “mode” enables (ON or 1) or disables (OFF or 0) the specified ECL Trigger bus line.

Parameters

Name	Type	Range of Values	Default Value
n	numeric	0 or 1	N/A
<mode>	boolean	ON | OFF | 1 | 0	OFF | 0

Comments

When OUTPut:ECLTrgn:STATe ON is set, a trigger pulse occurs each time a channel is closed during a scan.

OUTPut:ECLTrg*n*[:STATe]?

OUTPut:ECLTrg*n*[:STATe]? queries the state of the ECL trigger bus line specified by n. A “1” is returned if the line is enabled; a “0” is returned if it is disabled. Valid values for n are 0 and 1.

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OUTPut[:EXTernal][:STATe]

OUTPut[:EXTernal][:STATe] <mode> enables or disables the “Trig Out” port on the E1406 command module.

OUTPut[:EXTernal][:STATe] ON|1 enables the port and
OUTPut[:EXTernal][:STATe] OFF|0 disables the port.

Parameters

Name	Type	Range of Values	Default Value
<mode>	boolean	ON | OFF | 1 | 0	OFF | 0

Comments

Abbreviated Syntax: OUTPut subsystem commands :EXTernal and :STATe are optional subcommands. The OUTPut command can be abbreviated by executing OUTPut ON or OUTPut OFF.

Enabling “Trig Out” Port: When enabled, the “Trig Out” is pulsed each time a channel is closed during scanning. When disabled, the “Trig Out” is not pulsed. The output pulse is a +5 V negative-going pulse.

“Trig Out” Port Shared by Switchboxes: Once enabled, the “Trig Out” port may be pulsed by the switchbox each time a channel is closed in a switchbox during scanning. To disable the output for a specific switchbox, send the OUTPut[:EXTernal][:STATe] OFF or OUTPut[:EXTernal][:STATe] 0 command for that switchbox. The OUTP OFF command must be executed following use of this port to allow other instrument drivers to control the “Trig Out” port.

Related Commands: [ROUTe:]SCAN, TRIGger:SOURce

***RST Condition:** OUTPut:EXTernal[:STATe] OFF (port disabled)

Example

Enabling “Trig Out” Port

```
OUTP ON                    Enable "Trig Out" port for pulse output
```

OUTPut[:EXTernal][:STATe]?

OUTPut[:EXTernal][:STATe]? queries the present state of the “Trig Out” port on the E1406 Command Module. The command returns “1” if the port is enabled or “0” if disabled.

Example

Query “Trig Out” Port State

```
OUTP ON                    Enable "Trig Out" port for pulse output
OUTP:STAT?                 Query port enable state
```


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OUTPut:TTLTrg*n*[:STATe]

OUTPut:TTLTrg*n*[:STATe] *<mode>* selects and enables which TTL Trigger bus line (0 to 7) will output a trigger when a channel is closed during a scan. This is also used to disable a selected TTL Trigger bus line. "*n*" specifies the TTL Trigger bus line (0 to 7) and "mode" enables (ON or 1) or disables (OFF or 0) the specified TTL Trigger bus line.

Parameters

Name	Type	Range of Values	Default Value
n	numeric	0 to 7	N/A
<*mode*>	boolean	ON | OFF | 1 | 0	OFF | 0

Comments

When OUTPut:TTLTrgn:STATe ON is set, a trigger pulse occurs each time a channel is closed during a scan.

Related Commands: [ROUTe:]SCAN, TRIGger:SOURce, OUTPut:TTLTrgn[:STATe]?

***RST Condition:** OUTPut:TTLTrgn[:STATe] OFF (disabled)

Example

Enabling TTL Trigger Bus Line 7

```
OUTP:TTLT7:STAT 1          Enable TTL Trigger bus line 7 to output
                           pulse after each scanned channel is closed
```

OUTPut:TTLTrg*n*[:STATe]?

OUTPut:TTLTrg*n*[:STATe]? queries the present state of the specified TTL Trigger bus line. The command returns "1" if the specified TTLTrg bus line is enabled or "0" if disabled.

Example

Query TTL Trigger Bus Enable State

This example enables TTL Trigger bus line 7 and queries the enable state. The OUTPut:TTLTrgn? command returns "1" since the port is enabled.

```
OUTP:TTLT7:STAT 1          Enable TTL Trigger bus line 7
OUTP:TTLT7?                Query bus enable state
```


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[ROUTe:]

The [ROUTe:] command subsystem controls switching and scanning operations for the Multiplexer Modules in a switchbox.

Subsystem Syntax

```
[ROUTe:]
    CLOSe  <channel_list>
    CLOSe?  <channel_list>
    OPEN  <channel_list>
    OPEN?  <channel_list>
    SCAN  <channel_list>
        :MODE  <mode>
        :MODE?
    :PORT  <port>
```

[ROUTe:]CLOSe

[ROUTe:]CLOSe *<channel_list>* closes multiplexer channels specified in the <*channel_list*>. The <*channel_list*> is in the form (@*ccnn*), (@*ccnn,ccnn*), or (@*ccnn:ccnn*) where *cc* = card number (00-99) and *nn* = channel number (00-63 and 90-94).

Parameters

Name	Type	Range of Values	Default Value
<*channel_list*>	numeric	cc00 - cc31, cc90 - cc94	N/A

Comments

Closing Channels: To close:

- a single channel use ROUT:CLOS (@*ccnn*)
- multiple channels use ROUT:CLOS (@*ccnn,ccnn*,...)
- sequential channels use ROUT:CLOS (@*ccnn:ccnn*)
- groups of sequential channels use ROUT:CLOS (@*ccnn:ccnn,ccnn:ccnn*)

or any combination of the above.

Closure Order is Not Guaranteed. Closure order for multiple channels with a single command is not guaranteed. A list of channels will not all close simultaneously. The order channels close when specified from a single command is not guaranteed. Use sequential CLOSe commands if needed.

Special Case of Using Upper Range 99 in the Channel List: Specifying the last channel as 99 (such as @100:199) automatically closes all channels on the card number specified by *cc* including tree relays 90 through 94 (see following table for tree relay information).

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Closing the VSA, VSB, CS, RTA and RTB Tree Relays:

Tree Relay Name	Channel Number	Tree Relay Function
VSA	90	Connects bank A to the voltage sense bus
VSB	91	Connects bank B to the voltage sense bus
CS	92	Connects bank B to the current source bus
RTA	93	Connects reference thermistor to bank A
RTB	94	Connects reference thermistor to bank B

Closing VSA and/or VSB Tree Relays: Closing tree relays VSA and/or VSB is typically required for most uses of this multiplexer. This connects channels to the voltage sense lines of the analog bus. See Figure 4-1 for VSA and VSB connections to the analog bus.

Closing the CS Tree Relay: Closing the CS tree relay connects channels in bank B to the current source lines of the analog bus. This is required for four-wire measurements.

Related Commands: [ROUTe:]OPEN, [ROUTe:]CLOSe?

***RST Condition:** All multiplexer channels are open.

Example

Closing Multiplexer Channels

This example closes channel 00 of a card number 1 Multiplexer module and channel 15 of a card number 2 Multiplexer module in a single switchbox configuration.

```
CLOS (@100,215)
```

Close channels 100 and 215. 100 closes channel 00 of multiplexer #1. 215 closes channel 15 of multiplexer #2.

[ROUTe:]CLOSe?

[ROUTe:]CLOSe? *<channel_list>* returns the current state of the channel(s) queried. The <*channel_list*> is in the form (@*ccnn*). The command returns “1” if the channel is closed or returns “0” if the channel is open. If a list of channels is queried, a comma-delineated list of 0 or 1 values is returned in the same order of the <*channel_list*>.

Comments

Query is Software Readback: The ROUTe:CLOSe? command returns the current state of the hardware controlling the specified channel. It does not account for a failed switch element or a relay closed by direct register access (see Appendix B).

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Example

Query Multiplexer Channel Closure

```
CLOS (@100,215)          Close channels 100 and 215
CLOS? (@215)             Query channel 215
```

[ROUTe:]OPEN

[ROUTe:]OPEN <*channel_list*> opens the multiplexer channels specified in the <*channel_list*>. The <*channel_list*> is in the form (@*ccnn*), (@*ccnn*,*ccnn*), or (@*ccnn*:*ccnn*) where *cc* = card number (00-99) and *nn* = channel number (00-63, 90-94 and 99). Channel numbers 95, 96, 97 and 98 will generate an error.

Parameters

Name	Type	Range of Values	Default Value
<*channel_list*>	numeric	cc00 - cc63, cc90 - cc94, cc99	N/A

Comments

Using Upper Range 99 in the Channel List: Specifying the last channel as 99 (such as @100:199) automatically opens all channels on the card number specified by *cc*, including tree relays 90 through 94.

Opening Channels: To open:

- a single channel use ROUT:OPEN (@*ccnn*)
- multiple channels use ROUT:OPEN (@*ccnn,ccnn*,...)
- sequential channels use ROUT:OPEN (@*ccnn:ccnn*)
- groups of sequential channels use ROUT:OPEN (@*ccnn:ccnn,ccnn:ccnn*)

or any combination of the above.

Opening Order is not Guaranteed: Opening order for multiple channels with a single command is not guaranteed. A list of channels will not all open simultaneously. Use sequential OPEN commands if needed.

Opening the VSA, VSB, CS, RTA and RTB Tree Relays: Use channel numbers 90, 91, 92, 93 and 94 to open the VSA (ch 90), VSB (ch 91), CS (ch 92), RTA (ch 93) and RTB (ch94) Tree Relays. See [ROUTe:]CLOSe for a table describing these channels.

Related Commands: [ROUTe:]CLOSe, [ROUTe:]OPEN?

***RST Condition:** All channels open.

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Example Opening Multiplexer Channels

This example opens channel 00 of a card number 1 multiplexer module and channel 63 of a card number 2 multiplexer module in a single switchbox configuration.

OPEN (@100,263)	*Open channels 100 and 263. 100 opens channel 00 of multiplexer #1. 263 opens channel 63 of multiplexer #2.*

[ROUTe:]OPEN?

[ROUTe:]OPEN? *<channel_list>* returns the current state of the channel(s) queried. The <*channel_list*> has the form (@*ccnn*). The command returns "1" if the channel is open or returns "0" if the channel is closed. If a list of channels is queried, a comma-delineated list of 0 or 1 values is returned in the same order of the <*channel_list*>.

Comments

Query is Software Readback: The ROUTe:OPEN? command returns the current state of the hardware controlling the specified channel. It does not account for a failed switch element.

Example Query Multiplexer Channel Open State

OPEN (@100,263)	*Open channels 100 and 263. 100 opens channel 00 of multiplexer #1. 263 opens channel 63 of multiplexer #2.*
OPEN? (@263)	*Query channel 263*

[ROUTe:]SCAN

[ROUTe:]SCAN *<channel_list>* defines the channels to be scanned. The <*channel_list*> is in the form (@*ccnn*), (@*ccnn*,*ccnn*), or (@*ccnn*:*ccnn*) where *cc* = card number (00-99) and *nn* = channel number (00-63 and 99). See comments for explanation of using the special case of 99 in the <*channel_list*>.

Parameters

Name	Type	Range of Values	Default Value
<*channel_list*>	numeric	cc00 - cc63, cc99	N/A

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Comments

Special Case of Using Upper Range 99 in the Channel List: Specifying the last channel as 99 (such as @100:199) automatically scans all channels on the card number specified by *cc*, but does not close tree relays 90 through 94.

Defining Scan List: When ROUTe:SCAN is executed, the channel list is checked for valid card and channel numbers. An error is generated for an invalid channel list.

Scanning Operation: When a valid <*channel_list*> is defined, INITiate[:IMMediate] begins the scan and closes the first channel in the <*channel_list*>. Successive triggers from the source specified by TRIGger:SOURce advance the scan through the <*channel_list*>.

Four-Wire Resistance Scanning: ROUTe:SCAN:MODE FRES restricts the valid <*channel_list*> (see [ROUTe:]SCAN:MODE command).

Stopping Scan: See the ABORt command.

Closing the VSA, VSB, CS, RTA and RTB Tree Relays: The proper state of channels 90 through 94 is automatically controlled by the firmware during a scan and is based on the settings of ROUTe:SCAN:PORT and ROUTe:SCAN:MODE. These are invalid channels to explicitly place in a ROUTe:SCAN <*channel_list*>.

Related Commands: [ROUTe:]CLOSe, [ROUTe:]OPEN, [ROUTe:]SCAN:MODE, [ROUTe:]SCAN:PORT, TRIGger, TRIGger:SOURce

***RST Condition:** All channels open.

Example

Scanning Using External Devices

This BASIC language example shows how to scan channels using the E1406 Command Module and an E3457A Digital Multimeter via GPIB. This example uses the E1406 Command Module “Trig Out” port to synchronize the E1476A Multiplexer module (in a switchbox configuration) to the 3457A multimeter.

The trigger pulse from the "Trig Out" port triggers the 3457A multimeter for a measurement. See Chapter 2 for typical user connections to the multiplexer. The addresses used are 70900 for the E1406 Command Module, 722 for the 3457A Multimeter, and 70914 for the E1476A Multiplexer.

```
 10  OUTPUT 722;"TRIG EXT;DCV"          Multimeter to ext trig and measure dc volts
 20  OUTPUT 70914;"OUTP ON"             Enable "Trig Out" port on cmd module
 30  OUTPUT 70914;"TRIG:SOUR BUS"       Set switchbox to receive Bus triggers
 40  OUTPUT 70914;"SCAN:MODE VOLT"      Set switchbox to measure voltage
                                        during scanning
 50  OUTPUT 70914;"SCAN:PORT ABUS"      Set switchbox to close the appropriate tree
                                        relays during scanning
 60  OUTPUT 70914;"SCAN(@100:163)"      Select the channel list
 70  OUTPUT 70914;"INIT"                Start scanning cycle
 80  FOR I=1 TO 64                      Start count loop
 90    ENTER 722;A                      Enter multimeter reading into A
100    PRINT A                          Print reading in A
110    TRIGGER 70914                    Trigger the switchbox to advance the
                                        channel list
120  NEXT I                             Increment count
130  END
```


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[ROUTe:]SCAN:MODE

[ROUTe:]SCAN:MODE ***<mode>*** sets the multiplexer channels defined by the [ROUTe:]SCAN <*channel_list*> command for none, volts, two-wire ohms, or four-wire ohms measurements.

Parameters

Name	Type	Range of Values	Default Value
<*mode*>	discrete	NONE | VOLT | RES | FRES	NONE

Comments

Order of Command Execution: [ROUTe:]SCAN:MODE must be executed before [ROUTe:]SCAN <*channel_list*> because SCAN:MODE erases the current SCAN list.

NONE and VOLT Mode: When selected, <*channel_list*> is set for volts measurements.

RES Mode: When selected, <*channel_list*> is set for two-wire ohms measurements.

FRES Mode: When selected, <*channel_list*> is set up for four-wire ohms measurements. Only Bank A channel numbers can be scanned in the FRES mode (each Bank A channel is paired with a Bank B channel to comprise four wires). Use only channels 00 to 31 when specifying the channels with the [ROUTe:]SCAN <*channel_list*> command that follow the SCAN:MODE command.

Any channel that closes in Bank A channel automatically closes the paired channel in Bank B (for example, if channel 0 closes, channel 32 automatically closes along with it as do channels 1 and 33, etc.). An error is generated if you specify a channel from Bank B (channels 32 to 63) in a <*channel_list*> for the ROUT:SCAN command while the scan mode is SCAN:MODE FRES (4-wire resistance).

Related Commands: [ROUTe:]SCAN

***RST Condition:** [ROUTe:]SCAN:MODE NONE

Example

Selecting 4-Wire Ohms Mode

```
TRIG:SOUR EXT          Select external trigger source
SCAN:MODE FRES         Select the 4-wire ohms scanning mode
SCAN (@100:107)        Set channel list
INIT                   Start scanning cycle
```


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[ROUTe:]SCAN:MODE?

[ROUTe:]SCAN:MODE? Returns the current state of the scan mode. The command returns NONE, VOLT, RES, or FRES if the scan mode is in the none, volts, two-wire ohms, or four-wire ohms measurement mode, respectively.

Example

Query Scan Mode

Since this example selects the FRES (4-wire ohms) mode, the query command returns FRES.

```
SCAN:MODE  FRES          Select the 4-wire ohms scanning mode
SCAN:MODE?               Query the scanning mode
```

[ROUTe:]SCAN:PORT

[ROUTe:]SCAN:PORT ***<port>*** enables/disables closing the VSA, VSB, CS, RTA and RTB tree relays during scanning. SCAN:PORT ABUS allows the switch driver to close tree relays connecting channels to the analog bus and is required to make scanning measurements from the analog bus.

For correct measurement switching, set the appropriate measurement mode with ROUTe:SCAN:MODE. ROUTe:SCAN:PORT NONE prevents closing the tree relays during scan operation. This is useful if your measurement instrument is not connected to the analog bus.

Parameters

Name	Type	Range of Values	Default Value
<port>	discrete	ABUS | NONE	NONE

Comments

Order of Command Execution: The [ROUTe:]SCAN:PORT command can be executed after the [ROUTe:]SCAN *<channel_list>* command but must occur before the scan is initiated with the INIT command.

***RST Condition:** [ROUTe:]SCAN:PORT NONE. *RST opens all switches on the card and resets the port to ROUTe:SCAN:PORT NONE. Most uses of this multiplexer will require use of ROUTe:SCAN:PORT ABUS to allow subsequent channel connection to the analog bus.

Example

Selecting the ABUS Port

```
TRIG:SOUR  EXT           Select external trigger source
SCAN:MODE  FRES          Select the 4-wire ohms scanning mode
SCAN:PORT ABUS           Select the ABUS port
SCAN  (@100:107)         Set channel list
INIT                     Start scanning cycle
```


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STATus

The STATus subsystem reports the bit values of the Operation Status Register. It also allows you to unmask the bits to be reported from the Standard Event Register and to read the summary bits from the Status Byte Register.

Subsystem Syntax

```
STATus
    :OPERation
        :CONDition?
        :ENABle  <unmask>
        :ENABle?
        [:EVENt?]
    :PRESet
```

The STATus system contains four registers that reside in a SCPI driver, not in the hardware (see Figure 4-1). Two registers are under IEEE 488.2 control: the Standard Event Status Register (*ESE?) and the Status Byte Register (*STB?).

The operational status bit (OPR), service request bit (RQS), standard event summary bit (ESB), message available bit (MAV) and questionable data bit (QUE) in the Status Byte Register (bits 7, 6, 5, 4 and 3 respectively) can be queried with the *STB? command.

Use the *ESE? command to query the “unmask” value for the Standard Event Status Register (the bits you want logically ORed into the summary bit). The registers are queried using decimal weighted bit values. The decimal equivalents for bits 0 through 15 are included in Figure 4-1.

A numeric value of 256 executed in a STAT:OPER:ENABle <*unmask*> command allows only bit 8 to generate a summary bit. The decimal value for bit 8 is 256.

The decimal values are also used in the inverse manner to determine which bits are set from the total value returned by an EVENt or CONDition query. The “SWITCH” driver exploits only bit 8 of Operation Status Register. This bit is called the Scan Complete bit that is set whenever a scan operation completes. Since completion of a scan operation is an event in time, bit 8 will never appear set when STAT:OPER:COND? is queried. However, you can find bit 8 set with the STAT:OPER:EVEN? query command.

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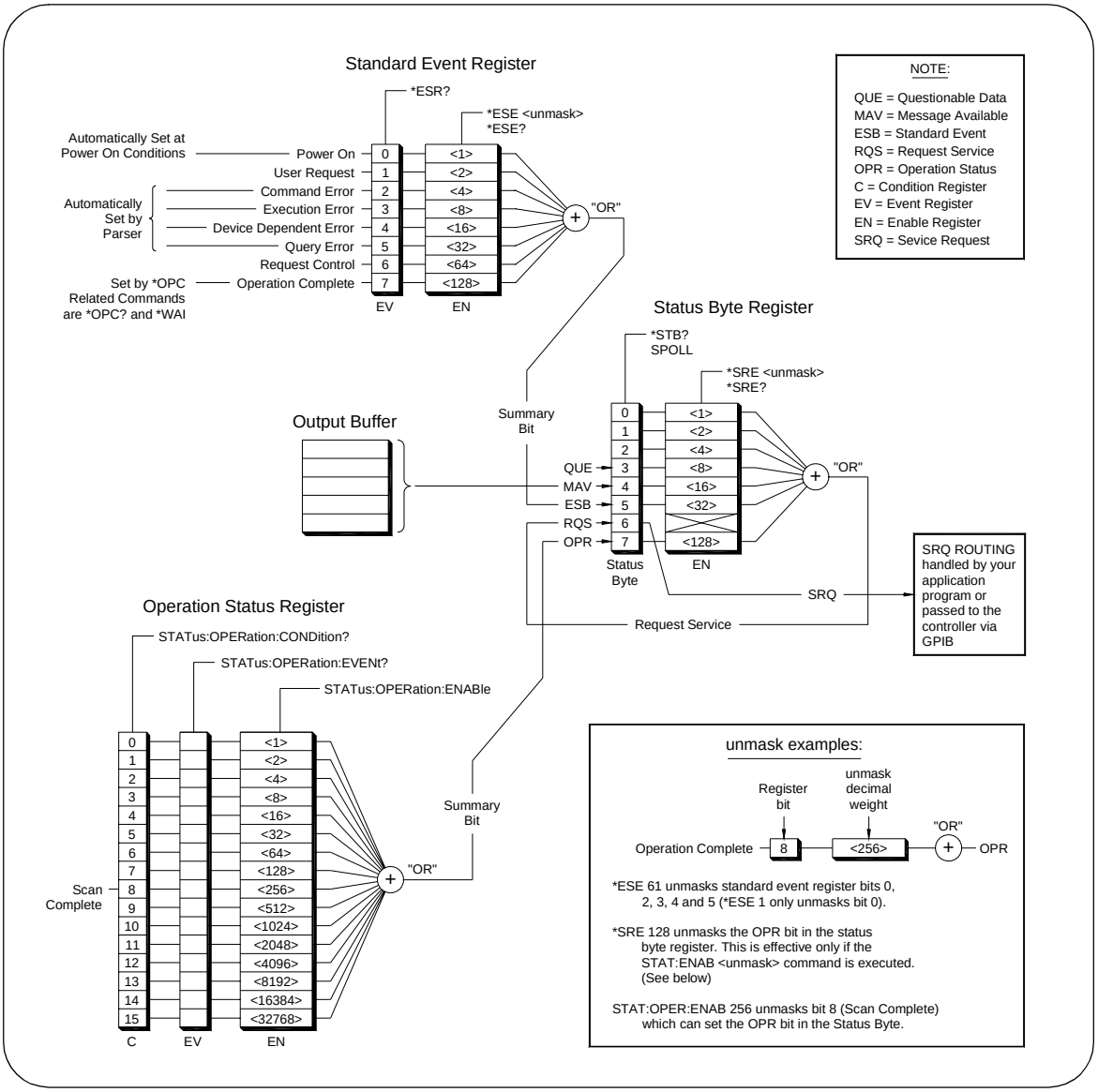


Figure 4-1. E1476A Multiplexer Module Status System

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STATus:OPERation:CONDition?

STATus:OPERation:CONDition? returns the state of the Condition Register in the Operation Status Group. The state represents conditions which are part of the instrument's operation. The “SWITCH” driver does not set bit 8 in this register (see STATus:OPERation[:EVENt]?).

STATus:OPERation:ENABle

STATus:OPERation:ENABle ***<unmask>*** sets an enable mask to allow events recorded in the Event Register to send a summary bit to the Status Byte Register (bit 7). For multiplexer modules, when bit 8 in the Operation Status Register is set to 1 and that bit is enabled by STATus:OPERation:ENABle, bit 7 in the Status Register is set to 1.

Parameters

Name	Type	Range of Values	Default Value
<*unmask*>	numeric	0 through 65,535	N/A

Comments

Setting Bit 7 of the Status Byte Register: STATus:OPERation:ENABle 256 sets bit 7 of the Status Byte Register to 1 after bit 8 of the Operation Status Register is set to 1.

Related Commands: [ROUTe:]SCAN

Example

Enabling Operation Status Register Bit 8

STAT:OPER:ENAB 256	*Enable bit 8 of the Operation Status Register to be reported to bit 7 (OPR) in the Status Byte Register.*

STATus:OPERation:ENABle?

STATus:OPERation:ENABle? returns which bits in the Event Register (Operation Status Group) are unmasked.

Comments

Output Format: Returns a decimal weighted value from 0 to 65,535 indicating which bits are set to true.

Maximum Value Returned: The value returned is the value set by the STAT:OPER:ENAB <*unmask*> command. However, the maximum decimal weighted value used in this module is 256 (bit 8 set to true).

Example

Query the Operation Status Enable Register

STAT:OPER:ENAB?	*Query the Operation Status Enable Register*

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STATus:OPERation[:EVENt]?

STATus:OPERation[:EVENt]? returns the bits in the Event Register (Operation Status Group) that are set. The Event Register indicates when there has been a time-related instrument event.

Comments

Setting Bit 8 of the Operation Status Register: Bit 8 (scan complete) is set to 1 after a scanning cycle completes. Bit 8 returns to 0 (zero) after sending the STATus:OPERation[:EVENt]? command.

Returned Data after sending the STATus:OPERation[:EVENt]?**:** The command returns “+256” if bit 8 of the Operation Status Register is set to 1. The command returns “+0” if bit 8 of the Operation Status Register is set to 0.

Event Register Cleared: Reading the Event Register with STATus:OPERation:EVENt? clears the register.

Aborting a Scan: Aborting a scan will leave bit 8 set to 0.

Related Commands: [ROUTe:]SCAN

Example

Reading the Operation Status Register After a Scanning Cycle

STAT:OPER?	*Return the bit values of the Operation Status Register*
read the register value	*+256 shows bit 8 is set to 1.* *+0 shows bit 8 is set to 0.*

STATus:PRESet

STATus:PRESet affects only the Enable Register by setting all Enable Register bits to 0. It does not affect either the “status byte” or the “standard event status”. PRESet does not clear any of the Event Registers.

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SYSTem

The SYSTem subsystem returns the error numbers and error messages in the error queue of a switchbox. It can also return the types and descriptions of modules (cards) in a switchbox.

Subsystem Syntax

```
SYSTem
   :CDEScription? <number>
   :CPON <number> | ALL
   :CTYPe? <number>
   :ERRor?
```

SYSTem:CDEScription?

SYSTem:CDEScription? *<number>* returns the description of a selected module (card) in a switchbox.

Parameters

Name	Type	Range of Values	Default Value
<*number*>	numeric	1 through 99	N/A

Comments

64-Channel 3-Wire Relay Multiplexer Module Description: The SYSTem:CDEScription? command returns:

"64 Channel 3 Wire Relay Multiplexer"

Example

Reading the Description of a Card #1 Module

```
SYST:CDES? 1                    Return the description
```

SYSTem:CPON

SYSTem:CPON *<number>* | ALL opens the selected module (card), or all modules in a switchbox to their power-on state.

Parameters

Name	Type	Range of Values	Default Value
<*number*>	numeric	1 through 99	N/A

Comments

Differences between *RST and CPON: SYSTem:CPON ALL and *RST opens all channels of all modules in a switchbox, while SYSTem:CPON <*number*> opens the channels in only the module (card) specified in the command.

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Example Setting Card #1 Module to its Power-on State

```
SYST:CPON 1          Set module #1 channels to power-on state (open)
```

SYSTem:CTYPe?

SYSTem:CTYPe? *<number>* returns the module (card) type of a selected module in a switchbox.

Parameters

Name	Type	Range of Values	Default Value
<*number*>	numeric	1 through 99	N/A

Comments

E1476A Multiplexer Module Model Number: SYSTem:CTYPe? <*number*> returns: HEWLETT-PACKARD,El476A,0,A.08.00 where the 0 after E1476A is the module serial number (always 0) and A.08.00 is an example of the module revision code number.

Example Reading the Model Number of a Card #1 Module

```
SYST:CTYP? 1         Return the model number
```

SYSTem:ERRor?

SYSTem:ERRor? returns the error numbers and corresponding error messages in the error queue of a switchbox. See Appendix C for a listing of switchbox error numbers and messages.

Comments

Error Numbers/Messages in the Error Queue: Each error generated by a switchbox stores an error number and corresponding error message in the error queue. The error message can be up to 255 characters long, but typically is much shorter.

Clearing the Error Queue: An error number/message is removed from the queue each time the SYSTem:ERRor? command is sent. The errors are cleared first-in, first-out. When the queue is empty, each following SYSTem:ERRor? query returns +0, “No error”. To clear all error numbers/messages in the queue, execute the *CLS command.

Maximum Error Numbers/Messages in the Error Queue: The queue holds a maximum of 30 error numbers/messages for each switchbox. If the queue overflows, the last error number/message in the queue is replaced by -350, “Too many errors”. The least-recent error numbers/messages remain in the queue and the most recent are discarded.

Example Reading the Error Queue

```
SYST:ERR?            Query the error queue
```


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TRIGger

The TRIGger command subsystem controls the triggering operation of the E1476A Multiplexer modules in a switchbox.

Subsystem Syntax

```
TRIGger
    [:IMMediate]
    :SOURce <source>
    :SOURce?
```

TRIGger[:IMMediate]

TRIGger[:IMMediate] causes a trigger to occur when the defined trigger source is TRIGger:SOURce BUS or TRIGger:SOURce HOLD. This can be used to trigger a suspended scan operation.

Comments

Executing the TRIGger[:IMMediate] Command: A channel list must be defined with [ROUTe:]SCAN <*channel_list*> and INITiate[:IMMediate] must be executed before TRIGger[:IMMediate] will execute.

BUS or HOLD Source Remains: If selected, the TRIGger:SOURce BUS or TRIGger:SOURce HOLD commands remain in effect after triggering a switchbox with the TRIGger[:IMMediate] command.

Related Commands: INITiate, [ROUTe:]SCAN, TRIGger:SOURce

Example

Advancing Scan Using TRIGger Command

```
TRIG:SOUR HOLD          Set trigger source to HOLD
SCAN (@100:163)         Define channel list
INIT                    Start scanning cycle
loop statement          Start count loop
TRIG                    Advance scan to next channel
increment loop          Increment loop count
```


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TRIGger:SOURce

TRIGger:SOURce ***<source>*** specifies the trigger source to advance the channel list during scanning.

Parameters

Name	Type	Description
BUS	discrete	*TRG or GET command
ECLTrgn	numeric	ECL Trigger bus line 0 or 1
EXTernal	discrete	“Trig In” port
HOLD	discrete	Hold Triggering
IMMediate	discrete	Immediate Triggering
TTLTrg*n*	numeric	TTL Trigger bus line 0 - 7

Comments

Enabling the Trigger Source: The TRIGger:SOURce command only selects the trigger source. The INITiate[:IMMediate] command enables the trigger source. The trigger source must be selected using the TRIGger:SOURce command before executing the INIT command.

One Trigger Input Selected at a Time: Only one input (ECLTrg0 or 1; TTLTrg0, 1, 2, 3, 4, 5, 6 or 7; or EXTernal) can be selected at one time. Enabling a different trigger source will automatically disable the active input. For example, if TTLTrg1 is the active input and TTLTrg4 is enabled, TTLTrg1 will become disabled and TTLTrg4 will become the active input.

Using the TRIGger Command: You can use TRIGger[:IMMediate] to advance the scan when TRIGger:SOURce BUS or TRIGger:SOURce HOLD is selected.

Using External Trigger Inputs: With TRIGger:SOURce EXTernal selected, only one switchbox at a time can use the external trigger input at the E1406 “Trig In” port.

Using TTL or ECL Trigger Bus Inputs: These triggers are from the VXI backplane trigger lines ECL[0,1] and TTL[0-7]. These may be used to trigger the “SWITCH” driver from other VXI instruments.

Using EXTernal, TTLTrgn, and ECLTrgn Trigger Inputs: After using TRIGger:SOURce EXT|TTLTn|ECLTn, the selected trigger source remains assigned to the “SWITCH” driver until it is relinquished through use of the TRIG:SOUR BUS | HOLD command. While the trigger is in use by the “SWITCH” driver, no other drivers operating on the E1406 command module will have access to that particular trigger source.

Likewise, other drivers may consume trigger resources which may deny access to a particular trigger by the “SWITCH” driver. You should always release custody of trigger sources after completion of an activity by setting the trigger source to BUS or HOLD (TRIG:SOUR BUS|HOLD).

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Using Bus Triggers: To trigger the switchbox with TRIGger:SOURce BUS selected, use the IEEE 488.2 common command *TRG or the GPIB Group Execute Trigger (GET) command.

"Trig Out" Port Shared by Switchboxes: See the OUTPut command.

Related Commands: ABORt, [ROUTe:]SCAN, OUTPut

***RST Condition:** TRIGger:SOURce IMMediate

Example Scanning Using External Triggers

In this example, the trigger input is applied to the E1406 Command Module "Trig In" port.

```
TRIG:SOUR EXT          Set trigger source to external
SCAN (@100:163)        Set channel list
INIT                   Start scanning cycle
(trigger externally)   Advance channel list to next channel
```

Example Scanning Using Bus Triggers

```
TRIG:SOUR BUS          Set trigger source to bus
SCAN (@100:163)        Set channel list
INIT                   Start scanning cycle
*TRG                   Advance channel list to next channel
```

TRIGger:SOURce?

TRIGger:SOURce? returns the current trigger source for the switchbox. Command returns BUS, EXT, HOLD, IMM, TTLT0-7, or ECLT0-1 for sources BUS, EXTernal, HOLD, IMMediate, TTLTrgn, or ECLTrgn, respectively.

Example Querying the Trigger Source

This example sets external triggering and queries the trigger source. Since external triggering is set, TRIG:SOUR? returns "EXT".

```
TRIG:SOUR EXT          Set external trigger source
TRIG:SOUR?             Query trigger source
```


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SCPI Commands Quick Reference

The following table summarizes the SCPI commands for the E1476A 64-Channel Relay Multiplexer used in a switchbox.

Command		Description
ABORt		Abort a scan in progress
ARM	:COUNt *<number>* :COUNt? [MIN|MAX]	Multiple scans per INIT command Query number of scans
DISPlay	:MONitor:CARD *<number>* | AUTO :MONitor:CARD? :MONitor[:STATe] *<mode>* :MONitor[:STATe]?	Select module to be monitored Query the card number Select monitor mode Query the monitor mode
INITiate	:CONTinuous ON | OFF :CONTinuous? [:IMMediate]	Enable/disable continuous scanning Query continuous scan state Start a scanning cycle
OUTPut	:ECLTrgn[:STATe] ON | OFF | 1 | 0 :ECLTrgn[:STATe]? [:EXTernal][:STATe] ON | OFF | 1 | 0 [:EXTernal][:STATe]? :TTLTrgn[:STATe] ON |OFF | 1 | 0 :TTLTrgn[:STATe]?	Enable/disable the specified ECL trigger line Query the specified ECL trigger line Enable/disable the “Trig Out” port on the command module Query the external state Enable/disable the specified TTL trigger line Query the specified TTL trigger line
[ROUTe:]	CLOSe *<channel _list>* CLOSe? *<channel _list>* OPEN *<channel_list>* OPEN? *<channel _list>* SCAN *<channel_list>* SCAN:MODE *<mode>* SCAN:MODE? SCAN:PORT *<port>*	Close channel(s) Query channel(s) closed Open channel(s) Query channel(s) opened Define channels for scanning Set scan mode to NONE, VOLT, RES, or FRES Query the scan mode Enable channel connections to analog bus (ABUS or NONE)
STATus	:OPERation:CONDition? :OPERation:ENABle *<unmask>* :OPERation:ENABle? :OPERation[:EVENt]? :PRESet	Return contents of the Operation Condition Register Enable events in the Operation Event Register to be reported Return the unmask value set by the :ENABle command Return the contents of the Operation Event RegisterSets Enable Register bits to 0
SYSTem	:CDEScription? *<number>* :CPON *<number>* | ALL :CTYPe? *<number>* :ERRor?	Return description of module in a switchbox Open all channels on specified module(s) Return the module type Return error number/message in a switchbox error queue
TRIGger	[:IMMediate] :SOURce BUS :SOURce ECLTrg*n* :SOURce EXTernal :SOURce HOLD :SOURce IMMediate :SOURce TTLTrg*n* :SOURce?	Cause a trigger to occur Trigger source is *TRG Trigger is the VXIbus ECL trigger bus line n Trigger source is “Trig In” (on the E1406) Hold off triggering Trigger source is the internal triggers Trigger is the VXIbus TTL trigger bus line n Query scan trigger source

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IEEE 488.2 Common Commands Reference

This table lists the IEEE 488.2 Common (*) commands accepted by the E1476A Multiplexer module. For more information on Common Commands, see the ANSI/IEEE Standard 488.2-1987. The common commands *RCL, *SAV and *TST? perform specific actions with the E1476A as described in the table.

Command	Description
*CLS	Clears all status registers (see STATus:OPERation[:EVENt]?) and clears the error queue
*ESE *<register value>*	Enable Standard Event
*ESE?	Enable Standard Event Query
*ESR?	Standard Event Register Query
*IDN?	Instrument ID Query; returns identification string of the module
*OPC	Operation Complete
*OPC?	Operation Complete Query
*RCL *<numeric state>*	Recalls the instrument state saved by *SAV. You must reconfigure the scan list.
*RST	Resets the module. Opens all channels and invalidates current channel list for scanning. Sets ARM:COUN 1, TRIG:SOUR IMM, and INIT:CONT OFF.
*SAV *<numeric state>*	Stores the instrument state but does not save the scan list
*SRE *<register value>*	Service request enable, enables status register bits
*SRE?	Service request enable query
*STB?	Read status byte query
*TRG	Triggers the module to advance the scan when scan is enabled and trigger source is TRIGger:SOURce BUS
*TST?	Self-test. Executes an internal self-test and returns only the first error encountered. Does not return multiple errors. The following is a list of responses you can obtain where “cc” is the card number with the leading zero deleted. +0 if self test passes +cc01 for firmware error +cc02 for bus error (problem communicating with the module) +cc03 for incorrect ID information read back from the module's ID register +cc05 for hardware and firmware have different values Possibly a hardware fault or anoutside entity is register programming the E1476A +cc10 if an interrupt was expected but not received +cc11 if the busy bit was not held for a sufficient amount of time
*WAI	Wait to Complete

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Notes:

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Appendix A
Specifications

General

Module Size/Device Type:
C-Size VXIbus, Register based, A16/D16

Interrupt Level:
1-7, selectable

Connectors Used:
P1 and P2

Relay Life (typical):

Condition	Number of Operations
Single Levels Load	500 x 10^7
Full Load	> 5 x 10^7

Relays are subject to normal wearout based on the number of operations.

Power-up and Power-down States:
all relays open

Reference Junction Measurement Accuracy:
(18° to 28°C operating): 0.38°C

Terminal Wire Size:
22-26AWG

Power Requirements:

Voltage:	+5	+12
Peak Module Current (A):	0.80*	0.01
Dynamic Module Current (A):	0.40	0.00

*1.0A with all relays energized

Watts/slot: 4

Cooling/slot:
0.10 mm H_2O @ 0.30 Liter/sec for 10°C rise

Operating Temperature:
0 - 55°C

Operating Humidity:
65% RH, 0 - 40°C

Input Characteristics

Maximum Input Voltage:
120 Vdc or acrms Terminal to Terminal
120 Vdc or acrms Terminal to Chassis

Maximum Current per Channel (non-inductive):35 mA

Maximum Switchable Power per Channel: 4VA

DC Performance

Thermal Offset per Channel:
<4µV
<2µV (10 samples averaged)

Closed Channel Resistance:
100Ω , ±5Ω

Insulation Resistance (between any two points):
>109 W (at ≤40°C, 95% RH)

AC Performance

Closed Channel Capacitance:
<175 pF (H-L)
<300 pF (L-G)
<1500 pF (G-C)

Minimum Bandwidth (-3dB, 50Ω source/load):
100 kHz

Crosstalk(db) (Channel-to-Channel):
-70 (100kHz)
-45 (10 MHz)

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Appendix B
Register-Based Programming

Using This Appendix

This appendix contains information you can use for register-based programming of the E1476A 64-Channel, 3-Wire Multiplexer, including:

- Register Programming vs. SCPI Programming 101
- Register Addressing 101
- Register Descriptions 104
- Program Timing and Execution 108
- Programming Example 110

Register Programming vs. SCPI Programming

The E1476A is a register-based module which does not support the VXIbus word serial protocol. When a SCPI command is sent to the multiplexer, the instrument driver resident in the E1406 Command Module parses the command and programs the multiplexer at the register level.

NOTE *If SCPI is used to control this module, register programming is not recommended. The SCPI Driver maintains an image of the card state. The driver will be unaware of changes to the card state if you alter the card state by using register writes.*

Register-based programming is a series of reads and writes directly to the multiplexer registers. This increases throughput speed since it eliminates command parsing and allows the use of an embedded controller. Also, register programming provides an avenue for users to control a VXI module with an alternate VXI controller device and eliminate the need for using an E1406 Command Module.

Register Addressing

Register addresses for register-based devices are located in the upper 25% of VXI A16 address space. Every VXI device (up to 256 devices) is allocated a 32 word (64 byte) block of addresses. With eight registers, the E1476A multiplexer uses eight of the 64 addresses allocated. Figure B-1 shows the register address location within A16as it might be mapped by an embedded controller. Figure B-2 shows the location of A16 address space in the E1406 Command Module.

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The Base Address

When you are reading or writing to a multiplexer register, a hexadecimal or decimal register address is specified. This address consists of a base address plus a register offset. The base address used in register-based programming depends on whether the A16 address space is outside or inside the E1406 Command Module.

A16 Address Space Outside the Command Module

When the E1406 Command Module is not part of your VXIbus system (Figure B-1), the multiplexer's base address is computed as shown, where the "16" at the end of the address indicates a hexidecimal number.

$$C000_{16} + (LADDR * 64)_{16} \textbf{ or } 49{,}152 + (LADDR * 64)$$

$C000_{16}$ (49,152) is the starting location of the register addresses, LADDR is the multiplexer's logical address, and 64_{10} is the number of address bytes per VXI device. For example, the multiplexer's factory-set logical address is 112 (7016). If this address is not changed, the multiplexer will have a base address of $C000_{16} + (112 * 64)_{16} = C000_{16} + 1C00_{16} = DC00_{16}$ ***or*** (decimal) 49,152 + (112 * 64) = 49,152 + 7168 = 56,320.

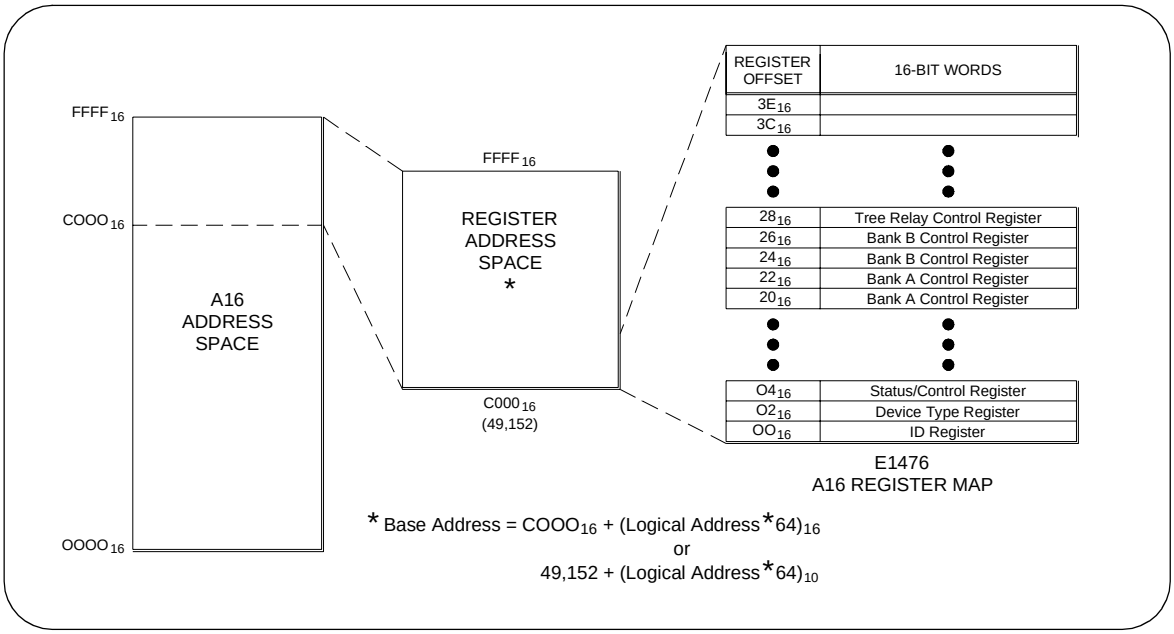


Figure B-1. Registers Within A16 Address Space

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A16 Address Space Inside the Command Module or Mainframe

When the A16 address space is inside the E1406 Command Module (Figure B-2), the multiplexer's base address is computed as $1FC000_{16}$ + (LADDR * $64)_{16}$ **or** 2,080,768 + (LADDR * 64). $1FC000_{16}$ (2,080,768) is the starting location of the VXI A16 addresses, LADDR is the multiplexer's logical address, and 64 is the number of address bytes per register-based device.

The multiplexer's factory set logical address is 112 if this address is not changed, the multiplexer will have a base address of $1FC000_{16}$ + (112 * $64)_{16}$ = $1FC000_{16}$ + $1C00_{16}$ = $1FDC00_{16}$ ***or*** 2,080,768 + (112 * 64) = 2,080,768 + 1536 = 2,087,936.

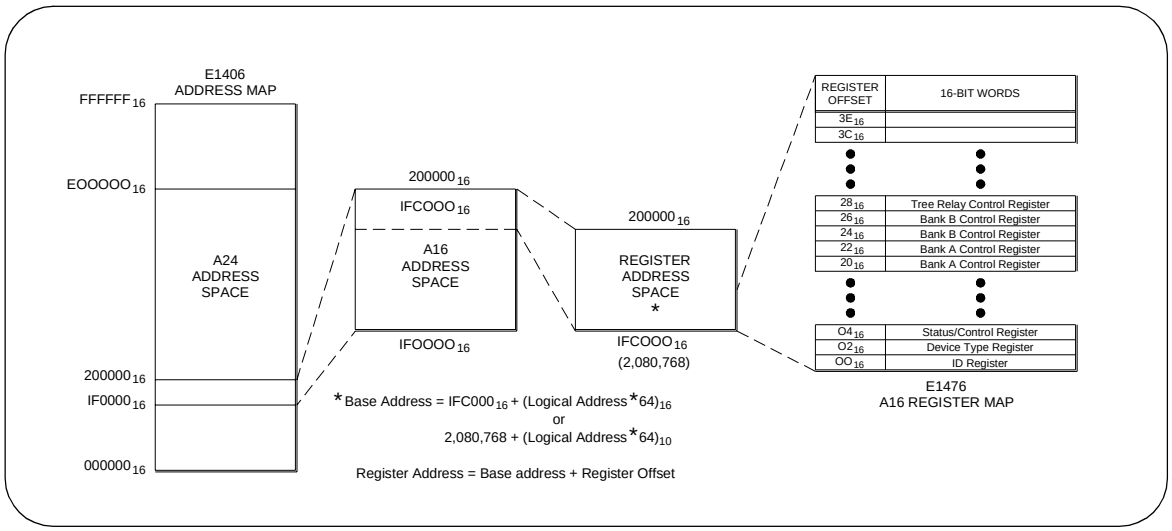


Figure B-2. Registers Within the Command Module A16 Address Space

Register Offset

The register offset is the register's location in the block of 64 address bytes. For example, the multiplexer's Status/Control Register has an offset of 04_{16}. When you write a command to this register, the offset is added to the base address to form the register address. For example, $DC00_{16}$ + 04_{16} = $DC04_{16}$ or $1FDC00_{16}$ + 04_{16} = $1FDC04_{16}$ ***or*** 56,320 + 4 = 56,324 or 2,087,936 + 4 = 2,087,940.

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Register Descriptions

There are six WRITE and eight READ registers on the multiplexer. This section contains a description of the registers followed by a bit map of the registers in sequential address order. Undefined register bits appear as "1" when the register is read and have no effect when the register is written to.

The WRITE Registers

You can write to the following multiplexer registers:

- Status/Control register (base + 04_{16})
- Channels 0 through 15 Relay Control Register (base + 20_{16})
- Channels 16 through 31 Relay Control Register (base + 22_{16})
- Channels 32 through 47 Relay Control Register (base + 24_{16})
- Channels 48 through 63 Relay Control Register (base + 26_{16})
- Tree Relays 90 through 94 Control Register (base + 28_{16})

The READ Registers

You can read the following multiplexer registers:

- Manufacturer ID Register (base + 00_{16})
- Device Type Register (base + 02_{16})
- Status/Control Register (base + 04_{16})
- Channels 0 through 15 Relay Control Register (base + 20_{16})
- Channels 16 through 31 Relay Control Register (base + 22_{16})
- Channels 32 through 47 Relay Control Register (base + 24_{16})
- Channels 48 through 63 Relay Control Register (base + 26_{16})
- Tree Relays 90 through 94 Control Register (base + 28_{16})

The ID Register

Reading the ID register returns $FFFF_{16}$ indicating the manufacturer is Hewlett-Packard and the module is an A16 register-based device. See "Programming Example" to see how to read the ID Register.

base + 00_{16}	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Write	Undefined															
Read	Manufacturer ID - returns $FFFF_{16}$ in Hewlett-Packard A16 only register based card															

The Device Type Register

Reading the Device Type Register returns 0218_{16} which identifies the device as the E1476A 64-Channel Multiplexer. See "Programming Example" to see how to read the Device Type Register.

base + 02_{16}	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Write	Undefined															
Read	0218_{16}															

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The Status/Control Register

Writes to the Status/Control Register (base + 04_{16}) enables you to disable/enable the interrupt generated when channels are closed.

base + 04_{16}	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Write	Undefined									D	Undefined					R
Read	Unde-fined	M	Undefined						B	D	Undefined					

Status/Control Register Bits Defined:

*WRITE BITS (Status/Control Register)		
bit 0	R	Writing a "1" to this bit resets the switch to the power-on state (all channels open). You must set bit 0 back to a logical "0" before resuming normal operations of the module such as closing and opening switches.
bit 6	D	Disable interrupt by writing a "1" to this bit (this is set back to "0" with a reset).

**READ BITS (Status/Control Register)		
bit 6	D	Interrupt Status; "1" = disabled, "0" = enabled.
bit 7	B	Busy Status; "1" = not busy, "0" = busy.
bit 14	M	MODID bit; if the bit is "0", module has been selected.

To disable the interrupt generated when channels are opened or closed, write a “1” to bit 6 of the Status/Control Register (base + 04_{16}). Typically, interrupts are only disabled to “peek-poke” a module. Refer to your command module's operating manual before disabling the interrupt. Interrupts must be enabled to operate the “SWITCH” and “VOLTMTR” instrument drivers.

Reading the Status/Control Register Module Status

Each relay requires about 1msec execution time during which time the multiplexers are “busy”. Bit 7 of this register is used to inform the user of a busy condition. The interrupt generated after a channel has been closed can be disabled. Bit 6 of this register is used to inform the user of the interrupt status.

As an example, if the Status Register (base + 04_{16}) returns "BDFF (1011110111111111)" the multiplexer module is not busy (bit 7 set), and the module interrupts are disabled (bit 6 set).

Relay Control Registers

Writes to the Relay Control Registers (base + 20_{16} to 28_{16}) allows you to open or close any of the 64-channel relays or the five tree relays. Any number of relays per bank can be closed at a time.

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For example, to connect both bank A and bank B to the analog bus, write a "1" to bits 0 and 1 of the Tree Relay Control Register (base + 28_{16}) to close channel 90 (VSA) and channel 91 (VSB). All other bits must be set to "0".

base + 20_{16}	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Write	ch15	ch14	ch13	ch12	ch11	ch10	ch9	ch8	ch7	ch6	ch5	ch4	ch3	ch2	ch1	ch0
Read																

base + 22_{16}	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Write	ch31	ch30	ch29	ch28	ch27	ch26	ch25	ch24	ch23	ch22	ch21	ch20	ch19	ch18	ch17	ch16
Read																

base + 24_{16}	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Write	ch47	ch46	ch45	ch44	ch43	ch42	ch41	ch40	ch39	ch38	ch37	ch36	ch35	ch34	ch33	ch32
Read																

base + 26_{16}	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Write	ch63	ch62	ch61	ch60	ch59	ch58	ch57	ch56	ch55	ch54	ch53	ch52	ch51	ch50	ch49	ch48
Read																

base + 28_{16}	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Write	undefined											RTB ch94	RTA ch93	CS ch92	VSB ch91	VSA ch90
Read	undefined															

* Write a "1" to close a channel; write a "0" to open a channel.
** Reading the channel bit indicates the state of the relay driver circuit only. It cannot detect a defective relay.

Tree Relay Control Bits		
bit 0	VSA (ch90)	Connects the Voltage Sense H-L-G terminals of the Analog Bus to Bank A.
bit 1	VSB (ch91)	Connects the Voltage Sense H-L-G terminals of the Analog Bus to Bank B.
bit 2	CS (ch92)	Connects the Current Source H-L-G terminals of the Analog Bus to Bank B.
bit 3	RTA (ch93)	Connects the Reference Thermistor to Bank A for voltage sense.
bit 4	RTB (ch94)	Connects the Reference Thermistor to Bank B for current source.

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Resetting the Multiplexer

There are two ways to reset the multiplexer:

1. You can write a “0” to all bits in the Relay Control Registers.
2. You can use bit 0 (R) in the Status/Control Register. The R bit in the Status/Control Register must be set to “1” to reset the E1476A module and subsequently set to "0" to restore normal operation.

NOTE *You must wait at least 100 msec after writing a “1” to the R bit of the Status/Control Register before you write a “0” to that bit to restore normal operation.*

Reading the Relay Control Registers

Reading the Relay Control Registers returns a hexadecimal number that indicates a “1” for each bit representing a channel that is closed. A bit that is “0” indicates the channel is open.

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Program Timing and Execution

This section contains generalized flowcharts and comments for performing program timing and execution and other procedures. The flowcharts identify the registers used and the status bits monitored to ensure execution of the program.

Closing Channels

This flowchart shows how to close (or open) a multiplexer channel and determine when it has finished closing (or opening). The address of the multiplexer Status Register is base + 04_{16}. The address of the channel is the base address plus the channel offset. Multiplexer Status Register bit 7 (the BUSY bit) is monitored to determine when a multiplexer channel can be closed (or opened) and when a channel has finished closing (or opening).

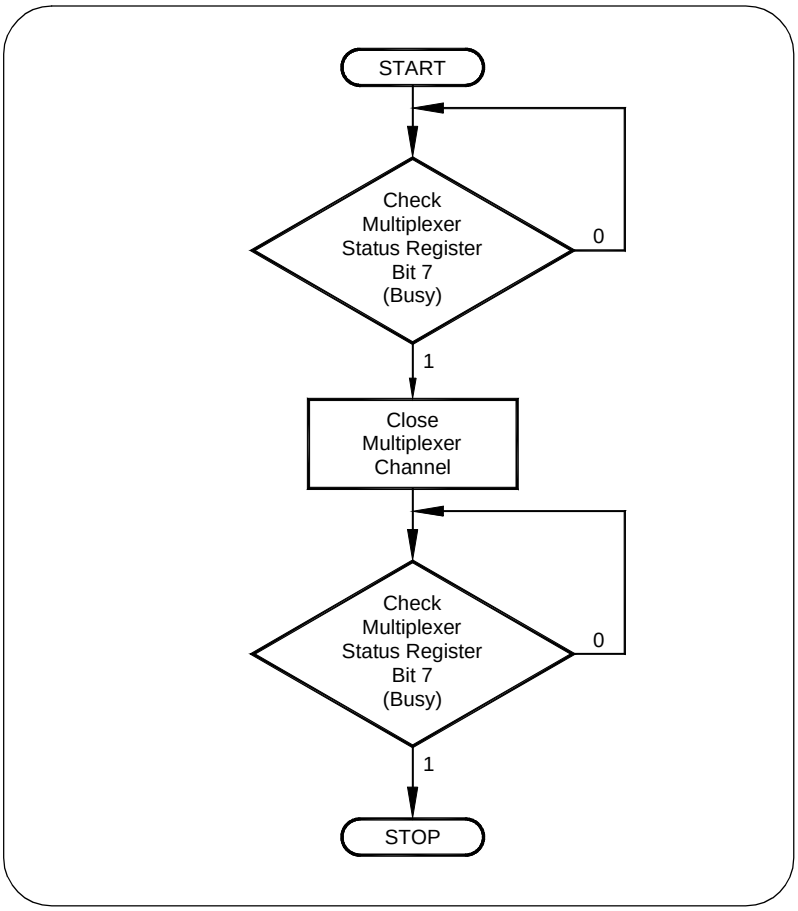


Figure B-3. Closing/Opening a Multiplexer Channel

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Using a Multimeter with the Multiplexer

This flowchart shows the timing sequence between closing an E1476A multiplexer channel and triggering an E1326/E1411 multimeter.

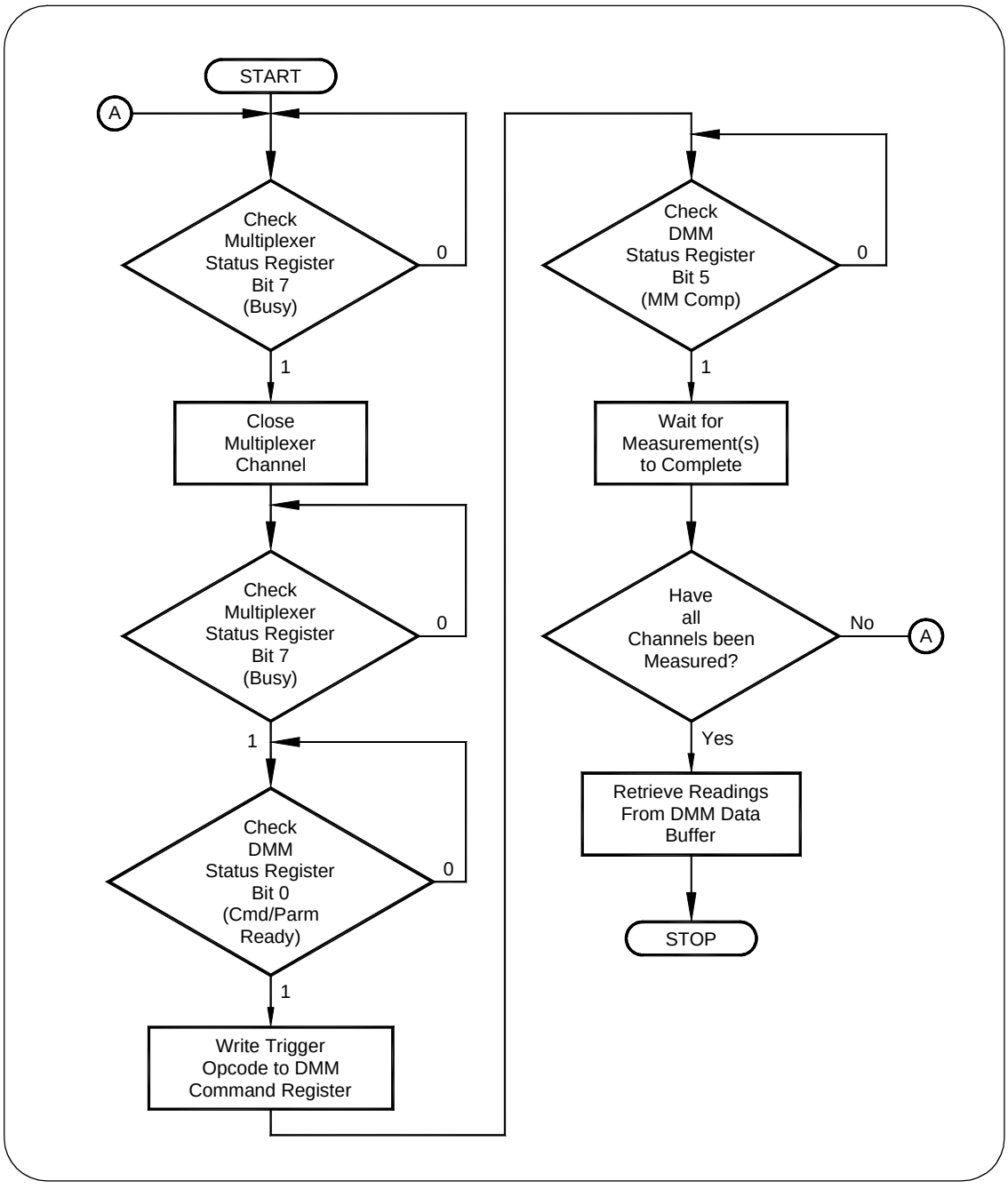


Figure B-4. Program Timing Between Multiplexer and Multimeter

The registers used are:

- Multiplexer: Multiplexer Status Register (base + 04_{16})
- Multimeter: Multimeter Status Register (base + 04_{16})
- Multimeter: Multimeter Command Register (base + 08_{16})

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Multiplexer Status Register bit 7 (BUSY bit) is monitored to determine when a channel can be closed (or opened), and when a channel has finished closing (or opening). Multimeter status bit 0 (ready for command) is monitored to determine when a trigger opcode can be written to the Command Register (flowchart assumes the multimeter is already configured).

Multimeter status bit 5 (multimeter complete) is monitored to determine when the analog-to-digital (A/D) conversion is in progress, and thus, when to advance the channel. This enables each channel to be measured before the readings are read from the buffer.

The channel can also be advanced by monitoring bit 4 (Data Ready). However, before measuring the next channel, readings from the previous channel must be read from the buffer in order to clear the bit. Multimeter Autozero is often turned on in order to detect when bit 5 is active.

Programming Example

The example program in this section demonstrates one way to register program the multiplexer, including:

- Reading the ID, Device Type, and Status Registers
- Closing/Opening a channel
- Stand-Alone Multiplexer Measurements
- Scanning through channels

System Configuration

The following C language example programs use Borland's Turbo C++® programming language and the SICL interface library. However, you can use a PC connected via GPIB to the E1406 Command Module.

NOTE *If you use the E1406 with SCPI commands, you can use the 1476A SCPI driver installed in the E1406 firmware and register programming is not necessary. Chapter 4 describes the SCPI commands for the switchbox driver.*

Example Program

The following example program contains segments that:

- Read the ID and Device Type Registers
- Read the Status Register
- Close a group of channels and the associated tree relay
- Resets the module to open all channels
- Scans through all the channels on the module

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Beginning of Program

```
/* This program resets the E1476A, reads the ID Register, reads the Device */
/* Type Register, closes tree relays and channels and reads the multiplexer's */
/* Relay Control Registers, opens channels and scans all 64 channels on the */
/* module.*/
/* (Borland Turbo C++ program using SICL I/O calls.) */
#include <sicl.h>
#include <stdio.h>
#include <stdlib.h>
#include <math.h>
#include <dos.h>

/* function prototypes */
void reset_mux(char *base_addr);
void delay (unsigned milliseconds);
```

Program Main

```
void main(void)
{  double ldexp(double i, int exp);
   char *base_addr;
   int j, k;
   unsigned short chan_0_15_reg, chan_16_31_reg;/* Bank A channels */
   unsigned short chan_32_47_reg, chan_48_63_reg;/* Bank B channels */
   unsigned short chan_tree_reg;/* Tree relays */
   unsigned short id_reg, dt_reg;/* ID and Device Type */
   unsigned short stat_reg; /* Status Register */

   /* create and open a device session */
    INST e1476a; e1476a = iopen("vxi,112");

   /* map the E1476A registers into user memory space */
    base_addr = imap(e1476a, I_MAP_VXIDEV, 0, 1, NULL);

   /* clear the user screen */
    clrscr();

   /* reset the E1476A */
    reset_mux(base_addr);
```

Read ID and Device Type Registers

```
/********* read the multiplexer's ID and Device Type registers *********/

    id_reg = iwpeek((unsigned short *)(base_addr + 0x00));
    dt_reg = iwpeek((unsigned short *)(base_addr + 0x02));
    printf("ID register = 0x%4X\nDevice Type register = 0x%4X\n",
    id_reg, dt_reg);
```

Read Status Register

```
/*************** read the multiplexer's status register *************/

    stat_reg = iwpeek((unsigned short *)(base_addr + 0x04));
    printf("Status register = 0x%4X\n", stat_reg);
```


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Close and Open Channels

```
/******************** close and open channels ******************/

 /* close channels 0-15 by setting all bits in register (base + 0x20) to 1 */
   iwpoke((unsigned short *)(base_addr + 0x20), 0xffff);

   /* write a 1 to the register for tree relay 90 (base + 0x28) */
   /* so channels 0-15 can be connected to the analog bus */
    iwpoke((unsigned short *)(base_addr + 0x28), 1);

   /* read the E1476A relay control registers and print their value */

    chan_0_15_reg = iwpeek((unsigned short *)(base_addr + 0x20));
    chan_16_31_reg = iwpeek((unsigned short *)(base_addr + 0x22));
    chan_32_47_reg = iwpeek((unsigned short *)(base_addr + 0x24));
    chan_48_63_reg = iwpeek((unsigned short *)(base_addr + 0x26));
    chan_tree_reg = iwpeek((unsigned short *)(base_addr + 0x28));

    printf("Channels 00-15 register = 0x%4X\n", chan_0_15_reg);
    printf("Channels 16-31 register = 0x%4X\n", chan_16_31_reg);
    printf("Channels 32-47 register = 0x%4X\n", chan_32_47_reg);
    printf("Channels 48-63 register = 0x%4X\n", chan_48_63_reg);
    printf("Channels 90-94 (tree) register = 0x%4X\n", chan_tree_reg);

    delay (2000); /* waits 2 seconds before resetting mux */

    /* reset the E1476A to open all closed channels */
    /* writing a 0 to the channels registers will also open channels */
    reset_mux(base_addr);
```

Scan Channels

```
/********************** scanning channels **********************/

   /* connect Bank A and Bank B to the analog bus by */
   /* closing the VSA and VSB tree relays (bits 0 and 1) */
    iwpoke ((unsigned short *)(base_addr + 0x28), 3);

   /* scan channels 0-15 in bank A (register offset 0x20) */
    for (k=0; k<=15; k++)
    {
    iwpoke ((unsigned short *)(base_addr + 0x20), ldexp(1,k));
    /* take measurement here after each iteration of the loop */
    }
    /* set all bits to 0 to open last closed channel */
    iwpoke ((unsigned short *)(base_addr + 0x20), 0);

   /* scan channels 16-31 in bank A (register offset 0x22) */
    for (k=0; k<=15; k++)
    {
    iwpoke ((unsigned short *)(base_addr + 0x22), ldexp(1,k));
    /* take measurement here after each iteration of the loop */
    }
```


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```
     /* set all bits to 0 to open last closed channel */
     iwpoke ((unsigned short *)(base_addr + 0x22), 0);

    /* scan channels 32-47 in bank A (register offset 0x24) */
     for (k=0; k<=15; k++)
     {
     iwpoke ((unsigned short *)(base_addr + 0x24), ldexp(1,k));
     /* take measurement here after each iteration of the loop */
     }
     /* set all bits to 0 to open last closed channel */
     iwpoke ((unsigned short *)(base_addr + 0x24), 0);

    /* scan channels 48-63 in bank A (register offset 0x26) */
     for (k=0; k<=15; k++)
     {
     iwpoke ((unsigned short *)(base_addr + 0x26), ldexp(1,k));
     /* take measurement here after each iteration of the loop */
     }
     /* set all bits to 0 to open last closed channel */
     iwpoke ((unsigned short *)(base_addr + 0x26), 0);

    /* close SICL session */
     iclose(e1476a);
  } /* end of main */
```

Reset Function

```
/*************************************************************/
void reset_mux(char *base_addr)
   /* reset the mux to open all relays (write a 1 to status bit 0)*/
   /* delay 100 ms for reset then set bit to 0 to allow closing*/
   /* switches        */
{
    /* this function resets the multiplexer */
    iwpoke((unsigned short *)(base_addr + 0x04), 1);
    delay (100);  /* must wait at least 100 usec before writing a "0" */
    iwpoke((unsigned short *)(base_addr + 0x04), 0); }}
```

Program Output

Printout from example program:

ID register = 0xFFFF
Device Type register = 0x 218
Status register = 0xFFBE
Channels 00-15 register = 0xFFFF
Channels 16-31 register = 0x 0
Channels 32-47 register = 0x 0
Channels 48-63 register = 0x 0
Channels 90-94 (tree) register = 0xFF01

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Notes:

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Appendix C
E1476A Error Messages

Error Types

Table C-1 lists the error messages generated by the E1476A Multiplexer module firmware when programmed by SCPI. Errors with negative values are governed by the SCPI standard and are categorized in . Error numbers with positive values are not governed by the SCPI standard. See the *E1406 Command Module User's Manual* for further details on these errors.

Table C-1. Error Types

Range	Error Types Description
-199 to -100	Command Errors (syntax and parameter errors).
-299 to -200	Execution Errors (instrument driver detected errors).
-399 to -300	Device Specific Errors (instrument driver errors that are not command nor execution errors).
-499 to -400	Query Errors (problem in querying an instrument).

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Table C-2. Multiplexer Error Messages

Code	Error Message	Potential Cause(s)
-211	Trigger ignored	Trigger received when scan not enabled. Trigger received after scan complete. Trigger too fast.
-213	Init Ignored	Attempting to execute an INIT command when a scan is already in progress.
-222	Data out of range	Parameter value is outside valid range.
-224	Illegal parameter value	Attempting to execute a command with a parameter not applicable to the command.
-240	Hardware error	Command failed due to a hardware problem.
-310	System error	Internal driver error. This error can result if an excessively long parameter list is entered.
1500	External trigger source already allocated	Assigning an external trigger source to a switchbox when the trigger source has already been assigned to another switchbox.
1510	Trigger source non-existent	Selected trigger source is not available on this platform (e.g., some triggers are not available on E1300/E1301 VXI B-Size mainframes).
2000	Invalid card number	Addressing a module (card) in a switchbox that is not part of the switchbox.
2001	Invalid channel number	Attempting to address a channel of a module in a switchbox that is not supported by the module (e.g., channel 99 of a multiplexer module).
2006	Command not supported on this card	Sending a command to a module (card) in a switchbox that is unsupported by the module.
2008	Scan list not initialized	Executing a scan without the INIT command.
2009	Too many channels in channel list	Attempting to address more channels than available in the switchbox.
2010	Scan mode not allowed on this card	The selected scanning mode is not allowed with this module or you have misspelled the mode parameter (see SCAN:MODE command).
2011	Empty channel list	No valid channels are specified in the channel_list.
2012	Invalid Channel Range	Invalid channel(s) specified in SCAN <*channel_list*> command. Attempting to begin scanning when no valid channel list is defined.
2017	Config error 17, Slot 0 functions disabled	Attempt to run a downloaded scan list with ARM:COUNt set to a value other than 1. Applies to FET switches only.
2600	Function not supported on this card	Sending a command to a module (card) in a switchbox that is not supported by the module or switchbox.
2601	Channel list required	Sending a command requiring a *channel_list* without the *channel_list*.

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Appendix D
Relay Life

Replacement Strategy

Electromechanical relays are subject to normal wear-out. Relay life depends on several factors. The replacement strategy depends on the application. If some relays are used more often or at a higher load than other relays, the relays can be individually replaced as needed.

If all relays see similar loads and switching frequencies, the entire circuit board can be replaced when the end of relay life approaches. The sensitivity of the application should be weighed against the cost of replacing relays with some useful life remaining.

NOTE *Relays that wear out normally or fail due to misuse should not be considered defective and are not covered by the product's warranty.*

Relay Life Factors

Some effects of loading and switching frequency on relay life follow.

- **Relay Load.** In general, higher power switching reduces relay life. In addition, capacitive/inductive loads and high inrush currents (for example, turning on a lamp or starting a motor) reduces relay life. Exceeding specified maximum inputs can cause catastrophic failure.
- **Switching Frequency.** Relay contacts heat up when switched. As the switching frequency increases, the contacts have less time to dissipate heat. The resulting increase in contact temperature also reduces relay life.

End-of-Life Determination

A preventive maintenance routine can prevent problems caused by unexpected relay failure. The end of life of a relay can be determined by using one or more of three methods: contact resistance maximum value, contact resistance variance, and/or number of relay operations. The best method (or combination of methods), as well as the failure criteria, depends on the application in which the relay is used.

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- **Contact Resistance Maximum Value.** As the relay begins to wear out, its contact resistance increases. When the resistance exceeds a predetermined value, the relay should be replaced.
- **Contact Resistance Variance.** The stability of the contact resistance decreases with age. Using this method, the contact resistance is measured several (5-10) times, and the variance of the measurements is determined. An increase in the variance indicates deteriorating performance.
- **Number of Relay Operations.** Relays can be replaced after a predetermined number of contact closures. However, this method requires knowledge of the applied load and life specifications for the applied load.

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