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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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Edition 2 . . . . . October 1993
Edition 3 . . . . . August 1995

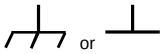
Safety Symbols



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.



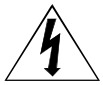
Frame or chassis ground terminal—typically connects to the equipment's metal frame.



Alternating current (AC).



Direct current (DC).



Indicates hazardous voltages.

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

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declares, that the product:

Product Name: 8-Channel Strain Gage Multiplexer Module

Model Number: E1355A, E1356A, E1357A, E1358A

Product Options: All

conforms to the following Product Specifications:

Safety: IEC 1010-1 (1990) Incl. Amend 1 (1992)/EN61010-1 (1993)
CSA C22.2 #1010.1 (1992)
UL 1244

EMC: CISPR 11:1990/EN55011 (1991): Group1 Class A
IEC 801-2:1991/EN50082-1 (1992): 4kVCD, 8kVAD
IEC 801-3:1984/EN50082-1 (1992): 3 V/m
IEC 801-4:1988/EN50082-1 (1992): 1kV Power Line

Supplementary Information: 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.

Tested in a typical configuration in an HP B-Size VXI mainframe.



July 20, 1995 **Jim White, QA Manager**

European contact: Your local Hewlett-Packard Sales and Service Office or Hewlett-Packard GmbH, Department HQ-TRE, Herrenberger Straße 130, D-71034 Böblingen, Germany (FAX +49-7031-14-3143).

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Chapter 1
Getting Started with the Strain Gage Multiplexers

About This Chapter

This chapter describes the physical and functional characteristics of the HP E1355A, E1356A, E1357A, and E1358A Strain Gage Multiplexers; and explains how the multiplexers are prepared for use in a VXIbus system. The sections of this chapter are:

- Strain Gage Multiplexer Overview . . . . . Page 13
- Using the Multiplexers in a VXIbus System. . . . . Page 14

Strain Gage Multiplexer Overview

The strain gage multiplexers, together with the HP E1326B/E1411B Multimeter, provide static and dynamic strain measurement capabilities for an HP Series B or Series C VXIbus system.

Physical Description

The HP E1355A and E1356A are B-size, 8-channel, 120Ω and 350Ω **RELAY** Strain Gage Multiplexers, respectively. The HP E1355A and E1356A terminal modules use the HP E1345-66201 component assembly. The relay multiplexers use a single B-size or C-size mainframe slot.

The HP E1357A and E1358A are B-Size, 8-channel, 120Ω and 350Ω **FET** Strain Gage Multiplexers, respectively. The E1357A and E1358A terminal modules use the HP E1351-66201 component assembly. The FET multiplexers also use a single B-size or C-size mainframe slot.

Functional Description

The measurement capabilities of the relay and FET strain gage multiplexers include the following:

- ¼ Bridge Measurements
  - 8 Channels
  - Rosettes
- ½ Bridge Measurements
  - 8 Channels
  - Bending ½ Bridge
  - Poisson ½ Bridge

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- Full Bridge Measurements
  - 8 Channels
  - Bending Full Bridge
  - Bending Poisson Full Bridge
  - Poisson Full Bridge

- Guarded DCV Voltage and 2-wire Resistance Measurements
  - 8 Channels
  - Allowed with strain measurements on adjacent channels

- Diagnostics
  - Leadwire Resistance (channels 0 and 1)
  - Internal Half Bridge Voltage
  - Shunt Verification (E1355A and E1356A only)
  - Guard Voltage
  - Bridge Excitation Voltage

Strain measurement examples are found in Chapter 3. The diagnostics are covered in Appendix C.

Note The electrical characteristics and strain measurement circuitry used by the strain gage multiplexers are covered in Chapter 4.

Using the Multiplexers in a VXIbus System

This section prepares the strain gage multiplexers for use in a VXIbus system.

Identifying the Terminal Module

The card ID jumpers and card ID switch (Figure 1-1) indicates which terminal assembly is used. Since the HP E1345-66201 and HP E1351-66201 assemblies are used with a variety of terminal modules, the ID jumpers or ID switch may need to be changed. To reduce setup time and avoid configuration errors, check the jumper or switch setting to make sure they match the terminal module used.

Relay Multiplexers

When the relay strain gage multiplexers are shipped from the factory, the card ID jumpers are set according to the terminal module (E1355A/E1356A) shipped with them (Figure 1-1). The system is able to identify the multiplexer with or without the terminal module attached.

Note If the jumper setting does not match the terminal module attached, the system will identify the card based on the jumper setting.

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FET Multiplexers

When the FET strain gage multiplexers are shipped from the factory, the card ID switches are set to the "OPEN" (0) position (Figure 1-1). The terminal module is identified when the module is plugged onto the component assembly and when the mainframe is turned on.

Note When the terminal card is not attached, the system identifies the multiplexer as an HP E1351A 16-channel FET multiplexer when the card ID switches are in the OPEN (0) position.

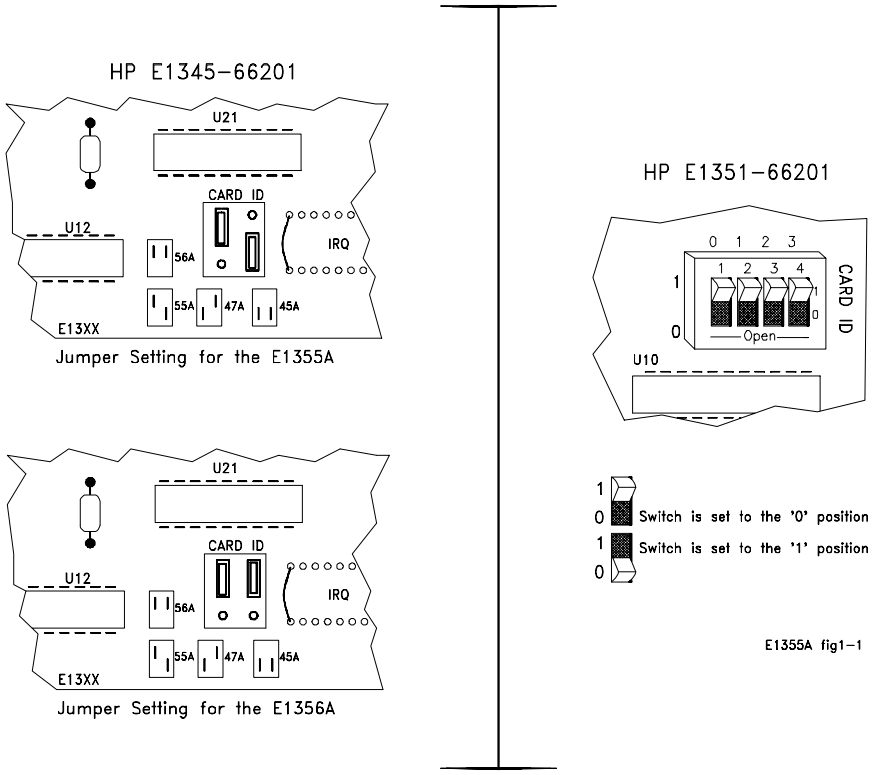


Figure 1-1. Checking the Card ID Jumper/Switch

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Setting the Card ID Switch

In certain applications it may be necessary for the system to identify the FET strain gage multiplexer without the terminal card attached. Figure 1-2 shows the card ID switch settings which identify the HP E1357A and HP E1358A FET Strain Gage Multiplexers.

Note Make certain the card ID switch setting matches the terminal card used. If they do not match, a configuration error may occur or the wrong terminal card may be identified.

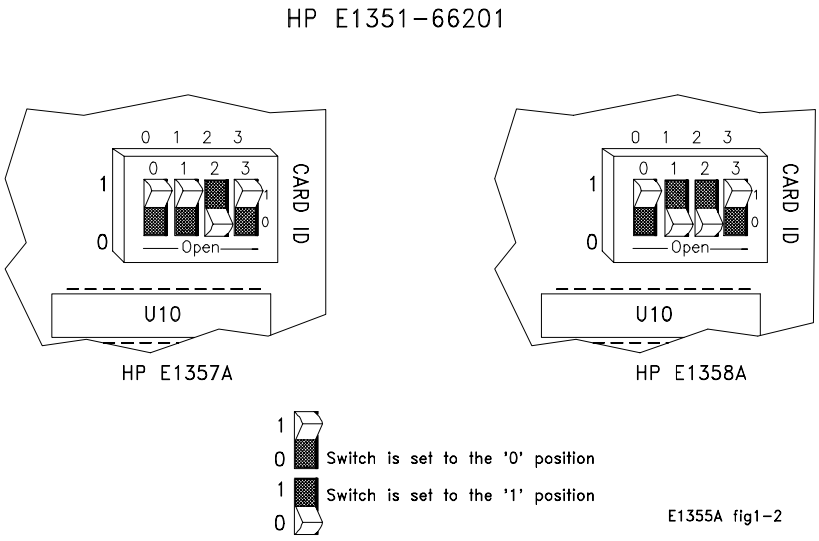


Figure 1-2. Identifying the HP E1357A/E1358A

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Selecting the Interrupt Line Number

The multiplexer's IRQ jumper/switch (Figure 1-3) selects one of seven interrupt lines used to communicate with the system's Slot 0 module.

In a scanning multimeter configuration (see "Strain Gage Multiplexer Configurations" on page 19), the multiplexer's (relay and FET) do not use an interrupt line since communication is between the multimeter and the Slot 0 module.

In a switchbox configuration, the multiplexers use an interrupt line. At the factory, the IRQ jumper (or switch) is set to line 1. Since the system instrument in the Series B mainframe is assigned to each line and the Series C command module (E1406A) is assigned line 1 by default, it is not necessary to change the IRQ jumper/switch setting. If the command module in Series C systems is assigned another line and the switchbox is to use that line, the IRQ jumper/switch must be set accordingly.

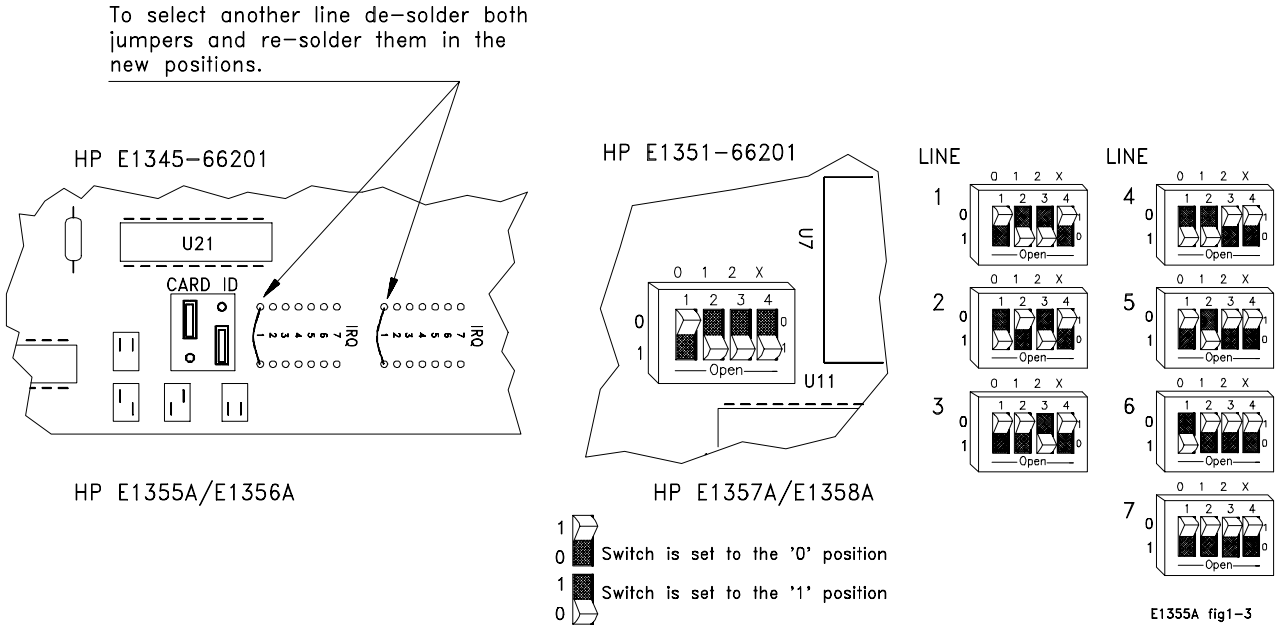


Figure 1-3. The IRQ Jumper/Switch

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Internally Supplied Bridge Excitation Voltage

A feature of the strain gage multiplexer is the availability of an internally supplied bridge excitation voltage. This voltage, which drives the multiplexer's Wheatstone Bridge strain measurement circuitry (Chapter 4), is capable of driving eight channels of full bridge measurements.

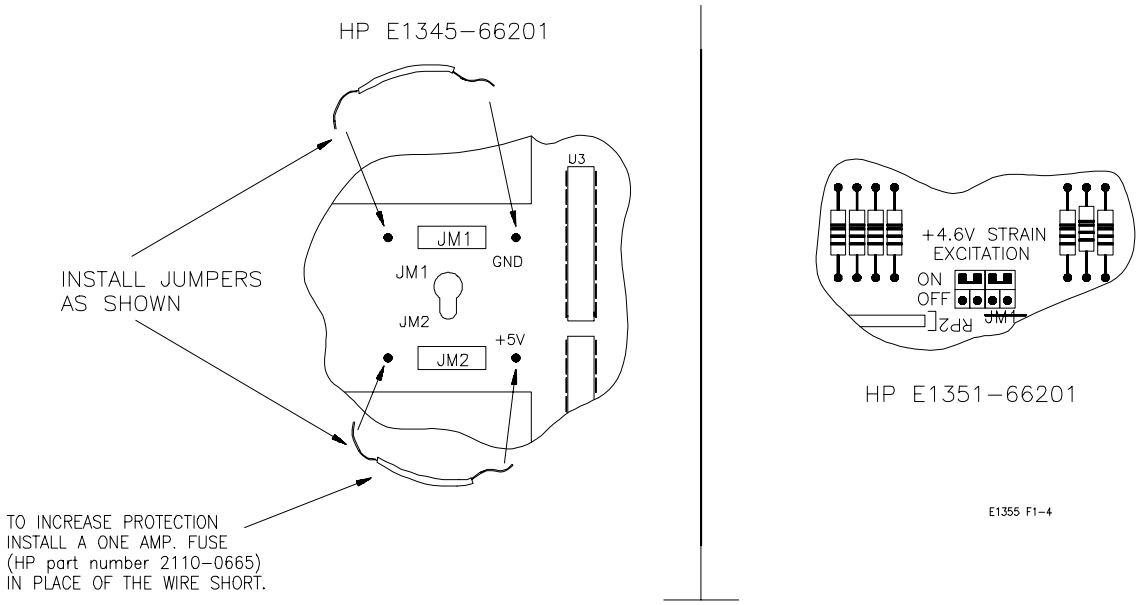


Figure 1-4. Internally Supplied Bridge Excitation Voltage

Relay Multiplexer Excitation Voltage

The internal bridge excitation voltage for the HP E1355A/E1356A relay strain gage multiplexers is +5V, fused at 4A. This voltage is accessed by installing jumpers on the component assembly as indicated in Figure 1-4. Note, however, that this signal may not be stable enough or pure enough for some strain measurements.

CAUTION **If jumpers are installed and then the +5V Bridge Excitation is shorted, the main fuse on the PC board may blow and reset the mainframe. This would set all instruments in the mainframe to their power-on state. To increase protection, install a one amp fuse (HP part number 2110-0665) in place of the wire short.**

When the relay multiplexers are shipped from the factory, the jumpers are not installed. Thus, the excitation voltage must be externally supplied as explained in Chapter 2.

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FET Multiplexer Excitation Voltage

The internal bridge excitation voltage for the HP E1357A/E1358A FET strain gage multiplexers is +4.6V referenced to mainframe chassis, and current limited at 450 mA. The voltage is accessed as indicated by the (movable) jumper setting shown in Figure 1-4.

When the FET multiplexers are shipped from the factory, the jumper is in the "ON" position. If the jumper is moved to the "OFF" position, the excitation voltage must be externally supplied as explained in Chapter 2.

CAUTION **If the bridge excitation voltage is externally supplied, be sure that the jumper is not installed, or with the FET multiplexers, ensure that the "STRAIN EXCITATION" jumper is in the "OFF" position. Otherwise, unpredictable strain measurements may result.**

Strain Gage Multiplexer Configurations

In a B-Size or C-Size VXIbus system, the strain gage multiplexers can be used in two configurations:

- Scanning Multimeter
  (multiplexers are used with an HP E1326B/E1411B Multimeter)
- Switchbox
  (multiplexers are used with an external voltmeter)

Guidelines for creating a scanning multimeter and switchbox follow.

Creating a Scanning Multimeter Instrument

In a scanning multimeter instrument, signals measured by the HP E1326B/E1411B Multimeter are input via the multiplexer channels. Channel openings and closings are controlled by the multimeter through commands sent to the multimeter. To create a scanning multimeter instrument:

- The instrument must have one module (the multimeter) assigned as the instrument identifier. The instrument identifier is the module with a logical address that is a multiple of 8 (8, 16, 24, …). The HP E1326B/E1411B Multimeter has a factory set logical address of 24.
- The modules in the scanning multimeter instrument must have successive logical addresses, beginning with the logical address of the multimeter. For example, with a multimeter logical address of 24, the logical addresses of the multiplexers must be 25, 26, and so on.
- The strain gage multiplexers have a factory set logical address of 112. The logical address is changed using the logical address switches shown in Figure 1-5.

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Creating a Switchbox Instrument

In a switchbox instrument, signals are routed (switched) to a voltmeter external to the HP 75000 Series B or Series C mainframe. Multiplexer channel openings and closings are controlled by the user through commands sent directly to the switchbox. A switchbox instrument is created as follows:

- The instrument must have one module (multiplexer) assigned as the instrument identifier. The instrument identifier is the module with a logical address that is a multiple of 8 (8, 16, 24, …).
- The multiplexers in the switchbox instrument must have successive logical addresses, beginning with the logical address of the instrument identifier. For example, the multiplexers in a switchbox might have logical addresses of 112, 113, 114, and so on.
- All strain gage multiplexers have a factory set logical address of 112. The logical address is changed using the logical address switches shown in Figure 1-5.

Note

Detailed information on creating virtual instruments in a VXIbus system can be found in the *HP 75000 Series B Installation and Getting Started Guide*, or in the *HP E1406A Command Module User's Manual.*

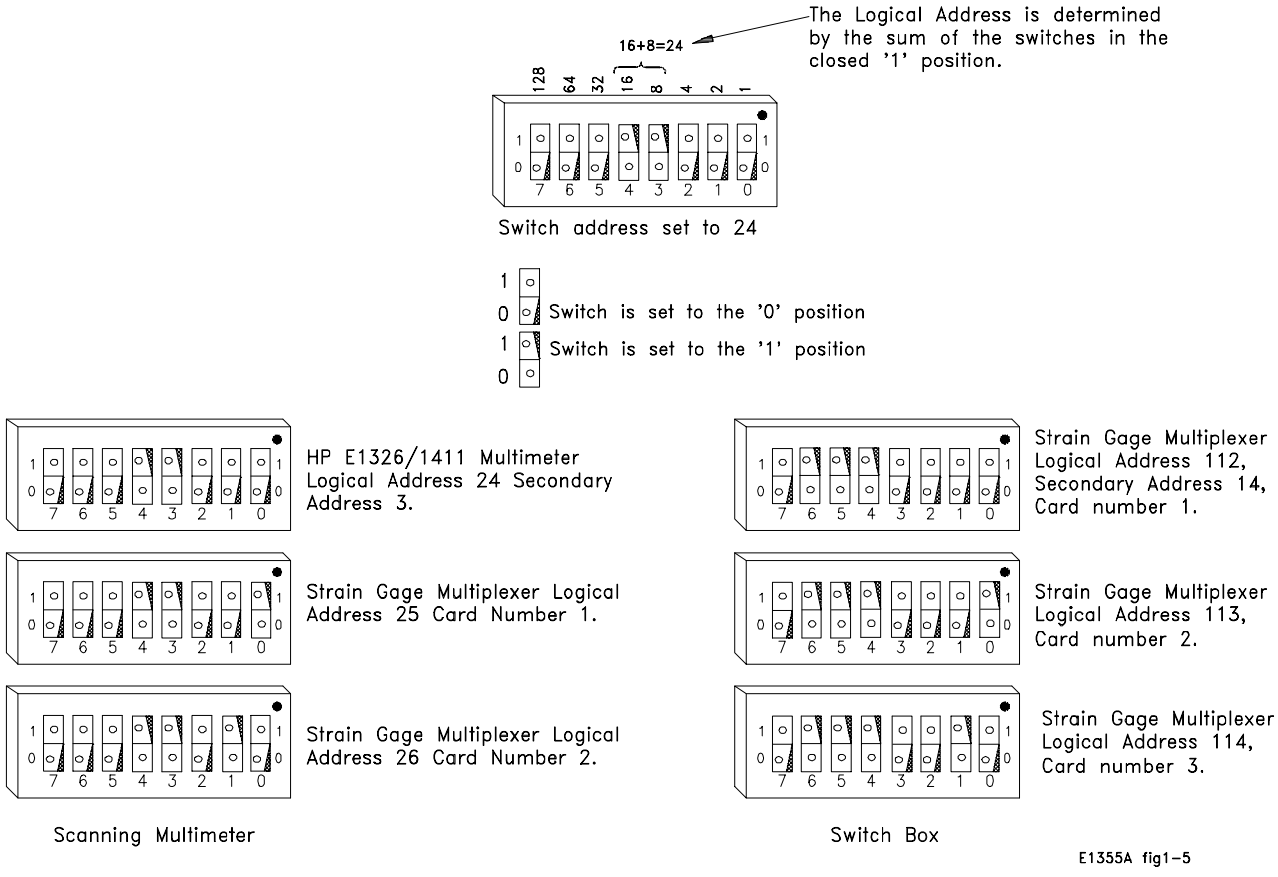


Figure 1-5. Creating a Scanning Multimeter and a Switchbox

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Instrument Addressing

Instruments in an HP 75000 Series B or Series C mainframe are located with an HP-IB address. The HP-IB address is a combination of the computer's interface select code, the primary HP-IB address of the mainframe's system instrument, and the secondary HP-IB address of the virtual instrument. Addresses of this form in an HP BASIC statement might appear as:

```
OUTPUT 70903;"...
OUTPUT 70914;"...
```

Interface Select Code (7): Determined by the address of the HP-IB interface card in the computer. In most Hewlett-Packard computers, this card has a factory set address of 7.

Primary HP-IB Address (09): This is the address of the HP-IB port on the Series B mainframe and on the Series C HP E1406A Command Module. The mainframe and command module have a factory set address of 9.

Secondary HP-IB Address (03) (14): This address is determined by dividing the logical address of the instrument identifier by 8. Thus, for a scanning multimeter with an instrument identifier logical address of 24, the secondary address is 03. For a switchbox with an instrument identifier logical address of 112, the secondary address is 14.

Multiplexer Card Numbers

The multiplexer modules in a scanning multimeter and switchbox instrument assume card numbers within the instrument (Figure 1-4). The multiplexer with the lowest logical address is card number 1, the next lowest logical address is card number 2, and so on. Thus, in the following configurations, the multiplexer card numbers would be:

Scanning Multimeter

Logical address = 24	(multimeter)
Logical address = 25	(multiplexer - card number 1)
Logical address = 26	(multiplexer - card number 2)
Logical address = 27	(multiplexer - card number 3)

Switchbox

Logical address = 112	(multiplexer - card number 1)
Logical address = 113	(multiplexer - card number 2)
Logical address = 114	(multiplexer - card number 3)
Logical address = 115	(multiplexer - card number 4)

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Multiplexer Channel Addresses

The strain gage multiplexer channels within the scanning multimeter and switchbox are specified in the form:

(@ccnn)	- single channel
(@ccnn,ccnn)	- multiple channels
(@ccnn:ccnn)	- sequential channels
(@ccnn:ccnn,ccnn:ccnn)	- groups of sequential channels

where "cc" is the card number and "nn" is the channel number. For example:

(@100:107)

specifies channels 0 through 7 on (multiplexer) card number 1. The leading 0 in the card number can be omitted.

Chapter 3 contains example programs showing how a channel (and channel list) is specified in a strain measurement command. The strain measurement commands are described in detail in Chapter 5.

Connecting the Multiplexers

In scanning multimeter and switchbox instruments, the multiplexers are connected to the multimeter and to other multiplexers with an analog bus cable, or with an analog bus cable and a digital bus cable (Figure 1-6). The cables used are determined as follows:

1. If the scanning multimeter or switchbox uses **relay (strain gage) multiplexers only**, the **analog bus cable** is used.
2. If the scanning multimeter or switchbox uses **FET (strain gage) multiplexers only**, the **analog bus cable** and the **digital bus cable** are used.
3. If the scanning multimeter or switchbox uses a **combination** of **relay** and **FET multiplexers**, only the **analog bus cable** is used.

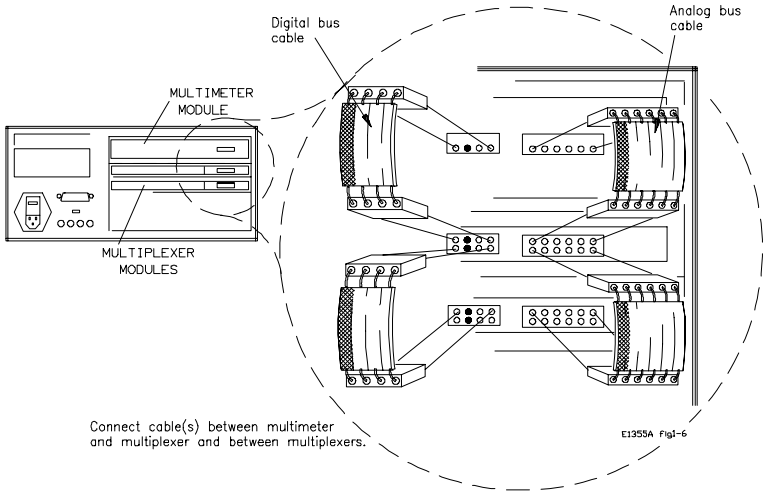


Figure 1-6. Connecting the Analog and Digital Bus Cables

Descriptions of the analog bus and digital bus cables are found in the *HP E1326B/E1411B Multimeter Manual*.

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Chapter 2
Connecting Strain Gages to the Multiplexers

About This Chapter

This chapter explains how the strain gage multiplexer terminal module is configured for measurements, and how ¼, ½, and full bridge configurations are connected to the terminal module. The sections of this chapter are:

- Terminal Module Configuration . . . . . Page 23
- Wiring a Terminal Module . . . . . Page 26
- Strain Gage Wiring Diagrams . . . . . Page 27

Terminal Module Configuration

The strain gage terminal module used with each multiplexer accessory is shown in Figures 2-1A and 2-1B. The terminal module is used to:

- select the bridge arrangement on each channel;
- supply the bridge excitation voltage (external source);
- connect the strain gages to the bridge completion channels.

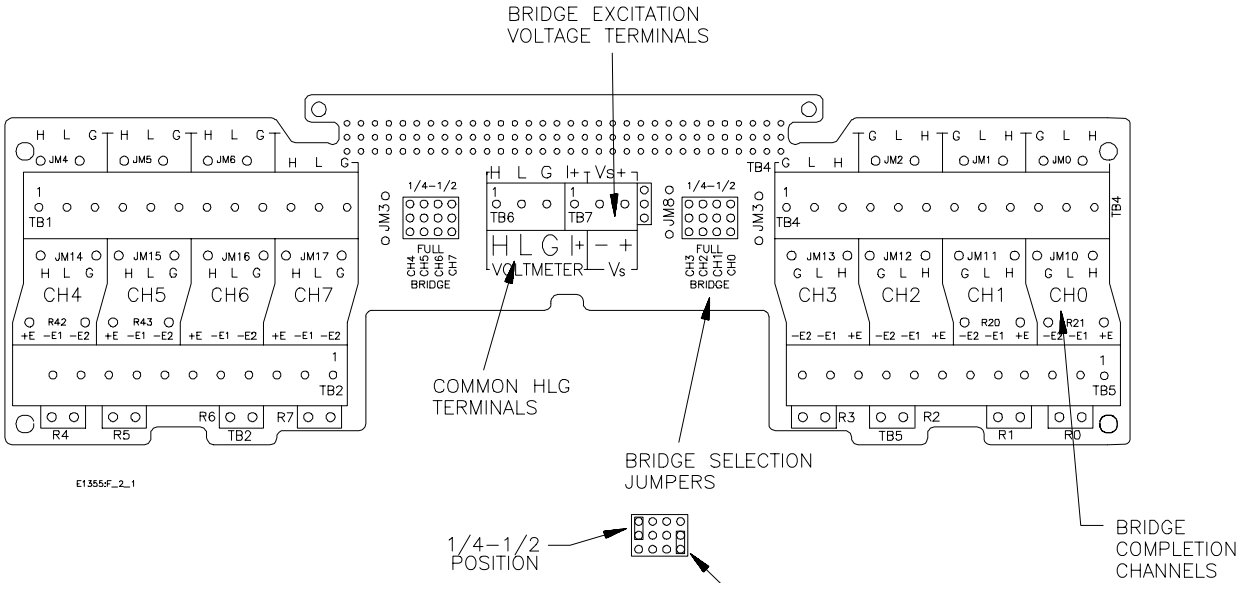


Figure 2-1A. Terminal Module Configuration

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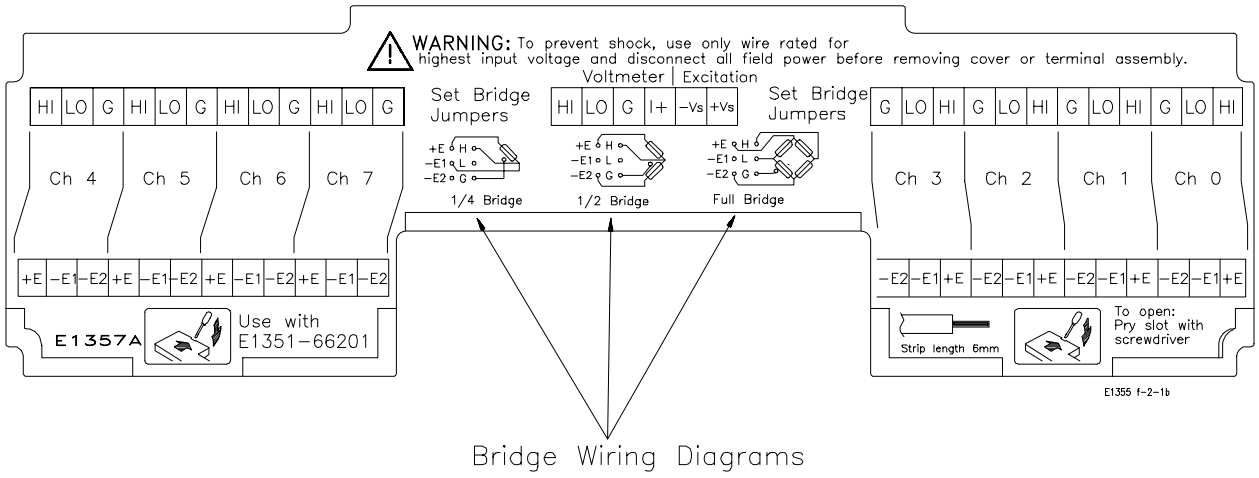


Figure 2-1B. Terminal Module Configuration

Bridge Selection Jumpers

The eight bridge selection jumpers (Figure 2-1B) select the bridge arrangement for each channel individually. Thus, a single strain gage multiplexer can have any combination of ¼, ½, and full bridge arrangements connected to the module.

When making ¼ or ½ bridge measurements, the corresponding bridge selection jumper must be set to the "¼ - ½" position.

When making full bridge measurements, DC voltage measurements, or 2-wire resistance measurements, the channel's bridge selection jumper must be set to the "FULL" position.

Bridge Excitation Voltage Terminals

When the excitation voltage which drives the Wheatstone Bridge circuitry is externally supplied, the voltage is connected to the "Vs" terminals on the terminal module.

The bridge excitation voltage required for each bridge arrangement (¼, ½, full) and a recommended power supply are found in Table 2-1.

Table 2-1. Bridge Excitation Voltage and Power Requirements

¼ or ½ Bridge Arrangements	Voltage	Power
8 channels of 120Ω bridge arrangements	5V @ 200 mA	1.0W
8 channels of 350Ω bridge arrangements	5V @ 70 mA	0.35W
Full Bridge Arrangements	**Voltage**	**Power**
8 channels of 120Ω bridge arrangements	5V @ 400 mA	2.0W
8 channels of 350Ω bridge arrangements	5V @140 mA	0.7W
PARD (periodic and random deviation from DC value):		
1 mVp-p 20 Hz to 20 MHz		
Recommended Power Supply:		
HP 6414C or equivalent		

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Bridge Completion Channels

The strain gages mounted to the specimen are connected to the terminal module bridge completion channels via the +E, -E1, -E2, H, L, and G terminals. Each channel contains these six terminals in order to accommodate a ¼, ½, or full bridge arrangement. A wire is connected to a terminal by:

1. loosening the screw on the terminal,
2. inserting the wire into the opening opposite the screw,
3. tightening the screw to secure the wire in place.

Routing the wires under the strain relief clamp will prevent the wires from being pulled out of the terminal.

Bridge Wiring Diagrams

The ¼, ½, and full bridge wiring diagrams on the terminal module cover (Figure 2-1B) indicate the connections between the strain gage bridge arrangement and the channel terminals. The six points on the diagrams: +E, -E1, -E2, H, L, and G correspond to the six wiring terminals on each bridge completion channel. These points also correspond to the points shown on the Wheatstone Bridge on page 54. The terminals used by the bridge configurations are:

- ¼ bridge - +E -E1 H G
- ½ bridge - +E -E2 H G
- full bridge- +E -E2 H L G

An example of how the diagram relates to gage wiring is shown for the ¼ bridge arrangement in Figure 2-2.

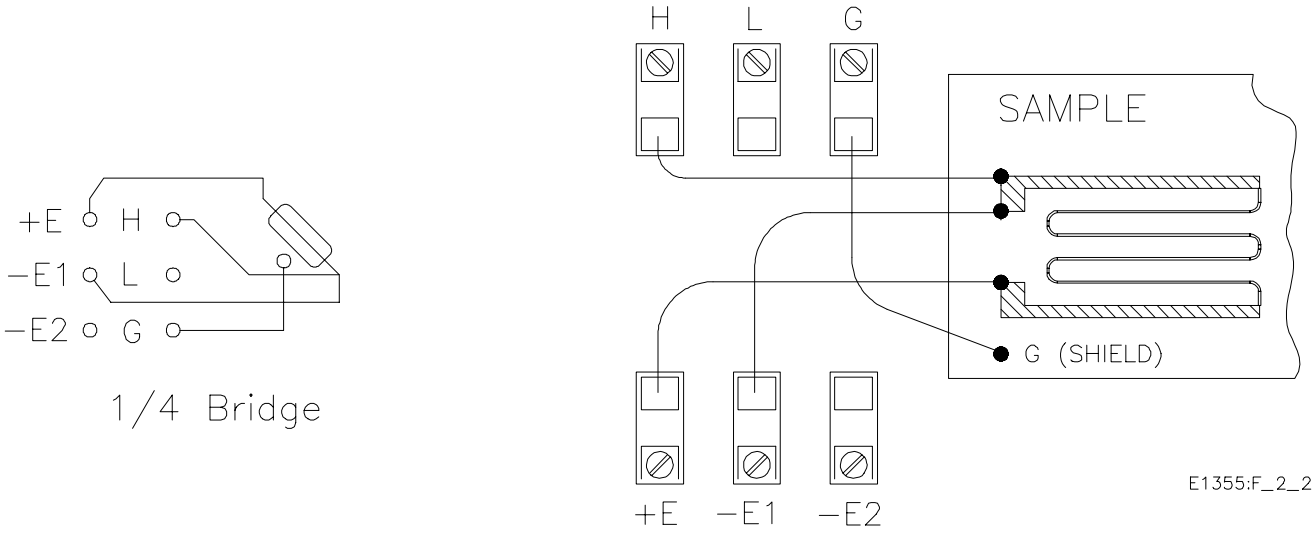


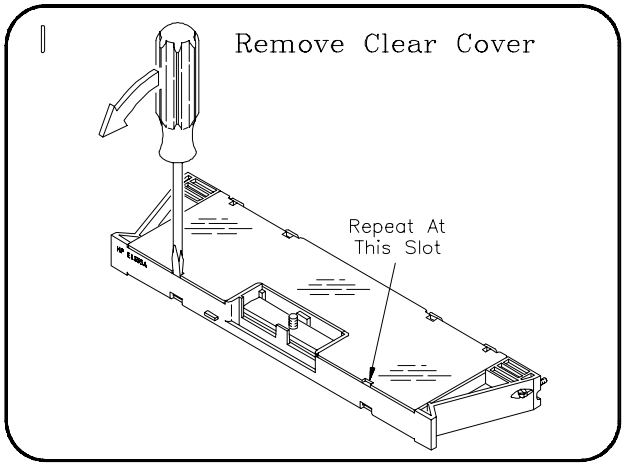
Figure 2-2. 1/4 Bridge Arrangement Wiring Diagram

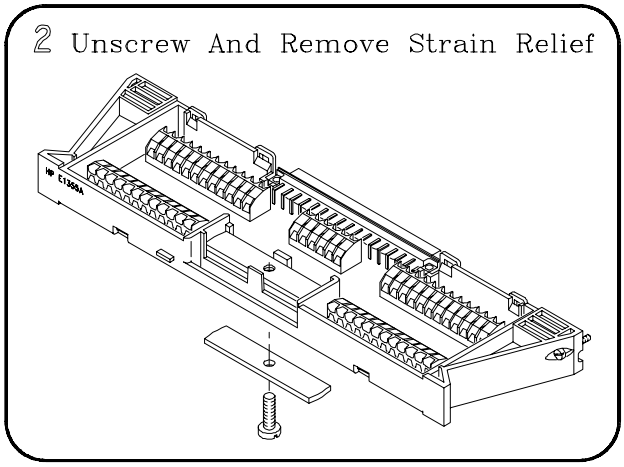
H L G Voltmeter Terminals

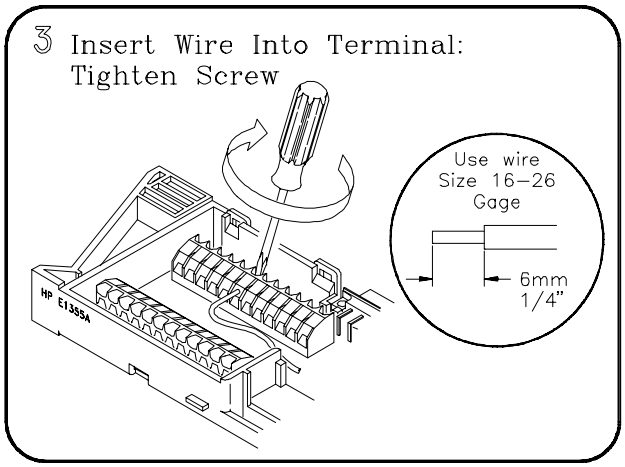
The common high (H), low (L), and guard (G) terminals are the same point electrically as the H, L, and G terminals of the bridge completion channels. These common terminals allow for strain measurements using an external voltmeter (see "Measurements Using an External Voltmeter" on page 63).

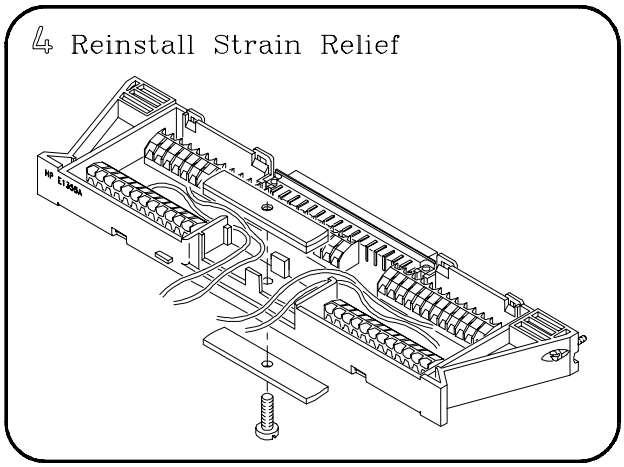
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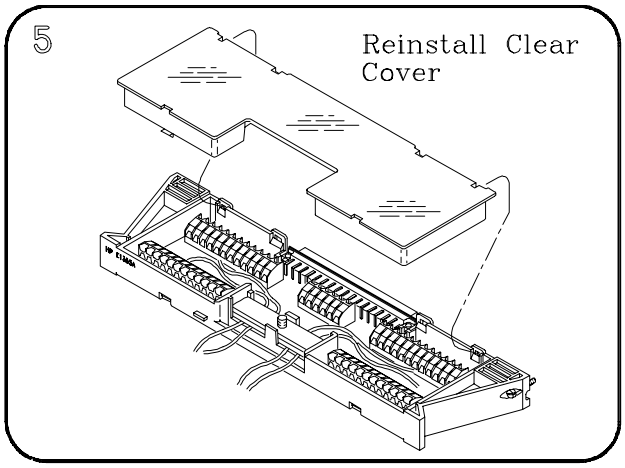
Wiring a Terminal Module

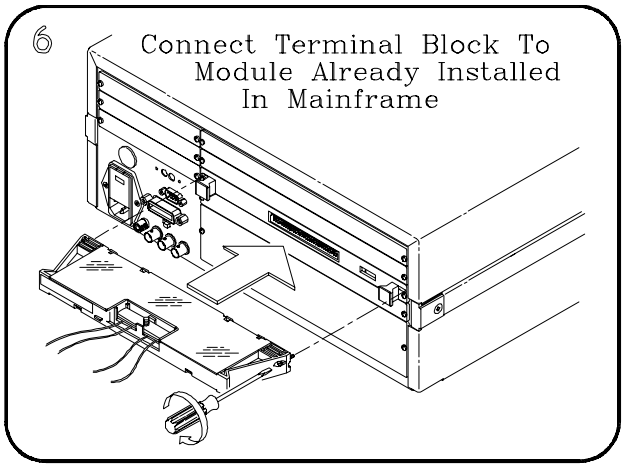












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Strain Gage Wiring Diagrams

This section contains the wiring diagrams for the strain measurement configurations available with the multiplexers. The section also shows how to connect an external voltmeter to a switchbox in order to make strain measurements. The example programs in Chapter 3 also refer to these diagrams.

Wiring Considerations

Before connecting strain gages to the bridge completion channels, consider the following.

Using a Twisted-Shielded Cable

To ensure the most accurate measurements possible, a twisted-shielded cable should be used when connecting the strain gages to the bridge completion channels (see Figure 2-3).

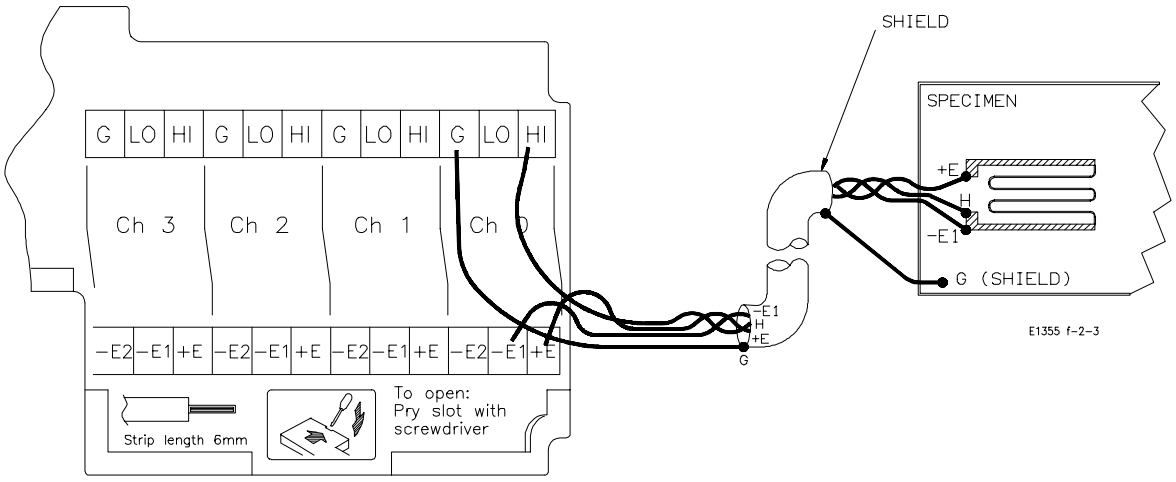


Figure 2-3. Using a Twisted-Shielded Cable

Connecting the shield to the specimen and to the G (guard) terminal of the channel will help keep noise induced currents out of the conductor (H, L) leads. The guard connection also takes advantage of the multiplexer's Wagner Ground (see "The Wagner Ground" on page 57). The Wagner Ground drives the midpoint of the bridge to the same potential as the specimen, thus preventing stray leakage currents from affecting measurement accuracy. Note that the shield must be connected to the specimen and not the gage.

Twisting the conductor leads reduces the loop area formed by the Wheatstone Bridge arms which may be exposed to magnetic fields which can degrade measurement accuracy.

Wire Gage

Another factor to consider is wire gage since leadwire resistance can affect measurement accuracy when long cable runs are involved. The effects of leadwire resistance can be predicted and corrected for by using the wire resistance table in Appendix B and the Leadwire Resistance Diagnostic on page 108.

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1/4 Bridge Diagrams

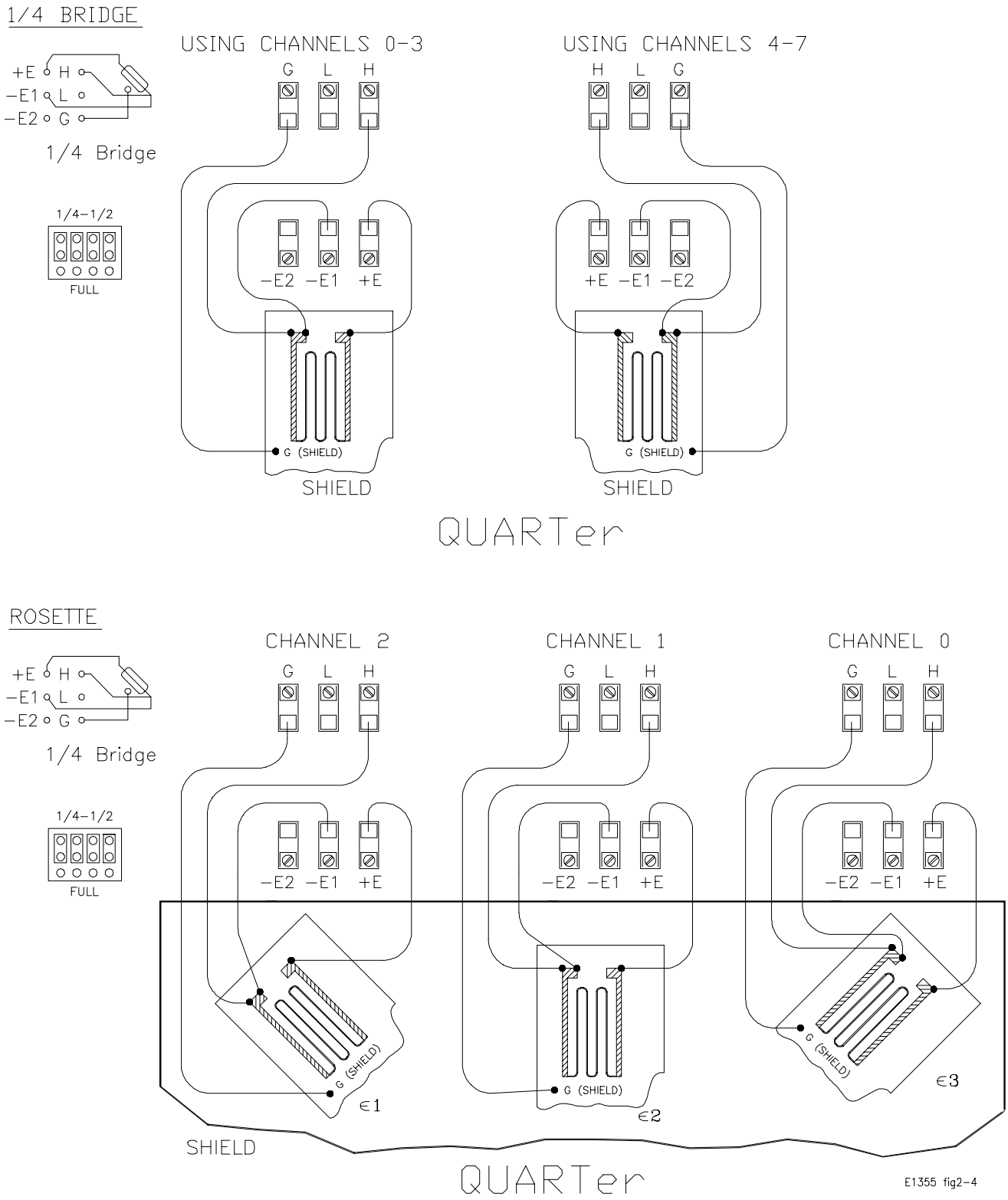


Figure 2-4. Connecting Strain Gages in 1/4 Bridge Arrangements

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1/2 Bridge Diagrams

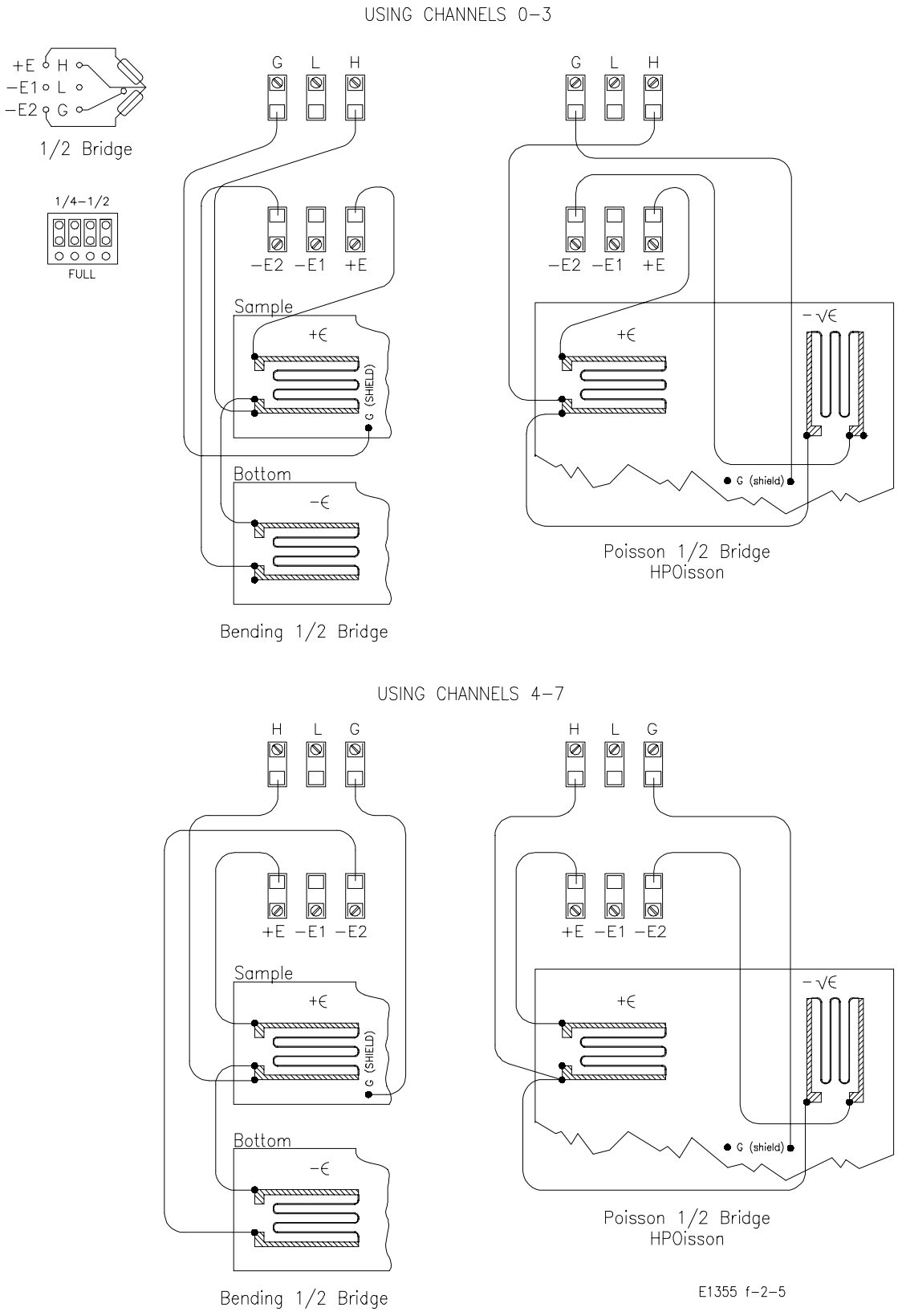


Figure 2-5. Connecting Strain Gages in 1/2 Bridge Arrangements

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Full Bridge Diagrams

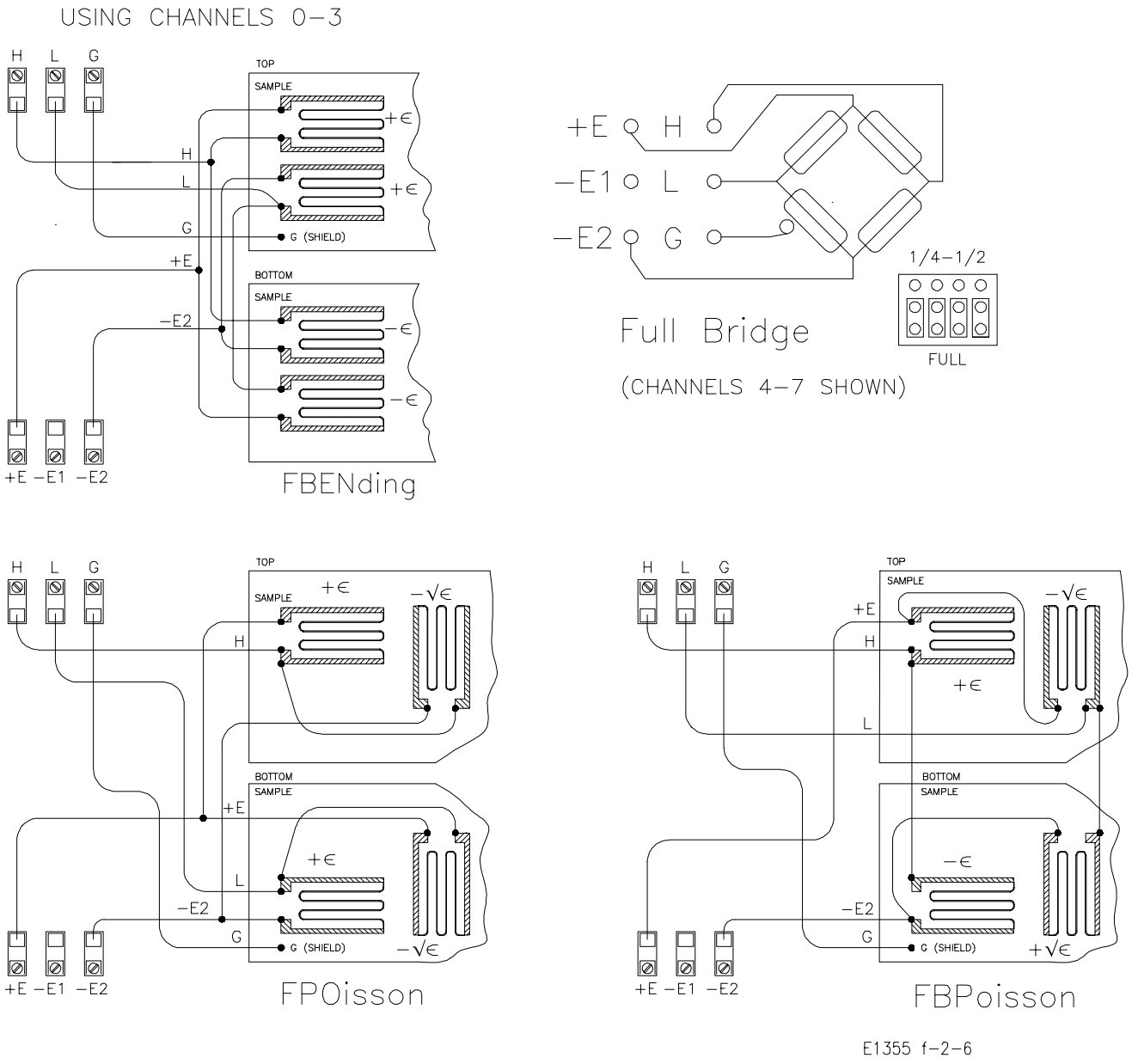


Figure 2-6. Connecting Strain Gages in Full Bridge Arrangements

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Connecting Relay Strain Gage Multiplexers to an External Voltmeter

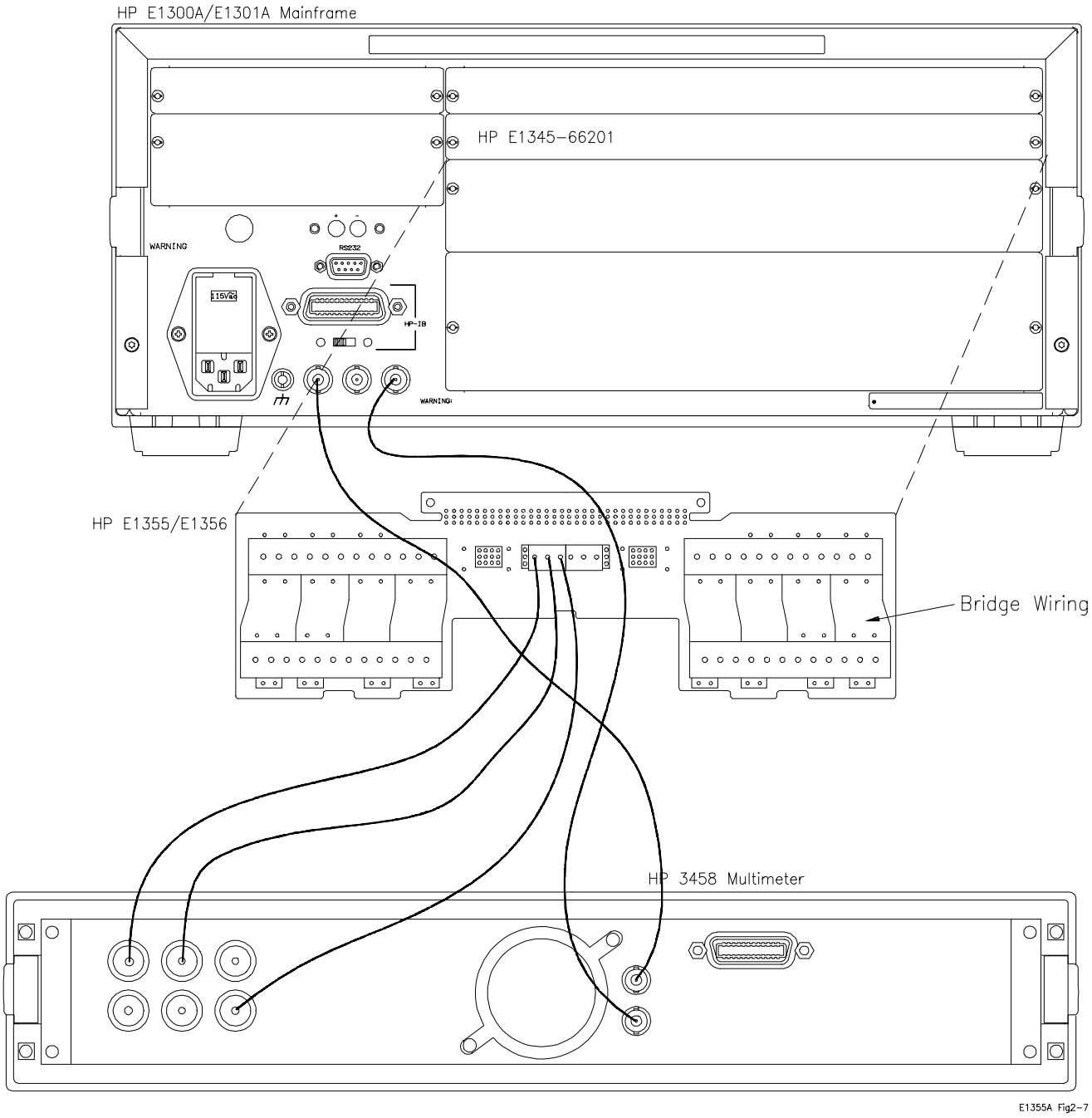


Figure 2-7. Connecting Relay Strain Gage Multiplexers to an External Voltmeter

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Connecting FET Strain Gage Multiplexers to an External Voltmeter

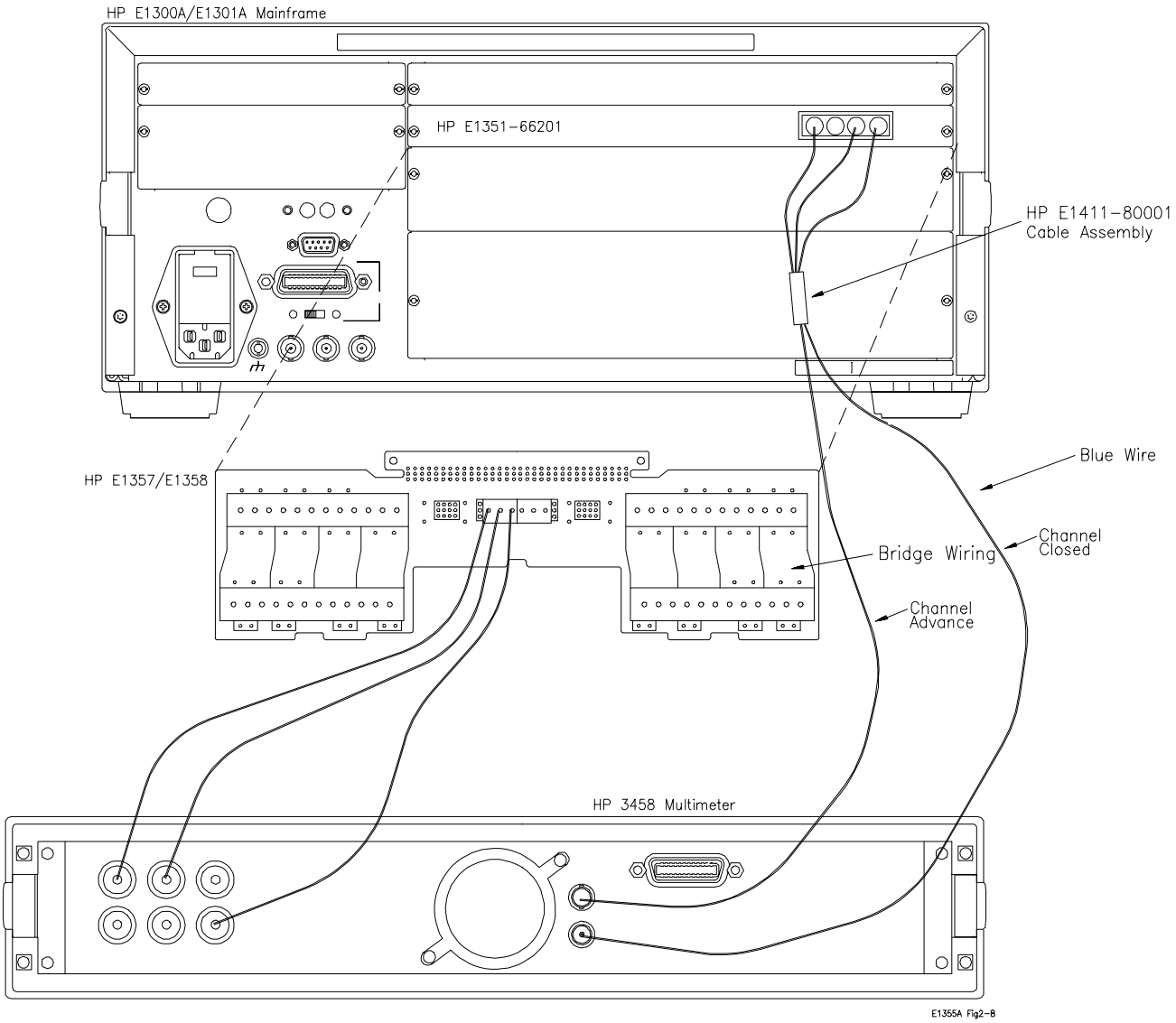


Figure 2-8. Connecting FET Strain Gage Multiplexers to an External Voltmeter

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Chapter 3
Making Strain Gage Measurements

About This Chapter

This chapter contains example programs which make strain gage measurements with various bridge configurations. The examples in this chapter include:

- Single-Channel ¼ Bridge Measurements . . . . . Page 35
- Multi-Channel ¼ Bridge Measurements. . . . . Page 36
- Dynamic Strain Measurements . . . . . Page 37
- Rosette Measurements . . . . . Page 39
- Single-Channel Bending Full Bridge Measurement. . . . . Page 40
- Relay Strain Gage Measurements with an External Voltmeter . . . . . Page 41
- FET Strain Gage Measurements with an External Voltmeter . . . . . Page 43
- Measurements with Downloaded Unstrained References. . . . . Page 46

Using the Example Prog ams r

The purpose of the chapter is to provide example programs that show you how to make strain gage measurements, and to provide programs that can be used directly in your applications.

Programming Language

The example programs are shown in the HP BASIC language and assume the multimeter is controlled from an HP 9000 Series 300 computer over the HP-IB.

When using HP BASIC, a command is sent to the scanning multimeter instrument with the OUTPUT statement:

```
OUTPUT 70903;"MEAS:STR:QUAR?  (@100)"
```

The destination specified (70903) is the interface select code of the computer (7), plus the HP-IB addresses of the HP 75000 Series B mainframe or Series C command module (09), plus the multimeter instrument address (03). The multimeter command is enclosed between quotation marks.

Data from the multimeter instrument is entered into the computer using the ENTER statement:

```
ENTER 70903;variable
```


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Note

Except as noted, each program in this chapter assumes the strain gage multiplexer (relay and FET) is used with the HP E1326B/E1411B multimeter as part of a scanning multimeter instrument at secondary HP-IB address 03.

Connecting Strain Gages

Chapter 2 contains the wiring diagrams for connecting strain gages to the multiplexer bridge completion channels. Each example program indicates the wiring diagram used.

Strain Measurement Procedure

Strain measurements with the strain gage multiplexers and HP E1326B/E1411B multimeter are made as follows:

1. Specify the Gage Factor and, for Poisson configurations, the Poisson Ratio.
2. Measure the unstrained reference voltage (Vout/Vs) unstrained.
3. Add tension to the specimen.
4. Configure the multimeter and make the strain measurement (Vout/Vs) strained.

Each example in this chapter uses this procedure. Chapter 4 covers the procedure in detail.

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Single-Channel 1/4 Bridge Measurements

This program makes a ¼ bridge strain measurement on channel 0 of multiplexer card number 1.

```
!Clear and reset the multimeter.
CLEAR 70903
OUTPUT 70903;"*RST"

!Specify the gage factor for the channel measured.
OUTPUT 70903;"STR:GFAC 2.11E-6,(@100)"

!Measure the channel's unstrained reference.
OUTPUT 70903;"CAL:STR  (@100)"

DISP "Add tension to the specimen; then press 'Continue'"
PAUSE
DISP ""

!Measure the strain on the channel.  Enter and display the reading.
OUTPUT 70903;"MEAS:STR:QUAR?  (@100)"
ENTER 70903;Strn_rdg
PRINT Strn_rdg
END
```

Comments

- The wiring diagram used for this example is on page 28.
- Specifying the gage factor as 2.11E-6 returns the strain measurement in microstrain.
- A gage factor must be specified and an unstrained reference must be measured for each channel.

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Multi-Channel 1/4 Bridge Measurements

This program makes ¼ bridge strain measurements on channels 0, 1, and 2 of multiplexer card number 1.

```
!Dimension a computer variable to store the strain measurements.
DIM Strn_rdgs(1:3)

!Clear and reset the multimeter.
CLEAR 70903
OUTPUT 70903;"*RST"

!Specify the gage factor for each channel measured.
OUTPUT 70903;"STR:GFAC 2.11E-6,(@100:102)"

!Measure the unstrained reference for each channel.
OUTPUT 70903;"CAL:STR  (@100:102)"

DISP "Add tension to the specimen; then press 'Continue'"
PAUSE
DISP ""

!Measure the strain on the specified channels. Enter and display the readings.
OUTPUT 70903;"MEAS:STR:QUAR?  (@100:102)"
ENTER 70903;Strn_rdgs(*)
PRINT Strn_rdgs(*)
END
```

Comments

- The wiring diagram used for this example is on page 28.
- Specifying the gage factor as 2.11E-6 returns the strain measurements in microstrain.
- A gage factor must be specified and an unstrained reference must be measured for each channel.

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Dynamic Strain Measurements

This program makes 2,000 ¼ bridge strain measurements over a period of one second. The measurements are made on channel 0 of multiplexer card number 1.

```
!Dimension computer variables to store the data header and readings. Assign
!an input/output path between the multimeter and computer. This is a path for
!data in the REAL 64 format. Clear the path and reset the multimeter.
DIM Ndig$[1],Count$[9],Strn_rdgs(1:2000)
ASSIGN @Dmm TO 70903;FORMAT OFF
CLEAR @Dmm
OUTPUT 70903;"*RST"

!Specify the gage factor for the channel measured.
OUTPUT 70903;"STR:GFAC 2.11E-6,(@100)"

!Measure the channel's unstrained reference.
OUTPUT 70903;"CAL:STR  (@100)"

DISP "Add tension to the specimen; then press 'Continue'"
PAUSE
DISP ""

!To increase throughput speed, specify the multimeter's REAL 64 data format
!and turn off the mainframe display. Configure the multimeter for ¼ bridge
!strain measurements on channel 0. To achieve 2000 measurements in 1
!second, specify a fixed (lowest) range, set the aperture time to accept the
!necessary sample period, turn autozero off, specify the number of
!measurements to be taken, and specify the source of the sample signal and the
!sample period.
OUTPUT 70903;"FORM REAL,64"
OUTPUT 70903;"DISP:MON OFF"
OUTPUT 70903;"CONF:STR:QUAR  (@100)"
OUTPUT 70903;"    VOLT:RANG MIN"
OUTPUT 70903;"    VOLT:APER 100E-6"
OUTPUT 70903;"    CAL:ZERO:AUTO OFF"
OUTPUT 70903;"    SAMP:COUN 2000"
OUTPUT 70903;"    SAMP:SOUR TIM"
OUTPUT 70903;"    SAMP:TIM 500E-6"

!Measure the strain on the specified channel.
OUTPUT 70903;"INIT"
OUTPUT 70903;"FETC?"

!Enter and display the readings.
ENTER @Dmm USING "#,X,K,K";Ndig$;Count$[1;VAL(Ndig$)]
ENTER @Dmm;Strn_rdgs(*)
ENTER @Dmm
PRINT Strn_rdgs(*)
END
```


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Comments

- The wiring diagram used for this example is on page 28.
- Specifying the gage factor as 2.11E-6 returns the strain measurements in microstrain.
- A gage factor must be specified and an unstrained reference must be measured for each channel.
- The REAL,64 format is selected because the HP 9000 Series 200/300 computer stores readings in that format.
- REAL,64 data is transferred to the computer in the IEEE 488.2-1987 Definite Length Arbitrary Block format. Data in this format is preceded by a header consisting of: # <non-zero digit> <block length>. In this program, the header preceding the measurement data is #516000. The 5 represents the number of digits indicating the block length (16000), and 16000 is the block length (2,000 readings * 8 bytes/reading).
- When HP BASIC is used, the program's ENTER @Dmm USING… statement is used to remove the Arbitrary Block header:

  # - tells the computer not to terminate the ENTER until all ENTER statements have completed.

  X - tells the computer to skip the first character of the Arbitrary Block header (#).

  K,K - stores the <non-zero digit> and <block length> portions of the header in the Ndig$ and Count$ variables respectively.

- The ENTER @Dmm;Rdgs(*) statement enters the readings into the computer. Since a Line Feed (LF) follows the last reading, ENTER @Dmm removes the LF character from the multimeter output buffer. If the LF character is not removed, error -410 "Query Interrupted" occurs the next time data is sent to the buffer. This (third) ENTER statement is only required when using the REAL data formats.

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Rosette Measurements

This program makes a rectangular rosette measurement on channels 0, 1, and 2 of multiplexer card number 1.

```
!Dimension a computer variable to store the strain measurements.
DIM Strn_rdgs(1:3)

!Clear and reset the multimeter.
CLEAR 70903
OUTPUT 70903;"*RST"

!Specify the gage factor for each channel measured.
OUTPUT 70903;"STR:GFAC 2.075E-6,(100,102);:GFAC 2.11E-6,(@101)"

!Measure the unstrained reference for each channel.
OUTPUT 70903;"CAL:STR  (@100:102)"

DISP "Add tension to the specimen; then press 'Continue'"
PAUSE
DISP ""

!Measure the strain on the specified channels. Enter and display the readings.
OUTPUT 70903;"MEAS:STR:QUAR?  (@100:102)"
ENTER 70903;Strn_rdgs(*)
E1=Strn_rdgs(1)
E2=Strn_rdgs(2)
E3=Strn_rdgs(3)
Epsilon=.5*(E1+E3+((E1-E3)^2+(2*E2-E1-E3)^2)^.5)
Sigma=(10.4/2)*((E1+E3)/(1-.32)+1/(1+.32)*((E1-E3)^2+(2*E2-E1-E3)^2)^.5)
Theta=.5*ATN((2*E2-E1-E3)/(E1-E3))
PRINT Epsilon
PRINT Sigma
PRINT Theta
END
```

Comments

- The wiring diagram used for this example is on page 28.
- A gage factor must be specified, and an unstrained reference must be measured for each channel.
- A rosette measurement is a series of three ¼ bridge measurements (channels 100 - 102). Each measurement is substituted into the applicable equation.
- The rosette equations used in this program are listed in Appendix B. For this program, a poisson ratio (ν) of 0.32 and modulus of elasticity (E) of 10.4 are assumed.

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Single-Channel Bending Full Bridge Measurements

This program makes a bending full bridge strain measurement on channel 7 of multiplexer card number 1.

```
!Clear and reset the multimeter.
CLEAR 70903
OUTPUT 70903;"*RST"

!Specify the gage factor for the channel measured.
OUTPUT 70903;"STR:GFAC 2.115E-6,(@107)"

!Measure the channel's unstrained reference.
OUTPUT 70903;"CAL:STR  (@107)"

DISP "Add tension to the specimen; then press 'Continue'"
PAUSE
DISP ""

!Measure the strain on the channel.  Enter and display the reading.
OUTPUT 70903;"MEAS:STR:FBEN?  (@107)"
ENTER 70903;Strn_rdg
PRINT Strn_rdg
END
```

Comments

- The wiring diagram used for this example (FBENding) is on page 30.
- When making full bridge measurements, the channel's bridge selection jumper must be in the "FULL" position.
- Specifying the gage factor as 2.115E-6 returns the strain measurements in microstrain.
- A gage factor must be specified and an unstrained reference must be measured for each channel.

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Relay Strain Gage Measurements with an External Voltmeter

This program shows how strain measurements are made using a relay strain gage multiplexer switchbox and an external (HP 3458A) voltmeter.

```
!Dimension computer variables to store the readings.
DIM Vout_unstr(1:3),Vout_str(1:3),Vr(1:3),Epsilon(1:3)

!Clear and reset the external multimeter.
CLEAR 722
OUTPUT 722;"RESET"

!Configure the external multimeter for DC voltage measurements. Configure its
!trigger system such that the multimeter is externally triggered (when the
!multiplexer channel is closed), and so that it outputs a trigger signal when the
!measurement is complete (to trigger the multiplexer).
OUTPUT 722;"PRESET NORM"
OUTPUT 722;"    MEM FIFO"
OUTPUT 722;"    TBUFF ON"
OUTPUT 722;"    TRIG EXT"
OUTPUT 722;"    EXTOUT RCOMP,NEG"

!Configure the relay multiplexer switchbox so that it outputs a trigger signal
!(via the mainframe "Trig Out" port) when a channel is closed, and so that it is
!externally triggered (via the mainframe "Event In" port) to close a channel.
!Connect the analog bus, which carries the bridge output and excitation
!voltages, to the HI, LO, and Guard terminals on the multiplexer terminal
!module.
OUTPUT 70914;"*RST"
OUTPUT 70914;"OUTP ON"
OUTPUT 70914;"TRIG:SOUR EXT"
OUTPUT 70914;"SCAN:PORT ABUS"

!Download the scan list to measure Vout and Vs unstrained. Close the first
!channel in the list to start the scan.
OUTPUT 70914;"SCAN (@100:102,115)"
OUTPUT 70914;"INIT"

DISP "Add tension to the specimen; then press 'Continue'"
PAUSE
DISP ""

!Download the scan list to measure Vout and Vs strained. Close the first
!channel in the list to start the scan.
OUTPUT 70914;"SCAN (@100:102,115)"
OUTPUT 70914;"INIT"

!Compute and display the 1/4 bridge strain measurements.
ENTER 722;Vout_unstr(*),Vs_unstr,Vout_str(*),Vs_str
CALL Strn_cmput(Vr(*),Vout_str(*),Vout_unstr(*),Vs_str,Vs_unstr)
END
SUB Strn_cmput(Vr(*),Vout_str(*),Vout_unstr(*),Vs_str,Vs_unstr)
    FOR I=1 TO 3
        Vr(I)=Vout_str(I)/Vs_str-Vout_unstr(I)/Vs_unstr
        Epsilon(I)=-4*Vr(I)/2.11E-6*(1+2*Vr(I))
        PRINT Epsilon(I)
    NEXT I
SUBEND
```


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Comments

- The strain gage wiring diagram used for this example is on page 28. The diagram showing how the HP 3458A Multimeter is connected to the relay strain gage multiplexer (via the mainframe) is on page 31.

- When making strain measurements with an external voltmeter, the following voltages are measured in the sequence shown:

  bridge output voltage (Vout: channels 100 - 102) unstrained

  bridge excitation voltage (Vs: channel 115) unstrained

  bridge output voltage (Vout: channels 100 - 102) strained

  bridge excitation voltage (Vs: channel 115) strained

  These measurements are used to compute Vr, which in equation form is defined as:

  Vr = [(Vout/Vs)strained - (Vout/Vs)unstrained]

  Vr is then substituted into the equation (Table 4-1) for ¼ bridge measurements.

- The HP E1300/E1301 mainframe's "Event In" and "Trig Out" ports are connected to the voltmeter's "VM Compl" and "Ext Trig" ports, respectively. Thus, when a multiplexer channel is closed, a "channel closed" pulse from the mainframe's "Trig Out" port is applied to the voltmeter's "Ext Trig" port. When the voltmeter measurement is complete, the voltmeter complete signal is applied to the "Event In" port which triggers the multiplexer to close the next channel in the list.

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FET Strain Gage Measurements with an External Voltmeter

This program shows how strain measurements are made using a FET strain gage multiplexer switchbox and an external (HP 3458A) voltmeter.

```
!Dimension a computer variables to store the readings.
DIM Vout_unstr(1:3),Vout_str(1:3),Vr(1:3),Epsilon(1:3)

!Clear and reset the external multimeter.
CLEAR 722
OUTPUT 722;"RESET"

!Configure the external multimeter for DC voltage measurements. Configure its
!trigger system such that the multimeter is externally triggered (when the
!multiplexer channel is closed), and so that it outputs a trigger signal when the
!measurement is complete (to trigger the multiplexer).
OUTPUT 722;"PRESET NORM"
OUTPUT 722;"    MEM FIFO"
OUTPUT 722;"    TBUFF ON"
OUTPUT 722;"    TRIG EXT"
OUTPUT 722;"    EXTOUT RCOMP,NEG"

!Configure the FET multiplexer switchbox so that a channel is closed when a
!trigger is received via the digital bus. Close the multiplexer tree relays
!necessary to make a DC voltage measurement. Connect the analog bus, which
!carries the bridge output and excitation voltages, to the HI, LO, and Guard
!terminals on the multiplexer terminal module. Set a delay between when the
!trigger to close a channel is received, and when the channel closed trigger is
!generated. This prevents voltmeter triggers from occurring too fast.
OUTPUT 70914;"*RST"
OUTPUT 70914;"TRIG:SOUR:DBUS"
OUTPUT 70914;"SCAN:MODE VOLT"
OUTPUT 70914;"SCAN:PORT ABUS"
OUTPUT 70914;"SETT:TIM MAX,(@100)"

!Download the scan list to measure Vout and Vs unstrained.
OUTPUT 70914;"SCAN  (@100:102,115)"
OUTPUT 70914;"INIT"

DISP "Add tension to the specimen; then press 'Continue'"
PAUSE
DISP ""

!Download the scan list to measure Vout and Vs strained.
OUTPUT 70914;"SCAN  (@100:102,115)"
OUTPUT 70914;"INIT"

!Compute and display the ¼ bridge strain measurements.
ENTER 722;Vout_unstr(*),Vs_unstr,Vout_str(*),Vs_str
CALL Strn_cmput(Vr(*),Vout_str(*),Vout_unstr(*),Vs_str,Vs_unstr)
END
SUB Strn_cmput(Vr(*),Vout_str(*),Vout_unstr(*),Vs_str,Vs_unstr)
    FOR I=1 TO 3
        Vr(I)=Vout_str(I)/Vs_str-Vout_unstr(I)/Vs_unstr
        Epsilon(I)=-4*Vr(I)/2.11E-6*(1+2*Vr(I))
        PRINT Epsilon(I)
    NEXT I
SUBEND
```


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Comments

- The strain gage wiring diagram used for this example is on page 28. The diagram showing how the HP 3458A Multimeter is connected to the FET strain gage multiplexer is on page 32.

- When making strain measurements with an external voltmeter, the following voltages are measured in the sequence shown:

  bridge output voltage (Vout: channels 100 - 102) unstrained

  bridge excitation voltage (Vs: channel 115) unstrained

  bridge output voltage (Vout: channels 100 - 102) strained

  bridge excitation voltage (Vs: channel 115) strained

  These measurements are used to compute Vr, which in equation form is defined as:

  Vr = [(Vout/Vs)strained - (Vout/Vs)unstrained]

  Vr is then substituted into the equation (Table 4-1 on page 52) for ¼ bridge measurements.

- The channel closed/measurement handshake sequence between the FET multiplexer switchbox and the voltmeter occurs over the multiplexer's digital bus. When connected as shown in Figure 2-8, the digital bus cable (HP Part Number E1411-80001) connects the multiplexer's "channel advance" and "channel closed" pins to the voltmeter's "VM Compl" and "Ext Trig" ports, respectively. Thus, when a multiplexer channel is closed, a "channel closed" pulse from the multiplexer is applied to the voltmeter's "Ext Trig" port. When the voltmeter measurement is complete, the voltmeter complete signal triggers the multiplexer via the "channel advance" line.

Continued on Next Page

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- The FET multiplexer switchbox can be used with an external voltmeter without using the digital bus cable. Connect the voltmeter to the switchbox as indicated in Figure 2-7 on page 31. However, **do not connect the cable between the voltmeter's "voltmeter complete" port and the mainframe's "Event In" port.** Modify the previous program as follows:

```
!Configure the external multimeter for DC voltage measurements. Configure its
!trigger system such that the multimeter is externally triggered (when the
!multiplexer channel is closed).
OUTPUT 722;"PRESET NORM"
OUTPUT 722;"    MEM FIFO"
OUTPUT 722;"    TBUFF ON"
OUTPUT 722;"    TRIG EXT"

!Configure the FET multiplexer switchbox so that it outputs a trigger pulse
!when a channel is closed. Set the switchbox to be triggered by the *TRG
!command. Close the multiplexer tree relays necessary to make DC voltage
!measurements. Connect the analog bus, which carries the bridge output and
!excitation voltages, to the HI, LO, and Guard terminals on the multiplexer
!terminal module.
OUTPUT 70914;"*RST"
OUTPUT 70914;"OUTP ON"
OUTPUT 70914;"TRIG:SOUR:BUS"
OUTPUT 70914;"SCAN:MODE VOLT"
OUTPUT 70914;"SCAN:PORT ABUS"

!Measure Vout and Vs unstrained. INIT closes the first channel in the list.
!(*TRG) is used to advance and complete the scan. The WAIT statements allow
!the voltmeter measurement to complete before the next channel is closed.
OUTPUT 70914;"SCAN  (@100:102,115)"
OUTPUT 70914;"INIT"
WAIT .1
FOR I=1 TO 4
    OUTPUT 70914;"*TRG"
    WAIT .1
NEXT I

DISP "Add tension to the specimen; then press 'Continue'"
PAUSE
DISP ""

!Measure Vout and Vs strained. Again, INIT closes the first channel in the list.
!Backplane triggers (*TRG) are issued to advance and complete the scan. The
!WAIT statements allow the voltmeter measurement to complete before the next
!channel is closed.
OUTPUT 70914;"SCAN  (@100:102,115)"
OUTPUT 70914;"INIT"
WAIT .1
FOR I=1 TO 4
    OUTPUT 70914;"*TRG"
    WAIT .1
NEXT I
```

This modification allows the multimeter to be triggered when a multiplexer channel is closed. However, the multiplexer is triggered by the user (*TRG) which advances the scan.

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Measurements with Downloaded Unstrained References

In certain applications, it may not be possible to measure unstrained references ((Vout/Vs)unstrained) prior to making the actual strain measurements. A feature of the strain gage multiplexers is the ability to measure unstrained references, store the references in a computer, and then download them at the time the strain measurements are made.

The following example shows how unstrained references are measured, stored in a computer, and then downloaded when the strain measurements are made.

```
!Dimension computer variables to store the unstrained reference measurements
!and strain measurements.
DIM Unstr(0:2),Strn_rdgs(0:2)

!Clear and reset the multimeter.
CLEAR 70903
OUTPUT 70903;"*RST"

!With the specimen in an unstrained state, call the subprogram which measures
!the unstrained references for each channel. Store the references in a computer
!variable.
CALL Ref_meas(Unstr(*))

!Once the specimen is in a strained state, the strain measurements can be made.
PAUSE

!Make three sets of strain measurements. For each set, specify the gage factor,
!download the unstrained references and then measure the strain. Enter and
!display the readings.
OUTPUT 70903;"STR:GFAC 2.11E-6,(@100:102)"
CALL Ref_load(Unstr(*))
FOR J=1 TO 5
    OUTPUT 70903;"MEAS:STR:QUAR?  (@100:102)"
    ENTER 70903;Strn_rdgs(*)
    PRINT Strn_rdgs(*)
NEXT J
PRINT

WAIT 5

OUTPUT 70903;"STR:GFAC 2.11E-6,(@100:102)"
CALL Ref_load(Unstr(*))
FOR J=1 TO 5
    OUTPUT 70903;"MEAS:STR:QUAR?  (@100:102)"
    ENTER 70903;Strn_rdgs(*)
    PRINT Strn_rdgs(*)
NEXT J
PRINT

WAIT 5
```

Continued on Next Page

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```
OUTPUT 70903;"STR:GFAC 2.11E-6,(@100:102)"
CALL Ref_load(Unstr(*))
FOR J=1 TO 5
    OUTPUT 70903;"MEAS:STR:QUAR?  (@100:102)"
    ENTER 70903;Strn_rdgs(*)
    PRINT Strn_rdgs(*)
NEXT J
END

!This subprogram measures the unstrained references, queries the references,
!and then stores the references in a computer variable for later use.
SUB Ref_meas(Unstr(*))
    OUTPUT 70903;"CAL:STR  (@100:102)"
    OUTPUT 70903;"STR:UNST?  (@100:102)"
    ENTER 70903;Unstr(*)
SUBEND

!This subprogram downloads the unstrained references prior to the strain
!measurements.
SUB Ref_load(Unstr(*))
    FOR I=0 TO 2
        OUTPUT 70903;"STR:UNST  ";Unstr(I);",(@";100+I;")"
    NEXT I
SUBEND
```

Comments

- This program makes ¼ bridge measurements on channels 0, 1, and 2 of multiplexer card number 1. The wiring diagram used is on page 28.
- Since each strain measurement must have an unstrained reference, the unstrained references are downloaded prior to each set of measurements.
- The unstrained references can be stored on disk for later use.

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Chapter 4
Understanding the Strain Gage Multiplexers

About This Chapter

This chapter describes the strain measurement procedure used by the examples in Chapter 3, and also describes the measurement circuitry associated with ¼, ½, and full bridge measurements. The sections of this chapter are:

- Making Strain Measurements . . . . . Page 49
- Strain Gage Multiplexer Block Diagrams . . . . . Page 52
- Understanding the Strain Gage Measurement Circuits . . . . . Page 53
- Understanding the Bridge Configurations . . . . . Page 58
- Measurements Using an External Voltmeter . . . . . Page 63
- Voltage and Resistance Measurements . . . . . Page 64

Making Strain Measurements

This section explains the procedure used to make strain measurements. Also covered are the equations (in the instrument firmware) which calculate the measured strain.

Strain Measurement Procedure

The procedure for making strain measurements with the HP E1355A - E1358A Strain Gage Multiplexers and HP E1326B/E1411B Multimeter is:

1. Specify the Gage Factor and, for Poisson configurations, the Poisson Ratio.

   STRain:GFACtor *gage_factor*,(@*channel_list*)
   STRain:POISson *poisson_ratio*,(@*channel_list*)

   One *gage_factor* and *poisson_ratio* (Poisson configurations) must be specified for each channel.

2. Measure the unstrained reference voltage.

   CALibration:STRain (@*channel_list*)

   One unstrained reference voltage measurement must be made on each channel. Note that this command leaves the HP E1326B/E1411B Multimeter configured for an unstrained reference voltage measurement. The multimeter must be reconfigured to make the strain measurement (Step 4).

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The unstrained reference measurement is made because of the unbalanced bridge method of strain measurement. Instead of balancing (nulling) the bridge before each measurement, an unstrained reference ((Vout/Vs)unstrained) is measured for each channel. The unbalanced bridge measurement technique is described in the next section.

3. Add tension to the specimen.

4. Configure the multimeter and make the strain measurement(s).

   MEASure:STRain:*strain_function*? (@*channel_list*)
   or
   CONFigure:STRain:*strain_function*,(@*channel_list*)

   When MEASure is used, the multimeter is configured and the measurement is immediately taken. Because of this, variations to the multimeter configuration (range, aperture time) are limited to the values set by the MEASure command (see the table on page 77).

   When CONFigure is used, the multimeter is configured but the measurement is not taken until READ? or INIT is executed. Thus, low-level multimeter commands (covered in the multimeter manual) can be used to change the configuration (range, aperture time) before the measurement is made.

Note The strain measurement commands identified in this procedure are HP E1326B/E1411B Multimeter commands. Information on how these commands relate to strain measurements and how the multimeter makes strain measurements is contained in this manual. Information on the entire multimeter command set and on general multimeter operation is contained in the *HP E1326B/E1411B User's Manual*.

Unbalanced Bridge Measurement Technique

The strain gage multiplexers measure strain using an unbalanced Wheatstone Bridge (see "Understanding the Strain Gage Measurement Circuits" on page 53). Unbalanced bridge measurement techniques do not require the bridge to be balanced (manually or electronically) before strain measurements are made.

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Calculating Vr

Residing in the instrument firmware are the equations used to calculate the measured strain (Table 4-1 on page 52). One parameter common to each equation is Vr. Vr is the difference in ratios of the Wheatstone Bridge output voltage (Vout) to the bridge excitation voltage (Vs), under strained and unstrained conditions. In equation form, Vr is represented as:

$$Vr = [(Vout/Vs)strained - (Vout/Vs)unstrained]$$

The strain measurement procedure involves measuring the voltages which determine Vr. Once Vr is known, the firmware calculates the value of strain.

When CALibration:STRain (@*channel_list*) is executed, the multimeter measures the unstrained bridge output voltage (Vout) and the bridge excitation voltage (Vs), and computes the unstrained reference (Vout/Vs) for each channel.

When MEASure:STRain:*strain_function*? (@*channel list*) is executed, the multimeter measures the strained bridge output voltage (Vout) and the bridge excitation voltage (Vs). The ratio of Vout/Vs(strained) is calculated for each channel and is used with the channel's unstrained reference to determine Vr.

Note Vs unstrained and Vs strained is measured one time per channel list. If the channel list includes more than one multiplexer, Vs is measured one time on each multiplexer.

Downloaded Unstrained References

The strain gage multiplexers have the capability of measuring the unstrained reference voltages, storing the references in a computer, and then downloading the references at the time the strain measurements are made. This feature is useful in applications where repeated strain measurements are made once a single unstrained reference has been measured. The commands to measure, store, and download the unstrained reference are:

CALibration:STRain (@*channel_list*)
(measures the unstrained reference)

STRain:UNSTrained? (@*channel_list*)
(queries the references and returns them to the output buffer from where they are entered into the computer)

STRain:UNSTrained *reference*,(@*channel_list*)
(downloads the unstrained references)

An example of how unstrained references are downloaded is found on page 46.

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Strain Measurement Equations

The equations in the instrument firmware which calculate the measured strain are given in Table 4-1.

Table 4-1. Strain Measurement Equations

Arrangement	Equation	Parameter
¼ Bridge Bending ½ Bridge Poisson ½ Bridge Bending Full Bridge Bending Poisson Full Bridge Poisson Full Bridge	$\varepsilon = -4Vr/GF(1 + 2Vr)$ $\varepsilon = -2Vr/GF$ $\varepsilon = -4Vr/GF[(1 + \nu)-2Vr(\nu - 1)]$ $\varepsilon = -Vr/GF$ $\varepsilon = -2Vr/GF(\nu + 1)$ $\varepsilon = -2Vr/GF[(\nu + 1) -Vr(\nu - 1)]$	QUARter HBENding HPOisson FBENding FBPoisson FPOisson
ε = strain. For results in microstrain, multiply the calculated (measured) strain by 1E-6. NOTE: tensile strain is (+), compressive strain is (-) Vr = [(Vout/VS)strained - (Vout/VS) unstrained] Vout = bridge output voltage Vs = bridge excitation voltage GF = Gage Factor ν = Poisson Ratio		

Strain Gage Multiplexer Block Diagrams

The manner in which strain-related signals are routed from the specimen to the multimeter is illustrated with the block diagrams in Figure 4-1.

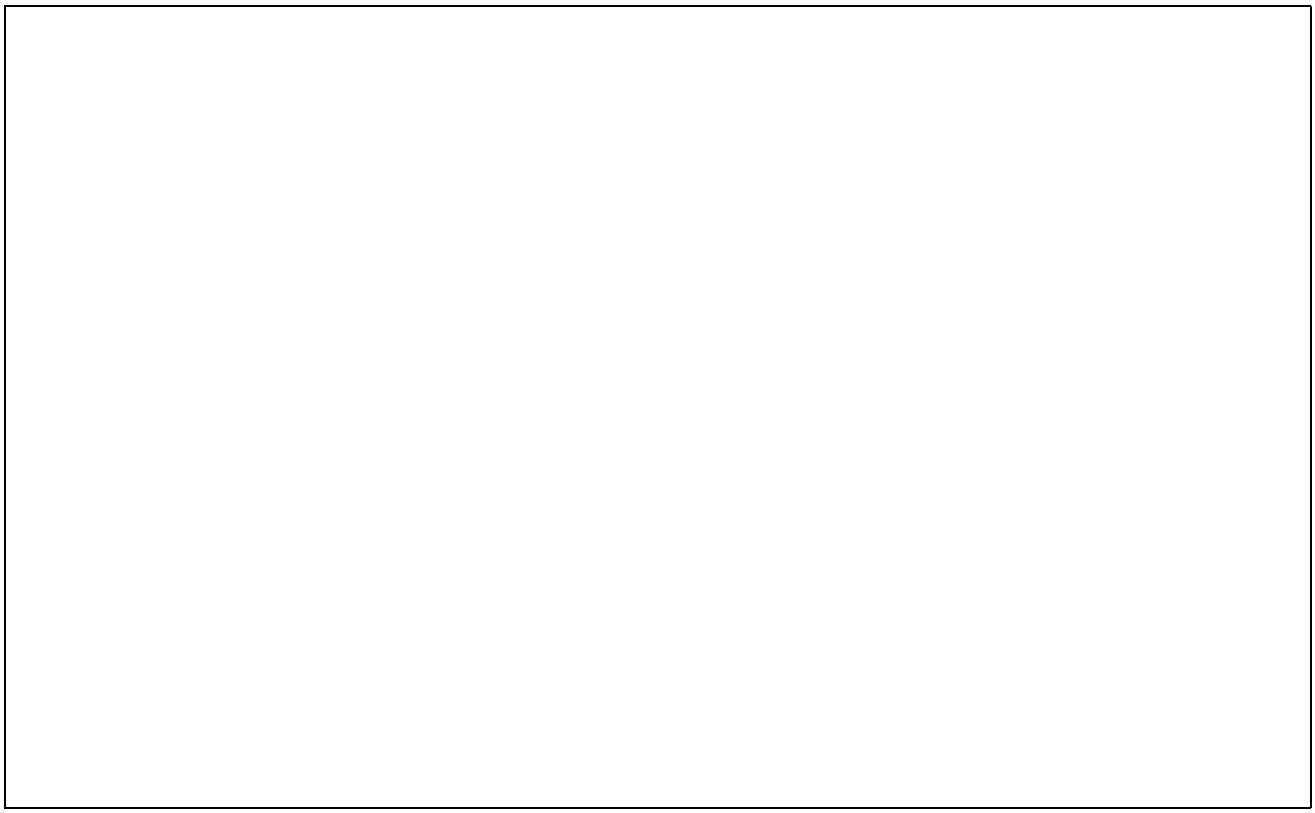


Figure 4-1. Strain Gage Multiplexer Block Diagrams

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Block Diagram Description

For all strain measurements, the bridge configuration is wired from the specimen to selected +E, -EI , -E2, H, L, and G terminals on the strain gage multiplexer terminal module.

When a strain (measurement) command is executed, the bridge completion channel's relay or FET switch is closed, as is the multiplexer's tree relay or tree switch. This passes the H, L, and G signals from the strain gage to the multimeter, via the analog bus. The +E, -E1, and -E2 signals are wired directly to the strain gage measurement circuitry on the terminal module. The measurement circuitry is covered in the following sections.

Understanding the Strain Gage Measurement Circuits

This section describes the strain gage measurement circuits used by each strain gage multiplexer. These circuits include:

- Wheatstone Bridge
- Chevron Bridge
- Wagner Ground

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The Wheatstone Bridge

The Wheatstone Bridge Circuit shown in Figure 4-2 is the fundamental strain measuring circuit.

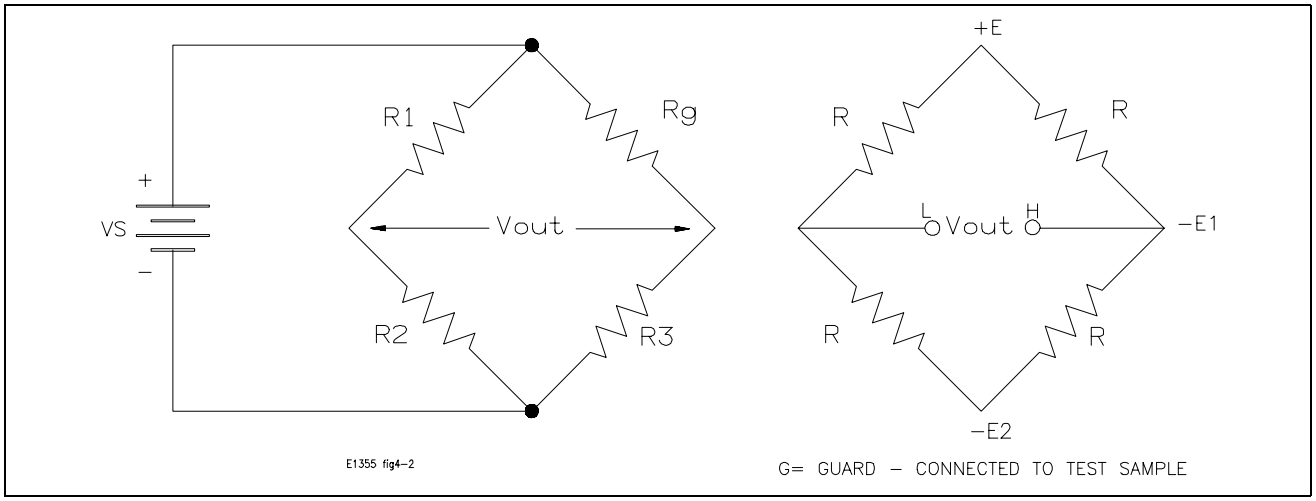


Figure 4-2. The Wheatstone Bridge

When a strain gage is wired to a bridge completion channel, it completes the Wheatstone Bridge circuit as indicated in Figure 4-3. This circuit represents a ¼ bridge arrangement where only one arm contains an active element (strain gage). The other arms are fixed value resistors (as shown) or they may represent unstrained gages.

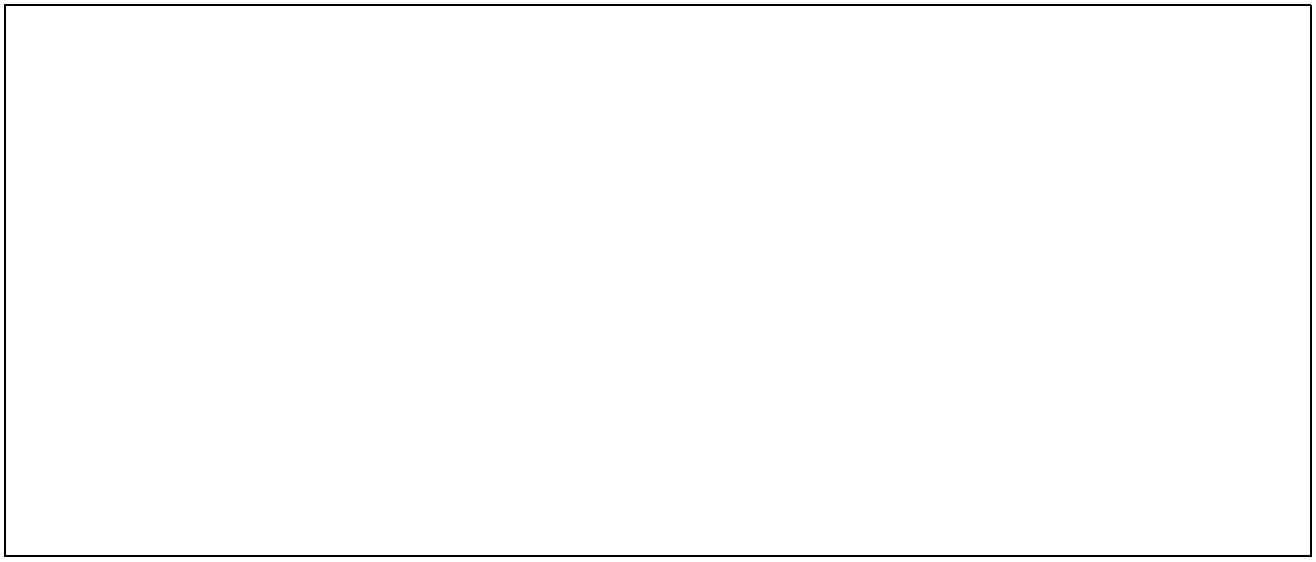


Figure 4-3. Bridge Completion Circuitry - 1/4 Bridge

In a ½ bridge arrangement, the 120Ω or 350Ω bridge completion resistor is replaced by a strain gage when the gages are connected to the terminals as indicated in Figure 4-4.

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Figure 4-4. Bridge Completion Circuitry - 1/2 Bridge

For a full bridge arrangement, strain gages comprise all four arms of the Wheatstone Bridge (Figure 4-5). Note the position of the bridge selection jumper required to configure the channel for full bridge measurements.

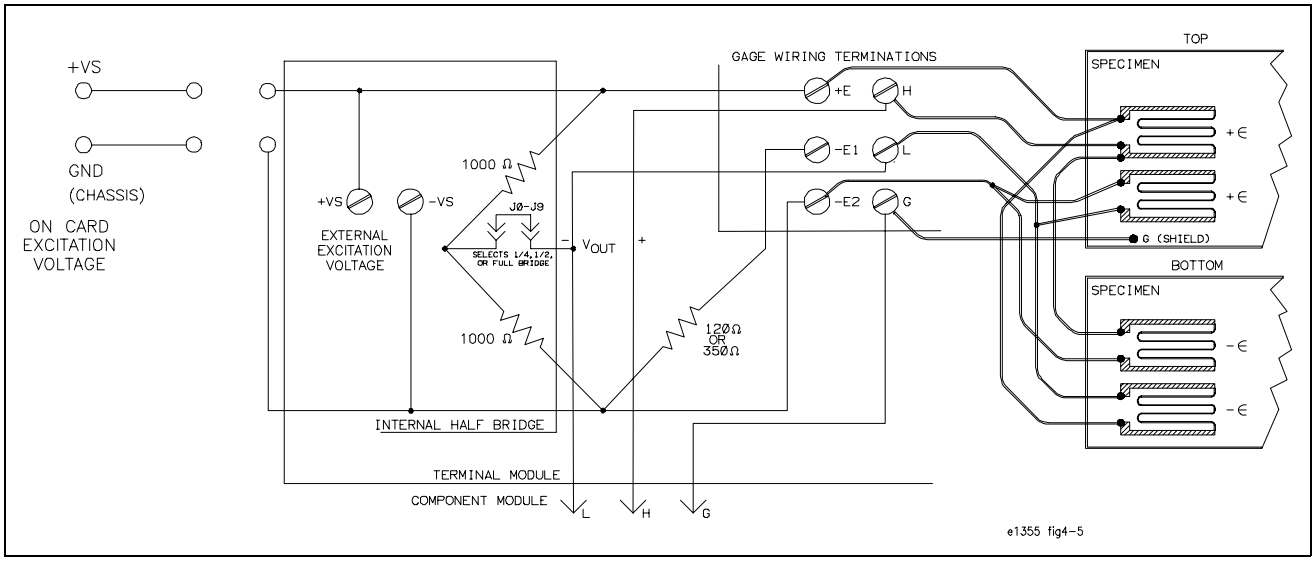


Figure 4-5. Bridge Completion Circuitry - Full Bridge

120Ω and 350Ω Multiplexers

A 120Ω strain gage multiplexer is distinguished from a 350Ω multiplexer by the value of the Wheatstone bridge completion resistor shown in Figure 4-3. **When strain is measured with a ¼ bridge arrangement, a 120Ω strain gage multiplexer is required for 120Ω gages, and a 350Ω multiplexer is required for 350Ω gages**. In the ½ and full bridge arrangements, the bridge completion resistor is replaced by a strain gage (Figures 4-4, 4-5). **Thus, any strain gage multiplexer can be used with any value of gage resistance when measuring strain with a ½ or full bridge arrangement**.

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The Chevron Bridge

When measuring strain with ¼ and ½ bridge arrangements, the strain gage accessories use a variation of the Wheatstone Bridge known as the Chevron Bridge (Figure 4-6). The ¼ bridge and ½ bridge arrangements still complete the Wheatstone Bridge; however, the Chevron Bridge enables the bridge excitation voltage (VS) and the precision internal half bridge resistors (R1/R2) of the bridge completion circuitry to be shared among all channels.

Because the multiplexers use an unbalanced bridge for strain measurements (see "Unbalanced Bridge Measurement Technique" on page 50), the accuracy of the measurement depends on the resistance of the bridge arms remaining constant. The resistance must remain constant for the unstrained measurement and the strain measurement. The only resistance which changes is the resistance of the active gage(s).

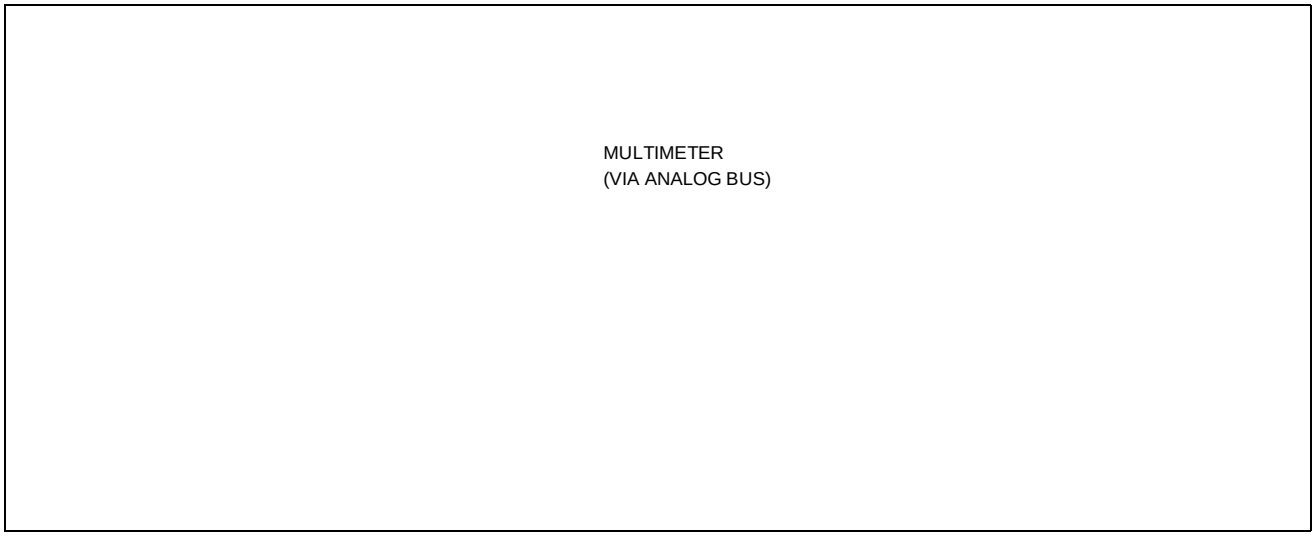


Figure 4-6. The Chevron Bridge

The Chevron Bridge ensures that the bridge arm resistance remains constant by switching the outputs of the bridge completion channels (HI (high), LO (low), G (guard)) to the input of the multimeter. By switching the outputs rather than switching the bridge arms, the gages are "permanently" wired to the bridge completion channels via the +E, -E1, and -E2 terminals. This eliminates any resistance changes due to self heating and variations in switch or relay contact resistance.

Note G (guard) is not switched on the FET multiplexers.

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The Wagner Ground

To increase measurement accuracy, the **relay** strain gage multiplexers contain a Wagner Ground circuit similar to that shown in Figure 4-7. The purpose of the Wagner Ground is to reduce stray leakage currents by driving the midpoint (-E1) of the Wheatstone Bridge via the guard lead to the same potential as the specimen. Because of this circuit, the strain gage accessories are identified as having a "driven guard".

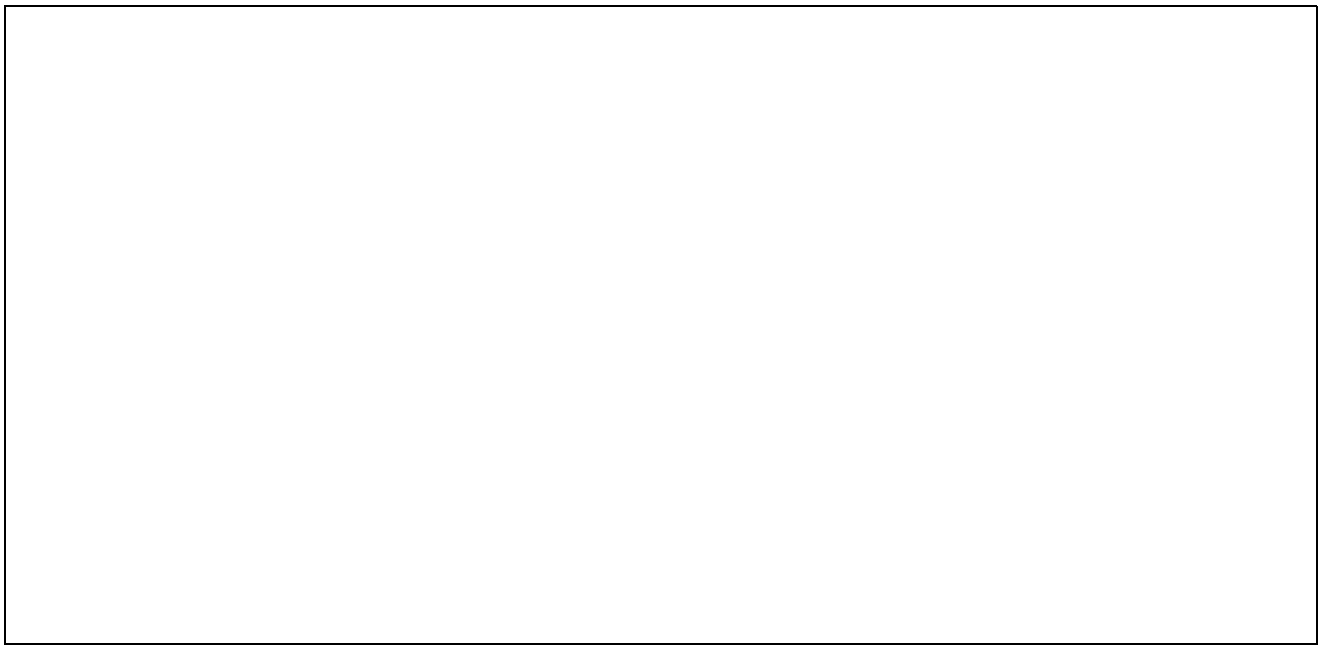


Figure 4-7. The Wagner Ground

When the strain gage (Rg) is mounted to the specimen, there is generally thousands of Megohms of isolation resistance between the gage and the specimen. If a difference in potential exists between the specimen and the midpoint of the bridge, stray leakage currents are generated (current = voltage/resistance). These leakage currents in turn, introduce random voltages along the measurement path which are then interpreted as strain related signals. By keeping the potential on the specimen and the midpoint of the bridge the same, leakage current is reduced.

In applications where the specimen is maintained at a specific potential by an external source, the Wagner Ground will "float" (set) the midpoint of the bridge to the same potential. For example, if 100V is applied to the specimen and the bridge excitation voltage is 5.0V, the +E point on the Bridge is floated to 102.5V, -E2 is floated to 97.5V, and the midpoint (-E1) is maintained at 100V.

The Wagner Ground circuit is only in effect when the guard lead is connected from the specimen to the G terminal on the bridge completion channel. The guard lead will generally be the shield surrounding the conductors on a twisted-shielded cable. Note that if several gages are mounted to the specimen, the guard (shield) must be connected to each channel to maintain the Wagner Ground. This is because the guard (G) terminal (on the relay multiplexers) is switched to the multimeter in addition to the HI and LO bridge outputs (see "The Chevron Bridge" on page 56).

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Note When using the FET multiplexers with several strain gages on a single specimen, only one guard lead needs to be connected since the guard is not "switched" with the HI and LO terminals.

Understanding the Bridge Configurations

This section describes each bridge configuration in detail.

1/4 Bridge Measurements (QUARter)

In a ¼ bridge arrangement, there is one active element (gage) in the Wheatstone Bridge circuit (Figure 4-8). A single strain gage has the lowest sensitivity of the bridge arrangements available; however, accurate measurements can still be made when following the wiring guidelines covered in Chapter 2.

Rosette Measurements

¼ bridge measurements are used when measuring strain with rosettes. A three element rosette, for example, would be connected to three bridge completion channels. Each channel would then be programmed for a ¼ bridge measurement. Each measurement ($\varepsilon_1,\varepsilon_2,\varepsilon_3$) is then substituted into the applicable rosette equation in Appendix B.

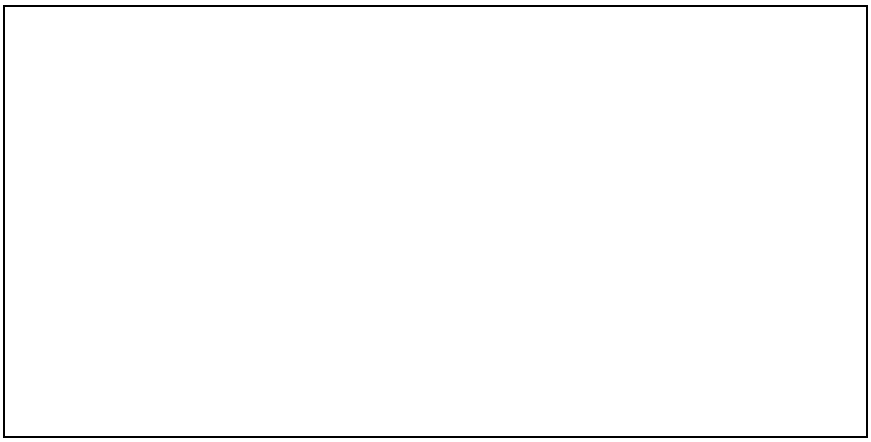


Figure 4-8. 1/4 Bridge Arrangement

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1/2 Bridge Measurements

In a ½ bridge arrangement, there are two active elements (gages) within the Wheatstone Bridge circuit (Figure 4-9). The ½ bridge arrangement has twice the sensitivity as the ¼ bridge arrangement and the additional strain gage compensates for temperature induced apparent strain. The ½ bridge strain measurements available based on gage positioning on the specimen are described in the following sections.

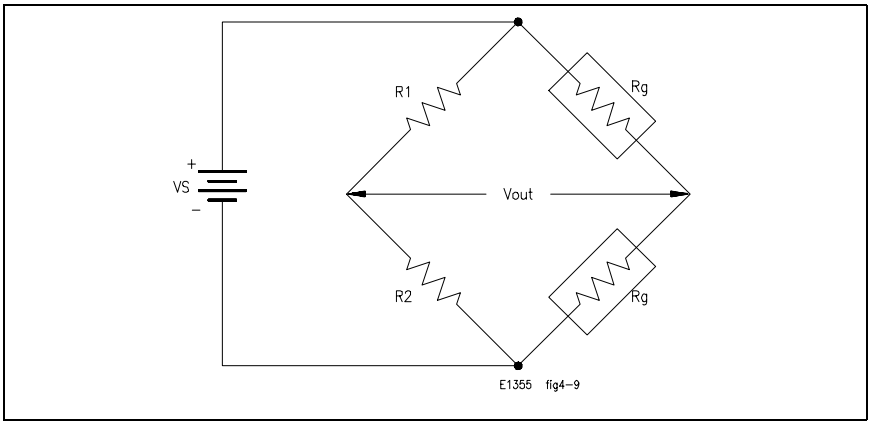


Figure 4-9. 1/2 Bridge Arrangement

Bending 1/2 Bridge (HBENding)

The maximum sensitivity achieved with a ½ bridge arrangement is when the strain gages are mounted to the specimen as indicated in Figure 4-10. When the beam is strained, strain gage Rg1 will be strained in tension and strain gage Rg2 will be strained in compression. When both gages are strained the same amount simultaneously, the output of the bridge (sensitivity) is doubled. Since the gages represent adjacent legs in the Wheatstone Bridge circuit, any temperature induced strain is cancelled.

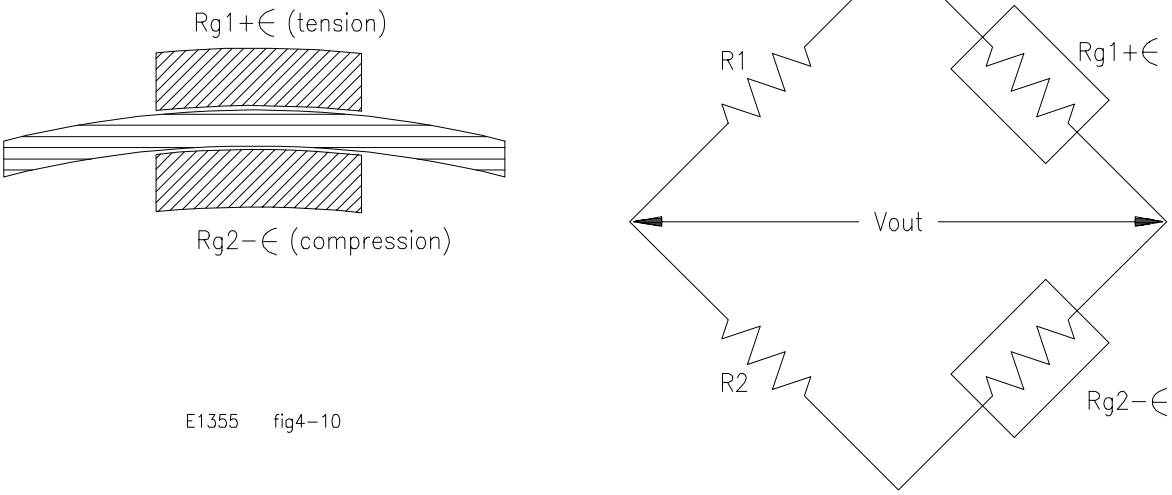


Figure 4-10. Bending 1/2 Bridge

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Poisson 1/2 Bridge (HPOisson)

In applications where there is no equal strain of opposite sign as there is for the beam in Figure 4-10, an increase in measurement sensitivity and temperature compensation is achieved by mounting the strain gages at right angles on the specimen. Mounting the gages in this manner is known as a Poisson arrangement and is represented in Figure 4-11. With a Poisson arrangement, the sensitivity is not as great as with the bending ½ bridge; however, it is approximately 25% greater than a ¼ bridge arrangement. Again, since the gages are adjacent legs of the Wheatstone Bridge circuit, complete temperature compensation is achieved.

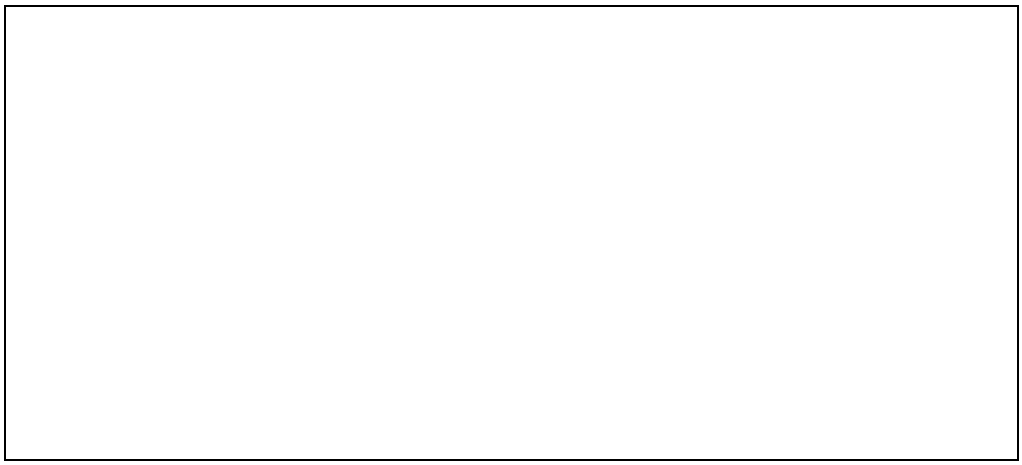


Figure 4-11. Strain Gages in Poisson Arrangement

Dummy Gage

In a dummy gage configuration, one of the strain gages in the ½ bridge arrangement is mounted to an unstrained portion of the specimen (Figure 4-12). This gage arrangement provides complete temperature compensation; however, measurement sensitivity is not increased since a ¼ bridge measurement is made with the one active gage.

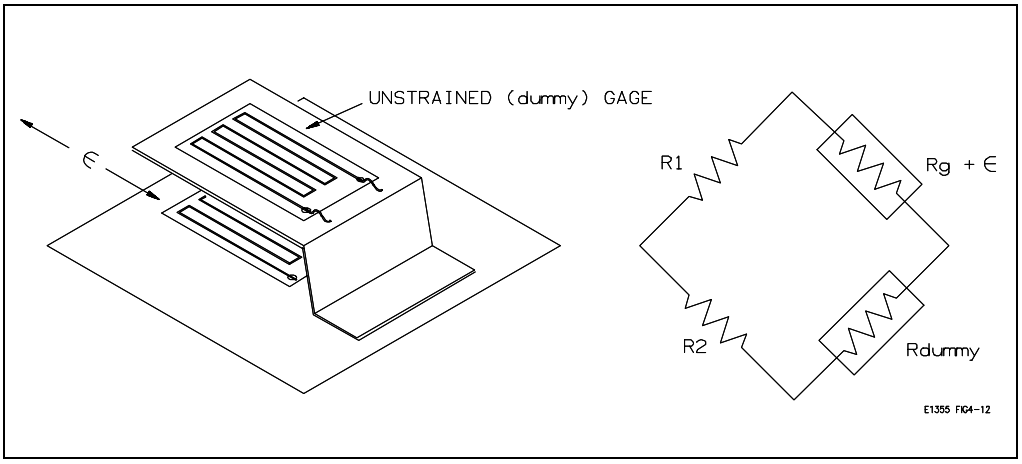


Figure 4-12. Dummy Gage Arrangement

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Full Bridge Measurements

In a full bridge arrangement, strain gages are used in all four legs of the Wheatstone Bridge circuit (Figure 4-13). The full bridge arrangement has the highest sensitivity and accuracy of any bridge arrangement, and it provides complete temperature compensation for temperature induced apparent strain. The full bridge strain measurements available based on gage positioning are described in the following sections.

Figure 4-13. Full Bridge Arrangement

Bending Full Bridge (FBENding)

The maximum sensitivity achieved with a full bridge arrangement is when the strain gages are mounted to the specimen as indicated in Figure 4-14. When the beam is strained, gages Rg1 and Rg2 are strained in tension and gages Rg3 and Rg4 are strained in compression. When all gages are strained the same amount simultaneously, the bridge sensitivity is increased by a factor of four. Since the gages undergoing tensile and compressive strain are adjacent legs in the Wheatstone Bridge circuit, any temperature induced strain is cancelled.

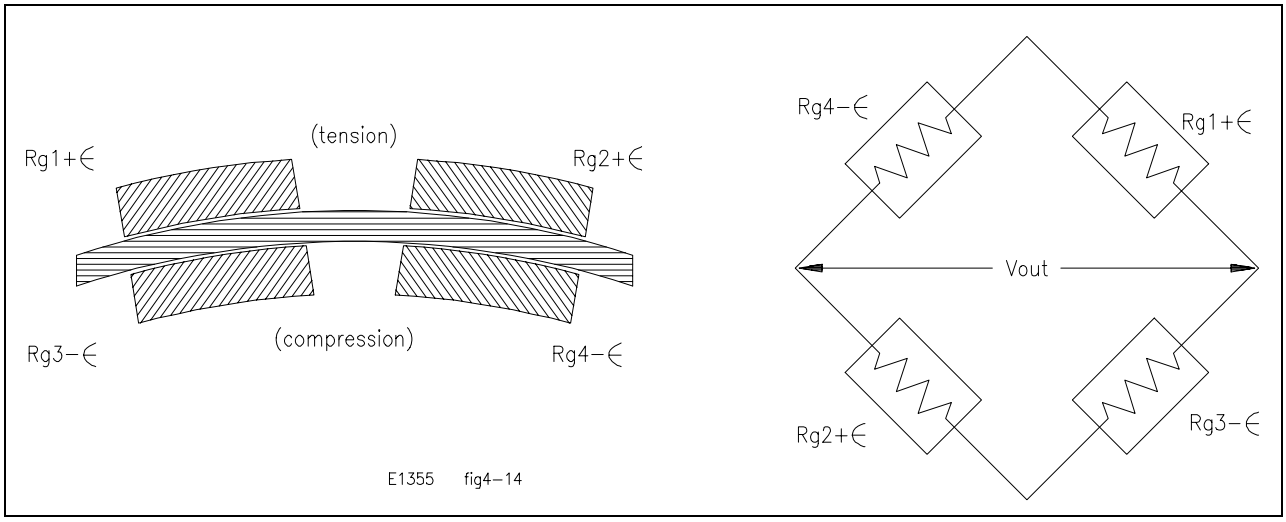


Figure 4-14. Bending Full Bridge

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Bending Poisson Full Bridge (FBPoisson)

In applications where there is no equal strain of opposite sign as there is for the beam in Figure 4-14, Poisson strain can be measured by mounting the strain gages at right angles on the specimen. Mounting the gages in this manner is known as a Poisson arrangement and is represented in Figure 4-15. With a Poisson arrangement, the sensitivity is not as great as with the bending full bridge. However, since the gages are adjacent legs of the Wheatstone Bridge circuit, complete temperature compensation is achieved.

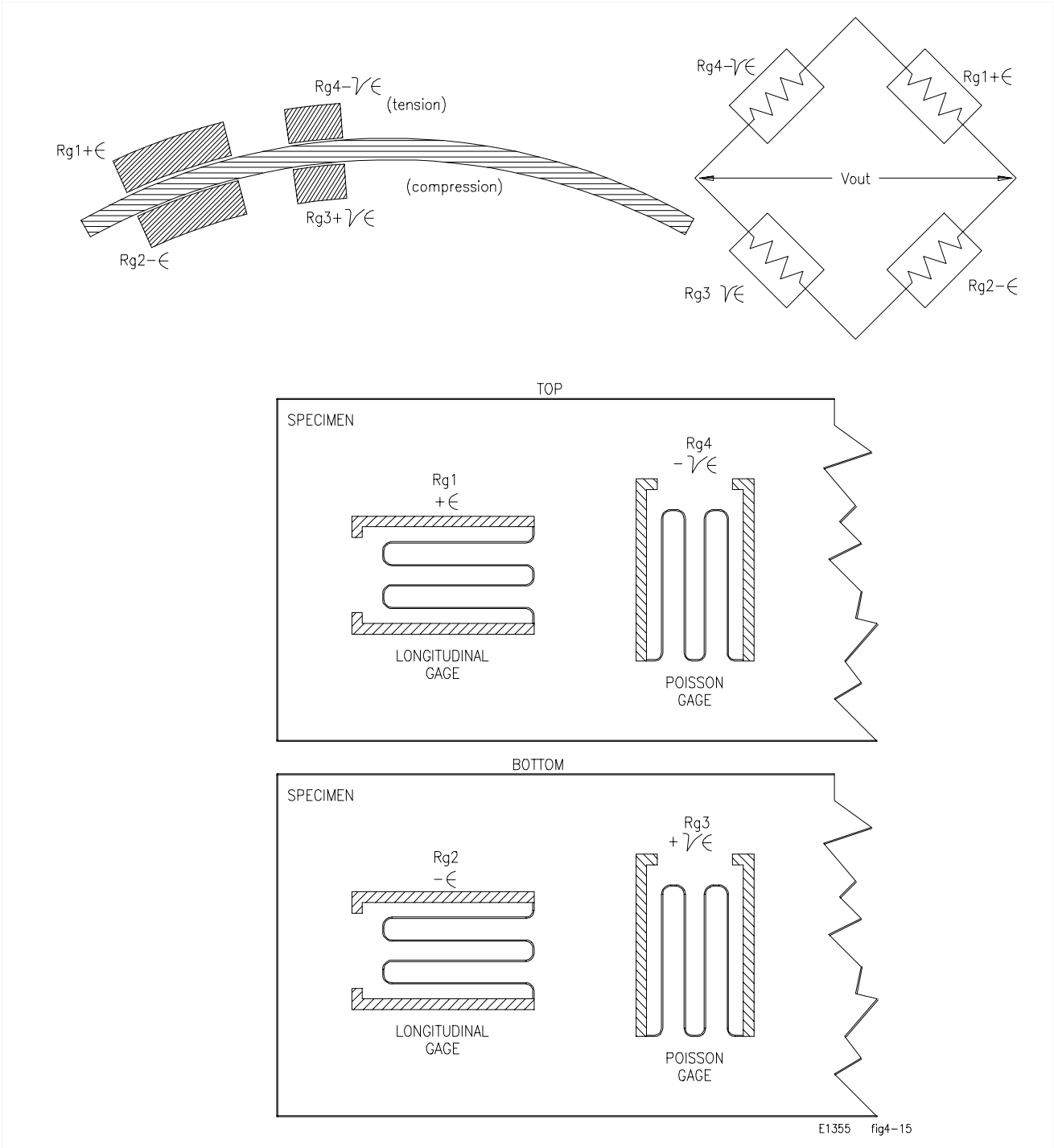


Figure 4-15. Bending Poisson Arrangement

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Poisson Full Bridge (FPOisson)

In applications where the specimen is stressed lengthwise, the measurement sensitivity is increased and temperature compensation is achieved when the gages are mounted to the specimen as indicated in Figure 4-16.

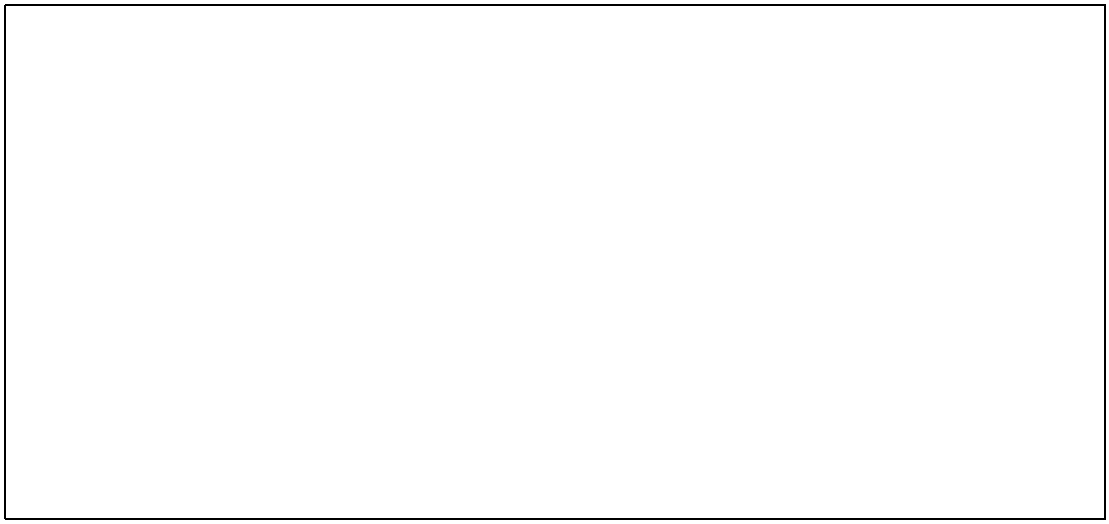


Figure 4-16. Poisson Arrangement

Measurements Using an External Voltmeter

This section describes how measurements are made using a strain gage multiplexer switchbox and a voltmeter external to the HP 75000 Series B or Series C mainframe.

Set Up

When making strain measurements with an external voltmeter, the strain gage multiplexer is configured for ¼, ½, and full bridge measurements as described in Chapters 1 and 2.

The external voltmeter is connected to the multiplexer through the HI, LO, and G terminals on the multiplexer terminal module (Figures 2-7, 2-8).

Procedure

Measuring strain with an external voltmeter involves measuring the Wheatstone bridge output voltage (Vout) and the bridge excitation voltage (Vs) under strained and unstrained conditions. These measurements allow you to compute the value of Vr, which in equation form is defined as:

$$Vr = [(Vout/Vs)strained - (Vout/Vs)unstrained]$$

Vr is then substituted into the appropriate equation (Table 4-1 on page 52) based on the bridge arrangement used.

Examples of strain measurements using the relay and FET multiplexers and an external voltmeter are contained in Chapter 3.

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Voltage and Resistance Measurements

The strain gage multiplexers can be used for DC voltage and 2-wire ohms measurements. When making these measurements on the bridge completion channels, the channel's bridge selection jumper must be set to the FULL position. DC voltages and resistances are connected to the HI, LO, and G (guard) terminals of the bridge completion channels. If you are using an HP E1326B/E1411B Multimeter, the guard lead **must** be connected.

Note Two-wire resistance measurements with an HP E1357A or E1358A FET Strain Gage Multiplexer will be in error by hundreds of ohms. This is due to the "on resistance" of the FET which is in series with resistance being measured. Refer to the *HP E1326B/E1411B Multimeter User's Manual* for information on DC voltage and resistance measurements.

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Chapter 5
Strain Gage Multiplexer Command Reference

About This Chapter

This chapter describes Standard Commands for Programmable Instruments (SCPI) commands and summarizes IEEE 488.2 Common (*) Commands applicable to the relay and FET strain gage multiplexers. This chapter contains the following sections.

- Command Types . . . . . Page 65
- SCPI Command Reference . . . . . Page 67
- IEEE 488.2 Common Commands . . . . . Page 98
- Command Quick Reference . . . . . Page 99

Command Types

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

Common Command Format

The IEEE 488.2 standard defines the Common commands that perform functions like reset, self-test, status byte query, etc. 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 such as making measurements, querying instrument states, or retrieving data. A command subsystem structure is a hierarchical structure that usually consists of a top level (or root) command, one or more low-level commands, and their parameters. The following example shows a typical subsystem:

```
CALibration
    :LFRequency <frequency>
    :LFRequency? [MIN | MAX]
    :ZERO:AUTO <mode>
    :ZERO:AUTO?
```

CALibration is the root command, LFRequency, LFRequency?, and ZERO are second level commands, and AUTO and AUTO? are third level commands.

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Command Separator

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

```
CALibration:ZERO:AUTO
```

Colons separate the root command from the second level command (CALibration:ZERO) and the second level from the third level (ZERO:AUTO?). The parameters of a command are separated from the command by a blank space.

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.

Command keywords can be entered in their full form, as shown above, or can be entered in their short form. In this manual, the entry required in short form commands is always capitalized. The short form is generally used for examples in this manual.

Implied Commands

Implied commands are those which appear in square brackets (**[ ]**) in the command syntax. (Note that 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 excerpt from the [SENSe:] subsystem shown below:

```
[SENSe:]
    FUNCtion[:<function>]
    FUNCtion?
    RESistance
        :APERture <time>
        :APERture? [MIN | MAX]
        :NPLC <number>
        :NPLC? [MIN | MAX]
```

The root command [SENSe:] is an implied command. To set the multimeter's function to AC volts, for example, you can send either of the following command statements:

SENS:FUNC:VOLT:AC *or* FUNC:VOLT:AC

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Parameters

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

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 MIN, MAX, and DEF. MIN selects minimum value available, MAX selects maximum value available, and DEF selects default or reset value.
Boolean	Represents a single binary condition that is either true or false. 1 or ON; 0 or OFF.
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, DBUS, EXT, HOLD, or IMM.

Optional Parameters. Parameters shown within square brackets (**[ ]**) are optional parameters. (Note that 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 value 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  BUS;*TRG
```

Linking Multiple SCPI Commands. Use both a semicolon and a colon between the commands. For example:

```
ARM:COUN  1;:TRIG:SOUR  EXT
```

SCPI Command Reference

This section describes the Standard Commands for Programmable Instruments (SCPI) commands for the relay and FET strain gage multiplexer modules. Commands are listed alphabetically by subsystem and also within each subsystem.

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ABORt

The ABORt subsystem stops a scan in progress when the scan is enabled and the trigger modes are TRIGger:SOURce BUS or TRIGger:SOURce HOLD.

Subsystem Syntax

ABORt

Comments

- **ABORt Operation:**

  For **relay strain gage** multiplexers, ABORT invalidates the current channel list and sets ARM:COUNT 1 (one scanning cycle per INITiate command), sets INITiate:CONTinuous OFF (no continuous scanning), and sets TRIGger:SOURce IMMediate (continuous internal triggering).

  For **FET strain gage** multiplexers, ABORT resets the trigger system and places the multiplexer in the idle state. The scanning parameters remain as previously set. When a new trigger is received, the scan begins at the beginning of the scan list.

- **Stopping Scans Enabled from Interface:** When a scan is enabled from the HP-IB interface, use an interface CLEAR command or the HP E1301 front panel "Reset Instr" or "Clear Instr" key to stop the scan.

  When the scan is enabled from the HP-IB interface and the trigger source is TRIGger:SOURce BUS or TRIGger:SOURce HOLD, use ABORt or the HP E1301 front panel "Reset Instr" or "Clear Instr" keys to stop the scan.

- **Stopping Scans Enabled from Front Panel:** When a scan is enabled from the HP E1301 front panel execute *RST over the interface or the front panel "Reset Instr" or "Clear Instr" keys to stop the scan.

- **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  (@100:107)       Sets channel list.
INIT                   Starts scanning cycle.
 .
 .
 .
ABOR                   Aborts scan in progress.
```


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ARM

The ARM subsystem selects the number of scanning cycles (1 through 32767) for each INITiate command. This command does not apply to downloaded FET multiplexer scan lists. For downloaded scan lists, use the INIT:CONT ON command for multiple scans.

Subsystem Syntax

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

:COUNt

ARM:COUNt <*number*> MIN | MAX allows scanning cycles to occur a multiple of times (1 to 32767) with one INITiate command.

Parameters

Parameter Name	Parameter Type	Range of Values
number	Numeric	1 - 32767 | MIN | MAX

Comments

- **Number of Scans:** Use only values between 1 to 32767 for the number of scanning cycles (default is 1).
- **Downloaded Scan Lists:** ARM:COUNt does not apply to downloaded FET multiplexer scan lists.
- **Related Commands:** ABORt, INITiate[:IMMediate]
- ***RST Condition:** ARM:COUNt 1

Example

Setting Ten Scanning Cycles

```
ARM:COUN 10                 Set 10 scanning cycles.
SCAN  (@100:107)            Sets channel list.
INIT                        Starts scanning cycle.
```

:COUNt?

ARM:COUNt? [MIN | MAX] returns current number of scanning cycles set by ARM:COUNt. ARM:COUN? MIN returns the minimum allowable parameter (1) and ARM:COUN? MAX returns the maximum allowable parameter (32767).

Parameters

Parameter Name	Parameter Type	Range of Values
MIN | MAX	Numeric	MIN = 1, MAX = 32767

Comments

- **Related Commands:** INITiate[:IMMediate]

Example

Query Number of Scanning Cycles

```
ARM:COUN 10                 Sets 10 scanning cycles.
ARM COUN?                   Query number of scanning cycles;
                            returned value is 10.
```


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CALibration

The CALibration command subsystem is an **HP E1326B/E1411B Multimeter subsystem** used to measure the unstrained reference voltage for each channel on which strain is measured.

Refer to Chapter 5 in the *HP E1326B/E1411B User's Manual* for more information on the CALibration subsystem.

Subsystem Syntax

```
CALibration
    :STRain <channel_list>
```

:STRain

CALibration:STRain <*channel_list*> measures the unstrained reference voltage on the channels specified.

Parameters

Parameter Name	Parameter Type	Range of Values
channel_list	Numeric	00 - 07

Comments

- The unstrained reference that is measured is the bridge output voltage (Vout) and the bridge excitation voltage (Vs) under unstrained conditions. The reference is then computed as Vout/Vs (unstrained).
- One unstrained reference is required for each channel on which strain is measured.
- CALibration:STRain is equivalent to executing CONFigure:STRain:UNSTrained followed by INIT. Thus, it leaves the multimeter configured for unstrained reference voltage measurements. MEASure or CONFigure must be executed to configure the multimeter for a **strain** measurement.

Example

Measuring the Unstrained Reference

```
CAL:STR  (@100)
```

Measures the unstrained reference on channel 0.

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CONFigure

The **CONFigure** command subsystem is an **HP E1326B/E1411B Multimeter subsystem** which configures the multimeter for strain measurements. Unlike MEASure, CONFigure does not make a measurement immediately after setting the configuration. Thus, CONFigure is used in applications where the multimeter configuration must be changed using lower level commands (see below).

Executing CONFigure is equivalent to configuring the multimeter with the low-level commands shown in the following table.

Parameter	Command	Setting
Range	VOLTage:RANGe RESistance:RANGe	As specified or autorange.
Resolution	VOLTage:RESolution RESistance:RESolution	As specified, or as a function of range, integration time, or aperture time.
Aperture Time	VOLTage:APERture RESistance:APERture	16.7 ms (60 Hz) or 20 ms (50 Hz), or based on specified resolution.
Integration Time	VOLTage:NPLC RESistance:NPLC	1 power line cycle (PLC) or based on specified resolution.
Autozero	CALibration:ZERO:AUTO	ON (autozero is performed after every measurement).
Offset Compensation	RESistance:OCOMpensated	OFF (resistance measurements only).
Trigger Source	TRIGger:SOURce	IMM (trigger signal is always true). Measurement is taken when multimeter goes to trigger state.
Number of Triggers or Number of Scans	TRIGger:COUNt	1; number of triggers issued or number of scans through *channel list* before multimeter returns to idle state.
Trigger Delay	TRIGger:DELay	AUTO (delays are 0 seconds for DC voltage and resistance; 0.5 seconds for AC voltage).
Readings per Trigger	SAMPle:COUNt	1; number of measurements taken when trigger is received.
Sample Period	SAMPle:SOURce	IMM; period between measurements or the period between FET multiplexer scans.

Refer to Chapter 5 in the *HP E1326B/E1411B Multimeter User's Manual* for more information on the CONFigure subsystem.

Subsystem Syntax

```
CONFigure
    :STRain [:<strain_function>] <channel_list>
```


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:STRain

CONFigure:STRain[:<*strain_function*>] <*channel_list*> configures the multimeter for strain measurements using the specified bridge arrangement on the specified channel.

Parameters

Parameter Name	Parameter Type	Range of Values
strain_function	Discrete	[QUARter] HBENding HPOisson FBENding FPOisson FBPoisson QTENsion QCOMpression UNSTrained
channel_list	Numeric	00 - 07

Comments

- The strain measurements specified by the *strain_function* parameter are:

  QUARter = ¼ bridge measurements
  HBENding = Bending ½ bridge measurements
  HPOisson = Poisson ½ bridge measurements
  FBENding = Bending Full bridge measurements
  FPOisson = Poisson Full bridge measurements
  FBPoisson = Bending Poisson Full bridge measurements
  QTENsion = Tension shunt diagnostic
  QCOMpression = Compression shunt diagnostic
  UNSTrained = Unstrain reference voltage measurement

- The default *strain_function* is QUARter (¼ bridge measurements).

- QTENsion and QCOMpression are used for relay strain gage multiplexers only.

Example

Making ¼ Bridge Strain Measurements

```
STR:GFAC 2.11E-6,(@100:103)      Specify the gage factors for the channels.
CAL:STR  (@100:103)              Measure the unstrained references.
CONF:STR:QUAR  (@100:103)        Configure the multimeter and make ¼ bridge measurements.
VOLT:RANG MIN                    Set 0.125V range.
```


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DISPlay

The DISPlay subsystem monitors the state of the selected multiplexer channel. This command can only be used when the relay or FET strain gage multiplexers are used in a switchbox configuration. It operates with mainframes that have a display, such as the HP 75000 Series B Mainframe (HP Model Number E1301A). It also operates with terminals connected to the serial interface port.

Subsystem Syntax

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

:MONitor:CARD

DISPlay:MONitor:CARD <*number* | AUTO> selects the multiplexer in a switchbox to be monitored.

Parameters

Parameter Name	Parameter Type	Range of Values
number | AUTO	Numeric	1 - 99

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 multiplexer addressed by a switching command (for example, [ROUTe:]CLOSe).
- ***RST Condition:** DISPlay:MONitor:CARD AUTO

Example

Select Multiplexer #2 in a Switchbox for Monitoring

```
DISP:MON:CARD 2          Selects multiplexer #2 in a switchbox.
```


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:MONitor[:STATe]

DISPlay:MONitor[:STATe] <*mode*> turns the monitor mode on or off.

Parameters

Parameter Name	Parameter Type	Range of Values
mode	Boolean	0 | 1 | ON | OFF

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 multiplexer.

  DISPlay:MONitor[:STATe] OFF or DISPlay:MONitor[:STATe] 0 turns the monitor mode off.

- **Selecting the Module to be Monitored:** Use the DISPlay:MONitor:CARD <*number*> | AUTO command to select the multiplexer.

- **Monitor Mode on an HP 1301 Mainframe Display:** The following shows the types of displays you will get when monitoring relay and FET multiplexer channels:

  ```
  SWITCH_112: Chan: 0,1, , , , , ,    Relay channels 0 and 1 are closed.
  SWITCH_112: Chan:   1               FET channel 1 is closed.
  ```

- ***RST Condition:** DISPlay:MONitor[:STATe] OFF | 0

Example

Enabling the Monitor Mode

```
DISP:MON:CARD 2     Selects multiplexer #2 in a switchbox.
DISP:MON 1          Turns the monitor mode on.
```


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INITiate

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

Subsystem Syntax

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

:CONTinuous

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

Parameters

Parameter Name	Parameter Type	Range of Values
mode	Boolean	0 | 1 | ON | OFF

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 a trigger source selected 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 list and the scan cycle repeats.
- **Scanning a Set Number of Cycles:** The INITiate:CONTinuous OFF or INITiate:CONTinuous 0 command goes through the scan list the number of times specified by the ARM:COUNt command. Sending the INITiate[:IMMediate] command closes the first channel in the *channel list*. Each trigger from a trigger source selected 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 if the number of cycles has not reached the ARM:COUNt parameter, returns to the beginning of the scan list and closes the first channel. When the number of cycles equals the ARM:COUNt parameter, the scanning cycle stops. Note that ARM:COUNt does not apply to downloaded FET multiplexer scan lists.
- **Stopping Continuous Scans:** Continuous scanning can be stopped by the ABORt command for non-downloaded scans, and by a system reset or a power off for downloaded FET multiplexer scans.
- **Related Commands:** ABORt, ARM:COUNt, *RST, TRIGger, TRIGger:SOURce
- ***RST Condition:** INITiate:CONTinuous OFF

Example

Enabling Continuous Scans

```
INIT:CONT ON          Enables continuous scanning.
SCAN  (@100:107)      Sets channel list.
INIT                  Starts scanning cycle.
```


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:CONTinuous?

INITiate:CONTinuous? queries the scanning state. With continuous scanning enabled, the command returns 1. With continuous scanning disabled, the command returns 0.

Example

Query Continuous Scanning State

INIT:CONT ON	*Enables continuous scanning.*
INIT:CONT?	*Query continuous scanning state.*

[:IMMediate]

INITiate[:IMMediate] starts the scanning cycle and closes the first channel in the *channel list*. Successive triggers from the source specified by the TRIGger:SOURce command advance 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*. A trigger advances the scan through the *channel list*. An invalid *channel list* generates an error (see the [ROUTe:]SCAN command).
- **Stopping Scanning Cycles:** See the ABORt command.

Example

Enabling a Single Scan

SCAN (@100:107)	*Sets channel list.*
INIT	*Starts scanning cycle.*

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MEASure

The **MEASure** command subsystem is an **HP E1326B/E1411B Multimeter subsystem** which configures the multimeter for strain measurements. After configuring the multimeter, MEASure immediately makes the (strain) measurement.

Executing MEASure is equivalent to configuring the multimeter with the low-level commands shown in the following table.

Parameter	Command	Setting
Range	VOLTage:RANGe RESistance:RANGe	As specified or autorange.
Resolution	VOLTage:RESolution RESistance:RESolution	As specified, or as a function of range, integration time, or aperture time.
Aperture Time	VOLTage:APERture RESistance:APERture	16.7 ms (60 Hz) or 20 ms (50 Hz), or based on specified resolution.
Integration Time	VOLTage:NPLC RESistance:NPLC	1 power line cycle (PLC) or based on specified resolution.
Autozero	CALibration:ZERO:AUTO	ON (autozero is performed after every measurement).
Offset Compensation	RESistance:OCOMpensated	OFF (resistance measurements only).
Trigger Source	TRIGger:SOURce	IMM (trigger signal is always true). Measurement is taken when multimeter goes to trigger state.
Number of Triggers or Number of Scans	TRIGger:COUNt	1; number of triggers issued or number of scans through *channel list* before multimeter returns to idle state.
Trigger Delay	TRIGger:DELay	AUTO (delays are 0 seconds for DC voltage and resistance; 0.5 seconds for AC voltage).
Readings per Trigger	SAMPle:COUNt	1; number of measurements taken when trigger is received.
Sample Period	SAMPle:SOURce	IMM; period between measurements or the period between FET multiplexer scans.

Refer to Chapter 5 in the *HP E1326B/E1411B Multimeter User's Manual* for more information on the MEASure subsystem.

Subsystem Syntax

```
MEASure
    :STRain [:<strain_function>]? <channel_list>
```


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:STRain

MEASure:STRain[:<*strain_function*>]? <*channel_list*> measures strain using the specified bridge arrangement on the specified channel.

Parameters

Parameter Name	Parameter Type	Range of Values
strain_function	Discrete	[QUARter] HBENding HPOisson FBENding FPOisson FBPoisson QTENsion QCOMpression UNSTrained
channel_list	Numeric	00 - 07

Comments

- The strain measurements specified by the *strain_function* parameter are:

  QUARter = ¼ Bridge measurements
  HBENding = Bending ½ Bridge measurements
  HPOisson = Poisson ½ Bridge measurements
  FBENding = Bending Full Bridge measurements
  FPOisson = Poisson Full Bridge measurements
  FBPoisson = Bending Poisson Full Bridge measurements
  QTENsion = Tension shunt diagnostic
  QCOMpression = Compression shunt diagnostic
  UNSTrained = Unstrain reference voltage measurement

- The default *strain_function* is QUARter (¼ bridge measurements).

- QTENsion and QCOMpression are used for relay strain gage multiplexers only.

Example

Making ¼ Bridge Strain Measurements

```
STR:GFAC 2.11E-6,(@100:103)      Specify the gage factors for the channels.
CAL:STR  (@100:103)              Measure the unstrained references.
MEAS:STR:QUAR?  (@100:103)       Configure the multimeter and make ¼ bridge measurements.
```


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OUTPut

The OUTPut subsystem enables or disables the "Trig Out" port of the HP E1300/E1301 Mainframe.

Subsystem Syntax

```
OUTPut
    [:STATe] <state>
    [:STATe]?
```

[:STATe]

OUTPut[:STATe] <*state*> enables/disables the "Trig Out" port on the rear panel of the HP E1300/E1301 Mainframe. OUTPut[:STATe] ON | 1 enables the port and OUTPut[:STATe] OFF | 0 disables the port.

Parameters

Parameter Name	Parameter Type	Range of Values
state	Boolean	0 | 1 | ON | OFF

Comments

- **Downloaded FET Multiplexer Scans:** The OUTPut subsystem does not work with downloaded FET multiplexer scan lists. Downloaded scan lists are for use with the digital bus. OUTPut works with all other scanning modes.
- **Enabling "Trig Out" Port:** When enabled, the "Trig Out" BNC is pulsed each time a channel is closed during scanning.
- **Output Pulse:** The pulse is a +5 V negative-going pulse.
- **"Trig Out" Port Reserved by Switchboxes:** The "Trig Out" resource is a system resource, and can only be reserved by one switchbox instrument at a time.
- **Related Commands:** [ROUTe:]SCAN, TRIGger:SOURce
- ***RST Condition:** OUTPut[:STATe] OFF (port disabled)

Example

Enabling "Trig Out" Port

```
OUTP ON                    Enables "Trig Out" port for pulse output.
```

[:STATe]?

OUTPut:[STATe]? queries the present state of the "Trig Out" port. The command returns 1 if the port is enabled, or 0 if disabled.

Example

Query "Trig Out" Port State

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


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[ROUTe:]

The [ROUTe:] subsystem controls switching and scanning operations for the multiplexer modules in a switchbox configuration.

Subsystem Syntax

```
[ROUTe:]
    CLOSe <channel_list>
    CLOSe? <channel_list>
    OPEN <channel_list>
    OPEN? <channel list>
    SCAN <channel_list>
        :MODE <mode>
        :MODE?
        :PORT <port>
        :PORT?
    SETTling
        [:TIME]  <time>, <channel_list>
        :TIME? [MIN | MAX] <channel_list>
```

CLOSe

[ROUTe:]CLOSe <*channel_list*> closes multiplexer channels specified in the *channel list*.

For the **relay** strain gage multiplexers, the *channel_list* for CLOSe is in the form (@ccnn), (@ccnn,ccnn), or (@ccnn:ccnn) where cc = card number (00-99) and nn = channel number (00-15 - includes internal channels).

For the **FET** strain gage multiplexers, the *channel_list* for CLOSe is in the form (@ccnn), or in special circumstances, (@ccnn,ccnn), where cc = card number (00-99) and nn = channel number (00-15 includes internal channels).

Before using the CLOSe command with the FET multiplexers, you must specify the SCAN:MODE and SCAN:PORT, as these commands determine what tree switches will be closed on a given channel. **You can only have one channel closed on a FET multiplexer at a time.** If you want to close a channel on two different multiplexers in the same switchbox instrument (e.g., 102,202) you can use (@ccnn,ccnn).

Parameters

Parameter Name	Parameter Type	Range of Values
channel_list	Numeric	cc00 - cc15

Comments

- **Closing Channels - relay multiplexers:** To close:
  - a single channel, use CLOSe (@ccnn);
  - multiple channels, use CLOSe (@ccnn,ccnn);
  - sequential channels, use CLOSe (@ccnn:ccnn);
  - a group of sequential channels, use CLOSe (@ccnn:ccnn,ccnn:ccnn).

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- **Closing Channels - FET multiplexers:** To close:
  - a single channel, use CLOSe (@ccnn);
  - single channels on different cards, use CLOSe (@ccnn,ccnn).

  Closure order for multiple channels with a single command is not guaranteed.

- **Related Commands:** [ROUTe:]OPEN, [ROUTe:]CLOSe?, [ROUTe:]SCAN:MODE, [ROUTe:]SCAN:PORT

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

Example **Closing Multiplexer Channels**

These examples close channel 00 of switchbox multiplexer card number 1.

Relay Multiplexer Switchbox:

CLOS (@100)	*Closes channel 0 of multiplexer #1.*

FET Multiplexer Switchbox:

SCAN:MODE VOLT	*Selects the voltage scanning mode.*
SCAN:PORT ABUS	*Selects the analog bus port.*
CLOS (@100)	*Closes channel 0 of multiplexer #1.*

CLOSe?

[ROUTe:]CLOSe? <*channel_list*> returns the current state of the channel 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.

Comments

- **Query is Software Readback:** The [ROUTe:]CLOSe? command returns the current software state of the channel specified. It does not account for relay hardware failures.

Example **Query Multiplexer Channel Closure**

CLOS (@100)	*100 closes channel 0 of multiplexer #1.*
CLOS? (@100)	*Query channel 0.*

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OPEN

[ROUTe:]OPEN <*channel_list*> opens multiplexer channels specified in the *channel_list*. The *channel_list* is in the form (@ccnn), (@ccnn,ccnn), (@ccnn:ccnn) or (@ccnn:ccnn,ccnn:ccnn) where cc = card number (00-99) and nn = channel number (00-15).

Parameters

Parameter Name	Parameter Type	Range of Values
channel_list	Numeric	cc00 - cc15

Comments

- **Opening Channels - relay and FET:** To open:
  - a single channel, use OPEN (@ccnn);
  - for multiple channels, use OPEN (@ccnn,ccnn);
  - sequential channels, use OPEN (@ccnn:ccnn);
  - a group of sequential channels, use OPEN (@ccnn:ccnn,ccnn:ccnn);
  - or any combination.

  Opening order for multiple channels with a single command is not guaranteed.

- **Opening the AT, BT, AT2, and RT Tree Switches - relay multiplexers:** Use channel numbers 90, 91, 92, and 93 to open the AT, BT, AT2, and RT tree switches, respectively.

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

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

Example

Opening Multiplexer Channels

This example opens channel 0 of switchbox multiplexer card number 1.

```
OPEN (@100)          100 opens channel 0 of multiplexer #1.
```

OPEN?

[ROUTe:]OPEN? <*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 open or returns 0 if the channel is closed.

Comments

- **Query is Software Readback:** The [ROUTe:]OPEN? command returns the current software state of the channel specified. It does not account for relay hardware failures.

Example

Query Multiplexer Channel Open State

```
OPEN (@100)          100 opens channel 0 of multiplexer #1.
OPEN? (@100)         Query channel 0.
```


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SCAN

[ROUTe:]SCAN <*channel_list*> defines the switchbox channels to be scanned. The *channel_list* is in the form (@ccnn), (@ccnn,ccnn), (@ccnn:ccnn) or (@ccnn:ccnn,ccnn:ccnn) where cc = card number (00-99) and nn = channel number (00-15 - includes internal (diagnostic) channels).

Parameters

Parameter Name	Parameter Type	Range of Values
channel_list	Numeric	cc00 - cc15

Comments

- **Channel List - relay and FET multiplexers:** Valid scanning lists are:
  - a single channel, use (@ccnn);
  - for multiple channels, use (@ccnn,ccnn);
  - sequential channels, use (@ccnn:ccnn);
  - a group of sequential channels, use (@ccnn:ccnn,ccnn:ccnn);
  - or any combination.

- **Defining the Channel List:** When executing [ROUTe:]SCAN, the *channel list* is checked for valid card and channel numbers. An error is generated for an invalid *channel list*.

- **Downloading a FET Multiplexer Scanning List:** When TRIG:SOUR DBUS or TRIG:SOUR IMM is set, the *channel_list* for the SCAN command is automatically downloaded into RAM on the FET multiplexer. The channels are advanced via the digital bus, and no direct intervention by the mainframe CPU is required. If the switchbox instrument contains FET and relay multiplexers, the scan list is not "downloaded", but is still scanned.

- **Scanning Operation:** With a valid *channel list*, INITiate[:IMMediate] starts the scanning cycle and closes the first channel in the *channel list*. Successive triggers from the source specified by TRIGger:SOURce advances the scan through the *channel list*.

- **Stopping Scan:** See the ABORt command.

- **Closing the AT, BT, and AT2 Tree Switches - relay multiplexers:** See the [ROUTe:]SCAN:PORT ABUS command.

- **Related Commands:** TRIGger, TRIGger:SOURce

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

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Example Scanning Using External Devices

The following segments show how relay and FET strain gage multiplexer switchboxes are configured for strain measurements using an external multimeter (HP 3458A). Chapter 3 contains complete examples of making strain measurements using these configurations.

Relay Multiplexer Switchbox (see Figure 2-7 on page 31 for external connections):

OUTP ON	*Enables the E1300/E1301 mainframe "Trig Out" port to output a signal when a channel is closed.*
TRIG:SOUR EXT	*Set the switchbox to be externally triggered through the mainframe "Event In" port.*
SCAN:PORT ABUS	*Connect the analog bus to the HI, LO, and Guard terminals on the terminal module.*
SCAN (@100:102,115)	*Specify the multiplexer channel list to scan and measure.*
INIT	*Close the first channel in the scan list and start the scan.*

FET Multiplexer Switchbox (see Figure 2-8 on page 32 for external connections):

TRIG:SOUR DBUS	*Switchbox is triggered over the digital bus.*
SCAN:MODE VOLT	*Closes the tree switches required to make a voltage (bridge output) measurement.*
SCAN:PORT ABUS	*Connect the analog bus to the HI, LO, and Guard terminals on the terminal module.*
SETT:TIME MAX,(@100)	*Set the delay between the external trigger and the channel closed signal.*
SCAN (@100:102,115)	*Specify the multiplexer channel list to scan and measure.*
INIT	*Close the first channel in the scan list and start the scan.*

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SCAN:MODE

[ROUTe:]SCAN:MODE <*mode*> sets the multiplexer channels defined by the [ROUTe:]SCAN <*channel_list*> command for None, Volts, or 2-wire Ohms measurements. Strain measurements with a relay or FET switchbox and an external multimeter require the SCAN:MODE VOLT mode.

Parameters

Parameter Name	Parameter Type	Range of Values
mode	Discrete	NONE | VOLT | RES

Comments

- **Order of Command Execution:** The [ROUTe:]SCAN:MODE command must be executed before the [ROUTe:]SCAN <*channel_list*> and [ROUTe:]CLOSe <*channel_list*> commands.
- **NONE and VOLT Mode Description:** *Channel list* is set up for voltage measurements. This mode is required for strain measurements.
- **RES Mode Description:** Channel list is set up for 2-wire ohms measurements. When making 2-wire measurements using the relay strain gage multiplexer, the bridge selection jumper must be set to the "FULL" bridge position.
- ***RST Condition:** ROUT:SCAN:MODE NONE

Example

Selecting the Voltage Mode

This example scans four channels for DC voltage measurements.

```
TRIG:SOUR EXT                 Selects external trigger source.
SCAN:MODE VOLT                Selects the voltage scanning mode.
SCAN  (@100:102,115)          Sets channel list.
INIT                          Starts scanning cycle.
```

SCAN:MODE?

[ROUTe:]SCAN:MODE? returns the current state of the scan mode. The command returns NONE, VOLT, or RES if the scan mode is in the NONE, VOLT, or RES mode, respectively.

Example

Query Scan Mode

Since this example selects the VOLT mode, the query command returns VOLT.

```
SCAN:MODE VOLT                Selects the voltage scanning mode.
SCAN:MODE?                    Query the scanning mode.
```


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SCAN:PORT

[ROUTe:]SCAN:PORT <*port*> enables or disables the tree isolation switches (FET multiplexers), or the AT, BT, and AT2 tree switches (relay multiplexers). SCAN:PORT ABUS closes the appropriate tree switches for the analog bus connections. The [ROUTe:]SCAN:PORT NONE command disables the tree switches and leaves them open.

Parameters

Parameter Name	Parameter Type	Range of Values
port	Discrete	ABUS | NONE

Comments

- **Order of Command Execution:** The [ROUTe:]SCAN:PORT command must be executed before the [ROUTe:]SCAN <*channel_list*> and [ROUTe:]CLOSe <*channel_list*> commands.
- ***RST Condition:** [ROUTe:]SCAN:PORT NONE

Example

Selecting the ABUS Port

```
TRIG:SOUR EXT          Selects external trigger source.
SCAN:MODE VOLT         Selects the voltage scanning mode.
SCAN:PORT ABUS         Selects the ABUS port.
SCAN  (@100:107)       Sets channel list.
INIT                   Starts scanning cycle.
```

SCAN:PORT?

[ROUTe:]SCAN:PORT? returns the current state of the analog bus port. The command returns NONE if the analog bus connection control relays are disabled or ABUS if the control relays are enabled.

Example

Query Scan Port

This example selects the analog bus port, then queries the state. Because the analog bus port is selected, the query command returns ABUS.

```
SCAN:PORT  ABUS        Selects the ABUS port.
SCAN:PORT?             Query the port selection.
```


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SETTling[:TIME]

[ROUTe:]SETTling[:TIME] <*time*> , <*channel_list*> sets the delay between the multiplexer's receipt of a trigger command, and the generation of the "channel closed" pulse. The SETTling[:TIME] command applies to the FET (strain gage) multiplexers only. You must specify one and only one channel for each multiplexer in the switchbox instrument. The *time* applies to all channels on the multiplexer. The range is 1 µsec to 32.768 µsec.

Parameters

Parameter Name	Parameter Type	Range of Values
time	Numeric	1E-6 | 32.768E-3 | MIN | MAX
channel_list	Numeric	only one channel

Comments

- **Using an External Voltmeter:** When using an external voltmeter with the FET strain gage multiplexer switchbox, a "voltmeter complete" signal is often used to trigger the multiplexer to close a channel. Because of the speed at which a FET channel closes, the channel closed pulse often occurs before the multimeter is ready to make the measurement. The SETTling:TIME command delays the channel closed pulse until the voltmeter is ready.
- **Digital Bus Handshaking:** Operation of the digital bus is described in the *HP E1326B/E1411B Multimeter User's Manual*.
- **Related Commands:** TRIGger:SOUR DBUS, TRIGger:SOURce IMM

Example

Setting the Maximum Settling Time

```
TRIG:SOUR DBUS              Selects external trigger source.
SCAN:MODE VOLT              Selects the voltage scanning mode.
SCAN:PORT ABUS              Selects the ABUS port.
SETT:TIM MAX,(@100)         Sets the maximum channel closed
                            pulse delay.
SCAN  (@100:107)            Sets channel list.
INIT                        Starts scanning cycle.
```

SETTling:TIME?

[ROUTe:]SETTling:TIME? [MIN | MAX] , <*channel_list*> returns the current setting for a specified channel. MIN or MAX returns the minimum and maximum allowable settings.

Parameters

Parameter Name	Parameter Type	Range of Values
MIN | MAX	Numeric	MIN = 1 µsec MAX = 32768 µsec

Comments

- **Returned Value:** This is given in exponential notation.

Example

Querying the Settling Time

```
SETT:TIM  16E-6             Sets delay = 16 µsec.
SETT:TIM?                   Returns +1.600000E-005.
```


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[SENSe:]

The [SENSe:] command subsystem is an **HP E1326B/E1411B Multimeter subsystem** used to specify the Gage Factor and Poisson Ratio for strain gage measurements. This subsystem is also used for downloading unstrained references prior to strain measurements.

Refer to Chapter 5 in the *HP E1326B/E1411B User's Manual* for more information on this subsystem.

Subsystem Syntax

```
[SENSe:]
    STRain
        :GFACtor <gage_factor>,<channel_list>
        :GFACtor? <channel_list>
        :POISson <poisson_ratio>,<channel_list>
        :POISson? <channel_list>
        :UNSTrained <reference>,<channel>
        :UNSTrained? <channel_list>
```

STRain:GFACtor

[SENSe:]STRain:GFACtor <*gage_factor*> , <*channel_list*> specifies the gage factor for the strain gage on the channel specified. A gage factor must be specified for each channel.

Parameters

Parameter Name	Parameter Type	Range of Values
gage_factor	Numeric	as specified
channel_list	Numeric	00 - 07

Comments

- One gage factor must be specified for each channel measured.
- The gage factor must be specified before the strain is measured.
- Specifying the gage factor with an exponent of E-6 returns the strain measurement in microstrain.

Example

Specifying the Gage Factor

```
STR:GFAC 2.11E-6,(@100)
```

Specifies the gage factor; reading returned in microstrain.

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STRain:GFACtor?

[SENSe:]STRain:GFACtor? <*channel_list*> returns the gage factor set for the channel specified.

Parameters

Parameter Name	Parameter Type	Range of Values
channel_list	Numeric	00 - 07

Comments

- Returned value is given in exponential notation (e.g. +2.110000E-006).

Example

Querying the Gage Factor

```
STR:GFAC?  (@100)
```

Queries the gage factor for channel 0.

STRain:POISson

[SENSe:]STRain:POISson <*poisson_ratio*> , <*channel_list*> specifies the poisson ratio for the strain gage on the channel specified. A poisson ratio must be specified for each channel when measuring poisson configurations.

Parameters

Parameter Name	Parameter Type	Range of Values
poisson_ratio	Numeric	as specified
channel_list	Numeric	00 - 07

Comments

- One poisson ratio must be specified for each channel measuring a poisson configuration.
- The poisson ratio must be specified before the strain is measured.

Example

Specifying the Poisson Ratio

```
STR:POIS .32,(@100)
```

Specifies the Poisson Ratio.

STRain:POISson?

[SENSe:]STRain:POISson? <*channel_list*> returns the poisson ratio set for the channel specified.

Parameters

Parameter Name	Parameter Type	Range of Values
channel_list	Numeric	00 - 07

Comments

- Returned value is given in exponential notation (e.g. +3.200000E-001).

Example

Querying the Poisson Ratio

```
STR:POIS?  (@100)
```

Queries the poisson ratio for channel 0.

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STRain:UNSTrained

[SENSe:]STRain:UNSTrained <*reference*> , <*channel_list*> downloads a (previously measured and stored) unstrained reference voltage for the channel. An unstrained reference must be specified for each channel.

Parameters

Parameter Name	Parameter Type	Range of Values
reference	Numeric	as measured
channel_list	Numeric	00 - 07

Comments

- STRain:UNSTrained downloads unstrained references that are already known or that have been previously measured (and stored in a computer). This is used in applications where it is not possible to make the unstrained reference measurement just prior to the strain measurement. The unstrained reference is measured using **CALibration:STRain**.
- One unstrained reference must be specified for each channel measured.

Example

Downloading the Unstrained Reference

```
OUTPUT 70903;"STR:UNST  ";Unstr;",(@100)"
```

Downloads the reference from computer variable Unstr to channel 100.

STRain:UNSTrained?

[SENSe:]STRain:UNSTrained? <*channel_list*> returns the unstrained references for the channels specified.

Parameters

Parameter Name	Parameter Type	Range of Values
channel_list	Numeric	00 - 07

Comments

- The unstrained references are measured using **CALibration:STRain**. When queried, the unstrained references are returned to the multimeter output buffer where they are then entered into a computer.
- One unstrained reference is required per channel.

Example

Querying the Unstrained References

```
CAL:STR  (@100:102)
```

Measures the unstrained references for channels 100 - 102.

```
STR:UNST?  (@100:102)
```

Queries the unstrained references for channels 100 - 102.

```
ENTER variable
```

Enter readings into the computer.

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STATus

The STATus subsystem reports the bit values of the Operation Status Register. This subsystem enables a bit to be set to 1 in the Status Register, after a bit is set to 1 in the Operation Status Register.

Subsystem Syntax

```
STATus
    :OPERation
        :ENABle <number>
        [:EVENt?]
```

:OPERation:ENABle

STATus:OPERation:ENABle <*number*> enables the Operation Status Register to set a bit in the Status Register. For multiplexer modules, when bit 8 in the Operation Status Register is set to 1, bit 7 in the Status Register is set to 1.

Parameters

Parameter Name	Parameter Type	Range of Values
number	Numeric	1 to 32768

Comments

- **Setting Bit 7 of the Status Register:** STATus:OPERation:ENABle 256 allows bit 7 of the Status Register to be set to 1 after bit 8 of the Operation Status Register is set to 1.
- **Related Commands:** [ROUTe:]SCAN, *SRE, *STB?, *SPOLL

Example

Enabling the Status Register Bit 7

```
STAT:OPER:ENAB 256          Enables bit 7 of the Status Register to be set.
```

:OPERation[:EVENt]?

STATus:OPERation[:EVENt]? returns the bit value of the Operation Status Register (only bit 8 is used by the multiplexer modules).

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 after sending the STATus:OPERation[:EVENt]? command.
- **Returned Data after sending the STATus:OPERation[:EVENt]? Command:** 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.
- **Related Commands:** [ROUTe:]SCAN, *SRE, *STB?, *SPOLL

Example

Reading the Operation Status Register after a Scanning Cycle

```
STAT:OPER?                  Returns the bit values of the Standard Operation Status Register.
read and print the register value   +256 shows bit 8 is set to 1; +0 shows bit 8 is set to 0.
```


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SYSTem

The SYSTem subsystem returns the error numbers and error messages in the error queue of a switchbox, and returns the types and descriptions of multiplexers in a switchbox.

Subsystem Syntax

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

:CDEScription?

SYSTem:CDEScription? <*number*> returns the description of a selected multiplexer in a switchbox.

Parameters

Parameter Name	Parameter Type	Range of Values
number	Numeric	1 to 99

Comments

- **8-Channel 120Ω Relay Strain Gage Multiplexer Description:**
  The SYSTem:CDEScription? <*number*> command returns:

  ```
  8 Channel Relay Strain Gage 120 Ohms
  ```

- **8-Channel 350Ω Relay Strain Gage Multiplexer Description:**
  The SYSTem:CDEScription? <*number*> command returns:

  ```
  8 Channel Relay Strain Gage 350 Ohms
  ```

- **8-Channel 120Ω FET Strain Gage Multiplexer Description:**
  The SYSTem:CDEScription? <*number*> command returns:

  ```
  8 Channel FET Strain Gage 120 Ohms
  ```

- **8-Channel 350Ω FET Strain Gage Multiplexer Description:**
  The SYSTem:CDEScription? <*number*> command returns:

  ```
  8 Channel FET Strain Gage 350 Ohms
  ```

Example

Reading the Description of Multiplexer Card #1

```
SYST:CDES? 1                    Determine the description.
```


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:CPON

SYSTem:CPON <*number*> | ALL opens all channels of a selected multiplexer or all channels of all multiplexers in a switchbox.

Parameters

Parameter Name	Parameter Type	Range of Values
number	Numeric	1 to 99 | ALL

Comments

- **Differences between *RST and CPON:** SYSTem:CPON opens all channels of a selected multiplexer or all channels of all multiplexers in a switchbox. *RST opens all channels of all multiplexers, and sets all other multiplexer parameters to the power-on state.

Example

Opening all Channels on Multiplexer #1

```
SYST:CPON 1          Opens all channels on multiplexer #1.
```

:CTYPe?

SYSTem:CTYPe? <*number*> returns the type of multiplexer in a switchbox.

Parameters

Parameter Name	Parameter Type	Range of Values
number	Numeric	1 to 99

Comments

- **8-Channel 120Ω Relay Strain Gage Multiplexer Module Model Number:** The SYSTem:CTYPe? <*number*> command returns:

  ```
  HEWLETT-PACKARD,E1355A,0,A.03.00
  ```

- **8-Channel 350Ω Relay Strain Gage Multiplexer Module Model Number:** The SYSTem:CTYPe? <*number*> command returns:

  ```
  HEWLETT-PACKARD,E1356A,0,A.03.00
  ```

- **8-Channel 120Ω FET Strain Gage Multiplexer Module Model Number:** The SYSTem:CTYPe? <*number*> command returns:

  ```
  HEWLETT-PACKARD,E1357A,0,A.03.00
  ```

- **8-Channel 350Ω FET Strain Gage Multiplexer Module Model Number:** The SYSTem:CTYPe? <*number*> command returns:

  ```
  HEWLETT-PACKARD,E1358A,0,A.03.00
  ```

  Note: The 0 after the module number is the serial number of the module (always 0). A.03.00 is an example of the module revision code number.

Example

Reading the Model Number of Multiplexer Card #1

```
SYST:CTYP? 1         Determine the model number.
```


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:ERRor?

SYSTem:ERRor? returns the error numbers and corresponding error messages in the error queue of a switchbox. See Appendix E 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. Each error message can be up to 255 characters long.

- **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? command 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 may 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 subsystem commands control the triggering operations of the multiplexer switchbox.

Subsystem Syntax

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

[:IMMediate]

TRIGger[:IMMediate] executes a trigger when the defined trigger source is TRIGger:SOURce HOLD or TRIGger:SOURce BUS. Note that TRIGger[:IMMediate] is NOT the same as TRIGger:SOURce IMMediate.

Comments

- **Executing the TRIGger[:IMMediate] Command:** A *channel list* must be defined with [ROUTe:]SCAN <*channel_list*> and an INITiate[:IMMediate] command must be executed before TRIGger[:IMMediate] can trigger the switchbox.
- **HOLD or BUS Source Remains:** If selected, the TRIGger:SOURce HOLD or TRIGger:SOURce BUS commands remain in effect after triggering the switchbox with the TRIGger[:IMMediate] command.
- **Related Commands:** INITiate, [ROUTe:]SCAN

Example

Advancing Scan using the TRIGger Command

TRIG:SOUR HOLD	*Sets trigger source to hold.*
SCAN (@100:107)	*Sets channel list.*
INIT	*Starts scanning cycle.*
loop statement	*Start count loop.*
TRIG	*Advances scan to next channel.*
increment loop	*Increment count loop.*

:SOURce

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

Parameters

Parameter Name	Parameter Type	Range of Values
BUS	Discrete	*TRG command
DBUS	Discrete	Digital Bus
EXTernal	Discrete	Event In BNC port
HOLD	Discrete	Hold triggering
IMMediate	Discrete	Continuous triggering

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Comments

- **Enabling the Trigger Source:** The TRIGger:SOURce command only selects the trigger source. The INITiate[:IMMediate] command enables the trigger source.

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

- **Using Digital Bus Triggering:** TRIGger:SOURce DBUS selects the digital bus on the FET multiplexer as the trigger source. Any open collector TTL trigger source can be wired to the Channel Advance (left-most) lead. A negative-going pulse triggers the multiplexer and advances it to the next channel on the scanning list. After the SETTling:TIME delay, the multiplexer asserts "channel closed" (right-most lead) on the digital bus.

  Digital bus triggering is available with the FET multiplexers only.

- **Using External Trigger Inputs:** Only one switchbox at a time can use the TRIGger:SOURce EXTernal trigger input on the HP E1300/E1301 Mainframe "Event In" BNC port. The trigger input is assigned to the first switchbox requesting the external trigger source.

- **Assigning External Trigger:** A switchbox assigned with TRIGger:SOURce EXTernal remains assigned to that source until it receives a command to change the source. When the source is changed, the external trigger source is available to another switchbox (with a TRIGger:SOURce EXTernal command).

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

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

- **Related Commands:** ABORt, [ROUTe:]SCAN, SETTling[:TIME], TRIGger

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

Examples

Scanning Using External Triggers

In the following example, the trigger input is applied to the HP E1300/E1301 Mainframe's "Event In" port.

TRIG:SOUR EXT	*Sets trigger source to external.*
SCAN (@100:107)	*Sets channel list.*
INIT	*Starts scanning cycle.*
trigger externally	*Advances channel list to next channel.*

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Scanning Using Bus Triggers

```
TRIG:SOUR BUS          Sets trigger source to bus.
SCAN  (@100:107)       Sets channel list.
INIT                   Starts scanning cycle.
*TRG                   Advances channel list.
```

:SOURce?

TRIGger:SOURce? returns the current trigger source for the switchbox. Command returns either BUS, DBUS, EXT, HOLD, or IMM for trigger sources BUS, DBUS, EXTernal, HOLD, or IMMediate, respectively.

Example

Query Trigger Source

```
TRIG:SOUR EXT          Sets trigger source to external.
TRIG:SOUR?             Query trigger source; returns EXT.
```


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IEEE 488.2 Common Commands

The following table lists the IEEE 488.2 Common (*) Commands that the 8-Channel Relay and FET Strain Gage Multiplexer Modules accept. For more information on Common Commands, refer to the *HP 75000 Series B Mainframe User's Manual* (HP Model Number E1300/E1301) or the ANSI/IEEE Standard 488.2-1987.

Command	Title	Description
*IDN?	Identification	Returns identification string of the switchbox.
*RST	Reset	Opens all channels, and invalidates current *channel list* for scanning. Sets ARM:COUN 1, TRIG:SOUR IMM, and INIT:CONT OFF.
*TST?	Self-Test	Power-on interrupt returns +110. Incorrect MFR ID or model code returns +103. Test pass returns 0.
*OPC *OPC?	Operation Complete Operation Complete Query	See note below. See note below.
*WAI	Wait to Complete	See note below.
*CLS	Clear status	Clears all status registers (see STATus:OPERation[:EVENt]?).
*ESE *ESE?	Event status enable Event status enable query	See note below. See note below.
*ESR?	Event status register query	See note below.
*SRE *SRE?	Service request enable Service request enable query	Enables status register bits (see Chapter 4 for operation). See note below.
*STB?	Read status byte query	See note below.
*TRG	Trigger	Triggers the switchbox to advance the scan when scan is enabled and trigger source is TRIGger:SOURce BUS | HOLD.
*RCL	Recall instrument state	See note below.
*SAV	Store instrument state	See note below.
Note: These commands apply to many instruments and are not documented in detail here. See the *HP 75000 Series B E1300/E1301 Mainframe User's Manual* or the ANSI/IEEE Standard 488.2-1987 for more information.		

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Command Quick Reference

The following tables summarize SCPI and IEEE 488.2 Common (*) Commands for the Relay and FET Strain Gage Multiplexers.

SCPI Commands Quick Reference

Command Subsystem	Command/Parameter	Description
ABORt	ABORt	Abort a scan in progress.
ARM	:COUNt <*number*> [MIN | MAX] :COUNt? [MIN | MAX]	Multiple scans per INIT command. Query number of scans.
CALibration	:STRain <*channel_list*>	Multimeter command - measures the unstrained reference voltage on the strain measurement channel specified.
CONFigure	:STRain[:<*strain_function*>] <*channel_list*>	Multimeter command - configures the multimeter for strain measurements.
DISPlay	:MONitor:CARD <*number*> | AUTO :MONitor[:STATe] <*mode*>	Selects module to be monitored. Selects monitor mode.
INITiate	:CONTinuous <*mode*> :CONTinuous? [:IMMediate]	Enables/Disables continuous scanning. Queries scanning state. Starts a scanning cycle.
MEASure	:STRain[:<*strain_function*>]? <*channel_list*>	Multimeter command - configures the multimeter and makes the specified strain measurement.
OUTPut	[:STATe] <*mode*> [:STATe]?	Enables/Disables "Trig Out" pulse. Queries state of "Trig Out" port.
[ROUTe:]	CLOSe <*channel_list*> CLOSe? <*channel_list*> OPEN <*channel_list*> OPEN? <*channel_list*> SCAN <*channel_list*> SCAN:MODE <*mode*> SCAN:MODE? SCAN:PORT <*port*> SCAN:PORT? SETTling[:TIME] <*time*>,<*channel_list*> SETTling:TIME? [MIN | MAX],<*channel_list*>	Close channel(s). Query channel(s) closed. Open channel(s). Query channel(s) opened. Define channels for scanning. Selects appropriate tree isolation switches for measurements. Returns present state of scan mode. Enables tree isolation switches closure as part of a measurement. Query analog bus state. Sets delay between trigger pulse and channel closed pulse. Returns current parameter in SETTling:TIME.
[SENSe:]	STRain:GFACtor<*gage_factor*>,<*channel_list*> STRain:GFACtor? <*channel_list*> STRain:POISson <*poisson_ratio*>,<*channel_list*> STRain:POISson? <*channel_list*> STRain:UNSTrained <*reference*>,<*channel*> STRain:UNSTrained? <*channel_list*>	Specifies the gage factor for the strain channel. Queries the gage factor. Specifies the Poisson ratio for the strain channel. Queries the Poisson ratio. Downloads the unstrained reference voltage. Queries the unstrained reference voltages.
STATus	:OPERation:ENABle <*number*> :OPERation[:EVENt]?	Enables the Operation Status Register to set a bit in the Status Register. Returns status of Operation Status Register.
SYSTem	:CDEScription? <*number*> :CPON <*number*> | ALL :CTYPe? <*number*> :ERRor?	Returns description of module in a switchbox. Sets specified module to its power-on state. Returns the module type. Returns error number/message in a switchbox to error queue.

Continued on Next Page

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TRIGger	[:IMMediate] :SOURce BUS :SOURce DBUS :SOURce EXTernal :SOURce HOLD :SOURce IMMediate :SOURce?	Causes a trigger to occur. Trigger source is *TRG. Trigger source is Digital Bus. Trigger source is "Event In" BNC. Hold off triggering. Continuous (internal) triggering. Query scan trigger source.

IEEE 488.2 Common Commands Quick Reference

Command	Title	Description
*RST	Reset	Opens all channels and invalidates current channel list for scanning. Sets ARM:COUN 1, TRIG:SOUR IMM, and INIT:CONT OFF.
*TRG	Bus Trigger	When scan is enabled and trigger source is TRIG:SOUR BUS, use the *TRG command to trigger the switchbox to advance the scan.
*TST?	Self-Test	Power on interrupt returns +110. Incorrect MFR ID or model code returns +103. Test pass returns 0.

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Appendix A
HP E1355A, E1356A, E1357A, E1358A Specifications

HP E1355A/E1356A Relay Strain Gage Multiplexer

HP E1357A/E1358A FET Strain Gage Multiplexer

Maximum Voltage:
Terminal to Terminal or
Terminal to Chassis: 120V dc or AC RMS; 170V peak

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

Maximum Power per Channel: 1VA

Thermal Offset per Channel:
<4 µV (differential High to Low)

Closed Channel Resistance:
100Ω ±10% (the value of the protection resistor)

Input Impedance:
Insulation Resistance (Between any two points):
$>10^9\Omega$ (at 40°C, 65% RH)
Closed Channel Capacitance (@10 kHz):
High to Low: <150 pf
Low to Guard; <150 pf
Guard to Chassis: <2000 pf

Relay Life:
@No Load: 10^8 Operations
@Rated Load: 10^7 Operations

Bandwidth (-3 dB):
Z(source) = Z(load) = 50Ω (Protection resistors shorted) >10 MHz

Channel-Channel Crosstalk (Typical) (50Ω Source & Load):

1 kHz	-80dB
10 kHz	-80 dB
100 kHz	-80 dB
1 MHz	-60 dB
10 MHz	-40 dB

Protection resistors shorted and Low and Guard tied to chassis

Screw Terminal Wire Size:
16 AWG Max, 26 AWG Min

Module Size/Device Type:
B, register-based

Connectors Used: P1

Number of Slots: 1

VXIbus Interface Capability:
Interrupter, D16

Interrupt Level: 1-7, selectable

Power Requirements:

Voltage:	+5V	+12V
Peak module current, IPM (A):	0.53	0.13
Dynamic module current, IDM (A):	0.01	0.01

Strain Gage Excitation:
Maximum excitation voltage, +5.4 V

Watts/Slot: 1

Cooling/Slot:
0.02 mm H_2O @ 0.10 liter/sec

Humidity: 65% 0° to 40°C

Operating Temperature:
0° to 55°C

Storage Temperature:
-40° to 75°C

EMC, RFI, Safety:
meets FTZ 1046/1984, CSA 556B, IEC 348, UL 1244

Net Weight (kg): 0.9

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Maximum Voltage:
Terminal to Chassis: 15V peak
(input impedance less above 13V peak)

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

Maximum Offset Voltage:
25 µV (0° to 28°C)
250 µV (28° to 55°C)
(differential High to Low)

Input Impedance:
Power On (Vin <±10V)
High to Low: >10^8Ω
High or Low to Chassis: >10^8Ω
Guard to Chassis: 10 kΩ ±10%
Capacitance:
High or Low to chassis: <200pf
High to Low: <200pf

Power Off:
High to Low:
for Vin ≤13V: >1000Ω
for Vin >13V: >220Ω

Closed Channel Resistance:
<3.1 kΩ for high or low input
(Guard not switched)

Bandwidth (-3 dB):
50Ω source, 1 MΩ||10pf
termination: >500 kHz
(Low tied to chassis)

Screw Terminal Wire Size:
16 AWG Max, 26 AWG Min

Module Size/Device Type:
B, register-based

Connectors Used: P1

Number of Slots: 1

Interrupt Level: selectable

Power Requirements:

Voltage:	+5V	+12V
Peak module current, IPM (A):	0.53	0.13
Dynamic module current, IDM (A):	0.01	0.01

Strain Gage Excitation
(chassis referenced):
+4.63V ±10%
Max Current: 400mA
(short circuit protected)

Watts/Slot: 2.8

Cooling/Slot:
0.02 mm H_2O @ 0.10 liter/sec

Humidity: 65% 0° to 40°C

Operating Temperature:
0° to 55°C

Storage Temperature:
-40° to 75°C

EMC, RFI, Safety:
meets FTZ 1046/1984, CSA 556B,
IEC 348, UL 1244

Net Weight (kg): 0.9

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Relay Life

Electromechanical relays are subject to normal wear-out. Relay life depends on several factors. The effects of loading and switching frequency are briefly discussed below:

Relay Load. In general, higher power switching reduces relay life. In addition, capacitive/inductive loads and high inrush currents (e.g., 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 Detection

A preventive maintenance routine can prevent problems caused by unexpected relay failure. The end of the life of the relay can be determined by using one or more of the three methods described below. The best method (or combination of methods), as well as the failure criteria, depends on the application in which the relay is used.

Contact Resistance. As the relay begins to wear out, its contact resistance increases. When the resistance exceeds a predetermined value, the relay should be replaced.

Stability of Contact Resistance. 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 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.

Replacement Strategy

The replacement strategy depends on the application. If some relays are used more often, or at a higher load, than the others, the relays can be individually replaced as needed. If all the 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.

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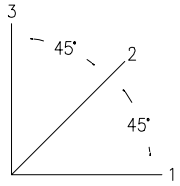
Appendix B
Strain Gage Equations and Material Tables

Rosette and Biaxial Stress State Equations

Rosette Equations

The following equations are used to calculate the strain measured with a three element rectangular or delta rosette. Rosette measurements are covered in Chapter 4, and an example which measures strains ε1, ε2, and ε3 is contained in Chapter 3.

Rectangular Rosette:

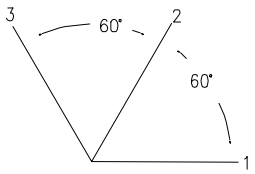


$$\varepsilon_{p,q} = \frac{1}{2}\left[\varepsilon_1 + \varepsilon_3 \pm \sqrt{(\varepsilon_1 - \varepsilon_3)^2 + (2\varepsilon_2 - \varepsilon_1 - \varepsilon_3)^2}\ \right]$$

$$\sigma_{p,q} = \frac{E}{2}\left[\frac{\varepsilon_1 + \varepsilon_3}{1-\nu} \pm \frac{1}{1+\nu}\ \sqrt{(\varepsilon_1 - \varepsilon_3)^2 + (2\varepsilon_2 - \varepsilon_1 - \varepsilon_3)^2}\ \right]$$

$$\theta_{p,q} = \frac{1}{2}\ TAN^{-1}\ \frac{2\varepsilon_2 - \varepsilon_1 - \varepsilon_3}{\varepsilon_1 - \varepsilon_3}$$

Delta Rosette:



$$\varepsilon_{p,q} = \frac{1}{3}\left[\varepsilon_1 + \varepsilon_2 + \varepsilon_3 \pm \sqrt{2\ [(\varepsilon_1 - \varepsilon_2)^2 + (\varepsilon_2 - \varepsilon_3)^2 + (\varepsilon_3 - \varepsilon_1)^2]}\ \right]$$

$$\sigma_{p,q} = \frac{E}{3}\left[\frac{\varepsilon_1 + \varepsilon_2 + \varepsilon_3}{1-\nu} \pm \frac{1}{1+\nu}\ \sqrt{2[(\varepsilon_1 - \varepsilon_2)^2 + (\varepsilon_2 - \varepsilon_3)^2 + (\varepsilon_3 - \varepsilon_1)^2]}\ \right]$$

$$\theta_{p,q} = \frac{1}{2}\ TAN^{-1}\ \frac{\sqrt{3}(\varepsilon_2 - \varepsilon_3)}{2\varepsilon_1 - \varepsilon_2 - \varepsilon_3}$$

where: $\varepsilon_{p,q}$ = Principal strains, $\sigma_{p,q}$ = Principal stresses, and $\theta_{p,q}$ = the acute angle from the axis of gage 1 to the nearest principal axis. When positive, the direction is the same as that of the gage numbering and when negative, opposite. NOTE: Corrections may be necessary for transverse sensitivity; refer to gage manufacturers literature.

Biaxial Stress State Equations

The following equations relate stress to strain for a biaxial stress state. Stress-strain relationships are described in detail in Hewlett-Packard's Application Note 290-1 *Practical Strain Gage Measurements.*

$$\varepsilon_x = \frac{\sigma_x}{E} - \nu\frac{\sigma_y}{E} \qquad \varepsilon_z = -\nu\frac{\sigma_x}{E} - \nu\frac{\sigma_y}{E} \qquad \sigma_y = \frac{E}{1-\nu^2}\ (\varepsilon_y + \nu\,\varepsilon_x)$$

$$\varepsilon_y = \frac{\sigma_y}{E} - \nu\frac{\sigma_x}{E} \qquad \sigma_x = \frac{E}{1-\nu^2}\ (\varepsilon_x + \nu\,\varepsilon_y) \qquad \sigma_z = 0$$

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Material Tables

Table B-1. Wire Resistance (solid copper wire)

AWG	Ohms/Foot (25 ºC)	Diameter (in.)
18	0.0065	0.040
20	0.0104	0.032
22	0.0165	0.0253
24	0.0262	0.0201
26	0.0416	0.0159
28	0.0662	0.0126
30	0.105	0.010
32	0.167	0.008

Table B-2. Average Properties of Selected Engineering Materials (exact values may vary widely)

Material	Poisson's Ratio, ν	Modulus of Elasticity, E psi $\times 10^6$	Elastic Strength[a] Tension (psi)
ABS (unfilled)	--	0.2 - 0.4	4500 - 7500
Aluminum (2024-T4)	0.32	10.6	48000
Aluminum (7075-T6)	0.32	10.4	72000
Red Brass, soft	0.33	15	15000
Iron-Gray, Cast	--	13 - 14	--
Polycarbonate	0.285	0.3 - 0.38	8000 - 9500
Steel-1018	0.285	30	32000
Steel-4130/4340	0.28 - 0.29	30	45000
Steel-304 SS	0.25	28	35000
Steel-410 SS	0.27 - 0.29	29	40000
Titanium alloy	0.34	14	135000

(a) Elastic strength may be represented by proportional limit, yield point, or yield strength at 0.2 percent offset.

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Appendix C
Strain Gage Diagnostics

About This Appendix

This appendix covers the diagnostics associated with the strain gage multiplexers. The diagnostics check configuration integrity and increase measurement accuracy. The diagnostics in this appendix include:

- Leadwire Resistance . . . . . Page 108
- Internal Half Bridge Voltage . . . . . Page 111
- Shunt Verification . . . . . Page 113
- Guard Voltage . . . . . Page 116
- Bridge Excitation Voltage . . . . . Page 118

Diagnostic Channels

The multiplexer diagnostics are accessed through "internal" channels as well as the "external" bridge completion channels. Table C-1 identifies the internal channel and the diagnostic on that channel.

Table C-1. Strain Gage Multiplexer Diagnostic Channels

Channel	Diagnostic
8/9	**Leadwire Resistance.** Channels 8 and 9 measure the voltage drop in the leadwires from the strain gage to the bridge completion circuit, for bridge completion channels 0 and 1. From this voltage and the value of the bridge completion resistor, the leadwire resistance can be determined so that leadwire desensitization corrections can be made.
10/11	**Internal Half Bridge Voltage.** Channels 10 and 11 measure the lower and upper legs of the internal half bridge voltage. This checks the stability of the 1,000Ω bridge completion resistors.
12/13	**Shunt Verification.** Channel 12 places a resistor in parallel with the bridge completion channel strain gage to simulate a known value of compressive strain. Channel 13 places a resistor in parallel with the upper leg internal bridge resistor to simulate a known value of tensile strain.
14	**Guard Voltage.** Channel 14 measures the guard voltage (Wagner Ground) to determine if it is 1/2 of the bridge excitation voltage.
15	**Bridge Excitation Voltage.** Channel 15 measures the bridge excitation voltage (Vs).

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Leadwire Resistance

The Leadwire Resistance diagnostic accessed through internal channels 8 and 9 enables you to determine the resistance of the leadwires from the strain gage to the bridge completion channel terminals. **The bridge completion channels on which this diagnostic is performed are channels 0 and 1.** The leadwire resistance diagnostic is used for ¼ bridge arrangements only.

Leadwire Desensitization Corrections

When the leadwire resistance is known, leadwire desensitization corrections can be made to the measured strain values. Leadwire desensitization is the measurement error caused by the leadwire resistance.

Correction for leadwire desensitization is achieved by multiplying the measured strain value by the quantity (1 + Rl/Rg). In equation form, this appears as:

$$e(actual) = \varepsilon(measured) \times (1 + Rl/Rg)$$

where ε(measured) is the measured (¼ bridge) strain, Rl is the leadwire resistance, and Rg is the resistance of the strain gage (120Ω or 350Ω).

Specification

There is no specification for leadwire resistance; however, typical values can range from a few tenths of an ohm to several ohms. Among the factors that will affect leadwire resistance are wire gage, wire length, and temperature.

Set Up

To perform the leadwire resistance diagnostic, your system should be configured as follows:

1. If the bridge excitation voltage is externally supplied, connect the supply to the terminal module as shown in Figure C-1. Set the voltage to 5.0V.
2. Connect the ¼ bridge arrangement to bridge completion channel 0 (Figure 2-4 on page 28.
3. Place the specimen in a constant (preferably unstrained) state throughout the procedure.

CAUTION **Use care when externally supplying the bridge excitation voltage. Voltages greater than 5.4V may damage the bridge completion resistors.**

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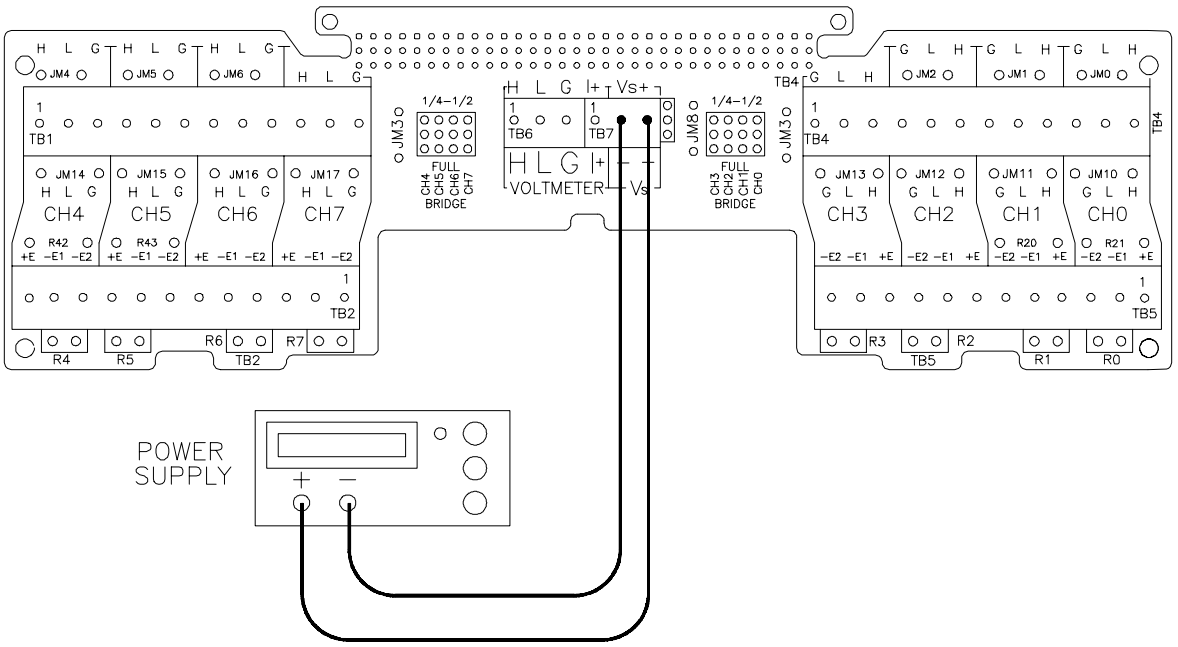


Figure C-1. Externally Supplied Bridge Excitation Voltage

Procedure The leadwire resistance is determined with the following parameters:

- the voltage across the lower leg 1kΩ internal half bridge resistor (V_lower)
- the bridge output voltage (Vout)
- the voltage across the leadwire (V_leadwire)
- the 120Ω or 350Ω bridge completion resistor (Rcomp).

These parameters are represented with the circuit of Figure C-2 and the leadwire resistance is calculated using the equation:

$$R_leadwire = (V_leadwire \times Rcomp)/(V_lower + Vout - V_leadwire)$$

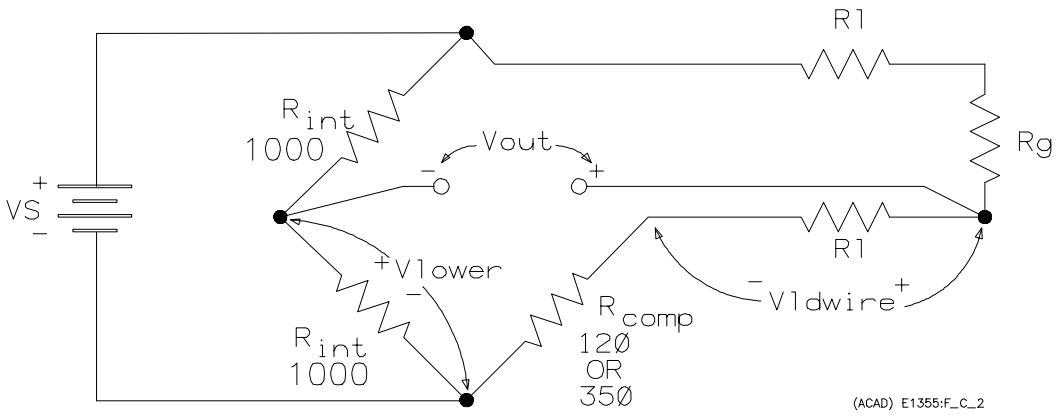


Figure C-2. Determining Leadwire Resistance

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1. Measure the voltage across the lower leg 1kΩ internal half bridge resistor.

   MEASure:VOLT:DC? (@110)

2. Measure the bridge output voltage (Vout) on channel 0. This is a DC voltage measurement.

   MEASure:VOLT:DC? (@100)

3. Measure the voltage on the leadwires (V_leadwire) for the strain gage on channel 0 or 1.

   MEASure:VOLT:DC? (@108) (channel 0)
   MEASure:VOLT:DC? (@109) (channel 1)

4. Compute the value of leadwire resistance by substituting the voltages and bridge completion resistance (120Ω or 350Ω) into the equation.

The following example determines the leadwire resistance on channel 0. The program assumes the strain gage multiplexer uses the HP E1326B/ E1411B Multimeter as part of a scanning multimeter instrument. The computer syntax used is HP BASIC running on a Hewlett-Packard Series 300 computer.

```
!Clear and reset the multimeter.
CLEAR 70903
OUTPUT 70903;"*RST"

!Measure the voltage across the lower leg of the internal ½ bridge resistor
!(V_lower).
OUTPUT 70903;"MEAS:VOLT:DC? (@110)"
ENTER 70903;V_lower

!Measure the bridge output voltage (Vout) on channel 0.
OUTPUT 70903;"MEAS:VOLT:DC? (@100)"
ENTER 70903;Vout

!Measure the voltage on the leadwires (V_leadwire).
OUTPUT 70903;"MEAS:VOLT:DC? (@108)"
ENTER 70903;V_leadwire

!Compute the value of leadwire resistance (350 ohm gage assumed).
R_leadwire=(V_leadwire*350)/(V_lower+Vout-V_leadwire)
PRINT “Leadwire resistance = ”;R_leadwire
END
```

A typical output from this program is:

```
Leadwire resistance =  .411719144
```


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Internal Half Bridge Voltage

The Internal Half Bridge Voltage diagnostic accessed through internal channels 10 and 11 measures the voltage across the 1kΩ internal half bridge resistors. These measurements check the ratio of upper leg to lower leg bridge resistance. The equations in the instrument firmware which calculate the actual strain measured, allow for a certain amount of bridge imbalance due to differences in these resistances. A voltage (resistance) ratio outside the tolerance causes a bridge imbalance not accounted for in the equations. This results in inaccurate strain measurements. Figure C-3 represents the internal half bridge resistors and where the measurements occur.

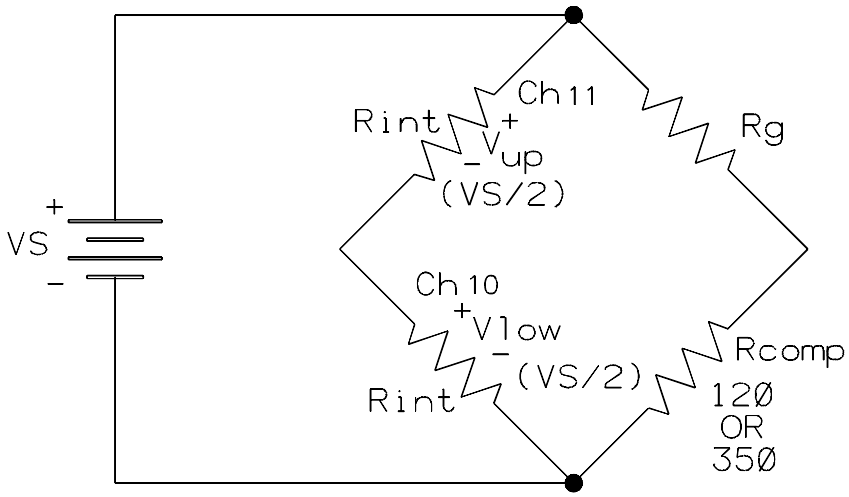


Figure C-3. Internal Half Bridge Measurements

Specification

The ratio of voltages on the upper and lower bridge legs should be 1% ±0.1%.

Set Up

To perform the internal half bridge voltage diagnostic, your system should be configured as follows:

1. If the bridge excitation voltage is externally supplied, connect the supply to the terminal module as shown in Figure C-1. Set the voltage to 5.0V.
2. If desired, connect the bridge arrangement to the bridge completion channels. Strain gages do not have to be connected for this diagnostic.

CAUTION **Use care when externally supplying the bridge excitation voltage. Voltages greater than 5.4V can damage the bridge completion resistors.**

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Procedure

1. Measure the voltage on the upper bridge leg.
   MEASure:VOLT:DC? (@111)

2. Measure the voltage on the lower bridge leg.
   MEASure:VOLT:DC? (@110)

3. Calculate the ratio of upper bridge leg to lower bridge leg voltages.

The following example determines the internal half bridge voltage ratio. The program assumes the strain gage multiplexer is used with the HP E1326B/E1411B Multimeter as part of a scanning multimeter instrument. The computer syntax used is HP BASIC running on a Hewlett-Packard Series 300 computer.

```
!Clear and reset the multimeter.
CLEAR 70903
OUTPUT 70903;"*RST"

!Measure the voltage across the upper leg of the internal ½ bridge resistor.
OUTPUT 70903;"MEAS:VOLT:DC? (@111)"
ENTER 70903;V_upper

!Measure the voltage across the lower leg of the internal ½ bridge resistor.
OUTPUT 70903;"MEAS:VOLT:DC? (@110)"
ENTER 70903;V_lower

!Compute the ratio of the upper bridge leg voltage to the lower bridge leg voltage.
V_ratio=V_upper/V_lower
PRINT “V_upper to V_lower ratio = ”;V_ratio
END
```

A typical output from this program is:

```
V_upper to V_lower ratio =  .999935
```


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Shunt Verification

The Shunt Verification diagnostic accessed through internal channels 12 and 13 checks the bridge completion circuitry and strain gage arrangement. The diagnostic places internal resistors in parallel with an internal bridge arm or strain gage to simulate a known value of tensile or compressive strain. This diagnostic can be used on any bridge completion channel.

A known value of tensile strain is simulated by placing a 158kΩ resistor in parallel with the upper leg 1kΩ internal half bridge resistor. A known compressive strain is simulated by placing a 59kΩ resistor in parallel with the strain gage on the bridge completion channel specified (Figure C-4).

If the (tensile or compressive) strain measured is equivalent to the simulated value, the bridge completion circuitry is functioning properly and the configuration is set up correctly.

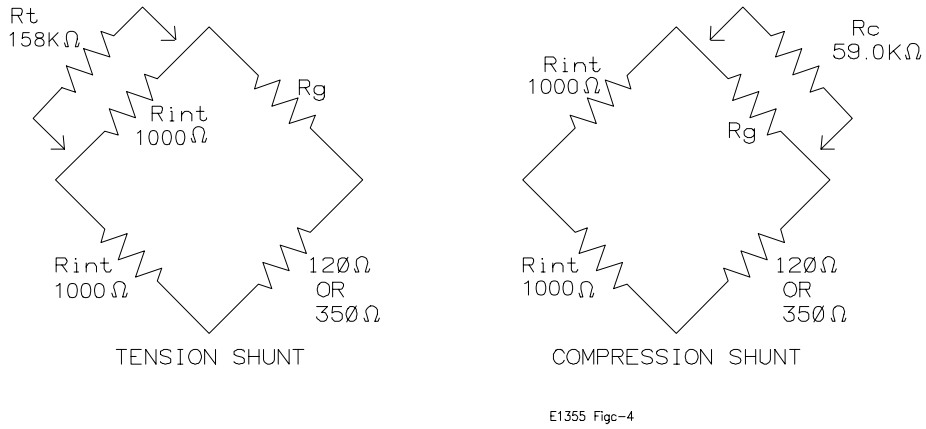


Figure C-4. Shunt Verification Resistors

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Specification

The nominal values of simulated tensile and compressive strain are given in Table C-2. Note that lead resistance between the strain gage and the bridge completion circuitry will affect the readings associated with the compression diagnostic for all bridge arrangements, and the tension diagnostic for full bridge arrangements.

Table C-2. Simulated Tension and Compression Strain Values

Channel	Diagnostic	Compression
	Nominal	Nominal
HP E1355A	3170	-1026
HP E1356A	3170	-2967

NOTES:

1. For full bridge arrangements only, add 12.5με for each ohm of lead resistance. For lead resistances <1 ohm, multiply the resistance by 12.5 to determine the amount of correction.
2. For all arrangements, subtract 16.7με for each ohm of lead resistance. For lead resistances <1 ohm, multiply the resistance by 16.7 to determine the amount of correction.
3. All values are in με.

To increase measurement accuracy, leadwire corrections are included in the table (under Notes) to compensate for leadwire resistances. Refer to the Leadwire Resistance diagnostic to determine the leadwire resistance of your bridge arrangement. (Determining the leadwire resistance is not a prerequisite for this diagnostic.)

Set Up

To perform the shunt verification diagnostic, your system should be configured as follows:

1. Connect the bridge excitation voltage to the terminal module as shown in Figure C-1. Set the voltage to 5.0V.
2. Connect the bridge arrangement(s) (¼, ½, or full) to undergo the diagnostic to the bridge completion channels.
3. Place the specimen in a constant (preferably unstrained) state throughout the procedure.

CAUTION **Use care when externally supplying the bridge excitation voltage. Voltages greater than 5.4V may damage the bridge completion resistors.**

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Procedure

Note This diagnostic requires that an internal channel (12 or 13) be closed with a bridge completion channel (0-7) simultaneously. Since the FET multiplexer can close only one channel at a time, the shunt verification diagnostic is only used with the relay strain gage multiplexers.

1. Measure the unstrained reference voltage on the bridge completion channel which the diagnostic is performed.
   CALibration:STRain (@*channel*)

2. Measure the simulated tension strain.
   MEASure:STRain:QTENsion? (@*channel*)

   The channel specified is the bridge completion channel (0-7). Internal channel 13 is closed automatically by the command.
3. Measure the simulated compressive strain.
   MEASure:STRain:QCOMpression? (@*channel*)

The channel specified is the bridge completion channel (0-7). Internal channel 12 is closed automatically by the command.

The following example measures the simulated tension and compression strain. The program assumes the relay strain gage multiplexer is used with the HP E1326B/E1411B multimeter as part of a scanning multimeter instrument. The computer syntax used is HP BASIC running on a Hewlett-Packard Series 300 computer.

```
!Clear and reset the multimeter.
CLEAR 70903
OUTPUT 70903;"*RST"

!Measure the unstrained reference voltage on the bridge output channel used.
OUTPUT 70903;"CAL:STR  (@100)"

!Measure the simulated tension strain on the bridge output channel.
OUTPUT 70903;"MEAS:STR:QTEN?  (@100)"
ENTER 70903;Tension

!Measure the simulated compressive strain on the bridge output channel.
OUTPUT 70903;"MEAS:STR:QCOM?  (@100)"
ENTER 70903;Compress

!Display the tension and compression shunt in microstrain.
PRINT “Tension shunt = ”;Tension*1.E+6
PRINT
PRINT “Compression shunt = ”;Compress*1.E+6
END
```

A typical output from this program is (HP E1356A used):

```
Tension shunt = 3170.007
Compression shunt = -2967.231
```


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Guard Voltage

The Guard Voltage diagnostic accessed through internal channel 14 measures the guard voltage. This measurement verifies that the guard on the relay strain gage multiplexers is driven to the necessary potential by the Wagner Ground. The proper potential minimizes leakage currents caused by low gage isolation resistance. Figure C-5 shows how the guard is driven to a known voltage, and where that voltage is measured.

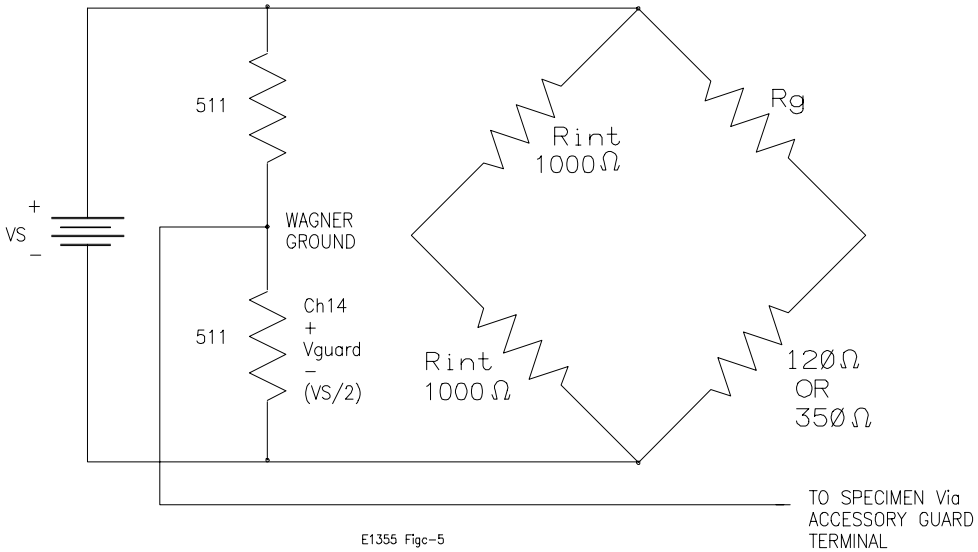


Figure C-5. Driving the Card

Specification The guard voltage should be ½ the bridge excitation voltage ± 2%.

Set Up To perform the guard voltage diagnostic, your system should be configured as follows:

1. If the bridge excitation voltage is externally supplied, connect the supply to the terminal module as shown in Figure C-1. Set the voltage to 5.0V.
2. If desired, connect the bridge arrangement to the bridge completion channels. Strain gages do not have to be connected for this diagnostic.

CAUTION **Use care when externally supplying the bridge excitation voltage. Voltages greater than 5.4V may damage the bridge completion resistors.**

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Procedure Measure the guard voltage on internal channel 14.

```
MEASure:VOLT:DC?  (@114)
```

The following example measures the guard voltage. The program assumes the strain gage multiplexer is used with the HP E1326B/E1411B multimeter as part of a scanning multimeter instrument. The computer syntax used is HP BASIC running on a Hewlett-Packard Series 300 computer.

```
!Clear and reset the multimeter.
CLEAR 70903
OUTPUT 70903;"*RST"

!Measure the guard voltage on internal channel 14.
OUTPUT 70903;"MEAS:VOLT:DC?  (@114)"
ENTER 70903;G_volt

!Print the guard voltage.
PRINT “Guard voltage = ”;G_volt
END
```

A typical output from this program is:

```
Guard voltage = 2.5233
```


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Bridge Excitation Voltage

The Bridge Excitation Voltage diagnostic accessed through internal channel 15 measures the bridge excitation voltage (Vs).

Set Up

If the bridge excitation voltage is externally supplied, connect the supply to the terminal module as shown in Figure C-1. Set the voltage to 5.0V.

If the bridge excitation voltage is internally supplied, ensure the jumpers on the multiplexer component assembly are set correctly (Chapter 1).

Procedure

Measure the bridge excitation voltage on internal channel 15.

```
MEASure:VOLT:DC?  (@115)
```

The following example measures the bridge excitation voltage. The program assumes the excitation voltage is externally supplied and that the strain gage multiplexer is used with the HP E1326B/E1411B Multimeter as part of a scanning multimeter instrument. The computer syntax used is HP BASIC running on a Hewlett-Packard Series 300 computer.

```
!Clear and reset the multimeter.
CLEAR 70903
OUTPUT 70903;"*RST"

!Measure the bridge excitation voltage on internal channel 15.
OUTPUT 70903;"MEAS:VOLT:DC?  (@115)"
ENTER 70903;Excit_volt

!Print the bridge excitation voltage.
PRINT “Excitation voltage = ”;Excit_volt
END
```

A typical output from this program is:

```
Excitation voltage = 5.0519
```

When measuring the internally supplied excitation voltage on the FET multiplexers, the voltage is typically 4.6V.

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Appendix D
Strain Gage Register-Based Programming

About This Appendix

The HP E1355A - HP E1358A Relay and FET Strain Gage Multiplexers are register-based modules which do not support the VXIbus word serial protocol. When an SCPI command is sent to the multiplexer (switchbox), the HP E1300/E1301 Mainframe (Series B) or the HP E1405/E1406 Command Module (Series C) parses the command and programs the multiplexer at the register level. When the strain gage multiplexers are used with the HP E1326B/E1411B Multimeter (which is also register-based), SCPI commands are parsed by the mainframe/command module and are written to the multimeter registers.

Register-based programming is a series of **reads** and **writes** directly to the multiplexer (or multimeter) registers. This increases throughput speed since it eliminates command parsing and allows the use of an embedded controller. Also, if slot 0, the resource manager, and the computer interface (HP-IB) are provided by other devices, a C-size system can be downsized by removing the command module.

This appendix contains the information you need for register-based programming. The contents include:

- Register Addressing . . . . . Page 120
- Register Descriptions . . . . . Page 123
- Relay Multiplexer Registers . . . . . Page 123
- FET Multiplexer Registers . . . . . Page 126
- Programming Examples . . . . . Page 133

Note This appendix covers relay and FET multiplexer register-based programming from a multiplexer switchbox standpoint. Register-based programming for scanning multimeter instruments (multimeters and multiplexers in a single instrument) is covered in the *HP E1326B/E1411B Multimeter User's Manual.*

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Register Addressing

Register addresses for register-based devices are located in the upper 25% of VXIbus A16 address space. Every VXIbus device (up to 256) is allocated a 64 byte block of addresses. The HP E1355A and E1356A Relay Strain Gage Multiplexers with five registers, use five of the 64 addresses allocated. The HP E1357A and E1358A FET Strain Gage Multiplexers with eight registers, use eight of the 64 addresses allocated.

Figure D-1 shows the register address location within A16. Figure D-2 shows the location of A16 address space in the HP E1405/E1406 Command Module and HP E1300/E1301 Mainframe. As an example, both figures show the register map for the HP E1351A/E1353A FET Multiplexers. This map is also the same for the HP E1357A/E1358A FET Strain Gage Multiplexers.

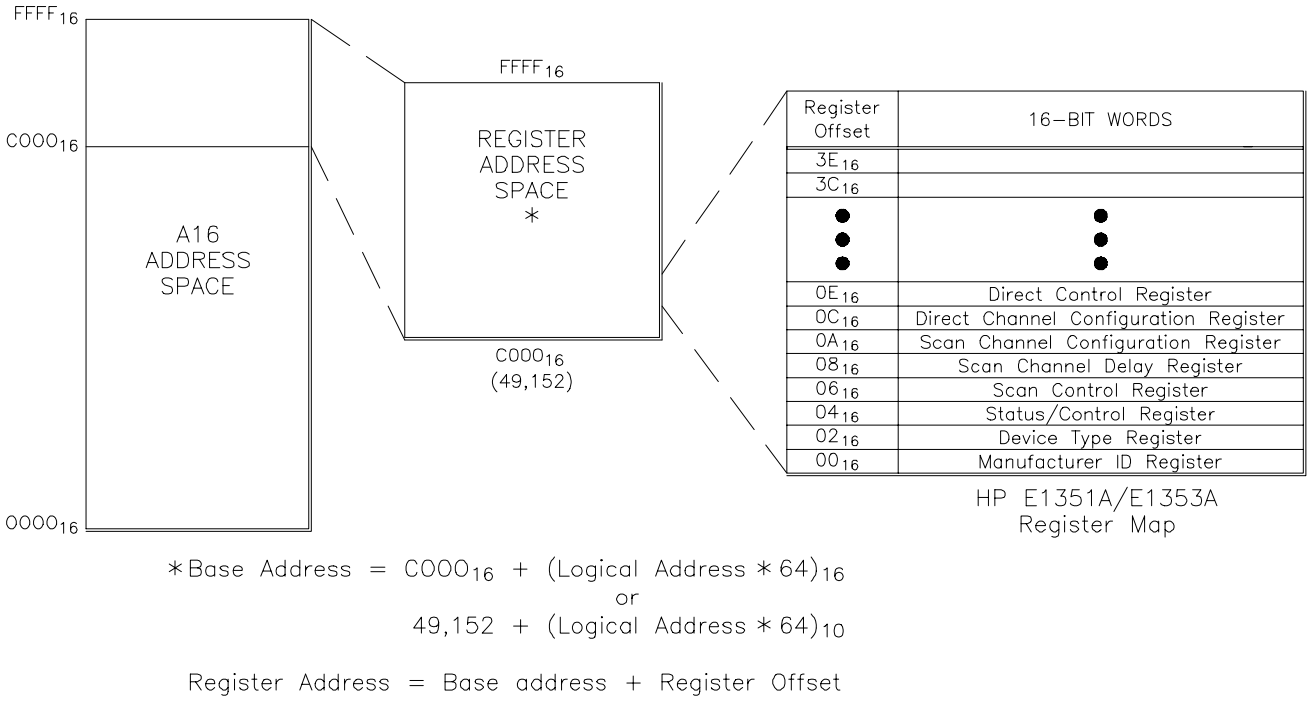


Figure D-1. Multiplexer Registers within A16 Address

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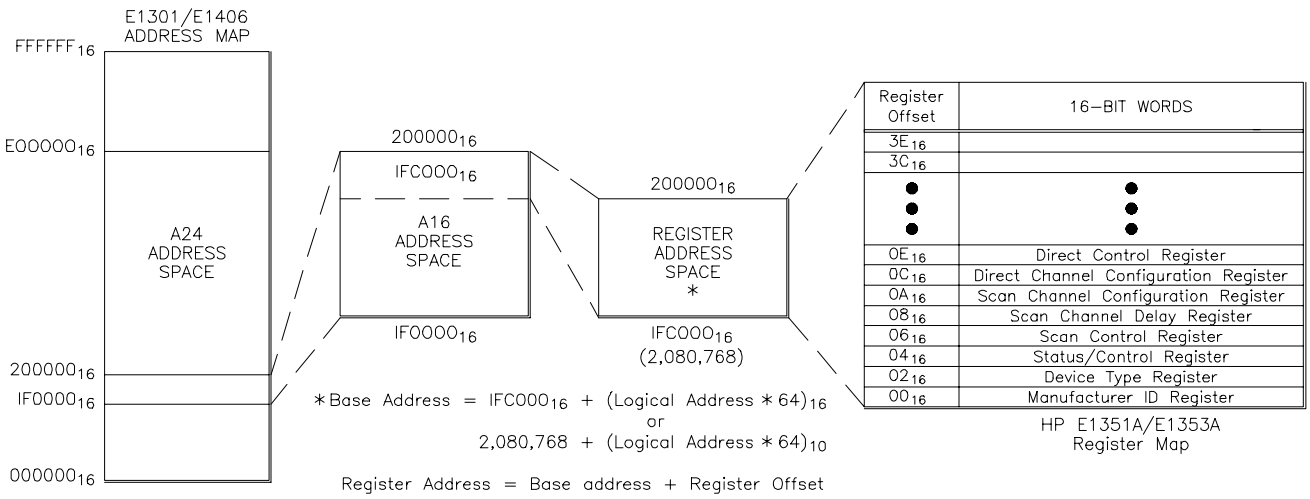


Figure D-2. Mainframe/Command Module A16 Address Space

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 HP E1405/E1406 Command Module or HP E1300/E1301 Mainframe.

A16 Address Space Outside the Command Module or Mainframe

When the Command Module or mainframe is not part of your VXIbus system (Figure D-1), the multiplexer's base address is computed as:[1]

$C000_{16} + (LADDR * 64)_{16}$

or

$49{,}152 + (LADDR * 64)$

where $C000_{16}$ (49,152) is the starting location of the register addresses, LADDR is the multiplexer's logical address, and 64 is the number of address bytes per VXIbus device. For example, the multiplexer's factory set logical address is 112. With this address, the multiplexer has a base address:

$C000_{16} + (112 * 64)_{16}$

$C000_{16} + 1C00_{16} = DC00_{16}$

or (decimal)

$49{,}152 + (112 * 64)$

$49{,}152 + 7{,}168 = 56{,}320$

1 The "$_{16}$" at the end of the address indicates a hexadecimal number.

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A16 Address Space Inside the Command Module or Mainframe

When the A16 address space is inside the command module or mainframe (Figure B-2), the multiplexer's base address is computed as:

$1FC000_{16} + (LADDR * 64)_{16}$

or

2,080,768 + (LADDR * 64)

where $1FC000_{16}$ (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. Again, 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 + 7,168 = 2,087,936

Register Offset

The register offset is the register's location in the block of 64 address bytes. For example, with a LADDR of 112 the multiplexer's Scan Channel Delay Register has an offset of 08_{16}. When you write a command to this register, the offset is added to the base address to form the register address:

$DC0016 + 0816 = DC08_{16}$ (A16 outside the command module)

$1FDC00_{16} + 08_{16} = 1FDC08_{16}$ (A16 inside the command module)

or

56,320 + 8 = 56,328 (A16 outside the command module)

2,087,936 + 8 = 2,087,944 (A16 inside the command module)

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Register Descriptions

This section describes the relay strain gage multiplexer and FET strain gage multiplexer registers.

Relay Multiplexer Registers

There are three READ and three WRITE registers on the relay strain gage multiplexers.

The READ Registers

The following READ registers are located on the relay strain gage multiplexer.

- ID Register (base + 00_{16})
- Device Type Register (base + 02_{16})
- Status Register (base + 04_{16})

ID Register

The relay multiplexer's ID Register indicates the classification, addressing mode, and the manufacturer of the device.

base + 00_{16}	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Read	Device Class		Address Mode		Manufacturer ID											

Device Class

Device Classification. Bits 15 and 14 classify a device as one of the following:

0	0	memory device
0	1	extended device
1	0	message-based device
1	1	register-based device

The HP E1355A/E1356A multiplexers are register-based devices.

Address Space

Addressing Mode. Bits 13 and 12 indicate the addressing mode used by the device:

0	0	A16/A24 address mode
0	1	A16/A32 address mode
1	0	RESERVED
1	1	A16 address mode

The HP E1355A/E1356A Relay Strain Gage Multiplexers use the A16 address mode.

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Manufacturer Identification

Manufacturer ID. Bits 11 through 0 identify the manufacturer of the device. Hewlett-Packard's ID number is 4095, which corresponds to bits 11 - 0 being set to "1".

Given the device classification, addressing space, and manufacturer of the HP E1355A/E1356A multiplexers, reading the ID register returns $FFFF_{16}$.

An example of how to read the ID Register is found in the "Programming Examples" section later in this appendix.

Device Type Register

The Device Type Register contains a model code which identifies the device.

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

Model Code

Model Code. The following model codes identify the HP E1355A and E1356A Relay Strain Gage Multiplexers. The model codes are set by the card ID jumpers located on the E1345-66201 component assembly.

$FF04_{16}$ - HP E1355A 8-Channel 120Ω Relay Strain Gage Multiplexer
$FF06_{16}$ - HP E1356A 8-Channel 350Ω Relay Strain Gage Multiplexer

Status Register

The relay strain gage multiplexer Status Register is monitored to determine when the multiplexer has finished opening or closing a channel.

base + 04_{16}	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Read	F F								BSY	1	1	1	1	1	1	1

BSY

Busy. A one (1) in bit 7 indicates the relay multiplexer is ready to receive a command. A zero (0) in bit 7 indicates the multiplexer is "busy" closing or opening a channel.

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The WRITE Registers

The following WRITE registers are located on the relay strain gage multiplexers:

- Control Register (base + 04_{16})
- Tree Switch Register (base + 06_{16})
- Channel Register (base + 08_{16})

Control Register

The Control Register on the relay strain gage multiplexer is used to reset the multiplexer to its power-on state (all channels open).

base + 04_{16}	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Write	Undefined															CRD RST

CRD RST

Card Reset. Writing a one (1) to bit 0 resets the multiplexer to its power-on state. While bit 0 is 1, the multiplexer continually resets.

Tree Switch Register

The relay multiplexer's Tree Switch Register controls tree relays 93, 92, 91, and 90.

base + 06_{16}	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Write	Undefined												93	92	91	90

Closing Tree Relay

Closing a Tree Relay. Writing a one (1) to bit 3, 2, 1, or 0 closes tree relay 93, 92, 91, or 90 respectively. When making strain measurements using a switchbox, tree relay 90 must be closed (DC voltage measurement).

Channel Register

The Channel Register is used to close the relay strain gage multiplexer internal channels and bridge completion channels.

base + 08_{16}	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Write	Ch15 Int	Ch14 Int	Ch13 Int	Ch12 Int	Ch7 B_c	Ch6 B_c	Ch5 B_c	Ch4 B_c	Ch11 Int	Ch10 Int	Ch9 Int	Ch8 Int	Ch3 B_c	Ch2 B_c	Ch1 B_c	Ch0 B_c

Int, B_c

Internal Channels and Bridge Completions Channels. The relay strain gage multiplexer contains internal channels (Int) which access the diagnostics, and bridge completion channels (B_c) to which the strain gages are connected.

Closing Channels

Closing a Channel. Writing a one (1) to bit 0 through 15 closes the corresponding internal, or bridge completion channel. Writing a zero (0) to the bit opens the channel.

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FET Multiplexer Registers

There are five READ and six WRITE registers on the FET strain gage multiplexer.

The READ Registers

The following READ registers are located on the FET strain gage multiplexer.

- ID Register (base + 00_{16})
- Device Type Register (base + 02_{16})
- Status Register (base + 04_{16})
- Scan Control Register (base + 06_{16})
- Scan Channel Delay Register (base + 08_{16})

ID Register

The FET multiplexer's ID Register indicates the classification, addressing mode, and manufacturer of the device.

base + 00_{16}	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Read	Device Class		Address Mode		Manufacturer ID											

Device Class

Device Classification. Bits 15 and 14 classify a device as one of the following:

0	0	memory device
0	1	extended device
1	0	message-based device
1	1	register-based device

The HP E1357A/E1358A FET Strain Gage Multiplexers are register-based devices.

Address Space

Addressing Mode. Bits 13 and 12 indicate the addressing mode used by the device:

0	0	A16/A24 address mode
0	1	A16/A32 address mode
1	0	RESERVED
1	1	A16 address mode

The HP E1357A/E1358A FET Strain Gage Multiplexers use the A16 address mode.

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Manufacturer Identification

Manufacturer ID. Bits 11 through 0 identify the manufacturer of the device. Hewlett-Packard's ID number is 4095, which corresponds to bits 11 - 0 being set to "1".

Given the device classification, addressing space, and manufacturer of the HP E1357A/E1358A multiplexers, reading the ID Register returns $FFFF_{16}$.

An example of how to read the ID Register is found in the "Programming Examples" section later in this appendix.

Device Type Register

The Device Type Register contains a model code which identifies the module.

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

Model Code

Model Code. The following model codes identify the HP E1357A and E1358A FET Strain Gage Multiplexers. The model codes are set by the terminal module attached to the HP E1351-66201 component module, or by the card ID switches on the component module.

$FF14_{16}$ - HP E1357A 8-Channel 120Ω FET Strain Gage Multiplexer
$FF16_{16}$ - HP E1358A 8-Channel 350Ω FET Strain Gage Multiplexer

Status Register

The FET multiplexer Status Register indicates if interrupts are enabled, if an interrupt has occurred, and if the multiplexer is busy closing or opening a channel.

base + 04_{16}	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Read	F F								1	1	1	BSY	1	1	IRQ	IRQ EN

IRQ EN

Interrupt Request Enabled. A zero (0) indicates enabled, a one (1) indicates disabled.

IRQ

Interrupt Request. A zero (0) indicates an interrupt, a one (1) indicates no interrupt. This bit remains one (1) if IRQ EN is disabled. Interrupt remains set until Card Reset or interrupt has been acknowledged.

BSY

Busy. This bit is set zero (0) during channel closing and the delay period. Triggers will not be accepted. BSY is unasserted at the beginning of the "channel closed" pulse. If a trigger occurs during the "channel closed" pulse, the pulse is terminated and the channel is advanced. Operates only with downloaded scan list (DIR is zero).

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Scan Control Register

Reading the Scan Control Register allows you to check the scan control settings.

base + 06_{16}	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Read	F F								1	1	1	1	CNT EN	IMM EN	DBS EN	CLR SCN

CLR SCN **Clear Scan List.** A one (1) in this bit indicates the scan list is cleared. The bit must be set back to zero (0) after it is cleared in order for another scan list to be accepted.

DBS EN **Digital Bus Enable.** A one (1) indicates the Digital Bus trigger mode is enabled. A zero (0) indicates it is disabled.

IMM EN **Immediate Enable.** A one (1) in this bit indicates the immediate trigger mode is set.

CNT EN **Continuous Enable.** A one (1) in this bit indicates the continuous scanning mode is set.

Scan Channel Delay Register

Reading the Scan Channel Delay Register returns the SETTling:TIME delay.

base + 08_{16}	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Read	F F								1	1	1	1	D3	D2	D1	D0

D3 - D0 **Data bits three to zero.** The delay is 2^n µsec and ^{n} has a range of 0 to 15 as determined by the settings of D3 through D0.

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The WRITE Registers

The following WRITE registers are located on the FET strain gage multiplexer.

- Control Register (base + 04_{16})
- Scan Control Register (base + 06_{16})
- Scan Channel Delay Register (base + 08_{16})
- Scan Channel Configuration Register (base + $0A_{16}$)
- Direct Channel Configuration Register (base + $0C_{16}$)
- Direct Control Register (base + $0E_{16}$)

Control Register

The Control Register is used to reset the multiplexer, enable interrupts, choose direct or scan list control of the channels, and to internally trigger channel closing.

base + 04_{16}	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Write	Undefined								X	X	X	TRG INT	DIR	IRQ EN	X	CRD RST

CRD RST **Card Reset.** Writing a one (1) to bit 0 resets the multiplexer. Writing a zero turns the reset function off. You must write a zero after a reset or the multiplexer will not operate. The Reset conditions are: all enables are set false (0), clear scan list, scan mode enabled (direct bit set 0), delay is 1 µsec and all channels opened.

IRQ EN **Interrupt Request Enable (Write).** A one (1) enables the card to generate interrupts, a zero (0) disables it.

DIR **Direct.** Selects between direct control and scan list control. A zero (0) indicates scan list control and a one (1) indicates direct control. For scan list control, the Direct Registers (base + 0C, base + 0E) are invalidated. For direct control, the Scan Channel Configuration Register is invalidated. The scan list, however, is not affected.

TRG INT **Trigger Internal.** A one (1) immediately advances a channel on the scan list, a zero (0) is the idle state. Bit is automatically set back to zero (0) upon channel advance.

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Scan Control Register

The Scan Control Register allows you to clear the scan list, set the trigger mode, and reset the pointer to the beginning of the scan list.

base + 06_{16}	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Write	Undefined								X	X	X	RST PTR	CNT EN	IMM EN	DBS EN	CLR SCN

CLR SCN **Clear Scan List.** A one (1) in this bit clears the scan list. The bit must be set back to zero (0) in order for another scan list to be accepted

DBS EN **Digital Bus Enable.** A one (1) enables the Digital Bus trigger mode. A zero (0) disables it.

IMM EN **Immediate Enable.** A one (1) in this bit sets trigger to immediate, which means that as soon as the first channel is closed by the TRG INT, the entire scan list is run without any further triggering. Channel advance speed is determined by the delay time specified. Extremely limited applications.

CNT EN **Continuous Enable.** A one (1) in this bit enables the card to continually cycle through the scan list. When this bit is enabled the last channel in a scan list resets the pointer back to the beginning of the scan list. When this bit is set to zero (0), the last channel in the scan list generates an interrupt if the channel is valid (VLD set true (0) - Scan Channel Configuration Register).

RST PTR **Reset Pointer.** Resets the pointer back to the beginning of the scan list. CNT EN true automatically resets the pointer at the end of the scan list.

Scan Channel Delay Register

The Scan Channel Delay Register sets the SETTling:TIME, the time between receipt of a channel closing trigger and the "channel closed" pulse. The delay is 2^n µsec and ^{n} has a range of 0 to 15. D3 to D0 set ^{n}.

base + 08_{16}	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Write	Undefined								X	X	X	X	D3	D2	D1	D0

D3 - D0 **Data bits three to zero.** These bits designate a number between 0 and 15 for ^{n}.

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Scan Channel Configuration Register

These bits set the *channel_list* for a scan list, set the type of measurement, and enable/disable the Tree Isolation switches. Note that the DIR in the Control Register must be set false to enable this register.

base + $0A_{16}$	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Write	VLD	A_D	B_D	C1	C0	X	X	X	X	X	X	X	D3	D2	D1	D0

D3 - D0 **Data bits three to zero.** The FET strain gage multiplexer channels and diagnostics are mapped into bits D3 through D0 as follows:

D3 - D0	
0 0 0 0	closes bridge completion channel 0
0 0 0 1	closes bridge completion channel 1
0 0 1 0	closes bridge completion channel 2
0 0 1 1	closes bridge completion channel 3
0 1 0 0	measures the leadwire resistance on bridge completion channel 0
0 1 0 1	measures the leadwire resistance on bridge completion channel 1
0 1 1 0	measures the lower leg of the internal half bridge voltage
0 1 1 1	measures the upper leg of the internal half bridge voltage
1 0 0 0	closes bridge completion channel 4
1 0 0 1	closes bridge completion channel 5
1 0 1 0	closes bridge completion channel 6
1 0 1 1	closes bridge completion channel 7
1 1 0 0	not used
1 1 0 1	not used
1 1 1 0	measures the guard voltage
1 1 1 1	measures the bridge excitation voltage

C1 - C0 **Configuration bits.** These bits determine the measurement mode as listed below.

C1	C0	
0	0	Volts (strain and diagnostic measurements)
0	1	2-wire ohms

B_D , A_D **B and A Tree Isolation Switch disable.** A zero (0) in either one disables the respective Tree Isolation Switch. Generally both disabled together to equal the SCAN:PORT NONE command.

VLD **Valid Channel.** A zero (0) indicates that the specified channel is valid. When entering a scan list the entire list must be loaded into each multiplexer. For the channels that are not on that multiplexer, VLD must be set false.

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Direct Channel Configuration Register

The Direct Channel Register allows you to specify channels to be closed individually. Note that the DIR bit in the Control Register must be set true for this register to be enabled.

base + $0C_{16}$	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Write	Undefined								X	X	X	X	D3	D2	D1	D0

D3 - D0 **Data bits three to zero.** The FET strain gage multiplexer channels and diagnostics are mapped into bits D3 through D0 as follows:

D3 - D0	
0 0 0 0	closes bridge completion channel 0
0 0 0 1	closes bridge completion channel 1
0 0 1 0	closes bridge completion channel 2
0 0 1 1	closes bridge completion channel 3
0 1 0 0	measures the leadwire resistance on bridge completion channel 0
0 1 0 1	measures the leadwire resistance on bridge completion channel 1
0 1 1 0	measures the lower leg of the internal half bridge voltage
0 1 1 1	measures the upper leg of the internal half bridge voltage
1 0 0 0	closes bridge completion channel 4
1 0 0 1	closes bridge completion channel 5
1 0 1 0	closes bridge completion channel 6
1 0 1 1	closes bridge completion channel 7
1 1 0 0	not used
1 1 0 1	not used
1 1 1 0	measures the guard voltage
1 1 1 1	measures the bridge excitation voltage

Direct Control Register

The Direct Control Register allows you to set the controls for individual channels. Note that the DIR bit in the Control Register must be set true for this register to be enabled.

base + $0E_{16}$	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Write	Undefined								X	X	X	VLD	A_D	B_D	C1	C0

C1 - C0 **Configuration bits.** These bits determine the measurement Mode as listed below.

C1	C0	
0	0	Volts (strain and diagnostic measurements)
0	1	2-wire ohms

B_D , A_D **B and A Tree Isolation Switch disable.** A zero (0) in either one disables the respective Tree Isolation switch. Generally both disabled together to equal the SCAN:PORT NONE command.

VLD **Valid Channel.** A zero (0) indicates that the channel is valid. The DIR bit in the Control Register automatically sets this bit. If DIR is valid and IRQ EN is true, a write to this register will generate an interrupt.

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Programming Examples

The examples in this section demonstrate how to program a relay and FET multiplexer switchbox at the register level. The examples include:

- Reading the ID Register
- Reading the Device Type Register
- Resetting the Switchbox
- Measuring the Bridge Excitation Voltage
- FET Multiplexer Scanning

The programs assume the A16 address space is inside the HP E1300A/ E1301A mainframe, HP E1405/E1406 Command Module and that the logical address of the switchbox is 112. The programs are written in Hewlett-Packard BASIC, and use the SCPI commands DIAGnostic:PEEK? and DIAGnostic:POKE to read and write to the registers.

Reading the ID Register

As previously mentioned, the ID Register indicates the classification, addressing mode, and manufacturer of the device. This program reads the ID Register and returns $FFFF_{16}$.

```
!Convert the switchbox base address to decimal and store the value in a variable.
COM Base_addr
Base_addr=DVAL("1FDC00",16)

!Call the subroutine which reads the ID Register.
CALL Peek_id
END

!Subroutine to read the ID Register.
SUB Peek_id
    COM Base_addr
    OUTPUT 70900;"DIAG:PEEK?";Base_addr+0;",16"
    ENTER 70900;Register
    Hex$=IVAL$(Register,16)
    PRINT Hex$
SUBEND
```

This program returns FFFF.

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Reading the Device Type Register

The Device Type Register contains the model code of the device. The model codes for the strain gage multiplexers are:

FF04 = HP E1355A

FF06 = HP E1356A

FF14 = HP E1357A

FF16 = HP E1358A

```
!Convert the switchbox base address to decimal and store the value in a variable.
COM Base_addr
Base_addr=DVAL("1FDC00",16)
!Call the subroutine which reads the Device Type Register.
CALL Peek_dt
END
!Subroutine to read the Device Type Register.
SUB Peek_dt
    COM Base_addr
    OUTPUT 70900;"DIAG:PEEK?";Base_addr+2;",16"
    ENTER 70900;Register
    Hex$=IVAL$(Register,16)
    PRINT Hex$
SUBEND
```

A typical return is FF06 (HP E1356A)

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Resetting the Switchbox

This program resets the switchbox (relay or FET) by writing to bit 0 of the Control Register.

```
!Convert the switchbox base address to decimal and store the value in a variable.
COM Base_addr
Base_addr=DVAL("1FDC00",16)

!Call the subroutine which resets the switchbox.
CALL Swbx_rst
END

!Subroutine which resets the switchbox by writing a 1 and a 0 to Control
!Register bit 0.
SUB Swbx_rst
    COM Base_addr
    OUTPUT 70900;"DIAG:POKE";Base_addr+4;",16,1"
    OUTPUT 70900;"DIAG:POKE";Base_addr+4;",16,0"
SUBEND
```

Measuring the Bridge Excitation Voltage

This program closes internal channel 15 and tree switch 90 in order to measure the bridge excitation voltage for a relay multiplexer switchbox.

```
!Convert the switchbox base address to decimal and store the value in a variable.
COM Base_addr
Base_addr=DVAL("1FDC00",16)

!Call the subroutine which measures the bridge excitation voltage.
CALL Ex_volt
END

!Subroutine which closes internal channel 15 in the Channel Register, and tree
!relay 90 in the Tree Switch Register in order to access (and measure) the
!bridge excitation voltage.
SUB Ex_volt
    COM Base_addr
    OUTPUT 70900;"DIAG:POKE";Base_addr+8;",16,#H8000"
    OUTPUT 70900;"DIAG:POKE";Base_addr+6;",16,#H1"
SUBEND
```

FET Multiplexer Scanning

This program makes ¼ bridge strain measurements on three FET multiplexer channels, using an external (HP 3458A) multimeter.

The program clears the FET multiplexer's Scan Control Register, downloads the scan list, sets the settling time, and then starts the scan. The multimeter is connected to the multiplexer as indicated in Figure 2-8.

```
!Dimension computer variables to store the bridge output and bridge excitation
!voltages.
DIM Vout_unstr(1:3),Vout_str(1:3),Vr(1:3),Epsilon(1:3)
```


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```
!Convert the FET switchbox base address to decimal and store the value in a
!variable.
COM Base_addr
Base_addr=DVAL("1FDC00",16)

!Set up the (external) voltmeter for DC voltage measurements, external
!triggering, and store the readings in voltmeter memory until all measurements
!have been taken.
OUTPUT 722;"PRESET NORM"
OUTPUT 722;"     MEM FIFO"
OUTPUT 722;"     NPLC 1"
OUTPUT 722;"     TRIG EXT"
OUTPUT 722;"     EXTOUT RCOMP,NEG"

!Call the subprogram which downloads the scan list, sets the settling time, and
!triggers the scan. The unstrained references are measured on this scan.
CALL Fet_scan

!Pause the program until stress is applied to the specimen. Call the subprogram
!again to set up the scan for the strain measurements.
PAUSE
CALL Fet_scan

!Enter the unstrained references and strain measurements from the multimeter
!into the computer. Call the subprogram to compute the strain.
ENTER 722;Vout_unstr(*),Vs_unstr,Vout_str(*),Vs_str
CALL Strn_cmput(Vr(*),Vout_str(*),Vout_unstr(*),Vs_str,Vs_unstr)
END

!Subprogram which sets up the scan list.
SUB Fet_scan
    COM Base_addr

    !Clear old the scan list and set up the Scan Control Register for the next scan.
    OUTPUT 70900;"DIAG:POKE";Base_addr+6;",16,#H1"
    OUTPUT 70900;"DIAG:POKE";Base_addr+6;",16,#H0"

    !Download the scan list. Scan bridge output channels 0, 1, 2; and bridge
    !excitation channel 15.
    OUTPUT 70900;"DIAG:POKE";Base_addr+10;",16,#H6000"
    OUTPUT 70900;"DIAG:POKE";Base_addr+10;",16,#H6001"
    OUTPUT 70900;"DIAG:POKE";Base_addr+10;",16,#H6002"
    OUTPUT 70900;"DIAG:POKE";Base_addr+10;",16,#H600F"

    !Set the settling time from when the channel advance pulse is received,
    !until the channel closed pulse is generated (32.768 msec).
    OUTPUT 70900;"DIAG:POKE";Base_addr+8;",16,#HF"

    !Set the switchbox to be externally triggered.
    OUTPUT 70900;"DIAG:POKE";Base_addr+6;",16,#H02"

    !Initiate the scan by closing the first channel in the list.
    OUTPUT 70900;"DIAG:POKE";Base_addr+4;",16,#H10"
SUBEND

!Subprogram which computes the measured strain.
SUB Strn_cmput(Vr(*),Vout_str(*),Vout_unstr(*),Vs_str,Vs_unstr)
    FOR I=1 TO 3
        Vr(I)=Vout_str(I)/Vs_str-Vout_unstr(I)/Vs_unstr
        Epsilon(I)=-4*Vr(I)/2.11E-6*(1+2*Vr(I))
        PRINT Epsilon(I)
    NEXT I
SUBEND
```


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Appendix E
Strain Gage Multiplexer Error Messages

Table E-1 lists the error messages associated with the strain gage multiplexer modules programmed by SCPI. See mainframe manual for a complete list.

Table E-1. Strain Gage Multiplexer Error Messages

No.	Title	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.
-224	Illegal parameter value	Attempting to execute a command with a parameter not applicable to the command.
+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.
+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	Sending a command to a module (card) in a switchbox that is unsupported by the module.
+2008	Scan list not initialized	Executing INIT command with no scan **<***channel_list***>**.
+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	Attempting to execute a SCAN:MODE which is not supported.
+ 2011	Empty channel list	No valid channels in 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	Incorrect ARM:COUNt	Attempting to run a downloaded scan list with ARM:COUNt set to value other than 1.
+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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