

# Accelerometers: Theory, Instrumentation and Installation

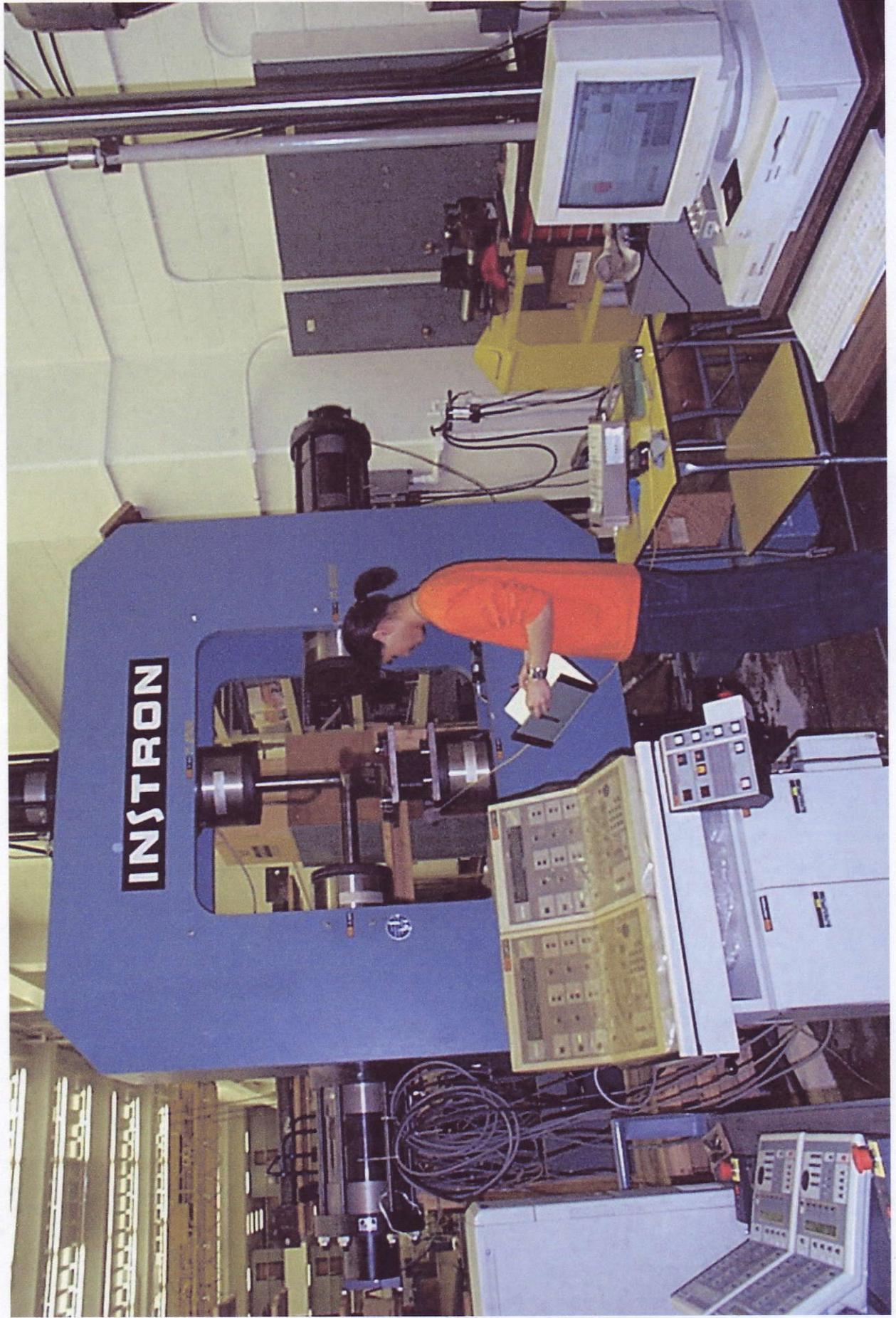
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# Newmark Structural Engineering Laboratory



## INTRODUCTION

The purpose of this manual is to provide the basic principles of theory and installation associated with accelerometers to users of the Newmark Structural Engineering Laboratory (NSEL). The material presented in this manual is based on 50 years of experience of NSEL and references listed at the end of this manual. Also, the experience of past users of NSEL was used while working on this manual. Many questions have been asked on which either direct answers were given or references were recommended in which answers could be found. That is why this manual was partially written in the question-answer format. Any critical comments and remarks of current users are also welcomed and they will be used in a future revision. This manual is divided into 3 sections: theory, instrumentation, and installation.

## THEORY

What is acceleration? Acceleration is the rate of change of velocity ( $\Delta v$ ) in a time interval ( $\Delta t$ ). Acceleration ( $a$ ) is given by:

$$a = \frac{\Delta v}{\Delta t}$$

1

The unit of acceleration is  $m/s^2$  or  $ft/s^2$  or  $g$ . The downward vertical acceleration due to Earth's gravity is called  $1g$ , and is equal to  $9.807 m/s^2$  or  $32.17 ft/s^2$ .

What is an accelerometer? It is a transducer that allows the measurement of acceleration of an object to which the base of the accelerometer is attached. The accelerometer produces an electrical output proportional to the acceleration motion of its base. Accelerometers are widely used during dynamic, vibration, and blast testing of structural materials and components.

There are three types of accelerometers: Resistance-wire strain-gauge accelerometer, piezoelectric accelerometer, and piezoresistive accelerometer. The piezoresistive type has become the most popular in research and industrial applications. It offers the advantages of lighter weight, smaller size, higher output, and higher frequency response when compared to the resistance-wire strain-gauge accelerometer. Unlike the piezoelectric type, the piezoresistive accelerometer is useful for measuring steady state acceleration (zero frequency). The zero frequency response is essential in making accurate long duration shock motion measurements. In this manual, only the piezoresistive accelerometer will be discussed.

How does the accelerometer work? A single-degree-of-freedom accelerometer can be represented by a mass element connected to a spring and mounted in a case (Figure 1). The case is attached to the moving part whose motion is to be measured. When the accelerometer is in motion, the inertial force on the mass element due to the acceleration results in a deformation of the piezoresistive element. This deformation changes the resistance of the element and the electrical output of the accelerometer. In a well designed accelerometer, the deformation and electrical output are directly proportional to acceleration over a wide range of frequencies.

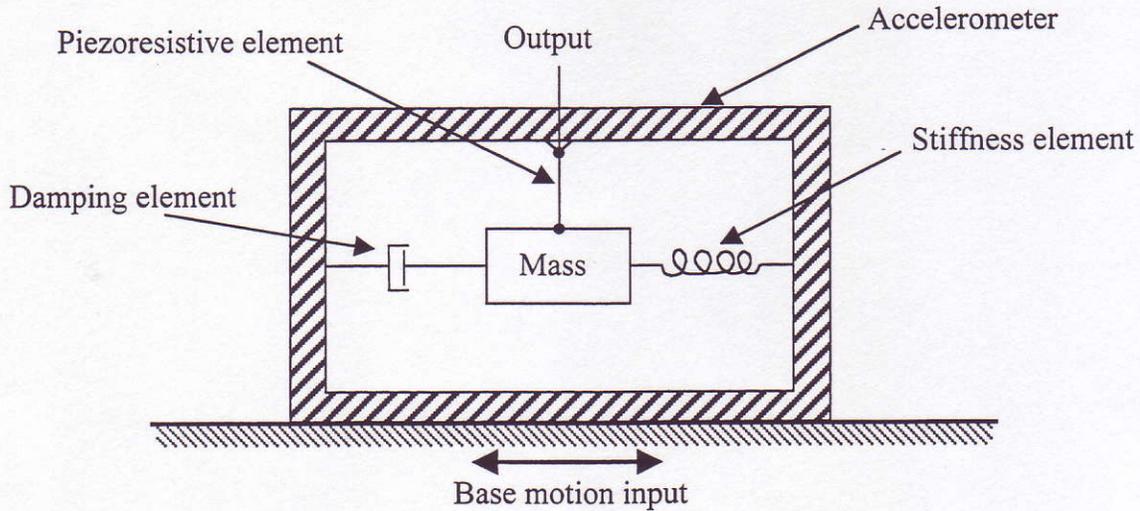


Fig.1 Representation of a single-degree-of-freedom accelerometer.

What is a piezoresistive element? It is a solid-state silicon resistor that changes electrical resistance proportional to applied mechanical stress. Young's Modulus for silicon is close to that of steel. Its yield strength in both tension and compression is greater than that of maximum-strength steel, and its modulus-to-density ratio is more than three times that of steel. Single-crystal silicon is used because unlike polycrystalline metals, it remains strong under repeated cycles of tension and compression. These characteristics, coupled with its linear elastic properties until fracture, make properly grown silicon an ideal material for mechanical integration into transducers. Single-crystal silicon is also the most commonly used semiconductor material.

An important characteristic of the piezoresistive element is that its change of resistance is large relative to its change in length. In other words, it has a large gauge factor that is typically between 50 and 200 as opposed to a gauge factor of 2 to 5 of a typical resistance strain gauge. This high gauge factor allows the piezoresistive element or other semiconductor strain elements to produce a large useable electrical signal output from a transducer with a stiff mechanical flexure, and therefore makes them attractive for use in accelerometer technology. The accelerometer uses usually four piezoresistive elements connected electrically in a Wheatstone full-bridge circuit in a way similar to other resistance strain gauge circuits.

A much more detailed discussion on the gauge factor and the Wheatstone-bridge circuit is available in the Strain Gauge Manual of NSEL (**Ref. 5**).

## INSTRUMENTATION

There are two types of accelerometers currently available for use at NSEL. These are Model 2262C-25 (Figure 2) from Endevco (see the included **Ref. 1** for the performance characteristics, and **Ref. 2** for the datasheet), and Model SA-102 (Figure 3) from Terra Technology see the included **Ref. 3** for specifications). The former requires 2100 Strain Gauge Conditioner and Amplifier System, while the latter has a built-in circuitry and requires any DC dual power supply for its operation.

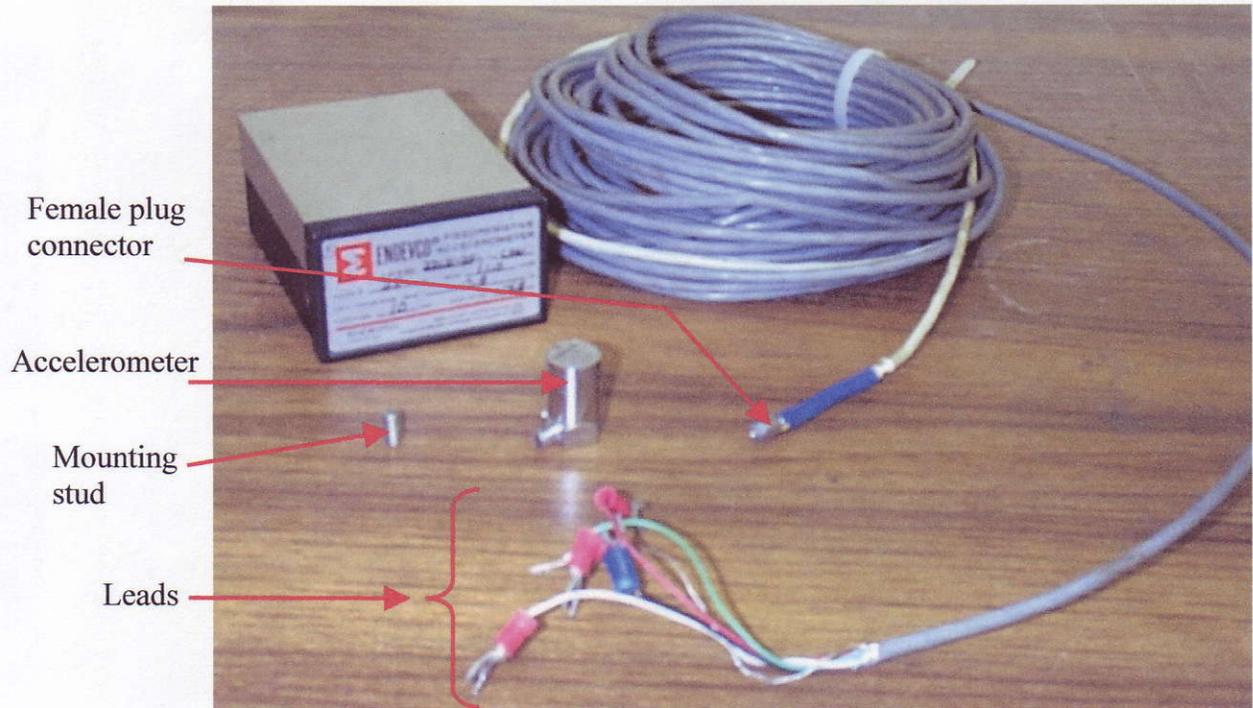


Fig. 2 Endevco 2262C-25 accelerometer.



Fig. 3 Terra Technology SA-102 accelerometer.

### 2100 Strain Gauge Conditioner and Amplifier System

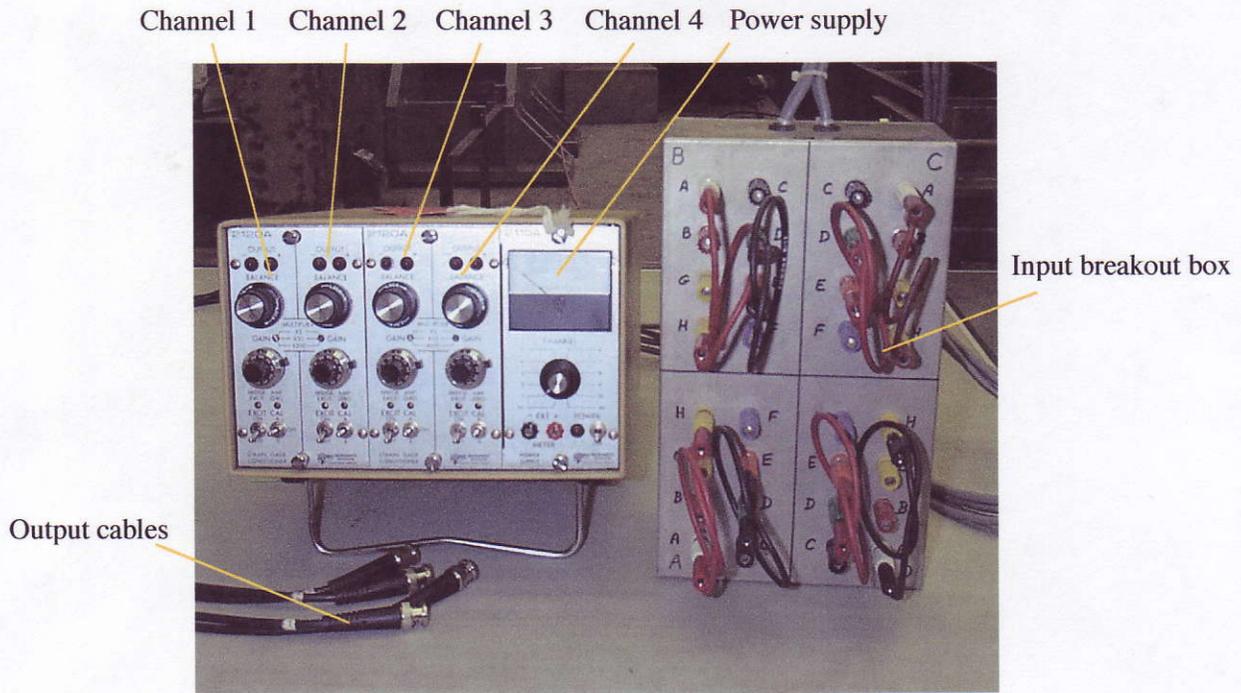
The intention of this section is to show, step by step, the procedure of connecting an accelerometer (e.g. Model 2262C-25) to the 2100 strain gauge conditioner and amplifier system (yellow box) in the full bridge configuration. A copy of the yellow box manual is included in this package (**Ref. 4**). This manual should be referred to if any questions or doubts occur.

Figure 4 shows a picture of the yellow box as well as an outline of power supply, single channel signal conditioner/amplifier, and schematic of the input breakout box for accelerometer leads connection. The yellow box is a four channel unit which allows strain measurement in quarter, half, and full bridge configurations. It also allows measurement by other transducers in a full bridge configuration. In this case, accelerometer is the transducer with four leads: Two for the bridge input so that a regulated excitation voltage is applied, and two for the bridge voltage output that varies with the acceleration applied. Figure 5 presents electrical diagrams for quarter, half, and full bridge configurations, which are used in most applications in the laboratory. The last diagram in Figure 5 shows the connections for the accelerometer in a full bridge configuration.

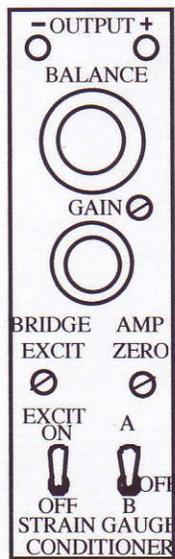
#### Operation of the 2100 system

1. Connect the yellow box to the 110 V, 60 Hz source of electrical power. Flip the toggle switch "POWER" on the power supply (Figure 4c). Using the "CHANNEL" selector, check both AC and DC lines using a voltmeter of power supply. Wait at least 30 minutes (warm-up time) before proceeding to step 2.
2. Turn the "CHANNEL" selector to channel 1 (Figure 4c). Turn the "EXCIT ON" for channel 1 (Figure 4b) and using the "BRIDGE EXCIT" resistor, adjust the excitation voltage to the required level; e.g. 10 VDC. A small screwdriver is needed to turn the "BRIDGE EXCIT" resistor. Repeat this operation for all channels to be used.
3. Turn the "EXCIT OFF" for all four channels (Figure 4b). Connect the four leads of an accelerometer to the selected channel (e.g. channel 1) of "Input breakout box" (Figure 4d) according to the "Full bridge: transducer" configuration in Figure 5 and Figure 6. If more than one accelerometer are being used, repeat this connection for all remaining channels. Refer to the "INSTALLATION" section of this manual to connect the accelerometer cable to the accelerometer.
4. Turn the "EXCIT ON" for channels being used (Figure 4b). Make sure that each channel is powered by the adjusted excitation voltage. Make additional adjustments, if necessary. Turn the "EXCIT OFF" for channel 1. Connect a voltmeter to an "output cable" corresponding to channel 1 (Figure 4a). Mount the accelerometer onto the calibrating frame (Figure 7a). Adjust the legs of the frame such that the measurement axis of the accelerometer lies perfectly parallel to the ground. By definition, the accelerometer should measure 0g in this configuration (Figure 7b). Using "AMP ZERO" resistor for channel 1 and the small screwdriver, adjust the output voltage so that it reads "zero" (0.000). Third decimal point may vary  $\pm 5$  mV. Repeat this procedure for all channels used. Several

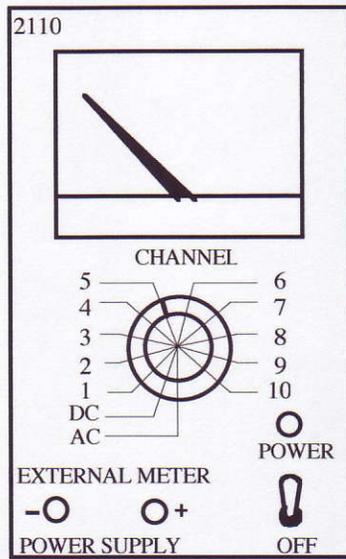
a)



b)



c)



d)

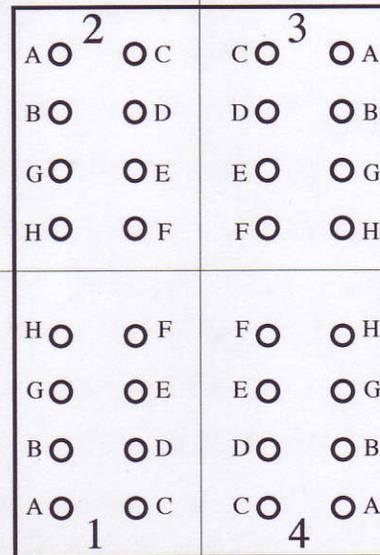
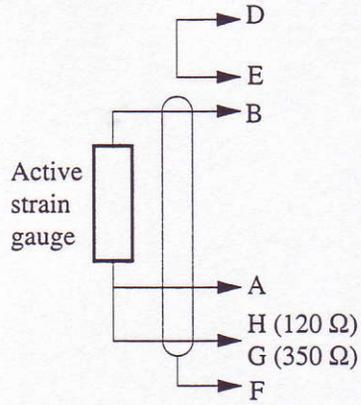
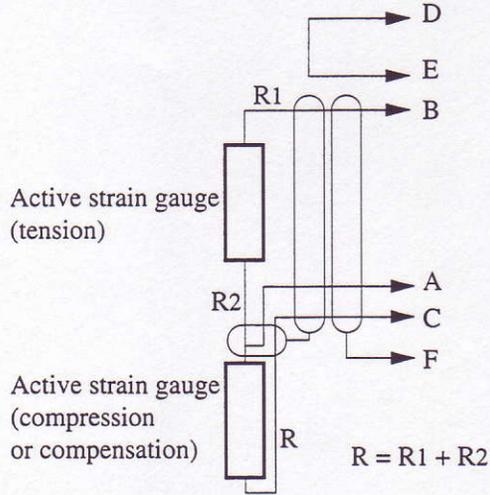


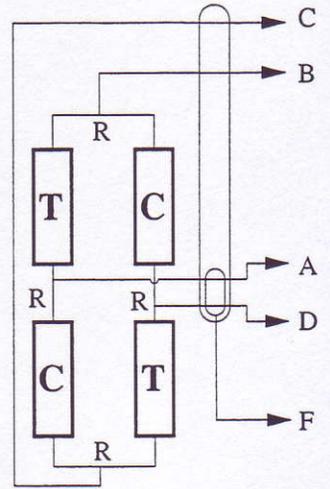
Fig. 4 Four channel, 2100 strain gauge conditioner and amplifier system (yellow box): a) picture of the 2100 system, b) single channel signal conditioner/amplifier, c) power supply, d) input breakout box.



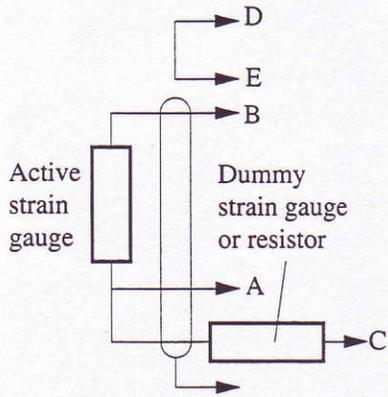
Quater bridge: internal dummy.



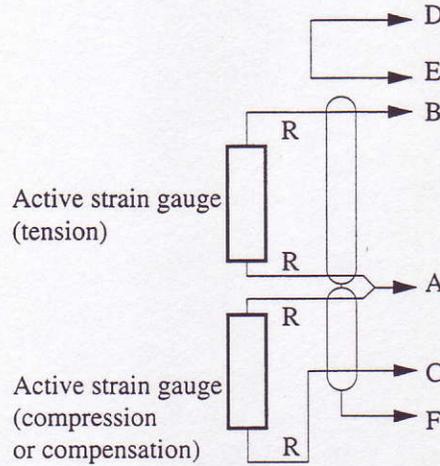
Half bridge: preferred.



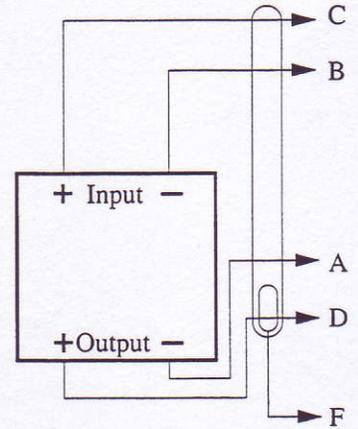
Full bridge: strain gauges.



Quater bridge: external dummy.



Half bridge: alternate.



Full bridge: transducer.

Fig. 5 Input breakout box's circuits.

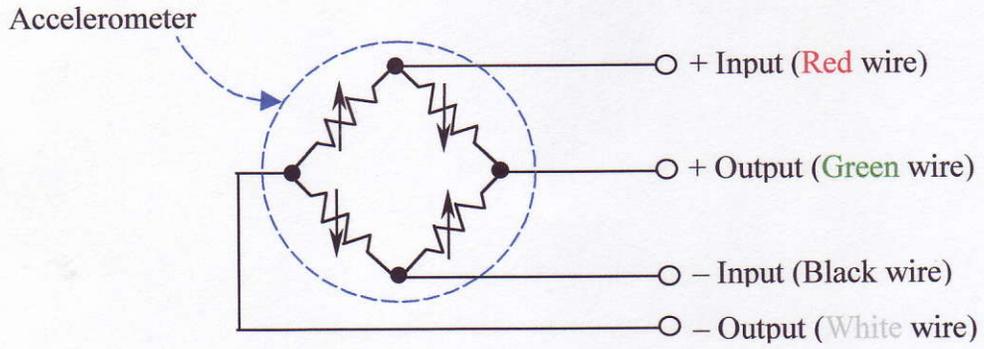


Fig. 6 Four-arm Full Bridge.

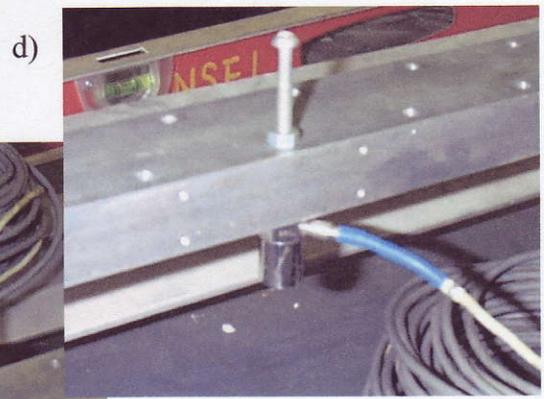
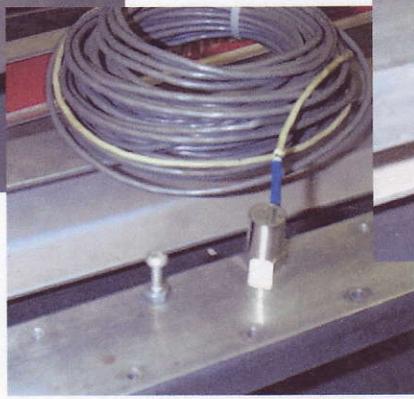
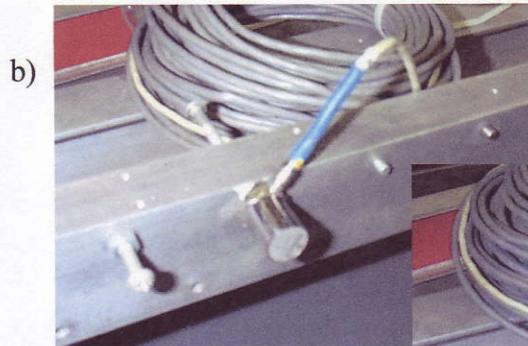
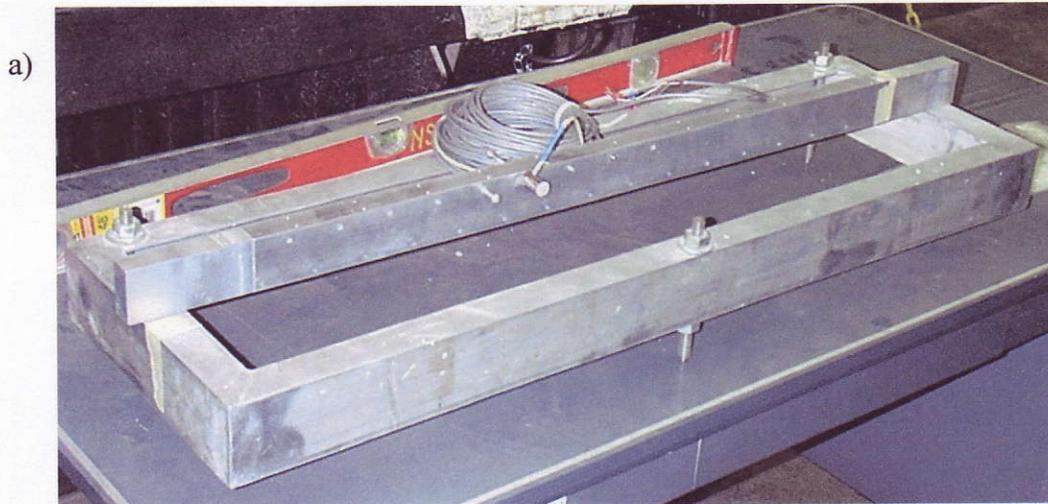


Fig. 7 Calibrating frame: a) General view, b) 0g configuration, c) +1g configuration, d) -1g configuration.

accelerometers can be mounted onto the calibrating frame so that each one connected to a different channel can be calibrated at the same time.

5. Turn the "EXCIT ON" for channels being used (Figure 4b). Connect the voltmeter to an "output cable" corresponding to channel 1 (Figure 4a). Using the "BALANCE" knob (Figure 4b) for channel 1, adjust the output voltage to read "zero" (0.000); both "OUTPUT" lights (+ and -) should be extinguished. The "BALANCE" resistor can correct for an approximately  $\pm 2,000 \mu\epsilon$  unbalance in  $350 \Omega$  quarter, half or full bridge. With bridge inputs other than  $350 \Omega$ , the balance range will be reduced for lower bridge resistance and increased for higher ones. For example, Model 2262C-25 with a  $1000 \Omega$  full bridge resistance significantly increases the balance range. If the balance range proves inadequate for the transducers in use, the balance resistor should be either replaced or shunted with an additional one. The latter option is used in the applications. Repeat this procedure for all channels used. When using an additional resistor, make sure you know the resistor color code available in **Ref. 11**.
6. To calibrate the accelerometer, decide on the range of accelerations expected during measurement. Adjust the calibrating frame such that the mounted accelerometer points up (Figure 7c). By definition, this is  $+1g$  due to Earth's gravitational pull. Connect the voltmeter to an "output cable" corresponding to channel 1 (Figure 4a). Assuming the maximum acceleration to be measured is known, adjust the gain using both "GAIN" screw and knob in such a way that 10 VDC output corresponds to the maximum acceleration expected. **For example:** When the maximum expected acceleration to be measured is  $5g$ , the output voltage must be:

$$U_{out} = \frac{10V \cdot 1g}{5g} = 2.000V$$

2

Adjust the calibrating frame such that the mounted accelerometer points down (Figure 7d). By definition, this is  $-1g$ , and the output voltage should read  $-2.0V$ . Bring the accelerometer parallel to the ground to check that the output voltage is still "zero" (0.000). Refer to "INSTALLATION" section of this manual for other calibration methods.

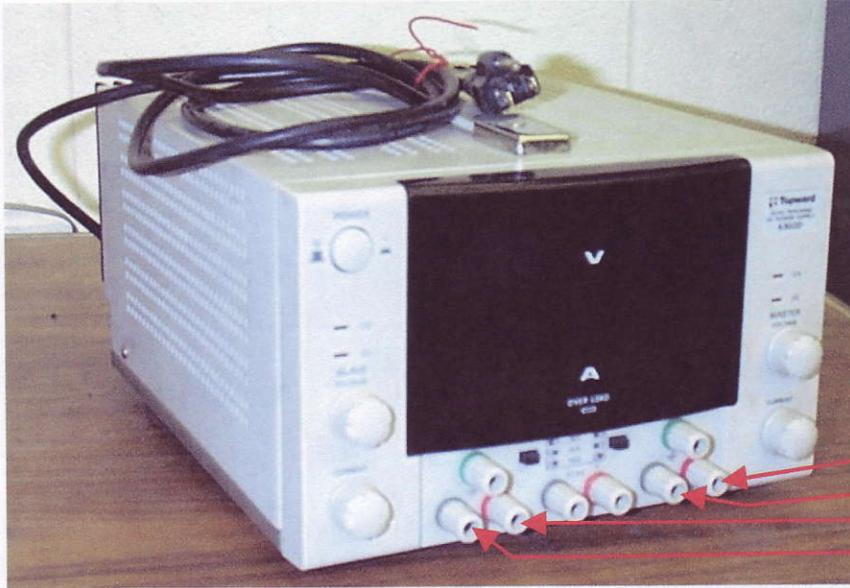
7. It is advisable to check both "AMP ZERO BAL" and "BALANCE" (points 4 and 5) on each channel just before data is taken. The "AMP ZERO BAL" (point 4) should be checked occasionally on an extended test.

#### DC Dual Power Supply

Since an accelerometer such as SA-102 has a built-in circuitry, which is an equivalent of the 2100 system, any DC dual power supply can be used for its operation. An example of DC dual power supply is shown in Figure 8.

#### Operation of DC Dual Power Supply

1. Connect a DC dual power supply to the 110 V, 60 Hz source of electrical power. Turn it on (Figure 8) and wait at least 30 minutes (warm-up time) before proceeding to step 2.

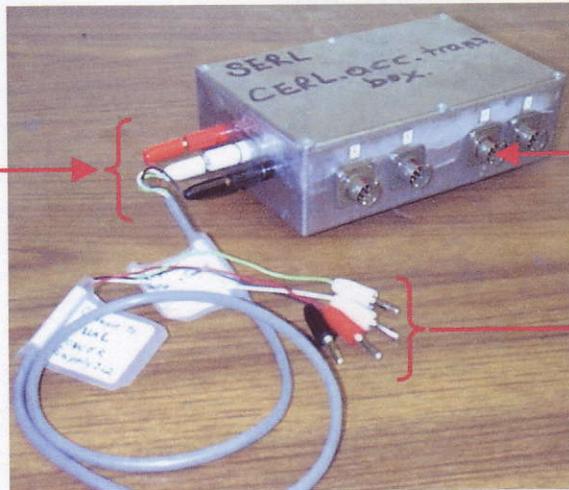


From transition box:  
White wire (+)  
Black wire (-)  
Red wire (+)  
Green wire (-)

Fig. 8 DC dual power supply.

a)

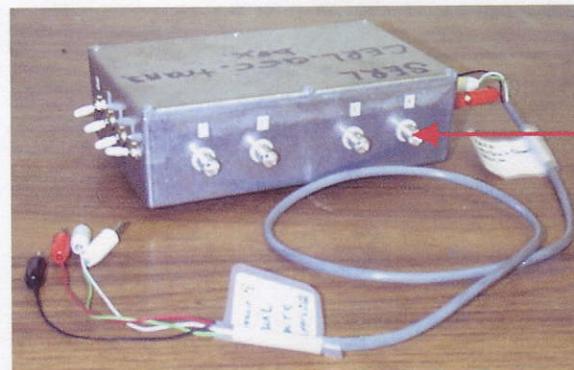
Red (+)  
White (COM)  
Black (-)



Accelerometer outlet

To power supply

b)



Analog output

Fig. 9 Transition box: a) Front view, b) Rear view.

2. Adjust the output DC voltage (excitation voltage) from the power supply to the value specified by the accelerometer manufacturer, 12 VDC for SA-102. Connect the output from DC power supply to the transition box shown in Figure 9. Make sure that the polarity is correct; minus goes to minus and plus goes to plus (Follow the color codes shown in Figures 8 & 9). If the polarity is reversed, the output from accelerometer will be close to zero.
3. Connect the accelerometer to one of four channels, say channel 1, of the transition box (Figure 9a). Also connect a voltmeter to an "output cable" corresponding to channel 1 (Figure 9b). Turn the "1g BIAS" switch "OFF" on the transition box for channel 1 (see "Note" below). Mount the accelerometer onto the calibrating frame in the 0g configuration (Figure 7b). Make sure zero V (0.00 V) output is achieved. To calibrate the accelerometer, decide on the range of accelerations expected during measurement. Adjust the calibrating frame such that the mounted accelerometer points up (Figure 7c). By definition, this is +1g due to Earth's gravitational pull. The maximum acceleration to be measured is 4g and is not adjustable. Since 10 VDC output corresponds to this maximum acceleration, output voltage should read 2.5V for 1g acceleration. Adjust the calibrating frame such that the mounted accelerometer points down (Figure 7d). By definition, this is -1g, and the output voltage should read -2.5V. Bring the accelerometer parallel to the ground to check that the output voltage is still "zero" (0.000). Refer to "INSTALLATION" section of this manual for other calibration methods.

*Note:* When "1g BIAS" is "OFF", 0.00V corresponds to 0g, and measurement range is -4g to +4g. When "1g BIAS" is "ON", 0.00V corresponds to +1g, and measurement range is -3g to +5g. "ON" position may be more convenient for some users when the accelerometer is mounted vertically on to the specimen and 0.00V is desired as the starting voltage. SA-102 measures accelerations always in the direction of the arrow drawn on it.

## INSTALLATION

Accelerometer mounting. The accelerometer must be properly attached to the test specimen to gather accurate data without any distortion. This requires that the accelerometer mounting be rigid over the frequency range of testing. Different mounting methods can be utilized for various applications depending on the practical requirements of the test system. The accelerometer can be directly mounted onto the test specimen or a fixture may be used.

Direct methods include using a standard mounting stud (Figure 2) or using an adhesive (cementing technique). A solid stud is the best means for mounting. Care should be taken to ensure a flush mate to a smooth flat surface so that the entire base of the accelerometer is in good contact with the test specimen. The mounting hole must be at a right angle to the surface.

As for the cementing technique, its efficiency depends entirely on the adhesive used for the particular application. Adhesives are useful when the mounting surface is irregular. On the other hand, they may not be able to provide the desired frequency response over the entire operational range of temperature of the accelerometer. To prevent damage to the accelerometer,

adhesive material must not be scraped or sanded off it. Appropriate solvents should be used to remove all traces of the adhesive from the accelerometer.

Fixtures may be used for mounting accelerometers to a test specimen. A common method in NSEL is to use little aluminum blocks with a threaded hole to which the accelerometer can be attached with a standard mounting stud (Figure 10). These mounting blocks are attached to the test specimen with an appropriate adhesive, such as PC7 heavy duty epoxy paste A & B. After removing the accelerometer from the mounting block, the adhesive can be scraped or sanded off the block without worrying about damaging the accelerometer.

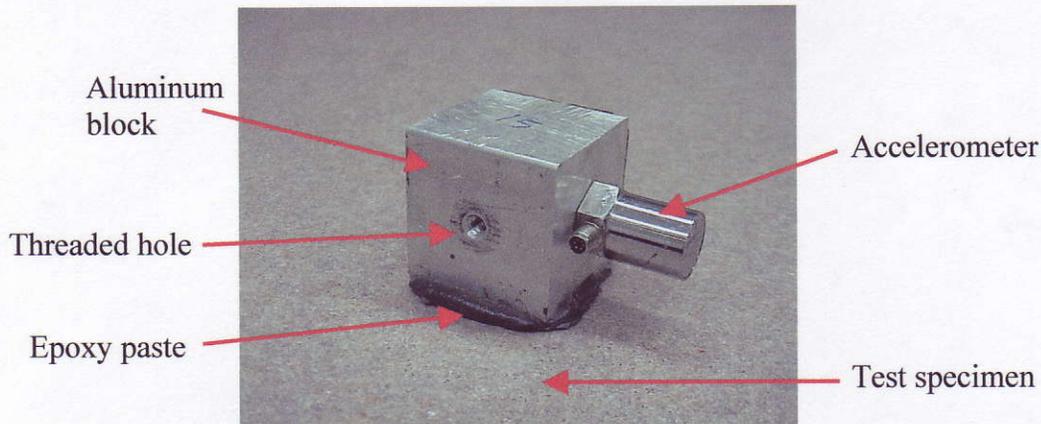


Fig. 10 Accelerometer mounted block.

For all methods of mounting mentioned above, the user must be aware of the fact that the mass of the accelerometer (and of the block/fixture) increases the mass of the test specimen, thereby decreasing the frequency content of the system. For most applications, this effect is not significant because the mass of the specimen is large compared to that of an accelerometer. Also, if the accelerometer is attached to a somewhat flexible specimen, it may introduce local stiffening which increases the frequency content of the system.

**Accelerometer cable connection.** The cable which connects an accelerometer to its matching electronics is an important and delicate part of the overall measurement system. It must transmit the accelerometer signal to the associated signal conditioning equipment without distortion or introduction of noise. Cable must also not affect accelerometer or test specimen characteristics.

The cable for the Endevco 2262C-25 accelerometer has a connector at its end (Figure 2). The connector is a six-contact female plug. To connect the cable to the accelerometer, line up the white dots on the cable and accelerometer connectors, push in the cable connector, then tighten the nut. **When attaching and detaching the cable, great care must be taken not to bend the pins of the accelerometer connector.** Cable connector should be securely tightened, with careful use of pliers, if necessary, to prevent loosening during operation at high frequencies. The cable also should be handled with care. It should not be stepped on, kinked, knotted, etc. When possible, the cable should be tied down within two to three inches of the accelerometer connector. Long, unsupported length of cable may load the test specimen and lead to cable damage.

Accelerometer calibration. The calibration technique described in the "INSTRUMENTATION" section of this manual is called the Turnover Calibration. It is performed under a single set of conditions for the basic sensitivity calibration. Other techniques include Centrifugal, Reciprocity, and Comparison Calibration. These methods can be utilized under various conditions to obtain frequency response calibration, temperature response calibration, amplitude linearity calibration, and others. The user is advised to see **Ref. 1** for a detailed explanation of accelerometer calibration.

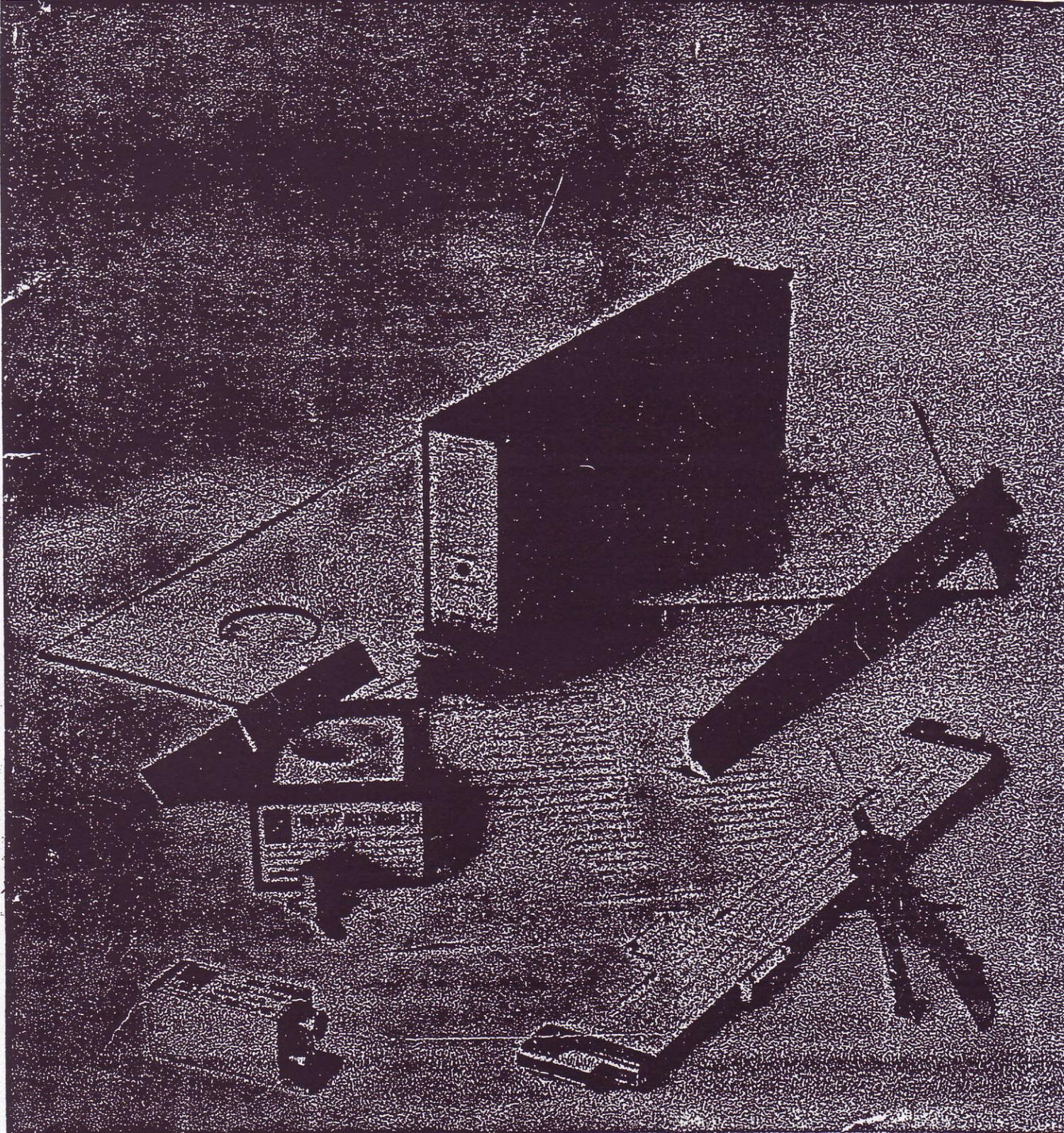
#### REFERENCES

- Ref. 1 Instruction Manual for Endevco Piezoresistive Accelerometers, Endevco, No. 121 (included).
- Ref. 2 Models 2262-25, 2262C-25 Low G Piezoresistive Accelerometers, Endevco Product Data, 1974 (included).
- Ref. 3 Servo Accelerometers, Terra-Flex Models SA-102 & SA-111, Terra Technology Corp., 1988 (included).
- Ref. 4 2100 SYSTEM, Strain Gage Conditioner and Amplifier System, Measurements Group, Instruction Manual (included).
- Ref. 5 Banas, G. and Simsir, C. Strain Gauges: Theory, Instrumentation and Installation, Second Edition, September 2002.
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- Ref. 8 <http://www.endevco.com/main/products-by-category/accelerometers-vibration.php>
- Ref. 9 <http://www.endevco.com/main/literature/tutorials.html>
- Ref. 10 <http://www.cee.uiuc.edu/classes/cee398kuc>
- Ref. 11 <http://kelim.jct.ac.il/electronics/webprogs/resistor/resistor.html>

# Reference 1

# INSTRUCTION MANUAL

FOR ENDEVCO®  
PIEZORESISTIVE ACCELEROMETERS



# INSTRUCTION MANUAL

## FOR ENDEVCO® PIEZORESISTIVE ACCELEROMETERS

NO. 121

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# INSTRUCTION MANUAL FOR ENDEVCO® PIEZORESISTIVE ACCELEROMETERS

## 1.0 INTRODUCTION

### 1.1 General Applications

A piezoresistive accelerometer is a transducer whose electrical output is proportional to the acceleration motion of its base. Although its application is similar to that of a strain gage accelerometer, the piezoresistive accelerometer offers the advantages of lighter weight, smaller size, higher output, and higher frequency response when compared to the resistance-wire strain-gage accelerometer.

Unlike the piezoelectric accelerometer, the piezoresistive accelerometer is useful for measuring steady state acceleration (zero frequency). The zero frequency response is essential in making accurate long duration shock motion measurements.

With their inherently high gage factors, 10 to over 100 times that of the conventional wire gages, piezoresistive type accelerometers provide a relatively large output signal. Because of their low output impedance, the accelerometers can operate directly into oscilloscopes, digital voltmeters, tape recorders, and computers without intervening electronics or amplification.

### 1.2 Identification

ENDEVCO® piezoresistive accelerometers are normally identified by a two-part model number. The first part consists of four digits representing the basic design and the second part indicates the rated acceleration level for the transducer.

For example, in the Part Number 2261A-2500, the 2261A identifies an accelerometer utilizing specific piezoresistive elements in a four-arm bridge mounted in a unique configuration. The -2500 indicates a full scale range of -2500 g to +2500 g.

A letter "C" after the basic part number identifies an accelerometer with two active arms connected in one half of a bridge circuit. The bridge is completed internally with two fixed, stable resistors. This configuration allows the accelerometer and readout equipment to be passively calibrated by shunt resistors. See Section 8.10.1.

An accelerometer which includes minor modifications of a standard product is designated with the basic model number followed by the letter M and a number. Characteristics of these accelerometers are listed in an "AE" Specification identified with the model number.

## 2.0 THEORY OF OPERATION

### 2.1 Accelerometers

An accelerometer is a transducer that produces an electrical output proportional to the acceleration motion of its base. The frequency of motion to be measured is lower than the resonance frequency of the accelerometer and the electrical output is essentially independent of frequency below one-fifth the resonance frequency. A single-degree-of-freedom accelerometer can be represented by a mass element connected to a spring and mounted in a case. The case is attached to the moving part whose motion is to be measured.

When the accelerometer is in motion, the inertial force on the mass element due to the acceleration results in a deformation of the sensing elements. This deformation changes the resistance of the elements and the electrical output of the accelerometer. In a well designed accelerometer the deformation and electrical output are directly proportional to acceleration over a wide range of frequencies.

The sensing elements and constraining parts in an accelerometer possess such a small amount of damping due to internal friction that it may be disregarded. Significant amounts of damping may be introduced artificially by filling the accelerometer with oil, or arranging the geometry to provide for air damping.

### 2.2 Sensing Elements

The piezoresistive strain gage element is a solid state silicon resistor which changes electrical resistance in proportion to applied mechanical stress. Since it is a single crystal it is not only strong but virtually free of mechanical hysteresis with inherent good linearity. The significant characteristic of this element is that its change of resistance is large relative to its change in length. It has a gage factor many times greater than the typical wire strain gage. Gage factors range typically from 50 to 200.

$$\text{Gage Factor } K = \frac{\Delta R/R}{\Delta L/L} \quad (2-1)$$

Where:

$\Delta R$  = change in resistance

$R$  = initial resistance

$\Delta L$  = change in length of element

$L$  = initial length of element

THE BRIDGE IS A "SECONDARY" TRANSDUCER

2.3 Sensing Bridge

Most piezoresistive accelerometers utilize four piezoresistive elements connected electrically in a Wheatstone Bridge in a way similar to other resistance strain gage circuits. See Figure 2-1. A regulated voltage excitation ( $E_x$ ) is applied to the bridge input, and the bridge voltage output ( $E_o$ ) varies with the acceleration applied.

If an accelerometer uses only two piezoresistive elements (half-bridge), two stable resistors must be connected to complete the bridge. Inactive ballast resistors, such as  $R_c$  in Figure 2-1, are usually included to compensate for thermal shifts in sensitivity.

2.4 Accelerometer Design

2.4.1 Sensing Elements

ENDEVCO® piezoresistive transducers utilize two or four piezoresistive elements in a configuration designed to sense the measurand. A typical ENDEVCO® strain element is shown in Figure 2-2 (U.S. Pat. No. 3,351,880).

2.4.2 Pixie Beam Transducer

In the ENDEVCO PIXIE® Transducer, Figure 2-3, the strain gage element is mounted across a slit in a small beam. Deflections of the beam cause this element to change length, resulting in a variation in the resistance of the element in some relation to the deflection. If a current is passed through the element, this current is modulated by the changing resistance. If the deflection is a result of a force caused by acceleration of the beam and its support, the change in resistance is proportional to acceleration.

2.4.3 Cantilever Design  
 Figure 2-4a illustrates the design of a typical piezoresistive accelerometer utilizing a cantilever mass. For any axial acceleration, two gage elements operate in compression and two in tension. The stress and change in resistance of the elements in tension are approximately equal to the stress on the elements in compression. All four elements are connected to form a four-arm balanced bridge as shown in Figure 2-4b. Proper electrical orientation of the gages (as illustrated) results in an output voltage proportional to applied acceleration.

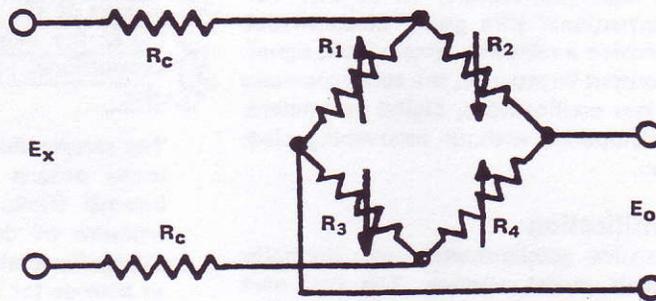


Figure 2-1. Typical connections within a piezoresistive transducer.

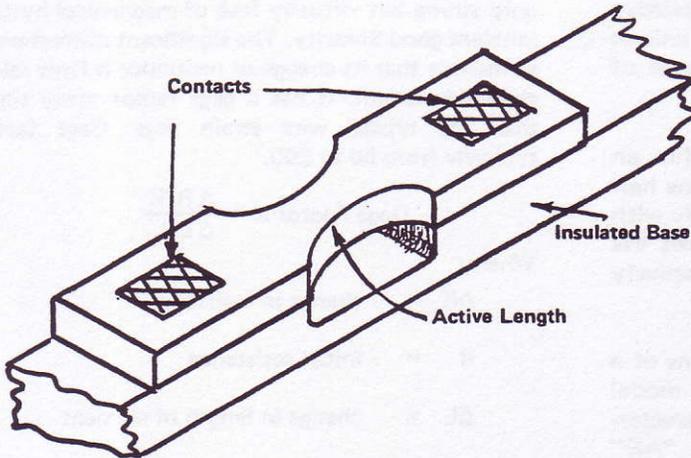


Figure 2-2. ENDEVCO® P-9 strain gage.

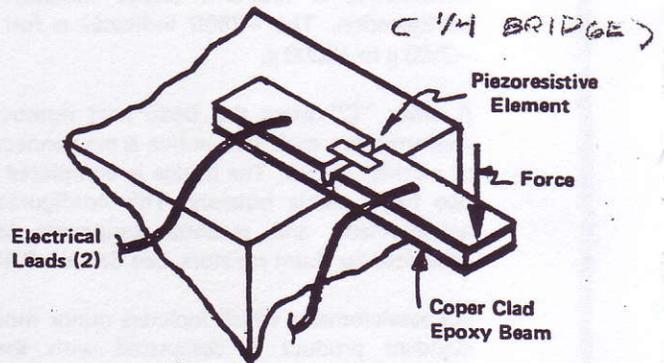


Figure 2-3. Pixie beam transducer

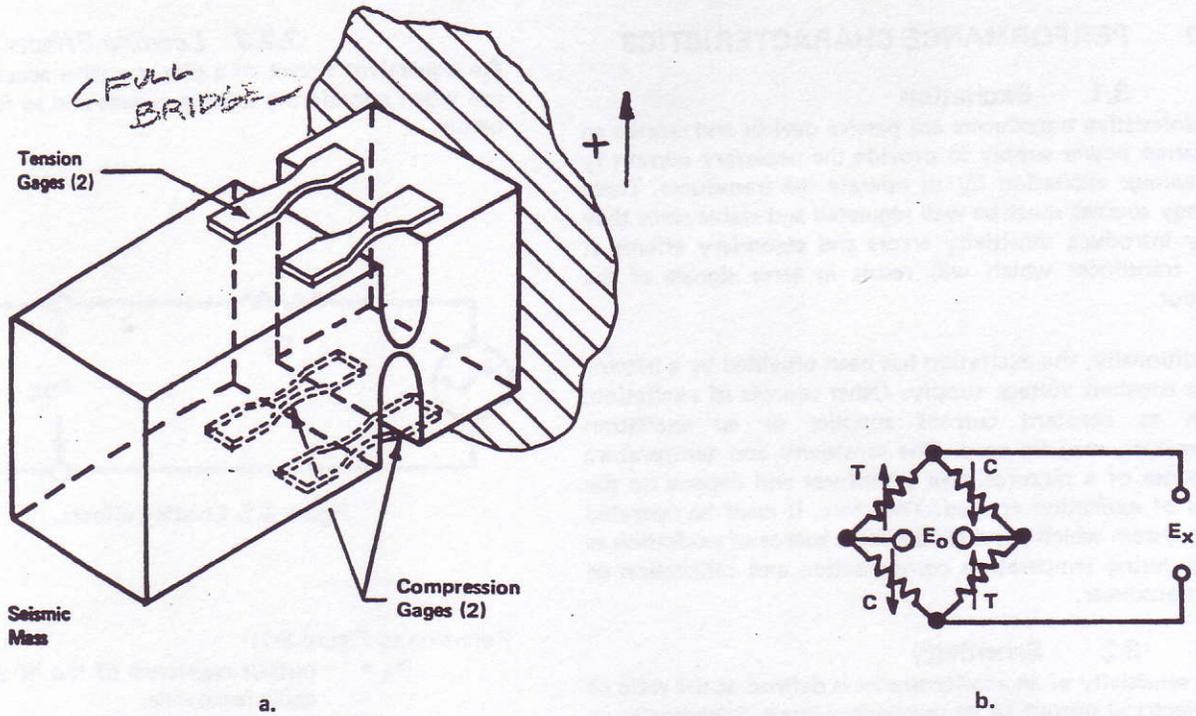


Figure 2-4 Typical piezoresistive accelerometer

#### 2.4.4 Column Design

An accelerometer design permitting the measurement of very high shock acceleration is illustrated in Figure 2-5. The short, stiff column has a very high resonance frequency, allowing the measurement of very short acceleration pulses. The horizontally oriented gages not only provide temperature compensation in the bridge, but also take advantage of Poisson's Ratio, in that they sense the transverse dimensional change that accompanies a longitudinal strain. The gages are connected to form a four-arm, balanced bridge similar to that shown in Figure 2-4b.

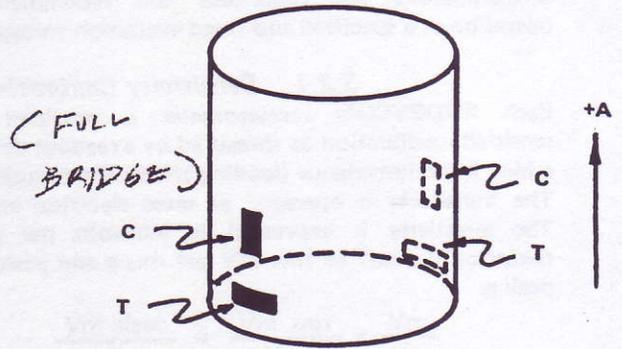


Figure 2-5. Column design.

### 3.0 PERFORMANCE CHARACTERISTICS

#### 3.1 Excitation

Piezoresistive transducers are passive devices and require an external power supply to provide the necessary current  $I_x$  or voltage excitation  $E_x$  to operate the transducer. These energy sources must be well regulated and stable since they may introduce sensitivity errors and secondary effects at the transducer which will result in error signals at the output.

Traditionally, the excitation has been provided by a battery or a constant voltage supply. Other sources of excitation, such as constant current supplies or ac excitation generators, may be used. The sensitivity and temperature response of a piezoresistive transducer will depend on the kind of excitation applied. Therefore, it must be operated in a system which provides the same source of excitation as used during temperature compensation and calibration of the transducer.

#### 3.2 Sensitivity

The sensitivity of an accelerometer is defined as the ratio of its electrical output to its mechanical input. Specifically, in the case of piezoresistive accelerometers, it is expressed as voltage per unit of acceleration at the rated excitation. Units of mV/g are used because ENDEVCO® accelerometers are calibrated and recommended for operation at a specified and fixed excitation voltage.

##### 3.2.1 Sensitivity Calibration

Each ENDEVCO® accelerometer is provided with a sensitivity calibration as measured by a readout device with a high input impedance (loading effects are discussed later). The transducer is operated at rated electrical excitation. The sensitivity is expressed in millivolts per g and is numerically equal to rms mV per rms g and peak mV per peak g.

$$\frac{\text{mV}}{\text{g}} = \frac{\text{rms mV}}{\text{rms g}} = \frac{\text{peak mV}}{\text{peak g}} \quad (3-1)$$

##### 3.2.2 Polarity

For many shock and vibration measurements, it is necessary to know the polarity of the system output signal relative to the direction of motion of the transducer. To determine this, the polarity of the accelerometer output and the input-output phase relationship of the amplifier must be known.

Unless otherwise specified, all ENDEVCO® accelerometers produce a positive output signal when the transducer is oriented with its base down and the direction of the acceleration motion is upward. Polarity of the excitation voltage must be applied in accordance with the specifications on individual transducer data sheets. ENDEVCO® maintains standard strain gage practice with color codes of red for positive excitation, black for negative excitation, green for positive output signal, and white for negative output signal.

#### 3.2.3 Loading Effects

An equivalent circuit of a piezoresistive accelerometer, for use when considering loading effects and so forth, is shown below.

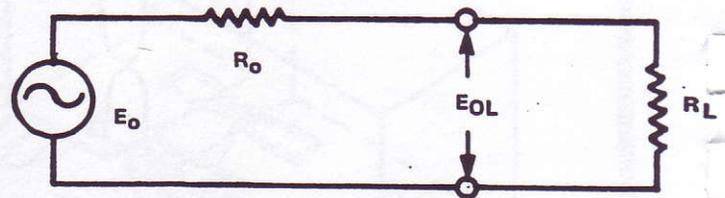


Figure 3-1. Loading effects.

Referring to Figure 3-1:

$R_o$  = output resistance of the bridge, including cable resistance.

$E_o$  = sensitivity into an infinite load

$E_{OL}$  = loaded output sensitivity

$R_L$  = load resistance

Using the equivalent circuit above and the output resistance supplied on the calibration card, the effect of loading may be directly calculated:

$$E_{OL} = E_o \left( \frac{R_L}{R_o + R_L} \right) \quad (3-2)$$

Because the resistance of the strain gage elements varies with temperature, output resistance must be measured at the operating temperature.

##### 3.2.4 Effect of Cable on Sensitivity

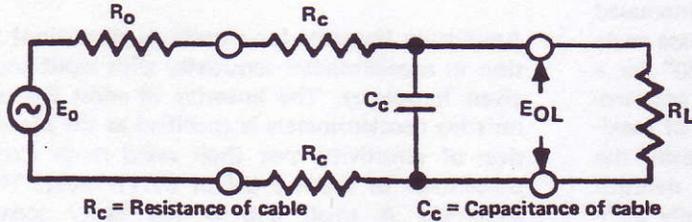
Each standard ENDEVCO® strain gage accelerometer is supplied with a specified length of cable. When utilizing long cables in a particular application, two effects must be noted:

The first effect is the signal attenuation resulting from line resistance. This attenuation may readily be calculated from the relation:

$$E_{OL} = E_o \left( \frac{R_L}{R_o + R_L + 2R_c} \right) \quad (3-3)$$

where the terms are as defined in Section 3.2.3, and  $R_c$  is the resistance of one conductor between transducer and load.

The second effect is the RC filtering which may be present in the shielded instrument leads. The stray and distributed capacitances present in the structure and cable of the accelerometer, alone, are such that any filtering effect is negligible to frequencies well beyond the usable range of the instrument. However, when long leads are connected between transducer and readout equipment, the frequency response at higher frequencies may be significantly affected.



$R_c$  = Resistance of cable  
 $C_c$  = Capacitance of cable  
 Figure 3-2. Simplified circuit with long cable.

Because the resistance and capacitance is actually distributed along the cable, the circuit of Figure 3-2 only approximates the effect of long wires. It is suggested that each 1000 feet of cable be considered as a separate RC network. Terminating a long cable with a load equal to the characteristic impedance of the cable will usually improve system high frequency response. For precise measurements, line filtering action must be determined experimentally as part of the system calibration.

### 3.2.5 Warmup Time

The dc or ac excitation voltage across the piezoresistive elements causes a finite current to flow through each element. The  $I^2R$  heating results in an increase in temperature of the elements slightly above ambient which increases the resistance of the elements. Differentials in this effect may cause the output voltage to vary slightly with time until the temperature is stabilized. It is, therefore, recommended that resistance measurements or vibration data not be taken until at least one minute after excitation voltage is applied to allow the resistance of all elements and temperature gradients to stabilize.

## 3.3 Frequency Response

### 3.3.1 Low Frequency Response

Piezoresistive accelerometers are essentially single-degree of-freedom systems. The use of a direct-current excited Wheatstone bridge allows the transducer to measure accelerations from steady state (dc) to relatively high frequencies. As the electrical signal generating network is essentially resistive, the frequency response at the transducer is unaffected by lead length and signal conditioning equipment impedances. As noted previously, care must be taken in the selection of cable, cable length and signal conditioning equipment.

### 3.3.2 High Frequency Response

The high frequency response of a piezoresistive accelerometer is a function of its mechanical characteristics. A piezoresistive accelerometer can be represented as a

single-degree-of-freedom spring-mass system, the response of which is shown in Figure 3-3a as a function of frequency.

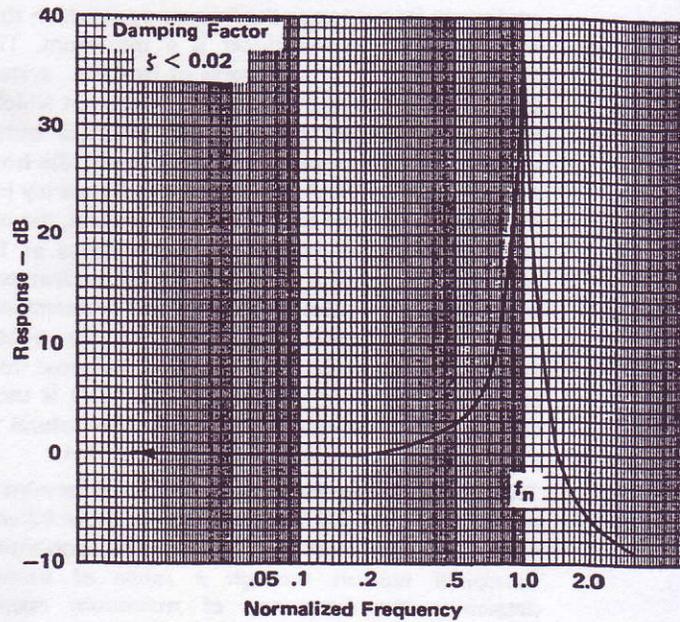


Figure 3-3 a

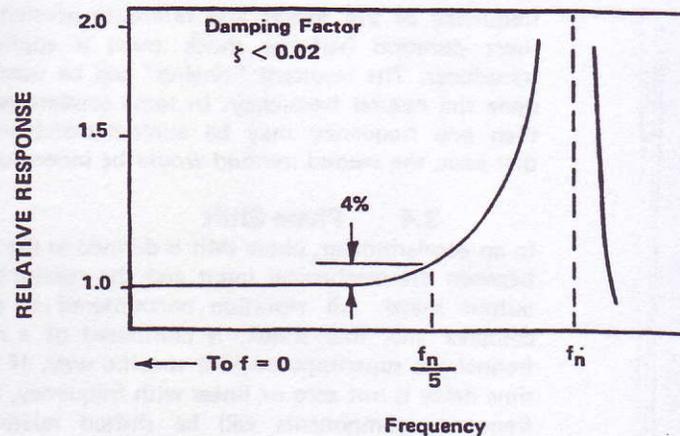


Figure 3-3 b

Response of a single-degree-of-freedom spring-mass transducer when the case is undergoing sinusoidal acceleration.

For the accelerometer, this curve can be considered as showing the variation in sensitivity of the transducer with frequency. The response curve Figure 3-3b shows that at  $1/5$  the resonance frequency, the response of the system is 1.04. This means that the sensitivity of the accelerometer is 4% higher at that frequency than at the lower frequencies. For this reason, the "flat" accelerometer frequency range should be considered limited to  $1/5$  the resonance frequency.

### 3.3.3 Resonance Frequency

The American National Standards Institute defines resonance frequency as the frequency at which the response (sensitivity) of a transducer is a maximum. The natural frequency of a single-degree-of-freedom system is the lowest frequency of sinusoidal excitation at which the mass element in the transducer (and electrical output of an accelerometer) lags behind the motion of the housing by a phase angle of  $90^\circ$ . As the excitation frequency is increased through the natural frequency and beyond, the phase angle continues through  $90^\circ$  to  $180^\circ$  and stays at  $180^\circ$  for a reasonable range of frequencies. For an undamped accelerometer (damping ratio  $\zeta \approx 0.1$ ), the frequencies of maximum sensitivity and  $90^\circ$  phase shift are practically the same. The frequency of maximum response for damped accelerometers ( $\zeta =$  approximately 0.7) is usually difficult to measure and, therefore, only the natural frequency at  $90^\circ$  phase shift is measured and specified.

Two methods are currently used to determine the resonance frequency of an undamped piezoresistive accelerometer. The first method is to drive the accelerometer with sinusoidal motion through a range of frequencies to determine the frequency of maximum response. The second method is employed when the resonance frequency of the accelerometer is higher than the resonance frequency of the shaker and reference accelerometer. A short duration half-sine shock pulse is applied to the transducer. The resultant "ringing" can be used to determine the natural frequency. In some accelerometers more than one frequency may be excited simultaneously. In that case, the second method would be inconclusive.

### 3.4 Phase Shift

In an accelerometer, phase shift is defined as the time delay between the mechanical input and the resulting electrical output signal. All vibration encountered in practice is complex and, like shock, is composed of a number of frequencies superimposed in a specific way. If transducer time delay is not zero or linear with frequency, the various frequency components will be shifted relative to one another and the resultant electrical output will be a distortion of the mechanical input.

To avoid distortion, transducer phase shift (over the useful frequency range) must be either constant ( $0^\circ$  or  $180^\circ$ ) or be linear with frequency. A piezoresistive accelerometer, with virtually no damping, has  $0^\circ$  phase shift to very near its resonance frequency, which is well beyond its useful frequency range. Although linear phase shift can be attained with a damping ratio of about 0.7, damping usually varies with temperature, resulting in a small amount of distortion for any but ambient temperature use. See Figure 4.3.

### 3.5 Dynamic Range and Linearity

The dynamic range (full scale) of an accelerometer is specified as the upper and lower limits of acceleration over which the accelerometer is intended to measure. The sensitivity of a accelerometer remains essentially constant over its operating range.

Although a piezoresistive accelerometer is theoretically linear down to zero g, a practical lower limit is imposed by the noise level of matching electronics. For very low vibration levels, an accelerometer having a high sensitivity should be selected to improve the signal-to-noise ratio. The maximum limits of range are established as a fraction of the maximum acceleration level that the unit will withstand without damage.

Amplitude linearity (or amplitude distortion) is the variation in accelerometer sensitivity with input amplitude at a given frequency. The linearity of most Endevco® piezoresistive accelerometers is specified as the maximum deviation of sensitivity over their rated range expressed as a percentage of reading (ANSI S2.11-1969). The effect of hysteresis is small and is not easily separated from linearity and, therefore, the two effects are combined into one characteristic specification.

In accordance with ISA Standard S37.1 (1969), the linearity of a transducer is the closeness of its calibration curve of output versus input to a specified straight line. The linearity of some Endevco accelerometers is specified as the maximum deviation of the calibration curve from a straight line between the outputs at the upper and lower limits of their range (end points). In this case the linearity is expressed in terms of percentage of full scale (end points of the range).

In addition to the linearity specification, Endevco® accelerometers are given environmental "acceleration limits" of maximum allowable vibration and shock input. These limits should not be exceeded since damage will most likely result from overranging.

In accelerometers designed for high shock motions, the moving element can be designed so that excessive stresses are avoided even at the highest shock motions normally encountered. However, for high sensitivity piezoresistive accelerometers designed for use at moderately low accelerations, the stresses are minimized by having patented built-in stops. These stops limit the motion of the mass element to deflections and stresses corresponding to accelerations slightly greater than the rated range of the transducer.

**CAUTION:** Although they are rugged instruments, accelerometers must be protected from extreme accelerations. An acceleration that exceeds the accelerometer's specified *environmental* limit is almost certain to damage the accelerometer. Excessive accelerations and physical damage may occur when an accelerometer is dropped accidentally to a hard surface. Tests at Endevco have shown that accelerations of 3000 to 5000 g will result from a free-fall drop of 3 to 4 feet to a typical laboratory floor, and 1000 g for a short drop to a hard bench top.

Overranging is a common cause of breakage. When the high frequency response of the associated instrumentation is limited, a narrow, high level shock pulse may not be observed or recorded. Thus an accelerometer may be subjected to damaging shock while readout equipment — due to its limited frequency response — indicates an inaccurate lower magnitude of acceleration.

### 3.6 Input and Output Resistance

The input and output resistances of piezoresistive accelerometers are specified on the individual data sheets. For an equal-arm four-element Wheatstone bridge, the input and output impedances are equal. However, temperature compensating and zero balance resistors may be internally connected in series with the sensing elements. These additional resistors will usually result in slightly differing input and output resistance. Many of the full-bridge transducers have series resistors for thermal sensitivity compensation located external to the bridge so that input resistance is about 1.5 times the output value.

### 3.7 Transverse Sensitivity

For any piezoresistive accelerometer there exists one axis which provides maximum response for an input acceleration. The electrical output along this axis for a 1 g input is  $Q_{max}$ , the maximum sensitivity. The sensitivity  $Q_{\theta}$  along any other axis (inclined at an angle  $\theta$  from the axis of  $Q_{max}$ ) is  $Q_{max} \cos \theta$ . In a perfect transducer, the vertical (y axis in Figure 3-4) axis and the axis of  $Q_{max}$  would coincide. In practical accelerometers, due to manufacturing tolerances and system gage element variations, they do not.

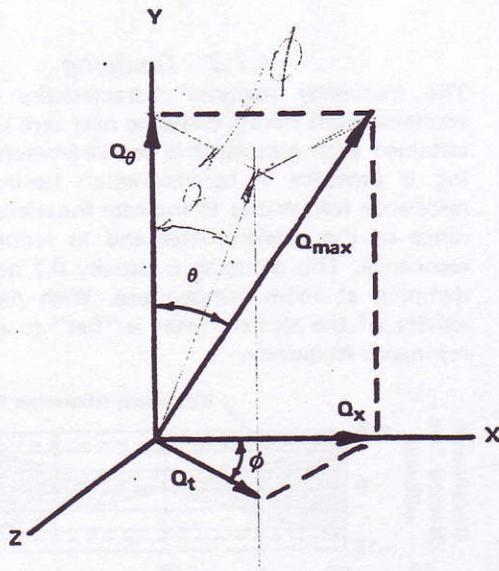


Figure 3-4. Transverse sensitivity of a piezoresistive accelerometer:  $Q_{\theta}$  is the basic transducer sensitivity and  $Q_t/Q_{\theta}$  is the transverse sensitivity, usually expressed as a percentage.

As a result, these transducers characteristically exhibit a basic sensitivity of  $Q_{\theta} = Q_{max} \cos \theta$  and a (maximum) transverse output of  $Q_T = Q_x = Q_{max} \sin \theta$ . Maximum transverse sensitivity is expressed as a percentage of the basic sensitivity and thus is defined as:

$$\text{Maximum Transverse Sensitivity} = \frac{Q_T}{Q_{\theta}} \times 100 = \tan \theta \times 100\% \quad (3-4)$$

For motion in the transverse (xz) plane along any other axis (inclined at an angle  $\phi$  from the X axis) the transverse sensitivity is  $Q_t = Q_T \cos \phi$ . Thus, a more general expression becomes:

$$\text{Transverse Sensitivity} = \frac{Q_t}{Q_{\theta}} \times 100 = \tan \theta \cos \phi \times 100\% \quad (3-5)$$

Equation 3-5 is plotted in Figure 3-5.

In most ENDEVCO® accelerometers, the transverse sensitivity  $Q_t$  varies from a maximum of 3% to a minimum of nearly zero (See Figure 3-5). Some models are available with a maximum transverse sensitivity of 2% or even 1% on special order. See individual data sheets on specific models.

A typical transverse sensitivity plot is shown in Figure 3-5, below.

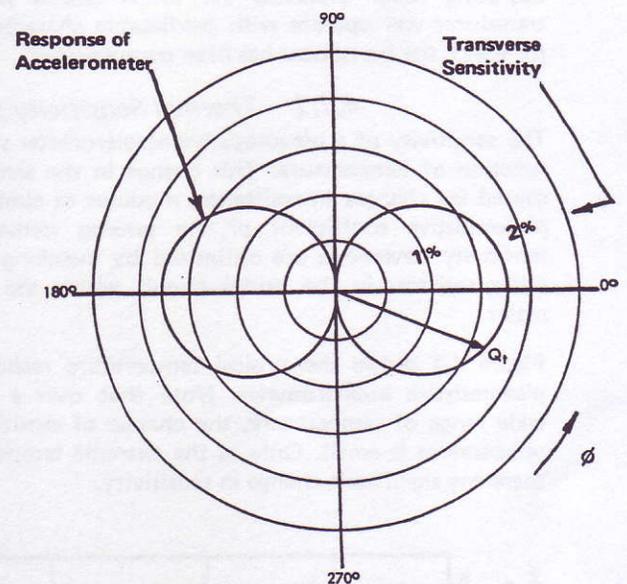


Figure 3-5. Plot of accelerometer output, expressed as a percentage of axial sensitivity, as a function of the direction of transverse motion in the plane of the base of the accelerometer.

### 3.8 Zero Measurand Output (Zero Balance)

Although the resistance elements in the bridge of a piezoresistive accelerometer are closely matched during manufacture, slight differences in resistance will exist. The differences result in a small offset or residual dc voltage at the output of the bridge. This residual voltage is called Zero Measurand Output. Circuitry within associated signal conditioning instruments may provide compensation or adjustment of the electrical zero. A suggested circuit is shown in Figure 5-6.

Zero Measurand Output is expressed in millivolts at the output of the transducer under room conditions with full rated excitation but no motion applied to the accelerometer.

### 3.9 Insulation

The case of the accelerometer acts as a mechanical and electrical shield for the sensing elements. It is normally electrically insulated from the elements but connected to the shield of the cable. If the case is grounded at the structure, the shield of the connecting cable may be left floating. When connecting the cable shield at the end away from the transducer, care must be taken to prevent ground loops.

### 3.10 Strain Sensitivity

The strain sensitivity of piezoresistive accelerometers is very small and may be disregarded in almost all applications. The magnitude of the output due to base or case strain is usually less than the normal noise level of the transducer and associated electronics.

## 4.0 NON-VIBRATION ENVIRONMENTS

### 4.1 Temperature

The operating and environmental temperature ranges for piezoresistive accelerometers are specified on individual data sheets. The environmental range indicates the limits within which the transducer will not be damaged. The operating range indicates the limits within which the transducer will operate with predictable characteristics or for which the transducer has been compensated.

#### 4.1.1 Thermal Sensitivity Shift

The sensitivity of a piezoresistive accelerometer varies as a function of temperature. This change in the sensitivity is caused by changes in resistance, modulus of elasticity and piezoresistive coefficient of the sensing elements. The sensitivity deviations are optimized by installing compensating resistors in the bridge circuit within the accelerometer.

Figure 4-1 shows the typical temperature response of a piezoresistive accelerometer. Note that over a relatively wide range of temperature, the change of sensitivity with temperature is small. Only at the extreme temperatures is there any significant change in sensitivity.

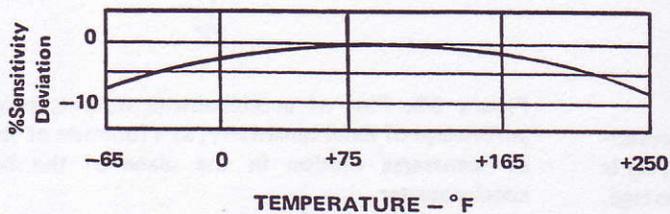


Figure 4-1.

#### 4.1.2 Thermal Zero Shift

Because of small differences in resistance change of the sensing elements as a function of temperature, the bridge may become slightly unbalanced when subjected to temperature changes. This unbalance produces changes in the dc voltage output of the bridge. Transducers are compensated during manufacture to minimize the change in dc voltage output (zero balance) of the accelerometer with temperature. Adjustment of external balancing circuitry should not be necessary in most applications.

#### 4.1.3 Damping

The frequency response characteristics of piezoresistive accelerometers having damping near zero are similar to that obtained with piezoelectric accelerometers. Viscous damping is provided in accelerometers having relatively low resonance frequencies to increase the useful high frequency range of the accelerometer and to reduce the output at resonance. This damping is usually 0.7 nominal of critical damping at room temperature. With damping, the sensitivity of the accelerometer is "flat" to at least 1/3 of its resonance frequency.

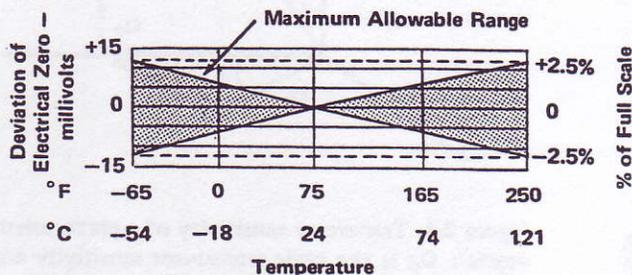


Figure 4-2. Zero shift of a compensated full-bridge accelerometer, Model 2260A.

The piezoresistive accelerometer using viscous damping is intended for use in a limited temperature range, usually 0°F to +200°F. At the high temperatures the viscosity of the oil decreases, resulting in low damping; and at low temperatures the viscosity increases, which causes high damping. Accordingly, the frequency response characteristics change as a function of temperature, as illustrated in Figure 4-3, in accordance with the relationship.

$$\text{Normalized Sensitivity} = \frac{1}{\sqrt{[1 - \beta^2] + [2\zeta\beta]^2}} \quad (4-1)$$

Where:

$$\beta = f/f_n \text{ Frequency Ratio}$$

$$\zeta = c/c_c \text{ Damping Ratio}$$

The frequency response of a piezoresistive accelerometer with oil damping is shown in Figure 4-3 below.

At 200°F the damping is near 0.2; and at 75°F the damping is about 0.7. For accelerometers using oil damping, it is desirable to perform frequency response calibrations throughout the operating temperature range if the accelerometer is normally used at temperature extremes.

As the damping ratio varies with temperature, the phase angle between the applied acceleration and electrical output will vary in accordance with the curves in Figure 4-4. Note that with 0.7 damping ratio the phase angle varies linearly with frequency, a desirable characteristic in shock accelerometers. Low air damping ( $\zeta = 0.01$  to 0.05) is provided in some ENDEVCO® accelerometers only to limit the maximum resonance amplitude.

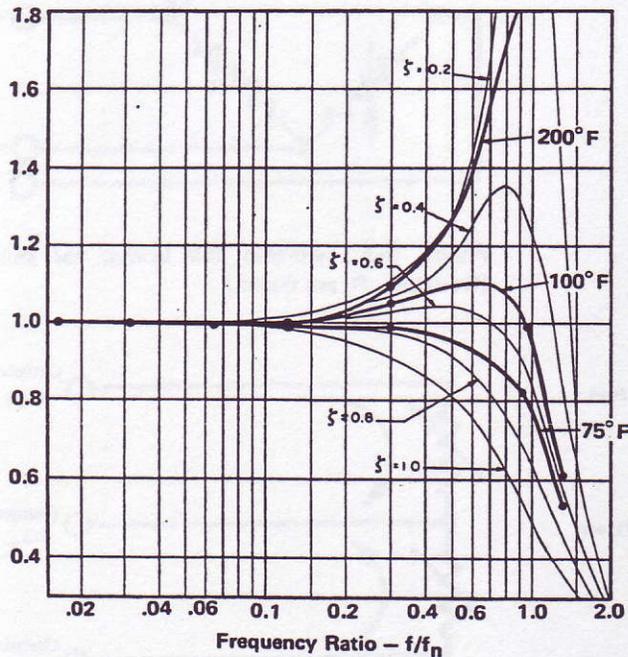


Figure 4-3. Frequency response ENDEVCO® model 2262 accelerometer.

### 4.2 Sealing

All ENDEVCO® accelerometers are sealed and will operate under normal conditions of humidity, salt spray, sand, dust and altitude. An epoxy seal has proven satisfactory for most environments. A true hermetic seal involves sealing by either fusion of glass to metal, welding, or soldering.

### 4.3 Acoustic Response

ENDEVCO® piezoresistive accelerometers exhibit negligible output under high acoustic pressure fields. There are no direct mechanical connections from the accelerometer case wall to the sensing elements. The accelerometer itself may respond mechanically to acoustically induced acceleration. It will respond to the pressure induced motion of the structure on which it is mounted. The resonance frequency ( $f_n$ ) of the accelerometer must be at least three times the highest acoustic frequency expected.

### 4.4 RF and Magnetic Fields

Normally encountered magnetic and RF fields have negligible effect on the piezoresistive strain gage elements. However, adequate isolation must be provided against ground loops and stray signal pickup. The Model 2986E Insulated Mounting Stud can be used for electrical isolation of the accelerometer case from ground. High intensity RF or magnetic fields may require special shielding of the accelerometer, cable, and amplifier.

When a transducer and its connecting wires are subjected to an intense magnetic field, such as the field of a nuclear blast, the transient error signal generated in the transducer and wires can be minimized by using a dual, opposed, constant current power supply. Induced currents or voltages in such a system tend to cancel at the transducer resulting only in small error signals at the output. The transducers must be specifically designed and built for this application. See Endevco Technical Paper No. 236.

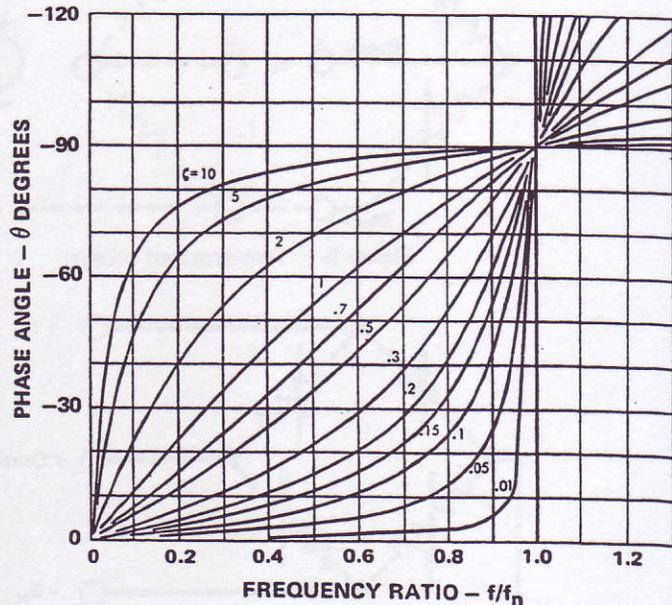


Figure 4-4. Phase angle response of a seismic accelerometer.

### 4.5 Nuclear Radiation

Complete information about the reaction of Piezite® elements to nuclear radiation is not yet available. The bulk silicon elements P-9 and P-11 utilized in standard ENDEVCO® piezoresistive transducers, have a relatively high resistivity. It is expected that these elements would show considerable change in resistance in a high fluence nuclear field.

Some accelerometers are specifically designed for operation in a nuclear field, with no organic materials or heavy elements used in their construction. These accelerometers have been operated in nuclear radiation flux as high as  $10^{15}$  neutrons/cm<sup>2</sup> without deterioration. It has also been reported that some accelerometers have been subjected to as high as  $10^8$  ergs/gram (C) of gamma radiation without damage.

The ENDEVCO® Model 2266 Series of piezoresistive accelerometers with Piezite® P-12 elements are small

lightweight accelerometers specifically designed for nuclear applications. They are available in a wide range of acceleration ranges. These are normally half-bridge transducers with bridge completion resistors located externally, in the signal conditioning equipment. Suffix letters on this series identify specific useful characteristics.

- Suffix Q – Oil damped transducer
- Suffix R – Bridge completion resistors mounted in transducer case.
- Suffix Z – Zero output, no acceleration output, used as dummy.

Inquiries are invited on transducers for specific nuclear applications. A complete description of the operating environment and test requirements should be forwarded to Endevco for review.

## 5.0 APPLICATION INFORMATION

### 5.1 Connection Diagrams

ENDEVCO® piezoresistive accelerometers are supplied with several different circuit configurations. Some of these are illustrated below.

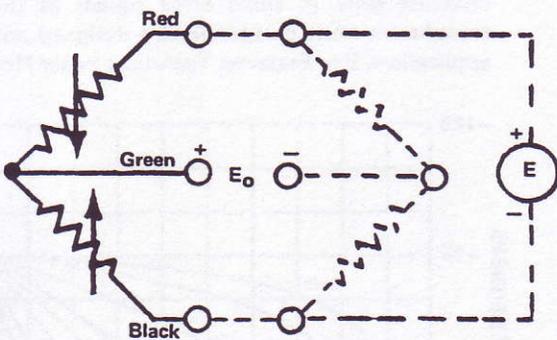


Figure 5-1. Two-arm half bridge.

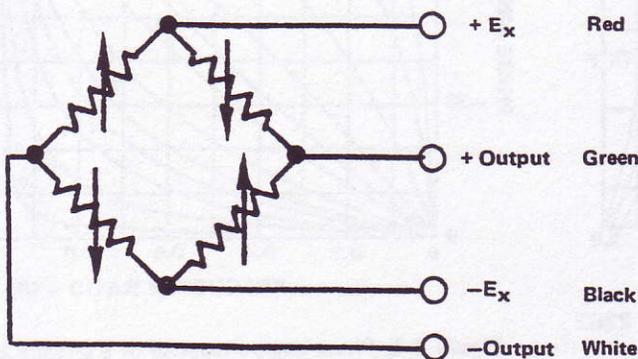


Figure 5-2. Four-arm full bridge.

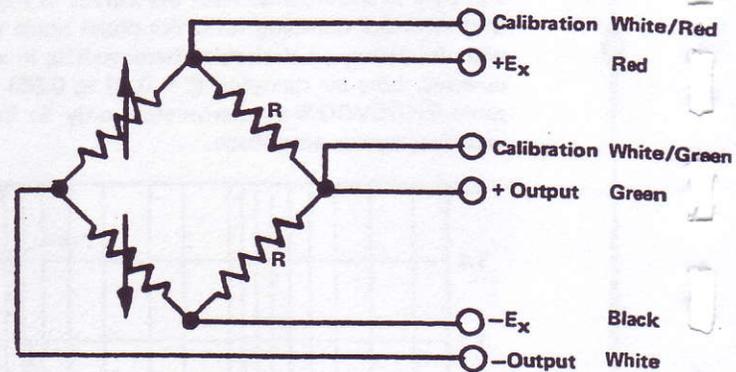


Figure 5-3. Two-arm full bridge for shunt calibration. (Resistors, R, are fixed.)

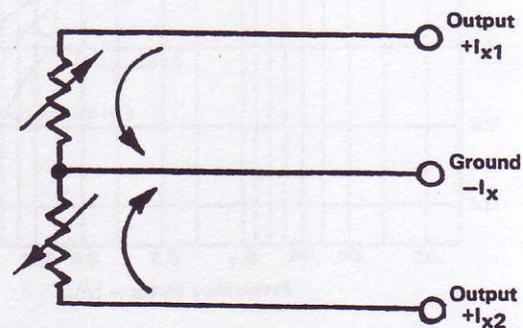


Figure 5-4. Two-arm half bridge with opposed constant current excitation.

## 5.2 Mounting Techniques

For an accelerometer to generate accurate and useful data, it must be properly coupled to the equipment under investigation. The method of attachment must not introduce any distortion. This requires that the accelerometer mounting be rigid over the frequency range of interest. In practice, many mounting methods are suitable for a wide variety of applications and depend on the practical requirements of the test system. For assistance in unusual situations, contact our Marketing Department.

A solid stud is the best means for mounting an accelerometer operating over its rated range of temperature. Cementing techniques will provide the same frequency response at room temperature as a solid stud. For other methods, the effect on an accelerometer is to reduce the mounted resonance frequency.

Attempts to use a piezoresistive accelerometer as a hand-held "probe" will result in severely limited accuracy. Indications obtained in this way should be understood to be only approximate and are limited to low frequencies.

### 5.2.1 Standard Stud Mounting

When possible, the best method is to mount the accelerometer with a stud (Model 2981-3 furnished with most accelerometers) so that the entire base of the accelerometer is in good contact with the test object. Care should be taken to ensure a flush mate to a smooth flat surface. The mounting hole must be at a right angle to the surface. Use 16 to 20 inch-pounds mounting torque for 10-32 studs. For other thread sizes, use the recommended mounting torque, shown on the transducer data sheet. Ordinary machine screws are to be avoided since without a flange or shoulder, it is possible to "bottom" the screw in the accelerometer, thereby changing its dynamic response.

It is recommended that the mounting surface and tapped hole conform to the following specifications. These are considered to be easily achieved by following good machine shop techniques:

Surface Flatness:	.0003" TIR
Surface Roughness:	32 ✓
Perpendicularity of Hole:	±6 minutes
Tap Class:	2

For all studs, the use of a drop of light oil between the mating surfaces is recommended when frequencies are above 5000 Hz or shock durations are correspondingly short.

Binding, seizing, or galling of a mounting stud within a test fixture's internal thread may cause some difficulty in removing the stud from the fixture. In the case of steel test

fixtures, a small amount of lubricating oil may be applied if this appears necessary. To prevent this with aluminum fixtures, the use of a thread lubricating, anti-seizing compound is recommended. This compound should be applied to the internal threads of the test fixture or the external threads of the stud, prior to mounting. It should be in contact with the threads only and not the mounting surface. This will ensure that the compound, which is sometimes gritty, does not adversely affect the high frequency response.

### 5.2.2 Insulated Mounting Studs

Insulated (electrically isolated) mounting studs available only from Endevco (U.S. Patent 2,972,006), provide insulation of the accelerometer case from structure ground, and they are particularly useful in preventing ground loops. ENDEVCO® insulated mounting studs are well proven and should be used when the accelerometer case and cable shield are connected to the power supply or instrumentation ground.

### 5.2.3 Cement Mounting

A series of cementing studs is available which permits accelerometer attachment to surfaces that cannot be drilled and tapped to accept normal, threaded studs. Use of these studs rather than cementing the transducer directly to the test specimen will prevent contaminating accelerometer mounting threads with adhesive. Removal of the accelerometer will also be facilitated.

Cements commonly used include Eastman 910 (Eastman-Kodak Company, Rochester, N.Y.) and Epon 828 (Shell Chemical Corporation, New York). Dental cements such as Grip (L.D. Caulk Company, Milford, Delaware) are useful when the mounting surface is irregular or when the transducer will be subjected to high humidity or immersion. Efficiency of this technique depends entirely on the adhesive used; thorough evaluation is recommended for the individual application.

Adhesive material must not be scraped or sanded off the accelerometer. Rough mounting surfaces can result in poor frequency response and/or an increase in transverse sensitivity. Appropriate solvents should be used to remove all traces of the adhesive. A popular solvent for Eastman 910 is N, N-Dimethylformamide which must be used with caution. See Tech Data No. A504.

When an accelerometer is mounted to a structure by means of pressure sensitive double-backed tape, its effective mounted resonance frequency will be lower than the resonance frequency determined with a solid mounting stud. It is recommended that such a mounting method be evaluated, particularly for measurement of vibration over a range greater than a few hundred hertz.

### 5.2.4 Fixtures

Fixtures may be used for either (1) mounting transducers to a test specimen, or (2) mounting a specimen to some source of input energy, such as a vibration shaker. Triaxial

mounting blocks, for example, are available to attach three accelerometers for measuring motion in each of three mutually perpendicular axes. In either case, the fixture, to be successful, must transmit the motion without distortion. In vibration testing, for example, fixtures originally designed for testing at low frequencies are improperly used for certain programs involving high frequencies. Many fixtures have resonance points which are below 2 kHz with high resonance amplitudes. This may result in severe under-or over-testing, with consequent high component failure rates or over-design.

In order to properly design a fixture, the exact nature of its use must be known — frequency range, g level and, of course, the mechanical specifications of the test object. Individual fixtures should be designed for each component or instrument to be tested above 500 Hz. A fixture that introduces spurious response into the test is not satisfactory. However, since it is impossible to design the ideal fixture, it is mandatory that its exact characteristics be known before it is put to use. Not only must the fixture be carefully designed, but it must be tested and the vibration plotted at several points on the fixture. The more complex the structure, the more points to plot.

### 5.2.5 Effects of Mounting

In some instances, the very act of performing a measurement affects the structure being measured and thus changes the nature of the data obtained. With piezoresistive accelerometers, this may occur for two reasons: (1) the fixture required to couple the accelerometer to a somewhat flexible structure may introduce local stiffening which changes structural response; and (2) the added mass of the transducer may change the system characteristics. Effects due to either cause can be reduced or eliminated by choosing an accelerometer as small and light as possible. ENDEVCO® Microminiature Accelerometers weigh only a few grams and are small enough to approach point loading in many cases.

For a simple spring-mass structure, the effect of adding a transducer is to reduce the system's resonance frequency. This amount of reduction can be calculated from the following equation:

$$\Delta f_n = f_n \left( 1 - \frac{m}{m_a + m} \right) \quad (5-1)$$

Where:  $f_n$  = natural frequency of the structure

$\Delta f_n$  = change in natural frequency

$m$  = structure mass

$m_a$  = added mass of the accelerometer

A general approach to loading effects is based on mechanical impedance\* considerations. For piezoresistive accelero-

meters which have nearly zero internal damping, the apparent weight (and mechanical impedance) of the accelerometer is constant at all frequencies from zero up to approximately 0.9 times its resonance frequency and must be equal in value to its physical weight. Within this range, the effect of the accelerometer on the structure motion is given by:

$$a_r = a_o \frac{m_s}{m_s + w_t} \quad (5-2)$$

Where:

$a_r$  = resultant acceleration

$a_o$  = acceleration without accelerometer attached

$w_t$  = weight of accelerometer

$m_s$  = apparent weight of structure

This statement of *Norton's Theorem* indicates that mounting an accelerometer will change the motion of a structure, particularly at resonance, if the apparent weight of the structure is not large compared to the total weight of the accelerometer. For most applications, the effect of the accelerometer on the structure motion is not significant.

### 5.3 Cables

The cable which connects a transducer to its matching electronics is an important part of the over-all measurement system. It must transmit the transducer signal to the associated signal conditioning equipment without distortion or introduction of noise. Cable must also not affect transducer or test specimen characteristics. Good transducer cables are as small, light and flexible as possible, considering their specific intended application. Stiff or massive cables can severely distort normal response, particularly with light, flexible specimens.

\* Mechanical impedance (Z) of a structure is defined as the force (F) applied to a point on the structure divided by the velocity (V) which results from the applied force. The defining equation is:

$$Z = \frac{F}{V}$$

All terms are vectors and the phase angle between the applied force and resultant velocity must also be known to completely define the impedance of that point in the structure.

In actual measurement of mechanical impedance, it is frequently more convenient to measure resultant acceleration, rather than velocity. When force and acceleration are known, the equation  $F = ma$  applies, from which is derived the defining equation:

$$m = \frac{F}{a}$$

When acceleration is measured in units of g's, m represents apparent weight. If acceleration is measured in terms of basic units (cm/sec<sup>2</sup>, in./sec<sup>2</sup>, etc.), m is apparent mass.

Each ENDEVCO® accelerometer is supplied with an integral multiconductor cable or a cable assembly with a connector. The length and type of cable is specified on the individual accelerometer data sheet. Alternate lengths of cable may be ordered by giving the basic cable model number followed by a dash number indicating the length in inches. For example, 3022A-36 is a 3022A Cable Assembly (see below) 36 inches in length.

The 3022A Cable Assembly includes a four-conductor, shielded cable with a silicone rubber jacket designed for high flexibility. Individual wires are color-coded in accordance with ISA recommended practices. The connector is a six-contact, female plug. Cable only may be ordered under ENDEVCO® Part No. 12334.

The 3023A Cable Assembly includes a six-conductor, shielded cable with a silicone rubber jacket designed for high flexibility. Individual wires are color-coded in accordance with ISA recommended practices. The connector is a six-contact female plug. Cable only may be ordered under ENDEVCO® Part No. 13075.

Color Code

Red	Pin 1 or A	+ Excitation
Green	Pin 2 or B	+ Output
White	Pin 3 or C	- Output
Black	Pin 4 or D	- Excitation
White-Red	Pin 5 or E	Shunt Calibrate
White-Green	Pin 6 or F	Shunt Calibrate
Shield	-	Connector Shell

To connect a 3022A or 3023A Cable Assembly to a transducer, line up the *white dots* on the cable and transducer connectors, push in the cable connector, then tighten the nut.

Although fairly rugged, these cables should be handled with care; they can be damaged if misused. They should not be stepped on, kinked, knotted, etc. When attaching (and detaching) cables, care must be taken not to bend the pins of the transducer connector. Cable connectors should be securely tightened, with careful use of pliers, if necessary, to prevent loosening during operation at high frequencies.

When possible, the cable should be tied down within two to three inches of the transducer connector. Long, unsupported length of cable may load the test specimen and lead to cable damage. Good housekeeping should be observed; excess cable should be neatly coiled and tied down. In humid applications, it is good practice to provide a drip loop at the accelerometer. It may also be advisable to seal the cable connector to prevent moisture from entering the cable assembly. If the connector insulation has become damp (or otherwise contaminated), it should be wiped dry with alcohol or a dry, clean cloth.

5.4 Filtering Out Thermal Zero Drift

Many piezoresistive transducers have enough signal to be used at one-tenth or less of rated range. The limiting factor is the zero drift with temperature which becomes significant when operating at a small fraction of full range. This temperature shift is, in most cases, essentially a dc phenomenon.

Many applications do not require dc information but do require frequency response down to 1/2 or 1/10 Hz. The solution suggested is a high pass filter into the electronic system so that the dc thermal phenomena is rejected but the low frequency vibration signal is preserved. The method used is a simple high pass RC filter with a cutoff frequency (3 dB down) of:

$$f_c = \frac{1}{2\pi RC} \tag{5-3}$$

Where:

- R = Shunt Resistance
- C = Series Capacitor

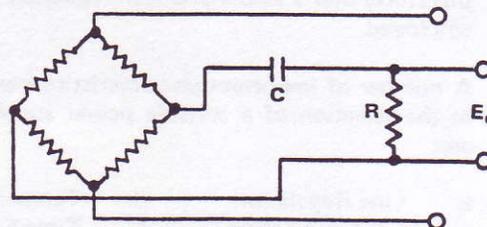


Figure 5-5. High pass filter.

When an amplifier cannot tolerate a high resistance on the input, the filter can be connected to the output of the amplifier using a suitable value of shunt resistance. The input resistance of the electronic equipment following the amplifier must be included in the calculation of the resistance.

5.5 Balancing Zero Measurand Output

Compensation or adjustment of the unbalanced output of a transducer (Zero Measurand Output) can easily be performed in the signal conditioning equipment. For a full-bridge transducer the balance potentiometer  $R_B$  is connected across the excitation terminals and a current limiting resistor connected between the wiper arm of the potentiometer and the bridge as shown in Figure 5-6a. For a half-bridge transducer a small, typically 100 ohm, balance potentiometer is connected between the bridge completion arms.

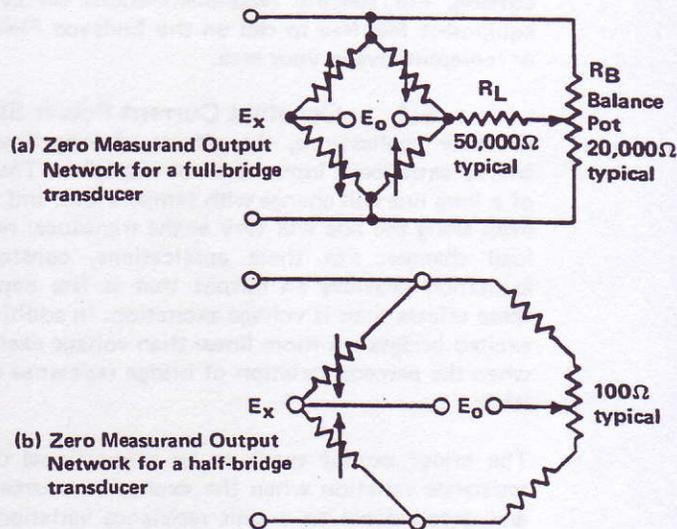


Figure 5-6.

## 6.0 ELECTRONICS

### 6.1 DC Power Supplies

Most ENDEVCO® piezoresistive transducers require a constant voltage supply for excitation. A constant current supply is not recommended unless the transducer is specifically designed or compensated for operation in this mode. Because the typical two-element or four-element accelerometer may not be perfectly balanced or matched, variations in excitation voltage or current, including ripple, will result in an error output signal. It is necessary, therefore, that a stable and well-regulated power supply be employed.

A number of important characteristics must be considered in the selection of a suitable power supply. Among these are:

- |                     |                          |
|---------------------|--------------------------|
| a. Line Regulation  | d. Temperature Stability |
| b. Load Regulation  | e. Time Stability        |
| c. Ripple and Noise | f. DC Isolation          |

In most applications, the output of the transducer is grounded at the readout instrument. This requires that the power supply be well insulated from ground. Not only must the power supply be well insulated to prevent dc leakage currents from flowing through the transducer, but in addition the ac coupling to ground and the power line must be minimized to prevent line transients and dynamic ground loops from generating error signals.

ENDEVCO® manufactures a series of instrument power supplies and signal conditioners. The characteristics of these instruments are optimized to meet the exacting requirements of strain gage or piezoresistive transducers. See the list of ENDEVCO® power supplies and signal conditioners in the Signal Conditioner Section of your ENDEVCO Catalog. For specific recommendations on ENDEVCO® equipment feel free to call on the Endevco Field Engineer or representative in your area.

### 6.2 Constant Current Power Supplies

In many applications, the effects of long line resistance and/or extraneous inputs are not negligible. The resistance of a long line will change with temperature, and the voltage drop along the line will vary as the transducer resistance or load changes. For these applications, constant current excitation provides an output that is less dependent on these effects than is voltage excitation. In addition, current excited bridges are more linear than voltage excited bridges when the percent variation of bridge resistance is relatively large.

The bridge output tends to be proportional on absolute resistance variation when the excitation source is current, and proportional to a unit resistance variation when the excitation is voltage. Thus, resistance gages or transducers which are to be used in a constant current system must be compensated and calibrated with constant current excita-

tion over their full range of operation. Piezoresistive accelerometers must be specifically designed for operation with constant current systems.

### 6.3 External Sensing

The voltage drop along long lines between a constant voltage supply and transducer results in a reduced and sometimes unpredictable voltage at the transducer. Errors and spurious signals may appear at the transducer output due to variations in the resistance of these lines due to temperature changes.

Many constant voltage supplies provide for external voltage sensing leads which connect directly to the transducer, independent of the power or excitation leads. Low current in the sensing leads reduces the voltage drop along these lines and the effects of changes in resistance. Thus, the voltage across the transducer is maintained constant and independent of resistance and current variations in the power leads.

### 6.4 AC Excitation

ENDEVCO® piezoresistive transducers may be excited with an ac carrier signal. The amplitude of the signal must be stable and the frequency should be five to ten times the maximum frequency of interest. ENDEVCO® piezoresistive transducers may be operated with up to 150% rated excitation voltage. With sinusoidal excitation voltages, the peak carrier signal will almost reach this limit. Therefore, it is recommended that the rms value of the carrier voltage be limited to the dc rated excitation voltage or less.

There exists a possibility of capacitive imbalance with any piezoresistive transducer, and this imbalance is no worse than any other resistive transducer. Also, because the individual elements may not be linear with excitation voltage, it is recommended that a physical calibration be performed at the carrier frequency and voltage at which the transducer will be used.

### 6.5 Signal Conditioning

Signal conditioning equipment provides the advantages of combining a stable and isolated constant voltage or constant current power supply with the necessary controls to "condition" the signal from the piezoresistive transducer. These instruments usually feature plug-in mode cards which establish a specific mode of operation and calibration for a specified type of transducer.

Controls are usually available to perform:

- Selection of Constant Voltage or Constant Current Operation.
- Bridge Zero Balance.
- Excitation Adjustment.
- Multipoint, Bipolar Calibration.
- Zero Calibration.
- Local Monitoring of Excitation and Data Signals.

- g. Remote Control, to duplicate local calibration operations.

### 6.6 Amplifiers

In most applications, the output signal from a piezoresistive accelerometer is large enough to require no amplification. However, amplifiers are sometimes necessary to provide gain, to match impedances, or to drive recording galvanometers.

The input impedance of an amplifier should be significantly larger than the output resistance of the connected transducer. See Section 3.2.3 for a discussion of the effect of load resistance on the sensitivity of a transducer. Single-ended inputs are most commonly used; however, differential input amplifiers may be required for special applications requiring isolation of both sides of the input signal. Differential amplifiers provide high common mode rejection which is required when the transducer is excited with a grounded power supply, one power supply provides excitation for a number of transducers, or external electrostatic or magnetic fields produce error signals at the input of the amplifier.

The frequency response of the amplifier must be adequate for the range of frequencies expected in the acceleration of shock input and the noise level should be well below the lowest signal to be measured. Other important characteristics to be considered in the selection of an amplifier are: gain accuracy and stability, zero stability, and the effect of temperature on gain and zero.

### 6.7 Systems

#### 6.7.1 Ground Loops

In addition to the characteristics of each component of the measurement system, the operation of the system as a whole must be considered. One particularly important system consideration is prevention of ground loops. This

problem can occur when the common connection (or signal return) in the system is grounded at more than one point. Differences in earth potential up to several volts may exist between various grounding points. This potential difference can produce circulating ground currents which result in noise and hum in the measuring system.

The only method of preventing ground loops is to ensure that the entire system is grounded at a single point. In general, the most satisfactory system ground point is at the readout input (Figure 6-1). (When several channels of data are being simultaneously fed to the same recorder, it is mandatory.) This requires that accelerometer, power supply and amplifier be insulated from ground. In Figure 6-1, signal ground is connected to earth at only one point, at the readout.

The sensing elements of all ENDEVCO® piezoresistive accelerometers are insulated from the mounting case. Grounding of the accelerometer case, connector shell and cable shield to the test structure protects the sensing elements and wires from external electrical fields. The cable shield should not be connected to the power supply or electronics ground. If the case is not grounded to the test structure, it should be connected to a nearby and convenient earth ground.

Matching electronics in which the case is tied to circuit ground can be satisfactorily isolated by wrapping with insulating material (electrical tape, etc.) or by simply placing it on paper or cardboard. (In severe environments, the amplifier can be wrapped with sponge rubber.)

If amplifier output cables are unjacketed, care must be taken that any exposed shields or connectors do not become inadvertently grounded ahead of the recorder input.

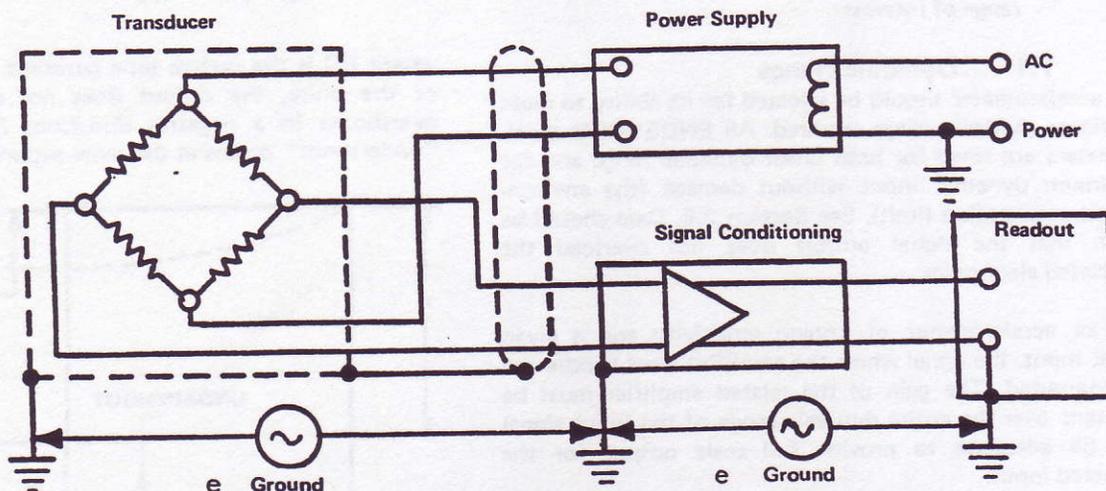


Figure 6-1. Ground loop potentials in a typical piezoresistive accelerometer installation.

### 6.7.2 Long Lines

When long cables connect a power supply to a PR accelerometer, the voltage drop along the wires reduces the excitation voltage at the transducer. This condition can be adjusted by increasing the voltage at the power supply until the voltage at the transducer is at rated excitation.

To improve control of excitation voltage at the transducer, select a power supply with external sensing leads. Run separate sensing wires to the transducer and the power supply will maintain the desired voltage regardless of

changes in the resistance of the power wires.

Another important factor relates to the effect of temperature on the accelerometer. Typically, a four-arm piezoresistive transducer changes input resistance at rated temperature extremes as much as plus and minus 50% from that at room temperature. This change results in a relatively large change in input current, and a proportional change in power line voltage drop. With external sensing wires, the power supply controls and maintains the voltage at the transducer at a constant level.

## 7.0 SHOCK TESTING

Special problems are encountered in shock testing which place stringent requirements on the measuring system.

Some of these problems are:

- a. High g levels
- b. Wide frequency content of pulses
- c. Transient characteristics of instrumentation

As a result, each part of the shock instrumentation system should be evaluated and selected for:

- a. Adequate linear dynamic range (including safety factor)
- b. Adequate linear frequency response over a wide range
- c. Ability to respond to transient inputs
- d. Negligible phase shift errors over the frequency range of interest

### 7.1 Dynamic Range

The accelerometer should be selected for its ability to meet the linear dynamic range required. All ENDEVCO® accelerometers are rated for both linear dynamic range and for maximum dynamic input without damage (the environmental acceleration limit). See Section 3.5. Care should be taken that the signal output does not overload the associated electronics.

For an accelerometer of known sensitivity and a given shock input, the signal which the amplifier must handle can be computed. The gain of the related amplifier must be constant over the entire dynamic range of the input signal and be adequate to provide full scale output for the expected input.

### 7.2 Low Frequency Response

Inadequate low frequency response in the measurement system will result in failure to accurately reproduce the shock pulse. Piezoresistive accelerometers respond to steady

state or zero frequency motion. When they are connected to dc amplifiers or dc readout instruments, there is no limit to the duration of a shock pulse.

When ac amplifiers or other equipment with limited low frequency response are connected in a system, the shock pulse wave shape will not be maintained. The nature of this inaccuracy can be seen by examining the effect on a rectangular pulse of duration T and amplitude A applied to the input of a signal conditioner which does not respond to dc (steady state) signals.

If this transient is passed through an ac system with first order low frequency response\*, the resultant output will be as shown in Figure 7-1. The output does not remain at the peak value for the full pulse duration, but decays exponentially. The output amplitude at any instant (during the pulse) can be expressed as:

$$a = Ae^{-\frac{t}{RC}} \quad (7-1)$$

where RC is the system time constant. At the termination of the pulse, the output does not return to zero, but overshoots in a negative direction. Recovery from this "undershoot" occurs at the same exponential rate as droop.

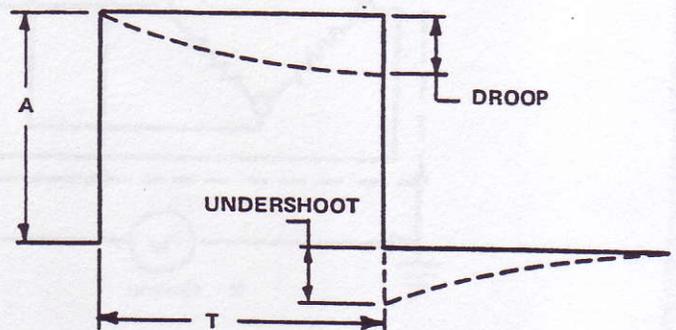


Figure 7-1. Response of a system with first order low frequency response to a rectangular pulse. (Input pulse is solid line, dashed line shows system response.)

The ratio of total pulse height to droop is a function of the ratio  $\frac{RC}{T}$ . The larger this ratio, the less error (and the less undershoot). For example, if this ratio is 20, there will be an approximately 5% error in the rectangular pulse amplitude; if the ratio is 50, there will be only a 2% error.

Although slightly more complex to analyze, it can be shown that similar low frequency effects occur for other pulse shapes. If the requirement for adequate  $\frac{RC}{T}$  is not satisfied, it is possible to predict the degree of error for these pulses and apply appropriate correction factors to the data obtained.

\* A first order system has the same low frequency response as a single resistor-capacitor high pass filter whose time constant in seconds is equal to RC (ohms x farads). Such a system exhibits a low frequency rolloff at 6 db/octave. It is 3 dB down at a frequency equal to  $\frac{1}{2\pi RC}$  and 5% down at a frequency of  $\frac{3}{2\pi RC}$ .

### 7.3 High Frequency Response

Consider again a rectangular pulse of duration T and amplitude A. If this transient is passed through a system with first order high frequency response (corresponding to a single RC low pass filter combination) the resultant output will be as shown in Figure 7-2. The effect of the high frequency rolloff is to slow the rise and fall time of the pulse, thus rounding both the leading and trailing edges.

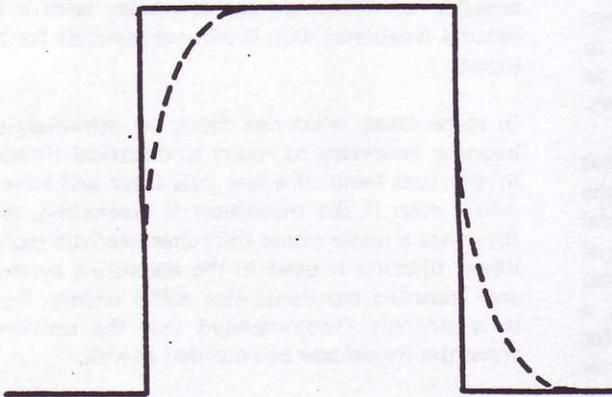


Figure 7-2. Response of a system with first order high frequency response to a rectangular pulse.

It is also of interest to note the effect of passing the rectangular pulse through a system possessing second order high frequency response. (Such a system corresponds to the electrical frequency response of a single LC low pass filter combination.) Figure 7-3 shows the resulting output. A high frequency ringing at approximately the high frequency cutoff frequency is superimposed on the shock pulse. The amplitude and duration of the ringing depend on the damping factor,  $\zeta$ .

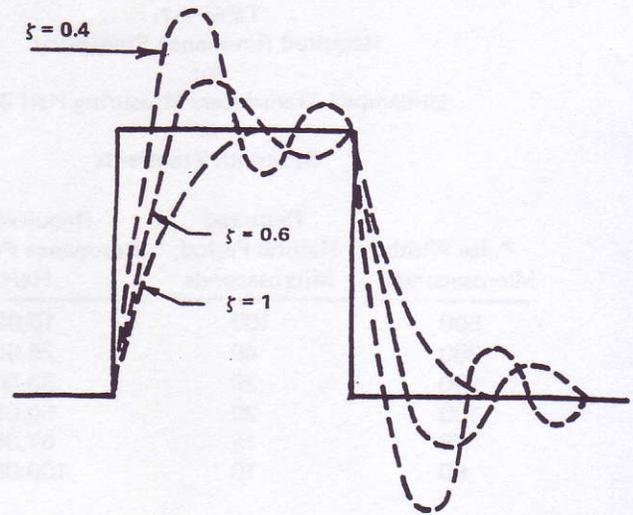


Figure 7-3. Response of a system with second order high frequency response to a rectangular pulse for various values of the damping factor,  $\zeta$ .

Fourier analyses show that short transients contain significant high frequency components. Both the transducer and associated systems must have adequate high frequency response to avoid undesirable measurement distortion.

The high frequency response of a piezoresistive accelerometer with very little damping is approximately a second order function and is determined by the transducer resonance frequency. The use of such devices provides desirable high frequency response along with minimum phase shift in the frequency range of interest.

Transients, however, may excite such a transducer to resonance; natural frequency "ringing" will then be superimposed on the basic transient.

In the case of short, rectangular or other transients with essentially zero rise time (very short rise time in proportion to the natural period of the transducer) almost 100% overshoot on the transient may occur along with subsequent excitation of accelerometer natural frequency. To minimize or prevent these distortions, the accelerometer should have a natural period (the reciprocal of the natural frequency) one third the expected rise time or less.

With half sine or sawtooth transients, the transducer natural period should be less than one fifth the pulse duration. This ensures that the indicated peak does not exceed the actual peak by more than 10%. Ten percent has been arbitrarily chosen as a desirable limit for practical work.

Resonance frequencies should be as shown in Table 7-1 in order that the natural period be one fifth the pulse duration.

Table 7-1.  
Required Resonance Frequency  
for  
Undamped Transducers Measuring Half Sine  
or  
Sawtooth Transients

Pulse Width, Microseconds	Required Natural Period, Microseconds	Required Resonance Frequency, Hertz
500	100	10,000
200	40	25,000
150	30	33,000
100	20	50,000
75	15	67,000
50	10	100,000

Damping reduces the peak amplitude of the resonance frequency ringing and extends the useful high frequency response of a transducer. It is purposely incorporated in accelerometers with low resonance frequencies. See Section 4.1.3.

If the matching amplifier possesses high frequency response flat to at least one-half the accelerometer resonance frequency, no appreciable error will be introduced by amplifier rolloff characteristics.

The most common types of readout devices are: (a) Oscilloscope, (2) Galvanometer, and (3) Magnetic Tape. The single peak reading meter, a special purpose device, is used where only the peak value of the shock is of interest. The oscilloscope is probably the most versatile and easy to use. A good quality scope will have a response from dc to above a megacycle so that it will not introduce any errors.

Galvanometer recorders are damped readout devices that serve to filter frequency components higher than the galvanometer undamped natural frequency. The natural frequency should be high such that minimum distortion of the basic transient is introduced. For a galvanometer damped to approximately 70% of critical damping, a natural frequency of at least 400 Hz is desirable for recording 10 millisecond half sine transients. For shorter half sine transients, the natural frequency should be higher in inverse proportion to the transient duration. Conversely, the galvanometer natural frequency can be correspondingly lower for longer half sine transients.

Magnetic tape recording is most useful where the shock information is to be fed into a computer for data reduction.

In general, the shock information is processed before recording to put it in the form which the magnetic tape and computer can accept. When this is done, the high frequency response is limited in some cases.

If the shock measuring system is to be airborne such as in a missile instrumentation, the telemetering link must be considered. Normally, this would include a voltage controlled oscillator and a telemetering transmitter. The center frequency of the VCO must be chosen sufficiently high so that distortion of the shock pulse does not occur due to the high frequency rolloff of the telemetering system.

#### 7.4 Phase Shift

Faithful reproduction of transients requires that the shock measurement system be free of phase distortion. As we have seen, undamped Endevco accelerometers exhibit 0° phase shift over their useful frequency range, and thus are not a source of this type of error. Matching amplifiers should be chosen for acceptable phase characteristics. Recording galvanometers, when properly damped, exhibit linear phase shift over their usable frequency range. Other readout devices do not, in general, introduce phase distortion.

If a virtually undamped accelerometer is subjected to shock which excites its resonance frequency, the magnitude of the accelerometer output does bear a fixed relationship to the mechanical input. This relationship, however, is so sharply dependent upon the input shock duration and rise time that the output signal is rarely of practical value. It is usually possible to select an accelerometer with a high enough natural frequency that it will not resonate for a given shock input.

In some cases, when rise times are extremely short, it may become necessary to resort to electrical filtering. The data in the pass band of a low pass filter will have quantitative value, even if the transducer is resonating, as long as the filter has a linear phase shift characteristic (constant delay). When filtering is used in the measuring system, the actual and recorded transients may differ widely. For this reason, it is strongly recommended that the unfiltered response from the transducer be recorded as well.

Accelerometers with approximately 0.7 of critical damping exhibit a linear phase shift with frequency and, therefore, reproduce the input pulse with little distortion. If the temperature of the transducer differs from room temperature, the damping factor may change significantly resulting in a change in phase shift characteristics and distortion in the output pulse wave shape.

## 8.0 CALIBRATION

### 8.1 Introduction

Piezoresistive accelerometers require eight basic calibrations. They are (1) Sensitivity, (2) Frequency Response, (3) Resonance Frequency, (4) Amplitude Linearity and Hysteresis, (5) Transverse Sensitivity, (6) Temperature Response, (7) Internal Resistance, and (8) Damping. For all but internal resistance, true calibration requires some form of mechanical excitation.

Calibration laboratories generally use a vibration exciter which produces sinusoidal motion, or a centrifuge which produces steady state acceleration. A shock calibrator (shock motion generator) can be used to provide high level mechanical excitation. Other techniques which do not provide actual mechanical excitation are classed as passive or "simulation calibration." Although some are valuable for checkout and verification purposes, such methods should not be confused with true dynamic calibration.

In simplest terms, the basic dynamic calibration of an accelerometer consists in (a) application of a known mechanical input, (b) measurement of the resulting accelerometer electrical output, and (c) calculation of the calibration factor or sensitivity, obtained by dividing electrical output by mechanical input. If performed under a single set of conditions, this procedure yields the basic sensitivity calibration. If performed at several different frequencies, a frequency response calibration is obtained; if at several input levels, an amplitude linearity calibration results; if at various temperatures, a temperature response calibration. In each case, however, the basic technique remains the same.

To be meaningful, calibrations must be as accurate as possible. This, in turn, requires precise measurement of both mechanical inputs and resultant electrical output. An unknown quantity may be measured either by a direct method (for example, Turnover, Centrifugal or Reciprocity) or by an indirect method by comparison with a previously calibrated system (the Comparison Method). All methods are useful.

## 8.2 Sensitivity Calibration

### 8.2.1 Turnover Calibration

For piezoresistive accelerometers with high sensitivities, the Turnover Method of calibration is both simple and accurate. In this method, the accelerometer is oriented with its sensitive axis in a vertical direction and the electrical output noted. The accelerometer is then turned over 180°, resulting in a change of 2 g, and the output voltage is again noted. The sensitivity is computed by dividing the change in output voltage by 2 g.

Low sensitivity accelerometers require amplification of output voltage to obtain a readable and accurate change in signal level. Thermal drift in the transducer and/or noise in

the amplifier may mask the signal resulting in inaccurate measurements.

### 8.2.2 Centrifugal Calibration

The dc response of PR accelerometers permit them to be calibrated on a centrifuge. For an accelerometer mounted on a centrifuge with the center of gravity of its mass at a distance  $r$  inches from the axis of rotation, rotating at  $n$  rpm, the acceleration is:

$$G = 0.00002842 r n^2 \quad (8-1)$$

where  $G$  is acceleration in  $g$ .

To perform the calibration, the accelerometer is mounted on the centrifuge with its axis of sensitivity carefully aligned along a radius of the circle of rotation. Signal leads from the pickup, as well as excitation power leads, usually are brought to the table of the centrifuge through specially designed "low-noise" slip rings and brushes. As with the Turnover Method, thermal drift in the transducer and noise generated by an amplifier, as well as the noise caused by slip rings will introduce spurious signals. A high signal to noise ratio will result in a more accurate measurement. After the sensitivity is determined with the accelerometer mounted in one direction, the unit should be turned over 180° and sensitivity determined for the opposite direction.

The sensitivity usually is determined by plotting the output of the accelerometer as a function of the acceleration for successive values of rotational frequency and determining the slope of the straight line fitted through the data. Errors result from the difficulty in locating the center of gravity of the seismic mass of the accelerometer, in measuring the rotating speed accurately, and in holding the speed constant during the time required to take a reading.

### 8.2.3 Comparison Method

In the Comparison Method of calibration, the output of the accelerometer under test is compared to the output of a reference standard at some convenient frequency, usually 100 or 400 Hz. The standard, usually a piezoelectric accelerometer, is previously calibrated by the reciprocity technique or comparison with a primary standard. Both the test unit and standard are rigidly mounted, back-to-back on a suitable shaker table (Figure 8-1) and subjected to sinusoidal motion. The sensitivity of the test accelerometer is equal to the ratio of the test output to the standard output, multiplied by the sensitivity of the standard accelerometer.

With a primary standard accelerometer such as the ENDEVCO® Model 2270 estimated sensitivity calibration errors not exceeding 1% can be achieved.<sup>1</sup>

<sup>1</sup> R. R. Bouche, "Vibration Standards for Performing Comparison Calibrations", Instrument Society of America, Preprint No. M18-3-MESTIND-67. Presented at the 22nd Annual ISA Conference and Exhibit, Sept. 11-14, 1967, Chicago, Ill.

This paper is available as Technical Paper No. 241 from Endevco, Pasadena, California.

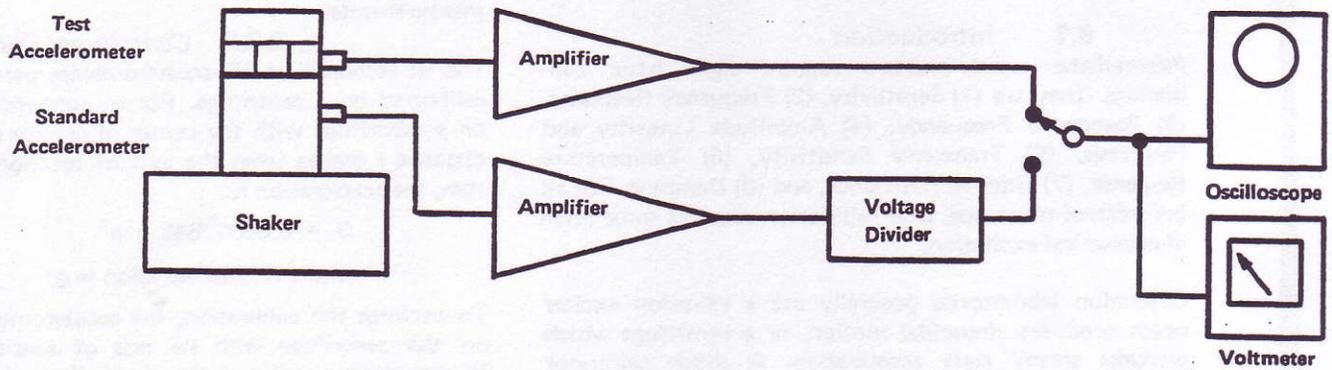


Figure 8-1. Block diagram — Comparison Calibration.

### 8.2.3.1 Vibration Exciters

It is desirable to use electrodynamic shakers designed specifically for calibration purposes. The shaker should be free of transverse motion and axial motion harmonic distortion. Usually the transverse motion results from resonances in the shaker moving element or resonances in the support system for the moving element. Distortion in the axial motion results either from transverse motion or from excitation of longitudinal resonances in the moving element by harmonic distortion in the power amplifier used with the shaker. Some shakers designed for calibration have transverse motion and axial distortion occurring at several frequencies within their operating range. It is, therefore, important to make transverse motion and axial distortion measurements on the shaker so that these frequencies may be avoided during calibration.

Sinusoidal calibrations should not be performed at frequencies where poor shaker motion occurs even though the accelerometer is subjected to these motions in service. The effects of such shaker motions on the performance of an accelerometer should be evaluated separately. See Endevco Technical Paper No. 252, "High Frequency Shaker for Accurate Accelerometer Calibration" by R. R. Bouche.

### 8.2.3.2 Standards

In comparison calibrations performed at Endevco, piezoelectric accelerometers are used as vibration standards throughout the frequency range of 5-10,000 Hz.

The piezoelectric standards used at Endevco are calibrated by the reciprocity method at 100 Hz. In addition, they are calibrated at 5 Hz by the direct viewing optical method described below. These standards are also calibrated from 10 Hz to 10,000 Hz by direct comparison to another vibration standard previously calibrated at the National Bureau of Standards.

The piezoelectric vibration standards are calibrated by these three methods at intervals not exceeding 12 months. These standards are used regularly to calibrate other accelerometers using the comparison method of directly measuring voltage ratios.

Test procedures and techniques for making comparison calibrations on piezoresistive accelerometers are similar to those used in calibrating piezoelectric accelerometers and are described in a number of Technical Papers available from Endevco.

### 8.2.4 Reciprocity Calibration

The Reciprocity Method for calibration of accelerometers involves the measurement of current, voltage, frequency, and mass. It is an absolute calibration method and, because the above measurements can be precise, the Reciprocity Method can result in high accuracies with estimated errors of  $\pm 0.5\%$ .

Although highly accurate, Reciprocity Calibration is time consuming and tedious. It should be performed only on a very stable accelerometer such as the ENDEVCO® Primary Standard Model 2270.

Test procedures and techniques for performing reciprocity calibrations are described in ANSI publications and in Endevco Technical Paper No. 251.<sup>2</sup>

### 8.2.5 Optical Calibration

Because of recent improvements in the precision and techniques for making comparison calibrations, optical calibration is not as popular now as the comparison method. In the direct viewing optical calibration method, the double amplitude displacement of the vibrating test accelerometer is measured with a high resolution microscope which views an illuminated light spot. This "target" is usually obtained by side-lighting a strip of fine grit emery or "Scotchlite" which is fastened to the accelerometer under test. The frequency of vibration must be accurately measured. With these data, the acceleration input to the accelerometer can be calculated and, subsequently, the basic sensitivity of the unit obtained.

To attain an estimated calibration error of less than 1%, considerable care is required to see that the root-sum-of-

<sup>2</sup> R. R. Bouche, "Accelerometer Calibration with Reciprocity Vibration Standards", *Measurements and Data*, Issue 22 (July-August, 1970), pp. 84-89.

squares of the individual instrument errors does not exceed 1%. This requires, among other things, a specially calibrated voltmeter, and a seismically mounted shaker-microscope assembly. The displacement measurement is usually limited to amplitudes greater than 0.050 peak-to-peak inches. This normally limits the use of this method to frequencies near 50 Hz on most shakers. Interferometer calibration, an optical method in which the double displacement amplitude is measured by observing interference patterns in light waves, permits calibration at higher frequencies than direct viewing. The procedures, however, are quite rigorous and require extreme care to attain useful accuracies.

### 8.3 Shock Motion Calibration

Shock motion calibration is used for determining amplitude linearity and verifying the environmental acceleration rating of an accelerometer over 100 g peak. It is recommended as a means for detecting malfunctions in an accelerometer not normally detected during sinusoidal calibrations and to determine the overall characteristics of a system particularly one which is intended to measure shock motion.

The ENDEVCO® Comparison Shock Calibrator, Model 2965C, is a ballistic drop-ball type of shock motion generator designed to produce acceleration pulses ranging from 20 g to over 10,000 g at pulse durations which vary from 3 milliseconds to 100 microseconds, respectively.

The test and primary standard accelerometers mount back-to-back on an anvil. A steel ball drops to impact on the anvil, subjecting the accelerometers to a half-sine shock pulse. Signals from the test and standard accelerometers are conditioned by individual amplifiers such as those in the ENDEVCO® Model 28350F Amplifier-Accelerometer Calibration Standard. Pulse wave shape and amplitude are observed on a calibrated storage oscilloscope, or photographed from the screen of a standard oscilloscope.

As with the Comparison Method, the sensitivity of the test accelerometer is equal to ratio of the test accelerometer peak output to the standard accelerometer peak output, multiplied by the sensitivity of the standard. Errors of less than  $\pm 5\%$  can be achieved with this calibrator.

### 8.4 Frequency Response

Frequency response calibrations are performed at Endevco using virtually the same comparison method as for the basic sensitivity measurement (Section 8.2.3), but are conducted over a range of frequencies, usually 20 to 4000 Hz. Special calibrations are also performed from 5 to 10,000 Hz. In the frequency response setup, only piezoelectric accelerometers are used as the reference standard. The error in the sensitivity of the test accelerometer does not exceed  $\pm 1.5\%$  at frequencies from 5 to 1000 Hz, and  $\pm 2.5\%$  from 1000 to 10,000 Hz.

Shakers used for calibrations should be carefully selected to operate over the required frequency range. A shaker should be used at frequencies at which the transverse motion is less than 25%, and distortion in the sinusoidal motion is less

than 5%. It is good practice to operate the power amplifier driving the shaker at a fraction of its rated power. This is recommended to avoid exciting resonances in the shaker harmonics of the driving frequency.

Sinusoidal calibration of an accelerometer is sufficient to demonstrate its suitability for making random vibration measurements if performed throughout the range of frequencies present in the random vibrations.

### 8.5 Resonance Frequency

Any measurement of resonance frequency requires mechanical excitation of the test specimen. The excitation may be either sinusoidal vibration or shock motion. To minimize calibration errors when excitation frequencies are above 5000 Hz, or shock pulses are correspondingly short, a drop of light oil is applied between mating surfaces.

#### 8.5.1 Sinusoidal Excitation

(a) Undamped Accelerometers ( $\zeta \leq 0.2$ ). The most accurate means of measuring the resonance frequency of an undamped accelerometer is to apply sinusoidal motion and determine the frequency of maximum response. This calibration is best performed on shakers that have resonances below the resonance frequency of the accelerometer. For most accelerometers it is necessary to avoid fixtures between the shaker and the accelerometer.

The internal damping of the accelerometer can be determined approximately by measuring the two frequencies where the response of the accelerometer is at its half power points, 0.707 times its maximum value (resonance). The difference  $\Delta f$  between these two frequencies is related to the damping factor by:

$$\zeta = \frac{\Delta f}{2 f_n} = \frac{1}{2Q} \quad (8-1)$$

Where:

$\zeta$  = damping ratio  $c/c_c$

$f_n$  = acceleration resonance frequency

$Q = \frac{A_r}{A_0}$  = amplification factor (transmissibility or amplification at resonance)

The above relationship applies only for lightly damped systems, in which the damping factor is less than 0.1. Since the internal damping of the accelerometer is very low, the difference frequency is small. For this reason the errors due to lack of flat frequency response in the shaker at these high frequencies are minimized.

(b) Damped Accelerometers ( $\zeta \approx 0.7$ ). Because there is little or no resonance rise in damped accelerometers, only the

natural frequency is measured. This is defined as the frequency at which the phase shift between input acceleration and electrical output is  $90^\circ$ . As the vibration frequency increases through and beyond the natural frequency, the phase angle continues through  $90^\circ$  to  $180^\circ$  and remains at  $180^\circ$  for a reasonable range of frequency. It is important to note that some accelerometers may exhibit a  $90^\circ$  phase shift at minor resonances, however, these frequencies should not be assumed to indicate the natural frequency.

### 8.5.2 Shock Excitation Method

Although the sinusoidal excitation method of measuring the resonance frequency is the most accurate available, its use is limited by the capabilities of available equipment. For resonance frequencies above 50,000 Hz and low sensitivity accelerometers, shock excitation is the only mechanical excitation method available.

Shock pulse resonance frequency calibration is performed by applying a half sine shock motion to the mounted accelerometer with a pulse duration approximately three times the reciprocal of the resonance frequency of the accelerometer. This requires a trial and error method of changing the padding on the shock machine anvil to obtain the desired pulse duration. It is best to photograph, on an oscilloscope, the accelerometer output before, during and after completion of the pulse. To accomplish this, a means for triggering the oscilloscope just before shock motion is applied must be provided. The reciprocal of the period of oscillation or ringing is the resonance frequency of the accelerometer.

In some cases the shock motion method will excite more than one resonance frequency simultaneously. The second frequency may be a second resonance in the accelerometer, or a resonance in the anvil to which the accelerometer is attached.

## 8.6 Amplitude Linearity

### 8.6.1 Introduction

At Endevco, the amplitude linearity of a piezoresistive transducer is usually specified as the maximum deviation of sensitivity from the average sensitivity determined over the operating range of the transducer at a single frequency. It is expressed as a percentage of reading (sensitivity). Procedures for determining the amplitude linearity of an accelerometer are described in American National Standard S2.11-1969.

The amplitude linearity of an accelerometer should be experimentally verified over the entire acceleration range for which the accelerometer is rated. The amplitude linearity calibration may be performed at any frequency within the rated frequency range of the accelerometer; i.e., up to one-fifth the resonance frequency for a lightly damped accelerometer. The several methods for calibrating

sensitivity, described in Sections 8.2 and 8.3 may be used for performing amplitude linearity.

### 8.6.2 Static Calibration

Static Linearity Calibration is best performed on a centrifuge. The maximum rotating frequency and length of the arm determine the highest acceleration that can be obtained.

The calibration is performed by mounting the accelerometer on the centrifuge and subjecting the unit to increasing levels of acceleration up to the rated limit of the transducer or centrifuge. At each acceleration level the electrical output of the unit is noted. After linearity measurements are taken for acceleration in one direction, the sensitive axis of the accelerometer should be reversed  $180^\circ$  and the measurements repeated.

For each acceleration level the sensitivity of the accelerometer is determined. The Amplitude Linearity of the accelerometer is the maximum deviation of any calibration point from the average sensitivity, expressed as a percentage of the average sensitivity.

### 8.6.3 Sinusoidal Method

The rated linear acceleration range for piezoresistive accelerometers varies from  $\pm 20$  g to over  $\pm 10,000$  g depending upon the accelerometer design. Except for a few electrodynamic shakers capable of performing calibrations up to approximately 100 g, it is necessary to utilize resonant mechanical systems in performing amplitude linearity calibrations. For accelerations up to at least 100 g, simple beams excited at their free-free transverse fundamental mode, may be used. At accelerations up to 500 g, axial rods operated at their fundamental longitudinal resonant mode may be used.

An ENDEVCO® Model 2270 Primary Standard Accelerometer or other calibrated accelerometer may be used at the center of the beam or the end of the rod. The test accelerometer is mounted on the 2270 or back-to-back with the calibrated accelerometer by means of a fixture. The beam or rod is usually rigidly connected to a shaker having a moving element weighing less than two pounds. The calibration is performed by carefully driving the beam or rod at its resonance frequency and measuring the ratio of the test and standard outputs. By operating the beam at resonance, sinusoidal motion is maintained. Since the internal damping of the beam is low, the resonance frequency and applied acceleration remain unchanged with time.

Careful design and choice of material for the beam can assure many hours of operation before beam failure occurs. (Fatigue cracks in the beam are readily detected by observing that the resonance frequency of the beam is suddenly lowered.) The standard accelerometer, or calibrated accelerometer with fixture, should be previously calibrated to accelerations of at least 500 g. This may be

performed by comparison or by shock excitation motion. Amplitude linearity is determined in a manner similar to the method described under Static Calibration, above. Any errors in the readout instruments must be taken into account when determining the amplitude linearity.

#### 8.6.4 Shock Methods

Even though special sinusoidal resonance systems have been developed for use above 500 g, the high accelerations are achieved at frequencies which may be beyond the rated frequency range of the test accelerometer. It is recommended, therefore, that shock motion excitation methods be used for calibrations in excess of 500 g.

Comparison calibrations can be performed using the ENDEVCO® Model 2270 at accelerations up to 10,000 g, and back-to-back fixtures to 5000 g. In the ENDEVCO® Model 2965C, Comparison Shock Calibrator, the Model 2270 Primary Accelerometer is mounted on an anvil, and the test accelerometer mounted on the 2270. The anvil is impacted by a steel ball and the outputs of the test and standard accelerometers are photographed on a dual beam oscilloscope. The comparison calibration is completed by measuring the ratio of the test and standard accelerometer peak output pulses.

From the data obtained by comparison calibration over the operating range of the test accelerometer, the amplitude linearity is determined in a manner similar to the method described under Static Calibration, above.

#### 8.7 Transverse Sensitivity

The transverse or cross-axis sensitivity of an accelerometer is the ratio of its voltage output due to unit acceleration applied perpendicular to the sensitive axis divided by the basic sensitivity. The transverse sensitivity is expressed as a percentage of the axial sensitivity of the accelerometer. To measure transverse sensitivity, sinusoidal motion must be applied in the transverse plane while maintaining virtually no motion along the sensitive axis of the accelerometer.

A mechanical exciter designed to satisfy this requirement is illustrated in Figure 8-2. This shaker is a simple crank mechanism driving a table along specially designed bearings. The shaker operates at an acceleration level of about 7 g at 11 Hz and is designed for production testing. It is equipped with a special mechanism to permit rotation of the accelerometer around its sensitive axis while the shaker is vibrating.

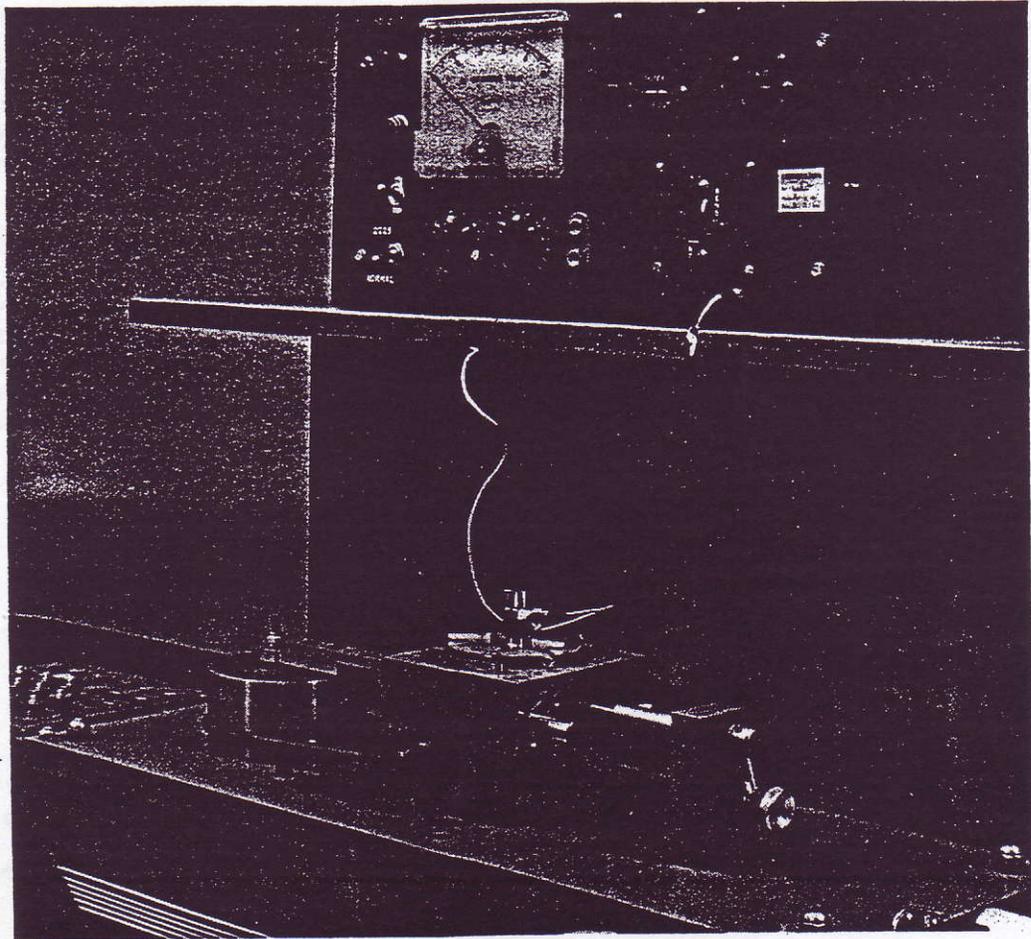


Figure 8-2. Transverse Sensitivity Calibrator.

In operation, the accelerometer is rotated by operating the crank at the lower right in Figure 8-2 while observing the minimum and maximum values of the transverse sensitivity on the meter. The maximum value obtained is reported as the transverse sensitivity of the accelerometer. This value is applicable only for motion along one diameter in the plane perpendicular to the sensitive axis of the accelerometer. The transverse sensitivity is less than this maximum value when the accelerometer is used along any other diameter. This means that the actual transverse sensitivity applicable in most tests will always be less than the maximum value reported on the calibration card.

For calibrating accelerometers with ultra-low transverse sensitivities, electrodynamic shakers should be used. A number of factors must be carefully considered: (1) transverse motion of the shaker, (2) building vibrations transmitted to the moving element of the shaker, (3) harmonic distortion of the power amplifier used with the shaker, (4) the residual noise of the amplifier used on the accelerometer output, and (5) providing sufficient amplification of the accelerometer output to maintain adequate signal noise ratio.

To Calibrate an accelerometer that has, for example, maximum transverse sensitivity of 0.5%, the shaker employed must have less than 0.1% axial transverse motion. Further, if the accelerometer axial sensitivity is 10 pC/g and the transverse excitation is to be 10 g, the calibration system must be able to accurately measure a 0.5 picocoulomb signal from the accelerometer. The requirements are even more severe for accelerometers with less than 10 pC/g axial sensitivity.

A test setup that satisfies these requirements is illustrated in Figure 8-3. The special fixture on the shaker permits manual rotation of the accelerometer around its sensitive axis. The accelerometer which monitors motion along the

sensitive axis of the test accelerometer is specially selected to have a transverse sensitivity of 0.1% or less (and is thus suitable for measuring transverse shaker motion in excess of 0.1%). The test accelerometer is connected to an amplifier with the gain of 1000. The filter serves to reject signals resulting from residual building vibrations which pass through the seismic block, shaker distortion due to harmonic distortion in the power amplifier, and residual noise in the 1000 gain amplifier.

A statistical analysis of results obtained on this test setup indicates that the error in transverse sensitivity values obtained on this setup is approximately 0.1%. It should be emphasized that this accuracy can only be achieved by using a shaker which has extremely good transverse motion characteristics.

### 8.8 Temperature Response

The temperature response of an accelerometer is the variation in sensitivity that occurs as the result of using the accelerometer at different temperatures. At Endevco, temperature response calibration of piezoresistive accelerometers is performed by the turn-over method described in Section 8.2.1. Accelerometers are mounted on a plate attached to a position indexed shaft and placed in an oven. After the temperature of accelerometers stabilize, the units are inverted 180° and the change in output voltage noted. The sensitivity of the transducer at the test temperature is equal to the change in voltage divided by 2 g.

Another, but more complex procedure for measuring the temperature response is the Comparison Method, similar to that described in Section 8.2.3. The variation in sensitivity is measured by subjecting the accelerometer to sinusoidal motion throughout the rated temperature range of the accelerometer. This calibration is usually performed at a single frequency near 50 Hz or 100 Hz, depending upon the transverse motion characteristics of the shaker. Sensitivity

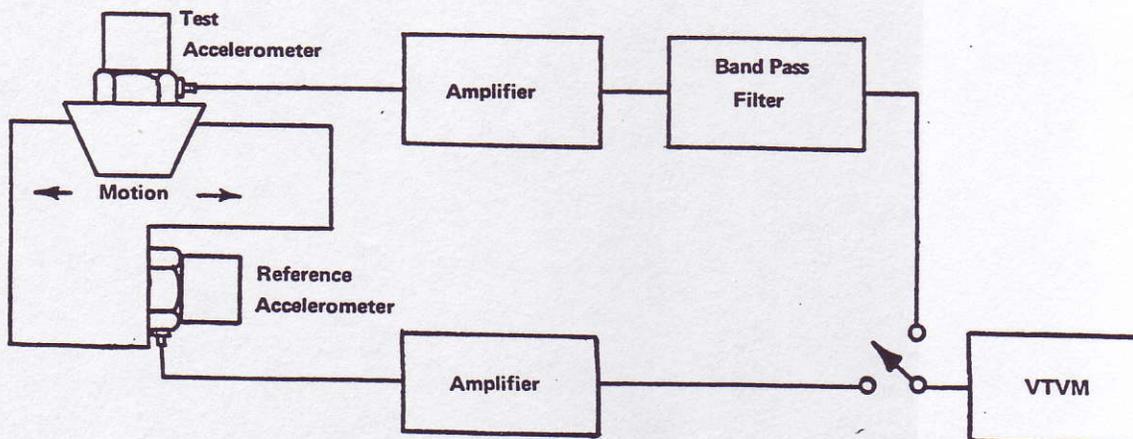


Figure 8-3. Block diagram — calibration equipment for measurement of very low transverse sensitivity.

deviation is measured by comparing transducer output to that of a standard accelerometer which is maintained at room temperature.

An electrodynamic shaker is positioned below the temperature chamber. An extension rod which passes through the chamber wall connects the shaker to the mounting table within the chamber. The mounting table is usually designed to accommodate a number of accelerometers. The standard accelerometer is mounted on the opposite end of the shaker moving element. Since the calibration is performed at low frequency, there is no relative motion between the accelerometers in the chamber and the standard accelerometer at the bottom of the shaker.

For test accelerometers with small damping, less than 0.1 of critical, it is not necessary to perform temperature response calibrations at high frequencies, since thermal sensitivity deviation is the same at high frequencies as at 50 or 100 Hz. The resonant rise at frequencies up to one-fifth the resonance frequency of the accelerometer is small and does not change appreciably over the normal temperature range.

Test accelerometers, with damping greater than 0.1 of critical, may exhibit a change in frequency response with temperature at frequencies above one-fifth the resonance frequency. See Figure 4-3. If an accelerometer with such damping is to be operated at extreme temperatures, and frequencies above one-fifth of the resonance frequency are important to the measurement, frequency response measurements should be performed at the operating temperatures.

This calibration is performed using a back-to-back fixture mounted in the temperature chamber. Both test and standard accelerometers are in the temperature environment. The combined temperature and frequency response characteristics of the standard accelerometer is previously determined from frequency response calibrations and resonance frequency measurements at the temperature extremes. The resulting data must be corrected for the deviation in sensitivity that occurs in the standard accelerometer at the various temperatures and frequencies. In addition, frequencies must be avoided where there is significant distortion resulting from shaker axial resonances and transverse motion. By careful control of calibration procedures, reasonable accuracy can be maintained.

### 8.9 Internal Resistance

Measurement of input and output resistance or the individual sensing element resistance of a piezoresistive transducer provides valuable information on the operating condition of the transducer. A damaged sensor appears as an open or high resistance circuit element. A continuity check with a low voltage ohmmeter quickly determines whether the transducer is ready for use.

Some transducers, particularly those which utilize Piezite® Element P-11, exhibit a significant change in resistance with

temperature. These transducers also change resistance with applied voltage due to heating from  $I^2R$  power losses. For most balanced bridges, the change in resistance with voltage and temperature is not significant, except as it may shift the zero balance.

When the accurate resistance of a transducer must be known it should be measured under actual operating conditions. This means that the measurement is determined by applying rated excitation voltage and computing the ratio of applied voltage to the resulting current after the current has stabilized.

Because of the significant change in resistance with applied voltage and temperature, most piezoresistive transducers should not be calibrated by the passive, shunt method. Shunt calibration should be performed on accelerometers with the suffix letter "C". This is discussed further in Section 8.10.

## 8.10 Passive Calibration

CWE WANT  
DO THIS

### 8.10.1 Shunt Calibration

Shunt or passive calibration, in contrast to dynamic calibration, is performed in applications where the transducer is already mounted on a test structure and cannot be dynamically calibrated. Shunt calibration provides a continuity check of the entire system from transducer to the readout, and, in addition, supplies a reference signal to the output device for future data reduction.

In shunt calibration, an accurate and stable fixed resistor is connected across one of the elements of the transducer bridge. This shunt resistor will change the output and electrically simulate a precalculated percentage of the full scale output of the transducer at room condition.

Piezoresistive transducer elements exhibit a wide variation of resistance with temperature, with as much as 2 to 1 change in resistance over the specified range of operating temperature. Shunt calibration, therefore, is not recommended for those transducers utilizing an active element in each arm of the bridge.

ENDEVCO® piezoresistive transducers identified with the suffix letter "C" may be shunt calibrated. These transducers use active elements on only one side of the bridge and the bridge is completed with fixed, accurate resistors with low temperature coefficient. Shunt calibration resistors may be connected across one of these fixed resistors. Separate calibration wires are provided, as shown on the individual schematic drawings, to minimize the line drop effects in the signal leads.

Calculation of the value of a shunt calibration resistor requires knowledge of the characteristics of the selected accelerometer and its operating conditions. When a resistor

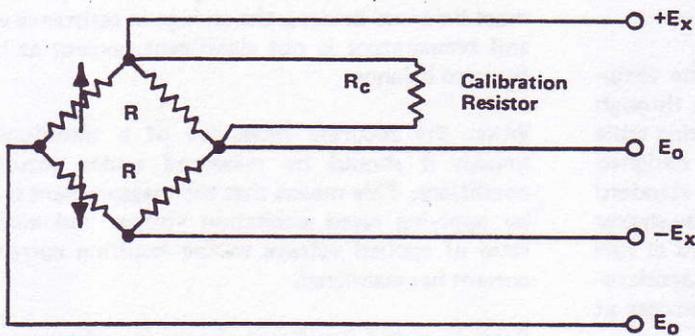


Figure 8-4. Shunt calibration.

is connected to the calibration wires of a bridge, as shown in Figure 8-4, the output voltage increases in an approximately inverse proportion to the value of the resistor.

In ENDEVCO® accelerometers, the fixed resistors  $R_g$  are normally 1000 ohms  $\pm$  1%. The desired change in output voltage is:

$$E_o = S G n \text{ Volts} \quad (8-4)$$

Where:

- S = Sensitivity of the transducer in Volts per g
- G = Full Scale acceleration in g
- n = Fraction of Full Scale

The value of the external shunt calibration resistor is:

$$R_c = \frac{R}{4} \left( \frac{E_x}{E_o} - 2 \right) \text{ Ohms} \quad (8-5)$$

Where:

- R = Value of internal fixed resistor in Ohms
- $E_x$  = Excitation voltage in Volts
- $E_o$  = Change in output voltage desired

### 8.10.2 Voltage Insertion Calibration

Any piezoresistive transducer may be calibrated by the voltage insertion method. This technique, as with the shunt

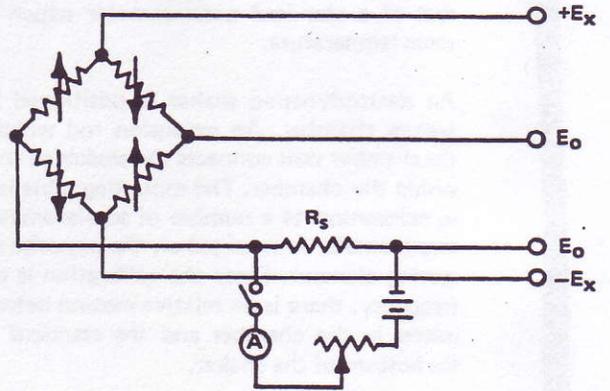


Figure 8-5. Voltage insertion calibration.

calibration method, is a passive calibration that provides a continuity check for the transducer, amplifier, and readout system. In addition, the output signal may be used as a reference level for data reduction at a later time.

The circuit for the voltage insertion method is shown in Figure 8-5. The resistor,  $R_s$ , connected in series with one of the output leads is typically 100 ohms. It should have a value significantly less than the input resistance of the following amplifier or readout equipment. The voltage produced across the resistor appears at the output terminals. Errors due to line voltage drop are avoided by using a precision resistor, measuring the current through the resistor, and calculating the actual voltage inserted. The calibrate voltage supply must not be grounded to the same ground as the transducer excitation voltage supply.

### 8.11 Sinusoidal Calibration for Shock Measurement

Sinusoidal calibrations may be used to verify the suitability of an accelerometer for making shock motion measurements at certain accelerations and pulse durations. Sinusoidal amplitude linearity calibrations must be performed at accelerations up to the peak acceleration expected in the shock measurement application. This amplitude calibration need be performed only at a single frequency within the rated frequency range for the acceleration. The frequency range is determined by the Fourier frequency components corresponding to the particular shock motion pulse. For certain shock motions of very high acceleration of special pulse shapes and durations, it may not be possible to use sinusoidal calibrations to verify accelerometer suitability. When this is the case, shock motion excitation should be used in the calibration. For example, a shock calibration should be performed for peak accelerations in excess of 500 g and pulse durations of less than 1 millisecond.

# Reference 2

ENDEVCO PRODUCT DATA



MODELS 2262-25  
2262C-25

±25g

LOW G  
PIEZORESISTIVE  
ACCELEROMETERS

The Models 2262-25 and 2262C-25 Accelerometers are designed to measure a broad variety of long duration, low level acceleration phenomena. Endeveco PIEZITE® Type P-11 elements are employed in a full bridge circuit to obtain a high level output of ±500 millivolts at ±25 g full scale. This output is high enough to drive most tape recorders and low frequency galvanometers directly without amplification. The Model 2262C is a 6-wire device that uses a pair of fixed resistors in half the bridge to present a fixed resistance to the extra pair of leads for shunt calibration techniques.

Although the rated range of these transducers is ±25 g, they may be used to ±50 g. A unique system of overrange stops (U.S. Pat. No. 3,474, 526) limits the movement of the seismic element allowing the units to withstand up to 80 times their rated range without calibration shift. The use of subcritical viscous damping extends their useful frequency range and reduces the effect of spurious, high frequency vibrations.

Typical applications for these accelerometers include transportation environment testing, transient accelerations on large structural members, and combined environments of steady state acceleration plus transient inputs.



ACTUAL SIZE

**SPECIFICATIONS FOR MODEL 2262-25 and 2262C-25 ACCELEROMETERS**

(According to ANSI and ISA Standards)

**DYNAMIC**

Rated Range  
Useful Range  
Overrange Limiting  
Sensitivity (at 10.00 V dc)  
Mounted Natural Frequency  
Frequency Response<sup>2</sup>

**MODEL 2262-25**

−25 to +25 g  
−50 to +50 g  
±60 to ±150 g<sup>1</sup>  
20 mV/g, nominal  
2500 Hz, nominal  
±5%, 0 to 750 Hz at 75°F (24°C);  
−35%/+10%, nominal at 0°F/200°F  
and 750 Hz.

**MODEL 2262C-25**

−25 to +25 g  
−50 to +50 g  
±60 to ±150 g<sup>1</sup>  
10 mV/g, nominal  
2500 Hz, nominal  
±5%, 0 to 750 Hz at 75°F (24°C);  
−35%/+10%, nominal at 0°F/200°F  
and 750 Hz.

Damping Ratio  
Transverse Sensitivity  
Linearity and Hysteresis  
Thermal Sensitivity Shift

0.7 nominal at 75°F  
3% maximum<sup>3</sup>  
±1% of reading, maximum, to ±25 g;  
±3% of reading, nominal, to ±50 g.  
−4%/0/−9%, nominal, at 0°/75°/200°F

**ELECTRICAL**

Excitation<sup>4</sup>  
Input Resistance (at 75°F)  
Output Resistance (at 75°F)  
Zero Measurand Output  
Thermal Zero Shift  
Insulation Resistance<sup>5</sup>

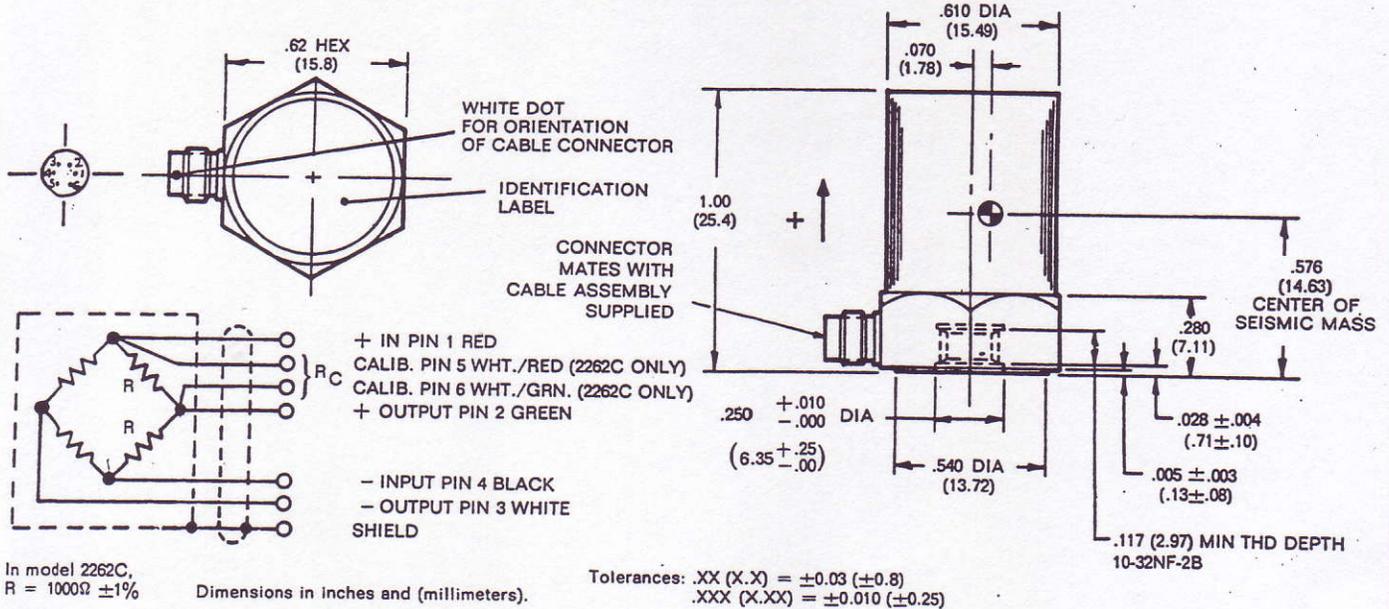
10.00 V dc  
2100 Ω, nominal  
1400 Ω, nominal  
±25 mV maximum at 10.00 V and 75°F  
±15 mV, maximum at 0°F and +200°F,  
reference 75°F  
100 MΩ, minimum

10.00 V dc  
1000 Ω, nominal  
1000 Ω, nominal  
±25 mV maximum at 10.00 V and 75°F  
±15 mV, maximum at 0°F and +200°F,  
reference 75°F  
100 MΩ, minimum

**NOTES:**

- <sup>1</sup>Unit output is continuous between rated range and the effective limit point, with performance to ±50 g as noted.
- <sup>2</sup>Response is ±5%, 0 to 175 Hz, over the temperature range of 0°F to 200°F.
- <sup>3</sup>Worst case error in any axis perpendicular to the sensitive axis. 1% selection is available on special order.
- <sup>4</sup>Unit is calibrated at 10.00 V dc. Lower excitation voltages may be employed but should be specified at time of order to obtain best thermal compensation. Warmup time to meet all specifications is 1.5 minutes, maximum. Endeveco® Model 4203 or 4204 Power Supplies, or Model 4470 Signal Conditioner are recommended as the excitation source.
- <sup>5</sup>Measured with 100 V dc maximum, all leads to case. Cable shield is common to case.

**SPECIFICATIONS FOR MODEL 2262-25 and 2262C-25**



**PHYSICAL**

**WEIGHT** 28 gram (1 oz.), nominal, plus cable at 6 gram (0.2 oz.) per foot.  
**MATERIAL** Stainless Steel  
**SENSING ELEMENTS** PIEZITE® Type P-11  
**MOUNTING** Tapped hole for 10-32 x 1/8" stud.  
 Recommended mounting torque: 18 in.-lb. (2 Nm).

**ELECTRICAL CONNECTION** Integral 6-pin connector.

**ACCESSORIES INCLUDED**

2262-25: Model 2981-3 Mounting Stud (10-32), or Model 2981-4 (M5 metric).  
 Model 3022A-30 Cable Assembly, 4-conductor, shielded, 30 inches long, with accelerometer mating connector.  
 2262C-25: Model 3023A-30 Cable Assembly, 6-conductor, shielded, 30 inches long, with accelerometer mating connector.

**ENVIRONMENTAL**

**ACCELERATION LIMITS** Static: 2000 g, in any direction  
 Vibration: 1000 g pk, in any direction  
 Shock: 2000 g, in any direction

**TEMPERATURE RANGE** Operating: 0°F to +200°F (-18°C to +93°C)  
 Non-operating: -20°F to +220°F (-29°C to +104°C)

**HUMIDITY** Hermetically sealed by glass to metal fusion and welding.

**BASE STRAIN SENSITIVITY** 0.05 equivalent g, maximum, at 250 μ in./in. strain.

Continued product improvement necessitates that Endevco reserve the right to modify these specifications without notice.

**RELIABILITY:** Endevco maintains a program of constant surveillance over all products to ensure a high level of reliability. This program includes attention to reliability factors during product design, the support of stringent Quality Control requirements, and compulsory corrective action procedures. These measures, together with conservative specifications, have made the name Endevco synonymous with reliability.

**CALIBRATION:** Each unit is calibrated at room temperature for sensitivity, input resistance, output resistance, maximum transverse sensitivity and zero measurand output. Temperature response at approximately 0°F, +75°F, +200°F, shock calibration and other calibrations are available on special order. See Calibration Bulletin No. 301.

U.S. Patent Nos. 3,351,880, 3,474,526 and 3,629,773 apply to this transducer.



RANCHO VIEJO ROAD · SAN JUAN CAPISTRANO, CA 92675 · TELEPHONE (714) 493-8181

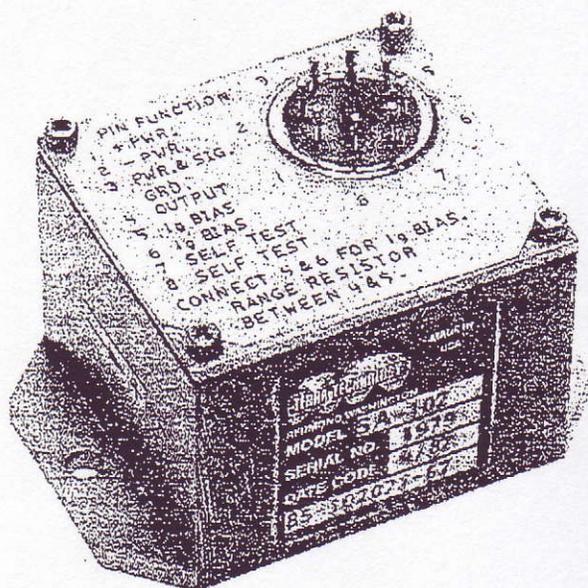
# Reference 3

**TERRA**  
TECHNOLOGY CORP.

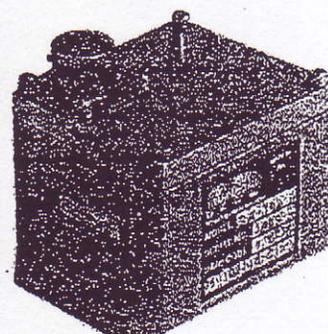
**SERVO**



**TERRA  FLEX® MODELS SA-102 & SA-111**



U.S. Patent No. 4,088,027



Shown with Optional Connector

- Rugged, Fluid Damped Flexure Suspension
- Low Thermal Coefficient
- Field Rangeable
- User Connectable 1g Bias
- Excellent Bias Stability

- Choice of Sensitive Axis
- Broad Dynamic Range
- Low Output Impedance
- Wide Frequency Response
- Choice of Header or MS Connector

Terra  Flex® SA Series Servo Accelerometers offer the unparalleled combination of excellent stability and ruggedness. Designed for maximum user flexibility, standard features include field rangeability, choice of sensitive axis direction, and a 1g bias network which can be user connected.

A special alloy flexure system and stable differential electronic detector/amplifier are combined to provide high sensitivity, broad dynamic range, ruggedness, long term stability and extremely low thermal drift. Essentially no hysteresis (<0.005%) and exceptional resolution ensures accurate data.

The flexure suspension, unlike pivot and jewel suspensions, is not subject to progressive deterioration in the presence of vibration and shock. High shock tolerance virtually eliminates breakage during handling. (Common with quartz suspensions).

The SA Series accelerometers operate from a wide range of input voltages and can be used for a variety of acceleration measurement applications. These applications include seismic monitoring, control systems, vibration monitoring, structural response, vehicle testing and tilt sensing.

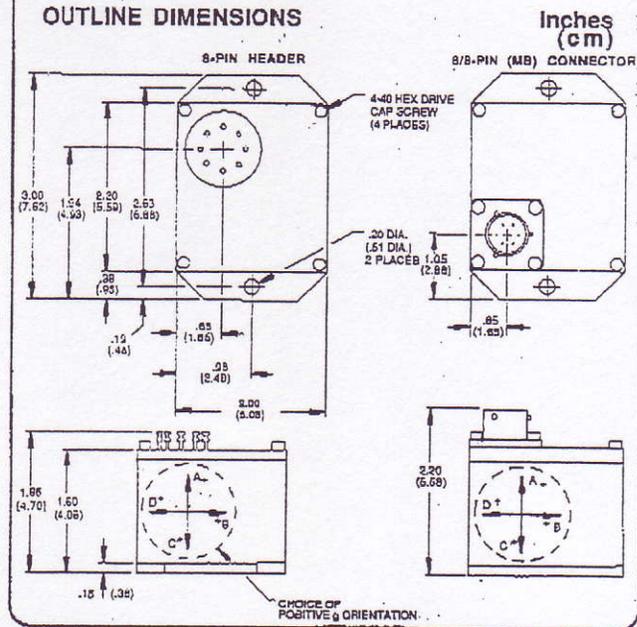
**SPECIFICATIONS FOR SA-102, SA-111**

<b>RANGE:</b> <sup>(1)</sup>	..... ±0.1 to ±5g	
<b>FULL SCALE OUTPUT:</b> <sup>(2)</sup>	..... ±5 VDC (std) to ..... ±10 VDC (max), ±1.0%	
<b>INPUT VOLTAGE:</b>	..... ±12 VDC (std); ..... ±9 to ±18 VDC (special order)	
<b>INPUT CURRENT:</b>	..... +15 mA, -8 mA (max)	
<b>OUTPUT IMPEDANCE:</b>	..... < 10 Ω	
<b>LINEARITY ERROR:</b>	..... < 0.05 % full scale	
<b>HYSTERESIS:</b>	..... < 0.005 % full scale	
<b>RESOLUTION:</b>	..... < 0.0005 % full scale	
<b>TURN-ON REPEATABILITY:</b> <sup>(3)</sup>	..... < 50 μg (DC)	
<b>CROSS AXIS SENSITIVITY:</b>	..... < 0.0005 g/g	
<b>FREQUENCY RESPONSE:</b> <sup>(4)</sup>	..... DC to 50 Hz, ..... damping ratio 0.7 ±0.1 (-1.6 dB to ..... -4.1 dB at the natural frequency).	
<b>NOISE:</b> <sup>(3)</sup>	0-50 Hz	< 5 μg (peak-to-peak)
	0-1000 Hz	< 10 μg (peak-to-peak)
	0-1 MHz	< 20 μg (peak-to-peak)
<b>SELF-TEST RESPONSE:</b>	..... 1.0 V/V, ±10%	
<b>CASE ALIGNMENT:</b>	..... < 0.5°	
<b>OPERATING TEMP. RANGE:</b>	..... -25°C to 85°C (std); ..... -55°C to 125°C (special order)	
<b>SHOCK:</b>	..... 500g, 5 msec; 3000g, 0.1 msec	
<b>VIBRATION (SINE, PEAK):</b>	..... 15g, 20-100 Hz; ..... 25g, 100-2000 Hz	
<b>WEIGHT:</b>	..... 7 oz (0.2 kg)	
<b>BIAS, HORIZONTAL:</b> <sup>(3)</sup>	<b>SA-102</b>	<b>SA-111</b>
	0.010g	0.005g
<b>BIAS, VERTICAL:</b> <sup>(3)</sup>	0.020g	0.010g
<b>HORIZ. BIAS TEMP. COEFFICIENT:</b>	90 μg/°C (max)	35 μg/°C (max)
<b>SCALE FACTOR TEMP. COEFFICIENT:</b>	180 ppm/°C (max)	90 ppm/°C (max)

**NOTES**

- (1) Units are internally ranged to 0.05g. External resistors added to increase range. Standard ranges are: ±0.1, 0.25, 0.5, 1.0, 2.0, and 5.0g. Asymmetrical and fixed range units available with factory installed internal resistors.
- (2) Full scale output should not exceed 10 VDC or 75% of input voltage, whichever is smaller.
- (3) Based on 1g range with 50 Hz natural frequency. Changing range or natural frequency can affect these specifications.
- (4) Standard factory settings of natural frequency can be from 20 Hz to 75 Hz. Tolerance on natural frequency is ±10%. Units with higher natural frequencies also available. Contact factory.

**OUTLINE DIMENSIONS**



**CONNECTIONS**

8-PIN HEADER (Standard)	CONNECTORS (MS) (Optional)		DESCRIPTION
	6-pin <sup>0</sup>	8-pin	
1	A	A	+ Power
2	B	B	- Power
3	C	C	Power & Sig. Grd
4 <sup>Δ</sup>	D	D <sup>Δ</sup>	Output
5 <sup>*Δ</sup>	N/A	E <sup>Δ</sup>	1g Bias
6 <sup>*</sup>	N/A	F <sup>*</sup>	1g Bias
7	E	G	Self-Test
8	F	H	Self-Test

- \* Jumper pins 5 & 6 for 1g bias, no connection for horizontal operation.
- Δ Range resistor connected between pins 4 (D) and 5 (E).
- 0 1g bias and range change not applicable.

**PERFORMANCE OPTIONS**

- A. NON-STANDARD RANGE: ..... (Specify)
- B. CASE ALIGNMENT: ..... 1/4°
- C. INITIAL BIAS: ..... 0.002g (horizontal)  
..... 0.005g (vertical)
- D. HORIZ. TEMP. COEF.: ..... 18 μg/°C (SA-111 only, not applicable to vertical bias).
- E. SCALE FACTOR TOLERANCE: ..... ±0.5% or ±0.1%
- F. SELF-TEST TOLERANCE: ..... ±2.0%

Specifications reflect standard configurations. When ordering specify: model no., input voltage, frequency, g-range, positive g orientation and performance options. Contact factory for custom designs. Because Terra Technology continually strives to improve its products, the specifications printed here are subject to change.

**WARRANTY** - TERRA warrants equipment of its own manufacture to be free from defects in material and workmanship, under normal conditions of use and service, and will replace any component found to be defective, on its return to TERRA, transportation charges prepaid, within one year of its original purchase. TERRA will extend the same warranty protection on accessories which is extended to TERRA by the original manufacturer. TERRA also assumes no liability, express or implied, beyond its obligation to replace any component involved. Such warranty is in lieu of all other warranties express or implied.



A Subsidiary of Rochester Instrument Systems, Inc.  
3860 14th Avenue, N.E., Redmond, Washington 98052 USA  
Phone: (206) 883-7300 Telex: 15-2070 FAX: (206) 882-1412



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# Reference 4

**2100 SYSTEM**

**Strain Gage Conditioner  
and  
Amplifier System**

*Instruction Manual*

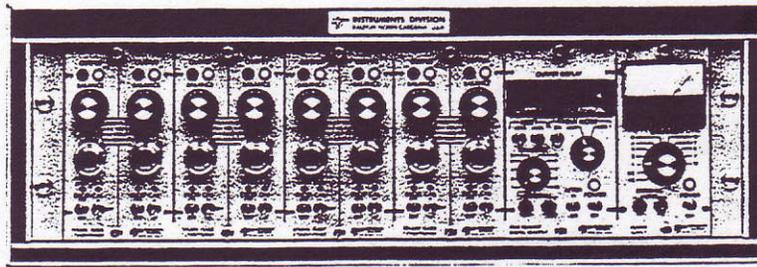


**INSTRUMENTS DIVISION  
MEASUREMENTS GROUP, INC.**

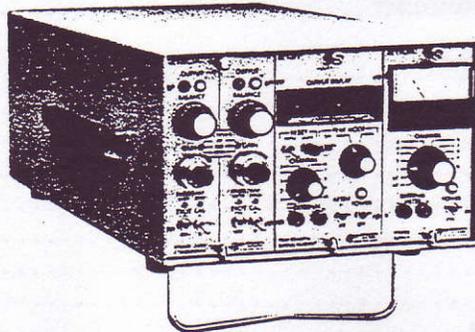
P.O. BOX 27777, RALEIGH, NORTH CAROLINA 27611, USA  
TELEPHONE (919) 365-3800  
FAX (919) 365-3945

**INSTRUCTION MANUAL**  
**MODEL 2100**  
**STRAIN GAGE CONDITIONER AND AMPLIFIER SYSTEM**

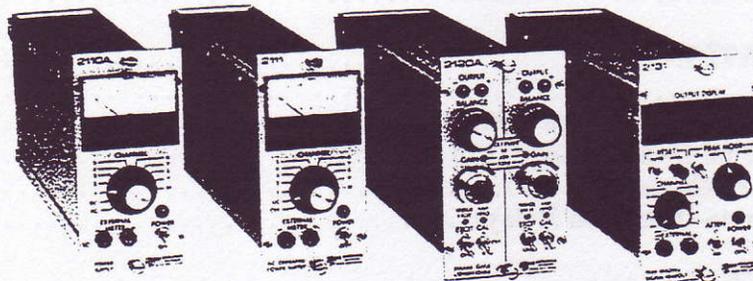
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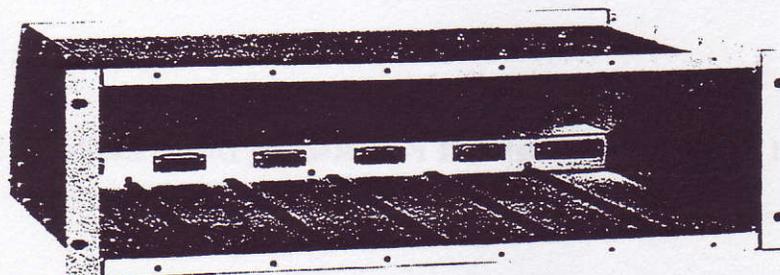
Eight-Channel 2100 System



Two-Channel System in 2160 Portable Enclosure



Left to Right: 2110A Power Supply Module, 2111 Power Supply Module, 2120A Conditioner Module, 2131 Digital Display



2150 Ten-Channel Rack Adapter

## 1.0 DESCRIPTION

### 1.1 GENERAL

The Series 2100 modules comprise a multi-channel system for generating conditioned high-level signals from strain gage inputs for display or recording on external equipment. A system would be comprised of:

- a) One or more two-channel 2120A Strain Gage Conditioners.
- b) One or more 2110A Power Supplies (each Power Supply will handle up to ten channels; i.e., five 2120A Conditioner/Amplifiers).  
Optionally, one or more 2111 DC-Operated Power Supplies (each 2111 module is capable of powering up to eight channels; i.e., four 2120A Conditioner/Amplifiers; or up to ten channels when maximum bridge voltage and output current are not required).
- c) One or more rack adapters or cabinets, complete with wiring, to accept the above modules.

### 1.2 SIGNIFICANT FEATURES

The principal features of the system include:

- Independently variable and regulated excitation for each channel (0.5 to 12 Vdc).
- Fully adjustable calibrated gain from 1 to 2100.
- Bridge-completion components to accept quarter- (120 $\Omega$ , 350 $\Omega$  and 1000 $\Omega$ ), half- and full-bridge inputs to each channel.
- LED null indicators on each channel — always active.
- 100 mA output.
- All supplies and outputs short-circuit proof with current limiting.
- Compact packaging — ten channels in 5.25 x 19 in (133 x 483 mm) rack space.

## 2.0 SPECIFICATIONS

All specifications are nominal or typical at +23°C unless noted.

### 2.1 2120A STRAIN GAGE CONDITIONER

NOTE: These specifications apply for each of two independent channels per module.

**INPUTS:**

**Input Impedance:** >100 M $\Omega$  (balance limit resistor disconnected).

**Source Current:**  $\pm 10$  nA typical;  $\pm 40$  nA max.

**Configuration:** Two- to seven-wire to accept quarter-, half-, or full-bridge strain gage or transducer inputs. Internal half bridge, dummy 350 $\Omega$  and dummy 120 $\Omega$  completion gages and three-wire calibration capability provided. See 4.3c for dummy 1000 $\Omega$  provision.

**Protection:** Input is protected from damage of inputs up to  $\pm 50$ V differential or  $\pm 25$ V common mode.

### AMPLIFIER:

**Gain:** 1 to 2100; continuously adjustable; direct reading. Gain steps X2, X20, X200; with ten-turn counting knob, X0.5 to X10.50  $\pm 1\%$  typical.

### Frequency Response (min):

Normal Range:

dc to 15 kHz: -3 dB at all gain settings and full output.

dc to 5 kHz: -0.5 dB at all gain settings and full output.

Extended Range: (configured by internal jumper — see 6.1c).

dc to 50 kHz: -3 dB at all gain settings and full output.

dc to 17 kHz: -0.5 dB at all gain settings and full output.

**Noise RTI\*:** (350 $\Omega$  source impedance)

1  $\mu$ V p-p at 0.1 Hz to 10 Hz;

2  $\mu$ V p-p at 0.1 Hz to 100 Hz;

2  $\mu$ Vrms at 0.1 Hz to 50 kHz.

**Noise RTO\*\*:**

50  $\mu$ V p-p at 0.1 Hz to 10 Hz;

80  $\mu$ V p-p at 0.1 Hz to 100 Hz;

100  $\mu$ Vrms at 0.1 Hz to 15 kHz;

200  $\mu$ Vrms at 0.1 Hz to 50 kHz.

**Temperature Coefficient of Zero:**

$\pm 1$   $\mu$ V/ $^{\circ}$ C RTI,  $\pm 210$   $\mu$ V/ $^{\circ}$ C RTO;

-10 $^{\circ}$  to +60 $^{\circ}$ C (after 30 minute warm-up).

**Common-Mode Rejection:** (dc to 60 Hz)

Gain Multiplier	CMR (dB)
X2	67
X20	87
X200	100

**Output Range:**  $\pm 10$ V (min) at  $\pm 100$  mA; current limited at  $\leq 140$  mA.

**Capacitive Loading:** Up to 0.15  $\mu$ F.

### EXCITATION:

**Type:** Constant voltage.

**Range:** 0.5 to 12 Vdc (continuously adjustable for each channel) with 120 $\Omega$  full-bridge load.

**Short-Circuit Current:** Less than 40 mA max.

**Noise:**  $\pm 2$  mV p-p dc to 20 kHz.

**Load Regulation:**  $\pm 0.2\%$  no-load to 120 $\Omega$  load (10% line change).

### BALANCE:

**Method:** Potentiometric.

**Range:**  $\pm 2000$   $\mu$  $\epsilon$ ,  $\pm 4000$   $\mu$  $\epsilon$  or  $\pm 6000$   $\mu$  $\epsilon$  (quarter, half or 350 $\Omega$  full bridge) ranges selected or disabled by internal jumpers.

\*Referred to input      \*\*Referred to output.

**CALIBRATION:** Controls: Two-position (center off) toggle switch.

**Standard Factory-Installed Resistors:** (174.8 K $\Omega$   $\pm$ 0.1%) simulate  $\pm$ 1000 $\mu\epsilon$  at GF=2.

**Optional Calibration Relays:** Provides remote operation of excitation (off/on) and shunt calibration.

Relays are powered by user-supplied voltage source, and must be specified when ordering rack adapters or cabinets.

**SIZE:** 5.25 H x 2.94 W x 10.97 D in  
(133 x 75 x 279 mm).

**WEIGHT:** 2.2 lb (1.0 kg).

## 2.2 2110A POWER SUPPLY (AC-OPERATED)

**OUTPUTS:**  $\pm$ 15 Vdc at 1.2A and +17.5 Vdc at 1.1A; all regulators current-limited against overload.

**INPUT:** 107, 115, 214, 230 Vac  $\pm$ 10% (selected internally); 50-60 Hz.

Power: 40W typical, 100W max.

**METER:** 0 to 12 Vdc (with switch) to read bridge excitation.

Also ac input and dc output go/no-go monitor.

**SIZE:** 5.25 H x 2.44 W x 12.34 D in  
(133 x 62 x 313 mm).

**WEIGHT:** 6.7 lb (3.1 kg).

## 2.3 2111 DC-OPERATED POWER SUPPLY

**OUTPUT:**  $\pm$ 15 Vdc at 1.0A and +17.5 Vdc at 1.0A; outputs are protected against overload.

**INPUT:** 12 Vdc nominal (9 to 18 Vdc range). Power 60W max; 78% efficiency at full load.

**Reverse Polarity Protection:** Internal shunt diode.

**METER:** 0 to 12 Vdc (with switch) to read bridge excitation.

dc output go/no-go monitor.

**SIZE:** 5.25 H x 2.44 W x 12.34 D in  
(133 x 62 x 313 mm).

**WEIGHT:** 3.0 lb (1.4 kg).

## 2.4 2150 RACK ADAPTER

**APPLICATION:** Fits standard 19-in (483-mm) electronic equipment rack.

Accepts one Power Supply and one to five Strain Gage Conditioners.

Completely wired.

**POWER:** 2-ft (0.6-m) three-wire line cord; 10-ft (3-m) extension available.

Fuse: 1A size 3 AG (32 x 6.4 mm dia.).

Receptacle to accept line cord from adjacent 2150 Rack Adapter.

**SIZE:** 5.25 H x 19 W x 14.17 D in overall  
(133 x 483 x 360 mm)

**WEIGHT:** 6.6 lb (3.0 kg).

## 2.5 2160 PORTABLE ENCLOSURE

**DESCRIPTION:** Completely self-contained adapter and cabinet with all wiring for two or four channels.

Accepts one Power Supply and one or two Strain Gage Conditioners.

**POWER:** 8-ft (2.4-m) detachable three-wire cord.

Fuse: 1A size 3 AG (32 x 6.4 mm dia.).

**SIZE:** 5.55 H x 8.75 W x 13.80 D in  
(141 x 222 x 350 mm).

**WEIGHT:** 5.2 lb (2.4 kg).

### 3.0 CONTROLS

#### 3.1 2110A/2111 POWER SUPPLIES

**BRIDGE VOLTS Meter** Displays the voltage on each input bridge (as selected by CHANNEL selector). Also used to monitor ac line and dc outputs of Power Supply (see below).

**CHANNEL Selector** Positions 1 to 10 select channel to display bridge excitation on Meter ("1" is channel farthest to left in cabinet, etc).

The DC position monitors a mixed output from the +15, -15, and +17.5V power supplies and should always read on the "DC" line at "10" on the Meter. The AC position (2110A only) monitors the peak-to-peak ac line input (at a fixed transformer tap). A reading anywhere in the band from 9 to 11 on the Meter indicates that the input voltage is proper for the selected transformer tap (see 4.1e). No reading indicates the equipment is ungrounded.

**EXTERNAL METER Jacks** Supplies Meter voltage to an external meter if desired for more precise adjustment of bridge supply voltages.

**POWER Switch** The central power switch for this supply and all Conditioners connected to it. (The pilot lamp may take several seconds to extinguish when the power is turned off.)

#### 3.2 2120A STRAIN GAGE CONDITIONER (one channel described; both identical and independent).

**OUTPUT Lamps** LED indicators always monitoring amplifier output. Primarily used to adjust AMP ZERO and Bridge BALANCE. (Fully lit with 0.07V output.)

**BALANCE Control** A ten-turn potentiometer to adjust bridge balance. Normal range  $\pm 2000 \mu\epsilon$ . (See 4.12a to extend range.) EXCIT must be ON to set bridge balance.

**GAIN Controls** **Multiplier Switch:** Provides gain steps of X2, X20 and X200.

**Potentiometer:** Ten-turn with counting knob provides multiplier of 0.50 to 10.50.

Total amplifier gain is the product of the multiplier switch and potentiometer settings.

**BRIDGE EXCIT Control** A 25-turn trimmer to adjust bridge excitation from 0.50 to 12 Vdc. The actual setting is monitored on the Meter and the EXTERNAL METER jacks on the Power Supply (the proper channel must be selected).

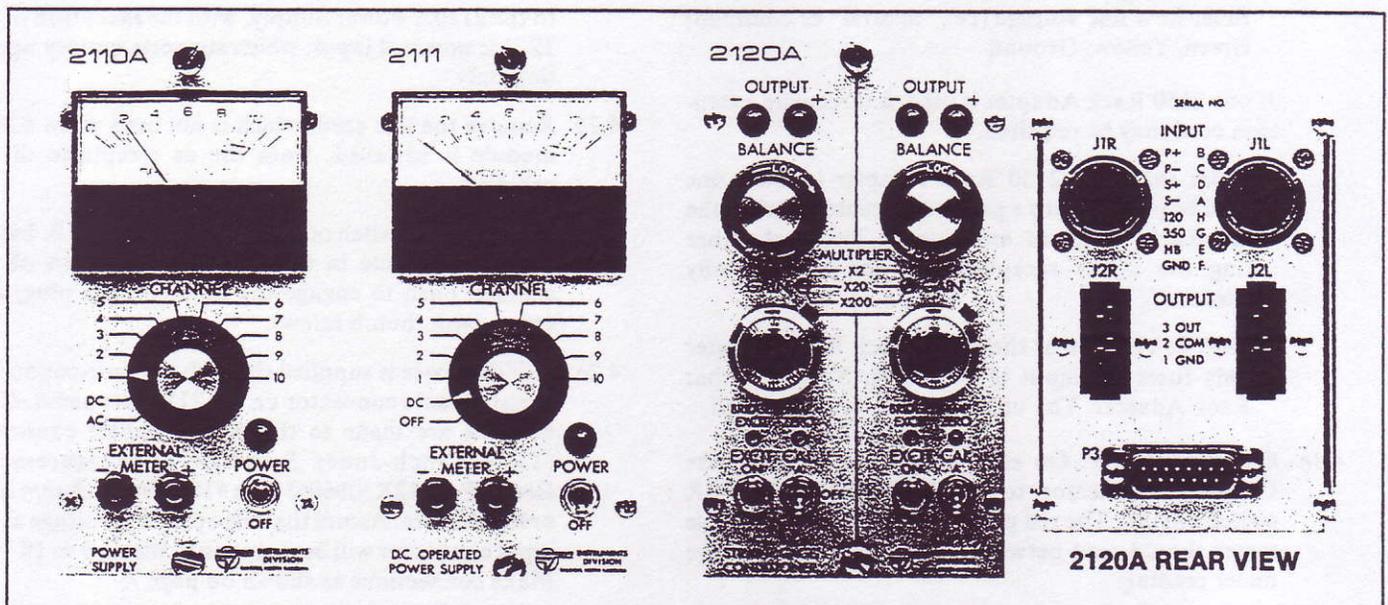
**AMP ZERO Control** A 25-turn trimmer used to set the electrical "Null" of the input amplifier zero. (EXCIT should be OFF and the input circuit connected when this is done.)

**EXCIT Switch** A toggle switch controlling the excitation to the input bridge. (Any amplifier output with EXCIT at OFF is dc amplifier offset, thermal EMF from the bridge or ac pickup in the wiring.)

**CAL Switch** A two-position (with center off) toggle switch to shunt-calibrate the input bridge. As delivered, "A" simulates  $+1000 \mu\epsilon$ , and "B" simulates  $-1000 \mu\epsilon$  by shunting the internal 350 $\Omega$  half bridge. Other shunt calibration configurations are possible by internal resistor and jumper changes (see 5.0 Shunt Calibration).

**INPUT Receptacle (Rear Panel)** A ten-pin quarter-turn connector to connect input gage(s). (Quarter, half and full bridges can be accepted simply by using the appropriate pins. See 4.3c for details.) Mating connector supplied.

**OUTPUT Receptacle** A three-pin connector delivers the amplifier output ( $\pm 10V$  at  $\pm 100$  mA). Mating connector supplied.



## 4.0 OPERATING PROCEDURES

### 4.1 SETUP AND AC POWER

- 4.1a The individual Conditioner and Power Supply modules are not stand-alone instruments. They are designed to plug into a prewired cabinet or rack adapter which (1) supplies ac line power (fused) to the Power Supply, (2) distributes dc regulated voltages to all Conditioners and (3) connects the bridge voltage monitoring meter in the Power Supply to the various channels.

If one or more 2150 ten-channel Rack Adapters are used, these should be mounted in a standard 19-in (483-mm) equipment rack; 5.25 in (133 mm) vertical height is required for each ten channels.

- 4.1b Before installing a 2110A Power Supply module in each cabinet or rack adapter, check that each 2110A module is set for the proper ac line voltage:

Slide the right-hand side cover almost all the way back to expose the two toggle switches on the printed-circuit board. One switch, as marked, sets for nominal 115 or 230V; the other sets for NORM line (115/230V  $\pm 10\%$ ) or LOW line (107/214V  $\pm 10\%$ ). Replace side cover.

The POWER switch on the front panel should be at OFF. Install the Power Supply in the right-hand position of the cabinet; push in to engage the input/output plug, and secure the thumb screws.

- 4.1c Install 2120A Conditioners in the remaining positions in the cabinet. Push the modules in to engage the power-input plugs, and secure the thumb screws. (Blank covers are available for unused positions.)
- 4.1d Plug the line cord into an ac receptacle, making certain that the third pin goes to a good ground. The equipment must be grounded for best performance.

**NOTE:** If the line plug must be replaced with a different type, observe this color code when wiring the new plug:

Brown: High line voltage  
Blue: Low line voltage (i.e., "neutral" or common)  
Green/Yellow: Ground

If one 2150 Rack Adapter is used, a three-wire extension cord may be required.

If more than one 2150 Rack Adapter is used, one should be plugged into a power ac receptacle, while the other Rack Adapters are plugged into each other (using the utility receptacles at the rear) in any sequence.

**NOTE:** The fuse at the rear of each Rack Adapter only fuses the input to the Power Supply in that Rack Adapter. The utility receptacle is not fused.

- 4.1e Check ac power. On each Power Supply, turn the CHANNEL selector to "AC". Turn the POWER switch on (up). The red pilot lamp should light and the meter should read between 9 and 11. If not, observe meter reading:

**Pegs at full scale.** Turn power off immediately. This indicates that the input voltage is much too high for the internal switch settings (probably a 230V input with switches set for 115V; see 4.1b).

**Reads low** (between 8 and 9-1/4). The ac line voltage is significantly below 115V (or 230V). Remove Power Supply and reset internal switch for LOW line.

**Reads around 5.** This indicates that the internal switches are probably set for 230V input, whereas the voltage is actually 115V. Turn POWER OFF, remove module, and set switches (see 4.1b).

**Reads 0** (no reading). Red pilot lamp not lit: The ac receptacle has no power or the fuse (at the rear of the instrument) is open. Pilot lamp lit: Equipment is not properly grounded. Either the third pin was not used, or the receptacle used is not properly grounded.

- 4.1f Check dc power. On the Power Supply, turn the CHANNEL selector to "DC". The meter should read very near the line at 10. If not, this indicates that either (1) there is an internal short in one of the Conditioner modules (remove them one at a time), or (2) one or more of the regulated power supply circuits is defective (see 6.4 *Internal Adjustments*).

- 4.1g Check bridge excitation regulators. Scan the CHANNEL switch through positions 1 to 10; all positions should read some voltage between 0.5 and 12V. (However, switch positions corresponding to channels not installed will, of course, read zero.)

- 4.1h The system is now ready for use. If it is planned to use the system immediately, it is suggested that the POWER be left on (for warm-up); otherwise turn all POWER switches to OFF.

### 4.2 DC POWER

- 4.2a The 2111 module is capable of powering up to eight channels (four Model 2120A modules) at maximum rated bridge voltage and output current or up to ten channels when maximum bridge voltage and output current are not required. The 2111 functions similarly to the 2110A Power Supply, with the exception of the 12 Vdc nominal input, which supports battery operation only.

- 4.2b Remove the line cord, which is not used when a 2111 module is installed, from the ac receptacle of the cabinet.

Set POWER switch on the front panel to OFF. Install the 2111 module in the right-hand position of the cabinet; push to engage the input/output plug, and secure with thumb screws.

- 4.2c 12 Vdc power is supplied through the four-conductor recessed male connector on the 2111 rear panel. Connections are made to the mating female connector (TRW/Cinch-Jones S-404-CCT; Measurements Group P/N 12X300606) with #16 AWG (1.3-mm dia), or larger, wire. Assure that the operating voltage at the input connector will be maintained within 9 to 18 Vdc. Make connections as shown on page 7:

NOTE: Leads marked "R" must be same length and size for best balance and stability.

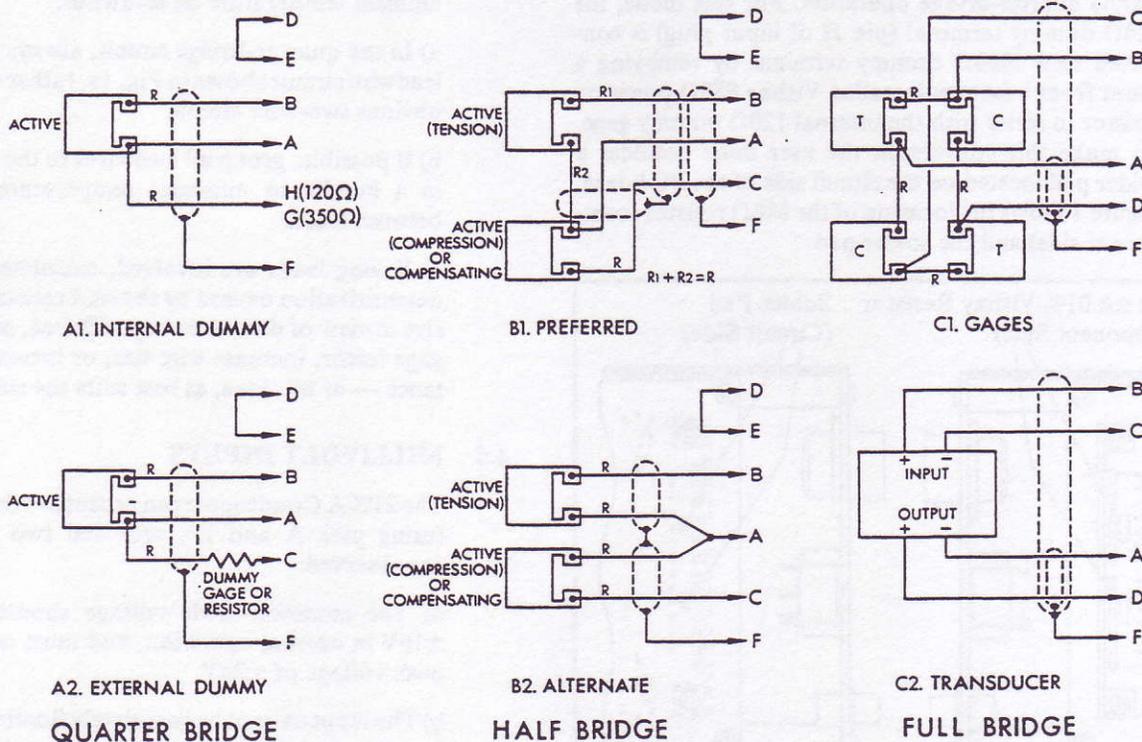


Fig. 1a: Input Circuits

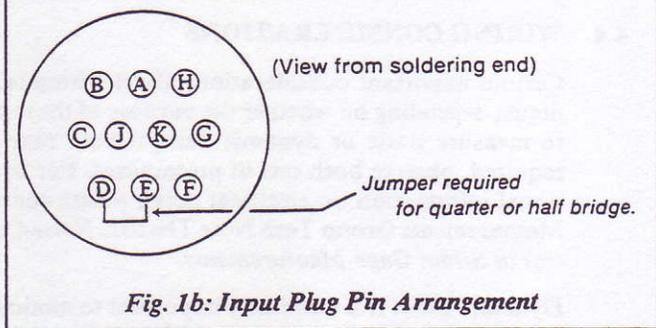
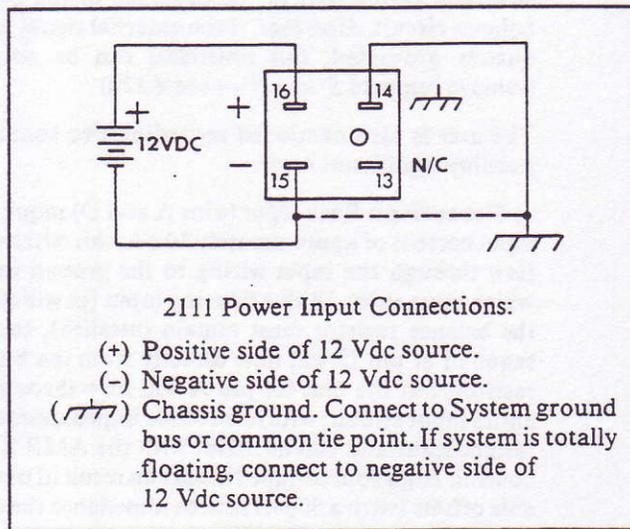


Fig. 1b: Input Plug Pin Arrangement

plugs are desired they are available from Measurements Group, Inc. or through electronic parts distributors.

Measurements Group 12X300515  
ITT/Cannon KPT06B12-10P  
Bendix PT06A-12-10P(SR)

4.2d Turn POWER on and check for proper operation as described in 4.1f through 4.1h for the 2110A.

### 4.3 INPUT CONNECTIONS

4.3a It is suggested that the system be turned on and allowed to stabilize while preparing the input connectors; power consumption is negligible. To prevent powering any input circuits at this time, turn the EXCIT toggle switches OFF on all channels.

4.3b Each channel uses a separate (and interchangeable) input plug. Two loose plugs are supplied with each 2120A Conditioner (one per channel). If additional

4.3c Connect the input to each channel, using the connectors supplied, in accordance with Figs. 1a and 1b.

NOTE: Except when using an external full bridge, there must be a jumper in the plug connecting pins D and E; this connects the midpoint of the internal 350Ω half bridge to the S+ amplifier input, thus completing the necessary full bridge for proper amplifier operation.

Generally, no modifications or jumpers are required inside the 2120A Conditioner regardless of the external bridge configuration used. (However, there are provisions for accepting 1000Ω quarter-bridge inputs and for changing the shunt calibration circuit — see the Note on the following page and 5.0 Shunt Calibration, respectively.)

**NOTE:** 2120A Strain Gage Conditioner, with serial numbers above 85000, provide the capability for 1000 $\Omega$  quarter-bridge operation. For this mode, the 120 $\Omega$  dummy terminal (pin H of input plug) is converted to a 1000 $\Omega$  dummy terminal by removing a shunt from a factory-installed Vishay 880 $\Omega$  precision resistor in series with the internal 120 $\Omega$  dummy gage. To make this conversion the user must desolder a solder pad located on the circuit side of the PC board. Figure 2 shows the location of the 880 $\Omega$  resistor (component side) and the solder pad.

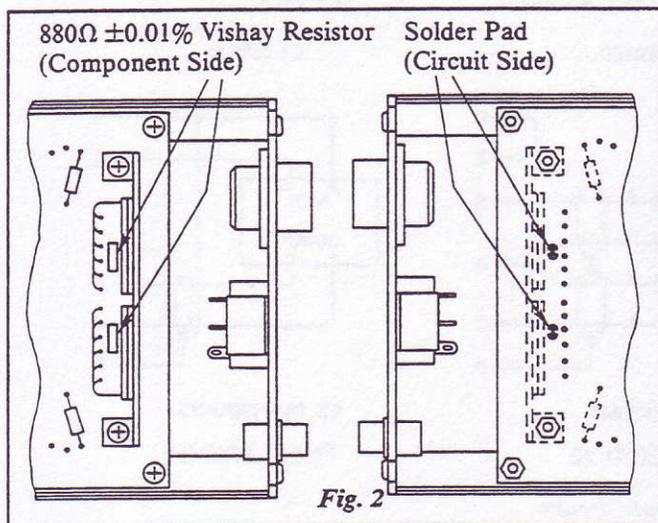


Fig. 2

#### 4.4 WIRING CONSIDERATIONS

Certain important considerations affect wiring technique, depending on whether the purpose of the test is to measure static or dynamic data; if both may be required, observe both sets of precautions. For additional information on electrical noise, please consult Measurements Group Tech Note TN-501, *Noise Control in Strain Gage Measurements*.

**Dynamic Data:** It is extremely important to minimize the electrical noise that the gages and leadwires pick up from the test environment; this noise is usually related to the 50 or 60 Hz line power in the area:

- a) Always use twisted multi-conductor wire (never parallel conductor wire); shielded wire is greatly preferred, although it may prove unnecessary in some cases using short leads.
- b) Shields should be grounded at one (and only one) end; normally the shield is grounded at the INPUT connector and left disconnected (and insulated against accidental grounding) at the gage end. Do not use the shield as a conductor (that is, do not use coaxial cable as a two-conductor wire).
- c) The specimen or test structure (if metal) should be electrically connected to a good ground.
- d) Keep all wiring well clear of magnetic fields (shields do not protect against them) such as transformers, motors, relays and heavy power wiring.
- e) With long leadwires, a completely symmetrical circuit will yield less noise (e.g., a half bridge on or near the specimen will usually show less noise than a true quarter-bridge connection).

**Static Data:** Precise symmetry in leadwire resistance is highly desirable to minimize the effects of changes in ambient temperature on leadwires.

- a) In the quarter-bridge circuit, always use the three-leadwire circuit shown in Fig. 1a, rather than the more obvious two-wire circuit.
- b) If possible, group all leadwires to the same channel in a bundle to minimize temperature differentials between leads.
- c) If long leads are involved, calculate the leadwire desensitization caused by the lead resistance. If excessive in view of data accuracy required, adjust effective gage factor, increase wire size, or increase gage resistance — or all three, as best suits the situation.

#### 4.5 MILLIVOLT INPUTS

The 2120A Conditioner can accept low-level dc inputs, (using pins A and D), provided two requirements are observed:

- a) The common-mode voltage should not exceed  $\pm 10V$  in normal operation, and must never exceed a peak voltage of  $\pm 25V$ .
- b) The input cannot be completely floating; there must be a ground return (generally less than 10 M $\Omega$ ), either external or within the 2120A. In the case of thermocouples welded to a nominally grounded structure, this return is adequate. A ground return exists within the standard 2120A due to the presence of the bridge-balance circuit. However, if the external signal is adequately grounded, this resistance can be removed (remove jumpers P and N — see 4.12a).

The user is also cautioned regarding two sources of possibly significant error:

- a) Bias current: Each input (pins A and D) requires an input current of approximately 10 nA; this current will flow through the input wiring to the ground return, which must exist. With a floating input (in which case the balance resistor must remain installed), the bias required at pin D will flow directly from the balance resistor, but the bias for pin A will flow through the entire input circuit; with low source impedances this is insignificant and can be offset with the AMP ZERO control. High source impedances can result in measurable offsets (with a 5000 $\Omega$  source impedance the offset may approach 0.2 mV RTI).
- b) Any nonsymmetry in the ground returns of the inputs will reduce the CMR of the amplifier to some degree.

#### 4.6 OUTPUT CONNECTIONS

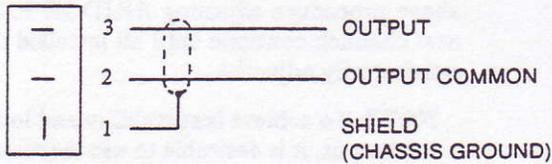
**CAUTION:** If it is possible in any way to damage the indicator or recorder connected to the OUTPUT with inputs of 15V or 140 mA, the OUTPUT should not be connected until the channels have been balanced (see 4.11 and 4.12).

- 4.6a Each channel uses a separate output plug. Two loose plugs are supplied with each 2120A Conditioner (one per channel). If additional plugs are desired they are

readily available from Measurements Group, Inc. or through electronic parts distributors:

Measurements Group 12X300556  
Cinch-Jones P-303-CCT-L

4.6b Three pins are provided for each channel:



It is generally not essential that the output leads be shielded, but with low-level output signals, it is advisable.

Pin 2 is output common, which is connected at one point to chassis-ground (in the cabinet or rack adapter harness). If the OUTPUT is connected to a low impedance device (such as a galvanometer), it is essential that this device be connected between pins 3 and 2; any other connection may cause crosstalk between channels. However, if the output is to be fed into a high impedance device (such as an oscilloscope) which has only a single input pin (plus ground), this input can be connected to pin 3 of the OUTPUT plug with little error (typically 1 mV referred to the output) due to crosstalk between channels; of course a differential input (using pins 3 and 2) is preferred.

4.6c It should be noted that the OUTPUT indicator lamps on the front of the 2120A at all times monitor the voltage between pins 3 and 2 of the OUTPUT receptacle. If both lamps are extinguished, the output voltage is zero (within 7 mV maximum circuit offset). Full brilliance of either lamp indicates a voltage in excess of 70 mV (possibly as high as 15V).

## 4.7 OUTPUT LIMITS

The output is capable of  $\pm 10V$  into a load of  $100\Omega$  or higher. With a load of  $100\Omega$  or lower, the output will deliver up to  $\pm 100$  mA, but in no case greater than 140 mA.

The maximum output can readily be limited to less than 140 mA by increasing the value of two resistors per channel (R34 and R37, normally  $6.2\Omega \pm 5\%$ ).

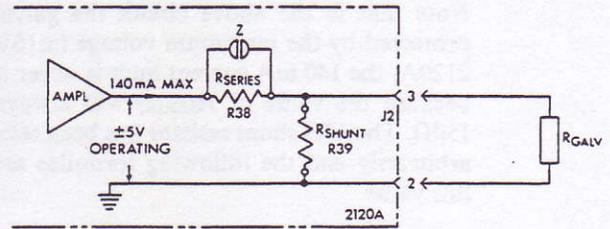
The desired value of R34 and R37 can be calculated with the following formula:

$$R_{C1} = \frac{870}{I_{MAX}} \quad (\text{Eq. 1})$$

where:  $R_{C1}$  = current limit resistor in ohms (R34, R37).  
 $I_{MAX}$  = maximum current output in mA.

## 4.8 GALVANOMETER MATCHING

4.8a Fluid-damped galvanometers are most frequently used due to their high frequency response and simple matching network requirements. A series resistor is always desirable and a shunt resistor must be provided in most cases to keep the peak galvanometer current below the 140 mA output of the 2120A.



If the "maximum safe current" of the galvanometer is less than 140 mA, calculate the shunt resistor:

$$R_{SHUNT} \leq R_{GALV} \times \frac{I_{SAFE}}{140 - I_{SAFE}} \quad (\text{Eq. 2})$$

where:  $I_{SAFE}$  = maximum safe current (mA).

$R_{GALV}$  = input impedance of the galvanometer.

If the maximum safe current is 140 mA or higher, the shunt resistor may be omitted.

(A more conservative solution for most galvanometers with a response below 2 kHz would be to recalculate the above, but for  $I_{SAFE}$  use the maximum required operating current — typically several times the "mA/inch" specification of the galvanometer — rather than the maximum safe current. This will establish the minimum value for  $R_{SHUNT}$ , but do not use a value below  $15\Omega$ . The original solution of Eq. 2 yielded the maximum value. Thus there is a rather large range of values acceptable, but never exceed the value originally calculated.)

Having chosen a value for the shunt resistor, now calculate the series resistor:

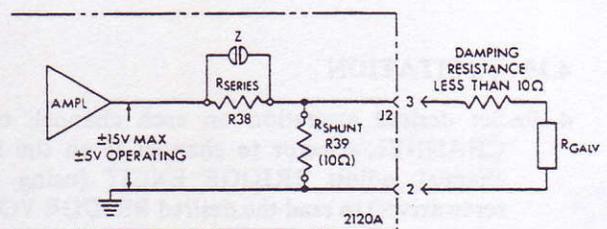
$$R_{SERIES} \cong \frac{\frac{5000}{mA_{FS}} - R_{GALV}}{1 + \frac{R_{GALV}}{R_{SHUNT}}} \quad (\text{Eq. 3})$$

where:  $mA_{FS}$  is the milliamperes required through the galvanometer for the desired full-scale deflection.

In the above equation, if no shunt resistor is used ( $R_{SHUNT} = \infty$ ), the denominator in the fraction is 1.

The series resistor value is never critical; any value within  $\pm 25\%$  of the above solution is adequate. The series resistor is most conveniently mounted as R38 on the 2120A pc board (first open the shorting jumper on the pc board pad Z). The shunt resistor can be located on the pc board as R39.

4.8b Magnetically damped galvanometers, require series "damping" resistors to achieve proper dynamic response. A three-resistor network is usually required:



Note that in the above circuit the galvanometer is protected by the maximum voltage ( $\pm 15V$ ) from the 2120A, the 140 mA current limit is never approached because the value of  $R_{SERIES}$  will always be above  $150\Omega$ . The  $10\Omega$  shunt resistor has been selected rather arbitrarily and the following formulas are based on this value.

$$R_{SERIES} \cong \frac{50 \times 10^6}{\mu A_{FS} (R_{GALV} + R_{DAMP})} \quad (\text{Eq. 4})$$

where:  $\mu A_{FS}$  is the microamperes required through the galvanometer for the desired full-scale deflection.

$R_{DAMP}$  is the specified damping resistance for the galvanometer, in ohms.

$R_{GALV}$  is the input impedance of the galvanometer.

An alternate solution is:

$$R_{SERIES} \cong \frac{50 \times 10^3}{mV_{FS}} \quad (\text{Eq. 5})$$

where:  $mV_{FS}$  is the millivolts required for "damped systems" for the desired full-scale deflection.

Most specification charts for magnetically damped galvanometers list data in  $mV/in$  ( $mV/cm$ ) for damped systems — note that this is the system voltage (including the damping resistor), not just the voltage across the galvanometer.

The series resistor value is never critical; any value within  $\pm 25\%$  of the above solution is adequate. Values will range between  $1000\Omega$  and  $25\,000\Omega$ . The series resistor and shunt resistor are most conveniently mounted as described at the end of 4.8a.

#### 4.9 OPERATION

- 4.9a On each channel make certain that the EXCIT switches are OFF (thus removing excitation to all gage circuits) and the CAL switches are in the center (OFF) position.
- 4.9b If it is possible to damage or overload the indicators or recorders connected to the OUTPUTS with 15 Vdc (or 140 mA for low-resistance devices), the OUTPUT plugs should not be connected at this time.
- 4.9c On the Power Supply module, turn the POWER switch on. The red pilot lamp should light.
- 4.9d On the Power Supply (2110A only) module, set the CHANNEL selector at AC; the meter should read within the AC band.
- 4.9e Turn the CHANNEL selector to DC; the meter should read on the DC check line.

#### 4.10 EXCITATION

- 4.10a Set desired excitation on each channel: turn the CHANNEL selector to channel 1; on the leftmost channel, adjust BRIDGE EXCIT (using a small screwdriver) to read the desired BRIDGE VOLTS on the Power Supply Meter.

If greater accuracy is desired than can be achieved with the built-in meter, connect an external meter to the EXTERNAL METER banana jacks on the Power Supply (the minus jack is nominally chassis-ground).

Turn CHANNEL selector to channel 2 and repeat the above procedure adjusting BRIDGE EXCIT on the next channel; continue until all installed channels are satisfactorily adjusted.

**NOTE:** To achieve best stability and lowest noise at the output, it is desirable to use the maximum excitation that the input to each channel can accept. Small or low-resistance gages or gages bonded to a poor thermal conductor (such as most plastics or composites) must necessarily use low excitation. For additional information on excitation selection, please consult Measurements Group Tech Note TN-502, *Optimizing Strain Gage Excitation Levels*.

- 4.10b Connect the gage INPUT plugs (if not already connected).

#### 4.11 AMPLIFIER ZERO

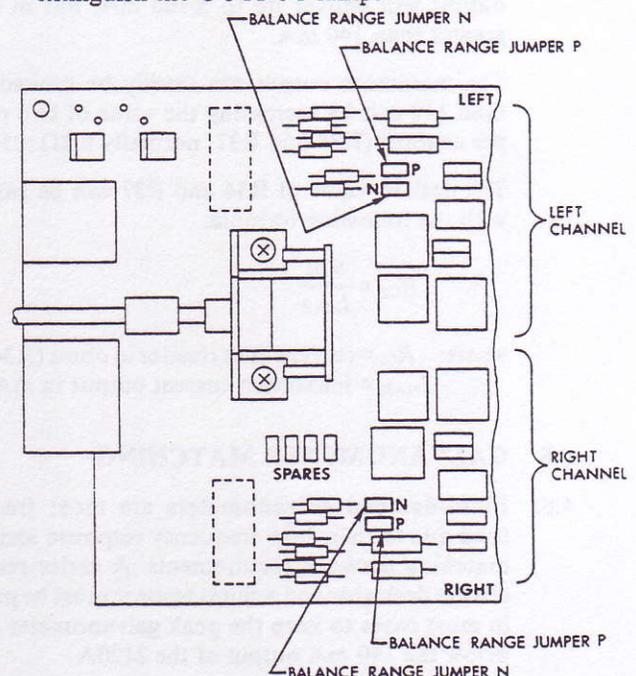
Adjust the AMP ZERO for each channel. (To some extent the amplifier balance is affected by symmetry of the source impedances seen by the amplifier inputs.)

Using a small screwdriver, adjust each AMP ZERO until both OUTPUT lamps are off. (If the "+" lamp is lit, turn the adjustment counterclockwise, etc.)

If, at best null, both lamps are lit, this is an indication of excessive noise (probably 50 or 60 Hz) at the input. Check wire shielding, etc. Refer to 4.4 *Wiring Considerations* for further discussion.

#### 4.12 BRIDGE BALANCE

- 4.12a Adjust balance. For each channel, turn the EXCIT switch to ON; then turn the BALANCE control to extinguish the OUTPUT lamps.



**NOTE:** As delivered, the BALANCE controls can correct for approximately  $\pm 2000\mu\epsilon$  unbalance in a quarter, half or  $350\Omega$  full bridge. With full bridge inputs other than  $350\Omega$ , the balance range will be reduced for lower bridge resistance and increased for higher resistances. For example, with a  $120\Omega$  full bridge, the balance range is reduced to under  $\pm 700\mu\epsilon$ . If the balance range proves inadequate for the gages or transducers in use, the "balance limit resistor" can be changed from  $75\ 000\Omega$  to  $37\ 000\Omega$  by moving the jumper from areas P to area N, thus doubling the balance range. Also, jumpers can be located at both area P and N, thus tripling the original balance range. An extension of the balance range will produce a reduction in the setability of the balance control. This is especially noticeable for strain gages with resistances of  $350\Omega$  and higher. Bridge balance may be disabled by removing both P and N jumpers. Spare or unused jumpers can be stored on the pins next to the right channel gain switch.

- 4.12b Connect OUTPUT plugs for each channel (unless already connected).

#### 4.13 GAIN

- 4.13a Adjust GAIN for each channel. There are two general methods of setting the GAIN control:

a) Mathematical: In many cases it is possible to predict and preset the amplifier gain required. For example, assume the input is one active gage with  $GF=2$  (this will produce  $0.5\ \mu V$  per  $\mu\epsilon$  per volt of excitation) and bridge excitation has been set at 5 Vdc. Further assume that the desired output from the 2120A is 2V for  $500\mu\epsilon$ . At  $500\mu\epsilon$  the bridge will deliver 1.25 mV ( $500\mu\epsilon \times 5V \times 0.5\ \mu V/V/\mu\epsilon = 1.25\ mV$ ). To achieve 2V output from the amplifier will require a gain of 1600 ( $2V/1.25\ mV = 1600$ ). Set the GAIN control at 8.00, and the multiplier switch at X200.

b) Empirical: Without regard to bridge excitation or amplifier output voltage, assume that the desired output is 25-mm deflection on a recorder for a  $500\mu\epsilon$  input. Using shunt calibration (such as the  $1000\mu\epsilon$  built into the 2120A Conditioner), adjust the GAIN as required to achieve the desired deflection — for example, a 50-mm deflection should occur when the  $1000\mu\epsilon$  shunt calibration resistor in the 2120A is selected (assuming  $GF=2$ , for which the calibration resistors are calculated).

In practice, even though the mathematical approach is possible in many situations, the shunt-calibration method should also be used as the final exact adjustment.

The user is cautioned to consider the effects of leadwire resistance and the calibration circuit actually in use when calculating the strain simulated by shunt calibration. See 5.0 *Shunt Calibration*.

- 4.13b All controls are now set. However, just before taking data, it is advisable to check balances on each channel:

a) Briefly turn EXCIT to OFF; if the OUTPUT lamps are not at null (both extinguished) adjust AMP ZERO as necessary. This can be done at any time during a test — and should be done occasionally on an extended test.

b) Under no-load conditions (and with CAL at OFF and EXCIT at ON) the OUTPUT lamps should indicate null; if not, adjust the BALANCE control.

**NOTE:** In both steps above, it may be desirable to observe the output recorder rather than the OUTPUT lamps. First there may be a very small offset (5-10 mV) between true zero output and the zero indicated by the lamps and, second, it may be necessary to compensate for a small mechanical or electrical zero offset in the recording device.

- 4.13c Once the GAIN and BALANCE control settings have been finalized, it is recommended that the knobs be locked in position to prevent accidental rotation. Counting knobs utilize a lever which must first be pulled away from the panel and then rotated clockwise (towards the bottom of the panel). The knob can be unlocked simply by rotating the lever back to the counterclockwise stop.

#### 4.14 NOISE

Before taking dynamic data, it is highly desirable to document the output noise attributable to wiring and other sources vs. the total dynamic output which includes this noise plus the dynamic strain signals:

Momentarily turn EXCIT to OFF. Any output observed now is NOT caused by strain (whether a dynamic strain is being generated or not). "White" noise (full spectrum) is due to the amplifier and cannot be reduced except by reducing GAIN — it should not exceed several microvolts rms referred to the input (that is, the observed signal divided by amplifier gain). A recurrent waveform (usually 50 or 60 Hz or multiples of this frequency) indicates electrical pickup at the gages or in the wiring to the gages: if excessive, the source should be located and corrective measures taken. For additional information on electrical noise, please consult Measurements Group Tech Note TN-501, *Noise Control in Strain Gage Measurements*.

## 5.0 SHUNT CALIBRATION

**NOTE:** It should be emphasized that the purpose of shunt calibration is to determine the performance of the *circuit* into which the gage(s) is wired, and in no way does it verify the ability of the *gage* itself to measure strain or the characteristics of its performance.

### 5.1 EQUATIONS

Shunt calibration can be achieved by shunting any one of the four arms of the input bridge (which includes an active gage(s) and the bridge completion resistors within the 2120A Conditioner). The 2120A provides for shunting any of these arms. No matter which arm is shunted, the same equation applies:

$$\mu\epsilon_{\text{CAL}} = \frac{R'_A}{K'(R_{\text{CAL}} + R'_A)} \times 10^6 \quad (\text{Eq. 6})$$

where:  $\mu\epsilon_{\text{CAL}}$  = strain simulated (microstrain).

$R'_A$  = precise effective resistance of arm shunted (ohms).

$K'$  = effective gage factor of strain gage.

$R_{\text{CAL}}$  = resistance of calibration resistor (ohms).

$K'$  may be the actual package gage factor of the strain gage in use, or it may be adjusted for leadwire desensitization:

$$K' = K \frac{R_G}{R_G + R_L} \quad (\text{Eq. 7})$$

where:  $K$  = package gage factor of active gage.

$R_G$  = resistance of strain gage (ohms).

$R_L$  = resistance of leadwire(s) in series with active gage (usually the resistance of one leadwire) (ohms).

When shunting either bridge arm to which the balance limit resistor is connected, it is theoretically necessary to correct for this shunting effect in determining  $R'_A$ . While the exact value depends on the position of the balance potentiometer, a good approximation (which assumes the pot is at mid position) is:

$$R'_A = \frac{R_A (R_P + 4R_{\text{BL}})}{2R_A + R_P + 4R_{\text{BL}}} \quad (\text{Eq. 8})$$

where:  $R_A$  = resistance of resistor or gage in arm.

$R_P$  = resistance of balance potentiometer.

$R_{\text{BL}}$  = resistance of balance limit resistor.

It should be noted that, for the 2120A Conditioner as shipped (where shunt calibration is across the 350 $\Omega$  dummy half bridge), this correction is only 0.2%.

### 5.2 SHUNTING INTERNAL HALF BRIDGE (350 $\Omega$ ):

**Use:** Quarter and half bridge (full bridge with reduced accuracy).

**Advantages:** Same resistors regardless of active gage resistance. No special wiring required. Can simulate tension and/or compression.

**Disadvantage:** Leadwire desensitization may be significant (use Eq. 7 in Eq. 6).

Location of resistors and jumpers on the printed circuit board is shown in Figs. 3, 4, and 5. (Note that separate resistors are used for CAL A and CAL B, so that these may be different values; to calculate strain use  $R'_A = 349.3\Omega$ ).

### 5.3 SHUNTING INTERNAL DUMMY GAGE (120 or 350 $\Omega$ ):

**Use:** Quarter bridge only.

**Advantage:** Automatically corrects for leadwire desensitization (using three-wire circuit). No special wiring. Accuracy independent of precise gage resistance.

**Disadvantage:** Only usable if internal dummy gages are in use. Simulates tension only.

Location of resistors and jumpers on the printed circuit board is shown in Fig. 6.  $R'_A$  is resistance of dummy resistor.  $K' = K$ .

### 5.4 SHUNTING ACTIVE GAGES

While there is no electrical problem in shunting active gages at the specimen (they must be accessible), accomplishing this at the Conditioner with only the usual three-lead connection will introduce serious errors if the leadwires have measurable resistance. The reason is that one signal lead, which is supposed to be only a remote voltage-sensing lead, now carries current (to the calibration resistor); the error thus introduced is approximately four times that which would be expected by normal "leadwire desensitization" equations.

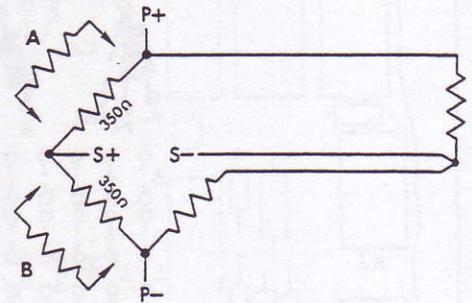
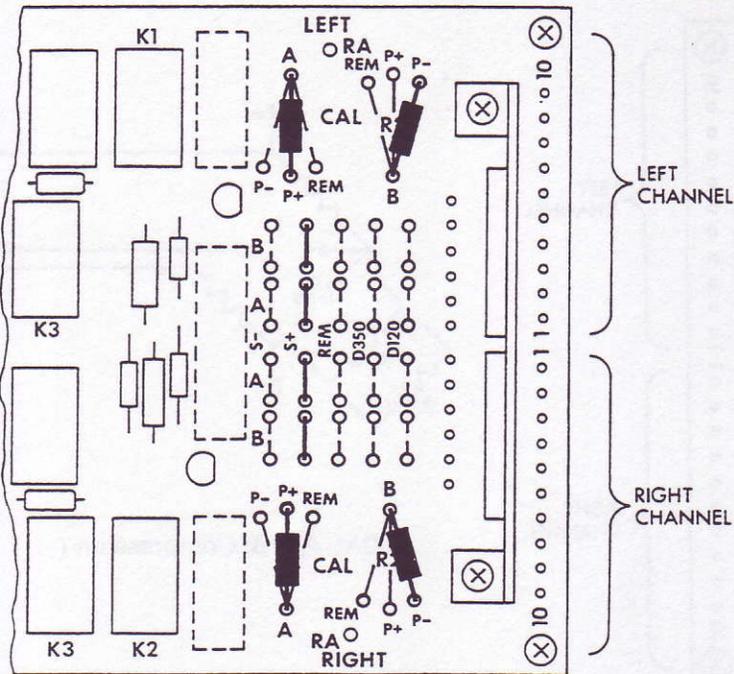
The above problem applies equally to active (or compensating) gages in stress analysis and to all transducer applications.

As a rough guide, 1% error will be introduced if the resistance of each lead is:

For 120 $\Omega$  gages:  
0.3 $\Omega$  (7 ft AWG 26, 30 ft AWG 20)  
(2.1 m, 0.4 mm dia; 9 m, 0.8 mm dia)

For 350 $\Omega$  gages:  
0.9 $\Omega$  (20 ft AWG 26, 85 ft AWG 20)  
(6 m, 0.4 mm dia; 25 m, 0.8 mm dia)

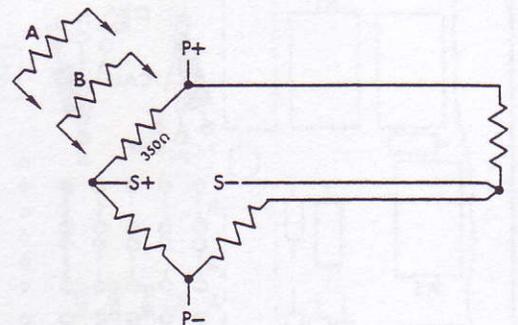
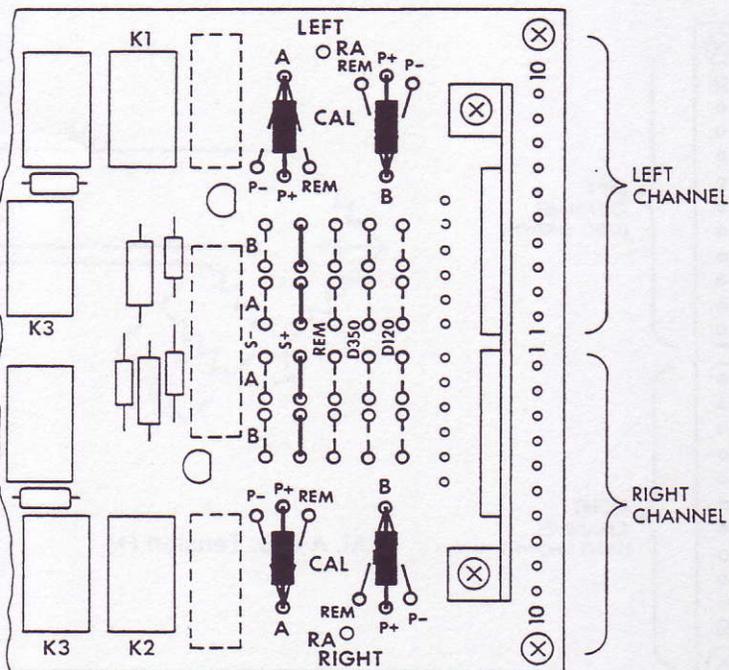
5.4a To properly shunt-calibrate active gages or transducers, the accepted technique is to provide two additional leads dedicated to the calibration circuit; for quarter-bridge operation this is customarily called the "five-leadwire circuit".



CAL A: Tension (+)  
 CAL B: Compression (-)

NOTE: This is standard configuration of the 2120A as shipped.

Fig. 3: CAL on Internal Half Bridge (Tension and Compression)



CAL A & B: Tension (+)

Fig. 4: CAL on Internal Half Bridge (Tension)

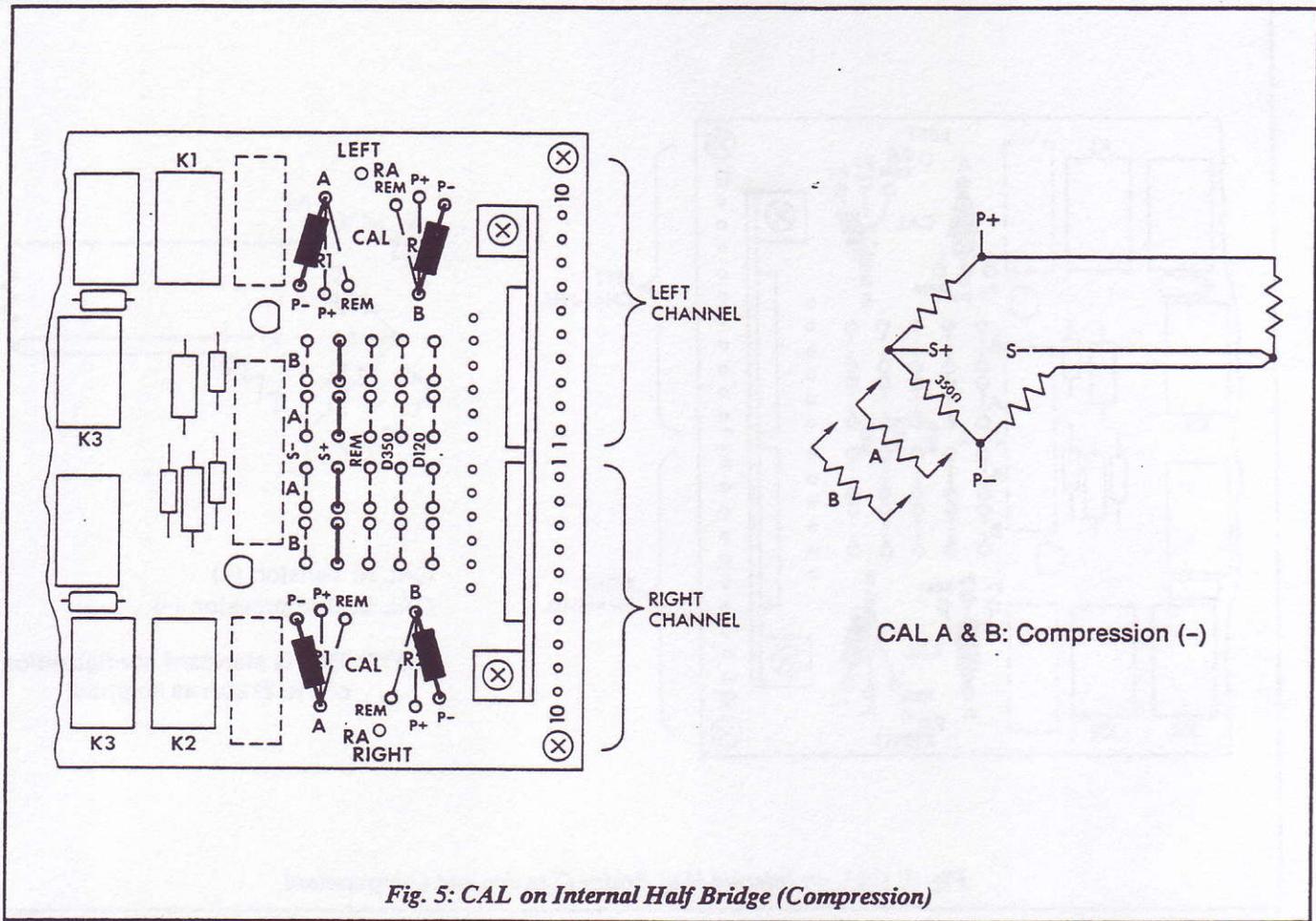


Fig. 5: CAL on Internal Half Bridge (Compression)

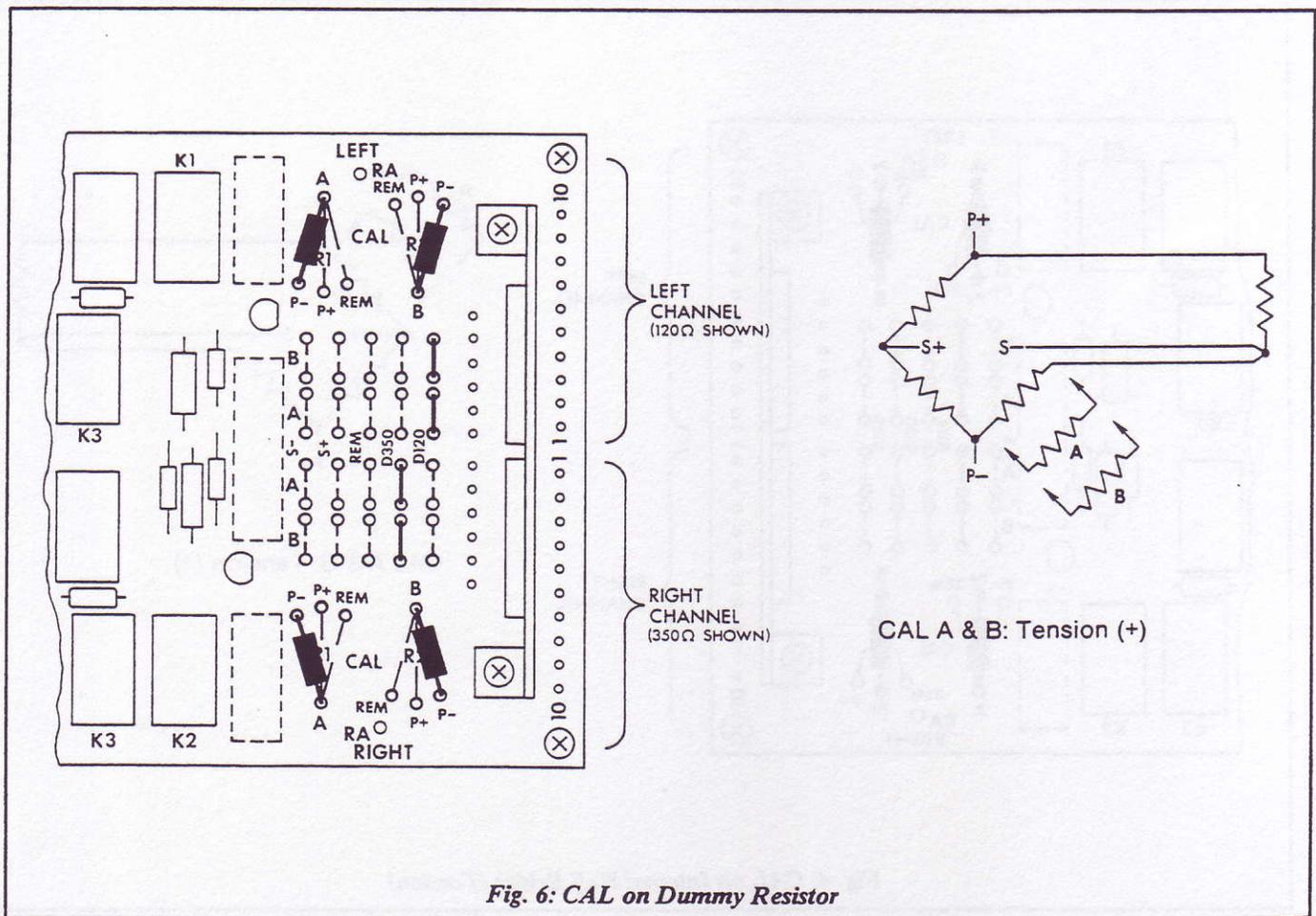


Fig. 6: CAL on Dummy Resistor

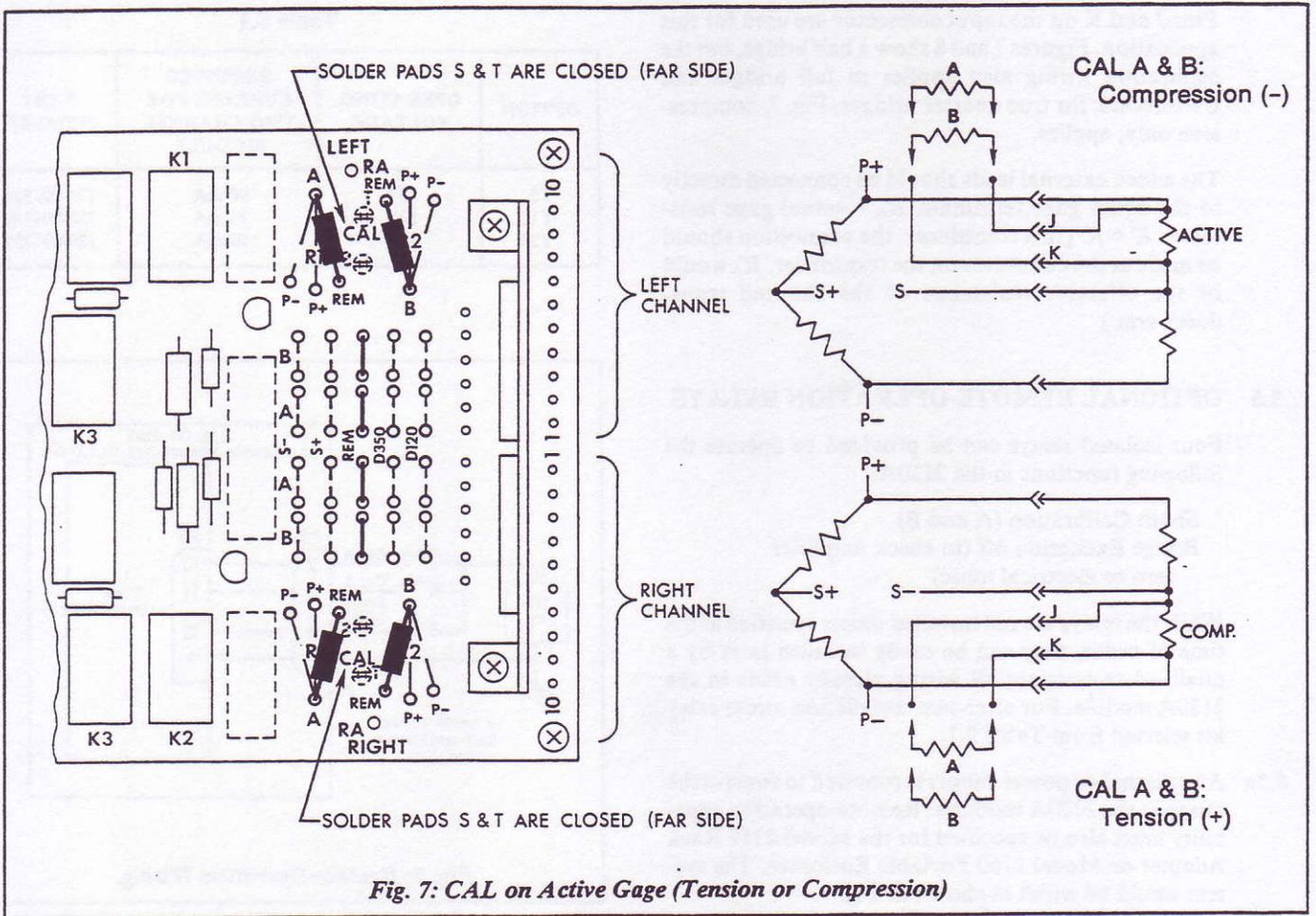


Fig. 7: CAL on Active Gage (Tension or Compression)

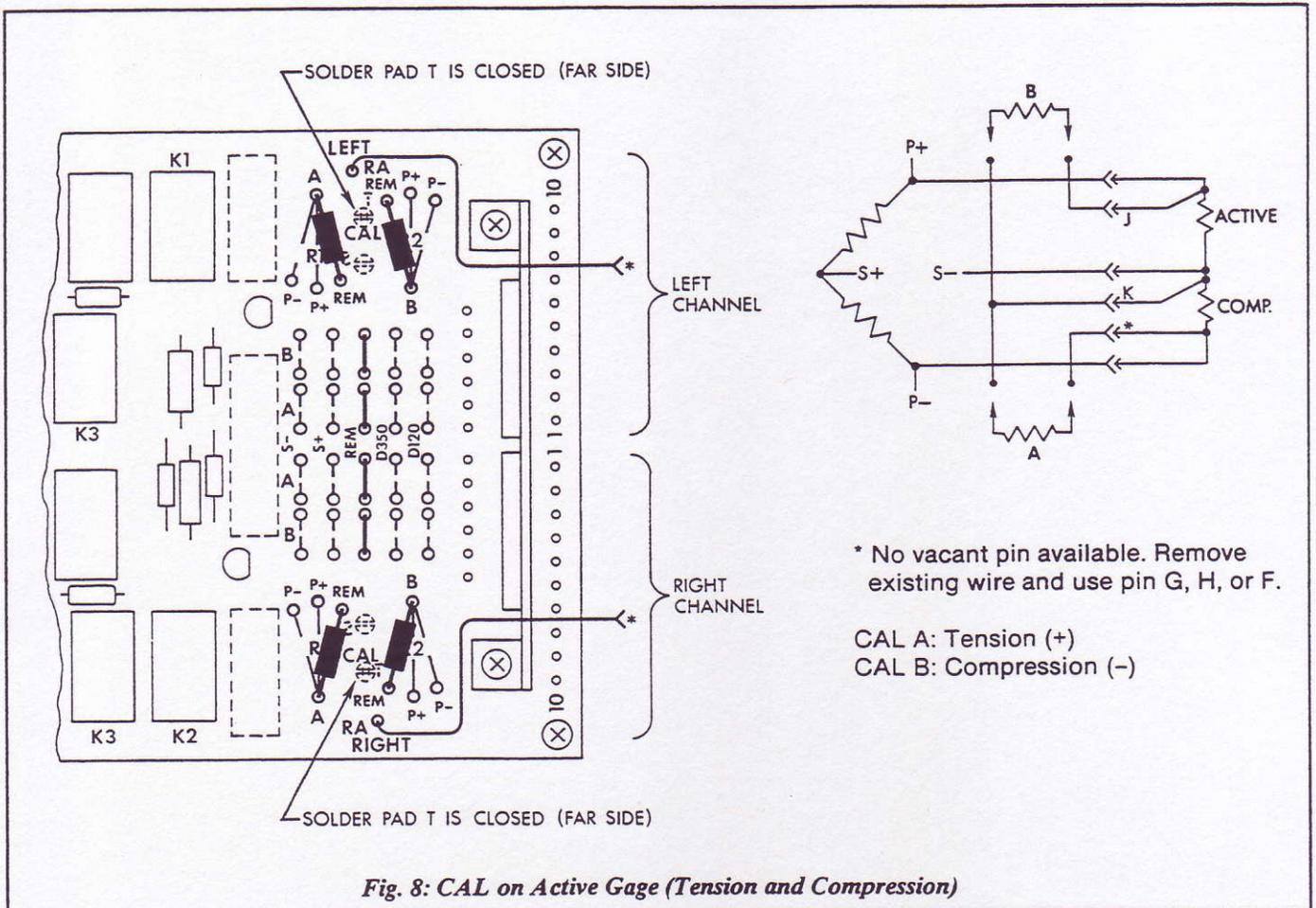


Fig. 8: CAL on Active Gage (Tension and Compression)

Pins J and K on the input connector are used for this application. Figures 7 and 8 show a half bridge, but the calibration wiring also applies to full bridges and transducers; for true quarter bridges, Fig. 7, compression only, applies.

The added external leads should be connected directly to the strain gage terminals.  $R'_A$  = actual gage resistance.  $K' = K$ . (In a transducer, the connection should be made at the connector on the transducer.  $R'_A$  would be the effective resistance of the shunted transducer arm.)

### 5.5 OPTIONAL REMOTE-OPERATION RELAYS

Four isolated relays can be provided to operate the following functions in the 2120A:

- Shunt Calibration (A and B)
- Bridge Excitation off (to check amplifier zero or electrical noise)

While the relays are not installed unless specified at the time of order, they can be easily installed later by a qualified technician; all wiring already exists in the 2120A module. For after-sale installation, order relay kit selected from Table 5.1.

5.5a An external dc power supply is required to control the relays in the 2120A modules. Remote-operation capability must also be specified for the Model 2150 Rack Adapter or Model 2160 Portable Enclosure. The system would be wired as shown in Fig. 9.

Table 5.1

OPTION	OPERATING VOLTAGE	REQUIRED CURRENT FOR TWO-CHANNEL MODULE	PART NUMBER
Y5	5V	90 mA	120-001338
Y12	12V	75 mA	120-001339
Y24	24V	50 mA	120-001330

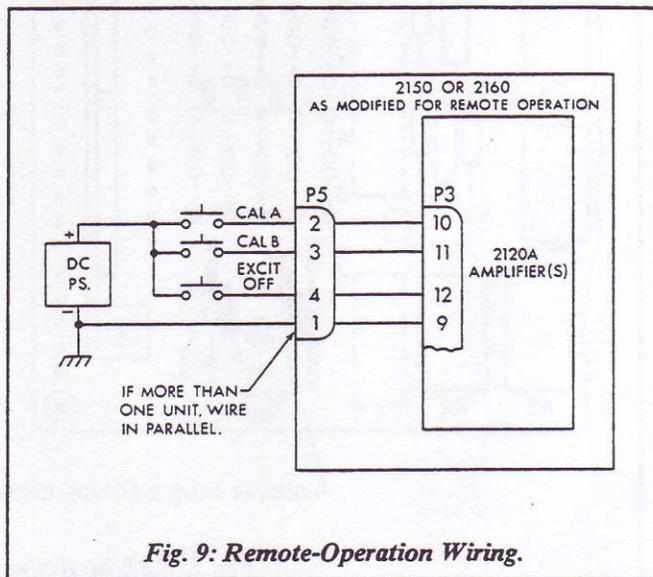


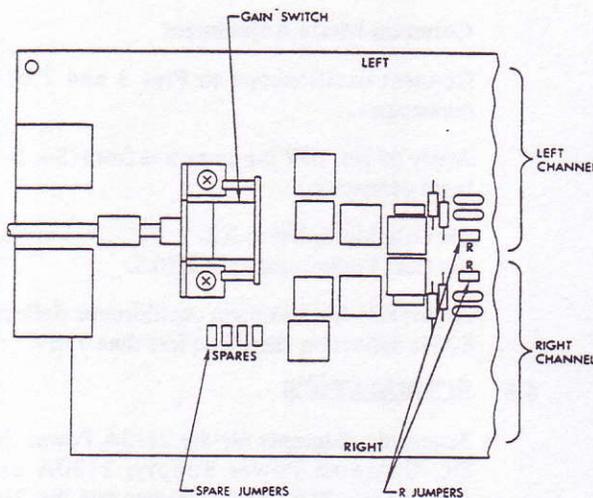
Fig. 9: Remote-Operation Wiring.

## 6.0 SERVICING DATA

### 6.1 CUSTOMER MODIFICATIONS

There are three simple modifications that can be made to suit specific measurement requirements. However, it should be noted that these modifications may, to some extent, affect overall performance:

- Shunt-calibration circuit. See 5.0 *Shunt Calibration*.
- Change bridge BALANCE range: See 4.12a.
- Change bandpass: As shipped the 2120A is configured for a bandpass of 15 kHz (-3.0 dB). Bandpass can be increased to 50 kHz by removing jumper R. Spare jumpers may be stored on pins next to gain switch.



### 6.2 SERVICING

Individual schematics of the various modules are included on the following pages. To facilitate service, 3-ft (0.9-m) extension cables are available to operate the modules outside the rack or enclosure:

- 15-pin (for 2120A) P/N 200-130596
- 25-pin (for 2110A/2111) P/N 200-130597

### 6.3 FIELD-REPLACEABLE COMPONENTS

It is recommended that a defective module be returned to the Measurements Group for repair and recalibration in order to preserve the factory warranty. At the expiration of factory warranty, user organizations with qualified electronic technicians and suitable calibration facilities may choose to repair the units by referring to circuit descriptions, internal adjustment procedures and schematic diagrams.

The components on the following list are those which may be required in the repair of a defective amplifier. Other components may be obtained from the Measurements Group by reference to the schematic designation and the serial number of the amplifier. Consult Measurements Group Applications Engineering Department for assistance.

## 2110A POWER SUPPLY

Description	Symbol	P/N
Meter, Bridge Volts	M1	200-130583
<b>Integrated Circuits:</b>		
Regulator (National, LM723CN)	U1-U3	14X700040
<b>Diodes and Rectifiers:</b>		
Diode, Rectifier (Motorola 1N4002)	CR1-CR17	14X400135
Diode, Rectifier (Motorola 1N4004)	CR18	14X400088
<b>Transistors:</b>		
Transistor, NPN (Motorola TIP-3055)	Q1-Q3	14X200191

## 2111 DC-OPERATED POWER SUPPLY

Connector, Power Input		12X300606
Meter, Bridge Volts	M1	200-130583
DC-DC Converter	Z1	26X100190
DC-DC Converter	Z2	26X100191

## 2120A STRAIN GAGE CONDITIONER

Input Plug		12X300515
Output Plug		12X300556
<b>Integrated Circuits:</b>		
Regulator (National, LM337LZ)	U1	14X700153
Regulator (National, LM723CN)	U2	14X700040
Amplifier (PMI, OP27EZ)	U3, U4	14X700162
Amplifier (PMI, OP01CP)	U5	14X700096
Amplifier (PMI, OP15EZ)	U6	14X700118
Amplifier (PMI, OP07DP)	U7	14X700087
<b>Diodes and Rectifiers:</b>		
Diode, Reference (National, LM336Z-5.0)	CR1	14X500108
Diode, Zener 13V (Motorola, IN4743)	CR2-CR5	14X500107
<b>Transistors:</b>		
Transistor, NPN (Motorola, MJE521)	Q1	14X200189
Transistor, NPN (Motorola, MPS8099)	Q2	14X200183
Transistor, PNP (Motorola, MPS8598)	Q3	14X200184
Transistor, PNP (Motorola, MJE371)	Q4	14X200190

## 6.4 INTERNAL ADJUSTMENTS

If equipment malfunction occurs during the warranty period, the defective unit should be returned to the Measurements Group in order to preserve the factory warranty. The following adjustment procedures are intended to aid the technician in the proper adjustment of the amplifier in the event that components are changed during troubleshooting and repair of the unit subsequent to the warranty period.

### 6.4a 2110A Power Supply Adjustments

Set line voltage switch to correspond with operating voltage. (See 4.1b)

Switch power to ON.

Place DVM probes across C11.

Adjust R6 for output voltage of  $+15V \pm 1\%$ .

Place DVM probes across C12.

Adjust R11 for output voltage of  $-15V \pm 1\%$

Place DVM probes across C14.

Adjust R16 for output voltage of  $+17.5V \pm 1\%$ .

### 6.4b 2111 DC-Operated Supply Adjustment

$\pm 15V$  outputs are fixed by design.

Switch power to ON.

Place DVM probes across C5.

Adjust R6 for output of  $+17.5V \pm 1\%$ .

### 6.4c 2120A Amplifier Adjustments

Unless otherwise specified, an input connector with S+, S- and Gnd terminals shorted together must be connected to the amplifier input for all the following tests. Repeat procedure for both left and right channels.

**NOTE:** Allow 30-minute warm-up before making final adjustments.

## Zero Adjustments

Set EXCIT switch to OFF.

Set Gain Multiplier to X200 and potentiometer to 10.50 (Gain = 2100).

Connect DVM from TP1 to Pin 2 of output connector (J2).

Set front-panel AMP ZERO control R20 8 turns clockwise from full counterclockwise position.

Adjust R13 for DVM reading of zero  $\pm 100 \mu V$ .

Set Gain Multiplier to X2.

Adjust R23 for DVM reading of zero  $\pm 100 \mu V$ .

Check and adjust zeros of R13 and R23 until there is no zero shift when switching between gain ranges of X2 and X200.

Move DVM from TP1 to Pin 3 of output connector.

Adjust R29 for reading of zero  $\pm 1 mV$ .

Both BALANCE LED's should be extinguished.

## Common-Mode Adjustment

Connect oscilloscope to Pins 3 and 2 of the output connector.

Apply 60 Hz, 10V p-p sinewave from (S+, S-) to Gnd on input connector.

Set Gain Multiplier to X2.

Set Gain Potentiometer to X10.5.

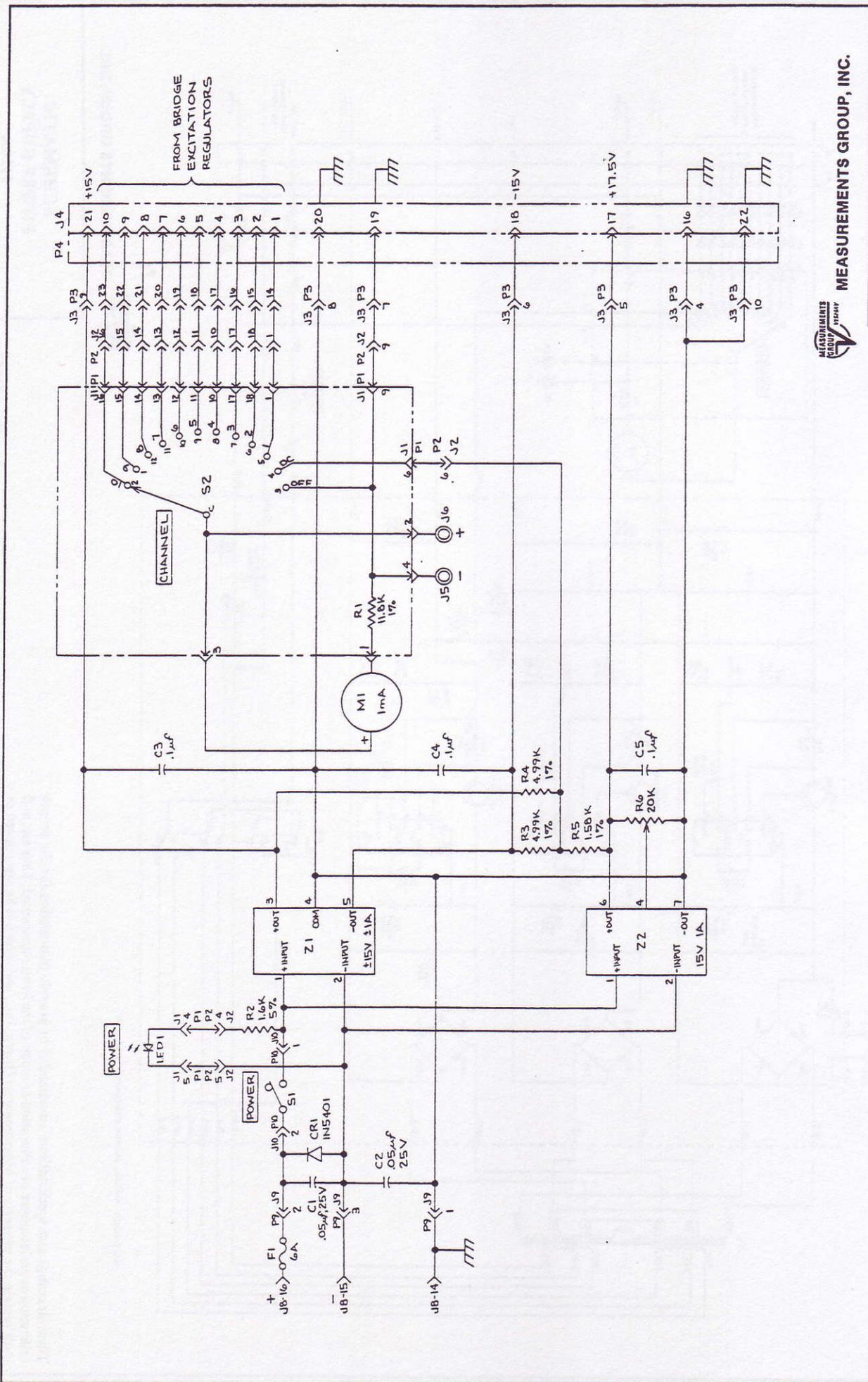
Adjust R21 for minimum oscilloscope deflection.

60 Hz deflection should be less than 7 mV.

## 6.5 SCHEMATICS

Schematic diagrams for the 2110A Power Supply, 2111 DC-Operated Power Supply, 2120A Strain Gage Conditioner, 2150 Rack Adapter and the 2160 Portable Enclosure are found on the pages that follow.





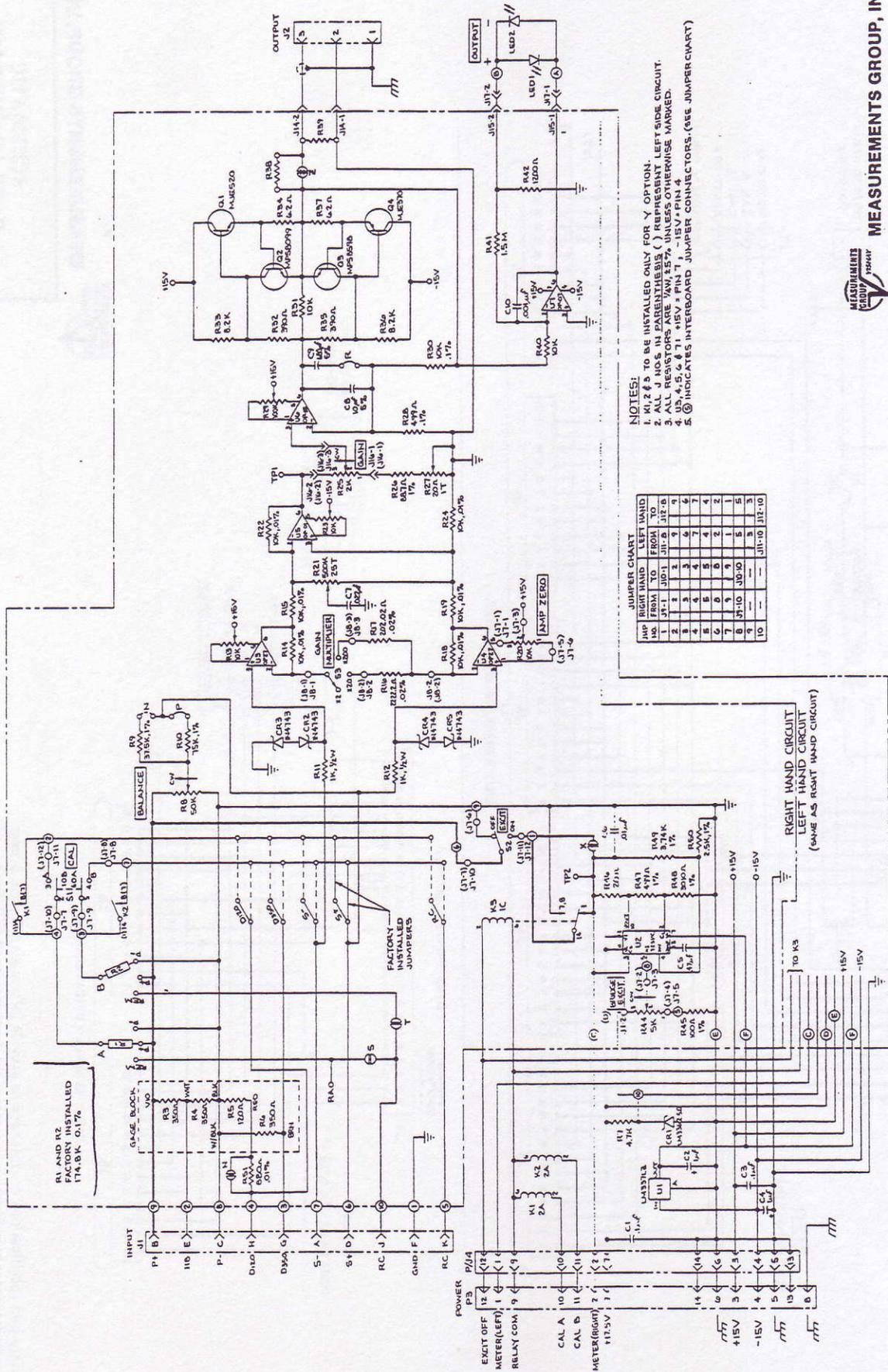
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MEASUREMENTS GROUP, INC.

**SCHEMATIC  
DC POWER SUPPLY  
2111**

300-045601A



- NOTES:
- K1, 2 & 3 TO BE INSTALLED ONLY FOR Y OPTION.
  - ALL J NO.6 IN PARENTHESIS ( ) REPRESENT LEFT/SIDE CIRCUIT.
  - ALL RESISTORS ARE  $\pm 1\%$  UNLESS OTHERWISE MARKED.
  - U.S., 4, 5, 6, 7, 11, 15V = PIN 7, -15V = PIN 4
  - Ⓢ INDICATES INTERBOARD JUMPER CONNECTORS. (SEE JUMPER CHART)

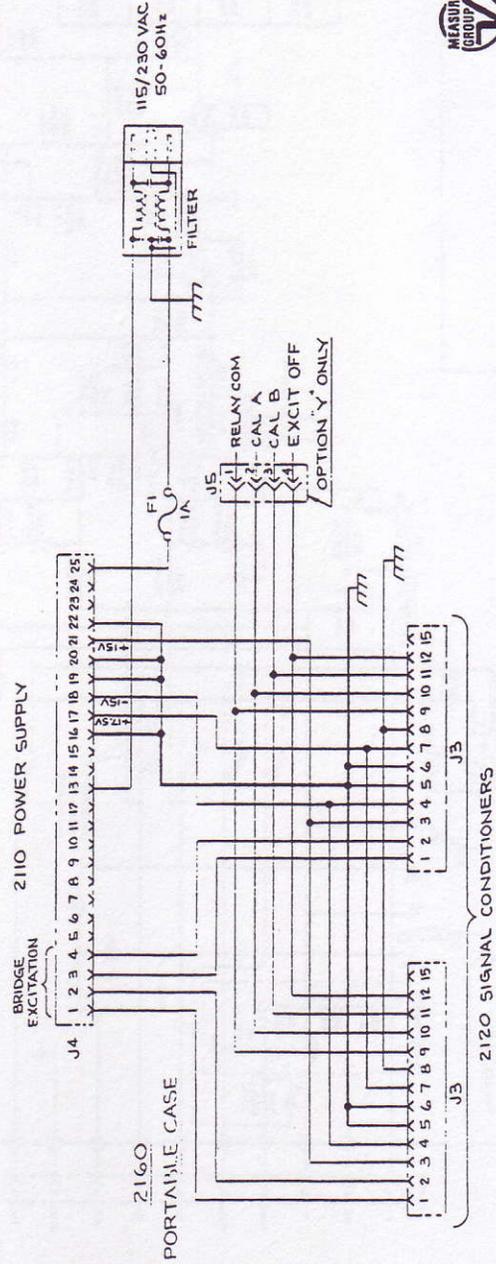
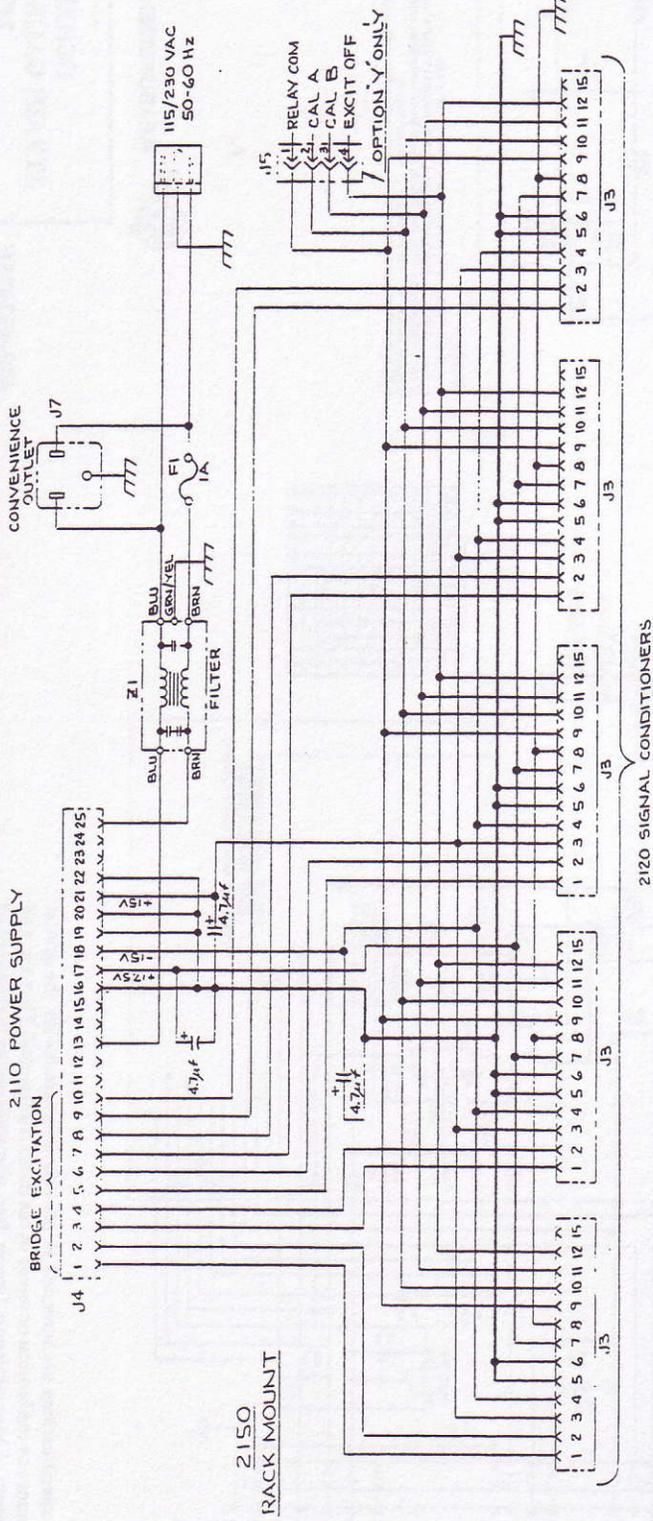
JUMPER CHART

JMP NO.	RIGHT HAND FROM	LEFT HAND TO
1	J1-1	J10-1
2	1	7
3	2	7
4	3	7
5	4	7
6	5	7
7	6	7
8	7	9
9	8	9
10	9	10

MEASUREMENTS GROUP  
**MEASUREMENTS GROUP, INC.**  
**SCHEMATIC**  
**STRAIN GAGE CONDITIONER**  
**2120A**

400-052875F

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MEASUREMENTS GROUP, INC.

SCHEMATIC  
RACK ADAPTER 2150  
PORTABLE ENCLOSURE 2160

300-044983H

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## WARRANTY

Measurements Group, Inc., warrants all instruments it manufactures to be free from defect in materials and factory workmanship, and agrees to repair or replace any instrument that fails to perform as specified within three years after date of shipment. Coverage of computers, cameras, rechargeable batteries, and similar items, sold in conjunction with equipment manufactured by Measurements Group, Inc. and bearing the identifying name of another company, is limited under this warranty to one year after the date of shipment. The warranty on non-rechargeable batteries and similar consumable items is limited to the delivery of goods free from defects in materials and factory workmanship. This warranty shall not apply to any instrument that has been:

i) repaired, worked on or altered by persons unauthorized by the Measurements Group in such a manner as to injure, in our sole judgment, the performance, stability, or reliability of the instrument;

ii) subjected to misuse, negligence, or accident;

or

iii) connected, installed, adjusted, or used otherwise than in accordance with the instructions furnished by us.

At no charge, we will repair, at our plant, or an authorized repair station, or at our option, replace any of our products found to be defective under this warranty.

**This warranty is in lieu of any other warranties, expressed or implied, including any implied warranties of merchantability or fitness for a particular purpose. There are no warranties which extend beyond the description on the face hereof. Purchaser acknowledges that all goods purchased from Measurements Group are purchased as is, and buyer states that no salesman, agent, employee or other person has made any such representations or warranties or otherwise assumed for Measurements Group any liability in connection with the sale of any goods to the purchaser. Buyer hereby waives all rights buyer may have arising out of any breach of contract or breach of warranty on the part of Measurements Group, to any incidental or consequential damages, including but not limited to damages to property, damages for injury to the person, damages for loss of use, loss of time, loss of profits or income, or loss resulting from personal injury.**

Some states do not allow the exclusion or limitation of incidental or consequential damages for consumer products, so the above limitations or exclusions may not apply to you.

The Purchaser agrees that the Purchaser is responsible for notifying any subsequent buyer of goods manufactured by Measurements Group of the warranty provisions, limitations, exclusions and disclaimers stated herein, prior to the time any such goods are purchased by such buyer, and the Purchaser hereby agrees to indemnify and hold Measurements Group harmless from any claim asserted against or liability imposed on Measurements Group occasioned by the failure of the Purchaser to so notify such buyer. This provision is not intended to afford subsequent purchasers any warranties or rights not expressly granted to such subsequent purchasers under the law.

The Measurements Group reserves the right to make any changes in the design or construction of its instruments at any time, without incurring any obligation to make any change whatever in units previously delivered.

The Measurements Group's sole liabilities, and buyer's sole remedies, under this agreement shall be limited to the purchase price, or at our sole discretion, to the repair or replacement of any instrument that proves, upon examination, to be defective, when returned to our factory, transportation prepaid by the buyer, within the applicable period of time from the date of original shipment.

Return transportation charges of repaired or replacement instruments under warranty will be prepaid by Measurements Group, Inc.

The Measurements Group is solely a manufacturer and assumes no responsibility of any form for the accuracy or adequacy of any test results, data, or conclusions which may result from the use of its equipment.

The manner in which the equipment is employed and the use to which the data and test results may be put are completely in the hands of the Purchaser. Measurements Group, Inc., shall in no way be liable for damages consequential or incidental to defects in any of its products.

This warranty constitutes the full understanding between the manufacturer and buyer, and no terms, conditions, understanding, or agreement purporting to modify or vary the terms hereof shall be binding unless hereafter made in writing and signed by an authorized official of Measurements Group, Inc.

# APPENDIX

## MODEL 2130 DIGITAL READOUT AND MODEL 2131 PEAK READING DIGITAL READOUT

### GENERAL

The 2130 module provides an LED digital display plus a channel selector in a 2100 System-compatible package. The 2131 also includes peak reading capability. These units simply slide into either the 2150 Rack Adapter or the 2160 Enclosure. An additional line connection is *not* required as power is derived from the 2110A or 2111 Power Supply through the rack adapter or enclosure. Standard cables (two supplied) make the necessary signal connection between the 2130/2131 and each of the 2120A Strain Gage Conditioner channels to be used in the display mode. The 2130/2131 will accept and switch up to ten inputs. Additionally, front-panel jacks are provided for utility inputs such as measuring bridge excitation via the 2110A or 2111 EXTERNAL METER jacks. The front-panel EXTERNAL input is single-sided on the 2130 and differential on the 2131. An external monitoring device, such as an oscilloscope, can also be connected to the rear-panel output connector to give simultaneous indications for a given selected input.

### SPECIFICATIONS

All specifications nominal or typical at +23° C unless noted.

#### 2130/2131 COMMON SPECIFICATIONS

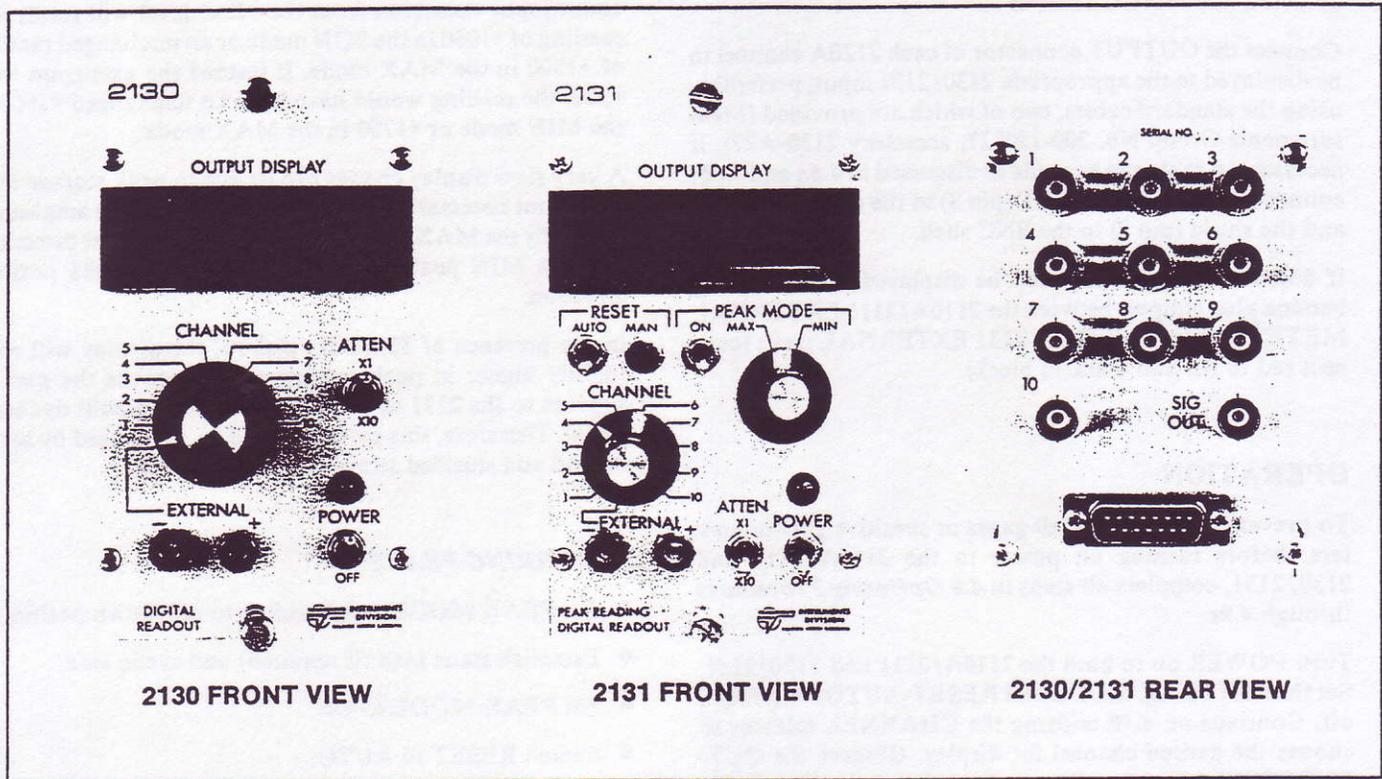
INPUT CAPACITY	10 channels, BNC (rear panel); 1 channel, banana jacks (front panel).
SWITCHED OUTPUT	Not attenuated, BNC (rear panel).
ATTENUATOR ACCURACY	±0.1% or better.
UPDATE RATE	3 readings/second, nominal.
DIGITAL DISPLAY	3-1/2 digit LED, ±1999 counts.
DISPLAY HEIGHT	0.3 in (7.6 mm).
POWER	2110A/2111 Power Supply.
SIZE & WEIGHT	5.25 H x 2.94 W x 10.97 D in (133 x 75 x 279 mm); 2 lb (0.8 kg).

#### 2130 SPECIFICATIONS

INPUT VOLTAGE RANGE	±1999 mV (X1 range); ±19 990 mV (X10 range).
INPUT IMPEDANCE	100 KΩ.
ACCURACY	±(0.05% reading +0.05% full scale) or better.
COMMON MODE COMPLIANCE	±100 mV (rear-panel input) minimum.

#### 2131 SPECIFICATIONS

INPUT VOLTAGE RANGE	±1999 mV (X1 range); ±10V (X10 range).
INPUT IMPEDANCE	Greater than 1 MΩ.
COMMON MODE INPUT RANGE	±10V (rear-panel input).
ACCURACY	<b>Step Input:</b> ±0.1% ±5 counts for step input of greater than 10 milliseconds duration.  <b>Repetitive Step Input:</b> ±0.2% ±5 counts for repetitive step inputs of greater than 500 μsec duration. Number of steps required $\geq \frac{10 \text{ milliseconds}}{\text{Pulse Duration}}$  <b>Repetitive Sine Wave Input:</b> ±5.0% ±5 counts for repetitive sine wave of frequency less than 1000 Hz.  ±1.0% ±5 counts for repetitive sine wave input of frequency less than 200 Hz.
STORAGE STABILITY	±3 counts/minute maximum at +75° F (+23° C).
PEAK MODES	MAX (usually positive) excursion and MIN (usually negative) excursion.
PEAK RESET	Manual or Automatic.



2130 FRONT VIEW

2131 FRONT VIEW

2130/2131 REAR VIEW

## CONTROLS

### OUTPUT DISPLAY

Provides a digital reading of the input as selected by CHANNEL selector. Typically used to monitor strain or bridge voltage.

### CHANNEL Selector

Positions 1 to 10 select the input channel for display. (Generally, position 1 is channel farthest to the left in rack, etc.)

The EXTERNAL position selects the input that is connected to the adjacent front-panel jacks.

### EXTERNAL Jacks

Provide ability to accept a front-panel input, typically bridge voltage from 2110A/2111 EXTERNAL METER jacks

### ATTEN Switch

X1 position gives  $\pm 2$  volt range.

X10 position gives  $\pm 20$  volt range ( $\pm 10V$  for 2131).

### POWER Switch

This switches the 17.5 Vdc power supply. The pilot lamp LED indicates when power is on.

### SIG OUT (Rear Panel)

BNC receptacle used to monitor the input signal on an external indicating instrument such as an oscilloscope. The desired channel is selected with the front-panel CHANNEL selector switch.

### Input Connectors (Rear Panel)

10 BNC receptacles (typ. connected to 2120A OUTPUT receptacles).

### RESET Switches (2131)

AUTO (Toggle Switch) — When set to AUTO, the stored peak reading is periodically reset to the existing input level. Automatic reset will occur approximately every 5 to 10 seconds.

MAN (Push-button Switch) — When pressed, resets peak reading to the existing input level; the button should be held 1 second or more for a complete reset.

### PEAK MODE Switches (2131)

ON—Display reads the stored peak reading. When off (down), display reads the existing input level.

MAX — The most positive (algebraic) input is stored.

MIN — The most negative (algebraic) input is stored.

## SETUP

Install the 2130/2131 into the rack or enclosure as discussed in *4.0 Operating Procedures*; the 2130/2131 is installed in exactly the same manner as the 2120A Conditioners, filling one of the rack or enclosure slots.

## INPUT CONNECTIONS

Connect the OUTPUT connector of each 2120A channel to be displayed to the appropriate 2130/2131 input, preferably using the standard cables, two of which are provided (Measurements Group No. 200-130827, accessory 2130-A27). If necessary, a cable can be made as discussed in 4.6a and 4.6b; connect the 2120A OUTPUT (pin 3) to the center BNC pin and the shield (pin 2) to the BNC shell.

If desired, bridge voltage can be displayed by connecting banana plug jumpers between the 2110A/2111 EXTERNAL METER jacks and the 2130/2131 EXTERNAL jacks (connect red to red and black to black).

## OPERATION

To prevent damage to small gages or sensitive galvanometers, before turning on power to the 2110A/2111 and 2130/2131, complete all steps in 4.0 *Operating Procedures* through 4.9e.

Turn POWER on to both the 2110A/2111 and 2130/2131. Set the 2131 PEAK MODE and RESET-AUTO switches to off. Continue on 4.10 utilizing the CHANNEL selector to choose the desired channel for display. Observe the OUTPUT DISPLAY when adjusting the 2120A balance and gain controls as well as when taking data. For convenience, the OUTPUT DISPLAY may be set up to read directly in engineering units.

The ATTEN switch is normally used in the X1 position but the X10 position is required when the reading goes over 1999 counts and the display flashes (indicating overrange). In the X1 mode, the 2130/2131 reads directly in millivolts (tens of millivolts in the X10 mode).

To use the 2131 without utilizing the peak reading feature, keep the PEAK MODE and RESET toggle switches set to the off (down) position. To take peak readings using the 2131, achieve desired calibration as discussed in the above paragraphs and proceed as follows depending upon type of input signal:

### NON-RECURRING PEAKS

- Set RESET-AUTO to off (down position).
- Set PEAK MODE rotary switch to MAX and the toggle switch to ON.
- Press RESET-MAN firmly (approximately 1 second).
- Load specimen or structure through the peak value of interest.
- Read OUTPUT DISPLAY.

If the MIN peak is of interest, turn PEAK MODE to MIN and press RESET-MAN again.

### NOTES

In both MAX and MIN modes, a peak reading can have either a positive or negative sign. For example, if RESET results in a +1500 count reading (static load offset), a -440

count input excursion from the offset level will result in a reading of +1060 in the MIN mode or an unchanged reading of +1500 in the MAX mode. If instead the excursion were +200, the reading would have been an unchanged +1500 in the MIN mode or +1700 in the MAX mode.

A very slow display change can be due to peak storage drift that is not necessarily due to change in the strain amplitude. Typically the MAX peak storage can drift in either direction, whereas MIN peak storage tends to drift in the positive direction.

In the presence of 50/60 Hz pickup, the display will read slightly higher in peak reading mode because the pickup appears to the 2131 as a normal (although small) dynamic signal. Therefore, this pickup should be minimized by using twisted and shielded strain gage input wiring.

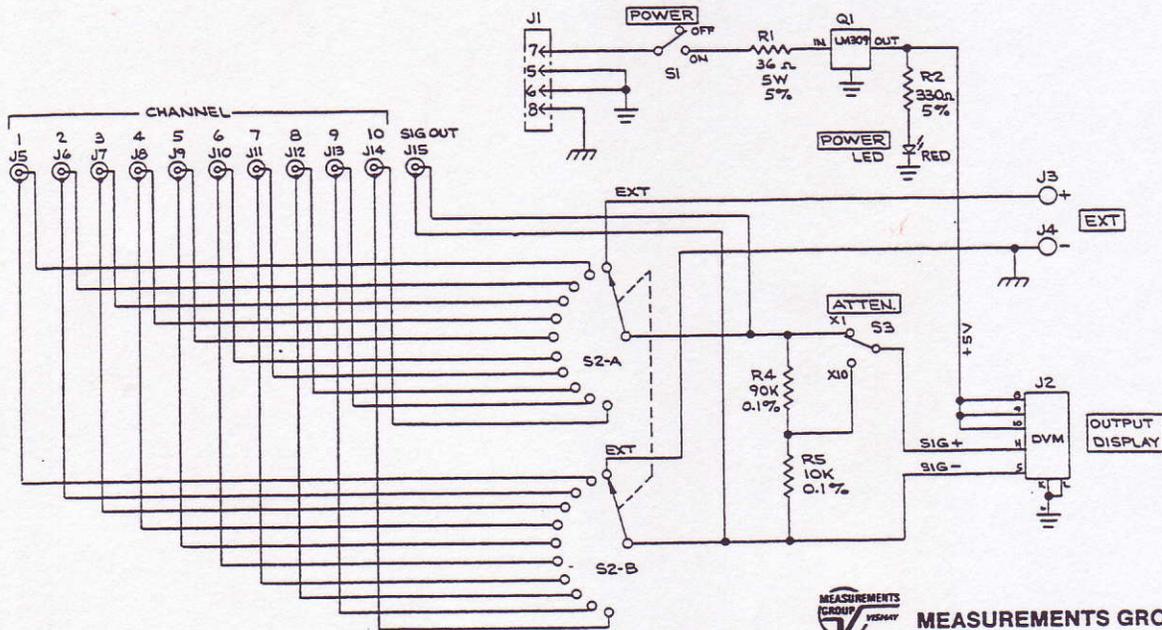
### RECURRING PEAKS

- Set PEAK MODE toggle switch to off (down position).
- Establish static load (if required) and cyclic load.
- Set PEAK MODE to ON.
- Switch RESET to AUTO.
- Press RESET-MAN firmly (approximately 1 second) or wait for automatic reset to reset display.
- MAX or MIN should now be displayed according to the position of the PEAK MODE control.
- To read the opposite peak, set PEAK MODE rotary switch accordingly and repeat prior two steps.
- To determine the peak-to-peak amplitude, algebraically subtract the MIN reading from the MAX reading.
- A decreased cyclic strain amplitude will be reflected in the display after reset occurs.

### SERVICE

A schematic of the 2130 and the 2131 can be found on the next page. Replacement parts can be obtained from the factory.

There is an internal adjustment in the 2130/2131 for span sensitivity. This can be trimmed by applying exactly  $\pm 1.900V$  to the input and adjusting the potentiometer at rear of meter until readout displays  $\pm 1900$ . A five-minute warm-up is recommended.

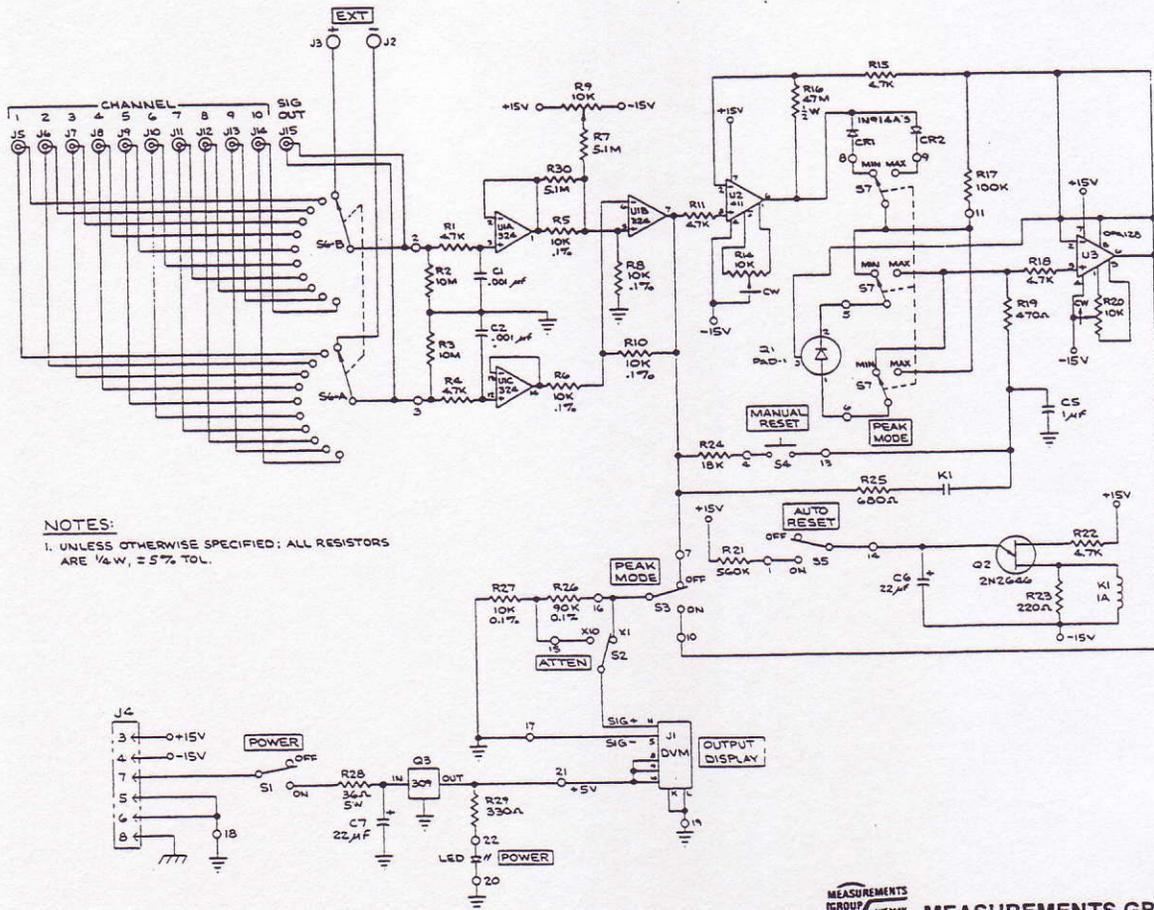


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200-130826C

**SCHEMATIC  
2130 DIGITAL READOUT**



**NOTES:**

1. UNLESS OTHERWISE SPECIFIED; ALL RESISTORS ARE 1/4 W, ±5% TOL.



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300-045251G

**SCHEMATIC  
2131 PEAK READING  
DIGITAL READOUT**