2300 SYSTEM

Signal
Conditioning Amplifier

2310
Instruction Manual

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INSTRUCTION MANUAL
MODEL 2310
SIGNAL CONDITIONING AMPLIFIER

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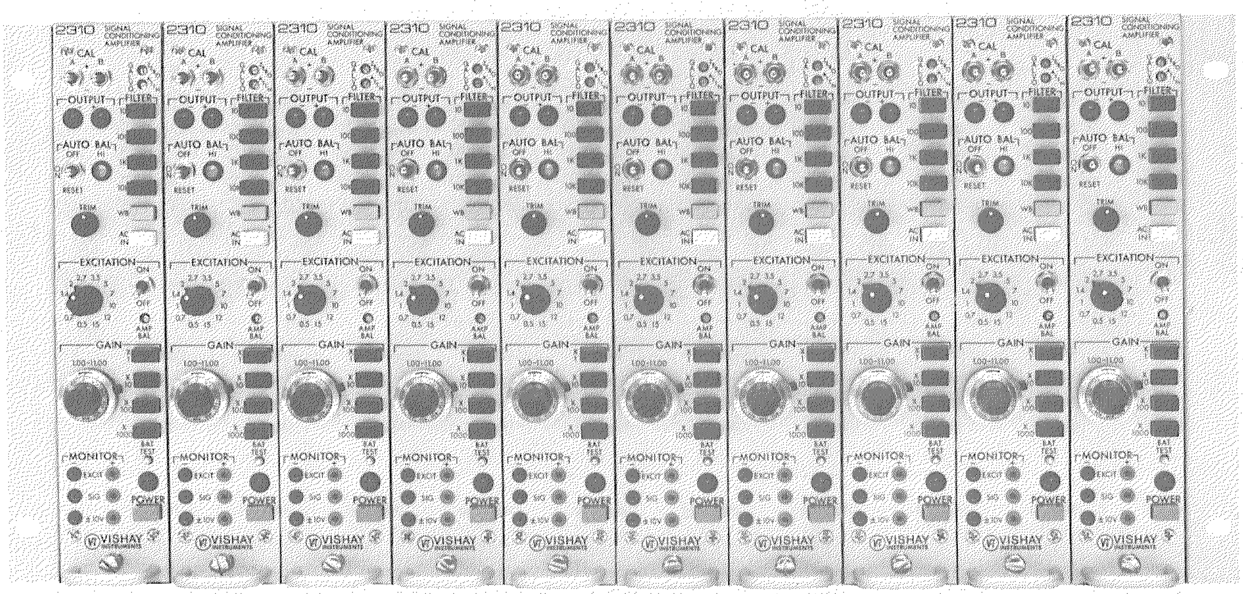
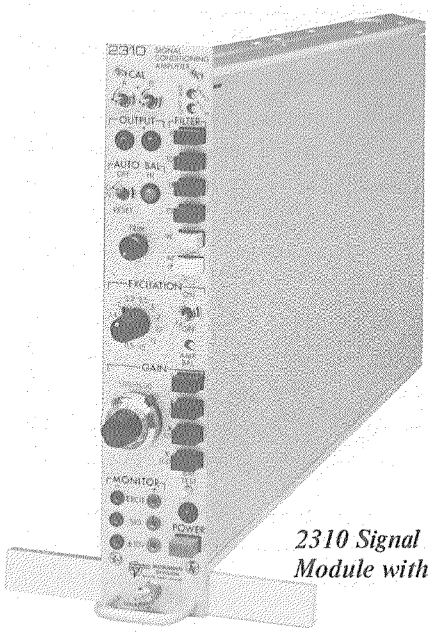
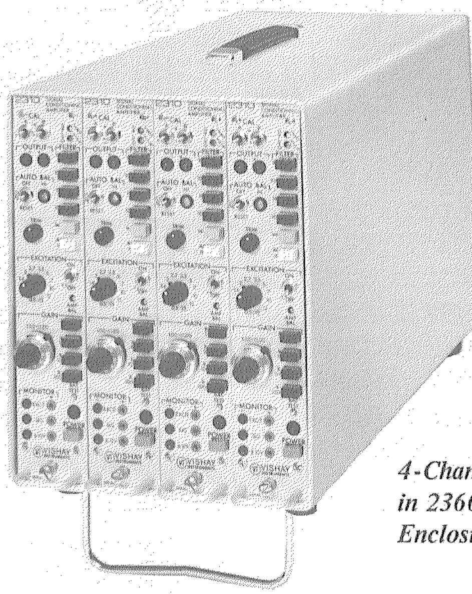


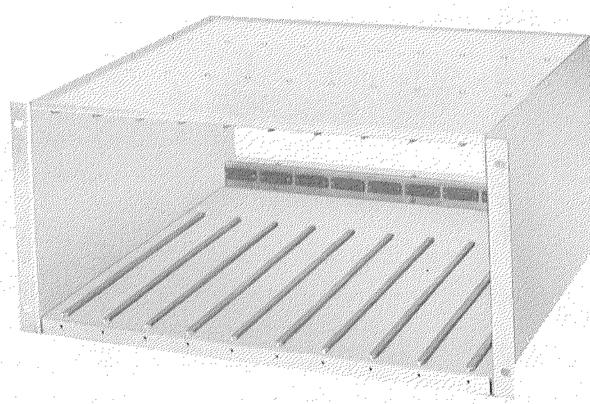
Complete 10-Channel 2300 System



2310 Signal Conditioning Amplifier Module with Stabilizer Accessory



4-Channel System in 2360 Portable Enclosure



2350 10-Channel Rack Adapter

1.0 DESCRIPTION

1.1 GENERAL

The 2300 Series instruments comprise a versatile multichannel system for conditioning and amplifying low-level signals from strain gages (or strain gage based transducers) for display or recording on external equipment. Each 2310 Signal Conditioning Amplifier is separately powered and electrically isolated from all others (and can be powered with a separate line cord), although groups of amplifiers are normally inserted into a multichannel rack adapter or portable enclosure.

The Model 2350 Rack Adapter accepts up to ten 2310 Amplifiers for mounting in a standard 19-in *(483-mm)* rack; the Model 2360 Portable Enclosure accepts up to four 2310 Amplifiers for more portable use.

Each Model 2310 Amplifier incorporates precision high-stability bridge completion resistors and dummy gages, and four shunt-calibration resistors, and is complete and ready for use as delivered — only ac power is required via the Portable Enclosure, Rack Adapter or separate ac line cord. Input and output connectors are supplied with each amplifier.

1.2 SIGNIFICANT FEATURES

The 2300 Series is designed to provide features essential for accurate stress analysis data in a broad range of measurement applications. Principal features include:

- Fully adjustable calibrated gain from 1 to 11 000.
- Accepts all strain gage inputs (foil or piezoresistive), potentiometers, DCDT's, etc.
- Bridge excitation from 0.5 to 15 Vdc (12 steps).
- Input impedance above 100 megohms.
- Three simultaneous buffered outputs: ±10V, ±1.4V (for tape recorders), and a 75-mA galvanometer output.
- Wide band operation exceeding 25 kHz, –0.5 dB at all gains and output levels.
- Four-frequency active filter (10 to 10 000 Hz).
- Dual-range (±5000 and ±25 000$\mu\epsilon$) automatic bridge balance, with keep-alive power to preserve balance for months without external power.
- Dual-polarity two-step double-shunt calibration.
- Optional remote calibration and auto balance reset.
- Playback mode to filter and observe or re-record previously recorded magnetic tape data.
- and many other convenience features.

2.0 SPECIFICATIONS

All specifications are nominal or typical at +23°C unless noted. Performance may be degraded in the presence of high-level electromagnetic fields.

2.1 2310 SIGNAL CONDITIONING AMPLIFIER

INPUT

Strain gages: quarter, half, or full bridge (50 to 1000Ω). Built-in 120Ω and 350Ω dummy gages; 1000Ω dummy capability. See Appendix, page 29.

Transducers: foil or piezoresistive strain gage types; DCDT displacement transducers; potentiometers.

EXCITATION

Twelve settings: 0.5, 0.7, 1, 1.4, 2, 2.7, 3.5, 5, 7, 10, 12 and 15 Vdc ±1% max.

Current: 0-100 mA, min, limited at 175 mA, max.

Regulation (0-100 mA, ±10% line change): ±0.5 mV ±0.04%, max measured at remote sense point. (Local sense: –5 mV, typical, @100 mA, measured at plug.)

Remote sense error: 0.0005% per ohm of lead resistance (350Ω load).

Noise and ripple: 0.05% p-p, max (dc to 10 kHz).

Stability: ±0.02%/°C.

Level: normally symmetrical about ground; either side may be grounded with no effect on performance.

BRIDGE BALANCE

Method: counter-emf injection at pre-amp; automatic electronic; dual range; can be disabled on front panel.

Ranges (auto ranging):
±5000$\mu\epsilon$ (±1% bridge unbalance or ±2.5 mV/V), resolution 2.5$\mu\epsilon$ (0.0012 mV/V).

±25 000$\mu\epsilon$ (±5% bridge unbalance or ±12.5 mV/V), resolution 12.5$\mu\epsilon$ (0.006 mV/V).

Balance time: 2 seconds, typical.

Manual vernier balance range: 100$\mu\epsilon$ (0.050 mV/V).

Interaction: essentially independent of excitation and amplifier gain.

Storage: non-volatile digital storage without line power for up to two years.

SHUNT CALIBRATION

Circuit (two-level, dual polarity): Single-shunt (for stress analysis) across any bridge arm, including dummy gage.

Double-shunt (for transducers) across opposite bridge arms.

Provision for four dedicated leads to shunt external arms.

CAL circuit selected by switches on p.c. board.

Standard factory-installed resistors (±0.1%) simulate:

±200 and ±1000$\mu\epsilon$ @ GF=2 across dummy half bridge;

±1000$\mu\epsilon$ @ GF=2 across dummy gage (120Ω and 350Ω).

±1 mV/V (double-shunt) for 350Ω transducer.

Remote-operation relays (Option Y): four relays (plus remote-reset relay for bridge balance and relay for excitation on/off). Each relay requires 10 mA @ 5 Vdc, except excitation on/off 25 mA.

AMPLIFIER

Gain: 1 to 11 000 continuously variable.

Direct reading ±1% max of reading ±0.5% max of full-scale vernier setting.

Frequency response (all gains >5, full output):

dc coupled: dc to 25 kHz, –0.5 dB max. dc to 65 kHz, –3 dB typical at 40% output;

ac coupled: 5 Hz to 25 kHz, –0.5 dB.

Input impedance: 100 mΩ, min, differential or common-mode, including bridge balance circuit.

Bias current: ±0.01 μA, typical, each input.

Source impedance: 0 to 1000Ω each input.

Common-mode voltage: ±10V.

Common-mode rejection (gain over X100):

Shorted input: 100 dB, min, at dc; 90 dB, min, dc to 1 kHz;

350Ω balanced input: 90 dB, typical, dc to 1 kHz.

Stability (gain over X100): ±2 μV/°C, max, RTI (referred to input).

Noise (gain over X100, all outputs):

0.01 to 10 Hz: 1μV p-p RTI.
0.5 to 50 kHz: 5 μVrms, max, RTI.

FILTER

Characteristic: low-pass active two-pole Butterworth standard.

Frequencies (–3 ±1 dB): 10, 100, 1000 and 10 000 Hz and wide-band.

Outputs filtered: any one or two or all (switch-selected on p.c. board).

AMPLIFIER OUTPUTS

Standard output: ±10V @ 5 mA, min.

Tape output: ±1.414V (1 Vrms) @ 5 mA, min.

Galvanometer output: ±10V @ 75 mA, min, current-limited at 100 mA, max (minimum load resistance for ±0.05% linearity: 50Ω).

Galvanometer attenuator (0-100%) and zero adjust (±1V) on front panel.

Linearity @ dc: ±0.02%.

Any output can be short-circuited with no effect on others.

PLAYBACK

Input: ±1.414V full scale; input impedance 20 kΩ.

Gain: X1 to tape output; X7.07 to standard output.

Filter selection: as specified above.

Outputs: All three, as specified above.

OPERATING ENVIRONMENT

Temperature: 0° to +50°C.
Humidity: 10 to 90%, noncondensing.

POWER

105 to 125V or 210 to 250V (switch-selected), 50/60 Hz, 10 watts, max.

Keep-alive supply (for bridge balance): Two Gold Peak S76E or equal. Shelf-life approximately two years.

SIZE & WEIGHT

Panel: 8.75 H x 1.706 W in *(222.2 x 43.3 mm).*

Case depth behind panel: 15.9 in *(404 mm).*

Weight: 6 lb *(2.7 kg).*

2.2 2350 RACK ADAPTER

APPLICATION

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

Accepts up to ten 2310 Amplifiers. AC line completely wired.

Wiring for remote calibration with Option Y.

POWER

115 or 230 Vac switch selected in amplifiers, 50/60 Hz, 100 Watts max.

SIZE & WEIGHT

8.75 H x 19 W x 19.06 D in overall *(222 x 483 x 484 mm).*

13.5 lb *(6.1 kg).*

2.3 2360 PORTABLE ENCLOSURE

DESCRIPTION

Enclosure to accept up to four 2310 Amplifiers.

AC wiring complete.

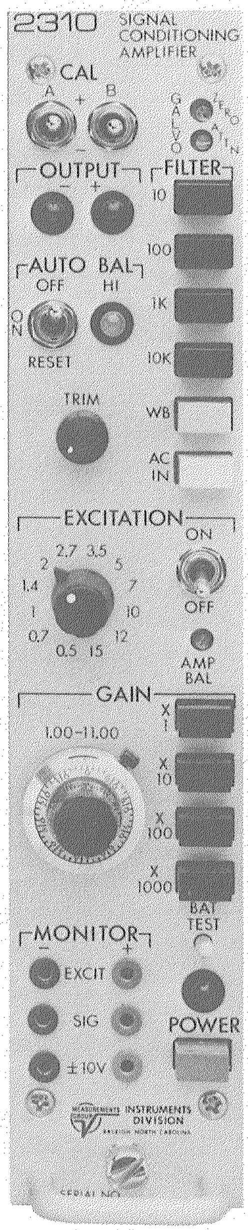
Wiring for remote calibration with Option Y.

POWER

115 or 230 Vac switch selected in amplifiers, 50/60 Hz, 40 Watts max.

SIZE & WEIGHT — 9.06 H x 7.20 W x 18.90 D in *(229 x 183 x 480 mm).*

6.75 lb *(3.1 kg).*



2310 Front Panel

3.0 CONTROLS

The following functional descriptions are of a general character for information only. The operating procedure is covered in *Section 4.0.*

3.1 2310 FRONT PANEL

CAL Switches — Momentary toggle switches to place shunt-calibration resistors across arms of the input bridge. "A" and "B" may simulate different input levels. (See *5.5 Standard Calibration Resistors* for standard factory-installed resistors.).

GALVO ZERO — A trimmer to adjust the zero-bias of the Galvanometer Output to correct for the mechanical zero error of a recording oscillograph or to suppress a static component. It does not affect other outputs.

GALVO ATTN — A trimmer to attenuate the gain at the Galvanometer Output only.

OUTPUT Lamps — LED indicators which always monitor the output. Primarily used to adjust AMP BAL and check bridge balance. Fully lit with 0.04 volt at ±10V Output.

AUTO BAL Controls — The toggle switch has three positions to control operation of the automatic bridge balance circuit:

OFF (up) disables the circuit; the amplifier outputs now represent true unbalance of the input bridge; stored balance point is retained.

ON (center) enables the automatic bridge balance circuit.

RESET (momentary down) triggers the automatic bridge balance circuit to seek a new balance point (the prior stored balance point is lost).

The "HI" lamp (yellow LED) lights when the automatic balance circuit is in its high range; it indicates a bridge unbalance exceeding 1%. If the unbalance exceeds 5% this lamp will cycle on and off continuously.

TRIM Control — A vernier control to refine bridge balance when desired. Normally the automatic balance circuit will achieve balance within several microstrain.

FILTER Buttons — Push buttons to reduce the upper frequency cut-off (10 to 10 000 Hz) to reject undesired noise during lower-frequency tests. Normally the "WB" button would be depressed, achieving wide-band operation (typically 75 kHz at −3dB).

The "IN" position of the "AC IN" button (alternate action) ac-couples the amplifier thus eliminating the dc component of the input signal. (However, modest bridge balance is still required – see *4.14 Dynamic Testing.*).

EXCITATION Controls — The rotary switch selects the desired bridge excitation. Most steps approximately double the power dissipation in the bridge arms.

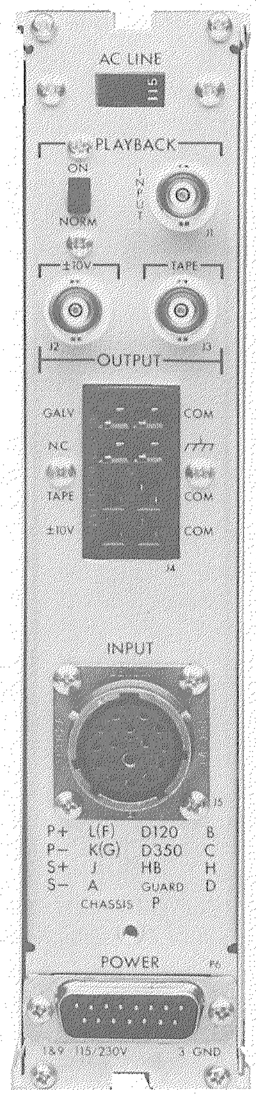
The toggle switch turns bridge power on or off. (Any amplifier output in the OFF position is dc amplifier offset, thermal emf from the bridge, or ac pickup in the wiring.)

AMP BAL A trimmer to adjust the amplifier balance (EXCITATION should be OFF when this is adjusted).

GAIN Controls Amplifier gain is the reading of the 10-turn control (1000 to 11 000) multiplied by the selected push button (X1 to X1000).

The indicated gain is the gain from the input to the ±10V Output. At the Galvanometer Output the gain will be this value or lower, depending on the GALVO ATTN setting. At the TAPE Output the gain will be lower by a fixed factor of 7.07.

The 10-turn counting knob is equipped with a lock which is engaged by pulling the lever *away* from the front panel and then displacing it downward.



2310 Rear Panel

MONITOR Jacks Three pairs of jacks accepting 0.080-in *(2-mm)* diameter plugs to monitor bridge excitation (EXCIT), bridge output (SIG) and the amplifier output (±10V).

BAT TEST A momentary push button to check the keep-alive batteries for the automatic bridge balance circuit. See ***4.11 Battery Test***.

POWER Button An alternate-action push button (and LED indicator lamp) to turn ac power "on" and "off". (Bridge balance is retained even with POWER off or the amplifier unplugged.)

3.2 2310 REAR PANEL

AC LINE Switch Selects nominal 115 or 230 Vac power operation.

PLAYBACK Switch The ON (up) position connects the adjacent Tape Recorder INPUT coaxial BNC connector to the input of the filter circuits (if selected on the front panel) and post amplifiers. Full-scale input is ±1.4V. All three outputs are operable.

NOTE: This switch must be returned to the NORM position to monitor incoming signals at input connector J5.

±10V Connector A coaxial BNC connector for the ±10V Output of the amplifier (in parallel with pins 7 & 8 of the large OUTPUT plug). The ±10V Output is the most standard of the several outputs provided, suitable for oscilloscopes, DVM's, etc.

TAPE Connector A coaxial BNC connector providing the output normally used with tape recorders (in parallel with pins 5 & 6 of the large OUTPUT plug). Full scale is ±1.414V (1 Vrms for sine waves).

OUTPUT Receptacle An 8-pin connector providing all three amplifier outputs. Mating plug supplied.

INPUT Receptacle A 15-pin quarter-turn connector to connect the input circuit to the 2310. Quarter, half, and full bridges, potentiometers, or voltage inputs can be accepted simply by using the appropriate pins; see ***4.2 Gage Input Connections*** for details. Mating plug supplied.

NOTE: PLAYBACK switch must be in the NORM position.

POWER Connector A male rack-and-panel connector which supplies ac power to the instrument. Normally it engages with a powered connector in the rack adapter, although an individual line cord is available (see paragraph *4.1f*).

Prewired for remote operation of shunt calibration, bridge excitation, and automatic bridge balance [see ***4.16 Remote-Operation Relays (Option Y)***].

4.0 OPERATING PROCEDURE

Prior to taking any readings with the 2310, each FILTER and GAIN push-button switch should be exercised several times for best performance and stability.

4.1 SETUP AND AC POWER

Each 2310 Signal Conditioning Amplifier has its own power supply and may be operated as a freestanding unit (see paragraph ***4.1e***), or one or more 2310's may be inserted into the Model 2350 Rack Adapter or the Model 2360 Portable Enclosure.

CAUTION: Prior to removing or installing the 2310 Amplifier or the 2331 Digital Readout into a rack adapter or enclosure, the ac power cord must first be unplugged. Refer system setup and all servicing to qualified technicians. If the 2300 System is used in a manner that is not in accordance with instructions and its intended use, the protection provided by the equipment may be impaired.

4.1a Turn off all 2310 Amplifiers before inserting them into the rack adapter or cabinet; the red POWER button should be in the "out" position, protruding about 3/8 in *(10 mm)* from the panel.

4.1b On the rear of each 2310, set the AC LINE slide switch to the nominal ac line voltage to be used (115 or 230V). Also on the rear panel check that the PLAYBACK switch is at the NORM (down) position.

4.1c Install the 2310 Amplifiers into the rack adapter or cabinet, securing the thumb-screw at the bottom of each front panel.

4.1d Plug the detachable line cord(s) into the appropriate 2350/2360 receptacle(s).

4.1e To power a freestanding 2310 for troubleshooting/servicing, an individual power cord is required.

A non-CE-approved accessory line cord is available from Measurements Group as part number 120-001196.

4.1f The line cord should be plugged into an ac receptacle which has a good earth ground for the third pin.

NOTE: If the plug on the power cord must be replaced with a different type, observe the following color code when wiring the new plug:

Black or brown: High line voltage
White or blue: Low line voltage ("neutral" or "common")
Green or green/yellow: Earth ground

4.2 GAGE INPUT CONNECTIONS

It is suggested that the 2310 be turned on (press the red POWER button) and allowed to stabilize while preparing the input connectors. To prevent powering the input bridge circuits at this time, turn the EXCITATION rotary switch to 0.5 and the toggle switch to OFF.

4.2a Each amplifier uses a separate input plug, which is supplied. Additional plugs are available from Measurements Group (see ***7.4 Component Replacement***) or from the plug manufacturer or distributor. Suggested types:

Bendix PT06A-14-15(SR)
ITT/Cannon KPT06B14-15P
Burndy BT06AC14-15P

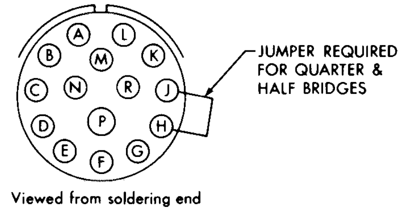


Figure 1: Input Plug Pin Arrangement

These connectors are designed to MIL-C-26482 and may be available from additional manufacturers.

As an aid to the technician, the pin arrangement for the above plugs is shown in Figure 1.

4.2b The basic input arrangements are shown in Figure 2. *Note that, except when using an external full bridge, there must be a jumper in the input plug connecting pins H and J;* this connects the midpoint of the internal half bridge to the S+ amplifier input. Precision 120Ω and 350Ω dummy gages are provided in each Model 2310. If using a quarter bridge with a resistance *other than* 120Ω, 350Ω, or 1000Ω, use circuit A2 in Figure 2. For 1000Ω quarter bridges, see Appendix.

4.2c When using an external full bridge (especially a precision transducer), it may be desirable to employ the remote-sense circuitry provided in the 2310 to maintain constant excitation *at the transducer* regardless of lead resistance. To enable this circuit, open the right side-cover of the 2310 and raise the small red SENSE switch to REMOTE (see Figure 5). Connect the sense leads between the transducer and pins F and G of the INPUT plug as shown in Figure 2, C2.

4.2d If it is desired to employ shunt-calibration across one of the *external* bridge arms, additional wiring is required to achieve maximum accuracy (see ***5.0 Shunt Calibration*** for details). However, for half- or quarter-bridge inputs, shunting the internal dummy half bridge or dummy gage is normally recommended; neither of these circuits requires additional wiring from that shown in Figure 2.

4.3 MILLIVOLT INPUTS

The 2310 Amplifier can accept dc inputs, such as thermocouples, provided two requirements are observed:

a) Neither input should exceed ±10V from circuit common in normal operation, and must *never* exceed a peak voltage of ±15V; and

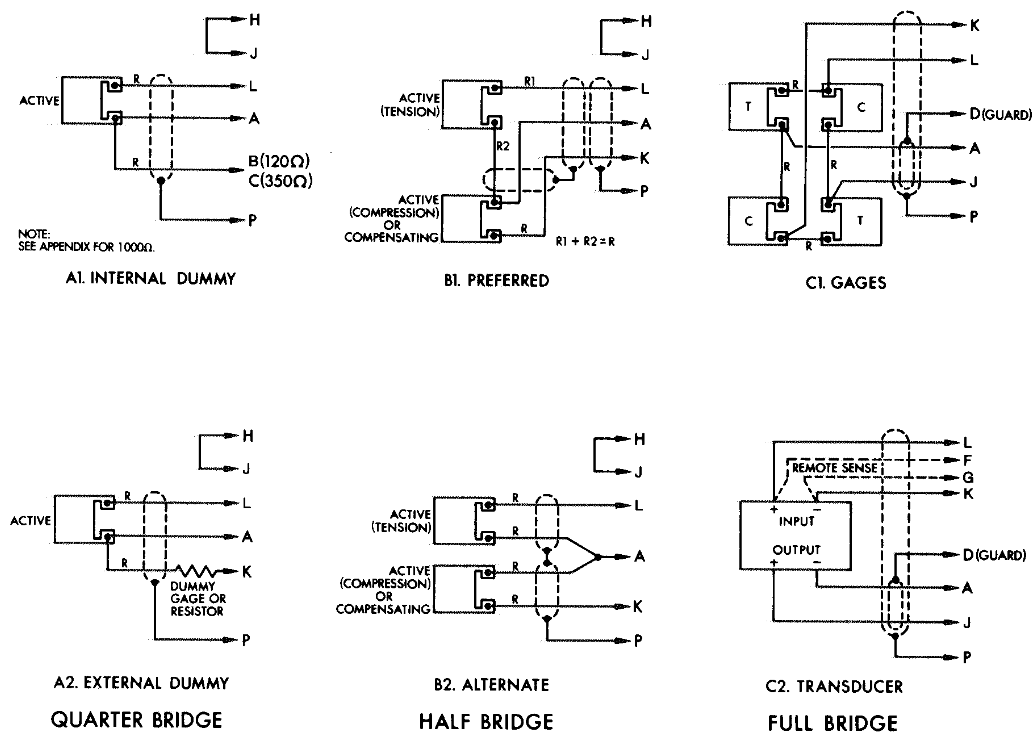


Figure 2: Gage Input Circuits

b) The input circuit cannot be completely floating; there must be some external return to circuit common for both input leads. In the case of thermocouples welded to a nominally grounded structure, this return is usually adequate.

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

a) Each input (pins A and J) requires a bias current of approximately +50 nA; this current will flow through the source impedance of each input (to circuit common) and may cause a measurable offset voltage.

b) Any nonsymmetry in the source impedances of the two inputs will somewhat reduce the CMR of the amplifier.

4.4 WIRING CONSIDERATIONS

In addition to the chassis ground available at pin P of the INPUT plug, the 2310 has an active "guard" connection available at pin D. This guard may be a more effective shield connection than chassis ground, but to be effective the shield must be left disconnected (and insulated against accidental groundings) at the gage end. Normally the guard shield is used inside a conventionally grounded shield, as shown in Figure 2C.

Certain important considerations affect wiring technique, depending on whether the purpose of the test is to measure static or dynamic data.

4.4a Dynamic Data: It is extremely important to minimize the extent to which the gages and leadwires pick up electrical noise from the test environment; this noise is usually related to the 50 or 60 Hz line power in the test area:

a) *Always* use twisted multiconductor 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 plug 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 (a half bridge on or near the specimen will usually show less noise than a true quarter-bridge connection; a full bridge would be still better).

4.4b Static Data: Precise symmetry in leadwire resistance is highly desirable to minimize the effects of changes in ambient temperature on these wires.

a) In the quarter-bridge circuit, *always* use the three-leadwire circuit shown in Figure 2, rather than the more obvious two-leadwire circuit.

b) Insofar as possible, group all leadwires to the same channel in a bundle to minimize temperature differentials between leads.

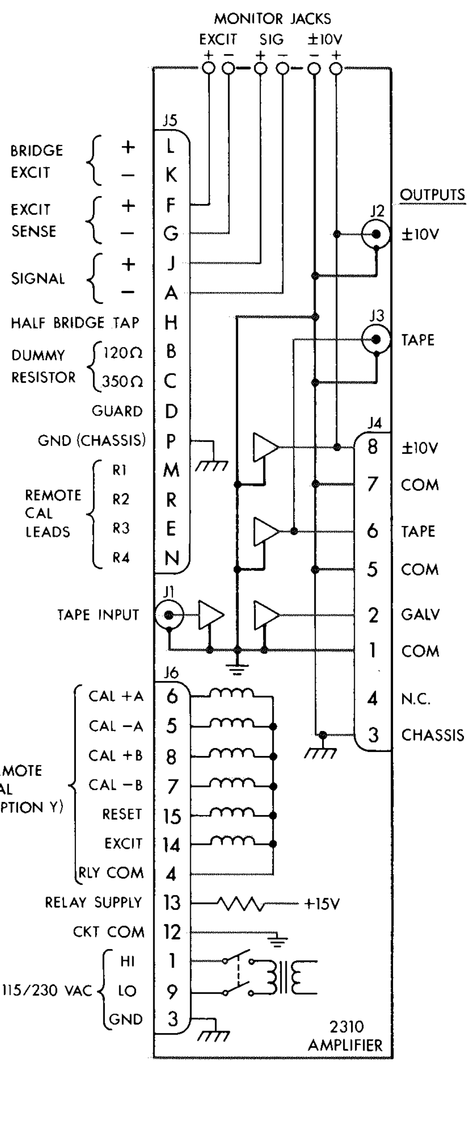


Figure 3: 2310 Connector Pin Identification

c) If long leadwires are involved, calculate the leadwire desensitization caused by the lead resistance. If excessive in view of the data accuracy required, use the adjusted gage factor (see ***5.3 Shunt Calibration — Stress Analysis***), increase gage resistance, or increase wire size — or all three.

4.5 OUTPUT CONNECTIONS

CAUTION: During typical use of this instrument, shorted or open inputs as well as AUTO BAL circuit usage will often cause the GALV and ±10V outputs to approach ±15V. (Tape output is limited to 2V.) The GALV output may deliver up to 100 mA maximum. If the output devices can be damaged by such levels, it is important that proper precautions be taken. In those situations, it is suggested that internal and/or external resistance be added to the output circuitry as discussed in ***4.6 Galvanometer Matching.***

In units with serial numbers starting at 52600, the 2310/2311 circuit common is internally connected to chassis ground at the output connector. When using the OUTPUT plug, pins 3, 5 and 7 may be used interchangeably as circuit grounds. Units with serial numbers lower than 52600 require pins 3 and 5 to be connected by either the suggested jumper shown in Figure 4, or by external wiring to a remote common ground point. The third prong on the power cord normally should establish an adequate chassis to earth ground connection. When connecting this system to the peripheral instruments, the user should be aware that noise-generating ground loops can be caused by having more than one system ground.

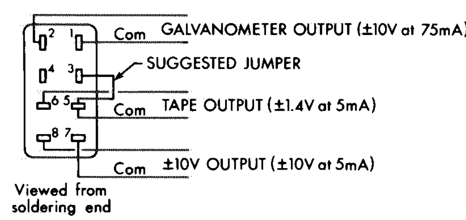


Figure 4: Output Plug Pin Arrangement

The 2310 Amplifier has three simultaneous noninteracting outputs; any one or all may be used in a particular test. All outputs (except the high-current GALV output) are accessible at the rear of the 2310 with either coaxial (BNC) connectors or solder pins in the eight-pin OUTPUT plug. See Figure 4 for details of the OUTPUT plug connections.

The ±10V Output ("±10V" BNC or pin 8 of the OUTPUT plug) would normally be connected to a scope, voltmeter, or multiplexer. Gain figures are direct-reading to this output.

The ±10V Output is also available at the MONITOR pin jacks on the front panel.

The TAPE Output (TAPE BNC or pin 6 of the OUTPUT plug) is normally used only for analog magnetic tape recorders. Full-scale amplifier output (10V at "±10V" Output) will be 1.414V at the TAPE Output, which is the customary full-scale input for tape recorders.

The GALV Output (pin 2 of the OUTPUT plug, with return to pin 1) is normally used to drive low-impedance devices, specifically the galvanometers in a recording oscillograph. This output will current-limit at 100 mA, maximum, to protect many galvanometers.

In using galvanometers, one or more resistors must be used between the amplifier output and the galvanometer for the following reasons:

a) If the "maximum safe current" of the galvanometer is less than 100 mA, a resistor *must* be provided to prevent excessive current flow through the galvanometer;

b) Magnetically damped galvos must have a series resistor to achieve the proper damping characteristics;

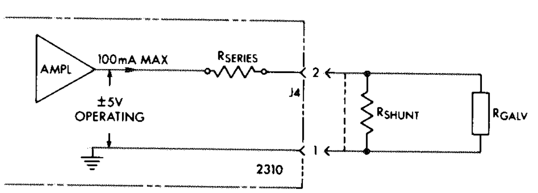
c) The total load resistance on the GALV Output of the 2310 should be at least 50 ohms to achieve sharp current-limit, good linearity and bandpass; and

d) The GALV Output voltage should be around 5V at full galvanometer deflection to achieve good resolution of the GALVO ATTN adjustment and to suppress any low-level noise in the amplifier.

Various resistive networks are available to achieve the above; the following are suggested:

4.6 GALVANOMETER MATCHING

4.6a 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 100 mA limit of the 2310.



If the "maximum safe current" of the galvo is less than 100 mA, calculate the shunt resistor:

$$R_{SHUNT} \leq R_{GALV} \times \frac{I_{SAFE}}{100 - I_{SAFE}} \qquad \text{(Eq. 1)}$$

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

If the maximum safe current is 100 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/in" 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 15Ω. The original solution of Equation 1 yielded the *maximum* value. Thus there is a rather large range of acceptable value, but *never exceed the value originally calculated.*)

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

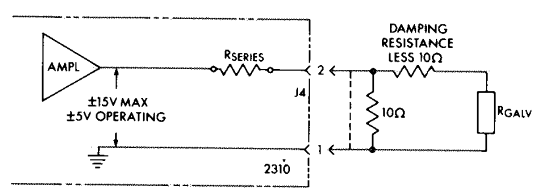
$$R_{SERIES} \cong \frac{\frac{5000}{mA_{FS}} - R_{GALV}}{1 + \frac{R_{GALV}}{R_{SHUNT}}} \qquad \text{(Eq. 2)}$$

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 unity.

The series resistor value is never critical; any value within ±25% of the above solution is adequate. The series resistor is most conveniently mounted between the GALV RES sockets on the 2310 p.c. board (first remove the solder from the p.c. board jumper pad just below the sockets with a hot soldering iron). See Figure 5.

4.6b Magnetically damped galvanometers, only available with a frequency response up to 300 Hz maximum, all require series "damping" resistors to achieve proper dynamic response. A 3-resistor network is usually required:



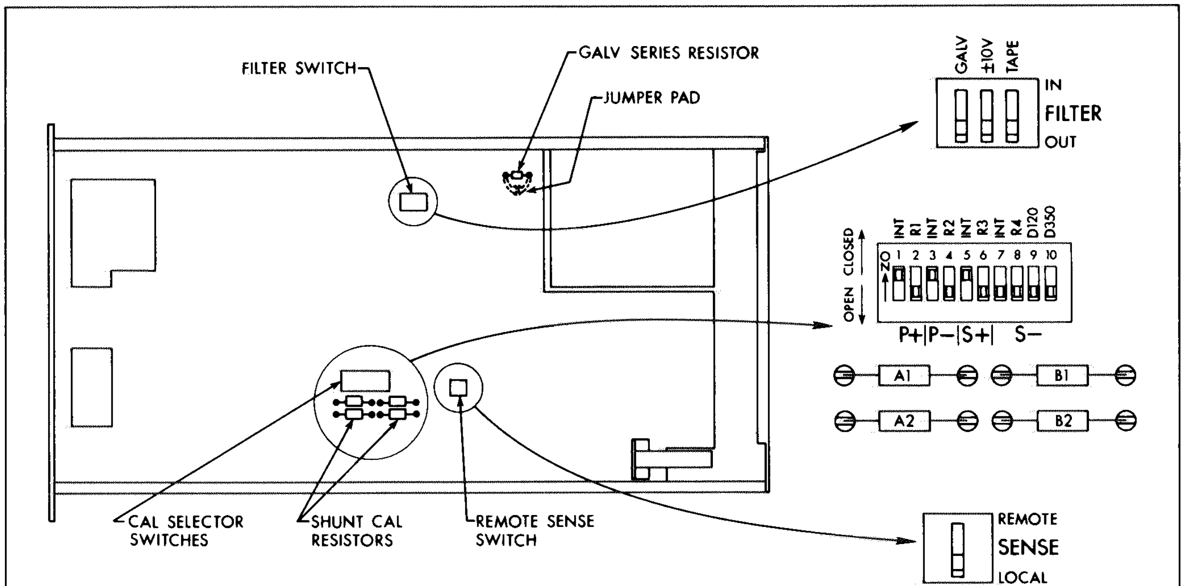


Figure 5: Switch Locations on P.C. Board

Note that in the above circuit the galvanometer is protected by the maximum *voltage* (±15V) from the 2310, and the 100 mA *current* limit is never approached because the value of R_{SERIES} will always be above 150Ω. The 10Ω shunt resistor has been selected rather arbitrarily and the following formulas are based on this value.

$$R_{SERIES} \cong \frac{50 \times 10^6}{\mu A_{FS}\,(R_{GALV} + R_{DAMP})} \qquad \text{(Eq. 3)}$$

where: μA_{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.

An alternate solution is

$$R_{SERIES} \cong \frac{50 \times 10^3}{mV_{FS}} \qquad \text{(Eq. 4)}$$

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

Most specification charts for magnetically damped galvanometers list data in mV/in (or *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 ±25% of the above solution is adequate. Values will range between 1 kΩ and 25 kΩ. The series resistor is most conveniently mounted between the GALV RES sockets on the 2310 p.c. board (first remove the solder from the p.c. board jumper pad just below the sockets with a hot soldering iron). See Figure 5.

4.7 FILTER OUTPUT SELECTOR

The 2310 Amplifier has a selectable low-pass filter. This filter, controlled by front panel push buttons, can be set for one of several frequencies or at wideband ("WB" button), in which case the filter is bypassed.

The filter can affect any one or all of the three outputs. To select the outputs to be filtered, open the right side-cover of the 2310 and note the three toggles on the red FILTER switch (near the top of the p.c. board) marked GALV, ±10V, and TAPE; this switch is shown in Figure 5. Any toggles in the IN (up) position indicate that that output will be filtered when any FILTER button other than WB is depressed; outputs for which the toggle is in the OUT (down) position will still be operating at wideband.

The characteristics of the filter are discussed in *4.13 Filter*.

4.8 EXCITATION

Select the desired bridge excitation with the EXCITATION selector switch.

In stress analysis, it is always desirable to use the highest excitation which the active gage can tolerate *under the test conditions*. Factors which increase this are high resistance (gage resistances of 350Ω or higher), long gage length and gage width, and a good heat-sinking material (such as aluminum). Clearly, small 120Ω gages on plastic materials are to be avoided if in any way possible; even *very* modest excitations may be excessive. Note that most increments on the EXCITATION selector switch represent a voltage increase of about 40%, or a 100% increase in power to the gage.

When using commercial transducers, the manufacturer usually specifies the bridge excitation. If the transducer uses metallic (foil) gages, this is a maximum value; while any excitation up to the "maximum" could be used, generally 50% to 75% of this maximum will yield improved transducer stability while retaining a good signal-to-noise ratio. However, when using transducers with *semiconductor (piezoresistive)* gages, the *specified excitation should be used*, if possible, to achieve the advertised performance.

The bridge excitation supply in the 2310 is semifloating. Unless some ground exists in the input circuit, the supply automatically centers itself about circuit common (e.g., when set at 5B, P+ will read +2.5V above common). However, either P+ or P– may be intentionally grounded if desired (to minimize leads to a multi-channel system, for example) without affecting total bridge excitation. (Accidental grounds may cause errors, depending on where the ground occurs. This is because up to 0.75 mA will flow through the ground connection. Both P+ and P– are, in effect, returned to ground through 15 kΩ resistors.)

The accuracy of the EXCITATION selector is guaranteed to within ±1%. If for any reason the exact setting must be known, it can be measured at the EXCIT MONITOR pin jacks on the front panel; the EXCITATION toggle switch must be ON to make this measurement.

Should the user desire to change the excitation voltage for any position on the EXCITATION selector switch, the resistor for that setting may be changed (it is located on the switch itself). The resistance required can be readily calculated:

$$R = 10\ 000 \times \frac{V}{18 - V} \qquad \text{(Eq. 5)}$$

where: R = required resistance in ohms

V = desired excitation in volts

4.9 AMPLIFIER BALANCE

With a strain gage or transducer connected to the INPUT, the EXCITATION switch still at OFF, and the X100 GAIN button depressed, both OUTPUT lamps at the top of the front panel should be completely dark. If not, turn the AMP BAL adjustment below the EXCITATION toggle switch (using a small screwdriver) to extinguish the lamps. (If the "–" lamp is lit, turn clockwise, etc.)

NOTE: If the AMP BAL adjustment does not have any effect on the OUTPUT lamps, check that the PLAYBACK switch (on the rear panel, is at NORM (down).

If both lamps are lit at best null, this is an indication of excessive noise. This noise is frequently from the 50 or 60 Hz line: check shielding and the instrument ground. See ***4.5 Output Connections***. Refer to ***4.4 Wiring Considerations*** for further discussion on shielding.

4.10 BRIDGE BALANCE

The input must, of course, be connected to balance this input. It is not necessary that the outputs be connected — in fact any device that could be damaged by a full-scale output should *not* be connected at this time.

Having selected the desired bridge excitation, turn the EXCITATION toggle switch to ON; one OUTPUT lamp will probably light fully.

Just below the OUTPUT lamps, momentarily press the AUTO BAL toggle switch all the way down to the RESET position, and release. In 1 to 3 seconds (8 seconds under the most extreme conditions) the OUTPUT lamps should extinguish, indicating balance. If, after several seconds, balance is not indicated, try again (occasionally a "spike" of noise from the environment will prematurely stop the balance operation).

Occasionally the lamps will dim, but not go out; this means that the output is within 0.04V of balance, which is usually adequate, but not zero. For precise balance turn the vernier TRIM knob to extinguish the lamps. (In the presence of noise below 5 kHz, AUTO BAL will normally stop short of true balance; below 500 Hz the error is half the peak-to-peak noise amplitude.) High levels of input noise may make it impossible to extinguish the lamps (both lamps may remain lit). Special input wiring, shielding, and grounding techniques may be necessary to reduce the noise. Even though both lamps are not extinguished (due to the noisy environment), it may be possible to take accurate data (depending upon the test situation).

If, when balance is achieved, the yellow HI lamp is lit, this is an indication that the Automatic Bridge Balance circuit is operating in the high range: bridge unbalance is between 1% and 5% (5000 and 25 000$\mu\epsilon$ at GF=2), which would usually be considered very abnormal if quality gages and good installation and wiring practices were used. Before taking data it may be advisable to explore the reason for this unbalance; possibly the gage should be replaced.

If the HI lamp constantly cycles on and off (4 seconds on, 4 seconds off), the unbalance at the input exceeds 5%, probably due to a gross fault or wiring error (or EXCITATION is not ON or the PLAYBACK switch is at ON).

Possible faults:

"+" OUTPUT lamp lit: open gage, 350Ω gage with 120Ω dummy, or P+ lead open.

"–" OUTPUT lamp lit: shorted gage, 120Ω gage with 350Ω dummy, or lead to D_{120} (or D_{350}) open.

The automatic bridge balance circuit uses a ratio voltage-injection technique and is thus essentially independent of both EXCITATION and GAIN. However, if either is changed significantly and a precise balance is desired, AUTO BAL should be RESET after final setup. A significant change in the null when EXCITATION is *increased* one position indicates that the new excitation is probably excessive (causing self-heating in the gage) and should be returned to the lower position; a similar change as EXCITATION is *decreased* would indicate that the higher setting was probably excessive.

4.11 BATTERY TEST

The automatic bridge balance circuit stores the balance value digitally. The value will not be lost when POWER is turned off (or there is a failure in the ac mains) since the 2310 has a keep-alive supply (two small silver-oxide batteries) to power this circuit at all times.

To check the condition of these batteries, ac POWER must be on. Then press the small BAT TEST button: the "+" OUTPUT lamp should light. If the "–" OUTPUT lamp lights, the batteries are very low and should be replaced (see *7.3 **Battery Replacement***); furthermore, instrument POWER should be left on at all times if retention of bridge balance is desired.

Battery drain to the circuit is insignificant (less than 0.1 mA-Hr/yr) so theoretical life is several decades. But any battery will self-discharge and should be routinely replaced every year or two.

4.12 GAIN

The GAIN controls on the 2310 Amplifier are direct-reading. The 10-turn control may be set anywhere between 1.000 and 11.000. This setting is then multiplied when the push button is depressed (X1, X10, etc). Thus any gain between 1 and 11 000 can be preset.

There is some overlap between ranges. For best accuracy, a gain of 1000 should be achieved with the dial at 10.000 and the X100 multiplier depressed, rather than 1.000 and X1000.

The user must be aware that "system gain" is the product of bridge excitation and amplifier gain. It is always desirable to operate at high bridge excitation and thus minimize amplifier gain – and consequently minimize the amplification of the small noise always present. But there are constraints on the maximum permissible excitation (see ***4.8 Excitation***), so amplifier gain becomes the dependent variable.

In stress analysis, if the desired output sensitivity is known, amplifier gain can be calculated:

$$V_{OUT} = V_{BR} \times A \times \frac{K}{4} \times \mu\epsilon \times 10^{-6} \quad \text{(Eq. 6)}$$

where: V_{OUT} = amplifier output in volts (at ±10V Output)
V_{BR} = bridge excitation in volts
A = amplifier gain
K = gage factor of the strain gage
$\mu\epsilon$ = strain in microstrain (microinches/inch)

Note that this equation assumes *one active gage*; additional active gages will increase the output.

Equation 6 can be rearranged as:

$$A = \frac{1}{V_{BR}} \times \frac{4}{K} \times \frac{V_{OUT}}{\mu\epsilon} \times 10^{6} \quad \text{(Eq. 7)}$$

The term $V_{OUT}/\mu\epsilon$ can be interpreted as system sensitivity in volts/microstrain, or V_{OUT} can be amplifier full scale (10V) and $\mu\epsilon$ the total strain to achieve full-scale output.

Using commercial transducers, where the full-scale output sensitivity is usually known (typically 2 mV output per volt of excitation), the output equation is very simple:

$$V_{OUT\ FS} = V_{BR} \times A \times k \times 10^{-3} \quad \text{(Eq. 8)}$$

where: $V_{OUT\ FS}$ = amplifier output at full-scale transducer input
k = transducer sensitivity in mV/V

Rearranging Equation 8:

$$A = \frac{V_{OUT\ FS}}{V_{BR} \times k} \times 10^{3} \quad \text{(Eq. 9)}$$

Shunt calibration is a very standard alternate technique for establishing amplifier gain, especially for stress analysis. It is a powerful method, when done correctly, since it compensates for any error in bridge excitation, amplifier gain, and the sensitivity of the external indicator or recorder; in some arrangements it even compensates for potential errors caused by the resistance of the wiring to the gages, even when that resistance is unknown.

While simple in concept, there are so many subtleties, alternate circuits available in the 2310, and equations, that the user is referred to in ***5.0 Shunt Calibration*** of this manual, which is devoted exclusively to this topic.

When using transducers, it is often most accurate and convenient to simply apply a known input (force, torque, pressure, etc.) and adjust GAIN to achieve the desired output. If this physical input is less than the full-scale rated input to the transducer, be careful that the amplifier (or recorder) will not limit or saturate with a full-scale input.

4.13 FILTER

The standard 2310 is equipped with a 2-pole low-pass active filter which, depending on which FILTER button is depressed on the front panel, will heavily suppress noise and signal components above the selected frequency: 10 Hz, 100 Hz, 1 kHz or 10 kHz. The gray button (marked WB) eliminates the filter so that the amplifier is operating at its full bandpass ("wide-band"). The marked frequencies are the frequencies at which the output is suppressed 3 dB (down 30% from normal), in accordance with standard electronic practice.

The filter can affect any or all of the three outputs. The switch to select outputs is mounted on the internal p.c. board; it is more fully described in *4.7 Filter Output Selector*.

The characteristic of the active filter is a modified Butterworth transfer function (see Figure 8A). This characteristic achieves a fairly sharp transition at the set frequency and is thus generally most satisfactory where most signal components approximate sine waves. However, should there be an abrupt step input (as with impact tests), the user is cautioned that the Butterworth filter has moderate overshoot (approximately 5% with 2 poles) and it may be desirable to observe the signal in the wide-band mode, thus avoiding the filter distortion.

The filter can be quite readily modified to the Bessel characteristic, if desired. While this eliminates the overshoot problem, the transition near the set frequency is not nearly as sharp. See *6.0 Active Filter* for further discussion of filters.

4.14 DYNAMIC TESTING

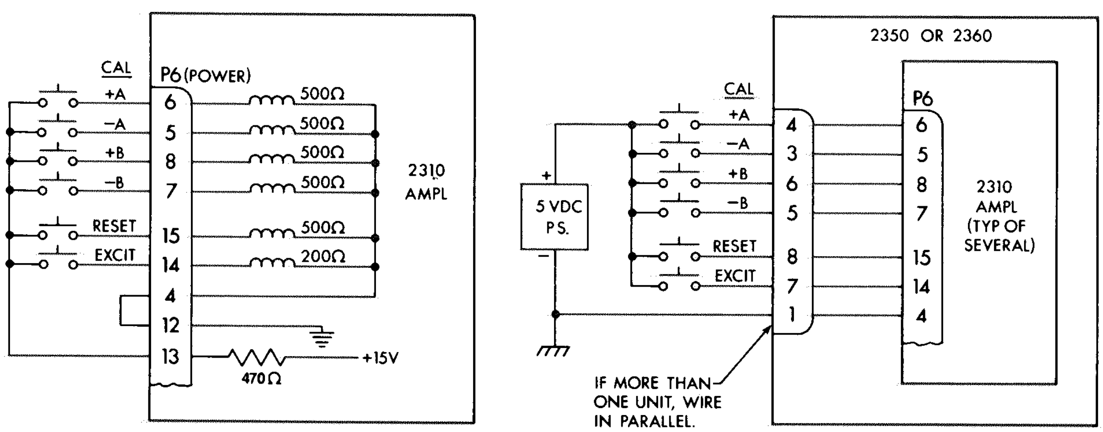
Occasionally the only data of interest is the peak-to-peak amplitude of dynamic signals or the frequency or shape of the dynamic component, and it may be desirable to suppress the static component.

To observe purely dynamic signal components, press the white AC button (below the FILTER buttons). This is an alternate-action push button: in the "in" position all signals are ac-coupled (after the preamp); in the "out" position all signals are dc-coupled. The coupling constant suppresses 5 Hz signals approximately 5% (the −3 dB frequency is about 1.7 Hz). NOTE: The automatic and trim balance controls will not affect the dc output level in the ac-coupled mode.

The preamplifier remains dc-coupled at all times to maintain good common-mode rejection. Even when ac coupling is selected, there is a maximum permissible differential dc input which must not be exceeded (to avoid saturation of the preamplifier); this limit is a function of the GAIN push button selected:

GAIN Button	Max DC Diff. Input
X1	±10 V
X10	±1 V
X100 or X1000	±0.1 V

It is recommended that bridge unbalance be held within 5% (25 000 $\mu\epsilon$ @ GF=2) when possible; the Automatic Bridge Balance circuit is still operable and will compensate entirely for this much unbalance. (With the EXCITATION toggle switch ON, simply press AUTO BAL to RESET momentarily.) Should the bridge unbalance exceed 5%, AUTO BAL must be OFF (all the way up) and the selection of GAIN button and EXCITATION must be made very carefully so as not to exceed the limits tabulated above.



A: Single Amplifier *B: Multichannel*

Figure 6: Remote-Operation Wiring

4.15 TAPE PLAYBACK

The 2310 Amplifier can be used to re-examine data previously recorded on magnetic tape. A suggested practice is to originally record the data with no filter on the TAPE output (TAPE FILTER selector toggle on the p.c. board set at OUT); the recorded tape thus contains all possible frequency components from the test. Even if the data were simultaneously observed and/or recorded on an oscillograph, with or without filtering, the tape-recorded data would still be wide-band.

At some later date the tape-recorded data can be played back through the 2310 and re-examined (using a scope or recording oscillograph); since the active filter in the 2310 is operable in this playback mode, any filter frequency (or WB) may be selected. Note that all three outputs are available.

To use the playback mode, move the PLAYBACK switch on the rear panel of the 2310 to ON (up). Connect the output from the tape recorder to the INPUT BNC connector near the top of the rear panel (full-scale input is ±1.414V, or 1 Vrms for a sine wave). Outputs (±10V, TAPE, and GALV) appear at their normal connectors.

The only controls on the front panel which are operable in the playback mode are:

FILTER buttons (10 to 10K and WB)
GALV ZERO adjustment
GALV ATTN adjustment

After using the playback mode, do not forget to *return the* PLAYBACK *switch to* NORM!

4.16 REMOTE-OPERATION RELAYS (Option Y)

Six isolated relays can be provided to operate the following functions in the 2310. See Figure 6.

Shunt CALibration (+A, –A, +B and –B)
Auto Balance RESET
Bridge EXCITation on/off (to check amplifier balance)

While the relays are not installed unless Option Y is specified at time of order, they can be easily installed later by a qualified technician; all wiring already exists in the 2310 Amplifier. Each relay requires 5 Vdc (10 mA each, except 25 mA for the bridge excitation relay). For after-sale installation, order one Relay Kit 120-001191 for each 2310 Amplifier.

To control the relays in a *single* 2310 Amplifier the internal +15V supply may be used, as shown in Figure 6A. When more than one 2310 is to be operated with a single set of switches (or external relays), an external 5 Vdc power supply is required (250 mA for each ten channels). Option Y must also be specified for the 2350 Rack Adapter or 2360 Portable Enclosure. (For after-sale installation, order one Cal Kit 120-001192 for each 2350 Rack Adapter, or Cal Kit 120-001193 for the 2360 Portable Enclosure.) The system would then be wired as in Figure 6B.

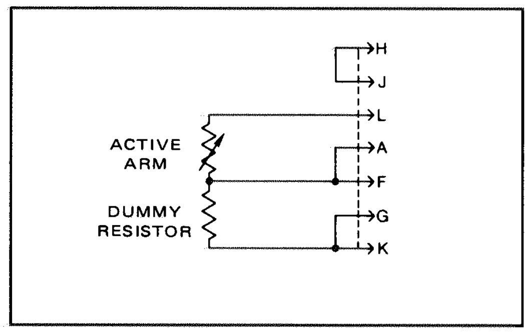
In order to remotely initiate an automatic bridge balance, the RESET line must first be active for a minimum of 50 milliseconds and *then* released. (The balance process *starts* after the voltage is released.) To remotely turn *off* the bridge excitation, the EXCITation off line must be made active (5 Vdc). The other functions (CALibration) are turned *on* when 5 Vdc is supplied to the appropriate pin and turned *off* when the voltage is removed.

4.17 QUARTER-BRIDGE NONLINEARITY

The output of a Wheatstone bridge is somewhat nonlinear with only one active arm. This nonlinearity is usually insignificant in stress analysis (percent error equals percent strain @ GF=2). Should high strains be encountered (post-yield studies or tests on some non-metallics), the error can be removed during data reduction, although the user is cautioned regarding uncertainty of the value of gage factor above 1% strain.

If it is desired to obtain an output which is linear with ΔR in one arm of a bridge, this can be achieved with the 2310.

This technique utilizes the remote-sense leads to maintain constant voltage across a dummy resistor, and therefore constant *current* through this resistor and through the active arm. Connections to the INPUT plug are as follows:



Two changes to the operating procedure are required:

a) The Remote SENSE switch on the p.c. board must be at REMOTE, and

b) The EXCITATION selector switch must be set at *half* the desired bridge excitation.

The user may notice that bridge balance is somewhat affected by this circuit (e.g., 0.5% with a 500Ω half bridge), but this is well within the range of the Automatic Bridge Balance circuit. (The source of this shift is the presence of R69 — 100 kΩ — across the active resistance.)

5.0 SHUNT CALIBRATION

5.1 INTRODUCTION

Shunt calibration is a very powerful technique to determine total system "gain" in Wheatstone bridge systems such as the 2310. In general, one arm of the input bridge is shunted with a specific resistance, which introduces a specific $-\Delta R$ into this arm (simulating a compressive strain in a strain gage). The amplifier output will respond exactly as if that specific $-\Delta R$ (i.e., strain) actually had occurred with the existing bridge excitation and amplifier gain. It is only necessary to calculate the simulated strain and read the amplifier output to determine the *system* sensitivity.

IMPORTANT: It should be emphasized that the intent of shunt calibration is to determine the performance of the *circuit and instrument* into which the gage is wired; in no way does it verify the ability of the *gage* itself to measure strain nor the characteristics of its performance.

While the basic shunt calibration concept and equations are simple and well-known, the presence of leadwire resistance can have *very* significant effects on the accuracy of the technique. Either the precise shunt circuit used must be chosen such that the leadwire resistance has no net effect, or a correction must be made for this effect.

The shunt calibration circuits available in the 2310 are designed to be exceptionally versatile and easy to change. Most circuits apply specifically to stress analysis applications; when using commercial strain gage transducers the double-shunt method is suggested (*5.4 Transducers*).

5.2 SHUNT CALIBRATION COMPONENTS IN 2310

The two CAL switches on the front panel normally provide two independent values (A and B) of simulated strain, each of which can be either + or –. (If both switches are operated simultaneously the values are algebraically additive.)

With Option Y additional relays are installed in the 2310 such that any of these four switch positions can be operated remotely [***4.16 Remote Operation Relay (Option Y)***].

Four calibration resistors, two associated with the "A" switch and two with the "B" switch, are installed in the miniature sockets on the right side of the p.c. board (see Figure 5). These resistors may be changed in the field to suit specific test requirements. See ***5.5 Standard Calibration Resistors.***

A blue ten-switch Calibration Circuit Selector is installed on the right side of the p.c. board (see Figure 5). Only two or three (or four for transducers) should ever be closed (up) for any given circuit.

Note that the swtiches are divided into four groups, as marked at the bottom: P+, P–, S+, and S–, corresponding to the four corners of the bridge. Each group has an "INT" switch, which connects the calibration circuit to the indicated corner of the bridge *internal* to the 2310; and an "R" switch, which connects the circuit to a dedicated pin in the INPUT connector – to be used when shunting a *remote* active gage. The S– group has two additional switches for shunting the internal dummy gages (D120 and D350).

5.3 SHUNT CALIBRATION – STRESS ANALYSIS

Shunt calibration can be achieved by shunting any one of the four arms of the input bridge – this includes the active gage and the bridge completion arms in the 2310. The same equation applies, but note the definition of R_a:

$$\mu\epsilon_{cal} = \frac{R_a}{K'(R_{cal} + R_a)} \times 10^6 \qquad \text{(Eq. 10)}$$

where: $\mu\epsilon_{cal}$ = strain simulated (microstrain)
R_a = resistance of leg shunted (ohms)
K' = effective gage factor of active gage
R_{cal} = resistance of calibration resistor (ohms)

R_a may not be equal to the resistance of the active gage when the shunt is across one arm of the dummy half bridge. (But also note that no correction factor is ever necessary for the shunting effect of the resistance balance circuit, since the 2310 does not use the shunt method for bridge balance.)

Gage factor (K′) in Equation 10 may be the actual package gage factor of the active strain gage (corrected for temperature, when necessary), or it may be a value adjusted for leadwire desensitization:

$$K' = K\frac{R_g}{R_g + R_\ell} \qquad \text{(Eq. 11)}$$

where: K = gage factor of active gage
R_g = resistance of active gage (ohms)
R_ℓ = resistance of leadwire(s) in series with active gage (usually the resistance of *one* leadwire) (ohms)

The specific gage factor correction applicable to the various circuits is indicated in Chart 1.

Chart 1 tabulates the recommended shunt calibration circuits available in the 2310, together with the switch settings and wiring necessary to achieve them.

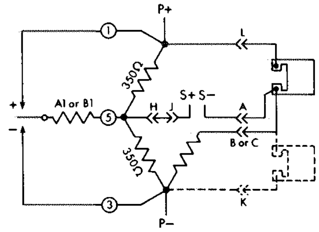
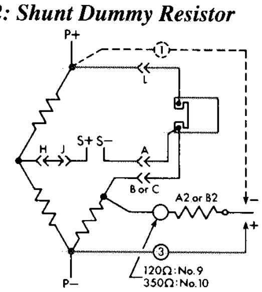
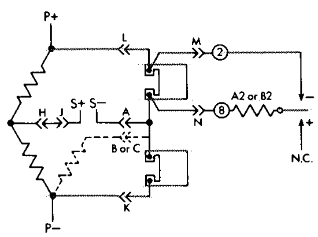
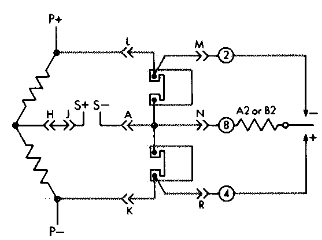
CKT 1: Shunt Internal Half Bridge  	Excitation SENSE: LOCAL Cal Selector Switches: #1 closed (P+ at INT) #3 closed (P− at INT) #5 closed (S+ at INT) Others open (down) $R_a = 350\Omega$ K′ from Equation 11	USE: Quarter and half bridge (full bridge with reduced accuracy). ADVANTAGES: Same resistors for any active gage resistance. No special wiring. + and − cal. DISADVANTAGES: Must correct for leadwire resistance.
CKT 2: Shunt Dummy Resistor  	Excitation SENSE: LOCAL Cal Selector Switches: #3 closed (P− at INT) #9 closed for 120Ω gage, or #10 closed for 350Ω gage (S− at D120 or D350) Others open (down) R_a = nominal gage resistance K′ = K (NOTE: If Cal Selector #1 is also closed, can also simulate compression, but for *compression* K′ must be from Equation 11).	USE: True quarter bridge. ADVANTAGES: Automatically corrects for leadwire resistance when using 3-wire circuit. No special wiring. Accuracy independent of precise gage resistance. DISADVANTAGES: Usable only if internal dummy gages are in use. Simulates tension only.
CKT 3: Shunt Active Gage  	Excitation SENSE: LOCAL Cal Selector Switches: #2 closed (P+ to R1) #8 closed (S− at R4) Others open (down) R_a = gage resistance K′ = K	USE: Quarter, half, full bridge. ADVANTAGES: Classic theory using *any* leadwire method for bridge wiring. DISADVANTAGES: Two added wires necessary. Simulates compression only.
CKT 4: Shunt Active Half Bridge  	Excitation SENSE: LOCAL Cal Selector Switches: #2 closed (P+ to R1) #4 closed (P− to R2) #8 closed (S− to R4) Others open (down) R_a = gage resistance K′ ≅ K	USE: Half or full bridge. ADVANTAGES: Classic theory using any leadwire method (except resistance between active gages must be negligible). Simulates + and −. DISADVANTAGES: Three added wires necessary.

Chart 1: Stress Analysis Shunt Calibration Circuits

The calibration resistor value (calculated from Equation 10) would apply to CAL Switch A if the resistor is installed at position A1 or A2, or it would apply to CAL Switch B if installed at position B1 or B2; CAL A and CAL B are totally independent. Provided that the Calibration Selector Switches are set as specified in the chart, resistors installed at positions not called for have no effect on the output; it is not necessary to remove them.

Many other arrangements are possible, but they must be used with great care. For example, the obvious method to shunt an active gage (quarter or half bridge) would be simply to close the Calibration Selector Switches for P+, P− and S− to INT, achieving a circuit functionally similar to Circuit 4. However, the effect of leadwire resistance is surprisingly high (some *four times greater than expected* from Equation 11), so the circuit should never be used; much more accurate results will be achieved in these cases with Circuit 1 (or especially Circuit 2, if using a true quarter bridge).

5.4 TRANSDUCERS

The term transducer in the context of a bridge conditioner can include any full bridge composed of strain gages with a known calibration. It may be simply four gages properly located on a part to measure force or torque (frequently a detail part of the mechanism under study), or it may be a more elaborate (and accurate) commercial transducer.

Commercial transducers are much more complex circuits since they typically have a number of additional resistive elements to correct for the effects of temperature and to achieve the desired precise span calibration. Nonetheless, this complexity can usually be overlooked without greatly compromising the accuracy of shunt calibration, if done properly.

Shunt Calibration per Calibration Certificate: Many transducer manufacturers provide shunt calibration information as part of the calibration certificate. When available, this is the most reliable method of calibration, but the specified resistance must be connected *precisely as indicated by the manufacturer.* Sometimes there are two separate pins dedicated to shunt calibration; additional leads are required to accomplish calibration with resistors installed inside the 2310. In other cases the pins may be one normal input lead and one normal output lead. Since the effects of leadwire resistance are very measurable, additional leads dedicated to the shunt calibration circuit must be used between the transducer connector and the INPUT connector to the 2310.

The complete schematic of the available connections for shunt calibration of transducers is shown in Figure 7.

As an example of transducer shunt calibration, assume that the certificate for the transducer specifies that a 10 kΩ resistor should be placed between the positive excitation (P+) pin and the negative output (S–) pin. A suggested method with the 2310 would be:

a) Install a 10 kΩ resistor in position "A2" on the p.c. board.

b) In addition to the normal 4-wire connection to the transducer (6-wire if remote excitation sense is used), connect two additional wires; one from

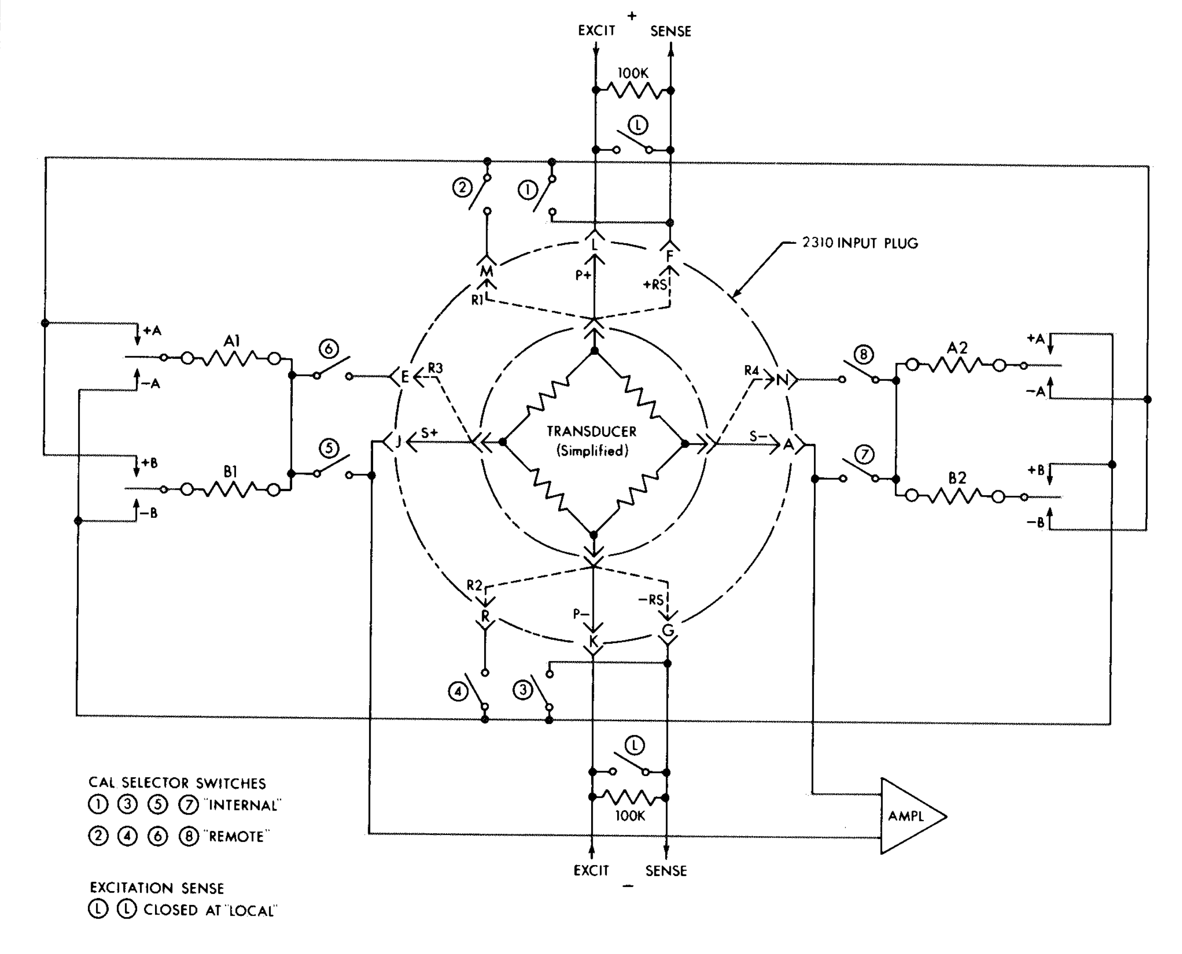


Figure 7: Transducer Shunt-Cal Circuitry

the positive excitation pin *on the transducer* to pin M of the 2310 INPUT plug, the other from the *transducer* negative output pin to pin N of the 2310 INPUT plug.

c) Inside the 2310, Calibration Selector Switches 2 and 8 should be ON (all others open, or down). Excitation SENSE would be at LOCAL, unless the basic 6-wire system is in use, in which case it would be at REMOTE.

d) To insert the 10 kΩ shunt, move the CAL A toggle (on the front panel) to "–".

If shunt calibration data is not known, the best procedure is to calculate values to be used in double-shunt calibration; this procedure corrects for any normal nonsymmetry in the transducer by simultaneously shunting two opposite legs of the bridge. To calculate the resistor value, use the following equation:

$$R_{double\text{-}shunt} = R_O\left(\frac{500}{k} - 0.5\right) \qquad \text{(Eq. 12)}$$

where: $R_{double\text{-}shunt}$ = value of each shunt resistor (ohms)
R_O = output resistance of transducer (usually 350 ohms)
k = output to be simulated (mV/V)

Common values would be as follows for a 350Ω transducer:

mV/V	Ohms (double-shunt)
3	58,158
2	87,325
1.5	116,492
1	174,825

The above resistors must be placed electrically *at the transducer connector* (rather than the 2310 INPUT plug) to eliminate the sizable effect of leadwire resistance. To achieve this, four "remote-calibration" pins (E, M, N and R) are provided in the INPUT plug, as shown in Figure 7.

The resistors (value as calculated in Equation 12) would be soldered to the p.c. board turrets in positions A1 and A2 (or B1 and B2). Now the selected transducer output, either + or –, can be simulated simply by operating the CAL A (or CAL B) front panel switch.

A common arrangement may be to calculate two resistor values (representing perhaps 100% transducer output and 25% output), putting one pair at A1 and A2, the other pair at B1 and B2; now either 100% or 25% of full output can be simulated by using either CAL A or CAL B.

It is important to emphasize that when using semiconductor (piezoresistive) transducers, EXCITATION must be set at the manufacturer's specified voltage to achieve proper calibration. Transducers using foil gages may be excited with any voltage below the maximum value specified by the manufacturer, although best overall system performance will usually be achieved with 50% to 75% of the permissible maximum.

5.5 STANDARD CALIBRATION RESISTORS

The 2310 is intended to be ready for use as received, with bridge completion resistors, dummy gages and shunt calibration resistors installed. The standard shunt calibration resistors have been selected for maximum flexibility for stress analysis. These resistors are as follows:

A1	–	874.8k	±0.1%
A2	–	59.94k	±0.1%
B1	–	174.8k	±0.1%
B2	–	174.8k	±0.1%

These values provide the following shunt calibration levels (for identification of Cal Selector Switches, see Figure 5):

Input Circuit	Arm Shunted	Cal Selector Switches ON	Strain Simulated @ GF=2
¼ & ½ bridge, 350Ω full bridge	Dummy half bridge	1, 3, 5	$\pm A = \pm\ 200\mu\epsilon$ $\pm B = \pm 1000\mu\epsilon$
120Ω ¼ bridge	Dummy resistor	3,9	$+A = +1000\mu\epsilon$
350Ω ¼ bridge	Dummy resistor	3, 10	$+B = +1000\mu\epsilon$
350Ω transducer (double-shunt)	All	1, 3, 5, 7	±B = ±1 mV/V*

**These values assume zero leadwire resistance.*

6.0 ACTIVE FILTER

6.1 FILTER CHARACTERISTICS

The standard 2310 is supplied with an active 2-pole filter with Butterworth characteristics having high-frequency cut-off at the following frequencies: 10, 100, 1000 and 10 000 Hz. The following field modifications are possible:

a) change one or more frequency selections

b) increase to 4 or 6 poles

c) change to Bessel characteristic

This section describes the reasons for these changes and methods to accomplish them.

The choice of filter characteristic (Butterworth or Bessel) is a compromise. With reference to Figure 8, note the following:

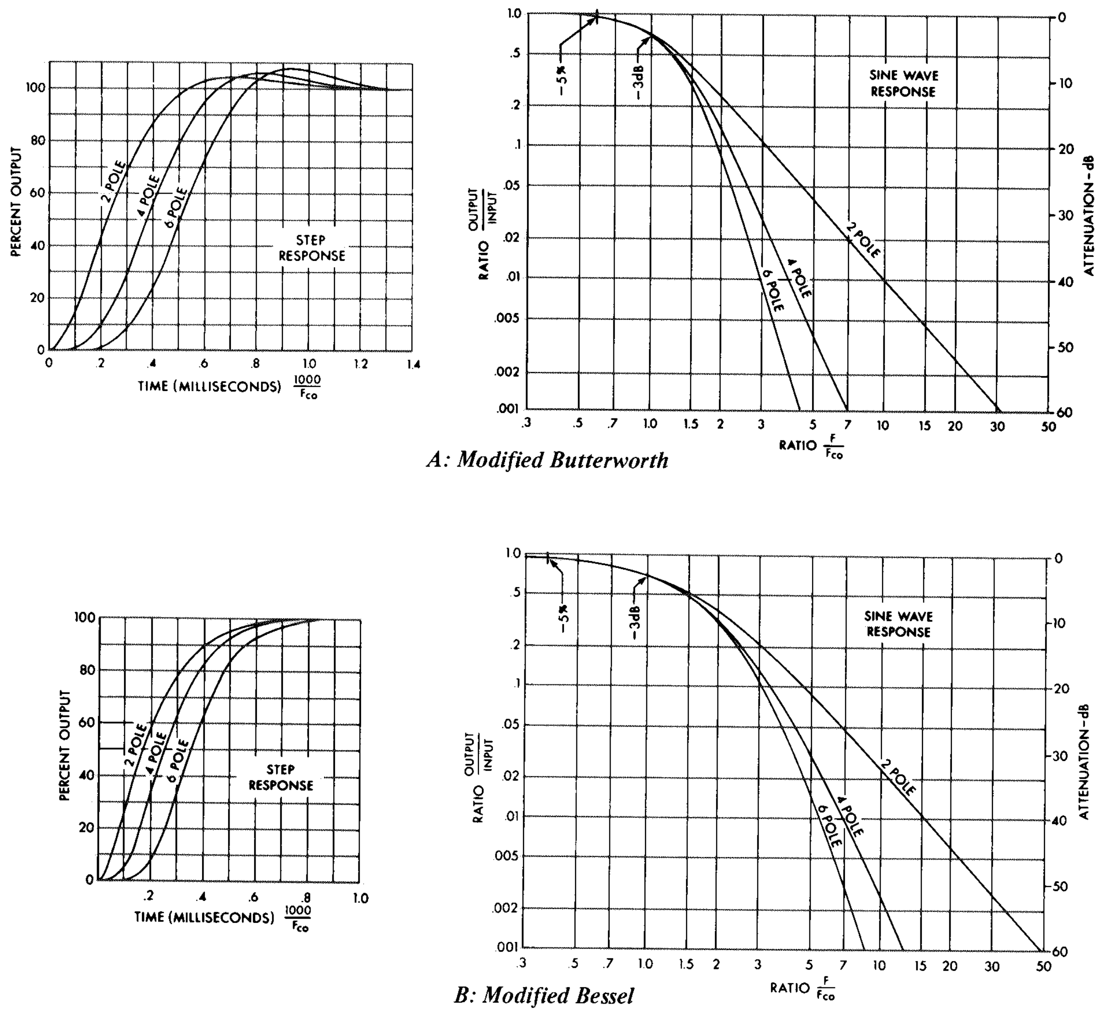
a) The Butterworth filter falls off much more sharply around the −3dB frequency (F_{co} in the curves).

b) While both filters (with equal poles) ultimately reach the same slope at high frequencies, the sharpness of the Butterworth filter at F_{co} results in better attenuation at any given high frequency.

c) Should there be an instantaneous step input, the Butterworth filter will produce 5 to 8% overshoot (assuming precise component values), whereas the Bessel filter has no overshoot.

Thus the choice of characteristic is very dependent on the type of testing performed. However, the Butterworth, with its sharper cut-off, is *generally* preferred.

When high noise rejection is required near F_{co}, a filter with 4 or more poles is highly desirable. Although, note from Figure 8 that there is no discernible improvement *below* F_{co} as the number of poles is increased.



A: Modified Butterworth

B: Modified Bessel

Figure 8: Filter Characteristics

The rise time (10% to 90%) for step inputs is virtually fixed; it is independent of both filter characteristic and number of poles:

$$\text{Rise time} \cong \frac{0.35}{F_{co}} \text{ in seconds} \qquad \text{(Eq. 13)}$$

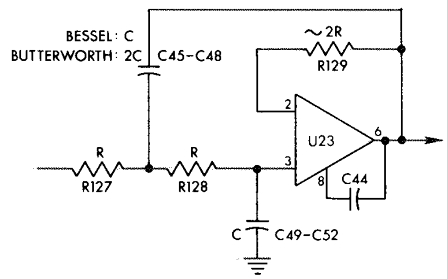
where: F_{co} is the cut-off frequency (−3dB) in Hz

All multipole filters introduce a significant time delay near and above the cut-off frequency. In multichannel dynamic studies where instantaneous outputs from several channels are to be compared or analyzed at a specific point in time (for example, reduction of a 3-element strain gage rosette), these channels must have identical filters to avoid "data skew" caused by different time delays in the several channels.

6.2 FILTER MODIFICATIONS

To change the push-button frequencies, either the resistors (R127 and R128) or capacitors (C45 thru C52) may be changed. However, it is generally advisable to keep the resistors in the 10 kΩ to 25 kΩ range (lower values require very large capacitors and higher values may cause excessive amplifier drift); furthermore, a resistor change would affect all frequencies – individual frequencies would be changed by changing two capacitors (for each 2 poles).

The following equation and tabulation show the relationship which must be satisfied in the accompanying circuit detail of one 2-pole filter section.



$$C = \frac{K}{F_{co} \times R} \qquad \text{(Eq. 14)}$$

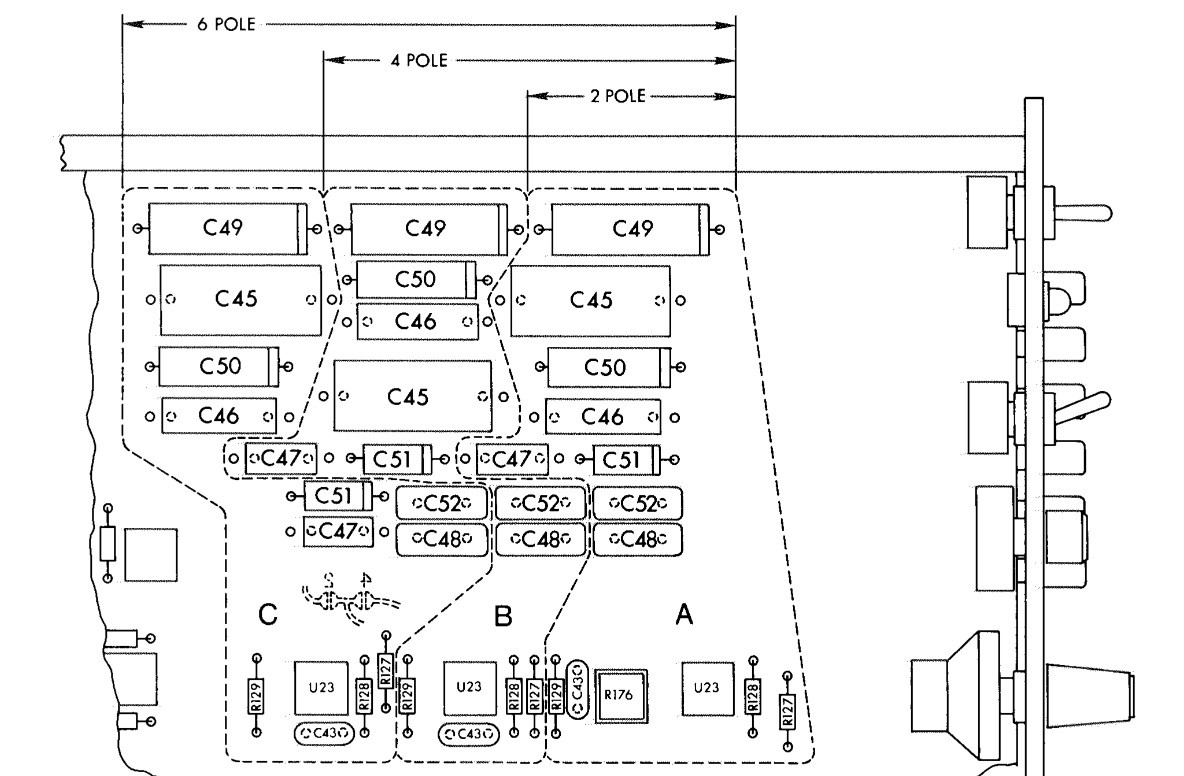


Figure 9: P.C. Board Layout – Active Filter

where: F_{co} is the cut-off frequency (–3 dB) in Hz
R is in kΩ (with suggested values tabulated below)
C is in μf
K is a constant, as tabulated

	K	R (suggested)
Butterworth		
2-pole	112.5	22.6 k
4-pole	90.28	18.2 k
6-pole	80.36	16.2 k
Bessel		
2-pole	102.4	20.5 k
4-pole	70.23	14.0 k
6-pole	55.70	11.0 k

To increase the filter to 4 poles (or 6 poles) it is necessary to add one (or two) additional IC's together with the necessary resistors and capacitors listed in Table 1. To preserve accurate frequencies and sharp cut-off, the indicated tolerances should be held (the 1% resistor values shown are from the standard mil spec 1% decade and are readily available). Figure 9 shows the location of the components on the p.c. board. The component numbers are identical for the three filter sections, followed by letters A, B and C for the different sections. The push button switch is prewired for all three sections.

Solder jumpers must be added or deleted at pads "2" or "4" on the p.c. board (these are located on the right side of the board). To remove a jumper, simply apply a clean soldering iron for a second or two. To short a pad, use plenty of solder, dabbing at the pad with rather quick strokes of the soldering iron.

Filter Kit 120-001194 is available from Measurements Group to change the filter characteristics in the field (only a soldering iron and solder are necessary). This kit, together with the components normally supplied in the 2310 (2-pole Butterworth filter), contains all components necessary to achieve a 2, 4 or 6-pole Butterworth or Bessel filter for the standard frequencies (10 Hz to 10 kHz). An extension of the Sallen-Key configuration (equal component value) is used in the 2310 to achieve the 4 and 6 pole versions. These versions, therefore, have roll-off characteristics that are somewhat different than the classical Butterworth and Bessel filters (see Figure 8).

Component		Butterworth			
		Value	Positions Installed		
			2 pole	4 pole	6 pole
C43	10%	.001 μf	↑	↑	↑
C45	5%	1 μf			
C46	5%	0.1 μf			
C47	5%	.01 μf			
C48	5%	.001 μf	A	A & B	A, B & C
C49	5%	0.5 μf			
C50	5%	.05 μf			
C51	5%	.005 μf			
C52	5%	470 pf			
U23		741C	↓	↓	↓
R127 R128	1%	22.6k	A	–	–
		18.2k	–	A & B	–
		16.2k	–	–	A, B & C
R129	10%	47k	A	–	–
		39k	–	A & B	–
		33k	–	–	A, B & C
Jumper "2"		–	Short	Open	Open
Jumper "4"		–	Open	Short	Open

Component		Bessel			
		Value	Positions Installed		
			2 pole	4 pole	6 pole
C43	10%	.001 μf	↑	↑	↑
C45	5%	0.5 μf			
C46	5%	.05 μf			
C47	5%	.005 μf			
C48	5%	470 pf	A	A & B	A, B & C
C49	5%	0.5 μf			
C50	5%	.05 μf			
C51	5%	.005 μf			
C52	5%	470 pf			
U23		741C	↓	↓	↓
R127 R128	1%	20.5k	A	–	–
		14.0k	–	A & B	–
		11.0k	–	–	A, B & C
R129	10%	39k	A	–	–
		27k	–	A & B	–
		22k	–	–	A, B & C
Jumper "2"		–	Short	Open	Open
Jumper "4"		–	Open	Short	Open

TABLE 1
Filter Values for Standard Frequencies (10 Hz - 10 kHz)

7.0 MAINTENANCE

Maintenance is to be done *only* by qualified technicians.

7.1 CIRCUIT DESCRIPTION

To assist in maintenance, the following general description of the circuits in the 2310 is provided:

7.1a The +15V and −15V dc power supplies both employ 723 precision regulators, U1 and U2, with external pass transistors Q1 and Q2. Current limiting will occur when approximately 0.6V is developed across R2 or R11 (the +15V supply uses circuitry in U1, whereas the −15V supply uses Q4 to cut off Q2).

7.1b The bridge excitation supply consists of U3 and several additional IC's and transistors. Regulator U3 develops +18V at pin 10 (relative to pin 7, which is essentially P–); this voltage is set by R162. This +18V becomes the positive supply for U5 and U6, and also the reference for the excitation selector switch, S11. The negative supply for U5 and U6 comes from U4, which develops –5V relative to P–.

The selected voltage appears at pin 3 of U5; it is established by the divider formed by R17 and the resistor selected at S11. U6 is a non-inverting follower for the two excitation sense leads; output 7 (negative bridge excitation) moves the entire supply system up or down, as required, such that pin 7 of U3 is at the negative bridge voltage — via the remote-sense lead, if used. Output 1 of U6 (positive bridge excitation) is compared with the selected voltage at U5 and drives pass transistor Q3 to achieve the set voltage. R20 and Q5 limit current through Q3 in the event of an overload.

U7 is a differential amplifier (with a gain of 0.67) to sense bridge excitation for the automatic bridge balance circuit. The network of U7 also provides a symmetrical 15k ground return for essentially both P+ and P–, so that the supply becomes symmetrical about ground, unless intentionally grounded otherwise.

7.1c The amplifier itself consists of IC's U19 through U26. U19 (a dual op amp) is the preamplifier; outputs 10 and 14 have a *common-mode* component equal to that of the inputs, but their *differential* component is the input amplified by 1, 10 or 100, as determined by the network of R97, R99, R109 and R110. U20, a differential amplifier, merely removes the common-mode component. Common-mode rejection requires perfect symmetry at U19 and U20; this is trimmed by R167 and C30 at high gain, and by R170 and R171 at low gain.

AC coupling, when selected, is achieved by C34 and R111. R169 and R112 supply the necessary bias current to U21 when ac coupling is used.

U21 is a unity-gain follower at most gains; when a gain of X1000 is selected, this stage has a gain of 10.

U22 is an inverting amplifier with a variable gain of X1 to X11, as determined by the setting of R186. The network at C41 is a peaking circuit to compensate for the distributed capacity of R186 when at high values (high gain settings).

U23 is only used when the active filter is selected. At low frequencies it is a unity-gain follower.

U24, part of the galvanometer output circuit, drives power buffers Q9 and Q10; the entire circuit has a gain of −1, although R182 may attenuate the available input. Q7 and Q8, together with R140 and R141, provide current limiting.

U25A is a fractional-gain (X0.141) amplifier for the tape output.

U26 is a unity-gain amplifier for the ±10V output.

U25B is normally a high-gain (X330) amplifier to drive the output LED's from the ±10V output. The load at the output of U25B is simply R157; the LED's are inside the feedback loop. Consequently the LED *current*, and thus brightness, is a linear function of the output of U26; full brilliance occurs with about ±13V across R157, corresponding to 40 mV at the ±10V output.

7.1d When S2 is depressed, the U25B/LED circuit is used to check the condition of the keep-alive batteries. If the batteries are at +2.1V the input at pin 6 of U25 will be zero and theoretically neither LED would light. With normal batteries (3.0V total) the "+" lamp will light; below 2.1 V the "–" lamp will light (and the batteries should be replaced). Note that this test is made at a load of 0.5 mA, far exceeding normal load.

7.1e U8 through U15 and U18 comprise the automatic bridge balance circuit.

U9A and U9B form a 1 kHz multivibrator, turned on as long as the output of U8C is low (0V). These pulses are fed to binary counters U10 and U11 (14 bits total, although the least-significant bit is not used).

U12 (together with U13A) is a multiplying DAC (digital-to-analog converter). The output of U13A is the product of bridge excitation (from U7) and the binary output of U10/U11, starting at zero volts and going positive as a linear 4096-step staircase. U13B inverts this and offsets it by half the output of U7, producing a negative-slope staircase passing through zero volts at mid-count of the DAC.

This voltage ramp is fed into the preamplifier (U19) using amplifier/inverter U18 with a circuit that (a) does not affect input impedance or CMR, (b) is corrected for preamplifier gain so that it represents a true RTI offset and (c) is proportional to bridge excitation via U7. The total effect is a linear ramp of effective bridge unbalance. Note that with bridge excitation turned off, there will be no ramp.

Initially the output at pin 3 of U11 is low; U14 is a normally closed switch. All resistors chosen will start the ramp at, effectively, −1% bridge unbalance. This will climb rapidly toward zero and, within seconds, the positive output of U21 will go through zero volts (the bridge is "balanced" – or, more properly, the voltage injected into the preamp is just sufficient to counteract the bridge unbalance, which really still exists).

"Balance" is sensed by U15, a zero-crossing detector. R62 and C23 remove high-frequency noise; C22 and R61 provide lead-control for steep ramps resulting from high gain and/or excitation. The output of U15 goes abruptly positive, driving the output of U8B positive, stopping the oscillator (U9A and U9B). The binary counter will hold its "number" (and thus the balance setting) indefinitely, unless reset.

The supply for the counter ("+3/15V") comes from a 3 V silver oxide battery when the instrument is not powered. The standby drain is some 5 to 10 nA, so shelf-life is by far the limiting factor on battery life. (When the instrument is turned on, the "+3 V" supply becomes +14.5 V.) To prevent spurious loads on the battery, U8 and U9 are also battery-operated and CR12 and CR13 block other drain paths; the reset circuit is inoperable when the instrument is not powered as this requires the +15 V supply.

S10 serves two purposes: S10B disconnects the output of the DAC when the balance circuit is turned off (the unbalance of the bridge will now be seen by all amplifier outputs). S10A (momentary) resets the circuit. While depressed, the output of U8B will be high; this resets the counter (pin 2 of U10 and U11) to binary 0. When S10A is released the output of U8A goes high so that U8C goes low (and is latched by the high output of U8D), starting the oscillator (U9A and U9B); the ramp restarts from zero, as described above.

7.1f If the circuit cannot achieve balance at full count to the DAC, the next step will make pin 3 of U11 go high. Three events occur. Both switches in U14 open: one lights the yellow HI LED lamp (to indicate range change) and the other raises the gain of U13B by five, which will now produce a steeper ramp (corresponding to ±5% bridge unbalance). Thirdly, U9C and U9D disable the oscillator for some 20 ms to allow U15 to recover from the very large *positive-going* zero-crossing that may occur. The ramp then resumes, but at five times the original slope and amplitude, presumably achieving "balance" and stopping, as before. (If balance still cannot be achieved, the binary counter goes to full count and the next count will yield binary 0, causing the HI LED to extinguish and start the process all over again at ±1% balance, then

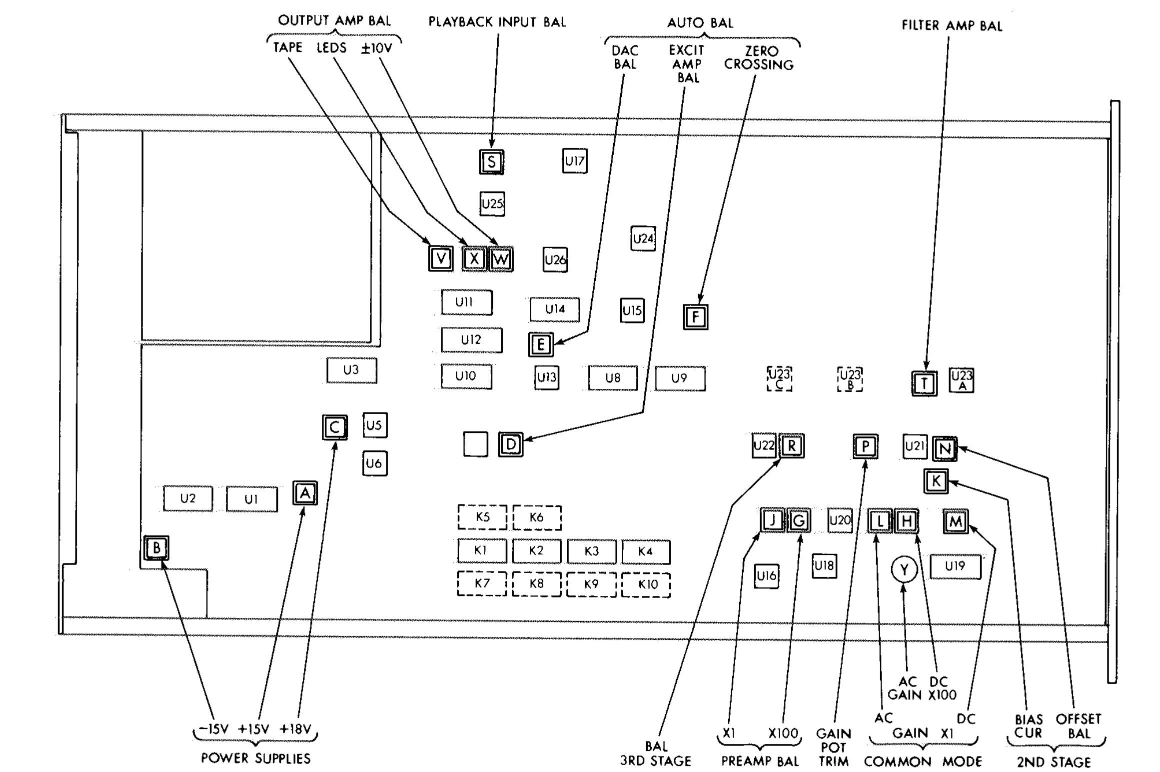


Figure 10: P.C. Board Layout – Trim Adjustments

±5%, etc. This would continue indefinitely, but may be stopped—erroneously—by some large spurious noise spike at the amplifier input after several minutes of cycling.)

7.2 ADJUSTMENTS

There are a number of trim adjustments on the p.c. board; no adjustment of these controls should be necessary unless a component is changed, principally one of the integrated circuits. Each trim control is marked on the p.c. board with a letter of the alphabet to assist the technician. Additionally, many test points are marked on the component side of the board (e.g., TP4); these points refer to the adjacent resistor lead. Both the control identification letters and TP numbers also appear on the schematic in this manual. Figure 10 shows the location of the various adjustments.

The 2310 must have ac power during servicing (see *4.1 Setup and AC Power*); accessory power cord 120-001196 is suggested.

The trim adjustments fall into three general categories: power supply set points, common-mode adjustment, and balance adjustments for most operational amplifiers.

The power supplies can be set with or without an input to the 2310, using a digital voltmeter. It is suggested that these be set within 0.1% (if possible) after 15 minutes warmup.

METER LEADS		READING	ADJUSTMENT
–	+		
J4, pin 7	TP 14	+15.00 V	A
J4, pin 7	TP 15	–15.00 V	B
TP 17	TP 16	+18.00 V	C

The amplifier balance controls should be set in the sequence listed at right, after the instrument has been warmed up for at least 15 minutes. Tie circuit common to chassis by connecting a jumper between pins 3 and 5 of the OUTPUT plug. The inputs must be shorted together and grounded by connecting INPUT plug pins A, J and P together. All readings should be made with a digital voltmeter or stable dc scope with a resolution of at least 1 mV; when possible set balances to within 0.2 mV of zero. All readings are relative to circuit common (OUTPUT pin 1). The front panel AMP BAL trimmer must be approximately centered (11 turns from one end), EXCITATION at OFF, and AC coupling button "out" (for dc coupling). Also, the front panel settings listed at right must be made prior to adjustment and not changed unless subsequently directed to do so.

Auto Balance adjustments should be made with a 350Ω bridge connected to the input; it should be possible to unbalance this bridge randomly up to about 3% unbalance.

METER LEAD	FRONT PANEL	ADJUSTMENT	IC BALANCED
TP 1	GAIN button X100	G	U18, U19
TP 1	GAIN button X1	J	U20
TP 1	GAIN button X1000	G	U18, U19
TP 2	–	N	U21
TP 2	AC button "out"	K	U21
TP 3	GAIN button X1 and dial 11.000	R	U22
TP 4	GAIN dial 11.000 FILTER 100	T	U23's
TP 6	FILTER WB	V	U25A
TP 7	–	W	U26
TP 8	–	X	U25B

Adjustments D and E are set to make the 2310 output (after "balancing" the bridge) independent of bridge excitation:

a) Set GAIN at approximately X100; bridge outputs (amplifier inputs) shorted together.
b) With EXCITATION at OFF, null LED's with AMP BAL.
c) EXCITATION ON, set at 15 V. Press RESET; use TRIM to extinguish LED's.
d) EXCITATION at 2 V; LED's should stay out. If + LED lights, turn adjustment E clockwise to slightly light – LED, and vice versa.
e) If an adjustment was required, repeat (c) and (d).
f) Unbalance the input bridge approximately 3% (10k shunt across one 350Ω arm suggested) and remove short across bridge output.
g) Follow steps (b) through (e), but trim adjustment D.

Adjustment F is set for best null (on average) using Auto Balance. The following procedure is suggested:

a) Set GAIN at 500 and EXCITATION at 5 V.
b) With EXCITATION at OFF, null LED's with AMP BAL.
c) With any random bridge unbalance, turn EXCITATION to ON and press RESET. If, at "balance", the + LED is lit somewhat, turn adjustment F counter-clockwise (and vice versa) until both LED's are extinguished at "balance".
d) Repeat above procedure with several random bridge unbalances to achieve best average performance. (If reading the ±10V output with a DVM, readings at "balance" ideally should be between 0 and –3 mV, which is the theoretical resolution of the circuit at these settings.)

Adjustments H, L, M, and Y all affect common-mode rejection in the preamplifier. They are most conveniently set using an audio oscillator (10 Hz to 5 kHz):

a) Connect the oscillator between circuit ground and the two amplifier inputs (INPUT pins A and J) shorted together. Set the oscillator for about 10 Vp-p (3.5 Vrms).
b) Connect oscilloscope to ±10V output, ac-coupled.

c) Set GAIN dial at 1.000 and press X1 button.
d) Set oscillator at 10 Hz; adjust M for best null on scope.
e) Set oscillator at 1 kHz; adjust L for best null.
f) Repeat (d) and (e) if adjustments were required.
g) Press X100 GAIN button.
h) Set oscillator at 10 Hz; adjust H for best null.
i) Set oscillator at 1 kHz; adjust capacitor Y for best null.
j) Repeat (h) and (i) if adjustments were required.
k) If (h) and (i) required significant adjustment, repeat from (c) on.

7.3 BATTERY REPLACEMENT

The current drain from the keep-alive batteries in the automatic bridge balance circuit is continuous with POWER off, whether the instrument is plugged in or not, but this current is so small (5 to 10 nA) that self-discharge (i.e., shelf-life) is far more significant.

The batteries should be replaced when the test circuit indicates low voltage (see ***4.11 Battery Test***), or routinely two years after installation.

The batteries used in the 2310 are widely used in cameras and hearing aids and are available at most photographic supply stores. Any of the following silver oxide batteries may be used (two required):

Gold Peak	S76E	Mallory	MS76
Burgess	76SO	Renata	357

To replace the batteries:

a) Disconnect power and remove cover on left side of the 2310.
b) Locate the battery holder near the main power switch at the rear of the 2310.
c) Note the orientation of the existing battery cells.
d) Remove and properly dispose of the old batteries.
e) Install the two new batteries with the positive ends (case of cell) toward the rear of the instrument, and the negative ends (button) toward the front.
f) Replace 2310 side cover.
g) Apply ac power to the 2310 and press BAT TEST: the + OUTPUT lamp should light.

7.4 COMPONENT REPLACEMENT

It is recommended that a defective 2310 be returned to Measurements Group for factory service, especially during the warranty period (to preserve the warranty); however, a qualified technician can often repair the unit in the field. Most electronic components used are standard commercially available items. Any component can be purchased from Measurements Group (if the Measurements Group part number is not listed below, please provide us with the component symbol and value — or an adequate description of the part — and the instrument serial number).

The following information may be of value for field service.

7.4a Resistors:

All unmarked resistors are 5%, 1/4W.

All 1% through 0.1% values are cermet or metal film (100 ppm/°C).

All 0.05% and tighter tolerances are Vishay S-102C (2 ppm/°C) and must be ordered from Measurements Group.

Resistors R71 through R74 are part of the bridge completion assembly and must be ordered as part 200-131240.

7.4b Connectors

Connectors	Symbol	P/N
Input plug, 15-pin [Bendix PTO6A-14-15P(SR)]	P5	12X300531
Output plug, 8-pin (Cinch-Jones P-308-CCT)	P4	12X300530
Mating power plug (not supplied) (ITT/Cannon DA15S or equal)	–	12X300151
Remote cal plug (for 2350/2360) (Cinch-Jones S-308-CCT)	–	12X300533
Line cord (for 2350 and 2360) (Belden 17742)	–	21X300126

7.4c Battery

Keep-alive supply (Gold Peak S76E)	B1	23X400001 (two required)

7.4d Toggle Switches

Filter selector (on p.c.b.) (Grayhill 76TC03)	S3	10X900046
Excitation sense selector (on p.c.b.) (Grayhill 76TD01)	S4	10X900047
Calibration selector (on p.c.b.) (CTS 206-10)	S5	10X900048
Cal A and Cal B (J-B-T JMT-127)	S8, S9	10X600120
Auto Balance (J-B-T JMT-233)	S10	10X600121
Excitation on/off (J-B-T JMT-223)	S12	10X600110

7.4e Relays

Calibration (CP Clare PRMA2A05)	K1, K2, K3, K4	11X500085
Remote cal & reset (CP Clare PRMA1A05)	K5, K7, K8, K9, K10	11X500078
Remote excitation on/off (Hamlin HE721C0500)	K6	11X500077

7.4f Transistors

NPN power (Motorola MJE800)	Q1, Q3, Q9	14X200169
PNP power (Motorola MJE700)	Q2, Q10	14X200175
NPN small sig (GE 2N3860)	Q5, Q6, Q7	14X200154

PNP small sig (GE MPS3638A)	Q4, Q8	14X200173

7.4g Integrated Circuits

Regulator (National LM723CN)	U1, U2, U3	14X700040
5V Regulator (Motorola MC79L05CP)	U4	14X700060
Quad NOR gate (Harris CD4001UBE)	U8, U9	14X700122
Binary counter (Harris CD4024BE)	U10, U11	14X700046
Multiplying DAC (Analog Devices PM7541AGP)	U12	14X700110
Analog switch Siliconix DG200ACJ)	U14	14X700058
Compensated op amp (Analog Devices OP-07DP)	U5, U16	14X700087
Uncompensated op amp (National LM301AN)	U15, U17, U22	14X700017
Compensated op amp (National LM741CN)	U7, U23	14X700054
Dual op amp (dual 741) (National LM1458N)	U6, U13, U18	14X700055
High-slew op amp (Signetics NE531N)	U20, U21	14X700056
Input op amp pair (Analog Devices OP-37EP)	U19A, B	14X700097
Compensated op amp (National LF356N)	U24	14X700093
Dual op amp (Analog Devices OP-14CP)	U25	14X700095
Compensated op amp (Analog Devices OP-01EP)	U26	14X700096

7.5 FUSE REPLACEMENT

Fuse replacement is intended to be done only be qualified technicians with all cabling disconnected including the power cord. All fuses are rated at 250V and are appropriate for both 115V and 230V operation. Substituting non-recommended fuse values may create hazardous conditions.

Model 2310/2311: The primary transformer power and wiring is fused internally with a time lag fuse as follows: UL-CSA: T .25 A IEC: T.2A

Model 2331: Two axial-lead internal power fuses are recommended as follows:

0.25A fast acting, Littelfuse #251.250 (UL/CSA).

Model 2350/2360: A power fuse is located on the rear panel. The following lists the recommended time lag fuse ratings:

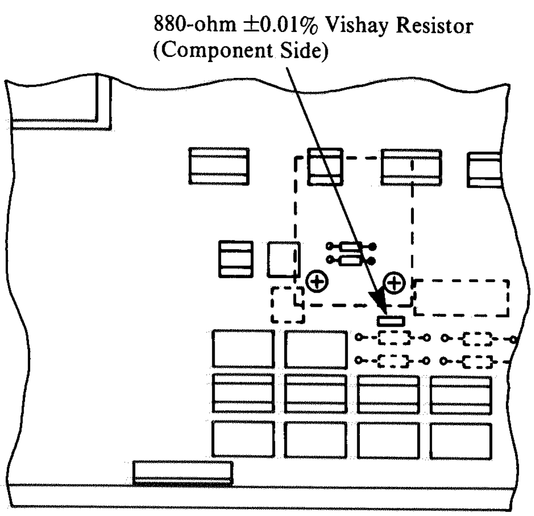
2350: UL-CSA: T 1 A IEC: T .8 A
2360: UL/CSA: T .5 A IEC: T .4 A

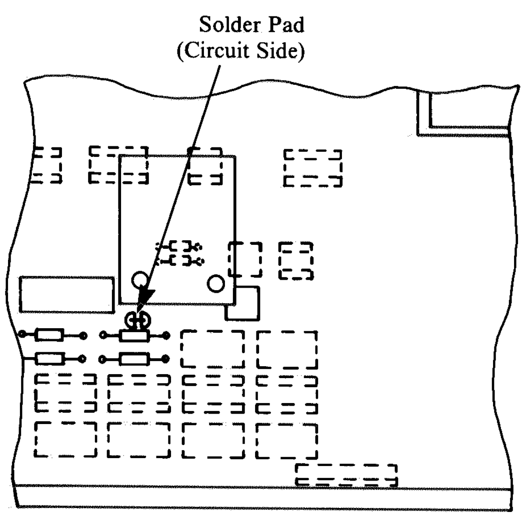
7.6 SCHEMATICS

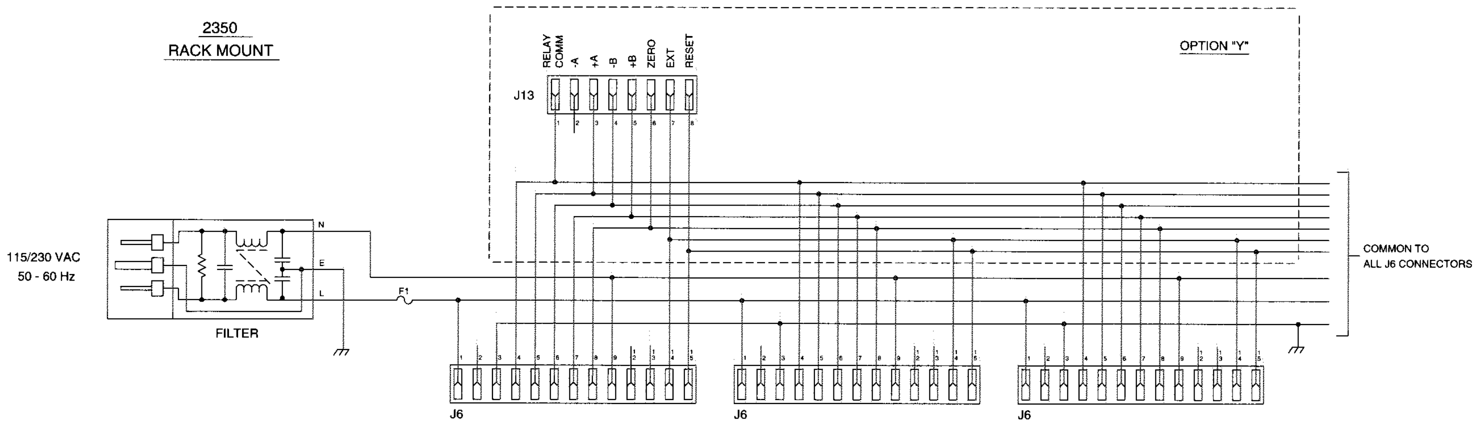
Schematics for the 2310 and 2350/2360 will be found on the following pages. Technicians are advised that Measurements Group may have made minor changes in circuits or values. If an addendum is included with this manual, it is suggested that the indicated schematic changes, if any, be made on the drawings.

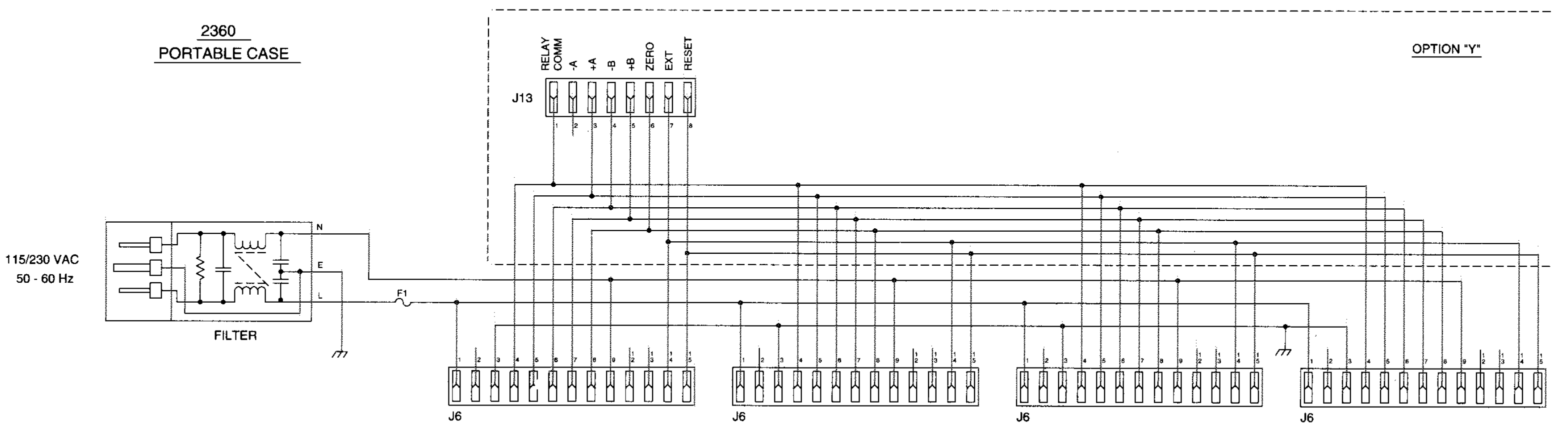
APPENDIX

2310 Signal Conditioning Amplifiers, starting with serial numbers above 85170, provide the capability for 1000-ohm quarter-bridge operation. For this mode, the 120-ohm dummy terminal (pin B of input plug) is converted to a 1000-ohm dummy terminal by removing a shunt from a factory-installed precision resistor in series with the internal 120-ohm dummy gage. To make this conversion the user must desolder a solder pad located on the circuit side of the PC board. The location of the 880-ohm resistor (component side) and the solder pad is shown below.









MEASUREMENTS GROUP, INC.
A Subsidiary of Vishay Intertechnology, Inc.

300-045401B

SCHEMATIC
RACK ADAPTER 2350
PORTABLE ENCLOSURE 2360

WARRANTY

Vishay Micro-Measurements 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 Vishay Micro-Measurements 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 Vishay Micro-Measurements in such a manner as to injure, in our sole judgment, the performance, stability, or reliability of the instrument;
ii. subject 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 Vishay Micro-Measurements 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 Vishay Micro-Measurements 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 Vishay Micro-Measurements, 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 Vishay Micro-Measurements 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 Vishay Micro-Measurements harmless from any claim asserted against or liability imposed on Vishay Micro-Measurements 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.

Vishay Micro-Measurements 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.

Vishay Micro-Measurements' 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 Vishay Micro-Measurements.

Vishay Micro-Measurements 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 uses to which the data and test results may be put are completely in the hands of the Purchaser. Vishay Micro-Measurements 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 Vishay Micro-Measurements.