1.0 DESCRIPTION

1.1 GENERAL

The 2300 Series instruments comprise a versatile multi-channel system for conditioning and amplifying low-level signals from strain gages (or strain-gage 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 separate line cords), although normally groups of amplifiers are inserted into a multi-channel rack adapter or portable enclosure.

The Model 2350 Rack Adapter accepts up to ten 2310 Amplifiers for mounting in a standard 19-inch (48.2-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, DC/DC's, etc.
- Bridge excitation from 0.5 to 15 Vdc (12 steps).
- Input impedance above 100 megohms.
- Three simultaneous buffered outputs: ±10 V, ±1 kV (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 or ±25 000 off automatic bridge balance, with keep-alive power to preserve balance for months without external power.
- Dual-polarity 2-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.

2.1 2310 SIGNAL CONDITIONING AMPLIFIER

INPUT

Strain gages: quarter, half, or full bridge (50Ω or 1000Ω). Built-in 120Ω and 350Ω dummy gages.

Transducers: foil or piezoresistive strain gage types.

Potentiometers.

DCDIT inductive transducers.

EXCIATION

Twelve settings: 0.5, 0.7, 1, 1.4, 2, 2.7, 3.5, 5, 7, 10, 15 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.

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

Ranges (auto ranging):

±5000μV (1% bridge unbalance or 2.5 mV V<sup>-1</sup>), resolution 2.5μV (0.0012 mV V<sup>-1</sup>).

±25 000μV (5% bridge unbalance or 12.5 mV V<sup>-1</sup>), resolution 12.5μV (0.006 mV V<sup>-1</sup>).

Balance time: 2 seconds, typical.

Manual vernier balance range: 100μV (0.050 mV V<sup>-1</sup>).

Interaction: essentially independent of excitation and amplifier gain.

Storage: non-volatile digital storage without power for up to 2 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 ±1000μΩ @ GP=2 across dummy half bridge;

±1000μΩ @ GP=2 across dummy gage (10Ω and 15Ω).

±1 mV/V (double-shunt) for 35Ω 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 11000 continuously variable.

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. differental-or common-mode, including bridge balance circuit.

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

Source impedance: 0 to 100Ω 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.

35Ω balanced input: 90 dB, typical, dc to 1 kHz.

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

Noise (gain over X100, all outputs):

0.01 to 10 Hz: 1 μV p-p RTI.

0.5 to 50 kHz: 5 μVrms, max. RTI

FILTER

Characteristics:

low-pass active 2-pole Butterworth standard.

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

Outputs filtered: any 1 or 2 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: 5Ω).

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: ±4.14V 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.

POWER

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

Keeps alive supply (for bridge balance): 2 Eveready 576E or equal. Shelf-life (approximately 2 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 2310 Amplifiers.

AC line completely wired.

Wiring for remote calibration with Option Y.

POWER

2-10 ft (0.6-3 m) 3-wire line cord; 10-ft (3-m) extension cord supplied.

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

Receptacle to accept line cord from adjacent 2350 Rack Adapter.

SIZE & WEIGHT

8.75 H x 19 W x 17.87 D in overall (222 x 483 x 454 mm).

13.5 lb (6.1 kg)

2.3 2360 PORTABLE ENCLOSURE

DESCRIPTION

Convenience enclosure to accept up to four 2310 Amplifiers.

AC wiring complete.

Wiring for remote calibration with Option Y.

POWER

8-ft (2.4-m) detachable 3-wire cord.

Fuse: 1/2 A size 3 AG (32 x 6.4 mm dia.).
3.0 CONTROLS

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

3.1 2310 FRONT PANEL

**CAL Switches**
- Momentary toggle switches to place dummy-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. )
- 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 ZERO**
- A trimmer to attenuate the gain at the Galvanometer Output only.

**ATTN Lamps**
- Low 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 ‘out’).

**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 adjust 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 “JC 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 110000) 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.

MONITOR
Three pairs of jacks accepting 0.080-in (2.0 mm) diameter plugs to monitor bridge excitation (EXCIT), bridge output (SIG) and the amplifier +10V 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
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 J1.

+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, as marked. 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 Gate 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 supplied 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 4.11).

Pre-wired for remote operation of shunt calibration, bridge excitation, and automatic bridge balance [see 4.16 Remote-Operation Keys (Option 3)].
4.0 OPERATING PROCEDURE

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 4.1f), or one or more 2310's may be inserted into the Model 2350 Rack Adapter or the Model 2360 Portable Enclosure.

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 If only one 2350 Rack Adapter is in use, plug the integral line cord into a powered ac receptacle. If more than one 2350 Rack Adapter is used, the next rack adapter is then plugged into the utility receptacle at the rear of the first 2350, etc. (The sequence is not significant.).

NOTE: The fuse at the rear of each rack adapter only fuses the amplifiers in that rack. The utility receptacle is not fused. Each amplifier above serial number 35333 is internally fused at 1/4 amp.

4.1e If a 2360 Portable Enclosure is used, plug the detachable line cord into a powered ac receptacle.

4.1f To power a freestanding 2310, an individual power cord is required. The mating connector is ITT/Cannon Type D15A, or equivalent. Line cord connections:
- Pin 1: High line voltage
- Pin 9: Low line voltage ("neutral" or "common")
- Pin 3: Earth ground

An accessory line cord is available from Measurements Group as part number 120-001196.

4.1g 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 (or the 2360 detachable line 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 Components Replacement) or from the plug manufacturer or distributor. Suggested types:
- Burndy TD6A-14-15(SR) ITT/Cannon KPD6B14-15P
- Burndy BT6AC14-15P

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.

![Diagram showing the pin arrangement of the input plug.](Image)

Figure 1: Input Plug Pin Arrangement

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 5 and 7; this connects the midpoint of the internal 350Ω half bridge to the 5+ amplifier input. Precision 120Ω and 350Ω dummy plugs are provided in each Model 2310. If using a quarter bridge with a resistance other than 120Ω or 350Ω, use circuit A2 in Figure 2.

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 3). Connect the sense leads between the transducer and pins F and G of the INPUT plug as shown in Figures 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 5.6 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

b) The input circuit cannot be completely floating: there must be some return to circuit common for both input leads. In the case of thermocouples bonded 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 nonlinearity 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 wire "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 grounding) 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 leads 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 2-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 leads, 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 3-leadwire circuit shown in Figure 2, rather than the more obvious 2-leadwire circuit.

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

c) If long leadwires are involved, calculate the leadwire demagnetization caused by the lead resistance. If excessive in view of the data accuracy required, use the adjusted gate factor (see 5.3 Shunt Calibration — Stress Analysis), increase gate 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 S10V Outputs to approach ±15 V. (True Output is limited to 2V.)

The GALV Output may deliver up to 100 mA maximum. If the output device can be damaged by such levels, it is important that protective 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. When using a galvanometer, pin 1 (GALV COM) should be used as the galvanometer common since sizable currents may exist and could otherwise cause measurable errors in the other outputs. 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.

The 2310 Amplifier has three simultaneous non-interacting 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 other coaxial (BNC) connectors or solder pins in the 8-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 multimeter. Coin figures are direct-reading to this output.

The ±10V Output is also available at the MONITOR pin jack 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 Galf 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 galvanometers must have a series resistor to achieve the proper damping characteristic;

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

d) The Galf 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 galvan is less than 100 mA, calculate the shunt resistor:

\[ R_{SHUNT} < \frac{R_{GALV} \times I_{SAFE}}{100 - I_{SAFE}} \quad (Eq. 1) \]

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 basic use, the maximum required operating current—typically several times the "mA/min" 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 1.5Ω. The original solution of Equation 1 yielded the maximum value. Thus there is a rather large range of acceptable values, but never exceed the value originally calculated.)

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

\[ R_{SERIES} \approx \frac{500}{\frac{I_{MAX}}{100 - I_{MAX} \times R_{SHUNT}}} \quad (Eq. 2) \]

where: \( I_{MAX} \) is the millampere 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 is 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 socket 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 100 Hz maximum, all require series "damping" resistors to achieve proper dynamic response. A 3-resistor network is usually required.
Note that in the above circuit the galvanometer is protected by the maximum voltage (±10V) from the 2310, and the 100 mA current limit is never approached because the value of \( R_{\text{SERIES}} \) will always be above 150Ω. The 10Ω shunt resistor has been selected rather arbitrarily and the following formulas are based on this value.

\[
R_{\text{SERIES}} = \frac{5 \times 10^6}{\mu \text{A}/(R_{\text{GALV}} + R_{\text{DAMP}})} \quad \text{(Eq. 3)}
\]

where: \( \mu \text{A} \) is the microamperes required through the galvanometer for the desired full-scale deflection, \( R_{\text{DAMP}} \) is the specified damping resistance for the galvanometer in ohms.

An alternate solution is

\[
R_{\text{SERIES}} = \frac{5 \times 10^3}{mV/\mu \text{A}} \quad \text{(Eq. 4)}
\]

where: mV/\( \mu \text{A} \) is the millivolts required for "damped systems" for the desired full-scale deflection.

Most specification charts for magnetically-damped galvanometers list data in mV/mA (or mV/\mu A) 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 wide-band ("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 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 wide-band.

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 gauge can tolerate under the test conditions. Factors which increase this are high resistance (gage resistances of 250Ω 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 excursions may be excessive. Note that most increment 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 excursion 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 2401 is semi-floating. Unless some ground exists in the input circuit, the supply automatically centers itself about circuit common (e.g., when set at 5V, 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 error, 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 5%. If for any reason the exact setting must be known, it can be measured at the EXCITATION jack 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 (as is located on the switch itself). The resistance required can be readily calculated:

\[
R = 10,000 \times \frac{V}{18 - V} \tag{Eq. 5}
\]

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 affect on the OUTPUT lamps, check that the PLAYBACK switch (on the rear panel) is at NORM (down).

If, at best null, both lamps are lit, this is an indication of excessive noise. The noise is frequency 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, press the AUTO BAL toggle switch all the way down momentarily 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 0.04 V 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 extinguished (due to the noisy environment), it may be possible to take accurate data (depending upon the test situation).

If, when balanced 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 imbalance is between 1% and 5% (5000 and 25,000 μV 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 imbalance; possibly the gage should be replaced.

If the HI lamp constantly cycles on and off (4 seconds on, 4 seconds off), the imbalance at the input exceeds 5%, probably due to a gross fault or wiring error (or EXCITATION is on NORM or the PLAYBACK switch is on ON).
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, 180, 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 3-dB frequency (F<sub>3D</sub> 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<sub>3D</sub> results in better attenuation at any given high frequency.
c) Should there be an instantaneous step input, the Butterworth filter will produce 5 to 6% 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<sub>3D</sub>, a filter with 4 or more poles is highly desirable. Although, note from Figure 8 that there is no discernible improvement below F<sub>CO</sub> as the number of poles is increased.

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:

\[ \text{Rise time} = \frac{0.35}{F_{CO}} \text{ in seconds} \]  
(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.

\[ C = \frac{K}{F_{CO} \times R} \]  
(Eq. 14)

Figure 9: P.C. Board Layout – Active Filter
where: \( F_{3dB} \) is the cut-off frequency (~3 dB) in Hz.

\[ R \text{ is in kΩ (with suggested values tabulated below)} \]

\[ C \text{ is in μF; } K \text{ is a constant, as tabulated} \]

<table>
<thead>
<tr>
<th>BUTTERWORTH</th>
<th>( K )</th>
<th>( R \text{ (suggested)} )</th>
</tr>
</thead>
<tbody>
<tr>
<td>2-pole</td>
<td>112.5</td>
<td>22.6 k</td>
</tr>
<tr>
<td>4-pole</td>
<td>90.28</td>
<td>18.2 k</td>
</tr>
<tr>
<td>6-pole</td>
<td>80.36</td>
<td>16.2 k</td>
</tr>
<tr>
<td>Bessel</td>
<td>102.4</td>
<td>20.5 k</td>
</tr>
<tr>
<td>2-pole</td>
<td>60.23</td>
<td>14.0 k</td>
</tr>
<tr>
<td>4-pole</td>
<td>55.70</td>
<td>11.0 k</td>
</tr>
</tbody>
</table>

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 pivoted for all three sections.

Solder jumpers must be added or deleted at pads "3" 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 120-00194 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).

<table>
<thead>
<tr>
<th>Component</th>
<th>Value</th>
<th>Butterworth</th>
<th>Positions Installed</th>
</tr>
</thead>
<tbody>
<tr>
<td>C43 10%</td>
<td>0.01 μF</td>
<td>2 pole A</td>
<td>4 pole A &amp; B</td>
</tr>
<tr>
<td>C44 20%</td>
<td>100 μF</td>
<td>2 pole A &amp; B</td>
<td>4 pole A &amp; B &amp; C</td>
</tr>
<tr>
<td>C45 5%</td>
<td>0.1 μF</td>
<td>2 pole A</td>
<td>4 pole A &amp; B</td>
</tr>
<tr>
<td>C46 5%</td>
<td>0.5 μF</td>
<td>2 pole A</td>
<td>4 pole A &amp; B</td>
</tr>
<tr>
<td>C47 5%</td>
<td>0.001 μF</td>
<td>2 pole A</td>
<td>4 pole A &amp; B</td>
</tr>
<tr>
<td>C48 5%</td>
<td>0.5 μF</td>
<td>2 pole A</td>
<td>4 pole A &amp; B</td>
</tr>
<tr>
<td>C49 5%</td>
<td>0.5 μF</td>
<td>2 pole A</td>
<td>4 pole A &amp; B</td>
</tr>
<tr>
<td>C50 5%</td>
<td>0.005 μF</td>
<td>2 pole A</td>
<td>4 pole A &amp; B</td>
</tr>
<tr>
<td>C51 5%</td>
<td>470 μF</td>
<td>2 pole A</td>
<td>4 pole A &amp; B</td>
</tr>
<tr>
<td>U23</td>
<td>741C</td>
<td>2 pole A</td>
<td>4 pole A &amp; B</td>
</tr>
<tr>
<td>R127 1%</td>
<td>22.6k</td>
<td>2 pole A</td>
<td>4 pole A &amp; B</td>
</tr>
<tr>
<td>R128</td>
<td>16.2k</td>
<td>2 pole A</td>
<td>4 pole A &amp; B</td>
</tr>
<tr>
<td>R129 10%</td>
<td>47k</td>
<td>2 pole A</td>
<td>4 pole A &amp; B</td>
</tr>
<tr>
<td>Jumper &quot;2&quot;</td>
<td>Open</td>
<td>2 pole A</td>
<td>4 pole A &amp; B</td>
</tr>
<tr>
<td>Jumper &quot;4&quot;</td>
<td>Open</td>
<td>2 pole A</td>
<td>4 pole A &amp; B</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Component</th>
<th>Value</th>
<th>Bessel</th>
<th>Positions Installed</th>
</tr>
</thead>
<tbody>
<tr>
<td>C43 10%</td>
<td>0.01 μF</td>
<td>A</td>
<td>A &amp; B</td>
</tr>
<tr>
<td>C44 20%</td>
<td>100 μF</td>
<td>A</td>
<td>A &amp; B</td>
</tr>
<tr>
<td>C45 5%</td>
<td>0.5 μF</td>
<td>A</td>
<td>A &amp; B</td>
</tr>
<tr>
<td>C46 5%</td>
<td>0.5 μF</td>
<td>A</td>
<td>A &amp; B</td>
</tr>
<tr>
<td>C47 5%</td>
<td>0.005 μF</td>
<td>A</td>
<td>A &amp; B</td>
</tr>
<tr>
<td>C48 5%</td>
<td>470 μF</td>
<td>A</td>
<td>A &amp; B</td>
</tr>
<tr>
<td>C49 5%</td>
<td>0.5 μF</td>
<td>A</td>
<td>A &amp; B</td>
</tr>
<tr>
<td>C50 5%</td>
<td>0.005 μF</td>
<td>A</td>
<td>A &amp; B</td>
</tr>
<tr>
<td>C51 5%</td>
<td>470 μF</td>
<td>A</td>
<td>A &amp; B</td>
</tr>
<tr>
<td>U23</td>
<td>741C</td>
<td>A</td>
<td>A &amp; B</td>
</tr>
<tr>
<td>R127 1%</td>
<td>20.5k</td>
<td>A</td>
<td>A &amp; B</td>
</tr>
<tr>
<td>R128</td>
<td>14.0k</td>
<td>A</td>
<td>A &amp; B</td>
</tr>
<tr>
<td>R129 10%</td>
<td>27k</td>
<td>A</td>
<td>A &amp; B</td>
</tr>
<tr>
<td>Jumper &quot;2&quot;</td>
<td>22k</td>
<td>A</td>
<td>A &amp; B</td>
</tr>
<tr>
<td>Jumper &quot;4&quot;</td>
<td>Open</td>
<td>A</td>
<td>A &amp; B</td>
</tr>
</tbody>
</table>

**Table 1**

Filter Values for Standard Frequencies (10 Hz - 10 kHz)
7.0 MAINTENANCE

7.1 CIRCUIT DESCRIPTION

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

7.1a The +15 V and −15 V dc power supplies both employ 723 precision regulators, U1 and U2, with external pass transistors Q1 and Q2. Current limiting will occur when approximately 0.6 V is developed across R2 or R11 (the +15 V supply uses circuitry as in U1, whereas the −15 V 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 +18 V at pin 10 (relative to pin 7, which is essentially P)—this voltage is set by R162. This +18 V 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 −5 V 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 at 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; output 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 X100 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 Q6, 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 113V across R157, corresponding to 40mA 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 +2.1 V the input at pin 6 of U25 will be zero and theoretically neither LED would light. With normal batteries (3.0 V total) the "9" lamp will light; below 2.1 V the "6" 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 (0 V). 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 input 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 RT1 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-opened switch. All resistors chosen will start the ramp at, effectively, −½ 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 U1B positive, stopping the oscillator (U8A and U9B). The binary counter will hold its "number" (and thus the balance setting) indefinitely, unless reset.

The supply for the counter ("+3V/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 inoperative 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 (momentarily) 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 USC 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, USC 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 +5% balance, then

![Image](image-url)
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 trim 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 120-001-196 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 work 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.

**MEETER 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. The circuit common to chassis by connecting a jumper between pins 3 and 5 of the OUT+17 plug. The inputs must be shorted together and grounded by connecting INPUT plug pins A, J, and F, respectively. All readings should be made with a digital voltmeter or stable dc scope with a resolution of at least 1 mV; if possible, set balances to within 0.2 mV of zero. All readings are stated to circuit common (OUT+17 pin 3). The front panel AMP BAL trimer must be approximately centered (11 turns from one end), EXCITATION at OFF, and AC coupling button "out" (for dc coupling). Also, the front panel button 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 35QZ bridge connected to the input; it should be possible to unbalance this bridge randomly up to about 3% imbalance.

---

**MEETER LEAD | FRONT PANEL ADJUSTMENT | KC | BALANCED**

| TP 1 | GAIN button X100 | G | U10, U19 |
| TP 1 | GAIN button X1000 | G | U18, U19 |
| TP 2 | N | U21 |
| TP 2 | AC button "in" | K | U21 |
| TP 3 | GAIN button X1 | R | U22 |
| TP 4 | GAIN dial 11100 | T | U23x |
| TP 6 | FILTER 100 | 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) should be 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 35QZ arm suggested) and remove shunt across bridge output.

g) Follow steps (b) through (c), 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,
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 2 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. Silver oxide batteries are installed by Measurements Group, although mercury batteries are also entirely satisfactory. Any of the following may be used (c required):

<table>
<thead>
<tr>
<th>Silver oxide</th>
<th>Mercury</th>
</tr>
</thead>
<tbody>
<tr>
<td>Eveready S/6E</td>
<td>E675 or EPX675</td>
</tr>
<tr>
<td>Mallory M575</td>
<td>RM675 or P675</td>
</tr>
<tr>
<td>Burpex 7650</td>
<td>HG675 or HP7675</td>
</tr>
<tr>
<td>RCA VS1776</td>
<td></td>
</tr>
</tbody>
</table>

To replace the batteries:

a) Remove cover on left side of 2310.
b) Locate the battery compartment near the AC power switch at the rear of the unit.
c) Remove the 3 screws securing the cover.
d) Remove the old batteries and discard.
e) Install the two new batteries, positive end toward the p.c. board (“button” contact at the top).
f) Replace battery cover and 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 1%, 1/4 W, Allen Bradley, composition.

All 1% and 1/8 W 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 an assembly and must be ordered as part 200-13693.

7.4b Connectors

<table>
<thead>
<tr>
<th>Symbol</th>
<th>P/N</th>
</tr>
</thead>
<tbody>
<tr>
<td>Input plug, 15-pin</td>
<td>P5</td>
</tr>
<tr>
<td>[Bendix PTO6A-14-15P/SR]</td>
<td>12X300531</td>
</tr>
<tr>
<td>Output plug, 8-pin</td>
<td>P4</td>
</tr>
<tr>
<td>(Vertron P-3308-CCT)</td>
<td>12X300530</td>
</tr>
<tr>
<td>Misting power plug (not supplied)</td>
<td>12X30051</td>
</tr>
<tr>
<td>(ITT/Cannon DA15S or equal)</td>
<td></td>
</tr>
<tr>
<td>Remote cal plug (for 2350/2360)</td>
<td>12X300533</td>
</tr>
<tr>
<td>(Vertron S-3308-CCT)</td>
<td></td>
</tr>
<tr>
<td>Line cord (for 2360)</td>
<td>21X090039</td>
</tr>
<tr>
<td>(Belden 17280)</td>
<td></td>
</tr>
</tbody>
</table>

7.4c Battery

Keep-alive supply (Eveready S762)

| BT1, BT2 | 23X400001 |

7.4d Toggle Switches

<table>
<thead>
<tr>
<th>Symbol</th>
<th>P/N</th>
</tr>
</thead>
<tbody>
<tr>
<td>Filter selector (on p.c.b.)</td>
<td>S3</td>
</tr>
<tr>
<td>(Grayhill 7650053)</td>
<td>10X900046</td>
</tr>
<tr>
<td>Excitation source selector (on p.c.b.) (Grayhill 76TD01)</td>
<td>S4</td>
</tr>
<tr>
<td>Calibration selector (on p.c.b.) (CTS 208-10)</td>
<td>S5</td>
</tr>
<tr>
<td>Cal A and Cal B</td>
<td>S8, S9</td>
</tr>
<tr>
<td>(J-B-T JMT-127)</td>
<td>10X600120</td>
</tr>
<tr>
<td>Auto Balance (J-B-T JMT-233)</td>
<td>S10</td>
</tr>
<tr>
<td>Excitation off</td>
<td>S12</td>
</tr>
<tr>
<td>(J-B-T JMT-223)</td>
<td>10X600110</td>
</tr>
</tbody>
</table>
**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
(Elec-trol RA30421051) K6 11X500077

**7.4f Transistors**

NPN power (Motorola MJE800) Q1, Q3, Q9 14X200169
PNP power (Motorola MJE700) Q2, Q10 14X200175
NPN small sig (GE 2N360) Q5, Q6, Q7 14X200184
PNP small sig (GE MPS3638A) Q4, Q8 14X200175

**7.4g Integrated Circuits**

Regulator (National LM723CN) U1, U2, U3 14X700040
5V Regulator (Motorola MC79L05CP) U4 14X700060
Quad NOR gate (RCA CD4001AE) U8, U9 14X700122
Binary counter (RCA CD4024BE) U10, U11 14X700646
Multiplying DAC (Analog Devices AD7531JN) U12 14X700057

**Analog Switch**
(Silvaco, DG200CJ) U14 14X700058
Compensated op amp (Fairchild UA307TC) U5, U16 14X700042
Uncompensated op amp (U15, U17, U22, U6, U26
Fairchild UA30147C) U7, U23 14X700054
Compensated op amp (National LM741CN) U6, U13, 14X700055
Dual op amp (dual 741) (Motorola MC1451CP) U18
High-slew op amp (Signetics NE531V) U20, U21 14X700056
Input op amp pair (PMC OP3772Z) U19 A, B 14X70097
Compensated op amp (PMI OP-01CP) U24 14X700096
Dual op amp (PMI OP-14CP) U25 14X700095

**SCHMATHS**

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