Model 362
Scanning Potentiostat
Instruction Manual

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Advanced Measurement Technology, Inc.

a/k/a Princeton Applied Research, a subsidiary of AMETEK®, Inc.

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This Warranty shall not apply to any instrument, which our inspection shall disclose to our satisfaction, to have become defective or unworkable due to abuse, mishandling, misuse, accident, alteration, negligence, improper installation, or other causes beyond our control. This Warranty shall not apply to any instrument or component not manufactured by Princeton Applied Research. When products manufactured by others are included in Princeton Applied Research equipment, the original manufacturer's warranty is extended to Princeton Applied Research customers.

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SHOULD YOUR EQUIPMENT REQUIRE SERVICE

A. Contact the Customer Service Department (865-482-4411) or your local representative to discuss the problem. In many cases it will be possible to expedite servicing by localizing the problem.

B. If it is necessary to send any equipment back for service, we need the following information.

1. Model number and serial number.
2. Your name (instrument user).
3. Your address.
4. Address to which the instrument should be returned.
5. Your telephone number and extension.
6. Symptoms (in detail, including control settings).
7. Your purchase order number for repair charges (does not apply to repairs in warranty).
8. Shipping instructions (if you wish to authorize shipment by any method other than normal surface transportation).

C. U.S. CUSTOMERS — Ship the equipment being returned to:

Advanced Measurement Technology, Inc.
801 S. Illinois Avenue
Oak Ridge, TN 37831
ATTN: Customer Service

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FAX: 865-483-2133

D. CUSTOMERS OUTSIDE OF U.S.A. — To avoid delay in customs clearance of equipment being returned, please contact the factory or the nearest factory distributor for complete shipping information.

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1. SAFETY CONSIDERATIONS

1.1 Safety Notice (Read Before Operating Instrument)

1.1.1 Introduction

The apparatus to which this instruction manual applies has been supplied in a safe condition. This manual contains some information and warnings that have to be followed to insure safe operation and to retain the apparatus in a safe condition. The described apparatus has been designed for indoor use.

1.1.2 Inspection

Newly received apparatus should be inspected for shipping damage. If any is noted, notify Princeton Applied Research and file a claim with the carrier. Be sure to save the shipping container for inspection by the carrier.

WARNING: The protective grounding could be rendered ineffective in damaged apparatus. Damaged apparatus should not be operated until its safety has been verified by qualified personnel. Damaged apparatus waiting for safety verification should be tagged to indicate to a potential user that it may be unsafe and that it should not be operated.

1.1.3 Safety Mechanism

As defined in IEC Publication *348 (Safety Requirements for Electronic Measuring Apparatus),* this is CLASS I apparatus, that is apparatus that depends on connection to a protective conductor to earth ground for equipment and operator safety. Before any other connection is made to the apparatus, the protective earth terminal shall be connected to a protective conductor. The connection is made via the earth ground prong of the power cord plug. The power cord plug shall only be inserted in a socket outlet provided with the required earth ground contact The protective action must not be negated by the use of an extension cord or adapter plug without a protective conductor.

WARNING: Any interruption of the protective conductor inside or outside the apparatus or disconnection of the protective earth terminal may make the apparatus dangerous. Intentional interruption is prohibited.

The cord plug provided is of the type illustrated in Fig. 1. If the provided plug is not compatible with the available power sockets, the plug or power cord should be replaced with an approved type of compatible design.

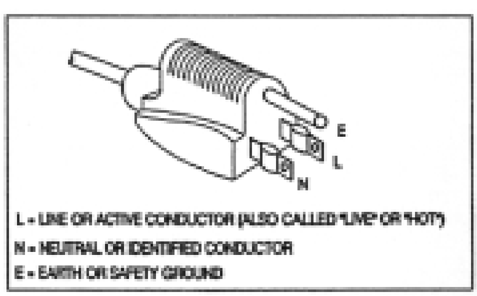


Fig. 1. Power Cord Plug with Polarity Indication.

1.1.4 Defects

Whenever it is likely that the protection provided by the connection to earth ground has been impaired, the apparatus should be made inoperative and secured against unintended operation. The protection is likely to be impaired if, for example, the apparatus:

1. shows visible damage,
2. fails to perform the intended measurements,
3. has been subjected to prolonged storage under unfavorable conditions, or
4. has been subjected to severe transport stresses.

Such apparatus should not be used until its safety has been verified by qualified service personnel.

1.1.5 Cable Leads

The Model 362 has a compliance of 30 V at 1 A. Thus potentials as high as 30 V can be present at the counter electrode lead of the cell cable. Although 30 V is not generally regarded as being a dangerous potential, *THE HIGH CURRENT CAPABILITY REQUIRES THAT REASONABLE PRECAUTIONS BE TAKEN IN HANDLING THESE LEADS.* The CELL switch should always be set to OFF when making the cell connections. It should similarly be set to OFF when the cable leads are being examined or disconnected.

1.1.6 Power Voltage Selection

1.1.6.1 Power Cord

Whenever possible, the instrument is furnished with a power cord plug that is compatible with the type of power socket in use where the instrument will be operated. If you have to provide a power cord, it should be an approved type with a standard EEC connector at one end for connection to the Model 362.

WARNING: If it is necessary to replace the power cord or the power plug, the replacement cord or plug must have the same polarity as the original. Otherwise a safety hazard from electrical shock, which could result in personal injury or death, might result.

The wires in the power cord supplied by Princeton Applied Research are color-coded to denote polarity. Whatever the actual plug configuration, the black wire should be the line or active conductor (also called “live” or “hot”), the white wire should be neutral, and the green wire should be earth ground.

Before connecting the power cord to the power source, make sure that the Model 362 is set for the voltage of the available ac supply.

1.1.6.2 Power Input Module

The Curtis Power Input module, illustrated in Fig. 2, is located on the right side of the rear panel. The Curtis module also contains the power connector, line fuse, and a removable printed-circuit card used for selected the input voltage. However, the details of line-voltage selection and fuse installation are quire different, as follows.

1.1.7 Line Voltage Selection

The Model 362 has Curtis Power Entry Module that allows the instrument to be configured for any one of four different line voltages. The voltage selections available are 100, 120, 220, and 240 volts. The allowable range for each selection is ±10%.

1.1.7.1 Cleaning Instructions

To clean the exterior of the instrument, proceed as follows:

1. Unplug the instrument.

2. Remove loose dirt on the outside of the instrument with a lint-free cloth.

3. Remove remaining dirt with a lint-free cloth dampened in a general purpose detergent and water solution. Do not use abrasive cleaners. CAUTION: To prevent getting moisture inside of the instrument during external cleaning, use only enough liquid to dampen the cloth or applicator.

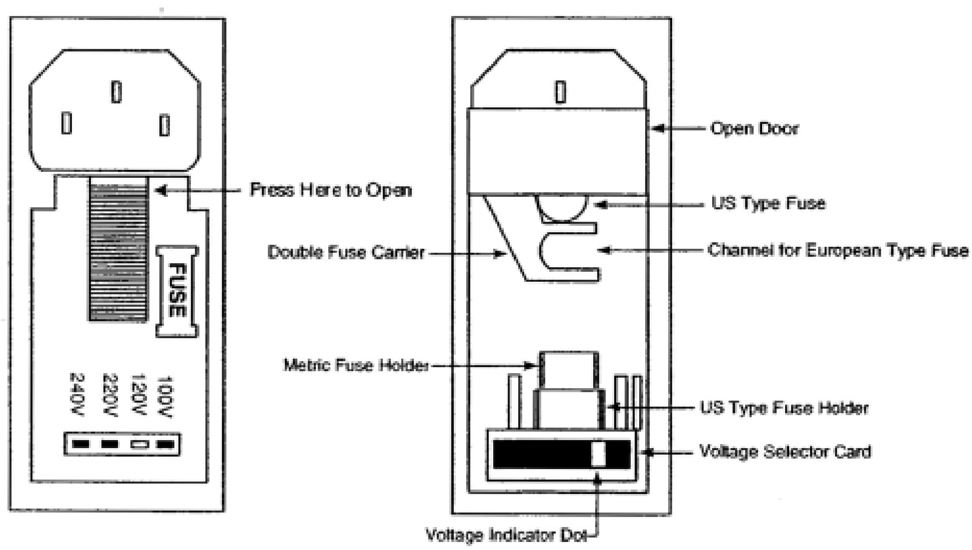


Fig. 2. Curtis Power Input Module.

4. Allow sufficient time for the instrument to dry before reconnecting power cord.

To confirm that the Model 362 is set for the correct line voltage: Referring to Fig. 2, not that there are four small line-voltage indicator windows near the lower edge of the module. These windows are aligned with the four available line-voltage setting printed on the cover module, 100V, 120V, 220V, and 240V. The selected voltage is indicated by the color red showing through the corresponding window. For example, if the selected line voltage is 120V, you will see red through the 120V window. The other three will be black.

The color you see through any window is determined by the position of the internal line-voltage selector card, which can be installed in any of four different orientations, each corresponding to a different line voltage. The procedure for selecting the line voltage follows.

1. Disconnect the power cord from the Model 362.

2. Open the Power Module door by pressing at the point indicated in the left-hand view of Fig. 2. because the door is hinged directly beneath the point where pressure is applied, you will need to push inwards, but with some upward thrust so that the door will swing open, exposing the interior of the module as shown in the righthand view of Fig. 2.

3. Using needle-nose plier, grasp the Voltage Selector Card firmly and pull it straight out of the module. Note that each edge of the card has the red dot in a different location, each corresponding to a different line voltage configuration selection.

4. Orient the card so that the red dot corresponding to the desired line voltage selection will align with the line voltage indication on the cover after the cover is closed. Then install the card by pressing it firmly into its socket.

5. Close the cover. The red dot should appear in the window corresponding to the desired line-voltage configuration.

6. Reconnect the power cord to the Model 362.

1.1.8 Replacing the Fuse

The Curtis Power Input module has a double fuse carrier which can accept either a US type fuse or a European type fuse. This carrier is located on the inner surface of the module door and becomes acccessible with the door is opened. Only one fuse can be installed at any time. The required fuse rating is printed on the panel near the Power Input module.

To replace the fuse:

1. Disconnect the power cord from the Model 362.

2. Open the Power Module door by pressing at the point indicated in the left-hand view of Fig. 2. because the door is hinged directly beneath the point where pressure is applied, you will need to push inwards, but with some upward thrust so that the door will swing open, exposing the interior of the module as shown in the righthand view of Fig. 2. When the door opens, the fuse comes free of the fuse holder and remains in the fuse carrier.

3. Remove the defective fuse and install the replacement fuse in its place. No particular precision is required in placing the fuse in its channel. The fuse will be automatically positioned correctly in the fuse holder when the door is closed. Be sure to use the correct channel of the fuse carrier. Figure 2 shows a US type fuse installed.

4. Close the door. As it closes the fuse will be correctly positioned and pressed into the proper fuse holder.

5. Reconnect the power cord.

1.1.9 Model 362 Standard Environmental Conditions

1.1.9.1 Operating Conditions

This equipment shall meet all specified performance criteria when subjected to any natural combination of stress.

Input Voltages

1. 90 to 130 volts AC 50 to 60 Hz.

2. 200 to 260 volts AC at 50 to 60 Hz.

Ambient Temperature: From 10°C to 40°C

1. The instrument shall operate from 10°C to 40°C but may not meet some temperature related specifications.

2. The instrument shall operate from 20°C to 30°C and meet all its specifications over this range.

Relative Humidity from 5% to 85% non-condensing.

Altitude from -500 to 9000 feet relative to sea level.

1.1.9.2 Non-Operating Conditions

This equipment shall exhibit no significant deterioration of performance after exposure to any natural combination of stress in a non-operating condition.

1. Ambient Temperature range from 0°C to 70°C.
2. Relative Humidity greater than 95% with modest local condensation or frost formation. Instrument must be allowed to remain at operating conditions for at least 24 hours before applying power.
3. Altitudes to 50000 feet.

1.1.9.3 International Standards

This equipment is designed to meet or exceed the requirements of the following standards:

1. BS EN55022 (1987), Class B
2. BS EN50082 (1992):
   a. IEC 801-2: 1991
   b. IEC 801-3: 1994
   c. IEC 801-4: 1988
3. BS EN61010-1 (1995), Installation Category II, Pollution Degree 2.

1.1.9.4 Voltage Levels on Systems Equipped with the /99 (Float) Option

WARNING: A unit operated in Float mode (set via the rear panel switch) may have potentials of up to ±300 volts on any or all pins of the Cell connector, depending on the nature and configuration of the cell to which the unit is connected. Extreme caution should be exercised when inserting or removing this connector in a floating system.

1.1.10 Ventilation

The Model 362 does not incorporate forced-air ventilation. With a power consumption of only 75 watts maximum, this instrument can be operated on any laboratory bench. Alternatively, it can be rack mounted, if desired. The only requirement is that the ambient temperature be restricted to a range of 15˚ to 45˚C If the temperature in the rack is near the high end of this range, forced air cooling of the rear-panel heat sink may be desirable, particularly if the Model 362 is to be operated for long periods at high current levels. Always leave adequate space behind the instrument for air to circulate freely. Six inches (15 cm) should be sufficient to prevent overheating.

1.2 Line Voltage and Equipment Safety

As previously discussed, the Model 362 can be operated from any of four different voltage ranges. The procedure for adapting the instrument from one range to another is provided in section 1.1.6

CAUTION:	The apparatus described in this manual may be damaged if the voltage applied is above the upper limit of the selected range.

2. CHARACTERISTICS

2.1 Introduction

The Model 362 Scanning Potentiostat is a 1A, 30 V potentiostat and galvanostat, as well as a versatile ramp generator capable of applying a ramping voltage or current to a electrochemical cell. The instrument can also charge and discharge a cell or battery at a constant current between pre-set INITIAL POTENTIAL and FINAL POTENTIAL levels.

All indicators, controls, and input/output connectors are located on the instrument's front-panel. Indicators include an analog meter for displaying the polarity and instantaneous magnitude of the cell's voltage or current. There are also two OVERLOAD lamps. One, the CURRENT OVERLOAD lamp, indicates that the cell current is more than twice the meter's full-scale range. The other, the CONTROL AMPLIFIER OVERLOAD lamp, turns on when the instrument's power amplifier is out of its linear operating region. Other indicators include an illuminated power switch and a CELL ON- OFF switch with a highlighted ON position. Controls include a pushbutton MODE switch for selecting CONTROL E or CONTROL I OPERATION, a bank of seven pushbutton CURRENT RANGE selectors, and a METER pushbutton that alternates the meter display between voltage and current readings. Two 4-digit thumbwheel switches establish voltage or current parameters for the instrument's static and scanning modes.

For operation in the CONTROL E MODE, the front panel also includes IR COMPENSATION controls, which compensate for the cell resistance between the reference electrode and the working electrode. (A feedback loop automatically adjusts for cell resistance between the counter electrode and the working electrode.) These controls apply positive feedback to the instrument's control amplifier.

When the instrument is in one of its flexible scanning modes, a group of front-panel controls and selectors interact to set the scanning parameters and select among a broad range of options. A bank of pushbutton switches allows the operator to initiate scans, select single or multiple scans, determine the endpoints for single scans, and reverse the direction of a scan that is underway. Scan control switches also allow the operator to halt scanning and either to freeze the output at its instantaneous level or to halt scanning and restore the initial level. The INITIAL POTENTIAL and FINAL POTENTIAL thumbwheel switches establish the turn-around points for the ramp function in CONTROL E scanning as well as the limits for the cell or battery potential in the CONTROL I, CONSTANT I scanning mode. In CONTROL I scanning, the INITIAL POTENTIAL setting serves as dimensionless multiplier of the CURRENT RANGE setting to establish the initial cell current.

A rotary SCAN RATE switch determines $\Delta v/\Delta t$ directly for CONTROL E scanning. This switch interacts with the INITIAL POTENTIAL and CURRENT RANGE settings to determine $\Delta i/\Delta t$ in CONTROL I scanning. In CONTROL I, CONSTANT I scanning the SCAN RATE switch sets the constant current as a percentage of the full-scale CURRENT RANGE setting.

Any voltage applied to the EXT IN BNC connector is summed with the INITIAL POTENTIAL setting and presented to the input of the cool amplifier. Thus a voltage generated by an external device or system can set or alter the cell's current or voltage. The instrument's provisions for signal output consist of three sets of binding posts, each set designed for straightforward connection to external apparatus such as X -Y or strip-chart recorders. The set labeled CURRENT MONITOR presents a 0 to 1 V signal proportional to the full-scale current. The POTENTIAL MONITOR connectors carry a signal in the range of ±9.999V and equal to the potential of the reference electrode with respect to the working electrode. The RAMP OUT connectors output a signal equal in magnitude (though opposite is polarity) to the ramping component of the voltage applied to the cell. This signal is also defined as $-E_{working}$ vs. $E_{initial}$. These signals are provided for connection to peripheral monitoring instrumentation or for use as feedback signals is complex control systems.

The Model 362 includes a built-in, unity-gain electrometer to buffer the reference electrode.

2.2 Specifications

Unless otherwise noted, all specifications assume a potential measured at the working electrode with respect to the reference electrode, a load resistance of 10 kΩ between the working and reference electrodes, and an ambient temperature of 25°C.

2.2.1 Static Functions

CONTROL E MODE

APPLIED POTENTIAL RANGE: ±9.999 V

APPLIED POTENTIAL RESOLUTION: 1 mV steps.

APPLIED POTENTIAL ACCURACY: ±3 mV ±0.4% of INITIAL POTENTIAL SETTING.

CONTROL AMPLIFIER OUTPUT VOLTAGE: > ±30 V.

MAXIMUM OUTPUT CURRENT (1 Ω resistive load): > 1 A.

RISE TIME: 10% to 90% with 1 V step function applied to EXT IN BNC:
10 kΩ resistive load: < 10 s.
1 Ω resistive load: < 15 s.

DRIFT WITH TIME. <200 µV/week.

DRIFT WITH TEMPERATURE: <30 V/˚C + 200 ppm of INITIAL POTENTIAL setting per ˚C.

NOISE AND RIPPLE
1 Hz to 3 kHz <200 µV rms.

LINE VOLTAGE SENSITIVITY
10% change in line: < 200 µV.

STABILITY WITH CAPACITIVE LOADS: Stable with Reference Electrode Impedance <30kΩ.

SLEW RATE >25 µV/ s.

CONTROL I MODE

ACCURACY: Better than ±0.4% of full-scale CURRENT RANGE setting.

DRIFT WITH TIME: < 0.02% of full-scale CURRENT RANGE/week.

DRIFT WITH TEMPERATURE: <0.01% of full-scale/˚C.

NOISE AND RIPPLE: < 200 µV rms.

RISE TIME (10% to 90% with 100 µA peak-to-peak step function applied to EXT IN BNC):
< 10 µs.

CURRENT MEASUREMENT RISE TIME: 2 μs.

ELECTROMETER

INPUT VOLTAGE (Reference electrode with respect to working electrode): ± 10 V.

INPUT CURRENT (At 25°C): 100 pA typical, 2 nA maximum.

INPUT CAPACITANCE (DC to 200 kHz): <20 pF

INPUT RESISTANCE: $2 \times 10^{10}\ \Omega$

FREQUENCY RESPONSE (-3 dB with 1Ω source): >1 MHz

DRIFT WITH TIME: <200 μV/week

DRIFT WITH TEMPERATURE: <30 μV/°C

SCANNING FUNCTIONS

CONTROL E, LINEAR SCANNING

SCAN RANGE: ±9.999 V to ±9.999 V

LIMIT RESOLUTION: 1 mV steps.

LIMIT ACCURACY: ±3 mV ±0.4% of INITIAL POTENTIAL setting.

SCAN RATE RANGE: 0.1 mV/s to 500 mV/s selected with front panel rotary switch

SCAN RATE MULTIPLIER SWITCH: Internal X10 slide switch.

SCAN RATE RESOLUTION: Selectable in multiples of 1, 2, and 5.

SCAN RATE ACCURACY: ±0.0l mV/s ±0.5% SCAN RATE setting.

TURN-AROUND ACCURACY (The point at which the slope of the scan-waveform changes polarity): POTENTIAL setting ±2 mV ±0.002 X SCAN RATE setting.

CONTROL I, LINEAR SCANNING

APPLIED CURRENT RANGE: 100 nA to >1 A.

SCAN RATE RANGE: 1 nA/s to 500 mA/s.

SCAN RATE RESOLUTION: Selectable in multiples of 1, 2, and 5.

SCAN RATE ACCURACY: $\pm 1 \times 10^{-5}$ x CURRENT RANGE ±0.5% OF SCAN RATE.

SCAN RATE MULTIPLIER SWITCH: Internal X10 slide switch.

TURN-AROUND ACCURACY: 2×10^{3} X CURRENT RANGE ±0.02% of SCAN RATE.

CONTROL I, CONSTANT I LINEAR SCANNING

APPLIED CURRENT RANGE: 100 nA to 1 A.

ACCURACY: ±0.4% of CURRENT RANGE ±0.5% resolution setting.

RESOLUTION: 10% to 200% of full-scale CURRENT RANGE setting in multiples of 1, 2, and 5 (10% to 100% of 1 A range).

INITIAL AND FINAL THRESHOLDS: ±9.999 V to ±9.999 V.

THRESHOLD RESOLUTION: 1 mV.

TURN-AROUND ACCURACY: POTENTIAL setting ±2 mV ±0.002 X SCAN RATE setting.

2.3 Description

2.3.1 Control E Mode

Figure 3 is a simplified block diagram of the Model 362 operated in the static Control E mode. As is shown in the figure, the control loop is simple. A voltage, E_A, is applied to the input. This voltage supplies current through a resistor *R* (all resistors of value *R* in the diagram are 10 kΩ) to the summing junction of the control amplifier. To satisfy the loop requirements, it is necessary that the summing junction of the control amplifier be at 0 V. As shown, there are two feedback paths, one from the reference electrode, the other from the working electrode, to the summing junction. They work together to establish the summing junction at the required 0 V level. Because E_A is applied to the inverting input of the control amplifier, the output of the amplifier is driven in the opposite direction. The amplifier drives the counter electrode. Note that the working electrode is returned to ground through R_L, a resistance determined by the selected current range. This resistance does not affect the cell current, but does determine the working electrode potential. The reference electrode will be at some intermediate potential. The objective in Control E operation is to establish the working electrode at E_A with respect to the reference electrode. Because of the drop across R_L, the working electrode is at a potential of iR_L volts, and the potential of the working electrode with respect to the reference electrode is simply iR_L-E, where E_r is the potential of the reference electrode with respect to ground.

Consider the two feedback paths. E_r is fed back directly to the summing junction of the power amplifier through a resistor of value R (U2 is a non-inverting unity gain electrometer amplifier).

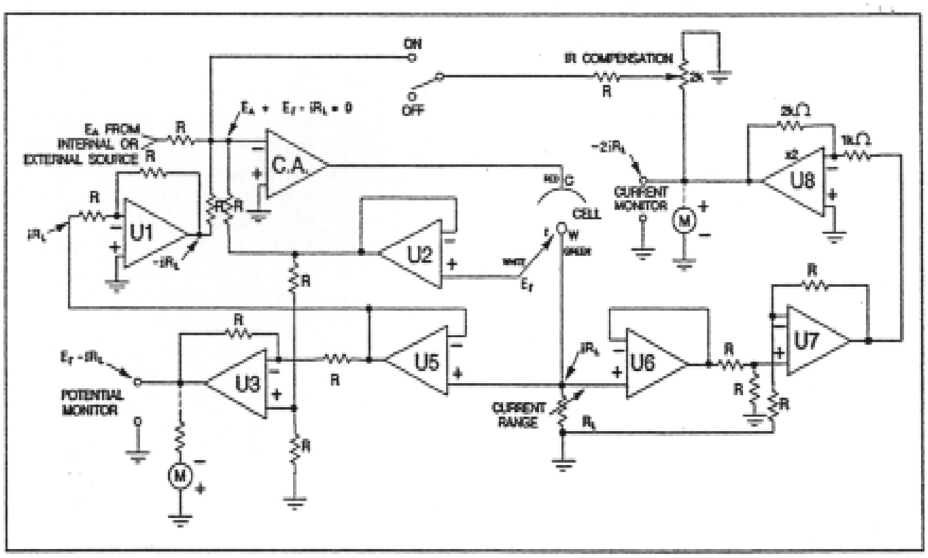


Fig. 3. Control E Mode.

The working electrode potential, on the other hand, is inverted by Ul to become $-R_L$ before being applied to the summing junction. With this arrangement, for the loop to be satisfied:

$$E_A + E_r - iR_L = 0, \text{ or } E_r = iR_L - E_A$$

Recall that the potential of the working electrode with respect to the reference electrode is $iR_L - E_r$, In this expression, $iR_L - E_A$, can be substituted for E_r giving E_W (potential of working electrode with respect to the reference electrode) = E_A, the desired relationship. In other words, the loop always works to make the working electrode potential (with respect to the reference electrode, not with respect to ground) the same as the applied potential.

The remaining circuits shown develop the POTENTIAL and CURRENT MONITOR Outputs. The POTENTIAL MONITOR output is simply the reference electrode potential with respect to the working electrode potential (each measured with respect to ground), and thus will be the same as E_A but of opposite polarity. The CURRENT MONITOR output is $-2R_L$ (the factor of two gain is provided by amplifier U8). The values of R_L and the gain are such as to provide a CURRENT MONITOR output voltage of 1 V if the cell current is full scale. As indicated, the panel meter connects to either the POTENTIAL MONITOR Output (meter polarity reversed) or to the *CURRENT* MONITOR Output (meter polarity same as Output polarity).

2.3.2 Control I Mode

Figure 4 is a simplified block diagram of the Model 362 operated in the static Control I mode. As shown, the control amplifier output drives the counter electrode. The polarity of that drive is inverted with respect to the input, E_A. As in Control E operation, the working electrode potential is iR_L. Since this voltage is the only one used to develop the feedback signal (the reference electrode potential is not in the control loop), the cell current is controlled independent of the reference electrode potential.

U6 is a non-inverting buffer that drives differential amplifier U7. The arrangement used prevents errors due to the voltage drop across the resistance of the cable's working electrode lead. The output of U7, also iR_L, is applied to the summing junction of the power amplifier through a resistor of value R/2. Because this resistor is ½ the resistance of the input resistance seen by E_A, the loop equation is $E_A + 2iR_L = 0$, or $i = -E_A/2R_L$. In other words, the cell current is of opposite polarity to E_A, and its magnitude is $E_A/2L_L$. The value of R_L is determined by the selected current range such that with an E_A of 1 V, i will equal one full scale on the selected current range, and yield +1 V out at the CURRENT MONITOR output.

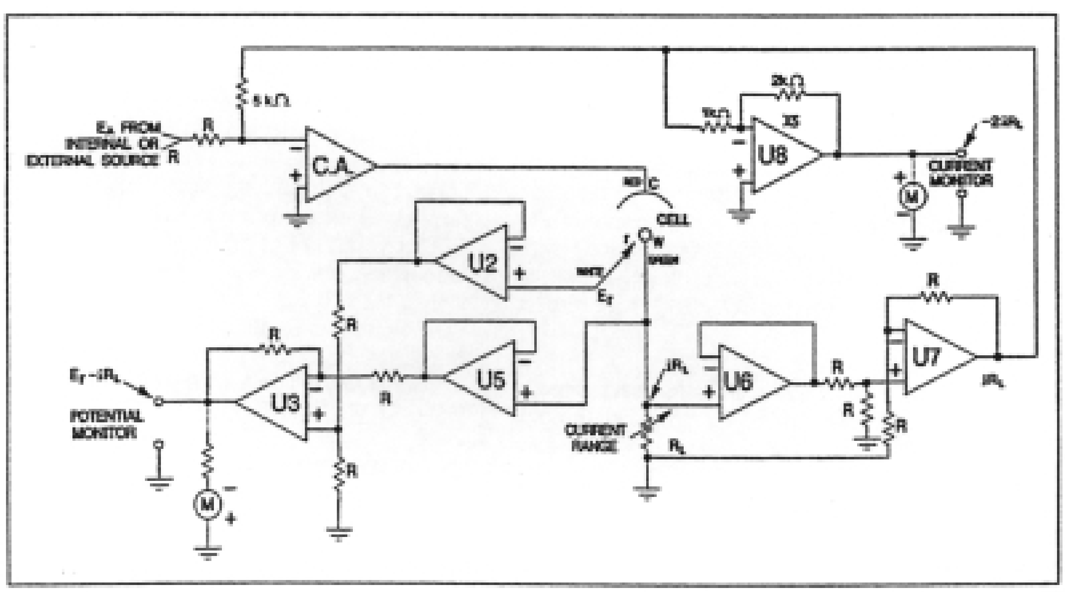


Fig. 4. Control I Mode.

The POTENTIAL MONITOR output is the same as in Control E operation, that is, the reference electrode potential with respect to the working electrode is provided at the POTENTIAL MONITOR output. If desired, the reference electrode can be omitted is CONTROL I operation, in which case the POTENTIAL MONITOR output voltage is indeterminate. Also, the panel meter connections are the same as in the CONTROL E mode.

2.3.3 Linear Scanning and Cyclic Modes

Figure 5 is a simplified block diagram showing the ramp generator and control logic that produces the instrument's scanning and cyclic functions. A central component of this functional diagram is U3009, an operational amplifier whose output is either a ramp function or a DC level. In the scanning and cyclic modes, this output becomes E_A (see Figs. 3 and 4), the input to the CONTROL AMPLIFIER, shown in these figures as an operational amplifier whose output is either a ramp function or a DC level. In the scanning and cyclic modes, this output becomes EA (See Figs. 3 and 4, the input to the CONTROL AMPLIFIER, shown in these figures as an operational amplifier labeled C.A.

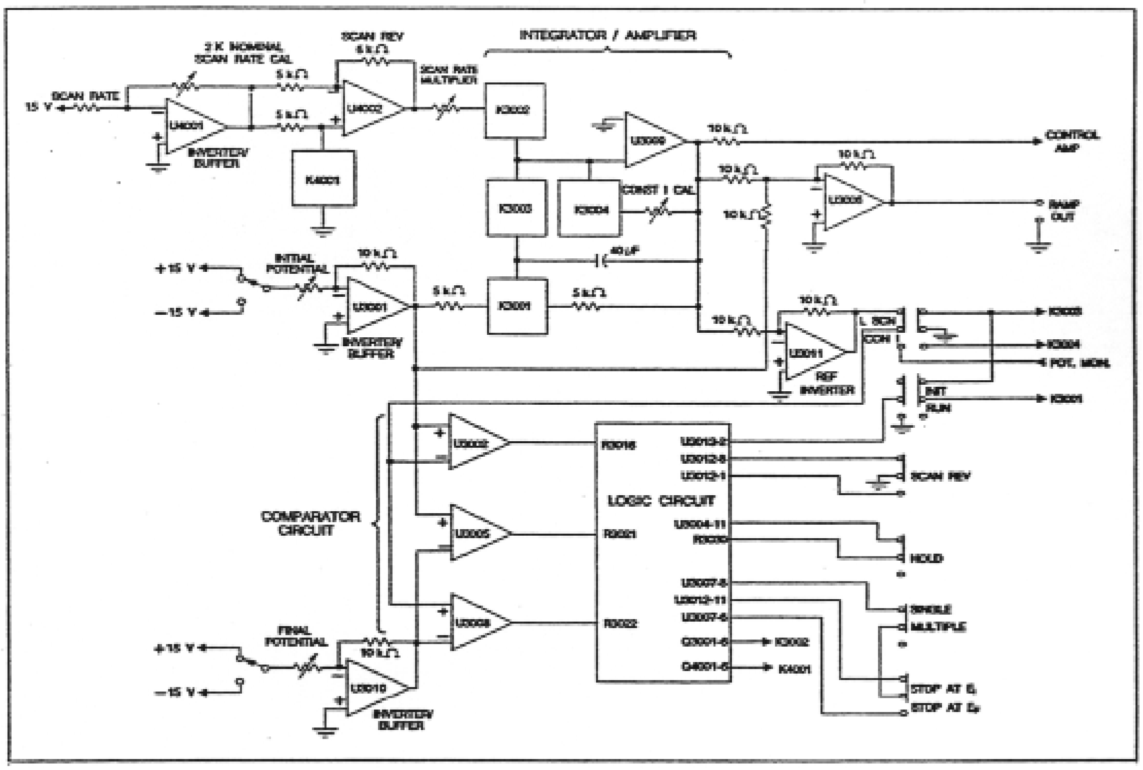


Fig. 5. Scanning Modes.

In the LINEAR SCAN mode, the front panel LINEAR SCAN-CONSTANT I switch opens K3004 and closes K3003 to create a feedback path for U3009 through the 40 F INTEGRATOR capacitor. As a result, operational amplifier U3009 becomes an integrator, and its output is a linear ramp whose slope is determined by the magnitude and polarity of the output of U4002, applied through the closed contacts of K3002. (The HOLD button and the LOGIC CIRCUIT can open this relay to halt ramping.) If the instrument is in its CONTROL I, CONSTANT I MODE, K3003 opens and K3004 closes, shunting the integrator capacitor, and creating a feedback path through the CONST I CAL resistor. In this instance, U3009 is simply an inverting amplifier, and its output is a DC level that ultimately results in a constant-current output from the CONTROL AMPLIFIER.

The SCAN RATE switch, which varies the resistance between + 15 V and the input of U4002, determines the magnitude of U4002's output. Relay K4001 determines its polarity. When K4001 opens, U4002 serves as a unity-gain, non-inverting amplifier. When the relay closes, U4002 serves as a unity gain, inverting amplifier. Whether this relay is open or closed is determined by the LOGIC CIRCUIT, which decodes not only the front-panel scan-control switches, but also the outputs of U3002, U3008, and U3005, arranged as a system of comparators.

If the RUN-$E_{INITIAL}$ switch is in the RUN position, K3001opens, and the output from U3009 is applied to the CONTROL AMPLIFIER. If this switch is in the $E_{INITIAL}$ position, and the LINEAR I switch is in the LINEAR SCAN position, the INITIAL POTENTIAL is applied to the input of the CONTROL AMPLIFIER through K3001. If this switch is in the CONSTANT I position while RUN is engaged, K3003 closes, converting U3009 from an integrator to an amplifier, and the POTENTIAL MONITOR output is applied to the comparator circuit. U3006 is simply an inverting buffer that drives the RAMP OUT output with a voltage that is equal in magnitude and opposite in polarity to the ramping voltage applied to the control amplifier.

Note that $E_{initial}$ is nulled out of the RAMP OUT signal, while both $E_{initial}$ and the ramping voltage are components of the POTENTIAL MONITOR signal.

3. INITIAL CHECKS

3.1 Introduction

The following procedure is provided to facilitate initial performance checking of the Model 362 Scanning Potentiostat. In general, this procedure should be performed after inspecting the instrument for obvious shipping damage (any noted to be reported to the carrier and to Princeton Applied Research). The basic intent of these checks is simply to determine that the instrument in good working order, not to demonstrate that it meets specifications. Each instrument receives a painstaking checkout before leaving the factory, and, ordinarily, if no shipping damage has occurred, it will perform within the limits of the stated specifications. Before proceeding, check to see if there are any addenda to this manual that affect the Initial Checks. Addenda are generally located inside the back cover. If any problems are encountered in carrying out these checks, contact the factory or the proper factory representative for aid.

3.2 Required Equipment

1. Model 362 to be checked and cell cable supplied with instrument.
2. One 10 kΩ 0.1% resistor (supplied with unit).
3. One 1 μF capacitor (supplied with unit).
4. Voltmeter suitable for monitoring the **Potential Monitor** and **Current Monitor** outputs.
5. Special adapter for connecting to Cell Cable pin jack. This adapter may be provided fully assembled, or may have to be assembled from parts provided with the unit, as follows.

   a. Locate the alligator clip and probe (Fig. 6A).

   b. Insert the probe in the clip. Then press onto a hard surface to seat the probe securely as shown in Fig. 6B. The finished adapter should appear as shown in Fig. 6C.

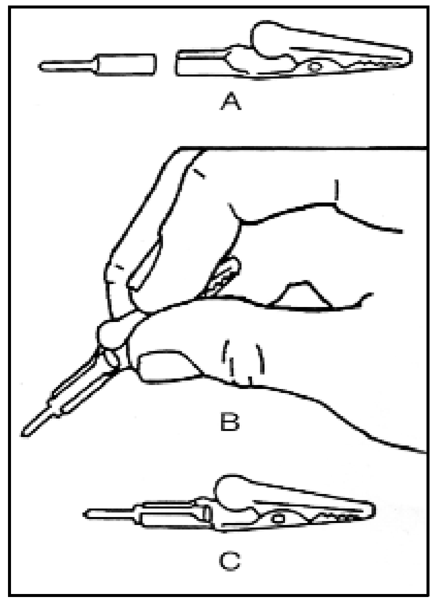


Fig. 6. Assembly of Pin-Jack Adapter.

3.3 Procedure

3.3.1 Setup

1. Plug in the power cord but do **Not** turn on the instrument.
2. Connect the cell cable to the front-panel CELL connector.
3. Connect the alligator clips at the other end of the cell cable to the 10 kΩ resistor. The green wire connects to one end of the resistor. The red wire connects to the other end. Using the special adapter, this end should additionally be connected to the cable pin jack (white cable lead). The black wire is not used. Take care that the alligator clip at the end of the black wire doesn't short to any of the other circuit elements. Fig. 7 shows the required connections.

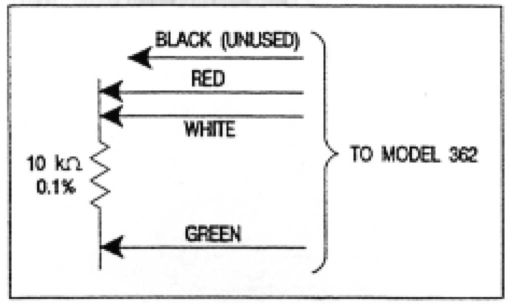


Fig. 7. Cell Cable Connections For Initial Checks.

3.3.2 Control E Checks

1. Set the Model 362 controls as follows.
   CELL: OFF
   INITIAL POTENTIAL: +1.000
   MODE: CONTROL E (out)
   METER: E (in)
   CURRENT RANGE: 1 mA(in)
   $E_{INITIAL}$: $E_{INITIAL}$ (out)
   POWER: ON (switch illuminated)
   IR COMPENSATION: OFF

2. Press in the CELL pushbutton (connects control amplifier output to the red lead of the cell cable).

3. Note the panel meter indication. It should be positive at 20% of full scale. Full-scale meter sensitivity with the meter pushbutton in the *E* selected position is ± 5 V. the 20% of full-scale deflection indicates that the potential at the working-electrode end of the external resistor is +1 V with respect to the reference-electrode end of the resistor.

4. Gradually increase the applied voltage by means of the INITIAL POTENTIAL control. The meter indication will track the control setting, reaching fall scale with a setting of +5.000 V.

5. Set the INITIAL POTENTIAL controls back to 1.000 V. The meter indication will return to 20% of full scale.

6. If an external voltmeter is available, connect it to the POTENTIAL MONITOR output. The indicated potential should be -1 ±5 mV. **Note:** For this tolerance to hold, the accuracy of the external meter must be ±0.1% or better.

7. Press the 100 µA Current Range pushbutton.

8. Release the METER pushbutton so that the meter will indicate the "cell" current. The meter indication should be positive full scale. With the 100 µA current range selected, a full-scale meter indication corresponds to a current of 100 µA through the 10 kΩ dummy cell resistor.

9. Press the 10 µA Current Range pushbutton. A CURRENT OVERLOAD indication should occur.

10. Press the 100 µA pushbutton. The CURRENT OVERLOAD lamp will extinguish and the meter indication will return to full scale.

11. If an external voltmeter is available, connect it to the CURRENT MONITOR Output. The indicated voltage should be +1V ±4 mV indicating a current of one full-scale current range, that is, + 100 µA. (For this tolerance to hold, the accuracy of the external meter must be ±0.1% or better.)

3.3.3 Control I Checks

1. Press the MODE pushbutton, that is, transfer to the CONTROL I mode.

2. Note the panel-meter indication. It should be positive full scale, indicating that the cement is being controlled at 100 µA (Initial Potential/Current setting of 1.000 x Current Range of 100 µA = 100 µA).

3. Press the METER pushbutton, that is, transfer the meter to the "E" display mode. The panel-meter indication should now be +20% of full scale, indicating that 100 µA dropped across the 10 kΩ dummy cell is 1 V (full-scale "E" meter range is ±5 V).

4. Set the INITIAL POTENTIAL control to 2.000. The panel meter indication will increase to +40% of full scale, indicating that the drop across the dummy cell resistance is now 2 V.

5. Release the METER pushbutton, that is, transfer the meter back to the I display mode. The panel meter indication will exceed positive full scale. With 2 V applied, the current is two times the selected current range (100 µA) and right on the edge of triggering a current overload indication. Try increasing the applied potential to 2.500. The CURRENT OVERLOAD lamp should light with 2.5 times overload established. Return the Initial Potential control to +2.000.

6. Press the 1 mA Current Range pushbutton, causing the controlled current to increase from 200 µA to 2 mA (current range is multiplied by the Initial Potential setting). The panel meter indication will still exceed positive full scale (1 mA).

7. If an external voltmeter is available, connect it to the CURRENT MONITOR output. The voltage there should be +2 V, verifying the 2 mA "cell" current.

8. Press the 10 mA pushbutton. The CONTROL AMPLIFIER OVERLOAD lamp will light, indicating that the control amplifier has reached its compliance limit. One hundred volts would be required to force 10 mA through the 10 kΩ resistor, and the compliance of the Model 362 Control Amplifier is limited to ±30 V.

9. Press the 100 µA pushbutton, and set the INITIAL POTENTIAL control to + 1.000, thereby restoring normal full-scale CONTROL I operation.

10. Release the MODE pushbutton, transferring to the CONTROL E mode. Then release the CELL pushbutton, disconnecting the output of the power amplifier from the dummy cell resistor.

3.3.4 Control E, Linear Scan Checks

Note: the remaining checks make frequent reference to a set of latching pushbutton controls that select one parameter or option when they are **in** and another when they are released. In the text that follows, the words **press** or **release** followed by the name of the required function will precede references to these buttons. **Press** implies **press in and latch**. **Release** implies **unlatch**. The instruction release CONSTANT I, for example, means invoke the LINEAR SCAN mode by unlatching the switch labeled LINEAR SCAN and CONSTANT I.

1. With the 10kΩ load resistor still connected as shown in Fig. 7, set the following controls as indicated:
   CELL: OFF
   AC: ON
   INITIAL POTENTIAL: +5.000
   FINAL POTENTIAL: -5.000
   SCAN RATE: 500 mV/SEC
   MODE: CONTROL E
   METER: E
   $E_{INITIAL}$. (released)

MULTIPLE (in)
LINEAR SCAN (released)
CURRENT RANGE :1 mA
IR COMPENSATION: OFF

2. Switch the CELL control ON. The panel meter will indicate +5 V, corresponding to the INITIAL POTENTIAL setting

3. Press RUN. This switches the instrument from its static modes to its scanning modes. In this case, RUN invokes the CONTROL E LINEAR SCAN mode, and the voltage across the dummy load, as well as the voltage indicated by the panel meter, will change at a constant rate from +5 V to -5 V is about 20 s and return to +5 V is another 20s. Since MULTIPLE scanning is enabled, the cycle will repeat until it is interrupted.

4. Release $E_{initial}$. The instrument will return to static CONTROL E operation; its output level and panel meter indication will return to +5 V, the INITIAL POTENTIAL. Release SINGLE and release STOP AT E_1. This prepares the instrument for a single scan, beginning at the INITIAL POTENTIAL, continuing to the FINAL POTENTIAL, and then returning to the INITIAL POTENTIAL again before halting. Press RUN. The panel meter needle will swing smoothly, tracking the changing output voltage, which will ramp from +5 V to -5 V, return to +5 V, and then halt.

5. Release $E_{INITIAL}$**.** The instrument's panel meter indication will remain at +5 V. Press the STOP button. Press RUN. The panel meter indication will swing from +5 V to -5 V and then stop. Release $E_{INITIAL}$. The panel meter indication will return to +5 V. Release the STOP button.

6. Press RUN, allow the panel meter indication to ramp toward -5 V, and press HOLD. Scanning will halt, and the panel meter will indicate a DC level. Release HOLD. The meter indication will continue toward -5 V. Press REVERSE and release it: The panel meter indication will change direction, return to +5 V, and then stop.

3.3.5 Control I, Linear Scan Checks

1. With the 10 kQ load resistor still connected as shown in Fig. 7, set the following controls as indicated:
CELL: OFF
AC: ON
INITIAL POTENTIAL: +1.000
FINAL POTENTIAL. -1.000
CURRENT RANGE: 1 mA
SCAN RATE: 500 mV/SEC
MODE: CONTROL I
METER: I
$E_{INITIAL}$ (released)
MULTIPLE (in)
LINEAR SCAN (released)
IR COMPENSATION: OFF

2. Set the CELL control to ON and press RUN. The panel meter's needle will swing smoothly from + 1(on the CURRENT range) to -1.0 in about four seconds and then return to +1.0.

3. With the instrument still scanning, set the SCAN RATE to 50 mV/SEC. The scan rate, reflected in the deflections of panel meter, will slow to approximately 10% of the initial rate.

4. Return the SCAN RATE to 500 mV/SEC. The scan rate will return to the initial rate.

5. Press HOLD. The panel meter will indicate that scanning has stopped. Release HOLD. Scanning will continue.

6. Press REVERSE momentarily. Scanning will reverse.

7. Change the INITIAL POTENTIAL setting to +2.500 and the final potential to -2.500. (This can be done while the instrument is still scanning.) These changes establish an initial current at 2.5 times the CURRENT RANGE setting and a final current at -2.5 times the CURRENT RANGE. The CURRENT OVERLOAD lamp will light briefly as the magnitude of the current light exceeds approximately twice full scale (±2 mA). The current ramp, however, continues in spite of the meter overload. When the magnitude of the current returns to within twice full-scale, the light goes out.

8. Change the INITIAL POTENTIAL setting to +4.000 and the FINAL POTENTIAL setting to -4.000. This establishes an initial current at 4 times the CURRENT RANGE and a final current at -4 times the current range. The panel meter will cycle from + 1.0 to -1.0 and the CURRENT OVERLOAD lamp will light when the current exceeds twice full-scale. The CONTROL AMPLIFIER OVERLOAD lamp will also light as the current approaches ±4 mA to indicate that CONTROL AMPLIFIER has lost loop control. In this case the CONTROL AMPLIFIER's output voltage, which is limited to approximately ±30 V, is not sufficient to push ±4 mA through the 10 kΩ dummy load.

9. Switch the CELL control OFF.

3.3.6 Control I, Constant I Scanning Checks

1. With the CELL switched OFF, replace the 10 kΩ dummy cell with the 1 µF capacitor provided with the instrument. See Fig. 8. The check to follow confirms that the instrument can serve as a constant current source and charge and discharge a cell between selected potential limits. A capacitive load is necessary here because a resistive load would charge and discharge instantly at a constant current, and the instrument would simply oscillate. The voltage across a capacitor ramps smoothly in time if it is charged with a constant current.
2. Set the instrument's controls as follows:

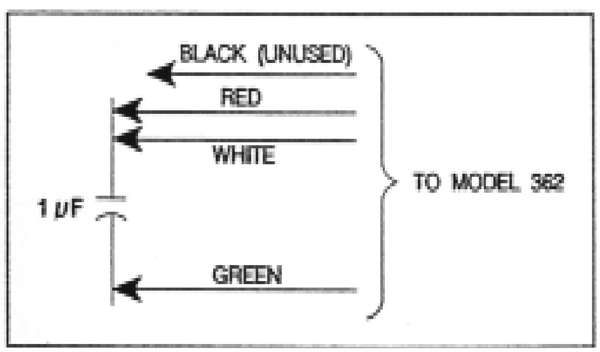


Fig. 8. Dummy Cell Connections for Control I, Constant I Checks.

CELL: OFF
AC: ON
INITIAL POTENTIAL: +5.000
FINAL POTENTIAL: -5.000
SCAN RATE: 100 % OF FULL SCALE
MODE: CONTROL I
METER: I
CURRENT RANGE: 1µA
$E_{INITIAL}$ (released)
MULTIPLE (in)
CONSTANT I (in)
IR COMPENSATION: OFF

3. Switch the CELL control ON. Press RUN. On the CURRENT scale, the panel meter's needle will deflect to the -1.0 position, remain there for a few moments, and then swing abruptly to the +1.0 position. This cycle will repeat until the scan is interrupted. The output indicated by the panel meter corresponds to the constant current output of the instrument, which changes polarity when the voltage across the cell (in this case, a capacitor) reaches the limits set by the INITIAL and FINAL POTENTIAL controls.

4. Press the METER control to select the E position. With E selected, the needle will swing smoothly back and forth from +5 to -5, indicating that the voltage across the cell is ramping up and down within the limits established by the POTENTIAL controls.

5. Switch the SCAN RATE to 200% OF FULL SCALE. The $\Delta v/\Delta t$, as shown by the panel meter, will double. Press HOLD. The panel meter reading will indicate a DC level on the cell. Release HOLD. Scanning will continue. Press REVERSE. Scanning will reverse.

6. Switch the SCAN RATE back to 100% OF FULL SCALE. When the panel meter indicates approximately 0. V, select SINGLE by releasing the SINGLE button Scanning will halt at either +5 or -5 V, depending upon the state of the STOP AT... control.

7. Turn the CELL control OFF, press $E_{INITIAL}$ turn the AC control OFF, and disconnect the dummy cell from the cell cable.

This completes the initial checks. If the indicated results were obtained, the user can be reasonably sure that the instrument has arrived in good working order.

4. OPERATING INSTRUCTIONS

All functions and specifications as per the existing manuals are the same. The new changes are that the previous units' "thumb-wheel switches" have been replaced with up-down cursor styled digital selection registers. The circuitry uses full battery back-up so the original thumb-wheel switch "*memory*" convenience is maintained.

Digital Panel Control Operation

NOTE: (Push buttons clock on the **RELEASE** of the press.)

The up arrow button functions as follows:

Up arrow single button pushes make the display count up one count at a time each time the button is pressed.
Holding the button in for about a second will cause fast up counting.
Continuing to hold the button in past about 4 seconds will cause a "gear shift" and faster counting.

The down arrow button functions as follows:

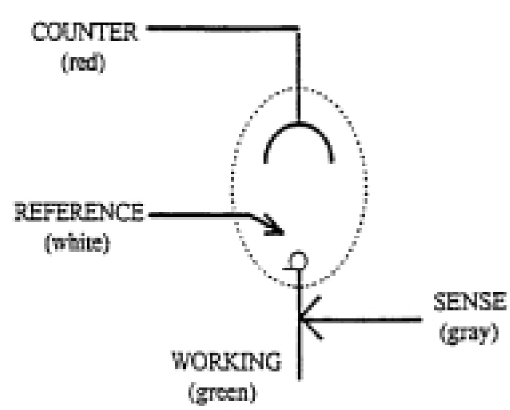
Down arrow single button pushes make the display count down one count at a time each time the button is pressed.
Holding the button in for about a second will cause fast down counting.
Continuing to hold the button in past about 4 seconds will cause a "gear shift" and faster counting.

The display will <u>count up</u> and "over-flow" to 0.000 following 9.999. Also the displays will "underflow" to 9.999 upon <u>counting down</u> past 0.000.

Pressing a set of up arrow and down arrow buttons in simultaneously will reset the display to 0.000.

Depending on how your fingers release the buttons can cause the display to count up or down leaving a non-zero count. This is a quick way of getting to this end of the counter register.

For the ULTIMATE in precision measurement a four wire cell cable is now standard equipment. The counter (red) electrode uses the (white) reference lead for remote sensing and the working (green) electrode uses the (gray) lead for remote sensing. For some non-high current experiments, simply connect the appropriate sense leads to their electrodes. NOTE: the sense lead must *<u>always</u>* be connected in the experiment for the system control feedback to be maintained. See cell block diagram below.



4.1 Introduction

Operation of the Model 362 Scanning Potentiostat is straightforward. The connections to the cell are made with the CELL pushbutton OFF. Then the controls are set as required to establish the desired operating mode and parameters. When satisfied that the system is ready, initiate the experiment by switching the CELL pushbutton ON. This section of the manual discusses the individual controls in greater detail. Static CONTROL E and CONTROL I modes are discussed first, followed by some general discussions of operating considerations. Sections 4.8 and 4.9 focus on the linear scanning modes of CONTROL E and CONTROL I operation.

4.2 Front Panel Controls and Connectors

4.2.1 Initial Potential

This set of five digital thumb switches sets the controlled potential, current level, or ramp limits. **NOTE:** When the position of one of these switches is changed, there is a momentary deferral to the setting of the less significant switches before the new level is established. For example, if the switches were set to 2.000, and the setting were changed to 1.000, there world be an instant in the transition when the switches would have an output equivalent to a setting of 0.000. This might prove a problem in certain applications.

1. **CONTROL E:** In this mode the INITIAL POTENTIAL value extends from -9.999 V to +9.999 V. Note that the limit of ±9.999 rests on the assumption that no signal is applied to the EXT IN input. If a signal is present, a more general limit applies, namely, that the algebraic sum of the INITIAL POTENTIAL setting plus the external input voltage cannot exceed ±9.999 V. In actual practice, the system may control slightly beyond the specified limits. At the point where the loop loses control, the CONTROL AMPLIFIER OVERLOAD lamp lights.

2. **CONTROL I:** In this mode the INITIAL POTENTIAL control works in conjunction with the CURRENT Range pushbuttons to set the current level. The pushbuttons define the "full scale" of the current scanning limit. The actual controlled current level will be the product of the selected current range times the INITIAL POTENTIAL setting. for example, if the 1 mA CURRENT Range pushbutton were depressed with the INITIAL POTENTIAL control set to +1.500, the current would be maintained at a constant 1.500 mA.. Note that it is perfectly possible to operate with a constant current greater than fall scale, the controlled current in the example being 1.5× full scale. Full scale simply defines the current that gives 1 V out at the CURRENT MONITOR output. The limit is two full scales (exception: The 1 A range, where the limit is 1 A). Higher currents will trigger an overload indication. Thus, in CONTROL I operation, the usable range of the INITIAL POTENTIAL control is limited to ±2.000, except on the 1 A range where the Limit is ± 1.000.

   Note that the limit of ±2.000 or ±1.000, whichever applies, rests on the assumption that no signal is applied to the EXT IN input. If such an input is present, a more general limit applies, namely, that the algebraic sum of the INITIAL POTENTIAL setting plus the external input voltage cannot exceed ±2.000 or ±1.000, whichever applies. The EXT IN input signal should always be a potential, even though current is the controlled parameter.

4.2.2 AC

This is the AC power switch. The switch is self-illuminated, indicating immediately whether the instrument is powered.

4.2.3 MODE

This pushbutton switch allows the operator to select either CONTROL E (pushbutton released) or CONTROL I (pushbutton in) operation.

4.2.4 EXT IN

The EXT IN input connector allows the user to apply external control signals that, together with the INITIAL POTENTIAL control, set the potential or current level The applied signal is summed algebraically with the setting of the INITIAL POTENTIAL control For example, during operating in the CONTROL E mode with an INITIAL POTENTIAL setting of +1.000, +1 V applied to the EXT IN connector establishes the working electrode potential at +2 V with respect to the reference electrode. The situation is similar in CONTROL I operation. An INITIAL POTENTIAL of +0.500 combined with + 1 V applied to the EXT IN connector yields a current of 1.5X the selected current range

4.2.5 Cell Switch, Connector & Cable

The Cell Cable (6020-0168) connects to the front-panel CELL connector. At the other end of the cable are four leads, three of which terminate is color-coded alligator clips, and one of which terminates in a pin jack. In both CONTROL E and CONTROL I operation, the red clip connects to the counter electrode and the green clip connects to the working electrode. The reference electrode output plugs into the white pin jack. The black clip is a ground. Although not **required** for any of the Model 362's operating modes, it is available if needed for some special purpose, such as to supply ground to a shielding screen surrounding the cell. If the ground lead isn't used, take care not to let it short against any of the other clips. The user may find it useful to read Princeton Applied Research Application Note TN117, *Grounding and Shielding in Electochemical Instrumentation - Some Basic Considerations*.

The CELL pushbutton, located directly above the connector, determines whether the CONTROL AMPLIFIER is connected to the cell. In the OFF position (released), the CONTROL AMPLIFIER is disconnected from the cell and there is zero cell current, allowing the cell connections to be made safely. In the ON position (in), the CONTROL AMPLIFIER is connected to the cell, making contact with the cell cable clips potentially hazardous. For this reason, the cell cable clips should only be handled when the CELL pushbutton is in the OFF position.

4.2.6 Meter Switch and Meter

The panel meter indicates either current or voltage, as selected by the METER pushbutton. When the METER pushbutton is released, the meter indicates the working electrode current, which is read from the upper meter scale. The polarity of the current indication is the same as that at the CURRENT MONITOR output. Full-scale meter deflection corresponds to a current equal to the selected current range.

When the METER pushbutton is depressed, the meter indicates the potential of the working electrode with respect to the reference electrode. Potential readings are taken from the lower meter scale, which has a range of ±5 V. The polarity of the meter indication will be opposite that at the POTENTIAL MONITOR output. The polarity conventions for the Model 362 are indicated in the specifications.

4.2.7 Current Range Pushbuttons

This set of seven pushbuttons sets the current range in both modes. However, the significance of the current range differs from one mode to another, as follows.

1. **CONTROL E:** The potential is controlled in this mode. The current assumes whatever value is appropriate for the various system parameters. The CURRENT RANGE pushbuttons give the operator the capability of making accurate current measurements over a range extending from a full scale of 1 A to a full scale of 1 A. For best accuracy, one should choose that current range which provides the highest on- scale meter indication. If the current range selected is too big, for example, 1 A with a 1 mA current, the resultant CURRENT MONITOR output and meter indication (meter in I mode) will be small, and the error, as a fraction of the signal level, will be large. If the current range is too small, for example, 1 mA with a 10 mA current, the current measuring circuits will overload (the CURRENT OVERLOAD indicator lamp lights at two times full scale). The potential control is maintained despite the overload in the current-monitoring circuits.

2 . **CONTROL I:** The CURRENT RANGE pushbuttons have a two-fold function in this mode. First, together with the INITIAL POTENTIAL control (and any EXIT IN signal) they determine the magnitude of the controlled current. (In the linear scanning mode, the setting of the SCAN RATE switch is also a factor in determining the controlled current.) The INITIAL POTENTIAL setting is multiplied by the current range to determine the current level. For example, with an input of 1.000 V, and a CURRENT RANGE setting of 1 mA, the current will be maintained at 1 mA. Second, the pushbuttons set the meter sensitivity (meter in I mode), the same as in Control E operation.

Again, for highest accuracy, it is desirable that the current range provide the highest on-scale meter indication. For example, suppose one wanted to control the current at 1 mA. One way would be to set the INITIAL POTENTIAL to 1.000 and select the 1 mA current range. The product would be 1 mA, the desired current level, and the meter sensitivity would be full-scale deflection with 1 mA of cell current. Alternatively, the same current level could be established by setting the INITIAL POTENTIAL to 0.100 and selecting the 10 mA current range. As before, the product would be 1 mA and the current would be controlled at that level. However, with a current range of 10 mA and a 10% of full scale settings, the inherent noise and drift of the instrument will be larger than with a 1 mA range and a 100% of full-scale setting. The reserve range at 10% of full scale, however, would extend to twenty times the controlled current (ratio of 20 mA to 1 mA), which could be a factor to consider in certain situations.

4.2.8 Potential Monitor Output

In both modes, the signal provided at this output is a voltage equal to the reference electrode with respect to the working electrode. The meter, on the other hand, indicates the potential of the working electrode with respect to the reference electrode. The two potentials are equal in magnitude but of opposite polarity. The output range is ±9.999 V and the output resistance is a few ohms (the current capability, however, is limited; the load resistance should not be less than 2 kΩ at full output).

4.2.9 Current Monitor Output

In both modes, the signal provided at this output is a voltage that varies directly with the cell current. The polarity is the same as the meter indication (I mode) and a full-scale meter indication corresponds to 1 V out. (The polarity convention is stated in the specifications). linear operation is assured up to 2 V out (two times full scale), except on the 1 A range, where the limit is 1 V out. Although the output resistance is only a few ohms, the load resistance should not be less than 2 kΩ at full output.

4.2.10 Ramp Out

The RAMP OUT output signal is a voltage equal in magnitude (but opposite in polarity) to any deviation between the INITIAL-POTENTIAL and the voltage applied to the cell as a result of the scanning modes. (In the static modes there is no deviation and the RAMP OUT level is 0 V.) In contrast, the POTENTIAL MONITOR output signal is a voltage equal in magnitude (but opposite in polarity) to the sum of the INITIAL POTENTIAL and any voltage added to or subtracted from it as a result of the scanning modes. (In the static modes, no ramping voltage is applied to the cell, so the POTENTIAL MONITOR signal is simply equal in magnitude and opposite in polarity to the INITIAL POTENTIAL setting.) The load resistance attached to the RAMP OUT output should be greater than 2 kΩ.

4.2.11 Overload Indications

There are two OVERLOAD lights, one labeled CURRENT and the other CONTROL AMPLIFIER. The significance of an overload indication depends on the operating mode, as follows.

1. **CONTROL E**: A CURRENT OVERLOAD indication means that the working electrode current is greater than two times the selected CURRENT Range. It does not mean that the loop is out of control. For example, suppose the controls were set to establish a potential of +0.752 V, and that, under the established condition, a cell current of 0.5 mA occurred. If the selected

CURRENT Range were I µA, 10 µA, or 100 µA, the current monitoring circuits would be driven beyond 2X full scale, causing a CURRENT OVERLOAD indication. Although the CURRENT MONITOR Output and meter indication (I display mode) would be invalid, the cell would still be controlled at +0.752 V, as programmed.

On the other hand, a CONTROL AMPLIFIER Overload indication means unequivocally that the loop is out of control, that is, the potential of the working electrode with respect to the reference electrode is NOT that programmed. This could result from a connection error (see Section 4.4), an electrode problem, or an unacceptably high solution resistance. It will also occur if the cell current exceeds 1 A. (Currents higher than 1 A cause the CONTROL AMPLIFIER Overload indicator to light, a sign that control has been lost.)

2. **CONTROL I:** A CURRENT OVERLOAD indication means that the working electrode current is greater than two times the selected Current Range. Since it is the current that is the controlled parameter in this mode, if the cell connections have been made properly, about the only way this can happen is if the setting of the INITIAL POTENTIAL, the ramp voltage, or the potential applied to the EXT IN input are such as to program a current higher than two full scales. A programmed level of 2.000 would result in the current being controlled at twice the selected current range. Higher settings would result in a CURRENT OVERLOAD indication.

   A CONTROL AMPLIFIER OVERLOAD indication means that the compliance of the amplifier has been exceeded (or that the current exceeds 1 A). In CONTROL I operation, this would normally only occur with a high resistance solution or an open cell connection.

4.3 Line Cord and Fuse Assembly (Rear Panel)

This assembly allows the operator to readily change the line fuse. It also has provision for optimizing the Model 362 power circuits to the prevailing line voltage over a wide range. These operations are discussed in detail in Chapter 1.

4.4 Installation

Generally speaking, the Model 362 can be operated on a typical laboratory bench in a typical laboratory environment without difficulty. Usually the experiment to be controlled would be located to one side or the other on the same bench. Be sure to allow at least six inches (15 cm) between the rear-panel heat sink and the back of the bench. This much space is required to assure reliable operation in a high-current application. If the Model 362 is operated at a high current in a closed area, such as rack cabinet, it is advisable that forced air cooling of the rear-panel heat sink be used to assure reliable operation.

Such cooling can be implemented by means of as external fan directed at the rear panel. Some equipment cabinets have built-in forced- air cooling adequate for this purpose.

Other than to provide the instrument with AC power as described in Section I, no special hookups are required. If the experiment is one that requires deoxygenation of the electrolyte, the necessary additional equipment and oxygen-free gas will have to be furnished (see Princeton Applied Research Electrochemical Accessories catalog).

Connections to the cell are made using the cable furnished with the instrument. One end of the cable terminates in a connector that mates with the front-panel CELL connector. At the other end are four leads. Three are color-coded leads, each terminated in a spring-loaded clip. The fourth one is terminated in a pin jack. The cell connections are made as follows.

WARNING:	For operator safety, do not install the cable, contact the cable leads, or make the cell connections unless the model 362 cell pushbutton is in the off (released) position.

1. **RED LEAD**: Connects to the counter (auxiliary) electrode in both modes.

2. **GREEN LEAD:** Connects to working electrode in both modes.

3. **BLACK LEAD:** Available as a source of ground potential. This is not a required connection for any operating mode.

4. **PIN JACK:** Connects to the reference electrode. Reference electrodes manufactured by Princeton Applied Research are furnished with a connecting lead that directly plugs into this pin jack Note that, whereas a reference electrode is essential in CONTROL E operation, in CONTROL I operation a reference electrode is not necessary for control, but only to provide a valid *E* meter indication and POTENTIAL MONITOR output.

4.5 Connection Error Detection

Although connection errors are not likely, they could occur. Most commonly the problem is that for one reason or another one of the clips has been removed from an electrode, and then forgotten. Subsequent attempts to establish operation will then prove unsuccessful. An electrode can be "open" for other reasons as well. Failure to fill the cell or the reference electrode with the appropriate solutions will give open-electrode indications. Bubbles on an electrode can also impair its performance. Thus, any time an experiment doesn't seem to be behaving properly, the first step should be to simply look at the cell and verify that the connections have been properly made and that the cell has been properly assembled and filled. If everything looks all right, try running the experiment and check the indications obtained against the following table:

Table 1. OPEN ELECTRODE INDICATIONS AS A FUNCTION OF OPERATING MODE

Mode	Open Electrode	I Meter	E Meter	Pot-stat Ovld	Current Ovld
Cont. E	Counter	“0"	OK	ON	OFF
Cont. E	Reference	Off Scale	Off Scale	ON	ON
Cont. E	Working	“0"	OK	OFF	OFF
Cont. I	Counter	“0”	OK	ON	OFF
Cont. I	Reference	OK	Off Scale	OFF	OFF
Cont. I	Working	“0"	OK	Off	Off

4.6 Control E Operation

In Control E operation, the potential of the working electrode with respect to the reference electrode is controlled at the potential set with the INITIAL POTENTIAL control, together with any voltage added or subtracted by the scanning modes or by the EXT INT input. For example, to control the working electrode at +0.755 V, the user would simply set the controls to +0.755. The voltage range over which control can be maintained is ±9.999 V.

It is important to understand that the potential established is with respect to the reference electrode and not with respect to ground. Both the reference and working electrodes are "off ground" when driven by a Model 362. The potential of the working electrode with respect to the reference electrode can be read from the panel meter if the meter *E* mode is selected.

Alternatively, a more accurate measurement can be made with an external voltmeter connected to the POTENTIAL MONITOR output. The potential provided at this output is that of the reference electrode with respect to the working electrode, that is, the inverse of the parameter of interest.

The following procedure should prove suitable for establishing operation in the CONTROL E mode.

1. Prepare the Cell. Be sure the electrodes are immersed in the solution. Also, check that the reference electrode is properly filled.

2. With the Model 362 AC power switch and CELL pushbutton both set to OFF, connect the cable. One end mates with the front-panel CELL connector. The other end connects to the electrodes at the cell. The red lead connects to the counter electrode and the green lead connects to the working electrode. The output lead of the reference electrode connects to the pin jack. The black (ground) lead is normally unused, although it could be used to establish a shield or other piece of peripheral apparatus at ground potential. If the black lead is unused, take care that it doesn’t short to any of the other active circuit elements.

   Two-electrode operation is also possible. In this configuration there is no reference electrode. The red lead and the white lead are shorted together and connected to the counter electrode. The green lead connects to the working electrode. As in three-electrode operation, the black lead is available as a convenient source of ground potential.

3. Set the AC power switch to the ON position.

4. Set the INITIAL POTENTIAL control to the intended control potential. The potential of the working electrode with respect to the reference electrode will be controlled at the set value. (This will not happen until the CELL switch is set to ON, a later step.) If a control signal is to be applied to the EXT IN connector, make the necessary connections at this time. Bear in mind that the working electrode will be controlled at the sum of the external control potential plus that set with the INITIAL POTENTIAL control, and that this sum cannot exceed ±9.999 V for control to be maintained.

5. Be sure the MODE pushbutton is in the CONTROL E (released) position.

6. Check the METER pushbutton. It should be set to *E* (in) That way, when the CELL pushbutton is switched ON (step 8), there will be immediate verifies of system control because the working electrode potential with respect to the reference electrode will be indicated. In this step, since the CELL pushbutton is still set to OFF, there is no counter electrode connection to the cell and the control loop is open. The reference electrode connection, however, is intact, with the result that *the meter displays the open circuit potential of the cell* (open-circuit working electrode with respect to reference electrode). This reading may or may not be an important parameter in the intended experiment.
7. Select the 1 A CURRENT RANGE. Once the measurement is underway, a current range appropriate to the current level present can be quickly established.

8. At this point the system should be ready. All that remains is to press the CELL pushbutton. When this is done, the panel meter will immediately indicate the closed-loop potential of the working electrode with respect to the reference electrode. This potential should be the same as the sum of the potential set with the INITIAL POTENTIAL control plus any external input. If the EXT IN input is not used, the meter indication will equal the INITIAL POTENTIAL setting, telling the operator that the control loop is functioning properly. An equal potential of opposite polarity will be available at the POTENTIAL MONITOR output. If the potentiostat is

not controlling, the CONTROL AMPLIFIER OVERLOAD indicator will light. (A cell current greater than 1 A will also cause this lamp to light.)

9. Having verified potentiostatic control, establish the *I* meter mode (release the METER pushbutton). Then select successively lower current ranges until the maximum on-scale meter indication is obtained. Full-scale current equals the selected current range, allowing the cell current magnitude and polarity to be quickly and easily read. A proportional voltage of the same polarity is available at the CURRENT MONITOR output.

   This procedure should prove adaptable to most real measurements. Potentiostatic control of the cell will be maintained until terminated by the operator (CELL pushbutton to OFF). Because of the switching transition characteristics of the INITIAL POTENTIAL control, users are advised to use caution in changing the setting of this control once CONTROL E operation is established. In most instances, when the setting of the most significant switch is changed, there is a momentary deferral to the less significant switches before the new level is established. For example, if the switches are set to 3.000 V, and the setting is changed to 2.000 V, there will be as instant in the transition when the switches will have an output corresponding to a setting of 0.000 V. This might prove a problem in certain applications.

4.6.1 IR Compensation

The Model 362 includes a set of front-panel controls to compensate for the cell resistance between the reference electrode and the working electrode. These controls, labeled IR COMPENSATION, are used in the CONTROL E mode only to apply positive feedback to the control amplifier. The feedback signal is a voltage produced by the current (I) in the resistance between the reference and working electrodes (R), hence the notation *IR compensation.* The instrument's control loop automatically compensates for cell resistance between the counter electrode and the reference electrode.

The front-panel controls consist of a latching ON-OFF toggle switch and a ten-turn potentiometer with a high-resolution dial. The toggle switch should be OFF whenever the instrument is not in the CONTROL E mode or whenever IR compensation is not desired. The amount of feedback varies with the potentiometer's dial setting. With the dial fully clockwise (indicating 10.00) the feedback is 100%. The feedback voltage is a portion of the CURRENT MONITOR signal.

4.6.2 Setting the IR Compensation Controls

The exact amount of positive feedback required in a given system is a function of many factors, including the system impedance, the uncompensated solution resistance and the nature of the signal being applied to the system. Because of the number of different factors involved, it is difficult to find a universally valid procedure for setting the IR compensation. Nevertheless, here's a general method that usually yields good results.

This method involves pulsing the working electrode in potential regions where no faradaic processes are occurring, while monitoring the current vs. time behavior of the system at the CURRENT MONITOR output. The ability of the working electrode to follow an applied square-wave signal is a function of the solution resistance, R, between the working and reference electrodes, and of the double-layer capacitance, C, of the working electrode.
This RC combination slows the response of the working electrode to the applied square wave. Positive feedback IR compensation increases the potential so that the solution RC can be quickly charged. The procedure for setting the IR compensation follows:

1. Prepare the cell in the usual manner. To prevent faradaic current, the potential applied with the INITIAL POTENTIAL control should be well below the half-wave potential of the reaction of interest

2. Set up an external square-wave generator to provide a small (10-50 mV pk-pk) square wave at 1 kHz or lower, and connect the square wave to the front-panel EXT IN connector. Note:

mate oscilloscopes are equipped with an internal calibrator that provides a square-wave signal at either 1 kHz or 60 Hz. Such a signal can be used to adjust the IR compensation.

3. Connect an oscilloscope to the CURRENT MONITOR connector and adjust the oscilloscope to the current vs. time relationship of the electrode response.

4. Turn the IR COMPENSATION dial fully clockwise. Turn the IR COMPENSATION switch ON. Then begin rotating the dial clockwise while monitoring the CURRENT MONITOR signal with the oscilloscope.

5. Adjust the dial for the smoothest fast-charging of the double-layer capacitance, as shown in Fig. 9. With too little compensation, the response will be slow and of low amplitude. As the compensation is increased, the amplitude of the observed waveform will increase and the charging time will become faster. Too much compensation results in a very high amplitude waveform with fast response and ringing that indicates the system is not well controlled. In many cases, it will even be possible to make the entire system oscillate completely out of control by setting the IR compensation too high. The correct setting is that which gives a response similar to that shown in the lowest curve of Fig. 9, that is, fast, but without ringing. If the IR compensation is too low with the dial fully clockwise, as may be the case in high-resistance solutions, operating with 100% positive feedback is the best you can do. IR compensation adjustment are critical in the sense that any change in the system (sensitivity, cell geometry, supporting electrolyte, etc.) will change the amount of compensation required. The IR compensation should always be adjusted with the CURRENT RANGE set to the intended operating range. If the CURRENT RANGE is changed in the course of the experiment, the IR compensation will have to be readjusted. Bear in mind that IR compensation has significance in CONTROL E operation only.

4.7 Control I Operation

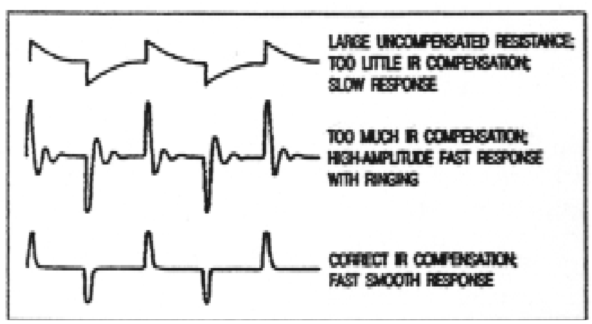


Fig. 9. IR Compensation Current Monitoring Waveforms.

In Control I operation, the cell current is maintained at the level set by the INITIAL POTENTIAL control, acting in conjunction with the selected range, and, if applicable, the scanning function. The setting limits are 2.000, that is, two times the full-scale CURRENT RANGE setting. As is Control E operation, the EXT IN function is active. If an external input is applied, it is summed with the INITIAL POTENTIAL setting to determine the control current level. The control range for the sum is the CURRENT RANGE setting, except on the 1 A Current Range where it is one full scale. An input of 1.000 V is required to establish a current equal to the selected range.

By furnishing the cell with a reference electrode connected in the same way as for Control E operation, a valid POTENTIAL MONITOR output will be available, and the potential of the working electrode with respect to the reference electrode can be read from the panel meter (*E* meter mode). This function is separate from the current control function, which does not require the presence of a reference electrode.

The following procedure should prove suitable for establishing Control I operation in many experiments.

1. Prepare the cell. Be sure the electrodes are immersed in the solution. Also, check that the reference electrode, if one is to be used, is properly filled and free of bubbles.

2. With the Model 362 AC power switch and CELL pushbutton both set to OFF, connect the cable. One end mates with the front-panel CELL connector. The other end connects to the electrodes at the cell. The red lead connects to the counter electrode and the green lead connects to the working electrode. If the cell includes a reference electrode, the output lead of the reference electrode should be connected to the pin jack. If the cell doesn't include a reference electrode, ground the pin jack (the black lead can serve as a convenient source of ground). With ground applied to the pin jack, the meter will indicate off scale in the E mode and the POTENTIAL MONITOR Output will go to full scale.)

   It is also possible to connect the pin jack to the red lead, which in turn is connected to the counter electrode. This configuration allows two-electrode potential measurements (useful in battery and fuel-cell experiments).

3. Set the AC power switch to the ON position.

4. Select the desired CURRENT RANGE. Usually, the best range will be that which allows the highest setting of the INITIAL POTENTIAL control in establishing the current level. For example, in setting a current level of 1 mA, a current range of 1 mA (requiring an INITIAL POTENTIAL setting of 1.000) will usually be preferable to a current range of 10 mA (requiring an INITIAL POTENTIAL setting of 0.100).

5. Set the INITIAL POTENTIAL control as required to establish the desired current. If a control signal is to be applied to the EXT IN connector, make the necessary connections at this time.

6. Be sure the MODE pushbutton is set to CONTROL I (in).

7. Be sure the METER pushbutton is set to display current (released).

8. At this point the system should be ready. If the open-circuit cell potential is of interest, press in the METER pushbutton and read the potential from the panel meter. (Alternatively, record the potential at the POTENTIAL MONITOR Output.) When this is done, or, if the open-circuit cell potential is of no interest, press the CELL pushbutton to establish current control The I Meter mode (METER pushbutton released) should be selected. The panel meter will indicate the actual current level, which should be that programmed. To monitor the working electrode potential (only possible if the system includes a properly connected reference electrode), simply select the *E* meter mode (METER pushbutton depressed) and read the potential from the panel meter. Alternatively, monitor the potential at the POTENTIAL MONITOR output with an external voltmeter; the potential at this output will be equal but opposite to that indicated by the panel meter. Again, the cell must be equipped with a reference electrode for the potential to be read at either the panel meter or the POTENTIAL MONITOR connector.

   The preceding procedure should prove adaptable to most real measurements. Galvanostatic control of the cell will be maintained until terminated by the operator (CELL pushbutton OFF). Because of the switching transition characteristics of the INITIAL POTENTIAL control, users are advised to use caution in changing the setting of this control once CONTROL I operation is established. In most instances, when the setting of the most significant switch is changed, there is a momentary deferral to the setting of the less significant switch before the new level is established. For example, if the switches are set to 2.000, and the setting is changed to 1.000, there will be an instant in the transition when the switches will have an output corresponding to a setting of 0.000. This might prove a problem in certain applications.

4.8 Linear Sweep Scanning Modes

The instrument's linear sweep scanning modes produce a voltage (CONTROL E) or current (CONTROL I) output that varies with time, beginning at a level set through the front-panel INITIAL POTENTIAL selector and continuing to a level corresponding to the FINAL POTENTIAL SETTING. The SCAN RATE switch governs the rate of the scan. The procedure for selecting a scan rate depends upon whether the instrument is in the CONTROL E or CONTROL I mode. An internal SCAN RATE MULTIPLIER switch allows the operator to select scan rates at X10 the front-panel setting.

A bank of seven SCANNING CONTROL pushbutton switches controls the scanning options and parameters. These controls are located in a vertical row on the left-hand side of the front-panel (viewed from the front of the instrument). All but the REVERSE switch are latching, and during normal operation are either *IN* or *RELEASED.* Labels to the right of the switch bank indicate how each switch affects the instrument's scanning modes.

As is the case with the non-scanning modes, the instruments output is not applied to the CELL electrodes until the CELL switch is ON.

4.8.1 Scanning Control Switches

$E_{INITIAL}$ (released): The $E_{INITIAL}$ position disables the scanning modes and returns the instrument's output to the CONTROL E or CONTROL I value selected through the INITIAL POTENTIAL setting. An exception to this is that in the CONTROL I CONSTANT I mode, releasing this button halts the current output.

RUN (in): This position initiates scanning toward the INITIAL POTENTIAL setting.

REVERSE (in): A momentary switch, REVERSE (in) causes the output ramp to change direction. If the output were moving from the INITIAL to the FINAL POTENTIAL setting, for example, and REVERSE were pressed, the output would change direction and ramp back toward the INITIAL POTENTIAL setting before continuing.

HOLD (in): If the instrument is scanning and HOLD is pressed scanning halts, and the output changes to a DC level equal to the instantaneous magnitude of the output when button is pressed. When HOLD is RELEASED, scanning continues.

SINGLE (in): Pressing SINGLE selects SINGLE rather than MULTIPLE scanning. If STOP AT E_F is selected, the output ramps from the INITIAL POTENTIAL value to the FINAL POTENTIAL value and halts. If STOP AT E_I is selected, the output ramps first to the FINAL POTENTIAL, then ramps back to the INITIAL POTENTIAL before halting.

MULTIPLE (released): Releasing this key instructs the instrument to ignore the STOP AT... selections and thus enables continuous scanning, which is halted only by operator intervention.

STOP AT E_F (in): When in, this button selects E_F, the FINAL POTENTIAL setting, as the endpoint for a single scan. This button has no effect when MULTIPLE scans are selected

STOP AT E_1, (released): This button selects the endpoint of a single scan as E_1, the INITIAL POTENTIAL setting. It is ignored if multiple scanning is selected.

LINEAR SCAN (released): This button selects linear scanning (ramp function output) in either the CONTROL E or CONTROL I modes.

CONSTANT I (in): Used while CONTROL I is enabled. This button instructs the instrument to apply a constant current to a cell or battery while cycling its potential between the INITIAL POTENTIAL and FINAL POTENTIAL settings (see Section 4.9). (Selecting CONSTANT I and CONTROL E simultaneously produces an output that is unpredictable and unrelated to other parameter and option settings.)

4.8.2 Scanning Mode Monitor Outputs

While the instrument is its scanning modes, it produces three output signals which can be connected to external monitoring apparatus, such as a recorder, or used as signal input to a complex control system. These signals are output on three separate sets of binding posts. Each set includes a black binding post, nominally at chassis ground potential, which carries the signal's reference level.

The RAMP OUT signal in a voltage equal in magnitude and opposite in polarity to the voltage added to or subtracted from the INITIAL POTENTIAL as a result the scanning functions. The polarity of the RAMP OUT signal is opposite the polarity of the instrument's output (as shown on the panel meter) but is the same as the polarity of the voltage on the counter electrode. For example, if the INITIAL POTENTIAL is set for 0.000 V and the FINAL POTENTIAL is set for +5.000 V, the panel meter will display a voltage increasing from 0.0 to +5 V at a rate set by the SCAN RATE control. The corresponding voltage on the RAMP OUT binding posts will be 0.0 to -5 V, (the green binding post with respect to the black).

The magnitude of the POTENTIAL MONITOR signal, on the blue binding post, is equal to the voltage of the working electrode with respect to the reference electrode. Thus, its limits are equal in magnitude and opposite in polarity to the INITIAL POTENTIAL and FINAL POTENTIAL settings. Like the RAMP OUT signal, its polarity is the same as that of the voltage on the counter electrode.

The CURRENT MONITOR signal, on the red binding post, is a voltage proportional to the cell current, where 1 V represents a full-scale CURRENT RANGE level. The polarity of this voltage matches that of the current as it is displayed on the front-panel meter. If the current exceeds approximately two times the full-scale current range value, the CURRENT OVERLOAD lamp will light. This is not of itself cause for alarm, as it simply means that the current is twice the full-scale meter value and that the voltage on the CURRENT MONITOR outputs may not be linear with respect to the cell current. Switching to a higher CURRENT RANGE should remedy the problem and bring the panel meter indication off full scale.

4.8.3 Control E Linear Scanning

The output of this mode is a voltage ramp applied to the working electrode with respect to the reference electrode. The ramp begins at a voltage level corresponding to the INITIAL POTENTIAL setting and extends to the FINAL POTENTIAL setting.

In the CONTROL E mode, the operation of the SCAN RATE switch is straightforward and allows selection of scan rates from .1 mV/SEC to 500 mV/SEC. Use the SCAN RATE switch to adjust the scan rate, then select other scanning parameters and options as necessary for the measurement at hand, and use the RUN and CELL ON switches to apply the excitation waveform to the cell

4.8.4 Control I Linear Scanning

The instrument's output in this mode is a current ramp, where the initial current is the product of the INITIAL POTENTIAL setting, used here as a dimensionless multiplier, and the CURRENT RANGE setting. For an initial current of 1 mA, for example, set the INITIAL POTENTIAL control to +1.000 and select a CURRENT RANGE of 1 mA. Similarly, for a final current of -1 mA, it is necessary to multiply the CURRENT RANGE setting (1 mA) by a FINAL POTENTIAL setting of -1.000.

In CONTROL I LINEAR SCANNING, the CURRENT RANGE setting, the INITIAL POTENTIAL selection, and SCAN RATE setting all interact to determine the $\Delta i/\Delta t$. Use the following formula to select a ramp with characteristics suitable for the measurement at hand:

$$\Delta i/\Delta t = (\text{Scan Rate}/\text{Initial Potential}) \times \text{Current Range}$$

The CURRENT RANGE button selects a value in units of amperes, while the SCAN RATE switch is calibrated is units of mV/SEC and the INITIAL POTENTIAL parameter is in units of volts. The units of volts factor out of the formula, leaving an expression in units of amperes/sec as is appropriate for the parameter. For example, if the INITIAL POTENTIAL is +1.000 (volts) and the SCAN RATE switch is 500 mV/SEC, the $\Delta i/\Delta t$ is 500 (mV/SEC)/1.000 (V), or 0.5/SEC, times the CURRENT RANGE. If the CURRENT RANGE were 1 µA, the $\Delta i/\Delta t$ would be 500 nA/SEC. If the CURRENT RANGE were 10 µA, the $\Delta i/\Delta t$ would be 5 µA/SEC, etc.

4.9 Control I, Constant I Scanning

This mode requires that CONTROL I (in) and CONSTANT I (in) be selected. The output of this mode is a constant current whose polarity depends upon the cell voltage (working electrode with respect to reference electrode) and the INITIAL POTENTIAL and FINAL POTENTIAL settings. This mode is especially suited for controlling charge-discharge cycles of batteries and cells.

The polarity of the current first applied to the cell when RUN is pressed will either charge or discharge the cell as necessary to take the cell voltage from the INITIAL POTENTIAL level to the FINAL POTENTIAL level. The CURRENT RANGE and SCAN RATE controls work together to determine the magnitude of this current. Outlined in black on the right-hand side of the SCAN RATE switch is a group of numbers ranging from 10 to 200. These numbers correspond to a legend below the switch, also outlined in black, CURRENT % OF FULL SCALE. The scan rate selected determines the percentage of the full-scale CURRENT RANGE selection applied to the cell. For example, if the CURRENT RANGE is 10 µA and the SCAN RATE is 50%, the constant-current output of the instrument is 50% of 10 µA, or 5 µA.

Assume that the working electrode is connected to the positive terminal of a 9 V secondary (rechargeable) battery and that the counter and reference electrodes are connected to the negative terminal. Assume further that the instrument's controls are set as follows:

CELL: OFF
E_{INITAL} : (released)
HOLD: (released
MULTIPLE: (released)
I: CONSTANT I (IN)
MODE: CONTROL I (in)
INITIAL POTENTIAL: - +8.000
FINAL POTENTIAL: +5.000
CURRENT RANGE: 1 mA
SCAN ROTE: 20 % OF FULL SCALE
IR COMPENSATION: OFF

As soon as the CELL is switched on and RUN is pressed, the instrument will attempt to discharge the battery at a rate of 20% of 1 mA or 200 µA. This discharge will continue until the battery voltage reaches the FINAL POTENTIAL of +5.000 V. Since MULTIPLE scans are selected in this example, the current will again reverse polarity and charge the battery at a rate of 200 µA until its voltage reaches the INITIAL POTENTIAL setting of 8.000 V. The cycle will continue until the operator intervenes.

The discussion of the RAMP OUT, POTENTIAL MONITOR, and CURRENT MONITOR outputs in the Section 4.8 also applies here.

4.10 Step Function Response

If a step function is applied to the EXT IN input, one might expect to see a faithful replica of the applied function at the CURRENT and POTENTIAL MONITOR outputs. This is not always the case. Sometimes, overshoot will be observed on the leading edge of the observed waveform, as shown in Fig. 10. The source of the overshoot is the time required for the cell current to charge the stray shunt capacitance of the cell cable.

Although the observed overshoot will behave as illustrated with a resistive cell only, the effect may have to be considered when working with a real cell. Usually, the distortion caused by the cell's capacitance will dominate that due to charging of the cable capacitance. Nevertheless, the cable charging effect could be noticeable in certain applications.

Although the cable is guarded to minimize capacitance effects, typically 100 pF of stray capacitance remains. This capacitance, together with the range resistance across which the current signal is developed, forms an RC time constant. The effect of the time constant is to cause the current to be momentarily higher than the correct step level. As shown in the figure, this current asymptotically decays to the feedback-determined level in five time constants. The actual time constant varies with the selected current range since the value of "R" is different for each range as shown in Table 2. The table also lists SRC, the time required for the overshoot to decay, versus range so that the duration of the overshoot can be easily determined.

As can be seen from the table, the overshoot Spike will not be seen on the high current ranges where 5RC is less than the potentiostat rise time of approximately 7 µcs. The effect should only be appreciable on the 10 µA and 1 µA ranges.

It is important to understand that the observed effect is different for each mode. In CONTROL E operation, the signal observed at the POTENTIAL MONITOR connector will not show the aforementioned overshoot. That at The overshoot is observed at the POTENTIAL MONITOR connector, but not at the CURRENT MONITOR connector.

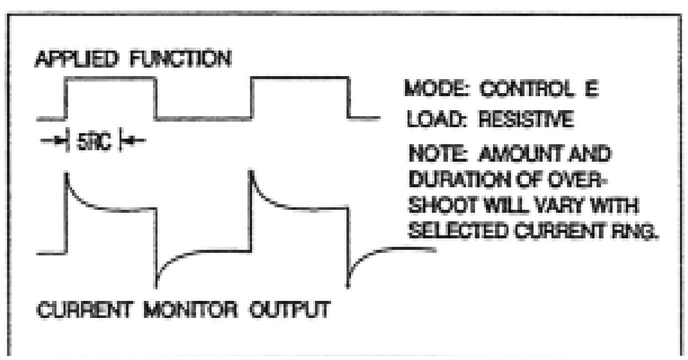


Fig. 10. Step-Function Overshoot.

Table 2. TYPICAL OVERSHOOT DURATION AS A FUNCTION OF CURRENT RANGE

CUR RANGE	RESIST	CAPAC	5RC
1A	0.5 Ω	100 pF	250 ps
100 mA	5.0 Ω	100 pF	2.5 ns
10 mA	50 Ω	100 pF	25 ns
1 mA	500 Ω	100 pF	250 ns
100 µA	5 kΩ	100 pF	2.5 µs
10 µA	50 kΩ	100 pF	250 µs
1 µA	500 kΩ	100 pF	250 µs

Applications could arise in which the user will wish to measure the current step-function response directly at the working electrode. Tektronix Inc. manufactures clip-on current probes designed for use with an oscilloscope. These probes are suitable for direct monitoring of the current waveform. The probe simply clips to the working electrode lead at the end of the cell cable, and the signal is observed at the associated oscilloscope.

4.11 Rack Mounting

Before the Model 362 can be rack mounted, it must be fitted with two mounting ears. These simply bolt to each side of the instrument at the front. The ears and mounting screws are available from Princeton Applied Research. The part numbers for the two ears are 1415-0780 and 1415-0781 respectively. The four required # 8 screws are designated as part number 2811-0261.

5. ALIGNMENT

5.1 Safety Considerations

WARNING:	Potentially lethal voltages are present inside this apparatus. These service instructions are for use by qualified personnel only. To avoid electric shock, do not service this apparatus unless you are qualified to do so.

Any adjustment, maintenance, or repair of the opened apparatus under voltage shall be avoided as far as possible and, if necessary, shall be carried out only by a skilled person who is familiar with the precautions used in working with hazardous voltages.

When the apparatus is connected to a supply circuit, terminals may be live, and the opening of covers or removal of parts is likely to expose live parts. The apparatus shall be disconnected from all voltage sources before it is opened for any adjustment, replacement, maintenance, or repair. Once the apparatus is open, power may be applied to carry out the necessary maintenance, but only by qualified personnel, and only if proper safety precautions are observed.

5.2 Introduction

The Model 362 Scanning Potentiostat is a reliable, conservatively designed instrument. High-quality, stable components are used throughout the unit, and one can reasonably expect a long period of trouble-free operation without need for realignment. However, to be assured of continued high confidence in measurement data obtained with this instrument, it is advisable to run through the following alignment after a long period (at least one year) of heavy use. Also, should the instrument ever have to be repaired, realignment before placing the instrument back in service is advised. Note that this procedure is not intended to be used for troubleshooting. Appropriate information on isolating malfunctions is provided in Chapter 6.

Because there could be considerable interaction between many of these adjustments, it is important that they be performed in the indicated sequence. Any decision to make a partial alignment should be reserved to personnel having sufficient knowledge of the instrument to fully understand all possible interactions.

Throughout the procedure, service personnel are asked to make measurements at specific test points. Most of the test points are in one of three locations. The first two are located on the Main Board. Viewing the instrument from the front, note that the first row of test points is located at the center of the printed circuit board and about one third of the way back. The second row is located a little further back to the right of center. The circuit monitored by each test point in the front row is indicated by lettering on the printed circuit board. For example, "1" identifies the test point that connects to the output of U1, "2" identifies the test point that connects to the output of U2, and so forth. "A" designates the test point that connects to the output of the Control Amplifier. Some of the test points in the second row are also identified by lettering on the printed circuit board. These two sets of test points are identified in Fig. 11. Note that power cannot be taken from the power supply monitor points; there is an internal 1kΩ resistor in series with each.

The third set of test points is located on the SCAN CONTROL BOARD. This board is mounted on the instrument's left hand rails, and is perpendicular to the MAIN BOARD. The test points are arranged in a vertical row toward the lower center of the board: See Fig. 13.

5.3 Required Equipment

1. Digital Voltmeter (typically 4-1/2 digit, 0.1% accurate) capable of measuring voltage across resistor that is floating "off ground". In addition, the meter must be able to measure 35 V with resolution of 100 mV, 15 V with a resolution of 100 mV, and 1 V with a resolution of 100 µV.

2. A dual-channel frequency counter/timer capable of measuring from event A to event B (t_B - t_A ≥ 20 s).

3. One 10 kΩ 0.1% accurate resistor (supplied with unit).

4. One 1Ω 0.1% accurate, 1 watt resistor (supplied).

5.4 Preliminary Steps

1. Observing the unit from the rear, verify that the selected line voltage corresponds to that actually available. The selected line voltage is a function of the number showing though the plastic window adjacent to the power connection at the rear of the unit.

2. Remove the top cover (secured by four screws, two on each side).

3. Plug the line cord into a suitable source of AC power.

4. Set the CELL pushbutton to the OFF (released), position.

5. Plug the cell cable into the mating front-panel connector.

6. At the other end of the cable, connect the pin jack (white lead) to the alligator clip at the end of the green lead. The black lead and the red lead are not used. However, take care that they do not short to each other, or to any other circuit element.

7. Set the front-panel controls as follow.
   $E_{INITIAL}$: IN
   INITIAL POTENTIAL: +0.000
   MODE: CONTROL E
   CELL PUSHBUTTON: OFF (released)
   METER: E ±5 V f.s.
   CURRENT RANGE: 100 µA
   AC POWER: ON
   IR COMPENSATION: OFF

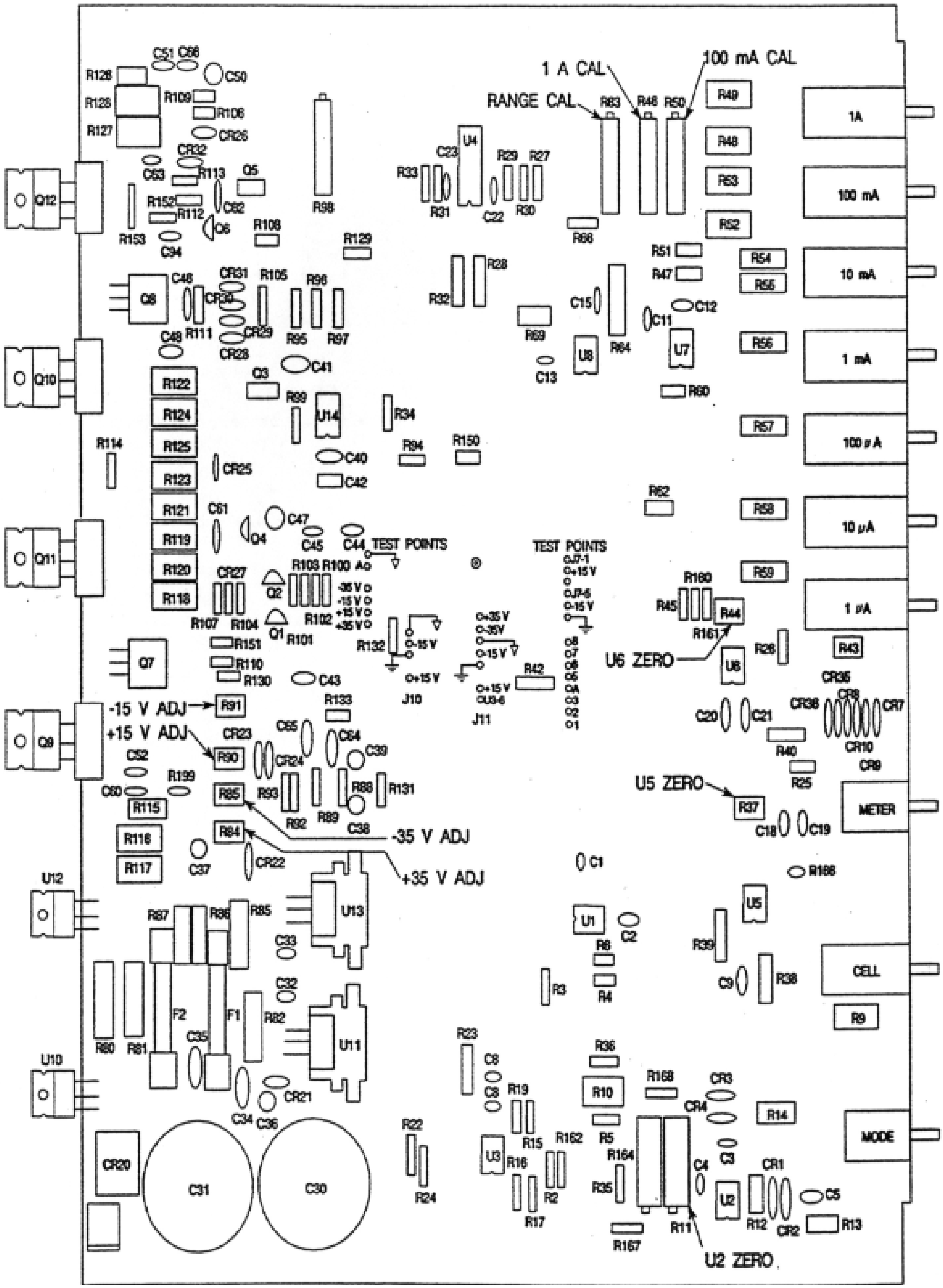


Fig. 11. Location and Adjustment of Main Board Test Points.

5.5 Power Supply Adjustments

1. Locate the power supply monitor test points on the Main Board (Fig. 11).

2. Connect the voltmeter to the +35 V test point. The meter input "low" can be connected to the right-most (ground) test point in this row.

3. Adjust R84 (+35 V ADJUST) for a meter indication of +35.5 V. **NOTE**: This is not an error. The control is adjusted for an indication of +35.5 V.

4. Transfer the voltmeter to the +15 V test point. Note the meter indication. If the reading is between + 14.8 V and + 15.2 V, go to the next step. If the reading is out of this range, adjust R90 (+15 V ADJUST) for a meter indication of +15.0 V.

5. Transfer the voltmeter to the -35 V test point.

6. Adjust R85 (-35 V ADJUST) for a meter indication of -35.5 V.

7. Transfer the voltmeter to the -15 V test point. Note the meter indication. If the reading is between -14.8 V and -15.2 V, go on to Section 5.5. If the reading is out of this range, adjust R91 (-15 V ADJUST) for a meter indication of -15.0 V.

5.6 Zero Adjustments

1. Transfer the voltmeter to TP8 on the Main Board.

2. Adjust R44 (U6, U7, U8 ZERO) for a meter indication of 0.000 V.

3. Transfer the voltmeter to TP5.

4. Adjust R37 (U5 ZERO) for a meter indication of 0.000 V.

5. Transfer the voltmeter to TP2.

6. Adjust R11 (U2 ZERO) for a meter indication of 0.000 V.

5.7 Range CAL

1. Connect the cell cable to the 10 kΩ 0.1% resistor as shown in Fig. 12.

2. Connect the voltmeter across the 10 kΩ 0.1% resistor as shown in Fig.12.

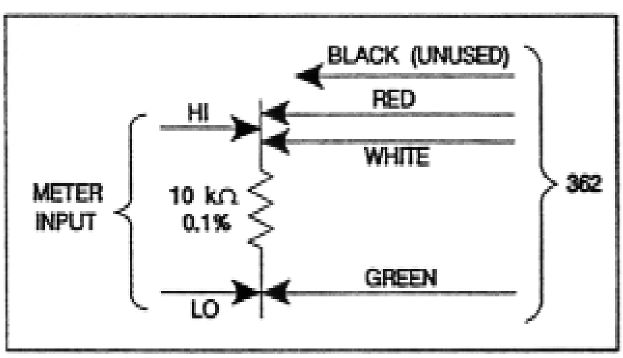


Fig. 12. Range Calibration Connections.

3. Set the INITIAL POTENTIAL control to +1.000.

4. Set the CELL pushbutton to the ON (depressed) position.

5. Adjust R90 (+15 V ADJUST) for a meter indication of -1 V ±100 µV.

6. Set the Initial Potential control to -1.000.

7. Adjust R91 (-15 V ADJUST) for a meter indication of +1 V ±100 µV.

8. Select the 100 µA current range.

9. Connect the voltmeter to the CURRENT MONITOR output.

10. Adjust R63 (RANGE CAL) for a meter indication of +1 V ±100 µv.

11. Release the CELL pushbutton (set it to OFF).

5.8 100 mA and 1 A Range Adjustments

1. Replace the 10 kΩ resistor with the one ohm resistor (0.1%,1 watt). As before, the green lead is connected to one end and both the red lead and the white lead are connected to the other end. Connect the voltmeter across this resistor.

2. Select the 100 mA current range and set the Initial Potential control to -0.100. Then set the CELL pushbutton to ON.

3. Note and RECORD the meter indication.

4. Transfer the voltmeter to the CURRENT MONITOR Output. Then adjust R50 (I00 mA CAL) for a voltmeter indication exactly ten times that recorded in step 3.

5. Select the 1 A current range and set the Initial Potential control to -1.000.

6. Connect the voltmeter across the 1 Ω dummy cell resistor (BE CAREFUL! THE RESISTOR WILL BE HOT.) Note and RECORD the meter indication.

7. Transfer the voltmeter to the CURRENT MONITOR Output and adjust R46 (1 A CAL) for a meter indication exactly equal to that recorded in step 6.

8. Set the CELL pushbutton to OFF.

5.9 Scan Rate Adjustment

1. Set the front-panel controls as follows:
   CELL: OFF
   $E_{INITIAL}$ (released)
   INITIAL POTENTIAL: + 1.000
   FINAL POTENTIAL: -1.000
   MODE: CONTROL I
   LINEAR SCAN (released)
   HOLD (released)
   MULTIPLE (in)
   LINEAR SCAN (in)
   SCAN RATE: 100 mV/SEC
   CURRENT RANGE: 100 µA
   IR COMPENSATION: OFF

2. Connect a 10 kΩ resistor (supplied with the unit) to the CELL cable as shown in Fig. 13 (Connection to the voltmeter input as shown in the figure is not necessary for this adjustment.)

3. Locate the SCAN CONTROL BOARD (mounted on the left-hand rails of the instrument). Toward the lower center of the board, locate the row of SCAN CONTROL test points (see Fig. 13). Connect a dual-channel timer capable of measuring intervals in excess of 20 s to TP10 (Channel A) and TP7 (Channel B). Set the timer's controls to measure an interval of approximately 20 s, triggered on a positive-going voltage transition. Turn the timer on.

4. Locate the SCAN RATE BOARD, mounted directly behind the front-panel SCAN RATE SWITCH. Locate R4004 at the center of this board. Step (5) requires that this potentiometer be adjusted.

5. Turn the instrument ON, switch the CELL ON and Press RUN. The panel meter's needle will move gradually in the negative direction until it indicates -1.0 (on the CURRENT range). Then it will reverse, triggering the timer. The timer will continue timing until the panel meter indicates +1.0 and the scan reverses again. Adjust R4004 on the SCAN RATE board and repeat this step as necessary to make the timed interval equal to 20 s ±20 ms.

6. Change the INITIAL POTENTIAL to -1.000 and the FINAL POTENTIAL TO + 1.000. Set the timer to trigger on negative- going voltage transitions. The scan time should be 20 s ±20 ms in spite of these changes. It may be necessary to adjust R4004 slightly to make the interval measured in this step equal to the interval measured in Step (5). If this is the case, repeat this step and Step (5) as necessary to make the intervals equal.

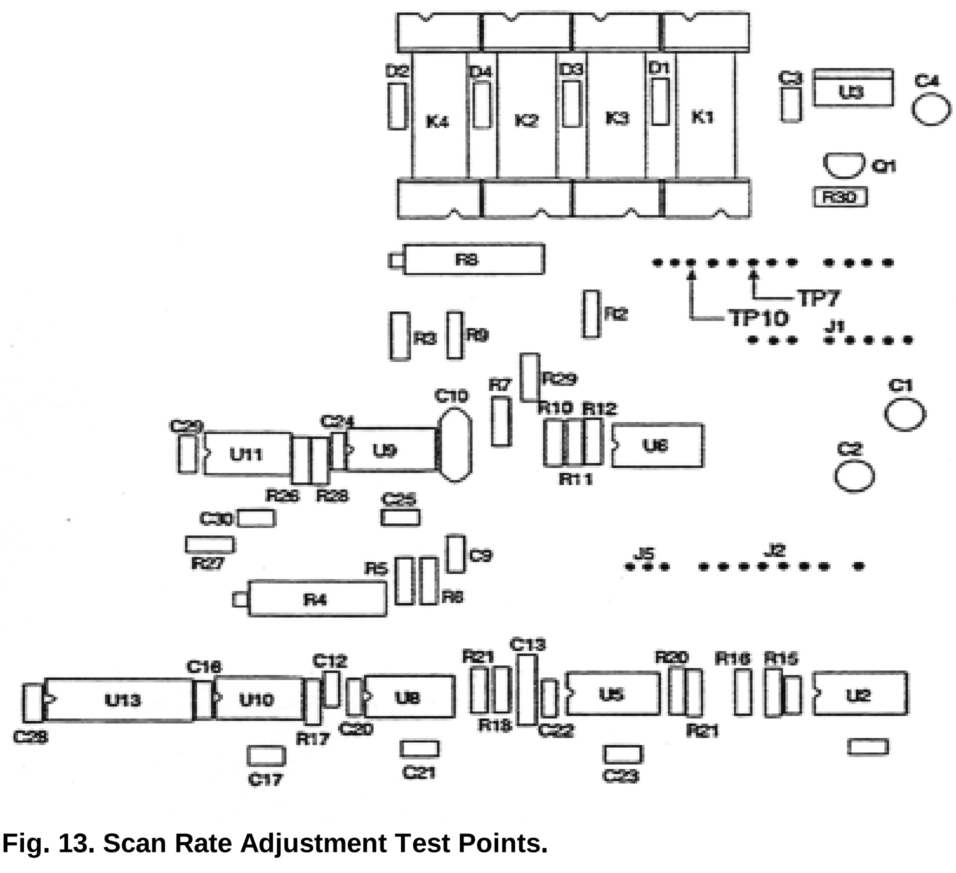


Fig. 13. Scan Rate Adjustment Test Points.

5.10 Linear Scan Adjustment

1. Set the instrument's controls as follows:
   CELL: OFF
   $E_{INITIAL}$ (released)
   INITIAL POTENTIAL: +1.000
   FINAL POTENTIAL: -2.000
   MODE: CONTROL I
   CONSTANT I (in)
   HOLD released
   MULTIPLE (in)
   LINEAR SCAN (in)
   SCAN RATE: 100 mV/SEC
   CURRENT RANGE. 100 µA
   IR COMPENSATION: OFF

2. Connect a voltmeter to the front-panel POTENTIAL MONITOR binding posts. Switch the cell on. Press RUN. The voltmeter should indicate 1.00 V ± 100 µV. Adjust R8 on the SCAN CONTROL board to achieve this reading.

6. TROUBLESHOOTING

6.1 Introduction

WARNING:	Potentially lethal voltages are present inside this apparatus. These service instructions are for use by qualified personnel only. To avoid electric shock, do not perform any servicing unless yon are qualified to do so.

Any adjustment, maintenance, or repair of the opened apparatus under voltage shall be avoided as far as possible and, if unavoidable, shall be carried out only by a skilled person who is aware of the hazard involved. When the apparatus is connected to a power source, terminals may be live, and the opening of covers or removal of parts is likely to expose live parts. The apparatus shall be disconnected from all voltage sources before it is opened for any adjustment, maintenance, or repair. Note that capacitors inside the apparatus may still be charged even if the apparatus has been disconnected from all voltage sources. Service personnel are thus advised to wait several minutes after unplugging the instrument before assuming that all capacitors are discharged. If any fuses are replaced, be sure to replace them with fuses of the same current and voltage rating and of the same type. The use of makeshift fuses and the short-circuiting of fuse holders are prohibited.

This section of the manual contains two kinds of discussions. First is an explanation, keyed to the schematics, of each circuit. This material should prove of value to service personnel by giving them the necessary background for troubleshooting the instrument. Second is a simple rote procedure useful for identifying a malfunctioning circuit. Although users might not necessarily have ready access to replacement parts, once the malfunctioning circuit has been identified, communications with factory service personnel should result in the required component being obtained as expeditiously as possible. In the case of units still in warranty, uses are advised not to attempt to repair the instrument unless specifically authorized to do so by factory personnel The reason for this recommendation is that any damage incurred as a result of unauthorized repairs may not be covered by the warranty.

6.2 Circuit Descriptions

6.2.1 Power Supply

AC power meters the instrument via the line cord. Following the line fuse, power switch and the line-voltage circuitry, the applied voltage is stepped down by the power transformer. The secondary of the transformer connects to a diode bridge (CR20) that provides the unregulated DC levels, both of which are fused. The positive unregulated DC level is applied to regulator U10 to develop the +35 V regulated DC required by the power amplifier. The +35 V level is also applied to a second regulator, U11, to develop the regulated +15 V distributed throughout the instrument. Similarly, U12 and U13 are used to develop the -35 V and -15 V regulated supply levels.

6.2.2 Control Amplifier

The Model 362 employs a wide-band, high-gain, hybrid control amplifier. Referring to the schematic, note that the input signal path is split. Both DC and AC components are applied directly to the input of integrated circuit U14. The AC components above nominally 160 Hz are routed through the high- pass network consisting of C42 and R99 to the base of transistor Q2. The network consisting of R94 and C40 rolls off the gain of U14, with a typical DC voltage gain of 10^5, providing most of the control amplifier's gain. The circuits that follow provide an additional voltage gain of about X15 (the ratio of R108 to the parallel combination of R101 and either R102 or R103, depending on whether the gain is computed with respect to the base of QI or Q2).

The various frequency compensation networks, including the feedback network consisting of C48, C49, and R129, provide a smooth frequency roll off with the gain-of-one point being crossed at 6 dB per octave, necessary for amplifier and system stability.

The output of U14 (DC and low frequency AC) is routed through low-pass network R100-C43 to the base of Q1. The R100-C43 network serves to drop U14's gain out of the picture altogether at higher frequencies. Note that the signal component due to the signal at the base of Q1 is not inverted, while that due to the signal at the base of Q2 is inverted. The net effect is to compensate for the inversion provided by U14, bringing the two components back into phase at the collector of Q2. This current signal is directed directly into the low-impedance emitter follower circuit of Q3 and is then developed across R108 in the collector circuit. Transistor Q5 simply functions as a current sink, allowing the collector of Q3 to swing over a range of nominally ±30 V at full current. Q3 drives emitter follower Q4, with Q6 serving as a current sink. Q4 in turn drives complementary emitter followers Q7 and Q8. These transistors in turn drive the output stage emitter followers Q9, Q10, Q11, and Ql2. Diodes CR28, CR29, CR30 and CR31 supply the necessary voltage drop to keep these transistors correctly biased. The quiescent current through the power stage is approximately 150 mA. Note that a number of 5.6 Ω resistors are used to provide some isolation between the output of the amplifier and its load (electrochemical cell). The high capacitance exhibited by many electrochemical electrodes make this isolation necessary for system stability.

6.2.3 Other Circuits on the Main Board

The remaining circuits on the Main Board, together with the details of the inter-circuit switching are depicted in its schematic diagrams. In addition to the schematics, readers may find it helpful to refer to the instrument's block diagram included in Chapter 7 and to Figs. 3 and 4 Chapter 2. A discussion of each integrated circuit follows.

1. U5: This gain-of-one, non-inverting amplifier has the working electrode potentials as its input. It buffers this potential and supplies it to both U3, the POTENTIAL MONITOR DRIVER, and to U1, which drives the CONTROL AMPLIFIER. U5 corrects for the working electrode's not being at ground.

2. U1: This IC amplifier is connected as a gain-of-one inverting amplifier. The gain is determined by the ration of R3 to R4. The output of this amplifier drives the input of the CONTROL AMPLIFIER through R5 to correctly phase working electrode signals applied to the CONTROL AMPLIFIER.

3. U2: This non-inverting gain-of-one amplifier serves as the electrometer. In both CONTROL I and CONTROL E operation, the reference electrode is connected to the input of this stage. In CONTROL E operation, U2 drives both U3 and the CONTROL AMPLIFIER, in addition to driving the shield of the electrometer via the R14. In CONTROL I operation, it drives U3 and the cable shield only.

4. U3: This stage provides the POTENTIAL MONITOR output. In both CONTROL E and CONTROL I operation, both inputs are active, with the output of U2 applied to the non-inverting input in both cases. The second input is the working electrode potential from the output of U5. U3 has a gain of one with respect to both signals. Since one of these signals is inverted, the actual POTENTIAL MONITOR output is equal to the reference electrode potential minus the working electrode potential. If the working electrode potential weren't subtracted in this way, the POTENTIAL MONITOR output would simply be the reference electrode potential with respect to ground.

5. U4: This integrated circuit contains four voltage comparators configured to detect overloads. Referring to the schematic note the "left" comparators detect current overload (other than 1 A overload), and that the "right" comparators detect overvoltage and I A current overloads. The input to the current overload is taken from the output of U88, the CURRENT MONITOR DRIVER. Should the CURRENT MONITOR output exceed ±2 V, current will be supplied to the CURRENT OVERLOAD indicator lamp, resulting in a visible indication of the overload.

The input to the voltage overload detectors is taken from the output of U14, the input stage of the CONTROL AMPLIFIER. As long as the system is under feedback control, the signal level at the output of this stage will be small. If the system goes out of control, because either the output voltage exceeds its limits or the current exceeds 1 A, a net large input to U14 will develop, causing voltages on the order of ±13 V to appear at its output. Divider R34-R31 reduce this voltage by a factor of four. Thus, the voltage swing at the output of U14 must exceed ±8 V for the 2 V overload threshold level to be exceeded. When the threshold is crossed, one comparator or the other will supply current to the CONTROL AMPLIFIER indicator lamp.

6. U6: This gain-of-one, non-inverting buffer monitors the voltage at current rang resistors and drives U7.

7. U:7 This amplifier measures the voltage drop across the selected range resistor. The arrangement used allows the resistor drop to be determined directly, that is, free of errors due to drops across the cable resistance. The voltage at that end of the range resistor which returns to the working electrode is applied through U6 to the non-inverting input of U7. The ground end of the range resistor is applied directly to the inverting input of U7. The output of U7 is the difference. Voltage, that is the drop as measured directly across the selected range resistor. Since the drop across the range resistor varies with the cell current, the output of U7 is an accurate analog of the cell current and can be used to provide a measure of the cell current. In effect, U7 provides a four-terminal measurement. U7 drives U8, the CURRENT MONITOR output amplifier.

8. U8: This inverting gain-of two amplifier provides the CURRENT MONITOR output in both CONTROL E and CONTROL I operation.

6.2.4 The Scan Rate Circuit

The signal output of the SCAN RATE board, a DC level, is the signal input to the SCAN CONTROL board. In the linear scan modes, this output is integrated, thereby generating a linear ramp, and applied to the input to the control amplifier. In the CONSTANT I, CONTROL I mode this output is applied to control amplifier as a buffered DC level.

Two controls determine the instrument's scan rate. The first, the front panel -SCAN RATE switch, is a dual, 12-position rotary switch. Section S1-A provides the switch's 1-2-5 sequence. Note that all the positions corresponding to multiples of 1, 2, and 5 respectively are hard-wired together (.1, 1, 10, and 100 are all connected to R1, etc). Although this switch has twelve positions, it connects one of only three resistors, R1, R2, or R3, between + 15 V and the inverting input of U1. Resistors R5 and R4 (a fine adjustment) provide a feedback path of nominally 2 k from the output of U1 to this input. The magnitude of the output required from U1 for loop control is -0.4 V for switch positions that are multiples of 1, -0.8 V for multiples of 2, and - 2.0 for multiples of 5.

U2 determines the polarity of the output of the SCAN RATE board, depending upon the state of relay K1. The output of U1 is fed into U2, a unity-gain buffer. When relay K1 is open, U2 is a non-inverting buffer. When K1 closes, the inverting input becomes a virtual ground, and U2's output is a voltage equal in magnitude and opposite in polarity to the level presented through R6 to its inverting input. The output of U2 can be monitored on TP2.

Relay K1 is driven by the SCAN REV signal generated by the logic the SCAN CONTROL circuit The signal, which enters the SCAN RATE board through J1-1, drives the base of Q1 through R18. When SCAN REV goes high (approximately +15 V), it turns on Q1, which saturates, providing a current path to ground through the coil of the relay. The resulting magnetic field closes K1 and grounds the non-inverting input of U2, configuring U2 as unity-gain, inverting buffer. When SCAN REV goes low, Q1 turns off, the magnetic field in K1 collapses (D1 and C3 protect Q1 from the resulting inductive kick), and the relay contacts open.

Except for the .1, .2 and .5 SCAN RATE switch settings, for each decade of 1-2-5 positions, the second section of the SCAN RATE switch, S-1B, connects the output of U2 to a set of two resistors, whose resistance is in a 10:1 ratio. Only one of these resistors is in circuit at a time, depending upon the position of the internal SCAN RATE MULTIPLIER switch, the second control that determines the scan rate. When the SCAN RATE MULTIPLIER switch is in its X1 position (and the scan rate is nominally equal to the front-panel setting) the switch selects a resistor that is ten times larger than the resistor it selects when it is in the X10 position.

For the .1, .2, and .5 positions, when the SCAN RATE MULTIPLIER switch is in the X1 position, the output of U2 is divided by a voltage divider consisting of R9 and R10 before being channeled to R11. When the SCAN RATE MULTIPLIER switch is in the X10 position, the output of U2 is shunted directly to U11.

The resistor selected by the action of S1-A and the SCAN RATE MULTIPLIER switch converts the voltage output of U2 to a current, which exits the SCAN RATE board on J1-9 and enters the SCAN CONTROL board on J2-9, where it becomes the RAMP I signal. Keep in mind that the direction of this current depends upon the state of K1, which determines whether U2 is an inverting or noninverting buffer.

6.2.5 The Scan Control Circuit

The SCAN CONTROL board, shown on Schematic Drawing 15900-D-SD, consists of an analog INTEGRATOR-AMPLIFIER circuit, an analog COMPARATOR circuit, a digital LOGIC circuit, and a 24 V regulator to power the board's relays. Each of these will be discussed in turn.

The RAMP I signal reaches the SCAN CONTROL board's INTEGRATOR- AMPLIFIER circuit through J2-9 from the SCAN RATE board. While a linear scan is underway, the RAMP I signal is presented through the closed contacts of relay K2 to the inverting input of U9, the INTEGRATOR-AMPLIFIER. One feedback path for U9 during a linear scan is the parallel combination of C5, C6, C7, and C8 through the closed contacts of relay K3. This feedback path configures U9 as an integrator. Since its input is a dc current from the SCAN RATE board, its output is a linear voltage ramp whose slope varies according to the front-panel scan rate setting. The polarity of the ramp depends upon the state of the SCAN REV signal, which operates a relay on the SCAN RATE board. When SCAN REV changes state, the polarity of RAMP I signal reverses, as does the slope of voltage ramp.

The other feedback path for U9 is R3, which, in combination with input resistor R2, configures U9 as a unity-gain inverting amplifier. The input to U9 through this path is E_1, from the MAIN board, inverted through U1, a unity-gain inverting amplifier. E_1 gives the linear scan mode an initial level by charging the integration capacitor to the E_1 level. When RUN is pressed, relay K1 opens and the RAMP I current is integrated and added to or subtracted from this initial level. The output of U9 is connected to the CONTROL AMPLIFIER input (labeled PSTAT on the schematic) through R29.

When CONSTANT I rather than LINEAR SCAN is selected, K3 and K1 open, K4 closes, and the feedback path for U9 becomes the series resistance of R9 and R8, nominally 250 kΩ. As a result, the output is a constant voltage which continues until it is reversed by the SCAN REV signal, interrupted by the HOLD button, or halted as a result of a changing logic level on the base of Q1 on the SCAN RATE board. (R8, a fine adjustment for the CONTROL I, CONSTANT I mode, compensates for R4 on the SCAN RATE board, which tailors the RAMP I current slightly to produce accurate voltage ramps across integration capacitors C5 through C8, whose total capacitance varies somewhat from unit to unit.)

The digital LOGIC circuit and the COMPARATOR circuit work together to translate front-panel control settings into the desired scanning modes. Operational amplifiers U2, U8, and U5 work together as a window comparator. The comparator's threshold voltages are E_b which enters the board on J3-3, and E_F, which enters the board on J4-3. Both voltages are derived from the

front-panel INITIAL POTENTIAL and FINAL POTENTIAL settings. (The inverted E_1, signal not only establishes a threshold voltage for the comparator, but also drives U6, the RAMP OUT buffer, and U9, the INTEGRATOR AMPLIFIER, when the instrument is in a non- scanning mode.)

The analog threshold voltages are converted to digital logic levels in a circuit consisting of U2, U8, U5 and two XOR (exclusive-or) gates from U4. E_1, inverted by U1, is presented to the non-inverting input of U2, one of two level detectors in the COMPARATOR circuit. Similarly, E_F,, inverted by U10, is the input to the inverting input of U5, the other level-detector. Because U2 and U5 are configured for high gain, any V between their inverting and non-inverting inputs, including the V generated by small differences in input currents, drives their outputs to either +15V or -15V, their normal operating levels. The output of U8, in an open-loop configuration, is also normally either + 15 V or -15 V.

These binary outputs are regarded as digital HIGH or LOW logic signals. The logic circuit includes three simple clamping networks (R16 and D5, R21 and D6, and R22 and D7) to convert these bipolar output levels to input levels acceptable to the 4000-series CMOS logic components used in the circuit. These networks allow a HIGH-level comparator output (+15 V) to pass unchanged as a HIGH input, but clamp a LOW-level comparator output (-15 V) to not more than 0.4 V below ground potential.

The COMPARATOR circuit compares its upper and lower threshold levels to a voltage selected through S1. In linear scanning, the voltage is the output of U9, the INTEGRATOR-AMPLIFIER, inverted by U11, a unity-gain inverting buffer. In the CONTROL I, CONSTANT I mode, this signal is the POTENTIAL MONITOR output. When this voltage crosses the threshold established by E_I or E_F the output of either U2 or U5 switches states, causing the XOR gate outputs on both pin 3 and pin 10 of U4 to switch state. The remainder of the logic circuit is largely straightforward and the outputs of individual gates and registers can be determined by tracing logic levels through the circuit for various control settings. It is worth noting that pin 3 of U12 is the output of a debouncing network designed to provide a single clock pulse to pin 3 of U7 each time the REV (REVERSE) button is pressed. U7 is configured as a D-type flip flop as far as output pins 1 and 2 are concerned, and a R-S type flip-flop with respect to the Q output on pin 12.

The function of one of the NAND gates of U12 (input on pins 5 and 6, output on pin 4) requires some elaboration. Its primary role is to compensate for the indeterminate output of U2 at the beginning of a linear scan. In instances where the instrument is in the $E_{INITIAL}$ and LINEAR SCAN modes, there is in theory no V between the inverting and non-inverting inputs of U2. in practice, however, there will be some ΔV between these inputs, and because of U2's high gain, even the slightest V between the inputs will drive the output to either + 15 V or -15 V. In these instances the logic level on the output of U4 can be either a HIGH or a LOW, depending upon the output of U8. Note that when the instrument is in the $E_{INITIAL}$ mode, there is always a logic HIGH on pin 2 of U13, which is pulled up to +15 V through R1. Since this is a two-input OR gate, its output is therefore HIGH, regardless of the state of the other input. This output level resets U7's Q output through the active-high R (asynchronous reset) input on pin 4. As a result, when RUN is pressed, there is at least one LOW input to the NAND gate of U12, and its output will be HIGH even though its other input, on pin 6, is the indeterminate output of U4 pin 3.

U3, a 78H24 three-terminal regulator, runs from a 35 V source that enters the board on J1-8. This regulator provides the instrument's relays with the voltage required to activate their coils. It is worth noting that the return for this supply is separate from the returns for both the logic circuit and analog circuits.

6.3 Circuit Checks

6.3.1 Required Equipment

1. DC voltmeter with an accuracy of 1% and an input resistance of 1 MΩ or higher.

2. Voltage source to supply 6 V ± 10 mV (necessary only for the checks outlined in Section 6.3.5).

3. One 10 kΩ 0.1% resistor.

6.3.2 Power Supply Checks

1. With the power off, check that the line voltage selected corresponds to that actually available. It should be possible to read the selected voltage through the clear plastic window adjacent to the power cord at the rear of the instrument. The operating voltage range corresponding to the number is visible through the window. If the range has to be changed, follow the procedure outlined in Section 1.1.6.

2. Remove the top cover, secured by four screws, two on each side.

3. At the front panel, put the CELL pushbutton in the released (OFF) position and set the Power switch to ON. The switch should glow, indicating that power has been applied. If it does not, it is possible that the line fuse has failed (Section 1.1.6).

4. Refer to Fig. 11 and determine the location of the test points mentioned in the following steps. Note that these are all high-impedance (1 kΩ) points, and that power cannot be drawn from them.

   a. Monitor the voltage at the +35 V test paint. The indicated voltage should be +35.5 V ±0.2 V. If the voltage is missing or incorrect, possibilities include U10, the +35 V regulator, and F1, the fuse that precedes it. It is, of course, possible that there is a short in the circuits served by the +35 V supply, or a short in the circuits served by the +15 V or +24 V supplies. Either possibility could cause the +35 V level to be loaded down.

   b. Similarly check the + 15 V, -35.5 V, and -15 V supply levels. In each case, any problem most likely lies with the associated regulator. Again, there is always the possibility of a fuse failure or of a short in the circuits powered by the regulator in question. Because the 15 V levels are derived from the 35 V supplies, a failure in a 35 V level will cause the 15 V level of the same polarity to fail as well. Less obvious is the possibility of a short in a circuit powered by a 15 V level causing both the 15 V level and the 35 V level to load down.

5. If the regulated supply levels are all within 200 mV of their nominally stated levels, proceed to Section 6.3.3. **NOTE:** Do not "touch up" the supply levels. The effect could be to require complete realignment of the instrument (Chapter 5), particularly in the case of the 15 V supply levels. In calibrating the instrument, the 15 V levels are not set to their nominally stated levels, but rather as necessary for the highest accuracy of the Initial Potential control.

6.3.3 Amplifier Zero Checks

Most of the Model 362 circuits can be checked with the CELL pushbutton in the OFF position, which causes an internal resistor to be connected around the Control Amplifier. In this configuration, all of the circuits are stable, and isolation checks can be readily conducted. The appropriate zero checks follow.

1. SETUP

    a. After making sure that the CELL pushbutton is in the OFF (released) position, connect the Cell cable to the mating connector at the front panel of the Model 362. At the other end of the cable, connect the white lead (pin jack), the green lead, and the black lead together. The red lead is not used. However, take care that it does not short against any other circuit element.

    b. Set the controls as follows.
    MODE: E
    METER: E 5 V f.s.
    CURRENT RANGE: 100 µA
    INITIAL POTENTIAL: +0.000
    IR COMPENSATION: OFF

2. U5

    a. On the circuit board, locate the test-point assembly having the output test points. Each test point in this group connects to the output of a different circuit, as indicated by lettering on the circuit board. For example, the test point identified by the number "5" connects to the output of U5. Test point "A" connects to the output of the Control Amplifier.

    b. Connect the voltmeter to the output of U5. Under the established conditions, the input of U5 is grounded, and the monitored voltage should be 0 V ±1 mV. If the indicated voltage is measured, one can be reasonably sure that U5 is functioning normally.

3. U2: Connect the voltmeter to the output of U2 Under the established conditions, the input of U2 is also grounded, and its output should be 0 V ± 1 mV. If the voltage is as indicated, one can be reasonably sure that U2 is functioning normally.

4. U3: Connect the voltmeter to the output of U3. Since the output of this state equals the output of U2 minus the output of U5, the monitored voltage should be 0 V ±2 mV if U3 is functioning normally.

5. U1: Monitor the output of U1 with the voltmeter. The input of U1 is the output of U5. Assuming that both U1 and U5 could have as much as 1 mV or zero offset, the monitored voltage should be 0 V ±2 mV. If the indicated voltage is measured, U1 is functioning normally.

6. CONTROL AMPLIFIER: Transfer the voltage to TPA. Under the established conditions, the internal feedback resistor around the CONTROL AMPLIFIER will cause it to act as an inverter with a gain of one. There are two inputs to this amplifier in the CONTROL E mode with the Cell pushbutton set to OFF. They are: (i) the output of U1, and, (ii) the output of the INITIAL POTENTIAL Control. With the Initial Potential control set to 0.000, the net input will be zero. U1 could be offset as much as 2 mV. If the CONTROL AMPLIFIER is allowed its own offset of nominally 1 mV, there could be as much as 3 mV offset altogether at its output. If the indicated voltage (0 V ±3 mV) is observed, the Control Amplifier is probably functioning normally.

7. U7: Connect the voltmeter to TP7, the output of U7. The input of U7 is driven by the output of U6. Since U7 can also have 1 mV of offset, the total offset, as measured at TP7, could be as much as 2 mV. If the measured voltage is as indicated, U7 is probably functioning normally.

8. U8: Connect the voltmeter to the output of U8. The observed offset will include contributions form both U7 and U8 (1 mV each). If the measured voltage is 0 V ±2 mV, U8 is probably functioning normally.

9. OVERLOAD DETECTORS: Both front-panel Overload indicator lights should be out. There are two inputs to the circuits that drive these lights, one taken from the Control Amplifier, the other from the output of U8. If both are at 0 V, and they should be under the established conditions, the overload detect thresholds will not be crossed, and both indicators will be out. A lighted overload indicator would probably be due to a failure in U4.

6.3.4 Amplifier Checks under Voltage

Although the zero checks (Section 6.3.2) are generally reliable, malfunctions could exist that would allow 0 V to be measured at the output of a malfunctioning amplifier having a grounded input. Where this is the case, the malfunctioning amplifier can usually be identified by applying a known non-zero voltage to its input, followed by measuring for the correct voltage at its output. In the following procedure, the Initial Potential controls are used as the known source and a precision resistor is used as a "dummy cell."

1. SETUP: Connect the cell cable to the 10 kΩ 0.1% resistor as shown in Fig. 12. As indicated, the white lead and the red lead conned to one end of the resistor, and the green lead connects to the other end. The black lead is not used, although care should be taken to be sure it doesn't short to any other circuit element. The front-panel controls should be set as follows.
   MODE: E
   METER: E 5 V f.s.
   CURRENT RANGE: 100 µA
   INITIAL POTENTIAL: -1.000
   CELL pushbutton: ON (depressed)
   POWER: ON

   The ON/OFF switch should be illuminated, both Overload lights should be out, and the panel meter should indicate nominally -20% of full scale. If the indicated behavior is observed, the system is under control, and the following checks can be made. if the meter indication is incorrect (particularly if off scale) and/or the CONTROL AMPLIFIER Overload indicator lights, the system is out of control and cannot be checked with a dummy cell in this manner. If this is the case, proceed to Section 63D for checks that can be made using an external voltage source. The advantage of those checks is that they can be made with the system uncontrolled (CELL pushbutton to OFF).

2. U2: Connect the voltmeter to TP2, the output of U2. The voltage should be +1.5 V, the same as the voltage at its input. If the voltage is incorrect, check the input to this amplifier (white lead of cell cable). As far as determining whether U2 is working correctly, the important thing is to verify that the voltage at its output is the same as the voltage at its input.

3. U5: Connect the voltmeter to TP5, the output of U5. The voltage should be +0.5 V. If the voltage is incorrect, check the input of this amplifier (green lead of cell cable). As far as determining whether U5 is working correctly is concerned, the important thing is to verify that the voltage at its output is the same as the voltage at its input.

4. U3: Connect the voltmeter to TP3, the output of U3. The voltage should be 1 V. U3 is a differential amplifier, that is, its output should be the output of U2 (1.5 V) minus the output of U5 (0.5 V). The important thing is this step is to verify that the required subtraction is taking place. Verify that this difference potential is also available at the POTENTIAL MONITOR output A potential monitor output of 1 V should cause the panel meter to deflect negative 20% of full scale.

5. U1: Connect the voltmeter to TP1, the output of U1. Since the function of U1 is simply to invert the output of U5, the measured potential should be -0.5 V. The important thing to verify is that U1 inverts and that its gain is one.

6. CONTROL AMPLIFIER: Connect the voltmeter to TPA, the output of the Control Amplifier. Under the conditions established, the measured voltage should be +1.5 V.

7. U6: Connect the voltmeter to TP6, the output of U6. The measured voltage should be +0.5 V. The input to this non-inverting gain-of-one buffer can be measured at the green lead of the cell cable.

8. U7: Connect the voltmeter to TP7, the output of U7. Although U7 is a differential amplifier, it can be considered as acting as a simple non-inverting buffer and its output should be +0.5 V.

9. U8: Connect the voltmeter to TP8, the output of U8. Since U8 is an inverting gain-of-two amplifier, its output will be -1 V if the output of U7, the stage that precedes it, is +O.5 V. Since U8 drives the CURRENT MONITOR output, there should be -1 V at the CURRENT MONITOR output as well.

10. OVERLOAD

    a. Increase the setting of the Initial Potential control to +2000. This should place the current monitoring circuits right at the edge of overload. If the CURRENT OVERLOAD light isn't ON, it will light when the control setting is increased a little more. After verifying this behavior, set the controls to + 1.000.

    b. Disconnect the white lead from the external "dummy cell" resistor. As soon as this is done, the Model 362 will go out of control, causing the CONTROL AMPLIFIER OVERLOAD light to glow. When the white lead is reconnected, the light will extinguish.

    c. If the overload test results indicated were observed, the Overload detect circuits are working normally. If not, the problem most likely lies with U4.

The steps to this point check all of the active circuits, not with respect to their meeting specifications, but with respect to establishing that they are behaving normally. If normal indications have been obtained to this point, it is reasonable to assume that the Model 362 will function properly when connected to actual cell. If it does not, the problem is beyond the scope.

6.3.5 Checks with External Voltage Source

1. SETUP: Release the CELL pushbutton (put it in the OFF position). The white lead and the green lead should be connected to one end of the external resistor, and the red lead to the other end. Set the Initial Potential control to +0.000.

2. Connect the external voltage source, set to provide -6 V, to the same end of the external resistor as that to which the white cable lead is connected (see Fig. 12).

3. U2: Connect the voltmeter to TP2, the output of U2. The measured voltage will be -6 V if U2 is working normally. U2 is a non-inverting gain-of-one buffer and its input is the -6 V from the external source. Note all readings are very approximate. For this reason all values here are rounded to the nearest volt.

4. U5: Connect the voltmeter to TP5, the output of U5. The measured voltage will be -1 V, the same as its input (can be checked at the green cable lead).

5. U3:Connect the voltmeter to TP3, the output of U3. The measured voltage will be -5 V. U3 is a differential amplifier that subtracts the output of U5 from that of U2. If the required difference potential is measured, the user can be reasonably sure that U3 is functioning normally.

6. U1: Connect the voltmeter to TP1, the output of U1. U1 is a gain-of-one inverter and, with -1 V applied to its input, its output should be at +1 V.

7. CONTROL AMPLIFIER: Transfer the voltmeter to TPA, the output of the Control Amplifier. Under the established conditions, there will be two inputs to this amplifier. They are +1 V

from the output of U1, and 0 V from the Initial Potential control. The path from the output of U2 to the Control Amplifier is opened by contacts of the CELL pushbutton switch when it is in the OFF position. The net effect is that the Control Amplifier behaves as a simple unit gain buffer. Its output voltage as measured at TPA is -1 V.

8. U6: Connect the voltmeter to TP7, the output of U7. Under the test conditions, the input of this amplifier should be at -1 V, and the same voltage should be measured at the output of this amplifier.

9. U8: Connect the voltmeter to TP8, the output of U8. With -1 V applied to its input, the output of this amplifier (gain of five) should be -5 V.

This completes the checks of the individual amplifiers. If the indicated behavior was observed, the Model 362 should have been able to pass the checks in Section 6.3D. If, for some reason, it could not, the problem is beyond the scope of this manual and users should contact the factory (or the factory authorized representative in their area) for advice.

6.3.6 Scan Rate Board Checks

1. Locate the row of test points toward the top center of the SCAN RATE board. These test points are on the component side of the board and begin with TP1, which is positioned toward the front panel of the instrument.

2. Connect the cell cable to the 10 kΩ resistor as shown in Fig. 12. As is indicated in the figure, the white lead and the red lead connected to one end of the resistor, and the green lead connects to the other end. The black lead isn't used, although care should be taken to assure that it doesn't short to any other circuit element. The front panel controls should be set as follows:
   AC: OFF
   CELL: OFF
   INITIAL POTENTIAL: +5.000
   FINAL POTENTIAL: -5.000
   METER: E (in)
   CONTROL E (released)
   LINEAR SCAN (released) MULTIPLE (in)
   SCAN RATE : .1 MV/SEC
   SCAN RATE MULTIPLIER SWITCH (internal): X1
   IR COMPENSATION: OFF

3. Connect the ground or common lead of the voltmeter to ground (TP4 or TP7), or any of the three black binding posts on the front-panel of the instrument. Turn the AC on. Check the power supply voltages on the following test points:
   TP3 +15 V
   TP5 -15 V
   TP6 +24 V

4. Check the voltage on TP1. It should be -0.4 V. Switch the SCAN RATE control to .2mV/SEC. The voltage on TP1 should change to -0.8. Switch the SCAN RATE to .5 mV/SEC. The voltage on TP1 should change of -2.0V. If these voltages are correct, it is safe to assume that U1 is working correctly. Sweep the SCAN RATE switch from .1 mV/SEC to 500 mV/SEC. At each setting that is a multiple of 1, the voltage on TP1 should be -0.4 V. For each setting that is a multiple of 2, the voltage on TP1 should be -0.8 V. For each setting that is a multiple of 5, the voltage on TP1 should be -2.0 V. If these voltages are correct, switch S1- A is working correctly.

5. Connect the voltmeter to TP2. Press RUN in. The magnitude of the voltage on TP2 should be the same as magnitude as one of the voltages measured in the previous step. The polarity may differ. Press RUN in. Press REVERSE in. The polarity of the voltage on TP2 should change, but the magnitude should remain the same. Press REVERSE is again. The

original polarity should return but the magnitude should remain the same. If the instrument passes these checks, jump to Section 6.3.7.

If the instrument fails these checks, there may be a problem with Q1, K1 or U2. First check the voltage on the node joining R18 and J1-1. This point is connected to the output of a CMOS digital logic gate whose HIGH state is approximately +15 V and whose LOW state is near ground potential. The voltage at this point at any time should be one of these digital states. Press REVERSE. The voltage level at this node should switch states. Press REVERSE again. The original level should return. If the instrument passes these checks, the SCAN REV signal from the SCAN CONTROL board is in order, and the problem lies with the SCAN RATE board.

Connect the voltmeter to the collector of Q1. The voltage measured there should be either approximately 24 V or ground. Press REVERSE. The voltage on the collector should switch from ground potential or to +24 V or from +24 V to ground. Press REVERSE again. The voltage on the collector should return to the original level. If the instrument passes this test, transistor Q1 is working properly.

Connect the voltmeter to pin 3 of U2. Switch the SCAN RATE switch to a scan rate that is a multiple of 2. The voltage at pin 3 should be at either ground potential or 2 V. Press REVERSE. The voltage should switch from ground to 2 V or from 2 V to ground. Press REVERSE again. The voltage should return to its original value. If the instrument passes the checks, it is likely that relay K1 is working and that the problem lies with U2.

6.3.7 Scan Control Board Checks

1. Locate the row of test points positioned in lower center of the component side of the SCAN CONTROL board. These test points are arranged is ascending order with TP1 positioned at the bottom of the row.

2. Connect the cell cable to the 10 kΩ resistor as shown in Fig. 12. As is indicated in the figure, the white lead and the red lead connect to one end of the resistor, and the green lead connects to the other end. The black lead isn't used, although care should be taken to assure that it doesn't short to any other circuit element. The front panel controls should be set as follows:
   AC: OFF
   CELL: OFF
   INITIAL POTENTIAL: +5.000
   FINAL POTENTIAL: -5.000
   METER: E (in)
   CONTROL E (released)
   LINEAR SCAN (released)
   MULTIPLE (in)
   SCAN RATE: .1 mV/SEC
   SCAN RATE MULTIPLIER SWITCH (internal): X1
   IR COMPENSATION: OFF

3. Connect the ground or common lead of the voltmeter to ground on TP3 or on any of the three black binding posts on the front-panel of the instrument. Turn the AC on. Check the power supply voltages on the following test points:
   TP2 +15 V
   TP4 -15 V
   TP1 +24 V

   The + 15 V and -15 V lines come from the main board and enter the instrument on J1. The +24 V supply is generated on the SCAN CONTROL board itself through the circuit associated with U3, a 24-volt, positive three-terminal regulator. If this supply is low, first check to make sure that U3 is receiving +35 V on J11-8 from the main board. If it is, it may be necessary to isolate U3's output from the rest of the circuit, provide it with a resistive load of approximately 100 Ω, and then check its output voltage. If it is able to regulate under these conditions, look for a defective relay downstream from the regulator.

If the output of U3 is significantly greater than +24 V, U3 is probably defective. Remove it and then check TP1 again to make sure that the +35 V supply is not somehow shorted to the +24 V line.

4. Release the $E_{INITIAL}$ switch. The voltage on TP5 should be -5 V, which is equal to the INITIAL POTENTIAL setting is magnitude, but opposite in polarity. If the voltage on TP5 is not -5 V, there may be a problem with U1. With the AC switch OFF, remove U1. Turn the AC switch back on, and check the voltage at pin 2 of U1's socket. If it is not +5 V, the E_I signal is not reaching the board. If it is +5 V, there is a high probability that U1 is defective.

5. The voltage on TP8 should be +5 V, which is equal to the E_F setting in magnitude, but opposite in polarity. If it is not, check U10 using the technique outlined in Step (4).

6. The voltage on TP9 should be approximately ground potential. If it is not, confirm that there is +5 V on pin 2 of U8 and - 5 V on pin 3. If these voltages are present, and the voltage at TP9 is not a ground potential, U8 is probably defective. Change the polarities of the INITIAL and FINAL POTENTIAL settings. The voltage on TP9 should be + 15 V. If it is not, confirm that there is -5 V on pin 2 of U8 and +5 V on pin 3. If these input levels are present and the voltage on TP9 is not + 15 V, U8 is probably defective.

7. Set the instrument's controls as follows:
AC: OFF
CELL: OFF
INITIAL POTENTIAL: + 1.000
FINAL POTENTIAL: -1.000
$E_{INITIAL}$ (released)
CONTROL E (released)
LINEAR SCAN (released)
STOP AT E_I (in)
METER: I (in)
SINGLE (released)
SCAN RATE: 500mV/SEC
CURRENT RANGE: 100 µA
SCAN RATE MULTIPLIER SWITCH (internal): X1
IR COMPENSATION: OFF

This check and several to follow assume that the test points are being monitored with a voltmeter that responds to DC levels, but may not indicate the algebraic addition of DC levels and fast, narrow pulses of the opposite polarity. If you are monitoring the test points with an oscilloscope, you may see narrow pulses not mentioned in the discussions that follow. These pulses are most likely to occur when the outputs of comparators U2, U8, and U5 change state.

Move the voltmeter to TP7. Turn the AC switch ON and switch the CELL ON. The voltage on TP7 should be either ground potential or + 15. Press RUN. The voltage on TP7 should be at ground potential during the scan (the front panel meter indication will swing smoothly from +1 to -1 to +1 again on the CURRENT range) then increase abruptly to +15 V when the scan is completed. If the voltage on TP7 doesn't change as outlined here, make a gross check of pin 2 of U2 to make sure that there is a changing voltage there while the instrument is scanning. If there is a changing voltage on this input, but no change on the output, U2 may be defective.

8. Release $E_{INITIAL}$. Change the polarity of the INITIAL and FINAL POTENTIAL settings. Press RUN. As the instrument scans, the voltage on TP7 should be +15 V. When it completes the scan, the voltage should go to ground potential. If this is not the case, follow the suggestions in Step (7).

9. Return to the control settings listed in Step (6). Move the voltmeter to measure the voltage on TP10. Press STOP AT $E_{F.}$ Press RUN. The voltage should be at ground potential at the beginning of the scan and switch to +15 V when the scan is completed. Release $E_{INITIAL}$. The voltage of TP10 should change to ground potential. Change the polarity of the INITIAL and FINAL POTENTIAL settings . The voltage should change to + 15 V. Press RUN. The voltage on TP10 should remain at +15 V during the scan and then return to ground potential when the scan is completed. If the instrument doesn't pass these tests, apply the techniques described in Step (7) to U10.

10. Set the instrument's controls as follows:
    AC: OFF
    CELL: OFF
    INITIAL POTENTIAL: + 1.000
    FINAL POTENTIAL: -1.000
    $E_{INITIAL}$ (released)
    CONTROL E (released)
    LINEAR SCAN (released)
    METER: I (in)
    MULTIPLE (in)
    SCAN RATE: 500 mV/SEC
    CURRENT RANGE: 100 µA
    SCAN RATE MULTIPLIER SWITCH (internal): X1
    IR COMPENSATION: OFF

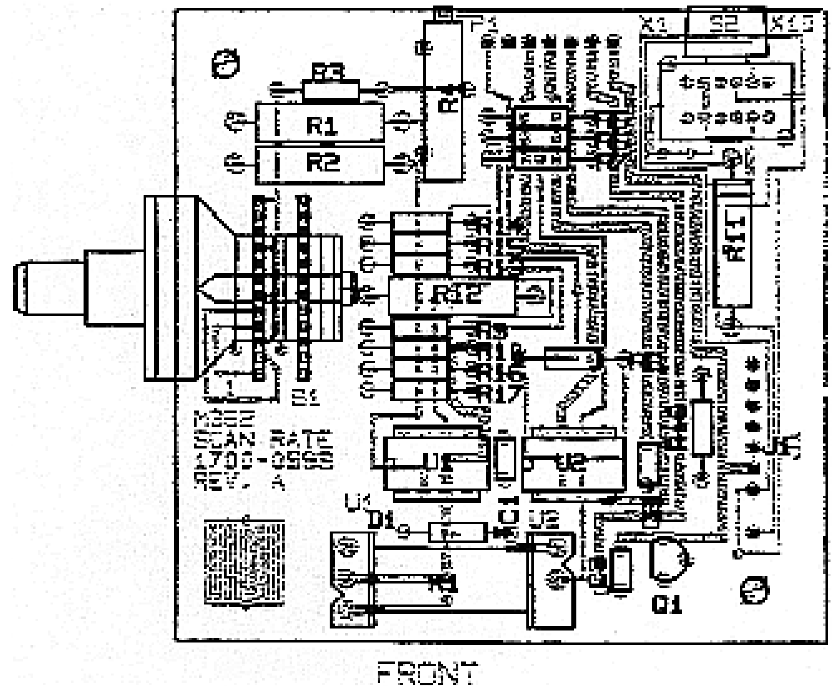
    Connect the voltmeter to TP12. Turn the AC switch on. The voltmeter should indicate 1V Change the INITIAL. POTENTIAL setting to +9.000 in steps of 1.000. The voltage measured on TP12 should track these changes. If it does not, U9 or K1 may be defective. Return the INITIAL POTENTIAL +1.000.

11. Switch the CELL ON and Press RUN. The voltage indicated by the meter should swing smoothly back and forth between +1 V and -1V. The magnitude and polarity of this voltage should be reflected in the indication on the panel meter's CURRENT scale. (Lower the SCAN RATE setting if necessary to see this.) If the instrument doesn't exhibit this behavior, there may be a problem with the digital circuitry that generates the SCAN REV signal, which is output on pin 4 of U4.

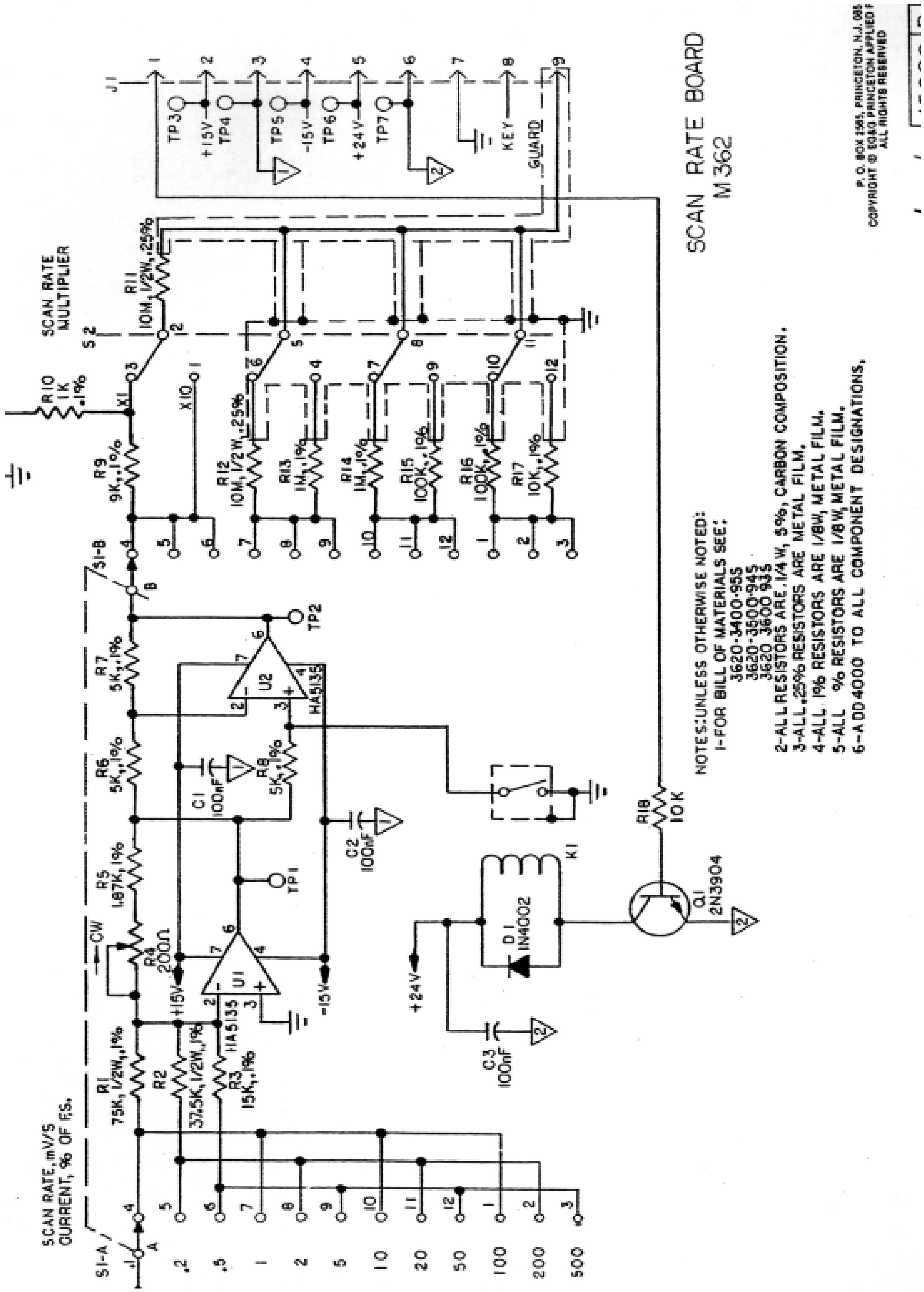
12. Press HOLD. Both the voltmeter and the panel meter (CURRENT range) should indicate the same steady DC level. If they do not, there may be a problem with K2 or excessive current leakage to or from the integrating capacitors C5 through C8.

13. Release $E_{INITIAL}$. Press STOP AT E_F and release SINGLE. Move the voltmeter to TP11. The voltmeter should indicate ground potential. Press RUN. The voltmeter reading should increase and then stop at approximately 2.0 V. At the same time the front-panel meter should indicate -1.0 on the CURRENT range. If the instrument fails this test, there may be a problem with U6 or related components.

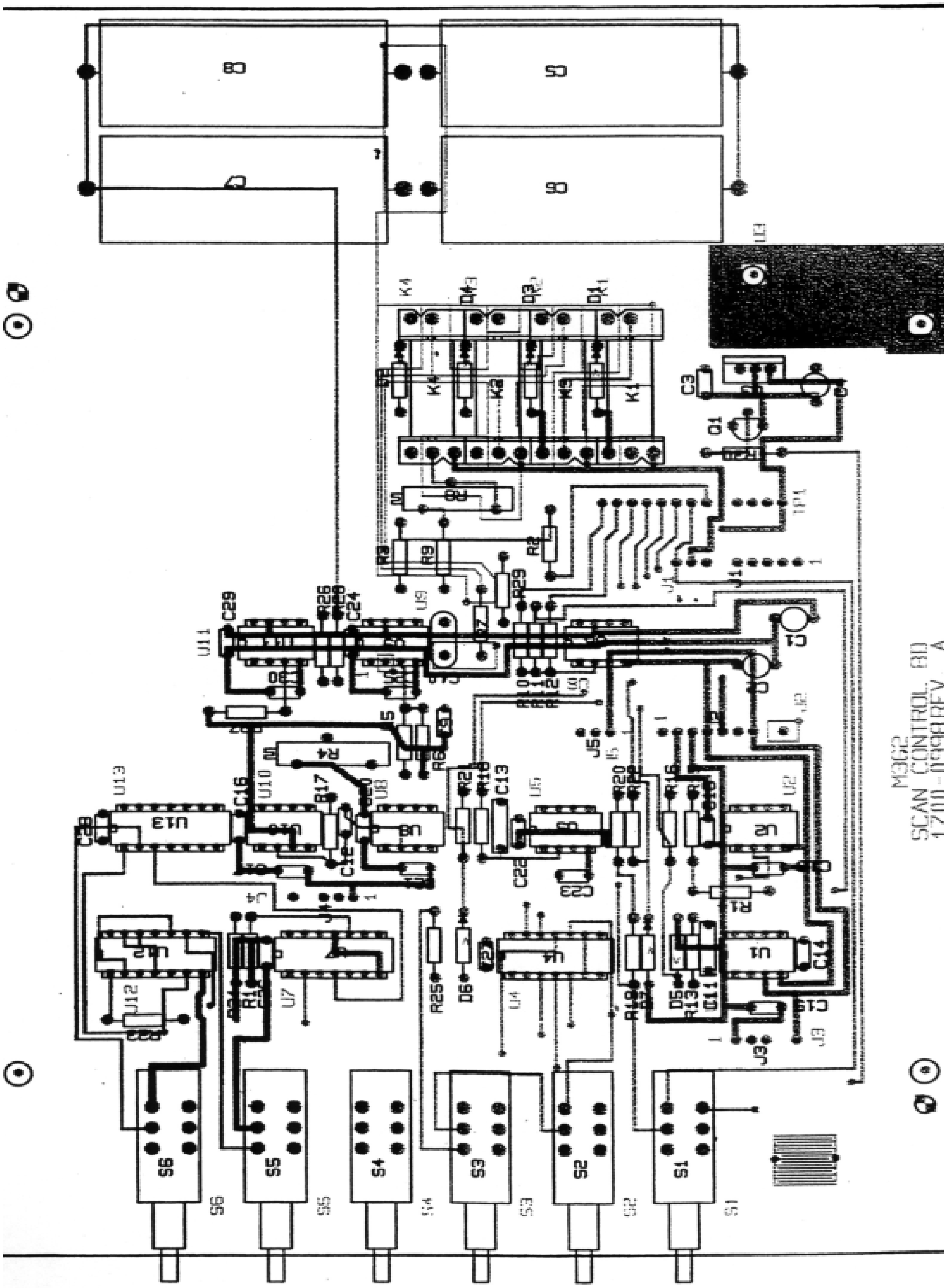
7. SCHEMATICS AND LAYOUT DIAGRAMS



Scan Rate Board Parts Location Diagram



Scan Control Board Schematic (15908-B-SD)



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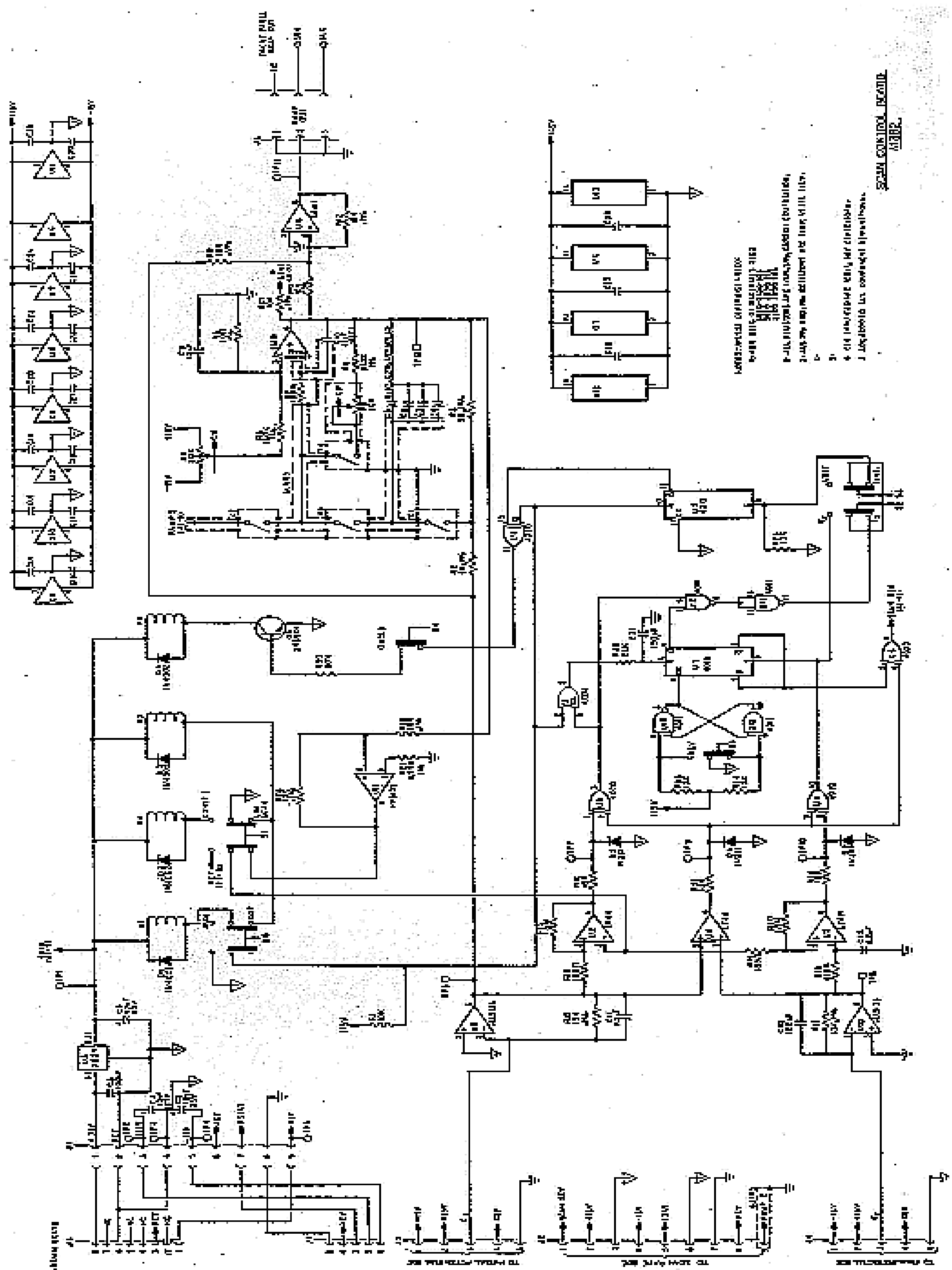
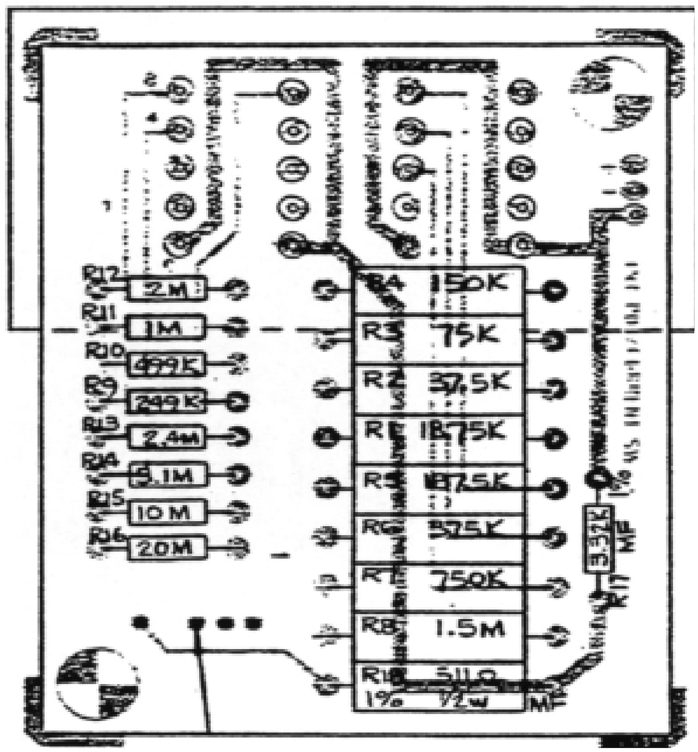
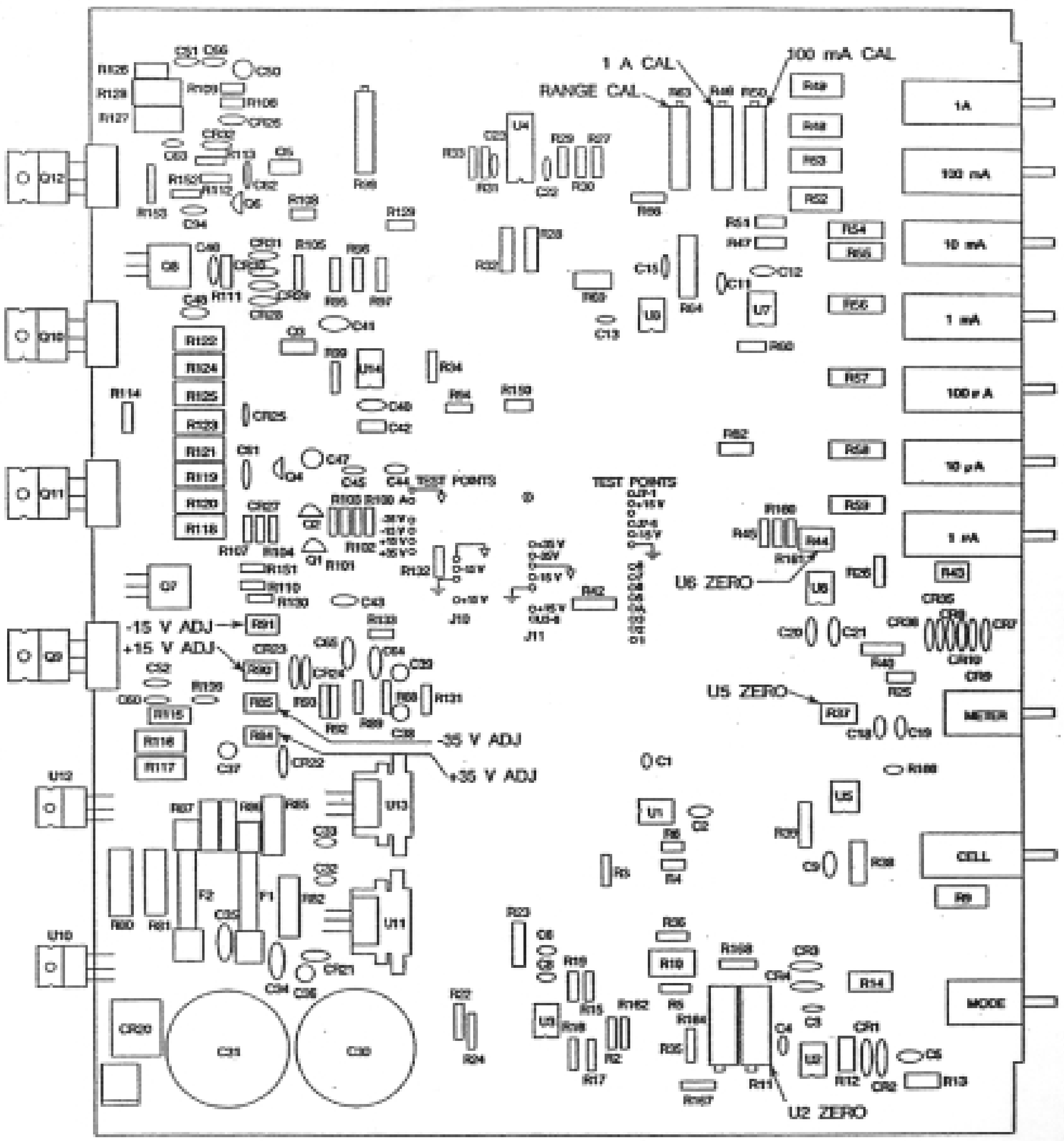


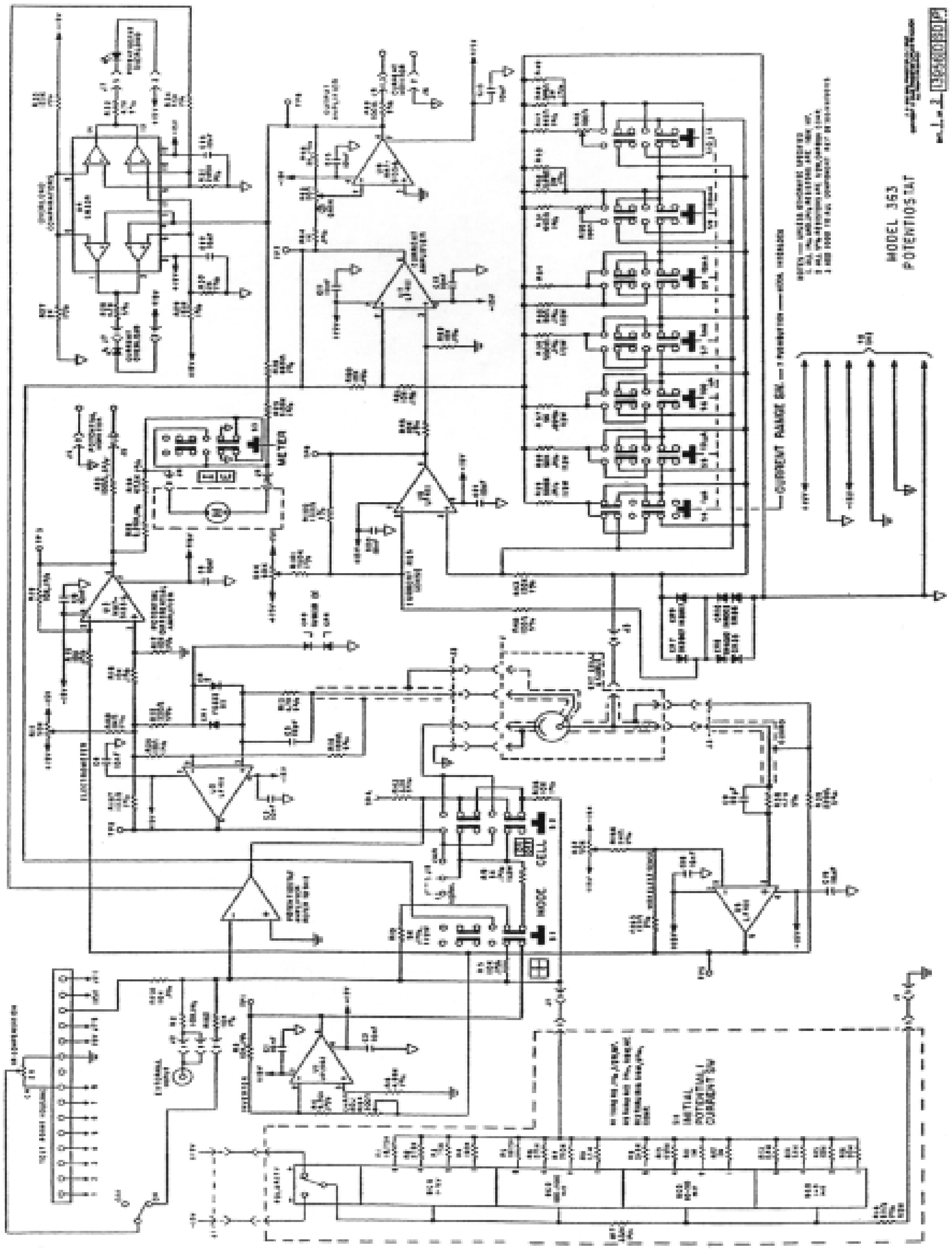
Scan Control Board Schematic (15900-D-SD)



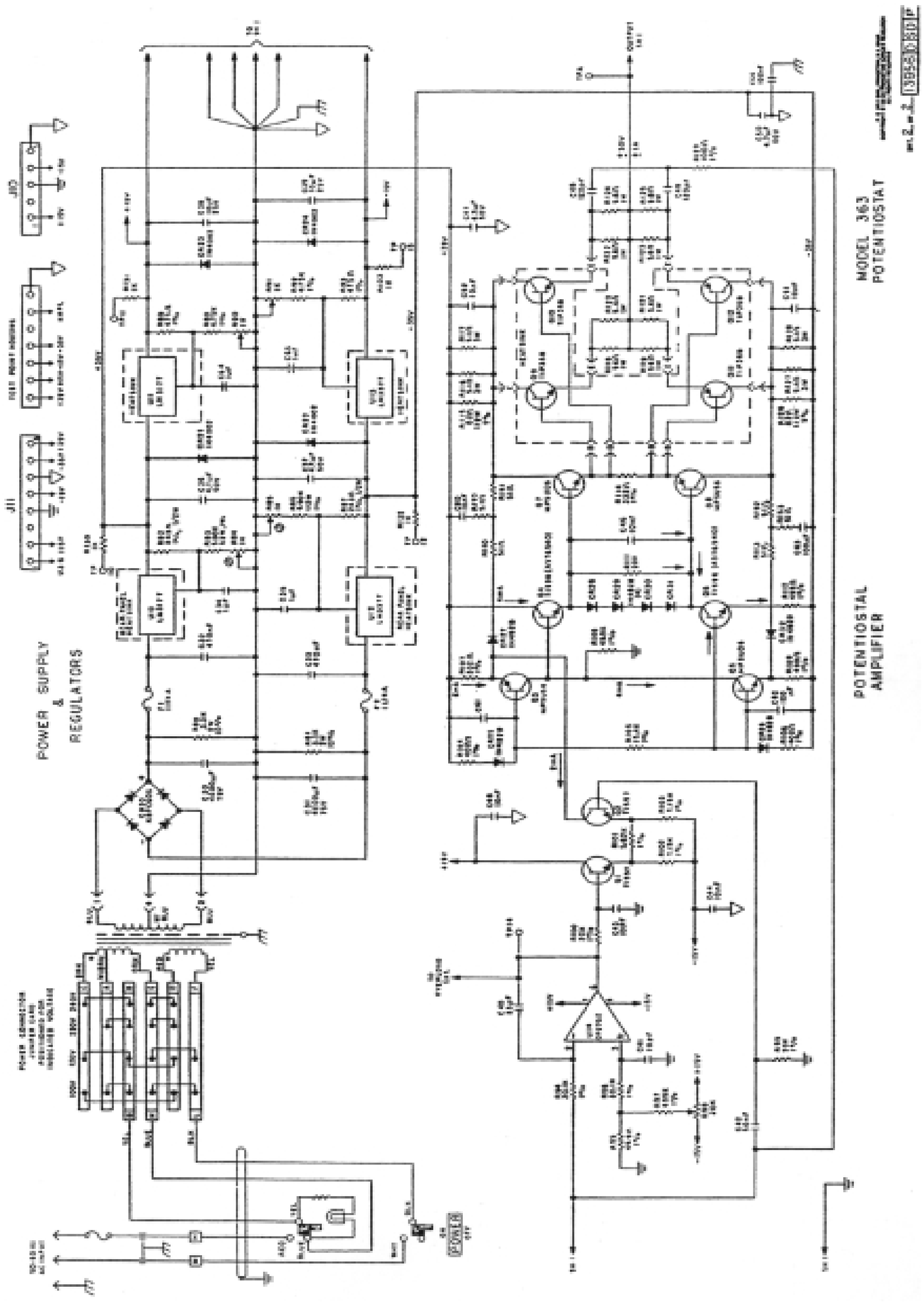
Potential Switchboard Parts Location Diagram



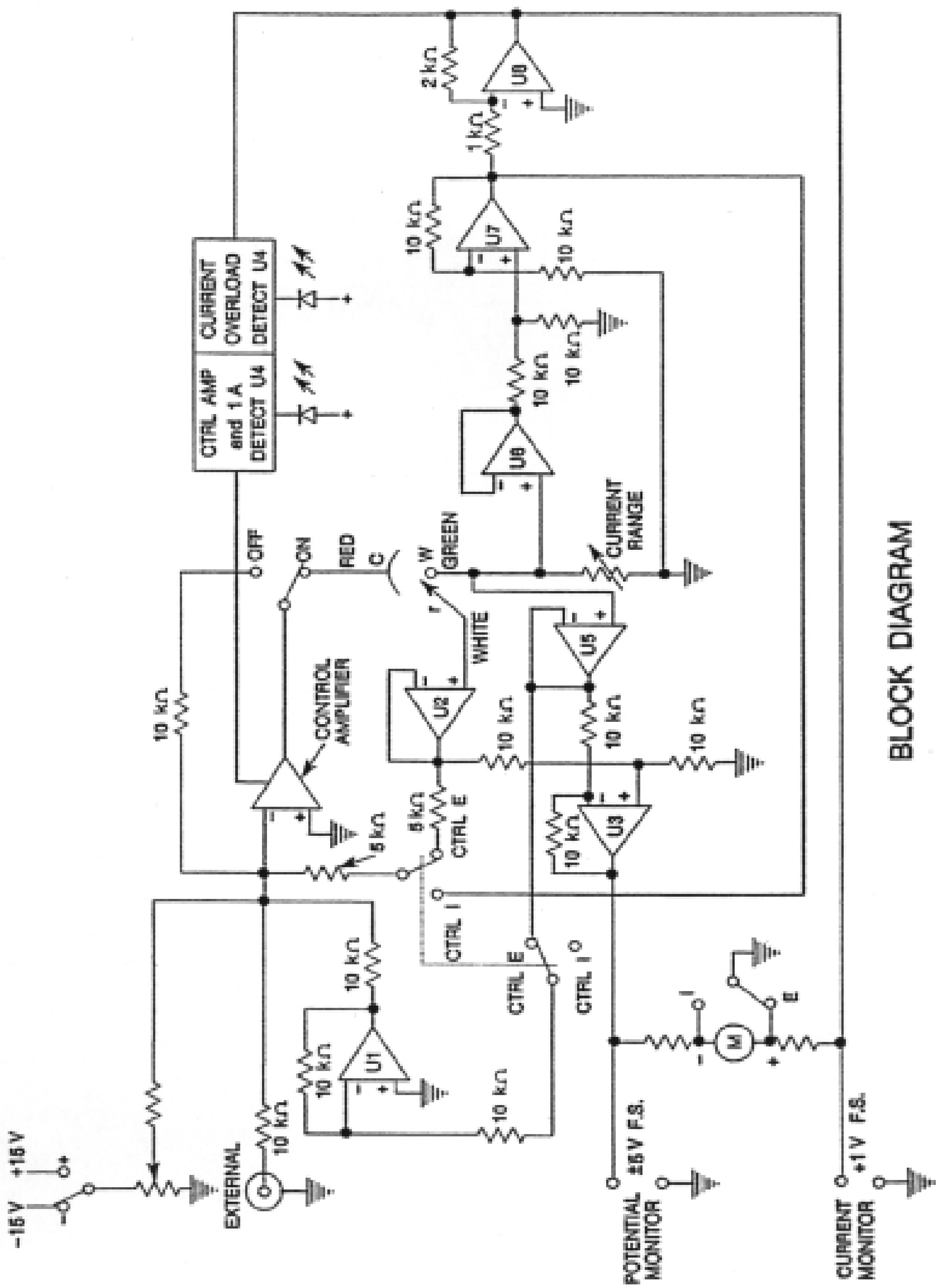
Main Board Parts Location Diagram



Main Board Schematic, Sheet 1 of 2 (13956-D-SD)



Main Board Schematic, Sheet 2 of 2 (13956-D-SD)



Main Board Block Diagram