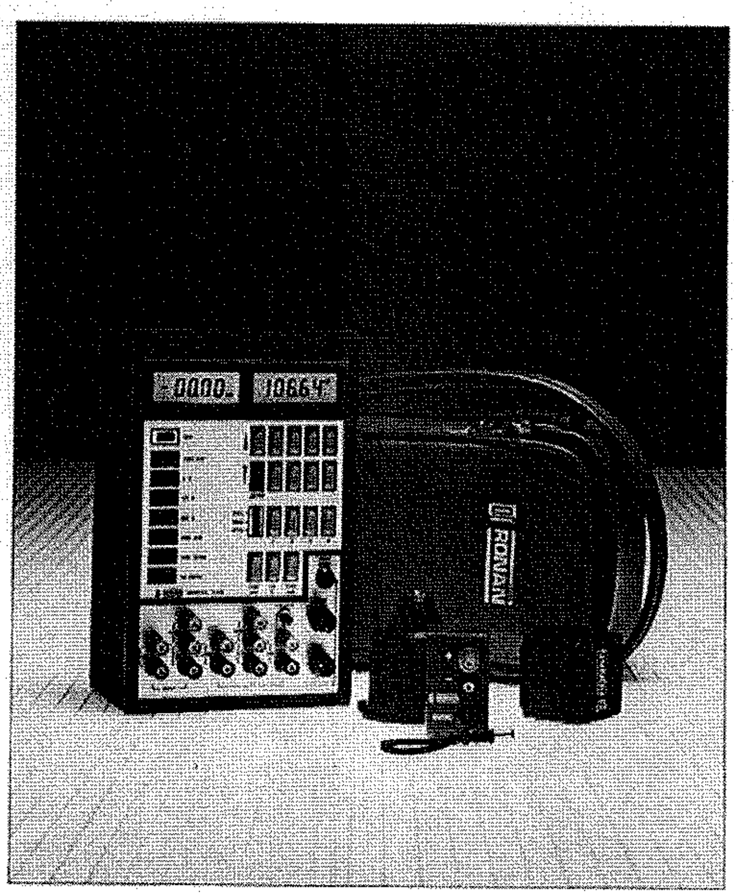
Instructions and Operating Manual

MODEL X86

PORTABLE CALIBRATOR



RONAN

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Warranty

Ronan warrants equipment of its own manufacture to be free from defects in material and workmanship under normal conditions of use and service, and will repair or replace any component found to be defective, on its return, transportation charges prepaid, within one year of its original purchase. This warranty carries no liability, either expressed or implied, beyond our obligation to replace the unit which carries the warranty.

1.0 GENERAL DESCRIPTION

The Ronan Model X86 Portable Calibrator is a versatile instrument, developed to calibrate and measure instruments and systems, utilizing current, voltage or ohms inputs and outputs. In addition to mA, mV and volt ranges, the Model X86 has a resistance capability that provides for calibration and measuring of resistance temperature detecting (RTD) devices. The Model X86 features separate input and output sections, each with full, independent controls and displays. The two, 4½-digit liquid crystal displays provide measurement and output resolutions of 0.01% of range (0.017% resolution for 60 mA output range). The input and output sections are isolated, so the Model X86 will not introduce ground loop problems, when it is fully utilized in instrumentation loops and systems.

The Model X86 features easy range and value selection through the use of individual pushbutton switches. Up to four output values can be stored and recalled from internal memory at the touch of a button. The calibrator can also be set to automatically sequence through the stored values at a selectable speed.

The Model X86 has a pair of two-wire terminals that provide simulation of a two-wire transmitter in a voltage-powered current loop.

2.0 SPECIFICATIONS

Specifications apply at 23 ± 2°C unless otherwise stated. Specifications are subject to change without notice.

Input Impedance
Voltage input: 10 Mohms
Current input: 10 ohms
Ohms input: 1 mA from internal current source

Input Ranges
0 to 100 mV: 10 μV resolution
0 to 1 V: 100 μV resolution
0 to 10 V: 1 mV resolution
0 to 60 V: 10 mV resolution
0 to 100 mA: 10 μA resolution
0 to 100 ohms: .01 ohm resolution
0 to 1 k ohms: .1 ohm resolution

Input Accuracy
mV, volts input: .01% of range, ± 0.02% of reading
100 mA input: .01% of range, ± 0.03% of reading
Ohms input: .02% of range, ± 0.03% of reading

Input Temperature Coefficient
Voltage, mA input: ± 0.001% of range, ± 0.003% of reading /°C
Ohms input: ± 0.001% of range, ± 0.005% of reading /°C

Output Impedance
Voltage output: Less than 0.2 ohms
mA output: >1 Mohm

Output Current
mV, voltage output: 10 mA, limited at approx. 15 mA
mA output: Specifications apply to 60 mA, limited to 99.99 mA

Output Ranges
0 to 100 mV: 10 μV resolution
0 to 10 V: 1 mV resolution
1 to 60 mA: 10 μA resolution
(Maximum current output is 99.99 mA.)
0 to 1100 ohms $\pm$ 10%

Output Accuracy
mV, volts output: $\pm$0.02% of range, $\pm$0.01% of reading
100 mA output: $\pm$0.02% of range, $\pm$0.025% of reading
1 to 60 mA range

Output Temperature Coefficient
mV, volts output: $\pm$0.001% of range, $\pm$0.003% of reading/°C
mA output: $\pm$0.001% of range, $\pm$0.004% of reading/°C

Recommended Operating Temperature
0 to +50°C

Two-Wire Transmitter Output
Maximum external supply voltage 60 Vdc
Maximum load resistance:

$$R_{Load} = \frac{\text{Supply voltage} - 4 \text{ volts}}{\text{Maximum load current}}$$

Input-to-Output Isolation
300 VRMS

Output Indicator
4½-digit liquid crystal display with selected function annunciation

Out-of-Range Indication
The flashing 1 digit on the displays indicates a probable output error for the following conditions:
a) The calibrator is set to the mA output range and the output loop is open.
b) The calibrator is set to the mA output range and the loop voltage drop is too high.
c) The calibrator is set to the mA output range and the display is set to more than 99.99 mA.
d) The calibrator is set to the mV or V output range and the display is set to more than 10.999 V or 109.99 mV.
e) The calibrator is set to the mV or voltage output ranges and the output current reaches the limited value.

Warm-up Time to Rated Accuracy
30 seconds

Power Requirements
Internal, removable and rechargeable 6 V battery pack

Battery Life
Greater than six hours for all ranges except mA output; greater than four hours on mA output range and 20 mA continuous output current

Low Battery Indication

LO BAT on output display indicates battery voltage is below operating range and needs recharge or replacement.

Recharge Time

14 hours or less depending upon the condition of the battery.

Operating Controls and Functions

Displays

Two 4½-digit liquid crystal displays indicate input and output signals simultaneously.

Power-on Switch

Applies internal Ni-Cad battery power to calibrator's circuits.

Input Range Selection

Individual pushbuttons select one of seven input ranges.

Output Range Selection

Individual pushbuttons select one of three output ranges. The resistance output range does not require selection.

Output Value Selection

Nine pushbuttons are provided to increment or decrement each digit on the output display. A ZERO pushbutton allows the output value and display to be set to zero. The pushbutton switch located above ZERO, if held in a depressed position, will toggle the first digit on display between zero and one.

Storing, Recalling and Sequencing of Preset Values

A three-position slide switch (STO, RCL or SEQ), used in conjunction with four pushbutton selectors, allows storing and recalling of up to four output values. The SEQ function will enable internal circuits to automatically sequence through the stored values at an adjustable rate of 10 to 60 seconds.

Ohms Adjustment

Coarse

1,000 ohm potentiometer used to adjust output resistance with .2 ohm resolution

Fine

100 ohm potentiometer used to provide fine control of output resistance with .06 ohm resolution

Read

Toggle switch used to measure the resistance by the input circuit, while adjusting output potentiometers. Input must be in OHM input mode and toggle switch pressed to READ OHMS position.

Traceability

The X86 calibration is directly traceable to the National Bureau of Standards.

Binding Posts

Five-way input and output terminals as follows:

OHM: (ohms, +) used for resistance input

mA, V: (+ , −) used for volts or milliampere input
2-WIRE: (+ , −) terminals for use
in simulating 2-wire transmitter output
OUTPUT: (+ , −) terminals for providing volts or mA output
OHM: (ohms, +) used for resistance output

Charger and Battery

Connector for battery charger input is located at the front panel. Battery is accessible from the bottom of the calibrator.

Weight

Approximately 4 lbs (1.8 kg).

Size

8.524" (21.64 cm) high, 5.276" (13.40 cm) wide, 4.000" (10.16) deep

Accessories

Supplied with calibrator are: carrying case, modular battery charger, two sets of test leads. *Other options:* Reference junction for T/C Type E, J, K, T, R, S; spare battery pack

3.0 OPERATION

3.1 Operating Controls

Refer to Figure 3-1 for the operating control locations.

3.1.1 Power-On Switch: Connects internal nickel/cadium battery to the calibrator circuits.

3.1.2 Input Range Switches: One of seven input ranges is selected by pressing the associated pushbutton switch.

a) *100 mV:* Measures dc voltages in the range of 0-100 mV with 10 microvolt resolution.
b) *1 V:* Measures dc voltages in the range of 0-1 V with 100 microvolt resolution.
c) *10 V:* Measures dc voltages in the range of 0-10 V with one millivolt resolution.
d) *60 V:* Measures dc voltages in the range of 0-60 V with 10 mV resolution.
e) *100 mA:* Measures dc current in the range of 0-100 mA with 10 microamp resolution.
f) *100 ohms:* Measures resistances in the range of 0-100 ohms with 10 milli-ohm resolution.
g) *1 Kohm:* Measures resistances in the range of 0-1,000 ohms with 0.1 ohm resolution.

3.1.3 Output Range Switches: One of three output ranges is selected by pressing the associated pushbutton switch.

a) *100 mV:* Outputs dc voltages in the range of 0-100 mV with 10 microvolt resolution.
b) *10 V:* Outputs dc voltages in the range of 0-10 V with one millivolt resolution.
c) *100 mA:* Outputs dc current in the range of 0-60 mA with 10 microamp resolution.

NOTE: The Model X86 Portable Calibrator provides a variable output resistance, which is always available at the ohm output terminals. See section 3.1.4.

3.1.4 Ohms Coarse and Fine Adjustment Controls and Read Ohms Switch: These controls are used to set the output resistance. An isolated, passive resistor is internally connected across the ohms output terminals. To read the value of this resistance and adjust it, the input must be set to one of the ohms ranges, and the momentary READ OHMS switch must be depressed. The resistor value will now be displayed on the input meter and can be adjusted using the 10-turn COARSE and FINE controls. When the READ OHMS switch is released, the resistor will be switched back to the ohms output terminals.

CAUTION: If a voltage input is connected, the +V input must be removed from the calibrator while depressing the READ OHMS switch to measure the ohms output, or an erroneous measurement will result.

3.1.5 MV, V, mA Output Adjustment: There are two rows of five pushbutton switches located just below the output value display. The top row, marked ▲, increments the output value on an individual digit basis. The bottom row, marked ▼, decrements the individual digits. The top four switches on the right correspond to the four output digits, which range from 0-9. The top left switch changes the 1 digit from zero to one to zero, etc. The four switches in the row under these correspond to the same digits as the right four switches of the top row. The bottom left switch labeled ZERO resets the display and the output value to zero.

3.1.6 Output Value Storage/Recall: The three-position slide switch labeled RCL, SEQ and STO and the four pushbutton switches next to it, labeled 1, 2, 3 and 4, are used to simplify the setting-up of output values. To store an output value, the three-position switch is set to the STO position, the required output value is set on the output display, and one of the storage location switches (1, 2, 3 or 4) is pressed. Up to four output values can be stored. To recall the stored value(s), set the three-position switch to the RCL position and press one of the four switches to recall an output value from one of the four storage locations. To cause the calibrator to automatically sequence through the stored values for "hands-off" operation, set the three-position switch to the SEQ position. The calibrator will automatically step through all four storage locations with a dwell time ranging from about ten to 60 seconds. The dwell time is adjustable by means of a single turn potentiometer, located behind the battery pack. To gain access to this control for adjustment of the dwell time for each recalled value, remove the battery pack and the control will be visible, facing the bottom of the X86. Turning the potentiometer counterclockwise increases the time to about 60 seconds at its maximum counter-clockwise position.

3.1.7 Input/Output Binding Posts: Five binding posts are provided for connecting the input signals or resistance. A pair of binding posts are provided for the mA and V inputs, the red binding post of each pair accepting the positive signal polarity. The resistance inputs are connected across the two red terminals labeled OHM. Similar terminals are provided to output mA, V and ohms and are polarized and labeled similarily to the input terminals. An additional pair of posts labeled 2-WIRE is used when the calibrator is used to simulate a two-wire transmitter. When used as a two-wire transmitter, the calibrator output must be in the mA mode and the required loop current set on the display.

3.1.8 Charge Connector: Receptable for plugging in the battery charger.

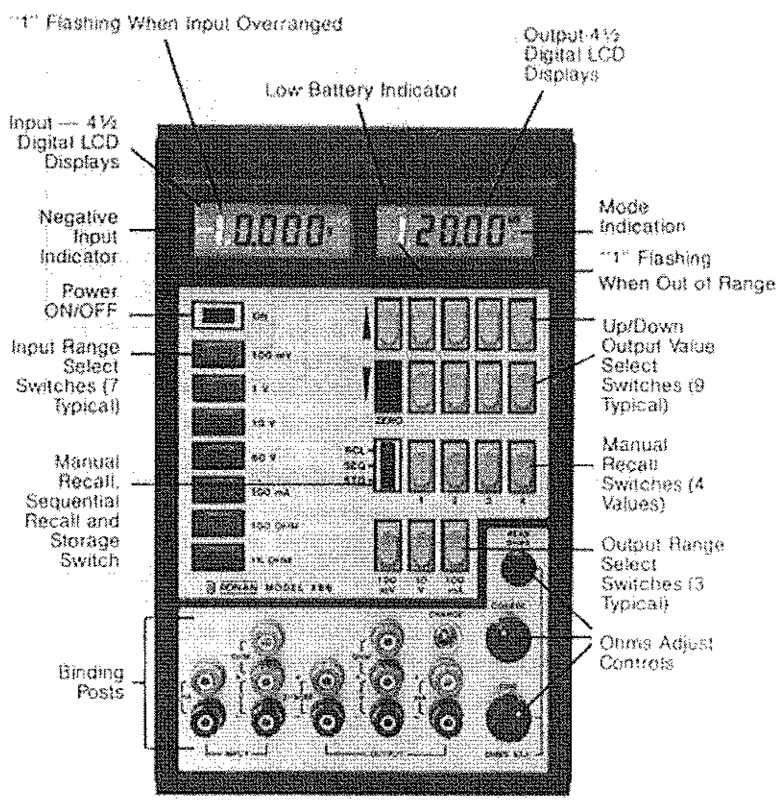


Figure 3-1

3.2 Thermocouple Inputs

The Model X86 can be used to measure the thermocouple by using one of the following procedures.

3.2.1 External Reference Junction: Connect the thermocouple to be measured, the reference junction and the Model X86 calibrator as shown in Figure 3-2, a or Figure 3-2, b.

a) Set the input to the 100 mV range.

b) Connect the copper or T/C alloy leads from the reference junction to the V+ and the V− input terminals. The T/C voltage is now displayed on the digital meter in mV. The mV measurement can now be converted to temperature by consulting the corresponding T/C tables. The Model X86 will accurately indicate negative values ("−" annunciator appears) on the 100 mV range and will indicate temperature below zero degrees Celsius as −mV.

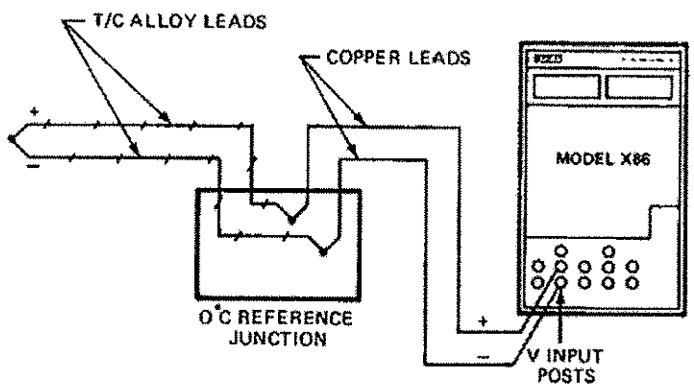


Figure 3-2, a: Thermocouple Measurements Using External Reference Junction

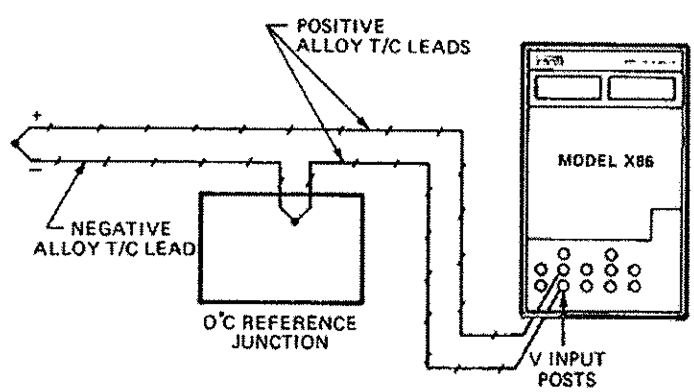


Figure 3-2, b: Thermocouple Measurements Using External Reference Junction

3.2.2 Direct T/C Connection to Calibrator: A T/C may be connected directly to the Model X86 Portable Calibrator as shown in Figure 3-3.

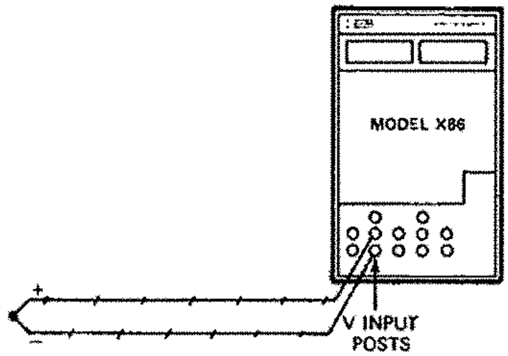


Figure 3-3: Direct Connection of T/C to Model X86 Portable Calibrator

When this set-up is used, there is a T/C junction at the binding post of the calibrator, which opposes the output of the T/C junctions to be measured. To find the correct "hot" junction temperature, this opposition voltage must be determined and added to the voltage indicated on the digital readout as follows.

a) Set the INPUT to the 100 mV range.

b) Connect the T/C positive alloy lead to the + INPUT binding post. Connect the T/C negative (red) alloy lead to the − INPUT binding post.

c) Measure with a thermometer the temperature at the INPUT binding posts. (This should be the same as the ambient temperature surrounding the Model X86.)

d) Using the T/C tables, look up the mV output for the kind of T/C used at the temperature measured in step c. Observe the mV reading on the display and add the mV from the tables to the value on the display.

e) Look up in the T/C tables the total value found in step d. The corresponding temperature from the tables is the temperature of the measured T/C.

3.3 Thermocouple Simulation

3.3.1 External Reference Junction: If an external reference junction is to be used, connect the Model X86 and the reference junction as shown in Figure 3-4.

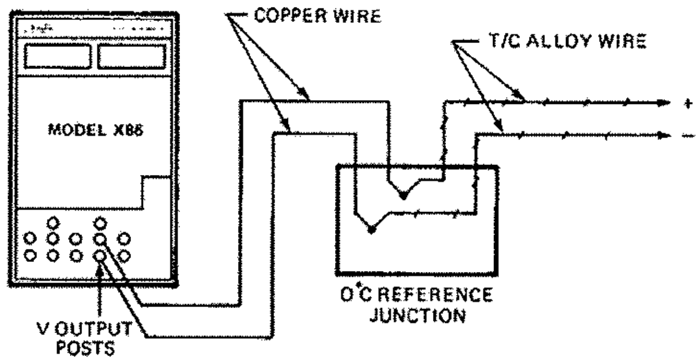


Figure 3-4: Thermocouple Simulation Using External Reference Junction

a) Set the OUTPUT to the 100 mV range.

b) Set the output to the mV value given in the T/C tables for the temperature to be simulated.

NOTE: If the instrument or system to be calibrated uses an external reference junction to read the T/C inputs, then neither reference junction is required and copper wire can be connected directly between the two. The T/C voltage can be directly set as in steps a and b.

3.3.2 Thermocouple Simulation without Use of External Reference Junction: Connect the Model X86 to the instrument of system being calibrated as shown in Figure 3-5.

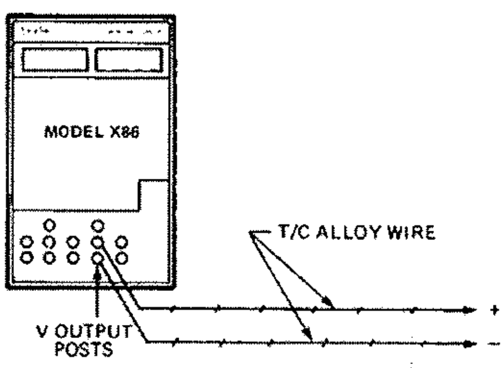


Figure 3-5: Thermocouple Simulation Using Direct Connection

a) Set the OUTPUT switch to the 100 mV range.

b) Measure the ambient temperature at the X86 output terminals and look up in the T/C tables the mV of the T/C being simulated at the ambient temperature measured. (This is an error voltage that is added to the internal voltage generated by the calibrator.)

c) Look up in the T/C tables the mV output of the T/C at the temperature to be simulated. Subtract the mV value found in step b from this value.

d) Set the value found in step c on the digital readout. If the answer in step c was negative, reverse the output leads and set up the value as a positive value on the readout.

3.4 Two-wire Transmitter Simulation

Terminals are provided for two-wire transmitter simulation. The calibrator is connected to the system to be calibrated as shown in Figure 3-6.

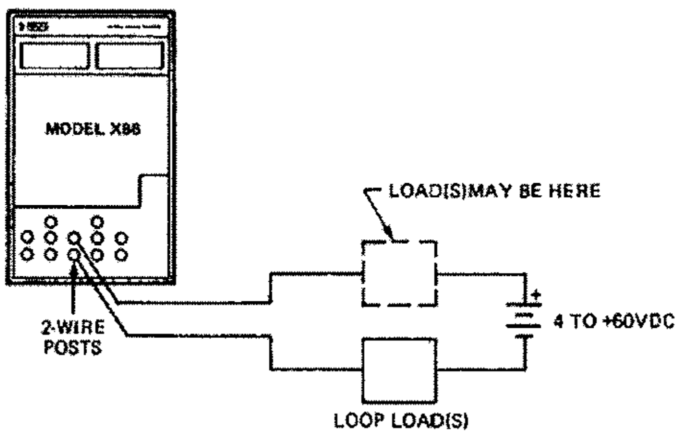


Figure 3-6: Two-wire Transmitter Simulation

a) Set the OUTPUT to the 100 mA range.

b) Connect the external current loop to the two-wire output posts, observing polarity as shown in Figure 3-6.

c) Adjust the OUTPUT for the required calibration current.

3.5 Transmitter Calibration

A transmitter with either mV, mA or RTD inputs and mA or V output can be calibrated with the test configuration shown in Figure 3-7. The output of the transmitter can be measured while it is receiving a calibration signal from the Model X86.

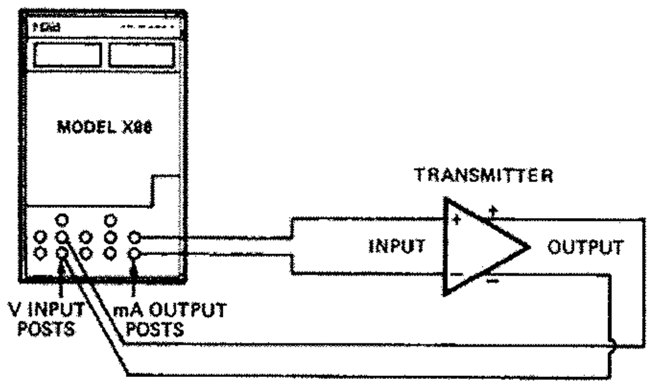


Figure 3-7: Transmitter Calibration

a) Set the OUTPUT to the required range and value. (For OHM output, see section 3.1.4 Ohms Coarse and Fine Adjustment Controls and Read Ohms Switch.)

b) Set the INPUT to the range corresponding to the output of the transmitter.

c) Connect from the appropriate OUTPUT posts on the calibrator to the input terminals of the transmitter.

d) Connect the transmitter output to the appropriate INPUT posts on the calibrator.

e) The transmitter output, corresponding to the calibrated input level from the calibrator, is now displayed on the digital input display.

NOTE: The four internal storage locations can be effectively utilized for rapidly recalling output values that will be repeatedly required.

3.6 Ohms Measurement

a) Set the INPUT to either the 100-ohm or 1-Kohm range.

b) If the calibrator test leads are to be used, short the ends together and observe the reading on the DPM (typically .05 ohms). The test lead resistance should then be subtracted from the total ohms reading, when the unknown resistance is measured. When resistance temperature detectors (RTDs) are measured, their leads can be a significant percentage of the RTD value. For accurate RTD measurements, the RTD lead resistance should be eliminated, measured or calculated, then subtracted from the total measurement.

3.7 Output Overload and Open Circuit Indication

When the Model X86's output is set to the mA range and there is no current loop connected to its output or the current loop opens or the loop resistance is too high for the calibrator to drive accurately, the 1 digit on the output display will flash, indicating improper operation. The flashing 1 will also occur in the mA mode if the output is set to more than 99.99 mA.

When the Model X86's output is set to the V mode and excessive current is drawn from its output (greater than approximately 15 mA), the 1 digit will flash. The 1 digit will also flash if the output is set to more than 10.999 or 109.99 mV, indicating probable output errors.

3.8 Input Overrange Indication

The 1 digit on the input display will flash when an overrange input is applied. The input will measure accurately to 199.99 mV, mA or ohms on the mV, mA and 100-ohm ranges; 1.9999 V, 19.999 V and 59.999 V on the 1 V, 10 V and 60 V ranges, and 1999.9 ohms on the 1 Kohm range. At input values above these, the 1 digit will flash, indicating an overrange input is applied. Negative input values up to full-scale can be applied on the 100 mV, 100 mA and 1 V range. Negative values should not be applied on the 10 V and 60 V ranges, as they will be erroneously displayed.

3.9 Circuit Protection

The volt and ohm input ranges to the Model X86 Portable Calibrator are protected against overvoltages up to ±200 Vdc or peak ac without the use of fuses. Voltages in excess of 200 Vdc may damage the unit. The 100 mA input has a fuse rated at ¼ amp, which protects the precision 10-ohm current sense resistor in the input measuring circuit.

The voltage output ranges are fuse-protected against the application of high voltage to the output terminals. In the mA output and two-wire transmitter simulation modes, the output circuits are not fuse-protected, but are protected against the application of a reverse dc voltage. Avoid connecting the mA output + post to the V output − post or to the two-wire − post. This will blow the power fuse, F2. The mA input protection fuse, F1; power fuse, F2, and the voltage output protection fuse, F3, are all located on printed circuit board, X86-1003.

3.10 Rechargeable Battery Pack

The Model X86 Portable Calibrator is powered by a rechargeable nickel-cadium battery. The battery voltage ranges from 6.5 to 7.5 V at full charge to about 5.6 V at the minimum value before recharging. With proper care, the battery can be expected to last for years. The battery pack can easily be removed and replaced. The battery pack can also be charged when not installed within the calibrator.

3.10.1 Recharging:

WARNING: Do not charge in hazardous areas.

A wall receptacle, plug-in battery recharger is supplied with the calibrator. The plug on the end of the charger cord is inserted into the receptacle labeled "CHARGE" on the calibrator front panel. A charge time of 14 to 16 hours is recommended to fully charge the battery. Moderate overcharging (e.g., an extra 24 hours occasionally) should not harm the battery. Care should be taken to not permit the instrument to recharge for long periods of time. Continuous overcharging will eventually destroy the battery.

CAUTION: Use only the recharger supplied with the calibrator. The use of another charging system may cause catastrophic damage to the battery.

An internal circuit detects when the battery needs to be recharged and indicates this with a "LO BAT" annunciator on the upper left corner of the output display. When this symbol appears, the calibrator should be recharged immediately. Possible cell damage can occur if the battery is allowed to discharge beyond this point. If the calibrator is inadvertently left on for long periods of time and becomes deeply discharged, the following steps should be taken to ascertain if it has undergone an incorrectable cell reversal.

a) Charge the battery for at least 20 hours.

b) Measure the battery voltage with an accurate DVM as follows. Set the OUTPUT RANGE switch to the 10 V position. Connect the DVM − input to the V OUTPUT− terminal. Carefully touch the DVM + input lead to the inside pin of the charge receptacle. The DVM should indicate more than 6.2 V. If the reading on the DVM is below 6.2 V, repeat the charge cycle and remeasure the battery. If the voltage is still below 6.2 V, the battery must be replaced.

4.0 CIRCUIT DESCRIPTION

4.1 General

The Model X86 has an input section that performs all the measurement functions, and an output section that provides the output parameters. The two sections function independently and are electrically isolated from each other. The power supplies are derived from two isolated windings on the power transformer. The battery and the power transformer driving circuits are common to both sections.

The circuits are contained on four printed circuit (PC) boards, including a board that carries the front panel switches and the two displays. The PC boards are mounted to the front panel and remain functional when the top cover is removed and the front panel and circuit boards are removed from the enclosure. The calibration adjustment controls are accessible at the top of the circuit boards when the top cover is removed from the enclosure.

4.2 Block Diagrams

4.2.1 Input Circuit Block Diagram (Drawing X86D16): The inputs enter the PC board X86-1001 through the header connector P5. The inputs are either applied directly, or divided by 100 and applied to amplifier U12, which has a gain of one or ten. The output of U12 is applied to a precision, 4½-digit, single-chip, analog-to-digital (A/D) converter. The multiplexed, binary-coded decimal (BCD) output and digit drives connect through receptacle J2 to the liquid crystal display (LCD) decoder/driver U1 on PC board X86-1000. The decoder/driver then controls the four full digits on the display. The "1" digit on the display is decoded and driven by some of the circuitry in the U3, U4 and U8 block.

The input range select switches S2 through S8 connect through P3 and J3 to the range control circuits on PC board X86-1001. The range control circuits control the input gain select switches and the display annunciator select switches. The display annunciators show the range selected and the decimal point location. A precision reference voltage, U1 circuit, is used to derive the + 1 V, + 2.5 V, + 5 V and − 5 V utilized by the input circuits.

4.2.2 Output Circuit Block Diagram (Drawing X86D17): The output circuits are located on PC boards X86-1002 and X86-1003, plus the output display and display drivers on PC board X86-1000. The output section contains a digital-to-analog converter (DAC) circuit, a current output amplifier, front panel switch interface circuits, digital display and the calibrator's power supply circuits. The DAC is a 4½-digit, binary coded decimal (BCD), addressable circuit, controlled by up/down BCD counters. The full-scale output level of the DAC is determined by the output function: mV, V or mA. The mA output amplifier derives its input from the DAC, when the calibrator is in the mA output mode.

The BCD counters that control the DAC also control the display decoder/drivers and provide an input to the random access memory (RAM) circuits. The RAM circuits are utilized when the output STO (store) or RCL (recall) function is used.

Both the X86-1002 and X86-1003 PC boards contain circuits that detect front panel switch closures and store this data and/or interface with the appropriate circuits.

A dc-dc converter power supply that provides the voltages required by the Model X86 Portable Calibrator is located on PC board X86-1003.

5.0 DETAILED CIRCUIT DESCRIPTION

5.1 Input Circuit (Schematics X86-1000 and X86-1001)

5.1.1 Volts Input: The + voltage input is routed from the front panel to connector pin P5-9 on PC board X86-1001. The signal is applied through switch Q3 on the 100 mV and 1 V ranges to the input amplifier U12. On the 10 V and 60 V input ranges, the signal is divided by 100, using R27, RN2 and R8, then applied through the switch U11D to the input of U12. The gain of U12 is 10 on the 100 mV and 10 V ranges, and one on the 1 V and 60 V ranges. The amplifier U12 is a chopper-stabilized device with low long-term and temperature drifts of input offset voltage.

5.1.2 mA Input: The + mA input is routed from the front panel to connector pin P5-10 on PC board X83-1001. A current path, provided by the precision 10-ohm resistor R28, routes the input current through P5-2 and, subsequently, to the front panel binding posts. Switch U11C is on (switch Q3 is off), which applies the voltage across R28 to the input of U12.

5.1.3 Ohms Input: The OHM input binding posts connect to P5-1 on PC board X86-1001 and to ground 3 (input circuit ground) at the power supply. A 1 mA current source, composed of U6, Q1, Q2 and associated components, is operable in the OHM input mode and connects to P5-1. This precision 1 mA flows through the resistance to be measured at the OHM binding posts, and the resultant voltage is applied to the input of U12. The amplifier U12 has a gain of 10 on the 100-ohm range and a gain of one on the 1-Kohm range. The switches U11A and U11B are turned on for all ranges except OHM, and provide an internal feedback path for the precision 1 mA. A voltage input of 1 V is developed across resistor R20 and applied to amplifier U6 through R9 and R22. Potentiometer R9 is used to calibrate the OHM input function.

5.1.4 Reference Voltage: The precision 2.5 V reference circuit U1 is used to derive the reference voltage for the A/D converter and the input circuitry. A reference voltage of about 1 V, adjustable by potentiometer R10, is applied to the REF pin of the A/D circuit, composed of U5 and associated components. Resistors R2 and R3, used in the voltage divider with R10, are precision, wire-wound resistors with matched temperature coefficients and excellent long-term stability. Operational amplifiers U2A and U2B, using the 2.5 V reference as an input, provide ± 5 V to the input circuits.

5.1.5 Analog-to-Digital Converter: The A/D converter used in the Model X86 is a precision 4½-digit, single-chip circuit. The A/D converter U5 utilizes the dual-slope conversion technique and provides multiplexed BCD output and digit drivers. A 50 KHz clock circuit for U5 is composed of U7B, C12, R25 and potentiometer R11. The reference voltage from R10 is applied to pin 2 of U5. The reference voltage is adjusted for a display of 1.000 V when the 1-V input range is selected and 1.000 V is applied to the input. The reference voltage will be approximately 1 V when calibrated. In the conversion process, the reference voltage is stored on C11 and utilized by U5 as a floating reference voltage, which can be used for positive and negative input voltages. Capacitor C10 is the auto-zero capacitor used to store small correction voltages in the auto-zero process. Capacitor C2 is used as the capacitor in the feedback path of the integrator circuit in the A/D converter.

5.1.6 Overrange Indication: An overrange is indicated by a flashing 1 when an input of over 199.99 mV, mA or ohms; 1.9999 V or Kohms; 19.999 V, or 59.99 V is connected to the input. The 1 is normally latched into a "D" flip-flop, U8B, through U4A and driven by U3B and U3C. If one of the above overrange conditions exists, pin 27 of U5 will have a pulsing output and flash the 1 through U3C.

A circuit that detects when the signal input is greater than 60 V on the 60-V input range and flashes the 1 digit, is made up of U7A, U7C, U8A, U3D, U4B, U4C and U4D. If this overrange condition exists on the 60-V range, pin 13 of U8A will be caused to go high. This output is applied to one input of the AND gate U4C and the busy output from U5 is applied to the other input. The busy signal goes high for part of each conversion cycle of U5. The output of U4C is, therefore, a flashing signal when U8A-13 is high and progresses through U3C and U3B to J2-22, then to the display board where it causes the 1 digit to flash. The circuit U3D is used as an OR gate whose output is high whenever any digit has the value of six or more. As the circuit is concerned only with the most significant full digit, D4, the flip-flop U8A is only clocked during the D4 output time. This clock timing is provided by U4B and U7C, which results in a narrow strobe pulse near the center of the D4 drive pulse.

The binary-coded decimal digit values are positive logic signals from U5-13, U5-14, U5-15 and U5-16, which are routed through J2 to the decoder/driver circuit U1 on the display board. These digit values may change for each digit-time D1 through D5 (D5 being the most significant digit) and are latched into the decoder/driver at each digit-time.

5.1.7 Switch Interface Circuits: The front panel range select switch closures are detected by the priority encoder circuit U18, encoded and latched into the four-to-16 line decoder U15. The priority encoder recognizes only the highest priority switch closure, if several switches are pressed at the same time.

The outputs of U15 control the input range switching and the range annunciators and decimal points on the display. Table 5-1 shows which switches and annunciators are controlled by each of the used outputs of U15.

Input Range	U15 Output Pin High	Input Range Switches Selected	Display Driver Switches Selected	Display Annunciators Selected
100 mV	8	Q3, U16B	U9B, U10C	mV, DP2
1 V	7	Q3, U16A	U9A, U10A	V, DP4
10 V	6	U11D, U16B	U9A, U10B	V, DP3
60 V	5	U11D, U16A	U9A, U10C	V, DP2
100 mA	10	U11C, U16A	U9C, U10C	mA, DP2
100 ohm	11	Q3, U16B	U9D, U10C	ohm, DP2
1 Kohm	9	Q3, U16A	U9D, U10D	ohm, DP1

Table 5-1: Internal Range Switching

5.2 Output Circuits (Schematics X86-1002 and X86-1003)

5.2.1 Power Supplies and Low Battery Detection Circuit: The power supply circuit on PC board X86-1003 utilizes the 6 V potential from the battery and provides the voltages required to operate the calibrator. A non-saturating, dc-dc converter, consisting of transformer T1, the oscillator circuit U12, V-MOS field-effect transistors Q3 and Q4, the secondary windings, rectifiers and filters perform the voltage conversion. Integrated circuit U12 is a symmetrical oscillator, operating at about 30 KHz. The oscillator alternately turns on the V-MOS switches Q3 and Q4, which provide current paths from the battery through each half of the center-tapped, primary winding of T1. Isolated ±7.5 V supplies are derived from secondary winding 8-9, which powers the input section of the calibrator. Winding 6-7 provides −7 V to the output section and winding 4-5 provides approximately +10 V, which is added in series with the battery to make +VI used in the output section. A precision voltage reference circuit, U10, provides a +2.5 V reference and, through U9, a −5 V reference.

A low battery detection circuit is provided by U8A and its associated components. Resistors R35 and R36 form a voltage divider across the battery. The voltage at their junction is compared to the +2.5 V reference by U8A. When the battery voltage is below approximately +5.7 V, U8A trips and causes the LO BAT indicator on the output display to appear. There are about 15 minutes of operating time left for the calibrator after the LO BAT indication initially appears.

5.2.2 Digital-to-Analog Converter (Schematics X86-1002 and X86-1003): The Model X86 uses a digital-to-analog converter (DAC) with 4½-digit BCD control. The conversion method of the DAC is a combination of pulse averaging and dc current summing. The DAC is controlled by five up/down BCD counters: U2 (D1), U3 (D2), U4 (D3), U5 (D4) and U1 (D5) on PC board X86-1002. When U1-6 is high, the 1 digit (10 V or 100 mV) is selected. A high at U1-6 is gated through U7D on the mV or V output range and applied to two of the inverter buffers in U13 connected in parallel. (A high signal on the X86-1002 PC board is 0 V and a low is − 5 V.) The output of U13-2 and U13-4 connects through P7-2 to potentiometer R5 and resistor R23 on PC board X86-1003, causing a current to flow from the summing junction of U4.

The counters U3, U4 and U5 control the address to three BCD rate multipliers, U15, U16 and U17. A fractional part of the pulses (up to 998 for every 1,000), originating at the oscillator circuit U18, are allowed through to U13, according to the addresses on the BCD rate multipliers. For example, if 8.260 V is set on the output display, the address to U17 is a BCD 8, the address to U16 is 2 and the address to U15 is 6. The rate multipliers U15, U16 and U17 are organized as units, tens and hundreds, respectively. Therefore, U15 with an address of 6 will allow through six pulses out of a thousand; U16 with a 2 address will allow through 20 pulses out of a thousand, and U17 with an address of 8 will allow through 800 pulses out of a thousand to the input of U13. The net number of pulses to U13 is the sum of the three, or 826 out of a thousand. These pulses are averaged to a dc voltage by the three-pole filter circuit of U4 on PC board X86-1003 and scaled, so the final amplifier output would be 8.260 V. The LSD D1 and the least significant bit of D2 utilize resistors that are driven directly by U2 and U3-6 to make up the D1 output and part of the D2 output. These resistors, R20 through R24 on schematic X86-1002, have a common connection, which is routed through P7-1 to the junction of R26 and R55 on PC board X86-1003. On the V output range, these bits represent 19 mV at the voltage output when they are all selected (10 V range).

The output of the filter amplifier U4 is applied to the chopper-stabilized output amplifier, consisting of U2 and U3, either directly or through a voltage divider. The full-scale output of U4 is + 2.5 V on all ranges and is applied directly to U2 on the 10 V range, divided by 100 on the mV range, and divided by 10 on the mA output range. The correct division ratio is selected by one of the switches in the quad switch circuit U1.

The voltage output amplifier, consisting of U2 and U3, has a chopper-stabilized input section, which provides excellent stability of zero offset with time and temperature variations. The gain of the output amplifier, determined by R11 and R12, is four. (The zero circuit resistors R17 and R16 are in parallel with R12 in the gain equation.) The voltage output amplifier is fuse-protected by F3, which will blow if a voltage higher than about ± 12 V and capable of supplying greater than 250 mA is applied to the output terminals. The constant current source diode CR5, R13, R20, R21 and comparator U6A detect when the output current reaches about 15 mA and flash the 1 digit on the output display.

5.2.3 Output Value Storage Circuits (Schematic X86-1002): The output value storage capability of the Model X86 is provided by U8, U9 and U10, which are four-word by eight-bit, random-access memory (RAM) circuits. Each device provides eight input-bit lines, pins 3 through 10, and eight output-bit lines, pins 13 through 20. The memory required for U2 and U3 is provided by U9; by U10 for U4 and U5, and by U8 for U1. The data from the counters (which is always displayed) is stored in one of the four memory locations of each RAM when the STO function is selected and one of the front panel storage location buttons is pressed. For example, pressing the button labeled *1* of the STO/RCL group causes the WD1 input, pin 1 of U8, U9 and U10 to go high, while a momentarily high pulse is applied to the WR input (pin 2). The pulse at the WR input causes the input data from the counters to be stored into the selected word location. When the RCL-SEQ-STO switch is in the RCL position, data previously stored in the RAMs can be *jammed* into the counters by pressing one of the STO/RCL function buttons. Pressing one of these buttons brings the data in the addressed word location to the output pins, which are connected to the jam inputs of the counters. The PE input of the counters is pulsed high while this data is present, causing the counter to assume this exact count. This recalled data (or input value) is then displayed and converted in the DAC to an analog output value.

5.2.4 Auto Sequence Circuit (Schematic X86-1002): The auto sequence circuit is enabled when the three-position RCL-SEQ-STO switch is in the SEQ position. The sequence circuit simulates the closing of the four RCL switches in a 1, 2, 3, 4 sequence. The sequencing circuit is made up of an oscillator, U24A and U24B, a frequency divider, U23, and a decade counter, U26. The outputs of U26 select one of the memory locations, as do the front panel switches, and cause the pulse-shaping circuit (consisting of U20A and U20B) to pulse the PE input of the counters. The rate of sequencing of the output values depends upon the frequency of the oscillator, which is adjustable by the single-turn potentiometer R15. At the counterclockwise and clockwise positions of R15, the frequency is approximately 400 Hz and 3.5 KHz, respectively. These frequencies correspond to dwell-times at each step from about 60 seconds to less than 10 seconds. Turning R15 clockwise causes the sequencing to go faster. Potentiometer R15 is accessible by removing the battery pack.

5.2.5 Output Display Annunciator Drivers (Schematic X86-1002): The display annunciators LO BAT, mV, mA, V and the decimal points are driven by the gate circuits U6, U7, U12 and U19. The exclusive OR gates U12A, U12C, U19A, U19B, U19C and U19D receive output range and LO BAT information from U7 and U8A on PC board X86-1003. One of the range inputs will be high and exclusively OR'd with the back-plane signal from U11-6, resulting in an inverted back-plane signal at this specific gate's output. An inverted back-plane signal drive to any one of the annunciators causes it to illuminate. The gates U6A, U6B, U6C, U7A, U7B, U7C and U12D detect the low-battery, overrange or abnormal conditions that the instrument has been designed to recognize and cause the 1 digit to flash through U12D.

5.2.6 Switch Interface Circuits (Schematics X86-1002 and X86-1003): The output increment/decrement switches interface through circuits utilizing U20, U21, U22, U24 and U25. The D1 decrement switch is OR'd with the D1 increment switch through CR9 and connected to U25A-12 and U21A-8. If either switch is pressed, the output of U25A goes low (− 5 V), the output of the low true OR gate U22A goes low and, after a delay per R6 and C7, the output of U20C goes high. A high output from U20C enables the oscillator circuit, made up of U24C, U24D and associated components. The outputs of the oscillator U20C and the closure of one of the aforementioned switches are applied to the three-input AND gate U21A. The oscillator frequency is, therefore, gated through to the D1 counter U2. U2 will count up or down, depending upon which switch is pressed: S13 (up) or S18 (down). If S18 is pressed, in addition to creating the action described above, a high input is applied to U25B-2, causing the output of U25B to go low for as long as S18 is pressed. The output of U25B is applied to the up/down control input of the counters and a low input will cause the counters to count down when a clock is applied to the CL input, pin 15. The circuit functions of the D2, D3, D4 and D5 switches are identical to D1 described above.

The ZERO switch applies a high level to the PE input of the counters, which causes their outputs to be jammed to a zero count. The jam inputs are pulled down to − V, as the outputs of the RAMs are of the three-state type and are in the high impedance mode, unless activated by a RCL input.

The output range select switches are routed to pins 3, 4 and 5 of J8 on PC board X86-1003. A closure of any of the mV, V or mA select switches applies a high level to one of the input pins of the priority encoder U11. If two or more switches are pressed at the same time, U11 will accept only the one assigned the highest priority. The output of U11 is applied to one of the latches of the quad latch U7 simultaneously with a latch control pulse that is derived from a positive transition at the Eo output, pin 15 of U11.

5.2.7 mA Output Amplifier (Schematic X86-1003): The mA output is controlled by amplifier U5 and its associated components. Amplifier U5 receives its signal input from the output of the voltage amplifier, which is adjustable by potentiometer R8. The output current flows from + V1, through the external loop, back through P9-11, Q1, and through the current-sensing resistor R38. The voltage across R38 is applied to the inverting input of U5, pin 2, and is controlled by the amplifier circuit to be equal to the voltage applied at pin 3. The comparator U6B and its associated components cause the 1 on the output display to flash when the calibrator is in the mA output mode and the output loop is open, or when the loop load resistance is too high for the calibrator to maintain an accurate output current.

6.0 CALIBRATION

It is recommended that the performance of the Model X86 be verified at three- to six-month intervals against precision standards referenced to the National Bureau of Standards (NBS). Internal calibration adjustments should not be performed without the use of precision laboratory equipment. The calibrator may be returned to Ronan Engineering Company for calibration, or it may be calibrated in a qualified standards laboratory.

6.1 Equipment Required

The calibration set-up described below requires the minimum amount of precision equipment. Alternate calibration configurations can be used if the calibration error is sufficiently low (0.01% total calibration error).

a) dc voltage standard, 0-10 V ± 0.005% of reading ± 50 microvolts or better (must have mV output range where output offset is less than 10 microvolts)

b) resistance standard, 100 ohms ± 0.005%

c) nullmeter with 10 microvolts resolution or better (The input section of the Model X86 can be used as the nullmeter.)

6.2 Input Calibration

6.2.1 Adjustment Potentiometers: The five potentiometers used to calibrate the input are located at the top of PC board X85-1001 and the potentiometers used to calibrate the output are at the top of PC board X86-1003. These potentiometers are accessible when the top plate of the calibrator is removed. See Figure 6-1, which shows the location of the adjustment potentiometers.

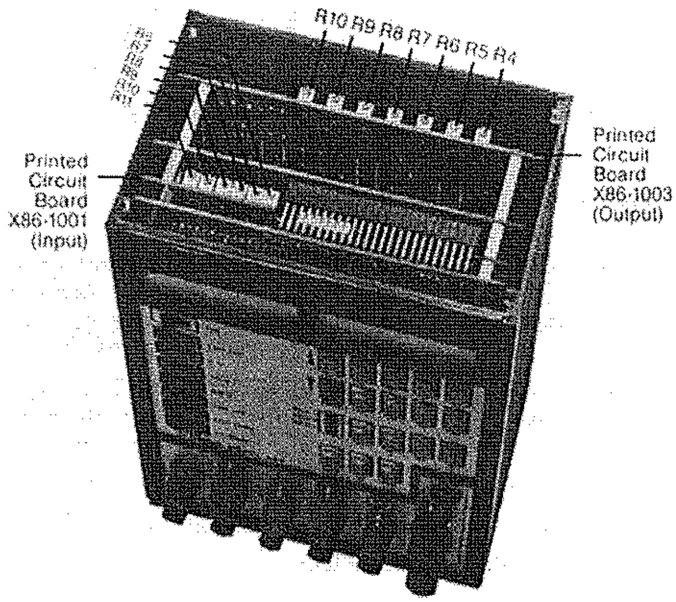


Figure 6-1

6.2.2 Input Zero Adjustment:

a) Set the calibrator to the 100 mV input range.

b) Plug a set of test leads into the V input posts and short the ends together.

c) The calibrator should indicate 00.00 mV on the input meter, after it has warmed up for a few minutes. Use potentiometer **R7** to adjust to zero, if necessary (PC board X86-1001).

6.2.3 Input Full-scale Adjustment:

a) Connect the X86 calibrator and the dc voltage standard as shown in Figure 6-2.

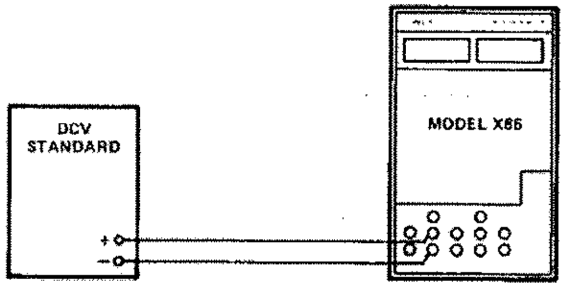


Figure 6-2: Voltage Input Calibration

b) Set the output of the dc voltage standard and the input range of the Model X86 as shown in Table 6-1. Adjust the corresponding potentiometer listed in the right column, for the correct display on the input meter, if necessary.

DCV Standard Output	Model X86 Input Range	Adjustment Potentiometer
1.000 V	1 V	R10
100.00 mV	100 mV	R6
10.000 V	10 V	R8

Table 6-1: Voltage Input Calibration

6.2.4 Ohms Measurement Adjustment:

a) Connect the Model X86 and the precision 100-ohm resistor as shown in Figure 6-3. Connect the resistor directly to the OHM binding posts to eliminate errors caused by test lead wire.

b) Set the Model X86 input to the 100-ohm range. Potentiometer R9 should be used to adjust the input display to 100.00, if necessary.

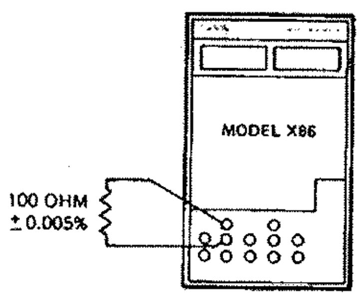


Figure 6-3: Ohms Input Calibration

6.3 Output Calibration

6.3.1 Voltage Output Zero Adjustment:

a) Connect the Model X86 Portable Calibrator, the dc voltage standard and the nullmeter as shown in Figure 6-4. All potentiometer adjustments referred to in this section are located on PC board X86-1003.

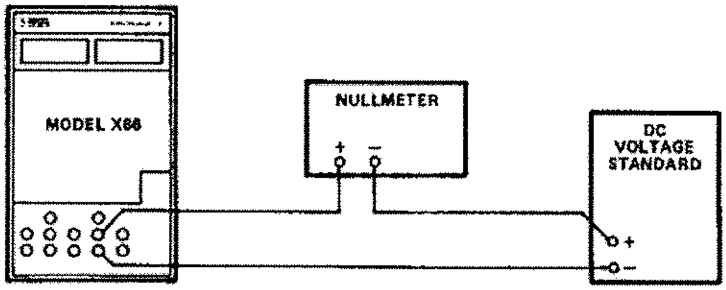


Figure 6-4: Voltage Output Measurement

b) Connect the two test leads to the dc voltage standard together. Set the Model X86 output to the mV range and set the output display to 00.00.

c) The nullmeter (10-microvolt resolution) should indicate 00.00 ± 0.01. Potentiometer R9 is used to adjust the mV zero, if necessary.

d) Set the Model X86 output to the V range and maintain the display of 0.000 V.

e) The nullmeter should indicate 00.00 ± 0.1 mV (0.1 mV is 0.001% of range). Potentiometer R7 is used to adjust the V zero, if necessary.

f) Repeat steps b and c.

6.3.2 Voltage Output Full-scale Adjustment:

a) Reconnect the two test leads to the dc voltage standard as shown in Figure 6-4.

b) Set the Model X86 output range, output value and dc voltage standard as shown in Table 6-2. Adjust the corresponding potentiometer, if necessary, to bring the error reading on the nullmeter to, or below, that given in Table 6-2.

X86 Output		dc Voltage Standard Output	Nullmeter Reading	Adjustment Potentiometer
Range	Display			
10 V	9.999 V	9.999V	0 ± 1 mV	R4
10 V	10.000 V	10.000 V	0 ± 1 mV	R5
100 mV	100.00 mV	100.00 mV	0 ± 0.01 mV	R6

Table 6-2: Output Calibration Data

6.3.3 mA Output Adjustment: Connect the Model X86 Portable Calibrator, the dc voltage standard, the 100-ohm precision resistor and the nullmeter as shown in Figure 6-5.

NOTE: The voltage output calibration steps must be performed before the mA output adjustment are done.

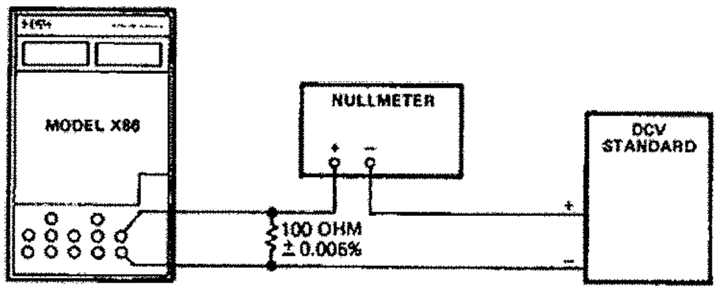


Figure 6-5: Current Output Measurement

a) Set the Model X86 to the mA output range.

b) Set the output display to 1.00 mA.

c) Set the dc voltage standard to 100.00 mV.

d) The nullmeter should indicate 0.0000 ± 0.001 V. Potentiometer R10 is used to adjust this value.

e) Set the Model X86 output display to 60.00 mA.

f) Set the dc voltage standard to 6.00 V.

g) The nullmeter should indicate 0.000 ± 0.001 V. Potentiometer R8 is used to adjust this value.

7.0 TROUBLESHOOTING GUIDE

Refer to Table 7-1 for some specific troubleshooting guidelines. For further assistance, refer to the circuit description sections and schematics in this manual. Ronan Engineering Company maintains a service and repair department where the calibrator may be sent for repair and calibration.

Abnormality	Possible Cause	Corrective Action
No display	Low or faulty battery, fuse F2, board X86-1003	Charge battery per section 3.10. If battery voltage is good, check fuse F2 on PC board X86-1003.
No voltage output	Fuse F3, board X86-1003	Check fuse F3 and replace, if required.
Unstable output display	Front panel switch left in SEQ position	Set to RCL position
No current output on mA output range. Voltage output normal.	mA output amplifier. See section 5.2.7	Replace defective component
OHM measurement incorrect. Voltage input okay.	Ohms circuit. See See section 5.1.3	Replace defective component
No reading on mA input. Voltage input okay.	Fuse F1, board X86-1003	Replace defective component.

Table 7-1: Troubleshooting Guide

PARTS LIST— MODEL X86 PORTABLE CALIBRATOR

X86-1000 Display and Switch Board

Item	Qty.	ID	Part No.
1	1		X86-1000
2	2	P1,4	929647-0525
3	1	P2	929647-04-22
4	1	P3	929647-04-08
5	4		SSK-122-S-G
6	7	S2,3,4,5,6,7,8	6450.0003
8	1	S14	6450.0005
9	16	S9,10,11,12,13,15,16,17,18,20, 21,22,23,24,25,26	6450.0001
10	1	S1	L202-2
11	1	S19	L203-01-1-MS-02-QA
12	2	DSP1,2	X86B1
13	1	U1	ICM7211IPL
14	4	U2,3,4 5	CD4055BE
15			

PARTS LIST— MODEL X86 PORTABLE CALIBRATOR

X86-1001 Input Board

Item	Qty.	ID	Part No.
1	1		X86-1001B
2	1	R17	RN55C2212
3	1	R20	RN55C1022
4	1	R21	RN55C1542
5	2	R18,27	RN55C2002
6	1	R25	RN55C2492
7	1	R19	RN55C2552
8	1	R1	RN55C3652
9	1	R4	RN55C7872
10	1	R15	RN55C2373
11	2	R5,16	
12	1	R14	RC07GF390J
13	1	R24	RC07GF221J
14	1	R26	RC07GF333J
15	8	R12,13,23,29,30,31,35,36	RC07GF104J
16	1	R39	RC07GF224J
17	1	R34	RC07GF106J
18	1	R37	RC07GF474J
19	1	R28	EI-71
20	1	R22	EI-27

Description	Vendor
Printed Circuit Board	Ronan
Header Strip, 25 Pins	A.P. Products
Header Strip, 22 Pins	A.P. Products
Header Strip, 8 Pins	A.P. Products
Socket Strip (for LCDs)	Samtec
Switch, Momentary, Dark Grey	Marquardt
Switch, Momentary, Black	Marquardt
Switch, Momentary, Grey	Marquardt
Switch, DPDT	C&K
Switch, DP3T	C&K
Liquid Crystal Display	Hamlin
LCD Decoder/Driver	Intersil
Decoder/Driver	RCA

Description	Vendor
Printed Circuit Board	Ronan
Resistor, M.F., ¼ W, 1%, 22.1 k	Mepco
Resistor, M.F., ¼ W, 1%, 10.2 k	Mepco
Resistor, M.F., ¼ W, 1%, 15.4 k	Mepco
Resistor, M.F., ¼ W, 1%, 20.0 k	Mepco
Resistor, M.F., ¼ W, 1%, 24.9 k	Mepco
Resistor, M.F., ¼ W, 1%, 25.5 k	Mepco
Resistor, M.F., ¼ W, 1%, 36.5 k	Mepco
Resistor, M.F., ¼ W, 1%, 78.7 k	Mepco
Resistor, M.F., ¼ W, 1%, 237 k	Mepco
Jumper	
Resistor, Carbon, ¼ W, 5%, 39 ohm	A.B.
Resistor, Carbon, ¼ W, 5%, 220 ohm	A.B.
Resistor, Carbon, ¼ W, 5%, 33 k	A.B.
Resistor, Carbon, ¼ W, 5%, 100 k	A.B.
Resistor, Carbon, ¼ W, 5%, 220 k	A.B.
Resistor, Carbon, ¼ W, 5%, 10 M	A.B.
Resistor, Carbon, ¼ W, 5%, 470 k	A.B.
Resistor, W.W., .01%, 10 ohm	Elliott Ind.
Resistor, W.W., .1%, 975 ohm	Elliott Ind.

PARTS LIST—
MODEL X86 PORTABLE CALIBRATOR

X86-1001 Input Board (continued)

Item	Qty.	ID	Part No.
21	1	R38	RC07GF473J
22	1	R33	EI-27
23	1	R32	EI-27
T/C Ratio, Matched Pair (R33, R32) — 5PPM Part Number X86B15-1			
24	1	R2	EI-27
25	1	R3	EI-27
T/C Ratio, Matched Pair (R2, R3) — 5PPM Part Number X86B15-2			
26	2	RN1,3	4310R-101-224
26	1	RN2	1776-9
27			
28	2	R6,9	89PR50
29	2	R8,10	89PR500
30	1	R7	89PR10K
31	1	R11	80PR100K
32			
33	1	C12	331R501M05
34	1	C13	102R102C20
35	1	C6	103R101C20
36	1	C15	103A101C20
37	9	C1,7,8,9,14,16,19,20,21	104A500C10
38	2	C17,18	104R101R10
39	3	C2,10,11	474A101K10
40	3	C3,4,5	685R350T10
41	1	C22	224R350T10
42			
43	2	CR1,4	IN4148D
44	1	CR2	IN0457A
45	1	CR3	IN4005D
46			
47	1	Q2	2N6719-5
48	1	Q1	2N6519-5
49	1	Q3	2N5396
50			
51	1	U1	MC1400AG2
52	1	U5	ICL7135CPI
53			
54	1	U12	ICL7650CPD
55	1	U2	LM358AN
56	1	U6	LM312H
57	2	U7,17	74C14N
58	1	U3	CD4070BE
59	1	U4	CD4081BE

Description	Vendor
Resistor, Carbon, ¼ W, 5%, 47 k	A.B.
Resistor, W.W., .1%, 7.20 k	Elliott Ind.
Resistor, W.W., .1%, 65.0 k	Elliott Ind.
Resistor, W.W., .1%, 24.75 k	Elliott Ind.
Resistor, W.W., .1%, 37.25 k	Elliott Ind.
Resistor Newtwork, 220 k	Bourns
Precision Voltage Divider	Caddock
Potentiometer, 50 ohm	Beckman
Potentiometer, 500 ohm	Beckman
Potentiometer, 10 k	Beckman
Potentiometer, 100 k	Beckman
Capacitor, Mica, 330 pFd	Arco
Capacitor, Ceramic, .001/1000	Sprague
Capacitor, Ceramic, .01/100	Sprague
Capacitor, Ceramic, .01/100	Unitrode
Capacitor, Ceramic, .1/50 V	Unitrode
Capacitor, Polyester, .1/100 V	ERO
Capacitor, Polycarb., .47/100 V	ERO
Capacitor, Tantalum, 6.8/35	Sprague
Capacitor, Tantalum, .22/35	Sprague
Diode, Signal	Fairchild
Diode, Low Leakage	Fairchild
Diode, Rectifier	Fairchild
Transistor, NPN	Motorola
Transistor, PNP	Motorola
Field-effect Transistor	Motorola
Precision Voltage Reference, 2.5 V	Motorola
Precision, 4½-digit A/D Converter	Intersil
Chopper-stabilized Operational Amp.	Intersil
Quad Operational Amplifier	National
Operational Amplifier	National
Hex Schmitt Inverters	National
Quad XOR Gate	RCA
Quad AND Gate	RCA

PARTS LIST— MODEL X86 PORTABLE CALIBRATOR

X86-1001 Input Board (continued)

Item	Qty.	ID	Part No.
60	1	U8	CD4013BE
61	4	U9,10,11,16	CD4066BE
62	1	U13	CD4025BE
63	1	U14	CD4071BE
64	1	U15	CD4514BE
65	1	U18	CD4532BE
66	1	J2	4455-BC-22-17-2222
67	1	J3	4455-BC-22-17-2082
68	1	P5	TSW-110-14-G-S (929647-08-10)

PARTS LIST— MODEL X86 PORTABLE CALIBRATOR

X86-1002 Switch Interface and DAC Circuits

Item	Qty.	ID	Part No.
1	1		X86-1002B
2	2	J1,4	SSW-125-01-G-S
3	1	J5	SSW-110-01-G-S
4	1	P6	960423
5	1	P7	960424
6	1	P8	960425
7			
8	1	R1	RC07GF100J
9	6	R3,10,11,12,13,18	RC07GF103J
10	1	R4	RC07GF223J
11	4	R5,8,9,25	RC07GF104J
12	3	R14,17,19	RC07GF224J
13	3	R6,7,16	RC07GF684J
14			
15			
16	1	R15	82PA100K
17	3	RN1,2,3	4310R-101-224
18			
19	1	R24	RN55C1003B
20	1	R20	RN55C1253B
21	1	R2	RN55C1373
22	1	R21	RN55C2493
23	1	R22	RN55C4993
24	1	R23	RN55C1004
25			

Description	Vendor
Dual "D" Flip-flop	RCA
Quad Bilateral Switch	RCA
Triple NOR Gate	RCA
Quad OR Gate	RCA
Four-bit Latch/Decoder	RCA
Eight-bit Priority Encoder	RCA
22-pin Bottom Entry Receptacle	Molex
Eight-pin Bottom Entry Receptacle	Molex
Ten-pin Header Assembly	Samtec (A.P. Products)

Description	Vendor
Printed Circuit Board	Ronan
Socket Strip, 25 Positions	Samtec
Socket Strip, 10 Positions	Samtec
Header Strip, 10 Pins	A.P. Products
Header Strip, 12 Pins	A.P. Products
Header Strip, Six Pins	A.P. Products
Resistor, Carbon, ¼ W, 5%, 10 ohm	A.B.
Resistor, Carbon, ¼ W, 5%, 10 k	A.B.
Resistor, Carbon, ¼ W, 5%, 22 k	A.B.
Resistor, Carbon, ¼ W, 5%, 100 k	A.B.
Resistor, Carbon, ¼ W, 5%, 220 k	A.B.
Resistor, Carbon, ¼ W, 5%, 680 k	A.B.
Potentiometer, 1T, 100 k	Beckman
Resistor Pack, 220 k	Bourns
Resistor, M.F., ¼ W, 0.1%, 100 k	Mepco
Resistor, M.F., ¼ W, 0.1%, 125 k	Mepco
Resistor, M.F., ¼ W, 1%, 137 k	Mepco
Resistor, M.F., ¼ W, 1%, 249 k	Mepco
Resistor, M.F., ¼ W, 1%, 499 k	Mepco
Resistor, M.F., ¼ W, 1%, 1 M	Mepco

PARTS LIST—
MODEL X86 PORTABLE CALIBRATOR

X86-1002 Switch Interface and DAC Circuits (continued)

Item	Qty.	ID	Part No.
26	3	CR3,13,14	IN0457A
27	11	CR1,2,4,5,6,7,8,9,10,11,12	IN4148D
28			
29	1	C3	121R501M05
30	1	C11	103A101C20
31	1	C12	503R101C20-2
32	7	C1,2,5,6,9,10,13	104A101C20
33	1	C8	684R101R10
34	1	C7	224R101R10
35	1	C4	685R350T20
36			
37	1	U24	CD4001BE
38	2	U12,19	CD4070BE
39	1	U25	CD4002BE
40	2	U21,22	CD4073BE
41	1	U6	CD4075BE
42	1	U7	CD4081BE
43	1	U20	CD40106BE or MCM74C14
44			
45	1	U26	CD4017BE
46	2	U11,23	CD4020BE
47	5	U1,2,3,4,5	CD4029BE
48	1	U18	CD4047BE
49	1	U13	CD4049BE
50	3	U15,16,17	CD4527BE
51	3	U8,9,10	CD4039AE

Description	Vendor
Diode, Low Leakage	Fairchild
Diode, Signal	Motorola
Capacitor, D.M. 120 pFd	Arco
Capacitor, Ceramic, .01 mfd	Unitrode
Capacitor, Ceramic, .05 mfd	Sprague
Capacitor, Ceramic, .1 mfd	Unitrode
Capacitor, Polyester, .68/100	Mepco
Capacitor, Polyester, .22/100	Mepco
Capacitor, Tantalum, 6.8/35	Sprague
Quad 2-input NOR Gate	RCA
Quad 2-input XOR Gate	RCA
Dual 4-input NOR Gate	RCA
Triple 3-input AND Gate	RCA
Triple 3-input OR Gate	RCA
Quad 2-input AND Gate	RCA
Hex Buffer, Schmitt Trigger	RCA
Decade Counter/Divider	RCA
Binary Counter/Divider	
Pre-settable Up/Down Counter	RCA
Astable Multivibrator	RCA
Hex Buffer/Inverter	
BCD Rate Multiplier	RCA
RAM 4 words × 8 bits	RCA

PARTS LIST—
MODEL X86 PORTABLE CALIBRATOR

X86-1003 Power Supply and Output Amplifier

Item	Qty.	ID	Part No.
1	1		X86-1003B
2			
3	1	R40	RC07GF220J
4	1	R13	RC07GF680J
5			
6	1	R39	RC07GF682J
7	11	R15,18,21,28,37,42,48, 49,50,52,53	RC07GF103J
8	1	R51	RC07GF183J
9	3	R14,19,29	RC07GF223J
10	1	R22	RC07GF473J
11	3	R33,34,41	RC07GF104J
12	1	R31	RC07GF105J
13	1	R32	RC07GF474J
14	3	R43,44,45	RC07GF224J
15			
16	1	R55	RN55C20R2B
17	1	R20	RN55C3571
18	1	R30	RN55C1242
19	1	R27	RN55C2000
20	1	R35	RN55C3243
21	1	R36	RN55C2493
22	1	R54	RN55C4992
23	1	R25	RN55C1003
24	1	R26	RN55C1823
25	1	R24	RN55C8251
26	2	R16,17	RN55C1004
27			
28	1	R46	EI27-10K, .1%
29	1	R47	EI27-19.9K, .1%
T/C Ratio Matched Pair (R46, R47) 5PPM — Part Number X86B15-4			
30	1	R1	EI27
31	1	R2	EI27
32	1	R3	EI27
T/C Ratio Matched Set (R1, R2, R3) 5PPM — Part Number X86B15-3			
33	1	R12	EI27
34	1	R11	EI27
T/C Ratio Matched Pair (R12, R11) 5PPM — Part Number X86B15-5			
35	1	R38	EI27
36	1	R23	TF02R-398.0K
37	1	RN1	T914-100K-100-05
38			

Description	Vendor
Printed Circuit Board	Ronan
Resistor, Carbon, ¼ W, 5%, 22 ohm	A.B.
Resistor, Carbon, ¼ W, 5%, 68 ohm	A.B.
Resistor, Carbon, ¼ W, 5%, 6.8 k	A.B.
Resistor, Carbon, ¼ W, 5%, 10 k	A.B.
Resistor, Carbon, ¼ W, 5%, 18 k	A.B.
Resistor, Carbon, ¼ W, 5%, 22 k	A.B.
Resistor, Carbon, ¼ W, 5%, 47 k	A.B.
Resistor, Carbon, ¼ W, 5%, 100 k	A.B.
Resistor, Carbon, ¼ W, 5%, 1 M	A.B.
Resistor, Carbon, ¼ W, 5%, 470 k	A.B.
Resistor, Carbon, ¼ W, 5%, 220 k	A.B.
Resistor, M.F., ¼ W, .1%, 20.2 ohms	Mepco
Resistor, M.F., ¼ W, 1%, 3.57 k	Mepco
Resistor, M.F., ¼ W, 1%, 12.4 k	Mepco
Resistor, M.F., ¼ W, 1%, 200 ohms	Mepco
Resistor, M.F., ¼ W, 1%, 324 k	Mepco
Resistor, M.F., ¼ W, 1%, 249 k	Mepco
Resistor, M.F., ¼ W, 1%, 49.9 k	Mepco
Resistor, M.F., ¼ W, 1%, 100 k	Mepco
Resistor, M.F., ¼ W, 1%, 182 k	Mepco
Resistor, M.F., ¼ W, 1%, 8.25 k	Mepco
Resistor, M.F., ¼ W, 1%, 1 M	Mepco
Resistor, W.W., 10 k ± 0.1%	Elliott Ind.
Resistor, W.W., 19.9 k ± 0.1%	Elliott Ind.
Resistor, W.W., 995 ohm ± 0.1%	Elliott Ind.
Resistor, W.W., 8.95 k	Elliott Ind.
Resistor, W.W., 89.95 k	Elliott Ind.
Resistor, W.W., 13.42 k ± 0.1%	Elliott Ind.
Resistor, W.W., 40.0 k	Elliott Ind.
Resistor, W.W. 10.0 ohm ± 0.05%	Elliott Ind.
Resistor, Prec. Film, 398 k ± 0.1%-5PPM	Caddock
Precision Resistor Network, 100 ks	Caddock

PARTS LIST—
MODEL X86 PORTABLE CALIBRATOR

X86-1003 Power Supply and Output Amplifier (continued)

Item	Qty.	ID	Part No.
39	1	R6	89PR-10
40	1	R8	89PR-100
41	1	R4	89PR-200
42	1	R5	89PR-5K
43	2	R9,10	89PR-100K
44	1	R7	89PR-20K
45			
46	2	C14,31	391R501M05
47	2	C2,13	681R301M05
48	1	C33	224R101R10
49	3	C17,18,21	503R101C20
50	2	C7,30	103R101C20
51	12	C1,4,5,6,10,11,12,15 16,22,29,32	104A101C10
52	7	C9,23,24,25,26,27,28	685R350T20
53	2	C8,9	104R101R10 (719A1CA104PK101SA)
54	1	C3	334R630K10
55	1	C20	684R101K10 (719B1GF684PK101SB)
56	1	C19	105R101K10 (719B1GG105PK101SB)
57			
58	9	CR12,13,14,15,16,17,18,19,21	IN4148D
59	2	CR22,23	IN0457A
60	1	CR3	IN5313
61	1	CR5	IN5287
62	1	CR4	IN5237B
63	2	CR1,2	IN5349A
64	1	CR25	IN4005D
65			
66	2	Q3,4	VN66AF or VN0106N3
67	1	Q1	VN88AF
68	1	Q2	2N4392
69	1	U1	CD4066BE
70	1	U7	CD4042BE
71	1	U11	CD4532BE
72	1	U12	CD4047BE
73	2	U3,9	LM10CN
74	2	U6,8	LM393N
75	1	U5	LM312HC
76	1	U4	μA714HC

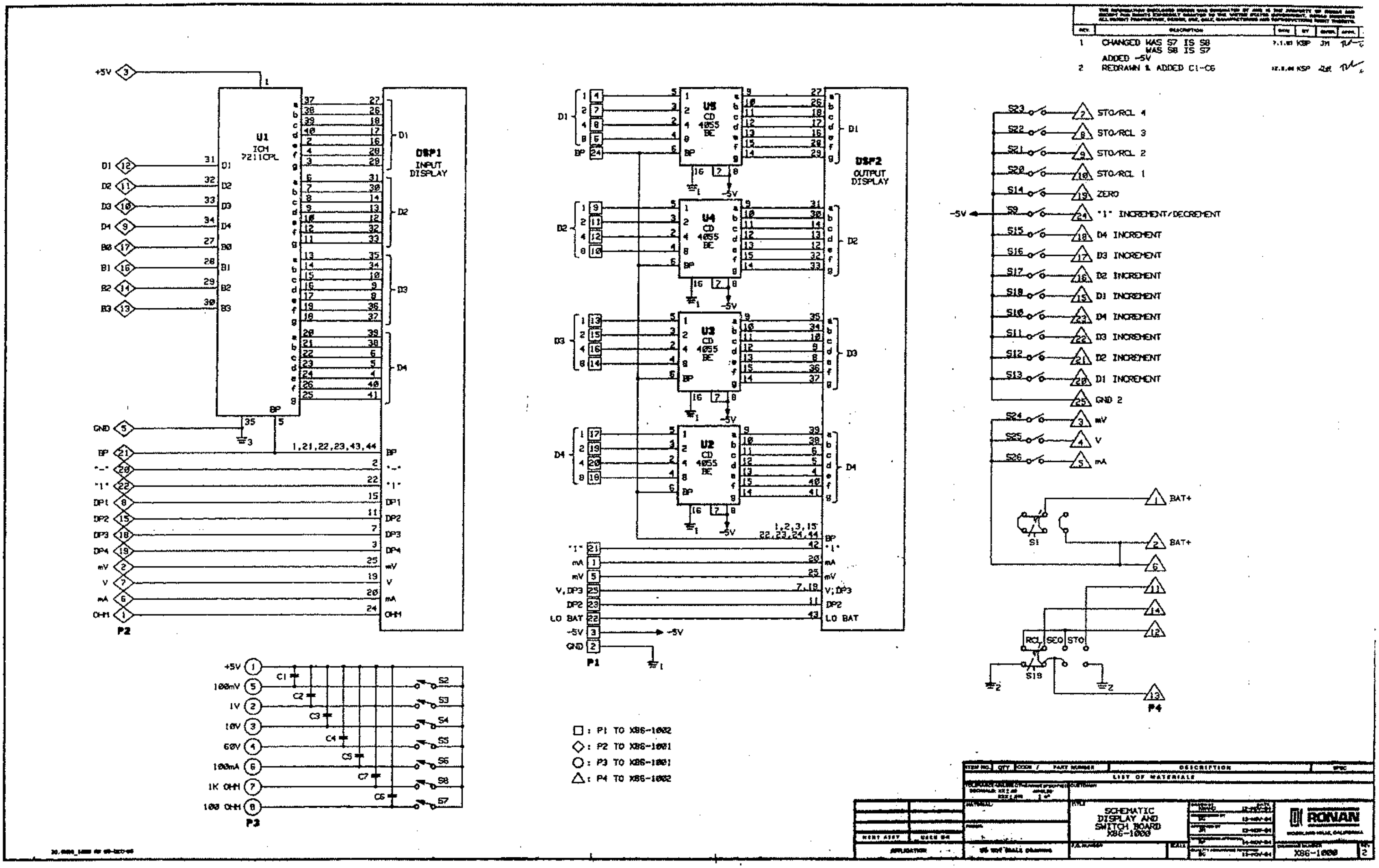
Description	Vendor
Potentiometer, 10T, 10 ohm	Beckman
Potentiometer, 10T, 100 ohm	Beckman
Potentiometer, 10T, 200 ohm	Beckman
Potentiometer, 10T, 5 k	Beckman
Potentiometer, 10T, 100 k	Beckman
Potentiometer, 10T, 20 k	Beckman
Capacitor, DM, 390 pFd	Arco
Capacitor, DM, 680 pFd	Arco
Capacitor, Polyester, .22/100	Mepco
Capacitor, Ceramic, .05 mfd	Sprague
Capacitor, Ceramic, .01 mfd	Sprague
Capacitor, Ceramic, .1 mfd	Unitrode
Capacitor, Tantalum, 6.8/35	
Capacitor, Polyester, .1 mfd	Mepco
Capacitor, Polycarbonate, .33/63 V	Mepco
Capacitor, Polycarbonate, .68/100 V	Mepco
Capacitor, Polycarbonate, 1/100 V	Mepco
Diode, Signal	Motorola
Diode, Low Leakage	Fairchild
Constant Current Source	Motorola
Constant Current Source	Motorola
Diode, Zener, 8.2 V	Motorola
Diode, Zener, 12 V	Motorola
Diode, Rectifier	Motorola
Transistor, V-MOS	Siliconix
Transistor, V-MOS	Siliconix
Field-Effect Transistor	Motorola
Quad Switch	RCA
Quad Latch	RCA
Priority Encoder	RCA
Oscillator with Flip-flop	RCA
Precision Operational Amplifier	National
Dual Comparator	National
Operational Amplifier	National
Precision Operational Amplifier	Fairchild

PARTS LIST—
MODEL X86 PORTABLE CALIBRATOR

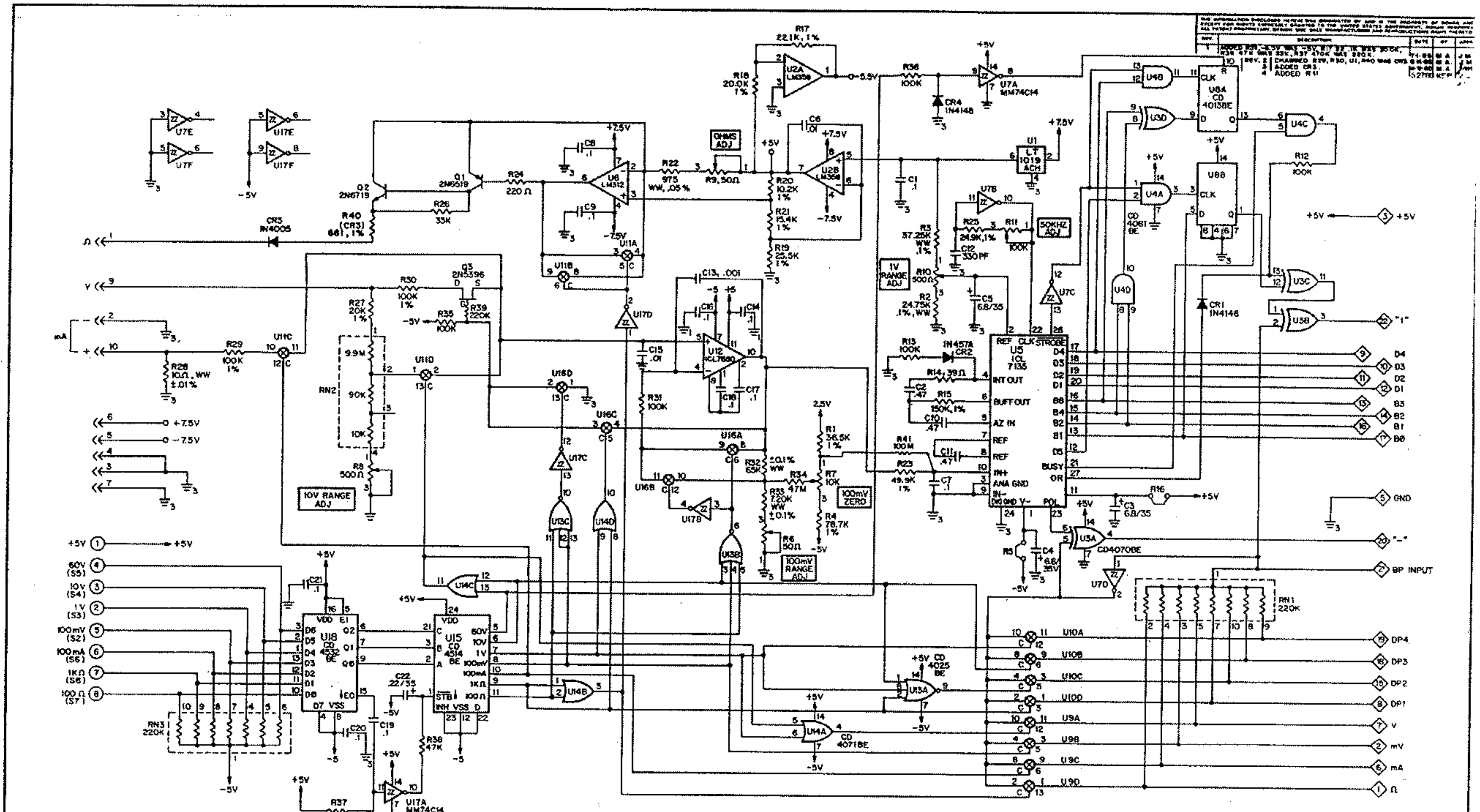
X86-1003 Power Supply and Output Amplifier (continued)

Item	Qty.	ID	Part No.
77	1	U2	ICL7650CPD
78	1	U10	MC1400AG2
79	2	F1,3	362.250
80	1	F2	362.500
81			
82	1	T1	X86B2
83	1	J6	SSW-110-01-G-S
84	1	J7	SSW-112-01-G-S
85	1	J8	SSW-106-01-G-S
86	1	P9	2461-09-80-1123
87	6		3529 or 926
88	1		60B065

Description	Vendor
Chopper-stabilized Operational Amp.	Intersil
Precision Voltage Reference, 2.5 V	Motorola
Fuse, ¼ Amp	Little Fuse
Fuse, ½ Amp	Little Fuse
Transformer	Mercury Mag.
Socket Strip, 10 Positions	Samtec
Socket Strip, 12 Positions	Samtec
Socket Strip, 6 Positions	Samtec
Plug, 12 Positions	Molex
Fuse Holder	Keystone Zierick
Battery Power Cord, 9"	



1 CHANGED WAS S7 IS S8 WAS S8 IS S7
ADDED -5V
2 REDRAWN & ADDED C1-C6
U1 ICM 7211CPL
DSP1 INPUT DISPLAY
DSP2 OUTPUT DISPLAY
U5 CD 4055 BE
U4 CD 4055 BE
U3 CD 4055 BE
U2 CD 4055 BE
STO/RCL 4
STO/RCL 3
STO/RCL 2
STO/RCL 1
ZERO
"1" INCREMENT/DECREMENT
D4 INCREMENT
D3 INCREMENT
D2 INCREMENT
D1 INCREMENT
GND 2
BAT+
P1
P2
P3
P4
□ : P1 TO X86-1002
◇ : P2 TO X86-1001
○ : P3 TO X86-1001
△ : P4 TO X86-1002
LIST OF MATERIALS
SCHEMATIC DISPLAY AND SWITCH BOARD X86-1000
RONAN
X86-1000



DO NOT REVISE DRAWING
WITHOUT APPROVAL BY
FACTORY MUTUAL

5. U9, U10, U11, U16 ARE CD4066BE. PIN14=+5V, PIN7=-5V
4. RESISTORS ARE 1/4W, 5%
3. RESISTOR VALUES ARE IN OHMS
2. CAPACITOR VALUES ARE IN MICROFARADS
≪: P5 TO X86-1002 (10 POS)
○: J3 TO X86-1000 (8 POS)
◇: J2 TO X86-1000 (22 POS)

NOTES: UNLESS OTHERWISE SPECIFIED

LIST OF MATERIALS

SCHEMATIC
INPUT BOARD

RONAN

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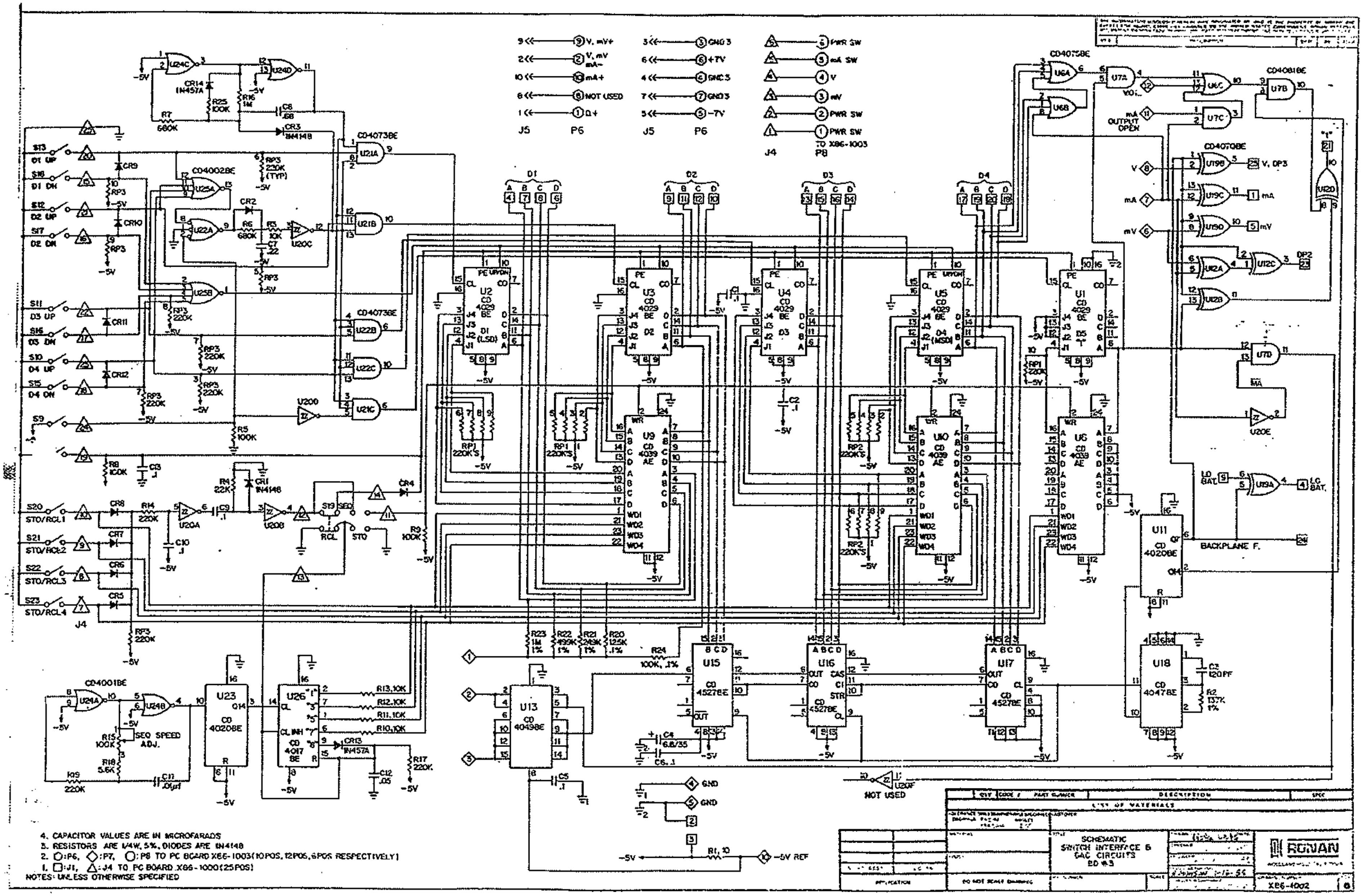
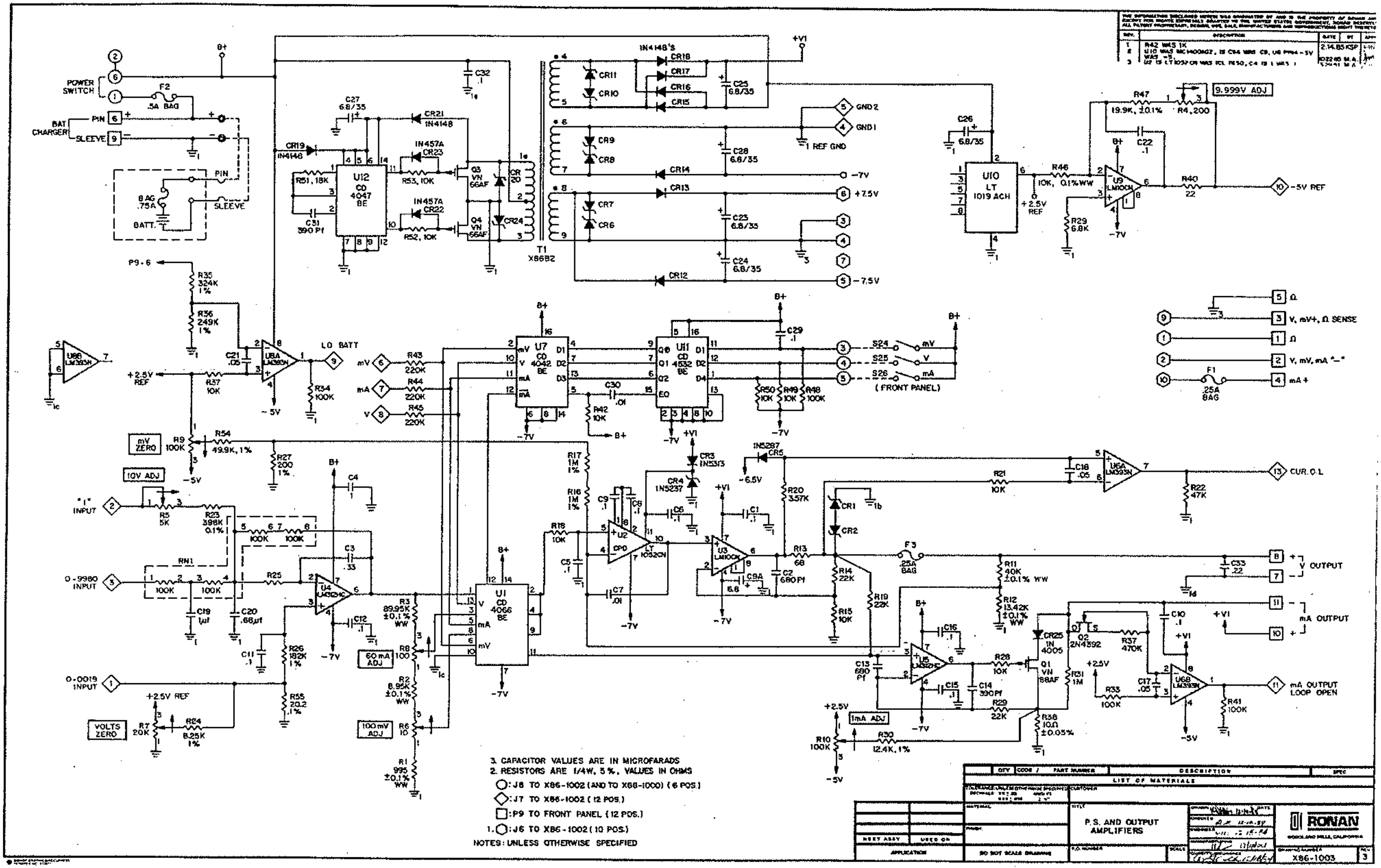
APPLICATION

X861S-1001

4


SCHEMATIC
SWITCH INTERFACE & DAC CIRCUITS
BD #3
RONAN
X86-4002
LIST OF MATERIALS
DO NOT SCALE DRAWING
4. CAPACITOR VALUES ARE IN MICROFARADS
3. RESISTORS ARE 1/4W, 5%, DIODES ARE IN4148
2. ◯:P6, ◇:P7, ◯:P8 TO PC BOARD X86-1003 (10 POS, 12 POS, 6 POS RESPECTIVELY)
1. ▢:J1, △:J4 TO PC BOARD X86-1000 (25 POS)
NOTES: UNLESS OTHERWISE SPECIFIED
BACKPLANE F.
SEQ SPEED ADJ.
OUTPUT OPEN
NOT USED
-5V REF



3. CAPACITOR VALUES ARE IN MICROFARADS
2. RESISTORS ARE 1/4W, 5%, VALUES IN OHMS
○: J8 TO X86-1002 (AND TO X86-1000) (6 POS.)
◇: J7 TO X86-1002 (12 POS.)
□: P9 TO FRONT PANEL (12 POS.)
1. ⬡: J6 TO X86-1002 (10 POS.)
NOTES: UNLESS OTHERWISE SPECIFIED

REV.	DESCRIPTION	DATE	BY
1	R42 WAS 1K	2.14.85	KSP
2	U10 WAS MC1400G2, IS C54 WAS C9, U6 PIN4 -5V WAS +5.	102280	M.A.
3	U2 IS LT1052 CN WAS ICL 7650, C4 IS 1 WAS 1		M.A.

LIST OF MATERIALS

P.S. AND OUTPUT AMPLIFIERS

RONAN
WOODLAND HILLS, CALIFORNIA

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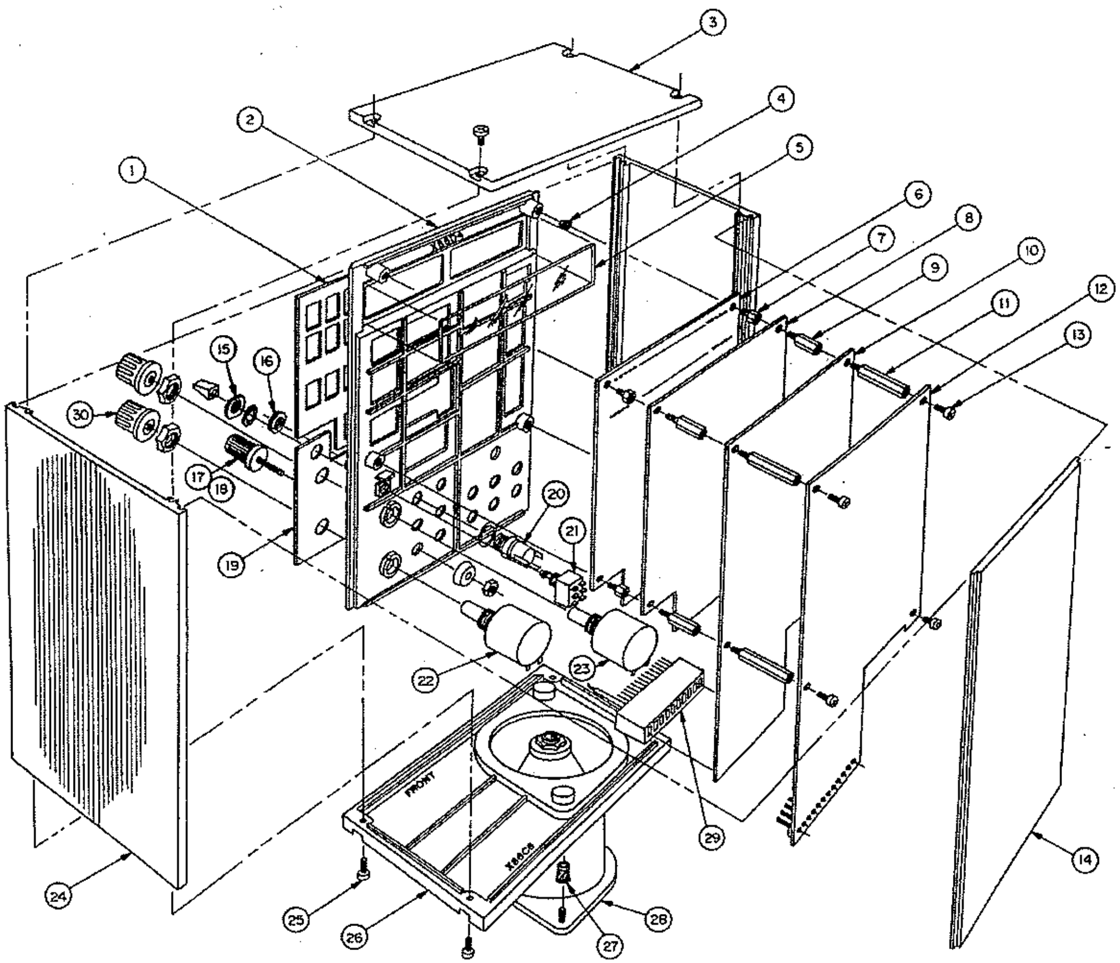
X86-1003 REV 3



REV.	DESCRIPTION	DATE	BY	APP
1	REVISED PART NO. ITEM 24 WAS X86B7, ITEM 14 WAS X86B14, ITEM 18 IS RED WAS BLK, ITEM 17 IS BLK WAS RED.		M.A	
2	ITEM 26,3,2 SPEC WAS GAYLORD PLAS IS LBM		M.A	
3	ADDED ITEM #31,#32			
4	ITEM 1 IS X86C9 WAS X86B9, ITEM 19 IS X86C11 WAS X86B11, ITEM 29 IS 09-50-7121 WAS 2139-09-50-7121		M.A	
5	REVISED ITEMS 7,9,11,14,15,17,18,22-24.		M.A	
6	ADDED -1 ITEM 1 & 19, ITEM 10 WAS X86-1002		M.A	
7	REVISED PER ECN 2636.		M.A	
8	REVISED PER ECN 3792.		M.A	
9	REVISED PER ECO 8291			

* SEE DRAWING X86C25 FOR LOCATION

	ITEM #	QTY	CODE / PART NUMBER	DESCRIPTION	SPEC
*	32	1	503R501C20	CAPACITOR C2	SPRAGVE
*	31	1	104A101C20	CAPACITOR C1	SPRAGVE
	30	2	PKX-50B-1/4	KNOB	ALCO
	29	1	09-50-7121	CRIMP TERMINAL HOUSING	MOLEX
	28	1	X85C54	BATTERY PACK ASSEMBLY	RONAN
	27	2	UI79136-4-4	ULTRA SONIC INSERT	SI
	26	1	X86C6	BOTTOM COVER	LBM
	25	8		6-32 X 3/8" BLACK PAN HD PHIL MACH. SCREW	WEST VALLEY
	24	2	X86B7	EXTRUSION	RONAN
	23	1	534-9598-102	POTENTIOMETER, 1K W/NUT	SPECTROL
	22	1	534-9905-101	POTENTIOMETER, 100 OHM W/NUT	SPECTROL
	21	1	7209-L41-YZBE	TOGGLE SWITCH	C&K
	20	1	712A	POWER JACK RECEPTACLE	SWITCHCRAFT
	19	1	X86C11-1	GRAPHIC PANEL (BOTTOM) ⚠	RONAN
	18	7	3015-102	MINI BINDING POST, RED W/NUTS	H.H. SMITH
	17	5	3015-103	MINI BINDING POST, BLK W/NUTS	H.H. SMITH
	16	1	T-2160	KNURLED NUT	SWITCHCRAFT
	15	1	7760	BLACK FINISH NUT	C&K
	14	1	X86B14	BACK COVER	RONAN
	13	4		4-40 X 1/4" PAN HD. PHIL	WEST VALLEY
	12	1	X86-1003	P.C. BOARD, POWER SUPPLY AND O.P. AMPS	RONAN
	11	4	8222	4-40 M.F. THD. SPACER	H.H. SMITH
	10	1	X86-1008	P.C. BOARD, DAC CIRCUITS	RONAN
	9	4	8218	4-40 M.F. THD. SPACER	H.H. SMITH
	8	1	X86-1001	P.C. BOARD, INPUT CIRCUITS	RONAN
	7	4	8216	4-40 M.F. THD. SPACER	H.H. SMITH
	6	1	X86-1000	P.C. BOARD, DISPLAY AND SWITCHES	RONAN
	5	1	X86B8	L.C.D. WINDOW ⚠	RONAN
	4	4	UI79136-2-8	ULTRA SONIC INSERT	SI
	3	1	X86C5	TOP COVER	LBM
	2	1	X86C4	FRONT PANEL	LBM
	1	1	X86C9-1	GRAPHIC PANEL (TOP) ⚠	RONAN

LIST OF MATERIALS

⚠ APPLY EPOXY OR SUPERGLUE TO MOUNT ON THE FRONT PANEL. AVOID ACESS AMOUNT OF GLUE VISIBLE FROM FRONT SIDE OF FRONT PANEL.

⚠ APPLY EPOXY OR SUPERGLUE TO MOUNT ON THE FRONT PANEL. AVOID EXCESS AMOUNT OF GLUE IN THE CUTOUT AREA

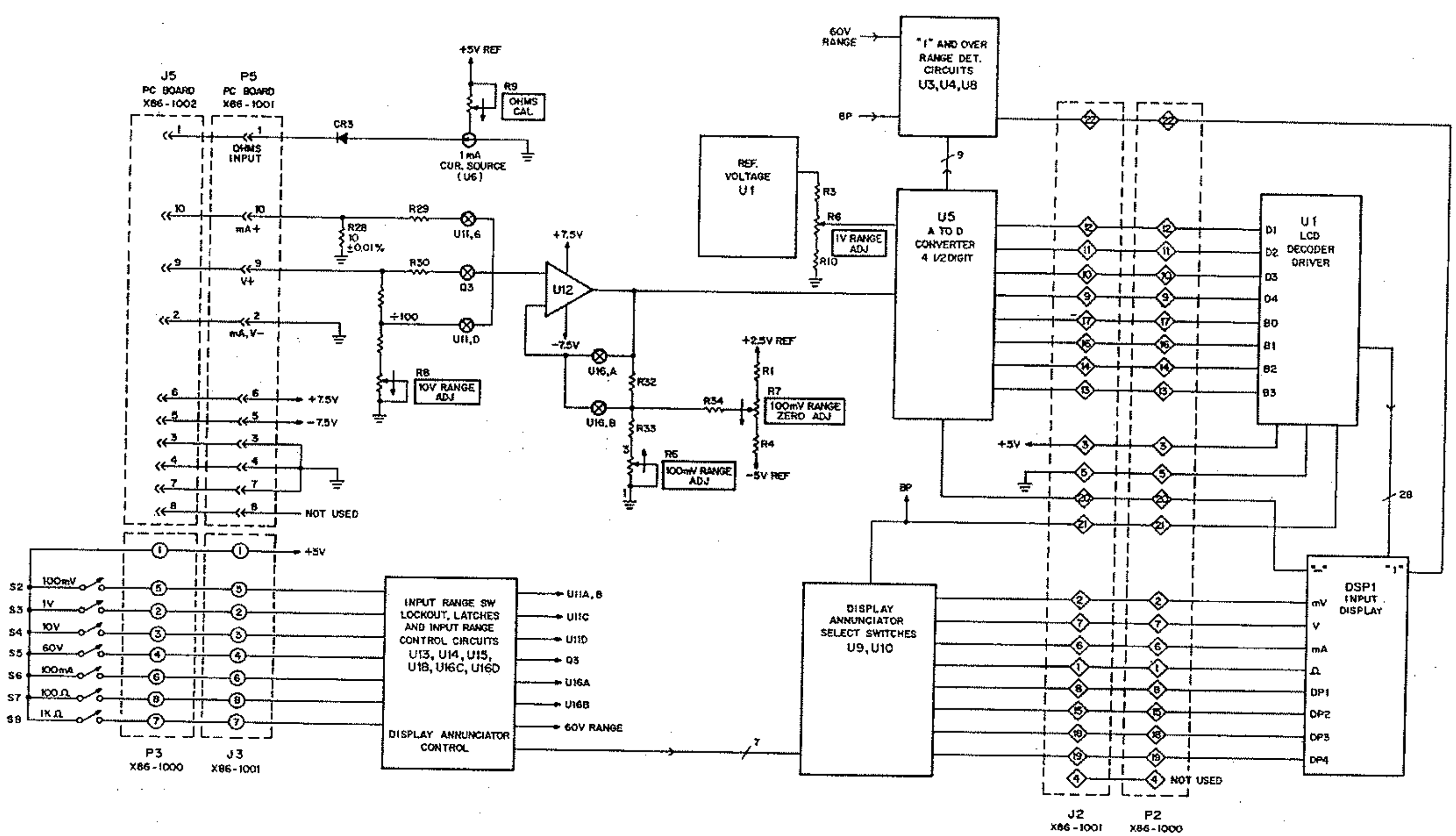
NOTES: UNLESS OTHERWISE SPECIFIED

NEXT ASSY | USED ON | APPLICATION | DO NOT SCALE DRAWING

TITLE: X86 CALIBRATOR ASSEMBLY

RONAN — WOODLAND HILLS, CALIFORNIA

DRAWING NUMBER: X86D13 REV 9



LIST OF MATERIALS

BLOCK DIAGRAM MODEL X86 INPUT CIRCUITS

RONAN

WOODLAND HILLS CALIFORNIA

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X86D16

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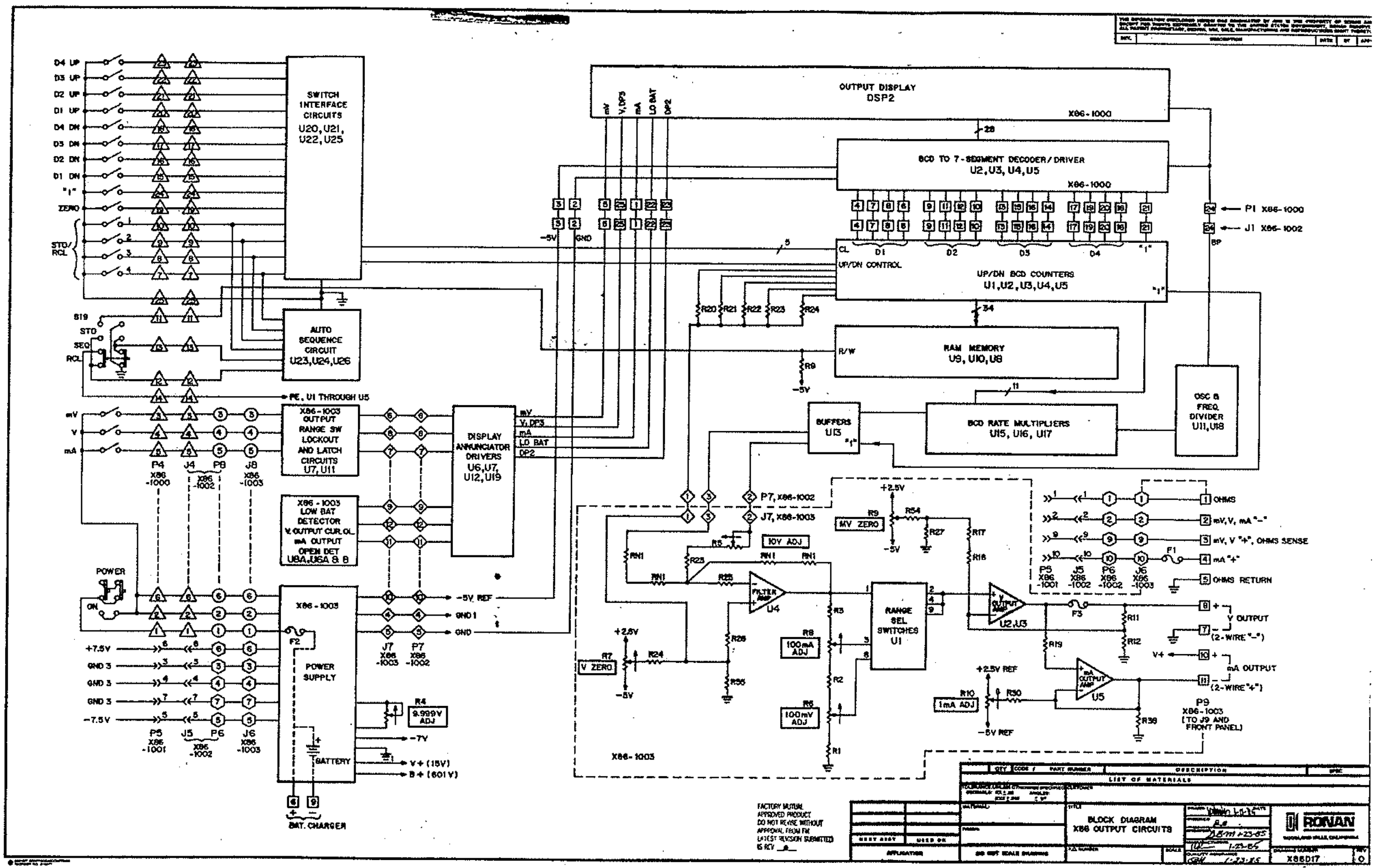

OUTPUT DISPLAY DSP2
X86-1000
BCD TO 7-SEGMENT DECODER/DRIVER U2,U3,U4,U5
UP/DN BCD COUNTERS U1,U2,U3,U4,U5
UP/DN CONTROL
RAM MEMORY U9, U10, U8
R/W
BCD RATE MULTIPLIERS U15, U16, U17
OSC & FREQ. DIVIDER U11,U18
BUFFERS U13
SWITCH INTERFACE CIRCUITS U20,U21, U22,U25
AUTO SEQUENCE CIRCUIT U23,U24,U26
X86-1003 OUTPUT RANGE SW LOCKOUT AND LATCH CIRCUITS U7,U11
X86-1003 LOW BAT DETECTOR V OUTPUT CUR OL mA OUTPUT OPEN DET U8A,U6A & B
DISPLAY ANNUNCIATOR DRIVERS U6,U7, U12,U19
X86-1003 POWER SUPPLY
BATTERY
BAT. CHARGER
D4 UP
D3 UP
D2 UP
D1 UP
D4 DN
D3 DN
D2 DN
D1 DN
"1"
ZERO
STO/RCL
S19
STO
SEQ
RCL
mV
V
mA
POWER
ON
+7.5V
GND 3
-7.5V
PE, U1 THROUGH U5
-5V REF
GND 1
GND
-7V
V+ (15V)
B+ (60V)
R4 9.999V ADJ
P1 X86-1000
J1 X86-1002
BP
P7, X86-1002
J7, X86-1003
FILTER AMP U4
RANGE SEL SWITCHES U1
V OUTPUT AMP U2,U3
mA OUTPUT AMP U5
R9 MV ZERO
10V ADJ
R7 V ZERO
R8 100mA ADJ
R6 100mV ADJ
R10 1mA ADJ
+2.5V REF
-5V REF
OHMS
mV,V, mA "-"
mV, V "+", OHMS SENSE
mA "+"
OHMS RETURN
V OUTPUT
(2-WIRE "-")
mA OUTPUT
(2-WIRE "+")
P9 X86-1003 (TO J9 AND FRONT PANEL)
X86-1003
LIST OF MATERIALS
BLOCK DIAGRAM X86 OUTPUT CIRCUITS
RONAN
X86017
FACTORY MUTUAL APPROVED PRODUCT DO NOT REVISE WITHOUT APPROVAL FROM FM LATEST REVISION SUBMITTED IS REV

Type S thermocouples — thermoelectric voltages, E(T), reference junctions at 0°C.

T °C	E μV	T °C	E μV	T °C	E μV	T °C	E μV
0	0.00	335	2645.62	670	5959.53	1005	9642.38
5	27.31	340	2692.23	675	6011.78	1010	9700.15
10	55.23	345	2738.98	680	6064.12	1015	9757.99
15	83.74	350	2785.79	685	6116.54	1020	9815.92
20	112.82	355	2832.73	690	6169.04	1025	9873.94
25	142.47	360	2879.78	695	6221.62	1030	9932.03
30	172.67	365	2926.93	700	6274.28	1035	9990.21
35	203.40	370	2974.18	705	6327.03	1040	10048.47
40	234.65	375	3021.53	710	6379.86	1045	10106.81
45	266.40	380	3068.98	715	6432.77	1050	10165.23
50	298.64	385	3116.53	720	6485.76	1055	10223.73
55	331.36	390	3164.17	725	6538.84	1060	10282.32
60	364.55	395	3211.90	730	6592.00	1065	10340.99
65	398.19	400	3259.73	735	6645.24	1070	10399.74
70	432.26	405	3307.65	740	6698.56	1075	10458.55
75	466.77	410	3355.65	745	6751.97	1080	10517.42
80	501.69	415	3403.74	750	6805.45	1085	10576.36
85	537.02	420	3451.92	755	6859.02	1090	10635.37
90	572.75	425	3500.18	760	6912.67	1095	10694.43
95	608.85	430	3548.53	765	6966.41	1100	10753.56
100	645.34	435	3596.95	770	7020.22	1105	10812.74
105	682.18	440	3645.46	775	7074.12	1110	10871.99
110	719.38	445	3694.05	780	7128.10	1115	10931.29
115	756.93	450	3742.72	785	7182.17	1120	10990.65
120	794.81	455	3791.47	790	7236.31	1125	11050.06
125	833.02	460	3840.29	795	7290.54	1130	11109.53
130	871.54	465	3889.19	800	7344.85	1135	11169.05
135	910.38	470	3938.17	805	7399.24	1140	11228.62
140	949.52	475	3987.22	810	7453.71	1145	11288.24
145	988.95	480	4036.35	815	7508.27	1150	11347.91
150	1028.67	485	4085.55	820	7562.91	1155	11407.63
155	1068.66	490	4134.83	825	7617.63	1160	11467.39
160	1108.93	495	4184.17	830	7672.43	1165	11527.20
165	1149.46	500	4233.59	835	7727.32	1170	11587.06
170	1190.24	505	4283.09	840	7782.29	1175	11646.96
175	1231.28	510	4332.65	845	7837.34	1180	11706.90
180	1272.56	515	4382.29	850	7892.47	1185	11766.88
185	1314.08	520	4432.00	855	7947.68	1190	11826.90
190	1355.83	525	4481.78	860	8002.98	1195	11886.96
195	1397.81	530	4531.63	865	8058.36	1200	11947.05
200	1440.01	535	4581.56	870	8113.82	1205	12007.19
205	1482.42	540	4631.55	875	8169.37	1210	12067.35
210	1525.04	545	4681.62	880	8224.99	1215	12127.55
215	1567.86	550	4731.76	885	8280.70	1220	12187.79
220	1610.89	555	4781.98	890	8336.49	1225	12248.05
225	1654.10	560	4832.27	895	8392.36	1230	12308.35
230	1697.51	565	4882.63	900	8448.32	1235	12368.67
235	1741.10	570	4933.06	905	8504.36	1240	12429.02
240	1784.87	575	4983.58	910	8560.48	1245	12489.40
245	1828.81	580	5034.16	915	8616.68	1250	12549.81
250	1872.93	585	5084.83	920	8672.96	1255	12610.24
255	1917.21	590	5135.57	925	8729.33	1260	12670.69
260	1961.66	595	5186.40	930	8785.78	1265	12731.16
265	2006.27	600	5237.30	935	8842.31	1270	12791.66
270	2051.03	605	5288.28	940	8898.92	1275	12852.17
275	2095.95	610	5339.35	945	8955.62	1280	12912.70
280	2141.01	615	5390.50	950	9012.40	1285	12973.25
285	2186.22	620	5441.74	955	9069.26	1290	13033.82
290	2231.57	625	5493.07	960	9126.20	1295	13094.40
295	2277.06	630	5544.48	965	9183.22	1300	13155.00
300	2322.68	635	5596.06	970	9240.33	1305	13215.60
305	2368.44	640	5647.74	975	9297.52	1310	13276.22
310	2414.33	645	5699.50	980	9354.79	1315	13336.85
315	2460.34	650	5751.34	985	9412.14	1320	13397.49
320	2506.48	655	5803.27	990	9469.58	1325	13458.13
325	2552.74	660	5855.27	995	9527.10	1330	13518.79
330	2599.12	665	5907.36	1000	9584.70	1335	13579.44

Type S thermocouples — thermoelectric voltages, E(T), reference junctions at 0 °C (continued).

T °C	E µV	T °C	E µV	T °C	E µV	T °C	E µV
1340	13640.11	1445	14912.91	1550	16176.16	1655	17418.93
1345	13700.77	1450	14973.37	1555	16235.89	1660	17477.42
1350	13761.44	1455	15033.80	1560	16295.57	1665	17535.83
1355	13822.11	1460	15094.21	1565	16355.21	1670	17594.16
1360	13882.77	1465	15154.60	1570	16414.79	1675	17652.41
1365	13943.44	1470	15214.96	1575	16474.32	1680	17710.54
1370	14004.10	1475	15275.29	1580	16533.80	1685	17768.56
1375	14064.76	1480	15335.59	1585	16593.23	1690	17826.43
1380	14125.41	1485	15395.86	1590	16652.60	1695	17884.14
1385	14186.06	1490	15456.11	1595	16711.92	1700	17941.68
1390	14246.70	1495	15516.32	1600	16771.18	1705	17999.03
1395	14307.33	1500	15576.49	1605	16830.38	1710	18056.17
1400	14367.95	1505	15636.63	1610	16889.52	1715	18113.08
1405	14428.56	1510	15696.74	1615	16948.60	1720	18169.75
1410	14489.16	1515	15756.81	1620	17007.62	1725	18226.17
1415	14549.75	1520	15816.84	1625	17066.58	1730	18282.30
1420	14610.32	1525	15876.83	1630	17125.47	1735	18338.15
1425	14670.87	1530	15936.78	1635	17184.30	1740	18393.68
1430	14731.41	1535	15996.69	1640	17243.06	1745	18448.89
1435	14791.93	1540	16056.56	1645	17301.76	1750	18503.75
1440	14852.43	1545	16116.38	1650	17360.38		

NOTE: °C = $\frac{5}{9}$ (°F—32)

Type R thermocouples — thermoelectric voltages, E(T), reference junctions at 0 °C.

T °C	E μV	T °C	E μV	T °C	E μV	T °C	E μV
0	0.00	335	2745.26	670	6388.25	1005	10569.31
5	26.79	340	2795.25	675	6446.77	1010	10635.57
10	54.26	345	2845.41	680	6505.40	1015	10701.93
15	82.39	350	2895.73	685	6564.16	1020	10768.41
20	111.16	355	2946.20	690	6623.04	1025	10834.99
25	140.56	360	2996.83	695	6682.04	1030	10901.69
30	170.57	365	3047.61	700	6741.17	1035	10968.49
35	201.18	370	3098.54	705	6800.41	1040	11035.39
40	232.38	375	3149.62	710	6859.77	1045	11102.41
45	264.13	380	3200.85	715	6919.26	1050	11169.53
50	296.45	385	3252.22	720	6978.87	1055	11236.76
55	329.30	390	3303.74	725	7038.59	1060	11304.10
60	362.68	395	3355.39	730	7098.44	1065	11371.54
65	396.57	400	3407.19	735	7158.41	1070	11439.09
70	430.97	405	3459.12	740	7218.50	1075	11506.72
75	465.85	410	3511.19	745	7278.70	1080	11574.45
80	501.22	415	3563.40	750	7339.03	1085	11642.27
85	537.05	420	3615.74	755	7399.47	1090	11710.18
90	573.33	425	3668.21	760	7460.04	1095	11778.18
95	610.06	430	3720.82	765	7520.72	1100	11846.26
100	647.23	435	3773.55	770	7581.52	1105	11914.43
105	684.82	440	3826.41	775	7642.44	1110	11982.69
110	722.83	445	3879.41	780	7703.48	1115	12051.02
115	761.24	450	3932.53	785	7764.64	1120	12119.43
120	800.04	455	3985.77	790	7825.91	1125	12187.93
125	839.23	460	4039.14	795	7887.31	1130	12256.50
130	878.80	465	4092.64	800	7948.82	1135	12325.15
135	918.74	470	4146.26	805	8010.44	1140	12393.87
140	959.05	475	4200.00	810	8072.19	1145	12462.67
145	999.70	480	4253.87	815	8134.05	1150	12531.54
150	1040.70	485	4307.86	820	8196.02	1155	12600.48
155	1082.04	490	4361.97	825	8258.12	1160	12669.49
160	1123.71	495	4416.20	830	8320.33	1165	12738.56
165	1165.70	500	4470.55	835	8382.65	1170	12807.71
170	1208.01	505	4525.02	840	8445.09	1175	12876.91
175	1250.63	510	4579.62	845	8507.65	1180	12946.18
180	1293.55	515	4634.33	850	8570.32	1185	13015.52
185	1336.77	520	4689.16	855	8633.11	1190	13084.91
190	1380.27	525	4744.10	860	8696.01	1195	13154.36
195	1424.06	530	4799.17	865	8759.03	1200	13223.87
200	1468.13	535	4854.35	870	8822.16	1205	13293.43
205	1512.47	540	4909.66	875	8885.41	1210	13363.05
210	1557.08	545	4965.07	880	8948.77	1215	13432.73
215	1601.95	550	5020.61	885	9012.24	1220	13502.45
220	1647.08	555	5076.26	890	9075.83	1225	13572.22
225	1692.45	560	5132.03	895	9139.54	1230	13642.05
230	1738.08	565	5187.91	900	9203.35	1235	13711.92
235	1783.94	570	5243.91	905	9267.28	1240	13781.83
240	1830.04	575	5300.02	910	9331.32	1245	13851.80
245	1876.36	580	5356.24	915	9395.47	1250	13921.80
250	1922.92	585	5412.58	920	9459.74	1255	13991.85
255	1969.70	590	5469.03	925	9524.12	1260	14061.93
260	2016.70	595	5525.60	930	9588.61	1265	14132.05
265	2063.91	600	5582.27	935	9653.22	1270	14202.22
270	2111.33	605	5639.05	940	9717.93	1275	14272.41
275	2158.95	610	5695.95	945	9782.76	1280	14342.64
280	2206.78	615	5752.95	950	9847.70	1285	14412.91
285	2254.81	620	5810.05	955	9912.74	1290	14483.20
290	2303.03	625	5867.27	960	9977.90	1295	14553.53
295	2351.45	630	5924.58	965	10043.18	1300	14623.88
300	2400.05	635	5982.10	970	10108.56	1305	14694.26
305	2448.83	640	6039.75	975	10174.05	1310	14764.67
310	2497.80	645	6097.53	980	10239.65	1315	14835.10
315	2546.95	650	6155.43	985	10305.36	1320	14905.55
320	2596.27	655	6213.45	990	10371.18	1325	14976.03
325	2645.76	660	6271.59	995	10437.12	1330	15046.52
330	2695.43	665	6329.86	1000	10503.16	1335	15117.04

Type R thermocouples — thermoelectric voltages, E(T), reference junctions at 0°C (continued).

T °C	E μV	T °C	E μV	T °C	E μV	T °C	E μV
1340	15187.56	1445	16670.01	1550	18145.82	1655	19601.56
1345	15258.11	1450	16740.54	1555	18215.70	1660	19670.16
1350	15328.67	1455	16811.06	1560	18285.54	1665	19738.67
1355	15399.24	1460	16881.56	1565	18355.33	1670	19807.10
1360	15469.82	1465	16952.04	1570	18425.06	1675	19875.44
1365	15540.41	1470	17022.50	1575	18494.75	1680	19943.67
1370	15611.01	1475	17092.93	1580	18564.38	1685	20011.76
1375	15681.62	1480	17163.35	1585	18633.96	1690	20079.71
1380	15752.23	1485	17233.73	1590	18703.48	1695	20147.50
1385	15822.85	1490	17304.10	1595	18772.95	1700	20215.11
1390	15893.47	1495	17374.43	1600	18842.36	1705	20282.52
1395	15964.09	1500	17444.73	1605	18911.71	1710	20349.72
1400	16034.71	1505	17515.00	1610	18980.99	1715	20416.70
1405	16105.32	1510	17585.24	1615	19050.22	1720	20483.42
1410	16175.94	1515	17655.45	1620	19119.37	1725	20549.88
1415	16246.54	1520	17725.62	1625	19188.47	1730	20616.07
1420	16317.15	1525	17795.75	1630	19257.49	1735	20681.95
1425	16387.74	1530	17865.85	1635	19326.45	1740	20747.53
1430	16458.32	1535	17935.90	1640	19395.34	1745	20812.77
1435	16528.90	1540	18005.92	1645	19464.15	1750	20877.67
1440	16599.46	1545	18075.89	1650	19532.90		

NOTE: °C = $\frac{5}{9}$ (°F—32)

Type E thermocouples — thermoelectric voltages, E(T), reference junctions at 0°C.

T °C	E μV	T °C	E μV	T °C	E μV	T °C	E μV
−50	−2786.81	215	14534.5	480	35381.9	745	55686.9
−45	−2522.27	220	14908.8	485	35786.0	750	57082.8
−40	−2254.44	225	15284.3	490	36190.3	755	57478.3
−35	−1983.37	230	15660.8	495	36594.6	760	57873.4
−30	−1709.13	235	16038.5	500	36999.0	765	58268.3
−25	−1431.77	240	16417.2	505	37403.4	770	58662.7
−20	−1151.34	245	16796.8	510	37808.0	775	59056.9
−15	−867.90	250	17177.5	515	38212.5	780	59450.7
−10	−581.48	255	17559.2	520	38617.1	785	59844.1
−5	−292.14	260	17941.8	525	39021.7	790	60237.2
0	0.00	265	18325.3	530	39426.3	795	60629.9
5	294.6	270	18709.6	535	39830.9	800	61022.3
10	591.3	275	19094.9	540	40235.5	805	61414.2
15	890.3	280	19480.9	545	40640.1	810	61805.8
20	1191.5	285	19867.8	550	41044.6	815	62197.1
25	1495.0	290	20255.5	555	41449.0	820	62587.9
30	1800.8	295	20643.9	560	41853.4	825	62978.3
35	2108.9	300	21033.1	565	42257.7	830	63368.3
40	2419.2	305	21423.0	570	42661.9	835	63757.9
45	2731.9	310	21813.6	575	43066.0	840	64147.1
50	3046.8	315	22204.9	580	43470.0	845	64535.9
55	3364.0	320	22596.9	585	43873.9	850	64924.3
60	3683.4	325	22989.5	590	44277.6	855	65312.2
65	4005.1	330	23382.7	595	44681.2	860	65699.7
70	4328.9	335	23776.5	600	45084.7	865	66086.8
75	4655.0	340	24170.9	605	45488.0	870	66473.3
80	4983.2	345	24565.9	610	45891.1	875	66859.5
85	5313.5	350	24961.4	615	46294.1	880	67245.2
90	5646.0	355	25357.4	620	46696.8	885	67630.4
95	5980.5	360	25754.0	625	47099.4	890	68015.1
100	6317.1	365	26151.0	630	47501.8	895	68399.3
105	6655.6	370	26548.5	635	47904.0	900	68783.1
110	6996.1	375	26946.5	640	48305.9	905	69166.4
115	7338.6	380	27344.9	645	48707.7	910	69549.1
120	7682.9	385	27743.8	650	49109.2	915	69931.4
125	8029.1	390	28143.0	655	49510.4	920	70313.2
130	8377.1	395	28542.7	660	49911.5	925	70694.5
135	8726.9	400	28942.7	665	50312.2	930	71075.3
140	9078.4	405	29343.1	670	50712.8	935	71455.6
145	9431.7	410	29743.9	675	51113.0	940	71835.3
150	9786.5	415	30144.9	680	51513.0	945	72214.6
155	10143.1	420	30546.3	685	51912.8	950	72593.4
160	10501.2	425	30948.0	690	52312.2	955	72971.7
165	10860.8	430	31349.9	695	52711.4	960	73349.6
170	11222.0	435	31752.2	700	53110.3	965	73727.0
175	11584.6	440	32154.7	705	53508.9	970	74103.9
180	11948.7	445	32557.4	710	53907.2	975	74480.5
185	12314.2	450	32960.3	715	54305.3	980	74856.6
190	12681.0	455	33363.5	720	54703.0	985	75232.3
195	13049.2	460	33766.9	725	55100.4	990	75607.7
200	13418.6	465	34170.4	730	55497.5	995	75982.7
205	13789.4	470	34574.1	735	55894.3	1000	76357.5
210	14161.3	475	34977.9	740	56290.8		

NOTE: °C = $\frac{5}{9}$ (°F—32)

Type J thermocouples — thermoelectric voltages, E(T), reference junctions at 0°C.

T °C	E μV	T °C	E μV	T °C	E μV	T °C	E μV
−50	−2431.0	155	8284.0	360	19640.2	565	31068.3
−45	−2196.8	160	8560.3	365	19916.0	570	31355.7
−40	−1960.4	165	8836.7	370	20191.8	575	31643.8
−35	−1721.9	170	9113.4	375	20467.5	580	31932.7
−30	−1481.4	175	9390.2	380	20743.2	585	32222.3
−25	−1238.9	180	9667.2	385	21018.8	590	32512.7
−20	−994.6	185	9944.4	390	21294.5	595	32804.0
−15	−748.4	190	10221.7	395	21570.2	600	33096.0
−10	−500.6	195	10499.0	400	21845.9	605	33388.9
−5	−251.1	200	10776.5	405	22121.6	610	33682.7
0	0.0	205	11054.1	410	22397.4	615	33977.4
5	252.6	210	11331.7	415	22673.2	620	34272.9
10	506.7	215	11609.3	420	22949.1	625	34569.3
15	762.2	220	11887.0	425	23225.1	630	34866.7
20	1019.0	225	12164.7	430	23501.2	635	35165.0
25	1277.0	230	12442.4	435	23777.5	640	35464.3
30	1536.4	235	12720.0	440	24053.8	645	35764.5
35	1796.8	240	12997.7	445	24330.4	650	36065.6
40	2058.4	245	13275.3	450	24607.1	655	36367.7
45	2321.1	250	13552.9	455	24884.0	660	36670.8
50	2584.8	255	13830.5	460	25161.1	665	36974.9
55	2849.4	260	14107.9	465	25438.4	670	37279.9
60	3115.0	265	14385.4	470	25716.1	675	37585.9
65	3381.4	270	14662.7	475	25993.9	680	37892.9
70	3648.7	275	14940.0	480	26272.1	685	38200.8
75	3916.8	280	15217.2	485	26550.6	690	38509.7
80	4185.6	285	15494.3	490	26829.5	695	38819.5
85	4455.2	290	15771.3	495	27108.7	700	39130.2
90	4725.4	295	16048.3	500	27388.2	705	39441.9
95	4996.2	300	16325.1	505	27668.2	710	39754.4
100	5267.7	305	16601.9	510	27948.7	715	40067.8
105	5539.7	310	16878.5	515	28229.5	720	40382.0
110	5812.3	315	17155.1	520	28510.9	725	40697.1
115	6085.3	320	17431.5	525	28792.7	730	41012.9
120	6358.8	325	17707.9	530	29075.1	735	41329.5
125	6632.8	330	17984.2	535	29358.0	740	41646.8
130	6907.1	335	18260.4	540	29641.5	745	41964.7
135	7181.8	340	18536.5	545	29925.6	750	42283.2
140	7456.9	345	18812.5	550	30210.3	755	42602.3
145	7732.3	350	19088.5	555	30495.7	760	42922.0
150	8008.1	355	19364.4	560	30781.6		

NOTE: °C = 5/9 (°F—32)

Type K thermocouples — thermoelectric voltages, E(T), reference junctions at 0 °C.

T °C	E μV	T °C	E μV	T °C	E μV	T °C	E μV
−50	−1889.07	215	8737.0	480	19788.4	745	31006.7
−45	−1708.94	220	8937.8	485	20001.2	750	31214.3
−40	−1526.64	225	9139.0	490	20214.1	755	31421.6
−35	−1342.25	230	9340.6	485	20427.1	760	31628.7
−30	−1155.85	235	9542.7	500	20640.2	765	31835.6
−25	−967.54	240	9745.2	505	20853.3	770	32042.2
−20	−777.38	245	9948.1	510	21066.4	775	32248.6
−15	−585.45	250	10151.5	515	21279.5	780	32454.7
−10	−391.86	255	10355.3	520	21492.7	785	32660.6
−5	−196.67	260	10559.6	525	21705.9	790	32866.3
0	0.00	265	10764.3	530	21919.1	795	33071.6
5	197.9	270	10969.3	535	22132.3	800	33276.8
10	397.0	275	11174.8	540	22345.5	805	33481.6
15	597.1	280	11380.7	545	22558.8	810	33686.3
20	798.1	285	11586.9	550	22771.9	815	33890.6
25	1000.2	290	11793.4	555	22985.1	820	34094.7
30	1203.1	295	12000.3	560	23198.3	825	34298.6
35	1406.9	300	12207.4	565	23411.4	830	34502.1
40	1611.4	305	12414.9	570	23624.4	835	34705.4
45	1816.6	310	12622.6	575	23837.5	840	34908.5
50	2022.4	315	12830.5	580	24050.4	845	35111.3
55	2228.8	320	13038.7	585	24263.3	850	35313.8
60	2435.7	325	13247.1	590	24476.2	855	35516.1
65	2642.9	330	13455.7	595	24688.9	860	35718.1
70	2850.3	335	13664.6	600	24901.6	865	35919.8
75	3058.0	340	13873.6	605	25114.2	870	36121.3
80	3265.7	345	14082.8	610	25326.7	875	36322.5
85	3473.3	350	14292.2	615	25539.1	880	36523.5
90	3680.9	355	14501.8	620	25751.4	885	36724.2
95	3888.2	360	14711.6	625	25963.5	890	36924.6
100	4095.3	365	14921.5	630	26175.6	895	37124.8
105	4301.9	370	15131.6	635	26387.5	900	37324.7
110	4508.1	375	15341.9	640	26599.3	905	37524.4
115	4713.8	380	15552.3	645	26810.9	910	37723.8
120	4919.0	385	15762.8	650	27022.4	915	37922.9
125	5123.5	390	15973.6	655	27233.8	920	38121.8
130	5327.4	395	16184.4	660	27445.0	925	38320.4
135	5530.8	400	16395.4	665	27656.0	930	38518.7
140	5733.5	405	16606.6	670	27866.9	935	38716.8
145	5935.6	410	16817.9	675	28077.6	940	38914.7
150	6137.2	415	17029.3	680	28288.1	945	39112.2
155	6338.3	420	17240.9	685	28498.4	950	39309.6
160	6538.9	425	17452.6	690	28708.6	955	39506.6
165	6739.2	430	17664.4	695	28918.6	960	39703.4
170	6939.2	435	17876.3	700	29128.3	965	39900.0
175	7138.9	440	18088.4	705	29337.9	970	40096.3
180	7338.4	445	18300.5	710	29547.2	975	40292.3
185	7537.9	450	18512.8	715	29756.4	980	40488.1
190	7737.3	455	18725.2	720	29965.3	985	40683.7
195	7936.9	460	18937.6	725	30174.0	990	40878.9
200	8136.6	465	19150.2	730	30382.5	995	41074.0
205	8336.4	470	19362.8	735	30590.8	1000	41268.7
210	8536.6	475	19575.6	740	30798.9		

NOTE: °C = 5/9 (°F—32)

Type T thermocouples — thermoelectric voltages, E(T), reference junctions at 0°C.

T °C	E μV	T °C	E μV	T °C	E μV	T °C	E μV
−170	−5069.41	−30	−1120.67	110	4748.7	250	12011.3
−165	−4968.91	−25	−939.91	115	4987.0	255	12290.9
−160	−4865.20	−20	−756.70	120	5227.0	260	12571.7
−155	−4758.29	−15	−571.04	125	5468.8	265	12853.8
−150	−4648.23	−10	−382.98	130	5712.2	270	13136.9
−145	−4535.03	−5	−192.61	135	5957.3	275	13421.3
−140	−4418.72	0	0.00	140	6204.1	280	13706.8
−135	−4299.30	5	194.6	145	6452.4	285	13993.4
−130	−4176.81	10	390.9	150	6702.4	290	14281.1
−125	−4051.24	15	589.2	155	6953.9	295	14569.9
−120	−3922.62	20	789.4	160	7207.0	300	14859.8
−115	−3790.99	25	991.7	165	7461.6	305	15150.8
−110	−3656.36	30	1196.2	170	7717.8	310	15442.8
−105	−3518.76	35	1402.7	175	7975.5	315	15735.9
−100	−3378.24	40	1611.4	180	8234.7	320	16030.0
−95	−3234.83	45	1822.2	185	8495.3	325	16325.2
−90	−3088.56	50	2035.2	190	8757.5	330	16621.4
−85	−2939.46	55	2250.3	195	9021.1	335	16918.6
−80	−2787.55	60	2467.5	200	9286.1	340	17216.8
−75	−2632.87	65	2686.8	205	9552.5	345	17516.1
−70	−2475.44	70	2908.1	210	9820.3	350	17816.4
−65	−2315.27	75	3131.5	215	10089.6	355	18117.6
−60	−2152.41	80	3356.8	220	10360.2	360	18419.9
−55	−1986.89	85	3584.1	225	10632.1	365	18723.1
−50	−1818.74	90	3813.3	230	10905.4	370	19027.2
−45	−1648.01	95	4044.4	235	11179.9		
−40	−1474.73	100	4277.3	240	11455.8		
−35	−1298.94	105	4512.1	245	11732.9		

NOTE: °C = $\frac{5}{9}$ (°F—32)

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