THE IIHR PORTABLE LINEAR-THERMISTOR TEMPERATURE METER

by

John R. Glover

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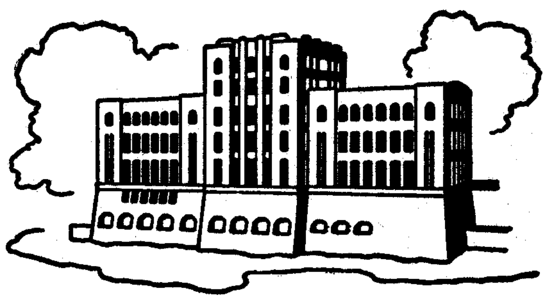
Commonwealth Edison Company
Chicago, Illinois



IIHR Report No. 144

Iowa Institute of Hydraulic Research
The University of Iowa
Iowa City, Iowa

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deflection is greater than zero. A frequency should also be indicated. Now, using the BALANCE control, decrease the frequency to a value between 0 and 1 Hz. This adjustment is critical for proper operation and must be repeated as required. Good operating procedure would include the checking of this adjustment before each measurement until the zero reading becomes stable.

F. The temperature indicated by the instrument is equal to the temperature selected by the RANGE switch plus the meter deflection. For example, a meter reading of 3 ma for position 20 of the RANGE switch would correspond to 23°C. The counter display for this temperature would be 300 Hz. Temperature readings for meter deflections equal to or less than zero are invalid.

G. If a direct-reading counter readout is desired, set the RANGE switch to position 0. For the temperature range of 0°C to 45°C, the counter will then display temperature directly even though the meter deflection is greater than 5 ma (the meter cannot be overloaded in this instrument under normal conditions). The temperature-frequency coefficient is 1000 Hz/°C, and the origin is at 0°C. For example, a frequency of 1000 Hz would correspond to 10.00°C.

H. The ZERO SUPPRESSION switch reduces the meter deflection by one half when pressed. It should be used only when the counter is not being used and when temperature fluctuations are such that the meter deflection periodically exceeds 5 ma. For position 20 of the RANGE switch, a meter deflection of 2.5 ma, and the ZERO SUPPRESSION pressed, the temperature would be 25°C.

IV. CALIBRATION

Calibration of the instrument is accomplished in the following way. The required equipment consists of:

1. Ice bath.
2. Precision thermometer, -1°C to 11°C.
3. H-P Model 5302A counter or equivalent.
4. 50K, 10-turn potentiometer.
5. 1K, 10-turn potentiometer.
6. Accurate d.c. voltmeter.

Before undertaking calibration, these preliminary steps must be taken:

1. Charge batteries for 16 hours prior to calibration.
2. Connect 50K and 1K potentiometers in series to form a variable 51K resistor. Connect the resistor between pins B & C of the PROBE connector.
3. Connect the counter to the OUTPUT BNC connector.

The ensuing steps in the calibration process are as follows:

A. Battery Regulator & Bridge Supply Card.

1. Connect the d.c. voltmeter to the output of the -15-volt regulator (pin 1), and adjust potentiometer 3 on the card until the voltmeter indicates -15 volts.
2. Connect the voltmeter to the output of the +15 volt regulator (pin 3) and adjust potentiometer 2 on the card until the voltmeter indicates +15 volts.

B. Voltage-to-Frequency Converter.

1. Depress the ZERO switch and adjust the BALANCE control until meter deflection is zero.
2. Depress the ZERO switch and adjust the zero potentiometer on the voltage-to-frequency card until the frequency is 1 Hz. Release the ZERO switch.
3. Adjust the variable resistor connected to the PROBE SOCKET until meter deflection is 5 ma.
4. Adjust the Span potentiometer on the voltage-to-frequency card until the frequency is 500 Hz.

C. Metering Circuit Card.

1. Depress the ZERO switch and adjust the BALANCE control until the frequency is 1 Hz.
2. Adjust the variable resistor connected to the PROBE socket until the frequency is 500 Hz.
3. Depress the ZERO SUPPRESSION swtich and adjust potentiometer 1 on the card until the counter indicates a frequency of 250 Hz. Meter deflection should be mid-scale when the frequency is 250 Hz.

D. Range Switch Potentiometers and Bridge Supply Voltage.

1. Remove the variable resistor from the PROBE connector and connect a thermistor probe to the instrument.
2. Set the temperature of the probe to 0°C.
3. Set the RANGE switch to position 0.
4. Depress the ZERO switch and adjust the BALANCE control until the frequency is 1 Hz. Release the ZERO switch.
5. Adjust potentiometer 2 until the frequency is 1 Hz.
6. Set the temperature of the probe to 5°C.
7. Adjust the bridge supply voltage (potentiometer 1 on Battery Regulator and Bridge Supply Card) until the frequency is 500 Hz.
8. Remove the probe and connect the variable resistor between pins B & C on the PROBE Socket.
9. Set the RANGE switch to position 0.
10. Adjust the variable resistor until the frequency is 5000 Hz.
11. Set the RANGE switch to the positions indicated in the table and adjust the corresponding potentiometer for the frequencies listed.

Position	Potentiometer	Frequency
45	11	500
40	10	1000
35	9	1500
30	8	2000
25	7	2500
20	6	3000
15	5	3500
10	4	4000
5	3	4500

12. Set the RANGE switch to position 0 and adjust the variable resistor until the frequency is 1000 Hz.
13. Set the RANGE switch to position -5 and adjust potentiometer 1 until the frequency is 1500 Hz.

Reference

(1) "YSI Thermilinear Component Specifications," Yellow Springs Instrument Company, Yellow Springs, Ohio.

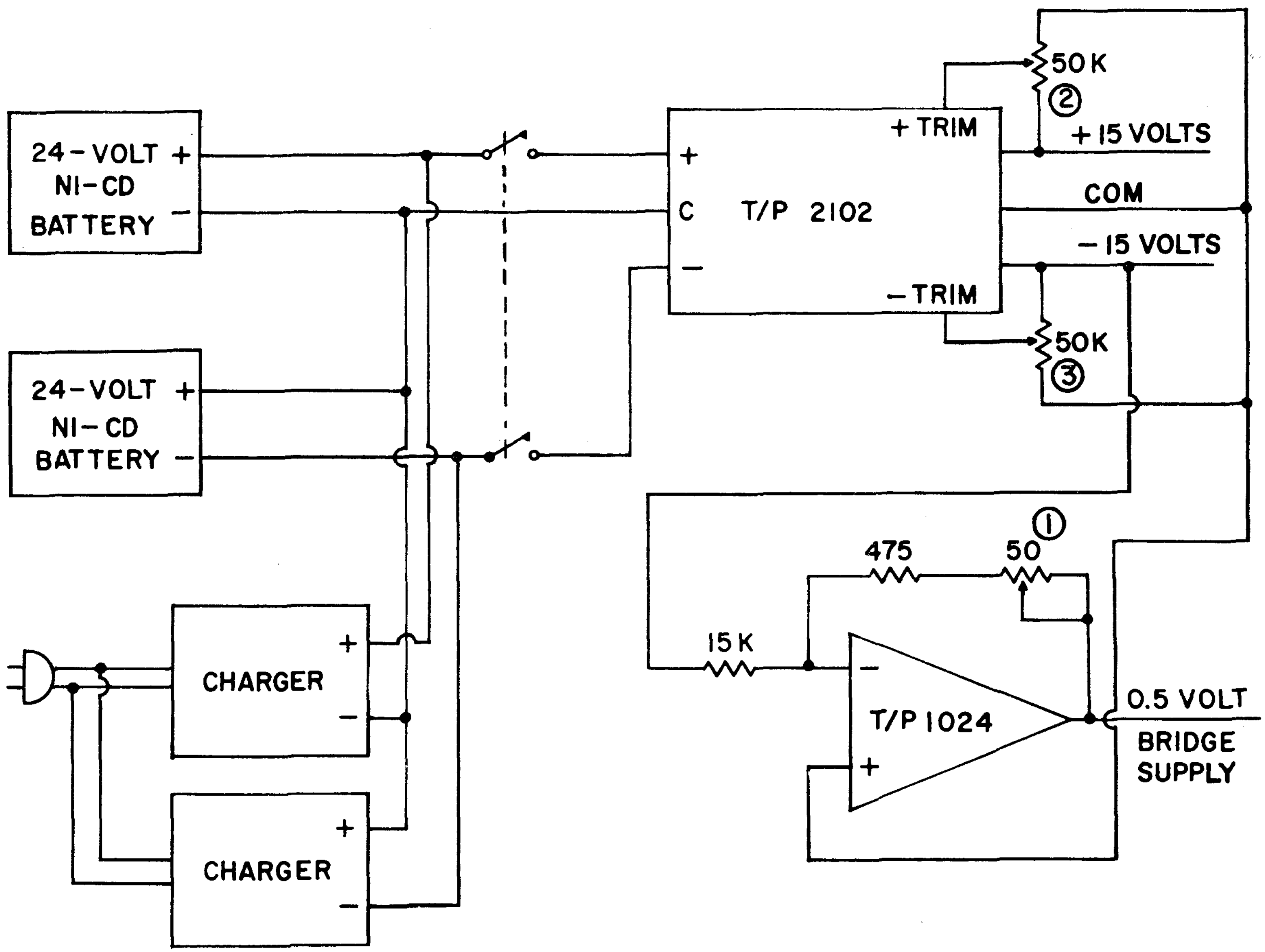

Figure 1. Battery Regulator & Bridge Supply

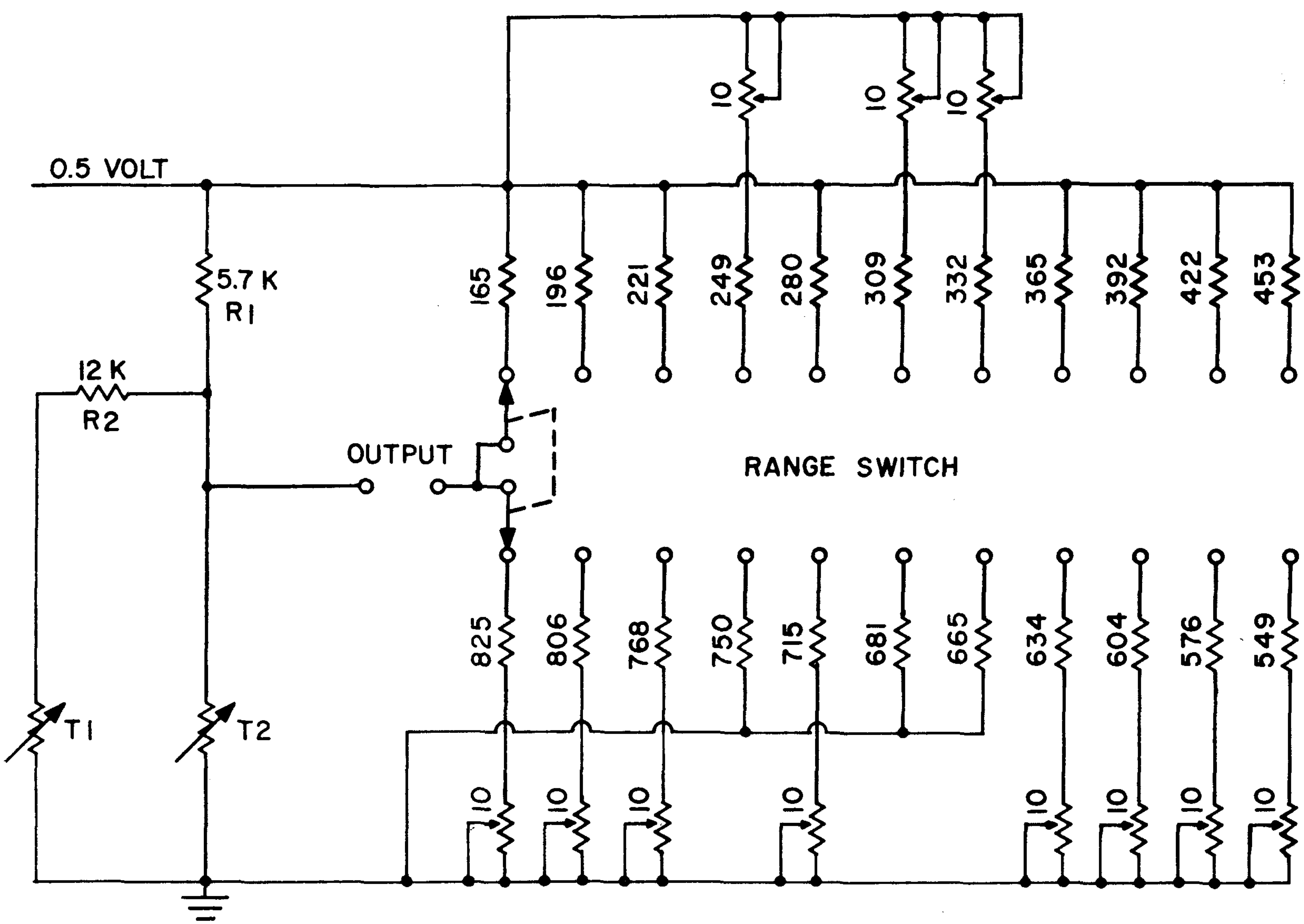

Figure 2. Bridge Network

ABSTRACT

THE IIHR PORTABLE LINEAR-THERMISTOR TEMPERATURE METER

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The IIHR Portable Linear-Thermistor Temperature Meter is a portable instrument for measuring temperatures within the range of -5°C to 45°C. Direct meter readout and the capability for digital display of temperature to the nearest 0.01°C are special features of the instrument. Thermistor accuracy and interchangeability over the full range are ± 0.2°C. Linearity deviation is ± 0.1°C for the full range when the included voltage-to-frequency converter is used together with an electronic counter.

ACKNOWLEDGEMENTS

The development of this instrument was sponsored by the Commonwealth Edison Company, Chicago, Illinois. The author wishes to thank Dr. V.S. Hastings and Mr. E.H. DuSold of Commonwealth Edison Company for their cooperation. Grateful acknowledgement is extended to Mr. Ernest E. Schwab of the Institute electronics staff for instrument construction, and to Dr. John F. Kennedy, Director of the Institute of Hydraulic Research.

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THE IIHR PORTABLE LINEAR-THERMISTOR TEMPERATURE METER

I. INTRODUCTION

The IIHR Portable Linear-Thermistor Temperature Meter was designed specifically as a reliable field instrument for accurate measurement of short-term-average temperatures. The temperature measurement range of the instrument is divided into eleven 5°C divisions to span temperatures between -5°C to 45°C. In addition to direct meter readout of temperature, an integrating voltage-to-frequency converter is included for operation with a portable electronic counter. The meter readout displays the measured temperature to the nearest 0.1°C while the counter, for a 1-sec integration time, displays the measured temperature to the nearest 0.01°C. Unique features of the instrument are its linearity, stability, and meter-protection circuit.

Linearity of the instrument is a direct result of using Yellow Springs Instrument Co. Thermilinear Components which consist of two YSI precision thermistors packaged as a single sensor and a resistor composite consisting of two separate precision metal-film resistors. The thermistor and resistor composites are connected as two legs of a Wheatstone bridge, while the other two legs of the bridge are precision resistors selected to permit direct display of temperature.

The low voltage-drift characteristic of the instrument is achieved by utilizing chopper operational amplifiers rather than chopper-stabilized operational amplifiers. The latter type of operational amplifier is limited to amplifier circuit configurations which have low-impedance, non-differential input characteristics. Such characteristics would affect the linearity of the temperature-voltage relationship for the YSI Thermilinear Thermistor-Resistor Composite, and hence render the instrument unsuitable for this application. The chopper operational amplifier, however, is usable in amplifier circuit configurations which create high-impedance, differential input characteristics. As a result, the low voltage-drift characteristic permits higher gain and better resolution of the temperature being measured.

Protection of the meter for displaying temperature is necessary for proper reliability and performance of the instrument. However, the improved resolution mentioned above is incompatible with a wide temperature-display range when the meter is protected by a circuit which limits the applied voltage. By supplying the meter current from a differential source which has large common-mode, but limited differential capabilities, this incompatibility is removed without damaging the display meter by excessive current. This unique circuit makes it possible for a digital display of temperature for the range of 0°C to 45°C directly to nearest 0.01°C, while providing back-up meter display to the nearest 0.1°C if required.

In addition to the above mentioned features, the instrument is powered by two rechargable Ni-Cd batteries with built-in rechargers. Battery-condition meters indicate the level of charge and electronic regulation is used to insure calibration stability.

II. CIRCUIT DESCRIPTION

A. Battery Regulator & Bridge Supply. As seen from figure 1, power for the instrument is derived from two 24-volt, 1-amp-hour Ni-Cd batteries, connected in series to give plus and minus 24 volts. A Philbrick Model 2101 Dual Voltage Regulator is used to supply regulated plus and minus 15 volts for operating the circuits. This regulator can supply 100 milliamperes at rated voltage for input voltages as low as 20 volts. Once the battery voltage drops below 20 volts, regulation ceases and the instrument will not operate properly. Two potentiometers are used for adjusting the output voltages of the regulator. The potentiometers are initially adjusted so that the supplies give plus and minus 15 volts.

Chargers for the batteries are included with the instrument, and charging begins as soon as the power cord is connected to 110 volts a.c. The instrument will operate while the batteries are being charged, although the charging time is increased. Normal charging time is 16-18 hours for completely discharged batteries.

A low-impedance, nominal 1/2-volt, bridge-supply voltage is generated by a voltage-dividing operational-amplifier circuit referenced to the minus 15-volt supply. This voltage is adjustable even though the voltage-temperature relationship for the thermistor-resistor network is very precise. Errors that create the need for adjustment are the resistors in the bridge, amplifier, and metering networks; and since the amplifier and metering networks are more difficult to adjust, sensitivity is controlled by the potentiometer located in the feedback network of the supply.

B. Bridge Network. When resistor R2 in figure 2 is combined with the two thermistors, T1 and T2, the network is readily recognized as a Wheatstone bridge. The values for the resistors selected by the RANGE switch are determined by the equation giving the voltage-temperature relation for the combined resistors, R1 and R2, and thermistors, T1 and T2; this equation (1) is

$$E_o = (-0.0056846\ E_i)\ T + 0.805858\ E_i \qquad 1.$$

Although the RANGE switch resistors are precision resistors, they are not exactly equal to values needed to satisfy equation 1. For this reason adjustable 10-ohm resistors are placed in series with the appropriate leg of the bridge circuit to insure proper ranging.

C. Bridge Amplifier. The amplifier circuit shown in figure 3 acts as a high input-impedance differential amplifier provided R1/R2 = R4/R3. The differential gain of the amplifier circuit is given by the expression:

$$\text{Gain} = 1 + R4/R3 \qquad 2.$$

and for the resistance values shown in the figure, the gain is 70.4. This gain is the value needed to give an output voltage of one volt when the bridge is unbalanced by a voltage corresponding to a temperature difference of +5°C from balance.

As mentioned in the introduction, the amplifiers used are chopper operational amplifiers rather than chopper-stabilized operational amplifiers. Because all frequency components of the signal pass through the chopper and demodulator, the frequency response is limited to less than the chopper driver frequency (approximately 500 Hz for these amplifiers). For the values of the compensation capacitors shown in figure 3, the upper frequency limit is approximately 5 Hz. This very low frequency response characteristic is not a disadvantage or instrument limitation, because only mean temperatures are to be measured.

The BALANCE control is a trimming potentiometer used to reduce the input offset voltage to zero when the inputs to the amplifier are equal. The input offset voltage is dependent on both the ambient temperature and supply voltage, and hence will vary as the batteries discharge and as the ambient temperature changes. Output voltage deviations from zero caused by input offset add directly to the temperature indicated by the meter. It is therefore necessary periodically to check the output of the amplifier when the inputs are shorted together and to adjust the BALANCE potentiometer as required.

D. Metering Circuit. The schematic diagram for the metering circuit is shown in figure 4. Amplifiers 1 and 2 along with their associated components constitute two precision half-wave rectifier circuits. Amplifiers 3 and 4 are simply follower amplifiers and drive the 0-5 ma meter. The d.c. transfer characteristics for the two rectifier circuits are shown in figure 5. The solid lines represent the circuit characteristics when the ZERO SUPPRESSION switch is in the normal or grounded position and the dashed lines when it is depressed.

As can be seen from figure 5, the output of amplifier 4 is zero when the input voltage is greater than -1.15 volts. The 130K amplifier-4 input resistor causes the "point of conduction" to shift from the origin to the point indicated in figure 5. Since the "point of conduction" for amplifier 1 has not shifted, the output voltage of amplifier 3, and hence meter current, is proportional to the input voltage for the voltage range of -1.15 to 0. For input voltages less than -1.15 volts, amplifier 4 increases with the same sensitivity as amplifier 3. Therefore, the voltage difference between the outputs of amplifiers 3 and 4 remains constant. The meter is thus protected from overloads for all input voltages less than -1.15 volts.

For positive input voltages, the output voltages of amplifiers 3 and 4 are both essentially zero. Amplifier 3 output can go negative slightly (approximately 0.1 volt) because of the 50K resistor shunting diode

D1. This transfer characteristic is necessary for detecting positive input voltages to the metering circuit, and making the condition of zero meter current correspond to an input voltage of zero. Without the 50K resistor across diode D1, meter current would be zero for all input voltages equal to or greater than zero, and the condition of zero output voltage for the bridge circuit would be difficult to determine.

The reason for such an elaborate meter-protection circuit is to preserve the linearity of the thermistor signal for an extended range. This makes it possible to utilize the full-scale output of the amplifiers in conjunction with a voltage-to-frequency converter to give digital readout to the nearest 0.01°C for the temperature range of 0°C to 45°C. In other words, when the RANGE switch is set to position 0, temperature is displayed digitally in °C by the counter measuring the output frequency of the voltage-to-frequency converter.

E. Voltage-to-Frequency Converter. The voltage-to-frequency converter is a special unit manufactured by Anadex Instruments, Inc. The nominal conversion coefficient is 1000 Hz/volt. To make the frequency correspond directly with temperature, a 50K precision resistor is connected in series with the input of the converter to reduce the conversion coefficient by a factor of two to 500 Hz/volt. This coefficient gives temperature directly to the nearest 0.01°C.

III. OPERATING PROCEDURE

Operation of the instrument proceeds as follows:

A. Connect a Y.S.I. Model 710 Thermistor to the connector marked PROBE.

B. Connect a Hewlett-Packard Model 5320A Counter to the connector marked OUTPUT. Counter Input B should be used. If this portable counter is not available, any counter able to accept 1 μsec. negative pulses can be used. Consult the counter Operation Manual for additional details concerning the counter.

C. Turn the instruments on.

D. Adjust the RANGE switch until the meter is in the range of 0 to 5 ma.

E. Press the ZERO switch and rotate the BALANCE control until the meter

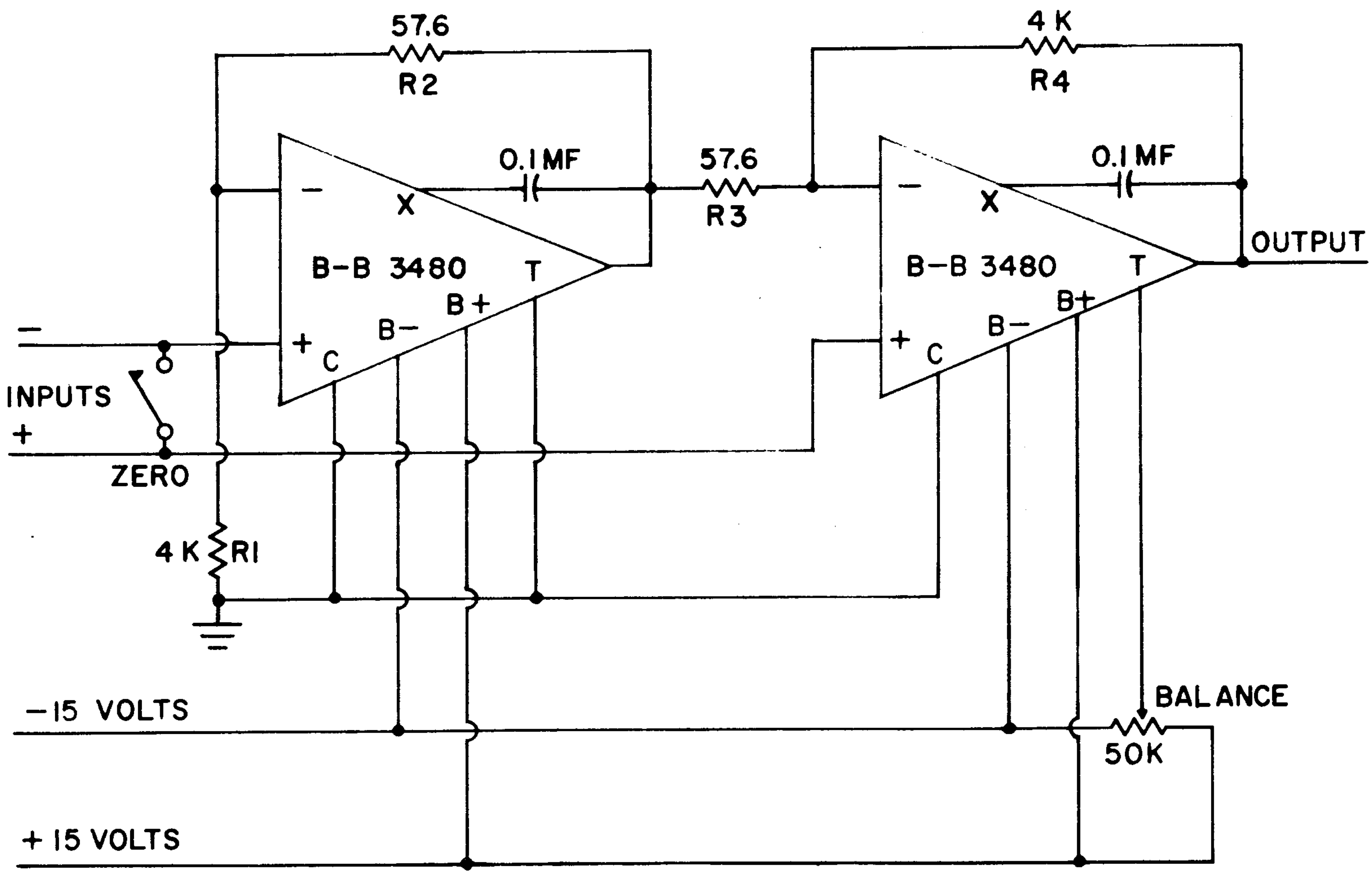

Figure 3. Bridge Amplifier

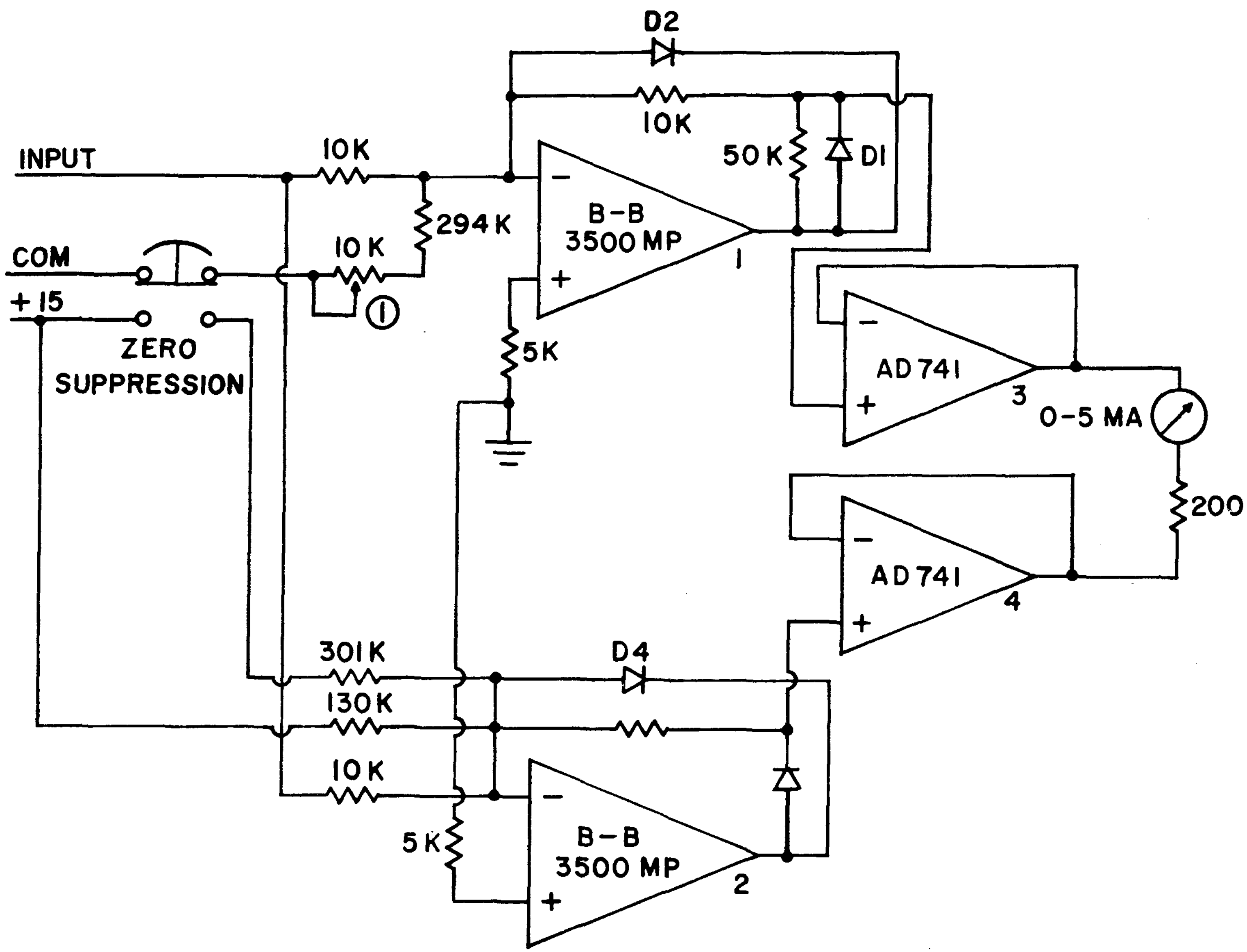

Figure 4. Metering Circuit

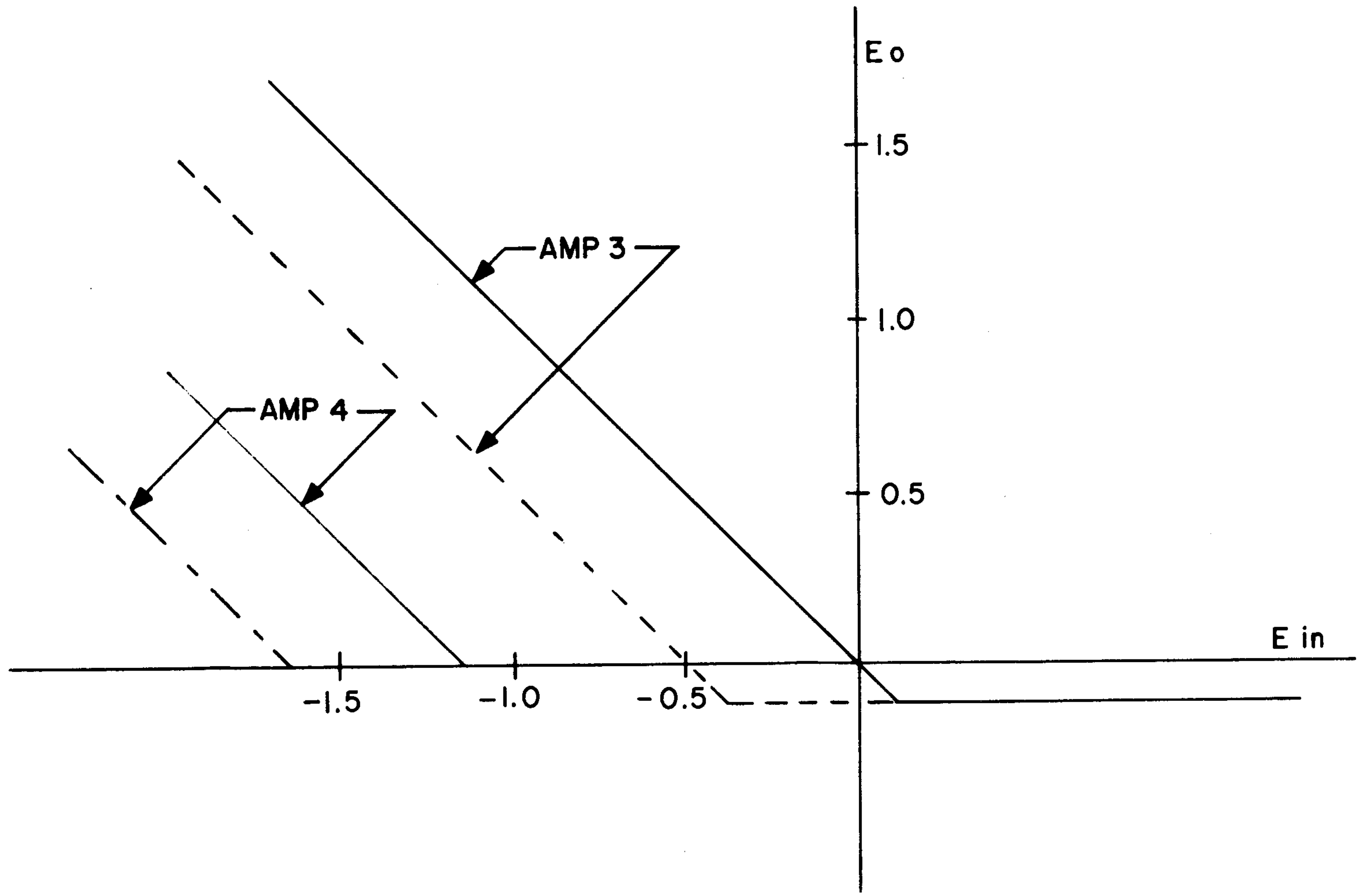

Figure 5. Metering Circuit Transfer Characteristics