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HR-33T Dew Point Microvoltmeter
Instruction/Service Manual
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M2820-1

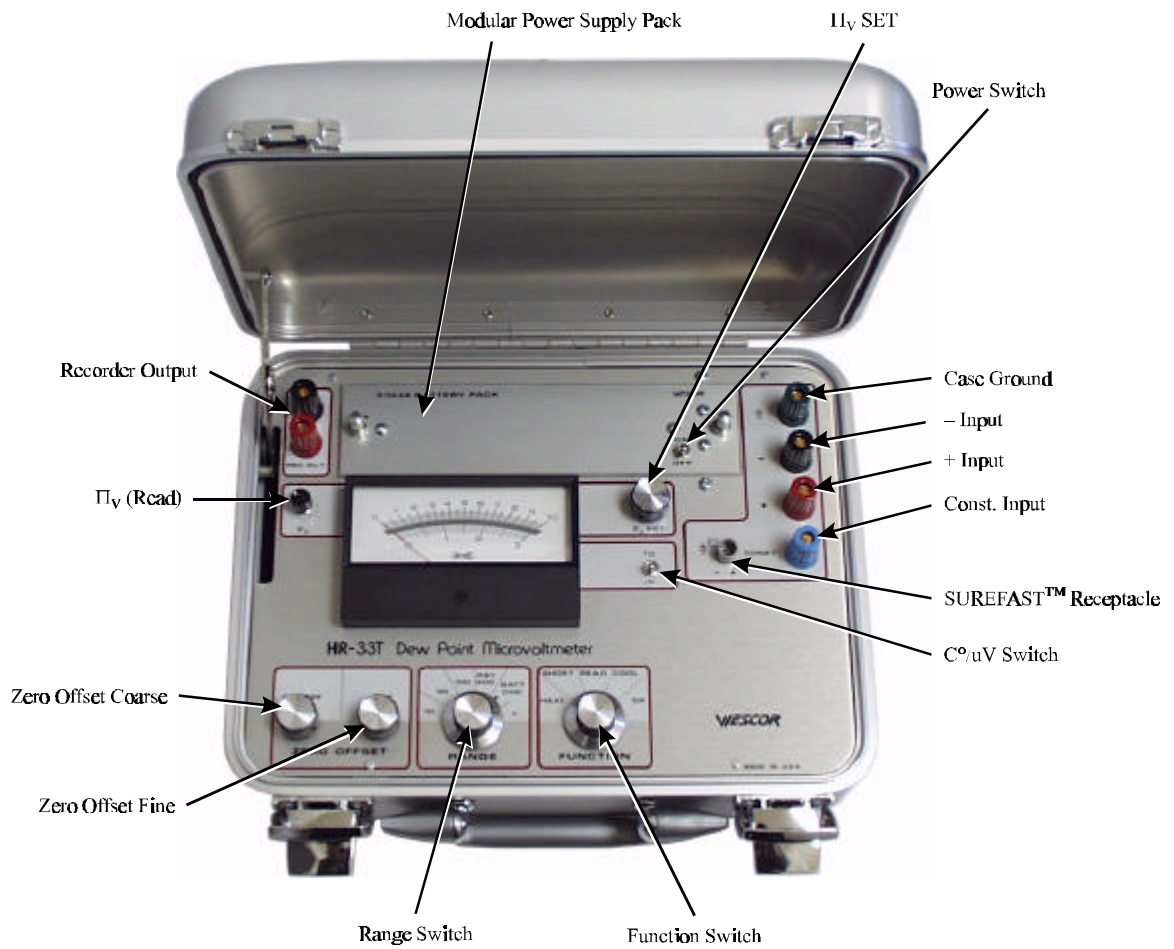
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HR-33T
Figure 1



SECTION 1 – INSTRUMENT SPECIFICATIONS

| | |
|----------------------------|---|
| Standard Power Supplies | <p>HR-33T: 5103A Modular Battery Pack (included with instrument). Batteries: Four Eveready type 522 or equivalent. Battery Life: 10 hours nominal.</p> <p>HR-33T-R: 5112 Rechargeable Battery Pack (included with instrument). Consists of 30 Nicad batteries in a case which is interchangeable with the 5103A Battery Pack or the AC power supplies. The HR-33T-R will operate approximately 20 hours per charge.</p> |
| Optional AC Power Supplies | <p>Model 5106: 115V 50-60 Hz.</p> <p>Model 5109: 230V 50-60 Hz.</p> |
| Controls | <p>ON/OFF (power supply module)</p> <p>ZERO OFFSET COARSE</p> <p>ZERO OFFSET FINE</p> <p>RANGE</p> <p>FUNCTION</p> <p>I_v SET</p> <p>I_v (Read)</p> <p>$^{\circ}\text{C}/\mu\text{V}$ (temperature/microvolts)</p> |
| Ranges | 10, 30, 100, and 300 μvolts full scale plus positive and negative battery voltage, temperature 0°C to 30°C , 0 - 100°C (with accuracy as specified below) |
| Functions | HEAT, INPUT SHORT, READ, COOL, DEW POINT |
| Accuracy | <p>$\pm 1\%$ of full scale-recorder output</p> <p>$\pm 2\%$ of full scale-panel meter</p> <p>Temperature $\pm 0.5^{\circ}\text{C}$ from 0°C to 40°C (refer to Figure 3)</p> |
| Zero Drift | <p>Less than 0.5 μvolts per 24 hours</p> <p>Less than 0.1 μvolts per 1°C</p> |
| Noise | Less than 0.1 μvolts p-p |
| Input Impedance | 100 ohms or less (higher impedances will degrade accuracy) |
| Rise Times | 2 seconds (10% - 90%) |
| Zero Suppression | $\pm 75 \mu\text{volts}$ |
| Recorder Output | 10 volts full scale (10mA) |
| Connectors | <p><i>SUREFAST</i>TM bulkhead connector</p> <p>Binding Posts</p> <p>(constantan binding post for reference junction)</p> |
| External Dimensions | 23 cm x 30 cm x 13 cm |
| Weight | 3.3 kg with batteries |



SECTION 2 – BASIC OPERATING PROCEDURE

The HR-33T permits water potential determination with a variety of sensors in either the dew point or the psychrometric mode. Both methods of measurement, after proper calibration, should give the same water potential. The dew point method of water potential measurement is affected much less by changes in ambient temperature than the psychrometric method. The sensitivity coefficient of the dew point method is approximately twice that of the psychrometric method. For these reasons, the dew point method is often preferred. Either method may at different times appear to be the better choice, depending upon the circumstances and conditions of a particular experiment. Procedures for both methods are detailed in the following.

2.1 – Dew Point Mode

Be sure that the battery pack or the power supply is supplying the proper voltage (see section 6).

The following step-by-step procedure will enable you to obtain consistent and meaningful results from any type of thermocouple psychrometer, including thermocouples mounted in sample chambers.

1. Always set the FUNCTION switch on INPUT SHORT while connecting or disconnecting to the input terminals. If the sensor is equipped with a *SUREFAST*TM connector, plug the connector into the *SUREFAST* receptacle on the front panel. If the sensor does not have a connector, the leads should be connected to the binding posts. The wire from the chromel side of the hygrometer/psychrometer should be connected to the black binding post and the wire from the constantan side of the hygrometer/psychrometer should be connected to the red binding post. The constantan wire from the temperature measurement thermocouple should be connected to the blue binding post. On Wescor hygrometer/psychrometers, the copper lead from the temperature measurement thermocouple is also connected to the constantan side of the hygrometer/psychrometer thermocouple. If a sensor is used which has these two leads separate, both should be connected to the red post.

The temperature measurement thermocouple can be connected at the same time as the psychrometer. Temperature measurements can be made by moving the C°/μV switch to the C° position as explained in Paragraph 2.4.

2. Determine and set “ Π_v ” as follows:
(If “ Π_v ” for the sensor to be used is known, adjust the Π_v SET knob while depressing the Π_v switch until the meter is at the desired value).
 - a. Allow the thermocouple to equilibrate in a dry, isothermal, surrounding (dew point depression > 1°C). If the sensor is a C-52 Sample Chamber, it is sufficient to empty and dry the sample chamber by wiping it with a kimwipe. Room air is usually sufficiently dry. Soil psychrometers or sample chambers which rely upon a waterbath or an insulated box for thermal stability must be air dried and thermally insulated while Π_v is determined.
 - b. With the FUNCTION switch in the READ position and the RANGE switch set to 30 μvolts, adjust the ZERO OFFSET control to bring the meter reading to zero. It is necessary to accurately zero the meter before determining Π_v .
 - c. Rotate the FUNCTION switch to cool for a few seconds, then to DEW POINT. Depending upon the position of the Π_v set knob, the meter will tend to (1) fall back toward zero, (2) hold steady, or (3) climb upscale. Rotate Π_v SET until the meter holds relatively steady and the reading is between 15 and 30 on the bottom scale. (If the needle is rising or pegged upscale, rotate the control clockwise).
 - d. When the Π_v button is depressed, the meter will give a reading proportional to the position of the

Π_v SET control. The numerical value of the reading on the 100 μ volt scale is the cooling coefficient, Π_v , of the thermocouple being used. (See Section 4, Theory of Operation).

3. If the thermocouple is in a sample chamber, insert the sample to be tested and allow sufficient time for thermal and vapor equilibration. If using a soil psychrometer or a similar sensor, allow time for equilibration after installation (Paragraph 3.2).
4. With the RANGE switch set to the anticipated range and the FUNCTION switch on READ, bring the meter reading to zero by adjusting the ZERO OFFSET control.
5. Rotate the FUNCTION switch to COOL long enough to ensure that water has condensed on the junction. Cooling times required will vary from 5 seconds or less for very wet samples to 30 seconds or more for dry samples. Once the necessary cooling time has been determined for a given water potential range and sample type, this time should be used for all measurements within that range, including calibration measurements.
6. The temperature of the thermocouple will fall below the dew point temperature during COOL (assuming the sample is within the measurement range). When switched to DEW POINT, the temperature will converge to the dew point. The e.m.f. produced by the temperature difference between the junction at the dew point temperature and the ambient temperature is a linear function of the water potential. The proportionality constant is approximately $-0.75 \mu\text{volts bar}^{-1}$. Within the normal range of temperatures encountered in water potential measurements, little, if any, correction for ambient temperature is required. However, it is necessary to maintain the proper Π_v setting, as explained in Paragraph 3.5.

2.2 – Psychrometric Mode

The psychrometric mode does not require the determination or setting of Π_v . To use the HR-33T in the psychrometric mode, follow the procedure outlined in Paragraph 2.1 through step 5, omitting step 2. After cooling the junction (step 5), rotate the FUNCTION switch to READ. The meter will indicate a “plateau” signal before falling to zero. The proportionality constant for psychrometric determination of water potential is approximately $-0.47 \mu\text{volts bar}^{-1}$. The microvolt output divided by this number can be used for rough approximations of water potential. The temperature correction given below must be used if the temperature is different from 25°C. More accurate measurements can be obtained by individually calibrating each psychrometer.

A correction for the temperature of the thermocouple can be made using the relationship:

$$\text{CORRECTED READING} = \text{READING} / (0.325 + 0.027T)$$

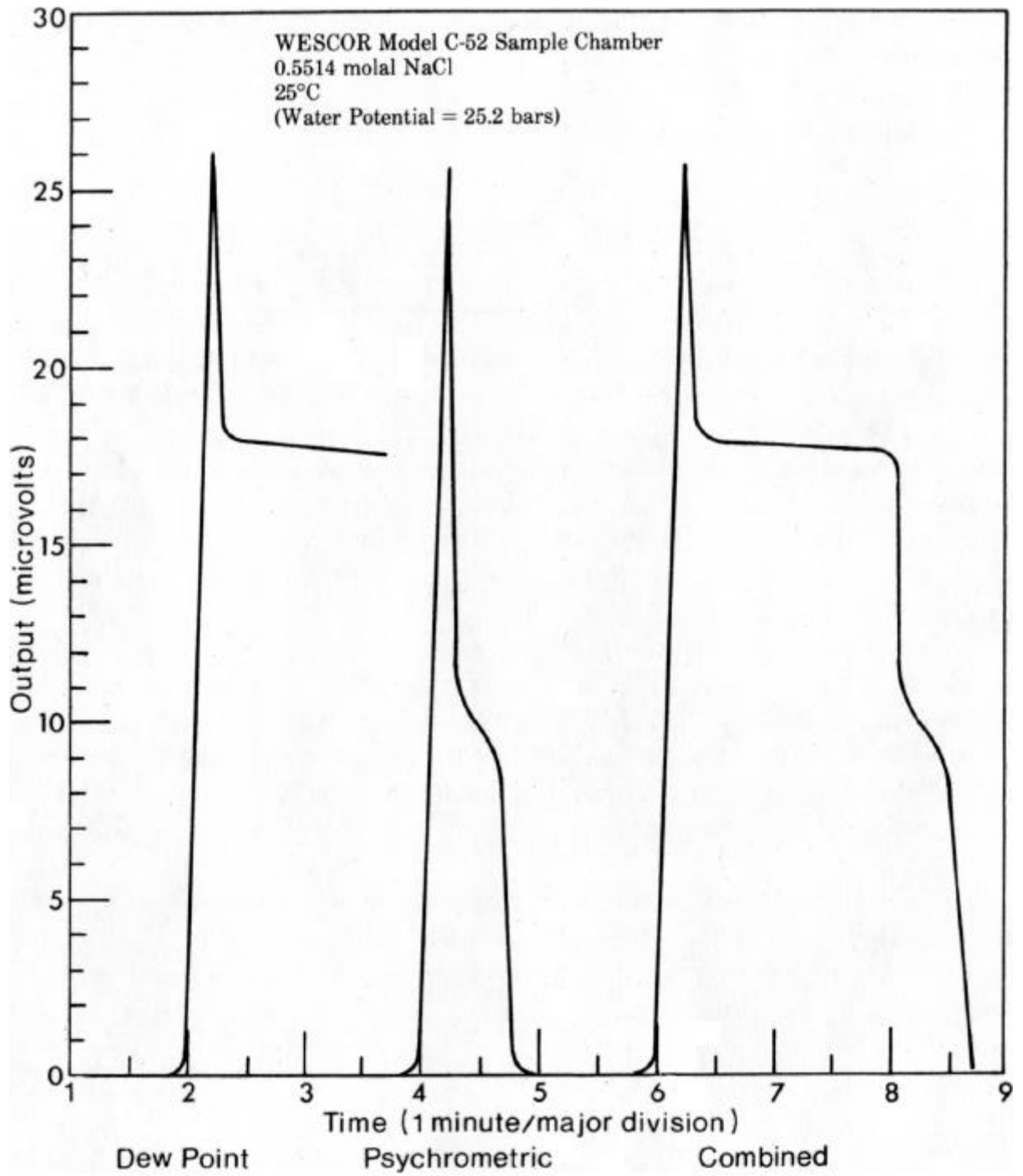
where T is in degrees Celsius.

2.3 – Combined Dew Point and Psychrometric Mode

Combined dew point and psychrometric measurement is sometimes useful. This can be accomplished by switching the FUNCTION switch from DEW POINT to READ upon completion of the dew point measurement. The plateau should be identical to the plateau obtained using the psychrometric mode for the same cooling time. If the plateau is wider, then water has been added to the thermocouple during the dew point measurement period. If the plateau is narrower, then water has evaporated during the dew point measurement period. A strip chart recorder should be employed for this evaluation.

The combined mode permits Π_v to be experimentally determined under wet thermocouple conditions. The value of Π_v must be adjusted until the duration of the plateau is the same as in psychrometric measurement. In re-adjusting Π_v , remember that increasing the Π_v setting decreases the cooling of the thermocouple which will decrease the width of the plateau.

Figure 2 shows the output for each of the three modes of operation presented above. The recordings were made with a 0.5514 molal NaCl solution in a C-52 Sample Chamber. The psychrometric output for all psychrometers should be between $-0.34 \mu\text{volts bar}^{-1}$ and $-0.55 \mu\text{volts bar}^{-1}$ at 25°C .



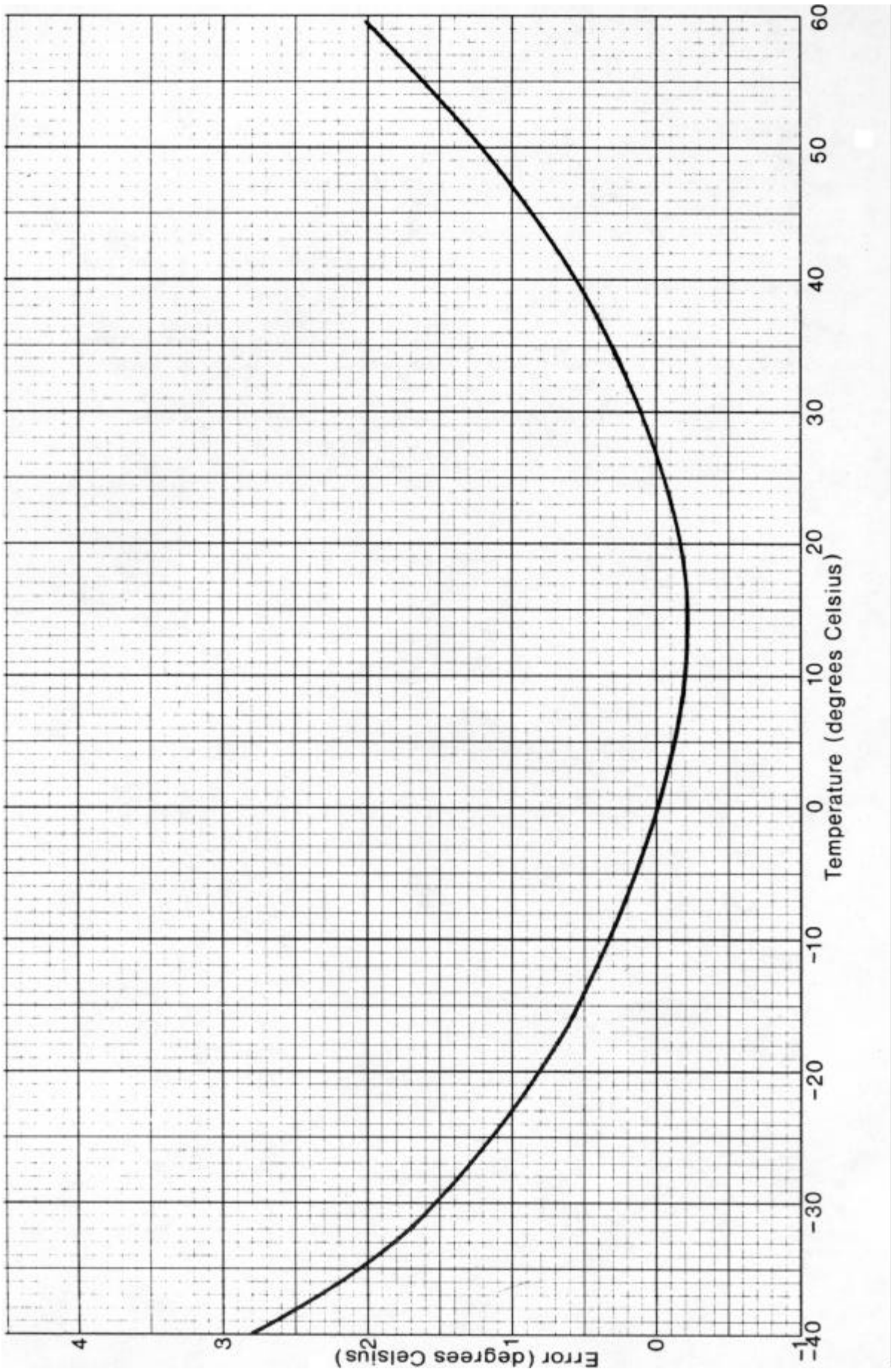
Output For Dew Point, Psychrometric, and Combined Modes
Figure 2

2.4 – Temperature Measurements

Use the following procedure to measure temperature with a copper-constantan thermocouple.

1. Connect the hygrometer/psychrometer using the *SUREFAST*TM connector if it is so equipped. If a *SUREFAST*TM connector is not provided on the sensor, connect the constantan wire to the blue binding post and the copper wire to the red binding post. It is not necessary to disconnect the hygrometer/psychrometer sensor leads while making temperature measurements nor is it necessary to disconnect the temperature measurement thermocouple while making psychrometer measurements.
2. Set the C°/ μ V switch to C° and the RANGE switch to 30 for measurement of temperatures between 0° and 30° Celsius. Above 30°, use the 100 scale.
3. Read the temperature in degrees Celsius directly from the meter.

For optimum accuracy, correct the reading using Figure 3.



Temperature Correction Curve
Figure 3



SECTION 3 – ADDITIONAL OPERATING INFORMATION

The measurement of water potential using the dew point method is relatively straightforward and eliminates errors that might otherwise occur in reading the “plateau” signal from a thermocouple using the wet bulb/dry bulb temperature comparison, or psychrometric method. Nevertheless, while the resulting output from the dew point meter is less subject to interpretive evaluation, the electronic process by which this output is derived from the thermocouple is somewhat more involved than with the psychrometric method. It is therefore recommended that the operator familiarize himself with the principles employed to obtain the dew point reading, as reviewed here and in Section 4, Theory of Operation, in order that he will have a better understanding of the overall operation of the instrument and the results obtained. Inherent limitations in the electronic switching circuitry prevent the instrument from being used in the dew point mode for water potential readings between zero and -1 bar (approximately 0.75 μ volts).

3.1 – Π_v Set Adjustment

The dew point method requires that the electronic gain of the duty cycle control circuitry be matched to the cooling coefficient (Π_v) of the thermocouple being used. This operation is easily performed using the procedure in Paragraph 2.1, step 2, which allows the numerical value of Π_v to be read on the meter. The alternative procedure described in Paragraph 2.3 may also be used. This gain-matching procedure is essential, since it ensures the energy-balance condition that will cause the junction temperature to converge to the dew point. If, during the matching procedure, Π_v is set so that the meter drifts downward, then while a dew point reading with a wet thermocouple is being taken, water slowly evaporates from the junction. Conversely, if Π_v is such that the meter drifts upward, then the junction will slowly accumulate water. In other words, failure to correctly adjust Π_v SET to match the Π_v of the thermocouple being used will result in the thermocouple being held at a temperature slightly above or slightly below the dew point. If the junction gradually loses its water until it is dry, then the reading will become meaningless and decay toward zero.

The cooling coefficient determines the ultimate limit of the thermocouple’s range in measuring water potential since it represents the maximum temperature depression that can be reached by the junction through Peltier cooling. If the dew point is below this temperature, no measurement can be made in the dew point mode since it will not be possible to condense water from the sample onto the junction.

For example, if a given junction has $\Pi_v = 50 \mu$ volts, the lowest potential that can be measured by the junction will be

$$\frac{50 \mu\text{volts}}{-0.75 \mu\text{volts bar}^{-1}} = -66.6 \text{ bars}$$

Using the psychrometric method, this same junction would produce a maximum signal of approximately 31 μ volts.¹

Wescor junctions typically exhibit cooling coefficients of 50 to 80 μ volts, with some units as low as 40 μ volts or as high as 90 μ volts.²

¹Researchers have reported measurements as low as -3000 bars using a sample exchange technique in a Wescor Sample Chamber, but this technique can only be employed in conjunction with the psychrometric method.

²Wescor Soil Psychrometers are individually tested and labeled for cooling coefficient, Π_v . A strip chart recording showing the psychrometric response to a 0.55 molal NaCl calibration solution is included with each sensor.

3.2 – Thermal and Vapor Equilibration

Thermal equilibration can be easily determined by comparing the reading on INPUT SHORT and on READ. The difference between these two readings represents the difference between the junction temperature and the temperature at the head of the psychrometer chamber where the chromel and constantan wires fasten to the connecting pins. The offset should be less than 3 μ volts for meaningful measurements. Higher offsets are evidence of excessive thermal gradients (Section 7).

Vapor equilibration can occur very rapidly for a sample chamber containing a solution (often less than one minute). For a ceramic cup in a calibration solution, equilibration may take one or two hours. For ceramic cups buried in soil, it is necessary that the disturbed soil come to equilibrium with the surrounding soil. It is advisable to allow 24 hours after installing soil psychrometers before reading the water potential.

The equilibration time for in situ measurement of water potential of leaves with the L-51 or L-51A Leaf Psychrometers varies with the type of leaf being measured and the conditions of measurement. Some leaves equilibrate in 15 minutes or less but others may require several hours.

Repeatable water potential readings indicate that equilibration has occurred. Care must be taken that the period between measurements is long enough to detect small changes, especially where long equilibration times are involved.

3.3 – Effect of Zero Drift on Reading

Given the condition of water condensed on the junction at the dew point temperature, the direct reading of the instrument in dew point mode will continue indefinitely. However, the accuracy of the reading will be directly affected by any thermally induced zero offset that occurs in the thermocouple or intermediary connecting points, or in the instrument itself. Zero drift in the instrument will normally be negligible, but other effects may become substantial. Therefore, sustained continuous readings over several minutes in duration should not be relied upon for accuracy unless extreme care has been taken to allow complete temperature equilibration and unless ambient temperature variations and thermal gradients have been eliminated.

3.4 – Ancillary Instrument Functions

In addition to the operational functions used to measure water potential as described in Section 2, the HR-33T also features three additional functions that are incorporated in the RANGE switch and the FUNCTION switch:

| | |
|-------|--|
| HEAT | supplies heating current to the thermocouple to dry the junction when necessary. |
| +BATT | measures internal battery voltage |
| -BATT | (full scale = 30 volts) |

3.5 – Π_v Versus Temperature

It has been found, both theoretically and empirically, that Π_v changes by a factor of 0.7 $\mu\text{volts}/^\circ\text{C}$ with Wescor Psychrometers. Π_v for temperatures other than the temperature at which Π_v was measured is given by the formula:

$$\Pi_{v,T_1} = 0.7(T_1 - T_0) + \Pi_{v,T_0}$$

where Π_{v,T_1} is the value of Π_v at the new temperature (T_1), and Π_{v,T_0} is the value of Π_v at the temperature of measurement (T_0).

An example of such a correction is as follows:

Given: Π_v at $25^\circ\text{C} = 55 \mu\text{volts}$
 $T = 12^\circ\text{C}$
 Π_v at $12^\circ\text{C} = 0.7(12 - 25) + 55 = 45.9 \mu\text{volts}$

For maximum accuracy, Π_v should be readjusted to the correct value whenever operating at temperatures different from T_0 .



SECTION 4 – THEORY OF OPERATION

4.1 – Thermocouple Cooling Coefficient

In a thermocouple consisting of substances a and b, a temperature difference ΔT between the two junctions will cause a thermoelectric e.m.f., E , to be set up between the junctions. The magnitude and direction of E is determined by the thermoelectric properties of the two substances and is given by

$$E = P_{ab}\Delta T \quad (1)$$

where P_{ab} is the sensitivity of the thermocouple in volts/degree.

When a current, I , is caused to flow through the junction in the direction of its thermoelectric e.m.f., the junction is cooled by an amount proportional to the current. This is known as the Peltier Effect after Peltier who discovered it in 1834.

$$\frac{dW_p}{dt} = -\Pi_{ab}I \quad (2)$$

dW_p/dt is the rate of energy transfer. The coefficient Π_{ab} is known as the Peltier Coefficient. For very small currents, a linear relationship exists between the thermoelectric e.m.f. and Peltier cooling; the coefficients P_{ab} and Π_{ab} are related by the equation³

$$\Pi_{ab} = T P_{ab} \quad (3)$$

where T is the absolute temperature.

Equation (2) may lead one to believe that the junction can be cooled to any desired temperature simply by providing a sufficient amount of cooling current. At higher values of I , however, this simple relationship does not hold true inasmuch as the current passing through the junction not only cools by the Peltier Effect, but heats the junction as a result of the resistance. Equation (2) must therefore be modified to account for this effect such that

$$\frac{dW_p}{dt} = -\Pi_{ab}I + RI^2 \quad (4)$$

³Smith, Jones, and Chasmar, "The Detection and Measurement of Infra-Red Radiation," (Oxford University Press, 1960) p. 62.

where R is the electrical resistance of the junction and thermocouple lead wires in the immediate vicinity of the junction. The second, or heating, term of the equation is negligible at small values of I, but because the heating effect increases with the square of I, it rapidly becomes the dominant factor in the equation. Thus, in thermocouple psychrometers, there is an optimum value of cooling current that will produce maximum temperature depression, beyond which a further increase in current will actually reduce the cooling effect. Furthermore, microscopic differences in the geometry and alloy makeup of the junctions influence the value of R and hence the net cooling effect. Thus, while the thermocouple voltage - temperature sensitivity, P_{ab} , and the Peltier Coefficient, Π_{ab} , will be identical in every junction made from the same two materials, the maximum cooling capability of a junction will vary somewhat from one junction to the next.

When the temperature of the junction is depressed by means of Peltier cooling, heat will begin to flow into it from its surroundings. This transfer of energy will limit the maximum realizable temperature depression, depending upon numerous factors including chamber geometry, volume, and materials. When these factors are fixed, however, the maximum realizable temperature depression of the junction is also fixed. This maximum temperature depression is of concern in thermocouple psychrometry, and of particular interest where the dew point method is used.

From the foregoing, it is clear that the Peltier Coefficient, Π_{ab} , does not, by itself, determine the maximum temperature depression of the junction. For our purposes, therefore, we shall define a slightly different coefficient which we shall call the cooling coefficient. It shall be a characteristic parameter of a given thermocouple psychrometer, representing its maximum junction temperature depression resulting from the passage of a nominally optimum cooling current. Since the temperature of the junction is directly related to its thermoelectric e.m.f., the cooling coefficient will be expressed in microvolts (this is in harmony with the Peltier Coefficient which, as defined above, also has units of Watts-Ampere, or Volts).

DEFINITION: The cooling coefficient Π_v , for a given thermocouple psychrometer is defined as the differential e.m.f. in microvolts that results from the passage of a specified nominally optimum cooling current through the junction at a specified ambient temperature.

Stated mathematically: $\Pi_v = P_{ab}\Delta T_m$ (5)

where ΔT_m is the temperature differential that results from the given current. *The measurement of Π_v must be performed in such a way that the differential e.m.f. is measured immediately after cessation of cooling current flow, and is completely independent of any consequential effects of the current other than the temperature depression of the junction.* These requirements are fulfilled in the HR-33T.

Statistical data on a large number of Wescor Thermocouple Psychrometers have shown that the optimum cooling current is typically 8.0 milliamperes. This value of cooling current is standard in the HR-33T Dew Point Microvoltmeter (RMS current = 8 mA at 95% duty cycle).

4.2 – Psychrometric Method

Thermocouple psychrometers provide a measurement of water potential in situ or in sample chambers through their ability to sense the relative humidity of their environment, this parameter being linearly related to water potential within the range from 0 to approximately -70 bars. With the psychrometric method, the junction is cooled by the passage of an electrical current through it (Peltier Effect) to a temperature below the dew point, thus causing pure water to condense upon the junction. Having accomplished this, the cooling current is discontinued, and the condensed water allowed to evaporate from the junction back into the surrounding atmosphere. The evaporating water draws heat from the junction (heat of vaporization), depressing the temperature of the junction from that of the surrounding air temperature. The magnitude of the temperature depression depends upon the relative humidity and the temperature of the surrounding air; the drier (and warmer) the air, the faster the evaporation rate and the greater the depression. The temperature of the junction is measured by electrical means prior to cooling and during evaporation. The differential temperature of the junction is an explicit function of the relative humidity and hence of the water potential in the media being measured.⁴ Thermocouple psychrometers have a typical responsivity near $0.47 \mu\text{volts bar}^{-1}$ at 25°C . Because the effects of temperature must be removed from the measurement, a correction for ambient temperature, if other than 25°C , is made to obtain the true water potential (refer to Paragraph 2.2).

4.3 – Dew Point Method

In the psychrometric method, the temperature that the junction attains while water evaporates from its surface is always lower than the ambient, but higher than the dew point temperature. This fact becomes obvious when one recognizes that if the junction were somehow to be held at the dew point temperature, no water would evaporate from it. This simple observation is the fundamental principle upon which the dew point thermocouple method is based, to wit:

If held at the dew point temperature, a wet thermocouple junction will neither lose water through evaporation nor gain water through condensation.

⁴Rigorous analyses of the principles of thermocouple psychrometry are available in the literature. A simplified and generalized description of the process is used here to provide a basis for comparison with the dew point method.

Consider a hypothetical thermocouple junction whose temperature is determined exclusively by the heat transferred to it or away from it by condensing or evaporating water. Assume also that the junction has an initial temperature T , and that it is covered with water. If T is above the dew point, water will evaporate from the junction, carrying with it the heat of vaporization until the temperature of the junction falls to the dew point, at which time evaporation will cease. If T is below the dew point, additional water will condense upon its surface, and the heat of condensation will raise the temperature of the junction until it reaches the dew point, at which time condensation will cease.

Therefore, given the aforesaid independence from all heat transfer except that due to water, the temperature of a wet junction will always converge upon the dew point.

4.4 – HR-33T Dew Point System

In the real world, it is not possible for a thermocouple junction to be independent of heat transfer mechanisms that nature calls into play. Nevertheless, considering the circumstances that will prevail whenever a measurement of water potential is to be made, it is possible to simulate the above described hypothetical situation. During the measurement, the wet junction temperature will always be below the temperature of its surroundings. Therefore, heat will tend to flow from the surroundings to the junction. Using Peltier cooling, a counter flow of heat can be created whose magnitude is adjusted electrically to exactly balance the heat inflow for a net energy transfer of zero. If this balanced condition is set up on a dry thermocouple to account for all heat transfer mechanisms other than condensing or evaporating water, then when the junction is wet, its temperature will be influenced only by the water, just as in the hypothetical example.

To illustrate, let the heat transfer from the surroundings to the dry thermocouple be represented by the relationship

$$\frac{dW_s}{dt} = k\Delta T \quad (6)$$

where k is a proportionality constant representing effective thermal conductivity, and ΔT is the temperature differential between the temperature of the surroundings and the thermocouple junction.

Although the general mathematical description for radiative and conductive transfer mechanisms to and from the junction are considerably more complex than the above relationship, for small ΔT , such as applies here, the simple linear model of equation (6) is sufficiently accurate.⁵

⁵Smith, et al, op cit, p. 48.

Heat transfer due to Peltier cooling and resistive heating is given by equation (4). Assuming an optimum value of cooling current, the maximum temperature depression ΔT_m will be obtained. If the cooling current is pulsed at a regular periodic rate, the actual cooling effect can be varied linearly between zero and maximum. The average temperature depression of the thermocouple junction will be given by

$$\Delta T = L\Delta T_m \quad (7)$$

The cooling duty cycle, L , is a unitless number between 0 and 1 and is given by

$$L = \frac{t_a}{t_b} \quad (8)$$

where t_a = “on” time of cooling current, and t_b = period of electronic impulses. (In the HR-33T, L is restricted by design to the range from 0 to 0.95.)

By controlling the value of L , we are able to adjust the magnitude of cooling to exactly balance heat inflow. Then using equations (5), (6), and (7), we have

$$\frac{dW_p}{dt} = \frac{dW_s}{dt} = \frac{kL\Pi_v}{P_{ab}} \quad (9)$$

The psychrometer output is given by $P_{ab}\Delta T$. If we use this output to control the value of L such that

$$L = \frac{P_{ab}\Delta T}{\Pi_v} \quad (10)$$

then the exact energy balance stated in (9) is satisfied. The instrument output is divided electronically by the value of Π_v which is set into the instrument using the Π_v SET control.

To illustrate, assume Π_v SET has been adjusted for a given thermocouple and the thermocouple has been placed in position for measurement. The junction temperature is lowered below the dew point for a short time to condense water upon its surface (when in COOL, the cooling duty cycle is always at its maximum value, or 0.95). When the FUNCTION switch is rotated to DEW POINT, the cooling duty cycle immediately assumes a value dictated by the microvoltmeter output such that heat is removed from the junction at the same rate it flows in from the surroundings. Since the junction temperature is below the dew point, water continues to condense, liberating the heat of condensation. As the temperature of the junction rises, ΔT becomes smaller as does the psychrometer output and the duty cycle L so that Peltier cooling continues to remove exactly the amount of heat flowing in from the surroundings. This automatic process continues until the junction temperature reaches the dew point and condensation ceases. The system will then maintain the dew point temperature. *However, if a change in ambient temperature occurs, the meter output will be affected proportionately, since the initial ambient temperature is used as a reference point from which the dew point depression is measured.*

4.5 – Effect of Ambient Temperature

Thermocouple output as a function of water potential and ambient temperature is easily obtained for the HR-33T. Thermocouple output is simply the thermocouple sensitivity, P_{ab} multiplied by the dew point depression, ΔT . When the dew point depression is small (as is the case for water potential measurement), $\Delta T = \Delta e/S$, where Δe is the difference between saturation and chamber vapor pressure, and S is the slope of the vapor pressure-temperature function at ambient temperature. The Clausius-Clapeyron equation gives S as a function of temperature, saturation vapor pressure, (e_0), and latent heat of vaporization (λ):

$$S = \frac{e_0 \lambda}{RT^2} \quad (11)$$

where R is the universal gas constant. A relationship between Δe and water potential (λ) is obtained using the expression,

$$e = e_0 \exp \frac{\psi}{RT} \quad (12)$$

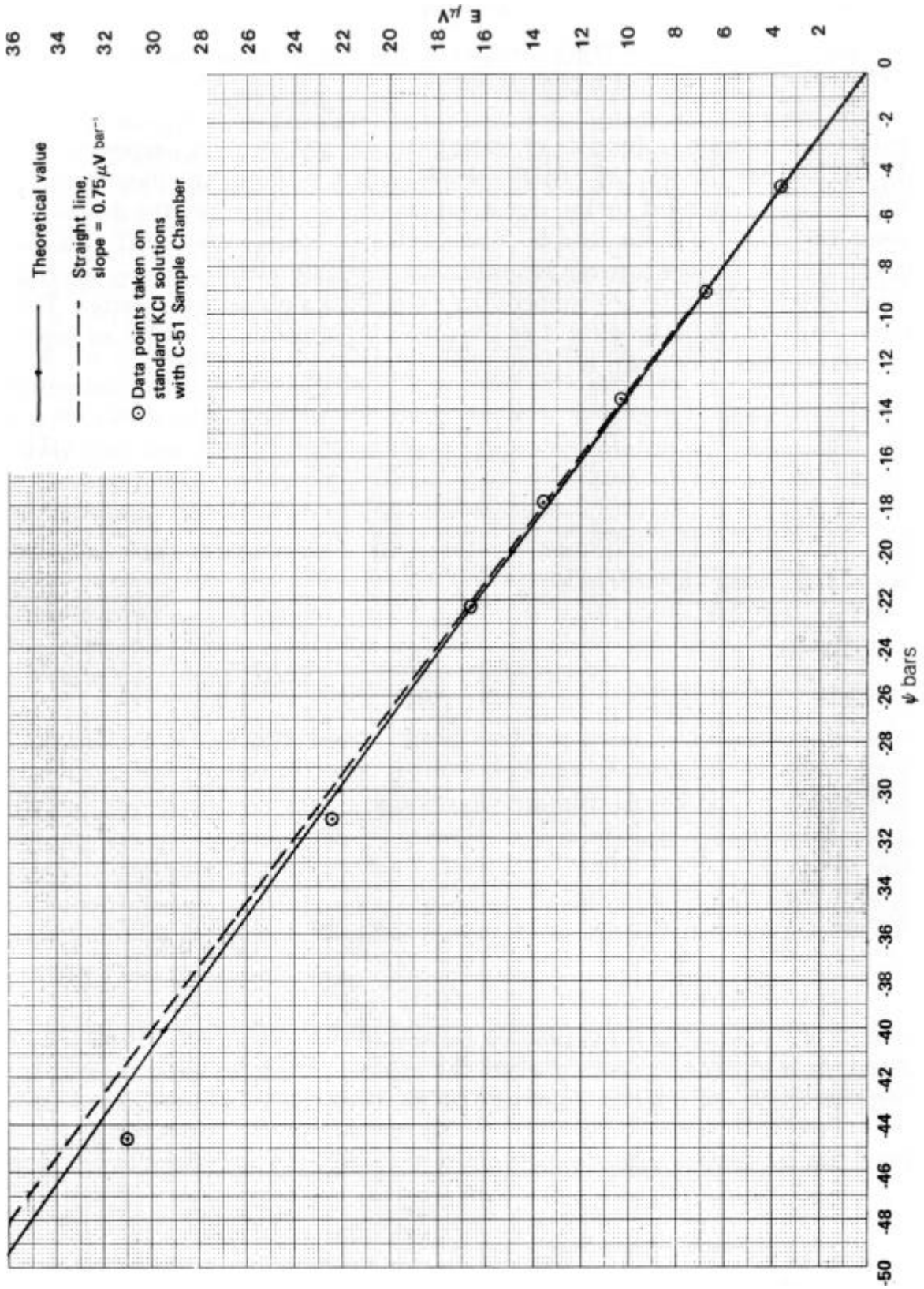
Thus,
$$\Delta e = e_0 - e = e_0 \left(1 - \exp \frac{\psi}{RT} \right) \quad (13)$$

and
$$\Delta E = P_{ab} \Delta T = P_{ab} \Delta e / S = \frac{P_{ab} RT^2}{\lambda} \left(1 - \exp \psi / RT \right) \quad (14)$$

Equation (14) is the desired relationship between thermocouple output and water potential. At high water potentials where the exponential can be approximated by the first two terms of a series, equation (14) becomes

$$E = \frac{-P_{ab} T \psi}{\lambda} \quad (15)$$

indicating a linear relationship between E and λ with a sensitivity of about $-0.75 \mu\text{volts bar}^{-1}$. Figure 4 shows the agreement between theoretical and actual calibration curves. Values of constants used were $T = 298^\circ\text{K}$, $R = 4.60 \text{ bars } ^\circ\text{K}^{-1}$, $\lambda = 24330 \text{ bars}$ and $P_{ab} = 63 \mu\text{volts } ^\circ\text{K}^{-1}$.



Theoretical vs. Actual Instrument Output
 Figure 4

Change in sensitivity with temperature is found by dividing Equation (15) by ψ and differentiating with respect to temperature. This gives

$$\frac{d(E/\psi)}{dT} = \frac{-P_{ab}}{\lambda} \quad (16)$$

Since P and λ increase with temperature at about the same rate, the change in sensitivity with temperature remains approximately constant at about $2.5 \times 10^{-3} \mu\text{volts bar}^{-1} \text{ } ^\circ\text{C}^{-1}$ or about 0.3 percent per degree from 10 to 50°C. Thus, over the normal range of temperatures encountered in water potential measurements, little, if any, temperature correction for thermocouple sensitivity is required. However, Π_v does change with temperature. This temperature dependence is discussed in Paragraph 3.5.

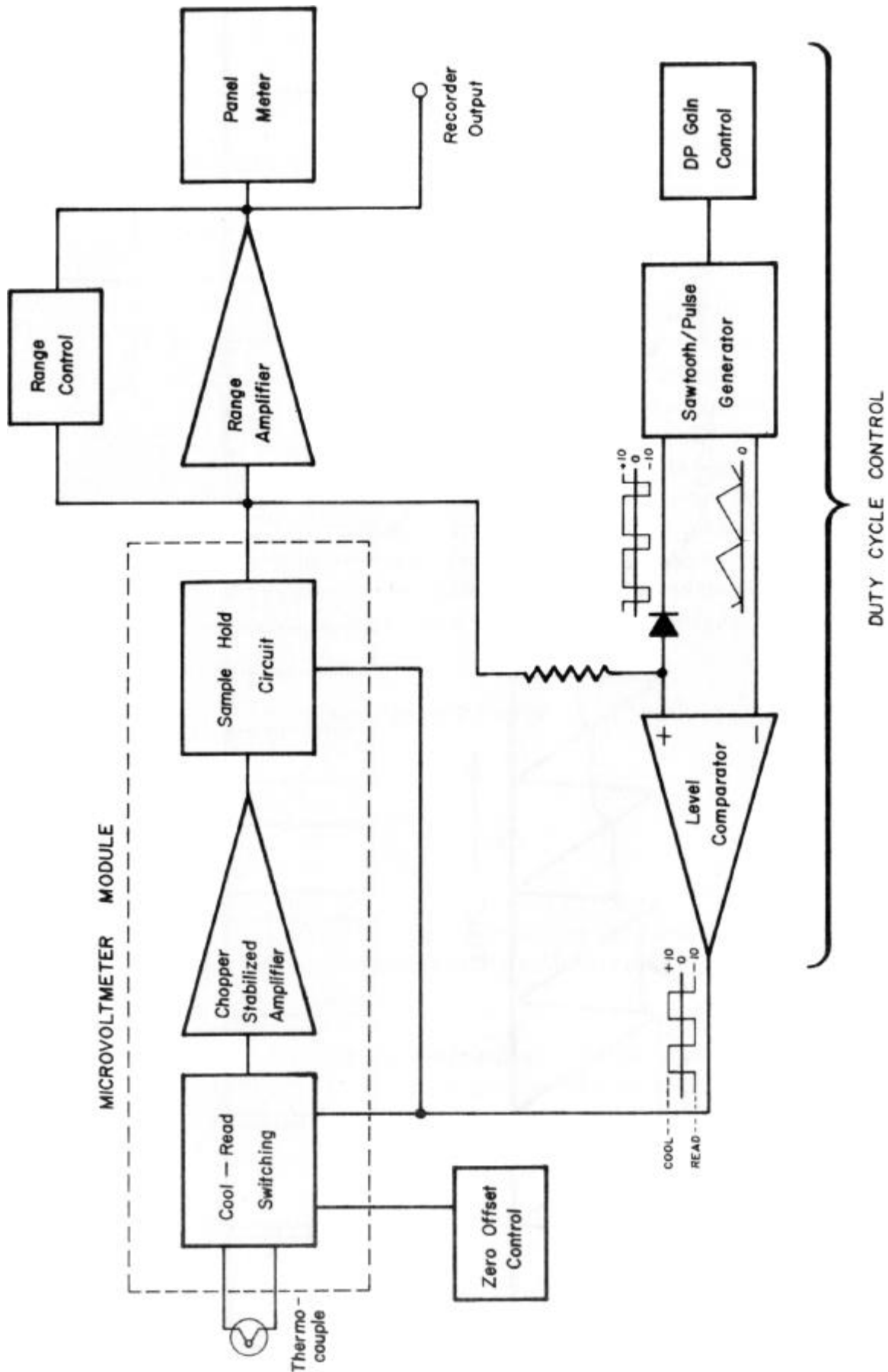
SECTION 5 – ELECTRONICS

The electronic system of the HR-33T, when in the DEW POINT operational mode, is depicted in the block diagram, Figure 5. The voltage signal from the thermocouple is processed through the microvoltmeter section of the instrument, amplified by a gain of 10. This signal is fed to the panel meter through the range amplifier and into the non-inverting input of a level comparison circuit whose bistable logic output is either “high” (positive) or “low” (negative) depending upon whether the voltage at the + input terminal is higher or lower than the voltage at the – input terminal. The microvoltmeter signal is compared to the sawtooth ramp voltage by this circuit. Since the ramp voltage starts at zero, and assuming that some finite signal is present from the thermocouple (thermocouple temperature depressed from ambient), the comparator output will initially be “high,” and the thermocouple will receive cooling current through the electronic switching circuits. When the ramp voltage becomes higher than the signal voltage, the output of the comparator switches to “low,” and the cooling current is discontinued. The microvoltmeter indicates the thermocouple voltage during this interval, and the sample hold circuit maintains the signal level from one reading interval to the next. The negative pulses produced by the sawtooth/pulse generator circuit are added to the thermocouple signal at the + input of the comparator. These pulses represent a 0.05 duty cycle, and limit the cooling duty cycle to a maximum of 0.95, ensuring a minimum read interval of at least 0.05 to maintain the output signal in the sample hold circuit.

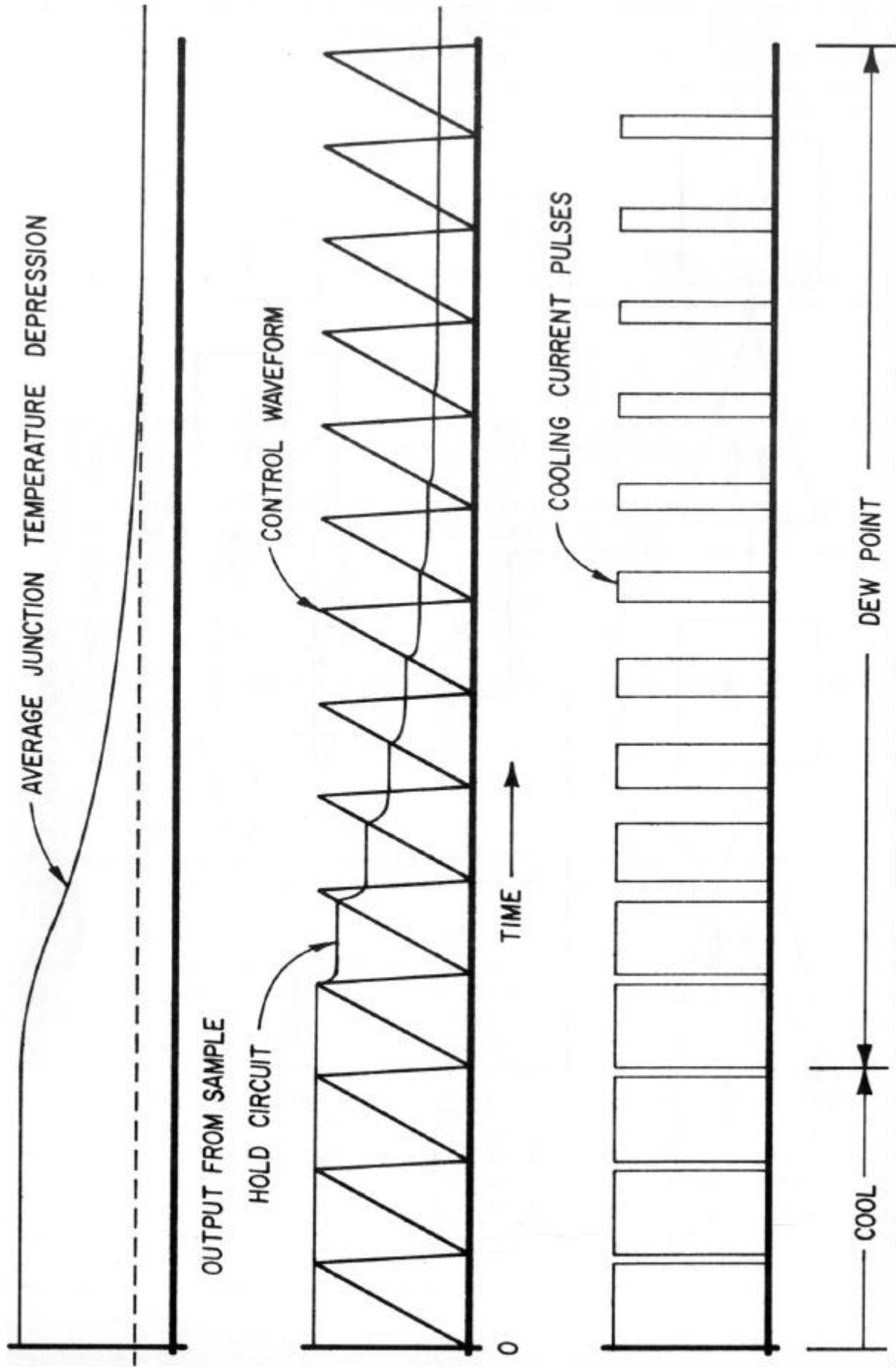
The height of the sawtooth waveform is adjusted by the Π_v SET control such that for a given thermocouple, the cooling duty cycle, as dictated by the thermocouple temperature depression signal, will remove precisely that amount of heat that is flowing into the junction from its surroundings. If the water on the junction then causes a movement of the junction temperature toward the dew point, the output signal will change, dictating a corresponding change in the cooling duty cycle, thus maintaining a balance of thermal energy being conducted into and out of the junction.

To further illustrate, Figure 6 depicts the temporal relationship between the various signal and control waveforms and levels as they will appear during initial cooling and as the junction temperature converges to the dew point. The height of the sawtooth waveform is determined by the Π_v SET control to match the thermocouple cooling coefficient, Π_v . For another junction having a different cooling coefficient, a different sawtooth height will accordingly be set in the instrument.

At output levels below approximately 0.75 μ volts (-1 bar), the cooling duty cycle becomes so small that the frequency response characteristics of the processing circuitry begin to affect the linearity of the system, such that automatic dew point operation cannot be maintained in this range.



HR-33T Electronic System, Dew Point Mode
Figure 5



Typical Control and Signal Waveforms vs. Junction Temperature
 Figure 6

The FUNCTION control switch establishes appropriate interconnections among the instrument's control and measuring circuits for the operational mode selected by the operator. The cooling duty cycle and instrument output indication for each operational mode are set forth in Table 1.

Table 1
Instrument Operation Versus Function Switch Position

| Operational Mode | Cooling Duty Cycle | Meter Reading | Notes |
|------------------|---|---|--|
| HEAT | No cooling | Not meaningful | Psychrometer junction heated to drive off moisture |
| INPUT SHORT | No cooling | Controlled by the offset | Allows OFFSET to be set to zero. Protects meter while changing connections |
| READ | No cooling | Not meaningful | Microvolt output from the psychrometer thermocouple |
| COOL | 0.95 | Microvolt output from the psychrometer thermocouple | Maximum cooling |
| DEW POINT | Automatically controlled between 0 - 0.95 | Microvolt output from the psychrometer thermocouple | Junction converges to dew point temperature |

SECTION 6 – MAINTENANCE

6.1 – General Maintenance

The instrument is constructed using solid state circuitry and high quality components throughout. There is no requirement for general periodic maintenance other than battery replacement in the 5103A power supply module. As with any precision equipment, reasonable care should be exercised to protect the instrument from severe mechanical shock or from extremes in temperature. The instrument panel and case may be cleaned using a soft cloth and mild soap solution, if necessary.

6.2 – Batteries

The HR-33T with the 5103A battery pack uses four Eveready alkaline type 522 (or equivalent) storage batteries. They are connected in series to provide +18, -18, and zero volt connections to power the instrument. The batteries are mounted in the power supply module which is removed from the instrument by rotating the fasteners and lifting straight up.

The battery voltage can be tested at any time by moving the RANGE switch to +BATT or -BATT. The reading will be in volts with full scale = 30 volts. Two batteries are read at one time to give nominal readings of plus or minus 18 volts respectively. Batteries should be replaced anytime the voltage reading falls below 16 volts.

CAUTION

Remove used batteries promptly to avoid the danger of instrument damage by corrosive leakage. In no event should the instrument be stored for extended periods without first removing the batteries.

The useful operating battery life is theoretically 10 hours, but actual service may vary substantially from this depending upon operating condition and freshness of the batteries when placed in service.

The HR-33T-R with the 5112 rechargeable battery pack uses 30 nickel cadmium batteries in a case which is interchangeable with the 5103A battery pack. A charger is supplied with the 5112 battery pack. The charger supplies 25 mA current to the batteries. A discharged battery can be completely recharged in 14 to 16 hours. The charger should not be left connected to the power supply for longer than two days or the batteries may deteriorate and become inoperative. A fully charged power supply will provide approximately 20 hours of operation.



SECTION 7 – TROUBLESHOOTING

If the instrument fails to operate satisfactorily, check the batteries and replace when needed, as outlined in Section 6.

If the batteries are satisfactory but the instrument does not operate properly, one of the following circumstances may be the reason:

[a] *Leads Improperly Connected to the Binding Posts*

Make sure that the leads are connected to the binding posts as outlined in Section 2.

It may be impossible to tell from inspection of the lead wires which wire is connected to the constantan and which to the chromel wire. To determine if the leads are connected properly, set the RANGE to 100. If the lead wires are connected properly, the meter needle should rise from 0 to 30 μ volts (with the thermocouple in dry air) in about 7 seconds after the FUNCTION switch is rotated to COOL. The meter will then approach a maximum value asymptotically. When the FUNCTION switch is rotated to DEW POINT, the needle will gradually rise or fall, depending on the Π_v setting (Paragraph 2.1, 2c), but will generally not rise more than 10 μ volts. If the leads are reversed, the needle rapidly rises to 20 μ volts (2 to 3 seconds). It will continue to rise to and beyond 100 μ volts on COOL and on DEW POINT.

[b] *Open Thermocouple*

Measure the thermocouple resistance with an ohmmeter. If the resistance is less than 2 ohms, the thermocouple is probably shorted. If it is greater than 20 ohms, it is probably open or has a bad connection.

[c] *Loose Connection*

If the meter can be controlled with the ZERO OFFSET controls when the FUNCTION switch is in the SHORT position but not in the READ position, then the binding posts may be loose from the meter or the psychrometer leads loose from the binding posts. These should be cleaned and tightened.

[d] *Wet Measuring Junction*

If the measuring junction is wet, readings will generally be near zero. Wet junctions may occur if readings are repeated without waiting for the junction to dry completely (this may require 5 minutes or more at water potentials approaching zero). Wet junctions apparently also persist for long periods in soil psychrometers, perhaps resulting from temperature gradients. Detection and avoidance of wet junctions differs with the type of psychrometer and the way in which it is being used.

- (1) *Wescor C-52 Sample Chamber*: If a wet junction is suspected, turn the FUNCTION switch to READ and observe the meter needle while the chamber is opened and the sample pulled partway out to allow dry air to enter the chamber. If the junction is wet, the needle will quickly rise to high readings and after several seconds drop to zero. The time is dependent upon the quantity of water condensed on the junction. The chamber is then closed and, after a short vapor and equilibration time, is ready for another reading. If the junction is dry, the reading drops to zero within one or two seconds after transient excursions associated with pressure changes on opening the chamber.
- (2) *In-situ Soil Psychrometer*: If condensation is suspected, turn the FUNCTION switch to HEAT to evaporate all water. This may take 10 seconds or more. Switch to READ and allow 5 minutes for thermal and vapor equilibration, then make a reading. One problem associated with use of the HEAT function is that water evaporated from the junction will condense on the nearest surface, i.e., the thermocouple mount, rather than in the soil, possibly leading to erroneous readings.

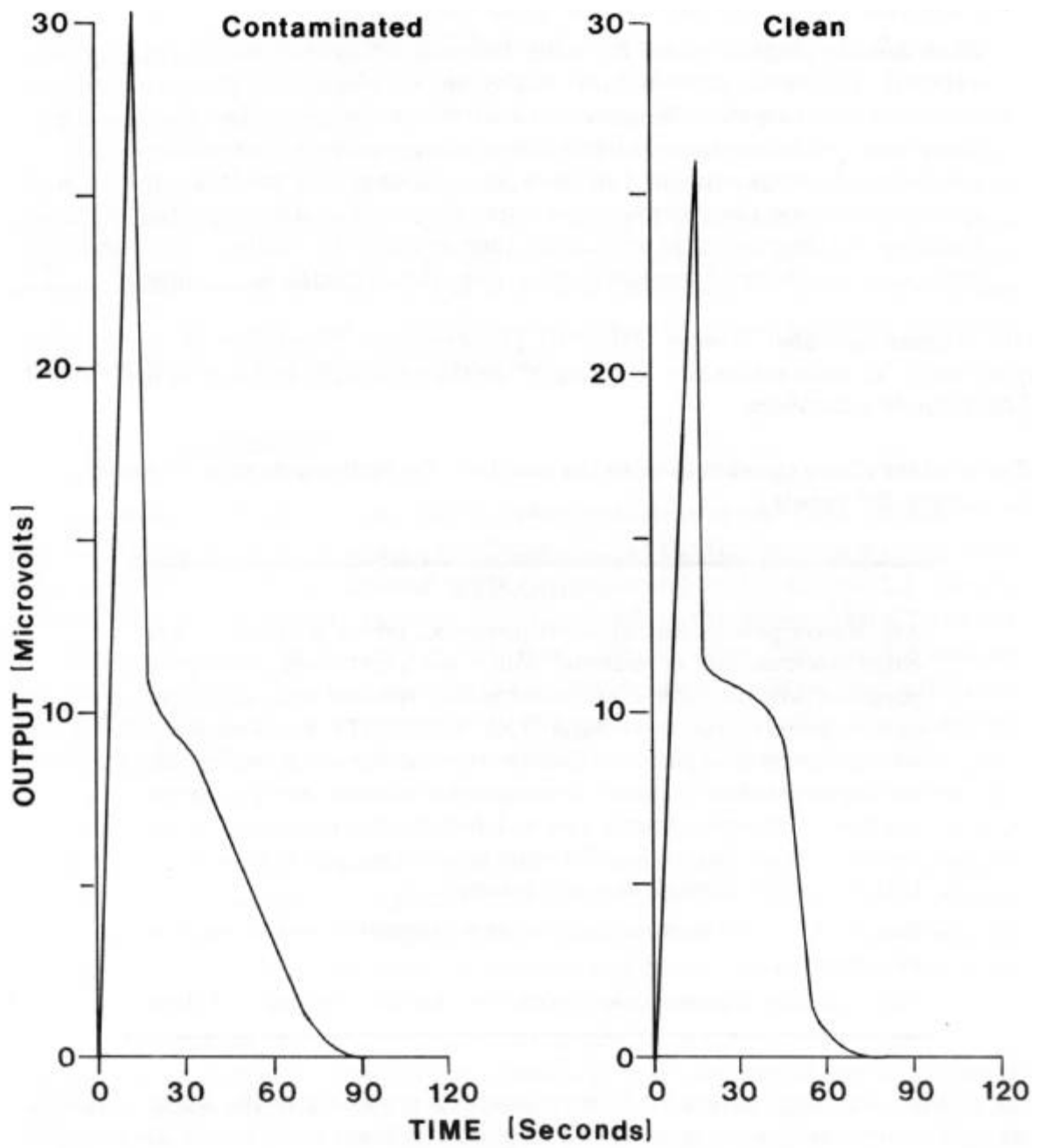
Repeated or prolonged cooling of the junction can gradually build up moisture in the psychrometer, even without use of the HEAT function, and this water is only slowly dissipated throughout the soil. Thermal gradients may also cause condensation within the chamber.

[e] *Excessive Temperature Gradients*

These can be detected in single junction psychrometers as a difference in readings where the FUNCTION switch is alternated between READ and INPUT SHORT. Differences above 1 μ volt indicate undesirable temperature gradients, and above 10 μ volts often preclude reliable determinations. Solution: Place the psychrometer perpendicular to the temperature gradient, and wait until its temperature is uniform with the offset near zero to make readings. Routine checks of zero offset are highly recommended.

[f] *Contaminated Chamber or Thermocouple*

The thermocouple or the chamber in which it is mounted may become contaminated, making accurate water potential measurements impossible. One method of detecting a contaminated thermocouple is to compare the psychrometric plateau with the plateau produced by a clean psychrometer for the same water potential and the same cooling time. Figure 7 shows typical curves for a clean and for a contaminated thermocouple. The fall-off from the plateau begins earlier and is more gradual for a contaminated psychrometer.



Output Characteristics for Contaminated and Clean Thermocouples
Figure 7

Often a soil psychrometer can be cleansed by running clean water over the unit for a period of several hours. If this is not successful, the case must be removed. The thermocouple and mount can be cleansed by rinsing in distilled water several times, and drying by blowing with clean air. *Distilled or deionized water used for rinsing must have a resistance of 1 megohm mL⁻¹ or better.* Rinse water of lower quality may preclude successful cleaning of the thermocouple.

Most sample chambers can be easily taken apart so that the thermocouple is exposed. The same method that was given for cleaning a disassembled soil psychrometer can then be used to clean the sample chamber thermocouple. Sometimes with a sample chamber it is necessary to remove the o-ring and clean around the thermocouple and in the o-ring groove with a wet swab, taking care to avoid touching the thermocouple wire. In all cases, it is important to avoid touching the thermocouple wire as the thermocouple is fragile and can easily be broken. *After cleaning, contamination tests should again be performed.*

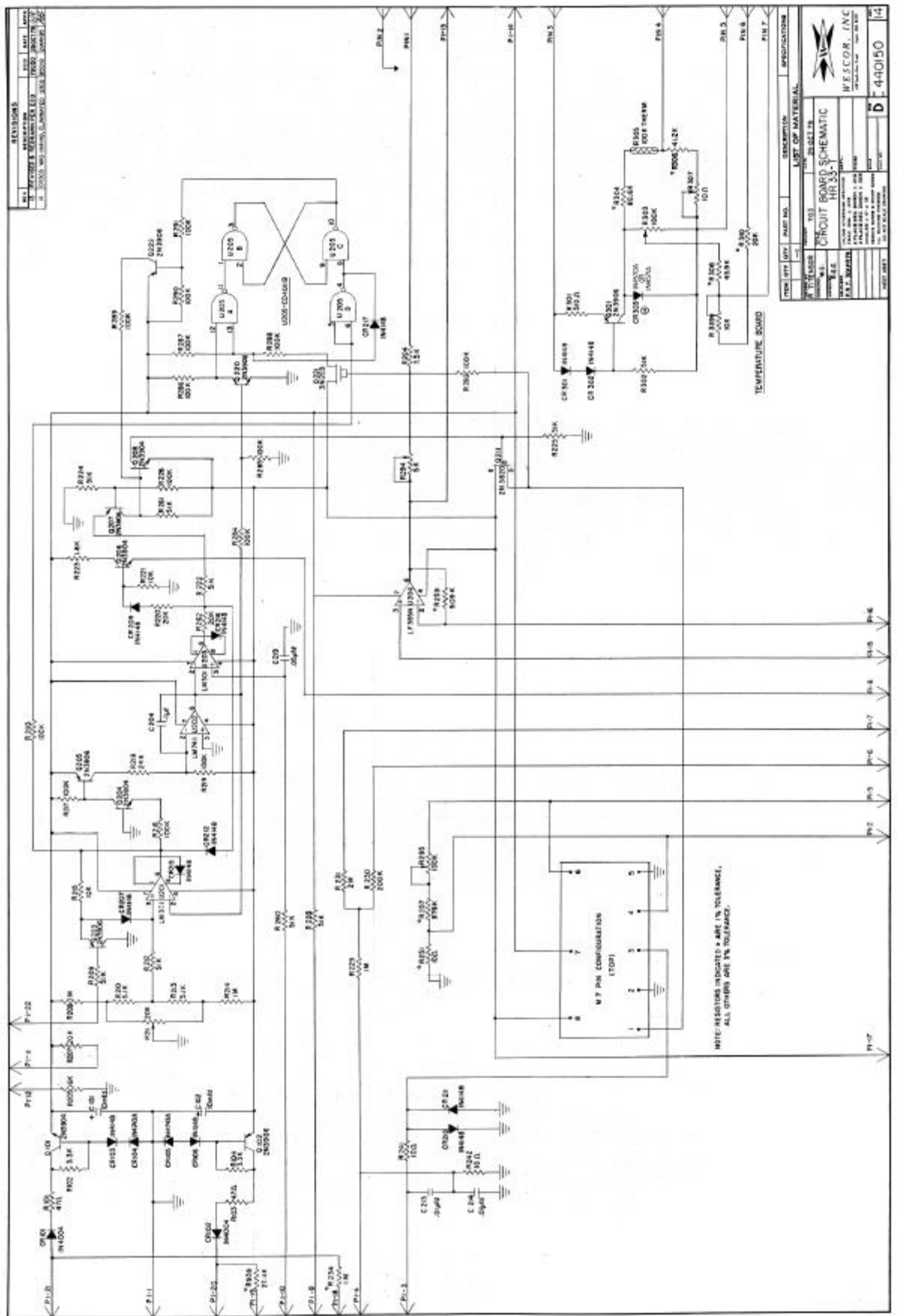
If none of the above appears to solve the problem, the instrument may be returned to the factory for repair. Before returning an instrument for service, please contact Wescor for return authorization and instructions. (See front pages of this manual for contact information). Customers outside the USA must pay customs brokerage fees and freight charges both ways. Freight to the factory should be prepaid. Customs brokerage fees will be invoiced at the time instrument is returned to customer.

If return is impractical, or if you prefer to make your own repairs, a qualified electronics technician who has access to a standard VOM (20,000 ohm per volt) and an oscilloscope may be able to identify and replace any defective part or component. Some parts can be obtained from any radio electronic supply house, or they can be ordered from the factory using the part numbers listed in Section 8.

A schematic diagram of the instrument is shown in Figure 8. The power supply schematics are shown in Figure 9. Test point locations and waveforms are detailed in Figures 10 and 11. A thermocouple psychrometer can be simulated for checkout purposes by attaching a 10 ohm resistor to the instrument binding posts. The ZERO OFFSET controls can be used to simulate a varying signal at the input terminals, and the complete electronic system can be analyzed to isolate and identify any faulty component.

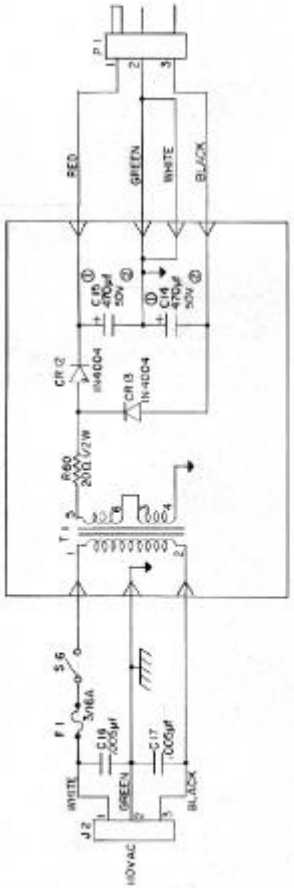
CAUTION

Instrument damage resulting from repairs attempted by non-factory-authorized personnel may void the warranty.

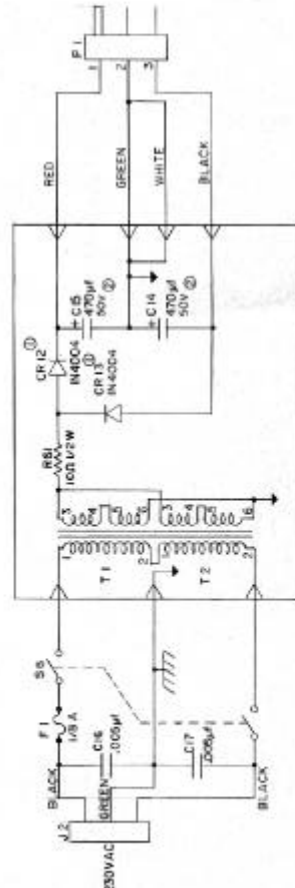


HR-33T Schematic Diagram
Figure 8

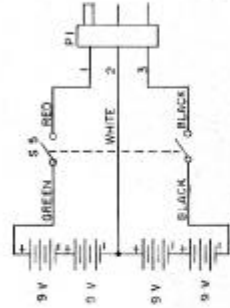
| REVISIONS | | | |
|-----------|-----|------|----------------------|
| REV. | ECO | DATE | BY |
| 1 | GE | ECO | 850408-2-85 AB |
| 2 | CHG | DR | 8.10.92 # 8-92A, 1.2 |



5106 PWR SUPPLY



5103 PWR SUPPLY

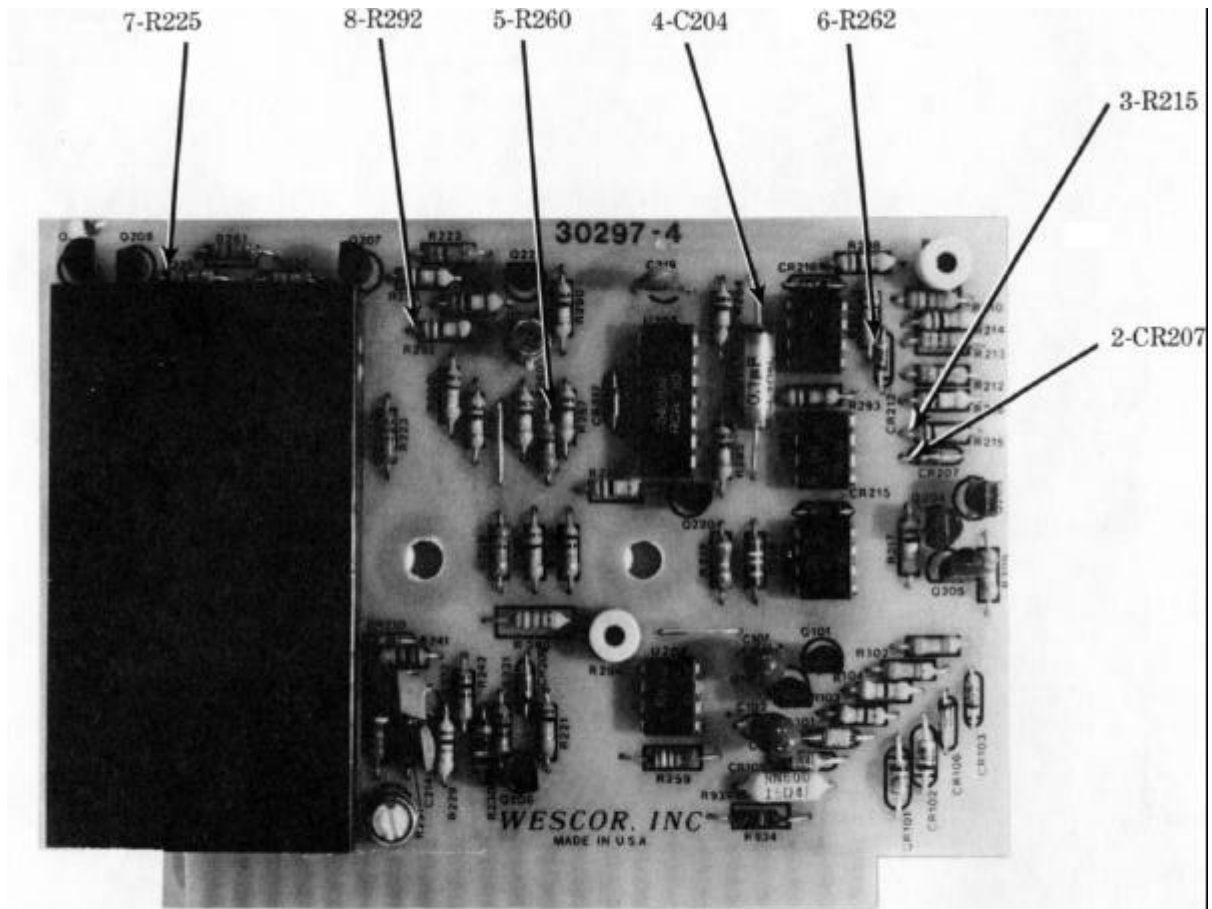


5103 BATTERY: EVEREADY 246, 30-0100
5103A BATTERY: 9 VOLT ALKALINE, 30-0114

5103 E 5103A POWER SUPPLY

| ITEM | QTY | PART NO. | DESCRIPTION | SPECIFICATIONS |
|--|-----|----------|-----------------|----------------|
| 1 | 1 | 5103 | 5103 PWR SUPPLY | |
| LIST OF MATERIAL | | | | |
| REVISED: 8.10.92 | | | | |
| DATE: 8.10.92 | | | | |
| DRAWN BY: [Signature] | | | | |
| CHECKED BY: [Signature] | | | | |
| APPROVED BY: [Signature] | | | | |
| TITLE: HR-33T POWER SUPPLIES SCHEMATIC | | | | |
| SCALE: AS SHOWN | | | | |
| PROJECT: HR-33T | | | | |
| DRAWING NO.: 430456 | | | | |
| REV: 2 | | | | |

HR-33T Power Supply Schematic Diagram
Figure 9

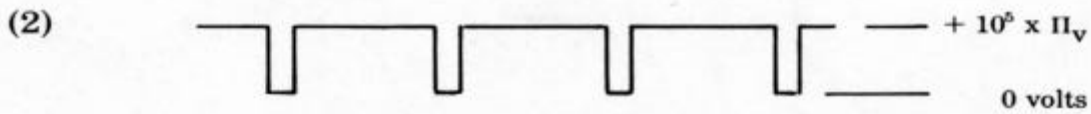


1-Test point 1 is the wiper of the I_{V} set potentiometer located on front panel (*not shown here*)

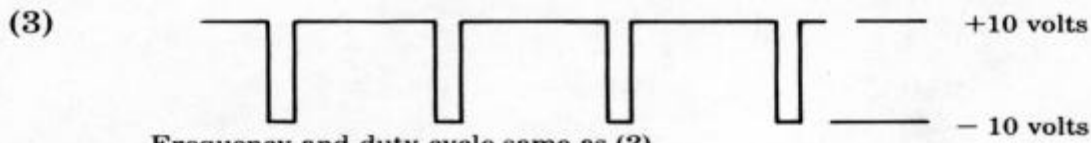
Test Point Locations
Figure 10

TEST POINT

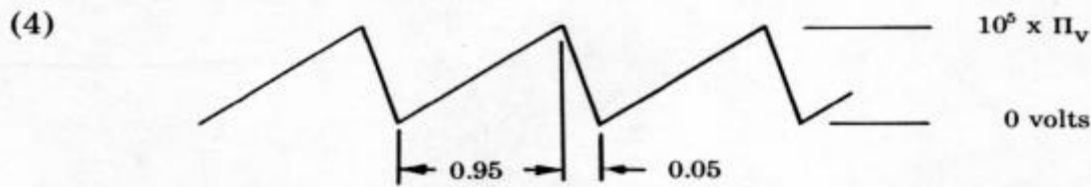
(1) Wiper on Π_V Set pot DCV = $10^5 \times \Pi_V$



Frequency approximately 30 Hz to 60 Hz, varies inversely with Π_V

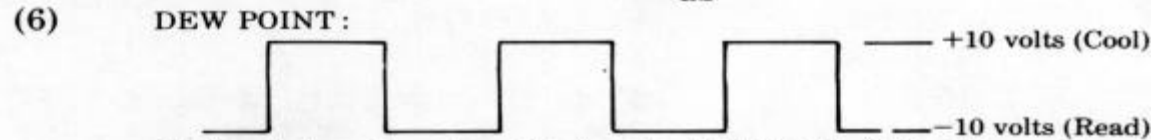


Frequency and duty cycle same as (2)

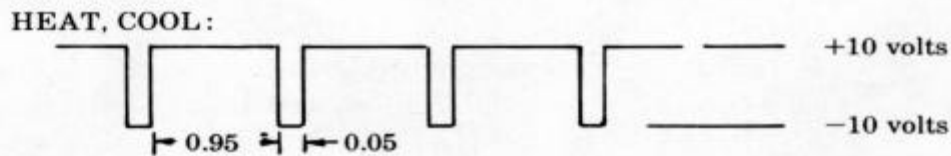


Frequency approximately 30Hz to 60Hz, varies inversely with height

(5) INPUT SHORT, READ: -10 volts
HEAT COOL: +10 volts
DEW POINT: $+10^5 \alpha_{ab} \Delta T$

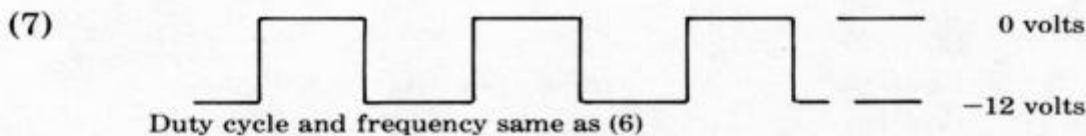


Cooling duty cycle varies with signal and DP GAIN ADJ setting
Frequency approximately 30 to 60 Hz

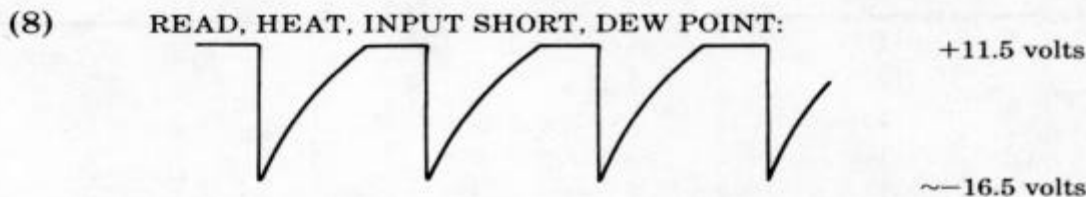


Frequency approximately 30 to 60 Hz

INPUT SHORT, READ



Duty cycle and frequency same as (6)

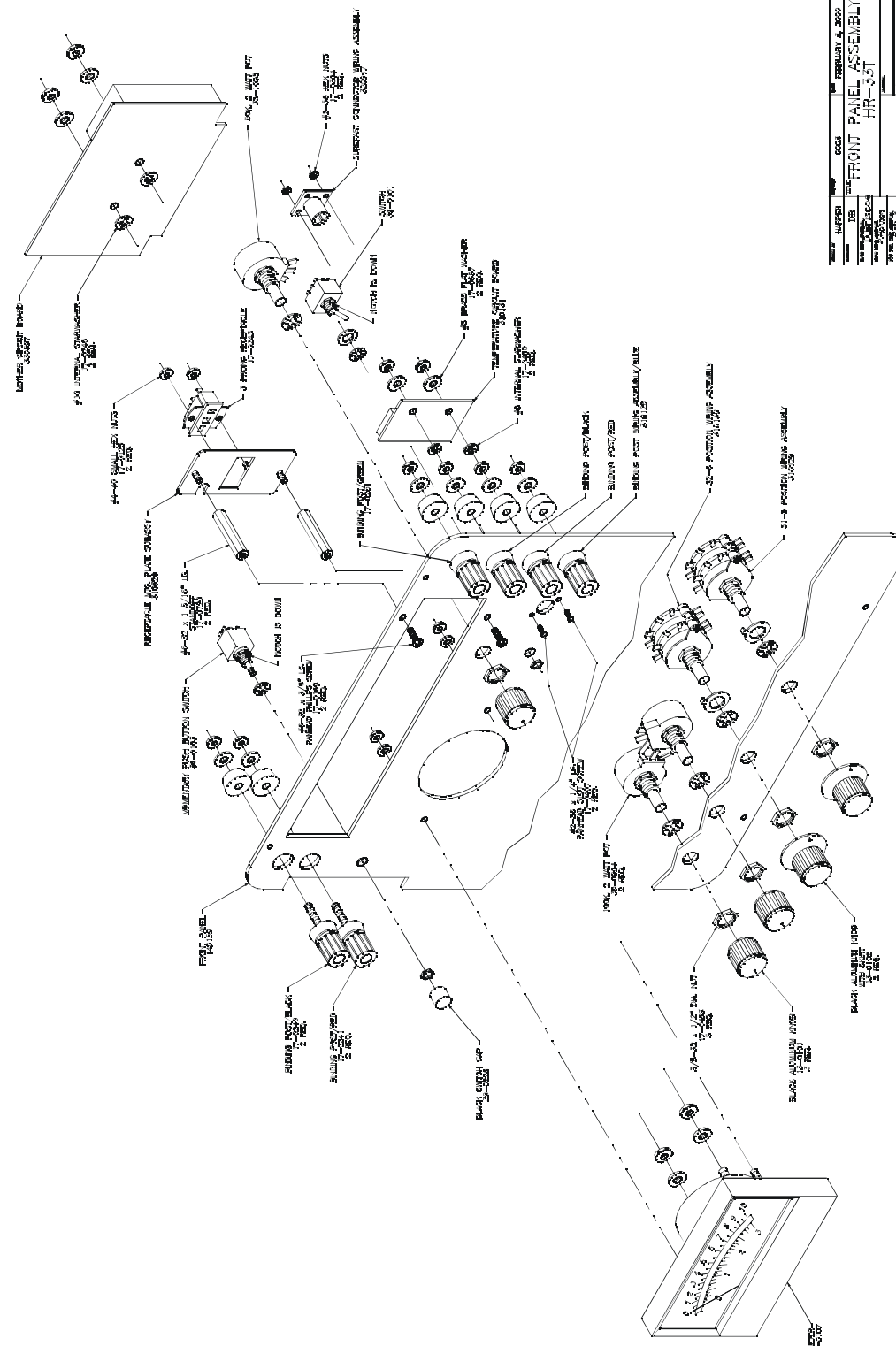


COOL: -12 volts DC

This waveform only appears during "on" portion of duty cycle

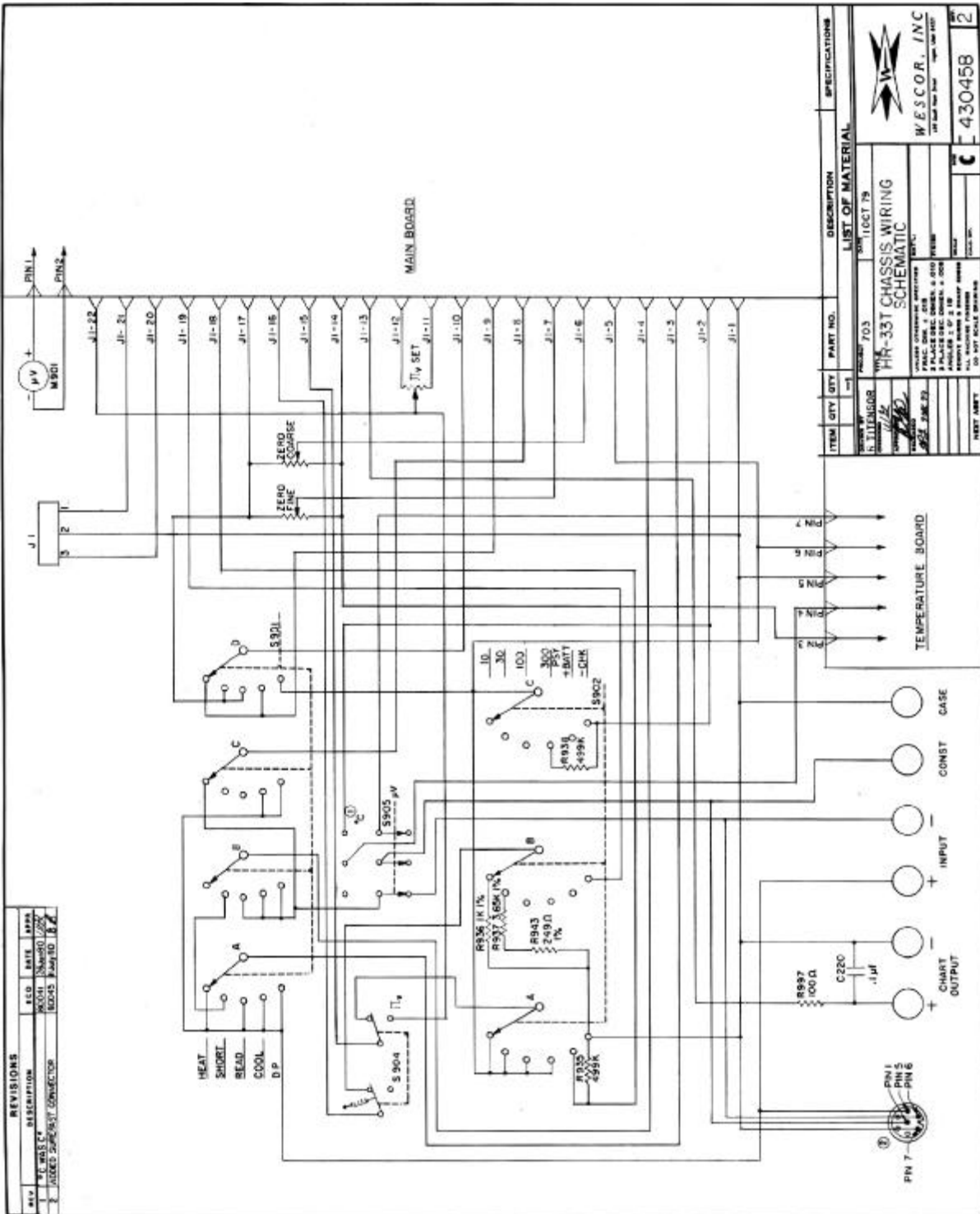
Test Point Data & Waveforms
Figure 11

| REV | DESCRIPTION | DATE | APP'D |
|----------------------|-------------------------|------|-------|
| 1 | REVISION A/B (REVISION) | | |
| DESCRIPTION | | DATE | APP'D |
| FRONT PANEL ASSEMBLY | | | |



| | | | | |
|----------------------|----------|----------------------|-------|-------|
| DATE | REVISION | DESCRIPTION | DATE | APP'D |
| 1/28/2008 | 1 | FRONT PANEL ASSEMBLY | | |
| DESCRIPTION | | DATE | APP'D | |
| FRONT PANEL ASSEMBLY | | | | |
| FRONT PANEL ASSEMBLY | | | | |
| FRONT PANEL ASSEMBLY | | | | |
| FRONT PANEL ASSEMBLY | | | | |
| FRONT PANEL ASSEMBLY | | | | |
| FRONT PANEL ASSEMBLY | | | | |
| FRONT PANEL ASSEMBLY | | | | |

Front Panel Assembly
Figure 12



Chassis Wiring Schematic
Figure 13

SECTION 8 – PARTS LIST

5106 - 110 Volt AC Power Supply

| Ref. No. | Part No. | Qty. | U.M. | Description | |
|-----------|----------|---------|------|--|-----------------------------------|
| C16,C17 | 05-0116 | 2 | EA | CAPACITOR .005 uF 1000 W VDC +/- 20% CERAMIC DISC | |
| | 120364 | 1 | EA | HR-33T NICAD BATTERY PACK & POWER SUPPLY HOLDER | |
| | 120370 | 1 | EA | HR-33T 5106 & 5109 POWER SUPPLY FRONT PANEL | |
| | 17-0101 | 2 | EA | 6-32 NUTSERT ALUMINUM | |
| | 17-0124 | 2 | EA | 4-40 HEX NUT STANDARD | |
| | 17-0128 | 2 | EA | STANDOFF 6-32 THD X 1/4" OD X 1.25" L | |
| | 17-0154 | 2 | EA | 6-32 X 3/8 FLATHEAD PHILLIPS CAD | |
| | 17-0160 | 6 | EA | 6-32 X 3/8" L PANHEAD PHILLIPS ZINC PLATED | |
| | 17-0226 | 1 | EA | ADJUSTABLE RIGHT HAND GRIP LATCH W/ STEEL KNOB | |
| | 17-0227 | 1 | EA | ADJUSTABLE LEFT HAND GRIP LATCH W/STEEL KNOB | |
| | 17-0245 | 2 | EA | 6-32 HEX NUT STANDARD | |
| | 17-0250 | 2 | EA | SPACER #6 x .250 LG x 1/4 OD ALUMINUM | |
| | 17-0314 | 2 | EA | 4-40 x 3/4 LG PANHEAD SLOTTED SCREW ZINC PLTD | |
| | 17-0390 | 1 | EA | CONNECTOR 3 PRONG MALE | |
| | 330698 | 1 | EA | HR-33T 5106 POWER SUPPLY PCB ASSEMBLY (115 VOLT) | |
| | C14,C15 | 05-0117 | 2 | EA | 470 uF 50 V ALUMINUM ELECTROLYTIC |
| | | 17-0124 | 1 | EA | 4-40 HEX NUT STANDARD |
| 17-0244 | | 1 | EA | 4-40 x 1/4 LG PANHEAD SLOTTED SCREW ZINC PLTD | |
| R60 | 35-0308 | 1 | EA | 20 OHM 5% 1/2W | |
| CR12,CR13 | 36-0116 | 2 | EA | 1N4004 1 AMP RECTIFIER DIODE | |
| T1 | 44-0100 | 1 | EA | POWER TRANSFORMER 50/60 HZ 7.5V @ .6A | |
| | 930245 | 1 | EA | HR-33T 5106 POWER SUPPLY PC BOARD | |
| S6 | 39-0102 | 1 | EA | SWITCH SPDT ON-OFF-ON | |
| | 39-0113 | 1 | EA | FUSE 3/16A 250V SLO-BLO 1/4 DIA X 1-1/4 LONG | |
| | 39-0150 | 1 | EA | FUSE HOLDER | |
| | 39-0235 | 1 | EA | IEC CONNECTOR, BOTTOM FLANGE W/SOLDER TERMINAL | |

5109 - 230 Volt AC Power Supply

| Ref. No. | Part No. | Qty. | U.M. | Description |
|----------|----------|------|------|--|
| C16,C17 | 05-0116 | 2 | EA | CAPACITOR .005 uF 1000 W VDC +/- 20% CERAMIC DISC |
| | 120364 | 1 | EA | HR-33T NICAD BATTERY PACK & POWER SUPPLY HOLDER |
| | 120370 | 1 | EA | HR-33T 5106 & 5109 POWER SUPPLY FRONT PANEL |
| | 17-0101 | 2 | EA | 6-32 NUTSERT ALUMINUM |
| | 17-0124 | 2 | EA | 4-40 HEX NUT STANDARD |
| | 17-0128 | 2 | EA | STANDOFF 6-32 THD X 1/4" OD X 1.25" L |
| | 17-0154 | 2 | EA | 6-32 X 3/8 FLATHEAD PHILLIPS CAD |
| | 17-0160 | 6 | EA | 6-32 X 3/8" L PANHEAD PHILLIPS ZINC PLATED |
| | 17-0226 | 1 | EA | ADJUSTABLE RIGHT HAND GRIP LATCH W/ STEEL KNOB |

| Ref. No. | Part No. | Qty. | U.M. | Description |
|------------|----------|------|------|--|
| | 17-0227 | 1 | EA | ADJUSTABLE LEFT HAND GRIP LATCH W/STEEL KNOB |
| | 17-0245 | 2 | EA | 6-32 HEX NUT STANDARD |
| | 17-0250 | 2 | EA | SPACER #6 x .250 LG x 1/4 OD ALUMINUM |
| | 17-0314 | 2 | EA | 4-40 x 3/4 LG PANHEAD SLOTTED SCREW ZINC PLTD |
| P1 | 17-0390 | 1 | EA | CONNECTOR 3 PRONG MALE |
| | 340337 | 1 | EA | HR-33T 5109 POWER SUPPLY PCB ASSEMBLY (230 VOLT) |
| C14, C15 | 05-0117 | 2 | EA | 470 uF 50 V ALUMINUM ELECTROLYTIC |
| | 17-0124 | 2 | EA | 4-40 HEX NUT STANDARD |
| | 17-0244 | 2 | EA | 4-40 x 1/4 LG PANHEAD SLOTTED SCREW ZINC PLTD |
| R61 | 35-0301 | 1 | EA | 10 OHM 5% 1/2W |
| CR12, CR13 | 36-0116 | 2 | EA | 1N4004 1 AMP RECTIFIER DIODE |
| T1, T2 | 44-0100 | 2 | EA | POWER TRANSFORMER 50/60 HZ 7.5V @ .6A |
| | 940184 | 1 | EA | HR-33T 5109 POWER SUPPLY PC BOARD |
| S6 | 39-0104 | 1 | EA | SWITCH DPDT 0N-0N MINI BAT TOGGLE |
| | 39-0136 | 1 | EA | FUSE 1/8 AMP 250 VOLT 3AG (TYPE T) |
| | 39-0150 | 1 | EA | FUSE HOLDER |
| | 39-0235 | 1 | EA | IEC CONNECTOR, BOTTOM FLANGE W/SOLDER TERMINAL |

Battery Pack No. 5103A

| Ref. No. | Part No. | Qty. | U.M. | Description |
|----------|----------|------|------|---|
| | 130678 | 1 | EA | HR-33T 5103A BATTERY PACK BRACKET |
| | 17-0128 | 2 | EA | STANDOFF 6-32 THD X 1/4" OD X 1.25" L |
| | 17-0154 | 2 | EA | 6-32 X 3/8 FLATHEAD PHILLIPS CAD |
| | 17-0160 | 4 | EA | 6-32 X 3/8" L PANHEAD PHILLIPS ZINC PLATED |
| | 17-0226 | 1 | EA | ADJUSTABLE RIGHT HAND GRIP LATCH W/STEEL KNOB |
| | 17-0227 | 1 | EA | ADJUSTABLE LEFT HAND GRIP LATCH W/STEEL KNOB |
| | 17-0245 | 2 | EA | 6-32 HEX NUT STANDARD |
| | 17-0323 | 2 | EA | #6 WASHER FLAT STEEL |
| P1 | 17-0390 | 1 | EA | CONNECTOR 3 PRONG MALE |
| | 17-0464 | 4 | EA | BATTERY CLIP (9 VOLT) |
| | 17-0585 | 8 | EA | RIVET 0.118 DIA 0.156 L 0.218 HEAD BRASS |
| | 30-0114 | 4 | EA | BATTERY 9 VOLT ALKALINE |
| S5 | 39-0104 | 1 | EA | SWITCH DPDT 0N-0N MINI BAT TOGGLE |

Case

| Ref. No. | Part No. | Qty. | U.M. | Description |
|----------|----------|------|------|---|
| | 340472 | 1 | EA | HR-33T CASE SUBASSEMBLY |
| | 17-0339 | 4 | EA | RUBBER BUMPER 5/8" DIA X 5/16" H FOR #6 SCREW |
| | 17-0160 | 4 | EA | 6-32 X 3/8" L PANHEAD PHILLIPS ZINC PLATED |
| | 17-0245 | 4 | EA | 6-32 HEX NUT STANDARD |
| | 17-0407 | 4 | EA | 2-56 X 1/4 PANHEAD SLOT CAD SCREW |

Front Panel

| Ref. No. | Part No. | Qty. | U.M. | Description |
|----------|----------|------|------|--|
| | 13-0101 | 3 | EA | KNOB WITHOUT SKIRT FOR 1/4" SHAFT |
| | 13-0102 | 2 | EA | KNURLED KNOB W/ARROWHEAD ON SKIRT FOR 1/4" SHAFT |
| | 17-0125 | 2 | EA | 4-40 HEX NUT SMALL |
| | 17-0160 | 2 | EA | 6-32 X 3/8" L PANHEAD PHILLIPS ZINC PLATED |
| | 17-0240 | 2 | EA | BINDING POST BLACK |
| | 17-0241 | 2 | EA | BINDING POST RED |
| | 17-0243 | 1 | EA | RECEPTACLE 3 PRONG |
| | 17-0248 | 2 | EA | #10 WASHER INTERNAL STAR STEEL |
| | 17-0251 | 1 | EA | BINDING POST GREEN |
| | 17-0304 | 2 | EA | 2-56 HEX NUT STANDARD |
| | 17-0407 | 2 | EA | 2-56 X 1/4 PANHEAD SLOT CAD SCREW |
| | 17-0480 | 2 | EA | #8 WASHER INTERNAL STAR STEEL |
| | 17-0493 | 5 | EA | 3/8-32 NUT 1/2" DIA X 3/32" THICK STEEL CAD |
| | 17-0657 | 2 | EA | WASHER #8 BRASS 3/8" OD X 1/16" THICK X .172" ID |
| | 17-0720 | 2 | EA | 6-32 x 1.312" LG FEMALE STANDOFF 1/4" HEX ALUM |
| | 18-0107 | 1 | EA | METER ANALOG 0-1 MA SCALE |
| | 310329 | 1 | EA | HR-33T RECEPTACLE MTG PLATE SUBASSEMBLY |
| | 340324 | 1 | EA | HR-33T 5103A BATTERY PACK ASSEMBLY |
| | 340541 | 1 | EA | HR-33T FRONT PANEL, SCREENED |
| | 35-0904 | 2 | EA | 100K 1 TURN PANEL MOUNT 2 WATT |
| | 35-1055 | 1 | EA | 50K 1 TURN PANEL MOUNT |
| | 39-0101 | 1 | EA | SWITCH 3 POLE ON-NONE-ON |
| | 39-0103 | 1 | EA | SWITCH DPDT PUSH BUTTON MOMENTARY SNAP-ACTION |
| | 39-0226 | 1 | EA | SWITCH CAP SMALL BLACK PLASTIC FOR ALCO MSP-5 |

Temperature Board

| Ref. No. | Part No. | Qty. | U.M. | Description |
|--------------|----------|------|------|---|
| R301 | 35-0165 | 1 | EA | 510 OHM 5% 1/4W |
| R302 | 35-0213 | 1 | EA | 51K 5% 1/4W |
| R306 | 35-0508 | 1 | EA | 41.2 OHM 1% 1/4W |
| R310 | 35-0614 | 1 | EA | 20.0K 1% 1/4W |
| R308 | 35-0680 | 1 | EA | 49.9K 1% 1/4W |
| R304 | 35-0720 | 1 | EA | 80.6K 1% 1/4W |
| R309 | 35-1000 | 1 | EA | 10K 1 TURN 1/4" DIA |
| R307 | 35-1004 | 1 | EA | 10 OHM 1 TURN 1/4" DIA |
| R303 | 35-1009 | 1 | EA | 100K 20 TURN SIDE ADJUST |
| R305 | 35-1071 | 1 | EA | 100K 1% WITH 7 IN. LEADS THERMISTOR |
| CR301, CR302 | 36-0103 | 2 | EA | 1N4148 SWITCHING DIODE |
| Q301 | 36-0110 | 1 | EA | 2N3906 PNP TRANSISTOR GENERAL PURPOSE |
| CR303 | 36-0204 | 1 | EA | 1N4570A/1N4571A DIODE ZENER 6.4V-400 MILLIWATTS |
| | 910027 | 1 | EA | HR-33T TEMPERATURE PC BOARD |

Mother Board

| Ref. No. | Part No. | Qty. | U.M. | Description |
|-------------|----------|------|------|--|
| C101,C102 | 05-0100 | 2 | EA | 10 uF 25VDC +/- 20% TANTALUM DIPPED |
| C213,C214 | 05-0107 | 2 | EA | CAP,CER,.01uF,X7R,10%,.1"LEADS,50V |
| C219 | 05-0109 | 1 | EA | CAPACITOR,CERAMIC,RADIAL 0.2,0.047uF,X7R,50V |
| C204 | 05-0113 | 1 | EA | 0.1 uF 100 V 10 % METALLIZED POLYESTER |
| U205 | 21-0106 | 1 | EA | 4011 QUAD 2-INPUT NAND GATE |
| U204 | 21-0144 | 1 | EA | LF355N OP AMP |
| U202 | 21-0190 | 1 | EA | LM741CN OP AMP |
| U201,U203 | 21-0191 | 2 | EA | LM301N OP AMP |
| | 320777 | 1 | EA | 5500 AMP BOARD DC-M7 ASSEMBLY |
| R241,R242 | 35-0124 | 2 | EA | 10 OHM 5% 1/4W |
| R101,R103 | 35-0140 | 2 | EA | 47 OHM 5% 1/4W |
| R223 | 35-0177 | 1 | EA | 1.6K 5% 1/4W |
| R102,R104 | 35-0184 | 2 | EA | 3.3K 5% 1/4W |
| R210,R213 | 35-0189 | 2 | EA | 5.1K 5% 1/4W |
| R240 | 35-0193 | 1 | EA | 7.5K 5% 1/4W |
| R215,R221 | 35-0196 | 2 | EA | 10K 5% 1/4W |
| R205 | 35-0201 | 1 | EA | 16K 5% 1/4W |
| R262 | 35-0203 | 1 | EA | 20K 5% 1/4W |
| R207,R220 | 35-0203 | 2 | EA | 20K 5% 1/4W |
| R218 | 35-0205 | 1 | EA | 24K 5% 1/4W |
| R209,R212 | 35-0213 | 2 | EA | 51K 5% 1/4W |
| R222,R224 | 35-0213 | 2 | EA | 51K 5% 1/4W |
| R225,R228 | 35-0213 | 2 | EA | 51K 5% 1/4W |
| R260,R261 | 35-0213 | 2 | EA | 51K 5% 1/4W |
| R216,R217 | 35-0220 | 2 | EA | 100K 5% 1/4W |
| R226 | 35-0220 | 1 | EA | 100K 5% 1/4W |
| R284-R293 | 35-0220 | 10 | EA | 100K 5% 1/4W |
| R230 | 35-0227 | 1 | EA | 200K 5% 1/4W |
| R219 | 35-0235 | 1 | EA | 430K 5% 1/4W |
| R214,R229 | 35-0244 | 2 | EA | 1.0M 5% 1/4W |
| R208 | 35-0244 | 1 | EA | 1.0M 5% 1/4W |
| R231 | 35-0251 | 1 | EA | 2.0M 5% 1/4W |
| R251 | 35-0500 | 1 | EA | 10.0 OHM 1% 1/4W |
| R259 | 35-0568 | 1 | EA | 9.09K 1% 1/4W |
| R939 | 35-0625 | 1 | EA | 27.4K 1% 1/4W |
| R257 | 35-0802 | 1 | EA | 976K 1% 1/4W |
| R934 | 35-0810 | 1 | EA | 1.00M 1% 1/4W |
| R211 | 35-1001 | 1 | EA | 20K 1 TN 1/4 DIA TOP ADJ |
| R295 | 35-1003 | 1 | EA | 100K 1 TURN 1/4" DIA |
| R294 | 35-1030 | 1 | EA | 5K 1 TURN 1/4" DIA |
| Q221 | 36-0102 | 1 | EA | DUAL-GATE MOSFET SK3991 |
| CR215-CR217 | 36-0103 | 3 | EA | 1N4148 SWITCHING DIODE |
| CR207 | 36-0103 | 1 | EA | 1N4148 SWITCHING DIODE |
| CR209-CR212 | 36-0103 | 4 | EA | 1N4148 SWITCHING DIODE |
| CR103,CR106 | 36-0103 | 2 | EA | 1N4148 SWITCHING DIODE |
| CR104-CR105 | 36-0108 | 2 | EA | 1N4743A DIODE 1 WATT 13V |
| Q220 | 36-0109 | 1 | EA | 2N3904 NPN TRANSISTOR GENERAL PURPOSE |
| Q101,Q204 | 36-0109 | 2 | EA | 2N3904 NPN TRANSISTOR GENERAL PURPOSE |
| Q206,Q208 | 36-0109 | 2 | EA | 2N3904 NPN TRANSISTOR GENERAL PURPOSE |
| Q205,Q207 | 36-0110 | 2 | EA | 2N3906 PNP TRANSISTOR GENERAL PURPOSE |
| Q222 | 36-0110 | 1 | EA | 2N3906 PNP TRANSISTOR GENERAL PURPOSE |
| Q102,Q203 | 36-0110 | 2 | EA | 2N3906 PNP TRANSISTOR GENERAL PURPOSE |
| CR101-CR102 | 36-0116 | 2 | EA | 1N4004 1 AMP RECTIFIER DIODE |
| Q211 | 36-0159 | 1 | EA | FET, P-CHANNEL, GENERAL PURPOSE, DEPLETION MODE |
| | 930297 | 1 | EA | HR-33T MOTHER PC BOARD |

5112 Battery Pack

| Ref. No. | Part No. | Qty. | U.M. | Description |
|----------|----------|------|------|---|
| | 110070 | 2 | EA | HR-33T NICAD BATTERY PACK END PAD INSULATION |
| | 120364 | 1 | EA | HR-33T NICAD BATTERY PACK & POWER SUPPLY HOLDER |
| | 120570 | 1 | EA | HR-33T 5112 NICAD BATTERY PACK FRONT PANEL |
| | 120802 | 1 | EA | HR-33T NICAD BATTERY PACK BOTTOM PAD INSULATION |
| | 14-0138 | 1 | EA | CONNECTOR JACK FOR .312 HOLE W/SILVER PLATED LUG |
| | 17-0101 | 2 | EA | 6-32 NUTSERT ALUMINUM |
| | 17-0128 | 2 | EA | STANDOFF 6-32 THD X 1/4" OD X 1.25" L |
| | 17-0154 | 2 | EA | 6-32 X 3/8 FLATHEAD PHILLIPS CAD |
| | 17-0160 | 4 | EA | 6-32 X 3/8" L PANHEAD PHILLIPS ZINC PLATED |
| | 17-0226 | 1 | EA | ADJUSTABLE RIGHT HAND GRIP LATCH W/ STEEL KNOB |
| | 17-0227 | 1 | EA | ADJUSTABLE LEFT HAND GRIP LATCH W/STEEL KNOB |
| | 17-0390 | 1 | EA | CONNECTOR 3 PRONG MALE |
| | 30-0121 | 1 | EA | NICAD BATTERY PACK |
| | 39-0104 | 1 | EA | SWITCH DPDT 0N-0N MINI BAT TOGGLE |

