HP 431C

431C
POWER METER

OPERATING AND SERVICE MANUAL

HEWLETT hp PACKARD

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MODEL 431C
POWER METER

SERIALS PREFIXED: 548

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF ILLUSTRATIONS

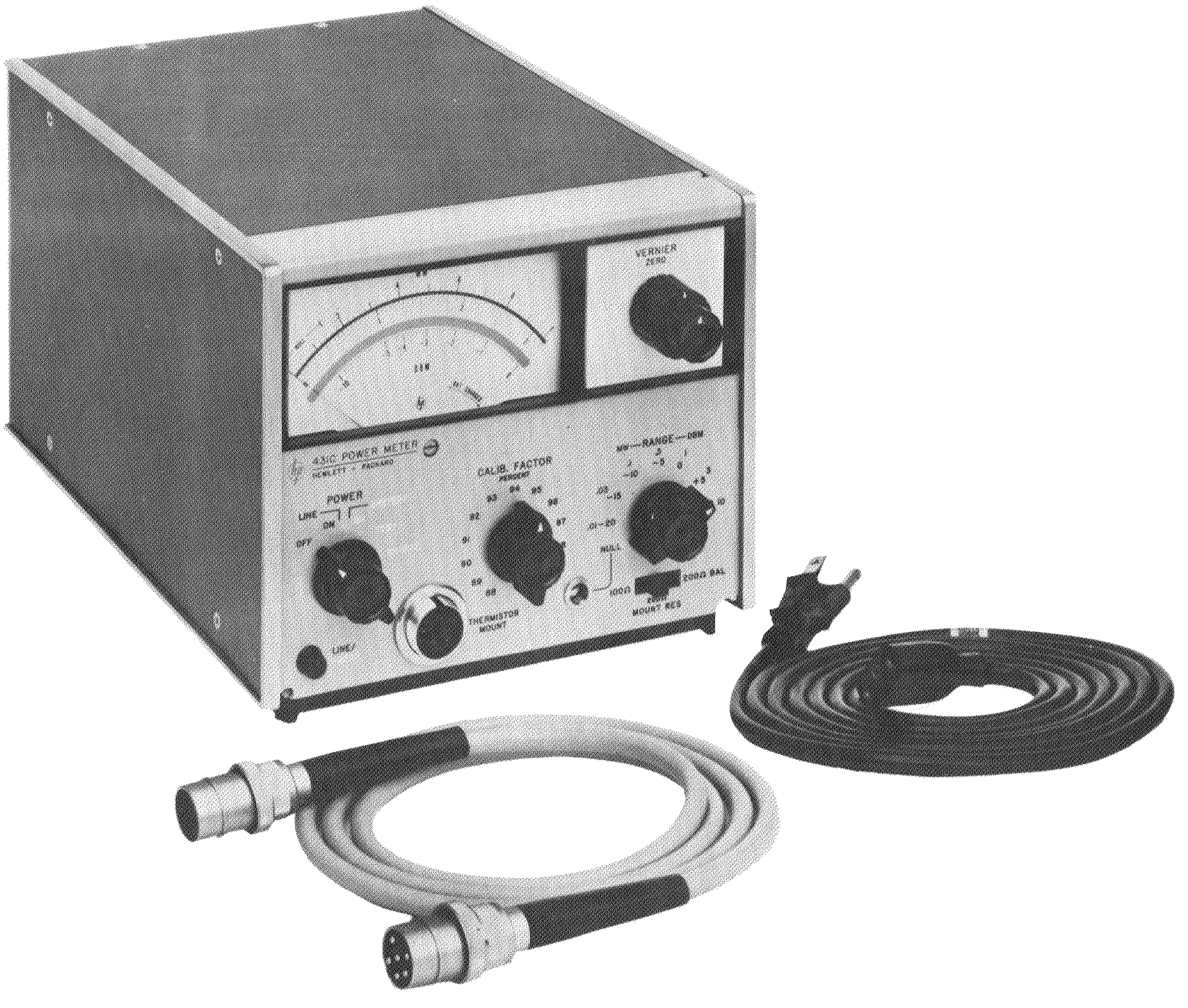


Figure 1-1. Model 431C Power Meter

SECTION I
GENERAL INFORMATION

1-1. DESCRIPTION

1-2. The Hewlett-Packard Model 431C Power Meter, with hp temperature-compensated thermistor mounts, measures RF power from 10 microwatts (-20 dBm) to 10 milliwatts (+ 10 dBm) full scale in the 10-MHz to 40-GHz frequency range. Direct reading accuracy of the instrument is ±1% of full scale. By selector switch, the instrument normalizes the power meter reading to compensate for the Calibration Factor of a thermistor mount used for a given measurement. A rechargeable nickel-cadmium battery is included with Option 01 instruments for portable operation. Complete specifications are presented in Table 1-1.

1-3. The Model 431C makes provision for using the DC substitution method of measuring RF power and to assure accuracy of the power meter calibration. Outputs are provided for a digital voltmeter readout, permanent recording of measurements, operation of alarm or control systems, or to allow the Power Meter to be used in a closed-loop leveling system.

1-4. INSTRUMENT IDENTIFICATION. The Model 431C carries an eight-digit serial number (000-00000). When the SERIALS PREFIXED number on the title page of the manual is the same as the first three digits of the instrument serial number, the manual applies directly to the instrument. For other serial numbers, see the change sheet enclosed with the manual.

1-5. ACCESSORIES. Two accessories are supplied with the Model 431C Power Meter: a 7.5-foot (2290 mm) detachable power cable and a 5-foot (1520 mm) cable that connects a thermistor mount to the instrument. Thermistor mounts are available (refer to Table 1-2) but not supplied with the power meter. A rechargeable battery with installation kit is also available. Supplied and available accessories are listed in Table 1-1.

Table 1-1. Specifications

Power Range: 7 ranges with full-scale readings of 10, 30, 100, and 300 μW, 1, 3, and 10 mW; also calibrated in dBm from -20 dBm to +10 dBm full scale in 5 dB steps.

Accuracy: ±1% of full scale from +20°C to +35°C, ±2.5% of full scale from 0°C to +55°C.

Calibration Factor Control: 13 position switch normalizes meter reading to account for thermistor mount Calibration Factor (or Effective Efficiency). Range: 100% to 88% in 1% steps.

Thermistor Mount: External temperature-compensated thermistor mounts required for operation (hp 478A and 486A series listed in Table 1-2).

Meter Movement: Taut-band suspension, individually calibrated mirror-backed scales. Milliwatt scale greater than 4.25 in.(108 mm) long.

Zero Carryover: Less than 0.5% of full scale when zeroed on most sensitive range.

Zero Balance: Continuous control about zero point. Range below zero is equivalent to at least 3% of full scale.

Voltmeter Output: With load impedance of 500 k ohms or more, voltmeter output is 1.000Vdc ±0.3% at full scale meter deflection. BNC female connector.

Recorder/Leveler Output: With load impedance of 600 ohms or more, output is approximately 1 volt dc at full scale meter deflection. BNC female connector.

DC Calibration Input: Binding posts for calibration of bridge with hp 8402B Calibrator or precise dc standards.

RFI: Meets all conditions specified in MIL-I-6181D.

Power: 115 or 230 volts ±10%, 50 to 400 Hz, 2.5 watts. Optional rechargeable battery provides up to 24 hours continuous operation.

Dimensions: 7-25/32 in. wide, 6-3/32 in. high, 11 in. deep from front of side rail (190 x 155 x 279 mm).

Weight: Net, 7 lb (3,2 kg), 9 lb (4,1 kg) with battery.

Furnished: 5-ft (1520 mm) cable for hp temperature compensated thermistor mounts; 7.5 ft (2290 mm) power cable, NEMA plug.

Available: 00415-606 Rechargeable Battery Pack for field installation.

5060-0797 Rack Adapter Frame, (holds two instruments the side of the 431C, e.g., 431C and 415E SWR Meter).

H01-8401A Leveler Amplifier.

8402B Power Meter Calibrator.

Combining Cases:
1051A, 11-1/4 in. (286 mm) deep.
1052A, 16-3/8 in. (416 mm) deep.

These Combining Cases accept the small hp module instrument for bench use or rack mounting.

Table 1-1. Specifications (Cont'd)

Options:

01. Rechargeable battery installed, provides up to 24 hours continuous operation.

02. Rear thermistor mount input connector wired in parallel with front panel input connector.

09. With 10-foot (3050 mm) cable for 100Ω or 200Ω mount.

10. With 20-foot (6100 mm) cable for 100Ω or 200Ω mount.

11. With 50-foot (15240 mm) cable for 100Ω mount.

12. With 100-foot (30480 mm) cable for 100Ω mount.

13. With 200-foot (60960 mm) cable for 100Ω mount.

21. With 50-foot (15240 mm) cable for 200Ω mount.

22. With 100-foot (30480 mm) cable for 200Ω mount.

23. With 200-foot (60960 mm) cable for 200Ω mount.

Table 1-2. Model 431C Thermistor Mounts

hp Type			
Coaxial	Waveguide	Frequency Range	Operating Resistance in Ohms
478A		10 MHz to 10 GHz	200
	S486A	2.6 to 3.95 GHz	100
	G486A	3.95 to 5.85 GHz	100
	J486A	5.3 to 8.2 GHz	100
	H486A	7.05 to 10.0 GHz	100
	X486A	8.2 to 12.4 GHz	100
	M486A	10.0 to 15.0 GHz	100
	P486A	12.4 to 18.0 GHz	100
	K486A	18.0 to 26.5 GHz	200
	R486A	26.5 to 40.0 GHz	200

SECTION II
INSTALLATION

2-1. INITIAL INSPECTION.

2-2. Before shipment this instrument was inspected and found free of mechanical or electrical defect. As soon as the instrument is unpacked, inspect for any damage that may have occurred in transit. Check for the supplied accessories. Electrical performance may be tested using the performance test procedure outlined in Paragraph 5-5. If there is any damage or deficiency, or if electrical performance is not within specifications, notify the carrier and your nearest Hewlett-Packard Sales and Service Office immediately.

2-3. RACK MOUNTING.

2-4. The Model 431C is narrower than full-rack width. This is termed a "sub-modular" unit. When used alone, the instrument can be bench mounted. When used in combination with other sub-modular units it may be bench or rack mounted. The hp combining case and the adapter frame are specifically for this purpose.

2-5. COMBINING CASE. The Model 1051A Combining Case is shown in Figures 2-1 and 2-2. This case is a full-rack width unit which accepts varying combinations of sub-modular instruments. The case itself is a full-module unit. It can be bench or rack mounted; a rack-mounting kit is supplied with the case.

2-6. ADAPTER FRAME. The 5060-0797 Adapter Frame is shown in Figure 2-3. The frame accepts a variety of sub-modular units in a manner suitable for rack mounting. Sub-modular units, in combination with any necessary spacers are assembled within the frame. The sub-modular units and the adapter frame, together forming a complete assembly, can then be

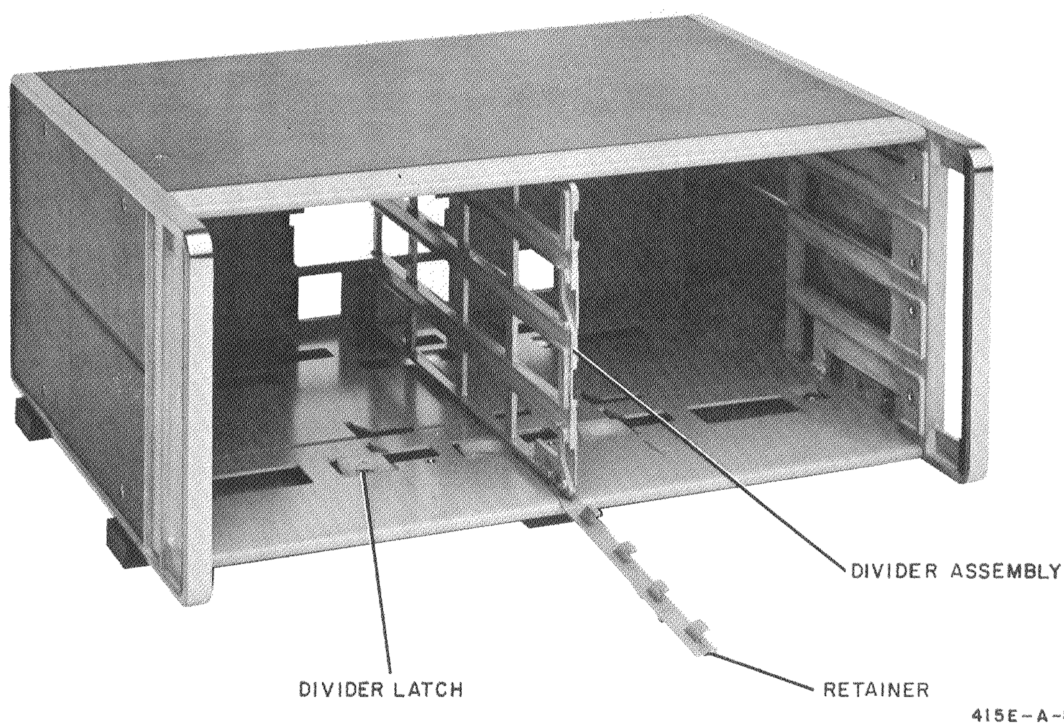


Figure 2-1. The Combining Case

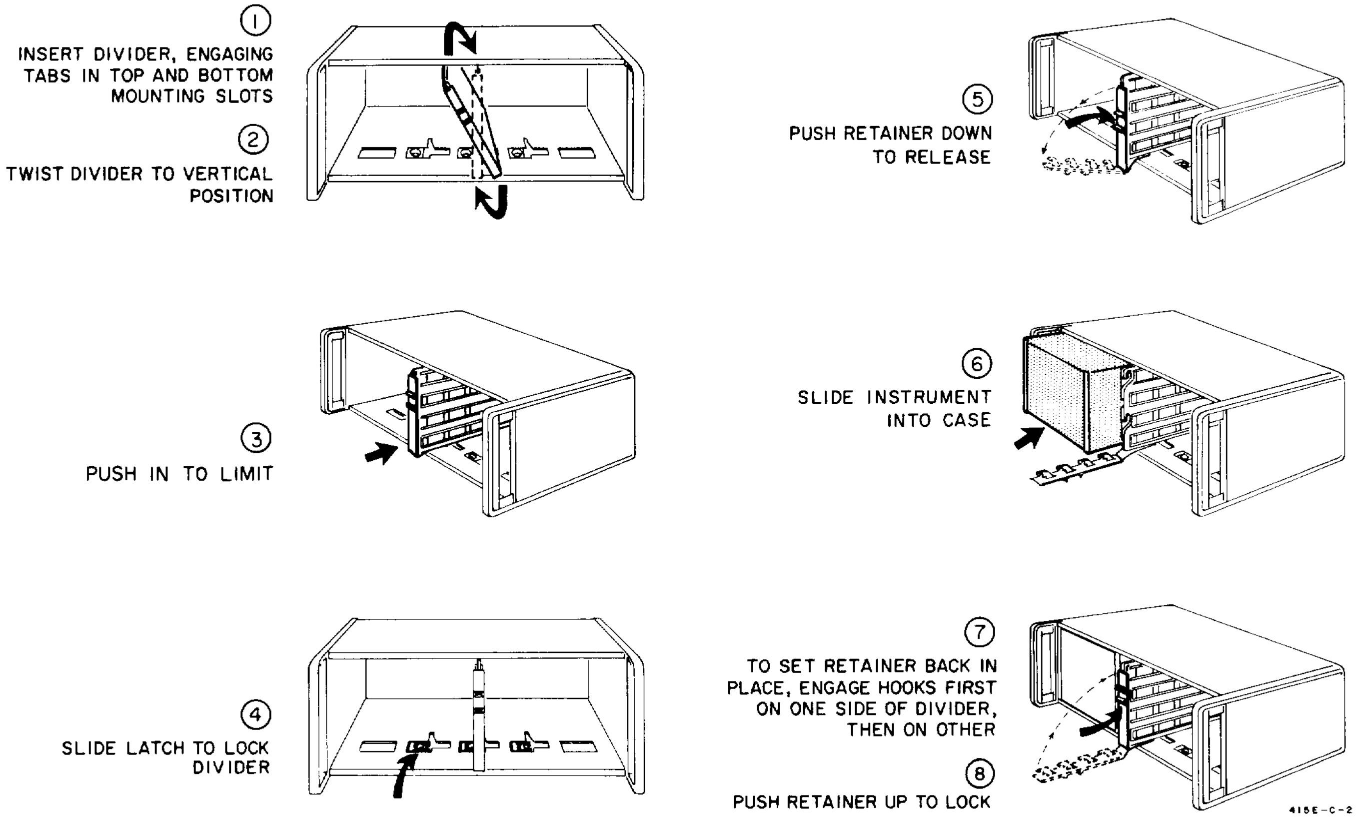


Figure 2-2. Steps to Place Instrument in Combining Case

mounted in a standard rack. The sub-modular units cannot be removed individually when the adapter frame is used. Instructions for assembly of the adapter frame and sub-modular units are given below. Refer to Figure 2-4.

a. Place the adapter frame on the edge of a bench, step 1.

b. Stack the sub-modular units in the frame, step 2.

c. Place the spacer clamps between the instruments, step 3.

d. Place the spacer clamps on the two end instruments. Push the combination into the frame, step 4.

e. Insert screws on either side of the frame, step 5. Tighten until the sub-modular units are tight in the frame.

2-7. PRIMARY POWER REQUIREMENTS.

2-8. The Model 431C can be operated from an AC or DC primary power source. The AC source can be either 115- or 230-volt, 50 to 400 Hz. The DC source is a 24-volt rechargeable battery. The rechargeable battery is supplied with Option 01 instruments.

CAUTION

For AC operation, set the rear-panel 115-230 volt switch to the proper position before connecting the power cord to the service outlet.

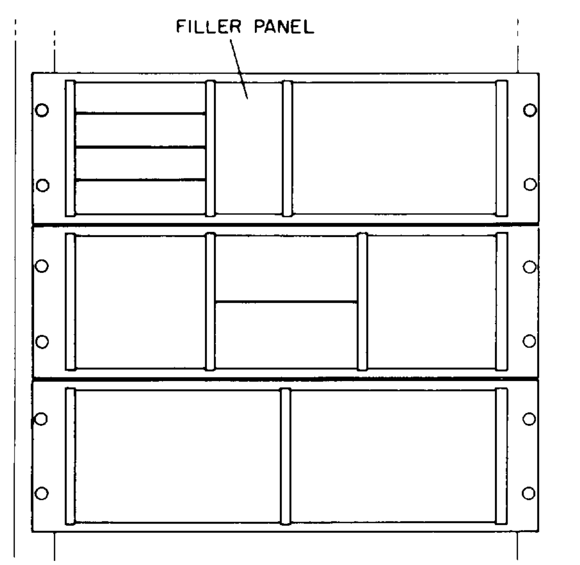


Figure 2-3. Adapter Frame Instrument Combinations

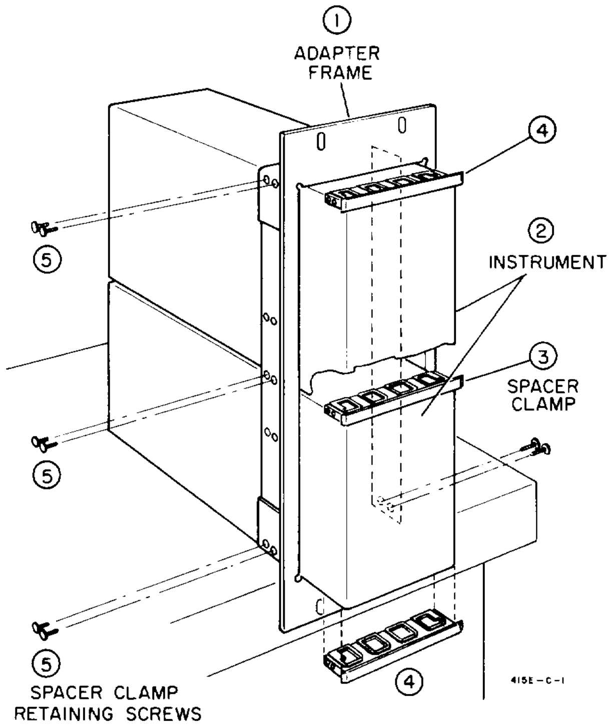
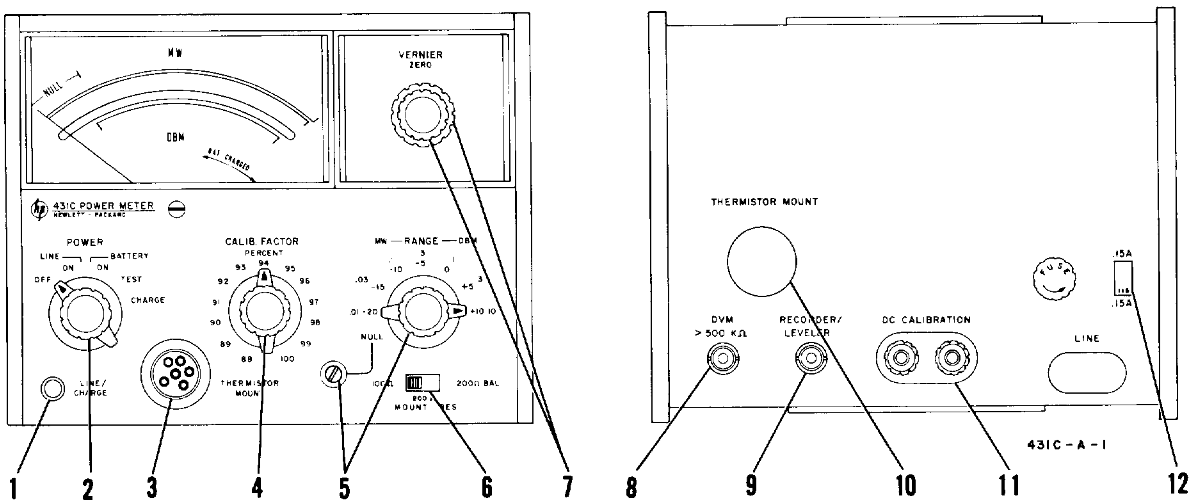


Figure 2-4. Two Half Modules in Rack Adapter

2-9. THREE-CONNECTOR POWER CABLE.

2-10. To protect operating personnel, the National Electrical Manufacturers' Association (NEMA) recommends that the instrument panel and cabinet be grounded. This instrument is equipped with a three-conductor power cable which, when plugged into an appropriate receptacle, grounds the instrument. The offset pin on the power cable three-prong connector is the ground wire. To preserve the protection feature when operating the instrument from a two-contact outlet, use a three-prong to two-prong adapter and connect the green pigtail on the adapter to ground.



1. LINE/CHARGE. Lamp lights when the POWER switch is in the LINE ON or BATTERY CHARGE position.

2. POWER. Determines connections to primary power sources and the battery charging circuit.

   LINE OFF: Instrument off.

   LINE ON: Instrument on. Trickle charge applied to battery.

   BATTERY ON: Instrument on, battery powered.

   BATTERY TEST: Meter indicates battery charge.

   BATTERY CHARGE: Instrument off. Trickle change applied to battery.

3. THERMISTOR MOUNT. Accepts the thermistor mount cable.

4. CALIB FACTOR. Switch compensates for the Calibration Factor of the thermistor mount. Calibration Factor values from 88% to 100% may be set in 1% steps.

5. RANGE. Sets power range; also includes a NULL position which, in conjunction with the adjacent null screwdriver adjustment, ensures that the metering bridge is reactively balanced.

6. MOUNT RES. A three position slide switch which sets the power meter to accommodate thermistor mounts of 100 ohm, 200 ohm and 200 ohm balanced operating resistances.

7. ZERO and VERNIER. Sets the meter pointer over the zero mark. The VERNIER control is a fine adjustment of the ZERO control setting.

8. DVM > 500 KΩ. A BNC type jack providing an output voltage linearly proportional to the meter indication. A DC voltmeter with an input impedance greater than 500 k ohms is required to minimize introduction of measurement error (refer to Paragraph 3-49).

9. RECORDER/LEVELER. A BNC type jack providing a DC voltage of low source impedance for a recorder or leveler amplifier.

10. In Option 02 instruments a thermistor mount connector is wired in parallel with the front panel connector. Two mounts cannot be connected simultaneously.

11. DC CALIBRATION. This connector permits a DC input for power meter calibration and DC substitution method of power measurement.

12. LINE VOLTAGE. Selects 115- or 230-volt line operation.

Figure 3-1. Front and Rear Panel Controls, Connectors, and Indicators

SECTION III
OPERATION

3-1. INTRODUCTION.

3-2. This section presents the basic information required to operate the Model 431C Power Meter. A discussion of microwave power measurement with emphasis on modern techniques, accuracy considerations and sources of error is available in Application Note 64, available from any Hewlett-Packard Sales and Service Office.

3-3. The Model 431C is an automatic self-balancing power-measuring instrument employing dual-bridge circuits. The power meter is designed to operate with hp temperature-compensated thermistor mounts such as the Model 478A Coaxial and Model 486A Waveguide series. Power may be measured with these mounts in 50-ohm coaxial systems from 10 MHz to 10 GHz, and in waveguide systems from 2.6 GHz to 40 GHz. Full-scale power ranges are 10 microwatts to 10 milliwatts and -20 dBm to +10 dBm. Extended measurements may be made to 1 microwatt and to -30 dBm. The total measurement capacity of the instrument is divided into seven ranges, selectable by a front panel RANGE switch.

3-4. ZERO and VERNIER zero-set controls zero the meter. Zero carry-over from the most sensitive range to the other six less sensitive ranges is accurate to ±0.5%. Greater accuracy can be obtained by setting the zero point on the particular range to be used. When the RANGE switch is in the NULL position, the meter indicates inherent metering bridge unbalance, and a front panel NULL screwdriver adjustment is provided for initial calibration.

3-5. The CALIB FACTOR switch allows the introduction of discrete amounts of compensation for measurement uncertainties related to SWR, and measurement errors caused by substitution error and thermistor mount efficiency. The appropriate selection of a Calibration Factor value permits direct meter reading of the RF power delivered to an impedance equal to the characteristic impedance (Z_0) of the transmission line connecting the thermistor mount to the RF source. Calibration Factor values are determined from the data marked on the label of each hp Model 478A or 486A thermistor mount.

3-6. The Model 431C has a DC CALIBRATION jack on the rear panel that can be used for DC substitution method of power measurement. DC substitution is an extension of the power measurement technique normally used. Through the use of DC substitution, instrument error can be reduced from a nominal value of ±1% to ±0.16% of reading, or less, depending on the care taken in procedure and accuracy of auxiliary equipment.

3-7. The MOUNT RES switch on the front panel permits the use of three types of thermistor mounts with the 431C. Model 486A waveguide mounts can be used by setting the MOUNT RES switch to the 100Ω or 200Ω position, depending on the microwave band used (refer to Table 1-2). The 200Ω position is used with Model 478A thermistor mounts and the 200Ω BAL position is used with a balanced thermistor mount.

3-8. Two output BNC type jacks are provided on the rear panel of the instrument, labeled DVM and RECORDER/LEVELER. The DVM jack provides a voltage linearly proportional to the meter current; 1 volt equal to full scale meter deflection. A DVM connected to the 431C must have an input impedance greater than 500 k ohms on the range used. The RECORDER/LEVELER jack furnishes a DC voltage of low source impedance necessary for isolation between a recorder or leveler amplifier and the metering circuit of the power meter. The output voltage is proportional to the power measured and is offset ±40 mV or less from its nominal value, depending on the load impedance. This output voltage allows the Model 431C to be used in a number of additional applications (refer to Paragraph 3-53).

3-9. CONTROLS, CONNECTORS, AND INDICATORS.

3-10. The front and rear panel controls, connectors, and indicators are explained in Figure 3-1. The descriptions are keyed to the corresponding items which are indicated on the figure. Further information regarding the various settings and uses of the controls, connectors, and indicators is included in the applicable procedures of this section.

3-11. BATTERY OPERATION.

3-12. The Model 431C can be operated from a battery instead of a conventional 115- or 230-volt primary power source. A rechargeable Nickel-Cadmium battery is factory installed in Option 01 instruments. The same battery can be ordered and later installed in the basic instrument, thereby modifying the power meter to the Option 01 configuration. The rechargeable battery installation kit may be ordered by hp stock number 00415-606.

3-13. OPTIMUM BATTERY USAGE. It is recommended that the Model 431C be operated by the battery for up to 8 hours, followed by 16 hours of recharge. If continuous battery operation is required for more than 8 hours, the recharge time should be double the operating time. Continuous battery operation is possible for up to 24 hours but this must be followed by a prolonged recharge period.

3-14. INITIAL BATTERY USE. When the Model 431C is to be battery operated for the first time, perform the following steps:

a. Set the POWER switch to the BATTERY TEST position and note meter pointer indication. A meter pointer indication within the "BAT CHARGED" area indicates the internal battery is properly charged and ready for use. A meter pointer indication to the left of the "BAT CHARGED" area means that the battery must be charged as described below. Actual battery voltage can be measured on the 0-3 mW scale. Battery voltage is equal to 10 times meter scale reading.

b. Connect the Model 431C to AC power source. Set POWER switch to BATTERY CHARGE and charge the battery until a meter pointer indication within the "BAT CHARGED" region can be obtained as in step a.

3-15. BATTERY STORAGE. Storage of the battery at or below room temperature is best. Extended storage at high temperatures, less than 60°C (140°F), will reduce the cell charge but will not damage the battery. Charge the battery after removal from storage and before using the Model 431C for battery operation.

3-16. OPERATING INSTRUCTIONS.

3-17. Figure 3-8, Turn-On and Nulling Procedure, and Figure 3-9, DC Substitution, present step-by-step instructions for operating the Model 431C. Steps are numbered to correspond with the appropriate control, connector, or indicator on the power meter and/or required auxiliary equipment.

3-18. MAJOR SOURCES OF ERROR IN MICROWAVE POWER MEASUREMENT.

3-19. A number of factors affect the overall accuracy of power measurement. Major sources of error are presented in the following paragraphs to show the cause and effect of each error. Particular corrections or special measurement techniques can be determined and applied to improve overall measurement accuracy. The following are the major sources of error to consider: 1) Mismatch error, 2) RF losses, 3) DC-to-microwave substitution error, 4) Thermoelectric effect error, and 5) Instrumentation error.

3-20. MISMATCH ERROR. The following discussion uses the terms conjugate power, Z_0 available power, conjugate match and mismatch, and Z_0 match and mismatch. These basic terms are defined as follows:

Conjugate power is the maximum available power. It is dependent on a conjugate match condition in which the impedance seen looking toward the thermistor mount is the complex conjugate of the impedance seen looking toward the RF source. A special case of this maximum power transfer is when both the RF source and the thermistor mount have the same impedance as the transmission line.

Z_0 available power is the power a source will deliver to a Z_0 load. It is dependent on a Z_0 match condition in which the impedance seen looking into a transmission line is equal to the characteristic impedance of the line.

3-21. In a practical measurement situation, both the source and thermistor mount have SWR, and the source is seldom matched to the thermistor mount without the use of a tuner. The amount of mismatch loss in any measurement depends on the total SWR present. The impedance that the source sees is determined by the actual thermistor mount impedance, the electrical length of the line, and the characteristic impedance of the line, Z_0.

3-22. In general, neither the source nor the thermistor mount has Z_0 impedance, and the actual impedances are known only as reflection coefficients, mismatch losses or SWR. These forms of information lack phase information data. As a result, the power delivered to the thermistor mount and hence the mismatch loss can only be described as being somewhere between two limits. The uncertainty of power measurement due to mismatch loss increases with SWR. Limits of mismatch loss are generally determined by means of a chart such as the Mismatch Loss Limits charts in Application Note 64.*

3-23. An example may explain how imperfect match affects the uncertainty of power measurement. A typical Z_0 available power measurement situation can involve a source with an SWR of 1.7 ($\rho_s = 0.26$) and a thermistor mount with an SWR of 1.3 ($\rho_m = 0.13$). Figure 3-2 shows a plot of power levels and mismatch power uncertainties that result from source and thermistor mount mismatch. The source Z_0 mismatch results in a power loss of -0.29 dB from the maximum power that would be delivered by the source to a conjugate match. The power level that results from this loss is the Z_0 available power. The thermistor mount Z_0 mismatch causes an additional power loss of -0.07 dB. However, on the thermistor mount Z_0 mismatch loss is an uncertainty resulting from the unknown phase relationships between the impedances of the source and thermistor mount. This uncertainty is +0.30 dB to -0.28 dB and can be determined from the Mismatch Loss Limits charts in Application Note 64.

3-24. The result of the total mismatch loss uncertainty on the Z_0 available power level is determined by algebraically adding the thermistor mount loss to the uncertainty caused by source and thermistor mount Z_0 mismatch SWR. Thus, the Z_0 available power uncertainty is (-0.07 dB) + (+0.30 dB), and (-0.07 dB) + (-0.28 dB), equal to a range of +0.23 dB to -0.35 dB or +5.5% to -8.2%. The power delivered by the source to a Z_0 load, with source and thermistor mount mismatch as in this example, would be somewhere between 0.23 dB (5.5%) below the maximum power and 0.35 dB (8.2%) above the minimum power actually entering the thermistor mount.

3-25. Power measurement uncertainty caused by mismatch loss is one source of error to consider when measuring Z_0 available power without a tuner. A continuation of this example is given in Paragraphs 3-38 through 3-39 to discuss the basic principle of Calibration Factor correction to a measurement of Z_0 available power.

*Detailed analysis of accuracy degradation due to SWR in the transmission line is presented in Application Note 64. The Application Note may be obtained from any Hewlett-Packard Sales and Service Office.

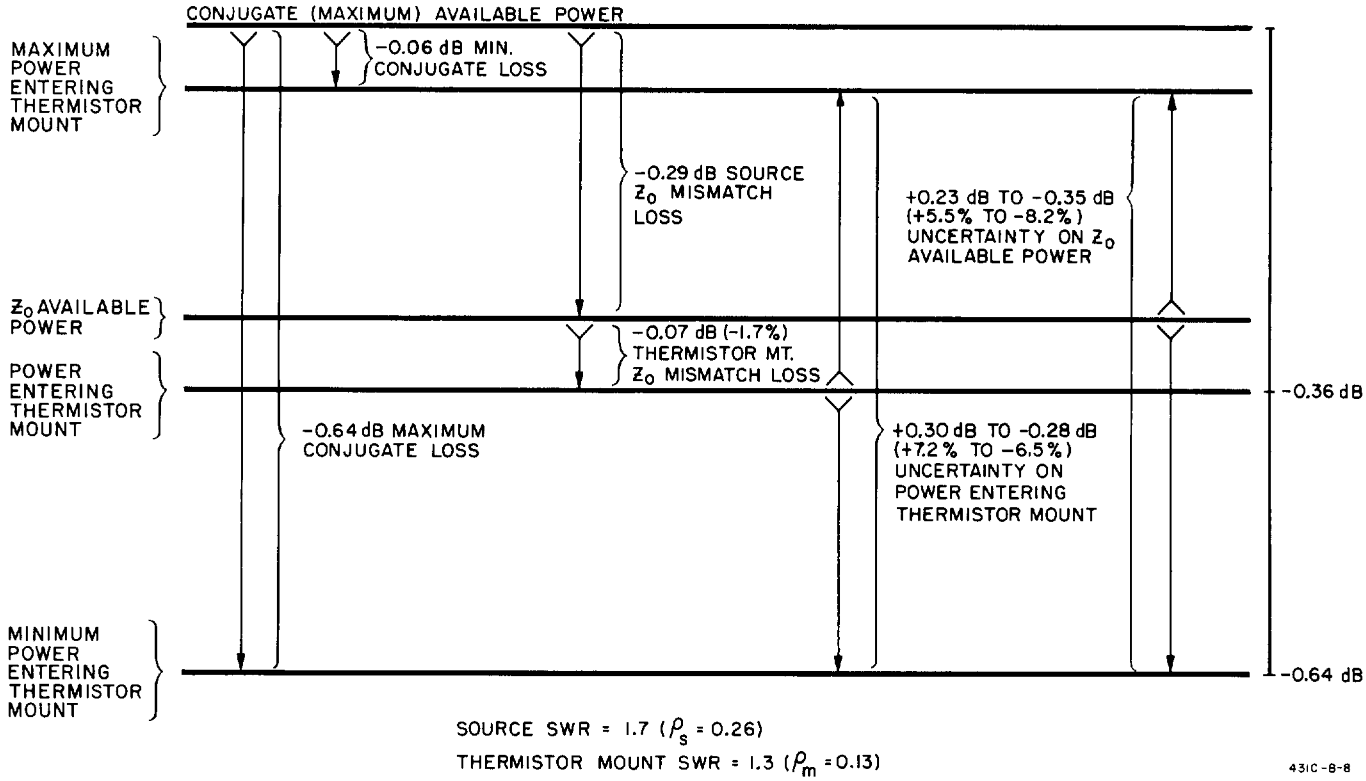


Figure 3-2. Mismatch Power Measurement Uncertainty

3-26. RF LOSSES AND DC-TO-MICROWAVE SUBSTITUTION ERROR. RF losses account for the power entering the thermistor mount but not dissipated in the detection thermistor element. Such losses may be in the walls of a waveguide mount, the center conductor of a coaxial mount, capacitor dielectric, poor connections within the mount, or due to radiation. DC-to-microwave substitution error is caused by the difference in heating effects of the substituted audio bias or DC power and the RF power in a thermistor. The difference results from the fact that the spatial distributions of voltage, current, and resistance within the thermistor element are not the same for audio, DC and RF power. RF losses and DC-to-microwave substitution error are generally combined for the simplicity of analysis.

3-27. THERMOELECTRIC EFFECT ERROR. A mild thermocouple exists at each point of contact where the connecting wires join to the thermistor elements. Each thermocouple creates a DC voltage. Thus, two thermocouple voltages of opposite relative polarity are formed, one at each junction to each thermistor element.

3-28. Ideally, each thermocouple voltage would be equal in magnitude so that they cancel with no resultant effect on the accuracy of power measurement. In practice, however, each point of contact does not have identical thermocouple characteristics, and in addition, the temperatures at each junction may not be the same. These differences cause an incomplete cancellation of the thermoelectric voltages, resulting in a voltage that causes a thermoelectric effect error. The magnitude of the error is important when making DC substitution measurements on the 0.1 mW, 0.03 mW, and 0.01 mW ranges. On other ranges, the effect is negligible. For hp mounts maximum error introduced by thermoelectric effect is about 0.3 μW and is typically 0.1 μW on the .01 mW range.

3-29. THERMOELECTRIC EFFECT ERROR CORRECTION. Use the following technique to correct for thermoelectric effect error.

a. Measure power.

b. Connect an hp Model 8402 Power Meter Calibrator to the power meter DC CALIBRATION jack.

Note

If a balanced thermistor mount is being used, an 8402B Calibrator is required.

c. Zero and null power meter.

d. By DC Substitution (see Figure 3-9), duplicate power measurement made in step a. Calculate and record substituted power as P_1.

e. Reverse connection polarity between the calibrator and power meter.

f. Re-zero and re-null power meter, if necessary.

g. By DC Substitution, duplicate power measurement made in step a. Calculate and record substituted power as P_2.

h. Calculate arithmetic mean of the two substitution powers P_1 and P_2. This mean power includes a correction for thermoelectric effect error.

$$\text{Power} = \frac{P1 - P2}{2}$$

3-30. INSTRUMENTATION ERROR. The degree of inability of the instrument to measure the true substitution audio bias or DC power supplied to the thermistor mount is called power meter accuracy or instrumentation error. Instrumentation error of the Model 431C is ±1% of full scale, +20°C to +35°C. Instrumentation error can be reduced to ±0.16% of reading, or less, by using DC substitution as described in Figure 3-9.

3-31. CALIBRATION FACTOR AND EFFECTIVE EFFICIENCY.

3-32. Calibration Factor and Effective Efficiency are two power ratios used as correction factors to improve overall accuracy of microwave power measurement. The ratios are used under different measurement conditions. Calibration Factor is used when the thermistor mount is coupled to the RF source without a tuner. Calibration Factor corrects for both SWR and inefficiency of the thermistor mount. Effective Efficiency is used when a tuner matches the source to the thermistor mount. Effective Efficiency corrects only for the inefficiency of the thermistor mount.

3-33. Each thermistor mount has a particular impedance. This impedance, and hence the mount SWR, remain constant over the major portion of the mciro-wave band for which the mount is designed to operate. For hp thermistor mounts this constant SWR is low; thus the mismatch uncertainty is small. Since the mount impedance and corresponding SWR deviate significantly only at the high and low ends of a microwave band, it is generally unnecessary to use a tuner. However, a tuner or other effective means of reducing mismatch error is recommended when the source SWR is high or when high accuracy is required. To minimize mismatch between the source and the thermistor mount without the use of a tuner, a low SWR precision attenuator can be inserted in the transmission line to isolate the thermistor mount from the source. Since a tuner is not often used, Calibration Factor is a more practical term than Effective Efficiency.

3-34. CALIBRATION FACTOR. Calibration Factor is the ratio of substituted audio or DC power in the thermistor mount to the microwave RF power incident upon the mount.

$$\text{Calibration Factor} = \frac{P_{DC}\ \text{Substituted}}{P_{\mu wave}\ \text{Incident}}$$

Calibration Factor is a figure of merit assigned to a thermistor mount to correct for the following sources of error: 1) RF reflected by the mount due to mismatch, 2) RF loss caused by absorption within the mount but not in the thermistor element, and 3) DC-to-microwave substitution error.

3-35. The CALIB FACTOR switch on the front panel allows rapid power measurements to be made with improved accuracy. The switch is set to the Calibration Factor value, appropriate to the frequency of measurement, imprinted on the thermistor mount label. With the proper setting, the 431C compensates for the Calibration Factor of the thermistor mount.

3-36. Calibration Factor is applied as a correction factor to all measurements made without a tuner. Under this condition, the power indicated is the power that would be delivered by the source to a load impedance equal to Z_O. This measured power is called Z_O available power.

3-37. Calibration Factor correction ensures that a power measurement uncertainty range is centered on the Z_O available power level instead of on the power delivered to the thermistor mount impedance. Total measurement uncertainty limits for a given power measurement using Calibration Factor are the sum of the uncertainties contributed by: 1) Mismatch loss, 2) Calibration Factor uncertainty, and 3) Instrumentation error.

3-38. An example of power measurement uncertainty caused by source and thermistor mount mismatch is given in Paragraphs 3-23 through 3-25. Continuing the example will show the basic principle of Calibration Factor correction to a measurement of Z_O available power. Figure 3-3 shows the relationship and limits of error before correction. A source SWR of 1.7 and a thermistor mount SWR of 1.3 result in a Z_O available power uncertainty of +5.5% to -8.2%. Assuming a thermistor mount Calibration Factor of 94% (accuracy of ±2%), the Calibration Factor uncertainty is (-6%) + (±2%), or -4% to -8%. The 431C Power Meter has an instrumentation error of ±1% (may be reduced by DC substitution, Figure 3-9). The algebraic addition of Calibration Factor, instrumentation and Z_O available power uncertainties determines the limits of error before Calibration Factor correction. In this case, the limits are +2.5% to -17.2%.

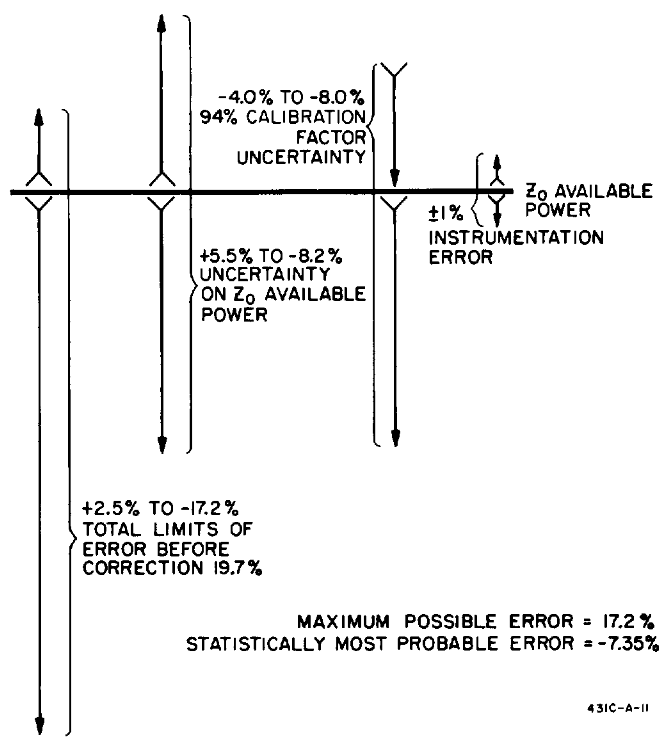


Figure 3-3. Limits of Error Before Correction

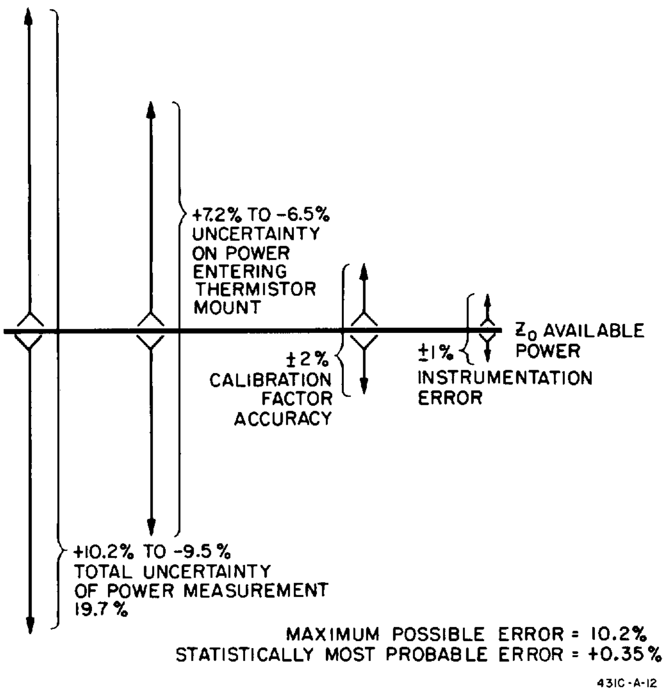


Figure 3-4. Total Uncertainty After Correction

Before correction, the maximum possible error is 17.2% and the statistically most probable error is -7.35%.

3-39. Figure 3-4 shows the total power measurement uncertainty after Calibration Factor correction. Note that the range of uncertainty, 19.7%, is the same as it was before correction. However, the measurement uncertainty range has shifted, and is now more symmetrical about the Z_0 available power level.* The total uncertainty after correction is the algebraic sum of the instrumentation error (±1%), the accuracy to which Calibration Factor is determined (±2%), and the uncertainty on the power actually entering the thermistor mount. After correction, the power measurement uncertainty on the Z_0 available power is +10.2% to -9.5%. The maximum possible error is 10.2% (was 17.2%) and the statistically most probably error is +0.35% (was -7.35%). This is a typical example showing how the use of Calibration Factor correction to a measurement of Z_0 available power not only reduces the maximum possible error, but more importantly, the magnitude of the statistically most probable error is reduced to very near the Z_0 available power level.

*The relationship between indicated power on the 431C and the Z_0 available power is given by the following equation:

$$P_0 = \frac{P \text{ indicated } (1 \pm \rho_s \rho_m)^2}{\text{Calibration Factor}}$$

Where: P_0 = Z_0 available power
ρ_s = source reflection coefficient
ρ_m = thermistor mount reflection coefficient

$$\rho = \frac{SWR - 1}{SWR + 1}$$

3-40. EFFECTIVE EFFICIENCY. Effective Efficiency is the ratio of substituted audio or DC power in the thermistor mount to the microwave RF power dissipated within the mount.

$$\text{Effective Efficiency} = \frac{P_{DC} \text{ Substituted}}{P_{\mu wave} \text{ Dissipated}}$$

This power ratio corrects for RF losses and DC-to-microwave substitution error in the thermistor mount. It is largely independent of the level of input RF power. When a tuner is used to present either a conjugate or Z_0 match to the microwave RF source, Effective Efficiency is to be applied as a correction factor to the power measurement because all of the power incident upon the mount is absorbed in the mount. The use of a tuner and application of Effective Efficiency is the most accurate method of measuring power since source and thermistor mount power reflections are eliminated, and thus, measurement uncertainty due to mismatch is eliminated. Tuner loss will generally be small. However, its effects on power measurement can be corrected for by dividing the indicated power by the tuner-loss ratio, power out/power in.

3-41. Effective Efficiency can be applied as a correction factor to both conjugate available and Z_0 available power measurements. The CALIB FACTOR switch is set to the Effective Efficiency value, appropriate to the frequency under test, imprinted on the thermistor mount label. The type of application of the tuner determines if the power measured is conjugate available or Z_0 available.

3-42. Conjugate available power is measured when the system consisting of the RF source, transmission line, tuner and thermistor mount is tuned for a maximum power level on the 431C. In this application, the system-mount combination presents a conjugate match to the source. The power measured is the actual power that would be delivered by the source to a conjugate load.

3-43. Z_0 available power is measured when a tuner-thermistor mount combination is tuned for minimum reflection caused by mount mismatch at the frequency of interest. The tuner adjustment is made on a reflectometer or slotted line system, external to the measurement system used for power measurement. After the tuner adjustment, the tuner-thermistor mount combination is connected to the transmission line and RF source on which a power measurement is made.

3-44. HIGH ACCURACY OF POWER MEASUREMENT USING DC SUBSTITUTION.

3-45. The instrumentation source of error can be reduced by using DC substitution. With precision instruments used in a DC substitution set up, and careful procedure, instrument error can be reduced from ±1% of full scale to ±0.16% of reading, or less. The technique involves: 1) applying the RF power to be measured to the thermistor mount and noting the power meter reading, 2) removing the RF power from the thermistor mount and substituting a DC current from an external DC power source to precisely duplicate the meter reading obtained in step 1, and 3) calculating the power from the substituted DC current and thermistor operating resistance.

3-46. EQUIPMENT USED FOR DC SUBSTITUTION. Figure 3-9 shows the instrument setup for a DC substitution measurement. The hp Model 8402B Calibrator conveniently provides DC power and appropriate switching to perform DC substitution measurement with the Model 431C. If the 431C is being used with a balanced 200 ohm thermistor mount, the 8402B must be used. If the 431C is used with an unbalanced thermistor mount such as hp Model 478A Coaxial or 486A Waveguide types, the 8402B may be replaced with an 8402A Power Meter Calibrator.

3-47. Although the DC substitution technique is the most accurate method of measuring RF power, there are sources of error that must be considered. The accuracy of DC substitution depends largely upon: 1) how accurately substituted DC is known, 2) how precisely the power meter reading is duplicated, and 3) the actual operating resistance of the thermistor.

3-48. SUBSTITUTION FUNCTION MEASUREMENT ACCURACY. Voltmeter terminals are located on the rear panel of the 8402B Calibrator. These terminals provide a means to monitor the magnitude of calibrator output currents by presenting a DC voltage proportional to the substituted current. For the purpose of calculating a substituted power, this voltage carries a total uncertainty of ±0.12%. This uncertainty includes a ±0.06% uncertainty of the thermistor resistance function of the calibrator (steps 8 through 11 of Figure 3-9). However, the output impedance of this voltage is finite (100 ohms on 1.0 mW through 10 mW ranges; 1 k ohms on lower ranges). This output impedance requires the use of a differential or high impedance voltmeter in order to obtain an accurate measurement of the calibrator output. At null, a differential voltmeter does not draw current from the calibrator voltage output circuitry. For this reason, a differential voltmeter will not introduce measurement error due to loading. When using a voltmeter other than a differential type, correction must be made for the measurement error that is introduced by the voltmeter input impedance. For example, a digital voltmeter with an input impedance of 1 megohm will introduce a measurement error of 0.1% when used to measure calibrator output on ranges below 1.0 mW. Substitution current measurement error corrections must be doubled since the power measured is proportional to the square of the substituted current. Twice the voltage uncertainty is the power uncertainty introduced by the voltmeter. Therefore, the correction to be applied in the above example is 0.2%. Corrections should be added to voltmeter readings since voltmeter impedance loading causes voltage measurements to decrease.

3-49. POWER METER DVM OUTPUT MEASUREMENT. A digital voltmeter can be connected to the 431C DVM jack to increase resolution of a power meter reading. This feature provides a convenience to the operator and allows an easy method of repeating a precise measurement readout value. Measurement error corrections for voltmeter impedance loading must be made when using a voltmeter to measure the voltage output of the 431C Power Meter. The DC voltage at the DVM jack on the rear panel is developed across a 1 k ohm resistor. Therefore, a voltage measurement made with a digital voltmeter having an input impedance of 500 k ohms will introduce an error of 0.2%. A digital voltmeter with an input impedance of 10 megohms will introduce a much smaller error of 0.01%. Correction percentages should be added to voltmeter readings.

3-50. DETECTION THERMISTOR RESISTANCE. Steps 8 through 11 of Figure 3-9 list a procedure to determine the operating resistance of the RF detection bridge at balance and thus measure the operating resistance of the detection thermistor element (R_d) during a power measurement. The actual operating resistance of detection thermistors may deviate as much as ±0.5% from their nominal values. For this reason, the actual operating resistance should be checked. The true operating resistance must be known in order to accurately calculate substituted DC power in a DC substitution measurement.

3-51. The hp Model 8402B Calibrator provides a convenient method of determining the detection thermistor operating resistance. The thermistor mount cable is connected between the 431C Power Meter THERMISTOR MOUNT and 8402B Calibrator RESISTANCE STANDARD connectors. By the THERMISTOR RESISTANCE switch, the 8402B Calibrator substitutes precision resistance vaules in place of the thermistor elements normally in the 431C bridge circuits. The switched resistances provide a method of determining a oscillation/no-oscillation state of the 431C Power Meter.

3-52. With the 431C RANGE switch at NULL, a stable reading greater than zero indicates an audio-bias oscillation state. While changing the substituted resistances, the operator can determine when oscillations

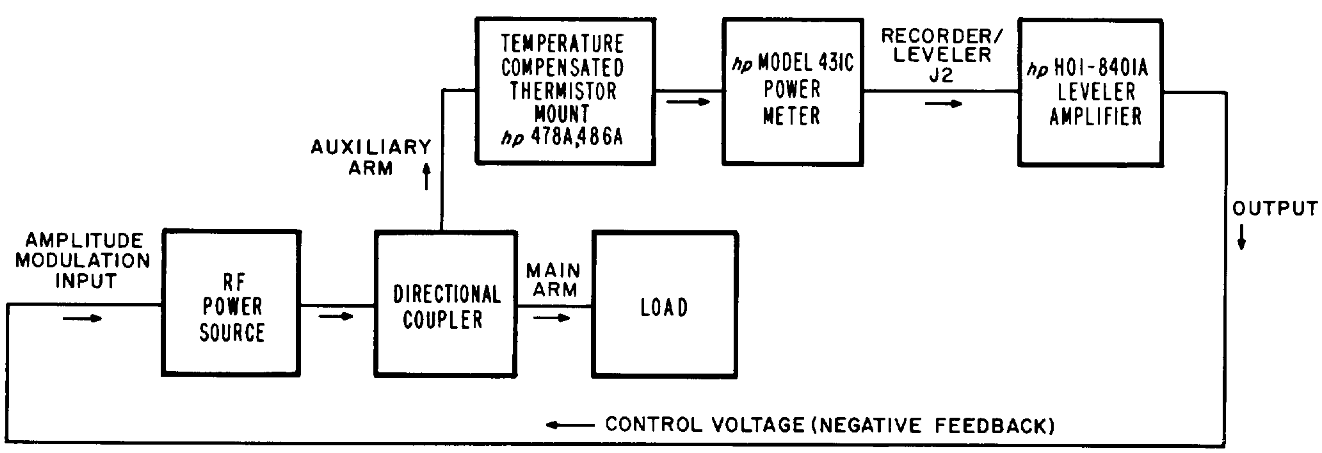


Figure 3-5. Output Power Leveling

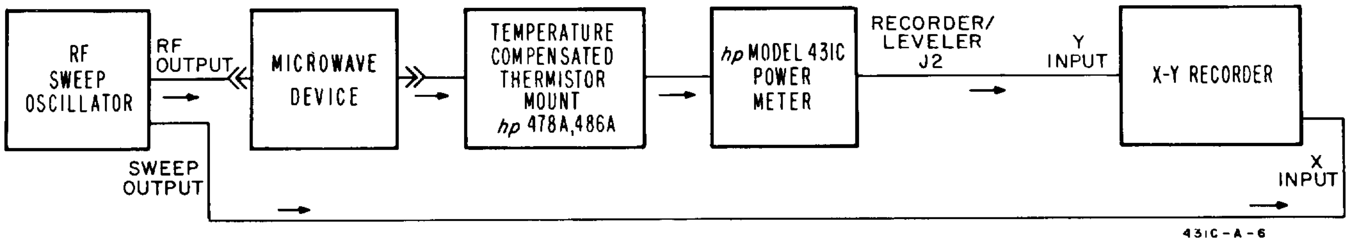


Figure 3-6. Insertion Loss or Gain Measurement

cease by noting a change of meter reading to zero. The operating resistance of the detection thermistor element is measured by reading the resistance deviation in percent directly from the switch setting that causes oscillations to cease.

3-53. ADDITIONAL APPLICATIONS.

3-54. A discussion of microwave power measurement applications is available in Application Note 64, available from any Hewlett-Packard Sales and Service office. The RECORDER/LEVELER output allows the 431C to be used in systems of greater capability than would be possible with a meter indication alone. Important applications include: 1) permanent recording of measurement data, 2) output power leveling, 3) insertion loss or gain measurement and, 4) control system monitoring. These applications are discussed in the following paragraphs. Other applications include readout of the level of a microwave RF power source at a remote location, and using the ratio of two power meter DVM outputs to make precise measurements of small attenuations.

3-55. OUTPUT POWER LEVELING. A block diagram of an output power leveling system is shown in Figure 3-5. The power meter is used as an element in a control circuit that maintains a constant power level at a particular point in the system. The thermistor mount, connected to the auxiliary arm of a directional coupler, senses a portion of the power incident upon the directional coupler. The power meter RECORDER/LEVELER output provides a DC voltage that is proportional to the power measured at the thermistor mount. This voltage can be directly applied to the power meter leveling input of one of the hp Model 690 Sweep Oscillators, or to the input of a leveler amplifier. At the leveler amplifier, the voltage is compared to an internal reference, the difference voltage amplified, and applied as negative feedback to the amplitude modulation input of the source. The feedback maintains a constant RF power level at the sampling point on the auxiliary arm of the directional coupler. This control will hold the forward power at the main arm of the coupler at a constant level.

3-56. INSERTION LOSS OR GAIN. Figure 3-6 shows a block diagram of a system to determine insertion loss or gain as a function of frequency. Initially, the device to be tested is not connected into the system and the thermistor mount is connected directly to the sweep oscillator output. Variations in power amplitude are measured by the power meter as the frequency range of interest is swept by the sweep oscillator. This is a reference measurement and is recorded by the X-Y recorder. The device to be tested is then inserted between the sweep oscillator and the thermistor mount. Power amplitude versus frequency is again measured and recorded. The difference between the second reading and the reference, at any frequency, is the insertion loss or gain of the device at that frequency.

3-57. CONTROL SYSTEM MONITORING. The arrangement of a system to actuate alarm or control circuits is shown in Figure 3-7. A relay circuit can be connected directly to the RECORDER/LEVELER output. This type of curcuit will provide a control system operated by full-scale magnitude power changes of the power meter. Small magnitude power change control can be achieved through the use of a comparison reference level and a differential amplifier. The differential amplifier output can be connected to the relay circuit to actuate the alarm or control circuits.

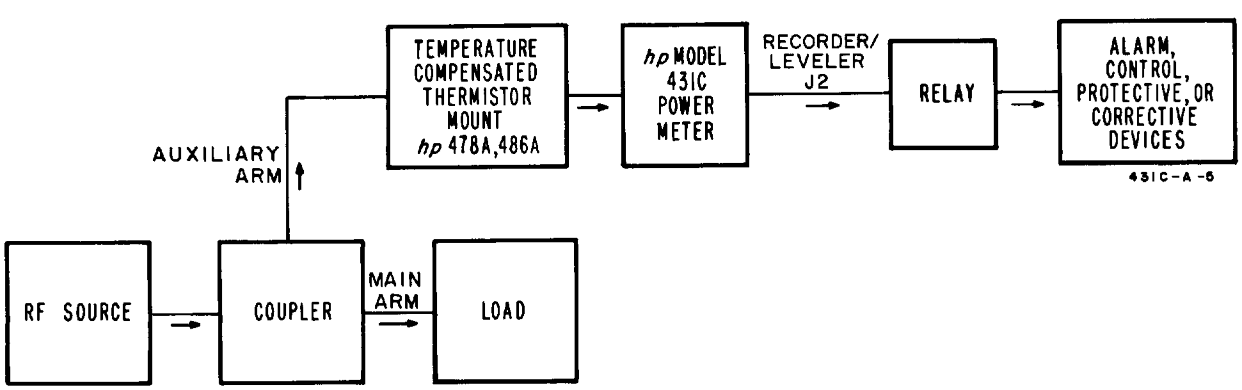
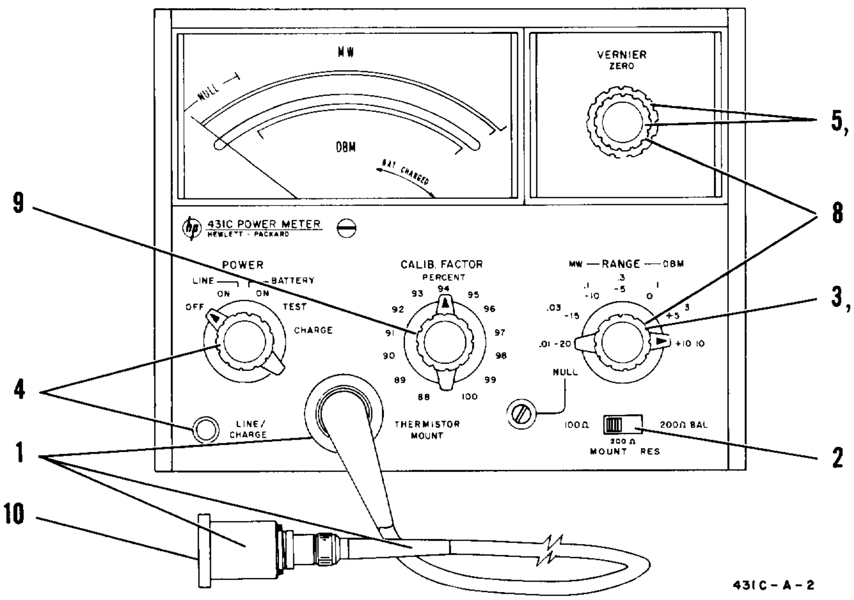


Figure 3-7. Control System Monitoring



1. Connect thermistor mount and cable to THERMISTOR MOUNT connector. Refer to Table 1-2 for recommended thermistor mounts and their frequency ranges.

Note

When using an hp Model 478A or other 200 ohm unbanalced coaxial thermistor mount, the power meter should be zeroed and nulled with the RF power source turned off and connected to the thermistor mount. If the RF power source cannot be turned off, the power meter must be zeroed and nulled while the RF input connection of the thermistor mount is terminated in the same 10 kHz impedance as that presented by the power source (short, open, or 50 ohm). These precautions are not necessary when waveguide mounts such as the hp Model 486A series or balanced 200 ohm coaxial mounts are used.

2. Set MOUNT RES switch to correspond to the operating resistance and type of thermistor mount used.

3. Set RANGE to .01 mW.

4. Set POWER to LINE ON. If instrument is to be battery operated, rotate POWER to BATTERY ON.

5. Adjust ZERO control for 25% to 75% of full scale on meter.

6. Rotate RANGE switch to NULL and adjust NULL screwdriver adjustment (adjacent to NULL on RANGE switch) for minimum reading.

7. Repeat steps 5 and 6 until NULL reading is within NULL region on the meter.

8. Set RANGE switch to the power range to be used and zero-set the meter with ZERO and VERNIER controls.

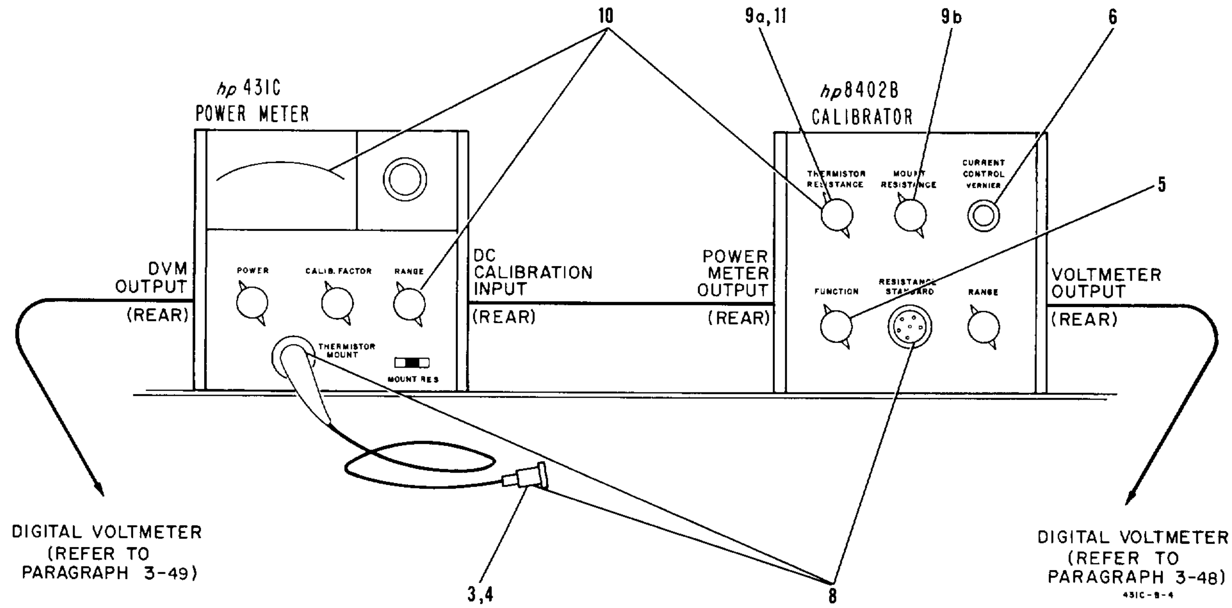
Note

Range-to-range zero carryover is less than 0.5% if the zero is set on the most sensitive range. For maximum accuracy, zero set the meter on the range to be used.

9. Set CALIB FACTOR switch to correspond with Calibration Factor imprinted on hp thermistor mount label.

10. Apply RF power at the thermistor mount. Power is indicated on the meter directly in mW or dBm.

Figure 3-8. Turn On and Nulling Procedure



1. Connect the equipment shown above. DC substitution is discussed in Paragraphs 3-44 through 3-52.
2. Set the 431C Power Meter for normal operation using the procedure given in Figure 3-8.
3. Apply RF power to the thermistor mount; then note and record the reading of the power meter as indicated by the digital voltmeter. This recorded value is a reference to be precisely duplicated in the DC substitution measurement, step 6.

Note

If the .01, .1, 1, or 10 mW power meter ranges are used, the digital voltmeter reads directly. If the .03, .3, or 3 mW power meter ranges are used, the digital voltmeter reading must be multiplied by .0316, .316, or 3.16 respectively.

4. Turn off, or disconnect, the RF source.
5. Turn on 8402B Calibrator by setting the FUNCTION switch to CURRENT OFF; then apply a substitution current by setting FUNCTION switch to SUBSTITUTE.
6. Using 8402B Calibrator CURRENT CONTROL and VERNIER controls, adjust the substitution current until the reference reading of step 3 is precisely duplicated.
7. Note 8402B VOLTMETER output DVM reading. On .01, .03, .1 and .3 mW ranges, reading is substituted current (I_{DC}) in mA. On other ranges multiply reading by 10 to obtain I_{DC} in mA.
8. Disconnect thermistor mount from thermistor mount cable. Connect thermistor mount cable between 431C Power Meter THERMISTOR MOUNT and 8402B Calibrator RESISTANCE STANDARD connectors.
9. Set 8402B Calibrator controls as follows:
   a. THERMISTOR RESISTANCE . . . -.5%
   b. MOUNT RESISTANCE to correspond with resistance and type of thermistor mount used.
10. Set 431C Power Meter RANGE switch to NULL. Rotate THERMISTOR RESISTANCE switch on 8402B Calibrator clockwise until the 431C Power Meter changes from a zero reading to a stable reading greater than zero.
11. The operating resistance of the detection thermistor (R_d) is the nominal value indicated on the thermistor mount label plus or minus the correction indicated by the setting of the THERMISTOR RESISTANCE switch. The percentage correction is a value in-between the limits set by the two positions of the THERMISTOR RESISTANCE switch that correspond to the zero reading and the stable meter reading obtained in step 10. If desired, the average of these two values may be calculated and used as the correction value.
12. Calculate power in mW from the following expression:

$$\text{Power (mW)} = \frac{(I_{DC})^2\,(R_d)\,(10^{-3})}{4}$$

Where: I_{DC} = Substitution current in mA (from step 7)
R_d = Operating resistance of the detection thermistor (from step 11)

Figure 3-9. DC Substitution

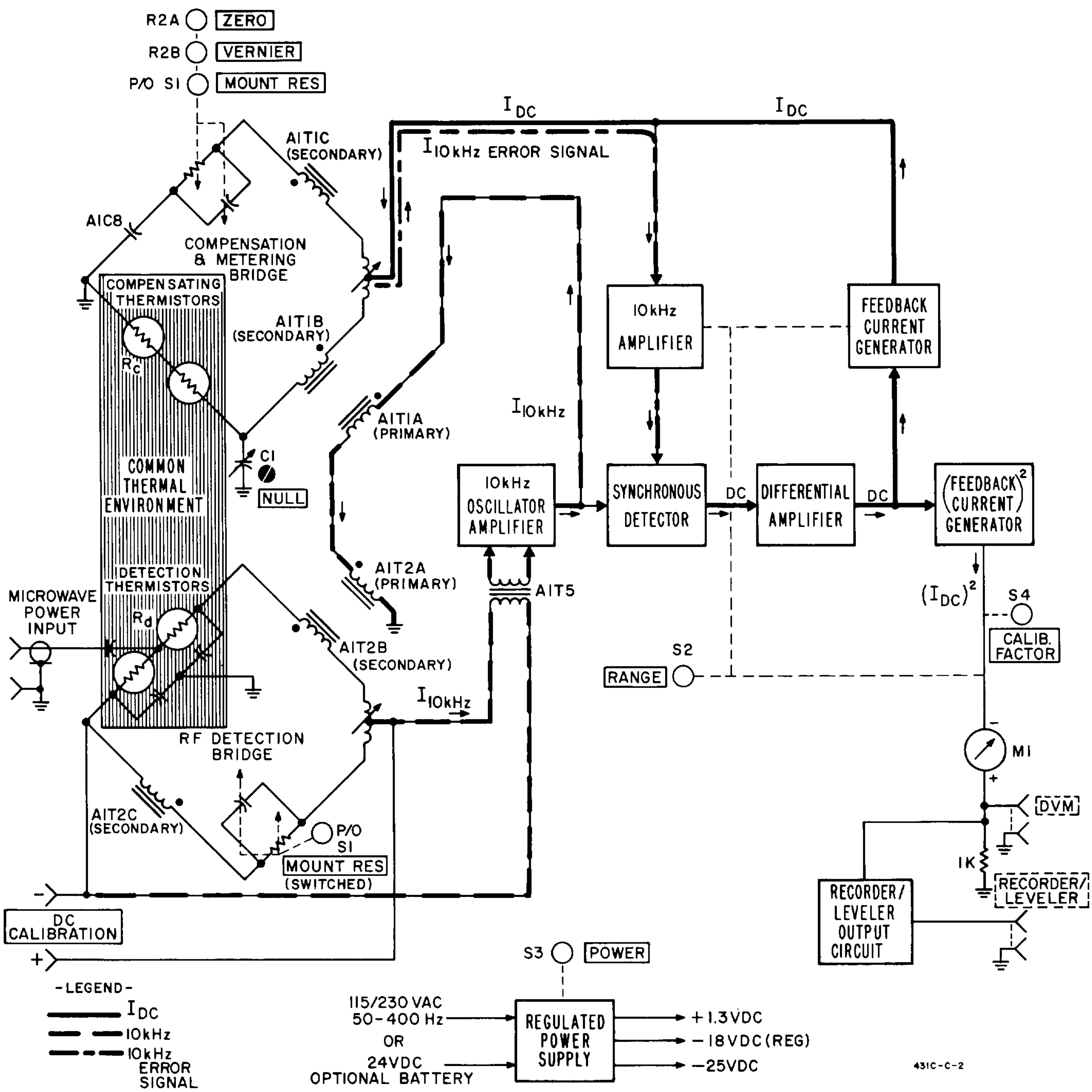


Figure 4-1. Block Diagram

SECTION IV
PRINCIPLES OF OPERATION

4-1. OVERALL DESCRIPTION.

4-2. Figure 4-1 is a block diagram which shows the Model 431C Power Meter with an associated thermistor mount. The thermistor mount contains two sets of thermistor elements, R_c and R_d, which are mounted in an identical thermal environment with R_c isolated from applied microwave power. Thermistor elements R_d absorb the microwave power applied to the mount and initiate a power level data conversion to a corresponding meter indication. Thermistor elements R_c provide compensation in the metering circuit to correct for ambient temperature changes at the thermistor mount.

4-3. The power meter circuitry incorporates two bridges which are made self-balancing by means of separate feedback loops. Regenerative (positive) feedback is used in the detection loop; degenerative feedback in the metering loop. Thermistor elements are used in one arm of each of the self-balancing bridges. In the detection loop, the 10 kHz oscillator-amplifier supplies enough 10 kHz power (I_{10} kHz) to bias thermistor element R_d to the operating resistance which balances the RF bridge. The same amount of 10 kHz power is also supplied to thermistor element R_c by the series-connected primaries of transformers A1T1 and A1T2.

4-4. When RF power is applied to thermistor element R_d, an amount of 10 kHz power equal to the RF power is removed from thermistor element R_d by the self-balancing action of the RF bridge. Since the primaries of A1T1 and A1T2 are series-connected, the same amount of 10 kHz power is also removed from thermistor element R_c, thus, the action which balances the RF bridge unbalances the metering bridge. The metering bridge loop automatically re-balances by substituting DC power for 10 kHz power. Since the 10 kHz power equaled the applied RF power, the substituted DC power is also equal to the applied RF power. Instead of metering the feedback current directly, which would require the use of a nonlinear meter scale, an analog current is derived which is proportional to the square of the feedback. Since power is a square-law function of current, the analog current thus derived is proportional to RF power, making possible the use of a linear scale on the meter.

4-5. There is little drift of the power meter zero point when ambient temperature at the thermistor mount changes because of compensating thermistors. For example, if the ambient temperature at the mount increases, a decrease in electrical power to the thermistors is required to hold their operating resistances constant. The decrease, for both thermistors, is made automatically by the detection loop which reduces 10 kHz power. The amount of DC power in the metering loop remains unchanged however, and since this DC power controls the meter action, the ambient temperature changes do not affect the meter indication. The compensation capability depends upon the match of thermistor temperature characteristics. When thermistor mounts are built, the thermistors are selected to insure optimum match of thermal characteristics.

4-6. CIRCUIT DESCRIPTION.

4-7. RF DETECTION BRIDGE. A simplified schematic diagram of the RF detection bridge is shown in Figure 4-2. The RF detection bridge combines with a high gain 10 kHz tuned amplifier to form a 10 kHz oscillator-amplifier. The bridge and amplifier are connected in a closed loop (the detection loop) which provides positive feedback to the input of the amplifier. The feedback causes the amplifier and associated bridge circuitry to oscillate. The RF bridge includes thermistor elements R_d, secondary windings of transformer A1T2, capacitance represented by C_a and C_b, and a fixed resistance bridge arm consisting of A1R10 and parallel resistances selected by the MOUNT RES switch.

4-8. When the power meter is off, thermistor R_d is at ambient temperature and its resistance is about 1500 ohms; the RF bridge is unbalanced. When the power meter is turned on, this unbalance of the RF bridge causes a large error signal to be applied to the 10 kHz oscillator-amplifier. Consequently, maximum 10 kHz bias voltage is applied to the RF bridge. As this 10 kHz voltage biases R_d to its operating resistance (100 or 200 ohms) the RF bridge approaches a state of balance and regenerative feedback diminishes until there is just sufficient 10 kHz bias power to hold R_d at operating resistance. This condition is equilibrium for detection loop.

4-9. With application of RF power, the resistance of thermistor R_d decreases causing the regenerative signal from the RF bridge to decrease. Accordingly, 10 kHz power diminishes, the thermistor returns to operating resistance and the detection loop regains equilibrium.

4-10. The MOUNT RES switch, S1, changes the resistance arm of the RF detection bridge so that the bridge will function with either a 100 ohm, 200 ohm, or 200 ohm balanced thermistor mount. The 200Ω BAL position allows the power meter to be operated with balanced thermistor mounts. When the MOUNT RES switch is in this position two equal capacitors are connected in series across the thermistors with their

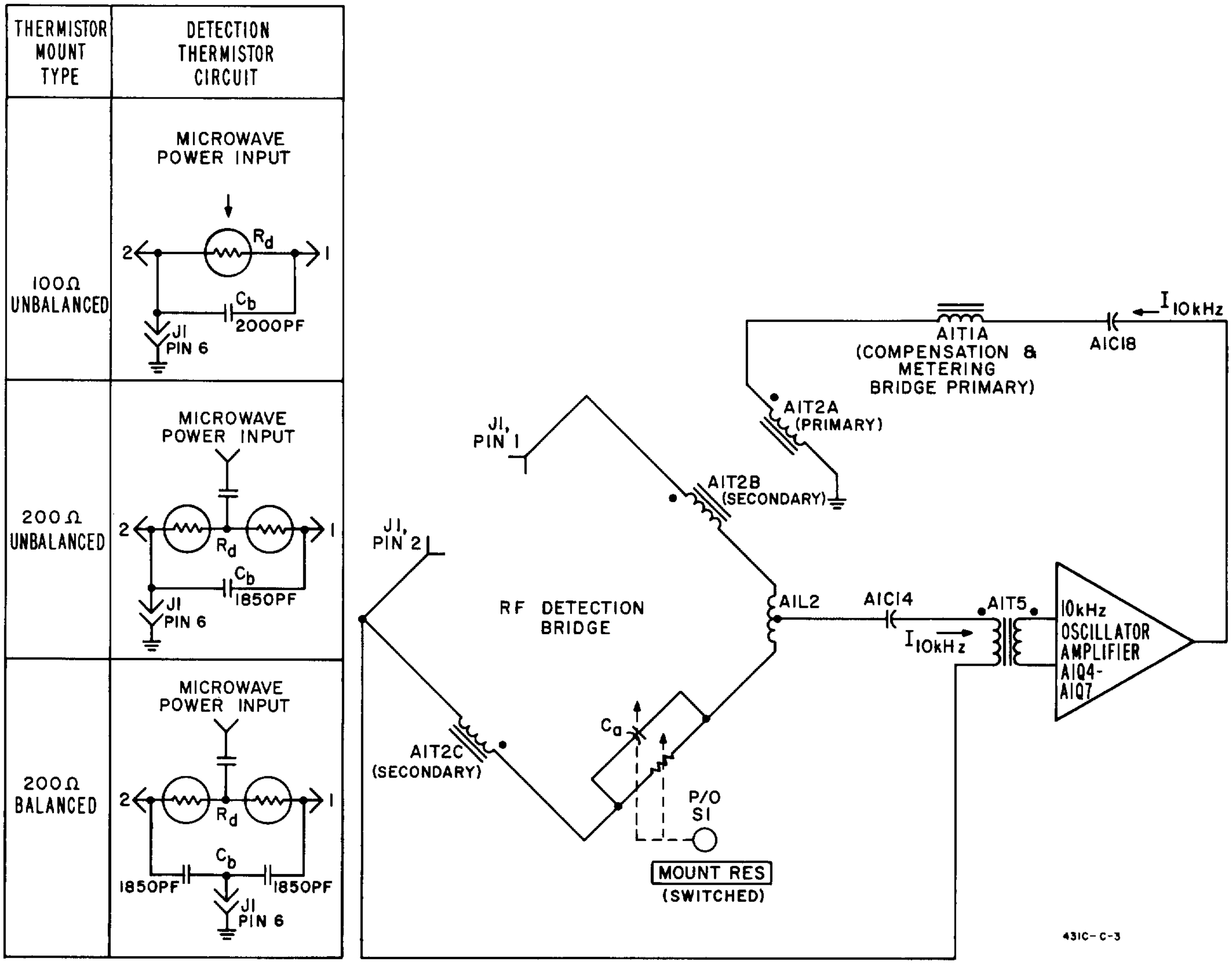


Figure 4-2. RF Detection Bridge

common point grounded. Identical capacitors are connected in a similar manner across A1R10 in the resistance arm of the RF detection bridge. All other grounds are removed from the bridge so that the entire bridge is floating with respect to DC ground. This circuit configuration provides a virtual 10 kHz ground at the RF input point to the balanced thermistor mount.

4-11. COMPENSATION AND METERING BRIDGE CIRCUIT.

4-12. A simplified schematic diagram of the compensation and metering bridge circuit is shown in Figure 4-3. Operation of the metering bridge circuit is similar to the RF detection bridge circuit. It uses the same principle of self-balancing through a closed loop (metering loop). The major difference is that DC rather than 10 kHz power is used to re-balance the loop. The resistive balance point is adjusted by the ZERO and VERNIER controls which constitute one arm of the bridge. The MOUNT RES switch, which is mechanically linked to both the RF bridge and metering bridge, changes metering bridge reference resistance from 100 to 200 ohms. When the MOUNT RES switch is in the 200Ω or 200Ω BAL position some of the feedback current is shunted to ground through R1. This maintains the I^2R function constant when mount resistance is changed from 100 or 200 ohms. The switch also adds the necessary reactance for each position.

4-13. The same 10 kHz power change produced in the RF bridge by RF power also affects the metering bridge through the series connection of A1T1 and A1T2 primaries. Although this change of 10 kHz power has equal effect on both the RF and metering bridges, it is initiated by the RF bridge circuit alone. The metering bridge cannot control 10 kHz bias power, but the 10 kHz bias power does affect the metering circuit. Once a change in the 10 kHz bias power has affected (unbalanced) the metering bridge, a separate, closed DC feedback loop (metering loop) re-establishes equilibrium in the metering circuit.

4-14. Variations in 10 kHz bias level, initiated in the RF bridge circuit, cause proportional unbalance of the metering bridge, and there is a change in the 10 kHz error signal (I_{10} kHz) applied to the 10 kHz tuned amplifiers in the metering loop. These error signal variations are amplified by three 10 kHz amplifiers, and rectified by the synchronous detector. From the synchronous detector the DC equivalent (I_{DC}) of the 10 kHz signal is returned to the metering bridge, and is monitored by the metering circuit to be indicated by the meter. This DC feedback to the metering bridge acts to return the bridge to its normal, near-balance condition.

4-15. The reactive components of the metering bridge are balanced with variable capacitor C1 and inductor A1L1. Null adjust, C1, is an operation adjustment and L1 is a maintenance adjustment. Null adjust C1, is adjusted with the RANGE switch in the NULL position. The 10 kHz signal is taken at the synchronous detector, rectified by A1CR8, and read on the meter. The rectified signal contains both reactive and resistive voltage components of the bridge unbalance.

4-16. SYNCHRONOUS DETECTOR.

4-17. A simplified schematic of the synchronous detector is shown in Figure 4-4. The synchronous detector converts the 10 kHz error signal from the metering bridge to a varying DC signal. The detector is a bridge rectifier which as a rectifier in series with a linearizing resistance in each of its arms. Two

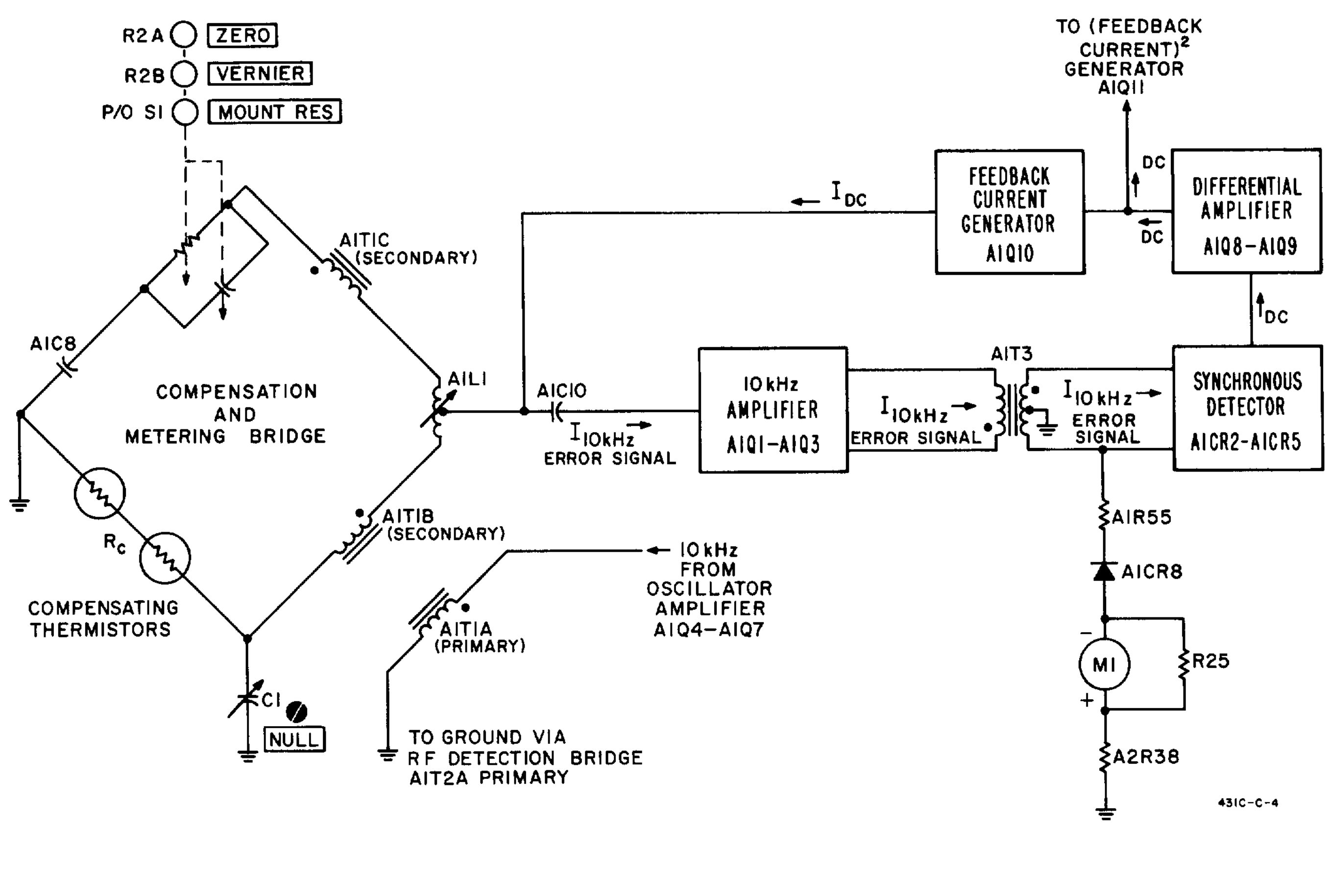


Figure 4-3. Compensation and Metering Bridge

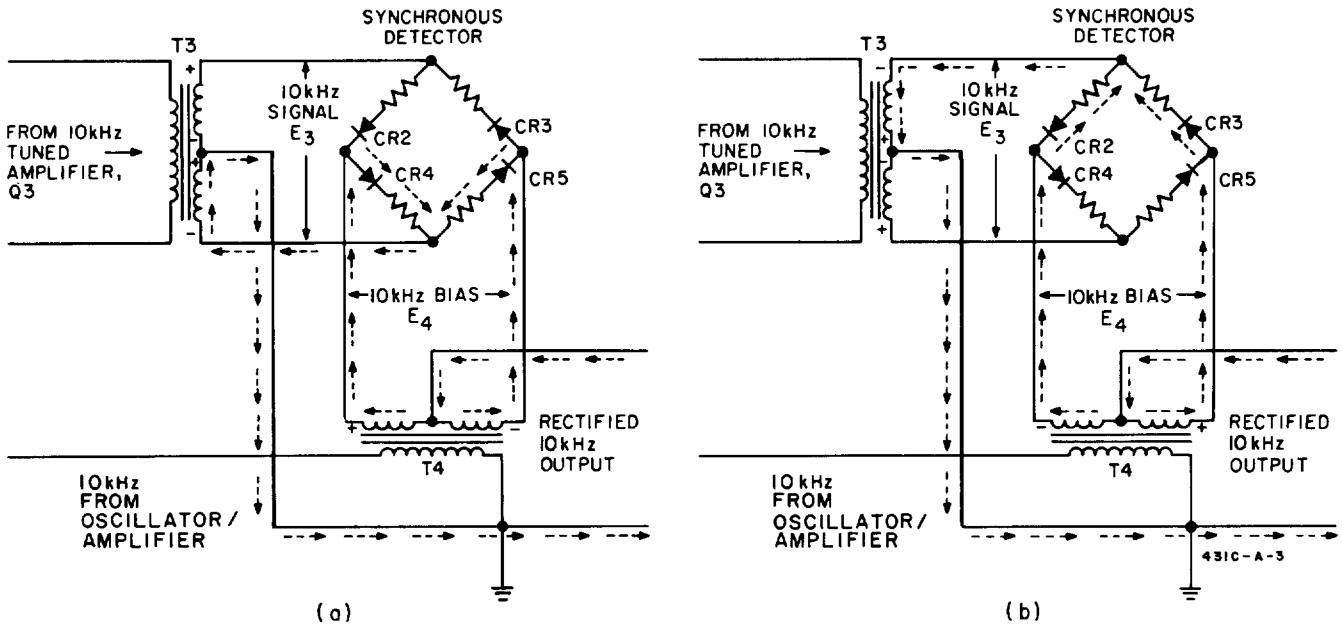


Figure 4-4. Synchronous Detector

10 kHz voltages, designated E3 and E4 in Figure 4-4, are applied to the bridge; 1) voltage E3, induced in the secondary of transformer A1T3, is proportional to the metering bridge error signal and is incoming from 10 kHz tuned amplifier Q3; 2) voltage E4, induced in the secondary of A1T4, is proportional to a voltage supplied by the 10 kHz oscillator-amplifier. Voltage E4 is much larger than voltage E3 and switches appropriate diodes in and out of the circuit to rectify voltage E3. Section (a) of Figure 4-4 shows the current path through diodes A1CR2 and A1CR3 for a negative-going signal. The rectified output is taken at the center taps of transformers A1T3 and A1T4.

4-18. The synchronous detector operates in the following manner. When the left side of A1T4 is positive with respect to the right side, as in Figure 4-4(a), diodes A1CR4 and A1CR5 conduct while diodes A1CR2 and A1CR3 are biased off. With the polarities reversed, as in Figure 4-4(b), the diodes A1CR4 and A1CR5 are biased off. The resultant output is a pulsating DC signal equivalent to the applied 10 kHz error signal. The pulsating DC signal is filtered and applied to differential amplifier A1Q8 and A1Q9.

4-19. The operation of the synchronous detector requires an in-phase relationship between E3 and E4. The amplitude of E4 must be greater than that of E3 at all times.

4-20. FEEDBACK DIFFERENTIAL AMPLIFIER.

4-21. A simplified schematic diagram of the feedback differential amplifier is shown in Figure 4-5. The feedback circuit differential amplifier comprises A1Q8, A1Q9 and associated circuitry. Pulsating DC from the synchronous detector is filtered by A1C19, A1C20, and A1R35, amplified by A1Q8 and fed to both the feedback current-squared generator A1Q11, and the feedback current generator A1Q10. Temperature compensation and low emitter circuit resistance for A1Q10 is provided by A1Q9. Diode A1CR7 protects A1Q10 and A1Q11 from excessive reverse bias when A1Q8 is not conducting.

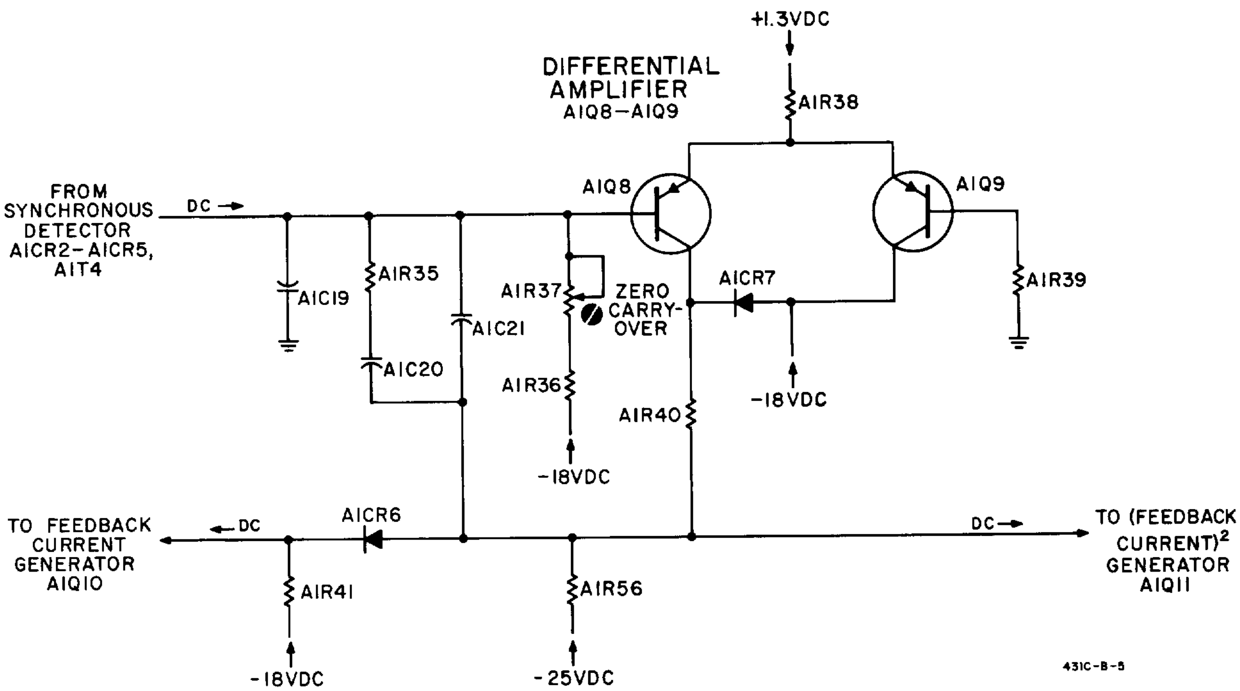


Figure 4-5. Feedback Differential Amplifier

4-22. FEEDBACK CURRENT GENERATOR.

4-23. A simplified schematic diagram of the feedback current generator is shown in Figure 4-6. The DC signal from the differential amplifier is applied to the feedback current generator A1Q10. A1Q10 serves two functions: 1) it completes the metering loop to the metering bridge, and 2) it operates in conjunction with the first 10 kHz amplifier, A1Q1, and the RANGE switch to change metering loop gain so that the meter will read full scale for each power range. Potentiometer adjustments are provided to accurately set the calibration on each range. Diode A1CR6 provides temperature compensation for A1Q10.

4-24. METER CIRCUIT.

4-25. A simplified schematic diagram of the meter circuit is shown in Figure 4-7. The meter circuit includes feedback current-squared generator A1Q11, a squaring circuit, the meter, RECORDER/LEVELER and DVM jacks, J2 and J4. The purpose of the meter circuit is to convert a linear voltage function, proportional to applied power, to a square function so that power may be indicated on a linear meter scale. The linear voltage function is applied to the base of A1Q11 and is converted to a square law function by the squaring circuit in series with A1Q11 emitter.

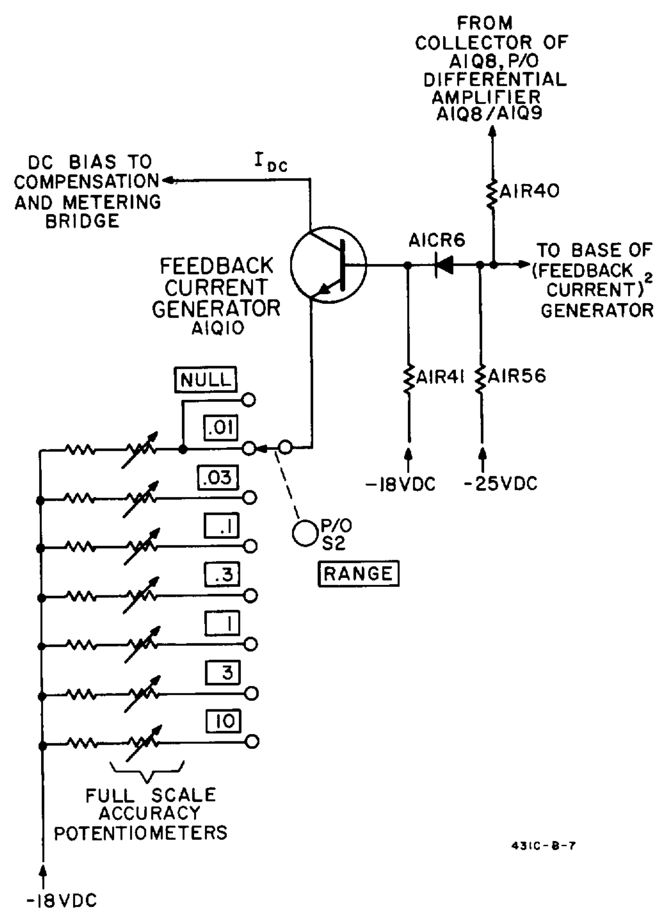


Figure 4-6. Feedback Current Generator

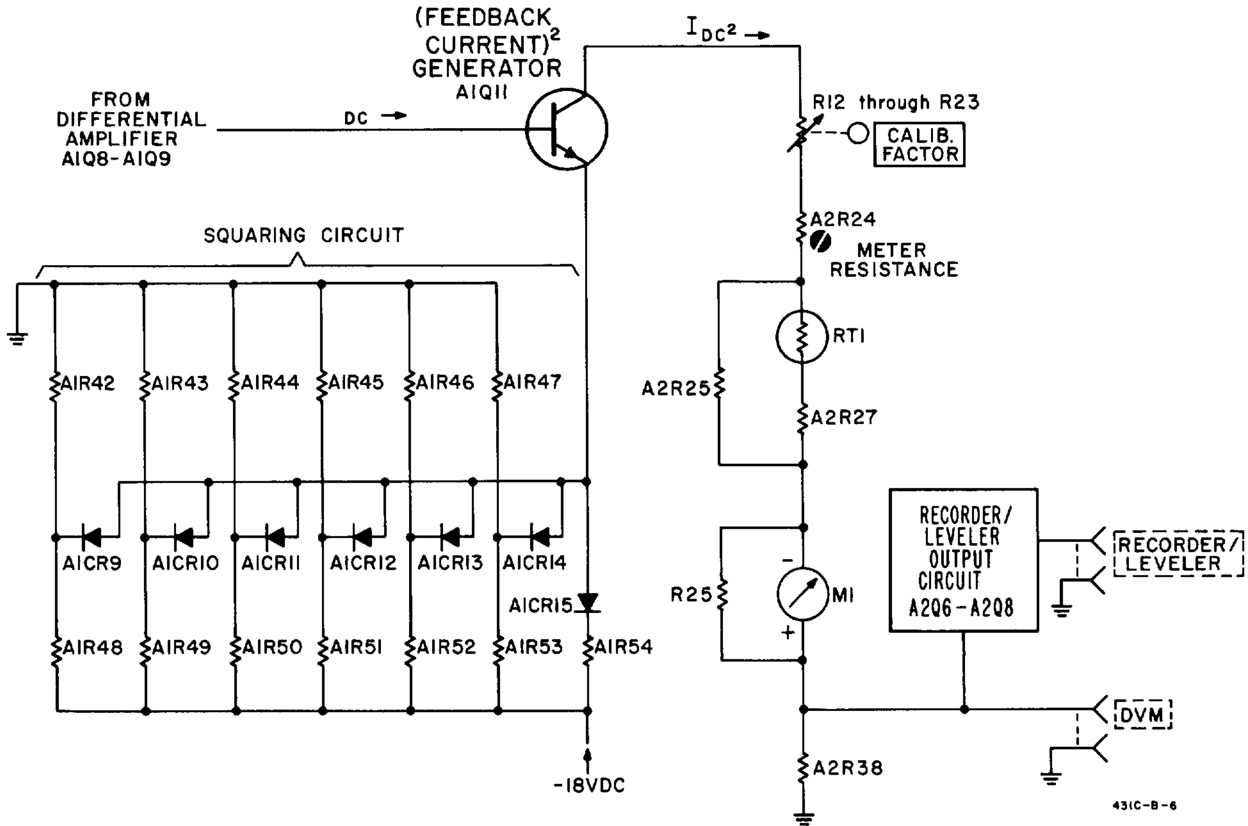


Figure 4-7. Meter Circuit

4-26. METERING CIRCUIT DIFFERENTIAL AMPLIFIER.

4-27. The metering circuit RECORDER/LEVELER output is a voltage of low source impedance necessary for isolation between a recorder or leveler amplifier and the metering circuit of the power meter. The isolation circuit comprises the differential amplifier A2Q6-A2Q7 and output transistor A2Q8. The voltage developed across A2R38 for the DVM output is referenced at the base of A2Q6 for comparison to the voltage at the RECORDER/LEVELER jack placed on the base of A2Q7. Any difference voltage creates an error voltage that changes the base-emitter bias on A2Q8. A corresponding change in A2Q8 collector current occurs and the RECORDER/LEVELER voltage across A2R41 automatically adjusts to maintain the same magnitude as the DVM reference voltage.

4-28. SQUARING CIRCUIT. A simplified schematic diagram of the squaring circuit is shown in Figure 4-7. The squaring circuit includes diodes A1CR9-14, and resistors A1R42-54. Temperature compensation for the squaring circuit is provided by A1CR15.

4-29. The design of the squaring circuit is such that individual diodes are normally reverse-biased. The diodes are biased so that they conduct one after another at discrete values of emitter voltage. This causes the emitter resistance to be proportionately greater for

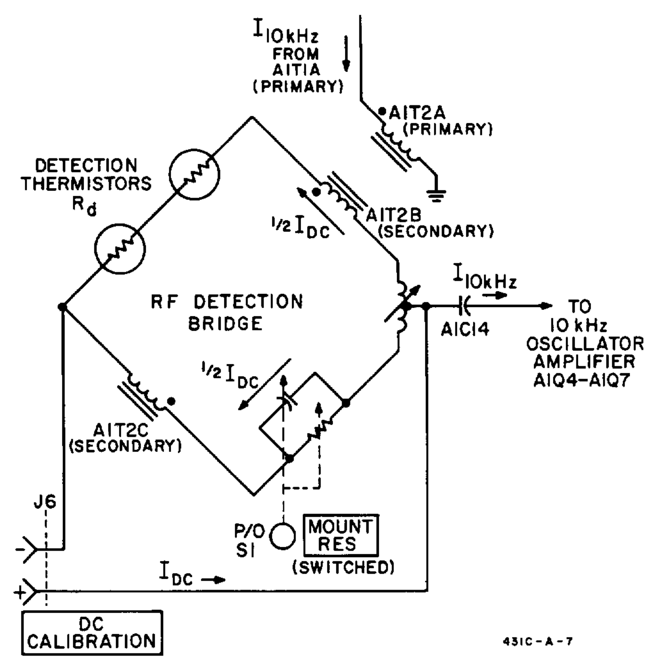


Figure 4-8. DC Calibration and Substitution

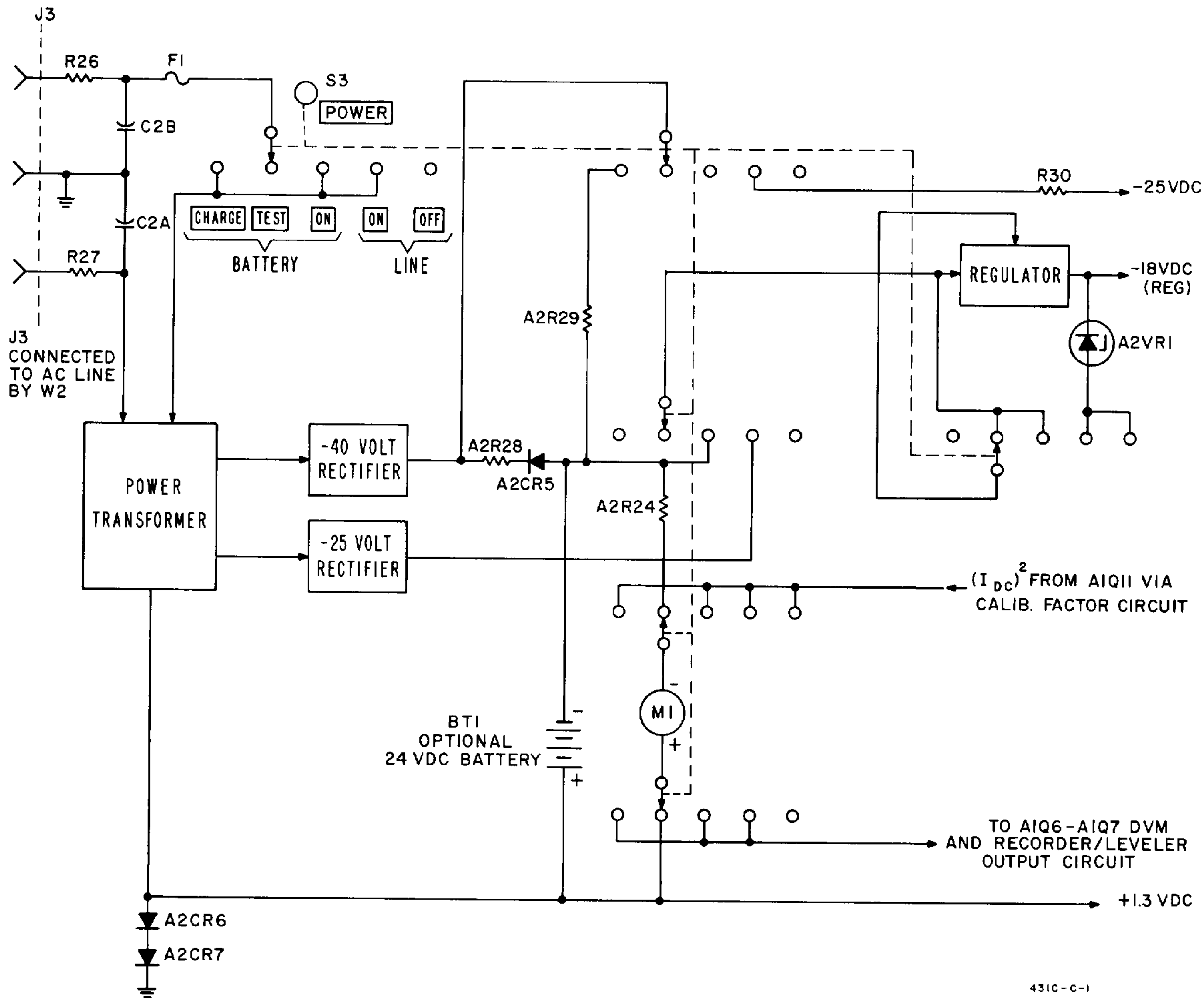


Figure 4-9. Power Switch Arrangement

larger currents. Thus, the collector current of A1Q11 is made to approximate a square law function, and the meter indicates power on a linear scale.

4-30. ZEROING. Perfect balance of the metering bridge would mean that no 10 kHz error signal would be applied to the 10 kHz amplifiers, there would be no DC feedback from A1Q10, and the metering loop would be open. With an open metering loop, zero reference could not be accurately established. In the Model 431C this occurrence is prevented by insuring a closed metering loop even when the ZERO control causes the meter pointer to deflect down-scale from zero. By the combined actions of A1R36 and A1R33, the zero setting of the meter pointer does not coincide with absolute balance of the metering bridge. A slight unbalance of the bridge is maintained by A1R36, while A1R33 provides a counter-action in the feedback current-squared generator, A1Q11, so that the meter can indicate zero even though the metering bridge is not perfectly balanced. Resistor A1R33 also sets the full scale accuracy of the meter.

4-31. DC SUBSTITUTION.

4-32. A simplified schematic diagram of the DC Substitution and Calibration circuit is shown in Figure 4-8. A block diagram of the auxiliary equipment required to perform DC substitution is presented in Figure 3-9 and discussed in Paragraphs 3-34 through 3-36. An accurately determined DC current, I_{DC}, is supplied to the DC CALIBRATION terminals on the rear panel and adjusted to allow the RF detection bridge to precisely duplicate the RF power measurement reading. Calculation of DC power from the substituted DC current gives an accurate measure of the unknown RF microwave power.

4-33. REGULATED POWER SUPPLY.

4-34. A simplified schematic diagram of the power supply is shown in Figure 4-9. The power supply operates from either a 115- or 230-volt, 50 to 400 Hz AC source or from an optional 24 volt, 30 mA rechargeable battery. Three voltages and two current outputs are provided by the power supply. Regulated voltages of -18, +1.3, and -25 VDC operate the power meter circuits. The current outputs are used for maintaining a trickle battery charge for recharging the battery.

4-35. The -18 VDC is regulated by a conventional series regulator, A2Q1 through A2Q5. The unregulated -25 VDC is developed across A2CR1 and A2CR4. The +1.3 VDC is taken across the series diodes, A2CR6 and A2CR7. The -18 VDC supply is adjusted by A2R36.

4-36. POWER SWITCH.

4-37. A simplified schematic diagram of the power switch arrangement is shown in Figure 4-9. The POWER switch has five positions: LINE OFF, LINE ON, BATTERY ON, BATTERY TEST, and BATTERY CHARGE. In the LINE ON position the instrument operates from the conventional line voltage. If a rechargeable battery has been installed, a trickle charge is supplied to the battery. In the BATTERY ON position, instrument operation is dependent on the battery. In the BATTERY CHARGE position, -25 volts is connected to the battery for recharging. In the BATTERY TEST position, battery voltage can be measured on the 0-3 mW scale. Battery voltage is 10 times meter scale reading. Proper charge of the battery is indicated by a reading within the BAT CHARGED region on the bottom of the meter face.

SECTION V
MAINTENANCE

5-1. INTRODUCTION.

5-2. This section provides instructions for performance testing, calibration adjustments, troubleshooting and repairing the 431C Power Meter. Front panel controlled performance tests allow the instrument to be checked for conformance to specifications. If performance is not within specifications, adjustment and troubleshooting instructions are provided.

5-3. Test equipment and accessories required to perform maintenance are listed in Table 5-1. Equipment other than the recommended models can be used provided their performance equals or exceeds the critical specifications.

5-4. MECHANICAL METER ADJUSTMENT. When the meter is properly zero-set, the pointer rests over the zero mark on the meter scale when the instrument is: 1) at normal operating temperature, 2) in its normal operating position, and 3) turned off. Set the pointer as follows to obtain best accuracy and mechanical stability:

a. Turn instrument off.

b. Rotate the meter mechanical adjustment screw clockwise until the meter pointer is to the left of zero and moving up the scale towards zero. Stop when the pointer is exactly over the zero mark. If the pointer overshoots, repeat step b.

c. When the pointer is exactly on zero, rotate the adjustment screw approximately 15 degrees counterclockwise. This frees the adjustment screw from the meter suspension. If the pointer moves during this step, repeat steps b and c.

Table 5-1. Recommended Test Equipment

Instrument Type	Critical Specifications	Recommended Model
Direct Current Power Source	Range: 0.01 to 10 mW Accuracy: ±0.1%	hp 8402B
Electronic Counter	Sensitivity: 4V rms Frequency: 10 kHz Accuracy: ±0.01% or better Resolution: Five digits	hp 5512A
DC Voltmeter	Range: 0.5 to 50 volts DC Accuracy: ±0.05% Input Impedance: 10 Megohms, floating Resolution: Three or more digits	hp 3440A with 3443A plug-in unit
Ohmmeter	Range: 1 ohm to 10 Megohms Accuracy: ±5%	hp 410B/C hp 412A hp 427A
AC Voltmeter	Range: 10 to 100 mV Accuracy: ±5% Input Impedance: 1 Megohm	hp 403A/B hp 427A
Oscilloscope	Bandwidth: 100 kHz Accuracy: ±5% Input Impedance: 1 Megohm Sensitivity: 1 mV/division	hp 140A with 1400A and 1402A plug-in units
Thermistor Mount	Refer to Table 1-2 for recommended thermistor mounts	hp 478A hp 486A Series
Decade Capacitor	Range: 0.0 to 0.01 uF Capacitance per step: 100 pF Accuracy: ±2%	General Radio 1419-B
Audio Oscillator	Frequency: 10 kHz Accuracy: ±2%	hp 200AB hp 200CD

5-5. PERFORMANCE TESTS.

5-6. PURPOSE. The procedures listed in Table 5-2 test power meter performance for incoming inspection, periodic evaluation, calibration and troubleshooting. The tests can be performed without access to the instrument interior. Specifications in Table 1-1 are the performance standards. If the power meter fails to meet any of the performance test specifications, refer to the adjustment procedures. If a circuit malfunction is suspected refer to the troubleshooting paragraphs.

5-7. ADJUSTMENTS.

5-8. GENERAL. The following procedures outline the adjustments necessary to calibrate the power meter. The actual adjustments should be made only when it is determined that the instrument is out of adjustment, and not malfunctioning due to a circuit failure.

5-9. To avoid errors due to possible ground loop currents, isolate the power meter from ground used for other auxiliary equipment. A power plug adapter that removes the ground connection at the line outlet can be used to isolate the power meter.

5-10. Several circuit component parts of the power meter are selected at the factory to meet specific circuit requirements. The factory selected parts are indicated by an asterisk on the schematic diagrams and in the replaceable parts list. Table 5-3 lists the circuit requirements for factory selected parts.

5-11. COVER REMOVAL AND REPLACEMENT.

5-12. The side covers can be removed and replaced independently of the top and bottom covers. Each side cover is held in place by four screws retained by nuts which are fastened to the side frames.

5-13. TOP COVER REMOVAL.

a. At the rear of the instrument, remove the two screws which retain the cover.

Table 5-2. Performance Tests

1. ACCURACY: ±1% of full scale from +20°C to +35°C.

Procedure

a. Connect equipment as shown in Figure 3-9.

b. Set 8402B Calibrator controls as follows:
FUNCTION. . . . . CURRENT OFF
RANGE . . . . .01 mW
MOUNT RESISTANCE to correspond with resistance and type of thermistor mount used.

c. Set 431C Power Meter controls as follows:
CALIB FACTOR 100%
POWER. . . . . ON
RANGE . . . . .01 mW
MOUNT RES to correspond with resistance and type of thermistor mount used.

d. Null and zero-set the power meter (refer to Turn-On and Nulling Procedure, Figure 3-8).

e. Set 8402B FUNCTION switch to CALIBRATE. Successively set RANGE (mW) switch on calibrator and RANGE switch on power meter to identical range values starting with the counterclockwise position of .01 mW. The power meter should read the power set on the calibrator within ±1% of full scale.

f. Set RANGE (mW) switch on calibrator and RANGE switch on power meter to 10 mW.

g. If necessary, adjust ZERO and VERNIER controls on power meter to obtain an exact 10 mW reading.

h. Successively set RANGE (mW) switch on calibrator to 8, 6, 4, and 2 mW positions while observing power meter reading. The power meter should read the power set on the calibrator within ±1% of full scale.

2. ZERO CARRYOVER: Less than +0.5% of full scale when zeroed on most sensitive range.

Procedure

a. Connect hp 3440A DC Voltmeter to DVM output jack on rear of 431C Power Meter (refer to Paragraph 3-49).

b. Set power meter controls as follows:
POWER. . . . . ON
RANGE . . . . .01 mW
CALIB FACTOR 100%
MOUNT RES to correspond with resistance and type of thermistor mount used.

c. Adjust ZERO for 0.000 VDC reading on 10 volt range of DC voltmeter.

d. Rotate power meter RANGE switch clockwise through remaining ranges. Reading on DC voltmeter should remain within 0.000 ±.005 VDC on each range.

3. VOLTMETER OUTPUT: 1.000 VDC ±0.3% into 500 k ohm or greater load at full scale meter deflection.

Procedure

a. Perform steps a through d of ACCURACY performance test.

b. Set 8402B FUNCTION switch to CALIBRATE. Reading on DC voltmeter should be 0.997 to 1.003 VDC, and correspond with full scale meter reading of power meter.

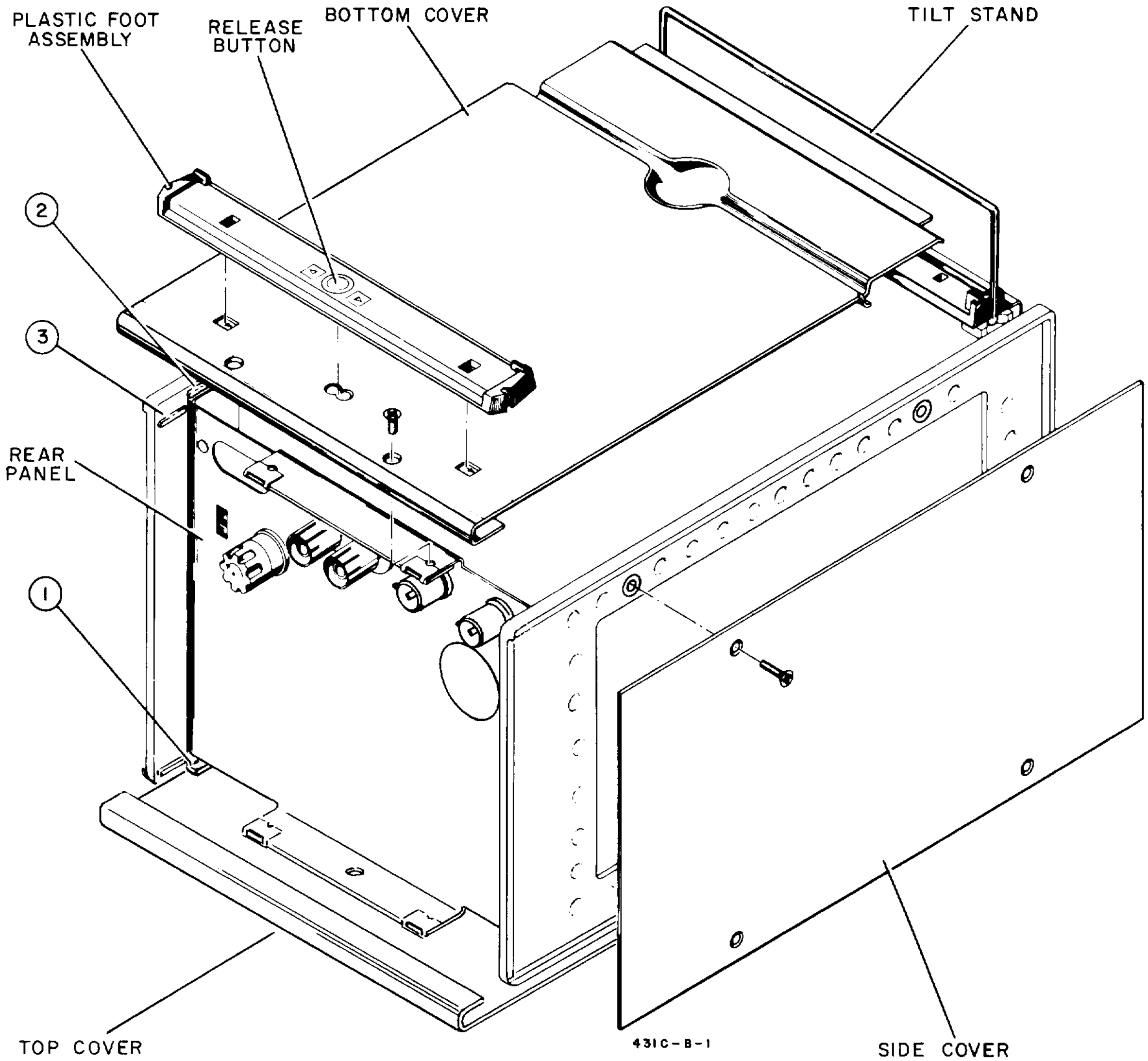


Figure 5-1. Cover Removal

b. Grasp the cover from the rear, slide it back 1/2 inch, then tilt forward edge of the cover upward and lift the cover from the instrument.

5-14. TOP COVER REPLACEMENT.

a. Rest the cover flat on the cast guides projecting inward near the top of each side frame (see ①, Figure 5-1).

b. Slide the cover forward allowing its forward edge to enter the groove in the front panel.

c. Replace the two cover retaining screws.

5-15. BOTTOM COVER REMOVAL.

a. Set the tilt stand as shown in Figure 5-1.

b. Remove the two retaining screws at the rear of the cover.

c. Slide the cover rearward far enough to free its forward edge from the front foot assembly.

d. Tilt the forward edge of the cover upward and lift the cover from the instrument.

5-16. BOTTOM COVER REPLACEMENT.

a. Set the tilt stand as shown in Figure 5-1.

b. Rest the bottom cover flat on the cast guides projecting inward near the bottom of each side frame (see ②, Figure 5-1).

c. Slide the cover forward on the guides so that the formed portion at the rear of the cover slides over the two short projections at the rear corner of each side frame (see ③, Figure 5-1).

d. Replace the two retaining screws and the rear foot assembly.

Table 5-3. Circuit Requirements for Factory Selected Parts

Part Ref. Desig.	Circuit Requirements
R25	Full scale deflection of meter M1 when 1 mA of DC flows through the combination of the meter and R25.
A1R7	Balance of RF detection bridge when using a 100 ohm thermistor mount with no microwave power applied.
A1R9	Balance of RF detection bridge when using a 200 ohm thermistor mount with no microwave power applied.
A1C1	NULL capacitor, C1, set near midrange for null when using a 200 ohm thermistor mount. Refer to Paragraph 5-20.
A1C2	NULL capacitor, C1, set near midrange for null when using a 100 ohm thermistor mount. Refer to Paragraph 5-20.
A1C3	10 kHz oscillation of oscillator amplifier, A1Q4-Q7, when using a 100 ohm thermistor mount. Refer to Paragraph 5-22.
A1C22	Frequency of 10 kHz for A1T5/A1C15 tuned circuit combination. Refer to Paragraph 5-21.

5-17. POWER SUPPLY ADJUSTMENT.

Procedure

Note

An adjustment of the power supply voltage may require a readjustment of the full scale accuracy potentiometers (refer to Paragraph 5-18).

a. Connect a DC voltmeter between pin W, XA2 and ground.

b. Adjust A2R36 for -18.00 ±0.02 VDC.

5-18. FULL SCALE ACCURACY ADJUSTMENTS.

Procedure.

a. Connect equipment as shown in Figure 3-9.

b. Set 8402B Calibrator controls as follows:

FUNCTION. . . . . CURRENT OFF
MOUNT RESISTANCE to correspond with resistance and type of thermistor mount used.

c. Set 431C Power Meter as follows:

POWER . . . . ON
CALIB FACTOR 100%
MOUNT RES to correspond with resistance and type of thermistor mount used.

d. Null and zero-set the power meter (refer to Turn On and Nulling Procedure, Figure 3-8).

e. 200 OHM THERMISTOR MOUNT. Set calibrator and power meter controls and make corresponding adjustment as listed below.

Range (mW)	8402B Calibrator	431C Power Meter	
	Function	Adjust	Reading
.01	CURRENT OFF	ZERO	0.0
.01	CALIBRATE	A2R14	.01 mW
.03	CURRENT OFF	ZERO	0.0
.03	CALIBRATE	A2R13	.03 mW
.1	CURRENT OFF	ZERO	0.0
.1	CALIBRATE	A2R12	.1 mW
.3	CURRENT OFF	ZERO	0.0
.3	CALIBRATE	A2R11	.3 mW
1	CURRENT OFF	ZERO	0.0
1	CALIBRATE	A2R10	1.0 mW
3	CURRENT OFF	ZERO	0.0
3	CALIBRATE	A2R9	3.0 mW
10	CURRENT OFF	ZERO	0.0
10	CALIBRATE	A2R8	10.0 mW

f. 100 OHM THERMISTOR MOUNT. Set calibrator and power meter controls and made corresponding adjustments as listed below.

Range (mW)	8402B Calibrator	431C Power Meter	
	Function	Adjust	Reading
.01	CURRENT OFF	ZERO	0.0
.01	CALIBRATE	A2R1	.01 mW
.03	CURRENT OFF	ZERO	0.0
.03	CALIBRATE	A2R2	.03 mW
.1	CURRENT OFF	ZERO	0.0
.1	CALIBRATE	A2R3	.1 mW
.3	CURRENT OFF	ZERO	0.0
.3	CALIBRATE	A2R4	.3 mW
1	CURRENT OFF	ZERO	0.0
1	CALIBRATE	A2R5	1.0 mW
3	CURRENT OFF	ZERO	0.0
3	CALIBRATE	A2R6	3.0 mW
10	CURRENT OFF	ZERO	0.0
10	CALIBRATE	A2R7	10.0 mW

5-19. ZERO AND VERNIER CONTROL ADJUSTMENT.

Procedure

a. Perform steps a through c of ZERO CARRY-OVER performance test, Table 5-2.

b. Rotate 431C Power Meter RANGE switch clockwise through remaining ranges. Adjust A1R37 to hold DC voltmeter reading within 0.000 ±0.005 VDC on each range.

5-20. COARSE NULL ADJUSTMENT.

Procedure

100 OHM THERMISTOR MOUNT

a. Connect 100 ohm thermistor mount to power meter.

b. Connect oscilloscope or ACvoltmeter from A1R55 to ground.

c. Set power meter controls as follows:

POWER	ON
RANGE	.01 mW
CALIB FACTOR	100%
MOUNT RES	100Ω

d. Adjust ZERO control for an on-scale meter reading.

e. Mechanically center NULL capacitor, C1.

f. Adjust A1L1 for a voltage null at A1R55. Fine adjust NULL capacitor C1 for less than 1.5 volts peak to peak.

g. Set power meter RANGE switch to NULL, and fine adjust NULL capacitor C1 for a zero power meter reading. C1 should remain near mechanical center of range ±10°.

h. Rotate power meter RANGE switch clockwise through remaining ranges. Voltage null at A1R55 should remain less than 1.5 volts peak to peak.

200 OHM THERMISTOR MOUNT

i. Connect 200 ohm thermistor mount to power meter.

j. Connect oscilloscope or AC voltmeter from A1R55 to ground.

k. Set power meter controls as follows:

POWER	ON
RANGE	.01 mW
CALIB FACTOR	100%
MOUNT RES	200Ω

m. Adjust ZERO control for an on-scale meter reading.

n. Mechanically center NULL capacitor C1.

o. Select capacitor A1C1 (refer to Table 5-3) for a voltage null at A1R55. Fine adjust NULL capacitor C1 for less than 1.5 volts peak to peak.

p. Set power meter RANGE switch to NULL, and fine adjust NULL capacitor C1 for a zero power meter reading. C1 should remain near mechanical center of range ±45°.

Note

If a null cannot be obtained, do not select A1C1 for a value greater than 1000 pF. Increase A1C2 in 50 pF steps, and repeat steps d through g until limits are met.

5-21. OSCILLATOR TANK CIRCUIT TUNING.

Procedure

a. Connect 100 or 200 ohm thermistor mount to power meter.

b. Set power meter MOUNT RES switch to correspond to resistance and type of thermistor mount used.

c. Disconnect negative side of capacitor A1C18 from power meter assembly board A1.

d. Connect 200CD Oscillator output and electronic counter input between negative lead of capacitor A1C18 and ground.

e. Connect oscilloscope probe between point of circuit from which A1C18 was disconnected and ground.

f. Set vertical sensitivity of oscilloscope to 0.2V/division.

g. Adjust 200CD Oscillator amplitude to obtain a sine wave display on the oscilloscope.

h. Using a decade capacitance, select a value for A1C22 that causes a peak display on the oscilloscope at a frequency of 10.00 ±0.02 kHz. Range of A1C22: 300 pF to 6000 pF.

i. Install selected value of A1C22 and reconnect negative lead of A1C18 to assembly board A1.

5-22. OSCILLATOR FREQUENCY ADJUSTMENT.

Procedure

a. Connect 100 or 200 ohm thermistor mount to power meter.

Note

Oscillator frequency will vary approximately ±0.1 kHz depending on thermistor mount terminating impedance. For the following adjustments, terminate the thermistor mount with a standard 50 ohm termination. Balanced and waveguide mounts do not require termination.

b. Set power meter controls as follows:

POWER	ON
CALIB FACTOR	100%

MOUNT RES to correspond to resistance and type of thermistor mount used.

c. Connect an electronic counter between the positive side of capacitor A1C18 and ground.

d. Perform the following adjustment that corresponds to the resistance and type of thermistor mount connected to power meter.

(1) 100 OHM THERMISTOR MOUNT. Use a decade capacitance to select a value for A1C3 (1000 pF maximum) that causes an oscillation frequency of 10.00 ±0.05 kHz. Install selected value of A1C3.

(2) 200 OHM THERMISTOR MOUNT. Adjust A1L2 for an oscillation frequency of 10.00 ±0.01 kHz.

5-23. TROUBLESHOOTING.

5-24. Check the fuse to ensure that it is not open. Make a thorough visual inspection for burned out or loose components, loose connections, contaminated switch contacts or any condition that may suggest a source of trouble.

5-25. The first step in troubleshooting the 431C is to isolate the trouble to either the thermistor mount and thermistor-mount cable combination or the power meter. The operating note furnished with hp thermistor mounts gives a procedure to check the thermistor mount. This procedure will indicate any deficient performance of the mount. An ohmmeter continuity check can be used to determine if the thermistor mount cable or cable connectors are defective.

5-26. TROUBLE ISOLATION. Circuits in the 431C can be divided into five basic functional units as follows: 1) RF detection bridge and 10 kHz oscillator-amplifier (A1Q4-A1Q7), 2) compensation and metering bridge, 10 kHz amplifier (A1Q1-A1Q3) and synchronous detector, 3) differential amplifier (A1Q8-A1Q9) and feedback current generator (A1Q10), 4) feedback current-squared generator (A1Q11) and metering circuits, and 5) power supply.

5-27. The procedure in Table 5-4 allows front panel controls and indications to be used to isolate failures to particular basic functional circuits. The procedure is limited by the extensive use of feedback loops and interdependence of circuit operation.

5-28. The following assumptions are made throughout the front panel trouble isolation procedure: 1) the thermistor mount and thermistor-mount cable combination is working properly, 2) transformers in the detection

Table 5-4. Front Panel Trouble Isolation

Step	Instructions	Indication	Action or Trouble Circuit
1.	a. Connect thermistor mount b. Set RANGE to .01 mW c. Set POWER to ON d. Adjust ZERO for zero meter reading, if possible e. Rotate RANGE from .01 through 10 mW	No meter reading	Proceed with step 2
		Meter reads below low scale limit or meter reads above high scale limit	Proceed with step 3
2.	a. Set RANGE to 10 mW b. Apply RF power to thermistor mount c. Decrease RANGE from 10 mW until reading is obtained	No meter reading	Proceed with step 3
		Any meter reading	a. Perform ACCURACY performance test, Figure 5-2. Particular range inaccuracy: check first for improper range resistance selected by RANGE switch (A1S2). All range inaccuracy: 10 kHz amplifier (A1Q1-A1Q3) and feedback current generator (A1Q10) combination or power supply. b. Proceed with step 3.
3.	a. Remove RF power from thermistor mount b. Set RANGE to NULL c. Adjust NULL screwdriver adjustment	Meter reading that changes with NULL adjustment	Proceed with step 4
		Meter reading that does not change with NULL adjustment	Compensation and metering bridge, 10 kHz amplifier (A1Q1-A1Q3) and synchronous detector combination
		No meter reading	RF detection bridge, and 10 kHz oscillator-amplifier (A1Q4-A1Q7) combination
			Power supply
4.	a. Set RANGE to .01 mW b. Adjust ZERO for zero meter reading c. Rotate RANGE from .01 through 10 mW	Zero	Feedback current-squared generator (A1Q11) and metering circuits
		No zero	Differential amplifier (A1Q8-A1Q9) and feedback current generator (A1Q10) combination
		Zero does not carry-over within specifications	Differential amplifier (A1Q8-A1Q9) and feedback current-squared generator (A1Q11) combination

bridge, metering bridge and synchronous detector have not failed, and 3) only one basic functional circuit has failed.

5-29. Front panel trouble isolation is intended only to suggest the most probable functional circuit failure and to give a general direction in which to look before starting a detailed troubleshooting procedure.

5-30. It is important that the procedures listed in Table 5-4 be performed in the order listed. Each step forms the basis on which the indications of a subsequent step are analyzed.

5-31. DETAILED TROUBLESHOOTING. To assist detailed troubleshooting, normal-operation waveforms are given in Figures 7-3 and 7-8. Locations of test points and components are given in Figures 7-2, 7-4, and 7-6. In addition, normal-operation voltages relative to chassis ground are provided on the schematic diagrams for the collector, base and emitter of every transistor in the instrument. Waveforms and voltage measurements were made with a thermistor mount connected, and the instrument nulled, according to instructions given in Figure 3-8. The first detailed troubleshooting checks should be performed in the following order: 1) check for power supply output voltages of +1.3, -18, and -25 VDC, 2) check at test point 6 to ensure that the 10 kHz oscillator - amplifier, A1Q4-A1Q7, has the proper output waveform, 3) check at test point 2 for correct output of the 10 kHz amplifier, A1Q1-A1Q3. For signal tracing through the amplifier stages, capacitor A1C10 can be disconnected from A1L1 and used as a means to inject a 10 kHz test signal to the input of the first 10 kHz amplifier, A1Q1.

5-32. COMPONENT TROUBLE ISOLATION. The following procedures and data are given to aid in determining whether a transistor is operational. Tests are given for both in-circuit and out-of-circuit transistors and should be useful in determining whether a particular functional circuit trouble is due to a faulty transistor or an associated component.

5-33. IN-CIRCUIT TESTING. The common causes of transistor failures are internal short- and open-circuits. In transistor circuit testing the most important consideration is the transistor base-emitter junction. Like the control grid of a vacuum tube, this is the operational control point in the transistor. This junction is essentially a solid-state diode. For the transistor to conduct, the diode must conduct; that is, the diode must be forward biased. As with simple diodes, the forward bias polarity is determined by the materials forming the junction. Use the transistor symbol on the schematic diagram to determine the bias polarity required to forward-bias the base-emitter junction. The A part of Figure 5-2 shows transistor symbols with terminals labeled. The emitter arrow points toward the type N material. The other two columns of the illustration compare the biasing required to cause conduction and cut-off in transistors and vacuum tubes. If the transistor base-emitter diode (junction) is forward-biased, the transistor conducts. If the diode is heavily forward-biased, the transistor saturates. However, if the base-emitter diode is reverse biased, the transistor is cut off (no conduction). The voltage drop across a forward-biased emitter-base diode varies with transistor collector current. For example, a germanium transistor has a typical forward bias, base-emitter voltage of 0.2 - 0.3 volts when collector current is 1 - 10 mA, and 0.4 - 0.5 volts when collector current is 10 - 100 mA. In contrast, forward-bias voltage for silicon transistors is about twice that for germanium types: about 0.5 - 0.6 volts when collector current is low, and about 0.8 - 0.9 volts when collector current is high.

5-34. Figure 5-2, part B, shows simplified versions of the three basic transistor circuits and gives the operating characteristics of each. When examining a transistor stage, first determine if the emitter-base diode is biased for conduction (forward-biased) by measuring the voltage difference between emitter and base. When using an electronic voltmeter, do not measure directly between emitter and base since there may be sufficient loop current between the voltmeter leads to damage the transistor. Instead, measure each voltage separately with respect to a voltage common point (e.g., chassis). If the emitter-base diode is forward biased, check for amplifier action by shorting base to emitter while observing collector voltage. The short circuit eliminates base-emitter bias and should cause the transistor to stop conducting (cut off). Collector voltage should then shift to near the supply voltage. Any difference is due to leakage current through the transistor and, in general, the smaller this current, the better the transistor. If collector voltage does not change the transistor has either an emitter-collector short circuit or emitter-base open circuit.

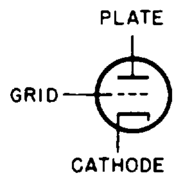
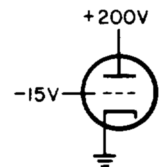
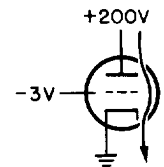
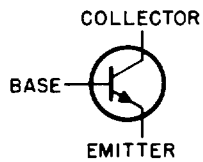
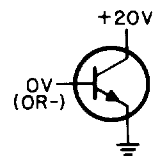
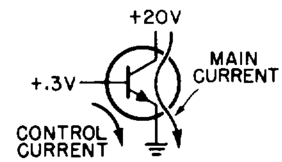
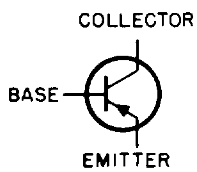
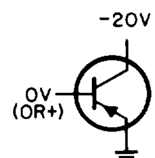
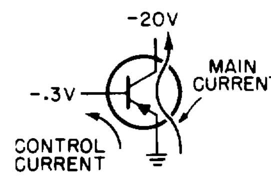
5-35. OUT-OF-CIRCUIT TESTING. Remove the transistor from the circuit and use an ohmmeter to measure internal resistance. Refer to Table 5-5 for measurement data.

Table 5-5. Out-of-Circuit Transistor Resistance Measurements

Transistor Type		Connect Ohmmeter		Measure Resistance (ohms)
		Pos. lead to	Neg. lead to	
PNP Germanium	Small Signal	emitter	base*	200-500
		emitter	collector	10k-100k
	Power	emitter	base*	30 - 50
		emitter	collector	several hundred
NPN Silicon	Small Signal	base	emitter	1 k - 3 k
		collector	emitter	very high (might read open)
	Power	base	emitter	200-1000
		collector	emitter	high, often greater than 1M

*To test for transistor action, add collector-base short. Measured resistance should decrease.

A. TRANSISTOR BIASING

DEVICE	SYMBOL	CUT OFF	CONDUCTING
VACUUM TUBE			
N P N TRANSISTOR			
P N P TRANSISTOR			

B. AMPLIFIER CHARACTERISTICS

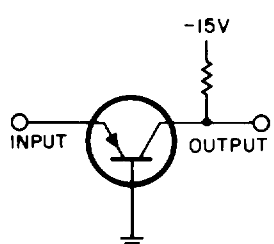
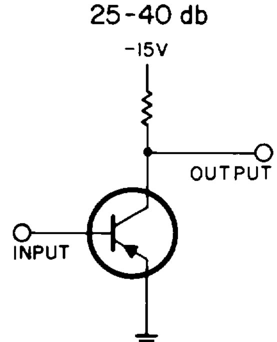
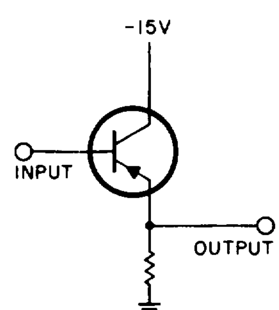
CHARACTERISTIC	COMMON BASE	COMMON EMITTER	COMMON COLLECTOR
INPUT Z	30-50 Ω	500-1500 Ω	20-500K Ω
OUTPUT Z	300-500K Ω	30-50K Ω	50-1000 Ω
VOLTAGE GAIN	500-1500	300-1000	< 1
CURRENT GAIN	< 1	25-50	25-50
POWER GAIN	20-30 db	25-40 db	10-20 db
			

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Figure 5-2. Transistor Biasing and Operating Characteristics

CAUTION

Most ohmmeters can supply enough current or voltage to damage a transistor. Before using an ohmmeter to measure transistor forward or reverse resistance, check its open-circuit voltage and short-circuit current output ON THE RANGE TO BE USED. Open-circuit voltage must not exceed 1.5 volts and short-circuit current must be less than 3 mA.

Table 5-6. Safe Ohmmeter Range for Transistor Resistance Measurements

Ohmmeter	Safe Range(s)	Open Ckt Voltage	Short Ckt Current	Lead	
				Color	Polarity
hp 412A hp 427A	R x 1 k R x 10 k R x 100 k R x 1M R x 10M	1.0V 1.0V 1.0V 1.0V 1.0V	1 mA 100 μA 10 μA 1 μA 0.1 μA	Red Blk	+ -
hp 410C	R x 1 k R x 10 k R x 100 k R x 1M R x 10M	1.3V 1.3V 1.3V 1.3V 1.3V	0.57 mA 57 μA 5.7 μA 0.5 μA 0.05 μA	Red Blk	+ -
hp 410B	R x 100 R x 1 k R x 10 k R x 100 k R x 1M	1.1V 1.1V 1.1V 1.1V 1.1V	1.1 mA 110 μA 11 μA 1.1 μA 0.11 μA	Blk Red	+ -
Simpson 260	R x 100	1.5V	1 mA	Red Blk	+ -
Simpson 269	R x 1 k	1.5V	0.82 mA	Blk Red	+ -
Triplett 630	R x 100 R x 1 k	1.5V 1.5V	3.25 mA 325 μA	Varies with Serial Number	
Triplett 310	R x 10 R x 100	1.5V 1.5V	750 μA 75 μA		

SECTION VI
REPLACEABLE PARTS

6-1. INTRODUCTION.

6-2. This section contains information for ordering replacement parts. Table 6-1 lists parts in alpha-numerical order of their reference designators and indicates the description and hp stock number of each part, together with any applicable notes. Miscellaneous parts are listed at the end of Table 6-1. Table 6-2 lists parts in alpha-numerical order of their hp stock number and provides the following information on each part:

a. Description.

b. Manufacturer of the part in a five-digit code; see list of manufacturers in Table 6-3.

c. Manufacturer's part number.

d. Total quantity used (TQ column).

6-3. ORDERING INFORMATION.

6-4. To obtain replacement parts, address order or inquiry to your local Hewlett-Packard Field Office (see list at rear of this manual for addresses). Identify parts by their Hewlett-Packard stock numbers.

6-5. To obtain a part that is not listed, include:

a. Instrument model number.

b. Instrument serial number.

c. Description of the part.

d. Function and location of the part.

REFERENCE DESIGNATORS

A = assembly
B = motor
BT = battery
C = capacitor
CP = coupler
CR = diode
DL = delay line
DS = device signaling (lamp)
E = misc electronic part
F = fuse
FL = filter
J = jack
K = relay
L = inductor
M = meter
MP = mechanical part
P = plug
Q = transistor
R = resistor
RT = thermistor
S = switch
T = transformer
TB = terminal board
TP = test point
V = vacuum, tube, neon bulb, photocell, etc.
W = cable
X = socket
Y = crystal

ABBREVIATIONS

A = amperes
A. F. C. = automatic frequency control
AMPL = amplifier

B. F. O. = beat frequency oscillator
BE CU = beryllium copper
BH = binder head
BP = bandpass
BRS = brass
BWO = backward wave oscillator

CCW = counter-clockwise
CER = ceramic
CMO = cabinet mount only
COEF = coefficient
COM = common
COMP = composition
CONN = connector
CP = cadmium plate
CRT = cathode-ray tube
CW = clockwise

DEPC = deposited carbon
DR = drive

ELECT = electrolytic
ENCAP = encapsulated
EXT = external

F = farads
FH = flat head
FIL H = fillister head
FXD = fixed

GE = germanium
GL = glass
GRD = ground(ed)

H = henries
HEX = hexagonal
HG = mercury
HR = hour(s)

IF = intermediate freq
IMPG = impregnated
INCD = incandescent
INCL = include(s)
INS = insulation(ed)
INT = internal

K = kilo = 1000

LIN = linear taper
LK WASH = lock washer
LOG = logarithmic taper
LPF = low pass filter

M = milli = 10^{-3}
MEG = meg = 10^{6}
MET FLM = metal film
MET OX = metallic oxide
MFR = manufacturer
MINAT = miniature
MOM = momentary
MTG = mounting
MY = "mylar"

N = nano (10^{-9})

N/C = normally closed
NE = neon
NI PL = nickel plate
N/O = normally open
NPO = negative positive zero (zero temperature coefficient)
NRFR = not recommended for field replacement
NSR = not separately replaceable

OBD = order by description
OH = oval head
OX = oxide

P = peak
PC = printed circuit
PF = picofarads = 10^{-12} farads
PH BRZ = phosphor bronze
PHL = Phillips
PIV = peak inverse voltage
P/O = part of
POLY = polystyrene
PORC = porcelain
POS = position(s)
POT = potentiometer
PP = peak-to-peak
PT = point
PWV = peak working voltage
RECT = rectifier
RF = radio frequency
RH = round head

RMO = rack mount only
RMS = root-mean square
RWV = reverse working voltage
S-B = slow-blow
SCR = screw
SE = selenium
SECT = section(s)
SEMICON = semiconductor
SI = silicon
SIL = silver
SL = slide
SPL = special
SST = stainless steel
SR = split ring
STL = steel

TA = tantalum
TD = time delay
TGL = toggle
TI = titanium
TOL = tolerance
TRIM = trimmer
TWT = traveling wave tube

U = micro = 10^{-6}

VAR = variable
VDCW = dc working volts

W/ = with
W = watts
WIV = working inverse voltage
WW = wirewound
W/O = without

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Table 6-1. Reference Designation Index

Reference Designation	ⓗ Stock No.	Description #	Note
A1	00431-6001	BOARD ASSEMBLY, AMPLIFIER	
A1C1	0140-0198	C:FXD MICA 200PF 5% 300VDCW FACTORY SELECTED PART: TYPICAL VALUE GIVEN	
A1C2	0160-2201	C:FXD MICA 51 PF 5% FACTORY SELECTED PART: TYPICAL VALUE GIVEN	
A1C3	0140-0198	C:FXD MICA 200PF 5% 300VDCW FACTORY SELECTED PART: TYPICAL VALUE GIVEN	
A1C4	0160-0185	C:FXD MICA 2100PF 1% 300VDCW	
A1C5	0160-0185	C:FXD MICA 2100PF 1% 300VDCW	
A1C6	0180-0116	C:FXD ELECT TA 6.8 UF 10% 35VDCW	
A1C7	0180-0116	C:FXD ELECT TA 6.8 UF 10% 35VDCW	
A1C8	0180-0106	C:FXD ELECT TA 60UF 20% 6VDCW	
A1C9	0170-0069	C:FXD POLY 0.1UF 2% 50VDCW	
A1C10	0160-0174	C:FXD CER 0.47UF +80-20% 25VDCW	
A1C11	0160-0174	C:FXD CER 0.47UF +80-20% 25VDCW	
A1C12	0170-0069	C:FXD POLY 0.1UF 2% 50VDCW	
A1C13	0180-0116	C:FXD ELECT TA 6.8 UF 10% 35VDCW	
A1C14	0180-0116	C:FXD ELECT TA 6.8 UF 10% 35VDCW	
A1C15	0170-0069	C:FXD POLY 0.1UF 2% 50VDCW	
A1C16	0180-0116	C:FXD ELECT TA 6.8 UF 10% 35VDCW	
A1C17	0180-0116	C:FXD ELECT TA 6.8 UF 10% 35VDCW	
A1C18	0180-0049	C:FXD AL ELECT 20UF 50VDCW	
A1C19	0180-0045	C:FXD ELECT 20UF 25VDCW	
A1C20	0180-0045	C:FXD ELECT 20UF 25VDCW	
A1C21	0160-0174	C:FXD CER 0.47UF +80-20% 25VDCW	
A1C22	0140-0159	C:FXD MICA 3000PF 300VDCW FACTORY SELECTED PART: TYPICAL VALUE GIVEN	
A1CR1	1901-0025	DIODE,JUNCTION:5MA AT 1V 100 PIV	
A1CR2	1910-0016	DIODE:GERMANIUM 100MA AT 0.85V 60PIV	
A1CR3	1910-0016	DIODE:GERMANIUM 100MA AT 0.85V 60PIV	
A1CR4	1910-0016	DIODE:GERMANIUM 100MA AT 0.85V 60PIV	
A1CR5	1910-0016	DIODE:GERMANIUM 100MA AT 0.85V 60PIV	
A1CR6	1901-0450	DIODE:SILICON	
A1CR7	1901-0025	DIODE,JUNCTION:5MA AT 1V 100 PIV	
A1CR8	1901-0025	DIODE,JUNCTION:5MA AT 1V 100 PIV	
A1CR9	1901-0450	DIODE:SILICON	
A1CR10	1901-0450	DIODE:SILICON	
A1CR11	1901-0450	DIODE:SILICON	
A1CR12	1901-0450	DIODE:SILICON	
A1CR13	1901-0450	DIODE:SILICON	
A1CR14	1901-0450	DIODE:SILICON	
A1CR15	1901-0450	DIODE:SILICON	
A1L1	9140-0122	COIL:VAR 2X 9-20 UHY EACH	
A1L2	9140-0122	COIL:VAR 2X 9-20 UHY EACH	
A1L3	9110-0040	INDUCTOR:AUDIO	
A1L4	9110-0040	INDUCTOR:AUDIO	
A1Q1	1853-0020	TRANSISTOR:SILICON PNP	
A1Q2	1854-0071	TRANSISTOR:SILICON NPN 2N3391	
A1Q3	1853-0020	TRANSISTOR:SILICON PNP	
A1Q4	1854-0071	TRANSISTOR:SILICON NPN 2N3391	

See list of abbreviations in introduction to this section

Table 6-1. Reference Designation Index (Cont'd)

Reference Designation	ⓗ Stock No.	Description #	Note
A1Q5	1853-0020	TRANSISTOR:SILICON PNP	
A1Q6	1854-0071	TRANSISTOR:SILICON NPN 2N3391	
A1Q7	1853-0020	TRANSISTOR:SILICON PNP	
A1Q8	1853-0020	TRANSISTOR:SILICON PNP	
A1Q9	1853-0020	TRANSISTOR:SILICON PNP	
A1Q10	1854-0071	TRANSISTOR:SILICON NPN 2N3391	
A1Q11	1854-0071	TRANSISTOR:SILICON NPN 2N3391	
A1R1	0811-0066	R:FXD WW 887 OHM 1% 8/100W	
A1R2	0811-0065	R:FXD WW 511 OHM 1.0% 1/20W	
A1R3	0811-0065	R:FXD WW 511 OHM 1.0% 1/20W	
A1R4	0757-0199	R:FXD MET FLM 21.5K OHM 1% 1/8W	
A1R5	0811-1571	R:FXD WW 189 OHM 0.1% 1/8W	
A1R6	0811-1572	R:FXD WW 255 OHM 0.1% 1/8W	
A1R7	0757-0460	R:FXD MET FLM 61.9K OHM 1% 1/8W FACTORY SELECTED PART, TYPICAL VALUE GIVEN	
A1R8	0811-1645	R:FXD WW 202.1 OHM 0.1% 1/8W	
A1R9	0757-0123	R:FXD MET FLM 34.8K OHM 1% 1/10W FACTORY SELECTED PART, TYPICAL VALUE GIVEN	
A1R10	0811-1566	R:FXD WW 200 OHM 0.1% 1/8W	
A1R11	0757-0417	R:FXD MET FLM 562 OHM 1% 1/8W	
A1R12	0757-1094	R:FXD MET FLM 1.47K OHM 1% 1/8W	
A1R13	0757-0279	R:FXD MET FLM 3.16K OHM 1% 1/8W	
A1R14	0698-0085	R:FXD MET FLM 2.61K OHM 1% 1/8W	
A1R15	0757-0440	R:FXD MET FLM 7.50K OHM 1% 1/8W	
A1R16	0757-0279	R:FXD MET FLM 3.16K OHM 1% 1/8W	
A1R17	0757-0280	R:FXD MET FLM 1.00K OHM 1% 1/8W	
A1R18	0757-0440	R:FXD MET FLM 7.50K OHM 1% 1/8W	
A1R19	0698-3156	R:FXD MET FLM 14.7K OHM 1% 1/8W	
A1R20	0698-3157	R:FXD MET FLM 19.6K OHM 1% 1/8W	
A1R21	0698-3157	R:FXD MET FLM 19.6K OHM 1% 1/8W	
A1R22	0757-0279	R:FXD MET FLM 3.16K OHM 1% 1/8W	
A1R23	0698-3438	R:FXD MET FLM 147 OHM 1% 1/8W	
A1R24	0757-0465	R:FXD MET FLM 100K OHM 1% 1/8W	
A1R25	0698-3452	R:FXD MET FLM 147K OHM 1% 1/8W	
A1R26	0698-3440	R:FXD MET FLM 196 OHM 1% 1/8W	
A1R27	0757-0442	R:FXD MET FLM 10.0K OHM 1% 1/8W	
A1R28	0698-3160	R:FXD MET FLM 31.6K 1% 1/8W	
A1R29	0757-0199	R:FXD MET FLM 21.5K OHM 1% 1/8W	
A1R30	0757-0442	R:FXD MET FLM 10.0K OHM 1% 1/8W	
A1R31	0757-0280	R:FXD MET FLM 1.00K OHM 1% 1/8W	
A1R32	0757-0280	R:FXD MET FLM 1.00K OHM 1% 1/8W	
A1R33	0757-0280	R:FXD MET FLM 1.00K OHM 1% 1/8W	
A1R34	0757-0280	R:FXD MET FLM 1.00K OHM 1% 1/8W	
A1R35	0698-0084	R:FXD MET FLM 2150 OHM 1% 1/8W	
A1R36	0698-3450	R:FXD MET FLM 42.2K OHM 1% 1/8W	
A1R37	2100-0144	R:VAR COMP 250K OHM 30% LIN 1/5W	
A1R38	0698-3447	R:FXD MET FLM 422 OHM 1% 1/8W	
A1R39	0757-0417	R:FXD MET FLM 562 OHM 1% 1/8W	
A1R40	0757-0274	R:FXD MET FLM 1.21K OHM 1% 1/8W	
A1R41	0698-3449	R:FXD MET FLM 28.7K OHM 1% 1/8W	

See list of abbreviations in introduction to this section

Table 6-1. Reference Designation Index (Cont'd)

Reference Designation	ⓗ Stock No.	Description #	Note
A1R42	0698-4028	R:FXD MET FLM 48.64K OHM 1/2% 1/8W	
A1R43	0698-4029	R:FXD MET FLM 53.39K OHM 1/2% 1/8W	
A1R44	0698-4027	R:FXD MET FLM 64.45K OHM 1/2% 1/8W	
A1R45	0698-4026	R:FXD MET FLM 89.90K OHM 1/2% 1/8W	
A1R46	0698-4025	R:FXD MET FLM 128.5K OHM 1/2% 1/8W	
A1R47	0698-4024	R:FXD MET FLM 259.6K OHM 1/2% 1/8W	
A1R48	0698-4023	R:FXD MET FLM 130.4K OHM 1/2% 1/8W	
A1R49	0698-4034	R:FXD MET FLM 84.32K OHM 1/2% 1/8W	
A1R50	0698-4033	R:FXD MET FLM 62.26K OHM 1/2% 1/8W	
A1R51	0698-4032	R:FXD MET FLM 51.22K OHM 1/2% 1/8W	
A1R52	0698-4031	R:FXD MET FLM 43.25K OHM 1/2% 1/8W	
A1R53	0698-4030	R:FXD MET FLM 40.77K OHM 1/2% 1/8W	
A1R54	0698-4028	R:FXD MET FLM 48.64K OHM 1/2% 1/8W	
A1R55	0757-1094	R:FXD MET FLM 1.47K OHM 1% 1/8W	
A1R56	0698-3449	R:FXD MET FLM 28.7K OHM 1% 1/8W	
A1T1	9120-0066	TRANSFORMER:AUDIO	
A1T2	9120-0066	TRANSFORMER:AUDIO	
A1T3	9120-0065	TRANSFORMER:AUDIO	
A1T4	9120-0065	TRANSFORMER:AUDIO	
A1T5	9100-1677	TRANSFORMER:INPUT	
A2	00431-6009	BOARD ASSY., POWER SUPPLY	
A2C1	0180-0138	C:FXD ELECT 100UF -10+100% 40VDCW	
A2C2	0180-0049	C:FXD AL ELECT 20UF 50VDCW	
A2C3	0150-0093	C:FXD CER 0.01UF +80-20% 100VDCW	
A2C4	0150-0012	C:FXD CER 0.01 UF 20% 1000VDCW	
A2C5	0160-0174	C:FXD CER 0.47UF +80-20% 25VDCW	
A2C6	0180-0059	C:FXD ELECT 10UF -10%+100% 25VDCW	
A2C7	0180-0105	C:FXD ELECT SEMI-POLARIZED 50UF 25VDCW	
A2C8	0150-0096	C:FXD CER 0.05UF 100VDCW	
A2C9	0180-0060	C:FXD ELECT 200UF -10%+100% 3VDCW	
A2CR1	1901-0025	DIODE,JUNCTION:5MA AT 1V 100 PIV	
A2CR2	1901-0025	DIODE,JUNCTION:5MA AT 1V 100 PIV	
A2CR3	1901-0025	DIODE,JUNCTION:5MA AT 1V 100 PIV	
A2CR4	1901-0025	DIODE,JUNCTION:5MA AT 1V 100 PIV	
A2CR5	1910-0016	DIODE:GERMANIUM 100MA AT 0.85V 60PIV	
A2CR6	1901-0026	DIODE:SILICON 200 PIV 0.5 AMP	
A2CR7	1901-0026	DIODE:SILICCN 200 PIV 0.5 AMP	
A2Q1	1853-0020	TRANSISTOR:SILICON PNP	
A2Q2	1850-0064	TRANSISTOR:GERMANIUM PNP 2N1183	
A2Q3	1853-0020	TRANSISTOR:SILICON PNP	
A2Q4	1854-0071	TRANSISTOR:SILICON NPN 2N3391	
A2Q5	1854-0071	TRANSISTOR:SILICON NPN 2N3391	
A2Q6	1854-0071	TRANSISTOR:SILICON NPN 2N3391	
A2Q7	1854-0071	TRANSISTOR:SILICON NPN 2N3391	
A2Q8	1853-0020	TRANSISTOR:SILICON PNP	
A2R1	2100-1613	R:VAR COMP 2K OHM 20% LIN 1/5W	
A2R2	2100-1617	R:VAR COMP 1K OHM 20% LIN 1/5W	
A2R3	2100-1612	R:VAR COMP 500 OHM 20% LIN 1/5W	
A2R4	2100-1612	R:VAR COMP 500 OHM 20% LIN 1/5W	

See list of abbreviations in introduction to this section

Table 6-1. Reference Designation Index (Cont'd)

Reference Designation	Stock No.	Description #	Note
A2R5	2100-1616	R:VAR COMP 200 OHM 20% LIN 1/5W	
A2R6	2100-1615	R:VAR COMP 100 OHM 20% LIN 1/5W	
A2R7	2100-1615	R:VAR COMP 100 OHM 20% LIN 1/5W	
A2R8	2100-1615	R:VAR COMP 100 OHM 20% LIN 1/5W	
A2R9	2100-1615	R:VAR COMP 100 OHM 20% LIN 1/5W	
A2R10	2100-1616	R:VAR COMP 200 OHM 20% LIN 1/5W	
A2R11	2100-1612	R:VAR COMP 500 OHM 20% LIN 1/5W	
A2R12	2100-1612	R:VAR COMP 500 OHM 20% LIN 1/5W	
A2R13	2100-1617	R:VAR COMP 1K OHM 20% LIN 1/5W	
A2R14	2100-1613	R:VAR COMP 2K OHM 20% LIN 1/5W	
A2R15	0698-3337	R:FXD MET FLM 1.37K OHM 1% 1/2W	
A2R16	0757-0826	R:FXD MET FLM 2.43K OHM 1% 1/2W	
A2R17	0757-0436	R:FXD MET FLM 4.32K OHM 1% 1/8W	
A2R18	0757-0440	R:FXD MET FLM 7.50K OHM 1% 1/8W	
A2R19	0698-3581	R:FXD MET FLM 13.7K OHM 1% 1/8W	
A2R20	0757-0451	R:FXD MET FLM 24.3K OHM 1% 1/8W	
A2R21	0757-0456	R:FXD MET FLM 43.2K OHM 1% 1/8W	
A2R22	0698-3582	R:FXD MET FLM 41.2K OHM 1% 1/8W	
A2R23	0698-0063	R:FXD MET FLM 5.23K OHM 1% 1/8W	
A2R24	2100-1615	R:VAR COMP 100 OHM 20% LIN 1/5W	
A2R25	0757-0399	R:FXD MET FLM 82.5 OHM 1% 1/8W	
A2R26		NOT ASSIGNED	
A2R27	0811-1562	R:FXD WW 8 OHM 1% 1/4W	
A2R28	0757-0279	R:FXD MET FLM 3.16K OHM 1% 1/8W	
A2R29	0698-3155	R:FXD MET FLM 4640 OHM 1% 1/8	
A2R30	0698-3132	R:FXD MET FLM 261 OHM 1% 1/8W	
A2R31	0757-0279	R:FXD MET FLM 3.16K OHM 1% 1/8W	
A2R32	0698-3155	R:FXD MET FLM 4640 OHM 1% 1/8	
A2R33	0757-0279	R:FXD MET FLM 3.16K OHM 1% 1/8W	
A2R34	0757-0278	R:FXD MET FLM 1.78K OHM 1% 1/8W	
A2R35	0757-0442	R:FXD MET FLM 10.0K OHM 1% 1/8W	
A2R36	2100-0182	R:VAR COMP 3.3K OHM 10% LIN 0.15W	
A2R37	0698-3155	R:FXD MET FLM 4640 OHM 1% 1/8	
A2R38	0698-3491	R:FXD MET FLM 1K OHM 0.1% 1/8W	
A2R39	0757-0290	R:FXD MET FLM 6.19K OHM 1% 1/8W	
A2R40	0757-0463	R:FXD MET FLM 82.5K 1% 1/8W	
A2R41	0757-0441	R:FXD MET FLM 8.25K OHM 1% 1/8W	
A2R42	0757-0180	R:FXD MET FLM 31.6 OHM 1% 1/8W	
A2RT1	0839-0011	THERMISTOR:100 OHM 10%	
A2VR1	1902-0017	DIODE:BREAKDOWN:6.81V 10% 400 MW	
A2VR2	1902-0017	DIODE:BREAKDOWN:6.81V 10% 400 MW	
A2VR3	1902-0018	SEMICON DEVICE:DIODE SILICON 1N941 11.7V	
		CHASSIS PARTS	
C1	0121-0035	C:VAR AIR 7.2-143.7PF	
C2	0150-0119	C:FXD CER 2 X 0.01 UF 20% 250VACW	
DS1	1450-0048	LAMP:NEON	
F1	2110-0017	FUSE:CARTRIDGE 0.15 AMP SLOW BLOW	
F1	1400-0084	HOLDER:FUSE POST TYPE 3AG	
J1	1251-0149	CONNECTOR:6 FEMALE CONTACTS THERMISTOR MOUNT	

See list of abbreviations in introduction to this section

Table 6-1. Reference Designation Index (Cont'd)

Reference Designation	ⓗ Stock No.	Description #	Note
J2	1250-0083	CONNECTOR:BNC	
		RECORDER LEVELER	
J3	1251-0148	CONNECTOR:POWER 3 PIN MALE	
J4	1250-0083	CONNECTOR:BNC	
		DVM	
J5	1251-0149	CONNECTOR:6 FEMALE CONTACTS	
		THERMISTOR MOUNT OPT 2	
J6	-	CONNECTOR:DC CALIBRATION INCLUDES:	
	1510-0006	BINDING POST ASSEMBLY:BLACK	
	1510-0007	BINDING POST ASSEMBLY:RED	
	0340-0086	INSULATOR:BINDING POST	
	0340-0090	INSULATOR:BINDING-POST DOUBLE	
M1	1120-1101	METER	
R1	0698-3444	R:FXD MET FLM 316 OHM 1% 1/8W	
R2	2100-0342	R:VAR WW 10K 10% 800 OHM 10% LIN 2W	
R3		NOT ASSIGNED	
R4	0698-3151	R2FXD MET FLM 2.87K OHM 1% 1/8W	
R5	0757-0421	R:FXD MET FLM 825 OHM 1% 1/8W	
R6	0698-3444	R:FXD MET FLM 316 OHM 1% 1/8W	
R7	0698-3158	R:FXD MET FLM 23.7K OHM 1% 1/8W	
R8	0757-0280	R:FXD MET FLM 1.00K OHM 1% 1/8W	
R9	0698-3441	R:FXD MET FLM 215 OHM 1% 1/8W	
R10	0757-0398	R:FXD MET FLM 75 OHM 1% 1/8W	
R11	0757-0180	R:FXD MET FLM 31.6 OHM 1% 1/8W	
R12	0757-0277	R:FXD MET FLM 49.9 OHM 1% 1/8W	
R13	0757-0277	R:FXD MET FLM 49.9 OHM 1% 1/8W	
R14	0757-0277	R:FXD MET FLM 49.9 OHM 1% 1/8W	
R15	0698-3566	R:FXD MET FLM 53.0 OHM 1% 1/8W	
R16	0698-3566	R:FXD MET FLM 53.0 OHM 1% 1/8W	
R17	0698-3566	R:FXD MET FLM 53.0 OHM 1% 1/8W	
R18	0757-0395	R:FXD MET FLM 56.2 OHM 1% 1/8W	
R19	0757-0395	R:FXD MET FLM 56.2 OHM 1% 1/8W	
R20	0757-0395	R:FXD MET FLM 56.2 OHM 1% 1/8W	
R21	0757-1104	R:FXD MET FLM 60.0 OHM 1% 1/8W	
R22	0757-1104	R:FXD MET FLM 60.0 OHM 1% 1/8W	
R23	0757-1104	R:FXD MET FLM 60.0 OHM 1% 1/8W	
R24	0698-3160	R:FXD MET FLM 31.6K 1% 1/8W	
R25	0698	RESISTOR, FIXED 17.8KOHM-TO INFINITY	
R26	0757-0401	R:FXD MET FLM 100 OHM 1% 1/8W	
R27	0757-0401	R:FXD MET FLM 100 OHM 1% 1/8W	
R28	0698-3160	R:FXD MET FLM 31.6K 1% 1/8W	
R29	0698-3404	R:FXD MET FLM 383 OHM 1% 1/2W	
R30	0757-0821	R:FXD MET FLM 1.21K OHM 1% 1/2W	
S1	00431-6005	SWITCH ASSEMBLY, MOUNT RES INCLUDES R1	
S2	00431-6002	SWITCH ASSEMBLY, RANGE INCLUDES:	
		R4 THRU R11	
	3100-1817	SWITCH:ROTARY	
S3	00431-6004	SWITCH ASSEMBLY: POWER INCLUDES:	
		R24,R28 THRU R30	
	3100-1820	SWITCH:ROTARY	

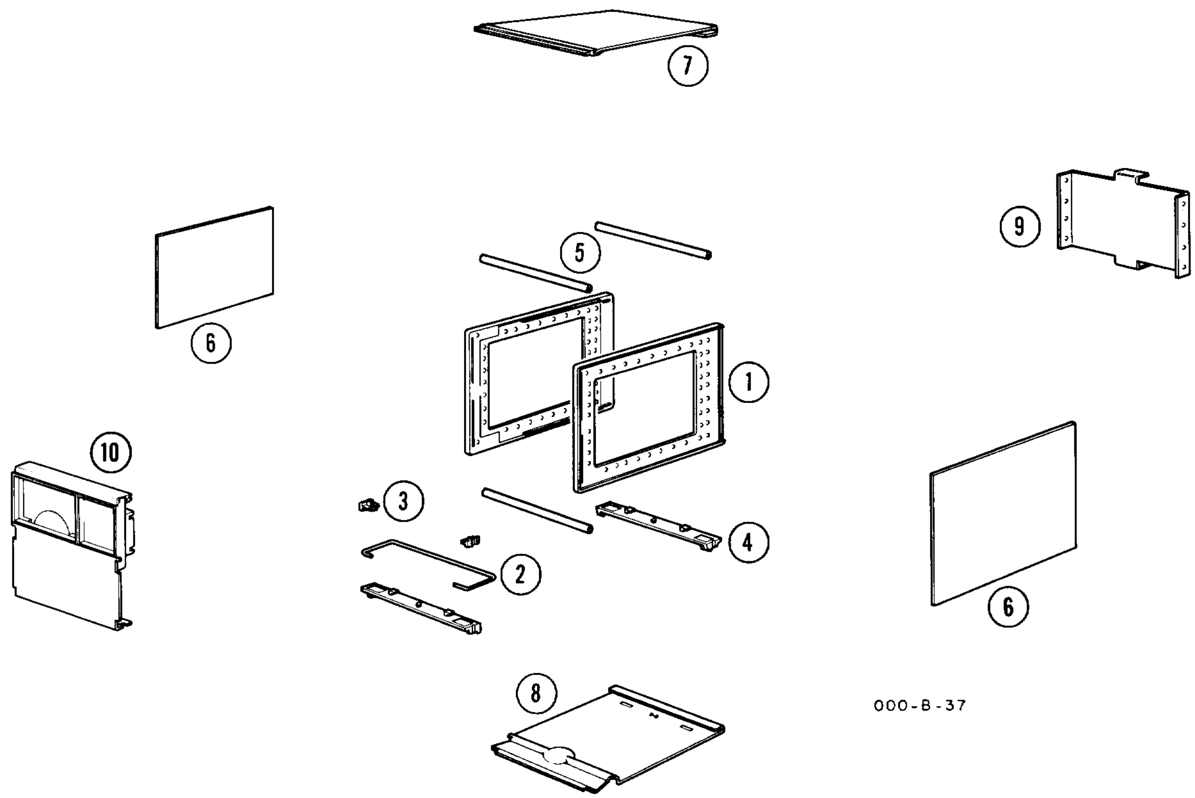
See list of abbreviations in introduction to this section

Table 6-1. Reference Designation Index (Cont'd)

Reference Designation	Stock No.	Description #	Note
S4	00431-6003	SWITCH ASSEMBLY, CALIB INCLUDES:	
		R12 THRU R23	
	3100-1818	SWITCH:ROTARY	
T1	9100-0400	TRANSFORMER:POWER	
W1	00431-6011	CABLE ASSY:THERMISTOR MOUNT, 5 FT.	
W2	8120-0078	CABLE:POWER 7.5FT.	
XA1	1251-0233	CONNECTOR:PC 44 CONTACTS	
XA2	1251-0233	CONNECTOR:PC 44 CONTACTS	
		MISCELLANEOUS	
	0370-0064	KNOB	
		VERNIER	
	0370-0067	KNOB:BLK CONCENTRIC 1 IN. OD 17/64IN. HOLE	
		ZERO	
	0370-0112	KNOB:BLK BAR W/ARROW 3/4 IN. OD 1/4 SHAFT	
		POWER	
		CALIB FACTOR	
		RANGE	
	5020-0705	TRIM:METER	
	5040-0701	EXTENDER:METER CASE	
	00431-0004	BRACKET, PANEL	
		OPTION 01	
	00415-606	BATTERY INSTALLATION KIT, INCLUDES:	
BT1	1420-0009	BATTERY:RECHARGEABLE 24V 1.25AH	
	00415-006	COVER:BATTERY	
	2420-0001	NUT:HEX ST NP 6-32 X 5/16 W/LOCKWASHER	

See list of abbreviations in introduction to this section

Table 6-1. Reference Designation Index (Cont'd)



Reference Designation	ⓗⓟ Stock No.	Description #	Note
		CABINET PARTS	
1	5060-0703	FRAME ASSEMBLY	
2	1490-0032	STAND:TILT, HALF-MODULE	
3	5040-0700	HINGE	
4	5060-0728	FOOT ASSEMBLY:HALF-MODULE	
5	5020-0701 2370-0015	CABINET SPACER SCREW:SS,FH,SLOT DR 6-32 X 3/8"	
6	5000-0703 2370-0020	COVER:SIDE SCREW:SS,FH,PHILLIPS DR 6-32 X 3/16"	
7	5060-0720 2370-0016	COVER:TOP SCREW:SS,FH,PHILLIPS DR 6-32 X 5/16"	
8	5000-0717 2370-0016	COVER:BOTTOM SCREW:SS,FH,PHILLIPS DR 6-32 X 5/16"	
9	00431-0003 2370-0015	PANEL:REAR SCREW:SS,FH,SLOT DR 6-32 X 3/8",W/EXT LOCKWASHER	
10	00431-0002 2370-0002	PANEL:FRONT SCREW:SS,FH,SLOT DR 6-32 X 3/8"	

See list of abbreviations in introduction to this section

Table 6-2. Replaceable Parts

ⓗⓟ Stock No.	Description #	Mfr.	Mfr. Part No.	TQ	
0121-0035	C:VAR AIR 7.2-143.7PF	28480	0121-0035	1	
0140-0159	C:FXD MICA 3000PF 300VDCW	04062	RDM19F302G3S	1	
0140-0198	C:FXD MICA 200PF 5% 300VDCW	04062	RDM15F201J3C	2	
0150-0012	C:FXD CER 0.01 UF 20% 1000VDCW	56289	29C214A3-H-1038	1	
0150-0093	C:FXD CER 0.01UF +80-20% 100VDCW	91418	TA	1	
0150-0096	C:FXD CER 0.05UF 100VDCW	91418	-TA	1	
0150-0119	C:FXD CER 2 X 0.01 UF 20% 250VACW	56289	36C219A	1	
0160-0174	C:FXD CER 0.47UF +80-20% 25VDCW	56289	5C11A	4	
0160-0185	C:FXD MICA 2100PF 1% 300VDCW	14655	RDM20F212F3C	2	
0160-2201	C:FXD MICA 51 PF 5%	28480	0160-2201	1	
0170-0069	C:FXD POLY 0.1UF 2% 50VDCW	56289	114P1042R5S3	3	
0180-0045	C:FXD ELECT 20UF 25VDCW	56289	30D206-G0-25UB-6M1	2	
0180-0049	C:FXD AL ELECT 20UF 50VDCW	56289	30D206G050DC6M1	2	
0180-0059	C:FXD ELECT 10UF -10%+100% 25VDCW	56289	30D106G025BB4	1	
0180-0060	C:FXD ELECT 200UF -10%+100% 3VDCW	56289	30D207G003DC4	1	
0180-0105	C:FXD ELECT SEMI-POLARIZED 50UF 25VDCW	56289	D34114	1	
0180-0106	C:FXD ELECT TA 60UF 20% 6VDCW	56289	150D606X0006B2	1	
0180-0116	C:FXD ELECT TA 6.8 UF 10% 35VDCW	56289	150D685X9035B2	6	
0180-0138	C:FXD ELECT 100UF -10+100% 40VDCW	56289	D36254	1	
0340-0086	INSULATOR:BINDING POST	28480	0340-0086	1	
0340-0090	INSULATOR:BINDING-POST DOUBLE	28480	0340-0090	1	
0370-0064	KNOB:VERNIER	28480	0370-0064	1	
0370-0067	KNOB:BLK CONCENTRIC 1 IN. OD 17/64IN. HOLE	28480	0370-0067	1	
0370-0112	KNOB:BLK BAR W/ARROW 3/4 IN. OD 1/4 SHAFT	28480	0370-0112	1	
0698-0063	R:FXD MET FLM 5.23K OHM 1% 1/8W	28480	0698-0063	1	
0698-0084	R:FXD MET FLM 2150 OHM 1% 1/8W	28480	0698-0084	1	
0698-0085	R:FXD MET FLM 2.61K OHM 1% 1/8W	28480	0698-0085	1	
0698-3132	R:FXD MET FLM 261 OHM 1% 1/8W	28480	0698-3132	1	
0698-3151	R2FXD MET FLM 2.87K OHM 1% 1/8W	28480	0698-3151	1	
0698-3155	R:FXD MET FLM 4640 OHM 1% 1/8	28480	0698-3155	3	
0698-3156	R:FXD MET FLM 14.7K OHM 1% 1/8W	28480	0698-3156	1	
0698-3157	R:FXD MET FLM 19.6K OHM 1% 1/8W	28480	0698-3157	2	
0698-3158	R:FXD MET FLM 23.7K OHM 1% 1/8W	19701	MF5C T-0	1	
0698-3160	R:FXD MET FLM 31.6K 1% 1/8W	28480	0698-3160	3	
0698-3337	R:FXD MET FLM 1.37K OHM 1% 1/2W	28480	0698-3337	1	
0698-3404	R:FXD MET FLM 383 OHM 1% 1/2W	28480	0698-3404	1	
0698-3438	R:FXD MET FLM 147 OHM 1% 1/8W	28480	0698-3438	1	
0698-3440	R:FXD MET FLM 196 OHM 1% 1/8W	28480	0698-3440	1	
0698-3441	R:FXD MET FLM 215 OHM 1% 1/8W	28480	0698-3441	1	
0698-3444	R:FXD MET FLM 316 OHM 1% 1/8W	28480	0698-3444	2	
0698-3447	R:FXD MET FLM 422 OHM 1% 1/8W	28480	0698-3447	1	
0698-3449	R:FXD MET FLM 28.7K OHM 1% 1/8W	28480	0698-3449	2	
0698-3450	R:FXD MET FLM 42.2K OHM 1% 1/8W	28480	0698-3450	1	
0698-3452	R:FXD MET FLM 147K OHM 1% 1/8W	28480	0698-3452	1	
0698-3491	R:FXD MET FLM 1K OHM 0.1% 1/8W	28480	0698-3491	1	
0698-3566	R:FXD MET FLM 53.0 OHM 1% 1/8W	28480	0698-3566	3	
0698-3581	R:FXD MET FLM 13.7K OHM 1% 1/8W	28480	0698-3581	1	
0698-3582	R:FXD MET FLM 41.2K OHM 1% 1/8W	28480	0698-3582	1	
0698-4023	R:FXD MET FLM 130.4K OHM 1/2% 1/8W	28480	0698-4023	1	
0698-4024	R:FXD MET FLM 259.6K OHM 1/2% 1/8W	28480	0698-4024	1	

See list of abbreviations in introduction to this section

Table 6-2. Replaceable Parts (Cont'd)

ⓗ Stock No.	Description #	Mfr.	Mfr. Part No.	TQ	
0698-4025	R:FXD MET FLM 128.5K OHM 1/2% 1/8W	28480	0698-4025	1	
0698-4026	R:FXD MET FLM 89.90K OHM 1/2% 1/8W	28480	0698-4026	1	
0698-4027	R:FXD MET FLM 64.45K OHM 1/2% 1/8W	28480	0698-4027	1	
0698-4028	R:FXD MET FLM 48.64K OHM 1/2% 1/8W	28480	0698-4028	2	
0698-4029	R:FXD MET FLM 53.39K OHM 1/2% 1/8W	28480	0698-4029	1	
0698-4030	R:FXD MET FLM 40.77K OHM 1/2% 1/8W	28480	0698-4030	1	
0698-4031	R:FXD MET FLM 43.25K OHM 1/2% 1/8W	28480	0698-4031	1	
0698-4032	R:FXD MET FLM 51.22K OHM 1/2% 1/8W	28480	0698-4032	1	
0698-4033	R:FXD MET FLM 62.26K OHM 1/2% 1/8W	28480	0698-4033	1	
0698-4034	R:FXD MET FLM 84.32K OHM 1/2% 1/8W	28480	0698-4034	1	
0757-0123	R:FXD MET FLM 34.8K OHM 1% 1/10W	28480	0757-0123	1	
0757-0180	R:FXD MET FLM 31.6 OHM 1% 1/8W	28480	0757-0180	2	
0757-0199	R:FXD MET FLM 21.5K OHM 1% 1/8W	28480	0757-0199	2	
0757-0274	R:FXD MET FLM 1.21K OHM 1% 1/8W	28480	0757-0274	1	
0757-0277	R:FXD MET FLM 49.9 OHM 1% 1/8W	28480	0757-0277	3	
0757-0278	R:FXD MET FLM 1.78K OHM 1% 1/8W	28480	0757-0278	1	
0757-0279	R:FXD MET FLM 3.16K OHM 1% 1/8W	28480	0757-0279	3	
0757-0280	R:FXD MET FLM 1.00K OHM 1% 1/8W	28480	0757-0280	6	
0757-0290	R:FXD MET FLM 6.19K OHM 1% 1/8W	28480	0757-0290	1	
0757-0395	R:FXD MET FLM 56.2 OHM 1% 1/8W	28480	0757-0395	3	
0757-0398	R:FXD MET FLM 75 OHM 1% 1/8W	28480	0757-0398	1	
0757-0399	R:FXD MET FLM 82.5 OHM 1% 1/8W	28480	0757-0399	1	
0757-0401	R:FXD MET FLM 100 OHM 1% 1/8W	28480	0757-0401	2	
0757-0417	R:FXD MET FLM 562 OHM 1% 1/8W	28480	0757-0417	2	
0757-0421	R:FXD MET FLM 825 OHM 1% 1/8W	28480	0757-0421	1	
0757-0436	R:FXD MET FLM 4.32K OHM 1% 1/8W	28480	0757-0436	1	
0757-0440	R:FXD MET FLM 7.50K OHM 1% 1/8W	28480	0757-0440	3	
0757-0441	R:FXD MET FLM 8.25K OHM 1% 1/8W	28480	0757-0441	1	
0757-0442	R:FXD MET FLM 10.0K OHM 1% 1/8W	28480	0757-0442	3	
0757-0451	R:FXD MET FLM 24.3K OHM 1% 1/8W	28480	0757-0451	1	
0757-0456	R:FXD MET FLM 43.2K OHM 1% 1/8W	28480	0757-0456	1	
0757-0460	R:FXD MET FLM 61.9K OHM 1% 1/8W	28480	0757-0460	1	
0757-0463	R:FXD MET FLM 82.5K 1% 1/8W	28480	0757-0463	1	
0757-0465	R:FXD MET FLM 100K OHM 1% 1/8W	28480	0757-0465	1	
0757-0821	R:FXD MET FLM 1.21K OHM 1% 1/2W	28480	0757-0821	1	
0757-0826	R:FXD MET FLM 2.43K OHM 1% 1/2W	28480	0757-0826	1	
0757-1094	R:FXD MET FLM 1.47K OHM 1% 1/8W	28480	0757-1094	2	
0757-1104	R:FXD MET FLM 60.0 OHM 1% 1/8W	28480	0757-1104	3	
0811-0065	R:FXD WW 511 OHM 1.0% 1/20W	28480	0811-0065	2	
0811-0066	R:FXD WW 887 OHM 1% 8/100W	99957	M3A/887-1%	1	
0811-1562	R:FXD WW 8 OHM 1% 1/4W	28480	0811-1562	1	
0811-1566	R:FXD WW 200 OHM 0.1% 1/8W	28480	0811-1566	1	
0811-1571	R:FXD WW 189 OHM 0.1% 1/8W	28480	0811-1571	1	
0811-1572	R:FXD WW 255 OHM 0.1% 1/8W	28480	0811-1572	1	
0811-1645	R:FXD WW 202.1 OHM 0.1% 1/8W	28480	0811-1645	1	
0839-0011	THERMISTOR:100 OHM 10%	33173	2D-204	1	
1120-1101	METER	28480	1120-1101	1	
1250-0083	CONNECTOR:BNC	28480	1250-0083	2	
1251-0148	CONNECTOR:POWER 3 PIN MALE	60427	H-1061-2	1	
1251-0149	CONNECTOR:6 FEMALE CONTACTS	02660	91-PC6F-1000	2	

See list of abbreviations in introduction to this section

Table 6-2. Replaceable Parts (Cont'd)

ⓗ Stock No.	Description #	Mfr.	Mfr. Part No.	TQ	
1251-0233	CONNECTOR:PC 44 CONTACTS	28480	1251-0233	2	
1400-0084	HOLDER:FUSE POST TYPE 3AG	75915	342014	1	
1420-0009	BATTERY:RECHARGEABLE 24V 1.25AH	28480	1420-0009	1	
1450-0048	LAMP:NEON	28480	1350-0048	1	
1490-0032	STAND:TILT HALF-MODULE	28480	1490-0032	1	
1510-0006	BINDING POST ASSEMBLY:BLACK	28480	1510-0006	1	
1510-0007	BINDING POST ASSEMBLY:RED	28480	1510-0007	1	
1850-0064	TRANSISTOR:GERMANIUM PNP 2N1183	02735	2N1183	1	
1853-0020	TRANSISTOR:SILICON PNP	28480	1853-0020	9	
1854-0071	TRANSISTOR:SILICON NPN 2N3391	89473	16A792	9	
1901-0025	DIODE,JUNCTION:5MA AT 1V 100 PIV	28480	1901-0025	7	
1901-0026	DIODE:SILICON 200 PIV 0.5 AMP	28480	1901-0026	2	
1901-0450	DIODE:SILICON	28480	1901-0450	8	
1902-0017	DIODE,BREAKDOWN:6.81V 10% 400 MW	28480	1902-0017	2	
1902-0018	SEMICON DEVICE:DIODE SILICON 1N941 11.7V	04713	1N941	1	
1910-0016	DIODE:GERMANIUM 100MA AT 0.85V 60PIV	28480	1910-0016	5	
2100-0144	R:VAR COMP 250K OHM 30% LIN 1/5W	28480	2100-0144	1	
2100-0182	R:VAR COMP 3.3K OHM 10% LIN 0.15W	28480	2100-0182	1	
2100-0342	R:VAR WW 10K 10% 800 OHM 10% LIN 2W	28480	2100-0342	1	
2100-1612	R:VAR COMP 500 OHM 20% LIN 1/5W	28480	2100-1612	4	
2100-1613	R:VAR COMP 2K OHM 20% LIN 1/5W	28480	2100-1613	2	
2100-1615	R:VAR COMP 100 OHM 20% LIN 1/5W	28480	2100-1615	5	
2100-1616	R:VAR COMP 200 OHM 20% LIN 1/5W	28480	2100-1616	2	
2100-1617	R:VAR COMP 1K OHM 20% LIN 1/5W	28480	2100-1617	2	
2110-0017	FUSE:CARTRIDGE 0.15 AMP SLOW BLOW	75915	313.150	1	
2420-0001	NUT:HEX ST NP 6-32 X 5/16 W/LOCKWASHER	78189	OBD#	5	
3100-1817	SWITCH:ROTARY	28480	3100-1817	1	
3100-1818	SWITCH:ROTARY	28480	3100-1818	1	
3100-1820	SWITCH:ROTARY	28480	3100-1820	1	
5000-0703	COVER:SIDE 6X11 SM	28480	5000-0703	1	
5000-0717	COVER:HALF-MODULE BOTTOM	28480	5000-0717	1	
5020-0701	SPACER:CABINET	28480	5020-0701	1	
5020-0705	TRIM:METER	28480	5020-0705	1	
5040-0700	HINGE	28480	5040-0700	1	
5040-0701	EXTENDER:METER CASE	28480	5040-0701	1	
5060-0703	COVER:6 X 11 SIDE	28480	5060-0703	1	
5060-0720	COVER:HALF-RECESS TOP	28480	5060-0720	1	
5060-0728	FOOT ASSY:HALF MODULE	28480	5060-0728	1	
8120-0078	CABLE:POWER 7.5FT.	70903	KH4147	1	
9100-0400	TRANSFORMER:POWER	28480	9100-0400	1	
9100-1677	TRANSFORMER:INPUT	28480	9100-1677	1	
9110-0040	INDUCTOR:AUDIO	98734	9110-0040	2	
9120-0065	TRANSFORMER:AUDIO	28480	9120-0065	2	
9120-0066	TRANSFORMER:AUDIO	28480	9120-0066	2	
9140-0122	COIL:VAR 2X 9-20 UHY EACH	28480	9140-0122	2	
00415-006	COVER:BATTERY	28480	00415-006	1	
00415-606	BATTERY INSTALLATION KIT	28480	00415-606	1	
00431-6001	BOARD ASSEMBLY, AMPLIFIER	28480	00431-6001	1	
00431-0002	PANEL, FRONT	28480	00431-0002	1	
00431-0003	PANEL, REAR	28480	00431-0003	1	

See list of abbreviations in introduction to this section

Table 6-2. Replaceable Parts (Cont'd)

ⓗⓟ Stock No.	Description #	Mfr.	Mfr. Part No.	TQ	
00431-0004	BRACKET, PANEL	28480	00431-0004	1	
00431-6002	SWITCH ASSEMBLY, RANGE	28480	00431-6002	1	
00431-6004	SWITCH ASSEMBLY, POWER	28480	00431-6004	1	
00431-6003	SWITCH ASSEMBLY, CALIB	28480	00431-6003	1	
00431-6009	BOARD ASSY., POWER SUPPLY	28480	00431-6009	1	
00431-6011	CABLE ASSY:THERMISTOR MOUNT 5 FT.	28480	00431-6011	1	

See list of abbreviations in introduction to this section

TABLE 6-3.

CODE LIST OF MANUFACTURERS

The following code numbers are from the Federal Supply Code for Manufacturers Cataloging Handbooks H4-1 (Name to Code) and H4-2 (Code to Name) and their latest supplements. The date of revision and the date of the supplements used appear at the bottom of each page. Alphabetical codes have been arbitrarily assigned to suppliers not appearing in the H4 handbooks.

Code No.	Manufacturer	Address
00000	U.S.A. Common	Any supplier of U.S.
00136	McCoy Electronics	Mount Holly Springs, Pa.
00213	Sage Electronics Corp.	Rochester, N.Y.
00287	Cemco Inc.	Danielson, Conn.
00334	Humidial	Colton, Calif.
00373	Garlock Inc., Electronics Products Div.	Camden, N.J.
00656	Aerovox Corp.	New Bedford, Mass.
00779	Amp, Inc.	Harrisburg, Pa.
00781	Aircraft Radio Corp.	Boonton, N.J.
00815	Northern Engineering Laboratories, Inc.	Burlington, Wis.
00853	Sangamo Electric Co., Pickens Div.	Pickens, S.C.
00866	Goe Engineering Co.	Los Angeles, Calif.
00891	Carl E. Holmes Corp.	Los Angeles, Calif.
01121	Allen Bradley Co.	Milwaukee, Wis.
01255	Litton Industries, Inc.	Beverly Hills, Calif.
01281	TRW Semiconductors, Inc.	Lawndale, Calif.
01295	Texas Instruments, Inc., Transistor Products Div.	Dallas, Texas
01349	The Alliance Mfg. Co.	Alliance, Ohio
01589	Pacific Relays, Inc.	Van Nuys, Calif.
01930	Amerock Corp.	Rockford, Ill.
01961	Pulse Engineering Co.	Santa Clara, Calif.
02114	Ferroxcube Corp. of America	Saugerties, N.Y.
02286	Cole Rubber and Plastics Inc.	Sunnyvale, Calif.
02660	Amphenol-Borg Electronics Corp.	Chicago, Ill.
02735	Radio Corp. of America, Semiconductor and Materials Div.	Somerville, N.J.
02771	Vocaline Co. of America, Inc.	Old Saybrook, Conn.
02777	Hopkins Engineering Co.	San Fernando, Calif.
03508	G.E. Semiconductor Prod. Dept.	Syracuse, N.Y.
03705	Apex Machine & Tool Co.	Dayton, Ohio
03797	Eldema Corp.	Compton, Calif.
03877	Transitron Electric Corp.	Wakefield, Mass.
03888	Pyrofilm Resistor Co., Inc.	Cedar Knolls, N.J.
03954	Singer Co., Diehl Div. Finderne Plant	Somerville, N.J.
04009	Arrow, Hart and Hegeman Elect. Co.	Hartford, Conn.
04013	Taurus Corp.	Lambertville, N.J.
04062	Elmenco Products Co.	New York, N.Y.
04222	Hi-Q Division of Aerovox	Myrtle Beach, S.C.
04354	Precision Paper Tube Co.	Chicago, Ill.
04404	Dymec Division of Hewlett-Packard Co.	Palo Alto, Calif.
04651	Sylvania Electric Products, Microwave Device Div.	Mountain View, Calif.
04713	Motorola, Inc., Semiconductor Prod. Div.	Phoenix, Arizona
04732	Fitron Co., Inc. Western Div.	Culver City, Calif.
04773	Automatic Electric Co.	Northlake, Ill.
04796	Sequoia Wire Co.	Redwood City, Calif.
04811	Precision Coil Spring Co.	El Monte, Calif.
04870	P.M. Motor Company	Westchester, Ill.
05006	Twentieth Century Plastics, Inc.	Los Angeles, Calif.
05277	Westinghouse Electric Corp. Semi-Conductor Dept.	Youngwood, Pa.
05347	Ultronix, Inc.	San Mateo, Calif.
05593	Illumitronic Engineering Co.	Sunnyvale, Calif.
05616	Cosmo Plastic (c/o Electrical Spec. Co.)	Cleveland, Ohio
05624	Barber Colman Co.	Rockford, Ill.
05728	Tiffen Optical Co.	Roslyn Heights, Long Island, N.Y.
05729	Metro-Tel Corp.	Westbury, N.Y.
05783	Stewart Engineering Co.	Santa Cruz, Calif.
05820	Wakefield Engineering Inc.	Wakefield, Mass.
06004	Bassick Co., The	Bridgeport, Conn.
06175	Bausch and Lomb Optical Co.	Rochester, N.Y.
06402	E.T.A. Products Co. of America	Chicago, Ill.
06475	Western Devices Inc.	Burbank, Calif.
06540	Amatom Electronic Hardware Co., Inc.	New Rochelle, N.Y.
06555	Beede Electrical Instrument Co., Inc.	Penacook, N.H.
06666	General Devices Co., Inc.	Indianapolis, Ind.
06751	Nuclear Corp. of America U.S. Semcor Div.	Phoenix, Arizona
06812	Torrington Mfg. Co., West Div.	Van Nuys, Calif.
06980	Eitel-McCullough Inc.	San Carlos, Calif.
07088	Kelvin Electric Co.	Van Nuys, Calif.
07126	Digitran Co.	Pasadena, Calif.
07137	Transistor Electronics Corp.	Minneapolis, Minn.
07138	Westinghouse Electric Corp. Electronic Tube Div.	Elmira, N.Y.
07149	Filmohm Corp.	New York, N.Y.
07233	Cinch-Graphik Co.	City of Industry, Calif.
07261	Avnet Corp.	Los Angeles, Calif.
07263	Fairchild Camera & Inst. Corp. Semiconductor Div.	Mountain View, Calif.
07322	Minnesota Rubber Co.	Minneapolis, Minn.
07387	Birtcher Corp., The	Monterey Park, Calif.
07700	Technical Wire Products Inc.	Cranford, N.J.
07910	Continental Device Corp.	Hawthorne, Calif.
07933	Raytheon Mfg. Co., Semiconductor Div.	Mountain View, Calif.
07966	Shockley Semi-Conductor Laboratories	Palo Alto, Calif.
07980	Hewlett-Packard Co., Boonton Radio Div.	Rockaway, N.J.
08145	U.S. Engineering Co.	Los Angeles, Calif.
08289	Blinn, Delbert Co.	Pomona, Calif.
08358	Burgess Battery Co.	Niagara Falls, Ontario, Canada
08664	Bristol Co., The	Waterbury, Conn.
08717	Sloan Company	Sun Valley, Calif.
08718	ITT Cannon Electric Inc., Phoenix Div.	Phoenix, Arizona
08792	CBS Electronics Semiconductor Operations, Div of C.B.S. Inc.	Lowell, Mass.
08984	Mel-Rain	Indianapolis, Ind.
09026	Babcock Relays Div.	Costa Mesa, Calif.
09134	Texas Capacitor Co.	Houston, Texas
09145	Atohm Electronics	Sun Valley, Calif.
09250	Electro Assemblies, Inc.	Chicago, Ill.
09569	Mallory Battery Co. of Canada, Ltd.	Toronto, Ontario, Canada
10214	General Transistor Western Corp.	Los Angeles, Calif.
10411	Ti-Tal, Inc.	Berkeley, Calif.
10646	Carborundum Co.	Niagara Falls, N.Y.
11236	CTS of Berne, Inc.	Berne, Ind.
11237	Chicago Telephone of California, Inc.	So. Pasadena, Calif.
11242	Bay State Electronics Corp.	Waltham, Mass.
11312	Microwave Electronics Corp.	Palo Alto, Calif.
11534	Duncan Electronics Inc.	Costa Mesa, Calif.
11711	General Instrument Corp., Semiconductor Div., Products Group	Newark, N.J.
11717	Imperial Electronic, Inc.	Buena Park, Calif.
11870	Melabs, Inc.	Palo Alto, Calif.
12136	Philadelphia Handle Co.	Camden, N.J.
12697	Clarostat Mfg. Co.	Dover, N.H.
12859	Nippon Electric Co., Ltd.	Tokyo, Japan
12881	Metex Electronics Corp.	Clark, N.J.
12930	Delta Semiconductor Inc.	Newport Beach, Calif.
12954	Dickson Electronics Corp.	Scottsdale, Arizona
13103	Thermolloy	Dallas, Texas
13396	Telefunken (GmbH)	Hanover, Germany
13835	Midland-Wright Div. of Pacific Industries, Inc.	Kansas City, Kansas
14099	Sem-Tech	Newbury Park, Calif.
14193	Calif. Resistor Corp.	Santa Monica, Calif.
14298	American Components, Inc.	Conshohocken, Pa.
14433	ITT Semiconductor, A Div. of Int. Telephone & Telegraph Corp.	West Palm Beach, Fla.
14493	Hewlett-Packard Company	Loveland, Colo.
14655	Cornell Dublier Electric Corp.	Newark, N.J.
14674	Corning Glass Works	Corning, N.Y.
14752	Electro Cube Inc.	So. Pasadena, Calif.
14960	Williams Mfg. Co.	San Jose, Calif.
15203	Webster Electronics Co.	New York, N.Y.
15291	Adjustable Bushing Co.	N. Hollywood, Calif.
15558	Micron Electronics	Garden City, Long Island, N.Y.
15772	Twentieth Century Coil Spring Co.	Santa Clara, Calif.
15818	Amelco Inc.	Mt. View, Calif.
15909	Daven Div. Thomas A. Edison Ind. McGraw-Edison Co.	Long Island City, N.Y.
16037	Spruce Pine Mica Co.	Spruce Pine, N.C.
16179	Omni-Spectra Inc.	Detroit, Ill.
16352	Computer Diode Corp.	Lodi, N.J.
16688	Ideal Prec. Meter Co., Inc. De Jur Meter Div.	Brooklyn, N.Y.
16758	Delco Radio Div. of G.M. Corp.	Kokomo, Inc.
17109	Thermonetics Inc.	Canoga Park, Calif.
17474	Tranex Company	Mountain View, Calif.
18042	Power Design Pacific Inc.	Palo Alto, Calif.
18476	Ty-Car Mfg. Co., Inc.	Holliston, Mass.
18485	Radio Industries	Des Plaines, Ill.
18583	Curtis Instrument, Inc.	Mt. Kisco, N.Y.
18873	E.I. DuPont and Co., Inc.	Wilmington, Del.
18911	Durant Mfg. Co.	Milwaukee, Wis.
19315	Bendix Corp., The Eclipse-Poineer Div.	Teterboro, N.J.
19500	Thomas A. Edison Industries, Div. of McGraw-Edison Co.	West Orange, N.J.
19644	LRC Electronics	Horseheads, N.Y.
19701	Electra Mfg. Co.	Independence, Kansas
20183	General Atronics Corp.	Philadelphia, Pa.
21226	Executone, Inc.	New York, N.Y.
21335	Fafnir Bearing Co., The	New Britain, Conn.
21520	Fansteel Metallurgical Corp.	N. Chicago, Ill.
24455	G.E. Lamp Division	Nela Park, Cleveland, Ohio
24655	General Radio Co.	West Concord, Mass.
26365	Gries Reproducer Corp.	New Rochelle, N.Y.
26462	Grobet File Co. of America, Inc.	Carlstadt, N.J.
26992	Hamilton Watch Co.	Lancaster, Pa.
28480	Hewlett-Packard Co.	Palo Alto, Calif.
33173	G.E. Receiving Tube Dept.	Owensboro, Ky.
35434	Lectrohm Inc.	Chicago, Ill.
36196	Stanwyck Coil Products Ltd.	Hawkesbury, Ontario, Canada
37942	P.R. Mallory & Co. Inc.	Indianapolis, Ind.
39543	Mechanical Industries Prod. Co.	Akron, Ohio
40920	Miniature Precision Bearings, Inc.	Keene, N.H.
42190	Muter Co.	Chicago, Ill.
43990	C.A. Norgren Co.	Englewood, Colo.
44655	Ohmite Mfg. Co.	Skokie, Ill.
47904	Polaroid Corp.	Cambridge, Mass.
48620	Precision Thermometer & Inst. Co.	Southampton, Pa.
49956	Microwave & Power Tube Div.	Waltham, Mass.
52090	Rowan Controller Co.	Westminster, Md.
52983	Sanborn Company	Waltham, Mass.
54294	Shallcross Mfg. Co.	Selma, N.C.
55026	Simpson Electric Co.	Chicago, Ill.
55933	Sonotone Corp.	Elmsford, N.Y.
55938	Raytheon Co. Commercial Apparatus & Systems Div.	So. Norwalk, Conn.
56137	Spaulding Fibre Co., Inc.	Tonawanda, N.Y.
56289	Sprague Electric Co.	North Adams, Mass.
59446	Telex, Inc.	St. Paul, Minn.
59730	Thomas & Betts Co.	Elizabeth, N.J.
60741	Triplett Electrical Inst. Co.	Bluffton, Ohio
61775	Union Switch and Signal, Div. of Westinghouse Air Brake Co.	Pittsburgh, Pa.
62119	Universal Electric Co.	Owosso, Mich.
63743	Ward-Leonard Electric Co.	Mt. Vernon, N.Y.
64959	Western Electric Co., Inc.	New York, N.Y.
65092	Weston Inst. Inc. Weston-Newark	Newark, N.J.
66295	Wittek Mfg. Co.	Chicago, Ill.
66346	Revere Wollansak Div. Minn. Mining & Mft. Co.	St. Paul, Minn.
70276	Allen Mfg. Co.	Hartford, Conn.
70318	Allmetal Screw Product Co., Inc.	Garden City, N.Y.
70485	Atlantic India Rubber Works, Inc.	Chicago, Ill.
70563	Amperite Co., Inc.	Union City, N.J.
70903	Belden Mfg. Co.	Chicago, Ill.
70998	Bird Electronic Corp.	Cleveland, Ohio
71002	Birnbach Radio Co.	New York, N.Y.
71041	Boston Gear Works Div. of Murray Co. of Texas	Quincy, Mass.
71218	Bud Radio, Inc.	Willoughby, Ohio
71286	Camloc Fastener Corp.	Paramus, N.J.
71313	Cardwell Condenser Corp.	Lindenhurst L.I., N.Y.
71400	Bussmann Mfg. Div. of McGraw-Edison Co.	St. Louis, Mo.
71436	Chicago Condenser Corp.	Chicago, Ill.
71447	Calif. Spring Co., Inc.	Pico-Rivera, Calif.
71450	CTS Corp.	Elkhart, Ind.
71468	ITT Cannon Electric Inc.	Los Angeles, Calif.
71471	Cinema Plant, Hi-Q Div. Aerovox Corp.	Burbank, Calif.
71482	C.P. Clare & Co.	Chicago, Ill.
71590	Centralab Div. of Globe Union Inc.	Milwaukee, Wis.
71616	Commercial Plastics Co.	Chicago, Ill.
71700	Cornish Wire Co., The	New York, N.Y.
71707	Coto Coil Co., Inc.	Providence, R.I.
71744	Chicago Miniature Lamp Works	Chicago, Ill.
71753	A.O. Smith Corp., Crowley Div.	West Orange, N.J.
71785	Cinch Mfg. Co., Howard B. Jones Div.	Chicago, Ill.
71984	Dow Corning Corp.	Midland, Mich.
72136	Electro Motive Mfg. Co., Inc.	Willimantic, Conn.
72354	John E. Fast Co., Div. Victoreen Instr. Co.	Chicago, Ill.
72619	Dialight Corp.	Brooklyn, N.Y.
72656	Indiana General Corp., Electronics Div.	Keasby, N.J.
72765	Drake Mfg. Co.	Chicago, Ill.
72825	Hugh H. Eby Inc.	Philadelphia, Pa.
72928	Gudeman Co.	Chicago, Ill.
72964	Robert M. Hadley Co.	Los Angeles, Calif.
72982	Erie Technological Products, Inc.	Erie, Pa.
73061	Hansen Mfg. Co., Inc.	Princeton, Ind.
73076	H.M. Harper Co.	Chicago, Ill.
73138	Helipot Div. of Beckman Inst., Inc.	Fullerton, Calif.
73293	Hughes Products Division of Hughes Aircraft Co.	Newport Beach, Calif.
73445	Amperex Electronic Co., Div. of North American Phillips Co., Inc.	Hicksville, N.Y.
73506	Bradley Semiconductor Corp.	New Haven, Conn.
73559	Carling Electric, Inc.	Hartford, Conn.
73682	George K. Garrett Co., Div. MSL Industries Inc.	Philadelphia, Pa.
73734	Federal Screw Products Inc.	Chicago, Ill.
73743	Fischer Special Mfg. Co.	Cincinnati, Ohio
73793	General Industries Co., The	Elyria, Ohio
73846	Goshen Stamping & Tool Co.	Goshen, Ind.
73899	JFD Electronics Corp.	Brooklyn, N.Y.
73905	Jennings Radio Mfg. Corp.	San Jose, Calif.
74276	Signalite Inc.	Neptune, N.J.
74455	J.H. Winns, and Sons	Winchester, Mass.
74861	Industrial Condenser Corp.	Chicago, Ill.
74868	R.F. Products Division of Amphenol-Borg Electronics Corp.	Danbury, Conn.
74970	E.F. Johnson Co.	Waseca, Minn.
75042	International Resistance Co.	Philadelphia, Pa.
75378	James Knights Co.	Sandwich, Ill.
75382	Kulka Electric Corporation	Mt. Vernon, N.Y.
75818	Lenz Electric Mfg. Co.	Chicago, Ill.
75915	Littlefuse, Inc.	Des Plaines, Ill.
76005	Lord Mfg. Co.	Erie, Pa.
76210	C.W. Marwedel	San Francisco, Calif.
76433	General Instrument Corp., Micamold Div.	Newark, N.J.
76487	James Millen Mfg. Co., Inc.	Malden, Mass.
76493	J.W. Miller Co.	Los Angeles, Calif.
76530	Monadnock Mills	San Leandro, Calif.
76545	Mueller Electric Co.	Cleveland, Ohio
76854	Oak Manufacturing Co.	Crystal Lake, Ill.
77068	Bendix Corp., The Bendix Pacific Div.	N. Hollywood, Calif.
77075	Pacific Metals Co.	San Francisco, Calif.
77221	Phanostran Instrument and Electronic Co.	South Pasadena, Calif.
77252	Philadelphia Steel and Wire Corp.	Philadelphia, Pa.
77342	American Machine & Foundry Co. Potter & Brumfield Div.	Princeton, Ind.
77630	TRW Electronic Components Div.	Camden, N.J.
77638	General Instrument Corp., Rectifier Div.	Brooklyn, N.Y.
77764	Resistance Products Co.	Harrisburg, Pa.
77969	Rubbercraft Corp. of Calif.	Torrance, Calif.
78189	Shakeproof Division of Illinois Tool Works	Elgin, Ill.
78283	Signal Indicator Corp.	New York, N.Y.
78290	Struthers-Dunn Inc.	Pitman, N.J.
78452	Thompson-Bremer & Co.	Chicago, Ill.
78471	Tilley Mfg. Co.	San Francisco, Calif.
78488	Stackpole Carbon Co.	St. Marys, Pa.
78493	Standard Thomson Corp.	Waltham, Mass.
78553	Tinnerman Products, Inc.	Cleveland, Ohio
78790	Transformer Engineers	San Gabriel, Calif.
78947	Ucinite Co.	Newtonville, Mass.
79136	Waldes Kohinoor Inc.	Long Island City, N.Y.
79142	Veeder Root, Inc.	Hartford, Conn.
79251	Wenco Mfg. Co.	Chicago, Ill.
79727	Continental-Wirt Electronics Corp.	Philadelphia, Pa.
79963	Zierick Mfg. Corp.	New Rochelle, N.Y.

00015-41
Revised: November, 1965

From: FSC. Handbook Supplements
H4-1 Dated JULY 1965
H4-2 Dated NOV 1962

TABLE 6-3.

CODE LIST OF MANUFACTURERS (Continued)

Code No.	Manufacturer	Address
80031	Mepco Division of Sessions Clock Co.	Morristown, N.J.
80120	Schnitzer Alloy Products Co.	Elizabeth, N.J.
80130	Times Telephoto Equipment	New York, N.Y.
80131	Electronic Industries Association. Any brand Tube meeting EIA Standards-Washington, DC.	
80207	Unimax Switch, Div. Maxon Electronics Corp.	Wallingford, Conn.
80223	United Transformer Corp.	New York, N.Y.
80248	Oxford Electric Corp.	Chicago, Ill.
80294	Bourns Inc.	Riverside, Calif.
80411	Acro Div. of Robertshaw Controls Co.	Columbus, Ohio
80486	All Star Products Inc.	Defiance, Ohio
80509	Avery Adhesive Label Corp.	Monrovia, Calif.
80583	Hammarlund Co., Inc.	New York, N.Y.
80640	Stevens, Arnold, Co., Inc.	Boston, Mass.
81030	International Instruments Inc.	Orange, Conn.
81073	Grayhill Co.	LaGrange, Ill.
81095	Triad Transformer Corp.	Venice, Calif.
81312	Winchester Elec. Div. Litton Ind., Inc.	Oakville, Conn.
81349	Military Specification	. . . .
81415	Wilkor Products, Inc.	Cleveland, Ohio
81483	International Rectifier Corp.	El Segundo, Calif.
81541	Airpax Products Co., The	Cambridge, Mass.
81860	Barry Controls, Div. Barry Wright Corp.	Waterton, Mass.
82042	Carter Precision Electric Co.	Skokie, Ill.
82047	Sperti Faraday Inc., Copper Hewitt Electric Div.	Hoboken, N.J.
82142	Jeffers Electronics Division of Speer Carbon Co.	Du Bois, Pa.
82170	Fairchild Camera & Inst. Corp., Defense Prod. Division	Clifton, N.J.
82209	Maguire Industries, Inc.	Greenwich, Conn.
82219	Sylvania Electric Prod. Inc. Electronic Tube Division	Emporium, Pa.
82376	Astron Corp.	East Newark, Harrison, N.J.
82389	Switchcraft, Inc.	Chicago, Ill.
82647	Metals & Controls Inc. Spencer Products	Attleboro, Mass.
82768	Phillips-Advance Control Co.	Joliet, Ill.
82866	Research Products Corp.	Madison, Wis.
82877	Rotron Mfg. Co., Inc.	Woodstock, N.Y.
82893	Vector Electronic Co.	Glendale, Calif.
83053	Western Washer Mfg. Co.	Los Angeles, Calif.
83058	Carr Fastener Co.	Cambridge, Mass.
83086	New Hampshire Ball Bearing, Inc.	Peterborough, N.H.
83125	General Instrument Corp., Capacitor Div.	Darlington, S.C.
83148	ITT Wire and Cable Div.	Los Angeles, Calif.
83186	Victory Engineering Corp.	Springfield, N.J.
83298	Bendix Corp., Red Bank Div.	Red Bank, N.J.
83315	Hubbell Corp.	Mundelein, Ill.
83330	Smith, Herman H., Inc.	Brooklyn, N.Y.
83385	Central Screw Co.	Chicago, Ill.
83501	Gavitt Wire and Cable Co. Div. of Amerace Corp.	Brookfield, Mass.
83594	Burroughs Corp. Electronic Tube Div.	Plainfield, N.J.
83740	Eveready Div. National Carbon Div. Union Carbide Corp.	New York, N.Y.
83777	Model Eng. and Mfg., Inc.	Huntington, Ind.
83821	Loyd Scruggs Co.	Festus, Mo.
84171	Arco Electronics Ing.	Great Neck, N.Y.
84396	A.J. Glesener Co., Inc.	San Francisco, Calif.
84411	TRW Capacitor Div.	Ogallala, Neb.
84970	Sarkes Tarzian, Inc.	Bloomington, Ind.
85454	Boonton Molding Company	Boonton, N.J.
85471	A.B. Boyd Co.	San Francisco, Calif.
85474	R.M. Bracamonte & Co.	San Francisco, Calif.
85660	Koiled Kords, Inc.	Hamden, Conn.
85911	Seamless Rubber Co.	Chicago, Ill.
86197	Clifton Precision Products Co., Inc.	Clifton Heights, Pa.
86579	Precision Rubber Products Corp.	Dayton, Ohio
86684	Radio Corp. of Americal. Electronic Comp. & Devices Div.	Harrison, N.J.
87216	Philco Corporation (Lansdale Division)	Lansdale, Pa.
87473	Western Fibrous Glass Products Co.	San Francisco, Calif.
87664	Van Waters & Rogers Inc.	San Francisco, Calif.
87930	Tower Mfg. Corp.	Providence, R.I.
88140	Cutler-Hammer, Inc.	Lincoln, Ill.
88220	Gould-National Batteries, Inc.	St. Paul, Minn.
88421	Federal Telephone & Radio Corp.	Clifton, N.J.
88698	General Mills, Inc.	Buffalo, N.Y.
89231	Graybar Electric Co.	Oakland, Calif.
89665	United Transformer Co.	Chicago, Ill.
90179	US Rubber Co., Consumer Ind. & Plastics Prod. Div.	Passaic, N.J.
90970	Bearing Engineering Co.	San Francisco, Calif.
91260	Connor Spring Mfg. Co.	San Francisco, Calif.
91345	Miller Dial & Nameplate Co.	El Monte, Calif.
91418	Radio Materials Co.	Chicago, Ill.
91506	Augat Inc.	Attleboro, Mass.
91637	Dale Electronics, Inc.	Columbus, Nebr.
91662	Elco Corp.	Willow Grove, Pa.
91737	Gremar Mfg. Co., Inc.	Wakefield, Mass.
91827	K F Development Co.	Redwood City, Calif.
91929	Honeywell Inc., Micro Switch Div.	Freeport, Ill.
91961	Nahm-Bros. Spring Co.	Oakland, Calif.
92180	Tru-Connector Corp.	Peabody, Mass.
92367	Elgeet Optical Co. Inc.	Rochester, N.Y.
92196	Universal Industries, Inc.	City of Industry, Calif.
92607	Tensolite Insulated Wire Co., Inc.	Tarrytown, N.Y.
93332	Sylvania Electric Prod. Inc. Semiconductor Div.	Woburn, Mass.
93369	Robbins and Myers, Inc.	New York, N.Y.
93410	Stevens Mfg. Co., Inc.	Mansfield, Ohio
93788	Howard J. Smith Inc.	Port Monmouth, N.J.
93929	G.V. Controls	Livingston, N.J.
94137	General Cable Corp.	Bayonne, N.J.
94144	Raytheon Co., Comp. Div., Ind. Comp. Operations	Quincy, Mass.
94148	Scientific Electronics Products, Inc.	Loveland, Colo.
94154	Tung-Sol Electric, Inc.	Newark, N.J.
94197	Curtiss-Wright Corp. Electronics Div.	East Paterson, N.J.
94222	South Chester Corp.	Chester, Pa.
94310	Tru-Ohm Products Memcor Components Div.	Huntington, Ind.
94330	Wire Cloth Products, Inc.	Bellwood, Ill.
94682	Worcester Pressed Aluminum Corp.	Worcester, Mass.
94696	Magnecraft Electric Co.	Chicago, Ill.
95023	George A. Philbrick Researchers, Inc.	Boston, Mass.
95236	Allies Products Corp.	Miami, Fla.
95238	Continental Connector Corp.	Woodside, N.Y.
95263	Leecraft Mfg. Co., Inc.	Long Island, N.Y.
95264	Lerco Electronics, Inc.	Burbank, Calif.
95265	National Coil Co.	Sheridan, Wyo.
95275	Vitramon, Inc.	Bridgeport, Conn.
95348	Gordos Corp.	Bloomfield, N.J.
95354	Methode Mfg. Co.	Chicago, Ill.
95712	Dage Electric Co., Inc.	Franklin, Ind.
95984	Siemon Mfg. Co.	St. Charles, Ill.
95987	Weckesser Co.	Chicago, Ill.
96067	Huggins Laboratories	Sunnyvale, Calif.
96095	Hi-Q Div. of Aerovox Corp.	Olean, N.Y.
96256	Thordarson-Meissner Inc.	Mt. Carmel, Ill.
96296	Solar Manufacturing Co.	Los Angeles, Calif.
96330	Carlton Screw Co.	Chicago, Ill.
96341	Microwave Associates, Inc.	Burlington, Mass.
96501	Excel Transformer Co.	Oakland, Calif.
97464	Industrial Retaining Ring Co.	Irvington, N.J.
97539	Automatic & Precision Mfg.	Englewood, N.J.
97979	Reon Resistor Corp.	Yonkers, N.Y.
97983	Litton System Inc., Adler-Westrex Commun. Div.	New Rochelle, N.Y.
38141	R-Troncis, Inc.	Jamaica, N.Y.
98159	Rubber Teck, Inc.	Gardena, Calif.
98220	Francis L. Moseley	Pasadena, Calif.
98278	Microdot, Inc.	So. Pasadena, Calif.
98291	Sealectro Corp.	Mamaroneck, N.Y.
98731	General Mills Inc., Electronics Div.	Minneapolis, Minn.
98821	North Hills Electronics, Inc.	Glen Cove, N.Y.
98978	International Electronic Research Corp.	Burbank, Calif.
99109	Columbia Technical Corp.	New York, N.Y.
99313	Varian Associates	Palo Alto, Calif.
99515	Marshall Ind. Elect. Products Div.	San Marino, Calif.
99707	Control Switch Division, Controls Co. of America	El Segundo, Calif.
99800	Delevan Electronics Corp.	East Aurora, N.Y.
99848	Wilco Corporation	Indianapolis, Ind.
99934	Renbrandt, Inc.	Boston, Mass.
99942	Hoffman Electronics Corp. Semiconductor Div.	El Monte, Calif.
99957	Technology Instrument Corp. of Calif.	Newbury Park, Calif.

THE FOLLOWING HP VENDORS HAVE NO NUMBER ASSIGNED IN THE LATEST SUPPLEMENT TO THE FEDERAL SUPPLY CODE FOR MANUFACTURERS HANDBOOK.

Code No.	Manufacturer	Address
0000F	Malco Tool and Die	Los Angeles, Calif.
0000M	Western Coil Div. of Automatic Ind., Inc.	Redwood City, Calif.
0000Z	Willow Leather Products Corp.	Newark, N.J.
000AA	British Radio Electronics Ltd.	Washington, D.C.
000AB	ETA	England
000BB	Precision Instrument Components Co.	Van Nuys, Calif.
000MM	Rubber Eng. & Development	Hayward, Calif.
000NN	A "N" D Mfg. Co.	San Jose, Calif.
000QQ	Cooltron	Oakland, Calif.
000WW	California Eastern Lab.	Burlington, Calif.
000YY	S.K. Smith Co.	Los Angeles, Calif.

00015-41
Revised: November, 1965

From: FSC. Handbook Supplements
H4-1 Dated JULY 1965
H4-2 Dated NOV. 1962

SECTION VII
SCHEMATIC DIAGRAMS

7-1. INTRODUCTION.

7-2. Schematic presentations in this manual show electrical circuit operation and are not intended to serve as wiring diagrams. Figure 7-1 lists notes which apply to the schematic diagrams.

7-3. Some switch and circuit board assemblies are shown in part on different pages. To find a specific instrument component, refer to the "REFERENCE DESIGNATIONS" box which appears on each schematic diagram. Reference designations within assemblies are abbreviated. The full designation includes the assembly on which the component is mounted, and the individual component designation. For example, Resistor R1 mounted on Assembly A1 has the complete reference designation of A1R1. Certain parts are not included on assemblies, and are classified as chassis parts. Chassis parts are assigned only the reference designation shown on the schematic diagram.

7-4. This section also contains information on component and test point locations within the instrument. Figure 7-4 shows the Power Meter Assembly, A1, and Figure 7-6 shows the Power Supply Assembly, A2. Figure 7-2 shows switch component locations.

7-5. Figures 7-3 and 7-8 illustrate normal-operation waveforms obtained at test points 1 through 6. Normal-operation voltages are given on the schematic diagrams, adjacent to the point of measurement. All voltages and waveforms were taken with the instrument zeroed and nulled and a 200 ohm thermistor mount connected in accordance with Figure 3-8, Turn-On and Nulling Procedure. Full scale voltage measurements were made by setting the meter to full scale deflection with the ZERO control.

7-6. An asterisk indicates a factory selected part; the component value shown is the typical or most commonly selected value. Circuit requirements that determine the values of factory selected parts are listed in Table 5-3.

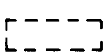
7-7. Component procurement information and specific component descriptions are included in Section VI. Refer to page 6-1 for information on how to order parts.

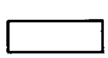
1. Resistance in ohms, capacitance in microfarads unless otherwise indicated. pF indicates picofarads, equivalent to micro-microfarads.

2. Module board assemblies A1 and A2 plug into connectors XA1 and XA2 respectively.

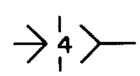
3.  Screwdriver adjustment.

4.  Panel control.

5.  Rear panel designation.

6.  Front panel designation.

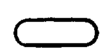
7.  Voltage regulator (breakdown) diode.

8. 

Indicates plug-in socket number.

9. Circuit assembly borderline.

10.  DC feedback signal.
10 kHz feedback signal.
10 kHz error signal.

11.  Wire color is standard color code (MIL-STD-681). First number identifies ground color, second number identifies wide stripe, third number identifies narrow stripe. E.g., 947 denotes white ground, yellow wide stripe, violet narrow stripe.

12. * Factory selected part: typical value shown. Refer to Table 5-3 for circuit requirements that determine part values.

Figure 7-1. Schematic Diagram Notes

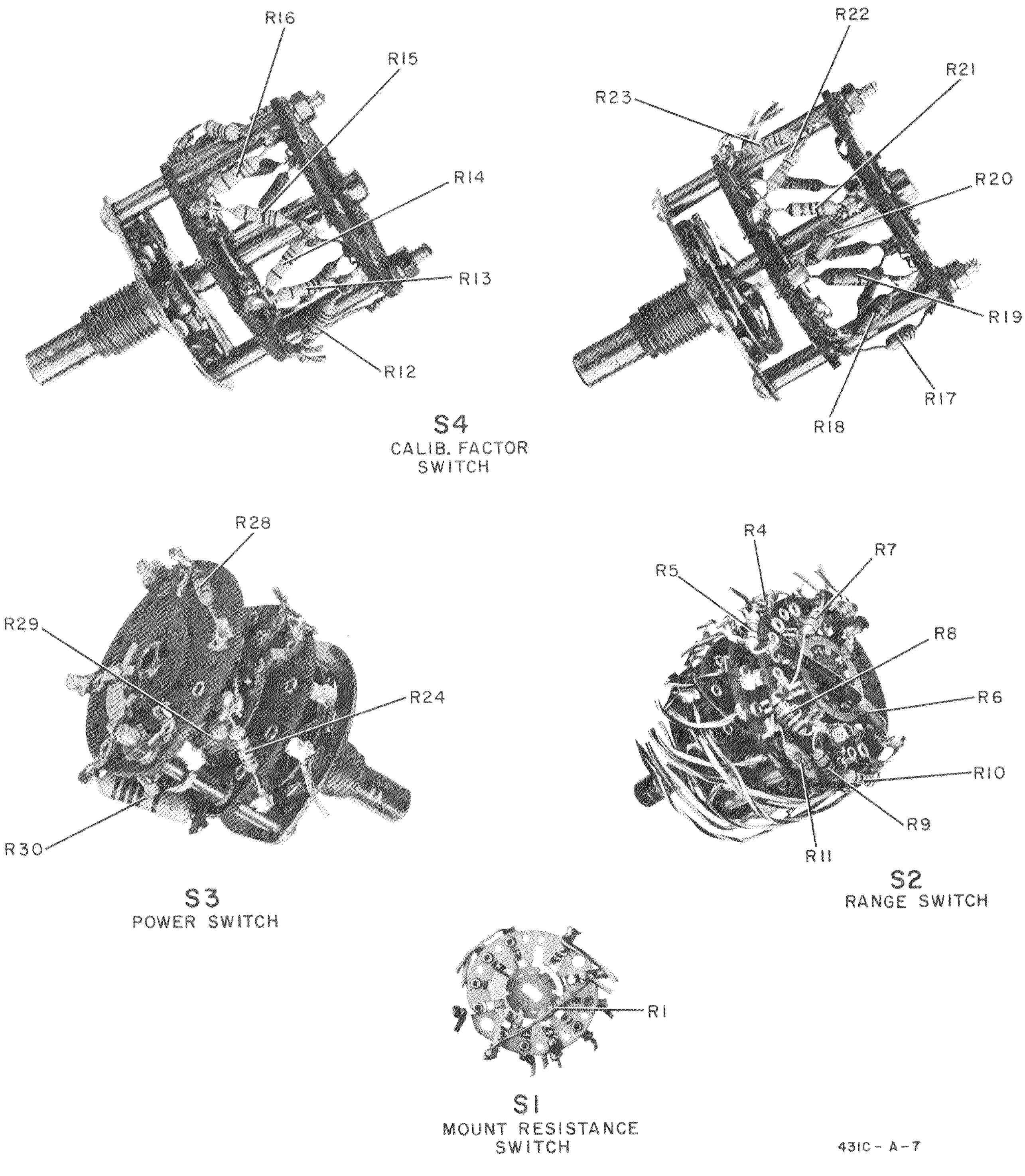


Figure 7-2. Switch Component Locations

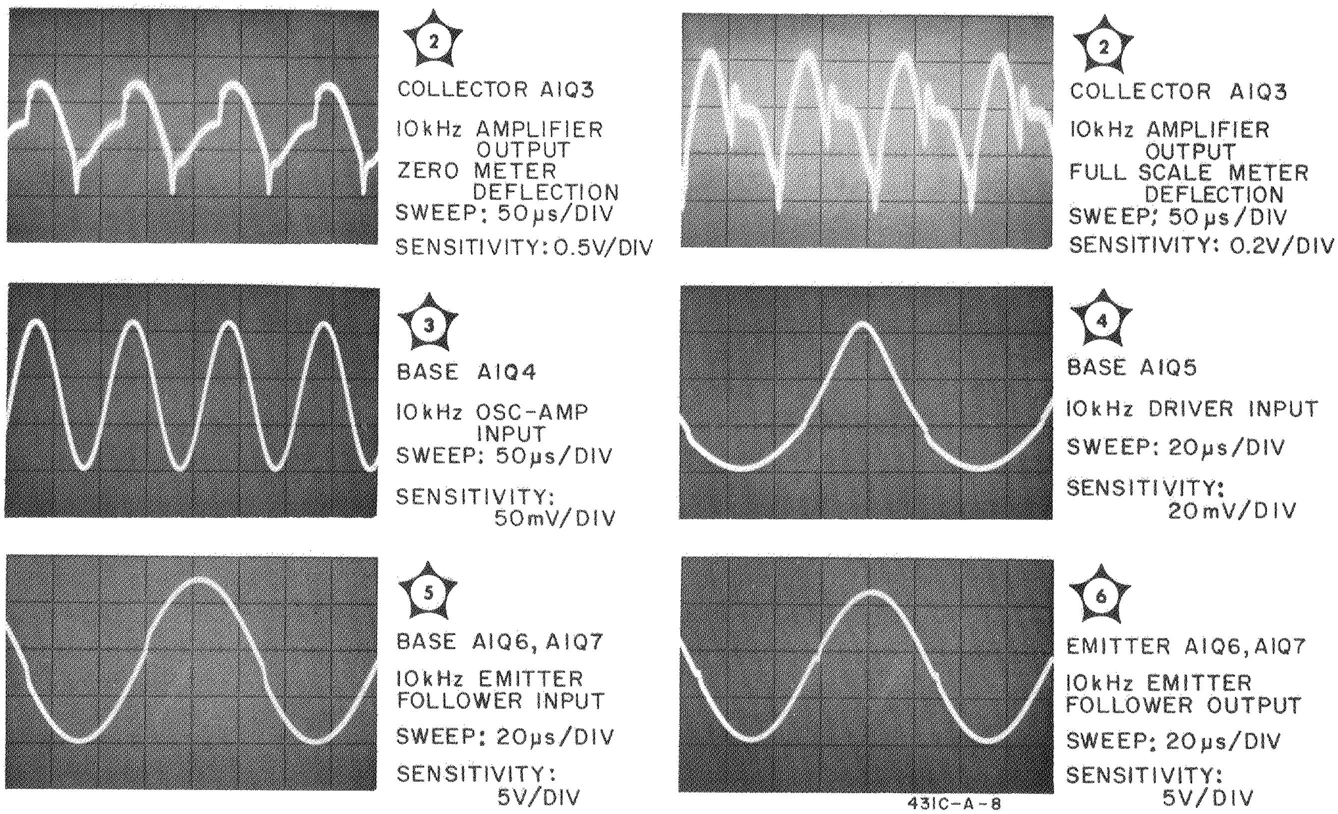


Figure 7-3. Assembly A1 Waveforms

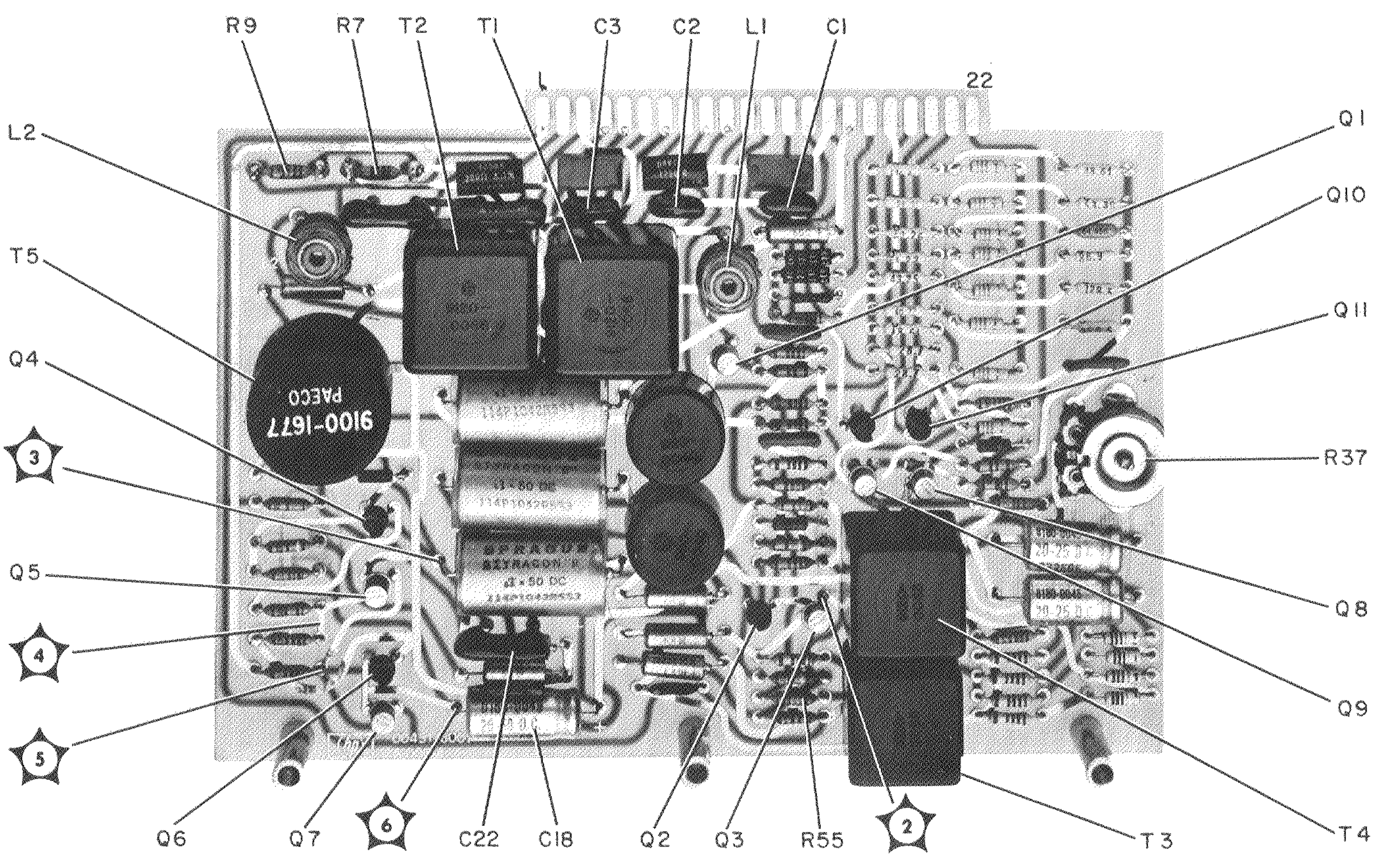
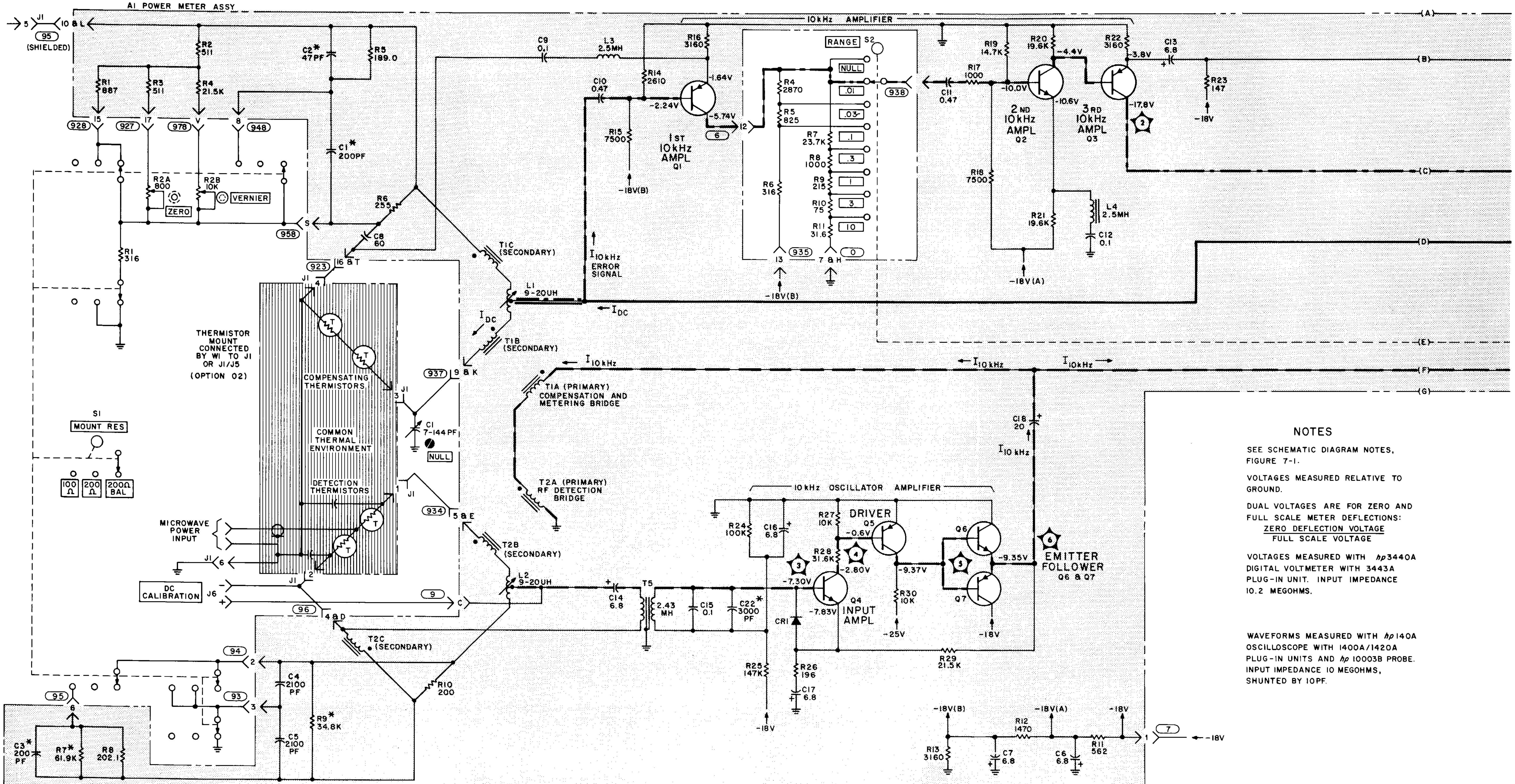


Figure 7-4. Power Meter Assembly A1



NOTES

SEE SCHEMATIC DIAGRAM NOTES, FIGURE 7-1.

VOLTAGES MEASURED RELATIVE TO GROUND.

DUAL VOLTAGES ARE FOR ZERO AND FULL SCALE METER DEFLECTIONS:
ZERO DEFLECTION VOLTAGE / FULL SCALE VOLTAGE

VOLTAGES MEASURED WITH hp 3440A DIGITAL VOLTMETER WITH 3443A PLUG-IN UNIT. INPUT IMPEDANCE 10.2 MEGOHMS.

WAVEFORMS MEASURED WITH hp 140A OSCILLOSCOPE WITH 1400A/1420A PLUG-IN UNITS AND hp 10003B PROBE. INPUT IMPEDANCE 10 MEGOHMS, SHUNTED BY 10PF.

Figure 7-5. Detection and Metering Bridges with 10 kHz Oscillator Amplifier and 10 kHz Amplifier

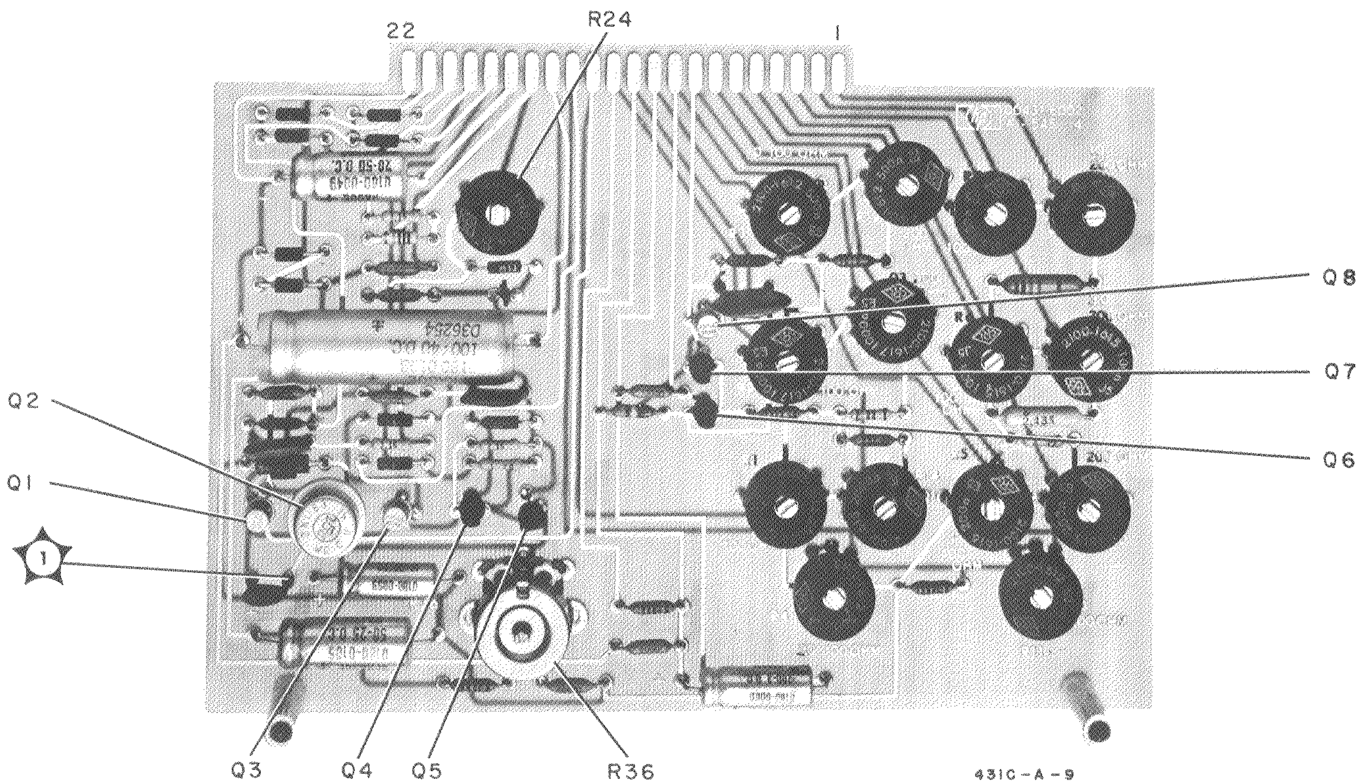
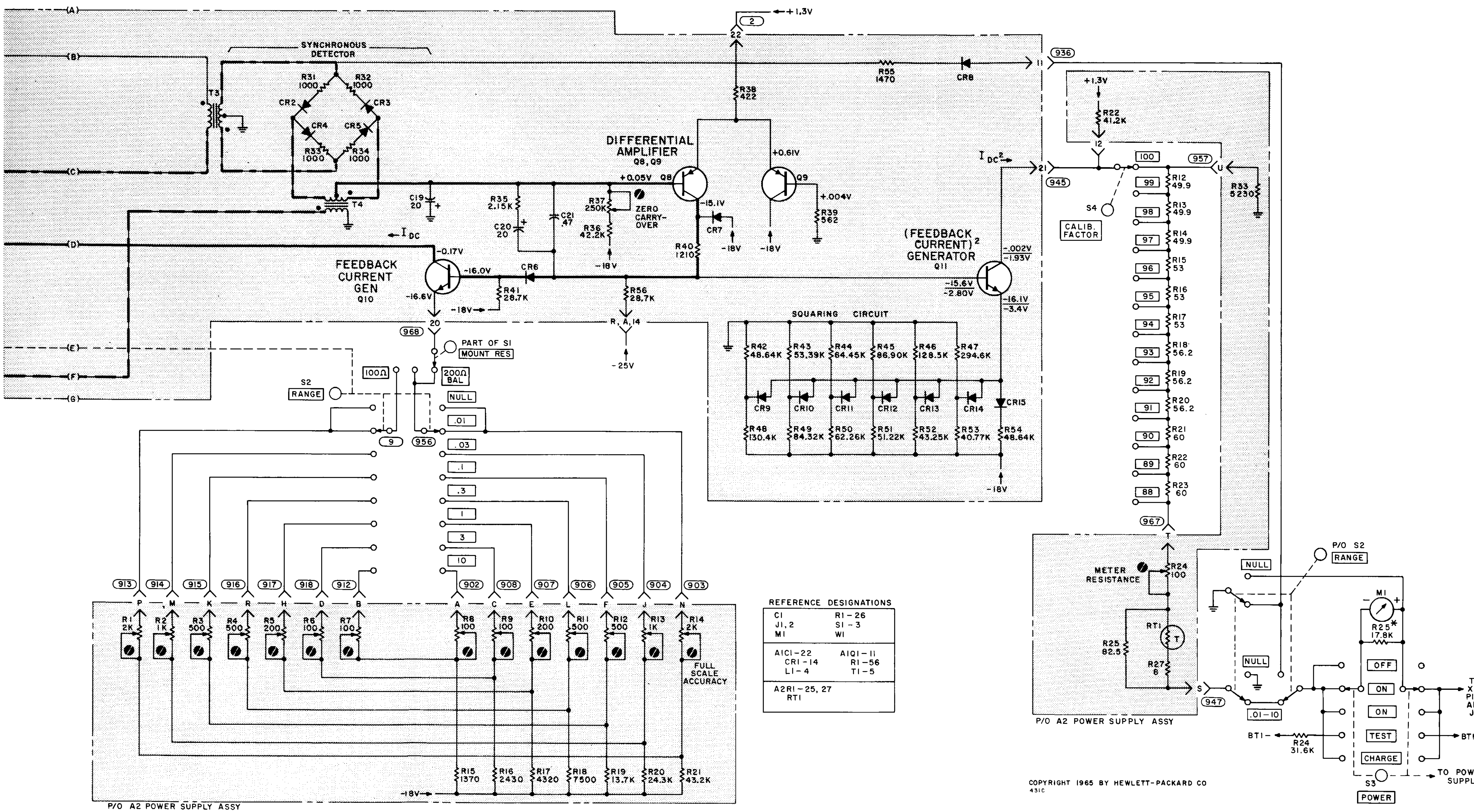


Figure 7-6. Power Supply Assembly A2



REFERENCE DESIGNATIONS	
C1 J1, 2 M1	R1 - 26 S1 - 3 W1
A1C1 - 22 CR1 - 14 L1 - 4	A1Q1 - 11 R1 - 56 T1 - 5
A2R1 - 25, 27 RT1	

Figure 7-7. Synchronous Detector, Feedback and Metering Circuits

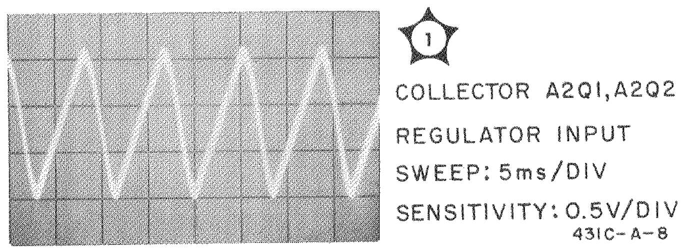


Figure 7-8. Power Supply Waveform

NOTES

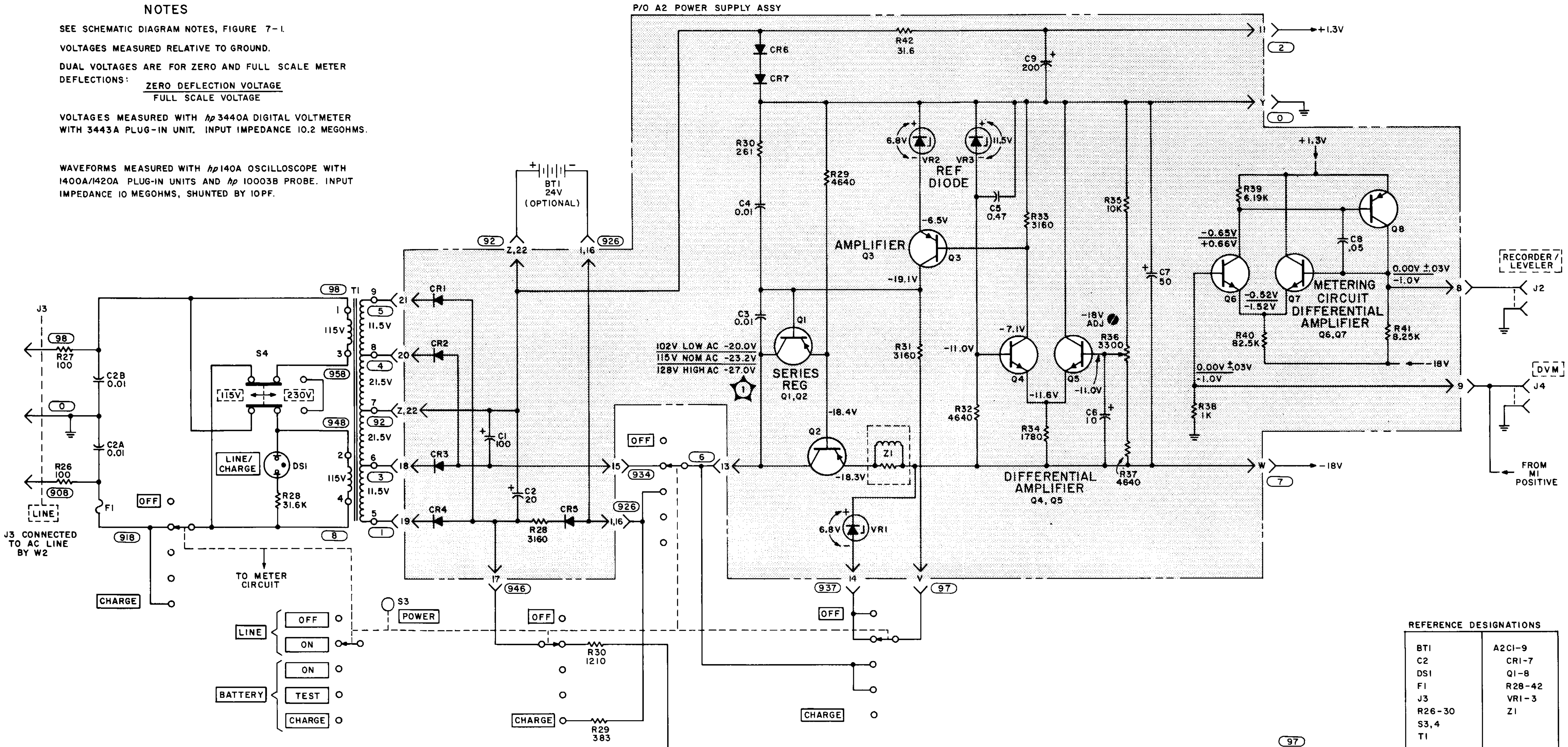
SEE SCHEMATIC DIAGRAM NOTES, FIGURE 7-1.

VOLTAGES MEASURED RELATIVE TO GROUND.

DUAL VOLTAGES ARE FOR ZERO AND FULL SCALE METER DEFLECTIONS: $\frac{\text{ZERO DEFLECTION VOLTAGE}}{\text{FULL SCALE VOLTAGE}}$

VOLTAGES MEASURED WITH *hp* 3440A DIGITAL VOLTMETER WITH 3443A PLUG-IN UNIT. INPUT IMPEDANCE 10.2 MEGOHMS.

WAVEFORMS MEASURED WITH *hp* 140A OSCILLOSCOPE WITH 1400A/1420A PLUG-IN UNITS AND *hp* 10003B PROBE. INPUT IMPEDANCE 10 MEGOHMS, SHUNTED BY 10PF.



REFERENCE DESIGNATIONS

BT1	A2C1-9
C2	CR1-7
DS1	Q1-8
F1	R28-42
J3	VR1-3
R26-30	Z1
S3,4	
T1	

Figure 7-9. Power Supply and Metering Output

APPENDIX I
OPTION 01

A1-1. The 431C Option 01 instrument consists of a standard Model 431C Power Meter with a rechargeable battery installed. A list of Option 01 component parts is given in Table 6-1. Instruction for installation of the battery is given in the following paragraph.

A1-2. OPTION 01 INSTALLATION PROCEDURE.

a. Set POWER switch to LINE OFF and remove power plug from power meter.

b. Remove top and bottom instrument covers.

c. Refer to Figure A1-1 which shows the battery cover disassembled from the battery. Install the battery and battery cover from the bottom of the instrument into the top chassis. Note that the battery is installed so that the two battery terminals are toward the top and front of the instrument.

d. Secure the battery in place with four retaining nuts.

CAUTION

Be careful not to short the battery terminals; battery cell damage may result.

e. Solder a red wire (No. 22 gauge, stranded) between the positive battery terminal and circuit board connector XA2, pin Z.

f. Solder a black wire (No. 22 gauge, stranded) between the negative battery terminal and circuit board connector XA2, pin 1.

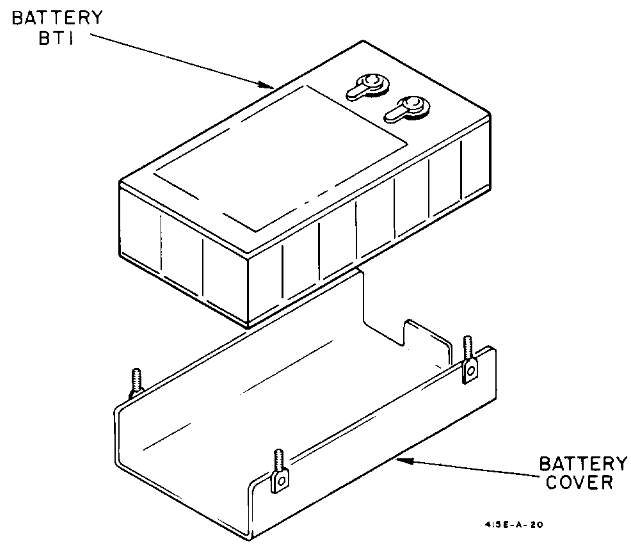


Figure A1-1. Battery and Battery Cover Assembly

HEWLETT hp PACKARD
GmbH

MANUAL CHANGES

MODEL 431 C

POWER METER

Manual Serial Prefixed: 548-
Manual Printed: Feb. 1966

To adapt this manual to instruments with other serial prefixes check for errata below, and make changes shown in tables.

Instrument Serial Prefixes		Make Manual Changes
G-615-	and above	
G-615-00221	and above	1
G-615-00261	and above	1 - 2
G-615-00341	and above	1 - 3
G-647-00561	and above	1 - 4
G-647-00811	and above	1 - 5

ERRATA: For instruments supplied with "German Schuko" power cable change W2 to cable power -hp- Stock No. 8120-0100

Paragraph 3-12:
Add the sentence, "Option 01 installation instructions are given in Appendix 1".

Paragraph 3-29, step h:
Change equation to read, "... Power = $\frac{P1 + P2}{2}$."

Paragraph 4-34:
Change fourth sentence to read: "... and unregulated -25 VDC operate..."

Paragraph 3-7 and Figure 3-8, step 2, add the following:

CAUTION
To avoid severe damage to the thermistor mount, be careful not to move the MOUNT RES switch while operating the RANGE switch.

March 17. 1967

MODEL 431C

ERRATA: (Cont.)

Figure 7-9:
Add connection between terminal "V" and the -25V lead to R30.
Paragraph 4-25
Change third sentence to read:
"... proportional to the square root of applied power..."
Figure 7-5, 7-7, and Parts List:
Change R6, A1C4, A1C5, and A1R36 to factory selected parts, typical value shown.
Figure 7-7:
Change A1R47 to 259.6 K

Table 1-1:
Change Zero Carryover specification to read, "Zero-Carryover: Less than ±1.0 % of full scale..."

Paragraph 3-4:
Change second sentence to read, "... is accurate to ±1.0 %..."
Table 5-2:
Change Performance Test 2, ZERO CARRYOVER to read, "Less than ±1.0 % of full scale..."
Change step c to read, "Adjust ZERO for 0.00 VDC..."
Change step d to read, "... within 0.00 ±0.01 VDC..."
Paragraph 5-19:
Change step b to read, "... within 0.00 ±0.01 VDC..."
Tables 6-1 and 6-2, add: -hp- Stock No.
A2Z1, choke, 431A-60A
Table 1-1 and 5-2, change "Accuracy" to read:

Accuracy: (+20°C to +35°C)
±1 % of full scale (.1 mw range and above)
±1.5% of full scale (.03mw range)
±2 % of full scale (.01mw range)
(0°C to +55°C)
±3 % of full scale on all ranges

Paragraph 1-2: Delete reference to 1 % accuracy.

CHANGE 1:	J1,5:	Change Connector - recept.6 pin to	1251-1280
CHANGE 2:	A1C4, A1C5:	Change to C:fxd., 2250 pF 1% 300VDCW	0140-0235
CHANGE 3:	VR1:	Change to Diode-avalanche 6.81V ± 5%	1902-0048

MODEL 431C

ERRATA: (Cont.)

Figure 3-8: Change the Note following step 8 to read as follows:

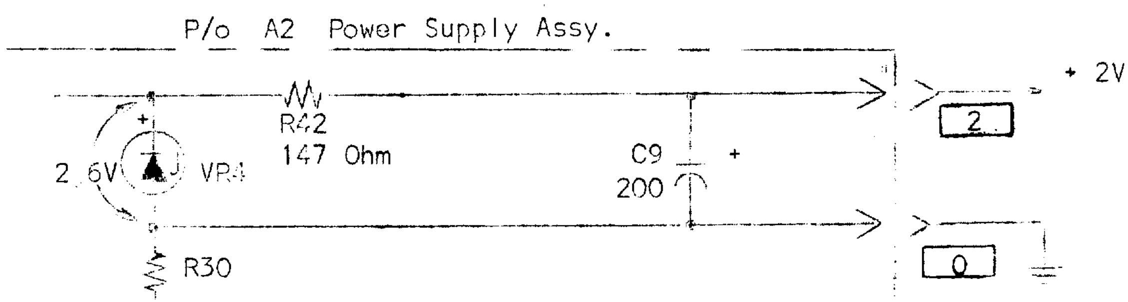
NOTE

Range - to - range zero carryover is less than ± 1,0 % if the meter has been properly adjusted mechanically (Paragraph 5-4) and the instrument has been properly zero - set electrically on its most sensitive range. For maximum accuracy, zero - set the power meter on the range to be used.

CHANGE 4:

			-hp- Stock No.
Change:	R32:	R:fxd., to 1.21 K Ohm, ±1%, 1/8W	0757-0274
	R33,37:	R:fxd. to 10 K Ohm, ±1%, 1/8W	0757-0442
	R34:	R:fxd., to 5.81 K Ohm, ±1%, 1/8W	0757-0439
	VR3:	Diode to Zener 9.0 V	1902-0071
Delete:	A1C2:	Capacitor-fixed (51 pF normally)	0160-2201

CHANGE 5: Change Figure 7-9, Power Supply and Metering Output as follows:



Change:	R4 *	R:fxd., met flm to 3.4 K Ohm, ±1%, 1/8W	0698-3440
	A2R42	R:fxd., met flm to 147 Ohm, ±1%, 1/8W	0698-3438
	VR3	Diode Zener to	1902-0596
Add:	A2VR4	Diode breakdown 2,61 V	1902-0126
Delete:	A2CR6,7	Diode - Si 200 PIV .5 Amp.	1901-0026

March 17, 1967

33-0167-20000

HEWLETT hp PACKARD GmbH

MANUAL CHANGES

MODEL 431 C

POWER METER

Manual Serial Prefixed: 707-
Manual Printed: März 1967

To adapt this manual to instruments with other serial prefixes check for errata below, and make changes shown in tables.

Instrument Serial Prefixes		Make Manual Changes
G-726-	and above	

			-hp- Stock No.
ERRATA:			
Change:	R4	to R4* R:fxd., 3.5K Ohm, ±1%, 1/8W(fac.sel.val.)	0698-3440
	A1C4	C:fxd., to 2250 pF, ±1%, 300 VDCW	0140-0235
	A2R2	R:var. to 1 K Ohm, ± 20 %	2100-1617
	A2R42	R:fxd., to 147 Ohm, ±1%, 1/8W	0698-3438
	A2VR1	to Diode - avalanche 6.81 V ± 5 %	1902-0043
	R24	R:fxd. to 28.7 K Ohm, ±1%, 1/8W	0698-3449
	S1	Switch Assy:Mount Res. to	00431-6005
	S4	Switch Assy:Cal. incl.: R12-R2, R33 to	00431-6003
Delete:	A2CR6,7	Diode - Si 200 PIV .5Amp.	1901-0026
	J1	Connector : 6 Female Contacts	1251-1280
	J1	Nut : knurled	1251-1281
Add:	A2VR4	Diode breakdown 2.61 V	1902-0126
	J1	Insert Connector	1251-1628
	J1	Insulator Connector	1251-1629
	J1	Body female connector	00431-2011
	S5	Switch - slide	3101-0033
	For instruments supplied with German "Schuko" power cable change:		
	W2	Cable : Power to	8120-0100

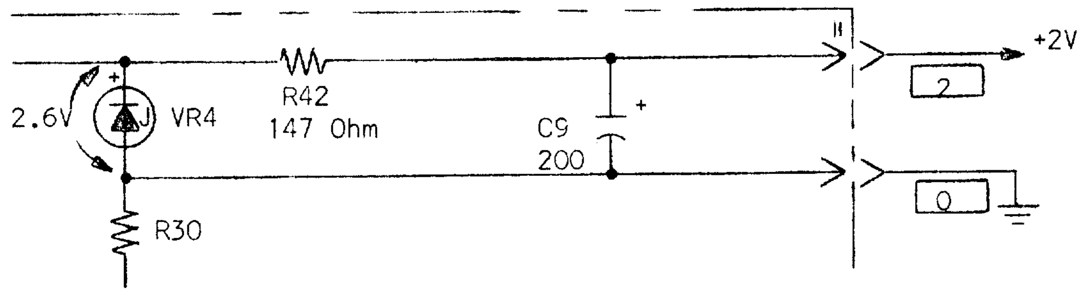
9282 - 0572

MODEL 431C

ERRATA: (Cont.)

In Figure 7-9, Power Supply and Metering Output change as follows:
S4 should read S5

P/o A2 Power Supply Assy.



Page 1-1, Table 1-1, Change Accuracy specification to read:
+20°C to + 35°C
±1% 100 uW Range and above
±1.5% 30 uW Range
±2% 10uW Range
0°C to + 55°C
±3% on all Ranges.

33-0567-10000