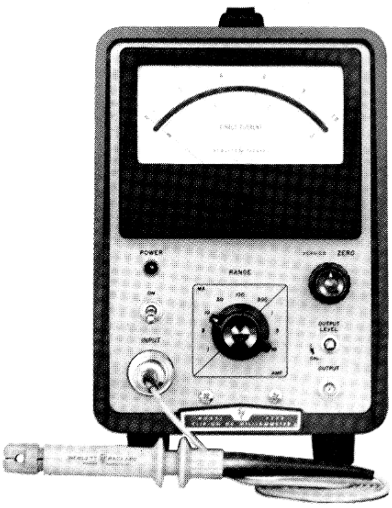
OPERATING AND SERVICE MANUAL

CLIP-ON DC MILLIAMMETER

428B



HEWLETT hp PACKARD

HP 428B

428B SPECIFICATIONS

Table 1-1.

Current Range:
1 mA to 10 A full-scale, nine ranges.

Accuracy:
±3% of full-scale ±0.15 mA, from 0°C to 55°C. (When instrument is calibrated to probe).

Probe Inductance:
Less than 0.5 µH.

Probe Induced Voltage:
Less than 15 mV peak (worst case at 20 kHz and harmonics).

Output:
Variable linear output level with switch position for calibrated 1 V into open circuit (corresponds to full-scale deflection).
1.5 V Max. into open circuit in uncalibrated position.
0.73 ± .01 V into 1 kΩ in calibrated position.

Noise:
1 mA Range, < 15 mV rms across 1 kΩ.
3 mA Range, < 5 mV rms across 1 kΩ.
10 mA thru 10 A Ranges, < 2 mV rms across 1 kΩ.

Frequency Range:
DC to 400 Hz (3 dB point).

AC Rejection:
Signals above 5 Hz with peak value less than full-scale affect meter accuracy less than 2%. (Except at 40 kHz carrier frequency and its harmonics). On the 10 A range, ac peak value is limited to 4 A.

Probe Insulation:
300 V Max.

AC Power:
115 or 230 V ± 10%, 48 to 440 Hz, 71 W.

Operating Temperature:
- 20°C to + 55°C.

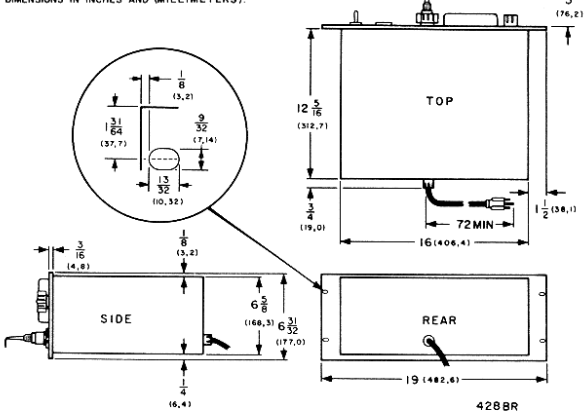
Weight:
Rack Mount
Instrument weight: 18 3/4 lbs. (8.5 kg)
Shipping weight: 30 lbs. (13.6 kg)
Cabinet Mount
Instrument weight: 16 5/8 lbs. (7.5 kg)
Shipping weight: 19 lbs. (8.6 kg)

Accessories Available:

-hp- Model 3529A	Magnetometer Probe
-hp- Model 11035A	Output Cable
-hp- Model 10110A	Output Adapter

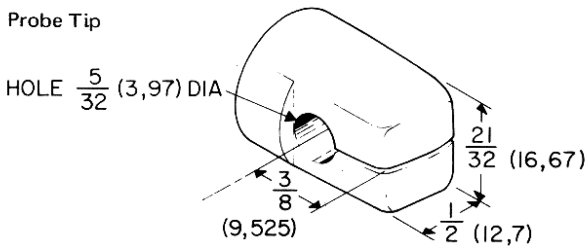
Dimensions:
Rack Mount

NOTE
DIMENSIONS IN INCHES AND (MILLIMETERS).



Cabinet Mount:
7½" wide, 11½" high, 14½" deep (190,5 x 292,1 x 368,3 mm).

Probe Tip



SECTION I
GENERAL INFORMATION

1-1. INTRODUCTION.

1-2. The -hp- Model 428B Clip-On DC Milliammeter measures the magnetic field which exists around a wire carrying dc current. Operating the instrument is simple. After zero setting, the two jaws of the probe are clamped around the wire (arrow on probe head indicates direction of conventional current flow) and the meter will indicate the current.

1-3. There are nine current ranges from 1 mA to 10 amp full-scale deflection. The sensitivity can be increased even further by looping the wire several times through the opening in the probe. The current indication is virtually insensitive to superimposed ac signals and the series loading of the circuit is less than 0.5 μH. A large amount of feedback provides great stability.

1-4. OTHER PROBE HEADS.

1-5. Other probe heads are available to extend the usefulness of your Clip-On DC Milliammeter. Write to the nearest Sales and Service Office (listed in Appendix C) for further information. At the time of publication of this manual, the following accessory probe heads were available:

a. -hp- Model 3529A Magnetometer Probe (1 gauss = 1 amp).

b. -hp- Model 3529A Option C11 Magnetometer Probe (1 gauss = 1 mA).

1-6. Write to the nearest Sales and Service Office (listed in Appendix C) stating your complete requirements for information concerning special applications.

1-7. INSTRUMENT AND MANUAL IDENTIFICATION.

1-8. Hewlett-Packard uses a two-section serial number. If the first section (serial prefix) of the serial number on your instrument does not agree with those on the title page of this manual, change sheets supplied with the manual will define the differences between your instrument and the Model 428B described in this manual. Some serial numbers may have a letter separating the two sections of the number. This letter indicates the country in which the instrument was manufactured.

Figure 1-1. Model 428B Clip-On DC Milliammeter.

SECTION III
OPERATING INSTRUCTIONS

3-1. INTRODUCTION.

3-2. This section contains instructions and information necessary for operation of the Model 428B Clip-On DC Milliammeter.

3-3 OPERATING PRECAUTIONS.

CAUTION

a. BEFORE APPLYING OPERATING POWER TO THE 428B, VERIFY THAT THE LINE VOLTAGE SWITCH ON THE REAR PANEL INDICATES THE LINE VOLTAGE TO BE USED AND THAT THE INSTRUMENT IS PROPERLY FUSED.

b. THE PROBE IS INSULATED TO WITHSTAND 300 VOLTS MAXIMUM. DO NOT USE THIS PROBE ON A BARE WIRE WHICH IS MORE THAN 300 VOLTS *PEAK* ABOVE GROUND.

c. DO NOT USE THE 428B PROBE IN THE PRESENCE OF STRONG RF FIELDS.

d. DO NOT EXPOSE THE 428B PROBE TO TEMPERATURES EXCEEDING 130° F (55°C). DO NOT LAY THE PROBE ON TOP OF THE 428B CABINET (OR ANY OTHER HOT SURFACE). PROBE UNBALANCE AND EVENTUAL DAMAGE WILL RESULT.

e. DO NOT DROP THE PROBE OR RELEASE THE FLANGES ABRUPTLY SO THAT THE JAWS SNAP TOGETHER.

f. DO NOT OPERATE THE DEGAUSSER FOR MORE THAN THREE MINUTES CONTINUOUSLY.

g. BECAUSE THE 428B IS COOLED BY CONVECTION, PLACE THE 428B WHERE AIR CAN CIRCULATE FREELY THROUGH THE INSTRUMENT.

h. DO NOT USE THE 428B TO MEASURE DC IN A WIRE WHICH CARRIES MORE AC THAN FULL-SCALE READING ON THE METER.

3-4. OPERATING CONSIDERATIONS.

3-5. INTERCHANGING PROBE HEADS.

3-6. Each probe is calibrated at the factory with a particular instrument and carries the serial number of that instrument (serial number appears on probe connector). If a probe has to be replaced, a realignment and recalibration of the instrument is necessary (see also Section V Maintenance).

3-7. EFFECT OF MEASUREMENT ON CIRCUIT.

3-8. Reflected Impedance.

3-9. The probe will add a small inductance to the circuit of less than 0.5 microhenries due to the magnetic core and magnetic shield. This makes it ideal for measuring current in very low impedance paths such as ground loops where other instruments would disturb the circuit.

3-10. Induced Voltage.

3-11. The gating signal, driving the core in and out of saturation, will induce a voltage in the wire carrying the dc current. This induced voltage is less than 15 millivolts peak. If more than one loop is passed through the probe the induced voltage will be multiplied by the number of loops.

3-12. EFFECT OF CIRCUIT ON MEASUREMENT.

3-13. Circuit Impedance.

3-14. The impedance of the circuit being measured has practically no effect on the dc current measurement. A shorted loop inserted along with a wire carrying dc current will decrease the reading by only 0.2% of full scale.

3-15. AC Fields & Superimposed AC Current.

3-16. The instrument is designed to allow a high amount of ac ripple in the dc being measured. The presence of ac whose peak value equals full-scale reading (limited to 4 amperes peak on 10-ampere range) will cause less than 2% error in the dc reading. Examples of such high ac currents are found in the input of dc filter sections of power supplies.

3-17. Ac currents having frequency components of 40 kHz or harmonics thereof will cause error, as such signals will interfere with the 40 kHz output signal of the probe. The meter will indicate a beat reading if the interfering frequency is within approximately 15 cycles of 40 kHz or its harmonics. Although this situation is very improbable, accurate dc current readings can be obtained by shifting the frequency of the external ac signal slightly.

3-18. The instrument as well as the probe head should not be used in strong ac stray fields. Such fields may exist in the vicinity of open core power transformers, or large dc filter chokes, etc.

3-19. Magnetic Fields.

3-20. If the jaws of the probe are incompletely closed, the *magnetic shielding and the magnetic circuit* will have an air gap. The result is that dc fields, not associated with the dc current being measured, will cause a shift in the meter reading.

3-21. However, there will be an indication of a *strong* external dc field even with the jaws perfectly closed. Usually zero setting with the ZERO control compensates such residual readings for a particular probe location.

3-22. EARTH'S MAGNETIC FIELD. The earth's magnetic field will affect the reading if the jaws of the probe are not completely shielded (jaws partially open). The effect of this field is relatively strong – comparable to deflection due to about 500 mA of current. Complete closure of the jaws can be checked by switching to the 1 mA range with no dc current input. If the jaws mate properly, the zero set should stay within 0.2 mA while rotating the probe head with respect to the earth's magnetic field (probe aligned in an East-West direction).

3-23. If the zero shift is greater, the mating surfaces of the jaws need to be cleaned or the probe wiring may be open (see *Section V*).

3-24. FIELDS OF PERMANENT MAGNETS. Meter magnets have strong stray fields, which can cause shift in the current indication. Such fields are detected by bringing the closed probe in the area where the measurement is to be made and observing the zero shift (1 mA range).

3-25. FERROUS WIRE. Wires made out of magnetic materials can cause a current reading of 2-3 mA without any connection to the wire. This fact is *important* as leads of most transistors are made out of magnetic material.

3-26. OPERATING PRACTICES.

3-27. MECHANICAL OPERATION OF PROBE.

3-28. The probe jaws are opened by simply squeezing together the two flanges on the probe body. An internal spring returns the jaws to their proper position when the flanges are released. (See Paragraph 3-3e.).

3-29. DEGAUSSING OF PROBE HEAD.

3-30. To demagnetize the probe, proceed as follows:

a. Insert probe into degausser at the rear of the instrument (*located on front panel of rackmount models*) with arrow on probe in same position as arrow marked on chassis.

b. Depress degausser switch S3 to energize degausser.

c. Withdraw probe very slowly for the first few inches while depressing the degausser switch until probe is removed approximately one foot.

d. Zero instrument on 1 mA range with ZERO control.

3-31. Under normal operating conditions, degaussing may be necessary after measuring current on the 1 thru 10 AMP RANGE.

3-32. Normally, it takes about 10 seconds to degauss the probe when using the above method (see Caution, Paragraph 3-3f).

3-33. ELECTRICAL ZERO SET.

3-34. If the instrument cannot be zero set electrically (with ZERO control) there are two probable causes:
1) Incomplete closure of probe jaws, 2) Magnetization of probe head.

3-35. Dust deposits on the lapped surfaces of the probe jaws create an air gap. If the jaws are not completely closed, the earth's magnetic field will affect the reading. With the RANGE *switch at 1 mA, rotation of the closed probe* should not vary the zero set more than 0.2 mA. Cleaning of the jaws will restore proper operation conditions (see Section V, Cleaning of Probe Jaws).

3-36. Magnetic shields protect the probe head from stray magnetic fields. However, excessive dc currents (such as short circuit discharge currents from electrolytic capacitors, etc.) will magnetize the probe. For demagnetization of probe head, see Paragraph 3-29, Degaussing of Probe Head.

3-37. POLARITY OF CURRENT.

3-38. The arrow on the probe head indicates the direction of the conventional current flow for upscale reading. Reversal of the current flow direction will reverse the indication on the meter (see Figure 3-2).

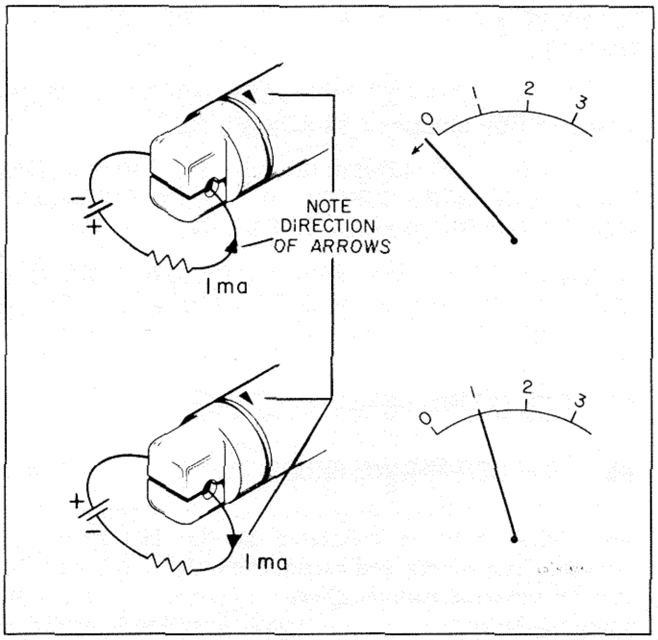


Figure 3-2. Polarity of Current.

3-39. INCREASING THE ABSOLUTE SENSITIVITY.

3-40. The sensitivity of the instrument can be increased by looping the wire (carrying the dc current) several times through the opening of the probe (see Figure 3-3). For example, three turns increase the sensitivity three times. With an increased sensitivity, however, the induced voltage between the probe and the circuit under measurement will increase also.

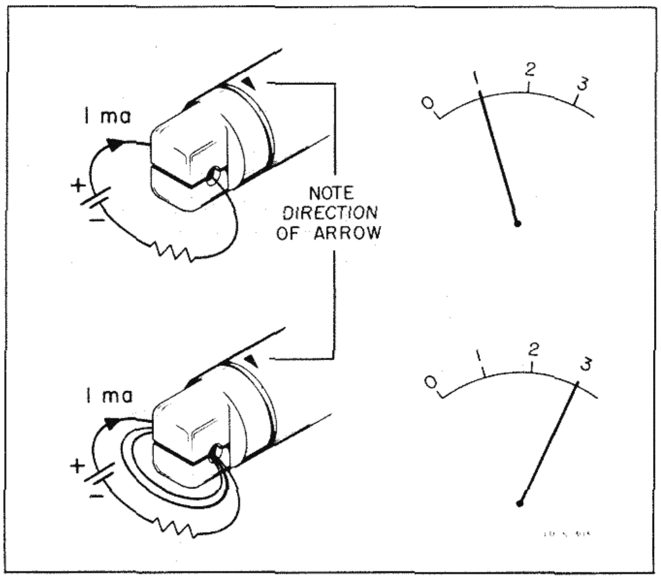


Figure 3-3. Increasing The Absolute Sensitivity.

3-41. CURRENT CHECK LOOPS.

3-42. In restricted situations such as printed circuit boards, wire loops for the probe can be built into the circuit to allow convenient current measurements with the Model 428B. Here, currents can then be measured under operating conditions with the same ease as voltage measurement.

3-43. Circuits can also be modified to accept an impromptu loop for testing. As an example, to measure the collector current of a transistor for troubleshooting purposes, the collector lead can be removed from the board and a loop of fine wire soldered between the collector lead and the board. To measure current through a resistor, lift one lead and install a series loop, clip the 428B probe around the loop and measure current through the resistor. As an alternative, an eqivalent resistor with long leads can be installed to replace the resistor in question.

3-44. NULLING CURRENTS.

3-45. The resolution of the 428B can be increased by nulling one current against another and measuring the difference between the two. To null the reading, clip the probe over both wires at once with the wires so arranged that the currents are going in opposite directions. The considerations mentioned in Paragraph 3-39 also apply to current nulling. For example, assume that a 0.6 A current source is to be tested against a 0.4 A standard. The 0.6 A supply should be looped twice through the probe jaws and the 0.4 A supply should be looped three times through the jaws such that the two currents oppose each other. It should be remembered when making such a measurement, that the absolute value of any deviations observed have been multiplied. If, in the above example, the 0.6 A supply wavered by .01 A, the change would be read as .02 A on the meter.

3-46. USE OF OUTPUT JACK.

3-47. The OUTPUT jack enables the 428B to be used as a dc-coupled amplifier/I-E transducer/isolator. The basic action of the 428B (considered as an input/output device) is to sense the magnetic field around a current carrying wire and deliver a proportional voltage at the OUTPUT jack. The value of the output can be varied by using the OUTPUT LEVEL control to produce as much as 1 1/2 volts at 1 mA. While the 428B meter registers average dc (ignoring ac), the output at the OUTPUT jack contains both the dc and ac components of the signal being measured.

3-48. With Oscilloscope.

3-49. To display the output of the 428B on an oscilloscope:

a. If the oscilloscope is dc coupled, it can be calibrated as in Paragraph 3-51.

b. Clip the probe around the wire which contains the signal to be displayed.

c. Connect the oscilloscope input to the 428B OUTPUT jack.

d. Adjust the 428B RANGE switch to the appropriate range.

3-50. With Recorder.

3-51. To record the output of the 428B on a graphic recorder:

a. Insure that the recorder's input impedance exceeds 1400 ohms.

b. Connect the recorder input to the 428B OUTPUT jack.

c. Zero the 428B on the 1 mA Range, turn OUTPUT LEVEL to minimum output.

d. Zero the recorder.

e. Adjust the 428B ZERO control for full-scale on the 428B meter.

f. Adjust the 428B OUTPUT LEVEL control for full scale on the recorder.

g. Zero the 428B, switch to the appropriate range and clamp the 428B probe around the wire which carries the signal to be measured.

3-52. When recording current variations with the 428B, it should be borne in mind that the 428B displays some long term zero drift. The 428B zero drift normally amounts to about 300 μA (indicated) per day so periodic checks should be made to determine whether or not the ZERO controls need adjustment.

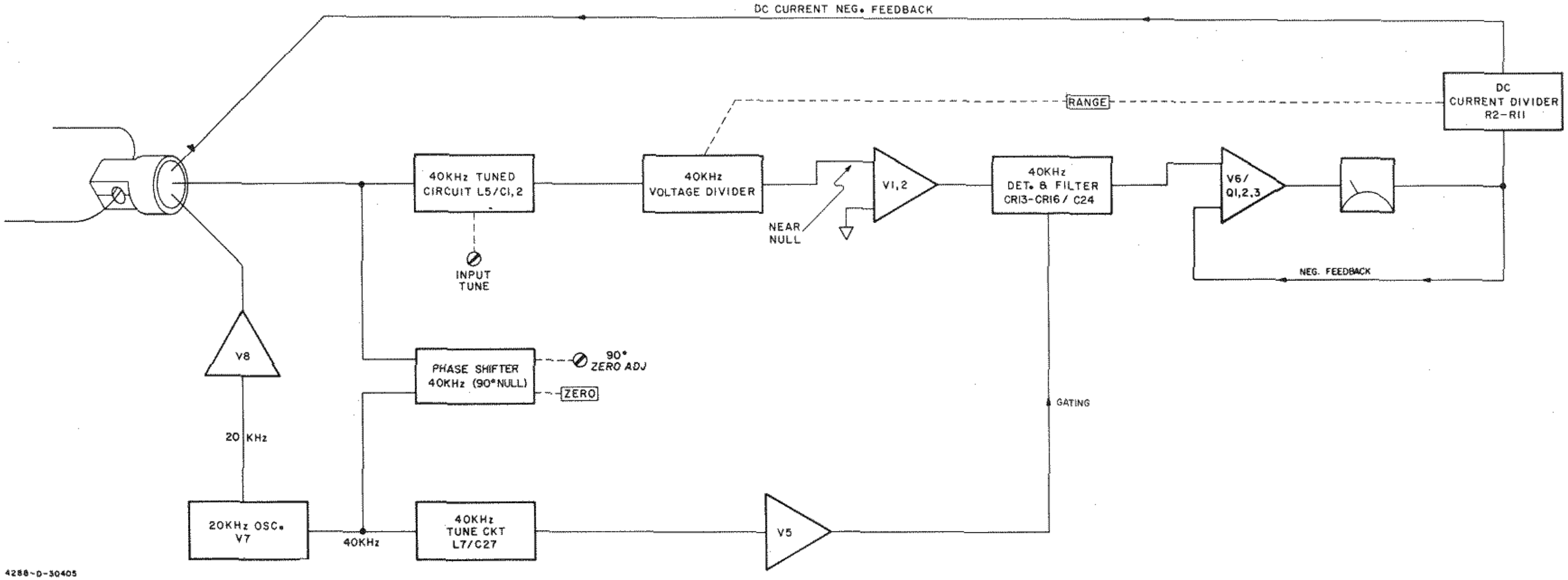


Figure 4-1. Block Diagram.

SECTION IV
THEORY OF OPERATION

4-1. INTRODUCTION.

4-2. This section describes the overall operation of the Model 428B, the operating principle of the current probe and the function of the different circuits of the instrument.

4-3. THEORY OF OPERATION.

4-4. The simplified block diagram of Figures 4-1 and 4-2 shows the basic operation of the Model 428B Clip-On DC Milliammeter.

4-5. The probe clips around a wire carrying dc current and delivers a 40 kHz output signal which is proportional to the dc current. For transducing the dc current into a 40 kHz signal, the probe requires a 20 kHz gating signal, as described in detail under Paragraph 4-9, Current probe.

4-6. The 40 kHz output signal of the probe is amplified, detected and fed back as negative feedback current to the probe head cancelling the effect of the measured dc current and thus reducing the 40 kHz output signal almost to zero. The negative feedback current, being proportional to and magnetically almost equal to the dc current of the inserted wire, is used to indicate the measured dc current.

4-7. The 20 kHz oscillator has two functions: First, it supplies a 20 kHz signal for driving the probe head, and also provides a 40 kHz (second harmonic) signal for gating the 40 kHz Synchrononous Detector.

4-8. Due to slight unbalances, the probe head output contains a small 40 kHz signal, even with no dc current being measured. A 40 kHz phase-shifter output cancels such residual 40 kHz signal (zero-set controls).

4-9. CURRENT PROBE.

4-10. The probe head is a specially designed second harmonic flux-gate type of magnetometer used to measure the magnetic field around a wire carrying direct current.

4-11. The flux gate principle is easily understood by referring to the mechanical model shown in Figure 4-3.

4-12. Coil A (representing wire through probe), is energized with dc, producing a dc flux in the core. Armature is rotating at a constant rate (F), gating the flux 2F times per second inducing a voltage of 2 F frequency in coil B. The amplitude is determined by the dc in coil A.

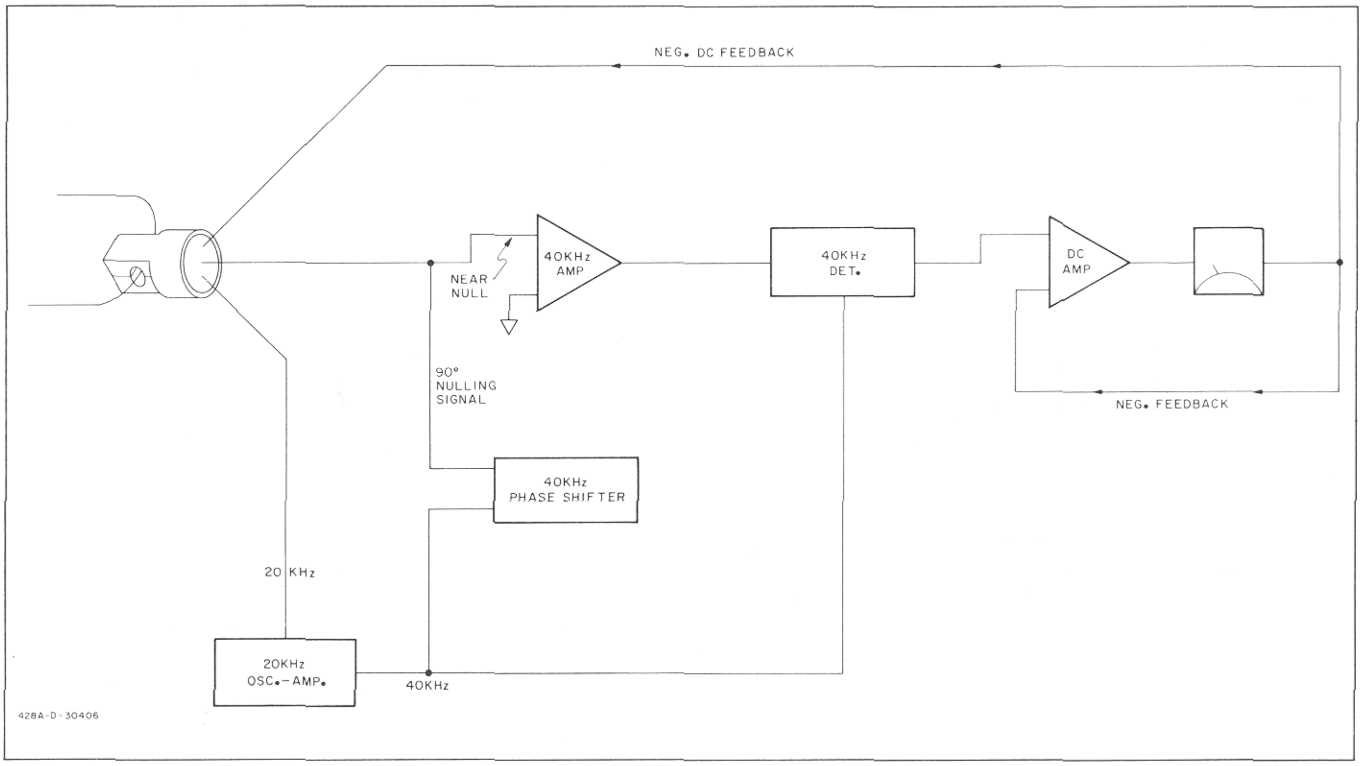


Figure 4-2. Simplified Block.

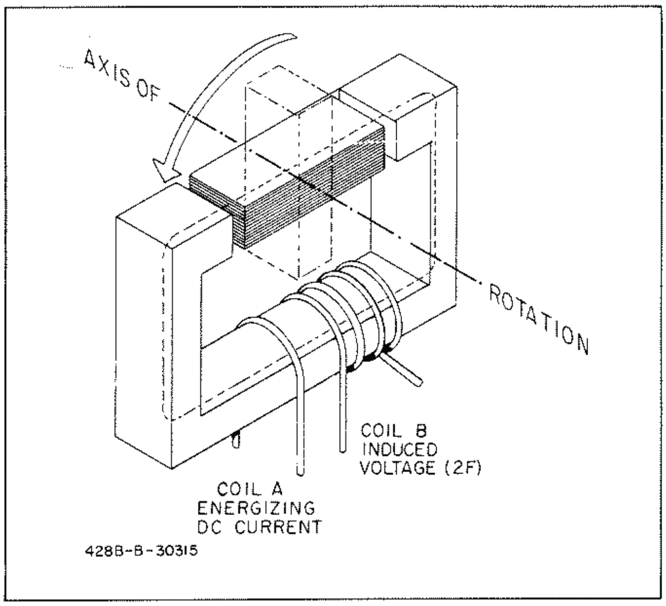


Figure 4-3. Magnetic Mechanical Analogy.

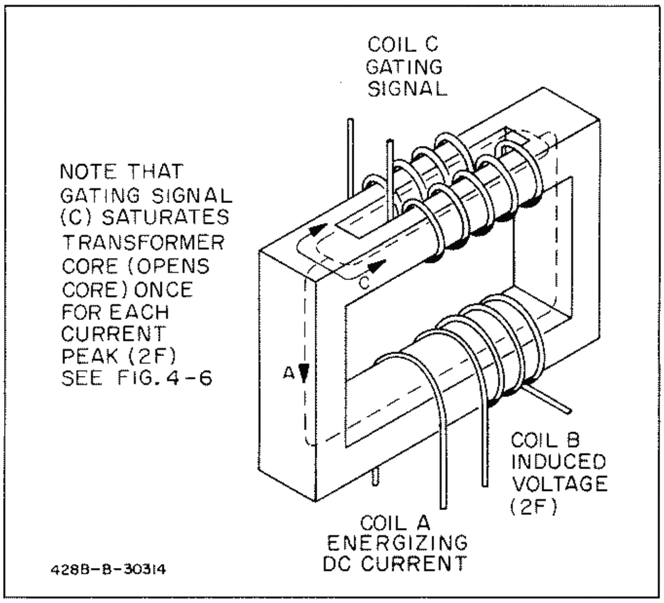


Figure 4-4. Basic Flux Gate.

4-13. The Model 428B head uses this principle in a similar way. Figure 4-4 shows the basic concept of a saturable flux gate.

4-14. A magnetic core in saturation loses permeability and, therefore, is comparable to a core that has been mechanically opened (low permeability due to air gap).

4-15. Coil C saturates the core periodically with a 20 kHz signal, driving the small cores in and out of saturation twice per cycle or once for each peak (positive or negative) of the input current.(See Figure 4-6) **The only function of the 20 kHz signal is to gate the dc flux in the core of the current probe.**

4-16. The 428B probe head is actually analogous to the flux gate shown in Figure 4-5. The energizing dc current produces flux path "A". Flux path "A" is periodically interrupted by saturation of the (transformer type) core, a result of the two flux paths "C". Refer to Figure 7-3 and note that the current enters L3 and L4 from the same end and that the coils are wound in opposite directions causing opposite magnetic polarities and the consequent circular flux path (c).

4-17. The four coils in the 428B probe head serve 3 purposes: (a) To saturate the cores, a result of the 20 kHz current that flows between pins 1 and 2. This current is generated by the 20 kHz oscillator-amplifier circuits. (b) To act as a secondary, picking up a chopped signal from the

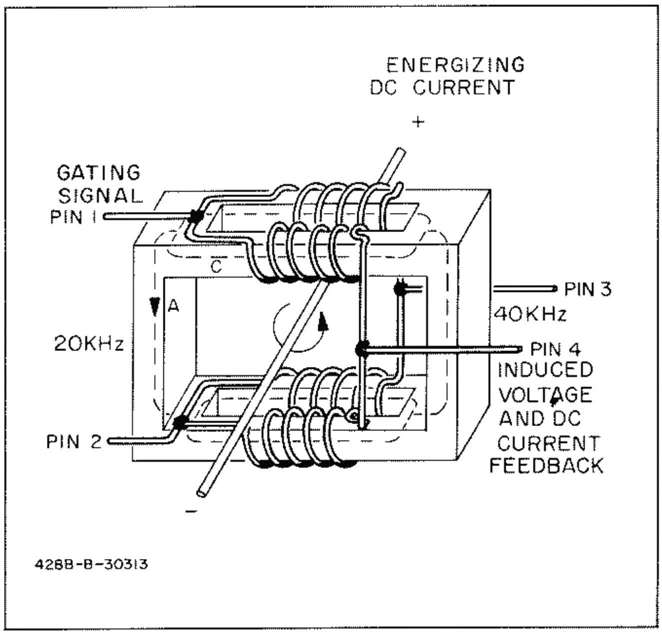


Figure 4-5. 428B Flux Gate.

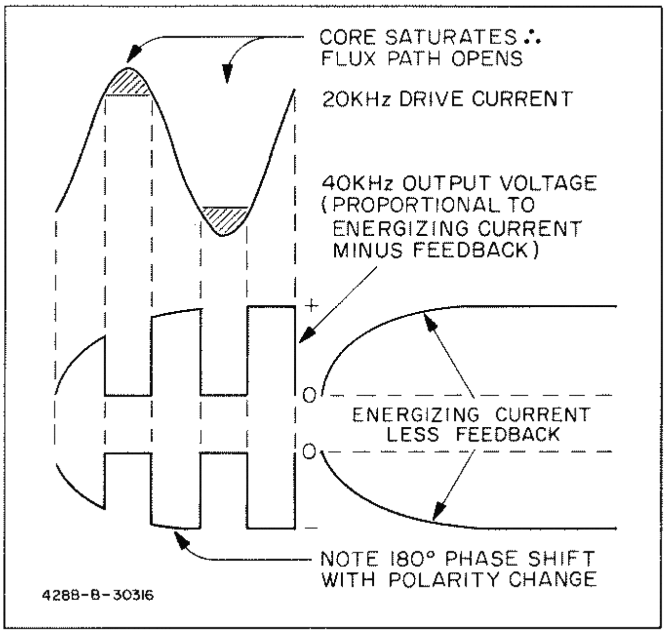


Figure 4-6. Waveforms.

wire that is clamped in the probe jaws. (c) To conduct the dc feedback current that tends to annul the energizing dc current from the wire being measured.

4-18. Because the coils are electrically arranged in a balanced bridge circuit, the 20 kHz signal is balanced at the output of the bridge (pins 3 and 4); and there is no 20 kHz differential signal at this point. The 40 kHz signal and the dc feedback current are also nulled out by the balanced bridge so that these signals do not appear as a differential voltage across pins 1 and 2. The dc feedback current is isolated from the 40 kHz amplifier by capacitor C11. The 40 kHz is kept out of the dc circuitry by RF choke L6.

4-19. 20 kHz OSCILLATOR.

4-20. The function of the 20 kHz oscillator is to generate a balanced 20 kHz signal which, after amplification, is used for driving the probe head in and out of saturation.

4-21. The circuit of the 20 kHz oscillator is shown in Figure 7-3. The oscillator V7 is operating in push-pull having a plate circuit tuned to 20 kHz. Transformer coupling provides positive feedback through resistors R94 and R95 to the oscillator control grids. The control grids of oscillator V7 supply the drive signal for the push-pull head drive amplifier V8. The oscillator level is adjusted by controlling the cathode current of V7.

4-22. The common cathodes of oscillator V7 supply the 40 kHz signal (2 pulses per 20 kHz cycle) needed for the synchronous detector gate amplifier V5 and the 40 kHz phase shifter.

4-23. HEAD-DRIVE AMPLIFIER.

4-24. The head-drive amplifier V8 supplies the balanced 20 kHz signal for the probe head. Drive balance adjustment R98 controls the current ratio of the two triode sections, and hence the second harmonic output. The dc bias voltage for the oscillator and the head-drive amplifier is obtained from reference tube V11.

4-25. DETECTOR GATE AMPLIFIER.

4-26. The 40 kHz resonant circuit C1, C2, and L5 increases the level of the gate signal and filters out all signals except 40 kHz. It also allows phase adjustment of the signal to correspond to the phase of the Synchronous Detector.

4-27. The operation of the Synchronous Detector requires a high level 40 kHz signal. The 40 kHz output signal of the oscillator V7 passes through a tuned circuit and drives the gate amplifier V5. The output of V5 delivers a 40 kHz gate signal to the Synchronous Detector.

4-28. 40 kHz INPUT/AMPLIFIER CIRCUIT.

4-29. The 40 kHz output voltage of the probe head is resonated by a 40 kHz series resonant circuit (L5 and C1/C2). Resistor R1 broadens the resonance response by lowering the Q to minimize drift problems. The 40 kHz signal passes through a voltage divider S1B, which keeps the loop gain constant for all current ranges by maintaining a constant input level range to stage V1. The output of the 40 kHz amplifier V1 is band-pass coupled to the 40 kHz detector driver stage V2. The output signal of V2 is isolated from ground by transformer T2, and fed to the 40 kHz synchronous detector.

4-30. SYNCHRONOUS DETECTOR AND FILTER (C24).

4-31. The Synchronous Detector detects the amplitude and the phase of the 40 kHz signal. Phase detection is necessary to preserve negative feedback at all times. Since the probe may be clipped over the wire in either of two ways the phase of the signal may vary by 180°. If phase detection were not present this 180° phase reversal would cause positive feedback and the instrument would oscillate. With phase detection the polarity of the feedback will change also, maintaining the feedback negative around the system at all times.

4-32. The synchronous detector requires a large 40 kHz gating signal, having the frequency of the desired signal. Figure 4-7 shows the synchronous detector drawn as a bridge circuit.

4-33. On one half-cycle, with A much more positive than E and with B equally more negative that E, the balanced circuit ACB conducts hard, and C becomes effectively equal to point E. Circuit BDA is opened at this time by its back-biassed diodes,and only the signal that appears across the conducting half of the T2(FC) will charge C24.

4-34. On the next half-cycle BDA conducts, ACB becomes open, and the signal across FD will charge C24. If signal F is positive with respect to C on the first half-cycle, signal F will be positive with respect to D on the second half-cycle, and the top of C24 will consistently be charged positively. If the signal at F changes phase by 180° with respect to the gating signal at T3, the top of C24 will consistently be charged negatively.

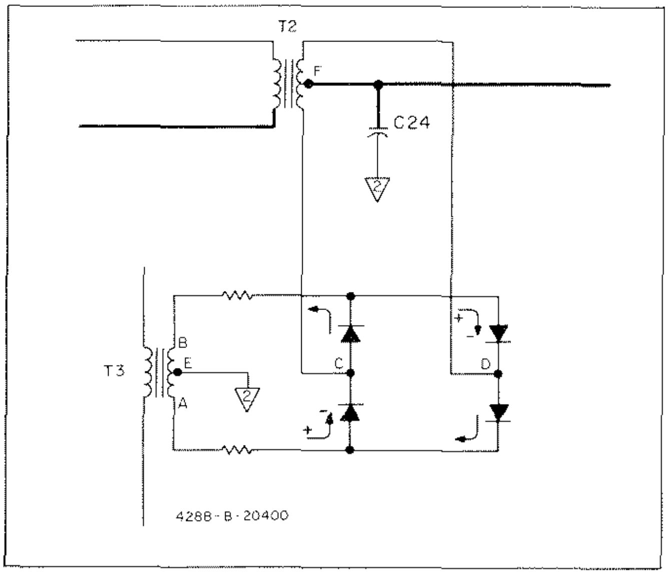


Figure 4-7. Detector Bridge.

4-35. In summary then, C and D are alternately grounded, and the polarity of the signal across T2 changes as C and D are switched to produce an output wherein the polarity is dependent on the phase of the input. Where C is in phase with A, F will be negative when C and D are grounded. Where C is 180° out of phase with A, F will be positive when C and D are grounded.

4-36. DC AMPLIFIER.

4-37. The dc amplifer supplies a negative dc feedback current to the probe proportional to the output of the synchronous detector. The polarity of the negative feedback current changes if the polarity of the dc current (measured in the probe) changes. In this way the feedback of the system remains negative at all times thus maintaining the stability of the instrument.

4-38. In addition, this local negative feedback loop stabilizes the gain of the DC Amplifier.

4-39. Tube V6 is a differential amplifier in which a signal of approximately 1 volt (for full-scale deflection) is fed to pin 7 and compared with the signal on pin 2. The output of V6 is fed to the base of Q3.

4-40. Transistor Q3 drives the current-amplifiers Q1 and Q2 which are used as emitter-followers in a push-pull NPN-PNP pair combination.

4-41. The output current from the complimentary pair, Q1 and Q2, goes through the meter circuit to the current divider S1A which feeds a portion of this current, appropriate for the range this instrument is working on, to the probe head as negative current feedback.

4-42. After passing through S1A and the probe head, the combined current goes through the parallel resistor network R60-64. This develops a voltage at the junction of R61 and R62 which is proportional to the feedback current. This voltage is applied to pin 2 of V6 to complete the local feedback loop of the DC Amplifier. This circuit makes the output current of the DC Amplifier proportional to the voltage applied to the input grid, pin 7, of V6.

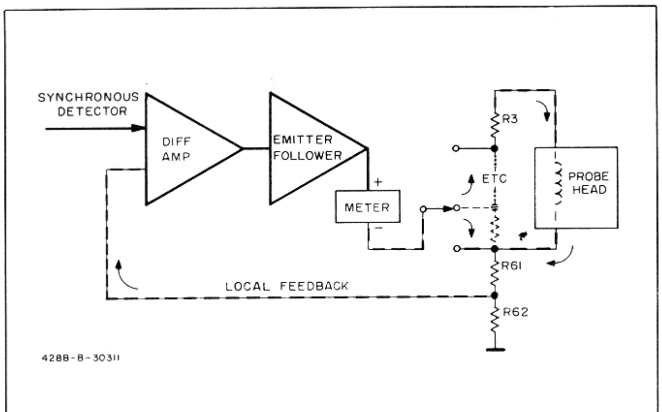


Figure 4-8. Negative Feedback.

4-43. NEGATIVE FEEDBACK CURRENT CIRCUIT.

4-44. The negative feedback current path is shown in Figure 4-8 . Current divider S1A divides the feedback current in proportion to the dc current being measured*. For a dc input of 10 A, approximately 50 mA feedback current is fed to the probe head. Since an equal number of ampere-turns are necessary for canceling the main dc flux, the feedback coil inside the head requires approximately 200 turns.

* Maintaining the current through meter M1 constant (5 mA maximum) for all current ranges. Inductance L6 isolates the 40 kHz signal from the dc current circuit.

4-45. 40 kHz PHASE SHIFTER.

4-46. The output of the 40 kHz phase shifter is fed to the head of the probe to cancel any residual 40 kHz output signal which exists when zero dc is being measured. The canceling signal is obtained by adding two voltages which are 90° out of phase and variable in amplitude. Figure 4-9 shows the circuit and the idealized phase relationship of the two output voltages with respect to the signal from the oscillator.

4-47. By adding the two output voltages (vector A and B) a 40 kHz signal is obtained, having phase angle and amplitude to cancel exactly the residual 40 kHz signal from the probe (vector C). Once the residual 40 kHz signal of the probe has been canceled, the ZERO control compensates for any normal variations of zero shift. This control is necessary only on the lower ranges.

4-48. POWER SUPPLY.

4-49. A single series-regulated power supply of the conventional type provides 272 volts regulated for the circuits of the instrument. Voltage reference zener diodes CR10 and CR17 provide a constant cathode potential at control tube V10, and this is the reference potential for the control grid of V10.

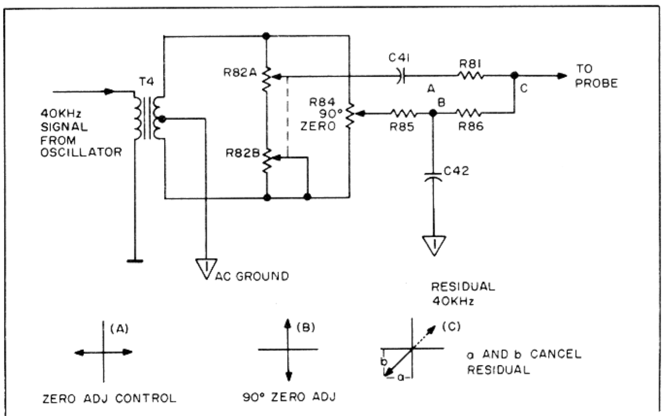


Figure 4-9. 90° Phase Shift.

SECTION V
MAINTENANCE

5-1. INTRODUCTION.

5-2. This section contains the service information which is required to properly maintain the 428B Clip-On DC Milliammeter. Included are performance checks, adjustment and calibration procedures, and servicing and trouble-shooting information. A Performance Check Test Card is provided at the end of this section.

5-3. TEST EQUIPMENT REQUIRED.

5-4. The test equipment required to perform the operations outlined in this section is listed in Table 5-1. This table includes the type of equipment, critical specifications, purpose, and recommended model. If the model recommended is not available, equipment which meets or exceeds the critical specifications listed may be substituted.

5-5. IN-CABINET PERFORMANCE CHECKS.

5-6. The performance checks described in Paragraphs 5-7 through 5-24 are front panel procedures designed to compare the Model 428B with its published specifications. These tests may be incorporated into periodic maintenance, post repair, and incoming quality control checks. The performance checks should be conducted before any attempt is made to adjust or calibrate the instrument. During the in-cabinet performance checks, the Model 428B should be connected to the ac line through a variable voltage device so that line voltage may be varied ± 10% from 115 or 230 Vac to assure that the instrument operates correctly at various ac line voltages.

5-7. CLEANING OF PROBE JAWS.

5-8. When the probe shows excessive sensitivity to the magnetic fields around it, the probe jaws should be cleaned (to determine excessive sensitivity, see Paragraph 5-24 Step a). Excessive sensitivity to external fields can be caused by foreign material between the probe jaws or by overheating (see Paragraph 3-3 Step d). **The probe jaws should always be cleaned prior to calibration, adjustment or repair of the 428B.**

5-9. To clean the probe jaws, open the probe and brush off the mating surfaces with the brush which is supplied with the instrument. If the brush will not remove the contaminant, disassemble the probe and clean it with a pencil eraser as illustrated in Figure 5-1. When reassembling the probe, be sure that the arrow on the body of the probe points to the heavy red wire as shown in Figure 6-1.

Table 5-1. Recommended Test Equipment.

Equipment	Required Characteristics	Use	Recommended Model
Variable Line Voltage Device	Input 115 V, output 103 - 127 V, 75 W	Alignment	Metered Variac, General Radio Co., Type W5MT3A
Meter Calibrator or other accurate current source	± 0.2% of reading ± 0.1% FS	Alignment Performance Checks	-hp- Model 6920B AC/DC Meter Calibrator
Function Generator	DC to 400 Hz > 10 mA output	Alignment	-hp- Model 3310A Function Generator
Oscilloscope	DC to 40 kHz 100 mV/cm ± 3%	Performance Checks Troubleshooting	-hp- Model 130C 200 μV/cm Oscilloscope
Oscilloscope Probe	Input impedance: 10 megohms	Troubleshooting	-hp- Model 10001A Resistive Divider Probe
Counter	Reads 40 kHz ± 20 Hz	Alignment Troubleshooting	-hp- Model 5300A with 5301A Module
Multimeter	DC: ± .25% at 730 mV AC: Resolves 2 mV Battery operated Ohms: Input impedance: ⩾ 1 megohm	Alignment Performance Checks Troubleshooting	-hp- Model 3470 System: Modules; 34740A Display, 34740A Battery Pack, 34702A Multimeter

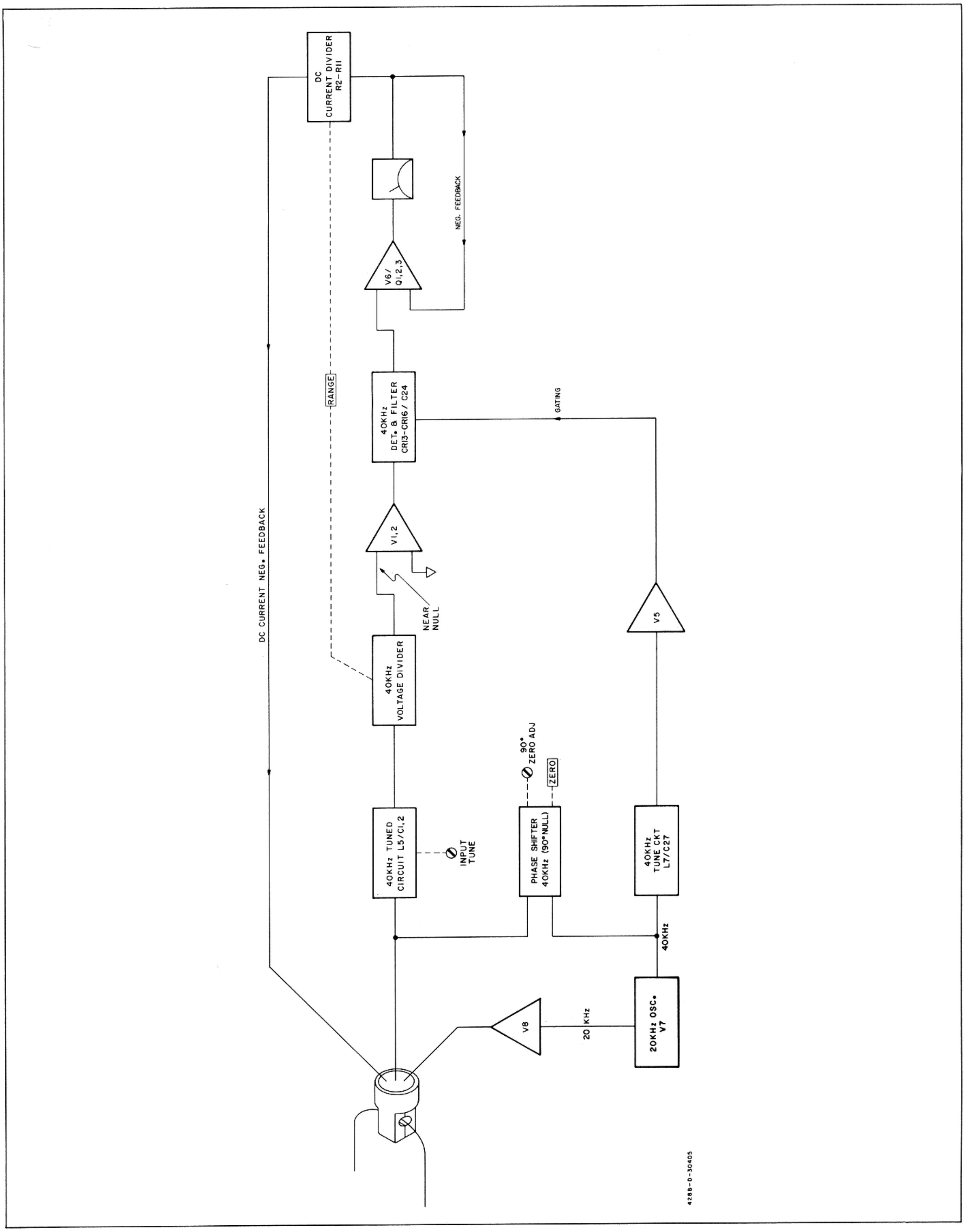
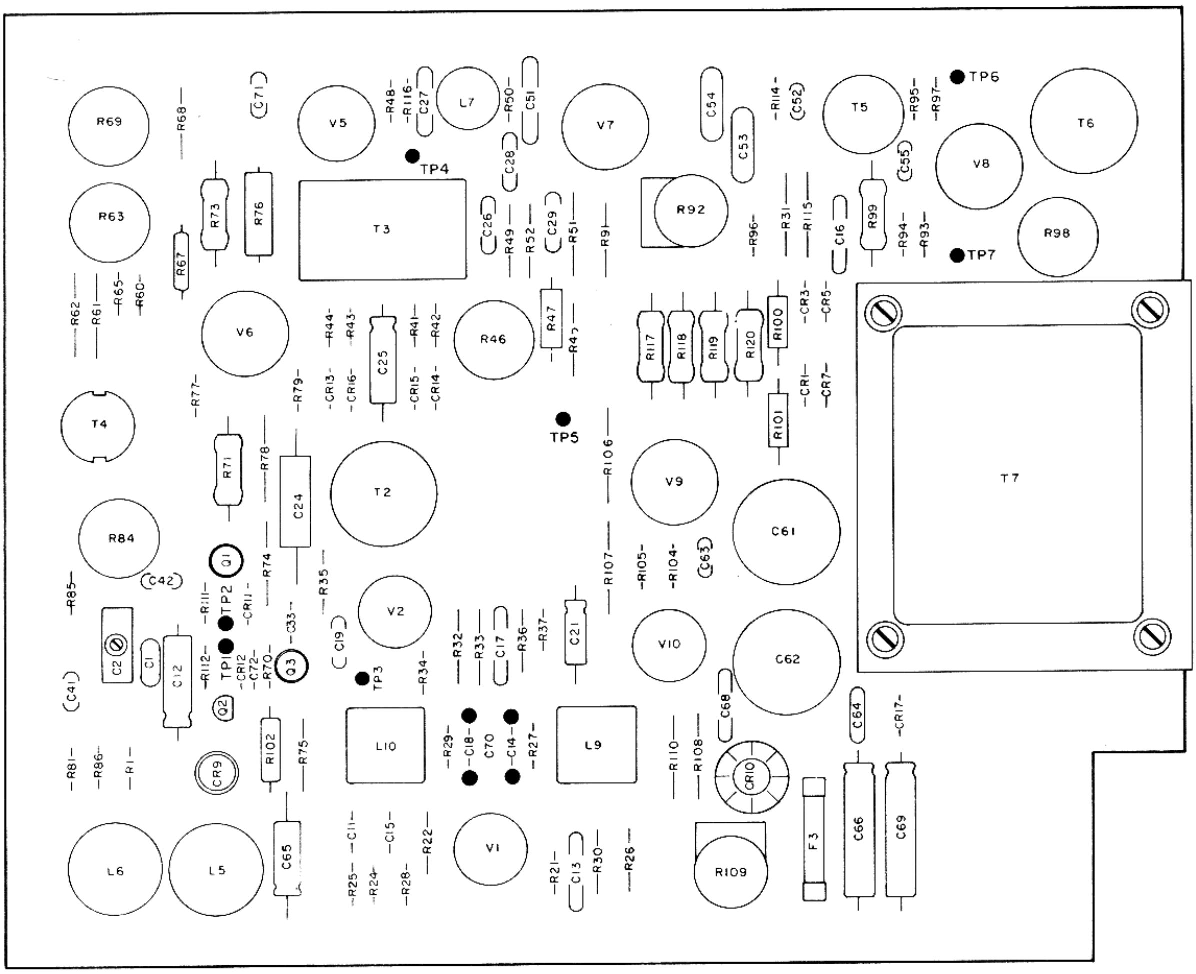
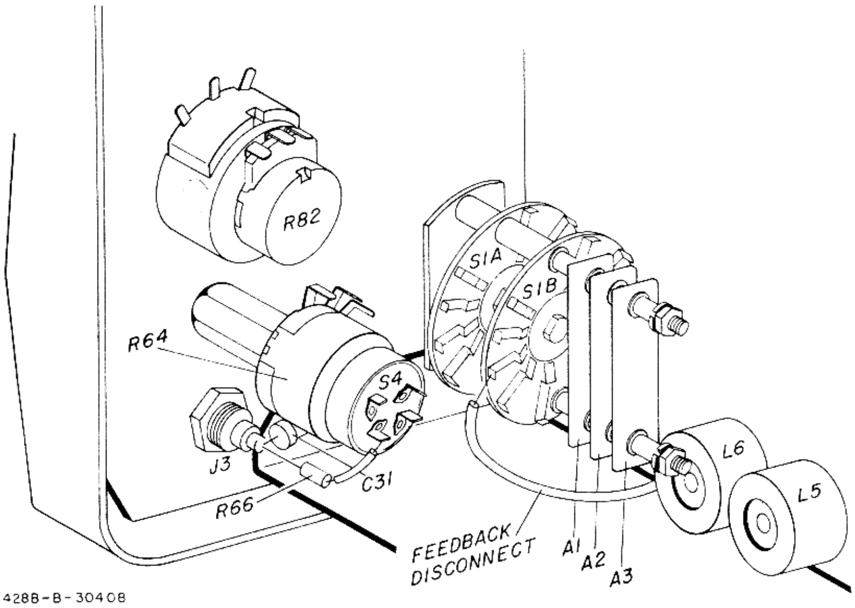


Figure 7-1. Block Diagram.



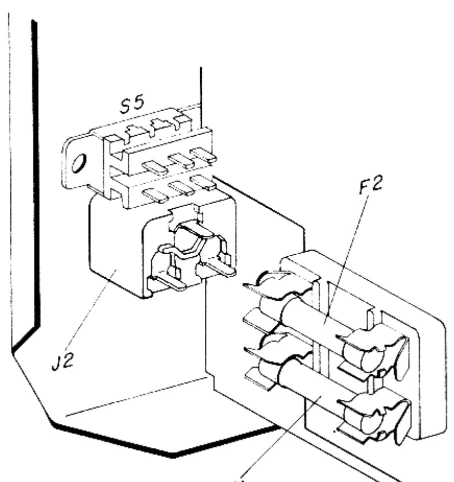
428B-C-30404

Component Locator for Circuit Board Part No. 00428-66501.



428B-B-30408

Front Panel Component Locator.



428B-B-30409

Rear Panel Component Locator.

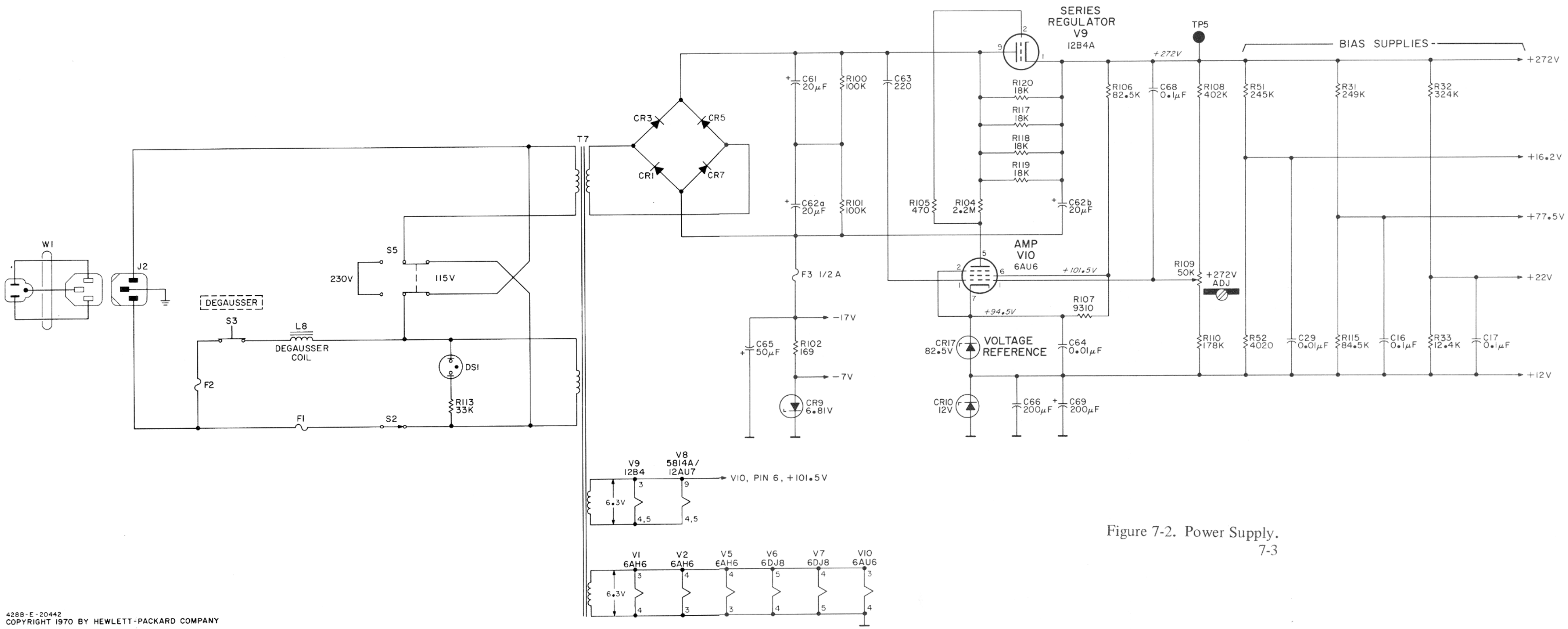
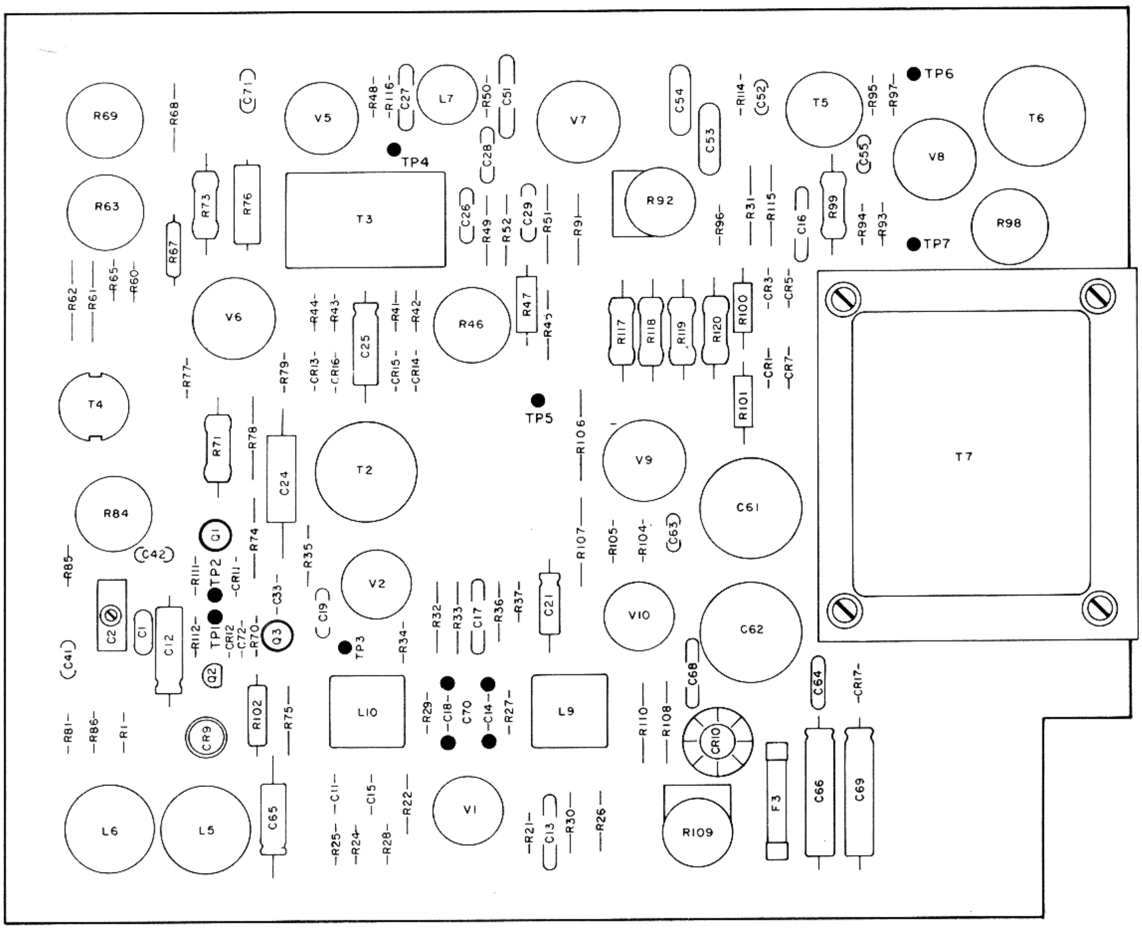
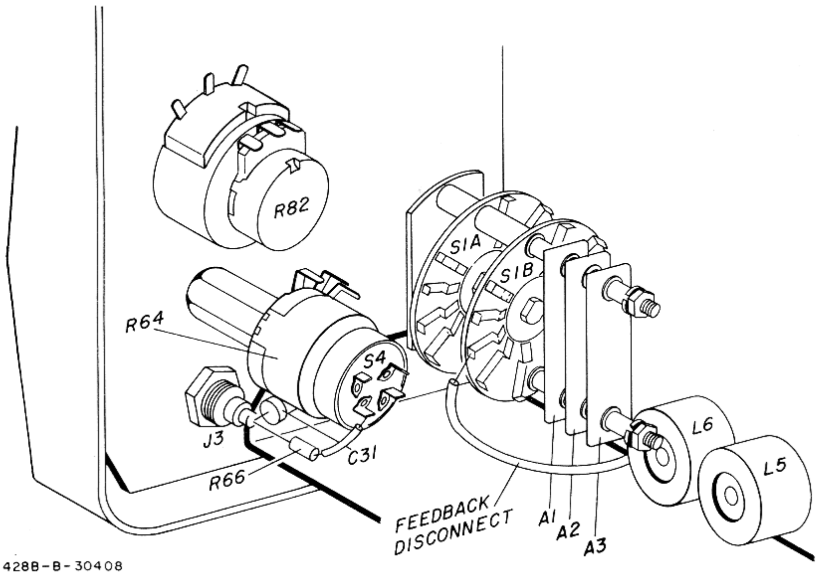


Figure 7-2. Power Supply.



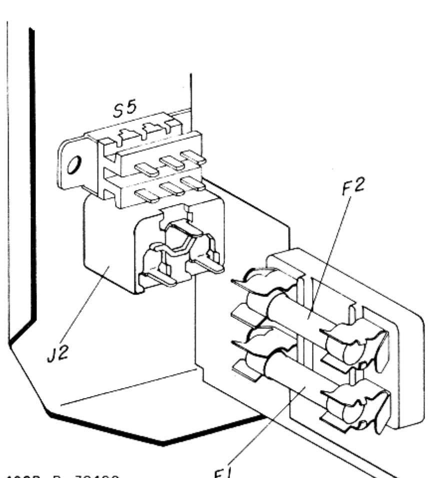
428B-C-30404

Component Locator for Circuit Board Part No. 00428-66501.



428B-B-30408

Front Panel Component Locator.



428B-B-30409

Rear Panel Component Locator.

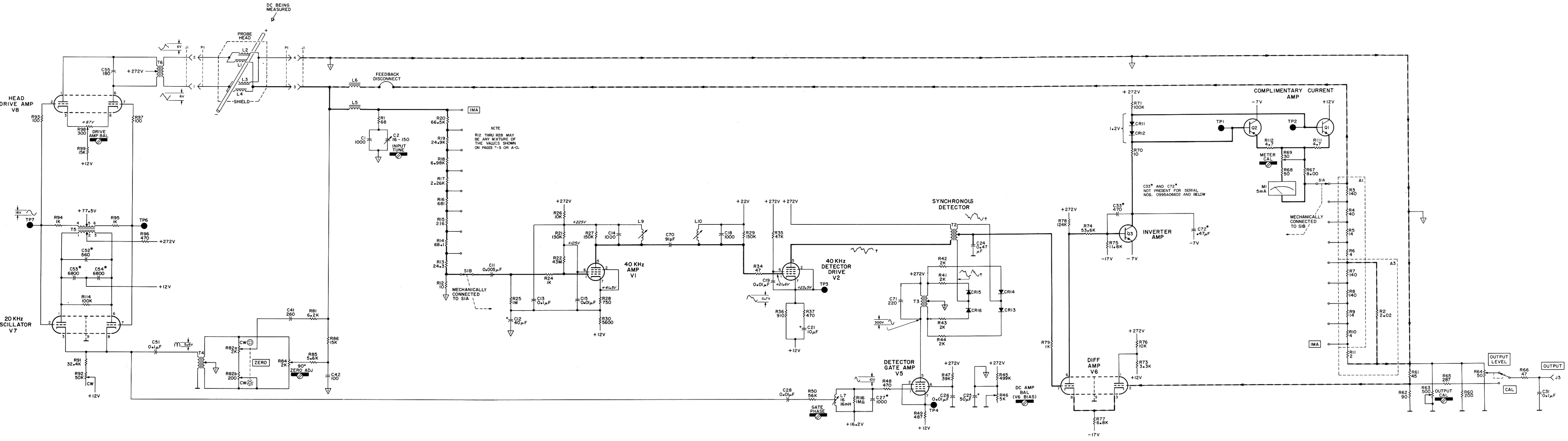


Figure 7-3. Metering Circuit.

APPENDIX A

MANUAL BACKDATING CHANGES

Appendix A manual backdating information makes this manual applicable to earlier instruments. Instrument component values that differ from those in the manual, yet are not listed in this appendix, should be replaced using the part number given in Table 6-1.

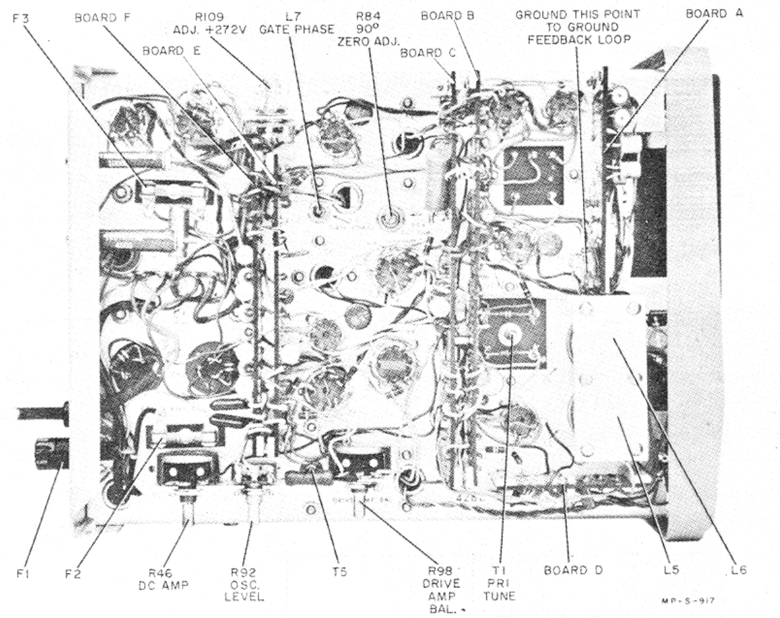
Instrument Serial Prefix	Make Manual Changes
601-05250 and below	1, 2, 3
0995A06150 and below	2, 3
ALL	3

CHANGE NO. 1:
Replace Figure 7-3 with backdating schematic, Figure A-2, Page A-7/A-8. Figure A-1, 428B Side Views apply. Replace items in Table 6-1 with parts list on Pages A-3 thru A-5. In Paragraph 4-49, replace "zener diodes CR10 and CR17 with "tube VII".

CHANGE NO. 2:
Delete C33* and C72* from Table 6-1 and Figure 7-3.

CHANGE NO. 3:
Part numbers in Table 6-1 are for brown instruments; part numbers for blue instruments are as follows:

Part No.	Description
428A-1C	Dust cover (rack only)
428A-21A	Probe Assembly (see Figure 6-1)
428B-2A	Panel (cabinet only)
428B-2R	Panel (rack only)
428B-44	Assembly: cabinet
5020-0653	Bezel



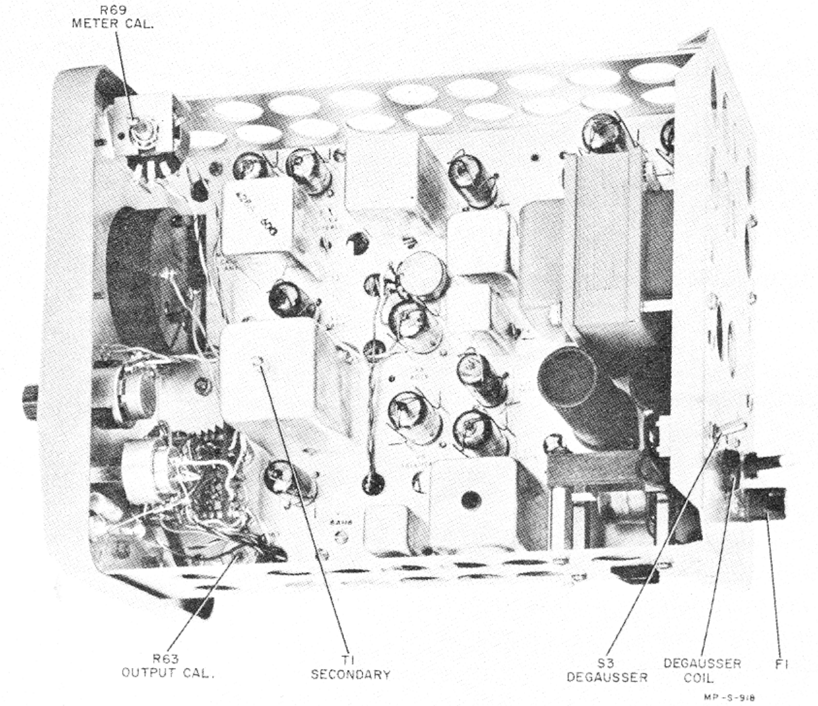


Figure A-1. 428B Side Views.

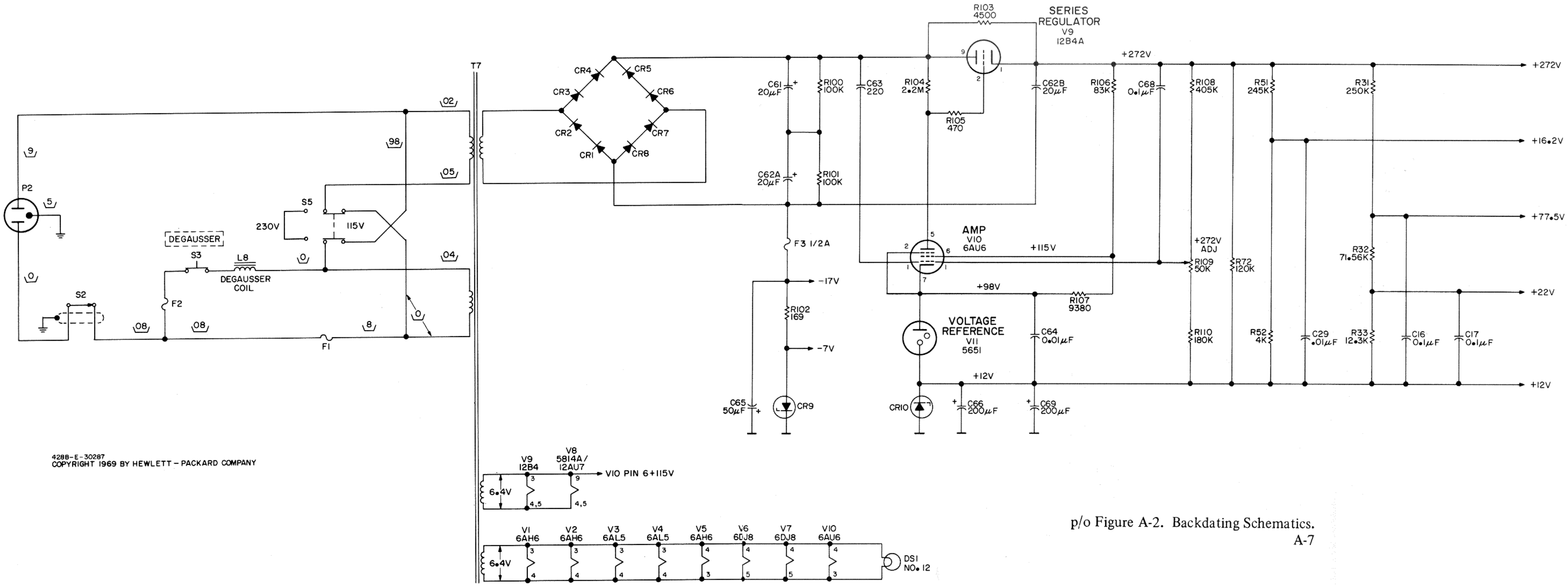
Circuit Reference	ⓗ Stock No.	Description #
A1, 2	428B-26A	Assembly: ww resistor, A1 includes, R3 thru R6 A2 includes, R7 thru R10
A3	428B-26B	Assembly: ww resistor, includes R2, 11
C1	0140-0099	fxd, mica, 1K pf ±1%, 500 vdcw
C2	0131-0004	var, mica, 14-150 pf, 175 vdcw
C3 thru C10		Not Assigned
C11	0150-0014	fxd, cer, 5K pf, 500 vdcw
C12	0180-0050	fxd, elect, 40 uf -15% + 100%, 50 vdcw
C13	0170-0022	fxd, my, 0.1 uf ±20%, 600 vdcw
C14		nsr, part of T1 assembly
C15	0150-0012	fxd, cer, 10K pf ±20%, 1000 vdcw
C16, 17	0170-0019	fxd, my, 0.1 uf ±5%, 200 vdcw
C18		nsr, part of T1 assembly
C19	0150-0012	fxd, cer, 10K pf ±20%, 1000 vdcw
C20		Not Assigned
C21	0180-0059	fxd, elect, 10 uf -10% + 100%, 25 vdcw
C22, 23	0150-0015	fxd, TiO_2 2.2 pf ±10%, 500 vdcw
C24	0170-0078	fxd, my, 0.47 uf ±5%, 150 vdcw
C25	0180-0058	fxd, elect, 50 uf -10% + 100%, 25 vdcw
C26	0150-0012	fxd, cer, 10K pf ±20% 1000 vdcw
C27	0140-0099	fxd, mica, 1K pf ±1%, 500 vdcw
C28, 29	0150-0012	fxd, cer, 10K pf ±20%, 1000 vdcw
C30		Not Assigned
C31	0170-0019	fxd, my, 0.1 uf ±5%, 200 vdcw
C32	0140-0034	fxd, mica, 22 pf ±5%, 500 vdcw
C33 thru C40		Not Assigned
C41	0140-0108	fxd, mica, 253 pf ±2%, 300 vdcw
C42	0140-0041	fxd, mica, 100 pf ±5%, 500 vdcw
C43 thru C50		Not Assigned
C51	0170-0019	fxd, my, 0.1 uf ±5%, 200 vdcw
C52	0140-0149	fxd, mica, 470*pf ±5%, 300 vdcw
C53, 54	0140-2102	fxd, mica, 8.2K*pf ±2%, 500 vdcw
C55	0140-0147	fxd, mica, 180 pf ±5%, 500 vdcw
C56 thru C60		Not Assigned
C61	0180-0011	fxd, elect, 20 uf, 450 vdcw
C62A/B	0180-0012	fxd, elect, 2 sect, 20 uf/sect, 450 vdcw
C63	0140-0031	fxd, mica, 220 pf ±10%, 500 vdcw

Circuit Reference	ⓗ Stock No.	Description #
C64	0150-0012	fxd, cer, 10K ρf ±20%, 1000 vdcw
C65	0180-0058	fxd, elect, 50μf -10% + 100%, 25 vdcw
C66	0180-0104	fxd, elect, 200 μf, 15 vdcw
C67		Not Assigned
C68	0170-0022	fxd, my, 0.1 μf ±20%, 600 vdcw
C69	0180-0104	fxd, elect, 200 μf, 15 vdcw
CR1 thru CR8	1901-0028	Diode, Si
CR9	1902-0013	Diode, Si
CR10	1902-0014	Diode, Si
DS1	2140-0012	Lamp: indicating, #12, 2 pin base
F1, 2	2110-0007	Fuse: 1 amp, s-b (F1 115 V operation)
	2110-0008	Fuse: 1/2 amp, s-b (F1 230 V operation)
F3	2110-0012	Fuse: 1/2 amp
J1	1251-0089	Connector: female, 4 pin
J2		Not Assigned
J3	1250-0118	Connector: BNC, female
L1 thru L4		nsr; part of probe assembly (see misc.)
L5, 6	428B-60K	Assembly, choke
L7	9140-0049	Inductor: var, 16 mh
L8	9110-0025	Inductor: degaussing
M1	1120-0116	Meter: 0-5 ma, 6-10 ohms
P1	1251-0090	Connector: male, 4 pin
P2	8120-0050	Cable, power
Q1	1854-0039	Transistor: Si NPN 2N3053
Q2	1853-0016	Transistor: Si PNP 2N3638
Q3	1854-0003	Transistor: 2N1564
R1	0687-6801	fxd, comp, 68 ohms ±10%, 1/2 W
R2		nsr; part of A3 assembly
R3 thru R10		nsr; part of A1, A2 assembly
R11		nsr; part of A3 assembly
R12	0727-0335	fxd, dep c, 10 ohms ±10%, 1/2 W
R13	0757-0002	fxd, mfg, 24.3 ohms ±1%, 1/2 W
R14	0727-0035	fxd, dep c, 68.4 ohms ±1/2%, 1/2 W
R15	0727-0060	fxd, dep c, 225 ohms ±1%, 1/2 W
R16	0727-0085	fxd, dep c, 680 ohms ±1%, 1/2 W
R17	0727-0120	fxd, dep c, 2250 ohms ±1%, 1/2 W
R18	0727-0145	fxd, dep c, 6960 ohms ±1%, 1/2 W
R19	0727-0178	fxd, dep c, 24.7K ohms ±1%, 1/2 W

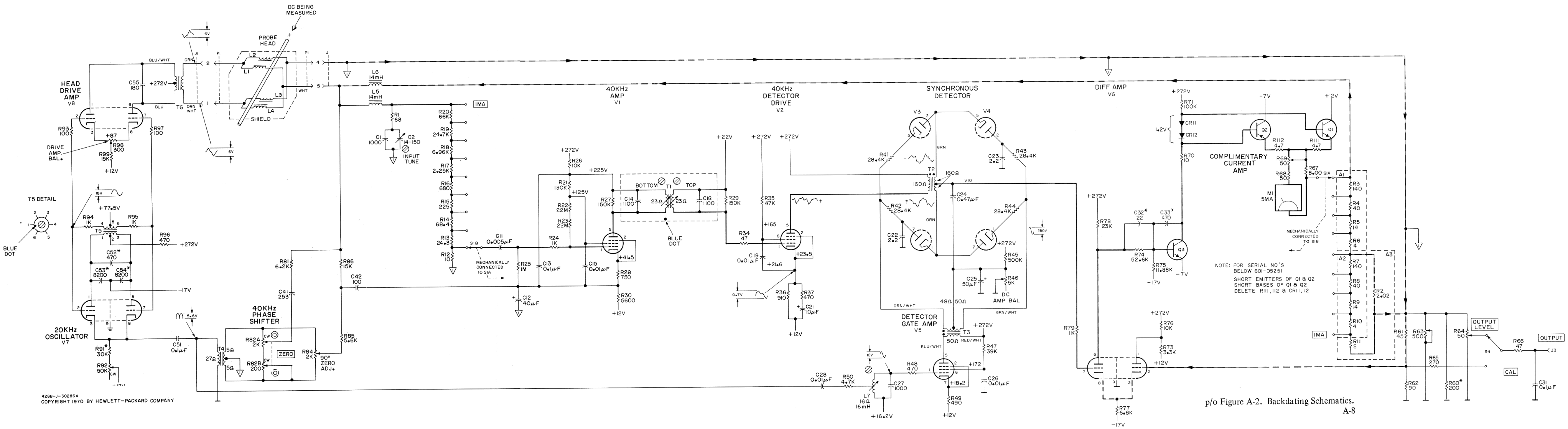
Circuit Reference	Stock No.	Description#
R20	0727-0198	fxd, dep c, 66K ohms ±1%, 1/2 W
R21	0686-1345	fxd, comp, 130K ohms ±5%, 1/2 W
R22, 23	0687-2261	fxd, comp, 22M ±10%, 1/2 W
R24	0687-1021	fxd, comp, 1K ohms ±10%, 1/2 W
R25	0687-1051	fxd, comp, 1M ±10%, 1/2 W
R26	0687-1031	fxd, comp, 10K ohms ±10%, 1/2 W
R27	0687-1541	fxd, comp, 150K ohms ±10%, 1/2 W
R28	0689-7515	fxd, comp, 750 ohms ±5%, 1 W
R29	0687-1541	fxd, comp, 150K ohms ±10%, 1/2 W
R30	0687-5621	fxd, comp, 5.6K ohms ±10%, 1/2 W
R31	0727-0226	fxd, dep c, 250K ohms ±1%, 1/2 W
R32	0727-0201	fxd, dep c, 71.56K ohms ±1%, 1/2 W
R33	0730-0032	fxd, dep c, 12.3K ohms ±1%, 1 W
R34	0687-4701	fxd, comp, 47 ohms ±10%, 1/2 W
R35	0690-4731	fxd, comp 47K ohms ±10%, 1 W
R36	0689-9115	fxd, comp, 910 ohms ±5%, 1 W
R37	0687-4711	fxd, comp, 470 ohms ±10%, 1/2 W
R38 thru R40		Not Assigned
R41 thru R44	0727-0184	fxd, dep c, 28.4K ohms ±1%, 1/2 W
R45	0727-0244	fxd, dep c, 500K ohms ±1%, 1/2 W
R46	2100-0006	var, ww, 5K ohms ±10%, 2 W
R47	0689-3935	fxd, comp, 39K ohms ±5%, 1 W
R48	0687-4711	fxd, comp, 470 ohms ±10%, 1/2 W
R49	0727-0075	fxd, dep c, 490 ohms ±1%, 1/2 W
R50	0687-4721	fxd, comp, 4.7K ohms ±10%, 1/2 W
R51	0730-0080	fxd, dep c, 245K ohms ±1%, 1 W
R52	0727-0132	fxd, dep c, 4K ohms ±1%, 1/2 W
R53 thru R59		Not Assigned
R60	0687-6811	fxd, comp, 680 ohms ±10%, 1/2 W
R61	0727-0021	fxd, dep c, 45 ohms ±1%, 1/2 W
R62	0727-0038	fxd, dep c, 90 ohms ±1%, 1/2 W
R63	2100-0022	var, ww, lin, 500 ohms ±20%, 1 W
R64	2100-0270	var, ww, lin, 50 ohms ±10%, 2 W
R65	0687-2711	fxd, comp, 270 ohms ±10%, 1/2 W
R66	0687-4701	fxd, comp, 47 ohms ±10%, 1/2 W
R67	0812-0015	fxd, ww, 8 ohms ±3%, 2 W
R68	0727-0023	fxd, dep c, 50 ohms ±1%, 1/2 W
R69	2100-0002	var, ww, 50 ohms ±10%, 2 W
R70	0687-1001	fxd, comp, 10 ohms ±10%, 1/2 W
R71	0693-1041	fxd, comp, 100K ohms ±10%, 2 W
R72	0690-1241	fxd, comp, 120K ohms ±10%, 1 W
R73	0764-0003	fxd, mfg, 3300 ohms ±5%, 2 W
R74	0727-0196	fxd, dep c, 52.6K ohms ±1%, 1/2 W
R75	0727-0163	fxd, dep c, 11.88K ohms ±1%, 1/2 W
R76	0816-0008	fxd, ww, 10K ohms ±10%, 10 W
R77	0687-6821	fxd, comp, 6.8K ohms ±10%, 1/2 W
R78	0730-0072	fxd, dep c, 123K ohms ±1%, 1 W
R79	0687-1021	fxd, comp, 1K ohms ±10%, 1/w
R80		Not Assigned
R81	0686-6225	fxd, comp, 6.2K ohms ±5%, 1/2 W
R82A/B	2100-0197	var, comp, dual pot, ±10%, 2 W R82A, 2K ohms R82B, 200 ohms
R83		Not Assigned
R84	2100-0153	var, comp, 2K ohms ±20% 1/3 W
R85	0687-5621	fxd, comp, 5.6K ohms ±10%, 1/2 W
R86	0687-1531	fxd, comp, 15K ohms ±10%, 1/2 W
R87 thru R90		Not Assigned
R91	0727-0195	fxd, dep c, 50K ohms ±1%, 1/2 W
R92	2100-0013	var, comp, lin, 50K ohms ±20%
R93	0687-1011	fxd, comp, 100 ohms ±10%, 1/2 W
R94, 95	0687-1021	fxd, comp, 1K ohms ±10%, 1/2 W
R96	0687-4711	fxd, comp, 470 ohms ±10%, 1/2 W
R97	0687-1011	fxd, comp, 100 ohms ±10%, 1/2 W
R98	2100-0038	var, ww, 300 ohms
R99	0767-0010	fxd, mfg, 15K ohms ±5%, 3 W
R100, 101	0690-1041	fxd, comp, 100K ohms ±10%, 1 W
R102	0811-0041	fxd, ww, 169 ohms ±1%, 3 W
R103	0819-0011	fxd, ww, 4.5K ohms ±10%, 20 W
R104	0687-2251	fxd, comp, 2.2M ±10%, 1/2 W
R105	0687-4711	fxd, comp, 470 ohms ±10%, 1/2 W
R106	0730-0063	fxd, dep c, 83K ohms ±1%, 1 W
R107	0727-0154	fxd, dep c, 9380 ohms ±1%, 1/2 W
R108	0727-0240	fxd, dep c, 405K ohms ±1%, 1/2 W
R109	2100-0013	var, comp, lin, 50K ohms ±20%

Circuit Reference	ⓗ Stock No.	Description#
R110	0727-0218	fxd, dep c, 180K ohms ±1%, 1/2 W
S1	428B-19A	Assembly: range switch, includes, R2 thru R20, R61, R62
S2	3101-0001	Switch: tog, SPST
S3	3101-0018	Switch: tog, SPST, momentary
S4		Not Assigned
S5	3101-0033	Switch, sl: DPDT
T1	9120-0052	Assembly: transformer, interstage, includes, C14, C18
T2	428A-60G	Transformer, detector signal
T3	428A-60C	Transformer, gate
T4	428B-60J	Transformer, zero balance
T5	9120-0051	Transformer, osc
T6	428A-60D	Transformer, head drive
T7	9100-0104	Transformer, power
V1, 2	1923-0017	Tube, electron: 6AH6
V3, 4	1930-0013	Tube, electron: 6AL5
V5	1923-0017	Tube, electron: 6AH6
V6, 7	1932-0022	Tube, electron: 6DJ8/ECC88
V8	1932-0029	Tube, electron: 12AU7
V9	1921-0010	Tube, electron: 12B4A
V10	1923-0021	Tube, electron: 6AU6
V11	1940-0001	Tube, electron: 5651
		MISCELLANEOUS
	428A-21A	Assembly: probe, includes L1 thru L4, P1
	428B-65C	Assembly: circuit board "C" includes R65, R67, R68
	428B-75H	Assembly: circuit board "A" includes C32, C66, C69, CR9, CR10, Q1 thru Q3, R70, R71 R74, R75, R102
	428B-75B	Assembly: resistor board "B" includes C13 R26, 27 C15 R35, 36 C21 R41, 42 C25 R45 R21 thru R23 R73
	428B-75C	Assembly: circuit board "C" includes C16, C17, C24 C41, C42 R30 thru R33 R43, R44 R77 thru R79 R81 R85, R86
	428B-75D	Assembly: resistor board "D" includes C1, C2 C11, C12 R1 R25

Circuit Reference	ⓗ Stock No.	Description#
	428B-75E	Assembly: resistor board "E" includes C27 thru C29 C51 R47 thru R52 R72 R91 R94 thru R96
	428B-75F	Assembly: resistor board "F" includes C53, C54 C68 CR1 thru CR8 R106 R108 R110
	G-74AW	Knob: red, 3/4" w/arrow
	G-74J	Knob: black, 1", concentric shaft ZERO
	G-74N	Knob: bar, RANGE
	1200-0003	Socket, tube: 9 pin miniat
	1200-0017	Socket, tube: 7 pin miniat
	1400-0008	Fuseholder
	1400-0084	Fuseholder
	1450-0020	Jewel, pilot light
	8520-0017	Electric shaver brush
	1205-0011	Heat dissipator, semiconductor



p/o Figure A-2. Backdating Schematics.



p/o Figure A-2. Backdating Schematics.