# SECTION III
# THEORY OF OPERATION

## 3-1. GENERAL

3-2. The ATS is a semi-automatic AC-DC transfer standard which provides a dc output voltage equal to the true rms value of complex (i.e., pulsed, square-wave, triangular-wave and other non-sinusoidal signals having a crest factor of up to 10:1) or sinusoidal signals. The dc output voltage generated is applied to an auxiliary readout instrument such as a DC differential or digital voltmeter, which indicates the dc equivalent to the true rms value of the applied ac voltage.

## 3-3. SIMPLIFIED BLOCK DIAGRAM ANALYSIS

3-4. The ATS consists of 15 major functional circuits interconnected as shown in figure 3-2. AC signals to be measured are applied to one of two AC INPUT connectors, depending on the signal level, and are applied to a removable transfer assembly which contains attenuators, a thermoelement and an overload protection circuit. The applied ac signal is attenuated by a resistive attenuator network controlled by the RANGE VOLTS switch so that the voltage coupled to the thermoelement heater elements does not exceed its maximum voltage rating of approximately 0.45 volts rms.

3-5. An overload protection circuit is located between the attenuator output and thermoelement heater to disconnect the applied signal from the attenuator should the signal be greater than the measurement range selected by the RANGE VOLTS switch.

3-6. The thermoelement being an rms responding device, develops a dc output related to the rms value of the attenuated input signal. Since the thermoelement has a maximum output level of approximately 7 millivolts, this low level dc voltage is chopped and fed to an amplifier. The use of a chopper/amplifier eliminates the drift problems normally associated with the measurement of low-level dc voltages.

3-7. **MANUAL BALANCE OPERATION.** When the mode selector switch is set to MANUAL BALANCE and the AC indicator is illuminated, the operator adjusts the settings of the MANUAL BALANCE COARSE and MANUAL BALANCE FINE controls until the voltage at the input to the chopper is 0 volts. At this point the front panel meter indicates a null. When the operator momentarily depresses the TRANSFER-RESET pushbutton switch, the DC indicator illuminates and the output of either the low or high voltage amplifier is coupled to the same attenuator and the applied ac signal under measurement is disconnected. Since the output of the applicable voltage amplifier was 0 volts at the moment of transfer, the thermoelement output will decrease immediately after transfer. This results in the generation of an error voltage which is fed to the chopper. The polarity of this error voltage is such to cause the amplifier to drive the thermoelement so that the error voltage is reduced to zero. At this time the dc output of the voltage amplifier, which is present at the DC OUTPUT binding posts, is equal to the rms value of the applied ac signal.

3-8. **AUTO OPERATION.** When the mode selector switch is set to AUTO, the AC indicator illuminates and the ac signal under measurement is coupled to the thermoelement in the same manner as for manual balance operation. The dc output of the thermoelement is chopped, amplified, and applied to a memory circuit which automatically develops a dc voltage which balances the thermoelement output. At this point the voltage amplifier output is 0 volts and the meter indicates a null. After a short delay interval, the transfer circuitry is automatically triggered and the output of the voltage amplifier is coupled to the attenuator and the applied ac signal is disconnected. The resulting action is identical to that for the manual transfer mode.
An automatic periodic recycle mode from DC to AC is switch selectable. This recycle mode acts as an Auto Zero circuit to minimize the effects of thermal drift.

3-9. **MANUAL TRANSFER MODE.** The manual transfer mode is virtually identical to the automatic transfer mode except that the transfer is accomplished by depression of the TRANSFER-RESET pushbutton switch instead of being automatic.

## 3-10. DETAILED THEORY OF OPERATION

3-11. **TRANSFER ASSEMBLY A1.** Transfer assembly A1 (Model 11600A) contains the major components of the transfer standard, and can be employed as a conventional AC/DC transfer standard when removed from the ATS. The

transfer assembly contains the range selector switch and associated resistive attenuators, a thermoelement, and an overload protection circuit as well as a power supply for operation of the reed relays.

3-12. Range Selection. Since the thermoelement has a full scale rated input voltage of 0.45 volts rms, the applied ac signal to be measured must be attenuated so that the thermoelement is not damaged. Attenuation of the signal is accomplished by two attenuator networks both controlled by RANGE VOLTS switch A1S3.

3-13. When the RANGE VOLTS switch is set to measure any voltage between 0.25 and 32 volts (see figure 2-2) and the overload protection circuit (refer to paragraph 3-15) is not triggered, A1A1Q9 is conducting heavily and its collector is near ground. When the ATS is in the ac balance state and the RANGE VOLTS switch is set to 0.25 TO 0.5, +28 volts is coupled to the coil of A1L2 and, through steering diodes A1CR1 through A1CR6, to the coils of A1L3 through A1L8. In the 1600A only relays A1S5 through A1S22 are closed and resistors A1R1 through A1R8 are placed in parallel to form an equivalent 20-ohm resistor. This resistor, in series with the thermoelement heater, limits the voltage applied to the 90-ohm heater element at 0.45 volts. As the RANGE VOLTS switch is rotated clockwise (see table 3-1) up to the 16 TO 32 position, steering diodes A1CR1 through A1CR6 successively become back biased and cause A1L2 through A1L7 to become de-energized. This results in the effective series multiplying resistance of the attenuator to increase. The 1600A MOD 88 employs three additional relays on the 1, 2 and 5 V ranges and switches a multiplying resistor for each range without paralleling multipliers. (See Fig. 5-2A and Fig. 3-3A) Since the ATS is in the ac balance state, transfer relay K1 is energized and +28 volts is applied to A1A1; this causes the contacts of A1S4 to close and couple the applied ac signal from AC INPUT 0.25 – 32V connector A1J4 to the input of the low voltage attenuator. Note that, when the RANGE VOLTS switch is set for voltages above 32 volts, A1L1 is no longer coupled to the +28 volt supply and the contacts of A1S4 open to disengage A1J4 from the low voltage attenuator.

3-14. When the RANGE VOLTS switch is set to measure any voltage between 32 and 1000 volts (see figure 3-4) and the overload protection circuit is not triggered, A1A1Q9 is conducting heavily and its collector is near ground. When the ATS is in the ac balance state and the RANGE VOLTS switch is set to 32 TO 64, +28 volts is coupled to the coils of paralleled relays A1K19 and A1K20. The normally-open contacts close and insert resistor A1R39 in series with the thermoelement heater. As the RANGE VOLTS switch is rotated clockwise (see table 3-2), relay pairs are energized to insert the proper value resistance multiplier. Since the ATS is in the ac balance state, +28 volts is applied across the coils of relays A1K10 and A1K22. Energization of A1K10 couples the signal at the AC INPUT 32 – 1000 V connector A1J6 through the selected multiplier and energization of A1K22 applies the attenuated signal to the heater of A1TC1. Note that, when the RANGE VOLTS switch is set for voltages below 32 volts, relays A1K10 and A1K22 become de-energized to open-circuit the voltage applied at A1J6 and disconnect the high voltage attenuator output from the thermoelement input.

3-15. **Overload Protection Circuitry.** The voltage applied to the heater of thermoelement A1TC1 is monitored by a bipolar peak-sensing overload protection circuit. Under normal operation conditions in the ac balance state, the voltage is coupled to the gate of A1A1Q1, part of a high input impedance differential preamplifier. The high impedance provided by the field effect transistor ensures that the waveform coupled to the thermoelement is not distorted and does not load the thermoelement. The overload circuit is fully effective to 10 MHz and derates for peak amplitude protection at approximately 5% per MHz there after. Although the circuit protects when using dc or other non-sinnsoidal inputs, it is optimized for use with sinusoidal inputs.

3-16. The outputs of the differential preamplifiers, taken at the collectors of A1A1Q3 and A1A1Q4 are detected by A1 A1CR1 and A1A1CR2 and summed across A1A1R10. Should the peak voltage level of the ac signal coupled to the thermoelement exceed 1.75 times the value of the selected RANGE VOLTS scale rms voltage, the positive-going voltage at the collector of A1A1Q5 drives A1A1Q7 into conduction. This causes the collector voltage of A1A1Q7 to rise positively and trigger silicon controlled rectifier A1A1Q8 into conduction, cutting off A1A1Q9. When A1A1Q9 is driven into cutoff, a ground return path for the attenuator multiplier selection relays is no longer provided and the applied signal is disconnected from the thermoelement. This overload disconnect time is approximately 1 millisecond and the signal voltage must not rise more than 25% in this reaction time to avoid damage to the thermocouple.

After removal of the overload condition, the protection circuit is reset by pushing the overload protection push to reset switch S2. This shunts the current through SCR A1A1Q8 and when S2 is released, the reset action is completed. The overload protection circuit can be disabled by holding down the "Overload Protection Push to Disable" switch S3. This action opens switch A1S12 which disconnects the overload circuit from the thermoelement.

At the same time, a dc biasing current is applied to the base of A1A1Q6 through A1A1CR3, A1A1R12 and A1A1CR4 preventing the compactor from changing state and switches A1A1Q8 and A1A1Q9 remain undisturbed.

**NOTE**

Always avoid overloads since no non-loading protective circuit can be produced which will protect against every transient overload.

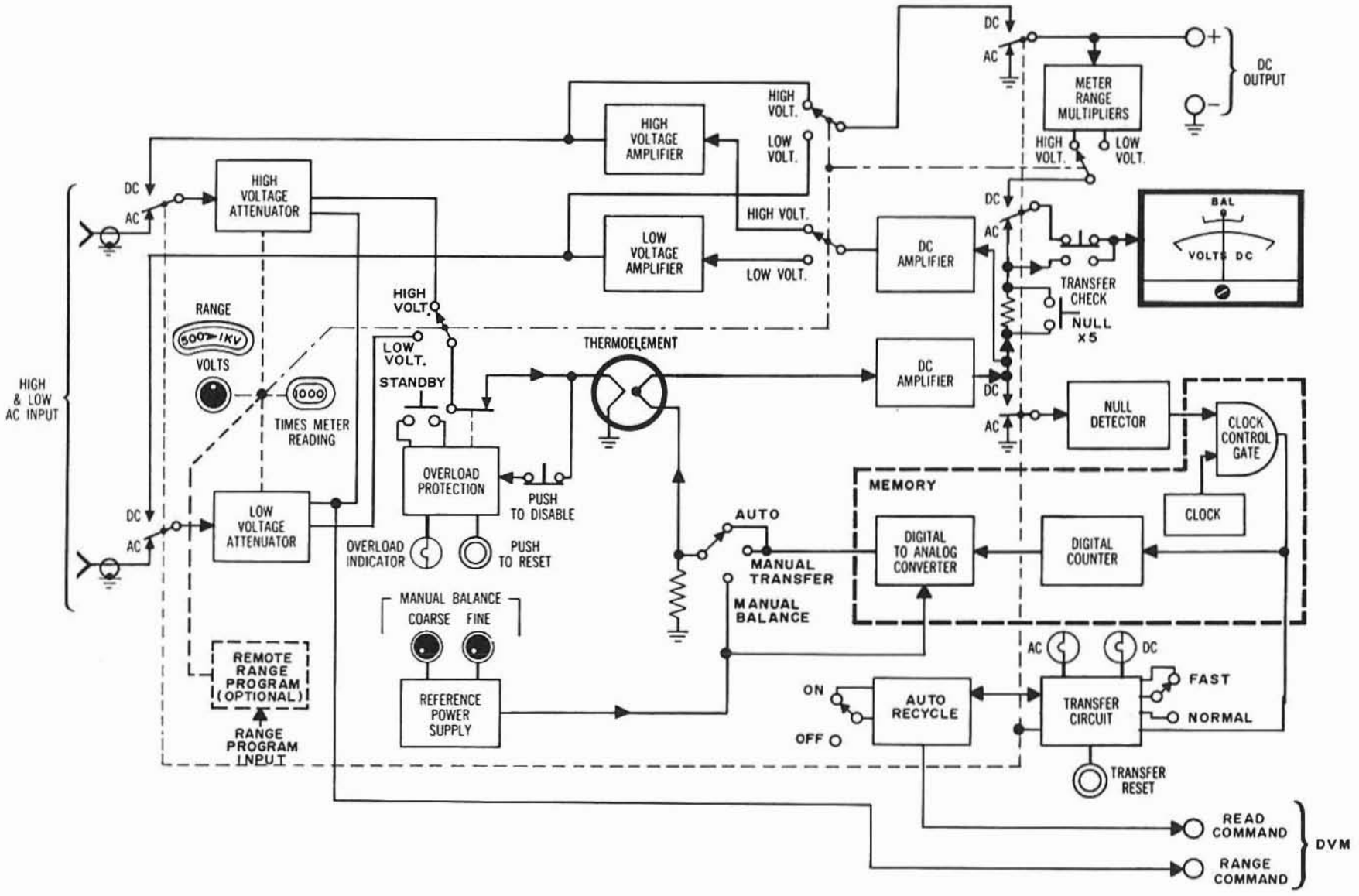



**Figure 3-2. Block Diagram**

When the 1600A is in the dc Mode, the overload protection circuit is inhibited by the action of A1A1Q11 and A1A1Q10. The base of A1A1Q11 is tied to the ground return side of the transfer relay (K-1) coil through biasing network A1A1R15 and A1A1R22. In the ac Mode +28 V is applied, saturating A1A1Q11 and disconnecting the emitter of A1A1Q10 from the base of A1A1Q6 by the switch action of diode A1A1CR5. In the dc Mode, the base of A1A1Q11 is turned off and A1A1Q10 turned on hand. The emitter current of A1A1Q10 flowing through A1A1R7 and A1A1R16 biases A1A1Q6 on so that the comparator will not change state and switches A1A1Q8 and A1A1Q9 remain undisturbed.

In order to eliminate the possibility of damaging the thermoelement when changing cables or signal levels in AC mode a "STANDBY switch" S6 is provided. When the standby switch is depressed, the overload circuit is activated disconnecting the input from the thermoelement. When ready to resume operation, the Overload Protection Push to Reset switch S2 is pushed resetting the circuits.

Remotely Programmed activation of "STANDBY" is accomplished by closing a contact closure to ground. Pin 20 of J16 is the connector access point. Avoid ac interference on this program line and suitably decouple against dc levels. The switch impedance when shorted to ground should not exceed 1 kΩ and the time duration of the closure must be longer than 2 milliseconds.

3-17. **Thermoelement A1TC1.** The output of either the low voltage or high voltage attenuator (depending on the setting of the RANGE VOLTS switch) is applied to the heater of thermoelement A1TC1. The thermoelement which is a heat-sensitive device, produces a dc output voltage proportional to the power level (square of the applied rms voltage) coupled to its heater element. The dc output of the thermoelement is applied in series with R3 to chopper G1.

3-18. **MANUAL BALANCE MODE.** The following discussion assumes that the RANGE VOLTS switch is set to 0.5 to 1.0.

3-19. **AC Balance.** In the ac balance state of operation, coil A1L1, which controls low-voltage input switch A1S4, is energized (see figure 3-5). When this coil is energized, the normally open contacts of switch A1S4 close. The ac input is applied to the heater portion of thermoelement A1TC1 through closed contacts of low-voltage input switch A1S4, input reed relay A1S11, and resistor A1R7. The thermoelement produces a dc output in series with resistor R3 that is applied as an input to the chopper system consisting of chopper G1 and transformer T3. The output of T3 is then applied to chopper amplifier A2. Simultaneously, a dc reference voltage of opposite polarity, taken from the 3.9 volt reference power supply, is applied (through MANUAL BALANCE controls R1 and R2) across resistor R3 and into the chopper amplifier system. Since these two voltages are opposite in polarity, they tend to cancel each other. Therefore, only their difference remains as an input to the chopper amplifier. (For a detailed description of the chopper amplifier circuitry refer to paragraph 3-37). The output of chopper amplifier is supplied as an input to DC amplifier and filter A3. The DC amplifier and filter provides amplification to two different voltage levels. One output (terminal 14) is applied to the panel null meter through normally closed contacts of de-energized transfer relay K1-8 and TRANSFER CHECK switch S5. This provides the operator a visual indication of balance between the two opposing input voltages. A higher level output (terminal 3) is used as an input to the low voltage amplifier A4. (For a detailed description of the DC amplifier and filter, refer to paragraph 3-38.) The low voltage amplifier (refer to paragraph 3-40) develops the transfer voltage that is equal to the rms value of the unknown ac input voltage. Its output (terminal 9) is not used during the ac balance state.

3-20. To transfer from the ac balance to the dc output states, the operator pushes the TRANSFER RESET pushbutton. This action provides a ground return path for the coil of transfer relay K1, which is already connected to a +28 VDC supply. Relay K1, thus energized, opens its normally-closed contacts and closes its normally-open contacts, thereby changing the overall circuit configurations and establishing the dc output state.

3-21. **DC Output State.** In the dc output state, the magnetic coil A1L1 that controls low-voltage input switch A1S4 is de-energized. When this coil is de-energized, the original ac input voltage is replaced by its dc equivalent provided by the low voltage amplifier at terminal 9. This dc equivalent voltage is made available at the DC OUTPUT terminals (through the closed contacts from the now-energized transfer relay K1-6) for external measurement. Observe that the DC OUTPUT terminals were previously grounded during the ac balance state through closed contacts de-energized transfer relay K1-6. This means that a dc output is available only in the dc output state. A few millivolts may appear on the DC output during AC Balance mode because of extraneous currents but these may be ignored since they do not contribute error during the DC output state.

3-22. The −15 volt supply provides 100 microamperes current to the zero-center reading panel meter M1 via normally open-contact of energized transfer relay K1-8 and TRANSFER CHECK switch S5. This current deflects the meter pointer toward the left edge of the meter scale graduations, converting the instrument into a conventional left-to-right voltage indicating meter. Simultaneously, the transfer voltage output available to the DC OUTPUT terminals is applied through resistor A1R16 to the panel meter. Thus the panel meter gives a moderately accurate (±5%) indication of the value of the transfer voltage.

3-23. **AUTO MODE.** The following description of the operation of the ATS in the AUTO mode assumes that a high-voltage ac input of 32 to 64 volts is to be measured.

3-24. **AC Balance.** In the ac balance state, energizing power is applied to relays A1K10, A1K19, A1K20, and coil A1L10 associated with reed relay A1S13. The high-voltage ac input is applied to the heater of thermoelement A1TC1 through closed contacts of high-voltage input relay A1K10, front attenuator relay A1K19, attenuator resistor A1R39, rear attenuator relay A1K20 and high-voltage isolation reed switch A1S13. The thermoelement produces a dc output in series with summing resistor R3 that is applied as an input to the chopper system consisting of chopper G1 and transformer T3. The chopper and transformer combination converts the dc thermoelement output into a 93-Hz square-wave voltage which is applied as an input to the chopper amplifier circuit amplifies the square-wave voltage, demodulates it, then passes it along as an input to the DC amplifier and filter A3. (For a detailed description of the chopper amplifier, refer to paragraph 3-37).

3-25. The DC amplifier and filter circuit provides three different output voltage levels. A low-level dc output (terminal 14) is applied to the panel null meter through normally-closed contacts of de-energized transfer relay K1-8 and TRANSFER CHECK switch S5. A series multiplier resistor calibrates nulling sensitivity. This multiplier resistor may be partially deleted by the NULL x 5 switch to increase NULL sensitivity to 10 ppm/Div. A higher-level dc output (terminal 13) is applied as an input to a comparator circuit on the clock and gating board through wafer C of the mode switch S1. A still higher-level dc output (terminal 3) is applied as an input to the high voltage amplifier A12. (Refer to paragraph 3-38 for a detailed description of the DC amplifier and filter circuitry).

3-26. The comparator (zero detector) circuit on clock and gating board A8, which obtains its input at terminal A from the DC amplifier and filter circuit, controls the 16-stage up/down binary counter consisting of the two 8-Stage F/B counter boards A6 and A7. The comparator circuit (see figure 5-9) determines whether the counter should count up or down to achieve a balance of the ATS transfer standard. Since only the resultant of the applied ac input voltage appears across resistor R3 at this time, the counter must be commanded to count upward to develop a reference dc voltage related to the ac input voltage. The comparator circuit, composed of complementary transistors A8Q1 and A8Q5, senses the presence and polarity of a voltage input at terminal A, and responds accordingly. A positive voltage existing at terminal A turns transistor A8Q1 on and transistor A8Q5 off. A negative voltage at terminal A has the opposite effect. If no voltage is present at terminal A, both transistors are turned off. When a positive voltage appears at terminal A, therefore transistor A8Q1 is turned on and transistor A8Q5 remains turned off. Transistor A8Q2 is also turned off since it is connected in the collector circuit of A8Q5. This produces an up enable command for the counter and converter.

3-27. The logic state of the gating circuits associated with the comparator up enable output is such that the voltage levels at output terminals 4 and 3 are high, and those at terminals 5 and 2 are low. Meanwhile, a clock oscillator, consisting of transistors A8Q6 and A8Q9, provides trigger 5 kHz pulses which, in conjunction with the comparator outputs, advance the counter upward. As the counter advances upward it drives the ladder and buffer amplifier network A5 which, in turn, progressively builds up a reference voltage that is applied across summing resistor R3 through wafer D of mode switch S1. The polarity of this reference voltage is such that it tends to cancel or "buckout" the thermoelement output voltage. Thus only the difference between the two voltages remains as an input to the chopper amplifier circuit.

3-28. When the reference voltage builds up to a level equal to the applied thermoelement output voltage, there is no difference voltage applied to the chopper amplifier circuit and consequently none to the comparator circuit. Therefore transistors A8Q1, A8Q5, and A8Q2 are all turned off. The logic state of the gates associated with the comparator "null" output is such that the voltage levels at output terminals 4 and 2 are low, and those at terminals 3 and 5 are high. Thus the 16-stage counter receives no further command to count upward, so it stops counting.

3-29. The 16-stage binary counter is composed of two 8-Stage F/B counter boards, A6 and A7, connected together in cascade. These boards are identical and interchangeable (see figure 5-8). Each contains a typical arrangement of flip-flops (bistable multivibrators) and NAND gates, but their interconnection is such that the counter has the capability of counting downward as well as upward. In counting downward, the complementing level change comes from the 0 terminal of the preceding flip-flop rather than the 1 terminal. The counting sequence is the reverse of up counting. The operation of the counter is controlled by the clock and gating circuit A8. Commands to the counter from the clock and gating circuit arrive at terminals R.S.K.P., and 12. The logic of the gating system is such that when the voltage input levels at terminals R and K are high and those at 12 and S are low simultaneously with a low-level clock pulse at terminal P, the counter is triggered upward (increasing dc output from the D to A converter). Conversely, when the voltage input levels at terminals R and K are low and those at terminals 12 and S are high simultaneously with a low-

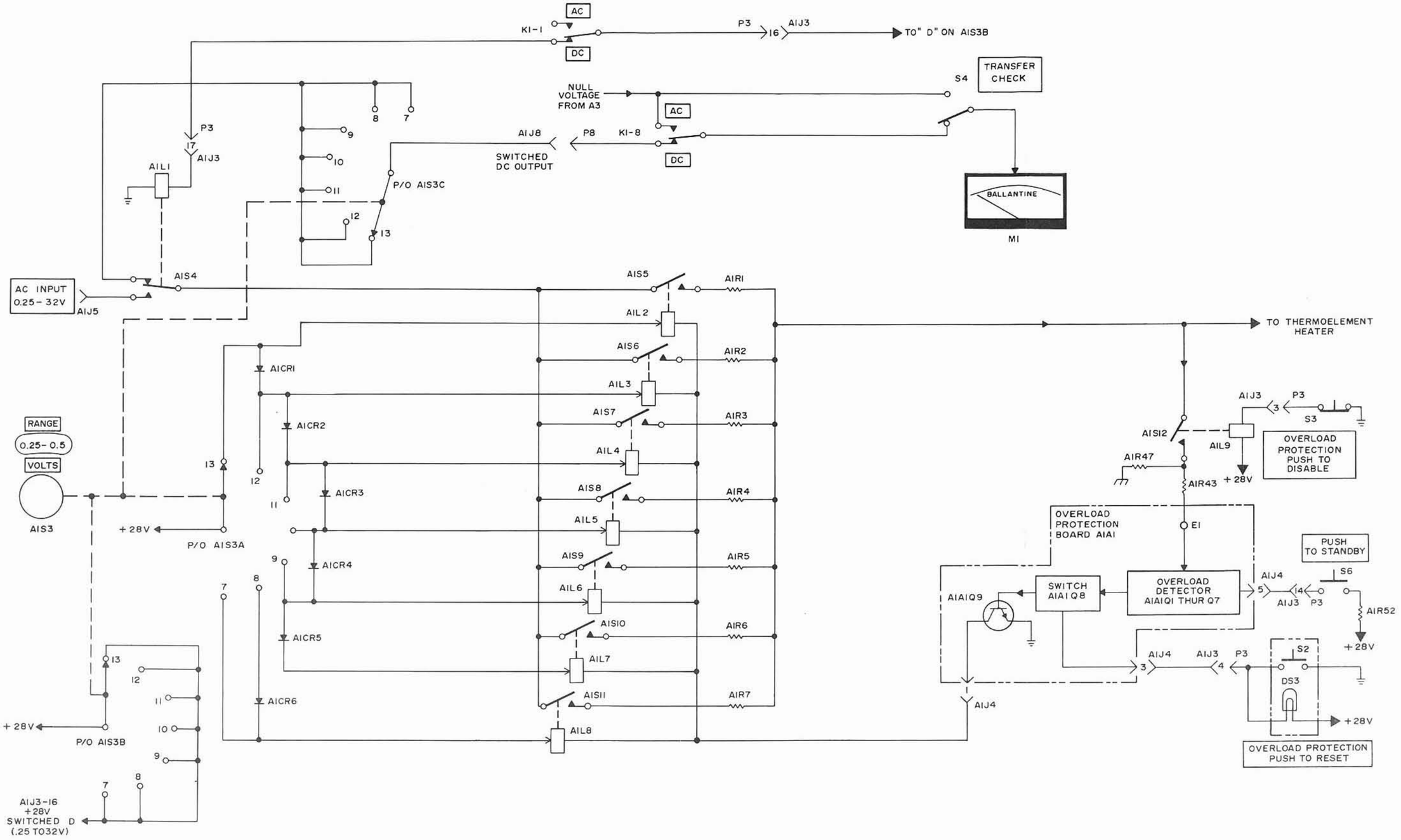



Figure 3-3. Low Voltage Attenuator, 1600A, Detailed Block Diagram

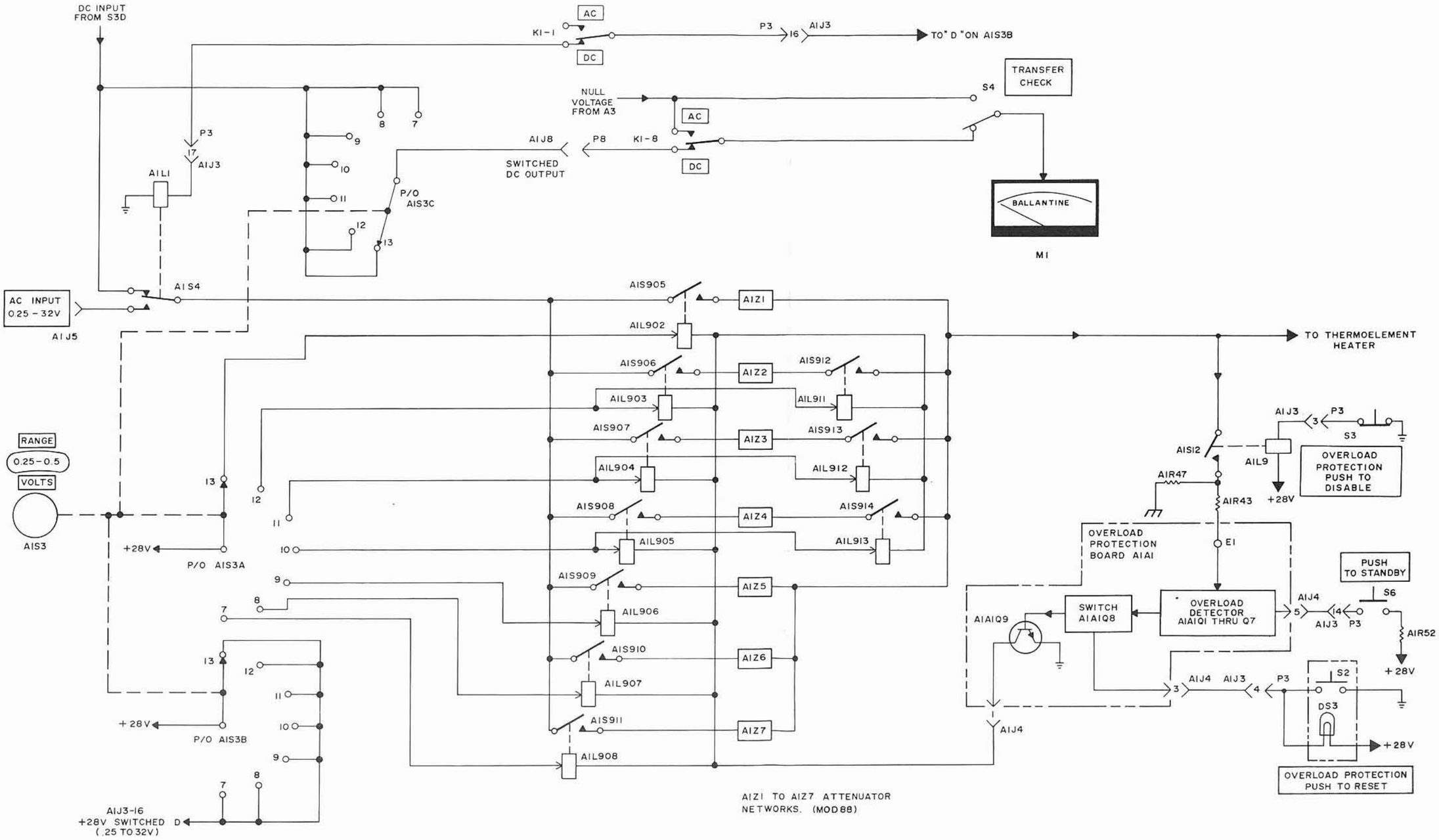



Figure 3-3A. Low Voltage Attenuator, 1600A MOD 88, Detailed Block Diagram



Note: See Fig. 5-2A for Low Voltage Attenuator Schematic on 1600A MOD 88

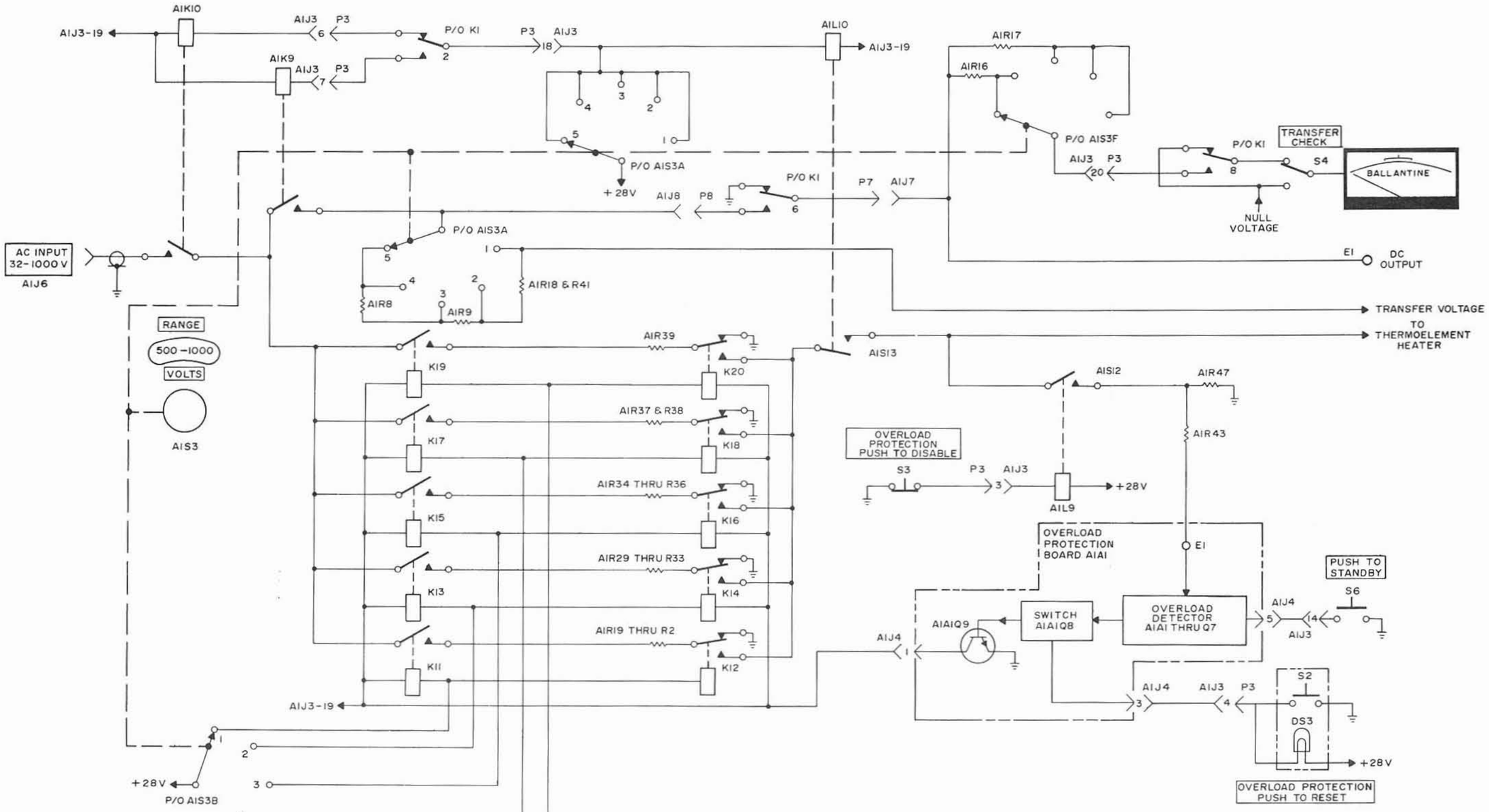



Figure 3-4. High Voltage Attenuator, Detailed Block Diagram

TABLE 3-1. LOW VOLTAGE ATTENUATOR OPERATION

| RANGE VOLTS Switch Setting | 1600A | | Effective Series Resistance | | 1600A MOD 88 Relay Coils Energized | Signal Attenuation |
|---|---|---|---|---|---|---|
| | Relay Coils Energized | Resistors Placed in Parallel | 1600A | 1600A MOD 88 | | |
| 0.25 to 0.5 | A1L2 thru A1L8 | A1R1 thru A1R7 | 20 Ω | 20 Ω | A1L902 | 1.25:1 |
| 0.5 to 1.0 | A1L3 thru A1L8 | A1R2 thru A1R7 | 120 Ω | 105 Ω | A1L903 & L911 | 2.5:1 |
| 1 to 2 | A1L4 thru A1L8 | A1R3 thru A1R7 | 320 Ω | 321 Ω | A1L904 & L912 | 5:1 |
| 2 to 4 | A1L5 thru A1L8 | A1R4 thru A1R7 | 725 Ω | 691 Ω | A1L905 & L913 | 10:1 |
| 4 to 8 | A1L6 thru A1L8 | A1R5 thru A1R7 | 1.5 kΩ | 1.465 Ω | A1L906 | 20:1 |
| 8 to 16 | A1L7 thru A1L8 | A1R6 and A1R7 | 3.1 kΩ | 3.16 kΩ | A1L907 | 40:1 |
| 16 to 32 | A1L8 | A1R7 | 6.32 kΩ | 6.34 kΩ | A1L908 | 80:1 |

TABLE 3-2. HIGH VOLTAGE ATTENUATOR OPERATION

| RANGE VOLTS Switch Setting | Relays Energized | Resistor(s) Inserted | Effective Series Resistance | Signal Attenuation |
|---|---|---|---|---|
| 32 TO 64 | A1K19 and A1K20 | A1R39 | 12.7K Ω | 160:1 |
| 64 TO 125 | A1K17 and A1K18 | A1R37 and A1R38 | 24.8K Ω | 312:1 |
| 125 TO 250 | A1K15 and A1K16 | A1R34 thru A1R36 | 50.7K Ω | 645:1 |
| 250 TO 500 | A1K13 and A1K14 | A1R29 thru A1R33 | 100K Ω | 1250:1 |
| 500 TO 1000 | A1K11 and A1K12 | A1R19 thru A1R28 | 200K Ω | 2500:1 |

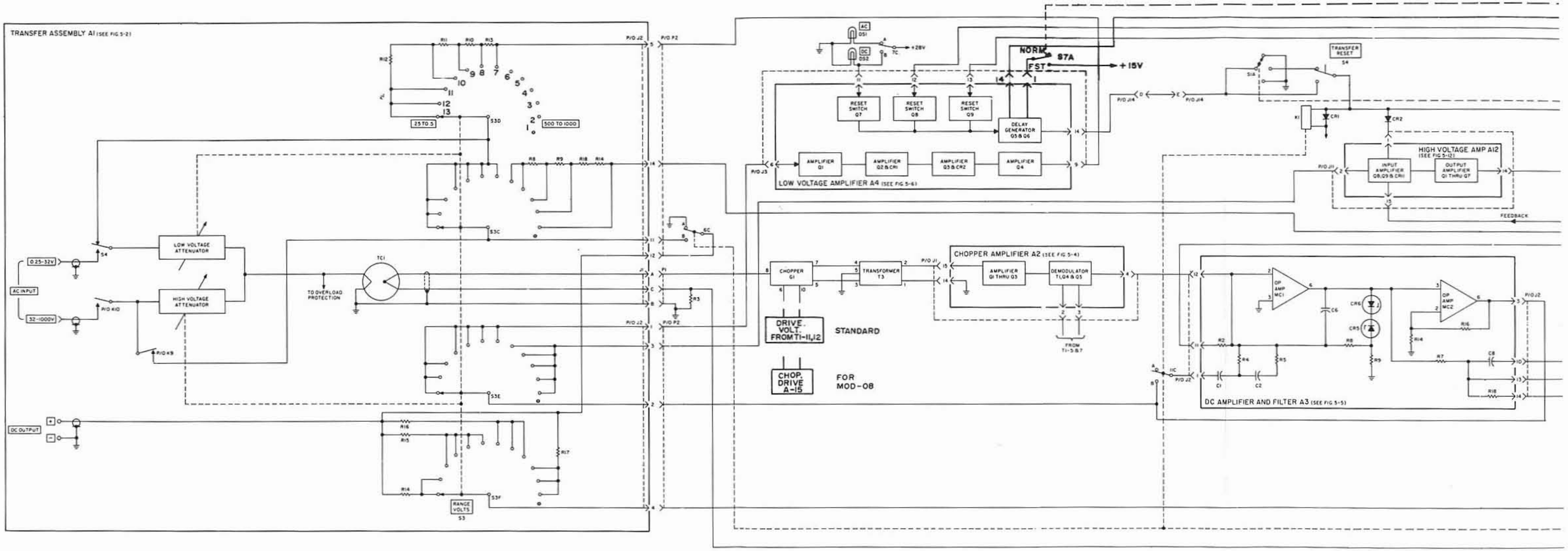
level clock pulse at terminal P, the counter is triggered downward (decreasing dc output from the D to A converter). When the voltage input levels at terminals R and S are low and those at terminals 12 and K are high simultaneously with a low-level clock pulse at terminal P, the counter does not trigger at all.

The binary Digital to Analog Converter has 16 bit resolution. It divides the precision 3.9 volt dc reference supply voltage into 65536 resolvable steps. Some of these are lost in the over and under range detecting circuits but more than 50,000 steps are available to discretely null the output from the thermoelement A1TC1 which appears across summing resistor R3.

3-30. The ladder (figure 5-7) is a voltage decoding network driven by the binary counter so that each step of the counter is decoded into a different voltage level. Starting from 0 volts, the dc nulling voltage increases in a stepwise manner as the count increases. Since the clock drives the counter, each step results in a count and voltage change by one increment. When the counter steps downward, of course, the ladder output voltage decreases in a corresponding manner. The digital to analog converter therefore acts as the system memory.

3-31. If, for any reason, the counter should arrive at its maximum or minimum capacity before the dc nulling voltage is developed, a gating circuit on the clock and gating board automatically stops the counter. Inputs for this gating circuit are derived from comparator circuit outputs along with the three topmost counter outputs and their respective complements.

3-32. After the dc nulling voltage is developed and the counter is stopped, there follows a six second time delay interval during which the ATS waits for any change in the value of the applied ac input voltage. This delay is accomplished by means of a 3-transistor NOR gate and a capacitor connection in the automatic transfer circuit (see figure 5-6). The NOR gate consists of transistors A4Q7, A4Q8, and A4Q9. When the counter is commanded to count upward, a positive voltage is applied to the base of transistor A4Q9 through board terminal 12. This voltage turns the transistor on and thereby effectively short-circuits capacitor A4C4, which is connected to the emitter of unijunction transistor A4Q6. Thus the unijunction is quiescent and silicon controlled rectifier A4Q5 is nonconducting. Conversely, when the counter is commanded to count downward, a positive voltage is applied to the base of transistor A4Q8 through board terminal 13, producing the same results. (The third


TRANSFER ASSEMBLY A1 (SEE FIG 5-21)
AC INPUT
0.25-32V
32-1000V
DC OUTPUT
LOW VOLTAGE ATTENUATOR
HIGH VOLTAGE ATTENUATOR
TO OVERLOAD PROTECTION
TC1
25 TO 5
500 TO 1000
RANGE VOLTS
S3
P/O J2
P/O P2
P/O J3
P/O J4
P/O J1
P/O J2
LOW VOLTAGE AMPLIFIER A4 (SEE FIG 5-6)
RESET SWITCH Q7
RESET SWITCH Q8
RESET SWITCH Q9
DELAY GENERATOR Q5 & Q6
AMPLIFIER Q1
AMPLIFIER Q2 & CR1
AMPLIFIER Q3 & CR2
AMPLIFIER Q4
NORM
FST
+15V
+28V
TRANSFER RESET
S4
HIGH VOLTAGE AMP A12 (SEE FIG 5-21)
INPUT AMPLIFIER Q8,Q9 & CR11
OUTPUT AMPLIFIER Q1 THRU Q7
FEEDBACK
CHOPPER AMPLIFIER A2 (SEE FIG 5-4)
CHOPPER G1
TRANSFORMER T3
AMPLIFIER Q1 THRU Q3
DEMODULATOR T1,Q4 & Q5
FROM T1-5 & 7
DRIVE VOLT. FROM T1-11,12
STANDARD
CHOP. DRIVE A-15
FOR MOD-08
DC AMPLIFIER AND FILTER A3 (SEE FIG 5-5)
OP AMP MC1
OP AMP MC2

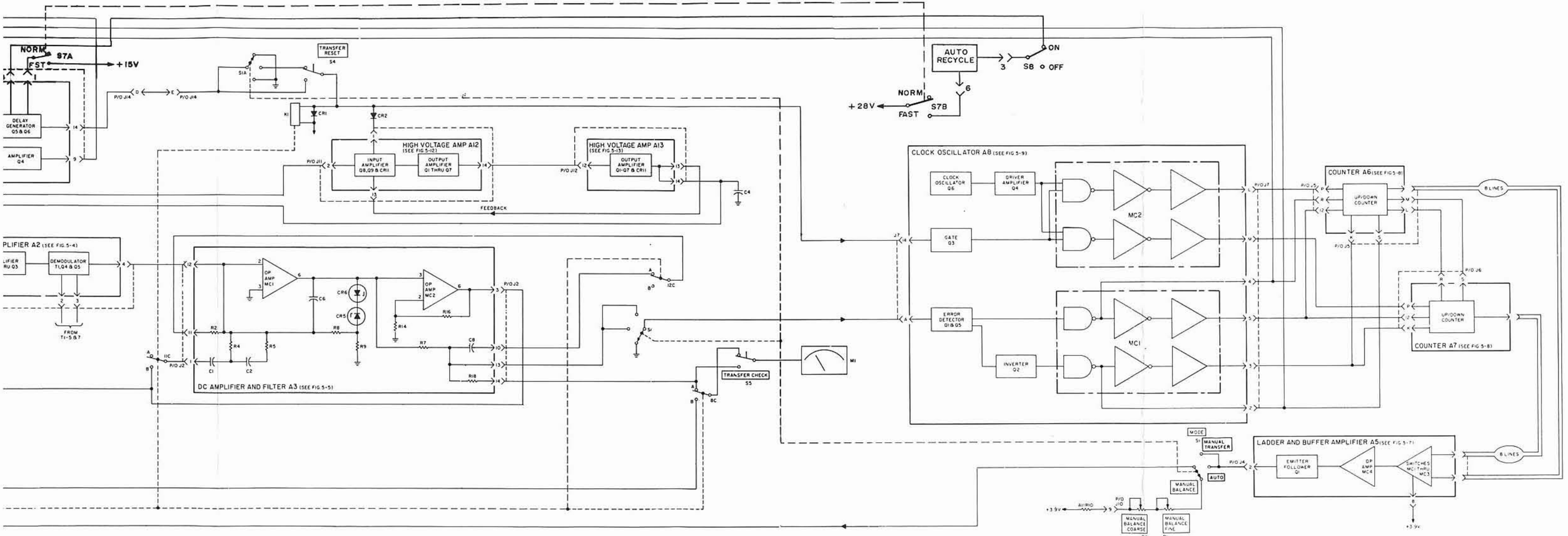



Figure 3-5. Detailed Block Diagram

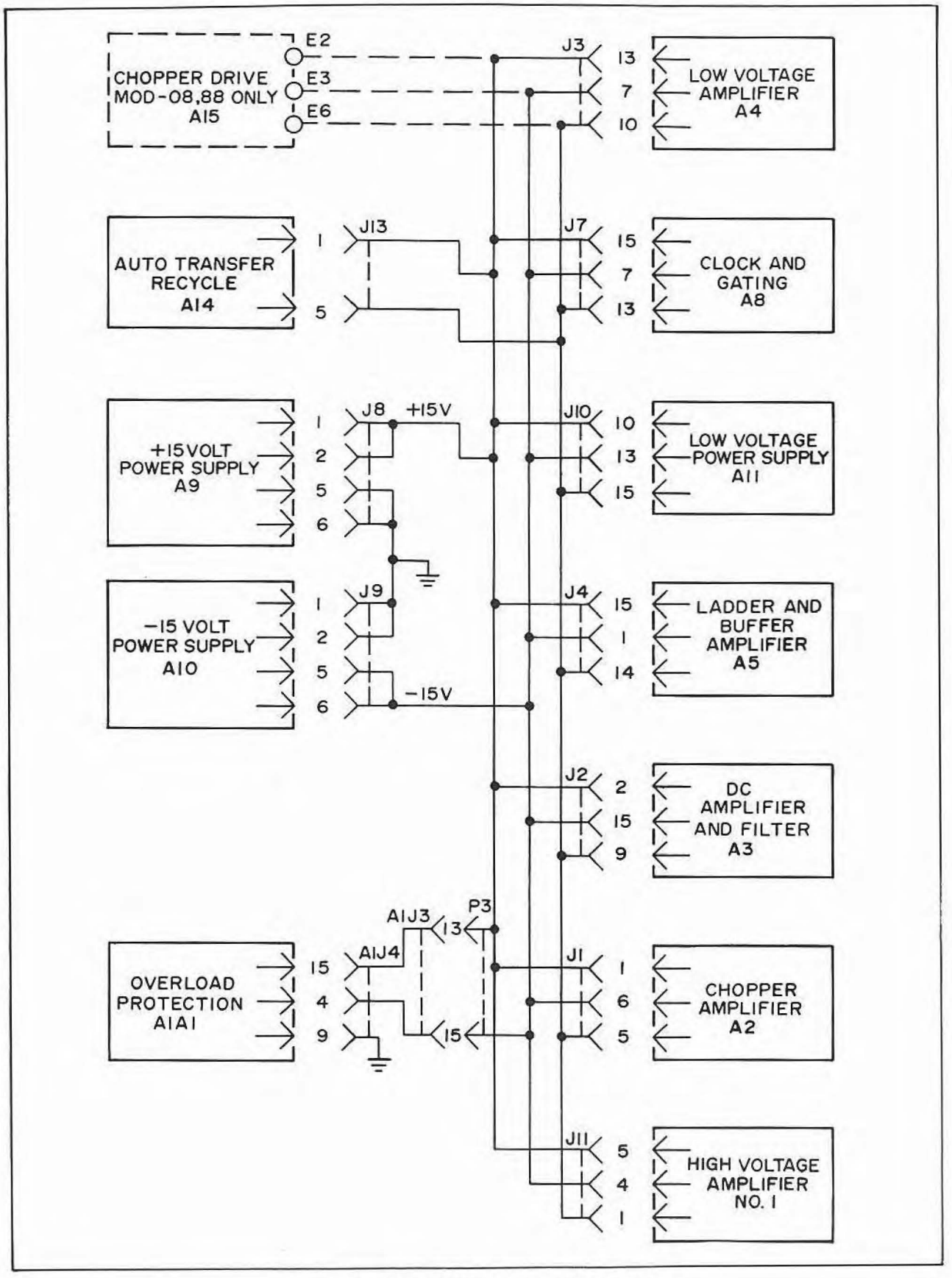



Figure 3-6. 15 Volt Power Distribution

transistor A4Q7 is turned on only when the ATS transfers to the dc output state.) The time delay interval begins when all three transistors are turned off, i.e., the counter is ordered to stop counting. Capacitor A4C4 begins to charge up to the predetermined level necessary to fire the unijunction transistor, which takes approximately six seconds to 10 seconds when the FAST/NORMAL toggle switch S7 is in the NORMAL mode. This longer waiting time assures that the thermoelement has settled to better than 100 ppm and that the input signal is stable to nominally better than 20 ppm per second. Full auto transfer accuracy is available in NORMAL mode.

The FAST mode reduces the resistor which charges A4C4 and increases its charging rate. The waiting time is reduced to nominally 3 to 6 seconds and input signals with drift and instability to 100 ppm per second may be accommodated in the Auto-Transfer mode. Measurement accuracy is somewhat reduced in the FAST mode and it should only be used for drifty input signals which do not permit AUTOmatic transfer in the NORMAL mode. For extremely unstable signals use the MANUAL TRANSFER mode.

When the unijunction transistor fires, it triggers the SCR which, in turn, begins to conduct. Since the ground return terminal of transfer relay K1 is connected to board terminal 14 and +28 vdc power is already connected, the relay is energized through the conducting SCR. Thus energized, transfer relay K1 opens its normally closed contacts and closes its normally open contacts, thereby transferring the ATS from the ac balance to the dc output state.

3-33. **DC Output State.** In the dc output state, relay A1K10 is de-energized and relay A1K9 is energized instead. Thus the high-voltage ac input to the thermoelement circuit is removed and replaced by an equivalent dc voltage from terminal 14 of high voltage amplifier 2, A13. This dc voltage, which will exactly balance the reference voltage output from the ladder and buffer amplifier, is the transfer voltage made available at the DC OUTPUT terminals through transfer relay contacts K1-6 for external measurement.

3-34. Normally-closed transfer relay contacts K1-8 that provided an indication of balance (null) to the panel meter in the AC state are now transferred to provide a needle pointer offset negative voltage (left-to-right dial conversion) and a voltage level indication. Terminals 10 and 11 of the DC amplifier and filter board, previously tied together through normally-closed contacts K1-12, are disconnected and terminals 1 and 3 are connected together instead (through normally-open contacts K1-11) for the dc output state configuration.

3-35. **MANUAL TRANSFER MODE.** The MANUAL TRANSFER mode of operation incorporates features of both the MANUAL BALANCE and AUTO modes. The procedures for setting up and operating the ATS in MANUAL TRANSFER is exactly the same as for AUTO mode, and the equipment performance is the same throughout the ac balance state, except that no automatic transfer to the dc output state occurs. When a balance of ac rms value versus dc reference voltage is achieved, the ATS simply waits for the operator to make the transfer by pushing the TRANSFER RESET pushbutton switch S4. If the amplitude of the ac input voltage changes (before transfer is made) within the limits of the RANGE VOLTS switch position, the ATS will seek a new balance and wait again. Signals which cause constant null meter movement may be measured by the operator pushing the TRANSFER switch S4 when he sees the needle at NULL Balance.

3-36. **AMPLIFIER CIRCUIT BOARDS.** Chopper amplifier A2 and the DC amplifier and filter A3 are involved in all three modes of operation and in both the ac balance and dc output states. Either the low voltage or the high voltage amplifier, depending upon the magnitude of the voltage being measured, is involved in all three modes in the dc output state.

3-37. **Chopper Amplifier A2 & A15.** To amplify the low voltage generated by the thermoelement, it is necessary to avoid the drift problem introduced by a direct-coupled amplifier and use a-c amplification instead.

In the Ballantine 1600A MOD 08, the thermoelement output voltage is converted into an 93 Hz (±20 Hz) square wave voltage by low noise chopper G1. The 93 Hz drive voltage for the chopper is provided by chopper driver assembly A15. Monolithic operational amplifier A15U1 is used as a sine wave oscillator. A15DS1 acts as the nonlinear element which maintains constant sine wave amplitude. Transistor A15Q1 is used to provide 6-volt drive to the chopper coil (G1) through step-down transformer A15T1.

The 93 Hz nominal chopping frequency is non-related to the normal range of line frequency components to avoid beats and related interferences.

The signal voltage derived from the thermoelement is chopped and then transformer coupled to chopper amplifier A2 (see figure 5-4). Transistors A2Q1, A2Q2, and A2Q3 provide three stages of amplification. The output is applied to the primary winding of transformer A2T1. A phase sensitive demodulator circuit composed of the secondary winding of transformer A2T1 and transistors A2Q4 and A2Q5 with their associated components, converts the amplifier 83 Hz ac voltage back into a dc voltage. The demodulator portion of the system is driven from the 93 Hz oscillator on A15.

The following description is applicable for ATS units which operate only on a power line frequency range of 50 to 60 Hz.

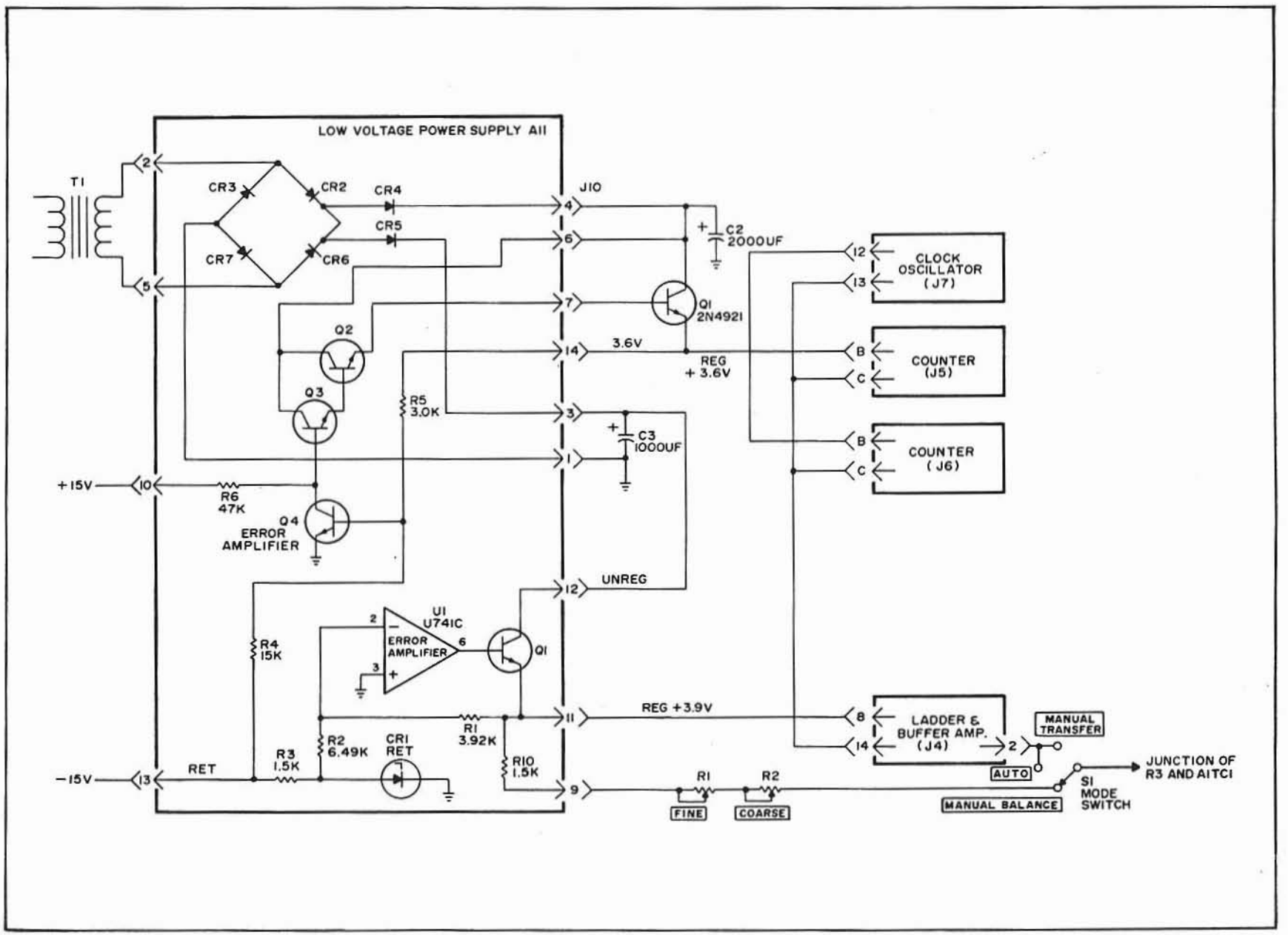



**Figure 3-7. 3.6 Volt and 3.9 Volt Power Distribution**

In the ATS, the thermoelement dc output voltage is converted into a line frequency (50 or 60 Hz) square wave voltage (by chopper G1) that then is amplifier by chopper amplifier A2 (see figure 5-4). Transistors A2Q1, A2Q2, and A2Q3 provide three stages of amplification. The output is applied to the primary winding of transformer A2T1. A phase-sensitive demodulator circuit composed of the secondary winding of transformer A2T1 and transistors A2Q4 and A2Q5 with their associated components, converts the amplified ac voltage back into a dc voltage. The demodulator portion of the system is driven by a center-tapped winding on power transformer T1.

3-38. **DC Amplifier And Filter A3.** Two interconnected high-gain operational amplifiers (A3MC1 and A3MC2) comprise the DC amplifier and filter (see figure 5-5). The output from the chopper amplifier is applied to the inverting input terminal 2 of amplifier A3MC1. Thus the output of amplifier A3MC1 is opposite the polarity of the input voltage. This output is applied through resistor A3R7 to the comparator circuit on the clock and gating board and through resistor A3R18 to the panel null meter. It is also applied through resistor A3R13 as an input to the non-inverting input terminal 3 of amplifier A3MC2. The output from amplifier A3MC2 serves as the input to either low voltage amplifier A4 or high voltage amplifiers A12 and A13, depending upon the attenuator voltage range selected by the operator.

3-39. In the dc output state, terminals 1 and 3 are tied together through transfer relay contacts K1-11. In the ac balance state terminals 10 and 11 of the DC Amplifier and Filter are tied together through transfer relay contacts K1-12. These connections provide low frequency phase compensation to prevent circuit oscillation. Diodes A3CR1 through A3CR4 limit the input voltage to the operational amplifiers and zener diodes A3CR5 and A3CR6 provide a non-linear characteristic to the panel meter null scale.

3-40. **Low Voltage Amplifier A4.** The voltage input for the low voltage amplifier board at terminal 6 (see figure 5-6) arrives from the DC Amplifier and Filter board. Transistors A4Q1 through A4Q4, connected in cascade, provide four stages of amplification with an output appearing from the emitter of transistor A4Q4 at terminal 9. Since the output of the low voltage amplifier must go up to 32 volts, the collector voltage for the final two stages is +43 volts; provided by a separate power supply on the circuit board.

3-41. **High Voltage Amplifiers A12 and A13.** Two circuit boards are needed to mount the components comprising the high voltage amplifier function (see figure 5-12). The input for the high voltage amplifier arrives from the DC amplifier and filter at terminal 2. It is amplified by a cascade combination of transistors A12Q9 and A12Q8, then fed into the bottom transistor (A12Q1) of a series array of transistors composed of transistors A12Q1 through A12Q7 and A13Q1 through A13Q7. This "totem pole" arrangement enables us to produce up to the 1 kV dc output required for the higher ac input voltages with relatively low voltage transistors.

3-42. **POWER SUPPLIES.** Seven different rectifier power supplies provide the power required by the ATS. They are physically located at various places within the unit.

3-43. **+28 VDC Power Supply.** Inside transfer assembly A1 is the rectifier power supply providing the power for energizing control relays and reed switch coils. (See figure 5-1). Essentially, it is a conventional diode bridge rectifier circuit drawing power from the secondary winding of transformer A1T1. Filtering is accomplished by a series resistance and capacitor A1C1. Pushbutton POWER PUSH illuminating lamp DS1 is connected across the power supply output and energized when the ATS is turned on. The 28 Volt supply also powers A15 the 93 Hz chopper driver.

3-44. **±15-Volt Power Supplies A9 and A10.** Two identical circuit boards provide the positive and negative 15-volt power required for operation of balanced transistor circuits and operational amplifiers on A15 and ten circuit boards (see figure 3-6). The negative output terminal of one of these is grounded and the positive output terminal forms the +15 volt supply line. The positive output terminal of the other 15-volt power supply is grounded and the negative output terminal forms the −15 volt supply line. Since both power supply circuits are the same, it is necessary to consider only one for purposes of analysis. The schematic diagram is shown in figure 5-10.

3-45. The 15-volt power supply is a conventional series-regulator power supply with a differential amplifier circut composed of transistors A9Q2 and A9Q3 used as the error amplifier. Transistors A9Q1 and A9Q4 form the series-regulating element and the reference voltage is obtained from Zener diode A9CR3. Zener diode A9CR4 provides collector bootstrapping for the error amplifier and potentiometer A9R7 provides adjustment of the output voltage. A9Q5 provides overcurrent protection. Full-wave rectification of power derived from a secondary winding of transformer T1 is accomplished by diodes A9CR1 and A1CR2.

3-46. **+3.6 and +3.9 Volts Power Supply.** Two regulated dc power supplies are developed to provide voltages to the clock and gating circuit (with the two counter boards) and to the ladder and buffer amplifier network (see figure 3-7). The bridge is driven by a secondary winding of power transformer T1 (see figure 5-11). The +3.6-volt output has a three-transistor series-regulating element consisting of transistors A11Q2, A11Q3, and Q1 mounted on the main frame chassis. Transistor Q1 dissipates appreciable heat and the chassis serves as a convenient heat sink. The −15-volt input from the negative 15-volt power supply provides the ref-

erence voltage and transistor A11Q4 is the error amplifier. Capacitor A11C2 provides filtering.

3-47. The +3.9-volt power supply provides a voltage to the ladder network from which the transfer reference voltage is developed; hence a very high degree of regulation and stability is needed. The short term drift of the +3.9 volt supply is typically less than 20 ppm per 10 seconds. Here transistor A11Q1 is the series regulating element. The reference voltage source is low noise temperature compensated reference, zener diode A11CR1 and operational amplifier MC1 functions as the error amplifier. Capacitor C3 provides filtering.

3-48. **+43 Volt Power Supply.** A diode bridge rectifier mounted on the board and connected to a secondary winding of power transformer T1 provides power for the operation of low voltage amplifier circuit (see figure 5-6). Filtering is accomplished by means of capacitor A4C5 and resistor A4R12. Zener diode A4CR7 provides regulation.

3-49. **+1500-Volt Power Supply.** The voltage requirements for operation of the high voltage amplifier circuit (built on two boards) is delivered by a power supply located on the second circuit board A13 (see figure 5-12). A diode bridge consisting of diodes A13CR2 through A13CR5 is driven by the secondary winding of power transformer T2 and filtered by choke L1 and capacitor C1 on the main frame. The output power developed is 1500 dc volts. The diodes in parallel with the choke and the small input capacitor C6 serve to improve regulation at low line voltage. Diodes CR4 and CR5 are in series across L1 for voltage derating. They prevent power supply noise in choke input filters caused by limited choke inductance and avoid the cessation of current flow when the rectifier diodes are switching.

The HV power supply is inhibited at its input on A12 by the application of a +28 volt bias on pin 3. The inhibit circuit prevents application of maximum voltage when the attenuator range relays are in standby (open) and when the ATS is in the AC Balance mode. A diode switching network (CR2 and CR3) quickly activates the inhibit but slowly releases the high voltage in a time constant controlled by A12 C3.

3-50. **Auto Re-cycle.** In the Auto-Transfer mode the ac input signal is measured and automatically nulled. The transfer to the dc readout mode occurs after a satisfactory null is established. The digital memory retains the thermoelement nulling potential and in the dc mode the dc amplifiers are servoed to re-balance the thermoelement emf against the previous ac null potential stored in the memory.

It takes approximately 10 to 15 seconds for the thermoelement to arrive at a final stabilized point which is within 0.01% of its final reading. The dc amplifier systems will track the thermoelement time constant so that the DC output voltage may be read 10 to 15 seconds after the ATS transfers from AC to DC.

The Auto Re-cycle assembly (A-14) provides a negative going > 3.5 volt (open circuit) 200 $\mu$s trigger approximately 15 seconds after transfer when in the NORMAL mode. An external DVM may be triggered to read its A to D converter by this pulse. Consecutive measurements are made at the same point in the time constant which optimizes repeatibility of results.

In the FAST mode the trigger delay is reduced to 4 to 10 seconds. This speeds up readings at the expense of measurement precision. Chosing alternate valves for A14R1 controls the time delay.
As the time after the optimum dc reading point increases, the various thermal effects and circuit drifts begin to effect accuracy. It must especially be noted that the thermoelement, although adequately thermally lagged to one time constant of 30 minutes for a 5°C change, has a temperature coefficient of 2000 ppm/°C.

It is, after all, a thermal sensing device. The ATS therefore may be expected to have a DC output voltage stability of 20 ppm for the any ten second period shortly following the initial 15 seconds after transfer. This holds in a constant ambient temperature and for voltage ranges below 125 Volts where attenuator heating effects are minimal.

The ATS would therefore be out of its tolerance range in a minute or two because of zero drift. It is proper technique to timely read the DC output voltage and to repeat the reading AC to DC measurement cycle less than once each minute.

A unique Auto-Zero feature is incorporated in the 1600A which resets the instrument to AC balance mode approximately 45 seconds after transfer to DC Readout mode. This Auto-Recycle feature may be selected in Auto mody by switch S8 located on the rear panel.

The Auto Recycle circuitry is described below.

The Auto Recycle board A14 generates two time intervals. The first is nominally 15 seconds after the 1600A transfers from ac to dc. This is the optimum time to read the dc output voltage of the ATS. The read command pulse is a single negative going pulse of > 3.5 volts amplitude (open circuit). Its source impedance is nominally 1 k$\Omega$ and the output is directly coupled through pin 14 on connection J16. This command pulse may be used to initiate a single read cycle on the Ballantine 3600A DVM or any equivalent "command to read" programmable DVM.

The second time interval generated is 45 seconds after transfer. The Auto-recycle circuit then automatically resets the ATS to AC balance mode by switching transfer relay K-1 back to AC. This effectively rezero's the ATS and avoids long term readout errors.

A14Q1 and the RC network A14R1, A14R16 and A14C1 initiate the 15 second timing pulse. Power is applied when

transfer relay K-1 switches from ac to dc. C1 is charged through resistors A14R1 and A14R16 till the firing potential of A14Q1 is reached. (If faster read time is wanted, A14R16 is shorted by the front panel NORMAL-FAST switch). C1 discharges rapidly through A14Q1 and A14R3 generating a positive pulse that is coupled to the base of A14Q2 through A14CR1.

A14Q2 and A14Q3 are an emitter coupled bistable switch. Whenever board A14 is energized A14Q3 will always be in the on state. When a positive pulse is coupled into the base of A14Q2, A14Q2 is turned on, A14Q3 turns off. The positive transition on the collector of A14Q3 is coupled to the base of A14Q4 via differentiator A14C2 and A14R11. A14Q2 remains in the on state until power is removed. A14Q4 is normally off, its collector is fixed at about +4 Volts by A14R12 and A14R13. When the collector of A14Q13 goes positive, the positive spike developed by the differentiating network turns A14Q11 on to saturation. The collector of A14Q4 falls to zero transmitting a single negative pulse through the output at J16 pin 14.

When power is applied through transfer relay K1 at the start of the dc cycle, A14C4 charges through A14R14 until the firing potential of A14Q5 is reached after about 45 seconds. A14C4 discharges through A14Q5 and A14R16 generating a positive pulse that saturates switch A14Q6, energizing relay A14RLY1. Closure of the contacts of the relay short circuits the current through SCR A4Q5 of the low voltage amp board A4. When A14CR4 is completely discharged, switch A14Q6 opens, Relay A14RLY1 opens and the ground return for transfer-relay K-1 is opened causing K-1 to revert to the ac mode and the cycle repeats.

The 45 second time delay may be varied by increasing A14C4 to lengthen the delay or by decreasing A14C4 to shorten the time delay. The adjustments should not normally exceed the range of 20 seconds to 90 seconds.

If the recycling feature is not wanted, it can be disabled by turning slide switch S8 on the rear panel to OFF.

# SECTION IV
# MAINTENANCE

## 4-1. GENERAL

4-2. This section contains maintenance, alignment and calibration instructions for the ATS. Included are a list of test equipment necessary for maintenance of the unit, minimum performance standards checks to evaluate whether the equipment operates within published specifications, systematic troubleshooting procedures to localize a malfunction to an individual subassembly or circuit and alignment and calibration procedures necessary to restore the equipment to proper operating condition after the required repairs have been accomplished.

## 4-3. TEST EQUIPMENT REQUIRED

4-4. The test equipment required for the maintenance and calibration of the ATS is listed in table 4-1. Equipment having similar characteristics may be substituted for those listed.

## 4-5. MINIMUM PERFORMANCE STANDARDS CHECKS

4-6. The minimum performance standards checks are aids to evaluating whether the ATS is functioning within the specifications listed in Section I. Should the ATS fail to provide the normal indication as specified, the equipment is not operating properly, and the operator should refer to the applicable troubleshooting, replacement, repair, alignment and/or calibration procedures to restore the equipment to normal operating condition. These checks are particularly applicable to routine periodic performance certifications and initial receiving inspections.

4.7 Minimum performance checks include:

a) Overload protection for thermocouple.
b) Functional checks with DC/DC transfer operation.
c) DC/DC transfer accuracy on all ranges
d) AC/DC transfer accuracy (optional)

This test requires NBS certified working standards and null testing equipment.

## 4-8. OVERLOAD PROTECTION FOR THERMOCOUPLE

a) Set-up as shown in Figure 4-1 with 421B set to zero output.
b) Set 421B frequency to 1 kHz RMS.
c) Set 1600A to manual balance and press TRANSFER RESET switch to Light "AC" lamp. Set RANGE switch to the 4 to 8 Volt range.
d) Slowly increase the output voltage from the 421B, until overload lamp lights. Do not go beyond 16 Volts RMS.
e) The overload circuit should trip at approximately 10 Volts RMS ±10%.
f) If tripping is satisfactory, set 421B output to 11 Volts RMS.
g) Press overload reset switch-lamp; and release. Lamp should remain lit.
h) Set 421B to 9 Volts.
i) Press reset switch-lamp; and release. Lamp should go out indicating that the overload circuit has been reset.
j) Press TRANSFER-RESET switch to light "DC" lamp.
k) Set RANGE switch to the 1 to 2 Volt range.
l) Press TRANSFER-RESET switch to light "AC" lamp. Overload should trip.
m) Set RANGE switch to the 4 to 8 Volt range.
n) Repeat step 9 above.

Fill in (check) Test Record Form 1600A-TR01. (Record Form 4-1) If any of the above steps do not check out perform the necessary readjustment procedures specified later in this Maintenance Section.

## 4-9. FUNCTIONAL CHECKS WITH DC/DC TRANSFER OPERATION

Connect Fluke 332B DC Voltage Standard to the 1600A input using a junction box at the 1600A with provision for remote sensing for the voltage standard. (See Figure 4-2) Connect a 5½ digit DVM either to the DC output binding posts of the 1600A or the input junction box via a "quick" interchange low thermal cable assembly.

Observe careful grounding. Only connect the ATS or the DC Voltage Standard to the power line ground.

Record data on test record 1600A-TR02. (Record Form 4-2)

a) Switch 1600A RANGE to 4 to 8 Volts.
b) Apply 4 Volts DC (half scale input)

Fill in Test Record after recording both ATS input and DC

## CAUTION

INPUT CURRENTS EXCEEDING 6.5mA ± dc or ac rms will destroy dc reversal error performance of the high precision dual bottle thermal element. Never exceed 6.5mA input current.

Take special care to keep input current from exceeding 6.5mA when adjusting the overload protection trip adjustment A1A1R16.

Input overloads greater than 6.5mA rms will destroy the dc reversal error performance but will not burn out the heater in the thermal element which is protected against catastrophic burn out by the overload protection circuit.

## Table 4-1. Required Test Equipment List for Model 1600A

1) 1 complete set of thermal converters with NBS reference Calibration thru 100 MHz

| | |
|---|---|
| 0.25 V to 0.5 V | 5 V to 10 V |
| 0.5 V to 1 V | 10 V to 20 V |
| 1 V to 2 V | 20 V to 50 V |
| 2 V to 5 V | 50 V to 100 V |

Ballantine 1394A Series and NBS calibrated 11600A for 100 to 1 kV calibration

2) 1 – Lindeck Galvanometer – Battery powered
Fluke Model 840B (Modified by Ballantine) or HP 3420B 1 ppm DC Δ Volt/Ratiometer

3) 1 – 20 MHz dual trace scope
Ballantine 1066B or equal with probes, T & BNC/BNC cables

4) 1 – AC Voltage Standard 10 Hz to 100 kHz to 100 V rms
HP 745A

5) 1 – DC Voltage Standard to 1 kV
Fluke 332B or Kintel 303B or equal

6) 1 – True RMS Voltmeter 300 μV F.S., 2 Hz to 20 MHz (50 MHz – 3 dB)
Ballantine 323L or equal with battery operation and Fluke 931B 100 kHz battery operated true RMS Voltmeter

7) 1 – 100 kHz 1 kV rms power amplifier
Singer LTP-11 or HP-746A or equal.

8) 1 – Digital Voltmeter 4¾ digits 100 μV resolution 0.01% accuracy.
Ballantine 3600A or equal

9) 1 – Digital Multimeter – DC Volts to 1 kV; AC Volts to 500 V 20 kHz; DC/AC Amps to 1 A, 100 Ω to 10 MΩ
Ballantine 3/24 or equal

10) 1 – Power Line Variac
General Radio 5 Amp with voltmeter and ammeter (or equal)

11) 1 – DC Digital Voltmeter
Cimron 6753 with 0.1 μV resolution or equivalent DVM

12) 1 – RF Power Amplifier 10 MHz to 500 MHz
Hewlett Packard Type 230A or equal

13) 1 – Line Regulator
Sola Transformer Type CVS-23-25-210

14) 1 – Oscillator, Constant Amplitude 50 kHz to 50 MHz or 100 MHz
Tektronix 190 or 191 or equal

15) 1 – Oscillator, 40 MHz to 250 MHz
General Radio 1021 P-3B, with power supply Type 1021 P1 or equivalent

16) 1 – 11600A NBS Certified Attenuator Head

17) 1 – Variable Frequency Power Supply, 250 V A/70 to 130 Volts/260 V 40 to 2 kHz
Vectron Inc. VFS-250 or equal

18) 1 – DVM – DC, 10 μV Resolution, 5-1/2 Digits
DANA 5500 or equal

19) 1 – AC/DC Calibrator
Ballantine 421B

20) Power Oscillator & Amplifier
to 1 MHz, 120 Volts – Optimation PA-25

21) 1 – Frequency Counter 500 MHz, 0.1 Hz Resolution, 10 mV sensitivity
Ballantine 5700A

22) AC Calibration Source, 30 Hz to 100 KHz, 1 mV to 1 kV, Stability 20 ppm in 5 minutes,
Ballantine 6300A or equivalent.

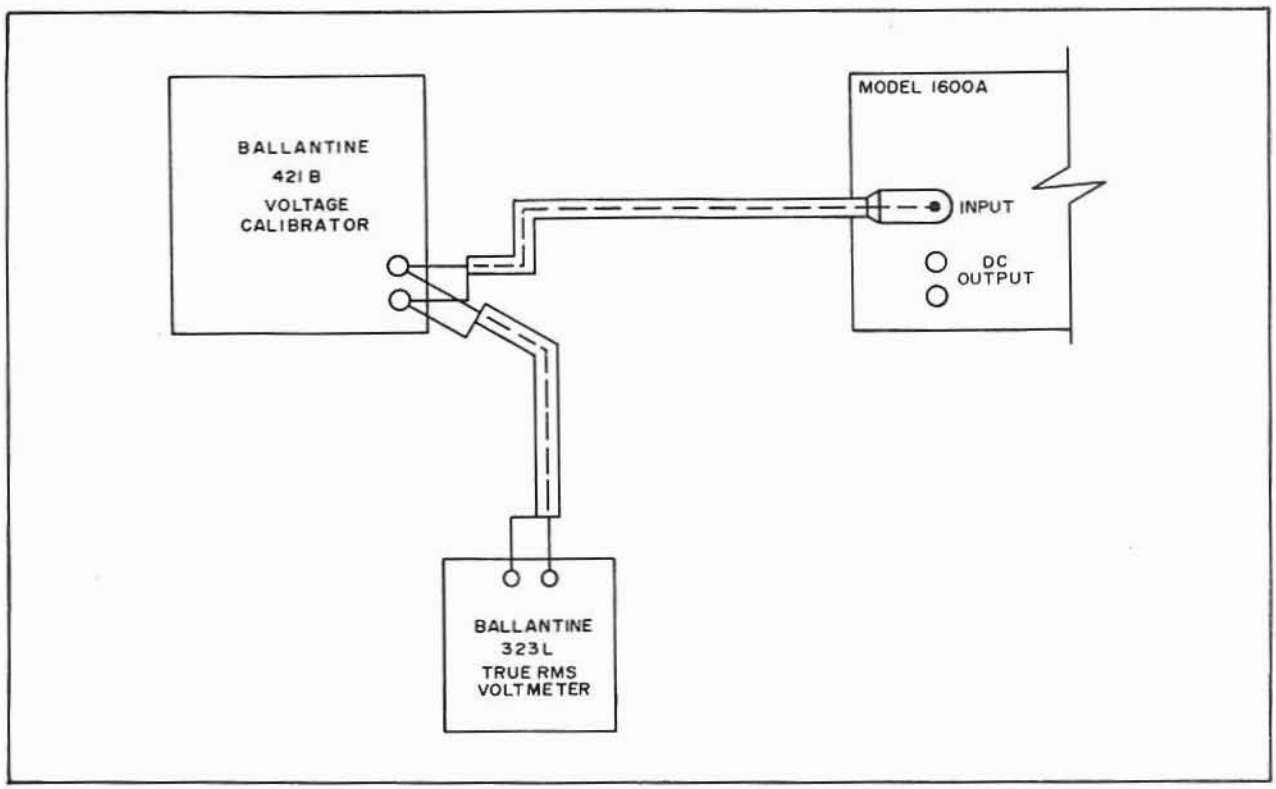



Figure 4-1. Overload Test Equipment Setup

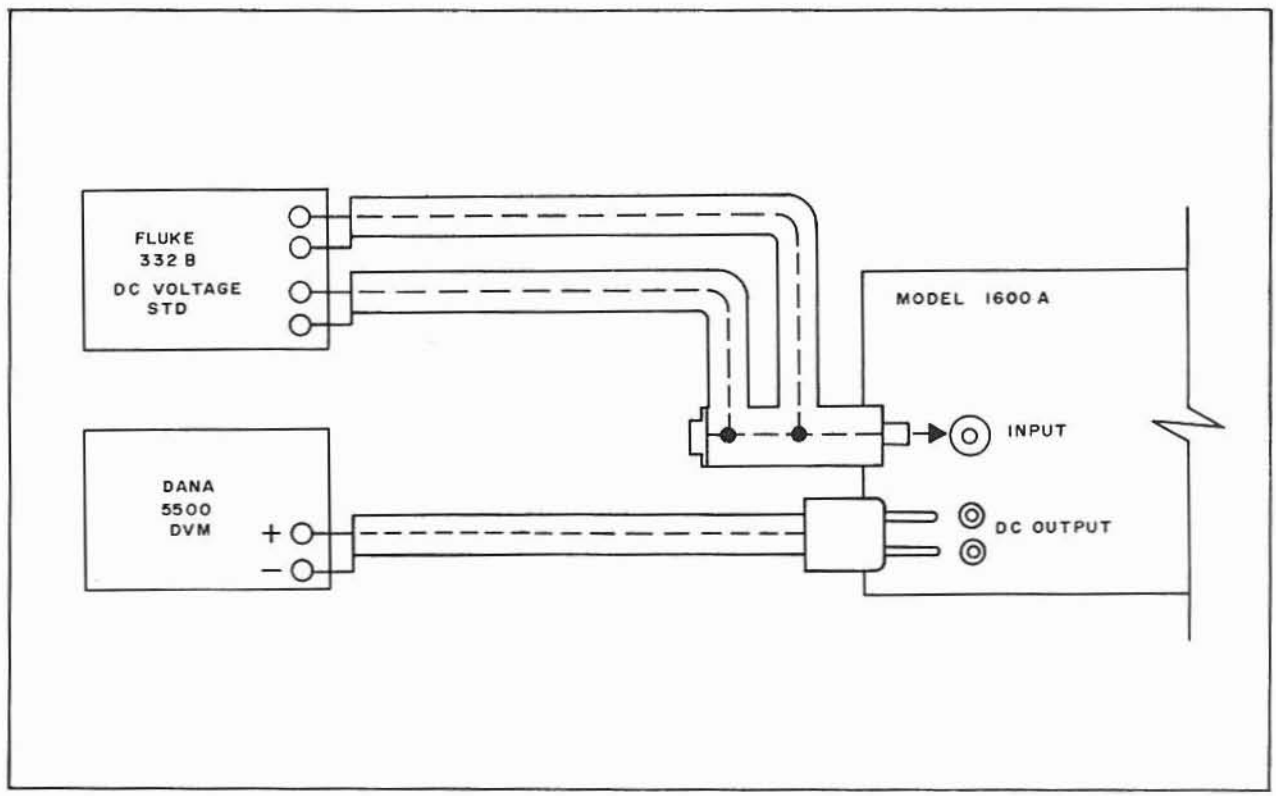



Figure 4-2. DC/DC Transfer Operation Setup

output voltages with DVM. Use 20 second settling time after thorough warm up. Make three readings of input and output. Record fourth reading (or average of second, third and fourth) on the test record. Reach transfer for each of the following functional modes. See Form 4-2.

1. Manual BAL _____
2. AUTO _____
   Normal _____
   Fast _____
3. Manual Transfer _____

c) Repeat above with 8 Volts (Full scale) Input.

1. Manual BAL _____
2. AUTO _____
   Normal _____
   Fast _____
3. Manual Transfer _____

If any of the above checks do not provide the accuracies specified on the Test Record Form (1600A-TR02) perform the readjustment procedures detailed later in this Maintenance Section.

## 4-10. DC/DC TRANSFER ACCURACY – ALL RANGES

a) Connect Fluke 332B DC Voltage Standard and DANA 5500 DVM to 1600A ATS as shown in Figure 4-3.

b) Record data on Test Record 1600A-TR01 (Record Form 4-1)

c) After time for stabilization in constant ambient of 23° ±2°C make several measurements in AUTO NORMAL Mode and allow 20 seconds for DC readout (measurement delay interval) to check operation. Be sure stable and repeatable measurements are obtained in the AUTO and MANUAL BALANCE Modes.

d) Apply full scale (±5%) positive DC Voltages at full range for each attenuator setting beginning with 0.5 Volts. Measure input with the DVM and record in Column A of the Test Record form.

Record the last of three consecutive readings.

**NOTE**

Measure Input Voltage when 1600A is in AC mode and measure DC output voltage when 1600A is in DC readout mode and after DVM reading becomes steady. MANUAL TRANSFER mode may be used instead of AUTO MANUAL for operator convenience and minimal error correction.

e) Complete test on each range and fill in columns A and B of the test record.

f) Complete the calculations of the test record and compare % Measured Error with the allowable error.

Correct allowable error for Noise contribution (100 $\mu$V or 90 dB below full scale; whichever is greater) and voltage coefficient (1 ppm/V over 25 Volts) as required. Note that AUTO Balance operation adds 50 ppm error. For optimum specified accuracy use MANUAL BALANCE mode with Null x5 10 ppm resolution. All these errors are additive to the measured error. The test record accuracies refer to MANUAL BALANCE operation.

1600A must meet specification on all 12 input ranges as indicated on the Test Record Form (1600A-TR01). If discrepancies exist check measurement technique and accuracy of test equipment. If required, perform readjustments detailed later in this Maintenance Section.

## 4-11. DC OUTPUT RIPPLE AND NOISE (Optional)

If desired the optional DC output ripple and noise test may be performed to fully complete the Test Record Form 1600A-TR01. (Form 4-1).

Set up Equipment as shown in Figure 4-4. Record data on Test Record 1600A-TR01. (Test Record Form 4-1).

a) Set-up as shown below: Set Fluke 332B DC Voltage Standard to 6.0V. Set RANGE switch to 4 to 8 Volts.

b) Set mode switch to MANUAL BALANCE.

c) If necessary, press TRANSFER RESET switch to light "AC" lamp.

d) Adjust coarse and fine balance controls for a balance, as shown on the meter.

e) Press the TRANSFER-RESET switch to light "DC" lamp.

f) Move RANGE switch to 0.5 Volt range.

g) Record RMS noise as viewed on 50 MHz AC and 100 kHz True RMS Voltmeters operated by batteries.

h) Move RANGE switch to 0.5 to 1.0 and record noise as in g above.

i) In like manner, measure noise on all ranges up to and including the 250 to 500 V range and note on the test record.

j) With the RANGE switch set at 250 to 500 V and the "DC" lamp lighted, adjust the coarse balance control for a reading on the meter of 250 V.

k) Move range switch to 500 to 1000 V range and record noise as before.

**NOTE**

Step j is necessary to limit the DC input voltage to the AC voltmeters to a value within the voltage rating of the input capacitors of these instruments. If not strictly followed, the voltmeters may be damaged.

## 4-12. AC/DC TRANSFER ACCURACY

Figure 4-5 shows the test set-up for calibrating the attenuator using another NBS certified Ballantine 1600A or 1394A Thermal Convertor. Link up the input ports of the two instruments via a GR874 TEE connector. Connect the thermocouple output port of the standard to the galvanometer/Lindeck (Fluke 840B Modified) arrangement as shown. The thermocouple output of the instrument being tested should be connected to the digital voltmeter Cimron

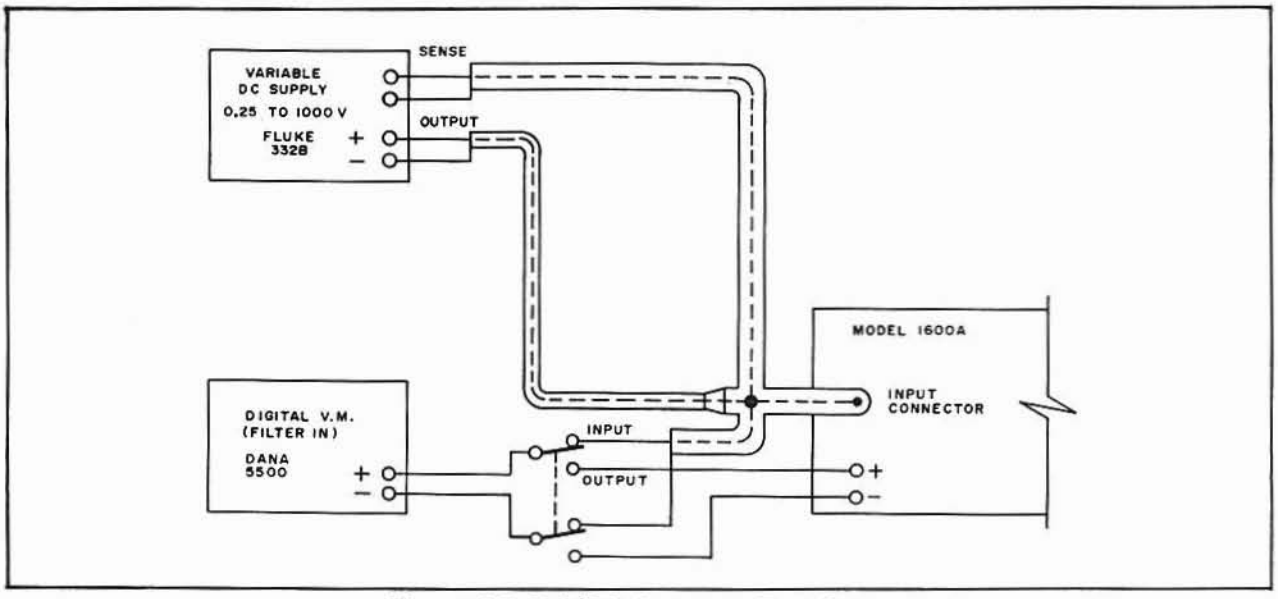



Figure 4-3. DC/DC Accuracy Test Setup

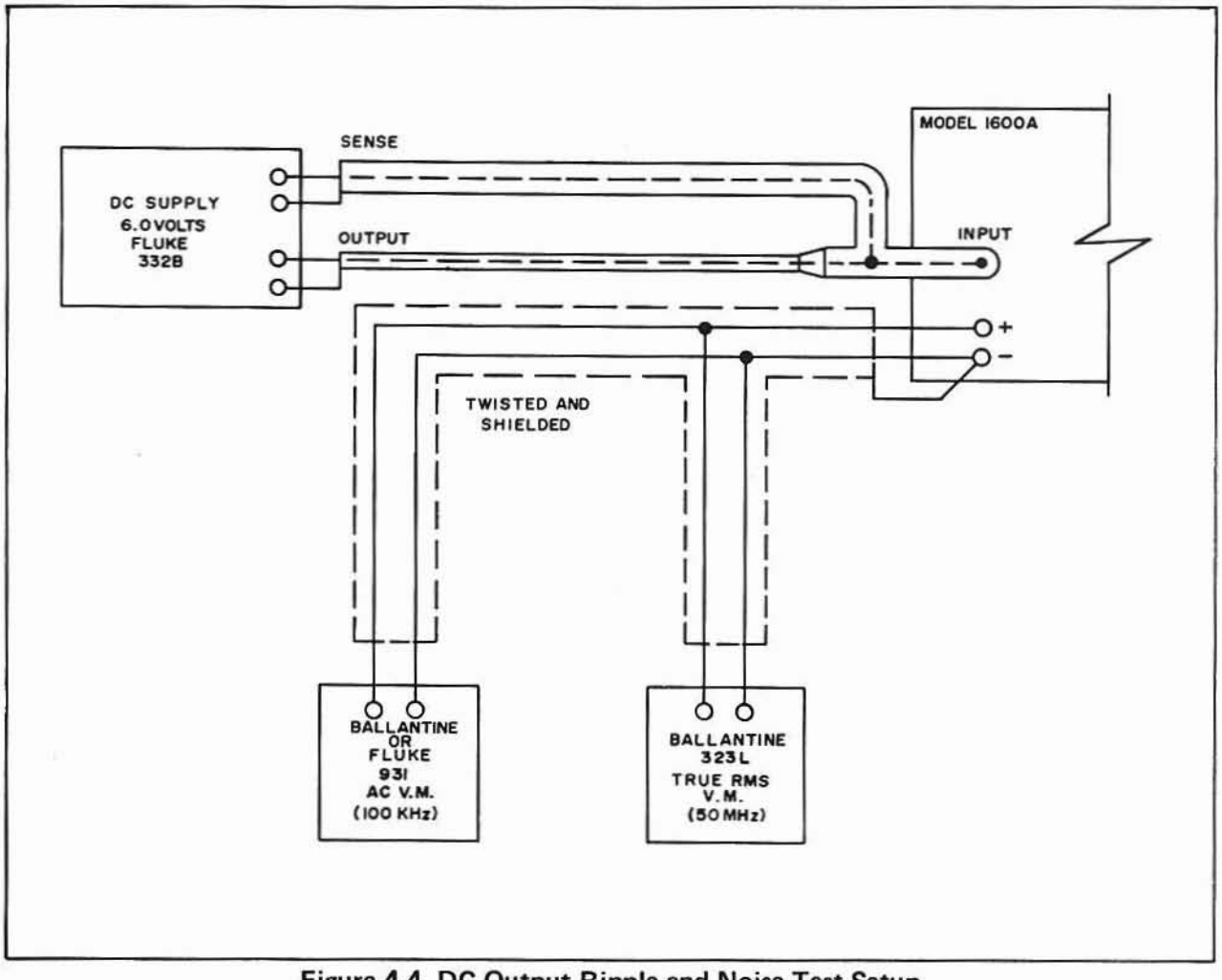



Figure 4-4. DC Output Ripple and Noise Test Setup

Ballantine Laboratories, Inc.

TEST RECORD 1600A-TR01(A)

# 11600A FINAL CHECKOUT
# NOISE & OUTPUT CURRENT

11600A TRANSFER ASSEMBLY S/N _____
1600A S/N _____
DATE _____
METROLOGIST _____

| RANGE | RMS OUTPUT RIPPLE | | | DC TRANSFER CURRENT | | DC TO DC ACCURACY at FULL RANGE in AUTO MODE NORMAL | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Actual rms 50 MHz | Actual rms 100 KHz | Allowable rms max. 100 KHz (-90dB FS) | Actual | Allowable min. | Input Volt. (A) | Output Volt. (B) | Measured Error (B-A) | % Meas. Error 100 (B-A)/A | Allow Error % |
| 0.25 to 0.5 | | | 100µV | | 5.0mA | | | | | 0.01 |
| 0.5 to 1.0 | | | 100µV | | 5.0mA | | | | | 0.01 |
| 1 to 2 | | | 100µV | | 5.0mA | | | | | 0.01 |
| 2 to 4 | | | 120µV | | 5.0mA | | | | | 0.01 |
| 4 to 8 | | | 240µV | | 5.0mA | | | | | 0.01 |
| 8 to 16 | | | 490µV | | 5.0mA | | | | | 0.01 |
| 16 to 32 | | | 1mV | | 5.0mA | | | | | 0.01 |
| 32 to 64 | | | 2mV | | 5.0mA | | | | | 0.01 |
| 64 to 125 | | | 3.8mV | | 5.0mA | | | | | 0.01 |
| 125 to 250 | | | 7.5mV | | 5.0mA | | | | | 0.01 |
| 250 to 500 | | | 15mV | | 5.0mA | | | | | 0.015 |
| 500 to 1000 | | | 30mV | | 5.0mA | | | | | 0.019 |

-All readings taken at FULL RANGE. (Allowable error does not include noise or voltage coefficient of 1 p-p µ/V.)
-Ripple measured with 10 megohm loading over 50MHz bandwidth with BALLANTINE 323L True RMS Voltmeter operated on batteries and 100KHz measured with a FLUKE 931A Differential DVM operated on batteries, 1600A chassis earthed
-Current measured with DC Milliammeter presenting <10 Ohm load.

-Overload trip voltage.....(9V min.- 11V max. on 4 to 8 Volt range)
-Overload reset lockout.....(Lamp ON at 11V rms)
-Overload reset.....(Lamp OFF at 9V rms)
-Overload trip on switch to AC..(9V rms input on 1 to 2V range)(9V rms input on 2 to 4V range)

FORM 4-1

Ballantine Laboratories, Inc.
TEST RECORD 1600A-TR02

# 11600A FINAL CHECKOUT
# DC-DC ACCURACY WITH FUNCTION

RANGE 4 TO 8 VOLTS

11600A Transfer Assembly S/N _____
1600A S/N _____
DATE _____
METROLOGIST _____

DC REVERSAL ERROR

| INPUT | OUTPUT READING |
|---|---|
| Positive 8V | _____ V |
| Negative 8V | _____ V |
| Difference | _____ V |

$= \frac{100 \times \text{Difference}}{8} =$ _____ %

| | | | Input + DC Voltage (DVM) (A) | Output Voltage (DVM) (B) | Measured Error (B-A) | % Measured Error $\frac{100(B-A)}{A}$ | Allowable % Error |
|---|---|---|---|---|---|---|---|
| +4 Volt Input | MANUAL BAL. | | | | | | 0.008 |
| | AUTO | Normal | | | | | 0.02 |
| | | Fast | | | | | 0.03 |
| | MANUAL TRANSFER | | | | | | 0.01 |
| +8 Volt Input | MANUAL BAL. | | | | | | 0.005 |
| | AUTO | Normal | | | | | 0.01 |
| | | Fast | | | | | 0.02 |
| | MANUAL TRANSFER | | | | | | 0.008 |

FORM 4-2

Ballantine Laboratories, Inc.

# FREQUENCY RESPONSE

11600A S/N _____

Traceable to NBS through 1394A and 11600A working standards. Manual Balance Mode.

| RANGE | DVM READING OF OUTPUT DC | | | | | % Error Correction of Standard | % Absolute Accuracy |
|---|---|---|---|---|---|---|---|
| | (1 kHz Input) Volts | Test Frequency | Volts | (1 kHz Input) Volts | Difference | | |
| .25 to .5 | | 30 MHz | | | | | |
| .5 to 1 | | 30 MHz | | | | | |
| 1 to 2 | | 30 MHz | | | | | |
| 2 to 4 | | 30 MHz | | | | | |
| 4 to 8 | | 30 MHz | | | | | |
| 8 to 16 | | 100 KHz | | | | | |
| 16 to 32 | | 100 KHz | | | | | |
| 32 to 64 | | 100 KHz | | | | | |
| 64 to 125 | | 100 KHz | | | | | |
| 125 to 250 | | 20 KHz | | | | | |
| 250 to 500 | | 20 KHz | | | | | |
| 500 to 1kV | | 20 KHz | | | | | |

DATE _____ METROLOGIST _____

Absolute accuracy is subject to NBS uncertainty.

FORM 4-3 (Standard 1600A)

6753. Use shielded leads and connectors as well as low noise cable suitable for microvolt DC discrimination. The 1 kHz reference is an H-P 745 while the low frequency HV power source is an LTP-11 and the high frequency power source is a GR1021P-3B and Tek 190 oscillator and H-P 230A Tuned Power Amplifier.

a) **Preliminary Adjustments**

1. *Sensitivity:* Set the digital Voltmeter on the millivolts X1000 range. The 5th digit represents 0.1 $\mu$V. The galvanometer/Lindeck arrangement should have a minimum sensitivity/resolution of 0.1 $\mu$V.

2. *Polarity:* If, at the test frequency, more alternating Voltage is required to obtain the same thermocouple output as measured at the reference frequency, then the associated error shall be considered **positive.**

3. *Stability:* All supplies should be turned on for several hours before use, to insure good stability.

4. *Grounding:* The only ground on the system should be that on the signal source. Plug the 11600A into the line via an adapter to remove its ground. The connectors on the thermocouple outputs should have their negative pins connected to the shell.

Record all data on Test Reports 1600A-TR10. (Test Form 4-3). (1600A-TR03 through TR08 for 1600A-MOD88) Test Forms 4-5 to 4-10.

b) **Sequence of Operations for Attenuator Certification**

1. Select the range required on the attenuators and/or 1394A thermal convertor. Note that the overload protection circuit is not active.

2. Connect the 1 kHz reference oscillator via coaxial cable to the GR874-T. Use remote sensing.

**NOTE**

A DC Reference Standard (Fluke 332B) may be used as the reference source if reversed readings are taken to compensate for reversal error.

3. Adjust the reference oscillator so that the DVM reads about 7.0000 mV.

4. Adjust the Lindeck potentiometer Fluke 840B until the reference galvanometer is balanced. **Record the DVM reading of step 4 at that point.**

5. Select the desired frequency on the test oscillator and set its amplitude at the approximate output required.

6. Disconnect the reference source and connect the test oscillator. Adjust the output voltage from the test oscillator until the balance is restored on the reference galvanometer. **Record the DVM reading.**

7. Reconnect the reference source TRANSFER switch back to DC state, and adjust reference oscillator output till reference galvanometer is again balanced. **Record DVM reading.**

8. The readings from paragraphs 4 and 7 should not differ more than 2 digits (±0.2 $\mu$V). This insures that the reference remains unchanged throughout the calibration. Repeat the measurement if error allowance is exceeded. The difference between the readings recorded in paragraphs 6 and 7 is indicative of the frequency error of the instrument being calibrated. Follow arithmetic on the test forms to calculate % error after allowing for square low response of the thermoelement.

c) For the ranges between 64 V and 1000 V, the output from the test oscillator (H-P 745A to 100 V and LTPS-11 from 100 V to 1 kV) is applied to the right hand input GR connector on the 1600A.

**NOTE**

For 1 MHz to 100 MHz checks, use Tektronix 190 or 191 Oscillator and GR 1021-P-3B Oscillator with H-P 230A Power Amplifier. Operate all equipment from line voltage regulator.

d) Complete all attenuator ranges and frequencies listed on Test Report 4-3 1600A-TR10 (1600A-TR03 through TR08 for 1600A-MOD88). All ranges must meet specification. Noise and voltage coefficient are added as required.

If discrepancies exist perform the readjustment procedure detailed later in this Maintenance Section.

## 4-13. COMPONENT LOCATIONS

4-14. The location of major assemblies and subassemblies are illustrated in figure 4-6 through 4-8.

## 4-15. POWER SUPPLY CHECKS

4-16. Improper operation of the equipment may be due to a malfunction within one of the power supplies: main frame power +28 VDC supply, and pc boards A4, A9, A10, A11, A12 and A15. To ascertain that the required voltages are being developed, proceed as directed in the following steps:

a) Remove eight screws and the bottom plate from the ATS to gain access to terminal measurement points.

b) Couple the ATS to line power as described in Section II. Use a Line Voltage Control Vaviac and set to 115 (250) volts.

c) Measure the voltages present between the points specified in table 4-3. See figures 4-6 thru 4-9 for the location of terminal measurement points.

d) Measure the +28 VDC unregulated output of main frame power supply by connecting a DMM between junction of A1R40-A1C1, and chassis ground. A reading of between +24 and +30 volts should be obtained.

## 4-17. LOCATING TROUBLE WITHIN POWER SUPPLIES

4-18. To localize a malfunction within one of the dc power supply circuits, proceed as directed in table 4-3.

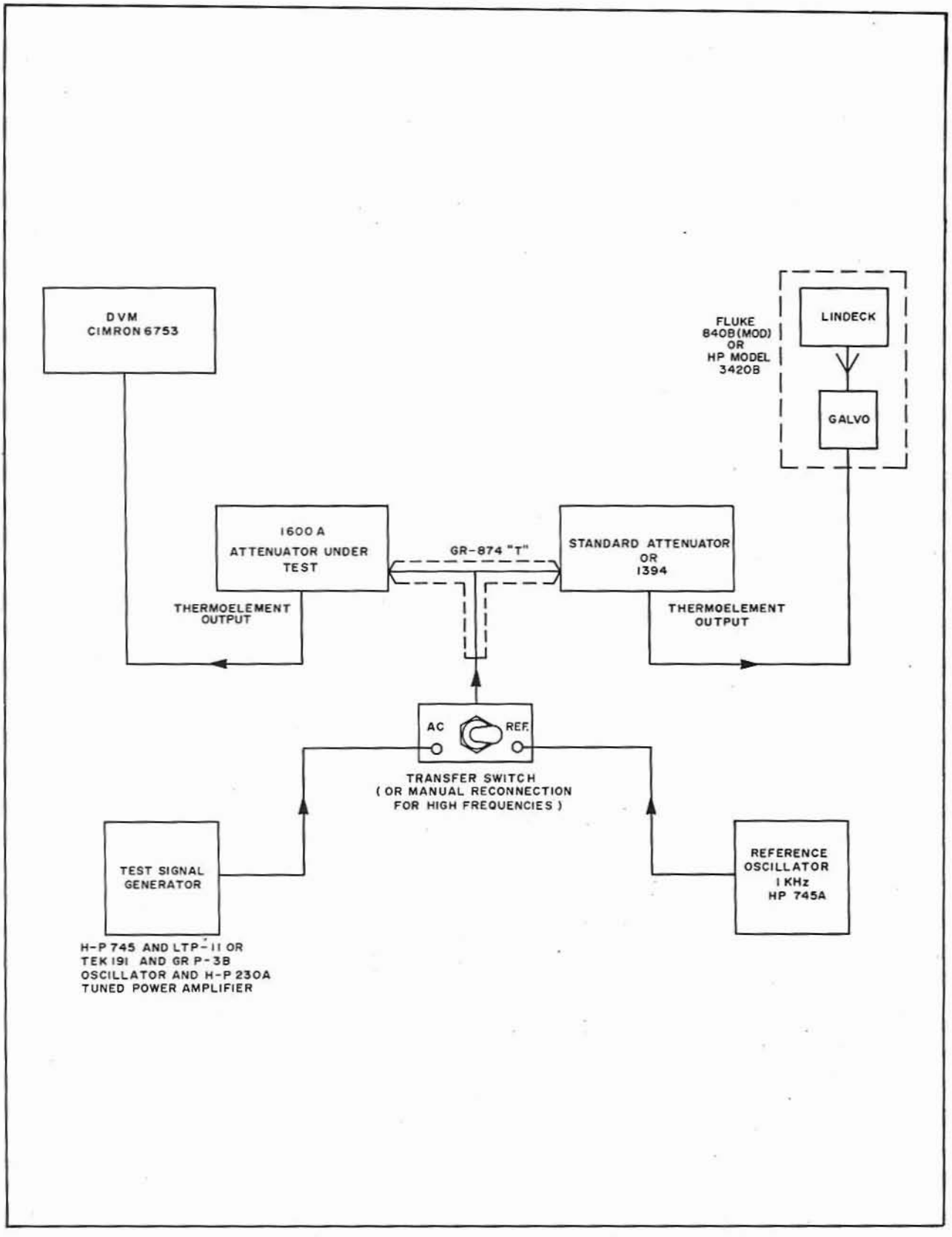



**Figure 4-5. AC Calibration Test Setup**

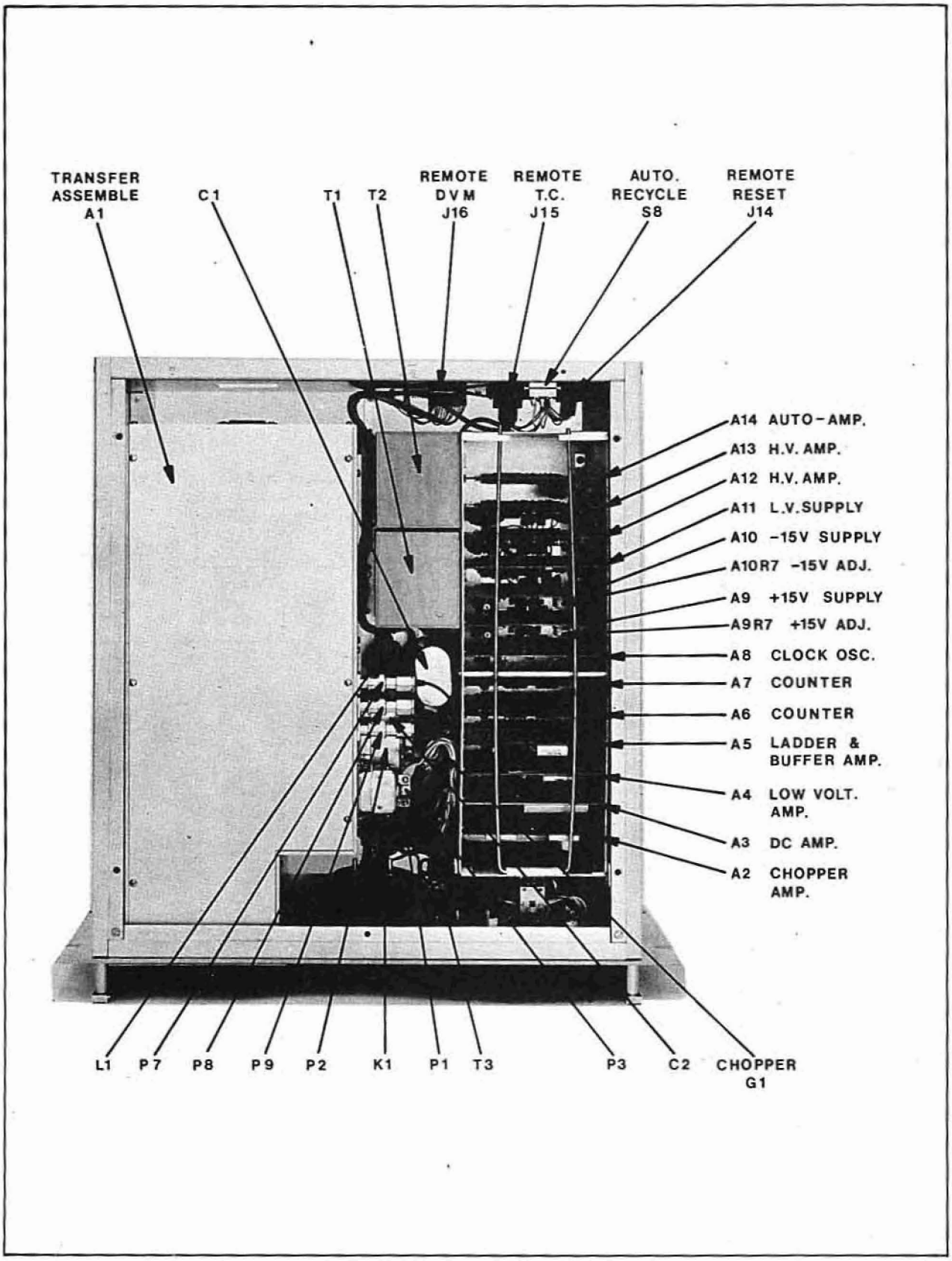



Figure 4-6. 1600A Top View

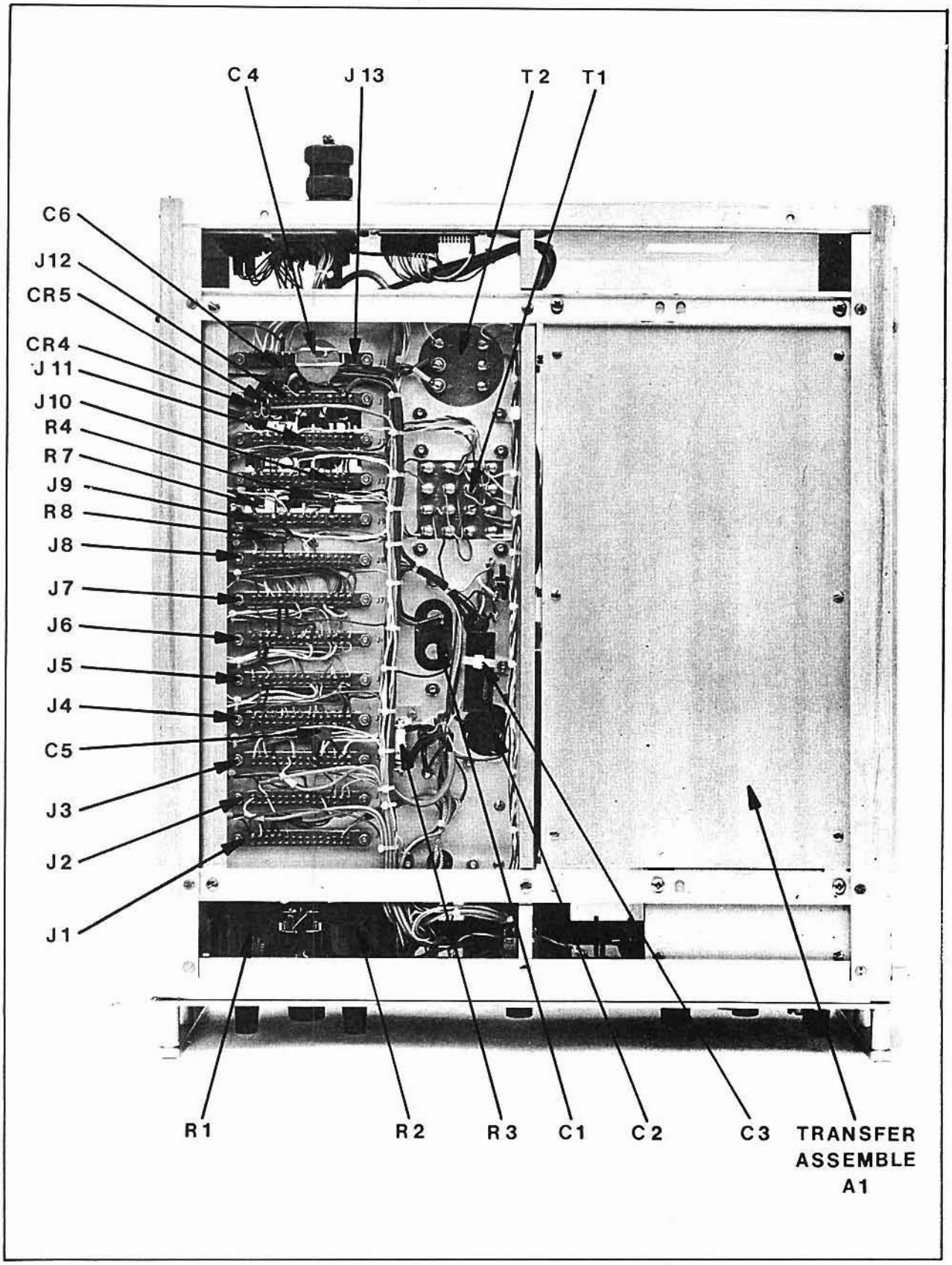



Figure 4-7. 1600A Bottom View

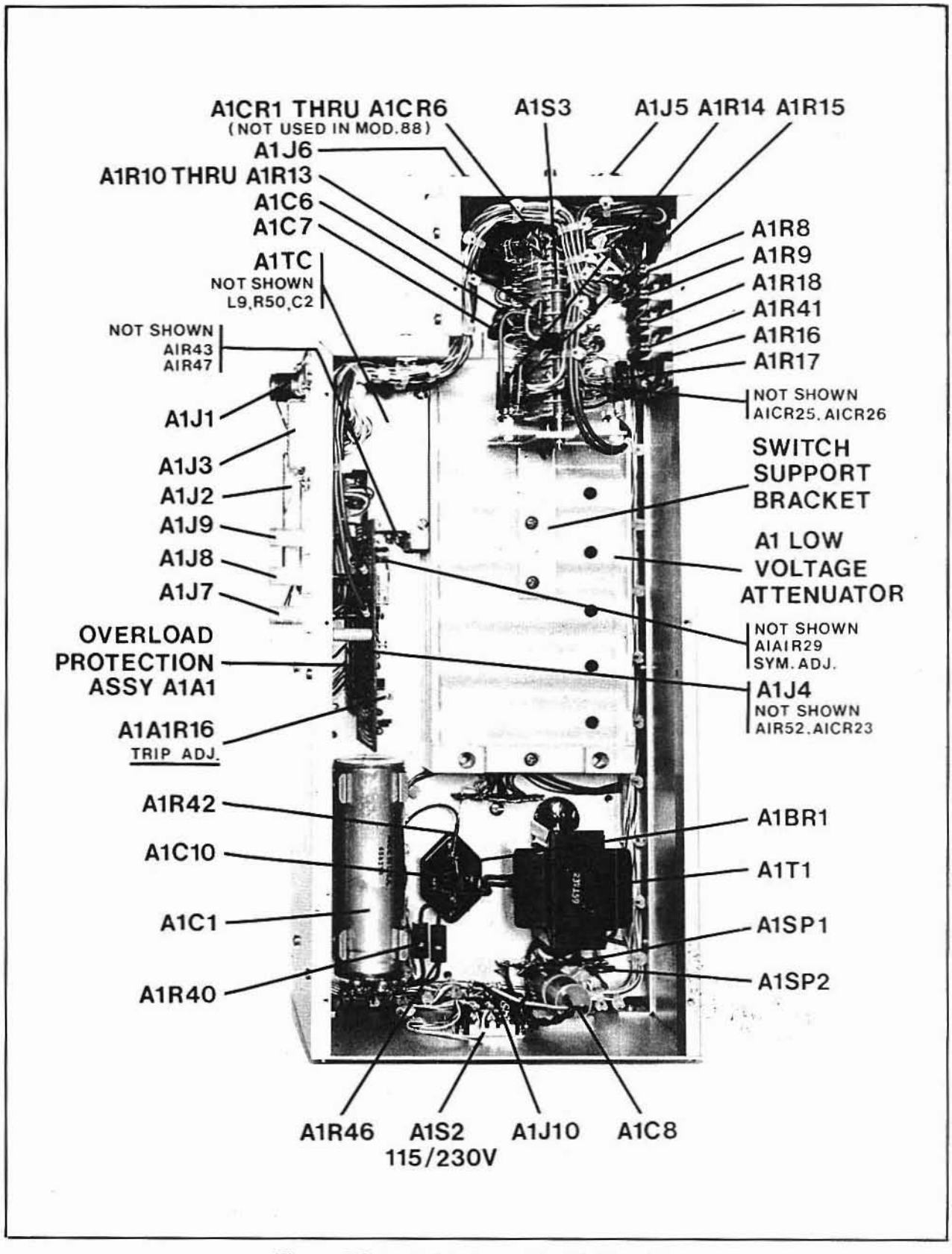



Figure 4-8. Transfer Assembly A1, Top View

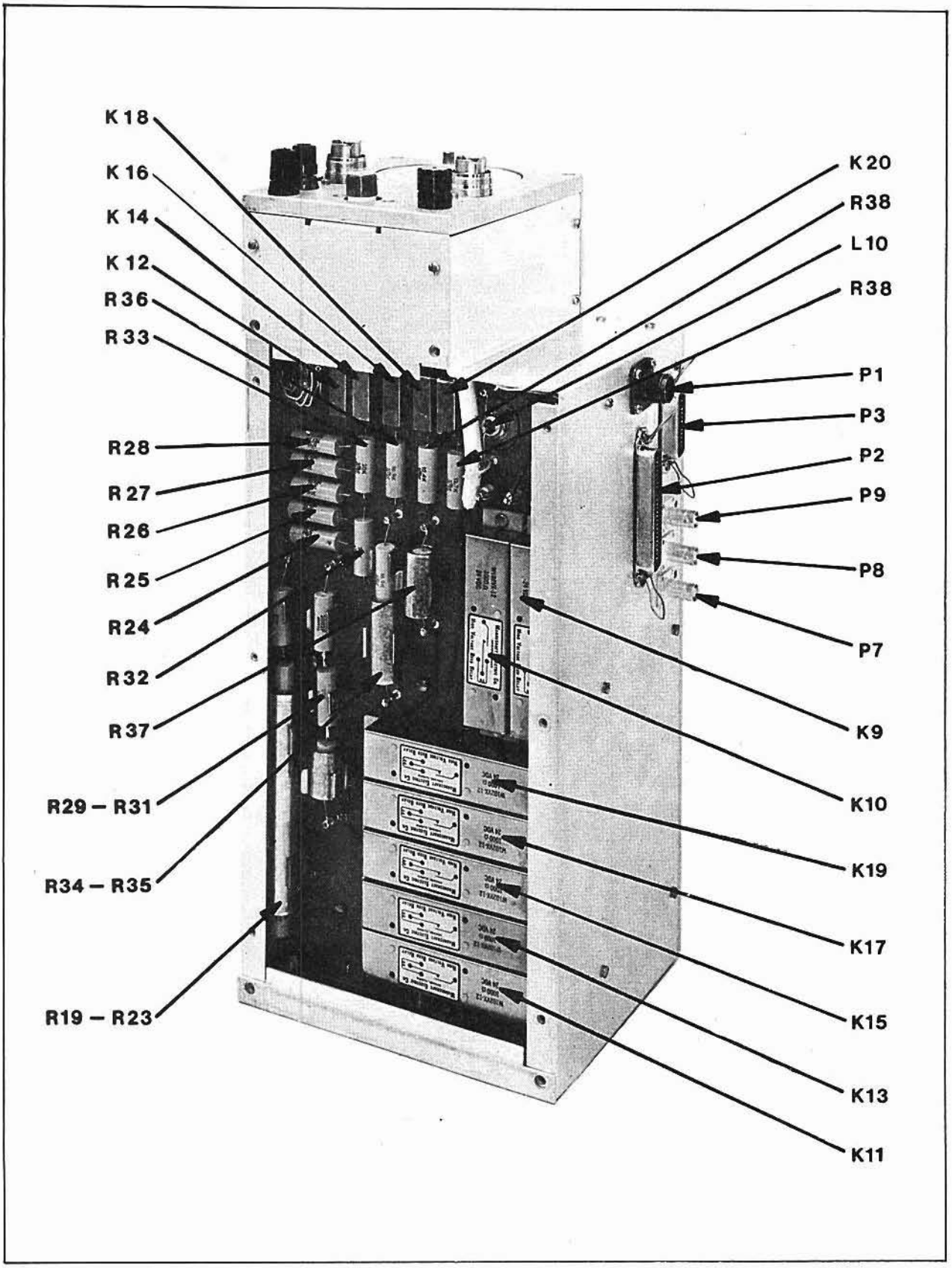



Figure 4-9. Transfer Assembly A1, Bottom View

TABLE 4-3. POWER SUPPLY CHECK [at 115 (230) V midline]

| Connect Positive DMM Lead To | Connect Common DMM Lead to | Normal Indication |
|---|---|---|
| J8-1 | Chassis | +15 v ±0.2 v |
| Chassis | J9-6 | +15 v ±0.02 v |
| J10-14 | Chassis | +3.6 v ±0.2 v |
| J10-11 | Chassis | +3.9 v ±0.15 v |
| J3-9 | Chassis | +43 v +5.0 v -3 v |
| J12-1 | Chassis | +1500 v ±200 v |

TABLE 4-4. POWER SUPPLY TROUBLE LOCALIZATION PROCEDURE

| Step | Instructions | Normal Indication | If Indication Is Normal | If Indication Is Abnormal |
|---|---|---|---|---|
| 1 | Couple the ATS to line power as described in Section II. Set line to 115 (230) V. | POWER PUSH push-button illuminates. | Proceed to step 2. | Check lamp A1DS1 inside pushbutton.<br>Check 0.5A delay fuse A1F1.<br>Check a-c line cord.<br>Check POWER PUSH switch A1S1 and associated wiring.<br>Check filter A1C1 and A1R40.<br>Check bridge rectifier unit A1BR8.<br>Check power transformer T1 and line switch S2. |
| 2 | Measure the voltage developed between junction of resistor A1R40 - capacitor A1C1 and chassis. | Reading should be between +24 and +33 volts d-c. | Proceed to step 3. | Follow procedures given above in step 1. |
| 3 | Measure the voltage developed between connector J8-1 and chassis. | Reading should be between +14.8 and +15.2 volts d-c. | Proceed to step 4. | Check adjustment of trim potentiometer A9R7, see paragraph 4-18.<br>Check +15 volt power supply board, diodes A9CR1 and A9CR2.<br>Check transistor A9Q1 through A9Q4.<br>Check diodes A9CR3 and A9CR4. |

TABLE 4-4. POWER SUPPLY TROUBLE LOCALIZATION PROCEDURE (Cont'd)

| Step | Instructions | Normal Indication | If Indication Is Normal | If Indication Is Abnormal |
|---|---|---|---|---|
| | | | | Check potentiometer A9R7 and all other fixed resistors, and capacitors A9C1 and A9C2. |
| 4 | Measure the voltage developed between connector J9-1 and chassis. | Reading should be between -14.8 and 15.2 volts d-c. | Proceed to step 5. | Follow procedures given above in step 3. Board A9 and A10 are identical except for circuit polarity connections. |
| 5 | Measure the voltage developed between connector J3-9 and chassis. | Reading should be between +40 and +48 volts d-c. | Proceed to step 6. | Check Low Voltage Amplifier board, diodes A4CR3 and A4CR6.<br><br>Check filter resistor A4R12 and capacitor A4C5.<br><br>Check Zener diode A4CR7.<br><br>Check secondary winding (terminals 13 and 14) of power transformer T1. |
| 6 | Measure the voltage developed between connector J10-14 and chassis. | Reading should be between +3.40 and 3.8 volts d-c. | Proceed to step 7. | Check voltages developed by both 15-volt Power Supply boards A9 and A10 before troubleshooting this board.<br><br>Check diodes A11CR2 through A11CR7.<br><br>Check transistors A11Q2 through A11Q4 and Q1 mounted on main frame.<br><br>Check capacitor C2 mounted on main frame.<br><br>Check resistors A11R4 through A11R8. |
| 7 | Measure the voltage developed between connector J10-11 and chassis. | Reading should be between 3.75 and 4.05 volts d-c. | Proceed to step 8. | Check voltage developed by both 15-Volt Power Supply boards A9 and A10 (steps 3 and 4) before troubleshooting this board. |

TABLE 4-4. POWER SUPPLY TROUBLE LOCALIZATION PROCEDURE (Cont'd)

| Step | Instructions | Normal Indication | If Indication Is Normal | If Indication Is Abnormal |
|---|---|---|---|---|
| | | | | Check diode A11CR1.<br><br>Check transistor A11Q1 and operational amplifier A11MC1.<br><br>Check capacitor C3 mounted on main frame. |
| 8 | Measure the voltage developed between connector J12-1 and chassis. | Reading should be between +1300 and +1700 volts. | | Check High Voltage Amplifier board, diodes A13CR2 through A13CR5.<br><br>Check filter capacitor C1 and choke L1 both mounted on main frame.<br><br>Check secondary winding on power transforner T2 (terminals 5 and 6), mounted on main frame. |

## 4-19. SETTING ±15 VOLT SUPPLIES

4-20. +15-Volt Supply. To set the output of the +15-volt supply circuit A9, proceed as directed in the following steps:

a) Remove the top and bottom cover plates from the equipment and rest the unit on its side.

b) Remove A9 from its slot in the equipment and place the service extender board A14 in the slot normally occupied by A9. Insert A9 into the top connector of the service extender board.

c) Couple the ATS to line power as directed in Section II.

d) Connect a digital voltmeter between connector J8-1 and chassis ground.

e) While observing the digital voltmeter display, carefully adjust trimmer potentiometer A9R7 for 15 ±.020 volts.

**CAUTION**

If output voltage exceeds 18 volts, do not attempt to adjust. Remove circuit board immediately. The excess voltage may damage other circuits of the equipment. Refer to Power Supply Trouble Localization Procedure table 4-4.

f) Replace A9 in its proper slot within the unit.

4-21. Setting -15 Volt Supply. To set the output voltage of the -15 volt power supply board, follow the same procedure given above but work with A10 instead.

## 4-22. AC CALIBRATIONS

Perform the Assurance test detailed in paragraph 4-12.

BE ABSOLUTELY CERTAIN YOU HAVE NBS CERTIFIED STANDARDS and proper test equipment.

**CAUTION**

Do not attempt to make any attenuator compensation adjustments or attenuator parts replacement without proper care and test equipment. Improper servicing or adjustment will void your warranty.

a) Always check attenuator, relay contact resistance and performance. Always calibrate with OVERLOAD circuit disabled.

b) Check nominal 200 Ω/Volt input resistance with a current limited ohmmeter. Never apply input currents exceeding 5 mA. Do not use multimeter or multitesters having ohmmeter supply voltages in excess of the attenuator range full scale voltage.

c) Always replace parts exactly as installed at the factory. Use only replacement parts supplied by Ballantine. Epoxy capacitor sleves in place to prevent misalignment.

d) Use a new low wattage soldering iron and low thermal solder when servicing attenuator signal and dc output circuits.

e) NEVER disturb the distributed capacitive sleeves over the resistors in the high voltage attenuators or the low voltage attenuator parts in the 1600 MOD-88 unless the entire instrument is recalibrated.

The 1600A MOD88 also contains frequency compensations which were precisely set at the factory. DO NOT disturb their location or frequency calibration will be altered.

f) When replacing the thermo element, maintain all spacing, lead lengths and thermal lagging. Use low thermal solder.

**NOTE**

Do not attempt to maintain or repair the attenuator assembly unless you have the equipment, NBS certified working standards, factory supplied parts or tools.

Ballantine offers a full factory maintenance service with NBS certified standards and it is recommended that the 11600A transfer assembly be returned to Ballantine for maintenance, repairs, overhaul or recertification to assure that the precision and specified accuracy is maintained.

4-23. If you are fully equipped to recalibrate the 1600A start with the 1 kV range. Adjust the capacitive compensation sleeves over the 1 kV attenuator resistors to get best accuracy at 50 kHz as compared to 1 kHz.

Then proceed in order with the calibrating the 500 Volt, 250 V, 125 V, and 64 Volt ranges. Use full scale input voltages (approximately) and compare highest rated frequency to the 1 kHz reference standard.

In the 11600A no adjustments are provided for the 0.5 V through 32 Volt attenuator ranges although the capacitor which may parallel the thermo element is chosen by obtaining best overall response and is optimized at 32 Volts and 100 kHz and on the 16 Volts range and 1 MHz.

Do not disturb the low voltage coaxial attenuator unless parts replacement appears absolutely required.

The 1600A MOD88 has additional calibrated range accuracy to 100 MHz. See specifications section of this manual for full details.

4-24. The 11600A MOD88 low voltage attenuator incorporates controlled inductance leads as well as one inductive adjustment (−5 V range) and several capacitive frequency adjustments. Adjust compensations on the 5 adjustable ranges for best transfer accuracy at 30 MHz. Check 10 MHz and 100 MHz for specified accuracy and touch up adjustment to meet spec at 10 MHz, 30 MHz and 100 MHz. Calibration is made with reference to NBS traceable 1394A coaxial thermal converter and GR 874 TEE connector.

Always have NBS certified working standards and fully calibrated test equipment as well as adequate tools and factory parts. **If not fully equipped, do not attempt to recalibrate the AC compensations in the attenuator** but return the instrument to Ballantine for recertification and needed maintenance.

## 4-25. CHOPPER DRIVER (MOD08 and MOD88 only)

The frequency of the chopper driver is set by fixed components in the operational amplifier sine wave oscillator. The frequency is nominally 93 Hz (±20 Hz). Check the oscillator components and replace only if output frequency is outside the 73 to 113 Hz range. Check the lamp which acts as a non-linear element in the oscillator if no oscillations are evident. Always replace the lamp with an exact equal.

No oscillator or driver circuits are required in standard ATS where line frequency powers the chopper.

## 4-26. TROUBLE LOCALIZATION

4-27. A symptomatic trouble localization guide (see table 4-5) is provided to enable the technician to isolate a malfunction to an individual or group of assemblies. Once the malfunction has been localized, the operator can effect the necessary repairs through the use of the appropriate voltage measurements provided in paragraph 4-26.

## 4-28. THERMOELEMENT REPLACEMENT

4-29. If thermoelement A1TC1 is found to be defective, it should be replaced as follows:

a) Remove the top cover from the equipment.

b) Remove the seven screws which secure the top plate to the transfer assembly. Remove the top plate.

c) Remove the four screws which secure the cover plate to the thermoelement housing. Remove the cover plate and thermal lagging.

d) Observe the orientation and connections of the original thermoelement before removing it from its mounting. Thermoelements are color coded to insure proper polarity when they are replaced. The replacement item will have a red or black dot identifying one of the lead wires. In either case, the red dot lead is to be connected to the terminal with the red wire, the black dot lead to the terminal with the black wire.

e) Remove the original thermoelement and install the replacement using as little heat as possible in the operation. Use heat sink clamps during soldering. Do not crack the glass.

**NOTE**

If a factory-supplied replacement thermoelement is installed, the accuracy of the ATS will not be impaired and previous calibration data will still be valid.

f) Replace the thermal lagging, thermoelement housing cover plate, transfer assembly top plate, (and ATS top cover plate where used).

TABLE 4-5. TROUBLE LOCALIZATION

| Symptom | Probable cause of trouble |
|---|---|
| 1. Overload protection system does not function. | Defective Overload Protection circuit board A1A1. |
| 2. Overload protection system will not reset. | Defective thermoelement A1TC1. |
| 3. A null cannot be obtained on a given RANGE VOLTS setting. | Defective attenuator circuit. Return equipment to manufacturer. |
| 4. A d-c output cannot be obtained on any RANGE VOLTS setting at low end (32V or less) but equipment works normally at high end (32V or more). | Defective Low Voltage Ampl circuit board A4. |
| 5. A d-c output cannot be obtained on any RANGE VOLTS setting at high end (32V or more) but equipment works normally at low end (32V or less). | Defective High Voltage Ampl circuit boards A12 and/or A13. |
| 6. A null cannot be obtained on any range in AUTO mode, normal operation in MANUAL BALANCE. | Defective circuit board:<br>Clock and Gating A8<br>Counter A6 and/or A7<br>Ladder & Buffer Ampl A5<br>+3.6 and +3.9 Volt Power Supplies |
| 7. A null cannot be obtained in MANUAL BALANCE mode, normal operation in AUTO and MANUAL TRANSFER. | Defect in COARSE and FINE adjustment circuit. |
| 8. A null cannot be obtained in any mode. | Defective circuit board:<br>Chopper Ampl A2<br>DC Ampl and Filter A3<br>Faulty Chopper Driver A15 (MOD08 & 88) |
| 9. A null is obtained but no dc output voltage is developed. | Defective DC Ampl and Filter circuit board A3. |
| 10. Equipment will not transfer from AC to DC status in AUTO mode, normal operation in MANUAL BALANCE and MANUAL TRANSFER. | Defective Low Voltage Ampl circuit board A4. |
| 11. Equipment will not transfer in any mode. | Defective transfer relay K1 circuit. |

## 4-30. OVERLOAD PROTECTION BOARD A1A1, CALIBRATION

4-31. To set the overload protection circuitry, proceed as directed in the following steps.

a) With mode switch set to AUTO, no signal coupled to either AC INPUT connector and the AC indicator illuminated, connect an unground VOM between A1A1TP1 and A1A1TP2.

b) Adjust A1A1R5 to obtain a DMM indication of 0 Volts, (using lowest voltage range).

c) Set the RANGE VOLTS switch to 8 and 16 and the mode switch to MANUAL BALANCE.

d) Momentarily depress the TRANSFER RESET switch to illuminate the DC indicator.

e) Adjust the MANUAL BALANCE COARSE and FINE controls to obtain a front panel meter DC OUTPUT VOLTS scale indication of 1.0.

f) Couple a low-distortion ac source (such as the Ballantine 421B) set to 10 volts rms at 1 kHz, to the AC INPUT 0.5 –32 V connector.

g) Depress the TRANSFER RESET switch; the AC indicator should illuminate.

h) Adjust the ac source output level to obtain a front panel meter indication of 0 on the BAL scale.

i) Set the RANGE VOLTS switch to 4 to 8.

NOTE

The overload protection circuitry may trip.

j) Adjust A1A1R16 (resetting the OVERLOAD PROTECTION PUSH TO RESET switch as required) until the overload protection circuitry just barely trips.

## 4-32. VOLTAGE MEASUREMENTS

4-33. Voltage measurements for all the assemblies referenced in the troubleshooting procedures are contained in tables 4-6 through 4-17. Note that all measurements were made with a DMM with respect to equipment ground.

TABLE 4-6. VOLTAGE MEASUREMENTS, OVERLOAD PROTECTION BOARD A1A1

| Reference Symbol Number | Transistor Type | Nominal Emitter Voltage | Nominal Base Voltage | Nominal Col' ctor Voltage |
|---|---|---|---|---|
| Q1(FET) | 2N3329 | +0.1(S) | 0.0(G) | -11.0(D) |
| Q2(FET) | 2N3329 | +0.1(S) | 0.0(G) | -11.0(D) |
| Q3 | 2N3904 | -11.8 | -11.0 | +1.7 |
| Q4 | 2N3904 | -11.8 | -11.0 | +1.7 |
| Q5 | 2N3904 | +4.3 | +1.2 | +15.0 |
| Q6 | 2N3904 | +4.3 | +4.9 | +15.0 |
| Q7 | 2N3906 | +15.0 | +15.0 | -1.5 |
| Q8(SCR) | 2N2323 | +24(A) | -0.6(G) | 0.0(K) |
| Q9 | 2N1711 | 0.0 | +0.8 | +0.3 |
| Q10 | 2N3904 | +0.1 | +0.1 | +28 |
| Q11 | 2N3904 | 0.0 | +0.7 | +0.1 |

Note: All voltages measured with ATS in the a-c balance state, overload circuitry operative and no signal applied to ATS.

TABLE 4-7. VOLTAGE MEASUREMENTS, CHOPPER AMPLIFIER A2

| Reference Symbol Number | Transistor Type | Nominal Emitter Voltage | Nominal Base Voltage | Nominal Collector Voltage |
|---|---|---|---|---|
| Q1 | 2N3391A | -0.5 | 0.0 | +2.0 |
| Q2 | 2N3391A | +1.4 | +2.0 | +4.3 |
| Q3 | 2N3391A | +3.7 | +4.3 | +15.0 |
| Q4 | 2N1306 | 0.0 | -7.9 | 0.0 |
| Q5 | 2N1306 | 0.0 | -7.9 | 0.0 |

Note: All voltages measured with ATS in MANUAL BALANCE mode, d-c output state and no signal applied.

TABLE 4-8. VOLTAGE MEASUREMENTS, DC AMPLIFIER AND FILTER A3

| Reference Symbol Number | Type | Terminal No. | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
| MC1 | $\mu$A741 | | 0.0 | 0.0 | -15.0 | | 0.0 | +15.0 | |
| MC2 | $\mu$A741 | | 0.0 | 0.0 | -15.0 | | -5.4 | +15.0 | |

Note: All voltages measured with ATS in MANUAL BALANCE mode, d-c output state and no signal applied.

TABLE 4-9. VOLTAGE MEASUREMENTS, LOW VOLTAGE AMPLIFIER A4

| Reference Symbol Number | Transistor Type | Nominal Emitter Voltage | Nominal Base Voltage | Nominal Collector Voltage |
|---|---|---|---|---|
| Q1 | 2N3904 | 0.0 | +0.6 | +10.0 |
| Q2 | 2N3906 | +10.5 | +10.0 | +0.8 |
| Q3 | 2N3904 | 0.0 | +0.6 | +25.1 |
| Q4 | 2N3904 | +24.5 | +25.1 | +43.0 |
| Q5(SCR) | 2N2323 | 0.0(A) | +0.4(G) | 0.0(K) |
| Q6(UJ) | 2N4870 | 0.0 | +0.4($B_1$) | +14.0($B_2$) |
| Q7 | 2N3904 | 0.0 | +0.7 | 0.0 |
| Q8 | 2N3904 | 0.0 | +0.1 | 0.0 |
| Q9 | 2N3904 | 0.0 | +0.1 | 0.0 |

Note: All voltages measured in d-c output state with RANGE VOLTS switch set to 8 TO 16 and MANUAL BALANCE controls adjusted for 15.00 volt output.

TABLE 4-10. VOLTAGE MEASUREMENTS, LADDER AND BUFFER AMPLIFIER A5

| Reference Symbol Number | Transistor Type | Nominal Emitter Voltage | | Nominal Base Voltage | | | Nominal Collector Voltage | | |
|---|---|---|---|---|---|---|---|---|---|
| Q1 | 2N3904 | +3.3 | | +3.9 | | | +15.0 | | |
| | | Pin Number | | | | | | | |
| | | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
| MC4 | $\mu$A741 | | +3.3 | +3.3 | -15.0 | | +4.0 | +15.0 | |

Note: All voltages measured in d-c output state with RANGE VOLTS switch set to 8 TO 16 and MANUAL BALANCE controls adjusted for 15.00 volt output.

TABLE 4-11. VOLTAGE MEASUREMENTS, CLOCK AND GATING BOARD A8

| Reference Symbol Number | Transistor Type | Nominal Emitter Voltage | Nominal Base Voltage | Nominal Collector Voltage |
|---|---|---|---|---|
| Q1 | 2N3391A | 0.0 | 0.0 | +1.4 |
| Q2 | 2N3904 | -15.0 | -15.0 | +1.4 |
| Q3 | 2N3904 | 0.0 | 0.0 | +1.4 |
| Q4 | 2N3904 | 0.0 | +0.3 | +1.2 |
| Q5 | 2N3906 | 0.0 | 0.0 | -15 |
| Q6 | 2N4870 | +5.7 | 0.56($B_1$) | +14.0($B_2$) |

Note: All voltages measured in d-c output state with RANGE VOLTS switch set to 8 TO 16 and MANUAL BALANCE controls adjusted for 15.00 volt output.

TABLE 4-12. VOLTAGE MEASUREMENTS +15-VOLT SUPPLY A9

| Reference Symbol Number | Transistor Type | Nominal Emitter Voltage | Nominal Base Voltage | Nominal Collector Voltage |
|---|---|---|---|---|
| Q1 | 2N3904 | +15.7 | +16.3 | +24.0 |
| Q2 | 2N3904 | +5.6 | +6.2 | +15.0 |
| Q3 | 2N3904 | +5.6 | +6.2 | +16.3 |
| Q4 | 40326 | +15.0 | +15.7 | +24.0 |

Note: All voltages measured in d-c output state with RANGE VOLTS switch set to 8 TO 16 and MANUAL BALANCE controls adjusted for 15.00 volt output. Power line voltage set to 115V (230V).

TABLE 4-13. VOLTAGE MEASUREMENTS, -15 VOLT SUPPLY A10

| Reference Symbol Number | Transistor Type | Nominal Emitter Voltage | Nominal Base Voltage | Nominal Collector Voltage |
|---|---|---|---|---|
| Q1 | 2N3904 | +0.65 | +1.27 | +9.5 |
| Q2 | 2N3904 | -9.4 | -8.8 | 0.0 |
| Q3 | 2N3904 | -9.4 | -8.8 | +1.3 |
| Q4 | 40326 | 0.0 | +0.65 | +9.5 |

Note: All voltages measured in d-c output state with RANGE VOLTS switch set to 8 TO 16 and MANUAL BALANCE controls adjusted for 15.00 volt output. Power line voltage set to 115V (230V).

TABLE 4-14. VOLTAGE MEASUREMENTS, LOW VOLTAGE SUPPLY A11

| Reference Symbol Number | Transistor Type | Nominal Emitter Voltage | | | Nominal Base Voltage | | | Nominal Collector Voltage | |
|---|---|---|---|---|---|---|---|---|---|
| Q1 | 40326 | +3.9 | | | +4.5 | | | +8.1 | |
| Q2 | 40326 | +4.3 | | | +5.0 | | | +7.5 | |
| Q3 | 2N3904 | +5.0 | | | +5.6 | | | +7.5 | |
| Q4 | 2N3904 | 0.0 | | | +0.6 | | | +5.6 | |
| | | Pin Number | | | | | | | |
| | | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
| MC1 | $\mu$A741 | | 0 | 0 | -15.0 | | +4.5 | +15.0 | |
| Q1 on Chassis | 2N4921 | +3.6 | | | +4.5 | | | +7.5 | |

Note: All voltages measured in d-c output state with RANGE VOLTS switch set to 8 TO 16 and MANUAL BALANCE controls adjusted for 15.00 volt output. Power line voltage set to 115V (230V).

TABLE 4-15. VOLTAGE MEASUREMENTS, HIGH VOLTAGE AMPLIFIER A12

| Reference Symbol Number | Transistor Type | Nominal Emitter Voltage | Nominal Base Voltage | Nominal Collector Voltage |
|---|---|---|---|---|
| Q1 | 40327 | 0 | +0.562 | +92.7 |
| Q2 | 40327 | +92.7 | +92.2 | +192 |
| Q3 | 40327 | +192 | +189 | +293 |
| Q4 | 40327 | +293 | +287 | +396 |
| Q5 | 40327 | +396 | +388 | +500 |
| Q6 | 40327 | +500 | +492 | +607 |
| Q7 | 40327 | +607 | +601 | +716 |
| Q8 | 2N3906 | +1.345 | +0.699 | +0.566 |
| Q9 | 2N3904 | 0 | +0.664 | +0.701 |

Note: All voltages measured in d-c output state with RANGE VOLTS switch set to 64 TO 125 and MANUAL BALANCE controls adjusted for 115 volt output. Power line voltage set to 115V (230V).

TABLE 4-16. VOLTAGE MEASUREMENTS, HIGH VOLTAGE AMPLIFIER A13

| Reference Symbol Number | Transistor Type | Nominal Emitter Voltage | Nominal Base Voltage | Nominal Collector Voltage |
|---|---|---|---|---|
| Q1 | 40327 | +1275 | +1272 | +1383 |
| Q2 | 40327 | +1172 | +1163 | +1275 |
| Q3 | 40327 | +1075 | +1063 | +1172 |
| Q4 | 40327 | +978 | +968 | +1075 |
| Q5 | 40327 | +885 | +878 | +978 |
| Q6 | 40327 | +798 | +795 | +885 |
| Q7 | 40327 | +716 | +716 | +798 |

Note: All voltages measured in d-c output state with RANGE VOLTS switch set to 64 TO 125 and MANUAL BALANCE controls adjusted for 115 volt output. Power line voltage set to 115V (230V).

TABLE 4-17. VOLTAGE MEASUREMENTS, CHASSIS ASSEMBLY

| Reference Symbol Number | Transistor Type | Nominal Emitter Voltage | Nominal Base Voltage | Nominal Collector Voltage |
|---|---|---|---|---|
| Q1 | 2N4921 | +3.6 | +4.5 | +7.5 |

Ballantine Laboratories, Inc.
TEST REPORT 1600A-TR05

# FREQUENCY RESPONSE

11600A S/N _____

Traceable to NBS through 1394A and 11600A working standards. Manual Balance Mode.

| RANGE | DVM READING OF OUTPUT DC | | | | Difference Measured Error $V_h - V_g$ | % Measured Error $\frac{100(V_h - V_g)}{2V_h}$ | Allowable Error ±% | CALCULATED | |
|---|---|---|---|---|---|---|---|---|---|
| | Volts (1 kHz Input) | Test Freq. | Volts $V_g$ | Volts $V_h$ (1 kHz Input) | | | | % Error Correction of Standard | % Absolute Accuracy |
| .25 to .5 | | 1 MHz | | | | | 0.08 | | |
| .5 to 1 | | 1 MHz | | | | | 0.06 | | |
| 1 to 2 | | 1 MHz | | | | | 0.06 | | |
| 2 to 4 | | 1 MHz | | | | | 0.06 | | |
| 4 to 8 | | 1 MHz | | | | | 0.06 | | |
| 8 to 16 | | 1 MHz | | | | | 0.06 | | |
| 16 to 32 | | 1 MHz | | | | | 0.06 | | |
| 32 to 64 | | 1 MHz | | | | | 0.20 | | |
| 64 to 125 | | 1 MHz | | | | | 0.25 | | |
| 125 to 250 | - | | | | | | | | |
| 250 to 500 | - | | | | | | | | |
| 500 to 1kV | - | | | | | | | | |

DATE _____ METHOLOGIST _____ Absolute accuracy is subject to NBS uncertainty.

FORM 4-7

Ballantine Laboratories, Inc.
TEST REPORT 1600A-TR06

# FREQUENCY RESPONSE

11600A S/N _____

Traceable to NBS through 1394A and 11600A working standards. Manual Balance Mode.

| RANGE | DVM READING OF OUTPUT DC | | | | Difference Measured Error $V_h - V_g$ | % Measured Error $\frac{100(V_h - V_g)}{2V_h}$ | Allowable Error ±% | CALCULATED | |
|---|---|---|---|---|---|---|---|---|---|
| | Volts (1 kHz Input) | Test Freq. | Volts $V_g$ | Volts $V_h$ (1 kHz Input) | | | | % Error Correction of Standard | % Absolute Accuracy |
| .25 to .5 | | 10MHz | | | | | .408 | | |
| .5 to 1 | | 10MHz | | | | | .405 | | |
| 1 to 2 | | 10MHz | | | | | .405 | | |
| 2 to 4 | | 10MHz | | | | | .405 | | |
| 4 to 8 | | 10MHz | | | | | .405 | | |
| 8 to 16 | | 10MHz | | | | | .405 | | |
| 16 to 32 | - | | | | | | | | |
| 32 to 64 | - | | | | | | | | |
| 64 to 125 | - | | | | | | | | |
| 125 to 250 | - | | | | | | | | |
| 250 to 500 | - | | | | | | | | |
| 500 to 1kV | - | | | | | | | | |

DATE _____ METHOLOGIST _____ Absolute accuracy is subject to NBS uncertainty.

FORM 4-8

Ballantine Laboratories, Inc.

# FREQUENCY RESPONSE

11600A S/N _____

TEST RECORD 1600A-TR03

Traceable to NBS through 1394A and 11600A working standards. Manual Balance Mode.

| RANGE | DVM READING OF OUTPUT DC | | | | Difference Measured Error $V_h - V_g$ | % Measured Error $\frac{100(V_h - V_g)}{2V_h}$ | Allowable Error % | CALCULATED | |
|---|---|---|---|---|---|---|---|---|---|
| | Volts (1 kHz Input) | Test Freq. | Volts $V_g$ | Volts $V_h$ (1 kHz Input) | | | | % Error Correction of Standard | % Absolute Accuracy |
| .25 to .5 | | 50 KHz | | | | | 0.018 | | |
| .5 to 1 | | 50 KHz | | | | | 0.015 | | |
| 1 to 2 | | 50 KHz | | | | | 0.015 | | |
| 2 to 4 | | 50 KHz | | | | | 0.015 | | |
| 4 to 8 | | 50 KHz | | | | | 0.015 | | |
| 8 to 16 | | 50 KHz | | | | | 0.015 | | |
| 16 to 32 | | 50 KHz | | | | | 0.015 | | |
| 32 to 64 | | 50 KHz | | | | | 0.015 | | |
| 64 to 125 | | 50 KHz | | | | | 0.015 | | |
| 125 to 250 | | 50 KHz | | | | | 0.020 | | |
| 250 to 500 | | 50 KHz | | | | | 0.035 | | |
| 500 to 1kV | | 50 KHz | | | | | 0.090 | | |

DATE _____ METROLOGIST _____ Absolute accuracy is subject to NBS uncertainty.

**FORM 4-5 (Mod 88 only)**

Ballantine Laboratories, Inc.

# FREQUENCY RESPONSE

11600A S/N _____

TEST REPORT 1600A-TR04

Traceable to NBS through 1394A and 11600A working standards. Manual Balance Mode.

| RANGE | DVM READING OF OUTPUT DC | | | | Difference Measured Error $V_h - V_g$ | % Measured Error $\frac{100(V_h - V_g)}{2V_h}$ | Allowable Error % | CALCULATED | |
|---|---|---|---|---|---|---|---|---|---|
| | Volts (1 kHz Input) | Test Freq. | Volts $V_g$ | Volts $V_h$ (1 kHz Input) | | | | % Error Correction of Standard | % Absolute Accuracy |
| .25 to .5 | | 100KHz | | | | | 0.03 | | |
| .5 to 1 | | 100KHz | | | | | 0.03 | | |
| 1 to 2 | | 100KHz | | | | | 0.03 | | |
| 2 to 4 | | 100KHz | | | | | 0.03 | | |
| 4 to 8 | | 100KHz | | | | | 0.03 | | |
| 8 to 16 | | 100KHz | | | | | 0.03 | | |
| 16 to 32 | | 100KHz | | | | | 0.03 | | |
| 32 to 64 | | 100KHz | | | | | 0.05 | | |
| 64 to 125 | | 100KHz | | | | | 0.05 | | |
| 125 to 250 | | 100KHz | | | | | 0.05 | | |
| 250 to 500 | | 100KHz | | | | | 0.06 | | |
| 500 to 1kV | | 100KHz | | | | | 0.100 | | |

DATE _____ METROLOGIST _____ Absolute accuracy is subject to NBS uncertainty.

**FORM 4-6**

Ballantine Laboratories, Inc.
TEST REPORT 1600A-TR07

# FREQUENCY RESPONSE

11600A S/N _____

Traceable to NBS through 1394A and 11600A working standards. Manual Balance Mode.

| RANGE | DVM READING OF OUTPUT DC | | | | Difference Measured Error $V_h-V_g$ | % Measured Error $\frac{100(V_h-V_g)}{2V_h}$ | Allowable Error % | CALCULATED | |
|---|---|---|---|---|---|---|---|---|---|
| | Volts (1 kHz Input) | Test Freq. | Volts $V_g$ | Volts $V_h$ (1 kHz Input) | | | | % Error Correction of Standard | % Absolute Accuracy |
| .25 to .5 | | 30MHz | | | | | 1.208 | | |
| .5 to 1 | | 30MHz | | | | | 1.205 | | |
| 1 to 2 | | 30MHz | | | | | 1.205 | | |
| 2 to 4 | | 30MHz | | | | | 1.205 | | |
| 4 to 8 | | 30MHz | | | | | 1.205 | | |
| 8 to 16 | | 30MHz | | | | | 1.205 | | |
| 16 to 32 | - | | | | | | | | |
| 32 to 64 | - | | | | | | | | |
| 64 to 125 | - | | | | | | | | |
| 125 to 250 | - | | | | | | | | |
| 250 to 500 | - | | | | | | | | |
| 500 to 1kV | - | | | | | | | | |

DATE _____ METHOLOGIST _____ Absolute accuracy is subject to NBS uncertainty.

FORM 4-9

Ballantine Laboratories, Inc.
TEST REPORT 1600A-TR08

# FREQUENCY RESPONSE

11600A S/N _____

Traceable to NBS through 1394A and 11600A working standards. Manual Balance Mode.

| RANGE | DVM READING OF OUTPUT DC | | | | Difference Measured Error $V_h-V_g$ | % Measured Error $\frac{100(V_h-V_g)}{2V_h}$ | Allowable Error % | CALCULATED | |
|---|---|---|---|---|---|---|---|---|---|
| | Volts (1 kHz Input) | Test Freq. | Volts $V_g$ | Volts $V_h$ (1 kHz Input) | | | | % Error Correction of Standard | % Absolute Accuracy |
| .25 to .5 | | 100MHz | | | | | 5.008 | | |
| .5 to 1 | | 100MHz | | | | | 5.005 | | |
| 1 to 2 | | 100MHz | | | | | 5.005 | | |
| 2 to 4 | | 100MHz | | | | | 5.005 | | |
| 4 to 8 | | | | | | | | | |
| 8 to 16 | - | | | | | | | | |
| 16 to 32 | - | | | | | | | | |
| 32 to 64 | - | | | | | | | | |
| 64 to 125 | - | | | | | | | | |
| 125 to 250 | - | | | | | | | | |
| 250 to 500 | - | | | | | | | | |
| 500 to 1kV | - | | | | | | | | |

DATE _____ METHOLOGIST _____ Absolute accuracy is subject to NBS uncertainty.

FORM 4-10