INSTRUCTION MANUAL

Quan-Tech® MODEL 2173-C
TRANSISTOR NOISE ANALYZER
CONTROL UNIT

FOR SERIAL NO. ____________

Quan-Tech
DIVISION OF STANSBURY INDUSTRIES, INC.

P.O. BOX 28, ROUTE 206 / FLANDERS / NEW JERSEY 07836 PHONE (201) 927-1766-7 / TWX 710-987-7500

PRINTED IN U.S.A.

TABLE OF CONTENTS

LIST OF ILLUSTRATIONS

SECTION 1
GENERAL

A. DESCRIPTION

The Quan-Tech Model 2173-C Transistor Noise Analyzer Control Unit provides the means for applying the dc bias, and the noise monitoring circuitry required for measuring the various noise parameters of transistors within the range of the equipment.

The Control Unit is automatically calibrated to provide a constant gain characteristic which is independent of the parameters of the transistor under test or the quiescent operating condition.

When used with an appropriate filter unit, such as the Model 2181, noise measurements may be made over the frequency range of from 10Hz to 100KHz. Measurements are typically made of the equivalent noise voltage (E_N), equivalent noise current (I_N), and/or Noise Figure for any desired input Resistance.

B. SPECIFICATIONS

Collector Voltage:	0.3 to 60 volts. Metered in four ranges: 3, 10, 30, and 100V, full scale.
Collector Current:	0.3 microamperes to 30 milliamperes. Metered in ten ranges: 1, 3, 10, 30, 100, microamperes, .3, 1, 3, 10, and 30 ma. full scale.
Gate Voltage:	Zero to ±15 VDC. Polarity selected with meter range switch. Meter ranges 3, 10, 30 volts full scale.
Base Resistance:	Short circuit to one megohm. The following resistors selected with a front panel switch: 0, 500 ohms, 1K, 10K, 100K ohms, and 1 megohm. Mounting terminals and a switch position are provided to permit the use of a particular value of external base resistance.
Output Parameters:	Voltage gain: AGC circuitry maintains constant gain of ten thousand. Bandpass: 5Hz to 100KHz. Output Impedance: 1K ohm. Max. Output Voltage: 5.5 VRMS.
Power Input:	117/234 volts, 60Hz.
Dimensions:	5¼" x 19" standard rack panel, 16" deep overall.
Weight:	30 pounds.

C. ACCESSORIES:

One Type 1113 Cable is supplied. This cable is used to connect the Model 2173C to the Filter Unit.

SECTION 2
OPERATION

A. FIRST TIME OPERATION

The procedure given below will enable an operator to energize the equipment and through the use of an appropriate Filter Unit make basic transistor noise measurements. It is highly recommended, however, that the remainder of SECTION 2 be read to obtain a greater understanding of the function of the equipment.

1. Plug the line cord of the Filter Unit into the line receptacle provided at the rear of the Control Unit.
2. Connect the noise output of the Control Unit to the noise input of the Filter Unit using the Type 1113 cable provided.
3. Plug the line cord of the Control Unit into a suitable supply of 117V, 60Hz line power and turn the power switch to ON.
4. Set the Control Unit front panel controls as follows:
   a) NPN/PNP selector for proper type.
   b) COLLECTOR/DRAIN VOLTAGE switch and ADJ. control for desired transistor collector voltage.
   c) COLLECTOR/DRAIN CURRENT switch to desired current range and ADJ. mid range.
   d) BASE RESISTANCE switch to E_N position.
   e) BIAS SELECTOR switch to the COLLECTOR/DRAIN CURRENT position.
   f) BI POLAR - FET switch to the BI POLAR position.
5. Set Filter Unit attenuators and multipliers to fully clockwise positions.
6. Insert the transistor to be tested and close the shield cover.

   WARNING! Never insert a transistor in the test socket when the interlock button is depressed, as damage to the transistor may result.

   NOTE: The instrument should now be operating and the CURRENT meter should come up to read approximately mid scale. A relay "click" may be heard after the CURRENT meter has come up to a stable reading. The fact that this relay has energized indicates that the Control Unit is functioning in the normal way.
7. Set the COLLECTOR/DRAIN CURRENT ADJ. control for the desired collector current.

   NOTE: If conditions for a proper noise measment are not met in the Control Unit there will be no input to the Filter Unit and all noise meters will read zero. (The relay mentioned above does this switching at the output of the Control Unit). The relay can be expected to temporarily operate if either the CURRENT or VOLTAGE is changed at a rate sufficient to block the noise amplifier channel.
8. Set the NOISE VOLTAGE F.S. switch and the SCALE MULTIPLIERS on the Filter Unit for on scale meter indications at all measuring frequencies.

The NOISE meters are now indicating the equivalent noise voltage parameter (E_N) of the transistor under test.

Noise figure measurements are made by inserting the desired base resistance in the test circuit, reading the total noise voltage on the NOISE meters and converting to noise figure either through the use of the conversion chart given in Figure 2-1 or by computation.

The equivalent noise current parameter (I_N) of the transistor under test is measured by inserting a high value base resistance in the test circuit, reading the total noise voltage on the NOISE meters and applying the following equation:

$$I_N = \frac{\left(E^2_{Total} - E^2_N - E^2_{Thermal}\right)^{1/2}}{/Zg/}$$

where:

I_N = equivalent RMS noise current generator referred to the base of the transistor under test for a one Hz bandwidth.

$/Zg/$ = Magnitude of the complex series base impedance in ohms. (R_g shunted by the stray capacitance of the Model 2173c test circuit of approximately 30pf).

E_{Total} = Noise voltage read on panel meters with $/Zg/$ in the test circuit.

E_N : equivalent RMS noise voltage generator measured in the E_N (R_g = 0) position of the BASE RESISTANCE switch. E_N is also referred to the base of the transistor under test for a one Hz bandwidth.

$E_{Thermal}$ = RMS thermal noise voltage of the real part of the complex series base impedance for a one H_Z bandwidth.

B. FRONT PANEL METERS AND CONTROLS

1. Test Jig Cover
   The very low measuring levels of this equipment require that the test sockets, test transistor and base resistors be shielded when a noise measurement is being made. The hinged cover accomplishes the required shielding and also activates an interlock switch which removes the voltages from the test socket for loading and unloading. This cover should therefore be closed when a noise measurement is being made.
   WARNING!
   Never insert a transistor in the test socket when the interlock button is depressed, as damage to the transistor may result.
2. BASE RESISTANCE
   The external base resistance for the transistor under test may be selected with this switch over the range from a short circuit to one megohm. A switch position and solder terminals are provided for using a resistance value not provided.
3. NPN, N CHANNEL – PNP, P CHANNEL
   The polarity of the d-c COLLECTOR/DRAIN VOLTAGE is selected with this switch. Either positive or negative base/gate voltage is available for both positions of the switch.
4. BIAS SELECTOR
   The transistor under test may be biased by programming either the collector/drain current or the base/gate voltage. Meters and controls are provided for each of these modes of bias.
5. GATE BIAS VOLTAGE Meter, Range Switch and ADJ.
   When the BIAS SELECTOR switch is in the GATE BIAS VOLTAGE position, the polarity of the gate to source bias voltage is selected with the GATE BIAS VOLTAGE meter range switch. The magnitude of the bias voltage is selected with the ADJ control. Note that the BIAS VOLTAGE meter reads correctly only when the test fixture shield cover is closed, and does not read at all in the COLLECTOR/DRAIN CURRENT position of the BIAS SELECTOR switch.
6. COLLECTOR/DRAIN CURRENT Meter, Range Switch and ADJ.
   a. In the GATE BIAS VOLTAGE position of the BIAS SELECTOR switch, the CURRENT meter and range switch function strictly as a multi-range ammeter. Under these conditions the ADJ control does not function.
   b. In the COLLECTOR/DRAIN CURRENT position of the BIAS SELECTOR switch the range switch and the ADJ control actually determine the current in the device under test. Automatic bias circuitry provides any bias voltage between ± 10V to achieve the selected collector or drain current. The range of the ADJ control is from slightly less than one third of full scale to slightly greater than full scale on all current ranges.
7. BI POLAR - FET Switch.
   In the FET position of this switch the voltage gain of Amplifier #1 (Assembly 4740) is increased by 10 to 1 to accomodate the lower transconductance generally found in FETs. Normally the position of this switch is determined by the nature of the device under test.
8. COLLECTOR/DRAIN VOLTAGE Meter, Meter Multiplier and ADJ.
   The COLLECTOR/DRAIN VOLTAGE switch is a multiplier switch for the voltmeter and does not change the collector to emitter voltage. The voltage read on the voltmeter is the magnitude of the collector to emitter voltage of the transistor under test. This voltage may be preset before the transistor is inserted in the test socket as the voltmeter reads the applied voltage correctly with or without a transistor in the jig.
9. Power Switch
   The power switch on the Control Unit applies power to a line receptacle at the rear of the unit in addition to the unit itself. This feature is included to provide a switched power source for the accompanying Filter Unit which requires AC power but does not have its own power switch.

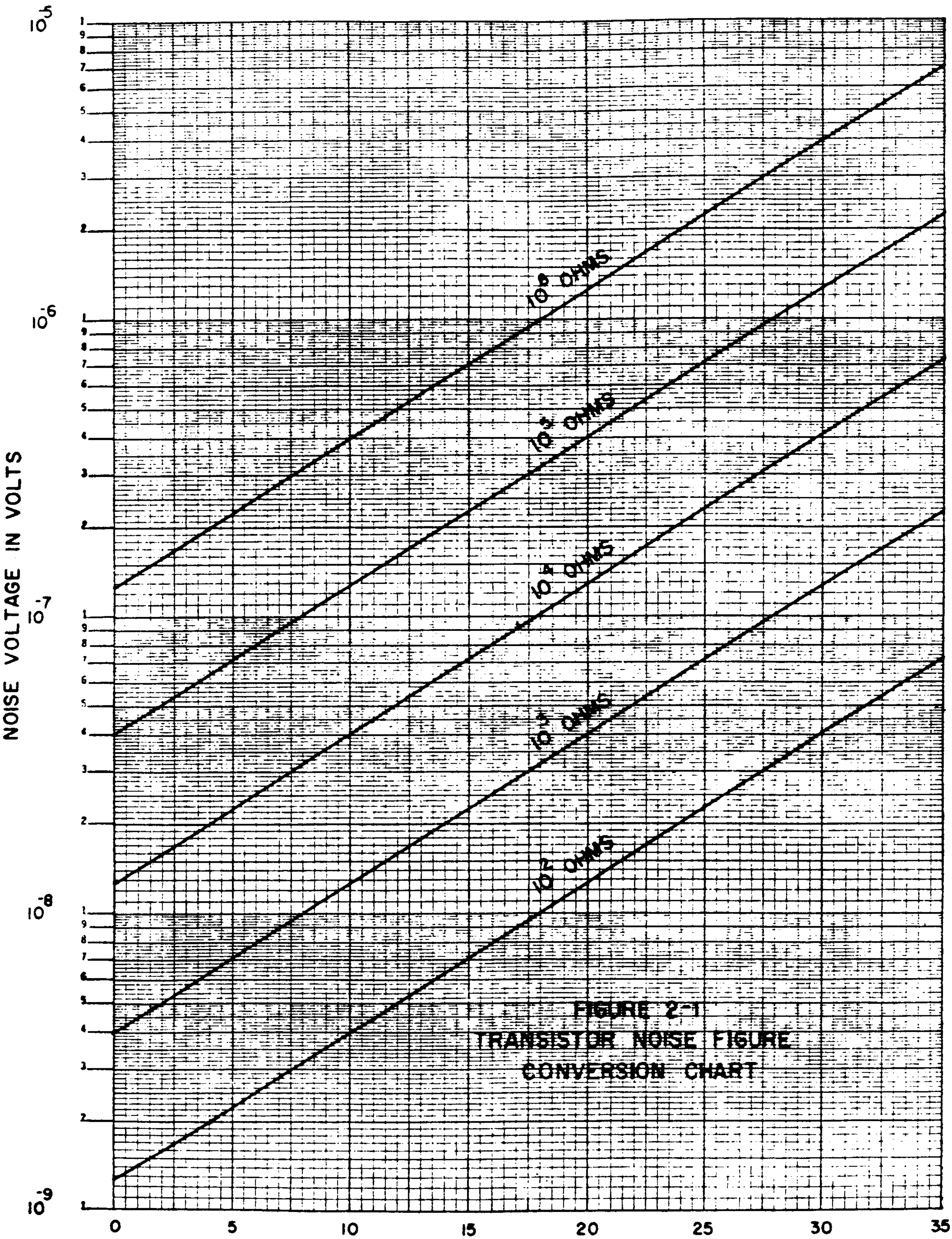


FIGURE 2-1
TRANSISTOR NOISE FIGURE
CONVERSION CHART

SECTION 3
THEORY OF OPERATION

A. GENERAL

The theory of operation of the Transistor Noise Analyzer Control Unit Model 2173-C can best be understood by referring to the Block Diagram shown in T-5420. The noise signal as well as the collector current of the transistor under test is applied to the preamplifier which is essentially a voltage amplifier and impedance converter designed for minimum noise at the input. From the preamplifier the DC current and voltage of the transistor under test is measured. The DC output of the preamplifier is fed into a voltage controlled oscillator whose AC output is directed proportional to the DC current in the collector of the transistor under test. The AC is then transformer coupled, rectified and applied as a feedback signal to the base of the transistor under test to maintain a constant collector current as required by the current controls. The noise or AC signal from the transistor under test is fed from the preamplifier to Amplifier #1 and the remainder of the amplifying channel.

A 4 KHz calibrating oscillator is connected to the emmitter of the transistor under test. The calibrating oscillator supplies the signal which is used to maintain a constant gain through the amplifier channel so that the noise or the signal at the output can be referred to the input using a constant amplification factor. The 4 KHz signal is sampled at the output point, amplified and compared against a Zener diode reference. The difference signal is then used to drive the compressor which completes the loop to maintain a constant overall voltage gain.

SECTION 4

CIRCUIT DESCRIPTION

A. GENERAL

The Block Diagram, T-5420, shows the basic connections between individual circuits in the Control Unit. In general, the assemblies shown as blocks on T-5420 are separate plug-in printed circuit boards.

Reference to the Block Diagram and appropriate Schematic Diagrams will enable the reader to follow the individual circuit descriptions.

B. POWER INPUT AND COLLECTOR VOLTAGE SUPPLY (Schematic T-5421)

The line connections, power switch and fuses are shown on this schematic. The multiple secondaries are labelled in accordance with their circuit association. The collector voltage supply is a straightforward regulated power supply. The control of the voltage is obtained by adjusting R117 which has a constant current supply to it through R107 from the reference diode CR105. A difference or change in the output voltage is monitored by Q102 and amplified through Q103 and the emitter followers Q105 and Q106. If excessive currents are encountered, Q104 will detect the voltage drop across R114 and cut off the supply. The collector supply for Q106 is a simple rectifier and RC filter.

C. +18 VOLT SUPPLY (Floating Ground) (Schematic T-5422)

The +18 Volt Supply to operate the preamplifier and associated circuitry floats above ground, referenced to the collector voltage supply. In this supply the difference between the reference diode CR204 and the voltage point obtained from the divider R203 and R204 is amplified by the double differential amplifier consisting of Q201, Q202, Q203, and Q204. The signal is then applied to Q205 which controls the output of the supply. Pre-regulation of the collector of Q203 is obtained from CR203.

D. -18 VOLT SUPPLY (Floating Ground) (Schematic T-5423)

The −18 Volt Supply is identical to the supply shown in T-5422 with the exception that the positive terminal is connected to the collector voltage supply.

E. +18 VOLT SUPPLY (Schematic T-5424) −18 VOLT SUPPLY (Schematic T-5425)

These supplies are identical to T-5422 with the exception that they have one output terminal referenced to ground and are used for the main amplifier channel power supplies.

F. VOLT METER CIRCUIT (Schematic T-5426)

The input attenuator to the voltmeter supplies 3V for a full scale reading to the voltmeter circuitry. In the PNP position Q601 and Q602 operate as an inverter having unity gain. In the NPN position the inverter is by-passed and the voltage from the attenuator is applied to the differential pair Q603 and Q604. Q605 is the second stage of amplification and negative feedback is provided by the gain determining resistors R613 and R614. The output of this amplifier drives the voltage analog and the voltmeter.

G. CONTROL OSCILLATOR AND 150 KHz RECTIFIER (Schematic T-5427)

An output voltage proportional to the current through one of the current sensing resistors associated with the preamplifier is fed into the differential pair Q701 and Q702 of the control oscillator. The second stage of amplification, Q703, drives the bridge rectifier consisting of CR707, CR708, CR709 and CR710 so that regardless of polarity a positive signal is applied to the collector of Q704. Temperature compensation of the diodes in the bridge is obtained from the diodes CR702, CR703, CR704 and CR705. The 150 KHz carrier output from the oscillator containing Q704 is proportional to the applied DC voltage. This output is transformer coupled to the rectifier circuit consisting of Q705, Q706 and Q707. The output of this circuit is a high impedance current generator whose current is rectified by CR711 and CR712.

H. AMMETER AND BASE SUPPLY (Schematic T-5428)

The output of the 150 KHz rectifier after filtering is amplified by Q801, Q802, and Q803. Differential input is provided for DC stability. The output of this amplifier drives the current meter on the front panel and provides an analog output. In addition to driving the ammeter the 150 KHz rectifier is coupled to the differential pair Q804 and Q805, the polarity input being determined by the PNP-NPN switch. Further amplification is obtained from Q806, Q807 and Q808. Since the differential pair of the base supply is referenced by the ADJ. potentiometer, R809, a constant current would then be maintained in the transistor under test.

SECTION 4
CIRCUIT DESCRIPTION

I. CALIBRATING OSCILLATOR AND TRANSISTOR TEST JIG (Schematic T-5429)

The calibration oscillator operates at 4 KHz as an off-channel calibration source for the Model 2173-C. Stability of the oscillator is provided by CR709. The oscillator is a simple emitter coupled feedback oscillator. Bias is applied to the transistor under test from the base supply through the filters C904 and C905 as well as the base resistance selected.

J. CURRENT RANGE SELECTOR AND PREAMPLIFIER (Schematic T-5430)

The output of the transistor under test is applied through the interlock switch S-901B to the input of preamplifiers 1, 2, or 3 as selected by the current range switch. The output of each preamplifier is applied to the resistors of the current range switch. The input differential transistor pair Q1001 and Q1002, are carefully selected for minimum noise. They are operated at optimum conditions for the 1, 3, 10 and 30 microampere ranges. Q1003, Q1004, and Q1005 provide further amplification to drive the resistor in the range switch. The preamplifier thus has a gain proportional to its resistance value, which, for varying Gm of the transistor under test, tends to give a constant output. Preamplifier #2 is the same as #1 except for changes in the operating currents of the transistors to provide an optimum noise match on the higher current ranges.

K. PREAMPLIFIER #3 and AMPLIFIER #1 (Schematic T-5431)

Preamplifier #3 is similar to Preamplifiers #1 and #2 with the exception of current changes for optimum noise match and additional dissipation capability provided by parallelling the output transistors. Amplifier #1 is a simple three-stage amplifier containing a push-pull output provided by Q1110 and Q1111.

The voltage gain of this amplifier is controlled by the position of the BI POLAR - FET switch. A 10:1 increase in gain is utilized in the FET position to extend the capability of the instrument to automatically calibrate on lower tranconductance field effect transistors.

L. COMPRESSOR, AMPLIFIER #2, NOTCH FILTER, COMPRESSOR AMPLIFIER and COMPRESSOR DRIVER (Schematic C-5432)

The input to pin E (#5) of the COMPRESSOR is the 4 KHz calibrate signal plus the transistor noise which is to be eventually metered. The COMPRESSOR and AMPLIFIER #2 serve to amplify both the calibrate signal and the noise signal. The calibrate signal is then passed through the 4 KHz NOTCH FILTER to the COMPRESSOR AMPLIFIER where it is transformed to DC whose magnitude is proportional to the 4KHz input. The COMPRESSOR DRIVER is a straightforward DC amplifier which compares the DC output of the COMPRESSOR AMPLIFIER to a constant DC reference (CR1205). The error signal is amplified and applied to the COMPRESSOR where the voltage gain of that circuit is corrected to minimize the error between the DC output of the COMPRESSOR AMPLIFIER and the constant DC reference voltage across CR1205. The actual gain change in the COMPRESSOR is accomplished by changing the DC current through the compressor diodes. The voltage gain of the COMPRESSOR circuit is directly proportional to the impedance of these two diodes since they represent the collector loads of Q1201 and Q1205. The relationship between the impedance of the compressor diodes and the DC current through them is very nearly a linear, inverse one.

The closed loop then represented on C-5432 serve to automatically adjust the voltage gain of the COMPRESSOR to cancel out the variation in gain in the transistor under test.

If for any reason the loop cannot be corrected and a unbalance exists across the bases of Q1212 and Q1215 (such as when there is no transistor in the test socket) Q1201 will be switched on to activate relay K1211 which grounds the noise output of th Control Unit. This provision prevents an erroneou noise reading from being taken.

L1203 and C1217, C1218 from a series trap to eliminate the 4KHz calibrate signal from the noise output at J1201. L1204 and C1221 perform in the same manner to eliminate the 150KHz bias carrier.

SECTION 5
MAINTENANCE AND CALIBRATION

A. GENERAL

1. The Model 2173-C Control Unit uses semiconductor components throughout with the exception of the AGC relay. Preventive maintenance is not, therefore, required.
2. It is recommended that the top of the case be removed only after the normal operation checks given below have been performed and the results indicate the necessity of doing so. Servicemen are cautioned not to change calibration adjustments unless it is firmly established that adment is required.
3. Main power should be turned off when connecting or disconnecting the printed circuit assemblies to avoid damaging semiconductor components through the transient voltages thus created. Care should be taken to insure proper alignment of the printed circuit assemblies when replacing them in their sockets.
4. If servicing is required, it is advisable to consult the warranty page for inwarranty servicing information.

B. NORMAL OPERATION

1. Gate Bias Voltage
   With no device in the test sockets, the shield cover closed and BIAS SELECTOR switch in the GATE BIAS VOLTAGF position the ranges of the voltmeter, the meter itself and the 0 to 15 volt range of the ADJ control can be checked.
2. Ammeter.
   The fastest and easiest method of checking for normal operation of the ammeter is to check with a transistor in the socket and the BIAS SELECTOR switch in the COLLECTOR DRAIN CURRENT position. Two things can be checked in this manner. With the ammeter reading a particular amount, there should be little change in scale reading when the range switch is changed through all the positions. With the current control fully clockwise, the ammeter should read off scale. If the ammeter functions in the way described, operation is normal. For calibration of the ammeter, refer to Paragraph E-3 of this section.
3. Voltmeter.
   The voltmeter and the collector voltage supply can be readily checked with or without a transistor in the test socket. With the collector/drain voltage switch in the 100 position, the voltmeter should read approximately zero with the ADJ. knob fully counterclockwise and should read slightly more than 60V with the ADJ. knob fully clockwise. Calibration of the voltmeter is described in Paragraph E-1 of this section.
4. AGC Relay
   The AGC relay short circuits the output terminal of the Control Unit when a noise measurement should not be made. This will occur when the jig shield cover is open, a transistor is not in the socket, the transistor in the socket is in some way faulty or if the bias condition on the transistor is not sufficient for normal transistor operation. In normal operation, the AGC relay will probably be heard as it operates after a transistor has been put in the jig and the current has stabilized.
5. BI POLAR - FET Switch
   Selecting the appropriate position of this switch as determined by the device under test is normally all that is required. If the switch is in the FET position when a bipolar transistor is in the test socket, the AGC relay will not operate and no noise measurements are allowed. This is the normal overload reaction for the AGC loop.

C. REMOVAL OF THE COVERS

Either the top or the bottom of the Control Unit may be removed for access to the inside of the equipment. No other screws on the sides or front should be loosened or removed.

D. CHANGING THE INPUT VOLTAGE

This instrument has been designed to operate from a 117V or 234 VAC power source. The plate on the rear of the instrument near the power cord indicates the voltage and frequency at which it should be operated. If the input voltage must be changed the following procedure should be observed.

NOTE: When the input voltage on the Model 2173C is changed the voltage at the rear outlet is also changed requiring the voltage change in the companion Filter Unit.

1. Remove the two self tapping screws which hold the voltage plate. If there is a small line voltage switch under the plate, simply change it to

SECTION 5

MAINTENANCE AND CALIBRATION

read the desired voltage and replace the plate with the proper voltage showing.

2. If there is no switch under the voltage plate, the voltage change must be made inside the equipment.
   a. Remove the end bell on the power switch side of the instrument(Two screws in front panel, throe screws in top, three screws in bottom and two screws in rear panel).
   b. Change the transformer primary connections by moving the jumpers indicated on the primary connection sketch; Figure 5-1
   c. Reverse the plate on the rear of the instrument to indicate the new power source, replace the end bell, and double check the companion Filter Unit to see if it is wired for the new voltage.

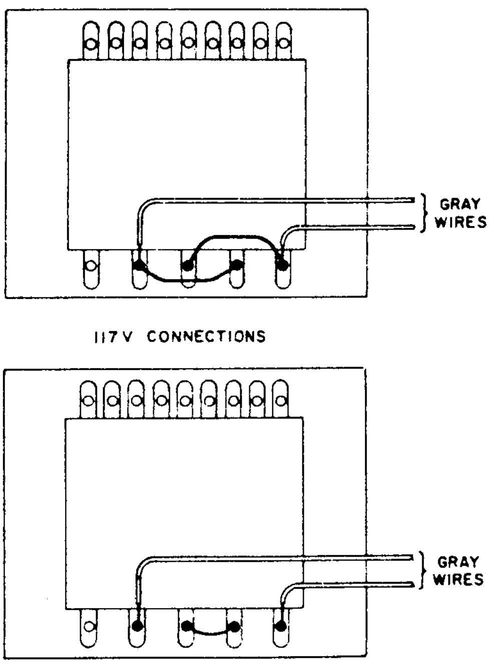


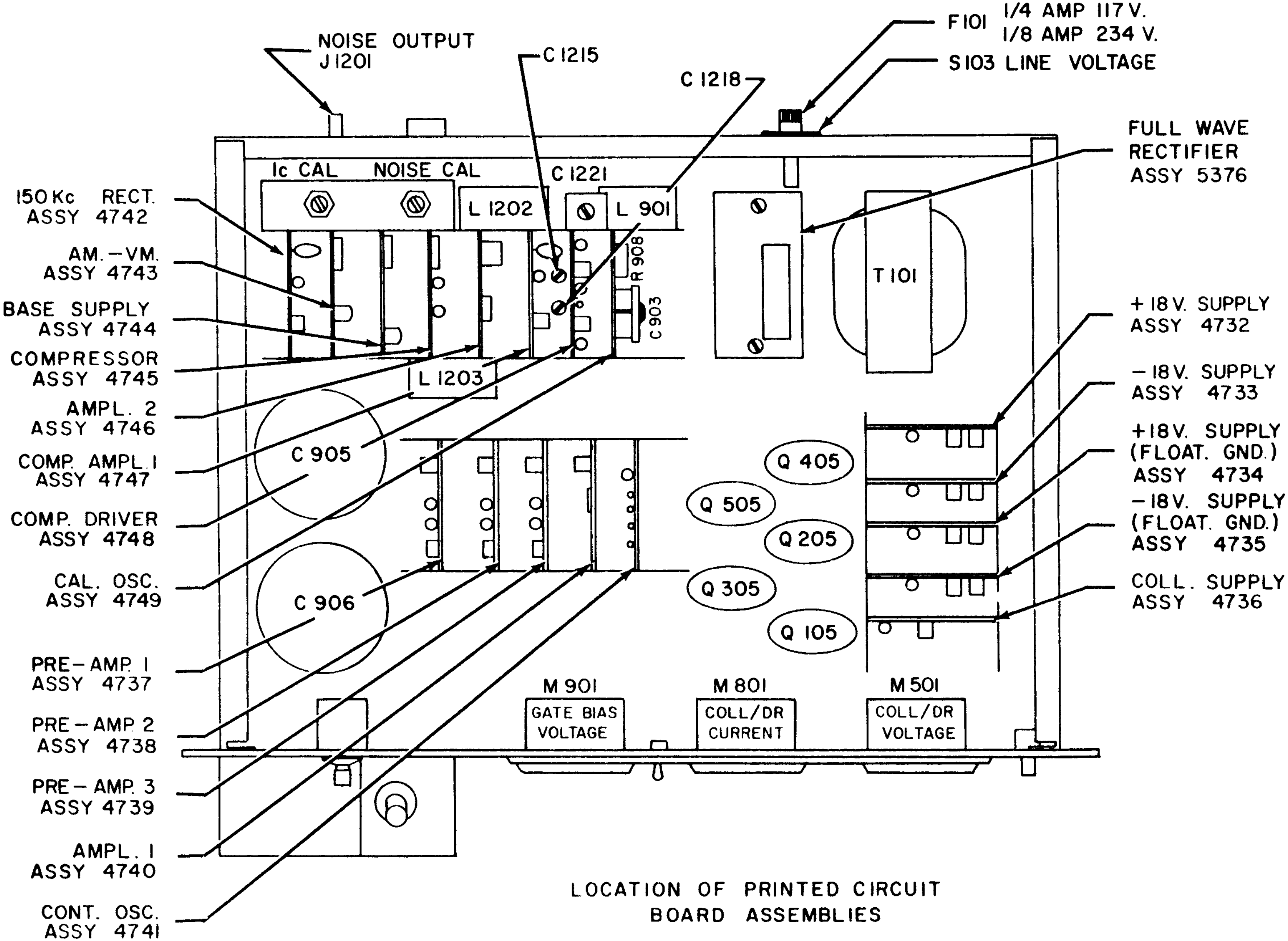
FIGURE 5-1
INPUT VOLTAGE CONNECTIONS

E. DETAILED CALIBRATION

1. Voltmeter
   The calibration of the voltmeter is obtained from 1% resistors installed at the factory and no further calibration should be required.
2. 18 Volt Bias Supplies
   All of the 18 volt bias supplies in the Control Unit are adjusted to 18 volts ($\pm$ 0.5 volts) using the same method. As an example, the plus 18 volt supply (Schematic T-5422) is adjusted through the selection of R206. The other three 18 volt supplies are adjusted with resistors corresponding to R206.
3. Ammeter
   Although the ammeter circuitry is somewhat complicated since it involves a controlled feedback to the transistor under test, the only adjustment that would normally be required would be that of R722. This can readily be done by connecting an external ammeter in series with the collector lead and making the adjustment so that the 2173-C panel meter agrees with the external meter. Any reasonable current range may be used for this.
4. Calibrate Oscillator
   C903 is adjusted to set the oscillator frequency to 4KHz. The output level of the calibrate oscillator is then set to 100 microvolts as measured at the test socket from the emitter lead to ground. A transistor need not be in the socket to make this adjustment.
5. 4KHz Notch Filer Alignment
   To align the two notch filters shown on Schematic C-5432 an oscilloscope should be used to detect magnitude of the 4KHz signal appearing on C1216. Adjust C1215 for a minimum of 4KHz. Moving the oscilloscope to the output terminal, adjust C1218 again for a minimum of 4KHz. To perform this a transistor must be in the socket and the shield cover closed.
6. 150KHz Trap Alignment.
   This trap is tuned in the same way as the 4KHz notch above. C1221 is tuned for minimum high frequency carrier at the noise output jack, J1201.
7. Noise Calibration
   The overall gain of the Control Unit is adjusted to 10,000 using R1238 in the compressor amplifier. The procedure is to apply a 100 Hz . signal to the white pin jack on the test jig panel and adjust the apparent gain from this point to the output jack to ten. The input attenuator made up of R910 and R911 provides the additional 1000 to 1 required for the proper gain adjustment. The input impedance at the pin jack is 600 ohms, thus matching a QTL Model 420 Noise Generator for calibration purposes.

8. System Noise Measurement
The automatic gain calibration technique used in the Model 2173C establishes the factthat system noise is dependent upon the transconductance of the device under test. When system noise must be accurately known it must be measured with the particular AGC level corresponding to the operating conditions of the device under test. The following procedure, although somewhat complicated, will give the actual system noise of the Model 2173C for a particular set of operating conditions. This technique requires two audio oscillators:
   a. Place the device to be tested in the test socket and set up the model 2173C front panel controls for the desired operating conditions.
   b. Tune one oscillator to 1KHz, connect it through a high value resistor (1 megohm for 30 microampere range and above, and 10 megohms for 10 microampere and below), to the collector connection of the test socket. Adjust the output level to cause full scale 1KHz meter deflection on the Model 2181 on a range at least 10-1 greater than the existing noise reading. The door interlock must be depressed for this operation.
   c. Remove the device under test. Leave the first oscillator connected as in para. 2 above, and connect the second oscillator, using the same value resistor as with the first, to the collector connection also. Tune the second oscillator to approximately 4 KHz. Depress the door interlock and adjust the 4 KHz output level to give approximately a full scale reading at 1 KHz. Fine tune the 4 KHz oscil- for a minimum meter reading. Readjust the output level of the 4 KHz oscillator for precisely full scale reading at 1 KHz.
   d. Remove the 1 KHz oscillator from the circuit. Leave the 4 KHz connections and depress the door interlock. The Model 2181 meters will now indicate system noise for the particular operating conditions of para. 1 above.

NOTE: The resistor in series with the 4KHz oscillator must be a low noise, metal film type.



LOCATION OF PRINTED CIRCUIT
BOARD ASSEMBLIES

SECTION 5

MAINTENANCE AND CALIBRATION

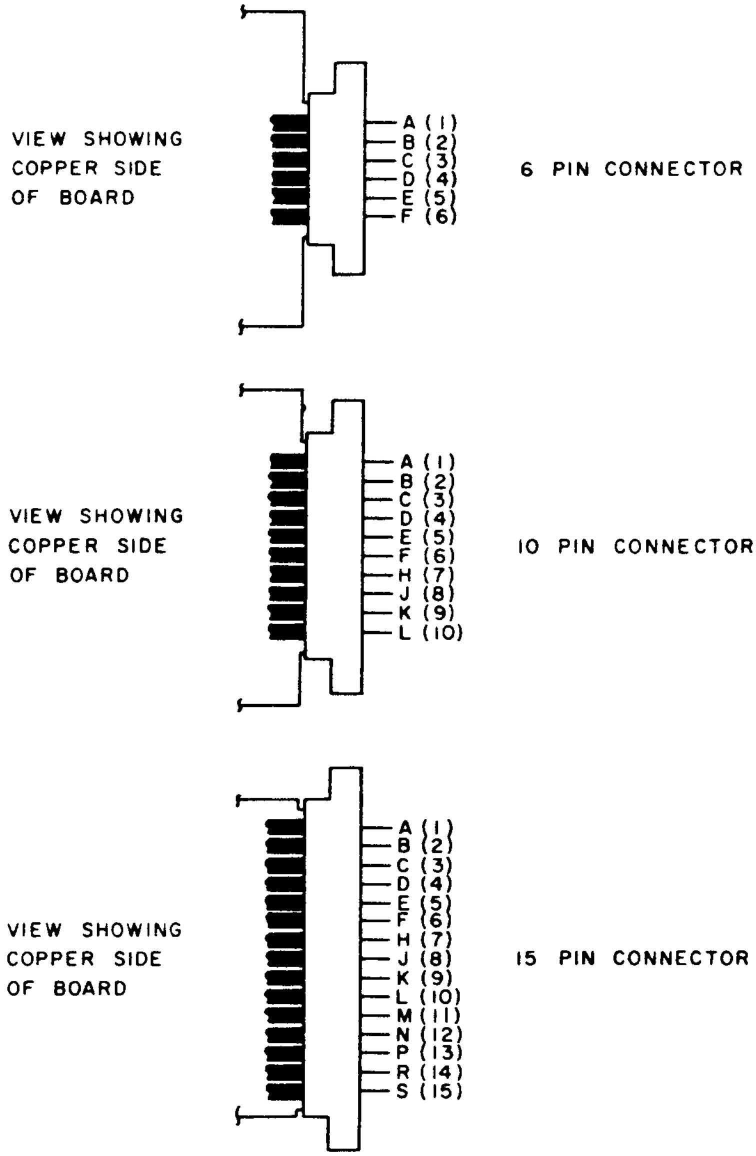


FIGURE 5-3

PRINTED CIRCUIT BOARD CONNECTOR LUG IDENTIFICATION

SCHEMATIC LEGEND

k = 1000

⊘ = Screw Driver Adjustment

▭ = Front Panel Control

* = Factory Select

Unless Otherwise Specified:

All Resistances in Ohms

All Resistors 1/2 Watt

All Capacitances in Microfarads

APPLICATION NOTE MODEL 2173

APPARENT NEGATIVE NOISE FIGURES WITH HIGH VALUES OF R_g

Apparent negative noise figures can be obtained using the 1 megohm (and to a lesser extent the 100 K) base resistance in the Model 2173. This is due to the fact that at the higher frequencies the base resistance is **not** a pure resistance, but a complex impedance formed by the base resistance shunted by the stray capacitance (approximately 30pf) of the socket, switch, and wiring in the Model 2173.

Noise figure is defined as the ratio expressed in db of the total measured noise to the thermal noise of the source resistance.

$$N.F. = 20 \log \left(\frac{\text{measured noise voltage}}{\text{thermal noise voltage}} \right)$$

In the Model 2173 the thermal noise voltage is developed only by the **real** part of the complex impedance formed by R_g shunted by the stray capacitance. The real part can be calculated from the following formula:

$$R_e = \frac{R_g}{1 + w^2C^2R_g^2}$$

Where R_e = real part of complex impedance
R_g = source resistance
C = stray capacitance (30pf)
$w = 2\pi f$

Approximate values of R_e and the thermal noise voltage developed by R_e are given in the following table:

R_g = 100 K

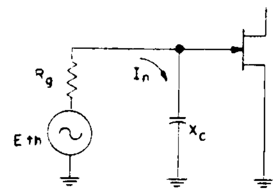
f	R_e	Eth of R_e
1 KHz	99K	39.9nV
10 KHz	96.8K	39.2nV
100 KHz	22.2K	18.8nV

R_g = 1 Meg

f	R_e	Eth of R_e
1 KHz	968K	125nV
10 KHz	222K	59.6nV
100 KHz	2.85K	6.8nV

These values of Eth should be used in the Noise Figure equation above to determine N. F. As can be seen above, 100K has considerable higher Eth than 1 megohm at 100 KHz. This can be checked in practice by measuring a good quiet field effect transistor in the 2173. The 100 KHz noise reading will be almost three times as high with 100K as with 1 megohm.

While this appears contradictory at first, it becomes logical if one considers the circuit as a thermal noise generator in series with a resistance feeding noise current through a reactance which is small compared to the resistance.

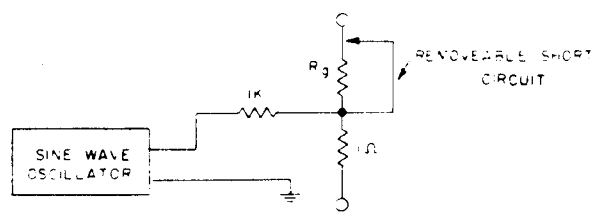


Where $X_c \cong$ 50K ohms at 100 KHz
Eth = 126 nV for R_g = 1 meg
Eth = 40 nV for R_g = 100 K

In spite of the fact that the above situation complicates matters, meaningful measurements can be made on the Model 2173 with high values of R_g provided correction factors are applied to reduce the error caused by the shunting effect of the stray capacitance. The situation is made even more complex by the fact that the 4 KHz calibrate signal, which is introduced into the emitter of transistor under test, may cause errors in the readings of the low frequency noise channels.

The following procedure will provide the information required to correct any frequency reading:

Connect an external R_g in series with a low resistance across the external R_g terminals of the 2173 as shown below. Set the BASE RESISTANCE switch to EXT.



With R_g shorted apply sufficient sine wave signal at the frequency in question to cause full scale deflection on one of the least sensitive noise ranges. Remove the short circuit and note the change in noise meter reading. The ratio of the shorted R_g reading to the unshorted R_g reading is the multiplying factor which must be applied to the unshorted noise reading with the oscillator disconnected.

A DISCUSSION OF ERRORS DUE TO BANDWIDTH WHEN MAKING SPOT NOISE MEASUREMENTS

Considerable confusion occasionally arises over the effect that bandwidth has on the accuracy of spot noise measurements which, by definition, refer to an equivalent noise bandwidth of one Hz. Practically all noise analyzers use an equivalent noise bandwidth much greater than one Hz and effectively divide the actual noise voltage by the square root of the bandwidth to obtain spot noise or noise spectral density. If the noise being measured is white (amplitude constant with frequency) there is no problem in accepting the above philosophy, however, most semiconductors generate considerable amounts of 1/f noise which has an amplitude characteristic inversely proportional to the square root of the frequency. The question arises as to how much error is introduced in a given bandwidth if 1/f noise is present. Some transistor specifications have even gone so far as to specify the bandwidth (200 Hz for 1 KHz spot noise figure) in an attempt to minimize the error. The following analysis has been made to show that bandwidth, within reason, contributes basically no error regardless of whether white or 1/f noise is present.

Spot noise measurements (equivalent noise bandwidth of one Hz.) taken on a Quan-Tech Laboratories Model 310 are actually made with filter bandwidths of typically 300 Hz and 900 Hz for the 1 KHz and 10 KHz channels respectively. The error in the noise measurement introduced by measuring over these particular bandwidths instead of one Hz bandwidth is as follows:

Conversion factors for white noise:

$$E_{\text{total in 300 Hz BW}} = E_{1KHz}\ (300)^{1/2} = E_{1KHz}\ (17.32)$$

$$E_{\text{total in 900 Hz BW}} = E_{10KHz}\ (900)^{1/2} = E_{10KHz}\ (30)$$

Conversion factors for 1/f noise

$$E_{\text{total in 300 Hz BW}} = E_{1KHz}\ (1KHz)^{1/2}\ \left(\ln \frac{f_2}{f_1}\right)^{1/2}$$

$$= E_{1KHz}\ (31.6)\ \left(2.3 \log \frac{1160}{860}\right)^{1/2}$$

$$= E_{1KHz}\ (17.30)$$

$$E_{\text{total in 900 Hz BW}} = E_{10KHz}\ (10KHz)^{1/2}\ \left(\ln \frac{f_2}{f_1}\right)^{1/2}$$

$$= E_{10KHz}\ (10^2)\ \left(2.3 \log \frac{10460}{9560}\right)^{1/2}$$

$$= E_{10KHz}\ (29.9)$$

It can be seen from the above that the error resulting from using the white noise conversion factor when the noise is actually 1/f is essentially zero. Even bandwidths as wide as 1KHz geometrically centered around 1 KHz contribute negligible error compared to the other errors usually associated with the measurement of random noise.

1 KHz SPOT NOISE FIGURE
vs
BROADBAND NOISE FIGURE

The following is an analysis of the difference to be expected between noise figure measurements made by these two presently accepted standards.

The 1 KHz spot noise figure is measured at 1 KHz with the bandwidth of the detector small as compared to 1 KHz. Both the thermal noise of the source and the white, as well as 1/f noise contributed by the device under test are measured at 1 KHz only.

In the broadband case, the noise figure is measured over a bandwidth extending from 10 Hz to 10,000 Hz. This bandpass is specified to be 3db down at 10 and 10,000 Hz, and to have a 6db/oct roll-off. The broadband noise figure is a measure of the white and 1/f noise generated within this bandpass, including the skirts.

Table No. 1 lists the noise figure for both the broadband and 1 KHz spot methods, assuming all white noise to be generated by the source resistance, and all noise generated by the device, to be 1/f. This results in the maximum deviation between the two methods. If the device under test contributes white noise (thermal and shot) as well as 1/f noise, the difference will be less.

TABLE NO. 1

1 KHz spot noise figure in db	Broadband noise figure in db	ΔN.F. in db
0.5	0.20	0.30
1.0	0.42	0.58
2.0	1.00	1.00
3.0	1.58	1.42
5.0	2.90	2.10
7.0	4.40	2.60
10.0	6.95	3.05
20.0	16.42	3.58

The noise voltage contained within a bandpass may be expressed as:

$$\overline{E^2}^{1/2} = \left[\int_0^\infty E^2(F)\,G^2(F)\,df\right]^{1/2} \qquad \textbf{EQUATION 1}$$

or the voltage squared:

$$\overline{E^2} = \int_0^\infty E^2(F)\,G^2(F)\,df \qquad \textbf{EQUATION 2}$$

where $E^2(F)$ describes the noisepower spectrum and $G^2(F)$ describes the power gain of the circuit.

Since the broadband measurement contains a low pass and a high pass filter, the gain function is:

$$G_{LP}(F) = \frac{1}{\left(1 + \frac{f^2}{f_2^2}\right)^{1/2}} \qquad \textbf{EQUATION 3}$$

$$G_{LP}^2(F) = \frac{f_2^2}{f_2^2 + f^2} \qquad \textbf{EQUATION 4}$$

$$G_{HP}(F) = \frac{1}{\left(1 + \frac{f_1^2}{f^2}\right)^{1/2}}$$ EQUATION 5

$$G_{HP}^2(F) = \frac{f^2}{f_1^2 + f^2}$$ EQUATION 6

where f_2 and f_1 are the upper and lower cutoff frequencies.

Thus the magnitude of the white noise contained in the broadband measurement where $E^2(f)$ is a constant for all frequencies and is assigned unit magnitude is given by:

$$\overline{E_W^2} = \int_0^\infty G_{LP}^2(F)\, G_{HP}^2(F)\, df$$ EQUATION 7

$$\overline{E_W^2} = \int_0^\infty \left(\frac{f^2}{f_1^2 + f^2}\right)\left(\frac{f_2^2}{f_2^2 + f^2}\right) df$$ EQUATION 8

By partial fraction expansion we have:

$$\overline{E_W^2} = \int_0^\infty \left[\frac{\frac{1}{(f_2^2 - f_1^2)}}{f_1^2 + f^2} + \frac{\frac{1}{(f_1^2 - f_2^2)}}{f_2^2 + f^2}\right] f_2^2\, f^2\, df$$ EQUATION 9

$$\overline{E_W^2} = \frac{f_2^2}{f_2^2 - f_1^2}\left(f - f_1 \tan^{-1}\frac{f}{f_1}\right) + \frac{f_2^2}{f_1^2 - f_2^2}\left(f - f_2 \tan^{-1}\frac{f}{f_2}\right)\Bigg|_0^\infty$$

EQUATION 10

$$\overline{E_W^2} = \frac{f_2^2}{f_2^2 - f_1^2}(f_2 - f_1)\frac{\pi}{2} = \frac{f_2^2}{f_2 + f_1}\quad\frac{\pi}{2}$$ EQUATION 11

$f_1 = 10$ Hz and $f_2 = 10{,}000$ Hz

Therefore:

$$\overline{E_W^2} = 15.7 \times 10^3 \text{ VOLTS}^2$$ EQUATION 12

The derivation of the magnitude of 1/f noise is similar to the above for white noise. Prior to integration, equation 9 should be multiplied by 1/f, since in this case the function $E^2(F) = 1/f$.

$$\overline{E_{1/f}^2} = \int_0^\infty \left[\frac{\frac{1}{(f_2^2 - f_1^2)}}{f_1^2 + f^2} + \frac{\frac{1}{(f_1^2 - f_2^2)}}{f_2^2 + f^2}\right] f_2^2\, f\, df$$ EQUATION 13

$$\overline{E^2_{1/f}} = \frac{1}{2} \frac{f_2^2}{f_2^2 - f_1^2} \left(\ln f^2 + f_1^2 - \ln f^2 + f_2^2\right) \Big|_0^{\infty}$$ EQUATION 14

$$\overline{E^2_{1/f}} = \frac{1}{2} \frac{f_2^2}{f_2^2 - f_1^2} \ln \frac{f^2 + f_1^2}{f^2 + f_2^2} \Big|_0^{\infty}$$ EQUATION 15

$$\overline{E^2_{1/f}} = \frac{f_2^2}{f_2^2 - f_1^2} \ln \frac{f_2}{f_1}$$ EQUATION 16

Again f = 10 Hz and f_2 = 10,000 Hz and

$$\overline{E^2_{1/f}} = 6.9 \text{ VOLTS}^2 \text{ (unit spectral density at 1Hz)}$$

EQUATION 17

The above solution is based on unit spectral density for the 1/f noise at 1 Hz. For comparison the 1/f noise should be set equal to the white noise at 1 KHz. Thus a multiplier of 1000 is required and:

$$\overline{E^2_{1/f}} = 6.9 \times 10^3 \text{ VOLTS}^2 \text{ (unit spectral density at 1KHz)}$$

EQUATION 18

$$\frac{\overline{E^2_{1/f}}}{E^2_W} = \frac{6.9 \times 10^3}{15.7 \times 10^3} = .44 \text{ or } -3.58\,\text{db}$$

EQUATION 19

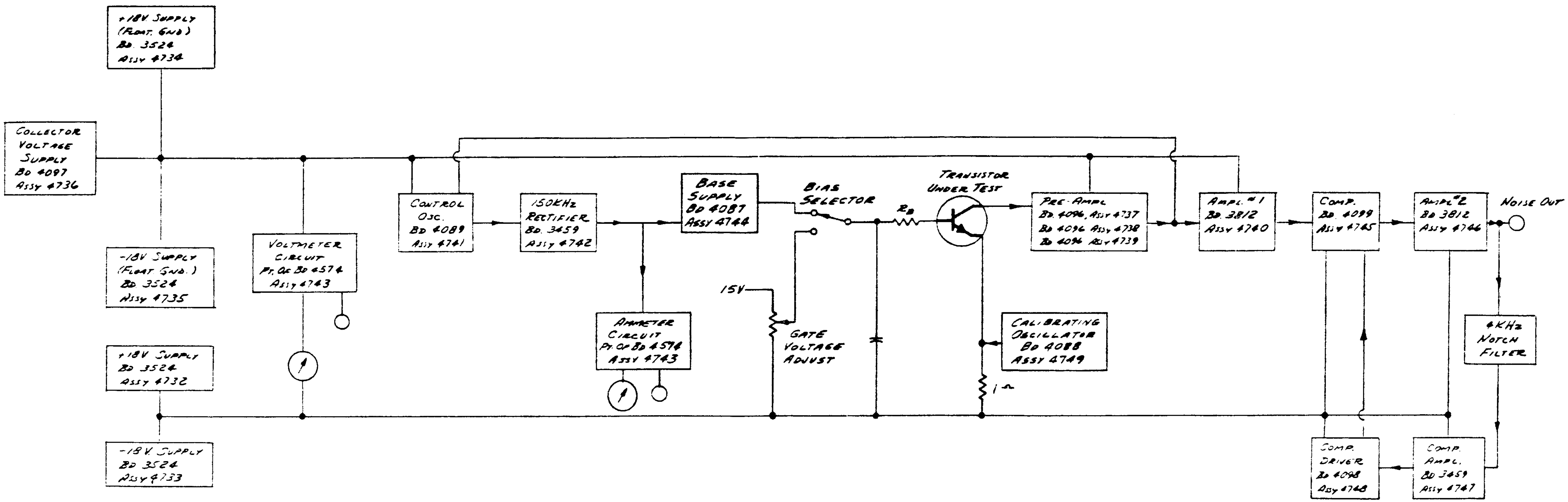
Table No. 1 is derived from equations 20 and 21.

$$\text{1KHz SPOT N.F.} = \frac{4kTRg + E^2_{1/f}}{4kTRg}$$ EQUATION 20

$$\text{BROADBAND N.F.} = \frac{4kTRg(15.7 \times 10^3) + E^2_{1/f}(6.9 \times 10^3)}{4kTRg(15.7 \times 10^3)}$$

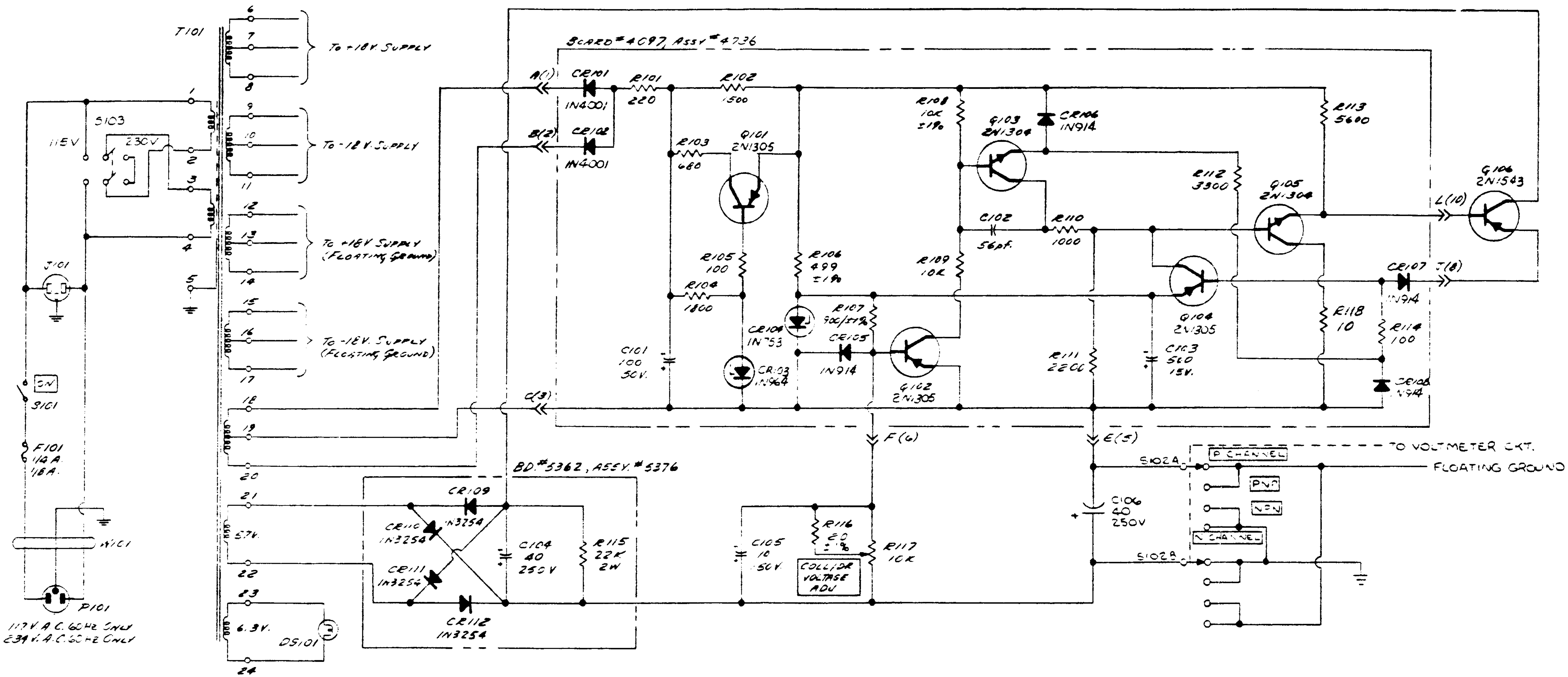
EQUATION 21

where Rg - generator or source resistance and $E^2_{1/f}$ = 1/f noise spectral density at 1 KHz.



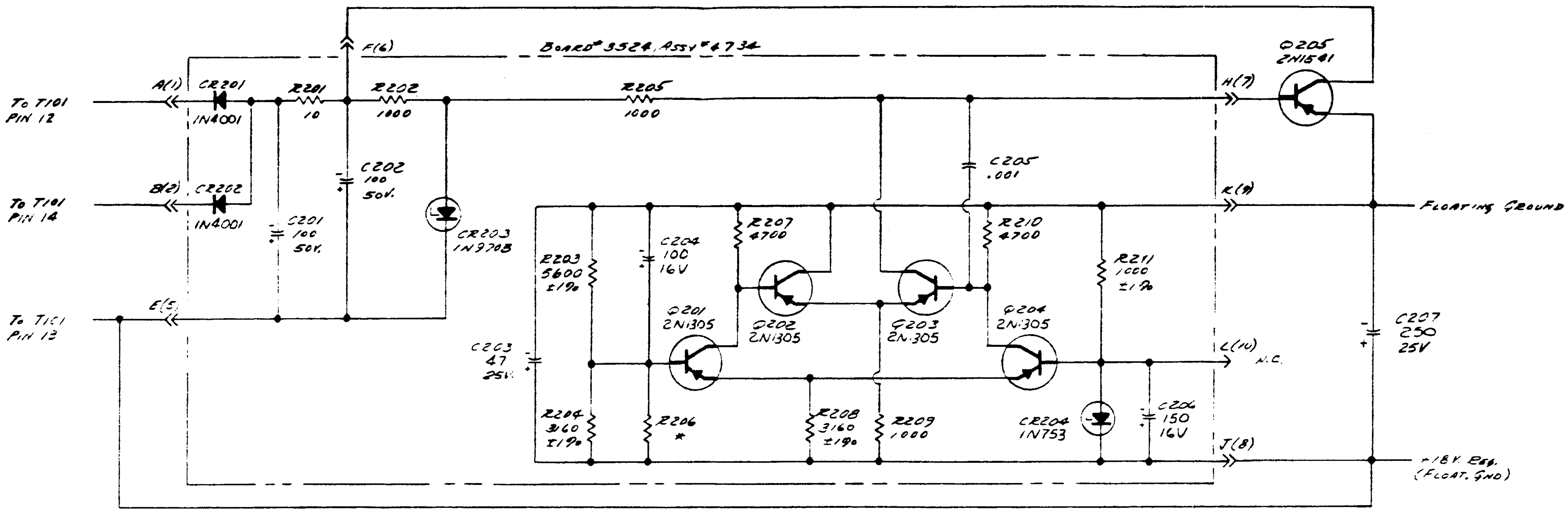
BLOCK DIAGRAM
CONTROL UNIT
MODEL 2173C

T-5420-C



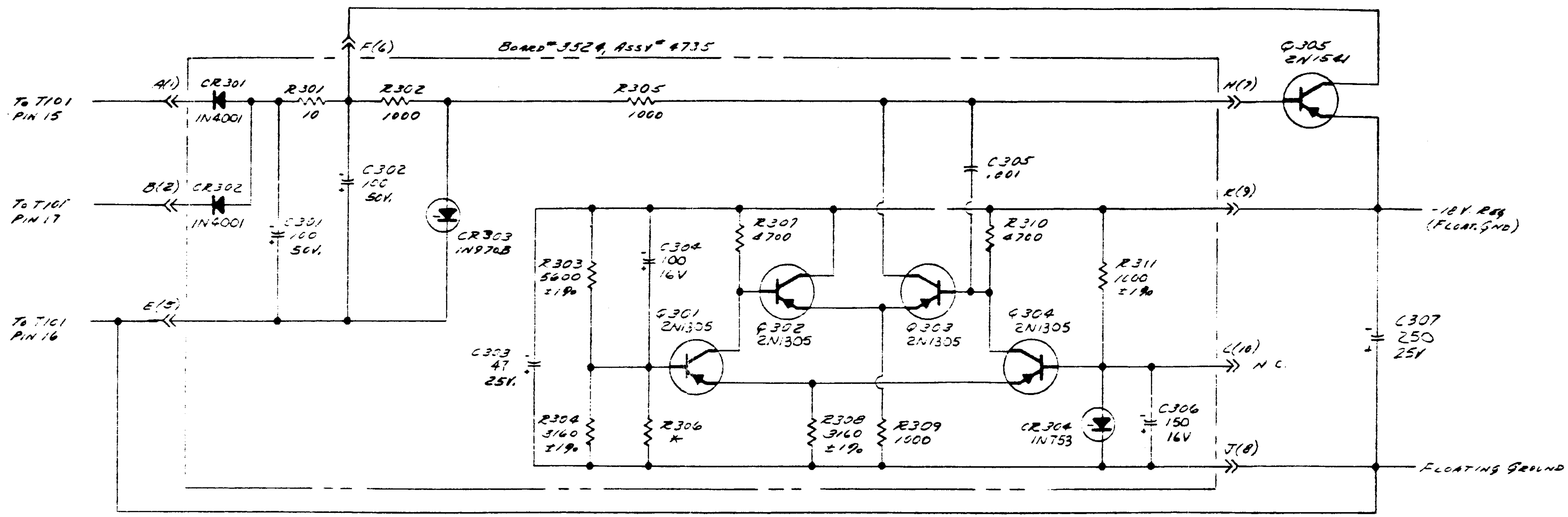
SCHEMATIC
POWER INPUT & COLLECTOR
VOLTAGE SUPPLY
MODEL 2173C

T-5421-E



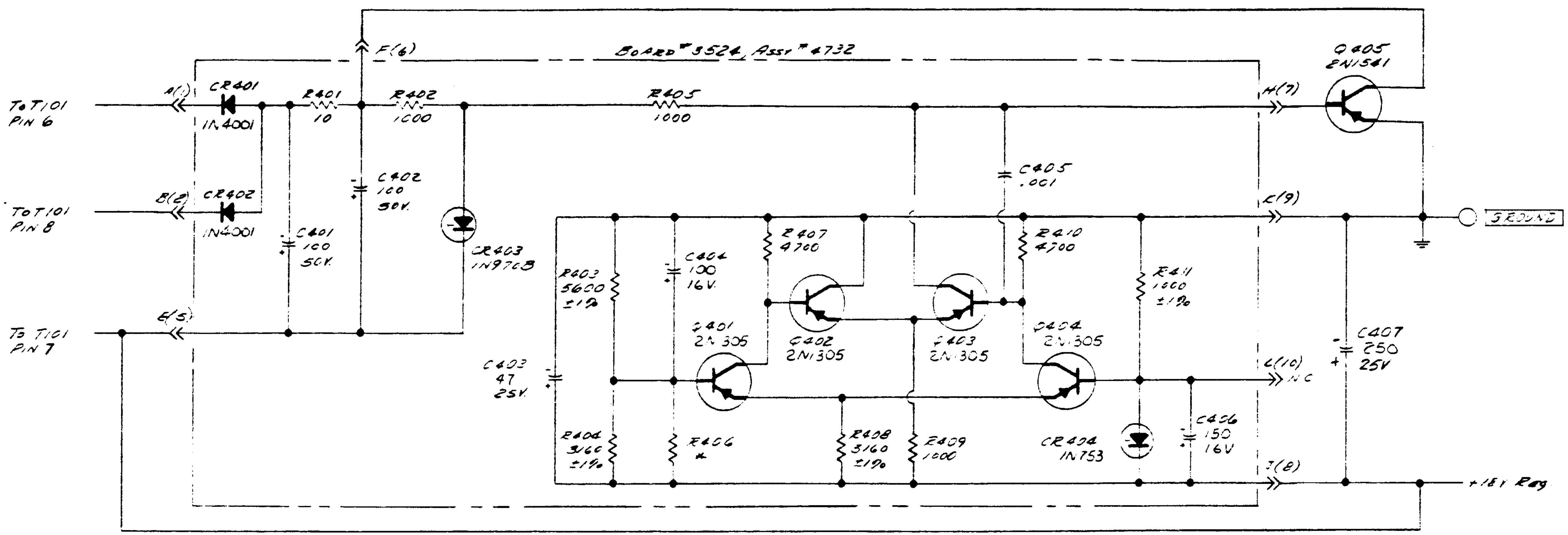
SCHEMATIC
+18 VOLT SUPPLY (FLOATING GROUND)
MODEL 2173C

T-5422-D



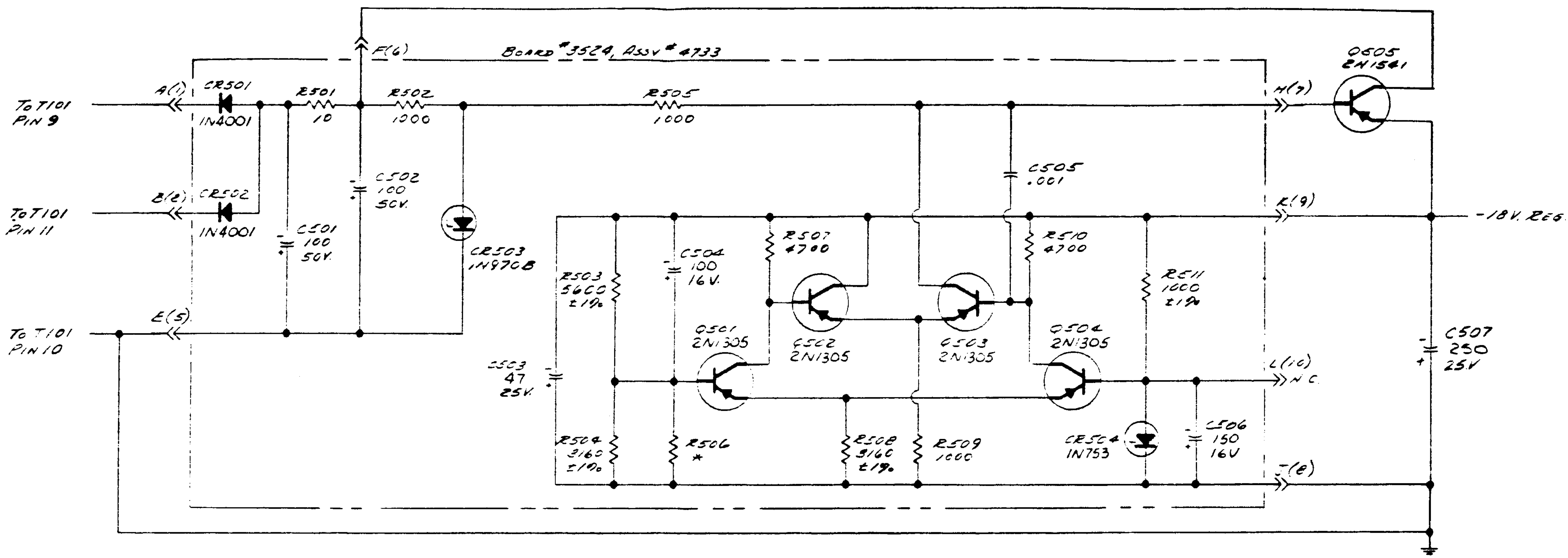
SCHEMATIC
-18 VOLT SUPPLY (FLOATING GROUND)
MODEL 2173C

T-5423-D



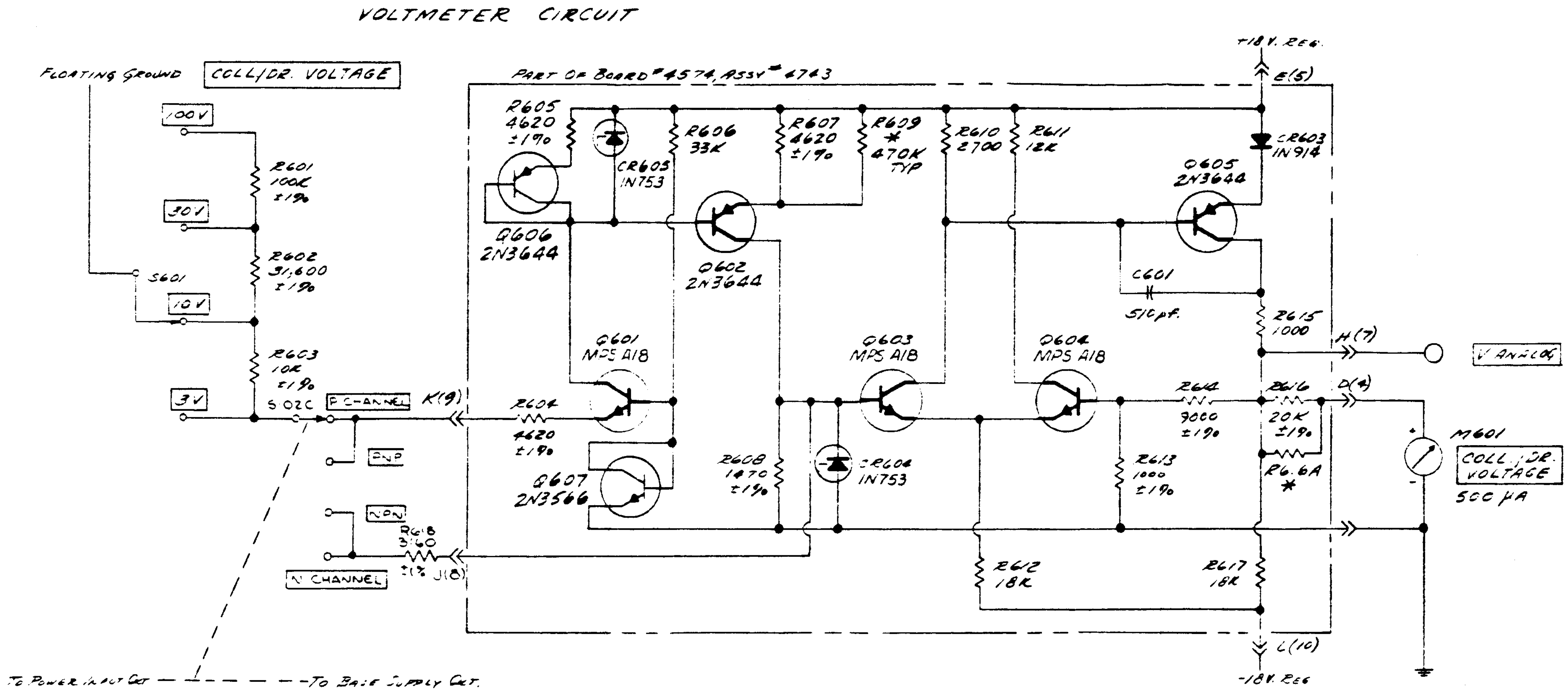
SCHEMATIC
+18 VOLT SUPPLY
MODEL 2173C

T-5424-D



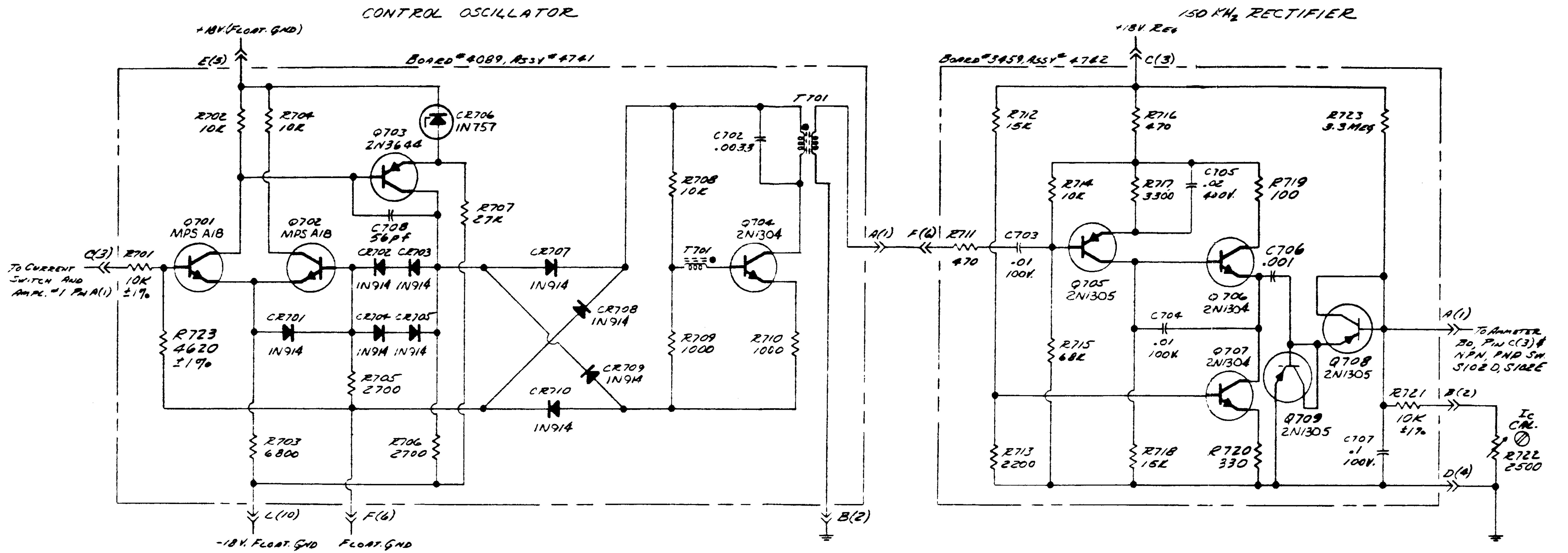
SCHEMATIC
-18 VOLT SUPPLY
MODEL 2173C

T-5425-D



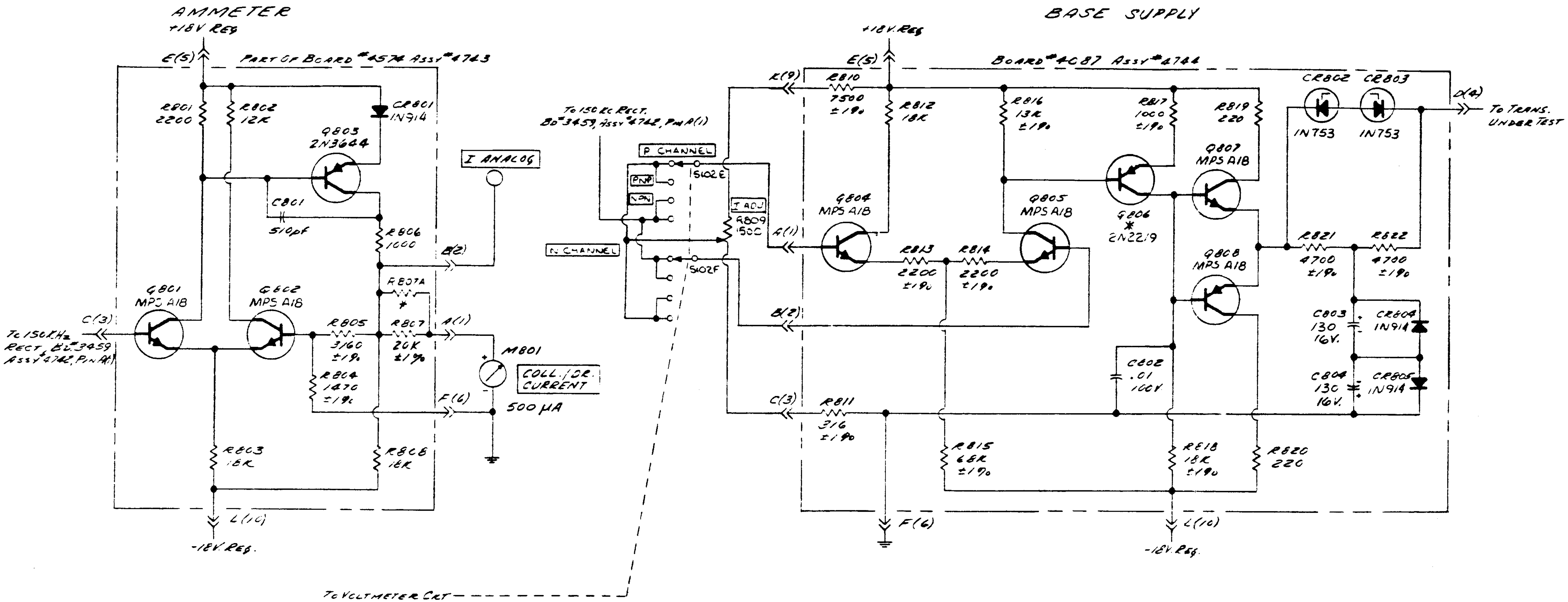
SCHEMATIC
VOLTMETER CIRCUIT
MODEL 2173C

T-5426-D



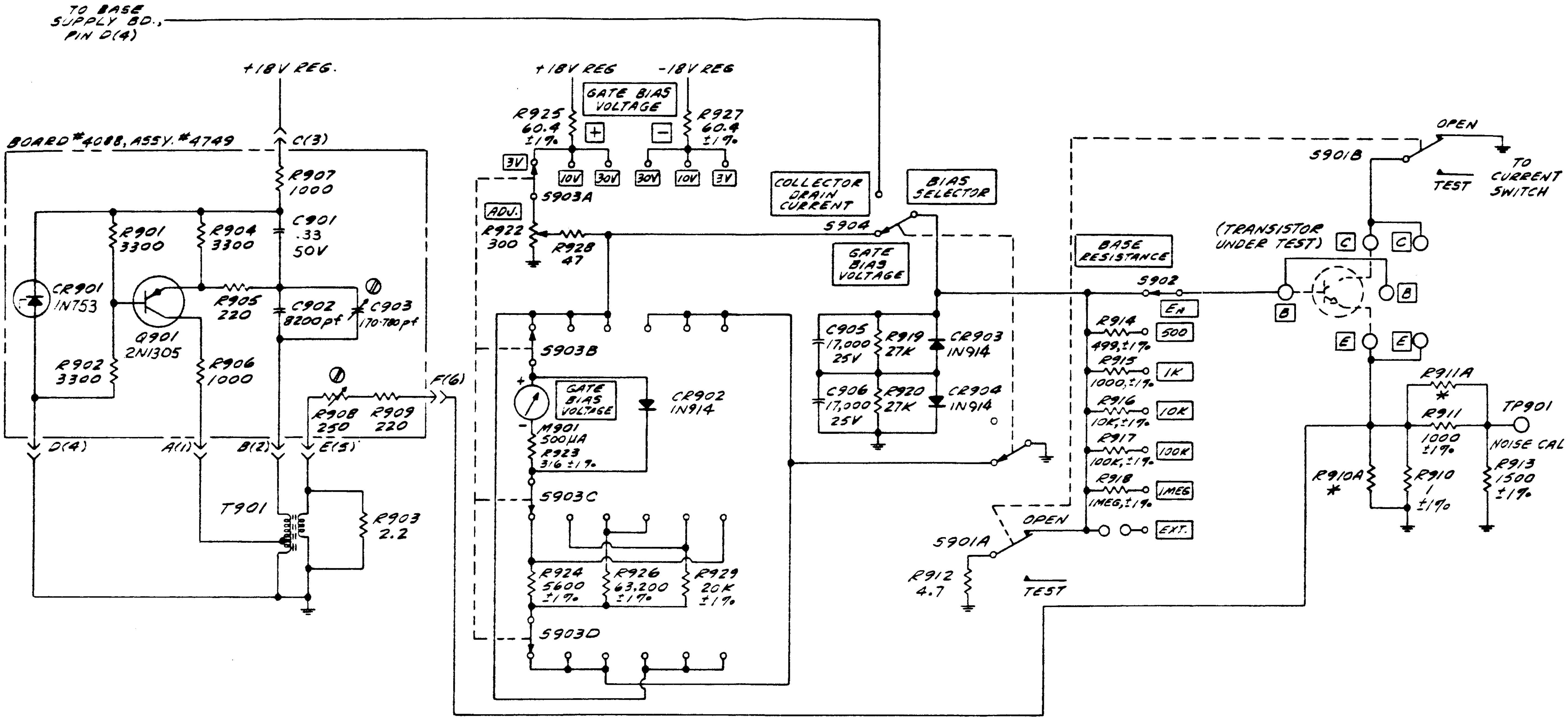
SCHEMATIC
CONTROL OSC. & 150KHz RECT.
MODEL 2173C

T-5427-C



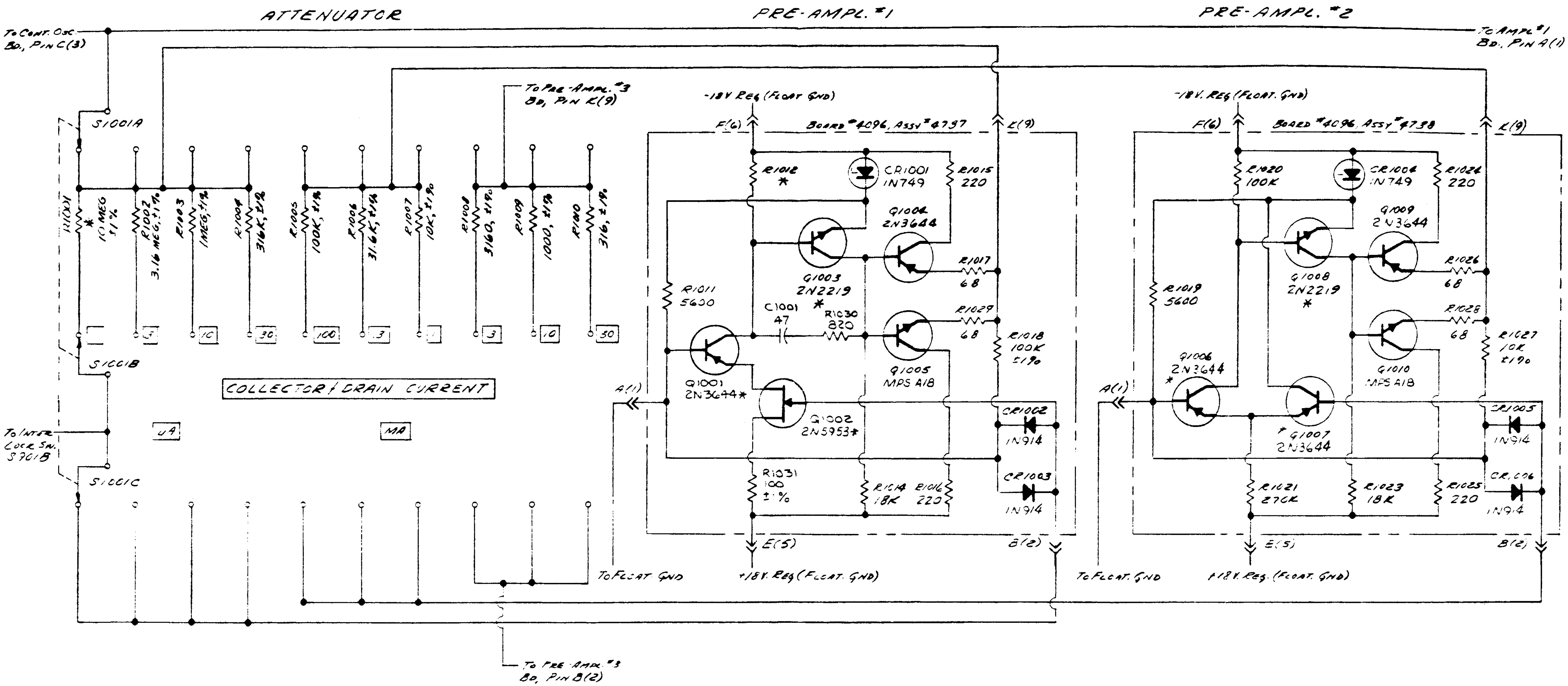
SCHEMATIC
AMMETER & BASE SUPPLY
MODEL 2173C

T-5428-D



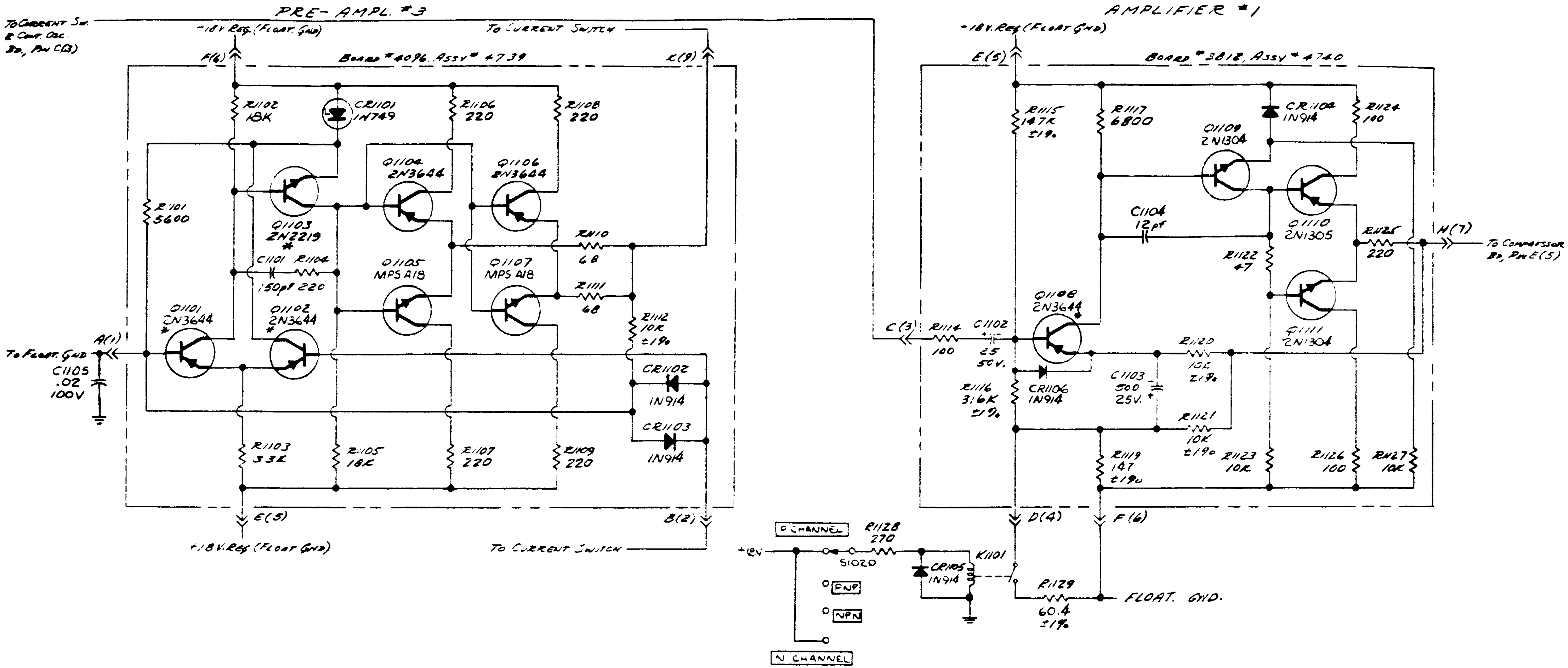
SCHEMATIC
CALIBRATING OSCILLATOR AND
TRANSISTOR TEST JIG
MODEL 2173C

T-5429-D



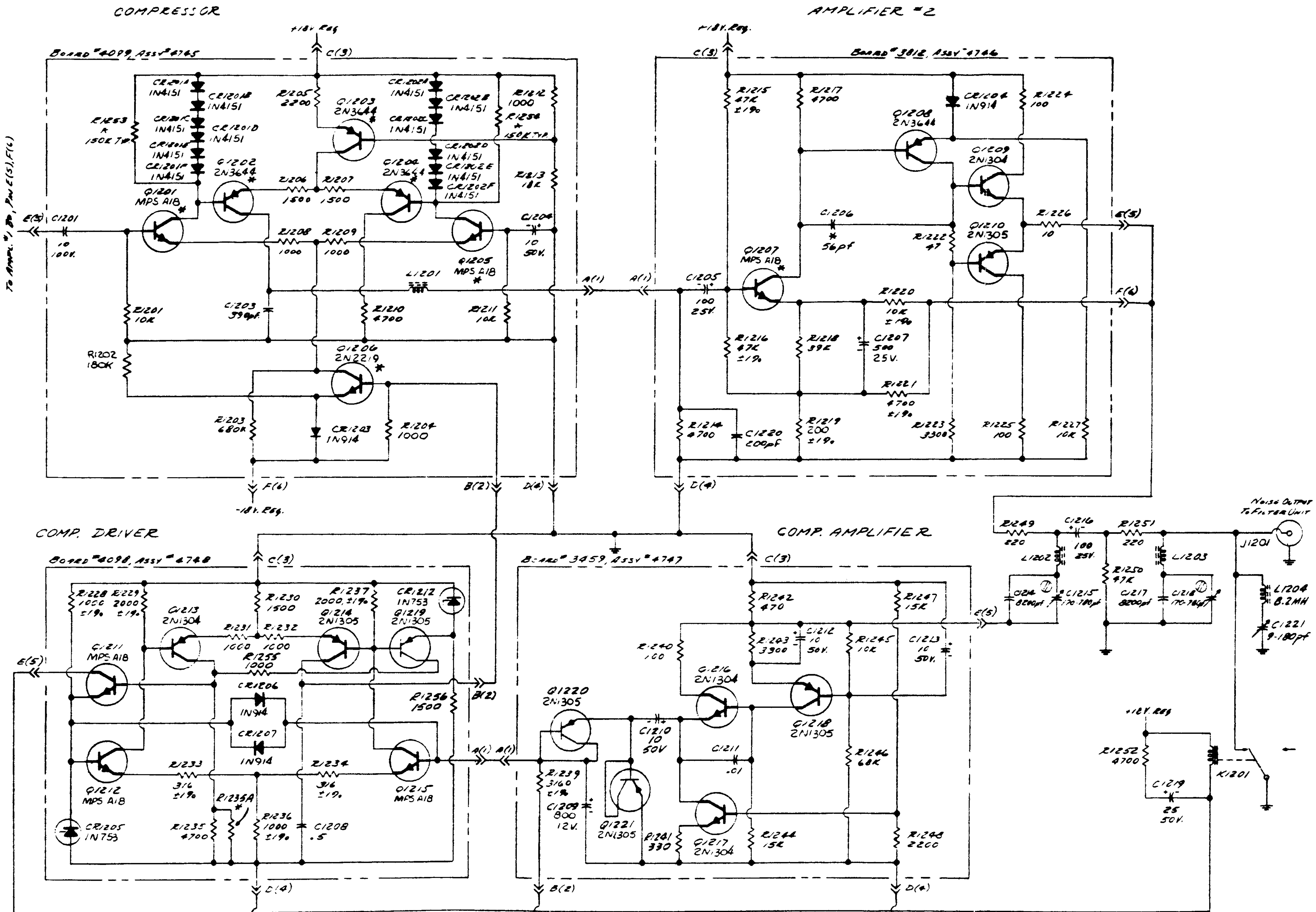
SCHEMATIC
ATTEN., PRE-AMPL. #1 & #2
MODEL 2173C

T-5430-F



SCHEMATIC
PRE-AMPL. #3 & AMPL. #1
MODEL 2173C

T-5431-H



SCHEMATIC
COMPRESSOR, AMPL. #2, NOTCH FILTER,
COMPL. AMPL. & COMP. DRIVER
MODEL 2173C

C-5432-H