Assembly and Operation of the HEATHKIT

DIGITAL MULTIMETER

MODEL IM-102

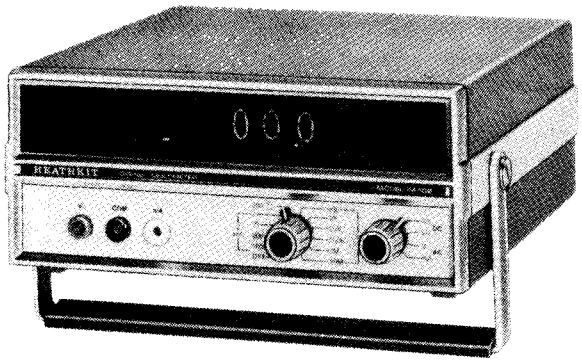

TABLE OF CONTENTS

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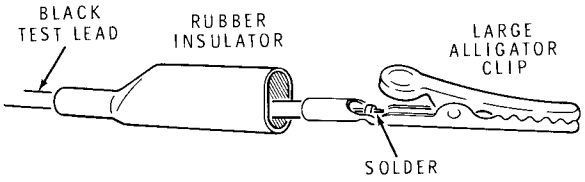
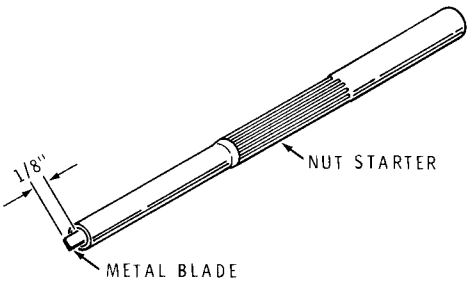
BENTON HARBOR, MICHIGAN 49022



Detail 25B



Detail 25C

( ) Refer to Detail 25B and install a black rubber insulator and a large alligator clip on the free end of the black test lead. After the solder has cooled, push the rubber insulator over the alligator clip.

( ) Refer to Detail 25C and with a pair of pliers push the 1" steel blade into the smaller end of the nut starter until 1/8" remains exposed. Use this tool for the calibration adjustments.

INITIAL TEST

Refer to Figure 1-1 for the following steps.

( ) If you have an ohmmeter, set it on the X1000 range and make the test measurements in the following two steps. If you do not have an ohmmeter, disregard the next two steps.

NOTE: If the resistance in either of the following steps is less than 3,000 Ω, it will probably be near 0. This indicates that either the negative or positive 12 volt supplies are short-circuited, possibly by a solder bridge between foils. This condition must be corrected before proceeding. If the trouble is not found by visual inspection, refer to the "In Case of Difficulty" section on Page 60. If the resistance measurements are satisfactory, proceed to the following step.

( ) Connect the common lead of the ohmmeter to the cathode (banded) end of diode ZD5, and the positive ohmmeter lead to the other lead of diode ZD5. The resistance should measure over 3,000 Ω.

( ) Move the positive ohmmeter lead to the cathode (banded) end of diode ZD4. The resistance should measure over 3,000 Ω.

( ) Disconnect the ohmmeter leads.

( ) Connect the line cord to the line cord connector on the rear panel.

DANGER: *Whenever the line cord is connected to an ac outlet, dangerous voltages will be present above and below the circuit board, even when the switch is in the OFF position. Except when an insulated tool is used, do not handle or work on this instrument when the covers are removed until the line cord has been disconnected. Refer to "High Voltage Areas" (fold-out from Page 45).*

( ) Connect the line cord plug to an ac outlet.

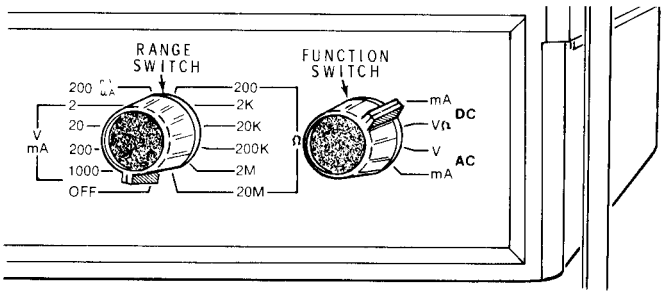
1. If the display tubes light, turn the RANGE switch until the tubes go out (OFF position). The switch will rotate in either direction from the OFF position.

Then disconnect the line cord and proceed to the "Knob Installation" section.

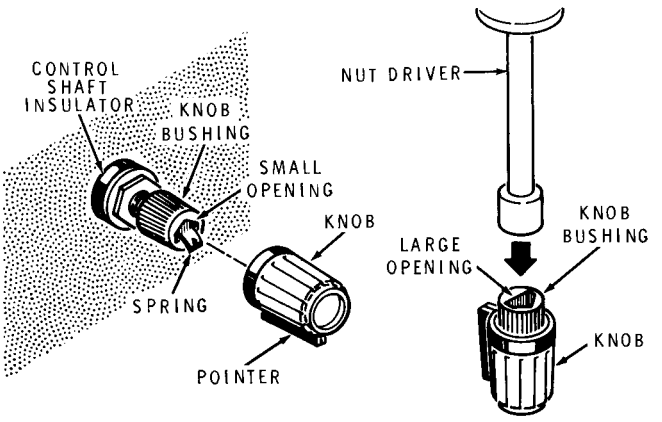
2. If the display tubes do not light, turn the RANGE switch one position in either direction and the display tubes should light. (If the tubes do not light, refer to the "In Case of Difficulty" section.) After the tubes light, return the RANGE switch to the OFF position.

Then disconnect the line cord and proceed to the "Knob Installation" section.

3. If you have plugged in the line cord without making the ohmmeter checks, the display tubes may flash on for a fraction of a second and then not light again. Unplug the line cord. If F301 (the fuse near the line cord connector) is blown, there is a short circuit in the unit which must be corrected (and the fuse replaced) before proceeding. Refer to the "In Case of Difficulty" section on Page 60.



PICTORIAL 26



Detail 26A

KNOB INSTALLATION

Refer to Pictorial 26 for the following steps.

( ) Make sure the RANGE switch is still at the OFF position.

( ) Turn the FUNCTION switch to its fully counterclockwise position.

( ) Make sure the line cord is disconnected.

NOTE: In the following steps, you will install knobs on the two switch shafts. Perform these steps carefully; it is difficult to remove a bushing after it is installed in a knob.

( ) Refer to Detail 26A and press a knob firmly onto the Range switch shaft bushing with the knob pointer toward the OFF position.

( ) Carefully remove the bushing from the shaft. Be careful that the knob does not come off the bushing. Then press the bushing all the way into the knob with a nutdriver, or other appropriate tool, as shown. Replace the knob on the switch shaft.

( ) In the same manner, install the remaining knob on the Function switch shaft with the pointer at the dc mA position.

CALIBRATION

The accuracy of your Digital Multimeter depends largely upon the accuracy of its calibration. As most people do not have access to expensive laboratory test equipment, a DC Calibrator (on a small circuit board) has been included in your kit. It has been assembled from precision resistors, is powered by a mercury cell, and has been calibrated at the factory. Its circuit is shown in the Schematic Diagram. It is illustrated in Figure 1-1.

If you do not have access to laboratory test equipment, use the DC Calibrator to insure accurate calibration of your Multimeter. Refer to "Connect Meter Leads" in the Calibration Chart (Page 46), and use the "DC Calibrator" columns for instructions on connecting your Multimeter test leads.

If you use laboratory test equipment for calibrating your Multimeter, connect the meter leads as shown in the "Laboratory Standards" columns. The calibrating adjustments to the Multimeter will be the same as when using the DC Calibrator, but the voltage and resistance standards used for calibration will have changed.

NOTE: Be sure the accuracy of your test equipment is at least five times more accurate than the Multimeter Accuracy specifications under Laboratory Equipment in the "Specifications" section of this Manual, starting on Page 67. That is, when the accuracy is listed at 0.1%, your calibration equipment must be accurate to at least 0.02%.

The black lead of the DC Calibrator serves as its on-off switch. The 1.35 volt mercury cell is connected into the circuit when the black lead is clipped onto terminal (foil) 1 of the circuit board. Remember to disconnect this lead (turn off the switch) when the Calibrator is not in use.

Now, connect your Multimeter to an ac outlet and let it warm up for 15 minutes. Then turn to the "Calibration Chart," and proceed with the calibration of your Multimeter.

Calibration Chart

1. Refer to Figure 1-1 (fold-out from Page 44) for the location of adjustment and test points.

2. Read the Legend (Page 47) before starting the calibration steps.

3. Perform each step in sequence. Attain the stated reading in each step before proceeding to the next step.

STEP	INPUT JACKS		RANGE SWITCH	FUNCTION SWITCH	USING DC CALIBRATOR		USING LABORATORY STANDARDS	
					CONNECT MULTIMETER TEST LEADS			
	BLACK LEAD	RED LEAD			BLACK	RED	BLACK (NOTE 6 on Page 47)	RED
( ) 1	COM	V Ω	200 mV	DC VΩ	Clip Together		Clip Together	
( ) 2A	COM	VΩ	1000V	DC VΩ	CAUTION: Unplug line cord before connecting or disconnecting leads.		CAUTION: Unplug line cord before connecting or disconnecting leads.	
( ) 2B			200V		Terminal #1 of Power Transformer	Terminal #2 of Power Transformer	Terminal #1 of Power Transformer	Terminal #2 of Power Transformer
( ) 2C			20V					
( ) 2D	Unplug the line cord and disconnect the test leads.							
( ) 3	COM	VΩ	200 mV	DC VΩ	Terminal #1 of Cal Bd	Terminal #.2 of Cal Bd	COM	+200 mV dc source
( ) 4	COM	VΩ	200 mV	DC VΩ	Terminal #.2 of Cal Bd	Terminal #1 of Cal Bd	COM	−200 mV dc source
( ) 5A	COM	VΩ	200 mV	DC VΩ	Terminal #1 of Cal Bd	Terminal #2 of Cal Bd	Omit	Omit
( ) 5B			2V			Terminal #2 of Cal Bd	COM	+2 Vdc source
( ) 6	COM	VΩ	20 kΩ	DC VΩ	Terminal #1 of Cal Bd	Terminal #2 of Cal Bd	Across 20 kΩ, 0.05% resistance	

4. Read each step completely, particularly the "Notes and Cautions" column, before performing the step.

5. Take care not to confuse the #2 and #2 foils of the DC Calibrator.

6. In the "Laboratory Standards" steps, COM refers to the common, or ground, terminal of the source device.

*LEGEND: TP = Test point
NC = No connection
Cal Bd = Calibrator board. Clip the lead onto the numbered foil.
Rocking polarity = Alternately illuminated + and – indicators. Occurs at 00.0 reading.

PURPOSE	PROCEDURE	NOTES AND CAUTIONS
Zero Adjust	Rotate the ZERO ADJ control for a 00.0 reading and rocking ± polarity indicators.	
40 kHz Oscillator Frequency Adjustment.	Rotate the 40 kHz ADJUST control for a 000 reading.	CAUTION: Unplug the line cord before connecting or disconnecting the Multimeter leads to the power transformer. This is the primary line voltage. The adjustment in the 20 V position is critical. The last digit may vary. Expect rocking polarity indicators.
	Rotate the 40 kHz ADJUST control for a 00.0 reading.	
	Rotate the 40 kHz ADJUST control for a 0.00 reading.	
Calibrate +200 mV dc to standard.	Clip the calibrator board black lead on Terminal #1 of the calibrator board. Then rotate the POS RANGE control for an OVER +00.0 reading.	If the display increases (counts up) continuously while the calibrator board is in use, this indicates a possible poor connection between one of the Multimeter leads and a calibrator board foil.
Calibrate -200 mV dc to standard.	Clip the calibrator board black lead on Terminal #1 of the calibrator board. Then rotate the NEG RANGE control for an OVER –00.0 reading.	Control R502 is factory calibrated and sealed. DO NOT attempt to disturb this adjustment.
	Repeat steps 3 and 4 as a check. Then remove the black lead from calibrator board terminal #1.	
Calibrate +2 Vdc to standard.	Connect the calibrator board red lead to the 3.5V TEST PIN on the main circuit board. Adjust R505 on the calibrator board (NOT the 500 Ω sealed control) for an OVER +00.0 reading.	
	Adjust the 2 VFS control for an OVER +.000 reading. Repeat this step as a check. Then disconnect the calibrator board red lead.	
Calibrate low ohms range.	Rotate the 20k ADJ control for an OVER 0.00 reading.	

Calibration Chart (cont'd.)

STEP	INPUT JACKS		RANGE SWITCH	FUNCTION SWITCH	USING DC CALIBRATOR		USING LABORATORY STANDARDS	
					CONNECT MULTIMETER TEST LEADS			
	BLACK LEAD	RED LEAD			BLACK	RED	BLACK (NOTE 6 on Page 47)	RED
( ) 7	COM	VΩ	20 MΩ	DC VΩ	See Note A		Across 20 M, 0-2% resistance.	
( ) 8A	NC	VΩ	20V	DC VΩ	NC	TP	Refer to "AC Frequency Compensation" procedure (Page 50).	
( ) 8B				AC V				
( ) 8C								
( ) 9A	COM	VΩ	200V	AC V	CAUTION: Unplug line cord before connecting or disconnecting leads. Terminal #1 of Power Transformer	Terminal #2 of Power Transformer	Omit	Omit
( ) 9B	Unplug the line cord and disconnect the test leads.							
( ) 10	COM	VΩ	20 kΩ	DC VΩ	See Note B.		Omit	Omit
( ) 11A	COM	mA	20 mA	AC mA	CAUTION: Unplug line cord before connecting or disconnecting leads. Terminal #1 of Power Transformer	See "Procedure" column	COM	10 mA source
( ) 11B	Unplug the line cord and disconnect the test leads.							
( ) 12	COM	mA	200 μA	DC mA	Black lead of Cal Bd	Terminal # 1 of Cal Bd	Omit	Omit

Proceed to the "AC Frequency Compensation" steps.

*LEGEND: TP = Test point
NC = No connection
Cal Bd = Calibrator board. Clip the lead onto the numbered foil.
Rocking polarity = Alternately illuminated + and – indicators. Occurs at 00.0 reading.

PURPOSE	PROCEDURE	NOTES AND CAUTIONS
Calibrate high ohms range.	Rotate the 20M ADJ control for an OVER 0.00 reading. Repeat step 6 as a check.	Due to the high resistance and low current, 30 or 40 seconds may elapse before a stable, accurate reading is obtained. Do not hold the leads or the resistor with your hand.
Calibrate ac volts.	Place the AC-DC switch on the circuit board in the DC position. Adjust the TP ADJUST control for a +9.00 center reading. The reading will vary several digits in both directions.	Insert the red test lead probe into the TP hole.
	Place the AC-DC switch in the AC position. Rotate the AC ADJ control on the AC Converter board for a center reading of OVER 0.00.	
	Repeat this step as a check. Then remove the red probe from the TP hole.	
Calibrate current.	Write down the voltage reading (this is the line voltage). Then remove the test leads from the power transformer.	
	Divide the voltage from the previous step by the resistance reading from this step. This calculation determines a reference current. EXAMPLE: First reading $\frac{E = 116V}{R = 9800} = .0118A = 11.8$ mA Second reading	
	DC CALIBRATOR: Cut the leads of the 10 kΩ, 7-watt, resistor to 1/2". Temporarily solder a lead of the resistor to terminal #2 of the power transformer. Then connect the red meter lead to the other resistor lead. Adjust the CURRENT ADJ control on the AC Converter circuit board until the meter reads the same amount of reference current calculated in the preceding step. Then remove the 10 kΩ resistor. LABORATORY STANDARDS: Adjust the CURRENT ADJ control on the AC Converter circuit board for a 10.00 reading.	
Check dc mA accuracy.	Meter display should read 93.1 μA ±3 digits if all previous steps were correctly performed.	If the display is incorrect, check the calibration steps. If they are OK, check the values of R106 through R111.

NOTE A: Connect the Multimeter test leads to the leads of the 20 MΩ, 1 watt, calibration resistor.

NOTE B: Connect the Multimeter test leads to the leads of the 10 kΩ, 7 watt, calibration resistor.

AC FREQUENCY COMPENSATION

Refer to Figure 1-1 (fold-out from Page 44) for the location of adjustment and test points.

Two methods of adjusting the trimmer capacitors are given below. If you do not have an ac calibrator, use the "Trimmer Capacitor Centering" steps. If an ac standard calibrator is available (such as Hewlett-Packard Model 745, Optimation Model AC110, or equivalent), complete the "AC Standard Calibrator" steps.

Trimmer Capacitor Centering

( ) Identify the LOW CAL and HIGH CAL trimmer capacitors on the AC calibrator circuit board.

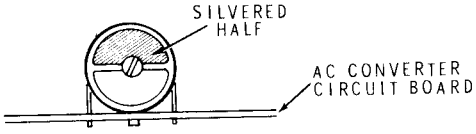


Figure 1-2

( ) Adjust each of these trimmers so the silvered half of each plate is positioned as shown in Figure 1-2. This centers the capacity of each trimmer within its range.

( ) Disconnect all test leads.

This completes the "Calibration." Proceed to "Final Assembly."

AC Standard Calibrator Steps

( ) Connect the Digital Multimeter and the ac calibrator to the ac line and turn them on.

( ) Set the controls of the Digital Multimeter as follows:

FUNCTION – AC Volts
RANGE – 2 Volts

( ) Set the frequency control of the ac calibrator at 400 Hz and the voltage output at 2 volts rms.

( ) Connect the output leads of the ac calibrator to the VΩ and COM inputs of the Digital Multimeter.

( ) Adjust the AC ADJ control on the AC Calibrator circuit board for a display of over .000±2 digits.

( ) Turn the Multimeter RANGE switch to the 1000 position.

( ) Set the frequency control of the ac calibrator at 20 kHz and the voltage output at 500 volts rms.

( ) Adjust the LOW CAL trimmer on the AC calibrator circuit board for a meter reading of 500±4 digits.

( ) Turn the Multimeter RANGE switch to the 200 V position.

( ) Set the ac calibrator for an output voltage of 200 volts rms.

( ) Adjust the HIGH CAL trimmer on the AC calibrator circuit board for a display of OVER 00.0±15 digits.

( ) Repeat this series of adjustments at least twice for optimum compensation, as there is interaction between the two trimmers.

( ) Disconnect all test leads.

This completes the "Calibration." Proceed to "Final Assembly."

CIRCUIT DESCRIPTION

GENERAL

This instrument is designed to measure ac and dc volts, ac and dc current, and resistance. All of the inputs are either scaled to, or converted to, the basic measuring ranges of 200 millivolts or 2 volts, depending on the range switch setting. The measuring circuit is a high impedance bipolar A/D (analog to digital) converter which operates on the dual-slope principle.

The dual-slope action is shown by waveform F of Figure 4-2 (fold-out from Page 72). 8,000 pulses of the clock oscillator are divided into two time elements, t_1 and t_2, shown in sloping lines or "ramps." During t_1 (ramp-up time), the integrator charges a capacitor. During t_2 (ramp-down time), the capacitor discharges. The time required to discharge the capacitor is counted, decoded, and displayed.

Resistance is measured by passing a scaled constant current through the unknown resistor and measuring the dc voltage across it.

Alternating voltages are converted to dc by an average-sensing, rms calibrated, converter assembly. Full scale output voltage for all ranges is 2 volts dc.

Current is measured by the voltage drop it establishes across a shunt network. If it is dc, the voltage drop is measured directly. If it is ac, the voltage drop is first applied to the ac converter and then measured. The full scale shunt voltage is 200 millivolts for all ranges.

The dc voltmeter and the several conversion circuits are interconnected by multi-section Range and Function switches which make possible: decimal point switching, polarity indicator switching, input ranging, gain changes in the A/D converter, shared usage of the precision attenuator, and a switchable protection function. More detailed descriptions of the several circuit areas follow.

Because the instrument is basically a dc voltmeter, a dc input voltage will first be used in describing the main circuits. Then various inputs and their associated circuits will be explained.

Refer to the Block Diagram (Figure 4-1), Waveforms (Figure 4-2), and to the Schematic Diagram (fold-out from Page 97) while you read this "Circuit Description." When the description of a circuit deals in polarity, a positive input to the Multimeter is assumed.

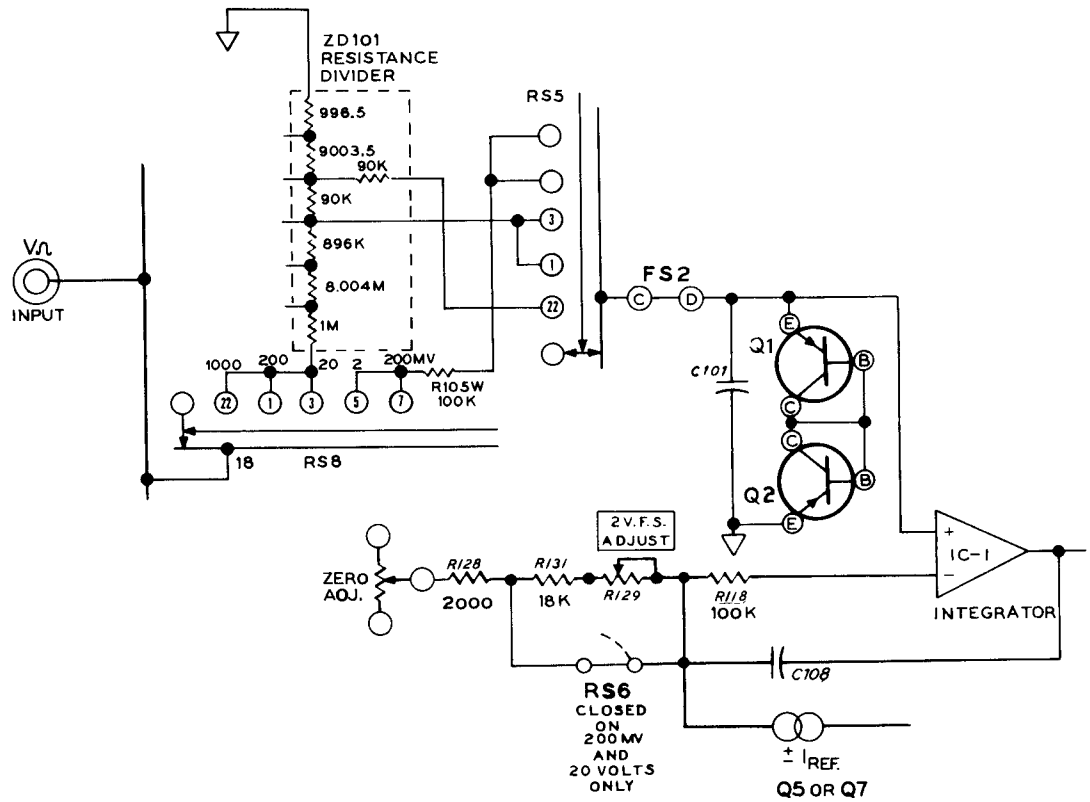


Figure 4-3

DC VOLTS

Volts Input

From the V Ω jack (see Figure 4-3), the input signal is applied to RS8 (wafer 8 of the Range switch). Signals on the 200 millivolt or 2 volt ranges are switched to RS5 through R105W. This buffering resistor serves as a balancing resistor and absorbs overloads. On the 20, 200, and 1,000 volt ranges, the input signal is switched to RS5 through resistance divider Z101 which is designed to provide 200 millivolts or 2 volts to the integrator input.

The input signal, having been scaled to 200 millivolts or 2 volts, moves through contacts C and D of wafer 2 of the function switch to the noninverting input of the integrator, IC-1.

Q1 and Q2, connected as zener diodes, provide overload protection. C101 gives some interference rejection.

The charging current must be changed as the basic voltage range is switched between the 200 mV and 2 V ranges. When the Range switch is on the 200 mV (or 20 V) range, RS6 is connected to bypass R129 and R131 and leave 2,000 Ω in the circuit. The Range switch opens in the other ranges and adds R129 and R131 for a total of 20 kΩ.

Integrator

The dual slope integrator circuit, as shown in Figure 4-4, consists of an operational amplifier connected as an augmenting integrator (integrator with voltage follower input) for a high impedance input. Constant current sources control the ramp-down discharge rate. The integrator output is shown as waveform F in Figure 4-2.

Waveform F of Figure 4-2 shows that the total time for one integrating cycle is 8,000 pulses of the 40 kHz oscillator, or 200 ms (milliseconds). The beginning of each time cycle occurs when waveform B joins waveform C at a low, or logic 0, which occurs only once each 8,000 cycles. The oscillator pulses which occur during the ramp-down time, t_2 are counted and displayed. Time t_1 is the charging time for C108. Thus, time t is divided into two portions whose sum is the number of pulses in the measuring cycle, and are therefore independent of clock accuracy.

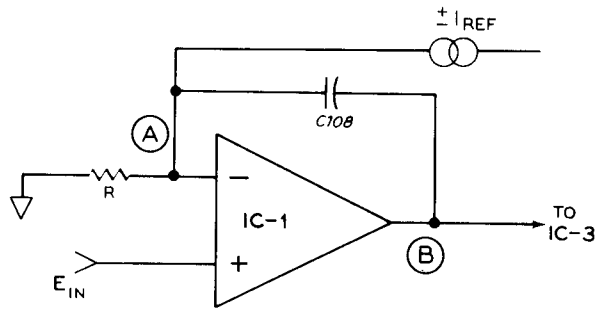


Figure 4-4

The count of 8,000 and the crossing of 0 by the integrator are the key events in each cycle. They initiate time t_2 and other events (to be described).

If 100 mV dc is applied to E_{in}, IC-1 will produce just enough voltage at point B to force the necessary current to flow through C108 and R to produce 100 millivolts at point A. However, to maintain the necessary current flowing through R, point B must keep going higher in voltage to overcome the charging of C108. If R is assumed to be 2,000 Ω, then 50 μA will flow through it as a result of the 100 millivolts at point A.

In the example above, IC-1 supplies 50 μA to charge C108 during time t_1. The constant current sources (±I Ref) supply 400 μA to dischage C108 during time t_2. Therefore, C108 will discharge at a rate of 350 μA (400 μA reference − 50 μA input = 350 μA discharge). The correct polarity of current to discharge C108 is selected by the digital control circuits.

As the input polarity in the example is positive, the positive current injected into the inverting input of the integrator will force it back to 0 at the end of t_2.

The cycle repeats every 200 ms. Unless the new count differs from the previous one, the display remains the same.

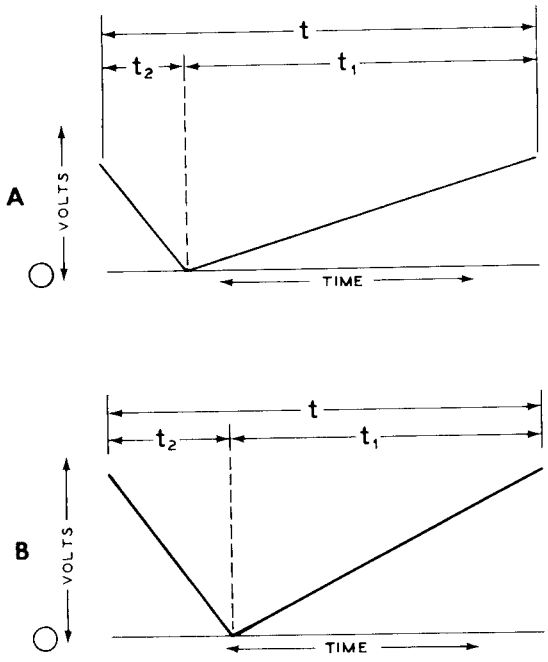


Figure 4-5

Figure 4-5 shows how the output waveform of the integrator varies with different input voltages. The angle formed by the "ramp-up" line t_1 with the zero voltage line indicates the rate of charge of C108.

Note that line t_2 in B is longer than in A as it is the result of a higher input voltage. Because the line is longer in B, more time is required for t_2 to reach zero, more counts of the clock oscillator will occur, and a higher voltage will be displayed.

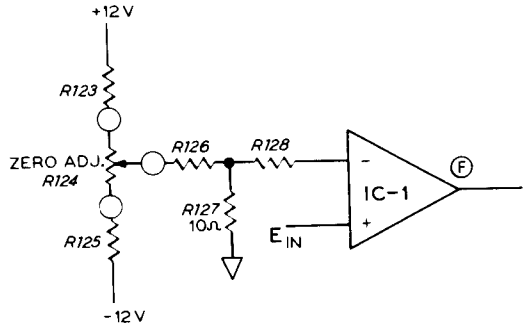


Figure 4-6

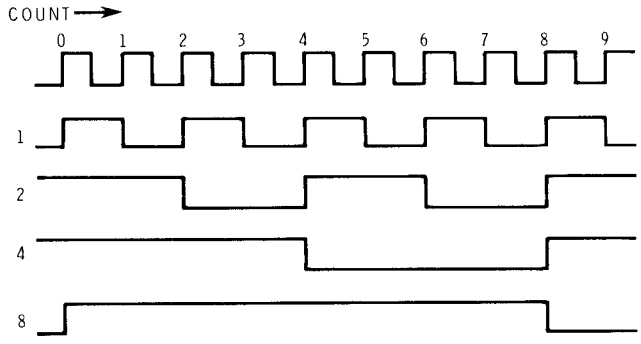
Offset Adjustment

Even with no input, offset voltages in IC-1 (unless compensated) will produce a continuous ramp at point F and the display will stabilize at some reading other than zero. To compensate, the ground end of the integrating resistor is connected to an adjustable, low-impedance source as shown in Figure 4-6.

R124 and its associated resistors provide a voltage source which can be adjusted to compensate for a possible 8 millivolt offset voltage in IC-1. Different voltage ranges do not require a change in this adjustment.

Counting Circuits

A 40 kHz oscillator, IC-9A and B, furnishes a signal to a series of three DCU's (decade counting units) which are followed by three divide-by-two binaries. A truth table and block diagram for the DCU's appear in Figure F in the "Identification Charts" (on Page 92). The three DUC's can count up to 999 and each drives a buffer storage unit. The binary output of the storage units is decoded by the three decoder-drivers, which drive the three display tubes.



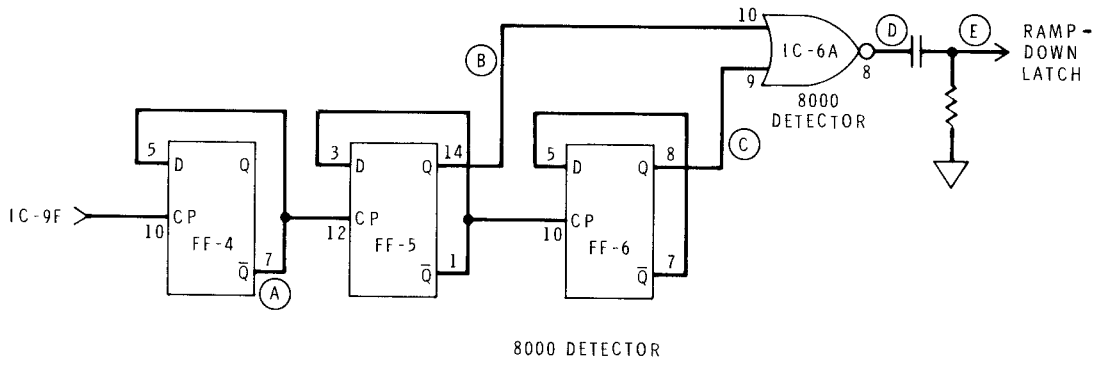
DCU OUTPUT WAVEFORMS
NEGATIVE LOGIC (LOW=LOGIC 1)
BINARY VALUES AT LEFT

Figure 4-7

Refer to Figure 4-7 for the waveforms of the DCU's. Note that negative logic is used. The output of IC-10 is inverted by IC-9F. This serves as the input to the three divide-by-two binaries which operate in positive logic. Their output waveforms are shown at A, B, and C of Figure 4-2. The points where these waveforms appear on the Block Diagram (Figure 4-1) are also designated by A, B, and C. The three binaries also provide for the 1000 count as well as overrange sensing and control functions.

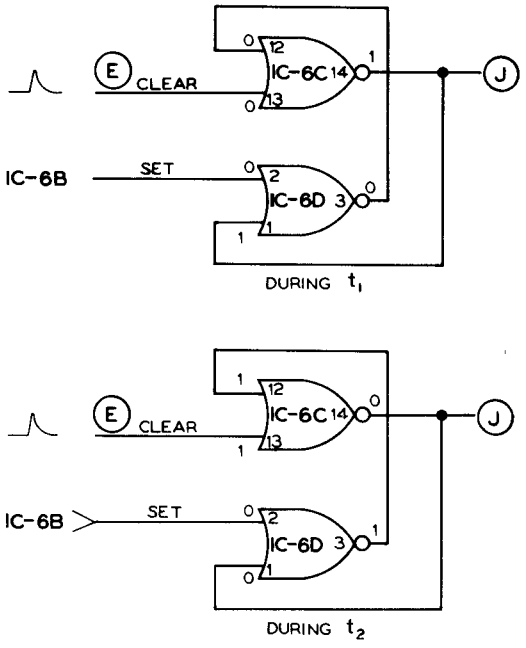
8,000 Detector and Ramp-Down Latch

The output of FF5 (Figure 4-8) joins the output of FF6 at a zero level on the count of 8,000 and starts time period t_2 as shown in Figure 4-2. The zero outputs of the two flip-flops are fed to the 8,000 detector, IC-6A, and cause a logic 1 output, waveform D. This waveform is differentiated into pulse E, which clears the ramp-down latch and causes its output, waveform J, to go to zero. Figure 4-9 shows the state of the ramp-down latch during time t_1 and t_2 by the insertion of the applicable logic levels at the gate inputs and outputs.



8000 DETECTOR

Figure 4-8



RAMP DOWN LATCH

Figure 4-9

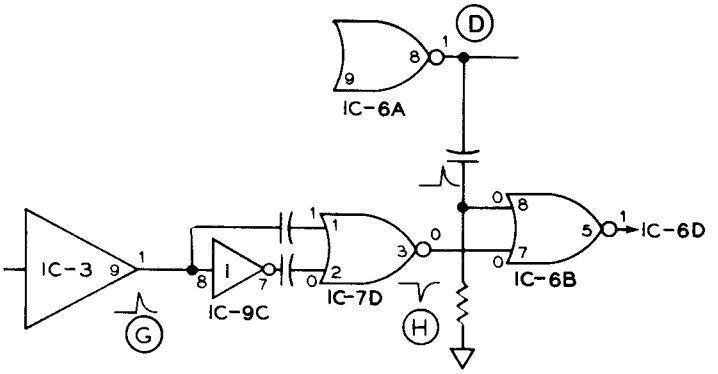
Voltage Comparator and Latch Reset

The output of the integrator is fed to a voltage comparator, IC-3. When the comparator input goes positive, its output is a logic 0; when the input goes negative, its output goes to a logic 1. These transitions are very abrupt, switching states at approximately zero volts input. When, at the end of time t_2, the ramp-down voltage reaches zero (having been positive), there will be an abrupt transistion of the comparator from 0 to the 1 state, causing a positive pulse on waveform G. (See Figures 4-2 and 4-10.) The waveform G is fed to the two inputs of the crossing shaper (IC-7D), one through inverter IC-9C and the other directly through a differentiating capacitor. One of the two signals is inverted by IC-9C so the inputs of the crossing shaper gate are at opposite logic levels as shown.

As the crossing shaper inputs are always complementary, the output of this NOR gate is always a negative pulse (waveform H) when the gate receives an input pulse. The output negative pulse is applied to the reset inverter, IC-6B, causing a positive pulse at its output. This positive pulse is applied to the set input of the ramp-down latch, resetting it to its state prior to the beginning of time t_2.

The positive transition of waveform D is coupled to the reset inverter, IC-6B, where the pulse provides a 6 μs inhibit period to prevent a logical race condition at zero input.

The positive transition of waveform J, when the ramp-down latch is reset, causes transfer of the count to the display tubes, controls the overrange driver, and inhibits the clock oscillator for a short period.



DRIVING PULSE G
RAMP-DOWN LATCH RESET

Figure 4-10

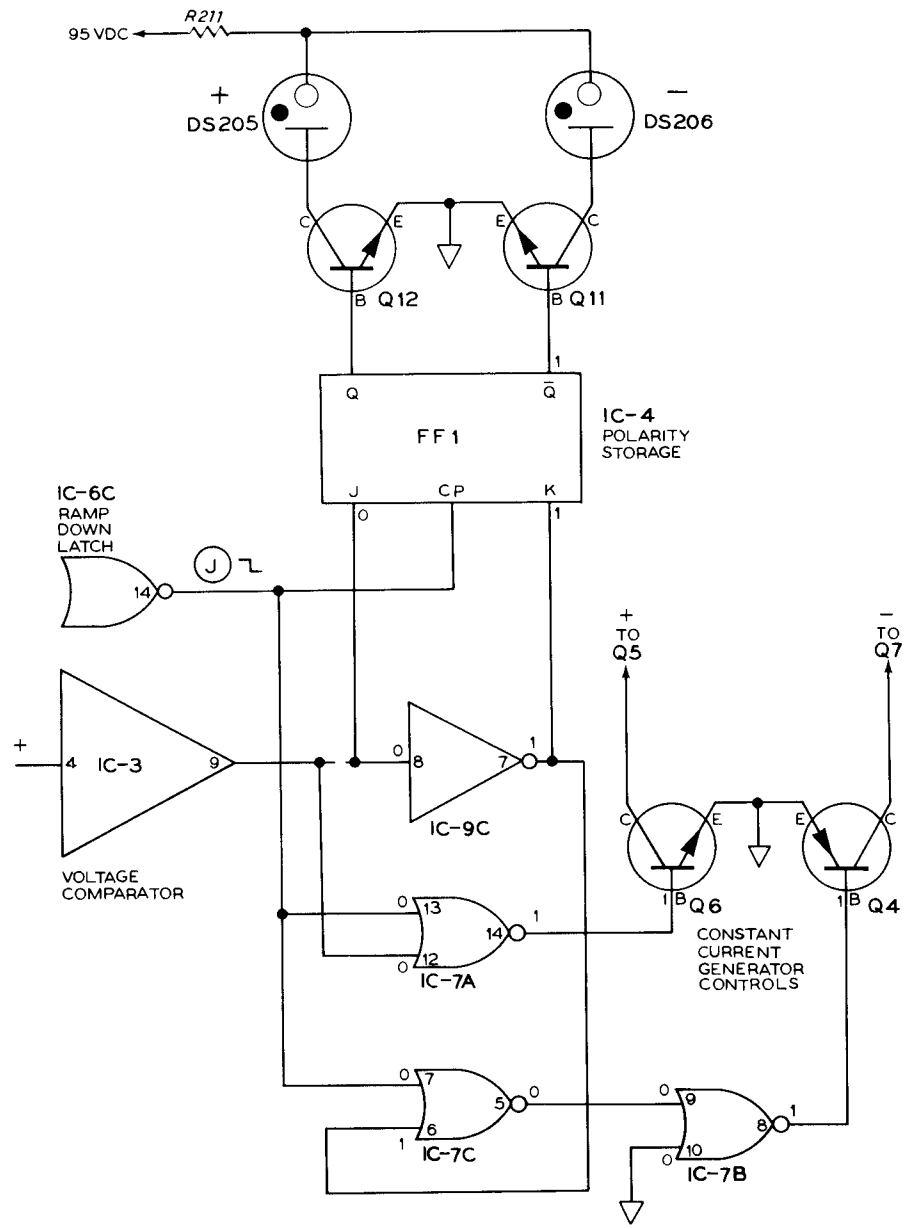


Figure 4-11

Polarity Determination

The logic 1 to 0 transition of waveform J (Figure 4-11) at the output of the ramp-down latch toggles the polarity storage flip-flop and causes its outputs to assume the polarities of its input signals. The output which is at logic 1 turns on its associated transistor, Q11 or Q12. This transistor grounds the circuit of its connected display tube and turns it on. The display tube will remain in this state as long as the polarity of the Multimeter input signal is unchanged.

IC-9C inverts the output of the voltage comparator. The J and K inputs to the polarity storage flip-flop are taken across the inverter and are therefore complementary. When the input signal is positive, the output of the voltage comparator is at logic 0 (waveform G, Figure 4-2). The output of inverter IC-9C is at logic 1 and is connected to the K input of the FF. When the pulse from the ramp-down latch is received at CP, the Q output (if not already in that state) will assume a logic 1. This logic 1 causes the base of Q11 to go high and turn on Q11. This completes the circuit to ground and the "+" display tube illuminates to show the positive polarity of the Multimeter input.

The logic 0 state of waveform J is connected to one input of IC-7A and one input of IC-7C. The logic 0 output of the voltage comparator is connected to the other input of IC-7A, and the logic 1 output of inverter IC-9C is applied to the remaining input of IC-7C.

The logic 1 output of IC-7A is connected to the base of Q6. The logic 0 output of IC-7C is inverted by IC-7B and connected to the base of transistor Q4. Note that Q4 is a PNP transistor whereas Q6 is an NPN device. The logic 1 at each base turns Q6 on and Q4 off. When one of these transistors is turned on, it will enable its associated constant current generator, Q5 or Q7, which will be of the proper polarity to discharge C108 during time t_2.

Buffer Storage

When waveform J goes high at the end of time t_2 (Figure 4-2), the ac coupling to inverter IC-9D causes a positive pulse (waveform K) which is shaped and inverted into a 1 μs negative pulse, waveform L. This low (logic 0) is applied to the gate inputs of storage registers IC-11, IC-14, and IC-17.

Prior to the receipt of the negative pulse, the storage register gates were high (logic 1) as shown in the truth table (Figure 4-12), and the outputs to the decoder-drivers maintained the state of the display tubes. When the negative pulse L is received and the gates go low, the outputs assume the same state as the respective inputs and the storage registers receive the accumulated counts of the DCU's developed during time t_2. As long as the negative pulse holds the gates low, the storage register will receive any carries which may have started prior to reset. Also, pulse L momentarily inhibits the clock oscillator to prevent any new pulses from entering the counter. At the termination of pulse L, the gates again go high and the outputs retain the states then present. The display tubes then remain constant until the end of time t_2 occurs again.

Note in Figure 4-2 that the negative transition of waveform J does not result in a pulse on waveform L as the input of the inverter (IC-9D) is already at logic 0 and the negative pulse has no effect.

TRUTH TABLE

GATE	I	Z	$\bar{Z}$
L	L	L	H
L	H	H	L
H	ANY	Q	$\bar{Q}$

H = HIGH
L = LOW
Q = THE STATE ASSUMED PRIOR TO "GATE HIGH" IS MAINTAINED.

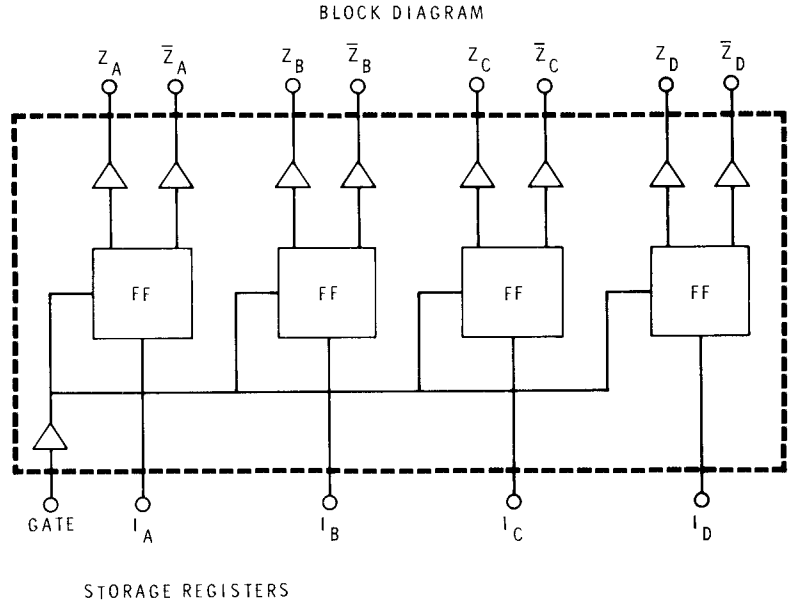


Figure 4-12

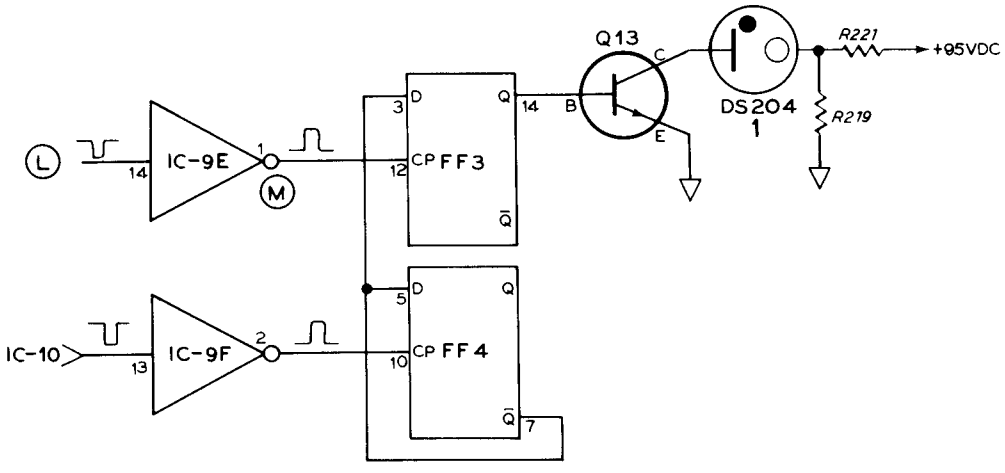


Figure 4-13

"1" Display

When the count during time t_2 exceeds 999, IC-10 will produce a negative pulse (Figure 4-13). This pulse will be inverted by IC-9F, to return to positive logic, and be applied to FF4. 8ecause all flip-flop inputs were zero at the beginning of the count, this clock pulse to FF4 will cause $\overline{Q}$ to assume a 1 state. This will force a 1 at the D input of FF3.

As described earlier, when the integrator crosses zero the ramp-down latch is reset and a chain of events causes negative waveform L. Waveform L is inverted by IC-9E to waveform M and is applied as a clock (transfer) pulse to FF3. This pulse at CP of FF3 causes the 1 at input D to be transferred to the Q output. This forces the base of transistor Q13 high, turning Q13 on. The circuit of tube DS204 is therefore grounded through Q13 and the tube is illuminated to display the digit "1".

Overrange Display

As shown in Figure 4-14, at the count of 8,000 (or 000 on the display lamps) pulse E will clear FF2. Therefore, while the count occurs during time t_2, the Q output of FF2 will be low and will hold transistor Q10 off. As Q10 is off, the Overrange lamp circuit is open and the lamp is off.

The vertical dashed line in Figure 4-2 indicates the end of time t_2 for a normal input (no overrange). This time is indicated by a Y on the waveform F line. At time Y, observe that waveform B is low. This is the Q output of FF5. The $\overline{Q}$ output will therefore be high as will the K input of FF2, which it is connected to. On the last count during time t_2, the K input of FF2 is high and the J input is low as it is tied to ground. As a result of the integrator having made a "zero crossing", pulse M is formed and it toggles FF2 which causes its Q output to assume a 0 state. See the truth table of Figure 4-14. Thus, the Overrange lamp is unlit; this is correct for a normal input.

Should the voltage input be too high for the Range switch setting, point X in Figure 4-2 will be higher above the zero voltage line of waveform F. The ramp-down discharge line will, for example, return to the zero voltage line at point Z.

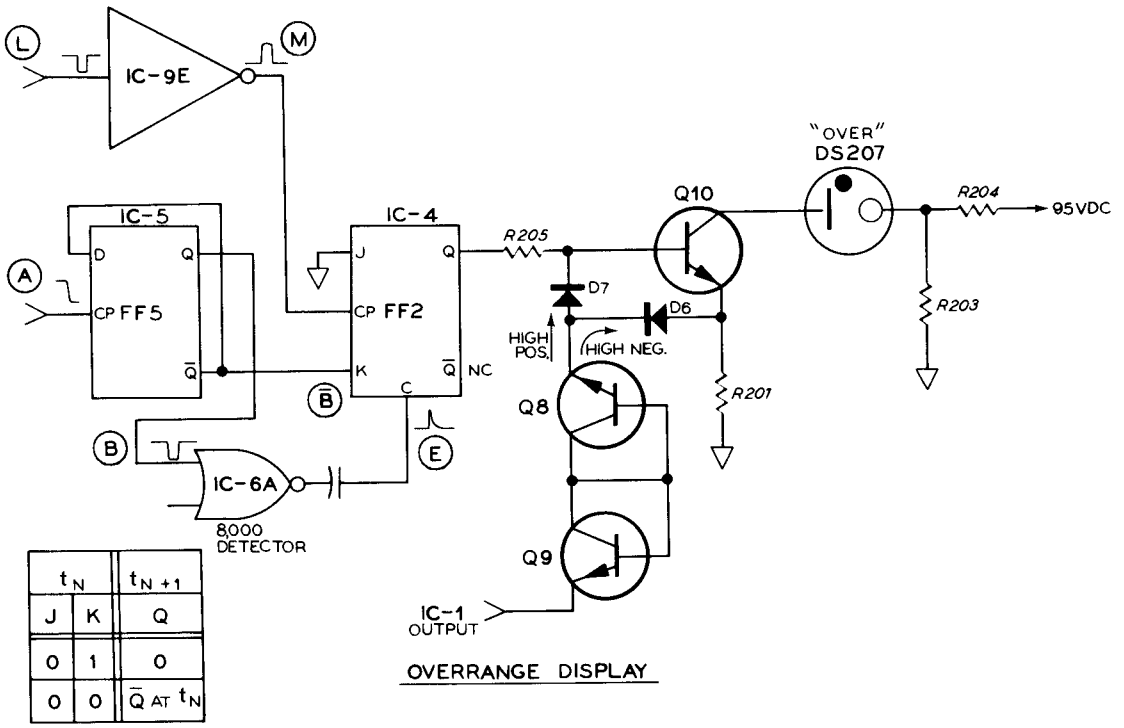


Figure 4-14

Figure 4-2 shows that waveform B will be high at this time, so waveform $\overline{B}$ and the K input of FF2 (Figure 4-14) will be low. As the $\overline{Q}$ output of FF2 was high (Q output low), toggle pulse M will cause a high at output Q because both the J and K inputs are low. The high at Q will force the base of transistor Q10 high and will turn on the transistor. This will complete the Overrange lamp circuit and the word "OVER" on the panel will be illuminated. This is correct for an overrange condition.

As also shown in Figure 4-2, the positive pulse of waveform K and the waveforms L and M are initiated by the zero crossing of the integrator output and will consequently be aligned with the point where the ramp-down line reaches the zero voltage line on waveform F.

Should the applied voltage, and consequently the Overrange, be so severe that the ramp-down line reaches the zero voltage line at a point to the right when waveforms B and C are both low, there would be a false indication by the Overrange lamp which would not be lighted under these circumstances.

If a high positive overrange occurs, the output voltage of IC-1 will overcome the threshold voltage of Q8 and Q9, which are connected as zener diodes, and cause diode D7 to conduct. This will force the base of transistor Q10 positive with respect to its emitter. The transistor will therefore turn on and cause the Overrange lamp to light. If a high negative overrange occurs, D6 will conduct and force the emitter of Q10 negative with respect to its base. The transistor will turn on and the Overrange lamp will light.

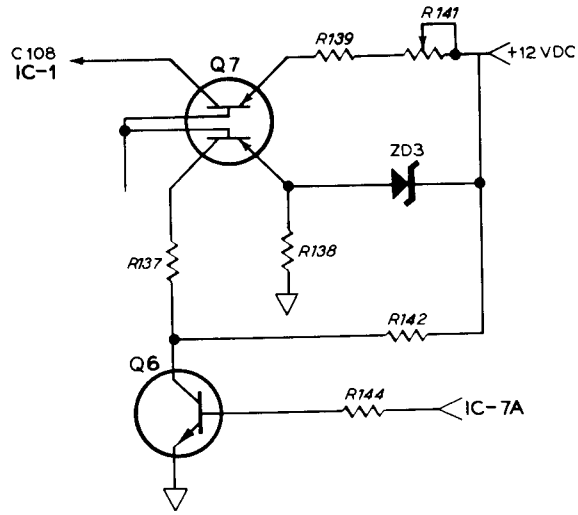


Figure 4-15

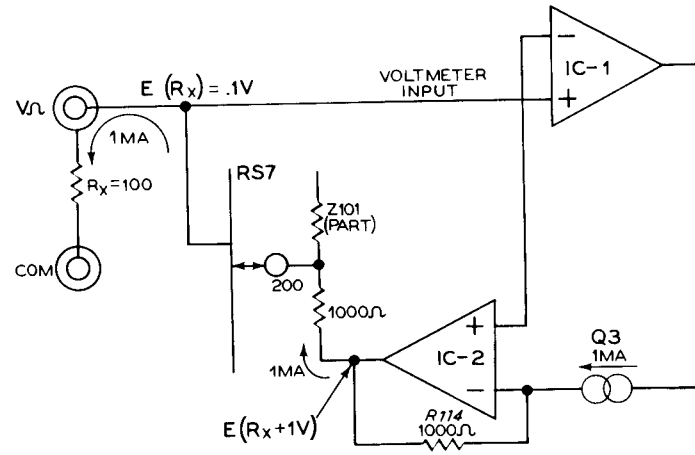


Figure 4-16

Constant Current Source

Each of the two reference current generators (one positive and one negative) consists of a common-base transistor constant current source. The positive source is shown in Figure 4-15.

Transistor Q7 is the constant current source and is controlled by the current in its emitters. The current is determined by resistors R139, R141, and zener diode ZD3. As the voltage drops across the two emitter-base junctions of Q7 tend to equalize, the emitter current will almost precisely equal the zener diode voltage divided by the sum of R141 and R142. The latter is variable to permit compensation for resistor and zener diode tolerance variations, and is adjusted during the calibration steps to provide a current of 400 μA.

Resistor R138 is provided to insure that ZD3 operates at a 7.5 mA point for best temperature stability. Resistors R137, R142, R144, and transistor Q6 provide the means to turn off the reference current source by turning off Q6 and biasing off Q7.

OHMS CONVERSION

Resistance is converted to a dc voltage by means of a current source according to the table below. The currents are scaled to produce full-scale voltages of +200 mV on the lower ohms ranges and 2 volts on the three highest ranges.

Range	Source	(Z101)	E (Rx) FS
200 Ω	1 mA	1 k	200 mV
2 k	100 μA	10 k	200 mV
20 k	10 μA	100 k	200 mV
200 k	10 μA	100 k	2 V
2 M	1 μA	1 M	2 V
20 M	100 nA	10 M	2 V

One volt is maintained across resistance divider Z101 on all ranges. As shown in Figure 4-16, constant current source Q3 applies 1 mA to the 1,000 ohm resistor, R114, which establishes the output of IC-2 at 1 volt above the output of IC-1. Assume R_x the unknown resistance to be measured, is 100 ohms. The 1 mA current from the constant current generator will now flow through 1,100 ohms (1,000 ohms + R_x) and a voltage drop of 1.1 volts will occur. One volt will have dropped across the 1,000 ohm portion of the voltage

divider, leaving .1 volt to appear as E (R_x). This voltage is connected to the non-inverting input of IC-1. The inverting input will equalize and the .1 volt will be fed back to the non-inverting input of IC-2. This voltage will add to the 1 volt that would be at the output of IC-2 if E were zero, and the voltage at that point will now be E (R_x) + 1 volt, or 1.1 volts across 1,100 ohm = 1 mA of current through the voltage divider.

The current through the voltage divider is now determined only by its own resistance, as shown in the "R scale" column in the table, and will be constant, independent of R_x. As negligible current is drawn by IC-1, the constant current will all flow through R_x to create the voltage to be measured.

Special design considerations for the 200 ohm range and the megohm ranges are discussed as follows:

200 Ohms

The nominal value of the resistance divider is 1,000 ohms. The input fuse, which provides overload protection, has about 3.5 ohms cold resistance which could introduce a scale error of 0.35%. The portion of the resistance divider marked 1,000 Ω is actually 996.5 ohms to compensate for the fuse resistance. Any variation in fuse resistance is not enough to force the instrument out of specification.

20 Megohms

The 20 MΩ range makes use of a 10 megohm scaling resistor to produce a 100 nA current source. Higher currents would force E (R_x) to unacceptable values. The 100 nA is not all available to R_x as up to 10 nA of bias current can be drawn by the input of IC-1. To compensate for this drain, the 10 megohm scaling resistor must be reduced and a range of 9 megohms to 10 megohms can be provided by adjustment of a 1 megohm variable resistor, R103.

2 Megohms

The 2 MΩ range, operating on a 1 μA current source, is susceptible to bias current effects to the extent of 1% of the reading. This small error does not warrant a compensation control, but the scaling resistor is decreased from 1 megohm to 966 kΩ to allow for an average value of bias current. Thus the 2 megohm range remains within specifications.

Input overload protection is provided on the 200 Ω and 2 kΩ ranges by fuse F101 and a clamp network (Figure 4-17). When switch RS10 is in the 200 or 2K position, it connects the input to the junction of diodes D1 and D3, the inputs for the negative and positive polarity clamp circuits. Assuming a .6 volt threshold voltage drop across diode D4, 11.4 Vdc will be dropped across R101; diode D3 will be back-biased by .6 volt. Consequently, if a positive voltage of more than 1.2 volts is applied to D3 (.6 volt threshold + .6 volt bias), the diode will conduct. D4 is already conducting and a bypass to ground is therefore provided.

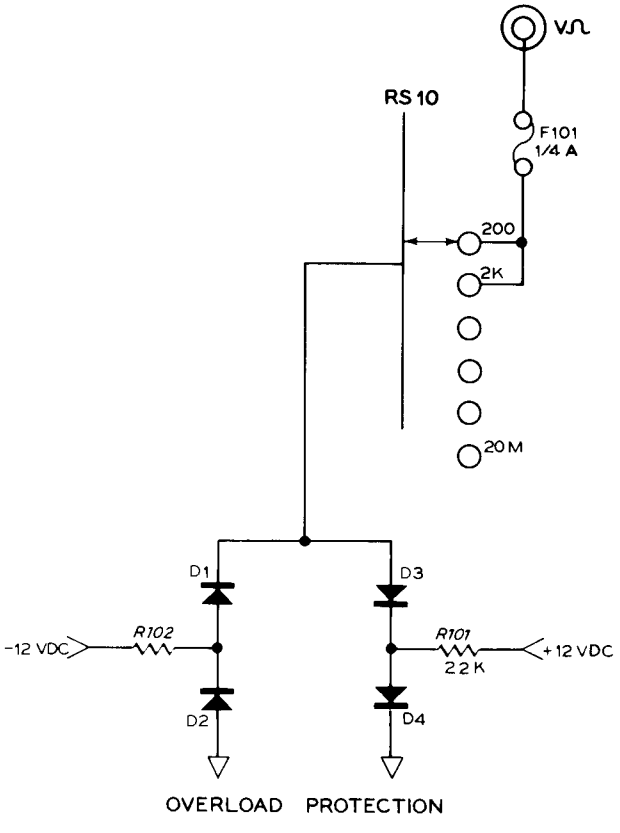


Figure 4-17

CURRENT CONVERSION (Figure 4-18)

Direct current is converted to voltage by passing the current through a series of 0.1% precision resistors arranged in decade steps such that the full scale shunt voltage between the switch tap and circuit ground will always be 200 millivolts. Function switch wafer #1 directs the developed voltage to the non-inverting input of IC-1.

On the highest current range, accuracy is maintained by using a four-terminal Kelvin connection for the 0.1 ohm resistor. Heavy currents in resistor leads which could cause small voltage drops and result in measurement errors are thus minimized.

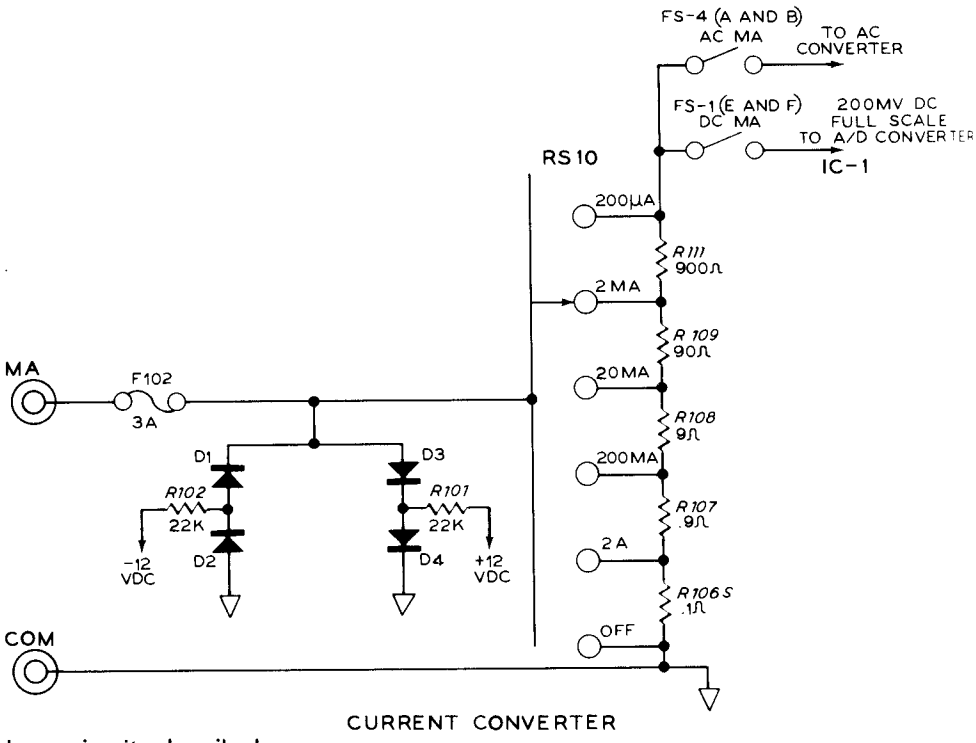


Figure 4-18

A 3-ampere fuse, F102, and the clamp circuits described under "2 Megohms" protect the shunts in the five resistance ranges from damage due to excessive current.

The above description applies to ac currents except that the 200 millivolt output of RS10 is fed by wafer #4 of the Function switch to the ac converter board before being applied to IC-1.

AC CONVERTER

AC Volts

In the ac volts position of the Function switch, the ac input signal is routed to C422 by contacts C and D of FS3 as shown in Figure 4-19. This switch controls the ac input circuit to protect the ac converter from high dc input voltages which might be accidentally applied if a single switch were used for both ac and dc volts. C422 blocks any dc components of the input signal.

Switch RS4 is followed by a stepped attenuator with taps at 1/100 and 1/1000 of the 1 megohm resistor string. Frequency compensation is provided by three fixed and two variable capacitors. These are large enough to swamp out the effects of switch and stray capacities. Signals on the 200 millivolt and 2 volt ranges are switched around the attenuator by RS4 and RS3 to the buffering circuit which drives IC-19, the operational amplifier.

Signals larger than 2 volts pass through the attenuator where the combined switching action of RS4 and RS3 taps off signals on the 20 and 200 volt ranges at 1/100 of their input value, and signals on the 1,000 volt range at 1/1000 of their input value. Thus, signals larger than 2 volts are reduced to full-scale values of 200 millivolts or 2 volts.

Should excessive voltages be accidentally applied, resistor R402 will first greatly reduce the voltage. Then diode D16 or D17 will conduct (according to the signal polarity) and the excess voltage will be grounded through diode ZD4 or ZD5 in the power supply.

divider, leaving .1 volt to appear as E (R_x). This voltage is connected to the non-inverting input of IC-1. The inverting input will equalize and the .1 volt will be fed back to the non-inverting input of IC-2. This voltage will add to the 1 volt that would be at the output of IC-2 if E were zero, and the voltage at that point will now be E (R_x) + 1 volt, or 1.1 volts across 1,100 ohm = 1 mA of current through the voltage divider.

The current through the voltage divider is now determined only by its own resistance, as shown in the "R scale" column in the table, and will be constant, independent of R_x. As negligible current is drawn by IC-1, the constant current will all flow through R_x to create the voltage to be measured.

Special design considerations for the 200 ohm range and the megohm ranges are discussed as follows:

200 Ohms

The nominal value of the resistance divider is 1,000 ohms. The input fuse, which provides overload protection, has about 3.5 ohms cold resistance which could introduce a scale error of 0.35%. The portion of the resistance divider marked 1,000 Ω is actually 996.5 ohms to compensate for the fuse resistance. Any variation in fuse resistance is not enough to force the instrument out of specification.

20 Megohms

The 20 MΩ range makes use of a 10 megohm scaling resistor to produce a 100 nA current source. Higher currents would force E (R_x) to unacceptable values. The 100 nA is not all available to R_x as up to 10 nA of bias current can be drawn by the input of IC-1. To compensate for this drain, the 10 megohm scaling resistor must be reduced and a range of 9 megohms to 10 megohms can be provided by adjustment of a 1 megohm variable resistor, R103.

2 Megohms

The 2 MΩ range, operating on a 1 μA current source, is susceptible to bias current effects to the extent of 1% of the reading. This small error does not warrant a compensation control, but the scaling resistor is decreased from 1 megohm to 966 kΩ to allow for an average value of bias current. Thus the 2 megohm range remains within specifications.

Input overload protection is provided on the 200 Ω and 2 kΩ ranges by fuse F101 and a clamp network (Figure 4-17). When switch RS10 is in the 200 or 2K position, it connects the input to the junction of diodes D1 and D3, the inputs for the negative and positive polarity clamp circuits. Assuming a .6 volt threshold voltage drop across diode D4, 11.4 Vdc will be dropped across R101; diode D3 will be back-biased by .6 volt. Consequently, if a positive voltage of more than 1.2 volts is applied to D3 (.6 volt threshold + .6 volt bias), the diode will conduct. D4 is already conducting and a bypass to ground is therefore provided.

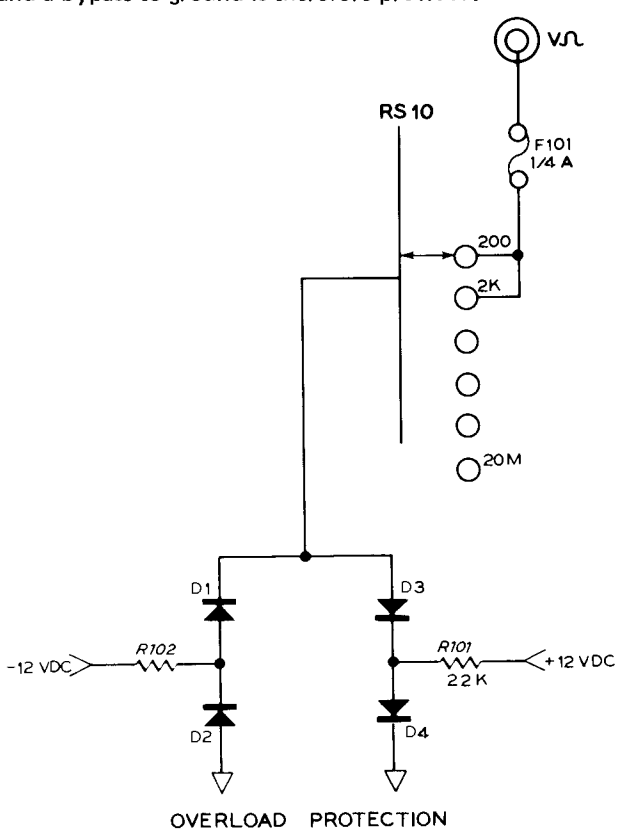


Figure 4-17

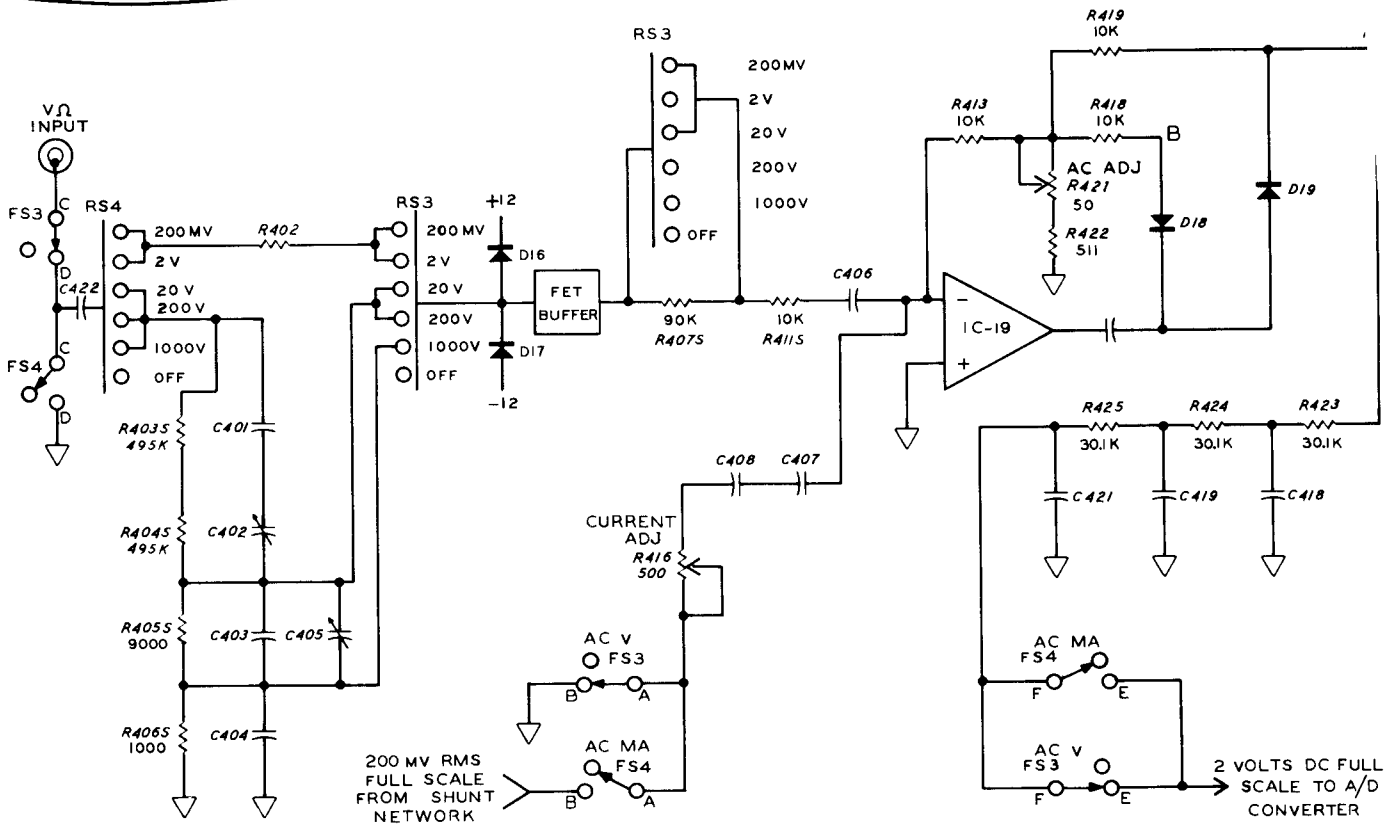


Figure 4-19

An FET/bipolar buffer circuit provides high input impedance and low output impedance at approximately unity gain. The output of this circuit passes through a switched input network for the operational amplifier, IC-19. RS3 bypasses signals on the 200 mV and 20 volt ranges around 90 kΩ resistor R407S to R411S. Signals on the remaining ranges pass through R407S and R411S, a total of 100 kΩ. The switching action and resistance networks combine to maintain a full scale input current of 20 μA for IC-19.

The input signal is applied to the inverting input of IC-19 which provides gain. A positive half cycle input produces a negative rectified half-wave at point B, and a negative input half cycle produces a positive rectified half-wave at point A. The feedback ratio is adjustable to provide a peak output voltage of 6.28 volts for a 20 μA input signal.

The rectified half-wave at point A is filtered by a three section low pass filter designed to minimize ripple and avoid excessive response-time delays. The impedance presented by the low pass filter to the A/D converter is 100 kΩ to maintain the source impedance balance required by the A/D converter for good zero stability.

The output of the ac converter in the ac volts mode is returned to the integrator, IC-1, through contacts E and F of FS3.

AC Current

When the Function switch is placed in the AC mA position, contacts A and B of FS4 connect the 200 mV rms output of the shunt network used for current conversion (Figure 4-18) to control R416 on the ac converter circuit board. This control is used to adjust the current input to 20 μA at full scale and it takes into account the high source impedance of the shunt network. The input voltage bypasses the input attenuator and the buffer circuitry and is connected directly to IC-19 and its associated circuitry. The dc output is connected back to the integrator through contacts E and F of FS4.

To prevent undesirable interaction and pickup of spurious signals, the ac volts input of the ac converter is grounded by contacts C and D of FS4 when the Function switch is in the AC mA position.

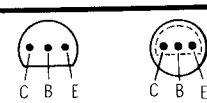
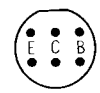
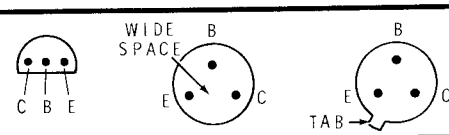
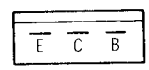
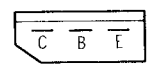
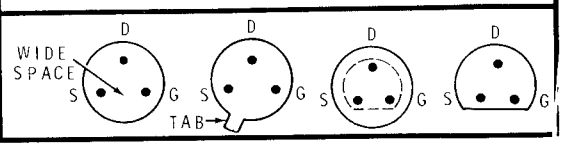
IDENTIFICATION CHARTS

INTEGRATED CIRCUITS

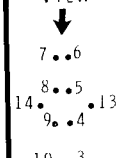
IC NUMBER	HEATH PART NUMBER	MANUFACTURER'S NUMBER	TYPE	REFER TO FIGURE
1	442-35	SL11862	Operational amplifier	A
2, 19	442-23	TOA8709	Operational amplifier	B
3	442-3	SN72710	Differential comparator	D
4	443-48	MC776P	Dual JK FF	E
5, 8	443-49	MC778P	Dual type D FF	E
6	443-8	MC724P	Quadruple NAND/NOR GATE	C
7	443-21	MC717P	Quadruple NAND/NOR GATE	C
9	443-14	MC789P	Hex inverter	E
10, 13, 16	443-28	CμL9958	DCU	F
11, 14, 17	443-29	CμL9959	Buffer storage	G
12, 15, 18	443-92	MC9860P	Decoder driver	H

*NOTE: Refer to the MAX (maximum) and MIN (minimum) voltages in Figures F, G, and H. These are voltages which the device will always recognize. For example, in Figure F a voltage of +1.2 or higher will always be recognized by the IC as a "high," and a voltage of +.45 or lower will always be recognized as a "low."

TRANSISTORS

Q DESIGNATION	HEATH PART NUMBER	MFGR. OR TYPE NUMBER	BASE VIEW
Q1, Q2	417-271	SPS1317	
Q3, Q6, Q8, Q9, Q15	417-67	2N2712	
Q4, Q18	417-201	X29A829	
Q5	417-191	TD101	
Q7	417-261	TD401	
Q10, Q11, Q12, Q13	417-173	ETS083	
Q14	417-175	2N5294	
Q16	417-272	D40C1	
Q17	417-140	2N4304	

DISPLAY TUBES

V201, V202, V203	411-264	NATIONAL ELECTRONICS NL905S OR BURROUGHS 3-5859S	BASE VIEW 

PIN	CONNECTION
1	NUMERAL 1
2	NUMERAL 2
3	NUMERAL 3
4	NUMERAL 4
5	NUMERAL 5
6	NUMERAL 6
7*	ANODE
8	NUMERAL 7
9	NUMERAL 8
10*	ANODE
11	NUMERAL 9
12	NUMERAL 0
13	RT. DEC. PT.
14	LFT. DEC. PT

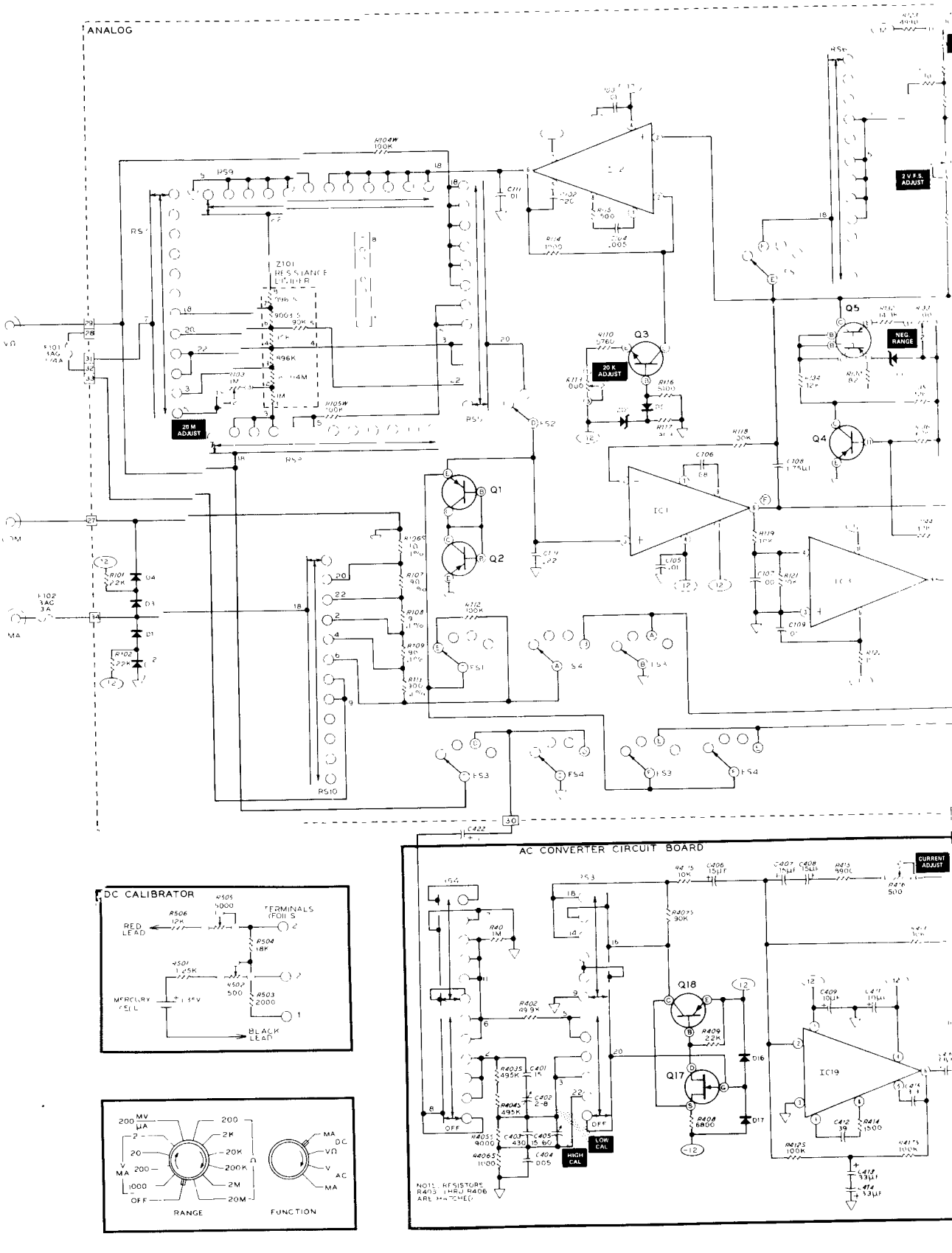
* CONNECTED INTERNALLY

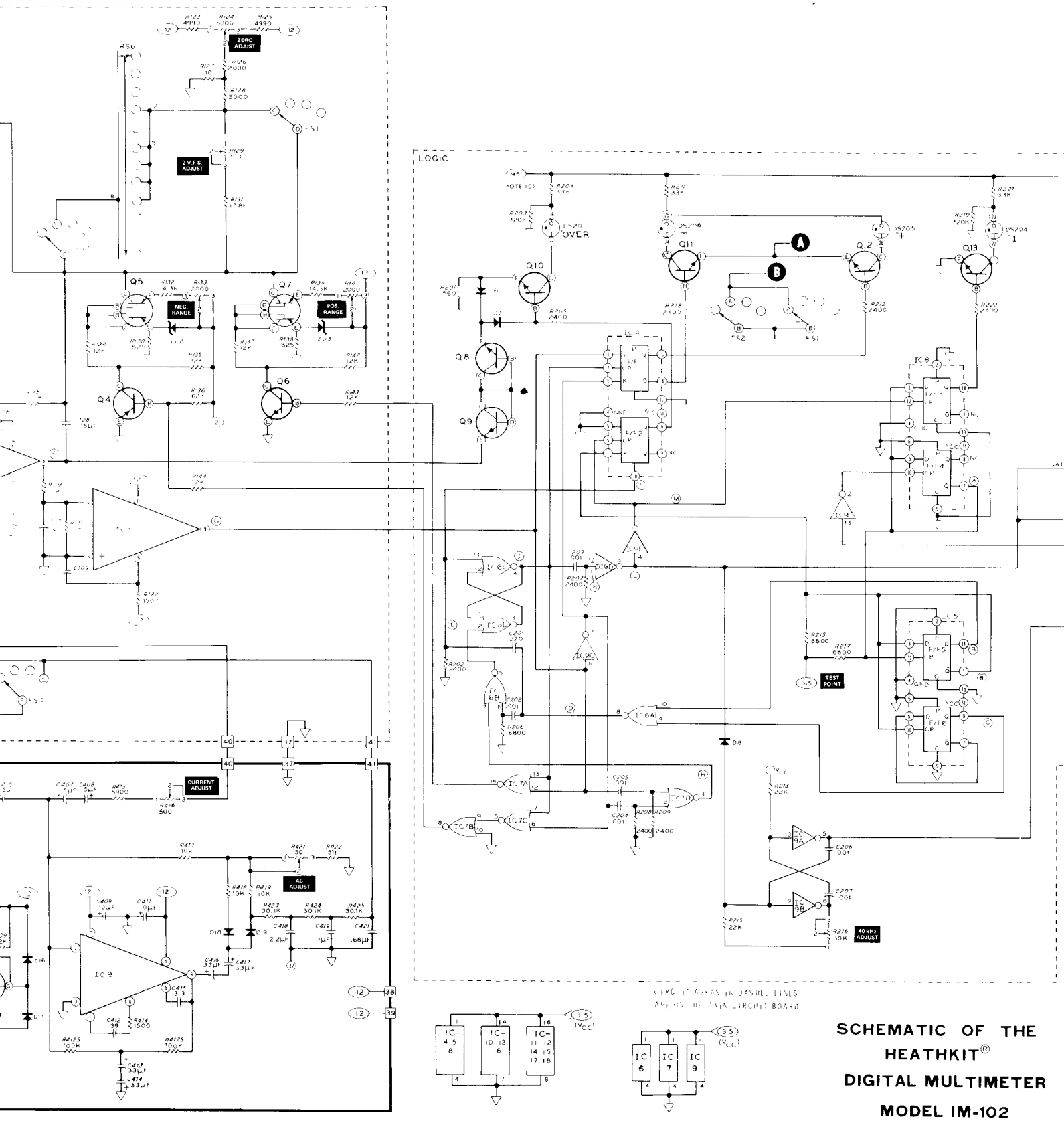
DIODES

SCHEMATIC NUMBER	HEATH PART NUMBER	MANUFACTURER'S TYPE NUMBER	ZENER VOLTAGE
Zener Diodes			
ZD1	56-91	1N823	6.2
ZD2, ZD3	56-71	1N825A	6.2
ZD4, ZD5	56-90	1N4742A	12.0
ZD6*	56-59	1N750A	4.7
Other Diodes			
D1, D3,	57-71	S-5A05**	
D10, D11, D12, D13	57-65	1N4002	
D14, D15, D9	57-27	1N2071	
D5	56-28	See note**	
D6, D7	56-78	FH6259	
D8	56-26	1N191	
D16, D17	56-93	FD333	
D18, D19	56-87	FH1100	
D2, D4	57-42	3A1	

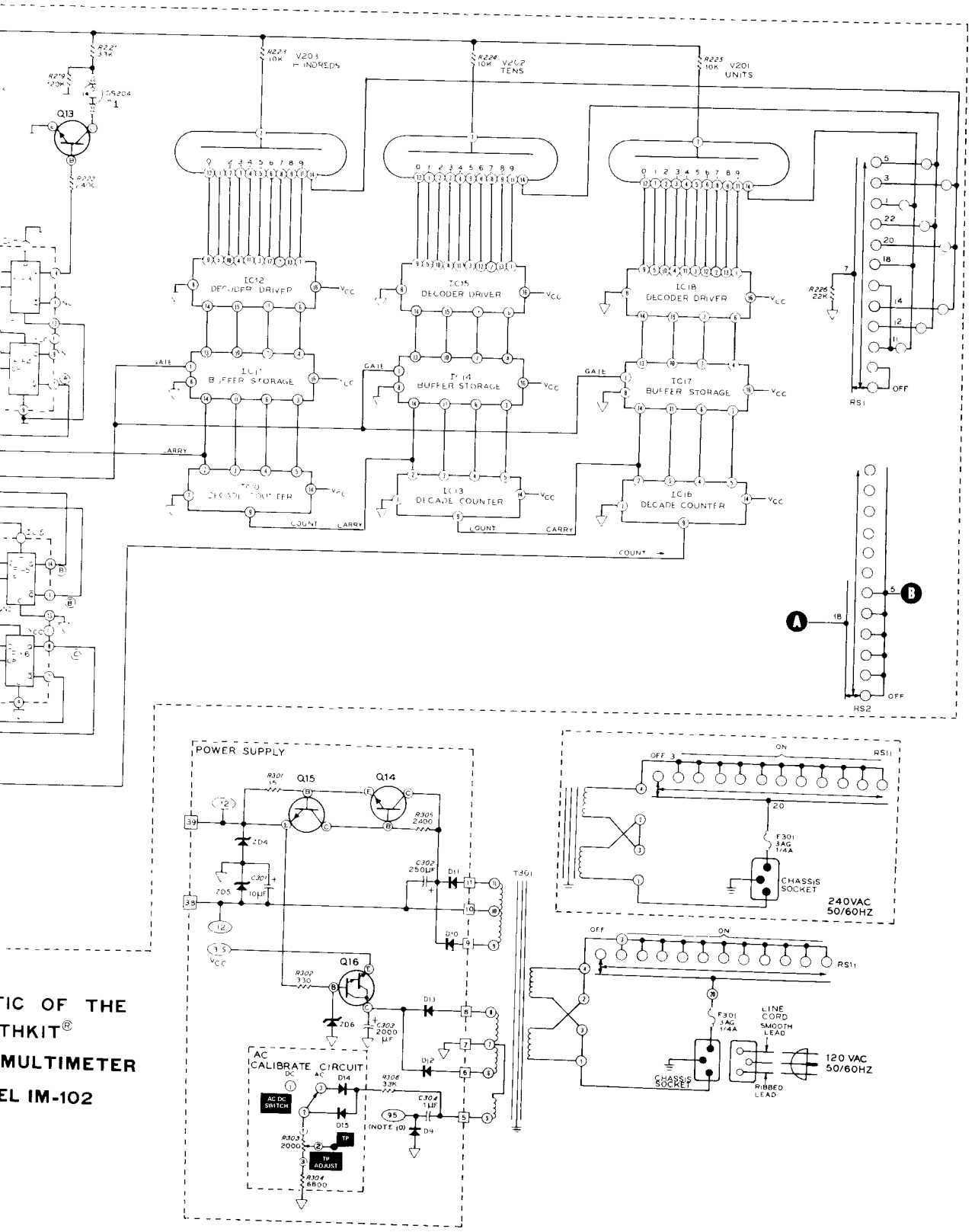
*Colored violet-green-black-brown.

**NOTE: Manufactured to Heath Company specifications.


ANALOG
2 V F.S. ADJUST
NEG. RANGE
20 K ADJUST
20 M ADJUST
Z101 RESISTANCE LINEARIZER
Q1
Q2
Q3
Q4
Q5
IC1
IC2
IC3
RS1
RS2
RS10
FS1
FS2
FS3
FS4
S1
S2
S3
S4
D1
D2
D3
D4
VΩ
MA
AC CONVERTER CIRCUIT BOARD
CURRENT ADJUST
Q18
Q17
IC19
D16
D17
HIGH CAL
LOW CAL
OFF
DC CALIBRATOR
RED LEAD
BLACK LEAD
TERMINALS
MERCURY CELL
RANGE
FUNCTION



SCHEMATIC OF THE HEATHKIT® DIGITAL MULTIMETER MODEL IM-102



TIC OF THE
THKIT®
MULTIMETER
EL IM-102