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PRECISION MEASUREMENT EQUIPMENT LABORATORY SPECIALIST

(AFSC 32450)

Volume 2

AC/DC Electrical Measurement Standards/TMDE

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Preface

THIS VOLUME of your CDC is entitled AC/DC Electrical Measurement Standards/TMDE. Chapter 1 of this volume deals with instruments which comprise the electrical standards console and its application in a PME laboratory. In Chapter 2 you will cover AC voltage standards, DC voltage standards, and power supplies. Chapter 3 will introduce you to the instrument calibrators used in most laboratories today, and in Chapter 4 you will cover the different types of meters you are likely to encounter in the field.

Foldouts 1 through 7 are bound separately as a supplement.

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Acknowledgement

INFORMATION and illustrations used to support the material on the electrical standards console were adapted from manuals prepared by the companies listed below:

Electro Scientific Industries.

Leeds and Northrup Company.

COHU Electronics.

Information and illustrations used to support the material on Model 332( )DC Voltage Standard, Instrument Calibrator, and Model 5200A/5205A AC Calibrator were adapted from instruction manuals prepared by John Fluke Company.

Contents

Electrical Standards Console and Accessories

YOUR PROFICIENCY advancement in the ''resistance, capacitance, and inductance'' area of your AFS will be much easier if you understand what the electrical standards console is supposed to do and how it is operated. In this section, you will learn about the standards for resistance, capacitance, and inductance currently used by the Air Force and the techniques and theory employed when using these items.

1-1. DC Section Components

The electrical standards console is an instrument that you can use to calibrate certain airbase standards included in the PME laboratory inventory. The standards will include such items as decade capacitors, decade resistors, decade dividers, ratio transformers, inductors, and RCL bridges.

PME laboratories that have added the electrical standards console to their inventory have the capability to raise the average accuracy level of standards used in low-frequency AC and DC electrical measurement. If this console has been added to your PME laboratory, many of the base standards that you have been sending to higher echelon laboratories for calibration will be calibrated in your base laboratory.

The electrical standards console consists primarily of a DC section, an AC section, a power supply section, and a section which includes auxiliary components used with the console. An explanation of individual components of each section and the interrelationships of components and sections will be given. As the title implies, the DC section of the console will be used in measurement of DC voltage, current, and resistance. The DC section is composed basically of a power supply (generator) and detector, a four-terminal ratio bridge, a four-terminal resistance decade, a seven-place Kelvin-Varley divider, and a lead compensator.

200. State the purpose of the guard circuit in the Model ESI 801 DC generator.

DC Section Components. The ESI Model 801 is a DC generator and null detector (microvoltmeter). The instrument features double-chassis construction, or guarding, to greatly reduce stray leakage paths to ground. Leakage from the high generator and the high detector terminals to ground has been virtually eliminated. Insulation of the other terminals is kept at 10^{11} ohms or greater.

The output of the generator is continuously variable and is limited to a maximum of 1 watt into a matched load. A front panel control selects six output impedance ranges to match loads from 1 ohm to 100 kilohms.

An active circuit line regulator reduces the effect of line transients by a factor of more than 10. Unique guarded relays that control generator power allow remote operation of the generator. In this way, an operator can control the generator with a foot switch, or the instrument can be operated by automatic equipment. The generator output terminals are short-circuited when the generator is turned off. This short-circuiting inhibits transient pulses at the instant of turn-on.

The detector features a very sensitive modulator-type DC amplifier. Trouble caused by stray AC pickup from the device under test is greatly reduced by a rejection filter. The modulator operates above the AC line frequency, thus further reducing the AC pickup.

The double-chassis construction and complete integrity of guarding allow either the detector or the generator to be floated more than 600 volts above ground.

The unique design features of the Model 801 make it suitable to a number of applications:

(1) Very high resistance bridge measurements can be made with superior accuracy because of the special guarding and shielding features, and because of line transient reduction.

(2) Very low resistance bridge measurements can also be made with high accuracy because of the detector sensitivity and the provision for matching the generator to the load.

(3) The same features apply to make the 801 an ideal generator-detector combination for calibrating precision voltage dividers. A detailed description of this application may be found in ESI's ''Design Ideas,'' Volume 1, number 1.

(4) The 801 can be used directly to measure extremely low conductance (high resistance).

(5) The 801 generator can be used separately wherever a variable, guarded, and power-limited DC supply is needed.

(6) The 801 detector can be used separately as a voltmeter or microvoltmeter with ranges up to 1000 volts.

Exercises (200):

1. What is the purpose of the 801 guard circuit?

2. How is the stray AC pickup from the device under test reduced?

201. Specify the operational characteristics of the ESI 801 generator.

Generator Theory of Operation. The 801 generator is a line-regulated, guarded DC power supply with variable output power and a provision for matching the output impedance to a wide range of values. The guarding of the generator makes accurate high-resistance bridge measurements possible.

In the unguarded circuit shown on the left in figure 1-1, the leakage impedances Z_2 and Z_3 appear in parallel with bridge arms A and B. If these were high-resistance arms, an appreciable error would result. The leakage impedance Z_1 is also in parallel with each of arms A and B. Since this leakage is at a higher emf than those at the terminals, it will cause even more error.

The 801 generator uses the guarded circuit shown on the right in figure 1-1. Z_1 and Z_3 appear in parallel with the generator, and cause no trouble. Z_2 is kept to better than 10^{11} ohms by use of high quality insulators, both as a feed-through insulator for the low terminal and as support insulators for the guard chassis. By keeping bridge arm B (or whatever resistance is attached to the low terminal) small relative to 10^{11} ohms, no appreciable error is experienced. The guarding also keeps any AC voltage across Z_1 from getting into the detector via bridge arms A and B, since this AC voltage is returned to the low terminal.

The primary of the power transformer is separately shielded and air-insulated from the core to prevent capacitive coupling and leakage of AC voltages to the guard chassis. If an AC voltage were present on the guard chassis, it would appear from the low output terminal to ground and, thus, directly across the bridge arm B (fig. 1-1) in bridge measurements. The AC would then appear on the detector and would cause an error in null reading. The separate shielding of the transformer is connected to ground to prevent this error.

The generator is line-operated and has a solid-state line voltage regulator. The input voltage, which may be 115 volts or 230 volts AC, is increased (if necessary) by the input transformer to 230 volts. This voltage is clipped by the line regulator to 115 volts, which is applied to a continuously variable autotransformer. The autotrans-former former output is applied to a high-isolation guarded transformer which supplies power to the rectifier and filter networks. Filtered DC is supplied to the output terminal through various resistances. The resistance and output voltages are selected by the generator RANGE selector. Each voltage and resistance combination is calculated to allow no more than 1 watt in any measurement circuit connected to the generator terminals.

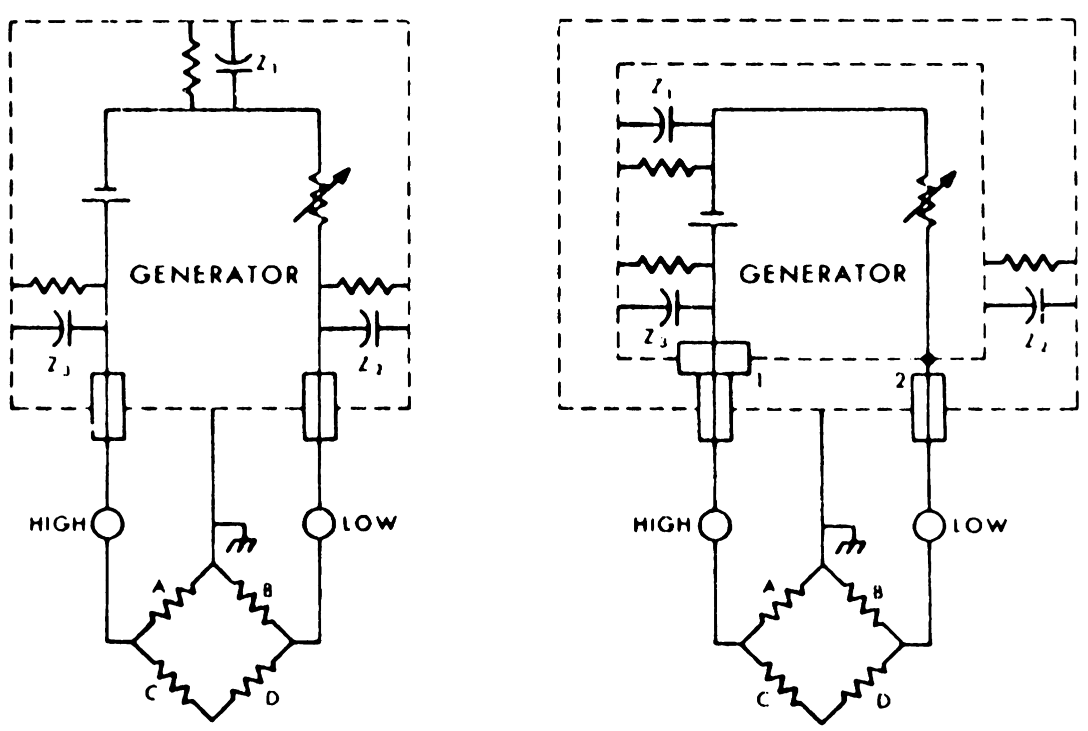


Figure 1-1. Generator circuits.

Exercises (201):

1. Does the 801 generator have a fixed or variable output?

2. Why is the primary of the power transformer shielded and air-insulated from the core?

3. What is the power input requirement for the 801 generator?

202. Specify the operational characteristics of the ESI detector.

Detector. The detector of the Model 801 is a high-sensitivity solid-state DC voltmeter. It has the following basic circuits: (1) an input attenuator, (2) a modulator and demodulator, (3) an AC amplifier, (4) a DC amplifier, (5) a meter, and (6) a feedback control circuit. Figure 1-2 is a block diagram of the detector.

A DC voltage measured by the detector is applied to the input attenuator, which is a resistive divider operated by the RANGE switch. Table 1-1 lists the attenuation factors for each range.

The DC output of the input attenuator is modulated by the modulator, which consists of two photocells that are alternately illuminated by two neon lamps. The output of the modulator is a square wave with an amplitude that is proportional to the amplitude of the DC input voltage.

The square wave output of the modulator is amplified by a six-stage, high-gain AC amplifier. The output of the AC amplifier is applied to the demodulator. The demodulator output is a DC voltage with an amplitude proportional to the square-wave output of the AC amplifier. The output of the demodulator is applied to a three-stage DC voltage and power amplifier. The gain provided by the AC and DC amplifiers is listed for each range in table 1-1.

The output of the DC amplifier, approximately 1 volt full scale, is applied to the meter and to the OUTPUT terminals on the front of the panel.

The feedback control circuit consists of a resistive voltage divider controlled by the range switch and a sensitivity control. When the SENSITIVITY control is in the CALIBRATED position, it is disconnected, and only the voltage divider has any effect. The feedback provided by the feedback control circuit with SENSITIVITY at CALIBRATED is listed for each range in table 1-1. Subtracting the feedback from the open-loop gain gives the closed-loop gain. The closed-loop gain, in conjunction with the input attenuation factor, provides 18 calibrated full-scale ranges from 3 microvolts to 1000 volts. When the SENSITIVITY control is not in the CALIBRATED position, it reduces the feedback and thus increases the closed-loop gain. By thus reducing the feedback, the sensitivity of the detector can be increased to about four times the calibrated sensitivity.

Exercises (202):

1. What is the output of the DC amplifier?

2. What is the modulator made up of?

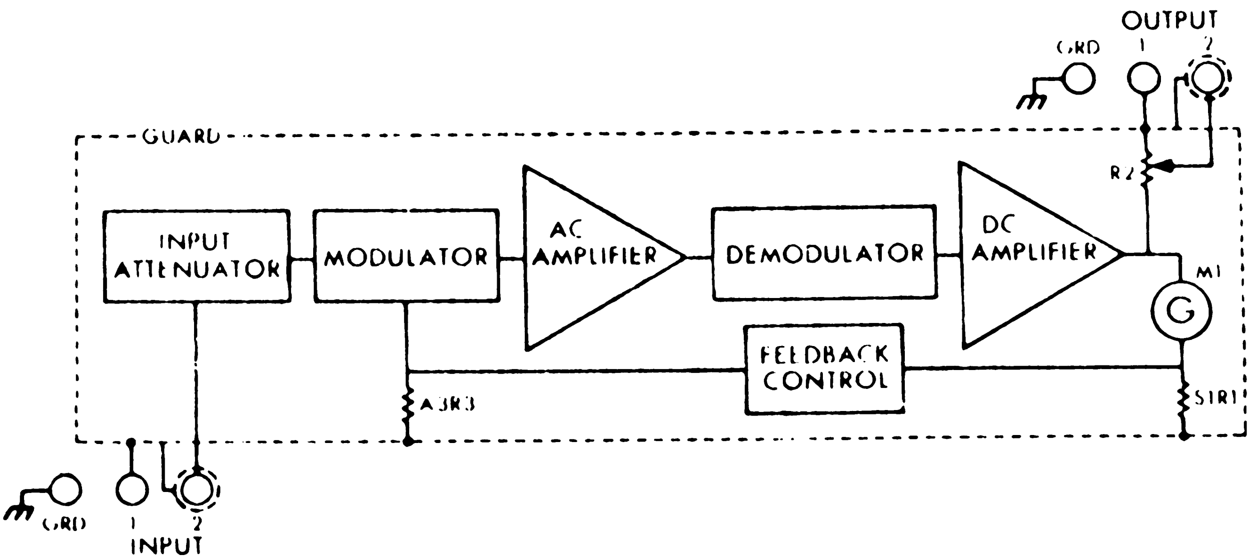


Figure 1–2. Detector block diagram.

TABLE 1-1
AMPLIFIER CHARACTERISTICS

RANGE	ATTENUATION FACTOR	OPEN LOOP GAIN	FEEDBACK
3 μV	1:1	150 dB	40 dB
10 μV	1:1	150 dB	50 dB
30 μV	1:1	150 dB	60 dB
100 μV	1:1	150 dB	70 dB
300 μV	1:1	130 dB	60 dB
1000 μV	1:1	130 dB	70 dB
3 mV	1:1	120 dB	70 dB
10 mV	10:1	120 dB	60 dB
30 mV	10:1	120 dB	70 dB
100 mV	10^2:1	120 dB	60 dB
300 mV	10^2:1	120 dB	70 dB
1000 mV	10^3:1	120 dB	60 dB
3 V	10^3:1	120 dB	70 dB
10 V	10^4:1	120 dB	60 dB
30 V	10^4:1	120 dB	70 dB
100 V	10^5:1	120 dB	60 dB
300 V	10^5:1	120 dB	70 dB
1000 V	10^6:1	120 dB	60 dB

3. What results take place when the sensitivity control is not in the CALIBRATED position?

203. Compare the Kelvin ratio bridge with the Wheatstone bridge as to reduction of errors.

Kelvin Ratio Bridge. The Kelvin-Varley principle is applied when two nearly equal resistances are compared. The panel controls for the Kelvin ratio bridge used with the electrical standards console are shown in figure 1-3.

The ratio bridge operates with a special lead compensator, which is an integral part of the instrument, and a resistance standard such as the model RS925 decade resistance. The controls used for lead compensation are identified in figure 1-3. Their functions will be explained later. The terminals used for connecting the standard resistance to the bridge are also identified in figure 1-3. Once the instrument has been mounted in the console rack, the leads which connect these terminals to the decade resistance standard will remain connected.

The Model 240 Kelvin ratio bridge is a modification of the Kelvin double bridge which was originally designed to measure resistances of very low values with greater accuracy than the Wheatstone bridge. Although the Kelvin double bridge is similar in construction and principle to a Wheatstone bridge, it differs in that the error introduced by contact resistance encountered in a Wheatstone bridge measurement is reduced to an absolute minimum. This error reduction is made possible by the use of four-terminal connections (as compared with two-terminal connections) and by the use of a yoke (fig. 1-4).

The bridge in figure 1-4,B is basically the same as the simple Wheatstone bridge illustrated in figure 1-4,A. If the bridge and power supply of figure 1-4,A, were rotated 90° in a counterclockwise direction, it would be easy for you to see that except for the arrowhead and the yoke in the bridge of figure 1-4,B, the Wheatstone bridge in the figure 1-4,A, is basically the same as the Kelvin bridge of the figure 1-4,B. A variation of the Kelvin bridge, called the Kelvin double bridge, is illustrated in figure 1-4,C.

Exercises (203):

1. What errors commonly found in Wheatstone bridge measurements are reduced by the use of a Kelvin bridge?

2. How does the construction of the Kelvin bridge accomplish this error reduction?

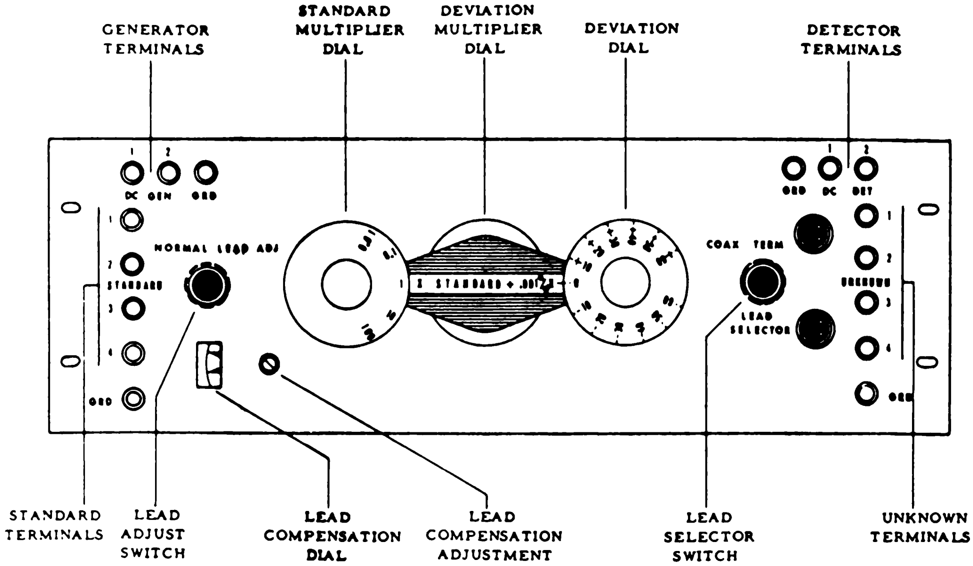


Figure 1–3. Kelvin ratio bridge panel.

204. From a given diagram, compute resistor values under conditions of shorting and nonshorting.

Standard Multiplier Controls. The standard multiplier control shown in figure 1-3 can produce ratios of 0.01:1, 0.1:1, 1:1, 10:1, and 100:1, as indicated on the dial, by positioning the multiplier wiper as shown in figure 1-5.

In figure 1-5, you can see that if the wipers are positioned as indicated, the 90k and 900k resistors are shorted out, and the total resistance from A to C or from B to D is 10k. This means that the ratio of AC/CE or DB/DF is 10k/10k, or 1:1. At this time, the standard multiplier control will be in the 1 position. If the wipers are moved to the positions indicated as X in figure 1-5, the resistance shorted will now be 900k, and the total resistance A to C or B to D is 100k. This means that the ratio of AC/CE or BD/DF is now 100k/10k, or 10:1. At this time, the standard multiplier control will be in the 10 position. The additional ratios 0.01:1, 0.1:1, and 100:1 are obtained in the same manner.

Exercises (204):

1. In figure 1-5, if none of the resistors are shorted out, and the value of the standard resistor is 47 ohms, what is the value of the unknown resistor, RX?

2. Which resistors in figure 1-5 are shorted out when the ratio selected is .01:1?

205. State how to make a lead compensation in the Kelvin ratio bridge.

Lead Compensation. Referring to figure 1-3, you can see that the Kelvin ratio bridge used with the electrical standards console has the circuits necessary for lead compensation. The front panel of the ratio bridge has a two-position lead adjust switch mounted on the left side. To minimize errors caused by leads, this switch is placed in the LEAD ADJ position. The lead selector switch located on the right side of the same panel should be positioned as appropriate for the type of lead used in a given measurement. Both of the lead compensation controls discussed and the lead compensation (screwdriver) adjustment control are electrically combined to form a Wheatstone bridge which is capable of measuring test lead resistance. The lead compensation circuit is an integral part of the bridge measuring circuit and therefore is not removed.

Figure 1-6 illustrates the Kelvin ratio bridge circuit in the 240. Compare this circuit with the one shown in figure 1-4,B. The terminals marked 1 through 4 correspond to the terminals illustrated in figure 1-3 used for connection of the standard and unknown resistances.

Prior to making the lead compensation adjustment, the number 2 and number 3 unknown terminals must be shorted together. This connection removes the unknown resistor from the circuit. When the lead adjust switch is placed in the LEAD ADJUST position, the standard resistor is shorted internally by the contacts of the lead adjust switch, and the connection between the number 4 standard and unknown terminals is opened, eliminating the yoke from the bridge.

The resulting lead compensation circuit will be a referenced Wheatstone bridge, as shown in figure 1-7. Note

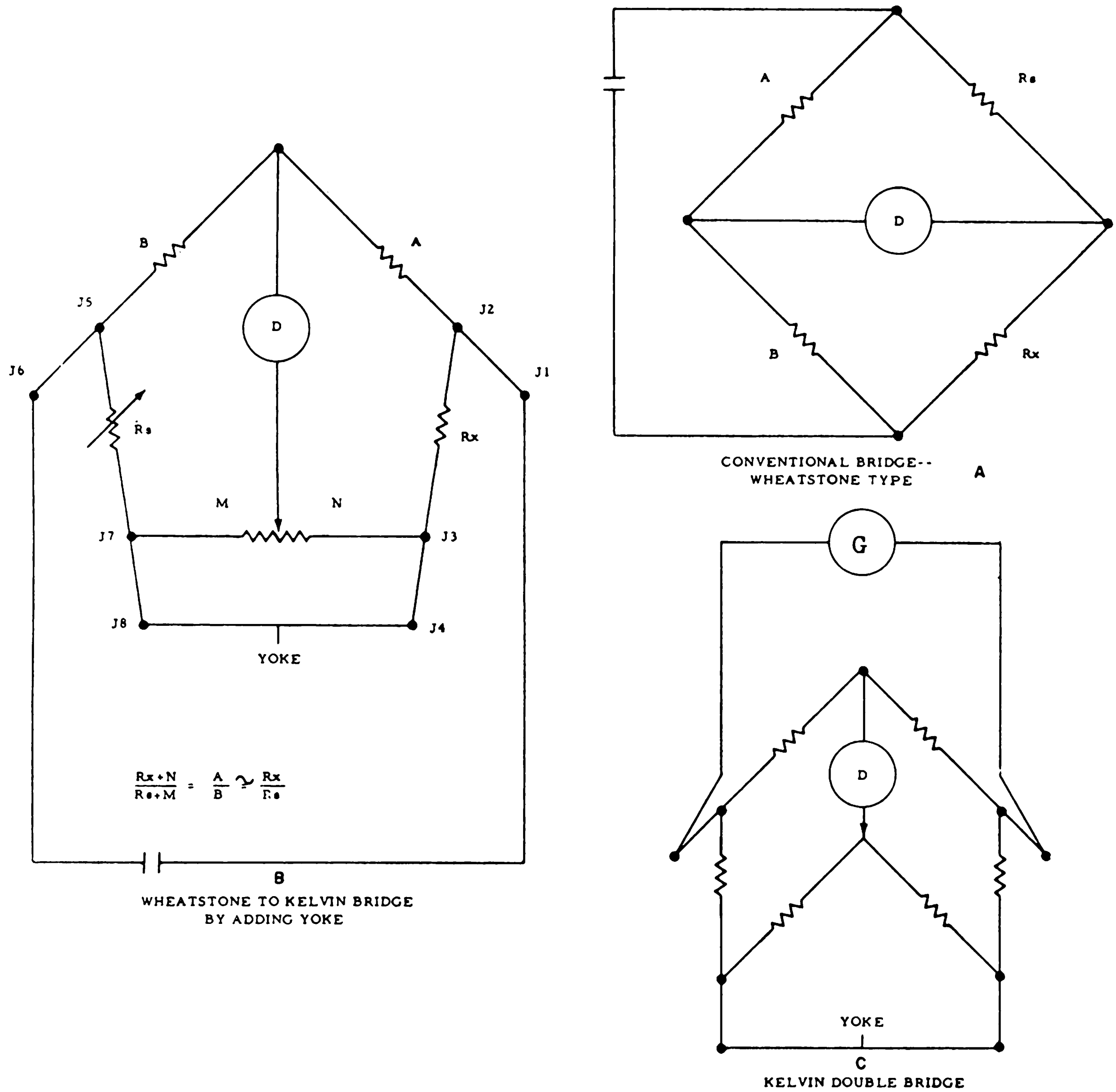


Figure 1–4. Wheatstone and Kelvin bridge circuits.

that the wiper arm of the lead adjust resistor in the "a" ratio arm has been opened. This means that the only variable resistance in the bridge is now the lead adjust resistor in the "A" ratio arm. R_L represents the lead resistance connected between the unknown number 2 and 3 terminals. The "A" ratio arm now consists of the multiplier dial resistance plus the resistance of the "A" lead adjust. The "a" ratio arm is equal to the "a" lead adjust resistance (now fixed), plus the multiplier dial resistance, plus R_L. The "B" ratio arm is nominally equal in resistance to the "b" arm. The equation representing bridge balance is:

$$\frac{A}{B} = \frac{a}{b}$$

where

A = lead adjust "A" + the multiplier dial resistance,
B = deviation range resistance + deviation dial resistance,
a = fixed lead adjust "a" + multiplier dial resistance + lead resistance
b = B.

Since b = B, the equation resolves to:

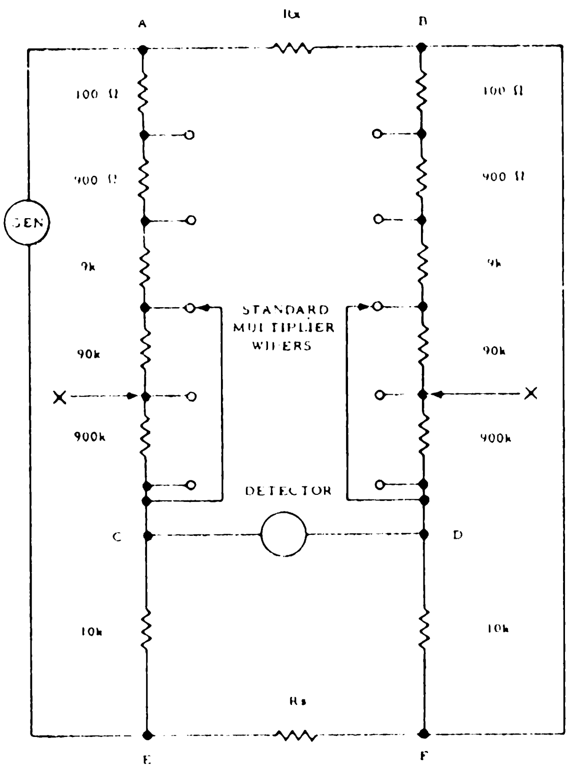


Figure 1–5. Multiplier control circuit.

A = a or
Lead adjust "A" + R_M (multiplier resistance)
Lead adjust "a" + R_M + R_L,

and bridge balance becomes a matter of adjusting lead adjust "A" to equal fixed lead adjust "a" plus R_L,
and bridge balance becomes a matter of adjusting lead adjust "A" to equal fixed adjust "a" plus R_L.

Although the wiper of lead adjust "a" is open during lead compensation adjustment, it is being automatically positioned with the lead adjustment control. When the lead adjust switch is placed in the NORMAL position, the arms "a" and "A" will be equal and the ratio

$$\frac{A}{B} = \frac{R_X}{R_S}$$

will be true and compensated for lead resistance
R_X will be equal to

$$\frac{R_s \times A}{B}$$

A being the multiplier dial setting, and B being the deviation range and dial settings. The 240 controls are so constructed that the R_s readout times the multiplier setting will equal the value of the unknown resistor.

When Kelvin leads are used for a measurement, the compensation adjustment for their resistance is the same as that for ordinary leads (terminals) except for the position of the lead selector switch shown in figure 1-3. Place this switch in the COAX position.

When Kelvin leads are used in a measurement, you must remember that the two leads are connected internally to the 1 and 2 posts of the unknown terminals on the front panel of the 240 ratio bridge. This connection is made by a special female two-hole plug mounted on the right side of the instrument panel. This plug is shown in figure 1-3.

Since each lead goes to a separate insulated jaw of the Kelvin clips, when you clamp both jaws to the third terminal of the unknown terminals, you have made the connection necessary to remove the unknown resistor from the circuit.

Exercises (205):

1. What changes in the basic circuitry of the 240 Kelvin ratio bridge take place when the lead adjust switch is placed in the LEAD ADJ position?

2. What is accomplished by balancing the bridge in the lead adjustment procedure?

3. What external changes must be made before you make the lead adjustment?

206. Identify its component symbol and state the function of the RS925 when used in a ratio resistance measurement.

Variable Resistance Standard. The operation of the Kelvin ratio bridge requires the use of an accurate resistance standard, such as the model RS925. The RS925 is selected because of its construction, its accuracy, and its adaptability to the console. Resistance standards of like construction and accuracy can be used. It should be understood at this point that the RS925 or similar standard, when used with the Kelvin ratio bridge, becomes the RS (resistance standard) illustrated in figures 1-4,A, 1-4,B, and 1-5. The front panel controls and the equivalent circuit for a typical wide range four-terminal decade resistance standard are shown in figures 1-8, 1-9, 1-10, and 1-11.

When you combine the circuits shown in figures 1-8, 1-9, and 1-10, you will have an equivalent measurement circuit for determining the value of an unknown resistor using a ratio bridge such as the Kelvin 240 and a resistance standard such as the RS925. The composite equivalent measurement circuit is shown in figure 1-3.

Figures 1-8, 1-9, 1-10, and 1-11 are included so that you can see how the functions of three instruments, typical of those used with the electrical standards console, are

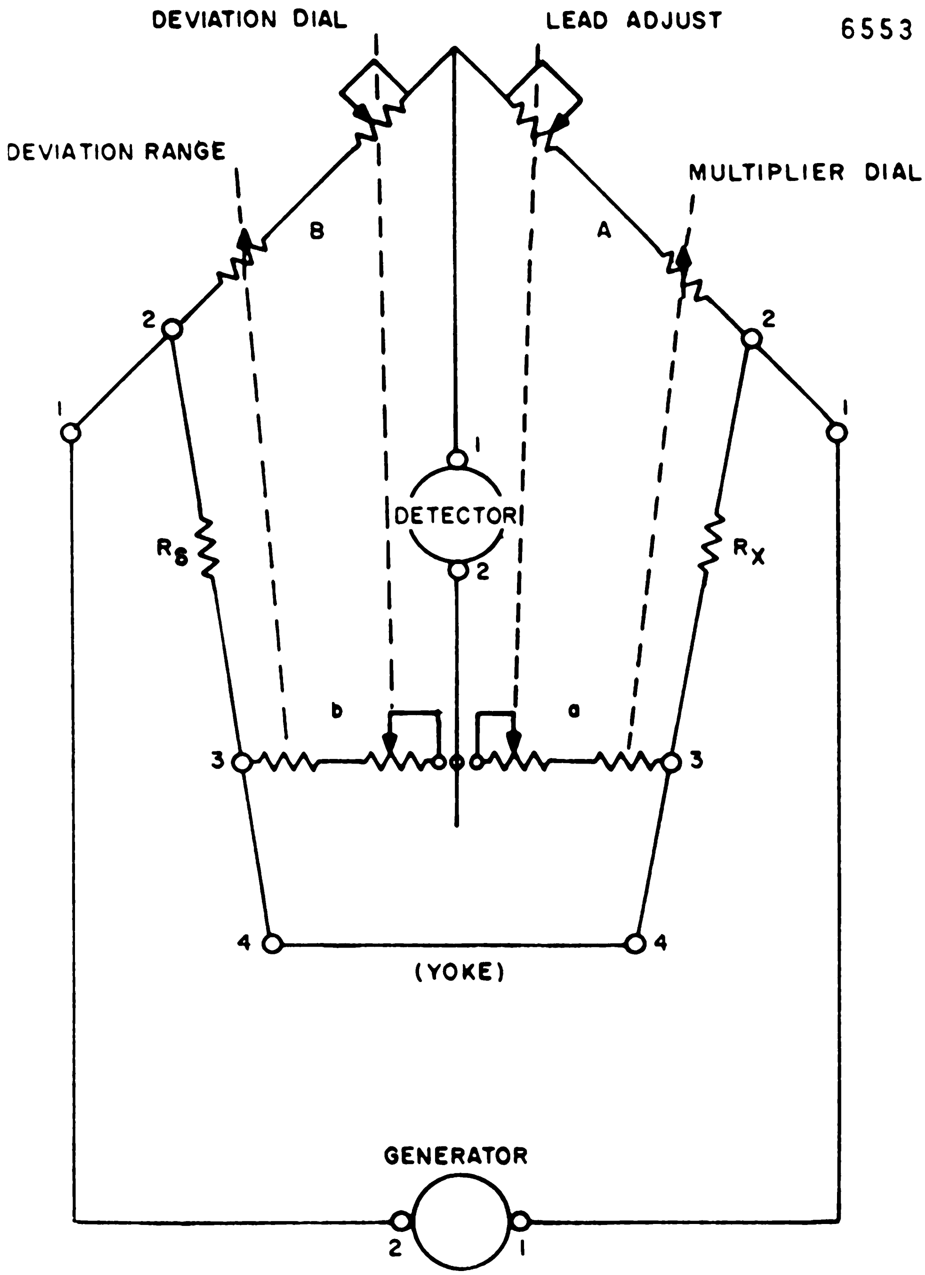


Figure 1–6. Kelvin ratio bridge.

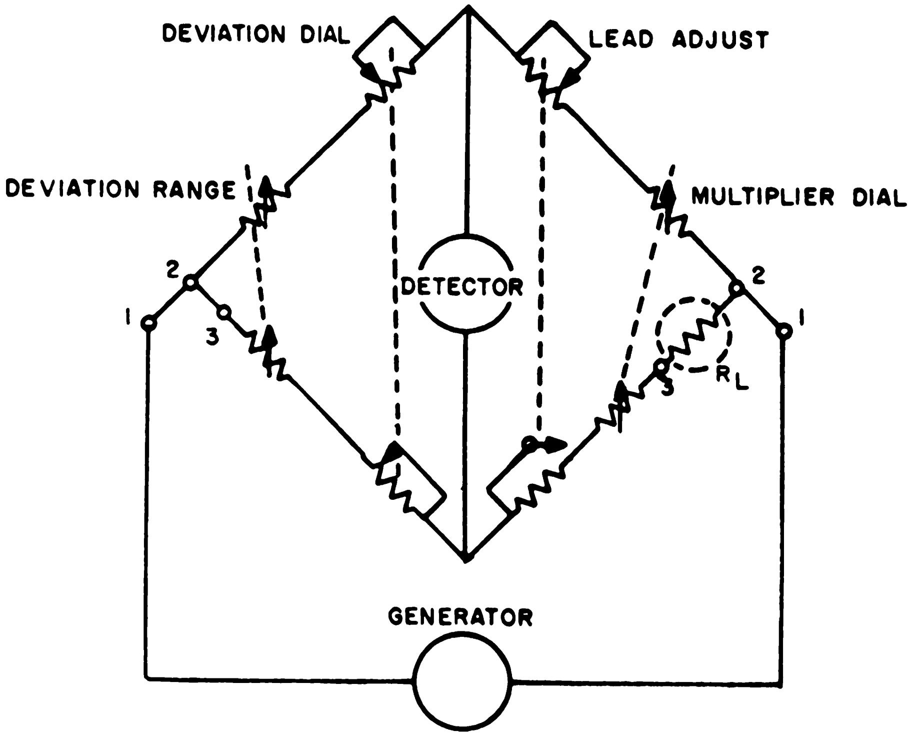


Figure 1–7. Model 240 lead compensation.

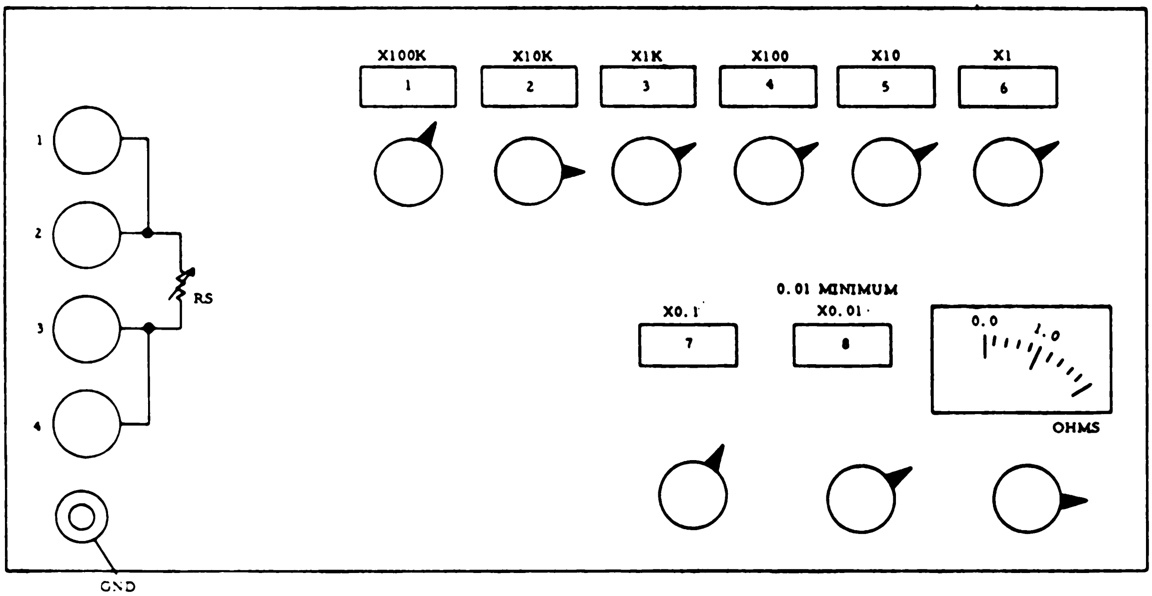


Figure 1–8. Resistance standard panel controls.

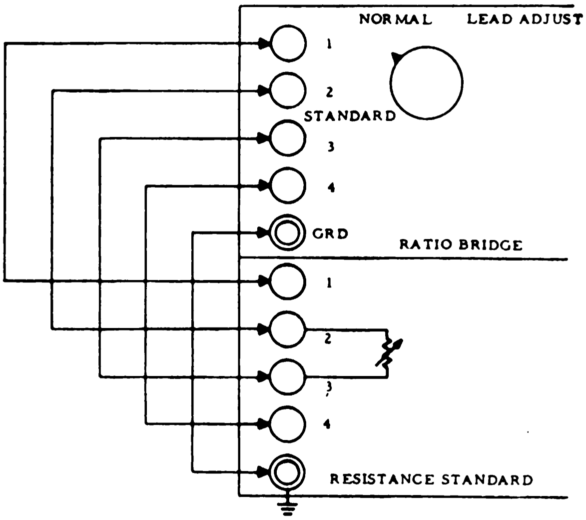


Figure 1–9. Resistance standard connections.

combined in making a resistance measurement. The instruments referred to are included in the measurement circuit of figure 1-11. The DC generator and detector identified in the measurement circuit of figure 1-11 represent the model 800 generator-detector previously discussed. The resistor R_x represents the resistor whose value is to be determined, and the resistance standard represents the variable precision standard RS925.

Exercises (206):

1. Which component symbol in the Kelvin bridge circuit identifies the RS925?

2. How is the RS925 normally used in a ratio measurement of resistance?

207. Given the null settings from a Kelvin-Varley resistance measurement, calculate the value of the unknown resistance.

Voltage Divider Measurement. To assure that PME laboratories have the capability of calibrating the base standard voltage divider, the electrical standards console is equipped with a precision Kelvin-Varley resistive voltage divider. Since either of the two referenced dividers may be used with the console at your installation, the operating principle and some principles of construction will be explained for each of the two dividers.

Kelvin-Varley voltage divider. The Kelvin-Varley divider is typical of ratio devices which are used to provide highly accurate ratios of known to unknown resistances. The principle applied in the Kelvin-Varley divider is illustrated in figure 1-12.

Figure 1-12 is a schematic diagram of the RV722 resistive voltage divider. This divider is designed to maintain a constant input resistance for all divider settings. It consists of seven decades. Two resistors in each decade

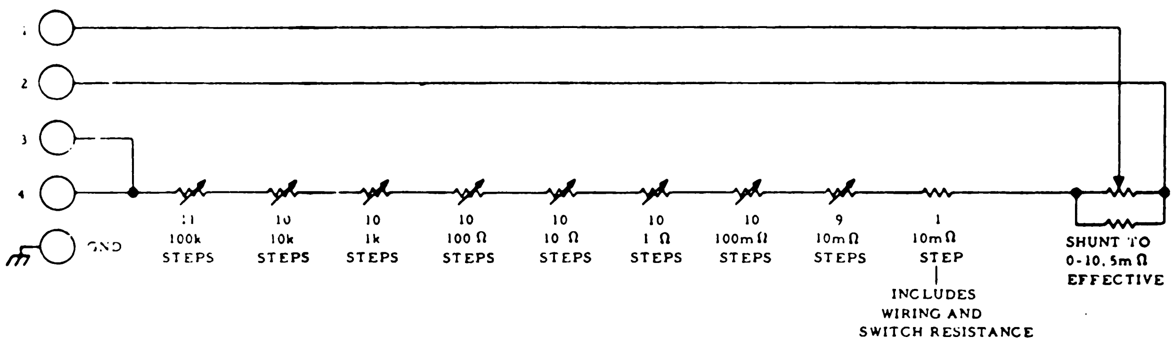


Figure 1–10. Resistance standard circuit.

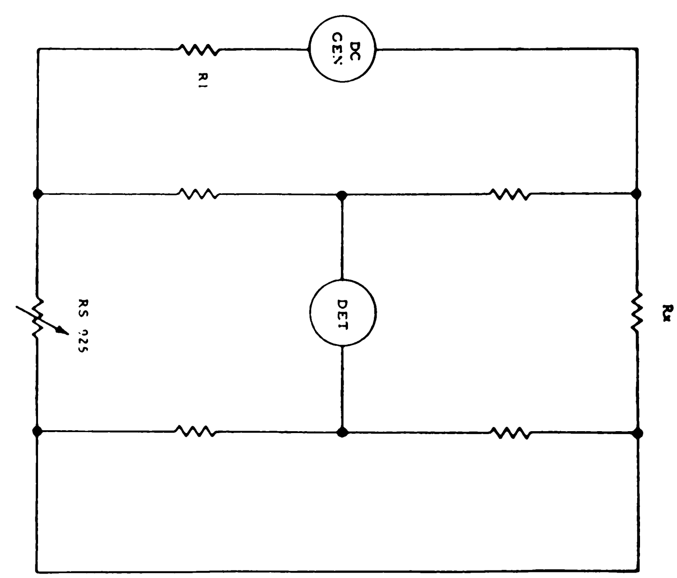


Figure 1–11. Resistance standard in a measurement circuit.

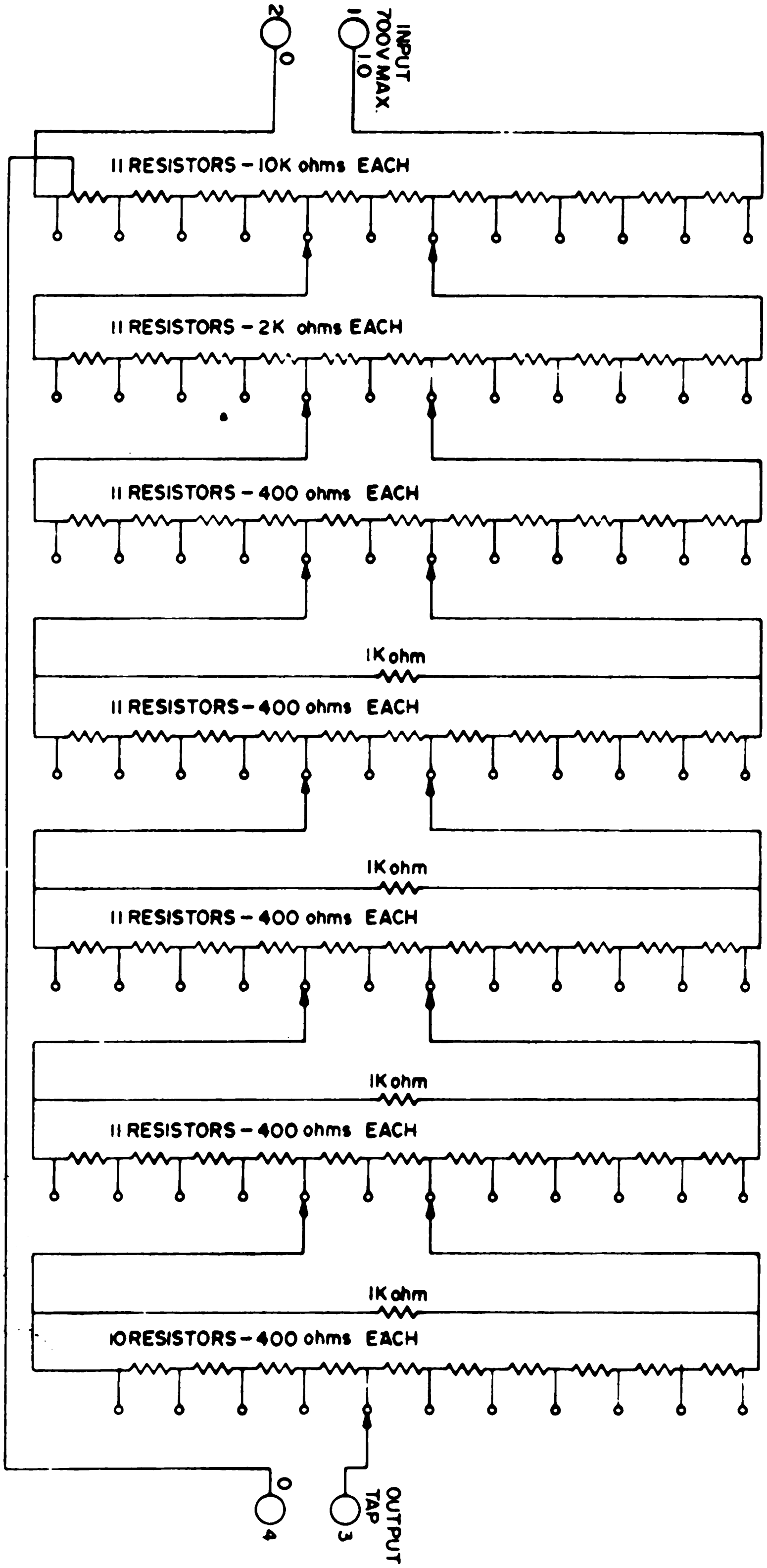


Figure 1-12. Kelvin Varley voltage divider.

are bridged by the 11 resistors of the next decade. Bridging two resistors in each decade by the entire resistance of the next decade effectively halves the value of the two resistors that are bridged, thus creating a 10-step divider in each decade. This circuit leads to a 5 to 1 ratio between the resistors in each decade. If the first decade contains 10K ohm resistors, the second will contain 2K ohm resistors, and the third will contain 400 ohm resistors. In the circuit of figure 1-12, the fourth decade contains 400 ohm resistors also. The fourth decade is shunted by a 1K ohm resistor. This arrangement effectively halves the value of the two resistors in the third decade that are bridged. The fifth, sixth, and seventh decades use the same resistance values as the fourth decade. Only ten 400 ohm resistors are required in the seventh decade.

The decade dials of a Kelvin-Varley divider indicate the output voltage in proportional parts of the input. The compensated voltage at the output common (terminal 4) is factory-adjusted to equal the voltage at the output tap (terminal 3) when the divider is set to zero.

The Kelvin-Varley divider is designed for use in null-balance circuits. The input resistance will remain constant provided no current is drawn from the output terminals. The resistance ratios between the taps of a Kelvin-Varley divider are not linearly related to the voltage ratios, and the divider cannot be used as a decade resistor. When a load is placed across the output of the divider, the output voltage will change.

The Kelvin-Varley divider is used to calibrate low resistances as shown in figure 1-13. The divider setting, S, indicates the ratio of output voltage, E_{out}, to input voltage, E_{in}. The voltage from the tap of the divider to the bottom of the divider, E_{out}, is equal to the input voltage, E_{in}, times the divider setting, S. Thus, the two following equations are appropriate.

$$S = \frac{E_{out}}{E_{in}}$$

$$E_{out} = S \times E_{in}$$

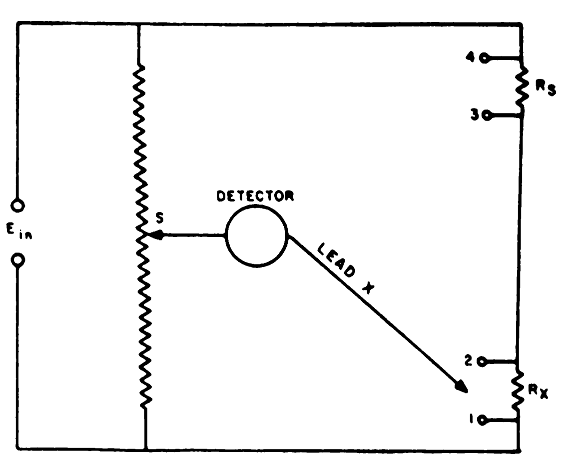


Figure 1–13. Low resistance measurement.

To measure the unknown resistor, R_x in figure 1-13, connect lead X to terminal 4 and adjust the divider to obtain a null on the detector. At null, the divider setting, S_4, times the input voltage, E_{in}, equals the voltage drop from terminal 4 to the bottom of the divider, E_4:

$$E_4 = S_4 \times E_{in}$$

In a similar manner:

$$E_3 = S_3 \times E_{in}$$
$$E_2 = S_2 \times E_{in}$$
$$E_1 = S_1 \times E_{in}$$

The voltage drop across R_s (E_s) is equal to the voltage at terminal 4, (E_4), minus the voltage at terminal 3 (E_3). Thus, the following equations apply:

$$E_s = E_4 = E_3$$

and

$$E_x = E_2 = E_1$$

Since voltage divides in direct proportion to resistance:

$$\frac{R_s}{R_x} = \frac{E_s}{E_x}$$

$$\frac{R_s}{R_x} = \frac{E_4 - E_3}{E_2 - E_1}$$

$$\frac{R_s}{R_x} = \frac{E_{in}(S_4 - S_3)}{E_{in}(S_2 = S_1)}$$

and

$$\frac{R_s}{R_x} = \frac{S_4 - S_3}{S_2 - S_1}$$

so that

$$R_x = R_s \frac{S_2 - S_1}{S_4 - S_3}$$

This procedure eliminates the effects of lead and contact resistance. The value of input voltage is not known. Only the four divider settings and the value of the standard resistor are required for the calculation of the unknown resistor.

Applications for the Kelvin-Varley divider will include comparisons of voltages, whose values are to be determined with the voltage of a calibrated standard cell. The accuracy of such measurements will depend on the sensitivity of the galvanometer, the calibration of the standard cell, and the linearity of the Kelvin-Varley divider. These dividers can be calibrated to achieve accuracies of a few parts per million. Accuracies of 0.001 percent can be obtained with saturated standard cells.

The amplitude of the voltage applied in a given measurement is not one of the prime considerations in assuring the necessary sensitivity for the galvanometer. Usually a microvolt per millimeter, or better, is desirable.

A simplified circuit in which a divider of the Kelvin-Varley type is used to compare the value of an unknown voltage with that of the standard cell is shown in figure 1-14. The 1-megohm resistor in series with the galvanometer is used to limit the current through the galvanometer of figure 1-14. As the Kelvin-Varley wiper approaches a point where the ratio R1/R2 is such that the voltage taken from the divider nearly equals the standard cell voltage, the detector (galvanometer) will approach a null. At this point, the sensitivity of the indicating instrument (detector) can be increased by closing the switch S2, thereby shorting the series 1-megohm resistor. When you have adjusted the equipment so that a null is indicated, it means that the value of the voltage taken from the Kelvin-Varley divider is exactly equal to the standard cell voltage. Since you know the ratio of the voltages R2/R1 + R2 or ER2/ER1 + ER2 (from the divider dial) and since you know the value ER2, (ER2 is equal to the cell voltage at null), you can determine the unknown voltage E_x. If the voltage ratio (R2/R1 + R2) in figure 1-14 is 1/5 and the standard cell voltage is 1.0188 volts, the value of the unknown voltage will be:

$$E_x = \frac{1.0188}{0.0666}$$

$$= 15.3 \text{ volts (approx)}$$

Exercises (207):

1. What value of resistance lies between the input terminals of the Kelvin-Varley divider in figure 1-12?

2. What is indicated by the readout on the Kelvin-Varley dials?

3. In figure 1-13, the following Kelvin-Varley settings are obtained. What is the value of the unknown resistance?

S_1 = 0.007, (RS = 10.0 ohms)

S_2 = 0.839,

S_3 = 0.838,

S_4 = 0.998.

208. Specify the smallest voltage division of the 4397–M divider, and cite its method of lead compensation.

The 4397–M Divider. The electrical standards console in your PME laboratory will use the 4397–M resistive divider or one which approximates its capabilities. The 4397–M resistive voltage divider is used to provide accurate

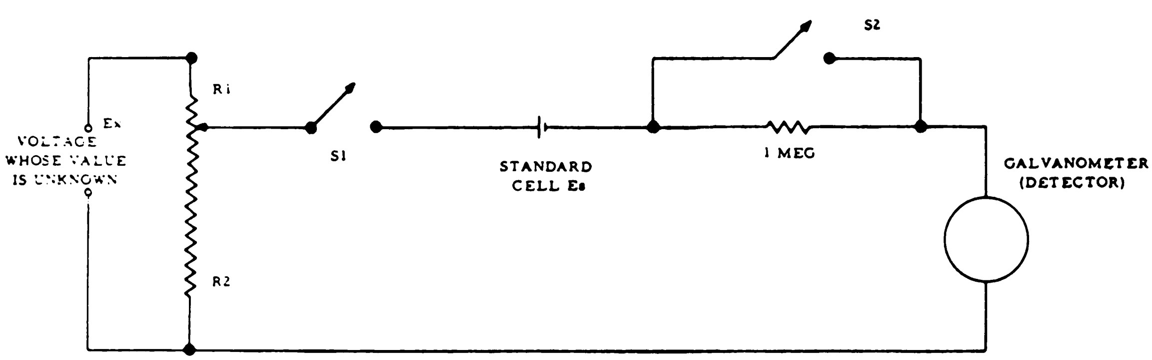


Figure 1–14. Simplified divider comparison circuit.

divisions of low-frequency AC or DC voltage ratios as small as 1:10,000,000. To accomplish small voltage ratios, the divider is composed of 10,000,000 equal parts.

The 4397–M divider has a constant input resistance of 100,000 ohms and is designed to divide voltages whose values range between 0 and 750 volts AC or DC. Readout values from the front panel of the instrument are obtained from the setting of the seven dials on its front panels. The dials are marked as shown in figure 1-15. The individual dial setting value is obtained by multiplying the dial reading (above the dial) by its multiplier (below the dial). Since the first dial in figure 1-15 is in the 4 position and its multiplier is 10^{-1}, our readout value is 0.4. For the second dial, we have 5×0.01 or 5×10^{-2} or 0.05. For the third dial we have 6×0.001 or 6×10^{-3} or 0.0006. For the remaining dials we have values of 0.0002, 0.00003, 0.0000040, and 0.00000010. When we add these values, we have.

0.4
0.05
0.006
0.0002
0.00003
0.000004
0.0000001
0.4562341

This value, 0.4562341, represents the decimal portion of the input voltage which will appear across the output of the divider. This means that if the input voltage were 140 volts, the output voltage would be 140 × 0.4562341, or 63.8727740 volts. The principle on which the 4397–M divider operates is essentially the same as that for the Kelvin-Varley circuit previously discussed.

Since the resistive (Kelvin-Varley) divider will be used in the calibration of other precision dividers, all factors which may tend to decrease the accuracy of the calibration must be considered and all possible errors reduced to an absolute minimum. One of the prime sources of errors encountered in the calibration of dividers is that of lead resistance for which the circuit has not been compensated. An equivalent circuit such as the one shown in figure 1-16 may be used for the calibration of a voltage divider when a divider such as the 4397–M is used as a standard.

In analyzing the circuit shown in figure 1-16, we must assume that the two dividers have the same input impedance. When the voltages developed across resistances Ss and Sx are equal, the detector will indicate a null. Since the lead resistance is a consideration in the resistance of Ss and Sx, the indicated null will not represent a true relationship between the magnitudes of Ss and Sx. To eliminate the error in measurement caused by lead resistances, connections, and compensations such as those shown in figure 1-17 are used. The taps a and b in figure 1-17 are positioned so that the series resistance of the leads can be equally divided between the two dividers. Since adding the same constant (resistance) to both dividers does not change the relative values (ratios) of the dividers, this method of lead compensation is used. The taps on both dividers are set at zero, and tap a is moved until a null is indicated. After nulls have been indicated at zero and unity (both extreme positions on the dividers), lead resistance error has been compensated and an accurate comparison of dividers can be made.

Exercises (208):

1. What is the smallest voltage division ratio provided by the 4397–M divider?

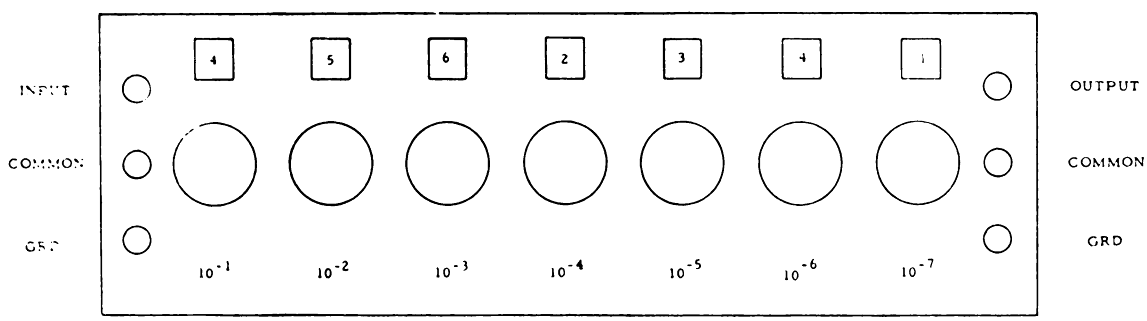


Figure 1–15. Resistive divider panel.

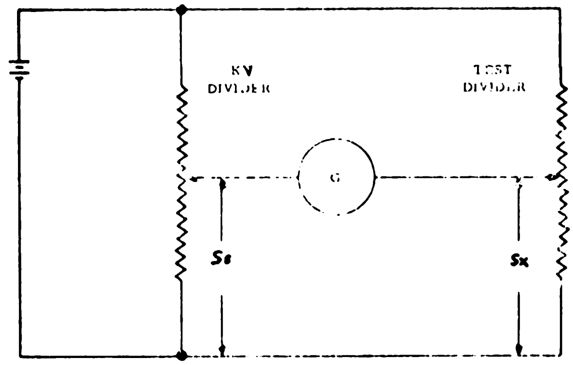


Figure 1–16. Voltage divider comparison.

2. Describe the method of lead compensation when the 4397–M is being used to calibrate another voltage divider.

209. Specify procedures for calibration when using the LC-875B.

Lead Compensator. The electrical standards console is designed to calibrate dividers using a lead compensator such as the LC-875B. The front panel controls for this compensator are shown in figure 1-18.

Figure 1-19 illustrates a lead compensated setup for a voltage divider calibration. The circuit of figure 1-17 has been modified by feeding each end of the divider combination through a low resistance tapped divider. The output voltage of both dividers can now be made to agree at zero and full-scale settings.

The bottom divider, Bal 2, is adjusted for null when both dividers are set to zero. The top divider, Bal 1, is adjusted for null when both dividers are set to full scale. These adjustments permit the "absolute linearity" of the unknown divider to be calibrated.

Any two dividers with an input resistance ratio of 1:1 to 250:1 can be compared directly using the model LC–875B. When you compare two dividers that have different input impedances (fig. 1-19), connect the divider with the lowest input impedance to the "A" divider terminals of the Model LC-875B.

The lead compensator consists, basically, of A1, A2, A3, and A4 in figure 1-19. The values of A1 and A2 are variable from approximately 0 to 42 ohms, and A3 and A4 from approximately 0 to 0.1 ohm. It is possible to place a much larger resistance in series with the "B" divider than the "A" divider. The resistance of Bal 1 and Bal 2 causes no appreciable change in current flow in either divider. The increased voltage drop between the generator and "B" divider input terminals will be enough to change the potential at zero and full-scale settings.

When the same potential exists at zero and unity of the dividers, you can make a comparison of the unknown divider against the standard divider. This comparison permits the deviation from true linear division of the unknown divider to be found.

Exercises (209):

1. When calibrating a voltage divider, what must be the settings on both the standard divider and the unknown divider when Bal 1 is adjusted?

2. Which of the balance controls do you adjust when both dividers are set to their minimum ratios?

3. When you compare two dividers having different input impedances, which of them will be connected to the divider B terminals?

1-2. AC Section Components

Ordinarily, the AC section of the console will be mounted on the left side and will consist of an AC ratio divider, an AC ratio accessory, a capacitance bridge, an AC-DC/DC comparator, and a standard AC power supply. When these individual sections or instruments are connected in proper combination, they provide a capability for the calibration of all types of AC standards, such as standard capacitors, inductors, impedance measuring standards, phase measuring standards, precision AC voltages, and AC/DC ratios.

Some problems that were encountered in the functions of the DC section of the console will also be apparent in AC calibrations. Some of these problems will be multiplied because of the presence and effects of varying magnetic fields. Because of the phase shifts and other undesirable effects inherent in AC circuits, special compensation circuits

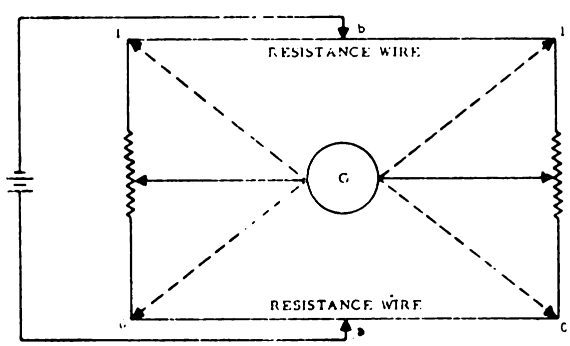


Figure 1–17. Modified divider lead compensation circuit.

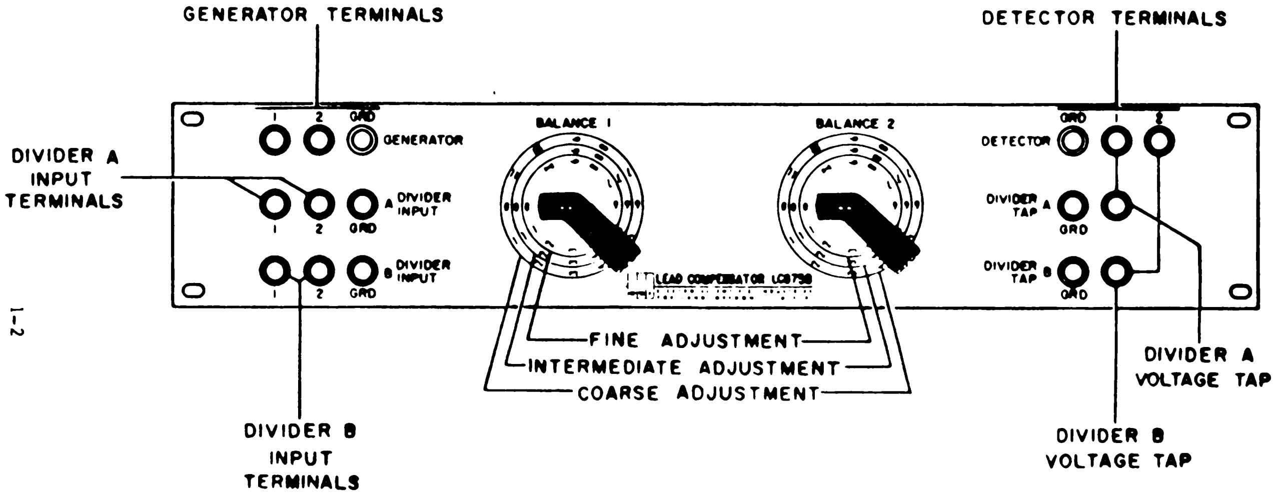


Figure 1–18. Lead compensator panel controls.

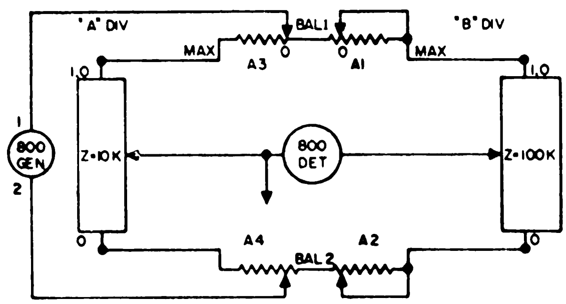


Figure 1–19. Divider calibration (compensated).

are incorporated in the AC ratio measurement circuit. We will discuss one of the instruments in the AC ratio section of the console.

210. State how to determine the maximum input voltage and calculate the output voltage.

Inductive Voltage Divider. An inductive voltage divider, such as the DT–72A, is an absolute necessity in the calibration of capacitors and inductors and in taking AC ratio measurements. You will get the most accurate measurement if the inductive divider used with the console possesses the capabilities of the DT–72A. This divider, which is sometimes referred to as a decade transformer (dekatron), is basically an autotransformer used to step a given input voltage down to a specific value. The windings on such a device have a division accuracy of one part per million at 400 hertz and a resolution of one part in 10 million. The circuits of the DT–72A are designed so that there is a 10-percent overlap between decades. You can see this overlap in the circuit schematic of figure 1-20.

The voltage applied to the DT–72A is limited by the frequency. The input voltage should never be greater than .35 times the frequency in Hertz, or 350 volts maximum.

Analyzing the arrangement and steps for the DT–72A decades shown in figure 1-20, you will realize that the principle of overlap here is very similar to the overlap principle incorporated in the 303A DC voltage standard. In the 303A each decade was designed with 10 normal steps and an 11th step designated as X. You will remember that the X position represented a voltage equal to the voltage of the first step in the following decade. This arrangement existed because of an overlap of values between decades. This inclusion of the 11th step in the decades of figure 1-20 indicates a similar overlap between decades in the DT–72A.

The output voltage of the DT–72A is equal to the input voltage times the decimal reading of the DT–72A. An example of this would be if the input voltage equals 250 volts and the DT–72A is set to .3668425. The output voltage would be computed as follows:

$$E_{out} = 250 \text{ volts} \times .3668425$$
$$E_{out} = 91.710625$$

Switching transients are reduced in the design of the instrument by the use of a special make-before-break type of switch. To further reduce instrument losses, the fourth, sixth, and seventh decades are excited by one turn in the preceding decade, as shown in figure 1-20. This method of excitation eliminates losses generated by poor switch contacts.

A typical hookup for an AC measurement, in which an AC power source and detector and an inductive divider such as the DT–72A is used to determine the unknown values for a component placed in a bridge circuit, is shown in figure 1-21.

In the circuit shown in figure 1-21, whenever you tune the generator to a given frequency, you also tune the detector to approximately the same frequency. With the selectivity switch in the SHARP position, you can adjust the fine tuning control until the detector frequency is exactly the same as the generator frequency. When you

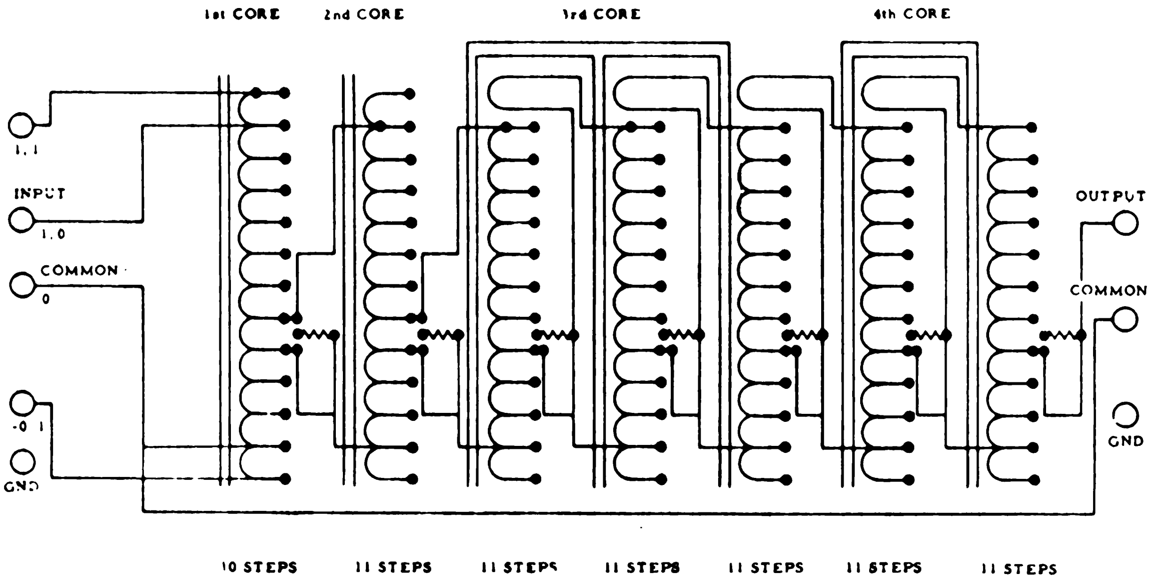


Figure 1–20. Inductive voltage divider schematic.

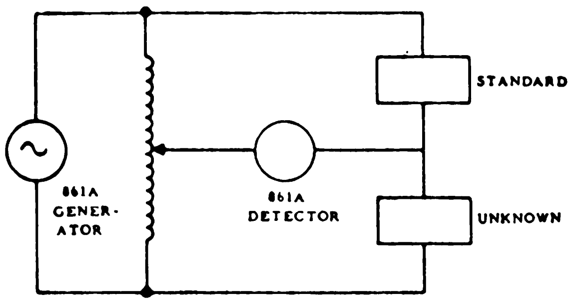


Figure 1–21. AC measurement circuit using inductive divider.

have completed this adjustment, you can adjust the DT–72A for a null, and take a reading from the meter and/or the DT–72A (in some measurements, a null on the meter will be sufficient).

Exercises (210):

1. How is the maximum safe input voltage to the DT–72A determined?

2. The input voltage to the DT–72A is 150 volts. The DT–72A is set to .5463992. What is the output voltage?

211. Cite operational characteristics of the RA–79 ratio accessory.

Ratio Phase Accessory. When you make measurements with the AC section of the electrical standards console, a problem arises because of the phase difference between units being compared and the console standards used in the comparison. To get an accurate, sharp, ratio null, there must be some means to nullify or compensate for the undesirable effects caused by the phase differences. A phase compensator, such as the RA–79 AC ratio accessory, is used with the electrical standards console.

The RA–79 ratio accessory is essentially a quadrature generator and a voltmeter. Basically, this instrument is composed of three parts: a precision decade transformer, a solid-state quadrature (integrating) amplifier, and a solid-state voltmeter. The quadrature generator (with amplifier) supplies an adjustable output voltage which is phase-shifted 90° from the input voltage. The output of the generator is proportional to the input, and its magnitude is adjusted by quadrature ratio controls.

A simplified block diagram of the quadrature generator-voltmeter is shown in figure 1-22. Figure 1-22 represents the basic components of the RA–79 previously mentioned, a decade transformer, a quadrature generator, and a voltmeter. Components of the RA–79 are also represented in figure 1-23. The quadrature generator and decade transformer are represented by "Q", and the referenced voltmeter is positioned to show that it is detachable and can be switched to measure the upper or lower half or the entire DT–72A voltage. You can use the voltmeter to indicate the voltage across the external generator by placing the input select switch in the V21 position. Place this switch in the

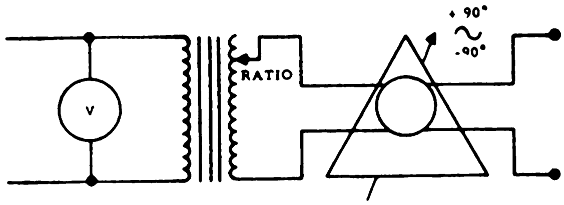


Figure 1–22. Phase compensator block diagram.

V21 position for most AC measurements (impedance comparisons, voltage divider calibration, and phase corrections).

The RA–79 is usually used as a part of a system in AC ratio measurement. Since the quadrature output of the generator is connected in series with the tap voltage of a standard decade transformer, you can determine both the real and imaginary components of a complex voltage ratio by the dial settings of the decade transformer (DT–72A) and the RA–79. In the circuit of figure 1-23, apply the generator voltage to the test divider and to the standard decade transformer (DT–72A), which are connected in parallel. The output difference between the uncalibrated test divider and the transformer is indicated by the detector. You can balance the in-phase voltage differences (resistive) by adjusting the calibrated decade transformer dials. Use the dials of the RA–79 to balance the quadrature voltage differences.

The circuit of figure 1-23 can be used in measurement of an unknown impedance by replacing the test divider with a standard impedance which is in series with an impedance whose magnitude is to be determined. Connect the detector at the junction of the known and unknown impedances. If you adjust the ratio dials on the RA–79 and the dials on the decade transformer (the ratio dials must be readjusted each time the standard decade transformer dials are changed), you can get a null indication and then determine the value of the unknown impedance.

When you must find the impedances of unknown resistance, capacitors, or inductors, using the AC ratio measuring system of the console, you must use specially derived formulas which are applicable to this system. In the formulas which follow, these symbols are used:

s = dial setting of the standard divider.
q = dial setting of the quadrature ratio dials.
D1 = dissipation factor of standard.
D2 = dissipation factor of unknown.
Z1 = impedance of standard.
Z2 = impedance of unknown.

A typical measurement system to which the preceding symbols might apply is shown in figure 1-24.

When the measurement equipment is connected as shown in figure 1-24, find the impedance ratio Z1/Z2, using the relationship

$$\frac{Z1}{Z2} = \left[\frac{s^2 + q^2}{(1 - s)^2 + q^2} \right]^{1/2}$$

or

$$Z2 = Z1 \left[\frac{(1 - s)^2 + q^2}{s^2 + q^2} \right]^{1/2}$$

However, quite often it is not the ratio of the impedances that is desired. Instead, the ratio of the reactances .(X1, X2), or even more specifically, the ratios of the capacitances (C1, C2), inductances (L1, L2), or resistances (R1, R2) in the equivalent series circuit are desired. The equations for these quantities are:

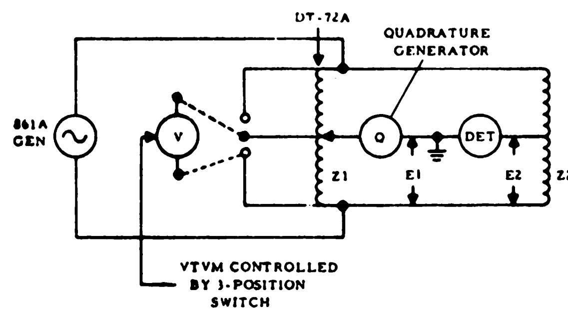


Figure 1–23. Phase compensator circuit.

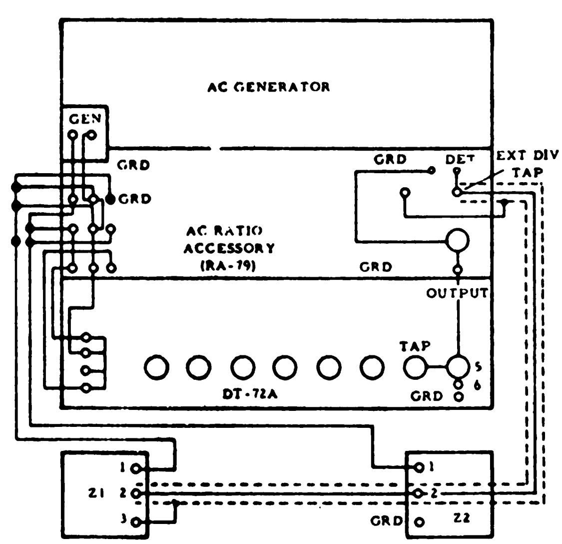


Figure 1–24. Impedance measurement system.

$$R2 = R1 \left[\frac{\frac{q}{D1} - q^2 + s(1 + s)}{s^2 + q^2} \right]$$

$$\cong \left[\frac{\frac{q}{D1} + s(1 - s)}{s^2} \right] \quad \text{for } q < s$$

NOTE: < means much less than; ≅ means approximately equal to.

$$C2 = C1 \left[\frac{s + qD2}{(1 - s) - qD1} \right]$$

$$L2 = L1 \left[\frac{(1 - s) - qD1}{S + qD2} \right]$$

where the number 1 indicates the standard and 2 indicates the unknown. By making assumptions about D1, the above equations may be simplified. In most cases the D of a standard resistor will approach infinity. The first equation will then be

$$R2 \cong R1 \left[\frac{1 - s}{s} \right] \begin{matrix} \text{for } q < s \\ D \to \infty \end{matrix}$$

With most standard capacitors the D will be nearly zero. The second equation will then be

$$C2 \cong C1 \left[\frac{s}{1 - s} + \frac{d^2}{s(1 - 2^2) - a^2} \right] D \to 0$$

NOTE: → means approaches. For high Q inductors the third equation will reduce to

$$2 \cong L1 \left[\frac{s}{\quad} - 1 \right]$$

The phase angle difference (< Z1 − < Z2) between the voltage across the unknown and the generator voltage is given by the formula:

$$Z1 - Z2 = a - \beta \text{ (beta)}$$

Where

$$a = \tan^{-1} \frac{q}{s}$$

$$\beta = \tan^{-1} \frac{q}{(1 - s)}$$

The preceding formulas and symbols apply to the symbols and the equipment hookup referenced in figure 1-24. If we use a different arrangement of equipment for a different measurement, we will have to use different symbols and formulas. For an example of the change required in measurement symbols and formulas, you can compare the measurement system and symbols used in figure 1-24 with the system and symbols of figures 1-25, 1-26, and 1-27.

Exercises (211):

1. What is the RA–79 used for in AC measurements?

2. Basically, the RA–79 consists of what two components?

3. How do you balance quadrature voltage differences which occur in an AC measurement?

4. During an AC measurement, how are the in-phase voltage differences balanced?

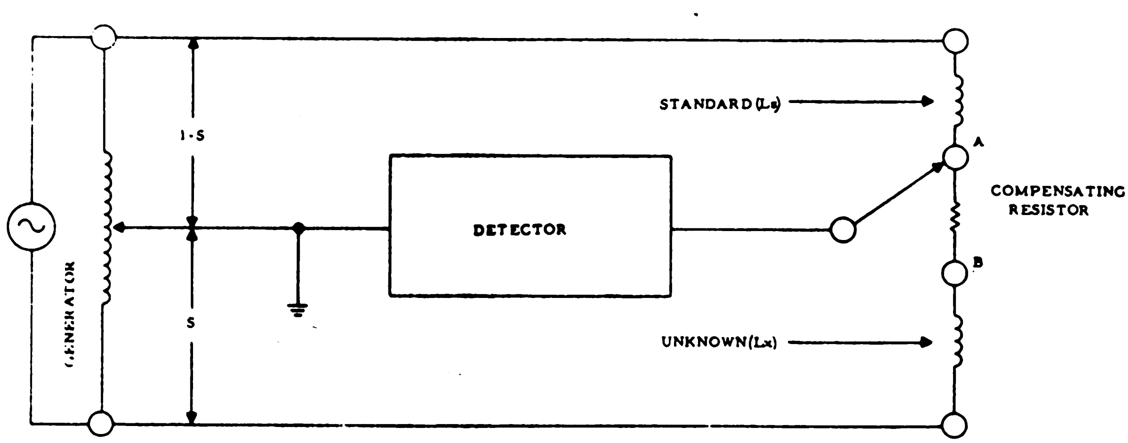


Figure 1–25. Inductance measuring circuit.

212. State the use of standard inductors and capacitors in ratio measurements and compute the value of an unknown capacitance.

Standard Inductor and Capacitor. In the circuit of figure 1-25, an inductive divider, which is used in the measurement of AC ratios, AC voltage, resistance, capacitance, and inductance, is connected for the measurement of an unknown inductance (L_x). the unknown inductance is compared to a standard inductor (L_s) such as a type 1482–L (100 millihenries). You can see from the connection of the circuit that the balance equation for this circuit is

$$\frac{1 - S}{S} = \frac{L_S}{L_X} \text{ or } L_X = \frac{S}{1 - S} L_s$$

When you use the RS925 and DT–72A with the standard inductor for an inductance measurement, you can calculate the inductance with the equation

$$L_X = \frac{S_2 - S_1}{S_4 = S_3} L_s$$

where S_1, S_2, S_3, and S_4 are identified in figure 1-26. You will note that this equation is essentially the same as the equation for the circuit in figure 1-25.

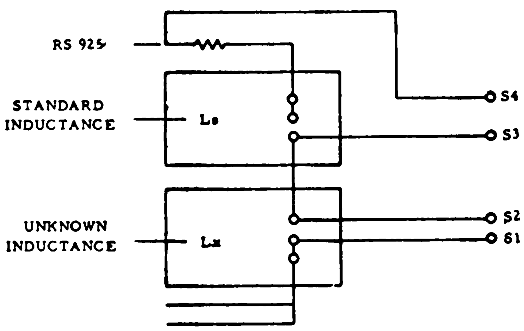


Figure 1–26. Inductance measurement connections.

The circuit of figure 1-27 is very similar to that of figure 1-25, except that a standard capacitor (C_s) is used. Both the standard inductor and capacitor are supplied with the console.

The standard capacitor (type SC 1000 or equivalent) has an accuracy of 50 ppm (0.005 percent) or better. The instrument contains a stable transfer unit, of a conventional value, which you will use to calibrate bridges or other capacitors. A certificate that shows the date of calibration and the measured capacitance at a frequency of 1 kHz and a temperature of 23° C, is attached. The nominal value of the standard is 1 nanofarad (1×10^{-9} farads). The reading given on the certificate requires that the case be tied to a guard point; and if connecting leads are used, at least one of these leads must be shielded completely, and the shielding material must be tied to the guard point. Since complete shielding is difficult to achieve, you should shield both leads and tie both shields to the guard point.

Although the principle for capacitance measurement is the same as that for an inductance measurement, the method of determining the value of the unknown capacitance is slightly different. From your study of capacitance, you know that the value of capacitance is inversely proportional to its impedance or capacitive reactance. Since the voltage applied to the measurement circuit will divide in a ratio determined by the impedances, it follows that the ratio for calculating C_x in figure 1-27 will be

$$\frac{1 - S}{S} = \frac{C_X}{C_s} \text{ or } C_X = \frac{1 - S}{S} C_s$$

Exercises (212):

1. Why is the ratio for a capacitance measurement inversely proportional to that for an inductance or resistance measurement?

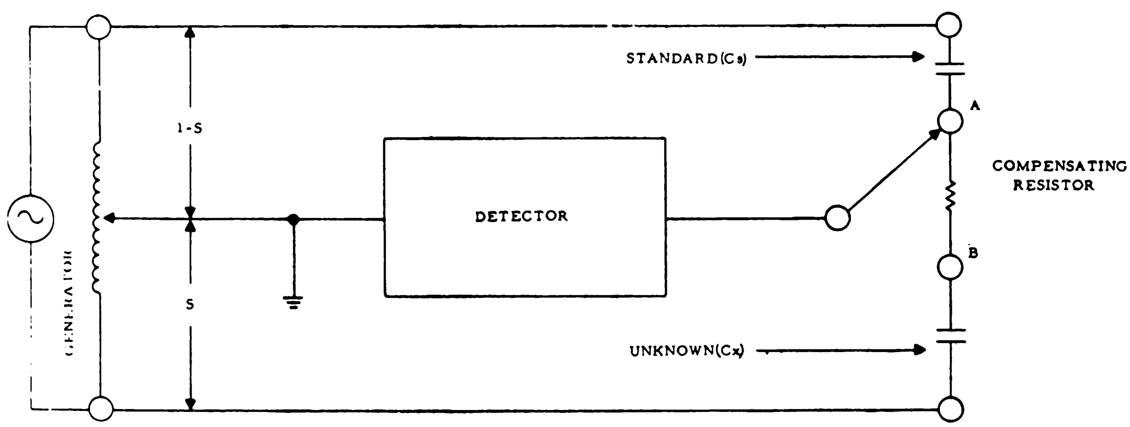


Figure 1–27. Capacitance measurement circuit.

2. What is the recommended method for shielding the SC 1000 standard capacitor?

3. While measuring C_x in figure 1-27, the following setting is obtained. What is the value of the unknown capacitance, if the SC 1000 is used as the standard?

S = 0.175377.

213. Specify which component of the 707B Capacitance Bridge is adjusted by the capacitance dials; tell what the deviation dials show; and state the significance of the capacitance deviation if the deviation selector switch is off.

Capacitance Bridge. When you use the electrical standards console for the measurement of two- and three-terminal capacitors, and the dissipation factor of capacitors, you will use a capacitance bridge such as model 707B. This bridge has the capability of measuring two- and three-terminal capacitors in the range of 0 to 1.2 microfarads with a resolution of 0.0001 picofarad on the lowest range. The capacitor whose value is unknown is measured in terms of the capacitance and dissipation factor of its equivalent series circuit. The front panel of the instrument is constructed so that the dial positions present capàcitance values as in-line readings, including the decimal point and measurement unit. The front panel deviation dial shown in figure 1-28 indicates the percentage difference between the value of the unknown capacitor and the setting of the capacitance dial.

Stabilization of operation is made possible by hermetically sealing the standard capacitor, whose temperature coefficient of capacitance is very low, and by the use of a ratio transformer circuit. The panel in figure 1-28 is included so that you can see the controls and panel connections as we discuss circuits and the effects that varying certain controls will have on these circuits.

The bridge title is indicative of the titles we might expect for the dials. Use the range selector to choose any of six ranges of operation for capacitance readings. The lowest of these ranges (A) is 0 to 12 picofarads (0.0001 picofarads per dial division), and the highest of the ranges (F) is 0 to 1.2 microfarads. Adjust the four dials located in line with the range selector to determine the equivalent series capacitance value of the capacitor being measured.

To assure that capacitance readings are within the tolerance of the instrument, the instrument's capacitance

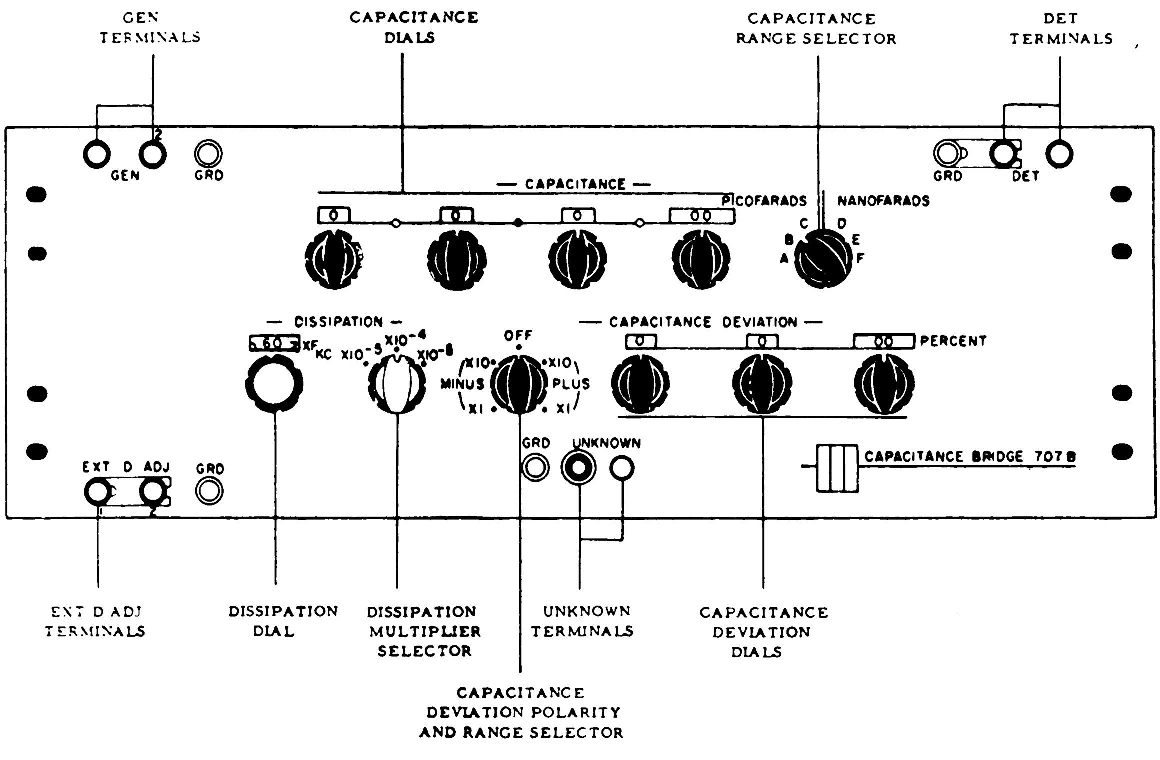


Figure 1–28. Capacitance bridge panel controls.

standard should be adjusted to agree with your calibrated reference standard (SC 1000). The recommended frequency range for measurements and adjustments is 100 to 1000 Hz. The ranges for the capacitance deviation circuit are indicated on the instrument's front panel.

When you turn the capacitance range selector dial to its OFF position, the other capacitance deviation dials have no effect on bridge balance; therefore, you can read capacitance values directly from the capacitance dials.

When measuring an unknown, two-terminal capacitor, insert the capacitor into the front panel unknown terminals (C_x in fig. 1-29). With the capacitor connected to the unknown terminals, a null is obtained by adjusting the capacitance range, capacitance dials, and dissipation controls (R_s and C_d). Remove the capacitor from the unknown terminals, and obtain a second null by adjusting the capacitance dials and dissipation controls on the same capacitance range. The first reading is the value of the unknown capacitor plus stray shunt capacitance. The difference between the two readings is the value of the unknown capacitor. The accuracy of this method is limited by the fact that the stray capacitance is not a fixed value.

If the capacitor, C_x, is placed in a shield as shown in figure 1-30, and a third terminal connected to the shield, it becomes a three-terminal capacitor. The shunt capacitances, C_a and C_b, become fixed values which are connected into the bridge, where they have little or no effect on the measurement of C_x.

In figure 1-30, capacitor C_b, shunts the detector and can cause no error in the measurement. However, a large value of C_b can decrease detector sensitivity. C_a shunts the range winding of the decade transformer. Large values of C_a can be tolerated in this position.

R_s and C_d are used in the measurement of the dissipation factor of C_x in figure 1-29. When a null is obtained, the two impedances (Z_s and Z_x) are in phase and the dissipation factors are equal. This means that:

$D_x = D_s$ and
$D_s = R_s [\, 2\pi f (C_s + C_d) \,]$

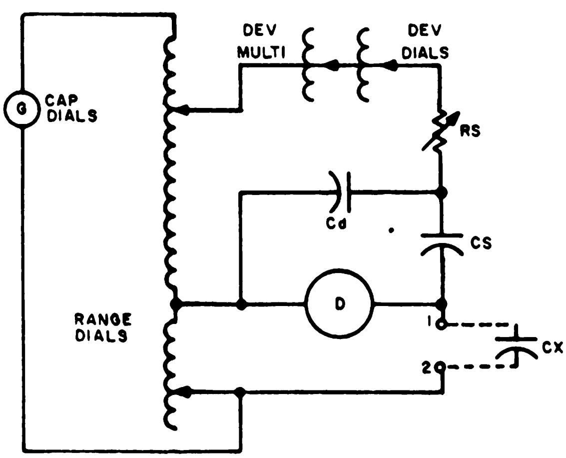


Figure 1–29. Model 707B capacitance bridge circuit.

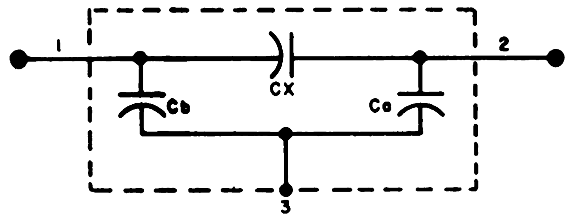


Figure 1–30. Three terminal capacitor diagram.

Exercises (213):

1. What is actually adjusted by the capacitance dials on the 707B?

2. What is indicated by the capacitance deviation dials?

3. What is the significance of the capacitance deviation indication when the deviation selector switch is in the OFF position?

1-3. Console Accessories

In addition to those console equipment items previously discussed, there are some accessories that are necessary for maximum accuracy and efficiency in your use of the console. The ones we will discuss are the decade resistance standard and the standared cell enclosure.

214. Specify which SR 1010 decades are calibrated first and cite the standards; state how error is shown on the chart; and define voltage divider linearity deviation.

Decade Resistance Standard. A decade resistance standard such as the CA 1234 resistance transfer standard extends the capabilities of the console in the determination of resistance values.

The CA 1234 consists of six decade resistors of the SR 1010 type. Each decade contains 12 resistors and is constructed so that you can make a variety of resistance measurements. The six decades provide resistance in values of 1 ohm per step in the 1 ohm box, 10 ohms per step in the 10 ohm box, etc., through 100K ohms per step in the highest decade, the 100K ohm box.

When you make precision resistance measurments, the calibration of any resistor must be traceable through a succession of precise resistance comparisons to a certified reference standard. At present, the resistance reference standard is the Thomas pattern 1 ohm resistor. These resistors are certified by the National Bureau of Standards to an accuracy of ±2 parts per million after the stability of the particular resistor has been demonstrated.

Standards presently available at other resistance values cannot be certified to as high an accuracy since they are typically somewhat less constant in resistance than the Thomas 1 ohm pattern over extended periods of time, or when subjected to environmental changes or mechanical shock. The short-term stability of a precision resistor in a laboratory environment, however, is typically much better than its long-term calibration accuracy.

When you use the Thomas-type, 1 ohm resistor, you can transfer NBS accuracies to the console in the calibration of console dividers, bridges, resistance standards, and ratio devices. A set of decade (SR 1010) boxes is particularly useful for such high-accuracy calibration, since the SR 1010 is designed for the transfer of calibration from one resistance level to another. This is done by calibrating decade boxes at one resistance level and then reconnecting the decade box resistors to yield a different resistance value known to be equally accurate.

The comparisons at each resistance level can be made at a 1 to 1 resistance ratio, assuring maximum accuracy. Thus, the only certified resistance standard a laboratory needs to maintain is its 1 ohm reference standards. The traceable calibration of other standards over a wide range of resistance values should be made with a set of SR 1010 resistance transfer standards and a 1 to 1 Kelvin comparison bridge or double ratio set whenever the established period of greatest short-term accuracy has been exceeded.

Decade standard calibration. When you make precision linearity measurements of a voltage divider, it is necessary first to calibrate a standard voltage divider. Due to its excellent short-term stability and its four-terminal construction, which makes it simple to calibrate, a decade resistance standard such as the Model SR 1010 is ideal for use as a standard voltage divider. Before using the decade resistance standard for linearity measurements, you should calibrate the decade box (SR 1010 or equivalent).

The calibration chart shown in figure 1-31 is attached to the end of each SR 1010. This chart provides resistance calibration data for individual resistors and groups of resistors in the SR 1010, in terms of their deviation from nominal value, expressed in parts per million. These values are based on four-terminal measurements; two-terminal measurements must be corrected for the connection (binding post) resistances.

To accomplish the necessary changes in deviation values listed on the box calibration chart, compare each resistor in the 1 ohm decade with the Thomas-type 1 ohm standard and calculate correction values. These correction values are applied to the measured values and the final corrected values listed, as shown in column A of figure 1-32. By connecting each resistor of the 1 ohm box (SR 1010 or equivalent) to the unknown terminals of a measurement bridge and by using the Thomas-type 1 ohm resistance standard, you can determine the deviation from nominal value for each resistor of the decade. Record these values in parts per million. To determine the average deviation in ppm, you merely sum the deviations for the first nine resistors and divide by 9. This process of determining the

ESI SR1010 OHM/STEP
ELECTRO SCIENTIFIC INDUSTRIES
DEVIATION FROM NOMINAL

INSP: DATE TEMP. SER NO.

	Individual (ppm)	Cumulative (ppm)
R1	+2	+2
R2	+4	+3
R3	-1	+2
R4	+4	+2
R5	+5	+3
R6	-3	+2
R7	+3	+2
R8	-5	+1
R9	+2	+1
R10	+5	+2
R11	+4	+2
R12	+2	+2

Figure 1-31. Decade standard calibration chart.

average (mean) linearity deviation is illustrated by the chart of figure 1-32.

Analyzing the chart of figure 1-32, you can see that the average deviation of the first nine resistors listed in column A is 2.6 ppm. The calculation may be written in the form of the equation

$$\Delta ave = \frac{1}{n} \sum_{i=1}^{9} \Delta n_i$$

where Δ ave represents the average or mean value of the measured deviations of the first nine resistors. The number of resistors whose mean deviation is to be determined is represented by n. The 9 and the i = 1 indicate that the resistive values involved will be those of the first through the ninth resistor. The Greek letter Sigma (Σ) means "the sum of" or total value of the individual parts. Since the Greek symbol Delta (Δ) represents deviation, Δn would represent the deviations from the nominal for successive resistors R1, R2, R3, R4, etc. The preceding notational formula can be written.

$$\Delta\ ave = \frac{1}{n} \sum_{i=1}^{9} \Delta Ni = \frac{\Delta R1 + \Delta R2 + \Delta R3}{n}$$

$$+ \frac{\Delta R4 + \Delta R5 + \Delta R6 + \Delta R7 + \Delta R8 + \Delta R9}{n}$$

or $\frac{23.5}{9}$ = 2.6 ppm (average deviation in parts per million for the first nine resistors of the decade).

The preceding information applies to one of the methods you use to find the means (average) deviation for a given set of deviations (column A in the chart). The values for

	A Measured Individual Deviations	B Corrected Individual Deviations	C Cumulative Sum	D Cumulative Average
R1	-3.6	+2.1	+2.1	+2.1
R2	+5.7	+4.2	+6.3	+3.2
R3	-0.3	-1.2	+5.1	+1.7
R4	+5.3	+3.8	+8.9	+2.2
R5	-1.6	-3.1	+5.8	+1.2
R6	+4.9	+3.4	+9.2	+1.5
R7	+4.5	+3.0	+12.2	+1.7
R8	-3.2	-4.7	+7.5	+0.9
R9	+4.0	+2.5	+10.0	+1.1
R10	+6.6	+5.1	+15.1	+1.5
R11	+3.2	+1.7	+16.8	+1.5
R12	-2.7	-4.2	+12.6	+1.0

9) 23.5 Sum

2.6 Average

Measured group average for nine resistors = +1.1

Minus group average calculated from measured individual deviations = -2.6

Correction to be added to measured individual deviations = -1.5

ESI SR1010 OHM/STEP

ELECTRO SCIENTIFIC INDUSTRIES

DEVIATION FROM NOMINAL

		Individual (ppm)	Cumulative (ppm)
INSP.	R1	+2	+2
	R2	+4	+3
	R3	-1	+2
	R4	+4	+2
DATE	R5	-3	+1
	R6	+3	+2
	R7	+3	+2
TEMP.	R8	-5	+1
	R9	+2	+1
	R10	+5	+2
	R11	+2	+2
SER NO.	R12	-4	+1

Figure 1-32. Calibration chart calculations.

column B (corrected individual deviations) are computed as indicated on the chart. If the first 9 or 10 resistors were paralleled and connected as a unknown bridge resistance, a value (measured group average) such as the 1.1 ppm shown in figure 1-32 would result.

As indicated by the chart, the calculated group average (2.6 ppm) determined from individual deviation values is subtracted from the measured group average (mean −1.1 ppm). This subtraction resulted in a correction factor (−1.5) which was added to all of the measured deviation values in the first column (A), providing the corrected individual deviation values for column B (fig. 1-32). We get the values in column C by adding each corrected deviation value in column B to the preceding cumulative deviation value in column C. The values listed in Column C represent cumulative deviation values of groups of resistors whose individual corrected deviation values are listed in column B. These cumulative deviations and their respective groups can be identified as:

Deviation of Individual Resistors Column B	*Cumulative Deviations Column C*
	0.0
2.1 (0.0 + 2.1)	2.1
4.2 (4.2 + 2.1)	6.3
−1.2 (−1.2 + 4.2 + 2.1)	5.1

Resistors Groups	*Last Resistor in Series Resistors*
Group 1—(R1) R1	R1
Group 2—(R1 + R2)R2	R2
Group 3—(R2 + R2 + R3)	R3

You get the values listed in column D by dividing each value in column C by its corresponding position number (the first value by 1, the second value by 2, etc).

In the chart of figure 1-32, you can see that the corrected individual deviation values listed in column B have been rounded off and listed in the first column of the decade calibration chart (inset in fig. 1-32). A close look at column

D will show that these values have been rounded off and listed in the second column of the decade calibration chart (inset in fig. 1-32). Compare the values in the inset in figure 1-32 with the values shown in the chart of figure 1-32.

The same principle and method applied in the calibration of the 1 ohm box are applicable in the calibration of individual resistors in the 10 ohm box, except that the series resistance of the first 10 resistors of the 1-ohm box will be used as, and connected in place of, the resistance standard.

Upon completion of the calibration of the resistors in the 10 ohm box, you will list the resultant nominal deviation values in the calibration chart for the 10 ohm box in the same manner as the values for the 1-ohm box were listed in the chart shown in figure 1-32. It should be obvious at this point that you will use the same method and principle used in the calibration of the 1- and 10-ohm boxes to calibrate the 100- and 1000-ohm (1 kilohm) boxes.

Decade standard connections. The standard (SR 1010) is used in four-terminal resistance connections. The equivalent circuit for series resistors connected in four-terminal and two-terminal connections and the instrument's hookup panel are shown in figure 1-33.

The four connections shown in figure 1-33 are made to the two pairs of binding posts at either end of any of the resistors. The resistors are internally connected in series. To connect to "9" resistors in series, it is necessary only to connect to the opposite ends of the first and ninth resistors.

The junction design that connects the resistors in series and to the binding post terminals is such that it contributes less than 1- microhm resistance to that of a four-terminal measurement of the individual resistors.

You can connect any number of resistors of an SR 1010 in parallel by means of shorting bars (ESI Model SB 103 or equivalent), as shown in figure 1-34,A. For individual resistors of less than 100 ohms, the paralleling leads and contact resistance may cause significant errors. When you connect 10 resistors in parallel, these errors can be essentially eliminated if you use a special compensation network for making four-terminal parallel connections, as shown in figure 1-34,B.

Any use you may make of the SR 1010 decade requires that you consider linearity deviations. Let us discuss this topic briefly to see what it is and how it concerns measurements made with the SR 1010 or equivalent.

Linearity deviation. To calibrate the SR 1010, or comparable unit, as a voltage divider, we need to know the difference between the actual ratio of the output to input voltages and the setting. This difference is called linearity deviation:

$$L = \frac{E_{out}}{E_{in}} - S$$

L—linearity deviation

E_{in}—actual input voltage

E_{out}—actual output voltage

S—divider setting

Since the voltage and resistance divide proportionately, the linearity deviation can be found by a precision comparison of the resistors in the divider string. By using 10 resistors of the SR 1010 in the divider string, the output can be set to integral multiples of a 10th of the input voltage. The linearity deviation for this divider can be written as:

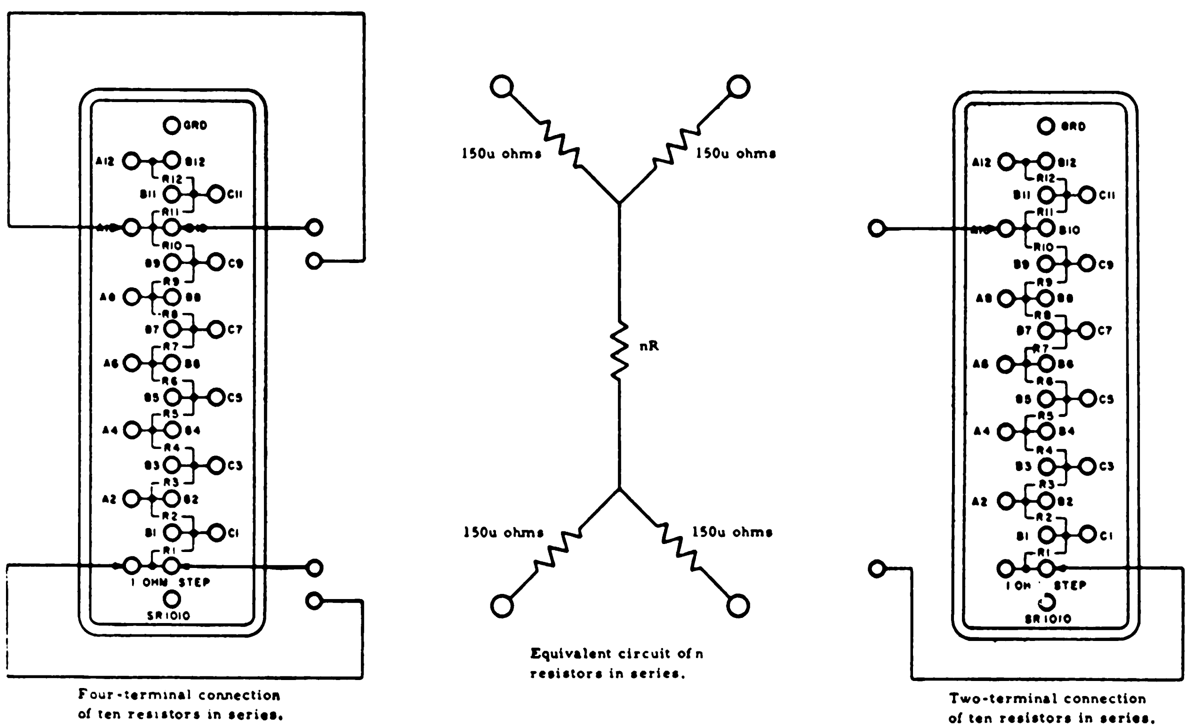


Figure 1–33. Decade standard two- and four-terminal series connections.

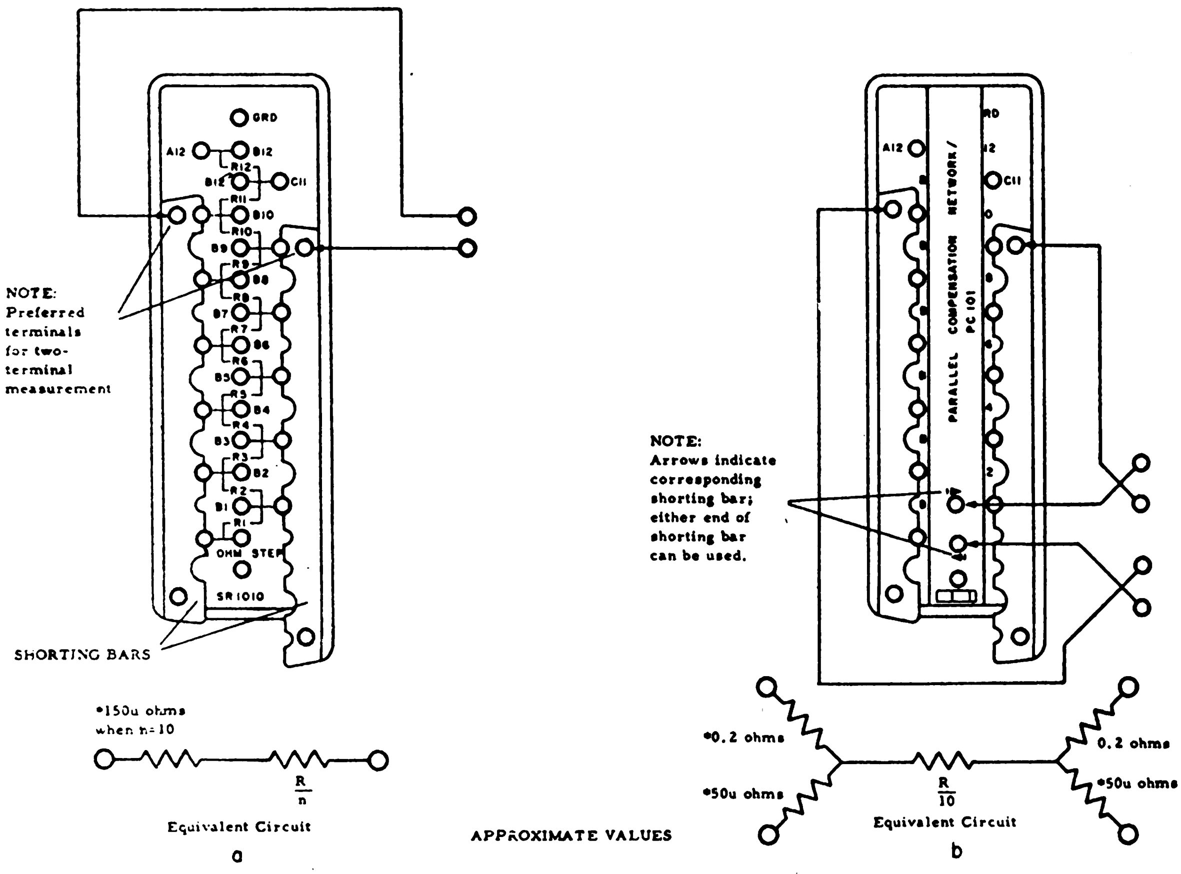


Figure 1-34. Application of shorting bar and compensating network (parallel connections).

$$L = \frac{\sum_{n=1}^{10S} R_n}{\sum_{n=1}^{10} R_n} - S$$

L—linearity deviation

R_n—resistance of nth resistor

$\sum_{n=1}^{10S} R_n$—resistance from COM to OUT in ohms

$\sum_{n=1}^{10} R_n$—total input resistance in ohms

S—divider setting

If all of the resistors in the string were equal, the voltage would divide equally. To find how far from the ideal this divider is, compare each resistor (R_n) of the string to a standard resistor. To maintain the ultimate in measurement accuracy, you should make four-terminal measurements. You will then use the measured resistance deviation to calculate the linearity deviation.

Exercises (214):

1. Which of the SR 1010 decades should be calibrated first?

2. What is the standard during this calibration?

3. What is the standard during the calibration of the SR 1010 100-ohm decade?

4. How is error indicated between the nominal and actual values of the individual resistors in the decade, on the calibration chart?

5. What is linearity deviation in a voltage divider?

AC/DC Voltage Standards and Power Supplies

IN THIS chapter, you will learn about the voltage standards and power supplies currently in use in most Air Force labs today. Although we cannot cover all the items you will see in your career, we can help you progress smoothly through your upgrade training by providing you with information that you can apply to a multitude of items that you'll be responsible for calibrating and repairing in the future. Let's begin by covering the DC voltage standard.

2-1. DC Voltage Standard

215. Specify the basic operation of the 332 ( ) DC voltage standard.

332 ( ) DC Voltage Standard. Refer to figure 2-1 for the following explanation. In a conventional series-regulated power supply, the stable output is maintained by comparing a portion of the output voltage (voltage developed across R3) to a very stable reference voltage (E reference). If there is a difference in these two voltages, the difference (error) is amplified by the error amplifier. The output from the error amplifier varies the conduction of Q1 and consequently the voltage applied to the load. The output voltage will be changed until the voltage developed across R3 is equal to the reference voltage. Thus, a constant output is maintained by varying the conduction of Q1.

Refer to figure 2-2 for the following explanation. Basically, the 332 is a series-regulated power supply with a variable output. Notice that the reference voltage is not applied directly to the error amplifier as it is in figure 2-1. Because the reference voltage is referenced to the voltage applied to the load, a constant current flows through resistors R1 and R2.

The error amplifier maintains point A at the same potential as point B by varying the conduction of Q1. Point B is referred to as the summing point. Assume the sample string resistor (value of sample string controlled by readout dials) is set for zero ohms. With R2 set to zero ohms, the input to the error amplifier at point D would be zero volts and the voltage drop across R1 would be 15 volts. The output applied to the load would also be zero volts because the error amplifier maintains point A at the same potential as point B. The output voltage, applied to the load, is equal to the ratio of R2 to R1 times the value of the reference voltage. Thus,

$$\frac{R^2}{R_1} \times 15$$

If R2 was set to a value of 1 megohm (1M), the voltage applied to the load would be 100 volts and the voltage developed across R2 would be 100 volts.

Because the 15 volt reference voltage is referenced to the output of the supply, it will always be 15 volts above the output of the power supply. Thus, the reference voltage maintains a constant current flow through R1 and R2. When R2 is set for zero ohms, the current flow through R1 and R2 would be 0.1 milliampere because

$$I = \frac{15V}{150K}$$

or 0.1 millampere. If R2 was set to a value of 500 kilohms, the output applied to the load would be 50 volts and the current flow through R1 and R2 would remain at 0.1 milliamperes. The current flow remains constant because the effective voltage applied to R1 and R2 is now 65 volts and the total resistance is 650 kilohms.

Using the values of R1 and R2 as shown in figure 2-2, the voltage that could be applied to the load would range from 0 to 100 volts. The maximum voltage which could be applied to the load would be increased by changing the value of R1, providing the rectifier circuit was capable of producing the maximum voltage desired. For example, if R1 was decreased to 15 kilohms, the voltage that could be applied to the load would range from 0 to 1000 volts. The constant current flow through R1 and R2 would now be 1 milliampere.

Exercises (215):

1. The reference voltage for the error amplifier in figure 2-2 is applied to point __________.

2. What type output does the 332 produce?

216. Analyze the 332 ( ) block diagram operation.

Refer to foldout 7 for the following explanation. A precise 15-volt reference is produced by the A5A1 module. Because the reference voltage is constant, the combination of the reference voltage and the A4 range resistors provides a constant current flow through the sample string resistor. The desired range resistor is selected with the voltage range

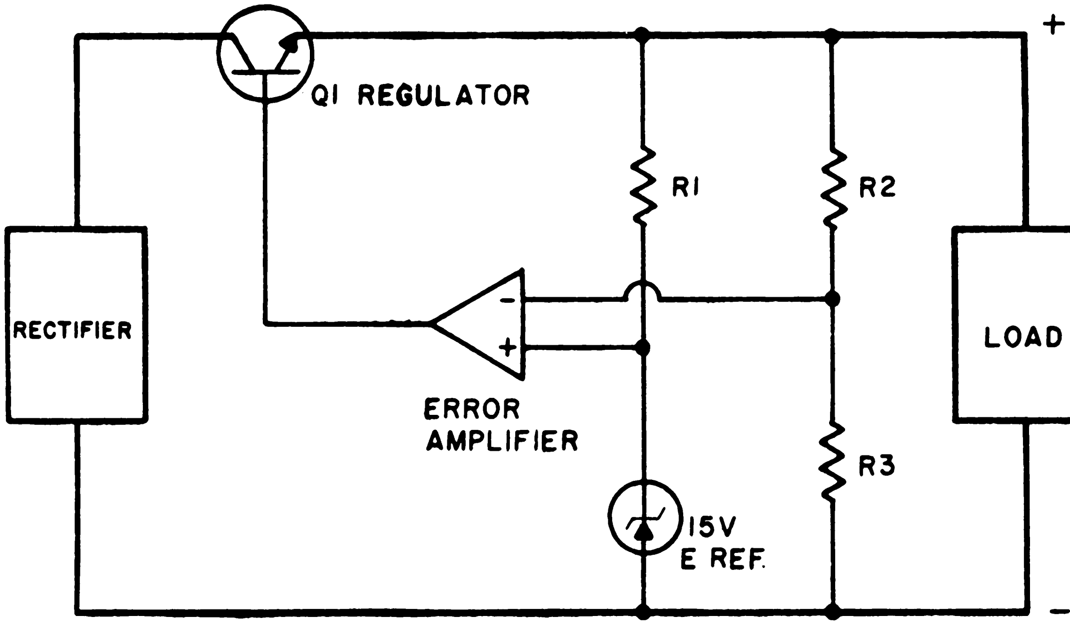


Figure 2–1. Conventional series regulated power supply.

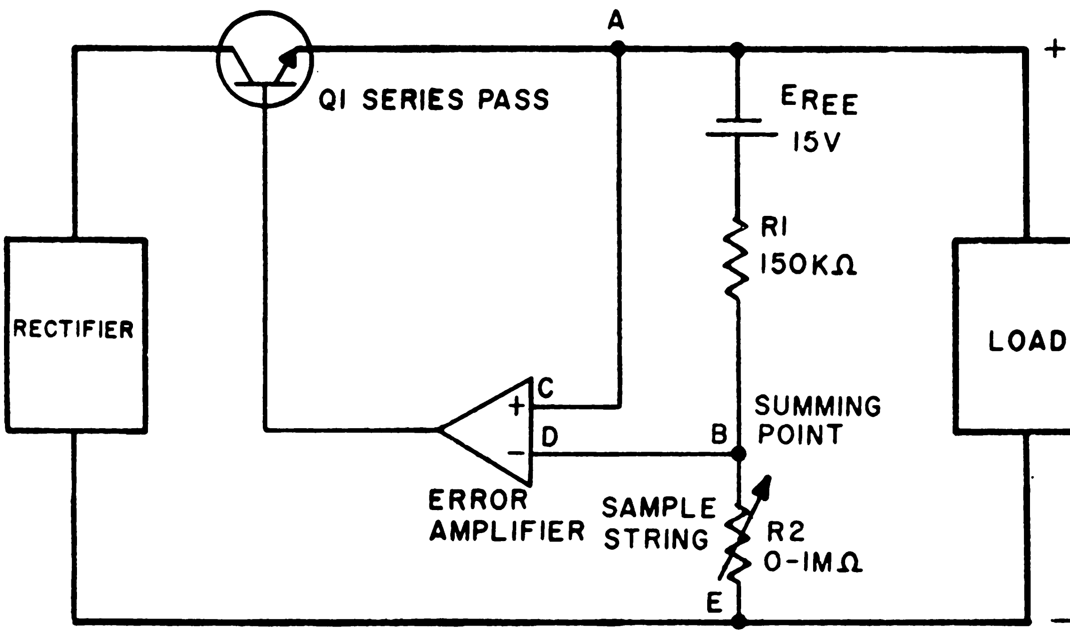


Figure 2–2. 332 simplified voltage control circuitry.

switch. Each change in the voltage range switch setting causes the constant current to change by a factor of 10. The output voltage changes by the same factor. The value of the sample string resistance is controlled with the readout dials.

The output of the instrument is equal to the ratio of the sample string to the range resistor selected, times the 15-volt reference. The error amplifier amplifies any difference of potential between the positive output of the instrument and the summing point (junction of sample string and range resistors). The chopper amplifier and the differential amplifier make up the error amplifier. From the differential amplifier the error signal is applied to the series pass driver where it is further amplified and applied to the series pass element. Thus, the output of the instrument is maintained at the desired constant voltage by controlling the conduction of the series pass element.

The output of the instrument is equal to the voltage developed across the sample string. Any change in the sample string resistance creates an error at the input to the chopper amplifier and differential amplifier. This error is amplified and applied to the series pass element, changing the element's conduction and thereby the output of the instrument. The series pass element changes the output of the instrument until it is equal to the voltage developed across the sample string. Thus, the summing point is the reference point for the regulator circuitry.

Conventional series-regulated power supplies have the inherent disadvantages of low efficiency. When providing a low output, the series pass element of the supply must dissipate the bulk of the power supplied by the high voltage transformer circuit. In addition to the conventional regulator circuitry found in conventional power supplies, the 332 has a preregulator circuit which greatly increases its efficiency. The purpose of the preregulator circuit is to supply only the power to the high voltage rectifier and filter circuit, A7, which is required by the load connected to the output terminals. Therefore, the series pass element does not have a large amount of excessive power to dissipate when the instrument is providing low voltage outputs. The preregulator circuitry consists of the oscillator and the preregulator.

The circuit that controls the output of the oscillator monitors the voltage across the series pass element. Pulses generated by the oscillator are applied to the preregulator, A7A2, to control the power applied to T2. The power supplied to T2 is decreased when the voltage across the series pass element exceeds a predetermined value. Due to the decreased power, the rectifier and filter circuit develop a lower voltage. Thus, the power supplied to T2 is controlled to provide only that amount necessary to satisfy the load requirements.

The 332 has several circuits that are used for protection of personnel as well as external equipment. The protection circuits are primarily the interlock circuit, the trip circuit, and the limiter. The interlock circuit deenergizes the high voltage circuits within the instrument when the covers are removed. The trip and limit circuits allow the operator to set the 332 output voltage and/or current limits. When the output voltage or current reaches the set limits, the instrument output is deenergized. Therefore, sensitive instruments being calibrated can be protected from excessive voltage and current.

The interlock circuit provides the ground path for relays K1 and K2. Under normal operating conditions, these relays would be energized to apply power to the preregulator circuit and to close the negative output path of the rectifier and filter circuit. Any time the top or bottom cover of the 332 is removed, the interlock circuit removes the common path for relays K1 and K2. Thus, the relays deenergize, removing power from the preregulator and opening up the negative output path of the rectifier and filter circuit. Relays K1 and K2 are used both for the protection circuitry and the time delay circuit.

The trip circuit monitors the current and voltage condition of the instrument. Should a large overvoltage or overcurrent condition occur, the trip circuit will bypass power from relays K1 and K2, causing them to deenergize. The overvoltage portion of the trip circuit is controlled with the trip adjust, VOLTAGE TRIP control. Any time the predetermined voltage set in by the operator is exceeded, relays K1 and K2 are deenergized. Whenever relays K1 and K2 are deenergized by the trip circuit, the power switch must be recycled to STANDBY/RESET and then back to OPERATE to restore power to the instrument.

The current limiter, A5A6, sets the limiting point of the output current. The limiter circuit monitors the output current of the instrument and couples this signal to the differential amplifier. The differential amplifier will bypass a portion of the sample string current when the preset current limit is exceeded. Due to the reduced current flow through the sample string, the output voltage of the instrument is reduced and subsequently the output current is also reduced.

The time delay circuit prevents the energizing of relays K1 and K2 for a short time period after power is applied to the instrument. This action assures that the control amplifiers are operating before power is applied to the high voltage rectifier and filter circuit, A7.

Exercises (216):

1. By what factor does each successive change of the voltage range switch change the current flow through the sample string?

2. If the voltage across the series pass element decreases below the predetermined value, how would the power applied to T2 react?

3. Which circuit(s) can remove power from the rectifier and filter circuit?

2-2. AC Voltage Standards

217. Analyze the 5200A simplified block diagram.

5200A/5205A AC Calibrator System. The 5200A/5205A AC calibrator system provides the PME laboratory with an easy to use and precisely controlled AC voltage source. The 5200A AC calibrator is the heart of the system. For that reason, we will now discuss the theory of operation to a functional block level. The 5205A precision power amplifier is an X100 amplifier that retains the accuracy of the source.

The main function of the Model 5200A is to generate an AC voltage which can be precisely selected over wide ranges of frequency and amplitude. Output sensing of the amplitude is provided, either at the load or the calibrator output, so that the calibrator operates as a closed-loop control system and provides accurate output voltages over a wide range of loads and selected amplitudes.

A simplified block diagram of the 5200A is presented in figure 2-3. The AC signal source is a double-integrator type oscillator. The oscillator output is selectable over a wide range of frequencies by means of the front panel switches and is fed to the input of a power amplifier. The power amplifier provides the gain necessary to accommodate the two higher amplitude ranges (not counting the 1000V range) and feeds the attenuator that accommodates the four lower amplitude ranges. The attenuator output connects the selected AC signal to the load, which can be converted to either the front panel or the rear panel connectors.

To maintain precise control of the output amplitude, the calibrator operates as a closed-loop control system using the output sense connections to complete the loop. The sense connections are made at either the load or the attenuator output. These connections feed the sense signal back into the calibrator via a high-impedance input within the AC-DC converter. A wideband rectifier contained in the AC-DC converter converts the AC sense signal to a proportional DC value. The DC sense signal is then compared (summed) with an amplitude reference voltage of the opposite polarity, and a difference (error) voltage is produced to adjust the oscillator amplitude to the proper value.

The amplitude reference voltage is produced within the calibrator as a result of the amplitude selector switches located on the front panel. That is, the reference assembly interprets the settings of the front panel switches and generates a corresponding reference voltage. The reference voltage is compared to the DC sense voltage, and any error voltage produced by the integrator is fed to the oscillator control assembly. The oscillator control assembly, in turn,

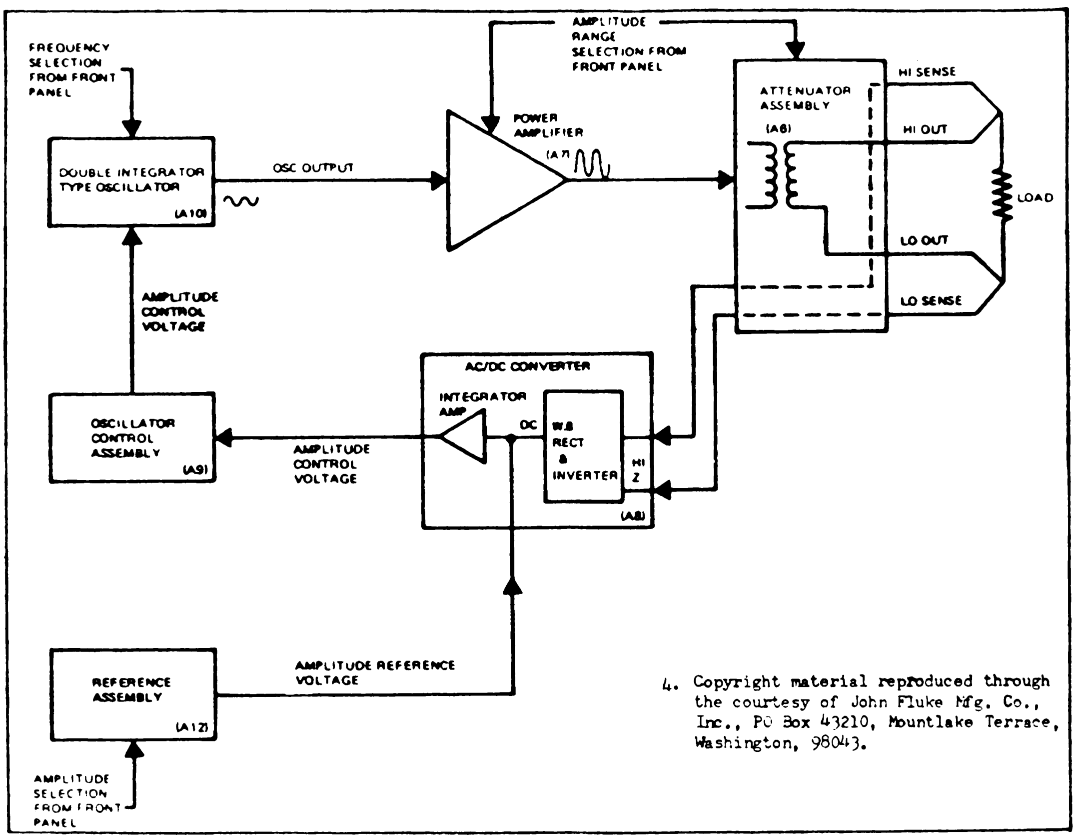


Figure 2–3. 5200A simplified block diagram.

uses the error voltage (amplitude control voltage) to control the amount of the feedback voltage to the oscillator.

The action of the described control loop is such that when a different output amplitude is selected, a change in amplitude reference voltage (produced by the reference assembly) results. Since the sense input has not yet changed and the DC sense voltage is compared with the changed amplitude reference voltage, a resulting amplitude control voltage (error voltage) is fed to the oscillator control assembly. The oscillator control assembly uses the amplitude control voltage to adjust the oscillator amplitude in the proper direction.

When the calibrator output reaches the selected amplitude, the DC sense voltage (at the wideband rectifier output) becomes balanced with the amplitude reference voltage, and no error voltage is produced. At this point, the oscillator control assembly ceases to alter the oscillator amplitude.

The oscillator control assembly controls oscillator amplitude over a 12:1 range. The two selectable gain values of the power amplifier and several settings of the attenuator provide amplitude range selection. Frequency and frequency range selection are made by switching selected values of resistance and capacitance within the oscillator. In addition, all front panel amplitude and frequency selection switches (except the error measurement feature) can be duplicated by a remote programming source when that option is installed in the calibrator.

Exercises (217):

1. What is the main function of the 5200A?

2. When does the amplitude reference voltage change?

3. Over what range does the oscillator control assembly control oscillator amplitude?

218. Cite operational characteristics of the 5200A oscillator.

Oscillator. The heart of the 5200A is a double-integrator type, RC oscillator contained in the oscillator assembly (A10) and shown in foldout 6 of the schematic handout. A summing amplifier, a quadrature amplifier, an oscillator amplifier, and their associated resistors and capacitors comprise the oscillators. The quadrature and oscillator amplifiers, in conjunction with their frequency select resistors and frequency range select capacitors, form a pair of integrators, each providing a phase shift of 90°; or a total phase shift of 180°. The output of the oscillator amplifier is fed back through a resistor (R1) into the summing amplifier, which provides an additional 180° of phase shift by means of signal inversion. The result of the combined phase shifts around the loop is approximately 360° at all frequencies. As a result, the loop is on the verge of sustaining oscillations at a frequency that yields unity gain. It needs only the parallel, electronically controlled feedback paths on the oscillator control PC board to bring the combined loop phase shifts to exactly 360° and thus, sustain oscillation at the selected frequency.

The oscillator frequency is controlled over a 12:1 range by switching values of the frequency select resistors at the inputs of the quadrature and oscillator amplifiers. The range of frequencies is controlled by the frequency range select capacitors (located on the oscillator control assembly) whose values are switched in accordance with the desired frequency range. The switching of the oscillator frequency select resistors is accomplished entirely by means of FET switches, and the switching of the frequency range capacitors is accomplished with reed relays. Both are controlled by either the front panel switches or the remote control unit.

Exercises (218):

1. What is the total phase shift through the oscillator at any selected frequency?

2. What must be adjusted to select a specific frequency within any range?

219. Specify the operation of the 5200A power amplifier.

Power Amplifier Assembly. The power amplifier accepts the 0.33 to 4.0 volts rms output from the oscillator and provides the gain necessary to obtain attenuator inputs of 1.0 to 120 volts rms. The power amplifier has two fixed gain settings of 3 and 30; the latter is used only on the 100-volt range.

As shown in foldout 6, the oscillator output signal is fed to the negative side of the power amplifier input stage, while the positive side is connected to the output of a low-drift DC amplifier. The purpose of the low-drift DC amplifier is to compensate for any DC offset voltages developed within the power amplifier, which result in an error at the output. Since the output is fed back through R1/R2 and R4 to the DC amplifier and the output of the amplifier feeds the positive side of the input stage, any DC voltage appearing at the power amplifier output is compensated for. That is, any error on the negative side of the input stage is matched on the positive side by the DC amplifier, resulting in a net DC error at the assembly output of zero.

The midstage of the power amplifier drops the DC level of the amplified oscillator output to −190 volts and provides voltage gain. The output stage operates in conjunction with a bootstrap amplifier to produce the 1 to 120 volts rms output to the attenuator. The function of the bootstrap amplifier is to eliminate the need to connect the output stage directly across the +190-volt and −190-volt regulated supplies by allowing the stage to float between these potentials. The low voltages produced by zener diodes CR8 and CR9 provide the necessary collector voltages for the output transistors, in place of the 190-volt supplies.

The overall detector senses the current being drawn from the −190 volt regulator. When that current exceeds a preset limit, the overload detector energizes relays K3 and K4 located to the buffer amplifier on the AC/DC converter assembly to receive a sense potential that is within its limits, no matter what the actual AC sense potential is. The overload detector also energizes an overload indicator on the front panel to alert the operator. It should be noted that an overload condition existing in the 5200A does not remove the output from the output terminals.

Exercises (219):

1. What is the total voltage gain received from the power amplifier?

2. Where is the positive side of the power amplifier input stage connected?

220. Analyze the operation of the 5200A attenuator.

Attenuator Assembly. Since the output of the power amplifier is always greater than 1V rms, the attenuator is necessary to obtain calibrator outputs in the range of 0.1 to 1000 mV rms. Foldout 6 shows that the attenuator assembly inserts a series of ratio transformers into the calibrator output when operated in the 1 mV, 10 mV, and 1 V ranges. For operation in the 10-volt and 100-volt ranges, the ratio transformers are bypassed. When operating in the 100V range, the power amplifier has a gain of 30 so that the input to the attenuator is in the range of 10 to 120V rms, depending upon the front panel amplitude selection. For all other amplitude ranges, the power amplifier has a gain of 3, which results in an attenuator input of 1 to 12V rms.

Three ratio transformers are used to provide an output for any of the four lower ranges that is flat over the entire frequency range of the calibrator. The transformers have a primary-to-(full) secondary step-down ratio of 10:1 to accommodate the 1V range. The secondary winding of each transformer is also tapped to provide step-down ratios of 100:1, 1,000:1, and 10,000:1 to accommodate the 100 mV, the 10 mV, and the 1 mV ranges, respectively. Switching within the attenuator selects the correct tap on the correct transformer in accordance with the front panel amplitude ranges selection and connects that tap to the calibrator output.

The attenuator also provides the necessary division or attenuation of the sense input signal. When operating in the 1-, 10-, and 100-volt ranges, the sensing may by internal within the calibrator or external at the load. In the 1-volt range, the sense signal is taken directly from the load or calibrator output with no attenuation required for application to the AC-DC converter assembly. In the 10 volt range, the sense signal is inductively divided by a factor of 10, and in the 100 volt range, the sense signal is resistively divided by a factor of 100.

On the 1-, 10-, and 100-millivolt ranges, sensing is always internal and is derived from the ratio transformers used in these ranges to step down the power amplifier output to a level suitable for application to the AC-DC converter. Since the ratio transformers are fixed, the outputs that supply the sense are proportional to the amplitude of the calibrator output and are in the range of 0.1 to 1.2V rms, as required by the AC-DC converter assembly. External sensing cannot be provided in the three lower ranges due to the 0.1V to 1.2V rms sense input requirement of the AC-DC converter assembly.

Exercises (220):

1. In what ranges must the 5200A be for the ratio transformers to be bypassed?

2. On the 1-, 10-, and 100-millivolt ranges, is sensing external or internal?

221. State operational characteristics of the 5200A reference assembly.

Reference Assembly. The reference assembly receives the amplitude selection information (except for the least significant digit) from the front panel switches (or from the remote control unit) and generates a corresponding DC reference voltage used to control the calibrator output amplitude. The output of the reference assembly is referred to as the variable reference signal. This output is fed to the AC-DC converter where it is compared with the rectified AC sense signal to control the oscillator amplitude.

To generate the variable reference signal, which is proportional to the selected output amplitude, a 10-mHz clock is employed to drive a digital counter. The counter divides the clock signal by a factor of 1.3×10^5, and all counter inputs are fed (in parallel) to one set of inputs on a digital comparator. The other set of inputs to the digital comparator is supplied by the front panel switches (or by the remote control unit). The comparator accepts both sets of inputs and, when the counter reaches the same state as selected on the front panel amplitude switches, produces a "compare" output. The compare output pulse sets a flip-flop which, by means of FET switches, removes the output of a 7-volt reference supply from the input of a five-pole, active filter and replaces it with ground.

When the counter reaches full count and resets to zero, a pulse is fed into the clear input of the flip-flop. When the flip-flop is cleared, it changes state to open the ground connection and reconnects the 7-volt reference supply to the active filter. The result of the opening and closing of the

FET switches is the generation of DC pulses at the active filter input. The duty cycle of this 7-volt peak to peak rectangular waveform is directly proportional to the time required by the counter to count up to the front panel setting, causing the comparator to generate a compare pulse. The active filter removes all AC components from this rectangular waveform, leaving a DC voltage that is proportional to the duty cycle of the waveform. The DC voltage is then applied to the integrator within the AC-DC converter.

The reference assembly also provides the error measurement feature. Error measurement is made by slightly adjusting the 7-volt reference supply in either direction. Since the variable reference signal is derived from the 7-volt supply and also controls calibrator output amplitude, adjustment of the supply results in adjustment of the calibrator output amplitude.

Exercises (221):

1. What is the output from the reference assembly referred to as?

2. How are error measurements made?

222. Analyze the operation of the 5200A AC/DC converter.

AC-DC Converter Assembly. The AC-DC converter produces an amplitude control voltage, which is derived from the sense signal input and a selected reference input, for use by the oscillator control assembly.

As shown in foldout 6, the 0.1 to 1.2 volt rms sense signal is fed to the buffer amplifier within the AC-DC converter. The buffer amplifier has a high impedance input to minimize voltage drop in the sense leads. The output of the buffer amplifier is fed to a wideband rectifier for conversion to a precise proportional DC value. The rectifier is a multipath operational amplifier and is equipped with diodes in the feedback paths.

The DC output of the rectifier is summed with the variable reference voltage produced by the reference assembly. The rectifier output is of the opposite polarity to the reference; and when the two are in the proper ratio to each other, the input to the high-gain integrator amplifier is zero and the output from the 5200A is constant. If either the DC sense signal or the variable reference voltage changes value, the integrator amplifier output amplitude changes accordingly. The oscillator control assembly, in turn, adjusts the amplitude of the oscillator in the proper direction and by the required amount to return the input to the integrator amplifier to zero. In this manner, the servo action of the amplitude control loop adjusts the oscillator amplitude in response to load changes and amplitude selection changes.

The input to the integrator is also directly affected by selection of the amplitude least significant digit. Front panel (or remote) selection of the least significant amplitude digit adds to or subtracts a positive voltage from the integrator input. This action results in a change of amplitude control voltage.

Exercises (222):

1. What does the AC-DC converter assembly compare?

2. What causes the amplitude control loop to adjust oscillator amplitude?

223. Analyze the operation of the 5200A oscillator control assembly.

Oscillator Control Assembly. The two main functions of the oscillator control assembly are to adjust the amplitude of the oscillator output in accordance with a negative amplitude control voltage from the AC-DC converter and to keep the oscillator output in phase with some external reference frequency when that feature is used. Oscillator amplitude control is a function of feedback from the output of the quadrature amplifier (contained in the oscillator assembly) to the input of the summing amplifier, effecting an adjustment in phase shift around the loop to provide a means of oscillator amplitude adjustment.

As shown in foldout 6, the quadrature amplifier output is fed from the oscillator assembly to the y-input of an analog multiplier (U3) contained in the oscillator control assembly. The output of the multiplier is fed to the input of the summing amplifier to control the oscillator output amplitude in accordance with the x-input of the multiplier. The x-input of the multiplier (U3) is derived from the negative amplitude control voltage (produced by the AC-DC converter) after comparison with the peak output of the oscillator quadrature amplifier. The comparison of the quadrature amplifier output to the amplitude control voltage creates a secondary control loop and is provided for by a diode switch operated indirectly by the oscillator output signal.

The oscillator output signal is fed to a zero-crossing detector. The zero-crossing detector operates to produce an output pulse whenever the oscillator output passes through zero while going from negative to positive (i.e., once each cycle). The quadrature amplifier output is 90° out of phase with the oscillator output, and the zero crossing pulses close the diode switch for a brief period of time when the quadrature amplifier output is at its + peak. The quadrature amplifier output and the negative amplitude control voltage (from the AC-DC converter) are both fed to the input of a DC amplifier that precedes the diode switch. As a result, the diode switch supplies a signal to the succeeding integrator whenever the peak positive voltage of the quadrature amplifier output is different from the negative amplitide control voltage. The integrator output is connected to the x-input of the analog multiplier to control the amplitude of the oscillator accordingly.

The action of this secondary control loop is such that any change in the amplitude control voltage causes an output from the integrator next time the diode switch closes. The integrator output causes the analog multiplier to adjust the amplitude of the oscillator output in accordance with the change in oscillator control voltage. This control loop operates within the previously described main control loop that employs the sense input and the AC-DC converter assembly.

The oscillator control assembly also provides for the phase-lock feature of the calibrator. The external phase-lock input is squared-up and applied to one input of a phase detector. The second input of the phase detector is derived from a one-shot multivibrator triggered by the zero-crossing detector. The one shot supplies a pulse to the phase detector that compares the phase relationship of the oscillator output and the external phase-lock reference signal. The phase detector produces an output proportional to their difference, which is summed with the other inputs to the summing amplifier. The phase detector provides a slight adjustment of oscillator loop gain, and thus, provides a small amount of frequency control.

The action of the phase-lock loop is such that any phase difference between the oscillator output and phase-lock reference input results in a proportional phase detector output. The output of the phase detector is summed with the other oscillator inputs and adjusts the total oscillator feedback by an amount necessary to bring about synchronism with the reference phase-lock input.

Exercises (223):

1. When is the zero-crossing detector used?

2. Must the input to the switch driver be negative or positive?

3. What is the output of the phase detector proportional to?

2-3. Power Supplies and Voltage Regulation

A PME specialist must be familiar with many different types of electronic test and measuring equipment. Normally, each electronic device requires a power supply. Since the power supply is a part of the test equipment you will calibrate, you should review the principles of power supplies.

Our brief discussion of power supplies will include a review of power supply sources, transformers, rectifiers, filters, and voltage regulators.

224. Specify the relation between the resistances of the windings of a typical power transformer.

Transformers. Most of the electronic test equipment and electronic standards use a battery for a DC source—or have some way of changing the voltage from an AC source to DC. Before the AC source voltage is changed to DC, it is usually changed in value to an amount which will meet the demands of the circuits being supplied. A transformer is normally used for this purpose.

If the AC source voltage is to be increased, the transformer is called a step-up transformer. A step-down transformer is one in which the AC source voltage is decreased. The types of transformers used in power supplies are as numerous as their applications. For the purpose of our discussion, power transformers to be discussed will be limited to filament, high-voltage, and combination high-voltage-filament transformers:

a. Filament transformers are step-down transformers whose output voltage is usually either 5 volts or 6.3 volts.

b. High-voltage transformers are step-up transformers whose output voltages may be several hundred volts or as high as several thousand volts.

c. Combination transformers have both high-voltage and filament-voltage outputs and are wound on the same core.

All three types of transformers have one primary winding and one or more secondary windings.

Schematics of the three classifications of transformers listed are shown in figure 2-4. In most cases a transformer performs one or more specific functions under a given set of operating conditions. Thus, a transformer that is designed to operate with 400-Hz AC will not operate efficiently with 60-Hz AC. Similarly, if a 115-volt transformer is connected to a 230-volt source, the output voltages are doubled; and since the insulation in the transformer is designed to withstand lower values of voltage, there is an obvious danger of insulation breakdown and arcing. Each winding of a transformer is designed to carry a given amount of current. If we exceed this limit, we overload the transformer—as evidenced by overheating and by burning insulation.

The wires which protrude from the transformer will be color-coded. Typical color codes used with transformers can be seen in table 2-1. If there is more than one primary tap, other colored tracers on black will be used to identify them. If the code for identifying the various leads is not available, it is often possible to identify them by means of resistance measurements. The filament windings carry large values of current and consist of a few turns of heavy wire. As a result, the resistance of a filament winding is practically zero. The high-voltage windings, on the other hand, are made of many turns of fine wire because very little current is carried by these windings. The resistance of a high-voltage winding is comparatively high and is different for different transformers. For a given power transformer, however, the high-voltage winding has the greatest resistance. The primary winding has fewer turns than the high-voltage secondary but more than the filament windings. The primary carries more current than high-voltage secondary but less than the filament secondaries.

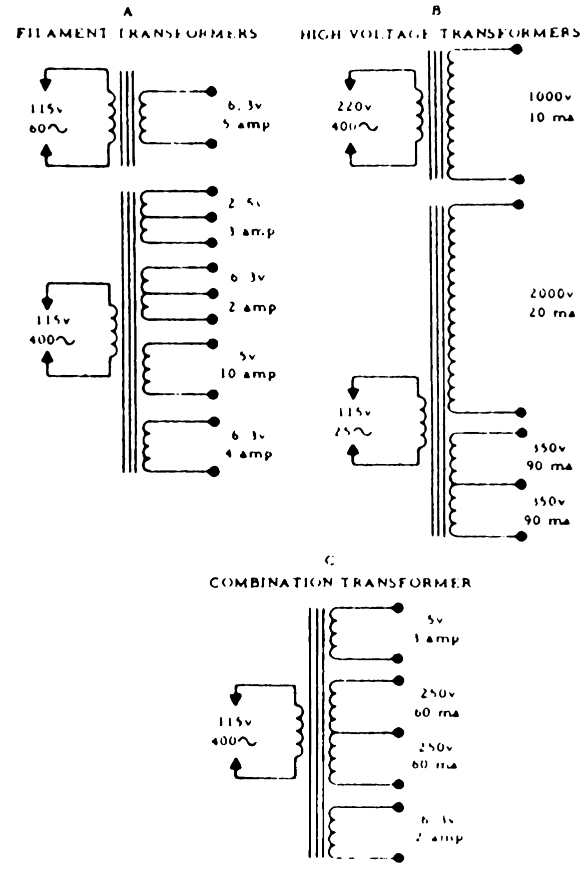


Figure 2–4. Typical power transformer.

Thus, the size of the wire used for the primary is usually between that of the filament windings and that of the high-voltage winding. As a result, the resistance of the primary may be expected to be greater than that of the filament windings but, less than that of the high-voltage windings.

Exercises (224):

1. Which winding of a typical power transformer has the greatest resistance, the filament winding or the primary winding?

2. Which winding has the least resistance, the high-voltage secondary or the primary winding?

225. Differentiate between the three types of rectification used in the typical power supply and cite their operational characteristics.

Rectifiers. You will recall that a rectifier is a device used to change AC to DC. Rectifiers are classified generally as half-wave, full-wave, or bridge-type rectifiers. We will discuss these three general classifications.

Half-wave rectifiers. The single-phase, half-wave rectifier is the simpliest type of rectifier circuit. It consists of a semiconductor diode in series with the alternating source and the load. Since the rectifier conducts in only one direction, electrons flow through the load and through the rectifier only once during each complete cycle of the input voltage. Thus, the electron flow through the load occurs in pulses, one pulse for every other half cycle of the input voltage. In figure 2-5, parts A and B illustrate a semiconductor diode, CR1, used in two variations of a basic single-phase, half-wave rectifier circuit. These two circuit variations each employ a transformer (T1) either for isolation or to step up the alternating source voltage to a higher value in the secondary. The use of a transformer in this circuit permits either DC output terminal to be placed at ground potential. The two circuit variations shown in parts C and D of figure 2-5 do not use a transformer, but operate directly from the AC source. Both of the circuits place one side of the AC source at a DC potential, and thus restrict the output of the supply to either a positive DC potential (C) or a negative DC potential (D).

In the four circuits illustrated in figure 2-5, the function of semiconductor diode CR1 is the same for each circuit. Because of the manner in which the diode is placed in the circuit, electrons flow through the load in the direction indicated by the arrow adjacent to the load resistance. The DC output polarity for each circuit is indicated by the signs associated with the load resistance. The triangle in the graphic symbol for diode CR1 points in the direction of forward current flow; electron flow is in the opposite direction. The letter K assigned to one terminal of the graphic symbol for CR1 indicates that this terminal corresponds to the cathode (filament) of an electron-tube diode. Therefore, the terminal represented by the pointed-arrow portion of the graphic symbol corresponds to the plate of an electron-tube graphic diode.

Each of the four circuits in figure 2-5 shows a resistor, Rs, in series with the semiconductor diode. This resistor, called the *surge resistor,* limits the peak current through the rectifier to a safe value. The value of resistor Rs is influenced by the circuit design; determination of its value includes the consideration of several other factors, such as the applied AC voltage, the resistance of the load circuit, the filter-circuit input capacitance, and the peak current rating of the semiconductor diode. If there is sufficient resistance in the secondary winding of transformer T1 (shown in parts A and B) or in the AC source (parts C and D), the resistor may be omitted; also, if the load circuit of the supply includes a choke-input filter, the resistor may be omitted.

The operation of the half-wave rectifier circuit can be understood from the simplified circuits shown in parts A and B of figure 2-6 and the waveforms shown in part C of the figure.

Assume that the AC voltage applied to the input terminals of the rectifier circuit during the initial half-cycle has the polarity indicated in part A of the figure. Electrons flow in the direction indicated by the small arrows; hence,

TABLE 2–1

TYPICAL COLOR CODES FOR A POWER TRANSFORMER

Color	Winding
Black	*Primary
Red	High-voltage secondary.
Red with yellow tracer	Center tap of above, if used
Yellow	Rectifier filament secondary
Yellow with blue tracer	Center tap of above, if used
Green	Filament secondary No. 1
Green with yellow tracer	Center tap of above, if used
Brown	Filament secondary No. 2
Brown with yellow tracer	Center tap of above, if used
Slate (pale gray)	Filament secondary No. 3
Slate with yellow tracer	Center tap of above, if used
*If primary is tapped	
Black	Common lead
Black with yellow tracer	Tap lead
Black with red tracer	Finish lead

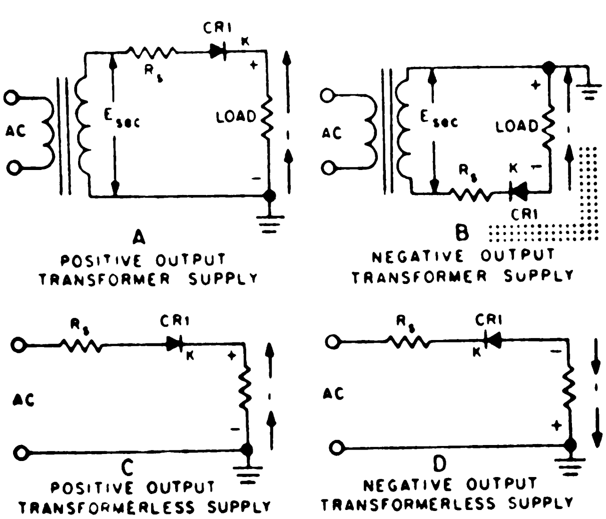


Figure 2–5. Basic half-wave rectifier circuits.

their path is from the lower (negative) input terminal, through the load, through the rectifier CR, and to the upper (positive) input terminal. Thus, during the initial half-cycle, rectifier CR passes maximum current in the forward direction, and an output voltage is developed across the load resistance. In other words, when the rectifier conducts, electrons pass through the load to develop a corresponding output-voltage pulse, as shown in part C of figure 2-6.

During the next half-cycle, the polarity of the applied AC input is as indicated in part B of the figure. Except for possibly a very small value of reverse current, the rectifier does not conduct, the reverse resistance remains high, and the small current that flows can be neglected. Normally, the reverse resistance of the rectifier is extremely high as compared with the circuit load resistance. Thus, during the second half-cycle, very little voltage is developed across the comparatively low load resistance. In other words, because the rectifier is nonconducting and few electrons pass through the load, there is almost no output from the circuit.

The waveforms shown in part C indicate that, on positive half cycles of the applied voltage, current passes through

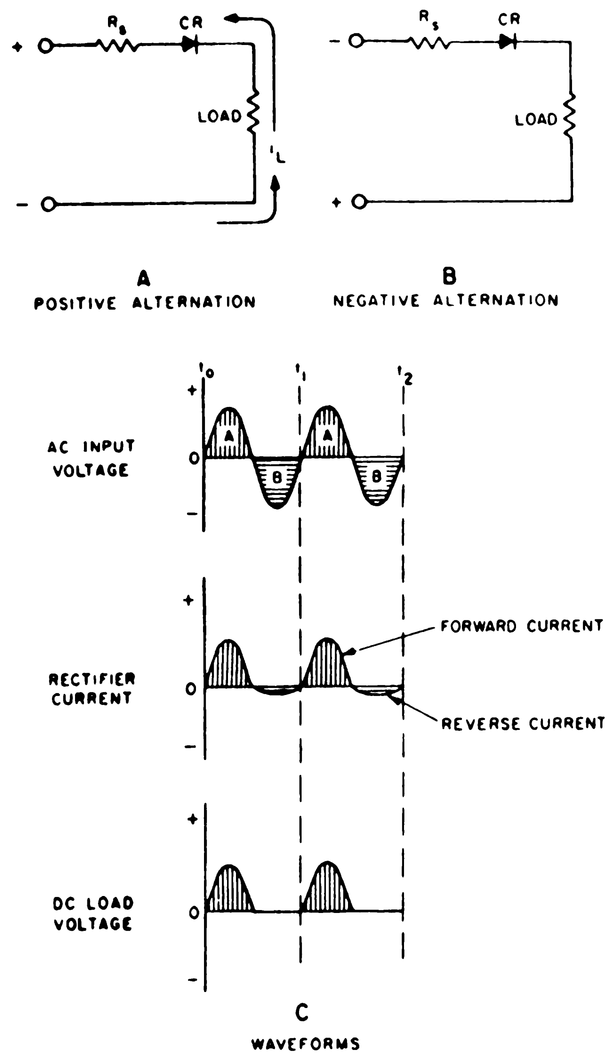


Figure 2–6. Typical half-wave rectifier circuit operation and waveforms.

the rectifier and the load resistance, producing an output voltage across the load resistance. The output voltage has a pulsating waveform (irregularly shaped ripple voltage); the frequency of the ripple voltage is the same as the frequency of the AC source. Since the output voltage and current are not continuous, the half-wave rectifier circuit requires considerable filtering to smooth out the ripple and produce a steady DC voltage.

The *peak-inverse voltage* of the semiconductor rectifier is defined as the maximum instantaneous voltage in the direction opposite to that in which the rectifier is designed to pass current. Assuming that the output of the supply is filtered, the peak-inverse voltage across the rectifier in a half-wave rectifier circuit is approximately 2.83 times the rms value of the applied (or transformer secondary) voltage during the time when the rectifier is nonconductive.

The output of the half-wave rectifier circuit is normally connected to a suitable filter circuit to smooth the pulsating direct current for use in the load circuit. Because of the very low forward resistance of the semiconductor rectifier and its associated low internal-voltage drop, which is practically independent of load current, the half-wave power supply using a semiconductor diode will have somewhat better regulation characteristics than the equivalent electron-tube circuit. However, the regulation is still considered to be relatively poor.

Full-wave rectifiers. The single-phase, full-wave rectifier is one of the most common types of rectifier circuits employed in electronic equipment. It may be used as a low-voltage DC supply for the operation of relays, motors, electron-tube filaments, telephone and teletype circuits, and semiconductor circuits, or as a high-voltage DC supply for the operation of electron-tube circuits. The full-wave rectifier circuit consists of a transformer with a center-tapped secondary winding. At least two semiconductor diodes are used in the circuit; one diode is connected to one end of the transformer secondary, and the other diode is connected to the other end.

The load is connected between the center tap of the secondary winding and the common junction of the two semiconductor diodes. Since the secondary winding is center-tapped, the voltages developed in the two halves of the secondary winding are in series with each other; therefore, only one rectifier conducts at any instant. As a result, electrons flow through one-half of the secondary winding, the load, and a rectifier on each half-cycle of the impressed voltage, with first one diode conducting and then the other. Thus, the electrons flow through the load in pulses, one pulse for each half-cycle of the impressed voltage.

In parts A and B of figure 2-7, two semiconductor diodes, CR1 and CR2, are used in a basic single-phase, full-wave rectifier circuit. Although the schematic shows only two diodes in the circuit, in some instances for high-voltage operation each diode symbol represents two or more diodes in series to obtain the necessary peak-inverse characteristics. The circuit uses a single transformer, T1, either to step up the alternating-source voltage to a higher value in each half of the secondary winding or to step down the voltage to a lower value. The circuit application and the values of the input and output voltages determine whether a step-up or step-down transformer is required.

A series surge resistor, R_s, is generally used only in high-voltage supplies and is eliminated in low-voltage supplies. Since the resistor is placed in the circuit between the transformer center tap and ground, it is common to both rectifiers. A variation of this design practice uses two resistors, one resistor in series with each rectifier.

The circuit arrangement shown in part A of the figure is typical of many low-voltage positive output supplies. The circuit shown in part B is typical for bias supply applications requiring a negative voltage. In the basic circuits illustrated, either terminal of the load may be placed at ground potential, depending on whether you desire a positive or negative DC output. When the DC output terminal associated with the transformer center tap is grounded, the secondary-to-core insulation need not be as great as it would be if the secondary winding were above

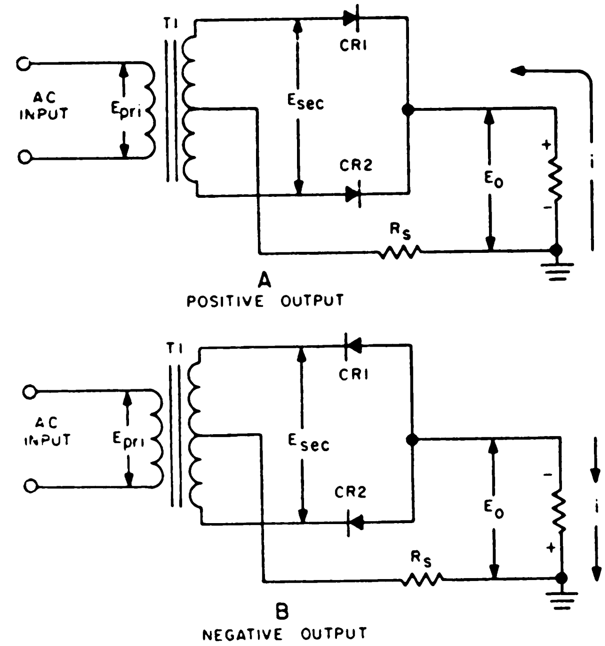


Figure 2–7. Basic single-phase full-wave rectifier circuits.

ground by the amount of the DC output voltage. For this reason, the two circuits shown in parts A and B are the commonly used circuits, as they do not require that special design consideration be given to the secondary-winding insulation.

The full-wave rectifier circuit uses the transformer (T1) for a greater percentage of the input cycle than does the half-wave rectifier previously described, because there are two pulsations of current in the output for each complete cycle of the applied alternating voltage. Since only one-half of the secondary winding is in use at any one time, the total secondary voltage (e_{sec}) must be twice the secondary voltage that would be required for use with a half-wave rectifier circuit. Each half of the secondary winding is electrically equal to the other; the current passes first in one direction through one-half of the secondary winding and then in the other direction through the other half of the secondary winding. Therefore, little DC core saturation occurs, and the efficiency of the transformer is relatively high. As a result, the full-wave rectifier circuit is more efficient, has less output ripple amplitude, and has better voltage regulation than the half-wave rectifier circuit. Although the efficiency of the full-wave rectifier is better than that of the half-wave rectifier, the circuit is not as efficient as a bridge rectifier circuit.

The peak-inverse voltage across a semiconductor rectifier in a full-wave circuit, during the time it is nonconducting, is approximately 2.83 times the rms voltage across half of the transformer secondary,

$$\frac{(e_{sec})}{2}$$

or approximately 1.41 times the rms voltage across the entire secondary (e_{sec}).

In a full-wave rectifier circuit designed to furnish high-voltage DC to the load, the peak-inverse voltage rating of the semiconductor rectifier is an important consideration. For such applications, several identical-type rectifiers may be placed in series, or stacked, to withstand the peak-inverse voltage and avoid the possibility of rectifier breakdown. Generally, whenever a single rectifier unit is used in the full-wave circuit, it is chosen to have a peak-inverse voltage rating that is conservative and thus provide a safety factor. The single unit may actually be an assembly of several cells or elements connected in series to obtain the desired rating.

The output of the full-wave rectifier circuit is connected to a suitable filter circuit to smooth the pulsating direct current for use in the load circuit. Because of the very low forward resistance of the semiconductor rectifier and its low internal-voltage drop, which is practically independent of load current, full-wave power supply using semiconductor diodes has regulation characteristics that approach or equal those of the equivalent electron-tube circuit using mercury-vapor rectifiers. Hence, its regulation characteristics are somewhat better than those of the electron-tube circuit which uses high-vacuum rectifiers.

Full-wave bridge rectifier. The single-phase, full-wave bridge rectifier circuit uses two semiconductor rectifiers in series on each side of a single transformer secondary winding; thus, four rectifiers are incorporated in the bridge circuit, one in each arm of the bridge. During each half-cycle of the impressed AC voltage, two rectifiers, one at each end of the secondary, conduct in series to produce an electron flow through the load. Thus, the electron flow through the load occurs in pulses, one pulse for each half-cycle of the impressed voltage. Since two DC output pulses are produced for each complete input cycle, full-wave rectification is obtained, and the output is similar to that of the conventional full-wave rectifier circuit.

One advantage of the bridge rectifier circuit over a conventional full-wave rectifier is that for a given transformer total-secondary voltage the bridge circuit produces an output voltage nearly twice that of the full-wave circuit. Another advantage is that the peak-inverse voltage across an individual rectifier, during the period of time it is nonconducting, is approximately half the peak-inverse voltage across a rectifier in a conventional full-wave circuit designed to produce the same output voltage.

In many power-supply applications, it is desirable to provide two voltages simultaneously—one voltage for high-power stages and the other for low-power stages. For these applications the single-phase, full-wave bridge rectifier circuit can be modified to supply an additional output voltage equal to one-half of the voltage provided by the full-wave bridge rectifier circuit.

Figure 2-8 shows a single-phase, full-wave bridge rectifier using semiconductor diodes. Four identical semiconductor rectifiers, CR1, CR2, CR3, and CR4, are connected in the bridge circuit across the secondary winding of transformer T1. Each rectifier forms one arm of the bridge circuit; the load is connected between the

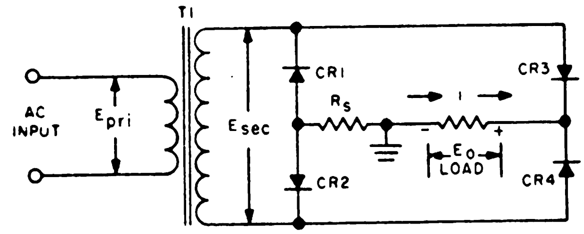


Figure 2–8. Basic single-phase full-wave bridge rectifier circuit.

junction points of the balanced arms of the bridge. The circuit uses a single transformer, T1, either to step up the alternating source voltage to a higher value in the secondary winding or to step down the voltage to a lower value. The circuit application and the values of the input and output voltages determine whether a step-up or step-down transformer is required. The series surge resistor (Rs) is generally used only in high-voltage supplies, it is not normally required in low-voltage supplies. The resistor, when used, is common to all of the rectifiers, since it is placed in series with the load and filter circuit.
either terminal of the load to be placed at ground potential, depending upon whether a positive or negative DC output is desired.

You should be able to understand the operation of the full-wave bridge rectifier circuit. It can be understood from the simplified circuit schematic shown in parts A and B and the waveforms shown in part C of figure 2-9, and by reference to the explanation given for the equivalent electron-tube bridge circuit. The basic bridge rectifier schematic, provided previously, has been simplified and redrawn to show the action that occurs on alternate half-cycles of the applied voltage. The rectifier reference designations used correspond to those assigned in the basic bridge schematic.

During the first half-cycle, the transformer secondary winding may be considered as a voltage source of the polarity given in part A of the figure. As a result, electrons flow, in the direction indicated by the arrows, through the series circuit composed of rectifier CR2, resistor Rs, the load, and the rectifier CR3. This electron flow produces an output pulse of the polarity indicated across the load resistance. Also, during this period, rectifiers CR1 and CR4 are nonconducting.

During the next half-cycle, a secondary voltage is produced of the polarity shown in part B of the figure. As a result, electrons flow through the series circuit composed of rectifier CR1, resistor Rs, the load, and rectifier CR4. The electrons flowing in the series circuit once again produce an output of the same polarity as before across the load resistance. During this period, rectifiers CR2 and CR3 are nonconducting.

From the waveforms given in part C of the figure, you can see that two rectifiers in series conduct at any instant of time; thus, on alternate half-cycles, electrons flow through the load resistance to produce a pulsating output voltage, e_o.

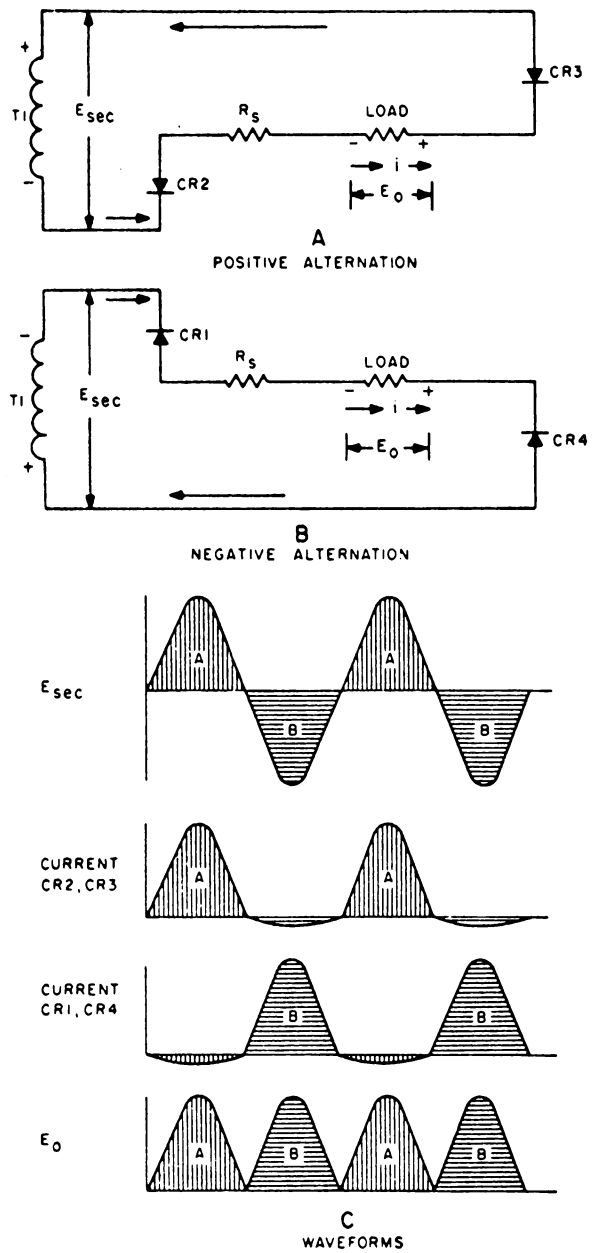


Figure 2–9. Simplified full-wave bridge rectifier circuit and waveforms.

This pulsating waveform results in an irregularly shaped ripple voltage because the output voltage and current are not continuous; the frequency of the ripple voltage is twice the frequency of the AC source. The output of the full-wave bridge rectifier circuit requires filtering to smooth out the ripple and produce a steady DC voltage.

The full-wave bridge rectifier circuit makes continuous use of the transformer secondary; therefore, there are two pulsations of current in the output for each complete cycle of the applied AC voltage. The DC load current passes through the entire secondary winding, flowing in one direction for one half-cycle of the applied voltage, and in the opposite direction for the other half-cycle; thus, there is no tendency for the transformer core to become permanently magnetized. Since little DC core saturation occurs, the effective inductance of the transformer, and therefore the efficiency, is relatively high.

The peak-inverse voltage across an individual rectifier in a full-wave bridge rectifier circuit during the period of time the rectifier is nonconducting is approximately 1.41 times the rms voltage across the secondary winding. The secondary voltage, e_{sec}, is applied to two rectifiers in series. Therefore, since approximately one-half of the peak-inverse voltage appears across each rectifier, the bridge circuit can be used to obtain a higher output voltage than can be obtained from a conventional full-wave rectifier circuit using identical rectifiers.

In bridge circuits designed to furnish high-voltage DC to the load, the peak-inverse voltage rating of the semiconductor rectifier is an important consideration. For such applications, several identical rectifiers may be placed in series, or stacked, to withstand the peak inverse voltage and avoid the possibility of rectifier breakdown.

The output of the full-wave bridge rectifier is similar to that of the conventional full-wave rectifier circuit. For the same total transformer secondary voltage and DC output current, the bridge rectifier provides twice as much output voltage as does the full-wave rectifier circuit using a center-tapped secondary. The output of the bridge rectifier circuit is connected to a suitable filter circuit to smooth out the pulsating direct current for use in the load circuit.

Exercises (225):

1. What is the output ripple frequency of a half-wave rectifier?

2. Why is the ripple frequency from a full-wave rectifier twice that of the half-wave rectifier?

3. What advantage does the bridge-type rectifier have over the full-wave rectifier?

4. What is a rectifier?

5. What are the three types of rectifier circuits?

6. What does the letter K assigned to one terminal of the graphic symbol for CR1 indicate?

7. In a rectifier circuit, what is the purpose of the "surge resistor" Rs?

8. Where is the load connected in a full-wave rectifier?

9. Which rectifier circuit is the most efficient?

10. What is the peak-inverse voltage across a semiconductor rectifier in a full-wave circuit?

11. What is the peak-inverse voltage across an individual rectifier in a bridge circuit?

226. Compare the choke input filter with the capacitive input filter.

Filters. You will notice from the illustrations shown in figures 2-6 and 2-8 that the output voltages from the types of rectifiers mentioned are pulsating DC voltages. To minimize the distortion that variations in voltages cause, practically all rectifiers are followed by a filter circuit.

Capacitor-input filter. Figure 2-10 shows a half-wave rectifier using a capacitor-input pi-type filter. As the electrons flow in the path indicated by the solid arrows in figure 2-10, capacitors C1 and C2 are charged with the polarity shown. On the conducting half-cycle the polarity of the high-voltage secondary is as shown in figure 2-10. Thus, the voltage applied to V1 at any instant is the value of the AC voltage (EAC in figure 2-10 minus the voltage (EC1) across C1, figure 2-11). As a result, the current flow from the diode ceases as soon as EC1 reaches the maximum (peak) value of EAC. If RL is not connected to the output terminals and if the filter capacitors are assumed to have no leakage, the output voltage across the output terminals is a pure DC equal to maximum value of EAC, or 1.414 EAC. When the load resistor (RL) is connected across the output terminals, capacitors C1 and C2 begin to discharge through it. The discharge path is shown in figure 2-10 by the broken line arrows. The extent to which the capacitors discharge depends upon the load which, in turn, depends upon the impedance of the load, RL. If RL is large, C1 loses some of its charge, and the voltage across it begins to decrease to point 2 shown in figure 2-11,B. At point 2, the AC voltage across V1 has reached the point where it exceeds the

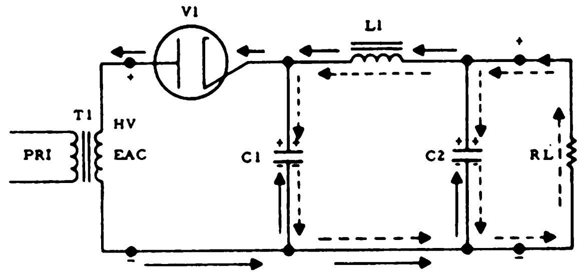


Figure 2–10. Capacitor input filter.

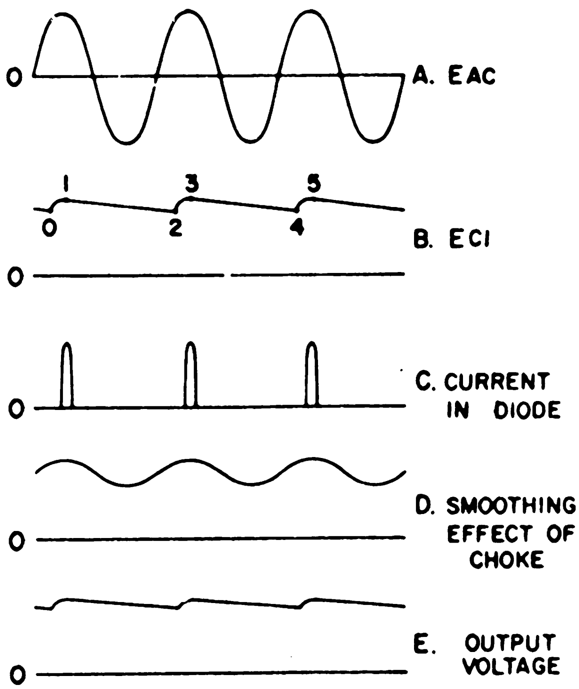


Figure 2–11. Capacitor input filter waveforms.

voltage across C1, and the tube conducts until C1 is again fully charged (point 3). From 3 to 4 the process is the same as from 1 to 2.

Examination of figure 2-11,B, shows that the only time V1 conducts is during the intervals 0 to 1, 2 to 3, and 4 to 5; that is V1 conducts only when the filter capacitors require recharging. The flow of current in V1 is shown graphically in figure 2-11,C. The amplitude and duration of these current pulses depend upon the value of the load, since all the current used by the load device is produced during these short pulses.

The current flow from C1 through RL must pass through the choke L1. An inductance opposes changes in current, and the changes are greatest at points 0, 2, and 4 of figure 2-11,B. If C2, shown in figure 2-10, were omitted, the output voltage would resemble the waveform shown in figure 2-11,D. The average voltage at this point has dropped only slightly because of the DC voltage drop across L1. This decrease in voltage is equal to the product of the load current and the resistance of L1. Since the resistance of the wires in L1 is small and the load is light, the voltage drop across L1 is negligible. The filtering action of C2 is similar to that of C1, and the output is practically a pure DC voltage, as seen in figure 2-11,E.

You should recognize the circuit in figure 2-12 as being one of a full-wave rectifier using a pi-type, capacitor-input filter. You will recall that this circuit has many advantages over the half-wave rectifier. All the advantages of the full-wave rectifier result from its greater ripple frequency. The characteristics of a full-wave rectifier with a capacitor-input filter may be summarized as follows:

a. Output voltage is approximately 1.414 EAC, depending on the magnitude of the load. However, the load may be greater than that of half-wave rectifiers.

b. Ripple frequency is equal to twice the frequency of the input AC.

c. Filtering action is good with light loads and poor with heavy loads.

d. Voltage regulation is poor because output voltage depends on the value of the load.

e. Each diode conducts heavily during short intervals but not as heavily as in half-wave rectifiers.

f. The AC voltage of the high-voltage secondary is about twice that required for a half-wave rectifier with the same DC output voltage.

g. The peak-inverse voltage is about twice the maximum value of the AC applied across each diode, or 3.8 EAC or 2 EDC.

Choke-Input Filters. The choke-input filter is superior to the capacitor-input filter in that it provides better voltage regulation. As a result, the choke-input filter is used almost exclusively in power supplies for transmitters and for other electronic circuits which require a large amount of DC. The use of a choke-input filter, however, gives less DC output voltage for a given AC input and requires full-wave rectification. Half-wave rectifiers are not ordinarily used with choke-input filters, because current flows in them for only half a cycle (180°); choke-input filters require, for proper operation, current which flows for 360° of the AC input cycle.

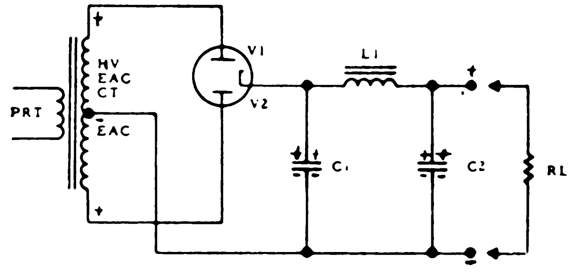


Figure 2–12. Full-wave rectifier with capacitor input filter.

The output voltage obtained with an L-type filter is considerably less than that obtained with a capacitor-input filter. This result is to be expected because the ripple has been attenuated by L1, and the filter capacitor (C1) charges to a lower value than it did when it was connected directly to the output of the rectifier. Since the ripple is reduced to such a large extent, an increase in load does not lower the output voltage to the extent that it does when capacitor-input filters are used. Therefore, choke-input filters do a better job of voltage regulation. The tubes conduct considerably less than they do with capacitor-input filters. As a result, the cathodes need not be capable of emitting large quantities of electrons in short periods of time. The use of choke-input filters contributes to longer tube life and better overall efficiency. The characteristics of full-wave rectifiers using choke-input filters may be summarized as follows:

a. Output voltage is equal to approximately 0.9 EAC.

b. Ripple frequency is equal to twice that of the input AC.

c. Filtering action is fair—not as good as capacitor input with light loads but better than capacitor input with heavy loads.

d. Voltage regulation is good.

e. Smaller peak currents are required from diodes.

f. The peak-inverse voltage is 2.828 EAC or 2 EDC.

Exercises (226):

Compare the choke-input filter with the capacitor-input filter with regard to the following:

1. Output voltage.

2. Filtering action.

3. Voltage regulation.

227. From figure 2-14, determine whether the regulator is series or shunt; and state results if voltage output decreases.

Voltage Regulators. Changes in load conditions in electronic circuits can occur in millionths of a second. To insure that these load variations do not cause the DC voltage output of the power supply to vary with load variations, we must use a sensitive voltage regulator.

When used properly, voltage regulator (VR) tubes absorb all but 5 percent of the voltage changes. Vacuum-tube regulators will absorb all but 1 percent of the voltage variations. Obviously, the vacuum-tube regulator is much more effective than the gas-tube regulator. The type of regulator depends upon the degree of regulation required. Figure 2-13 shows the circuit for a full-wave rectifier with a pi-type filter. The output of this power supply is regulated by a VR–105–30 tube.

By taking advantage of the high amplification of pentode vacuum tubes, voltage-regulator circuits have been devised to give output voltages of very high stability. One such circuit, shown in figure 2-14, provides an output which is independent of both rectifier output and load conditions over a wide range. The regulated output voltage appears across the series bleeder resistors R3, R4, and R5. This output voltage is in series with V1, whose resistance (bias) is varied by the rest of the circuit. These variations in plate resistance keep the output voltage constant.

Exercises (227):

1. Is the regulator in figure 2-14 series or shunt?

2. Describe the signal flow in the regulator if the voltage output should attempt to decrease.

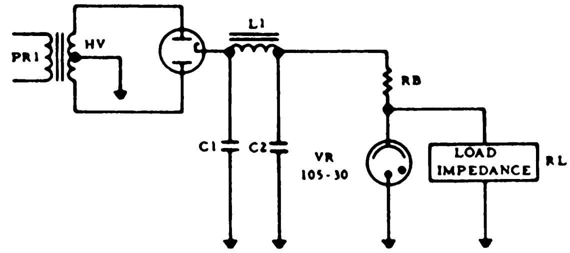


Figure 2–13. Power supply with a gas tube regulator.

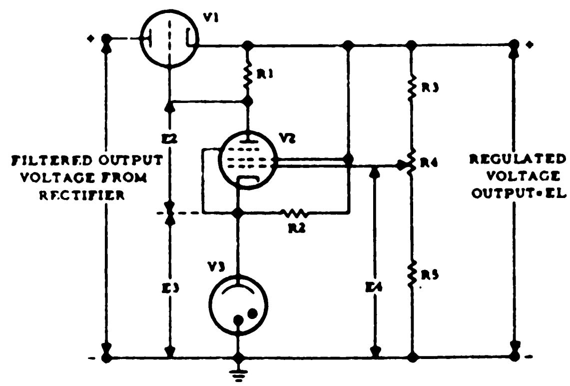


Figure 2–14. Electronic voltage regulator.

228. State the origin and uses of power in the 6202B power supply.

The 6202B Power Supply. The 6202B power supply is completely transistorized and is suitable for either bench or relay rack operation. It is a compact, well-regulated, constant voltage/constant current supply that will furnish full rated output voltage at the maximum rated output current or can be continuously adjusted throughout the output range. The CURRENT controls can be used to establish the output current limit (overload or short circuit) when the supply is used as a constant voltage source, and the voltage controls can be used to establish the voltage limit (ceiling) when the supply is used as a constant current source. A single meter is used to measure either output voltage or output current in one of two ranges.

Let's look at a block diagram of the 6202B power supply and see how it works. Refer to figure 2-15 for the following discussion.

The power supply, as shown on the overall block diagram, consists of a power transformer, a rectifier and filter, a series regulator, the mixer and error amplifiers, an "OR" gate, a constant voltage input circuit, a constant current input circuit, a reference regulator circuit, a bias supply, and a metering circuit.

The input line voltage passes through the power transformer to the rectifier and filter, where it is converted to raw DC. The DC current passes through the series regulator to the positive output terminal via a current sampling resistor. The regulator, part of the feedback loop, is made to alter its conduction to maintain a constant output voltage or current. The voltage developed across the current sampling resistor is the input to the constant current input circuit. The output voltage of the power supply is sampled by the voltage input circuit by means of the sensing terminals (±S). Any changes in output voltage/current are detected in the constant voltage/constant current input circuit, amplified by the mixer and error amplifiers, and applied to the series regulator in the correct phase and amplitude to counteract any change in output voltage/output current. The reference circuit provides stable reference voltages which are used by the constant voltage/current input circuits for comparison purposes. The bias supply furnishes voltages that are used throughout the instrument for biasing purposes. The meter circuit provides an indication of output voltage or current.

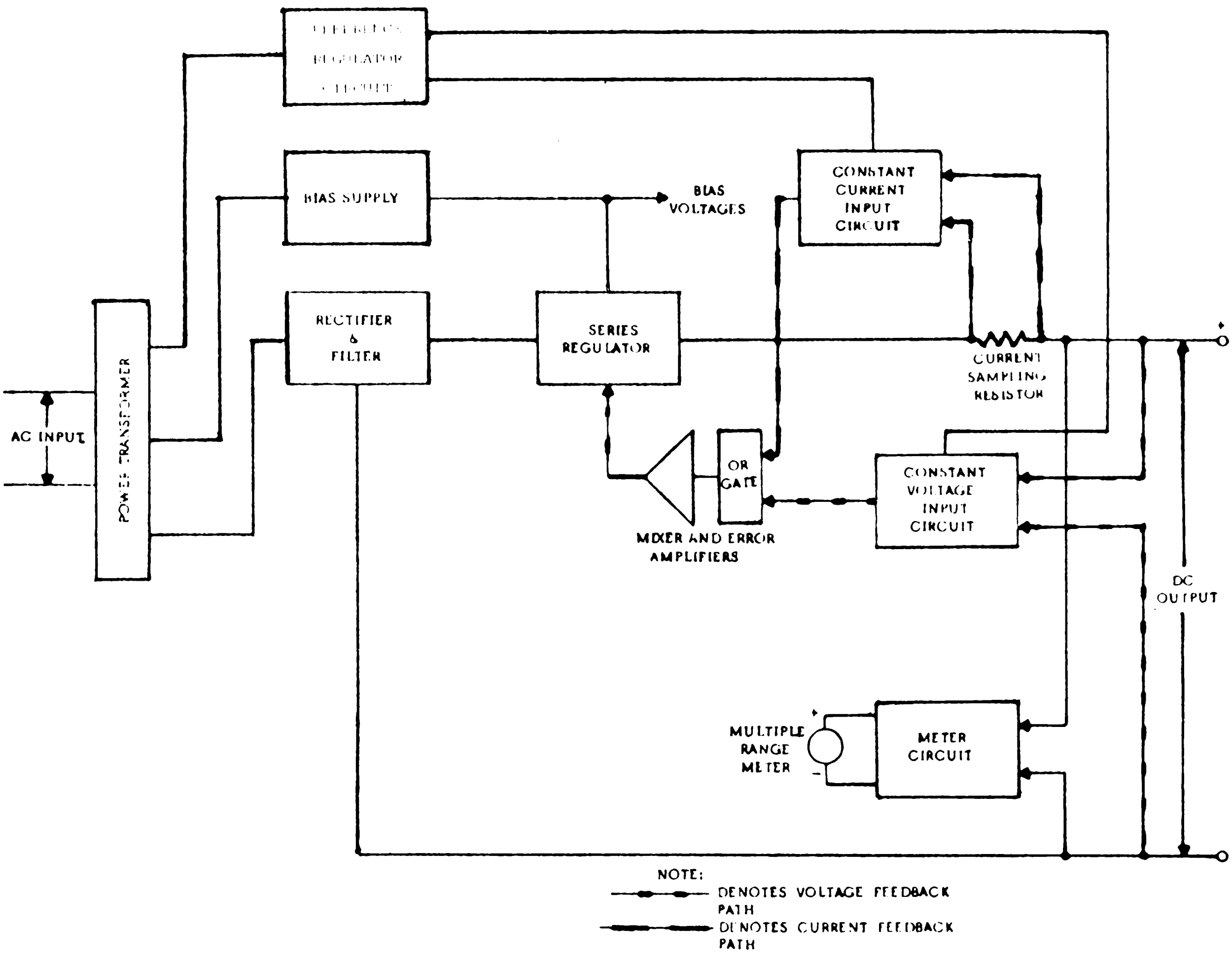


Figure 2-15. Block diagram of the 6202B power supply.

Exercises (228):

1. The constant current input circuit of the 6202B power supply is developed where?

2. What does the bias supply of the 6202B provide?

229. Specify the operational characteristics of the internal instrument power supply of the 6202B.

Now that you've been through the basic block diagram of the 6202B power supply, let's take a closer look at some of the individual circuits for a better, more thorough understanding of them.

A simplified schematic of the power supply is shown in figure 2-16. It shows the operating controls, the ON-OFF switch, the voltage programming controls (R10A) and R10B), and the current programming controls (R16A) and R16B). The meter switch, included in the meter circuit block on figure 2-16, allows the meter to read output voltage or current in either of two ranges. Figure 2-16 also shows the internal sources of bias and reference voltages and their nominal magnitudes. Diode CR34, connected across the output terminals of the power supply, is a protective device which prevents internal damage that might occur if a reverse voltage were applied across the output terminals. Output capacitor C20 is also connected across the output terminals when the normal strapping pattern shown in figure 2-16 is employed. Note that this capacitor can be removed if an increase in the programming speed is desired. Under these conditions, capacitor C19 serves to insure loop stability.

Series Regulator. The series regulator consists of transistor stages Q6 and Q7. The transistors are connected in parallel so that approximately half of the output current flows through each one. The regulator serves as a series control element by altering its conduction so that the output voltage or current is kept constant. The conduction of the transistors is controlled by the feedback voltage from the error amplifier. Diode CR11, connected across the regulator circuit, protects the series transistors against reverse voltages that could develop across them during parallel or auto-parallel operation if one supply is turned on before the other.

Exercises (229):

1. See figure 2-16. If reverse voltage is applied across the output terminals of the 6202B, how is the instrument protected?

2. Why are the output current transistors of the 6202B connected in parallel?

230. Specify the operational characteristics of the constant voltage input circuit of the 6202B power supply.

Constant Voltage Input Circuit. The circuit (fig. 2-17) consists of the coarse and fine programming resistors (R10A and R10B), and a differential amplifier stage (Q1 and associated components). Transistor Q1 consists of two silicon transistors housed in a single package. The transistors have matched characteristics minimizing differential voltages due to mismatched stages. Moreover, drift due to thermal differentials is minimized since both transistors operate at essentially the same temperature.

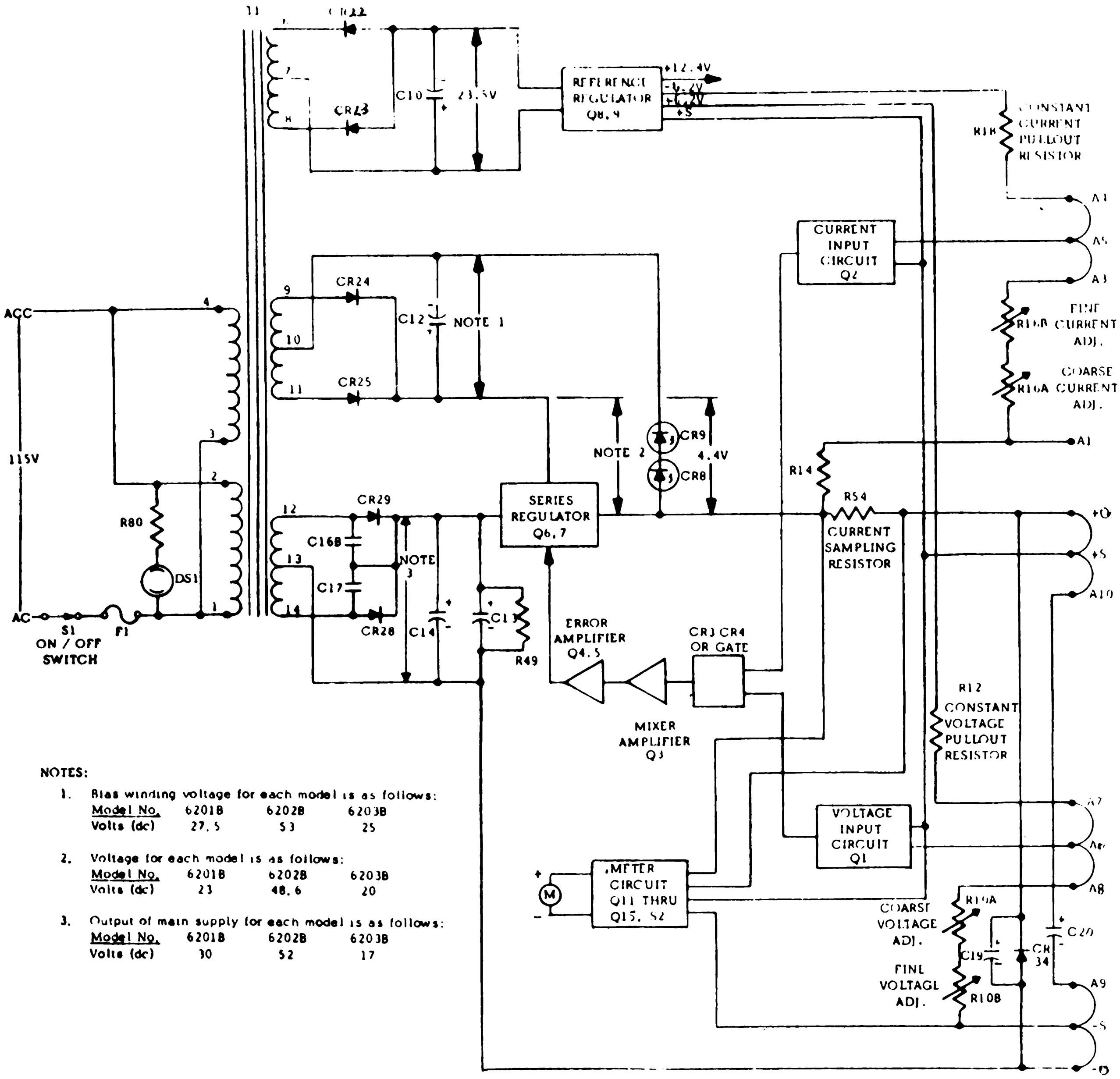
The constant voltage input circuit continuously compares a fixed reference voltage with a portion of the output voltage and, if a difference exists, produces an error voltage whose amplitude and phase is proportional to the difference. The error output is fed back to the series regulator through an OR gate and the mixer/error amplifiers. The error voltage changes the conduction of the series regulator which, in turn, alters the output voltage so that the difference between the two input voltages applied to the differential amplifier is reduced to zero. This action maintains the output voltage constant.

Stage Q1B of the differential amplifier is connected to a common (+S) potential through impedance equalizing resistor R5. Resistor R6 and R8 are used to zero bias the input stage, offsetting minor base to emitter voltage differences in Q1. The base of Q1A is connected to a summing point at the junction of the programming resistors and the current pullout resistor R12. Instantaneous changes in output voltage result in an increase or decrease in the summing point potential. Q1A is then made to conduct more or less in accordance with summing point voltage change. The resultant output error voltage is fed back to the series regulator via the remaining components of the feedback loop. Resistor R1, in series with the base Q1A, limits the current through the programming resistors during rapid voltage turn-down. Diodes CR1 and CR2 form a limiting network which prevents excessive voltage excursions from over driving stage Q1A. Capacitors C1 and C2, shunting the programming resistors, increase the high frequency gain of the input amplifier. Resistor R13, shunting pullout resistor R12, serves as a trimming adjustment for the programming current.

Exercises (230):

Refer to figure 2-17 as necessary to answer the following questions.

1. How are thermal drift differentials in the input circuit of the 6202B kept to a minimum?



4-4 SIMPLIFIED SCHEMATIC

4-5 A simplified schematic of the power supply is shown in Figure 4-2. It shows the operating controls; the ON-off switch, the voltage programming controls (R10A and R10B), and the current programming controls (R16A and R16B). The METER switch, included in the meter circuit block on Figure 4-2, allows the meter to read output voltage or current in either of two ranges. Figure 4-2 also shows the internal sources of bias and reference voltages and their nominal magnitudes. Diode CR34, connected across the output terminals of the power supply, is a protective device which prevents internal damage that might occur if a reverse voltage were applied across the output terminals. Output capacitor, C20, is also connected across the output terminals when the normal strapping pattern shown on Figure 4-2 is employed. Note that this capacitor can be removed if an increase in tne programming speed is desired. Under these conditions, capacitor C19 serves to insure loop stability.

Figure 2-16. Simplified schematic.

4-6 SERIES REGULATOR

4-7 The series regulator consists of transistor stages Q6 and Q7 (see schematic at rear of manual). The transistors are connected in parallel so that approximately half of the output current flows through each one. The regulator serves as a series control element by altering it's conduction so that the output voltage or current is kept constant. The conduction of the transistors is controlled by the feedback voltage from the error amplifier. Diode CR11, connected across the regulator circuit, protects the series transistors against reverse voltages that could develop across them during parallel or auto-parallel operation if one supply is turned on before the other.

4-8 CONSTANT VOLTAGE INPUT CIRCUIT (Figure 4-3)

4-9 The circuit consists of the coarse and fine programming resistors (R10A and R10B), and a differential amplifier stage (Q1 and associated components). Transistor Q1 consists of two silicon transistors housed in a single package. The transistors have matched characteristics minimizing differential voltages due to mismatched stages. Moreover, drift due to thermal differentials is minimized, since both transistors operate at essentially the same temperature.

4-10 The constant voltage input circuit continuously compares a fixed reference voltage with a portion of the output voltage and, if a difference exists, produces an error voltage whose amplitude and phase is proportional to the difference. The error output is fed back to the series regulator, through an OR gate and the mixer/error amplifiers. The error voltage changes the conduction of the series regulator which, in turn, alters the output voltage so that the difference between the two input voltages applied to the differential amplifier is reduced to zero. This action maintains the output voltage constant.

4-11 Stage Q1B of the differential amplifier is connected to a common (+S) potential through impedance equalizing resistor R5. Resistor R6 and R8 are used to zero bias the input stage, offsetting minor base to emitter voltage differences in Q1. The base of Q1A is connected to a summing point at the junction of the programming resistors and the current pullout resistor R12. Instantaneous changes in output voltage result in an increase or decrease in the summing point potential. Q1A is then made to conduct more or less, in accordance with summing point voltage change. The resultant output error voltage is fed back to the series regulator via the remaining components of the feedback loop.

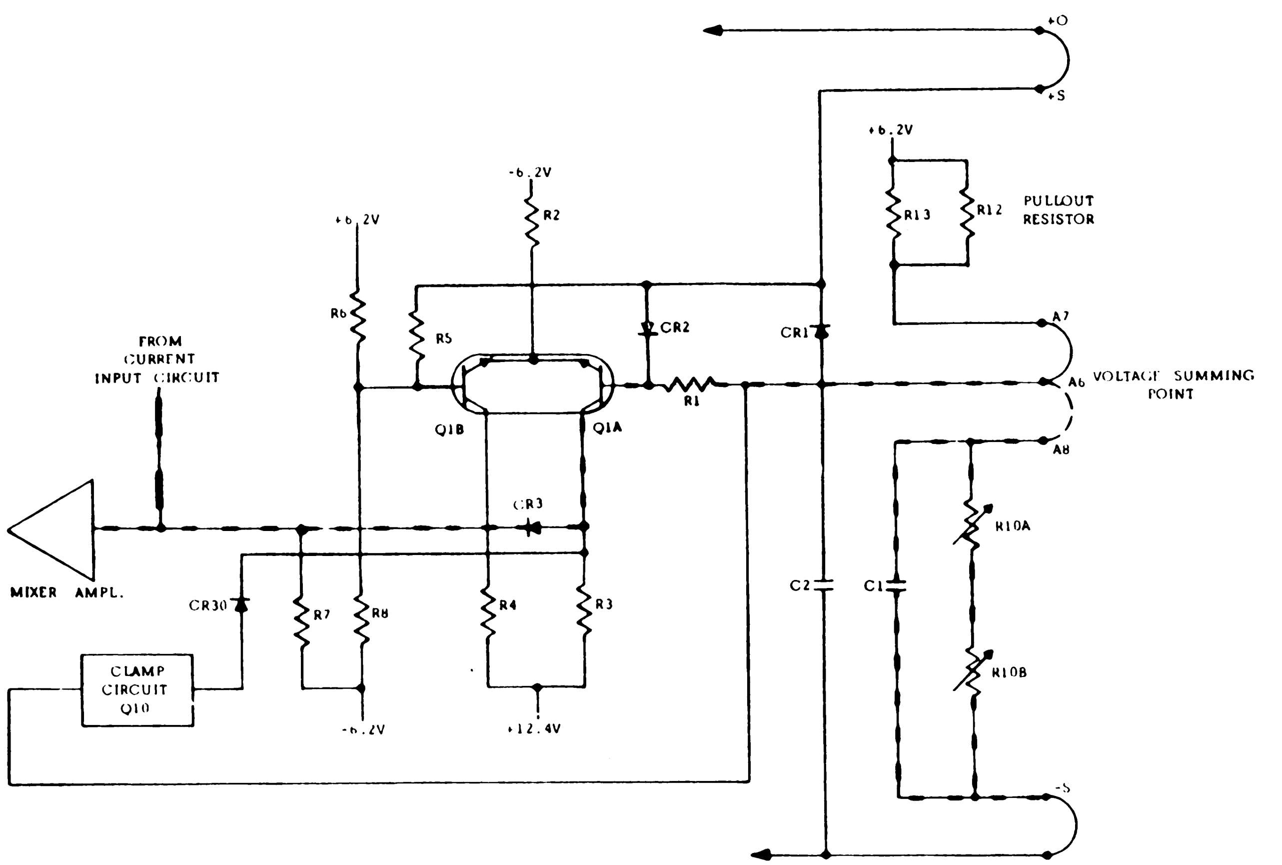


Figure 2-17. Constant voltage input circuit.

2. The error output voltage is fed where?

3. How is high frequency gain of the input amplifier accomplished?

231. Specify the operational characteristics of the constant current input circuit of the 6202B Power Supply.

Constant Current Input Circuit. This circuit (fig. 2-18) is similar in appearance and operation to the constant voltage input circuit. It consists of the coarse and fine current programming resistors (R16A and R16B), and a differential amplifier stage (Q2 and associated components). Like transistor Q1 in the voltage input circuit, Q2 consists of two transistors, having matched characteristics, that are housed in a single package.

The constant current input circuit continuously compares a fixed reference voltage with the voltage drop across current sampling resistor R54. If a difference exists, the differential amplifier produces an error voltage which is proportional to this difference. The remaining components in the feedback loop (amplifiers and series regulator) function to maintain the drop across the current sampling resistor, and consequently the output current, at a constant value.

Stage Q2B is connected to the +S through impedance equalizing resistor R26. Resistors R25 and R28 are used to zero bias the input stage, offsetting minor base to emitter voltage differences in Q2. Instantaneous changes in output current on the positive line are felt at the current summing point and, hence, the base of Q2A. Stage Q2A varies its conduction in accordance with the polarity of the change at the summing point. The change in Q2A's conduction also varies the conduction of Q2B due to the coupling effects of the common emitter resistor, R22. The error voltage is taken from the collector Q2B and fed back to the series regulator through OR-gate diode CR4 and the remaining components of the feedback loop. The error voltage then varies the conduction of the regulator so that the output current is maintained at the proper level.

Resistor R20, in conjunction with R2 and C3, helps stabilize the feedback loop. Diode CR5 limits voltage excursions on the base of Q2A. Resistor R19, shunting the pullout resistor, serves as a trimming adjustment for the programming current flowing through R16A and B.

Exercises (231):

Refer to figure 2-18 as necessary to answer the following questions.

1. What is the purpose of the constant current input circuit?

2. What two resistors are used to zero bias the input stage?

232. Specify the operational characteristics of the 6202B meter circuit.

Meter Circuit. The meter circuit (fig. 2-19) provides continuous indications of output voltage or current on a single multiple range meter. The meter can be used either as a voltmeter or an ammeter, depending upon the position of meter switch S2 on the front panel of the supply. This switch also selects one of two meter ranges on each scale. The metering circuit consists basically of a selection circuit (switch S2 and associated voltage dividers), a stable differential amplifier stage (Q11 through Q14), and the meter movement.

The selection circuit determines which voltage divider is connected to the differential amplifier input. When S2 is one of the voltage positions, the voltage across divider R58, R60, and R61 (connected across the output of the supply) is the input to the differential amplifier. When S2 is in one of the current positions, the voltage across divider R56, R57, and R58 (connected across current sampling resistor R54) is the input to the differential amplifier. The amplified output of the differential amplifier is used to deflect the meter.

The differential amplifier is a stable device having a fixed gain of 10. Stage Q11 of the differential amplifier receives a negative voltage from the applicable voltage divider when S2 is in one of the voltage positions while stage Q13 is connected to the +S (common) terminal. With S2 in a current position, stage Q3 receives a positive voltage from the applicable voltage divider while stage Q11 is connected to the +S terminal. The differential output of the amplifier is taken from the collectors of Q12 and Q14. Transistor Q15 is a constant current source which sets up the proper bias current for the amplifier. Potentiometer R63 permits zeroing of the meter. The meter amplifier stage contains an inherent current limiting feature which protects the meter movement against overloads. For example, if METER switch S2 is placed in position 4 (low current range) when the power supply is actually delivering a higher ampere output, the differential amplifiers are quickly driven into saturation. This action limits the current through the meter to a safe value.

Resistor R1, in series with the base Q1A, limits the current through the programming resistors during rapid voltage turn-down. Diodes CR1 and CR2 form a limiting network which prevent excessive voltage excursions from over driving stage Q1A. Capacitors C1 and C2, shunting the programming resistors, increase the high frequency gain of the input amplifier. Resistor R13, shunting pullout resistor R12, serves as a trimming adjustment for the programming current.

4-12 CONSTANT CURRENT INPUT CIRCUIT (Figure 4-4)

4-13 This circuit is similar in appearance and operation to the constant voltage input circuit. It consists of the coarse and fine current programming resistors (R16A and R16B), and a differential amplifier stage (Q2 and associated components). Like transistor Q1 in the voltage input circuit, Q2 consists of two transistors, having matched characteristics, that are housed in a single package.

4-14 The constant current input circuit continuously compares a fixed reference voltage with the voltage drop across current sampling resistor R54. If a difference exists, the differential amplifier produces an error voltage which is proportional to this difference. The remaining components in the feedback loop (amplifiers and series regulator) function to maintain the drop across the current sampling resistor, and consequently the output current, at a constant value.

4-15 Stage Q2B is connected to the +S through impedance equalizing resistor R26. Resistors R25 and R28 are used to zero bias the input stage, offsetting minor base to emitter voltage differences in Q2. Instantaneous changes in output current on the positive line are felt at the current summing point and, hence, the base of Q2A. Stage Q2A varies its conduction in accordance with the polarity of the change at the summing point. The change in Q2A's conduction also varies the conduction of Q2B due to the coupling effects of the common emitter resistor, R22. The error voltage is taken from the collector Q2B and fed back to the series regulator through OR-gate diode CR4 and the remaining components of the feedback loop. The error voltage then varies the conduction of the regulator so that the output current is maintained at the proper level.

4-16 Resistor R20, in conjunction with R2 and C3, helps stabilize the feedback loop. Diode CR5 limits voltage excursions on the base of Q2A. Resistor R19, shunting the pullout resistor, serves as a trimming adjustment for the programming current flowing through R16A and B.

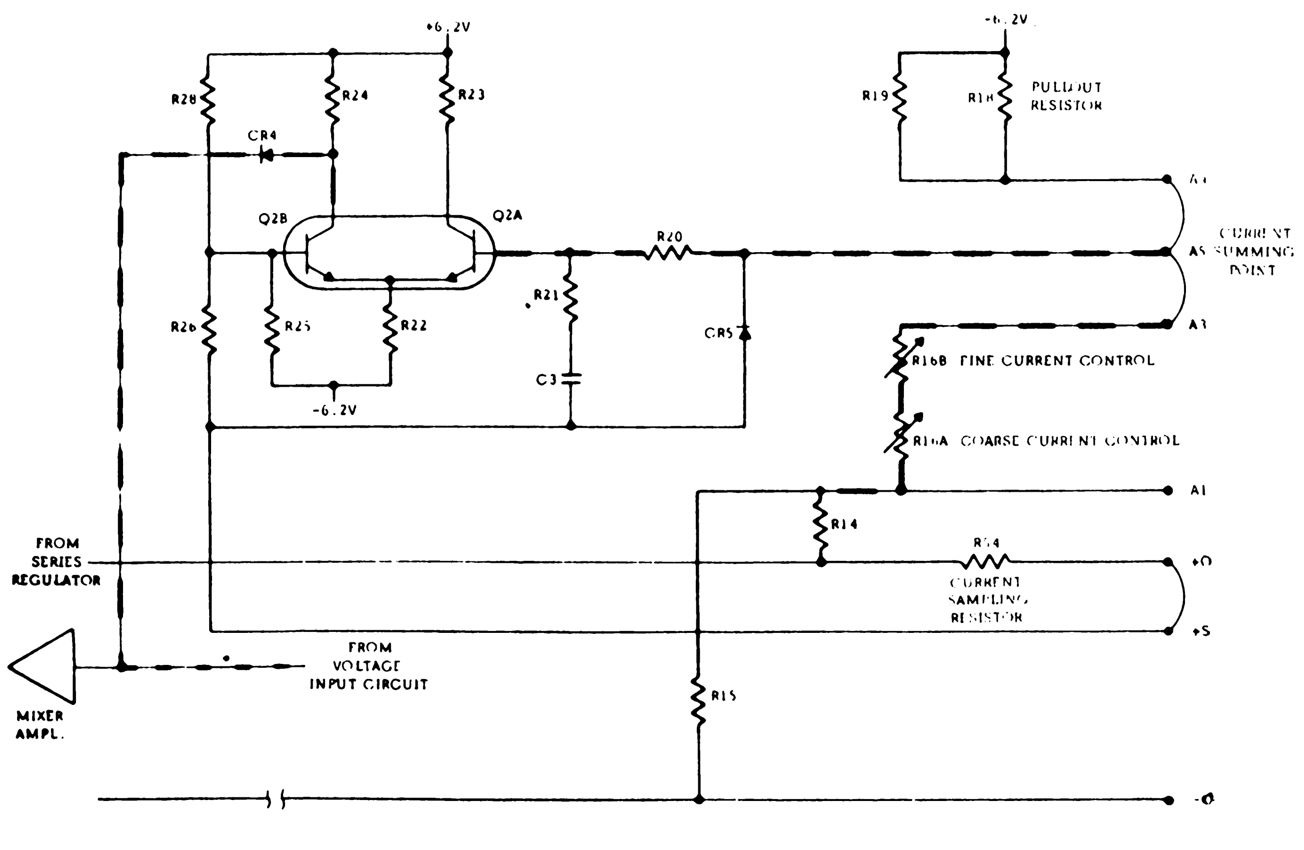


Figure 2–18. Constant current input circuit.

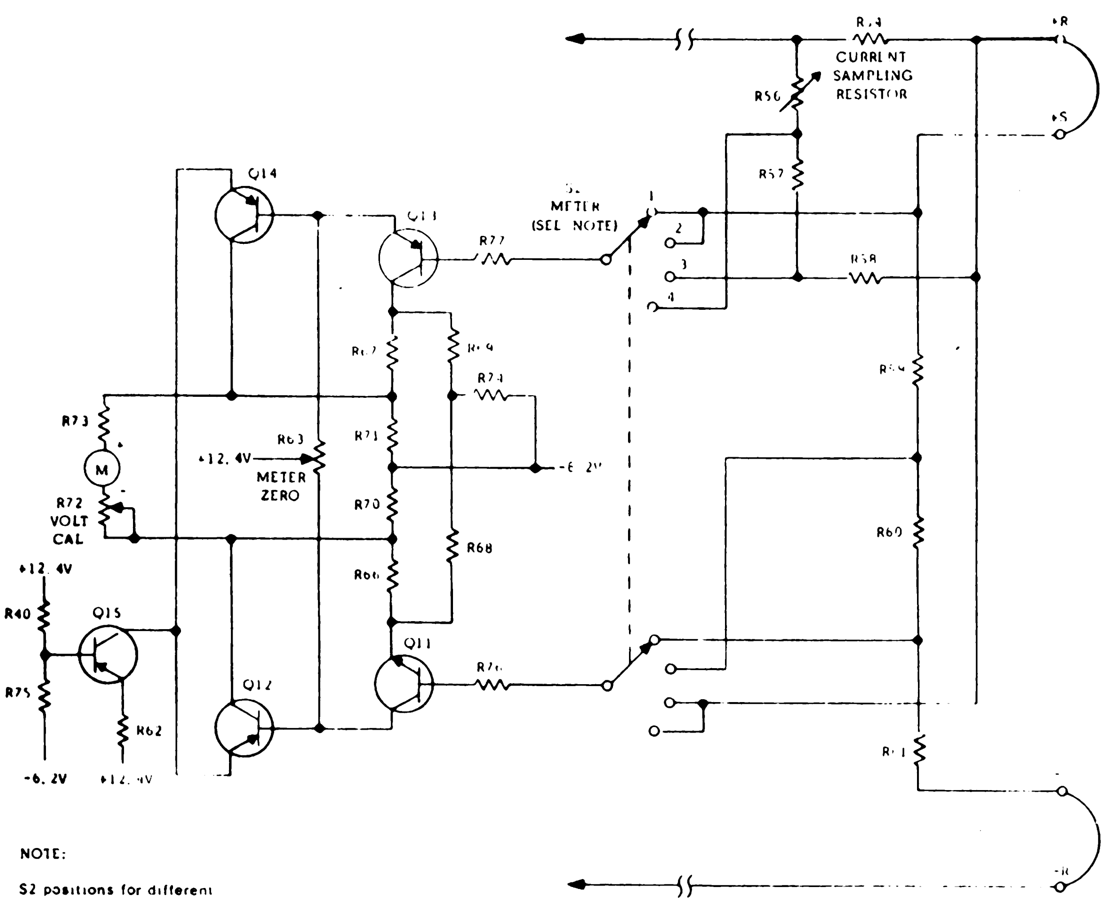
4-23 REFERENCE CIRCUIT

4-24 The reference circuit (see schematic) is a feedback power supply similar to the main supply. It provides stable reference voltages which are used throughout the unit. The reference voltages are all derived from smoothed dc obtained from the full wave rectifier (CR22 and CR23) and filter capacitor C10. The +6.2 and -6.2 voltages, which are used in the constant voltage and current input circuits for comparison purposes, are developed across temperature compensated Zener diodes VR1 and VR2. Resistor R43 limits the current through the Zener diodes to establish an optimum bias level.

4-25 The regulating circuit consists of series regulating transistor Q9 and error amplifier Q8. Output voltage changes are detected by Q8 whose base is connected to the junction of a voltage divider (R41, R42) connected directly across the supply. Any error signals are amplified and inverted by Q8 and applied to the base of series transistor Q9. The series element then alters its conduction in the direction and by the amount necessary to maintain the voltage across VR1 and VR2 constant. Resistor R46, the emitter resistor for Q8, is connected in a manner which minimizes changes in the reference voltage caused by variations in the input line. Output capacitor C7 stabilizes the regulator loop.

4-26 METER CIRCUIT (Figure 4-7)

4-27 The meter circuit provides continuous indications of output voltage or current on a single multiple range meter. The meter can be used either as a voltmeter or an ammeter depending upon the position of METER switch S2 on the front panel of the supply.



NOTE:

S2 positions for different models are shown below

Model	S2 TERMINAL NOS.			
	1	2	3	4
6201B	2.4V	24V	1.4A	.14A
6202B	[illegible]V	[illegible]V	.9A	.09A
6203B	.9V	9V	4A	.4A

Figure 2-19. Meter circuit.

Exercises (232):

Refer to figure 2-19 as necessary to answer the following questions.

1. Does the 6202B have both a voltage meter and a current meter?

2. What is the gain of the differential amplifier?

3. What purpose does R63 serve?

Instrument Calibrators

THE NECESSITY for accuracy in voltmeters, ammeters, and ohmmeters has been greatly increased by the closer tolerances needed to maintain modern equipment. Since the duties of a PME specialist include the calibration of all types of meters, the calibration standards used to assure meter accuracy will be discussed in this chapter.

3-1. RFL 829 Series Instrument Calibrator

There are several different instrument calibrators available for use in PME laboratories throughout the Air Force. Although they differ in many respects, their principles of voltage and current development are similar. The most common calibrator now in use is the RFL (Radio Frequency Laboratory) 829 series instrument calibrator.

233. Specify the basic capabilities of the RFL 829G, type of oscillator it utilizes, and two safety operating parameters.

Basic Capabilities of the RFL 829G. The Model 829 AC/DC calibration standard is a highly stable and precise instrument. It has the ability to supply a wide range of AC-DC voltage and current and preset resistance values; to measure AC-DC voltage and current of the same parameters which it can supply; and to measure a broad range of resistance value (fig 3-1).

Frequencies of 50, 60, 400, and 1000 Hz may be selected by means of a single front panel control. Overall voltage and current feedback is designed into the amplifier sections and rolloff control is incorporated to prevent high frequency bursts from occurring in the output waveform. The amplifier is applied to a transformer capable of handling all output voltage and current, both AC and DC. Precise value of output voltage or current is measured at the output terminals by means of the digital readout instrumentation. The output of the oscillator and the input circuit of the preamplifier are accessible through rear panel connections. These connections provide necessary synchronization points when two instruments (or one instrument plus an auxiliary AC source) are used for wattmeter calibration. The Model 829G AC/DC calibration standard incorporates internal protective circuitry to provide protection for the operator, the Model 829G, and the instrument under test. The possibility of damaging an instrument under test is minimized by interlock circuitry associated with the range and function selectors. The instrument is protected by sparkgap/SCR circuitry that is energized in the event of excessive voltage (transient or constant) in critical circuits when operated by its internal oscillator/amplifier. The SCR trip circuit is also associated with the sense and chassis group terminals to protect against excessive EMF Levels at these points. In the measurement mode, the Model 829G utilizes its switching circuitry and precision measurement section consisting of the digital panel meter, precision shunts and multipliers, operation amplifier for DC functions, and an operational rectifier for AC functions.

Outputs of AC and DC voltages or currents, or resistances, are obtained from the calibration source portion (fig. 3-2) of the calibration standard. This portion contains an oscillator (bridged T), which can produce an output at any one of four frequencies (50, 60, 400, or 100 Hz). The frequency is selected by use of the frequency front panel control. The 400 Hz frequency is selected when the calibration standard is used to produce a DC output. The oscillator output is applied to a preamplifier/power amplifier circuit through a coarse attenuator, a fine attenuator, and the normal/run-up circuit. The attenuators are manually set by means of the coarse and med/fine front panel amplitude controls to establish the desired calibration standard output signal level. Overall voltage and current feedback is designed into the amplifier circuits. Also, roll-off control is incorporated to prevent high frequency bursts in the output waveform. The power amplifier output, at an amplitude level determined by the settings of the coarse and med/fine controls and at a frequency determined by the frequency control, is transformer coupled to the coupling and filter circuits. The coupling and filter circuits consist of the necessary rectifiers and filters needed to produce DC outputs compatible with the output range, mode (+supply or −supply) and function selected by these three front panel controls. These circuits also contain the necessary coupling paths, less the filters, for AC outputs. Through the sense terminals, which are strapped to the + and − output terminals, respectively, the calibration standard outputs are applied to the measurement section. This section provides a front panel digital indication of the precise value of the output current or voltage. The calibration standard incorporates protection circuits. These circuits protect the operator, the calibration standard, and the instrument under test. The output terminals of the calibration standard are covered by a plexiglas shield. This shield must be lowered over the terminals before the standard can produce an output or display a measurement. While the standard is energized, raising of the shield causes the output to drop to ground potential and the displayed measurement to go to zero. To reenergize the standard, the shield must be in its lowered position and the reset switch depressed or the coarse control placed momentarily in its ZERO position. The possibility of damaging an instrument under test is

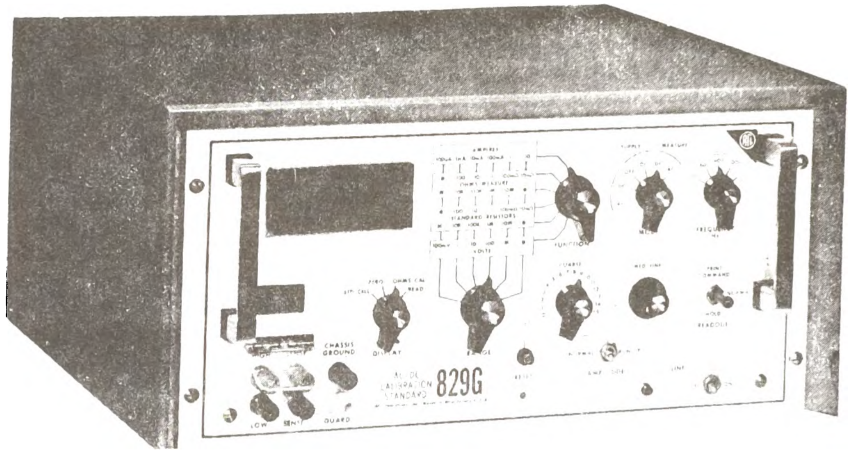


Figure 3–1. 829G front panel.

minimized by wired interlock circuitry associated with the range and function controls. In addition, an overrange detection circuit is incorporated as part of the protection circuits. The overrange detection circuit receives the full transformer coupled output of the power amplifier from the secondary winding of the power amplifier output transformer. Should this output exceed the maximum allowable output level, an SCR is gated on and the following occurs simultaneously:

a. The output terminals are shorted together.

b. The oscillator output is grounded.

c. The input to the digital panel meter is grounded.

d. The DC measurement path during resistance measurements is opened.

The calibration standard is further protected from overheating by use of a heat sink thermostat. Overheating can occur if the calibration standard is operated in excessively high ambient temperature environments or if an attempt is made to work at overloaded output conditions for any length of time. A snap-action thermostat activates, if the calibration standard heat sinks exceed 227°F. (125°C.). Once tripped, the self-restoring thermostat prevents operation until the heat sinks return to normal temperature.

Exercises (233):

1. What type of an oscillator is the 829G?

2. What three things does the RFL 829G supply and measure?

3. In what position must the plexiglas shield be before the 829G will produce an output?

4. (T or F) The 829G operates independently of ambient temperatures.

3-2. Fluke 5100B Calibrator

The Fluke 5100B calibrator is another commonly used instrument calibrator.

234. Specify the basic capabilities of the 5100B and identify the functions of the front panel controls.

Basic Capabilities of the Fluke 5100B. The 5100 Series B calibrator is a microprocessor controlled calibrator. Outputs are programmable from the front panel or through an optional remote interface. A wide range of DC voltages and current, AC voltages and current, and resistance outputs are available. Connections on the front panel include terminals for output, sense, voltage guard, and current guard. A chassis binding post is available on the rear panel. Available on the front panel is a BNC output connector for use with the Wideband Option -03 which extends the frequency range of the instrument. The connector is installed in all instruments, allowing addition of the option at some later date, if desired.

The output can be modified using the front panel error mode controls or through an optional remote interface. This allows the operator, in all outputs except frequency, to modify the output and read the deviation from the base in percentage or digits on the front panel or the remote device.

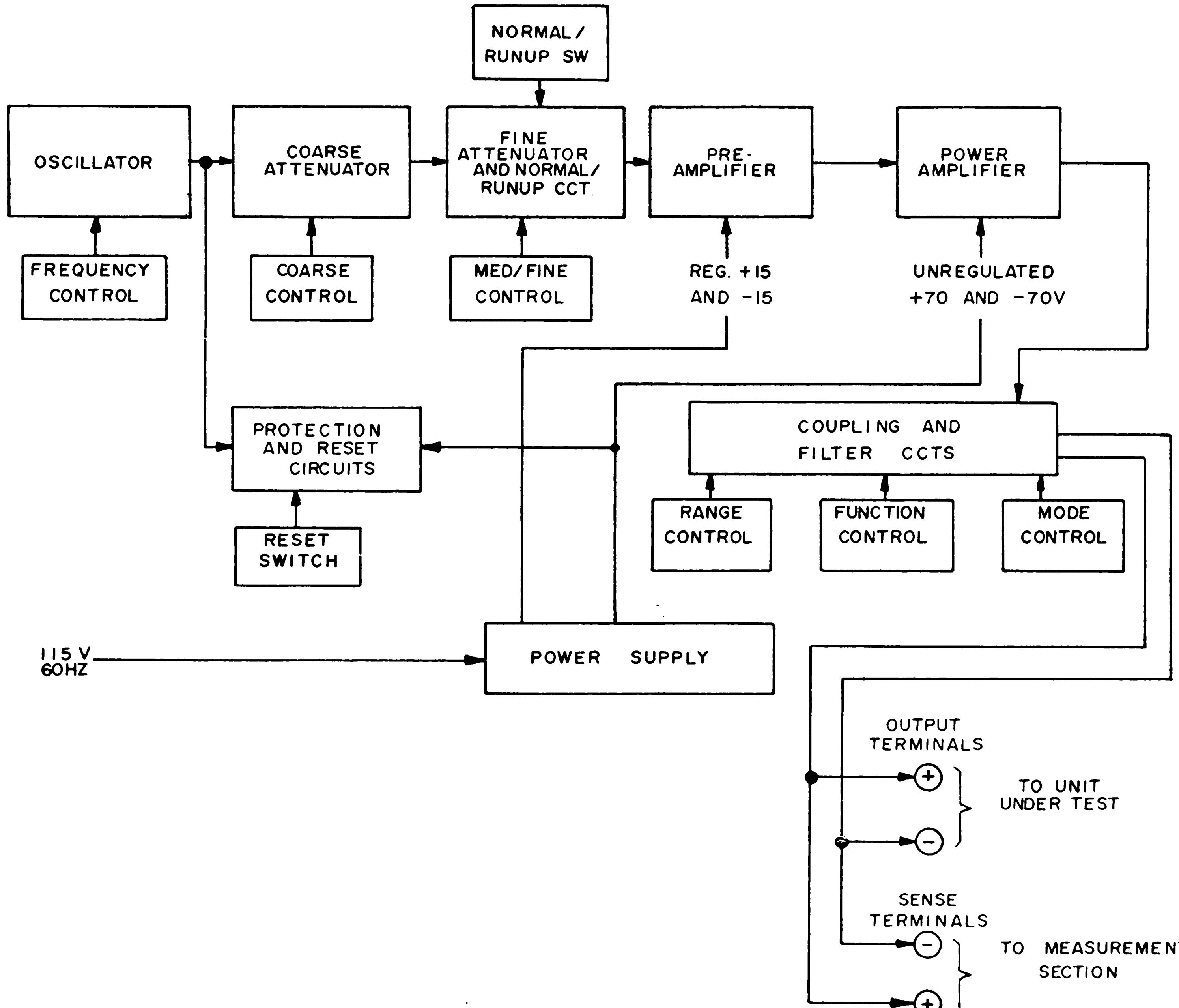


Figure 3–2. Calibration source, block diagram.

Frequency can be modified to step through the entire range of the meter under test with a minimum amount of reprogramming by the operator.

The calibrator can provide DC voltage outputs from 0 to 1100 volts on six ranges with resolutions ranging from 0.1 microvolts to 10 millivolts. Direct current outputs are available from 10 microamps to 2 amps on five ranges, with resolution between 1 nanoamp and 10 microamps.

AC voltage outputs between 1 millivolt and 1100 volts are available from the 50 Hz minimum frequency up to 1 kHz. From that point the maximum voltage available is 110 volts up to 10 kHz, dropping to a 20 volt maximum from 30 kHz to 50 kHz. Six ranges are available for AC voltage outputs with resolution varying from 0.1 microvolt to 10 millivolts. Five alternating current ranges control output from 10 microamps to 2 amps at frequencies of 50 Hz to 1 kHz, with resolution between 1 nanoamp and 10 milliamps.

Some 5100 Series B calibrators have the Wideband Option -03. This allows outputs of 300 μ V to 3.1623 V rms at frequencies from 10 Hz to 10 MHz into a load impedance of 50 ohms. The output impedance is 50 ohms, and a 50-ohm coaxial cable should be used to transfer the output signal.

All instruments have the capability to extend their voltage (power) and current limits through the boost function using the Y5000 Interface Accessory and selected external amplifiers. Loads up to 200 mA can be handled when a Fluke Model 5220A/5215A is connected through the interface accessory and the applicable cable. Output currents up to ±19.9999A are available when a Fluke Model 5220A is connected through the interface and the applicable cable.

Resistance outputs at the cardinal values from 1 ohm to 10 megohms are available. The outputs from 1 ohm to 10 kilohm have a four-terminal measurement capability. The 100 kilohm, 1-megohm, and 10-megohm outputs use two-terminal measurements with the OUTPUT HI and SENSE HI terminals being internally connected together, and the OUPUT LO and SENSE LO terminals also being connected together internally.

Modification of the output to measure the deviation in a percent of error figure is displayed for each change of the output from the base. The frequency may be altered for AC outputs to cover a range of frequencies; however, there is no percent of error display. The modifications can be programmed from either the front panel or a remote source.

The front panel is divided into seven different groups (fig. 3-3). These are the (1) power switch, (2) data entry keys, (3) control keys, (8) error mode controls, (6) (7) displays and (4) (5) output terminals, and (9) storage system keys and tape drive. The storage system keys and tape drive are available only on the 5101B model that has storage capability.

The power switch is located in the lower right-hand corner of the front panel of the 5100. When this switch is pushed, power is applied to the 5100 and the initialization procedure begins. The central display will indicate the revision level of the internal firmware for 1 to 2 seconds and then, if all is working correctly, go blank. The earliest version of firmware with which you should come in contact is "1.0.4." All 5100Bs should have at least "1.0.5" firmware, and those units which are new enough to have the single board controller should be revision level "1.0.6" or newer.

The data entry keys located in the center of the front panel are the primary method for entering all output parameters. The polarity, numerical, multiplier, and function keys are self-explanatory. The enter key must be pushed to load each program line into the 5100. If a keystroke mistake has been made, pushing the clear key once will clear the data entry buffer. Pushing the clear key twice will clear the entire instrument back to the power on reset condition. The recall key allows you to display the entered parameters on the Central Display. The limit keys allow you to set the maximum amplitude for any given output so that you may protect an instrument under test from accidental damage. They also allow the setting of the acceptable tolerances for a given instrument under test. The external oscillator key enables you to use a separate frequency source for AC outputs. This would be desirable if the instrument under test requires the checking of odd frequency points. We will discuss the wideband and boost keys when we study those options.

There are four control keys on the front panel located in the upper left corner. The standby/operate key is self-explanatory. The Local/Rem key allows front panel selection of the control input. With this key you may toggle back and forth between Front Panel control and Remote control of the 5100. The internal external sense key allows selection of the two-wire or four-wire mode of the output. The 50-ohm divider key allows override of the normal operation of the lowest two voltage ranges.

The error mode controls are located in the upper right corner of the front panel. The enable key engages the error mode and lights the digit on the output display that is to be edited. The decade keys, both left and right, change the digit that is to be edited. The New Ref/Cal 1 ohm key has a dual function. It allows the immediate changing of a reference point around which the tolerance is set on a given output, and it allows the engaging of the precise 1 ohm reference during the resistance calibration of an instrument.

The storage system keys are only available on units that have the mini-cassette recorder. They are located just to the left of the recorder and allow the manipulation of the main memory and the recorded program sequences.

There are two major displays on the front panel of the 5100. These are the output display and the central display. The output display indicates the actual output that is programmed at any given time, with the exception of the frequency for an AC output. The central display indicates the program being prepared on the data entry keys, the AC output frequency, or the error messages listed in the instruction manual.

All of the output terminals are located in the lower left corner of the front panel. All of the terminal markings are self-explanatory except the Wideband Output. This BNC connector is active only when the Wideband option is installed and called up.

The rear panel of the 5100 contains the input power connector and fuse, a ground terminal, the cooling fan air

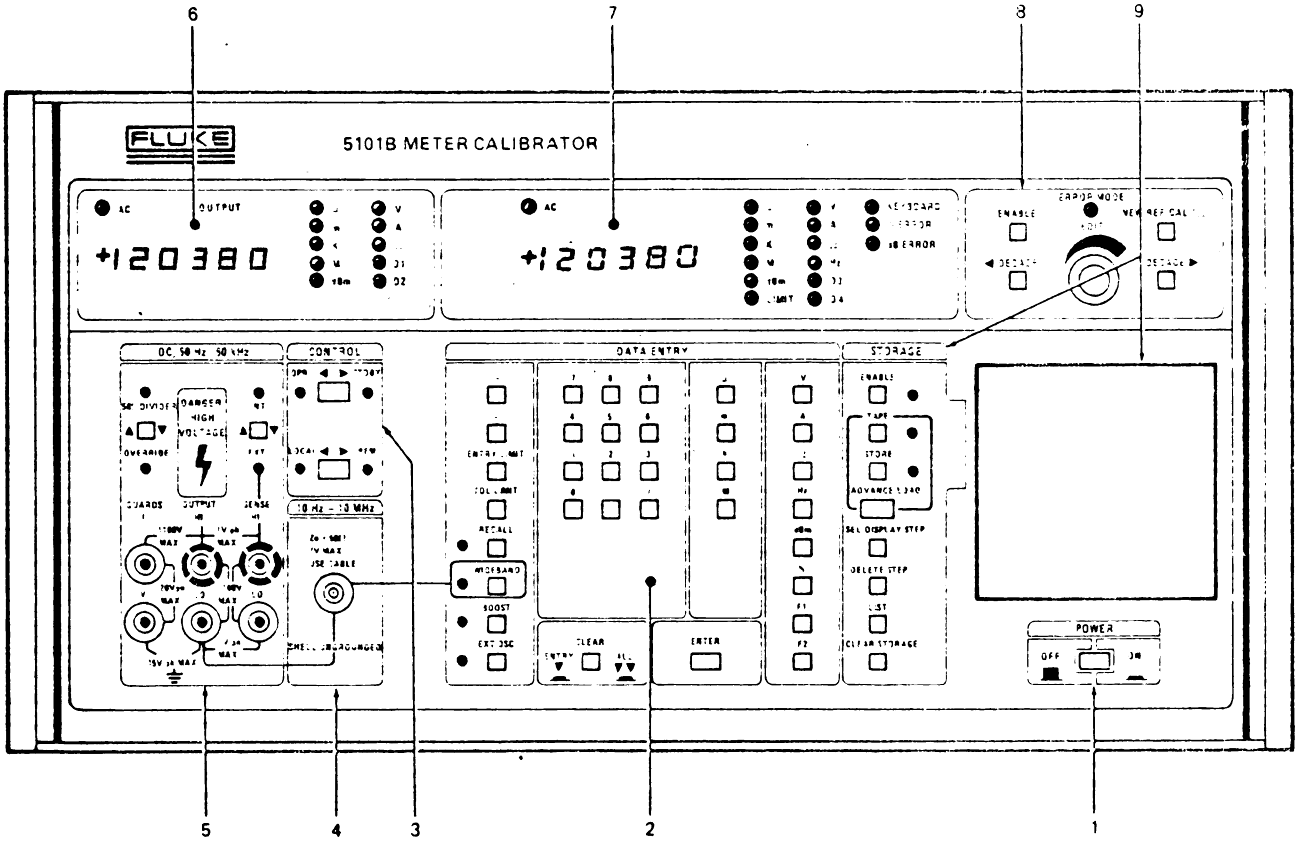


Figure 3–3. 5101B meter calibrator, front panel controls.

filter, the digital interface connector (if applicable), the Y5000 interface connectors, and the description decal. This decal identifies the operating parameters of the individual 5100.

Exercises (234):

1. What type outputs are available from the 5100B?

2. What is the maximum AC voltage frequency without the wideband option (-03) installed?

3. The model 5220A is used for what?

4. What must you do to correct a keystroke mistake made when entering information into the 5100B?

5. What key must you depress in order to engage the error mode?

CHAPTER 4

Meters

THERE ARE FOUR basic types of meters that you will use constantly during your PMEL career—passive-type multimeter, the digital-type multimeter, the electronic voltmeter, and the differential voltmeter. In this chapter, we will cover a typical example of each type of meter in use in the Air Force labs today.

4-1. Passive Meters

Two of the most common and highly used passive type meters you will be associated with in the PMEL are the Simpson 260 Series and the AN/PSM37. Therefore, we will briefly cover these two instruments first and then move on to another type of meter.

235. Given values of resistance and sensitivity of a basic voltmeter, calculate the values of multiplier resistance required to extend its range to a specified value.

Extension of Voltmeter Range. To extend the range of a voltmeter, we place a resistor in series with the meter movement, as shown in figure 4-1. Note that the series resistor is labeled Rx. This resistor is called a multiplier.

The method of computing the value of a multiplier is to divide the voltage range desired by the full-scale current of the meter movement; then you subtract the resistance of the meter movement from the result and thus get the value of the multiplier. For example, if the meter has a 50-millivolt, 0- to 1-mA movement, you can compute the multiplier's value for the 10-volt range as follows:

$$Rt = \frac{10}{0.001} = 10{,}000 \text{ ohms}$$

$$Rx = 10{,}000 - 50 = 9950 \text{ ohms}$$

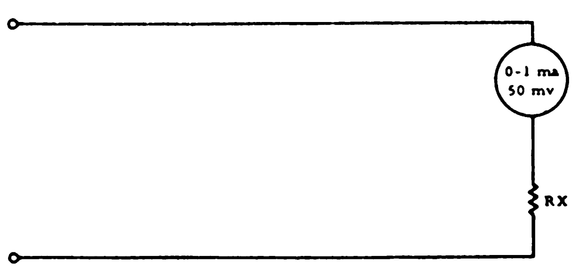


Figure 4–1. Computing the value of a multiplier.

Figure 4-2,A, shows the schematic of a voltmeter with three ranges; 0-10 volts, 0-100 volts, and 0-500 volts. If the meter has a 0- to 1-mA 75-millivolt movement, you can calculate the values of the multipliers as follows:

$$R1 + 75 = \frac{10}{0.001}\ 10{,}000 \text{ ohms}$$

$$R1 + 10{,}000 - 75 = 9925 \text{ ohms}$$

$$R2 + 75 = \frac{100}{0.001} = 100{,}000 \text{ ohms}$$

$$R2 = 100{,}000 - 75 = 99{,}925 \text{ ohms}$$

$$R3 + 75 = \frac{500}{0.001} = 500{,}000 \text{ ohms}$$

$$R3 = 500{,}000 - 75 = 499{,}925 \text{ ohms}$$

To obtain either a 10-volt, a 50-volt, or a 100-volt range, you can connect the same meter movement in the manner shown in illustration B of figure 4-2. Note that R1 is in series with the meter movement for the 10-volt range and R2 is added in series for the 100-volt range. You can find the values of R1, R2, and R3 as follows:

$$R1 + 75 = \frac{10}{0.001}\ 10{,}000 \text{ ohms}$$

$$R1 = 10{,}000 - 75 = 9925 \text{ ohms}$$

$$R2 + 10{,}000 = \frac{50}{0.001} = 50{,}000 \text{ ohms}$$

$$R2 = 50{,}000 - 10{,}000 = 40{,}000 \text{ ohms}$$

$$R3 + 50{,}000 = \frac{100}{0.001} = 100{,}000 \text{ ohms}$$

$$R3 = 100{,}000 - 50{,}000 = 50{,}000 \text{ ohms}$$

Exercises (235):

1. How is the measurement range of a voltmeter extended?

2. If a 0- to 1-mA meter movement is to be used to measure 2.5 volts, what is the value of the multiplier?

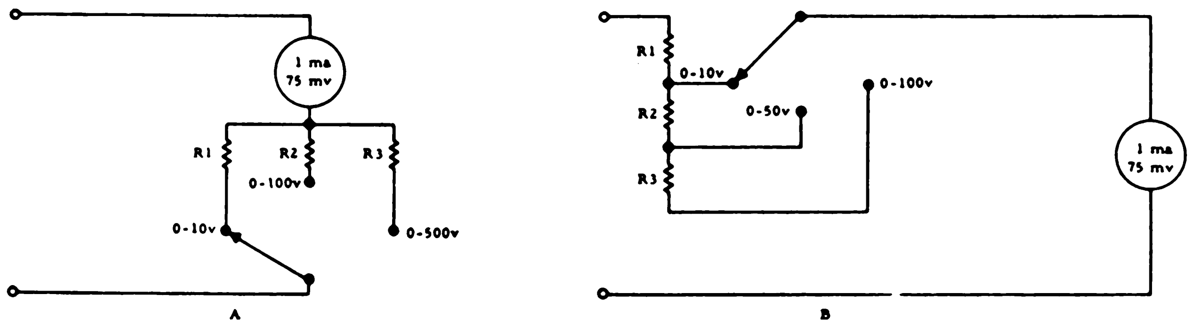


Figure 4–2. Schematic of a voltmeter with three ranges.

3. If the same meter movement is used to measure 250 volts, what is the value of the multiplier?

236. State the method used used to measure DC voltages up to 1000 volts using the 260–AFP–1.

Multimeter 260–AFP–1. There are several types of multimeters available but you will likely use the Simpson Model 260–AFP–1 most frequently. For this reason we are including a review of the 260–AFP–1 in this volume. Refer to foldout 1 for familiarization with the controls, switches, and front panel of the multimeter.

DC Voltage Measurements. Objectives 236 and 237 with DC voltage measurements. Note that when used as a DC voltmeter, the Simpson Model 260–AFP–1 operates on the same principle as described in objective 235. Below we list the procedures to follow when measuring DC to 250 millivolts and to 1000 volts.

Measuring DC voltages to 250 millivolts.

a. Set function switch at +DC position.

b. Plug the black test lead in the COMMON-jack and the red test lead in the 50 I AMPS jack.

c. Set range switch at the 50 I AMPS position (common position with 50V).

d. Connect black test lead to negative side of circuit to be measured, and red test lead to the positive side of the circuit.

e. Read the voltage on the black arc marked DC; use the figures marked 0–250 to read directly in millivolts.

f. Disconnect test leads.

Measuring DC voltages to 1000 volts.

a. Set function switch at +DC position.

b. Plug black test lead in the COMMON-jack and the red test lead in the +jack.

c. Set range switch at one of the five voltage range positions marked 2.5V, 50V, 250V, or 1000V; choose the voltage range position which contains anticipated voltage to be measured.

NOTE: When in doubt as to the voltage present, use the 1000V position as a protection to the multimeter.

d. Connect black test lead to negative side of the circuit to be measured and red test lead to positive side of the circuit.

e. Apply power to the circuit to be tested. If the multimeter pointer deflects to the left of zero, polarity is reversed. To correct the polarity as applied to the multimeter, remove power from test circuit and set function switch at -DC position. Then apply power to test circuit.

f. Read the voltage on the black arc marked DC as follows:

(1) For the 2.5V range, use the 0-250 figures, and divide by 100.

(2) For the 10V, 50V, and 250V ranges, read the figures directly on the scale.

(3) For the 1000V range, use the 0-10 figures and multiply by 100.

NOTE: If the voltage is within a lower range, set the range switch at the lower range position to obtain a more accurate reading.

g. Disconnect power from test circuit; disconnect test leads.

Exercises (236):

1. If measuring an unknown voltage results in a meter deflection to the left of zero, what must you do to get an on-scale reading?

237. Distinguish between correct and incorrect statements concerning the method used to measure DC voltages up to 5000 volts using the 260–AFP–1.

Measuring DC Voltages to 5000 Volts. When working with this high a voltage, be extremely careful. Do not touch the multimeter or test leads while power is applied to the circuit being measured, and perform the following procedures:

a. Set function switch at +DC position.

b. Set range switch at 5000V position (common position with 1000V).

c. Plug black test lead in the COMMON-jack and the read test lead in the DC 5000V jack.

d. Make sure power is off in the circuit to be measured and all its capacitors have been discharged. Connect black test lead to negative side of the circuit to be measured and the red test lead to positive side of circuit.

e. Apply power to the circuit to be tested. Do not touch the test leads or multimeter. If the multimeter pointer deflects to the left of zero, polarity is reversed. Remove power from test circuit and set function switch at −DC position to correct the polarity as applied to the multimeter. Then apply power to test circuit.

f. Read the voltage on the black arc marked DC; use the 0–50 figures and multiply by 100.

g. Disconnect power from test circuit, disconnect test leads.

Exercises (237):

Indicate whether the following are true or false. Correct false statements.

____ 1. To use the 5000-volt function, it is only required that the range switch be moved to the 5000-volt range.

____ 2. Before connecting the test leads to the circuit, you should remove power from the circuit.

238. State the method used to measure AC voltages up to 5000 volts using the 260–AFP–1.

AC Voltage Measurements. This objective deals with AC voltage measurements and output voltage measurements. When used as an AC voltmeter, the Simpson Model 260–AFP–1 operates on the same principle as described in objective 235.

Measuring AC voltages to 1000 volts.

a. Set function switch at AC position.

b. Set range switch at one of the five voltage range positions marked 2.5V, 10V, 50V, 250V, or 1000V; choose the voltage range position which contains anticipated voltage to be measured.

NOTE: When in doubt as to the voltage present, use the 1000V position as a protection to the multimeter.

c. Plug black test lead in the COMMON-jack and the red test lead in the +jack.

d. Be sure power is off in the test circuit and connect the test leads across the voltage source.

e. Apply power to test circuit and read the voltage as follows:

NOTE: This multimeter measures AC voltage in terms of the rms value of a sine wave.

(1) For the 0-2.5V range, read the voltage directly on the red arc marked 2.5 VAC ONLY.

(2) For the 10V, 50V, and 250V ranges, use the red arc marked AC and read the voltage directly using the black figures immediately above the arc.

(3) For the 1000V range, read the red arc marked AC; use the black 0–10 figures and multiply by 100.

NOTE: If the voltage is within a lower range, set the range switch at the lower range position to obtain a more accurate reading.

f. Disconnect power from test circuit; disconnect test leads.

Measuring AC voltages to 5000 volts.

NOTE: Be extremely careful when working in high voltage circuits. Do not touch the multimeter or test leads while power is applied to the circuit being measured.

a. Set function switch at AC position.

b. Set range switch at 5000V position (common position with 1000V).

c. Plug black test lead in the COMMON-jack and the red test lead in the AC 5000V jack.

d. Be sure power is off in the circuit to be measured and all its capacitors have been discharged. Connect the test leads into the circuit.

e. Apply power to the circuit to be measured. Do not touch the test leads or the multimeter.

f. Read the voltage on the red arc marked AC; use the 0–50 figures and multiply by 100.

g. Remove power from test circuits; disconnect the test leads.

Measuring output voltages.

NOTE: When there is a mixture of AC and DC voltages, as occurs in amplifier circuits, output voltage is the AC component only.

a. Set function switch at AC position.

b. Plug black test lead in the COMMON-jack and the red test lead in the OUTPUT jack.

c. Set range switch at one of the voltage range positions marked 2.5V, 10V, 50V, or 250V.

d. Connect black test lead to the grounded side of circuit to be measured and the red test lead to the "hot" side.

e. Apply power to the test circuit. Read the output voltage as follows:

(1) For the 0–2.5V range, read the value directly on the red arc marked 2.5V VAC ONLY.

(2) For the 10V, 50V, and 250V ranges, use the red arc marked AC and read the voltage directly using the black figures immediately above the arc.

f. Disconnect power from test circuit; disconnect test leads.

Exercises (238):

1. To measure 1.5 VAC, which red scale would you use?

2. What do we use the output function to measure?

239. State how to measure DC currents using the 260–AFP–1.

Direct Current Measurements. In conducting these measurements never connect the test leads directly across any voltage when the multimeter is used as an ammeter. Always connect the meter in series with the load across the voltage source. When measuring direct currents to 50 microamperes, do the following:

a. Set function switch at +DC position.
b. Plug the black test lead in the COMMON-jack and red test lead in the 50 μAMPS jack.
c. Set range switch at 50 μAMPS position (common position with 50V).
d. Open the circuit in which the current is to be measured. Connect the meter in series with the circuit; connect red test lead at the positive side and black test lead at the negative side.
e. Apply power in the circuit to be measured. Observe the meter. If the pointer is deflected to the left, the current polarity is reversed. To correct the polarity, remove power in test circuit and reverse the test lead connections. Then apply power to test circuit.
f. Read the current on the black DC arc. Use the 0–50 figures to read directly in microamperes.
g. Switch off the circuit power. Disconnect the test leads and restore test circuit continuity.

When measuring direct currents to 500 milliamperes, follow these procedures:

a. Set function switch at +DC position.
b. Plug black test lead in the COMMON-jack and the red test lead in the +jack.
c. Set range switch at one of the four range positions marked 1 MA, 10 MA, 100 MA, or 500 MA, as required.
d. Open the circuit in which the current is to be measured. Connect the meter in series with the circuit; connect red test lead at the positive side and black test lead at the negative side.
e. Apply power in the circuit to be measured. Observe the meter. If the pointer is deflected to the left, the current polarity is reversed. To correct the polarity, remove power in test circuit and set the function switch at the −DC position. Then apply power to the test circuit.
f. Read the current, in milliamperes, on the black arc marked DC as follows:
(1) For the 1 MA range, use the 0–10 figures and divide by 10.
(2) For the 10 MA range, use the 0–10 figures directly.
(3) For the 100 MA range, use the 0–10 figures and multiply by 10.
(4) For the 500 MA range, use the 0–50 figures and multiply by 10.

g. Switch off the circuit power. Disconnect the test leads and restore test circuit continuity.

When measuring direct currents to 10 amperes, do the following:

a. Plug black test lead in the −10A jack and the red test lead in the +10A jack.
b. Set the range switch at 10 AMPS position (common position with 10 MA).
c. Open the circuit in which the current is to be measured. Connect the meter in series with the circuit; connect red test lead at the positive side and black test lead at the negative side.
d. Apply power in the circuit to be measured. Observe the meter. If the pointer is deflected to the left, the current polarity is reversed. To correct the polarity, remove power in test circuit and reverse the test lead connections. Then apply power to test circuit.
NOTE: The function switch has no effect on polarity for the 10 AMPS range.

e. Read the current on the black DC arc. Use the 0–10 figures to read directly in amperes.
f. Switch off the circuit power. Disconnect the test leads and restore test circuit continuity.

Exercises (239):

1. To measure current, how must the meter be connected?

2. When measuring direct currents to 50 microamperes, what is your first step?

240. State how to measure resistance using the 260–AFP–1.

Resistance Measurement. Your first step here is to set the range switch in one of the resistance range positions as follows:

a. Use R × 1 for resistance readings from 0 to 200 ohms.
b. Use R × 100 for resistance readings from 200 to 20,000 ohms.
c. Use R × 10,000 for resistance readings above 20,000 ohms.

Next, set the function switch at either −DC or +DC position, and plug the black test lead in the COMMON-jack and the red test lead in the +jack.

When resistances are measured, multimeter batteries B1 and B2 furnish power for the circuit. Since batteries are subject to variations in voltage and resistance over long periods of time, you must adjust the meter for zero ohms prior to measuring a resistance, as follows:

a. Connect the clip ends of test leads together to short out the resistance circuit.

b. Observe the meter indication; the pointer should indicate 0 on the right hand end of the OHMS arc at top of dial.

c. If the meter indication is not 0, rotate the ZERO OHMS control until the pointer indicates 0. If the pointer will not indicate 0, replace batter B1 or B2. Replace 1.5-volt battery B1 if the Range Switch is set at either the R × 1 or the R × 100 position. Replace 5-volt battery B2 if the range switch is in R x 10,000 position.

d. When the pointer indicates zero, disconnect the clip ends of test leads. The ohmmeter circuit is now ready to use.

NOTE: Check and adjust for zero ohms each time the range switch is positioned to a different range.

Now, connect test leads across the resistance to be measured. If there is a "forward" and "backward" resistance such as in rectifiers, the resistance should be quite small in one direction (for forward polarity) and very large in the opposite direction. Vary the Function Switch between the two DC positions to reverse the polarity to determine that there is a large difference between the resistances in the two directions. The resistance of such rectifiers will measure different values on different resistance ranges of the multimeter. For example, a crystal diode which measures 80 ohms on the R × 1 range may measure 300 ohms on the R × 100 range. The difference in values is a result of the diode characteristic and does not indicate any fault in the multimeter.

Next, observe the reading on the OHMS arc; note that this arc reads from right to left for increasing values. Multiply the reading by the multiplier factor at the range switch position to obtain the resistance value in ohms. K on the dial equals 1000. Finally, disconnect the test leads from the test circuit.

Exercises (240):

1. What range on the 260–AFP–1 would you use to measure a resistance whose nominal value is 15K ohms?

2. What must you do to measure the front-to-back ratio in a diode?

241. State operational characteristics of the 260–AFP–1 overload protection circuit.

Overload Protection. With the exception of the 10 ampere DC, and the 1000 volt and 5000 volt AC and DC ranges, all ranges are protected against inadvertent overload damage by a unique protection system. The sensing circuit is completely electronic and does not depend on unreliable mechanical means for actuation. Instead, a highly sensitive semiconductor senses the voltage drop across the meter circuit and actuates a relay when the voltage reaches a predetermined level. Power for the relay is supplied by the same battery that is used for the R × 10,000 resistance range. Sensing of the voltage drop across the meter is done by means of a bridge network, so that overload protection is provided regardless of the polarity. The protection relay operates at a uniform percentage of overload since the meter circuit is common to all ranges.

Since the same battery is used for the high ohms range and the protection circuit, the tester is designed so that the protection circuit will function normally as long as the high ohms range can be set to zero. To supplement protection of the meter, a diode network is connected across the movement to bypass any transient overloads.

Instructions for Testing Condition of Overload Battery.

a. Set range switch at the R × 10,000 position.

b. Set function switch to the −DC position.

c. With black test lead plugged into the common (negative) input jack, touch other end of black lead to the 50 μa input jack.

d. Reset button should pop out indicating that the internal battery is good.

e. No damage will occur as a result of this test.

NOTE: The overload protection circuit will not function properly if B2 battery voltage is below the minimum level needed to zero the R × 10,000 range.

f. Disconnect test leads.

When an overload of sufficient magnitude to trigger the protection circuit is applied to the multimeter, the RESET button will pop up and extend approximately 3/16 inch above front panel surface. To reset the multimeter for normal operation, remove the overload, then press the RESET button all the way down and release it. The multimeter is then ready for normal operation.

Exercises (241):

1. On what does the correct operation of the overload circuit depend?

2. How do you reset the multimeter for normal operation?

242. State the function of the front panel controls of the AN/PSM 37 multimeter.

Another passive meter you will encounter in the PMEL is the AN/PSM 37 multimeter. This ruggedly built multimeter is a precision general-purpose test instrument that combines the functions of an AC and DC voltmeter (with 10 megohm, 20 KΩ/ and 1 KΩV meter sensitivities) an ammeter, and an ohmmeter. The function, range, and polarity switches control the characteristics and range of the meter. Following is a discussion of the operating controls of the AN/PSM 37.

Function Switch. The function switch (fig. 4-3) is located at the lower left of the multimeter panel and provides the means for setting the instrument for the particular electrical characteristic to be measured.

Range Switch. The range switch (fig. 4-3) is located at the lower right of the panel. Once the function switch has been set, the correct instrument range to provide an accurate scale indication is set with the range switch.

Polarity Switch. The polarity switch (fig. 4-3) is located near the middle of the right side of the panel but is not marked as such. It turns the multimeter on and off and selects the nature of the measurement to be made, DC+, DC−, or AC. The "+" and "−" polarity indicates the polarity applied to the red jack when the meter reads upscale on DC measurements, and the output polarity of the red jack when making OHMS measurements.

OHMS ADJ. The OHMS ADJUST control (fig. 4-3) is located near the middle of the left side of the panel and is used only to set full-scale deflection with the test leads shorted prior to making resistance measurements. This control adjusts for variations due to battery condition, temperature, and range and function settings.

Push to Open and Reset. This control is located adjacent to the meter on the right side of the panel (fig. 4-3). The overload circuit breaker is manually opened when this button is depressed, permitting changes in range and function settings without disconnecting the test leads from the circuit. Depressing this button also resets the overload breaker if it has been actuated.

Overload. The overload indicator is located just above the overload reset button (fig. 4-3). When an overload has occurred that has caused the overload breaker to open, a red indicator shaft appears in the transparent plastic dome. The red indicator retracts when the push to open and reset button is depressed, and remains retracted upon release of the button if the overload has properly reset.

Exercises (242):

1. What is the purpose of the push to open and reset button?

2. Before troubleshooting an inoperative AN/PSM 37, what should you do first?

243. Specify how to make voltage measurements safely of up to 1000 volts using the AN/PSM 37.

Voltage Measurements. AC and DC voltages may be measured directly on the AN/PSM 37 in the range of 0 to 1000 volts at input impedances of 1000 ohms/volt or 10000 ohms/volt, or at a fixed 10 megohms. These impedance functions are marked on the front panel of the multimeter under the volts caption around the function switch. Measurements of small signals up to 100 millivolts at 1000 ohms (10,000 ohms/volt) are available under the SPECIAL function marked on the panel under the AMPS function. To measure voltages in the range of 0 to 1000 volts, proceed as follows:

a. Set function switch to 20K/V, 1K/V, or MEG as desired. (Note: The 10 MEG function is inherently protected against overload and is recommended for initial measurements.)

b. Set range switch to desired full-scale range. (CAUTION: Whenever taking an unknown voltage measurement, always set range switch to the highest range and decrease until the proper range is reached.)

c. Turn polarity switch to DC+, DC−, or AC as desired.

d. Connect test leads to meter jacks—red lead to red (+) jack, black lead to black (−) jack.

e. Connect test lead tips to circuit being measured, with black lead to ground or lower voltage point (If known). If meter indicates in reverse direction on DC measurements, change polarity switch to opposite polarity.

f. If a voltage below 100 millivolts is indicated, you may set the function switch to SPECIAL and take measurements. The position of the range switch does not affect full-scale value of the special function. (NOTE: The 10-MEG function employs a blocking capacitor when set to AC polarity and permits the reading of low level AC signals present on higher level DC voltages.)

Exercises (243):

1. When measuring an unknown voltage, to what range should you set the RANGE switch?

2. What function is protected against overload and is recommended for initial use?

244. Specify how to make high voltage measurements safely using the AN/PSM 37 multimeter.

High Voltage or High Impedance Voltage Measurements. The use of test prod MX−1410/U permits DC voltage measurements up to 5000 volts at an input impedance of 100 megohms. When used with the 500-volt range of the 20K/V function, a full-scale value of 5000 volts is obtained. When used with the 10 MEG function, it becomes a 10 times voltage divider and will produce full-scale deflection from 5 to 10,000 volts. Do not make measurements over 5000 volts. To make high voltage or high impedance measurements, take the steps listed below.

a. Set function switch to 20K/V or MEG as desired. (WARNING: Make sure equipment is turned off when connecting or disconnecting where high voltages may be present. Do not change FUNCTION switch while

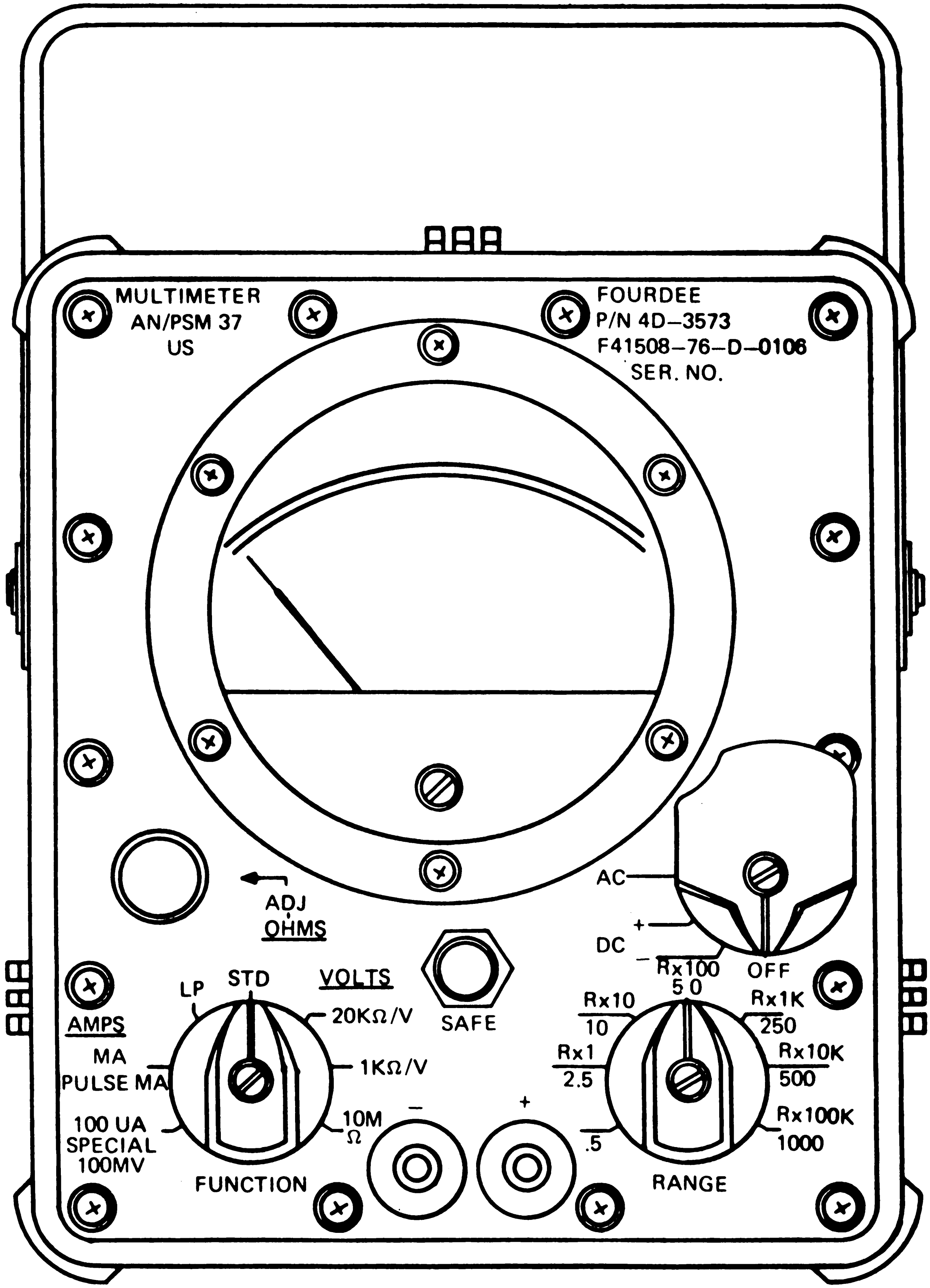


Figure 4–3. AN/PSM 37 operating controls.

equipment under test is energized, or damage to multimeter may occur.)

b. Set range switch to 500 for 5000-volt full-scale indication. Other full-scale values may be selected only on the 10 MEG function, and will have a full-scale value equal to 10 times the switch setting.

c. Set polarity switch to DC+.

d. Plug red test lead tip into MX–1410/U.

Exercises (244):

1. When measuring high voltages, what range should the range switch be on?

2. What accessory is used with the AN/PSM 37 to measure high voltages?

245. State how to make a current measurement using the AN/PSM 37.

Current Measurements. AC and DC currents (including pulsed DC) from 0 to 1 ampere may be measured directly on the multimeter, and currents up to 10 amperes may be measured with the use of the multirange instrument shunt, MX–9127/PSM–37. The procedure is as follows.

a. Set function switch to MA/PULSE MA.

b. For measurements up to 1 ampere, set range switch to desired range.

c. Set polarity switch to DC+, DC–, or AC as desired.

d. Plug test leads into meter jacks. Connect other end of leads in series with circuit under test while the power is off. Turn on power and read meter.

e. For measurements above 1 ampere, connect test lead tips to pin jacks in shunt MX–9127/PSM–37. Connect circuit under test to appropriate load circuit binding posts. Set the RANGE switch to 2.5 or 10 to correspond with the shunt section used.

f. Turn on power and read meter. For a 2.5-ampere shunt section, the meter is set for 2.5 and reads a 2.5 amperes full-scale. Use of the 10-ampere shunt section results in a full-scale value of 10 amperes.

g. If a current below 100 microamperes is indicated, the function switch may be set to SPECIAL and a full-scale value of 100 microamperes obtained. This function is also useful for standard external shunts.

Exercises (245):

1. When you are using the MX–9127/PSM–37 shunt, what is the maximum amperage that you can measure?

2. If you wish to measure a current 100 microamps or less, to what function should you set the function switch?

246. State how to measure resistance with the AN/PSM 37.

Resistance Measurements. To measure resistance from 0 to 100 megohms, take the following steps.

a. Set function switch to OHMS LP or OHMS STD, depending on whether 100-millivolt or 1.4-volt output is desired. OHMS LP is generally used to measure in-circuit resistance where semiconductor junctions will block out the effect of other components. OHMS STD is best to check semiconductors for forward and reverse conduction and to minimize the effects of thermal, chemical, or leakage voltage.

b. Set polarity switch to DC+.

c. Set range switch at proper multiplier so that the resistance measured falls in the center portion of the green OHMS scale on the meter.

d. Plug test leads into meter jacks, short circuit the free ends of the test leads, and adjust OHMS ADJ until full-scale deflection (0 ohms) is obtained.

e. Clip the test leads across the item to be measured. Read resistance on the OHMS scale and multiply by the range setting.

f. If resistance in the opposite direction is also desired, change POLARITY switch to DC– and read. The polarity of the red jack matches the setting of the polarity switch. An internal regulator circuit precludes resetting zero for routine range-to-range, function-to-function, or battery discharge effects. This permits rapid in-circuit measurements at LP and STD, forward and reverse polarity, without disconnecting the leads during test to rezero. Different forward and reverse readings will be obtained on a known passive device only if outside power is passing through the device.

Upon completion of measurements, turn POLARITY switch to OFF position. The internal amplifiers draw battery current whenever the polarity switch is not OFF. The batteries when fresh will operate the multimeter for at least 500 hours with test leads open on the LP OHMS functions and for 250 hours on OHMS STD. Because of a mechanical interference interlock incorporated into the POLARITY switch knob, the multimeter must be off before the cover will fit properly?

Exercises (246):

1. When is the OHMS LP function used on the AN/PSM 37?

2. If you want to measure forward and reverse conduction of semiconductors, what function is best to use?

4-2. MD1A Insulation Breakdown Tester

There is one piece of ancillary equipment that needs to be mentioned at this time. This is the MD1A insulation breakdown tester. This instrument is used to check insulation resistance and breakdown of various insulating materials. Although it has many applications, you will probably see it used most often in your lab's meter section checking the insulation of meters such as the AN/PSM 37.

WARNING: To protect personnel from electrical shock hazards, compliance with the intent of TO 33–1–32 to the effect that all cord-connected equipment be grounded is mandatory. The equipment must have a three-conductor power cable. The third conductor must be connected so that, when the equipment power cable is plugged into an appropriate receptacle, the equipment is grounded.

247. Specify operational characteristics of the MD1A insulation breakdown tester.

Input power is brought to the test set through either AC Power Cable Assembly W1 or DC Power Cable Assembly W2 connected to POWER receptacle J1 on the instrument panel (fig. 4-4). If a 115-volt, AC source is used, power is fed through J1 terminals 1 and 2 and fuse F2, and it is applied across the 115-volt winding (terminals 1-3) of filament-vibrator transformer T1. If a nominal 24-volt DC source is used, power is applied through J1 terminals 3 and 4 and fuse F1 to the input of plug-in vibrator G1. The alternating voltage output of the vibrator at approximately 180 Hz is applied to the 28–0–28–volt winding (terminals 7–9) of transformer T1, and produces approximately 115 volts AC across T1 terminals 1 and 3. The voltage across these terminals is therefore the same regardless of which source is used. Capacitor C1 and resistor R1 connected across the 115-volt winding reduce vibrator contact sparking and enhance the waveshape of the transformer output voltage.

The moment source power is applied, regardless of test set control positions, green-jeweled POWER lamp DS1 lights, and the filaments of rectifier tubes V1 and V2 receive power.

When ON-OFF switch S2 is set to ON, red-jeweled OPERATE lamp DS2 lights to indicate that the high voltage supply is receiving input power. At the same time, meter lamps DS4 and DS5 illuminate the scales of meters M1 and M2, respectively. Depending upon the setting of voltage range switch S1, 115V AC, zero volts, or 15V AC is applied from the 115-volt winding of transformer T1 across voltage control potentiometer R2. Any portion of the applied voltage, from zero to the full value, is fed through section A of switch S2 to the primary of high voltage transformer T2. With 115 volts applied to the tranformer primary, the maximum AC output across the secondary is approximately 8500 volts.

A cascade voltage doubler circuit, including rectifier tubes V1 and V2 and capacitors C2 and C3, rectifies and increases the output to approximately 17,000 volts DC. Resistor R3 is connected in series with the high voltage line to limit the output current. The negative side of the output is then connected directly to breakdown jack J2, and through resistor R7 to resistance jack J3. Resistor R7 further limits the output current available at jack J3 to prevent damage to the specimen when insulation tests are made. Sphere gap E1 is connected across the output of the high voltage supply, and it is adjusted to arc over when the output voltage is on the order of 16–16.5KV. Arc-over of sphere gap E1 is accompanied by flashing of neon. METER OVERLOAD lamp DS3, serves as a momentary visual indication that voltage control potentiomenter R2 has been advanced too far clockwise. Additionally, the reading of kilovolt meter M2, and the test set output voltage, will drop to a value just below that at which the gap is set.

A kilovoltmeter circuit connected across the test set output functions as follows: Meter M2, a DC microammeter, has an added internal shunt which is connected across the meter by external switching. The basic movement, in series with meter multiplier assembly R5, provides a full-scale value of 1.5kV. This same combination, plus the added meter shunt, provides a full-scale value of 15kV. Section B of VOLTAGE RANGE switch S1 establishes the ranges and also shorts the meter for shock protection when switch S1 is set to the SHORT position. Section A of switch S1 applies 115V AC (15kV position), zero volts (SHORT position), or 15V AC (1.5kV position) across voltage control potentiometer R2 at the input to the high voltage transformer. Meter multiplier assembly R5 consists of a basic 28.5-megohm resistor, with additional small series composition resistors when necessary, to bring the total resistance to 30 megohms ± 1 percent. The kilovoltmeter has a red line at the 10kV point which, if this setting is used, simplifies the Ohm's law calculation for insulation resistance measurements.

The microammeter circuit functions as follow: DC microammeter M1 has an added internal shunt connected by external switching. When current range switch S3 is set to the 100 A position, the basic movement is connected in series with 100 A screwdriver adjustment control R4 between the positive side of the high voltage output and ground. With switch S3 set at 500 A, the same circuit is maintained, except that screwdriver adjustment control R6, labeled 500 A, is connected in parallel with R4. With switch S3 at SHORT, control R4 alone is returned directly to ground, and meter M1 is shorted to protect it from shock. METER OVERLOAD neon lamp DS3 is shunted across each of the combinations mentioned above together with capacitor C4, which stabilizes the voltage drop. This voltage drop can be varied to cause lamp DS3 to strike when the current drawn by the external load is at a particular point from 100–200 percent of full-scale value on either current range. Control R4 establishes the voltage drop for the 100 A range; control R6 for the 500 A range. A steady glow of neon lamp DS3 therefore indicates excessive load on the test set. Flashing of lamp DS3 also occurs when the insulation of a test specimen breaks down.

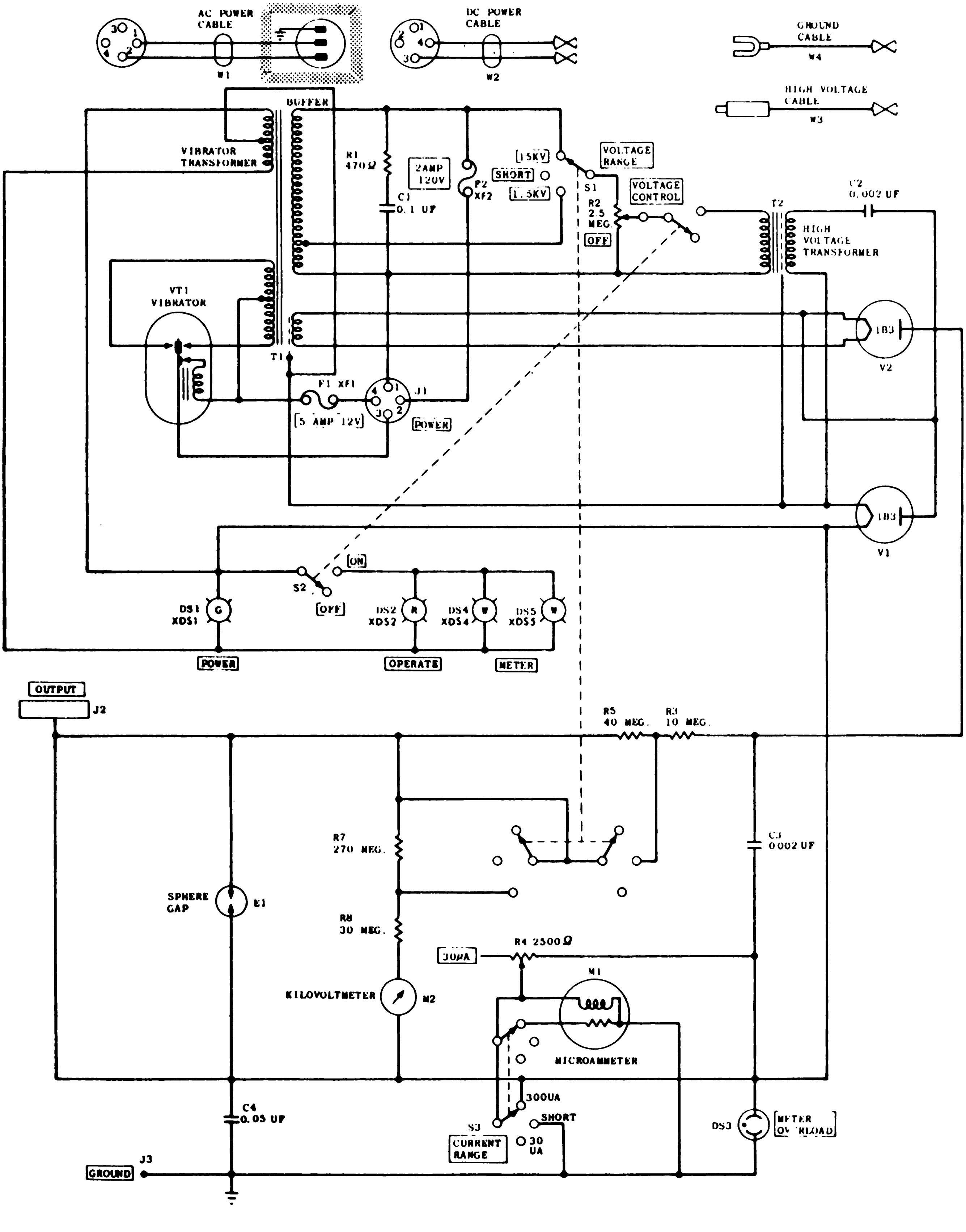


Figure 4–4. MD1A schematic.

Exercises (247):

1. What are the power requirements for the MD1A?

2. What is the visual indication if the insulation of a test instrument breaks down?

3. What is the output of the MD1A?

4-3. Digital Voltmeters

The 8800A circuitry can be divided into three major sections. The first of the three sections, termed the input signal conditioners, is comprised of the ohms converter, VDC buffer, and AC converter. The second section is the A/D (analog-to-digital) converter, and the third is the control and display section.

248. State the purposes of the signal conditioners in the 8800A digital multimeter.

Input Signal Conditioners. The term "input signal conditioner" describes the basic function of the three subsections grouped under it. The ohms converter, AC converter, and VDC buffer provide the A/D converter with a DC analog voltage representative of the input (AC volts, DC volts, or resistance) applied to the instrument. The basic path that each input signal follows as it is conditioned for the A/D converter is illustrated in figure 4-5.

When you are making a DC voltage measurement, the unknown voltage applied to the INPUT HI and LO terminals is directed to the DCV buffer. The buffer then either amplifies the input voltage (200mV range), passes the entire input voltage (2V range), or divides the input voltage by some power of ten (20, 200, and 1200V ranges) so that a "conditioned" signal of 2 volts DC at the A/D converter is representative of a full-scale instrument input for all ranges.

AC voltage inputs applied to the INPUT HI and LO terminals are directed through closed switch contacts to the AC converter. These AC input voltages are then converted to DC voltages so that a full-scale AC voltage input on any range will produce an AC converter output to the A/D converter of 2 volts DC.

When you are measuring an unknown resistance, the INPUT HI and LO terminals must be connected to the respective SOURCE HI and LO terminals. The shorting links provided on the front panel make the connection for two-terminal ohms measurements, and the input leads attached to the terminals make the connection during four-terminal ohms measurements.

The unknown resistance (RX) is supplied with current from the Ohms Converter while the voltage drop across RX, caused by the current, is applied to the VDC buffer as a representation of the unknown resistance. The ohms converter also applies the same current through a known resistance value to develop a reference voltage used in the A/D Converter in the KΩ function.

Exercises (248):

1. When you are making a DC voltage measurement, between which two terminals do you connect?

2. When measuring ohms, between which two terminals do you connect?

3. What amount of voltage arrives at the A/D converter for a full-scale indication?

249. Describe the slope operation of the A/D converter.

A/D Converter. A dual slope integration technique is used in the 8800A. The A/D converter receives the DC voltage output from one of the input signal conditioners and integrates it for 100ms. Figure 4-6 is an illustration of the output of the A/D integrator. The slope of the integrator output voltage during the integrate period is proportional to the input applied to the instrument. At the end of the integrate period, the signal conditioner DC voltage is disconnected from the A/D input; and a DC reference voltage, of opposite polarity, is connected to the input (start of the read period). The A/D converter then integrates the reference voltage so that the slope of the read period is always constant. Since the read period slope is held constant, the time required for the A/D integrator output voltage to return to the zero detect point is then proportional to the instrument input.

The digital representation of the input is obtained by counting the number of cycles of a clock oscillator frequency that occur from the start of the read period to the point where the A/D integrator output voltage returns to the zero detect level. The A/D converter supplies the control and display section with a compare signal at the end of the read period. The compare signal stops the counting of the clock oscillator pulses so that the analog value of the instrument input is now digitally represented by the number of oscillator pulses counted.

Exercises (249):

1. What is the integration time of the input signal at the A/D converter?

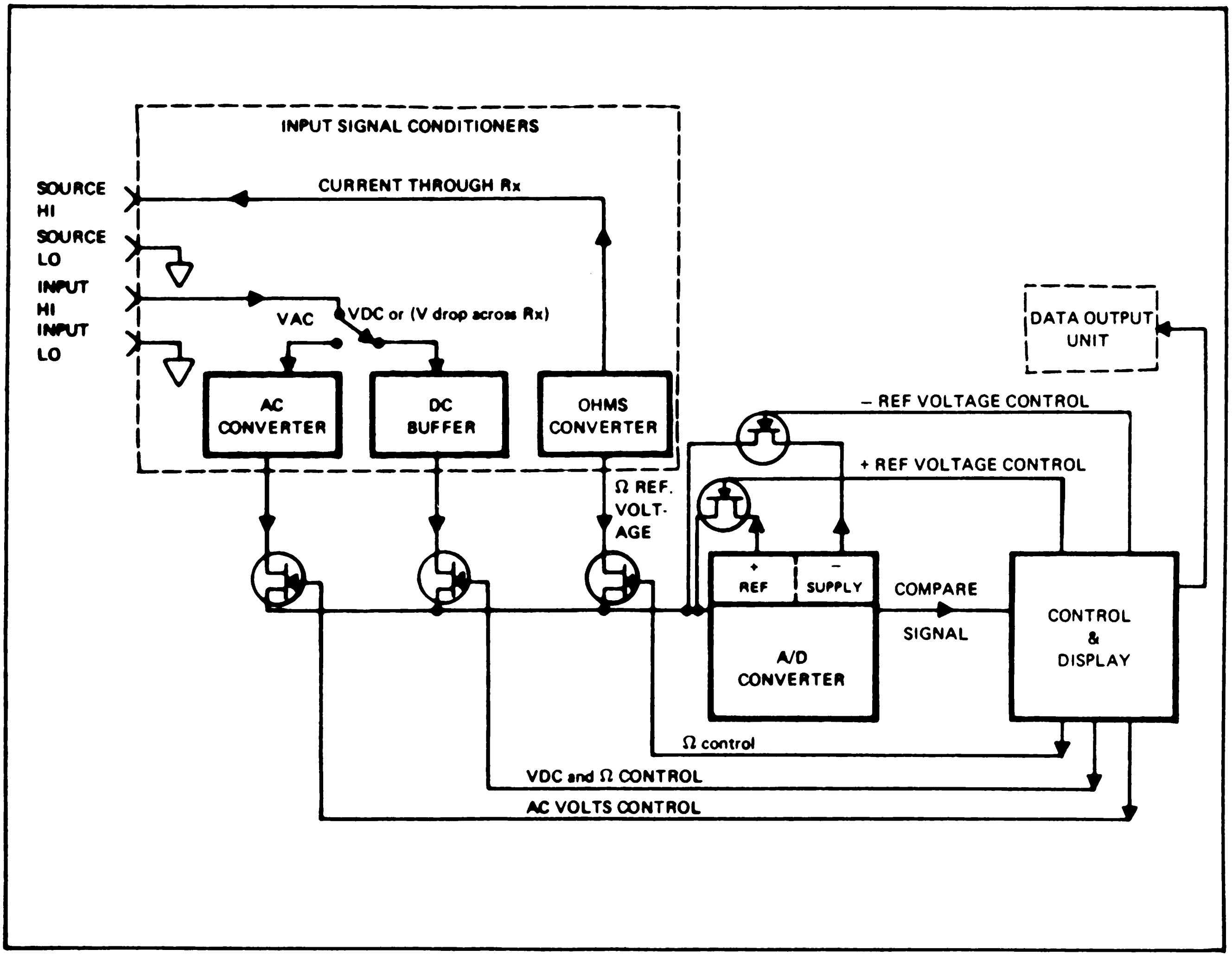


Figure 4–5. 8800A block diagram.

2. Where does the "compare" signal come from?

250. State the purpose of the control and display portion of the 8800 digital multimeter.

Control and Display. The control and display section provides the properly timed signals that direct the output of the correct input signal conditioner to the A/D converter during the integrate period. At the end of integrate time period, the control and display section connects the appropriate reference supply to the A/D converter input for the read period. The output of the 1 MHz oscillator is used to maintain the proper timing of the control signals.

The clock oscillator pulse count, accumulated during the read period, is applied to the LED display to produce the digital readout of the instrument input signal. The range information for the selected range positions the decimal point and illuminates the proper display annunciator.

Exercises (250):

1. What do the LEDs actually display?

4-4. Electronic Voltmeters

The Hewlett Packard Model 410C electronic voltmeter is typical of some of the electronic voltmeters you will be using in your job. You can use it to measure DC voltage and DC current, and AC voltage and resistance. Positive and negative DC voltages from 15mV to 1500V full scale and

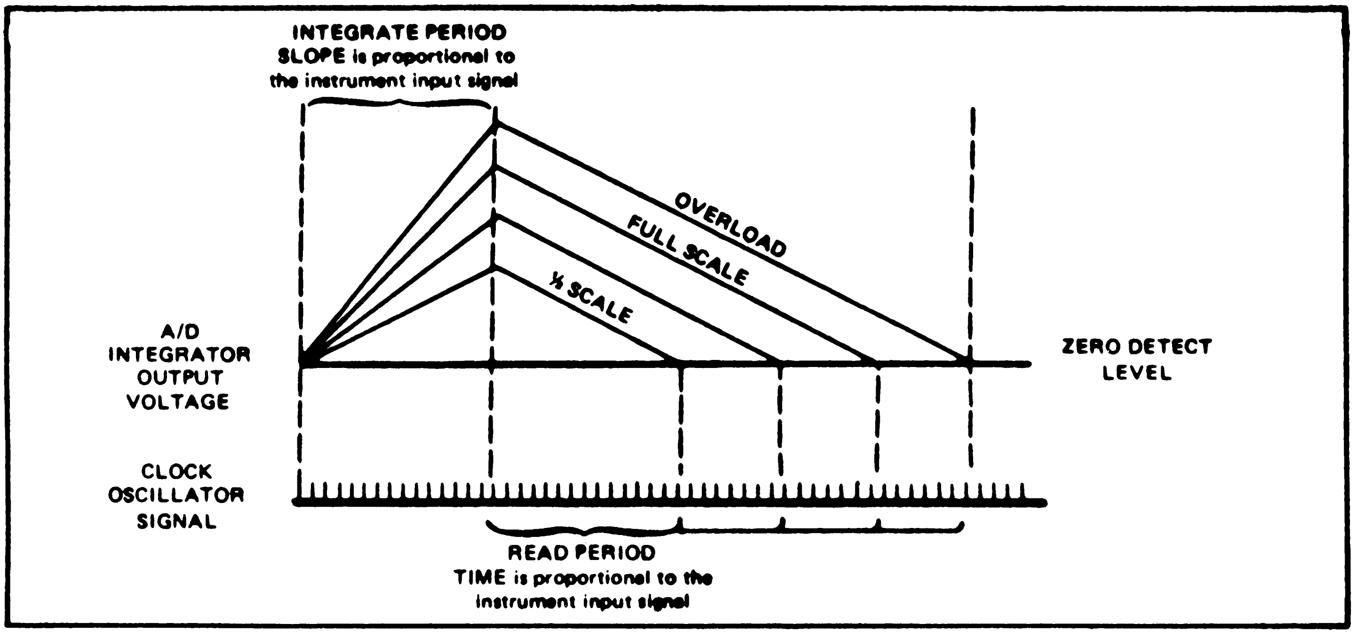


Figure 4–6. Timing diagram for dual-slope A/D conversion.

positive and negative DC currents from 1.5A to 150mA can be measured full scale. Resistance from 10 to 10 mid-scale can be measured with an accuracy of ±5 percent; resistance from 0.2 to 500M can be measured with reduced accuracy.

With the Model 11036A detachable AC probe, the voltmeter can be used to measure AC voltage in the frequency of 20 Hz to 700 MHz.

251. State the purposes of the 410C accessories.

Accessories are available that extend the AC and DC measuring capabilities of the voltmeter. A description of these accessories and their specifications is given in the following paragraphs.

The Model 11036A AC Probe. This accessory, when used with the Model 410C, permits AC voltage measurements from 0.5V rms to 300V rms, full scale over a frequency range of 20 Hz to 700 MHz. Reference calibration accuracy at 400 Hz (sinusoidal) is ± 3 percent of full scale. Frequency response is ± 10 percent from 20 Hz to 700 MHz, with indications obtainable to 3000 MHz. Frequency response at 100 MHz is within ±2 percent. The Model 11036A responds to the positive-peak-above-average value of the signal applied. The Model 410C is calibrated to read in rms volts for sine wave inputs.

The Model 11039A Capacitive Voltage Divider. This accessory (formerly the Model 452A) extends the AC voltage range of the Model 410C to 25 kV. The divider permits measurements of extremely high AC voltage, such as that encountered in dielectric heating equipment, over a frequency range of 25 Hz to 20 MHz. A fixed gap is provided so that breakdown will occur if the applied voltage exceeds 28 kV at low frequencies. Voltage division is 1000:1 ± 3 percent, and input capacity is 15pF. A Model 11018A adapter is also required to connect the Model 11036A AC probe to the shielded banana plug fitting of the divider.

The Model 11040A Capacity Divider. This accessory (formerly the Model 453A) extends the AC voltage range of the voltmeter to 2000V rms. The divider is for use at frequencies above 10 kHz. Voltage division is 100:1,± 1 percent, and input capacity is approximately 2 pF.

The Model 11042A Probe T Connector. This accessory (formerly the Model 455A) is used for connecting the Model 11036A probe across a 50Ω transmission line using type N connectors. The T joint is such that connection of the probe into a transmission line will not cause a standing wave ratio greater than 1.1 at 500 MHz and 1.2 at 1000 MHz. With this device, measurement of power traveling through a transmission line may be made with reasonable accuracy to 1000 MHz. The usual precautions must be taken to provide accurate impedance matching and the elimination of standing waves along the line through which power is floating. By using a dummy load at the receiving end of this T joint, power output of various devices can be measured. In many applications power going into a real load, such as an antenna, can be conveniently measured up to 1000 MHz with good accuracy.

The Model 11043A Type N Connector. This accessory (formerly the Model 458A) allows the AC probe to be connected to a 50Ω coaxial line. The connector uses a male type N connector and a receptacle for receiving the probe. Terminating resistor is not included.

The Model 11045 DC Divider. This accessory extends the maximum DC voltage range of the Model 410C to 30 kV. Voltage division is 100:1, ±5 percent, and input resistance is 9900M. When used with the Model 410C, input resistance is 10,000M. This probe offers maximum safety and convenience for measuring high voltages, such as that in television equipment. The maximum current drain is 2.5 amps.

Exercises (251):

1. What is the frequency response of the Model 11036A, AC probe?

2. How much can the Model 11039A capacitive voltage divider accessory extend the AC range of the 410C?

3. Does the 11043A Type N connector accessory allow the DC probe to be connected to a 50 ohm coaxial line?

252. State the operating procedures of the 410C for the different modes of operation.

Introduction. The Model 410C is used to measure AC and DC voltage, DC current, and resistance. All measurement inputs are located on the front panel; a DC output connector is located on the rear panel. Front panel controls and indicators are color-coded. DC voltage, DC current, and resistance knobs and indicators are in black; AC voltage controls and indicators are in red.

Figure 4-7 describes the function of all front and rear panel controls, connectors, and indicators. A description of each control, connector, and indicator is keyed to the figure.

Preliminary. The mechanical zero should be checked before you use the 410C for a measurement. You can do this before you first turn the unit on. If the unit has been in use, you must turn the unit off for 2 hours or install a short across the meter terminals. Rotate the mechanical zero-adjustment screw on front panel clockwise until pointer reaches zero, moving up scale. If for some reason the pointer should overshoot zero, continue turning the screw clockwise until the desired results are obtained. When the pointer has been positioned at zero, rotate the zero-adjust screw slightly counterclockwise to free it. If the meter pointer moves to the left during this action, repeat the procedure.

After the mechanical zero adjust has been made, connect the unit to the appropriate voltage source and let it warm up for 5 minutes.

DC Voltage Measurements. The Model 410C is normally floating; however, a shorting bar can be connected at the DC AMPLIFIER OUTPUT connector on the rear panel. When the instrument is floating, the COM Lead should not be connected to voltages greater than 400V DC.

Use the following steps to make a DC voltage measurement:

a. Depress the AC power switch (neon-switch combination).
b. Set FUNCTION SELECTOR to polarity desired (+DCV or −DCV).
c. Set RANGE to desired voltage position.
d. Connect COM Lead to the ground of circuit under test.
e. Touch DCV probe to test point.
f. Read voltage on the VOLTS-AMPS scale.

Aging of the neon lamps in the chopper assembly can cause a change in chopper frequency which produces a low amplitude oscillatory movement of the meter pointer. If the meter pointer oscillates, rotate A3R5 ccw until oscillation stops.

DC Current Measurements. General instructions for the measurement of DC current are the same as those given for DC voltage measurements.

Use the following steps to make a DC current measurement:

a. Depress the AC power switch (neon-switch combination).
b. Set FUNCTION SELECTOR to the polarity desired (+DCA or −DCA).
c. Set RANGE to desired current position.
d. Connect COM Lead to the ground of circuit under test.
e. Connect the DCA ohms probe to the circuit to be tested.
f. Read the current on the VOLTS-AMPS scale.

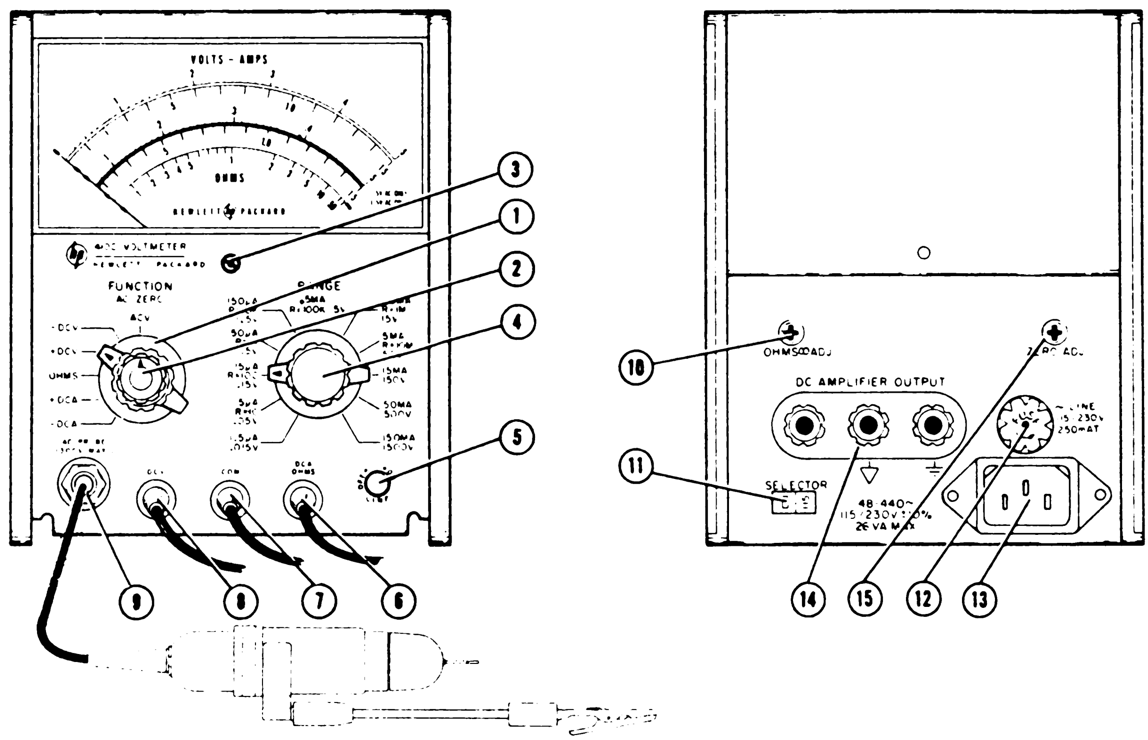
AC Voltage Measurements. Special cautions must be kept in mind when making AC voltage measurements. These cautions are discussed in the following paragraphs.

Although the Model 410C indicates a full-scale AC range of 500V, the optional Model 11036A AC probe should not be connected to AC voltages in excess of 300V rms. AC voltage referenced to a DC voltage may be measured, but the AC probe clip (alligator type) must be connected to the ground of the circuit under test.

When measuring AC referenced to DC, the peak AC voltage plus DC voltage connected to the probe must not exceed 420V.

One side of almost all power distribution systems is grounded. You must use extreme caution if you try direct measurement of power line voltages. If the ground clip lead is accidentally connected to the ungrounded side of the line, severe damage to the 410C is possible because of the short circuit created. Power line voltages can best be measured by using the probe tip only. Contacting the grounded power conductor will give a reading of 0V; contacting the ungrounded lead will give full voltage reading.

Before measuring voltage at frequencies above 100 MHz, refer to the TO for the 410C to determine the maximum amount of voltage that can be applied at the frequency.



(1) FUNCTION SELECTOR: This control is used for selecting type of measurement to be made. They are: ± DC Voltage, ± DC Current, AC Voltage, and resistance measurements.

(2) AC ZERO: This control provides adjustment for zero-setting the meter before making ac voltage measurements.

(3) MECHANICAL ZERO ADJUST: This adjustment mechanically zero-sets the meter prior to turning on Voltmeter.

(4) RANGE: This control selects the full scale meter range.

(5) AC POWER SWITCH: This pushbutton-lamp combination, when depressed, turns the instrument power on or off. The pushbutton glows when the Voltmeter power is on.

(6) DCA-OHMS: This lead is used in conjunction with the COM Lead to measure dc current or ohms. The FUNCTION SELECTOR determines which measurement is made.

(7) COM: This lead is used with the input leads for dc current, dc voltage, and resistance measurements. The COM Lead is normally floating; however, a shorting bar can be connected from the floating ground terminal to the chassis ground terminal on the DC AMPLIFIER OUTPUT connector. If a shorting bar is not used, the COM Lead is floating except when the FUNCTION SELECTOR is set to ACV.

(8) DCV: This lead is used in conjunction with the COM Lead to measure ± dc voltage.

(9) AC PROBE (300 V MAX): Receptacle for telephone-type plug of Model 11036A AC Probe. With probe connected, the Voltmeter may be used to make ac voltage measurements.

(10) ∞ ADJUST: This control is used to set meter pointer to ∞ before resistance measurements are made. Only periodic adjustment of this screwdriver adjusment is necessary.

(11) LINE VOLTAGE: This two-position slide switch sets the instrument to accept either 115 or 230 V ac primary power.

(12) FUSEHOLDER: The fuseholder contains a 0.25 ampere slow-blow fuse for both 115 V ac and 230 V ac modes of operation.

(13) AC POWER CONNECTOR: Accepts power cable supplied with the instrument.

(14) DC AMPLIFIER OUTPUT: Provides dc voltage output proportional to meter indication for driving external recorder. 1.5 V dc output for full scale meter deflection.

(15) ZERO ADJUST: This control is used to set meter pointer to zero when calibrating for dc and resistance measurements.

Figure 4–7. Front and rear panel controls.

To make an AC voltage measurement, take the following steps:

a. Connect the Hp Model 11036A AC probe to the Model 410C at the AC PROBE receptacle.

b. Set FUNCTION SELECTOR TO ACV. (NOTE: COM and chassis are internally connected when the FUNCTION SELECTOR is set to ACV.)

c. Set RANGE to 0.5V.

d. Depress the AC power button (neon-switch combination) and allow 5-minute warmup.

e. Short AC probe tip with ground clip.

f. Adjust AC ZERO for a zero indication on the meter.

g. Set RANGE to the desired voltage range.

h. Connect AC probe clip (alligator) to ground of circuit to be tested, and touch probe tip to test point. At lower frequencies, COM Lead can be substituted for the AC Probe clip.

i. Read AC voltage on the VOLTS-AMPS scale. (NOTE: When RANGE is on the 0.5V and 1.5V positions, use red meter scale.)

General Consideration of Complex Waveforms. Waveforms containing appreciable harmonics or spurious voltages will introduce error in the meter indication since the meter has been calibrated to read rms values of true sine waves while the Model 11036A probe is a peak-above-average responding device. The magnitude of error that may be expected when harmonics are present on the measured waveform is indicated in TO 33A1-12-701-1.

Voltage Measurement at High Frequencies. At frequencies above 100 MHz, the distance between the point of voltage measurement and the anode of the probe diode must be made as short as possible. If feasible, substitute a small disc-type capacitor of approximately 50 pF for the removable tip on the probe. Solder one terminal of the button capacitor to the measurement point in the circuit and not to the probe contact. The probe contact (with tip removed) can then contact the other terminal of the capacitor for the measurement.

At frequencies above 100 MHz, considerable voltage may be built up across ground leads and along various parts of a grounding plane. Consequently, to avoid erroneous readings when measuring medium and high frequency circuits, use the ground clip lead on the shell of the probe to connect the circuit ground. In some cases at the higher frequencies, it may be necessary to shorten the grounding lead on the probe.

For all measurements at higher frequencies, hold the molded nose of probe as far from the the external ground plane or from the object at ground potential as can conveniently be done. Under typical conditions, this practice will keep the input capacitance several tenths of a pF lower than otherwise.

For measurements above approximately 250 MHz, it is almost mandatory that measurements be made on voltages which are confined to coaxial transmission line circuits. For applications of this type, the Model 11036A probe is particularly suitable because the physical configuration of the diode and probe is that of a concentric line, and with a few precautions it can be connected to typical coaxial transmission line circuits with little difficulty.

To connect the probe into an existing coaxial transmission line, cut the line away so that the center conductor of the line is exposed through a hole large enough to clear the body of the probe. The nose of the probe should be removed for this type of measurement. Connect one terminal of a button-type capacitor of approximately 50 pF to the center conductor of the coaxial line so that the other terminal of the capacitor will contact the anode connection of the probe. A close-fitting metal shield or bushing should be arranged to ground the outer cylinder of the probe to the outer conductor of the transmission line. This type of connection is likely to cause some increase in the standing wave ratio of the line at higher frequencies. The Model 11042A Probe T connector is designed to do this job with SWR of less than 1.1 at 500 MHz.

Effect of Parasitics on Voltage Readings. At frequencies above 500 MHz, leads or portions of circuits often resonate at frequencies two, three, or four times the fundamental of the voltage being measured. These harmonics may cause serious errors in the meter reading. Owing to the resonant rise in the probe circuit at frequencies above 1000 MHz, the meter may be more sensitive to the harmonics than to the fundamental. To make dependable measurements at these frequencies, the circuits being measured must be free of all parasitics.

Effect of DC Present with AC Signal. When measuring an AC signal at a point where there is a high DC potential, such as at the plate of a vacuum tube, the high DC potential may cause small leakage current through the blocking capacitor in the tip of the Model 11036A AC probe. When the AC signal under measurement is small, the error introduced into the reading can be significant. To avoid leakage, an additional capacitor with a dielectric, such as Mylar or polystyrene, which has high resistance to leakage is required. (Use 5 pF or higher, and insert the capacitor between the point of measurement and the probe tip.)

Measuring Resistance. Before making resistance measurements, remove power from the circuit to be tested. Also, make sure capacitors are discharged to eliminate any residual voltage.

To make a resistance measurement, take the following steps:

a. Depress AC power switch (neon-switch combination).

b. Set the FUNCTION SELECTOR to OHMS.

c. Set RANGE to desired position.

d. Adjust OHMS ADJ control on rear panel to obtain a 0 reading on the meter if necessary.

e. Connect COM and DCA OHMS leads across circuit to component to be tested.

f. Determine resistance by multiplying the reading on the OHMS scale by the range factor. Example: If reading is 1.5 and factor is 10K, then resistance equals 15K.

Exercises (252):

1. How long should the 410C be warmed up before it is used to make a measurement?

2. What test leads do you use to make an AC voltage measurement?

3. You have the 410C in the AC mode and have the range set to 0.5V. With what do you short the AC probe before you adjust the AC ZERO?

4. Before making a resistance measurement, what precautions must you observe?

253. Specify the basic principles of operation for the 410C electronic voltmeter.

The Model 410C includes an input network, a modulator-amplifier-demodulator, and a meter circuit. A block diagram of the Model 410C is shown in figure 4-8.

'Signals to be measured are applied through the appropriate input lead to the input network. AC voltages are detected in the AC probe, and therefore all signals to the input network are DC. The input network attenuates the DC signal to a level determined by RANGE and FUNCTION SELECTOR settings. The network includes a precision voltage divider, which by means of the function selector and range switches, provides a maximum of 15mV at the modulator input regardless of the range set and signal applied.

In DC Current Measurements. The purpose of the input network is to provide proper attenuation of the currents applied. A change in input impedance is varied by using DC current shunts in conjunction with the RANGE switch. The DC voltage developed across these shunt resistors, when applied through the modulator-amplifier-demodulator network to the meter, provide a deflection on the meter proportional to the DC current being measured.

During DC Voltage Measurements. The purpose of the input network is to attenuate accurately the input signal to a maximum of 15 mV at the modulator input. The network presents an input impedance of 10M on the three most sensitive ranges and 100 M on all other ranges.

In Resistance Measurements. The purpose of the input network is to place approximately 0.6V DC source in series with a known (reference) resistance. The resistance to be measured is placed in parallel with the known resistance, which changes the voltage proportionally. The maximum change in voltage applied to the modulator is 15 mV because of attenuation provided.

During AC Voltage Measurements. The voltage at the AC probe is converted to DC and applied to the input network. The input signal is attenuated to produce a maximum of about 15 mV at the modulator input. AC zero adjustment of meter pointer is made with the AC ZERO control.

The attenuated DC voltage is applied to the modulator which converts the DC to AC for amplification. The

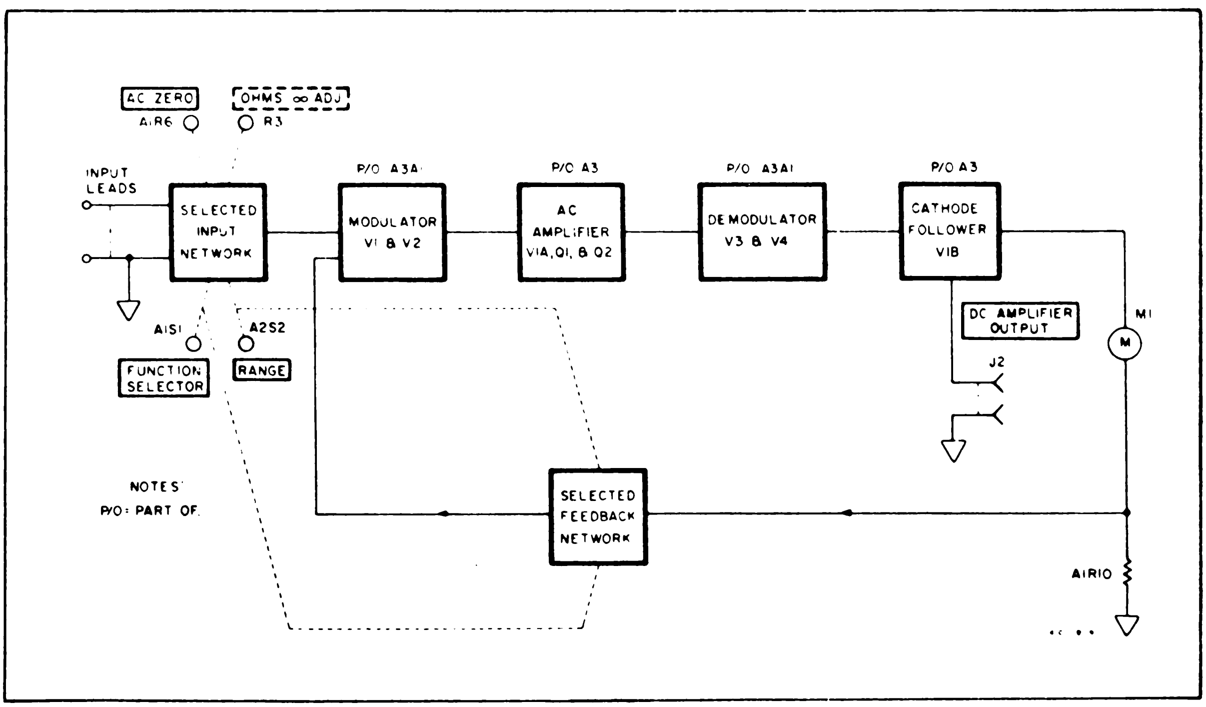


Figure 4–8. Block diagram, model 410C.

amplified AC signal is converted back to DC voltage in the demodulator and coupled to cathode follower VIB. The cathode follower output to the DC AMPLIFIER OUTPUT connector and meter circuit is a DC voltage proportional to the amplitude of the signal applied to the input. A portion of the voltage to the meter circuit is returned to the modulator as feedback. When the feedback voltage and attenuated DC voltage are nearly equal, the meter stabilizes.

Mechanical Analogy. Now refer to the mechanical analogy schematic in figure 4-9 as you learn more about the modulator, demodulator, and feedback circuits.

The input network applies approximately 15 mV DC for full-scale meter deflection (positive or negative), depending on the polarity of the voltage or current being measured to the neon-photo-conductor chopper. Also applied to the opposite side of the chopper is the amplifier feedback voltage, which is of the same polarity and approximately 5 V lower in amplitude than the input voltage. The modulator-chopper consists of two photoconductors, which are alternately illuminated by two neon lamps. The neon lamps are part of a relaxation oscillator whose frequency is controlled by variable resistor. The oscillator frequency is nominally set to 100 Hz for operation from a 60 Hz power line, or to 85 Hz for operation from a 50 Hz line. This frequency is selected so that it is not harmonically related to the power line frequency, precluding possible beat indications on the meter.

As the photoconductors are alternately illuminated by the neons, their respective resistances are low (conductive) when illuminated and high (nonconductive) when darkened. Therefore, the input voltage and feedback voltage are alternately applied to the input amplifier. The amplitude of the resultant signal to the amplifier is the voltage difference between the input and feedback voltages.

The chopped DC signal is amplified by a three-stage RC amplifier, consisting of A3V1A, A3Q1, and A3Q2. The amplified signal to the input of the demodulator-chopper is 180° out-of-phase with the output of the modulator-chopper.

The demodulator-chopper consists of two photoconductors and V4, which are alternately illuminated by neon lamps. Approximately 150 mV square wave is applied to the demodulator from the amplifier. Since the same neon lamps illuminate both the modulator and demodulator photoconductors, operation of the two choppers is synchronous. Therefore, when V1 is sampling the input voltage, V3 is clamping the amplified and inverted difference voltage to ground. Alternately, when V2 is sampling the feedback voltage, it is charging capacitors A3C13 and A3C14 to the peak value of the square wave. These capacitors maintain this charge so long as the input voltage remains constant by virtue of having no discharge path and because they are being repetitively recharged by the demodulator.

Therefore, a DC potential, proportional to the difference between the input and feedback voltages, is applied to the grid of the cathode follower and subsequently to meter circuit and DC AMPLIFIER OUTPUT connector. A portion of the meter circuit voltage is fed back to the modulator. The meter stabilizes when the feedback and input voltages are nearly equal.

The feedback network drives the meter and determines the DC gain of the amplifier. The feedback is varied depending on the position of the function and range selectors (fig. 4-9).

Exercises (253):

1. What is the maximum input to the modulator of the 410C electronic voltmeter?

2. True or false. During a resistance measurement the unknown resistor under test is placed in series with a known resistor in the input network of the 410C electronic voltmeter.

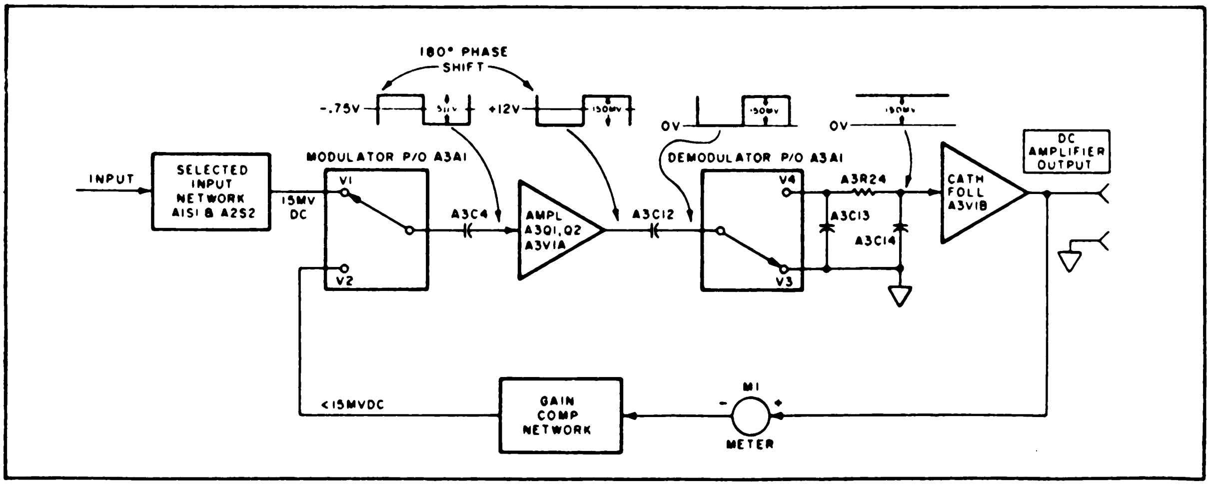


Figure 4–9. Modulator-demodulator mechanical analogy.

3. The amplitude of the modulator output is the voltage difference between two voltages. What are these two voltages?

4. What is the oscillator frequency adjusted to in the modulator?

254. Specify the operational characteristics of the Hewlett Packard Model 411A RF millivoltmeter.

The Hewlett Packard Model 411A RF Millivoltmeter is a sensitive AC voltmeter which will measure accurately from 0.01 volt rms to 10 volts rms full scale in the frequency range of 500 kHz to 1000 mHz (1 gHz). The 411A probe, when used without accessories, will respond to frequencies up to 4 gHz and may be used as an indicator up to this frequency. The Model 411A is supplied with a BNC-type screw-on probe tip that provides easy and rapid measurement at low frequencies. Other probe tips, which make possible convenient measurement at 1000 mHz, are available. The Model 411A has a recorder output with an adjustable level.

Preliminary Considerations. Look at figures 4-10 and 4-11. For the majority of your uses (measuring continuous

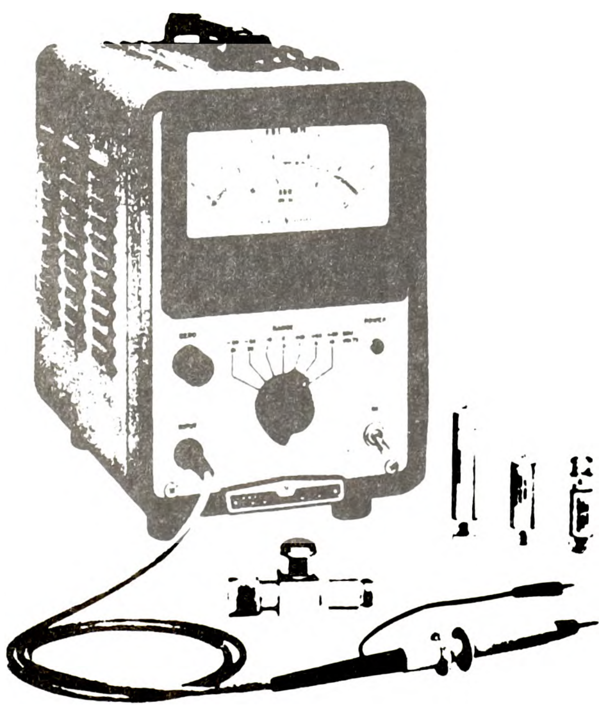


Figure 4–10. Model 411A RF millivoltmeter.

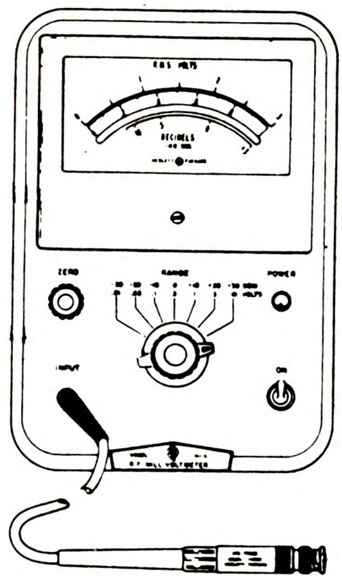


Figure 4–11. Model 411A front panel.

sine waves), the Model 411A will indicate the root-mean-square value directly.

Good RF measurements require proper grounding. The Model 411A contains a line filter to eliminate stray RF from the power line. Therefore, you must GROUND THE INSTRUMENT CHASSIS PROPERLY TO AN EARTH GROUND to make significant measurements. In addition, the filter configuration is such that, if you do not ground the instrument, its chassis assumes a voltage of about one-half the line voltage, and you can damage circuits under test.

Probe Tips. Five probe tips are available for the Model 411A. These probe tips enable you to use the Model 411A for almost any measuring application. Data to guide you in the selection of the proper probe tip follows.

Probe Tip	*Model No.*	*Frequency Range*
Clip-on	11022A	500 kc— 50 mHz
VHF	11023A	500 kc— 250 mHz
Type N "T"	11024A	1 mc—1000 mHz
BNC (supplied)	11025A	500 kc— 500 mHz
100:1 Divider	11026A	500 kc— 250 mHz

A complete probe-tip kit containing these probe tips plus an extra replacement cartridge in a handy case is available from Hewlett Packard as 11027A Probe Kit.

BNC OPEN CIRCUIT PROBE TIP, Hewlett Packard Model 11025A, has a frequency range of 500 kHz to 500 mHz and a maximum voltage of 200 volts DC or 30 volts peak-to-peak AC. Its input resistance varies with the voltage and frequency applied.

The TYPE N "T" PROBE TIP, Hewlett Packard Model 11024A, has a frequency range of 1 mHz to 1000 mHz and a maximum input of 10 volts DC and 30 volts AC. It has an SWR of less than 1.15 when terminated in 50 ohms.

Insertion loss is less than 1 dB (less than 0.1 dB up to 150 mc).

The PEN-TYPE PROBE TIP, Hewlett Packard Model 11022A, has a frequency range of 500 kHz to 50 mHz and a maximum input of 200 volts DC and 30 volts peak-to-peak ac. Its input resistance varies with voltage and frequency.

The VHF PROBE TIP, Hewlett Packard Model 11023A, has a frequency range of 500 kHz to 250 mHz and a maximum input of 200 volts dc and 30 volts peak-to-peak AC. Its input resistance also varies with voltage and frequency.

The CAPACITIVE DIVIDER (100:1), Hewlett Packard Model 11026A, has a frequency range of 500 kHz to 250 mHz and a maximum input of 1000 volts peak (DC + peak AC). Its shunt capacity is 2 pf, and its division accuracy is ± 1 percent.

Mechanical Meter-Zero. When the meter is properly zero set, the pointer rests over the zero calibration mark on the meter scale when the instrument is (1) at normal operating temperature, (2) in its normal operating position, and (3) turned off. Zero-set as follows to obtain best accuracy and mechanical stability.

a. Allow the instrument to operate for at least 20 minutes; this allows meter movement to reach normal operating temperature.

b. Turn the instrument off and allow 30 seconds for all capacitors to discharge.

c. Rotate the mechanical zero-adjustment screw clockwise until the meter pointer is to left of zero and moving upscale toward zero.

d. Continue to rotate the adjustment screw clockwise; *stop* when pointer is right on zero. If the pointer overshoots zero, repeat steps c and d.

e. When pointer is exactly on zero, rotate the adjustment screw approximately 15° *counterclockwise*. This is enough to free the adjustment screw from the meter suspension. If the pointer moves during this step, you must repeat steps *c* through *e*.

Zero Adjustment. As this control is turned counterclockwise, it has control until the meter reaches zero. When the meter reads below zero, the action of the zero control is sluggish. However, the zero does not always have to be set accurately. A slight error in zero-setting becomes less important (at a square-law rate) as the input voltage is increased. For example, if the zero-set is off 1 minor division, this would be about 0.8 μv of DC, equivalent to about 0.2 mv of rf. At 1 mv of rf (1/10th full scale), about 15 μv DC is developed at the probe output, meaning that the error in zero-set would be only 5 percent of the reading. At full scale it would only be about 0.05 percent.

a. To check the electrical zero, turn the instrument on and remove all input to the probe (short probe tip if vhf).

b. Turn the range switch to the 1 volt or greater range. The meter pointer should be on zero. If it is not, the cathode follower bias must be reset. Turn the range switch to the blank, fully clockwise, position. In this position the feedback loop is opened.

c. Adjust the BIAS ADJ control (on rear) until the meter reads zero.

d. Switch the range switch to 0.01 volt range.

e. Turn the ZERO control fully clockwise. Now turn the ZERO control counterclockwise until the meter reads zero.

Note that, if the probe tip is connected to a test set-up that is at a different temperature than the probe tip, the zero indication will drift until both diodes in the probe are at the same temperature.

To make a measurement after zeroing, simply turn the range switch to the expected voltage and connect the probe to the point to be measured. (Connect the ground lead, if used, to ground.) Then read the amount of voltage on the appropriate scale.

No interpretation of the meter reading is necessary with continuous sinusoidal signals with no DC component. Since the 411A is a peak-responding meter, a DC voltage component would increase the meter indication.

When a nonsinusoidal signal is measured, the meter indication is useful only as a relative measurement.

Exercises (254):

1. What probe tip would you use to measure a signal with a frequency of 1000 mc?

2. To measure an AC voltage of 100 VAC at 100 MHz, which probe tip would you need to use?

3. To perform the mechanical zero-adjustment, the unit should be at normal operating temperature. (true/false)

4. The front panel electrical zero control is adjusted with the range control in what position?

4-5. Differential Voltmeters

The last type of meter we will discuss is the differential voltmeter. These meters are commonly used because of their accuracy and because there is very little or no current drain upon the circuit under test. The two meters we will discuss are the Fluke 893A DVM and the Fluke 887A/AB DVM.

255. Cite operational characteristics of the Fluke 893A differential voltmeter.

Fluke 893A Differential Voltmeter. The 893A is one of a variety of dual mode voltmeters. It provides both a conventional transistorized voltmeter (TVM) mode (with a measurement uncertainty of ±3 percent) and a differential voltmeter (which is as much as 250 times more accurate than the TVM).

Refer to figure 4-12 for the following explanation. The 893A circuitry is composed of a reference supply, a Kelvin-Varley divider, a DC input divider, a null detector, a meter, an AC converter, and a recorder output. Basically, a Kelvin-Varley divider is a precise voltage divider that provides a constant input resistance and a variable output voltage. These circuits are interconnected by various switching arrangements when performing selected AC or DC conventional or differential voltage measurements.

When used as a conventional transistorized DC voltmeter, the circuits are connected as shown in figure 4-12. The DC input divider is connected across the input terminals to provide a constant input impedance of 100 megohms on all ranges. With a full-scale voltage applied to the input terminals, the tap of the DC input divider selected by the range switch provides a DC input voltage of ±1 millivolt to the input of the null detector. The null detector amplifies this 1-millivolt input to drive the front panel meter. The gain of the null detector is precisely controlled by a negative feedback network and provides a full-scale meter deflection for any full-scale input. The mode switch reverses the meter input terminals. This allows positive and negative voltage measurements.

When the mode switch is placed in the AC position, the circuitry is connected as a conventional transistorized AC voltmeter. Resistor R12 and the AC converter are connected across the input terminals, providing a constant input impedance of 1-megohm on all AC voltage ranges. The overall gain of the converter amplifier is controlled by the negative feedback network selected with the range switch. A full-scale input voltage at the input to the AC converter results in an AC converter output voltage of 1-volt DC. This 1-volt DC ouput is applied to the DC input divider where it is reduced to the required 1-millivolt prior to being applied to the null detector amplifier. The null detector drives the meter, which indicates the magnitude of the AC voltage being measured.

When used as a DC differential voltmeter, the mode switch is placed to the desired "+" or "−" position and the range switch to the desired voltage range. In the differential mode of operation, the NULL SENS switch selects a suitable resistance value from the DC input divider resistors for the meter full-scale sensitivity desired. The NULL SENS switch also applies the Kelvin-Varley divider output to the common input of the null detector. The null detector then compares the DC input voltage to the Kelvin-Varley divider output voltage. Any resulting difference is amplified and used to drive the meter. Meter deflections to the right correspond to input voltages above the precisely controlled Kelvin-Varley divider output voltage. Meter deflections to the left correspond to input voltages below the divider output voltage. When a null is indicated by the meter, the 893A input impedance is infinite because there is no current drawn from the circuit being measured. The mode switch allows reversal of the Kelvin-Varley divider input voltage for plus and minus DC voltage measurements.

With the NULL SENS switch in any of the null positions and the mode switch in the AC position, the instrument operates as an AC differential voltmeter having an input impedance of 1 megohm. The AC converter operates in the same manner as when the instrument is operated as an AC TVM, and supplies 1 volt DC to the DC input divider for a full-scale input. The remaining circuitry operates the same as when the instrument is functioning as a DC differential voltmeter.

The recorder output circuit provides isolation between the null detector output and recorder output terminals. The null detector output voltage is modulated by a 3-kilohertz drive signal derived from the reference supply. The modulated signal is transformer coupled to a demodulator driven at the same 3-kilohertz rate as the modulator. The signal is then demodulated, and the resulting DC voltage is applied through a variable resistor to the recorder output terminals. The variable resistor provides adjustment of the recorder output voltage.

The reference supply produces DC voltages of 1.1, 11, 110, and 1100 volts, which are applied to the Kelvin-Varley divider. The supply also develops a 3-kilohertz signal, which is applied to the null detector and the recorder output circuits. The accuracy and stability of the 893A is dependent upon the voltages produced by the reference supply.

Exercises (255):

1. When the 893A is functioning as a conventional voltmeter, what does a full-scale input produce to the null detector?

2. When can the maximum input impedance of the 893A be obtained?

256. Analyze the circuit operation of the 893A DC input divider.

DC Input Divider. Refer to foldout 2 for the following explanation. The DC input divider is composed of seven series-connected resistors, R1 through R7, having a total resistance of 100.1 megohms.

When the voltmeter is operated as a conventional DC TVM, the input impedance is a constant 100.1 megohms on all DC voltage ranges. The range switch is used to select the desired tap on the divider network. When the 893A is used as a conventional DC TVM, the voltage applied to the HI input terminal (upper left-hand of foldout 4) is coupled through the selected contacts of the mode switch and applied to the DC voltage divider consisting of R1 through R7. The desired voltage from the divider network is selected by section S1BR of the range switch. A full-scale input for any particular range will provide a 1-millivolt (±10 percent overranging) output from the voltage divider for AC or DC TVM operation. For example, when the range switch is in the 1-VOLT position, the output applied to the null detector assembly is developed across R4 through R7. The total resistance of R4 through R7 is 100 kilohms and the total resistance of R1 through R3 is 100

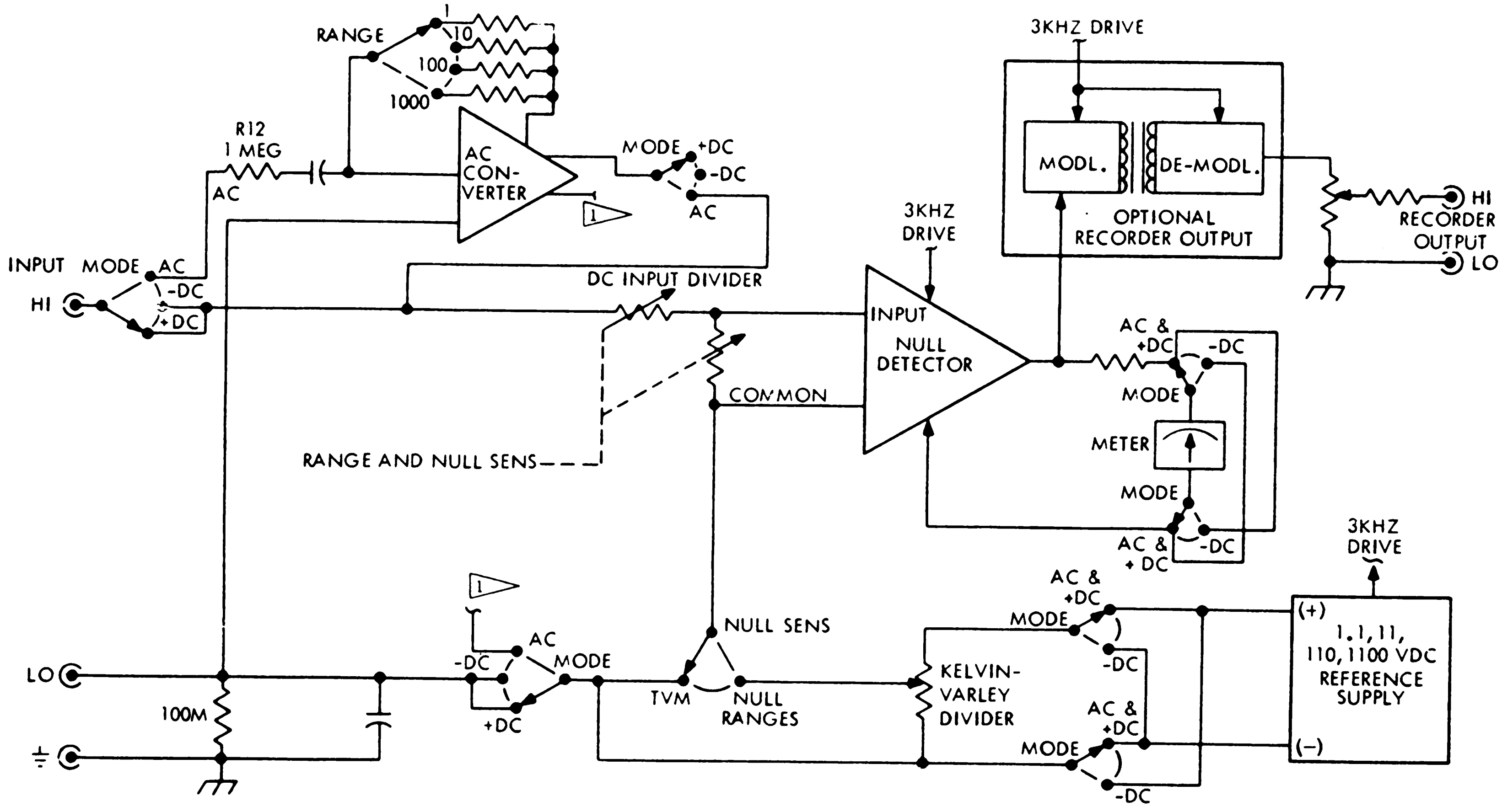


Figure 4–12. 893A block diagram.

megohms. Thus the resistance ratio is 1000 to 1. With 1 volt applied to the divider network, the voltage developed across R4 through R7 is one millivolt. The one millivolt output is coupled through the range and mode switch, S4, to pin 2 of A4, the null detector assembly.

When the instrument is functioning as a DC differential voltmeter, resistors R13 and R14 are added to the divider network in some positions of the range and null switches. The input impedance varies between 10 megohms and infinity, depending on the meter deflection. The input impedance approaches infinity when the meter is at a null.

When functioning as a DC or AC TVM, the null detector common (the bottom of R7) is connected to the DC reference common by section S3AF of the null switch, as shown in foldout 5.

Thus resistors R1 through R7 of the DC divider network divide the input voltage when functioning as an AC or DC TVM. When functioning as an AC or DC differential voltmeter, the divider network becomes a comparison network because the S3AF section of the null switch connects the output of the Kelvin-Varley divider to the null detector common, bottom of R7, as shown in foldouts 2 and 5.

Exercises (256):

1. When is the divider network utilized as a comparison network, when the 893 is functioning as an AC or as a DC differential voltmeter?

2. When the 893A is used as an AC or DC TVM, a full-scale input applied to the input of the voltmeter will provide a 1-millivolt output from the DC divider when the range switch is in what range?

257. Analyze the operation of the 893A differential voltmeter AC converter circuit.

AC Converter. Refer to foldout 2 for the following explanation. Basically, differential voltmeters are DC measuring instruments. Therefore, there must be some circuit within the instrument to convert all AC voltages to a DC voltage having a value proportional to the amplitude of the AC voltage being measured. In most differential voltmeters such a circuit is called an AC converter. In the 893A, the AC converter circuitry consists of feedback networks selected with the range switch; half-wave detectors, CR3 and CR4; a power supply comprised of CR5 and CR6; and a "transconductance amplifier" comprised of Q1 through Q10. A transconductance amplifier provides an output current proportional to its input voltage.

The transconductance amplifier amplifies input AC voltages, and the resulting transconductance amplifier output current flows through the half-wave detectors. The half-wave detectors produce a 1-volt output for a full-scale input for the particular range selected. The maximum 1-volt output from the half-wave detectors is applied to the DC input voltage divider and then to the input of the null detector circuit. A voltage proportional to the transconductance amplifier output current is fed back to the amplifier input through a feedback network selected with the range switch. This establishes a high degree of gain stability and AC ranging.

Refer to foldout 2 for the following explanation. From the HI input jack (upper left hand corner of FO 2) the AC voltages are coupled through the AC section of the mode switch and R12 to pin 1 of the AC converter assembly, A7. From pin 1 the AC voltages are coupled through A7C1 to the gate of A7Q1, a field effect transistor (FET), utilized because of its high input impedance and low noise features.

The input voltage applied to the gate of A7Q1 is developed across A7CR1, A7CR2, and resistors A7R28 through A7R35 and A7R37 through A7R40 as connected by the S9AR section of the range switch.

When the S9BR section of the range switch is in the one volt position, as shown in foldout 4, the input voltage applied to the gate of A7Q1 is developed across resistors A7R37, A7R34, A7R35 and diodes A7CR1 and A7CR2, which are limiting diodes. The maximum voltage applied to the gate of A7Q1 will be approximately 0.6 volt regardless of the input applied to pin 1 of the AC converter assembly.

The input impedance to the AC converter assembly is basically the value of R12 plus the stray capacity compensator. Thus, the input impedance is 1 megohm shunted by less than 20 picofarads for all AC ranges.

The signals coupled by A7C1 to the gate of A7Q1 are amplified and applied to the base of A7Q2. The signal is further amplified by A7Q4 and applied to the base of A7Q5. From the collector of A7Q5 the signal is applied to the base of A7Q7 for final amplification. From the collector of A7Q7 the signal is coupled by A7C12 to diodes A7CR3 and A7CR4 for rectification. We will cover the operation of the detection circuit, A7CR3 and A7CR4 and associated components later.

Transistor A7Q3 is a constant current source for A7Q2, providing the proper impedance to develop the bias for A7Q2. Transistor A7Q9 is a constant current source for A7Q6 and A7Q7, providing the bias for both transistors.

The purpose of the AC converter assembly is to convert all AC input signals with frequencies of 5 Hertz to 100 kilohertz to a proportional DC output. This conversion must be accomplished over a voltage range of 1 volt to 1000 volts. To accurately accomplish this AC to DC conversion, it is necessary to maintain a stable, linear gain of the amplifier section for the entire voltage and frequency range. To maintain stable, linear amplification of the AC signals, several feedback and frequency compensating networks are used.

In the base of A7Q4 is a filter circuit composed of A7C7, A7C25, A7R11, and A7R44. The filter networks are placed in the base circuit of A7Q4 by the S9BR-2 section of the range switch when the range switch is in the 10-, 100-, and 1000-volt positions. The purpose of the filter network is to stabilize the loop gain of the amplifier section. Loop gain is controlled by attenuating the signal applied to the base of A7Q4 when the filter network is placed in the circuit.

Maximum attenuation occurs when the range switch is in the 100- or 1000-volt position.

A degenerative feedback from the emitter of A7Q7 is coupled back to the emitter of A7Q4 by a network consisting of A7R14, A7R43, and A7C9. Additional degenerative feedback is coupled from the output of the amplifier, collector of A7Q7; through A7Q10 and A7C8 to the emitter circuit of A7Q4.

Transistor A7Q6 is the dynamic load at the output of the amplifier section. Notice that the collector output of A7Q7 is coupled by A7C11 to the base of A7Q6. Therefore, the effective resistance of A7Q6 will change as the output of A7Q7 varies.

The stability of the total loop gain of the AC converter amplifier section is primarily controlled by the degenerative feedback coupled from the output of the amplifier (junction of A7R27 and A7R49) by section S9BR–1 of the range switch to the input of A7Q1. Thus, the input to A7Q1 is a combination of the signal coupled by A7C1 (input signal) and the feedback signal coupled from the output by the range switch.

The output of the amplifier section, which is developed across the network consisting of A7R27, A7R49, and A7C18, is coupled back to the input of A7Q1 through the filter network selected with the S9BR–1 section of the range switch. This feedback signal causes a current directly proportional to the AC input to flow through half-wave detectors A7CR3 and A7CR4. Calibration of the AC voltage ranges is accomplished with variable resistors A7R29, A7R31, A7R33, A7R35, and variable capacitors A7C21 and A7C22. For example, to calibrate the gain of the AC converter for the 1-volt range, resistor A7R35 is adjusted for correct amplifier output for low frequencies and A7C22 is adjusted for correct amplifier output for high frequencies.

Frequency compensation at the amplifier output is provided by A7Q8. This provides a linear DC output from the amplifier for the total frequency range of 5 hertz to 100 kilohertz. The linear output is accomplished by the signal coupled by A7C15 from the collector of A7Q8 to the junction of A7R24 and A7R27. The signal coupled by A7C15 to the junction of A7R24 and A7R27 increases as the frequency of the input signal applied to the instrument increases. The signal coupled by A7C15 is out-of-phase with the signal coupled through A7C12, reverse biasing diodes A7CR3 and A7CR4. Thus, at high frequencies the conduction of A7CR3 and A7CR4 decreases.

Refer to foldout 3 for an explanation of the half-wave detector circuit. A7C12 couples the amplified signal from the collector of A7Q7 to diodes A7CR3 and A7CR4. A7CR3 rectifies the positive alternation of the signal, and A7C12 filters it. A7CR4 rectifies the negative alternation, and A7C14 filters it.

Notice that the DC reference common is at the function of A7C14 and A7R22. The DC reference common is connected to the junction of A7C14 and A7R22 by the S4AR-1 section of the mode switch any time the mode switch is in the AC position. This can be seen by referring to foldout 3. The S4AR–1 section of the mode switch is on the center right-hand side of foldout 2.

Refer to foldout 3. Because the DC reference common has been connected to the junction of A7C14 and A7R22, the total voltage developed across A7C13 and A7C14 is applied to A7 pin 3. The maximum voltage developed across A7C13 and A7C14 is 1 volt DC. The 1 volt DC is developed when a full-scale input is applied to the instrument. This DC voltage is applied through A7 pin 3 to the DC divider, consisting of resistors R1 through R7.

Return to foldout 2. Locate the connection at the junction of R3 and R4 of the DC divider. From the junction, the DC voltage that was developed by the AC converter assembly is applied to the TVM position of the S3BF section of the null switch (when the 893A is being used as an AC TVM). From the null switch, the DC voltage is coupled through the AC position of the S4BF–1 section of the mode switch to A4, the null detector assembly.

A maximum of 1 millivolt is applied through the S4BF–1 section of the mode switch to the A4 module when the instrument is being used as an AC or DC TVM. When the instrument is used as a DC TVM, section S1BR of the range switch selects the proper tap on the DC divider to provide A4 with a maximum of 1 millivolt. Remember, ranging for the AC functions is accomplished in the AC converter assembly by the feedback networks and section S9BR–1 of the range switch.

The bottom of R7 in the divider is connected to the null detector common. Referring to foldout 2, notice that section S3AF of the null switch (located at the right-hand center of FO5) connects the output of the Kelvin-Varley divider to the null detector common in all of the null sensitivity positions. But when the null switch is placed in the TVM position, the null detector common and DC reference common are connected.

Thus, the DC divider network is a divider when the instrument is used as an AC or DC TVM, but a comparison network when the instrument is used as an AC or DC differential voltmeter (when the null switch is not in the TVM position).

Return to foldout 2. The ±12 volt DC input voltages for the A7AC converter assembly are produced in the A3 reference inverter assembly and applied to pins 6 and 7 of the AC converter assembly. These 12-volt inputs are then reduced, filtered, and regulated by the network consisting of A7R41, A7C23, A7C24, and zener diodes A7CR5 and A7CR6 to provide the ±10-volt operating voltages for the A7 AC converter assembly.

The inputs to the DC divider are from the HI input jack of the 893A or from the AC converter assembly. From the DC divider, the voltage is coupled through S4BF–1 of the mode switch to the A4 null detector assembly. We will explain the operation of the null detector assembly next.

Exercises (257):

1. What is the output current of the amplifier section of the AC converter, Q1–Q10, proportional to?

2. Why is an FET used as the input stage of the AC converter amplifier?

3. Which transistor provides frequency compensation at the output of the AC converter amplifier section?

4. What is the maximum voltage developed across capacitors A7C13 and A7C14?

5. In what mode, AC differential voltmeter or DC differential voltmeter, is the 893A when the output from the Kelvin-Varley divider is applied to the DC divider resistors?

258. State operational characteristics of the 893A differential voltmeter null detector.

Null Detector. Refer to foldout 4 for the following explanation. The A4 null detector assembly is a stabilized DC amplifier that uses an insulated gate FET. It is composed of a low-pass filter, a carrier amplifier, a synchronous demodulator, a multivibrator, chopper driver, a chopper and a meter.

The 1-millivolt full-scale DC input is coupled through A4 pin 2 of the null detector assembly and applied to the low-pass filter and protection circuitry. Limiting diodes A4CR1 and A4CR2 form the protection circuit. The filter network is composed of A4R1, A4R2, A4C1, and A4C2. The DC voltages are square-wave modulated at an 84 Hertz rate by A4Q1. The signal coupled by A4C3 to the base of A4Q2 is proportional to the difference between the feedback voltage from the meter circuit, applied at the junction of A4R6 and the source of A4Q1, and the input voltage applied at A4 pin 2. The overall gain of the null detector is controlled by adjusting A4R5.

The signal coupled through A4C3 is amplified by the carrier amplifier consisting of four common-emitter amplifiers, A4Q2 through A4Q5, and a complementary push-pull output amplifier, A4Q6 and A4Q7. Negative feedback coupled through the network consisting of A4R10 and A4R15 through A4R18, A4C8, and A4C11 controls the gain of the carrier amplifier and consequently the null detector input impedance. Variable resistor A4R17 allows adjustment of the feedback voltage.

The amplified signal is taken from the emitter junction of A4Q6 and A4Q7 and coupled by A4C12 to the synchronous demodulator, A4Q8. Transistor A4Q8 is synchronized with the operation of the chopper, A4Q1, but is operated in the inverse mode. Thus, when A4Q8 is on, A4Q1 is off. The resulting demodulated signal is filtered by the low-pass filter composed of A4R21 and A4C13, and applied as a DC voltage through A4R22 to M1, the front panel meter. Current flow through the meter causes a deflection on the meter proportional to the magnitude of the null detector input voltage. As current flow through the meter varies, the voltage drop across resistors A4R4, A4R5, and A4R6 varies. This varying DC voltage is a negative feedback to A4Q1, which controls the overall gain of the null detector. The DC voltage from the junction of A4C13 and A2R22 is also coupled through pin 5 to pin 1 of the A6 recorder output assembly. The A6 module is located on the lower center section of foldout 4.

A collector-coupled multivibrator comprised of A4Q9, A4Q10, A4C14, A4C15, and A4R23 through A4R26 provides an 84 Hertz square wave synchronous drive signal for A4Q1 and A4Q8. The 84 Hertz square wave from the collector of A4Q10 is applied to A4Q11. From the emitter of A4Q11, the 84 Hertz square wave is applied as a drive signal to the gate of A4Q1. Potentiometer A4R27 provides adjustment of the amplitude of the square wave applied to the gate of A4Q1.

The collector signal of A4Q11 is differentiated by A4C5 and A4R7 and coupled by A4C4 to the output of A4Q1 where it is used to null out any spikes internally generated in A4Q1. Adjustment of this compensating signal is provided by potentiometer A4R31 located in the collector circuit of A4Q11.

The 3-kilohertz signal applied to pin 8 of the A4 null detector is half-wave rectified to provide the positive and negative 6.8 volt DC required by the null detector circuitry. A4CR3 and A4CR4, A4C16 through A4C19, and A4R33 and A4R34 form the power supply that produce the positive and negative 6.8 volts DC.

Exercises (258):

1. What is the purpose of the feedback signal coupled by A4C4 to the drain of A4Q1?

2. The synchronous drive signals for the null detector circuit are developed by ______________ and ______________.

259. Analyze the operation of the 893A differential voltmeter recorder output circuit.

Recorder Output. Refer to foldout 4 for the following discussion. The 893A has a recorder output circuit that is isolated from the null detector circuitry. The recorder output circuitry is composed of a modulator and demodulator separated by an isolation transformer. Each circuit is driven at a 3-kilohertz rate by a signal developed in the reference inverter assembly, A3.

The conduction of A6Q1 and A6Q2 is controlled by the 3-kilohertz signal applied to A6 pin 3. Therefore, the DC input voltage applied to A6 pin 1, which is the output from A4 pin 5, is modulated at a 3-kilohertz rate by alternate conduction of A6Q1 and A6Q2. Transformer TI couples the resulting signal to its secondary winding where demodulation is accomplished controlled by the 3-kilohertz signal applied to A6 pin 4. The demodulated DC voltage is filtered by A6C1 and R10. This DC voltage has the same value as the DC output from the null detector assembly. Potentiometer R10 provides adjustment of the recorder output voltage.

Exercises (259):

1. What do transistors A6Q3 and A6Q4 form?

260. Analyze the operation of the 893A differential voltmeter reference amplifier circuit.

Reference Amplifier. Refer to figure 4-13 for the following explanation. A DC power supply consisting of CR1, CR2, A2C1, and A2C2 develops an unregulated 26 volts DC. This 26 volts DC is applied to the collector of A2Q2 and to the emitter of A2Q1. The reference amplifier assembly reduces the 26 volts and applies it as a regulated 18.5 volts DC through A2 pin 2 to A3 pin 3, the reference inverter assembly. Foldout 5 is a schematic of the A3 module.

The following events occur upon initial application of 26 volts DC at the collector of A2Q2. The voltage developed at the junction of A2R1 and A2CR5 forward-biases A2CR1. The conduction of A2CR1 through A2R9 forward-biases A2Q4. Conduction of A2Q4 is initially through the low impedance path of A2CR2, which provides a DC input voltage to the zener current regulator, A2Q7, and to the differential (comparison) amplifiers, A2Q3, A2Q5, and A2Q6. This voltage biases A2Q7, A2Q3, A2Q5, and A2Q6 into conduction. As the DC voltage at the junction of A2R8 and the emitter of A2Q2 approaches the nominal 18.5 volts, diodes A2CR1 and A2CR2 are reversed biased. Transistor A2Q4 then functions as a buffer amplifier between the series-pass driver, A2Q1, and the comparison amplifier output from A2Q5. After the turn-on period the reference amplifier performs its regulatory function, providing DC output of 18.5 volts, 11 volts, and 1.1 volt at A2 pins 2, 5, an 4 respectively. The 18.5 volts DC is applied to the A3 reference inverter and the 11 volts and 1.1 volt DC is applied to the A5 Kelvin-Varley divider.

The regulated DC output of 11 volts and 1.1 volts are provided by the zener current regulator circuit composed of A2Q7 through A2Q9, zener A2CR3 and A2CR4, and associated resistors.

Notice that the voltage at the collector of A2Q7 is 17 volts DC. It is essential that this voltage is maintained at exactly 17 volts, because it is applied to zener diodes A2CR3, A2CR4, and factory selected resistor A2R14. The stable 17 volts establishes a fixed current through this circuit, which puts diodes A2CR3 and A2CR4 in a very low temperature coefficient region. In other words, very small changes in current flow or varying ambient temperature will not change the resistance of the diodes. This feature provides the instrument with very stable reference voltages. This voltage stability is primarily what gives the 893A its differential accuracy.

Transistors A2Q8 and A2Q9 form a differential amplifier. Diodes A2CR3 and A2CR4 provide a very stable reference voltage to the base of A2Q8. A voltage divider, consisting of A2R17 through A2R19, provides a sample of the 17 volts to the base of A2Q9. Any difference in the volts applied to the bases of A2Q8 and A2Q9 is amplified and applied to A2Q7. Any change in the voltage at the base of A2Q7 varies its resistance, resulting in a change in the voltage at the collector of A2Q7. For example, if the 17 volts increases, the collector and base of A2Q7 would be more positive, decreasing its conduction. Because of the common emitter resistor A2R20, the emitter of A2Q8 becomes more positive, decreasing the conduction of A2Q8. The decreased conduction of A2Q8 causes the base of A2Q7 to become more positive, decreasing its conduction. The decreased conduction of A2Q7 causes an increase in its resistance, resulting in more voltage being developed across A2Q7, and the voltage at the collector of A2Q7 returns to 17 volts. Variable resistor A2R19 provides adjustment of the output voltage of the zener current regulator for exactly 17 volts. Two resistive dividers composed of A2R26 through A2R31 and A2R32 through A2R36 are connected across A2CR3 and A2CR4. The divider network composed of A2R26 through A2R31 is used to provide a reference voltage to the DC-to-DC converter differential amplifier, A2Q3. The other divider network composed of A2R32 through A2R36 is used to develop the 1.1-and 11-volt DC reference voltages. The reference voltages are coupled through A2 pins 4 and 5 and applied to the Kelvin-Varley divider on the 1- and 10-volt ranges. Potentiometer A2R26 provides adjustment of the voltage applied to A2Q3. Resistors A3R33 and A2R35 provide adjustment of the 1.1- and 11-volt DC references.

The DC-to-DC converter regulator circuit composed of transistor A2Q1 through A2Q6 and associated components control the regulated 18.5 volt DC output at A2 pin 2. Transistor A2Q2 is the series-pass element whose conduction is controlled by the series-pass driver A2Q1 and the two differential amplifiers A2Q3, A2Q5 and A2Q6.

A reference voltage from the zener current regulator is applied to the base of A2Q3 through A2R25. A sample of the A3 reference inverter assembly DC output voltage, present at A2 pin 8, is developed across A2R21 and A2R22 and applied through A2R37 to the other base of A2Q3. any difference in the reference voltage to the differential amplifier composed of A2Q5 and A2Q6 will amplify the signal. The output of A2Q5 is applied to the series-pass drive, A2Q1 through buffer amplifier, A2Q4. Transistor A2Q1 controls the base current of A2Q2. Varying the conduction of A2Q2 determines the output voltage present at A2 pin 2, which is applied to A3 pin 3 of the reference inverter assembly as shown in foldout 6. The input voltage at A3 pin 3 is the drive voltage for A3. Thus, the output voltage from the reference amplifier assembly, A2, controls the output voltages of A3.

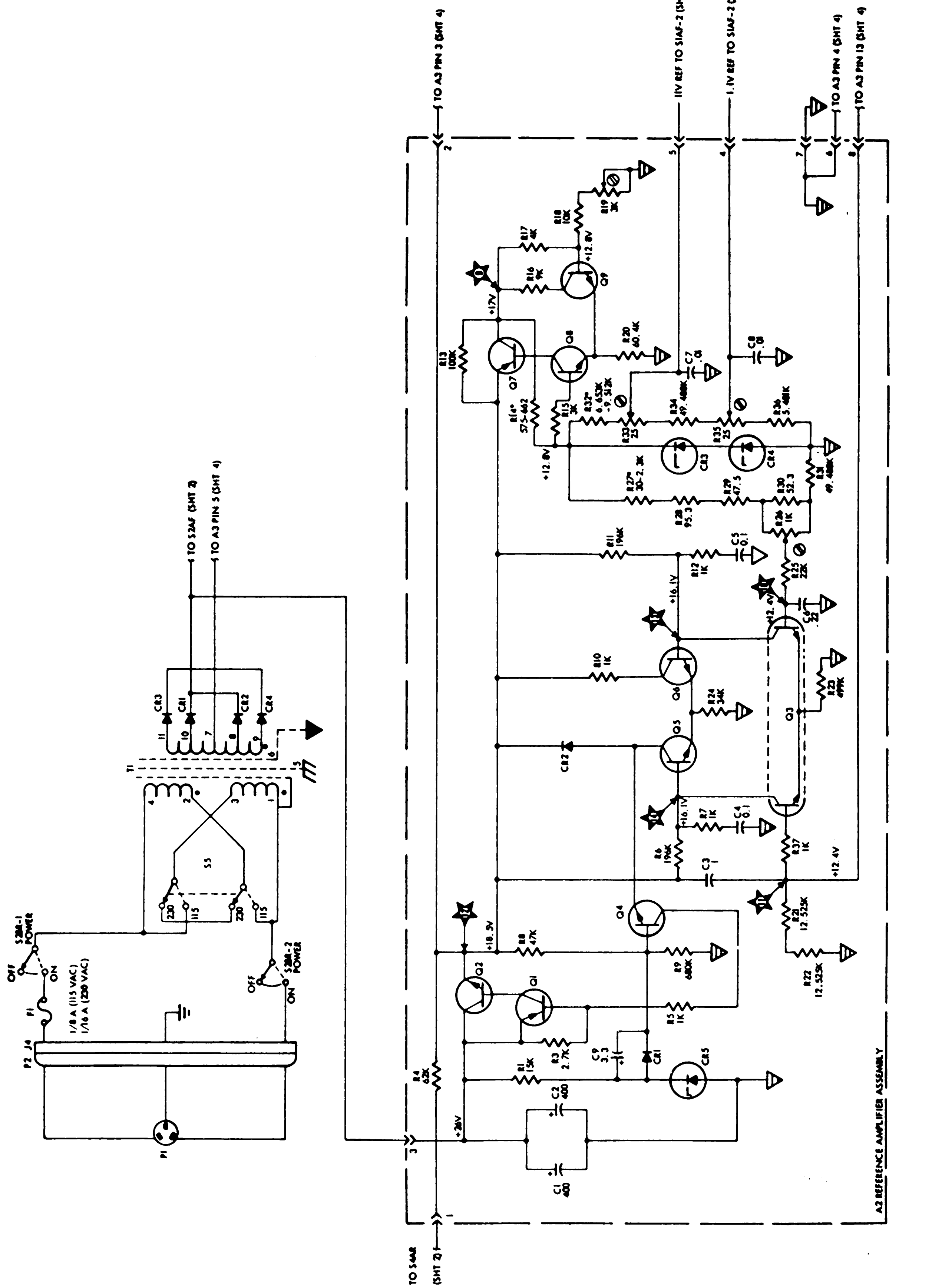


Figure 4-13. 893A reference amplifier circuit.

Exercises (260):

1. When does transistor A2Q4 function as a buffer amplifier?

2. What controls the output at A2 pin 2?

3. Which transistors control the conduction of A2Q7?

261. Analyze the operation of the 893A differential voltmeter reference inverter circuit.

Reference Inverter. Refer to foldout 5 for the following explanation. The A3 reference inverter assembly is primarily a DC-to-DC converter circuit that utilizes the positive 18.5 volts DC to produce the 110- and 1100-volt DC references used on the high differential voltage ranges. The positive 18.5 volts DC is also used as the operational voltage for the 3-kilohertz transformer coupled multivibrator, composed of A3Q1, A3Q2, A3T1, and associated components. A low-pass filter composed of A3C1, A3R1, and A3C2 prevents any 3-kilohertz signals from being coupled back to the A2 reference amplifier assembly. Resistor A3R2 provides the necessary DC current to the bases of A3Q1 to initially start the multivibrator. Diode A3CR1 functions as a clamper and capacitor A3C3 bypasses A3CR1 to provide a low resistance source to the bases of A3Q1 and A3Q2.

Upon the application of an input DC voltage, assuming that A3Q1 conducts harder than A3Q2, the collector of A3Q1 clamps the upper end of the centertapped winding of A3T1 to zero volts DC. Through transformer action a voltage is induced into the winding connected to the base of A3Q1. The voltage coupled to the base of A3Q1 is positive; therefore, the transistor is driven into saturation. When A3Q1 is saturated, the voltage induced into the winding connected to the base of A3Q1 is approximately 18.5 volts. This induced voltage has a polarity (positive at the base of A3Q1 and negative at the junction of A3R3 and the A3T1 winding) that opposes the DC voltage applied to the base. Therefore, if the induced voltage in the winding exceeds 18.5 volts, A3CR1 conducts, clamping the voltage at the junction of A3R2 and A3R3 to approximately 19 volts.

When A3Q1 is saturated through autotransformer action, the centertapped winding connected to the collector of A3Q2 applies a positive 18-volt potential to the collector. This induced voltage has a polarity that aids the DC voltage applied to the collector of A3Q2. Thus, the potential at the collector of A3Q2 at this period in time is a positive 36 volts. However, A3Q2 cannot conduct because the lower winding of A3T1 couples a negative 18 volts potential to the base of A3Q2. These conditions will persist for a period proportional to the flux capacity of the core of A3T1, which in this case is approximately 150 microseconds. At the end of the 150-microsecond period, the voltages induced in the windings of A3T1 are reversed because of the collapsing lines of flux. The collapsing lines of flux (field) apply a negative potential at the base A3Q1, cutting it off, and a positive potential at the base A3Q2, driving it into saturation. This action establishes the second alternation of the 3-kilohertz signal. The resulting 3-kilohertz signal is coupled to the secondary winding of A3T1. The filter networks consisting of A3L1, A3R17, A3L2, and A3R18 increase the circuit switching time to reduce high frequency radiation.

Notice that the top of A3T1 secondary winding is shielded. Potentiometer A3R5 provides a means of reducing the effects of any capacitive coupling between the shield and the winding of A3T1 inclosed by the shield.

The 3-kilohertz secondary signals of A3T1 available at A3 pins 8 through 10 are used as drive signals for the modulator and demodulator in the A6 recorder output assembly. The signal available at A3 pins 6 and 7 is applied to the A4 null detector assembly, where it is used to produce the required positive and negative 6.8 volts DC.

A full-wave voltage doubler composed of A3CR3, A3CR2, A3R6, and A3C4 through A3C6 produces the 110-volt DC reference available at A3 pin 2. The 1100-volt DC reference available at A3 pin 1 is produced by a full-wave voltage doubler composed of A3CR4 through A3CR7, A3R7, and A3C7 through A3C9. A resistive divider composed of A3R9 through A3R11 provides a load for the voltage doubler when the 1100-volt DC reference is not being used and functions as a bleeder when power is removed from the circuit. Diodes A3CR8, A3CR9, and capacitors A3C10 and A3C11 form a full-wave rectifier circuit that produces the positive and negative 12 volts for the A7 AC converter assembly.

Regulation of the 110- and 1100-volt DC reference is accomplished by feeding a sample of the selected reference voltage back to the DC-to-DC converter regulator circuit in the A2 reference amplifier assembly. Sections S1AR-1 and S1AR-2 of the range switch couple the selected 110- or 1100-volt DC reference to a voltage divider composed of resistors A3R12 through A3R16 and resistors A2R21 and A2R22 (fig. 4-13).

The 110-volt DC reference is coupled through the S1AR-1 section of the range switch. From the range switch, the voltage is applied to A3R14. Thus, when the range switch is in the 110-volt position, a divider composed of A3R14 through A3R16 and A2R21 and A2R22 (fig. 4-13) develops the sample voltage applied through A2R37 to the base of A2Q3. When the range switch is in the 1100-volt position, the divider network consists of resistors A3R12 through A3R16 and resistors A2R21 and A2R22.

If the 110- or 1100-volt output from the A3 reference inverter assembly increases, the sample voltage applied through A2R37 to the base of A2Q3 becomes more positive. The difference between this more positive voltage and the reference voltage applied through A2R25 to the other base of A2Q3 is amplified by differential amplifiers A2Q3, A2Q5, and A2Q6 and applied to the emitter of A2Q4. The amplified difference (error) is further amplified by A2Q4 and A2Q1 and applied as a less positive voltage to the base of A2Q2, the series regulator. This less positive potential at the base of A2Q2 decreases its conduction, causing the resistance of the transistor to increase. The increased resistance of A2Q2 results in reducing the positive 18.5 volts DC coupled through A2 pin 2 to A3 pin 3. Refer to figure 4-13. Remember, this DC input is the operating voltage for the multivibrator A3Q1 and A3Q2. Decreasing the DC operating voltage decreases the amplitude of the square wave output from A3Q1 and A3Q2. Decreasing the amplitude of the signal in the primary of A3T1 decreases the signal applied to the full-wave rectifiers. By reducing the signal applied to the rectifiers, the 110- and 1100-volt DC references are reduced. Thus, the 110- and 1100-volt DC references are precisely controlled, because the reference voltage for the differential amplifier, A2Q3, is a zener controlled voltage.

Notice that the S1AR-1 and S1AR-2 sections of the range switch are bypassed when the mode switch is in the AC position. When the 893A is used as an AC TVM or AC differential voltmeter, the 110-volt DC reference is used only to develop the sample feedback voltage. The 110- and 1100-volt DC references are not used when the 893A is functioning as an AC differential voltmeter. Therefore, the only requirement is that one of the reference voltages be used to develop the proper sample voltage to the base of A2Q3.

The input to the Kelvin-Varley divider is applied through the S4AF–1 section of the mode switch. When the mode switch is in the AC position the 1.1-volt reference from the A2 module is the only reference applied to the divider. Remember, the maximum output from the AC converter assembly was 1 volt DC. The 1-volt DC output from the A7 AC converter assembly represents a full-scale input for the particular voltage range selected. Thus, the maximum reference voltage required to be applied to the A5 Kelvin-Varley is dependent upon the position of the range switch.

Exercises (261):

1. What is the purpose of the filter network composed of A3R1, A3C1, and A3C2?

2. What determines the conduction time of A3Q1 and A3Q2?

3. When the 110- or 1100-volt DC reference decreases, what happens to the A3Q1 and A3Q2 multivibrator output signal?

4. What reference voltage(s) is/are applied to the divider when MODE switch is in the AC position?

5. What is the function of diode A3CR1?

262. Analyze the operation of the Kelvin-Varley divider circuit in the 893A differential voltmeter.

Kelvin-Varley Divider. Refer to foldout 5 for the following explanation. The Kelvin-Varley divider continuously divides the reference supply voltages, as selected by the readout dials, while presenting a constant load to the reference supply. The divider is composed of matched resistors A5R1 through A5R34, trimmers A5R35 and A5R36, potentiometer A5R37 and rotary switches S6 through S8.

The contacts of S6 select two series connected 100 kilohm resistors of the first divider and connect them in parallel with the 200 kilohm effective resistance of dividers two through four. This combined resistance provides an effective resistance value of 100 kilohms. This effective 100 kilohms is in series with the remaining ten 100-kilohms resistors of the first divider, providing a constant load resistance of 1.1 megohms to the reference supply.

The effective resistance of dividers two through four can be computed by beginning with the fourth divider. Trimmer A5R36 is adjusted until the total effective resistance of divider four, A5R35 through A5R37, is 8 kilohms. The 8 kilohms of divider four is in parallel with the two 4-kilohm resistors, A5R24 and A5R25. These resistors are selected by A5S8 of the third divider, providing an effective resistance of 4 kilohms. This 4 kilohms is in series with the remaining nine 4-kilohm resistors of the third divider. Thus, the combined resistance of dividers three and four provide an effective resistance of 40 kilohms. The effective 40 kilohms of the third and fourth dividers are in parallel with two 20-kilohm resistors, A5R13 and A5R14 of the second divider; they produce a combined effective resistance of 20 kilohms. This 20-kilohms is in series with the remaining nine 20 kilohms resistors of the second divider. Thus, the combined resistance of dividers two through four, is in parallel with the two 100-kilohm resistors, A5R1 and A5R2 of the first divider; producing a combined effective resistance or 100 kilohms. This effective 100 kilohms is in series with the remaining 10-kilohms resistors of the first divider, providing a total effective resistive load of 1.1 megohms to the reference voltages regardless of the setting of the readout dials.

There are 11 equal voltage steps available from the first divider that can be selected by the rotary switch A5S6. Since the reference voltage is either 1.1, 11, 110, or 1100 volts DC, A5S6 provides increments of 0.1, 1, 10, or 100 volts DC.

Basically, the second and third divider functions in the same manner as the first divider, with switches A5S7 and A5S8 allowing selection of the desired voltage. Each divider is composed of 11 equal resistors providing ten equal divisions of the preceding divider output voltage. The fourth divider has a potentiometer, A5R37, which provides a continuous variable output instead of the equal divisional output voltages provided by dividers one through three.

Resistors A5R35 and A5R36 provide the necessary trimming resistance for the fourth divider.

The voltage directly corresponds to the digit value of the readout dials for the particular reference voltage being applied to the divider. When the mode switch is in the + or - position, the S1AF-2 section of the range switch couples the appropriate reference supply voltage of 1.1, 11, 110, or 1100 volts DC to the Kelvin-Varley divider. These DC references voltages correspond to the 1-, 10-, 100- or 100-volt position of the range switch. When the mode switch is in the AC position, the 1.1 reference voltage is the only reference voltage applied to the Kelvin-Varley divider.

The S3AF section of the null switch applies the output from the Kelvin-Varley divider, wiper of A5R37, to the null detector common on all null ranges of this instrument. Thus the Kelvin-Varley output is the common, operational reference for the null detector assembly, as illustrated on foldout 6. It is also one input to the DC voltage divider, bottom of R7, as illustrated on foldout 4. When the unknown voltage applied to the input of the 893A and the output voltage from the Kelvin-Varley divider are equal, there is no difference in potential between A4 pin 2 and the null detector common. Thus, there is no input to the null detector circuit, and the front panel meter is at a null. The value of the unknown voltage is indicated by the front panel (Kelvin-Varley divider) readout dials.

Returning to foldout 5, notice that when the instrument is in the TVM mode, the S3AF section of the null switch disconnects the Kelvin-Varley divider from the null detector common and connects the DC reference common to the null detector common. Reversal of the Kelvin-Varley output voltage is provided by the S4AR-3 section of the mode switch. Depending on the setting of the range or mode switches, capacitor A4C1 or A5C2 connects the Kelvin-Varley divider output to the DC reference common. These capacitors bypass any AC present in the Kelvin-Varley DC output to the DC reference common.

Exercises (262):

1. What is the input resistance of the Kelvin-Varley divider?

2. When the range switch is in the 100-volt position and the mode switch is in the AC position, what is the input to the Kelvin-Varley divider?

3. What components make up the Kelvin-Varley Divider?

4. How many voltage steps are available from the first divider?

263. Specify operational characteristics of the 887 differential voltmeter.

Fluke 887A/AB DVM. The 887A/AB series instruments can be used as conventional voltmeters for rapid determination of voltages from 0 to 1100 volts DC and from 0.001 to 1100 volts AC, as differential voltmeters for precise measurement of DC voltages from 0 to +1100 volts, as accurate AC voltmeters for measurement of AC voltages from 0.001 to 500 volts, and as megohmmeters for measurement of resistance from 10 megohms to 11,000 megohms. No current is drawn from the unknown source at null up to 11 volts DC. Thus the determination of the unknown potential is independent of its source resistance. Above 11 volts DC, the input resistance is an excellent 10 megohms. To minimize errors due to common mode voltages, the 887A series is provided with extremely high leakage resistance to ground—typically several hundred thousand megohms. Also, where ground loop errors are a problem, the battery-operated mode of the 887AB eliminates these errors due to complete isolation from the power line. As additional features, the 887A series contains a polarity switch for equal convenience in measuring positive or negative DC voltages and an adjustable recorder output that makes the instrument particularly useful for monitoring the stability of almost any AC or DC voltage.

When used as a DC differential voltmeter, the 887A operates on the potentiometric principle. An unknown voltage is measured by comparing it to a known adjustable voltage with the aid of a null detector. An accurate standard for measurement is obtained from 11 volt DC reference supply derived from a pair of temperature-compensated zener diodes. The known adjustable reference voltage is provided by a Kelvin-Varley voltage divider with four decades of FLUKE precision wirewound resistors and a high-resolution interpolating vernier that are set accurately by five voltage readout dials to give a six digit readout. In this way, the 11 volts can be precisely divided into increments smaller than 10 microvolts. The unknown voltage is then simply read from the voltage dials. For voltages between 11 and 1100 volts DC, an input attenuator divides the unknown voltage by 100 before it is measured potentiometrically. When used as an accurate AC voltmeter, the 887A operates essentially the same as for DC differential measurements. The AC input voltage is converted to a DC voltage, and this DC voltage is measured by comparing it to a known adjustable reference voltage.

Figure 4-14 shows the block diagram for the 887A differential voltmeter. As seen in this figure, the circuit is mainly composed of an AC to DC converter, a DC input attenuator, a DC transistorized voltmeter (TVM), and an extremely accurate 0- to 11-volt reference. The DC input attenuator reduces the input voltage by a factor of 100 on the 1000 and 100 volt DC ranges. The TVM uses a null detector, an attenuator, and a meter to obtain high sensitivity. The 0- to 11-volt reference uses a range divider and a Kelvin-Varley attenuator to make the output of two well regulated zener diodes adjustable.

The overall operation of the voltmeter may be summarized as follows. To measure the approximate value

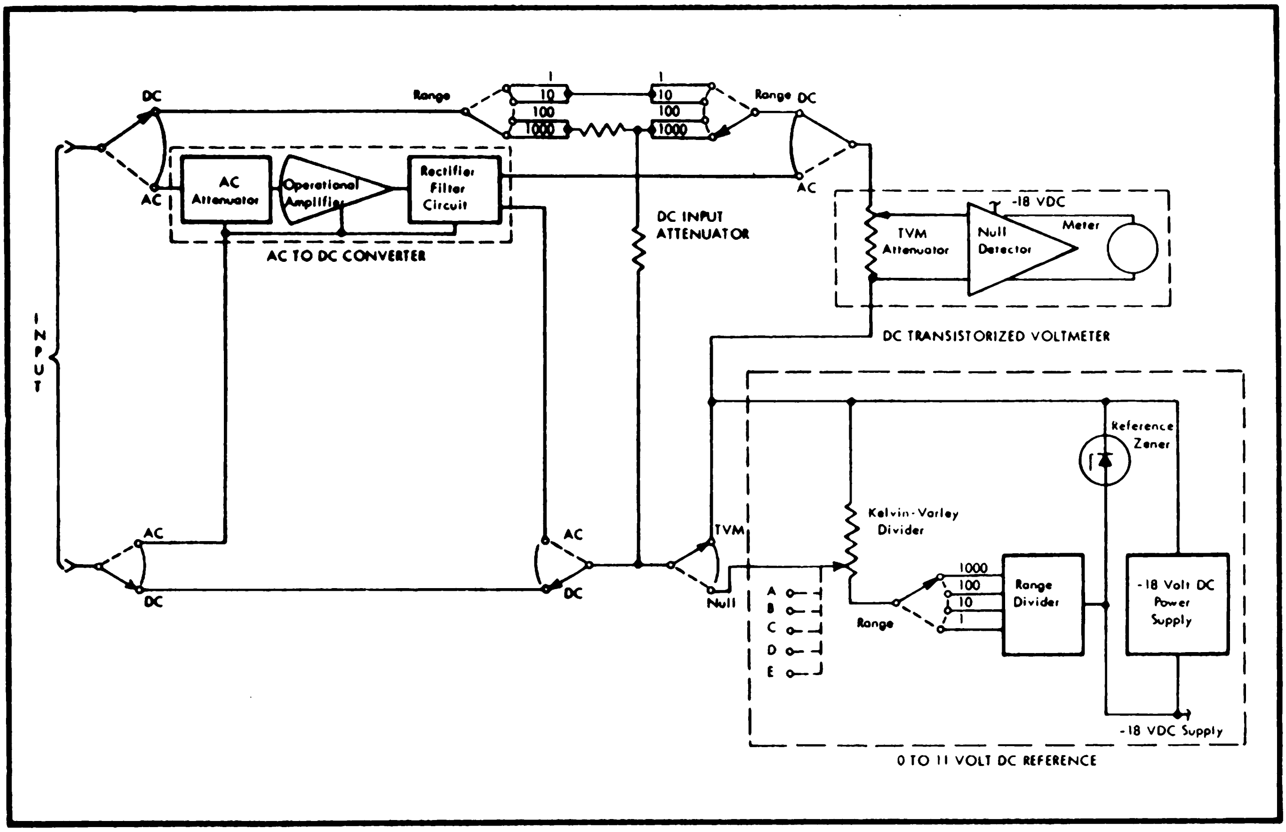


Figure 4–14. 887A block diagram.

of a DC voltage between 0 and 11 volts, the unknown voltage is connected directly across the TVM attenuator. This attenuator is set in such a way that the maximum voltage for each range is reduced to a signal of 1 millivolt (100 microvolts for the 1-volt range in the highest null mode). The signal is then applied to the null detector and causes 100 microamperes to flow through the meter for full-scale deflection. To accurately measure this DC voltage, the unknown voltage is connected across the series combination of the TVM and the 0- to 11-volt reference. The reference voltage is then adjusted with the five voltage readout dials until it matches the unknown voltage as indicated by the TVM. For voltages between 11 and 1100 volts, the DC input attenuator divides the unknown voltage by 100. The 883A then operates essentially the same as for measurements from 0 to 11 volts. All AC measurements are made by first converting the AC input voltage to a DC voltage by means of the AC to DC converter. The 887A then operates essentially the same as for approximate and accurate DC measurements.

Exercises (263):

1. Upon what principle does the 887A operate when used as a DC differential voltmeter?

2. Where does the 11-volt DC reference come from?

4-6. AC/DC Thermal Transfer

One process that needs to be mentioned here is the process of making highly accurate AC voltage or current measurements by changing the AC to DC by one means or another and measuring the DC. This is known as AC to DC thermal transfer. It is usually accomplished by heating either a thermal-converter or a thermocouple with AC and then measuring the DC level needed to obtain the same reading as the AC.

The instrument most used to make this measurement is the Fluke 540B AC/DC Thermal Transfer Standard.

264. Analyze the block diagram operation of the Fluke 540B AC/DC Thermal Transfer Standard.

Fluke 540B. Refer to Figure 4-15, Model 540B block diagram. With the mode switch in the AC SEARCH position, the input signal passes from the binding posts through the mode switch, through the first protection relay (K801), and to the search compensated attenuator. The output of the attenuator is connected to another section of

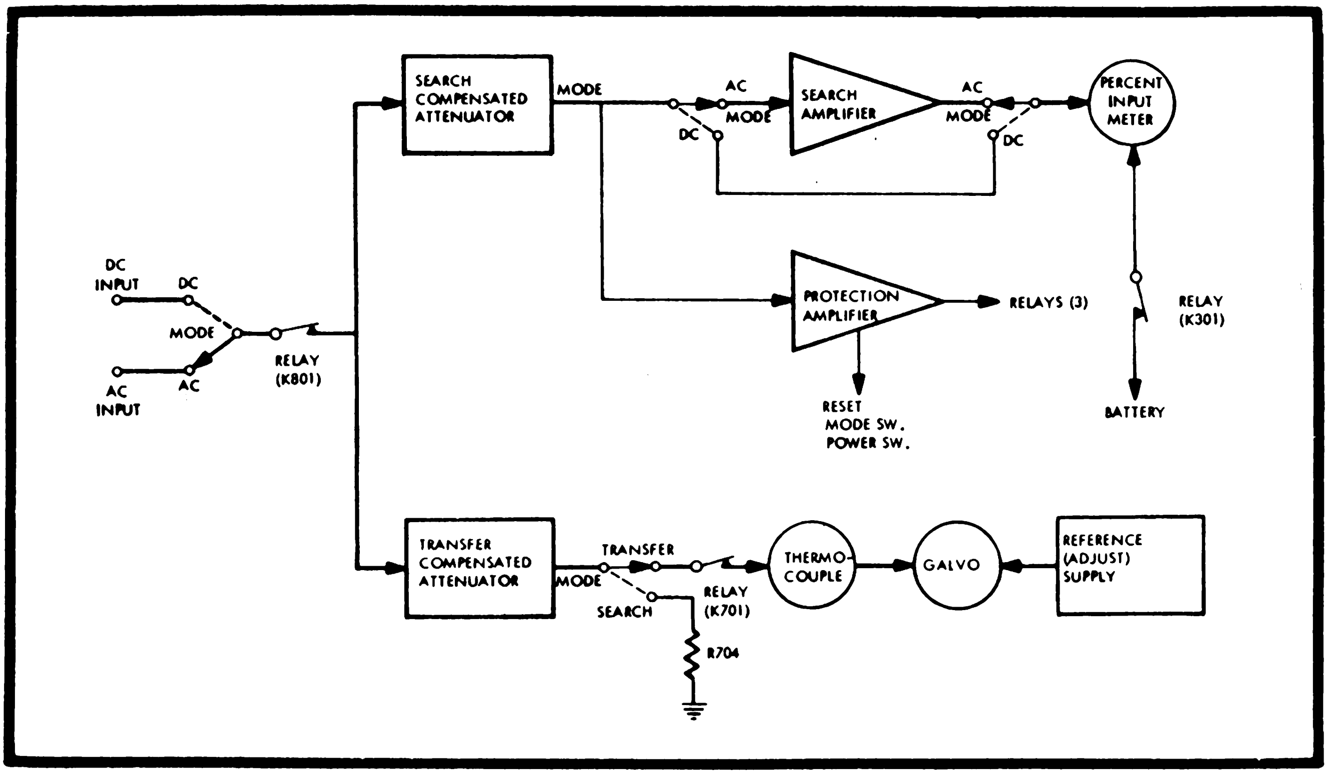


Figure 4–15. 540B block diagram.

the mode switch and to the protection amplifier. The signal path is thru the mode switch to the search amplifier, where the AC signal is amplified and then rectified and filtered. R704 is connected across the input in SEARCH to provide proper input impedance. The output of the search amplifier is then connected though the mode switch to the PERCENT INPUT meter, where the needle deflection is calibrated to read in percentage of input per range selected.

When the mode switch is in the DC SEARCH position, the indirect current path is identical with the AC path except that no amplification is required and the mode switch provides an alternate path around the search amplifier. Calibration adjustments are provided for the search ranges in the search amplifier and in the alternate DC path around the search amplifier.

With the mode switch in the AC or DC TRANSFER positions, the signal from the input terminals passes through the mode switch, then through the first protection relay (K801), and feeds both compensated attenuators. The search compensated attenuator output is connected to the protection amplifier and the search amplifier. The transfer compensated attenuator feeds through the mode switch, then through the second protection relay (K701). From the second protection relay, the signal feeds the thermocouple. The output of the thermocouple is fed to the galvanometer in such a manner that it is opposed or balanced by the output from the reference supply. The galvanometer indicates the null or balance between the two.

The protection amplifier is always connected to the output of the search attenuator. It is designed to function on a pre-set level of aC or DC. When the protection Amplifier operates, it causes relays K701 and K801 to disconnect the input from the attenuators and open the circuit to the thermocouple. The protection amplifier also causes relay K301 to close a circuit from the battery supply. This circuit causes the PERCENT INPUT meter needle to deflect into the OVERLOAD area of the meter scale. Once the protection amplifier has operated, it must be reset manually by turning the mode switch to OFF. The cause of the overload should be located and removed and the range increased or other remedial action taken before returning the mode switch to its operating position.

When the Model 540B is operated in the SHUNT mode, no protection is provided for either the Model 540B thermocouple or for the current shunt. It is necessary to exercise extreme caution when operating in this mode to prevent damage to the instrument.

Exercises (264):

1. What is the purpose of R704 in the Fluke 540B?

2. If the protection amp has been activated, what must you do before you use the 540B again?

Answers for Exercises

CHAPTER 1

Reference:

200 − 1. It greatly reduces the stray leakage paths to ground.
200 − 2. By a rejection filter.

201 − 1. Variable.
201 − 2. To prevent capacitive coupling and leakage of AC voltages to the guard chassis.
201 − 3. Either 115 or 230 VAC.

202 − 1. Approximately 1 volt full scale.
202 − 2. Two photocells alternately lit by two neon lamps.
202 − 3. Feedback is reduced and closed-loop gain is increased by approximately four times.

203 − 1. Errors caused by contact resistance in the Wheatstone bridge are reduced to an absolute minimum in the Kelvin bridge.
203 − 2. In the Kelvin bridge, four-terminal connections are employed in resistance measurements, and a yoke has been added; the result is fewer errors due to contact resistance.

204 − 1. When none of the resistors are shorted, the standard multiplier is set for a ratio of 100:1, and the value of RX is equal to RX × 100, or in this case, 4700 ohms. If no resistors are shorted in figure 1-5, the proportion required for a null indication is as follows:

$$\frac{AC}{CD} = \frac{RX + BD}{DV + RS}$$

$$\frac{1\ \text{megohm}}{10K\ \text{ohm}} = \frac{RX + \text{megohm}}{10K\ \text{ohm} + RS}$$

$$(1m)\ (10K) + (1M)\ (RS) = (10K)\ (RX) + (1M)\ (10K)$$

$$(1M)\ (RS) = (10K)\ (RX)$$

$$\frac{(1M)\ (RS)}{(10K)} = RX$$

$$100\ RS = RX$$

$$100 \times 47\ \text{ohms} = RX$$

$$4700\ \text{ohms} = RX$$

204 − 2. When the ratio selected is 0.01:1, the multiplier is 0.01, and all resistors except the 100-ohm resistors in the multiplier control circuit are shorted.

205 − 1. The yoke of the Kelvin bridge is eliminated, and the standard resistor is shorted out by the internal contacts of the switch. The wiper arm of the "A" ratio lead adjustment is also opened, leaving "A" ratio arm as the only adjustable leg in the bridge.
205 − 2. The bridge is balanced with the lead resistance included as a part of the bridge, assuring that the lead resistance will be eliminated from consideration when you make the actual resistance measurement.
205 − 3. The connecting leads for the unknown resistor are shorted together at the number 3 terminal, eliminating the unknown resistor from the circuit and replacing it with the lead resistance.

206 − 1. RS (standard resistor).
206 − 2. The RS925 is a variable standard resistance, against which the unknown resistor is compared.

207 − 1. Although there are 11 resistors in the first decade, two of them are shunted by the next decade, whose total resistance is equal to the value of one of the first decade's resistors. This arrangement results in an equivalent circuit for the first decade containing only 10 resistors. Each resistor is equal to 10K ohms, and the total resistance is 10 times that, or 100K ohms, at the input terminals.
207 − 2. The Kelvin-Varley readout indicates the proportion of the input voltage which will appear at the output terminals.
207 − 3. The formula for finding the unknown resistance is:

$$R_x = RS\frac{S2 - S1}{S4 - S3}$$

$$= 10.0\frac{0.839 - 0.007}{0.998 - 0.838}$$

$$= 10.0\frac{0.832}{0.160}$$

$$= 10.0\ (5.2)$$

$$= 52.0\ \text{ohms}$$

208 − 1. 1.0810 million.
208 − 2. In order to compensate for lead resistance in voltage divider calibration, variable resistances are connected between the tops and bottoms of the dividers. The taps of the dividers are adjusted for maximum ratio (1:1), and the top variable resistor is adjusted to null the detector. The divider taps are then moved to indicate minimum ratios, and the bottom variable resistor is adjusted for a null indication. At this time, the lead resistances are equal at the top and the bottom of the dividers, and have been effectively compensated.

209 − 1. Maximum.
209 − 2. Bal 2.
209 − 3. The divider having the highest input impedance.

210 − 1. The maximum input voltage equals 0.35 times the frequency or 350 volts rms maximum.
210 − 2. 150 volts times 0.5463992 = 81.95988 volts.

211 − 1. To nullify or compensate for phase differences between the test circuits and the measuring circuits.
211 − 2. Quadrature generator and voltmeter.
211 − 3. By adjusting the quadrature dials of the RA−79.
211 − 4. By adjustment of the calibrated decade transformer dials.

212 − 1. The impedances of resistors and inductors are directly proportional to the respective values of resistance and inductance. The impedance of a capacitor is inversely proportional to its capacitance. Since voltage and current divide

according to the ratio of impedance, in a capacitance measurement the voltage division will be in direct proportion to the impedance ratio, and in inverse proportion to the capacitance ratio.

212 – 2. Both connecting leads of the capacitor should be shielded, and both shields should be tied to the guard point.

212 – 3. $= \frac{1 - 0.175377}{0.175377} \times 1 \times 10^{-9}$

$= \frac{0.824623}{0.175377} \times 1 \times 10^{-9}$

$= 4.702 \times 1 \times 10^{-9}$ (approximate)

$= 4702 \times 1 \times 10^{-12}$ (approximately)

= 4702 picofarads (approximate)

213 – 1. The adjustment of the capacitance dials of the capacitance bridge adjusts the ratio tap of a variable standard inductor (inductive voltage divider).
213 – 2. The capacitance deviation dials indicate the amount by which the unknown capacitor differs from the value set on the capacitance dials.
213 – 3. Placing the deviation switch in its OFF position removes the capacitance deviation dials from the measurement circuit, and the dials, therefore, have no effect on the measurement.

214 – 1. Since the 1-ohm decade resistors may be directly compared with the Thomas 1-ohm standard resistor, the 1 ohm should be calibrated first.
214 – 2. The Thomas 1-ohm standard resistor.
214 – 3. When the 100-ohm decade is being calibrated, each resistor in the decade is compared with the first 10 resistors, in series, of the 10-ohm decade, as the standard.
214 – 4. The corrected individual deviations are rounded off to the nearest whole number (in ppm) and listed on the calibration chart which accompanies each decade.
214 – 5. The difference between the ratio setting on the divider and its actual division ratio.

CHAPTER 2

215 – 1. D.
215 – 2. A variable output.

216 – 1. 10.
216 – 2. It increased.
216 – 3. The trip and interlock circuits.

217 – 1. To generate an AC voltage.
217 – 2. When a change occurs in the amplitude selection switch.
217 – 3. 12.1.

218 – 1. Exactly 360°.
218 – 2. The frequency select resistors.

219 – 1. 3 or 30.
219 – 2. To the output of a low-drift DC amplifier.

220 – 1. 10 volts and 100 volts.
220 – 2. Internal.

221 – 1. Variable reference signal.
221 – 2. By slightly adjusting the 7-volt reference supply.

222 – 1. DC sense signal and variable reference.
222 – 2. Load and amplitude selection changes.

223 – 1. Anytime the 5200A is used.
223 – 2. Negative.
223 – 3. The difference in phase between the external phase-lock reference signal and the oscillator output.

224 – 1. Primary.
224 – 2. The primary winding has less resistance than the high- voltage winding, but more resistance than the filament winding.

225 – 1. In a half-wave rectifier, the output ripple frequency is equal to the input frequency.
225 – 2. Because conduction through the load takes place on both alternations of the input signal, and in the same direction, a pulse is felt across the load twice for each complete cycle of the input. Therefore, the output ripple frequency of the full-wave rectifier is twice the frequency of the input signal.
225 – 3. The primary advantage of the bridge-type rectifier over the full-wave rectifier is that the entire secondary of the input transformer can be used; whereas the full-wave rectifier has its secondary winding center tapped, so that only one-half of the secondary is in use at one time.
225 – 4. A device used to change AC to DC.
225 – 5. Half-wave, full-wave, and bridge.
225 – 6. The cathode.
225 – 7. It limits the peak current through the rectifier to a safe value.
225 – 8. Between the center tap of the secondary winding of the transformer and the common junction of the two semiconductor diodes.
225 – 9. The bridge rectifier circuit.
225 – 10. 2.83 times the rms voltage.
225 – 11. 1.41 times the rms voltage.

226 – 1. The capacitor-input filter has a higher output voltage than the choke-input filter with the same voltage input, depending upon the load.
226 – 2. The capacitor-input filter has better filtering action under light loading. Under heavy loads, the choke-input filter has better filtering action.
226 – 3. The choke-input filter provides much better voltage regulation than the capacitor-input filter.

227 – 1. Since the regulator tube is in series with the load, the voltage is series regulated.
227 – 2. A decrease in the output voltage of the regulator will be felt through the bleeder resistors, R3, R4, and R5. The tap on R4 will couple this decrease to the grid of control tube V2. A decreasing voltage on the grid of V2 will cause its plate to go in a positive direction. The positive-going voltage on the plate V2 is directly coupled to the control grid of the series regulator tube, V1, causing that tube to increase in conduction. Since V2 conducts through R3, R4, and R5, the current through those resistors will also increase, increasing the voltage drop across them and thereby increasing the voltage output to its prior level.

228 – 1. Across the current sampling resistor.
228 – 2. Voltages that are used throughout the instrument for bias purposes.

229 – 1. Diode CR34 is connected across the output terminals and acts as a protective device.
229 – 2. So that half the output current will flow through each of them.

230 – 1. By housing the differential transistors in the same package.
230 – 2. Back to the series regulator to maintain a constant output voltage.
230 – 3. By shunting the programming resistors with C1 and C2.

231 – 1. It continuously compares a fixed reference voltage drop across the current sampling resistor.
231 – 2. R25 and R28.

232 – 1. No. It has one meter that indicates either voltage or current, depending on the S2 switch position.
232 – 2. A fixed gain of 10.
232 – 3. It is a potentiometer that allows zeroing of the meter.

CHAPTER 3

233 – 1. Bridged T.
233 – 2. Current, resistance, and AC-DC voltages.
233 – 3. Down.
233 – 4. False.

234 – 1. DC voltage and current, AC voltage and current, and resistance.
234 – 2. 50 kHz.
234 – 3. To boost the current capability to ±19.999 amps.
234 – 4. Depress the clear key once.
234 – 5. Enable key.

CHAPTER 4

235 – 1. Place a resistor in series with the meter movement. The higher the resistance in series, the greater the range of voltage measurement.
235 – 2.]2450 ohms.
235 – 3.]249,950 ohms.

236 – 1. Place the function switch to −DC.

237 – 1. False. The red test lead must be moved to the 5000V DC jack.
237 – 2. True.

238 – 1. The one marked 2.5 VAC only.
238 – 2. AC voltages when DC voltages are present.

239 – 1. It must be in series with the circuit being measured.
239 – 2. Set the function at the +DC position.

240 – 1. R × 100.
240 – 2. Change the function switch to the other DC position.

241 – 1. The R × 10K battery (or B2) voltage must be sufficient to zero the R × 10K resistance range.
241 – 2. Remove the overload, then press the RESET button all the way down and release it.

242 – 1. Once depressed, it allows you to change ranges and functions without disconnecting the test leads from the circuit under test.
242 – 2. Check the overload indicator and reset it if it is tripped.

243 – 1. The highest (maximum) range available.
243 – 2. 10-Megohm range.

244 – 1. 500-volt range.
244 – 2. The MX–1410/U test prod.

245 – 1. 10 amps.
245 – 2. SPECIAL.

246 – 1. When measuring in-circuit resistance where semiconductor junctions will block out the effect of other components.
246 – 2. OHMS STD.

247 – 1. 115 VAC or 24 VDC.
247 – 2. Lamp DS3 flashes.
247 – 3. Approximately 17,000 volts DC.

248 – 1. INPUT HI and INPUT LO.
248 – 2. INPUT HI and INPUT LO but the SOURCE HI and SOURCE LO terminals must be shorted to the respective INPUT HI and INPUT LO terminals.
248 – 3. 2 volts.

249 – 1. 100 ms.
249 – 2. A/D converter.

250 – 1. The clock oscillator pulse count.

251 – 1.]20 Hz to 700 MHz.
251 – 2. To 25 kV.
251 – 3. No.

252 – 1. 5 minutes.
252 – 2. The AC probe, Model 11036A with ground connector.
252 – 3. Ground clip.
252 – 4. That power has been removed and capacitors have been discharged in the circuit under test.

253 – 1. 15 mV DC.
253 – 2. False. The unknown resistor under test is placed in *parallel* with the known resistor.
253 – 3. Input and feedback.
253 – 4. 100 Hz for 60 Hz line power, and 85 Hz for 50 Hz line power.

254 – 1. Type N "T".
254 – 2. Capacitive divider (100:1).
254 – 3. True.
254 – 4. .01-volt range.

255 – 1. 1 millivolt.
255 – 2. When it functions as a DC differential voltmeter.

256 – 1. Both.
256 – 2. Any range.

257 – 1. Its input voltage.
257 – 2. Because it provides high input impedance and low noise.
257 – 3. A7Q8.
257 – 4. 1 volt.
257 – 5. Both.

258 – 1. To cancel any spikes generated by the A4Q2 chopper.
258 – 2. A4Q9; A4Q10.

259 – 1. A demodulator.

260 – 1. After the initial turn-on period.
260 – 2. Q2.
260 – 3. A2Q8 and A2Q9.

261 – 1. To prevent 3-kilohertz signals from being coupled back to the reference assembly (A2).
261 – 2. The flux capacity of A3T1.
261 – 3. It increases.
261 – 4. 1.1 volts from the A2 module.
261 – 5. It functions as a clamper.

262 – 1. 1.1 M megohms.
262 – 2. 1.1 volts DC.
262 – 3. A5R1 through A5R34, trimmers A5R35 and A5R36, potentiometer A5R37, and rotary switch S6 through S8.
262 – 4. 11 equal voltage steps.

263 – 1. The potentiometric principle.
263 – 2. From a pair of temperature-compensated zener diodes.

264 – 1. It provides the proper input impedance.
264 – 2. Manually reset it by turning the MODE switch to OFF.

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