OPERATION AND SERVICE INSTRUCTIONS

DIGITAL VOLTMETER

MODEL 451

NLS

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SECTION I
GENERAL DESCRIPTION

1-1. INTRODUCTION.

1-2. The Model 451 Digital Voltmeter, shown in figure 1-1, is manufactured by Non-Linear Systems, Inc. It is designed to accurately measure d-c voltages within the range of zero to ±999. 9 volts and provide visual indications of the magnitude and polarity of these voltages in the form of a luminous digital display in a horizontal line. Other features of the instrument include, simplicity of operation, rapid automatic measurement of voltages, automatic polarity indication and decimal shifting, high input resistance, and accuracy within 0. 2 percent of the applied voltage or ±2 digits, whichever is greater. Applications of the digital voltmeter range from those of a secondary standard for the laboratory to those of continuous process production measurement.

1-3. GENERAL PRINCIPLES OF OPERATION.

1-4. The Model 451 Digital Voltmeter is a stepping switch type, self-balancing digital potentiometer that employs the principle of the comparison circuit to measure unknown voltages. An unknown input voltage is applied to the range circuit. The output of the range circuit is transmitted to one side of a chopper through the range selector switch. An internally synthesized feedback voltage, which is derived from a Thompson-Varley voltage divider and a reference battery, is fed to the other chopper input terminal. The chopper compares these two voltages and pulses generated in the amplifier vary the feedback voltage until it is equal to the unknown range output voltage. At this point of electrical balance, contacts of the stepping switches close circuits to specific lamps in the readout display to produce an illuminated digital indication of the unknown voltage, complete with decimal point and polarity sign. This is accomplished by illuminating certain lamps in the readout which in turn edge-light transparent lucite plates engraved with corresponding one-inch high numbers, polarity sign, and decimal point. Additional contacts on the stepping switch simultaneously provide contact closures which permit an accessory printer to record the information displayed in the readout. Connection to the accessory printer is made through a connector located on the back of the voltmeter.

1-5. Voltage measurements are made in three ranges: Zero to ±9. 999 volts dc; ±09. 99 to ±99. 99 volts dc; and ±099. 9 to ±999. 9 volts dc. Automatic placement of decimal points is accomplished in such a manner that each reading contains the maximum number of significant figures. For example, a measurement of plus 1. 2 volts appears as "+1. 200" rather than "+01. 20" or "+001. 2", even though the previous reading may have been in the hundred-volt range, such as "+120. 0". As previously stated, the accuracy of the readings is within 0. 2 percent of the applied voltage or ±2 digits, whichever is greater.

1-6. DESCRIPTION OF COMPONENTS.

1-7. LOCATION AND MOUNTING OF COMPONENTS. The Model 451 Digital Voltmeter is comprised of three main assemblies: The amplifier assembly; the stepping switch assembly; and the power supply. The three assemblies are mounted on a central chassis or framework, with the power supply on the left side, the amplifier assembly on the right, and the stepping switch assembly mounted in the center. The locations of the above components can be seen in figure 1-2, which shows the digital voltmeter with cover removed. The amplifier and power supply assemblies are vertically mounted, and their components are accessible from the sides, as indicated in figure 1-2. Either of these assemblies can be easily removed for maintenance if necessary, because they are track-mounted and slide in and out quite readily. Since the tracks also serve as a retainer, only two screws are required to secure these two assemblies. The stepping switch assembly is mounted in the center of the main chassis in such a manner that the switches extend downward into a container and are completely sealed in when the stepping switch mounting board is secured to the container by its mounting screws. As shown in figure 1-2 and 4-4, the readout assembly is attached to the stepping switch mounting board.

1-8. ETCHED CIRCUITS. Maximum use of etched circuits has been made in the construction of the digital voltmeter to facilitate construction and maintenance. Each of the three subassemblies is constructed in this manner. The etched circuits on the stepping switch mounting board can be seen in figures 1-2 and 4-4.

1-9. READOUT ASSEMBLY. When measuring an unknown voltage, the readout assembly (figure 1-2) is employed to translate the final condition of electrical balance to a luminous digital display that represents the magnitude of the unknown voltage. The readout assembly consists of five windows arranged horizontally. Transparent lucite plates with engraved numbers from 0 through 9, decimal points, or polarity signs are arranged in depth behind the appropriate window. (See figure 1-3.) A miniature replaceable edge-lighting lamp is positioned directly above each plate. Thus, a luminous in-line number, clearly visible at distances exceeding 30 feet, is produced. A polaroid sheet covering the face of the readout reduces incident light reflections and contributes to the sharply-defined brilliance of the luminous figures.

1-10. SPECIFICATIONS.

RANGE	RESOLUTION
Zero to ±9. 999 volts dc.	±0. 001 volts dc.
±09. 99 to ±99. 99 volts dc.	±00. 01 volts dc.
±099. 9 to 999. 9 volts dc.	±000. 1 volts dc.

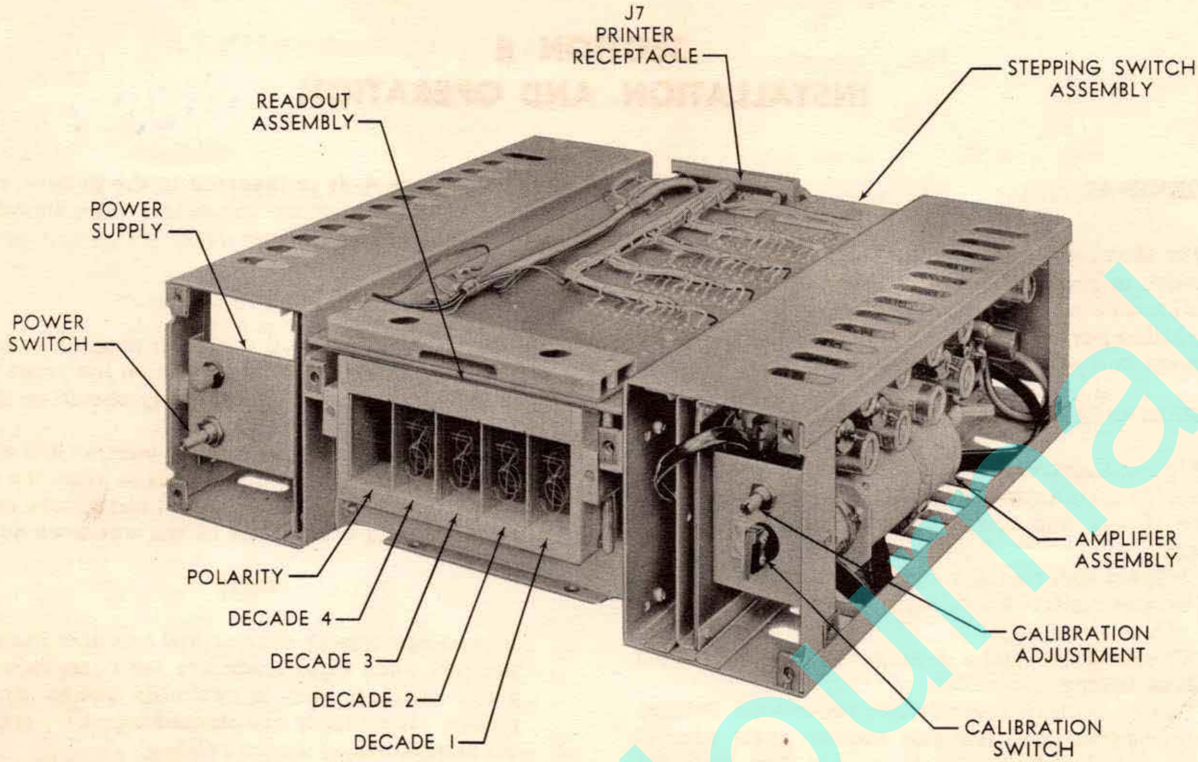


Figure 1-2. Digital Voltmeter, Cover Removed

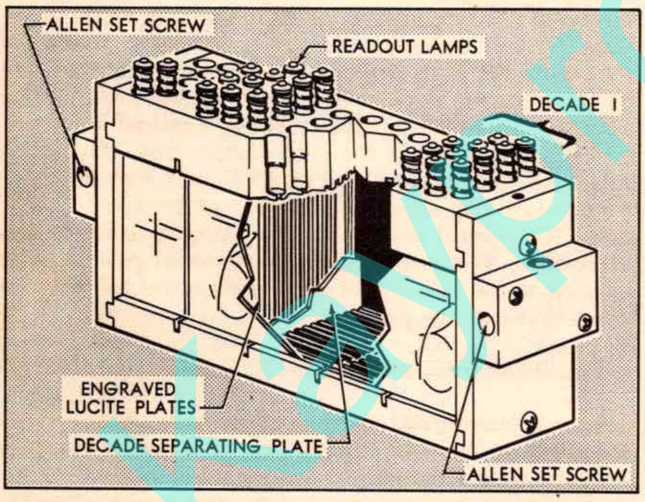


Figure 1-3. Readout Assembly, Cutaway View

ACCURACY: 0.2% of applied voltage or ±2 digits, whichever is greater.
READING RATE: One reading per second average.
CHOPPER SAMPLING RATE: 60 cycles per second.
INPUT IMPEDANCE: 11 megohms.
CALIBRATION VOLTAGE: One internal Weston Standard Cell supplies 1.018 volts dc at 20 degrees centigrade.
REFERENCE VOLTAGE SOURCE: Internally-mounted mercury-cell battery pack.
POLARITY INDICATION: "+" or "-" automatically prefixes the numerical display.
READOUT DECIMAL POINT: Positioned automatically depending on range.
STYLE:
Rack mount: 5-1/4" high; 19" wide; 15-1/8" deep.
WEIGHT: 40 pounds.
POWER: 115 ± 10 volts, 60 cycles, 75 watts.

SECTION II
INSTALLATION AND OPERATION

2-1. GENERAL.

2-2. The Model 451 Digital Voltmeter, while a complex instrument, is relatively simple to install and operate. Installation does not require the services of a technician, and unskilled personnel can be trained to operate the instrument in a short period of time.

2-3. PREINSTALLATION INSPECTION.

2-4. After the instrument has been carefully unpacked, and prior to installation, examine it as follows to determine if any damage has been sustained during shipment:

1. Inspect exterior for signs of damage, such as dents, broken control knob, fuse holder, or pilot light cover, etc.
2. Check to see that a 2-ampere fuse is inserted in the fuse holder.
3. Using a Phillips screwdriver, remove the Phillips head screws (two on either side and two at the rear of the instrument) that secure the cover; then slide the cover off.
4. Examine all tubes, plugs, and other chassis components to make certain each is in place and fully seated.
5. Check all visible wires for signs of broken solder connections or loose screw connections at terminal boards.
6. Replace the cover after completing the inspection.

2-5. INSTALLATION.

2-6. Since the digital voltmeter is designed for either bench-top or rack-mounting, the method of mounting is largely left to the discretion of the user. Despite the fact that adequate shielding has been provided in the design of the instrument, location of the instrument in areas where strong electrical fields are present should be avoided to prevent spurious changes in the readout indication. Electrostatic pickup is minimized by employing short shielded input lines and by connecting the chassis to a good earth ground.

2-7. To install the voltmeter, proceed as follows:

1. If the voltmeter is to be rack-mounted, place it in its designated location, and secure it by means of four screws.
2. Connect a two-wire shielded input line to the following terminals of TB2, located at the rear of the instrument: Positive lead to terminal 5; negative lead to terminal 6; and shield to terminal 4.
3. Connect the power plug to a 110-volt 60 cps source.
4. If an accessory printer is not used, make certain plug P7 (figure 4-4) is inserted in the printer receptacle J7 at the rear of the voltmeter. The digital voltmeter is now ready for operation.

2-8. OPERATION.

2-9. To operate the digital voltmeter proceed as follows:

1. Turn on the POWER switch on the front panel. The pilot light and readout assembly should be illuminated immediately.
2. Connect the input leads to an unknown d-c voltage.
3. Wait approximately 30 seconds to allow the equipment time to warm up. The readout should now indicate the polarity and magnitude of the unknown voltage.

NOTE

If readings appear erratic and unstable during periods when input leads are not connected to a d-c voltage, this is probably due to stray pickup. When leads are shorted together, readout should display a zero reading.

2-10. CALIBRATION. Calibration of the digital voltmeter serves to maintain its high accuracy, and also provides an indication that it is functioning normally. Since only a simple procedure is involved, it should be done periodically during the day or whenever the voltmeter is put into use, even after short periods of inoperation. To calibrate the voltmeter, press the CALIBRATE push button on the front panel and note the reading; it should be either +1.018, +10.18, or +101.8. If it differs numerically, remove the round screw cap just above the push button, and, while continuing to press the CALIBRATE push button, use a screwdriver to adjust the slotted shaft of the CALIBRATE rheostat until the above readout indication is obtained. The position of the decimal point has no bearing on the calibration of the instrument for reasons given in paragraph 3-8.

2-11. REMOVAL AND REPACKING FOR SHIPMENT.

2-12. If the digital voltmeter is to be removed for shipment to another location or to a repair facility, recrate it as follows:

1. Cover the front panel of the instrument with any soft felt-like material, and tape it in place.
2. Double-wrap the voltmeter in heavy wrapping paper.
3. Using the original shipping container or equivalent, place a four-inch layer of excelsior or rubberized hair in the bottom of the box, and put the voltmeter in the box.
4. Pack excelsior about the sides of the meter, and place enough on top so that the instrument is tightly packed when the cover is nailed on.

SECTION III
THEORY OF OPERATION

3-1. INTRODUCTION.

3-2. The Model 451 Digital Voltmeter operates essentially as a self-balancing digital potentiometer and incorporates circuits which make decimal location and polarity indications completely automatic. The general principles of operation of the digital voltmeter and a description of the components that comprise it is given in Section I. Before beginning a study of the operational theory which follows, familiarity with the voltmeter to the extent of the coverage in the preceding sections is desirable.

3-3. GENERAL THEORY.

3-4. The digital voltmeter employs a comparison circuit which automatically compares an unknown externally-located voltage with a known variable feedback voltage originating within the voltmeter itself. When the known and unknown voltages are equal, a condition of balance exists, and the edge-lighted readout display then indicates the magnitude and polarity of the unknown voltage. If the magnitude of the unknown voltage changes, the balance is destroyed. The comparison circuit then reacts instantly and initiates a series of actions which causes the known feedback voltage to be varied in discrete steps until it is again equal to the unknown voltage, and a condition of balance is again restored. The switching actions that are required to restore the electrical balance simultaneously cause the readout indication to be changed. The extent of the change is just sufficient to accurately reflect the actual increment of change in the unknown input voltage. The manner in which this is accomplished is explained in the succeeding paragraphs.

3-5. BLOCK DIAGRAM. (See figure 3-1.) The various components that comprise the digital voltmeter are shown in the block diagram, figure 3-1. Comparison of the unknown input and known feedback voltages is accomplished by the chopper, which alternately samples each voltage at a rate of 60 samplings per second. The source of the known feedback voltage is a reference battery consisting of a series-connected bank of mercury cells located in the amplifier. The voltage of the reference battery, while not critical, should be between 10 and 15 volts. Since the unknown voltages that can be measured fall within a range of 0 to ±999.9 volts, they will often greatly exceed the value of the reference voltage. It is obvious then that balance cannot always be achieved by direct comparison of the unknown input and feedback voltages, as previously implied. Therefore, as shown in figure 3-1, the unknown input voltage is fed first to the range switch and an associated voltage divider network. This switch automatically selects a voltage less than 10 volts from the voltage divider and transmits the voltage (indicated as "range output" in figure 3-1) to one side of the chopper. The reference voltage from the mercury cell battery pack in the amplifier is fed to the decade switches and an associated series of fixed precision resistors arranged to function as a highly accurate voltage divider of the Thompson-Varley type. The decade switches, together with the resistor network, function to change the magnitude of the feedback voltage to a value equal to that of the range output voltage. The feedback voltage is fed to the other side of the chopper for comparison to the range output voltage.

3-6. If the feedback voltage and range output voltage are equal, no signal is transmitted to the amplifier by the chopper. Consequently no further switching action occurs and, as previously stated, the readout display indicates the polarity and magnitude of the unknown voltage. (The manner in which the unknown voltage is translated to a luminous display of numbers corresponding to its exact magnitude will be explained in subsequent paragraphs.) If the feedback and range voltages are unequal, a square wave error signal is fed to the amplifier input stage — the amplitude of the error signal being in direct proportion to the degree of voltage difference. The amplifier, through a phase comparison process, develops "up" pulses or "down" pulses from the square wave input. These pulses are fed to the power supply, where further development and amplification occurs before they are fed to the polarity, decade, and range switches.

3-7. The preceding switches are stepping switches, a type of rotary, unidirectional, electromagnetic switch that moves in steps when its coil is energized by electrical pulses of sufficient amplitude. Each pulse causes the switch to "step" once. Thus, the so-called "up" and "down" pulses that originate in the amplifier are employed to actuate the six stepping switches used in the digital voltmeter. The functions of the range and decade stepping switches in connection with development of the range and feedback voltages have been discussed previously. As indicated in figure 3-1, additional functions include transmitting digital and decimal information to the visual readout and providing contact closures for the accessory printer through the printer receptacle. The polarity stepping switch receives the "up" and "down" pulses from the power supply and programs rotation of all the stepping switches; it also feeds polarity information to the readout, provides contact closures to the accessory printer, and automatically adjusts the polarity of the reference voltage to correspond to the polarity of the unknown voltage. Additional information pertaining to the stepping switches is given in paragraph 3-11 and table 3-2.

3-8. The function of the standard cell shown in figure 3-1 is to provide an accurately-known internal voltage for calibration purposes. During normal operation the standard cell performs no function and is not connected in the circuit. When the CALIBRATE switch is operated, the known voltage of the standard cell is substituted for the unknown voltage. Since this voltage is +1.018 volts, the digital voltmeter readout should

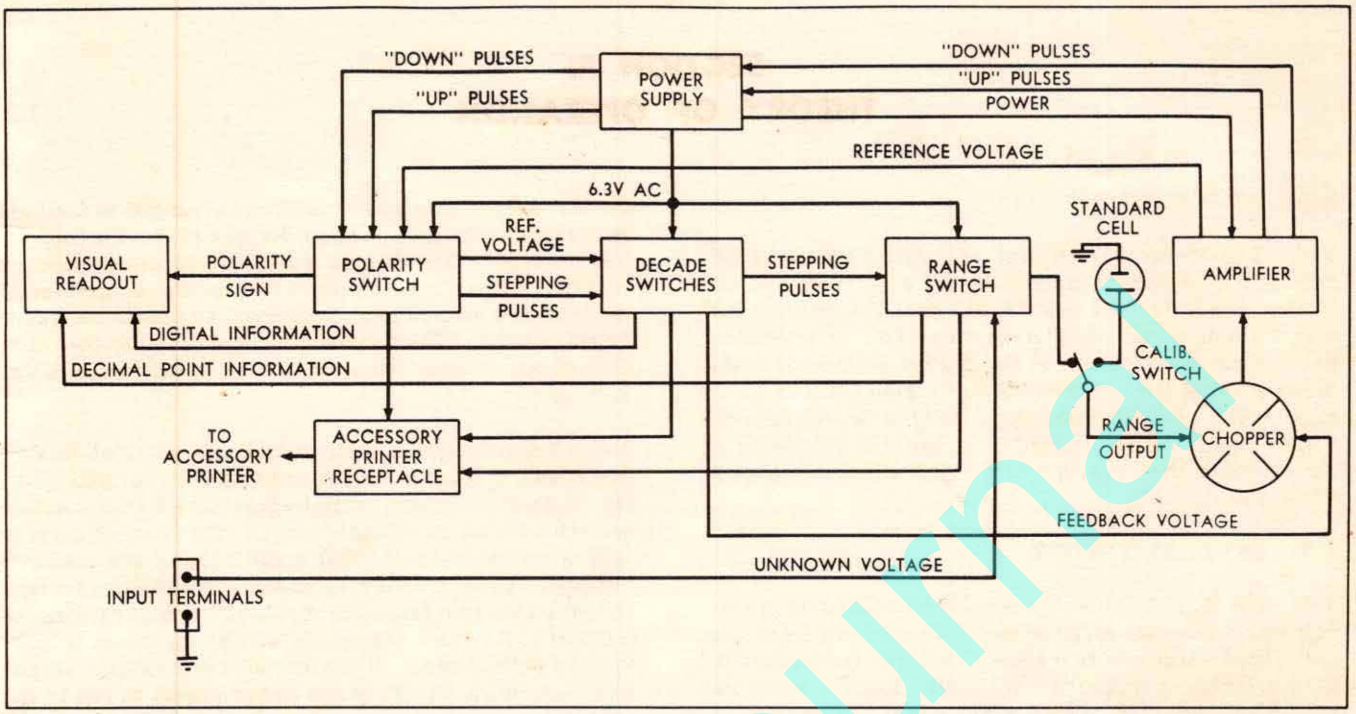


Figure 3-1. Block Diagram

indicate these numerals. If it does not, adjustment of the reference voltage by means of the CALIBRATE rheostat is indicated. As stated in paragraph 2-10, the readout indication obtained during calibration may be +1.018, +10.18, or +101.8. The position of the decimal point varies because the voltage of the standard cell is not fed through the range circuitry, but is fed directly to the chopper, as shown in figure 3-1. Consequently, whichever decimal position has been selected by the range switch at the moment of electrical balance is displayed on the readout.

3-9. Table 3-1 is a tabulation of the major electrical components that comprise the digital voltmeter; it includes a brief description of the functions of each component.

TABLE 3-1

MAJOR COMPONENTS AND THEIR FUNCTIONS

COMPONENT	FUNCTION
Readout Assembly	Provides a luminous visual display of digital information corresponding to magnitude of unknown voltage being measured. Also has provisions for polarity and decimal indications.
Chopper	Alternately samples range and feedback voltages and, if these voltages are unequal, feeds square wave error signal to amplifier.
Amplifier	Receives input (error) signal from chopper and generates pulses which (after amplification by power supply) actuate the stepping switches. Also contains the reference battery, which furnishes reference voltage to the polarity and decade stepping switches.
Power Supply	Supplies power to the amplifier and furnishes 6.3V ac to contacts of the stepping switches for illumination of readout edge-lighting lamps. Receives "up" and "down" pulses from the amplifier and amplifies them; they are then transmitted to the polarity switch and routed from there to the decade and range switches.

TABLE 3-1. (Continued)

COMPONENT	FUNCTION
Decade Switches 1 to 4	Develop feedback voltage from reference voltage; feed digital information to readout and accessory printer; provide switching for pulse circuits to control stepping switch movements.
Range Switch	Develops range output voltage from unknown input; feeds decimal information to readout and accessory printer; provides switching for pulse circuits to control stepping switch movements.
Polarity Switch	Reverses polarity of reference voltage, as required, to correspond to that of the unknown input voltage; transmits polarity information to readout and accessory printer; receives "up" and "down" pulses from power supply, and functions as a gate to program rotation of all stepping switches.
Standard Cell	Provides an accurate and stable source of known voltage for calibration purposes.

3-10. DETAILED THEORY.

3-11. STEPPING SWITCHES. Prior to beginning any discussion of circuits involving stepping switches it is advisable to consider the characteristics of these switches and the method of schematic representation that has been employed to depict them. In all, six stepping switches are used — one for each of the four decades, and one each for the range and polarity switch. With the exception of the decade 4 switch, all are identical. The switches are unidirectional and operate electromagnetically in steps through a spring-loaded detent mechanism. When a single electrical pulse is applied to the coil, the clapper is pulled down and energy is stored in a helical spring. When the pulse disappears, the spring pushes the clapper back to its original position, and at the same time "steps" the switch one position. The same thing can be accomplished by manual movement of the clapper. If pulses are applied at a rate of 60 cps, as occurs during extensive changes in the magnitude of the readout display, the switch rotates or "steps" continuously until the pulses are cut off.

3-12. Each switch (with the exception of decade 4) has six levels of stationary contacts with 12 contacts per level. (Decade 4 switch has seven levels but is otherwise identical.) Each switch also has three rotary wiper contacts per level spaced 120 degrees apart. Referring to the overall schematic diagram, figure 4-6, note how the stepping switches have been represented. Contacts are numbered 1 to 12, beginning at the top, and switch levels are lettered A to F, reading from left to right. Each level performs a specific switching function. For example, level B of decade 1 (S4) switches 6.3V ac to the lamps in the right hand window of the readout assembly. Wiper contacts are represented by arrowheads. Note that only two wipers are shown for each level. The third wiper is rotated to a position 120 degrees removed from the nearest wiper and hence it is not shown. As the switch rotates, the wipers move downward simultaneously. As the wiper on contact 1 moves to contact 2, the wiper that was on contact 12 moves off completely. Thus contacts 1 and 12 are the only contacts ever connected to two wipers simultaneously. As shown in figure 4-6, the number 1 contacts are used only as connecting terminals for the wipers. Hence only one wiper at a time can perform a switching function in conjunction with the contacts of its associated level.

3-13. DEVELOPMENT OF RANGE OUTPUT VOLTAGE. Figure 3-2 illustrates functionally how the range output voltage is developed. The range circuit functions automatically to reduce any unknown voltages (within the range of the instrument) to a level somewhere between 0 and 9.999 volts. The unknown input voltage is applied across a tapped voltage divider network consisting of twelve precision resistors, eleven of which are 1 megohms each, the other being 111,111 ohms. As shown in figure 3-2, the voltage divider is connected across the input terminals of the voltmeter, with one end grounded. Contacts of the range switch are connected to the top of the divider and to taps created by the junction of the tenth and eleventh 1-megohm resistors and the junction of the 111,111-ohm and 1-megohm resistors. Since ten of the 1-megohm resistors are connected in series, they can be considered a single 10-megohm resistor. Thus, for purposes of explanation, the voltage divider can be said to consist of three series-connected resistors with resistance values of 10 megohms, 1 megohm, and 111,111 ohms. The total resistance of the voltage divider is 11,111,111 ohms. The values of the three resistors have been established as stated in order to provide voltage-dividing factors of 10 and 100 at the taps. Letting E represent the unknown input voltage, the voltage at the junction of the 10-megohm and 1-megohm resistors (with respect to ground) is E/10; the voltage at the junction of the 1-megohm and 111,111-ohm resistors is E/100. If the 10-megohm, 1-megohm, and 111,111-ohm resistors are represented as R1, R2, and R3 respectively, the following mathematical relationship or proportion exists:

$$\frac{E}{R1 + R2 + R3} = \frac{\frac{E}{10}}{R2 + R3} = \frac{\frac{E}{100}}{R3}$$

3-14. Unknown voltages from 0 to ±9.999 volts are removed at the top of the divider by contacts of the range stepping switch and fed to the chopper without further reduction. When the range switch is in this position, contacts on a separate level feed a 6.3V ac illuminating voltage to the left decimal lamp in the

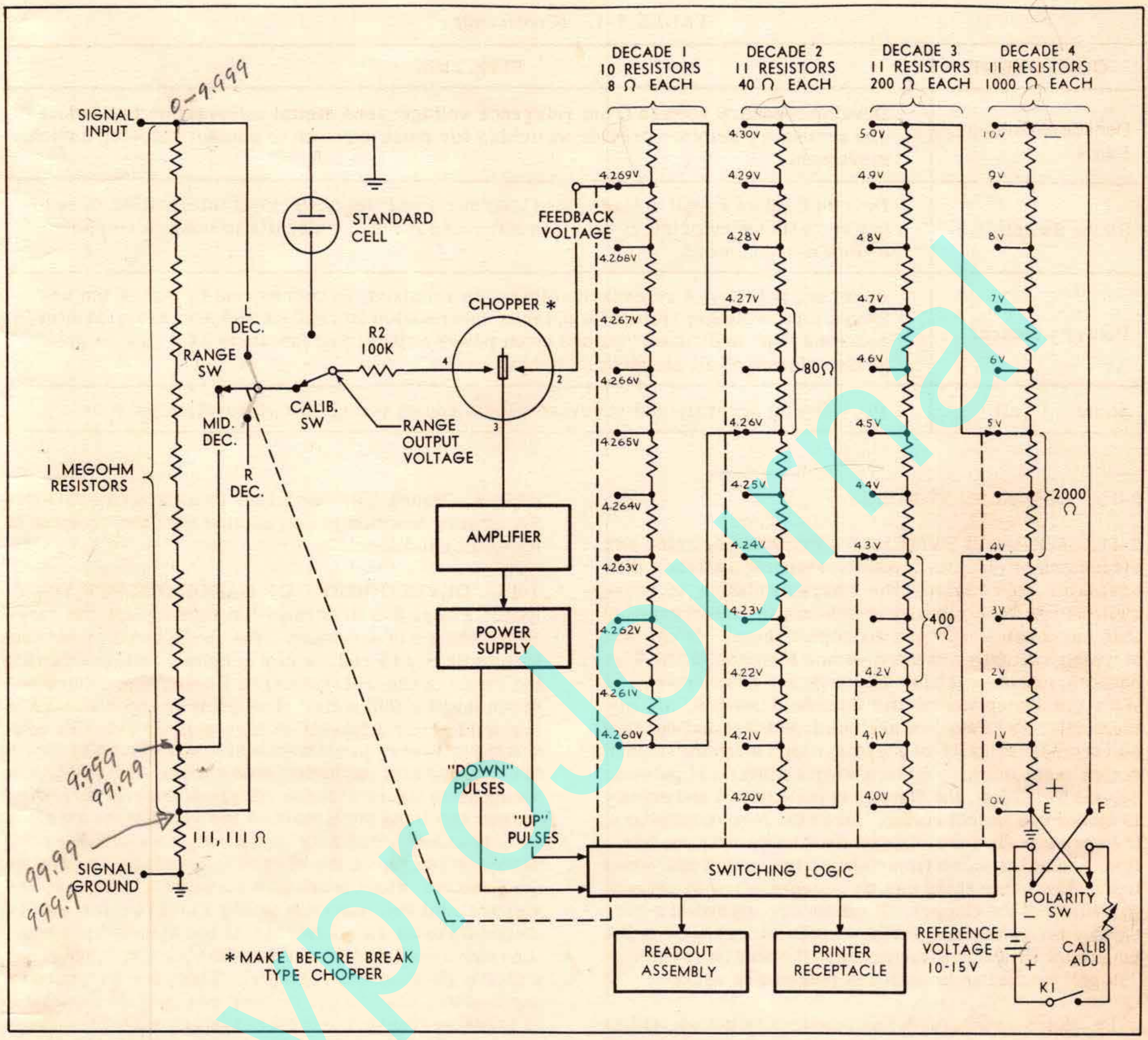


Figure 3-2. Functional Diagram

readout assembly. Unknown input voltages in excess of 9.999 volts, but not greater than 99.99 volts, are automatically reduced by a dividing factor of 10 before being accepted as the range output voltage. This is accomplished automatically by the range switch, which rotates until its contacts are connected to the tap created by the junction of the last two 1 megohm resistors at the bottom of the divider. When the range switch is so positioned, illuminating voltage is fed to the middle decimal lamp in the readout. Unknown voltages falling between 99.99 and 999.9 volts are tapped off in a similar manner at the junction of the 111,111-ohm and 1-megohm resistors, which reduces the unknown input voltage by a dividing factor of 100. When this occurs the right decimal indicator in the readout is illuminated. The automatic range selecting characteristics of the range switch is accomplished by the pulse circuitry, which actuates all of the stepping switches, rather than by any unique feature of the switch itself. The manner in which this is accomplished is discussed in paragraph 3-21.

3-15. DEVELOPMENT OF FEEDBACK VOLTAGE. The circuitry used to develop the feedback voltage is similar to the range voltage circuit to the extent that a voltage divider is employed to reduce the reference battery voltage to a value equal to the range output voltage. However, because of the extreme accuracy required, and since the feedback voltage must be variable in incremental steps of 1 millivolt to equal the range output voltage at any point within its 0 to ±9.999-volt limit, a more complex voltage divider network is required. A Thompson-Varley voltage divider has been incorporated in the digital voltmeter feedback circuit to fulfill this requirement. A series of precision resistors attached to stationary contacts of the decade stepping switches comprise the resistance elements of the voltage divider. Their arrangement is shown in the functional diagram of the digital voltmeter, figure 3-2. Compare the feedback circuit in figure 3-2 with the actual schematic diagram, figure 4-6, and note that it is identical except for the manner in which the actual switches are represented. The feedback circuit can be considered to function as a series of potentiometers interconnected in such a manner that the output of the voltage tap at one is applied as the input across the next adjacent potentiometer. Each succeeding potentiometer has a lower resistance value than the preceding one. With such an arrangement the last potentiometer in the series has the smallest applied voltage, and the increment of feedback voltage change as its tap is moved is quite small compared to the first potentiometer in the series.

3-16. As shown in figure 3-2, eleven equal 1000-ohm precision resistors comprise decade 4. Assuming a reference voltage of 10 volts applied across decade 4, the voltage is divided in one-volt steps as shown. Decade 3 has one fifth the resistance of decade 4 and bridges any two of the resistors of decade 4, depending upon the setting of the associated stepping switch. The two resistors bridged represent a resistance of 2000 ohms. When the decade 4 switch is in the position indicated in figure 3-2, a voltage between 4 and 5 volts is tapped off and applied across the decade 3 divider. (Actually any one of ten equal increments between zero and full voltage can be chosen depending upon the setting of the decade 4 stepping switch.) Similarly, decade 2 has one-fifth the resistance of decade 3 and bridges two resistors of the eleven 200-ohm resistors that comprise decade 3. In the example shown, a voltage between 4.2 and 4.3 volts is tapped off two resistors of decade 3. This voltage in turn is applied across decade 2, which further divides it in ten equal increments for application to decade 1, which is a conventional ten-step voltage divider. The setting of the decade 2 stepping switch as indicated in figure 3-2 is such as to tap off voltages between 4.26 and 4.27 volts for application to decade 1. The fourth digit of the feedback voltage is developed in the decade 1 voltage divider. In the example shown, a feedback voltage of 4.269 volts is being tapped off decade 1 by the contacts of its associated stepping switch and fed to pin 2 of the chopper. When each of the four decade switches is in the position shown, the contacts associated with level B of each switch are employed to feed 6.3V ac illuminating voltage to the proper readout lamps to produce the readout indication which corresponds to the unknown input voltage. Level A of each switch provides the proper switch closures for an accessory printer through printer receptacle J7 to permit the printer to record the above reading.

3-17. REFERENCE VOLTAGE CIRCUIT. As indicated in figure 3-2, the reference battery voltage is applied to the feedback voltage circuit through the contacts of the polarity switch. Levels E and F of this switch function effectively as a dpdt switch, because of the way its contacts are interconnected. When a negative unknown voltage is being measured, the pulse circuitry causes the polarity switch to be positioned as shown in figure 3-2, which in effect reverses the polarity of the reference voltage so that it matches the unknown voltage. Whenever the polarity of the unknown voltage changes, the polarity switch moves automatically, as directed by the pulse circuitry, to compensate for the change. At the same time, contacts of level B of the polarity switch feed illuminating voltage to the lamp associated with the appropriate polarity sign in the readout assembly. The calibration adjustment is a rheostat in the reference voltage circuit that is used to compensate for aging of the mercury cell battery. The standard cell voltage is substituted for the range output voltage, as described in paragraph 3-8, and the CALIBRATE rheostat is adjusted until the readout indicates the particular numerals that correspond to the standard cell voltage. Relay K1, the contacts of which are shown in the reference voltage circuit of figure 3-2, causes the reference circuit to open to conserve the battery when the digital voltmeter is not in use. It is automatically energized when the POWER switch is turned on.

3-18. AMPLIFIER ASSEMBLY. (See figure 4-6.) The previously-mentioned "up" and "down" pulses originate in the amplifier assembly and are used to actuate the stepping switches. They are developed in the following way. The presence of unequal feedback and range output voltages on pins 2 and 4, respectively, of the chopper causes the reed or moving contact (pin 3) to alternately assume the potential of the two different voltages as it vibrates. This results in the formation of a 60 cycle square-wave error signal, which is impressed on grid pin 2 of V2. It can be seen that the phase of this error signal is dependent upon the respective magnitudes of the range and feedback voltages. If either of these voltages is greater than the other, error signals of opposite phase are produced. It will soon be evident that this fact has an important bearing on the development of the "up" and "down" pulses. A neon tube (V1) is connected between contacts 2 and 4 of the chopper to limit the potential difference between the contacts when the unknown voltage is increased by a considerable degree and before the range circuit can compensate for it.

3-19. The square-wave error signal is amplified by section 1 of V2 and cathode-coupled to section 2 of the same tube. Because of this method of coupling, no phase reversal occurs. The error signal is then fed to the grid (pin 2) of V3. V3 functions in a manner identical to V2 and amplifies the signal further, but again without the usual phase inversion that is characteristic of cascade amplifiers. The signal is developed across gain control R9 (which functions also as a plate load resistor for section 2 of V3) and is coupled by capacitor C6 to the grid (pin 2) of V4. As in the preceding stages, the error signal is coupled to the cathode of section 2, and appears on the plate (pin 6) of that section without any phase reversal. Section 1 of V4 employs a plate load resistor, R13, across which the signal applied to this section of the tube is developed. Note that a phase inversion has now occurred for the first time, thereby creating two signals that differ in phase, one on each of the plates of V4.

3-20. The signal on one plate (pin 1) of V4 is coupled to the grid of V5, a type 5696 thyratron. The signal on the other plate (pin 6) of V4 is fed to the grid of another 5696 thyratron, V6. A 165-volt ac voltage is applied to the plates of V5 and V6 instead of a dc voltage. The grids are biased to -7 volts, obtained at the junction of resistors R24 and R25, which are connected in series between ground and the B- line. Under these conditions, V5 or V6 can fire only when the signal applied to the grid is in phase with the a-c voltage applied to the plate. Since the a-c voltage applied to the chopper coil and the plates of V5 and V6 is common to both, the error voltage is either in phase or 180° out of phase with the plate voltage, depending upon the relative magnitudes of the feedback and range voltages. Also, since the signals on the grids are of opposite phase, obviously only one thyratron can fire with an error voltage of a given phase. Recalling that the phase of the error voltage depends on whether the range or feedback voltage is greater, it is possible to produce a signal from V5 when the error voltage is of a given phase, and from V6 when it is just opposite in phase. When either of the thyratrons fire, the control grid assumes the same potential as the plate momentarily. Neon tubes V7 and V8, being connected directly to the grids of V5 and V6 respectively, fire each time the corresponding thyratron fires. When V7 fires, a "down" pulse is produced, which is fed to the power supply through isolating resistor R29; when V8 fires, an "up" pulse is produced, which is fed to the power supply through isolating resistor R32. It is significant to note that the pulses thus formed are identical insofar as amplitude and waveform are concerned; however, two separate pulse channels have been produced, and pulses occur at a 60-cps rate in one or the other depending on the phase of the error voltage.

3-21. PULSE CIRCUITS. Although the "up" and "down" pulses are amplified further by the power supply before being fed to the stepping switches, it is more appropriate to discuss the pulse circuitry at this time before considering the power supply. Two pulse channels are employed because of the unidirectional properties of the stepping switches. If the unknown voltage decreases 1 millivolt, the decade 1 switch must "step" in a forward direction, 1-2-3, etc., until it comes to the correct numeral, since it cannot be reversed to change the readout display by moving one step backward. Consequently, "up" and "down" pulses are utilized to differentiate between situations where the unknown voltage is higher or lower than the voltage indicated on the readout. Assuming a positive unknown input voltage, when the unknown voltage is lower, the phase of the error voltage is such as to produce "down" pulses; when it is higher, "up" pulses are produced. When the unknown voltage is of opposite polarity (negative), this situation is just reversed. Figure 3-3 illustrates the pulse circuitry, which includes the stepping switches and their various interconnections. As indicated, contact levels C and D of each switch are employed in the pulse circuits; decade 4 switch uses level E, also. Positions of each switch for a reading of +9.501 are shown. If the unknown voltage changes to +9.502, a single "up" pulse would be produced to cause the decade 1 switch to move one position to the contact of the switch associated with the second digit. If the unknown voltage shifts to +9.500, nine "down" pulses will be produced before the decade 1 window in the readout indicates "0", because of the inability of the switch to reverse direction.

3-22. Combinations of "up" and "down" pulses are normally required before balance can be restored and the new reading is displayed. This again can be attributed to the unidirectional characteristics of the switches as well as to the fact that they operate in sequence. As the decade switches rotate, the feedback voltage changes, often to the extent of reversing the initial starting relationship between the feedback and range voltages. Thus, the type of pulses being produced by the amplifier changes. A simple example of this situation occurs when the unknown voltage changes from +0.010 to +0.009 volts. The readout display changes as follows:

D4	D3	D2	D1	
0	.0	1	0	
0	.0	2	0	
0	.0	3	0	
.	.	.	.	
.	.	.	.	"Down pulses (1 step per 1/60 sec.)
.	.	.	.	
0	.0	9	0	
0	.0	0	0	
0	.0	0	1	
0	.0	0	2	
.	.	.	.	"Up" pulses
.	.	.	.	
.	.	.	.	
0	.0	0	9	Balance (No pulses)

3-23. Digital changes, polarity reversals, and placement of decimals, all are accomplished automatically by the pulse circuits. These circuits are designed in such a manner that when an unknown voltage is being measured, the resultant "up" or "down" pulses are channeled to all the stepping switches. One or more of the switches then rotate sequentially until the correct range (and hence range output voltage) has been selected, the polarity has been established, and the feedback voltage has been adjusted to equal the range output voltage. These functions have all been accomplished by the time balance has been achieved, at which time all switch action ceases. Additional contacts, shown only in figure 4-6, are employed to transmit numerical, polarity, and decimal position information to the readout assembly and accessory printer. The functions of the various levels of each stepping switch are listed in Table 3-2.

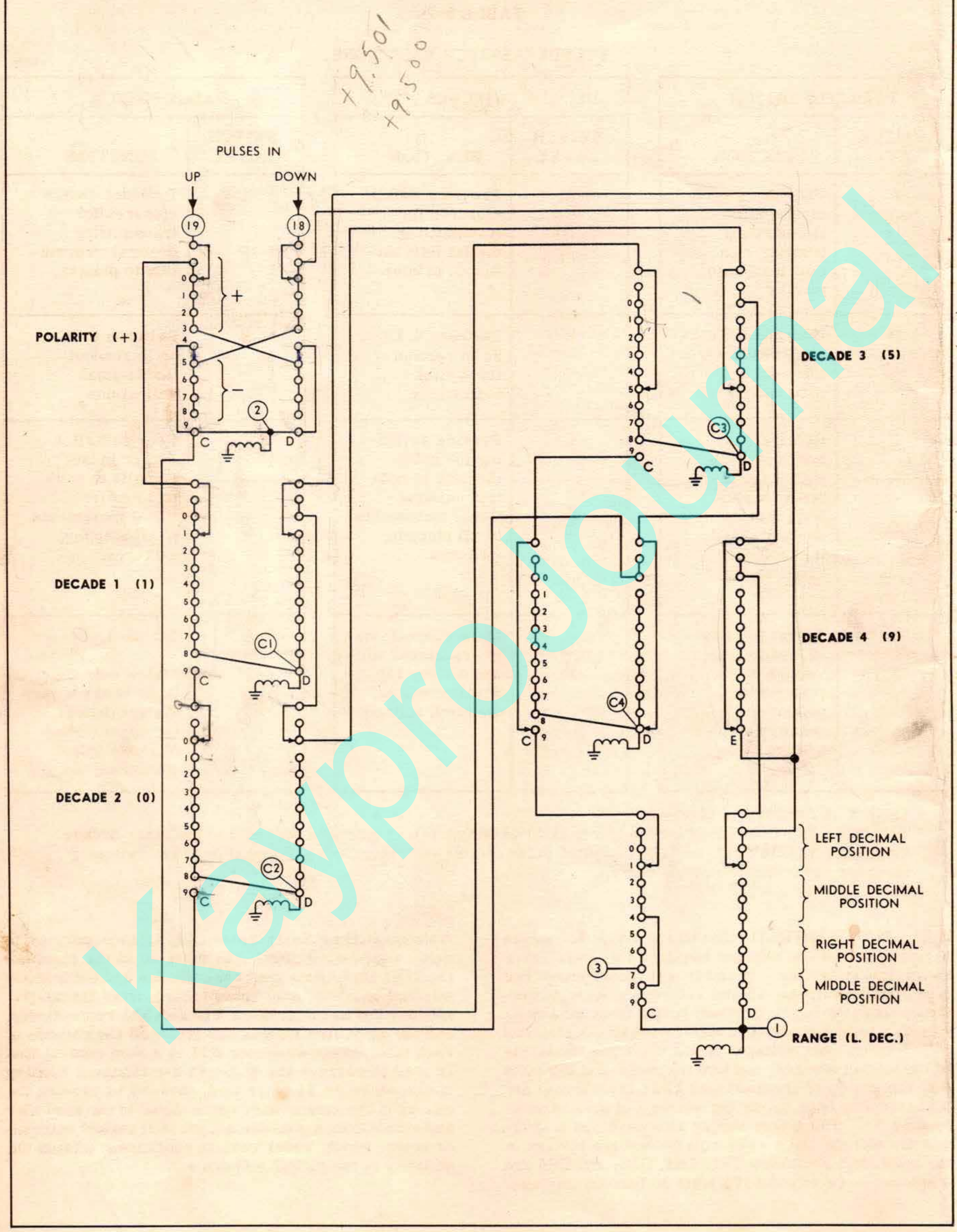


Figure 3-3. Pulse Circuits

TABLE 3-2

STEPPING SWITCH FUNCTIONS

POLARITY SWITCH	
SWITCH LEVEL	FUNCTION
A	Provides switch closures for transmitting polarity sign information to printer.
B	Switches 6.3V ac to readout for polarity indications.
C	Receive "up" and "down" pulses from power supply and program rotation of all the unidirectional stepping switches.
D	
E	Adjust polarity of feedback voltage to correspond to polarity of unknown voltage.
F	

DECADE SWITCHES 1-3*	
SWITCH LEVEL	FUNCTION
A	Provides switch closures for transmitting digital information to printer.
B	Switches 6.3V ac to readout for digital indications.
C	Provide switching for pulse circuits to control unidirectional movements of all stepping switches.
D	
E	Make connections to associated voltage divider for development of feedback voltage.
F	

RANGE SWITCH	
SWITCH LEVEL	FUNCTION
A	Provides switch closures for transmitting decimal information to printer.
B	Switches 6.3V ac to readout for decimal indications.
C	Provide switching for pulse circuits to control unidirectional movements of all stepping switches.
D	
E	Not used.
F	Makes connections to associated voltage divider for development of range output voltage.

* Level E of Decade 1 is not used.

* Decade 4 switch has seven switch levels (A to G) but performs functions identical to the other decade switches. Levels C, D, and E accomplish pulse circuit switching; levels F and G perform switching functions for feedback voltage circuit.

3-24. POWER SUPPLY. (See figure 4-6.) The power supply develops the voltages required for operation of the digital voltmeter. In addition it incorporates two type 2D21 thyratrons, V9 and V10, which serve to further amplify the "up" and "down" pulses from the amplifier to a level suitable for application to the stepping switch coils. A-c voltages of 6.3 volts (for the lamps of the readout assembly and tube filaments) and 165 volts (for the plates of the 5696 and 2D21 thyratrons) are taken directly from secondary windings of power transformer T1. The power supply also develops a -140-volt B- voltage and a +175-volt B+ voltage for use in the amplifier; rectifiers CR1, CR2, CR3, and CR4 are employed to rectify the 165 volts ac for this purpose. A thermal time delay relay, K3, is incorporated to delay application of the 165 volts ac to the plates of the 2D21 thyratrons until the cathodes are sufficiently warmed up. "Up" and "down" pulses from the amplifier are fed to the grids of V10 and V11 respectively, and the amplified signals are taken off the cathode of each tube. Potentiometer R35 is a hum control that is used to balance the 6.3-volt a-c filament winding of transformer T1 to ground, thereby improving the quality of the square-wave error signal in the amplifier and eliminating a possible source of transient voltages or noise, which, under certain conditions, affects the stability of the digital voltmeter.

SECTION IV
MAINTENANCE

4-1. OPERATIONAL ADJUSTMENTS.

4-2. AMPLIFIER GAIN CONTROL. When amplifier gain is insufficient, the visual readout display will not respond to input changes of 1 or 2 millivolts. On the other hand, excessively high amplifier gain may cause instability in the readout window associated with the first decade. The following procedure should be followed to adjust amplifier gain control R9, shown in figure 4-1:

1. Press the CALIBRATE switch pushbutton and observe a numerical readout display of 1018 or vicinity.
2. Slowly turn the slotted CALIBRATE rheostat shaft in a counterclockwise direction. Observe the magnitude of the decrease in readout display. If the readout display decreases in steps of 1-2 millivolts and no instability is encountered in the readout window associated with the first decade, no adjustment of amplifier gain should be made.
3. If the decreases observed in step 2 were greater than 2 millivolts for each change, increase the gain of the amplifier by turning R9 slightly clockwise. Repeat steps 2 and 3 until decreases of 1-2 millivolts are observed.
4. If instability develops in the first decade readout window, turn the gain control counterclockwise until the instability just disappears; then repeat step 2 to make certain that the readout display decreases in steps of 1-2 millivolts as R9 is rotated slowly counterclockwise.
5. Recalibrate the voltmeter in accordance with the procedure given in paragraph 2-10.

4-3. HUM CONTROL. Proper adjustment of the hum control, R35 (figure 4-2) is facilitated by the use of an oscilloscope. To make this adjustment, proceed as follows:

1. With power turned on, apply a voltage between ±10.00 and ±99.99 volts to the input terminals of the voltmeter.
2. Connect an oscilloscope to either of the two test points on the amplifier assembly and observe a square wave. (The test points are indicated in figure 4-1.) To increase the amplitude of the square wave, vary the CALIBRATE rheostat slightly until the square wave is more apparent on the oscilloscope. (If the control is moved too far, the reading will change; this should be avoided.)
3. Adjust hum control R35 in either direction for an optimum square wave.

4-4. REPLACEMENT OF COMPONENTS.

4-5. REFERENCE BATTERY REPLACEMENT. The reference battery consists of a series of mercury "A" cells stacked in a phenolic tube. The need for battery replacement is indicated by inability to obtain a visual readout display below +1.018 volts when the calibration rheostat is turned fully counterclockwise, and excessive reference voltage drift, as evidenced by a frequent requirement for calibration.

4-6. The reference battery is mounted on the underside of the amplifier assembly, as shown in figure 4-1. The phenolic tube containing the mercury cells is fitted with one stationary and one spring-loaded end plug. The diameter of the spring-loaded receptacle is smaller than that of the stationary plug. The mercury cells, 9 to 11 in number, are assembled in the phenolic tubes in such a manner that the polarity of the spring-loaded end plug is positive. The use of end plugs having different diameters makes it impossible to install the phenolic tube battery improperly.

4-7. READOUT LAMP REPLACEMENT. Replacement of individual readout lamps is accomplished as follows:

1. Remove the front escutcheon plate by removing the two Phillips head screws employed to secure it.
2. With the readout assembly now exposed, note that it is mounted on two guide posts, one at either end, and is secured in place by an Allen head set screw at each post. Support the readout assembly with one hand, and loosen the Allen head screws with the other until the assembly slides down, exposing the inverted readout illuminating lamps.
3. Remove the burned-out lamp and replace it with another, using the same spring that was removed with the lamp. If other lamps are accidentally dislodged, make certain when replacing them that they are inserted in the correct holes. (See figure 1-3.)
4. Slide the readout assembly up into its former position, and, with one hand, hold it securely in place against the spring tension resulting from compression of the lamp springs; with the other hand, tighten the Allen head set screws.

4-8. LUBRICATION.

4-9. Periodic lubrication of the stepping switches has been found to greatly extend their life and improve their performance. Under conditions where the digital voltmeter is used daily, lubrication at three month intervals, or after 200,000 readings (whichever occurs first), is recommended. To lubricate most points, a #4 Artists Sable Rigger brush is used. A "dip" is the amount of lubricant retained on the brush when it is dipped 3/8 inch into the lubricant and lightly scraped on the edge of the container to remove excess. Avoid excessive lubrication. To lubricate the stepping switches, remove the voltmeter cover and the stepping switch assembly and follow the procedure outlined in Table 4-1.

||||||
68k

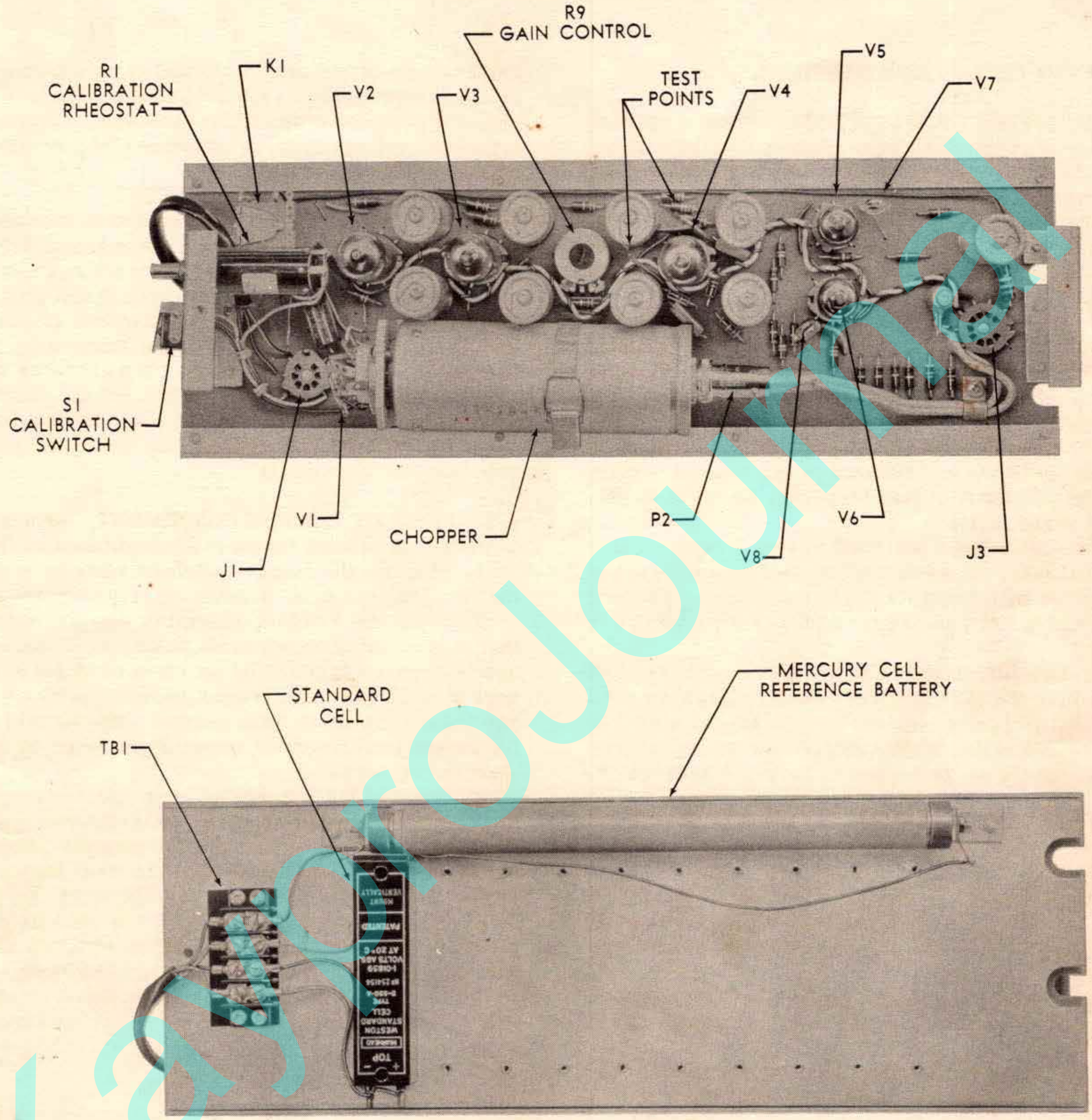


Figure 4-1. Amplifier Assembly, Top and Bottom Views

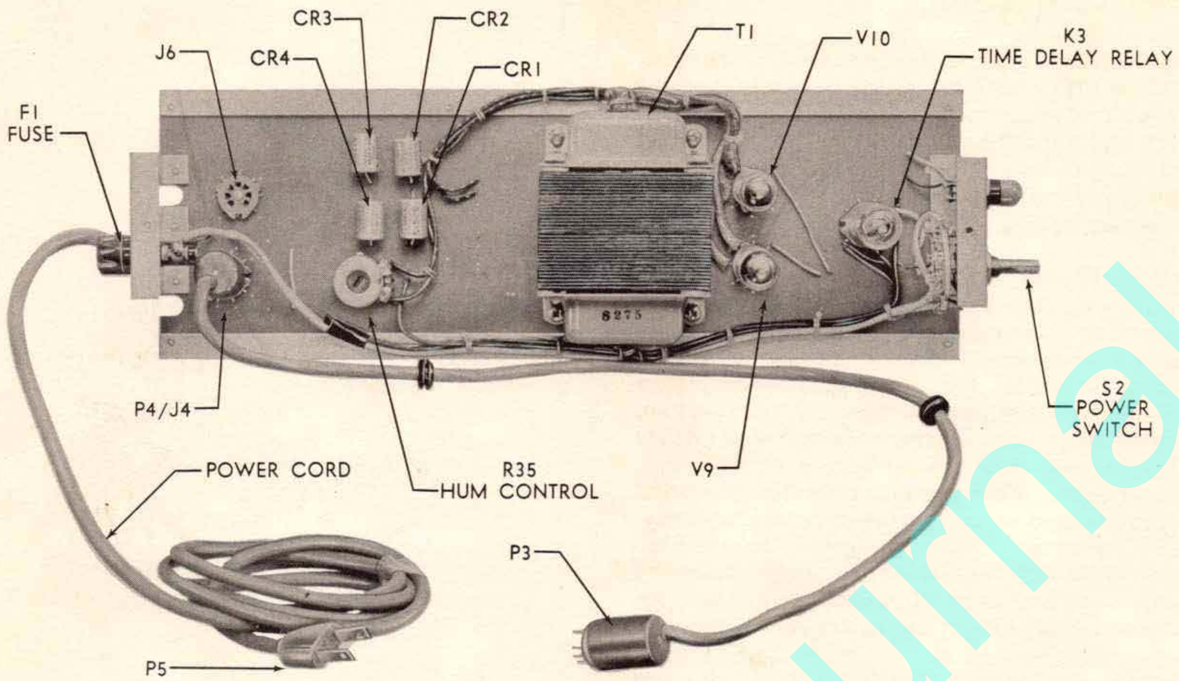


Figure 4-2. Power Supply Assembly, Top View

TABLE 4-1

LUBRICATION CHART

LUBRICATION POINT	TYPE LUBRICANT	LUBRICATION PROCEDURE
Wiper assembly bearing	Clock oil or equivalent	Apply one dip near the pointer.
Each pair of wiper contacts	Clock oil or equivalent	Draw a strip of bond paper, treated with two dips on each side, through the wiper contacts. Rotate assembly to distribute lubricant.
Inner sides of each pair of wipers where brush springs ride	Clock oil or equivalent	Apply one dip of oil at the points indicated.
Armature bearing	Light mineral oil	Apply one dip to each side of bearing.
Pawl bearing	Light mineral oil	Apply one dip to each side of bearing.
Pawl spring hooks	Light mineral oil	Apply one lean drop to the hooks at the eyelets.
Off-normal cam lobes	Light mineral oil	Apply one very lean dip to the lobes.
Ratchet teeth	50-50 mixture (by volume) of powdered mica and clock oil	Apply two dips to the ratchet teeth, rotating to distribute lubricant.

4-10. TROUBLE SHOOTING.

4-11. GENERAL. Only qualified maintenance personnel should be allowed to carry out trouble shooting procedures in connection with the digital voltmeter. Such personnel should be familiar with the physical makeup of the instrument, its installation and operating procedures, and the detailed theory of operation, as given in the preceding sections.

4-12. The first step in trouble shooting is to isolate the circuit in which the defective component is located. An understanding of the relationship and interdependence of the three main assemblies that comprise the digital voltmeter is essential. For example, if the amplifier is defective, the stepping switches will not function. If the power supply is defective, neither the amplifier or the stepping switches can perform properly. Improper functioning of the digital voltmeter is almost always accompanied by an improper readout display, whether in a transitory or stabilized condition. Detailed examination of the readout display in the light of theory of operation given in Section III, invariably will provide an indication as to the probable source of trouble.

4-13. Before employing exhaustive trouble shooting techniques to locate trouble, always look for the more obvious causes of trouble, such as broken leads, loose solder joints, defective tubes, blown fuse, weak batteries, etc. Consider the possibility of maladjustment of gain, calibration, or hum control adjustments. Make use of the fact that the neon tubes, V7 or V8, glow when "up" or "down" pulses are being produced by the amplifier.

4-14. PULSE TRACING. The use of an oscilloscope can greatly facilitate the isolation of troubles in the amplifier or pulse circuits. The oscilloscope can be used to check the amplifier by observing the square-wave error signal at the test points shown in figure 4-1. These test points are connected to the plates of V3 and V4, as indicated on the schematic diagram, figure 4-6. The procedure outlined in paragraph 4-3, step 2, should be followed to observe the waveform at the test points. In addition, a check of the "up" and "down" pulses at the amplifier output terminals can be made with an oscilloscope, using the same procedure. These pulses appear as shown in figure 4-3(A). Part B of the same figure is a representation of the normal waveform that appears at the coils of the stepping switches when they are operating. Direct access to these points is not necessary, since the points are brought out to solder terminals on the stepping switch mounting panel, figure 4-4. (These points are shown on the schematic diagram, figure 4-6, and are identified insofar as the actual equipment is concerned on figure 4-5.) To observe this waveform, produce continuous cycling by disabling the reference circuit (open K1), and connect terminal 2 on the stepping switch board to terminal 3. Points X and Y of figure 4-3(B) should be separated as shown. Insufficient separation indicates that the position of the stator of a stepping switch has changed, or that tension of the switch driving spring has decreased. Figure 4-3(C) depicts the waveform at the output of the power supply if there is no load connected to that line, such as might occur if a coil were open or if the printer receptacle plug were not making proper contact. This can be observed by opening the reference circuit and removing plug P7 at the printer receptacle. This serves as a check on the power supply, since the pulses being observed constitute its output of "up" and "down" pulses.

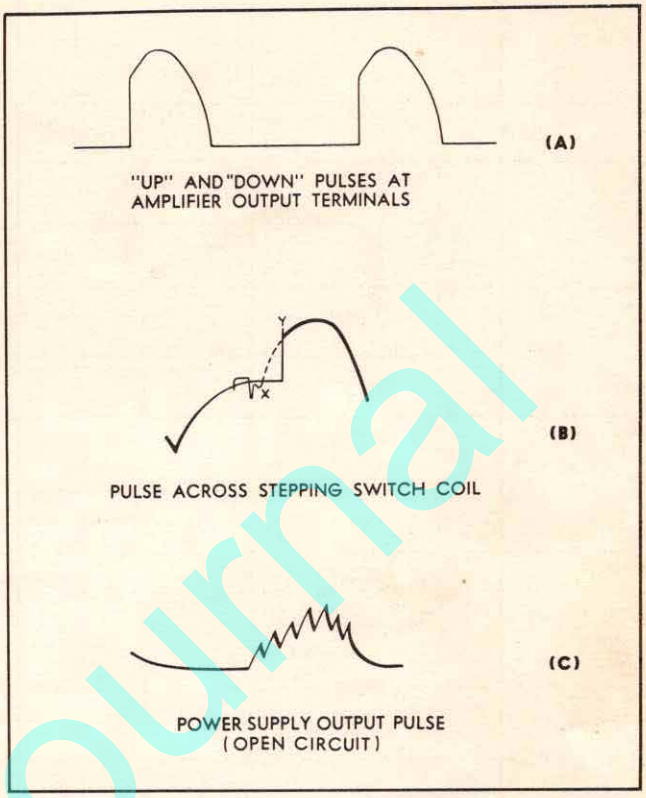


Figure 4-3. Typical Waveforms

4-15. STEPPING SWITCHES. Figure 4-3(B) represents the normal waveform of a pulse across the coil of a stepping switch when the switch is functioning normally. The dotted portion of the waveform represents an imaginary extrapolated extension of the visible portion of the sine wave. The position of the superimposed anomaly to the left of the dotted line, as shown in figure 4-3 (B), indicates a properly adjusted stepping switch. When viewing this waveform on an oscilloscope, if point X on the waveform is observed to be farther to the right than the corresponding point in figure 4-3(B), adjustment of the detent spring is indicated. Each stepping switch has a slotted detent spring adjusting screw, which can be seen if the switch is viewed from its coil end. To adjust this spring for proper tension, apply 105 volts dc to the input terminals of the voltmeter, loosen the adjustment screw locknut, and adjust the screw until the proper waveform is attained. (Instructions for observing this waveform are given in the preceding paragraph.) Lock the adjustment.

4-16. TUBE SOCKET VOLTAGES AND RESISTANCES. To aid in trouble shooting, the tube socket voltage and resistance readings for a normal digital voltmeter are listed in Table 4-2. With the exception of the filaments, all voltages and resistances are measured with respect to ground. Filament voltages are measured across the filament of each tube. Voltage readings are taken with a vacuum tube voltmeter, with the digital voltmeter in a balanced condition. Resistances are in ohms if not otherwise designated.

TABLE 4-2

TUBE SOCKET VOLTAGES AND RESISTANCES

TUBE	PIN 1	PIN 2	PIN 3	PIN 4	PIN 5	PIN 6	PIN 7	PIN 8
V2	+160	0	+1.7	6.3V ac	6.3V ac	+135	0	+1.7
	INF.	INF.	210K	0-100*	0-100*	INF.	INF.	210K
V3	+165	0	+1.65	6.3V ac	6.3V ac	+150	0	+1.65
	INF.	4.7M	205K	0-100*	0-100*	INF.	0	205K
V4	+150	0	+1.55	6.3V ac	6.3V ac	+140	0	+1.55
	INF.	4.7M	305K	0-100*	0-100*	INF.	0	305K
V5	-7	0	6.3V ac	6.3V ac	0	165V ac	-	-
	2M	26K	0-100*	0-100*	26K	20	-	-
V6	-7	0	6.3V ac	6.3V ac	0	165V ac	-	-
	2M	26K	0-100*	0-100*	26K	20	-	-
V9	-50	-	6.3V ac	6.3V ac	-	165V ac	-	-
	2M	100	100	100	100	20**	100	-
V10	-50	-	6.3V ac	6.3V ac	-	165V ac	-	-
	2M	100	100	100	100	20**	100	-

*Varies from 0 to 100 ohms depending upon setting of hum control R35.
**Reading taken with pins 3 and 8 of K3 jumpered.

4-17. TROUBLE SHOOTING CHART. Table 4-3 is a trouble shooting chart to indicate the troubles most commonly encountered and their causes. It is intended to serve as a guide to the technician who has studied the theory section but who lacks practical experience with the equipment.

TABLE 4-3

TROUBLE SHOOTING CHART

TROUBLE	PROBABLE CAUSE	REMEDY
Entire visual readout fails to light up.	POWER switch in off position.	Turn on POWER switch.
	No 110V ac line voltage.	Trace line failure.
	Power cable defective.	Repair or replace cable.
	Fuse blown.	Replace fuse.
	No 6.3V ac.	Check for 6.3V ac at various points.
Some characters in the visual readout display fail to light up.	Defective readout indicator lamp.	Replace lamp.
	No 6.3V ac available at center contact of lamp.	Trace 6.3V ac line through the associated stepping switch.
Unstable display in 1st decade readout window.	Amplifier gain too high.	Adjust amplifier gain as described in paragraph 4-2.
	Excessive ripple on unknown d-c input voltage.	Provide suitable filter between unknown voltage source and digital voltmeter leads.
	Stray noise voltage being picked up.	Connect chassis of digital voltmeter to good earth ground. Reverse 110-volt ac power plug.
	Microphonic 5751 1st amplifier tube.	Replace 5751 tube.
	Unstable 5696 thyratrons in power supply.	Replace 5696 tubes.
	Faulty reference battery connections.	Check and clean connections; clean batteries with contact cleaner or fine abrasive cloth.
	Decade 1 stepping switch contacts making intermittent contact.	Check contacts for proper tension (compare with others). Clean contacts with contact cleaner and lubricate in accordance with Table 4-2.

TABLE 4-3. (Continued)

TROUBLE	PROBABLE CAUSE	REMEDY
Readout display will not increase.	No error signal.	Replace chopper.
		Make point-to-point check of amplifier with oscilloscope.
	"Up" pulses missing.	Check range output voltage line from switch S8 to pin 4 of chopper.
		Replace V6 of amplifier and V10 of power supply.
		Replace defective neon tube V8.
		Check feedback voltage line from decade 1 switch to pin 2 of chopper.
	Low line voltage. (Less than 105V ac)	Remedy cause of low line voltage or employ a Variac.
Readout display will not decrease.	No error signal.	Replace chopper.
		Make point-to-point check of amplifier with oscilloscope.
	Low line voltage.	Correct cause of low line voltage.
	"Down" pulses missing.	Check feedback voltage line from decade 1 switch to pin 2 of chopper.
		Replace V5 of amplifier and V9 of power supply.
		Replace defective neon tube V7.
		Check range output voltage line from switch S8 to pin 4 of chopper.
Readout display will not increase or decrease.	Printer receptacle plug P7 not installed.	Insert plug P7 into its receptacle.
	Low line voltage.	Correct cause of low line voltage.
Readout display decreases in steps of more than 2 millivolts when input voltage is decreased very slowly.	Low amplifier gain.	Adjust amplifier gain as described in paragraph 4-2.
		Check amplifier tubes and replace any found to be weak or defective.
Visual readout display increases and stays at 999.9 volts when input voltage is less.	Feedback voltage missing at pin 4 of chopper.	Replace reference battery.
		Re-establish continuity of reference voltage circuit.
	Defective chopper.	Replace chopper.

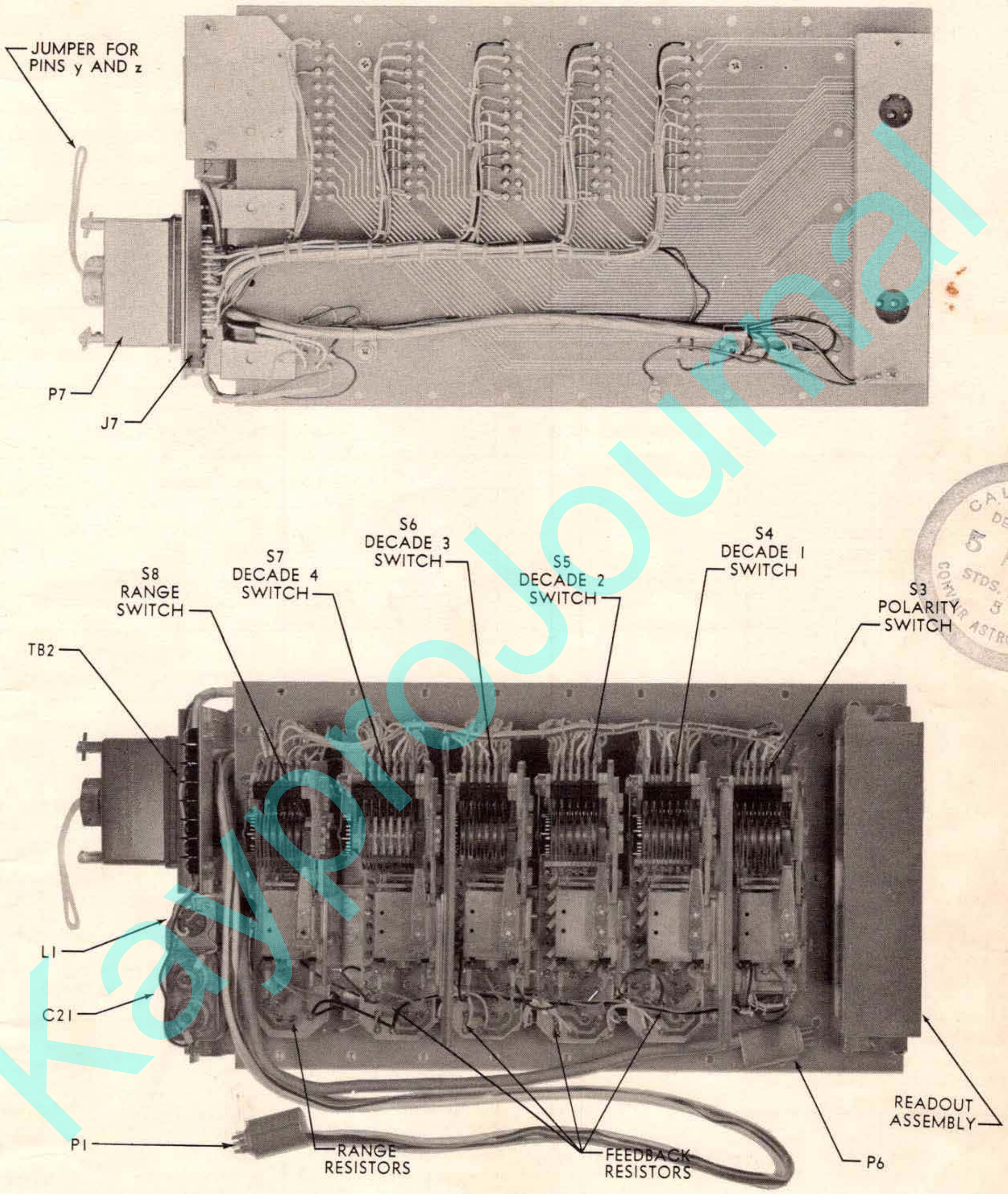
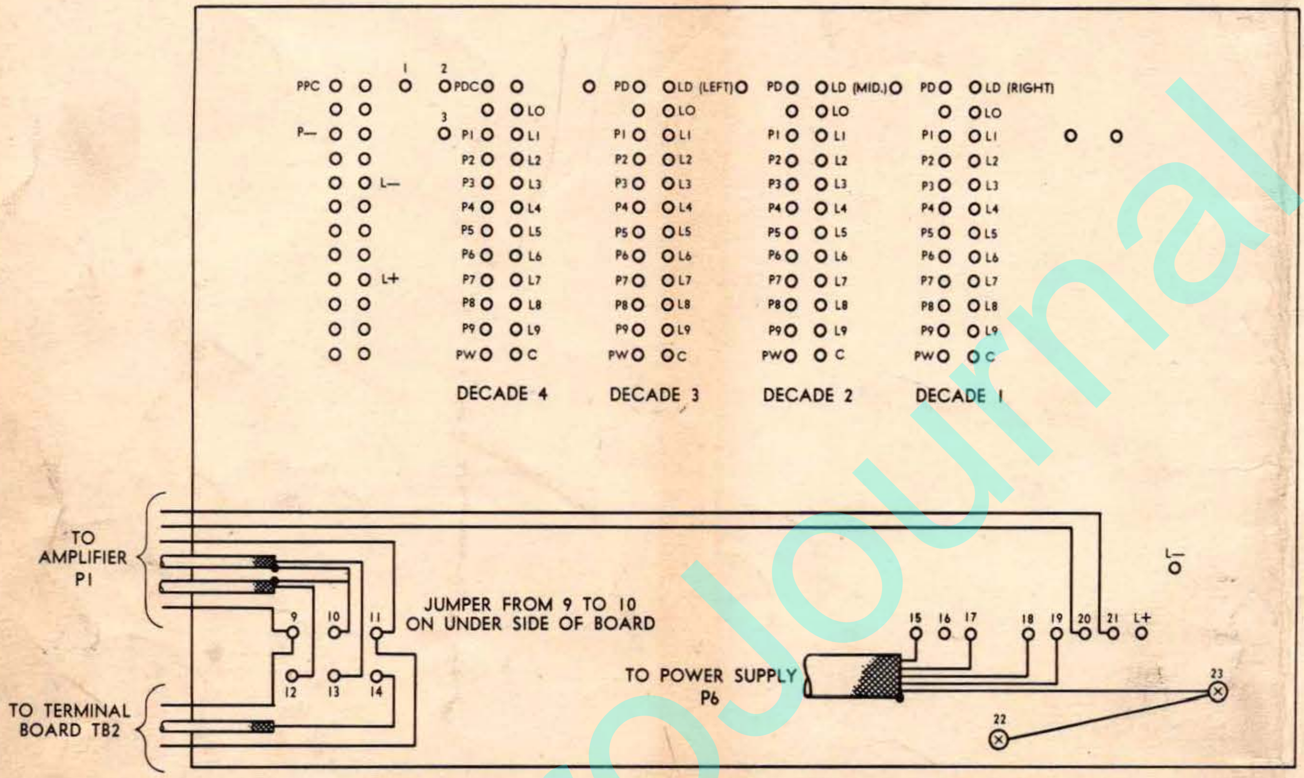


Figure 4-4. Stepping Switch Assembly, Top and Bottom Views

NOTE: HARNESS OF WIRES FROM STEPPING SWITCH BOARD TO RECEPTACLE J7 NOT SHOWN. SEE FIGURE 4-6 FOR SCHEMATIC



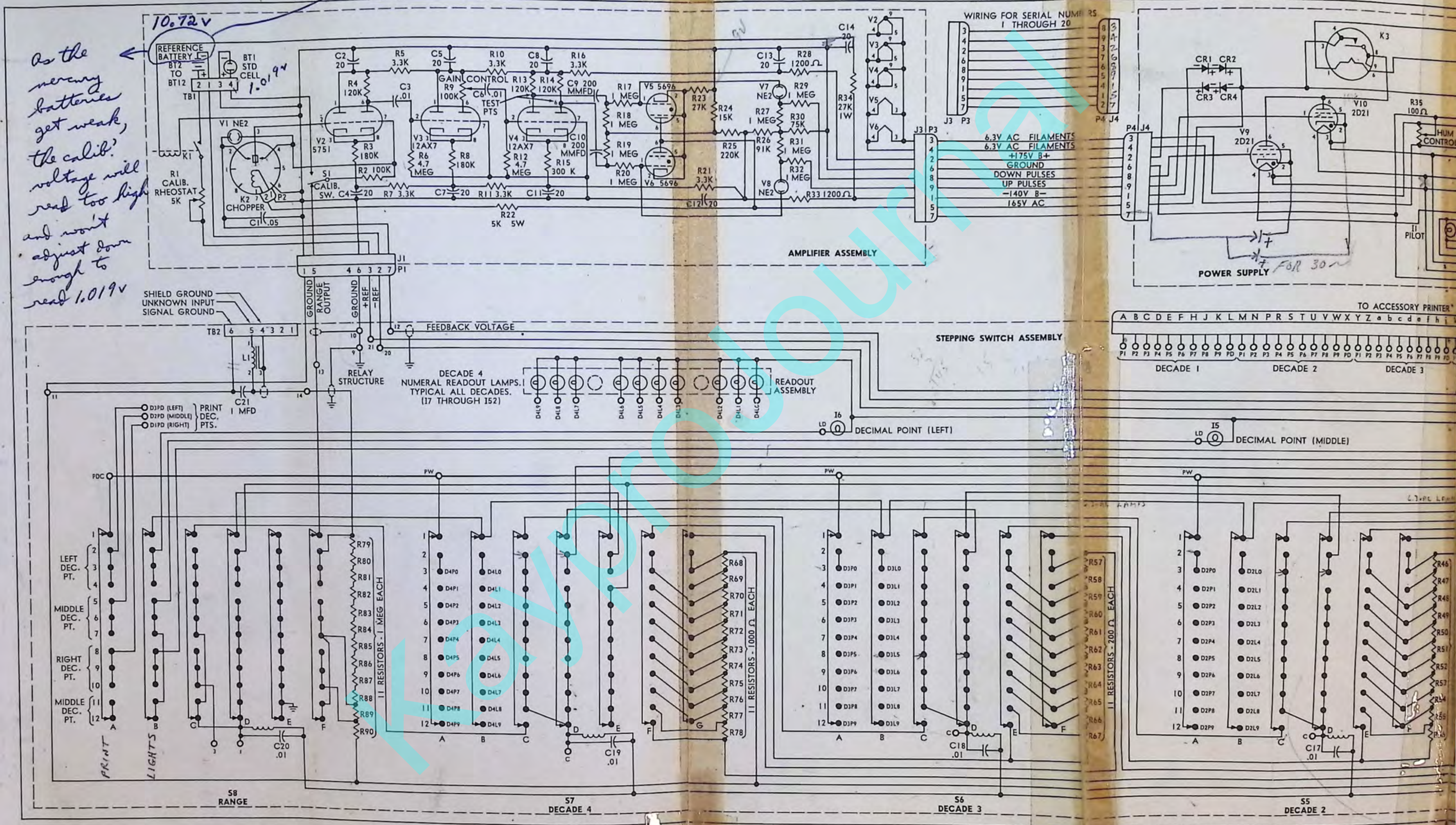
CODE	CONNECTS WITH	CODE	CONNECTS WITH	CODE	CONNECTS WITH
C	COIL OF CORRESPONDING DECADE	1	RANGE COIL	13	RANGE OUTPUT
LO, L1 ·· L9	CORRESPONDING NUMERAL LAMP IN READOUT	2	POLARITY COIL	14	RANGE INPUT
L+	+LAMP	3	PULSE OUT	15	PWR. GND.
L—	—LAMP	9	SHIELD GROUND		
LD	DEC. PT. LAMP OF CORRESPONDING DECADE	10	SWITCH SHIELD GROUND	16	COIL COMMON
P1 ·· P9	CORRESPONDING NUMERAL IN PRINT DEVICE	11	SIGNAL GND	17	6.3 V AC
P—	PRINT —	12	FEEDBACK	18	DOWN PULSE IN
PD	PRINT DEC. PT. OF CORRESPONDING DECADE			19	UP PULSE IN
PPC	PRINT POLARITY COMMON			20	—REFERENCE
PDC	PRINT DECIMAL COMMON			21	+REFERENCE
PW	PRINT WIPER OF CORRESPONDING DECADE			22	CHASSIS GROUND
				23	LIGHTS COMMON

Figure 4-5. Stepping Switch Mounting Board, Wiring Code

To use 451 without converter
Jumper pins P & R
" U.M. & N.
" L.E. & F.

8 mercury cells
at 1.34v each

516582



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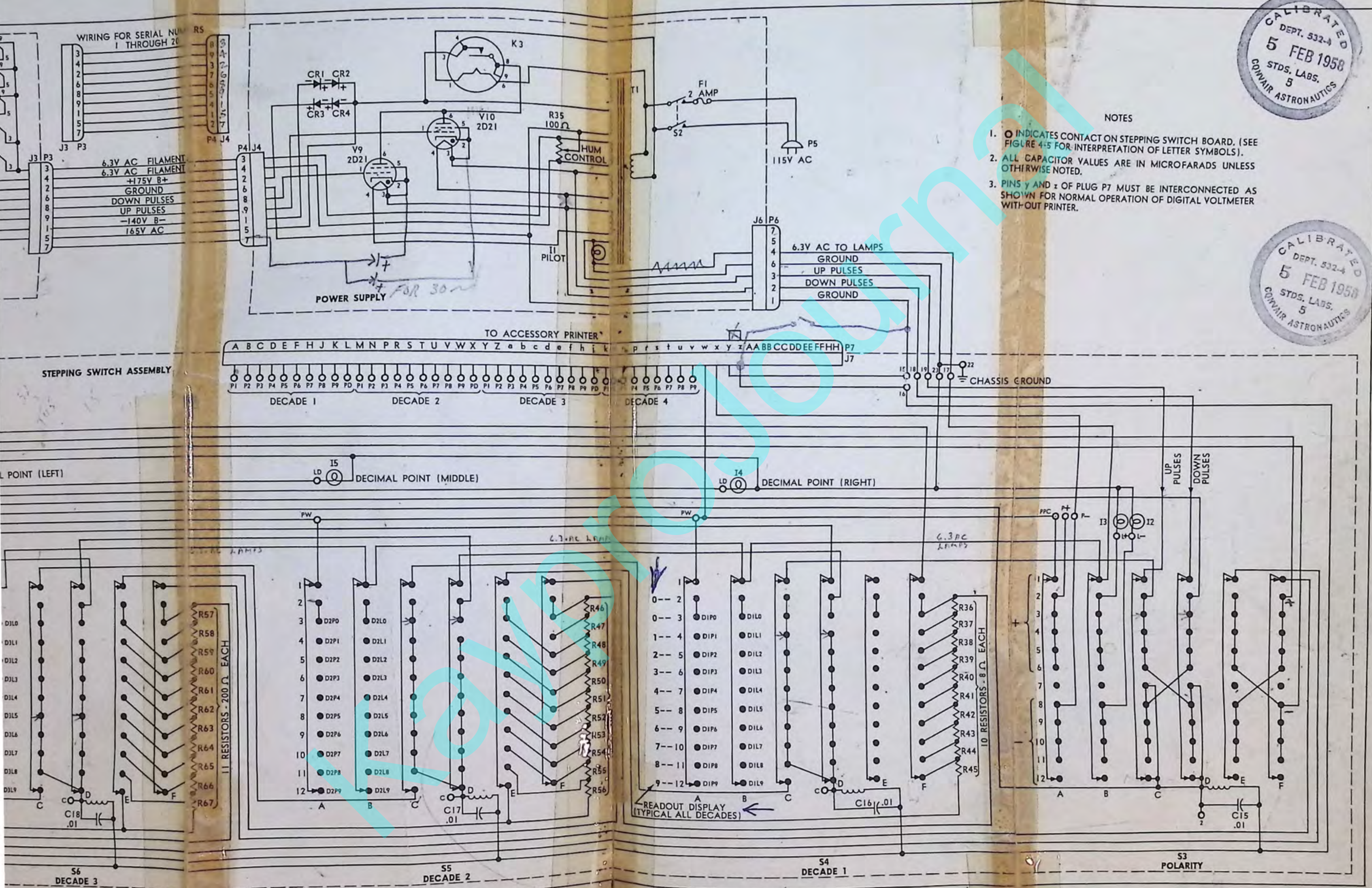

NOTES

1. O INDICATES CONTACT ON STEPPING SWITCH BOARD. (SEE FIGURE 4-5 FOR INTERPRETATION OF LETTER SYMBOLS).
2. ALL CAPACITOR VALUES ARE IN MICROFARADS UNLESS OTHERWISE NOTED.
3. PINS y AND z OF PLUG P7 MUST BE INTERCONNECTED AS SHOWN FOR NORMAL OPERATION OF DIGITAL VOLTMETER WITHOUT PRINTER.

Figure 4-6.
Model 451 Digital Voltmeter, Schematic Diagram

DATA

Interim Operation Instructions
Digital Voltmeter, Stepping Switch Model
Non-Linear Systems, Inc.

April 1956

Interim Operation Instructions
Digital Voltmeter, Stepping Switch Model
Non-Linear Systems, Inc.
Del Mar Airport
Del Mar, California

INTRODUCTION Digital Voltmeters manufactured by Non-Linear Systems, Inc., are designed for rapid and accurate measurement of a wide range of direct current voltages. These interim instructions are to aid users of this equipment prior to the completion of the Operation and Service Manual.

INSTALLATION The Digital Voltmeter is designed for bench-top or rack-mounting installation. In either case, it should be placed for most convenient viewing of the visual readout. The sensitivity and high input impedance of the instrument makes it desirable to use short shielded leads for the direct current input voltage to avoid stray pick-up. Although adequate shielding has been provided in the design of the instrument, operation in strong fields such as are found near transmitters and other high voltage sources may introduce spurious changes in readout indication.

Electrostatic pickup may be minimized by use of shielded input lines and with a good electrical ground on the chassis of the instrument. Sometimes reinserting the 115 volt alternating current power plug into the outlet receptacle in a position rotated 180 degrees from its previous position is helpful in reducing effects of stray pickup.

Our more recent instruments feature a special oil bath to constantly lubricate the stepping switches, thereby extending their trouble free life by a factor of at least 5. It is important that the instrument be kept level while operating to insure that all switches will be constantly lubricated. Where installation into sloping panels is required, it is recommended that only a remote readout be installed on the sloping panel and electrically connected to the digital voltmeter which may then be installed in a location where it may be kept level.

Contact the factory for further information on such installation.

CONNECTING THE INSTRUMENT

PRIMARY POWER SOURCE The Digital Voltmeter is designed to operate from a 60 cycle 115±10 volt alternating current line. The instrument is fused using an externally accessible, 2 AMP, type 3AG Littlefuse.

VOLTAGE TO BE MEASURED To obtain access to the input terminals, remove the small metal cover plate on the back of the instrument. Connect the input voltage to the Jones strip input terminals as follows:

Terminal 4, Shield ground
Terminal 5, Unknown input ("Positive")
Terminal 6, Signal Ground ("Negative")

Observe shielding instructions in the paragraph headed INSTALLATION. In areas where large amounts of electromagnetic radiation are prevalent it may be helpful to use twisted shielded test leads when measuring voltages from high impedance sources. However, the LC filter incorporated into the instrument rejects a large amount of normal pick-up and also serves to attenuate ripple present in the direct current voltage under measurement.

STARTING THE INSTRUMENT After connecting the power cord to a 60 cycle 115±10 volt source, turn on the power switch. Observe that the red "Power" pilot lamp lights, The pilot lamp is being eliminated from later models. Allow approximately 1 minute warm-up time. The instrument is now ready for calibration against the standard cells included in some models.

CALIBRATION Some models of the Digital Voltmeter contain standard cells. The simple procedure outlined below standardizes the instrument against these excellent voltage references, making high accuracy voltage measurements possible. The calibration procedure should be performed after the initial 1 minute warm-up following application of primary power, occasionally during long periods of use, and will assure high accuracy if performed just prior to making measurements of a critical nature.

1. Depress the Calibrate switch on the front panel.

2. Observe a reading of 1018 if your model contains one standard cell and 9167 if it contains nine standard cells.

3. Should the reading be other than listed above, continue to hold the calibrate switch in the depressed position and adjust the Calibrate control until the proper reading is achieved.

The Calibrate control is accessible for screwdriver adjustment through a hole in the front panel adjacent to the Calibrate switch. In rack mount models the hole is covered by a knurled screw which must first be removed.

NOTES: (a) Since the instrument's automatic decimal point locating range decade attenuator is not connected when the Calibrate switch is depressed, the decimal point will remain wherever it happened to be during the last reading. This does not affect the Calibration in any way.

(b) The e.m.f. of each standard cell has been certified to be within ±0.01% of 1.01859 volts absolute at 20° C. The e.m.f. at various temperatures is as follows:

Temp °C	10	15	20	25	30	35	40
E.M.F. Vabs	1.01889	887	859	836	810	780	748

Standard cell e.m.f. is somewhat affected when it is shaken. Normally this causes no trouble in instruments of 0.1% accuracy. When using instruments of 0.01% accuracy to their accuracy limit, it is advisable not to move the instrument from one location to another for 20 minutes prior to such use. After severe motion, such as that encountered during shipment, longer periods are advisable.

CONNECTION OF EXTERNAL REFERENCE VOLTAGE ON MODELS REQUIRING SAME

Such models are most generally used in conjunction with analog computers where it is desired to use a ground referenced, positive and negative, direct current voltage from the computer as the Digital Voltmeter's reference source. This external source replaces the reference batteries incorporated into other models of the Digital Voltmeter to energize the Digital Voltmeter's "Digital Voltage Divider". In computer application a reference voltage of plus and minus 100 volts is most commonly used. The reference voltage is connected to the same input connector (Jones strip) as is the unknown input voltage. See paragraph headed CONNECTING THE INSTRUMENT. Connect the external reference voltage as follows:

Terminal 1 - Positive
Terminal 2 - Negative
Terminal 3 - Ground

Improper connection can result in short circuits, or readout display of all 9's or all 0's. Excessive ripple on the reference voltage can result in erratic readings on the Digital Voltmeter.

ADJUSTMENTS The Digital Voltmeter contains three adjustments:

1. CALIBRATION: Refer to paragraph with this main heading.

2. AMPLIFIER GAIN: This has been properly adjusted at the factory. In some cases, however, changes in amplifier components with time may necessitate readjustment. The amplifier gain control potentiometer is located on the amplifier chassis and is accessible when the outer case is removed.

For best operation, the Digital Voltmeter should be operated at an amplifier gain setting of 1 millivolt. When amplifier gain is not high enough, the visual readout display will not respond to input voltage changes of 1 millivolt. Excessively high amplifier gain may cause instability in the readout window associated with the first decade. The following procedure should be followed when adjusting amplifier gain:

a. Maintain closure of the Calibrate switch and observe a readout display in the general range of 1018 or 9167.

b. Slowly turn the slotted calibration rheostat shaft, which is accessible from the front panel, in a counter-clockwise direction. Observe the magnitude of the decrease in readout display. If the readout display decreases in steps of 1 millivolt and no instability is encountered in the readout window associated with the first decade, no adjustment of amplifier gain should be made.

c. If slowly rotating the calibration rheostat shaft counter-clockwise results in a decrease of 2 or more millivolts in the readout display, the amplifier gain should be increased by turning the slotted gain control potentiometer shaft a small amount in the clockwise direction. Recheck the amount of readout display dropoff and repeat amplifier gain adjustment if necessary. In general, the gain is set properly when the amplifier gain control shaft is positioned approximately midway between the stops.

d. If instability develops in the readout window associated with the first decade, turn the gain control counter-clockwise until instability disappears, and the readout display decreases in steps of 1 millivolt as the calibration rheostat shaft is turned slowly counter-clockwise.

e. Adjust the calibration rheostat shaft until the readout display is as in step (a).

f. Momentarily operate the Calibrate switch. The gain and calibration settings have been properly made and the Digital Voltmeter is now ready for use.

3. HUM CONTROL: This has been properly adjusted at the factory, and should require no further adjustment. The hum control potentiometer is provided on the power supply chassis to aid in preventing stray pick-up and ripple originating outside the instrument from affecting the amplifier.

To set the hum control properly, proceed as follows:

a. Provide an input voltage for the instrument. Set the input voltage to obtain middle decimal point position on 4 digit models and right most decimal position on 5 digit models.

b. Connect an oscilloscope between amplifier ground and either plate (pin 1 or 6) of the last 12AX7 voltage amplifier. The latter are available as test points consisting of short, solid wires protruding upward beside the last 12AX7.

c. Observe the waveform shown in Figure 3.

d. Adjust the hum control to obtain as square a waveform as possible. This is the condition for most effective hum control positioning, A perfectly square waveform is not possible to achieve.

e. Adjustment is now proper and need not be changed again unless the stray pickup at the test site changes considerably.

NOTE: Fresh batteries only should be used as an input source for the Digital Voltmeter when adjusting hum control. When weak or high internal impedance batteries are used, the numerical readout will drift as the input filter capacitor charges and as the battery recuperates slowly from initial connection to the Digital Voltmeter filter.

RATE OF FOLLOWING The Digital Voltmeter is designed only for measuring direct current voltages. At the chopper, a difference of one millivolt between the unknown input and feedback voltage will cause the stepping switch coils to become energized. The Digital Voltmeter will faithfully follow an increase in unknown input voltage if the rate of change does not exceed 1 millivolt at the chopper in 1/60 second. Because unidirectional stepping switches are used it will follow decreasing voltages only if the rate of change does not exceed 1 millivolt in 11/60 seconds, By "following" is meant achieving a temporary, but detectable and accurate, balance.

DRIFT IN VOLTMETER READING, AND NOISE PROBLEMS Drifting readings are sometimes experienced and are often traceable to the method of using the Digital Voltmeter. The following information is given:

1. If voltages from an electro-chemical source are being measured such voltages often actually drift, although such is normally not noticed on non-digital, low sensitivity instruments. If a 45 volt, carbon-zinc, "B" battery is connected to the digital voltmeter the reading will often increase slowly in the last decade for 5 to 10 seconds. What occurs here is that the battery is charging the filter capacitor incorporated into the Digital Voltmeter input. Initial connection of the battery causes the battery's voltage to drop sharply, then rise slowly as it recuperates and also as the filter capacitor charges from the high internal impedance battery. This is particularly true of old batteries. Removal of the filter capacitor may be attempted, but often leads to noise problems caused by pick up and ripple in direct current sources other than batteries.

2. The Digital Voltmeter's reference battery (mercury cells) require a period of time to stabilize after the instrument is turned on. During this time it is necessary to calibrate the instrument against the standard cell periodically if great accuracy is required. However, the reference battery's changes are relatively slow and do not cause large impredictable errors.

> Some of our later models contain absolute direct current electronic power supplies referenced against the standard cell. This replaces the mercury cell reference battery and completely does away with the calibration procedure listed herein. Digital Voltmeters can be modified to include this feature at a nominal cost.

3. Drift and noise problems are often traceable to radiated pick-up and circulating currents in test cabling external to the Digital Voltmeter, and also to ripple present in the unknown input voltage source.

4. The Digital Voltmeter's reaction to noise is a function of noise frequency spectrum and noise phase angle relative to the 60 cycle line.

PRINTER CONNECTION Circuitry required for connecting a data printer is incorporated into the Digital Voltmeter. This greatly enhances the instrument's versatility by furnishing permanently printed records of voltages measured by the instrument without interfering with the instrument's visual readout. Further versatility is achieved with the AUTOMATIC PRINT CONTROL SELECTOR, also manufactured by Non-Linear systems, which permits either manual or automatic, unattended, cyclical printing of voltage data from the Digital Voltmeter. Complete systems including

Digital Voltmeter, automatic print control selector, data printer (either Clary Digital Recording Machine or electric typewriter) and all necessary cables are also available. Also, the print control can functiom to feed an IBM Summary Punch. The Digital Voltmeter's printer output is of the "parallel entry" type. That is, a wire is brought out for each step (1 to 9) of each decade, and one wire from each decade (corresponding to the number displayed on the Digital Voltmeter's visual readout for that decade) is energized simultaneously along with one wire from all other decades.

To connect a parallel entry type data printer when an automatic print control selector is not used, proceed as follows:

1. Remove the jumper soldered between terminals 15 and 16 of the stepping switch unit printed circuit board. This removes the ground return from all stepping switch coils.

2. Provide a single pole single throw switch and wire it to pins FF and HH of the printer connector found on the rear of the Digital Voltmeter. This switch, when closed, now replaces the soldered jumper removed in step (1) above. When the Digital Voltmeter has balanced, and a print out is desired, this switch should be opened, thereby preventing stepping switch operation (and therefore a change in reading) during the data printer's print cycle. This switch must be closed again to permit the Digital Voltmeter to rebalance.

3. Connect printer connector pins L, X, J and w to the power required by the data printer's "numerical print" solenoids.

4. Connect printer connector wires labeled P1 through P9 (see Digital Voltmeter schematic for printer connector pin numbers) for each decade to the corresponding "numerical print" solenoids in the data printer.

5. Connect printer connector pins DD and AA to the power source required by the data printer's "decimal print" and "polarity print" solenoids, respectively.

6. Connect printer connector pins BB and CC to the data printer's "polarity print" solenoids (BB is for a "polarity positive" print, and CC for "polarity negative").

7. Connect printer connector pins x,y, and z to the data printer's "decimal print" solenoids. Pin x is for decimal point in the right most position, pin y for decimal point in middle, and pin z for decimal point to the left.

8. Connect printer connector pin EE to the data printer "zero numerical print" leads. This enables printer to print zero if digital voltmeter displays a zero in any decade, and causes a blank to occur on the printers record if any data is missing.

NOTE: Special wiring of the printer connector has been provided on various models for some customers. Check the verbal instructions given above against the wiring schematic for your particular instrument before proceeding with printer wiring.

THEORY OF OPERATION The Digital Voltmeter is an automatic potentiometer which generates a "feedback voltage" proportional to the unknown input voltage which we wish to measure. Any error existing between the feedback voltage and input voltage drives what we might call a digital positioner to adjust a voltage divider to bring the error to zero. When zero error is achieved, the Digital Voltmeter is "balanced", and the unknown voltage may quickly be read on the Digital Voltmeter's visual readout. Figure 1 shows a simplified diagram of such a system.

Figure 2 shows the actual system in more detail. The standard cell, automatic range decade attenuator, automatic polarity reversing switch and reference battery are not present in all models. The voltage divider is shown as a potentiometer for simplicity but is actually a Kelvin-Varley voltage divider composed of precision, fixed, wire wound resistors. From figure 2 it may be seen that the maximum feedback voltage is 10 volts in models containing internal reference batteries, while the unknown input voltage can be much greater. A range decade attenuator is, therefore, employed to permit achieving an equality of input voltage and feedback voltage at the chopper, which condition is called "balanced". The unknown voltage and feedback voltage are alternately sampled by the chopper, which is synchronized with the 60 cycle line voltage, and impressed across the error amplifier. Thus, the error amplifier input is a square wave whose amplitude is proportional to the difference between the unknown and feedback voltages, and whose phase is either 0 or 180 degrees with respect to the 60 cycle line depending upon whether the feedback voltage is greater than or less than the unknown voltage at the chopper. See figure 3.If the difference between the unknown voltage and the feedback voltage at the chopper exceeds 1 millivolt, an amplifier output appears as pulses on either of two wires. If the feedback voltage is higher than the unknown voltage at the chopper, pulses appear on one wire only. We call these " down pulses". If the opposite condition prevails at the chopper, pulses appear on the other wire only. We call these "up pulses". These pulses are fed through contacts on the stepping switches in the range, polarity and voltage divider decades, and then through the coils of the stepping switches one at a time in a logical sequence which causes the digital voltmeter to balance. If balance is not achieved by switching resistors in and out of the voltage divider, the switching logic causes actuation of the polarity switch and/or range attenuator switch to cause balance. Additional contacts on the stepping switches are employed to energize the visual readout and data printer leads.

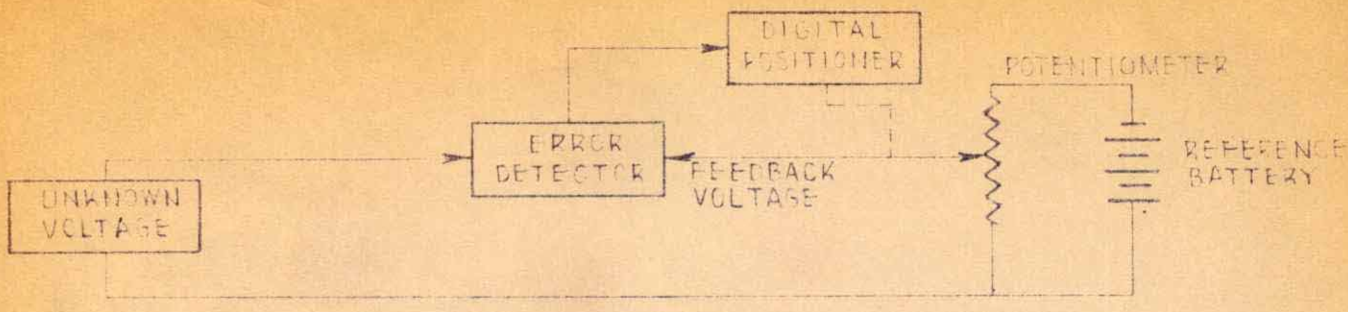

FIGURE 1 SIMPLIFIED DIAGRAM OF DIGITAL VOLTMETER

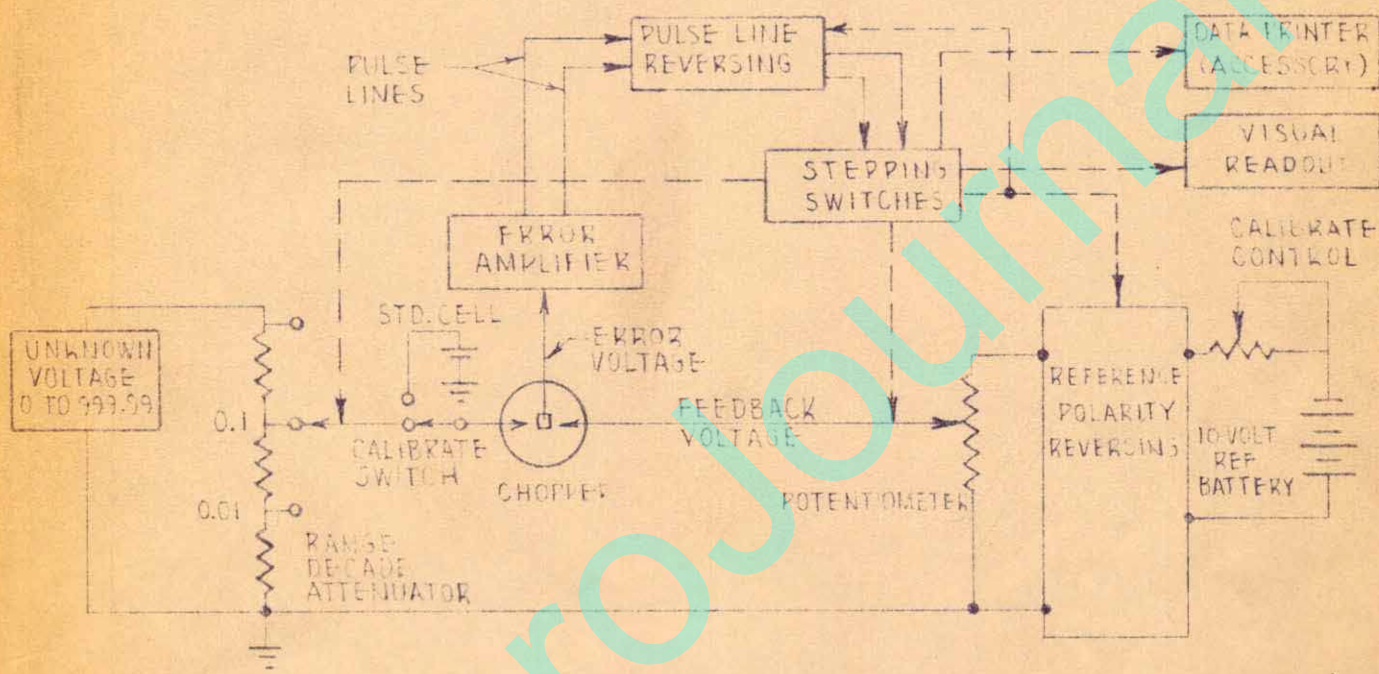

FIGURE 2. FUNCTIONAL DIAGRAM OF DIGITAL VOLTMETER

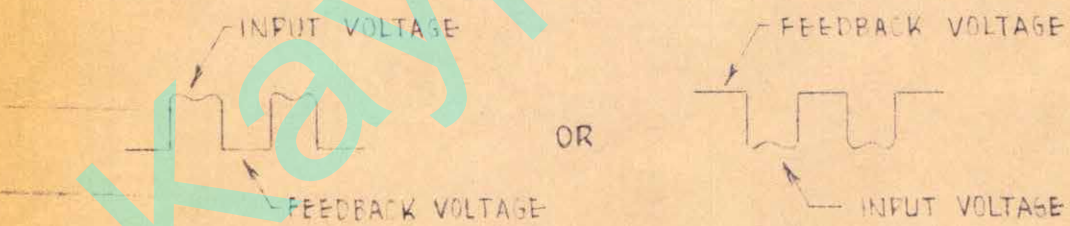

FIGURE 3. AMPLIFIER WAVEFORM ON PLATES OF LAST 12AX7 TUBE.