instruction manual

MODEL 481

INDUSTRIAL VOLTMETER

NLS

non-linear systems, inc.
SAN DIEGO COUNTY AIRPORT,
DEL MAR, CALIFORNIA

Warranty

Non-Linear Systems, Inc. warrants each instrument of its manufacture to be free from defects in material and workmanship. Our obligation under this Warranty is limited to servicing or adjusting any instrument returned to our factory for that purpose, and to making good at our factory any part or parts thereof except tubes, stepping switches, choppers, fuses or batteries which shall, within one year after making delivery to the original purchaser, be returned to us with transportation charges prepaid, and which on our examination shall disclose to our satisfaction to have been thus defective. Stepping switches are warranted for ninety days provided switches have been lubricated in accordance with manufacturer's instructions.

Instruments returned under this warranty will not be accepted at NLS plant without prior authorization by a Non-Linear Systems, Inc. representative or by the Service Manager, Non-Linear Systems, Inc.

Non-Linear Systems, Inc. reserves the right to make changes in design at any time without incurring any obligation to install same on units previously purchased.

This warranty is expressly in lieu of all other obligations or liabilities on the part of Non-Linear Systems, Inc., and Non-Linear Systems, Inc. neither assumes nor authorizes any other person to assume for them any other liability in connection with the sales of Non-Linear Systems, Inc. instruments.

481 HANDBOOK - ADDENDUM #1

CONVERTING MODEL 481 FOR MEASURING DC VOLTAGE RATIOS

The Model 481 can, with several wiring modifications, be converted to measuring DC voltage ratio over the range of .0001 to .9999.

An external reference voltage of 10 volts DC can be used in the ratio measurements. The supply can be either positive or negative (See paragraph below for qualifications to this statement). If an external reference of 5 volts is used, the effective resolution of the instrument will drop by a factor of 2. If an external reference voltage of 1 volt is used, the instruments resolution will drop by a factor of 10. Some of this decrease in resolution is sometimes avoidable by increasing amplifier gain by readjusting the internal gain control, R-20. Reference voltage higher than 10 volts can be used if the external sensitivity control knob is turned counter-clockwise.

To perform the modifications, proceed as follows:

1. Disconnect (at the amplifier board) the conductor which runs from the stepping switch assembly to the junction of R-13 and C-4; and connect the external reference voltage supply "hot" side to this conductor. Connect the reference voltage "low" side to signal ground.

2. Disconnect the wire that runs from the calibrate switch (S-1) arm to resistor R10.

3. Disconnect the wire which goes from capacitor C-1 to resistor R-5.

4. Now, connect the disconnected end of C-1 to the disconnected side of R-10. The input signal is now routed through the input filter (composed of L-1 and C-1) and then to the input of the amplifier through R-10. The range attenuator has been by-passed in this process.

5. Pull the red lead (hot side) off the coil of stepping switch K-5 (polarity and range switch), and insulate the lead.

6. If external reference voltage "hot" side is positive with respect to digital voltmeter ground, then manually step K-5 to the +10 volt range. If the external reference voltage "hot" side is negative with respect to the digital voltmeter ground, then step K-5 to the -10 volt range position. Be certain you haven't positioned K-5 to the "cross-over" position, wherein the zener supply is floating.

7. Digital voltmeter signal ground and digital voltmeter reference side ground and digital voltmeter chassis ground are all common, and short circuiting of the external reference source can occur or digital voltmeter printed wiring can burn out if proper external connections are not made.

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SECTION I

SPECIFICATIONS

MODEL 481

1. TYPE OF INPUT SIGNAL MEASURED: Absolute DC voltage.
2. NUMBER OF DIGITS DISPLAYED: 4
3. REFERENCE VOLTAGE: Internal, temperature compensated, zener diode type DC power supply with zener diode mounted in an oven.
4. STANDARDIZATION: Manual.
5. VOLTAGE RANGE, DC VOLTS: ± 9.999/99.99/999.9
6. RANGE CHANGING: Automatic.
7. POLARITY INDICATION: Automatic.
8. ACCURACY: LINEARITY: ± 0.01% of full scale.
   SCALE FACTOR ACCURACY: ± 0.01% of reading.
   STANDARDIZATION: ± 0.01% of reading + standard cell accuracy.
   STANDARD CELL ACCURACY: ± 0.01% of reading.
9. RESOLUTION: 1 digit.
10. AVERAGE BALANCING TIME: 1.0 seconds
11. INPUT IMPEDANCE: 10 megohms.
12. PRIMARY POWER: 115 volts, 60 cps, approximately 50 volt-amps.

SECTION II

GENERAL INFORMATION

2-1 DESCRIPTION.

A. GENERAL: The NLS digital voltmeter Model 481 measures voltages rapidly and with a high degree of accuracy, and presents the measured value directly in numerical form on a self-illuminated digital readout. Digital voltmeters are, essentially, self-balancing potentiometers. Range changing and polarity indication are automatic, and decimal point and polarity sign are automatically displayed. This instrument is useful as a general purpose laboratory, production, and field test instrument, and is adaptable for use as a component of larger testing systems. The advantages of the digital voltmeter are:

*** High Speed.

*** Its accuracy approaches that of laboratory type equipment while its ruggedness permits use under conditions in which most laboratory type equipment would not operate.

*** Wide measuring range.

*** Numerical readings and automatic range changing and polarity indication features permit error free readings even with untrained personnel, and prevent instrument burn-out which results in other types of instruments when the range switch is ignored.

*** High input impedance at balance minimizes loading of the circuit being measured.

*** High resolution.

B. CONSTRUCTION: Maximum use is made of etched copper circuitry on epoxy fiberglass board for uniformity of product. Maintenance is greatly enhanced by ready accessibility of all components. All connections to the stepping switches are made with AMP taper tabs for easy removal.

C. STEPPING SWITCH OPERATED CIRCUITS: The precision wire-wound resistors are mounted on solder plated etched circuits on high quality epoxy-fiberglass boards; and are connected to the stepping switches by a wiring harness which connects to the stepping switches by means of AMP tabs. This construction eliminates the need for touching a hot soldering iron to the resistors once they have been soldered into the circuit at the factory; thereby ensuring maintained accuracy after long use and maintenance operations, if any, on the switches themselves. The AMP taper tabs are easily removed and replaced while supplying adequate electrical connections (their use has been approved by the armed services), and are, in this application, more reliable than soldered connections. The resistors themselves are annealed after winding, molded into epoxy resin, and then subjected to multiple hot and cold cycling to ensure long-term stability. Loosening two bolts permits folding any stepping switch sub-assembly up and out to afford easy access to all wiring.

D. STEPPING SWITCHES: The stepping switches were designed for this specific application after extensive tests by NLS and the manufacturer. The unusual digital logic designed by NLS eliminates the need for off-normal and interrupter contacts on the stepping switches. This is very important since such contacts require periodic adjustment, fail during use, and shorten the life of the thyratrons which drive the stepping switch coil since the added friction and spring forces demand more stepping switch coil current.

The stepping switches used have the following features:

*** Extremely sturdy driving pawl and tool steel ratchet prevents fatigue failure and reduces wear.

*** Each deck on the switch is a molded assembly to keep contacts in permanent alignment. Each individual deck can be easily replaced if necessary.

*** Diallyl phthalate insulation is used to ensure extremely high and constant electrical leakage resistance.

*** Molded coil bobbin construction is used to insure complete rigidity and long insulation life.

*** The exceptionally rugged armature return stop cannot wear out during life of the switch.

*** These switches can be adjusted with ordinary socket wrenches.

SECTION III

OPERATING INSTRUCTIONS

3-1 PRIMARY POWER: The Model 481 digital voltmeter is designed to operate from 105 to 125 or 210 to 250 volts 60 cps power sources. Primary power requirements for this instrument are satisfied by most nominal 115 or 230 volt cps power lines. However, adverse operation of digital measuring equipment, as well as many other types of electronic equipment, can be caused by abnormal power line characteristics, such as low or high voltage; large transient changes; large amount of amplitude modulation; high voltage "spikes" generated by some types of welding equipment, and thyratron controlled machine tools, etc.; and large amounts of harmonic distortion, particularly third harmonic. The outputs of many types of line voltage regulators are very rich in third harmonic content. This can cause unstable operation and apparent loss of resolution in the digital instrument. Operation from such voltage regulators is, therefore, not recommended.

3-2 FRONT PANEL CONTROLS

A. PRIMARY POWER: Primary power is turned on by the front panel power switch. This switch also has a STANDBY position to permit keeping the instrument warmed up but the stepping switches turned off to reduce needless operation of the stepping switches. It also permits "locking" the reading at any point in time. After turning the power switch on, there is an operation delay of 15 to 30 seconds, controlled by a thermal timer, to keep the thyratron plate power off until filaments have become heated.

B. CALIBRATE: The instrument will require occasional standardization. The calibrate adjust control may be reached by removing the right hand protective cap on the panel. The standardization procedure is as follows:

1. Check that the sensitivity control is advanced full clockwise.

2. Check that the gain of the instrument is properly set. To accomplish this, hold the calibrate switch in the calibrate position and slowly back off on the calibrate adjust control, stopping each time the meter changes reading. The meter should drop one digit each time. If the reading drops more than one digit, or exhibits instability, adjustment of the internal gain control is necessary. Consult Section 5-2A for this procedure. Repeat backing off on the calibrate adjust control until ten steps have been satisfactorily completed. Once it has been ascertained that the gain adjustment is proper, the instrument may be accurately standardized.

3. While holding the calibrate switch in the calibrate position, slowly advance the calibrate adjust control until the reading just steps to "1019" and stop. The meter is now standardized.

NOTE: (1) The decimal point may appear in any location during the standardization procedure because the DC voltage range change circuitry becomes de-energized during this operation. (2) This standardizing procedure standardizes the internal reference voltage supply against a highly accurate and stable standard cell.

C. SENSITIVITY: The Model 481 digital voltmeter has a sensitivity and resolution of 1 part in 10,000 of the full scale value. If the input signal is rapidly changing more than this amount, the instrument will not give a fixed reading, but continually search for the proper reading. To enable proper operation under these conditions, a sensitivity control is provided to reduce the gain of the instrument. When measuring changing voltages slowly back off on the sensitivity control until the meter settles out on a fixed reading. This reading will be as accurate as the signal is stable. Always return the sensitivity control to the full clockwise position for proper operation with stable DC voltages.

3-3 CONNECTING THE INSTRUMENT

A. CONNECTION: Connect the red clip on the test lead to the signal "high" side, and the black clip to the signal ground.

CAUTION: The signal ground terminal (black clip) is connected to the chassis through a 2 amp fuse for protection of the printed circuitry. The chassis, in turn, may be connected to earth ground through the third wire of the power input cord. If a signal above ground is connected to the black clip, and if the chassis is connected to the power ground of the instrument being tested with the digital voltmeter, then a short circuit will occur and the fuse will blow.

B. SHIELDING AND GROUNDING: Adequate shielding and grounding are a must with high accuracy, high resolution, high input impedance instruments such as digital instruments. Personnel accustomed to making high precision measurements, particularly those in standards laboratories, are aware of the following necessities which should be observed when connecting digital instruments.

1. Shield both input leads. The lead connected to the digital instrument signal ground can act as an antenna and pick up stray noise, as can the input signal "high" side lead. The noise pick up problem increases, of course, when the impedance of the source being measured is high.

2. Ground the instrument chassis. In some locations the AC power line receptacle ground or a water pipe ground may be adequate; while in other locations a better earth ground may be required. If trouble is encountered, a measure of the potential differences between various grounds is often very revealing. Because of the effects of poor grounding with electronic equipment in general, many laboratories and test locations have a good earth ground available.

3. Always make sure that the black clip is connected to the "ground side" of the signal regardless of polarity. When measuring the voltage between two points isolated from ground, connect the black clip to the point having the lowest impedance to ground. As is true in most electronic measuring instruments energized from a power line (rather than isolated batteries) errors may result when measuring sources whose "low" side is not a ground potential.

4. Observe grounding precautions as required in most electronic instruments to prevent ground loops and their resultant bias and ripple effects.

5. Excessive electrical noise pick-up can cause one or a combination of the following: (1) Unstable readout; (2) A loss of resolution (i.e., the digital voltmeter will not respond to small changes in input signal); (3) A bias (i.e., offset) error in the readings.

   Please note that unstable readout of digital instruments can be caused by actual variation in input signal amplitude, which variations are often not detected with other types of instrumentation of lower resolution. Under such conditions, a stable reading may be achieved by backing off on the sensitivity control.

6. Where excessive electrical noise is present at the digital instrument input terminals, external filtering of the signals may prove helpful. Note that the series resistance of an external filter can cause errors because of the voltage drop across the external filter series resistance. While this is true with any type of instrument, the high resolution of digital instruments makes it more evident.

3-4 COOLING: Do not subject the instrument to operating ambient temperatures in excess of 110°F. Do not subject the standard cells to temperatures in excess of 122°F.

3-5 LEVELING: The instrument may be operated in any position.

CAUTION: Since the stepping switches are not located in an oil bath, it is essential to periodically lubricate the switches as described in Section 5-4D-2A

SECTION IV

THEORY OF OPERATION

4-1 BLOCK DIAGRAM CIRCUIT DESCRIPTION: This section presents a brief description of theory of operation. More detailed information is presented in Section 4-2, Detailed Circuit Description.

A. FUNDAMENTALS: Non-Linear Systems digital voltmeters are perhaps best described as "digital, self-balancing potentiometers," which in measuring the unknown input, set up an equal or proportional voltage. It is well, therefore, to review some principles of potentiometers. Herein the term "potentiometer" shall apply to a system composed of a variable voltage divider, a reference voltage source and null detector, employed to measure voltages by setting up a voltage equal to the input.

1. THE POTENTIOMETER PRINCIPLE: Consider the basic potentiometer circuit shown schematically in Figure 4-1. If an unknown voltage is applied, and the variable voltage divider adjusted until the voltage E_o is equal in magnitude to the unknown voltage, then zero current will flow through the galvanometer. This condition is called "balance," and no current is drawn from the input under the condition of exact balance. The unknown voltage can be computed from the formula:

$$\text{Unknown Voltage} = \frac{R_1}{R_1 + R_2} \times \text{Reference Voltage "E}$$

If the polarity of the input voltage is reversed then the reference voltage must also be reversed to obtain balance. The galvanometer pointer will now travel in an opposite direction (from previously) as the magnitude of the unknown voltage increases. It is this change in error signal sense which necessitates not only reversing the reference voltage, but also the error amplifier output lines in the digital voltmeter when input signal polarity is reversed.

2. MEASURING ABSOLUTE VOLTAGES WITH THE POTENTIOMETER: To measure the absolute value of an unknown voltage, the reference voltage must be known. Instead of accurately measuring the reference voltage directly, it can be adjusted to the proper value if an accurately known voltage is available for use as a calibration reference. In this method, a standard cell of known voltage is connected in place of the unknown voltage (See Figure 4-2), the variable voltage divider dial reading set to this known voltage, and the voltage across the variable voltage divider adjusted by means of the rheostat R_c to obtain balance. The potentiometer is now "calibrated," or "standardized," and ready for use as an absolute voltage measuring device. This

is analogous to the method employed in this digital voltmeter.

B. DIGITAL VOLTMETER BASIC PRINCIPLE: As previously mentioned, NLS stepping switch type digital voltmeters are essentially self-balancing digital potentiometers. Simplified schematics are shown in Figures 4-3 and 4-4. A stepping switch operated variable voltage divider, composed of wire wound resistors, divides a voltage, which is called the reference voltage, into a large number of precisely equal parts in the decimal number system. These particular stepping switches are called decade switches. An error amplifier compares this divided voltage, which is called the feedback voltage, with the input signal, and commands stepping switch motion in a logical sequence until the two voltages are equal within the limits of resolution of the instrument; whereupon stepping switch motion ceases, and the instrument is said to be at balance. Input to the error amplifier is through an electro-mechanical chopper. Automatic range and polarity changing features are accomplished by a combination range and polarity switch. (See Figure 4-4).

There is a basic relationship between the number of steps (assuming equal steps) in the stepping switch operated variable voltage divider, the reference voltage amplitude, and error amplifier "gain" (error amplifier gain being defined as the smallest difference between unknown input voltage and feedback voltage which will produce a pulse output from the error amplifier):

$$\text{Amplifier gain} = \frac{\text{Reference voltage amplitude}}{\text{Number of steps in variable voltage divider}}$$

Using, as an example, a four digit instrument with a 10 volt reference:

$$\text{Amplifier gain} = \frac{10}{10{,}000} = 0.001 \text{ volts.}$$

If the reference voltage is increased or decreased, the error amplifier gain must be proportionately decreased or increased, respectively, if the instrument is to be returned to normal operating conditions. If error amplifier gain or reference voltage is too high, the instrument may oscillate; and if either is too low, the resolution of the instrument will tend to decrease. However, if amplifier gain is lower than nominal, the instrument will still increase its numerical display in steps of one digit in the rightmost window of the digital readout as the input signal is slowly <u>increased</u>. But if amplifier gain is lower than nominal, the digital instrument will decrease its numerical display by "X" digits (where "X" is two times the quantity obtained by dividing actual error amplifier gain by nominal error amplifier gain) if the input signal is slowly decreased.

For example, if amplifier gain is supposed to be 0.001 volt but is actually 0.002 volts, then the displayed reading would decrease by

4 digits each time it changes (e. g. 4.959, 4.955, 4.951, etc.) if the input voltage is being slowly decreased. This is because the error amplifier is kept operating over only 0.001 volt of its null region as we slowly increase the input voltage, but the error amplifier must go from one end of its null region, through zero, and then to the opposite end of its null region each time the numerical display decreases by one digit in the rightmost window.

The sensitivity control on the panel enables the operator to reduce the gain from the nominal value so that varying signal voltages can be measured. This control should normally be in the full clockwise position.

C. REFERENCE VOLTAGE: The DC voltage impressed across the stepping switch operated Kelvin-Varley voltage divider is called the reference voltage. If absolute DC voltages are to be measured accurately, a precision DC reference voltage must be used. Unsaturated cadmium standard cells provide an extremely accurate and stable DC voltage, but are incapable of supplying the amount of current required to energize the Kelvin-Varley voltage divider. Therefore, reference voltage power supplies which use standard cells as primary references have been developed.

Matched zener diodes of equal and opposite temperature co-efficients perform the final regulation of the DC reference voltage. These diodes are located within a crystal oven which holds the temperature to within $\pm$ 1/2°C. As a result, the zener voltage is held stable to better than 1 part in 10,000 over considerable periods of time and wide ambient temperature variations. DC power is supplied to the zener diodes by a transformer-rectifier-gas reference tube-type supply. This supply is highly stable, but exhibits a long term drift which is compensated for manually by actuating the frontpanel "CALIBRATE" switch, and adjusting the front panel "CALIBRATE" control (screwdrive slotted shaft), until the displayed reading is "1019". This procedure standardizes the instrument by connecting an internal, unsaturated cadmium standard cell to the error amplifier input; the "CALIBRATE" adjustment permits changing the reference voltage supply output to the proper value using the precise emf of the standard cell as a standard voltage reference. Standardization will need to be made only once every several hours, once the equipment has warmed up.

D. ERROR AMPLIFIER: The error amplifier acts as the null detector, or balance detector, in the digital instrument. It compares the feedback voltage and unknown input (appearing at the range unit output), and issues pulses to drive the stepping switches to adjust the feedback voltage and cause the instrument to reach an electrical balance. The error amplifier is phase sensitive, and issues these pulses on its "up" pulse or "down" pulse output line depending upon the amplitude and polarity relationships between the unknown input voltage and feedback voltage (See Figure 4-5).

E. DIGITAL LOGIC, OR SWITCHING LOGIC: Digital logic, or switching logic means the pre-determined sequence of switching operations which cause the digital instrument to attain an electrical balance. This switching sequence is determined by the way of the "logic" levels on the stepping switches are connected in any one switch and between the switches. These "logic" levels are electrically isolated from all other switch levels. The inputs to the switching system logic levels are the "up" pulse and "down" pulse lines from the error amplifier. Each pulse applied to a stepping switch coil causes the switch to move one "step." Since the stepping switches are unidirectional in their motion, "up" pulses cause the switches to rotate in the same direction as "down" pulses; and the manner in which these "up" pulses and "down" pulses are routed from one stepping switch coil to another causes the switches to reach a position where the instrument is electrically balanced. A combination of "up" and "down" pulses are usually required to attain an electrical balance.

F. RANGE AND POLARITY CHANGING: Automatic range and polarity changing is accomplished with one stepping switch. One level of this switch operates the range attenuator, two levels reverse the reference voltage, and two more levels reverse the "up" and "down" pulse lines. An additional level is used to avoid a "0" in the left window when in the 1000 volt or 100 volt range; the most sensitive range is always selected because of this "interlock."

G. DIGITAL READOUT: The digital readout numerals and other symbols are engraved on plastic plates which are edge-lighted by incandescent lamps energized through an additional level on each stepping switch. These levels are electrically isolated from all other levels.

4-2 DETAILED CIRCUIT DESCRIPTION.

A. STEPPING SWITCH ASSEMBLY:

1. GENERAL: Incorporated in the stepping switch assembly are the range-polarity, and decade (feedback voltage generation) stepping switches, and the feedback voltage generating precision resistors (Kelvin-Varley circuit). Each stepping switch is mounted by two screws. Any switch may be rotated up for easy access by merely loosening these two screws. All external connections to a stepping switch are made with AMP taper taps. This allows the removal and replacement of any switch without the need of a soldering iron.

2. STEPPING SWITCHES: The switch consists of a bank of stationary contacts arranged semi-circularly, and a bank of mating rotary contacts (wipers), which are rotated by a driving mechanism. The switches are unidirectional in motion. When the driving mechanism electromagnet is energized by a sufficiently high

voltage, and armature, or clapper, is pulled toward the coil against the force of a helical spring. This same motion causes a pawl to move back one step along a ratchet mounted on the rotary contact bank shaft; this "cocks" the switch but does not advance the contacts. When the electromagnet is de-energized, the helical spring restores the armature to its original position, pushing the pawl assembly which is coupled to it. The pawl, in turn, rotates the ratchet and, therefore, advances the rotary contacts by one step.

Off normal and interrupter contacts are eliminated from stepping switches in NLS instruments because of the unique type of digital switching logic employed. Multi-level ("multi-deck") stepping switches are necessary since one set of electrically isolated contacts are used for operating the digital readout, several for the digital logic circuits, and several others for the potentiometric circuits (polarity reversal, range selection, and feedback voltage generation).

3. DEVELOPMENT OF FEEDBACK VOLTAGE: The feedback voltage is developed by a stepping switch operated Kelvin-Varley voltage divider which divides the reference voltage into a large number of equal increments. Figure 4-4 presents a circuit diagram of the Kelvin-Varley voltage divider circuit. Each decade is operated by an individual stepping switch. Such switches are called "decade switches". Herein, the least significant figure on the readout (rightmost window), the decade stepping switch, and Kelvin-Varley decade associated with it are referred to a "Decade 1." The other decades are numbered sequentially from right to left (from the least significant to the most significant figure). Each decade is capable of dividing the voltage applied across it into ten equal parts (Figure 4-4 shows this in detail). Therefore, the reference voltage can be divided into 10x10x10x10, or 10,000 equal steps. As an aid in understanding overall theory, it is repeated here that the nominal error amplifier gain should be such that an "up" or "down" pulse must be generated if the input and feedback voltages differ by an amount equal to one step of the Kelvin-Varley divider with the sensitivity control in the full clockwise position.

One advantage of the Kelvin-Varley type divider is that the reference voltage can be divided into 10,000 equal parts using only 43 resistors. Furthermore, the absolute accuracy of the resistors does not have to be ± 0.01% to achieve a linearity of ± 0.01% of full scale. The decade resistors associated with the most significant figure (leftmost readout window) are the most critical. These are matched at the factory for best overall accuracy; but the probability of achieving 0.01% linearity, when a 0.05% resistor is used as a replacement for one which has failed, is extremely favorable. The resistors of the second most significant figure decade are only one-tenth as critical as those in the most significant figure decade (leftmost readout window), etc., until, in the least significant decade, inaccurate (say 10% tolerance) resistors can be used without appreciable effect upon instrument linearity. However, highly accurate, stable, aged, wire-wound resistors are used in all decades to reduce somewhat the relatively stringent accuracy requirements of the two most significant decades, and to produce an instrument of overall high quality. Another Kelvin-Varley circuit advantage is that the effect of stepping switch contact resistance upon linearity decreases the farther we progress from the most significant figure decade (leftmost window). The Kelvin-Varley voltage divider is, in a sense, self-checking as described in Section 5, Maintenance.

B. DIGITAL LOGIC: An understanding of the basic digital logic is not necessary for understanding most aspects of the digital voltmeter, but is very valuable. After the digital logic is understood, the operations involved in attaining a balance when the input voltage is changed to a new value can be worked out with the aid of a digital voltmeter circuit diagram or a pulse circuit schematic. Two facts should be remembered when working out digital voltmeter operations:

*** The error amplifier generates pulses on its "up" pulse line whenever the feedback voltage is less positive than the unknown input voltage, and generates pulses on its "down" pulse line for the opposite condition. If the unknown input voltage is negative with respect to ground, these pulses are interchanged by the polarity switch before entering the rest of the digital logic circuitry. If the input voltage is positive, these pulses will pass directly through the polarity switch to the digital logic circuitry without being interchanged.

*** The stepping switches are unidirectional in operation; therefore, "up" and "down" pulses always move the wipers in the same direction. The manner in which "up" and "down" pulses are routed through the polarity, range, and numerical decade stepping switches permits attaining balance and decides upon the sequence of the operations in doing so. In attaining balance, the digital voltmeter's switching operations proceed in a logical sequence toward balance in a manner which required both "up" and "down" pulses.

1. PULSE SWITCHING CIRCUITS: Five stepping switches are used: one for range and polarity and four for the four decade Kelvin-Varley voltage divider. Each switch has several levels devoted for routing the up and down pulses to the proper stepping switch coil, (See Figure 4-6). Decade 1 uses two levels. Decade 2 and Decade 3 use three levels, Decade 4 uses four levels, and the range-

polarity switch uses three levels. The stepping sequence for the switches is:

Range-Polarity	Decade 4	Decades 1, 2 and 3
+ 1000 V	1	0
+ 100 V	0	1
+ 10 V	2	2
cross over	3	3
- 1000 V	4	4
- 100 V	5	5
- 10 V	6	6
cross over	7	7
	8	8
	9	9
	99	99

The "99" position and the "9" are different only in the logic switching levels.

2. UP PULSE ROUTING: Assuming that the input signal is positive, "up" pulses leaving the range-polarity switch are connected to the first decade (rightmost digit) stepping switch wiper and, through the switch contacts, will step it once per pulse. If balance is not attained within that decade, and the decade is driven to "99", the "up" pulses are transferred to the next numerical decade, and so forth, until all decades are driven to "99". Subsequent "up" pulses are transferred to the range-polarity stepping switch. Since the sequence of steps in the range-polarity switch is 1000 V, 100 V, 10 V, the switch must be driven through the negative positions (as described under down pulse routing) before getting back to the higher range positive position.

3. DOWN PULSE ROUTING: "Down" pulses are routed through the stepping switches on switch decks electrically isolated from all other wipers and decks. They enter through the polarity switch, as do the "up" pulses.

Assume that the range-polarity switch is in the + 1000 V position. Down pulses coming out of the pulse reversal levels of the range-polarity switch are routed in turn to the fourth, third, second and first decade. If any switch is in the "99" position, it is first stepped to "0" (1 in the fourth decade) before passing the pulse on to the next decade. Each pulse operates only one stepping switch one step at a time. If all the decades are at any position other than "99", down pulses drive the first decade to "0". If down pulses continue, they in turn drive the second and third decades to "0" and the fourth decade to "1". Continued down pulses will drive the range-polarity switch to a lower range until the 10 V range is reached. A down pulse at this point will drive the fourth decade to a "0". Another down pulse indicates that polarity reversal is necessary and the range-polarity switch is driven into the cross-over position. The next pulse, (it can be either up or down, since the zener supply is now disconnected) drives the fourth decade to the "2" position, and the following up or down pulse drives the range-polarity switch into the -1000 V position. At this point, the reading is - 200.0 V and operation is the same as previously described with the exception that the zener supply has been reversed as have the up and down pulse lines.

C. ERROR AMPLIFIER: The error amplifier compares the feedback voltage and unknown DC voltage, which appears at the output of the range attenuator, and issues pulses to drive the stepping switches if the difference between the two voltages is sufficiently large. Phasing of the error amplifier chopper vibration and thyratron plate voltage, which is an AC voltage of power line frequency, is such that pulses appear on the error amplifier's "up" pulse line when the feedback voltage is less positive than the unknown DC voltage, and pulses appear on the "down" pulse line when the feedback voltage is more positive than the known DC voltage (See Figure 4-5). Note that the terms "less positive" and "more positive" apply regardless of whether the unknown and feedback voltages are positive or negative with respect to instrument signal ground. Remember, if the unknown DC voltage is negative with respect to instrument signal ground, the "up" pulse line and "down" pulse line are interchanged by the automatic polarity switch before the pulses reach the rest of the digital logic circuits; this is necessary to preserve proper sensing throughout the instrument. A detailed explanation of error amplifier theory follows:

1. CHOPPER: The unknown DC voltage is applied to one stationary contact of an electromechanical chopper (K6), and the feedback voltage is applied to the other stationary contact. The waveform at the chopper's vibrating contact is a square wave whose peak-to-peak amplitude is the difference between the unknown voltage and the feedback voltage. If the unknown voltage is less positive than the feedback voltage, this square wave will have a certain phase relationship to the power line sinusoid; and if the unknown voltage is more positive, the phase relationship of this square wave will change by 180 electrical degrees, (See Figure 4-5). If the unknown input and feedback voltages are equal, the square wave peak-to-peak amplitude is zero. The absolute voltage values of the square wave are, of course, the absolute values of the unknown voltage and the feedback voltage. However, absolute values of the waveform are of little consequence in understanding amplifier operation since the amplifier's first stage effectively dis-

cards it and passes only the square wave component to the rest of the amplifier. The chopper contacts have a neon tube (V2) across them to protect the contacts from overload.

2. CALIBRATE SWITCH AND REHOSTAT: For calibrating the instrument, the calibrate switch (S1) permits inserting the known potential of a precise, unsaturated, cadmium standard cell into the amplifier input in place of the unknown input signal. THE CALIBRATE REHEOSTAT (R13) permits adjusting the reference voltage during the calibration procedure.

   A small resistance (R11) is placed between the negative terminal of the standard cell and power ground. The current which passes through the Kelvin-Varley voltage divider also passes through this resistance. The effect of this resistance is to reduce the standard cell voltage as seen by the error amplifier to exactly 1.019 volts. This resistance also corrects for the resistance of the input filter choke and any small error in the Kelvin-Varley bridge at "1019". By using this correction resistance, one standard cell may be utilized to an accuracy approaching .01%.

3. FIRST STAGE AMPLIFICATION: The first stage (V_3) operates in the following manner: The chopper is connected to the grids of the first stage. If the grid connected to the chopper vibrating contact ("first grid") becomes more positive with respect to the associated cathode, then plate current flow in that tube section increases, and both cathodes become more positive. As a result, the second grid is now more negative with respect to its cathode; less plate current flows in that tube section; and the plate potential becomes more positive. Thus, the input signal has been amplified but its phase has not been inverted. The capacitor in the output plate of this stage removes the DC component from the square wave and, consequently feeds the second stage of amplification an AC square wave. The "second grid" is connected to the output of the range attenuator to properly bias the input stage.

4. SECOND STAGE AMPLIFICATION: The second stage, (V_4) operates essentially the same as the first stage, and further amplifies the signal without inverting its phase. The potentiometer (R20) in the V_2 plate circuit permits adjusting error amplifier over-all gain, and is called the error amplifier gain control.

5. SENSITIVITY CONTROL: The sensitivity control (R23) is located between the two cathodes of the second stage. Inserting resistance between these two cathodes reduces the coupling and thus reduces the gain of the amplifier. Maximum sensitivity (normal operation) is obtained with the control set for zero resistance.

6. PHASE INVERTER STAGE: Tubes labeled V5A and V5B: The phase inverter stage converts the single waveform which is capacitively coupled to it from V_4 plate circuit, into two waveforms 180 electrical degrees out of phase with each other; this being required to generate two outputs ("up" pulse line and "down" pulse line) from the error amplifier. This stage operates as follows: Assume that the grid of V5A is driven more positive with respect to ground, V5A plate will thereby be driven more negative; hence, V5A output waveform is 180 electrical degrees out of phase with V5A grid waveform. V5A cathode potential becomes more positive; and, since V5A and V5B cathodes share a common cathode resistor, V5B cathode also becomes more positive. V5B grid is held at ground potential, and V5B cathode becoming more positive causes V5B plate potential to become more positive with respect to ground. Therefore, V5B plate waveform is in phase with V5A grid waveform.

7. THYRATRON DRIVER STAGE: Tubes labeled V6 and V7: This stage generates pulses, in response to signals from the phase inverter stage, to reliably drive the power stage thyratrons, (which furnish power pulses to operate the stepping switches) even in the presence of spurious noise signals, etc., of reasonable magnitude. The driver stage is unusual in that the output and input are on the same grid, which is the control grid, pin 1. Operation is as follows: The outputs of the phase inverter stage are capacitively coupled to the control grids, which are normally biased to cutoff by the resistive network connected to the B- supply. The grid voltage, at which the thyratrons fire, is essentially governed by the difference between the unknown input voltage and feedback voltage, the gain of preceding stages, and the grid bias voltage. The control grid bias is permanently set by fixed resistors, and the overall amplifier gain (minimum amplifier error voltage input which will cause pulses to be generated at the amplifier output) is adjusted by the gain control potentiometer (R20). Thyratron plate voltage is an AC voltage from the power supply transformer, so the thyratrons can fire only during the positive half cycle of plate voltage. Under these conditions, a thyratron can fire only if its control grid signal is in phase with the AC plate voltage. When a thyratron fires, its two grids and cathode assume plate potential (which is positive); the neon tube (V8 or V9) in its control grid circuit fires; and a positive pulse is emitted on the associated amplifier output line ("up" pulse or "down" pulse line). The thyratrons extinguish on the next half cycle of power line waveform, since the plate potential then becomes negative. The neons, V8 and V9, afford excellent electrical isolation between the driver thyratrons, V6 and V7, and the power thyratron grids of the next stage; the neons are biased negatively, and prevent any unwanted signals (spurious noise, etc.) on the driver thyratron grids from entering the power thyratron grids; also, when either

driver thyratron, V6 or V7 fires, the other drive thyratron is blocked from firing because both driver thyratron cathodes become positive.

8. SPEED CONTROL CIRCUIT: Thus far, it would appear that the amplifier pulse output occurs at power line frequency. However, this is not desirable, and the speed control circuit is incorporated to block driver thyratron firing on alternate positive cycle of the power line; hence, the stepping switch pulsing rate is reduced to one-half power line frequency. Speed control is accomplished by the addition of a capacitor C18 between the driver thyratron cathodes and ground. When a thyratron fires, all of the tube elements are at approximately the same voltage. This charges the capacitor to the same voltage as the plate. The thyratron extinguishes when the plate is still somewhat positive with respect to ground. The charge on this capacitor biases the thyratrons cut off beyond control of the grid signal until the charge leaks off through R39. The time duration of driver thyratron blocking is governed by the RC time constant. Increasing the capacitance permits decreasing the stepping switch speed to slower rates, should this ever be desired.

9. AMPLIFIER TEST POINTS: Two test points are provided to permit observation of error amplifier waveform before it reaches the driver thyratrons. They are located alongside V5A and V5B, and are connected directly to the plates of those tubes. To observe the waveform, connect an oscilloscope between either of these points and chassis ground. Waveform observation is useful in troubleshooting, as described in Section 5, Maintenance. Waveform observation also permits gaining greater resolution from the instrument in that one can see how close the instrument is to absolute null. Do not expect a perfectly clean, symmetrical square wave at this point; electrical noise pickup prevents this. When observing the waveform, beware of a very flat topped pattern as this usually indicates the error amplifier input signals are so large that the error amplifier is saturated. Under such conditions, the waveform will not change in response to small changes in the unknown input voltage.

D. ZENER DIODE REFERENCE VOLTAGE SUPPLY: The zener diode type reference voltage supply operates as follows: The line voltage is stepped up by the reference supply power transformer; rectified by a full wave semiconductor diode rectifier; filtered; intermediately regulated by a gas reference tube; and applied, through a series resistor, to the zener diodes which perform the final regulation. The zener diodes act as voltage regulators because, once the zener breakdown voltage is reached, a very constant voltage drop is maintained across them over a wide range of current passed through them. The initial operating current must be the proper value to achieve the full benefit of this effect. Relative freedom from reference voltage drift caused by temperature changes is achieved by locating the zener diodes in an oven which holds the temperature to $\pm$ 1/2°C. However, drift in reference voltage is possible, especially over periods of time. The reference voltage is returned to its proper value by executing the calibration procedure explained in Section 3-2B. The voltage appearing across the zener diodes is not exactly the value required by the instrument; and it is dropped to its proper value by additional series resistance, part of which is in the adjustable CALIBRATE rehostat described in Section 3-2B.

E. STANDARD CELL CHARACTERISTICS: The unsaturated cadmium standard cell provides an emf of sufficient accuracy for digital voltmeter use; has a relatively small temperature coefficient; and can be inverted. The unsaturated cadmium standard cells used in Non-Linear Systems Digital Voltmeters supply an emf which is constant within $\pm$ 0.01% from 4° C to 40° C, and which may increase by an additional 0.015% between 50°C and 60° C. The cells used by Non-Linear Systems are virtually free of hysteresis for periods as long as five years.

With standard cells, the following precautions should be observed: (a) Avoid drawing current from the standard cells. One hundred microamps may be drawn for several minutes without permanently affecting the emf. Current drains should be as low as possible and for only short periods of time. The emf of short circuited cells should be accurately measured and observed before re-use. As long as a month may be required for a cell, which has been short circuited for a 1/2 hour, to recover to within 0.01% of its original value, if it does so at all. It is best to replace any cells which have been short circuited. Approximately 0.001 microamp is drawn while actuating the CALIBRATE control. A 470K protective resistor (R10), in series with the standard cells, furnishes protection in the event of vacuum tube structural failure, etc.

(b) Store the cells vertically; inverted storage, for protracted periods, can result in emf changes.

(c) Store the cells at normal room temperature, or slightly below. Storage at 80° F can cause an 0.01% decrease in emf after a year.

(d) Avoid subjecting the cells to temperatures greater than 130° F or less than 39° F.

(e) Test show that cells will stay within $\pm$ 0.01% of their room temperature emf when soaked at -16° C (3.2°F). The emf may drop to less than one volt at -30° C (-22°F). When again exposed to room temperature, the emf normally recovers to within 0.1% of original room temperature emf in six to twelve minutes.

(f) Where continued high accuracy must be assured, check the standard cell emf at least once every 6 months.

(g) Remember, standard cells, like any other source of electrical energy, have an internal resistance; and this resistance causes the terminal voltage to drop when an electrical load is applied. Generally, standard cell internal resistance is between 500 and 1500 ohms.

F. POWER SUPPLY: B+ or B- voltages are derived from conventional semiconductor rectifiers energized by a winding on the power transformer. A time delay relay is used to keep the plate voltage off the thyratrons until the tubes have warmed up.

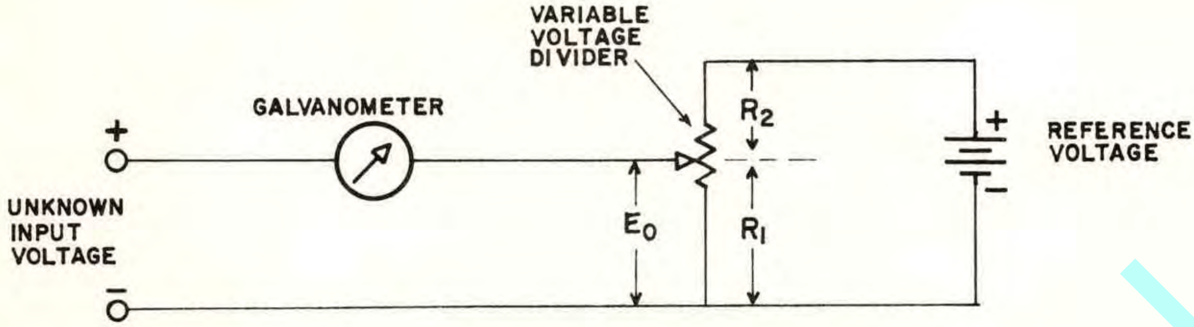


FIGURE 4-1. BASIC POTENTIOMETER CIRCUIT

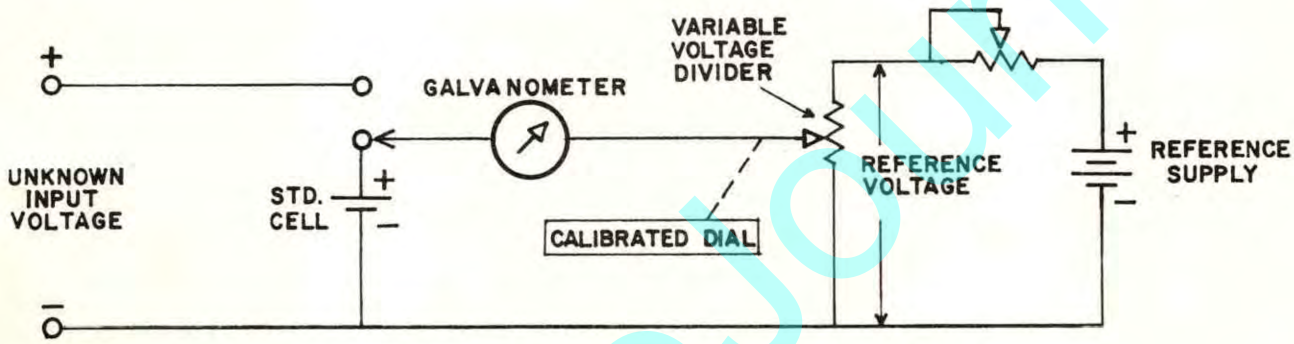


FIGURE 4-2. POTENTIOMETER WITH CALIBRATION RHEOSTAT.

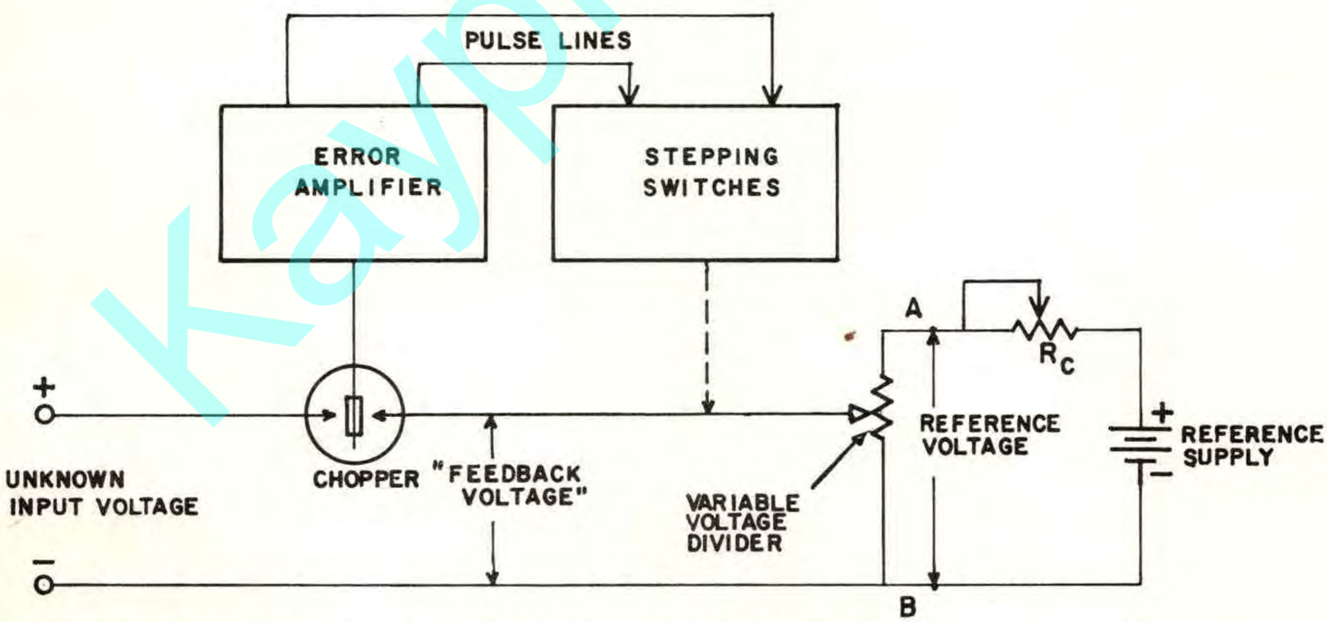


FIGURE 4-3 SIMPLIFIED SCHEMATIC, SINGLE RANGE DIGITAL VOLTMETER FOR MEASURING ABSOLUTE DC VOLTAGES

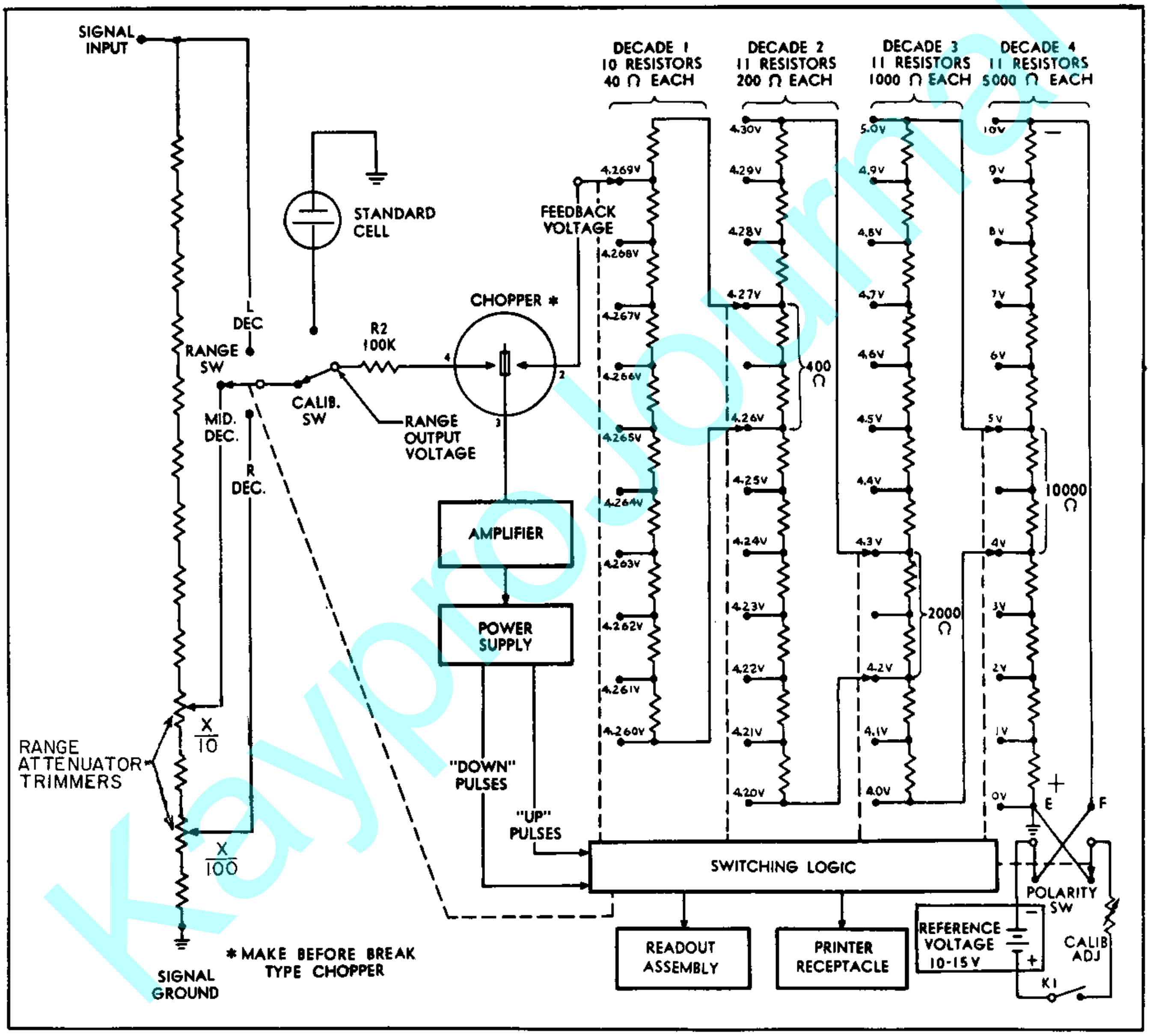
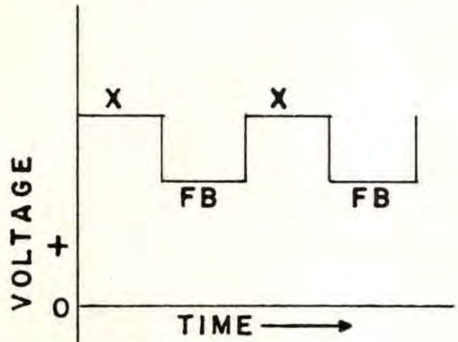
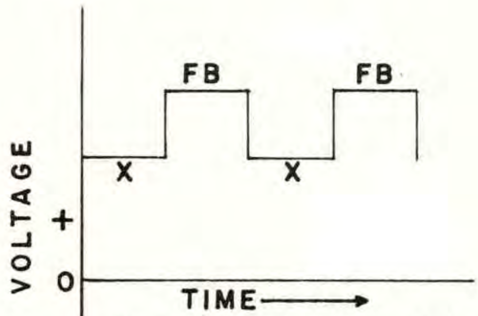


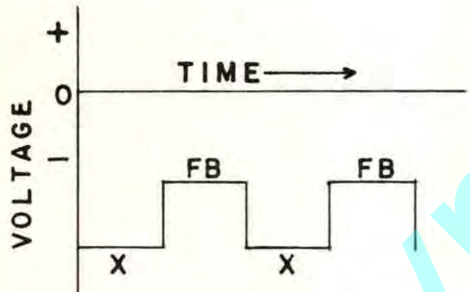
FIGURE 4-4. SIMPLIFIED CIRCUIT DIAGRAM: 4-DIGIT, MULTIRANGE, MANUALLY STANDARDIZED DIGITAL VOLTMETER FOR MEASURING ABSOLUTE DC VOLTAGES.



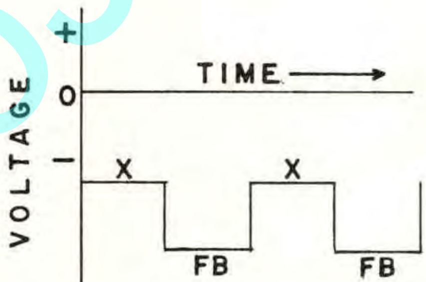
Voltages positive with respect to ground. FB less positive than X. Error amplifier generates "up" pulses, decade switches get "up" pulses.



Voltages positive with respect to ground, FB more positive than X. Error amplifier generates "down" pulses, decade switches get "down" pulses.



Voltages negative with respect to ground, FB more positive than X. Error amplifier generates "down" pulses, decade switches get "up" pulses because polarity switch reverses pulse lines.



Voltages negative with respect to ground, FB less positive than X. Error amplifier generates "up" pulses, decade switches get "down" pulses because polarity switch reverses pulse lines.

X = Unknown input voltage
FB = Feedback voltage

FIGURE 4-5. CHOPPER OUTPUT WAVEFORM AND RESULTING PULSES AT ERROR AMPLIFIER OUTPUT AND TO DECADE SWITCHES FOR VARIOUS RELATIONS BETWEEN UNKNOWN INPUT AND FEEDBACK VOLTAGE.

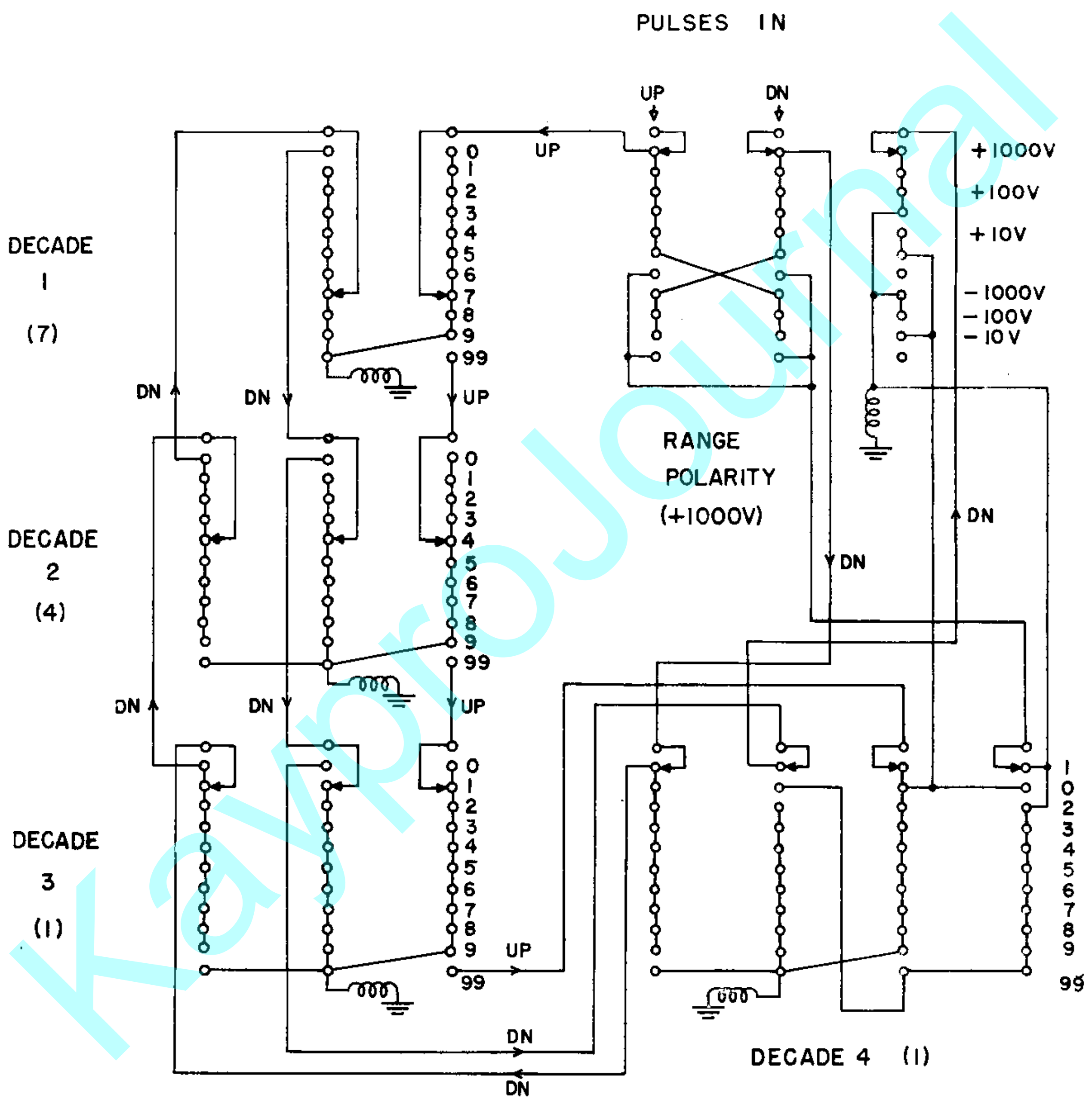


FIGURE 4-6

PULSE SWITCHING CIRCUITS

SECTION V

MAINTENANCE

5-1 ACCESS FOR MAINTENANCE: Access to the electronic assembly is gained by releasing the two "vibrex" fasteners on the rear of the hood, and sliding the hood to the rear. The stepping switch assembly is reached by merely removing the soundproof dust cover. Access to each stepping switch for lubrication or maintenance is easily gained by loosening the two screws which mount each switch to its bracket and then rotating the switch assembly up. The standard cell, range ass'y, and signal input filter may be reached by removing the four screws which mount the panel.

5-2 DC INSTRUMENT ADJUSTMENT, CALIBRATION AND TEST.

A. GAIN SETTING: For best results, the digital voltmeter should be operated with the amplifier gain set at one digit. If the amplifier gain is not set high enough, the resolution of the digital instrument will be too low. On the other hand, excessively high amplifier gain settings may cause instability of the readout display.

Remove the cover over the "CALIBRATE ADJUST" control on the front panel. Rotate the calibrate switch (S1) to "CALIBRATE".

After the visual readout has come to a balance, using a screw driver, slowly turn the "CALIBRATE ADJUST" control (R 13) in a counter-clockwise direction. Observe the magnitude of the decrease in readout display. If the readout display decreases in steps of one digit and does not become unstable, no adjustment of amplifier gain is necessary. If slowly rotating the calibration rheostat in a counter-clockwise direction results in a decrease of two or more digits in the rightmost window, the amplifier gain should be increased by slightly turning the slotted gain control potentiometer (R20) on the amplifier in a clockwise direction. (See Figure 5-3 for location). Again, observe the number of digits by which the readout display decreases when the calibrate rheostat shaft is slowly turned counter-clockwise. Repeat the amplifier gain adjustment, if necessary, to obtain a readout display decrease of one digit in the rightmost window. If instability develops in the readout display, turn the amplifier gain control counter-clockwise until the instability just disappears and the readout display decreases in steps of one digit in the right-most window as the calibration rheostat shaft is slowly turned counter-clockwise.

B. HUM CONTROL ADJUSTMENT:

1. CAUTION: Improper adjustment of the hum control will cause considerable error in calibration accuracy. The hum control is accurately set at the factory and should not be reset until it is definitely determined to be out of adjustment. Changing the input tube can throw the hum control out of adjustment. Be sure

that the input tube has been properly aged before resetting the hum control.

2. PROCEDURE: To adjust the hum control (R 53), which is located on the amplifier chassis, proceed as follows:

   (a) Connect the chassis to a good earth ground (the third pin on the power cord is connected to the chassis). Turn on the digital voltmeter and allow it to warm up for 15 minutes. Connect an oscilloscope between either of the two "Test Points" (See Figure 5-3) and ground. Calibrate the oscilloscope in terms of one digit error. To do this, turn the "calibrate" switch S1 to "CALIBRATE" and slowly back off on the calibrate adjust control R 13. Note the amount of error signal on the oscilloscope just prior to the time the thyratron fires. This error signal is equivalent to one digit if the gain is properly set as described in Section 5-2A and the sensitivity control is advanced full clockwise. The error signal is the vertical distance on the oscilloscope trace between the end of the sloped portion of the square wave and the beginning of the straight horizontal portion. (See Figure 5-1A).

   (b) With the meter in "OPERATE", short the input leads to obtain a reading of "± 0.000". Switch to "STANDBY". Remove the stepping switch cover. By hand, step the "Range-Polarity" switch (K5) until the meter reads "+00.00". Replace the stepping switch cover. Adjust the hum control (R 53) for zero error signal as displayed on the oscilloscope. It is necessary that the stepping switch cover, bottom plate and front panel be in position. The hum control is now properly set.

   (c) Check the error signal for all ranges (+00.00, +0.000, -000.0, -00.00, -0.000 and +000.0) each time removing the stepping switch cover, stepping the range-polarity switch by hand and replacing the cover. Do not move the hum control. The error signal for all range positions should be less than one-half digit. If the error exceeds one-half digit, there are two sources of trouble: (1) excessive hum pickup and (2) excessive grid current. Check all shields and ground leads. Replace the 5751 input tube. (Note: Do not substitute any other type tube).

C. STANDARDIZATION ADJUSTMENT:

1. GENERAL: The calibration procedure described in Section 3-2B enables the operator to standardize the voltmeter to an accuracy far exceeding the 0.1% accuracy normally possible with

one standard cell and one millivolt sensitivity. In order for the correct setting to be exactly "1019" several corrections must be made: (1) The standard cell voltage will generally differ slightly from 1.0190 volts (2) The input filter choke (L1) has a resistance of approximately 4000 ohms (3) The feedback signal might differ slightly from exactly 1.019 V and still be well within necessary tolerance. The current which passes through the Kelvin-Varley bridge (0.2 ma) also passes through R 11. This produces a small voltage which reduces the standard cell voltage as seen by the error amplifier and corrects for the errors listed above.

2. PROCEDURE: Before making any adjustment, make sure that the gain and hum controls are properly set and that the instrument is connected to a good earth ground. Calibrate the voltmeter as described in Section 3-2B. Connect a bank of nine standard cells, whose accuracy is known to at least 0.01%, to the input. The reading should be correct within one digit.

   CAUTION: Be sure to take into account the internal resistance of the standard cells. The Model 481 has an input resistance of ten megohms and with a nine volt signal will draw 0.9 microamps. If the reading is not correct, adjust R 11 and repeat the entire procedure. R 11 is located slightly above and to the right of the "calibrate adjust" control R 13. (See Figure 5-3). To adjust R 11 insert a small screwdriver from the rear through the 3/8" hole in the front bracket mounted on the amplifier printed circuit board.

D. FEEDBACK VOLTAGE LINEARITY TEST: One of several factors which may affect the accuracy of measurements made with digital voltmeters is the linearity characteristic of the Kelvin-Varley voltage divider. The digital Kelvin-Varley circuit develops a known feedback voltage, within the digital voltmeter, to which the unknown input voltage is compared during measurement. Many methods for testing the linearity of the digital Kelvin-Varley voltage divider exist, but the method described below has been found most satisfactory. It is assumed that error amplifier gain is properly adjusted before the test is started.

Only one piece of precision test equipment is required, a variable voltage divider with an accuracy five to ten times better than that of the digital instrument under test, and with an input resistance of 100,000 ohms (this high to prevent excessive current drain from the reference supply). Connect the input to the external precision voltage divider to the input of the Kelvin-Varley voltage divider in the Model 481. This can most easily be accomplished by connecting to the appropriate terminals on the bottom of the amplifier board. Disconnect the wire from the arm of S1 to the terminal next to R 10 on the amplifier printed circuit board. Connect the output of the external precision voltage divider to this terminal. Observe the shielding and grounding rules given in Section 3-3B. Adjust the standard divider to a reading 00000; the visual readout should display zero in each window. Adjust the standard voltage divider to read 99990; the visual readout display should be nine in each window. These two readout displays must be obtained for the indicated standard divider settings. If the instrument displays digits other than those indicated above for these two end points, an improper circuit condition exists and must be located and corrected before proceeding with the test. Now set the standard divider for various readings such as: .89990, .79990, .69990, --- .08990, .07990, --- .00890, .00790, --- .00080, .00070, --- etc.

The digital instrument visual readout display should be equal to the standard divider settings $\pm$ 1 digit.

One very desirable feature of the ratiometer method of testing voltage divider linearity is that reasonably large (20%) deviations in reference voltage from the nominal value of reference voltage have no significant effect upon test accuracy. This is true because the same voltage is furnished to the input of the internal voltage divider as well as the input of the external standard voltage divider. Thus, for equal settings of the two voltage dividers, the output voltages are equal if the input voltages are equal.

As an alternative method: The digital voltmeter linearity can be tested by connecting a stable and finely adjustable DC voltage source to its input terminals, monitoring this input voltage with a precise laboratory type potentiometer, varying the input voltage, and observing whether the digital voltmeter readings are proportional to the precision potentiometer readings within the accuracy limitations of both measuring devices. The advantage of this method is that all connections to the digital voltmeter are external when using this method. The disadvantage is that uncompensated drifts of the digital voltmeter or precision potentiometer reference voltages during the test will give a false indication that the digital voltmeter linearity is not within tolerance.

E. RANGE UNIT ADJUSTMENT: The range unit will require scale factor readjustment only if the range unit resistors change their ohmic value, or if the electrical loading of the unit output taps changes. The adjustment method described below requires several accurate voltage dividers and a stable DC source. This method permits accurate range unit scale factor adjustment regardless of any inaccuracies present in the digital Kelvin-Varley voltage divider. This is because, in the prescribed method, the Kelvin-Varley divider is always brought back to the same position (same numerical display on digital voltmeter, ignoring decimal point location) when the correspondence of scale factors on each range is checked. As in any other test, proper shielding and grounding techniques must be followed to prevent electrical noise pick up from interfering with the instrument's stability and resolution. Also, in checking each range, best accuracy is achieved when the test voltage used is as close to full scale for that range as is practicable. The precision voltage divider used in the range unit adjustment procedure must be compensated for the electrical loading effect of the digital voltmeter. The precision voltage divider accuracy should be five to ten times better than the accuracy to which the range unit is to be adjusted.

Access to the range trim potentiometers referred to below is gained by removing the left hand protective cap on the front panel. They are identified by "1000v" and "100v" on the printed circuit range board.

ADJUSTING THE 100 VOLT RANGE SCALE FACTOR

1. Connect the input terminals of a 10 to 1 precision voltage divider to a stable source of voltage, in the neighborhood of 95 to 99 volts.

2. Connect the input terminals of the digital voltmeter under test to the input of the voltage divider; observe the readout display and waveform at the error amplifier test points.

3. Connect the input terminals of the digital voltmeter to the output terminals of the voltage divider; observe the readout display and error amplifier waveform.

4. The 100 volt range is properly adjusted when the readout display in step 3 is exactly equal to one-tenth of the readout display observed in step 2 (for example: 95.93 in step 2, compared to 9.593 in step 3) and when the error amplifier waveform amplitude and phase are similar to that observed in step 2. If this correspondence is not present, adjust the 100 volt range trim potentiometer.

ADJUSTING THE 1000 VOLT RANGE SCALE FACTOR

1. Connect the input terminals of a 100 to 1 voltage divider to a stable source of DC voltage as close to 999 volts as is practicable. (Lower voltages, certainly no less than 200 volts, can be used, but accuracy will not be as good as when higher voltages are used).

2. Connect the input terminals of the digital voltmeter under test to the input terminals of the voltage divider; observe the readout display and waveform at the error amplifier test points.

3. Connect the input terminals of the digital voltmeter to the output terminals of the 100 to 1 voltage divider; observe the readout display and error amplifier waveform.

4. The 1000 volt range is properly adjusted when the readout display in step 3 is exactly one-hundredth of the readout display observed in step 2 (for example: 982.3 in step 2, compared with 9.823 in step 3) and when the error amplifier waveform amplitude and phase are similar to that observed in step 2. If this correspondence is not present, adjust the 1000 volt range trim potentiometer.

5-3 MAINTENANCE AND TROUBLESHOOTING.

A. GENERAL: Maintenance personnel must be thoroughly familiar with the physical make-up, specifications, installation and operating procedures, and detailed theory of operation of the digital voltmeter. The first step in correcting any trouble which may develop is to isolate that section of the circuit which is causing trouble. Improper operation of the digital voltmeter usually shows up as improper readout display, whether in a transitory or stabilized condition. Detailed examination of the readout display will almost invariably provide an indication to the probable source of trouble (See the troubleshooting charts in this section).

B. TEST EQUIPMENT: No special equipment is required for normal maintenance of NLS instruments. An ordinary oscilloscope is helpful in tracing amplifier output pulses. Resistance and voltage measurements, both AC and DC, can be made with a multimeter or VTVM, depending on circuit loading considerations.

C. REPLACEMENT OF COMPONENTS: A list of all replaceable parts is included in Section VI. NLS can supply electronic replacement parts at current net prices plus a handling charge. However, since most of the components are standard electronic and radio parts, we suggest you purchase them from your local dealer, if you can. NLS manufactures most of the mechanical parts and some of the components used in the instruments. When ordering a mechanical part, be sure to describe the part completely; also, furnish the model and serial numbers of the instrument to which the part is to be fitted. Contact our nearest Field Engineer or Representative if you have questions about replacement parts. Parts information may also be obtained by writing to the Service Department at our factory in Del Mar, California.

D. MAINTENANCE DETAILS: The Model 481 digital voltmeter consists of the following main assemblies: (1) electronic and (2) stepping switch, including readout. Operational adjustments for these items have been described in the paragraphs relating to the adjustment, calibration and test.

1. ELECTRONIC ASSEMBLY

(a) Error Amplifier: The amplifier compares the unknown input voltage with the known feedback voltage from the stepping switch assembly. Whenever these two voltages are unequal, a square wave error signal is generated by the chopper. This signal is amplified; and may be observed by connecting an oscilloscope between ground and either one of the two error signal test points on the error amplifier, in the plate circuit of the phase inverter stage vacuum tubes. When the digital voltmeter is at a balance, the error signal becomes a straight line, modified somewhat by hum and noise pickup. If no error signal is observed at the test points, trace back through the preceding stages to the output of the chopper, until the error signal once more becomes evident. If necessary, faulty components or tubes should be replaced to regain signal at the amplifiers test points. Existence of "up" or "down" pulses, generated by the type 5696 thyratrons in the amplifier, can be determined by observing which of the NE2 neon bulbs are glowing. Look at the amplifier from the front; when a "+" polarity sign is displayed in the readout; (1) "up" pulses are being generated if the right NE2 neon bulb is glowing; (2) "down" pulses are being generated if the left neon bulb is glowing. These pulses at the grid of the 2D21 take the configuration shown in Figure 5-1 (b). The amplifier output pulses, described above trigger one of the two type 2D21 thyratrons. These pulses from the 2D21's are routed to the logical switching circuits in the stepping switch assembly. If the stepping switch circuit is open and the switches do not step, the pulses from the power thyratrons will resemble Figure 5-1 (c) on an oscilloscope screen. The pulse waveform across the coil of a normally operating stepping switch will resemble Figure 5-1 (d) on an oscilloscope screen.

(b) Power Supply: The power supply in the DC digital voltmeter furnishes B+, B-, amplifier filament power, and power for the readout lamps. A thermal time delay relay withholds plate voltages from the type 2D21 and type 5696 thyratrons until the filaments are fully heated.

(c) Zener Reference Supply: This reference supply has very few components, and is normally trouble-free. The operation is explained in Section 4-2 (d). Access to the zener diodes is gained by disassembling the crystal oven. Should it be necessary to replace the zener diodes, make sure that the red dot (positive terminal) is connected to pin 8 of the octal socket.

(d) Replacing the Standard Cell: The standard cell may be reached by removing the front panel. Use extreme caution to avoid shorting out the standard cell, even with the fingers. Changing the standard cell requires restandardizing the voltmeter as described in Section 5-2 (c).

2. STEPPING SWITCH ASSEMBLY

(a) Stepping Switch Lubrication: Periodic lubrication is essential. To lubricate most points a #4 Artists Sable Rigger brush is used. A "dip" shall be the amount of lubricant retained on the brush when it is dipped 3/8" into the lubricant and lightly scrape on the edge of the container to remove excess. There shall not be sufficient lubricant on the brush to form a drop. Excessive lubrication shall be avoided. See Figure 5-2 for location of parts.

No lubrication required prior to placing into service unless shelf life has exceeded 3 months. Thereafter, lubricate at the following intervals:

at 25,000 revolutions or 3 months, whichever comes first
at 75,000 revolutions or 6 months, whichever comes first
at 200,000 revolutions or 9 months, whichever comes first
at every additional 200,000 revolutions or 9 months thereafter, whichever is the more frequent.

LUBRICATION CHART

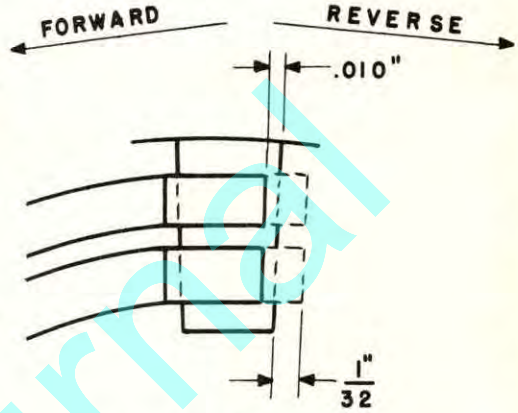
LUBRICATION POINT	TYPE LUBRICANT	LUBRICATION PROCEDURE
Wiper assembly bearing	Clock oil or equivalent	Apply one dip near the pointer
Each pair of wiper contacts	Clock oil or equivalent	Draw a strip of bond paper, treated with two dips on each side, through the wiper contacts. Rotate assembly to distribute lubricant.
Inner sides of each pair of wipers where brush springs ride	Clock oil or equivalent	Apply one dip of oil at the point 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.
Ratchet teeth	50-50 mixture (by volume) of powdered mica and clock oil	Apply two dips to the ratchet teeth, rotating to distribute lubricant.

NOTE: After a considerable number of operating hours of the stepping switch assembly, a black deposit will form on the decade resistor boards and adjacent areas due to normal stepping switch wear. The amount of this deposit will be quite moderate if regular lubrication is performed. However, if the switches are not lubricated frequently enough, the amount of deposit may become excessive. The deposit will not affect the operation of the meter since the resistor boards have a protective coating. If it is desired, the deposit may be periodically wiped off. Do not use solvents. If solvents are used, the printed circuit resistors must be very carefully cleaned, dried and then recoated.

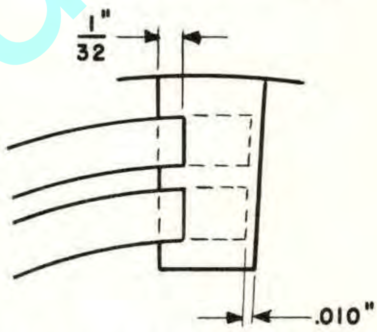
(b) Stepping Switch Adjustment: The Type 11 switch will hold adjustment for considerable life. Aside from lubrication no attention is required until life has reached 1/2 million revolutions. At this point and at every 1/2 million additional revolutions thereafter an adjustment inspection shall be made. The inspection shall be made in accordance with inspection procedures given below and in the sequence listed. Adjustments not within the inspection limits shall be corrected in accordance with the associated readjustment instruction. It shall be considered natural if some or all adjustments clear the inspection limits for one or more inspection period.

(1) Wiper Assembly

Inspection: With wipers on contact No. 1 rock wiper assembly gently forward and reverse by hand. Note contact area on which wiper tips play. The tips shall play within the limits shown on sketch.



BRIDGING WIPERS



NON-BRIDGING WIPERS

Readjustment: If tips play beyond forward motion limits the pawl stop shall be readjusted. It shall be moved slightly toward the pawl to check excessive forward motion of the wipers. The pawl stop face shall be carefully alighed to rest against the pawl as flatly as possible.

If tips play beyond reverse motion limits the detent spring shall be readjusted. It shall be moved slightly toward the ratchet to check excessive reverse motion of the wipers. The detent shall also drop freely into each tooth on manual stepping and shall be centered on the ratchet.

The readjustments above shall provide near-zero wiper play with tips approximately centered between inspection limits of sketch.

(2) Armature Backstop

Inspection: The armature shall rest against the backstop. Inspect by inserting a .0015" thickness gage between the armature and the stop. The gage shall drag on withdrawal.

Readjustment: If the gage has no drag on withdrawal, the backstop shall be readjusted. It shall be moved slightly forward to touch the armature but not far enough to lift the pawl from the pawl stop. Recheck for gage drag, and for manual stepping with positive detent spring action, after tightening stop screws.

To have the armature and pawl strike their respective stops with approximately equal force is considered an ideal adjustment.

(c) Digital Readout Maintenance: The only maintenance step normally required for the digital readout is lamp bulb replacement. However, if readout plates require cleaning because of subjection to extremely adverse dust or humidity conditions, clean them with commercial isopropyl alcohol and lint free paper, such as KIMWIPES 900-L, manufactured by Kimberly Clark, Neenoh, Wisconsin. Readout plates can be slid from their grooves after removing either structural end plate from the readout. Readout plate and bulb placement is shown on the schematic. However, to avoid any possible error, record the location of each readout plate as it is removed. As the readout is re-assembled, avoid reversing or inverting the readout plates, particularly 1, 0, 6, 8 and 9. The engraved side of the readout plates should face the rear of the readout. Avoid scratching the readout plates and polaroid filter. Also, if the polaroid filter is removed, it must be reinstalled with the proper side inward. Hold a piece of shiny metal against the filter sheet and look through at the metal. Turn the filter over and again look through at the metal. The correct side of the filter to face the rear of the readout is that which was in contact with the metal when the least glare was observed from the metal surface. Turn AC power off.

To replace burned-out lamps in the digital readout, proceed as follows:

(1) Lift the readout visor up and remove it.

(2) Spread the two side brackets which hold the readout assembly in place and allow the readout to rotate forward.

(3) Remove the readout. The bulbs are now accessible for replacement. A layout of the bulb location is given on the schematic. This is a diagram of the readout contact board, NOT the readout.

(4) To replace the readout, hold it horizontal and engage the two pivot screws. Rotate the readout up until the two side brackets lock the readout securely. Replace the visor.

(d) Kelvin Varley Voltage Divider - Any deficiencies which develop in the Kelvin-Varley voltage divider should become evident during a linearity test. However, most types of deficiencies will appear during normal use of the instrument, or during a test wherein the input voltage is slowly varied from zero to full scale on the instrument's lowest range (observing the error amplifier waveform during such a test is helpful). Some deficiencies are described below:

(1) If the instrument either oscillates at some point in its range, or reads all nines, look for open circuited resistors, broken wires, or stepping contact failure.

(2) If, as the input voltage is slowly increased, the readout display skips a number, it is probable that a resistor associated with the old and new displayed numbers is too low in ohmic value.

E. CONVERSION TO 230 VOLT OPERATION: The meter as normally shipped from the factory is connected for 115 vac operation. The meter may be easily converted for 230 vac operation by moving several jumper wires and changing the 2 amp power fuse to 1 amp. The schematic diagram shows the connections for both 115v and 230v operation. To change from 115v to 230v operation:

(1) Remove the two bare wire jumpers located just forward of the power transformer.

(2) Remove the wire from the power switch to the amplifier board (the wire which connects to the <u>black</u> transformer primary lead).

(3) Connect a jumper wire from the black transformer lead to the brown/white transformer lead.

(4) Connect a wire from the now vacant power switch arm to the brown transformer lead.

(5) Carefully check with the schematic that the wiring is correct.

(6) Change the 2 amp fuse to a 1 amp fuse.

F. TROUBLESHOOTING CHART DC DIGITAL VOLTMETER

TROUBLE	PROBABLE CAUSE	REMEDY
Entire visual read-out 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 6V AC	Check for 6V AC at various points.
	Power transformer open circuited.	Replace power transformer.
Some characters in the visual readout display fail to light up	Defective readout indicator lamp	Replace lamp.
	No 6V AC available at center contact of lamp	Trace 6V AC line through associated stepping switch.
Unstable readout display	Amplifier gain too high	Adjust amplifier gain.
	Excessive ripple on unknown DC input voltage	Provide suitable filter between unknown voltage source & digital voltmeter leads.
	Stray noise voltage being picked up	Connect chassis of digital voltmeter to good earth ground. Use shielded leads
	Microphonic or gassy 5751 (1st stage amplifier) tube	Replace 5751 tube.

F. TROUBLESHOOTING CHART DC DIGITAL VOLTMETER (CONTINUED)

TROUBLE	PROBABLE CAUSE	REMEDY
Unstable readout display	Unstable 5696 thyratron in amplifier	Replace 5696 tubes.
	Faulty reference voltage circuit connections	Check connections.
	Decade stepping switch contacts making intermittent contact	Increase wiper tension
	Reference voltage supply noisy or not regulating	See section of text dealing with reference supply.
	Noisy or partially shorted resistors in range attenuator or Kelvin-Varley divider	Replace faulty resistors.
	Faulty ground circuit connection inside instrument	Find and repair faulty connection.
Readout display decreases in steps of more than one digit when input voltage is decreased very slowly.	Low Amplifier gain	Adjust amplifier gain.
	Low Amplifier gain	Check amplifier tubes & replace any found to be weak or defective.
	Amplifier saturated with noise	Observe effective shielding and grounding procedures.
		Replace amplifier tubes.

F. TROUBLESHOOTING CHART DC DIGITAL INSTRUMENT (CONTINUED)

TROUBLE	PROBABLE CAUSE	REMEDY
Visual readout display increases and stays at full scale when input voltage is less than full scale.	Feedback voltage missing at chopper	Re-establish continuity of reference voltage circuit.
	Defective chopper	Replace chopper
Readout display will not increase.	No error signal	Replace chopper
		Make point-to-point check of amplifier with oscilloscope.
	"Up" pulses missing	Check range attenuator output voltage line from range stepping switch to pin 4 of chopper.
		Replace type 5696 tube in amplifier and 2D21 in power supply.
		Replace defective neon tube in amplifier assembly.
		Check feedback voltage line from decade one switch to chopper.
	Low line voltage (Less than 105V AC)	Remedy cause of low line voltage or employ a step up transformer.
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.

F. TROUBLESHOOTING CHART DC DIGITAL VOLTMETER (CONTINUED)

TROUBLE	PROBABLE CAUSE	REMEDY
Readout display will not decrease.	"Down" pulses missing	Check feedback voltage line from decade one switch to chopper.
		Replace type 5696 tube in amplifier and 2D21 in power supply.
		Replace defective neon tube in amplifier.
		Check range attenuator voltage line from range stepping switch to chopper.
Readout display will neither increase nor decrease.	Selector switch in "STANDBY" position	Turn selector switch to "ON" position.
	Time delay relay tube in power supply not functioning	Replace time delay tube in power supply.
	No "up" or "down" pulses available at stepping switch coils	Repair pulse lines from amplifier to power supply or from power supply to stepping switch assembly.
	Defective thyratrons in amplifier or power supply	Replace 5696 tube and 2D21 thyratrons.
	No error Signal	Trace error signal from chopper thru amplifier. Correct reason for loss of signal.
		Replace Chopper.
		Establish unknown input signal or feedback voltage at chopper.

F. TROUBLESHOOTING CHART DC DIGITAL VOLTMETER (CONTINUED)

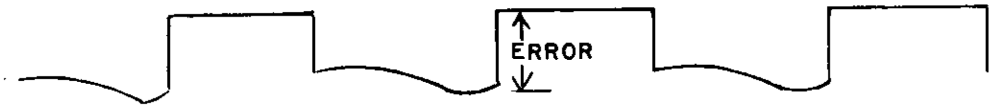
TROUBLE	PROBABLE CAUSE	REMEDY
Readout display will neither increase nor decrease.	Amplifier saturated with noise	Observe effective shielding and grounding procedures.
		Replace amplifier tubes.
When input signal polarity is reversed, numerical reading differs by more than one digit.	See listings under "Unstable readout display": input ripple, stray noise, faulty 5751 or 5696 tubes, stepping switch wiper tension low, reference voltage faults, noisy resistor, faulty ground circuits in instruments.	See associated remedies under "Unstable readout display." Consult Section 5-2B "Hum Control"
	Input signal DC amplitude actually changes when leads to instrument are reversed.	If differing readings are construed as "trouble," and not "desired data," then signal source may be at fault.
	Amplifier gain low	Readjust gain control.

G. VOLTAGE CHART

TUBE	V3	V4	V5	V6 & V7	V10 & V11
Pin 1	160 V	165 V	130 V	-9.0 V	-55 V
Pin 2	0 V	0	0	0	0
Pin 3	1.65 V	1.6 V	1.5 V	3.15 vac	0
Pin 4	2.2 vac	3.15 vac	3.15 vac	3.15 vac	6.3 vac
Pin 5	2.2 vac	3.15 vac	3.15 vac	0	0
Pin 6	130 V	135 V	135 V	150 vac	150 vac
Pin 7	0 V	0	0	0	0
Pin 8	1.65 V	1.6 V	1.5 V		
Pin 9	2.2 vac	3.15 vac	3.15 vac		

NOTES:

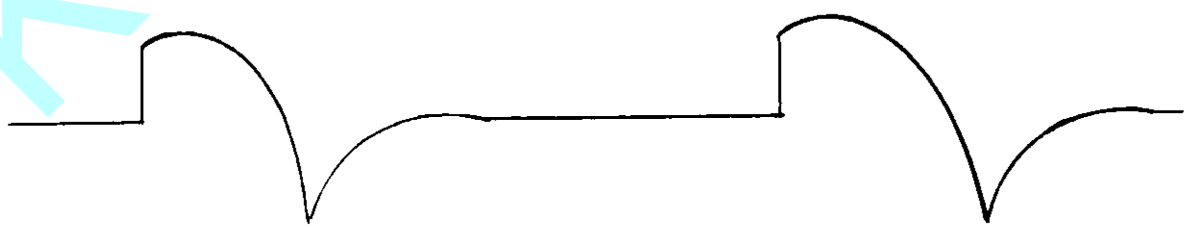
1. All voltages measured to ground with a VTVM.
2. Line voltage 115 vac.
3. Meter in "Operate" with a reading of: "+0.000" and the input leads shorted.
4. Sensitivity control in full clockwise position.
5. Filament voltages to ground will vary according to setting of hum potentiometer.



(A) ERROR SIGNAL AT TEST POINTS.

(B) "UP" AND "DOWN" PULSES AT 2D21 GRID.

(C) POWER THYRATRON OUTPUT PULSES WHEN STEPPING SWITCH COIL CIRCUIT IS OPEN CIRCUITED.



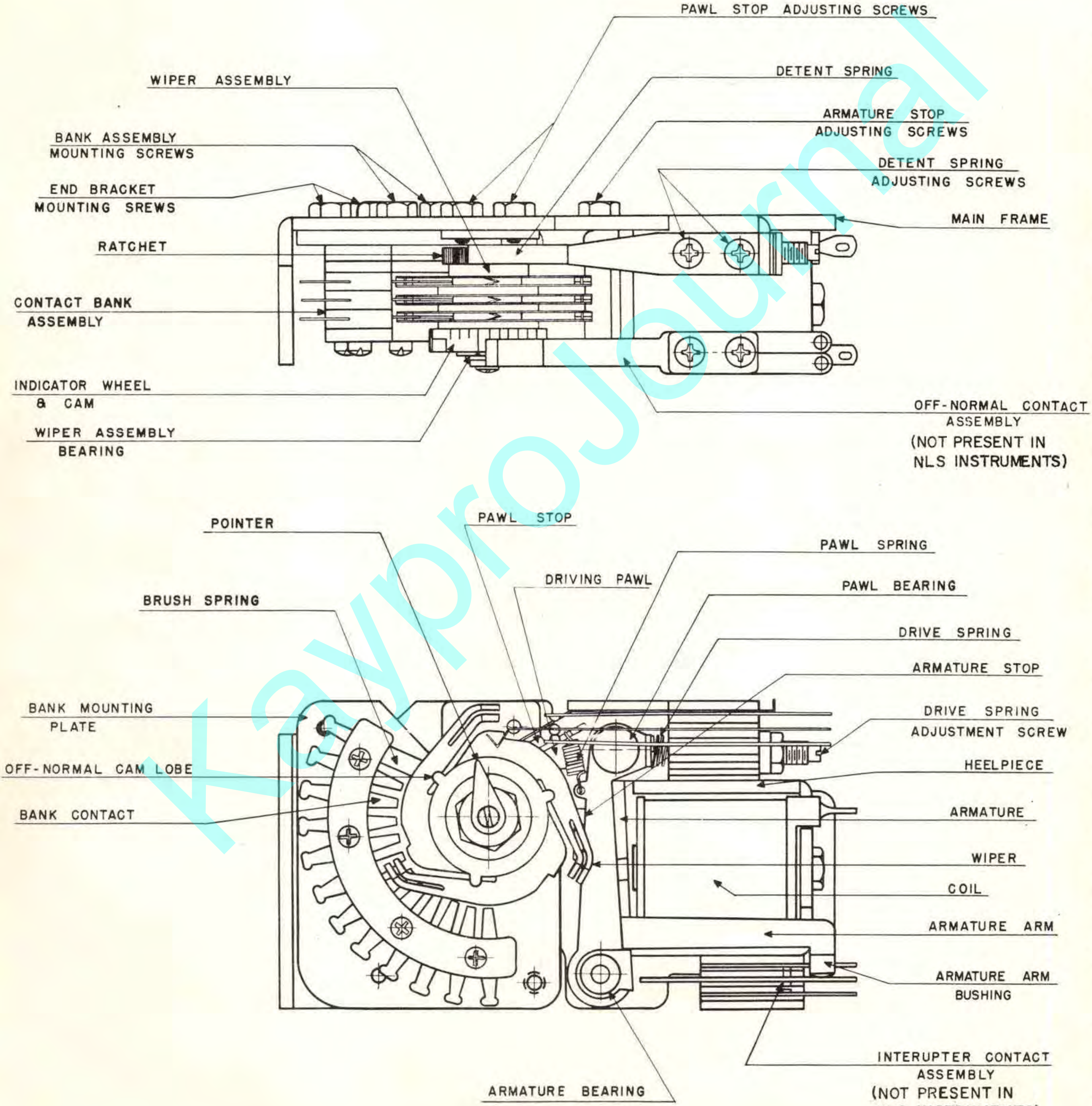
(D) PULSE ACROSS STEPPING SWITCH COIL.

FIGURE 5-1 TYPICAL PULSE WAVEFORMS.

FIGURE 5-2.

TYPE II SWITCH

IDENTIFICATION OF PRINCIPAL PARTS



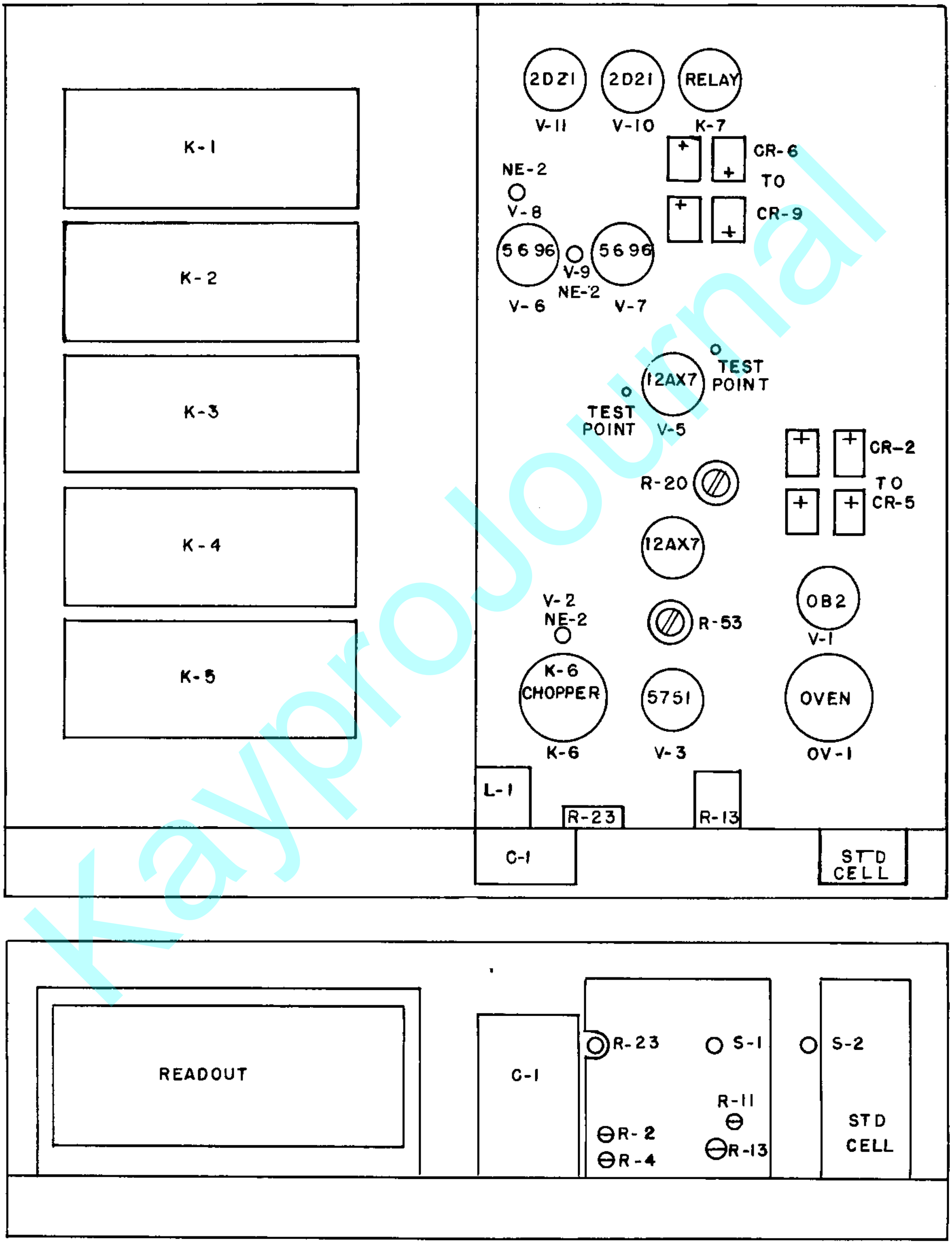


FIGURE 5-3 COMPONENT LOCATION FRONT PANEL AND CHASSIS

SECTION VI PARTS LIST

CIRCUIT REFERENCE	DESCRIPTION	PART NO.	MFR. CODE
C 1	Capacitor: fixed, oil filled 1.0 uf ± 20% 1000 vdcw	TJU-10010 J-1	J
C 2,3,6,8,9,10 12,13,14,17	Capacitor: fixed, electrolytic 20 uf 250 vdcw	PLP 2520	T
C 4	Capacitor: fixed, metalized paper 1.0 uf ± 20% 200 vdcw	M 2 - 30	K
C 5	Capacitor: fixed, paper .05 uf ± 20% 400 vdcw	GEM - 415	Q
C 7,11,21,22,23	Capacitor: fixed, ceramic .01 uf GMV 1000 vdcw	DD 103	E
C 15, 16	Capacitor: fixed, mica 200 uuf ± 20% 500 vdcw	5W5T2	J
C 18	Capacitor: fixed, metalized paper .25 uf ± 20% 400 vdcw	W4 - 22	K
C 19, 20	Capacitor: fixed, ceramic .05 uf GMV 600 vdcw	DF 503	E
CR 1	Diode, zener reference matched pair	IN 429-6	O
CR 2,3,4,5, 6,7,8,9	Rectifier, silicon	K 200	U
F 1, 2	Fuse, 3 AG, 2A	312002	P
J 1	Connector, male, 3 pin	XL-3-14	D
K 1	Stepping switch, 6 level	11271 - 411	NLS
K 2, 3	Stepping switch, 6 level	11271 - 412	NLS
K 4	Stepping switch, 8 level	11271 - 413	NLS
K 5	Stepping switch, 8 level	11271 - 414	NLS
K 6	Chopper	CH 457	V
K 7	Relay, time delay	115 NO 10 T	B
L 1	Choke	14741	X

CIRCUIT REFERENCE	DESCRIPTION	PART NO.	MFR. CODE
OV 1	Oven, crystal, 70° C 115 vac	FC - 100	C
R 1	Resistor: fixed wire wound 99.11K, ± 0.05% 1/2 w	PW 1719	NLS
R 2	Resistor: variable, wire wound 2K ± 5% 0.4 w	025 - 2K	I
R 3	Resistor: fixed, wire wound 890 K ± 0.05% 1/2 w	PW 1719	NLS
R 4	Resistor: variable, wire wound 20 K ± 5% 0.4 w	025 - 20 K	I
R 5	Resistor: fixed, wire wound 9 ea 1 Meg, ± 0.05% 1/2 w	PW 1719	NLS
R 6,7,8	Resistor: fixed, wire wound 2 K ± 5% 5 w		R
R 9	Resistor: fixed, wire wound 13 K ± 0.05% 1/2 w	PW 1719	NLS
R 10	Resistor: fixed, composition 470 K ± 10% 1/2 w		A
R 11	Resistor: variable, wire wound 8 ohm ± 20% 2 w	39 - 8	H
R 12	Resistor: fixed, wire wound 10 K ± 0.05% 1/2 w	PW 1719	NLS
R 13	Resistor: variable, wire wound 5 K ± 10% 1.5 w	SM 500	G
R 14,17,19, 24,28,29,41	Resistor: fixed, composition 3.3 K ± 10% 1/2 w		A
R 15,26,30	Resistor: fixed, composition 120 K ± 10% 1 w		A
R 16	Resistor: fixed, composition 180 K ± 10% 1/2 w		A
R 18, 25	Resistor: fixed, composition 4.7 meg ± 10% 1/2 w		A

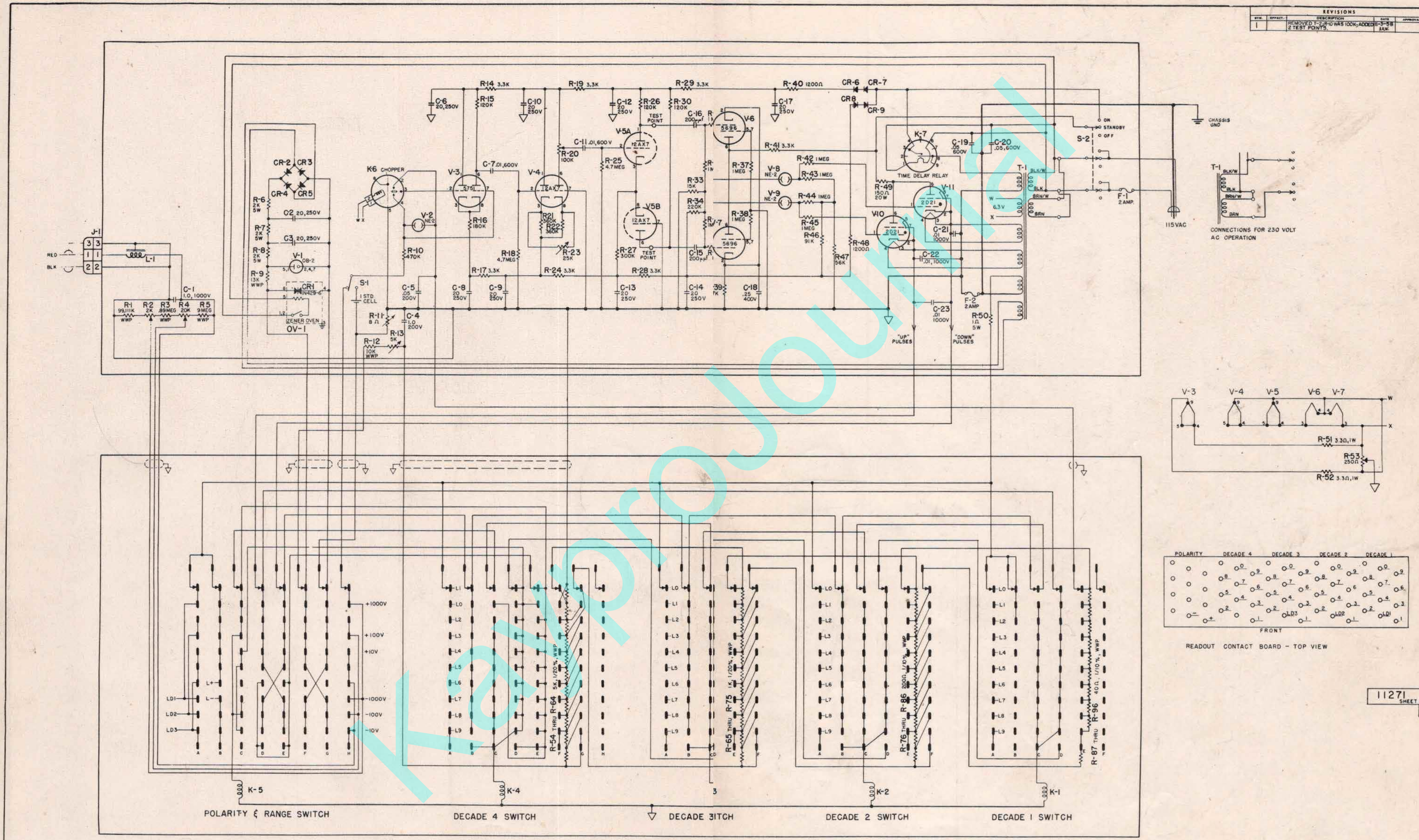
CIRCUIT REFERENCE	DESCRIPTION			PART NO.	MFR. CODE
R 20	Resistor: 100 K	variable, composition		CR 7734	F
R 21,22	Resistor: 360 K	fixed, composition ± 5%	1/2 w		A
R 23	Resistor: 25 K	variable, wire wound ± 5%	2 w	43C1 - 25K	H
R 27	Resistor: 300 K	fixed, composition ± 5%	1/2 w		A
R 31,32,35,36,37, 38,42,43,44,45	Resistor: 1 meg	fixed, composition ± 10%	1/2 w		A
R 33	Resistor: 15 K	fixed, composition ± 10%	1/2 w		A
R 34	Resistor: 220 K	fixed, composition ± 10%	1/2 w		A
R 39	Resistor: 27 K	fixed, composition ± 10%	1/2 w		A
R 40,48	Resistor: 1200 ohm	fixed, composition ± 10%	1/2 w		A
R 46	Resistor: 91 K	fixed, composition ± 5%	1/2 w		A
R 47	Resistor: 56 K	fixed, composition 10%	1/2 w		A
R 49	Resistor: 150 ohm	fixed, wire wound ± 5%	20 w		R
R 50	Resistor: 1 ohm	fixed, wire wound ± 5%	5 w		R
R 51,52	Resistor: 3.3 ohm	fixed, wire wound ± 10%	1 w		A
R 53	Resistor: 250 ohm	variable, composition		OH 2717	F
R 54 - R 64	Resistor: 5 K	fixed, wire wound 0.05%	1/2 w	PW 1719	NLS

CIRCUIT REFERENCE	DESCRIPTION	PART NO.	MFR. CODE
R 65 - R 75	Resistor: fixed, wire wound 1 K 0.05% 1/2 w	PW 1719	NLS
R 76 - R 86	Resistor: fixed, wire wound 200 ohm 0.1% 1/2 w	PW 1719	NLS
R 87 - R 96	Resistor: fixed, wire wound 40 ohm 0.1% 1/2 w	PW 1213	NLS
S 1	Switch, calibrate	11271 - 207	NLS
S 2	Switch, power	11271 - 208	NLS
T 1	Transformer, power	11271 - 206	NLS
V 1	Tube, electron, OB2		AA
V2,8,9	Tube, neon, NE2		AA
V 3	Tube, electron, 5751		AA
V 4,5	Tube, electron, 12AX 7		AA
V 6,7	Tube, electron, 5696		AA
V 10,11	Tube, electron, 2D21 W		AA
	MISCELLANEOUS		
	Knob, dial skirted round matte finish, black	70 - 3 - 2G	S
	Lamp, 6V	328	M
	Spring, readout lamp	12145 - 001 - 3	NLS
	Visor	10019 - 005	NLS
	Cable Ass'y input	11271 - 018	NLS
	Fastner, flush, Vibrex	F - 32	N
	Clamp Chopper	7 T	W
	Shockmount	1002 - 017	NLS
	Readout Ass'y	12148	NLS

CIRCUIT REFERENCE	DESCRIPTION	PART NO.	MFR. CODE
	Standard cell	Min 1	L
	Range Board Ass'y complete includes: printed circuit board, terminals, R1, R2, R3, R4, R5, R11	11271 - 210	NLS
	Decade 1 Ass'y complete includes: printed circuit board, bracket, resistors and wiring harness	11271 - 407	NLS
	Decade 2 Ass'y complete includes: printed circuit board, bracket resistors and wiring harness	11271 - 408	NLS
	Decade 3 Ass'y complete includes: printed circuit board, bracket resistors and wiring harness	11271 - 409	NLS
	Decade 4 Ass'y complete includes: printed circuit board, bracket resistors and wiring harness	11271 - 410	NLS
	Nyes Clock Oil	55022	Z
	Powdered Mica: "Motor Mica"		Y
	Colorless Mineral Oil (light)		BB

CODE LETTER	MANUFACTURER	ADDRESS
A	Allen Bradley Company	Milwaukee, Wis.
B	Amperite Company	New York, N.Y.
C	Bulova Watch Co., Inc. Quartz Crystal Division	Woodside, N.Y.
D	Cannon Electric Company	Los Angeles, Calif.
E	Centralab Division Globe-Union, Inc.	Milwaukee, Wis.
F	Chicago Telephone Supply Co.	Elkhart, Ind.
G	Circuit Instruments, Inc.	St. Petersburg, Fla.
H	Clarostat Mfg. Company	Dover, N.J.
I	Edcliff Instruments	Monrovia, Calif.
J	Cornell-Dubilier Electric Corp.	So. Plainfield, N.J.
K	Electron Products, Inc.	Pasadena, Calif.
L	Eppley Laboratory, Inc.	Newport, R.I.
M	General Electric Company Miniature Lamp Dept.	Cleveland, Ohio
N	General Tire & Rubber Company	Akron, Ohio
O	Hoffman Electronics Corp. Semi-Conductor Division	Evanston, Ill.
P	Littlefuse, Inc.	DesPlaines, Ill.
Q	P. R. Mallory & Company, Inc.	Indianapolis, Ind.
R	Ohmite Manufacturing Company	Skokie, Ill.
S	Raytheon Manufacturing Company Commercial Equipment Division	Waltham, Mass.
T	Sangamo Electric Company	Springfield, Ill.
U	Sarkes Tarzian, Inc. Rectifier Division	Bloomington, Ind.

CODE LETTER	MANUFACTURER	ADDRESS
V	Stevens - Arnold, Inc.	So. Boston, Mass.
W	Times Facsimile Corporation	New York, N.Y.
X	Triad Transformer Corp.	Venice, Calif.
Y	Scientific Lubricants Company	Chicago, Ill.
Z	Swartchild & Company	Chicago, Ill.
AA	Any brand tube meeting RETMA specifications	
BB	Any pharmacy	



3 WWP SIGNIFIES NLS WIRE WOUND PRECISION RESISTOR

2 ALL RESISTORS 1/2 W, 10%

1 CAPACITOR VALUES GIVEN IN MICROFARADS.

NOTES: UNLESS OTHERWISE SPECIFIED

UNLESS OTHERWISE SPECIFIED

DRAWN BY WALLIN

SCHEMATIC–DIGITAL VOLTMETER

MODEL 481

NON-LINEAR SYSTEMS INC.
DEL MAR AIRPORT
DEL MAR CALIFORNIA

11271