PHYSICS 4B

Lab Text Manual

Version 1.0

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PREFACE TO THE INSTRUCTOR

This Lab Text Manual evolved after years of providing Physics 4B students with a Lab Exercise Manual which included apparatus description, theory, and suggested exercises. We have eliminated the experimental exercises. This text includes the theory and descriptions of the apparatus that may be used to perform the experimental exercises which will follow under a separate cover.

The Physics 4A thru 4D lab program is predicated on the assumption that there is a minimum set of lab skills required for each course that prepares the student for subsequent courses in this sequence. In order for lab continuity in the Physics 4B, 4C & 4D program, the students should be exposed to the following Physics 4B concepts and exercises:

- **MEASUREMENT OF DC VOLTAGE AND CURRENT**
- **FAMILIARIZATION WITH A DUAL-TRACE OSCILLOSCOPE**
- **FAMILIARIZATION WITH A FUNCTION GENERATOR**

If you are teaching a lab in conjunction with other Physics 4B lab instructors during a given quarter, you should all agree on the choice and order of the labs to be performed. Equipment limitations and the complications of stocking the equipment on the storage carts prohibits each instructor from randomly "doing their own thing".

Please inform your students to put the lab equipment neatly and carefully back on the storage carts and to organize the equipment as they originally found it on the carts at the beginning of the lab period.

Any equipment which does not work properly should be tagged with some statement of the equipment difficulty and returned to the lab instructor. (Tags can be found near the door to the stockroom.)

Any suggestions for elaboration, correction or expansion should be directed to the authors; your comments are welcome.

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PREFACE TO THE STUDENT

This lab text is designed to provide you with reference material which describes in detail the apparatus used and the theory which supports experiments in DC (Direct Current) and AC (Alternating Current) circuit analysis, electric and magnetic phenomenon, and the conceptual physical processes that explain their behavior.

Not all of the experiments discussed in this lab text may be performed during any one quarter. Your instructor will provide you with the order of the lab experiments that the majority of you will be doing.

Much of the equipment used in this lab is expensive to purchase and to fix. Treat it with care. I f you are in doubt of how to properly use it, contact your lab instructor for help. It is also imperative that all equipment be returned to the lab carts in the order in which it was found. If any equipment is found be defective, please "tag" it with the tags found near the stockroom door and return it to your instructor.

In Physics 4B, the lab skills within a given lab group typically may vary over a wide range. No in-depth background in electronics is required for this lab as the experiments are designed to take a student with no prior skill to a level where he/she should be able to use an oscilloscope and the other lab equipment to take measurements with confidence and with understanding of the physical basis of why things are occurring. It is hoped that the experienced electronic technicians in the group can deepen their knowledge by doing these simple experiments. It is expected that each team will work as a **group** and that each member of the group understands thoroughly what is happening and why it happens before the experimentation proceeds further.

At the end of the quarter you will be evaluated individually on your success in achieving a set of specific lab-skill and/or lab record-keeping objectives common to most of the experiments performed. This set of objectives includes but it not limited to your ability to:

- Establish experimental objectives
- Pay attention to detail including units and significant digits
- Correctly use all equipment and measuring instruments
- Draw schematics and detailed pictorial diagrams
- Construct high-quality graphs using computer assisted techniques
- Record what is going on, in ink, as it happens directly in your lab record book
- Quantitatively analyze graphical presentations of data
- Use uncertainty analysis of data
- Perform discrepancy tests
- Draw valid conclusions based upon recorded data
- Derive theoretical models from fundamental principles
- Discuss experimental results and compare them with theory
- Apply learned lab skills to new situations

Lastly, when you have completed your lab, please return the equipment to the storage carts as neatly, or more neatly, than you found it at the lab beginning. "Neatness is a virtue" and facilitates the ease with which the students in the following labs quickly start their experimentation.

LAB INTRODUCTION

In learning how to make electrical measurements and to construct circuits which function effectively and efficiently in electronics oriented lab, each student should review the following guidelines. Check with your instructor before applying power to see if your circuit is connected correctly.

Study these guidelines carefully!!

THE "TOP 10" THINGS TO REMEMBER WHEN WORKING WITH ELECTRICITY

10. Assemble ALL circuits with the power disconnected and OFF.

9. Connect actual current-carrying circuit first. Whenever possible, use RED wires for HIGH potential and black wires for low. Then add the connections to the test equipment.

8. Double check all connections before turning on the power. If in doubt, have your instructor check your circuit before you turn on the power.

7. NEVER touch a circuit with both hands when the power is on.

6. Turn all voltage and current setting knobs on the power supply to ZERO before turning the power switch to ON, then slowly increase to the desired level. Turn OFF the power in the reverse order of the above. This technique will introduce less stress, both voltage and current, in the circuit.

5. Thoughtless knob twisting is a NO-NO. Before you set or change the setting on any measuring instrument, use physical reasoning first to predict the suspected outcome. This ability to predict the outcome is a measure of your understanding of what you are doing and what is going on.

4. Pull on the plug not the wire to remove the plug from the socket or jack.

3. Avoid mishandling the equipment by dropping it or by carelessly putting on the table.

2. Remember, "Neatness is a virtue". Make sure all equipment is turned off, all connecting wires are put away by type and color, your lab table area is clean and cleared, loose garbage is placed in garbage cans, and your lab stool is replaced in it's correct position.

1. NEVER CONNECT AN OHMMETER TO ANY COMPONENT CARRYING CURRENT.

EXPERIMENT 1: MEASUREMENT OF RESISTANCE

SPECIFIC OBJECTIVES:

- To use the **Resistor Color Code** and **Tolerance Code** to predict resistance values
- To measure resistance using a **VOM**, a **DMM**, and the **HP-DMM**

INTRODUCTION:

Some elementary particles (electrons, protons, etc.), have an intrinsic electrical property called **Electric Charge** (q). The motion of these particles **(Charge Carriers)** results in a displacement of electric charge (dq), the time-rate of which (dq/dt) is called **Electric Current** (I). Charge flow (current) is produced when a battery of **Electromotive Force** (**Emf = ε**) or some other source of electrical energy produces an **Electric Field** (**E**) in a **conductor** or other device which contains mobile charge carriers (electrons). The charge carriers are driven by the **Electric Force** (**F**) of the E-field. **Resistance** (R) is the measure of the opposition that a conductor or other device resents to the motion of charge carriers. Resistance is measured in the SI (System International) unit [OHMS] = [Ω].

The **GLOSSARY** at the end of this manual gives a more detailed definition and/or description of the words/terms/units/symbols used in this lab course.

A **Resistance Color Code** is used by resistor manufacturers to specify the **Resistance** and **Tolerance** of their resistors. These two characteristics are usually identified by four (or five) color bands, where each color represents a number. When resistors have 4 color bands, the first two bands, reading from left to right, represent the first two digits of the resistance value and the third band represents the multiplier, which is expressed as a power (n) of 10 (i.e., 10^n), and the 4-th band indicates the % tolerance.

[RESISTANCE COLOR CODE]

COLOR	DIGIT	MULT'R
Black	0	0
Brown	1	1
Red	2	2
Orange	3	3
Yellow	4	4
Green	5	5
Blue	6	6
Violet	7	-2
Grey	8	-1
White	9	

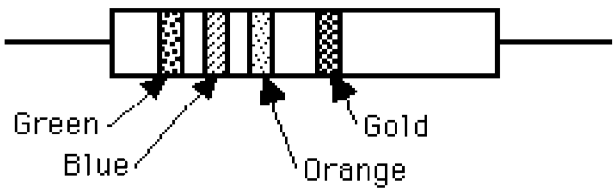
[TOLERANCE COLOR CODE]

COLOR	TOLERANCE
None	20%
Silver	10%
Gold	5%
Orange	3%
Red	2%
Brown	1%
Green	0.50%
Blue	0.25%
Violet	0.10%
Grey	0.05%

- **Fig.1.1 Resistor Color Code and Tolerance Table**

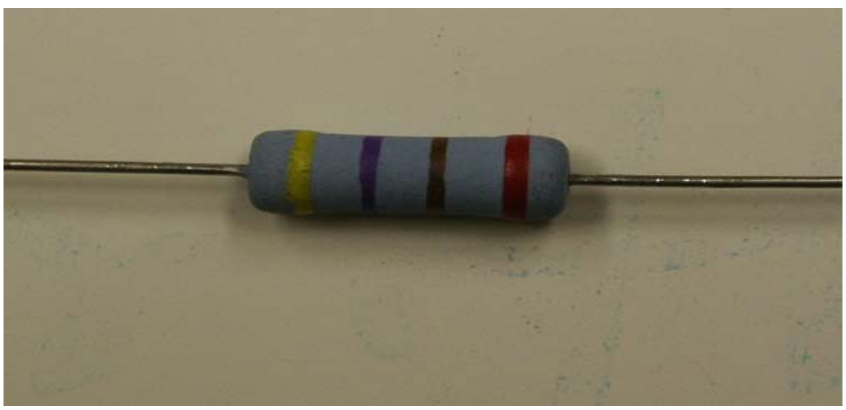
A typical color-coded resistor is shown in Fig. 1.2. Holding the resistor so that the colored bands are located to the left end of the resistor, the first and second colored bands represent the first two

significant figures of the resistance value. The third band gives the power of 10 and the fourth colored band is the tolerance value. The manufacturer color-coded this resistor stating that the resistance is within the range of
56,000 ± 2800 [Ohms].



- **Fig. 1.2 Color-coded Resistor [56,000 ± 5% Ohm]**

Fig. 1.3 is an example of another color-coded resistor in which the bands are not located at one end of the resistor. The bands are colored yellow, violet, and brown, red. Since yellow is NOT a color in the Tolerance Code, the resistor is positioned in the photograph to be read from left to right as
(470 ± 24) [Ohms].



- **Fig. 1.3 Color-coded Resistor [470 ± 5% Ohm]**

Resistance is measured using the **Ohmmeter** function of **multi-meters**. Common multi-meters include the **VOM** (Volt-Ohm-Milliameter)**,** the **DMM** (Hand-held Digital Multimeter) and the **HP-DMM** (Hewlett-Packard Digital Multimeter).The resistance-measuring circuit of the ohmmeter function supplies a known value of current to the unknown resistive device and then measures the voltage developed across the device. This voltage is then converted into a digital number readout or into an analog value on a meter face which corresponds to the resistance value of the device.

- **It is, therefore, necessary when using an ohmmeter to remove ALL external power supplied to the device or to the circuit under test. Serious damage to the ohmmeter may result if this warning is not followed.**

APPARATUS DESCRIPTIONS: **Refer to Appendix II for diagrams and details**.

1. **V0M**: Stands for **V**olt-**O**hm-**M**illiameter. This classic analog multi-meter can be used to make accurate measurements of the electrical properties of AC and DC Voltage (Potential Difference) in units of [**V**olts], **Resistance** in units of [Ohms], and Direct Current in units of [**M**illiamps].

2. **DMM**: A **D**igital **M**ulti-**M**eter is a small, hand held, battery powered multi-meter that produces a digital readout when measuring Potential Difference, **Resistance**, and/or DC Current. Although the readout is digital, a DMM, under certain conditions can display numbers (readouts) with an excessive number of non-significant digits.

3. **HP-DMM**: The **H**ewlett-**P**ackard 3468A/B **D**igital **M**ulti-**M**eter is non-portable and powered from the 120 volt AC line voltage. It can provide highly accurate and precise measurements of DC Voltage, true RMS AC voltage, **2- and 4-wire Resistance** and DC and true RMS AC Current. The HP-DMM is auto-zeroing and auto-ranging, has provisions to control the number of significant figures in the digital readout display and is computer programmable.

EXPERIMENT 2: MEASUREMENT OF DC VOLTAGE AND CURRENT

SPECIFIC OBJECTIVES:

- To learn how to use a VOM and both DMM's to measure DC voltage and current.
- To determine resistance using manual and computer-assisted graphical techniques
- To use two voltmeters to measure the current/voltage characteristics of a Type 47 lamp

INTRODUCTION:

Review Experiment 1 **INTRODUCTION** to refresh your understanding of the concept of electric current.

To produce a steady current in a conductor or other device, a source of **Electrical Energy** is needed. **Chemical Energy** in a battery is converted into Electrical Energy which shows up as **Kinetic Energy** of the charge carriers and this energy is converted into radiated **Heat Energy** in a resistive circuit. The loss of electric energy is measured by the decrease in the **Electric Potential** (V) in the circuit. The **Potential Drop** or **Voltage Drop** (ΔV) across a resistor is proportional directly to the current in the resistor.

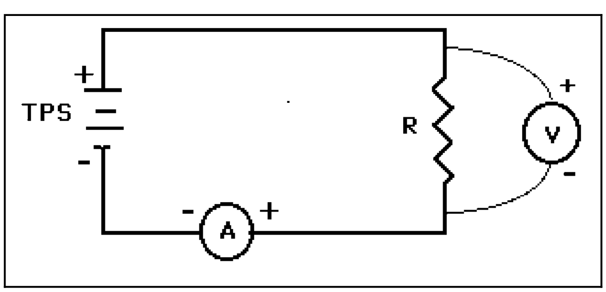
When there is no possibility for confusion, the term "voltage" will be used in place of "potential difference" and/or "voltage-drop". It is sometimes convenient to write V, instead of ΔV, in these cases.

Ohm's LAW is an empirical mathematical formula which states that, in a purely resistive element where electrical energy is converted entirely into heat energy, the current (I) is a linear function of the voltage drop (ΔV) across the element. Using (V) for (ΔV) we obtain: $I = G*V = (1/R)*V$, where G is the **Conductance** of the element and it's reciprocal, $R = 1/G$, is called **Resistance**.

APPARATUS CIRCUIT DESCRIPTIONS:

1) Refer to APPENDIX II for detailed descriptions of the **VOM,** the **DMM** and the **HP-DMM** and operating procedures for their use to **measure both voltage and current**.

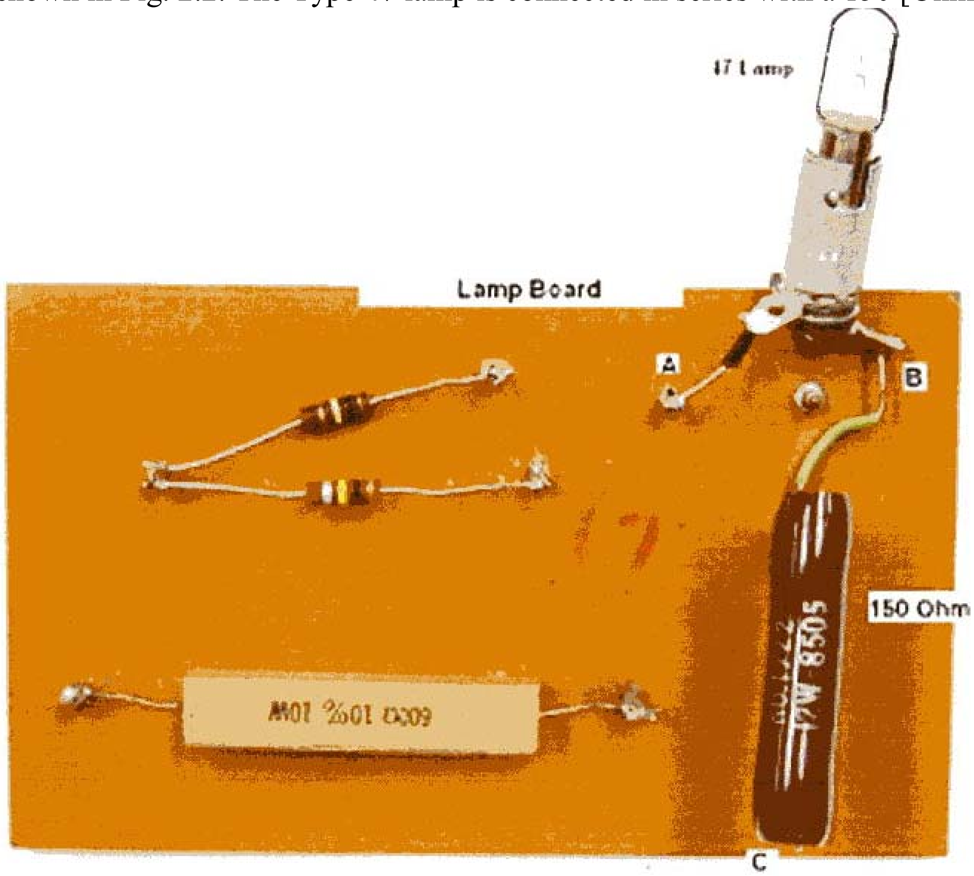
2) The resistance of a device can be graphically determined by compiling multiple sets of current in and voltage across a resistor. The schematic diagram, Fig. 2.1, shows a (TPS) (Transistorized Power Supply) (Refer to Appendix II) connected in series with a resistor (R) and ammeter (A) to form a **single-loop** circuit as shown by the **SOLID LINE** in the diagram. The ammeter (A) measures the DC current in the circuit. A voltmeter (V) is **then added** by connecting it across (in parallel with) the resistor, as shown by the DOTTED LINE. This meter measures the **DC voltage drop (ΔV)** across the resistor.



- **Fig. 2.1. Schematic Diagram of a Series Circuit to measure DC Current and Voltage.**

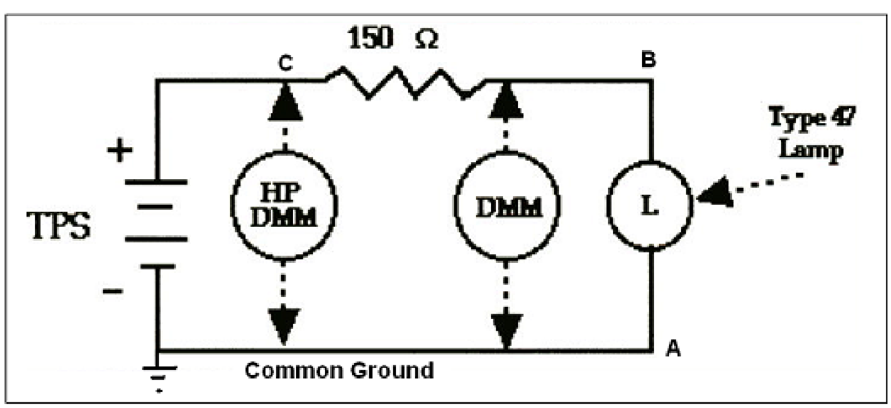
Since the current (I) in the resistor **depends upon** (is a function of) the voltage (ΔV) across the resistor, a plot of the dependent variable (I) in [Amperes] on the y-axis and the independent variable (V) in [Volts], where V = ΔV, on the x-axis should yield a "Characteristic Curve" of the resistor which is linear. Since I = (1/R) V, the reciprocal of the slope should be the graphical value of the resistance of the resistor.

A photograph of the circuit board that may be used to measure and collect current/voltage data is shown in Fig. 2.2. The Type 47 lamp is connected in series with a 150 [Ohm], 12 [Watt] resistor.



- **Fig. 2.2 Photograph of Lamp Board with several resistors.**

Fig. 2.3 is a schematic diagram of how two voltmeters can be connected to a series circuit containing a TPS power supply, a Type 47 lamp and a 150 [Ω] resistor.



- **Fig. 2.3. Schematic Diagram of a Series Circuit with Two Digital Voltmeters.**

The HP-DMM in schematic diagram, Fig. 2.3 is connected to measure the **DC Terminal Voltage** of the TPS and the DMM used to measure the **D.C. voltage** across the lamp. The difference between these two voltages (ΔV) = ($V_{HP\text{-}DMM}$ - V_{DMM}) divided by the "**measured"** value of resistance of the 150 Ω resistor is the current in the lamp; that is, the current $I = (V_{HP\text{-}DMM} - V_{DMM})/(R_{Measured})$. Several values of these two voltages provide sufficient current/voltage data to determine graphically the "characteristic resistance" of the lamp.

[Option A] If the 2-voltmeter method is used to gather very small current/voltage data for the lamp, the slope of the current-voltage data should be linear as at very low currents, the lamp is purely resistive as it producing only thermal heat. This low-current resistance value will be called the "cold" resistance of the lamp. As more energy is supplied to the lamp, the lamp begins to emit infrared and then visible radiation (light) energy so that the current-voltage relationship should no longer be linear.

[Option B] With the TPS disconnected from the circuit, the DMM is used to measure directly the "cold" resistance (in Ohms) of the Type 47 lamp bulb. The HP-DMM can then used to measure separately the voltage output (in Volts) of the DMM when it is set on the same Ohmmeter range as was used to measure the bulb resistance. The "cold" resistance of the bulb determined from this voltage/current data should approximate the initial slope of the very small current-voltage data graph.

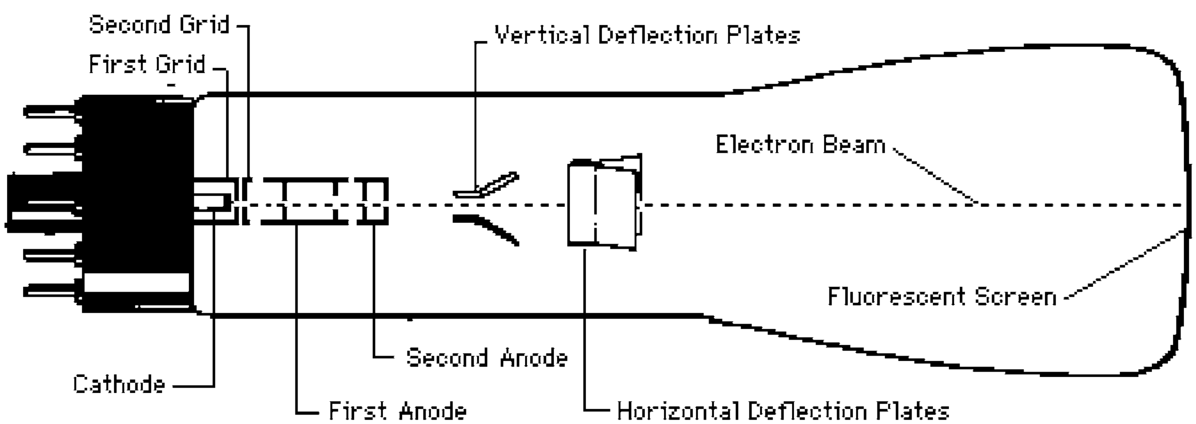
EXPERIMENT 3: INTRODUCTION TO THE CATHODE RAY TUBE (CRT)

SPECIFIC OBJECTIVES

- To learn how to operate and measure the output voltages from the Heathkit high-voltage DC supply (Refer: Appendix II) connected to a CRT.
- To measure the amount of deflection (D) of an electron beam in a CRT as a function of different acceleration (V_a) and deflection (V_d) voltages.

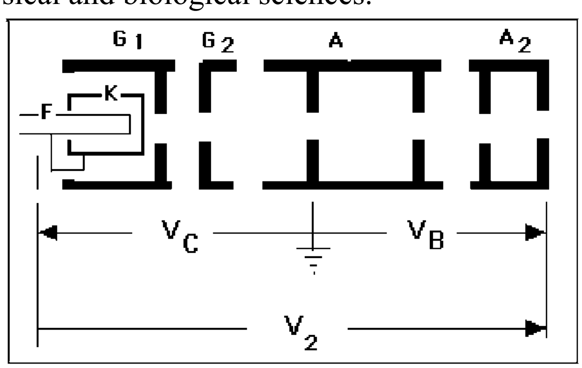
INTRODUCTION:

The central instrument in this experiment is an electron-beam tube called a **C**athode-**R**ay **T**ube (CRT). as shown in Fig. 1. It contains an "electron gun", whose cross-section is shown in Fig. 2, which emits electrons, accelerates them to some final speed, and then focuses the beam to produce a small spot of light on the face of the CRT. The inside face of the CRT is coated with a fluorescent screen which gives off light when bombarded (struck) with electrons. A deflecting potential difference (V_d) is applied across the vertical deflection plates shown in Fig. 1. This system is enclosed in a glass tube from which air has been evacuated to a very low atmospheric pressure to avoid scattering of the beam by collisions of the electrons with air molecules.



- **Fig. 3.1. <u>Pictorial</u> Diagram of a Cathode Ray Tube.**

In addition to providing an experimental arrangement for the study of electron motion, the CRT is also the most important component of an **Oscilloscope**, a valuable instrument for making measurements in both the physical and biological sciences.



- **G.3.2),Fig. 3.2. Cross-sectional View of Electron Gun in a CRT.**

The "electron gun" (Fig. 3.2) produces electrons that are thermally emitted from the barium/strontium oxide coated cathode (K) when heated to a temperature of about 1200 K (Kelvin) by the spiral filament (F) carrying (AC) current. The cylindrical, coaxial anodes (A_1) & (A_2) contribute to the focusing and acceleration of the beam. The grid (G_2) is used to control the intensity of the electron beam.

The two voltages ($-V_C$) & (V_B) are produced by the Heathkit IP-32 power supply (See APPENDIX II). They are connected in series at the common ground connected to the accelerating anode (A_1). The electron beam is accelerated to a <u>total</u> potential (V_2) given by:

[3.1] $V_2 = |-V_C| + |V_B|$.

A theory will be developed later to confirm that the deflection (D) of the electron beam is a function of the <u>ratio</u> of the deflecting potential difference (V_d) and the accelerating potential difference (V_2),

[3.2] $\pm D =$ (**Tube Constant**)$*(\pm V_d/V_2)$

where the deflecting potential difference (V_d) is supplied by a Transistorized Power Supply (TPS) (See APPENDIX II) and the **Tube Constant** is a function of **physical dimensions** of the CRT

Deflection data (D) will be collected for electrons of various kinetic energies (KE) as they pass through the horizontal deflecting plates. Vertical electric fields of various magnitudes and directions will contribute to various deflections. If this data is appropriately plotted on a single graph, a “**graphical Tube Constant**" can be determined from the **<u>single graph</u>** and can be compared with an “**algebraic Tube Constant**” derived from a later derived theory based upon physical principles as they apply to the electron motion and deflection within the CRT.

DESCRIPTION OF EQUIPMENT AND APPARATUS:

(See Fig. 3.3) If the CRT lies in a horizontal plane, the vertical component of the earth's magnetic field will always deflect the spot to the left of the center as you face the tube. If the axis of the tube is rotated so that it is parallel to the horizontal component of the earth’s magnetic field, the spot should lie on the y = 0 axis.

Some power supplies are constructed with vacuum tubes which contain filaments and cathodes that need to be "**warmed up**". The Heathkit IP-32 Power Supply should be turned to **STANDBY** for warm-up before applying any high voltages to the tubes

Note that the Heathkit IP-32 Power Supply has two meters: a voltmeter (V) and an ammeter (A). The high voltage outputs, V_C & V_B, are measured independently on the voltmeter by using the proper position of the **<u>slide switch</u>** located near the center of the power supply. The ammeter measures the electron beam current which, in this experiment, is negligible.

- **<u>If the plastic shield is removed</u>**, a small transparent grid can be taped to the front of the CRT, **BUT, <u>all students in your lab group must wear safety glasses</u>**.

The apparatus is shown connected in Fig. 3.3 on the next page. The TPS (transistorized power supply) which provides the deflecting voltage (V_d) may not be the Heathkit Model EUW-17 shown in Fig. 3.3. Any TPS which provides a DC output from 0 to 50 Volts, 250 mA maximum may be used.

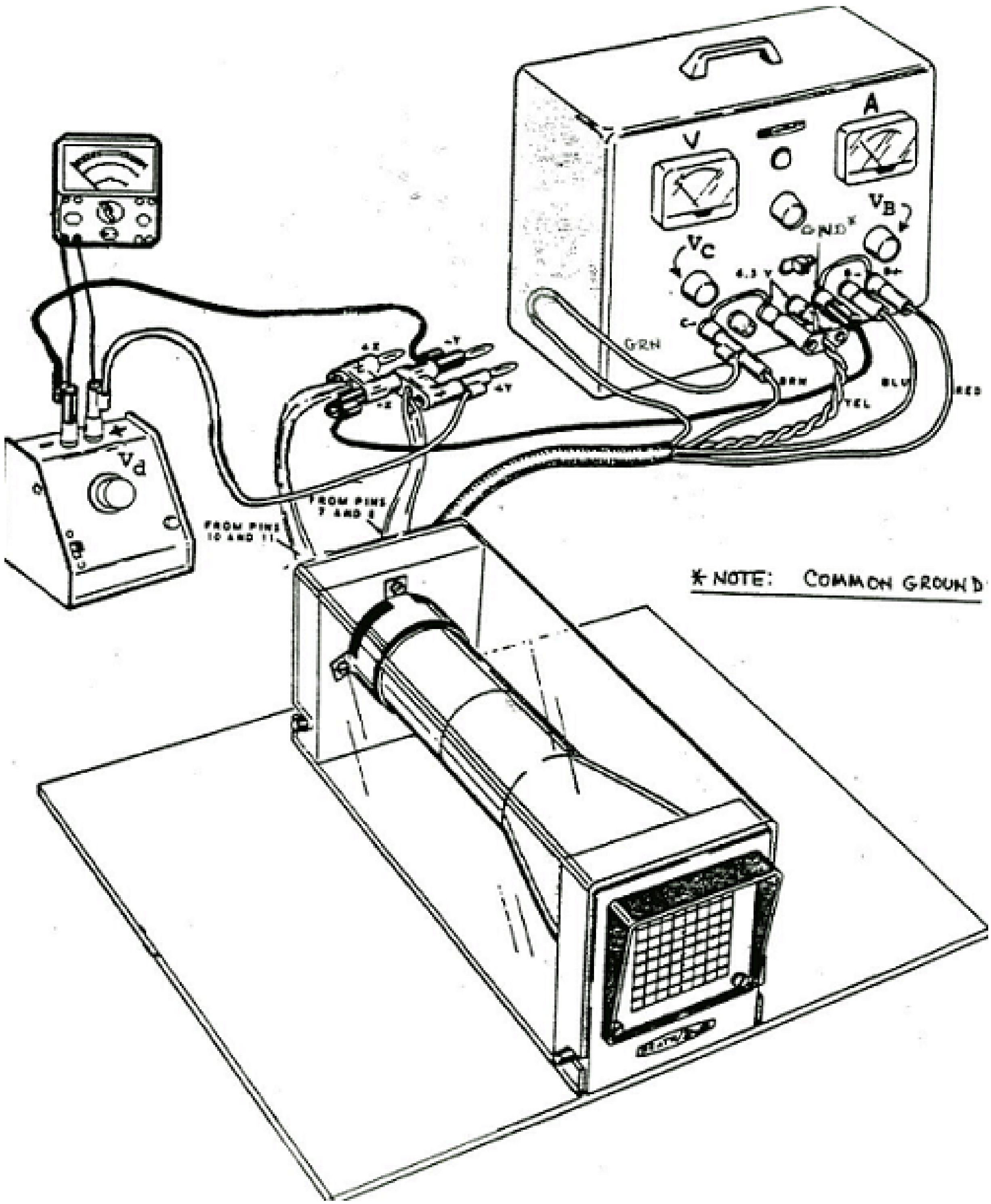


Fig. 3.3. <u>Pictorial</u> Diagram **of the Electron Deflection Apparatus.**

EXPERIMENT 4 ELECTRON MOTION IN ELECTRIC (E) FIELDS

SPECIFIC OBJECTIVES:

- To use fundamental physical principles to derive a mathematical function which describes the motion of electrons in a CRT
- To evaluate the slope of the derived deflection function using CRT data
- To compare the value of the slope calculated from the mathematical deflection function with the graphical value determined from the slope-intercept graph of Exp 3.

INTRODUCTION:

In the previous experiment we learned that electrons in an electron beam in a CRT are accelerated to a potential (V_2) given by $V_2 = |-V_C| + |V_B|$, where V_C & V_B are voltages produced by the high voltage power supply IP-32.

A potential difference (V_d) applied between the two horizontally-oriented plates separated by a distance (d) produces a transverse electric field given by $\mathbf{Ey} = \mathbf{-}\ (Vd/d)\ \mathbf{j}$ as seen in Fig. 4.1. A vertical force $\mathbf{F_y} = e*\mathbf{E_y}$ is exerted on the electrons during the time interval (Δt) it takes the electrons to pass horizontally between the plates. This electric force imparts an impulse to the electrons causing them to undergo a change in momentum in the vertical direction given by:

[4.1] $(\mathbf{F_y})\ (\Delta t) = (m)\ (\Delta \mathbf{v_y})$.

The time interval (Δt) is also the time it takes the electron to travel at an axial speed (v_z) along the z-axis a distance equal to the length of the plates (z). The axial speed is determined by the kinetic energy
(KE) = $(1/2)m(v_z^2)$ the electrons gain at the expense of the potential energy lost ($e*V_2$) during their transit of the electron gun:

[4.2] $e*V_2 = (1/2)\ m\ (v_z^2)$.

The deflection from horizontal of the electrons as they emerge from the deflecting plates is measured by the deflection angle (θ):

[4.3] $\mathrm{TAN}\ (\theta) = v_y/v_z$.

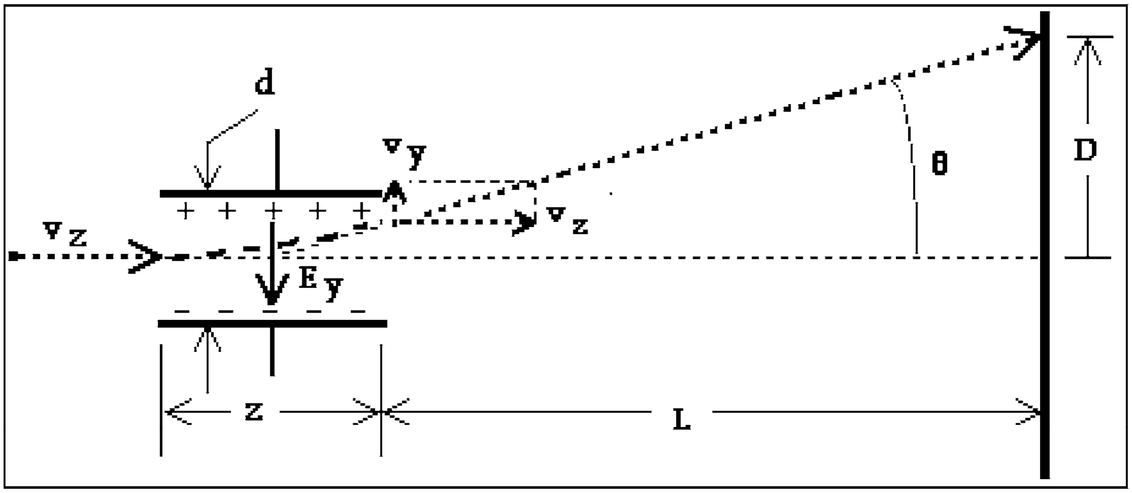
The vertical deflection distance (D) of the spot on the screen is also proportional to TAN (θ):

[4.4] $\mathrm{TAN}\ (\theta) = D/\ (L+z/2)$.

The deflection of the electron beam (D) is a function of both the accelerating potential (V_2) and the deflecting potential (V_d). An algebraic relation can be derived from the above physical principles which will allow an algebraic determination of a "TUBE CONSTANT" of the form:

[4.5] $\pm D = (\mathrm{TUBE\ CONSTANT})*(\pm V_d\ /\ V_2)$.

The TUBE CONSTANT is a function of physical dimensions of the CRT.



- **Fig. 4.1. Electrons in the beam of a CRT have an average velocity (+v_Z k) as they enter the vertically-directed electric field (-E j) between the deflection plates.**

The scale diagram in Fig.4. 2 shows the geometry of the CRT. The dimension (3-7/8"), as printed on the scale diagram, means 3 and 7/8 inches and is equal to (3" + 7/8").

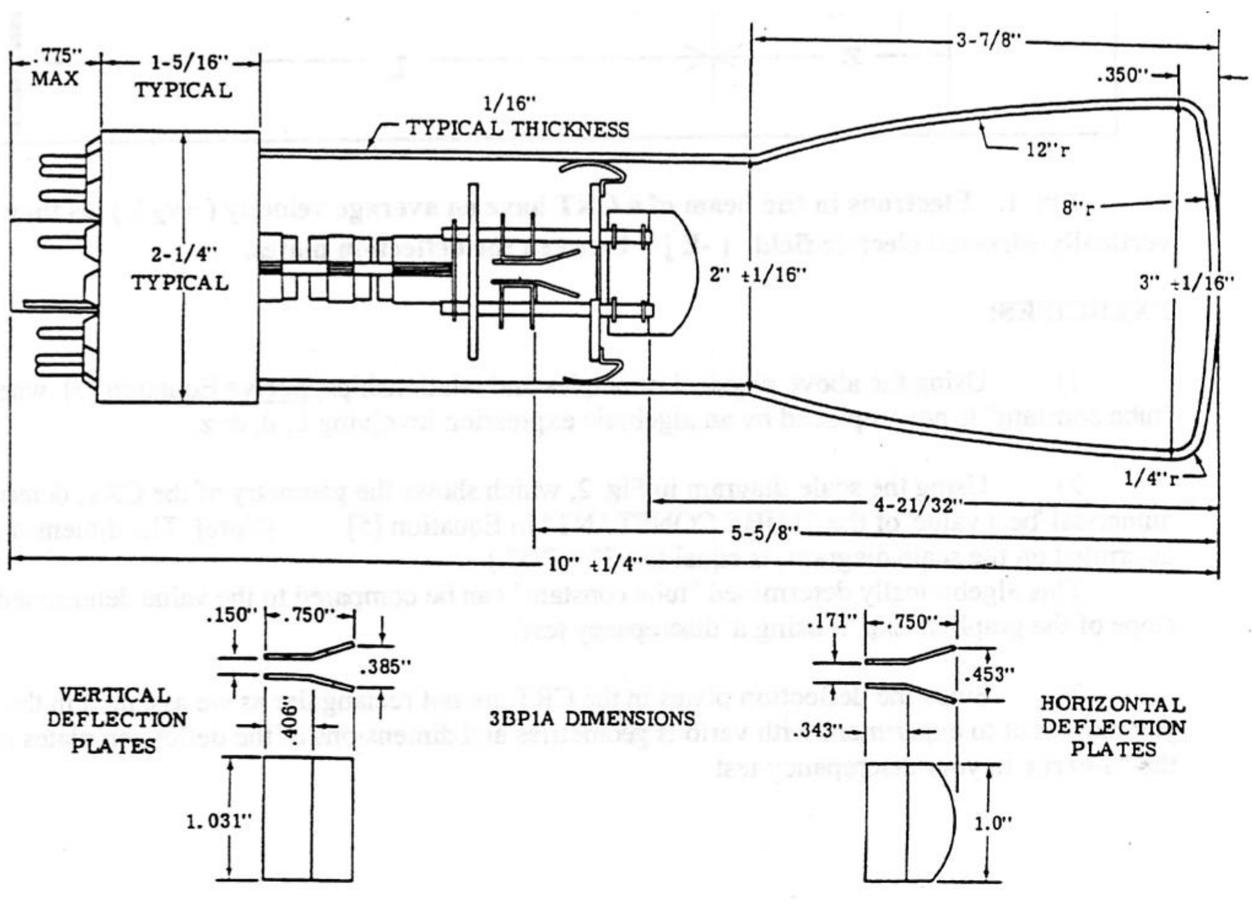


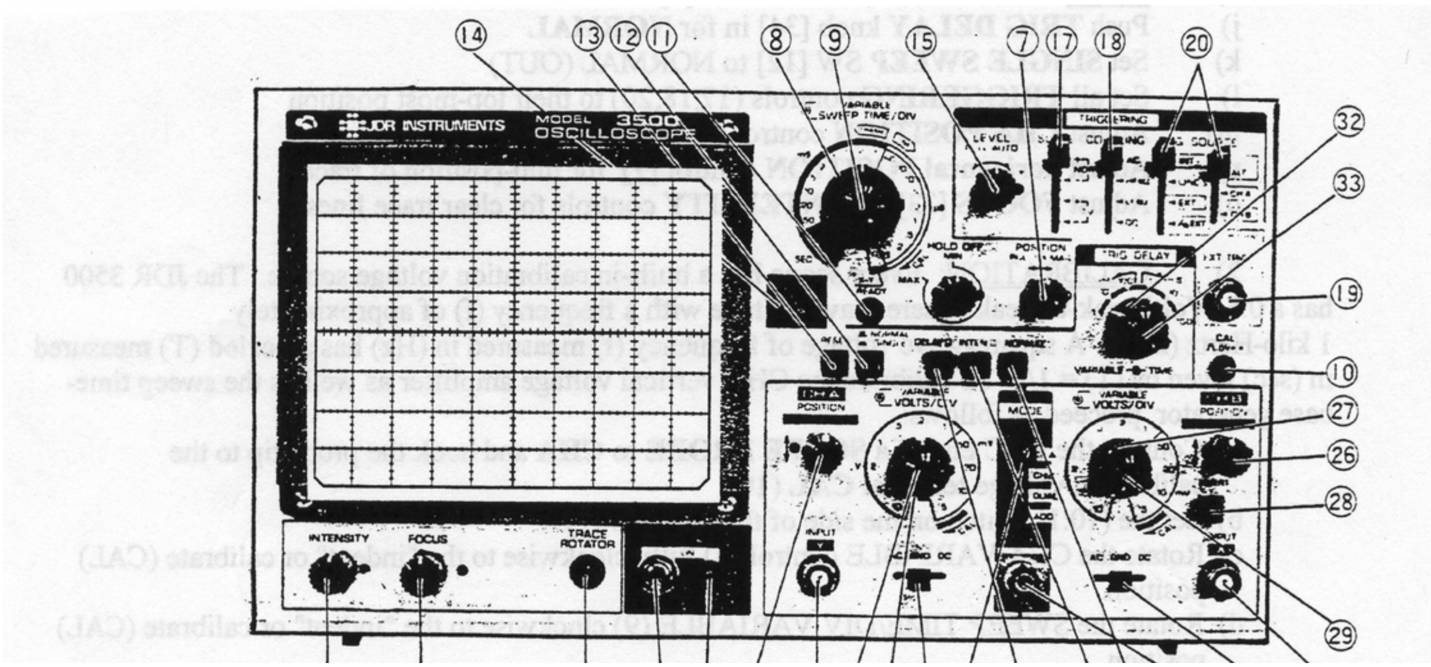
Fig. 4.2. Scale Drawing of the CRT used in Exp. 3 & 4.

EXPERIMENT 5: THE JDR MODEL 3500 OSCILLOSCOPE

SPECIFIC OBJECTIVES:

- To learn the initial **Set-up** procedure for an oscilloscope
- To learn how to measure DC voltage and frequency with an oscilloscope
- To learn how to calibrate voltage and time-sweep of an oscilloscope
- To learn how to **Zero Adjust** an oscilloscope
- To measure the DC voltage with an oscilloscope

INTRODUCTION:



- **Fig. 5.1. Front View of the JDR 3500 Oscilloscope.**

Essentially, an oscilloscope consists of a cathode ray tube, a horizontal sweep circuit, a trigger circuit which synchronizes the input signal with the horizontal sweep, horizontal and vertical voltage amplifiers, and high and low voltage power supplies.

The oscilloscope is actually a voltage measuring instrument which can measure voltage as a function of time (or as a function of another voltage). Both channels have a vertical sensitivity of 5 [mV/DIV] with a rise time of better than 10 [nsec] over a band width of 35 [MHz]. The inside surface of the face of a CRT contains a fluorescent coating which emits light when bombarded with high-energy electrons. A visible **trace** can be displayed when electrons are continually moved up & down and across the fluorescent screen. **Voltage** is displayed on the vertical axis as a function of time (or another voltage) on the horizontal axis. In this experiment we will be using the scope only to measure voltage as a function of time.

An 8 cm x 10 cm reticule (**grid**) in front of the CRT face provides calibration marks for measurements of voltage (vertical) and time (horizontal) Although the number of dials, knobs, input connectors, and switches is greater than those on either a VOM or a DMM, **the scope is simply just another "voltmeter"**.

OSCILLOSCOPE OPERATION:

1) INITIAL SCOPE SETTINGS: Prior to any measurements with the JDR 3500 scope, the below list summarizes the initial set-up procedure:

a) See that the **POWER** switch to **OFF**

b) Turn **CH A POSITION, CH B POSITION and the HORIZONTAL POSITION** controls to mid-position

c) Set **AC-GND-DC** switch for **CH A** to **DC**

d) Set **MODE** switch to **CHA**

e) Set the **POWER** switch to **ON**

f) Pull **TRIGGERING LEVEL** control for **AUTO**

g) Turn **INTENSITY** control to produce a display

h) **PUSH** the **PULL 5X MAG** control for **NORMAL**

j) Push **TRIG DELAY** knob in for **NORMAL**

k) Set **SINGLE SWEEP** SW to NORMAL (OUT)

l) Set all **TRIGGERING** controls to their top-most position

m) Adjust **CHA POSITION** control for mid-position of trace

n) Adjust **horizontal POSITION** control for mid-position of trace

o) Adjust **FOCUS** and **INTENSITY** controls for clear trace lines

2) CALIBRATION: Every scope has a built-in calibration voltage source. The JDR 3500 has a 0.5 [Volt] peak-to-peak square-wave voltage with a frequency (f) of approximately 1 kilo-Hertz (kHz). A square-wave voltage of frequency (f) measured in (Hz) has a **period** (T) measured in (sec) given by (T) = 1/f. To calibrate the **CHA** vertical voltage amplifier as well as the sweep time-base generator, proceed as follows:

a) Connect the **BNC** end of a **SCOPE PROBE** to **CHA** and hook the probe tip to the calibration voltage terminal **CAL**.

b) Set the **(10:1)** switch on the side of the probe to (1).

c) Rotate the **CHA VARIABLE** control fully clockwise to the "indent" or calibrate **(CAL)** position.

d) Rotate the **SWEEP TIME/DIV VARIABLE** clockwise to the "indent" or calibrate (CAL) position.

e) Calculate the correct setting of the **CHA VOLTS/DIV** control so that the CAL voltage is 5 cm high. [Note: 0.5 Volt = (5 cm)$*$(0.1 Volt/cm)

f) Calculate the setting of the **SWEEP-TIME/DIV** control to display one complete cycle in 10 cm.

Adjust the **TRIGGER LEVEL** control to obtain a stable trace.

g) A square-wave trace which is 5 cm by 10 cm should be displayed.

h) If either the vertical height or length (period) of the trace is not as calculated, fine adjustments of **CH A VOLTS/DIV** and/or **SWEEP TIME/DIV** may be necessary for calibration.

3) ZERO-ADJUSTING THE SCOPE: In order to make quantitative measurements of DC voltages using a scope, one must know where the reference voltage ZERO VOLTS (V= 0) is located on the vertical (voltage) axis.

a) Switch the **CHA** switch to **GND**; this has the same effect as "grounding" the end of the probe.

b) **Pull** the Trig **LEVEL** knob (15) to form a trace line.

c) Adjust **CHA POSITION** control until the horizontal trace of zero volts lies on one of the horizontal grid lines; this grid line now corresponds to zero (0) volts on the scope.

d) Switch **CHA** switch back to **DC**.

4) MEASURING DC VOLTAGE WITH A SCOPE. With the zero volts reference line established and the CHA switch set at DC, any up or down shift of the horizontal trace indicates the presence of a DC voltage.

The scope is a 35 MHz Dual-Trace Oscilloscope with both vertical amplifiers having a high sensitivity of 5 [mV/DIV]. When the vertical amplifier PULL 5X GAIN control is pulled, the vertical sensitivity is expanded to 1 [mV/DIV].

EXPERIMENT 6: THE FLUKE PM 3084 ANALOG OSCILLOSCOPE

SPECIFIC OBJECTIVES:

To learn the operational features of the Fluke PM3084 Oscilloscope and how to use them. These features include but are not limited to:

- STANDARD SETTING
- AUTO SETUP
- VERTICAL SETUP
- TIME BASE SETUP
- DIRECT TRIGGER SETUP
- CURSOR OPERATION

INTRODUCTION:

The PM3084 is a 4 channel 100 MHz oscilloscope with input sensitivities up to 2 [mV/div] and with 1% voltage and timing accuracy. The AUTOSET function automatically sets up the display and adjusts time, amplitude and triggering of any voltage connected to the input. Cursors give an extensive set of measurement possibilities including fully automated voltmeter functions. This instrument is designed to be used by personnel who have had experience using 2-channel oscilloscopes.

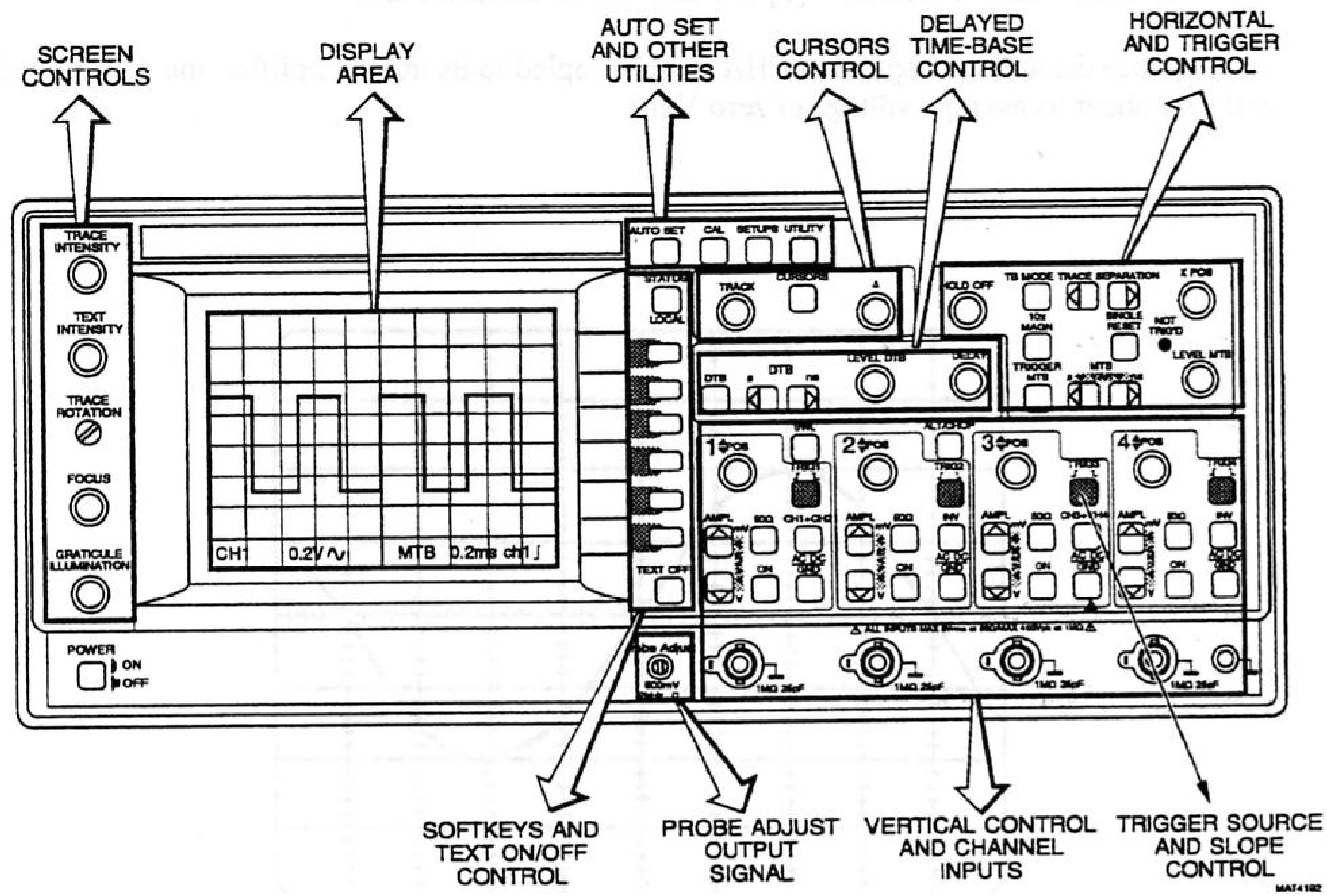


Fig 6.1. Front panel layout of the Fluke PM3084 Analog Oscilloscope

OSCILLOSCOPE OPERATION:

1) <u>TURNING ON A THE INSTRUMENT</u>:

a) Pull both handle ends outwards away from the scope and rotates the handles downward to one of the three sloping positions.

b) Pull the clamping lip on the top side of the front cover and remove the cover.

c) Connect the power cord and set the front panel power switch to ON. The instrument will perform an automatic built-in power-up routine and is immediately ready for use.

d) Press the STATUS key and TEXT OFF key simultaneously. This will set the instrument in a predefined default condition (STANDARD SETUP). A horizontal trace will be displayed on the screen with the text below.

2) <u>SCREEN CONTROLS</u>:

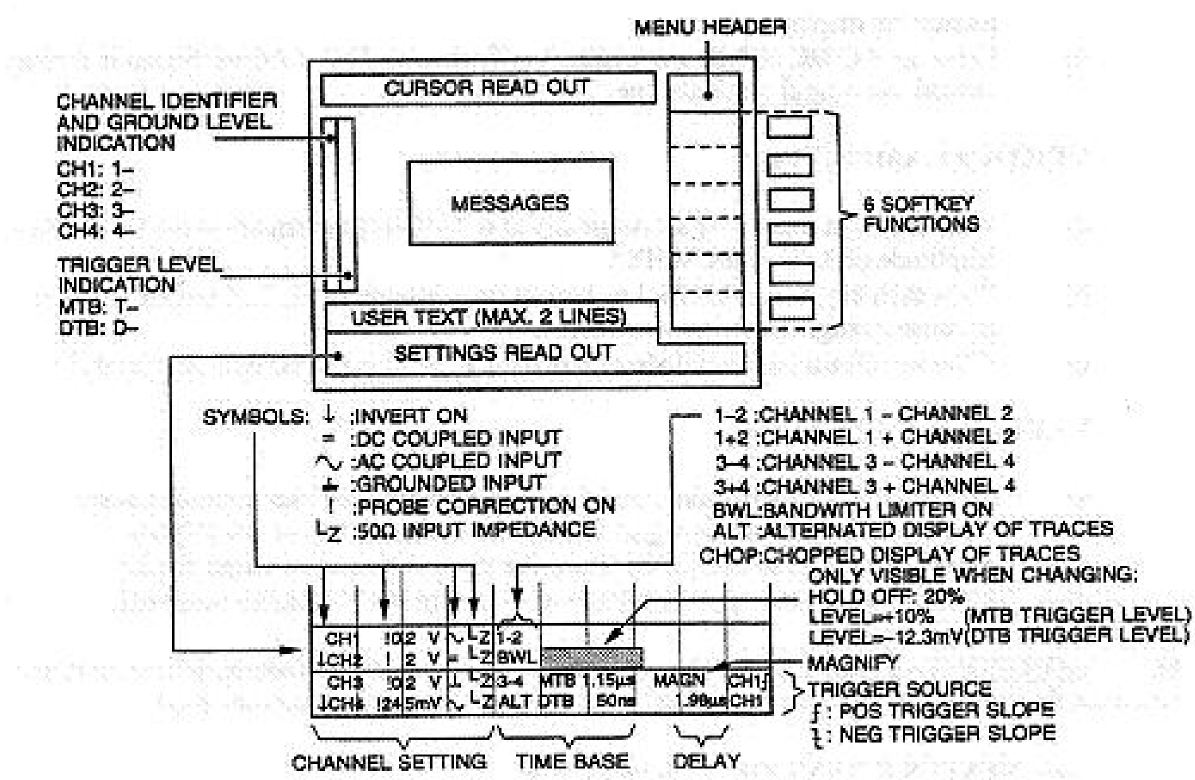
a) The TRACE INTENSITY control adjusts the brightness of the trace.

b) The TEXT INTENSIY control adjusts only the text brightness.

c) The sharpness of the trace AND text is optimized by the FOCUS control.

d) The trace should be parallel to the horizontal grid graticule lines. The lab instructor can adjust the screwdriver TRACE ROTATION control.

3) <u>DISPLAY LAYOUT</u>: The following illustration shows the layout of the display with a maximum of text. Most text is visible only when specific functions are activated.



- **Fig. 6.2 Display Layout with Maximum Text**

4) **<u>AUTO SETUP</u>:** The best way to start each measurement is by using the AUTOSET key. This automatically finds and scales all relevant parameters on all channels.

a) The PROBE ADJUST SIGNAL is a square wave with a lower level of 0 [V] and an upper level of 600 [mV]. The period of the square wave is 0.5 [ms].

5) **<u>VERTICAL SETUP</u>:** The main adjustments are **AMPL**itude, **POS**ition, and the input coupling keys for **GND**, **DC** and **AC**.

COUPLING:

a) The input coupling after AUTOSET is <u>AC</u>. This means that the vertical position of the displayed waveform is centered on the middle of the screen.

b) If the **AC DC (GND)** key is pressed once, <u>DC</u> input coupling is obtained

c) If the **AC DC (GND)** key is pressed again, <u>ground</u> coupling will be obtained. A straight line will be displayed representing zero 0 [V] (ground) level of the input signal. The VERTICAL POS adjustment is used to position the trace so that the ground level (zero Volts) is in the middle of the screen.

d) Pressing the **AC DC (GND)** key **again** will position the Probe Adjust Signal centered on the <u>central</u> graticule line.

VERTICAL AMPLITUDE:

a) If the input sensitivity is set originally at 0.2 [V/div], the square-wave should have an amplitude of 3 divisions.

b) Pressing each key of the **AMPL** key pair will step through the 1, 2, 5 sequence of the attenuator range.

VARIABLE AMPLITUDE:

a) Variable amplitude adjustments may be made by activating the **VAR** function by pressing the **AMPL** key pair simultaneously.

b) The amplitude of the signal may be varied with either the [mV] key or the [V] key.

c) Press the **AMPL** key pair simultaneously to turn the VARiable mode off.

6) **<u>HORIZONTAL DEFLECTION</u>:** Before starting with the horizontal deflection functions, you must first set the scope to the predefined state to create the correct start situation.

- Press **STATUS & TEXT OFF** simultaneously
- Connect the Probe Adjust Signal to Channel 1
- Press the **AUTOSET** key. Four periods of the square wave should be visible on the screen.

TIME BASE:

a) Press the left key (**s**) of the **MTB** key pair. Discuss what happens when you press this key several times.

b) Press the right key (**ns**) of the **MTB** key pair. Discuss the results.

c) Set the timebase to 0.2 [ms/div]. How many periods are displayed on the screen?

MTB VAR:

a) The VAR time base function is activated by pressing the **MTB** key pair simultaneously.

b) Press one key of the **MTB VAR** key pair. Notice and record the results. This enables accurate timing measurements.

c) Adjust the **MTB VAR** to 850 [μs/div]. Note that the timebase is set to the nearest step value. What is the nearest step value?

7) **<u>TRIGGERING</u>:**

a) Press the **AUTOSET** key to produce a square-wave signal on channel 1.

b) Turn on Channel 2 to display a second horizontal trace (no input signal). Note the **NOT**

TRIG'D LED is on.

c) Press the **TRIG 2** key. Discuss the results.

d) Press the **TRIG 1** key.

e) The next choice is to trigger on the positive or negative slope of the signal. Press the (**ns)** key of the **MTB** key pair until the timebase is set to 2 [μs/div].

f) The same key you used to select the trigger source is also used to toggle between the positive slope and the negative slope. Press the **TRIG 1** key several times to verify.

8) **CURSOR FUNCTIONS:** Cursors are computer generated lines on the screen used to make fast and accurate amplitude and time measurements. There are two sets of cursors. Voltage cursors are two horizontal lines and time cursors are two vertical lines. Dashed lines (**----**) are the Reference Cursors and dotted lines (····) are the Delta Cursors (Δ).

a) Preset the scope to the predefined **STANDARD SETTING**.

b) When the **CURSORS** key is pressed, the cursor menu appears next to the 6 blue "softkeys". By toggling through the top softkey you can turn the cursors **on, off** or **Vpp**.

c) In the **Vpp** mode the cursors are automatically positioned at the top and bottom of the signal for automatic peak-peak voltage measurements. What value do you measure?

d) Notice that the **TRACK** control moves both cursors. Turn the (Δ) control and observe that only the delta cursor moves. Summarize your observations.

Fig. 6.3 is a flow diagram of the **cursor menu structure** to be used when measuring voltage versus time (**X-DEFL** off). Some of the symbols used in the menu are:

(=) voltage measurement cursors

(‖) time measurement cursors

(#) voltage & time measurement cursors

(ΔT) time difference measurement

(ΔV) voltage difference measurement

(1/ΔT) frequency measurement when (ΔT) corresponds to one complete period

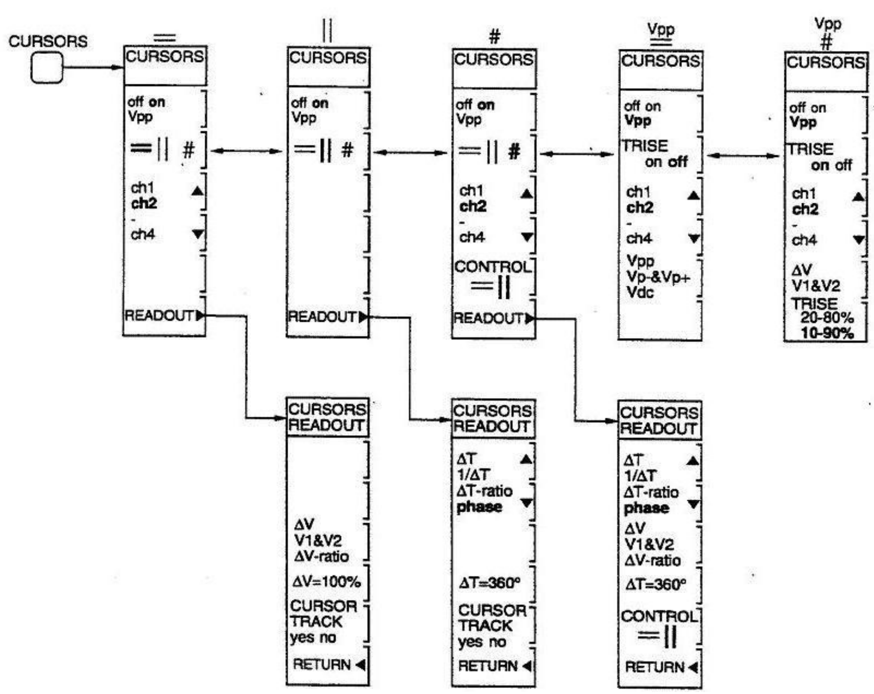


Fig 6.3 Cursor Menu Structure for Time-base Measurements

EXPERIMENT 7: EVALUATION OF HP FUNCTION GENERATOR

SPECIFIC OBJECTIVES:

- To learn the initial set-up procedures for the Function Generator
- To investigate the properties of an AC voltage with DC OFFSET

INTRODUCTION:

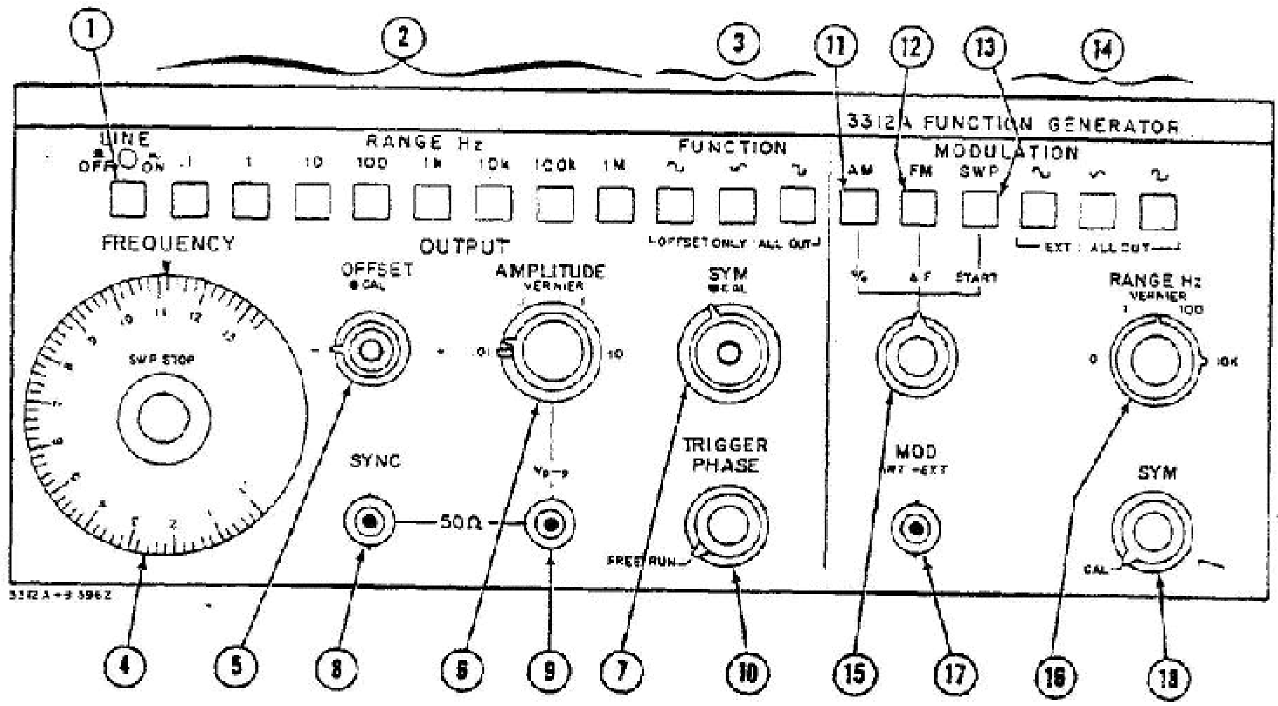
The HP-3321A Function Generator combines two separate function generators in one instrument: a **main** function generator and a **modulation** generator.

The frequency range of the main generator is 0.1 Hz to 13 MHz in eight decade ranges producing **sine**, **triangle**, and **square wave** output voltages of approximately 20 V (pk-pk) into an open circuit load or 10 V (pk-pk) into a 50 [Ω] load. This generator can also produce a constant DC Voltage < 10 [μV], to which you can superimpose (add) any of the time-dependent AC voltages.

The modulation generator will be used and studied in the Physics 4C lab program.

EXERCISES:

1) FAMILIARIZATION WITH THE FUNCTION GENERATOR: A front panel diagram of the generator is shown in Fig. 7.1.



- **Fig 7.1. HP 3312A Function Generator Front Panel**

2) SETTING UP THE FUNCTION GENERATOR to generate a 1k Hz, square-wave voltage with an amplitude of approximately 25 [V pk-pk].

a) Set the power (LINE) [1)] to OFF.
b) Set the RANGE Hz [2] to 100, the FUNCTION [3] to (square-wave), and the FREQUENCY dial [4] to 10.
c) Push in the blue CAL button on the OFFSET [5]. Push in the blue CAL button on the symmetry SYM control [7]. Rotate the TRIGGER PHASE control [10] counter-clockwise to FREE RUN.
d) For maximum output voltage, set the AMPLITUDE control [6] to 10 and the amplitude VERNIER [6] fully clockwise.
e) Disable the MODULATION section of the generator by putting all 6 top buttons [11-14] in the OUT position. Disregard the settings of controls (15, 16 & 18)].
f) When the generator is turned ON, it **should** produce a 10x100 Hz or 1 kHz square-wave voltage with amplitude of 20-25 V pk-pk.

5) **DC OFFSET**: As mentioned in the introduction to this experiment, the function generator can produce a time-dependent AC voltage superimposed on a constant DC voltage provided that the combined voltage, peak AC plus DC is less than ± 10 [V].

a) To produce a DC output voltage from the function generator, all three FUNCTION buttons [3] must be in the OUT position.
c) If the blue OFFSET CAL button [5] is IN and at mid-scale, the DC output of the generator is approximately zero volts DC.
d) If the OFFSET CAL button is OUT, maximum DC offset voltage is obtained by setting the AMPLITUDE [6] to 10 with the VERNIER fully clockwise.
e) The OFFSET control [5] varies the amplitude of the DC offset voltage.
f) FUNCTION [3] selects the type of AC output.
g) The AMPLITUDE of the AC output of the function generator to ± 2 [V] AC added to the + 5 V DC OFFSET.

EXPERIMENT 8: RC CIRCUITS

SPECIFIC OBJECTIVES:

- To learn how to use a 2 Channel oscilloscope to display two voltages simultaneously
- To determine the time-constant (τ) of an RC circuit
- To learn how to use an LCR meter to measure capacitance

INTRODUCTION:

When a battery of emf (ε) is connected in series with a resistor and a capacitor (a capacitor consists of a pair of parallel but separated conducting plates), the charge [q(t)] on each plate of the capacitor is a function of time (t) and is directly proportional to potential difference [V(t)] across the plates. The proportionality constant between q (t) & V (t) is called the **Capacitance** (C); that is:

[8.1] $q(t) = C*V(t)$ or simply $Q = C*V$.

At any point in time (t > 0) after the battery is connected to the RC circuit, Refer to Fig. 8.1, an electric charge q (t) will exist on the plates of the capacitor. If we apply Kirchhoff's Loop Rule to this circuit, the potential differences across the various elements at any point in time would add up to form the equation:

[8.2] $(\varepsilon) - I*R - q/C = 0$,

and since I= dq/dt, this equation can be written in the form of a single variable (q):

[8.3] $dq/dt + (1/RC)*q = (\varepsilon)/R$

Equation [8.3] is a linear, differential equation of a single variable q (t) and has a solution of the form:

[8.4] $q(t) = Q_o [1 - e^{-t/\tau}]$,

where $Q_o = C*\varepsilon$, and τ = $R*C$. Since the charge on a capacitor is directly proportional to the voltage across it, Equation 8.44 may, by dividing both sides by C, be written in terms of the time-dependent voltage across a charging capacitor:

[8.5] $V(t) = V_o [1 - e^{-t/\tau}]$.

The product R∗C is called the **Time-constant** (τ), **tau,** or the **Relaxation Time** of the circuit. It is the time it would take the charge (q) to rise to within 1/e-th of Q_o if the capacitor is being charged and to fall to 1/e-th of Q_o if the capacitor is discharging. [NOTE: The resistance (R) includes all resistance in the circuit including that in the connecting wires and any internal resistance in the battery.]

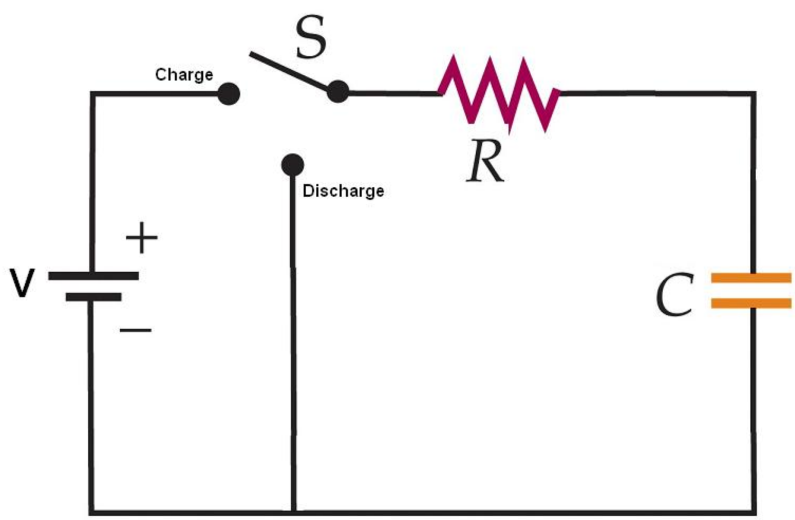
To discharge the capacitor, we would remove the battery from the circuit, i.e., $\varepsilon = 0$, and connect the resistor directly across the capacitor. The initial charge Q_o would decrease exponentially until the capacitor was completely discharged. The voltage at any instant of time during discharge would therefore be given by

[8.6] $V(t) = V_o[e^{-t/\tau}]$.

The **Half-life Time** ($t_{1/2}$) of the circuit is the time it takes to charge or discharge the capacitor to one-half of its maximum charge (Q_o). If Equation [8.4] is solved with $q(t) = (1/2)*Q_o$ or Equation [8.5] is solved with $V(t) = (1/2)*V_o$ then Equation [8.6] follows:

[8.7] $(t_{1/2}) = (\tau)*\ln(2)$.

Fig. 8.1 is a schematic diagram of a series RC circuit with a "Mechanical" Square-Wave Voltage Source. When the Switch (S) is closed in the "Charge" position, a constant DC voltage (V) with an Emf (ε) is applied to the series RC combination and the capacitor charges through the resistor R. When the Switch (S) is switched to the "Discharge" position, the capacitor discharges through the resistor R.



- **Fig. 8.1 Series RC Circuit with a "Mechanical" Square-Wave Voltage Source**

EQUIPMENT DESCRIPTION:

1) LAYOUT OF A "BREADBOARD". A schematic layout of the terminals on the circuit breadboard used to connect components, generators and oscilloscopes in this experiment is shown in Fig. 8.2. Alphabetic characters (letters) describe the 14 horizontal rows. Numerals are used to index the 47 columns.

In column 1, the 5 contacts A thru E are **common** (tied together) **buss**. This group of 5 contacts is called a **Component Buss** and is used to tie several components together. The 5 contacts F thru J in column 1 form a <u>different</u> component buss.

Row W has 35 common contacts. This row is called **Power Buss** and is used to distribute the power to the components in the circuit. Buss (W) will usually be used as the <u>most</u> positive (+) high-potential buss and the bottom buss (Z) is usually the <u>most</u> negative (-) or ground-potential buss.

The series RC circuit shown in Fig. 8.1 can be connected using the "Breadboard" shown in Fig. 8.2. The "Mechanical" Square-wave Voltage Source would be replaced with a Square-Wave Function Generator.

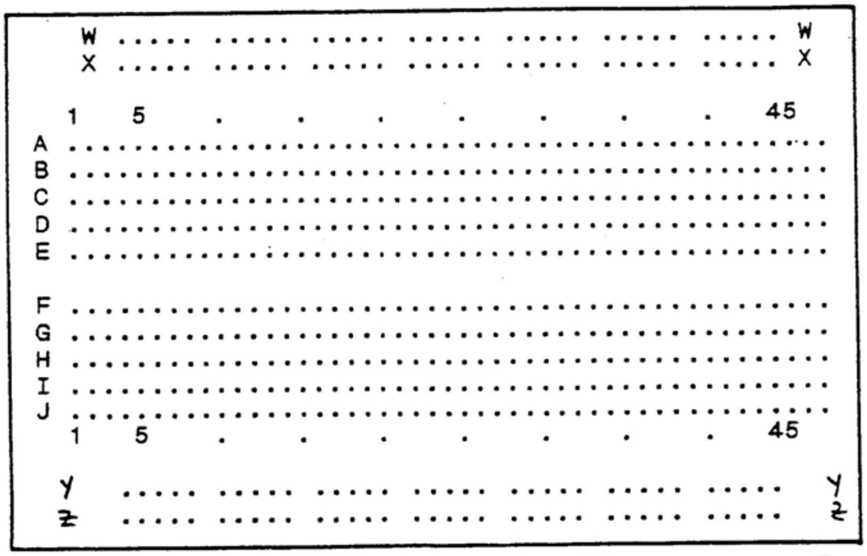


Fig. 8.1. Layout of Contacts on the Breadboard.

2) CONNECTING COMPONENTS TO THE BOARD. To facilitate connections from the breadboard to a generator, connections are made with short solid-wires from the four RED and BLACK banana terminals, which are NOT shown in this diagram, to proper Power and/or Component Busses. The RED terminal is usually used as the high-potential side of the circuit and the BLACK terminal the ground or low-potential side.

3) FREQUENCY OF THE FUNCTION GENERATOR: When the square-wave generator voltage goes positive, the generator will charge the capacitor thru the series resistor (R), and any internal resistance of the generator; and when the generator voltage falls to zero, the capacitor will discharge thru the resistance (R). We will wish to display on the scope at least ONE complete charge-discharge cycle of the capacitor. It is generally assumed that a capacitor will be "fully" charged (for all practical purposes) in 5(τ), that is, the voltage across the capacitor will be (V_o) times the factor $(1 - e^{-t/5\tau})$ = □$0.99*V_o$, and it will take another 5(τ) to discharge to 0.0067*Vo, which for all practical purposes is equal to zero.

Since $\tau = R*C$, the time for one period of a square-wave (T_{sq}) is equal to the time for one complete charge-discharge cycle of the capacitor, i.e., $\mathbf{T_{sq} = (10\tau)}$**,** The generator can be set so that it will produce a peak to peak square-wave voltage of 10 Volts with a frequency (ν) equal to the reciprocal of the period (T_{sq}) calculated above.

The scope-trace shown in Fig. 8.4 on the next page has been expanded to show approximately one-half of the complete charge-discharge cycle to improve the detail of the time and voltage measurements. Channel 1 is the voltage across the output of the Function Generator. Channel 2 is the voltage across the capacitor.

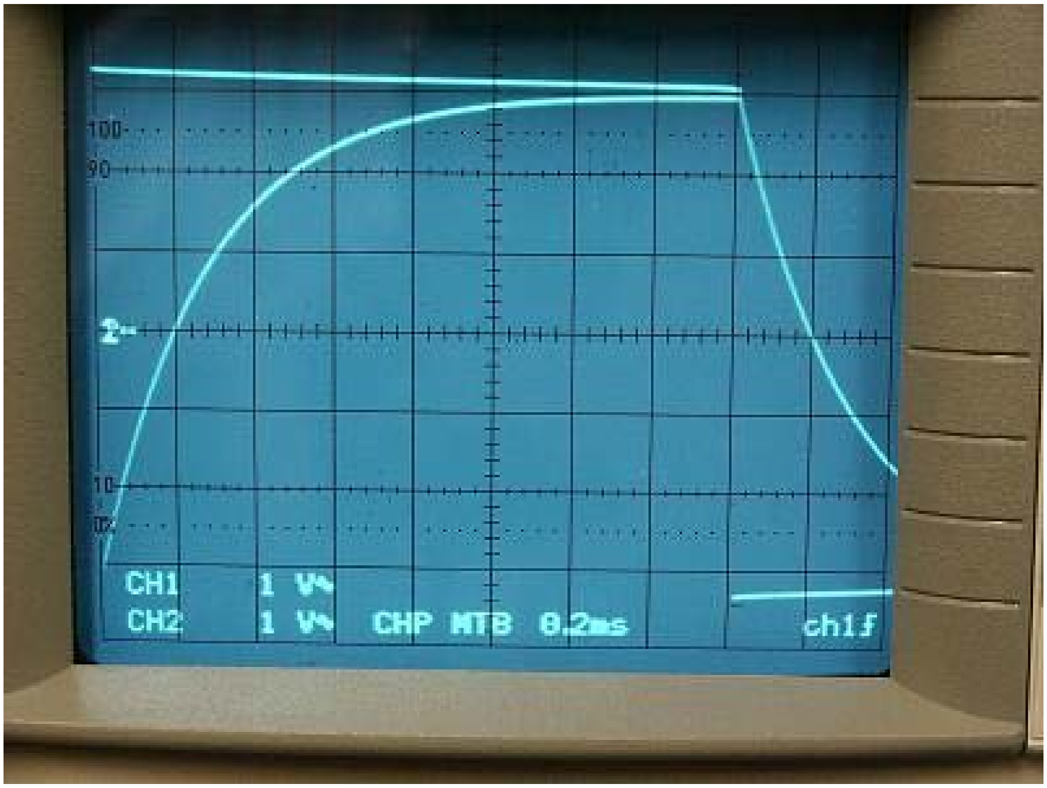


Fig. 8.4.Typical Dual-Trace Scope Presentation in a Series RC Circuit.

EXPERIMENT 9: MAGNETIC FORCE ON CURRENT ELEMENTS

SPECIFIC OBJECTIVES:

- To measure the magnetic force on various current-carrying wire segments in a uniform magnetic field
- To determine the magnitude of a magnetic field and the weight of a magnet assembly using graphical techniques

INTRODUCTION:

Force (F) is an influence, a push or pull, of one object caused by the presence of another that causes the first object to be accelerated. The acceleration (**a**) of the object is defined by Newton's 2nd Law: **a** = **F** /m. where (m) is the mass of the object. Recall the force of gravitational attraction of the earth on an object and the electrical force which exists between two electrically charged objects.

The basic magnetic interaction is the magnetic force one moving charge exerts on another moving charge. We call the agent which transmits this force the magnetic field. A moving charge produces a **magnetic field (B)**, and the field, in turn, exerts a force on the other moving charge. In this experiment we consider the force exerted by the magnetic field of a permanent magnet assembly on a wire segment carrying an electric current. Since bar and horseshoe-shaped magnets, as well as the rotating earth, have magnetic fields associated with them, they both must have relative motion of electric charges within.

It is observed experimentally that a magnetic field (**B**) can exert a Magnetic Force ($\mathbf{F_B}$) on an electrically charged particle (q) moving in it with a velocity (**v**). According to the Lorentz Force Law this force is expressed in terms of the vector product:

[9.1] $\mathbf{F_B} = q\,(\mathbf{v} \times \mathbf{B})$

The System-International (SI) units of Equation [1] are respectively: (q) in Coulombs [C], (v) in meters/sec [m/s], (F_B) in Newtons [N], and (B) in Tesla [T]. [Tesla] is an SI unit the equivalent of [Newton-sec/Coulomb-meter].

The product of the current (I) in an incremental wire-segment of length (Δl) is defined as a Current Element I (Δl). I (Δl) is vector whose direction is in the same as the direction of the current**.** This Current Element I (Δl) is equivalent to the product q **(v) of** a charged particle (q) moving with a velocity (**v**). That is; (I) (Δl) = ($\Delta q/\Delta t$) (Δl) = Δq (Δl /Δt) = Δq (**v**).

We can therefore, rewrite Equation [9.1] as a function of an equivalent current-element:

[9.2] $\Delta \mathbf{F_B} = I\,(\Delta l) \times \mathbf{B})$

Equation [9.2] states that a current-element I(Δl) in a magnetic field (**B**) will be accelerated by a force ($\Delta \mathbf{F_B}$) whose magnitude is proportional to the component of the current-element perpendicular to the field, that is $I(\Delta \mathbf{l} \sin\theta)$. The direction of this force will be perpendicular to both the direction of the current-element $I(\Delta \mathbf{l})$ and to the field (**B**).

Equation [9.2] can be simplified if we let the symbol ($\mathbf{l}$) represent a small length of wire ($\Delta \mathbf{l}$) and the symbol ($\mathbf{F_B}$) correspond with the incremental force ($\Delta \mathbf{F_B}$). Equation [9.2] then becomes simply $\mathbf{F_B} = I(\mathbf{l} \times \mathbf{B})$.

Quantities that are related linearly can be expressed in the form y = mx + b. If (**F**) represents the total force measured by the platform balance, then this total force would be equal to the weight (**W**) of the Magnet Assembly **plus** the magnetic force ($\mathbf{F_B}$) acting on the current-element. Expressing the simplified Equation [2] in **scalar form** we obtain,

[9.3] $F = (I\ \mathbf{l}) \sin(\theta) B + W$.

If we keep angle (θ) a constant and equal to 90°, slope-intercept analysis suggests that Equation [3] can be written in the form

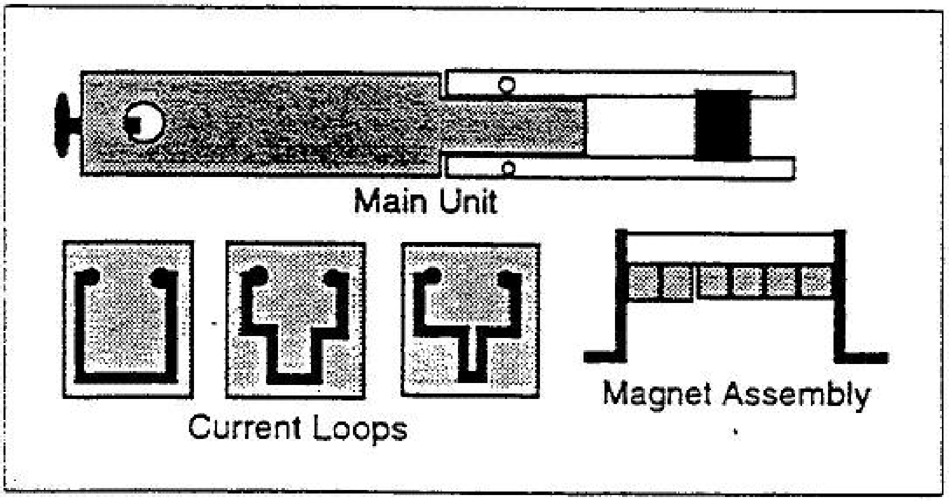
[9.4] $F = B(I\ \mathbf{l}) + W$,

which is equivalent to y = mx + b, where the total force (F) is the dependent y-variable, the current-element ($I\ \mathbf{l}$) is the independent x-variable, the magnetic field (B) is the slope and the weight of the magnet assembly (W) is the y-axis intercept of the graph.

Equation [9.4] is a numerical equality only if a consistent set of units is used for all quantities. **F** & **W**, in SI Units, would both be expressed in [Newtons], I in [Coulomb/sec = Amperes], $\mathbf{l}$ in [meters], and **B** in [Tesla]. In this experiment the balance used most likely reads in [grams] as the measure of force. Since we wish the actual force value in [Newtons], convert [grams] to [kilograms] and then using the gravitational form of Newtons' 2nd Law, F = mg, multiply [kg] by the gravitational constant g = 9.8 [Newtons/kg] to determine [Newtons].

ONE GRAPH can be produced where TOTAL FORCE (F) is plotted versus CURRENT ELEMENT ($I\ \mathbf{l}$). The slope of this graph would be equal to the magnitude of the magnetic field (B) and the y-intercept is equal to the Weight (W_o) of the magnet assembly.

1) FAMILIARITY WITH THE APPARATUS



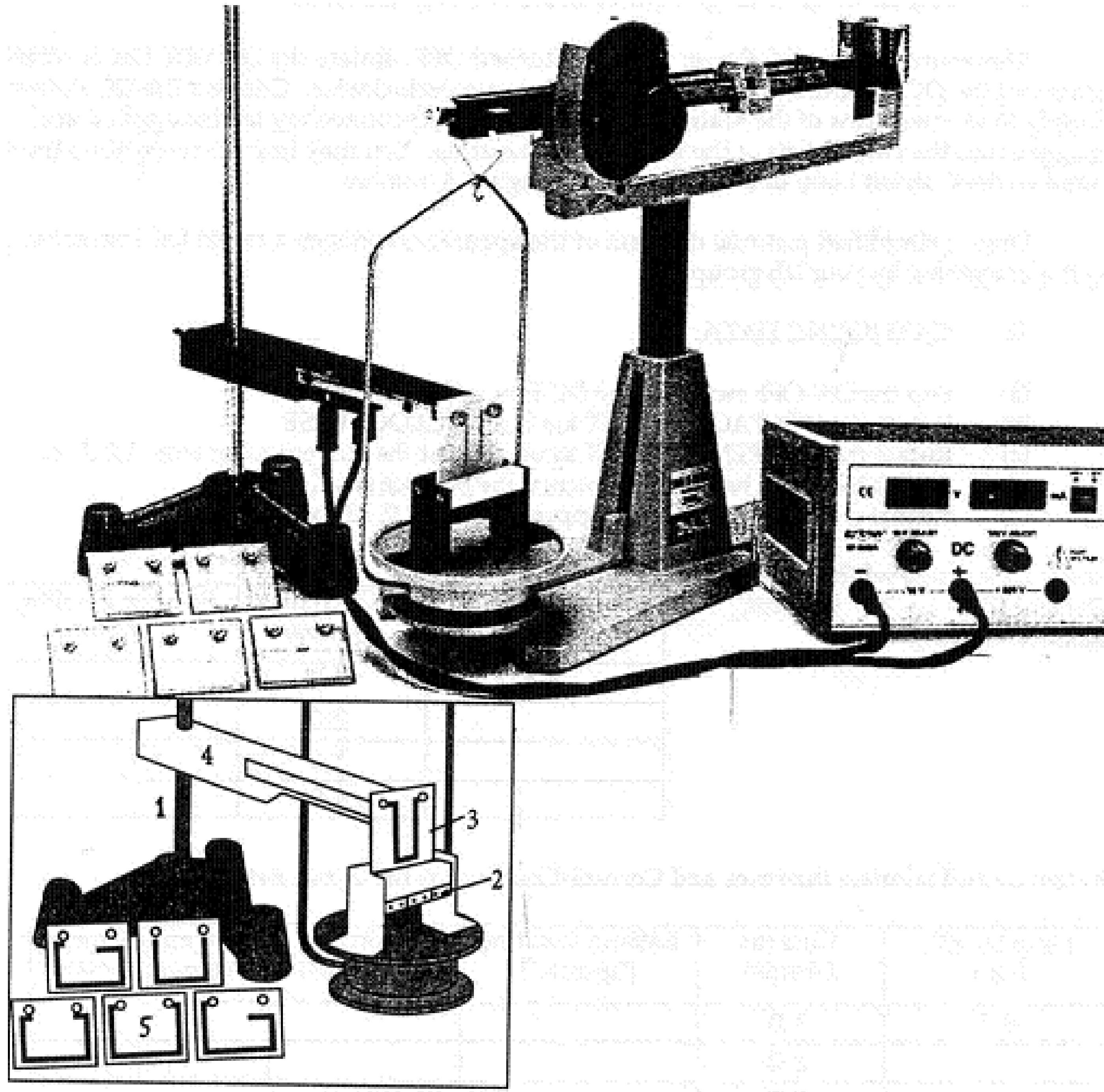
- **Fig. 9.1 Equipment included with the SF-8607 Basic Current Balance.**

The lengths in Fig. 9.2 were measured at the maximum length of the current-carrying metal foil. The effective length may be shorter by as much as 0.2 cm for single lengths and 0.4 cm for doubled lengths

- **Fig. 9.2 Maximum Foil Length of the six current loops.**

CURRENT LOOP (Number)	LENGTH (l) (cm)
SF 40	1.2
SF 37	2.2
SF 39	3.2
SF 38	4.2
SF 41	6.4
SF 42	8.4

2) THE CURRENT BALANCE APPARATUS. A pan balance or an electronic balance may be used instead of the triple-beam balance shown in the diagram.



- **Fig. 9.3 Basic Current Balance, Beam Balance and DC Power Supply**

The numbered items in the pictorial diagram above are respectively:

1) Stand with 3/8' diameter rod
2) Magnet Assembly
3) Current Loop mounted on Main Unit
4) Main Unit for holding Current Loops
5) Additional Current Loops

EXPERIMENT 10: MEASUREMENT OF TIME-DEPENDENT VOLTAGES

SPECIFIC OBJECTIVES:

- To describe time-dependent voltages V(t) using 5 different voltage models
- To understand how a SCOPE, a VOM, and a DMM respond to various V(t)
- To derive the theoretical models which describe the various V(t)

INTRODUCTION:

Alternating current (**AC**) is produced when a time-dependent voltage V(t), whose polarity alternates with time, is applied to a closed circuit. The most common periodic, alternating voltage is sinusoidal and is given by the equation: $V(t) = V_o * SIN(\omega t+\phi)$, where V_o is the amplitude of the voltage, ω is the angular frequency of the voltage in (sec^{-1}), and (ϕ) is the phase angle (in radians) whose value depends upon the value of V(t) at time t = 0 [seconds].

Several ways are used to describe the value of a time-dependent voltage: 1) the **peak-to-peak** value, 2) the **peak** value, 3) the **root-mean-square** (**rms**) value, 4) the **average** value, and 5) the **rectified average** value.

The peak value is equal to the amplitude of the voltage (V_o). The peak-to-peak value is twice the peak value. The rectified average value, described later, applies to both half-wave and full-wave rectified voltages.

The **RMS (root-mean-square)** value is that constant voltage which when the voltage is averaged over the complete period will produce the same amount of heat in a resistor as does the time-dependent voltage. The reason for this choice is based upon the argument that the **heat energy** dissipated by a resistor should be the same whether or not the current is constant or changing with time.

If an instantaneous voltage V(t) applied to a resistor produces an instantaneous current I(t), the power at that point in time is equal to

[10.1] $$P(t) = V(t)*I(t)$$

and the heat dissipated by the resistor in a time (dt) would be equal to

[10.2] $$dH = V*I*dt = I^2 R*dt.$$

Since a constant current (I_{rms}) and the time-dependent current I(t) must produce the same amount of heat in the resistor, it follows that

[10.3] $$(I_{rms})^2*R*dt = I(t)^2*R*dt$$

which leads to the conclusion that

[10.4] $$(V_{rms})^2*dt = V(t)^2*dt.$$

Expressed in integral form Equation (10.4) is equivalent to:

[10.5] $(V_{rms})^2 \int(dt) = \int(V(t)^2 * dt)$

which if integrated over a complete period (T) from 0 to T would yield:

[10.6]

$$V_{rms} = SQR[\frac{1}{T}\int_0^T V(t)^2 dt]$$

If $V(t) = V_o * \sin(\omega t+\phi)$,where $\omega = 2\pi f = 2\pi/T$, it is left as a student exercise to use Eq. [10.6] to derive Eq. [10.7].

[10.7] $V_{rms} = V_o/\sqrt{2}$.

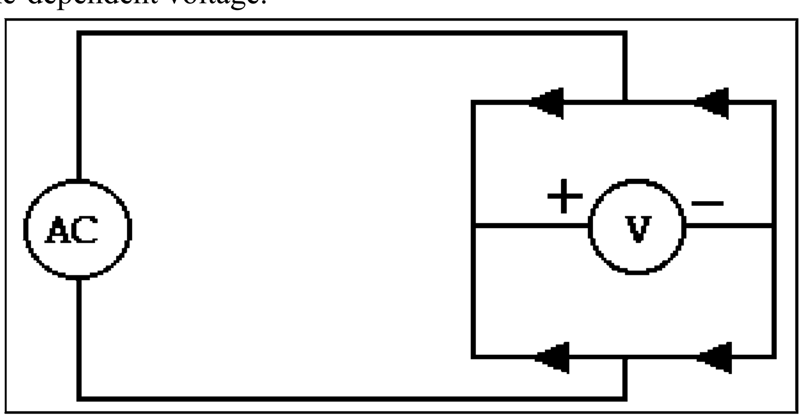
The simplest way to design an instrument to measure alternating current (ac) with a d'Arsonval meter movement (as used in a VOM), is to convert the current into a pulsating direct current (dc) by means of a rectifier made up of one or more diodes.

A common method is to use a full-wave rectifier, with four diodes connected as shown in Fig. 10.3 which inverts the negative half of the applied voltage so that the average voltage across the meter is given by

[10.10] $V_{ave} = (2/\pi)V_o = 0.637\ V_o$

For a meter movement with a full-wave rectifier, the RMS value of a sinusoidal voltage is greater than the rectified average voltage by a factor of $\pi/(2\sqrt{2}) = 1.111$. The VOM is just such an instrument which measures the rectified average of a sinusoidal voltage and displays the value on a scale calibrated in RMS voltages. It is left as a student exercise to show that the full-wave rectified average of a sinusoidal voltage multiplied by $\pi/(2\sqrt{2})$ is equal to the RMS value of that voltage.

If the ac meter scales on the VOM are calibrated to measure RMS values for a sinusoidal voltage, they will measure approximately 1.11 times the rectified average of a square-wave, a triangular wave, or any other type of time-dependent voltage.



- **Fig.10.3. A Circuit which creates and measures Full-wave Rectified Voltages.**

EXPERIMENT 11: LR CIRCUITS

SPECIFIC OBJECTIVES:

- To investigate the inductive time-constant (τ_L) of a series LR circuit
- To show that in an AC series LR circuit, the applied voltage leads the current
- To discuss different methods for determining phase (ϕ) in AC circuits
- To become familiar with Phasor Diagrams

INTRODUCTION:

There are similarities to RC circuits when time-dependent voltages are applied to (LR) circuits containing both inductance and resistance. If one connects a square-wave voltage (V_o) to a series LR circuit and applies Kirchhoff's Loop Rule to the circuit, one obtains the equation:

[11.1] $V_o - L\,(dI/dt) - I*R = 0.$

The solution for the current in this equation is similar to that for the growth of charge in a capacitor of an RC circuit. That is,

11.[2] $I(t) = (I_o)*[1-\exp(-t/\tau_L)]$, where the time-constant of the circuit is given by

[11.3] $\tau_L = L/R.$

If we connect a sine-wave generator, whose output voltage is given by the equation $V(t) = (V_o)*\sin(\omega t)$, in series with the LR circuit, Kirchhoff's loop equation applied to the circuit yields:

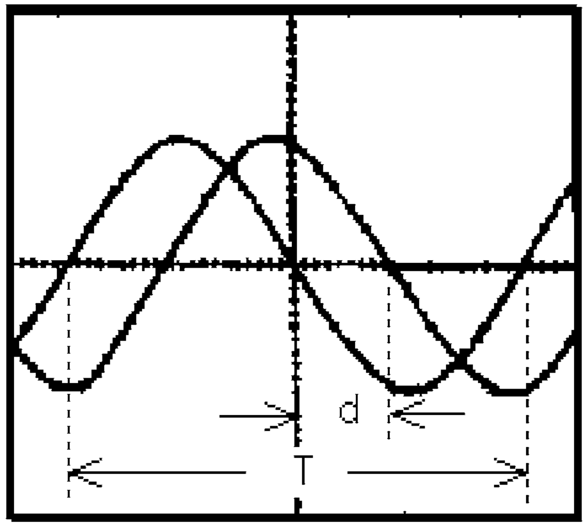
[11.4] $(V_o)*[\sin(\omega t)] - L\,(dI/dt) - IR = 0.$

Since the source, resistor, and inductor are all in series in this circuit, we expect the oscillating voltage source to produce an alternating current of the same angular frequency (ω) in each element. We also expect the voltage and the current to be out of phase with each other. The solution to the differential equation [11.4] is given by

[11.5] $I(t) = (I_o)[\sin(\omega t - \phi)]$,

where (ϕ) is the phase difference (an angle) between V(t) and I(t)].

The phase angle (ϕ) can be either positive or negative. When it is positive, the maximum value of the current (I_o) is reached at a later time than the maximum value of the voltage (V_o). In this case, we say that the voltage leads the current by the phase difference (ϕ). [See Fig. 11.1. on the next page.]



- **Fig. 11.1. Out-of-phase Sinusoidal Current & Voltage in a Series LR Circuit.**

If (f) is the frequency of the sine-wave generator, it can be shown that:

[11.5a] $\omega = 2\pi f$

[11.5b] $\tan(\phi) = +\omega(\tau_L) = \omega L/R$

[11.5c] $V_R = V_o \cos(\phi)$

[11.5d] $\tau_L = (L/R)$

DETERMINING TIME-CONSTANT OF LR CIRCUITS

1) MEASURE THE TIME-CONSTANT (τ_L) OF AN LR CIRCUIT. If the half-life time of the current (voltage across the resistor) is measured, the time-constant can be calculated using the relation [$(t_{1/2}) = (\tau_L)*\ln(2)$].

2) PHASE MEASUREMENT METHOD (A): If a sine-wave voltage is applied to an LR circuit, the frequency of the generator can be increased until voltage across the resistor (V_R) is equal to 1/2 of the applied voltage (V_o). Use Equations 11.5c 11.5b, &11.5a in that order to calculate an experimental value for τ_L.

3) PHASE MEASUREMENT METHOD (B): The phase difference between the applied voltage and the current can be measured directly using the calibrated sweep-time of the two traces. Since one complete cycle of a trace corresponds to 360°, the phase can be determined by the function:

[11.6] $\phi = (d/T)\ 360°$,

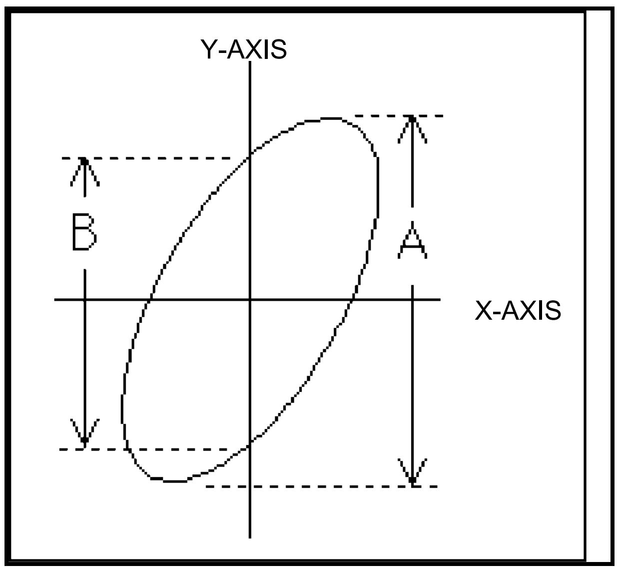
where (T) = the number of divisions corresponding to 1 complete cycle of one of the sine waves and (d) = the number of divisions between the intersection on the time axis of the two sine curves if they are both centered along the horizontal time axis. The time-constant (τ_L) can be calculated using Eq. [5b] and the phase determined from [11.6].

4) PHASE MEASUREMENT METHOD (C): The scope is set to display voltage on the y-axis versus voltage on the x-axis.. With this method two (2) time-dependent voltages will be applied to the two axes (x & y) of the scope to produce a Lissajous figure as shown in Fig. 2 on the next page.

If the applied voltage is of the form x = A*[sin (ωt)] is displayed on the (the x-axis) and if the voltage across the resistor V_R= R*I (t) of the form y = B [sin (ωt - ϕ)] is displayed on the (the y-axis), a Lissajous figure will be displayed. on the scope with the phase determined by Eq. [11.7]:

[11.7] sin(ϕ) = B/A.

Note that the voltage applied to the x-axis will be zero when ωt = 0. The trace will intercept the y-axis at y = ± B[sin(ϕ)] and by proportionality, Eq. [11.77] follows.



- **Fig. 11.2. The Elliptical Pattern used to Measure Phase Angle Difference.**

5) DIRECT MEASUREMENT OF L & R. The LRC meter can be used to directly measure the total resistance and inductance.

REACTANCE, IMPEDANCE, and PHASOR DIAGRAMS. If a sinusoidal voltage is applied to a purely resistive circuit, the current in the circuit will be in-phase with the applied voltage. [Refer to Eq. [11.4] with the omission of the term L(dI/dt).]

If the same sinusoidal voltage is applied to a purely inductive circuit with no resistance, then Kirchhoff's Loop Rule states that

[11.8] $(V_o)*\sin(\omega t) - L*dI/dt = 0.$

Integration leads to the conclusion that the current in a pure inductor would equal

[11.9] $I(t) = [V_o/(\omega L)]*\cos(-\omega t).$

If one applies the trig identity cos (A-B) to Eq. [11.9], one can conclude that

[11.10] $I(t) = [V_o/(\omega L)]*\sin(\omega t-\pi/2)$.

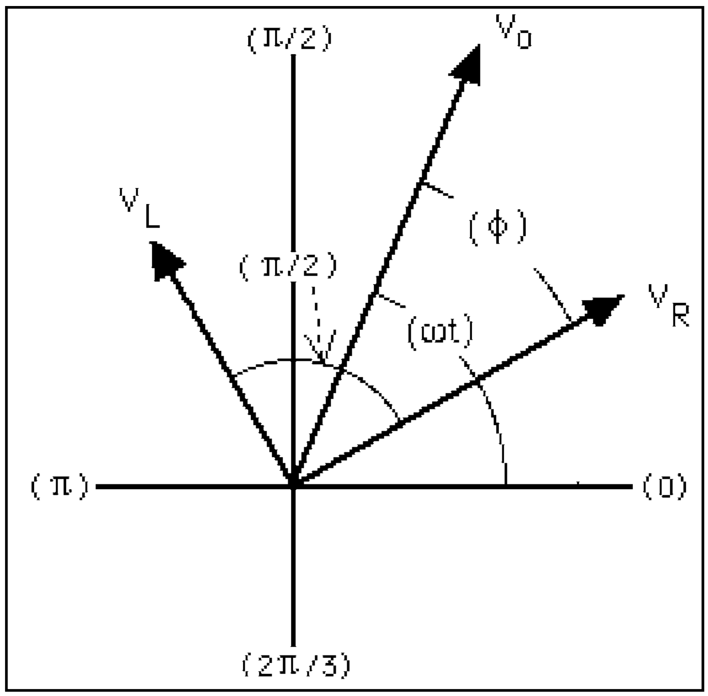
If we again consider the series LR circuit with a sinusoidal voltage applied, we can conclude that the instantaneous voltages across the source, the resistor and the inductor are respectively:

[11.11] $V(t) = (V_o)*\sin(\omega t) = Z(I_o)*\sin(\omega t)$,

[11.12] $V_R = (R)(I_o)*[\sin(\omega t - \phi)]$, and

[11.13] $VL = (\omega L)(I_o)*[\sin(\omega t - \phi + \pi/2)]$.

These three voltages are displayed as "rotating vectors" called PHASORS as shown in the PHASOR DIAGRAM Fig. 11.3.



- **Fig. 11.3. Phasor Diagram of Voltages in a Series LR Circuit.**

The quantity (ωL) in Eq. [11.13] is defined as inductive reactance (X_L) of an inductor and has the same SI unit as resistance. Eq. [11.11] includes the variable (Z) which is called the IMPEDANCE of the circuit. The phasor relationship of the three voltages in Fig. 11.3 suggests a Pythagorean relationship given by the relation:

[11.15] $V_o^2 = (I_oZ)^2 = (I_oR)^2 + (I_oX_L)^2$

Since the maximum current (I_o) is the same in all components in a series circuit, the total impedance (Z) of the circuit is related to the resistance (R) and the inductive reactance (X_L) by :

[11.16] $Z^2 = R^2 + X_L^2$.

This enables us to define an equivalent to Ohm's Law for AC circuits as given by

[11.17] $I_o = V_o/Z$.

GLOSSARY

AC (ALTERNATING CURRENT): Alternating current is a back and forth flow of electric charge which changes direction periodically with time. **UNIT: [Amperes]**

AC VOLTAGE: A potential difference that changes polarity with time and produces an alternating current (AC). The change is usually SINUSOIDAL but can also be square or triangular. **UNIT: [Volt]**

AMMETER: An instrument that measures the flow of electric charge [Amps]. An ammeter must be connected in series with the device through which it measures the current.

AMPERE: The unit of current in the SI system equal to 1 Coulomb/second.

AMPLIFIER: A device which increases (or decreases) the magnitude of a potential difference.

AMPLITUDE: The maximum displacement of a periodic oscillation from its equilibrium state.

AUTO-RANGING: The ability of some digital multi-meters to determine automatically the correct range for the quantity being measured.

BANANA PLUG: A common type of male connector, shaped like a banana, which plugs into a banana jack (receptacle).

BIAS: A potential difference, either + or -, applied across certain circuit elements.

BNC: **B**erkeley **N**ucleonic **C**orporation. A coaxial type, twist type connector which is used on and to secure coaxial cables.

BREADBOARD: A small board, for constructing temporary experimental circuits, which accepts a wide variety of devices and which makes circuit changes easy by simply plugging and unplugging wires and or components.

CAPACITANCE (C): That property of a body which is a measure of the amount of charge that can be stored in or on a body when a certain potential is applied to it. **UNIT: [Farad = Coul/Volt]**

CAPACITOR: A device that can store electric charge, and therefore, electric energy, when a potential difference is applied to it.

CHARACTERISTIC CURVE: The name of a graph which describes the dependence of the current in a circuit element as a function of the voltage across it.

ELECTRIC CHARGE (q): An intrinsic electrical property of some elementary particles, electrons (-q), protons (+q), which determines the magnitude of their electrical interaction. **UNIT: [Coulombs]**

CHARGE CARRIER: Any object that has net electric charge and is capable of moving from one position to another.

COAXIAL CABLE: A cable consisting of a conducting wire that is encircled by a coaxial conducting cylinder with an insulating material between them.

CONDUCTANCE (G): The proportionality constant which relates the linearity between current (I) in many materials to the applied voltage (V). **UNIT: [Siemens (S)]: [1 S = 1 $(\Omega)^{-1}$ = 1 mho].**

COULOMB: The SI (System International) unit of electric charge. One electron has an electric charge of (- 9.1 x 10^{-31}) [Coulombs].

CRT: An abbreviation for Cathode Ray Tube.

CURRENT (I): The rate at which electric charge passes thru a surface; the time-rate of charge flow; that is, I= dq/dt. **UNIT: [1 Ampere = 1 Coulomb/sec]**

DC OFFSET: The amount of constant voltage (DC) added to any AC signal which shifts, either plus or minus, the zero reference of an AC signal.

DC VOLTAGE (ΔV): A potential difference that does not change its polarity with time and produces a current (DC) that does not change direction with time. **UNIT: [Volt]**

DIODE: A diode is a device, such as a pn junction, which allows charge to flow through it in one direction and block the passage of current in the opposite direction.

DISCREPANCY TEST: Also called CALCULATING PERCENTAGE DIFFERENCE. This is done by taking the difference between the absolute values of two measurements, dividing this difference by the "best" value, and multiplying the fraction by 100%.

DMM: A **D**igital **M**ulti-**M**eter that is usually hand-held and battery powered that produces a digital readout when measuring voltage, current, or resistance.

ELECTRIC FIELD (E): A force producing quantity associated with a position in space due to the nearby presence of electric charge. The field will exert electrical force on other charged objects brought into it.

UNIT: [Newton/Coulomb = Volt/meter]

ELECTRIC POTENTIAL (V): The amount of work done (Joule) per unit charge (Coulomb) by an external force to move, at constant kinetic energy, a unit positive electric charge against an electric field from infinity (or where the electrical potential is zero) to the point in question.

[UNIT: Volt = 1 [J/C]

EMF (Emf) (ε□: Electro-motive force is the name given to a source of electricity produced at the expense of some other form of energy, such as a chemical change in a battery, mechanical energy in a generator, solar energy in a solar cell, etc. It is defined as the amount of electrical energy per coulomb of positive charge produced by the source.

UNIT: [Volt = Joule/Coulomb]

FARAD: A unit of capacitance equal to 1 [**Coulomb/Volt**].

FREQUENCY (ν) or **(f):** The number of times an event occurs in a given amount of time.

UNIT: [Hertz (Hz) = 1 cycle/sec.]

FUNCTION GENERATOR: An instrument that produces a voltage which alternatives in magnitude and/or direction in a variety of forms, frequencies, and magnitudes. A DC offset voltage may be available.

GAIN: A measure of the amount of amplification a given device can increase (or decrease) a given input signal. It is commonly expresses as a ratio of output voltage to input voltage.

GROUND POTENTIAL: The potential of the earth which is assigned a value equal to zero [volts].

HELMHOLTZ COILS: A pair of equal current-carrying coils with a common axis whose distance of separation is equal to their diameter and which produce a nearly uniform magnetic field between them.

HENRY (H): The SI unit of inductance. [1 Henry = 1 Volt-sec/Amp].

HERTZ (Hz): The SI unit of frequency. [1 Hz = 1 cycle per sec].

I**MPEDANCE (Z):** The opposition to an alternating current that is produced by a circuit containing both resistance and reactance. **UNIT:[Ohm]**

INDUCED EMF (Emf) (ε□: The energy per unit charge given to the charge carriers that traverse a coil or circuit when the magnetic flux thru the circuit changes with time.
UNIT: [Volt]

INDUCTANCE (L): That property of a body which produces a back or counter Emf in a device when the current thru the device is changed with time. **UNIT: [Henry]**

INDUCTOR: A circuit element (usually a coil of wire) which has the property of inductance.

JACK/SOCKET: A receptacle for a plug.

KIRCHOFF'S LOOP RULE: The sum of the potential differences around any closed loop in a circuit is equal to zero. (This rule is based upon the Law of the Conservation of Energy.)

KIRCHOFF'S JUNCTION RULE: The sum of all of the currents entering a junction in a circuit is zero. (This rule is based upon the Law of the Conservation of Charge.)

LCR METER: An instrument which is capable of measuring inductance (L), capacitance (C), and resistance (R).

LISSAJOUS FIGURE: A two-dimensional trace formed by an electron beam responding to two sinusoidal voltages of different phase, frequency, and/or amplitude applied to both sets of deflecting plates in a CRT or an oscilloscope.

MAGNETIC FIELD (B): A region of influence about a magnet or a wire carrying current which exerts force upon charged particles moving thru it. **UNIT: [Tesla (T) = Ns/Cm]**

MAGNETIC FLUX (Φ_B): The amount of a magnetic field (**B**) passing perpendicularly thru a surface times the area of that surface. **[UNIT: Weber = Tm^2]**

OHM (Ω): The unit of resistance. [1 Ohm = 1 Volt/Ampere].

OHM'S LAW: An empirical expression that describes the linear relation between the current (I) in many conductors over a range of applied voltages (V); that is, I = G*V, where G = 1/R.

OPEN CIRCUIT: A circuit which has a "break" in it so that no charge can flow in it.

OSCILLOSCOPE: An instrument that measures the voltage of an input signal as a function of time or as a function of another voltage and displays it/them on the screen of a cathode ray tube (CRT).

PARALLEL: Two elements are connected in parallel when the voltage across each element is the same and the current divides between the two elements.

PEAK TO PEAK: The difference between the highest and lowest value of a periodic signal or voltage. Abbreviated p-p **or** pk-pk.

PERIOD (T): The time that elapses between any two successive similar phases of a periodically varying voltage or current, i.e., the time to complete one cycle of oscillation. **UNIT: [Sec]**

PHASE (ϕ): The angular difference between the current in a circuit and the applied voltage at some point in time. **[Phase is measured in degrees or radians.]**

PHASOR: A phasor is a rotating vector with magnitude and angular position.

POWER: The rate at which energy is transformed to some other form of energy.
UNIT: [Watt = Joule/sec.]

PLUG: The male connector of connector-receptacle (plug-jack) system.

PN JUNCTION DIODE: A solid-state, two terminal device that allows charge carriers to flow easily in one direction, but not in the other.

POTENTIAL DIFFERENCE (ΔV): The difference in potential energy per unit test charge ($+q_o$) when the test charge is moved from one position to another. **UNIT: [Volt = Joule/Coulomb]**

RC CIRCUIT: A circuit that contains resistance and capacitance and if connected to a DC voltage source will have a current in the circuit which varies exponentially with time.

RLC CIRCUIT: A circuit that has resistance, capacitance, and inductance and has a current which is oscillatory and decays or grows exponentially with time.

REACTANCE (X_C or X_L): A property of capacitors and/or inductors that limits the current in an AC circuit. Reactance, unlike resistance, is frequency dependent. **UNIT: [Ohms]**

RECTIFY: To change a current from alternating (AC) to pulsating (DC).

RESISTANCE (R): That property of a body which opposes the passage of a direct current (DC) and which produces heat energy in the body at the expense of electric energy. **UNIT: [Ohm (Ω)]**

RMS: The **R**oot-**M**ean-**S**quare value of a quantity is the square root of the average value of the square of the quantity. It is the DC heat-energy equivalent of an AC quantity

SAWTOOTH VOLTAGE: A time dependent voltage that rises and falls linearly with time and has the appearance of the teeth of a saw blade.

SERIES: A combination of two or more elements in which the flow of charge (current) is the same in each element.

SHORT CIRCUIT: A circuit which has zero or very low resistance. Any element can be "short circuited" by connecting a wire of very low resistance across it.

SI: An abbreviation for SYSTEM INTERNATIONAL. The International system of **S**ymbols, **U**nits, and **N**omenclature was adopted at the International SUN Conference in 1960.

SIGNAL: A term used to specify any type of voltage or current, large or small, and constant or varying with time.

SINE-WAVE: Often used to describe a sinusoidal signal or voltage.

SINUSOIDAL: A quantity that changes with time whose variation is described by a sine or cosine function.

SQUARE-WAVE: A time-varying signal that changes from the OFF state to the ON state periodically and instantaneously.

TIME-BASE GENERATOR: The horizontal amplifier in an oscilloscope that controls the horizontal motion of the beam causing it to sweep out equal horizontal distances in equal intervals of time.

TIME CONSTANT (τ): The time constant in an RC or RL circuit is the time it takes for the voltage across the capacitive or inductive component to decrease to 1/e-th of its initial value during the discharge state. **UNIT: [sec.]**

TRACE: The path of light emitted by the phosphors on the back side of the face of the CRT in an oscilloscope as an electron beam falls upon them.

TRIGGER: Sets the level of the signal voltage at which the oscilloscope trace begins.

VOLTAGE (ΔV) or (V): The difference in electrical potential between two points in a circuit or in space; i.e., $(\Delta V) = (V) = V_2 - V_1$. **UNIT: [Volts].**

VOLTAGE DROP (ΔV): The decrease in electrical potential across a device, measured from the high potential end V_2 to the low potential end V_1 of the device, due to a loss in electrical energy per unit charge. **UNIT: [Volt]**

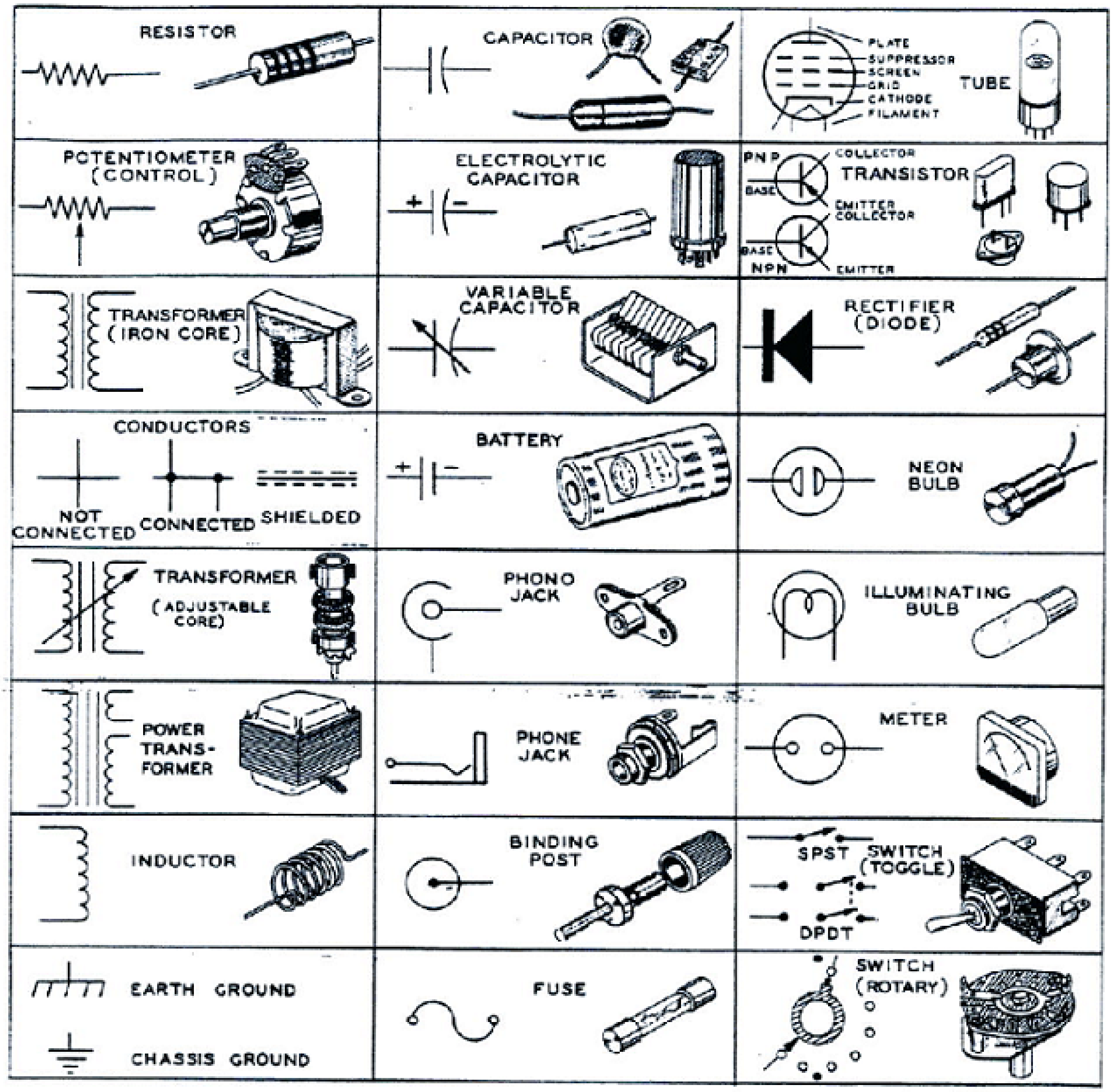
VOM: An abbreviation for **V**olt-**O**hm-**M**illiameter. A VOM is a common analog measuring instrument that measures voltage, resistance, and current.

WAVE A non-equilibrium disturbance that propagates through an elastic medium. Waves and their characteristics will be studied in Physics 4C.

WAVEFORM: The shape of a voltage-time trace as seen on the face of an oscilloscope screen. Waveforms can be sinusoidal, square, triangular, or some other form of a time dependent function..

APPENDIX I SYMBOLS, UNITS, AND NOMENCLATURE

The chart below is a summary of some commonly used symbols of electronic components.



APPENDIX II EQUIPMENT AND APPARATUS DESCRIPTIONS

1. SIMPSON MODEL 260 VOM (VOLT-OHM-MILLIAMMETER)

A. VOM FAMILIATITY. The typical Simpson Model 260 VOM has the following features:

a. 4 -position FUNCTION switch
b. 12 -position RANGE switch
c. ZERO OHMS adjustment knob
d. 8 different jacks to insert meter leads
e. Analog meter with 9 scales: 1 ohm scale, 3 DC scales, 4 AC scales and 1 dB scale.

B. ZERO ADJUSTMENT When resistance is measured, the INTERNAL batteries furnish power for the circuit under test. Since batteries are subject to discharge, the VOM must be adjusted to ZERO before measuring resistance.

a. Turn the range switch to the desired ohms range.
b. Plug the black lead into the (-) COMMON jack and the red lead into the (+) jack
c. Connect the leads together to short the VOM resistance circuit.
d. Rotate the ZERO OHMS control until the pointer indicates zero. If the pointer cannot be adjusted to zero, one or both of the batteries must be replaced. Contact your lab instructor.
e. Disconnect the shorter ends of the test leads.

C. MEASURING RESISTANCE Before measuring resistance in a circuit make sure the power is OFF and that all capacitors are discharged.

a. Set the range switch to one of the resistance range positions as follows:

1. Use R x 1 for resistance readings from 0 to 200 Ohms.
2. Use R x 100 for resistance readings from 200 to 20,000 Ohms.
3. Use R x 10,000 for resistance readings above 20,000 Ohms.

b. Zero adjust the meter for the range selected.
c. Connect resistance to be measured to the meter leads.
b. Observe the reading on the OHMS scale at the top of the dial.
c. To determine the actual resistance value, multiply the reading by the factor at the switch position.

C . RESISTANCE MEASUREMENTS OF SEMICONDUCTORS If there is a "forward" or "reverse" biased resistance, such as in diodes and pn junctions, the resistance is very low in one direction (for forward polarity) and higher in the opposite (or reverse biased) direction.

a. Rotate the function switch between the two DC positions (+ DC and - DC). This will determine if there is a difference between the resistances in the two directions.

b. The polarity of the internal ohmmeter battery voltage at the (+) jack is identical to the junction switch and opposite to the (-) common jack.

c. The nominal open-circuit voltage across the terminals of the VOM is 1.5 Volts on the R x 1 and R x 100 ranges. **Caution:** The open-circuit voltage is **9.0 Volts** on the R x 10,000 Ohm range.

D. (0 – 1 Volt) DC VOLTAGE MEASURMENT

a. Set function switch to +DC
b. Plug the red test lead into the (+1V) jack and the black test lead in (-) common jack
c. Set the range switch at the 1V position. (This position is common with +2.5V).
d. Connect the leads to the voltage being measured observing proper polarity.
e. Read the voltage on the BLACK scale marked DC and use the figures marked 0-10. Divide the reading by 10...

NOTE: The DC voltage accuracy is 2% of the full scale value. On the 10 Volt range an error of ±0.2 V is allowed for any point on the dial. The sensitivity when measuring DC Volts is 20,000 [Ω/Volt]. This implies that when measuring DC voltage on the 10 Volt range, the instrument presents a resistance to the circuit of 200,000 Ohms.

E. (0-2.5 THROUGH 0-500 V RANGE DC MEASUREMENT

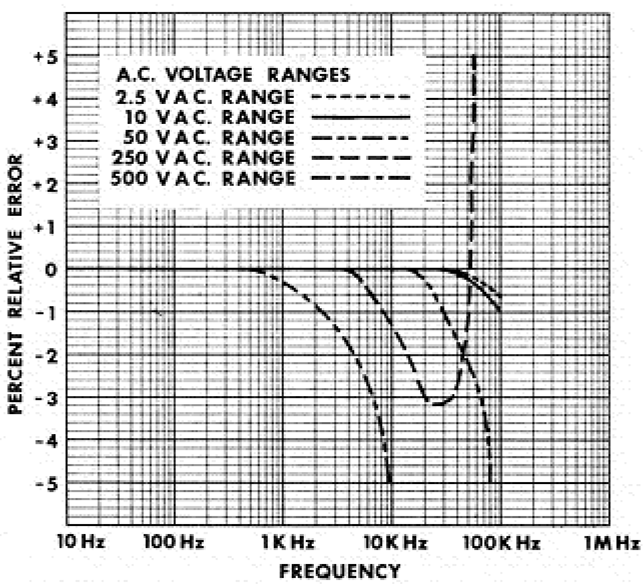
a. Set function switch to +DC
b. Plug the red test lead into the (+) jack and the black test lead in (-) common jack
c. Set the range switch to one of the five voltage range positions marked 2.5V, 50V, 250V or 500V depending on the voltage value being measured. If the voltage is within a lower range, the switch may be set for the lower range to obtain a more accurate reading.
d. Connect the black test lead to the negative side of the circuit being measured and the red test lead to the positive side of the circuit.
e. Turn on the power in the circuit being measured.
f. Read the voltage on the BLACK scale marked DC. For the 2.5V range, use the 0-250 figures and divide by 100. For the 10V, 50V and 250V ranges, read the figures directly. For the 500V range, use the 0-50 figures and multiply by 10.
g. Turn OFF the power to the circuit under test and wait until the meter indicates zero before disconnecting the test leads.

G. DC VOLTAGE MEASUREMENTS IN THE 0-250 mV and the 0-1000 V RANGES The Simpson 260 VOM is capable of DC voltage measurements in the range 0-250mV and in the range 0-

1000V range. Refer to the SIMPSON 260 SERIES OPERATOR'S MANUAL for details to measure voltages in these ranges.

H. AC VOLTAGE MEASUREMENTS 0-2.5 THROUGH 0-500 V RANGE. The 260 responds to the average value of an AC waveform. It is calibrated in terms of the RMS value of a pure sine-wave. If the waveform is not sinusoidal, the reading probably will differ from the true rms value. Refer to Exp. 10, MEASUREMENTS OF TIME-DEPENDENT VOLTAGES.

The AC voltage accuracy is 3% of full scale. Also, accuracy is lessened at higher input frequencies as shown in the following %-Relative Error versus Frequency graph..



a. Set function switch at AC

b. Plug the red test lead into the (+) jack and the black test lead in (-) common jack

c. Set the range switch to one of the five voltage range positions marked 2.5V, 50V, 250V or 500V depending on the voltage value being measured. If the voltage is within a lower range, the switch may be set for the lower range to obtain a more accurate reading.

d. Connect the test leads across the circuit voltage to be measured with the black lead to the grounded side of the circuit.

e. Turn on the power in the circuit being measured.

f. For the 2.5V range, read the voltage directly on the RED scale marked 2.5VAC. For the 10V, 50V and 250V ranges, read the RED scale marked AC and use the BLACK figure immediately above the scale. For the 500V range, read the RED scale marked AC and use the 0-50 figures. Multiply the reading by 10.

I. OTHER AC VOLTAGE MEASUREMENTS. The Series 260 VOM can also be used to measure DECIBELS, OUTPUT VOLTAGE and AC voltages in the range 0-1000. . Refer to the SIMPSON 260 SERIES OPERATOR'S MANUAL for details to measure voltages in these ranges.

2. HANDHELD DIGITAL MULTIMETERS. Typical handheld digital multimeters are shown. Each meter is capable of measuring DC Volts, AC Volts, DC Amps and Ohms. The bottoms two meters are capable of also measuring AC Amps.

The red test lead for measuring voltage or resistance is connected to the (+) or (V/Ω) terminal and the black lead to the (-) or common (COM) terminal. Contact resistance of rotary and/or push-button switches can lead to erroneous measurements. It is recommended that before any measurements are

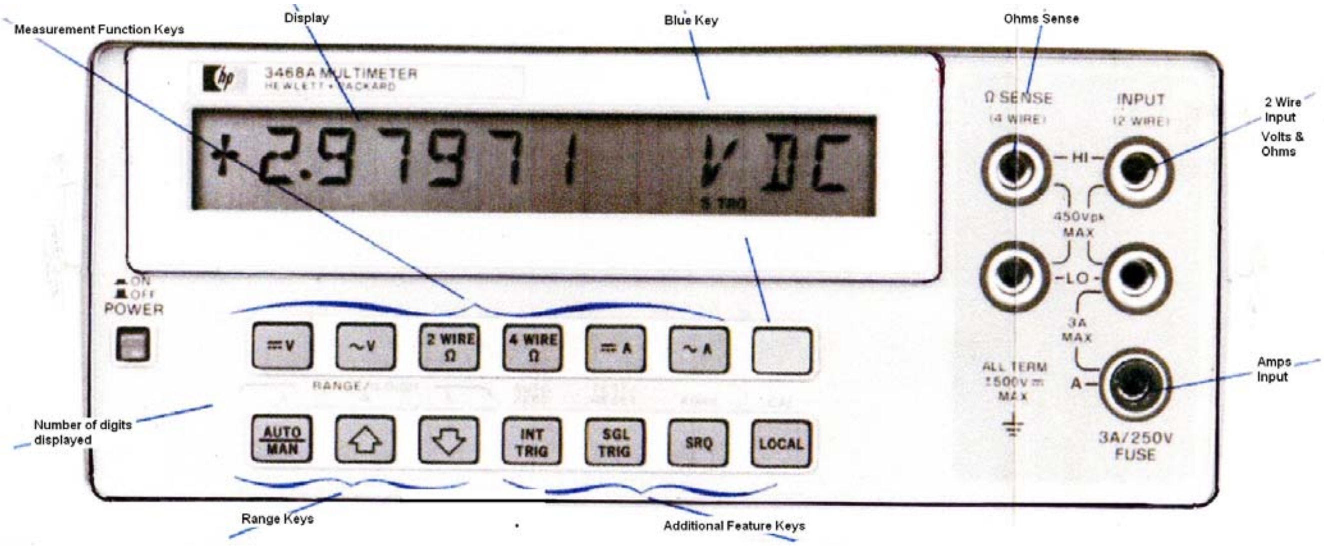
made that all switches be exercised by rotating or operating them several times through their various positions.

DC current measurements are made with the meter inserted in series with a branch of the circuit so that the current passes through the meter. The red test lead from the current measuring terminal (A), (+), or (mA) is connected to the higher potential side of the branch and the black test lead from the (-) or COM terminal is connected to the lower potential side of the branch.

For measuring larger currents, the 10A terminal is used along with the setting of the range switch to 10. This feature is usually unfused and requires care to insure that larger currents are not involved.

It is also good practice to insure that these, and other battery powered instruments, are turned OFF when not in use.

3. HP MODEL 3468A/B DIGITAL MULTIMETER



A. TURNING IT ON. The HP 3468A/B is a fully programmable digital Multimeter. It performs a complete internal self test at POWER ON. After the short test time, the meter is ready to use and is set to the following state:

FUNCTION: DC volts
RANGE: Autorange ON
DISPLAY: 5 1/2 Digits of Resolution
TRIGGER: Internal
AUTO-ZERO: ON

The 368A/B offers 3 1/2 to 5 1/2 digit resolution for measuring DC volts, true RMS AC volts, 2- and 4- wire ohms, and DC and RMS current.

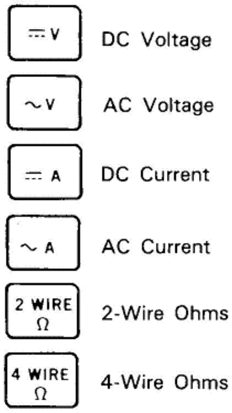
B. DETAILED OPERATING CHARACTERISTICS. A detailed description of operating characteristics is shown in the table below:

Operating Characteristics

DC VOLTS	1µvolt sensitivity (.3V range) to 300V Full Scale Zin: >10^{10}Ω, .3V and 3V range 10 MΩ ± 1%, 30V and 300V range
AC VOLTS	1µvolt sensitivity (.3V range) to 300V full scale True RMS Responding, Crest Factor = 4:1 at full scale Bandwidth: 20Hz to 100KHz (300KHz on 30V range) Zin: 1 MΩ ± 1%, in parallel with <60pF
DC AMPS	10µA sensitivity to 3A full scale Maximum Shunt Resistance = .33Ω Maximum Burden at Full Scale = <1V
AC AMPS	1µA sensitivity (.3A range) to 3A Full Scale Maximum Shunt Resistance '= .33Ω Bandwidth: 20Hz - 20kHz Maximum Burden at Full Scale = <1V
OHMS	1mΩ sensitivity (300 ohm range) to 30 megohms Full Scale Open Circuit Voltage: <6.5V Current through Rx: 300Ω, 3KΩ range - 1mA 30KΩ range - 100µA 300KΩ range - 10µA 3MΩ range - 1µA 30MΩ range - 100 nAnA

B. BLUE KEY. When the Blue Key is pressed before another key, the function above the key is executed. The "shifted" functions of the RANGE KEYS are used to select the number of display digits.

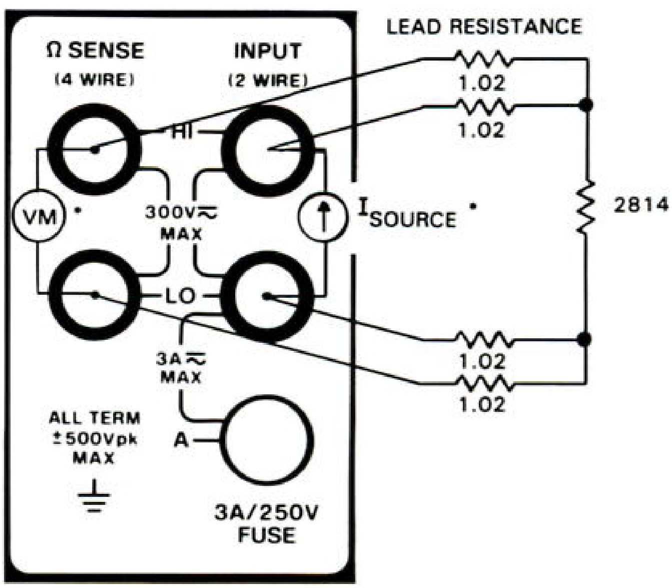
C. MEASUREMENT FUNCTION KEYS. The six (6) keys along the top row of the 3468A/B are used to select the type of measurement desired. Fig. 3.3 on the next page describes their function.



- **Fig. 3.3 Measurement Function Keys**

D. 2-WIRE RESISTANCE MEASUREMENTS. A known current is supplied by the 3468A/B to the device being measured connected across the INPUT 2-wire terminals. Inaccuracies can occur when using long test leads connected to devices with small resistance.

E. 4-WIRE RESISTANCE MEASUREMENTS. One set of test leads connects the device to be measured to the 2-wire terminals and a second set of test leads is connected outboard of the first to the 4-wire terminals. Fig. 3.4 illustrates the point. The current through the device(2814) is supplied by the 2-wire input and is the same regardless of the lead resistance. The voltmeter measures only the voltage across the device, not the voltage across the combined lead resistance. The I_{source}* is internal to the 3468A/B as is the VM*.



- **Fig. 3.4 4-WIRE OHMS MEASUREMENT**

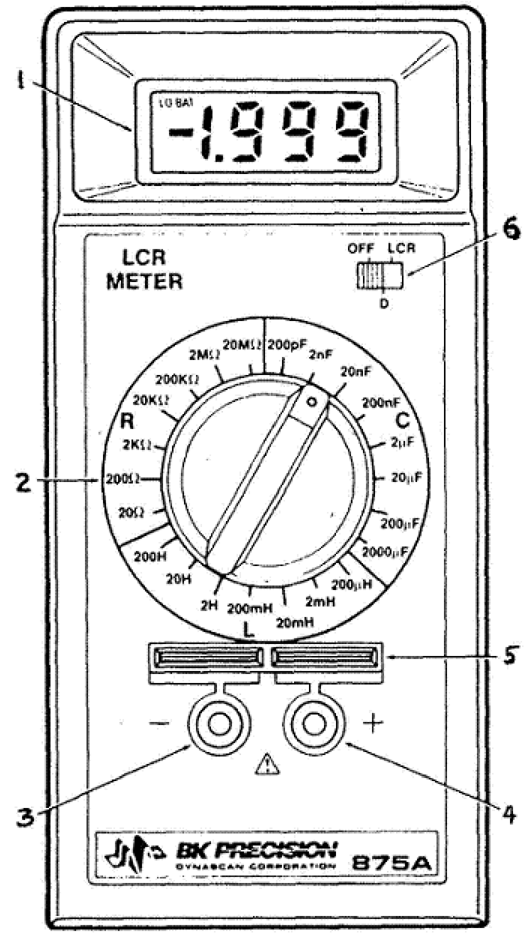
F. DC VOLTAGE MEASUREMENTS. Press the DC Voltage key and either select the appropriate range or allow the multimeter to autorange. Read the display directly.

G. AC VOLTAGE MEASUREMENTS. AC voltage measurements are straightforward just like the DC voltage measurements. The 3468A/B uses TRUE RMS AC TO DC converter for AC voltage and current measurements. Unlike VOM multimeters that use an average detector, the True RMS converter will accurately measure the True RMS value of saw tooth or triangular waveforms and square waves.

H. DC CURRENT MEASUREMENTS. The DC Amps key puts the 3468A/B into the DC current measuring mode. The Amps Input (A) terminal is used with the INPUT LO terminal. Only one range of 3 Amps is available for DC current measurements.

I. AC CURRENT MEASUREMENTS. Two ranges are available for AC current measurements. The specified ranges are 0.3 Amps and 3 Amps.

4. **BK PRECISION MODEL 875A LCR METER**



The BK Model 875A LCR meter, its controls and functions are described.

1. Display. 3 ½ digit display with automatic decimal point and (-) sign. Overrange is indicated by displaying most significant digit "1" and all other digits blank. LO BAT is also indicated.

2. Function/Range Switch. Selects function and upper range of measurement.

3. (-) Jack. Test jack for common, reference or foil side for black test lead.

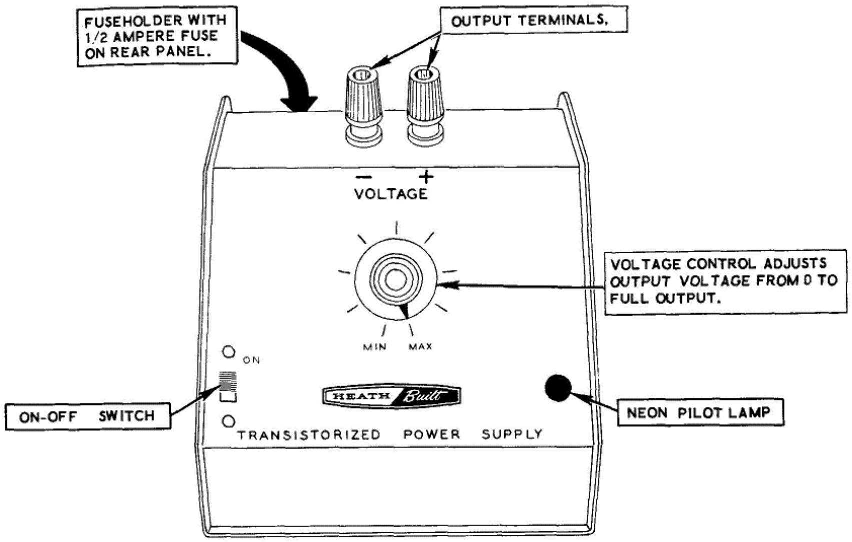
4. (+) Jack. Positive polarized test lead input jack for red lead.

5. Component Lead Receptacles. Use for direct plug in of component leads. Observe proper polarity when measuring polarized capacitors.

6. Power/Selector Switch. Turns unit on and off. The (LCR) position of this switch allows for measurements of inductance (L), capacitance (C) or resistance (R) depending upon position of Function/Range switch. The (D) position of this switch allows for measuring Dissipation Factor of capacitors or inductors as selected by the Function/Range switch.

7. Tilt Stand (Not shown). Folds out from rear of case.

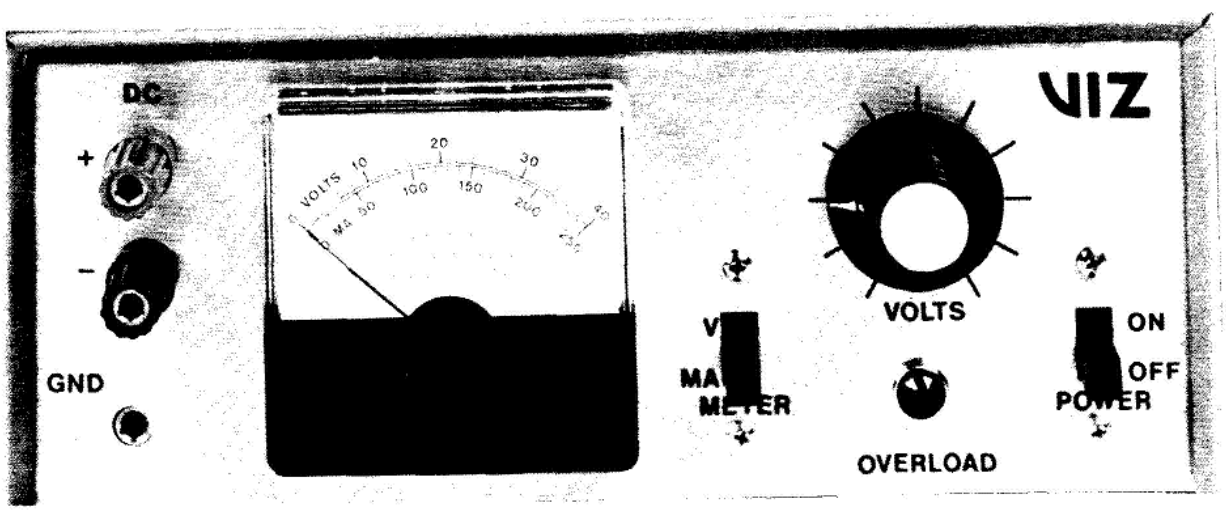
5. HEATHKIT MODEL EUW-17 TRANSISTORIZED DC POWER SUPPLY



• **Fig. II.5.1 Heathkit Model EUW-17 Transistorized Power Supply**

The Heathkit Model EUW-17 Power Supply was designed to supply low operating voltages and currents. The output voltage varies from 0 to 35 volts with no current output and 0 to 25 volts when producing a maximum output current of 200 [mA]. Note that the **neon pilot lamp** indicates only that the power supply is ON, but does **not** indicate if the unit is producing a DC output voltage.

6. VIZ MODEL WP-704A TRANSISTORIZED POWER SUPPLY



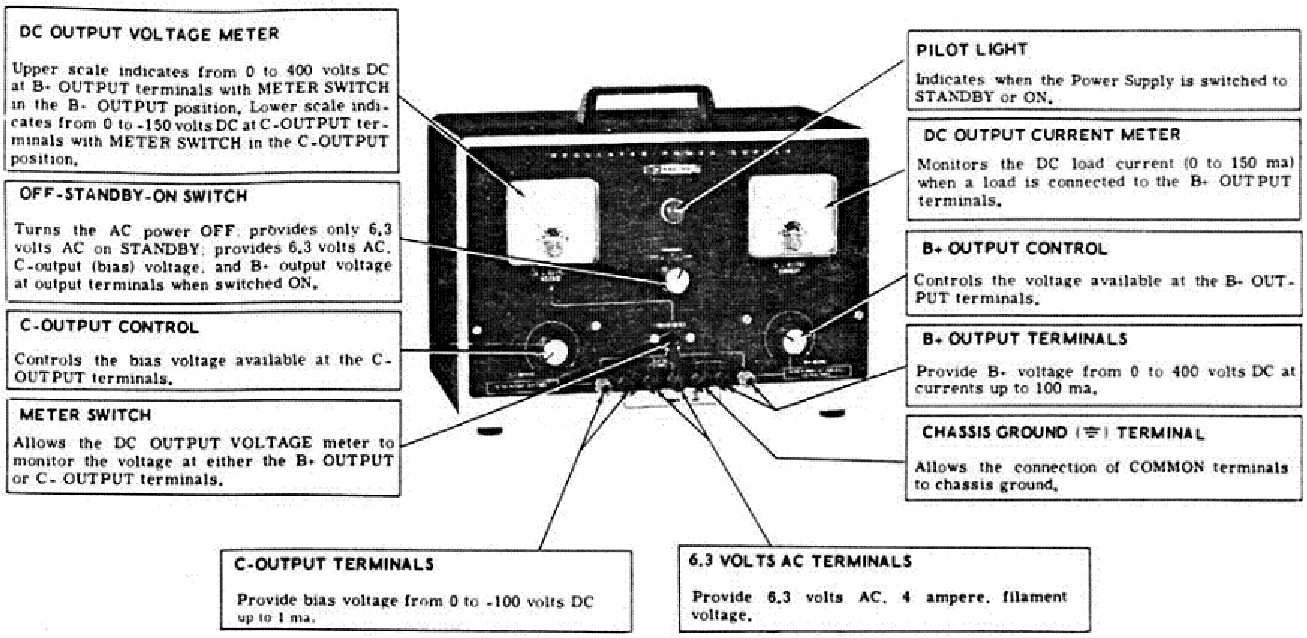
A solid-state transistorized DC supply which provides an adjustable output from 0 to 40 V DC with a maximum current of 250 mA. The Overload panel lamp glows when current approaches the maximum level. The meter can be switched to read either voltage or current output.

7. OTHER LOW VOLTAGE DC SOURCES:

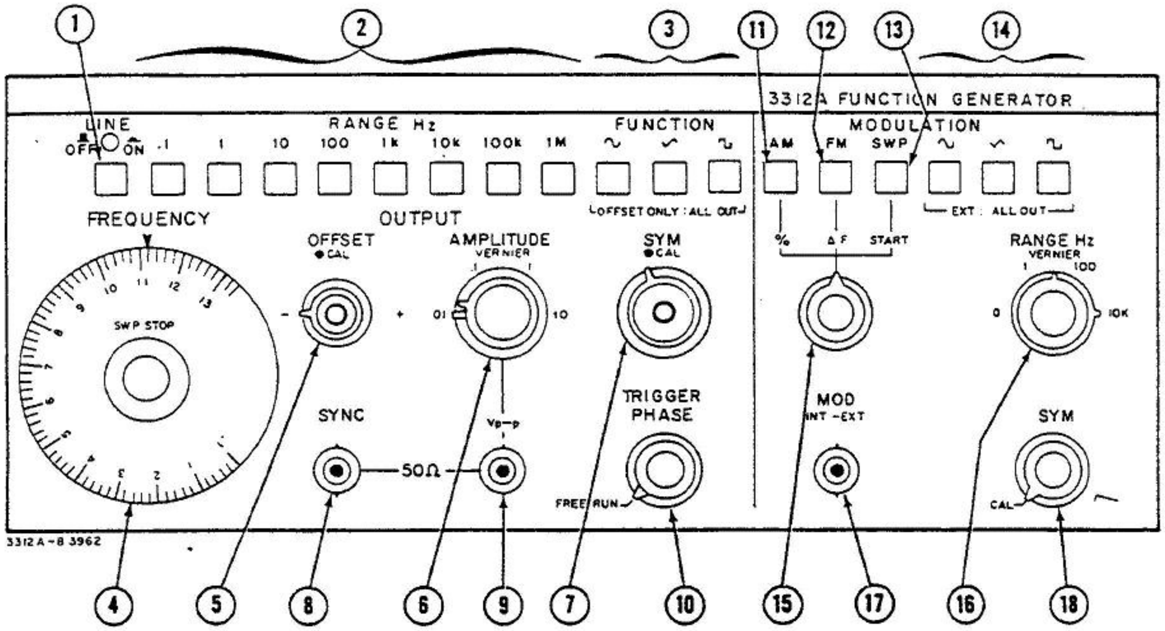
Dry-cells, or batteries, provide another portable source of electricity in which chemical energy is converted into electrical energy with a constant voltage output. Terminal voltages vary and the most common battery sizes are: 1.5, 6.0, 9.0, and 45 [Volts].

8. HEATHKIT MODEL IP-32 REGULATED DC POWER SUPPLY

An electronic voltage source, originally designed to supply operating voltages to equipment using vacuum tubes, contains 3 voltage sources with a 0 to 400 [Volt] DC, a 0 to -150 [Volt] DC and a 6.3 [Volt] AC supply. Since this power supply operates with vacuum tubes, it is recommended that the OFF-STANDBY-SWITCH be left in STANDBY when measurements are NOT being taken.



9. HP MODEL 3312A FUNCTION GENERATOR



(1) LINE: S18 switch applies or removes ac power. The green LED is lit when ON.

(2) RANGE Hz: S1 through S8, pushbuttons select frequency range. RANGE selection times the reading on the FREQUENCY dial determines the output frequency of the main generator.

(3) FUNCTION: Interlocked buttons select one of three functions. When they are all out, the dc level may be set accurately (S9, S10, S11).

(4) FREQUENCY: Sets the desired frequency within the range of any of the RANGE pushbuttons.

(5) OFFSET: R616 sets the dc operating point of any function. CAL position removes the dc offset. $E_{ac} + E_{dc}$ must be less than 10 V or clipping of the waveform will occur.

(6) AMPLITUDE: S22, R613(a), (b), adjust the peak-to-peak amplitude of the waveform. It is attenuated in steps of 1:1, 10:1, 100:1, 1000:1; the VERNIER adjusts from zero to maximum output volts for the particular range selected.

(7) SYM: R608 varies the symmetry of output waveforms and the SYNC output. CAL is symmetrical.

(8) SYNC: A square wave 180° out of phase with the main generator. Useful for synchronizing external instruments or driving a counter.

(9) OUTPUT: Terminal for all main generator functions. 20 V p-p into open circuit or 10 V p-p into 50 ohms, in the 1:1 attenuator position.

(10) TRIGGER PHASE: R615 sets the starting phase of the output signal in the burst mode. FREE RUN disables the burst.

(11) AM: Selects amplitude modulation. Functional for internal or external modulation.

(12) FM: S13 selects frequency modulation. Functional for internal or external modulation.

(13) SWP: S14 selects sweep mode. This function overrides AM and FM.

(14) ∼ ⋀⋀ ⊓⊔ : S15, S16, S17 select the modulating function. External modulation is possible when all buttons are out, and the modulating signal is applied to the MOD INT-EXT jack.

(15) % ΔF START: R612 selects the percent of AM, the deviation in FM, or the start frequency of the SWP.

(16) RANGE Hz: R602, S21 select one of the three ranges of modulating frequencies with continuous control within each range via the VERNIER. The 0 position is used to set the start sweep frequency.

(17) MOD INT-EXT: Input for external AM or FM. Waveforms of the modulation generator are also available at this output when internal modulation is used.

(18) SYM: R601 varies the symmetry of the modulation output waveform. CAL selects a 90:10 ramp for SWP and symmetrical for all other functions.

The main generator has two outputs, a main signal output and a SYNC output. The SYNC output provides a pulse which can be used for external timing (sync) purposes. The SYNC output level is 0.25 [V p-p] into 50 Ohms. The output impedance of both generators is 50 [Ohms] nominal.

4B LAB EQUIPMENT VERSION 6.0	**4B LAB EXPERIMENT NUMBERS**										
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**
VOM, Volt-Ohm-Milliameter, 260	1	1	1		1					1	
DMM, Hand-held Digital Multimeter	1	1			1					1	
HP-DMM, HP 3468A/B	1	1			1					1	
Red lead: Banana to alligator	1	2									
Black lead: Banana to alligator	1	2									
Red lead: Banana to banana		2	2		1			2	1		
Black lead: Banana to banana		1	2		1			1	1		
Resistors	2	2									
1.5 Volt dry cell		1			1						
Transistorized Power Supply: 0 – 24 [V]		1	1								
AC power cord	1	1	1		1	1	2	2	1	2	2
Lamp board, Type 47 lamp + Resistor		1									
Alligator clips							2			2	
Cathode Ray Tube with harness			1								
Regulated Power Supply, Heathkit IP-32			1								
Small transparent grid			1								
Safety glasses			1								
Coax cable, BNC to double banana							1	1		1	1
Oscilloscope: JDR Model 3500					1						
BNC to SCOPE PROBE					1						
Oscilloscope, Fluke PM 3084						1	1	1		1	1
Probe, Fluke						1	1	2		1	2
Function Generator, HP 3312A							1	1		1	1
Coax cable, BNC to BNC											
Circuit Breadboard								1			1
Resistor (20 – 50) [kΩ]								1			
Capacitor (0.005 to 0.01)[μF]								1			
Resistor (1 - 3) [kΩ]											1
Inductor (15 – 20) [mH]											1
Small solid-conductor insulated wires								3			3
PASCO Current Balance, SF-8607									1		
Current Loop PC boards									Set		
Magnet Assembly									1		
PASCO SF-9584 DC Power Supply									1		
Triple-beam or Electronic pan balance									1		
Lab stand with 3/8” diameter rod									1		
LCR meter BK 875A								1			1