جامعة فلسطين التقنية خضوري

م. قياسات كهربائية

مع تحيات مكتبة الطالب 2013/2014

0022408

Experiment #1
ERROR OF MEASUREMENT

Objectives:

1. To find the error in a resistive element.
2. To find the error in a inductive element.
3. To find the error in a capacitive element.

Apparatus required:

1. Variable ac, dc power supply.
2. DC Ammeters and voltmeters.
3. Resistances (100ohm) ,capacitance (40microfarad) and inductance (300mHinry).

Theoretical background :

When a number of independent measurement are taken in an effort to obtain the best possible answer (closest to the true value), the result is usually expressed as the arithmetic mean of all the readings, with the range of possible error as the largest deviation from that mean.

I. Some definitions

- Error : deviation from the true value of the measured variable .
- Accuracy : closeness with which an instrument reading approaches the true value of the variable being measured .
- Precision : a measure of the reproducibility of the measurements .
- Sensitivity : the ratio of out put signal or response of the instrument to a change of input .

II. Types of error:-

1. Gross error:

   Largely human errors, among them misreading of instruments, incorrect adjustment and improper application of instrument and computational mistakes.

2. Systematic error:

   This type of error is usually divided into two different categories:

   1- Instrumental errors, defined as shortcoming of instrument mechanical structure errors'.

2- <u>Environmental errors,</u> due to external conditions affecting the measurement.

(3) - **Random error:**

These error are due to unknown causes and occur even when all systematic errors have been accounted for. The only way to offset these errors is by increasing the number of readings and using statistical means to obtain the best approximation of the true value of the quantity under measurements.

III. Statistical analysis:

There are several way to use the statistical analysis like:

- **Arithmetic mean:**

  The arithmetic mean given by the following expression:

  $X = (X1 + X2 + X3 + \ldots\ldots\ldots + Xn)/n = \sum X/n$

  X : arithmetic mean

  X1, X2, …, Xn : readings taken.

  n: number of readings.

- **Deviation from the mean:**

  The deviation from the mean is expressed as

  $d1 = X1 - X \qquad d2 = X2 - X \qquad dn = Xn - X$

- **Average deviation:**

  The average deviation is the sum of the absolute values of the deviations divided by the number of the readings.

  It is expressed as:

  $D = (\ d1\ + \ d2\ + \quad + \ dn\ )/n$

- **Standard deviation:**

  The standard deviation of a finite number of data is given by:

  $\sigma = ((d1^2 + d2^2 + \ldots\ldots\ldots\ldots\ldots\ldots + dn^2)/n-1)^{1/2}$

  $\sigma = (\sum di^2/n-1)^{1/2}$

- **Probable error**

  The probable error is given by the formula

  $r = \pm\ 0.6745\ \sigma$

- **Range of error:**

  Let:

  E max. - E avg. = X

  E avg. - Emin. = Y

  The average range of error = (X+Y)/2

Absolute error (Δx) $= X_T - X_m$

True measure

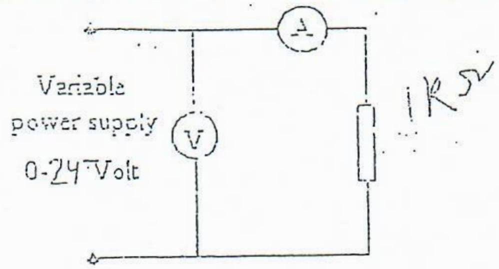
Precision $= 1 - \left|\frac{Xn - X_{av}}{X_{av}}\right|$

% error $= \frac{\Delta X}{\ } \times 100\%$

V = TP

Experimental procedure:

1. Connect the circuit as shown in the figure(1).



figure(1)

2. Change the supply voltage in steps from zero voltage to 24volt, measure the current in each step, tabulate your result in table(1).

Input voltage(V)	Current	R (Calculation)	Error	Error%
2				
4				
6				
8				
10				
12				
14				
16				
18				
20				
22				
24				

Table(1).

- Form your result calculate ~~Average resistance using~~
  - i- Range of error ~~method.~~
  - ii- Arithmetic mean ~~method.~~
  - iii- Deviations from the mean ~~method.~~
  - iv- Average deviation ~~method.~~
  - v- Probable error ~~method.~~

Exercise:

Nine measurements of the resistances are : 98.2Ω ,98.1Ω, 98.9Ω, 98.3Ω, 98.1Ω, 98.5Ω,98.9Ω, 98.0Ω ,98.6Ω.
If the only random errors are present.

Calculate:

1- The arithmetic mean.
2- The deviations from the mean.
3- The average deviation.
4- The probable error.

TECHNICAL PALESINE UNIVERSITY –KHADOORIE-TULKAREM

MEASUREMENT LAB

Prepared by: E.mohamad dradi

Experiment NO (2).

AC-DC Bridge

Objectives:

1-To find the unknown resistor by balance wheat stone Bridge.

2- To find the unknown inductor by using balance Maxwell Bridge.

3-To find the unknown capacitor by using balance schering Bridge.

Apparatus required:

1-function generator 2-multimeter 3-dc power supply

4-varipIe resistor, inductor, capacitor.

Theoretical background

<u>A) Wheat stone bridge</u>

It is used to determine an unknown resistance with standard resistance.

Balance condition

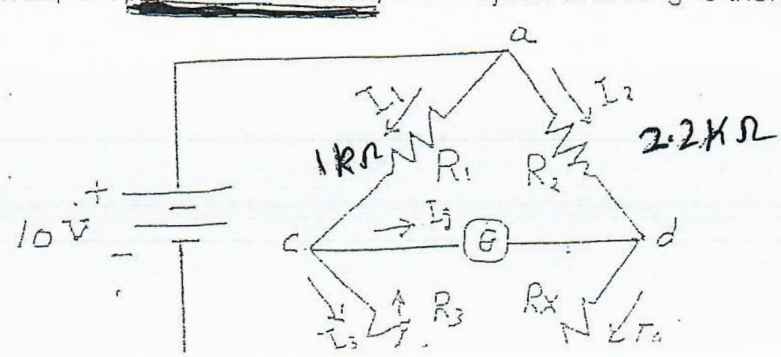
a) Ig=0
b) Vca=Vda or Vcb=Vdb

At balance **Rx =R3 *(R2/R1)**

Experiment Procedure:

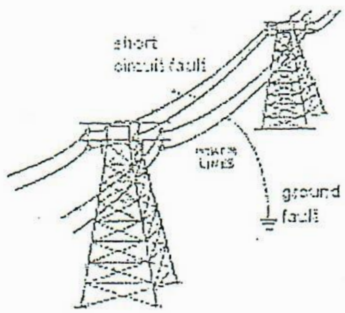
1-Connect the wheat stone circuit as shown choose (R2/ R1 =2)

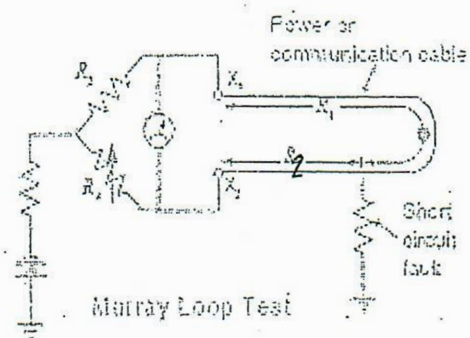
2-Choose Rx = 1Ω,1KΩ, and R3 resistance box, then adjust R3 until Ig=0 then find RX Vca, Vda, Vcb, and Vdb.



Application of Wheatstone Bridge

Loop test can be carried out for the location of either a ground or a short circuit fault.





Murray Loop Test

Let R=R1+R2

At balance condition:R3/R4=R1/R2

[illegible] [illegible]

$$R_2 = R\,\frac{R_4}{R_3+R_4}$$

$$R_1 = R\,\frac{R_3}{R_3+R_4}$$

X2 =R2 * Meter per ohm (At specific diameter and Temp)

$$\frac{R_3}{R_4} = \frac{R_1}{R_2} \implies R_3 R_2 = R_1 R_4$$

$$R_3 (R - R_1) = R_1 R_4$$

$$R_3 R - R_3 R_1 = R_1 R_4$$

$$R_1 R_4 + R_3 R_1 = R_3 R$$

$$R_1 (R_3 + R_4) = R_3 R$$

$$\implies R_1 = R\left(\frac{R_3}{R_3+R_4}\right)$$

B) Schering Bridge

It is used to determine an unknown inductance with standard capacitance.

At balance condition

Ig=0

$Cx = (R1/R2)*C3$ $RX=(C1/C3)*R2$

Experiment Procedure:

1-connect the circuit as shown with C1=1μf, C3=0.1μf, R1=1 KΩ

2-put unknown Cx and Rx and vary R2 until Ig=0 then record R2

3-repeat 2 with different Rx, Cx

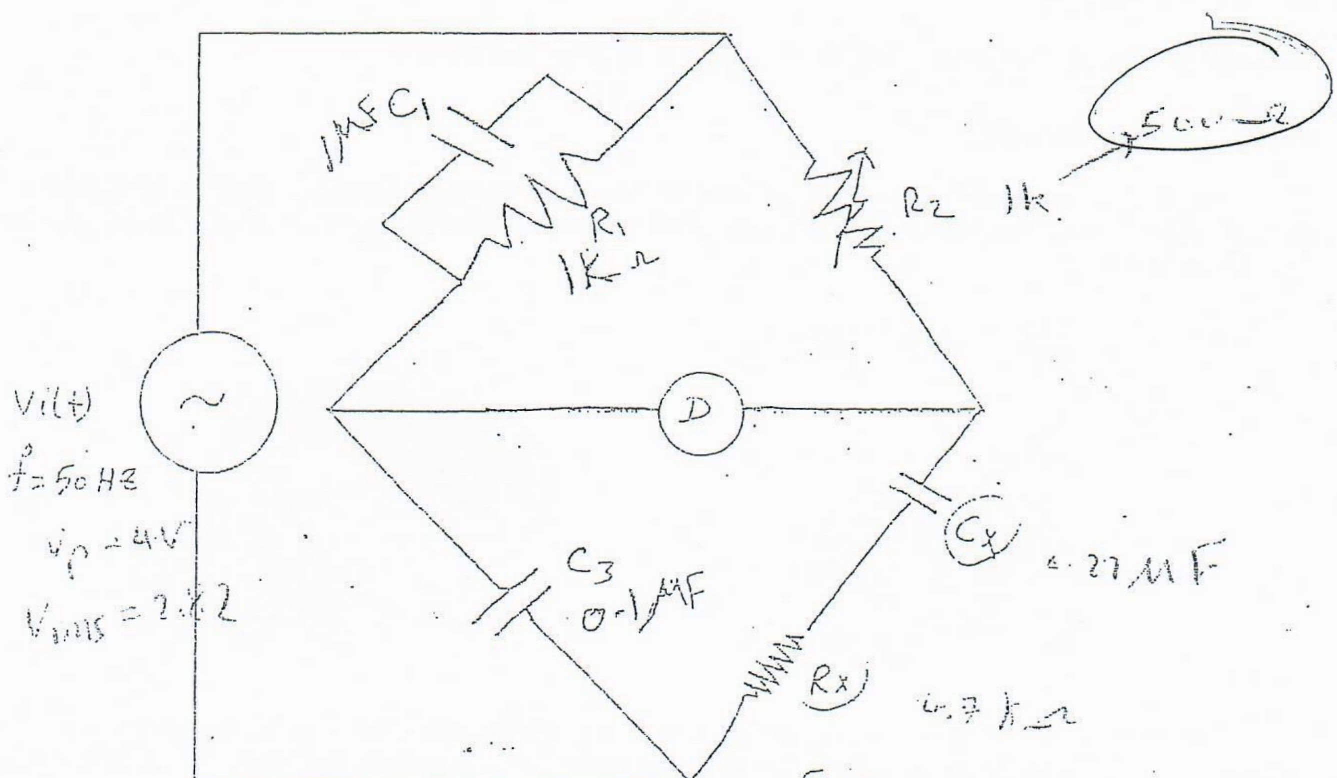


Fig 2

at balance Ig = 0

$$C_x = \frac{R_1}{R_2} C_3 \qquad R_x = \frac{C_1}{C_3} R_2$$

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MEASUREMENT LAB

Prepared by: E.mohamad dradi

Experiment NO (3)

Analog multimeter design

Objectives:

1-Study the operation of ammeter, voltmeter, ohmmeter.

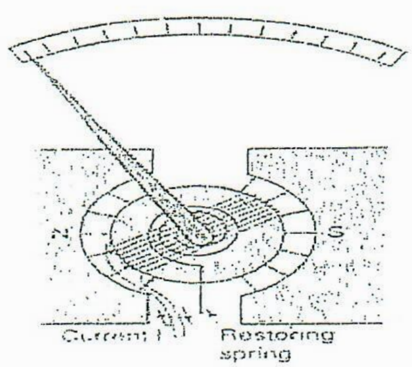
2-To find how you can increase the range of instrument.

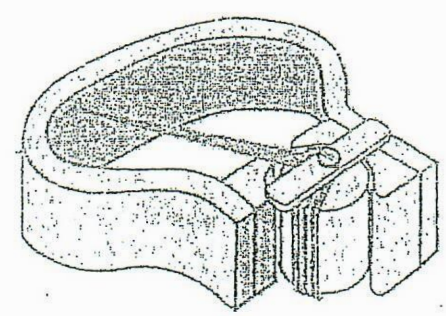
Apparatus required:

1-galvanometer 2-multimeter 3-rotating switch 4-3v dc power supply

Theoretical background

The torque on a current loop in a uniform magnetic field is used to measure electrical magnetic field is used to measure electrical currents. This current measuring device is called a moving coil galvanometer.





The galvanometer consists of a coil of wire often rectangular, carrying the current to be measured. There are generally many turns in the coil to increase its sensitivity. The coil is placed in a magnetic field such that the lines of B remain nearly parallel to the plane of wire as it turns. This is achieved by having a soft iron cylinder placed at the center of the coil. Magnetic field lines tend to pass through the iron cylinder, producing the field configuration. The moving coil is hung from a spring which winds up as the coil rotates; this winding up produces a restoring torque proportional to the winding up (or twisting) of the spring, i.e. to the angular deflection of the coil. The coil comes to equilibrium when this restoring torque k balances the torque due to the magnetic field balances the torque due to the magnetic field. Since by design field lines are radial,

We have $\sin\theta \sim 1$, so that for equilibrium

$k\sigma = INBA$ $\sigma = (NBA/K)*I$

Voltmeter Design

Some movements have full-scale deflection current ratings as little as 50 µA, with an (internal) wire resistance of less than 1000 Ω. This makes for a voltmeter with a full-scale rating of only 50 millivolts (50 µA X 1000 Ω)!

In order to build voltmeters with practical (higher voltage) scales from such sensitive movements, we need to find some way to reduce the measured quantity of voltage down to a level the movement can handle.

Using Ohm's Law (*E=I R*), we can determine how much voltage will drive this meter movement directly to full scale:

$E = I R$

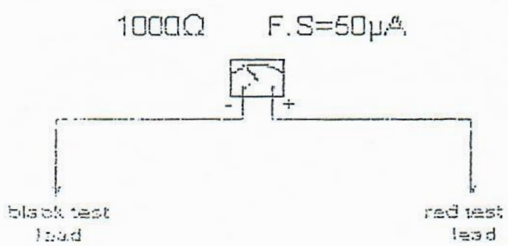
$E = (50\ \mu A)(1000\ \Omega)$

$E = 0.05$ volts

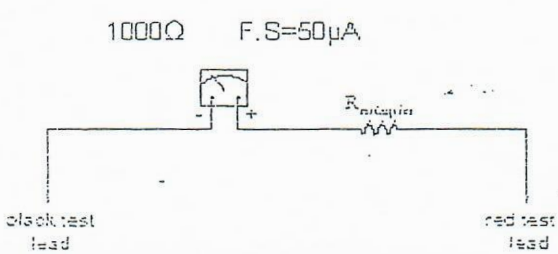
To get an effective voltmeter meter range in excess of 0.05 volt, we'll need to design a circuit allowing only a precise proportion of measured voltage to drop across the meter movement.

This will extend the meter movement's range to being able to measure higher voltages than before.

Correspondingly, we will need to re-label the scale on the meter face to indicate its new measurement range with this proportioning circuit connected.



Measuring Higher Voltages



What we need is a *voltage divider* circuit to proportion the total measured voltage into a lesser fraction across the meter movement's connection points. Knowing that voltage divider circuits are built from *series* resistances, we'll connect a resistor in series with the meter movement. Ohm's Law could be used to determine resistance (*R=E/I*) for the multiplier:

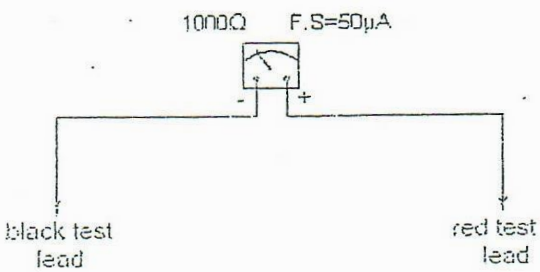
$R_{multiplier} = (E/I) - R$

Ammeter Design

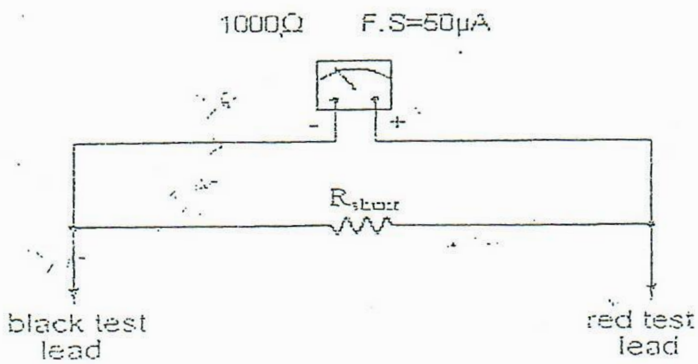
A meter designed to measure electrical current is popularly called an "ammeter" because the unit of measurement is "amps."

In ammeter designs, external resistors added to extend the usable range of the movement are Connected in parallel with the movement rather than in series as is the case for voltmeters. This is Because we want to divide the measured current, not the measured voltage, going to the movement, and because current divider circuits are always formed by parallel resistances.

As is the case with extending a meter movement's voltage-measuring ability, we would have to Correspondingly re-label the movement's scale so that it read differently for an extended current range. For example, if we wanted to design an ammeter to have a full-scale range of 5 amps using the same meter movement as before (having an intrinsic full-scale range of only 50 µA), we would have to re-label the movement's scale to read 0 A on the far left and 5 A on the far right, rather than 0 µA to 50 µA as before. Whatever extended range provided by the parallel-connected resistors, we would have to represent graphically on the meter movement face.



Using 5 amps as an extended range for our sample movement, let's determine the amount of parallel resistance necessary to "shunt," or bypass, the majority of current so that only 1 mA will go through the movement with a total current of 5 A:



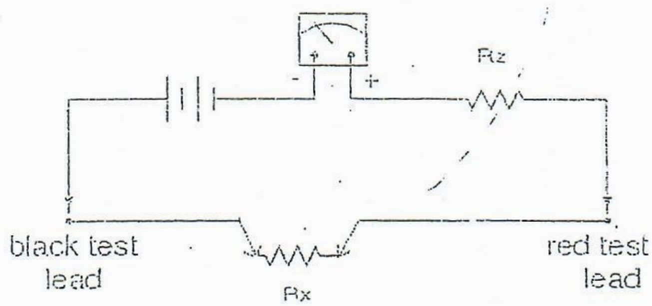
Using 5 amps as an extended range for our sample movement, let's determine the amount of parallel resistance necessary to "shunt," or bypass, the majority of current so that only [illegible] µA will go through the movement with a total current of 5 A.

Rsh = E/(Ish – IG)

Ohmmeter Design

The purpose of an ohmmeter, of course, is to measure the resistance placed between its leads. This resistance reading is indicated through a mechanical meter movement which operates on electric current. The ohmmeter must then have an internal source of voltage to create the necessary current to operate the movement, and also have appropriate ranging resistors to allow just the right amount of current through the movement at any given resistance.

Starting with a simple movement and battery circuit, let's see how it would function as an ohmmeter:



Rz = (E / Ifs) – Rm

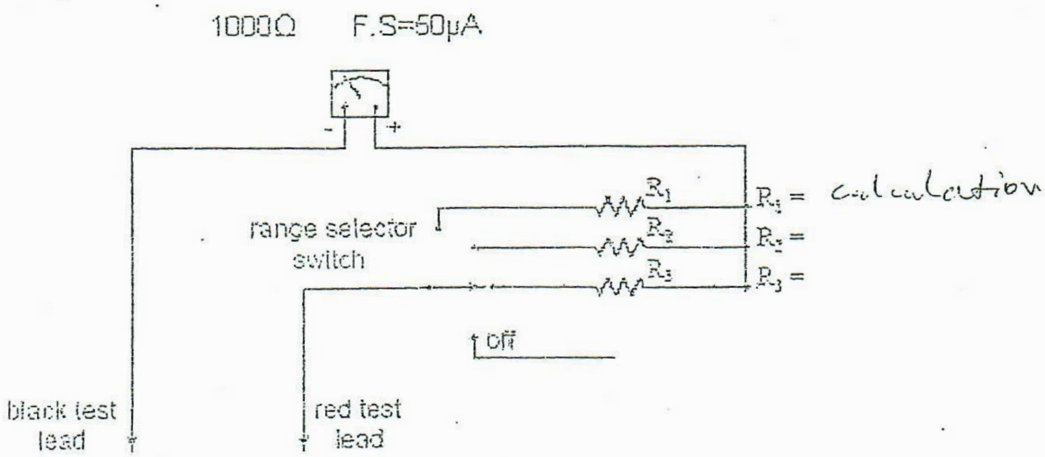
Then if you want to find Rx at a percent of scale deflection then apply this equation:

Rx = ((Rz+Rm)/P)-(Rz+Rm)

Experiment procedure:

A) multirange voltmeter.

1-Connect the circuit as shown in figure (1).
2-find R1 to measure 2V,R2 to measure 4V,R3 to measure 8V



figure(1)

B)

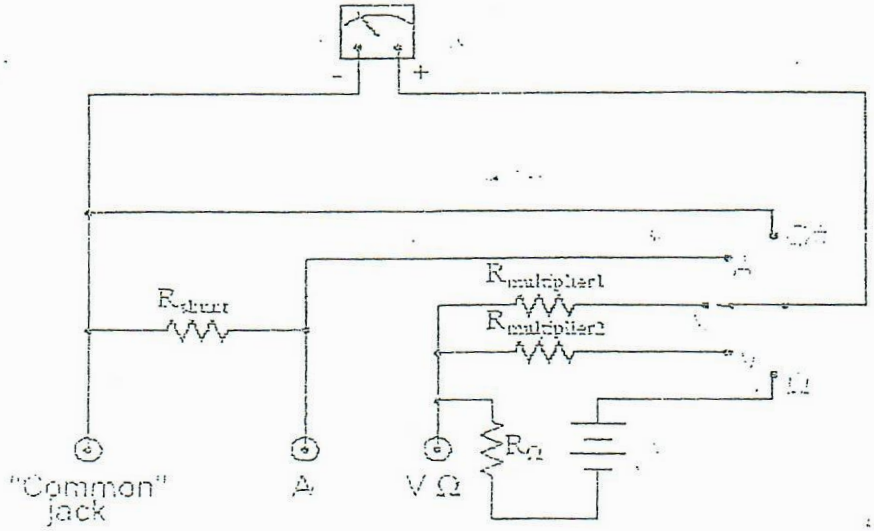
1-Connect the circuit as shown in figure (2).

2- Find R multiplier 1 to measure 1v.

3- Find Rmultiplier2 to measure 10v.

4- Find R shunt to measure 50mA.

5- Find RΩ to measure ex 100 KΩ



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MEASUREMENT LAB

Prepared by: E.moha.:ou dradi

Experiment NO (4)

Frequency and phase measurement

Objectives:

1-To find unknown frequency by using standard frequency.

2-To study Lissajous figure.

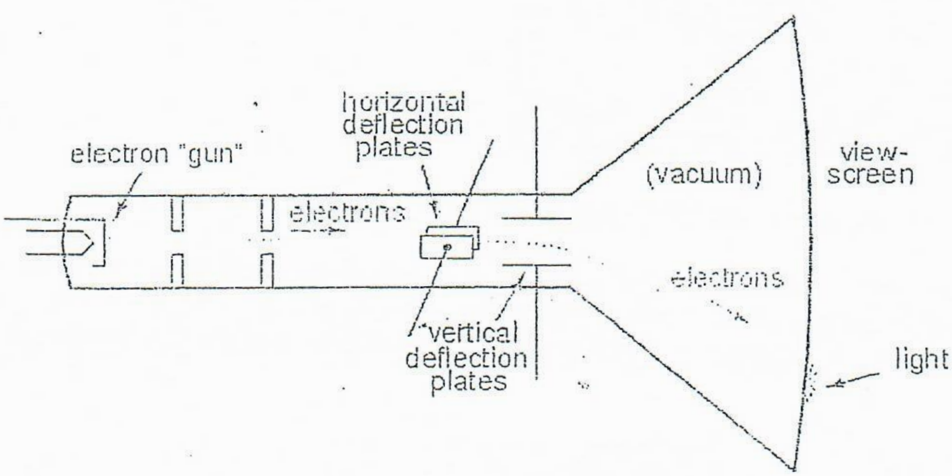
3-To find phase shift between voltage and current.

Apparatus required:

1-function generator 2-oscilloscope 3-resistor, capacitor 4-electronic kit 5-multimeter

Theoretical background

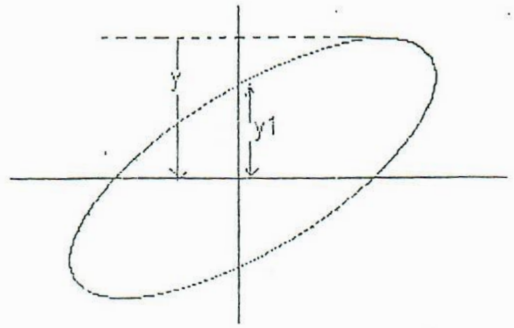
Now we get to the practical part: once we have a source of accurate frequency, how do we compare that against an unknown frequency to obtain a measurement? One way is to use a CRT as a frequency-comparison device. Cathode Ray Tubes typically have means of deflecting the electron beam in the horizontal as well as the vertical axis. If metal plates are used to electro statically deflect the electrons, there will be a pair of plates to the left and right of the beam as well as a pair of plates above and below the beam as in Figure below.



Cathode ray tube (CRT) with vertical and horizontal deflection plates.

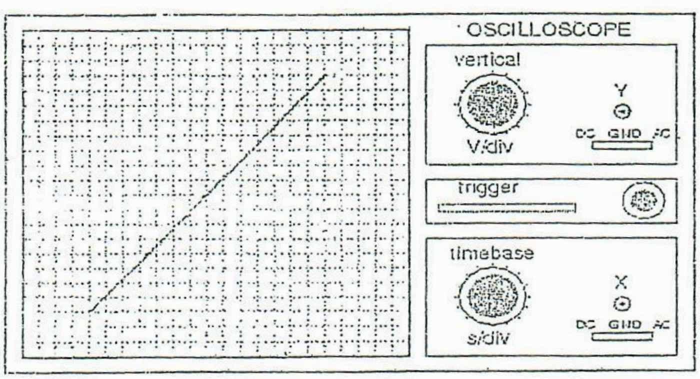
-If we allow one AC signal to deflect the beam up and down (connect that AC voltage source to the "vertical" deflection plates) and another AC signal to deflect the beam left and right (using the other pair of deflection plates), patterns will be produced on the screen of the CRT indicative of the ratio of these two AC frequencies. These patterns are called Lissajous figures and are a common means of comparative frequency measurement in electronics.

Phase measurement:



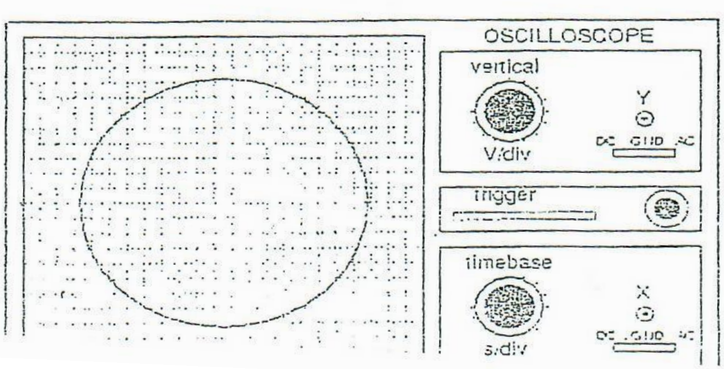
$$\phi = \sin^{-1}\frac{y1}{y}$$

Here is a sampling of Lissajous figures for two sine-wave signals of equal frequency, shown as they would appear on the face of an oscilloscope (an AC voltage-measuring instrument using a CRT as its "movement"). The first picture is of the Lissajous figure formed by two AC voltages perfectly in phase with each other: (Figure below)

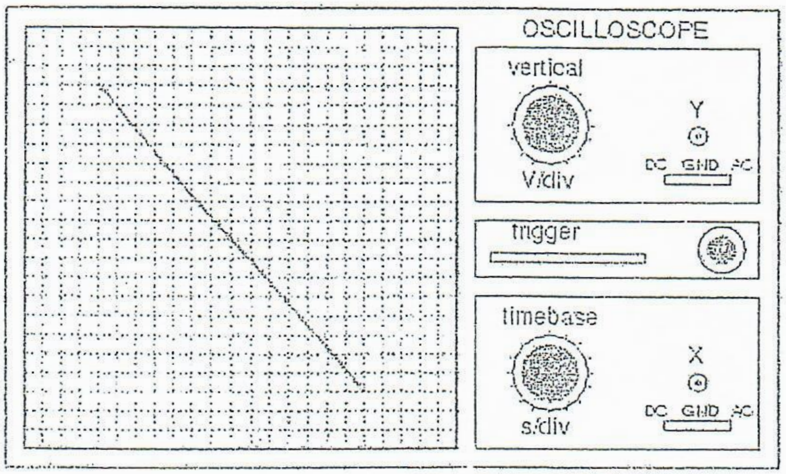


Lissajous figure: same frequency, zero degrees phase shift.

If the two AC voltages are not in phase with each other, a straight line will not be formed. Rather, the Lissajous figure will take on the appearance of an oval, becoming perfectly circular if the phase shift is exactly 90o between the two signals, and if their amplitudes are equal: (Figure below)



Finally, if the two AC signals are directly opposing one another in phase (180o shift), we will end up with a line again, only this time it will be oriented in the opposite direction: (Figure below)

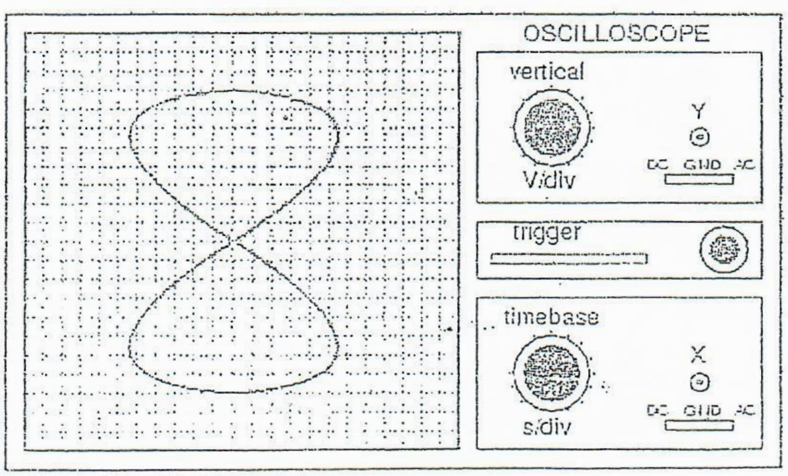


same freq.

Lissajous figure: same frequency, 180 degrees phase shift.

Frequency measurement:

When we are faced with signal frequencies that are not the same, Lissajous figures get quite a bit more complex. Consider the following examples and they're given vertical/horizontal frequency ratios: (Figure below)



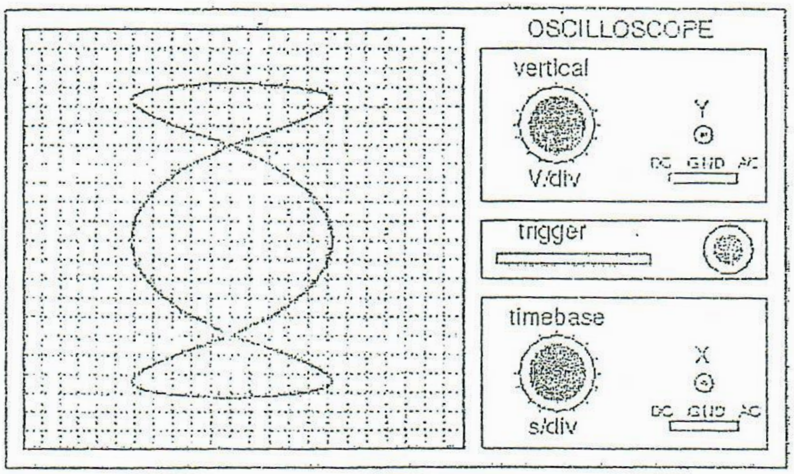
diff. freq.

Lissajous figure: Horizontal frequency is twice that of vertical.

$n_H = 2$, $n_V = 1$

$$\frac{f_V}{f_H} = \frac{n_V}{n_H} = \frac{1}{2} \qquad 1:2$$

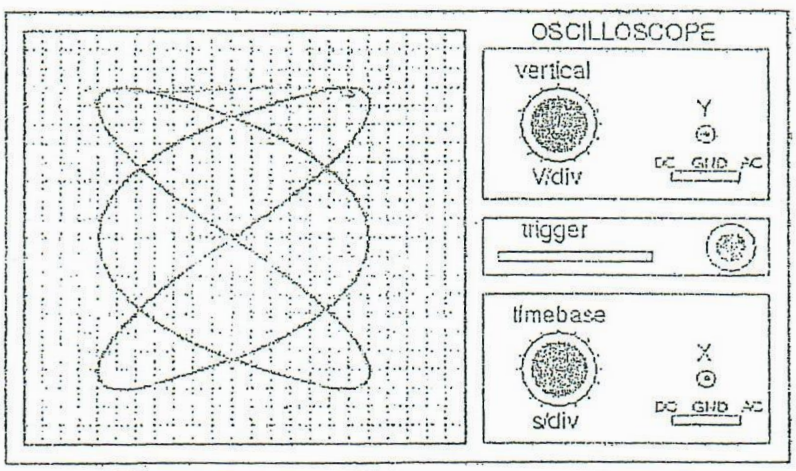
The more complex the ratio between horizontal and vertical frequencies, the more complex the Lissajous figure. Consider the following illustration of a 3:1 frequency ratio between horizontal and vertical: (Figure below)



$$\frac{f_V}{f_H} = \frac{n_V}{n_H} = \frac{1}{3}$$

Lissajous figure: Horizontal frequency is three times that of vertical.

. . . And a 3:2 frequency ratio (horizontal = 3, vertical = 2) in Figure below.



$$\frac{f_V}{f_H} = \frac{n_V}{n_H} = \frac{2}{3}$$

Lissajous figure: Horizontal/Vertical frequency ratio is 3:2

Lissajous figure: Horizontal/vertical frequency ratio is 3:2.

In cases where the frequencies of the two AC signals are not exactly a simple ratio of each other (but close), the Lissajous figure will appear to "move," slowly changing orientation as the phase angle between the two waveforms rolls between 0o and 180o. If the two frequencies are locked in an exact integer ratio between each other, the Lissajous figure will be stable on the view screen of the CRT.

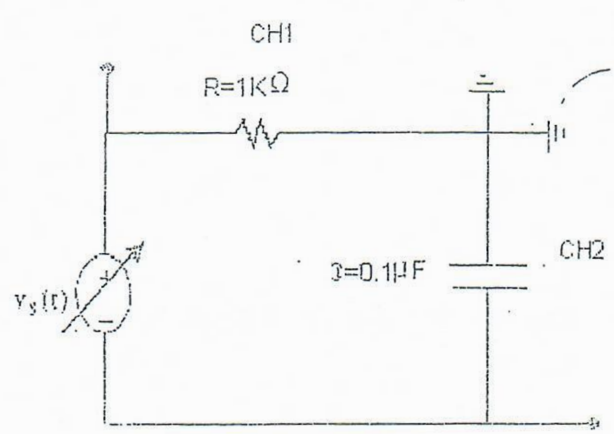
Experiment procedure

A)-

1- Connect the circuit as shown in figure (1) set ac voltage3 as a function generator with 2Vp,f=1khz.

2- Connect the two channels as shown and be sure to invert channel two.

3- Press x-y mode and from wave find the phase shift between voltage and current.



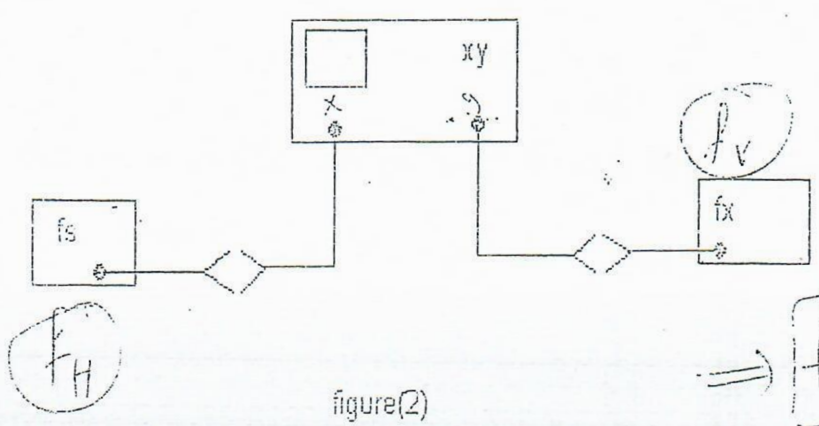
figure(1)

B)-

1-connect the circuit as shown in figure (2).

2-set fx=1khz then vary fs in order to find any Lissajous figures the find fx from this equation.

fx=fs*(NH/NV) ....(1)



figure(2)

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MEASUREMENT LAB

Prepared by: E.mohamad dradi

Experiment NO (5)

741-operation amplifier

Objectives:

1-Study the operation of op-amp 741.

2-To study op-amp as an inverting amplifier.

3- To study op-amp as non-inverting amplifier.

4- To study op-amp as summer amplifier

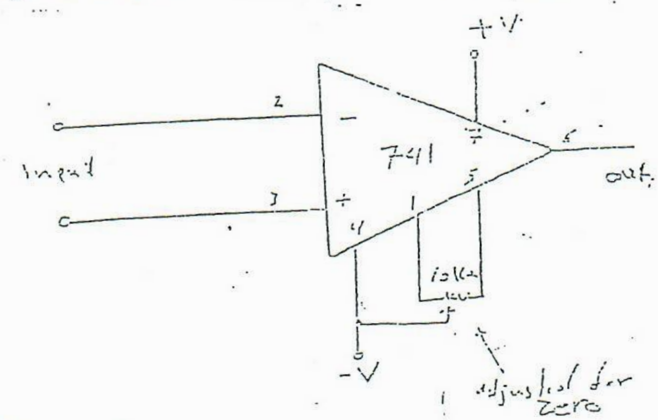
Apparatus required:

1-function generator 2-oscilloscope 3-741 op-amp 4-electronic kit 5-multimeter

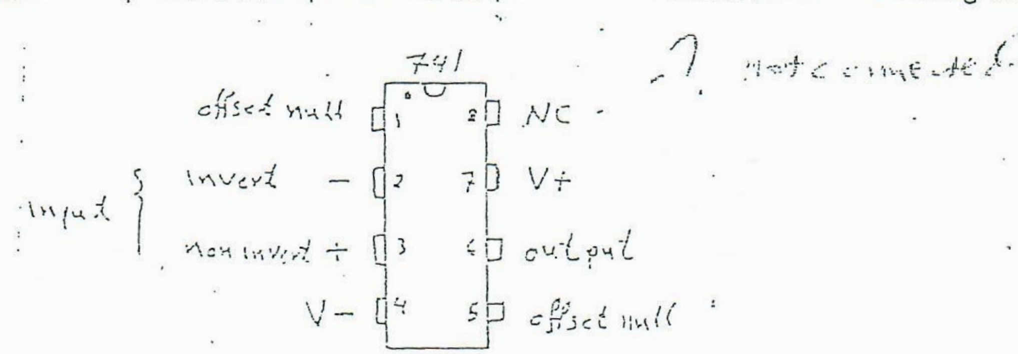
6-dc power supply

Theoretical background

The general symbol of the operational amplifier



The IC used to represent this operational amplifier is 741 which has the following terminals



The operational amplifier is probably the most frequently used linear integrated circuit a variable. There are two basic configurations for operational amplifier circuits:

1-the inverting amplifier
2-non-inverting amplifier

<u>Operational amplifier ideally has</u>

1-infinite input impedance (open)
2-infinite voltage gain.
3-zero output impedance

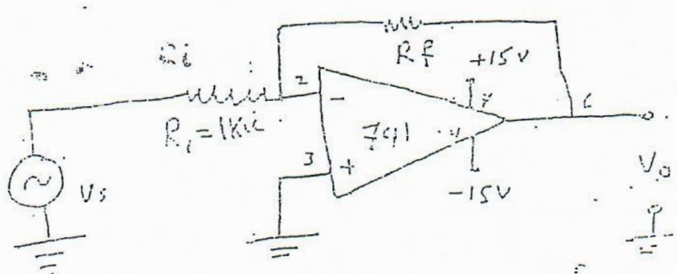
<u>Operational amplifier practically has</u>

1-Very high input impedance.
2-very high voltage gain
3-very small output impedance

Experiment procedure:

Inverting amplifier

Construct the following circuit



1-use a function generator as an ac source and adjust it to 2Vp, 1KHZ.

2-for Rf = 1KΩ observe both signals.Vs and Vo using oscilloscope on the dual mode and then draw the figure on your graph paper.

3-Repeat 2 if Rf=2kΩand Rf=10k Ω.

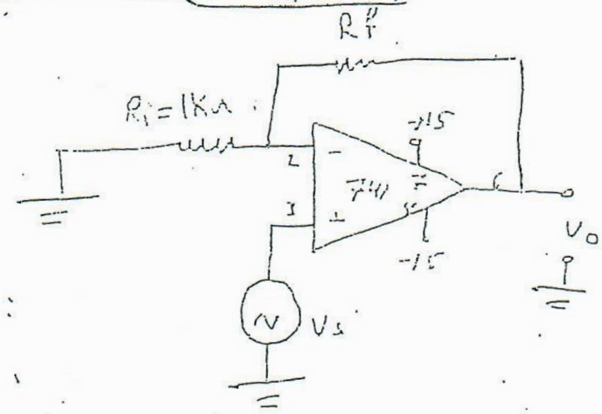
4- compare the voltage gain(Av=(Vo/ Vi))you notice from the graph by the value you get from the formula(Av= -(Rf / Ri))

Non-inverting amplifier

Construct the following circuit

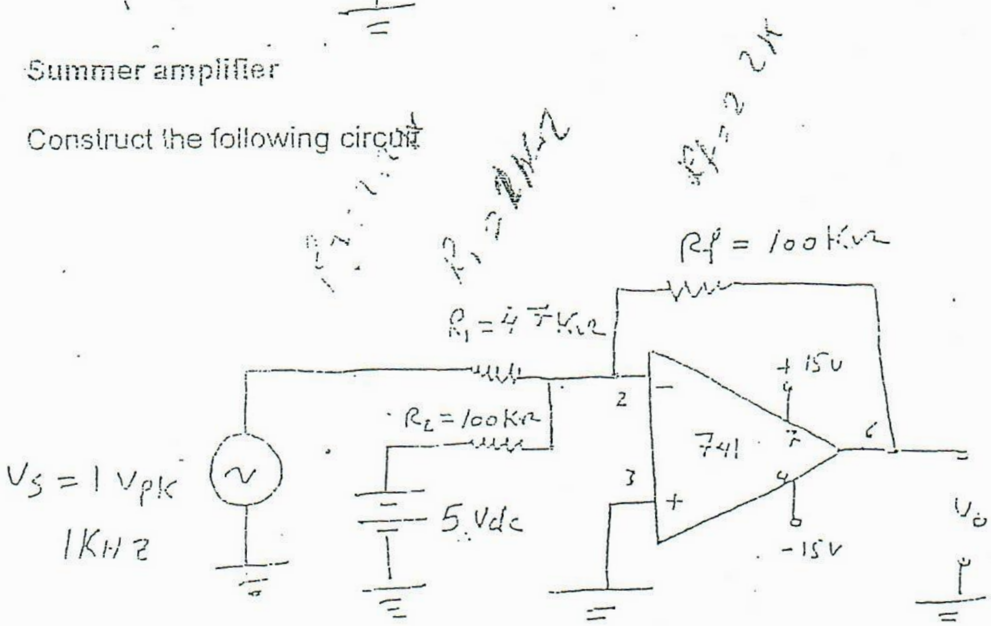
1-Repeat inverting procedures from 2-4

2-compare the voltage gain (Av =(Vo/Vi)) you notice from the graph with the voltage gain you get from the formula (Av =1+(Rf / R1))



Summer amplifier

Construct the following circuit



1-Adjust the oscilloscope to zero dc level before connecting to the circuit

2- Observes Vo and then draw the following

a) Vo when the dc source off and Ac source on
b) Vo when the dc source on and the Ac source off.
c) Draw Vo if dc source and Ac source on

3-Compare Vo in part (2-c) to the value you can get from the formula

TECHNICAL PALESINE UNIVERSITY –KHADOORIE-TULKAREM

MEASUREMENT LAB

Prepared by: E.mohamad dradi

Experiment NO (6)

Function generator

Objectives:

1-Study the operation of function generator.

2-To studies the construction of function generator.

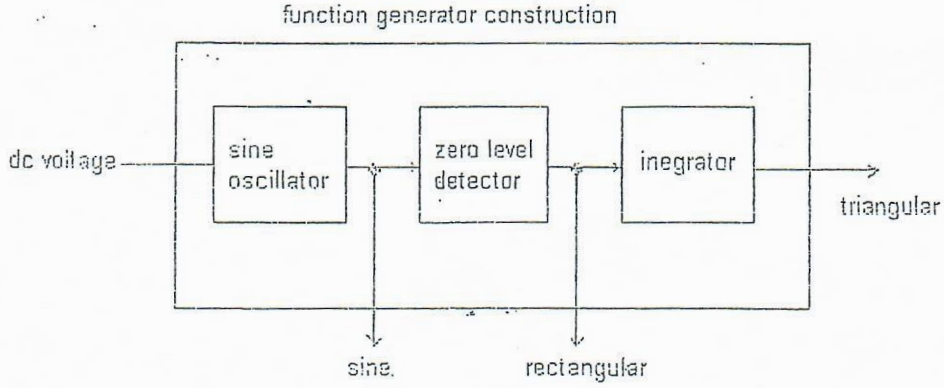
3-To studies zero level detector and integrator.

Apparatus required:

1-741 operational amplifier 2-oscilloscope 3-resistors and capacitors 4-electronic kit 5-multimeter

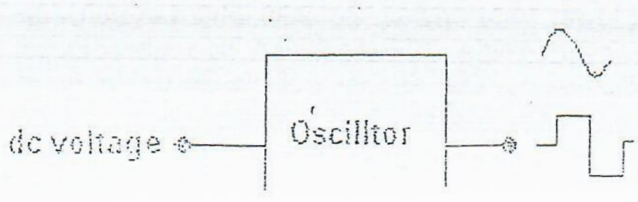
Theoretical background

Function generator consist of osciliator, zero level detector and integrator as shown in figure(1)



figure(1)

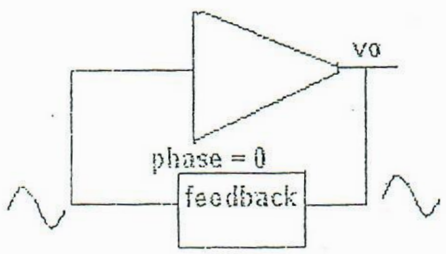
The oscillator: convert electrical energy from dc power to periodic waveform

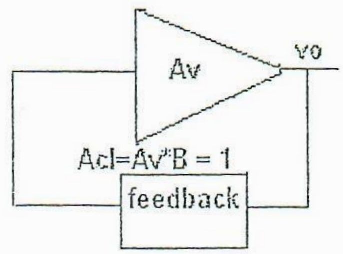


Conditions of oscillation:

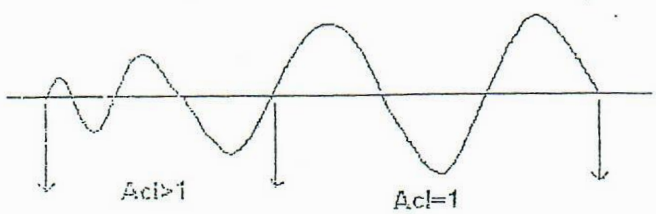
1- The phase shift around the feedback loop must be effectively 0°

2- The voltage gain Acl, A round the closed feedback loop must equal 1



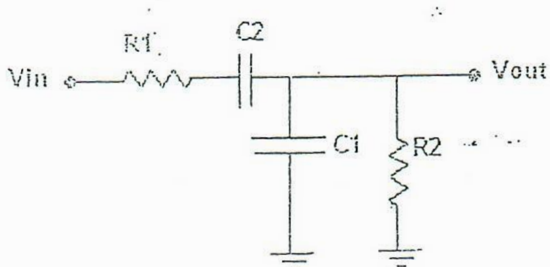


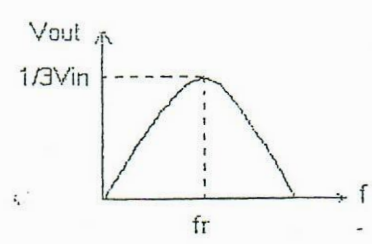
Starting of oscillation



A) The Wien bridge oscillator

One type of sinusoidal feedback oscillator is the Wien bridge oscillator. A fundamental part of Wien bridge oscillator is a lead-lag circuit like that

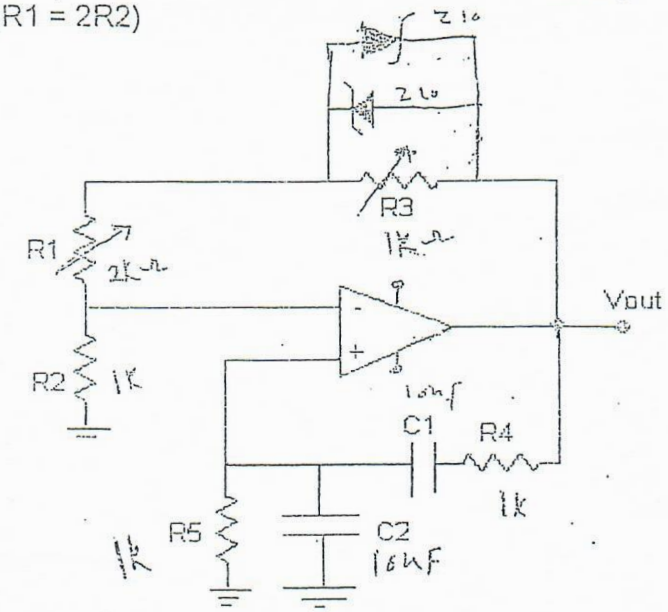




R1 and C1 together from the lag portion of the circuit; R2 and C2 from the lead portion. The operation of this lead-lag circuit is as follow. At lower frequencies, the lead circuit dominates due to the high reactance of C2. As the frequency increase, XC2 decrease thus allowing the output voltage to increase. At some specified frequency, the response of the lag circuit takes over and the decreasing value of XC1 causes the output voltage to decrease.

This circuit in figure(2) is a self starting wien bridge oscillator notice that the voltage-divider circuit has been modified to include an additional resistor R3 in parallel with a back –to –back zener diode arrangement .when dc voltage is first applied , both zener diodes appear as opens.

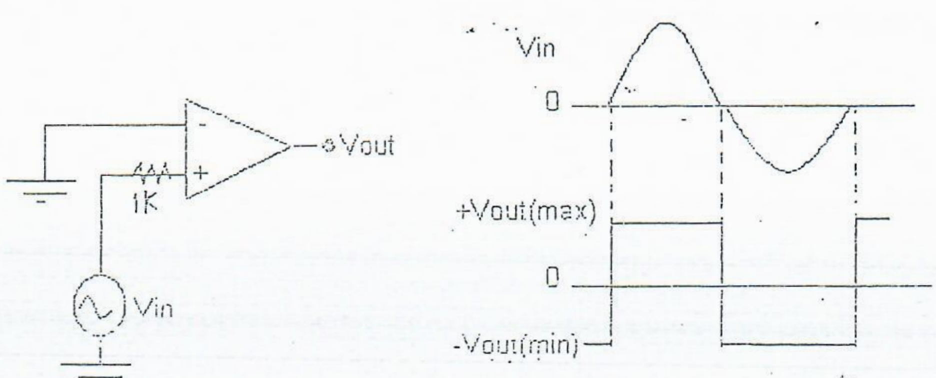
This places R3 in series with R1,thus increasing the closed-loop gain of the amplifier as follows (R1 = 2R2)



figure(2)

B) Zero level detector

One application of op-amp used as a comparator is to determine when an input voltage exceeds a certain level, Because of the high open-loop voltage gain, a very small difference voltage between the two inputs drives the amplifier into saturation, causing the output voltage to go to its limit as shown in figure (3).



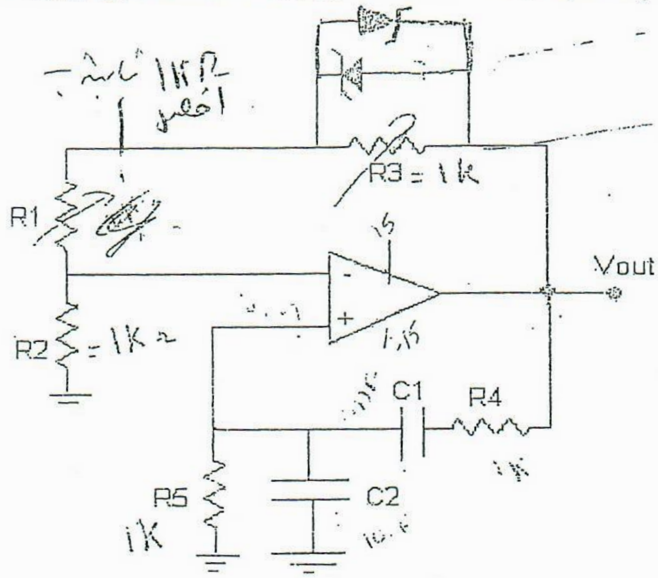
Experiment procedure

A) wein bridge oscillator

1-Connect the circuit shown in figure (2) set R1=2KΩ, R2=1KΩ, R3=1KΩ,C1=C2=0.1μF, R4=R5=1KΩ

2-Find the output frequency by using oscilloscope.

3-Which elements effect on the value of frequency.



figure(2)

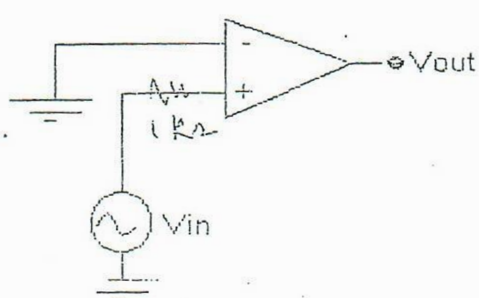
$f = \frac{1}{2\pi RC}$ Theory

B) zero level detector.

1-Connect the circuit as shown in figure (5) set ac source as function generator with 4Vp and f =50hz

2-Find the output of circuit by using oscilloscope

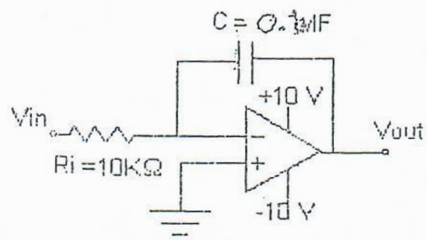
3- Find the output voltage max and min what do you conclude.



figure(5)

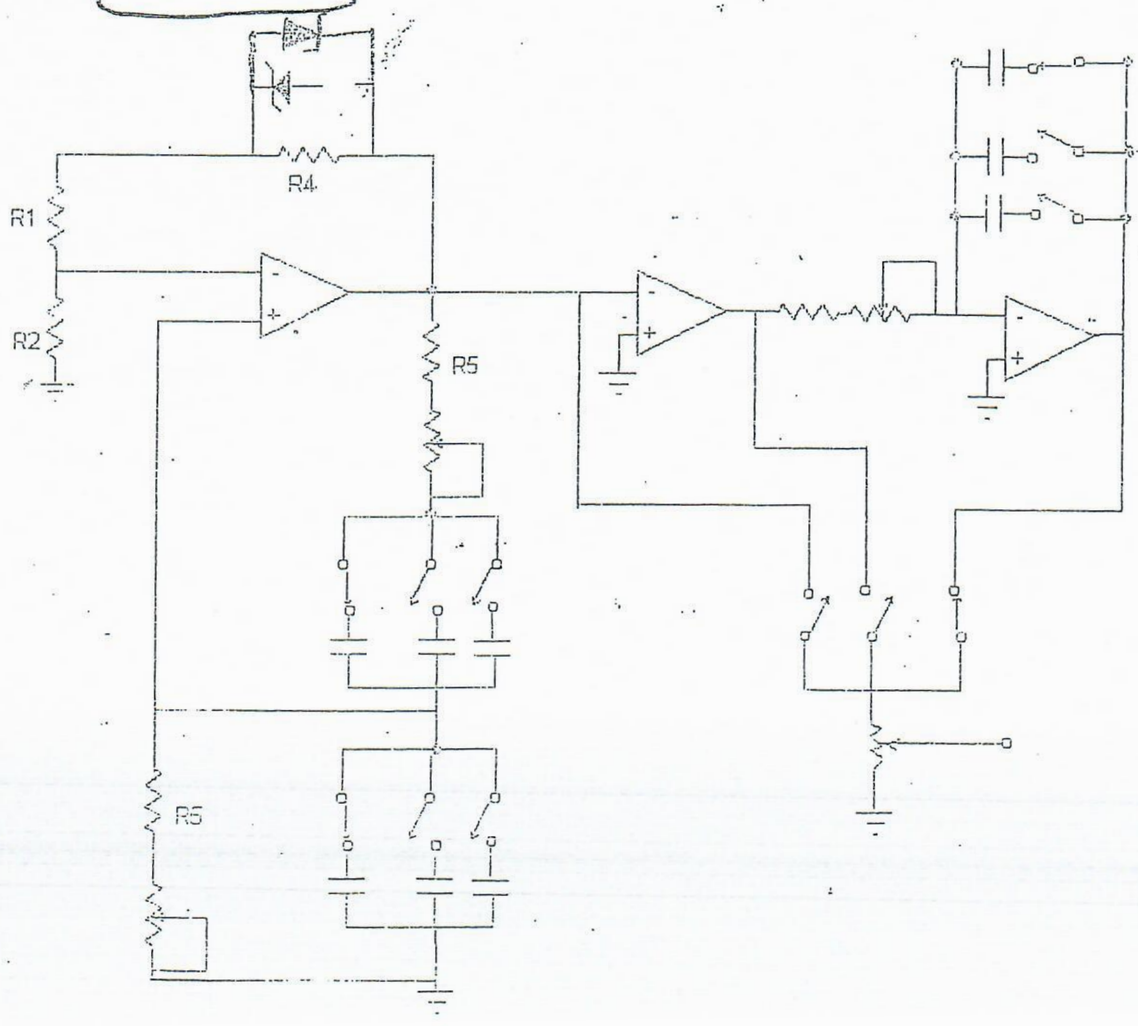
C) Integrator

One application of op-amp used as an integrator it integrate any signal for example pulse wave will be as shown in figure(4)



figure(4)

$$\frac{\Delta V_{out}}{\Delta t} = -\frac{V_{in}}{R_i C}$$

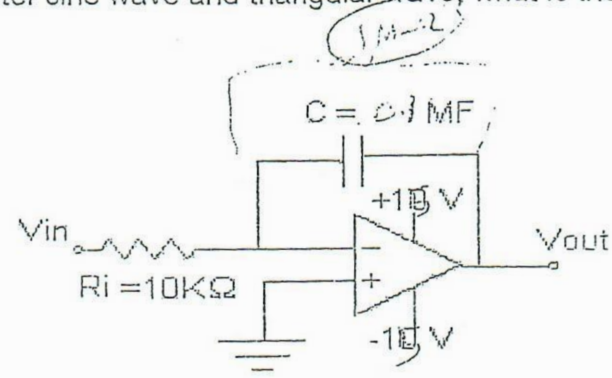


C)

1-Connect the circuit as shown in figure (6) .

2-Find the output voltage by using oscilloscope, then find it by calculations.

3-Enter sine wave and triangular wave, what is the output wave.



figure(6)

Chapter 5
Light Sensors

Objectives of this Chapter

Having studied this Chapter you will be able to:

- Discuss the characteristics of a filament lamp.
- Describe the construction and characteristics of a photovoltaic cell.
- Describe the construction and characteristics of a phototransistor.
- Describe the construction and characteristics of a photoconductive cell.
- Describe the construction and characteristics of a PIN photodiode.

Equipment Required for this Chapter

- DIGIAC 1750 Transducer and Instrumentation Trainer.
- 4mm Connecting Leads.
- Digital Multimeter.
- Opaque box to cover the clear plastic enclosure.

5.2 The Incandescent Lamp

The light source to be used in the experiments is a tungsten filament lamp. The filament glows more brightly as the power feeding the lamp is increased. Two factors will be affected as the lamp voltage is increased:

1. The temperature of the filament is proportional to the input power. Power varies with the square of the voltage, and is also affected by the resistance of the lamp, which increases as the filament temperature increases (it has a positive temperature coefficient).

2. The spectral response of the lamp varies with the filament temperature. At low temperatures the light is in the infra-red region of the visible spectrum and the light output gradually increases in frequency (red → orange → yellow . . .) as the temperature is raised.

These factors make it difficult to be too precise about the response of the sensors which will be investigated.

In order to determine the response of the filament lamp an acceptable reference must be established. The photovoltaic cell is a linear device, the output short circuit current being directly proportional to the luminous flux (lux) being received.

5.3 Practical Exercise
The Filament Lamp

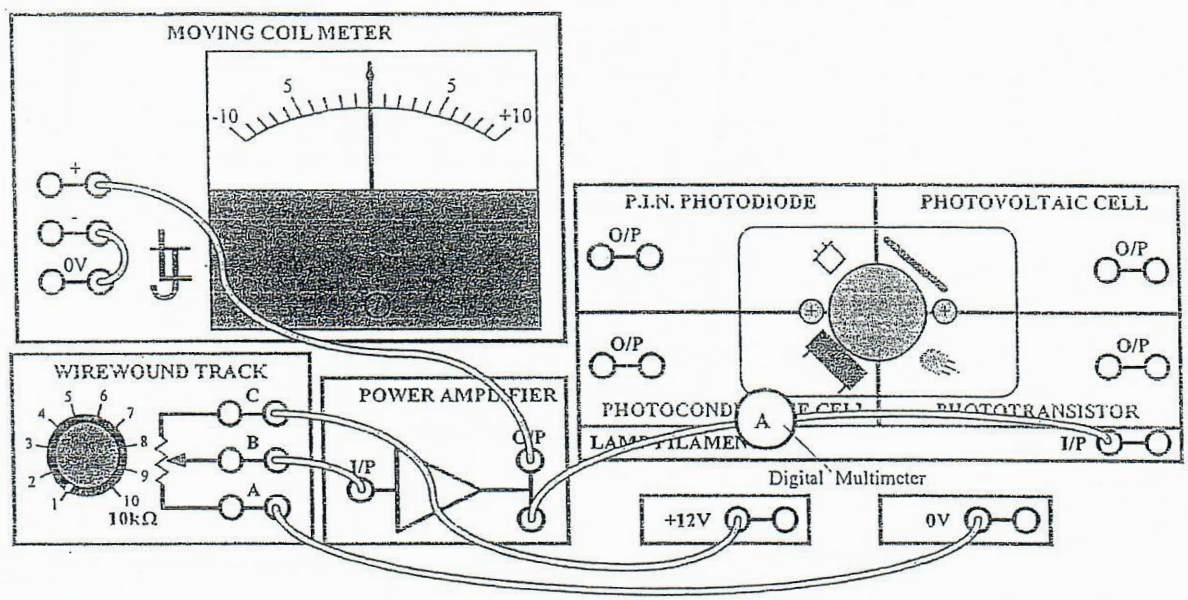


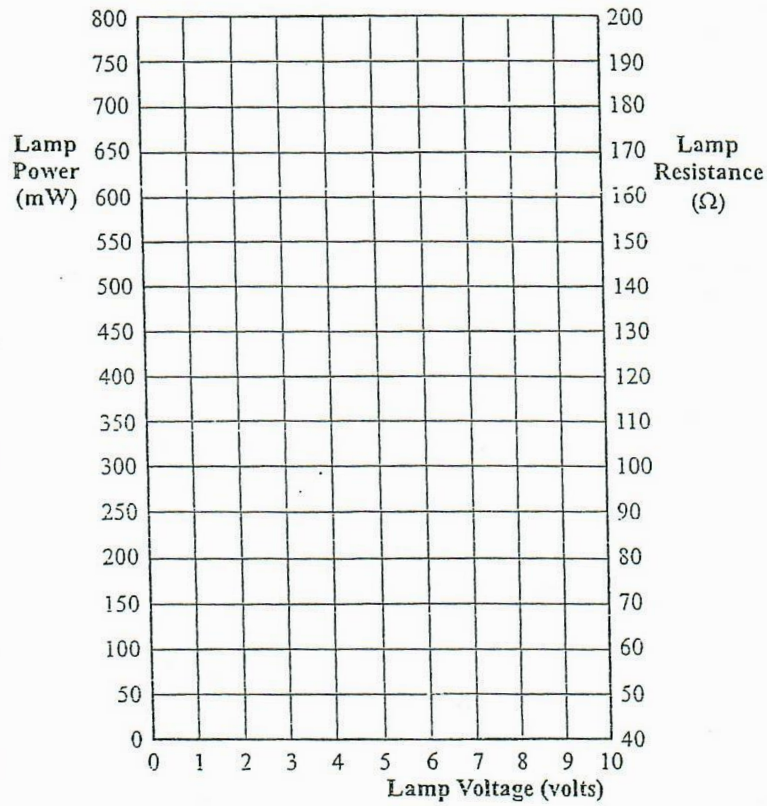
Fig 5.2

- Connect the circuit as shown in Fig 5.2 with the digital multimeter connected as an ammeter on the 200mA range in between the power amplifier and the lamp filament socket. Switch ON the power supply.
- Set the 10kΩ wirewound resistor to minimum for zero output voltage (on the moving coil meter) from the power amplifier.
- Take readings of lamp filament current as indicated on the digital multimeter as the lamp voltage is increased in 1V steps. Record the results in Table 5.1.

Lamp filament voltage (volts)	0	1	2	3	4	5	6	7	8	9	10
Lamp filament current (mA)											
Lamp filament power (mW)											
Lamp resistance (Ω)											

Table 5.1

- Calculate the corresponding values of lamp filament power (VxI) and resistance (V÷I), recording the results in Table 5.1.
- Plot the graphs of lamp power and resistance against applied voltage on the graticule provided.



Graph 5.1

5.3a **From your graph estimate and enter the lamp voltage necessary to give a power dissipation of 250mW.**

5.3b **From your graph estimate and enter the resistance of the lamp filament when the applied voltage is 4.5V.**

- Switch OFF the power supply.

5.4 Photovoltaic Cell

A photovoltaic cell is one which *generates an EMF* when light falls onto it.

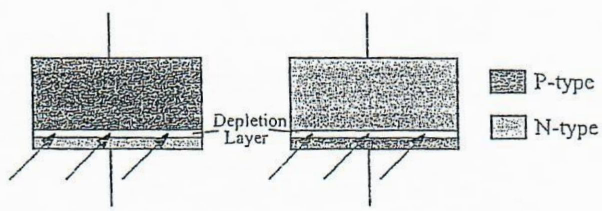


Fig 5.3

One of the regions is made very thin (about one millionth of a meter, 1μm). Light can easily pass through this without much loss of energy. When the light reaches the junction, at the depletion layer, it is absorbed and the released energy creates hole-electron pairs which diffuse across the junction.

The thin layer, which is only lightly doped, rapidly becomes saturated and charge carriers can be released into an external circuit to form a current, pushed around the circuit by the force (electro-motive force, EMF, electron-moving-force) of the surplus of charge carriers released by the energy absorbed.

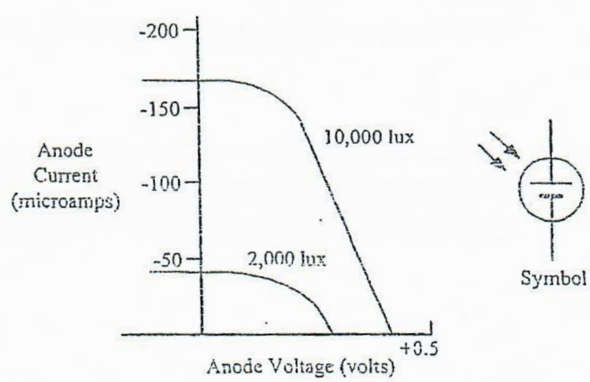
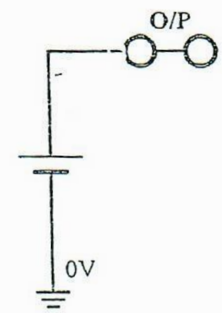


Fig 5.4

Note that the anode current is shown as negative because the internal current inside any source of EMF must flow with opposite polarity to the external current, the electrons arriving at the anode returning to the cathode inside the photo-cell.

The *lux* referred to in Fig 5.4 is the unit of incident light (light arriving at the cell).



Circuit Arrangement

Fig 5.5

Characteristics of Photovoltaic Cell Type MS5B	
Open circuit voltage (in sunlight)	500mV
Short circuit current (in sunlight)	10mA
Peak spectral response wavelength	840nm (IR)
Response time	10 μs

Note: IR = infra red

Table 5.2

If the output of the cell is short circuited there will be no output voltage at all, since this will all be dropped internally across the resistance of the cell. The short circuit output current obtained will vary from zero to maximum according to the incident light.

The device can be used either as a voltage source or as a current source and is inherently a linear device. To increase the output voltage, cells may be connected in series. Parallel connection allows a greater current to be drawn.

When used as an energy source they are known as *Solar Cells.*

Note:

For the characteristic to be linear it is necessary for the light output of the lamp to be of constant light frequency (spectral color) and for the light output (in lux) to be directly proportional to the power input.

5.5 Practical Exercise
The Photovoltaic Cell

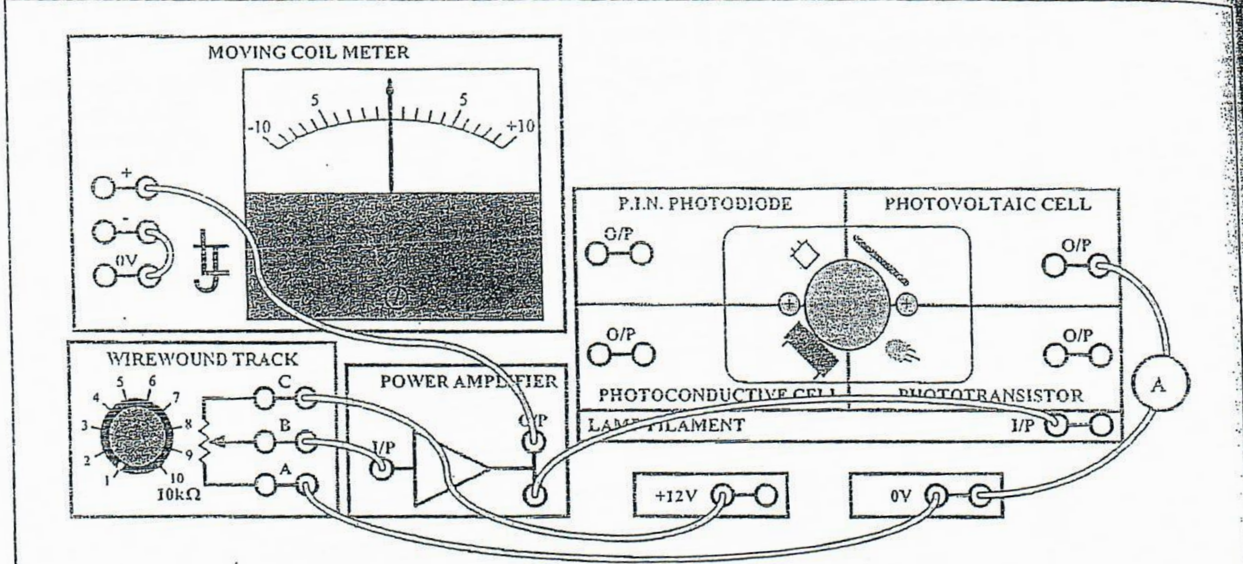


Fig 5.6

- Connect the circuit as shown in Fig 5.6 with the digital multimeter (ammeter) on the 2mA range to measure the short circuit current between the Photovoltaic Cell output and Ground. Fit an opaque box over the Clear Plastic Enclosure to exclude all ambient light.

- Switch ON the power supply and set the 10kΩ wirewound resistor to minimum for zero output voltage from the power amplifier.

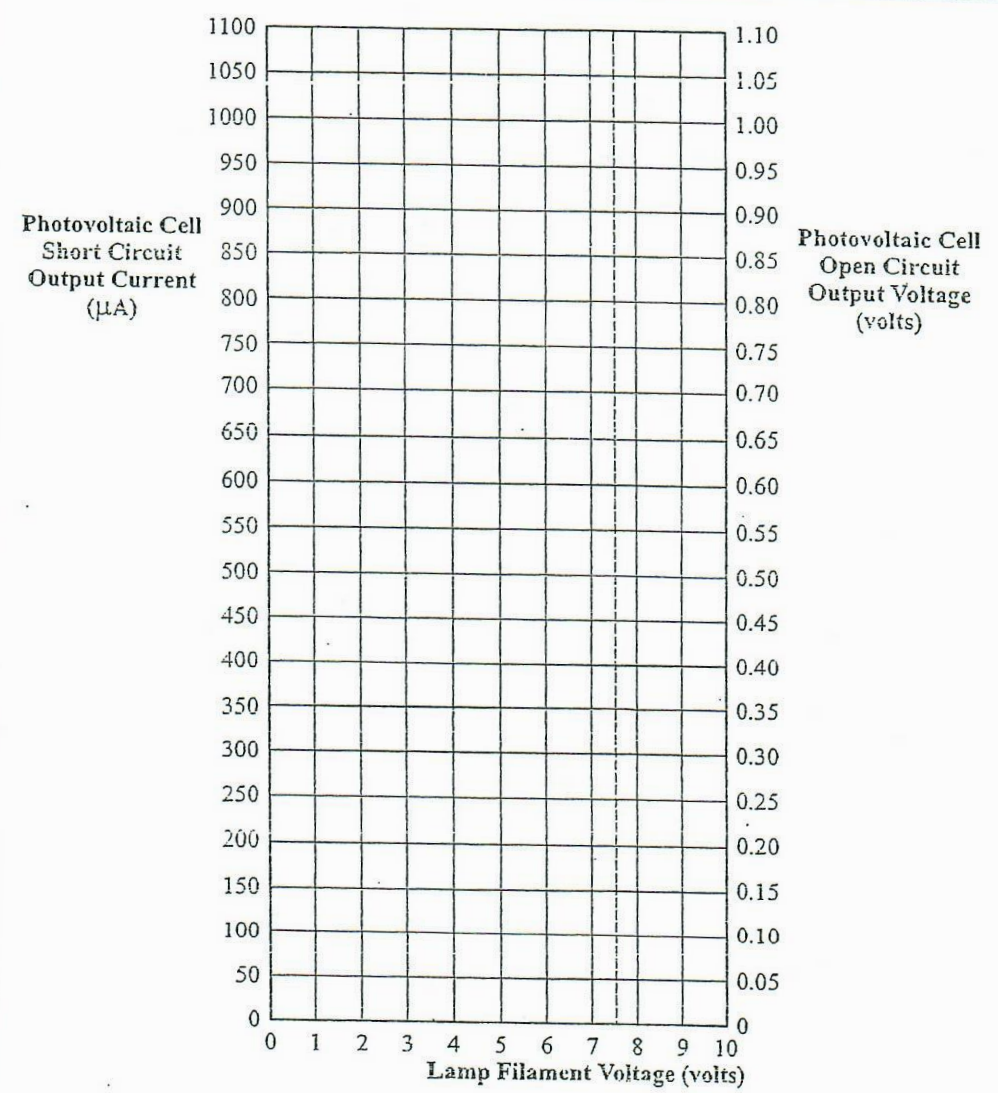
- Take readings of Photovoltaic Cell Short Circuit Output Current as indicated on the digital multimeter as the lamp voltage is increased in 1V steps. Record the results in Table 5.3.

Lamp filament voltage (volts)	0	1	2	3	4	5	6	7	8	9	10
Short Circuit Output Current	μA	μA	μA	μA	μA	μA	μA	μA	μA	μA	μA
Open Circuit Output Voltage	V	V	V	V	V	V	V	V	V	V	V

Table 5.3

- Switch OFF the power supply, set the multimeter as a voltmeter to read the Open Circuit Output Voltage. Switch ON the power supply and repeat the readings, adding the results to Table 5.3.

- Plot the graphs of Photovoltaic Cell Short Circuit Output Current and Open Circuit Output Voltage against Lamp filament voltage on the graticule provided.



Graph 5.2

5.5a **From your graph estimate and enter the short circuit output current in μA when the Lamp filament voltage is 7.5V.**

5.5b **Are the graphs linear?**

Yes or No

- Switch OFF the power supply.

5.6 The Phototransistor

The construction and circuit used are shown in Fig 5.7. The device is an NPN three layer semiconductor device similar to a normal transistor, the regions being called emitter (e), base (b) and collector (c).

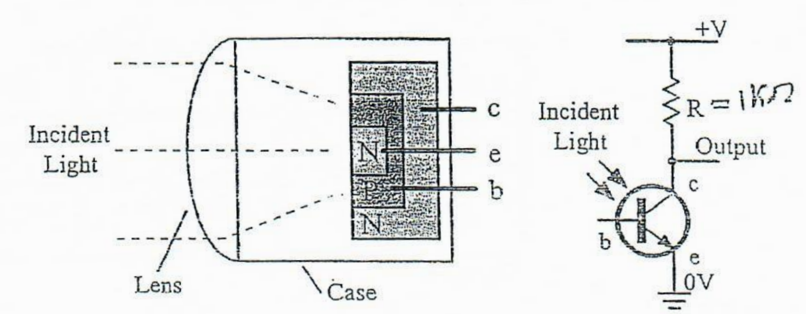


Fig 5.7

The device differs from the normal transistor in allowing light to fall onto the base region, focused there by a lens.

The circuit connection is shown in Fig 5.7, the collector being connected to the positive of a DC supply via a load resistor R. The base connection is not used in this circuit but is available for biasing to change the threshold level.

With no light falling on the device there will be a small leakage current flowing due to thermally generated hole-electron pairs and the output voltage from the circuit will be slightly less than the supply voltage due to the voltage drop across the load resistor R.

$V_{out} = V - I_c R$

When light falls on the base region the leakage current increases. With the base connection open circuit, this current flows out via the base-emitter junction and is amplified by normal transistor action to give a large change in the collector leakage current.

With increased current flowing in the load resistor R, the output voltage reduces and is dependent on the light falling on the device.

$$V_{out} = V - I_{ceo} R$$

where:

V = Supply voltage, I_{ceo} = Collector leakage current, R = Collector load resistance.

Fig 5.8 shows the circuit arrangement for the DIGIAC 1750 unit.

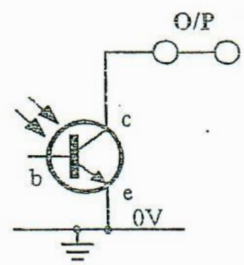


Fig 5.8

The main characteristics of the device are:

Type		MEL12
Collector Current	Dark	100nA
(Vce = 5V)	Typical ambient	3.5mA

Table 5.4

5.7 Practical Exercise
Characteristics of a Phototransistor

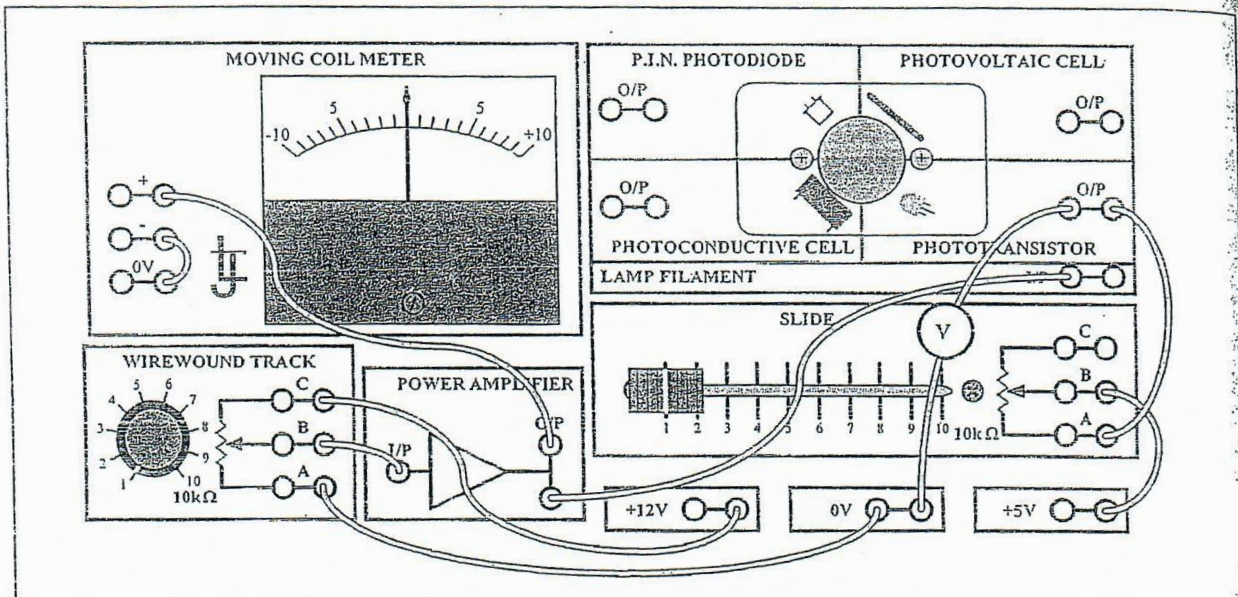


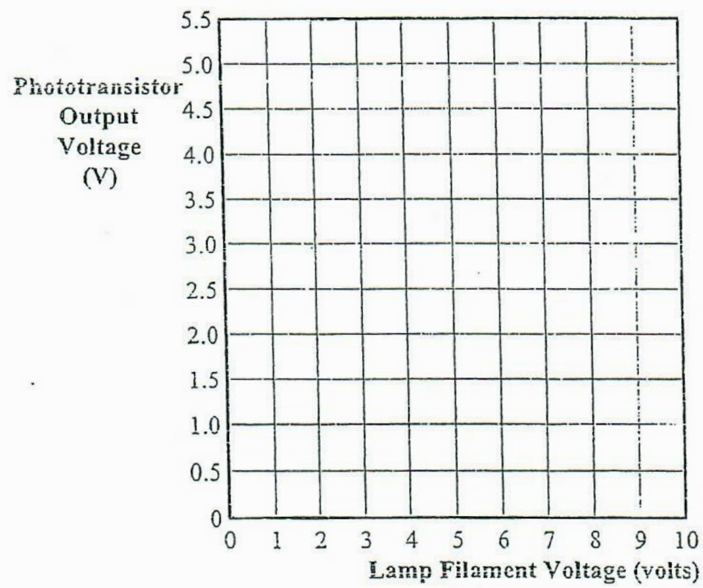
Fig 5.9

- Connect the circuit as shown in Fig 5.9 and set the 10kΩ carbon slider control to minimum setting (1) so that the Phototransistor load resistance is approximately 1kΩ (protection resistor only).
- Connect the digital multimeter on the 20V DC range to measure the Phototransistor output voltage. Fit the opaque box over the Clear Plastic Enclosure to exclude all ambient light.
- Switch ON the power supply and set the 10kΩ wirewound resistor to minimum for zero output voltage from the power amplifier.
- Take readings of Phototransistor output voltage as indicated on the digital multimeter as the lamp voltage is increased in 1V steps. Record the results in Table 5.5.

Lamp filament voltage (volts)	0	1	2	3	4	5	6	7	8	9	10
Phototransistor Output Voltage	V	V	V	V	V	V	V	V	V	V	V

Table 5.5

- Plot the graph of Phototransistor Output Voltage against Lamp filament voltage on the graticule provided.



Graph 5.3

5.7a **From your graph estimate and enter the filament input voltage when the Phototransistor output voltage is 2.5V.**

5.7b **As the filament input voltage increases the phototransistor output voltage 'levels out' at approximately:**

[a] 4.5-5.5V   [b] 3-4V   [c] 1.5-2.5V   [d] 0-1.0V

- Switch OFF the power supply.

5.8 The Photoconductive Cell, LDR

Fig 5.10 shows the basic construction of a photoconductive cell, consisting of a semiconductor disc base with a gold overlay pattern making contact with the semiconductor material. The circuit arrangement for the DIGIAC 1750 unit is also shown.

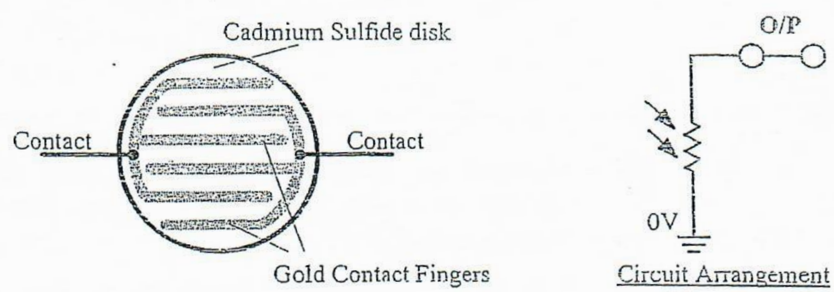


Fig 5.10

The resistance of the semiconductor material between the gold contacts reduces when light falls on it.

With no light on the material, the resistance is high. Light falling on the material produces hole-electron pairs of charge carriers and reduces the resistance.

Out of the various semiconductor materials available, a cadmium sulfide photoconductive cell is used on the DIGIAC 1750 unit because it responds to light with a range of wavelengths similar to those of the human eye (400-700nm).

An alternative name for this device is the *Light Dependent Resistor*, LDR.

	Dark	Ambient (typ.)
Cell Resistance	1MΩ	400Ω
Peak Spectral Response	530nm	

Table 5.6

When light is removed from the device, the hole-electron pairs are slow to reform and the response is sluggish. This is indicated by the large falling response time.

5.9 Practical Exercise
Characteristics of a Photoconductive Cell

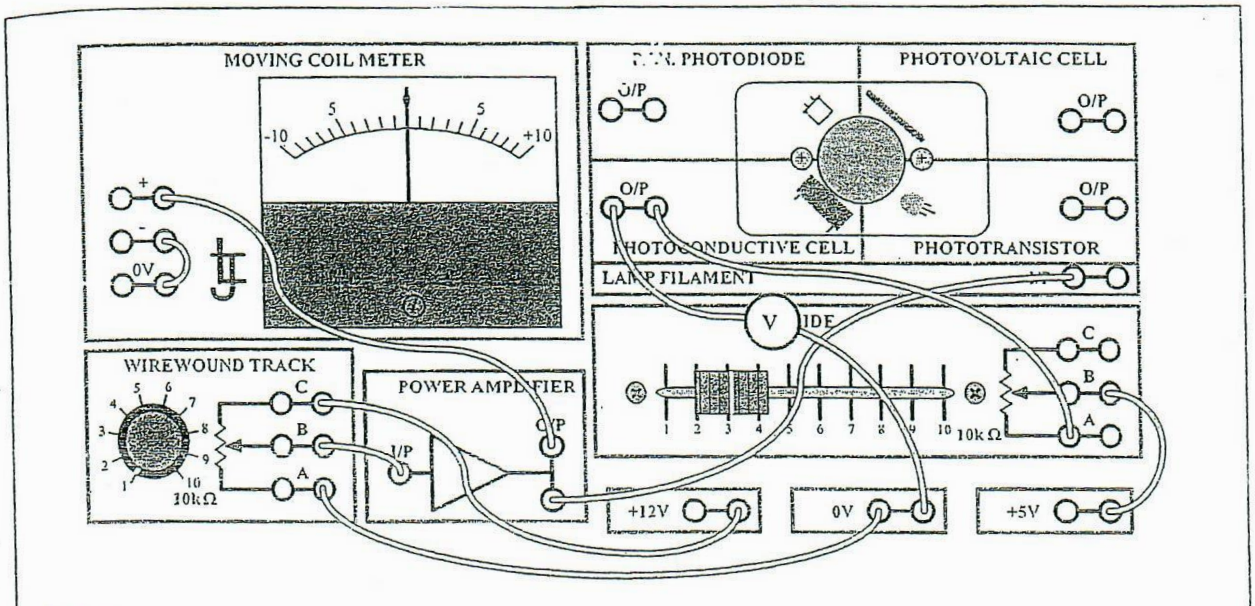


Fig 5.11

- Connect the circuit as shown in Fig 5.11 and set the 10kΩ carbon slider control to setting 3 so that the Photoconductive Cell load resistance is approximately 3kΩ.

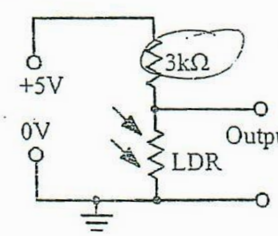


Fig 5.12

- Connect the digital multimeter on the 20V DC range to measure the Photoconductive Cell output voltage. Fit the opaque box over the Clear Plastic Enclosure to exclude all ambient light.

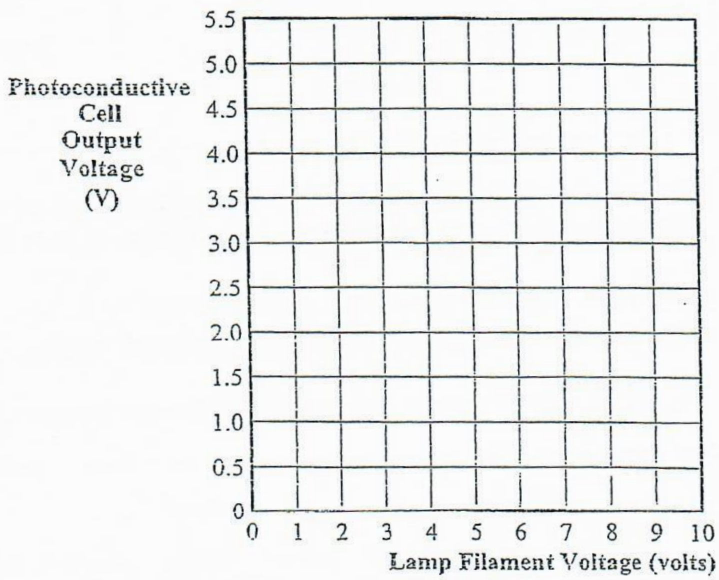
- Switch ON the power supply and set the 10kΩ wirewound resistor to minimum for zero output voltage from the power amplifier.

- Take readings of Photoconductive Cell output voltage as indicated on the digital multimeter as the lamp voltage is increased in 1V steps. Record the results in Table 5.7.

Lamp filament voltage (volts)	0	1	2	3	4	5	6	7	8	9	10
Photoconductive Cell Output	V	V	V	V	V	V	V	V	V	V	V

Table 5.7

- Plot the graph of Photoconductive Cell Output Voltage against Lamp filament voltage on the graticule provided.



Graph 5.4

5.9a **From your graph estimate and enter the lamp filament voltage when the circuit output voltage is 3V.**

- Switch OFF the power supply.

6.1 The Linear Variable Differential Transformer (LVDT)

The construction and circuit arrangement of an LVDT are as shown in Fig 6.1. It consists of three coils mounted on a common former and having a magnetic core that is movable within the coils.

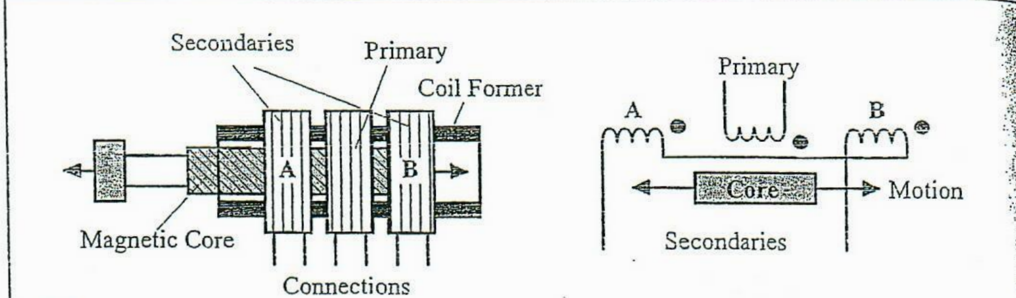


Fig 6.1

The center coil is the primary and is supplied from an AC supply. The coils on either side are secondary coils and are labeled A & B in Fig 6.1.

Coils A & B have equal number of turns and are connected in series opposing so that the output voltage is the difference between the voltages induced in the coils.

Fig 6.2 shows the output obtained for different positions of the magnetic core.

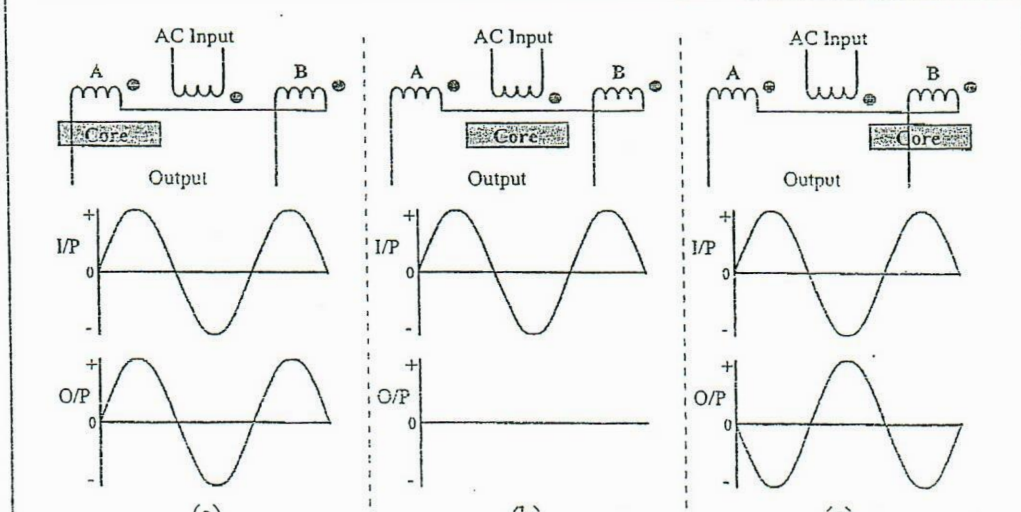


Fig 6.2

With the core in its central position as shown in Fig 6.2(b) there should be equal voltages induced in coils A & B by normal transformer action and the output voltage would be zero. In practice this ideal condition is unlikely to be found, but the output voltage will reduce to a minimum.

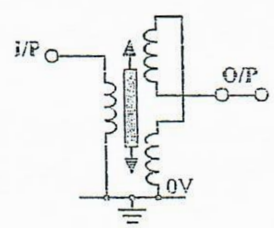
With the core moved to the left as shown in Fig 6.2(a), the voltage induced in coil A (V_a) will be greater than that induced in coil B (V_b). There will therefore be an output voltage $V_{out} = (V_a - V_b)$ and this voltage will be in phase with the input voltage as shown.

With the core moved to the right as shown in Fig 6.2(c) the voltage induced in coil A (V_a) will be less than that induced in coil B (V_b) and again there will be an output voltage $V_{out} = (V_a - V_b)$ but in this case the output voltage will be antiphase with the input voltage.

Movement of the core from its central (or neutral) position produces an output voltage. This voltage increases with the movement from the neutral position to a maximum value and then may reduce for further movement from this maximum setting. Note that the phase will remain constant on either side of the neutral position. There is no gradual change of phase, only an abrupt reversal when passing through the neutral position.

An amplitude only measurement of the output voltage, such as that provided by a meter, gives an indication of movement from the neutral position but will not indicate the direction of that movement. Used in conjunction with a phase detector, an output can be obtained that is dependent on both magnitude and direction of movement from neutral position. The oscilloscope gives both phase and magnitude indications.

Fig 6.3 shows the circuit arrangement and device characteristics of the DIGIAC 1750 unit.



Turns per coil	75
Inductance per coil	68 µH
Output Voltage	10mV/mm from neutral
Mechanical Travel	15mm

LVDT Characteristics

Fig 6.3

6.2 Practical Exercise
Characteristics of a Linear Variable Differential Transformer

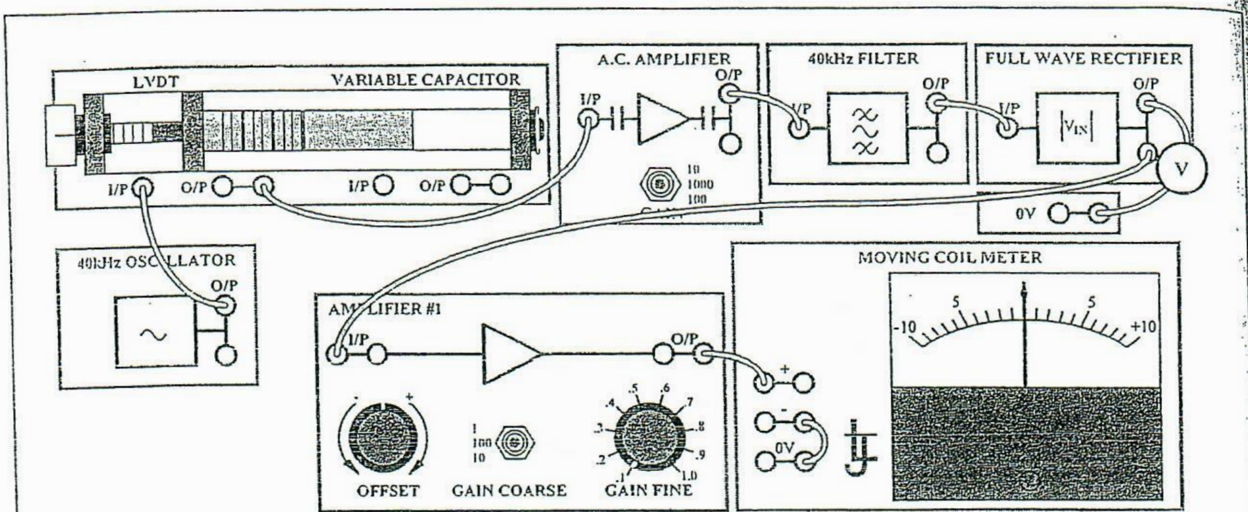


Fig 6.4

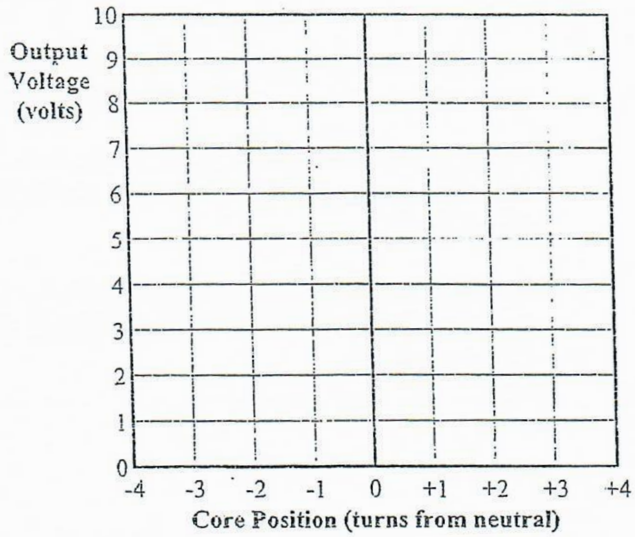
In this exercise you will measure the rectified output using the digital multimeter on the 20V DC range and also amplify and measure it using the M.C. analog meter, as this gives a better impression of the variation of output voltage with core position.

- Connect the circuit as shown in Fig 6.4 with the digital multimeter on the 2V DC range to monitor the output of the Full-Wave Rectifier. Switch ON the power supply.
- Set the A.C. Amplifier gain to 1000.
- Set the GAIN COARSE control of Amplifier #1 to 100 and GAIN FINE control to 0.2. Check that the OFFSET control is set for zero output with zero input and adjust if necessary.
- Adjust the core position by rotating the operating screw to the neutral position. This will give minimum output voltage. Note the value of this voltage from the digital multimeter and record in Table 6.1.
- Rotate the core control screw in steps of 1 turn for 4 turns in the clockwise direction (when viewing the control from the left-hand side of the D1750 unit) and record your results in Table 6.1. Then turn the control screw in the counter clockwise direction, again recording the results in Table 6.1.

Core position (turns from neutral)		-4	-3	-2	-1	0	+1	+2	+3	+4
Output Voltage	Digital meter	V	V	V	V	V	V	V	V	V
	Analog meter	V	V	V	V	V	V	V	V	V

Table 6.1

- Plot the graph of output voltage from the **analog** meter readings against core position on the axes provided.



Graph 6.1

6.2a **Enter your minimum voltage reading from the digital multimeter in mV.**

6.2b **Enter your voltage reading from the M.C. analog meter when the core is turned 2 turns out (-2) from the neutral position in V.**

- Switch OFF the power supply.

6.5 The Strain Gauge Transducer

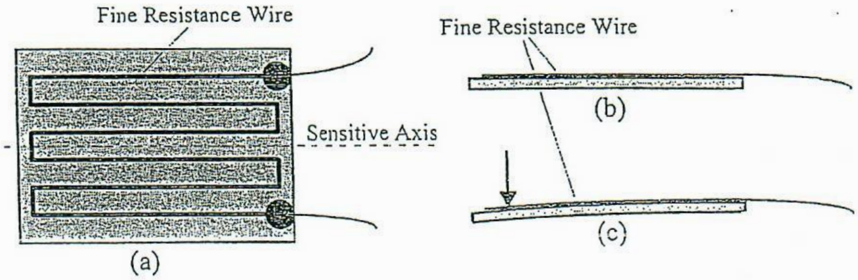


Fig 6.8

Fig 6.8 shows the construction of a strain gauge, consisting of a grid of fine wire or semiconductor material bonded to a backing material.

When in use, the unit is glued to the beam under test and is arranged so that the variation in length under loaded conditions is along the gauge sensitive axis (Fig 6.8(a)).

Loading the beam increases the length of the gauge wire and also reduces its cross-sectional area (Fig 6.8(c)). Both of these effects will increase the resistance of the wire.

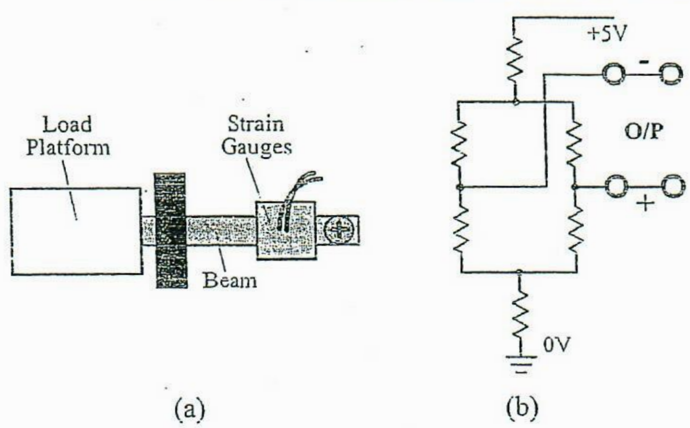


Fig 6.9

The layout and circuit arrangement for the DIGIAC 1750 unit is shown in Fig 6.9. Resistors are electro-deposited on a substrate on a contact block at the right-hand end of the assembly.

6.6 Practical Exercise
Characteristics of a Strain Gauge Transducer

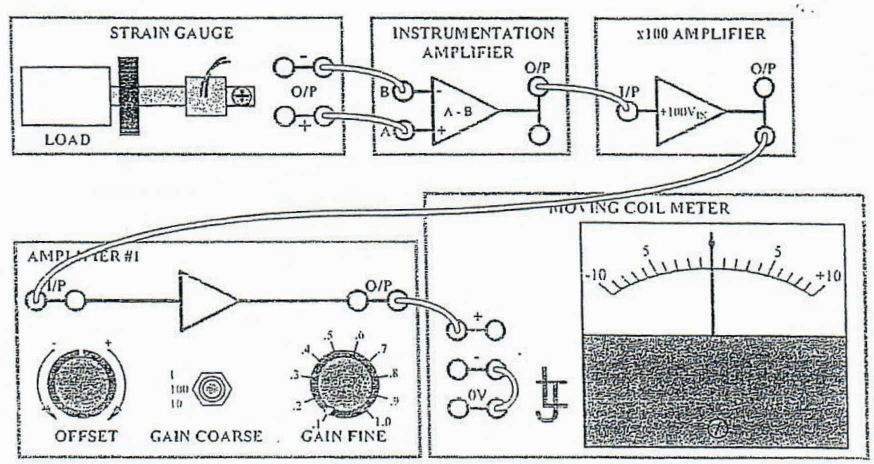


Fig 6.11

You will need ten similar weights, such as ten equal value coins, to increase the loading in regular steps.

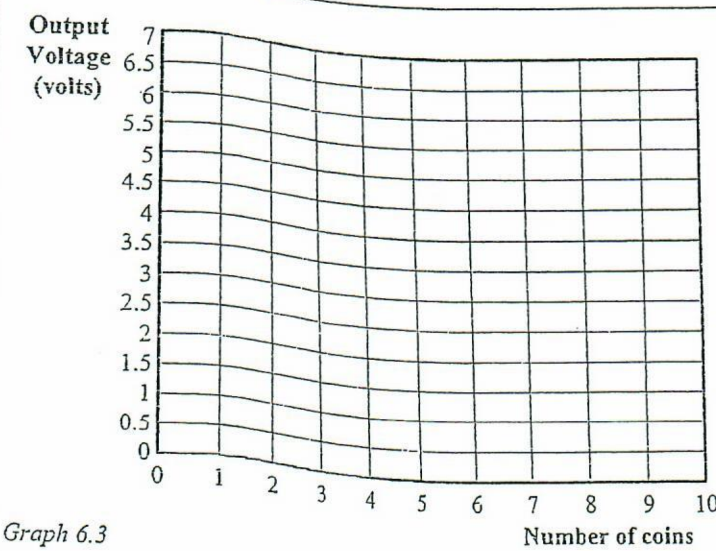
- Connect the circuit as shown in Fig 6.11 and set Amplifier #1 GAIN COARSE control to 100.
- Switch ON the power supply and with no load on the strain gauge platform, adjust the offset control of Amplifier #1 so that the output voltage is zero.
- Place all ten of your weights on the load platform and adjust the GAIN FINE control to give an output voltage of 7.0V as indicated on the moving coil meter.
  Note that this value of output voltage should cover all ranges of coins within the setting of the GAIN FINE control.
- Place one weight (coin) on the load platform and note the output voltage. Record the value in Table 6.5 overleaf.
- Repeat the process, adding further weights one at a time, noting the output voltage at each step and recording the values in Table 6.5.

more coins → R↑ (strain) → output of the bridge ↑ output voltage will be more.

Number of coins	0	1	2	3	4	5	6	7	8	9	10
Output Voltage	0 V	V	V	V	V	V	V	V	V	V	V

Table 6.5

- Plot the graph of output voltage against number of coins on the axes provided:



Graph 6.3

6.6a **Enter the output voltage obtained with four coins on the platform.**

6.6b **Your characteristic sketch is most similar to:**