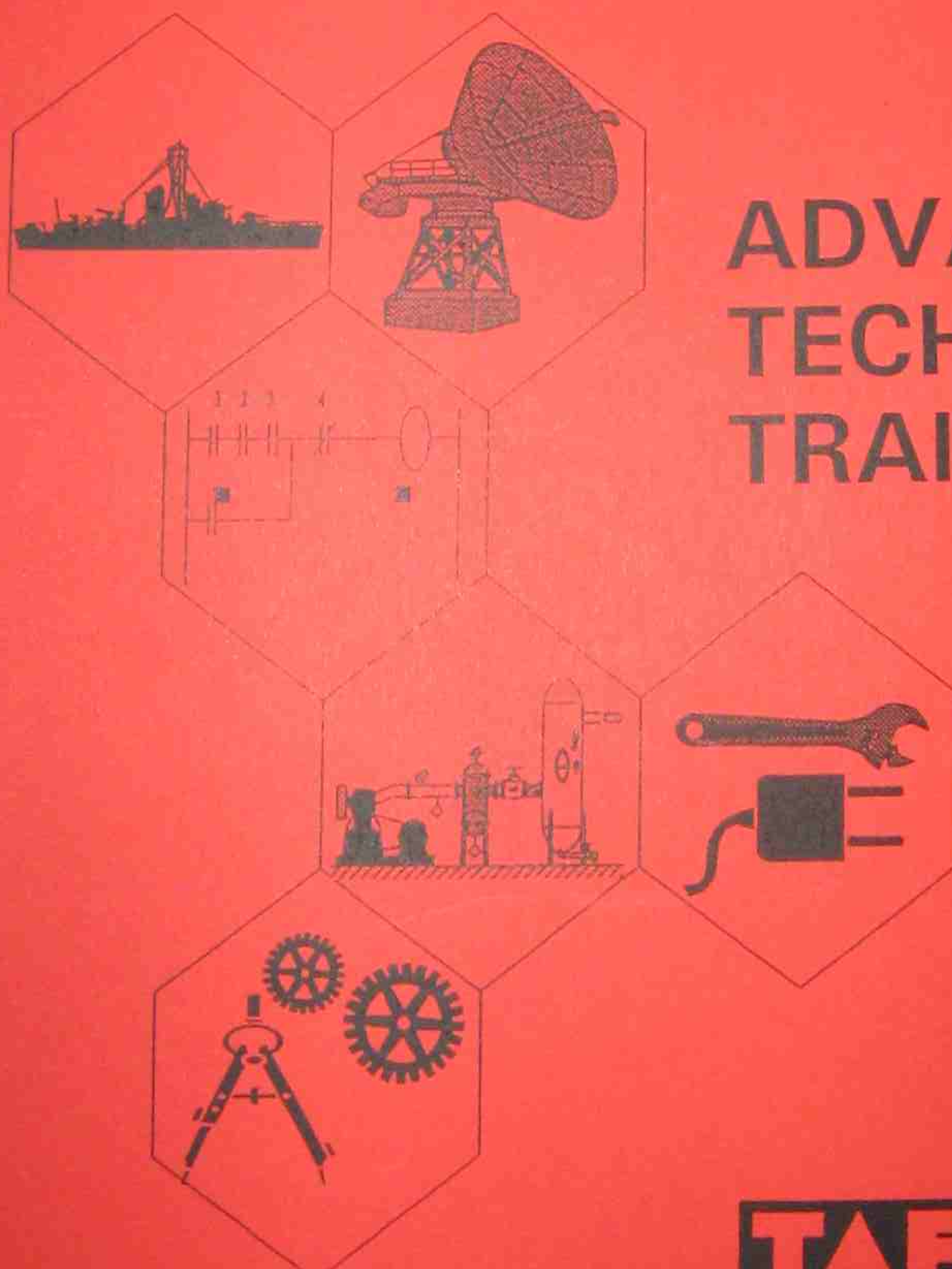
MANU ET MENTE

Sydney Institute of Technology
Ultimo



ADVANCED TECHNICAL TRAINING

TAFE NSW

EA904
CONTROL CONCEPTS

Introduction

CONTROL CONCEPTS

MODULE No. : EA904

SUBJECT No. : 6032A

DURATION : 40 hours (Full Module)

PREREQUISITES: Nil

PURPOSE :

This module aims to provide the student with the required basic knowledge of industrial/process control systems.

LEARNING OUTCOMES :

On completion of this module, the student will be able to :

1. List the characteristics of an ideal amplifier and describe the effect of negative feedback on these characteristics.
2. List and explain the operation of the main types of transducers used for temperature, force, speed and positional measurement.
3. List and explain the operation of the main types of final control elements.
4. Explain the function of the various functional blocks in a control system.
5. Explain the main types of control loops and the methods used to condition control signals.

MODULE STRUCTURE :

SECTION	TOPIC
1	Amplifiers
2	Industrial Transducers
3	Final Control Elements
4	Control Systems
5	Control Loops and Conditioning
-	Module Assessment

OUTLINE OF CONTENT :

This module contains :-

1. Amplifiers

1.1 Introduction
1.2 Amplifier Operation
1.3 Operational Amplifiers
1.4 Operational Amplifier Configurations
1.5 Review Questions
1.6 Skill Practice 1 : Amplifier Principles
1.7 Skill Practice 2 : Operational Amplifier Configurations

2. Industrial Transducers

2.1 Introduction
2.2 SI Units
2.3 Forms of Energy
2.4 Transducer Terminology
2.5 Temperature Measurement
2.6 Force Measurement
2.7 Speed Measurement
2.8 Positional Measurement
2.9 Review Questions
2.10 Skill Practice 3 : Temperature Measurement
2.11 Skill Practice 4 : Force Measurement
2.12 Skill Practice 5 : Speed and Positional Measurement

3. Final Control Elements

3.1 Introduction
3.2 Electromagnetic Devices
3.3 Valves
3.4 Solid State Switching Devices
3.5 Review Questions
3.6 Skill Practice 6 : Solid State Switching Devices

4. Control Systems

4.1 Automatic Control
4.2 Open Loop Control
4.3 Closed Loop Control
4.4 Control System Terminology
4.5 Control System Evaluation
4.6 Two Position Control
4.7 Proportional Control (P)
4.8 Proportional + Integral Control (P + I)
4.9 Proportional + Derivative Control (P + D)
4.10 Proportional + Integral + Derivative Control (P + I + D)
4.11 Review Questions
4.12 Skill Practice 7 : ON - OFF Control - Temperature Control
4.13 Skill Practice 8 : P + I Control - d.c. Motor Speed Control
4.14 Skill Practice 9 : P + D Control - Positional Control

5. Control Loops and Conditioning

5.1 Introduction
5.2 Control Loops
5.3 Converters (D to A and A to D)
5.4 Multiplexing
5.5 Review Questions
5.6 Skill Practice 10 : 4 - 20 mA Control Loop

ASSESSMENT

Students must obtain a mark of 50% or greater to pass this module. This mark is graded and is made up of **two** assessment components:-

Assessment Component 1 - Theory Tests (Weekly/Topic)	= 40 %
Assessment Component 2 - Theory Test (Week 10)	= 60 %
Total	=100%

Class mark grading - Grade Code 72 CAT D Graded

A - 83% or higher
B - 70% or higher
C - 50% or higher

CONTROL CONCEPTS - EA904 -LESSON STRUCTURE

LESSON	DURATION	TOPIC	PRACTICAL
1	4 hours	Amplifiers 1	Skill Practice 1- Amplifiers
2	4 hours	Amplifiers 2	Skill Practice 2 - Operational Amplifiers
3	4 hours	Industrial Transducers 1	Skill Practice 3 - Temperature Measurement
4	4 hours	Industrial Transducers 2	Skill Practice 4 - Force Measurement Skill Practice 5 - Speed and Positional Measurement
5	4 hours	Final Control Elements	Skill Practice 6 - Solid State Switching and Phase Control
6	4 hours	Control Systems 1	Skill Practice 7 -On/Off Control - Temperature Control
7	4 hours	Control Systems 2	Skill Practice 8 - Proportional and Proportional + Integral Control - d.c. Motor Speed Control
8	4 hours	Control Systems 3	Skill Practice 9 - Proportional + Integral + Derivative Control - Positional Control
9	4 hours	Control Loops and Conditioning	Skill Practice 10 - 4 - 20 mA Loop
10	4 hours	Revision and Assessment	Theory and Practical Assessment

TEACHER'S ASSESSMENT GUIDE (not to be issued to students)

Students must obtain a mark of 50% or greater to pass this module. This mark is graded and is made up of **two** assessment components.
Note: No marks between 45 to 49% to be given i.e. the student either passes with a mark of 50% or fails with a mark of 44% or lower.

- **Assessment Component 1 - Theory Test 1 (40%)**
    - Timing: Weekly or by topics
    - Duration: Approximately 10 minutes each quiz
    - Consist of weekly/topic quizzes given at the beginning of each lesson
    - Quizzes will test the previous lesson material
    - Should consist of the following format:
        - 10 multiple choice questions or
        - 5 multiple choice questions and 5 short answer questions or
        - 3 multiple choice questions and 3 short answer questions and 1 calculation, graphic etc type question
    - Each quiz to be given a mark out of 10
    - This mark is to be entered into the roll book
    - Total marks are added and recorded in the rollbook as a % and out of 40
    - Students to receive these quizzes back by the following lesson for review
    - Teachers to prepare own quizzes.
    - These quizzes are not class as confidential and may be return to the students

- **Assessment Component 2 - Theory Test 2 (60%)**
    - Timing: End of module
    - Duration: 1 hour 10 minutes
    - Marks recorded in the rollbook as a % and out of 60
    - Test papers are confidential and are **not** to be kept by the students as well as the student response sheets
    - Teacher to allow the students to review their answer sheets in the next lesson as feedback

TABLE OF SPECIFICATION

Module Name: Control Concepts
Module No.: EA904
Test No. /Description: Test 2

Subject No.: 6032A
Duration: 1 hour 10 minutes

Topic	Topic Objective	Learning Outcome	Section A Marks:30	Section B Marks:20	Section C Marks:50
Amplifiers					
Industrial Transducers					
Final Control Elements					
Control Systems					
Control Loops and Conditioning					

Section 1

AMPLIFIERS

PURPOSE

The purpose of this section is to provide the student with an understanding of basic electronic amplifier principles and the use of operational amplifier used in closed loop configuration. It covers learning outcome 1 of the National Module Descriptor.

TO ACHIEVE THE PURPOSE OF THIS SECTION :

This section represents around 20% of the module, and should take approximately 8 hours.

At the end of this section the student will be able to:

- Draw the equivalent model of a voltage amplifier and explain the function of each section.
- Calculate amplifier voltage gain, current gain and power gain.
- Explain the term input/output phase relationship.
- Describe and calculate the effects of source resistance on amplifier input signal level.
- Describe and calculate the effects of load resistance on amplifier output signal level.
- Measure the gain of an amplifier.
- Draw the operational amplifier symbol and explain the term operational amplifier.
- List four ideal operational amplifier characteristics and compare these to the characteristics of a practical operational amplifier.
- Explain the limitations in operating the operational amplifier in the open loop configuration.
- Identify and explain the operation of the following operational amplifiers closed loop configurations:
    - Inverting amplifier
    - Non-Inverting amplifier
    - Voltage Follower
    - Simple Integrator
    - Simple Differentiator

ASSESSMENT

Assessment for this section will be by way of practical and written tests to be held at the completion of the module.

CONTENTS

.1 INTRODUCTION

An amplifier is a device that takes an input signal and produces a larger version of that signal at its output.

Amplifiers are normally electronic, but can be magnetic, hydraulic, pneumatic or mechanical types.

Amplifier symbol is shown in Figure 1.

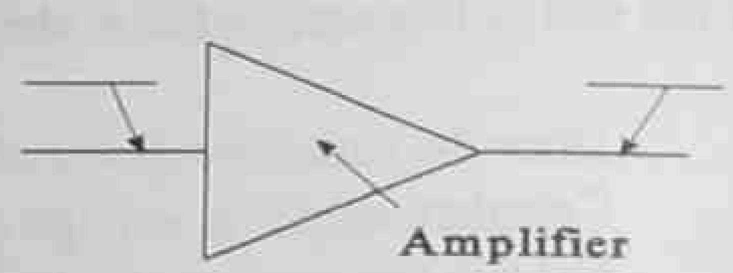


Figure 1

Amplifier connections - a d.c. power supply would always be connected to the amplifier as shown in Figure 2:

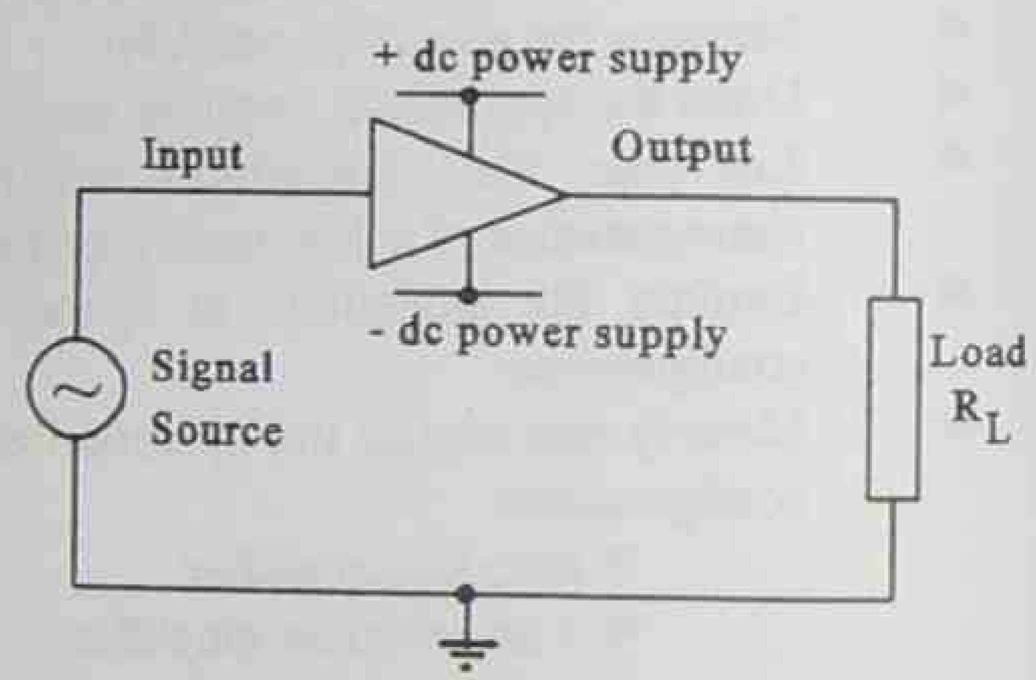


Figure 2

Amplifiers are used to increase the level of an electrical signal or for impedance matching, which is the matching of the signal source impedance to the load impedance.

Two broad categories of amplifiers exist, these are
(i) Small signal amplifiers - output less than 1 watt
(ii) Power amplifiers - output equal to or greater than 1 watt

- The choice of the type of amplifier circuit is determine by the following requirements:
  - Voltage gain (Av)
  - Current gain (Ai)
  - Power gain (Ap)
  - Impedance matching
- Amplifier circuits can employ three types of constructional method, these are:
  - Discrete components
  - Integrated circuits (I.C.)
  - Hybrid (discrete components and I.C.'s)

1.2. AMPLIFIER OPERATION

- The term amplification is used to describe the action of a electronic circuit that produces an output signal larger than the input signal. An *ideal* amplifier will produce an output signal that has exactly the *same* shape as the input signal, except it will be larger.

  N.B. The term amplification is derived from the term amplitude, which refers to the height of a waveform.

- The amplifier input signal is used to control the amount of power delivered from the d.c. supply to the output as shown in Figure 3.

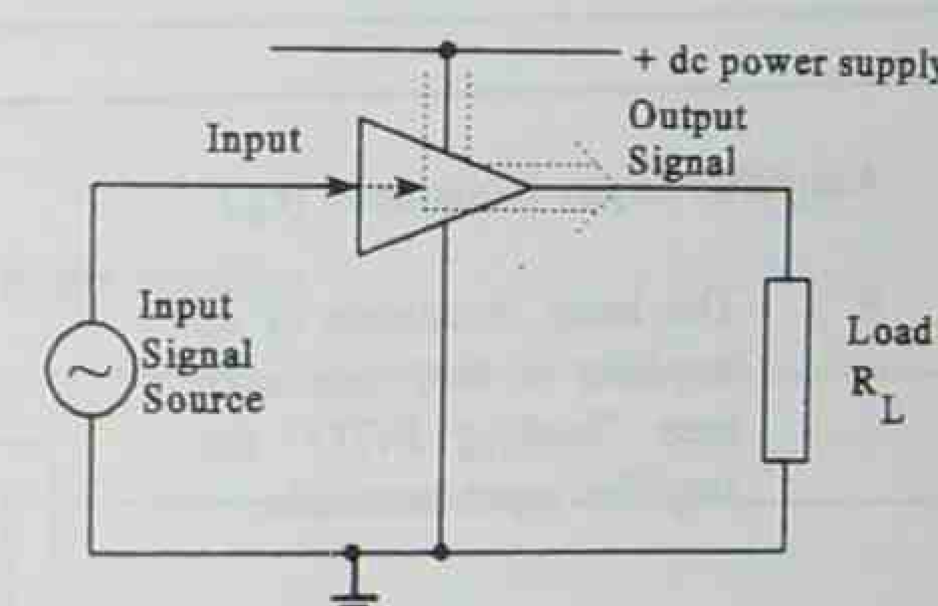


Figure 3

- **Amplifier Gain**
  - An amplifier can produce a gain in the signal voltage, current and/or power. The gain of an amplifier is a measure of "how many times larger the output is than the input. That is, a ratio of output to input. Amplification (or gain) is simply a number and has NO units.

- Voltage gain (Av) of any amplifier can be found by the following equation:

$$\boxed{\text{Voltage Gain } Av = \frac{Vo}{Vin}}$$

Where Vo = Output voltage (volts)
Vin = Input voltage (volts)

Student Exercise 1.1

An amplifier has an input voltage of 100mV and an output voltage of 1 volt. Determine the amplifier voltage gain.

____

____

Student Exercise 1.2

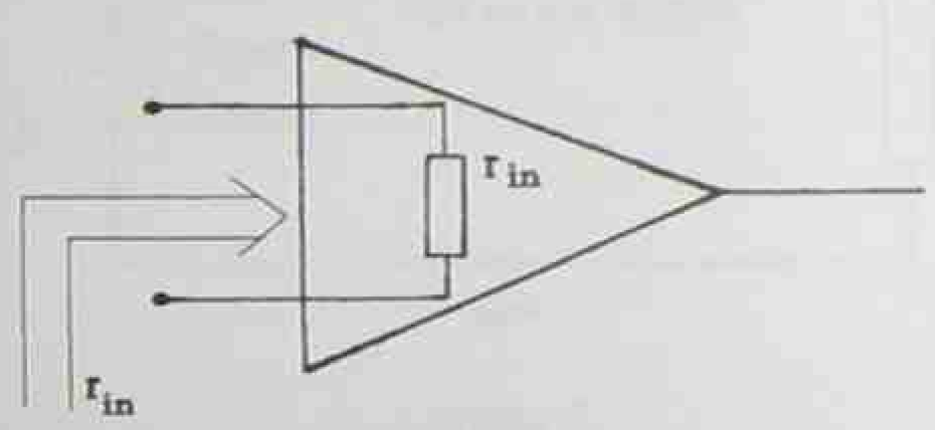
An amplifier has a gain of 25 and is fed with a 10mV input signal. The output signal will be:

____

____

- **Amplifier Input Resistance (r_{in})**

  - The input resistance of an amplifier is that resistance seen *"looking INTO"* the amplifier input terminals:



  - The value of amplifier input resistance is determined by the type of amplifier and can be calculated using Ohms law:

$$\boxed{\quad}$$

where V in = Input voltage (volts)
I in = Input current (amperes)

Student Exercise 1.3

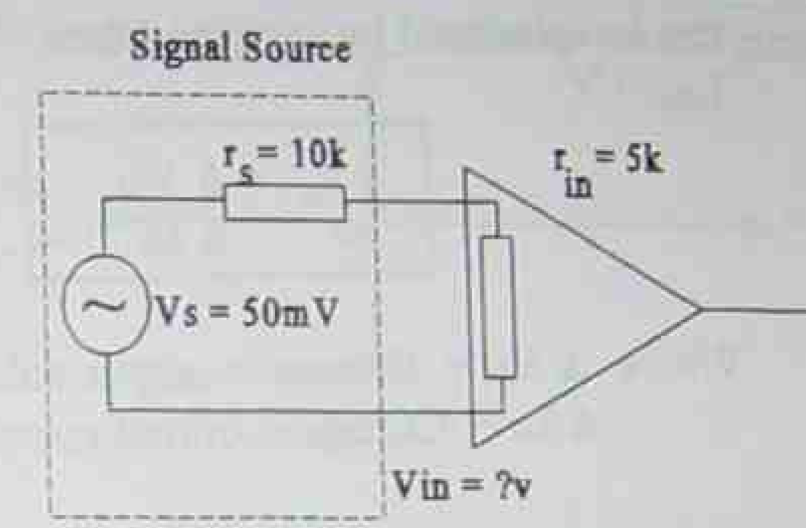
Calculate the amplifier input resistance when the input current is 5μA and the signal source voltage is 50mV.

____

____

Student Exercise 1.4

A signal source produces an open circuit voltage of 50mV and has an internal resistance of 10kΩ. If an amplifier having an input resistance of 5kΩ is connected to the signal source, what will be the input voltage to the amplifier?



____

____

____

____

Comment on the size of the input voltage to the amplifier

____

____

Student Exercise 1.5

If an amplifier having an input resistance of 1 MΩ was connected to the signal source in Student Exercise 4, determine the input voltage to the amplifier.

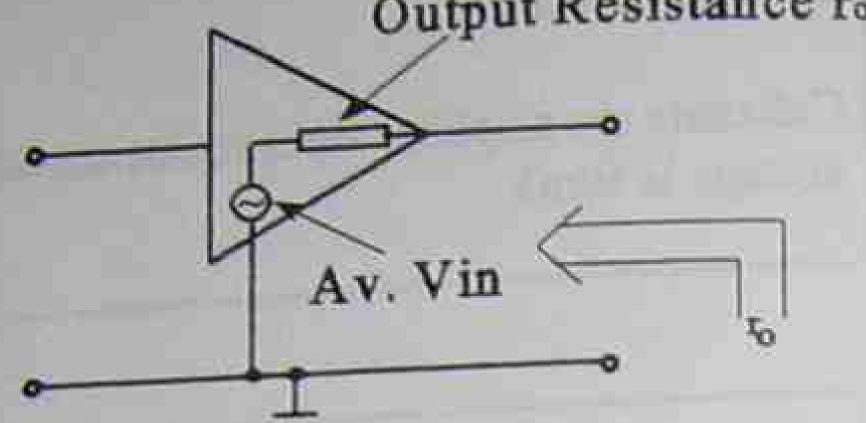
____

____

Comment on the size of the input voltage to the amplifier now.

____

- **Amplifier Output Resistance (r_o)**



The output resistance of an amplifier is that resistance seen looking "BACK INTO" the amplifier output terminals.

The output resistance has the effect of causing the output voltage (Vo) to decrease as the load is increased and can be calculated by applying Ohms Law:

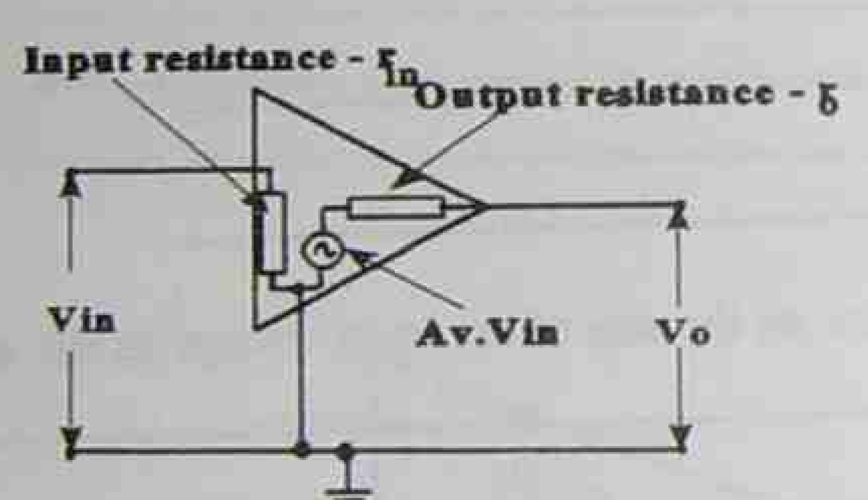
$$\boxed{r_o = \frac{\Delta V_o}{\Delta I_o}}$$

Where Δ Vo = Change in output voltage (volts)
Δ Io = Change in output current (amperes)

N.B. In the case of a voltage amplifier the lower the output resistance the better the performance of the amplifier.

- **Amplifier Equivalent Circuit**

The equivalent circuit for an amplifier consists of three main components, namely the input resistance (r_{in}), output resistance (r_o) and the internal signal generator (Av.Vin)



AMPLIFIER EQUIVALENT CIRCUIT

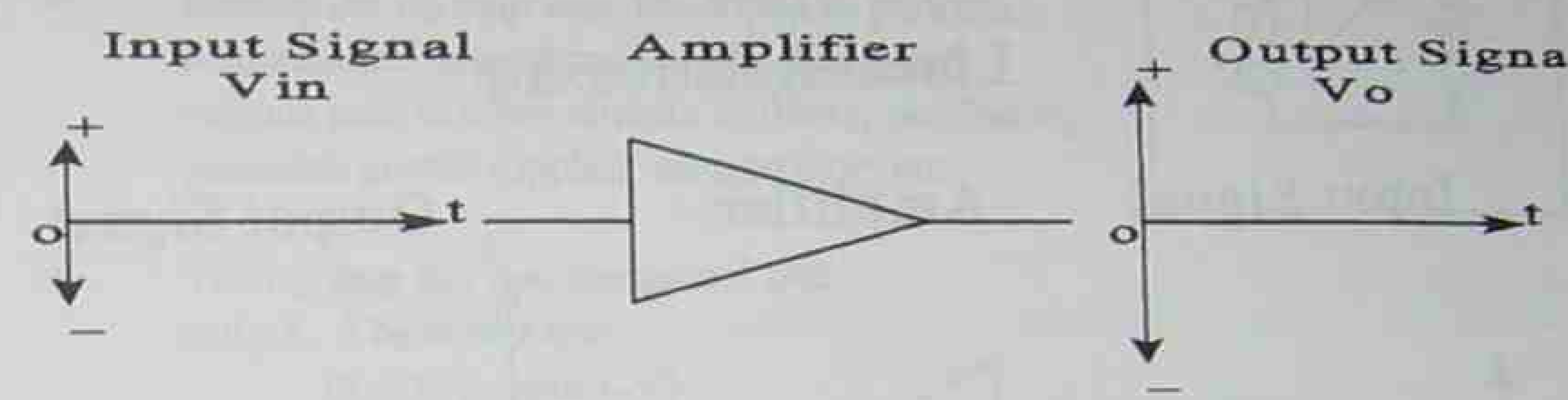
- **Frequency Response**

The frequency response of an amplifier describes the range of frequencies over which the amplifier provides satisfactory operation. Amplifiers cannot satisfactorily amplify signals at all frequencies but the amplify signal tends to drop at both low and high frequencies. (This is called "roll off" - decrease in Av)

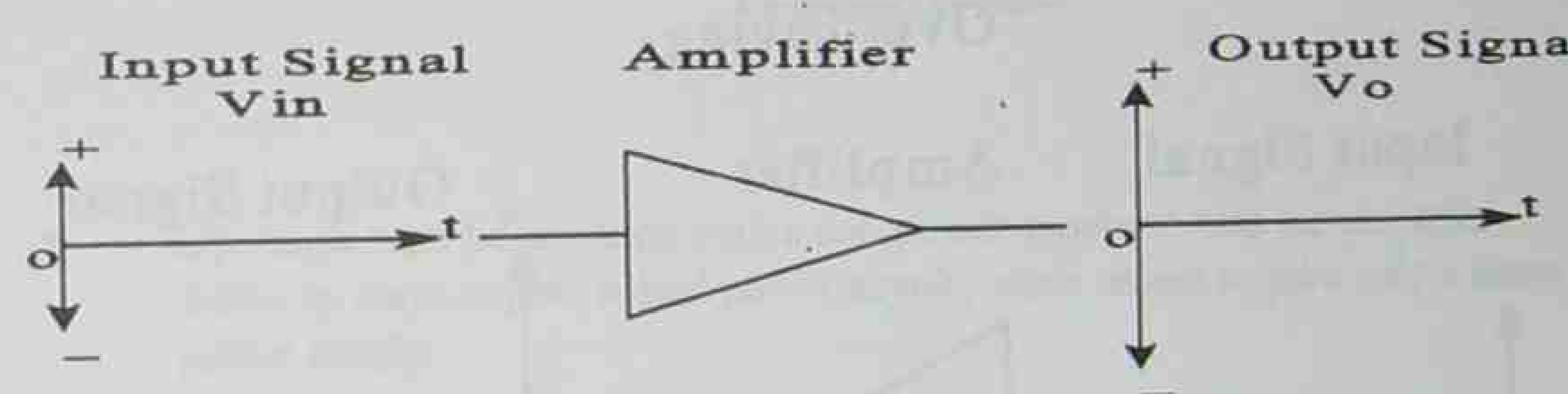
- **Phase Relationship**

  - Phase relationship is the relationship between the input and output waveforms of the amplifier. Typically the relationship can be:

    - Non-Inverting where Vo and Vin are "in-phase" with each other.



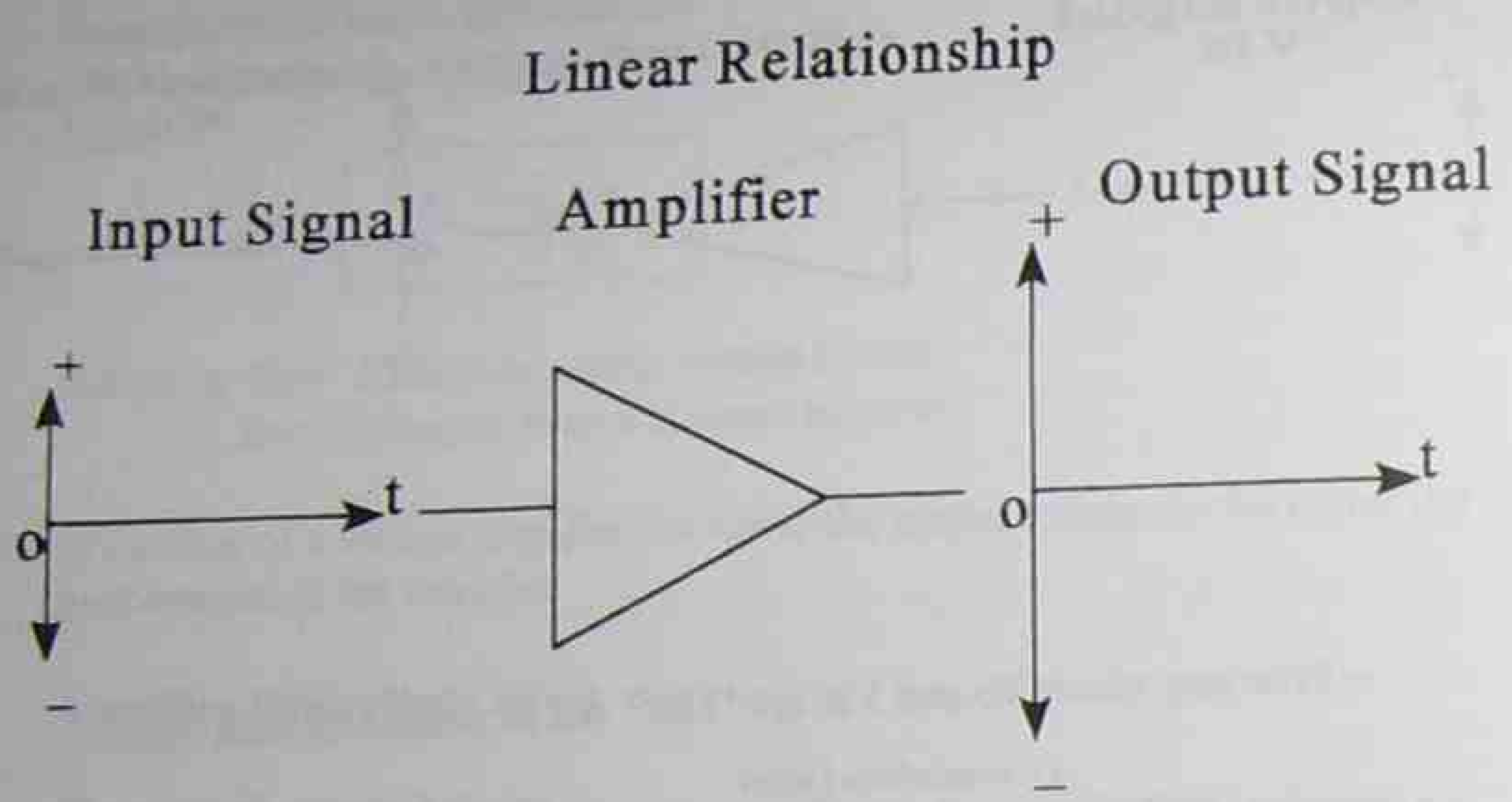
- Inverting where Vo and Vin are "180°" out of phase with each other.

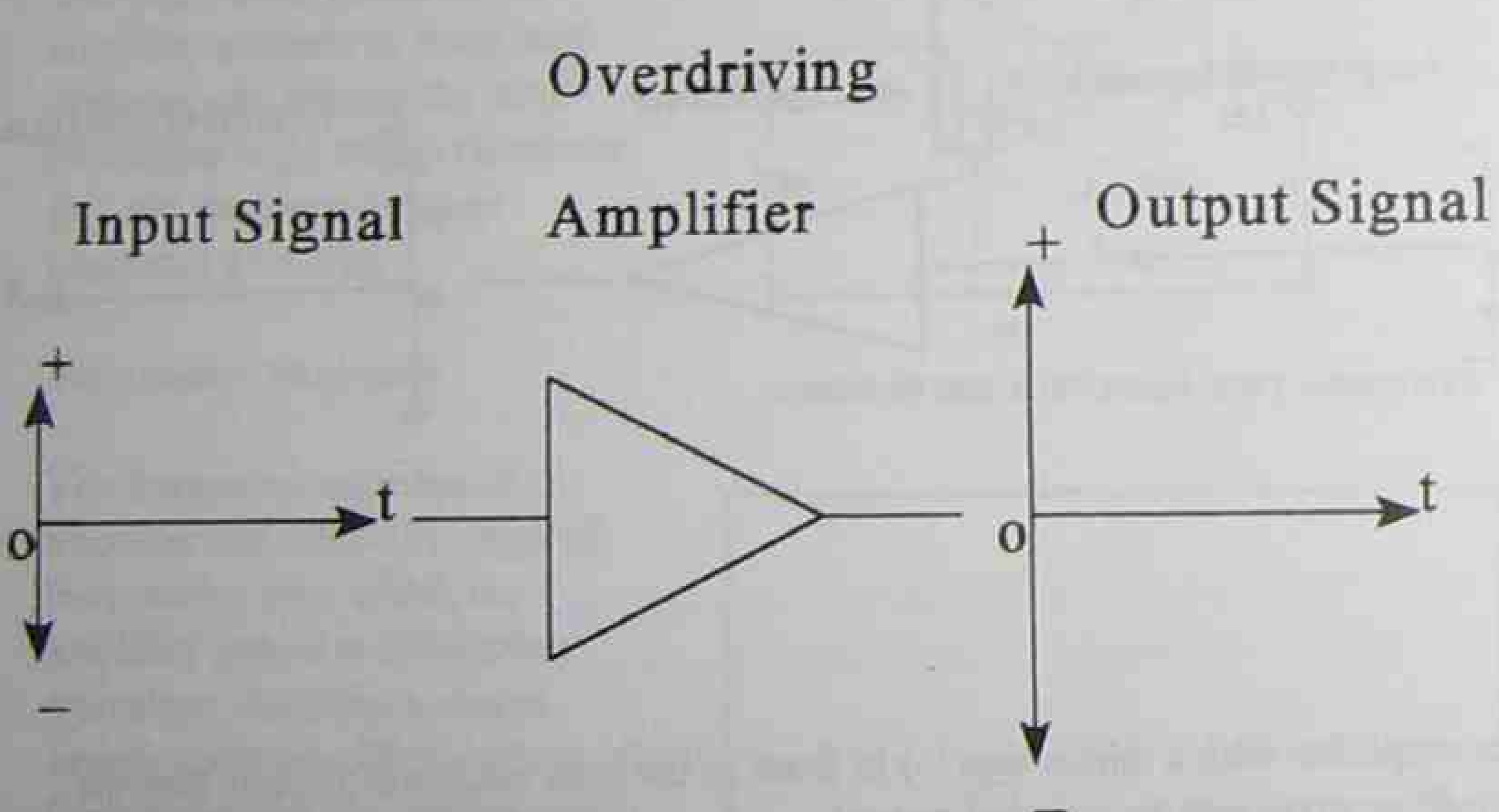


N.B. An amplifier with a minus sign (-) in front of the gain value will indicate that the amplifier produces an inverted output.

i.e. An amplifier with a gain of -20 (minus 20) means that the amplifier produces an output waveform 20 times larger than the input but inverted.

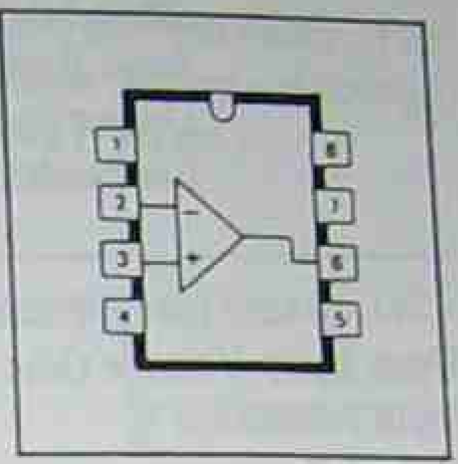
- **Amplifier Distortion**
  - The output waveform from the amplifier should be a true reproduction of the input wave form but larger. If the amplifier input signal is increased, this could cause the amplifier to start to "clip" the output waveform. This is often referred to as "overdriving" or distortion.



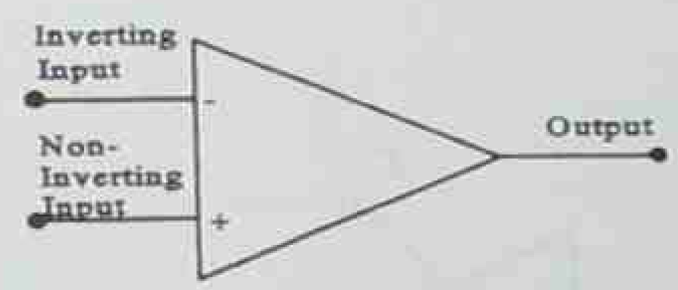


1.3 OPERATIONAL AMPLIFIERS

- The operational amplifier (op amp) is a direct - coupled amplifier having high gain, high input resistance and low output resistance.
- The op amp is manufactured in integrated circuit form.

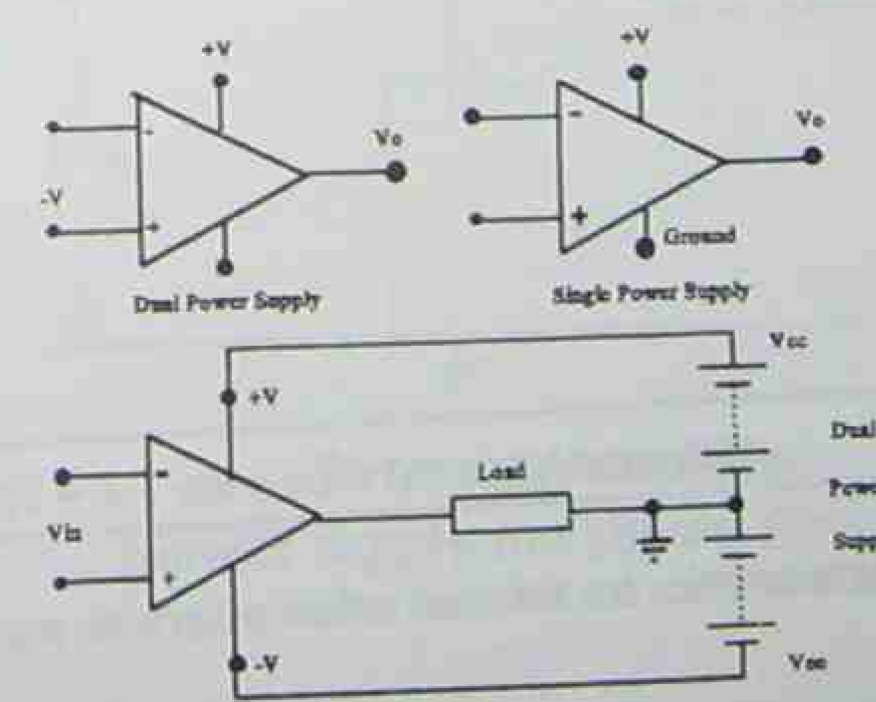


- Initially the op amp was developed to perform mathematical operations but has also found various uses in other circuits as filters, oscillators, precision power supplies, comparators etc.
- The op amp has two inputs and one output. The inputs are:
  - inverting input (-V)
  - non-inverting input (+V)



Operational Amplifier

- Op Amps must be provided with a d.c. power supply to bias the amplifier. Some op amps require a dual power supply, while others require only a single power supply.



Operational Amplifier Characteristics

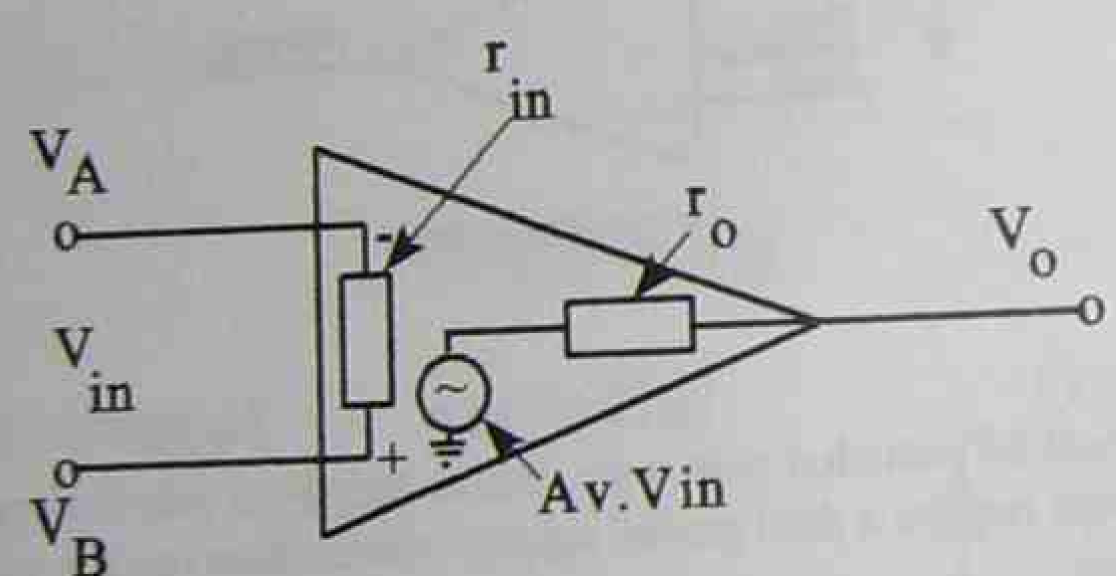
Ideal Op Amp

Open Loop Voltage Gain - infinity (∞)
Input Resistance r_{in} - infinity (∞)
Output Resistance r_o - zero (0)
Bandwidth BW - infinity (∞)

- 741 op amp (use the data sheet supplied, and list its characteristics)

Open Loop Voltage Gain - ____________
Input Resistance r_{in} - ____________
Output Resistance r_o - ____________
Bandwidth BW - ____________

Op Amp Equivalent Circuit (Ideal)



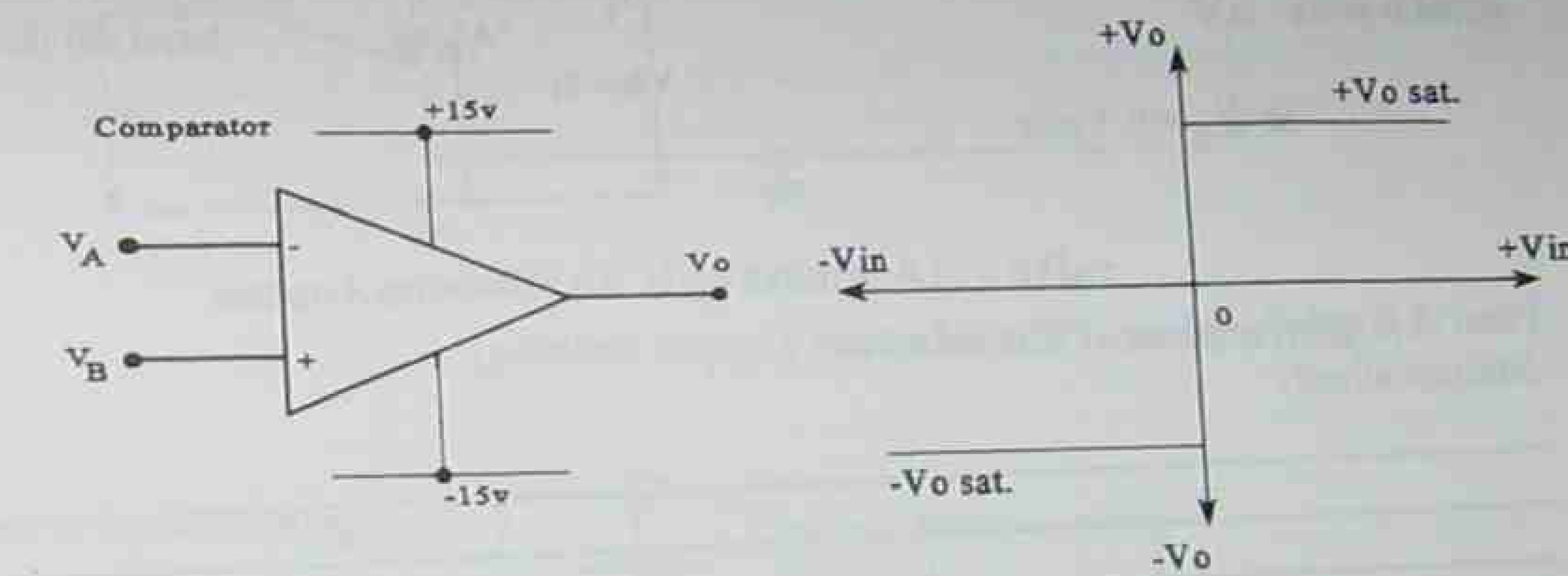
Output voltage = 0 volts when VA = VB

N.B. Ideal characteristics are assumed unless otherwise state.

1.4 OPERATIONAL AMPLIFIERS CONFIGURATIONS

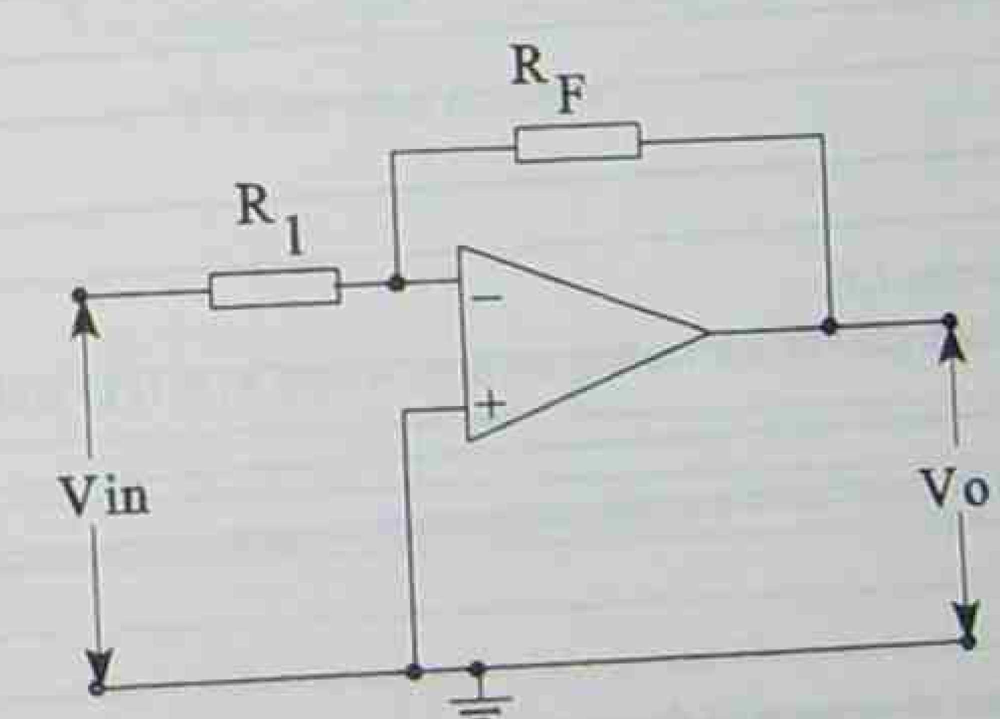
Comparator

Op amps can be used as comparators in open loop configuration (no feed back). The voltage gain of the circuit is very high, an input voltage will cause the output voltage to be either maximum positive (+Vo sat.) or maximum negative (-Vo sat.)



Inverting Amplifier

The inverting op amp input signal is fed into the inverting terminal, a resistor (Rf) provides feedback (closed loop configuration)



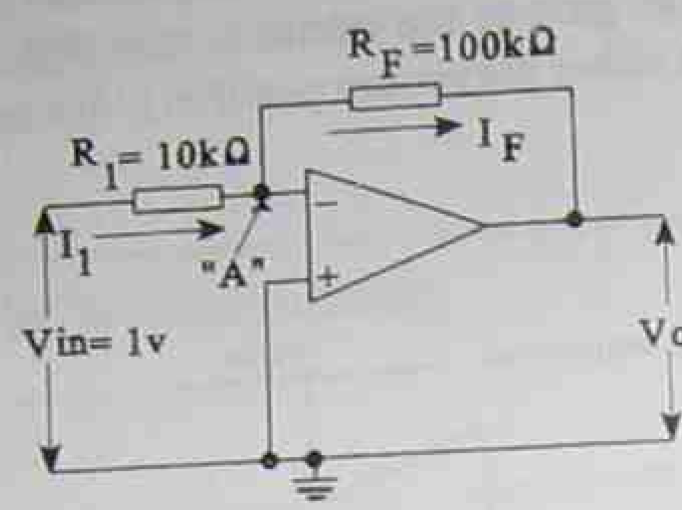
Inverting Amplifier
(power supply not shown for simplicity)

Operation of inverting Amplifier

Op amp (ideal) have infinite input resistance $\therefore$ Io = 0 Amperes

If Io = 0, there is no voltage drop across the op amp input terminals, voltage at each input terminal must be the same value and as the non-inverting terminal is grounded, the voltage at point "A" would equal 0 volts

ie. $V_A = 0$ Volts



Inverting Amplifier

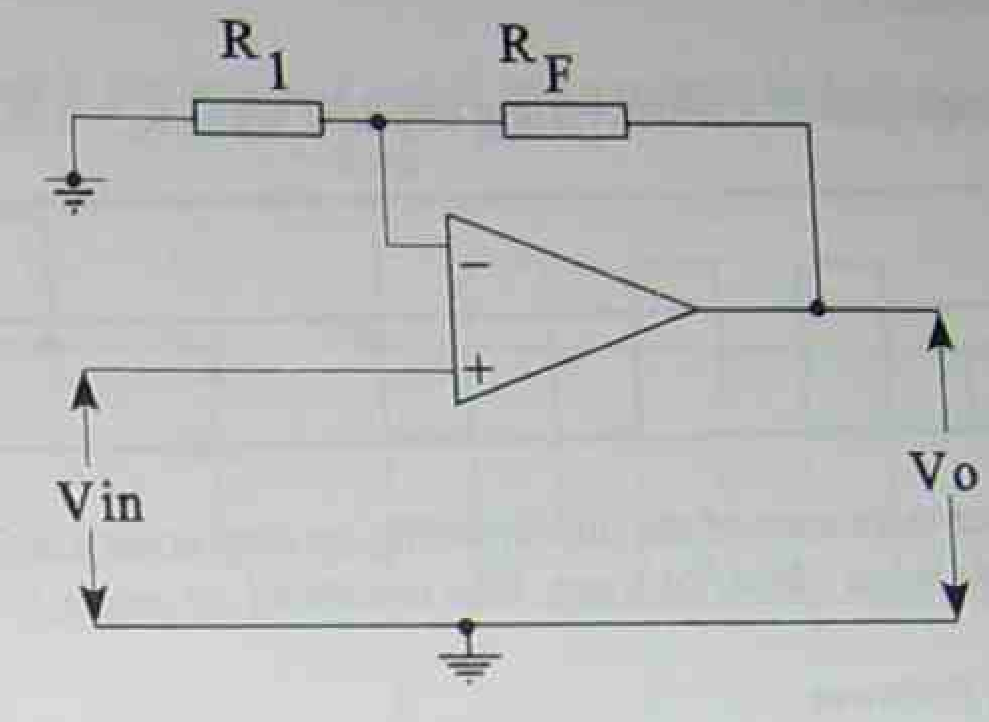
Point A is referred to as a *"Virtual earth"*
Mathematically:

Student Exercise 1.6
Find the voltage gain of a inverting op amp where $R_1 = 1k\Omega$ and $R_F = 100k\Omega$

N.B. The input resistance of the inverting op amp is set by the value of R_1 i.e. $R_1 = 10k\Omega$, $\therefore r_{in} = 10k\Omega$

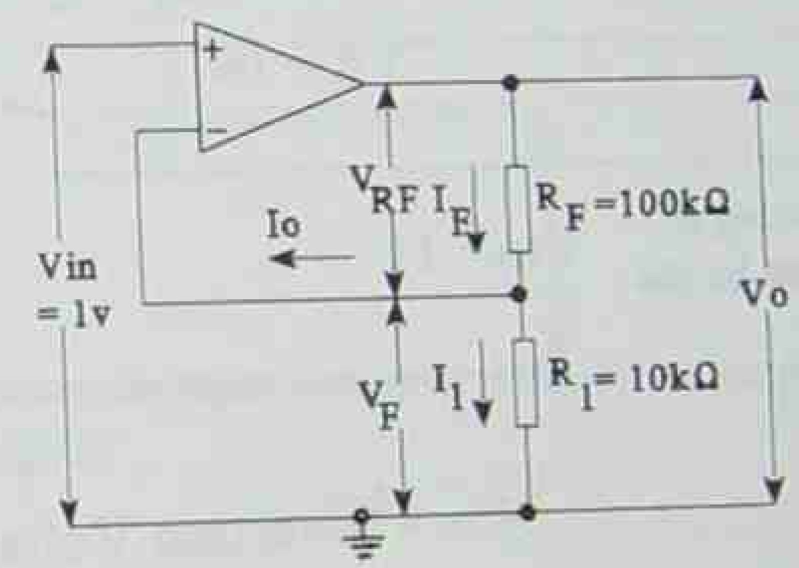
- **Non-Inverting Amplifier**

The non-inverting op amp input signal is fed into the non-inverting terminal (+), which will produce a output which is "in-phase" with the input.



Non -Inverting Amplifier
(power supply not shown for simplicity)

Operation of Non-Inverting Amplifier



Non -Inverting Amplifier

Differential input Voltage = 0v

$\therefore$ Voltage Grain Av =

Student Exercise 1.7

Find the voltage gain of a non-inverting amplifier when $R_1 = 10K\Omega$ and $R_F = 47K\Omega$

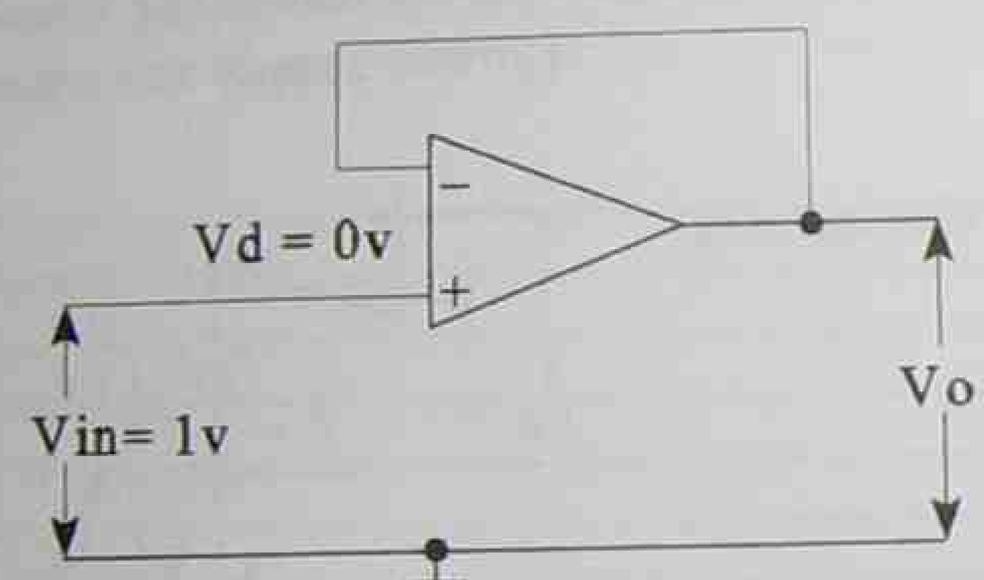
N.B. The input resistance of the non-inverting op amp is very high i.e. $\infty\ \Omega$ and the output resistance is very low (far lower than the stated op amp r_o).

■ Voltage Follower

This circuit provides 100% feedback and therefore has a voltage gain of 1.

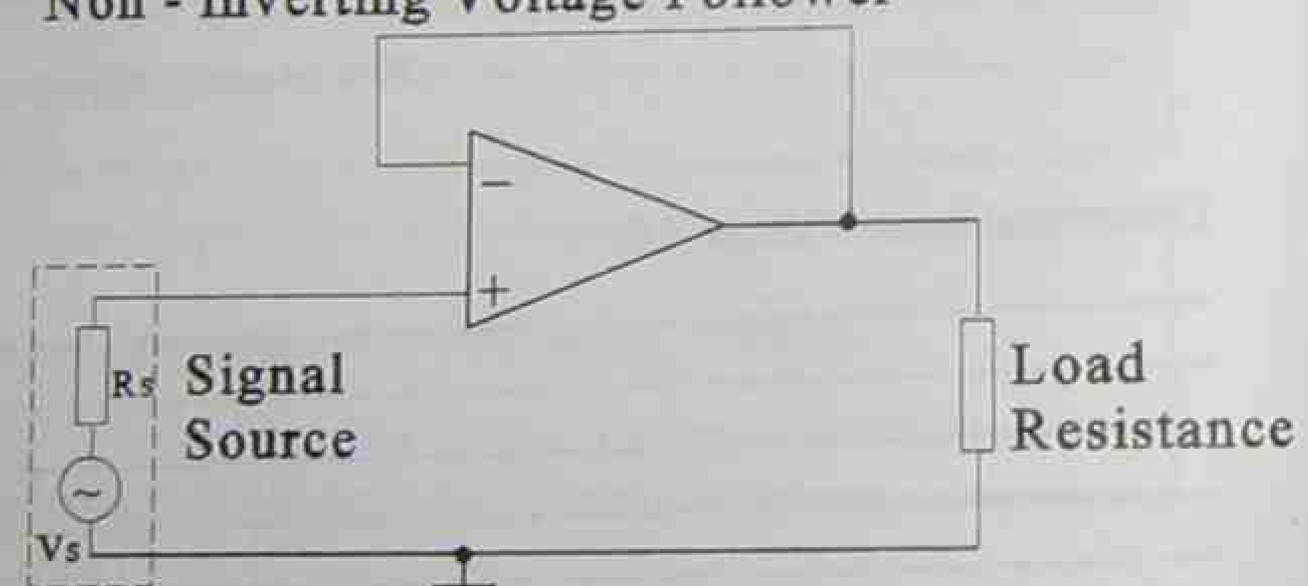
If Vin = 1V
Vd = 0V
Potentials at non-inverting & inverting terminals must be the same

∴ Vo = 1V
Av =



Non - Inverting Voltage Follower

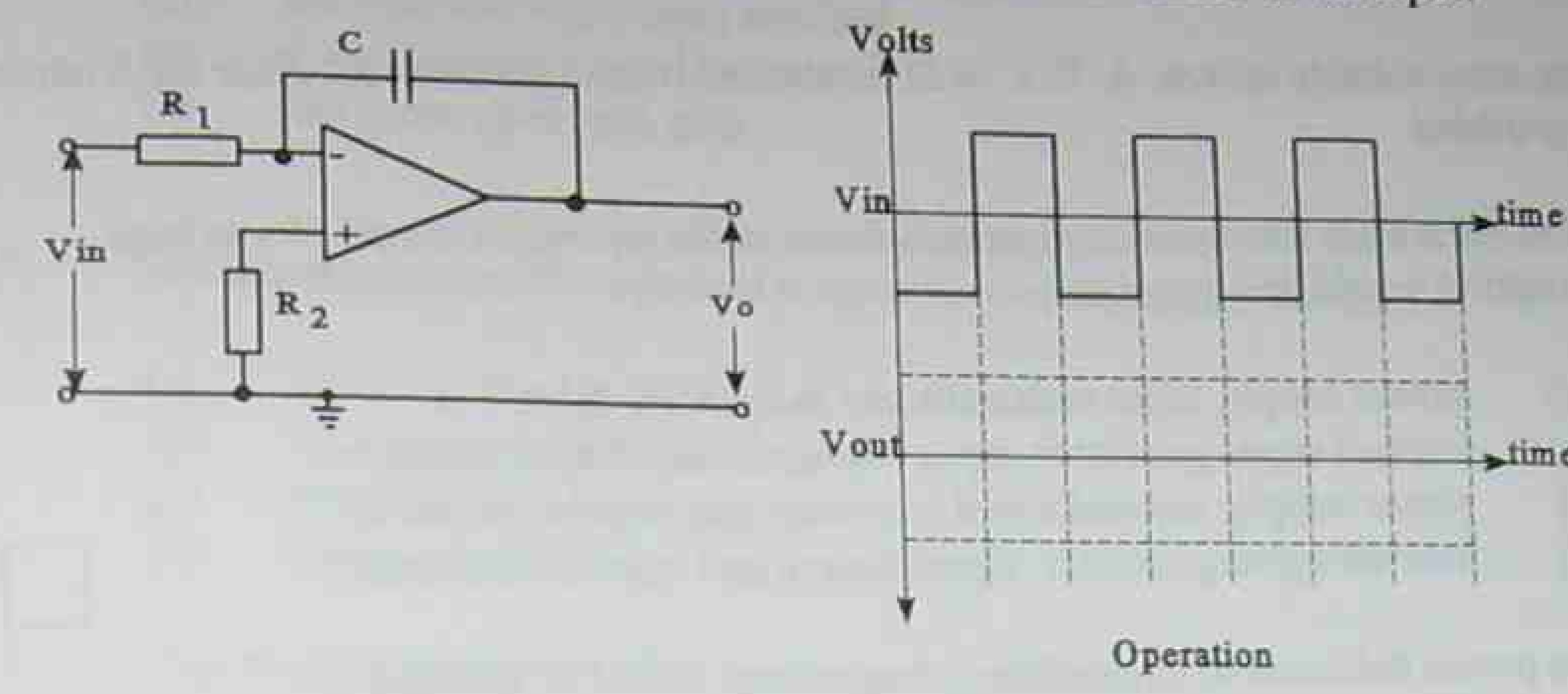
Voltage followers have exceptionally high input resistance and exceptionally low output resistance and therefore makes ideal "buffer" amplifier for connecting high resistance signal sources to low resistance loads i.e. impedance matching.



Voltage Follower as a Buffer

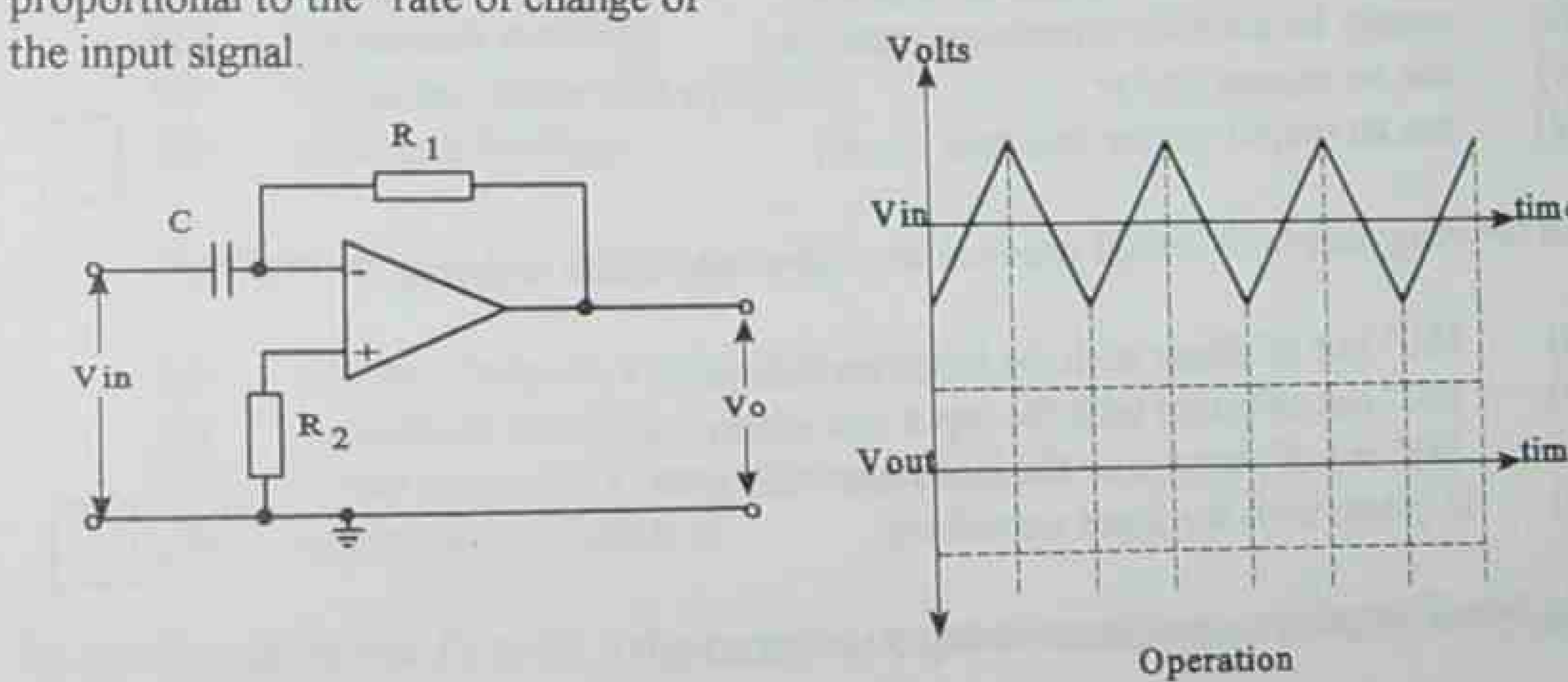
■ The Integrator

The integrator uses a capacitor in the feed back circuit and a resistor in the input.



■ The Differentiator

The differentiator uses a capacitor in the input circuit to produces an output that is proportional to the "rate of change of the input signal.



1.5 Review Questions

These questions will help you revise what you have learnt in Section 1.

Select the most suitable answer A, B, C or D for the following questions and place the letter in the box provided.

1. The three main functional components found in the equivalent model of a voltage amplifier would be:

   (a) power supply, input resistance and output resistance
   (b) internal signal generator, input resistance and output resistance
   (c) power supply, internal signal generator and internal resistance
   (d) internal signal generator, signal source and internal resistance ☐

2. The power delivered to an amplifier's output load would be supplied by:

   (a) the input signal source
   (b) the internal signal generator
   (c) the power supply
   (d) the output signal ☐

3. A small signal amplifier:

   (a) is another name for a power amplifier
   (b) cannot be used for impedance matching
   (c) has no output power
   (d) has an output power less than 1 watt ☐

4. An inverting amplifier would produce an output waveform which is:

   (a) 180° out of phase with the input waveform
   (b) 360° out of phase with the input waveform
   (c) 90° out of phase with the input waveform
   (d) in-phase with the input waveform ☐

5. The "ideal" amplifier would have an input resistance of:

   (a) zero resistance
   (b) equal to the signal source resistance
   (c) twice the signal source resistance
   (d) infinite resistance ☐

6. An operational amplifier:

   (a) is not able to amplify current
   (b) has only one signal input terminal
   (c) is an impedance matching device
   (d) has a low open loop gain ☐

7. An operational amplifier operated in open loop configuration would:

   (a) have negative feedback
   (b) have positive feedback
   (c) be a voltage follower
   (d) have no feedback ☐

8. The ideal characteristics of an operational amplifier are:

   (a) Open Loop $A_v = \infty$, $R_{in} = \infty$, $R_{out} = \infty$ and $BW = \infty$
   (b) Open Loop $A_v = \infty$, $R_{in} = 0$, $R_{out} = \infty$ and $BW = \infty$
   (c) Open Loop $A_v = \infty$, $R_{in} = \infty$, $R_{out} = 0$ and $BW = \infty$
   (d) Open Loop $A_v = 0$, $R_{in} = 0$, $R_{out} = \infty$ and $BW = 0$ ☐

9. Voltage followers are used to provide:

   (a) maximum amplification
   (b) impedance matching
   (c) maximum phase shift of signals
   (d) minimum feedback ☐

10. A simple integrator is used to provide:

    (a) a ramp change to a step input signal
    (b) impedance matching
    (c) a step change to a ramp input signal
    (d) maximum amplification ☐

To answers questions 11 to 20 write your one or more words answer in the space provided.

11. The choice of amplifiers used in a circuit is determined by the following requirements - voltage, current, power gain and/or ____________

12. When the amplifier is operated within its design parameters, the output waveform will be a true reproduction of ____________

13. The three types of amplifier circuit construction employed are:

(a) ______

(b) ______

(c) ______

14. What is the current gain of an amplifier?

______

15. Name the condition when a voltage and/or current is applied to an amplifier to set the steady state operating point of the circuit?

______

16. The open loop gain of an operational amplifier can be modified by adding

______

17. What is the meaning of "virtual earth"?

______

______

18. In which part of the simple differentiator operational amplifier circuit would you find a capacitor?

______

19. The input signal to a non-inverting operational amplifier circuit is connected to the

______

20. The open loop output resistance r_o of an operational amplifier is

______

Show **all** working out for questions 21 to 30.

21. Determine the voltage gain of an amplifier which has an output voltage of 2 volts peak to peak (p-p) and an input voltage of 21 mV p-p.

______

______

22. What input voltage would be required to be applied to an amplifier having a voltage gain of 15, to provide an output voltage of 1.5 V p-p?

______

______

23. Calculate the voltage at the input terminals of an amplifier having an input resistance of 1.6k ohm which is fed by a signal source with a 600 ohm output resistance if the signal source delivers 200 mV p-p with its terminals open-circuited.

______

______

______

24. Calculate the amplifier input resistance if the input voltage is 200 mV and the input current to the amplifier is 20 μA.

______

______

______

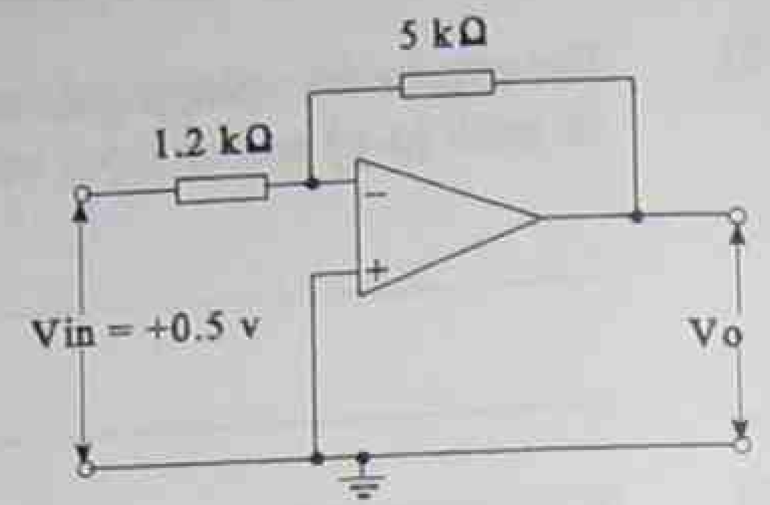
25. An amplifier has an output voltage of 2.5 volts at no load. When a load of 10 k ohm is connected, the output voltage drops to 1.7 volts. Calculate the amplifier output resistance

______

______

______

26. For the circuit shown, determine the :



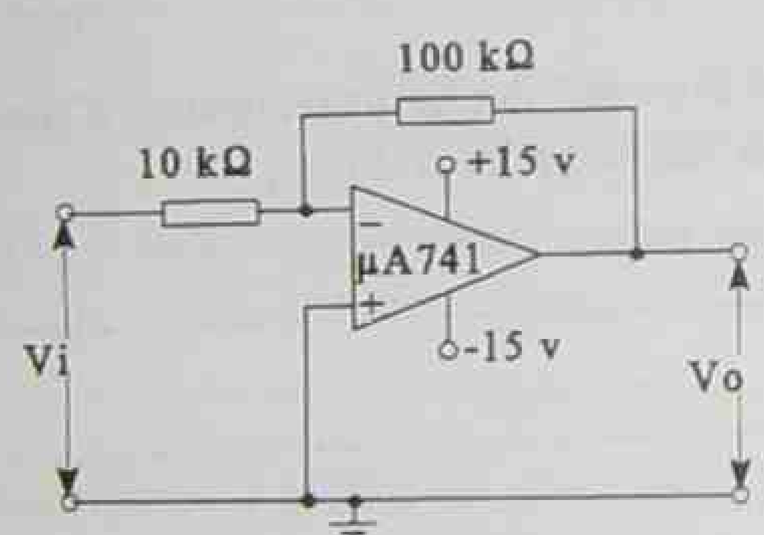
(a) Voltage Gain: ____________________

(b) Input Resistance: ____________________

(c) Output Voltage: ____________________

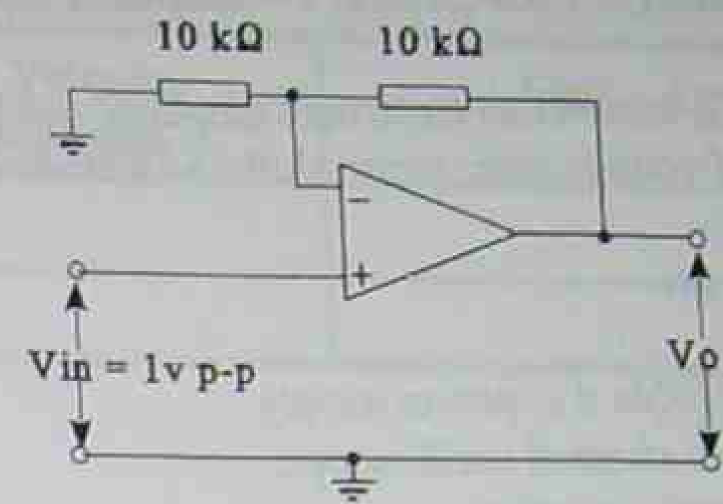
27. Draw the circuit diagram of an op amp connected so as to provide 180° phase shift and increase a 20 mV signal up to 1 V. The input resistance of the circuit is to be 6.8 k ohm.

28. Sketch the input and output voltages for the circuit shown if the input voltage to the circuit is:



(a) 1 V p-p sinewave.
(b) 0.5 V p-p squarewave.
(c) -0.1 V d.c.
(d) 2 V rms, sinewave.

29. For the circuit shown determine the:

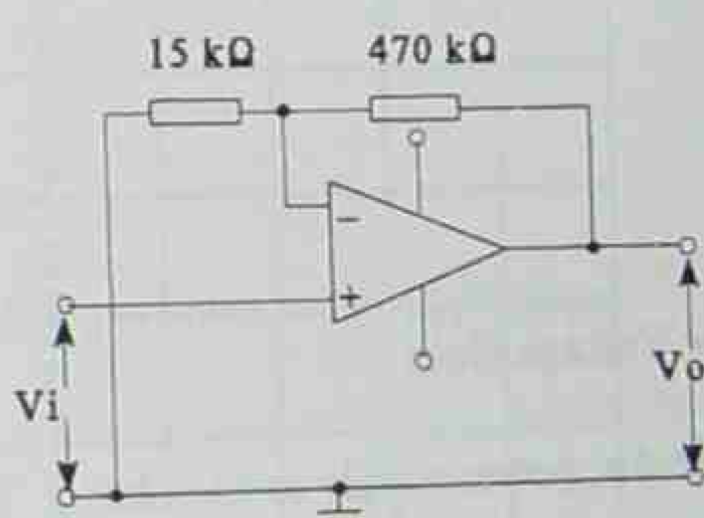


(a) Voltage Gain: ____________________

(b) Output Voltage: ____________________

(c) Phase Relationship: ____________________

30. Sketch the input and output voltages for the circuit shown if the input voltage to the circuit is:



(a) 10 mV p-p sinewave.
(b) 1 V p-p sinewave.
(c) 0.5 V p-p squarewave.
(d) -0.2 V d.c.

1.6 SKILL PRACTICE 1 - Amplifier Principles

Aim: To connect an electronic amplifier and to examine its operating characteristics in terms of voltage gain, phase shift and distortion.

Equipment:

- Variable d.c. power supply
- Dual channel oscilloscope
- Signal generator
- Digital Multimeter
- Amplifier PCB and Plug in Base
- Connection leads

Method: 1. Amplifier Connections

(a) Gather a set of equipment as listed above

(b) Connect up the circuit as shown in Figure 1.

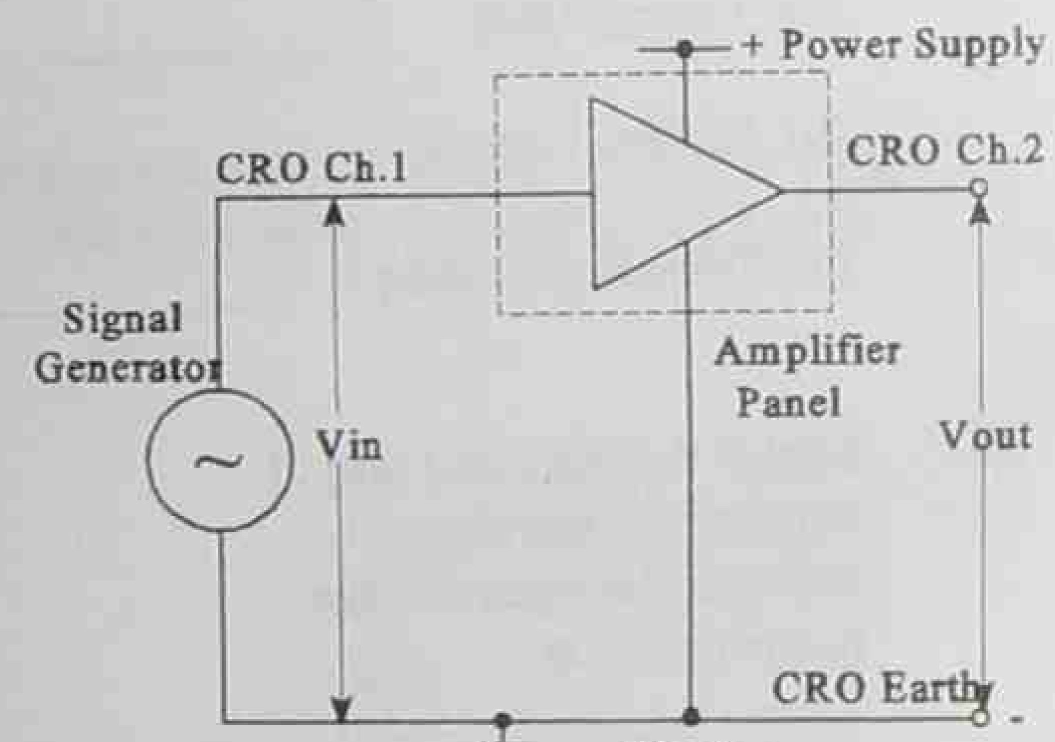


Figure 1

2. Amplifier Voltage Gain

(a) Set the d.c. power supply to 15 volts.

(b) Turn the power on.

(c) Set the signal generator to produce a 0.5 volt peak to peak sinewave at 1 kHz.

(d) Adjust the CRO to display both the input and output waveforms. Make sure the CRO is properly triggered, so that both waveforms are stable on the screen.

(e) Record the input voltage (Vin) and output voltage (Vout) in Table 1 and calculate the voltage gain of the amplifier.

(f) Adjust the signal generator output up to 1 volt peak to peak. Make sure the output voltage is not clipping (chopped off at the tops and/or bottoms) and record your results in Table 1.

Table 1

Input Voltage - Vin p-p volts	Output Voltage - Vout p-p volts	Gain - Av
0.5		
1		

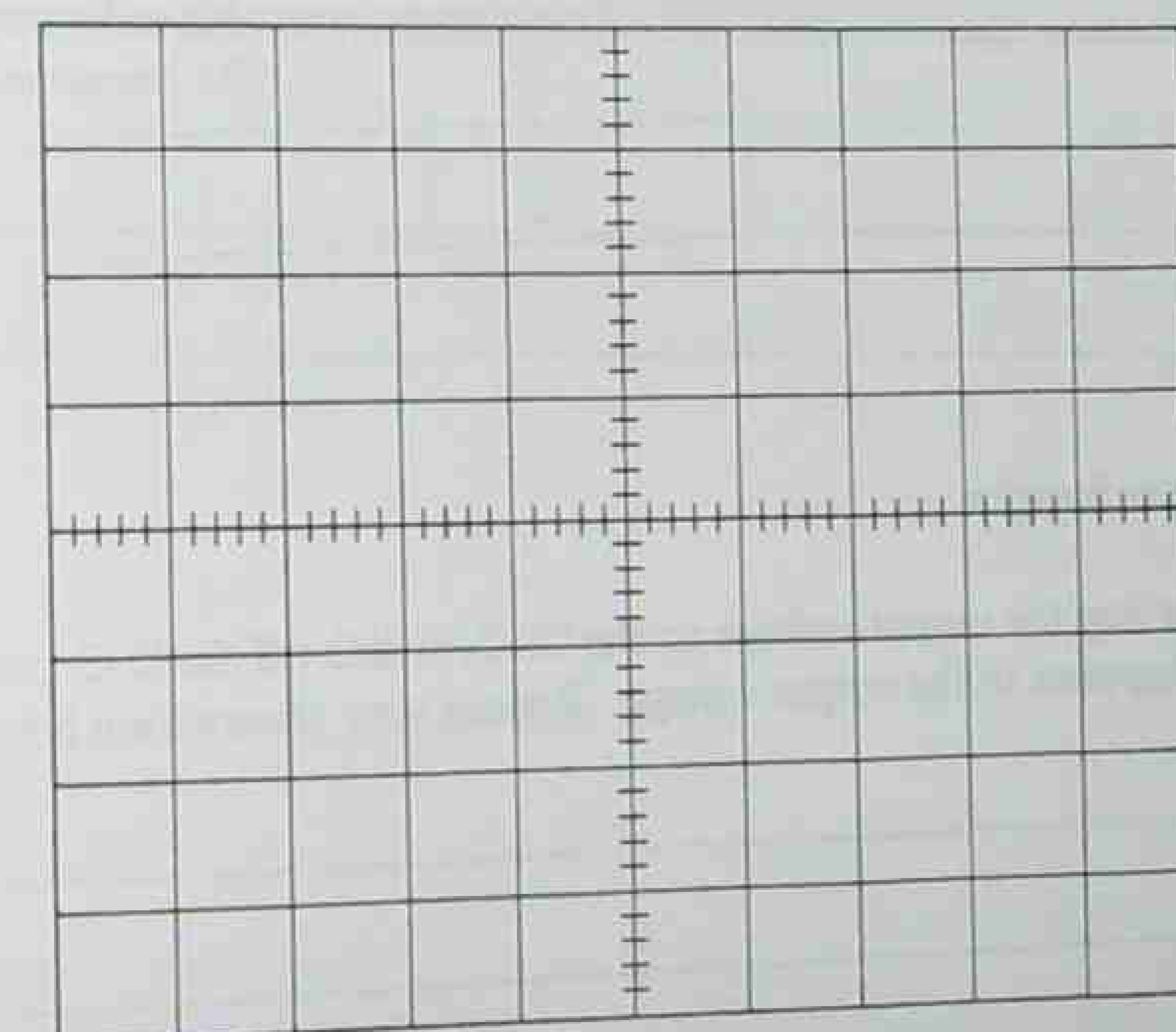
3. Amplifier Relationship

(a) Using the waveforms as obtained in Method 2, are the input and output voltages in phase or out of phase? Record your answer in Table 2 below.

Table 2

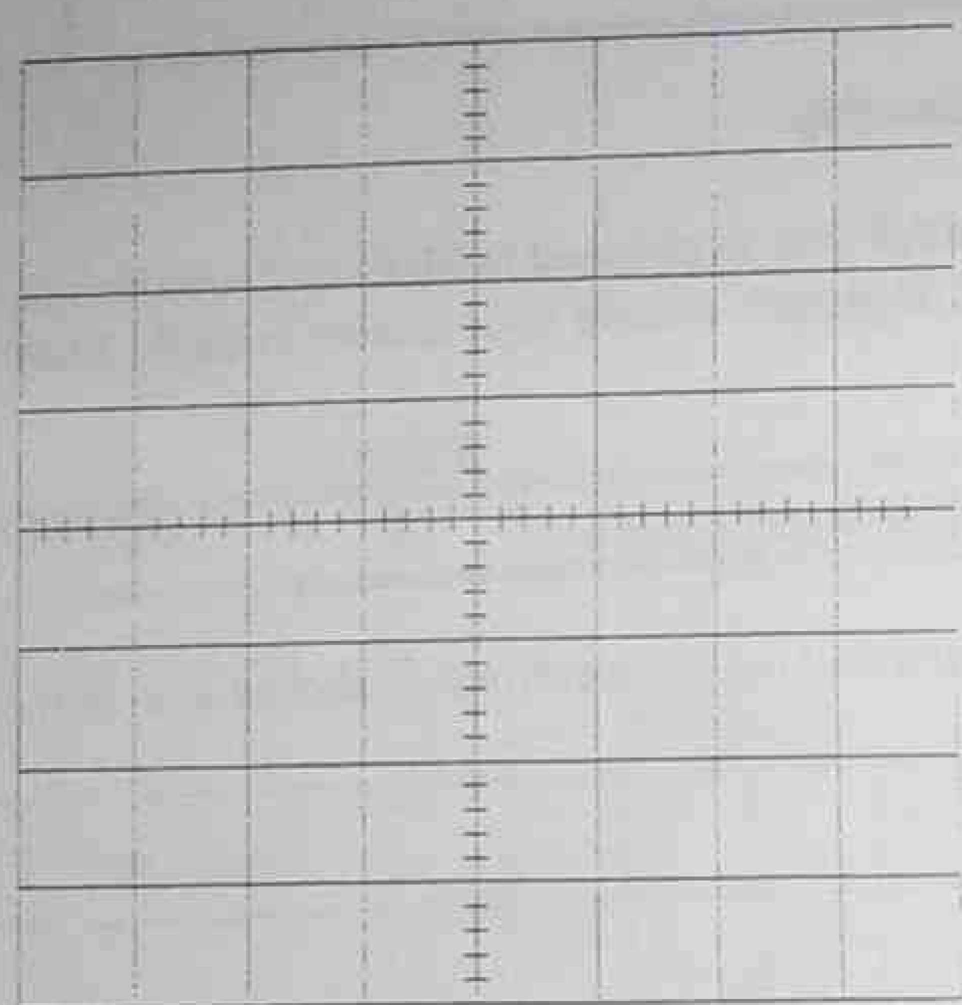
Input - Output Phase Relationship	

(b) Sketch the input and output waveforms, label all axis on the grid below.



4. Amplifier Distortion

(a) Adjust the signal generator up to the output waveform is clipped (either chopped off at the tops and/or bottoms) and sketch the input and output waveforms on the grid below.



5. Amplifier Power Supply

(a) While observing the output voltage on the CRO, switch off the D.C. power supply and note what happens to the output voltage. Record your observation below.

____

____

____

(b) Return all equipment to its proper location.

Conclusion:

1. Did the amplifier produce an output voltage larger that its input voltage?

____

2. Did the gain of the amplifier change a lot when a different input voltage was used?

____

____

3. From your answer in question 2, what can you say about the gain of an amplifier?

____

____

4. Why did the output voltage become distorted when the input voltage was increased?

____

____

5. Was the amplifier able to produce a reasonable output voltage when the D.C. power supply was turned off?

____

____

1.7 SKILL PRACTICE 2 - Operational Amplifier Configurations

Aim: To connect operational amplifiers in the inverting, non-inverting and voltage follower configurations to amplify d.c. and a.c. voltages.

Equipment:

- Variable dual d.c. power supply
- Dual channel oscilloscope
- Signal generator
- Digital Multimeter (D.M.M.)
- 1.5 volt battery
- 1kΩ potentiometer
- Operational Amplifier PCBs and Plug in Base
- Connection leads

Method: 1. Inverting d.c.Operational Amplifier Characteristics

(a) Gather a set of equipment as listed above.

(b) Connect up the circuit as shown in Figure 1 below.

(c) Set Vin to 1 volt using the potentiometer.

(d) Measure the output voltage (Vo) with the DMM and note the polarity.

Vo = ______ volts

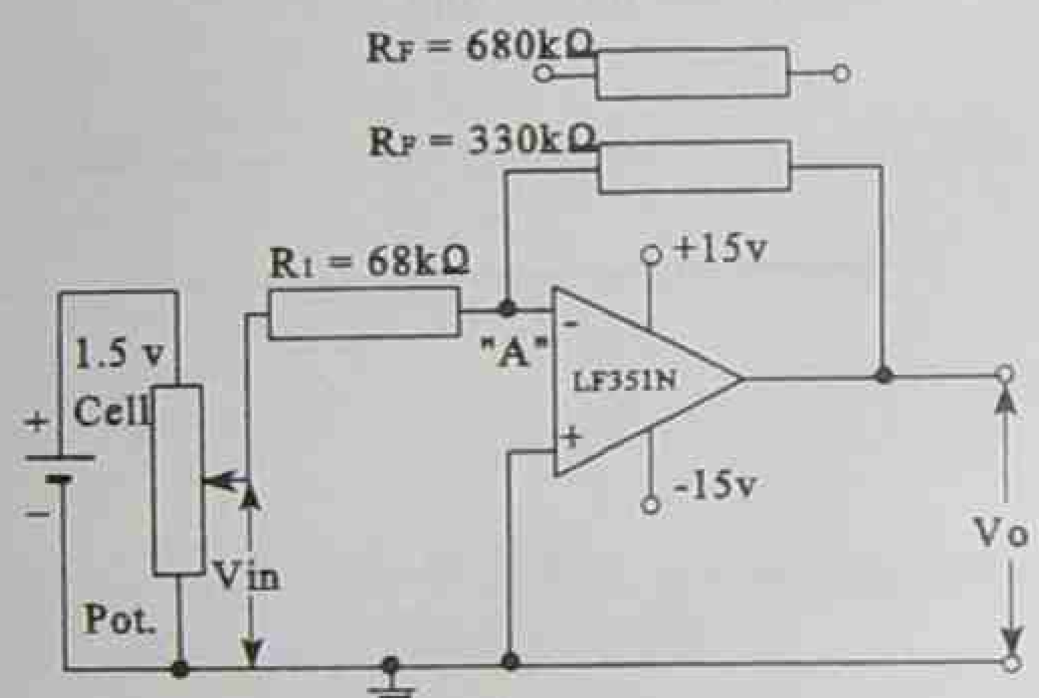


Figure 1

(e) Calculate the Voltage Gain (Av) using the measured values.

Av = Vo/Vin = _____ = _________

(f) Measure the voltage at point "A" ("virtual earth") with respect to ground (earth).

Point "A" V_A = ______ volts

(g) Change the feedback resistor (R_F) to the 680 kΩ resistor and set Vin to 1 volt.

(h) Measure Vo Vo = _______ volts

(i) Measure V_A V_A = _______ volts

2. Inverting a.c. Operational Amplifier

(a) Connect up the circuit as shown in Figure 2.

(b) Set the input voltage Vin to 0.5 volts peak to peak sine wave, 1kHz.

(c) Measure the output (Vo) using the CRO and observe the phase relationship between Vin and Vo.

Vo = _____ volts

Phase Shift = _____

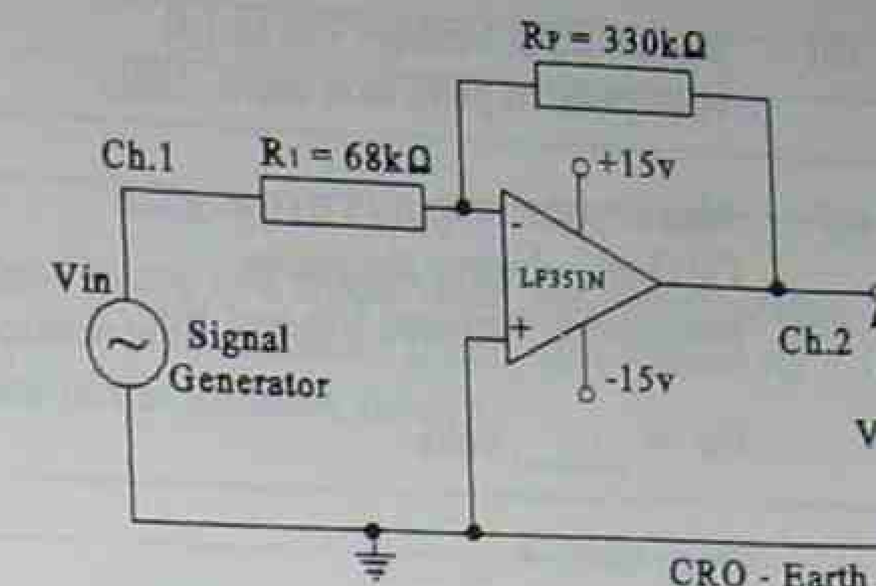


Figure 2

(d) Calculate the voltage gain using the measured results.

Av = Vo/Vin = _____ = _____

3. Non-Inverting d.c.Operational Amplifier.

(a) Connect up the circuit as shown in Figure 3.

(b) Adjust the potentiometer to set Vin to 1 volt .

(c) Measure the voltage V_F with the DMM and confirm that V_F = Vin.

(d) Measure the output voltage (Vo) with the DMM noting the polarity.

Vo = ______ volts

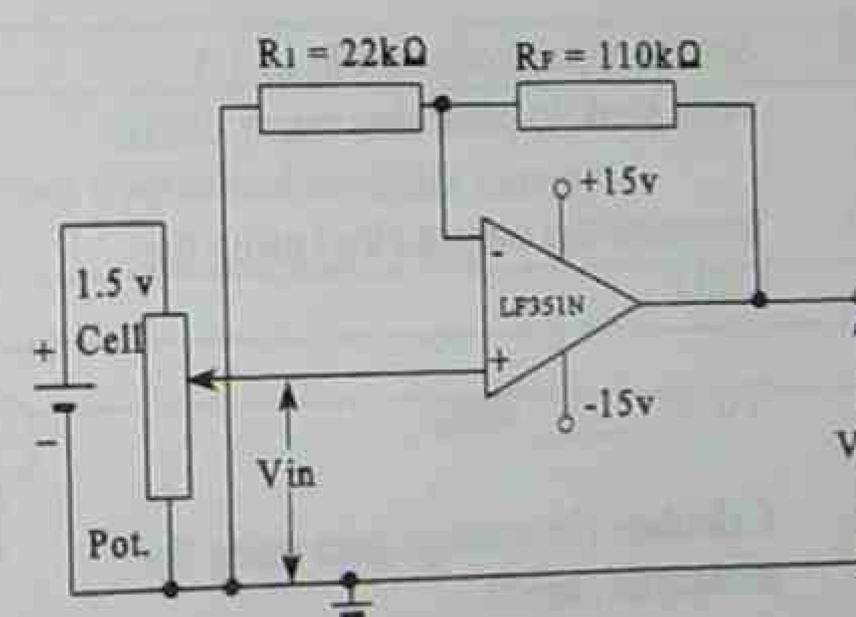


Figure 3

(e) Calculate the Voltage Gain (Av) using the measured values.

Av = Vo/Vin = _____ = _______

4. Non-Inverting a.c. Operational Amplifier

(a) Connect up the circuit as shown in Figure 4.

(b) Set the input voltage Vin to 1.0 volts peak to peak sine wave, 1kHz.

(c) Measure the output (Vo) using the CRO and observe the phase relationship between Vin and Vo.

Vo = _____ volts

Phase Shift = _____

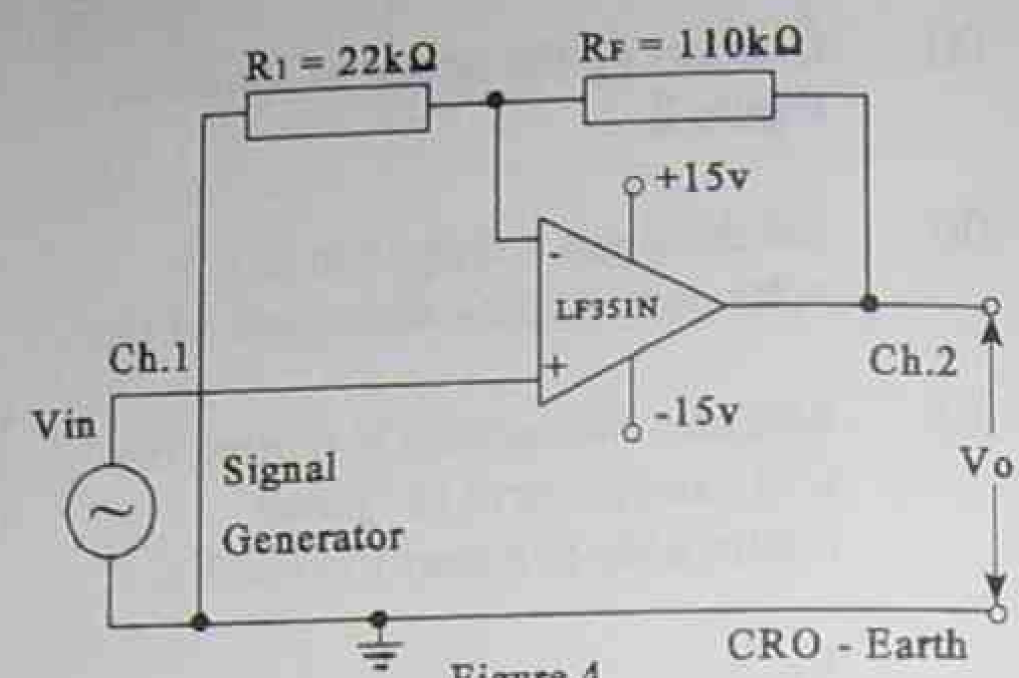


Figure 4

(d) Calculate the voltage gain using the measured results.

Av = Vo/Vin = _____ = _____

5. Operational Amplifier Used as a Voltage Follower

(a) Connect up the circuit as shown in Figure 5.

(b) Set the input voltage Vin to 1.5 volts peak to peak sine wave, 1kHz.

(c) Measure the output (Vo) using the CRO.

Vo = _____ volts

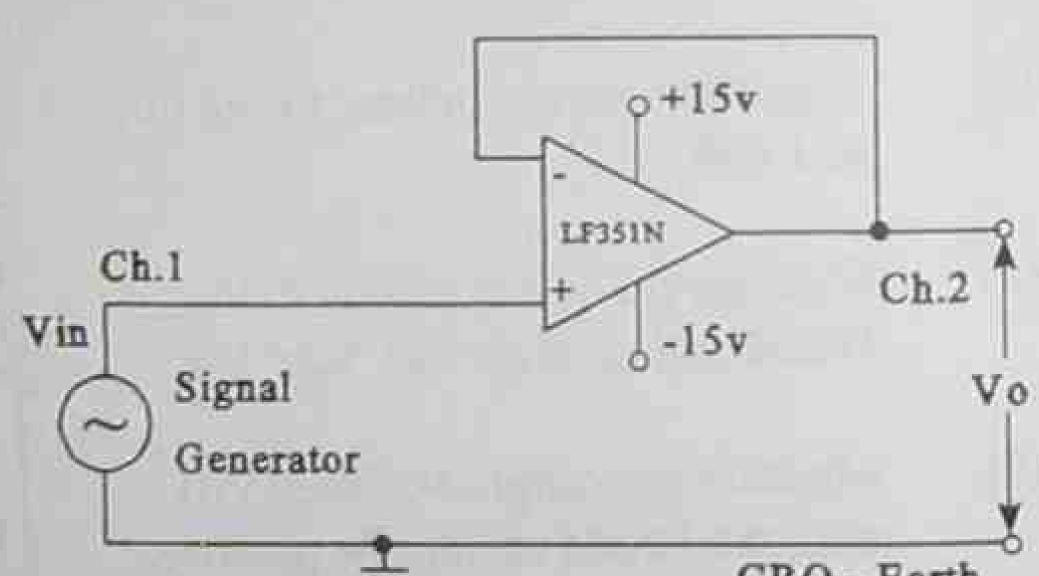


Figure 5

(d) Calculate the voltage gain using the measured results.

Av = Vo/Vin = _____ = _____

Conclusion:

1. Theoretically the virtual earth point should be zero volts. Was this the case in your practical? If not, give reasons for your answer.

2. When the feedback resistor was changed to one of a higher value, the output voltage should have increased. Was this the case in your practical? If not , give reasons for your answer. What would limit the size of this feedback resistor?

3 What is the purpose of an inverting operational amplifier circuit?

4. What is the purpose of an non-inverting operational amplifier circuit?

5. What is the purpose of a voltage follower operational amplifier circuit?

NOTES

Section 2
INDUSTRIAL TRANSDUCERS

PURPOSE

The purpose of this section is to provide the student with the basic knowledge of the principles of operation and application of common industrial transducers.

TO ACHIEVE THE PURPOSE OF THIS SECTION :

This section represents around 20% of the module, and should take approximately 8 hours.

At the end of this section the student will be able to :

- List the common variables monitored in industrial processes and the terminology used associated with transducers.
- Identify and explain the principle of operation of common temperature measurement transducers.
- Identify and explain the principle of operation of common force measurement transducers.
- Identify and explain the principle of operation of common speed measurement transducers.
- Identify and explain the principle of operation of common positional measurement transducers.

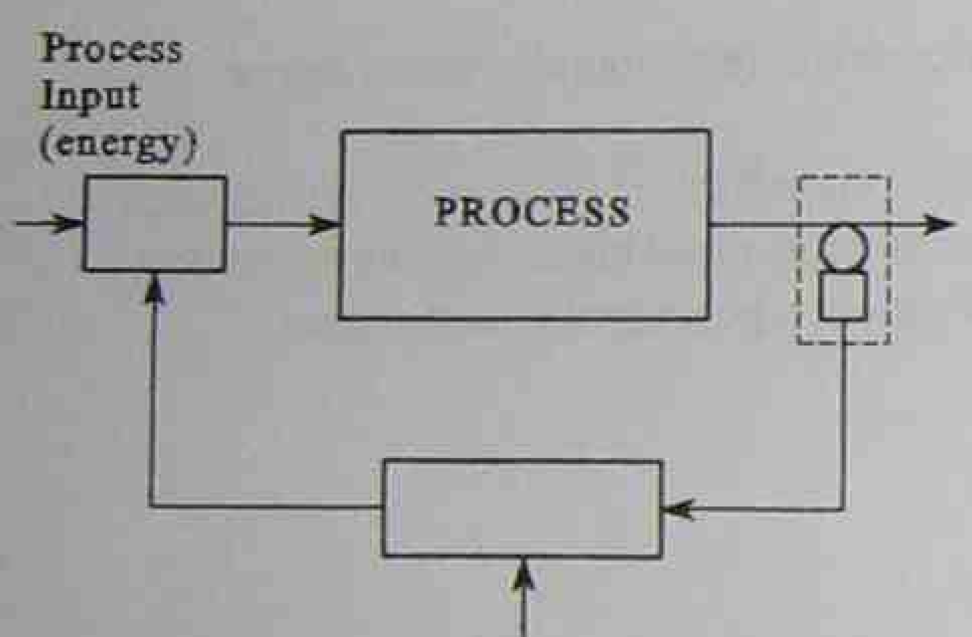
ASSESSMENT

Assessment for this section will be by way of practical and written tests to be held at the completion of the module.

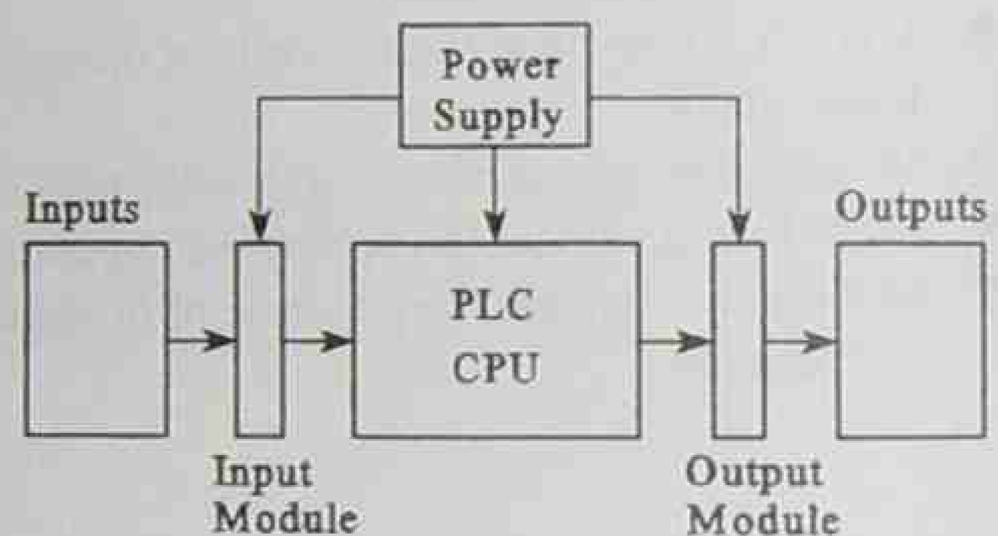
CONTENTS

2.1 INTRODUCTION

- Transducers form a important component in any closed loop control system or programmable controller (PLC) system used in industrial control.



Block Diagram of a Closed Loop Control System

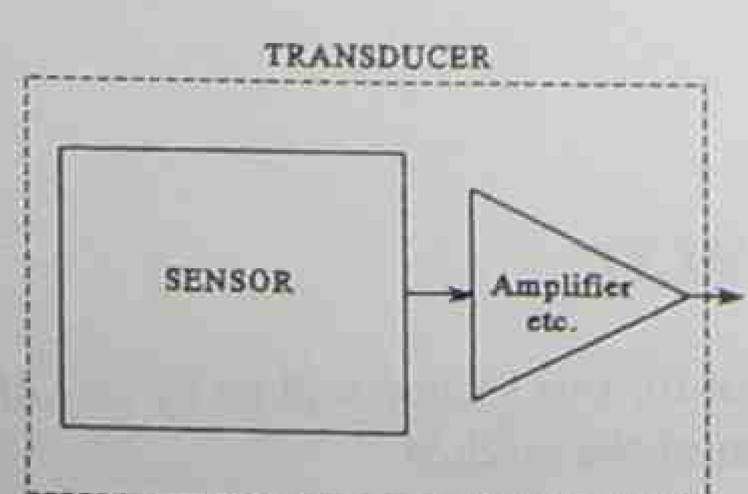


Block Diagram of a PLC System

Transducers and Sensors

- A **transducer** consists of the sensor and its associated circuitry to produce an output signal.

- A **sensor** is a device that detects a change in physical stimulus and convert this change to a signal that can be measured.



2.2 SI UNITS

The International Systems of Units (SI - Système International d'Unités) uses seven base quantities of:- Length (metre), Time (second), Mass (kilogram), Temperature (kelvin), Electric current (ampere), Amount of Substance (mole) and Luminous intensity (candela).

- **Length**

The unit of length is the metre (m), and is defined as the length of a path travelled by light in a vacuum during a time interval of 1.299,792,458 second. Area is measured in square metres (m^2), and volume in cubic metres - (m^3)

- **Time**

The unit of time is the second (s), and is the duration of 9,192,631,770 cycles of the radiation of a Caesium-133 atom. Frequency in terms of cycles per second or Hertz (Hz). Speed in metres per second ($m.s^{-1}$) and Acceleration in metres per second per second ($m.s^{-2}$).

- **Mass**

The unit of mass is the kilogram (kg). It is equal to the mass of the international protype of the kilogram Force is measured in newtons (N), Energy in Joules (J), and Power in Watts (W).

- **Temperature**

The unit for temperature is the Kelvin (K). The Kelvin is the fraction 1/273.16 of the thermodynamic temperature of the triple point of water. Other scales used are the Fahrenheit (°F) and Celsius (°C)

- **Electric Current**

The unit for electric current is the ampere (A) and is defined as the constant current that, if maintained in two straight parallel conductors of infinite length and negligible cross section area and placed one metre apart in a vacuum, would produce between these conductors a force equal to 2×10^{-7} Newton per metre of length.

- **Amount of Substance**

The unit for amount of substance is the mole and is defined as the amount of substance of a system which contains as many elementary entities as there are carbon atoms in 0.012 kilogram of carbon-12. The elementary entities must be specified and may be atoms, molecules, ions, electrons, other particles, or specified groups of such particles.

■ **Luminous Intensity**

The unit of luminous intensity is the candela (cd). The candela is the luminous intensity from a source of monochromatic radiation of 540 x 1012 Hertz and has a radiant intensity of 1/680 watt per steradian. Light flux is measured in lumens (1m).

A light source of 1 cd radiates 4 lumens in all directions.

2.3 FORMS OF ENERGY

There are six general types of signals that can be measured:-

- ■ *Radiant* : Visible, infrared and ultra-violet light, microwave, Xray, nuclear, etc.
- ■ *Mechanical* : Displacement, velocity, acceleration, force, pressure, flow, sound, etc.
- ■ *Thermal* : Temperature, conduction, heat flow, etc.
- ■ *Electrical* : Voltage, current, resistance, dielectric constant, etc.
- ■ *Magnetic* : Magnetic flux, field strength, etc.
- ■ *Chemical* : Composition, pH, acidity, etc.

2.4 TRANSDUCER TERMINOLOGY

- ■ Range : The given operating range of the transducer. i.e. a temperature transducer may have a range of (300 °C to 3000 °C).
- ■ Span: This is the difference between the upper and lower values of the range. i.e. the temperature transducer has a span of 2700 °C.
- ■ Linearity: The output of the transducer is directly proportional to its input over the entire range of operation.
- ■ Sensitivity: This describes the amount of output signal in relation to the transducer input signal. i.e. a temperature sensor could have a sensitivity of 0.5mV/degrees Celsius.
- ■ Resolution: This is the smallest change of input signal the transducer can respond to.

2.5 TEMPERATURE MEASUREMENT

■ **Introduction**

In industrial applications, temperature monitoring is one of the most common methods used in the control of a wide range of variables.

When temperature measurements are made, one of two variables can be determined:

- Temperature (analogous to voltage)
- Heat (analogous to current)

The material that makes up the composition of any mass within a thermal system can be:

- Solid
- Liquid
- Gas

The transmission of heat through a mass can take one of three paths, the three paths are:

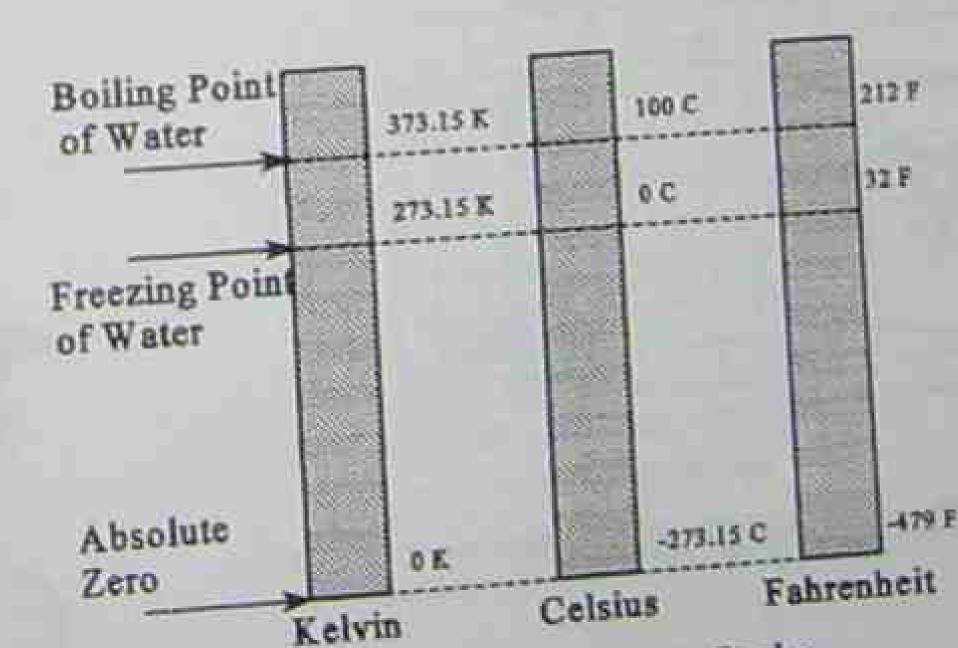
- Conduction - Heat energy is transferred by each molecule.
- Convection - Heat energy is transferred by circulating currents.
- Radiation - Heat energy is transferred by the radiation of waves.

Temperature measurement can be made in several ways, non electrical indicators such as thermometers or electronic circuits using a thermoelectric sensor.

Heat production can be from many sources, in varying amounts, for example, chemical reactions such as Iron rusting, Fossil fuels such as coal or gas, Electrical such as arc, resistance or induction furnaces.

Temperature measurement in industry can range from -267°C to +7500°C, these extremes of temperatures require a variety of sensors.

There are three different temperature scales that the Industrial electrician needs to be aware of, the Celsius and Kelvin scales are the common, and absolute temperature scales of the SI system of units.



Standard Temperature Scales

- Fahrenheit (°F)
- Celsius (°C)
- Kelvin (K)

Conversion

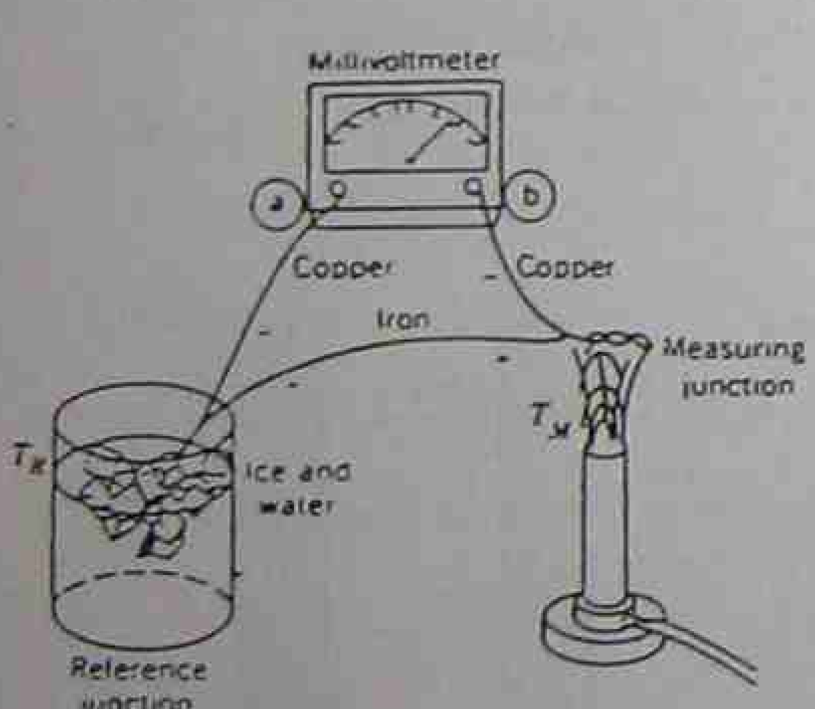
- 1 unit of Kelvin (K) = 1 unit of Celsius (°C)
- $°F = 9/5°C + 32$
- $°C = 5/9(°F - 32)$

The type of temperature sensor will depend on several factors, the most important factors are:

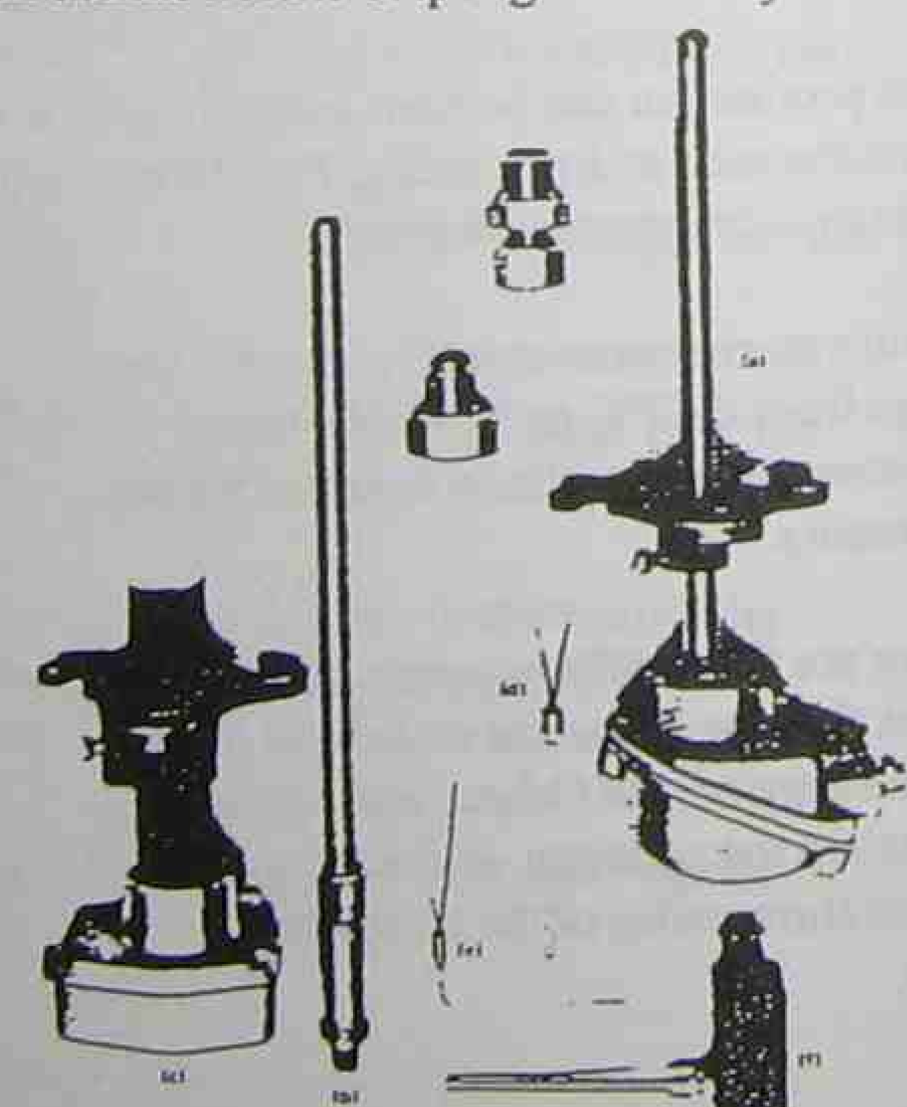
- Sensitivity - Rate of change of output for input changes.
- Accuracy = % error of total scale.
- Temperature range - Maximum temperature rating of sensor.

■ Thermocouples

Thermocouples are the most common method of measuring temperatures between 500°C and 1500°C. The thermocouple consists of two (2) dissimilar metal wires which have a junction in the region of the unknown temperature (called the Hot Junction - H.J.). The other junction is called the cold junction - C.J. and is normally at room temperature. The two junctions are connected to an instrument which measures a small thermoelectric output generated by the thermocouple in millivolts (mV.)



Thermocouple Circuit

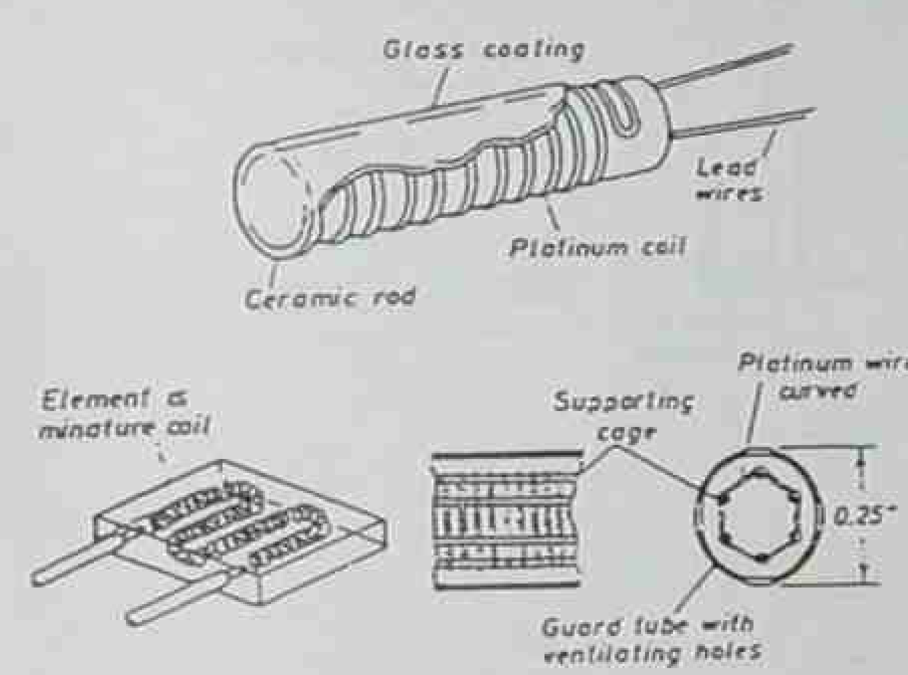


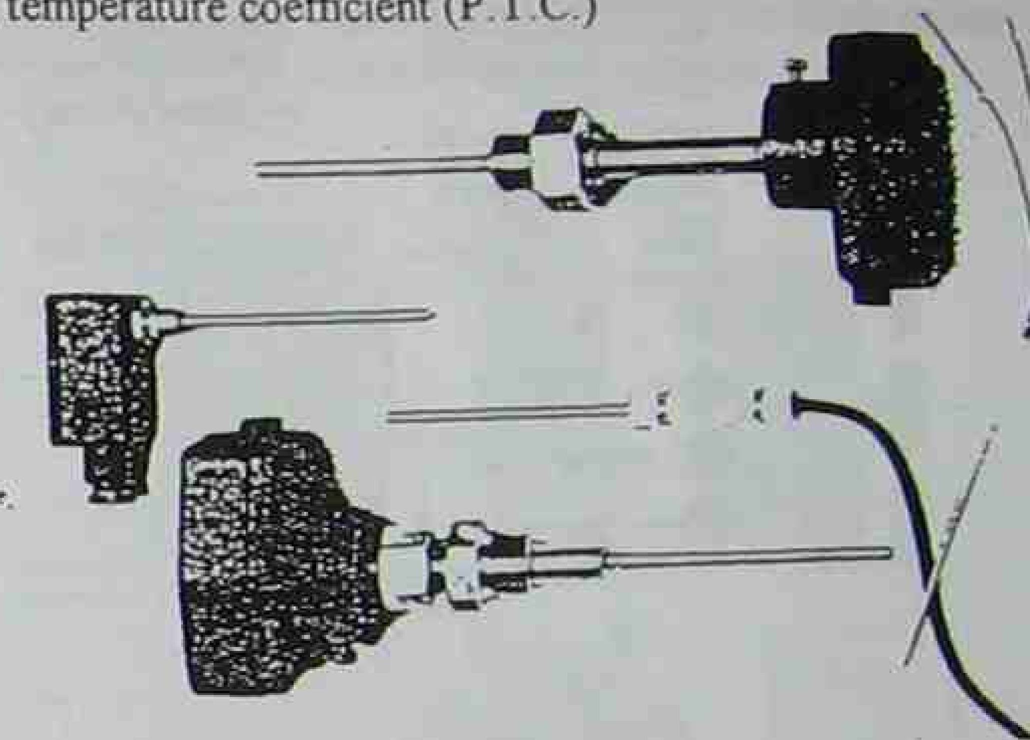
The output of the thermocouple can be converted to a temperature by referring to standard tables or graphs. (The cold junction temperature must be known.)

Thermocouples have the advantages of being relatively inexpensive, good response time, easy to interface to electrical circuits. Disadvantages of thermocouples are the non-linear output, poor accuracy and cannot be used with moving objects.

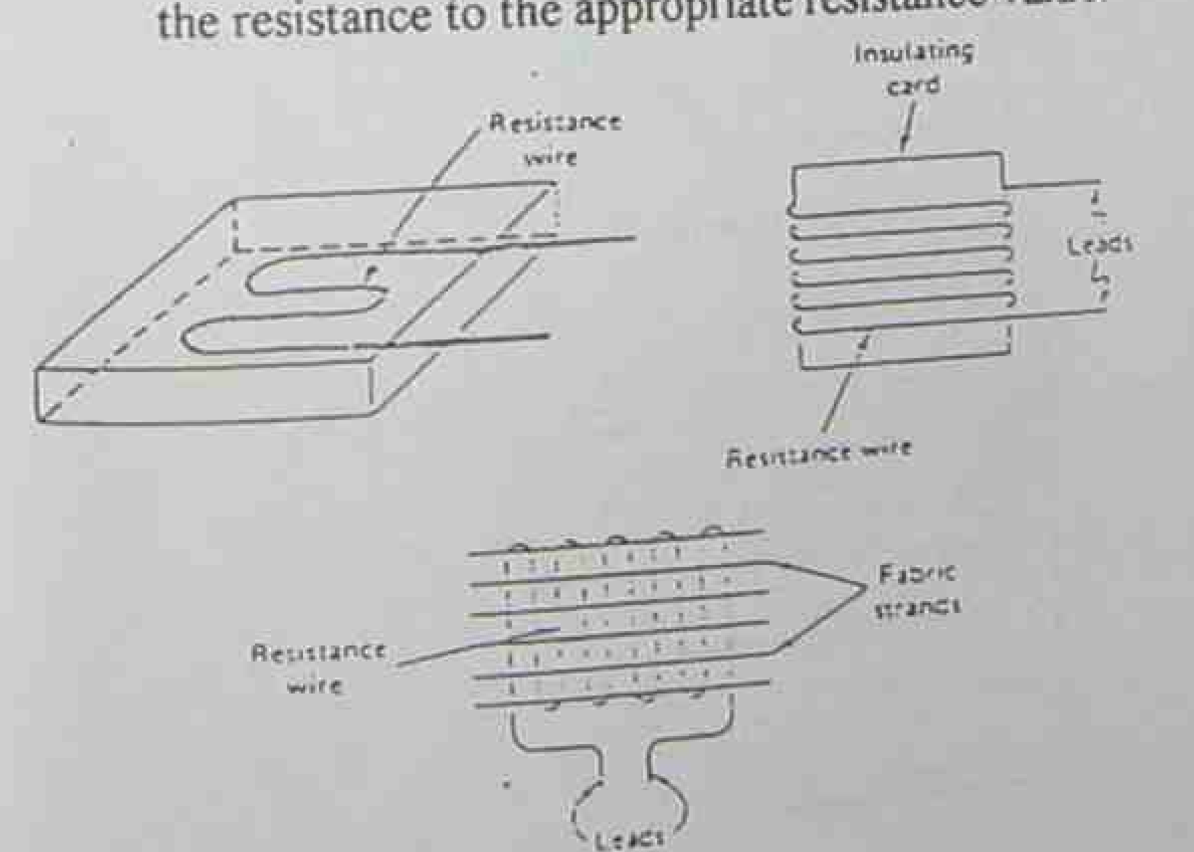
■ Resistance Temperature Detectors (R.T.D.s)

Also called resistance bulbs or resistance thermometers. The resistance temperature detector depends on the property that the resistance of pure metallic conductors **increases** with temperature rise i.e. they have a positive temperature coefficient (P.T.C.)

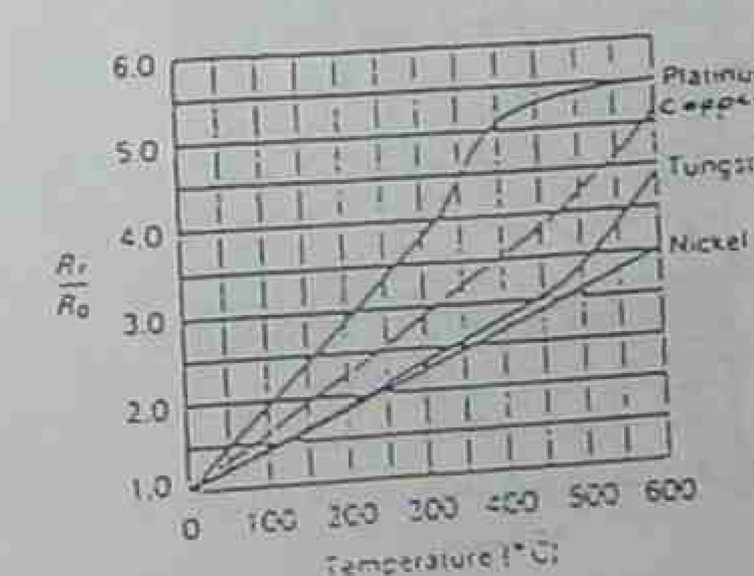




The R.T.D. consists of a length of metal wire with known reproducible and stable temperature/resistance characteristics wound on a non conductive former. Alternatively the metal can be deposited onto a ceramic substrate then an etching process can be used to trim the resistance to the appropriate resistance value.



Resistance-type surface temperature sensors.

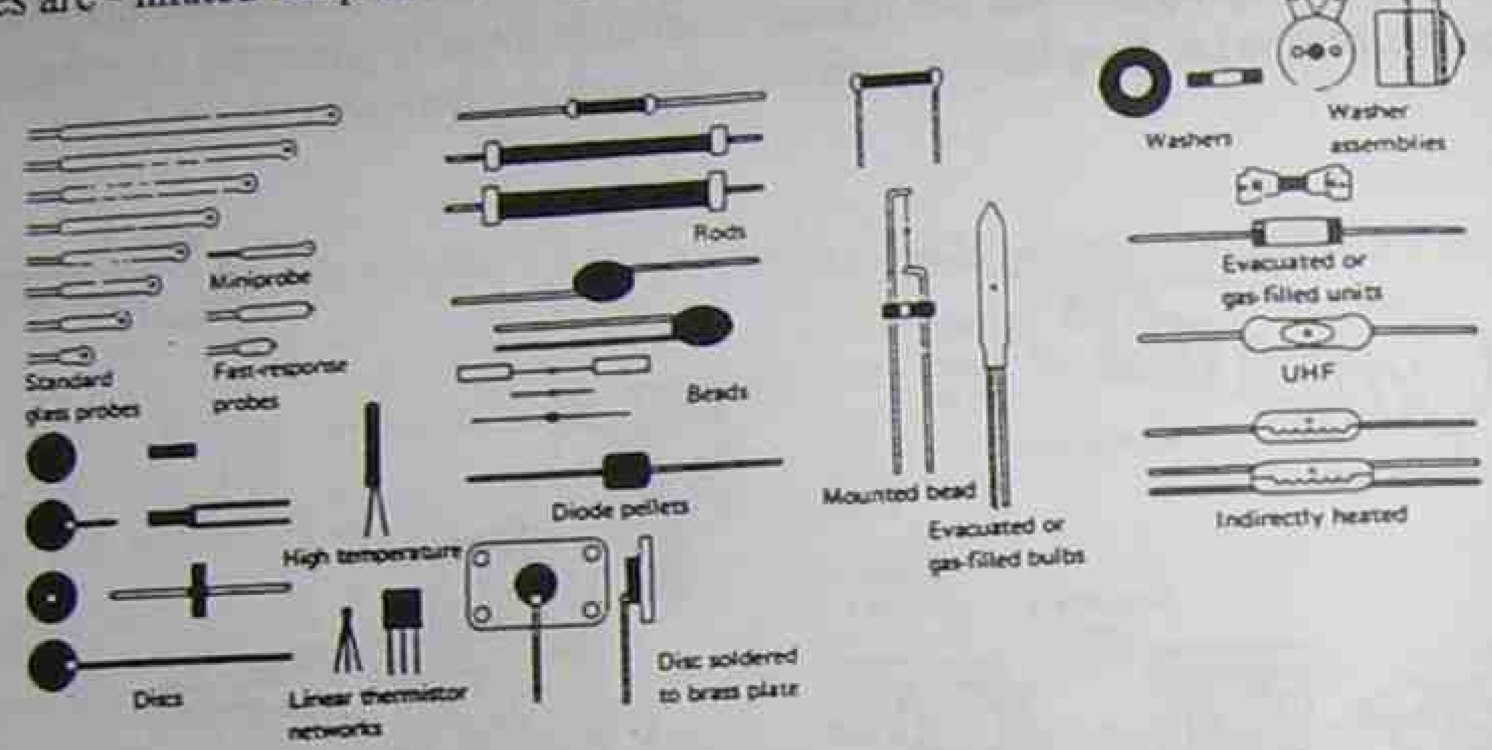


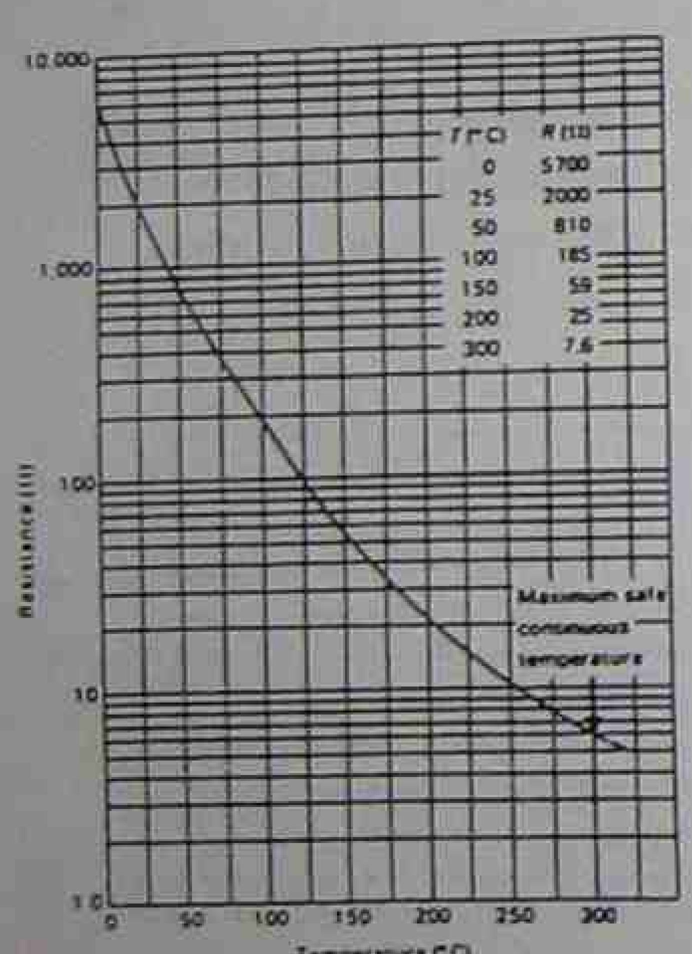
R_0 = Wire resistance at 0°C
R_t = Wire resistance at measured temperature

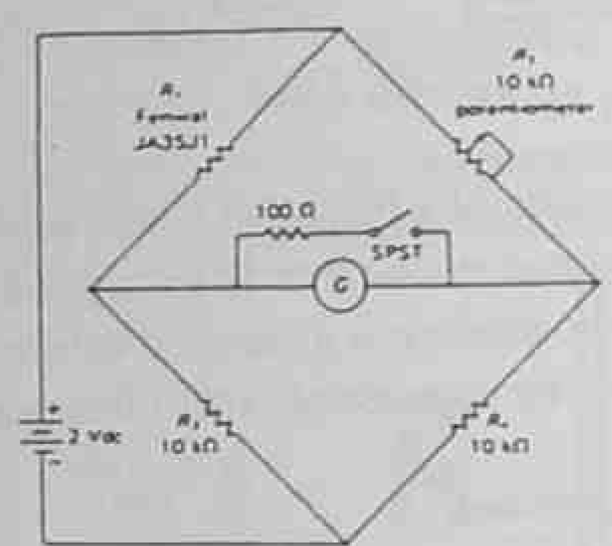
Advantages of R.T.D. are the accuracy (± 1/2%) and its reproducibility. Disadvantages are the higher cost, limited upper temperature limit and susceptibility to vibration.

- **Thermistors**

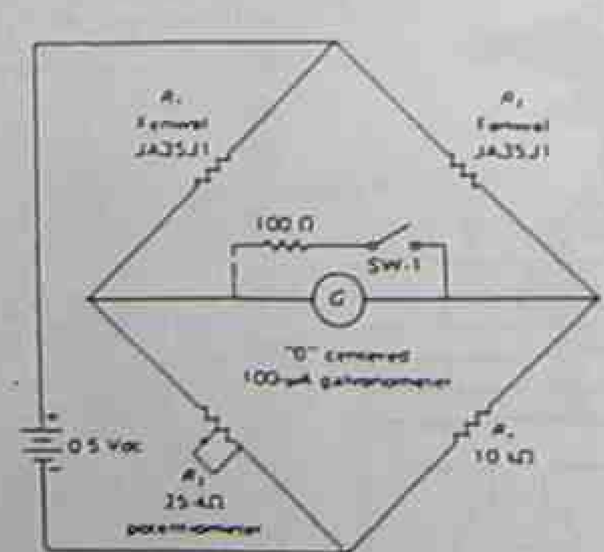
These devices are resistors which are made from metallic oxides and can either be positive temperature coefficient (PTC) or negative temperature coefficient (NTC)
The advantages of these devices are - fast response time, very sensitive, cheap, easy to use and can be very small.
The disadvantages are - limited temperature range (-100 °C to +300°C) and non-linear output characteristics.







Thermistor bridge.



Differential thermistor bridge.

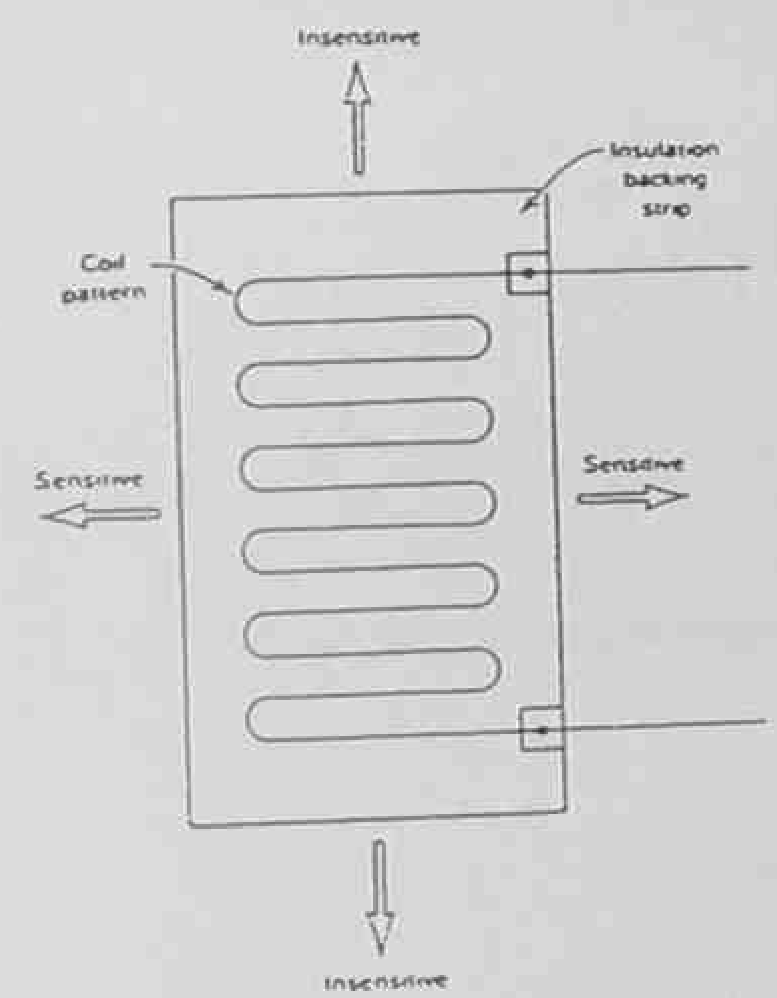
2.6 FORCE MEASUREMENT

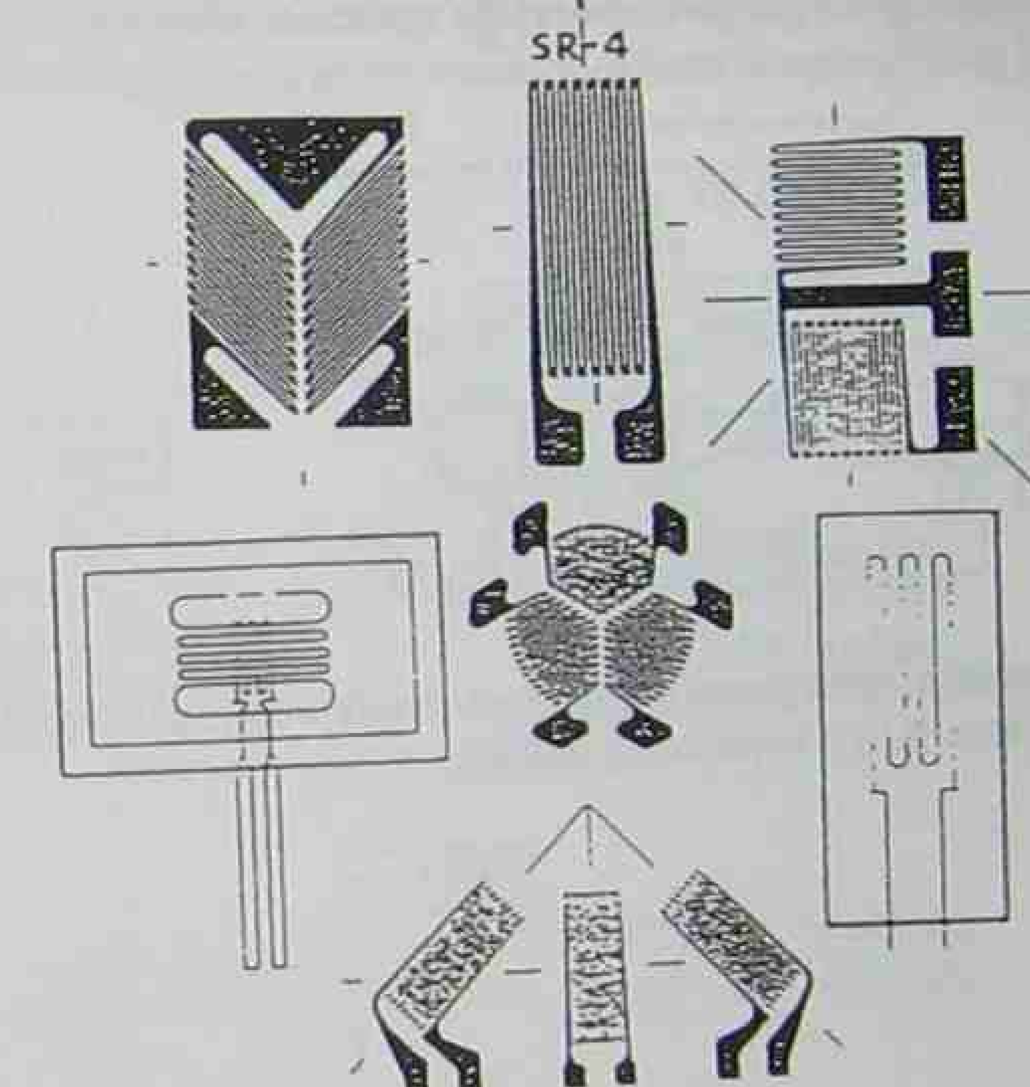
- **The Strain Gauge**

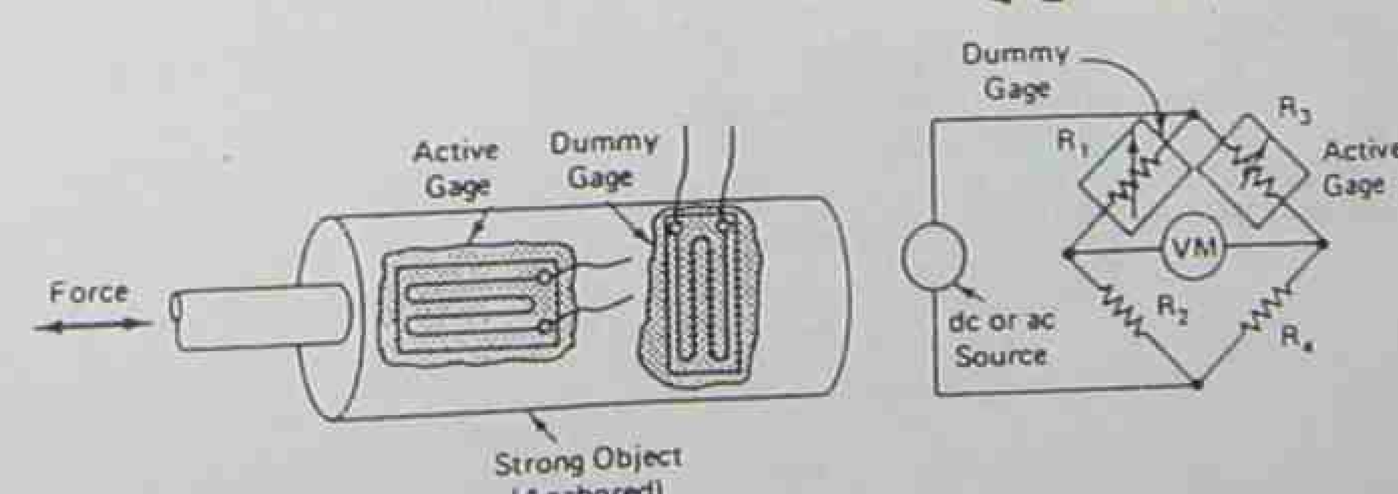
The strain, load, torque, acceleration and vibration on an object can be determined by measuring the displacement of predetermined points.

The amount of displacement is very small ie. µm, a sensor commonly used to determine the displacement is the resistance strain gauge.

The principle of operation in the strain gauge is that when a force is applied to the object that has the strain gauge attached, the gauge and the object will distort slightly. If the strain gauge is stretched its resistance will increase, if compressed its resistance will decrease.







When a gauge is attached to an object that is to be monitored the strain gauge may sense two strains, the transverse strain and/or the longitudinal strain.

To reduce the unwanted transverse strain response, foil strain gauges with wide tracks are used.

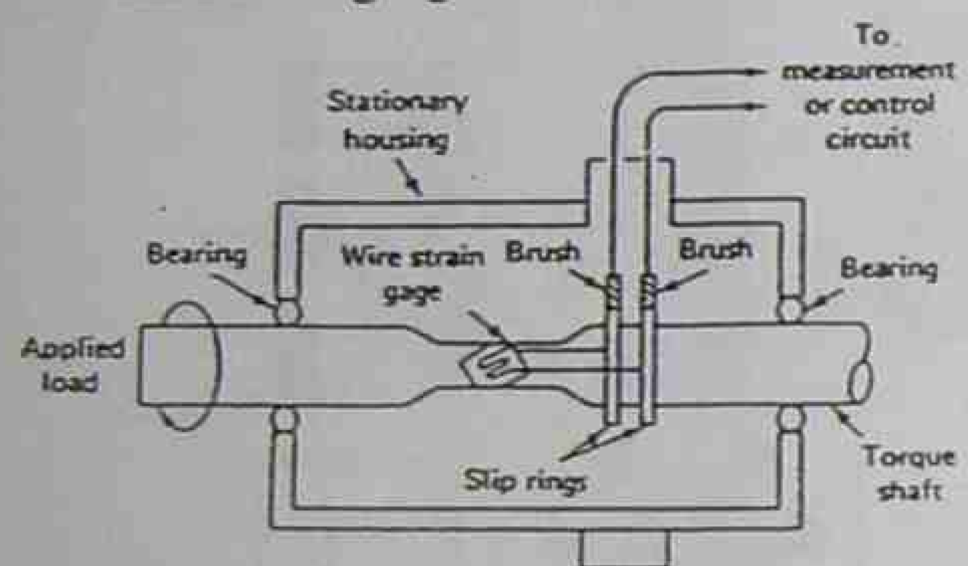
Foil gauges have the following advantages over wire gauges :-

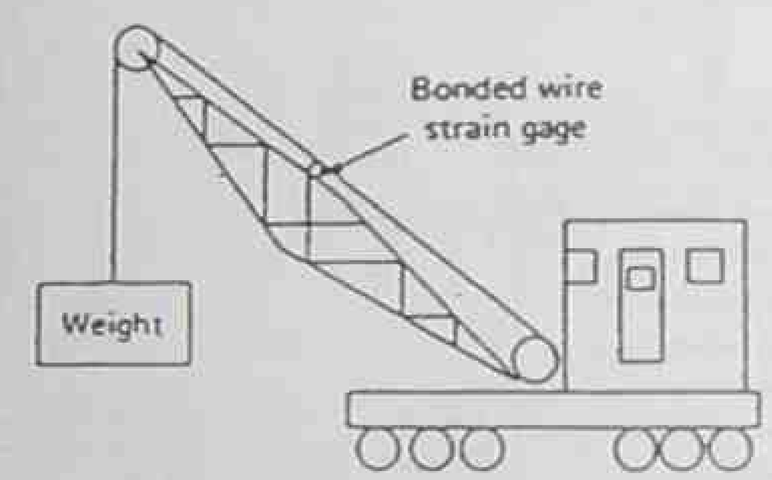
- Increased flexibility
- Higher power dissipation
- Larger area of termination

There are two basic types of strain gauges :-

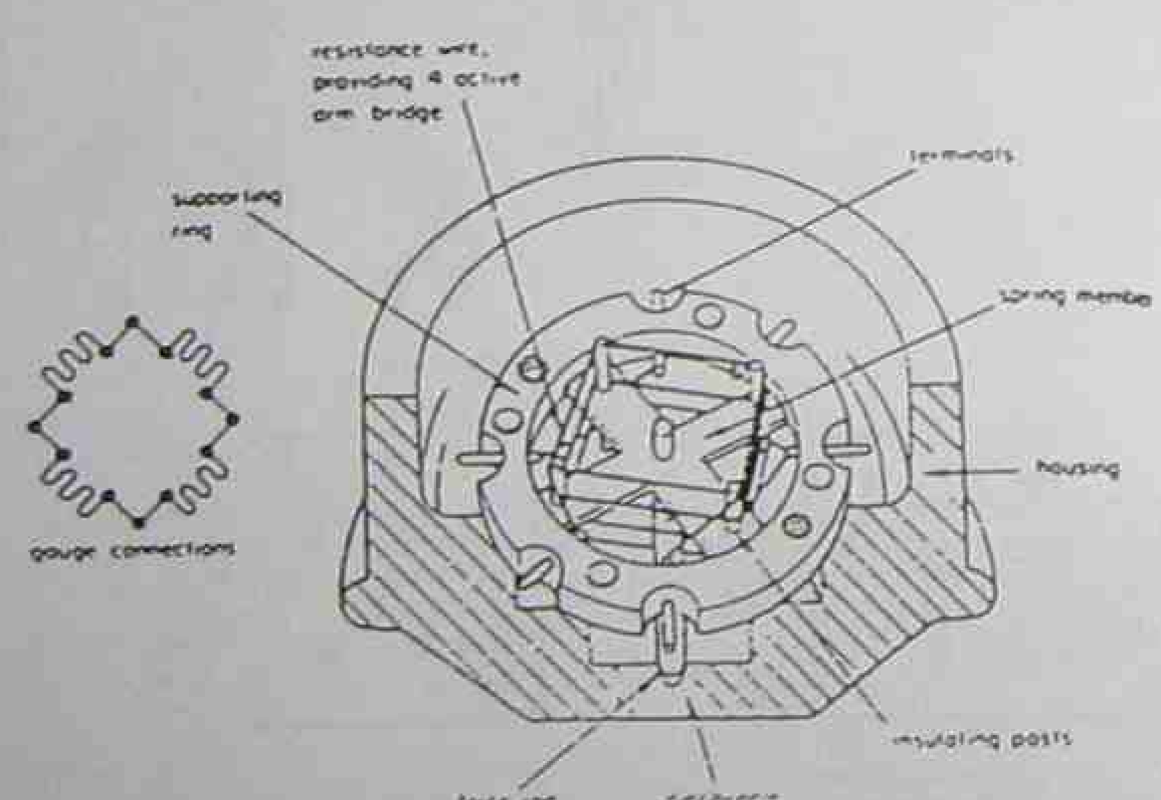
-Bonded -Unbonded

The bonded strain gauge consists of a resistance element bonded to a flexible membrane. The bonded strain gauge is used to measure strain at a specific location.





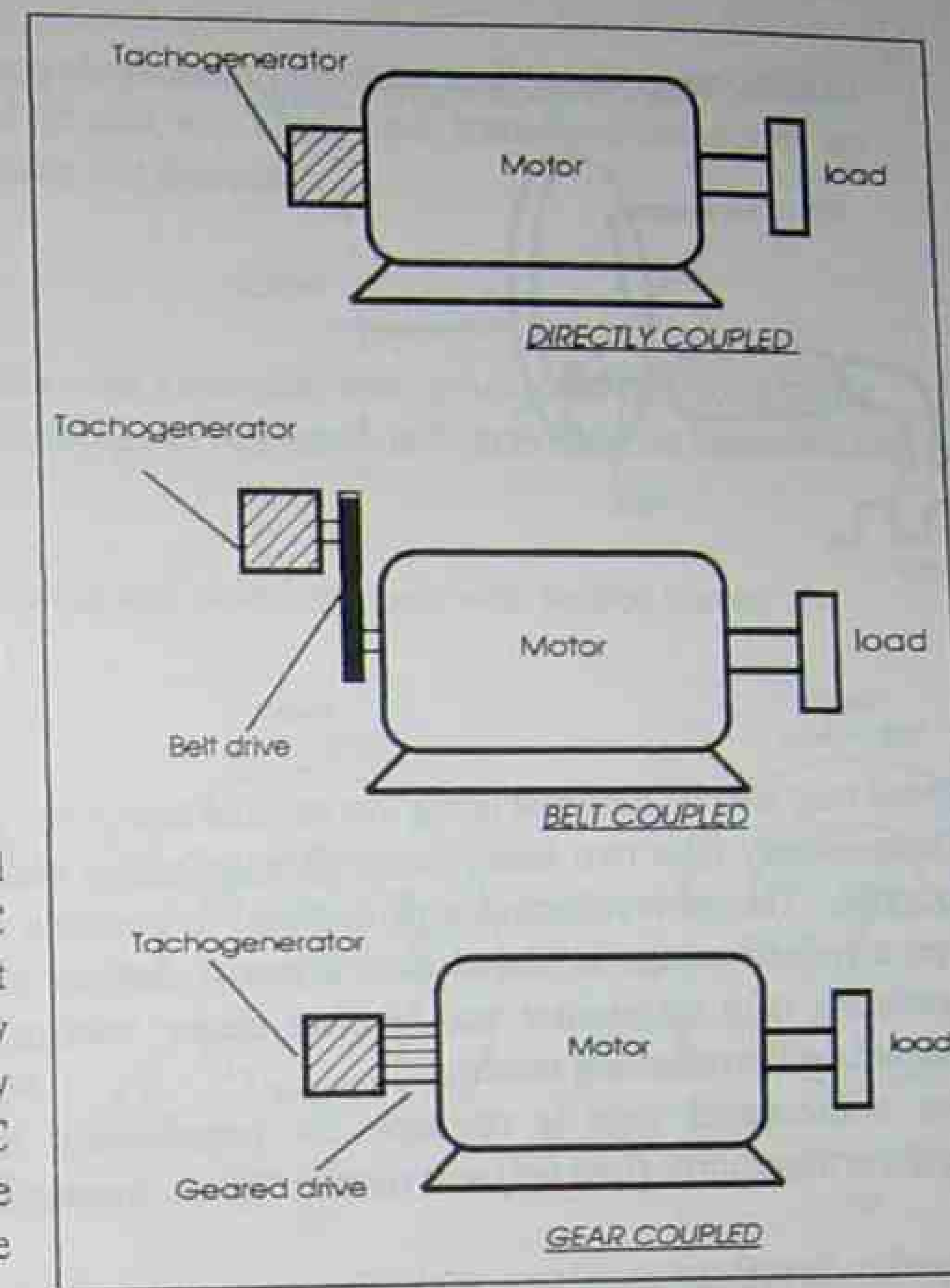
The unbonded strain gauge is used to measure very small displacements which are directly transferred to it by a mechanical linkage.



2.7 SPEED MEASUREMENT

■ Tachogenerator

Tachogenerators are usually small permanent magnet DC generators. They are coupled to the motor to be monitored with three methods shown being direct coupled belt driven or gear driven. The belt driven and gear driven provide a method of ratioing the speed to desired generator output level.



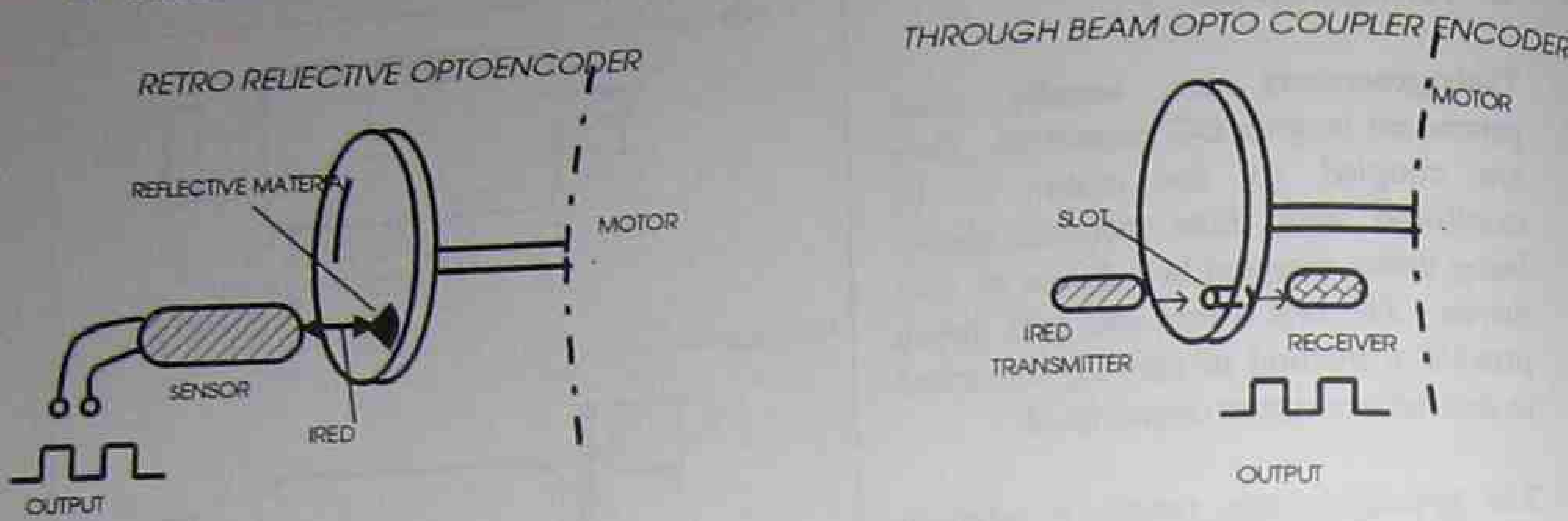
The tachogenerator output is rated in volts/rpm. eg. 1V/150 rpm. Therefore the output voltage is 10V at 1500rpm.

AC tachogenerators are available and mounted in the same way as a DC tachogenerator. The alternator output magnitude and frequency is directly proportional to motor speed. Usually the output is rectified to give a DC signal. Because of this rectification the output is unidirectional and therefore unsatisfactory to detect motor reversal.

Student Example 2.1

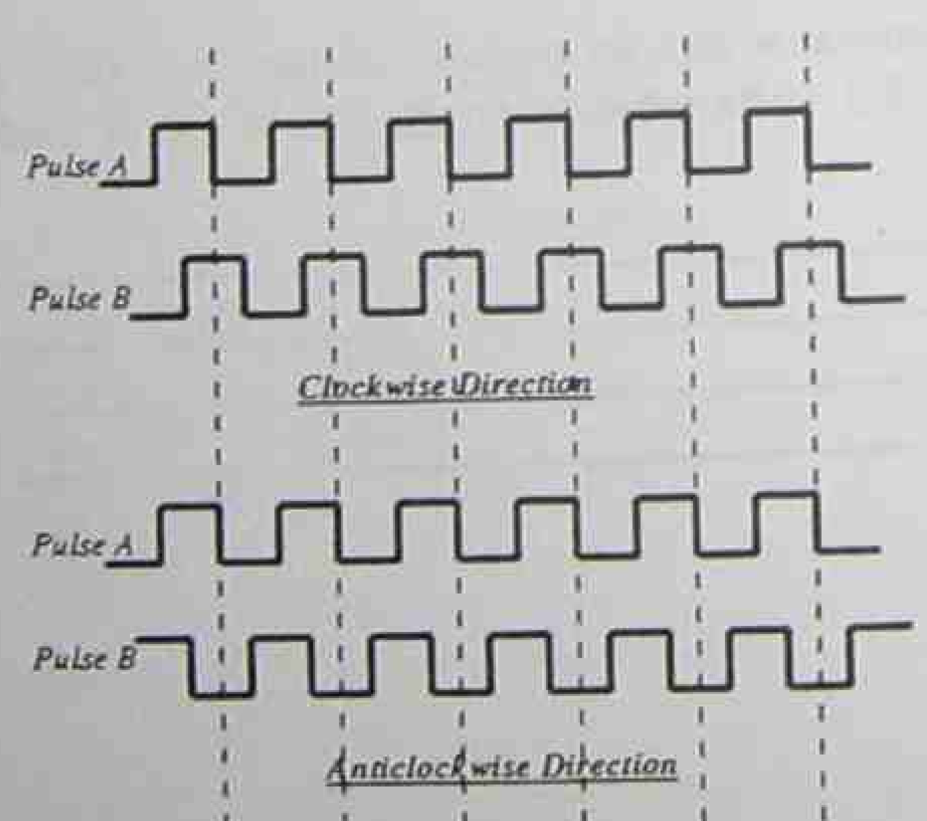
A tachogenerator has an output voltage of 2 volts per 1000 RPM. If its output voltage is 3.3 volts when connected to a motor shaft, determine the motor shaft speed.

■ **Encoders**



Speed may also be detected using incremental encoders (pulse generators). These usually take two basic forms <u>retro reflective</u> and <u>through beam optocoupler encoder.</u> The retro reflective type is suited to portable speed measurement. In this type a reflective tape is placed onto a motor shaft or coupling and the tachometer consisting of a transmitter and receiver sensor transmitting an infra red signal is focused on the reflecting material.
The optocoupled type is common for permanently mounted encoders using a separate transmitter (ired led) and receiver (phototransistor.)

Speed is directly proportional to the frequency of the output pulses and if direction is required a second photosensor may be provided that is displaced 90° electrical from the first photosensor.



Encoder Pulse Train

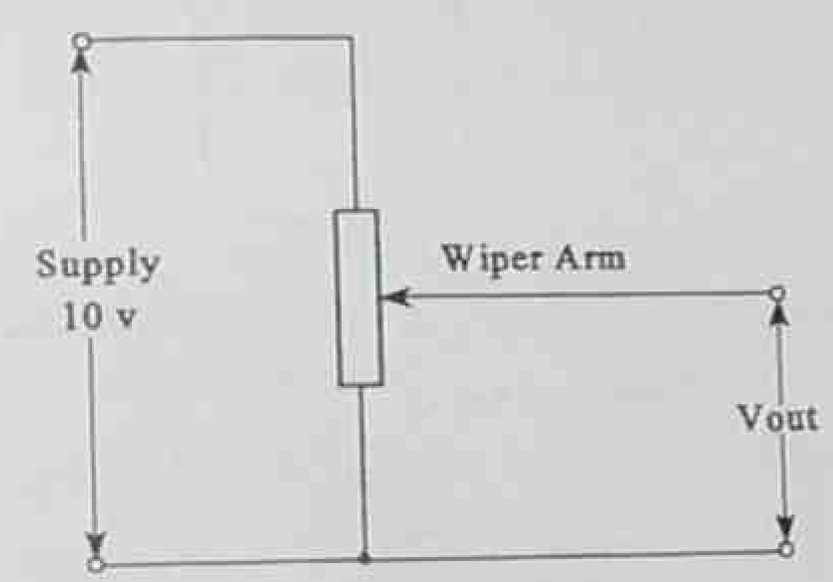
2.8 POSITIONAL MEASUREMENT

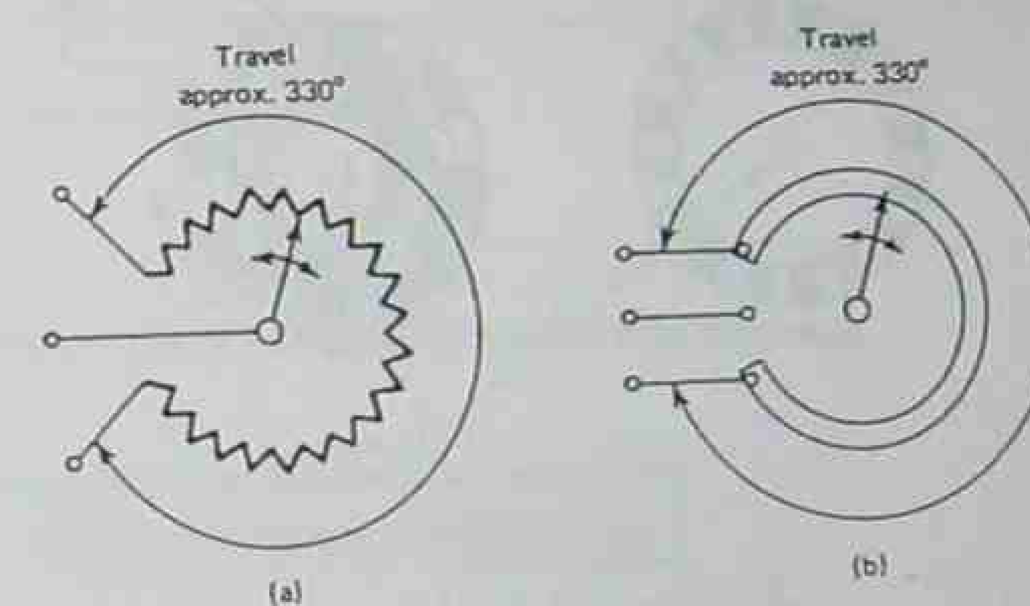
Position transducers are widely used in control systems to measure shaft position, position of objects, control valve position, levelling of lift cars, etc. Three basic transducer categories are available: Precision Potentiometers, Synchros and Encoders.

■ **Precision Potentiometers**

Typically consists of a circular resistive wire with a movable arm, or wiper in contact with its surface. This sensor converts position to a change of resistance and therefore can be converted into a output voltage signal.

Features - simple, cheap, subject to brush wear and electrical noise with limited travel.

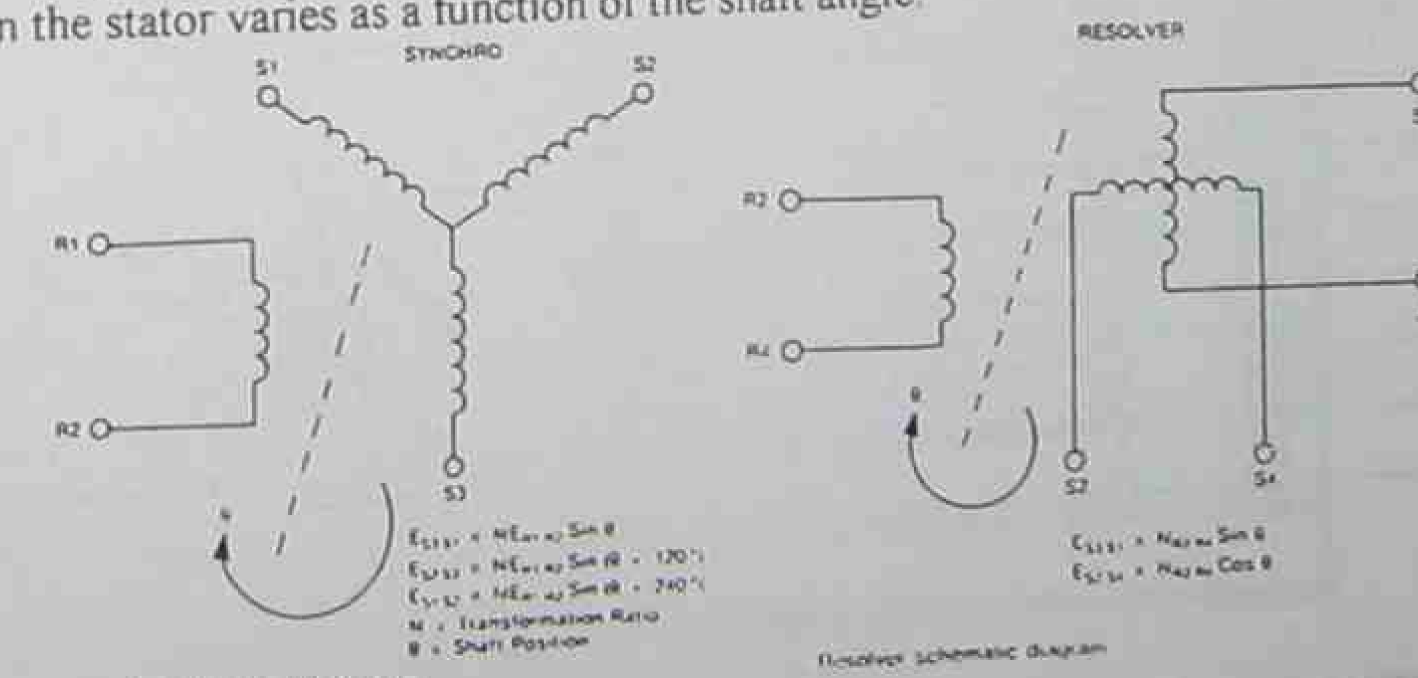




Angular motion potentiometer: (a) wire wound, (b) film type.

■ **Synchros**

A synchro (and a resolver) are a simple rotary transformer where the relationship between the primary (rotor) and the secondary (stator) is controlled by the shaft angle. Therefore the voltage induced in the stator varies as a function of the shaft angle.

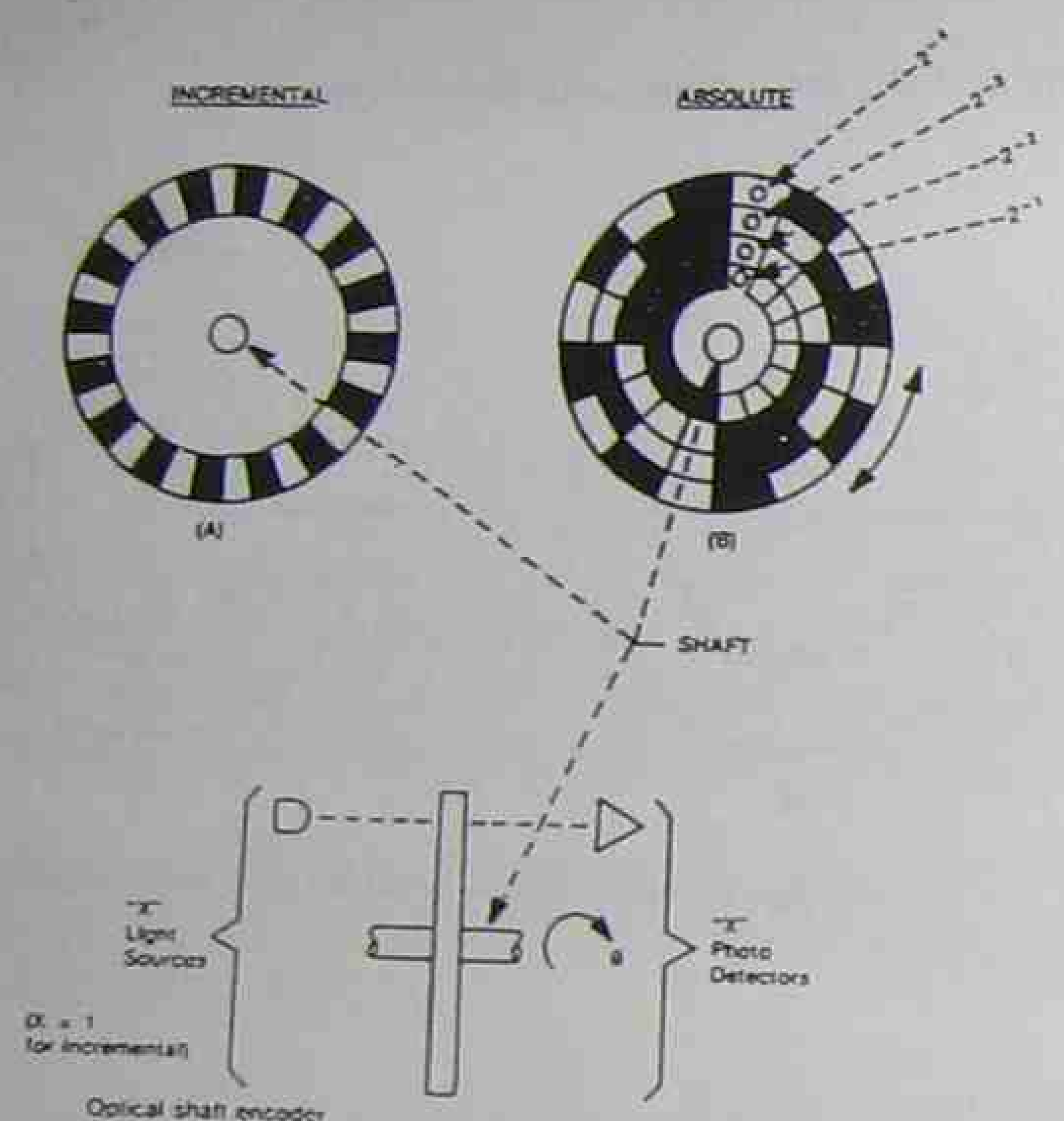


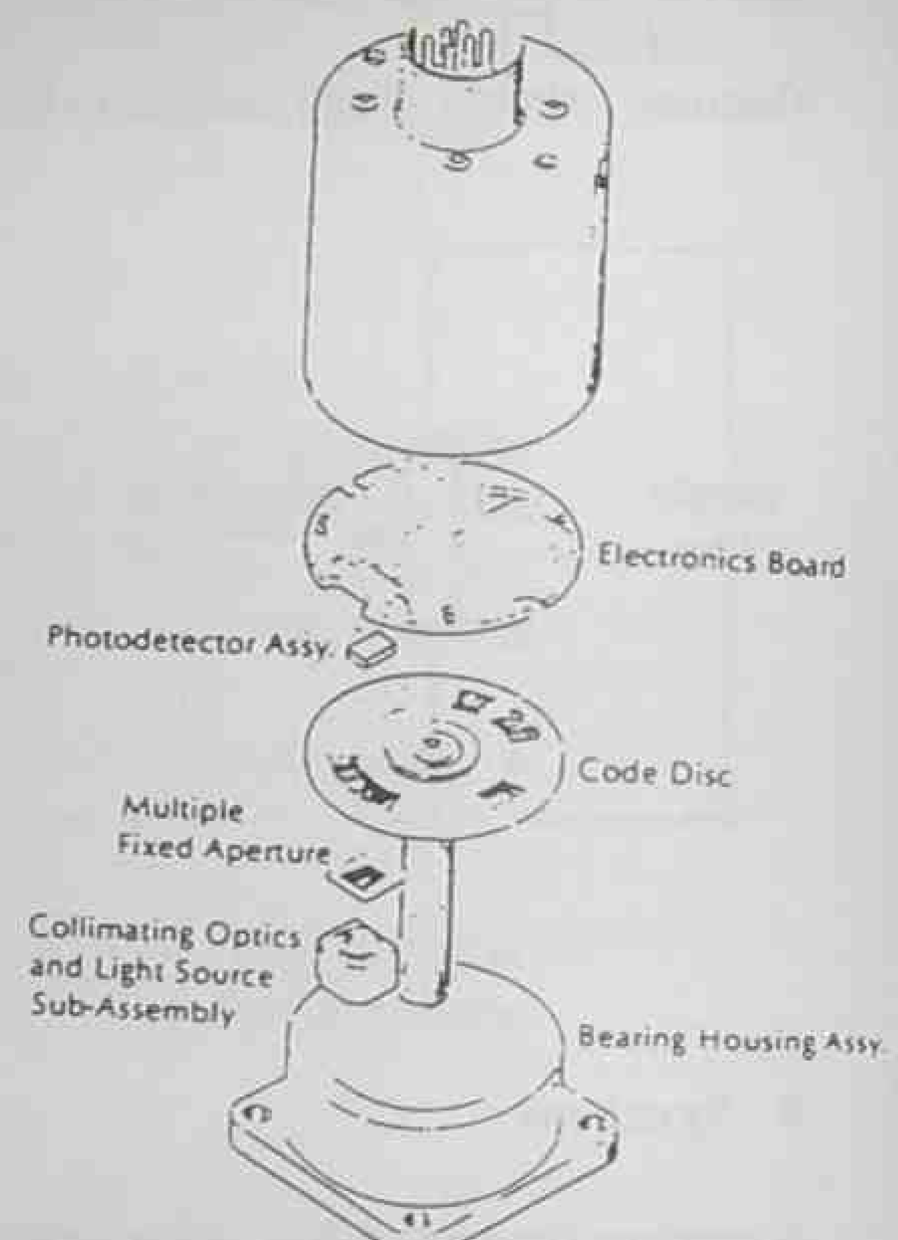
The resolver is considered a subclassification of a synchro and is based on the same principle. The difference is that the synchro has three stator winding displaced 120°E apart where the resolver has two stator winding displaced 90°E apart.

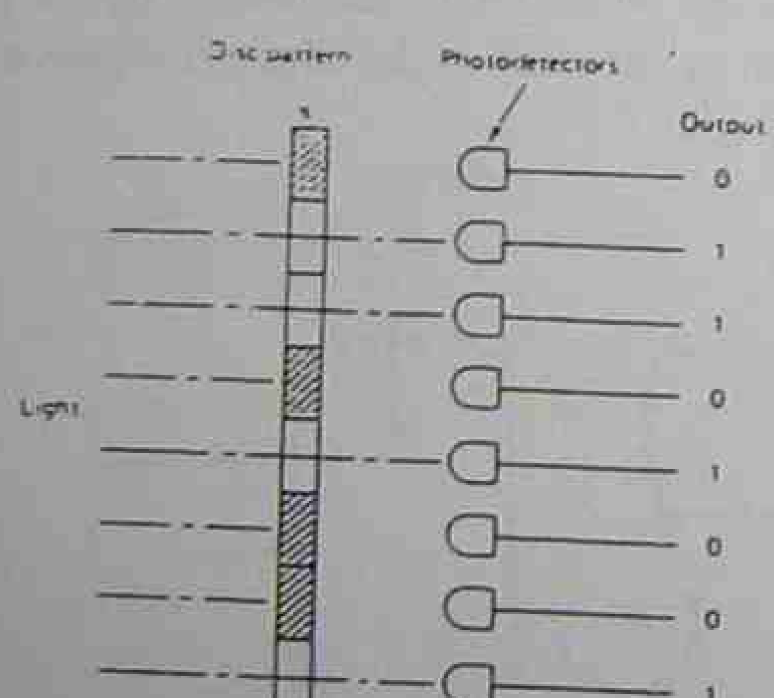
■ **Encoders**

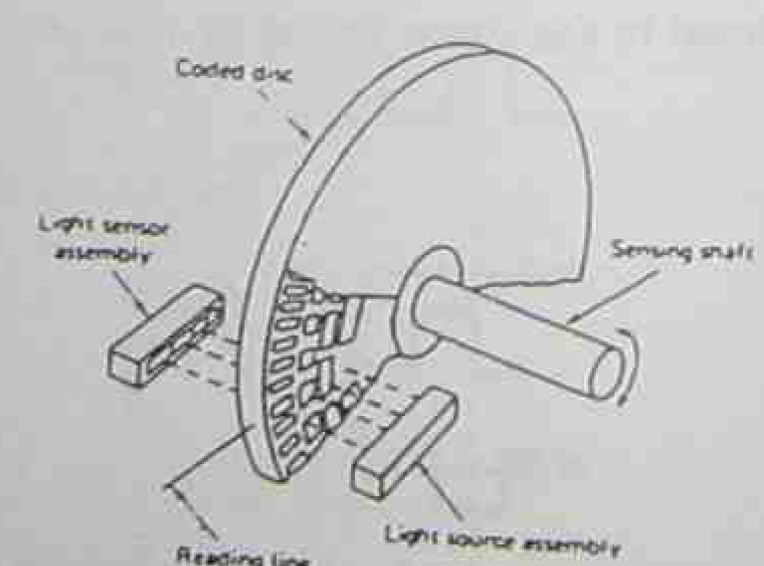
The most common type of encoder are the optical type. These are further divided into two categories - incremental and absolute.

An incremental encoder provides a digital output that indicates change in shaft position, while an absolute encoder indicates actual shaft position.









2.9 REVIEW QUESTIONS

These questions will help you revise what you have learnt in Section 2

1. Explain the role of transducers in a closed loop control system?

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2. Where would you connect the transducers to a P.L.C. system?

____

3. What is the difference between a sensor and a transducer?

____

4. Complete the table below by naming the S.I. unit of measurement associated with each phenomena.

PHENOMENA	UNITS OF MEASUREMENTS
1. Mass	
2. Length	
3. Displacement	
4. Velocity	
5. Temperature	
6. Acceleration	
7. Force	
8. Pressure	
9. Flow	
10. Speed	
11. Level	
12. Position	

5. A temperature controller is used to control the temperature of a boiler between 94° C to 100° C. What is the range and span of this controller?

6. Explain the principle of operation of the following temperature measuring devices:-
   (a) Thermocouple
   (b) RTD
   (c) Thermistor - PTC

7. Explain the operating principle of a foil bonded strain gauge.

8. What is the difference between the principle of operation of a tachogenerator and a optical encoder when used to measure the speed of a motor.

9. What is the difference between a incremental encoder and a absolute encoder?

10. Explain the operating principle of a synchro.

11. A tachogenerator has an output of 0.035v/RPM and rotates at a speed of 300 RPM. Calculate the diffence in voltage output if the motor was rotating at 250 RPM.

12. A potentiometer has a linear resistance, a rotation of 350 degrees and has rotated 154 degrees from the zero position. Calculate the voltage output if the supply voltage is 24 volts.

2.10 SKILL PRACTICE 3 : Temperature Measurement

Aims:

- Determine the linearity of RTDs, Thermistors and Thermocouples
- Calculate the sensitivity of RTDs, Thermistors and Thermocouples
- Identify the temperature co-efficient of RTDs, Thermistors and Thermocouples.
- State the output units of RTDs, Thermistors and thermocouples

Equipment:

- Temperature transducers (RTD, Thermistor and Thermocouple)
- Digital multimeter
- Heating oven
- Universal connecting block
- dc power supply - 2A
- Temperature control panel
- Connection Leads - 4mm Banana Leads

Method:

(a) Identify the various temperature transducer by observation and meter readings

(b) Connect the test circuit as shown in the Figure 1

(c) Complete the following Table of Results for the three transducers under test.

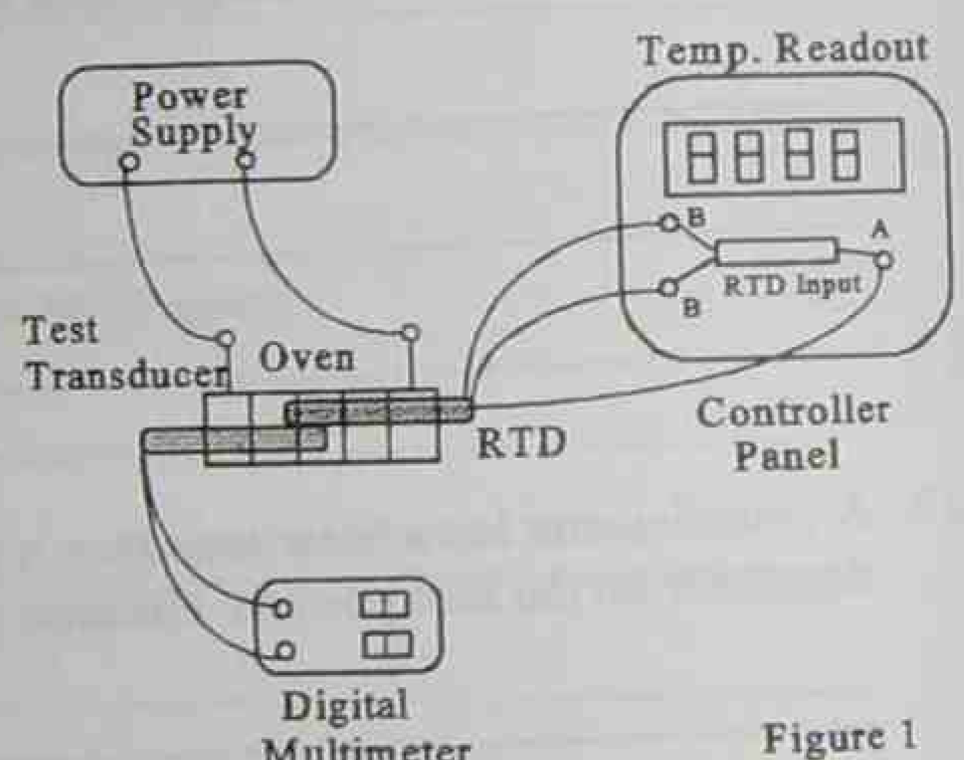


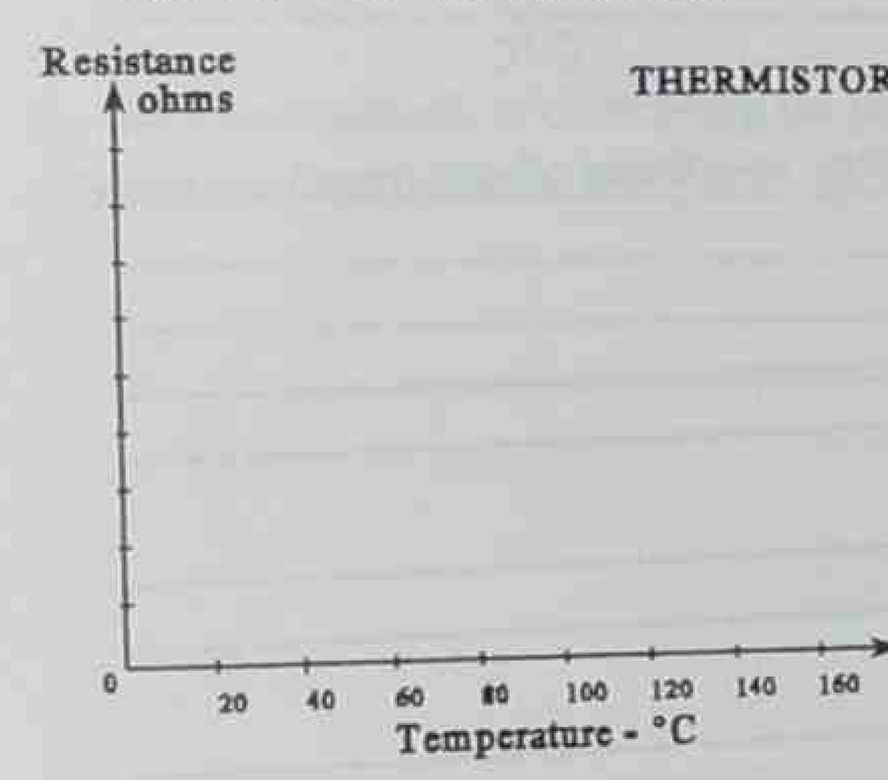
Figure 1

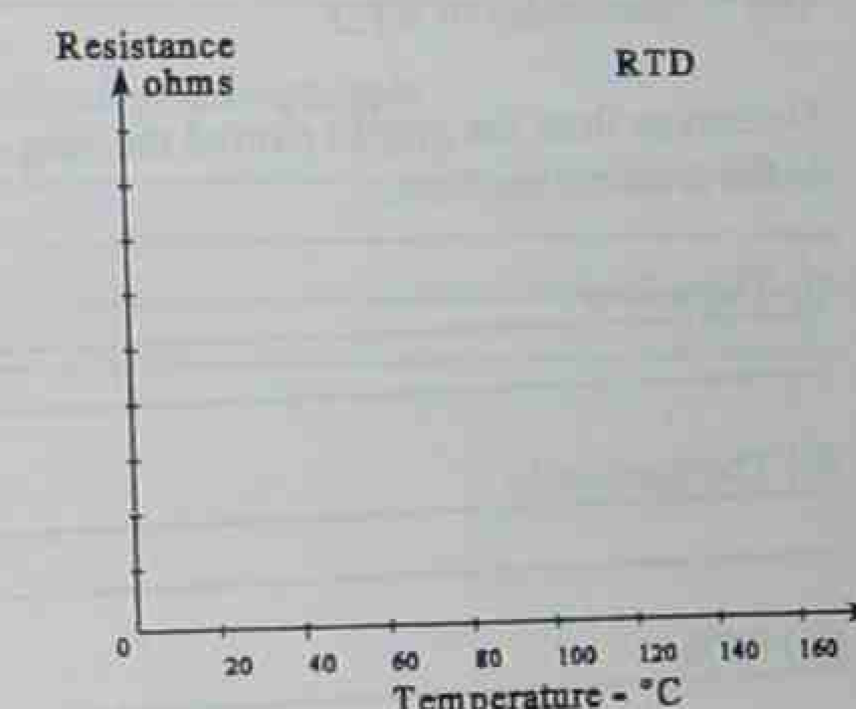
DANGER!!!
PLEASE REMEMBER THAT EQUIPMENT WILL BE VERY HOT.

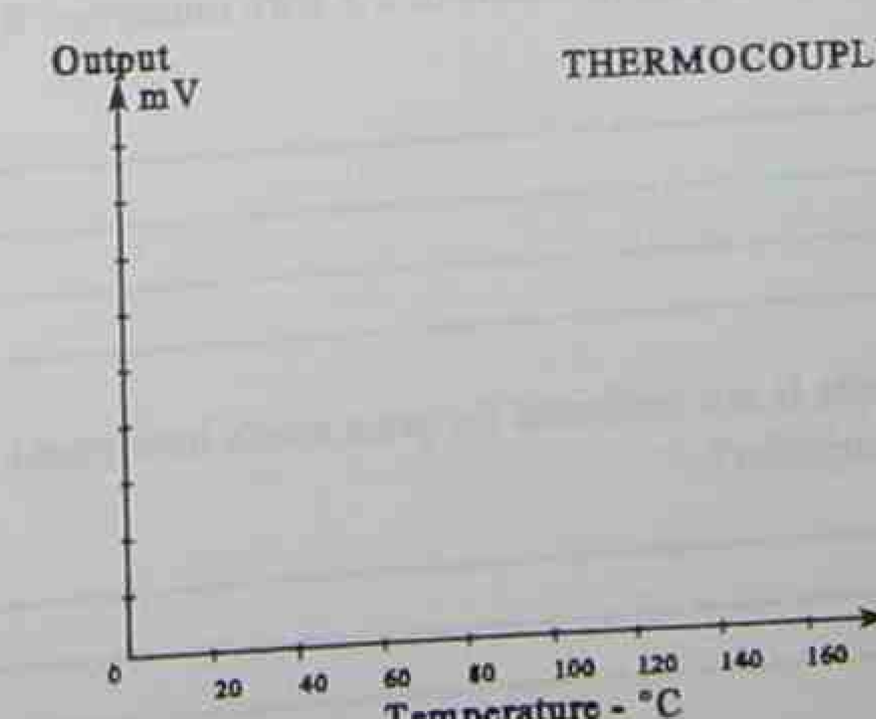
Table of Results

	Temperature °C												
Transducer Type	Rm	30	40	50	60	70	80	90	100	110	120	130	140
Thermistor (ohms)													
RTD (ohms)													
Thermocouple (mV)													

(d) Draw the transfer curves for the three test transducers on the axes provides from the results obtained in the Table of Results.







Conclusion:

1. Compare the linearity of the three transducers under test.

2. Determine the sensitivity of each of the transducers in terms of the output to the input.

   (i) Sensitivity of Thermistor .... Ω/°C
   (linear region only)

   (ii) Sensitivity of Thermocouple .... mV/°C

   (iii) Sensitivity of RTD .... Ω/°C

3. Determine from the graphs plotted the temperature co-efficient of each transducer tested in the practical exercise.

   (i) Thermistor:

   (ii) Thermocouple:

   (iii) RTD:

4. Describe a simple method of identifying the leads of a 3 wire unmarked RTD using a multimeter.

5. If the output of a thermocouple is not sufficient for your needs how could this output be increased <u>without</u> using an amplifier?

6. State the maximum temperature ranges for each of the transducer.

   (i) Thermistor:

   (ii) Thermocouple:

   (iii) RTD:

7. When applied to thermocouples explain what is meant by the terms <u>reversal and double reversal</u> and what effect would these have on any temperature readings.

   (i) reversal:

   (ii) double reversal:

8. State two methods of determining the polarity of a thermocouple.

2.11 SKILL PRACTICE 4 - FORCE MEASUREMENT

Aims:
- To determine the output characteristics of a strain gauge
- To investigate the operation and arrangement of a strain gauge in a working circuit

Equipment:

- Variable dual d.c. power supply
- Dual channel CRO
- Digital Multimeter (D.M.M.)
- Strain Gauge Panel
- Connection Leads - 4mm Banana Leads

Method:

(a) Connect the circuit up as shown in Figure 1.

(b) Switch on the supply.

(c) Adjust the trimpot on the amplifier panel to provide zero output for no load on the force beam using the DVM set to 200 mV range. Note the noise level peak to peak value of noise displayed on the CRO.

(d) Load the beam with 100g load masses and note the noise level and output in Table 1.

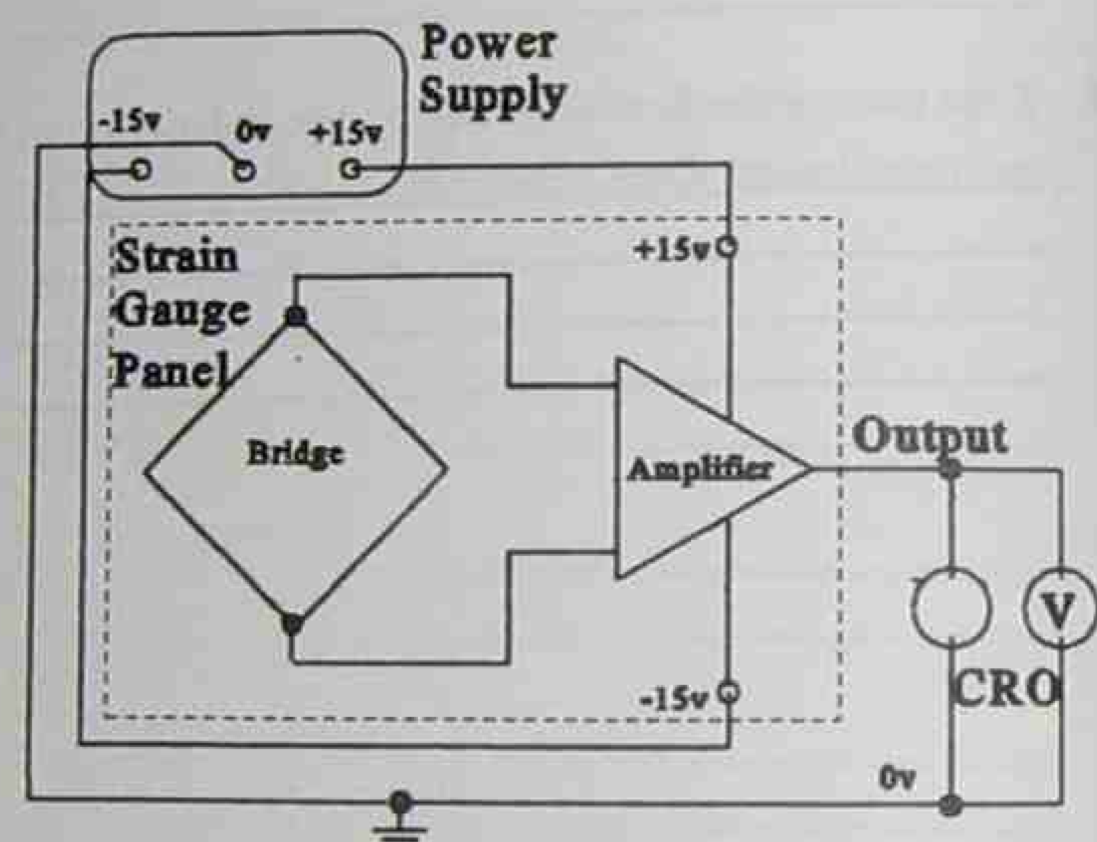


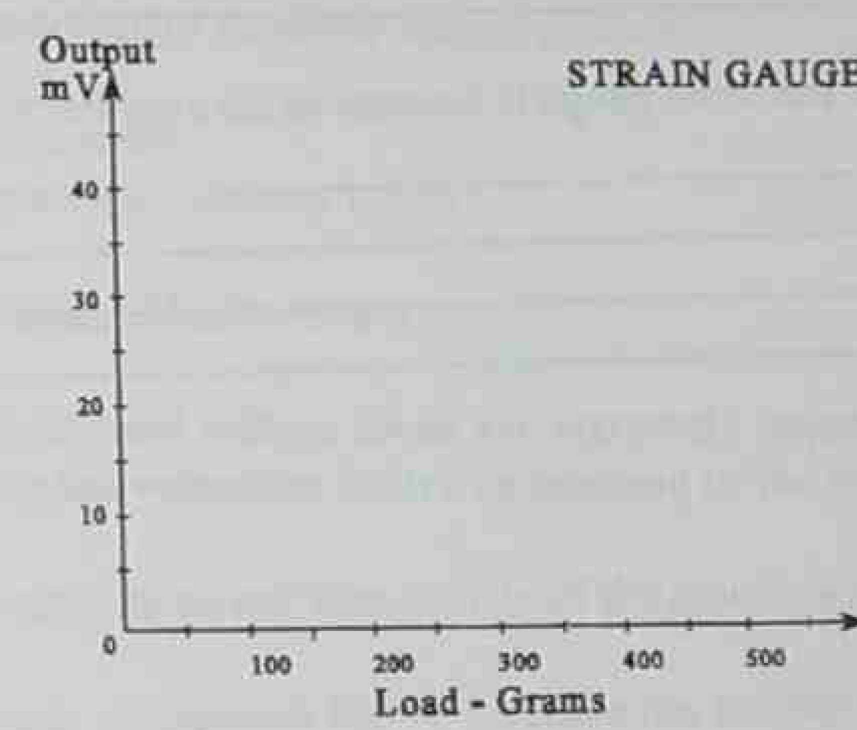
Figure 1

(e) Repeat step (d) for each load mass until a maximum load of 500g.

(f) Plot the graph of output DC voltage against load.

Table 1.

WEIGHT (grams)	NOISE (mV)	OUTPUT (mV)
0		
100		
200		
300		
400		
500		



Conclusion:

1. From the graph determine the LINEARITY of the strain gauge.

____

____

2. The output from the amplifier is in mV. What form is the output from the stain gauge itself?

____

____

3. What is the form of energy conversion in a strain gauge?

____

____

4. You will have noticed 2 gauges mounted on the force beam. One is the active gauge and the other the dummy gauge. Sketch both on the beam and identify each.

5. Describe the purpose of the dummy gauge.

____

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6. Why was it necessary for the strain gauge to connect to the amplifier via a BRIDGE?

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2.12 SKILL PRACTICE 5: SPEED AND POSITIONAL MEASUREMENT

Aims:

- To determine the relationship of position to voltage signal for a rotary position potentiometer.
- To compare the voltage to speed relationship of a tachogenerator used to monitor motor speed.

Equipment:

- Dual dc power supply
- Variable power supply
- Motor control unit (MS15 dc motor control module)
- Digital multimeter
- Command potentiometer
- Connection Leads - 4mm Banana Leads

Method: 1. Positional Measurement

Special Note: Polarity and voltage levels are extremely important and should be set and verified with the digital voltmeter before connecting to the supply.

(a) Set all power supply levels and then switch off the power supplies.

(b) Connect the circuit as shown in Figure 1. **(Have the teacher check the circuit)**

(c) Leave the command potentiometer output disconnected and connect the multimeter to the potentiometer output.. ***Switch on the supply now.***

(d) Make sure that the position potentiometer is connected to the drive shaft. Rotate the motor drive shaft until the potentiometer output reads zero.

(e) Check that this position corresponds to the pointer on the yellow position indicator. ***If it does not call the teacher***

(f) Complete the potentiometer Table 1. ***Switch off the supply***

(g) Disconnect the position potentiometer electrically and mechanically.

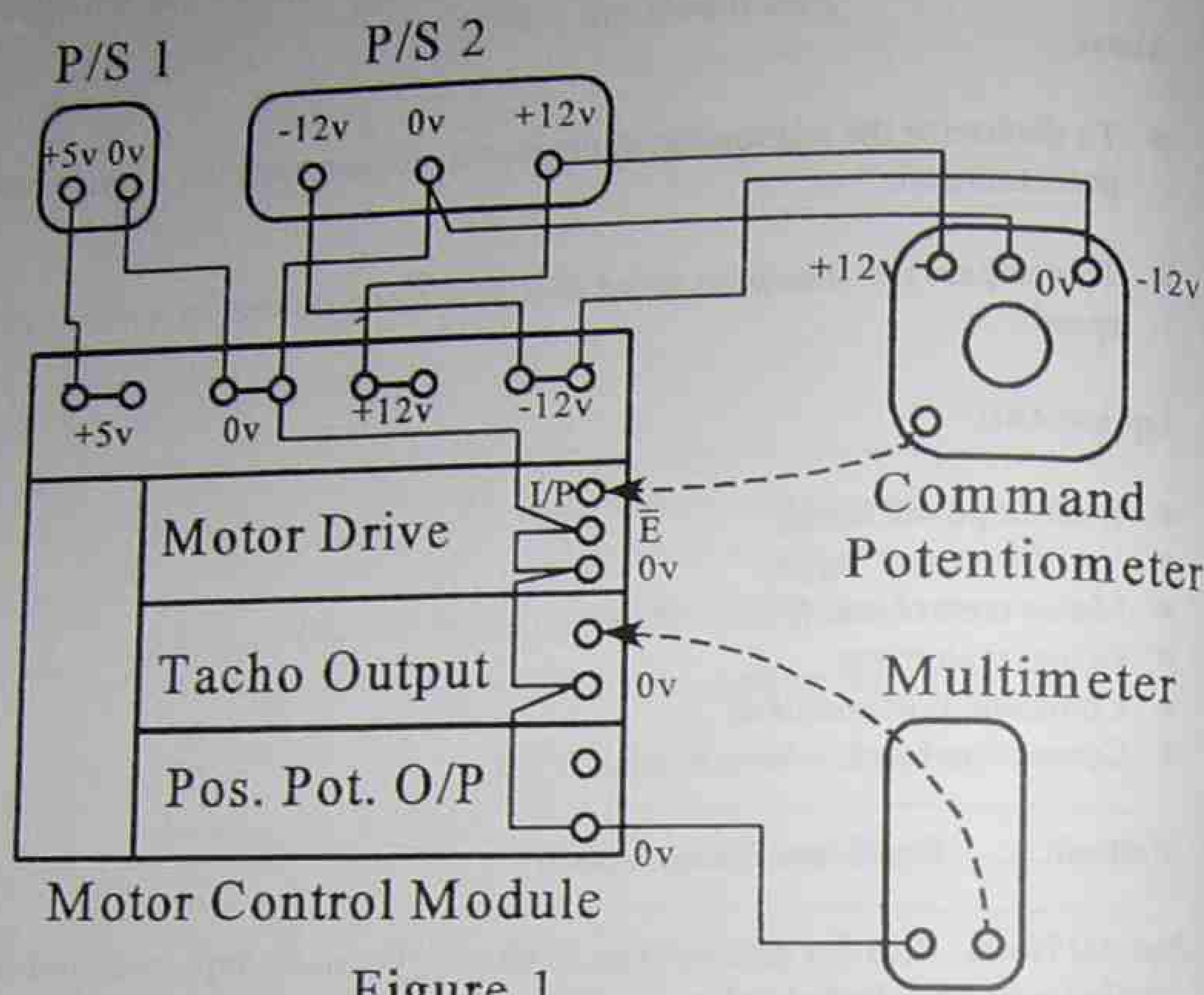


Figure 1

2. **Speed Measurement**

(a) Connect the multimeter to the tacho output.

(b) Connect the command controller to the motor drive input.

(c) *Switch on the supply* and adjust the command potentiometer to give 0 RPM

(d) Complete Table 2.

(e) *Switch off supply* and return equipment to its appropriate places.

(f) After completing Tables 1 and 2 neatly plot the corresponding Graphs 1 and 2.

Table 1 - Position Potentiometer

DEGREES	CLOCKWISE VOLTAGE	ANTI-CLOCK VOLTAGE
0		
30		
60		
90		
120		
150		
180		

Note polarity of voltage

Graph 1 - Positional Control - Voltage vs Position

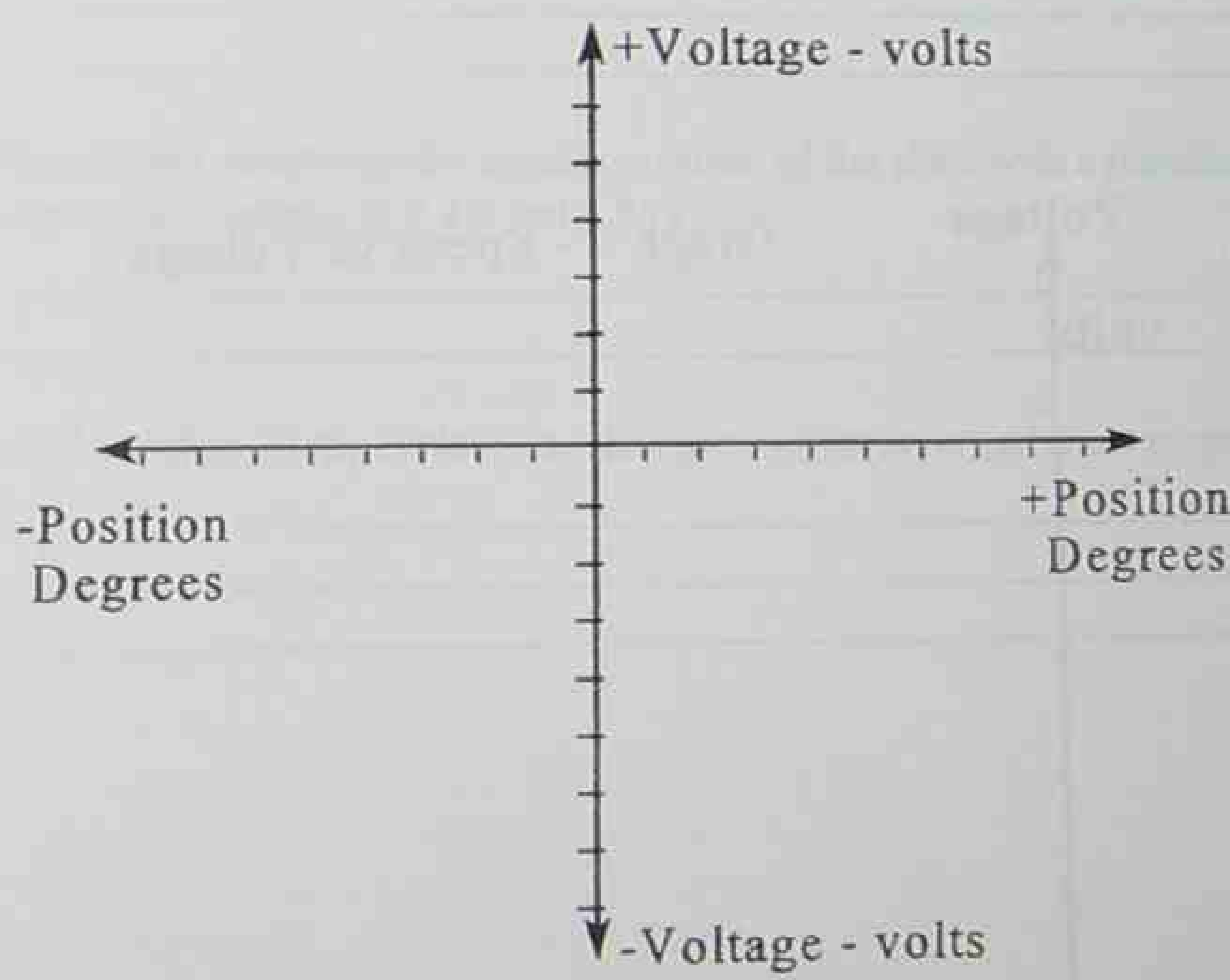
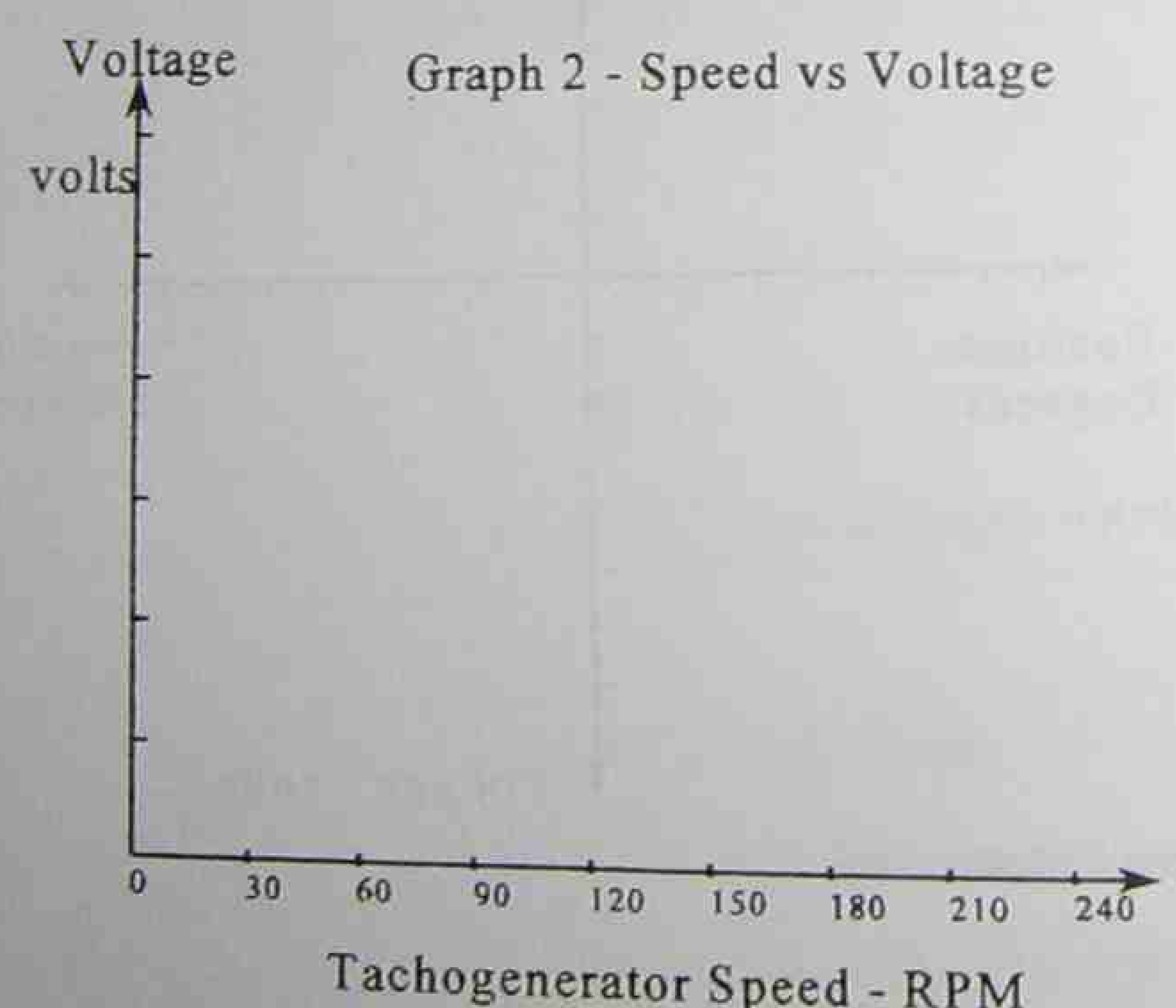


Table 2 - Tachogenerator

SPEED RPM	TACHO OUTPUT VOLTS
0	
30	
60	
90	
120	
150	
180	
210	
240	

Graph 2 - Speed vs Voltage



Conclusion:

1. From the results plotted in Graphs 1 and 2 what can be said about the LINEARITY of the two transducers.

____

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____

____

2. Give an example of an application for both transducers.

____

____

____

HINT: for the next two questions find volt/rpm and volts/degree

3. Using Table 2 results, estimated the output voltage from the tachogenerator at 750rpm and 45 rpm

____

____

4. Using Table 1 results, determine the angular position of the shaft with a position potentiometer output voltage of 2.4V and 1.86V

____

____

5. With the aid of a sketch briefly explain how an optocoupler style tachometer operates.

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Section 3

FINAL CONTROL ELEMENTS

PURPOSE

The purpose of this section is to provide the student with an understanding of commonly used final control elements used in control systems. It covers learning outcome 3 of the National Module Descriptor.

TO ACHIEVE THE PURPOSE OF THIS SECTION :

This section represents around 10% of the module, and should take approximately 4 hours.

At the end of this section the student will be able to:

- Explain the operation of the three main types of electro-mechanical devices used in control systems
  - Solenoids
  - Relays
  - Contactors
- List and explain the protection methods used with electro-mechanical devices
  - Contact protection
  - Interface circuit protection
  - Contact bounce protection
- List the four main types of valves
  - Electrical solenoid
  - Motor driven
  - Pneumatic
  - Hydraulic
- Explain the operation of the above four types of valves.
- List the two main types of solid state switches
  - Bipolar Junction transistor (B.J.T.)
  - Thyristors (S.C.R.s and TRIACS)
- Explain the operation of the above two types of switches.
- Connect and operate various solid state switching devices.

ASSESSMENT

Assessment for this section will be by way of practical and written tests to be held at the completion of the module.