LJ Technical Systems

An Introduction To Transducers And Instrumentation

Curriculum Manual IT02

Volume 1

DIGIAC

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IT02 Curriculum Manual
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Introduction to the IT02 Curriculum

This comprehensive course of study is based on a single - panel transducer and instrumentation trainer, the DIGIAC 1750.

The D1750 unit is a comprehensive Transducer and Instrumentation Trainer with examples of a full range of input and output transducers, signal conditioning circuits and display devices.

The unit is self contained and enables the characteristics of individual devices to be studied and also their interconnection to form complete closed loop systems. The only additional items recommended are:-

(1) An electronic voltmeter, 20V range, and preferably with a digital readout.
This is required to enable accurate voltage readings to be obtained with some of the circuits. The moving coil instrument provided has a relatively low impedance and the loading effect on some of the circuits, when connected, results in inaccurate voltage readings being obtained.

(2) An oscilloscope.
This is not absolutely necessary, but for the exercise with the LVDT (Linear Variable Differential Transformer) an oscilloscope can be used to study the output voltage polarity reversal as the core is moved through the neutral position.

This manual is divided into sections as follows:-

Volume 1

Volume 2

The manual is divided into two volumes, with each volume containing a number of sections. In each section, a description of the basic principles of the devices is given, together with practical exercises to illustrate the characteristics.

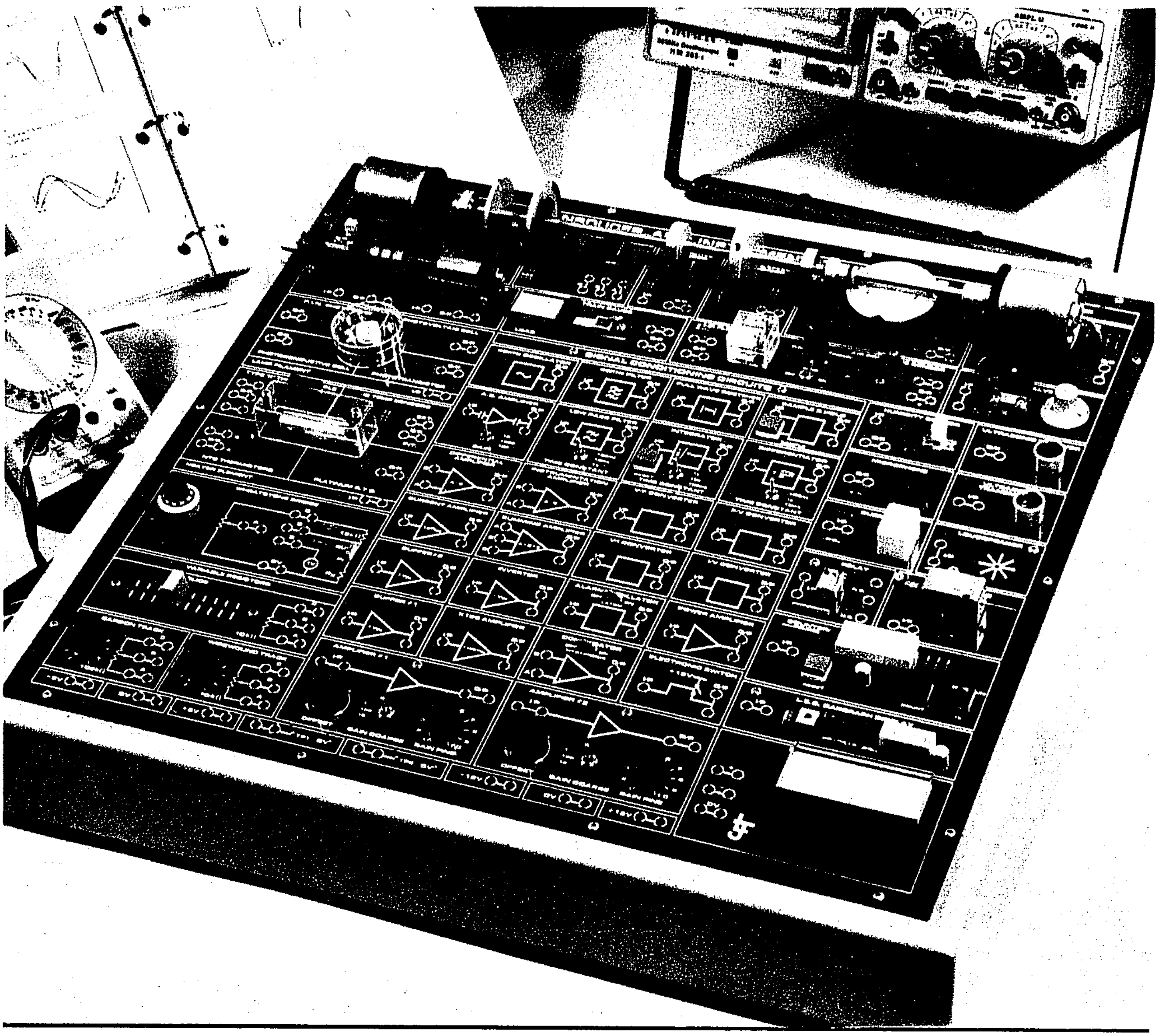
Little previous knowledge is assumed and it is hoped that with this manual and the DIGIAC 1750 unit, a student can proceed with the minimum of assistance and obtain an understanding of devices and control system operation.

The manual does not aim to cover the subject of devices and control systems in a mathematical manner but aims to give the student an understanding of the basic characteristics of devices, their connection to form a complete practical control system and to illustrate the various problems that can be encountered.

Hopefully a student will, with the knowledge gained, be able to select suitable components to form any required closed loop control system.

This manual is written in sections, but it is not imperative that the student follows the text in sequence, and indeed, it may be preferable not to operate in this way. When carrying out the various exercises to illustrate the device characteristics, it will be necessary to use the display devices and also possibly some signal processing equipment.

It may help therefore to turn to the relevant section on the display or signal processing circuits to study the characteristics of these before continuing with the exercise on the particular device. The mode of working will of course depend on the individual student and his previous knowledge.



This curriculum is based on the LJ Technical Systems DIGIAC 1750 Transducer And Instrumentation Trainer. The unit is shown here with a DM1 Digital Multimeter and an HM203 Dual Trace 20mHz Oscilloscope.

Section 1

Basic Control Systems Equipment And Terms Used

Chapter 1.1 Basic Control Systems Equipment And Terms Used

Objectives of this Chapter

Having studied this Chapter you should:-

- *Know the difference between open loop and closed loop systems.*
- *Know the expression for the overall gain of a negative feedback closed loop system.*
- *Know the basic components of a closed loop system.*
- *Know the meaning of the terms associated with control system equipment.*

Open loop system.

Fig 1 represents a block diagram of an open loop system. A reference input, or command signal, is fed to an actuator which operates on the controlled variable to produce an output.

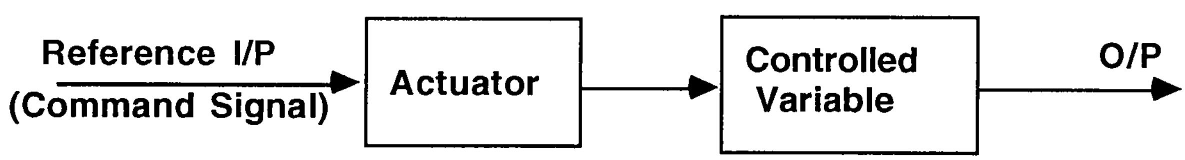


Figure 1

The output magnitude depends on the magnitude of the reference input signal but the actual output magnitude for a particular input may not remain constant but may vary due to changes within or exterior to the system.

For example, in a simple room heating application, a heater set for a certain output will result in a certain room temperature. The actual temperature will depend on the ambient temperature outside the room and also whether the doors and windows are open or closed.

Closed loop system.

Fig 2 shows a basic block diagram of a closed loop control system.

With this system, the output magnitude is sensed, fed back and compared with the desired value as represented by the reference input. Any error signal is fed to the actuator to vary the controlled variable to reduce this error.

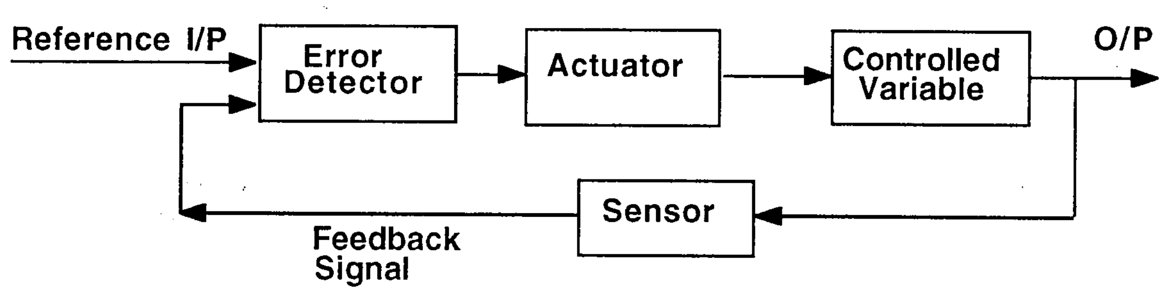
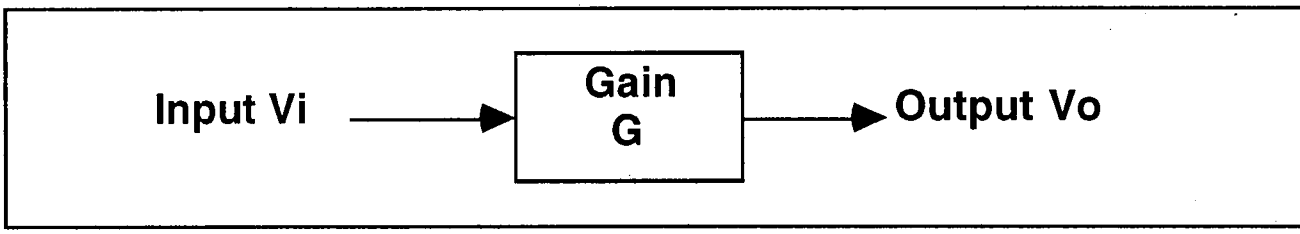


Figure 2

The system thus tends to maintain a constant output magnitude for a fixed magnitude input reference signal. The feedback signal is effectively subtracted from the reference signal input to obtain the error signal and hence the system is referred to as a negative feedback system.

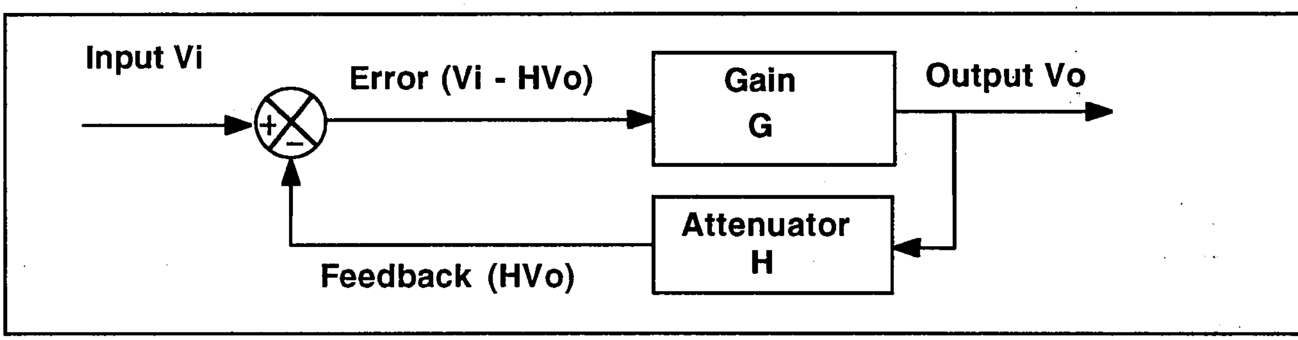
The magnitude of the reference signal required for a particular output magnitude for a closed loop system will be greater than that required for open loop operation because the negative feedback reduces the overall gain of the system.

Open loop system.



Output Vo = G Vi   Gain = G

Closed loop system.



H = The fraction of the output fed back to the input

The error signal $= V_i - HV_o$

The output $V_o = G(V_i - HV_o)$

$= GV_i - GHV_o$

$V_o + GHV_o = GV_i$

$V_o(1 + GH) = GV_i$

$$\frac{V_o}{V_i} = \frac{G}{1+GH}$$

i.e. $$\text{Gain} = \frac{G}{1+GH}$$

The gain is therefore reduced,and, if the gain G is very large, the gain is approximately given by :-

$$\textbf{Gain} = \frac{G}{GH} = \frac{1}{H}$$

The gain is then dependent only on the feedback fraction H.

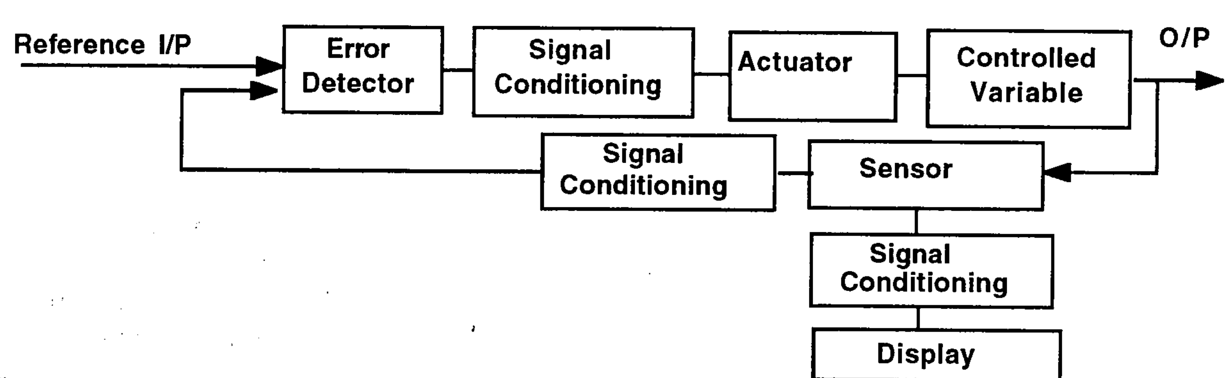


Figure 3

Fig 3. shows a block diagram of a practical closed loop control system. This shows signal conditioning blocks in the signal paths between the error detector and actuator and between the sensor and the error detector. It also shows a display which indicates the magnitude of the output variable and includes a signal conditioning block in the display path.

Signal conditioning may consist of signal amplification, attenuation or linearising, waveform filtering or modification, conversion from analogue to digital form or may be a matching circuit, these being necessary to convert the output from one circuit into a form suitable for the input to the following circuit or to improve the system accuracy.

For a particular industrial process there may be more than one controlled variable and each of the controlled variables will have its own closed loop control system.

The controlled variable may be:-

- **Position (Angular or linear)**
- **Temperature**
- **Pressure**
- **Flow rate**
- **Humidity**
- **Speed**
- **Acceleration**
- **Light level**
- **Sound level**

The control system may operate using pneumatic, hydraulic or electric principles and the sensors used for the measurement of the controlled variable must provide an output signal in a form suitable for the system in use.

This will normally involve a conversion from one energy system to another and devices used to accomplish this energy conversion are referred to as **TRANSDUCERS.** Sensors and actuators are both forms of transducer, sensors representing input transducers and actuators representing output transducers.

The DIGIAC 1750 unit is an electrical system and includes a full range of sensors, actuators, signal conditioning circuits and display devices. Used with this manual, the unit will introduce the student to the basic principles and characteristics of a comprehensive range of transducers and their application to practical closed loop control systems.

A layout diagram of the DIGIAC 1750 unit is shown overleaf in Fig 4.

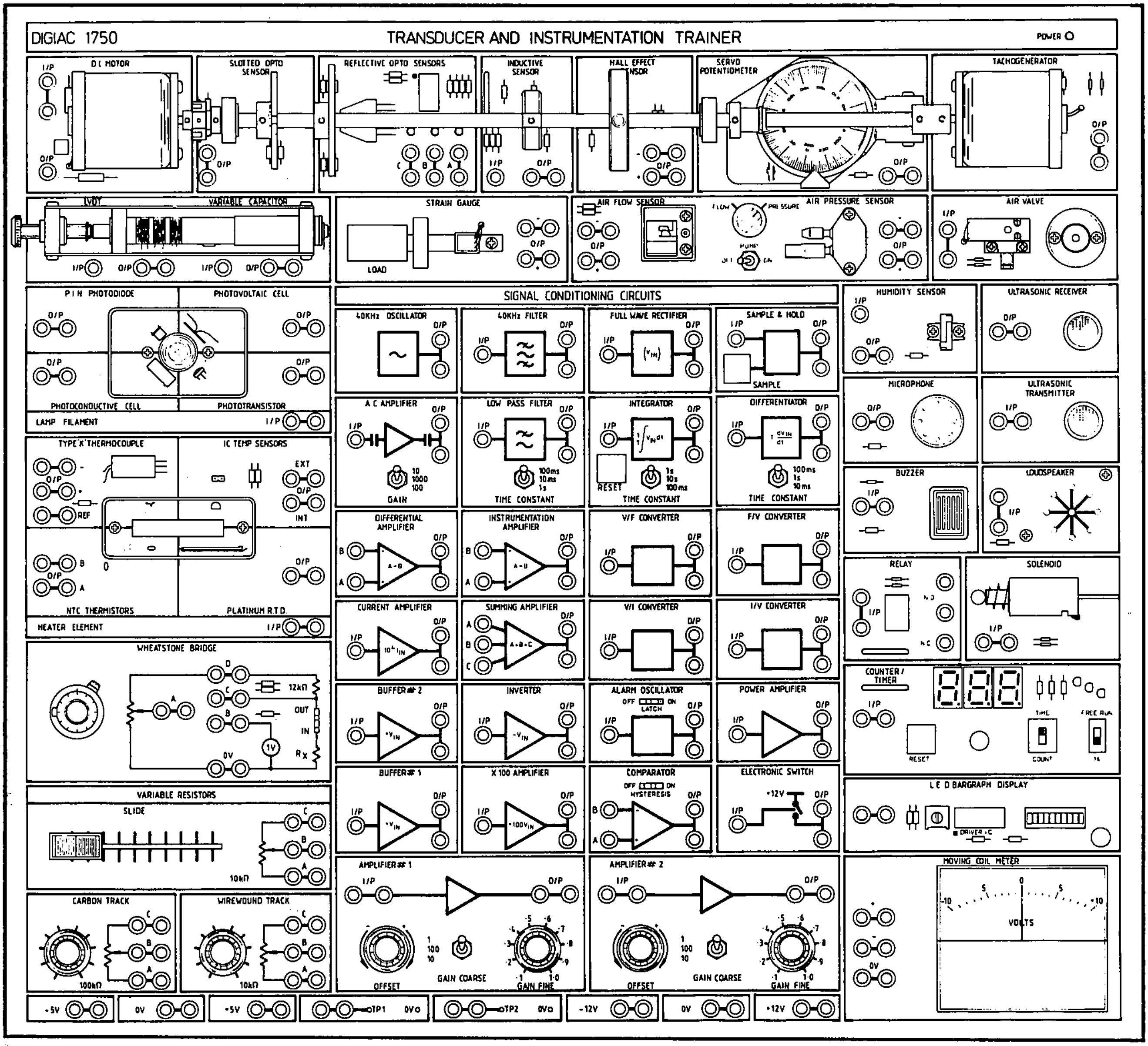
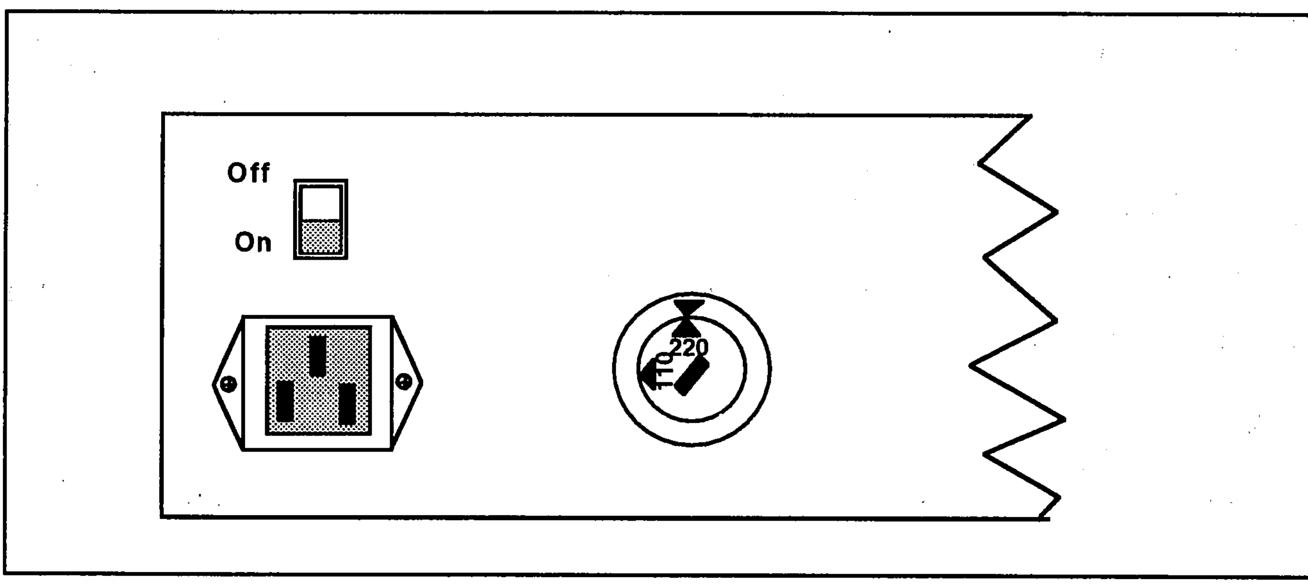

DIGIAC 1750
TRANSDUCER AND INSTRUMENTATION TRAINER
POWER
DC MOTOR
SLOTTED OPTO SENSOR
REFLECTIVE OPTO SENSORS
INDUCTIVE SENSOR
HALL EFFECT SENSOR
SERVO POTENTIOMETER
TACHOGENERATOR
LVDT
VARIABLE CAPACITOR
STRAIN GAUGE
LOAD
AIR FLOW SENSOR
AIR PRESSURE SENSOR
AIR VALVE
PIN PHOTODIODE
PHOTOVOLTAIC CELL
PHOTOCONDUCTIVE CELL
PHOTOTRANSISTOR
LAMP FILAMENT
SIGNAL CONDITIONING CIRCUITS
40KHz OSCILLATOR
40KHz FILTER
FULL WAVE RECTIFIER
SAMPLE & HOLD
HUMIDITY SENSOR
ULTRASONIC RECEIVER
A C AMPLIFIER
LOW PASS FILTER
INTEGRATOR
DIFFERENTIATOR
MICROPHONE
ULTRASONIC TRANSMITTER
TYPE 'K' THERMOCOUPLE
IC TEMP SENSORS
DIFFERENTIAL AMPLIFIER
INSTRUMENTATION AMPLIFIER
V/F CONVERTER
F/V CONVERTER
BUZZER
LOUDSPEAKER
NTC THERMISTORS
PLATINUM R T D
HEATER ELEMENT
CURRENT AMPLIFIER
SUMMING AMPLIFIER
V/I CONVERTER
I/V CONVERTER
RELAY
SOLENOID
WHEATSTONE BRIDGE
BUFFER # 2
INVERTER
ALARM OSCILLATOR
POWER AMPLIFIER
COUNTER / TIMER
VARIABLE RESISTORS
SLIDE
BUFFER # 1
X 100 AMPLIFIER
COMPARATOR
ELECTRONIC SWITCH
L E D BARGRAPH DISPLAY
CARBON TRACK
WIREWOUND TRACK
AMPLIFIER # 1
AMPLIFIER # 2
OFFSET
GAIN COARSE
GAIN FINE
MOVING COIL METER
VOLTS
+5V
0V
-5V
TP1
TP2
-12V
+12V

Figure 4

NOTE:- Before switching on your DIGIAC 1750 unit for the first time, ensure that the voltage adjustment is set correctly for the supply voltage available.

The unit can be operated from 110-130V or 220-240V A.C. supplies, the adjustment being at the rear of the unit near the supply input connection and supply ON/OFF switch as illustrated in the following diagram.



Check that the voltage is set to the appropriate value for your supply and adjust, using a small screwdriver, if this is necessary.

Terms Associated with Transducers.

Transducer:- A device which converts information from one energy system to another.

Sensor:- A device which senses, or measures, the magnitude of system variables. Normally they also convert the measured quantity into another energy system and hence they are also transducers.

Actuator:- A device which accepts an input in one system and converts it into another energy system, which is normally mechanical. These devices are also transducers.

Specification:- Data specifying the performance capabilities and requirements of equipment.

Accuracy:- The error present in a measurement as compared to the true value of the quantity.

Sensitivity:- The ratio of the output of a device compared to the magnitude of the input quantity.

Resolution:- The largest change in the input that produces no detectable change in the output. i.e. the degree to which a system can distinguish between adjacent values or settings.

Range:- A statement of the values over which the device can be used and within which the accuracy is within the stated specification.

Bandwidth:- The range of input signal frequencies over which a device or circuit is capable of being operated while providing an output within its stated specification.

Transfer function:- The mathematical relationship between two variables that are related.Normally the relationship between the input and output of a system.

Linear:- A relationship between two quantities that have a constant ratio.i.e. A straight line relationship.

Non Linear:- A relationship between two quantities that cannot be described by a linear relationship.

Linearity:- A measure of the deviation of a measurement from an ideal straight line response of the same measurement over the same range.

Response time:- The time taken in response to a change of input for the output to initially reach or be within a certain percentage of its final value.

Notes:

Terms Associated with Signal Conditioning Circuits.

Amplifier:- A circuit having an input and output that are related linearly and with the output greater than the input. The circuit may operate on both D.C. and A.C. circuits

Offset:- For a D.C. amplifier, with the input zero, the output may not be zero. This is referred to as the offset. With these amplifiers a control is provided and labelled :Offset" or "Set Zero" to set the output to zero with the input zero before the amplifier is used.

Gain:- The ratio of output to input for a circuit.

Attenuator:- A circuit having an input and an output that are related linearly and having an output less than the input.

A.C. Amplifier:- An amplifier that will amplify alternating signals only.

Differential Amplifier:- A voltage amplifier having two inputs and where the output voltage magnitude is proportional to the difference in voltages between the two inputs.

Summing Amplifier:- A voltage amplifier having multiple inputs, the output being the sum of the various applied inputs.

Inverter:- A voltage amplifier having the output the reverse of the input polarity. The output magnitude may be the same as the input, i.e. a gain of -1, or there may be a voltage gain associated with the polarity reversal.

Power Amplifier:- An amplifier with a large current output capability.

Buffer Amplifier:- An amplifier having a gain of unity normally,i.e. output equal to the input, and having a high impedance input circuit and a low impedance output circuit.

Comparator:- A circuit having two inputs A & B and an output that can be in one of two possible states depending on the magnitudes of the inputs.
With input A greater than B, the output will be in one state.
With input A less than B, the output will be in the alternative state.

Oscillator:- A circuit producing an alternating output at a particular frequency.

Alarm Oscillator:- A circuit having an input and an output. With the input magnitude below a certain level, the output is zero. When the input exceeds this value, an alternating voltage output is obtained.

Hysteresis:- The input/output characteristic for a device or circuit for conditions with the input increasing may differ from those with the input decreasing. The characteristic is referred to as "hysteresis".

For a switching circuit the term normally refers to the input switching voltages. The input voltage to cause switching for rising input voltages is arranged to be higher than that to produce switching for falling input voltages. The difference in the input switching voltages is referred to as the hysteresis.

Fig 5 shows diagrams representing the input/output characteristics of a circuit having non linearity and hysteresis and also shows the input switching levels for a circuit with hysteresis.

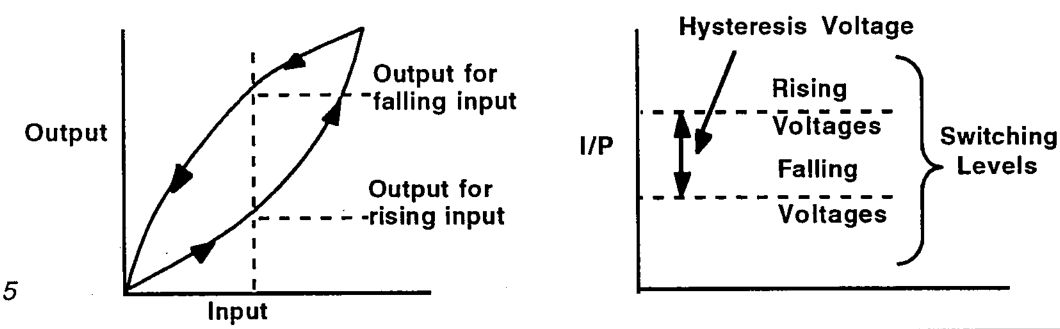


Figure 5

Latch:- A circuit having two possible output states depending on the magnitude of the input voltage. When operated with the input level sufficient to change the output to its alternative state, the output is held (or latched) in this state irrespective of the subsequent magnitude of the input voltage.

Filter:- A circuit designed to allow signals of a certain frequency range to pass through and stop all others.

Low Pass Filter:- A circuit allowing low frequency signals to pass while blocking the passage of higher frequencies.

High Pass Filter:- A circuit allowing high frequency signals to pass while blocking the passage of lower frequencies.

Band Pass Filter:- A circuit allowing signals over a certain frequency range to pass and stopping signals of higher and lower frequencies.

Full Wave Rectifier:- A circuit converting an alternating waveform into a unidirectional or D.C. waveform.

V/F Converter:- A circuit converting a D.C. input voltage to an alternating voltage, the frequency being dependent on the magnitude of the D.C. input voltage.

F/V Converter:- A circuit converting an alternating voltage input to a direct voltage output, the output voltage magnitude being proportional to the frequency of the input voltage.

V/I Converter:- A circuit converting an input direct voltage into an output current, the current magnitude depending on the magnitude of the input voltage.

I/V Converter:- A circuit converting an input curent to an output voltage, the voltage magnitude being dependent on the magnitude of the input current.

Integrator:- A circuit having an output voltage that is proportional to the product (input voltage x time).

Differentiator:- A circuit having an output voltage proportional to the rate of change of the input voltage.

Sample and Hold:- A circuit with input and output.
In the "sample" state, the output is equal to and follows the input voltage.

In the "hold" state, the output is held at the value of the input signal at the instant the "hold" signal was initiated.

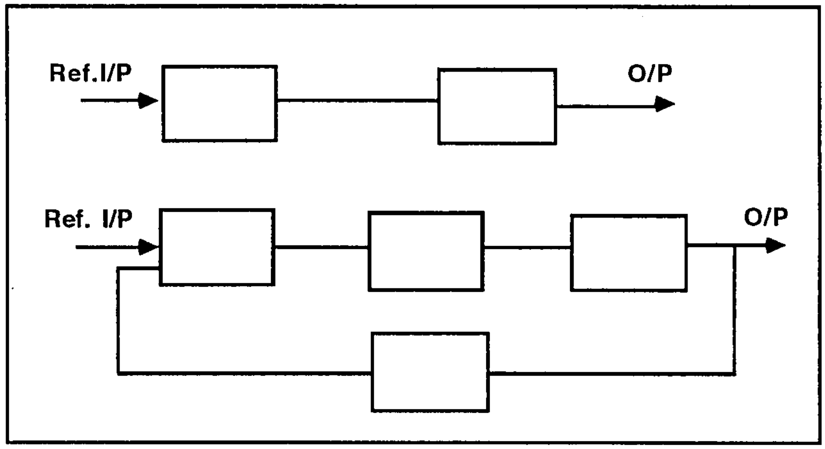
Ultrasonic:- A frequency above the normal audio range and hence inaudible to the human ear. (Normally > 16kHz).

Notes:

Notes:

Student Assessment 1.

1. Label the blocks of the following control systems:-



2. A closed loop control system has an open loop gain G and a negative feedback factor H. State the expression for the overall gain of the system when feedback is applied.

3. An electrical control system produces an output of 100V for a reference input of 1V under open loop conditions.

   If a fraction 0.1 of the output is fed back as negative feedback to the input, what input reference voltage is now required to produce an output of 100V ?

4. State 7 functions that may be performed by signal conditioning circuits.

5. Define the following terms:-
   (1) Transducer
   (2) Resolution
   (3) Transfer function

Student assessment questions continued overleaf

6. A device has an output that is variable in 250 equal increments and has a maximum output of 10V. State the resolution of the device.

7. State the type of filter represented by the following characteristics:-
   (1) A filter passing all frequencies above 10kHz
   (2) A filter passing frequencies in the range 20kHz to 30kHz.
   (3) A filter passing all frequencies up to 4kHz.

8. State what is meant by an electrical comparator and describe its characteristics.

9. What would be the difference in the characteristics of a comparator with hysteresis and a comparator with latch ?

Notes:

Section 2

Input Transducers

Chapter 2.1 Resistance Transducers for Angular or Linear Position Applications.

Objectives of this chapter.

Having studied this chapter you should:-

- *Know the basic construction of rotary and slider types of variable resistance.*
- *Know that the resistance section may be either a carbon track or may be wirewound.*
- *Know the difference between a logarithmic and a linear track.*
- *Know the basic characteristic of output voltage against variable control setting.*
- *Know the effect on the output voltage of loading the output circuit.*
- *Know that the resolution for a carbon track unit is better than that for a wirewound type.*

Construction.

The unit consists basically of a "track" having a fixed resistance and a variable contact which can be moved along and make continuous contact with the track.

With a voltage applied across the ends of the fixed track, a variable voltage can be obtained from the variable contact as it is moved along the track.The output voltage will depend on the position of the variable contact and hence the output voltage indicates the position of the variable contact.

If the track resistance is proportional to the length along the track (i.e. linear track), the output voltage will be proportional to the movement of the variable contact and the unit is suitable for use as a position transducer. These units are referred to as linear types.

Another type of unit has a track with the resistance not proportional to the length along the track.These are referred to as logarithmic types and are not suitable for use as positional transducers.

The track may comprise a film of carbon formed on a substrate or may be a length of resistance wire wound on an insulating former.

The unit may be constructed in a rotary form or may be straight as shown in the examples of Fig 6.

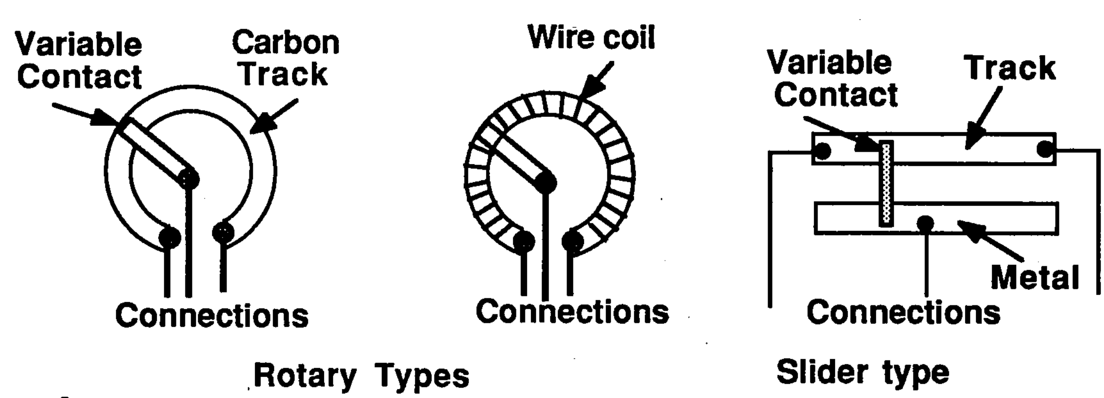


Figure 6

The characteristic of output voltage against variable contact setting for an ideal unit on no load is as shown in Fig 7.

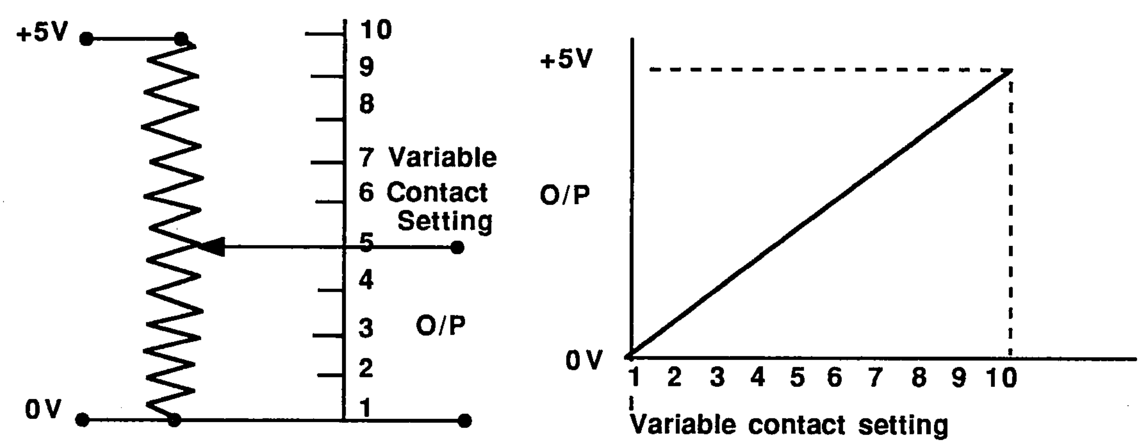


Figure 7

With a center tapped voltage source, the polarity of the output voltage will depend on the direction of the movement of the slider from its central position as shown in Fig 8.

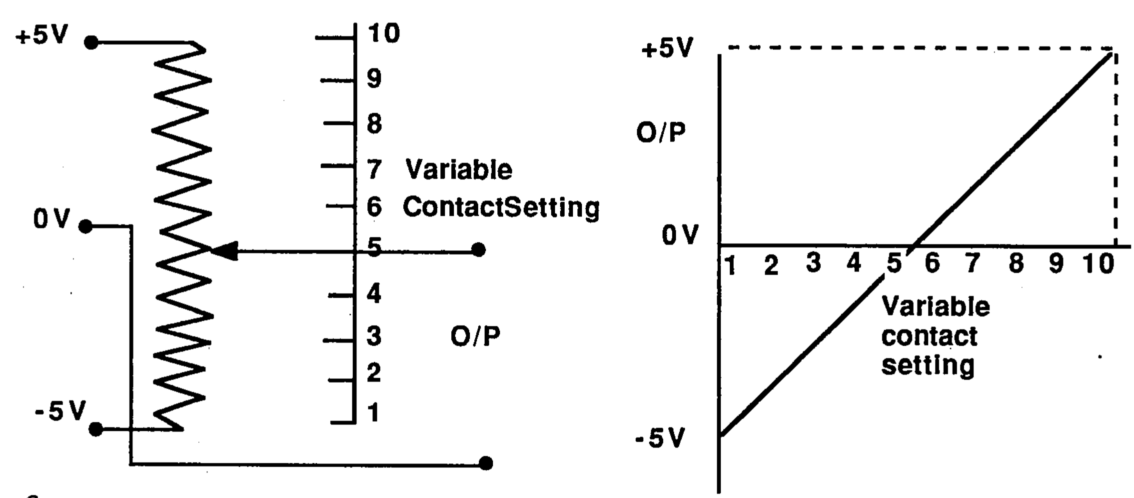


Figure 8

Effect of loading the output circuit.

Consider a resistor of value 10kΩ connected to a 10V supply and with the slider set in its central position. Wtih no load connected to the output circuit, the output voltage will be 5V. The sections of the resistor each side of the slider will be 5kΩ each.

If we now connect a resistor to the output circuit, a current will flow in this resistor and the current taken from the supply will increase. This increased current which must flow in the upper section of the resistor (as shown in Fig 9.) increases the voltage drop across it and hence the output voltage falls.

Fig 9 shows conditions with a 5kΩ load resistor connected to the output circuit.

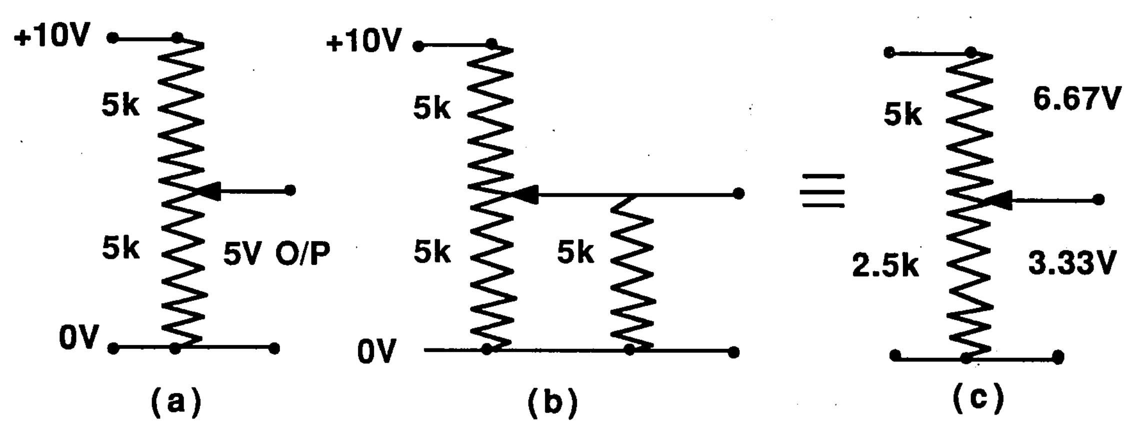


Figure 9

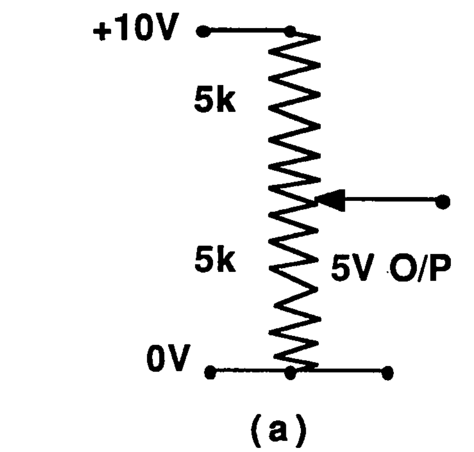


Figure 9a

Fig 9(a) shows conditions with no load connected to the output circuit with the variable contact in its center position. The output voltage is 5V.

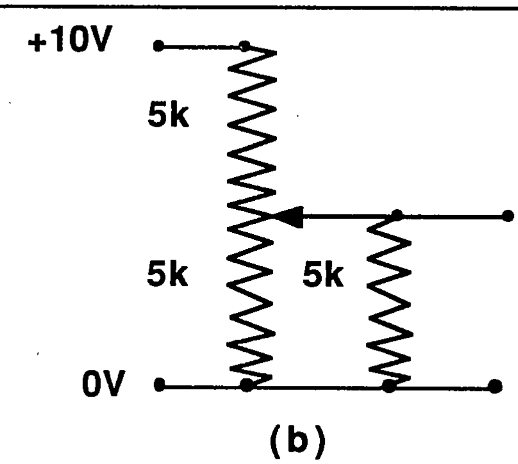


Figure 9b

Fig 9(b) shows conditions with a 5kΩ load resistor connected to the output circuit. Extra current will flow from the supply and the output voltage will fall.

The two 5kΩ resistors that are effectively in parallel across the output circuit are equivalent to a single resistor of 2.5kΩ.

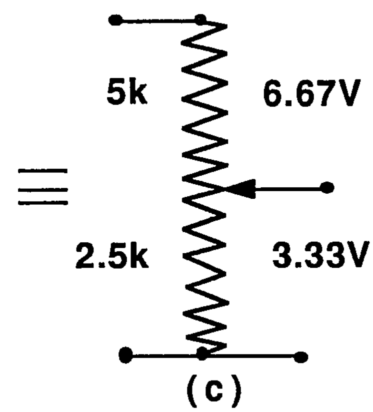


Figure 9c

The circuit is thus equivalent to the circuit shown in Fig 9(c).

The voltage across the 5kΩ section of resistance will be twice that across the 2.5kΩ resistance. There will thus be 6.67V drop across the 5kΩ section and 3.33V drop across the 2.5kΩ section. The output voltage will thus be 3.33V.

Connecting the 5kΩ load resistor has thus reduced the output voltage from 5V to 3.33V and this would be interpreted by a positional control system as a change in position when in fact there has been no change.

The error caused by output circuit loading increases as the current taken increases, and, in control system applications, any loading current must be kept to an absolute minimum and ideally to zero.

Most electrical circuits require a current input to their input circuits and a measure of the magnitude of this can be obtained from the value of their input impedance as stated in the device specification.

Circuit loading can be reduced by using a "buffer" amplifier.

Resolution.

The resolution provided by a carbon track resistor is good, the value being infinitely small.

The resolution for a wirewound resistor is worse, since the variable contact will in effect be moving from contact with one turn to contact with the next. The output voltage will therefore increase in steps, these representing the voltage per turn or a fraction of this.

This is represented in Fig 10 which is drawn to a large scale.

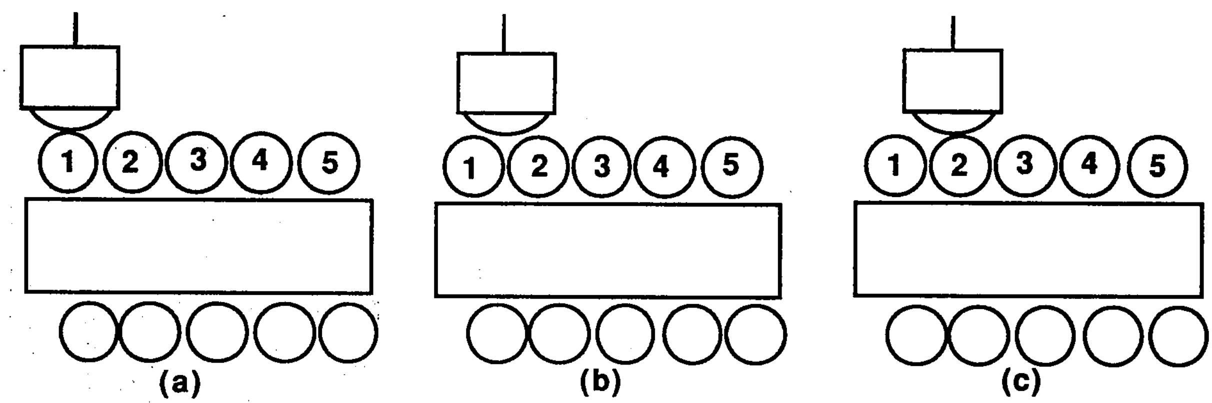


Figure 10

Fig 10(a) shows conditions with the contact connected to coil 1.

Fig 10(b) shows conditions with the contact connected to coils 1 and 2

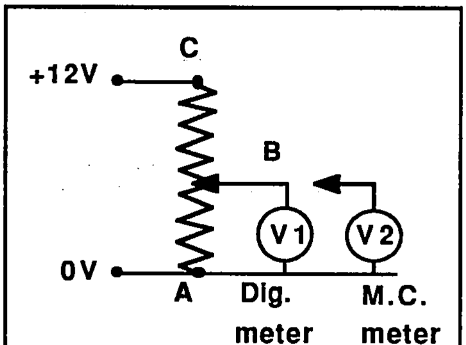
Fig 10(c) shows the contact connected to coil 2.

In practice, the contact will probably make contact with more than one turn, this depending on the value and power rating of the resistor.

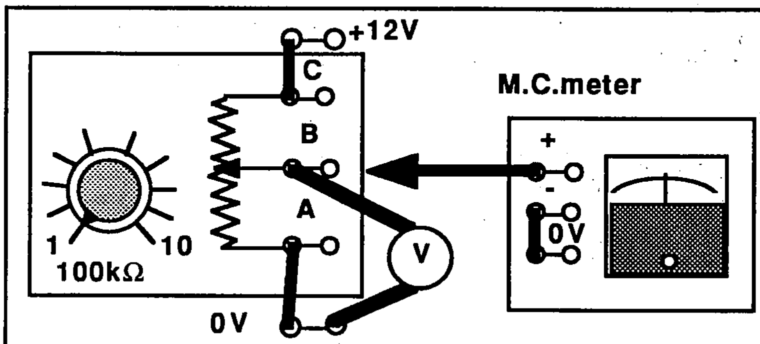
Exercise 1. Variation of Output Voltage with Setting for a Resistance Position Transducer.

Equipment:-

1 100kΩ Carbon track rotary resistor
1 10kΩ Wirewound rotary resistor
1 10kΩ Carbon track slider resistor
1 20V D.C. Digital voltmeter
1 10-0-10V Moving coil meter.
Connecting leads



Schematic Diagram



Physical layout diagram

Figure 11

- Connect the circuit as shown in Fig 11 using the 100kΩ resistor and with the digital meter only, connected to the output socket B.
- Set the resistor rotary control fully counter clockwise. i.e. to setting 1 as indicated in Fig 11.

- Check that the DIGIAC 1750 voltage adjustment is set correctly for the supply voltage available, adjust if necessary, and then switch the power supply ON.

- Note the output voltage:-
  (1) Using the digital meter only connected
  (2) Using the moving coil meter only connected
  (3) With both meters connected simultaneously.

  Enter the values in Table 1.

- Set the rotary control to setting 2 and repeat the readings for this setting,entering the values obtained in Table 1.

- Repeat the procedure for each setting of the rotary control from 3 to 10, entering the readings in the relevant column of Table 1.

Resistor	Control Setting												
100kΩ Rotary Carbon	O/P Voltage	Digital											
		M.C.Meter											
		Dig & M.C	Dig										
			M.C										

Table 1

Study the readings obtained.

The voltages obtained with the digital meter alone will be higher than those for the moving coil meter when used alone. Why is this ?

**With the digital and moving coil meters connected simultaneously, the readings should be basically the same and they should correspond with the values obtained using the moving coil meter alone.
Why is this ?**

The reason for the different readings is that the moving coil meter loads the output circuit.

The meter provided with the DIGIAC 1750 unit has a resistance of 20kΩ.

A digital meter normally has an input impedance of 10MΩ and hance will not load the output circuit.
The loading effect is increased with the DIGIAC 1750 unit resistors because a 1kΩ resistor is included in the variable output connection to prevent damage to the equipment that could be caused by incorrect connections and any output current will produce a volt drop in this resistance.

■ Repeat the procedure using the 10kΩ rotary wirewound resistor and then using the 10kΩ carbon slider resistor.Readings need only be taken with:-
(1) Digital meter only connected
(2) Digital and moving coil meters connected simultaneously.

Enter the values in Tables 2 and 3.

Resistor	Control Setting												
10kΩ Slider Carbon	O/P Voltage	Digital											
		Dig & M.C	Dig										
			M.C										

Table 2.

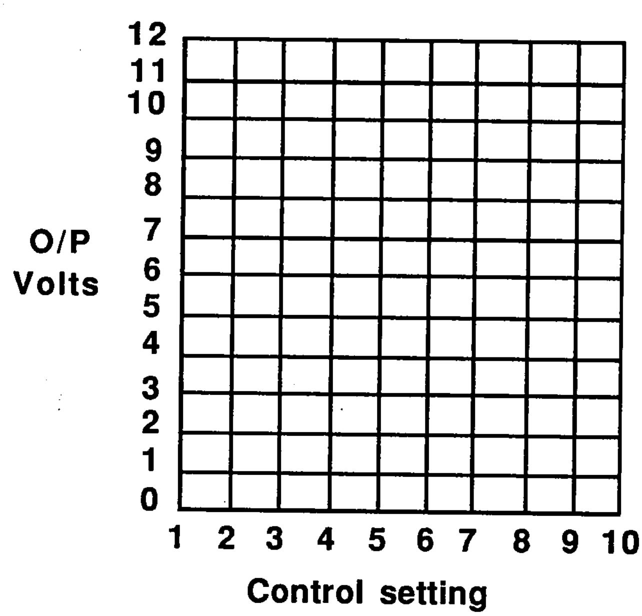
Resistor	Control Setting												
10kΩ Wire wound	O/P Voltage	Digital											
		Dig & M.C	Dig										
			M.C										

Table 3.

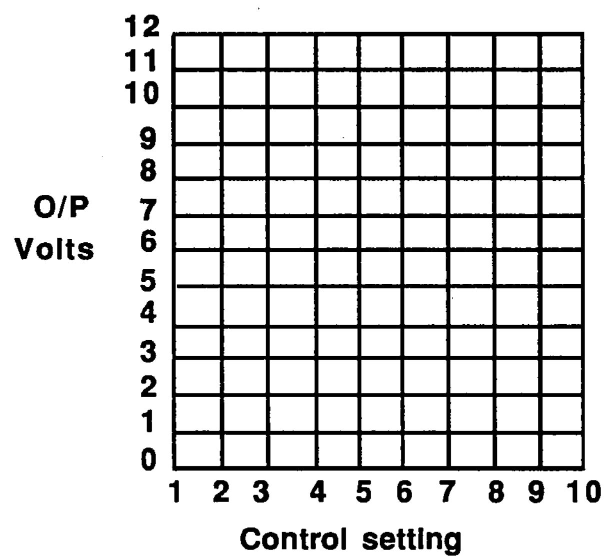
Study the readings.

The effect of the moving coil meter loading is less pronounced, due to the lower value resistors,10kΩ compared with the 100kΩ used for the previous readings.

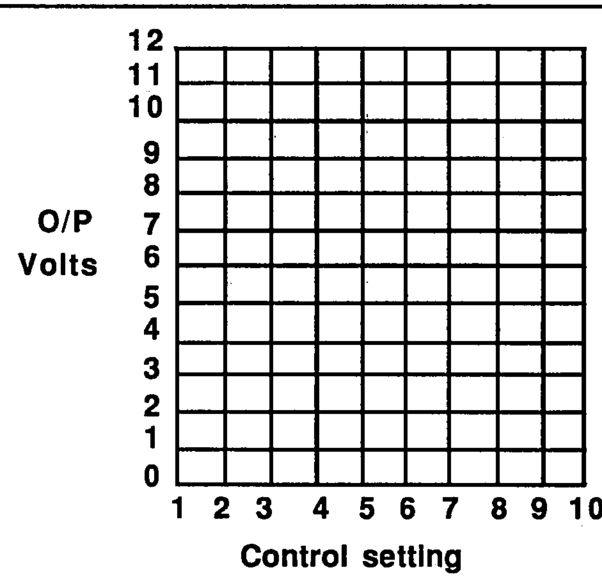
- Construct graphs of output voltage against control setting for the three resistors on the axes provided, using the readings obtained with the digital meter only.



100kΩ Carbon



10kΩ Wirewound



10kΩ Carbon

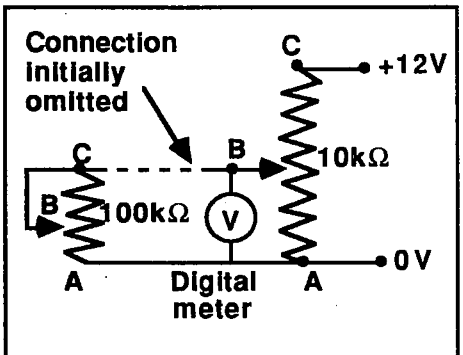
Are the characteristics linear ?
Some divergence from the ideal characteristic would be expected due to the difficulty in setting the control accurately.

Notes:

Exercise 2. The effect of circuit loading on the output voltage for a positional resistance transducer

Equipment:-

1 10kΩ Wirewound rotary resistor
1 100kΩ Carbon rotary resistor used for loading
1 20V D.C. Digital voltmeter
1 10-0-10V Moving coil meter
1 Buffer amplifier #1
Connecting leads.



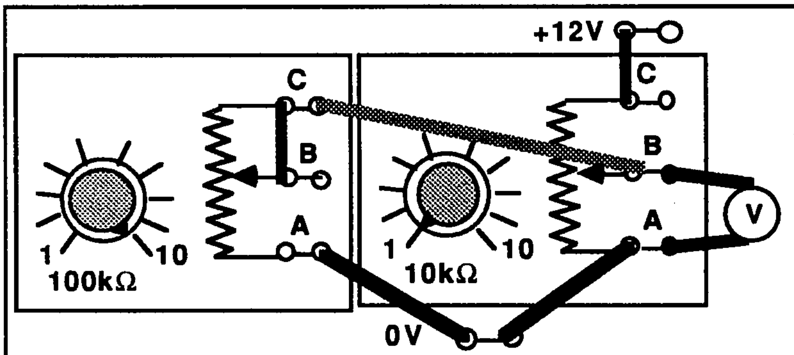


Figure 12

In this exercise, we will use the 10kΩ wirewound rotary resistor as a positional resistance transducer. The 100kΩ carbon rotary resistor will be used for loading purposes.

- With the power supply switched off, connect the circuit as shown in Fig 12, but omitting the link (shown shaded) between contact C of the 100kΩ load resistor, and wiper contact B of the 10kΩ positional resistance transducer. With this link omitted, the positional resistance transducer is unloaded.

- Switch the power supply ON and adjust the rotary control of the 10kΩ positional resistance transducer so that the output voltage is 6V. Do not re-adjust this setting during the exercise.

- Set the control of the 100kΩ load resistor fully clockwise, i.e. setting 10, and insert the link shown shaded in Fig 12. Note the output voltage and enter the value in Table 4.

100kΩ Control	o.c.	10	9	8	7	6	5	4	3	2	1
Output Voltage (volts)	6V										
Approx. Load Resistance KΩ	∞	100	90	78	67	56	45	34	23	11	1

Table 4 (o.c. = open circuit)

- Reduce the control setting of the 100kΩ resistor in steps from 10 to 1, noting the output voltage at each step. Enter the values in Table 4.

- Now disconnect the 100kΩ load resistor from the 10kΩ positional resistance tranducer, and connect the moving coil meter as the load. Note the digital meter reading for this loading.

  Moving coil meter connected: Output voltage =

Study your readings.

As the load resistance is decreased, thus increasing the load current, the output voltage falls.

From the reading taken with the moving coil meter as the load, what would you consider to be the resistance of the moving coil meter ?

- Now connect the moving coil (M.C.) meter to the 10kΩ positional resistance transducer, via the buffer #1 amplifier as shown in Fig 13. Note the output voltage indicated by the digital meter.

M.C. meter connected via buffer #1 amplifier:-

Output voltage =

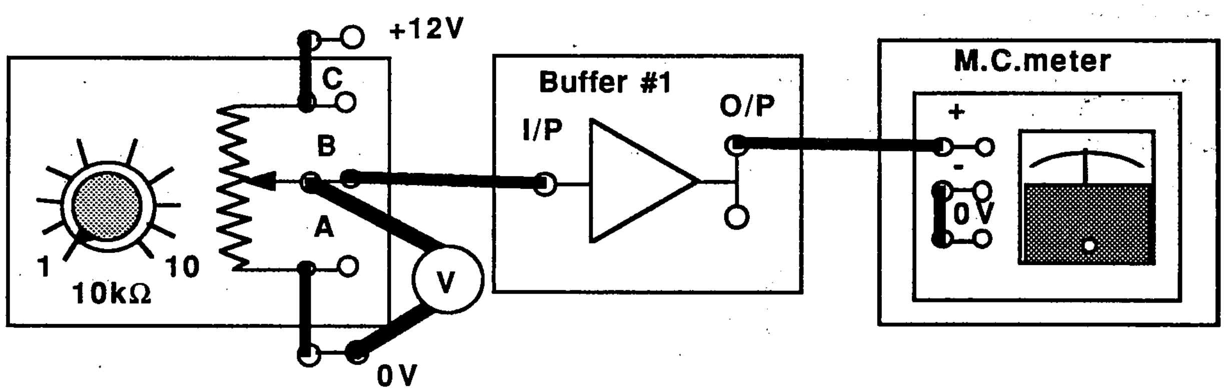


Figure 13

The output voltage will be higher than when the meter was connected directly because the buffer amplifier is effectively reducing the loading caused by the meter.

The voltage is still less than the open circuit voltage because the buffer amplifier input impedance is 100kΩ.

Does the voltage obtained agree with that obtained for the 100kΩ loading during the exercise ?

This illustrates the use of a buffer amplifier to reduce the effect of any circuit loading and also illustrates that the loading is not necessarily reduced to zero. The actual loading will depend on the design of the buffer amplifier unit.

Notes:

Exercise 3. The resolution of carbon track and wirewound resistance position transducers

Equipment:-

1 100kΩ Carbon rotary resistor
1 10kΩ Wirewound rotary resistor
1 10kΩ Carbon slider resistor
1 Amplifier #1
1 20V Digital voltmeter
Connecting leads.

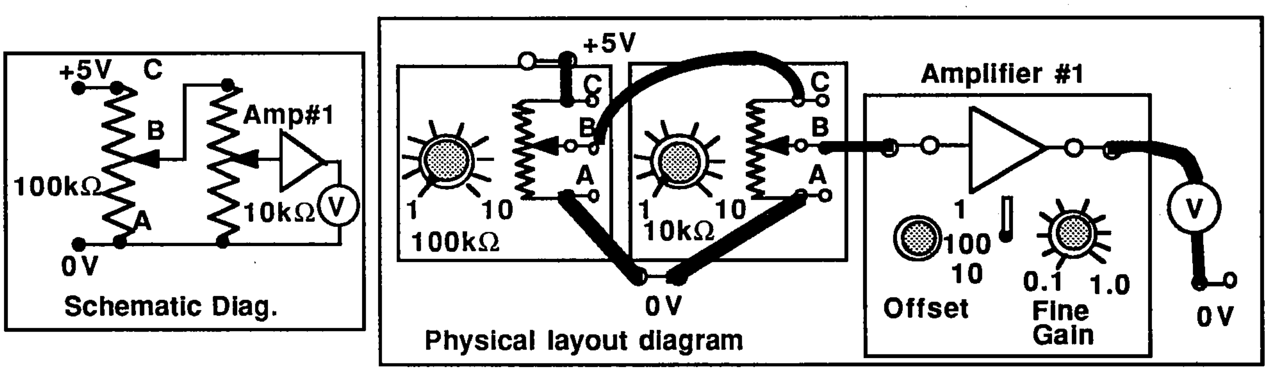


Figure 14

- Connect the circuit as shown in Fig 14, using the 10kΩ slider type carbon resistor first and set the output controls of both resistors fully counter clockwise,i.e. setting 1, so that the output will be zero.
- Set the amplifier #1 "Coarse" gain control to 10 and the "fine" gain to 1.0.

- Switch the power supply ON and adjust the "offset" control of the amplifier so that the voltage output as indicated by the voltmeter is zero.
- Now set the "coarse" gain to 100 and re-adjust the "offset" control for zero output.
- Set the control of the 10kΩ resistor fully to the right, i.e. setting 10, and then adjust the control of the 100kΩ resistor so that the output voltage from the amplifier is approximately 9V.
- Now return the control of the 10kΩ resistor fully to the left,i.e. setting 1. The output voltage indicated by the voltmeter should be zero. Re-adjust the "offset"control if necessary to set the output to zero.
- Now increase the output voltage, by adjusting the control of the 10kΩ resistor, in as small steps as possible. You should be able to increase the voltage in steps of 0.01V without difficulty.

  Can you ?
- Replace the 10kΩ carbon slider resistor with the 10kΩ wirewound resistor.
- With the 10kΩ resistor output control fully counter clockwise, i.e. setting 1, note the output from the amplifier and re-adjust the "offset" control for zero output if necessary.
- Now increase the output voltage, by adjusting the 10kΩ resistor control, in as small steps as possible and note the voltage values at each increment. You will note that the voltage increases in steps. Enter the values in Table 5.

Step	1	2	3	5	6	7	8
Voltage							

This exercise should have illustrated the poorer resolution obtainable from wirewound resistors.To illustrate this effectively we had to amplify the output signal,using an amplification of approximately 100.
We limited the maximum amplifier output to 9V to prevent any saturation of the amplifier circuit, the maximum output obtainable from the amplifier being of the order of 10V.
The magnitude of the voltage steps obtained could be increased by setting the output control to a lower value,say setting 4 for the 10kΩ resistor, when adjusting the 100kΩ resistor for an amplifier output of 9V.

Notes:

DIGIAC 1750 Resistor Circuit arrangement.

With the resistance transducers used in the previous exercises a 1kΩ resistor is included in the output circuit to protect the track from damage if misused, the circuit being shown in Fig 15.

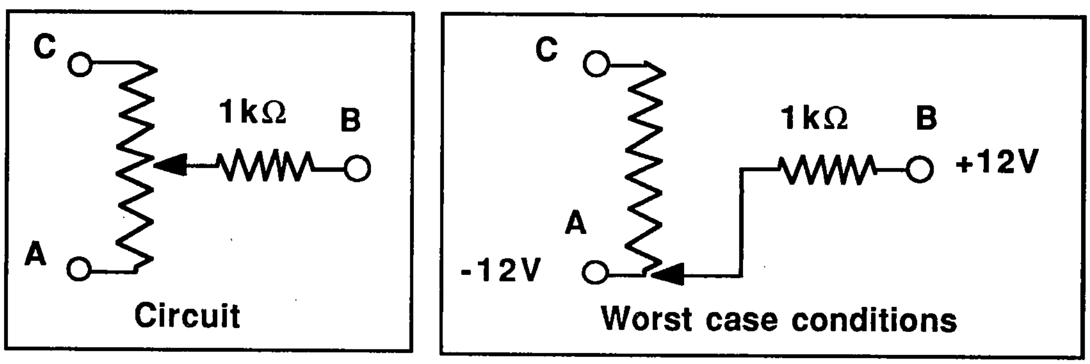


Figure 15

Fig 15 also shows the worst condition possible with the DIGIAC 1750 unit. This occurs when the +12V and -12V supplies are connected between connections A and B and with the slider set at end A as shown.

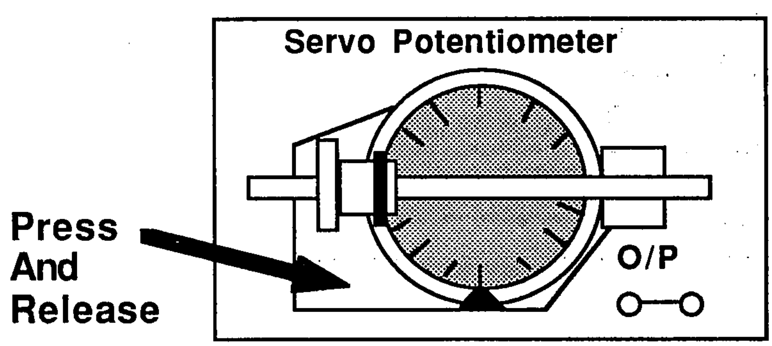
With the 1kΩ limiting resistor in circuit, the maximum current that can flow is limited to 24mA and this should not be sufficient to damage the unit.

If the 1kΩ resistor were omitted, the current under these conditions would be excessive and would damage the track at end A.

A further rotational resistance transducer is fitted to the motorised shaft assembly. This unit is capable of continuous rotation, the track covering almost the full 360°. (The rotational units used so far have a maximum rotation of 300°approximately).

The variable contact of this unit is friction driven from the motor shaft and, when not in use, it is disconnected from its friction drive by a toggle arrangement to minimise the wear on the assembly.

To engage the drive, press the mounting plate at the left hand side of the unit and then release it. To disengage the drive, repeat the process.



The drive gives a 4:1 speed reduction from the shaft speed. and the unit can be used for positional control applications. The unit is labelled "Servo Potentiometer" on the DIGIAC 1750 unit and the track ends are connected permanently to the +5V and -5V supply.

The output circuit of this unit includes a2.2kΩ resistor for protection.

Notes:

Exercise 4. Variation of output voltage with setting for the Servo Potentiometer

Equipment:-

1 Servo potentiometer
1 20V digital voltmeter
Connecting leads.

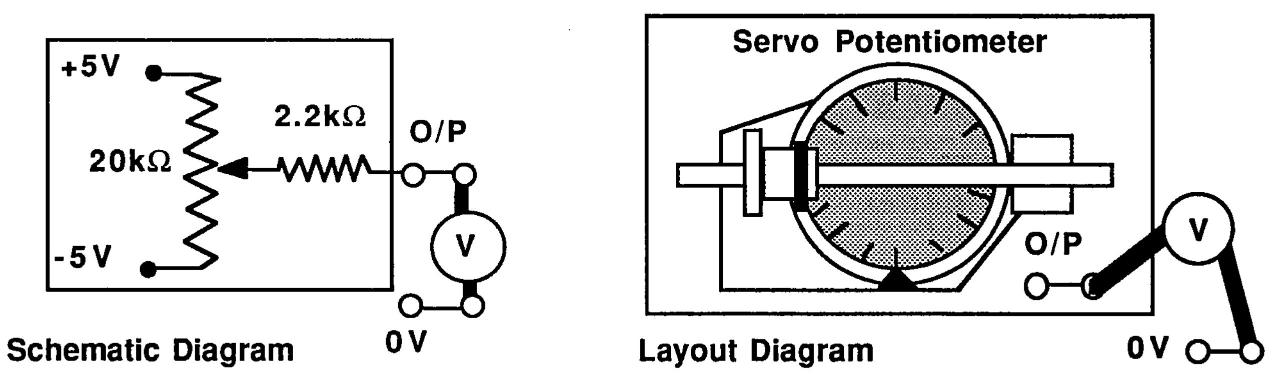


Figure 16

- Connect the voltmeter as shown in Fig 16 and switch the power supply ON.

- Set the control dial to the setting giving the maximum positive voltage output (approx. +5V). This will be at setting 178° approximately. Note the setting angle and the magnitude of the voltage and enter the values in table 6.

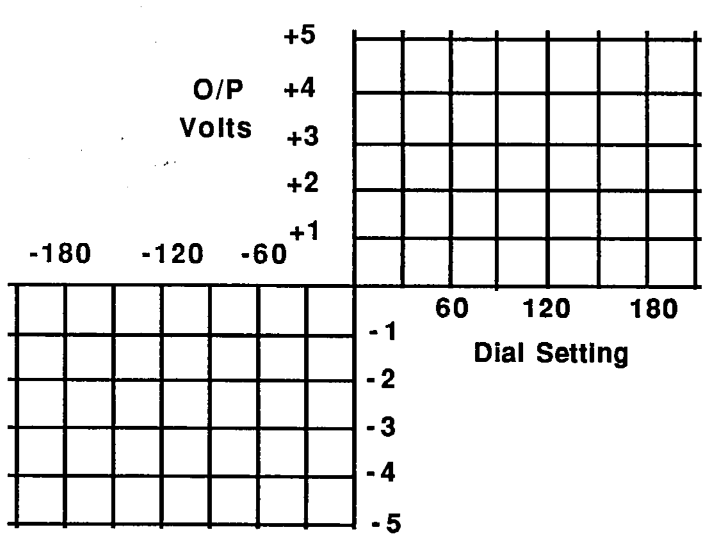
Control Dial							360	330	300	270	240	210	
Setting		150	120	90	60	30	0	-30	-60	-90	-120	-150	
Output Voltage													
	Max. Setting										Min. Setting		

Table 6

Note:- The dial may be moved manually with the unit in its disconnected position, or the drive may be engaged by depressing the mountig plate at the left hand side of the assembly and then releasing it. The dial setting can then be adjusted by rotating the drive shaft manually using the Hall effect disc.

- Rotate the dial in steps of 30° clockwise from the maximum voltage position, noting the output voltage at each step, and entering the values in Table 6. Note the dial setting giving the maximum negative voltage, this representing the other end of the track.

- Construct the graph of output voltage against dial setting on the axes provided.



Student Assessment 2.

1. State the difference between a 10kΩ linear and a 10kΩ logarithmic track resistor.

2. A resistor is stated to be wirewound. State with reasons whether you would consider this to be a linear or logarithmic type.

3. A linear potentiometer having control settings 1 to 10 is connected to a +9V,0V,-9V supply with the -9V connection made to the end corresponding with setting 1.

   State the voltages you would expect to obtain from each of the control settings with the output on no load.

4. A 10kΩ potentiometer is connected to a 12V supply.
   (a) With the output circuit on no load, what would be the output voltage with the control set
   (1) in the mid position &
   (2) in the maximum output setting ?

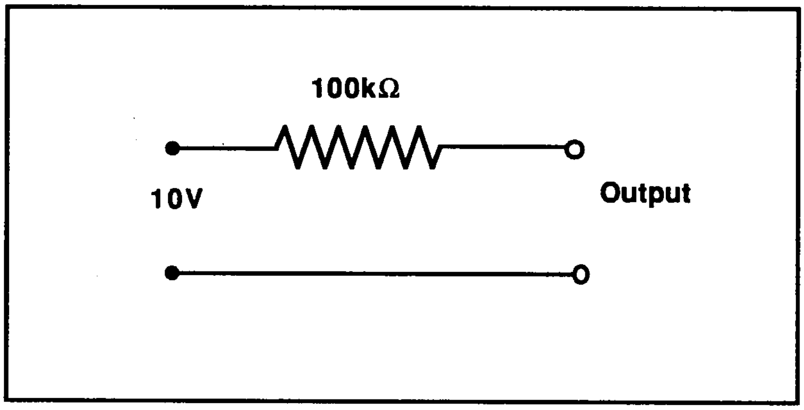
   (b) If the output voltages were measured using a moving coil meter having resistance of 5kΩ, what voltages will be indicated with the control set in
   (1) the mid position &
   (2) the maximum setting ?

5. A 5kΩ wirewound variable resistor consists of 1200 turns of wire. The slider makes contact with three turns simultaneously.

   With a voltage of 10V applied to the ends of the resistor, state the magnitude of the resolution in terms of the output voltage.

Student assessments continued overleaf

6. The power supply circuit shown below consists of a voltage source of 10V in series with a resistance of 100kΩ. What voltage would you expect to be indicated if the voltage at the output terminals were measured using:-
(a) A digital meter having input resistance 10MΩ ?
(b) A moving coil meter of resistance 10kΩ ?
(c) The same moving coil meter fed via a buffer amplifier having an input resistance of 100kΩ?



Notes:

Chapter 2.2 The Wheatstone Bridge Circuit And "Null Balance" Measurement And Application To The Measurement Of Resistance And Voltage

Objectives of this chapter.

Having studied this chapter you should:-

- *Know the principles of the basic Wheatstone Bridge circuit for resistance measurement.*
- *Know the term "null balance".*
- *Know the expression for calculating an unknown resistance from the circuit values at balance.*
- *Know that measurement accuracy does not depend on the meter accuracy or the supply voltage magnitude.*
- *Know the application of the three wire resistance circuit.*
- *Know the application of null methods to voltage measurement.*
- *Know the facilities provided with the DIGIAC 1750 unit and their application to measurement of resistance and voltage.*

Wheatstone Bridge Circuit.

Fig 17 shows the basic Wheatstone bridge circuit, consisting of four resistors and a sensitive center zero meter connected to a D.C. source.

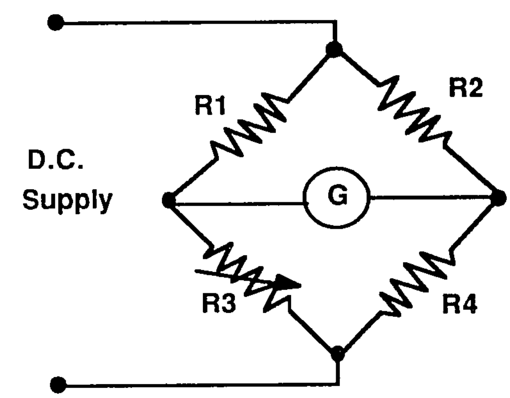


Figure 17

R1,R2 & R3 are accurate resistors, R3 being variable and calibrated over its full range, and R4 is the unknown resistor whose value is being measured.

During measurement, R3 is adjusted until there is no current flowing in the galvanometer circuit,i.e. the galvanometer current is zero or "null". Under these conditions, the bridge is said to be "balanced". Hence the term "null balance".

From the known values of R1,R2 & R3 at balance, the value of R4 can be calculated from:-

$$R4 = \frac{R2}{R1} \times R3$$

This expression is derived as follows:-

With no current in the galvanometer circuit, the voltages at the two connections to it must be at the same value. This means that the voltages across R1 and R2 must be the same value and similarly those across R3 and R4 must be the same value.

Also, with no current in the galvanometer, the current in R1 must equal that in R3 and the current in R2 must equal that in R4.

If current I1 flows in R1 and R3 and current I2 flows in R2 and R4:-

$$I_1R_1 = I_2R_2 \qquad (1)$$
$$I_1R_3 = I_2R_4 \qquad (2)$$

Dividing equation (1) by equation (2)

$$\frac{I_1R_1}{I_1R_3} = \frac{I_2R_2}{I_2R_4}$$

&

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

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

The unknown resistance R4 depends on the values of the ratio R2:R1 and the value of R3 at balance.

The resistors R1 and R2 are normally refered to as the "ratio arms" of the bridge.

Note:- 1. The value of the supply voltage or the magnitude of the currents flowing in the resistors does not affect the result. This means that the supply voltage need not be stabilised, and that the circuit currents can be kept to low values for a component where the self heating effect of the current flowing could affect the results.

2. The galvanometer current accuracy is unimportant, since, under balanced conditions, the current in it is zero. The main characteristics required for the galvanometer are a low resistance and a high sensitivity so that a small deviation of voltage from zero produces a large scale reading.

The three wire resistance measuring circuit.

With some resistance transducer circuits, the transducer may be situated a relatively large distance from the bridge circuit, and hence the resistance of the connecting leads may be significant and could affect the results. For these situations the three wire connection arrangement is used.

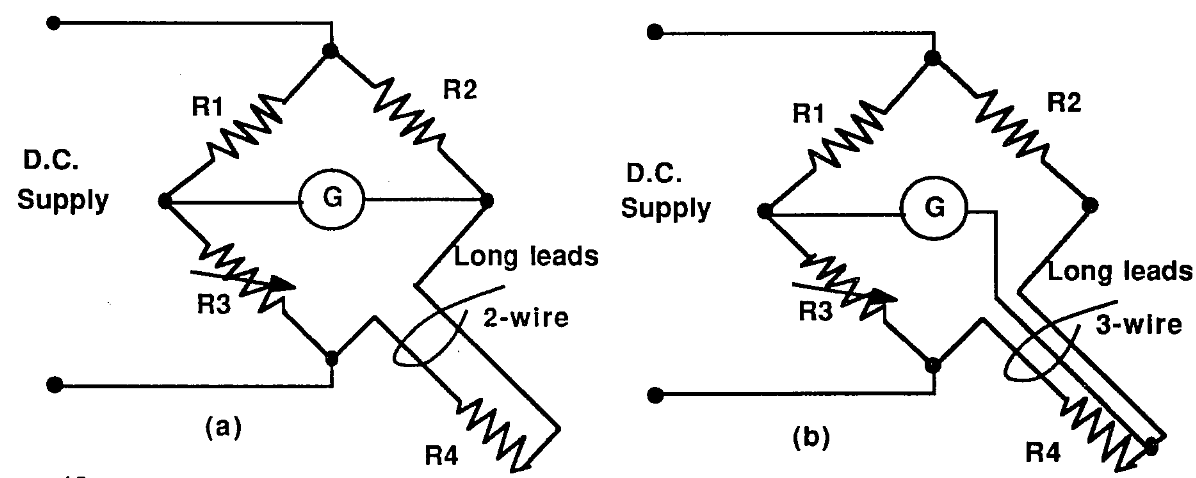


Figure 18

Fig 18 (a) shows the circuit with the transducer R4 situated remote from the bridge and connected via two wires. The resistance of these wires will be included in the measurement of R4.

Fig 18 (b) shows the three wire arangement. One of the wires to the transducer is now included in the R2 circuit and the other is in the R4 circuit. Both circuits will therefore be affected equally and the balance condition will not be affected.

The extra wire in the galvanometer circuit will have no effect at balance ,since there is no current flowing in it under this condition.

Measurement of voltage using"null balance" methods.

Method 1.

A calibrated variable resistor, calibrated voltage source and galvanometer are required, these being connected as shown in Fig 19.

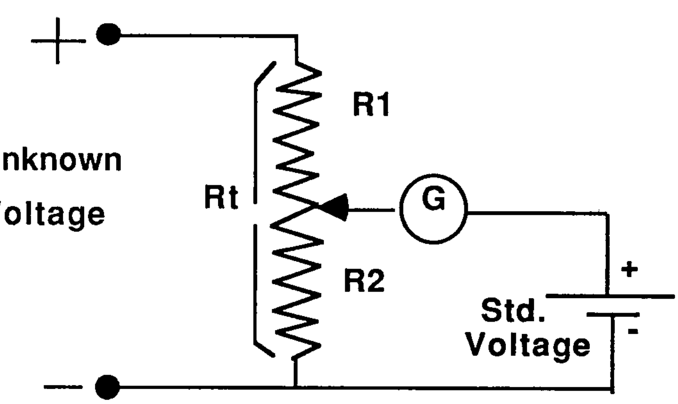


Figure 19

The position of the slider of the variable resistor is adjusted until the circuit is balanced, i.e. no current in the galvanometer circuit.

Under these conditions, the voltage across the R2 section of the variable resistance is equal to the value of the standard voltage supply and the unknown voltage can be calculated from:-

$$\textbf{Unknown voltage} = \frac{Rt}{R2} \times \textbf{Standard voltage.}$$

This method has disadvantages:-

(1) The unknown voltage source is loaded by the variable resistor and hence the voltage nay be affected
(2) The method only allows measurement of voltages exceding that of the known standard value.

Method 2.

This method requires an additional D.C. source of voltage magnitude exceeding the maximum value of the unknown voltages to be measured and a variable resistor Rs, the circuit being as shown in Fig 20.

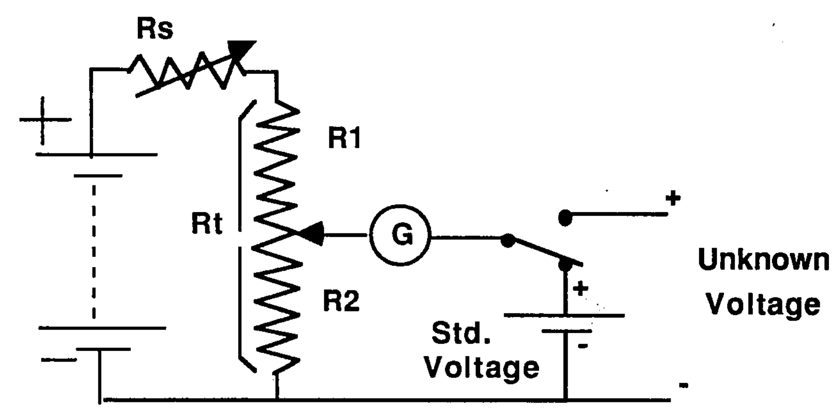


Figure 20

For measurement of voltages up to the value of the standard voltage, the slider of the variable resistor is set to its maximum output position and, with the galvanometer connected to the standard voltage source, the value of Rs is adjusted until there is no current in the galvanometer. i.e. the circuit is balanced.

The full resistance Rt is then calibrated to represent the value of the standard voltage.

To measure an unknown voltage, the galvanometer is connected to the unknown voltage and the slider position is again adjusted for circuit balance. The section R2 at balance represents the magnitude of the unknown voltage.

$$\text{Unknown voltage} = \frac{R2}{Rt} \times \text{Standard voltage}$$

For the measurement of voltages higher than the standard voltage, the variable resistor can be calibrated against the standard voltage with the slider set to a position lower than the maximum setting. This setting will now represent a magnitude equal to the standard voltage.
Balance with an unknown voltage is obtained as before and the unknown voltage calculated from :-

Unknown voltage =

$$\frac{\text{R2 (Unknown connected)}}{\text{R2 (Standard connected)}} \times \text{Standard voltage}$$

With this method, no current is taken from the unknown voltage source at balance and hence the circuit is not loaded. The voltage obtained should therefore be accurate, within the limits of accuracy of the variable resistor.

Notes:

The DIGIAC 1750 Facilities.

Fig 21 shows the Wheatstone Bridge layout provided with the DIGIAC 1750 unit. A high quality10 turn potentiometer is provided to fulfill the functions of the resistors R1 and R3 in the Wheatstone bridge circuits discussed previously.

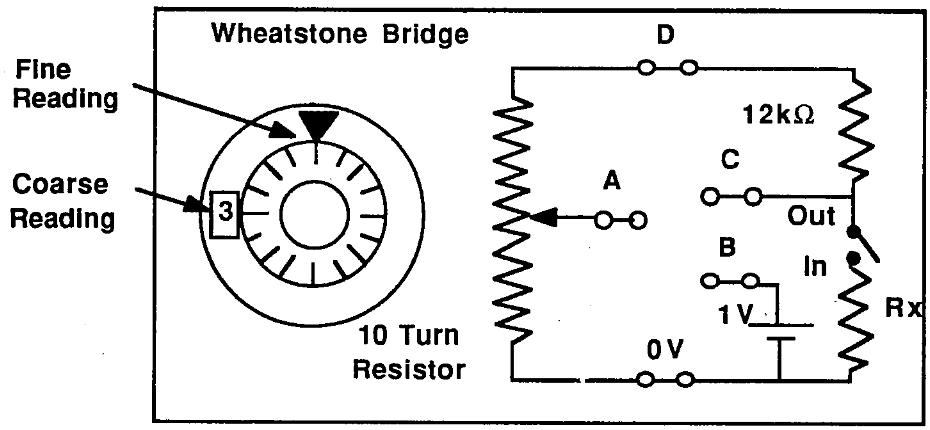


Figure 21

A 12kΩ resistor and an unknown are provided for the resistors R2 and R4 of the previous circuits.
A switch is provided to open circuit the unknown resistor and allow the measurement of other unknown resistors that can be connected between socket C and the 0V connection.

A standard voltage of 1V is available at socket B.
The 10 turn resistor is of value 10kΩ with a maximum non linearity of 0.25%. The "Fine" dial is calibrated 0 - 100 in steps of 2, and the "Coarse" reading is calibrated 0 - 10 thus enabling readings to be obtained from the dial with a resolution of 1, this representing a resolution of 10Ω.

The moving coil meter can be used as a center zero indicating instrument,but, since it is arranged as a 10V voltmeter, its sensitivity is insufficient for a direct application as a galvanometer. We can overcome this problem by using a differential amplifier followed by a high gain D.C. amplifier, Amplifier #1 or #2, to feed the voltmeter.

Notes:

Exercise 5. Measurement of Resistance using a Wheatstone Bridge Circuit

Equipment:-

1 Wheatstone Bridge unit
1 Differential amplifier
1 Amplifier #1
1 10-0-10V Moving coil voltmeter
1 10kΩ Wirewound resistor
Connecting leads.

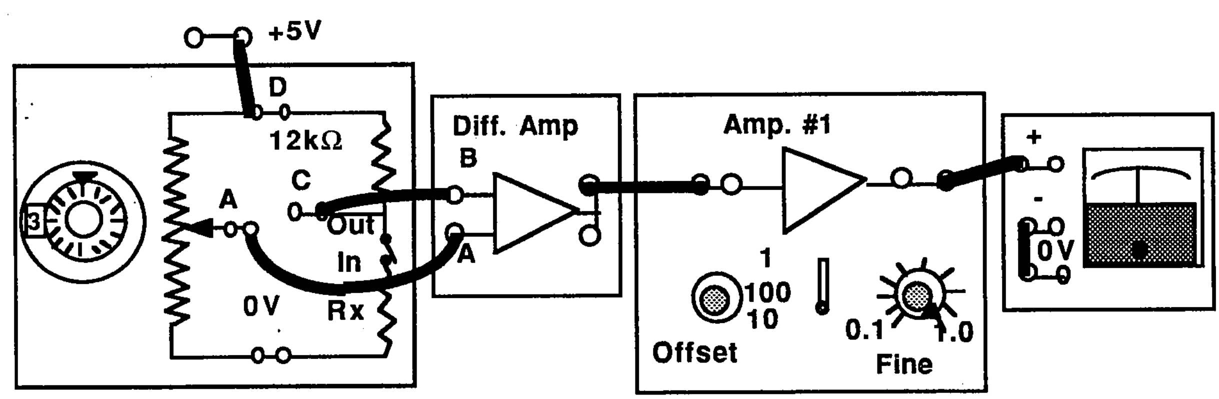


Figure 22

Initial procedure.

Fig 22 shows the complete circuit diagram required for the exercise.

We must initially set the amplifier and meter configuration which forms the sensitive galvanometer so that zero input produces zero output when the amplification is maximum.

- Connect the meter and amplifiers as shown , but with the + & - inputs to the differential amplifier short circuited with a lead so that the input is zero. Set the amplifier #1 "Coarse" gain control to 10 and the "fine" to 1.0.

- Switch the power supply ON and adjust the "offset" control so that the moving coil meter indicates approximately zero. Then set the "coarse" control to 100 and re-adjust the "offset" control for zero output precisely.

You will find this adjustment is very sensitive and is why we obtained an approximate setting first with the gain set to 10.

Note:- The setting of the offset control may require adjustment as the temperature of the unit varies during use and it is advisable to use the above procedure to check and re-adjust as necessary at regular intervals.

Resistance Measurement.

- With the switch on the Wheatstone bridge circuit set to IN, thus connecting in circuit the unknown resistor, set the amplifier #1 "coarse " control to 10 and then connect the circuit as shown in Fig 22.

- Adjust the control of the 10 turn resistor so that the moving coil meter reading is approximately zero, then set the "coarse" control to 100 and finally adjust the 10 turn resistor control accurately for zero meter reading, i.e. for bridge balanced conditions.

Note the resistor dial reading, this representing the resistance R3 in the circuits considered previously.

Dial reading =
Resistance R3 = 10 x dial reading =
Resistance R1 = 10,000 - R3 =

Resistance R2 **= 12,000Ω**

Unknown resistance R4 = $\frac{R2}{R1}$ **x R3 =**

- Carry out further resistance measurements to obtain familiarity with the equipment and its adjustments. Set the Wheatstone bridge switch to OUT to remove the unknown resistor labelled Rx from the circuit and connect the 10kΩ wirewound resistor connections A & B to the Wheatstone bridge circuit connections C & 0V.

- With the 10kΩ resistor control set fully clockwise, setting 10, measure its resistance as follows:-

  (1) Check that the amplifier offset is set correctly,and adjust if necessary.
  (2) With amplifier #1 "coarse" control set to10, obtain an approximate balance by adjusting the 10 turn resistor.
  (3) Set amplifier #1 "coarse" control to 100 and obtain final balance. Note the dial reading and enter the value in Table 7.

- Repeat the procedure to measure the resistance of the 10kΩ resistor for all the settings from 9 to 1, entering the dial readings at balance in Table 7 overleaf.

Calculate the resistance corresponding with each set of readings.

10kΩResistor Setting	Dial Reading at balance	R3 (10 x Dial)	R1 (10kΩ - R3)	R4 = $\frac{R3}{R1}$ x 12kΩ
10				
9				
8				
7				
6				
5				
4				
3				
2				
1				

Table7

The resistance values should vary in steps of approximately 1kΩ from a maximum of 11kΩ to a minimum of 1kΩ since there is a 1kΩ protective resistor included in the variable connection output circuit

Exercise 6. Measurement of Voltage using "Null Balance" Procedures (Method 1).

Equipment:-

1 10kΩ Wirewound resistor, used as the unknown voltage source.
1 Wheatstone bridge unit with 1V standard voltage source.
1 Differential amplifier + Amplifier #1 + M.C.meter, used as galvanometer
1 20V Digital voltmeter.
Connecting leads.

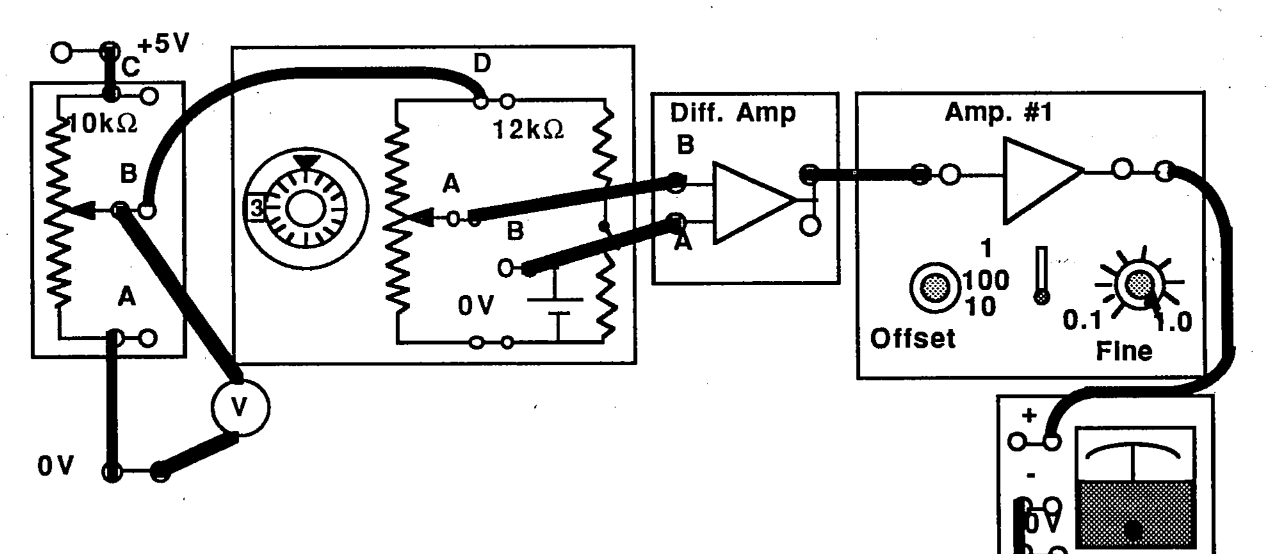


Figure 23

- Initially, set the "offset control of amplifier #1 using the same procedure used in Exercise 5. i.e. With the differential amplifier inputs connectedand amplifier #1 fine gain set 1.0, adjust the "offset" for approx. zero output with the "coarse" gain set 10 and then adjust finally for zero with the gain set 100.

- Connect the circuit as shown in Fig 23 and set the switch on the Wheatstone bridge circuit to OUT to disconnect the 12kΩ and unknown resistors from the circuit.

- Set the amplifier #1 coarse gain to 10 and set the output from the 10kΩ wirewound resistor to 4V as indicated by the digital meter, this representing the unknown voltage.

- Adjust the 10 turn resistor for approximate balance and then obtain final balance with amplifier #1 coarse gain set to 100. Note the dial reading at balance, enter the value in Table 8 and calculate the value of the unknown voltage from:-

$$\text{Unknown voltage} = \frac{1000}{\text{Dial reading}} \times \text{Standard}$$

$$= \frac{1000}{\text{Dial reading}} \times 1\text{V}$$

- Repeat the procedure with the "unknown" voltage input set to each of the values indicated in Table 8, entering the readings and calculating the voltages for each value.

"Unknown Voltage	Dial Reading At Balance	Calculated Voltage
4.0		
3.5		
3.0		
2.5		
2.0		
1.5		
1.0		

Table 8

From the readings taken ,it will be obvious that voltages less than that of the standard voltage cannot be obtained directly. The method also has the disadvantage of loading the unknown voltage source and this can be demonstrated as follows:-

- Set the "unknown " voltage to 2.0V and obtain balance conditions. This should be obtained with a dial reading of approximately 0500, thus indicating a voltage of 2.0V.
- Now remove the connection from the output of the wirewound resistor (socket B) to the Wheatstone bridge (socket D) and note the revised value of the unknown voltage as indicated by the digital voltmeter.

"Unknown" voltage
(When connected to the bridge) =
"Unknown " voltage
(Disconnected from the bridge) =

You will note that the voltage increases when the loading due to the 10 k‰ 10 turn resistor is removed.

Note:

Notes:

Exercise 7. Measurement of Voltages using "Null Balance" Procedures (Method 2)

Equipment:-

1 Wheatstone Bridge unit with 1V standard voltage source.
1 Differential amplifier + Amplifier #1+ M.C.Meter used as galvanometer
1 20V Digital voltmeter
1 10kΩ Wirewound resistor used as unknown voltage source
1 100kΩ rotary or 10kΩ carbon slider resistor used for dial calibration
Connecting leads.

You should be familiar with the procedures for initially setting the amplifier offset and balancing the bridge circuit by now, and hence the full procedures will not be repeated in this exercise.

Measurement of voltages less than the standard voltage available.

- Carry out the "offset" initiallising procedure and then connect the circuit as indicated in full lines in Fig 24 overleaf, using the 100kΩ resistor.

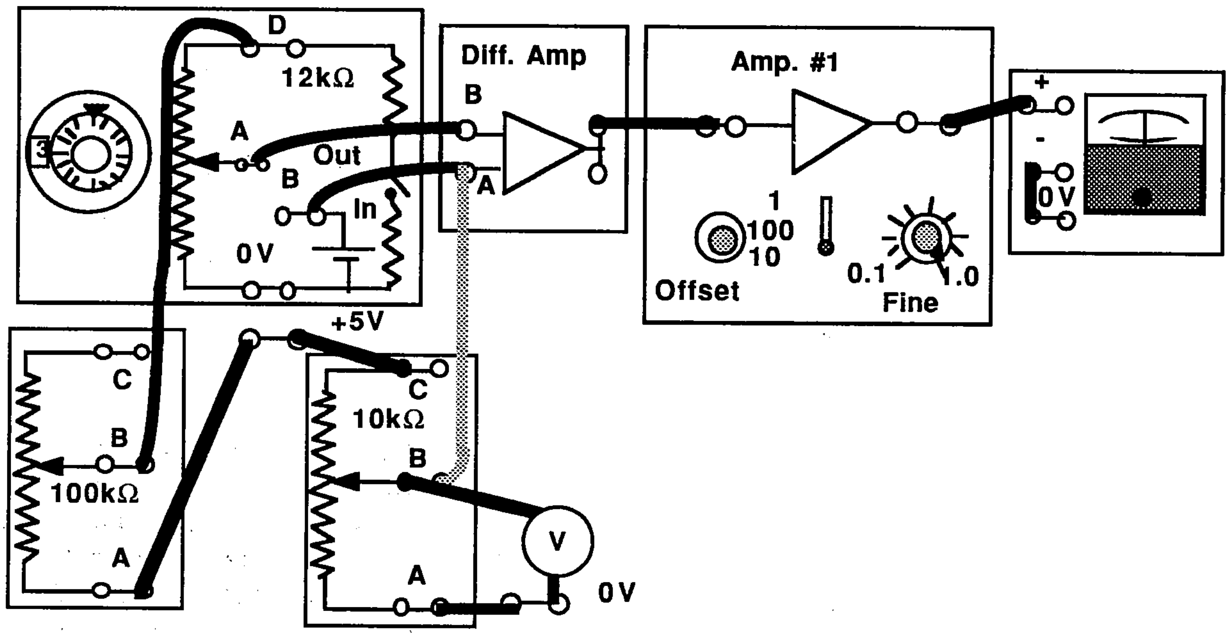


Figure 24

- Set the 10 turn resistor to its maximum setting (1000) and adjust the setting of the 100kΩ resistor for balanced conditions, i.e. null indication on the M.C. meter. Set amplifier #1 coarse gain control to 10 initially and then to 100 finally during the balancing.
When completed, the 10 turn resistor has been calibrated so that full scale reading of 1000 represents a voltage of 1.000V

- Connect the A socket of the differential amplifier to the "unknown" voltage as indicated dotted in Fig 24.

- Set the "unknown" voltage to a low value, say 0.25V, adjust the control of the 10 turn resistor for balance and note the dial reading for this balance condition. This reading will represent the unknown voltage directly.

Enter the value in Table 9 and compare with the reading indicated by the digital meter.

- Repeat the procedure for other "unknown" voltage inputs within the range 0 - 1V

"Unknown" Voltage Input	0.25						
Dial Reading At Balance							

Table 9.

Do the voltages compare ?

You will find that the equipment is very sensitive and enables voltages to be measured in 1mV steps. This enables the resolution of the 10kΩ wirewound resistor to be measured. Try this by measuring the values of the output voltage steps obtainable as the control of the 10kΩ resistor is increased from its zero setting and enter the values in Table 10.

Step Number	1	2	3	4	5	6	7	8
Output Voltage								

Table 10.

Measurement of voltages greater than the standard voltage

- Replace the 100kΩ resistor used for calibration with the 10kΩ slider unit and apply the +12V supply to the two units instead of the +5V.

- Set the control dial of the 10 turn resistor to setting 0100 and connect the A socket of the differential amplifier to socket B of the Wheatstone bridge as shown in full lines in Fig 24.

- Adjust the 10kΩ slider resistor control setting for bridge balance. When completed, the 10 turn resistance has been calibrated so that a dial reading of 0100 represents a voltage of 1.00V and a maximum dial reading of 1000 will represent a voltage of 10V.

- Connect the A socket of the differential amplifier to the B socket of the 10kΩ wirewound resistor as shown dotted in Fig 24 and apply various "unknown" voltages in the range 0 - 10V to the circuit . Note the dial reading for balance for each input voltage setting and enter the values in Table 11.

"Unknown" Voltage Input							
Dial Reading At Balance							
Measured Voltage (Volts)							

Table 11.

The loading effect of this circuit can be illustrated by setting the "unknown" output to say 5V and then noting the voltage change on the digital meter when the lead to the differential amplifier is removed.

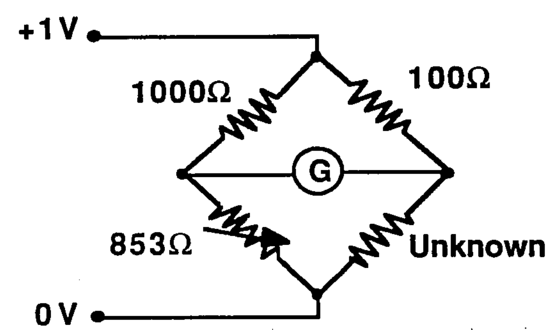
"Unknown" voltage (ouput connected to circuit) =
"Unknown" voltage (Disconnected from circuit) =

Is there any change of voltage ?

There will be a slight loading effect due to the input resistance of the differential amplifier but this is much less than the loading for the previous circuit. The loading would be zero if a sensitive moving coil galvanometer were available.

Student Assessment 3.

1 For the circuit shown, balance conditions were obtained with the values of resistance marked.



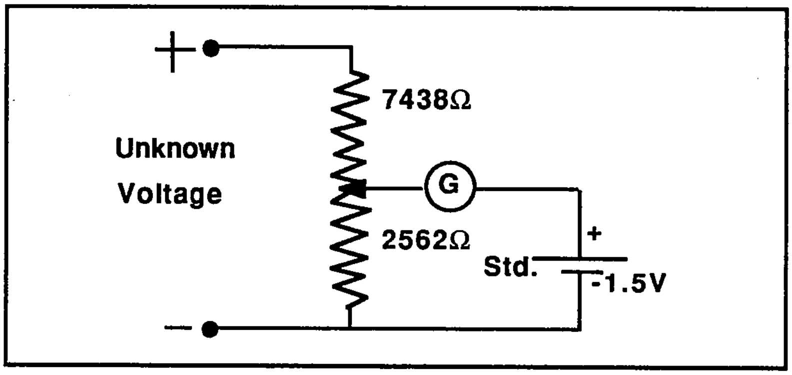
(a) What is the name given to the circuit ?
(b) Calculate the value of the unknown resistance.
(c) Would the balance condition be altered if the supply voltage were increased to 2V ?

2. State the desired characteristics of the galvanmometer used in the above circuit as regards:-
(a) Accuracy of the scale calibration,
(b) Sensitivity,
(c) Resistance.

3. A resistance transducer has a resistance variation over the range 100Ω to 120Ω. It is conneced to a Wheatstone bridge circuit using two wires, each of resistance 10Ω.
(a) What would be the range of resistance measured at the bridge ?
(b) If the transducer were connected using the three wire configuration, what range of values would now be measured if each connecting wire had resistance of 10Ω ?

Student assessment questions continued overleaf

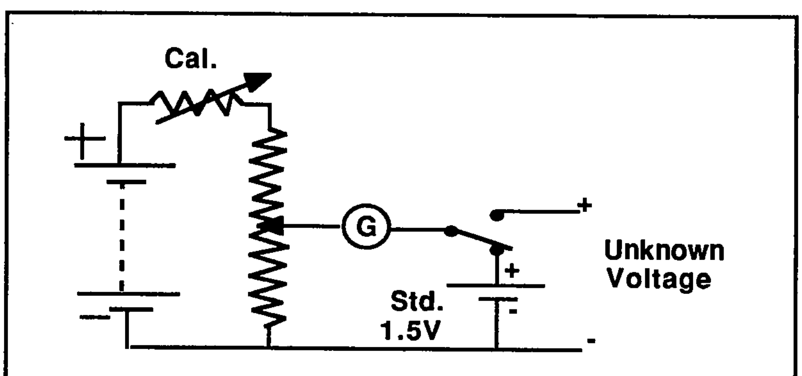
4. The circuit shown is used to measure an unknown voltage, the values shown representing balanced conditions.



(a) Calculate the value of the unknown voltage.
(b) State two disadvantages of this circuit for the measurement of voltage.
(c) What would be the effect if the polarity of the unknown voltage was reversed?

5. The circuit shown is used to measure voltage. The dial of the variable resistor has a scale range of 0 to 1000 in steps of 1. The dial is calibrated against the standard voltage with its setting set to 300.

An unknown voltage is then measured, balance conditions being obtained for a dial setting of 754. Calculate the value of the unknown voltage.



Chapter 2.3 Transducers For Temperature Measurement Applications

Objectives of this chapter.

Having studied this chapter you should:-

- *Know the basic characteristics of an I.C. temperature transducer.*
- *Have constructed a digital temperature display using the facilities of the DIGIAC 1750 unit.*
- *Know the construction and basic characteristics of a platinum R.T.D. resistance transducer*
- *Know the construction and basic characteristics of an N.T C. Thermistor*
- *Know the construction and basic characteristics of a thermocouple.*

The DIGIAC 1750 Temperature Transducer Facilities.

Fig 25 shows the layout of the temperature transducer facilities of the DIGIAC 1750 unit.
The active transducers are contained within a clear plastic container which includes a heater.
In the case of the N.T.C. thermistors and the thermocouples, a separate unit is mounted outside the heated enclosure.

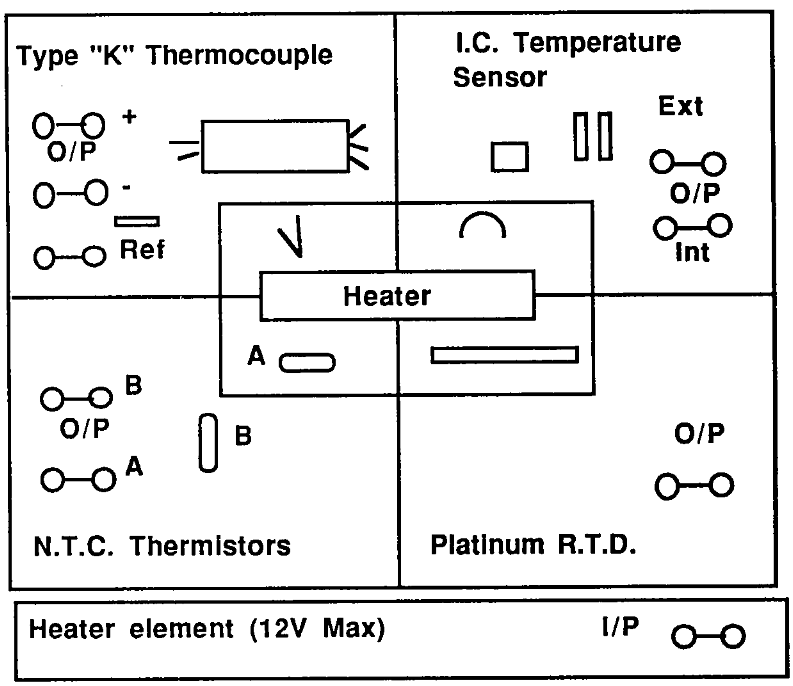


Figure 25

The I.C. Temperature Transducer.

This is an integrated circuit containing 16 transistors,9 resistors and 2 capacitors contained in a transistor type package.

The device reference number is LM 335 and it provides an output of 10mV/°K. A measurement of the output voltage therefore indicates the temperature directly in °K.
e.g. At a temperature of 20°C (293°K) the output voltage will be 2.93V.

The circuit arangement provided with the DIGIAC 1750 unit is shown in Fig 26.

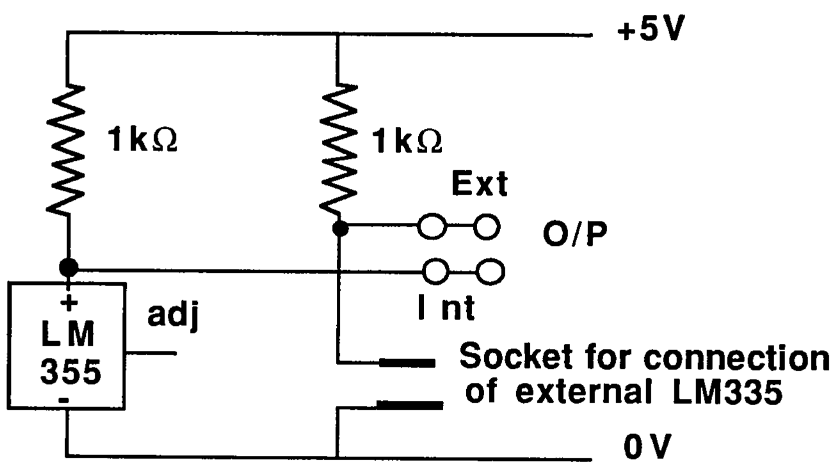


Figure 26

A 2-pin socket is provided for the connection of an external LM 335 unit if desired.
Note:- An LM 335 unit is mounted external to the heated enclosure and fitted in a heat sink with a type "K" thermocouple, its output being obtained from the "Ref" socket.

The output from this can be used as an indication of the ambient temperature outside the heated enclosure and that from the "Int" socket in Fig 26 indicates the temperature within the heated enclosure.

The output from the "Ref" socket does not give an accurate value of the room ambient temperature when the heater is in use, due mainly to heat passing along the baseboard by conduction from the heater. An LM 335 remotely mounted or some other method is necessary for accurate values of ambient temperature.

Exercise 8. The Characteristics of an LM 335 I.C. Temperature Transducer.

Equipment:-

1 LM 335 I.C. Temperature transducer
1 20V Digital voltmeter
Connecting leads.

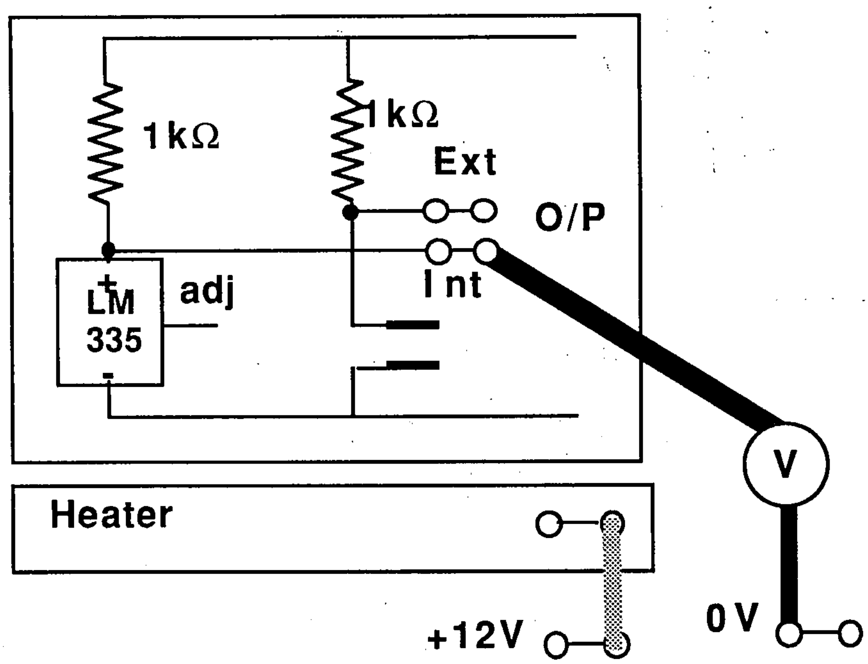


Figure 27

- Connect the voltmeter to the circuit as shown in Fig 27, switch the power supply ON and note the output voltage, this representing the temperature in °K.

- Now connect the +12V supply to the heater input socket and note the voltage reading every minute until the value stabilizes. Enter the values in Table 12.

Time (Mins)		**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
Voltage (Volts)												
Temperature	**°K**											
	°C											

Table 12.

This exercise illustrates the characteristics of the LM 335 transducer, indicates the maximum temperature rise possible using the heater supplied at 12V and also indicates the time scale required for the unit to reach stable conditions.

Notes:

Exercise 9. Construction of a Digital Thermometer using the Facilities of the DIGIAC 1750

Equipment:-

1 LM 335 I.C. Temperature transducer
1 Buffer amplifier
1 10kΩ Carbon slider resistor
1 Amplifier #1
1 V/F Converter
1 Differentiator
1 3-Digit Counter/Timer

General considerations.

The output voltage of the LM 335 is of the order of 2.93V. The V/F converter gives a frequency output of 1kHz/V The digital display has 3 digits and is capable of counting a maximum of 600 counts/s.

Reducing the LM 335 output by a factor of 10 will give an output voltage of the order of 0.293V which will result in a frequency of 293Hz being obtained from the V/F converter and this value is within the counting capability of the counter. The buffer amplifier is used to minimise the loading on the LM 335.

The 10kΩ resistor and amplifier #1 are used to set the voltage amplification during the calibration of the assembly. The differentiator is used to modify the output waveform from the V/F converter and make it more suitable for the input to the counter/timer.

- The offset control of amplifier #1 must be set correctly first. You should be familiar with the procedure by now but ,to refresh your memory , the procedure is given again.

  With the power supply switched ON, connect amplifier #1 input to 0V and connect the output to the M.C.meter + and connect the meter - socket to 0V.

  With amplifier #1 fine gain set 1.0 and coarse gain set 10 adjust the offset control for approximate zero output and then set the coarse gain to 100 and adjust for zero output.

  Set amplifier coarse and fine gain controls to 1 and 0.1 respectively.

- Connect the circuit as shown in Fig 28, set the 10kΩ slider fully to the right, the differentiator time constant to 1s and the counter controls to "count" and 1s.

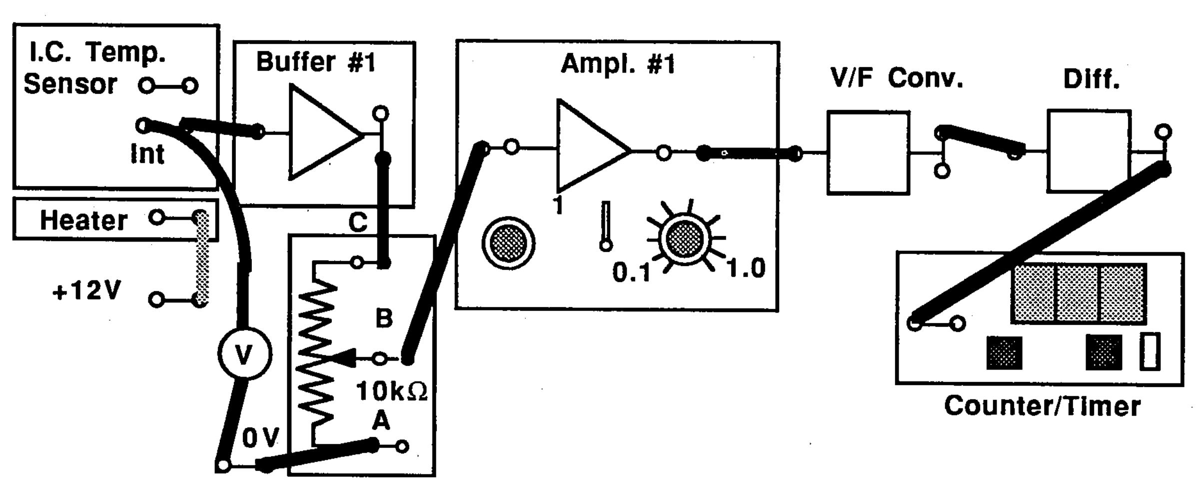


Figure 28

- Note the voltmeter reading and then press the "Reset" button of the counter and note the final displayed value.Compare this with the voltmeter reading.

  (a) If the displayed value exceeds the voltmeter reading,reduce the setting of the 10kΩ slider slightly and then press the reset button of the counter again and note the revised display. Compare this with the voltmeter reading. Repeat the process if necessary until the display and voltmeter readings are the same.

  (b) If the displayed value is less than the voltmeter reading, increase the "Fine" gain setting of amplifier #1 slightly and then press the "reset" button of the counter and note the revised display. Repeat the procedure as necesary until the display and voltmeter readings are the same.

The assembly should now be calibrated so that the 3-digit counter displays the temperature at the instant the reset button is pressed.

- Connect the 12V supply to the heater input, note the voltage indicated by the voltmeter, press the counter "reset" button and note the displayed value. Enter the values in Table 13.

- Repeat the process, noting the values of the voltmeter and counter displayed readings for comparison at intervals as the temperature increases. Enter the values in Table 13.

Voltmeter Reading									
Counter Display									

Table 13.

This exercise has illustrated the use of some of the other facilities available with the DIGIAC 1750 unit.

Do the readings compare ?

The readings may not be identical over the full range, but they will be sufficiently accurate to illustrate the basic principle. The accuracy depends on the accurate setting of the V/F converter.

The Platinum R.T.D. (Resistance Temperature Dependent) Transducer.

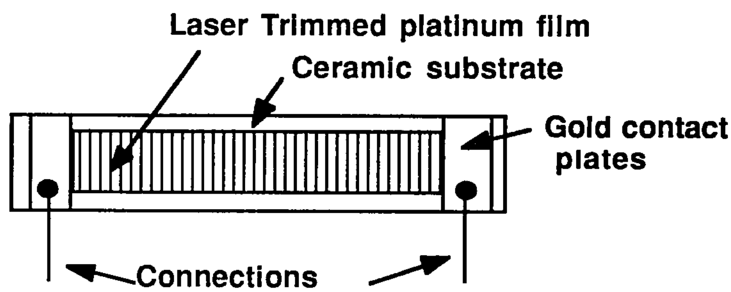


Figure 29

The construction of the platinum R.T.D. transducer is shown in Fig 29, consisting basically of a thin film of platinum deposited on a ceramic substrate and having gold contact plates at each end that make contact with the film.

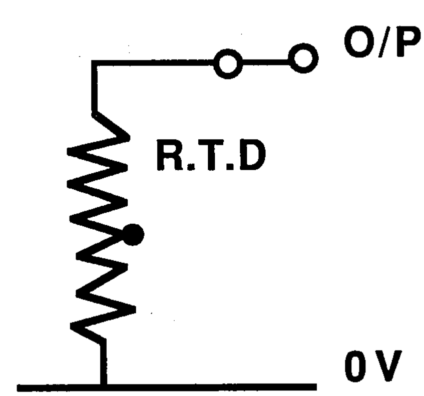
The platinum film is trimmed with a laser beam so that the resistance is 100Ω at 0°C.

The resistance of the film increases as the temperature increases, i.e. it has a positive temperature coefficient. The increase in resistance is linear, the relationship between resistance change and temperature rise being 0.385Ω/°C for the unit.

$R_t = R_o + 0.385t$
Where R_t = Resistance at temperature t°C
R_o= Resistance at 0°C = 100Ω

Normally, the unit would be connected to a D.C. supply via a series resistor and the voltage developed across the transducer is measured. The current flow through the transducer will then cause some self heating, the temperature rise due to this being of the order of 0.2°C /mW dissipated in the transducer.

The electrical circuit arrangement of the DIGIAC 1750 unit is as follows:-



Notes:

Exercise 10. The Characteristics of a Platinum R.T.D. Transducer.

Equipment:-

1 Platinum R.T.D. transducer
1 10kΩ Wirewound resistor
1 2/20V range Digital voltmeter
1 LM 335 I.C. temperature transducer .
Connecting leads.

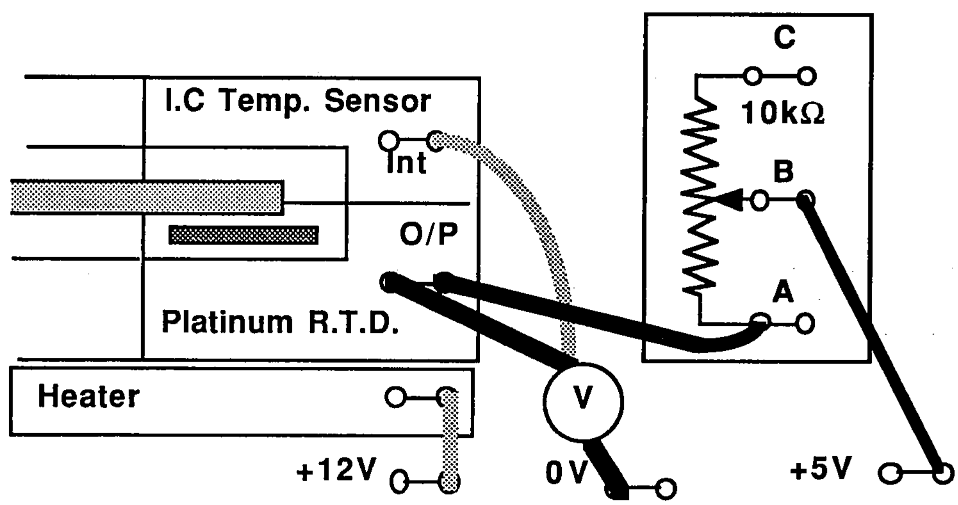


Figure 30

In this exercise we will connect the platinum R.T.D. in series with a high resistance to a D.C. supply and measure the voltage drop across it. Due to the small variation of resistance, the curr
ent change will be negligible and the voltage drop across the transducer will be directly proportional to its resistance.

- Connect the circuit as shown in Fig 30, with the voltmeter set to its 2V D.C. range.

- With the power supply switched ON, adjust the control of the 10kΩ resistor so that the voltage drop across the platinum R.T.D. is 0.108V as indicated by the digital voltmeter. This calibrates the platinum R.T.D. for an ambient temperature of 20°C, since the resistance of the R.T.D. at 20°C will be 108Ω.

  Note:- If the ambient temperature differs from 20°C, the voltage can be set to the correct value for this ambient temperature if desired.
  (1) Set the voltmeter to its 20V range and measure the output from the I.C. temperature transducer to obtain the ambient temperature in °K. Then °C = (°K - 273)
  (2) R.T.D. resistance = 100 + 0.385 x °C. Set the voltage drop across the R.T.D for this value.

- Now connect the +12V supply to the heater input and note the values of the voltage across the R.T.D.with the voltmeter set to its 2V range,(this representing the R.T.D. resistance) and the output voltage from the temperature transducer with the voltmeter set to its 20V range, (this representing the temperature of the R.T.D.).

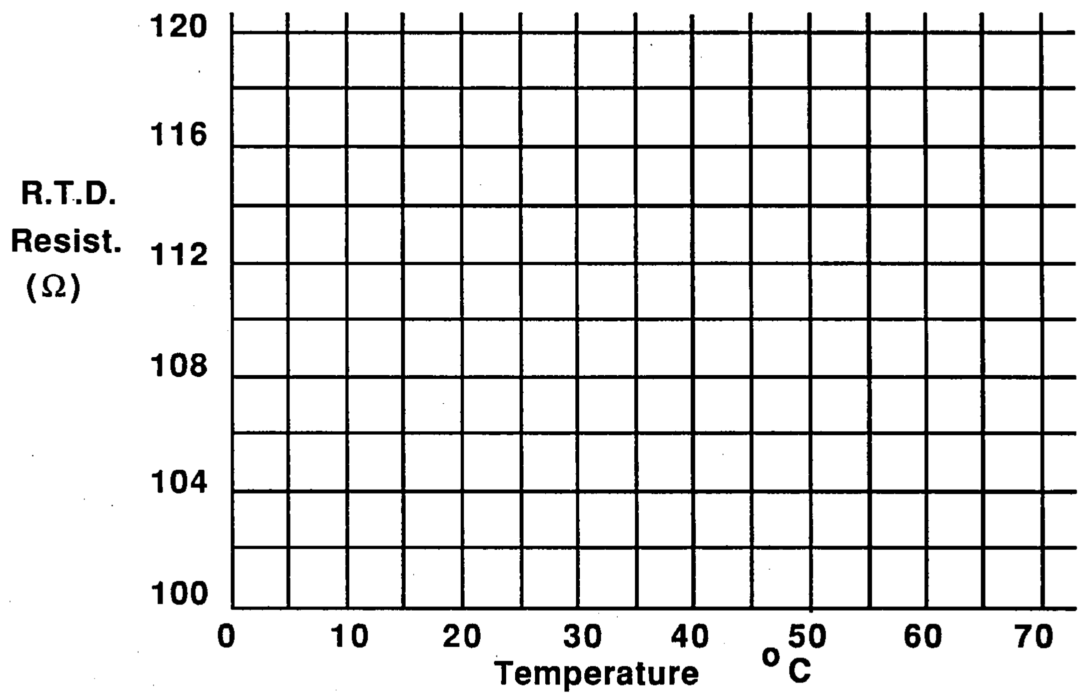
  Enter the values in Table 14.

- Repeat the readings at 1 minute intervals and enter the values in Table 14.

Time (minute)		0	1	2	3	4	5	6	7	8	9	10
R.T.D. Temperature	°K											
	°C											
R.T.D. Resistance												

Table 14.

Plot the graph of R.T.D. resistance against temperature on the axes provided.



Is the resistance/temperature characteristic linear ?

Is the resistance 100Ω at 0°C ?

During the exercise, the current flowing was of the order of 1 mA and the total circuit resistance was of the order of 5kΩ. The variation of 12Ω approx. in the R.T.D. transducer therefore had little effect on the circuit current and hence the voltage drop across it represented the resistance value reasonably accurately.

The current of 1mA in the R.T.D. represents a power of the order of 0.1mW dissipated in the R.T.D. so that the self heating effect would produce a temperature rise of 0.02°C which is negligible.

The N.T.C. (Negative Temperature Coefficient) Thermistor.

The construction of the N.T.C. thermistor is shown in Fig 31, consisting basically of an element made from sintered oxides of metals such as nickel, manganese and cobalt and with contacts made to each side of the element.

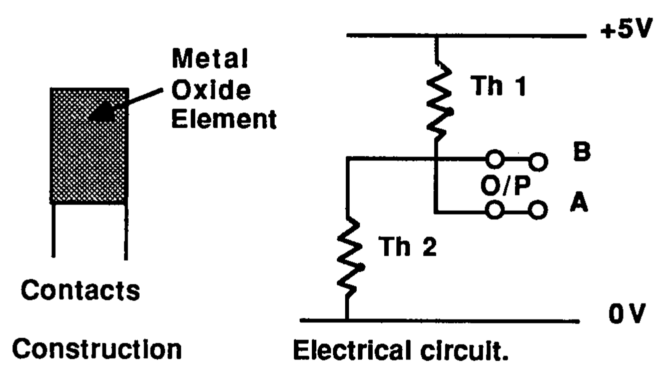


Figure 31

As the temperature of the element increases, its resistance falls, the resistance/temperature characteristic being non-linear.

The resistance of the thermistors provided with theDIGIAC 1750 unit is of the order of 5kΩ at an ambient temperature of 20°C (293°K).

The relationship between resistance and temperature is given by the formula:-

$$R2 = R1e^{\left(\frac{B}{T2} - \frac{B}{T1}\right)}$$

Where R1 = Resistance at temperature T1°K
R2 = Resistance at temperature T2°K
e = 2.718
B = Characteristic temperature = 4350°K

Two similar units are provided, one being mounted inside the heated enclosure, this being connected to the +5V supply and designated A. The other is mounted outside the heated enclosure, is connected to the 0V connection and is designated B. The circuit arrangement is shown in Fig 31.

Notes:

Notes:

Exercise 11. The Characteristics of an N.T.C. Thermistor.

Equipment:-

2 Thermistors A & B
1 10kΩ 10 turn resistor (From the Wheatstone Bridge circuit)
1 20V Digital voltmeter
1 LM 335 I.C. Temperature transducer (To indicate the temperature)
Connecting leads.

Resistance measurement method.

The resistance of the N.T.C thermistor varies over the range 5k to 1.5kΩ approximately for the temperature range available within the heated enclosure for an ambient temperature of 20°C. For this large range we cannot use the method we used in exercise 10 to measure the resistance. Also, if readings are to be taken at regular intervals of 1 minute, the readings of resistance must be obtained with the minimum of time.

The method used connects the thermistor in series with a calibrated resistor to the +5V supply. For each reading, the variable resistor is adjusted until the voltage at the junction of the thermistor and resistor is half the supply value. For this setting there will be the same voltage drop across the thermistor and the resistor and their resistances will be equal, and hence the value of the resistance read from the calibrated resistor scale represents the resistance of the thermistor.

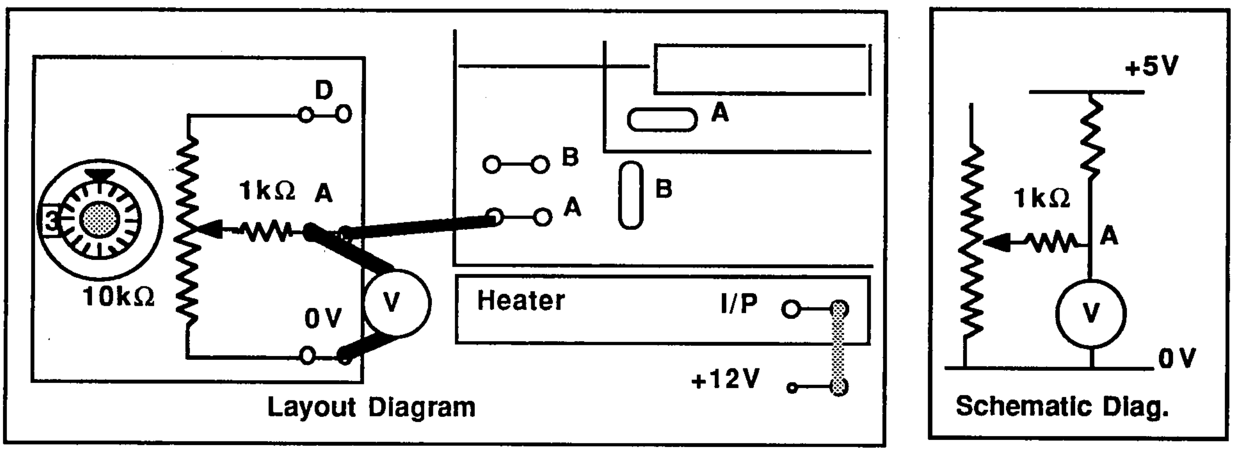


Figure 32

- Connect the circuit as shown in Fig 32, set the switch on the Wheatstone bridge circuit to OUT to disconnect the 12kΩ and Rx resistors from the circuit and set the resistor dial reading to 500 approximately.

- Switch the power supply ON, adjust the resistor control until the voltage indicated by the voltmeter is 2.5V and then note the dial reading and the temperature, by connecting the voltmeter temporarily to the "Int" socket of the I.C. temperature transducer.

  Note:- Since there is a 1kΩ resistor in the output lead of the resistance, the total resistance in the resistance circuit will be of value (10 x Dial reading + 1kΩ)

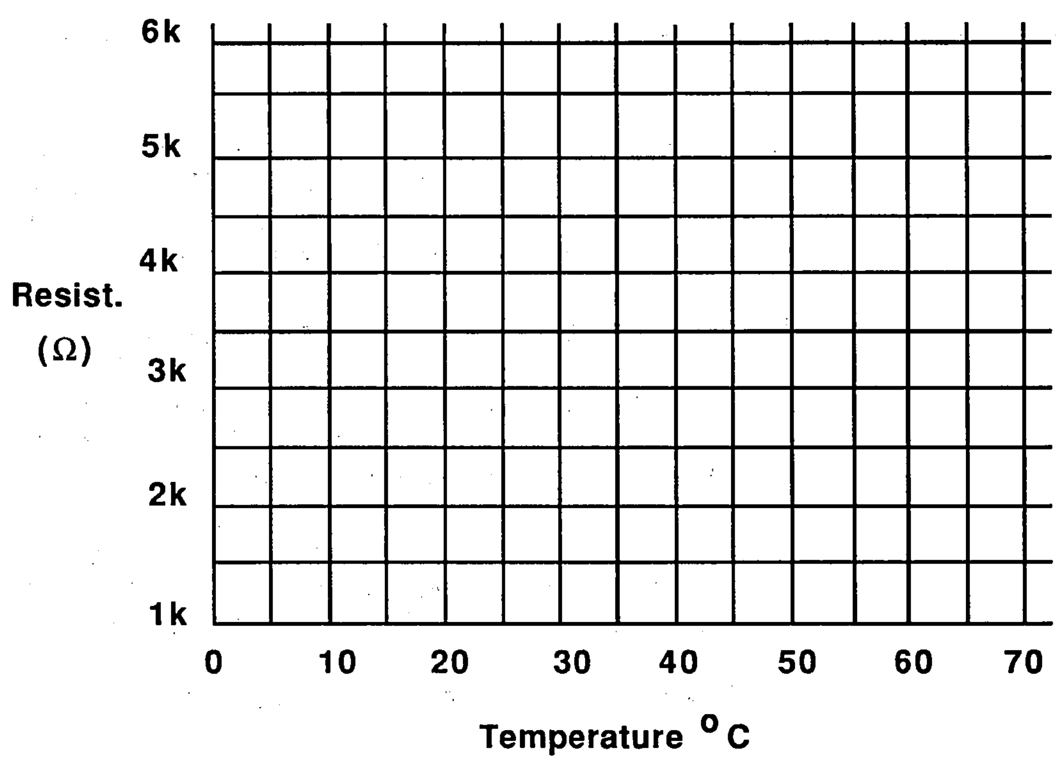
  Enter the values of dial reading and temperature in Table 15.

- Now connect the 12V supply to the heater input socket and, at 1 minute intervals, note the values of the dial reading to produce 2.5V across the resistance and also the temperature. Enter the values in Table 15.

Time (Minutes)		0	1	2	3	4	5	6	7	8	9	10
Temperature	°K											
	°C											
Dial reading for 2.5V												
Thermistor resistance												

Table 15.

Plot the graph of thermistor resistance against temperature on the axes provided.



Note that the graph is non-linear, with the resistance falling as the temperature increases.

The unit is not suitable for applications where an accurate indication of temperature is required, but is more suitable for applications in protection and alarm circuits where an indication of temperature exceeding a certain safe value is required.

Units are available having a rapid change of resistance when the temperature exceeds a certain value.

The resistance of the N.T.C. thermistor B which is mounted outside the heated enclosure does not remain constant, due mainly to conduction of heat from the heater along the baseboard and this reduces its resistance.

We cannot use the same procedure as for thermistor A to measure its resistance because the 10 turn resistor and thermistor B are both connected to the 0V supply connection. We can measure its resistance using the Wheatstone Bridge method but we will have no means of measuring the temperature of the unit.

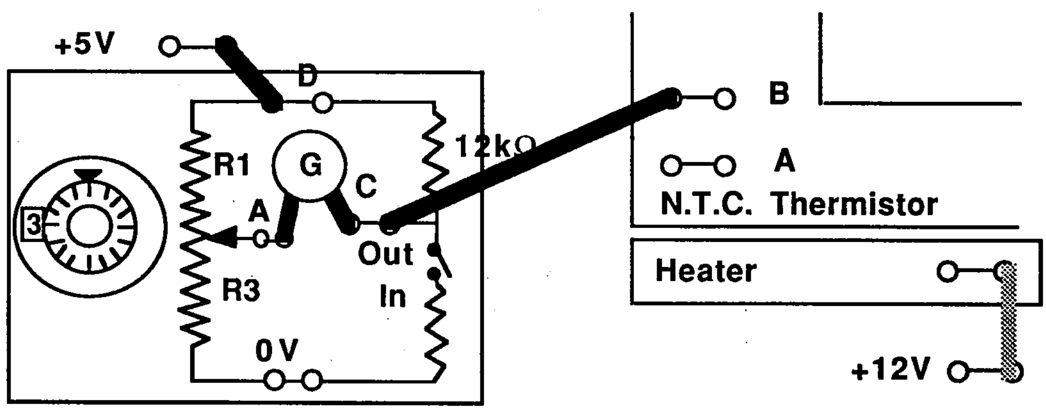


Figure 33

- Connect the circuit as shown in Fig 33 and set the switch on the Wheatstone bridge circuit to OUT.Use either the digital voltmeter or the combination of differential amplifier, amplifier #1 and moving coil meter as the galvanometer.

- Balance the bridge for conditions with the thermistor B (a) cold and (b) hot and calculate its resistance for each condition.

N.T.C. Thermistor cold:-

R3 at balance =

R1 at balance = 10,000 - R3 =

Thermistor B resistance = $\frac{R3}{R1} \times 12k\Omega =$

N.T.C. Thermistor Hot::-

R3 at balance =

R1 at balance = 10,000 - R3

Thermistor B resistance = $\frac{R3}{R1} \times 12k\Omega =$

When used for alarm or protection circuits, two thermistors would normally be used, these being connected in a bridge circuit as shown in Fig 34.

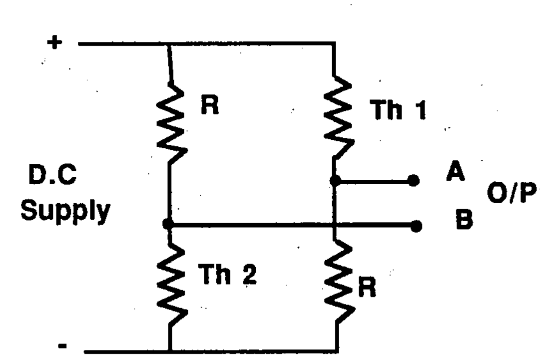


Figure 34

The two thermistors and two equal value resistors R having the same value resistance as the "cold" resistance of the thermistors are connected in the bridge circuit shown in Fig 34.

When cold, there will be no output at the connections AB because the bridge will be balanced under this condition.

As the temperature rises, the thermistor resistance will decrease and the potential of connection A will rise and that of connection B will fall, thus giving a larger output than would be obtained with a circuit using only one thermistor.

Notes:

Exercise 12. The Characteristics of N.T.C. Bridge Circuits with (a) one & (b) two active Thermistors.

Equipment:-

2 N.T.C. Thermistors
1 10kΩ 10 turn resistor
1 10kΩ Carbon slider resistor
1 10kΩ Wirewound resistor
1 20V Digital voltmeter
Connecting leads

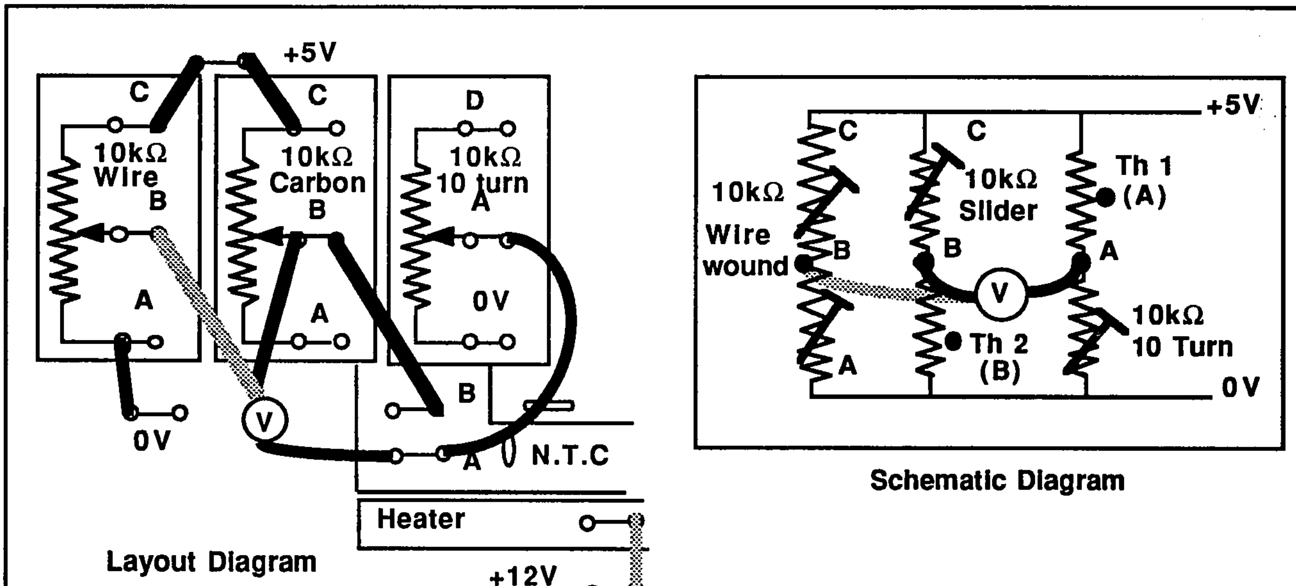


Figure 35

Th1, the 10kΩ 10 turn resistor and the 10kΩ wirewound resistor form the bridge circuit with one active thermistor.

Th1, the 10kΩ 10 turn resistor, Th2 and the 10kΩ carbon resistor form the bridge with two active thermistors.

- Connect the circuit as shown in Fig 35 and set the switch on the Wheatstone Bridge circuit to OUT.

■ Connect the voltmeter between the N.T.C. "A" socket and 0V. Switch the power supply ON and adjust the 10kΩ 10 turn resistor so that the voltmeter reading is 2.5V. The 10kΩ resistor and thermistor Th1 are now set for the same resistance.

■ Now connect the voltmeter between the N.T.C. "A" socket and the "B" socket of the 10kΩ wirewound resistor and adjust the control of the wirewound resistor for a voltage reading of zero.

■ Connect the voltmeter between the N.T.C. "A" socket and the "B" socket of the 10kΩ carbon slider resistor and adjust the slider position for an output voltage of zero.

Both bridges are now set for zero output with the thermistors at ambient temperature.

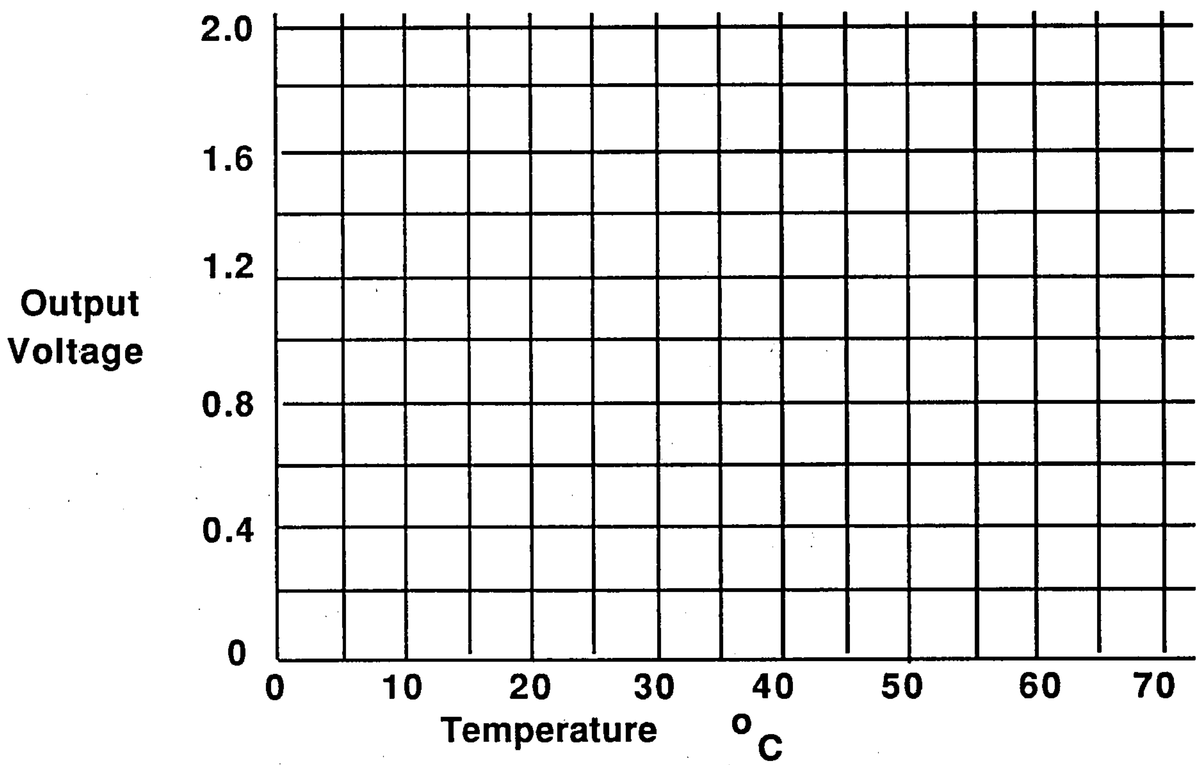
Note the temperature by measuring the voltage output from the "Int" socket of the I.C. temperature transducer and enter the value in Table 16.

■ Now connect the 12V supply to the heater input and at 1 minute intervals, note the temperature and the output voltages from each bridge circuit. The output voltages are measured between the N.T.C. socket "A" and the "B" sockets of the 10kΩ wirewound and 10kΩ carbon slider resistors. Enter the values in Table 16.

Time (Minutes			0	1	2	3	4	5	6	7	8	9	10
Temperature		°K											
		°C											
Bridge Output	1Active N.T.C												
	2Active N.T.C												

Table 16

Draw graphs of output voltage against temperature for the two bridge circuits on the same axes provided as follows.



Note that the output with two active thermistors exceeds that with only one thermistor. If both active thermistors were at the same temperature, the output would be twice that for one active thermistor.

Is the relationship linear ?

The Type "K" Thermocouple Temperature Transducer.

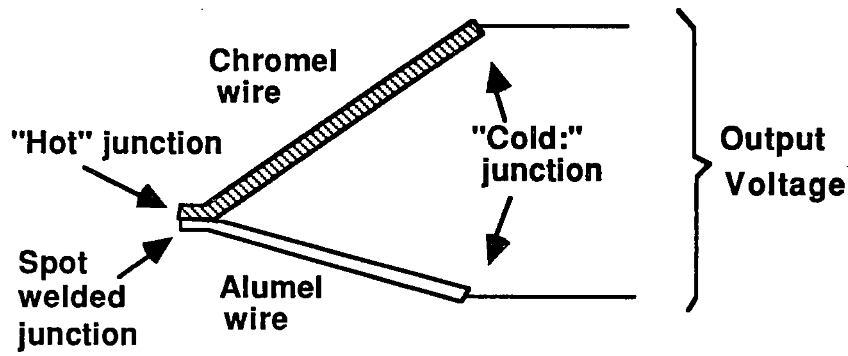


Figure 36

Fig 36 shows the basic construction of a thermocouple, consisting of two wires of different materials joined together at one end.

For the type "k" thermocouple the two materials are alumel and chromel.

With this arrangement, when the ends that are joined together are heated, an output voltage is obtained between the other two ends.

The ends that are joined together are referred to as the "hot" junction and the other ends are referred to as the "cold" junction.

The magnitude of the output voltage depends on the temperature diffference between the "hot" and "cold" junctions and on the materials used. For the type "K" thermocouple the output voltage is fairly linear over the temperature range 0 - 100°C and of magnitude 40.28 µV/°C difference between the "hot" and "cold" junctions.

Two thermocouples are provided with the DIGIAC 1750 unit, one being mounted within the heated enclosure, this being the active unit which will have its "hot" and "cold" junctions at different temperatures in operation.

The other unit is mounted outside the heated enclosure and is incorporated in a heat sink with an LM 335 I.C. temperature transducer so that the temperature of the "cold" junction of the active thermocouple can be measured. This second thermocouple is connected in series with the first with the wires of the same material connected together. This ensures that the connections to the output circuit are made from the same material and thus eliminates the possibility of an e.m.f. being introduced into the circuit by connections between different materials.

The second thermocouple does not contribute to the output voltage because its "hot" and "cold" junctions are maintained at the same temperature.

The circuit arrangement is as shown in Fig 37.

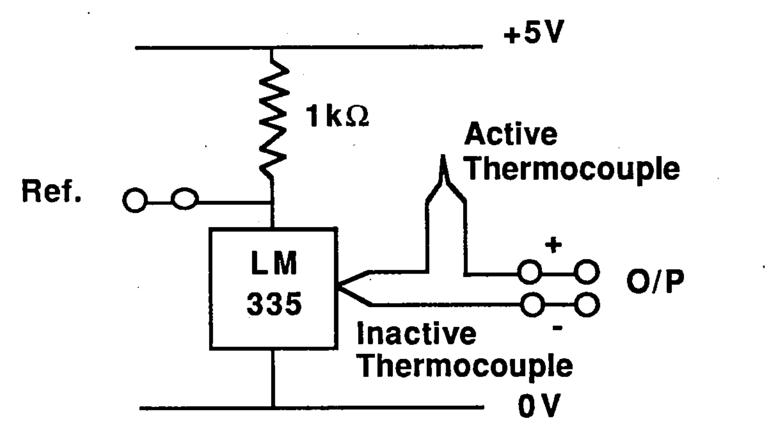


Figure 37

Due to the low voltage output, the output requires amplification, an amplification factor of 248 giving an output of 10mV/°C

During operation, the temperature of the "cold" junction varies,due mainly to heat conduction from the heater along the baseboard and the junction is in effect "floating".This is a common occurrance with thermocouple installations where the thermocouple leads are short.

To overcome the problem, extra leads of the same material or different materials having the same thermoelectric properties are used to extend the "cold" junction to a point where a steady temperature can be maintained. These cables are refered to as "Compensating cables".

Notes:

Exercise 13. The Characteristics of a "K" Type Thermocouple.

Equipment:-

1 Type "K" Thermocouple
1 Instrumentation amplifier
1 x 100 amplifier
1 Amplifier #1 with gain set 2.5 approximately
1 2/20V Digital voltmeter
Connecting leads.

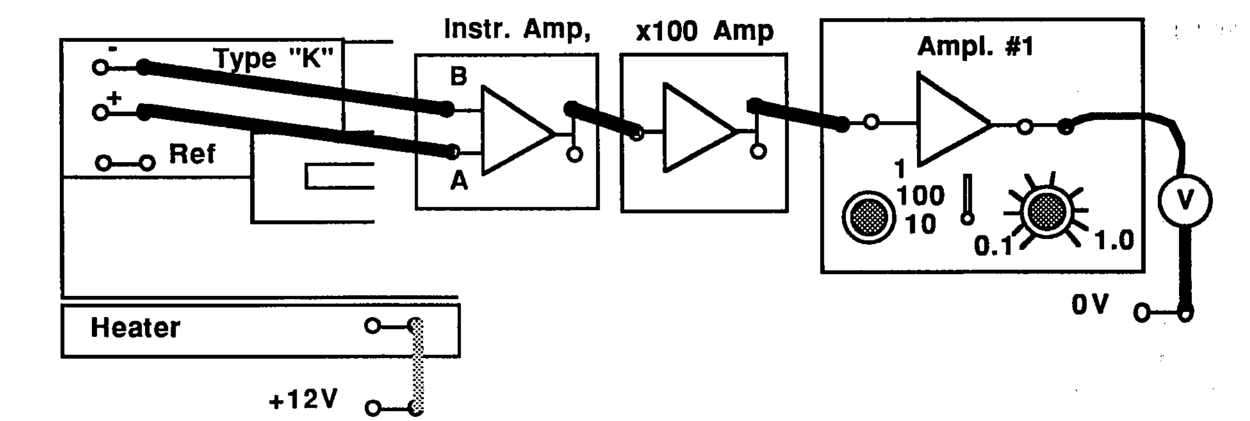


Figure 38

- Connect the circuit as shown in Fig 38, set the voltmeter to its 2V range and set amplifier #1 coarse and fine gain controls to 10 and 0.25 respectively.

- Switch the power supply ON and then set the offset control of amplifier # as follows.

  Short circuit the input connections to the instrumentation amplifier and adjust the offset control for zero indication on the voltmeter.

- Re-connect the thermocouple output to the instrumentation amplifier as shown in Fig 38. The output voltage should still be zero with the "hot" and "cold" junctions at the same temperature.

- Note the temperatures of the inside and outside of the enclosure (cold junction) by setting the voltmeter to its 20V range and then measuring the voltage output from the "Int" socket of the I.C. temperature transducer and then from the "Ref" output socket of the LM 335 provided on the type "K" thermocouple unit. Enter the values in Table 17.

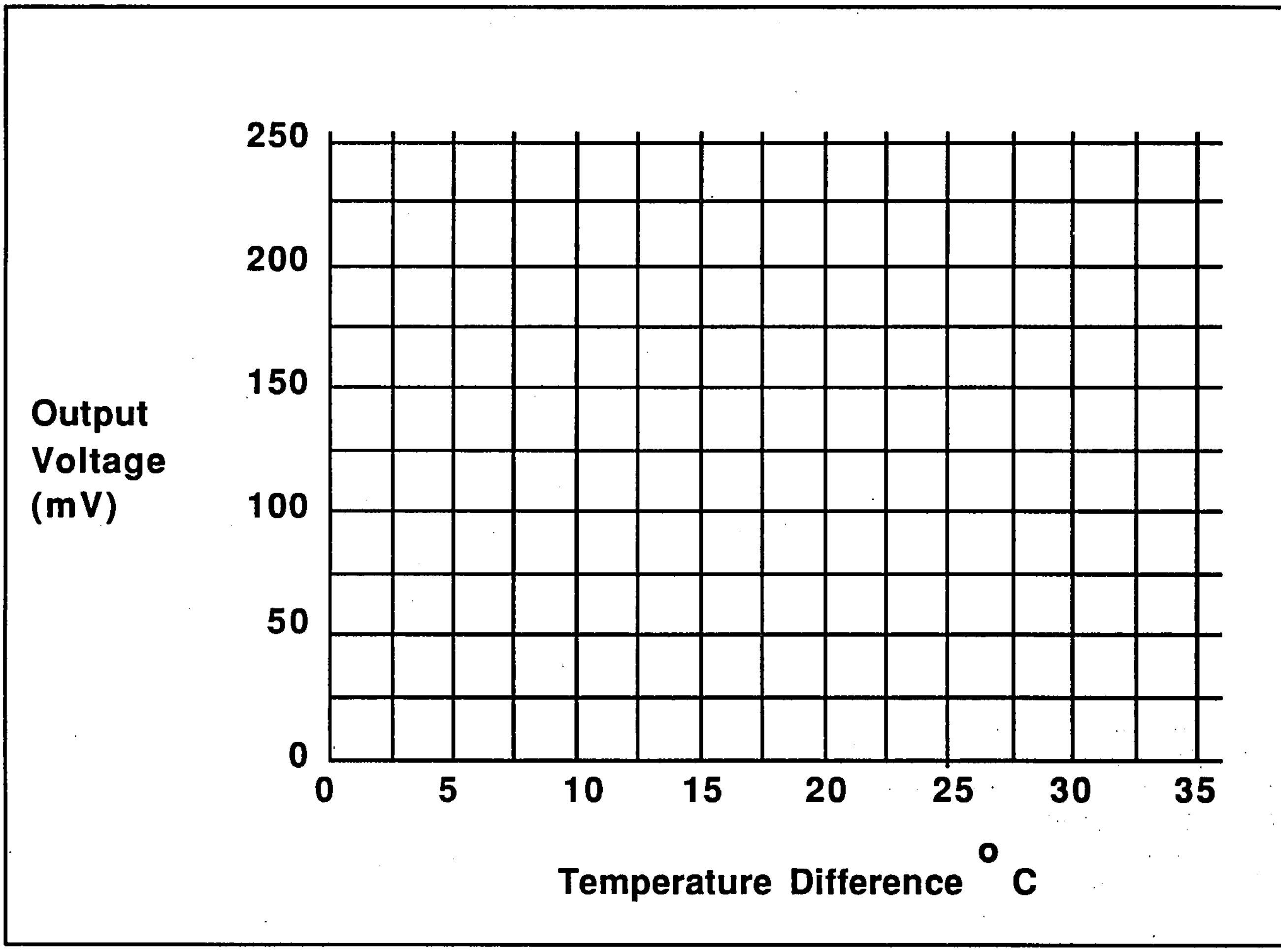
- Connect the 12V supply to the heater and at 1 minute intervals, note the values of the thermocouple output voltage and the voltages representing the temperatures of the "hot" and "cold" junctions of the thermocouple.

  Enter the values in Table 17.

Time (Minutes)		0	1	2	3	4	5	6	7	8	9	10
Temp. °K	Hot junction											
	Cold junction											
	Difference											
Thermocouple O/P(mV)												

Table 17.

Construct the graph of thermocouple output voltage against temperature difference between the "hot" and "cold" junctions on the axes provided.



Is the characteristic linear ?
If so, what is the relationship in mV/°C ?

The actual value will depend on the actual amplification provided by the amplifier system at the settings used.

Notes:

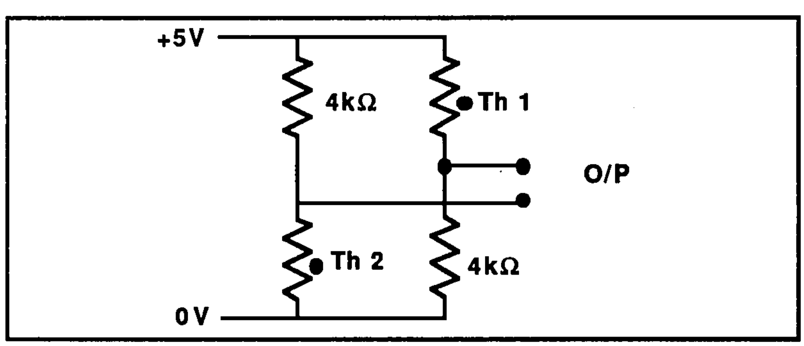
Student Assessment 4.

1. State the output voltages you would expect to obtain from an LM 335 temperature transducer at the following temperatures:-
   (a) 0°C
   (b) 50°C
   (c) -20°C

2. A platinum R.T.D. transducer has resistance of 100Ω at 0°C and 138Ω at 100°C
   (a) What would be its resistance at 50°C ?
   (b) What temperature would be represented by a resistance of 115.2Ω ?

3. The resistance of an N.T.C. thermistor is 5kΩ at 20°C and 1kΩ at 100°C. When its temperature is 60°C, state with reasons whether you would expect its resistance to be:-
   (a) 4kΩ
   (b) 3kΩ or
   (c) 1.8kΩ

4. Two thermistors having resistance 4kΩ at 20°C and 1kΩ at 60°C are connected in the bridge circuit shown. What would be the output voltage from the circuit at temperatures of:-
   (a) 20°C
   (b) 60°C



Student assessment questions continued overleaf

5. A thermocouple gives an output of 40 V for each °C difference in temperature between the "hot" and "cold" junctions. State the output voltages expected for the junction temperatures given below:-

	Cold	Hot
(a)	0°C	50°C
(b)	20°C	70°C
(c)	50°C	50°C
(d)	-20°C	60°C

What amplifier gain would be required to enable the thermocouple to produce an output of 1V for a temperature difference of 100 °C between the "hot" and "cold" junctions ?

Notes:

Chapter 2.4 Transducers For Light Measurement Applications

Objectives of this chapter:-

Having studied this chapter you should:-

- *Know the construction and basic characteristics of a photovoltaic cell.*
- *Know the construction and basic characteristics of a phototransistor.*
- *Know the construction and basic characteristics of a photoconductive cell.*
- *Know the construction and basic characteristics of a P.I.N. photodiode*

Facilities provided with the DIGIAC 1750 unit.

Fig 39 shows the arrangement of the light transducers provided with the DIGIAC 1750 unit.

The transducers are contained within a clear circular container and are illuminated by a lamp which is placed centrally.

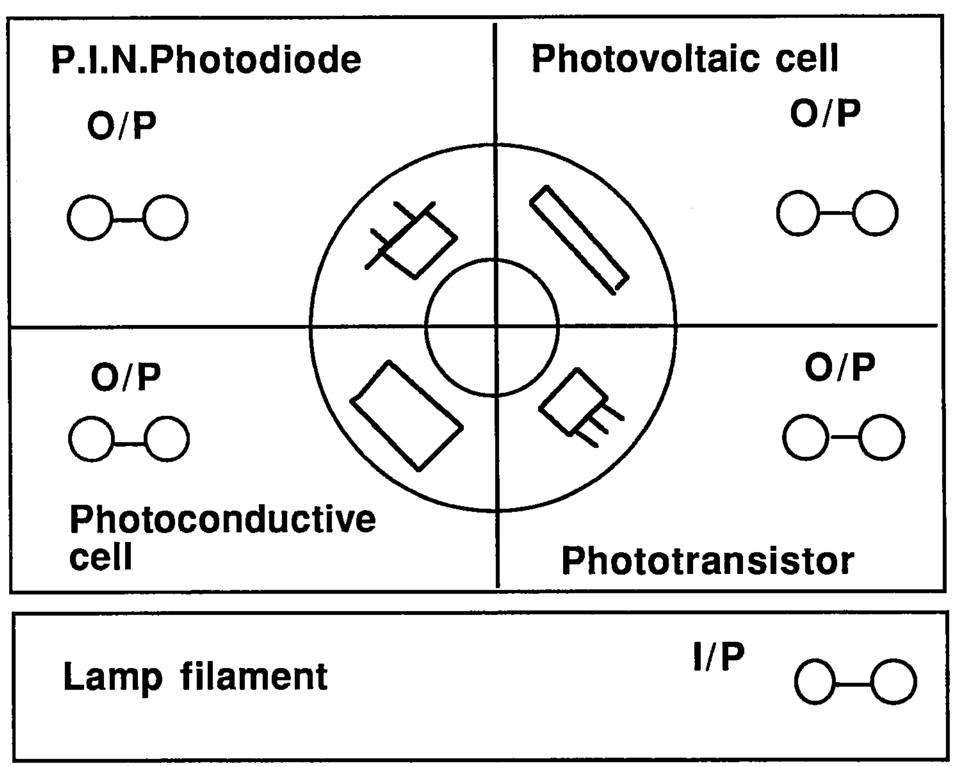


Figure 39

The Photovoltaic cell.

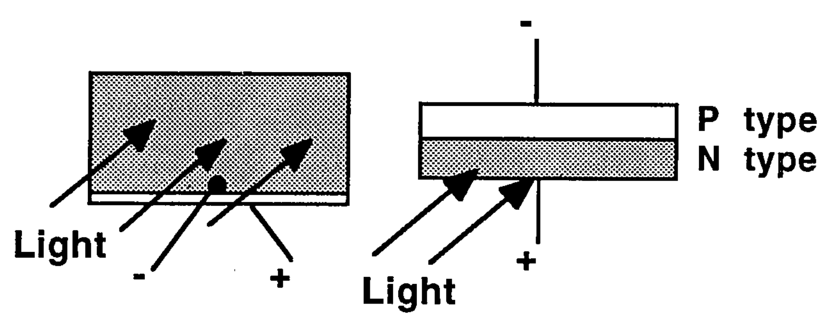


Figure 40

Fig 40 shows the basic construction of a semiconductor photovoltaic cell, consisting basically of a two layer silicon device.
A thin layer of P-type material is formed on an N-type substrate.
When light falls on the junction of the two materials, a voltage is developed with the N-type material positive with respect to the P-type.
The output voltage depends on the magnitude of the light falling on the device and is a maximum of the order of 0.6V.
With a load resistance connected to the output , a current will flow. The magnitude of the current depends on the magnitude of the light falling on the device and on the surface area of the device.

Series-parallel connection of the cells can be used to increase the magnitude of the voltage and current capabilities if desired.
Devices used for energy production are referred to as "Solar cells".

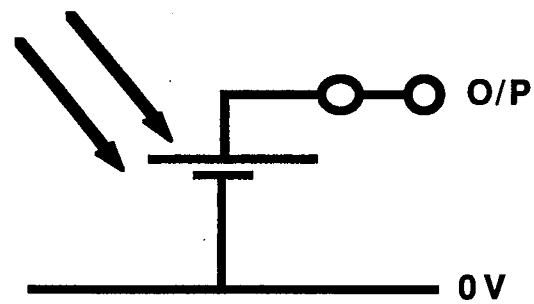


Figure 41

Fig 41 shows the circuit arrangement for the DIGIAC 1750 unit.

The main characteristics of the device are as follows:-

Type	**MS5B**
Open circuit voltage (In sunlight)	500mV
Short circuit current (In sunlight)	10mA
Peak spectral response wavelength	840nm (I.R.)
Response time	10 μs
I.R. = Infra red.	

Exercise 14. Characteristics of a photovoltaic cell.

Equipment:-

1 Photovoltaic cell
1 10kΩ wirewound resistor
1 Power Amplifier
1 2V Digital voltmeter
1 10-0-10V M.C. Meter

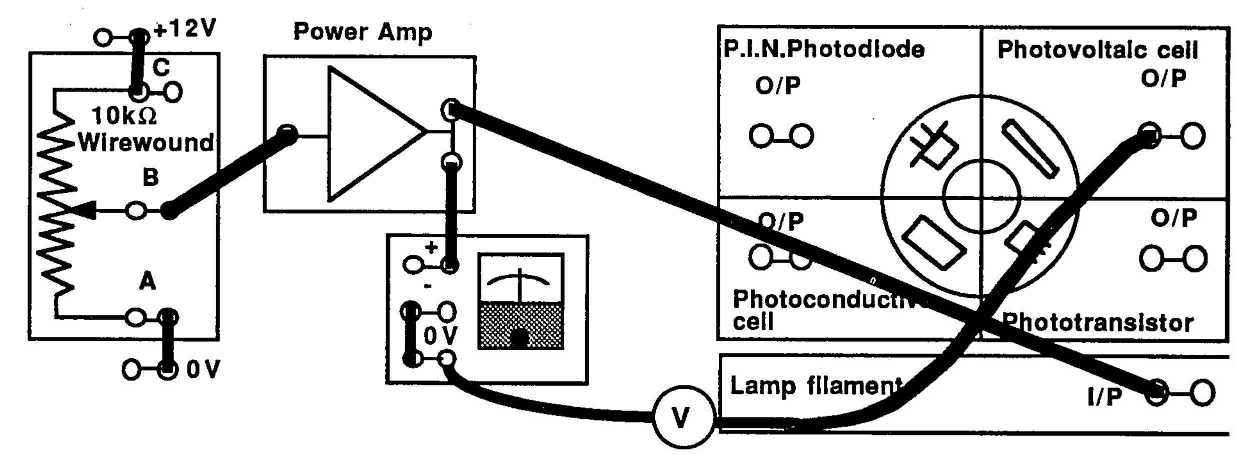


Figure 42

- Connect the circuit as shown in Fig 42.
- With the power supply switched ON, set the control of the 10kΩ wirewound resistor for zero output voltage from the power amplifier. Note the output voltage from the photovoltaic cell:-
  (a) With your hand covering the clear enclosure. i.e. with the cell dark.
  (b) With the cell exposed to the ambient light.

- Now adjust the control of the 10k‰ resistor to increase the output voltage from the power amplifier in steps of 1V. At each step, note the output voltage from the photovoltaic cell and enter the values in Table 18.

Lamp filament voltage	0	0	1	2	3	4	5	6	7	8	9	10
Photovoltaic cell voltage												

Table 18.

Dark Ambient

The readings will indicate an increase of photocell output voltage as the lamp filament voltage is increased. We cannot relate the output to the light level but the exercise illustrates the basic characteristics of the device.

Notes:

The Phototransistor

Fig 43.The basic construction and circuit used are shown in Fig 43. The unit is basically an NPN three layer semiconductor device as for a normal transistor, the connections to the N,P & N sections being labelled e (emitter), b (base) & c (collector).

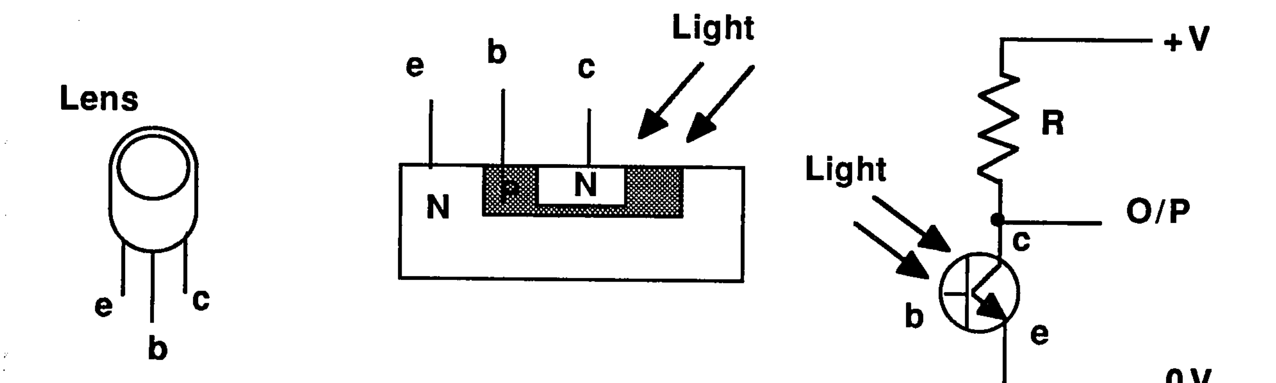


Figure 43

The device differs from the normal transistor in allowing light to fall on the collector-base junction.The basic circuit connection is shown in Fig 43, the collector being connected to the positive of a D.C. supply via a load resistor R. The base connection is not used in this circuit but is available for use in other circuits if desired.

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

With light falling on the collector-base junction the current flow increases. With the base connection open circuit, the collector-base current must flow in the base-emitter circuit and hence the current flowing is amplified by normal transistor action. The unit is thus more sensitive than a photodiode.

The output voltage from the circuit falls as the current increases and hence the output voltage is dependent on the light falling on the device.

$V_{out} = V - I_cR$ Where V = Supply voltage
I_c= Collector current
R = Collector load resistance

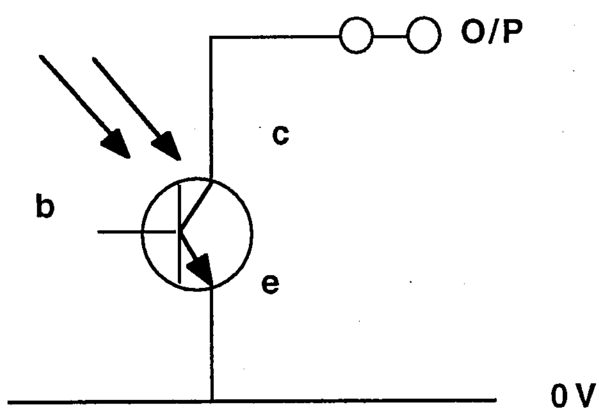


Figure 44

Fig 44 shows the circuit arrangement for the DIGIAC 1750 unit.

The main characteristics of the device are as follows:-

Type		MEL 12
Collector current (Vce = 5V)	Dark	100µA
	Typical ambient	3.5mA

Exercise 15. Characteristics of a phototransistor

Equipment::-

1 Phototransistor
1 10kΩ wirewound resistor
1 10kΩ Carbon slider resistor
1 Power amplifier
1 20V Digital voltmeter
1 10-0-10V M.C. Meter

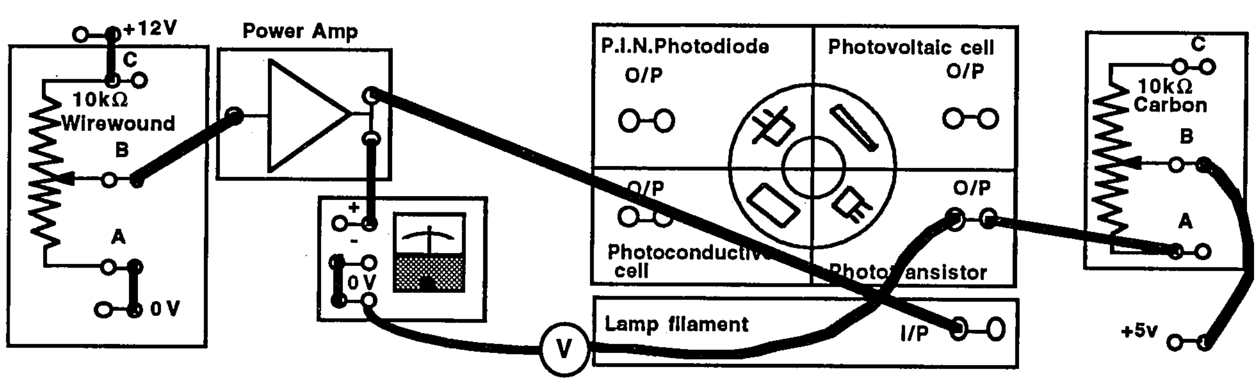


Figure 45

- Connect the circuit as shown in Fig 45 and set the 10kΩ carbon slider control to setting 2 so that the phototransistor load resistance is approximately 2kΩ.

- With the power supply ON, set the control of the 10kΩ wirewound resistor for zero output voltage from the power amplifier. Note the output voltage of the phototransistor collector:-

(a) With your hand covering the clear enclosure, &
(b) With the phototransistor exposed to the ambient lighting.

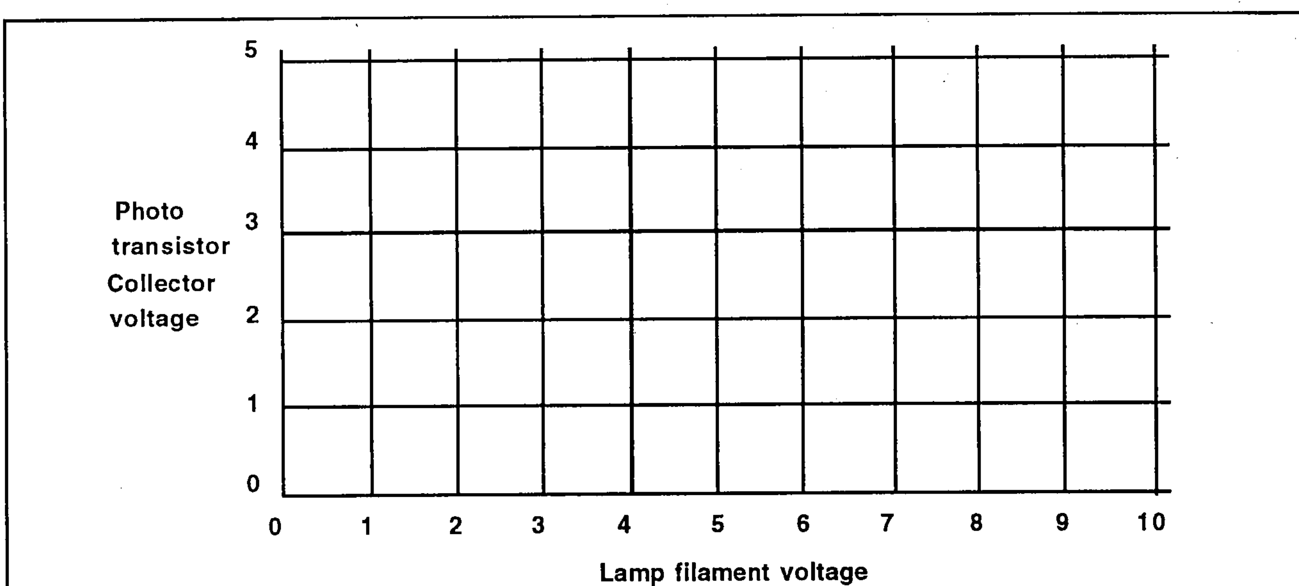
Enter the values in Table 19.

- Now increase the voltage output from the power amplifier in steps of 1V and at each step note the collector voltage of the phototransistor. Enter the values in Table 19.

Lamp filament voltage	0	0	1	2	3	4	5	6	7	8	9	10
Phototransistor Collector voltage												
	Dark	Ambient										

Table 19

Plot the graph of collector voltage against lamp filament voltage on the axes provided.



Why is there a minimum voltage of approximately 0.7V ?

The photoconductive cell.

Fig 46 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.

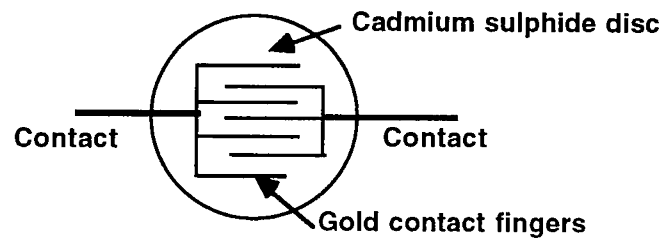


Figure 46

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

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

Various semiconductor materials are available, cadmium sulphide being used in the unit provided with the DIGIAC 1750 unit, this having a frequency response similar to that of the human eye.

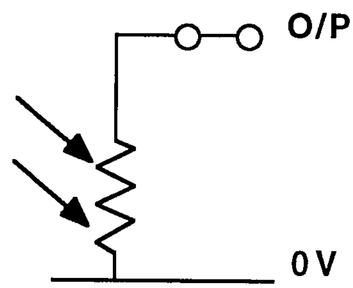


Figure 47

Fig 47 shows the circuit arrangement for the DIGIAC 1750 unit.

The main characteristics of the device are as follows:-

Cell resistance	**Dark**	**10MΩ**
	50Lux	**2.4kΩ**
	Typical ambient	**500Ω**
	100 Lux	**130Ω**
Response time	**Rising**	**75ms**
	Falling	**350ms**
Peak spectral response		**610nm (red)**

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 high falling response time.

Notes:

Exercise 16. Characteristics of a photoconductive cell.

Equipment:-

1 Photoconductive cell
1 10kΩ Wirewound resistor
1 10kΩ Carbon slider resistor
1 Power amplifier
1 20V Digital voltmeter
1 10-0-10V M.C. meter
Connecting leads.

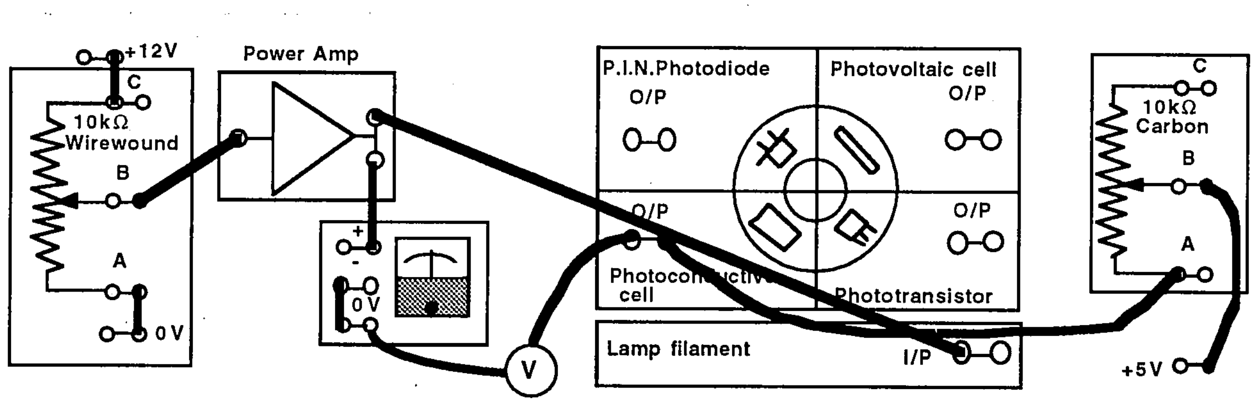


Figure 48

- Connect the circuit as shown in Fig 48 and set the 10kΩ carbon slider control to setting 2 so that the photoconductive cell load resistance is approximately 2kΩ .

- With the power supply ON, set the control of the 10kΩ wirewound resistor for zero output voltage from the power amplifier. Note the output voltage from the photoconductive cell circuit::-

  (a) With your hand covering the clear enclosure, &
  (b) With the photoconductive cell exposed to the ambient lighting.

  Enter the values in Table 20.

- Now increase the voltage output from the power amplifier in steps of 1V and at each step note the output voltage from the photconductive cell output socket.

  Enter the values in Table 20.

Lamp filament voltage.	0	0	1	2	3	4	5	6	7	8	9	10
Photoconductive cell output voltage (Volts)												
	Dark	Ambient										

Table 20.

Note that the output voltage falls as the lamp filament voltage increases,due to a reduction of the cell resistance.

Notes:

The P.I.N. Photodiode.

Fig 49 shows the construction of the P.I.N. photodiode. This differs from the normal PN diode by having a layer of intrinsic or very lightly doped silicon introduced between the P and N sections. This reduces the capacitance of the device and as a result, the response time is reduced.

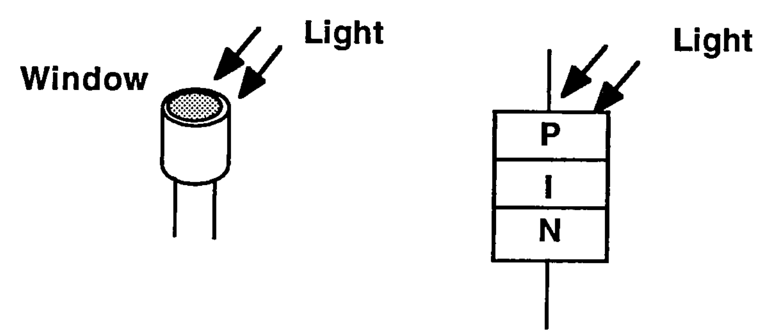


Figure 49

The device can be operated in one of two ways:-

(a) As a photovoltaic cell, measuring the voltage output, &

(b) By measuring the small output current and converting this to a voltage.

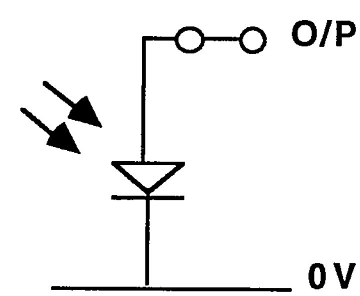


Figure 50

Fig 50 shows the circuit arrangement for the DIGIAC 1750 unit.

The basic characteristics of the device are as follows:-

Type	BPX 65
Dark current	1nA
Light current	10nA/Lux
Capacitance	15pF
Response time	50ns (With load resistance 5kΩ)
Peak spectral response	850nm (I.R.)

Notes:

Exercise 17. Characteristics of a P.I.N. Photodiode.

Equipment::-

1 P.I.N. Photodiode
1 Current amplifier
1 10kΩ wirewound resistor
1 Power amplifier
1 2V Digital voltmeter
1 10-0-10V M.C.meter
Connecting leads.

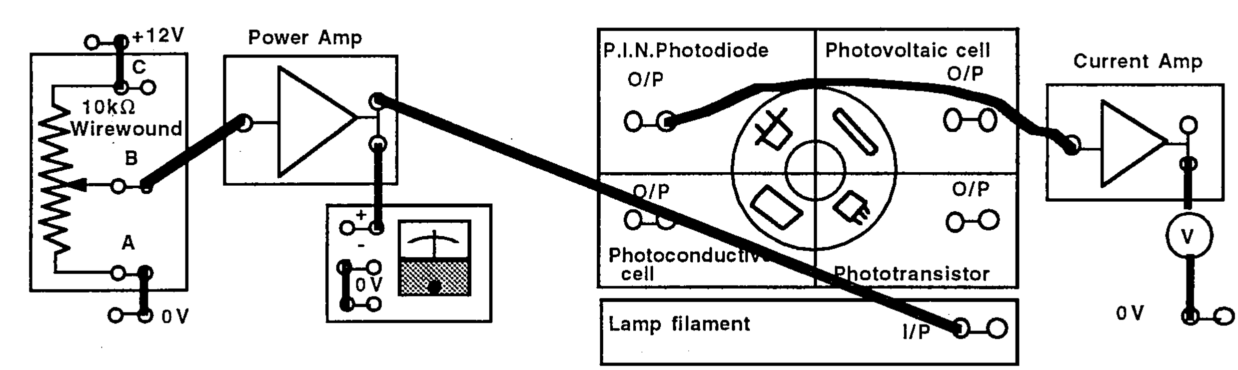


Figure 51

■ Connect the circuit as shown in Fig 51 and with the lamp filament voltage set zero, note the output voltage from the current amplifier:-
(a) With your hand covering the clear enclosure, &

(b) With the P.I.N. photodiode exposed to the ambient lighting.

Enter the values in Table 21.

■ Now increase the lamp filament voltage in steps of 1V and at each step note the output voltage from the current amplifier. Enter the values in Table 21.

Lamp filament voltage.	0	0	1	2	3	4	5	6	7	8	9	10
Current Amplifier output voltage (Volts)												

Table 21

Dark Ambient

Note that the output voltage increases with increasing illumination.

If necessary, the voltage can be increased by further amplification.

■ Now connect the output from the P.I.N. photodiode to a buffer amplifier and variable gain amplifier as shown in Fig 52.

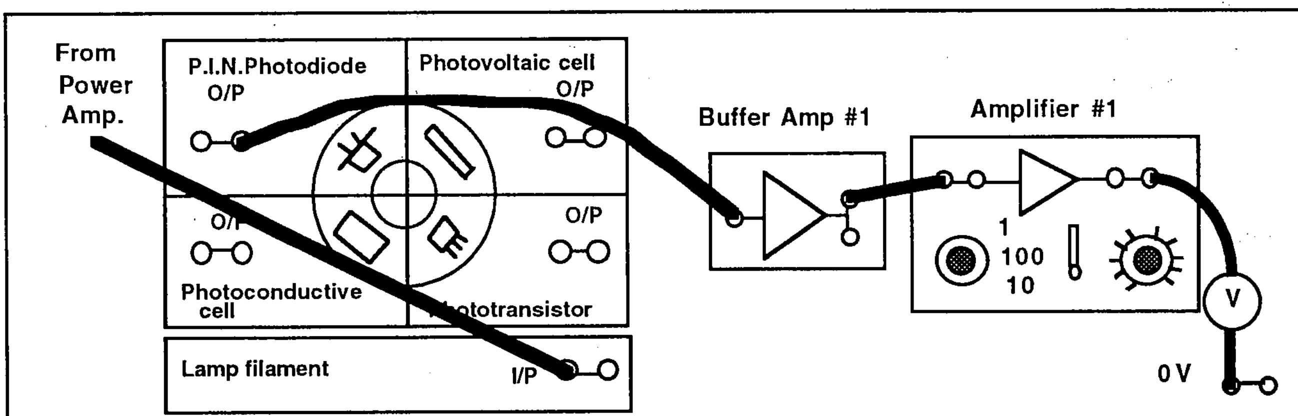


Figure 52

■ Set the coarse gain control of Amp 1 to 100 and set the fine gain to 0.3. Check that the offset is zero for zero input and adjust the control if necessary. Set the voltmeter to its 20V range.

■ Repeat the photodiode test ,noting the output voltage for lamp filament voltages from 0 to 10V in 1V steps. Enter the values in Table 22.

Lamp filament voltage.	0	0	1	2	3	4	5	6	7	8	9	10
Amplifier 1 Output												
	Dark	Ambient										

Table 22.

Note that the output voltage increases with increasing illumination.

The maximum value of the output voltage can be set to any desired value below approximately 10V by adjusting the gain of amplifier #1.

The maximum is limited to 10V by saturation in the amplifier circuit.

Notes:

Student Assessment 5.

1. A photovoltaic cell gives an output of 0.5V for a certain illumination level and is capable of a current output of 5mA. What would you expect to be the output capability with two identical units with the same level of illumination,
   (a) Connected in series

   (b) Connected in parallel ?

2. A phototransistor is connected to a 10V D.C. supply via a 2kΩ load resistor .

   (a) For a certain ambient illumination the collector current is 1mA. What will be the collector voltage ?
   (b) What would you expect the collector current and voltage values to be when the illumination is doubled ?

3. (a) A photoconductive cell has resistance of 6kΩ for a low illumination level and 200 for maximum illumination.

   State with reasons whether,at half maximum illumination you would expect the resistance to be 4.5kΩ ,3.1kΩ or 1.5kΩ .
   (b) What is the main disadvantage of the photoconductive cell ?

4. (a) State how the construction of a P.I.N. photodiode differs from that of a normal diode.
   (b) What effect does the P.I.N. diode construction have on the capacitance and response times ?

Notes:

Chapter 2.5 Transducers For Linear Position Or Force Applications.

Objectives of this chapter.

Having studied this chapter you should:-

- *Know the construction, principle and characteristics of an LVDT (Linear Variable Differential Transformer)*
- *Know the construction and characteristics of a variable capacitor.*
- *Know the construction and characteristics of a strain gauge.*

The Linear Variable Differential Transformer (LVDT).

The construction and circuit arrangement of an LVDT are as shown in fig 53, consisting of three coils mounted on a common former and having a magnetic core that is movable within the coils.

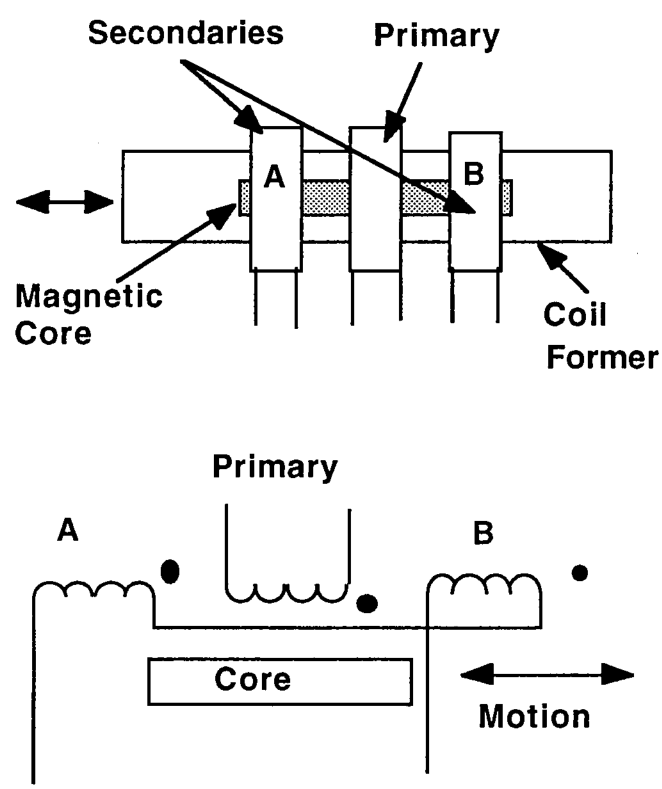


Figure 53

The center coil is the primary and is supplied from an A.C. supply and the coils on either side are secondary coils and are labelled A & B in Fig 53.

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 54, overleaf, shows the ouput obtained for different positions of the magnetic core.

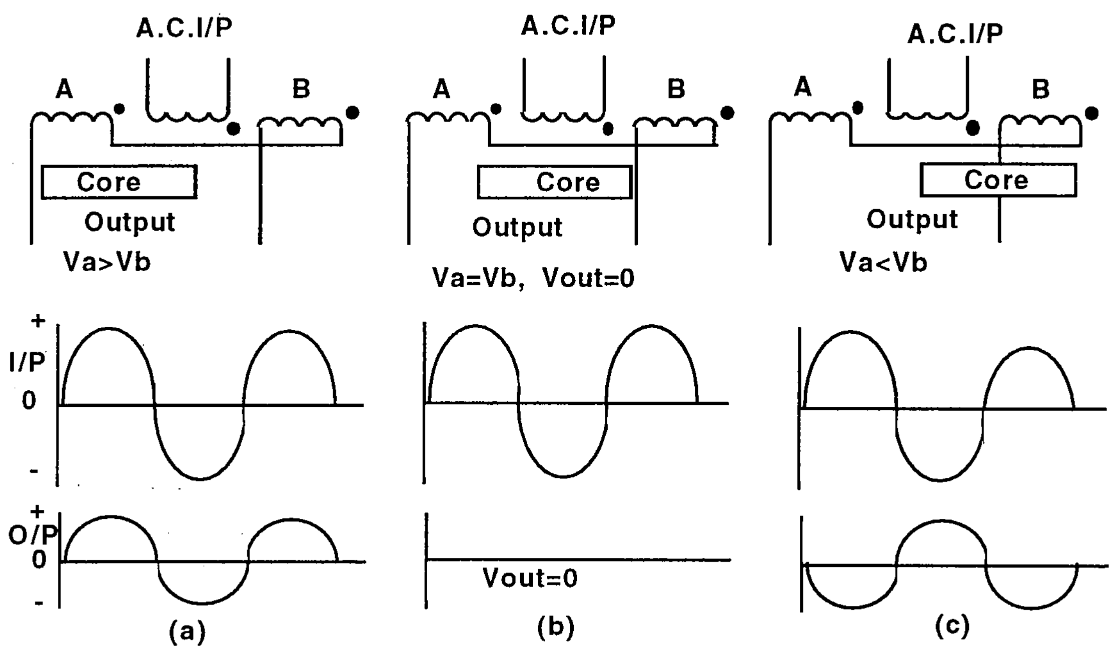


Figure 54

With the core in its central position as shown in Fig 54 (b) there will be equal voltages induced in coils A & B by normal transformer action and the output voltage will be zero. With the core moved to the left as shown in Fig 54 (a), the voltage induced in coil A (Va) will be greater than that induced in coil B (Vb). There will therefore be an output voltage Vout = (Va - Vb) and this voltage will be in phase with the input voltage as shown.

With the core moved to the right as shown in Fig 54 (c) the voltage induced in coil A (Va) will be less than that induced in coil B (Vb) and again there will be an output voltage Vout = (Va - Vb) but in this case the output voltage will be 180° out of phase with the input voltage as shown.

Movement of the core from its central (or neutral) position therefore produces an output voltage, this voltage increasing with the movement from the neutral position to a maximum value and then falling for further movement from this maximum setting.

A measurement of the output voltage therefore gives an indication of movement from the neutral position but will not indicate the direction of this movement.

Used in conjunction with a phase detector, an output is obtained that is dependent on the magnitude and the direction of the movement from neutral position.
Fig 55 shows a basic phase detector circuit.

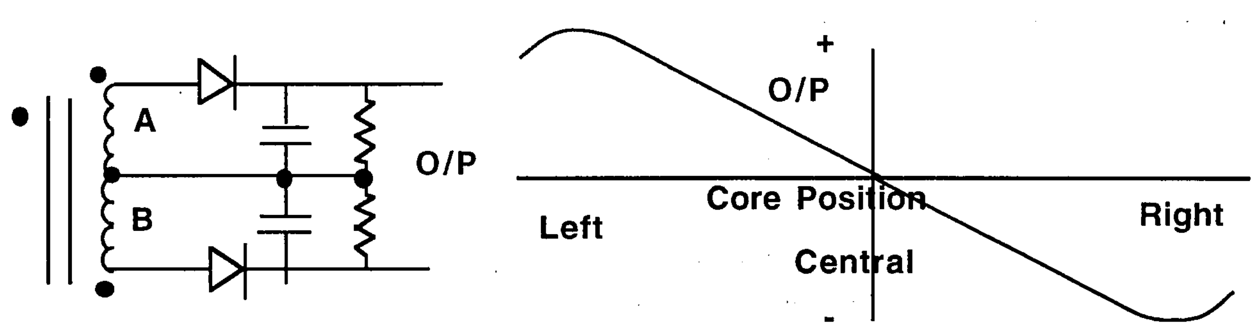


Figure 55

With the core moved to the left, the output voltage will be positive and for movement to the right the output voltage will be negative as shown in Fig 55.

In practice ,due to the low voltages involved,an operational amplifier diode detector circuit will be required instead of the basic diode shown.

A phase sensitive detector circuit is not provided with the DIGIAC 1750 unit.

Fig 56 shows the circuit arrangement of the DIGIAC 1750 unit.

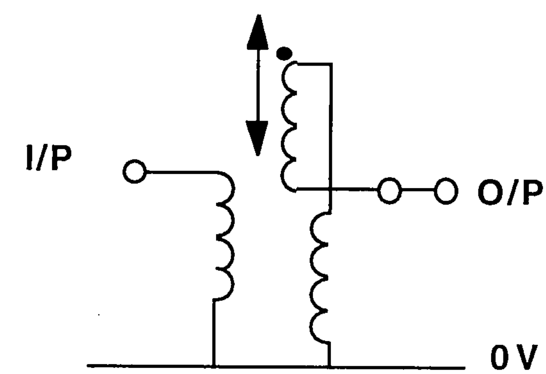


Figure 56

The main characteristics of the device are as follows:-

Turns per coil	75
Inductance per coil	68 µH
Output voltage	10mV/mm from neutral
Mechanical travel	15mm.

Exercise 18. Characteristics of a Linear Variable Differential Transformer

Equipment:-

1 LVDT Unit
1 40kHz Oscillator
1 A.C. Amplifier
1 40kHz Filter
1 Full wave rectifier
1 2V Digital Voltmeter
1 Amplifier #1
1 10-0-10V M.C. meter.
Connecting Leads

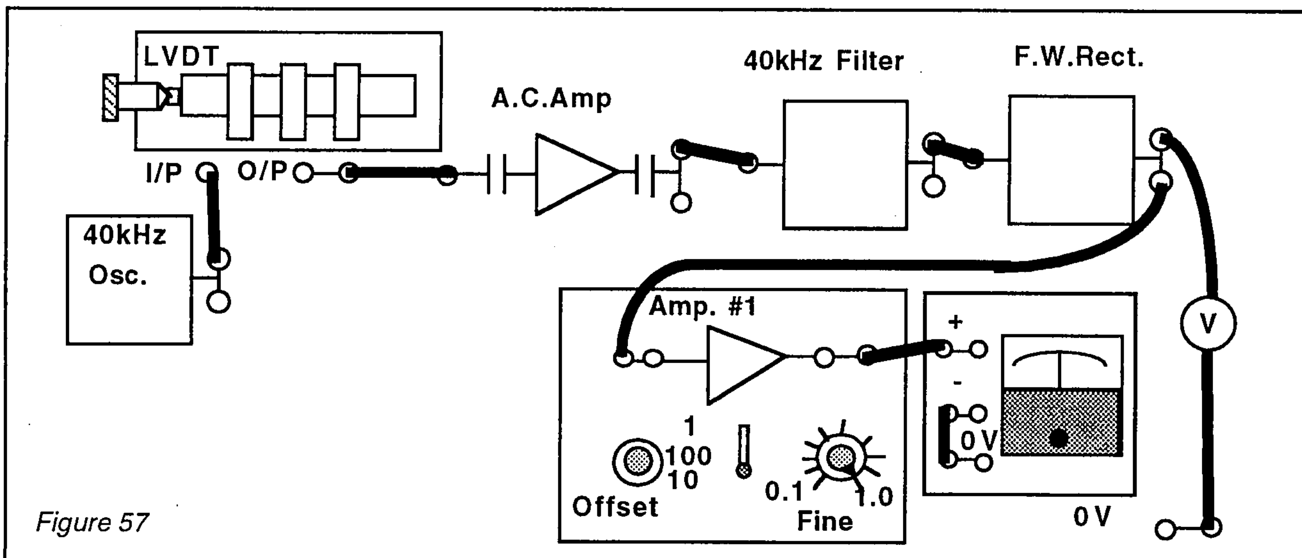


Figure 57

In this exercise we will measure the rectified output using the digital voltmeter and also amplify and measure it using the M.C. meter as this gives a better impression of the variation of output voltage with core position.

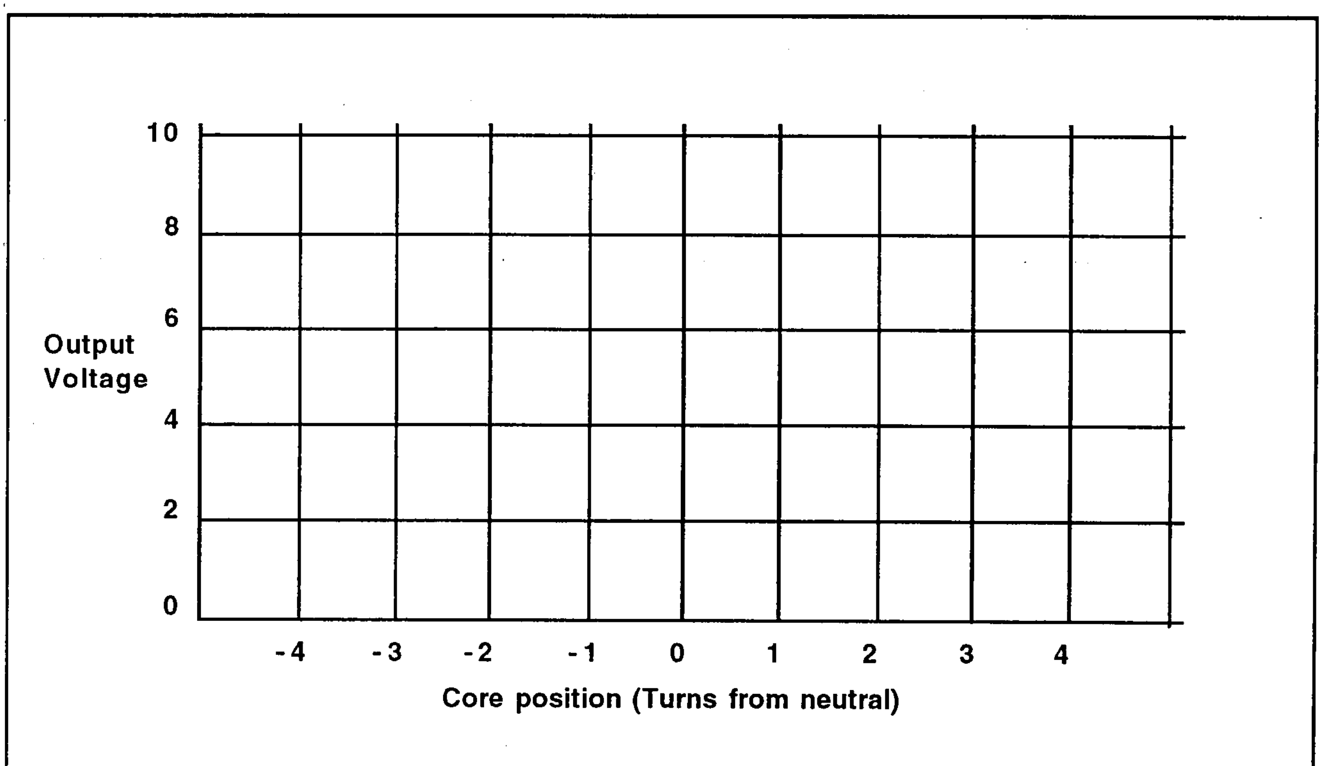
- Set the A.C. Amp. gain 1000, Connect the circuit as shown in Fig 57 and switch thesupply ON. Set the coarse control of amplifier 1 to 100 and its fine control to 0.2. Check that the offset control is set for zero output with zero input and adjust if necessary.

- Adjust the core position by rotating the operating screw to its neutral position, i.e. output voltage zero (or its minimum value). Note the output voltage and enter the value in Table 23.
- Now rotate the core control screw in steps of approximately 1 turn for 4 turns in the clockwise and then for 4 turns in the counter clockwise directions, entering the output voltages at each step in Table 23.

Core position (Turns from neutral)		-4	-3	-2	-1	0	1	2	3	4
Output voltage	Digital meter									
	M.C. Meter									

Table 23.

Plot the graph of output voltage against core position on the axes provided.



If a dual trace oscilloscope is available, the reversal of the phase of the output voltage can be observed by connecting the circuit as shown in Fig 58 and noting the waveforms as the core is moved through the neutral position.

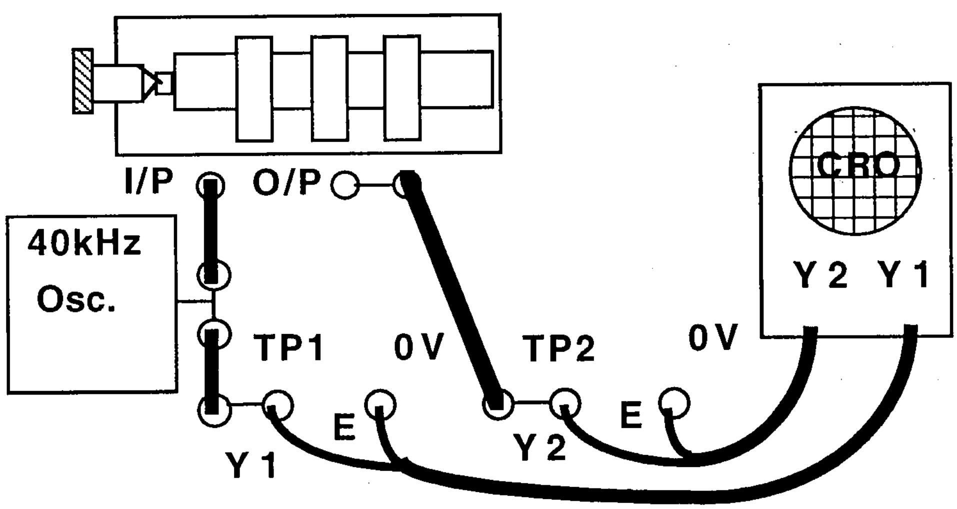


Figure 58

Notes:

The Linear Variable Capacitor.

A capacitor consists basically of two conducting plates separated by an insulator which is referred to as the dielectric. The capacitance of the device is directly proportional to the cross sectional area that the plates overlap and is inversely proportional to the separation distance between the plates .

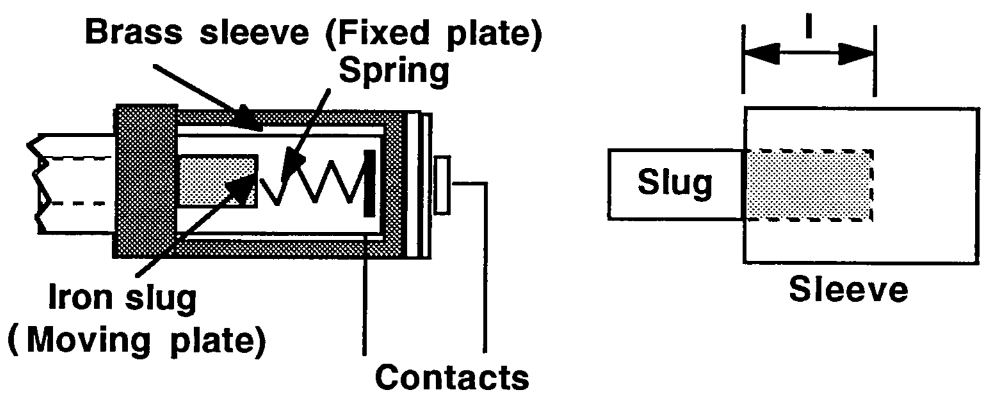


Figure 59

A variable capacitor can therefore be constructed by varying either the area of plates overlapping or the separation distance .

Fig 59 shows the construction of the capacitor fitted in the DIGIAC 1750 unit, this being fitted at the end of the coil former of the LVDT. This uses the magnetic slug core as one plate of the capacitor, the movlng plate. The fixed plate consists of a brass sleeve fitted around the coil former.

The capacitance magnitude depends on the length (l) of the slug enclosed within the brass sleeve, the capacitance increasing with increase of length l.

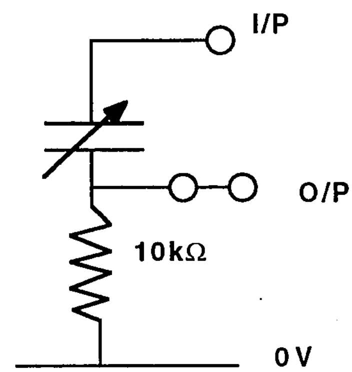


Figure 60

Fig 60 shows the circuit arrangement in the DIGIAC 1750 unit.

The main characteristics of the unit are as follows:-

Capacitance (minimum)	25pF
Capacitance (Maximum)	50pF
Mechanical travel	15mm

Notes:

Exercise 19. Characteristics of a variable capacitance transducer.

Equipment:-

1 Variable capacitance transducer
1 40kHz oscillato
1 A.C. Amplifier
1 40kHz Filter
1 Full wave rectifier unit
1 20V Digital voltmeter
Connecting Lead

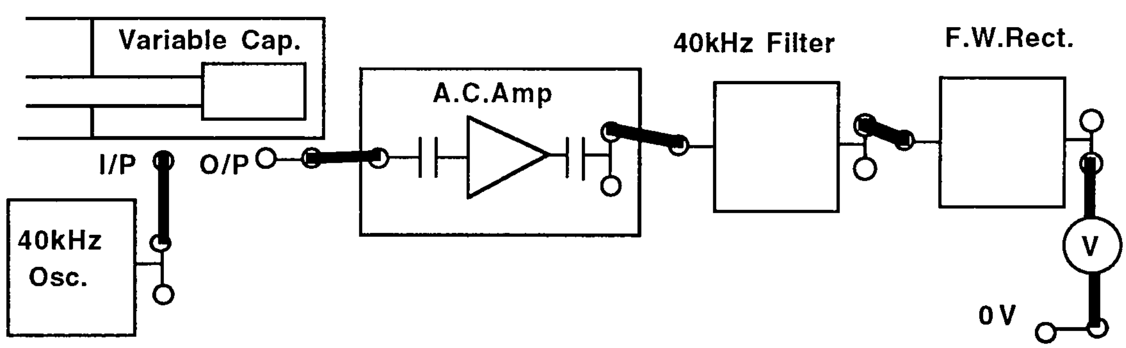


Figure 61

- Connect the circuit as shown in Fig 61 and set the capacitor moving plate fully in. This represents maximum capacitance. Set the A.C. Amp gain to 1000.
- Switch the supply ON and note the output voltage. Enter the value in Table 24.

- Now rotate the operating screw in steps of approximately 1 turn counter clockwise to reduce the capacitance and at each step note the output voltage and enter the value in Table 24.

Capacitance	Max								Min
Turns of screw	0	1	2	3	4	5	6	7	8
Output voltage									

Table 24.

Note that the voltage falls as the capacitance decreases, the decrease however being small.

Notes:

The Strain Gauge transducer.

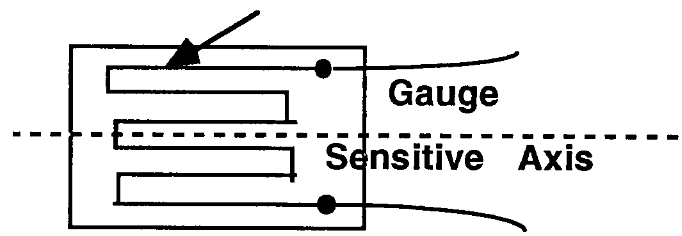


Figure 62

Fig 62 shows the construction of a strain gauge, consisting basically of a grid of fine wire or semiconductor material bonded to a backing material.

When in use, the unit is glued to the member under test and is arranged so that the variation in length under loaded conditions is along the gauge sensitive axis. Increase in loading then increases the length of the gauge wire and hence increases its resistance.

The gauge is normally connected in a Wheatstone Bridge arrangement with the bridge balanced under no load conditions. Any change of resistance due to loading unbalances the bridge and this is indicated by the detector (Galvanometer).

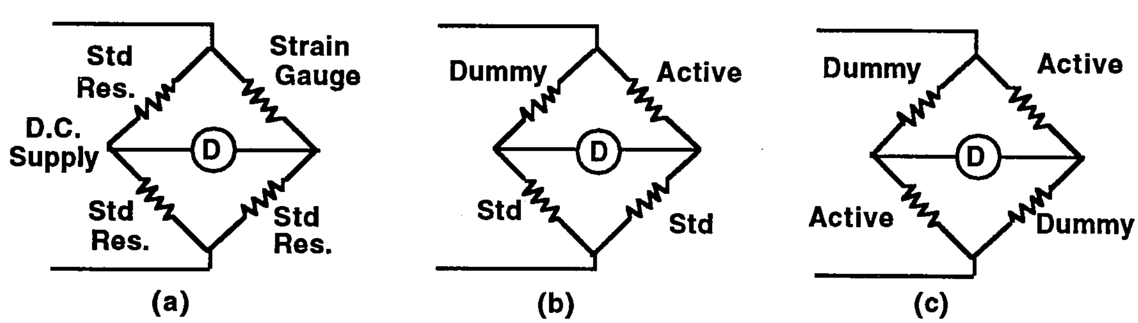


Figure 63

Fig 63 (a) shows the basic Wheatstone Bridge arrangement with one strain gauge transducer. This circuit is liable to give inaccurate results due to temperature changes. A temperature change will also produce a change of resistance of the gauge and this will be interpreted as a change of loading.

To correct for this an identical gauge is used and connected in circuit as shown in Fig 63(b). This gauge is placed near the other gauge but is arranged so that it is not subjected to any loading.

Any variation of temperature now affects both gauges similarly and there will be no effect on the bridge balance conditions. The gauge subjected to the loading is referred to as the the active gauge and the other is referred to as the dummy gauge.

The output from the circuit is small and to increase this , four gauges are normally used with two active gauges and two dummy ones as shown in FIg 63(c).

This is the arrangement used for the unit provided with the DIGIAC 1750 unit. and is shown in Fig 64

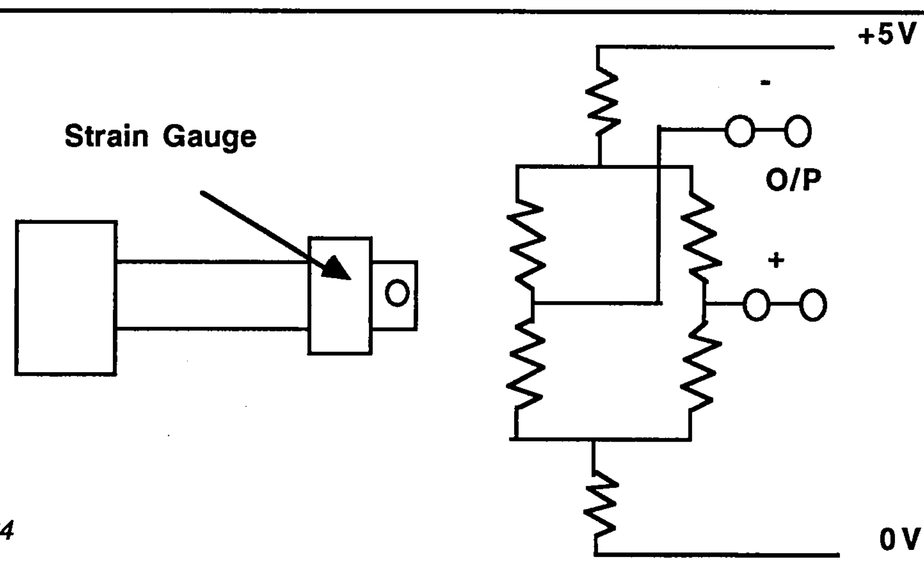


Figure 64

Resistors are electro-deposited on a substrate on a contact block at the right hand end of the assembly with two active ones formed along the axis of the beam and two dummy ones formed at right angles to these.

The layout and circuit arrangement for the DIGIAC 1750 unit is shown in Fig 64.

The main characteristics of the device are as follows:-

Load capacity	200g
Maximum deflection	0.5mm
Sensitivity	25 μ V/g
Non-linearity	0.025%
Hysteresis	0.05%
Creep	0.05%

Notes:

Exercise 20. The Characteristics of a Strain Gauge Transducer.

Equipment:-

1 Strain Gauge Transducer
1 Instrument Amplifier
1 x 100 Amplifier
1 Amplifier #1
1 M.C. Meter
Coins for loading the beam
Connecting leads

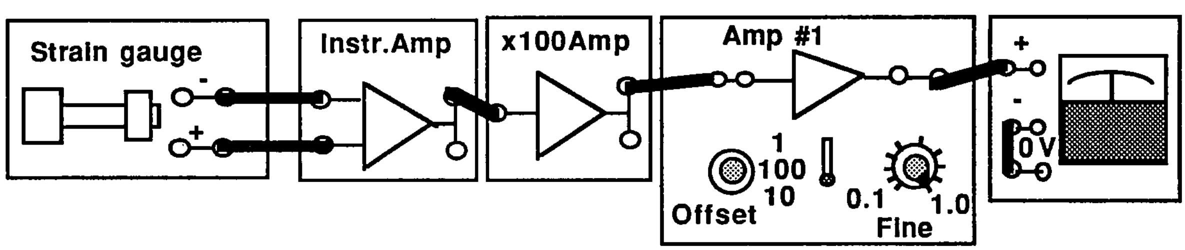


Figure 64

- Connect the circuit as shown in Fig 65 and set the Amplifier #1 coarse control to 100 and its fine control to 0.5.

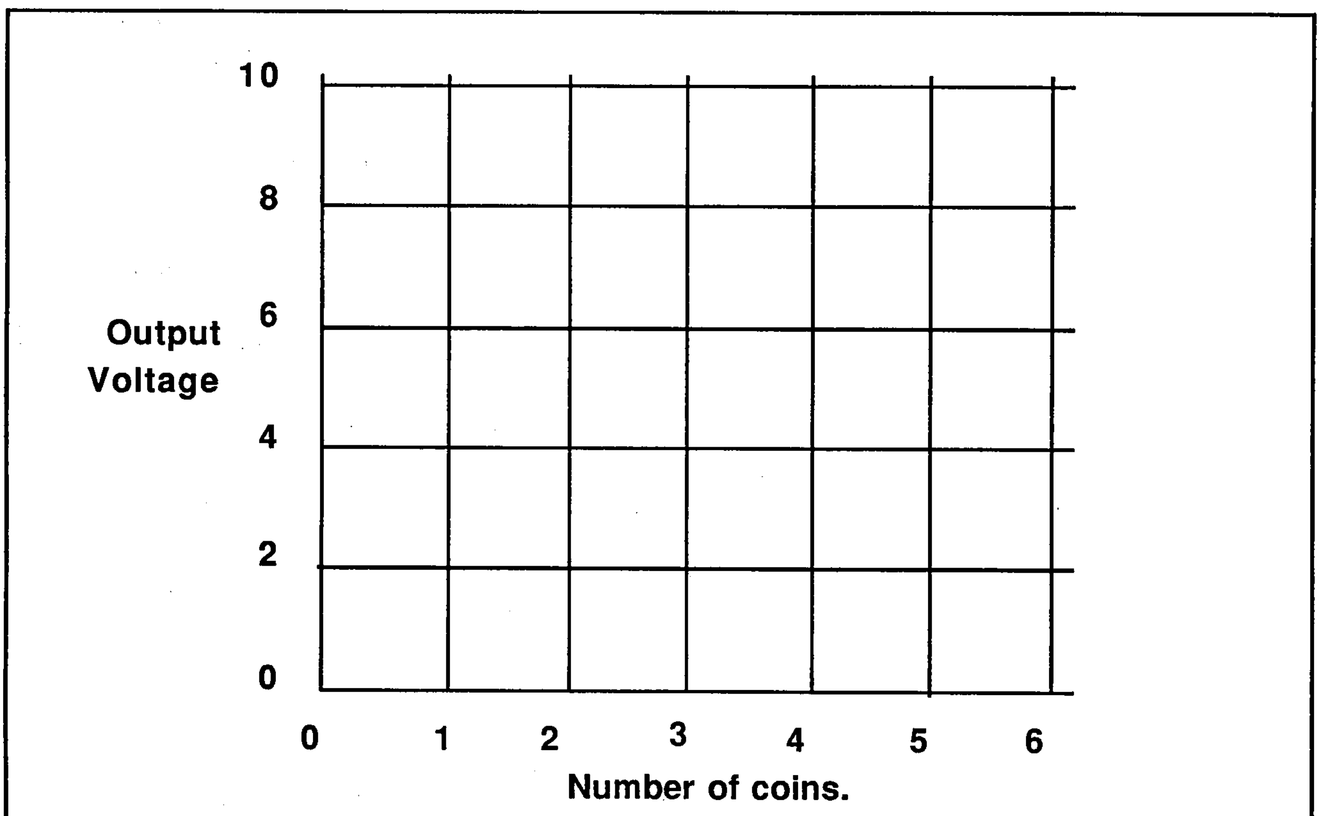
- Switch the supply ON and with no load on the strain gauge platform, adjust the offset control of amplifier #1 so that the output voltage is zero.

- Place a coin on the beam platform and note the output voltage. Enter the value in Table 25.
- Repeat the process, adding further coins one at a time, noting the output voltage at each step and entering the values in Table 25.

Number of coins	0	1	2	3	4	5	6
Output voltage							

Table 25

Plot a graph of output voltage against number of coins on the axes provided.



Is the graph linear ?

Student Assessment 6.

1. Sketch the graph of output amplitude against displacement relative to neutral position for an LVDT with the displacement extending to values outside its specification,the output being fed to:-
   (a) a full wave rectifier
   (b) a phase sensitive rectifier
   (c) a full wave rectifier but with the connections to one of the secondary coils reversed.

2. For an LVDT with the core in its central position, the voltage induced in one of the secondary coils is 500mV. What would be the voltage:-
   (a) induced in the other secondary coil
   (b) output from the secondary circuit ?

   With the core displaced 5mm to the left of neutral, the output voltage is 400mV p-p in phase with the input.

   What would be the output voltage with the cor displaced 5mm to the right of neutral

3. A capacitor having c.s.a. 200mm^2 and plate separation distance 2mm has capacitance 100pF.

   What would be the capacitance of the following similar capacitors:-
   (a) c.s.a. 100mm^2 and separation 2mm
   (b) c.s.a. 200mm^2 and separation 1mm
   (c) c.s.a. 400mm^2 and separation 1mm

4. An electrical conducting liquid is contained in an insulating cylindrical container. The liquid level is to be measured using a variable capacitor type of transducer.

   Show two ways that this could be accomplished an state how the capacitance would vary as the liqui level increased in each case.

Student assessment questions continued overleaf

5. Two strain gauges connected in a Wheatstone bridge circuit are to be fitted to a long beam to measure the stress . Sketch a diagram to illustrate how the active and dummy gauges should be arranged.

   Why is a dummy gauge used

   Why is it common to use four strain gauges for a Wheatstone bridge circuit ?

6. Show how four strain gauges could be used to measure the pressure in a cylindrical tank and indicate the physical position of the active and dummy gauges on the tank and their positions in the electrical circuit.

Notes:

Chapter 2.6 Transducers For Environmental Measurement Applications.

Objectives of this chapter.

Having studied this chapter you should:

- *Know the construction and characteristics of an air flow transducer.*
- *Know the construction and characteristics of an air pressure transducer.*
- *Know the construction and characteristics of a humidity transducer.*

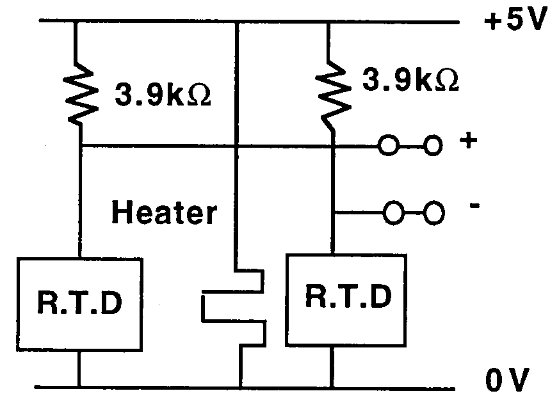


Figure 67

Fig 67 shows the electrical circuit arrangement for the DIGIAC 1750 unit.

The main characteristics of the device are as follows:-

Type	AWT25A2
Heater power	1W
Output impedance	1.7kΩ
Output voltage (-).Pump off	2.1V
Output voltage (+).Pump off	1.7V
Voltage Change (Airflow)	0.06V

Notes:

Exercise 21. Characteristics of an air flow transducer

Equipment:-

1 Air flow transducer unit.
1 20V Digital voltmeter
1 Instrumentation amplifier
1 Amplifier #1
1 M.C.Meter.
Connecting leads

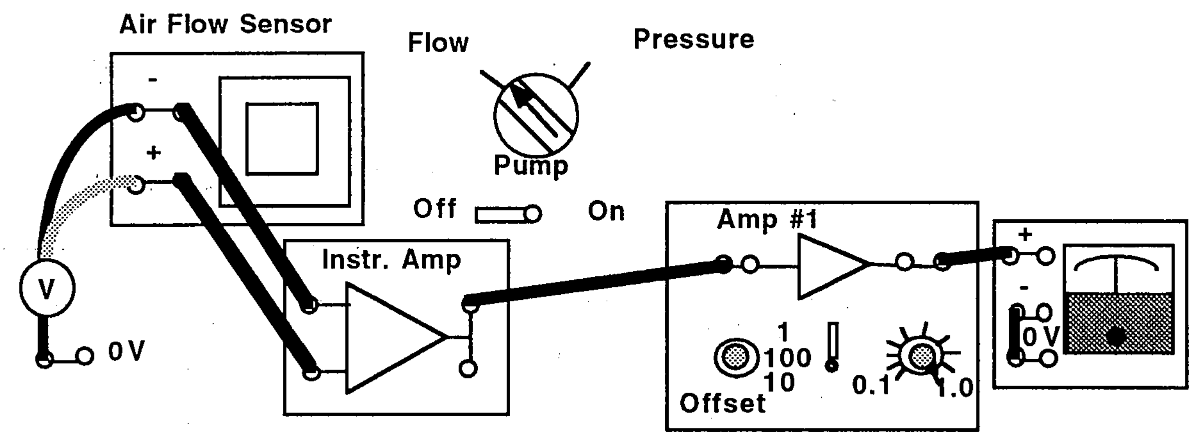


Figure 68

- Connect the circuit as shown in Fig 68 and set the coarse control of amplifier #1 to 10 and the fine control to 1.0. Check that the pump control is set to OFF.

- Switch the supply ON and allow the temperature to stabilize. Adjust the offset control of amplifier #1 for zero output continuously during this time ,setting the coarse control to 100 when stabilized conditions are approached.

- Set the Flow/Pressure control to Flow, check that the offset control is set for zero output voltage.

  Note the voltages at the + & - outputs from the transducer and enter the values in Table 26.

- Switch the pump ON and note the voltages again when conditions have stabilized, entering the values in Table 26.

	Pump OFF	Pump ON
Transducer O/P + voltage		
Transducer O/P - voltage		
Amplifier #1 O/P voltage	0	

Table 26.

The R.T.D's have a positive temperature coefficient.

Which output is connected to the heated R.T.D ?

Notes:

....

....

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....

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....

The air pressure transducer.

Fig 69 shows the basic construction of an air pressure transducer, consisting of an outer plastic case which is open to the atmosphere via two ports.

Within this case is an inner container from which the air has been evacuated and on the surface of this, a strain gauge Wheatstone bridge circuit is fitted.

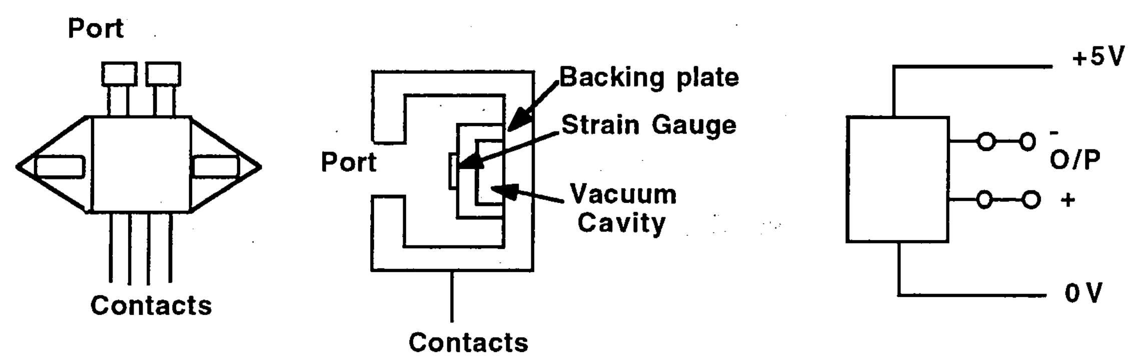


Figure 69

The air pressure in the outer container will produce an output from the bridge and variation of the pressure will produce a variation of this output..

The transducer output can be calibrated to indicate the absolute pressure and is termed an absolute pressure transducer.

With the DIGIAC 1750 unit, provision is made for air to be fed to the unit from the pump.

Fig 69 also shows the electric circuit arrangement of the DIGIAC 1750 unit

The main characteristics of the device are as follows:-

Type	**SPX200AN**
Sensitivity (Typical)	300μ V/kPa
Temperature coefficient	1350ppm/°C
Output voltage (Pump off)(-)	2.48V
Output voltage (Pump off)(+)	2.51V
Voltage difference(Pump off)	35mV
Voltage difference(Pump on)	39mV
Output impedance	1.6kΩ

Notes:

Execise 22. Characteristics of an air pressure transducer.

Equipment:

1 Air pressure transducer unit
1 Instrumentation amplifier
1 x100 Amplifier
1 Amplifier #1
1 M.C.Meter
Connecting leads

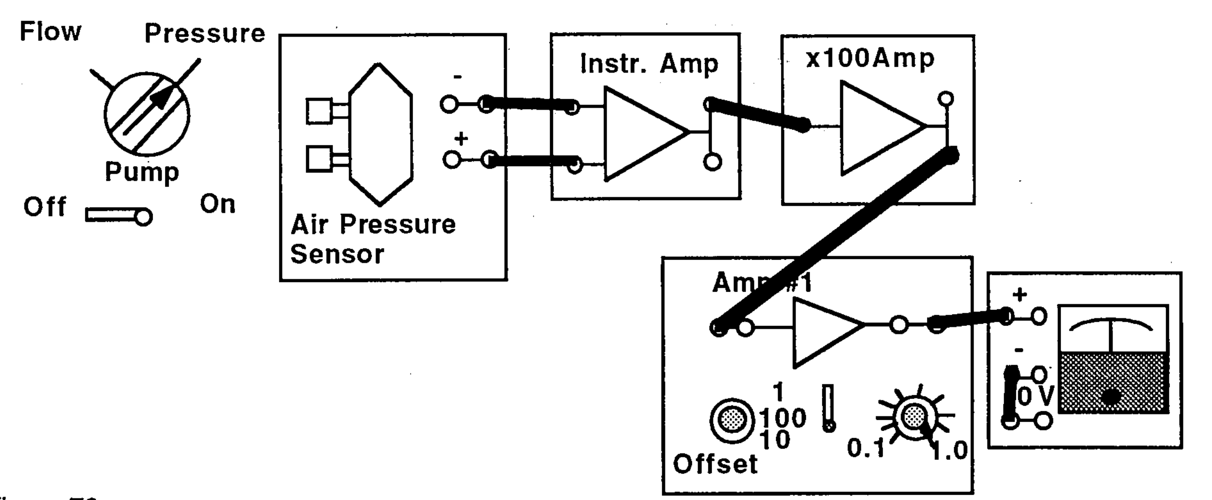


Figure 70

- Connect the circuit as shown in Fig 70 and set the amplifier #1 coarse control to 10 and the fine control to 1.0. Ensure that the pump switch is set OFF.

- Switch the supply ON and adjust the offset control of amplifier #1 for zero output voltage. The unit is now calibrated zero for the current value of the atmospheric pressure.

- Set the Flow /Pressure control to Pressure and then switch the pump ON. The output voltage from the amplifier #1 will increase. Note the value of this voltage.

Output voltage (Pump off) = 0V.
Output voltage (Pump on) =

Note that a large amplification is required due to the small output magnitude from the device.

Notes:

The humidity transducer.

Fig 71 shows the construction of a humidity transducer, consisting basically of a thin diaphragm disc of a material whose properties vary with humidity. Each side of the disc is metallised and the unit forms a capacitor, the capacitance varying with the humidity of the surrounding air.

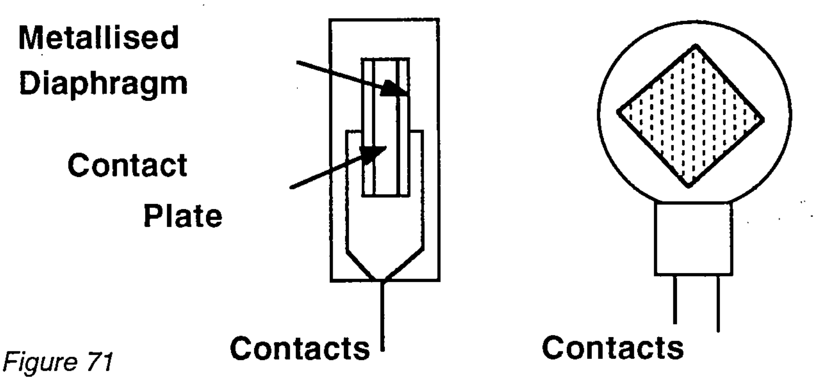


Figure 71

The unit is housed in a perforated plastic case.

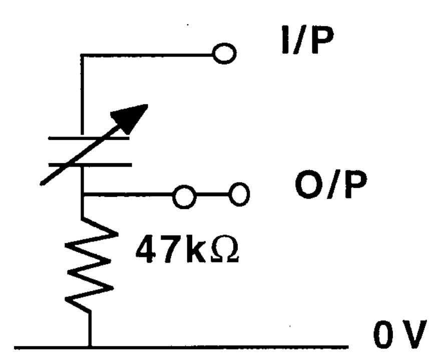


Figure 72

Fig 72 shows the electrical circuit arrangement for the DIGIAC 1750 unit.

The unit is connected in series with a resistor with the output taken from the resistor. With an alternating voltage applied to the input, the output voltage will vary with humidity due to the variation of capacitance of the transducer.

The main characteristics of the device are as follows:-

Type	90002
Capacitance (25°C,45%R/H)	122pF
Sensitivity	0.4pF/%R/H
Humidity range	10%-90%R/H
Output voltage (Typical ambient)	340mV
Output voltage change (after breathing)	20mV

The device is slow to respond fully to humidity changes, taking an of the order of minutes, but this will normally be of no consequence in practice since natural changes are very slow.

Exercise 23. Characteristics of a humidity transducer.

Equipment:

1 Humidity transducer unit
1 40kHz Oscillator
1 A.C. Amplifier
1 40kHz Filter
1 Full wave rectifier
1 20V digital voltmeter
1 Differential amplifier
1 Amplifier #1
1 10kΩ carbon slider resistor
1 M.C.Meter
Connecting leads

The variation of the output voltage from the circuit is only a small percentage of the output and this is difficult to detect. Normally an A.C. version of the Wheatstone Bridge circuit would be used so that changes from balanced conditions could be easily detected. This requires further equipment, including an A.C. detector , that are not available on the DIGIAC 1750 unit.

In this exercise we will use the signal processing circuits available to convert the output to a D.C. signal, balance out the standing D.C. level and thus enable amplification of the small voltage changes.

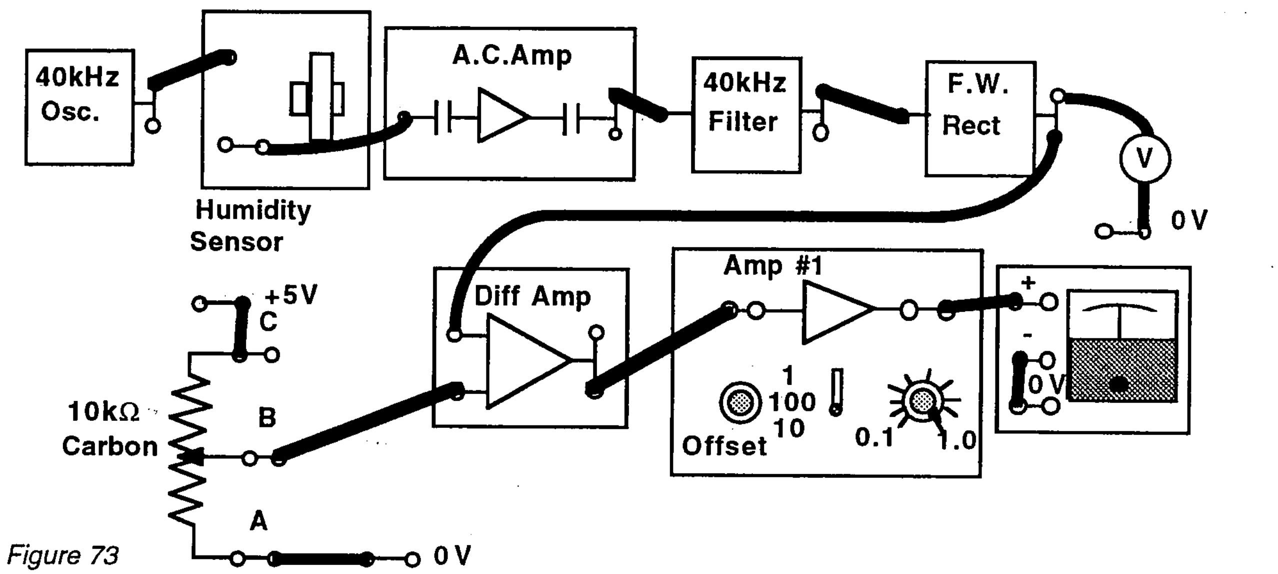


Figure 73

- Connect the circuit as shown in Fig 73,setting the A.C. amplifier gain control to 10 and the amplifier #1 gain controls to 10 and 1.0 for the coarse and fine controls respectively.

- Switch the supply ON, remove the leads from the differential amplifier input and short circuit the + & - input sockets. Adjust the offset control of amplifier #1 for zero output, adjusting it finally with the coarse gain set to 100.

- Now replace the connections to the input of the differential amplifier and adjust the control of the 10kΩ carbon resistor for zero output from amplifier #1. It may be advisable to set the coarse gain to 10 initially and then to 100 finally during this process. The bridge circuit is now balanced for the ambient conditions, the output from the 10kΩ resistor balancing that from the rectifier.
- Note the output voltage from the rectifier circuit as indicated by the digital voltmeter.

- Now place your mouth near the humidity transducer and breath on it for a short time. The reading indicated by the M.C. meter will change slowly.

  Note the maximum value of the voltage and also the reading of the digital voltmeter.

Output voltage (ambient conditions)	**(Digital meter)**	**=**
Output voltage (ambient conditions)	**(M.C. meter)**	**=**
Output voltage after breathing	**(Digital meter)**	**=**
Output voltage after breathing	**(M.C. meter)**	**=**

Considering the readings obtained, do you consider that the D.C. level balancing circuit with amplification and M.C. meter display gives a better indication of the small voltage changes ?

The time taken for the output voltage to return to zero after reaching the maximum voltage will illustrate the slow response of the device to humidity changes. Note the time taken for this.

Time taken for output to return to zero =

Note:- It is advisable to check the offset of amplifier #1 at regular intervals in case there has been any drift. This can be checked by just removing the input connections from the differential ampifier. The offset control can then be adjusted if necessary.

The ambient humidity conditions should not change during the test , but should a change occur, the bridge output will not return to zero.

Notes:

Student Assessment 7.

1. (a) State the basic operating principle of the air flow transducer provided with the DIGIAC 1750 unit.
   (b) Could N.T.C. thermistors be used in this type of application ?

2. (a) For the pressure transducer device provided with the DIGIAC 1750 unit at atmospheric pressure, state with reasons whether you consider there will be an output voltage between the two output connections ?
   (b) If the output is fed to an amplifier circuit and the output adjusted to zero under ambient conditions, will the output vary if the atmospheric pressure changes ?

3. The strain gauge of an air pressure transducer is fitted to the outside of the evacuated cavity and exposed to the atmosphere. Two active and two dummy gauges are used. Sketch the circuit arrangement , showing the active gauge that is connected to the + supply having its other end connected to an output connection A and the other active gauge connected to output connection B.

   When the pressure increases, state with reasons how the voltages at A and B will vary.

4. The output from a humidity detector circuit varies between D.C. values of 3.5V and 3.52V over its full humidity range.

   Indicate how signal processing circuits could be used to convert this to an output range of 0V to 10V.

Notes:

Chapter 2.7 Transducers For Rotational Speed Or Position Measurement Applications.

Objectives of this chapter.

Having studied this chapter you should:-

- *Know the construction,basic principles and application of slotted opto transducers to counting and speed measurement.*
- *Know the construction, basic principles and application of reflective opto transducers and coded disc to position measurement.*
- *Know the construction,basic principles and application of inductive transducers to speed measurement*
- *Know the construction,basic principles and application of Hall Effect transducers to speed and positional measurement.*
- *Know the construction, basic principles and application of a tachogenerator to speed measurement*

The slotted opto transducer

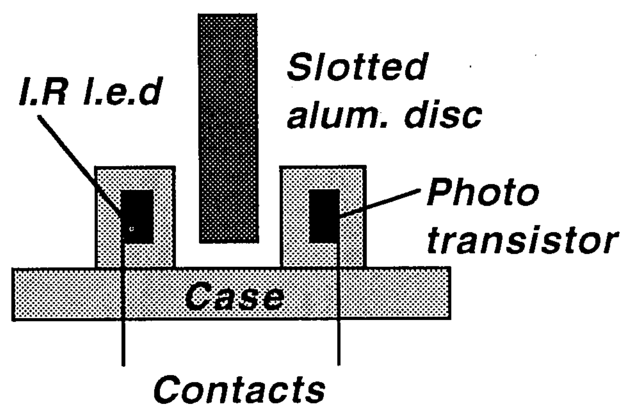


Figure 74

Fig 74 shows the construction of a slotted opto transducer,consisting of a gallium arsenide infra red L.E.D. and silicon phototransistor mounted on opposite sides of a slot, each being enclosed in a plastic case which is transparent to infra red illumination.

The slot between them allows the infra red beam to be broken when an infra red opaque object is inserted.
The collector current of the phototransistor is low when the infra red beam is broken and increases when the beam is admiited. Positive voltage pulses are obtained from the emitter circuit of the phototransistor each time the beam is admitted and hence the device is suitable for counting and speed measurement applications.

A slotted aluminium disc connected to the motor shaft assembly rotates in the transducer slot in the DIGIAC 1750 unit and an L.E.D. is provided to indicate when the slot position allows the beam to be admitted.

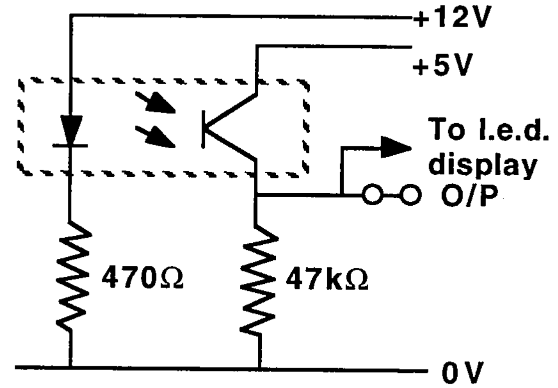


Figure 75

Fig 75 shows the electrical circuit arrangement for the DIGIAC 1750 unit

The main characteristics of the device are as follows:-

Type	K8102
Output voltage (Beam broken)	0.1V
Output voltage (Beam admitted)	4.9V

Notes:

Exercise 24. The characteristics of a slotted opto transducer and its application to counting and speed measurement.

Equipment:-

1 Slotted opto transducer unit.
1 Counter/Timer unit
1 20V Digital voltmeter
1 D.C. Motor
1 Power Amplifier
1 10kΩ wirewound resistor
Connecting leads.

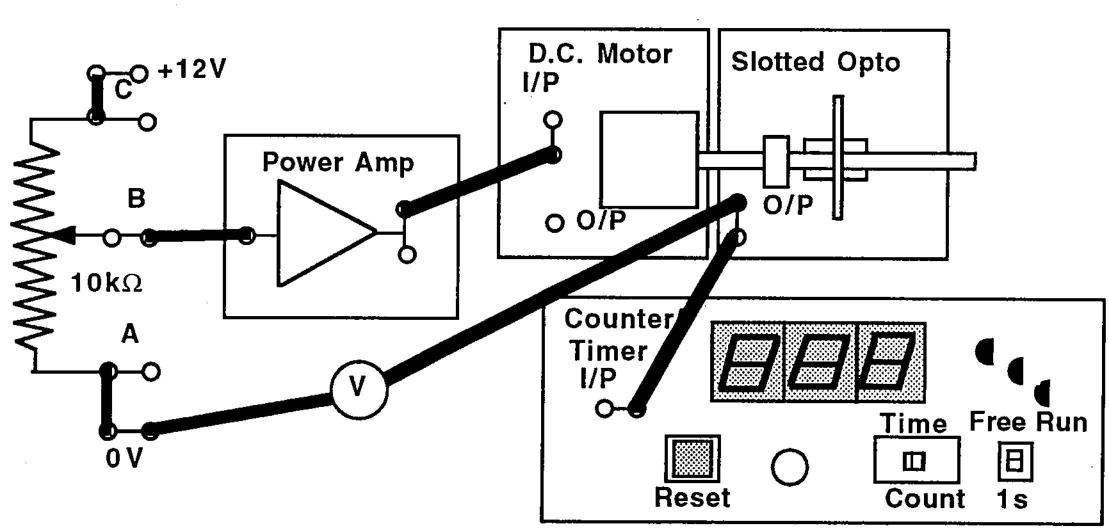


Figure 76

- Connect the circuit as shown in Fig 76 and set the 10kΩ wirewound resistor control for zero output voltage, i.e. fully counter clockwise .

- Switch the power supply ON and note the output voltage from the slotted opto transducer output socket and also the state of the indicating L.E.D :-
  (a) with the beam broken by the aluminium disc, &
  (b) with the beam admitted through the slot in the aluminium disc.

  Note:- The shaft can be rotated by hand using the large aluminium disc provided with the Hall effect device.

	Beam Broken	**Beam Admitted**
Output Voltage		
L.E.D. State		

- Set the Timer/Counter to "count" and "free run". The display should show zero, if not, press "reset". Now rotate the shaft assembly backwards and forwards so that the slot in the aluminium disc passes between the opto transducer.

  Note the counter display, this should increment by 1 each time the slot is in line with the transducer beam.

  Does it ?

  This illustrates the use of the opto transducer for counting applications.

- Now rotate the 10kΩ wirewound resistor control clockwise. The motor should operate and rotate the shaft. Set the speed to a low value. The control setting 2.5 should be suitable for this.

  The counter value will increment once for each revolution of the shaft and can be used to measure the shaft speed.

- Press the "reset" button and hold down. With a watch , or stop watch if available, release the reset button at a suitable time and then note the count value after one minute.

  This value represents the shaft speed in revolutions per minute (rev/min). Enter the value in Table 27.

- Repeat the procedure for slightly higher speeds and enter the values in Table 27.

Control Setting	2.5	3.0	3.5	4.0
Shaft Speed (rev/min)				

Table 27.

- Now set the Counter/Timer Free run/1s switch to 1s (1second). Set the 10kΩ resistor control to setting 5 so that the motor speed is higher. Press the "reset" button of the counter.

  The counter now counts for one second and the count value is "frozen" at the end of this time. The count displayed represents the number of revolutions per second of the shaft Press "reset" again, the displayed value should correspond with the previous value. Enter the value in Table 28.

- Repeat the procedure with resistor control settings as shown in Table 28 and for each setting note the shaft speed as displayed by the counter.

Control Setting	5	6	7	8	9	10
Shaft Speed (rev/min)						

Table 28.

The transducer and counter combination enables the speed to be determined quickly.

- Set the shaft speed to 1800 rev/min (30rev/sec) and note the control setting required for this.

  Control setting for speed of 1800 rev/min =

  Was it easy to set the speed as specified ?

Retain the circuit connections for the motor drive for use with the exercises for the remaining transducers on the shaft assembly

Notes:

The reflective opto transducer

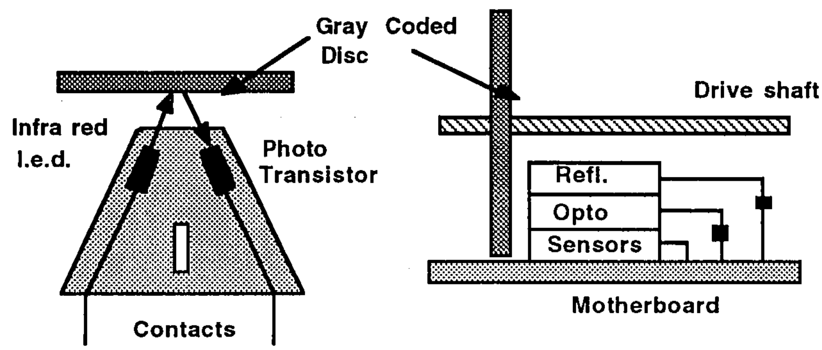


Figure 77

Fig 77 shows the construction of a reflective opto transducer,consisting of an infra red L.E.D. and phototransistor , as for the slotted optotransistor unit , but in this type the components are arranged so that the beam is reflected correctly if a reflective surface is placed at the correct distance. A non reflective surface breaks the beam.

Three separate units are provided with the DIGIAC 1750 unit, these being mounted in line vertically. The reflective surface is a Gray-coded disc,this being fixed approximately 4mm from the transducers.

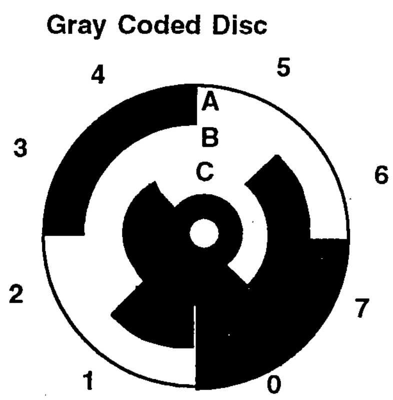
With the beam not reflected the output from the phototransistor emitter is low,and when the beam is reflected the output is high.

Three L.E.D's are provided to indicate when the beam is reflected from the respective transducer unit.

The output A is the least significant bit (l.s.b) and the output C is the most significant bit (m.s.b).

Gray Code

The Gray code is used for the encoded disc rather than normal binary because only one digit changes state at any boundary with this code and this minimises any possibility of error in identifying the actual position when at a segment boundary.
The arrangement of the Gray-coded disc and the respective L.E.D. outputs is shown in Fig 78.



Position	C	B	A
0	0	0	0
1	0	0	1
2	0	1	1
3	0	1	0
4	1	1	0
5	1	1	1
6	1	0	1
7	1	0	0

Figure 78

The black areas break the beam and produce a low output from the associated transducer and the clear areas reflect the beam and produce a high output.

The DIGIAC 1750 unit operates as a rotational angular position transducer but similar principles can be used for linear position applications and slotted opto devices could be used with a transparent disc.

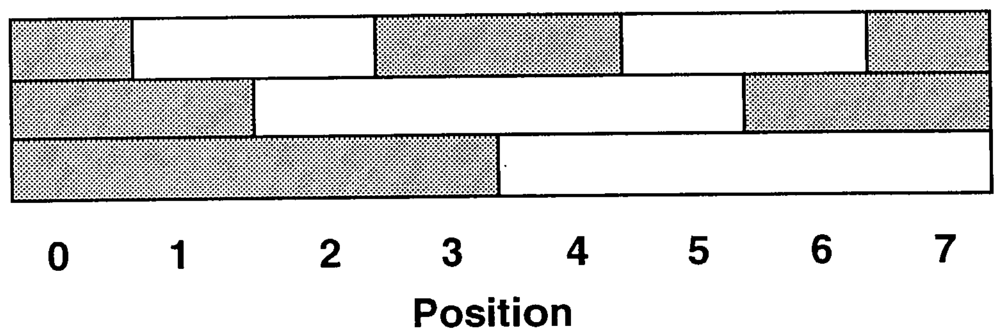


Fig 79 shows a linear Gray-coded disc, the upper segments representing the l.s.b. and the lower the m.s.b.
The positional resolution provided with three devices and a 3-bit code is poor but this can be improved by increasing the number of devices.

Note the Gray code pattern:-
l.s.b 1 measure '0' then 2 measures '1', 2 measures '0' etc.
next.s.b 2 measures'0' then 4 measures '1', 4 measures '0' etc.
next.s.b 4 measures '0' then 8 measures '1', 8 measures '0' etc.

The basic electrical circuit arrangement for the DIGIAC 1750 unit is as shown overleaf in Fig 80

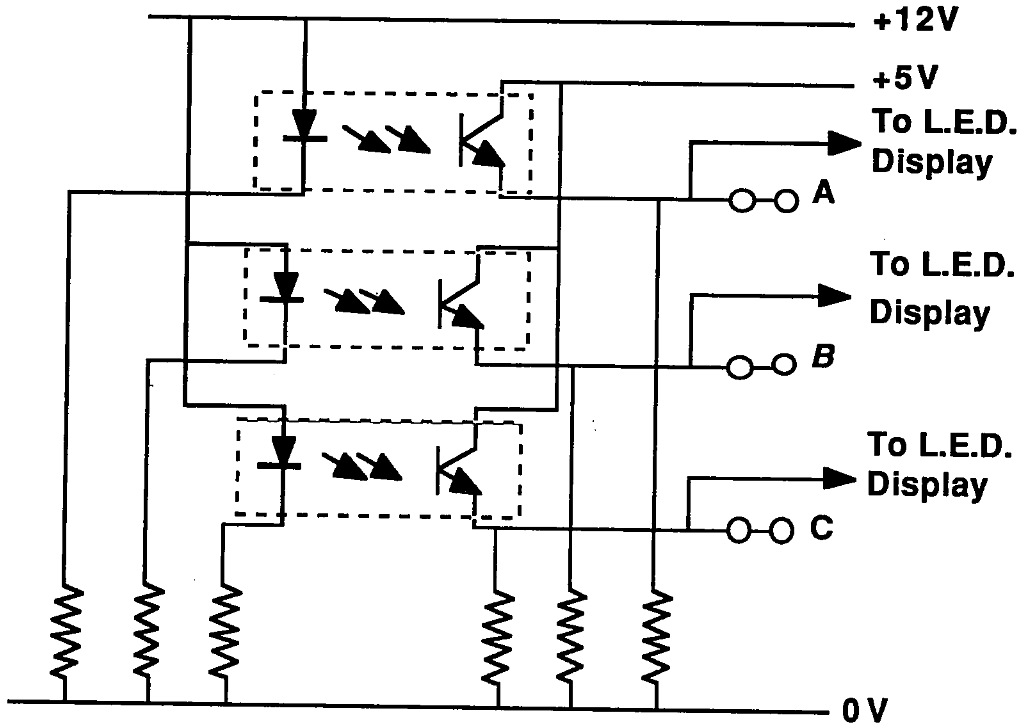


Figure 80

The main characteristics of the device are as follows:-

Type	K8711
Output voltage (Beam broken)	1V
Output voltage (Beam admitted)	4V

Exercise 25. The characteristics of reflective optotransducers and Gray-coded disc.

Equipment :-

1 Reflective opto transducer unit.
1 20V digital voltmeter

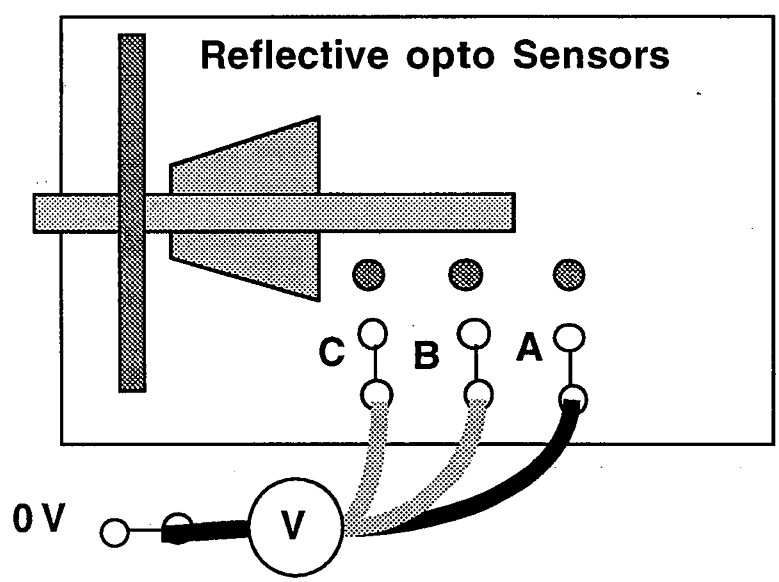


Figure 81

- Connect the circuit as shown in Fig 81 and with the supply ON, note the voltages at each output socket for conditions with the respective L.E.D. OFF and ON. Rotate the drive shaft by hand to alter the L.E.D.state.

Output A	L.E.D. OFF.	Output voltage =
	L.E.D. ON.	Output voltage =
Output B	L.E.D. OFF.	Output voltage =
	L.E.D. ON.	Output voltage =
Output C	L.E.D. OFF.	Output voltage =
	L.E.D. ON.	Output voltage =

- Now rotate the shaft until it is in the position with all L.E.D's OFF. Rotate the shaft and note the angle over which the L.E.D's are all OFF. This should be 45^{o}.

  Is it ?

- With the shaft initially in the position with all L.E.D's OFF, rotate the shaft counterclockwise, when looking at the coded side of the disc, and note the state of the L.E.D's at each change of state. Denote an L.E.D. OFF as logic state 0 and L.E.D. ON as logic state 1. Enter the values in Table 29.

Position	C	B	A
0			
1			
2			
3			
4			
5			
6			
7			

Table 29

Does the sequence agree with that shown in Fig 78 ?

The Inductive transducer.

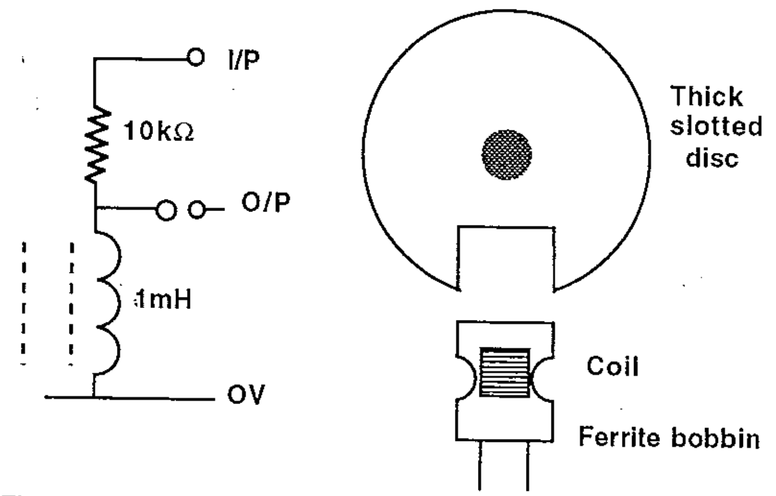


Figure 82

Fig 82 shows the construction and the elecrical circuit arrangement for the device provided with the DIGIAC 1750 unit.

This consists of a 1mH inductor and a slotted aluminium disc fitted to the drive shaft which rotates above this. The inductance of the unit varies with the position of the slot and with an aluminium disc the inductance increases with the slot positioned directly above the inductor.

With a magnetic disc used , the inductance would decrease for conditions with the slot above the inductor.

The main characteristics of the device are as follows:-

Inductance	(under slot)	1mH
Inductance change	(under disc)	15µH
Output voltage	(under slot)	130mV
Output voltage change	(under disc)	2mV

Exercise 26. The characteristics of an inductive transducer.

Equipment:-

1 Inductive transducer unit.
1 40kHz oscillator
1 A.C. Amplifier
1 Full wave rectifier
1 Differential amplifier
1 Amplifier # 1
1 Amplifier # 2
1 10-0-10V M.C.Meter
1 10k Ω 10 turn resistor.
Connecting leads

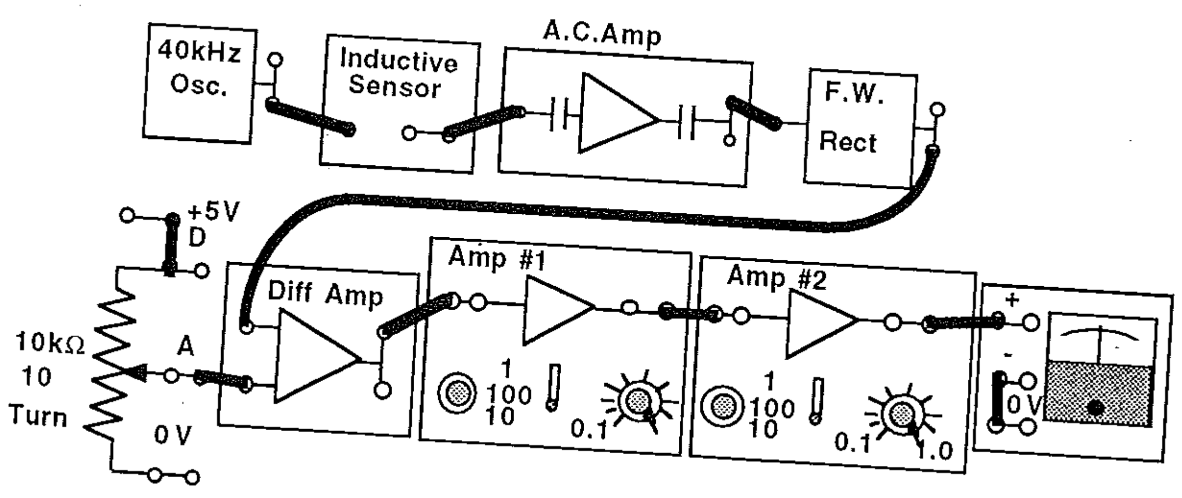


Figure 83

- Connect the circuit as shown in Fig 83, set the A.C. amplifier gain to 1000 and amplifiers #1 and #2 to 10 (Coarse) and 1.0 (fine) and set the drive shaft with the disc slot in the top vertical position.

- Remove the leads from the input to the differential amplifier and switch the supply ON .

- Connect the M.C.meter to the output of amplifier #1 and adjust its offset control for zero output approximately and then adjust finally with the coarse gain set 100. Now replace the meter lead in the output of amplifier #2 and adjust its offset control for zero output.

  The offsets of both amplifiers are now correctly set.

- Replace the leads to the input of the differential amplifier and adjust the control of the 10kΩ 10 turn resistor so that the meter reading is zero. It may be advisable to set the coarse gain of amplifier #1 to 10 initially to enable the balance setting to be determined approximately and then returning it to 100 for final adjustments since the control setting will be critical with such high overall amplifier gains.

- Note the meter reading with the disc in this position and also with the shaft rotated so that the slot is directly above the inductor.

  Output voltage with disc over the inductor =

  Output voltage with slot over the inductor =

Did the output change when the slot was over the inductor ?

This indicates an application of inductive transducers to proximity detection of metallic objects.

The device can also be used for counting or speed measurement applications.

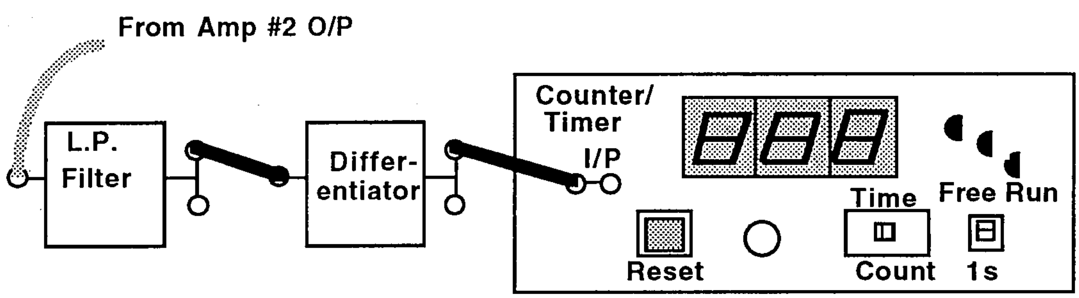


Figure 84

- Connect the output from amplifier #2 to the counter via a low pass filter and differentiator as shown in Fig 84 .

  Set the control of the low pass filter and the differentiator to 1s and set the counter to "count" and "1s".

- Set the coarse gain control of amplifier #2 to 100 and with the input leads to the differential amplifier removed, set the offset control of amplifier #2 for zero output voltage.

- Replace the input leads to the differential amplifier , set the disc slot away from the inductor and then adjust the 10kΩ 10 turn resistor so that the output voltage is +10V.

  With the slot over the inductor the output should change to -10V.

- Now apply an input to the D.C. motor so that the shaft rotates slowly. Press the counter reset button and note the displayed value, this representing the speed in rev/sec. Remove the counter input lead from the differentiator output and connect it to the output from the slotted opto transducer. Press the counter reset button and note the displayed reading which also represents the speed.

Compare the two values.

- Repeat the procedure for other settings of the shaft speed for comparison and enter the values in Table 30.

Shaft Speed (Rev/sec)	**Inductive Tran.**				
Shaft Speed (Rev/sec)	**Slotted opto**				

Table 30.

Do the values compare ?

You will note that a considerable amount of signal conditioning has been required for the inductive transducer unit due to the small output available, this output being A.C,and the susceptibility of the counter to voltage spikes.

A larger output could be obtained using a disc of magnetic material.

Alternatively, a magnet could be embedded in the disc as for the Hall effect unit, this producing output voltage pulses as the magnet passes over the inductor. This type of unit would be more suitable for speed measurement applications.

The Hall Effect transducer

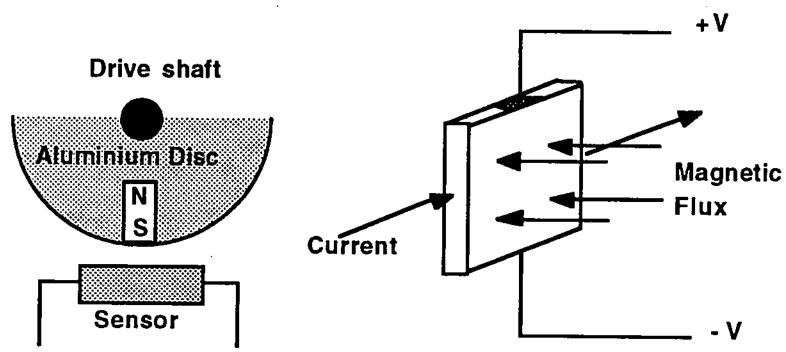


Figure 85

Fig 85 shows the layout of the Hall effect transducer assembly fitted to the DIGIAC 1750 unit.

The Hall Effect Principle.

When a direct current is passed between two opposite faces of a rectangular section conductor and there is a magnetic field through the material with its axis at 90^o to the current flow, then there is a direct voltage developed between the two faces that are mutually at 90^o to the current and the magnetic field.

The magnitude of the voltage is proportional to the current and the magnetic flux. The polarity of the voltage depends on the directions of the current and flux.

With metallic conductors the effect is small but it is appreciable for some semiconductors.

The transducer provided consists of a semiconductor device arranged in a bridge circuit Two outputs are provided, the output voltage from one increasing with the magnetic field and that from the other decreasing with the magnetic field.

The electrical circuit arrangement for the DIGIAC 1750 unit is shown in fig 86.

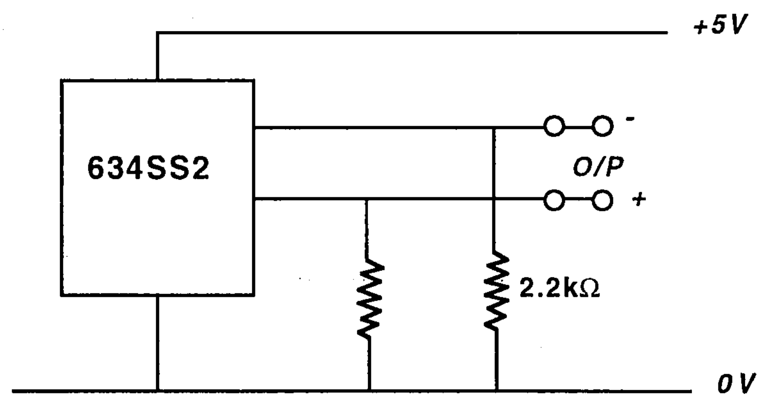


Figure 86

The main characteristics of the device are as follows:-

Type	634SS2
Output voltage (+) (No field)	1.75V
Output voltage (-) (No field)	1.6V
Output voltage change	9mV/mT
Output voltage change (under magnet)	600mV.

Exercise 27. The characteristics of a Hall effect transducer.

Equipment:-

1 Hall Effect transducer unit
1 Differential amplifier
1 20V Digital voltmeter
1 Amplifier #1
1 10-0-10V M.C.meter
1 Timer/Counter unit
Connecting leads.

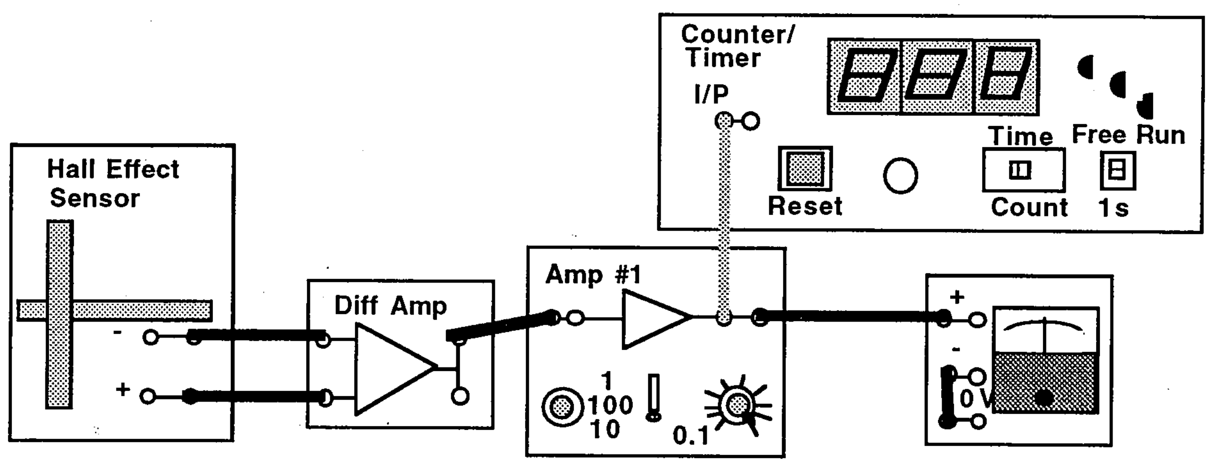


Figure 87

■ Connect the circuit as shown in Fig 87 and set the Amplifier #1 gain controls to 10 and 1.0 for the coarse and fine controls respectively.

- Set the drive shaft position so that the magnet in the Hall effect disc is in the horizontal axis so that there is no magnetic field cutting the Hall effect device. Note the output voltage from the + and - output sockets of the Hall effect device with the digital voltmeter.

- Now rotate the disc so that the magnet is directly above the Hall effect device. This position will be indicated by the maximum voltage change at either of the output sockets.

Note the voltages at both output sockets .

Output voltage	**(No magnetic field) (+)**	**=**
OUtput voltage	**(No magnetic field) (-)**	**=**
Output voltage	**(Max. magnetic field) (+)**	**=**
Output voltage	**(Max. magnetic field) (-)**	**=**

- Set the magnet in the horizontal position and then adjust the offset control of amplifier #1 for zero output indication on the M.C.meter.

- Now set the magnet directly above the Hall effect device and note the output voltage.

Output voltage	**(No magnetic field)**	**= 0V**
Output voltage	**(Max. magnetic field)**	**=**

These readings illustrate the basic characteristics of the Hall Effect device and indicate its application to proximity detection.

The device is also suitable for speed measurement applications.

- Connect the output of amplifier #1 to the Counter/Timer input and set the controls for "count" and "1s".
- Apply an input to the motor so that the shaft rotates slowly, press the "reset" button and note the displayed value, this representing the shaft speed in rev/sec.
- Remove the input to the counter from amplifier #1 output and place in the output of the opto transducer unit. Press the counter "reset" button and note the displayed value, this being the shaft speed for comparison with the previous reading. Enter the values in Table 31
- Repeat the procedure for values of speed over the full range available for comparison.

Shaft speed (Rev/sec) Hall Effect .					
Shaft speed (Rev/sec) Slotted opto.					

Table 31.

Do the values compare?

Hall Effect devices are available for proximity detection, linear or angular displacement , multiplier and current or magnetic flux density measurement applications.

The D.C.permanent magnet Tachogenerator.

Fig 88 shows the basic construction of a D.C permanent magnet tachogenerator, consisting basically of a set of coils connected to a commutator, these rotating inside a permanent magnet stator.

The rotating assembly is referred to as the armature.

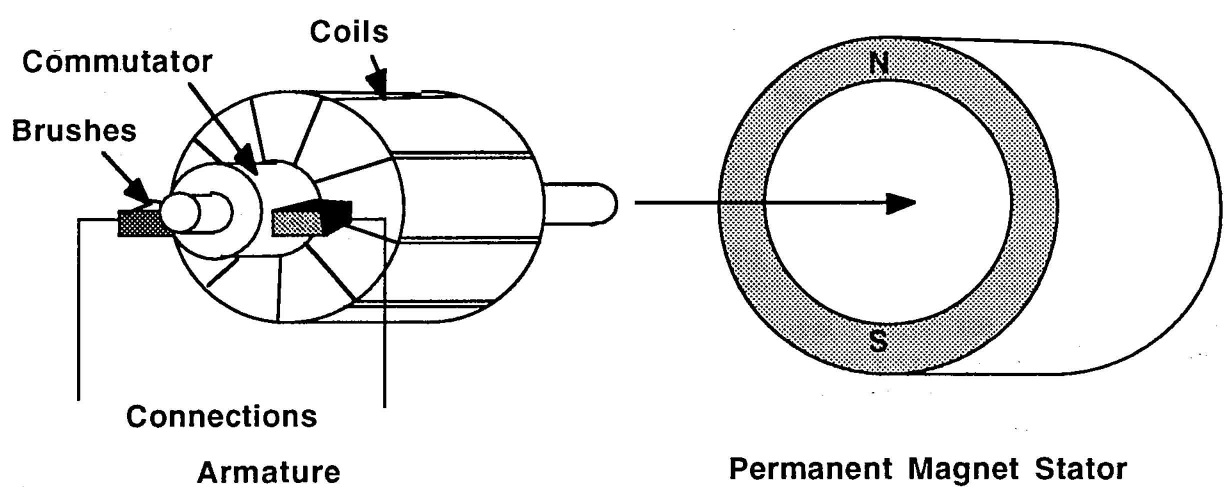


Figure 88

With the coils rotating, an alternating e.m.f. is generated in them and the commutator converts this to D.C.

The magnitude of the generated e.m.f. is proportional to the rotational speed and the polarity depends on the direction of rotation.

The electrical circuit of the device provided with the DIGIAC 1750 unit is shown overleaf in Fig 89.

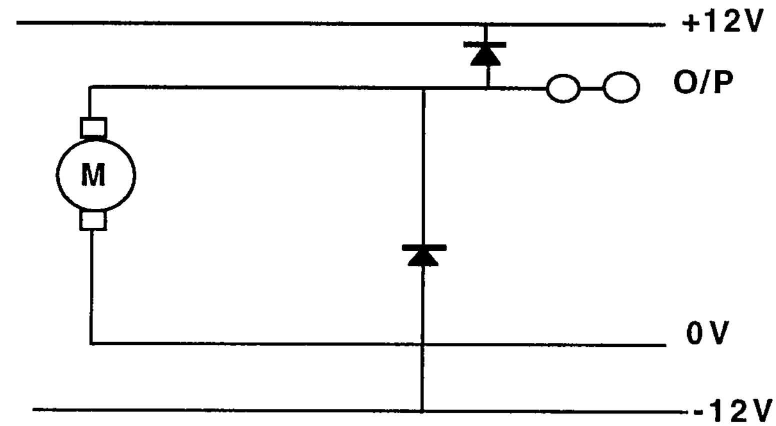


Figure 89

The diodes are fitted to limit any voltage spikes that may be generated by the commutation process (i.e. conversion from A.C. to D.C.) to a maximum of 12V.

The main characteristics of the device are as follows:-

Open circuit voltage (12V to motor)	= 10.5V
Short circuit current (12V to motor)	= 750mA
Output impedance	=7Ω
Output noise	=200mV p-p

Exercise 28. The Characteristics of a permanent magnet D.C. Tachogenerator

Equipment:-

1 D.C. Tachogenerator unit
1 20V Digital voltmeter
1 10-0-10V M.C.Meter
1 Amplifier #1
1 Slotted opto transducer unit
1 Timer/Counter .
Connecting leads.

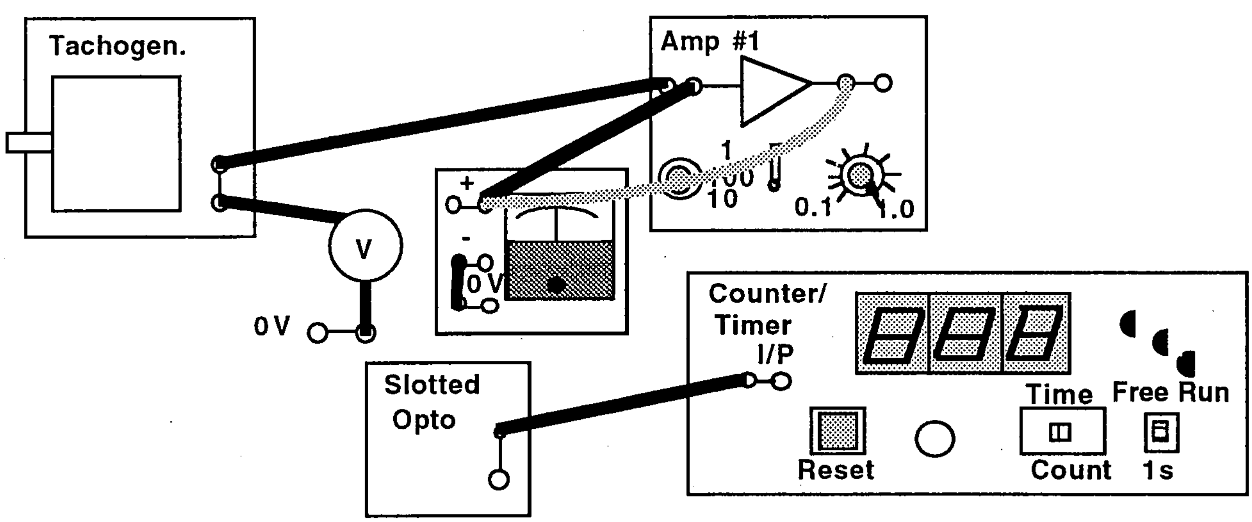


Figure 90

- Connect the circuit as shown in Fig 90, set the counter controls to "Count" and "1s".and set the gain controls of amplifier #1 to 10 and 0.1 for the coarse and fine controls respectively.

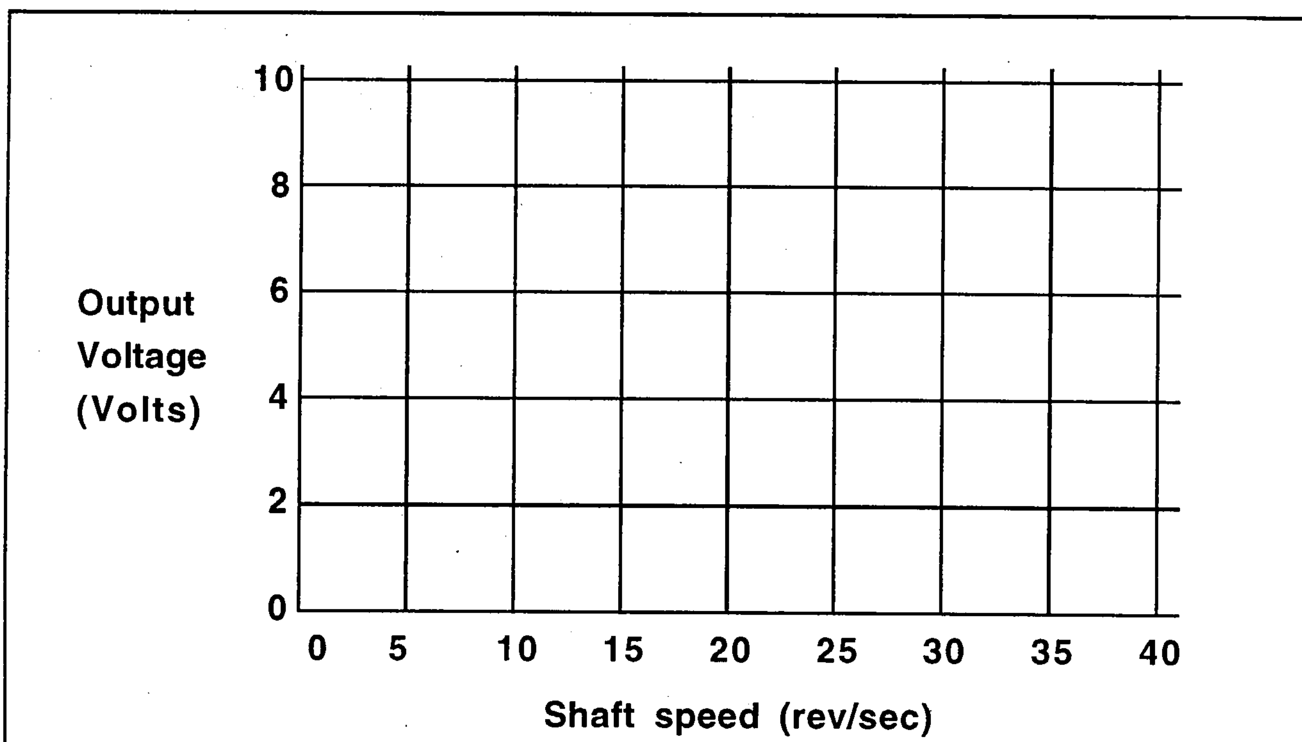
- Apply an input to the motor and set the shaft speed to 5 rev/sec as indicated by the counter after pressing the "reset" button. Note the output voltages indicated by the two voltmeters and enter the values in Table 32.
- Repeat the procedure for the other shaft speed settings indicated in Table 32 .

Shaft Speed (rev/sec)	5	10	20	30	40
Output Voltage (Digital)					
Output Voltage (M.C. Meter)					

Table 32.

Draw the graph of output voltage against shaft speed on the axes provided.

Is the output voltage proportional to the shaft speed ?



We will now calibrate the M.C. meter to indicate the speed directly.

The maximum speed of the shaft is of the order of 40 rev/sec, i.e. 2400 rev/min.

We will first calibrate the scale so that 10V represents 2000 rev/min.

- Remove the connection between the M.C. meter and the input of Amp #1.
- Connect the M.C. Meter to the output of Amp#1, as shown shaded in Figure 90.
- With the shaft stationary, adjust the offset control of amplifier #1 for zero reading on the M.C.meter.
- Apply an input to the motor and set the shaft speed to 2000 rev/min (33rev/sec). Adjust the fine gain control of amplifier #1 so that the M.C. meter indicates 10V. The voltage scale is now calibrated so that 10V represents 2000rev/min.

Check other values against those obtained from the opto transducer and counter

Voltmeter reading	**= 6V**
Shaft speed (6 x 20 = 1200rev/min)	**= 20rev/sec**
Shaft speed from opto transducer	**=**
Voltmeter reading	**= 3V**
Shaft speed (3 x 20 = 600 rev/min)	**= 10rev/sec**
Shaft speed from opto transducer	**=**

Do the readings compare?

- Now calibrate the voltmeter so that 10V represents 1000 rev/min. Check the calibration for other speeds.

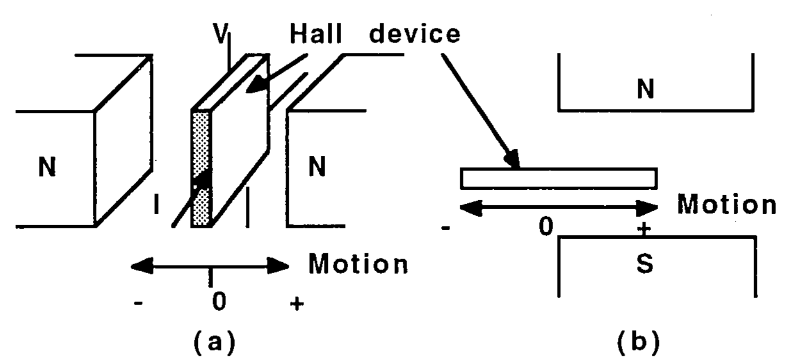
Notes:

Student assessment 8.

1. (a) For a slotted opto transducer unit with the output taken from the transistor emitter connection, state how the output voltage changes when the beam is admitted by the slot.
   (b) A slotted opto transducer is used with a disc having four slots. For a certain shaft speed the output count is 100 /sec. What is the shaft speed in rev/min ?

2. (a) Why are binary coded discs not used for positional displacement applications ?
   (b) Sketch a linear Gray coded disc suitable for use with four reflective opto transducers.
   (c) If the positional range covers 80mm, what distance is covered by each identifiable position ?

3. A Hall Effect device is moved between two permanent magnets as shown below.



Sketch graphs showing how the output voltage will vary with position of the Hall Effect device for each case.

Student assessment questions continued overleaf

4. A permanent magnet tachogenerator transducer gives an output of +6V when rotating clockwise at 1000 rev/min. What would be the output voltage for each of the following rotational speeds ?

   (a) 2500 rev/min clockwise
   (b) 500 rev/min clockwise
   (c) 1500 rev/min counter clockwise.

5. For the transducer types covered in this chapter, state which types would be suitable for the following applications:-

   (a) Proximity detection
   (b) Linear or angular position measurement
   (c) Speed measurement
   (d) Current measurement
   (e) Magnetic flux density measurement.

Notes:

Chapter 2.8 Transducers For Sound Measurement.

Objectives of this chapter.

Having studied this chapter you should:-

- *Know the basic construction and characteristics of a dynamic microphone*
- *Know the basic construction and characteristics of an ultrasonic receiver.*

The Dynamic Microphone.

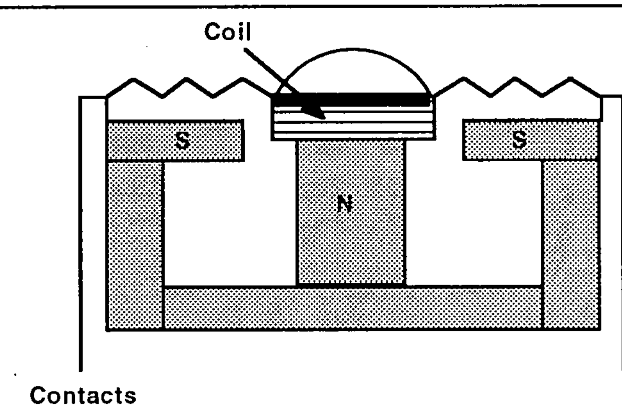


Figure 91

The basic construction of the dynamic microphone is shown in Fig 91, consisting of a coil attached to a thin diaphragm, the coil being suspended in the field of a permanent magnet. The diaphragm moves in response to any sound vibration in the air and causes the coil to move in the magnetic field. This induces an e.m.f. in the coil,the magnitude of the e.m.f. being proportional to the sound amplitude.

The electrical circuit for the device provided with the DIGIAC 1750 unit is shown in Fig 92.

The 680Ω resistor is fitted to provide a load correctly matched to the output impedance ,(600Ω), of the microphone.

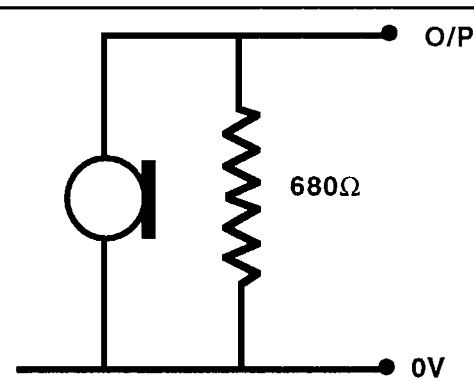


Figure 92

The main characteristics of the device are as follows:-

Output impedance	600ΩFrequency
response (-3dB)	60 - 18000Hz
Output voltage	5mV (normal max.)

Notes:

Exercise 29. The Characteristics of a Dynamic Microphone.

Equipment:-

1 Dynamic microphone
1 A.C. Amplifier
1 L.E.D. Bargraph display
Connecting leads.

In this exercise we are using the L.E.D. bargraph display because the response time of the other meters is too high. The M.C.meter could be used, but it will require feeding from the A.C. amplifier via a buffer amplifier so that it does not load the circuit. The voltage readings obtained will be low , due to the inertia of the moving coil system, but the meter will give an indication of an output voltage from the microphone.

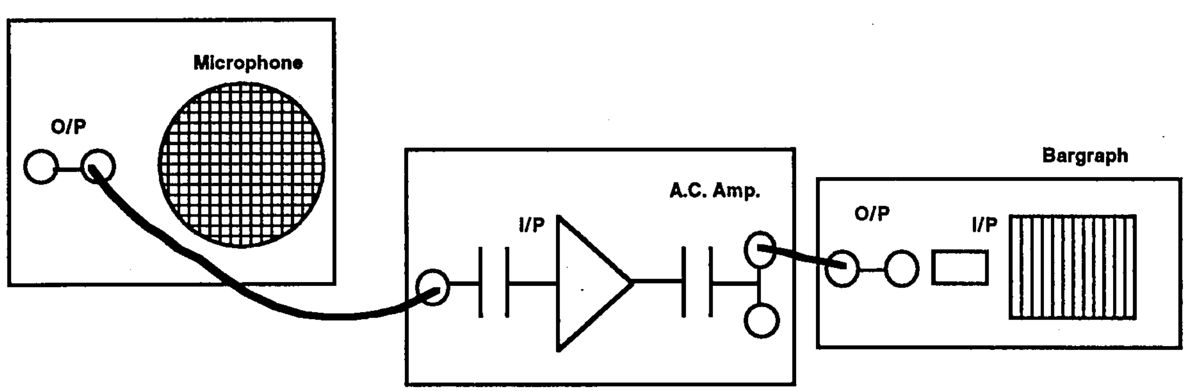


Figure 93

- Connect the circuit as shown in Fig 93 and set the A.C. Amplifier gain control to 1000.

- Switch the supply ON and note the display on the bargraph when the baseboard is tapped with the finger,lightly at first and then harder.

  Each L.E.D lit represents a voltage of 0.5V. There are 10 L.E.D's so that all ON represents a voltage of 5V.

  Is it possible to light all the L.E.D's ?

- Talk, cough or sing near the unit. You will find that the bargraph will respond to any sound made.

  Does it ?

- Connect the M.C. meter to the amplifier output via buffer #1 and tap the baseboard so that all L.E.D's of the bargraph are lit and note the maximum reading of the M.C. meter.

  Maximum voltage output (Bargraph) = 5V

  Maximum voltage output (M.C.meter) =

The M.C. meter should indicate a lower voltage.

Notes:

The Ultrasonic Receiver

The basic construction of an ultrasonic receiver and the electrical circuit for the device fitted to the DIGIAC 1750 unit is shown in Fig 94.

The device consists of a piece of ceramic material fixed to a small diaphragm inside the case of the unit.

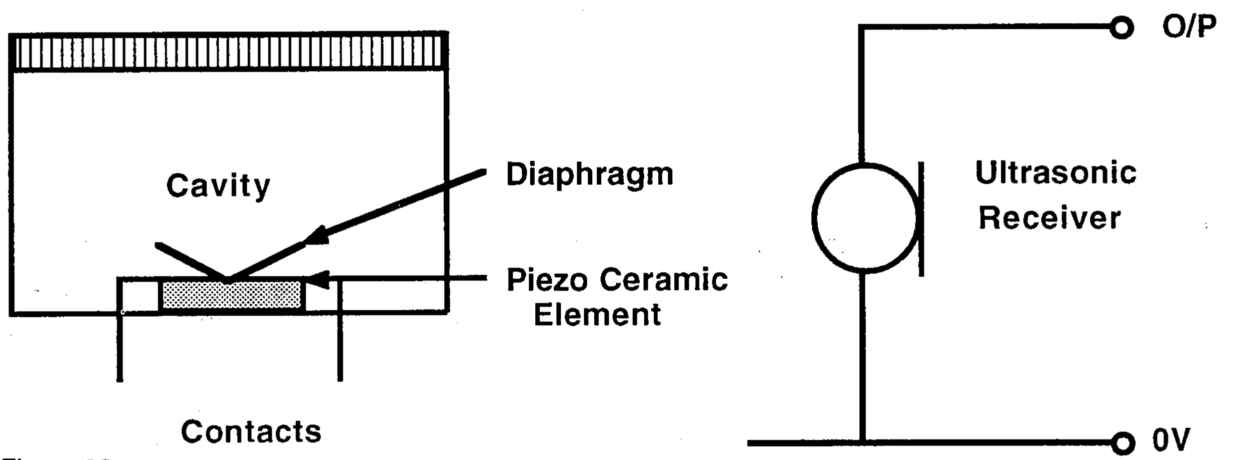


Figure 93

The operation of the device relies on the principle that certain ceramic materials produce a voltage when they are stressed. This is referred to as the "piezo-electric" principle.

Vibration of the diaphragm stresses the ceramic material and hence produces an output voltage.

The dimensions of the components are arranged so that there is resonance at around 40kHz. The device therefore gives an output for frequencies in the region of 40kHz. This is outside the normal audio range (maximum 20kHz) and hence is referred to as ultrasonic

The main characteristics of the device are as follows:-

Peak resonance (Typical)	40kHz
Directional angle	20°
Impedance	30kΩ
Output amplitude (min.)	5mV
(max.)	60mV

Notes:

Exercise 30. The characteristics of an ultrasonic receiver.

Equipment:-

1 Ultrasonic receiver unit
1 40kHz oscillator
1 Ultrasonic transmitter
1 40kHz filter
1 Full wave rectifier
1 Low pass filter
1 Amplifier #1
1 L.E.D. Bargraph display
Connecting leads.

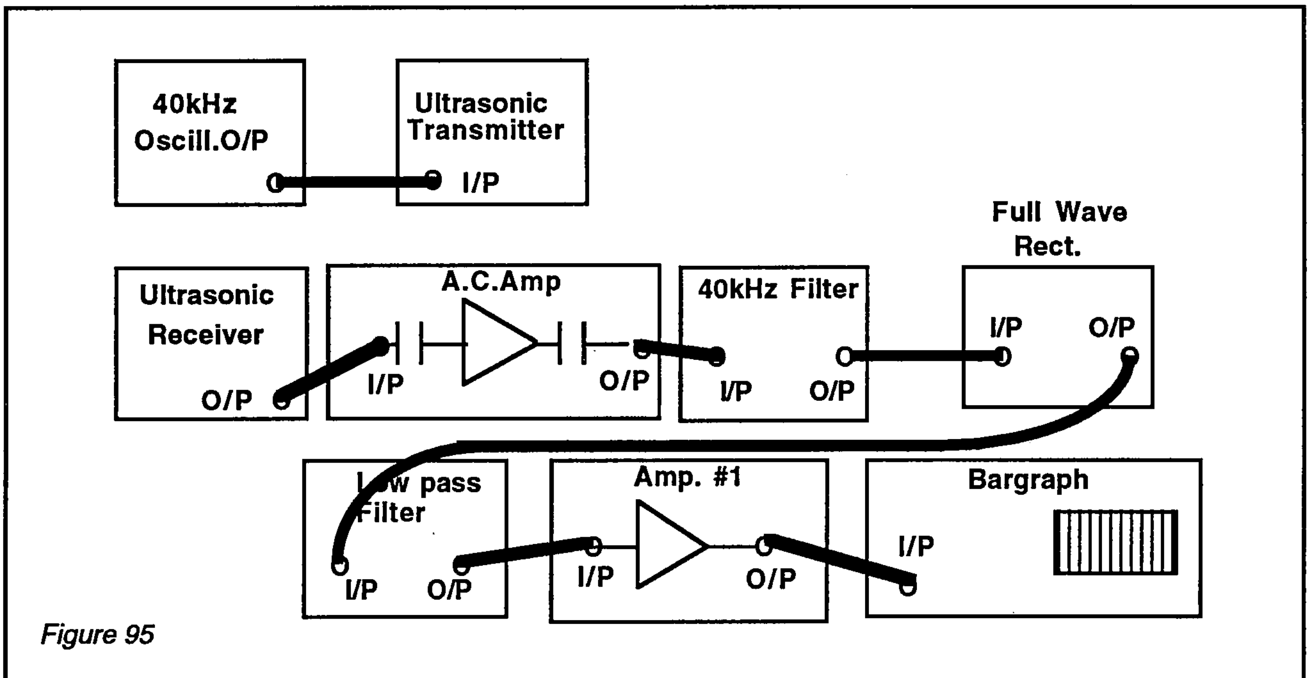


Figure 95

- Connect the circuit as shown in Fig 95 set the A.C. amplifier gain control to 1000, the low pass filter to 10ms and the coarse and fine gain controls of amplifier #1 to 10 and 0.5 respectively.

- Switch the supply ON and note the bargraph display as you hold your hand or any other object over the ultrasonic devices and move it towards or away from them. The display should respond, thus indicating the receipt of a signal of frequency 40kHz by the ultrasonic receiver.

  Does it ?

  Does the output amplitude displayed vary with the distance of the hand from the transmitter-receiver ?

  What is the effect of keeping your hand absolutely still ?

- Hold a thin object such as a pencil approximately 6 ins (150mm) over the beam and move it horizontally to left and right and note the distance over which there is any output response, note the value. This indicates the useful direction angle for the device.

  Height of object from transmitter-receiver =

  Distance over which response received =

- Put a sheet of paper or some other object over the transmitter unit thus breaking the beam.

  Is there any output response to movement of the hand over the devices now ?

  Does the device respond when the case is tapped, as did the dynamic microphone ?

In this exercise we have amplified the received signal, rectified it, filtered out the high frequencies and then amplified the low frequency to operate the display.

It is the amplitude modulation of the received signal caused by the hand movement, which produces frequency shifting, (Doppler effect) that is producing the displayed output.

Pulsed ultrasonic devices can be used for distance measurement to reflecting surfaces by measurement of the time between the transmission and receipt of the pulsed signal.

Notes:

Notes:

Student Assessment 9.

1. For a dynamic microphone, what would be the effect on the coil and the output voltage of:-
   (a) an increase in sound amplitude within its specification
   (b) an increase in sound frequency within its specification
   (c) a frequency input much higher than its specification.

2. An ultrasonic transmitter is stated to have a peak response at 50kHz and bandwidth of 5kHz. A receiver has a peak response at 40kHz and bandwidth 5kHz.

   State with reasons whether these could be operated as a transmitter-receiver combination.

3. An ultrasonic transmitter-receiver combination has an operating frequency of 50kHz. With a moving object in the beam, what would you expect to be the effect on
   (1) the amplitude and
   (2) the frequency of the received signal if the object is moving:-

   (a) towards the transmitter-receiver

   (b) away from the transmitter-receiver

Notes:

Section 3

Output Transducers

Chapter 3.1 Transducers For Sound Output.

Objectives of this chapter:-

Having studied this chapter you should :-

- *Know the construction and basic characteristics of a moving coil loudspeaker.*
- *Know the construction and basic characteristics of an ultrasonic transmitter.*
- *Know the construction and basic characteristics of a buzzer.*

The Moving Coil Loudspeaker.

The basic construction of a moving coil loudspeaker is shown in Fig 96, this being similar to that of the moving coil microphone.

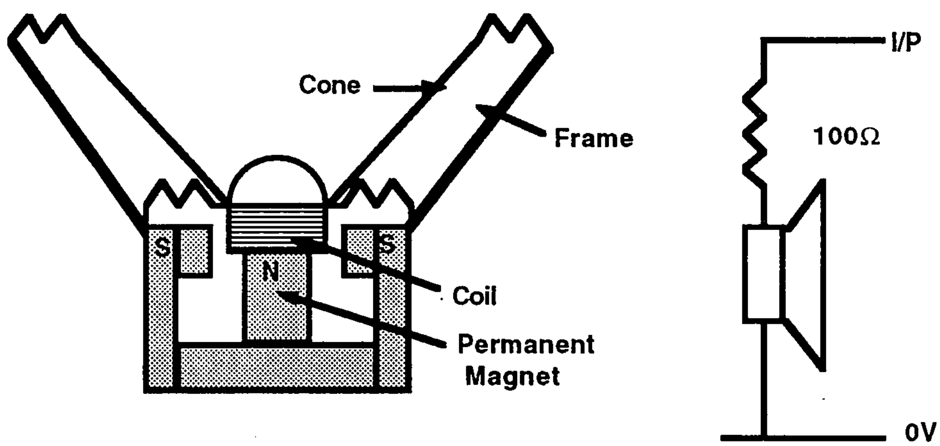


Figure 96

The permanent magnet coil and diaphragm are basically the same but in this device the diaphragm is attached to a large paper cone supported by a frame, the cone being free to move with the coil.

An alternating voltage applied to the coil causes it to move forwards and backwards in the magnetic field. With the applied frequency in the audio range (say 50 - 20,000Hz), the cone movement will cause a variation of the air pressure at this frequency and produce a tone that is audible to the human ear.

The electrical circuit of the device fitted to the DIGIAC 1750 unit is shown in Fig 96, the 100Ω resistor being fitted to limit the maximum power dissipation to 98mW.
The main characteristics of the device fitted to the DIGIAC 1750 unit are as follows:-

Impedance	8Ω
Power rating	200mW max.
Frequency response (3dB)	400 - 5000Hz

Exercise 31. Moving coil loudspeaker characteristics.

Equipment:-

1 Moving coil loudspeaker
1 V/F converter (Voltage to Frequency)
1 Power amplifier
1 10kΩ carbon slider resistor
Connecting leads.

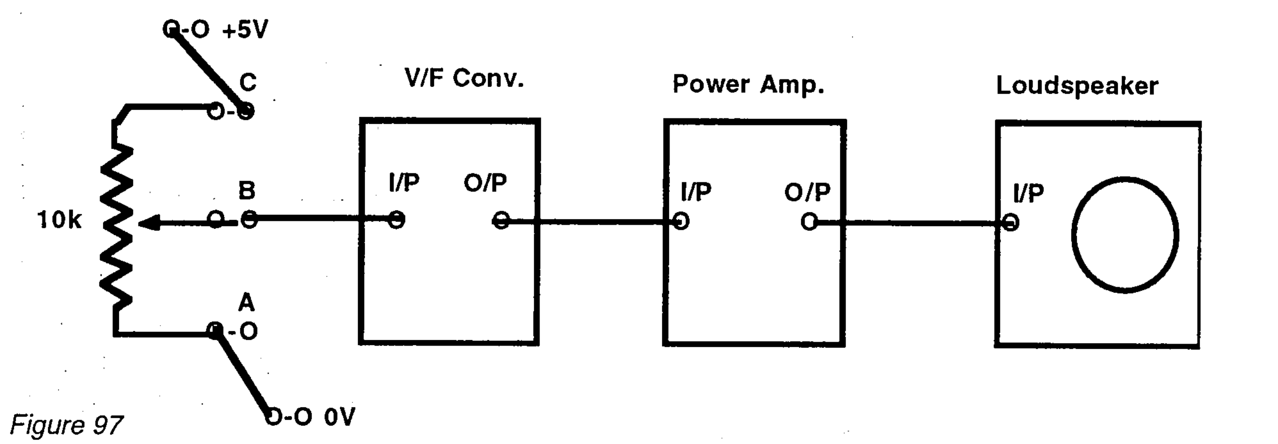


Figure 97

- Connect the circuit as shown in Fig 97 and switch the supply ON.
- Vary the setting of the 10kΩ resistor over its full range. This will vary the output frequency from the V/F converter from zero to a maximum of 5kHz and there will be a corresponding tone output from the loudspeaker.

Is this so ?

Note :- The output waveform is square wave and not sinusoidal so that the tone heard will not be pure, but the characteristics of the device are illustrated by the exercise.

The ultrasonic transmitter

The basic construction and the electrical circuit of the device fitted to the DIGIAC 1750 unit is shown in Fig 98.

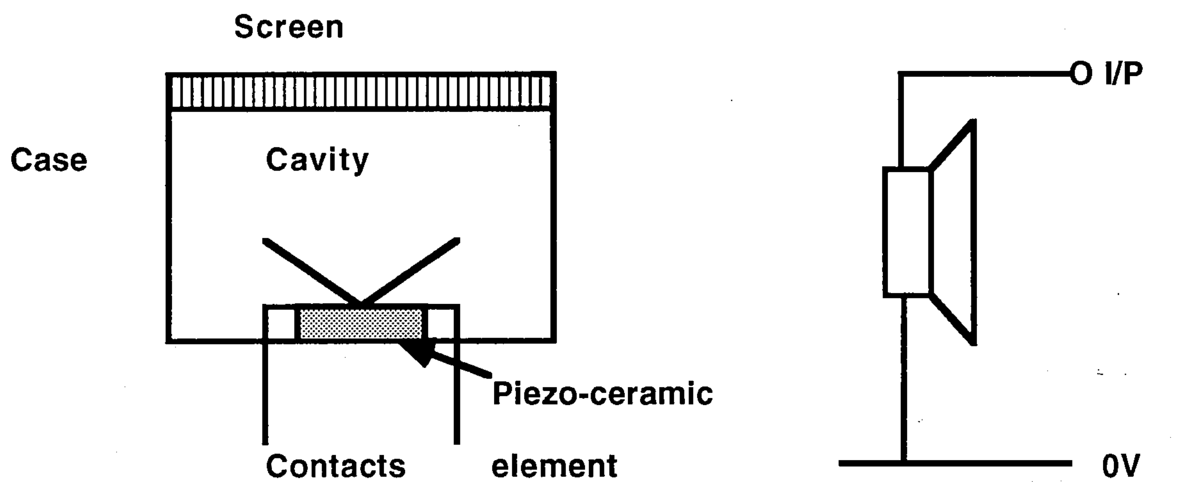


Figure 98

The construction is basically the same as for the ultrasonic receiver but a transmitter device is arranged to have a lower input impedance so that a larger power output is possible for a certain voltage input.

The basic characteristics of the device fitted to the DIGIAC 1750 unit are as follows:-

Peak resonant frequency	40kHz
Directional angle	20°
Input impedance	500Ω
Sensitivity	106dB

The device is fed from the 40kHz oscillator and has been used in the exercise on the ultrasonic receiver (Exercise 30.)

The Buzzer

The basic construction of the buzzer used in the DIGIAC 1750 unit is shown in Fig 99.

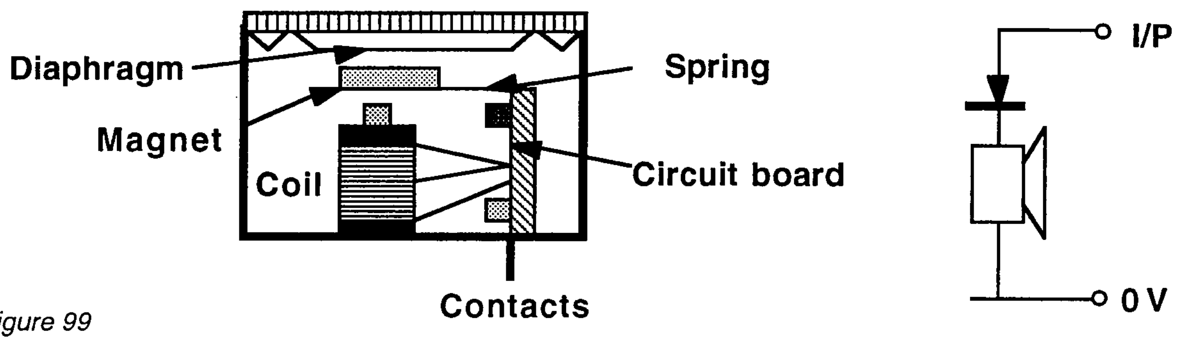


Figure 99

This consists of a small transistorised oscillator circuit which feeds an alternating e.m.f. to an iron cored coil. The alternating magnetic field produced by the coil attracts and repels a small permanent magnet attached to a spring. This magnet vibrates against a diaphragm and creates a loud noise.

In control system applications the device is used as an alarm indication.

The electrical circuit of the device is also shown in Fig 99, the diode being fitted to prevent damage to the transistorised circuit if the supply is connected with the incorrect polarity. The polarity of the input supply should be positive,the rated voltage being 12V.

The main characteristics of the device fitted to the DIGIAC 1750 unit are as follows:-

Supply voltage	8V	12V	16V (Max)
Supply current		11mA	18mA
Output frequency	350Hz	400Hz	450Hz
Output sound level	80dB (3metres away)		

Exercise 31. The Characteristics of a Buzzer

Equipment:-

1 Buzzer
1 Power amplifier
1 10kΩ carbon slider resistor
1 20V Digital voltmeter
Connecting leads

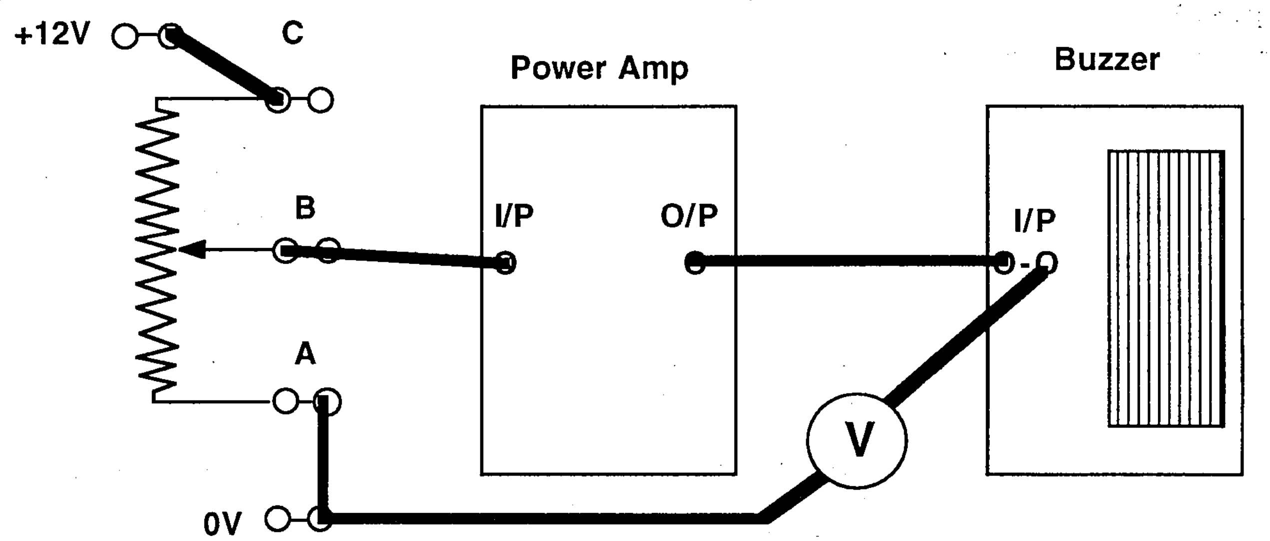


Figure 100

- Connect the circuit as shown in Fig 100 and set the control of the 10 kΩ resistor for zero output voltage (slider to left).

- Switch the supply ON and adjust the slider control to increase the voltage applied to the buzzer. Note the voltage at which the buzzer begins to operate.

Minimum voltage for buzzer to operate =

- Now increase the applied voltage to the maximum available.

  Does the frequency of the sound increase as the voltage is increased ?

  Does the magnitude of the sound increase as the voltage increases?

Notes:

Student Assessment 10.

1. Identify the devices described by the following:-

    (a) One that emits an alternating wave of constant frequency in the audio range when a D.C. voltage is applied.

    (b) One that emits an alternating wave at higher than audio frequencies but less than radio frequencies.

    (c) One that can emit alternating waves over a large range of audio frequencies.

2. (a) What is the approximate maximum frequency detectable by the human ear ?

    (b) Why was the diode fitted to the input circuit of the buzzer of the DIGIAC 1750 unit ?

    (c) What is the upper 3dB frequency of the loudspeaker fitted to the DIGIAC 1750 unit?

    (d) What is the direction angle of the ultrasonic devicesfitted to the DIGIAC 1750 unit ?

    (e) What is the operating frequency of the ultrasonic devices fitted to the DIGIAC 1750 ?

3. (a) A loudspeaker is fed with a 1kHz signal and placed in a vacuum. State ,giving reasons, whether a sound output would be detected.

    (b) Two identical loudspeakers fed with the same audio signal and having identical lead polarities are placed facing each other. Would a person centrally placed between the loudspeakers detect the direct sound from the speakers ?

Notes:

Chapter 3.2 Output Transducers For Linear Or Angular Motion

Objectives of this chapter.

Having studied this chapter you should:-

- *Know the basic construction and characteristics of a D.C. solenoid*
- *Know the basic construction and characteristics of a D.C. relay*
- *Know the basic construction and characteristics of a D.C. solenoid valve*
- *Know the basic construction and characteristics of a D.C. permanent magnet motor.*

The D.C. Solenoid

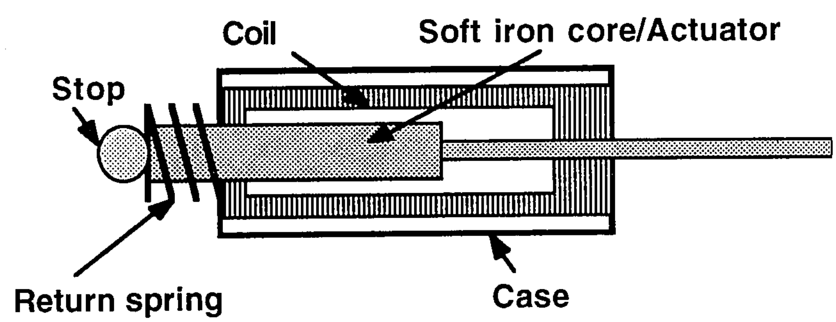


Figure 101

The basic construction of a D.C. solenoid is shown in Fig 101, consisting basically of a soft iron core and actuator shaft which is free to move in a coil. With the coil not energised, the core is held by a spring in its neutral position against a mechanical stop.

With the coil energised with its rated voltage,the soft iron core is attracted into the coil and is held in this position. With the coil de-energised, the core returns to its neutral position under the action of the spring.

The actual voltage required to attract the core into the coil will be less than its rated value and the value will depend on the load applied to the actuator shaft. The voltage at which the core is pulled in by the coil is referred to as the "pull-in voltage".
With the coil energised and the core attracted, if the coil voltage is now reduced gradually, when the voltage has fallen to a certain value the core will return to its neutral position under the action of the spring. This voltage is referred to as the "drop out" or "release" voltage. The value of this voltage will also depend on the load applied to the actuator shaft.

Fig 102 shows the electrical circuit diagram of the device fitted to the DIGIAC 1750 unit.

When a coil is de-energised a large e.m.f. can be induced in the coil, the magnitude of this depending on the coil inductance and the rate of change of the current. The diodes provided limit any induced voltage to a maximum amplitude of approximately 12V.

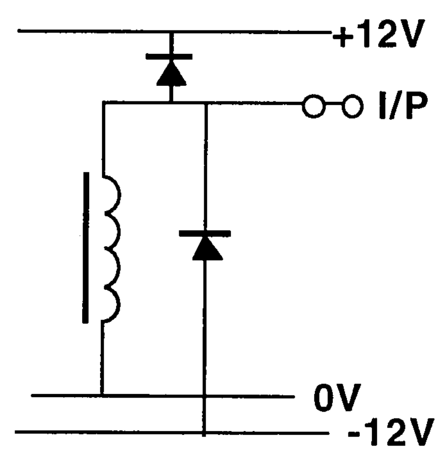


Figure 102

The main characteristics of the device fitted to the DIGIAC 1750 unit are as follows:-

Coil resistance	**50Ω**
Coil rated voltage	**12V**
Pull-in voltage	**6V**
Release voltage	**0.8V**
Coil power (12V applied)	**3W**

Exercise 32. The characteristics of a D.C. Solenoid

Equipment:-

1 D.C. solenoid
1 Power amplifier
1 10-0-10V M.C. meter.
1 10kΩ wirewound resistor
Connecting leads.

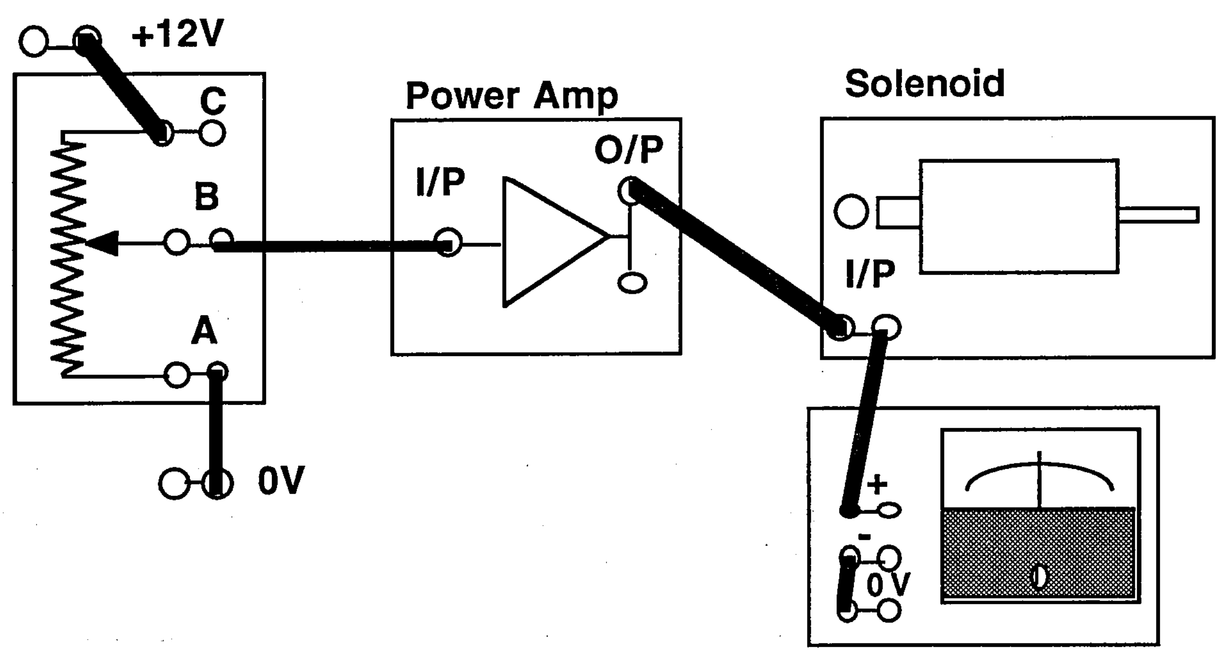


Figure 103

- Connect the circuit as shown in Fig 103 and set the 10kΩ resistor for zero output voltage (control set fully counter clockwise).

- Switch the supply ON and rotate the resistor control to gradually increase the voltage applied to the solenoid coil. Note the voltage at which the iron core of the solenoid is attracted fully into the coil. This value is the "pull-in " voltage.

  Note:- The core will start to move at a lower voltage than the pull-in value, the actual pull-in voltage will be the value when you hear the second click, as the core aligns itself inside the coil. In this position you will find it difficult to push the actuator back towards its neutral position.

  Pull-in voltage =

- Repeat the process with your finger against the actuator shaft to exert a little load and note the voltage now required for pull in. A higher voltage should be required.

  Is this so ?

- With the coil energised and the core in its pulled in position, gradually reduce the coil applied voltage and note the value at which the core returns to its neutral position, the "drop-out" or "release " voltage.

  Release voltage =

- Repeat the process with your finger against the actuator shaft to exert a little load and note the voltage now required for the release of the core. Release should now occur with a higher voltage.

  Is this so ?

The D.C. Relay.

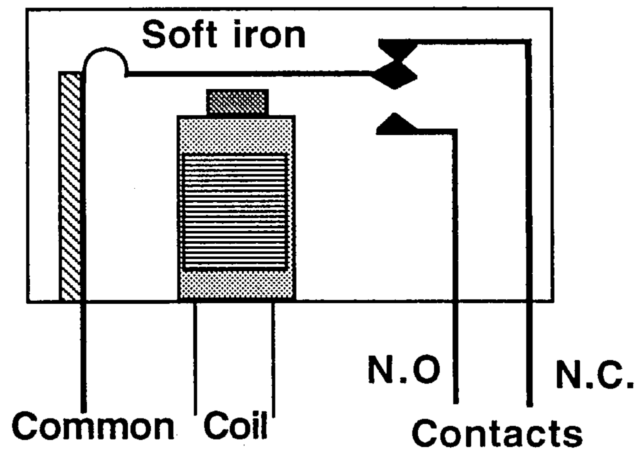


Figure 104

The basic construction of a D.C. relay is shown in Fig 104, consisting of a coil with an iron core and having a soft iron strip attached to a spring which holds the strip just above the core.

Changeover contacts are attached to the strip and with the strip in its normal position it makes contact with one of the contacts, this being referred to as the "normally closed" (N.C.) contact.

With the coil energised at its rated voltage, the core will be magnetised and attract the soft iron strip. This causes the connection to the N.C. contact to be broken and contact is made to the other contact., this contact being referred to as the "normally open" (N.O.) contact.

With contacts of this construction, the contacts will bounce for a short period each time they close or open (make or break) and this can cause problems with some circuits. This problem can be overcome using a debounce circuit or by use of a time delay prior to checking the contact state after operation.

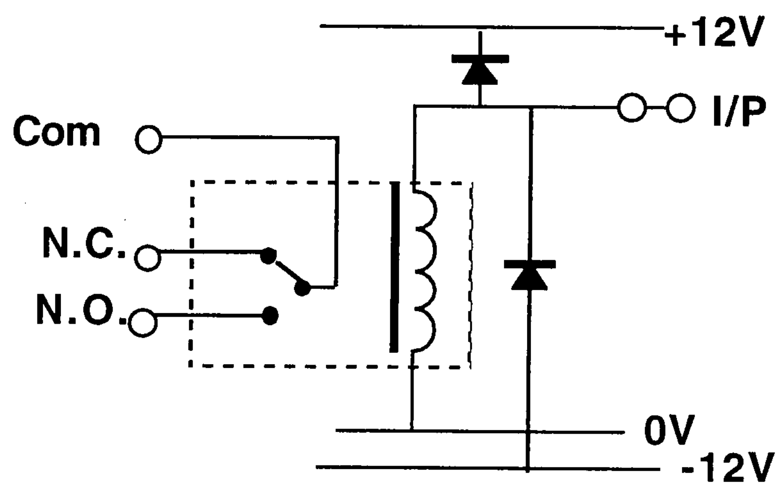


Figure 105

Fig 105 shows the electrical circuit of the device fitted to the DIGIAC 1750 unit. The diodes limit any induced voltages to a maximum of approximately 12V as for the solenoid device.

The main characteristics of the device fitted to the DIGIAC 1750 unit are as follows:-

Coil rated voltage	12V
Coil resistance	320Ω
Coil operating voltage	7.5V
Coil release voltage	1.8V
Operate/release time	5ms
Contact rating	12V, 1A
Lifetime cycles	5×10^6

Exercise 33. The Characteristics of a D.C.Relay.

Equipment:-

1 D.C. Relay
1 Power amplifier
1 20V Digital voltmeter
1 10-0-10V M.C.meter
1 10kΩ wirewound resistor
Connecting leads.

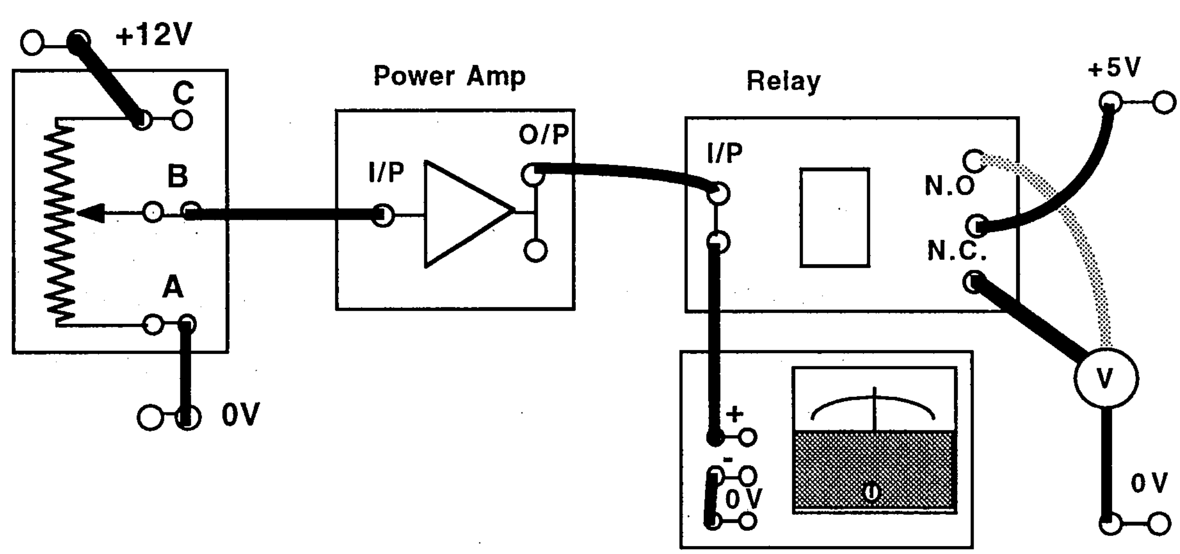


Figure 106

- Connect the circuit as shown in Fig 106 and set the resistor control for zero output voltage.

- Switch the supply ON. The relay will be in its de energised state. Note the voltages at the N.C. and N.O. contacts and enter the values in Table 33. A voltage of 5V represents contacts closed and a voltage of 0V represents contacts open. Enter the state of the contacts in Table 33.

- Apply a voltage of 10V to the relay so that the relay is energised and again note the voltages at the N.C.and N.O. contacts. Enter the values in Table 33 and complete the contact state column.

Relay		Contacts		
Coil Voltage	**State**	**Contact**	**Voltage**	**State**
0V	De energised	N.C.		
		N.O.		
10V	Energised	N.C.		
		N.O.		

Table 33.

The relaycoil will have "pull-in" and "release" voltage characteristics similar to those for a solenoid.

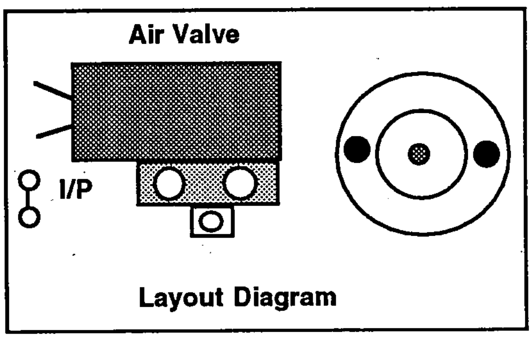
- Determine the pull-in and release voltages for this device by gradually increasing and decreasing the applied voltage. You will hear a click when the relay changes state or alternatively note when a change of reading occurs on the 20V digital voltmeter connected to one of the contacts.

Relay coil pull-in voltage =

Relay release voltage =

The Solenoid Air Valve.

Fig 107 shows the layout of the unit and the construction of the device fitted to the DIGIAC 1750 unit. The construction is similar to the solenoid considered previously, but the soft iron core now operates on two valves, the inlet and the exhaust valves.



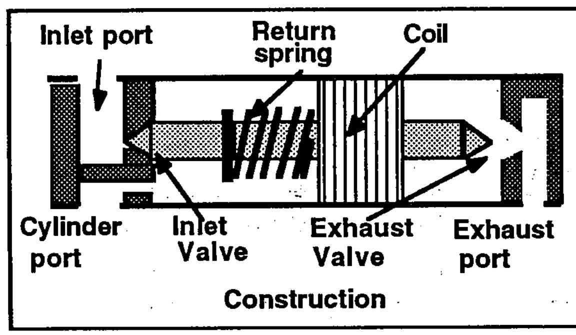


Figure 107

With the coil de-energised the core is held, by the return spring, in the position with the inlet valve closed and the exhaust valve open. In this position the cylinder port is connected to the exhaust port outlet.

With the coil energised, the core is attracted and is held in the position with the exhaust valve closed and the inlet valve open. In this position the inlet port is connected to the cylinder port

In the DIGIAC 1750 unit, the inlet port is connected to the pump and the cylinder port is connected to a pneumatic actuator. With the pump ON, the pneumatic actuator will be operated when the coil is energised and illustrates the principle of electrical control of pneumatic devices.

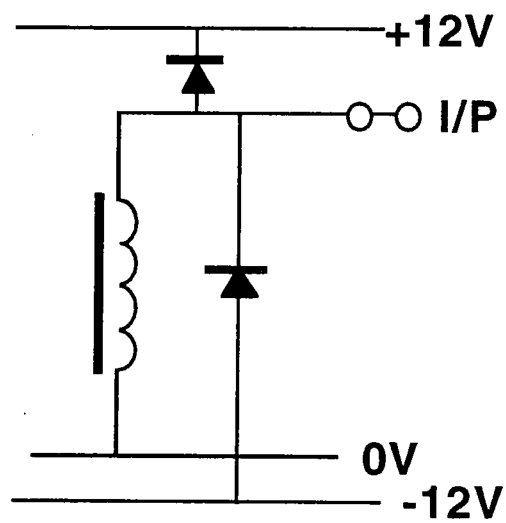


Figure 108

The electrical circuit of the device fitted to the DIGIAC 1750 unit is shown in Fig 108.

The main characteristics of the device are as follows:-

Rated Coil voltage	= 12V
Coil resistance	= 140Ω
Coil "operate" voltage	= 8.3V
Coil "release" voltage	= 1.7V

Exercise 34. The Characteristics of a Solenoid Air Valve.

Equipment:-

1 Air Valve
1 Power amplifier
1 10kΩ wirewound resistor
1 10-0-10V M.C.Meter
Connecting leads

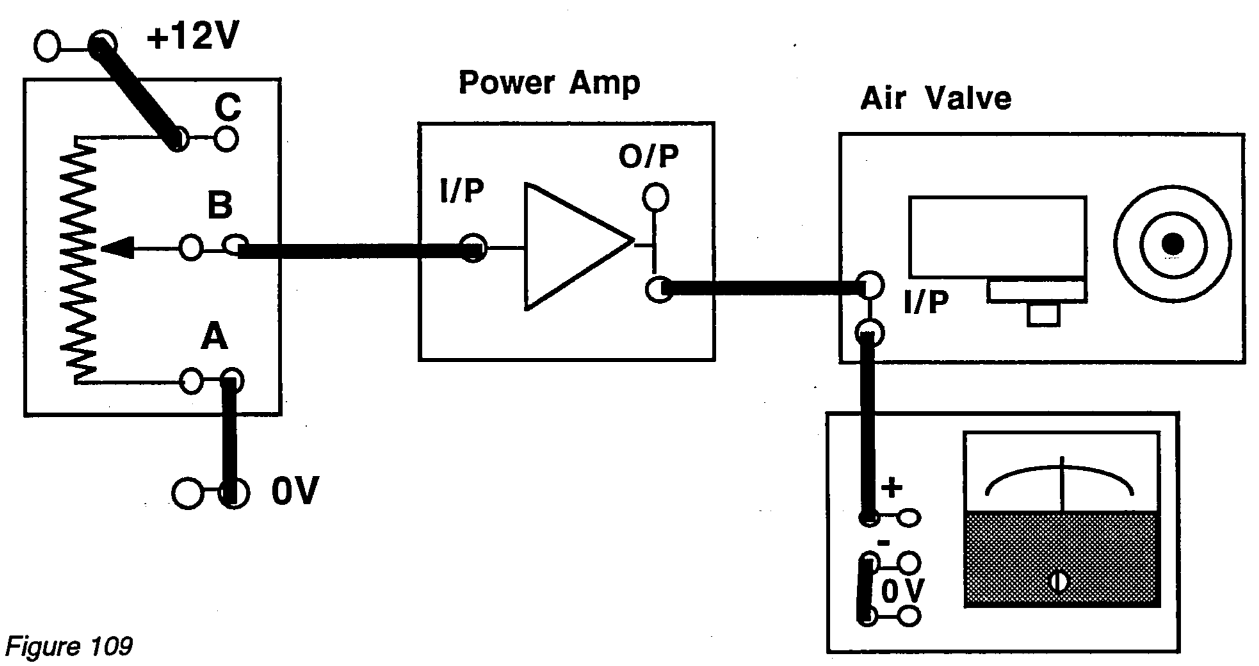


Figure 109

- Connect the circuit as shown in Fig 109, set the resistor control for zero output voltage (fully counter clockwise) and set the pump" Flow/Pressure" control to "Pressure".

- Switch the supply ON and then switch the pump ON. The coil is de-energised in this state, the inlet valve is closed, and the pneumatic actuator will not operate.

- Adjust the resistor control and apply 10V to the solenoid coil. The coil will now be energised and the inlet valve will open and the exhaust valve will be closed. The pump pressure will be applied to the pneumatic actuator and the actuator shaft will rise.

  Does it ?

- Check that variation of the coil applied voltage operates the pneumatic actuator.

  Does it ?

  Now switch the pump OFF. Operation of the solenoid now has no effect on the pneumatic actuator since there is no pressure.

The solenoid coil will have "pull-in" and "release" voltages as for any solenoid.

Determine these values for the device.

- Switch the pump OFF and then increase and decrease the coil applied voltage gradually and note the voltages at which switching occurs. You will hear a "click" when the device switches.

  Coil "pull-in" voltage =

  Coil "release" voltage =

Notes:

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The D.C. Permanent Magnet Motor

The basic construction of a permanent magnet D.C. motor is as shown in Fig 110. The unit is identical with the tachogenerator unit but for motoring applications, a D.C. supply is fed to the armature coils . Current flowing in the armature coils in the permanent magnet field produces a force which causes the armature to rotate.

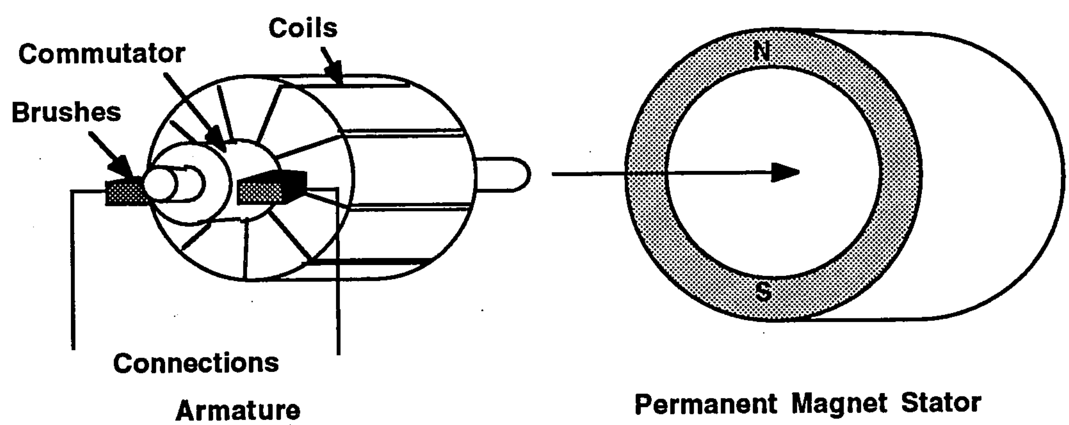


Figure 110

The force acting on the armature is proportional to the current flowing.

When the armature rotates, an e.m..f. is induced in the coils, exactly as for the tachogenerator, this e.m.f. opposes the applied voltage and is referred to as the "back e.m.f.". The armature will accelerate until the speed is such as to produce a back e.m.f. approximately equal to the voltage applied to the armature.

The speed with no load on the shaft is thus roughly proportional to the applied voltage.

When a load is applied to the shaft, the speed will tend to fall, thus reducing the back e.m.f. This allows more current to flow from the supply and the current taken will adjust to the value that produces a torque just sufficient to balance the load torque.

The speed will fall slightly with load due to the increase in voltage drop in the armature coils caused by the higher current.

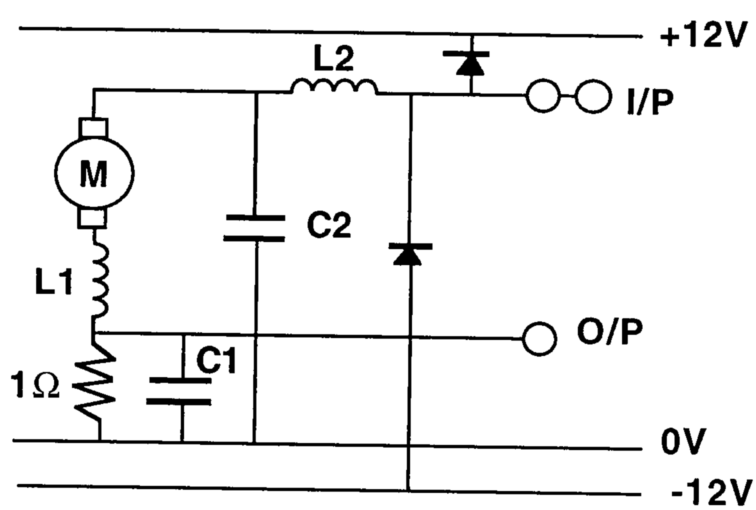


Figure 111

The electrical circuit of the device fitted to the DIGIAC 1750 unit is shown in Fig 111.

The 1Ω resistor is fitted to allow monitoring of the current taken by measurement of the voltage drop across it. The diodes limit any voltage spikes to a maximum of approximately 12V.

Capacitor C1 provides some noise filtering and the combination L1,L2 and C2 reduce radiated R.F. noise.

The main characteristics of the device fitted to the DIGIAC 1750 unit are as follows:-

D.C. Resistance	6.2Ω
No load current (12V applied)	120mA
Stall current (12V applied)	1.93A
Shaft speed (No load, 12V applied)	2400rev/min (Max)
Starting torque	7Ncm/A
Torque constant	3.5Ncm/A
Time constant	19.6ms
Efficiency	82% (Max.)

Notes:

Exercise 35. The Characteristics of a D.C. Permanent Magnet Motor

Equipment:-

1 D.C. Motor
1 Power Amplifier
1 10kΩ Wirewound resistor
1 20V Digital voltmeter
1 10-0-10V M.C.Meter
1 Slotted opto transducer
1 T imer/Counter
Connecting leads

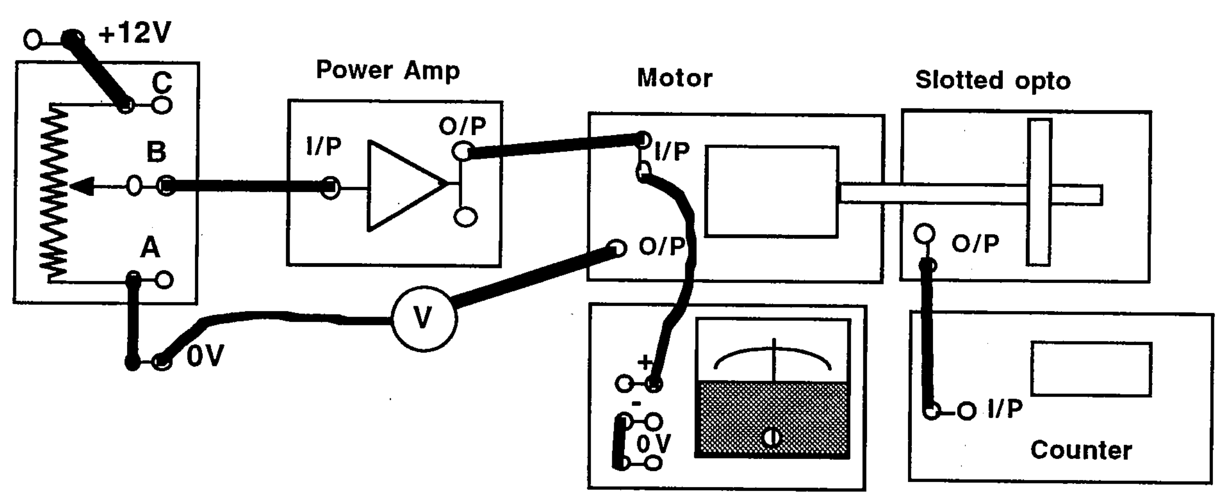


Figure 112

- Connect the circuit as shown in Fig 112, set the resistor control for zero output voltage, (control fully counter clockwise), and set the counter controls to "count" and "1s".

- Switch the supply ON and set the voltage applied to the motor, as indicated by the M.C. meter, to 10V. The motor should run at a high speed. Allow it to run for a short time and then note the reading of the digital voltmeter.

  This reading in volts represents the current, in amperes, taken by the motor, since it is the voltage drop across a 1Ω resistor.
  Press the counter "reset" button and note the displayed counter value. This represents the motor speed in rev/sec. Enter the values in Table 34

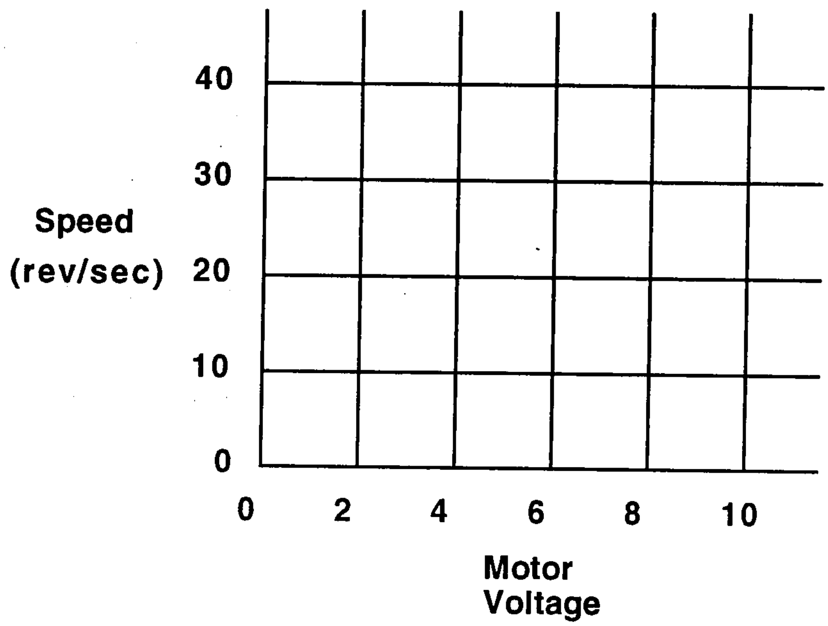
- Repeat the procedure, noting the speed and current readings for motor applied voltages of 8V,6V,4V and 2V.

  Enter the values in Table 34.

Motor Applied Voltage	2	4	6	8	10
Current (Amperes)					
Speed (rev/sec)					

Table 34.

Construct the graph of speed against applied voltage on the axes provided overleaf.



Study your results.

Is the speed proportional to the applied voltage ?

The load on the motor is reasonably constant. Is the current taken reasonably constant ?

- Set the applied voltage to 6V and note the speed and current taken on no load. Now place your hand near the Hall effect disc with the finger nails down and touching the baseboard of the DIGIAC 1750 unit. Move your fingers gently so that your middle finger comes between the Hall effect disc and the baseboard and thus exert a small load on the motor. You will note that the current increases and the speed falls. Apply a load so that the current is approximately 0.4A (0.4V reading on the digital voltmeter) and then note the speed by pressing the counter "reset" button.

No load:-	**Current =**	**Speed =**
Loaded:-	**Current = 0.4A**	**Speed =**

- Set the control of the 10kΩ resistor to the zero output voltage position. Now connect the lead from socket C of the 10kΩ resistor to the -12V supply instead of the +12V. Slowly increase the voltage output and note the direction of rotation of the motor. We have reversed the polarity of the voltage applied to the motor. What effect has this had on the direction of rotation ?

  Is the direction of rotation the same as before, or has the direction reversed ?

  Is the same speed range possible ?

  Is the no load current the same ?

This exercise has illustrated the basic characteristics of a permanent magnet D.C. motor.

The characteristics are typical for this size of machine, larger machines would not have such a large drop in speed with load.

Notes:

Notes:

Student Assessment 11.

1. Explain briefly the difference between (a) an electric solenoid actuator and (b) an electrically controlled pneumatic actuator.

2. A relay has changeover contacts marked N.C. and N.O.. Which contacts are closed with the relay de-energised ?

   What is the meaning of the abbreviations N.C. and N.O. ?

3. What is meant by the "pull in" and "drop out" (or "release") voltages of a solenoid.

   A solenoid has a coil rated for operation at 6V. What would you expect to be the "pull in" and "drop out" voltages for this coil ?

4. A D.C. permanent magnet motor runs at 1000rev/min for a certain load, taking a current of 0.5A from a +6V source.
   (a) What would be its speed for an input voltage of +12V ?
   (b) What would be its speed for an input voltage of -6V ?
   (c) What would be the current taken if the load torque were doubled ?

5. How could a D.C. motor be used for linear motion applications ?

Notes: