

Expt. No. 1

Title: Study of Digital multimeter , Function Generator, CRO/DSO, Dual power supply, connecting probes.

Aim: To study the working principles, functions, and applications of digital multimeters, function generators, cathode-ray oscilloscopes (CRO), digital storage oscilloscopes (DSO), dual power supplies, and connecting probes, and to understand their usage in electronic measurements and testing.

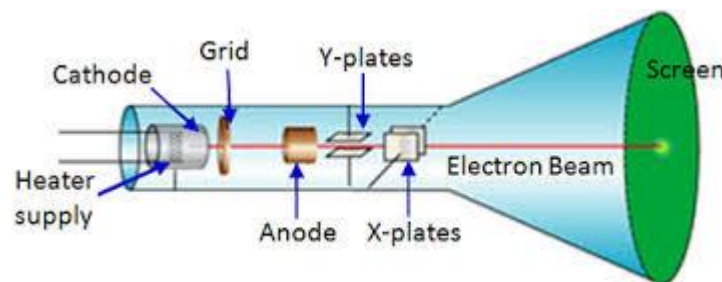
Apparatus Required:

- Cathode Ray Oscilloscope (CRO)
- Digital Multimeter
- Function Generator
- Power Supply
- Connecting Probes

Theory:

Cathode Ray Oscilloscopes

It is a device that draws a graph of a voltage over time, or a graph of the relationship between two different voltages. This information is given as a **trace** on a screen. Cathode-ray oscilloscopes (CROs) have an electron gun which emits a beam of electrons (historically called "cathode rays", hence the name) which is deflected according to the signal being measured. The trace is produced by the electrons striking a phosphor screen, which glows green where they hit.



Function Generator

A **function generator** is usually a piece of electronic test equipment or software used to generate different types of electrical waveforms over a wide range of frequencies. Some of the most common waveforms produced by the function generator are the sine, square, triangular and saw tooth shapes. These waveforms can be either repetitive or single shot (which requires an internal

or external trigger source). Integrated circuits used to generate waveforms may also be described as function generator ICs.

Other important features of the function generator are continuous tuning over wide bands with max-min frequency ratios of 10:1 or more, a wide range of frequencies from a few Hz to a few MHz, a flat output amplitude and modulation capabilities like frequency sweeping, frequency modulation and amplitude modulation.

Although function generators cover both audio and RF frequencies, they are usually not suitable for applications that need low distortion or stable frequency signals. When those traits are required, other signal generators would be more appropriate.

Some function generators can be phase-locked to an external signal source (which may be a frequency reference) or another function generator.



Digital Multimeter:

A digital multimeter (DMM) is a test tool used to measure two or more electrical values. Principally voltage (volts), current (amps) and resistance (ohms). It is standard diagnostic tool for technicians in the electrical/ electronics industries. The digital multimeter (DMM) is one of the most common items of test equipment used in the electronics industry today.

While there are many other items of test equipment that is available, the multimeter is able to provide excellent readings of the basic measurements of amps, volts and ohms.

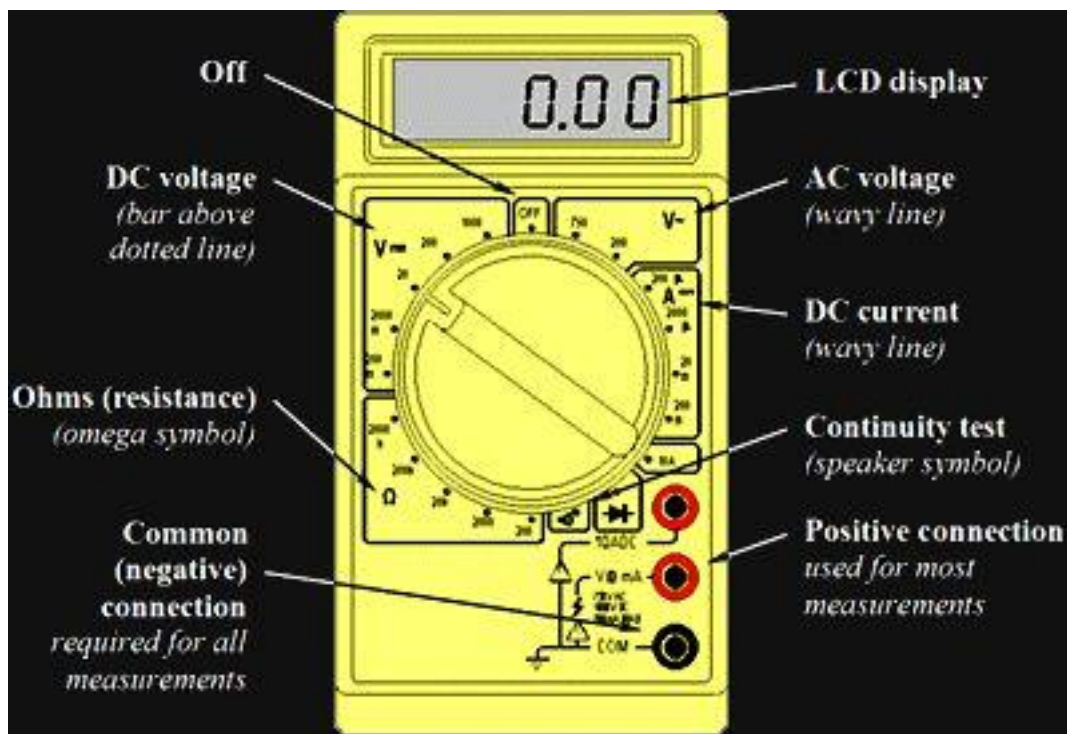
While the facilities that a digital multimeter can offer are much greater than their analogue predecessors, the cost of DMM is relatively low. DMM are able to offer as the basic measurements that would typically includes:

- Current (DC)
- Current (AC)

- Voltage (DC)
- Voltage (AC)
- Resistance

Digital multimeters are widely used and very useful item of test equipment. They enable measurement of quantities such as current, voltage and resistance to be made very quickly and easily. In addition to this, many DMMs are able to measure other useful parameters, making these items even more useful. While they do not allow more complicated measurements to be made, if many engineers were allowed only one item of test equipment, it would probably be the digital multimeter.

You need two wires to measure different values accordingly, the black lead is always common or ground point while you can change the probe position to resistance or voltage or current depending upon what you need to measure. You can also change the range depending upon the amount of voltage or current your circuit generates to measure it correctly.



Power Supply:

A DC power supply is one that supplies a voltage of fixed polarity (either positive or negative) to its load. Depending on its design, a DC power supply may be powered from a DC source or from an AC source such as power mains.

Direct Current (DC) is the unidirectional flow of electric charge. Direct current is produced by sources such as batteries, power supplies, thermocouples, solar cells or dynamos. Direct current may flow in a conductor as a wire, but can also flow through

semiconductors, insulators or even through a vacuum as in electron or ionized beams. The electric current flows in a constant direction, distinguished it from alternating current (AC).

The GPC-series (power supply) are triple output, 195-375W, linear DC power supplies. Channel 1 and 2 are fully adjusted and channel 3 is fixed at 5V/3A with ripple and noise at less than 2mVrms. Overload and reverse polarity protection keep GPC-series and its loads safe from unexpected conditions. The GPC-3030DQ contains a temperature- controlled cooling fan for thermal protection.



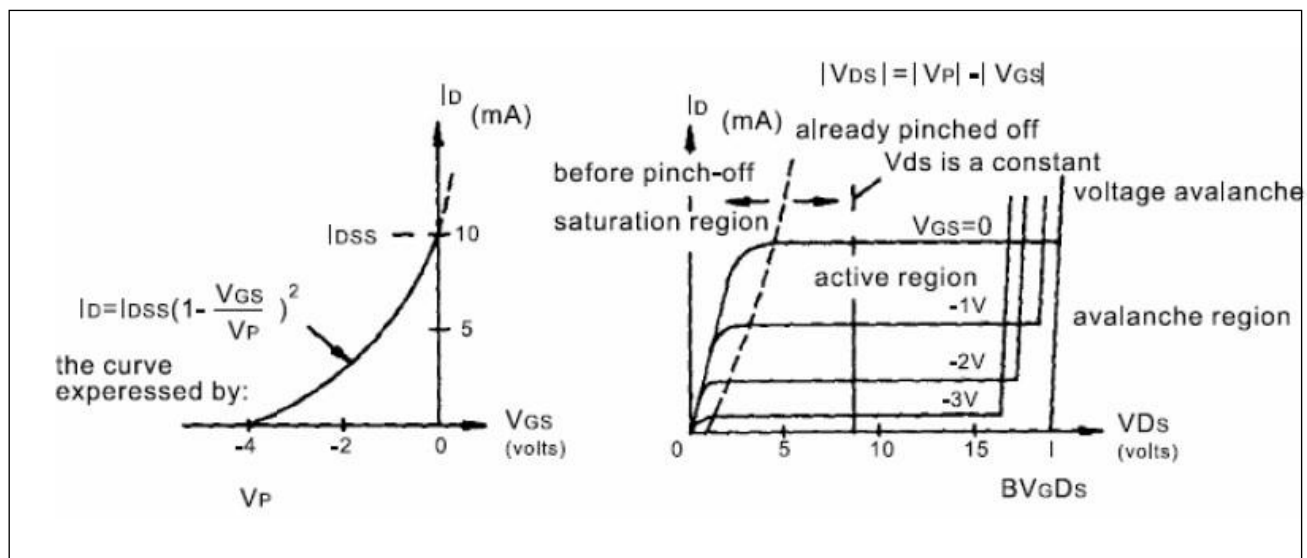
Expt. No. 2

Title: Study of FET (Reading data sheet, Terminal Identification, packages, testing & Plot FET characteristics)

Aim:

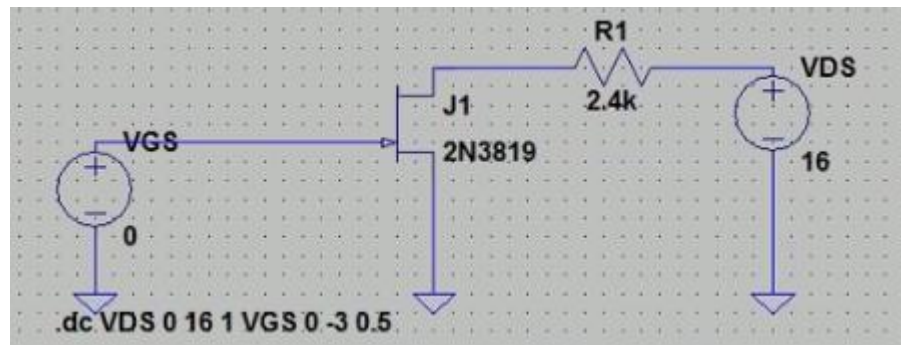
Theory :- The first and foremost advantage is LT Spice is a freeware software for Circuit design and analysis. It can serve as an alternate for the professional licensed software like Cadence, ADS, Altium, for study of circuit behavior. The key analysis in Circuit design like DC analysis, Frequency response, n-port analysis is much simpler to simulate in LT Spice than analyzing all these responses theoretically which is a time consuming task.

Characteristics of FET:- Transfer and Drain-Source Characteristic Curve for FET.



Drain-Source Characteristic Curve of FET :

If V_{GS} is increased (it's more negative to n-channel), depletion will be immediately generated in the channel so that the current required to pinch off the channel will be decreased. The curve corresponding to $V_{GS} = -1V$ is shown in Fig. From this result we can find out that the gate voltage functions as a controller capable of decreasing the drain current (at a specific voltage V_{DS}). If V_{GS} is more positive for p-channel JFET, the drain current will be decreased from I_{DSS} (as shown in Fig). If V_{GS} is continuously increased, the drain current will be decreased correspondingly. When V_{GS} reaches a certain value, the drain current will be decreased to zero and will be independent of the value of V_{DS} . The gate-source voltage at this time is called pinch-off voltage which is usually denoted as V_P or V_{GS} (cutoff). From Fig. we can find out that V_P is a negative voltage for n-channel FET and a positive voltage for p-channel FET.



Procedure: -

1. Open LT Spice Simulator.
2. Go to file, choose new schematic.
3. Select components N channel JFET , resistors, voltage sources and ground terminals.
4. Select the wire and connect components as shown in fig.
5. Name the voltage sources as VGS and VDS respectively.
6. Select JFET 2N3819,select R=2.4k
7. Apply voltage as VGS=0V AND VDS=16V
8. Run DC Sweep with
 - 1st source to sweep=VGS
 - Type of sweep=Linear
 - Start value=0
 - Stop value=-5
 - Increment=0.01
9. Input characteristic will be plotted.
10. For VDS Vs. IDS Graph,
11. Change name of 1st source to sweep in DC sweep to VDS(to make x axis VDS)
 - Type of sweep=Linear
 - Start value=0
 - Stop value=20
 - Increment=1V
12. For second source
 - 1st source to sweep=VGS
 - Type of sweep=Linear
 - Start value=0
 - Stop value= -3
 - Increment=0.5
13. Characteristics graph will be plotted.
14. To find pinch off voltage, saturation point and other parameters click on transistor and in pick new JFET option check model definition.

Observations: -



Conclusion:

The terminal identification and package types were understood using the datasheet. The testing of FETs confirmed their functionality and operational characteristics. The input and output characteristics were plotted, demonstrating the relationship between gate voltage, drain current, and drain-source voltage. This experiment provided practical insights into the working of FETs and their applications in amplification and switching circuits.

Expt. No. 3

Title: Study of MOSFET (Reading data sheet, Terminal Identification, packages, testing & Plot MOSFET characteristics)

Aim: The Aim of this experiment is:

- To Review basic principles of MOSFETs from ELEC 2210
- understanding of MOSFET switching circuits
- Study with the Bit Bucket breadboarding system and the oscilloscope

Introduction

A thorough treatment of MOSFETs can be found in Chapter 4 of the ELEC 2210 textbook, Microelectronics Circuit Design by R.C. Jaeger.

The acronym MOSFET stands for Metal Oxide Semiconductor Field Effect Transistor. MOSFETs are circuit elements that allow control of a working current by applying a control voltage. They are used primarily in switching circuits and amplifiers. This experiment will focus on the switching applications.

MOSFETs can be n- or p-channel, and they can be enhancement or depletion type. The MOSFET studied in this experiment is the ZVN4306A, which is an n-channel, enhancement MOSFET. The standard circuit symbol and notation for this type of transistor is shown in Fig. 1(a). The PSPICE circuit symbol is shown in Fig. 1(b).

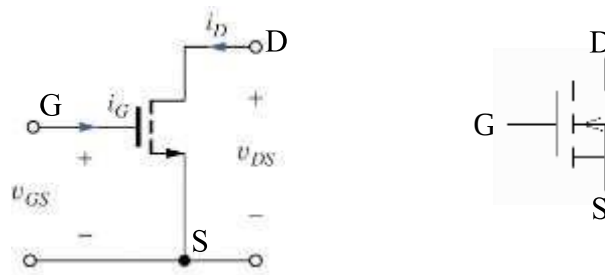


Figure 1. Circuit symbols and nomenclature for an n-channel enhancement MOSFET. (a) IEEE standard symbol (b) PSPICE symbol.

There are three terminals indicated on the circuit symbol: D = drain, S = source, and G = gate. Sometimes a fourth terminal is provided which provides contact to the substrate, or body of the device. When only three terminals are shown, it is assumed that the body is

internally connected to the source. The PSPICE symbol explicitly shows the body connected internally to the Source (S).

The mathematical model of the n-channel, enhancement MOSFET (not including breakdown or body effect) is given in Table 1:

Table 1. Mathematical model of the n-channel MOSFET.

Region	Condition(s)	Equation(s)
All		$i_G = 0 \quad i_B = 0$
Cutoff	$v_{GS} \leq V_{TN}$	$i_D = 0$
Triode (Linear)	$v_{GS} - V_{TN} \geq v_{DS} \geq 0$	$i_D = K_n (v_{GS} - V_{TN} - \frac{v_{DS}}{2}) v_{DS}$
Saturation	$v_{DS} \geq (v_{GS} - V_{TN}) \geq 0$	$i_D = \frac{K_n}{2} (v_{GS} - V_{TN})^2 (1 + \lambda v_{DS})$

In these equations, there are three device parameters:

V_{TN} is the threshold voltage. This is the gate-source voltage at which a channel is formed between the source and drain. The value is positive for an n-channel enhancement MOSFET. (The data sheet for the lab part calls this $V_{GS(th)}$.)

K_n is the transconductance parameter. This is the scale factor of the MOSFET for determining the magnitude of the current.

λ is the channel length modulation parameter. It determines the slope of the MOSFET curves in saturation. For an ideal device, λ is zero.

The output characteristics of a MOSFET with $V_{TN} = 1 \text{ V}$, $K_n = 12.5 \mu\text{A}/\text{V}^2$, and $\lambda = 0.325$ are shown in Fig. 2.

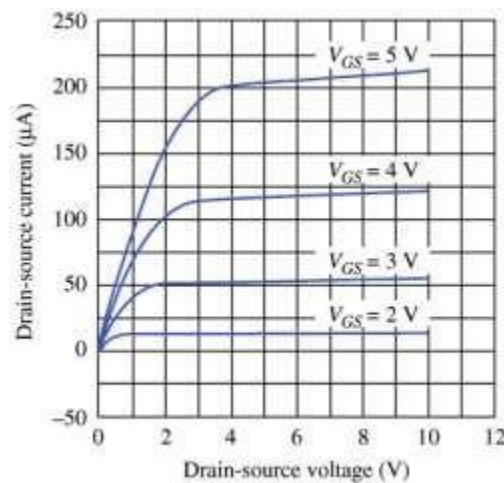


Figure 2. Example n-channel enhancement MOSFET output characteristics.

For each curve, the *saturation region* is the region to the right of the knee, i.e., the nearly flat part. The region to the left of the knee is the *triode region* (also called the linear region). For switching applications, the MOSFET is most like a closed switch when it is in the triode region, where v_{DS} is small. It is most like an open switch when it is in cutoff, with $i_D = 0$.

A MOSFET is often used as a voltage-controlled switch, as illustrated in Fig. 3

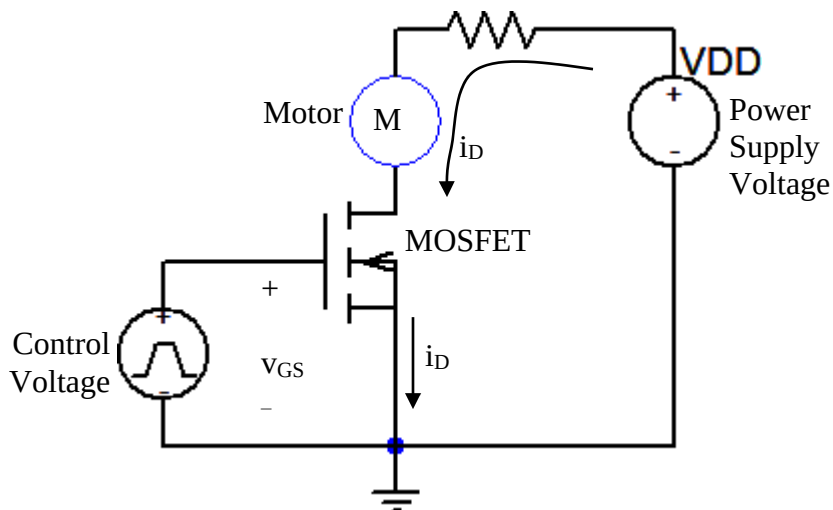


Figure 3. MOSFET switching circuit. When the control voltage exceeds the threshold voltage, the MOSFET is “ON” and current flows through the motor. Otherwise, the MOSFET is “OFF,” and no current flows.

The amount of current which flows is determined by the control voltage in accordance with the equations in Table 1. For most switching applications, the MOSFET is operated in the triode region when it is conducting current. In this region, the MOSFET channel presents a small resistance in series with the load, as desired.

Pre-Lab:

- (1) Obtain the data sheet for the ZVN4306 MOSFET from the class web site, or from

<http://www.zetex.com/3.0/pdf/ZVN4306A.pdf>

Use this to determine the values of the threshold voltage range, the maximum continuous drain current I_D , the maximum drain-source voltage, and the maximum allowed power dissipation, P_{tot} .

- (2) From the data you found in (1), what is the maximum allowed current if $V_{DS} = 15\text{ V}$? If $V_{DS} = 5\text{ V}$? Express your results in mA.

(3) In which region should the MOSFET be operating when it is a “closed switch?” Why? In which region should it be operating when it is an “open switch?” Why?

Lab Exercise:

There are 3 parts. Have your GTA sign off on each part before proceeding to the next part.

(1) Threshold Voltage

Obtain a ZVN4306 MOSFET. Using the data sheet as a guide, identify the drain, gate, and source terminals. Use the circuit shown in Fig. 4 to determine the threshold voltage. (The data sheet uses the notation $V_{GS(th)}$ for the threshold voltage, whereas our text uses the notation V_{TN} .) On the data sheet, the threshold voltage is defined to be the value of V_{GS} when $I_D = 1 \text{ mA}$. Proceed as follows:

- Make sure the Bit Bucket power is off
- Connect the DVM on the Bit Bucket to measure V_{GS} .
- Set the Variable DC source to the Minimum position.
- Turn on the Bit Bucket power.
- Increase the Variable DC source slowly, until $I_D = 1 \text{ mA} \pm 0.05 \text{ mA}$.

Does your value of V_{TN} fall within the range specified on the data sheet?

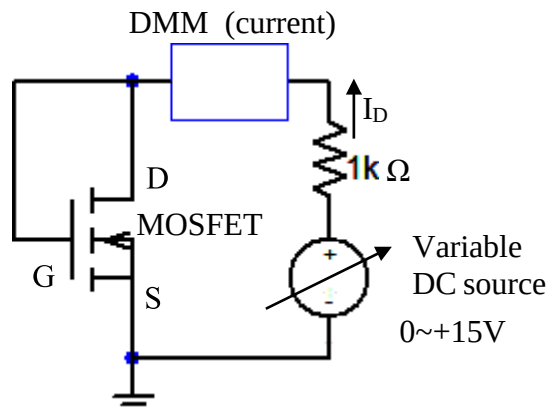


Figure 4. Circuit for determining the threshold voltage, V_{TN} .

(2) I_D vs. V_{DS} and Estimating K_n

In this part, you will use the oscilloscope to trace I_D as a function of V_{DS} for several values of V_{GS} . From your observations, you will estimate the value of K_n for your MOSFET.

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Construct the circuit shown in Fig. 5. The purpose for the 100Ω resistor in series with the MOSFET source is to provide a way for us to observe I_D on the oscilloscope. According to Ohm's law, a current of 1 mA will generate a voltage of 100 mV across this resistor.

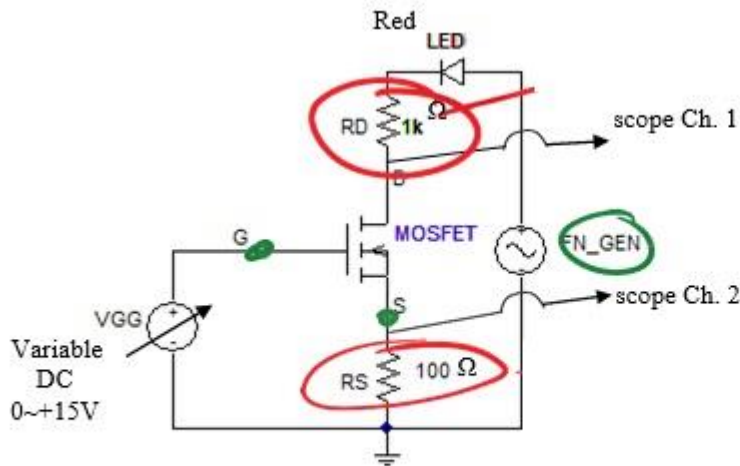


Figure 5. Circuit for plotting I_D vs. V_{DS} and Estimating K_n .

Use the following technique to plot I_D vs. V_{DS} .

- Make sure the Bit Bucket power is off.
- Connect the MOSFET drain voltage, V_D , to Channel 1 of the scope. Be sure the scope ground is the same as the Bit Bucket ground.
- Connect the MOSFET source voltage, V_S , to Channel 2 of the scope. Be sure the scope ground is the same as the Bit Bucket ground.
- Set the scope to XY mode (DISPLAY / FORMAT=XY)
- Set Channel 1 to 1 V / div. Set Channel 2 to 100 mV / div.
- Set the Bit Bucket function generator (FG) controls to sine, 1 kHz, minimum amplitude.
- Set the Bit Bucket variable DC to the Minimum position.
- Connect the Bit Bucket DVM to measure V_{GS} .
- Turn on the Bit Bucket power.
- Increase the FG amplitude to MAX.
- Slowly increase the Variable DC voltage until V_{GS} is just a little larger than V_{TN} (you recorded this in Part 1). Then you should get a trace similar to the one shown in Fig. 6.

The vertical axis in Fig. 6 is proportional to I_D , with 100 mV representing 1 mA. The horizontal axis is almost equal to V_{DS} , since V_S is fairly small.

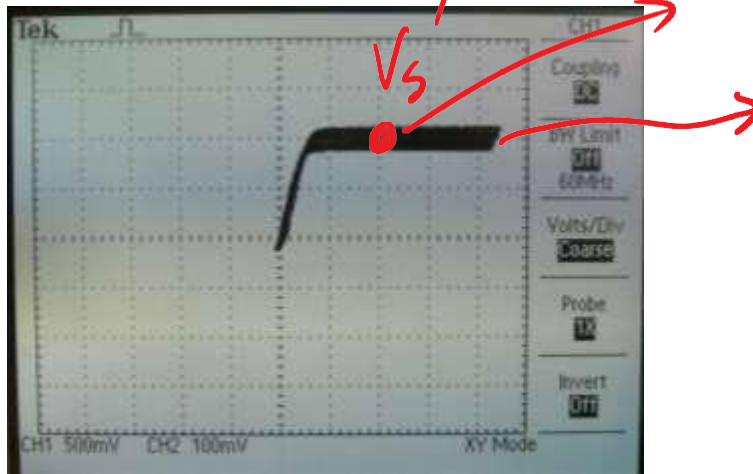


Figure 6. Display of V_S (vertical axis) vs. V_D (horizontal axis). This is essentially the same as plotting I_D vs. V_{DS} .

The current in saturation (the flat region) is called I_{DSAT} . Adjust V_{GS} to get I_{DSAT} equal to 2 mA, as shown in Fig. 6. Record the corresponding value of V_{GS} . If you assume that λ is approximately zero (is this valid from your observation?), you can use the saturation equation from Table 1 to estimate K_n .

Repeat this for at least two other values of I_{DSAT} , and record your K_n estimates for each. How consistent are they? What is the average value? (Suggested values of I_{DSAT} : 1 mA, 2 mA, and 3mA.)

(3) MOSFET Switching Circuits

Connect a switching circuit in which the load is each of the following:

(a) An LED. Construct the circuit shown in Fig. 7. Use a 330 ohm series resistor and 5V supply voltage. Use (i) a pushbutton and (ii) the function generator (FG) to provide the gate voltage.

When using the pushbutton, record the values of V_{DS} when the LED is on, and when it is off.

When using the FG, set it to sine wave, Max. amplitude. Set the frequency to about 5 Hz initially, and then try different blink rates. Observe V_{DS} on the oscilloscope and record what you see. (Set the scope display back to the Y-T mode, if it is still in X-Y mode from Part 2.)

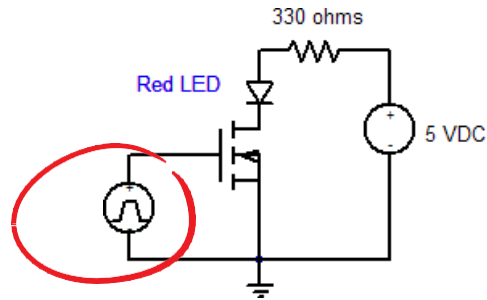


Figure 7. Circuit for switching an LED.

(b) A loudspeaker. Construct the circuit shown in Fig. 8. Use the function generator to provide the supply voltage. Use a pushbutton to provide the gate voltage. To start with, turn the FG amplitude all the way down, and set the frequency to about 500 Hz. Turn up the amplitude slowly until you can hear the sound. Vary the frequency to enjoy some “music.” (Hearing impaired instructions: Set the frequency to about 5 Hz, and you should be able to see the speaker vibrate when the amplitude is increased. Vary the frequency to see it vibrate faster or slower.)

With the FG set to a 500 Hz sine wave and the amplitude knob set to the 12 o’clock position, observe V_{DS} on the oscilloscope and record what you see.

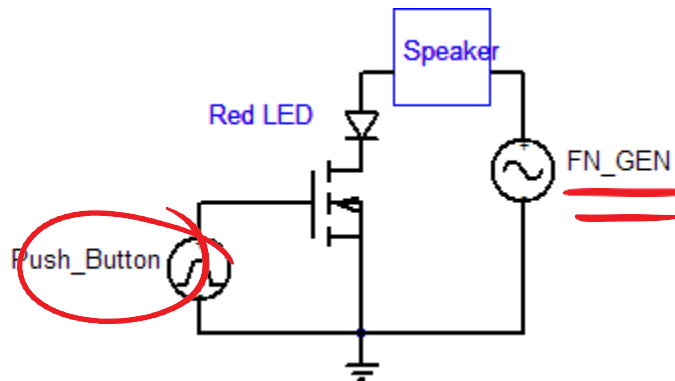


Figure 8. Circuit for switching a loudspeaker.

(c) A 5V DC fan. Construct the circuit shown in Fig. 9. Use 5 V as the supply voltage, and a Bit Bucket pushbutton as the control. No resistor is required.

Record the fan current when it is on, and compare to the rating marked on the fan housing.

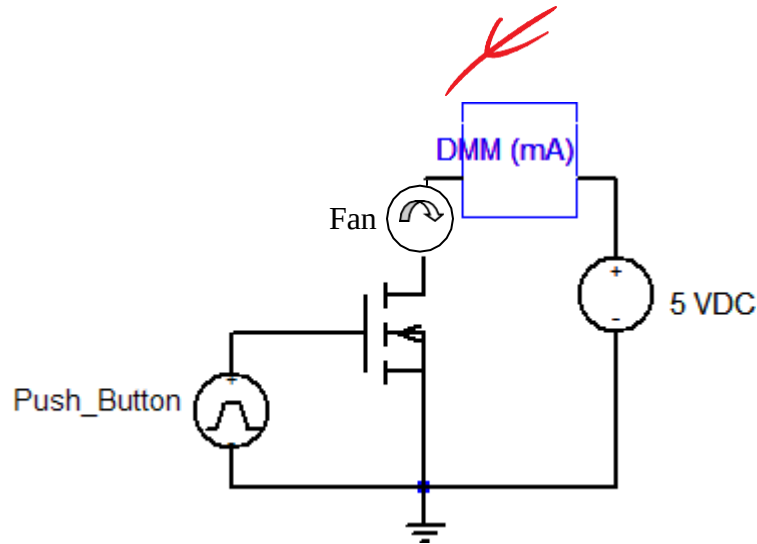


Figure 9. Circuit for switching a DC fan.

Expt. No. 4

Title: -To study & perform Op-amp application. (Adder, subtractor, integrator, Differentiator)

Aim: To design and verify adder, subtractor , differentiator & integrator using operational amplifier.

Apparatus required:

SI. No.	Particulars	Specification	Quantity
1	Op-Amp	IC - 741	1
2	Resistor	1k Ω 10k Ω 100k Ω	4 1 1
3	Capacitor	0.1 μ F 0.01 μ F	1 1
4	Regulated Power supply	0-12V, 3A	1
5	Function Generator	1– 3M Hz, 20 V _{p-p}	1
6	Cathode Ray Oscilloscope	0– 30M Hz	1
7	Voltmeter	0-10 V	1

Theory:

The Summing Amplifier is another type of operational amplifier circuit configuration that is used to combine the voltages present on two or more inputs into a single output voltage.

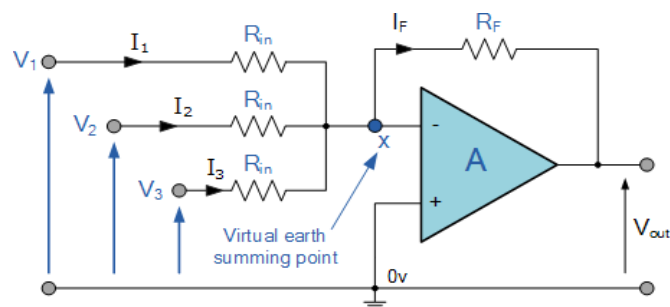
Summing Amplifier Circuit

Fig. 1 Summing Amplifier Circuit

In this simple summing amplifier circuit, the output voltage, (V_{out}) will be proportional to the sum of the input voltages, V_1 , V_2 , V_3 , etc.

$$I_F = I_1 + I_2 + I_3 = - \left[\frac{V_1}{R_{in}} + \frac{V_2}{R_{in}} + \frac{V_3}{R_{in}} \right]$$

$$\text{Inverting Equation: } V_{out} = - \frac{R_f}{R_{in}} \times V_{in}$$

$$\text{then, } -V_{out} = \left[\frac{R_F}{R_{in}} V_1 + \frac{R_F}{R_{in}} V_2 + \frac{R_F}{R_{in}} V_3 \right]$$

$$-V_{out} = \frac{R_F}{R_{IN}} (V_1 + V_2 + V_3 \dots \text{etc})$$

We now have an operational amplifier circuit that will amplify each individual input voltage and produce an output voltage signal that is proportional to the algebraic “SUM” of the three individual input voltages V_1 , V_2 and V_3 . We can also add more inputs. A direct voltage addition can also be obtained when all the resistances are of equal value and R_f is equal to R_{in} . Note that when the summing point is connected to the inverting input of the op-amp the circuit will produce the negative sum of any number of input voltages. Likewise, when the summing point is connected to the non-inverting input of the op-amp, it will produce the positive sum of the input voltages.

Subtractor

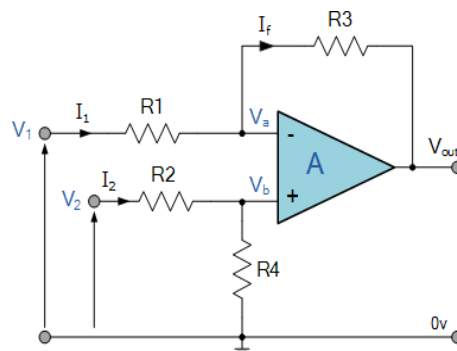


Fig. 2 Subtractor

Standard operational amplifier has two inputs, inverting and non-inverting, we can also connect signals to both of these inputs at the same time producing another common type of operational amplifier circuit called a differential Amplifier or subtractor. By connecting one voltage signal onto one input terminal and another voltage signal onto the other input terminal the resultant output voltage will be proportional to the “Difference” between the two input voltage signals of V_1 and V_2 .

$$I_1 = \frac{V_1 - V_a}{R_1}, \quad I_2 = \frac{V_2 - V_b}{R_2}, \quad I_f = \frac{V_a - (V_{out})}{R_3}$$

Summing point $V_a = V_b$

$$\text{and } V_b = V_2 \left(\frac{R_4}{R_2 + R_4} \right)$$

$$\text{If } V_2 = 0, \text{ then: } V_{out(a)} = -V_1 \left(\frac{R_3}{R_1} \right)$$

$$\text{If } V_1 = 0, \text{ then: } V_{out(b)} = V_2 \left(\frac{R_4}{R_2 + R_4} \right) \left(\frac{R_1 + R_3}{R_1} \right)$$

$$V_{out} = -V_{out(a)} + V_{out(b)}$$

$$\therefore V_{out} = -V_1 \left(\frac{R_3}{R_1} \right) + V_2 \left(\frac{R_4}{R_2 + R_4} \right) \left(\frac{R_1 + R_3}{R_1} \right)$$

If all the resistors are all of the same ohmic value, that is: $R_1 = R_2 = R_3 = R_4$ then the circuit will become a **Unity Gain Differential Amplifier** and the voltage gain of the amplifier will be exactly one or unity. Then the output expression would simply be $V_{out} = V_2 - V_1$. Also note that if input V_1 is higher than input V_2 the output voltage sum will be negative, and if V_2 is higher than V_1 , the output voltage sum will be positive.

Integrator

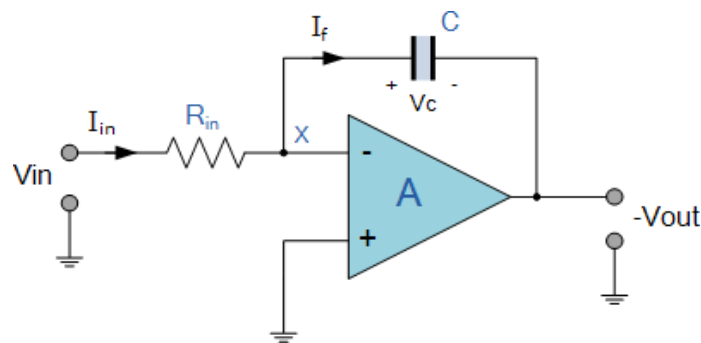


Fig. 3 Integrator

As its name implies, the Op-amp Integrator is an operational amplifier circuit that performs the mathematical operation of Integration, that is we can cause the output to respond to changes in the input voltage over time as the op-amp integrator produces an *output voltage which is proportional to the integral of the input voltage*. In other words the magnitude of the output signal is determined by the length of time a voltage is present at its input as the current through the feedback loop charges or discharges the capacitor as the required negative feedback occurs through the capacitor.

If we apply a constantly changing input signal such as a square wave to the input of an Integrator Amplifier then the capacitor will charge and discharge in response to changes in the input signal. This results in the output signal being that of a sawtooth waveform whose output is affected by the RC time constant of the resistor/capacitor combination because at higher frequencies, the capacitor has less time to fully charge. This type of circuit is also known as a Ramp Generator .

Op-amp Integrator Ramp Generator

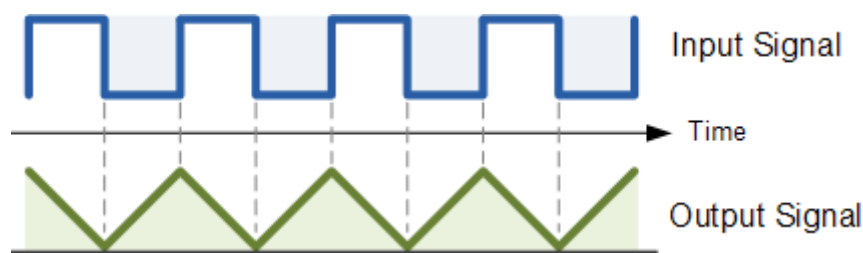


Fig. 4 Ramp generator

$$V_{out} = -\frac{1}{R_{in}C} \int_0^t V_{in} dt = -\int_0^t V_{in} \frac{dt}{R_{in} \cdot C}$$

Differentiator

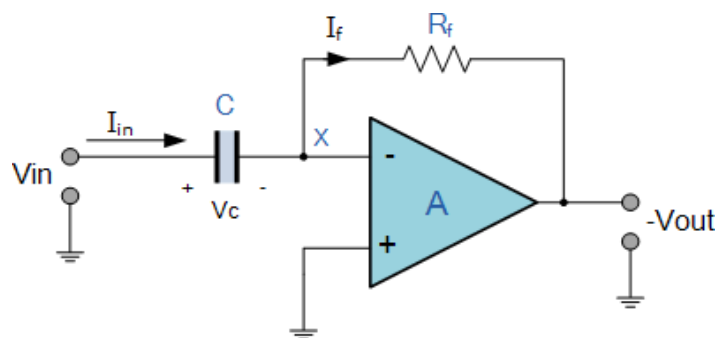


Fig. 5 Differentiator

The input signal to the differentiator is applied to the capacitor. The capacitor blocks any DC content so there is no current flow to the amplifier summing point, X resulting in zero output voltage. The capacitor only allows AC type input voltage changes to pass through and whose frequency is dependent on the rate of change of the input signal. At low frequencies the reactance of the capacitor is “High” resulting in a low gain (R_f/X_c) and low output voltage from the op-amp. At higher frequencies the reactance of the capacitor is much lower resulting in a higher gain and higher output voltage from the differentiator amplifier.

$$V_{OUT} = -R_F C \frac{dV_{IN}}{dt}$$

Circuit diagrams:

a) Adder

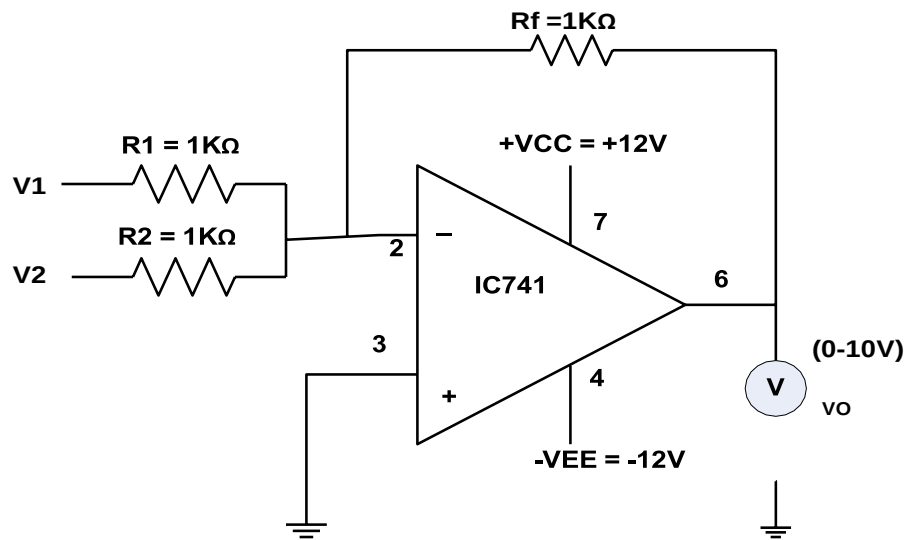


Fig. 6 Experimental circuit for realizing adder

b) Subtractor

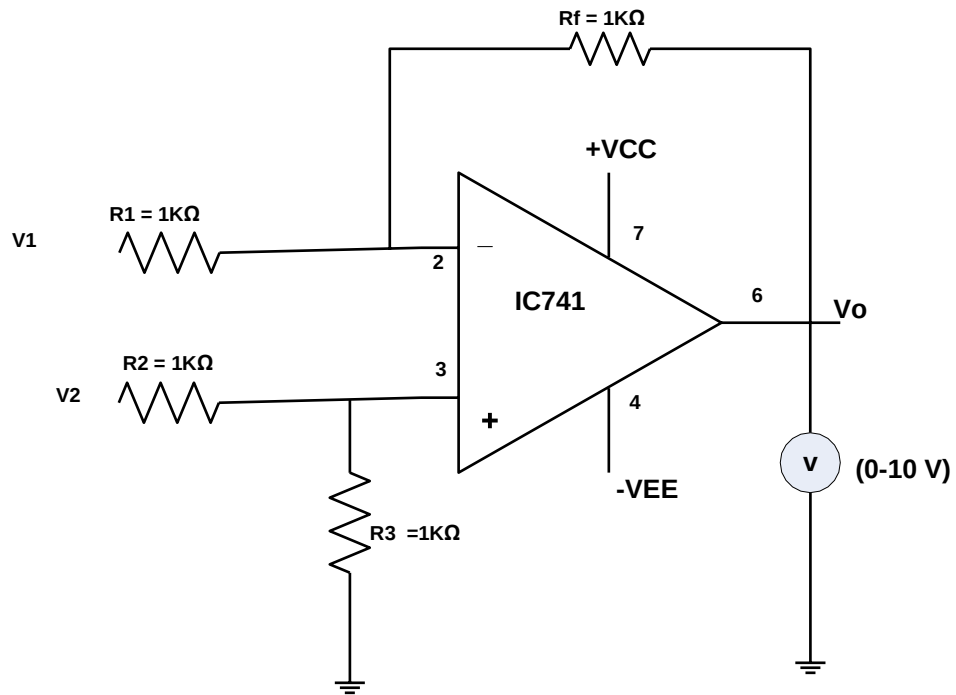


Fig. 7 Experimental circuit for realizing subtractor

c) Differentiator

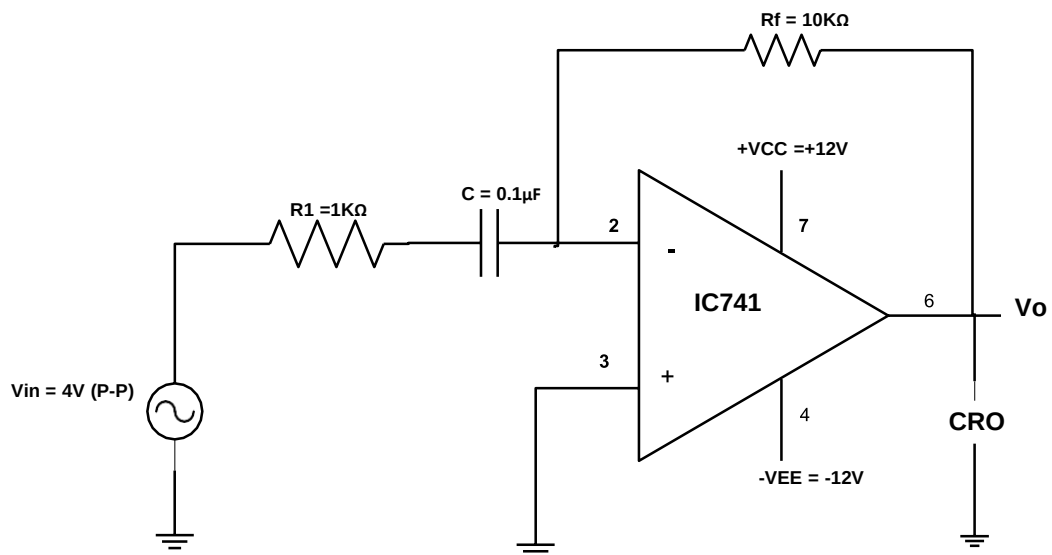
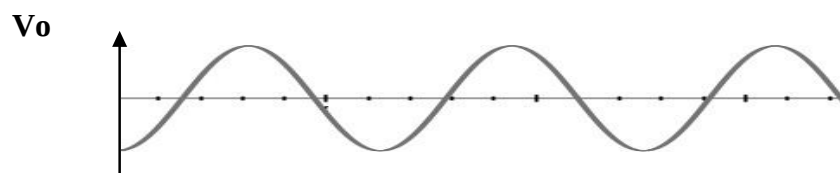
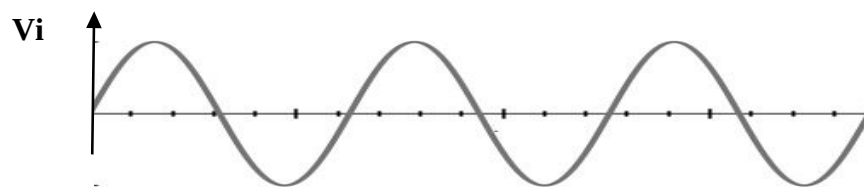
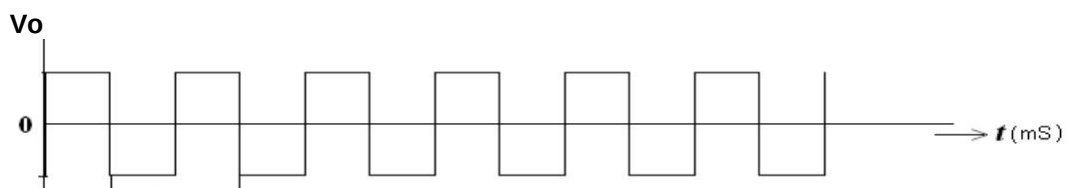
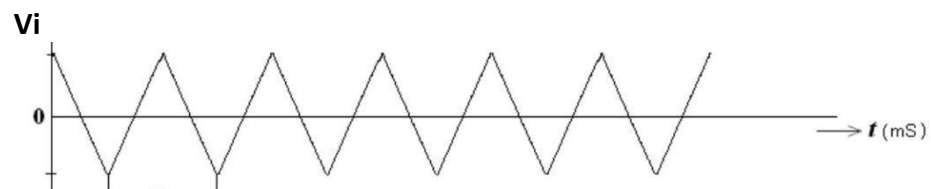
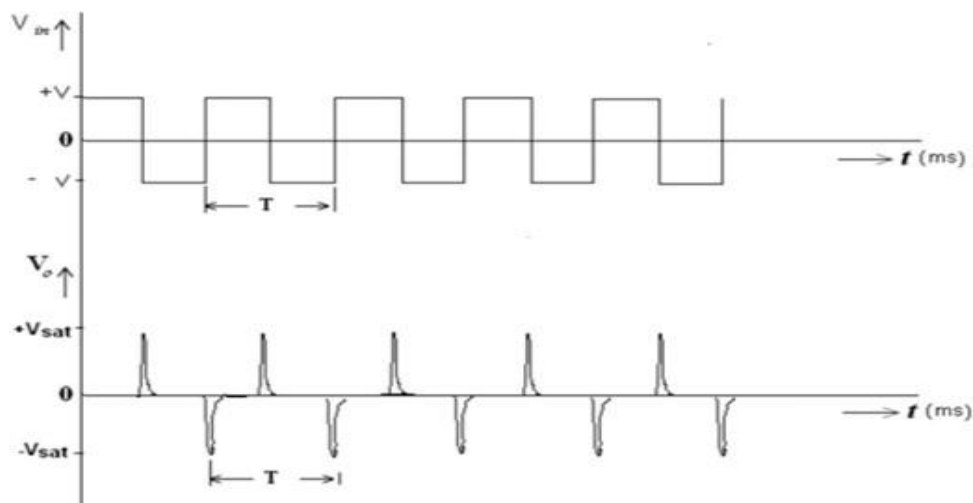


Fig. 8 Experimental circuit for realizing differentiator

Nature of graph for differentiator



d) Integrator

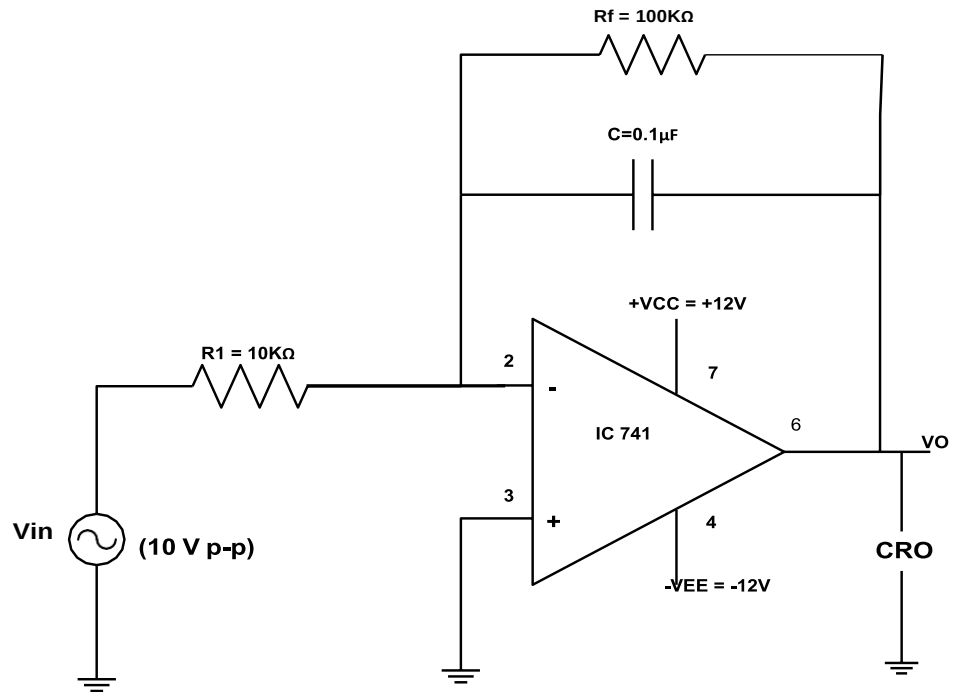
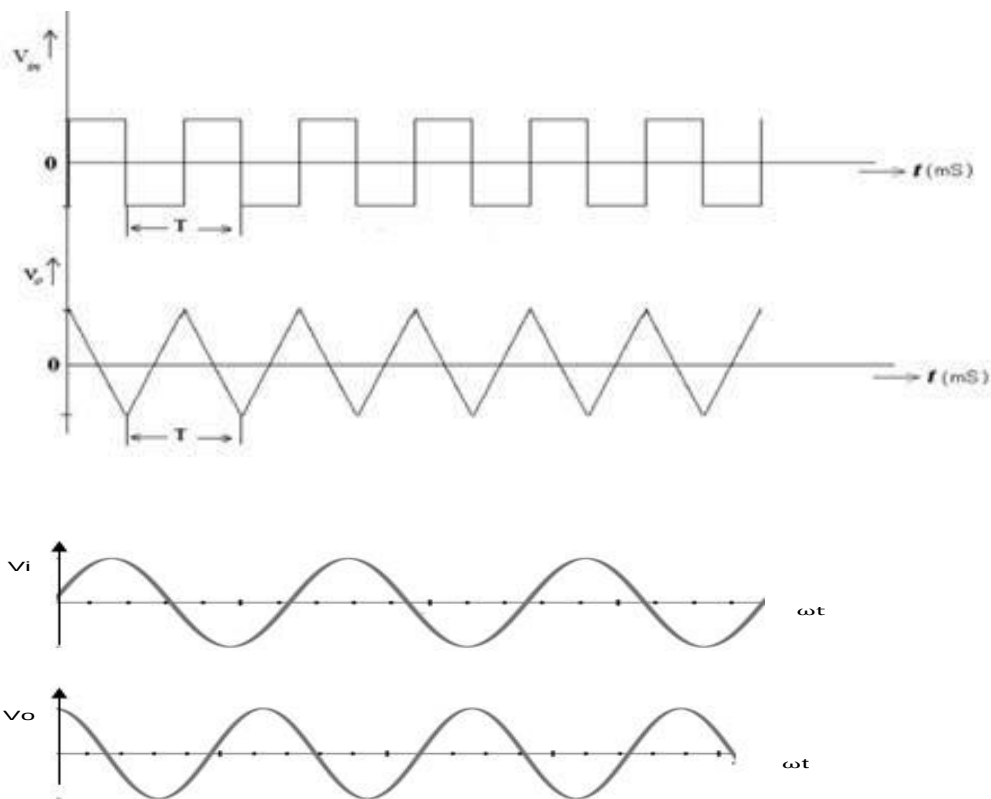


Fig. 9 Experimental circuit for realizing Integrator

Nature of graph



Procedure:**a) Adder:**

1. Connect the circuit as per the diagram shown in Fig 6.
2. Apply the biasing voltages of $\pm 12\text{V}$ to pin7 and pin4 of IC741 respectively.
3. Apply the inputs V_1 and V_2 as shown in Fig 6.
4. Note down the output obtained at pin 6 of the IC 741.
5. Notice that the output is equal to the sum of the two inputs.

b) Subtractor:

1. Connect the circuit as per the diagram shown in Fig 7.
2. Apply the biasing voltages of $\pm 12\text{V}$ to pin7 and pin4 of IC741 respectively.
3. Apply the inputs V_1 and V_2 as shown in Fig 7.
4. Note down the corresponding output at pin 6 of the IC 741.
5. Notice that the output is equal to the difference of the two inputs.

c) Differentiator

1. Connect the circuit as per the diagram shown in Fig 8.
2. Apply a square /sine /triangular wave input of 4V (p-p) at 150 Hz .
3. Observe the output at pin 6.
4. Note down the corresponding output at pin 6 of the IC 741.
5. Draw input and output waveforms as shown in nature of graph.

d) Integrator:

1. Connect the circuit as per the diagram shown in Fig 9.
2. Apply a square /sine /triangular wave input of 10V (p-p) at 1.5 KHz .
3. Observe the output at pin 6.
4. Note down the corresponding output at pin 6 of the IC 741.
5. Draw input and output waveforms as shown in nature of graph.

Specimen Calculations:

a) Adder

$$V_o = -(V_1 + V_2) \text{ [As gain is unity]}$$

If $V_1 = 2.5V$ and $V_2 = 2.5V$, then

$$V_o = -(2.5+2.5) = -5V.$$

b) Subtractor

$$V_o = (V_2 - V_1) \text{ [As gain is unity]}$$

If $V_1=2.5V$ and $V_2 = 3.3V$, then

$$V_o = 3.3 - 2.5 = 0.8V$$

c) Integrator (Design)

For $f_a = 1.5 \text{ KHz}$

Assuming $C_f = 0.01\mu f$, R_1 is given by $R_1 = 1/(2\pi f_a C_f)$

$$R_1 = 10 \text{ K}\Omega$$

$$R_f = 10 R_1$$

$$R_f = 100 \text{ K}\Omega$$

d) Differentiator (Design)

$f_a = 150 \text{ Hz}$

Assuming $C_1 = 0.1\mu f$, R_f is given by $R_f = 1/(2\pi f_a C_1)$

$$R_f = 10 \text{ K}\Omega$$

$$R_f = 10 R_1$$

$$R_1 = 1 \text{ K}\Omega$$

Observations:**a) Adder**

SI. No.	V ₁ (V)	V ₂ (V)	V ₀ (V) Theoretical	V ₀ (V) Practical
1	1	1		
2	2	1		
3	2	3		
4	4	2		

b) Subtractor

SI. No.	V ₁ (V)	V ₂ (V)	V ₀ (V) Theoretical	V ₀ (V) Practical
1	4	1		
2	3	1		
3	2	3		
4	4	2		

c) Differentiator

SI. No.	Input : sine wave		Output : (– cosine)	
	Amplitude (V _{P-P}) (V)	Time period (ms)	Amplitude (V _{P-P}) (V)	Time period (ms)
1				

SI. No.	Input : Triangular wave		Output : Square wave	
	Amplitude (V _{P-P}) (V)	Time period (ms)	Amplitude (V _{P-P}) (V)	Time period (ms)
1				

SI. No.	Input : Square wave		Output : Spikes	
	Amplitude (V _{P-P}) (V)	Time period (ms)	Amplitude (V _{P-P}) (V)	Time period (ms)
1				

Integrator

SI. No.	Input : Square wave		Output : Triangular wave	
	Amplitude (V_{P-P}) (V)	Time period (ms)	Amplitude (V_{P-P}) (V)	Time period (ms)
1				

SI. No.	Input : Sine wave		Output : Cosine wave	
	Amplitude (V_{P-P}) (V)	Time period (ms)	Amplitude (V_{P-P}) (V)	Time period (ms)
1				

SI. No.	Input : Triangular wave		Output : Parabola	
	Amplitude (V_{P-P}) (V)	Time period (ms)	Amplitude (V_{P-P}) (V)	Time period (ms)
1				

Result:

The Op-Amp is designed and verified as Adder, Subtractor, Integrator & Differentiator.

Expt. No. 5

Title: -To study & perform Voltage series feedback amplifier

Aim: To study the effect of voltage series feedback on Gain of the Amplifier.

Apparatus Required:

Sr. No	Component	Specification	Quantity
1.	Transistor	BC 107 / CL 100	1
2.	Regulated Power Supply	(0-30V, 1A)	1
3.	Resistors	33k Ω , 3.3k Ω , 330 Ω , 1.5k Ω , 2.2k Ω , 4.7k Ω , 1 k Ω .	1 each
4.	Capacitors	10 μ F ,100 μ F	2Nos
CRO (20 Mhz, dual-trace), Breadboard, Function Generator, Multimeter, Connecting wires			

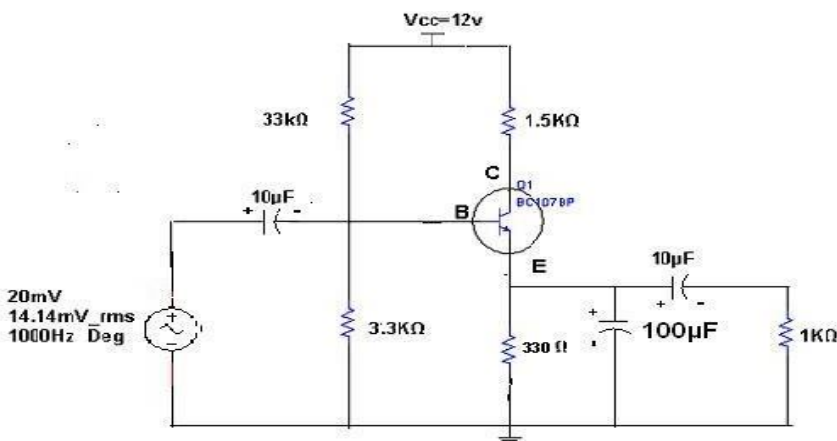
Theory:

When any increase in the output signal results into the input in such a way as to cause the decrease in the output signal, the amplifier is said to have negative feedback.

The advantages of providing negative feedback are that the transfer gain of the amplifier with feedback can be stabilized against variations in the hybrid parameters of the transistor or the parameters of the other active devices used in the circuit. The most advantage of the negative feedback is that by proper use of this, there is significant improvement in the frequency response and in the linearity of the operation of the amplifier. This disadvantage of the negative feedback is that the voltage gain is decreased.

In Voltage-Series feedback, the input impedance of the amplifier is decreased and the output impedance is increased. Noise and distortions are reduced considerably.

Circuit Diagram:



Procedure:

- $$A_v = 20 \log (V_o / V_i) \text{ dB}$$

- $$A_v = 20 \log(V_0 / V_i) \text{ dB}$$

- $$\text{B.W} = f_2 - f_1.$$

amplifier f_2 is upper cut off frequency

The gain-bandwidth product of the amplifier is calculated by using the expression Gain-Bandwidth Product = 3-dB midband gain X Bandwidth.

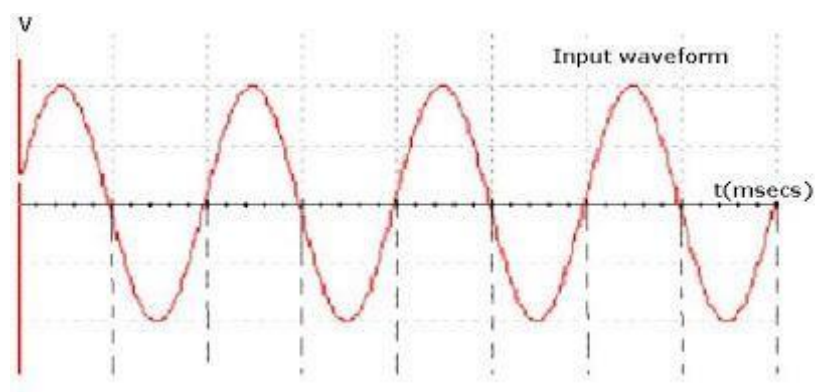
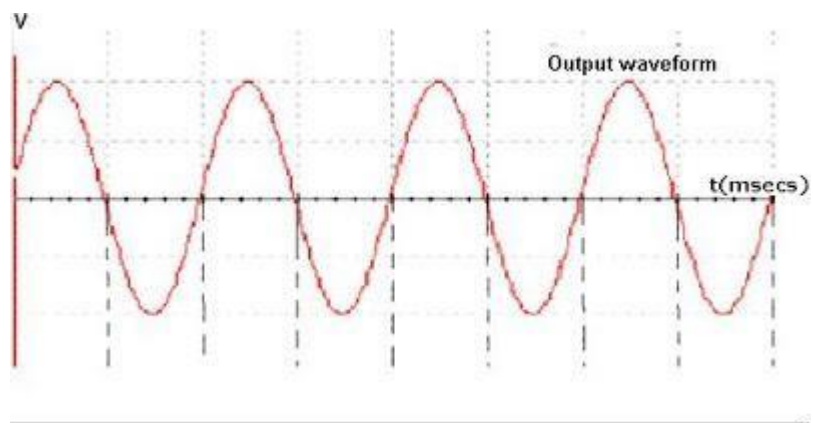
Voltage Gain:

[illegible]

Frequency Response: $V_i = 20\text{mV}$

S.NO	Frequency (Hz)	Output Voltage (V_o)	Gain $A = V_o/V_i$	Gain in dB $20\log(V_o/V_i)$

Model Waveforms:



Precautions:

1. While taking the observations for the frequency response, the input voltage must be maintained constant at 20mV.
2. The frequency should be slowly increased in steps.
3. The three terminals of the transistor should be carefully identified.
4. All the connections should be correct.

Result:

The effect of negative feedback (Voltage -Series Feedback) on the amplifier is observed. The voltage gain and frequency response of the amplifier are obtained. Also gain-bandwidth product of the amplifier is calculated.

Experiment No.6

Title:- RC Phase Shift Oscillator

Objective:

To produce frequency without using input voltage and to Study the Oscillator.

Components:

- 1- OPAMP $\mu A741$
- 2- Bread Board.
- 3- DC Dual power supply.
- 4- Oscilloscope.
- 5- Capacitors & Resistors.

Theory:

The basic RC Oscillator which is also known as a Phase-shift Oscillator, produces a sine wave output signal using regenerative feedback obtained from the resistor-capacitor combination. This regenerative feedback from the RC network is due to the ability of the capacitor to store an electric charge.

This resistor-capacitor feedback network can be connected to produce a leading phase shift (phase advance network) or interchanged to produce a lagging phase shift (phase retard network) the outcome is still the same as the sine wave oscillations only occur at the frequency at which the overall phase-shift is 360° .

By varying one or more of the resistors or capacitors in the phase-shift network, the frequency can be varied and generally this is done by keeping the resistors the same and using a 3-ganged variable capacitor.

In a Resistance-Capacitance Oscillator or simply an RC Oscillator, we make use of the fact that a phase shift occurs between the input to a RC network and the output from the same network by using RC elements in the feedback branch, for example.

RC Phase-Shift Network: The circuit on the left shows a single resistor-capacitor network whose output voltage “leads” the input voltage by some angle

less than 90° . An ideal single-pole RC circuit would produce a phase shift of exactly 90° , and because 180° of phase shift is required for oscillation, at least two single-poles must be used in an RC oscillator design.

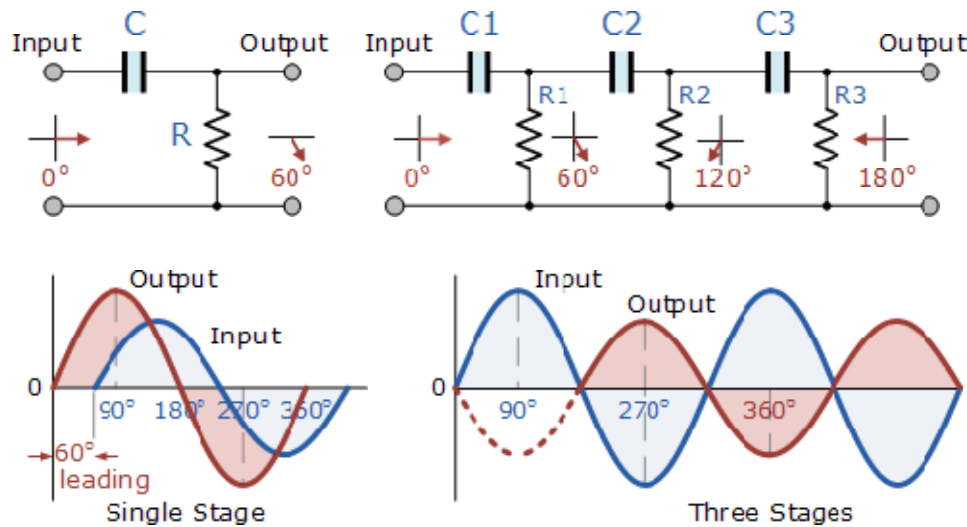


Fig.1: Phase Shift Network

Circuit Diagram:

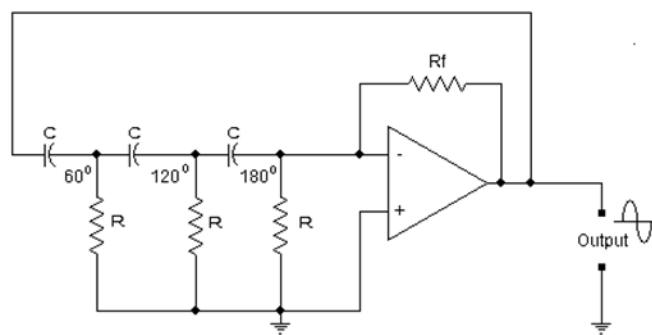


Figure 2: RC phase shift Oscillator using Op-amp

Procedure:

1. Construct the RC phase circuit on the breadboard as shown in the circuit diagram.
2. Use: $V_{++} = 14\text{ V}$, $V_{--} = -14\text{ V}$, $R_i = 10\text{ k}\Omega$, and $R_f = 470\text{ k}\Omega$.
3. Capacitor value is $0.0022\text{ }\mu\text{F}$.
4. Find f_c practically and theoretically.

Theoretical Frequency Calculation:

$$f_c = \frac{1}{2\pi RC\sqrt{6}} = \frac{1}{2\pi (10\text{ K})(0.0022\text{ uF})\sqrt{6}} = 2.95\text{ kHz}$$

Observations:

Graph:

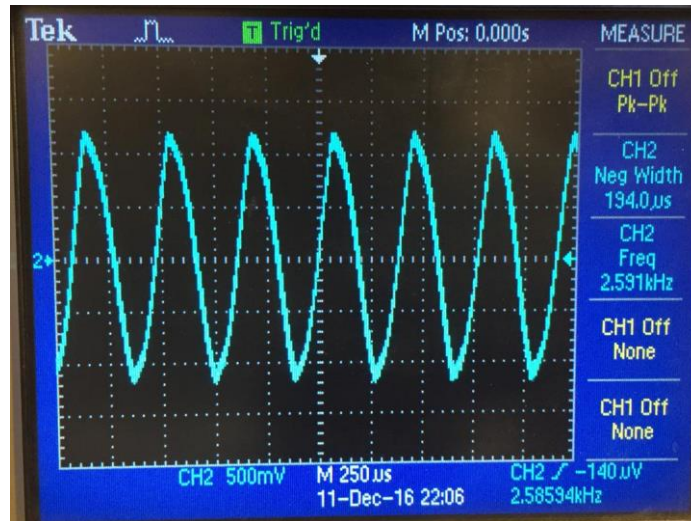


Fig.3: Output Wave with a Frequency =2.589KHz

Table1.1: Theoretical and Practical Frequencies of RCphase shift Oscillator

Observations	
Theoretical Frequency of the Oscillator	=2.95KHz
Practical Frequency of the Oscillator	=2.589KHz

Practical Frequency generated by RC Phase Shift Oscillator is $f_c=2.589\text{KHz}$

Conclusion:

The practical circuit of RC phase shift oscillator is successfully conducted, it has generated a sine wave of frequency $f_c=2.589\text{KHz}$, with an amplitude of $500\text{mV} \times 4.75 = 2.375\text{ Volts}$

The error percentage is 11 %.

Experiment No 7

Title :- To study & perform Colpitts, Hartley oscillator

Aim: To design and set up Colpitts & Hartley oscillator using BJT and to observe the sinusoidal output waveform.

Apparatus Required:

S.NO	APPARATUS	SPECIFICATION	QUANTITY
1.	Transistor	BC 107	1
2.	Resistors	11.64 K Ω , 552.2 Ω ,10.02K Ω 1.67k Ω	Each 1
3.	Capacitors	53.5nF,80 μ F, 100mF	2,1,1
4.	Inductor	0.78mH	1
5.	RPS	$\pm$ 12V	1
6.	CRO	1MHz	1
7.	Connecting wires	-	Req.

THEORY:

A Colpitts oscillator is the electrical dual of a Hartley oscillator, where the feedback signal is taken from an "inductive" voltage divider consisting of two coils in series (or a tapped coil). Fig. 1 shows the common-base Colpitts circuit. L and the series combination of C_1 and C_2 form the parallel resonant tank circuit which determines the frequency of the oscillator. The voltage across C_2 is applied to the base-emitter junction of the transistor, as feedback to create oscillations. Fig. 2 shows the common-collector version. Here the voltage across C_1 provides feedback. The frequency of oscillation is approximately the resonant frequency of the LC circuit, which is the series combination of the two capacitors

$$f_0 = \frac{1}{2\pi\sqrt{L\left(\frac{C_1C_2}{C_1+C_2}\right)}}$$

in parallel with the inductor

The **Hartley oscillator** is an electronic oscillator circuit in which the oscillation frequency is determined by a tuned circuit consisting of capacitors and inductors, that is, an LC oscillator. The Hartley oscillator is distinguished by a tank circuit consisting of two series-connected coils (or, often, a tapped coil) in parallel with a capacitor, with an amplifier between the relatively high impedance across the entire LC tank and the relatively low voltage/high current point between the coils. The Hartley oscillator is the dual of the Colpitts oscillator which uses a voltage divider made of two capacitors rather than two inductors. Although there is no requirement for there to be mutual coupling between the two coil segments, the circuit is usually implemented using a tapped coil, with the feedback taken from the tap, as shown here. The optimal tapping point (or ratio of coil inductances) depends on the amplifying device used, which may be a bipolar junction transistor.

Design Procedure for Colpitts oscillator:

Select an appropriate transistor and note down its specification such as V_{CE} , $I_{C(MAX)}$, $h_{fe(min)}$ and $V_{be(sat)}$.

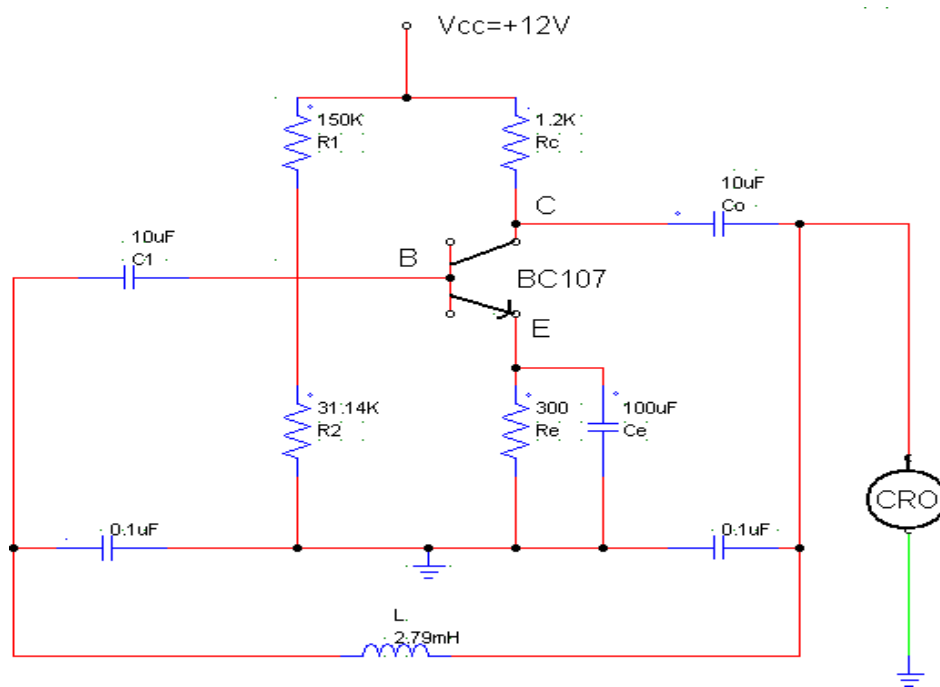
- $V_{CC} = V_{CEQ}$
- $R_2 = S * R_E$
- $V_{CC}[R_2/(R_1 + R_2)] = V_{BE} + V_{BE(SAT)}$

- $V_{R1} + V_{R2} = V_{CC}$
- $h_{fe} \geq C_1 * C_2 / (C_1 + C_2)$
- $X_{CE} \leq R_E / 10$

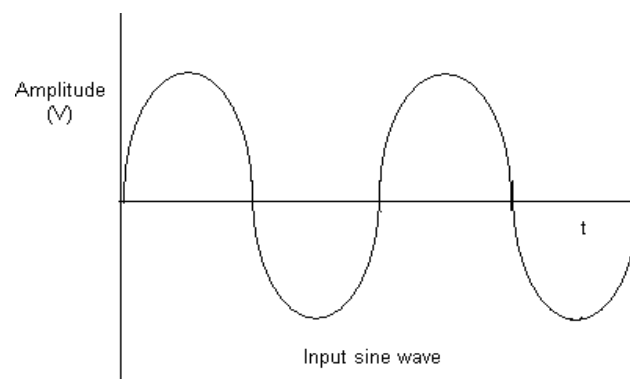
Procedure:

- Hook up the circuit as shown in the circuit diagram.
- Switch on the power supply.
- Slight modification in value of C_1 and C_2 can be made to get perfect sine wave output.
- Observe the output waveform in CRO.

Circuit Diagram:



Model Graph:



Tabulation:

Amplitude(Volts)	Time(ms)	Frequency (KHz)

Design Procedure for Hartley oscillator:

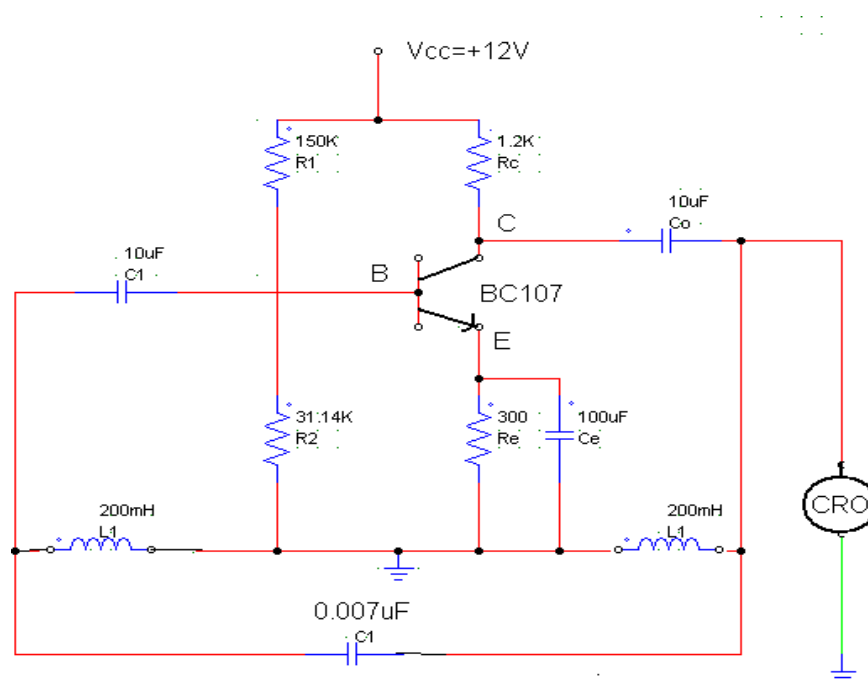
Select a appropriate transistor and note down its specification such as V_{CE} , $I_{C(MAX)}$, $h_{fe(max)}$ and $V_{be(sat)}$.

- $V_{CC} = V_{CEQ} + I_{CQ}(R_C + R_E)$
- $R_2 = S * R_E$
- $V_{CC}[R_2 / (R_1 + R_2)] = V_{BE} + V_{BE(SAT)}$
- $V_{R1} + V_{R2} = V_{CC}$

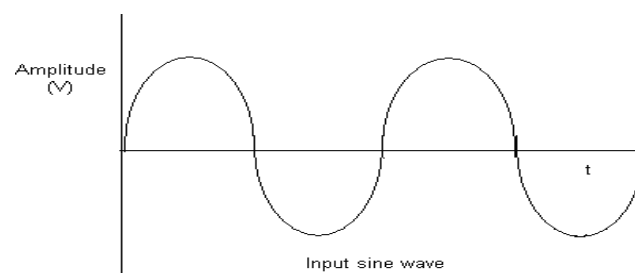
Procedure :

- Hook up the circuit as shown in the circuit diagram.
- Switch on the power supply.
- Slight modification in value of L_1 and L_2 can be made to get perfect sinewave output.
- Observe the output waveform in CRO.

Circuit diagram:



Model Graph:



Tabulation:

Amplitude(Volts)	Time(ms)	Frequency (KHz)

Result:

Thus the Colpitts oscillator & Hartley oscillator was designed and its output waveform was verified.

Experiment No.8

Title:- To Study of Sensors and transducers

Aim: To study the working principles, classifications, and characteristics of sensors and transducers, and to analyze their applications in measuring physical parameters such as temperature, light intensity, and pressure.

Theory:

Measurement is an important subsystem of a mechatronics system. Its main function is to collect the information on system status and to feed it to the micro-processor(s) for controlling the whole system.

Measurement system comprises of sensors, transducers and signal processing devices. Today a wide variety of these elements and devices are available in the market. For a mechatronics system designer it is quite difficult to choose suitable sensors/transducers for the desired application(s). It is therefore essential to learn the principle of working of commonly used sensors/transducers. A detailed consideration of the full range of measurement technologies is, however, out of the scope of this course.

Sensors in manufacturing are basically employed to automatically carry out the production operations as well as process monitoring activities. Sensor technology has the following important advantages in transforming a conventional manufacturing unit into a modern one.

1. Sensors alarm the system operators about the failure of any of the sub units of manufacturing system. It helps operators to reduce the downtime of complete manufacturing system by carrying out the preventative measures.
2. Reduces requirement of skilled and experienced labors.
3. Ultra-precision in product quality can be achieved.

Sensor

It is defined as an element which produces signal relating to the quantity being measured [1]. According to the Instrument Society of America, sensor can be defined as “*A device which provides a usable output in response to a specified measurand.*” Here, the output is usually an ‘electrical quantity’ and measurand is a ‘physical quantity, property or condition which is to be measured’. Thus in the case of, say, a variable inductance displacement element, the quantity being measured is displacement and the sensor transforms an input of displacement into a change in inductance.

Transducer

It is defined as an element when subjected to some physical change experiences a related change [1] or an element which converts a specified measurand into a usable output by using a transduction principle.

It can also be defined as a device that converts a signal from one form of energy to another form.

A wire of Constantan alloy (copper-nickel 55-45% alloy) can be called as a sensor because variation in mechanical displacement (tension or compression) can be sensed

as change in electric resistance. This wire becomes a transducer with appropriate electrodes and input-output mechanism attached to it. Thus we can say that ‘sensors are transducers’.

Sensor/transducers specifications

Transducers or measurement systems are not perfect systems. Mechatronics design engineer must know the capability and shortcoming of a transducer or measurement system to properly assess its performance. There are a number of performance related parameters of a transducer or measurement system. These parameters are called as sensor specifications.

Sensor specifications inform the user to the about deviations from the ideal behavior of the sensors. Following are the various specifications of a sensor/transducer system.

1. Range

The range of a sensor indicates the limits between which the input can vary. For example, a thermocouple for the measurement of temperature might have a range of 25-225 °C.

2. Span

The span is difference between the maximum and minimum values of the input. Thus, the above-mentioned thermocouple will have a span of 200 °C.

3. Error

Error is the difference between the result of the measurement and the true value of the quantity being measured. A sensor might give a displacement reading of 29.8 mm, when the actual displacement had been 30 mm, then the error is –0.2 mm.

4. Accuracy

The accuracy defines the closeness of the agreement between the actual measurement result and a true value of the measurand. It is often expressed as a percentage of the full range output or full-scale deflection. A piezoelectric transducer used to evaluate dynamic pressure phenomena associated with explosions, pulsations, or dynamic pressure conditions in motors, rocket engines, compressors, and other pressurized devices is capable to detect pressures between 0.1 and 10,000 psig (0.7 KPa to 70 MPa). If it is specified with the accuracy of about $\pm 1\%$ full scale, then the reading given can be expected to be within ± 0.7 MPa.

5. Sensitivity

Sensitivity of a sensor is defined as the ratio of change in output value of a sensor to the per unit change in input value that causes the output change. For example, a general purpose thermocouple may have a sensitivity of 41 $\mu\text{V}/^\circ\text{C}$.

6. Nonlinearity

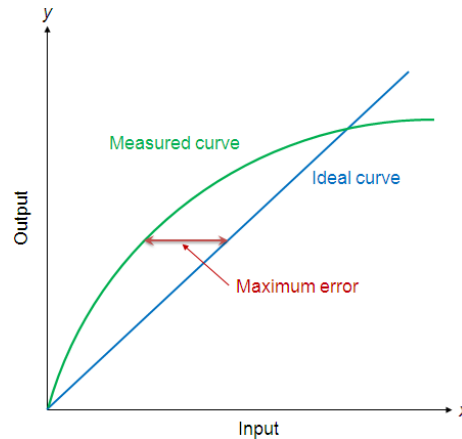


Figure 2.1.1 Non-linearity error

The nonlinearity indicates the maximum deviation of the actual measured curve of a sensor from the ideal curve. Figure 2.1.1 shows a somewhat exaggerated relationship between the ideal, or least squares fit, line and the actual measured or *calibration* line. Linearity is often specified in terms of *percentage of nonlinearity*, which is defined as:

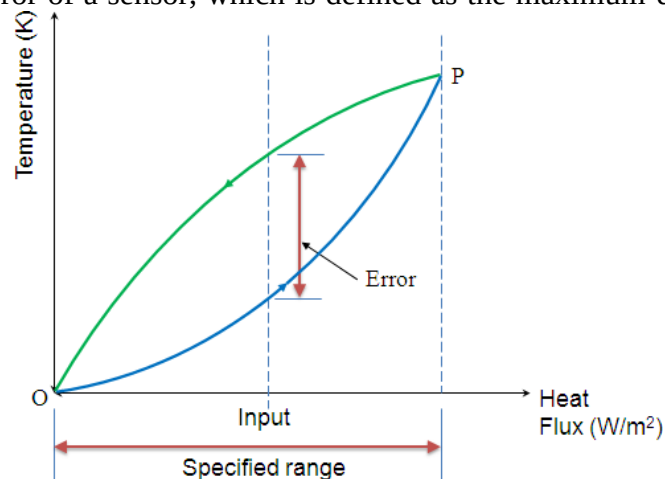
$$\text{Nonlinearity (\%)} = \text{Maximum deviation in input} / \text{Maximum full scale input} \quad (2.1.1)$$

The static nonlinearity defined by Equation 2.1.1 is dependent upon environmental factors, including temperature, vibration, acoustic noise level, and humidity. Therefore it is important to know under what conditions the specification is valid.

7. Hysteresis

Figure 2.1.2 Hysteresis error curve

The hysteresis is an error of a sensor, which is defined as the maximum difference in



output at any measurement value within the sensor's specified range when approaching the point first with increasing and then with decreasing the input parameter. Figure 2.1.2 shows the hysteresis error might have occurred during

measurement of temperature using a thermocouple. The hysteresis error value is normally specified as a positive or negative percentage of the specified input range.

8. Resolution

Resolution is the smallest detectable incremental change of input parameter that can be detected in the output signal. Resolution can be expressed either as a proportion of the full-scale reading or in absolute terms. For example, if a LVDT sensor measures a displacement up to 20 mm and it provides an output as a number between 1 and 100 then the resolution of the sensor device is 0.2 mm.

9. Stability

Stability is the ability of a sensor device to give same output when used to measure a constant input over a period of time. The term 'drift' is used to indicate the change in output that occurs over a period of time. It is expressed as the percentage of full range output.

10. Dead band/time

The dead band or dead space of a transducer is the range of input values for which there is no output. The dead time of a sensor device is the time duration from the application of an input until the output begins to respond or change.

11. Repeatability

It specifies the ability of a sensor to give same output for repeated applications of same input value. It is usually expressed as a percentage of the full range output:

Repeatability = $(\text{maximum} - \text{minimum values given}) \times 100 / \text{full range}$ (2.1.2)

12. Response time

Response time describes the speed of change in the output on a step-wise change of the measurand. It is always specified with an indication of input step and the output range for which the response time is defined.

PARAMETERS

The normal environmental conditions from where the data are made available through sensors are noisy and keep changing. The high fidelity mapping of such a varying reality requires extensive studies of 'fidelity' of the sensors themselves or in other words, sensors are required to be appropriately characterized. These are done in terms of certain parameters and characteristics of the sensors.

ENVIRONMENTAL PARAMETERS (EP)

These are the external variables such as temperature, pressure, humidity, vibration, and the like which affect the performance of the sensor. These parameters are not the ones that are to be sensed. For non-temperature transducers, temperature is the most important environmental parameter (EP). For any EP, the performance of the transducer can be studied in terms of its effect on the static and dynamic characteristics of the sensor as has already been discussed. For this study, one EP at a time is considered variable while others are held constant.

CHARACTERIZATION

Characterization of the sensors can be done in many ways depending on the types of sensors, specifically micro sensors. These are electrical, mechanical, optical, thermal, chemical, biological, and so on.

1. Electrical characterization

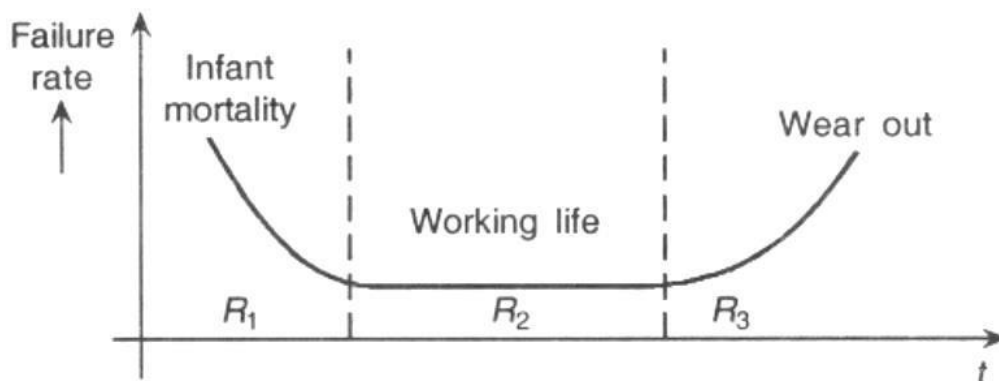
It consists of evaluation of electrical parameters like (a) impedances, voltage and currents, (b) breakdown voltages and fields, (c) leakage currents, (d) noise, (e) cross talk, and so on.

2. Mechanical and thermal characterization

It involves mechanical and thermal properties related to the overall reliability and integrity of the transducer, as well as relevant transduction process. Reliability is an important aspect of characterization. By means of testing, the functional and reliable portion of a batch of sensors or transducers is identified. Basically, failure analysis is performed and the mechanism of failure is attempted to be eliminated and thereby reduce the subsequent failures. In fact, the above two approaches are supplementary to each other.

Failure of transducers can be divided into two different categories:

- (i) Catastrophic early life failures, often called infant mortality: If the sensors is the complete failure in the normal operation. It is called wear out if it occurs in later life.
- (ii) Short term drifts in the sensor parameters, and Long term drifts and failures. Short term and long term drifts are, in effect, changes in sensor parameters and are, therefore, to be studied more intensely for the sensor characterization.



- a. **High temperature burn in:** The sensors are subjected to a high temperature over a stipulated period, usually at 125°C for 48 hours for SITS, when the defective units are burnt out and the remaining ones are expected to run for the expected life.
- b. **High temperature storage bake:** The units are baked at a high temperature, usually at 250°C for SITS, for several hours when the instability mechanisms such as contamination, bulk defects, and metallization problems are enhanced in some units which were initially defective. These units are then screened out.
- c. **Electrical overstress test:** Where progressively larger voltages upto 50% in excess of specification are applied over different intervals of time so that failures due to insulation, interconnection or oxide formation can occur in some units which were originally defective and are screened out.
- d. **Thermal shock test:** Mainly done for packaging defects where the units are subjected to a temperature between -65° and 125°C for about 10 seconds for every temperature. The time is gradually increased to 10 minutes and the cycle is repeated 10 times. The failed units are rejected.

3. Mechanical shock test:

Also for packaging, this test is performed by dropping the units from a specified height that varies from 3 to 10 m. Alternately the unit is shaken by attaching it to a shaking table for a specified period of time.

4. Optical characterization

It is usually done by ascertaining absorption coefficient, refractive index, reflectivity and the like. Here, again the consideration of the individual merit comes in.

5. Chemical/biological characterization

This is basically a test of the sensor with respect to its resistance to chemicals or corrosion in industrial as well as biological environment. Safety is an important aspect here particularly in case

Classification of sensors

Sensors can be classified into various groups according to the factors such as measurand, application fields, conversion principle, energy domain of the measurand and thermodynamic considerations. These general classifications of sensors are well described in the references [2, 3].

Detail classification of sensors in view of their applications in manufacturing is as follows.

A. Displacement, position and proximity sensors

- Potentiometer
- Strain-gauged element
- Capacitive element
- Differential transformers
- Eddy current proximity sensors
- Inductive proximity switch
- Optical encoders
- Pneumatic sensors
- Proximity switches (magnetic)
- Hall effect sensors

B. Velocity and motion

- Incremental encoder
- Tachogenerator
- Pyroelectric sensors

C. Force

- Strain gauge load cell

D. Fluid pressure

- Diaphragm pressure gauge
- Capsules, bellows, pressure tubes
- Piezoelectric sensors
- Tactile sensor

E. Liquid flow

- Orifice plate
- Turbine meter

F. Liquid level

- Floats

- Differential pressure
- G. Temperature
- Bimetallic strips
 - Resistance temperature detectors
 - Thermistors
 - Thermo-diodes and transistors
 - Thermocouples
 - Light sensors
 - Photo diodes
 - Photo resistors
 - Photo transistor

Electromechanical Sensors

Electromechanical sensor transforms mechanical energy into electrical signals. The main electromechanical sensors we focus on strain and pressure sensors.

According to their mechanisms, resistive and capacitive sensor attracts more attention due to their simple structures, mechanisms, preparation method, and low cost. Various kinds of Nano materials have been developed to fabricate them, including carbon Nano materials, metallic, and conductive polymers. They have great potentials for health monitoring, human motion monitoring, speech recognition, and related human-machine interface applications

Displacement sensors are basically used for the measurement of movement of an object. Position sensors are employed to determine the position of an object in relation to some reference point.

Proximity sensors are a type of position sensor and are used to trace when an object has moved within a particular critical distance of a transducer.

Displacement sensors

1. Potentiometer Sensors

Figure 2.2.1 Schematic of a potentiometer sensor for measurement of linear displacement

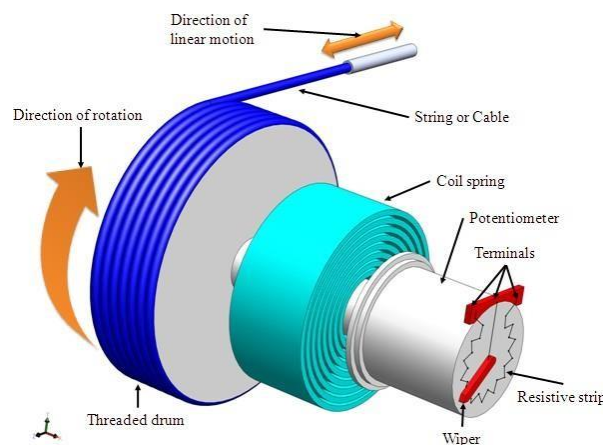


Figure 2.2.1 shows the construction of a rotary type potentiometer sensor employed to measure the linear displacement. The potentiometer can be of linear or angular type. It works on the principle of conversion of mechanical displacement into an electrical signal. The sensor has a resistive element and a sliding contact (wiper). The slider moves along this conductive body, acting as a movable electric contact.

The object of whose displacement is to be measured is connected to the slider by using

- a rotating shaft (for angular displacement)
- a moving rod (for linear displacement)
- a cable that is kept stretched during operation

The resistive element is a wire wound track or conductive plastic. The track comprises of large number of closely packed turns of a resistive wire. Conductive plastic is made up of plastic resin embedded with the carbon powder. Wire wound track has a resolution of the order of $\pm 0.01\%$ while the conductive plastic may have the resolution of about $0.1\ \mu\text{m}$.

During the sensing operation, a voltage V_s is applied across the resistive element. A voltage divider circuit is formed when slider comes into contact with the wire. The output voltage (V_A) is measured as shown in the figure 2.2.2. The output voltage is proportional to the displacement of the slider over the wire. Then the output parameter displacement is calibrated against the output voltage V_A .

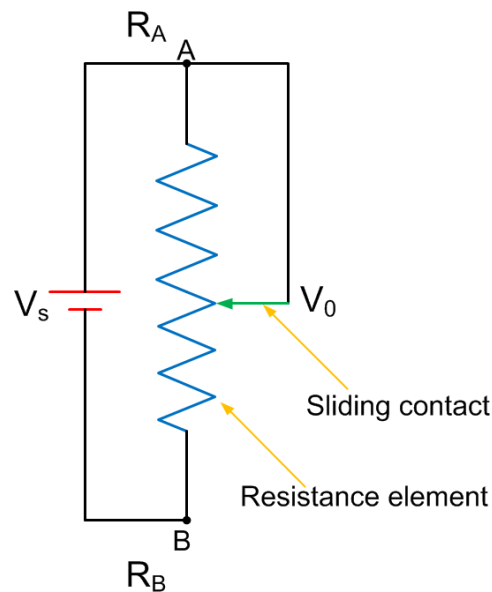


Figure 2.2.2 Potentiometer: electric circuit

$$V_A = I R_A \quad (2.2.1)$$

$$\text{But } I = V_s / (R_A + R_B) \quad (2.2.2)$$

$$\text{Therefore } V_A = V_s R_A / (R_A + R_B) \quad (2.2.3)$$

As we know that $R = \rho L / A$, where ρ is electrical resistivity, L is length of resistor

and A is area of cross section

$$V_A = V_S \frac{L_A}{L_A + L_B} \quad (2.2.4)$$

Applications of potentiometer

These sensors are primarily used in the control systems with a feedback loop to ensure that the moving member or component reaches its commanded position.

These are typically used on machine-tool controls, elevators, liquid-level assemblies, forklift trucks, automobile throttle controls. In manufacturing, these are used in control of injection molding machines, woodworking machinery, printing, spraying, robotics, etc. These are also used in computer-controlled monitoring of sports equipment.

2. Strain Gauges

The strain in an element is a ratio of change in length in the direction of applied load to the original length of an element. The strain changes the resistance R of the element. Therefore, we can say,

$$\Delta R/R \propto \epsilon;$$

$$\Delta R/R = G \epsilon \quad (2.2.5)$$

where G is the constant of proportionality and is called as gauge factor. In general, the value of G is considered in between 2 to 4 and the resistances are taken of the order of 100Ω .

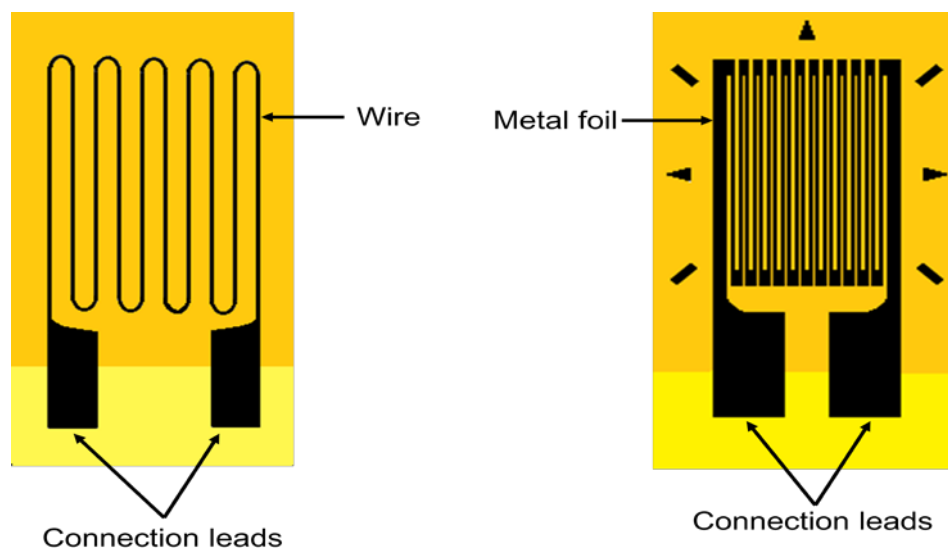


Figure 2.2.3 A pattern of resistive foils

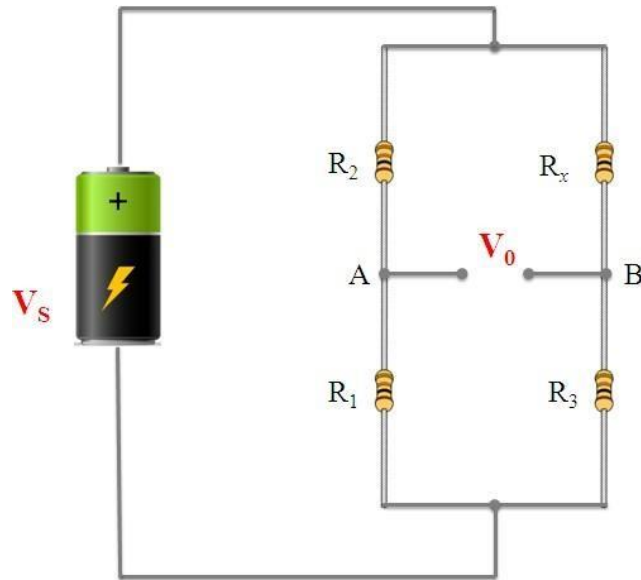


Figure 2.2.4 Wheatstone's bridge

Resistance strain gauge follows the principle of change in resistance as per the equation 2.2.5. It comprises of a pattern of resistive foil arranged as shown in Figure 2.2.3. These foils are made of Constantan alloy (copper-nickel 55-45% alloy) and are bonded to a backing material plastic (polyimide), epoxy or glass fiber reinforced epoxy. The strain gauges are secured to the workpiece by using epoxy or Cyanoacrylate cement Eastman 910 SL. As the workpiece undergoes change in its shape due to external loading, the resistance of strain gauge element changes. This change in resistance can be detected by using a Wheatstone's resistance bridge as shown in Figure 2.2.4. In the balanced bridge we can have a relation,

$$R_2 / R_1 = R_x / R_3 \quad (2.2.6)$$

where R_x is resistance of strain gauge element, R_2 is balancing/adjustable resistor, R_1 and R_3 are known constant value resistors. The measured deformation or displacement by the strain gauge is calibrated against change in resistance of adjustable resistor R_2 which makes the voltage across nodes A and B equal to zero.

Applications of strain gauges

Strain gauges are widely used in experimental stress analysis and diagnosis on machines and failure analysis. They are basically used for multi-axial stress fatigue testing, proof testing, residual stress and vibration measurement, torque measurement, bending and deflection measurement, compression and tension measurement and strain measurement.

Strain gauges are primarily used as sensors for machine tools and safety in automobiles. In particular, they are employed for force measurement in machine tools, hydraulic or pneumatic press and as impact sensors in aerospace vehicles.

3. Capacitive element based sensor

Capacitive sensor is of non-contact type sensor and is primarily used to measure the linear displacements from few millimeters to hundreds of millimeters. It comprises of three plates, with the upper pair forming one capacitor and the lower pair another. The

linear displacement might take in two forms:

- one of the plates is moved by the displacement so that the plate separation changes
- area of overlap changes due to the displacement.

Figure 2.2.5 shows the schematic of three-plate capacitive element sensor and displacement measurement of a mechanical element connected to the plate 2.

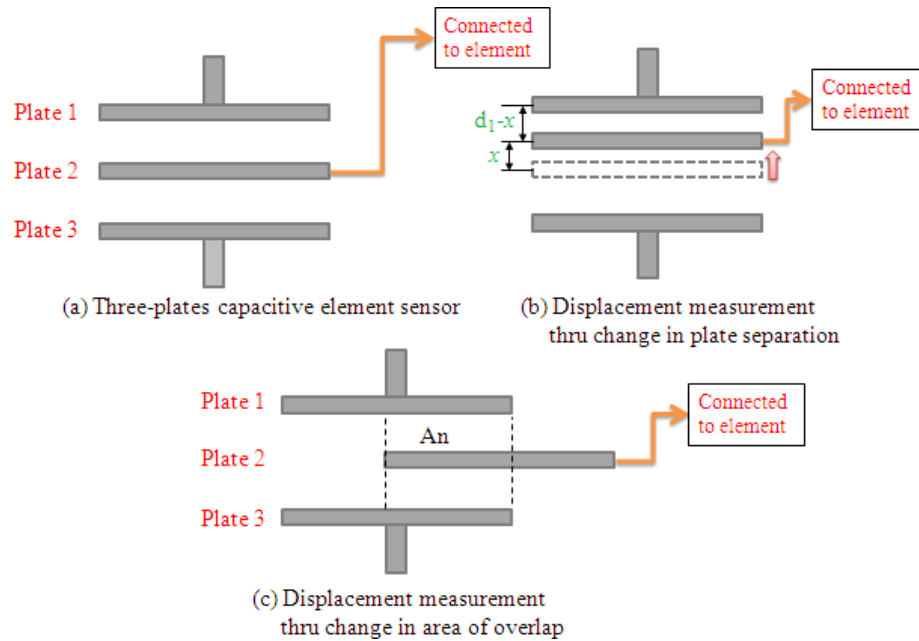


Figure 2.2.5 Displacement measurement using capacitive element sensor

The capacitance C of a parallel plate capacitor is given by,

$$C = \epsilon_r \epsilon_0 A / d \quad (2.2.7)$$

where ϵ_r is the relative permittivity of the dielectric between the plates, ϵ_0 permittivity of free space, A area of overlap between two plates and d the plate separation.

As the central plate moves near to top plate or bottom one due to the movement of the element/workpiece of which displacement is to be measured, separation in between the plate changes. This can be given as,

$$C_1 = (\epsilon_r \epsilon_0 A) / (d + x) \quad (2.2.8)$$

$$C_2 = (\epsilon_r \epsilon_0 A) / (d - x) \quad (2.2.9)$$

When C_1 and C_2 are connected to a Wheatstone's bridge, then the resulting out-of-balance voltage would be in proportional to displacement x .

Capacitive elements can also be used as proximity sensor. The approach of the object towards the sensor plate is used for induction of change in plate separation. This changes the capacitance which is used to detect the object.

Applications of capacitive element sensors

- Feed hopper level monitoring
- Small vessel pump control
- Grease level monitoring
- Level control of liquids
- Metrology applications
 - to measure shape errors in the part being produced
 - to analyze and optimize the rotation of spindles in various machine tools such as surface grinders, lathes, milling machines, and air bearing spindles by measuring errors in the machine tools themselves
- Assembly line testing
 - to test assembled parts for uniformity, thickness or other design features
 - to detect the presence or absence of a certain component, such as glue etc.

4. Linear variable differential transformer (LVDT)

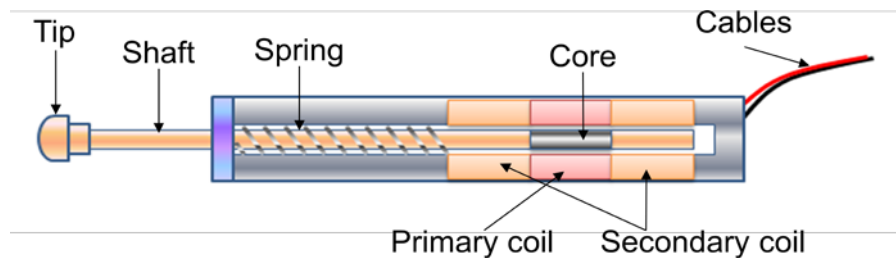


Figure 2.2.6 Construction of a LVDT sensor

Linear variable differential transformer (LVDT) is a primary transducer used for measurement of linear displacement with an input range of about ± 2 to ± 400 mm in general. It has non-linearity error $\pm 0.25\%$ of full range. Figure 2.2.6 shows the construction of a LVDT sensor. It has three coils symmetrically spaced along an insulated tube. The central coil is primary coil and the other two are secondary coils. Secondary coils are connected in series in such a way that their outputs oppose each other. A magnetic core attached to the element of which displacement is to be monitored is placed inside the insulated tube.

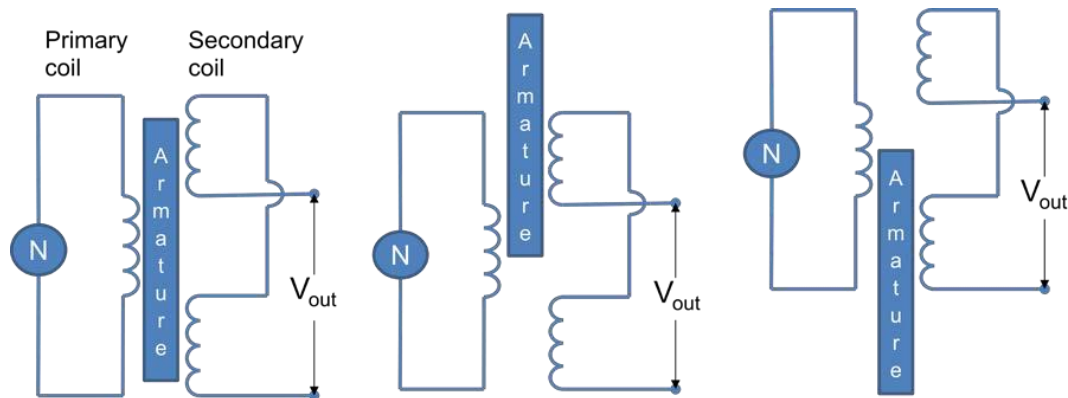


Figure 2.2.7 Working of LVDT sensor

Due to an alternating voltage input to the primary coil, alternating electro-magnetic forces (emfs) are generated in secondary coils. When the magnetic core is centrally placed with its half portion in each of the secondary coil regions then the resultant voltage is zero. If the core is displaced from the central position as shown in Figure 2.2.7, say, more in secondary coil 1 than in coil 2, then more emf is generated in one coil i.e. coil 1 than the other, and

there is a resultant voltage from the coils. If the magnetic core is further displaced, then the value of resultant voltage increases in proportion with the displacement. With the help of signal processing devices such as low pass filters and demodulators, precise displacement can be measured by using LVDT sensors.

LVDT exhibits good repeatability and reproducibility. It is generally used as an absolute position sensor. Since there is no contact or sliding between the constituent elements of the sensor, it is highly reliable. These sensors are completely sealed and are widely used in Servomechanisms, automated measurement in machine tools.

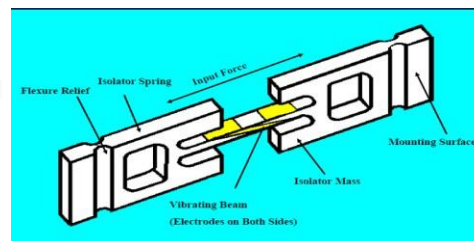
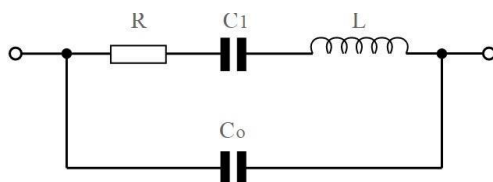
A rotary variable differential transformer (RVDT) can be used for the measurement of rotation. Readers are suggested to prepare a report on principle of working and construction of RVDT sensor.

Applications of LVDT sensors

- Measurement of spool position in a wide range of servo valve applications
- To provide displacement feedback for hydraulic cylinders
- To control weight and thickness of medicinal products viz. tablets or pills
- For automatic inspection of final dimensions of products being packed for dispatch
- To measure distance between the approaching metals during Friction welding process
- To continuously monitor fluid level as part of leak detection system
- To detect the number of currency bills dispensed by an ATM

Quartz Resonator Technology:

Quartz crystal resonator technology relies on the remarkable properties of quartz for its operation. When placed into an electronic circuit a quartz crystal acts as a tuned circuit. However it has an exceptionally high Quality. The operation of the quartz crystal is based around the fact that quartz exhibits the piezo-electric effect. This means that when a stress is set up across the crystal, an electromotive force or electric potential is seen. The reverse is also true, then when a potential is applied across the crystal, it deflects slightly. This means that piezo electric effect enables the mechanical and electrical domains to be linked.



- The widespread use of digital computers and digital control systems have generated a need for high accuracy, inherently digital sensors

Material Properties and Characteristics of Quartz Sensors

- Piezoelectric [pressure-charge generation]
- Anisotropic [direction-dependent] Elastic Modulus
- Piezoelectric Constants
- Coefficient of Thermal Expansion
- Optical Index of Refraction
- Velocity of Propagation
- Hardness

- Solubility [etch rate]
- Thermal and Electrical conductivity

Advantages of Quartz resonant Sensors

- High Resolution
- Excellent Accuracy
- Long Term Stability
- Low Power Consumption
- Low Temperature Sensitivity
- Low Susceptibility to Interference
- Easy to Transmit Over Long Distances
- Easy to Interface With Counter-Timers, Telemetry, and Digital Computer Systems