Al Imam Mohammad Ibn Saud Islamic University

College of Engineering

Department of Electrical Engineering

Electronic Devices Application Laboratory Manual

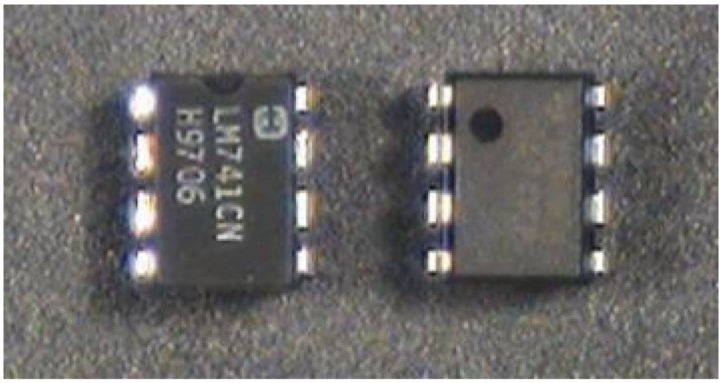
EE324

Index

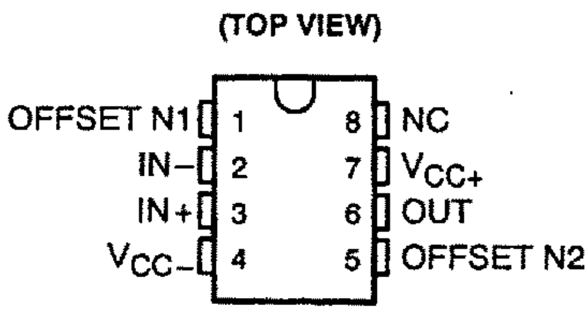
1. Introduction to the Operational Amplifiers (OP-AMPs)

The 741 OP AMP

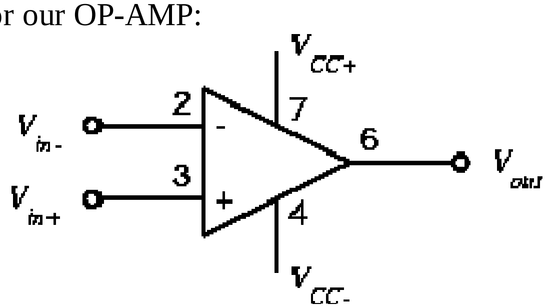
The 741 Operational Amplifier, or OP-AMP, comes in an 8-pin dual inline package (DIP) which looks like this



If you look closely at the package, you will find a notch at one end or a dot in one corner. This tells us how to find Pin 1: the dot is located next to Pin 1 and the notch is located between Pins 1 and 8. The rest of the pins are numbered like this:



Pin 8 is not connected (NC). Pins 1 and 5 are used to eliminate the offset voltage. We won't be using this feature, so don't connect anything to these pins. The remaining pins give us the following circuit symbol for our OP-AMP:



For more information, see the 741 data sheet.

In order to function, the OP-AMP must be connected to an external *power supply*. Since we want to produce both positive and negative output voltages, we need both positive and negative voltages for the power supply. These are labeled V_{CC+} and V_{CC-} on the diagram. For a 741, the nominal values are V_{CC+} = 15 V and V_{CC-} = -15 V.

To avoid clutter, we won't show the power supply terminals (pins 4 and 7) on any of the subsequent circuit diagrams. However, they must be connected or your amplifier will not operate.

Note that there is no ground terminal on the OP-AMP. The zero reference point is established by the external circuit and is not important to the OP-AMP itself.

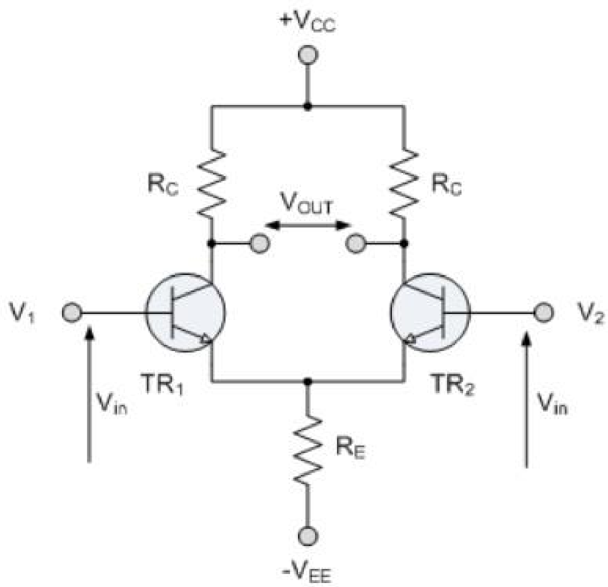
Ideal OP-AMP

As well as resistors and capacitors, OP-AMPs, or OP-AMPs as they are more commonly called, are one of the basic building blocks of Analogue Electronic Circuits. It is a linear device that has all the properties required for nearly ideal DC amplification and is used extensively in signal conditioning, filtering or to perform mathematical operations such as add, subtract, integration and differentiation. An ideal OP-AMP is basically a 3-terminal device that consists of two high impedance inputs, one an Inverting input marked with a negative sign, ("-") and the other a Non-inverting input marked with a positive plus sign ("+").

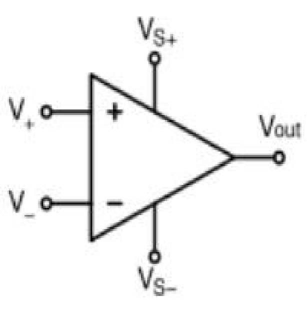
The amplified output signal of an OP-AMP is the difference between the two signals being applied to the two inputs. In other words the output signal is a differential signal between the two inputs and the input stage of an OP-AMP is in fact a differential amplifier as shown below.

Differential Amplifier

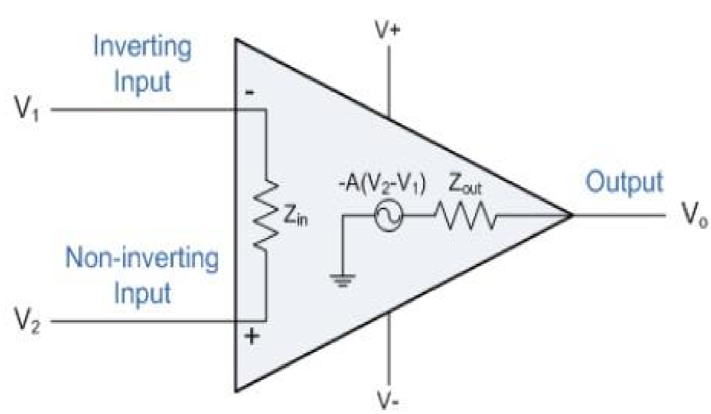
The circuit shows a generalized form of a differential amplifier with two inputs marked V_1 and V_2. The two identical transistors $TR_1$and TR_2 are both biased at the same operating point with their emitters connected together and returned to the common rail, $-V_{EE}$ by way of resistor R_E. The circuit operates from a dual supply $+V_{CC}$ and ï V_{EE} which ensures a constant supply. As the two base inputs are out of phase with each other, the output voltage, V_{OUT}, is the difference between the two input signals. So, as the forward bias of transistor $TR_1$is increased, the forward bias of transistor TR_2 is reduced and vice versa. Then if the two transistors are perfectly matched, the current flowing through the common emitter resistor, RE will remain constant.



Ideal OP-AMPs have an output of low impedance that is referenced to a common ground terminal and it should ignore any common mode signals. That means, if identical signals are applied to both the inverting and non-inverting inputs there should be no change at the output. However, in real amplifiers there is always some variation and the ratio of the change to the output voltage with regards to the change in the common mode input voltage is called the Common Mode Rejection Ratio or CMRR.
OP-AMPs have a very high open loop DC gain, commonly known as the Open Loop Differential Gain, and is given the symbol (Ao). By applying some form of Negative Feedback we can produce an OP-AMP circuit with a very precise gain characteristic that is dependent only on the feedback used. An OP-AMP only responds to the difference between the voltages at its two input terminals, known commonly as the "Differential Input Voltage" and not to their common potential. Then if the same voltage potential is applied to both terminals the resultant output will be zero.



Symbol of OpAmp



Equivalent Circuit for Ideal OpAmp

Idealized Characteristics

PARAMETER	IDEALIZED CHARACTERISTIC
Voltage Gain, (A)	Infinite - The main function of an OP-AMP is to amplify the input signal and the more open loop gain it has the better, so for an ideal amplifier the gain will be infinite.
Input impedance, (Zin)	Infinite - Input impedance is assumed to be infinite to prevent any current flowing from the source supply into the amplifiers input circuitry.
Output impedance, (Zout) be	Zero - The output impedance of the ideal OP-AMP is assumed to Zero so that it can supply as much current as necessary to the load.
Bandwidth, (BW)	Infinite - An ideal OP-AMP has an infinite Frequency Response and can amplify any frequency signal so it is assumed to have an infinite bandwidth.
Offset Voltage, (Vio)	Zero - The amplifiers output will be zero when the voltage difference between the inverting and non-inverting inputs is zero.

It is important to remember two properties known as the golden rules, as they help understand the working of the amplifier with regards to analysis and design of OP-AMP circuits.

1. No current flows into either input terminal (the current rule)
2. The differential input offset voltage is zero (the voltage rule).

However, real OP-AMPs (e.g. 741) do not have infinite gain or bandwidth but have a typical "Open Loop Gain" which is defined as the amplifiers output amplification without any external feedback signals connected to it and for a typical OP-AMP is about 100dB at DC (zero Hz). This output gain decreases linearly with frequency down to "Unity Gain" or 1, at about 1MHz and this is shown in the following open loop gain response curve.

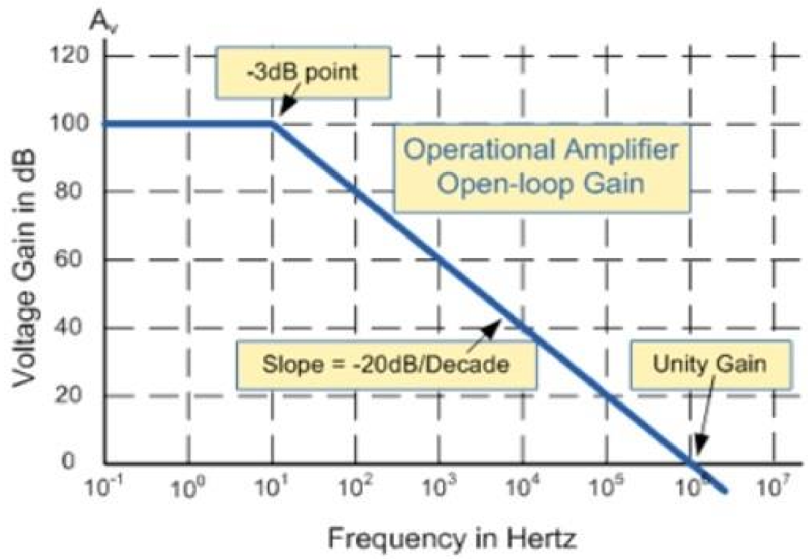
The Voltage Gain (A) of the amplifier can be found using the following formula:

$$\text{Gain, } A = V_o / V_i$$

and in Decibels or (dB) is given as:

$$20 \log A = 20 \log (V_o / V_i)$$

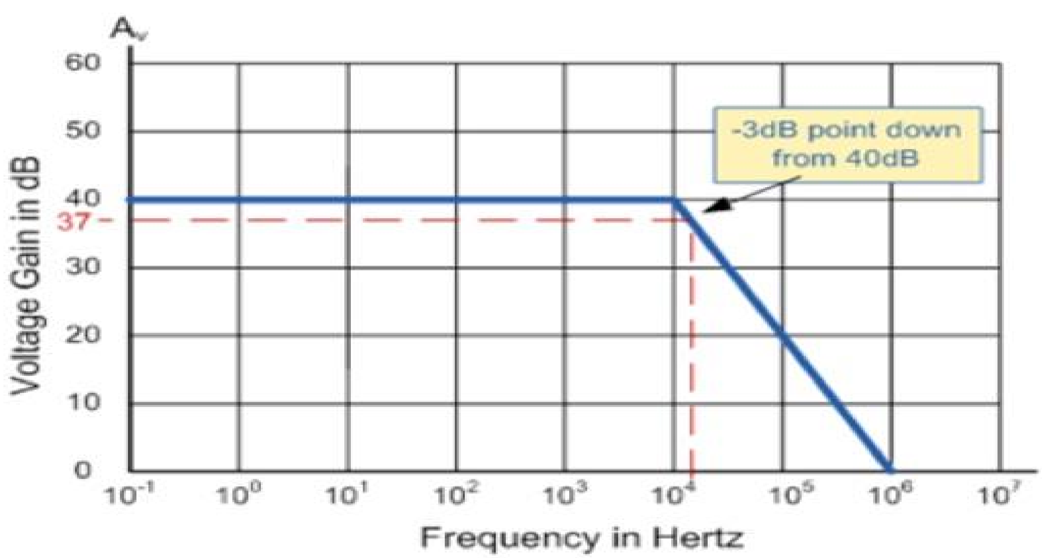
Open-loop Frequency Response Curve



From this frequency response curve we can see that the product of the gain against frequency is constant at any point along the curve. Also that the unity gain (0dB) frequency also determines the gain of the amplifier at any point along the curve. This constant is generally known as the Gain Bandwidth Product or GBP. Therefore, GBP = Gain × Bandwidth or A × BW.

For example, from the graph above the gain of the amplifier at 100 kHz =20dB or 10, then the GBP = 100,000Hz x 10 = 1,000,000.
Similarly, a gain at 1 kHz = 60dB or 1000, therefore the GBP = 1,000 x 1,000 = 1,000,000. The same!
The OP-AMPs **bandwidth** is the frequency range over which the voltage gain of the amplifier is above 70.7% or **-3dB** (where 0dB is the maximum) **of its maximum output value** as shown below.

Bandwidth of OP-AMP



Here we have used the 40dB line as an example. The -3dB or 70.7% of Vmax down point from the frequency response curve is given as 37dB. Taking a line across until it intersects with the main GBP curve gives us a frequency point just above the 10 kHz line at about 12 to 15 kHz.

We can now calculate this more accurately as we already know the GBP of the amplifier, in this particular case 1MHz.

Example No 1:
Using the formula 20 log (A), we can calculate the bandwidth of the amplifier as:
37 = 20 log A therefore, A = anti-log (37 ÷ 20) = 70.8
GBP ÷ A = Bandwidth, therefore, 1,000,000 ÷ 70.8 = 14.124Hz, or 14 kHz
Then the bandwidth of the amplifier at a gain of 40dB is given as 14 kHz as predicted from the graph.

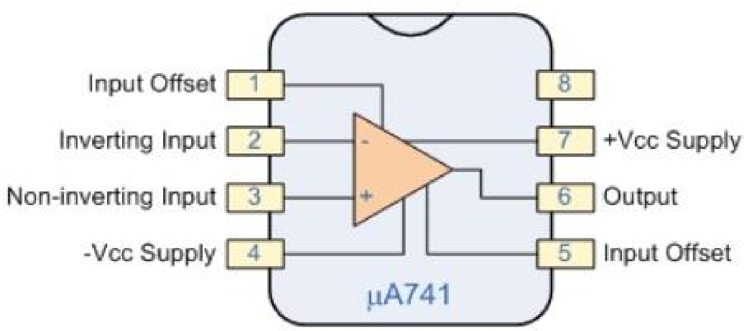
Example No 2:
If the gain of the OP-AMP was reduced by half to say 20dB in the above frequency response curve, the -3dB point would now be at 17dB. This would then give us an overall gain of 7.08, therefore A = 7.08. If we use the same formula as above this new gain would give us a bandwidth of 141.2 kHz, ten times more than at 40dB.

It can therefore be seen that by reducing the overall open loop gain of an OP-AMP its bandwidth is increased and vice versa. The -3dB point is also known as the "**half power point**", as the output power of the amplifier is at half its maximum value at this point.

OP-AMP types

OP-AMPs can be connected using external resistors or capacitors in a number of different ways to form basic "Building Block" circuits such as, Inverting, Non-Inverting, Voltage Follower, Summing, Differential, Integrator and Differentiator type amplifiers. There are a very large number of OP-AMP IC's available to suit every possible application.

The most commonly available and used of all OP-AMPs is the industry standard 741 type IC.

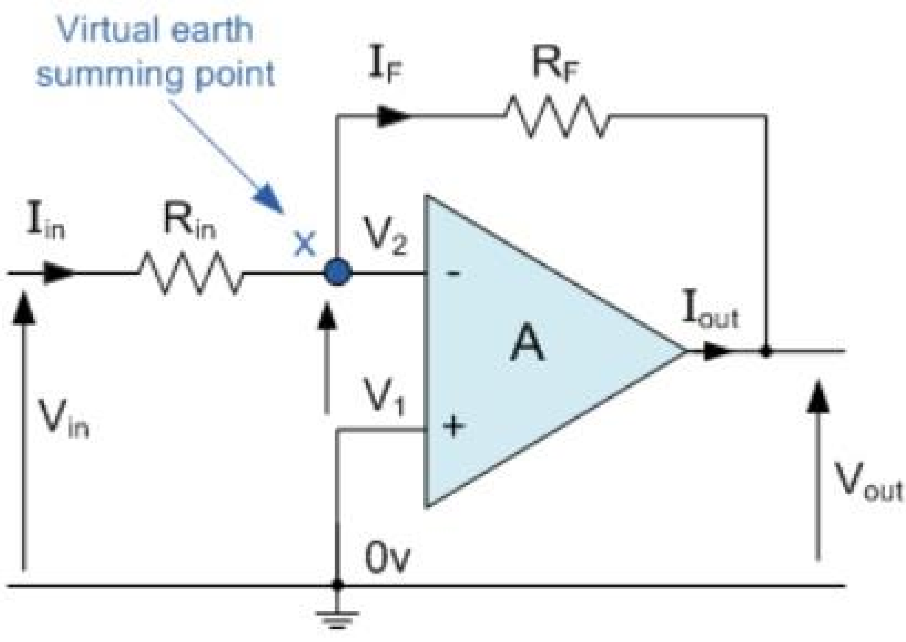


Inverting Amplifier

The open loop gain of an ideal OP-AMP can be very high, up to about 1,000,000 (120dB) or more. However, this very high gain is of no real use to us as it makes the amplifier both unstable and hard to control as the smallest of input signals, just a few micro-volts, would be enough to cause the output to saturate and swing towards one or the other of the voltage supply rails losing control. As the open loop DC gain of an OP-AMP is extremely high we can afford to lose some of this gain by connecting a suitable resistor across the amplifier from the output terminal back to the inverting input terminal to both reduce and control the overall gain of the amplifier. This then produces an effect known commonly as **Negative Feedback**, and thus produces a very stable OP-AMP system.

Negative Feedback is the process of "feeding back" some of the output signal back to the input, but to make the feedback negative we must feed it back to the **"Negative input" terminal** using an external Feedback Resistor called R_f. This feedback connection between the output and the inverting input terminal produces a closed loop circuit to the amplifier resulting in the gain of the amplifier now being called its **Closed-loop Gain**.

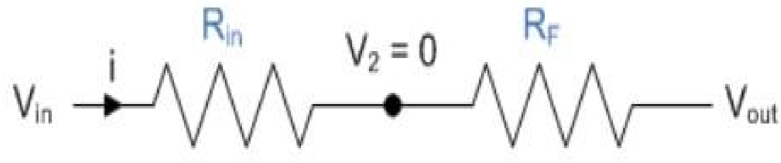
This results in the inverting input terminal having a different signal on it than the actual input voltage as it will be the sum of the input voltage plus the negative feedback voltage giving it the label or term of a **Summing Point**. We must therefore separate the real input signal from the inverting input by using an Input Resistor, R_{in}. As we are not using the positive non-inverting input this is connected to a common ground or zero voltage terminal as shown below. But the effect of this closed loop feedback circuit results in the voltage at the inverting input equal to that at the non-inverting input producing a **Virtual Earth** summing point because it will be at the same potential as the grounded reference input.



In inverting amplifier circuit the OP-AMP is connected with feedback to produce a closed loop operation. There are two very important rules to remember about inverting amplifiers: "no current flows into the input terminal" and that "V_1 equals V_2". This is because the junction of the input and feedback signal (X) is at the same potential as the positive (+) input which is at zero volts or ground then, the junction is a "Virtual Earth". **Because of this virtual earth node the input resistance of the amplifier is equal to the value of the input resistor, R_{in}.**

Then by using these two rules one can find the equation for calculating the gain of an inverting amplifier, using first principles. Current (i) flows through the resistor network as shown.

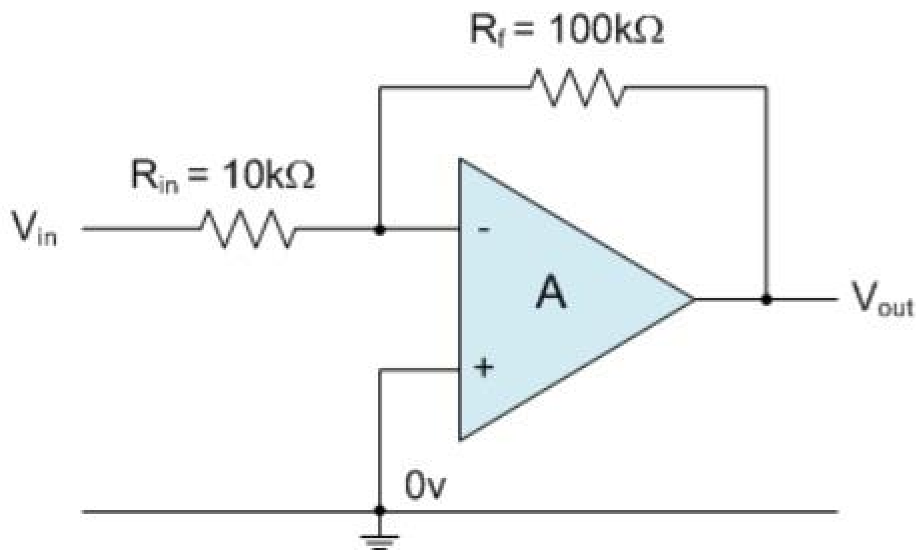
$$i = \frac{V_{in}}{R_{in}} = -\frac{V_o}{R_f}$$



The negative sign in the equation indicates an inversion of the output signal with respect to the input as it is 180^o out of phase. This is due to the feedback being negative in value.
Then, the **Closed-Loop Voltage Gain** of an Inverting Amplifier is given as.

$$\text{Gain} = V_{out} / V_{in} = - R_f / R_{in}$$

Example No 1
Find the closed loop gain of the given inverting amplifier circuit.



Using the previously found formula for the gain of the circuit
R_{in} = 10kÝ and R_f = 100kÝ.
Gain = - R_f / R_{in} = 100kÝ/10kÝ = 10.

Therefore, the closed loop gain of the given inverting amplifier circuit is 10 or 20dB.

Example No 2

The gain of the original circuit is to be increased to 40, find the new values of the resistors required.

Assume that the input resistor is to remain at the same value of 10KÝ, then by re-arranging the closed loop voltage gain formula we can find the new value required for the feedback resistor R_f.

Gain = - R_f / R_{in}

So, R_f = Gain x R_{in}

R_f = 400,000 or 400KÝ

The new values of resistors required for the circuit to have a gain of 40 would be,

R_{in} = 10KÝ and R_f = 400KÝ.

The formula could also be rearranged to give a new value of R_{in}, keeping the same value of R_f.

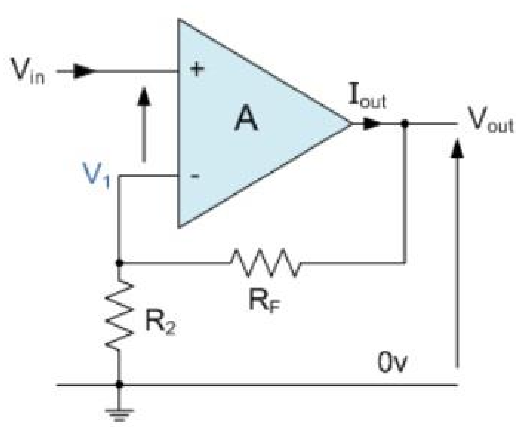
Unity Gain Inverter

One final point to note about Inverting Amplifiers, if the two resistors are of equal value, $R_{in} = R_f$ then the gain of the amplifier will be -1 producing a complementary form of the input voltage at its output as $V_{out} = - V_{in}$. This type of inverting amplifier configuration is generally called a **Unity Gain Inverter** of simply an **Inverting Buffer**.

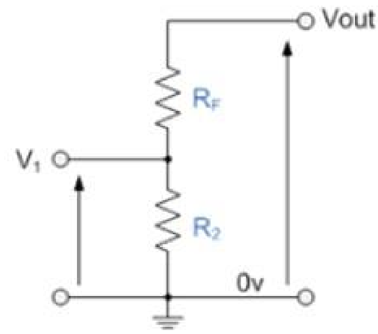
Non-inverting Amplifier

The second basic configuration of an OP-AMP circuit is that of a Non-inverting Amplifier. In this configuration, the input voltage signal, (V_{in}) is applied directly to the Non-inverting (+) input terminal which means that the output gain of the amplifier becomes "Positive" in value in contrast to the "Inverting Amplifier" circuit whose output gain is negative in value.

Feedback control of the non-inverting amplifier is achieved by applying a small part of the output voltage signal back to the inverting (-) input terminal via an R_f - R_2 voltage divider network, again producing negative feedback. This produces a Non-inverting Amplifier circuit with very good stability, a very high input impedance, R_{in} approaching infinity (as no current = flows into the positive input terminal) and a low output impedance, r_{out} as shown below.



Since no current flows into the input of the amplifier, $V_1 = V_{in}$. The resistors R_f and R_2 form a simple voltage divider network across the amplifier and the voltage gain of the circuit is determined by the ratios of R_2 and R_f as shown below.



Equivalent Voltage Divider Network

Then using the formula to calculate the output voltage of a potential divider network, we can calculate the output Voltage Gain of the Non-inverting Amplifier as:

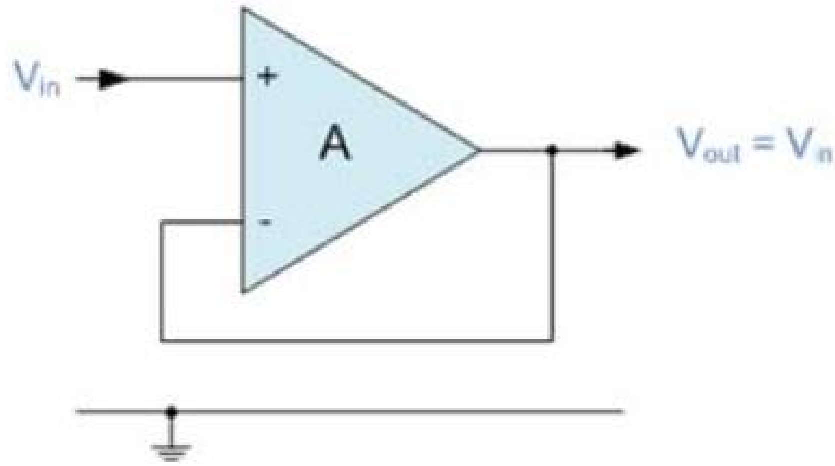
$$V_{out} = V_{in} (1 + (R_f / R_2))$$

$$Gain = V_{out} / V_{in} = 1 + (R_f / R_2)$$

We can see that the overall gain of a Non-Inverting Amplifier is greater but never less than 1, is positive and is determined by the ratio of the values of R_f and R_2. If the feedback resistor R_f is zero the gain will be equal to 1, and if resistor R_2 is zero the gain will approach infinity, but in practice it will be limited to the OP-AMPs **open-loop differential gain, (Ao)**.

Voltage Follower (Unity Gain Buffer)

If we made the feedback resistor, $R_f = 0$ then the circuit will have a fixed gain of "1" and would be classed as a **Voltage Follower**. As the input signal is connected directly to the non-inverting input of the amplifier the output signal is not inverted resulting in the output voltage being equal to the input voltage, $V_{out} = V_{in}$. This then makes the Voltage Follower circuit ideal as a **Unity Gain Buffer** circuit because of its isolation properties as impedance or **circuit isolation is more important than amplification**. The input impedance of the voltage follower circuit is very high, typically above 1MÝ.



In this circuit, R_{in} has increased to infinity and R_f reduced to zero, the feedback is 100% and V_{out} is exactly equal to V_{in} giving it a fixed gain of 1 or unity. As the input voltage V_{in} is applied to the non-inverting input the gain of the amplifier is given as:

$$V_{in} = V_+ \qquad V_{out} = V_-$$

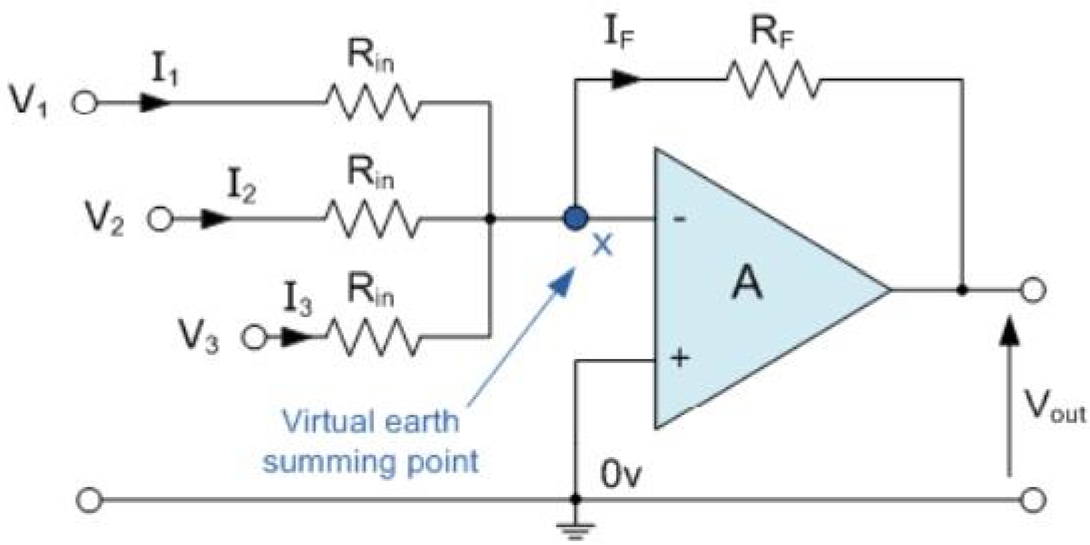
$$Gain = V_{out} / V_{in} = 1$$

The voltage follower or unity gain buffer is a special and very useful type of Non-inverting amplifier circuit that is commonly used in electronics to isolate circuits from each other, especially in **High-order state variable or Sallen-Key type active filters** to separate one filter stage from the other. Typical digital buffer IC's available are the 74LS125 Quad 3-state buffer or the more common 74LS244 Octal buffer.

One final thought, the output voltage gain of the voltage follower circuit with closed loop gain is Unity; the voltage gain of an ideal OP-AMP with open loop gain (no feedback) is infinite. Then by carefully selecting the feedback components we can control the amount of gain produced by an OP-AMP anywhere from 1 to infinity.

Summing Amplifier

The Summing Amplifier is a very flexible circuit based upon the standard Inverting OP-AMP configuration. We saw previously that the inverting amplifier has a single input signal applied to the inverting input terminal. If we add another input resistor equal in value to the original input resistor, R_{in} we end up with another OP-AMP circuit called a Summing Amplifier, "**Summing Inverter**" or even a "**Voltage Adder**" circuit as shown below



The output voltage, (V_{out}) now becomes proportional to the sum of the input voltages, V_1, V_2, V_3 etc. Then we can modify the original equation for the inverting amplifier to take account of these new inputs thus:

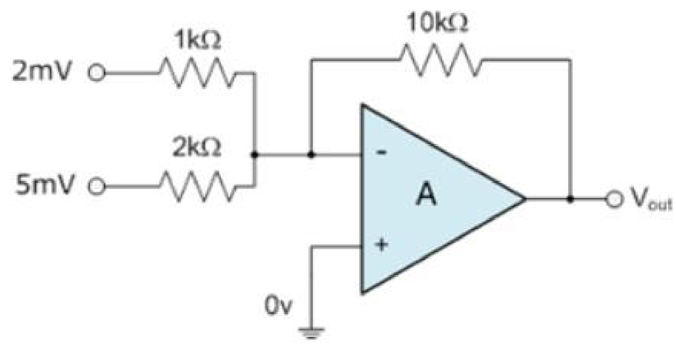
$$I_F = I_1 + I_2 + I_3 = -\left[\frac{V_1}{R_{in}} + \frac{V_2}{R_{in}} + \frac{V_3}{R_{in}}\right]$$

$$\textit{then,} \quad V_{out} = -\frac{R_F}{R_{in}}\left(V_1 + V_2 + V_3\right)$$

The Summing Amplifier is a very flexible circuit indeed, enabling us to effectively "Add" or "Sum" together several individual input signals. If the input resistors are all equal a **unity gain inverting adder** can be made. However, **if the input resistors are of different values a "scaling summing amplifier" is produced** which gives a weighted sum of the input signals.

Example No 1

Find the output voltage of the following Summing Amplifier circuit.



The gain of the circuit

$$\textbf{Gain} = \mathbf{V_{out} / V_{in} = - R_f / R_{in}}$$

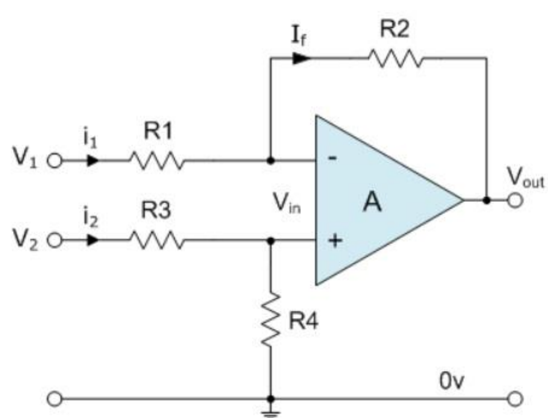
substituting the values of the resistors,
A1 = - 10 kq / 1 kq = - 10, A2 = - 10 kq / 2 kq = - 5

The output voltage is the sum of the two amplified input signals:
Vo = (-10(2 mV)) + (-5(5 mV)) = - 45 mV

If the input resistances of a summing amplifier are connected to potentiometers the individual input signals can be mixed together by varying amounts.

Differential Amplifier

Up to now we have used only one input to connect to the amplifier, using either the "Inverting" or the "Non-inverting" input terminal to amplify a single input signal with the other input being connected to ground / input signal. But we can also connect signals to both of the inputs at the same time producing another common type of OP-AMP circuit called a **differential amplifier**. The resultant output voltage will be proportional to the "Difference" between the two input signals, V_1 and V_2. This type of circuit can also be used as a **subtractor**.



The transfer function for a differential amplifier circuit is given as:

$$V_{out} = - V_1 (R_2 / R_1) + V_2 (1 + R_2 / R_1)(R_4/(R_3 + R_4))$$

When $R_1 = R_3$ and $R_2 = R_4$ the transfer function formula can be modified to the following:

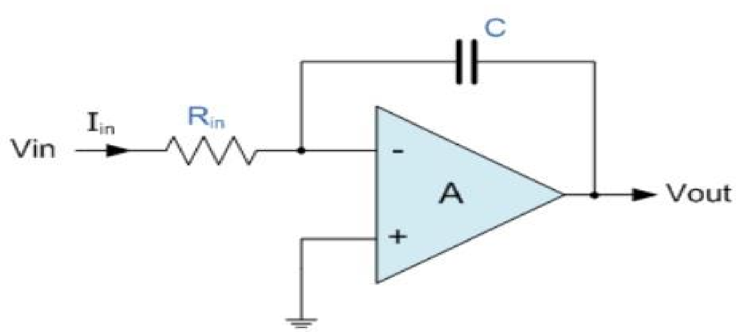
$$V_{out} = (V_2 - V_1) R_2 / R_1$$

If all the resistors are all of the same ohmic value the circuit will become a **Unity Gain Differential Amplifier** and the gain of the amplifier will be 1 or Unity.

One major limitation of this type of amplifier design is that its input impedances are lower compared to that of other OP-AMP configurations, for example, a non-inverting (single-ended input) amplifier. Each input voltage source has to drive current through an input resistance, which has less overall impedance than that of the OP-AMPs input alone. One way to overcome this problem is to **add a Unity Gain Buffer Amplifier** such as the voltage follower seen in the previous tutorial to each input resistor. This then gives us a differential amplifier circuit with very high input impedance and is the basis for most "**Instrumentation Amplifiers**", mainly used to amplify very small differential signals from strain gauges, thermocouples or current sensing resistors in motor control systems.

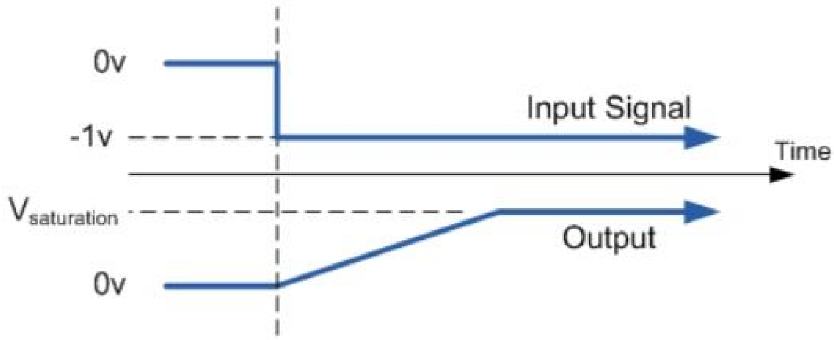
The Integrator Amplifier

Till now we saw how an OP-AMP can be used as part of a positive or negative feedback amplifier or as an adder or subtractor type circuit using pure resistors in both the input and the feedback loop. But what if we were to change the purely Resistive (R_f) feedback element of an inverting amplifier to that of a reactive element, such as a Capacitor, C.
We now have a resistor and capacitor combination forming an RC Network across the OP-AMP as shown below.

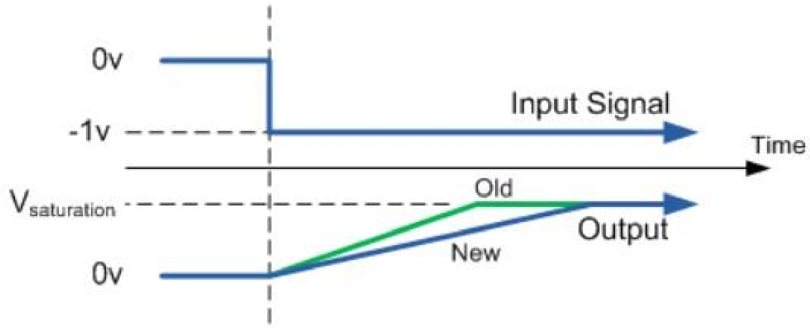


The integrator amplifier performs the mathematical operation of integration, that is, we can cause the output to respond to changes in the input voltage over time and the integrator amplifier produces a voltage output which is proportional to that of its input voltage with respect to time. In other words 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.
When a voltage, V_{in} is firstly applied to the input of an integrating amplifier, the uncharged capacitor C has very little resistance and acts a bit like a short circuit (voltage follower circuit) giving an overall gain of less than 1, thus resulting in zero output. As the feedback capacitor C

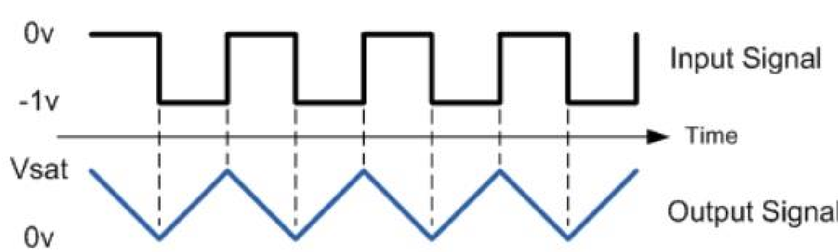
begins to charge up, the ratio of Z_f/R_{in} increases producing an output voltage that continues to increase until the capacitor is fully charged. At this point the ratio of feedback capacitor to input resistor (Z_f/R_{in}) is infinite resulting in infinite gain and the output of the amplifier goes into saturation as shown in the diagram. (**Saturation is when the output voltage of the amplifier swings heavily to one voltage supply rail or the other with no control in between**).



The rate at which the output voltage increases (the rate of change) is determined by the value of the resistor and the capacitor, "**RC time constant**". By changing this RC time constant value, either by changing the value of the Capacitor, C or the Resistor, R, the time in which it takes the output voltage to reach saturation can also be changed.



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 or discharge in response to changes in the input signal. This results in an output signal with a **saw tooth waveform** and its frequency is dependent upon the time constant (RC) of the circuit. This type of circuit is also known as a **Ramp Generator** and the transfer function is given below.



Since the node voltage of the integrating OP-AMP at its inverting input terminal is zero, the current I in flowing through the input resistor is given as:

$$I_{in} = V_{in} / R_{in}$$

The current flowing through the feedback capacitor C is given as:

$$I_{in} = C\, dV_{out} / dt$$

Assuming that the input impedance of the OP-AMP is infinite (ideal OP-AMP), no current flows into the OP-AMP terminal. Therefore, the nodal equation at the inverting input terminal is given as:

$$V_{in} / R_{in} = C\, dV_{out} / dt$$

From which we have an ideal voltage output for the Integrator Amplifier as:

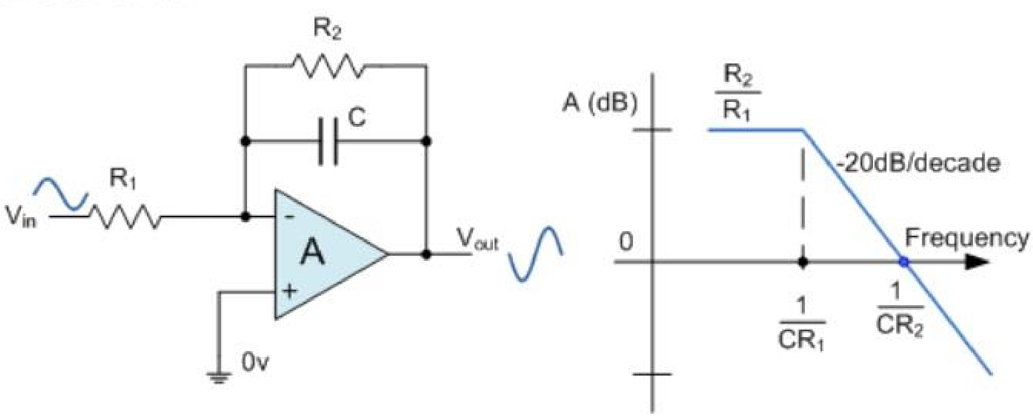
$$V_{out} = -\,(1 / R_{in}C) \int V_{in}\, dt$$

The output voltage V_{out} is a constant $1/R_{in}C$ times the integral of the input voltage V_{in} with respect to time. The minus sign (-) indicates an 180^0 phase shift because the input signal is connected directly to the inverting input terminal of the OP-AMP.

Active Low Pass Filter

If we changed the above square wave input signal to that of a sine wave of varying frequency the Integrator Amplifier begins to behave like an active "Low Pass Filter", passing low frequency signals while attenuating the high frequencies. However, **at DC (0Hz) the capacitor acts like an open circuit blocking any feedback voltage resulting in zero negative feedback from the output back to the input of the amplifier**. Then the amplifier effectively is connected as a normal open-loop amplifier with very high open-loop gain resulting in the output voltage saturating.

The addition of a **large value resistor, R_2 across the capacitor**, C gives the circuit the characteristics of an inverting amplifier with finite closed-loop gain of R_2/R_{in} at very low frequencies while acting as an integrator at higher frequencies. This then forms the basis of an **Active Low Pass Filter**.

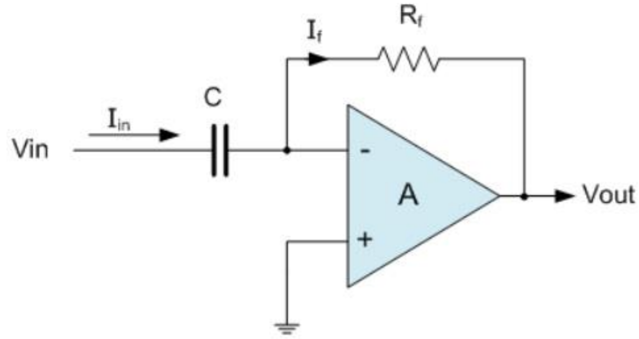


The AC Integrator with DC Gain Control

The Differentiator Amplifier

The basic differentiator amplifier circuit is the exact opposite to that of the Integrator OP-AMP circuit. Here, the position of the capacitor and resistor have been reversed and now the Capacitor, C is connected to the input terminal of the inverting amplifier while the Resistor, R_f forms the negative feedback element across the OP-AMP. This circuit performs the mathematical operation of Differentiation, i.e. it produces a voltage output which is proportional to rate-of-change of the input voltage and the current flowing through the capacitor. In other words the faster or larger the change to the input voltage signal, the greater the input current, the greater will be the output voltage change in response becoming more of a "spike" in shape.

As with the integrator circuit, we have a resistor and capacitor forming an RC Network across the OP-AMP and the reactance (X_C) of the capacitor plays a major role in the performance of a differentiator amplifier.



Since the node voltage of the OP-AMP at its inverting input terminal is zero, the current, i flowing through the capacitor will be given as:

$$I_{in} = I_F \quad \text{and} \quad I_f = -V_{out} / R_f$$

The Charge on the Capacitor = Capacitance x Voltage across the Capacitor

$$Q = C\,V_{in}$$

The rate of change of this charge is

$$dQ/dt = C\,dV_{in} / dt$$

but dQ/dt is the capacitor current i

$$i_{in} = C\,dV_{in} / dt = I_f$$

From which we have an ideal voltage output for the Differentiator Amplifier is given as:

$$V_{out} = -R_f\,C\,dV_{in} / dt$$

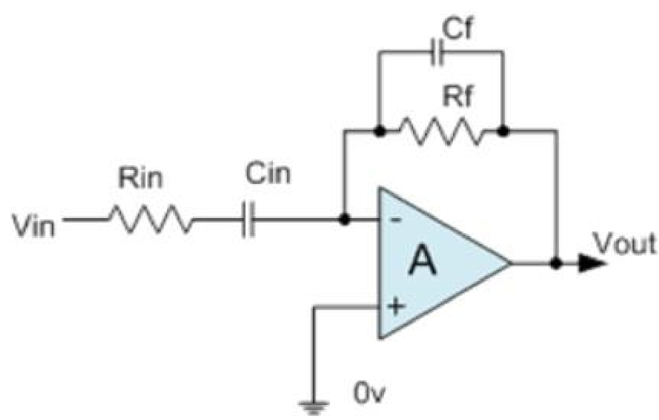
Therefore, the output voltage V_{out} is a constant $-R_f.C$ times the derivative of the input voltage V_{in} with respect to time. The minus sign indicates an 180^0 phase shift because the input signal is connected to the inverting input terminal of the OP-AMP.

Active High Pass Filter

The capacitor blocks any DC content only allowing AC type signals whose frequency is dependent on the rate of change of the input signal, to pass through.
At low frequencies the reactance of the capacitor is "High" resulting in a low gain (Rf/Xc) 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. Thus with sinusoidal wave at the input this circuit will act as an active high pass filter circuit.

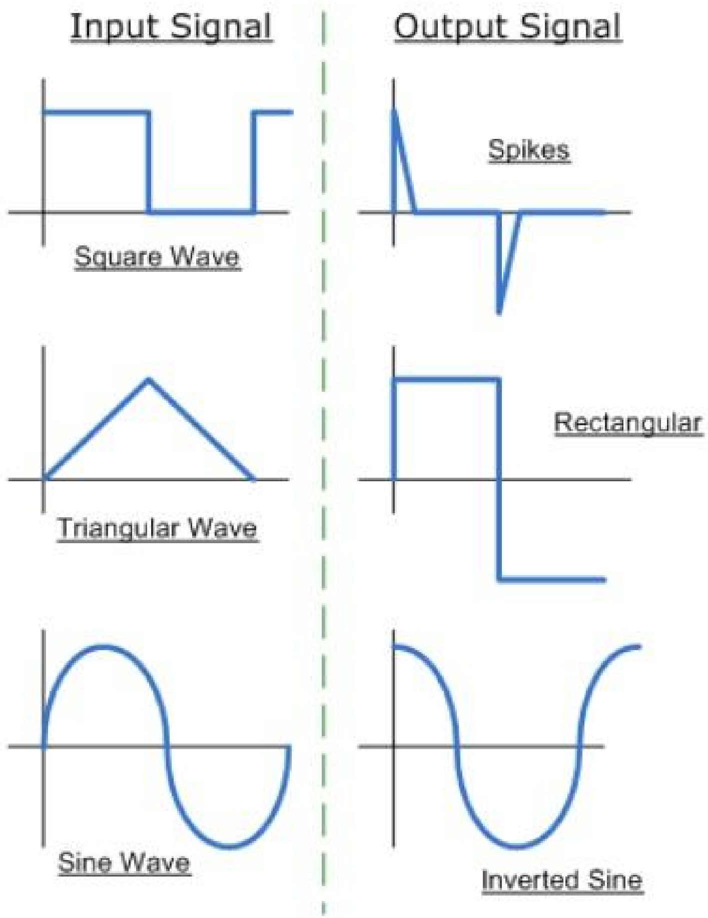
The basic single resistor and single capacitor differentiator circuit is not widely used to reform the mathematical function of differentiation because of the two inherent faults mentioned above: Instability and Noise.

At high frequencies a differentiator circuit becomes unstable and will start to oscillate. To avoid this, the high frequency gain of the circuit needs to be reduced by adding an additional small value capacitor, C_f, across the feedback resistor R_f. Also, the capacitive input makes it very susceptible to random noise signals and any noise or harmonics present in the circuit will be amplified more than the input signal itself. This is because the output is proportional to the slope of the input voltage. So some means of limiting the bandwidth in order to achieve closed-loop stability is required. In order to reduce the overall closed-loop gain of the circuit at high frequencies, an extra Resistor, R_{in} is added to the input as shown below. Thus, the new circuit acts like a Differentiator amplifier at low frequencies and an amplifier with resistive feedback at high frequencies giving much better noise rejection.



Differentiator Waveforms

If we apply a constantly changing signal such as a Square-wave, Triangular or Sine-wave type signal to the input of a differentiator amplifier circuit the resultant output signal will be changed and whose final shape is dependent upon the RC time constant of the Resistor/Capacitor combination.


Input Signal
Output Signal
Spikes
Square Wave
Rectangular
Triangular Wave
Sine Wave
Inverted Sine

Experiment No.1: The 741 OPAMP Comparators

Objectives:

(I) Powering-up the OP AMP

(II) The OP AMP as a Comparator

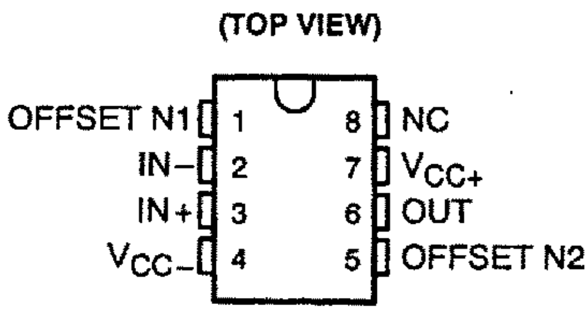
Components: OPAMP 741 chip, Resistors, Oscilloscope, DC voltage source, Bread board

Theory: Please refer to the OP-AMPs notes.

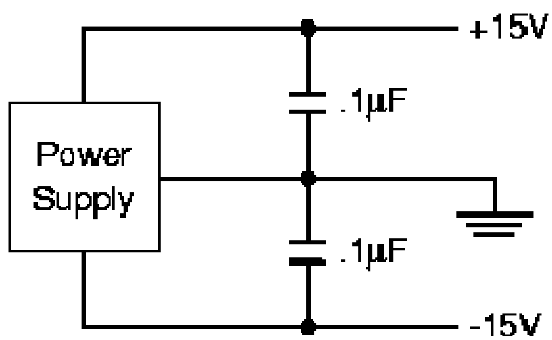
(I) Powering up the Op-Amp

Procedure:

1. Wire the bus strips on your breadboard to provide positive power, negative power and ground buses. Whatever color scheme you have chosen for your wires, you should use the green binding post for ground, the grey for -15 V, and the red for +15 V.



2. Connect a 0.1 µF capacitor between the +15 V power bus and ground. Connect another 0.1 µF capacitor between the -15 V power bus and ground. The power buses for your board should look like this:



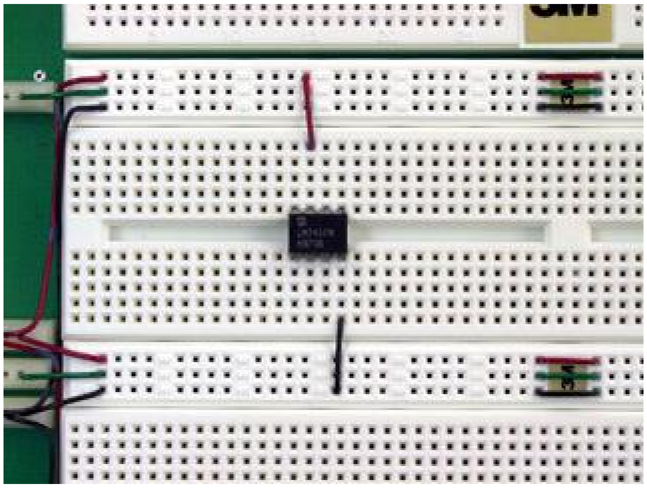
As we will see when we study control systems, feedback also has a dark side. In particular, feedback which becomes positive at some frequency can cause instabilities. Although we have not deliberately introduced any positive feedback, feedback can occur where we don't intend it. The purpose of these capacitors is to prevent it from occurring via the power supply, which at high frequencies is not a very ideal voltage source.

3. Plug an op-amp into the breadboard so that it straddles the gap between the top and bottom sections of the socket strip. If you have wired the power buses as suggested above, Pin 1 should be to the left.

Warning

Do not try to unplug the op-amp with your thumb and forefinger.
It's a good way to end up with the op-amp plugged into your fingertip.
Use the IC puller from your toolkit.

4. Connect Pin 4 (V_{CC-}) to the negative power supply bus (-15 V). Connect Pin 7 (V_{CC+}) to the positive power supply bus (+15 V).



(II) The OP AMP as a Comparator

a. Inverting Comparator:

The gain of the op-amp without feedback (so called "open loop" mode) is too high to be useful as an amplifier. But this high gain provides a very sharp threshold if we use the op amp as a switch or *comparator* (so called because it compares one voltage to another and gives an output signifying which is greater).

Caution

Always wire your circuit with the power turned off and
check your wiring carefully before turning the power on.

Procedure:

1. With the power turned off, wire the following circuit. This will compare the function generator output with an adjustable threshold implemented by the -3V to +3V supply.

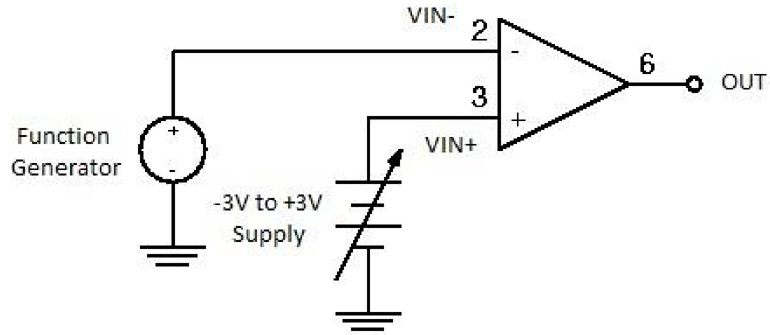


Fig.1.1 Inverting Comparator

2. Turn on the power supply and set the supply output to -3V.
3. Set the function generator to produce a 5 V p-p, 100 Hz triangle wave.
4. Connect the function generator output to VIN- of the circuit above. Connect `CH1` of the scope to VIN- and `CH2` to OUT. Make sure both channels of the scope are on `DC`.
5. Increase the supply in steps of 0.5 V until it reaches +3V. At each step sketch OUT, noting the positive and negative peak values and the duration of the high and low states.

Explain the waveforms observed in this Part.

b. **<u>Non-inverting Comparator</u>**:

1. With the power turned off, wire the following circuit. This will compare the function generator output with an adjustable threshold implemented by the -3V to +3V supply.

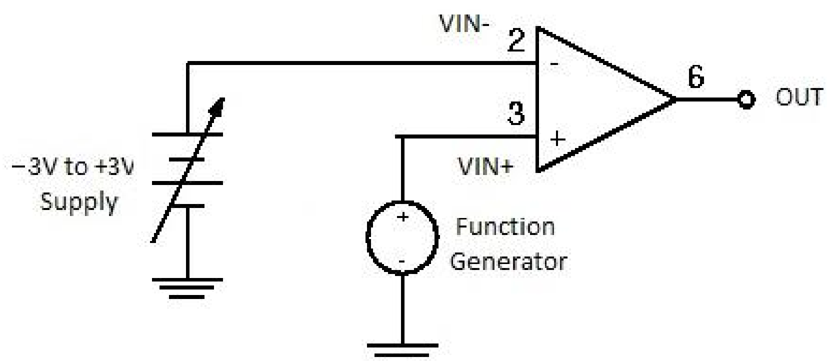


Fig.1.2 Non-Inverting Comparator

2. Repeat steps 2 to 5 and
3. Explain the waveforms observed in this part.

Experiment No.2 & 3: Study of the Basic OPAMP Configurations

Objectives:

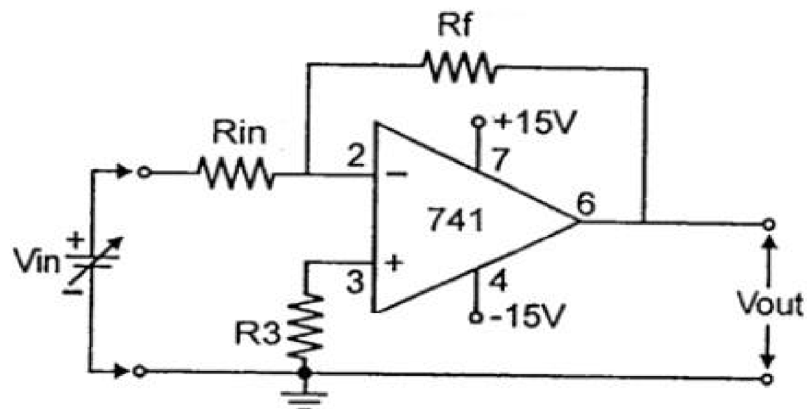
(I) Study of the inverting amplifier configuration and to find its gain

(II) Study of the non-inverting amplifier configuration and to find its gain

Components: OPAMP 741 chip, Resistors, Oscilloscope, DC voltage source, Bread board

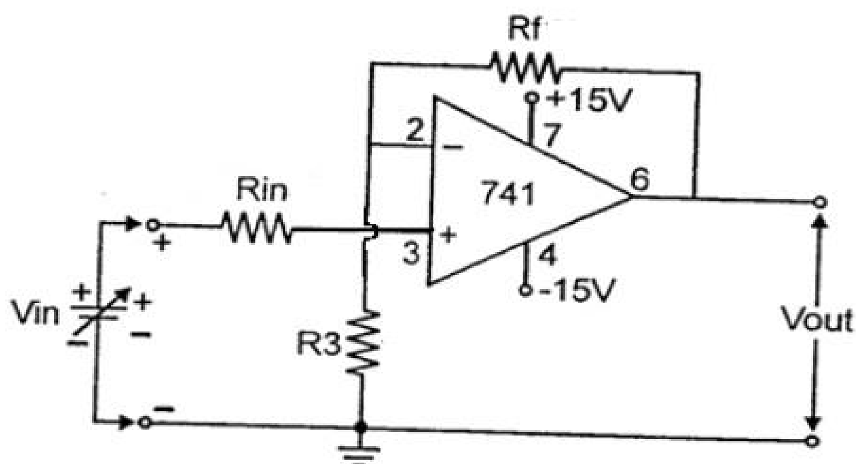
Theory: Please refer to the OP-AMPs notes.

Circuit Diagrams:



Inverting amplifier

$$Gain = V_o / V_{in} = - R_f / R_{in}$$



Non-inverting amplifier

$$\text{Gain} = V_o / V_{in} = 1 + (R_f / R_3)$$

Procedure:

(I) Inverting Amplifier

1. Configure the circuit as shown in the circuit diagram. Connect the pins 7 and 4 of the IC to the ±15V output terminals of the D.C. power supply. Connect the 0V terminal to ground. Choose R_{in} = 1KÝ and R_f = 1KÝ. Measure the resistance values with multimeter and calculate gain, - (R_f/R_{in}). Connect a resistor R_3 (= R_{in}Ɛ R_f) as shown in the circuit diagram so as to minimize offset due to input bias current.
2. Connect one of the output terminals of the D.C. power supply (0 - 30V) at the **inverting input (pin no. 2).**
3. Switch on the power supply and apply different voltages in the range 0 ï 20V in steps of 2V at the inverting terminal. Measure this input using a digital multimeter.
4. Measure the corresponding output voltages with the multimeter and calculate gain V_o/V_{in}. Note the sign of the output voltage.
5. Now, replace R_f by 10KÝ. Measure the resistance value with multimeter and calculate gain, - (R_f/R_{in}).

   Connect a resistor R_3 (= R_{in}Ɛ R_f) as shown in the circuit diagram so as to minimize offset due to input bias current.
6. Apply different voltages in the range 0 ï 2.0V in steps of 0.2V at the inverting terminal. Measure this input using a digital multimeter.
7. Measure the corresponding output voltages with the multimeter and calculate gain V_o/V_{in}.
8. Plot graphs for $V_{in} \sim V_o$ for both the values of R_F.
9. You may also use a function generator to give a **<u>sinusoidal input and notice the output waveform</u>** using an oscilloscope.

Observations Table (I):

R_{in} = 1KÝ and R_f = 1KÝ					R_{in} = 1KÝ and R_f = 10KÝ				
Obs. #	Input (V)	Output (V)	Gain Vo/Vin	Average	Obs. #	Input (V)	Output (V)	Gain Vo/Vin	Average
1	2				1	0.2			
2	4				2	0.4			
3	6				3	0.6			
4	8				4	0.8			
5	10				5	1.0			
6	12				6	1.2			
7	14				7	1.4			
8	16				8	1.6			
9	18				9	1.8			
10	20				10	2.0			

Plots and Comments on measurements:

Procedure:

(II) Non-inverting Amplifier

1. Configure the circuit as shown in the circuit diagram. Connect the pins 7 and 4 of the IC to the ±15V output terminals of the D.C. power supply. Connect the 0V terminal to ground. Choose R_{in} = 1KÝ and R_f = 1KÝ. Measure the resistance values with multimeter and calculate gain, 1 + (R_f/R_3).
   Connect a resistor R_{in} (= R_3Ɛ R_f) as shown in the circuit diagram so as to minimize offset due to input bias current.
2. Connect one of the output terminals of the D.C. power supply (0-30V) at the **noninverting input (pin no. 3).**
3. Switch on the power supply and apply different voltages in the range 0 ï 10V in steps of 1V at the noninverting terminal. Measure this input using a digital multimeter.
4. Measure the corresponding output voltages with the multimeter and calculate gain V_o/V_{in}. Note the sign of the output voltage.
   Now, replace R_f by 10KÝ. Measure the resistance value with multimeter and calculate gain, 1 + (R_f/R_{in}).
   Connect a resistor R_{in} (= R_3Ɛ R_f) as shown in the circuit diagram so as to minimize offset due to input bias current.
5. Apply different voltages in the range 0 ï 2.0V in steps of 0.2 V at the inverting terminal. Measure this input using a digital multimeter.
6. Measure the corresponding output voltages with the multimeter and calculate gain V_o/V_{in}.
7. Plot graphs for V_{in} ~ V_o for both the values of R_F.
8. You may also use a function generator to give a **sinusoidal input and notice the output waveform** using an oscilloscope.

Observations

Table (II):

R_{in} = 1KÝ and R_f = 1KÝ					R_{in} = 1KÝ and R_f = 10KÝ				
Obs. No.	Input (V)	Output (V)	Gain Vo/Vin	Average	Obs. No.	Input (V)	Output (V)	Gain Vo/Vin	Average
1	1				1	0.2			
2	2				2	0.4			
3	3				3	0.6			
4	4				4	0.8			
5	5				5	1.0			
6	6				6	1.2			
7	7				7	1.4			
8	8				8	1.6			
9	9				9	1.8			
10	10				10	2.0			

Plots and Comments on measurements:

Experiment No.4 & 5: Integrator and Differentiator

Objective : To study the Integrator and Differentiator Circuits.

Theory:

The purpose of this experiment is to demonstrate the operation of both a differentiator and an integrator using an op-amp. A differentiator is a circuit that calculates the instantaneous slope of the line at every point on a waveform. On the other hand, an integrator computes the area underneath the curve of a given waveform. Differentiation and integration are paired mathematical operations in that one has the opposite effect of the other. For example, if you integrate a waveform and then differentiate it, you obtain the original waveform.

The two circuits have opposite input/output relationships. The *integrator* converts a square wave into a triangle wave, and the *differentiator* converts a triangle wave into a square wave. An integrator produces an output that *is proportional to the area of its input waveform*. Note that the output waveform is shifted by 180° (as the input is applied to the *inverting* input). The area of a waveform can be calculated from

$$A = Vt$$

where A = the area of the waveform, V = the peak voltage of the waveform, & t = the pulse width of the waveform.

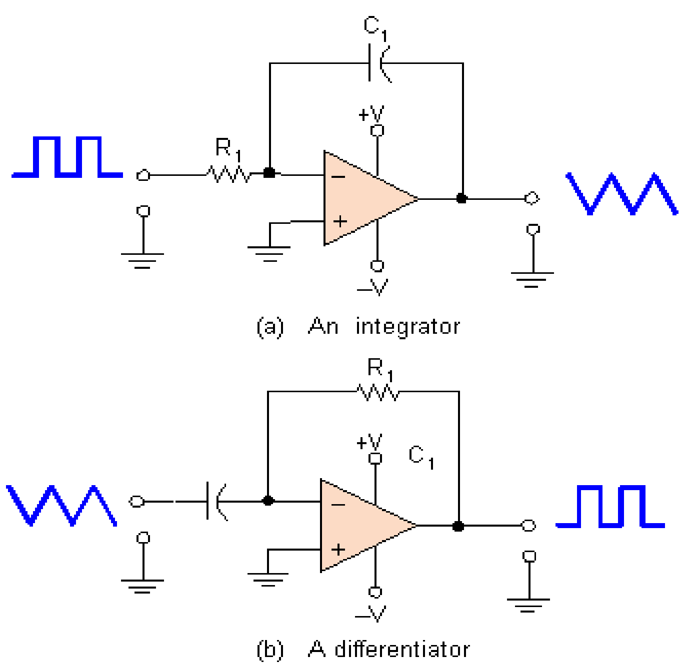


Figure.1. Op-amp Integrator and Differentiator.

a. The Integrator

Op-amps allow you to make nearly perfect integrators such as the practical integrator shown in figure 3. The circuit incorporates a large resistor in parallel with the feedback capacitor. This is necessary because real op-amps have a small current flowing at their input terminals called the "bias current". This current is typically a few nano-amps, and is neglected in many circuits where the currents of interest are in the microamp to milliamp range. However, if you apply a nanoamp current to a 0.1mF capacitor, it won't take long until it charges and becomes effectively an open circuit not allowing any current to flow! The feedback resistor gives a path for the bias current to flow. The effect of the resistor on the response is negligible at all but the lowest frequencies.

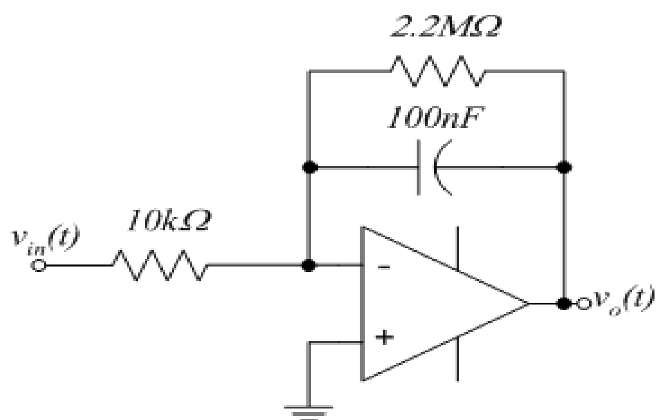


Fig.2: Integrator Circuit

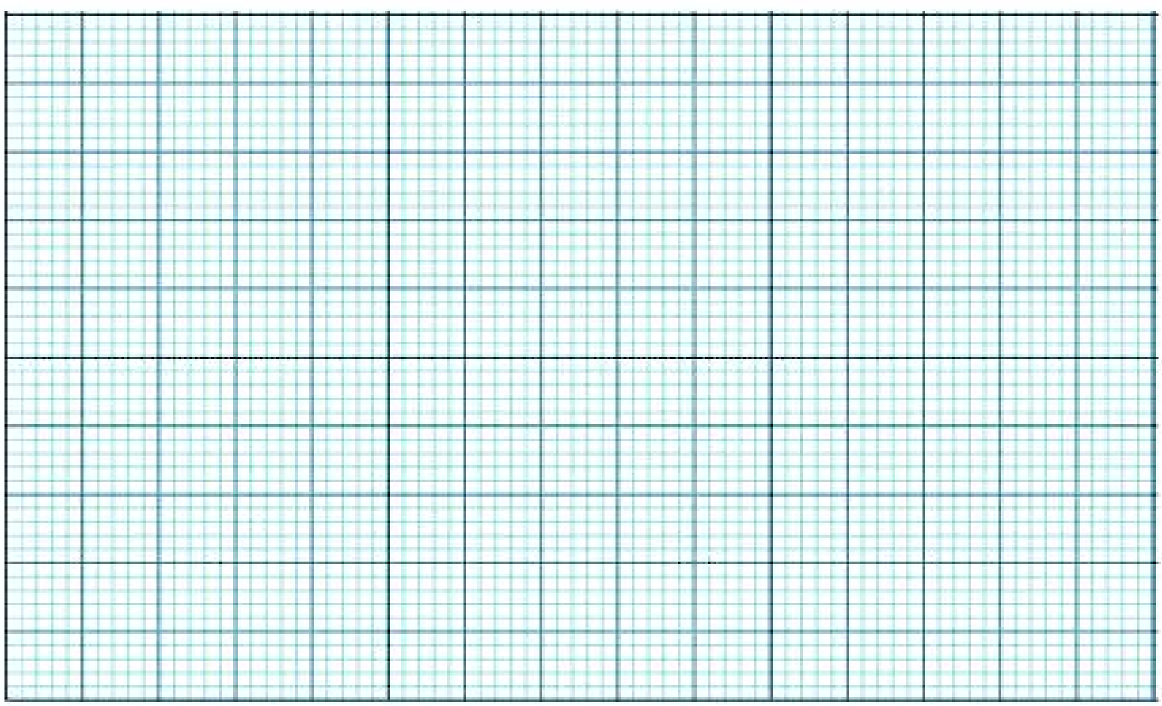
Procedure:

1. Wire up the practical op-amp integrator shown in figure 2 using your 741 op-amp.
2. Apply the input (via $v_{in}(t)$) with a 500Hz square wave of 2 V p-p amplitude. Sketch the input and output waveforms.
3. Has the input been integrated?
4. Repeat using a sine wave and a triangle wave.

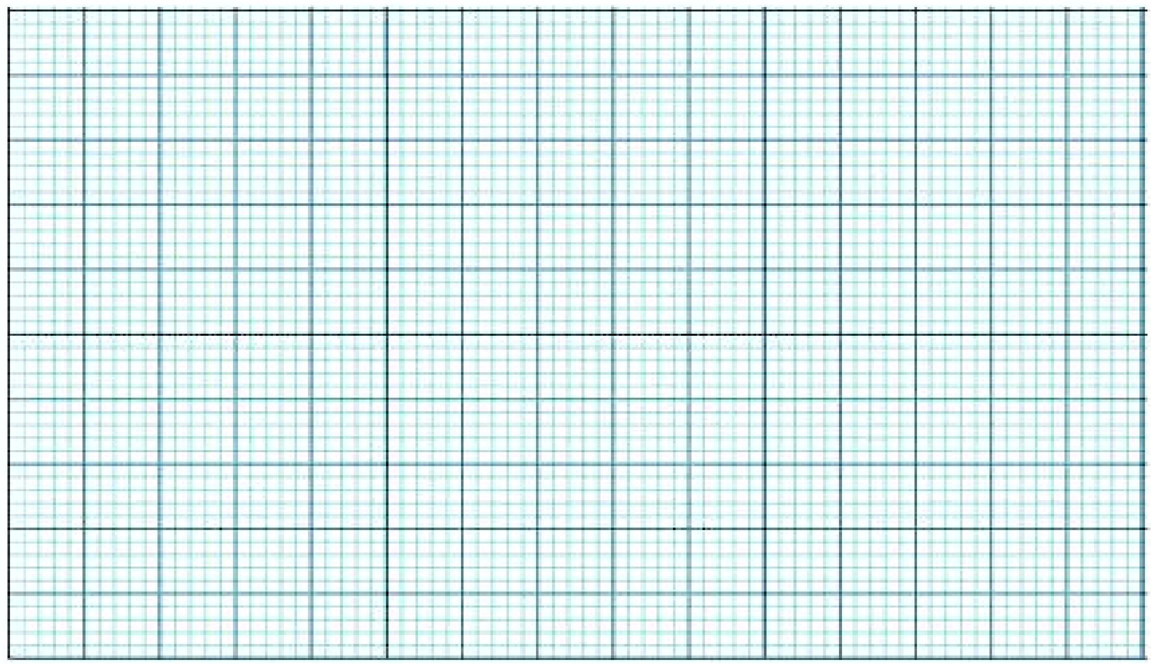
Tabular Column for Integrator:

Serial .No	Input Frequency	Peak Output
1	10K Hz	
2	4K Hz	
3	100 Hz	

Integrator Input :



Integrator Output:



b. The Differentiator

The ideal differentiator is inherently unstable in practice due to the presence of some high frequency noise in every electronic system. An ideal differentiator would amplify this small noise. For instance, if $v_{noise} = Asin(wt)$ is differentiated, the output would be $v_{out} = Awcos(wt)$. Even if $A = 1mV$, when $w = 2p(10MHz)$ v_{out} would have an amplitude of 63V! To circumvent this problem, it is traditional to include a series resistor at the input and a parallel capacitor across the feedback resistor as shown in figure 2, converting the differentiator to an integrator at high frequencies for filtering.

Circuit Diagram:

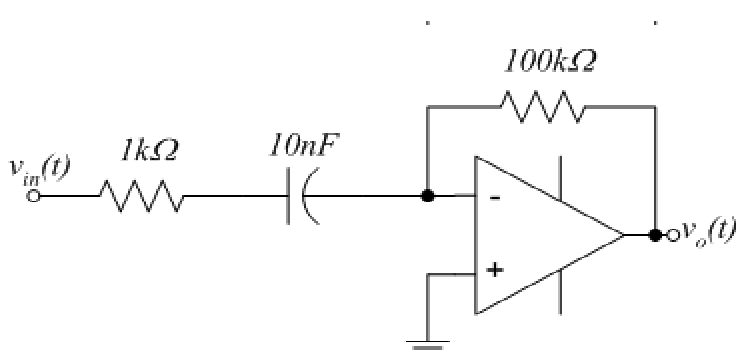


Figure.3: Differentiator Circuit

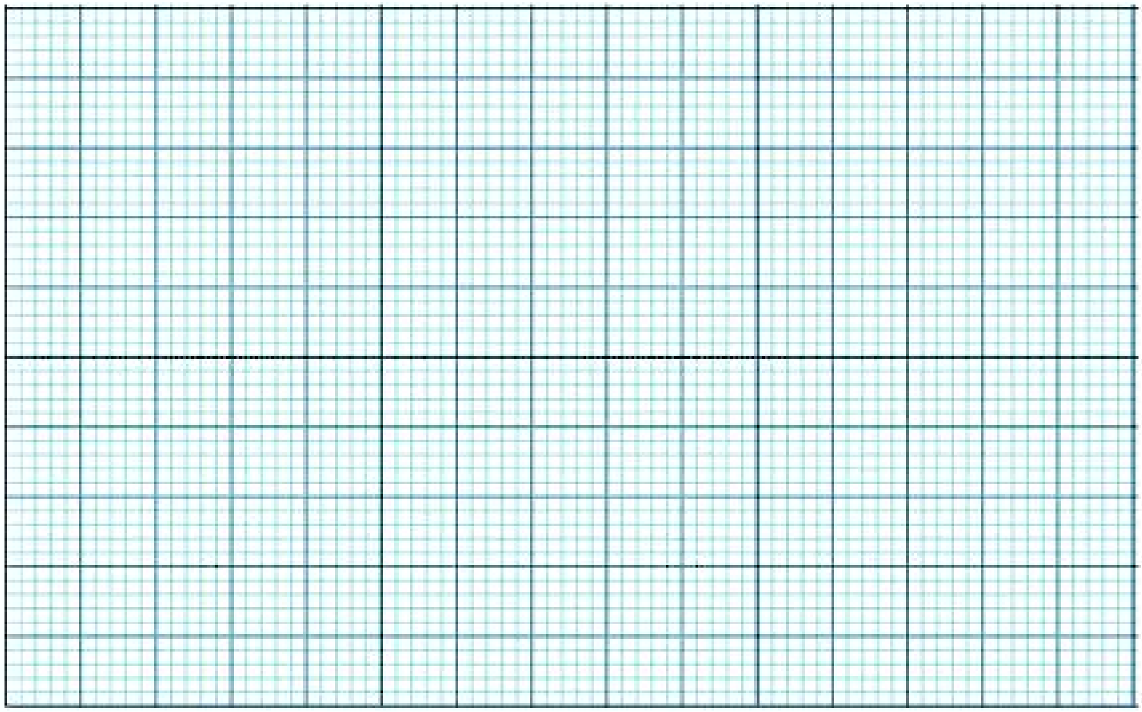
Procedure:

1. Wire up the practical op-amp differentiator shown in figure 3 using your 741op-amp.
2. Apply input signal ($v_{in}(t)$) with a 1kHz square wave, For each input signal, sketch the input and output waveforms. Vary the frequency as given in the tabular column and observe the response.
3. Repeat point 2 for sine and triangular wave.

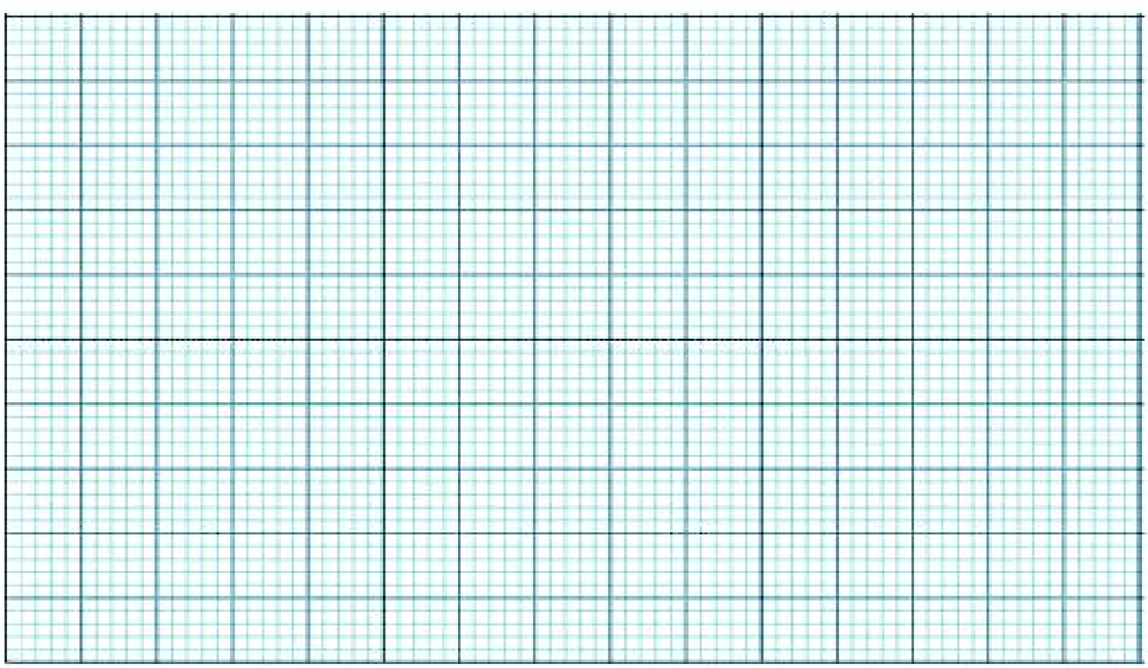
Tabular Column For Differentiator:

Serial .No	Input Frequency	Peak Output
1	400 Hz	
2	1K Hz	
3	30KHz	

Differentiator Input:



Differentiator Output:



Experiment No. 6: Study of Active Low Pass Filter using OPAMP

Objective:

(I) Study of the OP AMP in an active low pass filter

(II) Study of the OP AMP in an active low pass filter with two stages

Components: OPAMP 741 chip, Resistors, Capacitors, Oscilloscope, DC voltage source, Bread board

Theory: Please refer to the OP-AMPs notes.

OPAMP in an Active Filter:

A. Bandwidth of Amplifiers with Feedback.

An operational amplifier is useful over a certain range of frequencies, called its bandwidth. The bandwidth is dependent on the particular OPAMP used as well as the open loop and closed loop gains. Generally, the bandwidth is specified as the frequency limits where the voltage gain of the OPAMP is decreased to 0.707 that of the midrange gain. The voltage gain can be expressed in decibel units as: dB = 20 log A

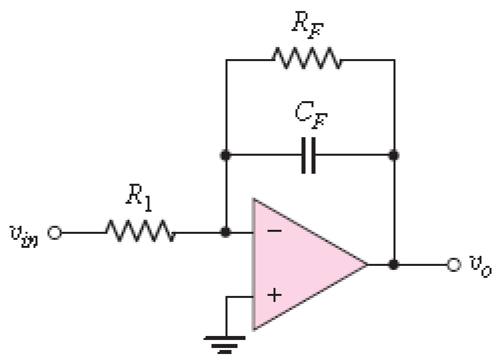
Therefore, the frequency limits for the bandwidth are called ñ-3 dBò points. (Sometimes the bandwidth is specified as the frequency where the open loop gain drops to unity.)

B. Active Low Pass Filter.

The passive RC filters are affected by changes in the impedance of circuits following them unless the impedances are very high. If the input impedance of the subsequent circuit is not high, loading affects both the efficiency and cutoff frequency of the filter.

The use of an operational amplifier as part of an ACTIVE filter dramatically reduces the problem. Active filters may be high pass, low pass, selective (amplify a specific frequency) or notch (reject a specific frequency). Many types of active filters are now available as integrated circuit (IC) components.

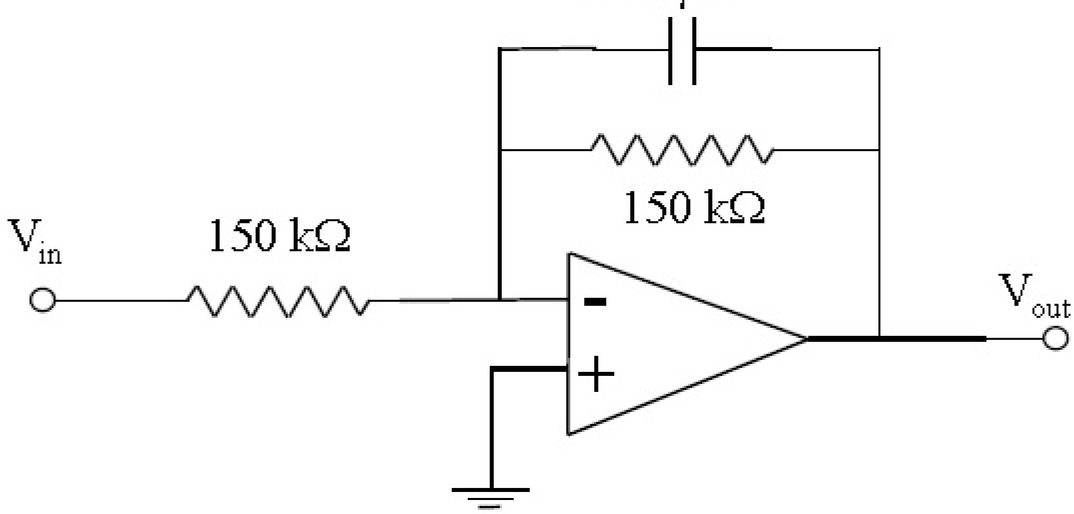
Consider the one-pole low-pass filter in Figure



$$T(s) = \frac{V_o(s)}{V_{in}(s)} = -\frac{R_F}{R_1}\frac{1}{1 + sR_FC_F}$$

One-pole low-pass filter

Circuit Diagram:



Procedure:

Construct the first order, low pass filter shown in the above Figure and measure the response as a function of frequency using a 1 Vp-p sine wave input from 50 Hz to 20 kHz for each.

Now build another, identical filter, and connect the output of one to the input of the other. Repeat the measurements.

Vin=______________________V (Constant)

S. No.	Frequency, Hz	Vo. V	Gain=Vo/Vin	Gain in dB =20log(Vo/Vin)
	50			
	150			
	500			
	1k			
	2k			
	5k			
	8k			
	10k			
	12k			
	14k			

	16k			
	18k			
	20k			

Plot gain vs. frequency on a log-log plot for the filter.

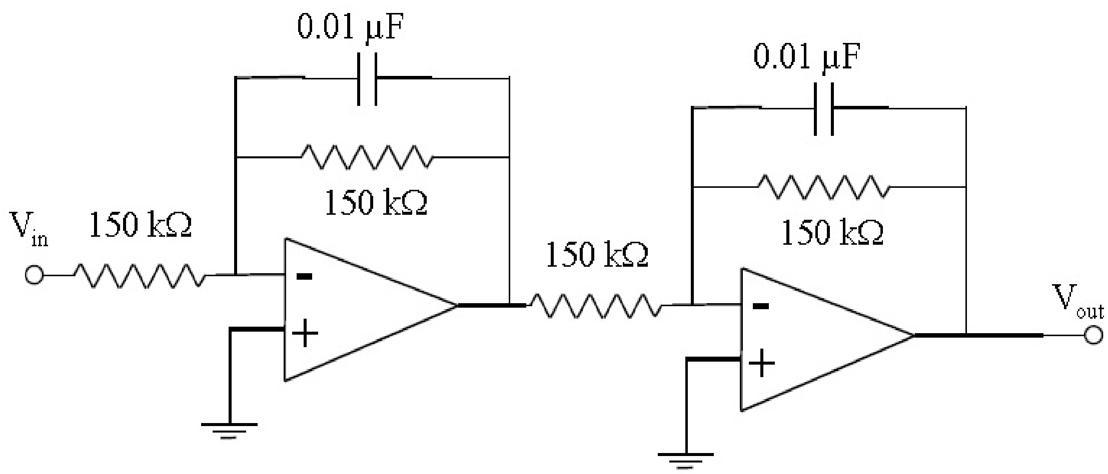
Is the roll-off the same?

Which is the better filter?

Comments on measurements:

C. Two Stage Active Low Pass Filter

Circuit Diagram:



Construct the two stage low pass filter shown in the above Figure and measure the response as a function of frequency using a 1 Vp-p sine wave input from 50 Hz to 20 kHz for each. Plot gain vs. frequency on a log-log plot for the filter.

Vin=____________________V (Constant)

S. No.	Frequency, Hz	Vo. V	Gain=Vo/Vin	Gain in dB =20log(Vo/Vin)
	50			
	150			
	500			
	1k			
	2k			
	5k			
	8k			
	10k			
	12k			
	14k			
	16k			
	18k			
	20k			

Is the roll-off the same?

Which is the better filter?

Comments on measurements:

Experiment No.7: Study of Active High Pass Filters using OPAMP

Objective:

(I) Study of the OP AMP in an active high pass filter

(II) Study of the OP AMP in an active high pass filter with two stages

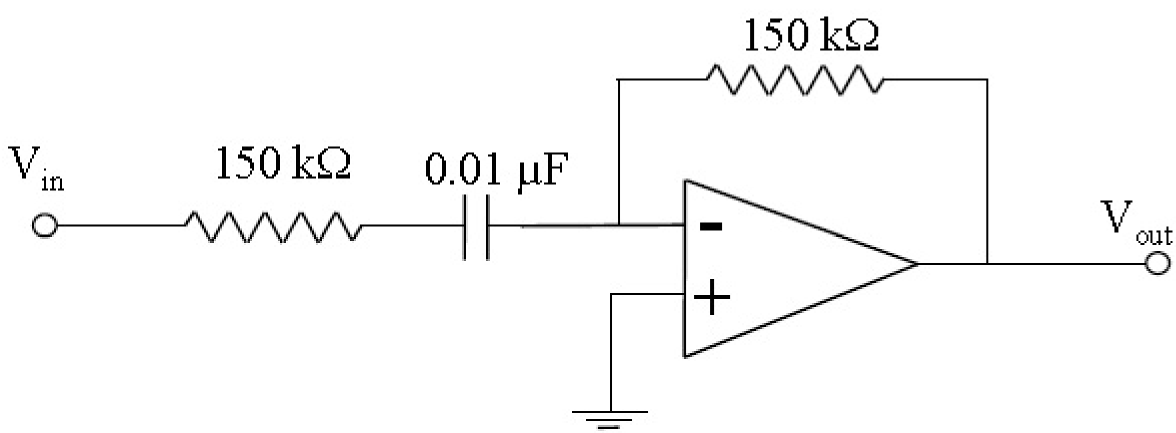
Components: OPAMP 741 chip, Resistors, Capacitors, Oscilloscope, DC voltage source, Bread board

Theory: Please refer to the OP-AMPs notes.

OPAMP in an Active Filter:

D. Active High Pass Filter.

Circuit Diagram:



Construct the high pass filter shown in the above Figure and measure the response as a function of frequency using a 1 Vp-p sine wave input from 50 Hz to 20 kHz for each.

Now build another, identical filter, and connect the output of one to the input of the other. Repeat the measurements.

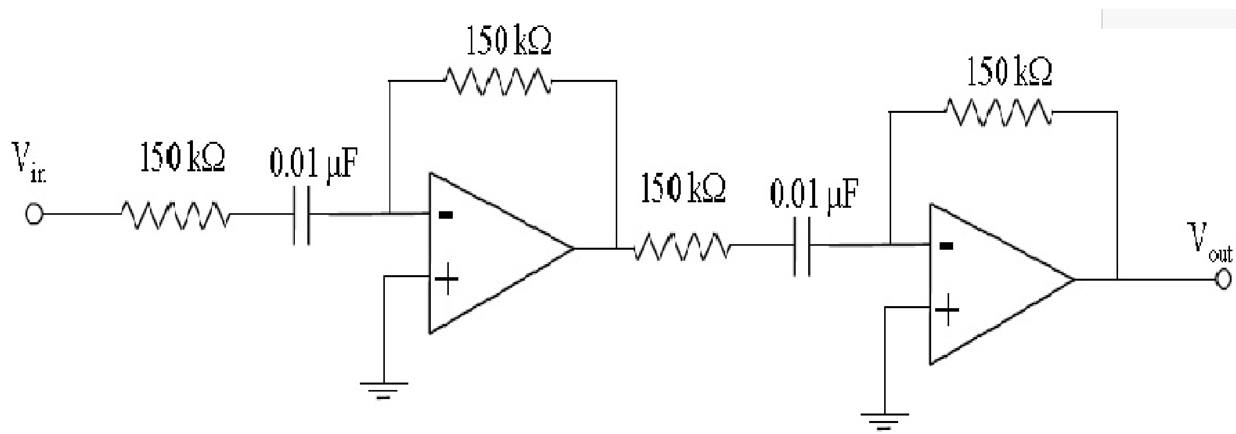
Plot gain vs. frequency on a log-log plot for each filter.

Is the roll-off the same?

Which is the better filter?

Comments on measurements:

E. Two Stage High Pass Filter :



Construct the two stage high pass filter shown in the above Figure and measure the response as a function of frequency using a 1 Vp-p sine wave input from 50 Hz to 20 kHz for each.

Plot gain vs. frequency on a log-log plot(semi log graph) for each filter.

Is the roll-off the same?

Which is the better filter?

Comments on measurements:

Experiment No.8: Study of Schmitt trigger using OPAMP

Objective: To study the switching action of a Schmitt trigger

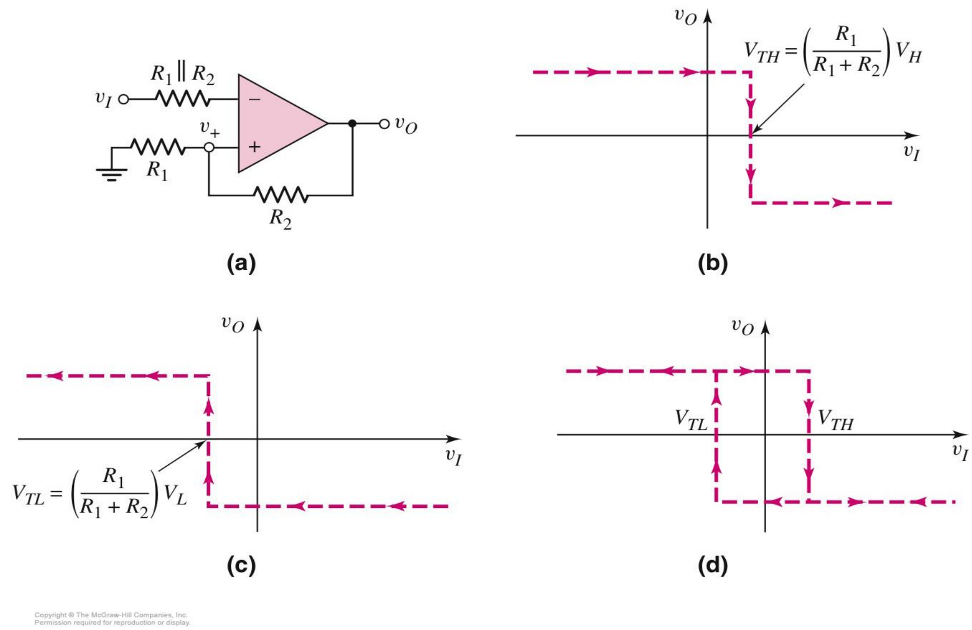
Theory: The Schmitt trigger is a variation of the simple comparator which has hysteresis, that is, it has a toggle action. It uses a positive feedback. When the output is high, positive feedback makes the switching level higher than it is when the output is low. A little positive feedback makes a comparator with better noise immunity.

Now, to understand what causes the hysteresis letôs analyze the circuit diagram given below, using the same rules as in the previous section for the comparator. The key in understanding this circuit will again be in calculating the voltages that cause its output to switch. If V_+ and V_- are the actual voltages at the non-inverting and inverting terminals of the OPAMP, then the output will be the following:

if $V_+ > V_-$, V_{out} å V_{++} & if $V_+ < V_-$, V_{out} å V_{--}.

Since v_o changes its state whenever v_+ crosses v_-, we need to find what value of v_I results in $v_+ = v_-$. The two values of v_I for which the output switches are called the trigger points. v_+ acts as a voltage divider formed by R_1 and R_2 between *ground* and v_o. Thus the trigger points of an inverting Schmitt trigger are shown in the following figure: Choosing suitable ratios of R_1 and R_2, enough hysteresis can be created in order to prevent unwanted noise triggers.

Circuit Diagram:



Procedure:

1. Construct the Schmitt trigger circuit on the breadboard as shown in the circuit diagram.
2. Use: V_{++} = 12 V, V_{--} = -12 V, R_1 = 1kq , and R_2 = 10kq .
3. Vary the input from from -2 V to 2 V with a step of 1 V.
4. Using the DMM, measure and tabulate v_I and v_o.
5. Make a plot of v_o versus v_I for each circuit.

Observations:

Obs. No.	v_I (V)	v_o (V)
1	**-2**	
2	**-1**	
3	**0**	
4	**1**	
5	**2**	

Discussions: Analyze the graph you obtained. Discuss the switching action.

Experiment No.9: Study of BJT Amplifier

AIM: a. To measure the voltage gain of a BJT amplifier

b. To draw the frequency response of the CC amplifier

APPRATUS:

Transistor BC107, Regulated Power Supply (0-15V), Function Generator, CRO

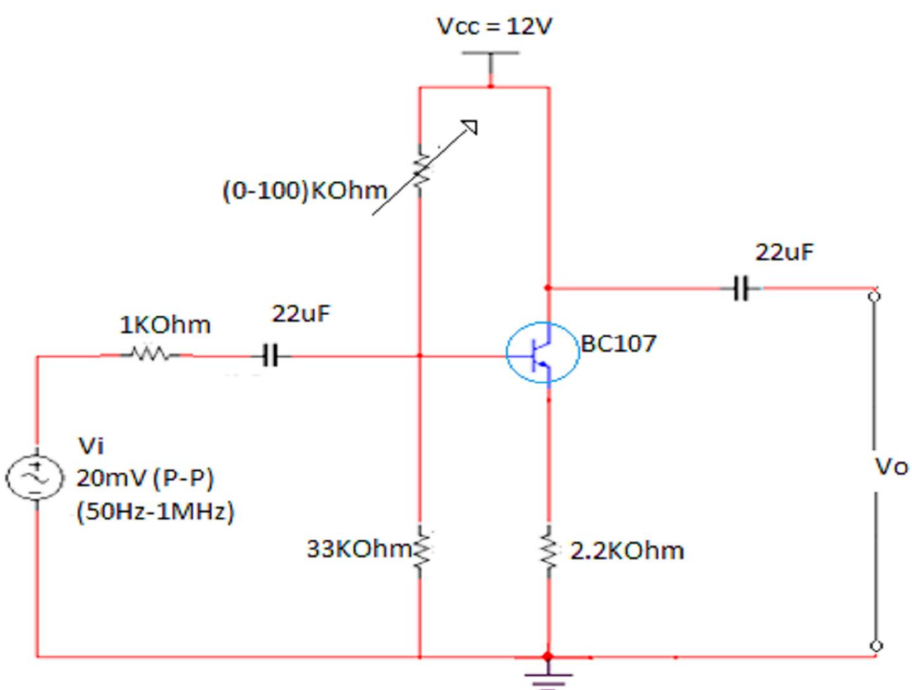
Resistors - 1Kq , 33Kq , 2.2Kq , Variable Resistor ï (0-100) Kq . Capacitors - 22εF

Breadboard, Connecting wires

THEORY:

In common-collector amplifier the input is given at the base and the output is taken at the emitter. In this amplifier, there is no phase inversion between input and output. The input impedance of the CC amplifier is very high and output impedance is low. The voltage gain is less than unity. Here the collector is at ac ground and the capacitors used must have a negligible reactance at the frequency of operation. This amplifier is used for impedance matching and as a buffer amplifier. This circuit is also known as emitter follower.

Circuit Diagram



PROCEDURE:

1. Connect the circuit as shown in circuit diagram

2. Apply the input of 20mV peak-to-peak and 50Hz frequency using function generator.

3. Measure the Output Voltage V_O (p-p).

4. Tabulate the readings in the tabular form.

5. The voltage gain can be calculated by using the expression $A_v= (V_0/V_i)$

6. For plotting the frequency response the input voltage is kept Constant at 20mV peak-to-peak and the frequency is varied from 50Hz to 1MHz Using function generator.

7. All the readings are tabulated and voltage gain in dB is calculated by using the expression

$A_v=20 \log_{10} (V_0/V_i)$

8. A graph is drawn by taking frequency on x-axis and gain in dB on y-axis on Semi-log graph.

The Bandwidth of the amplifier is calculated from the graph using the expression,

Bandwidth $BW=f_2-f_1$

Where f_1 is lower cut-off frequency of CC amplifier

f_2 is upper cut-off frequency of CC amplifier

The gain Bandwidth product of the amplifier is calculated using the expression,

Gain -Bandwidth product = (3dB mid-band gain) X (Bandwidth)

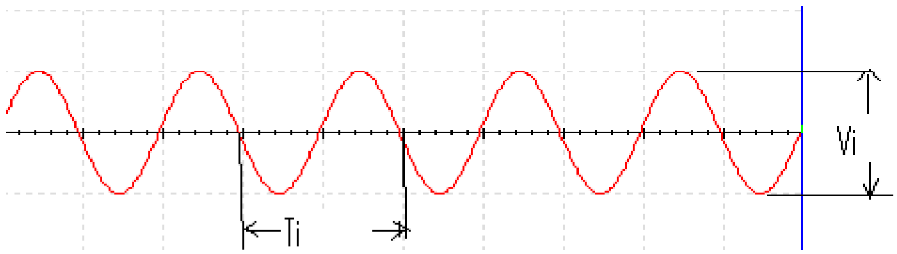
OBSERVATIONS:

FREQUENCY RESPONSE:

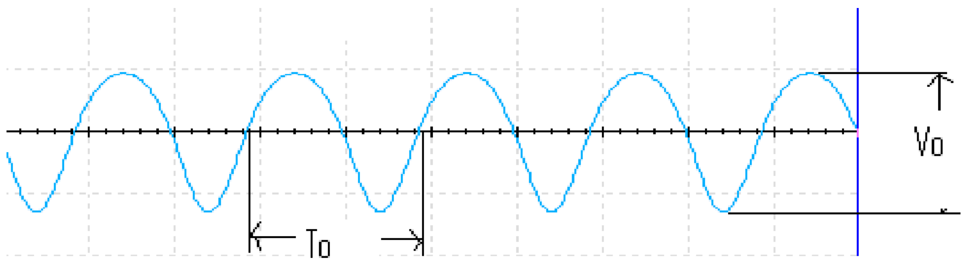
Frequency (Hz)	Input Voltage (V_i)	Output Voltage (V_0)	Gain in dB $A_v = 20*\log_{10}(V_o/V_i)$

MODEL WAVEFORMS:

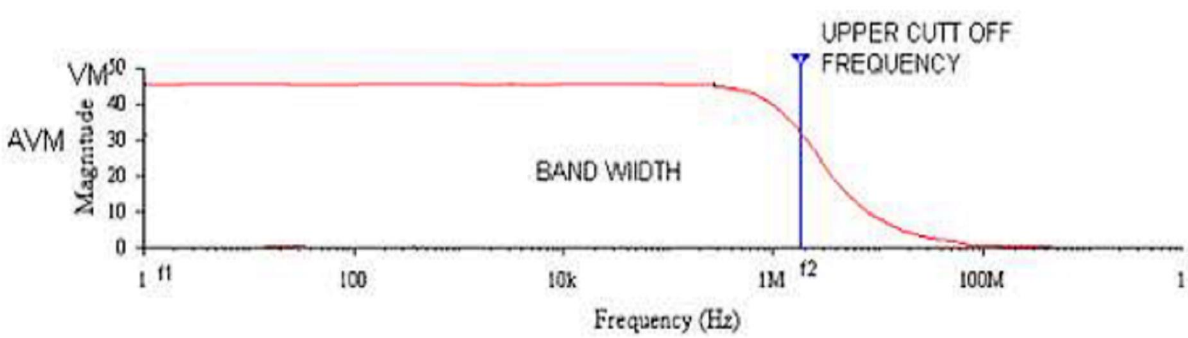
INPUT WAVEFORM:



OUTPUT WAVEFORM:



FREQUENCY RESPONSE:



RESULT:

The voltage gain and frequency response of the CC amplifier are obtained. Also gain Bandwidth product is calculated.

Experiment No.10: Frequency Response of BJT Amplifier

Aim: To design and setup an RC Coupled amplifier using BJT & to find the input and output impedance of the RC-Coupled amplifier.

Apparatus Required:

1 Bread Board
2 Cathode Ray Oscilloscope 20 MHz 1
3 Signal Generator 0 -1MHZ 1

3 Regulated Power Supply 0-30V,1A 1
5 Resistors:
6 Capacitors:
7 Transistors BC107
8 DRBs

Design:

Let $V_{cc} = 10V$

I= 5mA

\б = 100

To find R_E :

Let $V_{RE} = V_{CC}/10$;

$V_{RE} = 10/10 = 1V$.

i.e. $I_E R_E = 1V$

$R_E = 1V/I_E = 1V/I_C = 1/5mA = 200$ ɋ (since $I_C = I_E$)

Select $R_E = 220$ɋ

To find R_C**:**

$V_{CE}=V_{CC}/2=10/2=5V$

Apply KVL to CE loop,

$V_{CC} - I_C R_C - V_{CE} - V_{BE} = 0$

$10 - 5mR_C - 5 - 1 = 0$

$R_C = 800\Omega$

Select R_C as 820 Ω

To find R_1:

From the above biasing circuit,

$V_B = V_{BE} + V_{RE} = 0.7 + 1 = 1.7V$

$I_C = \beta I_B$ or $I_B = I_C / \beta = 5m/100 = 0.05mA$

Assume 10 I_B flows through R_1

$R_1 = V_{CC} - V_B / (10 I_B) = 16.6K\Omega$

Select $R_1 = 18k\Omega$

Assume 9 I_B flows through R2

$R_2 = V_B / 9I_B$

$= 1.7/9X0.05mA$

$R_2 = 3.7k\Omega$

Select R_2 as 3.9Kq

Bypass capacitor C_E and coupling Capacitor C_{C1} and C_{C2}

Let $X_{CE} = R_{E/10}$ at f = 100Hz

i.e. 1/2PifCe= $R_{E/10}$

there for C_E=10/2XPiX100X2200 =72 Micro Farad

Select C_E as 100 micro Farad

Also use $C_{C1} = C_{C2}$ = 0.47 micro Farad

To find C_C and C_E:

X_{CE}=1/2PiC_E=R_E/10=680/10=68

For frequency = 20Hz

C_E = 117Micro Farad

Choose C_E = 220Micro Farad

X_{CC}=1/2PiC_C=R_C/10=2200/10=220

For frequency = 20Hz

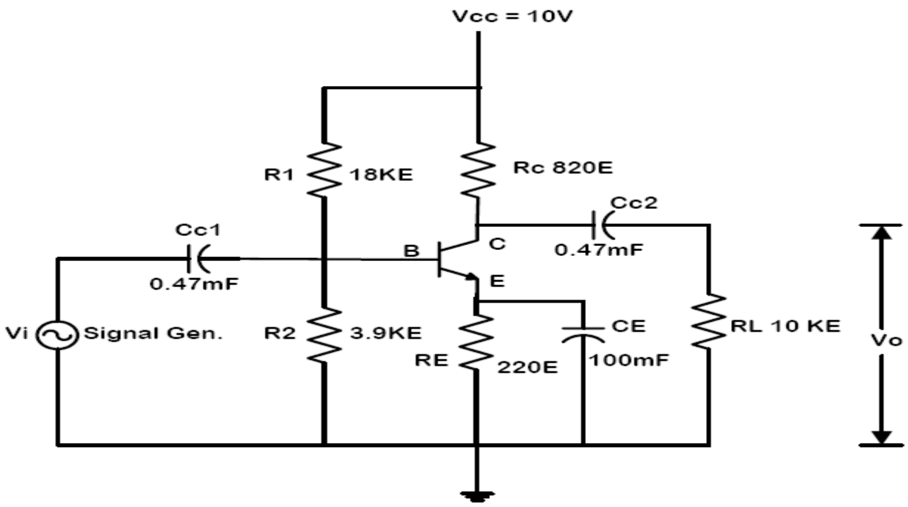
Choose C_C = 47 microFarad

Design of frequency selective circuit: Required frequency of oscillations, f=1 KH

$$f = \frac{1}{2\pi R_C\sqrt{6} + 4\frac{R_C}{R}}$$

Take R=4.7Kq and C=0.001micro Farad

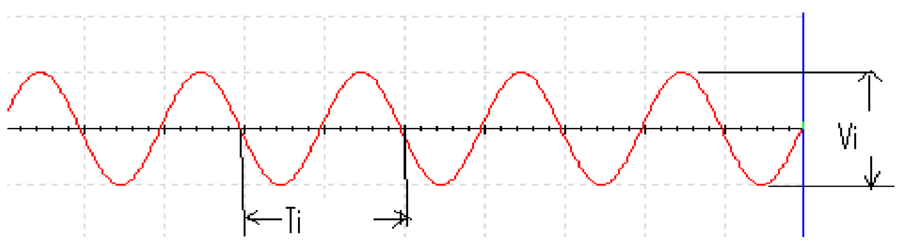
Circuit Diagram



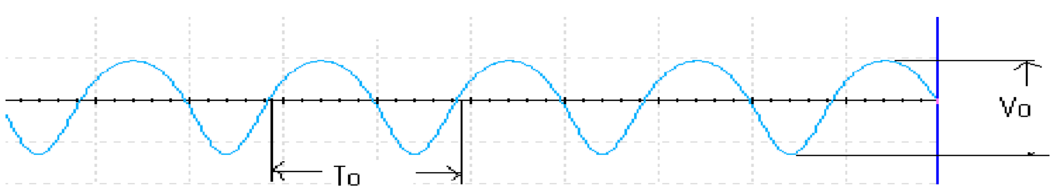
Procedure

1. Rig up the circuit
2. Apply the sinusoidal input of 50m(P-P) and observe the input and output waveforms simultaneously on the CRO screen
3. By varying the frequency of the input from Hz to maximum value and note down the output voltages
4. Plot the frequency response (gain in dB vs log f) and determine the bandwidth from the graph

INPUT WAVEFORM:



OUTPUT WAVEFORM:



bular Column:

V_{in}=---------------------------------Volts (Constant)

Freq. in Hz	$V_{o\ P\text{-}P}$	$A_V = V_O/V_{in}$	Gain in dB = 20 $\log_{10} A_V$
50 Hz . . . . 5 MHz			

<u>To measure input impedance and output impedance:</u>

I) Input impedance (R_i):

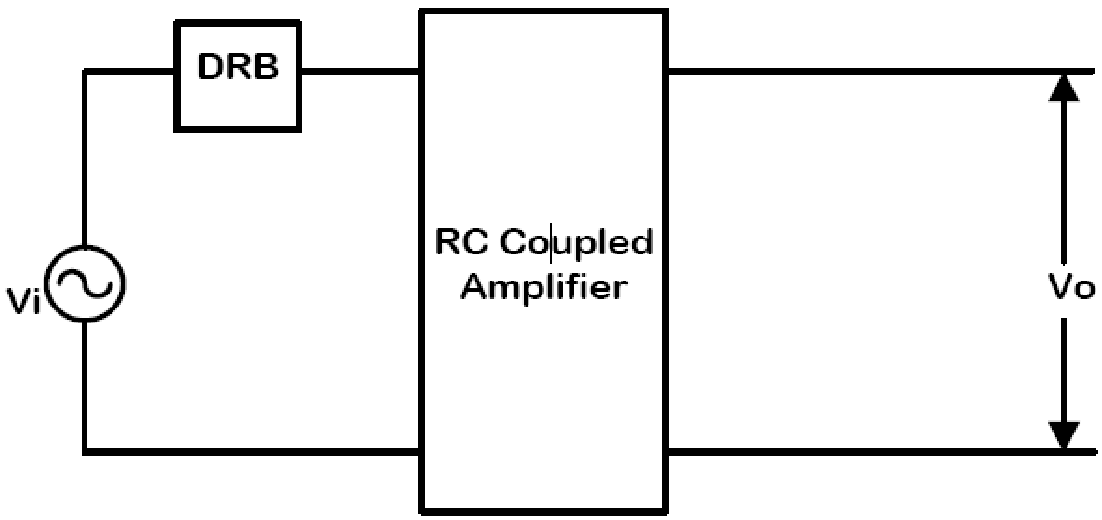
Procedure:

a. Set the DRB to a minimum value

b. Set the output to a convenient level and note down the output voltage

c. Increase the DRB value till V_o

d. The corresponding DRB value gives input impedance



II) <u>Output impedance (R_o):</u>

Procedure:

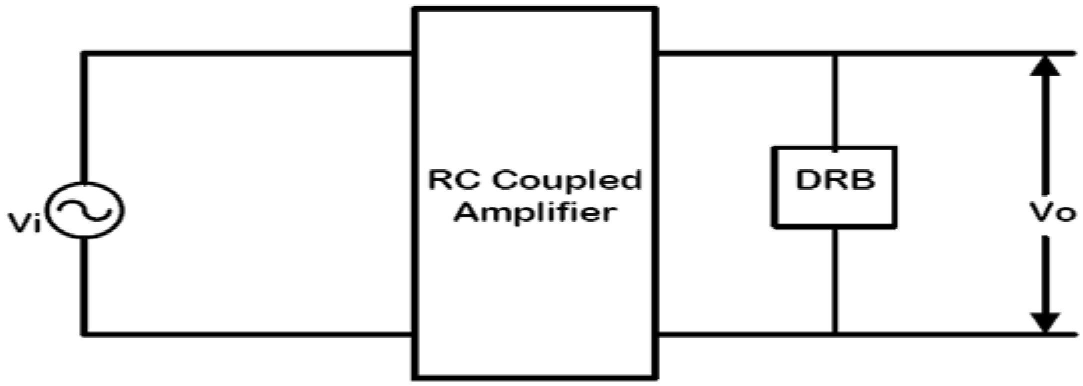
a. Connect the circuit as shown

b. Set the DRB to a maximum value

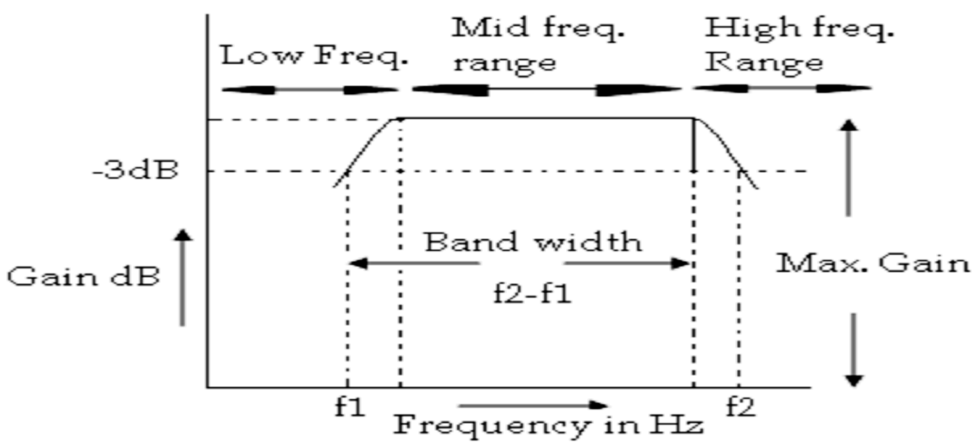
c. Set the output to a convenient level and note down the output voltage

d. Increase the DRB value till V_o becomes half of the maximum amplitude

e. The corresponding DRB value gives input impedance



Model Graph for Frequency Response



Result:

Bandwidth: ________________Hz

Input Impedance: __________q

Output Impedance: __________q

Experiment No.11: Study of Multistage Amplifier Frequency Response

Aim: To plot the frequency response characteristics of two stages RC coupled amplifier.

Apparatus Required:

Two stage RC Coupled Amplifier Bread Board, Cathode Ray Oscilloscope 20 MHz 1
Signal Generator 0 -1MHZ 1, Regulated Power Supply 0-30V,1A 1, Resistors:

Capacitors, Transistors BC107 ï two nos, Connecting wires etc.

Theory:

To improve gain characteristics of an amplifier, two stages of CE amplifier can be cascaded. While cascading, the output of one stage is connected to the input of another stage. If R and C elements are used for coupling, that circuit is named as RC coupled amplifier. Each stage of the cascade amplifier should be biased at its designed level. It is possible to design a multistage cascade in which each stage is separately biased

and coupled to the adjacent stage using blocking or coupling capacitors. In this circuit each of the two capacitors C_1 & C_2 isolate the separate bias network by acting as open circuits to dc and allow only signals of sufficient high frequency to pass through cascade.

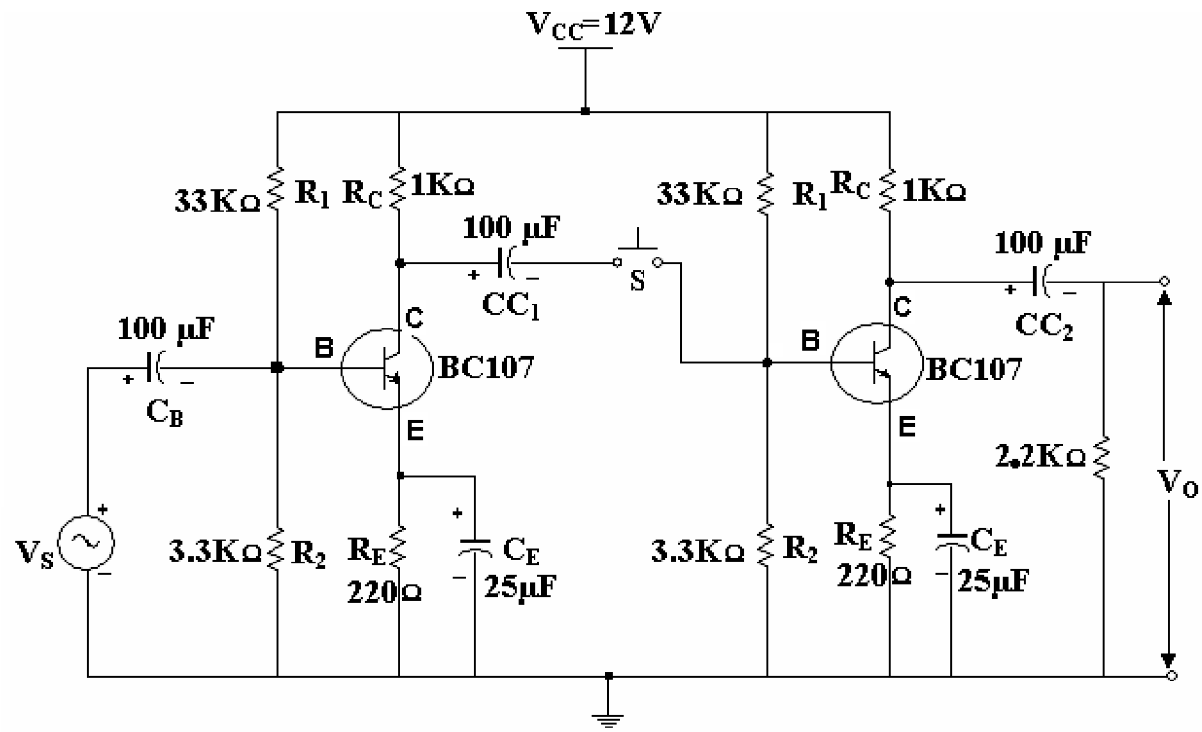


Fig A: Two stage RC Coupled Amplifier

Procedure:

1. Connect the circuit as per the circuit diagram.

2. Apply supply voltage, Vcc= 12V.

3. Now feed an ac signal of 20mV peak-peak at the input of the amplifier with different frequencies ranging from 20Hz to 1MHz and measure the amplifier output voltage, V_o.

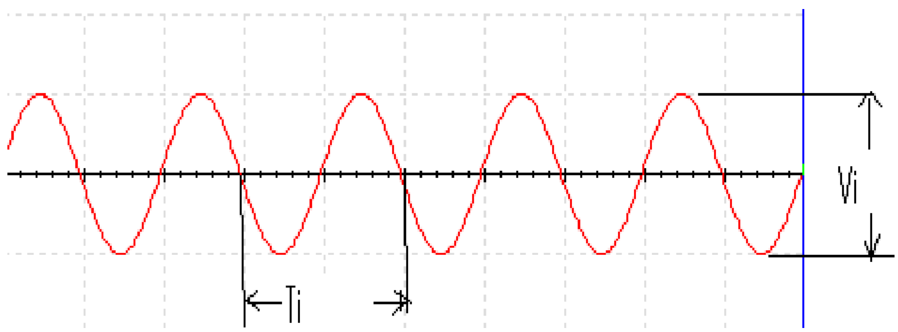
4. Now calculate the gain in dB for various input signal frequencies using $A_V = 20 \log_{10} (V_0/V_S)$.

5. Draw a graph with frequencies on X- axis and gain in dB on Y- axis.

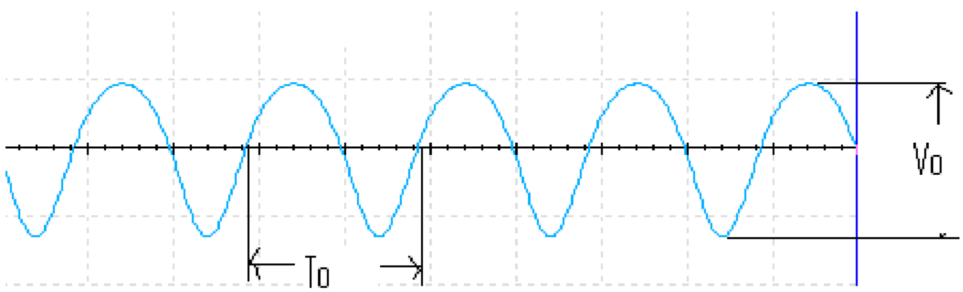
6. From graph calculate bandwidth.

Waveforms:

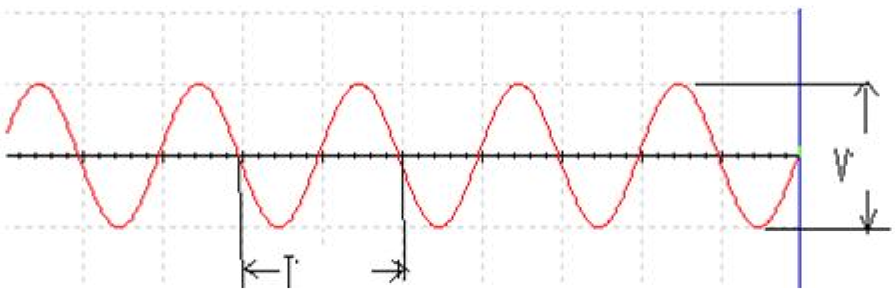
INPUT WAVEFORM:



OUTPUT OF FIRST STAGE :



OUTPUT OF 2ND STAGE:

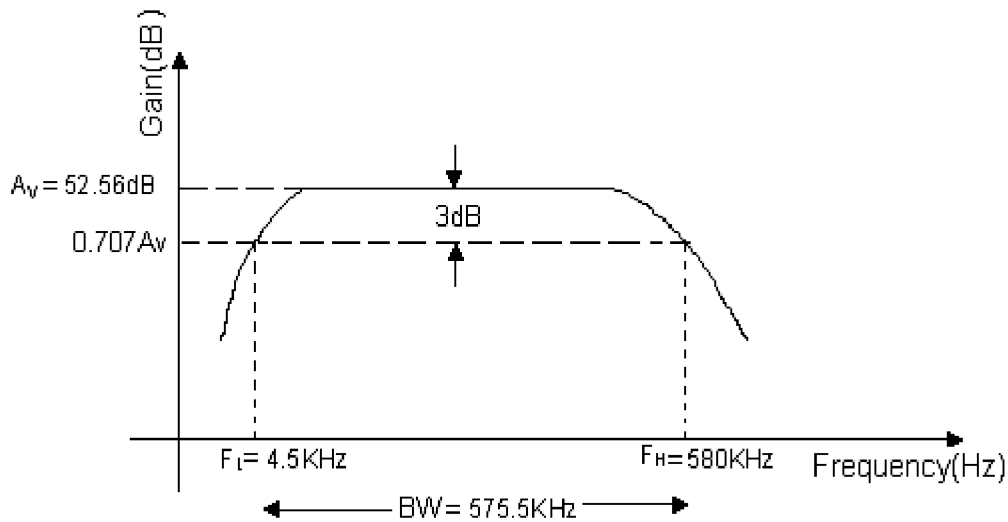


Tabular Form:

Input voltage, V_S = 20mV peak-peak

S. No	Input Frquency (Hz)	Output Voltage peak-peak Vo (mV)	Gain, Av = 20log(Vo/Vs) ,(dB)
1			
2			
3			
4			
5			
6			
7			
8			
9			
10			
11			
12			
13			
14			
15			
16			
17			
18			
19			
20			

Model Graph:



Observations:

Maximum gain (A_v) = 52.56dB

Lower cutoff frequency (F_l) = 4.5 KHz

Upper cutoff frequency (F_H) =580 KHz

Band width (B.W) = (F_H ï F_L) = 575.5 KHz

Gain bandwidth product = A_v (B.W) = 30.24M Hz

Precautions:

1. Connections must be given very carefully.

2. Readings should be noted without any parallax error.

3. The applied voltage and current should not exceed the maximum ratings of the given transistor.

Result: Frequency response of RC Coupled Amplifier Characteristics of was observed.

Experiment No.12: RC Phase Shift Oscillator

Aim: To design and set up an RC phase shift oscillator using BJT and to observe the sinusoidal output waveform.

Equipment Required:

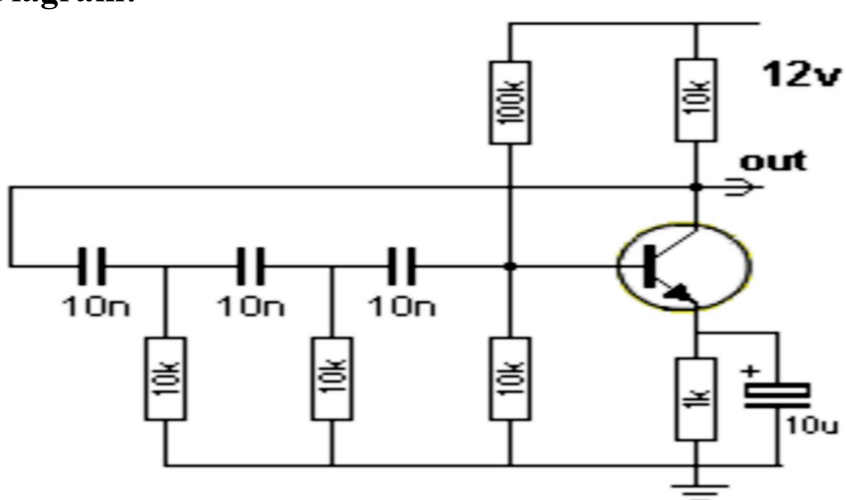
Transistor, dc source, capacitors, resistors, potentiometer, breadboard and CRO.

Theory:

An oscillator is an electronic circuit for generating an ac signal voltage with a dc supply as the only input requirement. The frequency of the generated signal is decided by the circuit elements. An oscillator requires an amplifier, a frequency selective network, and a positive feedback from the output to the input. The Barkhausen criterion for sustained oscillation is A_ = 1 where A is the gain of the amplifier and is the feedback factor. The unity gain means signal is in phase. (If the signal is 180° out of phase, gain will be 1.). If a common emitter amplifier is used, with a resistive collector load, there is a 180 phase shift between the voltages at the base and the collector. In the figure shown, three sections of phase shift networks are used so that each section introduces approximately 60_ phase shift at resonant frequency. By analysis, resonant frequency f can be expressed by the equation,

$$f = \frac{1}{2\pi RC\sqrt{6 + 4R_c/R}}$$

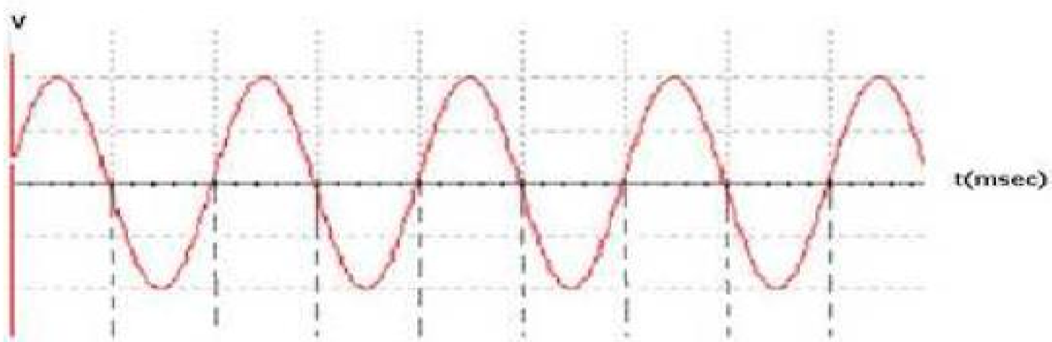
Circuit Diagram:

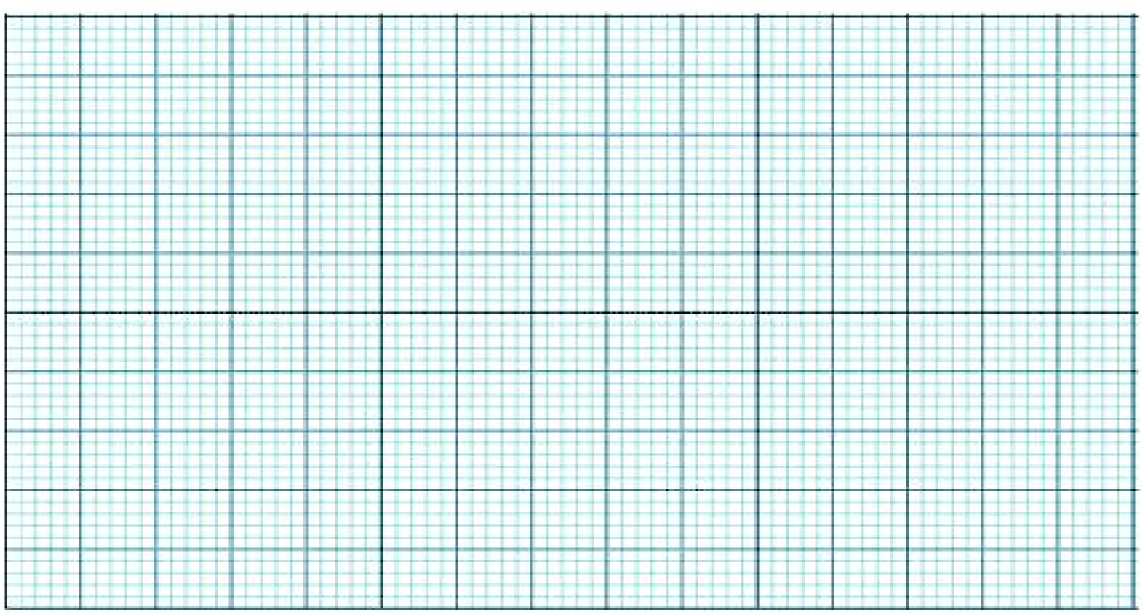


Procedure:

1. Connections are made as per circuit diagram.
2. Connect CRO output terminals and observe the waveform.
3. Calculate practically the frequency of oscillations by using the expression
   f = 1 / T (T= Time period of the waveform)
4. Repeat the above steps 2,3 for different values of L, and note down the practically values of oscillations of the RC-phase shift oscillator.
5. Compare the values of oscillations both theoretically and practically.

Model Waveform:





Result: