unit 4

Feedback and oscillators

Q: what is feedback? what are the basic types of feedback?

A: Feedback is the process of taking a part of the output signal and feeding it back to the input. There are two basic types of feedbacks namely 1) positive feedback & 2) negative feedback.

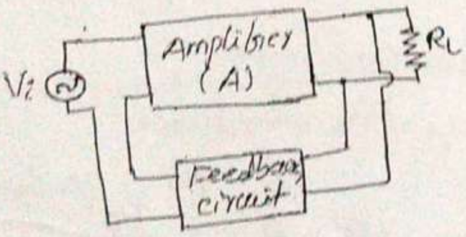
Q: what are positive feedback and negative feedback?

A: positive feedback: Feedback in which a part of the output fedback is in phase with the input. with positive feedback, voltage gain will increase.

Negative feedback:- Feedback in which feedback signal is in opposite phase with the input signal is called negative feedback. Negative feedback decreases the voltage gain of the amplifier.

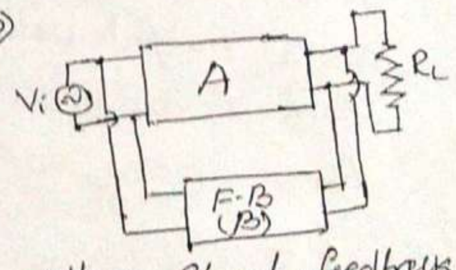
Q: Mention with block diagram, the four types of negative feedback connections.

A: a)



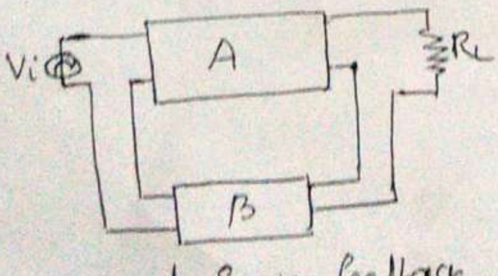
Voltage Series feedback

b)



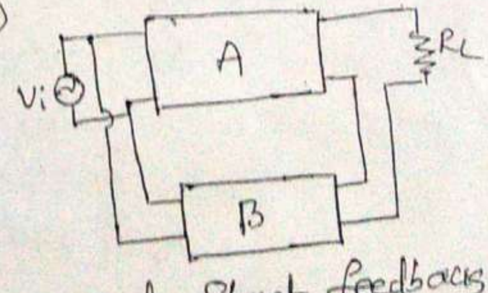
Voltage Shunt feedback

c)



current Series feedback

d)



current Shunt feedback

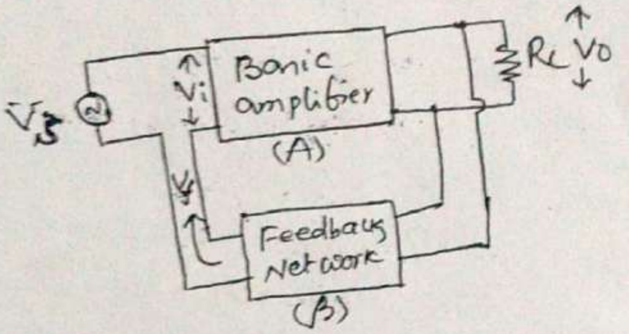
Q: Mention the advantages of negative feedback

A: Advantages of negative feedback are

a) Stability in gain
b) Increse in input impedence
c) Decrease in output impedence
d) decrese in distortion and noise
e) increase in Bandwidth.

Q: obtain the expression for voltage gain of a voltage Series negative feedback using block diagram.

A:



V_s = Source voltage
V_i = Net input to the basic amplifier
V_f = feedback voltage
β = Feedback factor
V_o = output voltage
A = Gain of the basic amplifier
A_F = Gain with negative feedback

W.K.T $\quad A = \frac{V_o}{V_i}$ & $A_F = \frac{V_o}{V_s}$

But $\quad V_i = V_s - V_f$

$V_i = V_s - \beta V_o \quad (\because V_f = \beta V_o)$

$V_i = V_s - \beta A V_i$

$(V_i + A\beta V_i) = V_s$

$V_i[1+A\beta] = V_s$

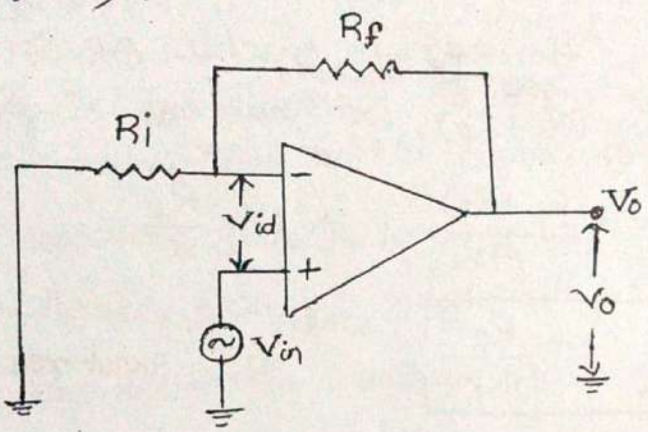
$\therefore \quad A_F = \frac{V_o}{V_i[1+A\beta]} = \frac{A}{1+A\beta} \quad \left[\because A = \frac{V_o}{V_i}\right]$

The voltage gain with feedback $A_F = \frac{A}{1+A\beta}$

<u>Note</u>: The expression of voltage gain for positive feedback is $A_F = \frac{A}{1-A\beta}$

Q: Derive the expression for the voltage gain of a noninverting amplifier (voltage series feedback amplifier).

A:



open loop voltage gain = $A = \frac{v_o}{v_{id}}$ ⟶ (1)

& closed loop voltage gain = $A_f = \frac{v_o}{v_{in}}$ ⟶ (2)

The differential input to the basic amplifier = $V_{id} = v_{in} - V_f$

Feedback voltage $v_f = \frac{R_1}{R_1+R_f} \times V_o$ ⟶ (3)

$$\therefore \quad v_{id} = v_{in} - \frac{R_1}{R_1+R_f} v_o$$

$$= v_{in} - \frac{R_1}{R_1+R_f} A V_{id}$$

[$\because v_o = A v_{id}$ from Eq (1)]

$$v_{id} + \frac{R_1}{R_1+R_f} A v_{id} = v_{in}$$

$$v_{id}\left[1 + \frac{AR_1}{R_1+R_f}\right] = v_{in}$$ ⟶ (4)

Substituting Equation (4) in equation (2) we have

$$A_F = \frac{V_o}{V_{id}\left[1 + \frac{AR_1}{R_1+R_f}\right]}$$

$$= \frac{V_o}{R_1 + R_f + AR_1} \times \frac{R_1 + R_f}{V_{id}}$$

$$A_F = \frac{(R_1 + R_f)A}{R_1 + R_f + AR_1} \longrightarrow (5)$$

This is the exact expression for the voltage gain with negative feedback.. However in practice $AR_1 \gg R_1 + R_f$.

Therefore neglecting $(R_1 + R_f)$. we have

$$A_F = \frac{(R_1 + R_f)A}{AR_1} \simeq 1 + \frac{R_f}{R_1}$$

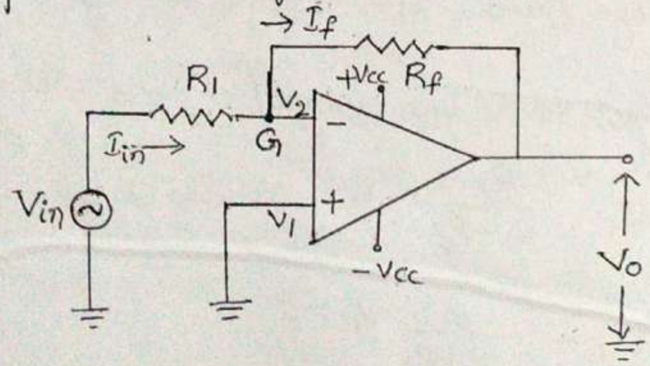
$$\boxed{A_F = 1 + \frac{R_f}{R_1}}$$

where R_f = feedback resistor

R_1 = Input resistor.

Q: Derive the expression for voltage gain of Inverting amplifier [Voltage Shunt feedback amplifier]

A:



Applying KCL to input node V_2 we have

$$I_{in} = I_f + I_B \longrightarrow (1) \text{ But } I_B \simeq 0$$

$$\therefore \quad I_{in} \simeq I_f \longrightarrow (2)$$

ie $$\frac{v_{in} - v_2}{R_1} = \frac{v_2 - v_o}{R_f} \longrightarrow (3)$$

W.R.T $A = \frac{v_o}{v_{id}}$ where $v_{id} = v_1 - v_2$

But $v_1 = 0$ and $v_{id} = -v_2$

$\therefore A = \frac{v_o}{-v_2} \Rightarrow v_2 = \frac{-v_o}{A}$

Substituting v_2 in equation (3) we get

$$\frac{v_{in} + \frac{v_o}{A}}{R_1} = \frac{-\left(\frac{v_o}{A}\right) - v_o}{R_f}$$

$$\therefore A_F = \frac{v_o}{v_{in}} = -\frac{AR_F}{R_1 + R_f + AR_1} \longrightarrow (4)$$

- Equation (4). is called exact equation and -ve sign indicates the input and output signals are out of phase by 180°. However, since A is very large. $AR_1 \gg R_1 + R_f$ ~~therefore~~ $(R_1 + R_f)$ can be neglected in Eq (4)

Therefore expression for voltage gain of inverting amplifier is $A_F = -\frac{AR_F}{AR_1}$

$$\boxed{A_F = -\frac{R_f}{R_1}} \quad \text{Ideal equation} \longrightarrow (5)$$

- Q: what is virtual ground ?

A: For an ideal op-amp, the open loop gain in very high and approaches infinity (∞)

ie Differential gain $A_d = \frac{v_o}{v_{id}} \rightarrow \infty$

This means $v_{id} = (V_1 - V_2) \rightarrow 0$, when the non inverting input is grounded ($V_1 = 0$), the voltage at the inverting input (v_2) must be 0. Therefore the V_2 point in the inverting amplifier is called virtual ground since it is not directly connected to ground.

Q: Discuss the effect of negative feedback on input resistance, output resistance, Distortion & noise, and bandwidth.

A: Effect of -ve feedback on input resistance (R_i):-
Negative feedback increases the input resistance of the amplifier R_i by a factor of $(1+A\beta)$. ie

Input resistance with feedback $R_{if} = R_i[1+A\beta]$

Effect of -ve feedback on output resistance (R_o):- -ve feedback decreases the output resistance of the amplifier R_o by a factor of $(1+A\beta)$

ie output resistance with feedback $R_{of} = \frac{R_o}{(1+A\beta)}$

Effect of -ve feedback on distortion & noise:- -ve feedback decreases distortion and noise of the amplifier by a factor of $(1+A\beta)$. Therefore

Distortion with feedback $D_f = \frac{D}{(1+A\beta)}$

where D is distortion without feedback.

Illy Noise with feedback $N_F = \frac{N}{1+A\beta}$

Effect of -ve feedback on Bandwidth :- -ve feedback increases the bandwidth of the amplifier (BW) by a factor of $(1+A\beta)$.

Hence Bandwidth with feedback $(B.W)_f = (B.W)[1+A\beta]$

Op-amp Applications

Q: What is an adder? Obtain the expression for its output.

A: An adder is a circuit, whose output is proportional to the algebraic sum of the input voltages. Below figure shows the circuit diagram of inverting adder.

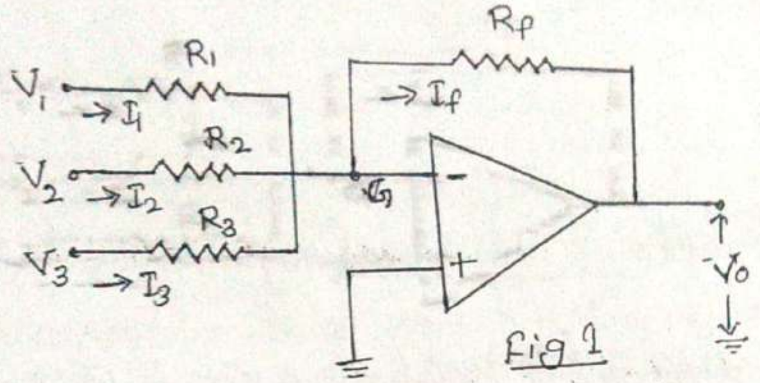


Fig 1

Let I_1, I_2 & I_3 be the three input currents set by the input voltages V_1, V_2 and V_3 respectively. Let I_f be the feed-back current in R_f.

From KCL, we have $I_1 + I_2 + I_3 = I_f \longrightarrow (1)$

where $I_1 = \frac{V_1}{R_1}$, $I_2 = \frac{V_2}{R_2}$ & $I_3 = \frac{V_3}{R_3}$ and $I_f = -\frac{V_o}{R_f}$

$$\therefore \frac{V_1}{R_1} + \frac{V_2}{R_2} + \frac{V_3}{R_3} = -\frac{V_o}{R_f} \longrightarrow (2)$$

or $$V_o = -\left[\frac{R_f}{R_1}V_1 + \frac{R_f V_2}{R_2} + \frac{R_f}{R_3}V_3\right]$$

If $R_1 = R_2 = R_3$ then

$$V_o = -\frac{R_f}{R}\left[V_1 + V_2 + V_3\right] \longrightarrow (3)$$

-ve sign is due to the inverting mode of op-amp

Thus the output voltage is proportional to the algebraic sum of the three inputs.

Note: Scaling or weighted amplifier:- If each input voltage is amplified by a different factor in an adder, the circuit is then called a scaling or weighted amplifier

Thus the output voltage $V_o = -\left[\frac{R_f}{R_1}V_1 + \frac{R_f}{R_2}V_2 + \frac{R_f}{R_3}V_3\right]$

where $\frac{R_f}{R_1} \neq \frac{R_f}{R_2} \neq \frac{R_f}{R_3}$ where $\frac{R_f}{R_1} = K_1$, $\frac{R_f}{R_2} = K_2$ & $\frac{R_f}{R_3} = K_3$

or $V_o = -\left[K_1 V_1 + K_2 V_2 + K_3 V_3\right]$

Average circuit :- It is a circuit in which output voltage is equal to the average of all the input voltages. Figure 1 shown in adder can be used as an averaging circuit.

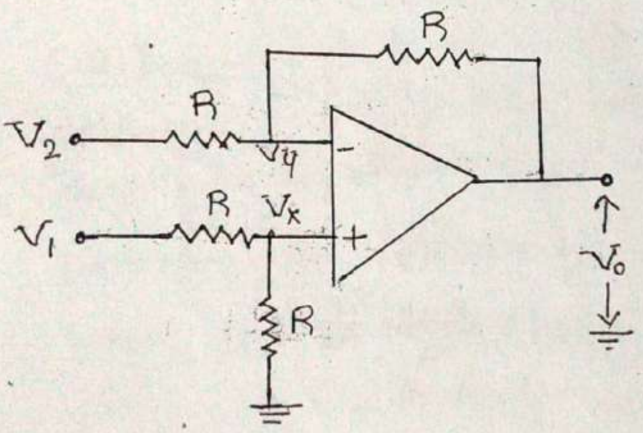
Consider o/p $v_0 = -\left[\frac{R_f}{R_1}V_1 + \frac{R_f}{R_2}V_2 + \frac{R_f}{R_3}V_3\right]$

If $R_1 = R_2 = R_3$ and $\frac{R_f}{R} = \frac{1}{3}$ we have

$$v_0 = -\left[\frac{v_1 + v_2 + v_3}{3}\right]$$

Q: What is a Subtractor? obtain the expression for its output.

A: A Subtractor or a differential amplifier is a circuit, whose output is equal to the difference between the input signals.



From Superposition theorem, the output voltage is the algebraic sum of output v_{01} due to inverting input voltage V_2 and output v_{02} due to noninverting input voltage V_x

ie $v_0 = v_{01} + v_{02} \longrightarrow (1)$

v_{01} is the output due to inverting input voltage V_2 only. therefore from inverting amplifier theory $\left[A = -\frac{R_f}{R_1}\right.$ or $\left.v_0 = -\frac{R_f}{R_1}v_i\right]$ $v_{01} = -\frac{R}{R}V_2 \longrightarrow (2)$

And v_{02} is the output voltage due to noninverting input voltage v_x only. Hence from noninverting amplifier theory $\left[A = \left(1 + \frac{R_f}{R_1}\right)\right.$ or $\left.v_0 = \left(1 + \frac{R_f}{R_1}\right)v_i\right]$

$v_{02} = \left(1 + \frac{R_f}{R}\right)V_x$ where $V_x = \left(\frac{R}{R+R}\right)V_1$

$$\therefore \quad v_{o2} = \left(1+\frac{R}{R}\right)\left(\frac{R}{R+R}\right)v_1$$

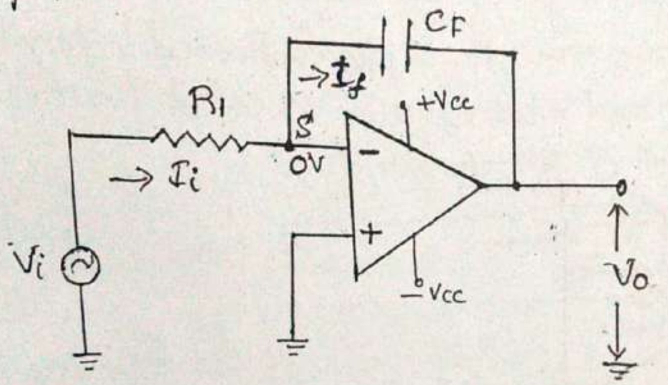
$$v_{o2} = v_1$$

$\therefore$ From Eq (1) we have $\quad v_o = -\frac{R}{R}v_2 + v_1$

or $\boxed{v_o = v_1 - v_2}$ Thus output voltage is the difference of two inputs.

Q: What is an integrator? obtain the expression for the output of integrator. Sketch the ~~output~~ wave forms.

A: A circuit in which output is proportional to integral of input is called an integrator.



Applying KCL to the node S, we have

$$I_i = I_f \longrightarrow (1)$$

But $\quad I_1 = \frac{v_i - 0}{R_1}$ —② & $I_f = C_f \frac{d(0-v_o)}{dt}$ —③

$$\therefore \quad \frac{v_i}{R} = -C\frac{d}{dt}v_o \quad —④$$

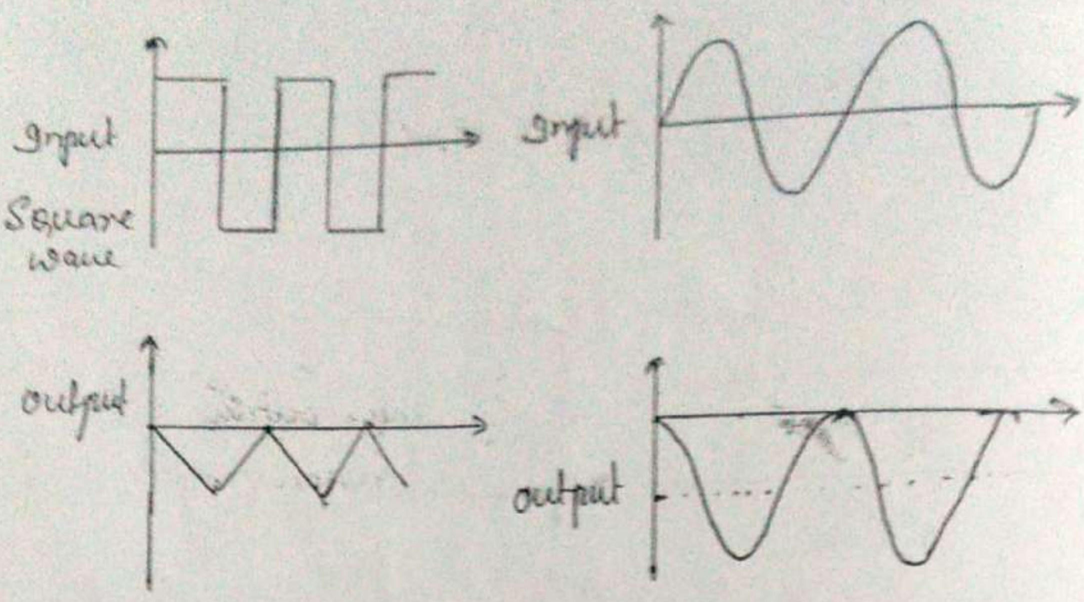
Integrating Eq (4) on both sides. we get

$$\int \frac{v_i}{R_1} = -C\int \frac{d}{dt} v_o$$

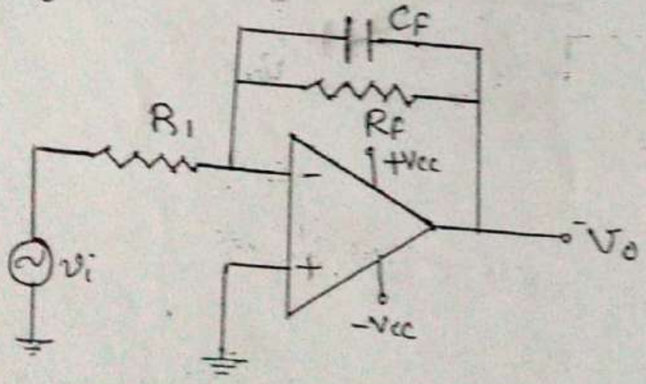
$$\Rightarrow \boxed{v_o = -\frac{1}{R_1 C_f}\int_0^t v_i \cdot dt + C} \longrightarrow (5)$$

where C is the constant of integration.

Equation (5) is the expression for output



Note:- practical integrator: In the integrator circuit shown above, the gain tends towards infinity at very low frequencies. As a result any small input voltage introduce an error voltage at the output. To minimise this error, a feedback resistor R_f is connected in parallel with the capacitor and this circuit is called practical integrator which is given below.



The limiting frequency at which the gain is 0 dB is

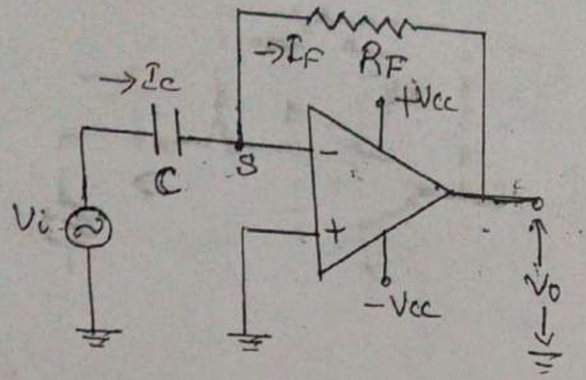
$$f_1 = \frac{1}{2\pi R_1 C_F}$$

The upper limiting frequency at which the gain decreases at a rate of 20 dB/decade is

$$f_2 = \frac{1}{2\pi R_F C_F}$$

Q: What is a differentiator?. obtain the expression for the output. Sketch the waveforms.

A: A circuit in which output voltage is proportional to the derivative of the input voltage is called a differentiator.



Applying KCL to the node S, we have $I_C = I_F \rightarrow (1)$

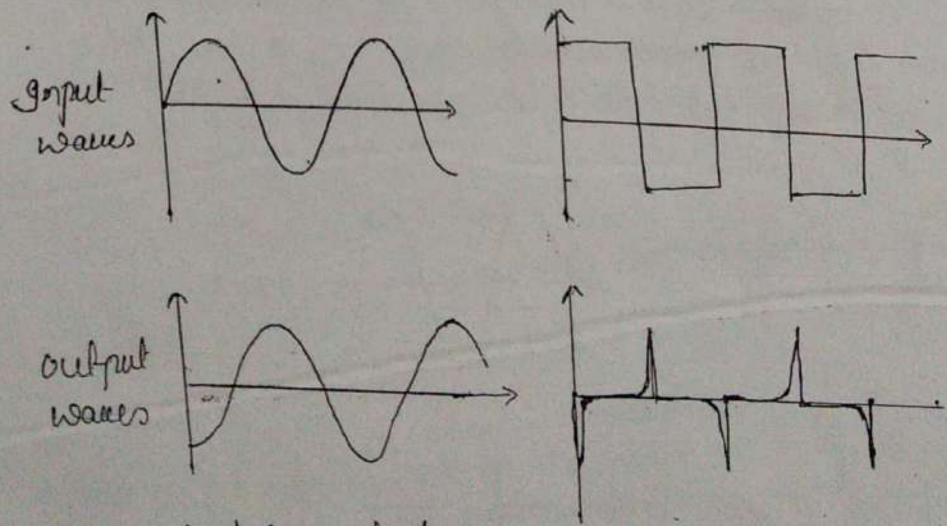
But $I_C = C\frac{d}{dt}(v_i - 0) = C\frac{dv_i}{dt}$ & $I_F = \frac{0 - v_o}{R_F} = -\frac{v_o}{R_F}$

$$\therefore \quad C\frac{d(v_i)}{dt} = -\frac{v_o}{R_F}$$

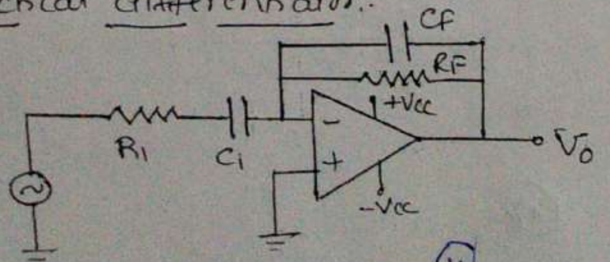
or

$$\boxed{v_o = -R_F C\frac{dv_i}{dt}}$$

Waveforms:

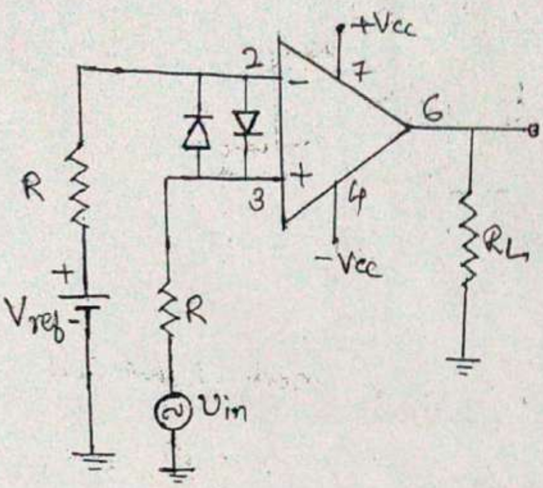


Practical differentiator:

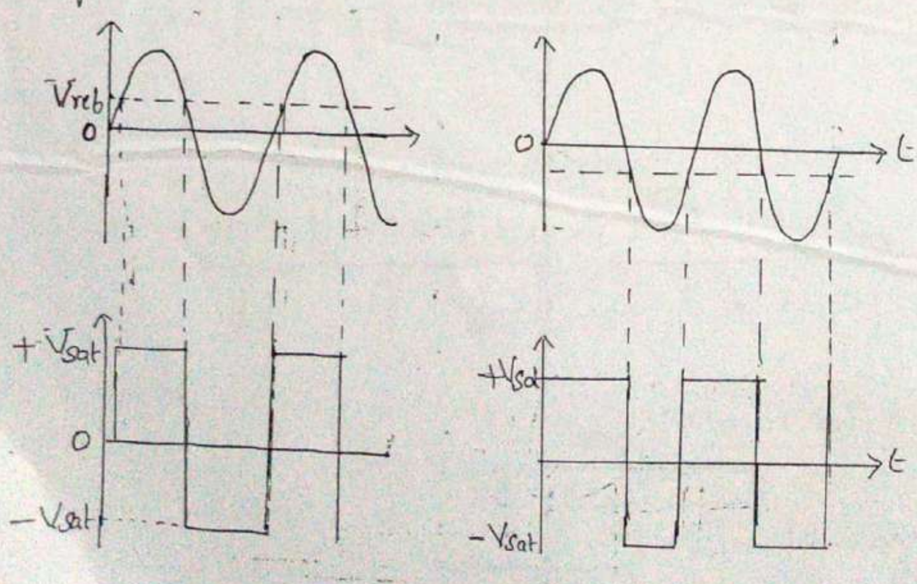


Q: What is a comparator? Explain the working of an op-amp comparator

A: Comparator is a circuit which compares a signal voltage on one input with a known voltage called the reference voltage on the other input.



A fixed reference voltage V_{ref} is applied to the negative input of the op-amp. The time dependent input signal is applied to the positive input. When V_{in} is less than V_{ref} the output voltage V_o will be at $-V_{sat}$. This is because the voltage at the negative input is higher than that at the positive input. When V_{in} is greater than V_{ref} the output V_o goes to $+V_{sat}$. In this manner V_o changes from one saturation level to another whenever $V_{in} \cong V_{ref}$. The comparator is also called as a voltage level detector.



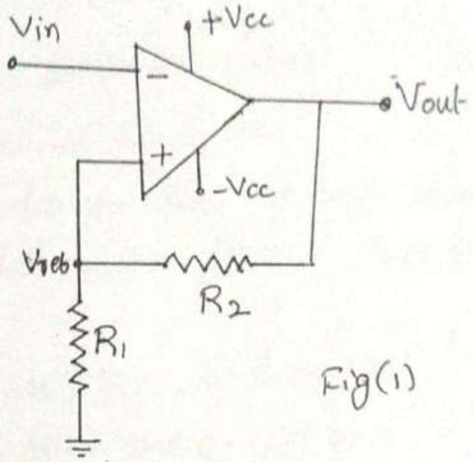
Note: characteristics of a Comparator

1) Speed of operation
2) Accuracy 3) compatability of the output.

Q: What is a Schmitt trigger?. Explain the working of op-amp Schmitt trigger.

A: A Schmitt trigger is a circuit which converts any kind of waveform in to a rectangular wave.

A comparator using a positive feedback becomes Schmitt trigger. When the output voltage is negatively saturated a negative voltage gets fed back to the noninverting input. This holds the output in the low state. When the output is positive saturated, a positive voltage gets fed back to the noninverting point. This positive feedback holds the output in the high state. The feedback fraction is



Fig(1)

$$\beta = \frac{R_1}{R_1+R_2}$$

When the output is saturated +vely the reference voltage applied to the noninverting input is

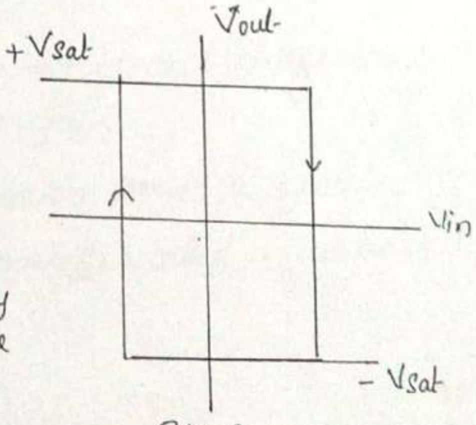


Fig 2

$$V_{ref} = +\beta V_{sat}$$

When the output is negatively saturated the reference voltage is $V_{ref} = -\beta V_{sat}$

The figure 2 is called a hysteresis curve. When the input crosses the reference voltage the output switches from $+V_{sat}$ to $-V_{sat}$. When the input goes below the negative reference voltage the output switches back to $+V_{sat}$. The difference between the two reference voltages gives the hysteresis voltage.

$$\text{Hysteresis voltage} = \beta\left[+V_{sat} - (-V_{sat})\right] = 2\beta V_{sat}$$

Active Filters

Q: what is a filter circuit? mention the different types of filters.

A: A filter is a frequency selective circuit which passes a specified band of frequencies and attenuates or blocks frequencies outside this band. Filters may be classified in a number of ways as follows.

1. Analog or digital filters
2. passive or active filters
3. Audio (AF) or Radio (RF) frequency filters.

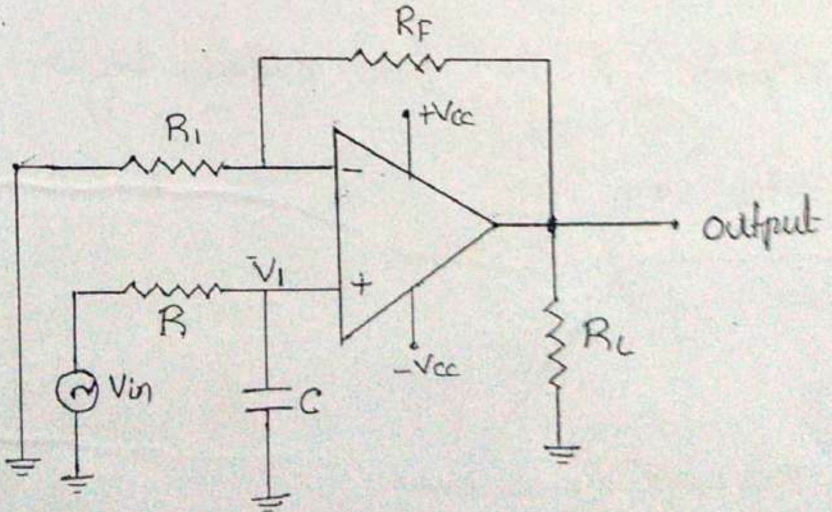
Q: what are active filters?. mention the types.

A: Filters which employ active devices like op-amps along with passive elements are called active filters. The different types of ~~are~~ filters are,

a) Low pass filter b) High pass filter c) Band pass filter d) Band stop or band reject filter and e) All pass filters.

Q: what is low pass filter?. with the circuit diagram obtain the expression for voltage gain.

A: A filter which passes low frequencies up to a specific frequency known as cut off frequency f_H is called a low pass filter.



In the circuit, op-amp is used in the noninverting configuration. Hence resistors R_1 & R_F determine the gain of the filter.

Scanned with CamScanner

According to the voltage divider rule, the voltage at the noninverting terminal is

$$v_1 = \frac{-jX_C}{R - jX_C} v_{in}$$

where $j = \sqrt{-1}$ and $-jX_C = \frac{1}{j2\pi fC}$

Therefore $v_1 = \frac{v_{in}}{1 + j2\pi fRC}$ and the output voltage

$$v_0 = \left(1 + \frac{R_F}{R_1}\right) v_1$$

$$v_0 = \left(1 + \frac{R_F}{R_1}\right) \frac{v_{in}}{1 + j2\pi fRC}$$

$$\frac{v_0}{v_{in}} = \frac{A_F}{1 + j(f/f_H)}$$

where $\frac{v_0}{v_{in}}$ = gain of the filter

$A_F = 1 + \frac{R_F}{R_1}$ pass band gain of the filter

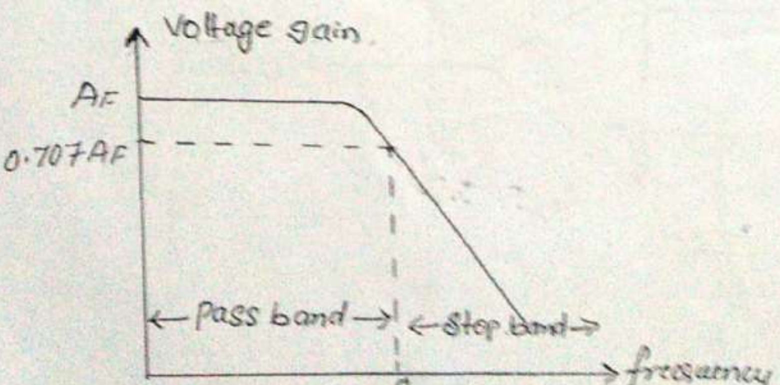
$f_H = \frac{1}{2\pi RC}$ = high cutoff frequency of the filter

At very low frequencies $f < f_H$, $\left|\frac{v_0}{v_i}\right| \simeq A_F$

At $f = f_H$ $\left|\frac{v_0}{v_i}\right| = \frac{A_F}{\sqrt{2}} = 0.707 A_F$

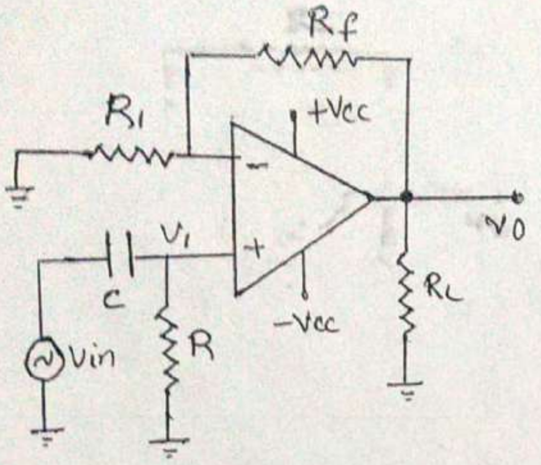
At $f > f_H$ $\left|\frac{v_0}{v_i}\right| < A_F$

Frequency response of low pass filter is shown below

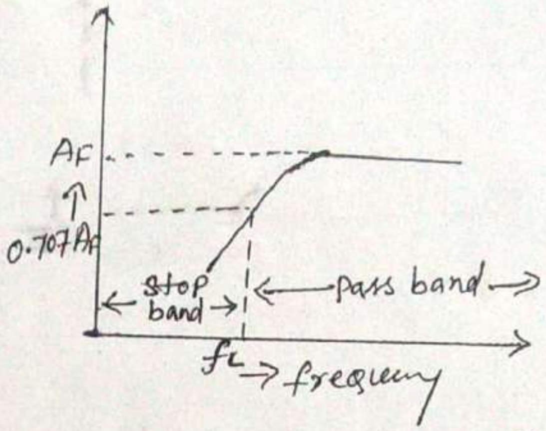


Q: What is a high pass filter? Write circuit diagram and obtain expression for voltage gain.

A: A filter which allows all high frequencies above a specific frequency known as cut off frequency f_L is called a high pass filter.



(1) circuit diagram



(2) Frequency response

For the above circuit of noninverting mode, the output voltage is

$$V_0 = \left(1+\frac{R_f}{R_1}\right)\frac{j2\pi fRC}{1+j2\pi fRC}\,V_{in}$$

$$\left[\because \quad V_1 = \frac{R}{R+\left(\frac{1}{j\omega C}\right)}V_{in} = \frac{j2\pi fRC\; V_{in}}{1+j2\pi fRC}\right]$$

Substituting $\frac{1}{2\pi RC} = f_L$ in the above equation we have

$$V_0 = \left(1+\frac{R_f}{R_1}\right)\frac{j\left(\frac{f}{f_L}\right)}{1+j(f/f_L)}\,V_{in}$$

But $\left(1+\frac{R_f}{R_1}\right) = A_F$

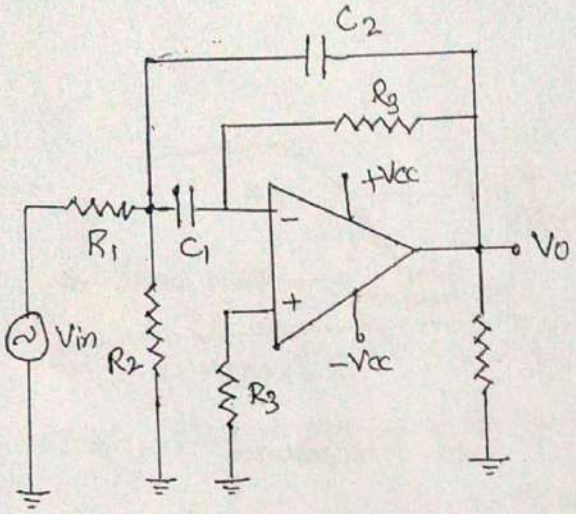
$$\therefore \quad \frac{V_0}{V_{in}} = A_F\left[\frac{j(f/f_L)}{1+j(f/f_L)}\right]$$

where $1+\frac{R_f}{R_1} = A_F$ = pass band gain. f = frequency of the input signal, $f_L = \frac{1}{2\pi RC}$ = low cut off frequency

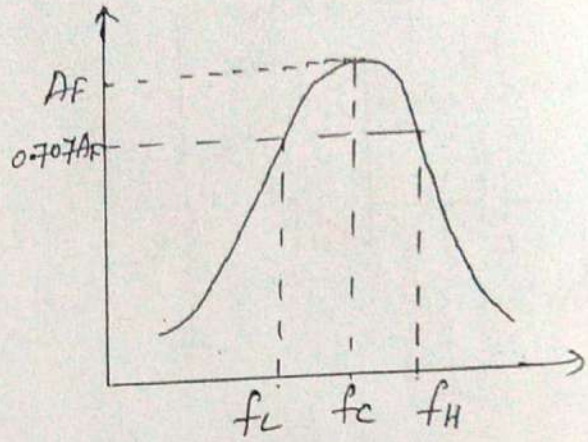
And $$\left|\frac{V_0}{V_{in}}\right| = \frac{A_F(f/f_L)}{\sqrt{1+(f/f_L)^2}}$$

Q: What is bandpass filter? write circuit diagram and frequency response of narrow band pass filter.

A: A filter which passes the signal between two cutoff frequencies f_H & f_L and attenuates or stops the other frequencies.



circuit diagram



Frequency response.

Q: what are band stop and All pass filters?

A: A filter which stops or attenuates a specific band of frequencies and allows the other frequencies is called as a bandstop or band reject filter.

A filter which passes all frequency components of the input signal providing predictable phase shifts for different frequencies