

28/06/2021

gain of Integrator:-

$$A_{CL} = \frac{V_o}{V_i} = \frac{-Z_f}{R} = \frac{-X_{cf}}{R} = -\frac{1}{sRCf}$$

$$RC = T$$

$$\therefore \frac{1}{RC} = f = \omega_b$$

$$A_{CL} = -\frac{1}{j\omega RCf} = \frac{j}{\omega RCf} = \frac{j\omega_b}{\omega}$$

$$A_{CL} = j \frac{f_b}{f}$$

$$|A_{CL}| = \frac{f_b}{f}$$

$$\text{if } f=0 \Rightarrow |A_{CL}| = \frac{f_b}{0} = \infty$$

$$\text{if } f=f_b \Rightarrow |A_{CL}| = \frac{f_b}{f_b} = 1 \text{ (unity)}$$

* f_b is called unity gain frequency of integrator.

$$\therefore f_b = \frac{1}{2\pi R_1 C_f} \rightarrow \text{frequency at which gain of the op-amp is becomes unity.}$$

ideal

* This ideal integrator becomes unstable at zero frequency. (gain is ∞)

* At zero frequencies the gain is infinite which produces the nonzero o/p without any i/p signal, so that non-zero o/p is called instability of the ckt. The non-zero o/p is because of capacitor.

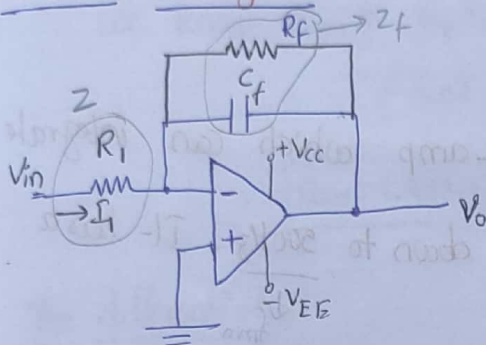
* Therefore this ideal integrated ckt is not used practically.

* It can be unstable even at low frequencies then we have to make the system is stable by adding a extra resistance.

* Due to capacitor in ideal integrator ckt, the gain is infinite at low frequencies because at low frequencies the capacitor is open.

* To control this gain we are using extra resistor R_f is parallel to C_f , so this ckt is called practical integrated ckt.

Practical Integrator:-



$$A_{CL} = \frac{-Z_f}{Z_i} \quad \left(Z_f = R_f \parallel \frac{1}{sC_f} \right) \\ \left(Z_i = R_1 \right)$$

$$|A_{CL}| = \frac{R_f/R_1}{\sqrt{1 + \left(\frac{f}{f_a}\right)^2}}$$

if $f=0$.

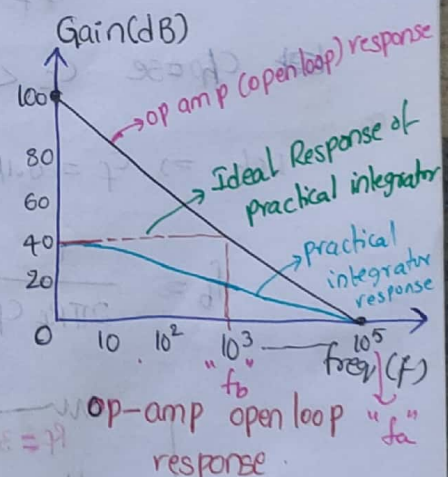
$$|A_{CL}| = \frac{R_f}{R_1}$$

if $f=f_a$

$$|A_{CL}| = \frac{R_f/R_1}{\sqrt{2}}$$

($f_a = \text{cut off freq.}^{(3\text{dB})}$)

$$\therefore f_a = \frac{1}{2\pi R_f C_f} \\ f_b = \frac{1}{2\pi R_1 C_f}$$



* upto $f=f_a$ gain is constant $\approx \frac{R_f}{R_1}$

* but after f_a gain falls at -20 dB/dec.

* Practical integrator will acts as integrator between f_a and f_b .

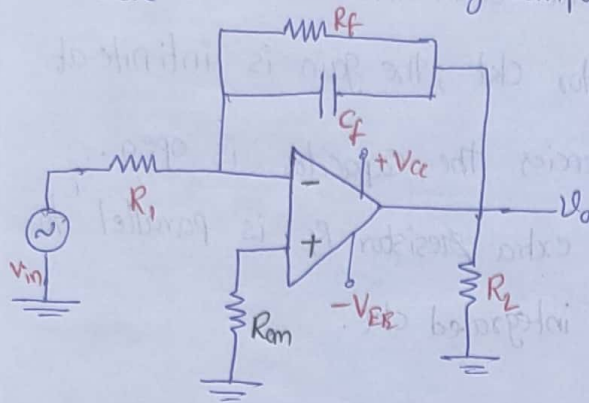
here $f_a < f_b$

$f_a = \frac{f_b}{10}$ → Practically (minimum 10 times less)

* if the timeperiod of 'T' ^(i/p signal) is should higher than $R_f C_f$, Then this is a perfect integrated ckt.

Applications

* These are used in analog computers, and ADC.



1/07/2021

* Designing an integrator ckt using op-amp which can integrate an i/p signal containing frequencies down to 500Hz. It has a gain of 0.1 at $f = 10\text{kHz}$.

Sol:-

$$f_{min} = 10 f_b$$

$$f_b = \frac{f_{min}}{10} = \frac{500}{10} = 50\text{Hz}$$

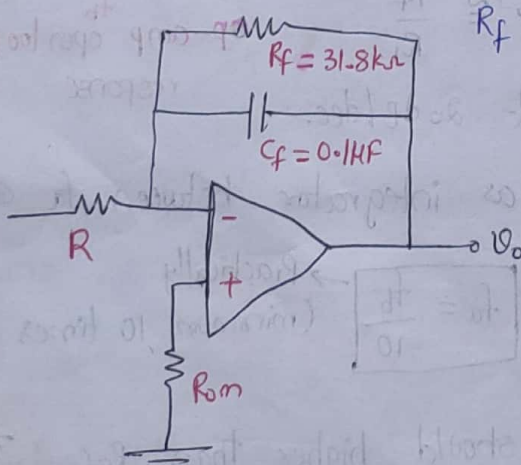
$$f_b = \frac{1}{2\pi R_f C_f} \Rightarrow R_f = \frac{1}{2\pi f_b C_f}$$

Choose $C_f < 1\mu\text{F}$

$$\text{Let } C_f = 0.1\mu\text{F}$$

$$f_b = \frac{1}{2\pi R_f C_f} \Rightarrow R_f = \frac{1}{2\pi f_b C_f}$$

$$R_f = \frac{1}{(2\pi)(50)(0.1\mu)} = 31.8\text{k}\Omega$$



Now we have to find
\$R\$ and \$R_{om}\$.

Given gain = 0.1 at $f = 10\text{kHz}$, we know $f_b = 50\text{Hz}$

$$|A_{CL}| = \frac{f_a}{f}$$

$$0.1 = \frac{f_a}{10\text{K}}$$

$$f_a = 1\text{KHz}$$

$$\text{here } f_a = \frac{1}{2\pi R C_f}$$

$$R = \frac{1}{2\pi f_a C_f}$$

$$R = \frac{1}{(2\pi)(1\text{K})(0.1\mu)} = 1.5\text{K}\Omega$$

$$\therefore R = 1.5\text{K}\Omega$$

$$\text{we know } R_{om} = R_f \parallel R_f$$

$$= (1.5\text{K}) \parallel (31.8\text{K}) = 1.43\text{K}\Omega$$

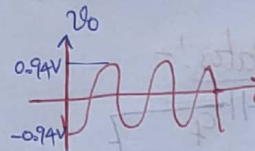
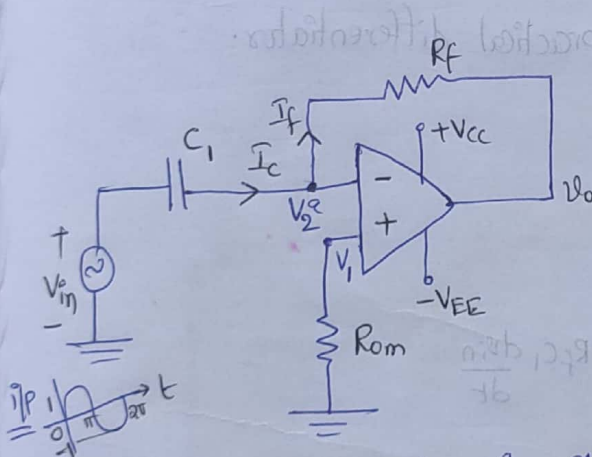
$$\therefore R_{om} = 1.43\text{K}\Omega$$

(R_{om} = parallel of all resistors present

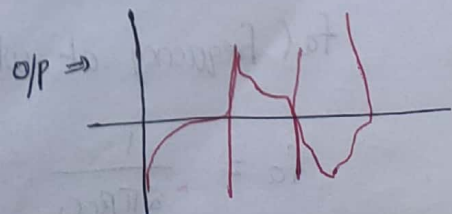
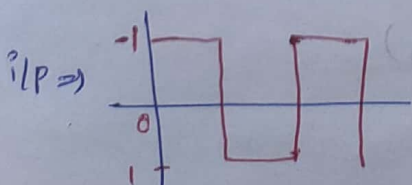
at the i/p side of the op-amp.)

The differentiator:-

- * It is opposite to the integrator.
- * The o/p waveform is the derivative of i/p waveform.



- * here the i/p resistor is replaced with capacitor
- * Suppose we apply sin wave as i/p waveform, then we get cosine as o/p waveform.
- * Suppose if i/p is square waveform, then the o/p is impulse function.



the o/p expression is

$$V_o = -R_f C_1 \frac{dV_i}{dt}$$

At node a

$$I_c = I_f$$

$$C_1 \frac{d(V_{in} - V_2)}{dt} = \frac{V_2 - V_o}{R_f}$$

by virtual ground $V_2 = 0$.

$$\text{Now } C_1 \frac{dV_{in}}{dt} = \frac{-V_o}{R_f}$$

$$\therefore \frac{dV_{in}}{dt} (-R_f C_1) = V_o$$

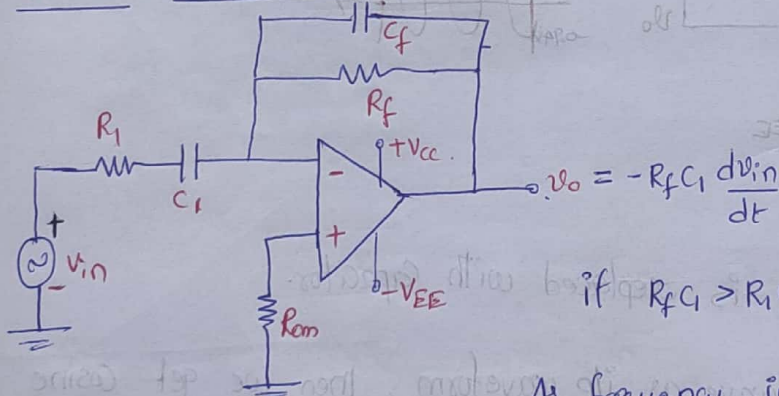
$$V_o = -R_f C_1 \frac{dV_{in}}{dt}$$

In ideal differentiator ckt some drawbacks are there.

* The ideal differentiator is unstable at high frequencies.

That's why we are going to practical differentiator.

Practical differentiator:-



if $R_f C_1 > R_1 C_1$ (or) $R_f C_f$

As frequency increases $\frac{R_f}{X_{C_1}} \uparrow$ so

gain $\uparrow$, ckt becomes unstable. (for ideal)

* as X_{C_1} is $\downarrow$ with frequency $\uparrow$

f_a (frequency at which gain 0dB)

$$f_a = \frac{1}{2\pi R_f C_1}$$

→ f_c is unit gain bandwidth of op-amp.

→ if applied frequency is between " f to f_b " → gain ↑ @ 20dB/dec.

after ' f_b ' → gain ↓ @ 20dB/dec.

Total 40dB/dec is given by $R_f C_f$ & $R_i C_i$

$$\therefore f_b = \frac{1}{2\pi R_i C_i}$$

(or)

$$f_b = \frac{1}{2\pi R_f C_f}$$

Break

or

cutoff frequency

→ $R_i C_i / R_f C_f$ reduce gain at higher frequencies.

Range : $f_a < f_b < f_c$ → for perfect differentiator, i/p 'T' should

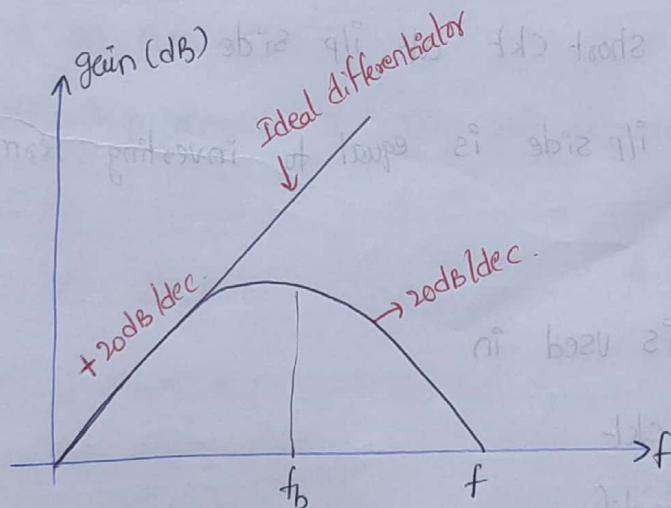
be

$$T \geq R_f C_f$$

$T \rightarrow$ Time period

$\therefore f_a =$ minimum frequency

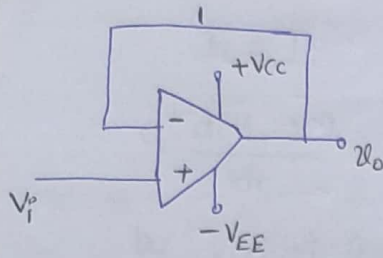
$$f_b = 2\omega f_a$$



frequency response of differentiator

2/07/2021

Voltage follower:- * This voltage follower is unity gain amplifier.



* it has very large impedance.

* The inverting terminal is shorted with output.

* The name is indicated that o/p voltage is replica of i/p.

$$V_o = V_i$$

* This ckt is modified non-inverting amplifier.

Gain of non-inverting amplifier is $1 + \frac{R_f}{R}$.

$$A = 1 + \frac{R_f}{R}$$

if $R_f = 0$ the gain becomes unity. ($A=1$).

$$V_o = A V_i$$

$$V_o = 1 \cdot V_i$$

$$V_o = V_i$$

due to the virtual short ckt at i/p side

* voltage at i/p side is equal to inverting terminal voltage.

$$\therefore V_o = V_i$$

This voltage follower is used in

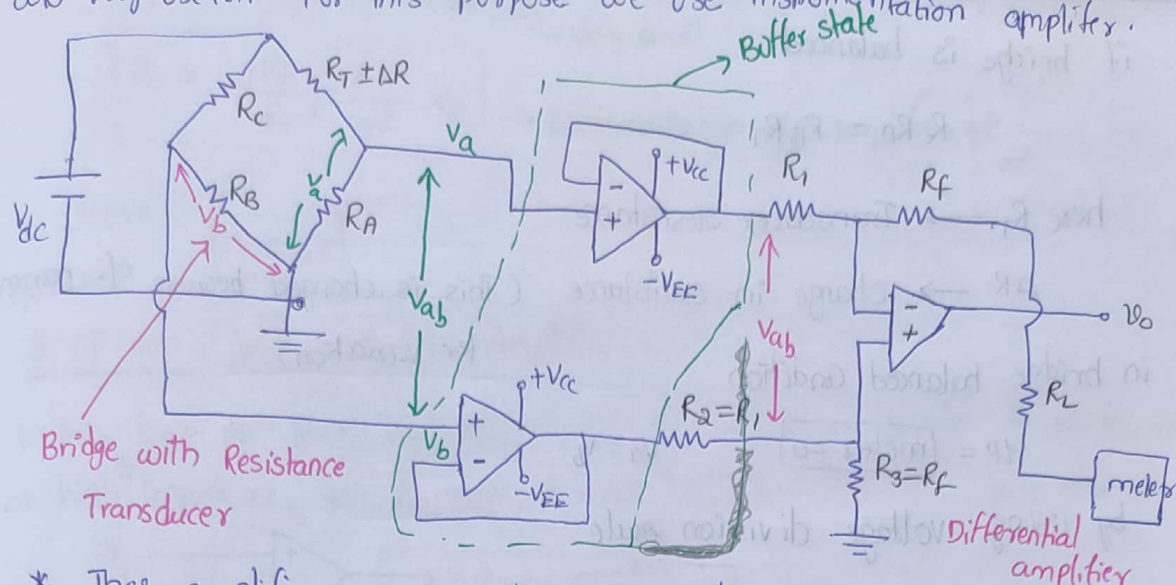
(a) sample and hold ckt

(b) Instrumentation Amplifier.

Instrumentation Amplifier:-

* In many instrumentation applications we will have very low signals from the sensors or transducers and then we have to amplify that signals and then we have to read that signals either controlling or

measurement purpose, at the output. so, in such situations op-amp are very useful. For this purpose we use instrumentation amplifier.



* These amplifiers are used in several applications.

- (i) motor controlling
- (ii) data acquisition
- (iii) automotive cks.

* These amplifiers are used in industrial and consumer applications.

* The major application is for amplifying the low level o/p signals of the transducers so that it can drive the indicate and displays.

* based on our requirement it has finite, accurate and stable gain.

* second requirement is ^{to} easy gain adjustability. in order to our.

* features:-

- (i) high gain accuracy
- (ii) high common mode Rejection Ratio
- (iii) high gain stability with
- (iv) low dc offset voltage
- (v) low power consumption
- (vi) high slew rate
- (vii) high i/p impedance
- (viii) low o/p impedance

* There are specially designed op-amps such as

⇒ A725 op-amp that satisfied the requirements which are discussed above.

From bridge ckt

if bridge is balanced

$$R_c R_A = R_B R_T$$

here $R_T \rightarrow$ Transducer resistance

$\Delta R \rightarrow$ change in resistance. (This is changed because of parameter variation).

in bridge balanced condition

$$o/p = \boxed{\text{meter} = 0}$$

$$V_a = V_b$$

by using voltage division rule

$$V_a = \frac{R_A}{R_A + R_T} V_{dc}$$

||y

$$V_b = \frac{R_B}{R_B + R_c} V_{dc}$$

$$o/p = 0$$

if there is changes in resistance (ΔR) due to parameter variation

$$\text{Now } V_a = \frac{R_A V_{dc}}{R_A + (R_T \pm \Delta R)}$$

$(V_a \downarrow \text{ due to change in } R)$

$$V_b = \frac{R_B V_{dc}}{R_B + R_c}$$

(No change)

$$V_{ab} = V_a - V_b$$

$$V_{ab} = \frac{R_A V_{dc}}{R_A + (R_T \pm \Delta R)} - \frac{R_B V_{dc}}{R_B + R_c}$$

if $R_A = R_B = R_c = R_T = R$

$$\text{Now } V_{ab} = \frac{R V_{dc}}{2R \pm \Delta R} - \frac{R V_{dc}}{2R}$$

$$\Rightarrow \frac{2R V_{dc} - 2R V_{dc} - \Delta R V_{dc}}{2(2R \pm \Delta R)}$$

$$\boxed{V_{ab} = \frac{-\Delta R V_{dc}}{2(2R \pm \Delta R)}}$$

$$V_o = \left(\frac{-R_f}{R} \right) V_{ab}$$

$$V_o = \frac{R_2}{R_1} (V_2 - V_1) = -\frac{R_2}{R_1} (V_1 - V_2) = -\frac{R_2}{R_1} V_1 + \frac{R_2}{R_1} V_2$$

(by difference amplifier)

$$V_0 = \left(-\frac{R_f}{R} \right) \frac{-(\Delta R) V_{dc}}{2(2R + \Delta R)} \rightarrow \text{very small}$$

$$\therefore V_0 = \left(\frac{R_f}{R_1} \right) \frac{\Delta R}{4R} V_{dc} \rightarrow \text{Instrumentation amp amplifier o/p.}$$

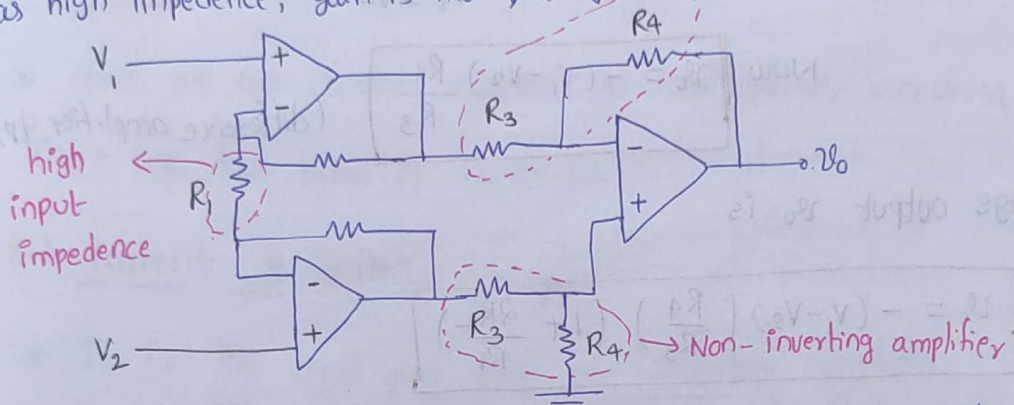
here

$$V_0 \propto \Delta R$$

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3-op amp instrumentation Amplifier:-

* This type of instrumentation amplifier can give special features, such as high ^{ill} impedance, gain is more, it rejects the common mode noise also.



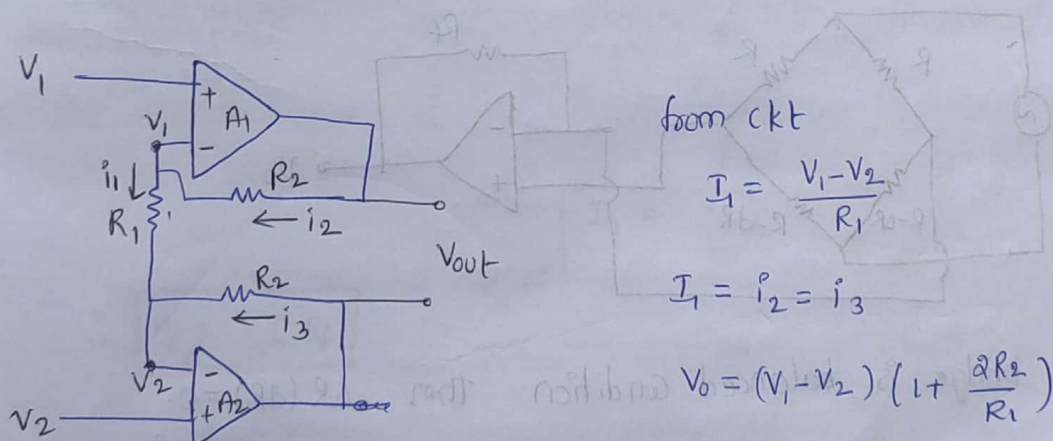
* It can put high pass filter and the low pass filter at the outputs.

* special features are

(i) high i/p. impedance (ii) high gain

(iii) It rejects the common mode noise.

Stage (I):-



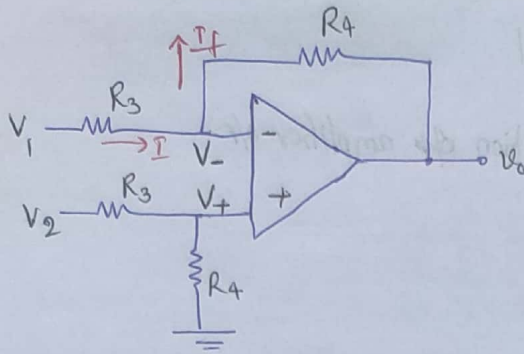
we know non-inverting gain is

$$\left(1 + \frac{R_f}{R} \right)$$

$\therefore$ first stage output is

$$V_0 = (V_1 - V_2) \left(1 + \frac{2R_2}{R_1} \right)$$

2nd stage:-



voltage at non-inverting terminal

$$V = V_+ = \frac{V_2 \cdot R_4}{R_3 + R_4}$$

voltage at inverting terminal

$$I_f = I \Rightarrow \frac{V_1 - V_-}{R_3} = \frac{V_- - V_0}{R_4}$$

by virtual ground concept

$$V_+ = V_-$$

Now

$$V_0 = -(V_1 - V_2) \frac{R_4}{R_3}$$

(difference amplifier o/p)

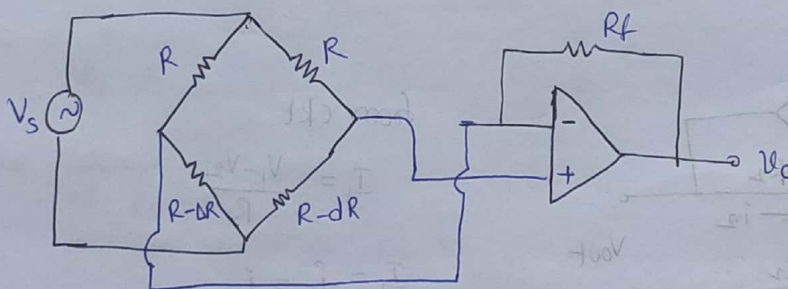
second stage output V_0 is

$$V_0 = -(V_1 - V_2) \left(\frac{R_4}{R_3} \right) \left(1 + \frac{2R_2}{R_1} \right)$$

$$V_0 = (V_2 - V_1) \left(\frac{R_4}{R_3} \right) \left(1 + \frac{2R_2}{R_1} \right)$$

Applications :-

① Strain gauge:-



* when bridge is balanced condition then $\Delta R (\delta R) = 0$.

* when bridge is unbalanced condition then $\Delta R \neq 0$.

* The bridge is unbalanced because of strain.

* due to some strain the bridge is unbalanced. (R will vary)

* The o/p of difference amplifier is proportional to ΔR signal.

② Thermistors

* These are used for temperature measurement.

③ Photo detector:- and LDR (light dependent Resistor):-

* The resistance is depending upon light.

④ Measurement of flow:-

⑤ Thermal conductivity:-

Converstors:-

* Here we can Convert Current to voltage or viceversa.

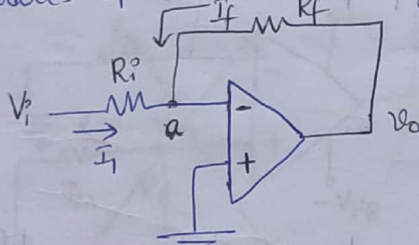
There are two types of Converstors.

(a) Current to Voltage Converter:-

* It is the modifying ckt of inverting amplifier.

* here i/p is current and o/p is voltage.

* This ckt takes the current from the sensor or transducer and which produces a proportional o/p voltage.



$$V_o = -\frac{R_f}{R_i}(V_i)$$

$$V_o = -\frac{V_i}{R_i}(R_f)$$

$$I_i = \frac{V_i - V_a}{R_i} \quad (\because V_a \approx 0 \text{ due to virtual ground})$$

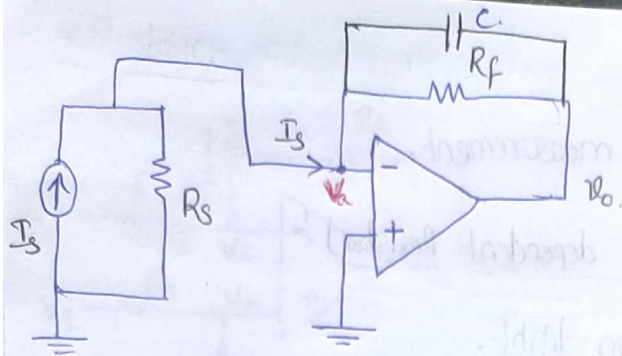
$$I_i = \frac{V_i}{R_i}$$

$$\therefore V_o = -I_i R_f$$

$$\frac{V_o}{I_i} = R_m = \text{Trans resistance gain.}$$

* This converter is also called as Trans resistance amplifier.

The actual ckt of current to voltage converter is



$V_a = 0$ (virtual ground)

$I = 0$ (because R_s very high)

* here $R_s \Rightarrow$ one end is connected to physical ground,
 $\Rightarrow$ another end is connected to virtual ground

* IT is used for photo electric devices.

* IT gives the current proportional to incident light energy.

$V_a = 0$, $I = 0$ as R_s .

$$\therefore I_s + I_f = 0 \quad (\text{at node } a)$$

$$I_s = -I_f$$

$$I_s + \frac{V_o - V_a}{R_f} = 0 \quad (V_a = 0)$$

$$\frac{V_o}{R_f} = -I_s$$

$$V_o = -I_s R_f$$

$$\therefore V_o \propto I_s$$

* Here the Capacitor is used for the purpose of high frequency noise signals.

(b) Voltage to Current Converter:-

* ~~input~~ This converter is also called as transconductance amplifier.

* It converts the voltage into current.

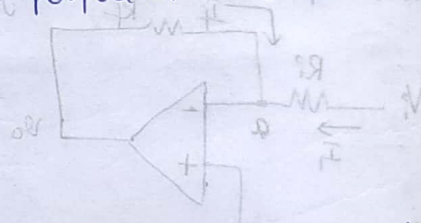
* The voltage is taken from the sensor or transducer output and which produces a proportional current.

* It is also called as voltage dependent current source.

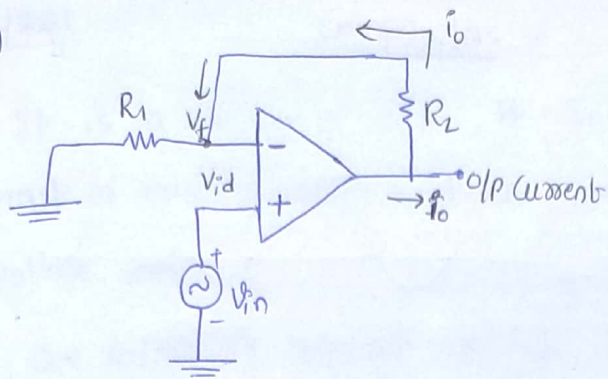
$\Rightarrow$ This is again two types

(i) Floating Ground (Load is floated)

(ii) Grounded Load



(i)



$$V_{in} = V_f \text{ (virtual ground)}$$

$$\text{here } V_f = I_o R_L \text{ and } I_o$$

$$I_o = \frac{V_f}{R_L}$$

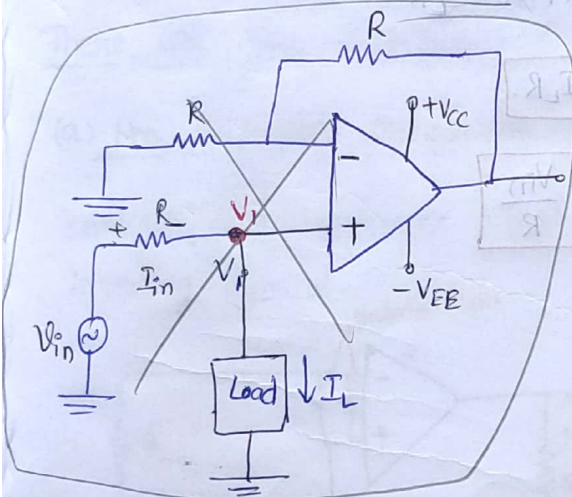
$$I_o = \frac{V_{in}}{R_L}$$

V.I. Converter

* It is used for low voltage AC, DC voltmeters.

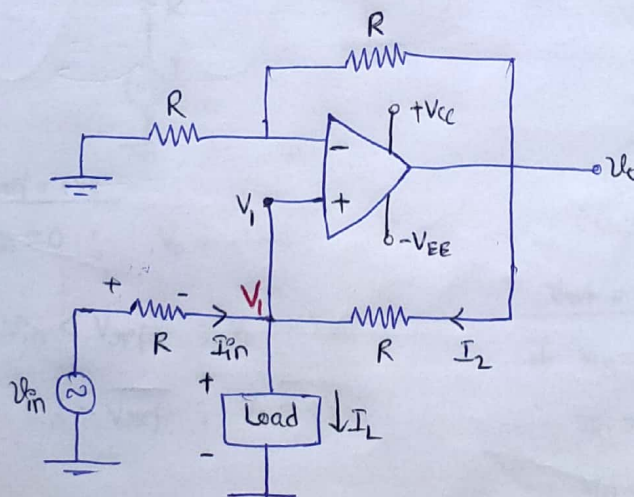
* It is used in LED's and zener diode tester.

(ii) Grounded Load:-



apply KCL at node

$$I_L =$$



apply KCL at node V_1

$$I_L = I_{in} + I_2$$

$$\text{here } I_L = \frac{V_{in} - V_1}{R} + \frac{V_o - V_1}{R}$$

$$I_L R = V_{in} - V_1 + V_o - V_1$$

$$I_L R = V_{in} + V_o - 2V_1$$

$$2V_1 = -I_L R + V_{in} + V_o$$

$$\therefore V_1 = \frac{V_{in} + V_o - I_L R}{2}$$

V_1 is applied at non-inverting terminal.

$$\Rightarrow \text{The o/p of non-inverting amplifier} \Rightarrow \left(1 + \frac{R}{R}\right) V_1$$

$$= 2V_1$$

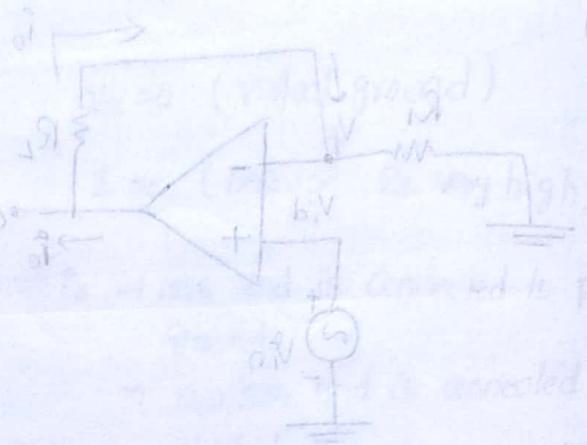
$$= 2 \left(\frac{V_{in} + V_o - I_L R}{2} \right)$$

$$\text{o/p} \Rightarrow V_o = V_{in} + V_o - I_L R$$

$$\therefore V_{in} = I_L R$$

$$\therefore I_L = \frac{V_{in}}{R}$$

— ○ —

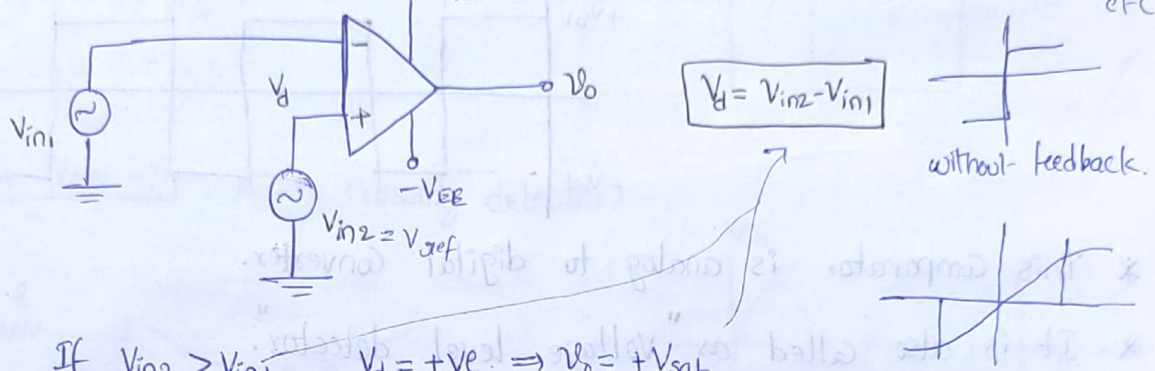


$$\frac{V_o}{R} = I_L$$

* It is an electronic ckt, it compares ^{two} signal voltages on one input of op-amp with a known voltage that is called reference voltage.

* One voltage is applied voltage, other one is reference input.

* These are used in digital interfaces, discriminators, voltage level detector etc.



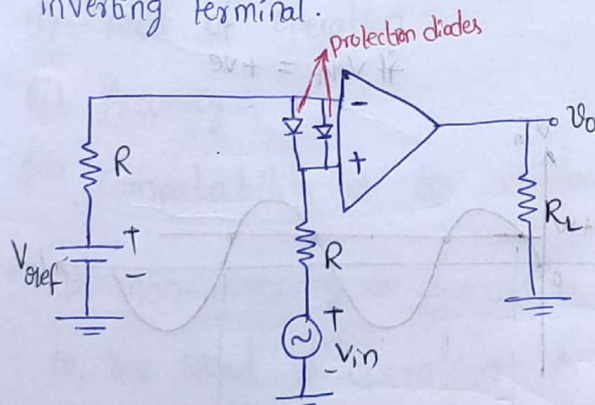
If $V_{in2} > V_{in1}$ $V_d = +ve \Rightarrow V_o = +V_{sat}$

If $V_{in1} > V_{in2}$ $V_d = -ve \Rightarrow V_o = -V_{sat}$

* These comparators are used in digital interfaces, discriminators, voltage level detector, oscillator.

There are two configurations of comparators.

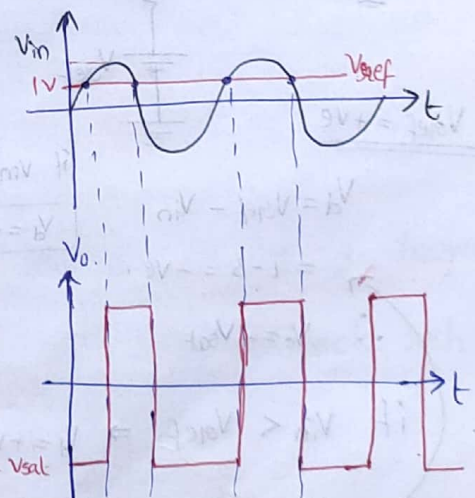
(a) Non-Inverting Comparator:- An input is applied at non-inverting terminal and reference signal is given at inverting terminal.



$V_{ref} = +ve$
if $V_{in} = 0$; $V_o = -V_{sat}$

(i) $V_{in} < V_{ref}$; $V_o = -V_{sat}$

(ii) $V_{in} > V_{ref}$; $V_o = +V_{sat}$

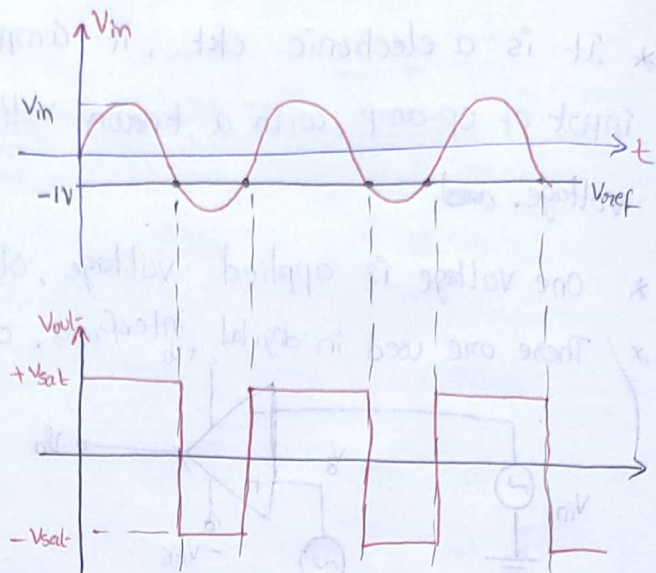


$V_{ref} = -ve$
if $V_{in} = 0$; $V_o = +V_{sat}$

$V_{in} > V_{ref}$; $V_o = +V_{sat}$

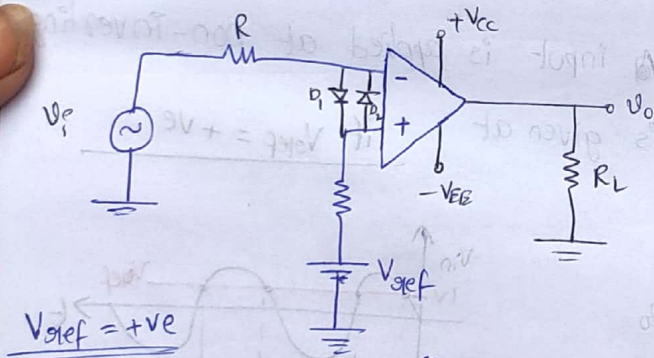
$V_{in} < V_{ref}$; $V_o = -V_{sat}$

If $V_{ref} = -ve$.



- * This Comparator is analog to digital Converter.
- * It is also called as "Voltage level detector".
- * The protection diodes are used to clamp the i/p waveform.
(0.7V (or) -0.7V)

(b) Inverting Comparator:- Here the reference voltage is applied at non-inverting terminal and i/p is applied at inverting terminal.



$V_{ref} = +ve$

$$V_d = V_{ref} - V_{in}$$

$$= 1 - 3 = -ve$$

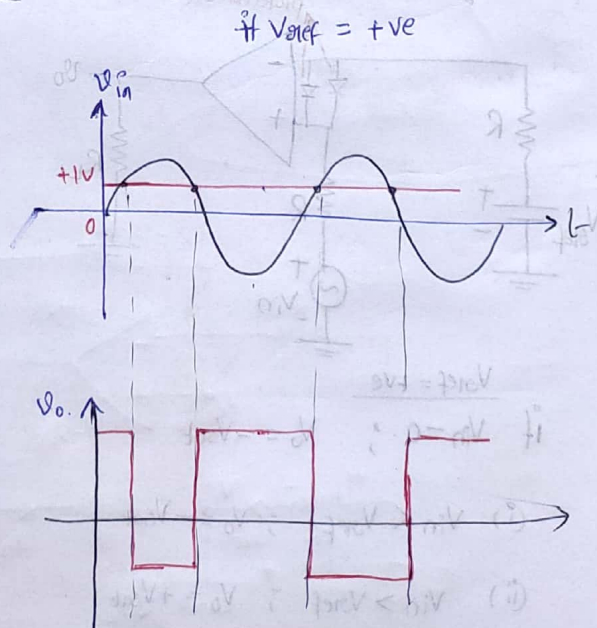
$$\therefore V_o = -V_{sat}$$

$$\text{if } V_{in} < V_{ref} \Rightarrow V_d = +V_{sat}$$

$$V_{in} > V_{ref} \Rightarrow V_d = -V_{sat}$$

if $V_{in} = 0$.

$$V_d = +V_{sat}$$



$$V_{ref} = -V_e$$

$$V_d = -V_{ref} - V_{in}$$

if $V_{in} = 0$.

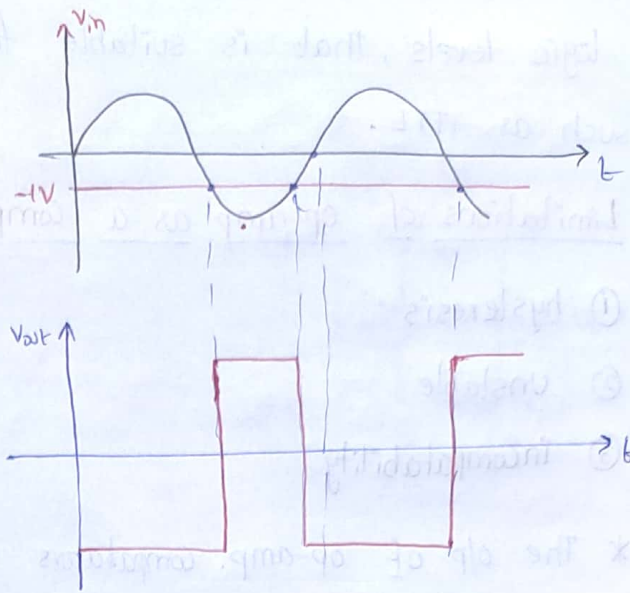
$$V_d = -V_{ref} = +V_{sat}$$

(i) if $V_{in} < V_{ref}$.

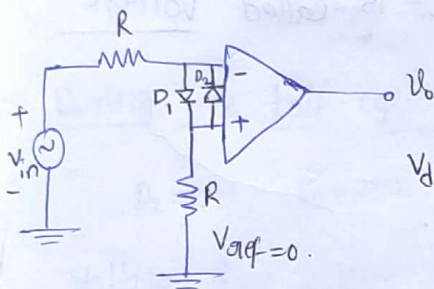
$$V_d = +V_{sat}$$

(ii) if $V_{in} > V_{ref}$.

$$V_d = -V_{sat}$$



With $V_{ref} = 0$:- (Zero Crossing detector)



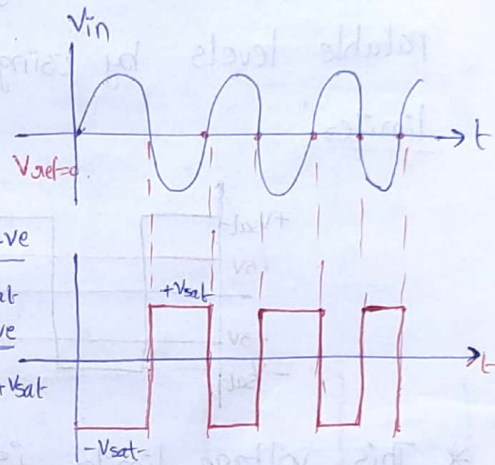
$$V_d = V_{ref} - V_{in} \\ = 0 - V_{in}$$

if $V_{in} = +ve$

$$V_d = -V_{sat}$$

if $V_{in} = -ve$

$$V_d = +V_{sat}$$



* This ckt is called zero crossing detector.

* This zero crossing detector is also called as a sin to square wave converter. (because the output is perfect square wave).

Comparator characteristics:-

(i) Speed of operation

(ii) Accuracy

(iii) Compatibility of o/p waveform

* In non-inverting comparator the o/p waveform is rapidly changes so, the speed of operation is improved with +ve feedback, such circuit is called a schmitt trigger.

* In inverting configuration, accuracy is based on offset parameters such as gain, common mode rejection ratio (CMRR).

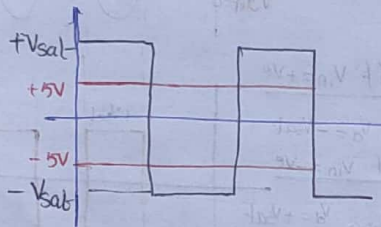
* In zero crossing detector, the o/p of comparator circuit is

logic levels, that is suitable for a certain logic families such as TTL.

Limitations of op-amp as a Comparator:

- ① hysteresis
- ② unstable
- ③ incompatibility

* The o/p of op-amp comparators should be matched with logic families, but due to high voltage swing, we have to limit to a compatible levels by using the diodes that is called "Voltage limiter".
(zener)



* This voltage limiter is special part of comparator, because of Voltage limiter.

* This voltage limiter is special part of comparator, as the comparator ckt which provides either $+V_{sat}$, $-V_{sat}$ as its output waveform. But to give this o/p to a next stage we have to limit the o/p waveform.

* If we give o/p waveform without limiting, it is not comfortable (suitable) with a particular logic family such as TTL.

* But it requires "TTL" (+5V/0V)

* To keep the output voltage swing within this specific limits, the op-amps are used with externally wired components. (those are diodes, zener diodes).

9/07/2021

(a) operation (with two zener diodes)

During +ve $\frac{1}{2}$ cycle of i/p, (o/p is -ve).

D_1 is ON & D_2 = OFF.

* In forward condition the zener diode is like ordinary diode.

$$D_1(\text{drop}) \Rightarrow V_{D1} = 0.7V \quad | \quad D_2 \Rightarrow V_{D2} = V_{Z2}$$

Reverse bias

$$\therefore \text{o/p} = -[+(V_{D1} + V_{Z2})] = -(V_{D1} + V_{Z2})$$

indicating inverting amplifier.

During -ve half cycle:- (o/p is +ve)

D_2 = ON, D_1 = OFF.

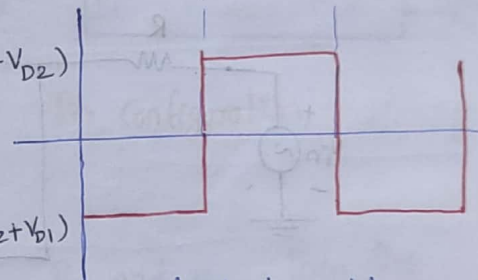
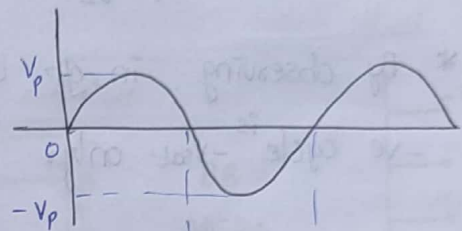
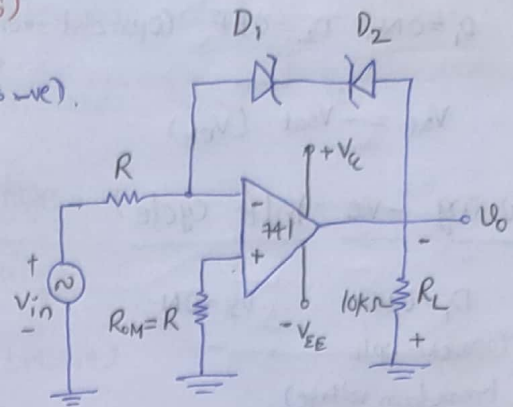
Voltage drop across D_1 is V_{Z1} .

Voltage drop across D_2 is V_{D2} .

$$\therefore \text{o/p} = -[-(V_{Z1} + V_{D2})]$$

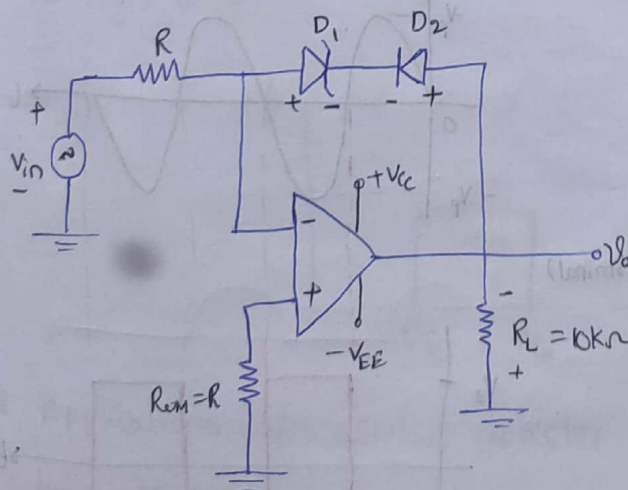
$$= (V_{Z1} + V_{D2})$$

$\therefore$ The o/p is limited between $-(V_{D1} + V_{Z2})$ and $(V_{Z1} + V_{D2})$



Two level clipper ckt

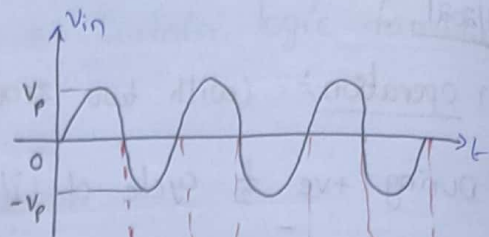
(b) with zener diode and ordinary diode



During +ve half cycle :-

$D_1 = \text{ON}, D_2 = \text{OFF}$ (open ckt $\rightarrow$ ordinary diode).

$$V_{out} = -V_{sat} \quad (V_{D1})$$

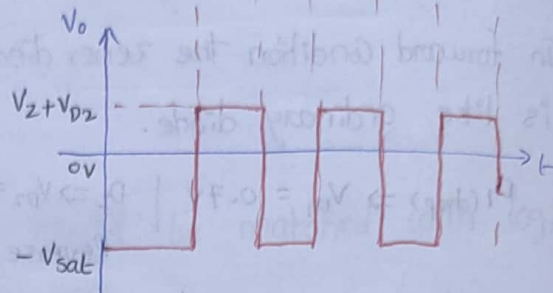


During -ve half cycle :-

$D_1 = \text{OFF}, D_2 = \text{ON}$
(open ckt upto breakdown voltage).

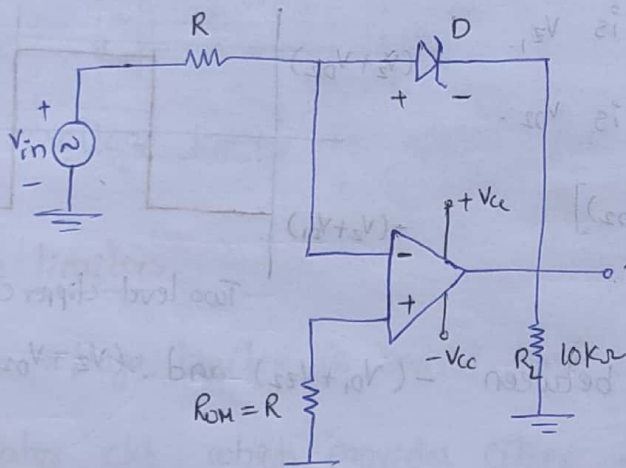
$$\therefore o/p = -(- (V_{Z1} + V_{D2}))$$

$$o/p = V_{Z1} + V_{D2}$$



* By observing, in op waveform only +ve cycle is limited and -ve cycle is $-V_{sat}$ only.

(c) with only one zener diode :-

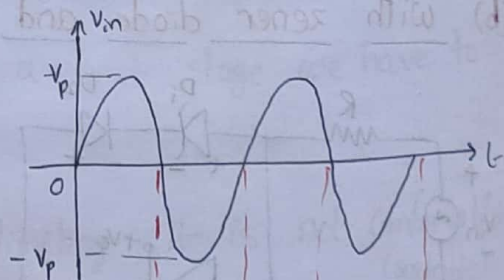


During +ve half cycle :-

$D = \text{ON}$

$$o/p = -0.7$$

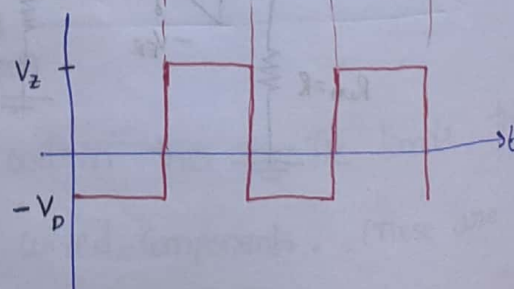
$o/p = V_D = -0.7$ (if is applied at inverting terminal)



During -ve half cycle :-

$D = \text{OFF}$

$$o/p = -(-V_Z) = V_Z$$



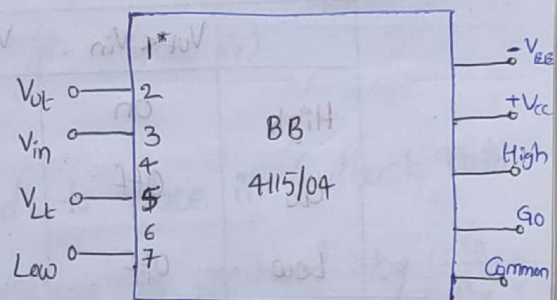
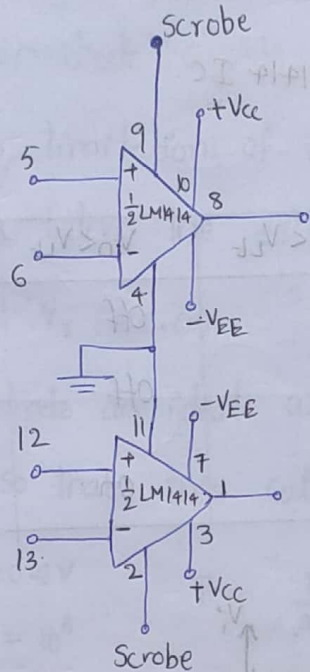
Window detector:

- * Sometimes there is a need to determine when an unknown input is between two precise reference thresholds V_{UT} and V_{LT} .

V_{UT} → Upper threshold voltage

V_{LT} → Lower threshold voltage

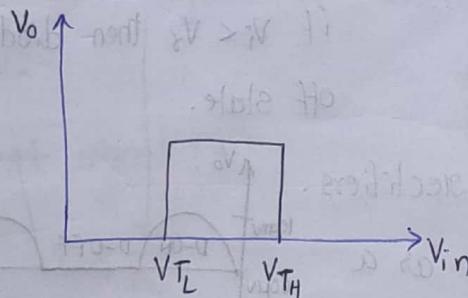
- * This is the basic dual Comparator. (LM1414)



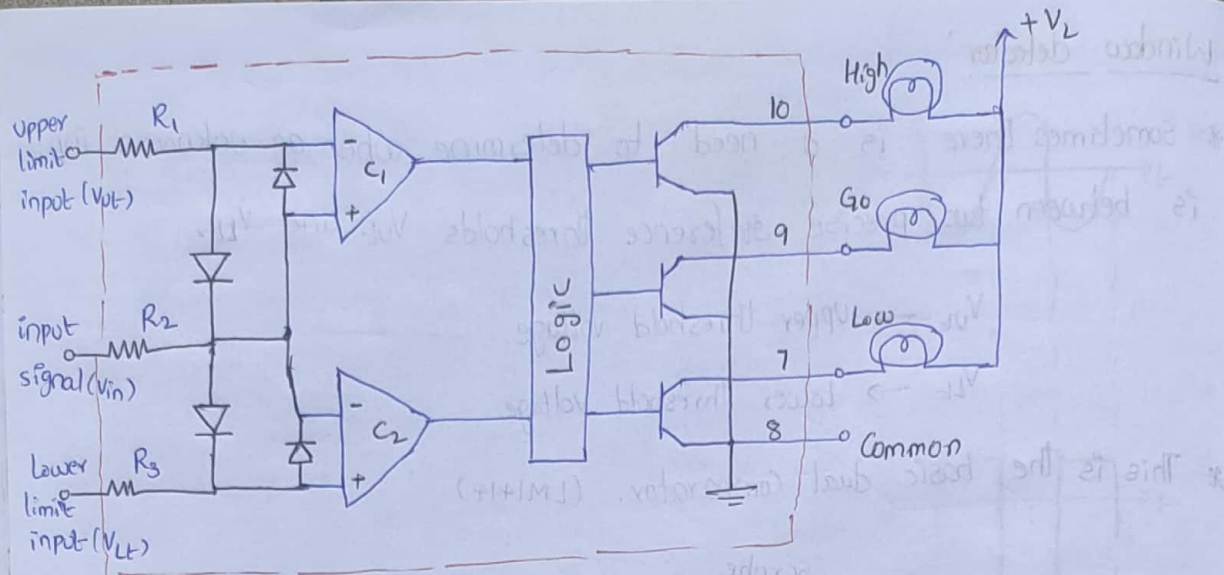
Pin Configuration

- * If the input signal (V_{in}) is in between V_{UT} and V_{LT} then the o/p goes to High G_O .

- * If the input signal (V_{in}) is above threshold voltage then the o/p is High value.



- * Applications of window detector is industrial areas, level detectors, digital computers, production line testing.

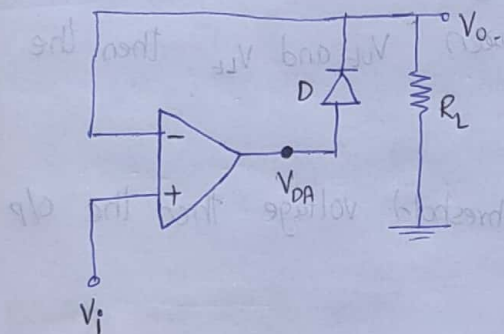


Internal structure of LM1414 IC.

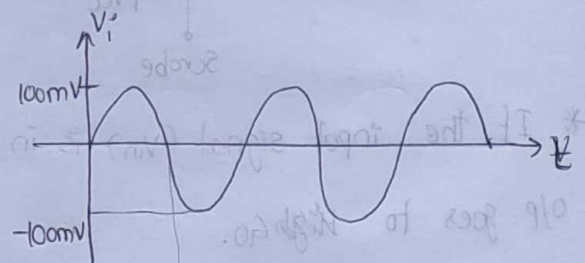
Truth table :-

	$V_{ut} < V_{in}$	$V_{lt} < V_{in} < V_{Lt}$	$V_{in} < V_{Lt}$
High	on	off	off
Go	off	on	off
Low	off	off	on

Precision Rectifiers



$V_r \rightarrow$ cutting voltage

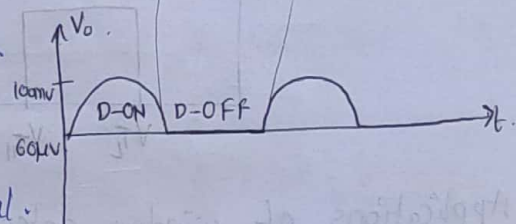


if $V_i \geq V_r$ then ordinary diode becomes conduction state.

if $V_i < V_r$ then diode remains in off state.

* Diodes are used as a rectifiers.

* Ordinary diode can act as a rectifier for a stronger of ac signal.



strong ac signal $\rightarrow$ 230V, 50Hz (or) 12V-0-12V

* Rectifier converts the ac signal into pulsating dc.

* If the ac signal is in order of mv, μ v, then this type of ordinary diode cannot rectified. (i.e. weak ac signal cannot rectified with ordinary diode).

* For that purpose we use precision rectifiers.

* This precision rectifier can rectify weak ac signals also.

* Using precision diode or super diode we can rectify these weak ac signals.

* The precision diode consists of one op-amp and ordinary diode.

* The major limitation of ordinary diode is, it cannot rectify the voltages below the cutting voltage. (below V_s).

i.e. $V_s (< 0.6V)$

* To make diode an ideal we need to place in feedback path of op-amp, so that this cutting voltage is reduced by $\frac{V_s}{A_{OL}}$.

$\Rightarrow$ if $V_s = 0.6V$
 $A_{OL} = 10^6$ Then $\frac{V_s}{A_{OL}} = \frac{0.6}{10^6} \approx 0.6\mu V$.

$\Rightarrow$ if $V_s = 0.6$
 $A_{OL} = 10^4$ Then $\frac{V_s}{A_{OL}} = \frac{0.6}{10^4} \approx 60\mu V$

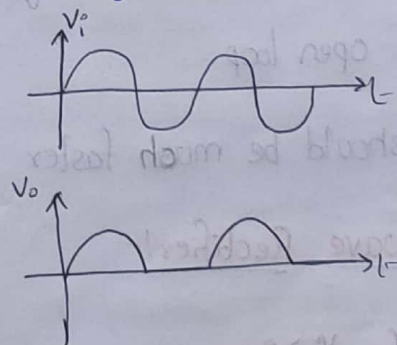
* If input is greater than $60\mu V$, it should be allowed.
 If input is less than $60\mu V$, it is not allowed.

* This precision diode is capable of rectifying the input signals in order of mv.

* If our input signal (V_i)

if $V_i > \frac{V_s}{A_{OL}}$

then $V_o = V_i \rightarrow$ voltage follower



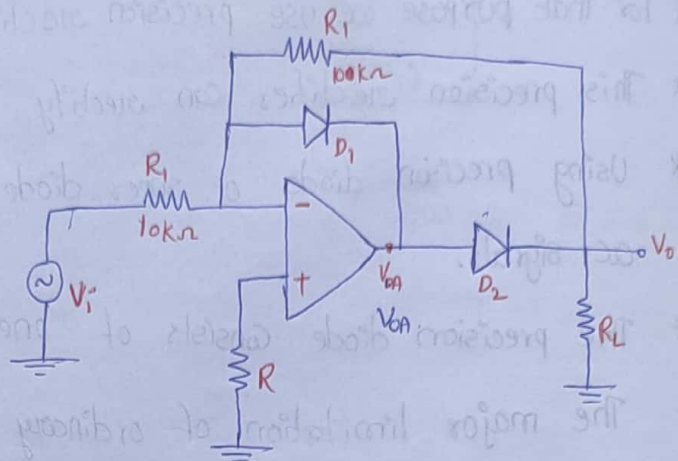
* due to virtual ground concept, V_i is appears at inverting node of op-amp.

if $V_i < \frac{V_r}{A_{OL}}$ (it will not conduct).

$V_i < 60\mu V$ (so it is not allowed).

$$\therefore V_o = 0V$$

a) Half wave rectifier:-

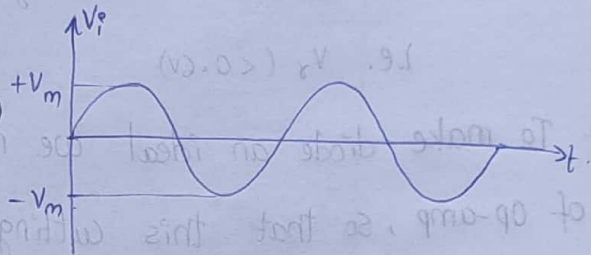


If $V_i \rightarrow +ve$:-

$$V_{OA} = -ve$$

$D_1 \Rightarrow FB$ & $-V_{OA}$ makes $D_2 \Rightarrow RB$. (OFF) (ON)

$$\therefore V_o = 0 \text{ open loop condition}$$



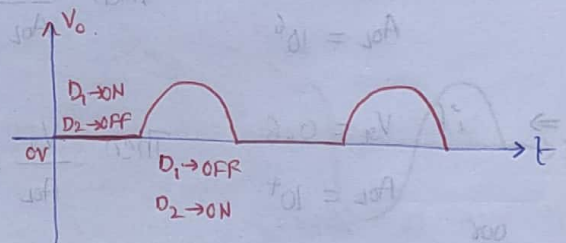
If $V_i \rightarrow -ve$ (or) $V_i < 0$.

$D_2 \rightarrow ON$ & $D_1 \rightarrow OFF$. (OC) (SC)

Now it is like inverting amplifier.

$$V_o = - \left(\frac{-R_f}{R} V_i \right) = \frac{10k}{10k} V_i$$

$$\therefore V_o = V_i \text{ (closed loop condition)}$$



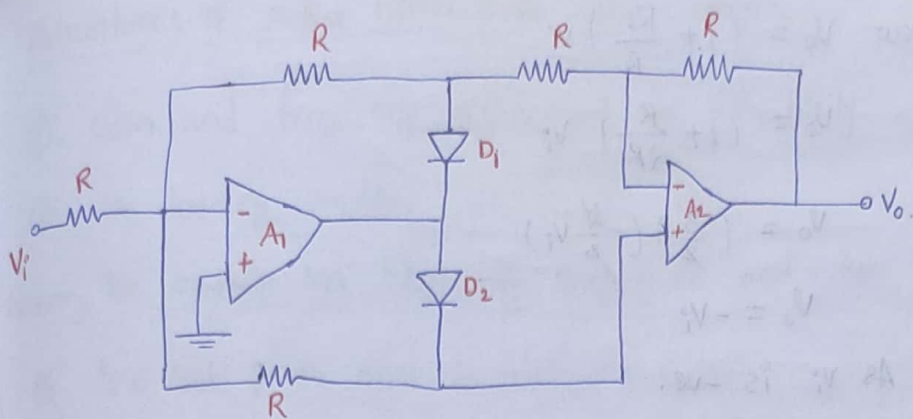
* The output waveform changes from open loop to closed loop then closed loop to open loop.

* It should be much faster, slew rate should be very high.

b) Full wave Rectifier:-

If $V_i > 0$

$D_1 \rightarrow ON$, $D_2 \rightarrow OFF$
(SC) (OC)



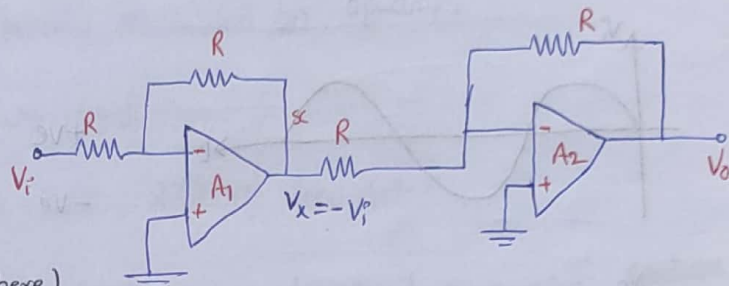
If $V_i > 0$

$D_1 \rightarrow \text{ON}$ $D_2 \rightarrow \text{OFF}$
(SC) (OC)

$$V_x = -V_i$$

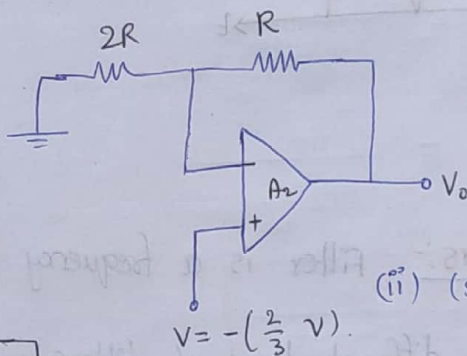
$$V_o = -\frac{R}{R}(-V_i) \quad (R_f = R \text{ here})$$

$$\therefore \boxed{V_o = V_i}$$



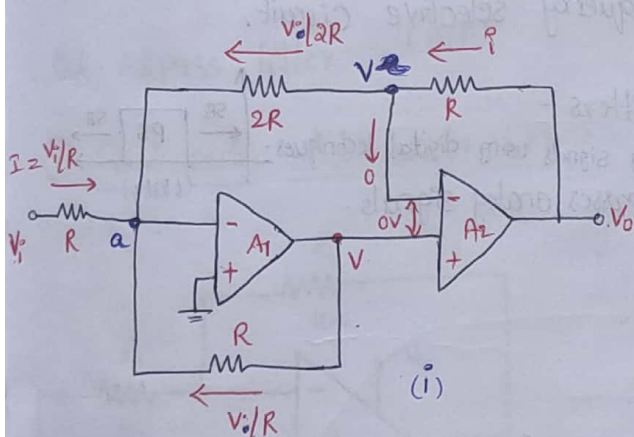
If $V_i < 0$

$D_1 \rightarrow \text{OFF}$ $D_2 \rightarrow \text{ON}$
(OC) (SC)



(ii) (simplified ckt-)

$$V = -\left(\frac{2}{3}\right)V_i$$



Apply KCL at node a

$$\frac{V_i}{R} + \frac{V}{R} + \frac{V}{2R} = 0$$

$$\frac{2V + V}{2R} = -\frac{V_i}{R}$$

$$\frac{3V}{2R} = -\frac{V_i}{R}$$

$$\boxed{V = -\frac{2}{3}V_i}$$

we know $V_o = (1 + \frac{R_f}{R}) V_i$

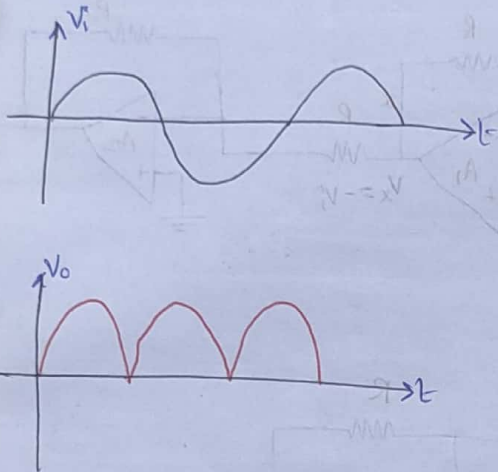
$$V_o = (1 + \frac{R}{2R}) V_i$$

$$V_o = (\frac{3}{2}) (-\frac{R}{3} V_i)$$

$$V_o = -V_i$$

As V_i is -ve.

$$\therefore V_o = V_i$$



+ve cycle $V_o = V_i$
-ve cycle $V_o = -V_i$

12/07/2021

Active Filters:- Filter is a frequency selective circuit.

There are different types of filters:-

- ① Analog or digital filter $\rightarrow$ passes analog signals.
- ② Passive or active filter
- ③ Audio (AF) or Radio (RF)

② Passive:- Here we are using passive components (R, L, C)

By using only passing elements $\rightarrow$ passive filter.

Active:- Active elements are (~~Transformer~~, Transistors, op-amp).

③ Audio (AF):- Generally the RC filters are commonly used for Audio frequencies (or) low frequencies. (R, C) and for high frequencies we are using LC filter and crystal filter.

Advantages of Active filters over passive filters:-

① Gain and frequency adjustment is flexibility.

② No loading problem

because of The op-amp has high i/p impedance and low o/p impedance

③ less Cost & No need to use an inductor.

* If we use inductor, it may effect the ^{other} components by its magnetic field. That's why it is purely restricted on op-amps.

④ size and weights are reduced.

* Due to availability of IC's, different low cost

* These are used in communications and signal processing.

① Low pass filter (LPF)

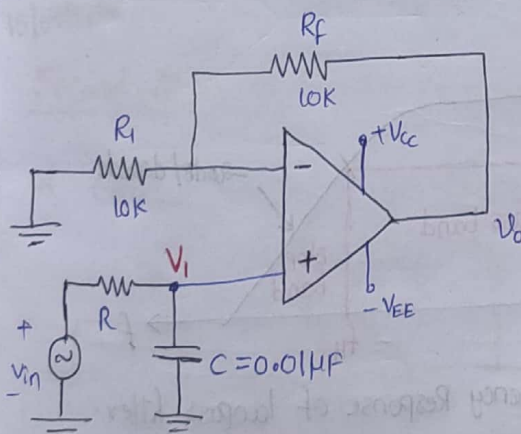
② High Pass filter (HPF)

③ Bandpass filter (BPF)

④ Bandstop filter (BSF)

⑤ Allpass filter (APF)

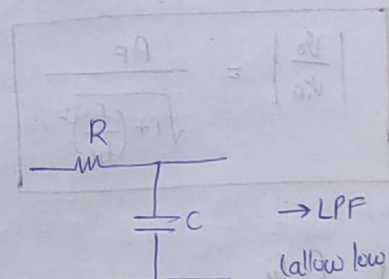
① First order Butterworth LPF:-



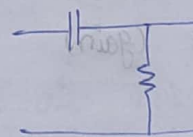
at +ve terminal:-

$$V_i = \frac{-jX_c}{R - jX_c} (V_{in})$$

$$X_c = \frac{1}{2\pi f C}$$



→ LPF
(allow low frequencies
and rejects high
frequencies)



→ HPF

$$V_1 = \frac{-\frac{j}{2\pi f C}}{R - \frac{j}{2\pi f C}} (V_{in}) = \frac{-\frac{j}{2\pi f C}}{-j + R2\pi f C} (V_{in})$$

$$\therefore \frac{V_1}{V_{in}} = \frac{-j}{-j + R2\pi f C} = \frac{-j}{j(1 - \frac{R2\pi f C}{j})} = \frac{1}{1 + j2\pi f R C}$$

$$V_1 = \left(\frac{1}{1 + j2\pi f R C} \right) V_{in}$$

$$V_o = \left(1 + \frac{R_f}{R_i} \right) V_1 \quad \text{we know for Non-inverting amplifier}$$

Now

$$V_o = \underbrace{\left(1 + \frac{R_f}{R} \right)}_{A_f} \left(\frac{V_{in}}{1 + j2\pi f R C} \right)$$

$$A_f = 1 + \frac{R_f}{R} \quad (\text{closed loop gain})$$

$$\frac{V_o}{V_{in}} = \frac{A_f}{1 + j2\pi f R C}$$

$$\left| \frac{V_o}{V_{in}} \right| = \left| \frac{A_f}{1 + j2\pi f R C} \right|$$

$$\therefore \frac{V_o}{V_{in}} = \frac{A_f}{1 + j \frac{f}{f_H}}$$

$$(f_H = \frac{1}{2\pi R C})$$

→ Higher cut-off frequency.

$$\left| \frac{V_o}{V_{in}} \right| = \frac{A_f}{\sqrt{1 + \left(\frac{f}{f_H} \right)^2}}$$

$$\phi = -\tan^{-1} \left(\frac{f}{f_H} \right)$$

if $f < f_H$

$$\left| \frac{V_o}{V_{in}} \right| \approx A_f \quad (\text{gain})$$

if $f = f_H$

$$\left| \frac{V_o}{V_{in}} \right| = \frac{A_f}{\sqrt{2}} = 0.707 A_f$$

if $f > f_H$

$$\left| \frac{V_o}{V_{in}} \right| = \frac{A_f}{\infty} \Rightarrow < A_f$$

$$\left| \frac{V_o}{V_{in}} \right| < A_f$$

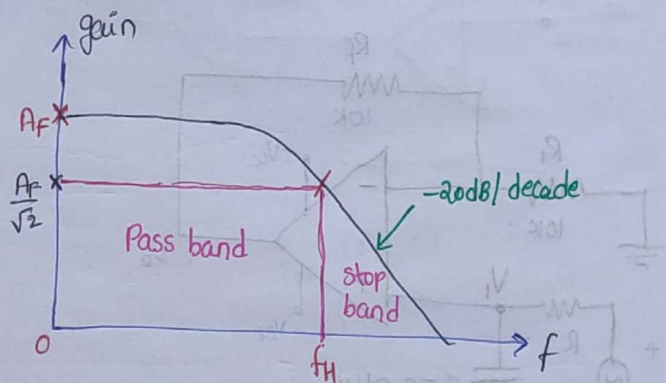


Fig: Frequency Response of lowpass filter.

f_H is called as "cut-off frequency"

(or)
Break frequency

(or)
Corner frequency

Design Procedure:

$f_H = 10\text{KHz}$ & Passband gain 2. (A_F)

$$\Rightarrow f_H = 10\text{KHz}$$

$C = 0.01\mu\text{F}$ [choose cap value less than $1\mu\text{F}$].

we know $f_H = \frac{1}{2\pi RC} \Rightarrow R = \frac{1}{2\pi f_H C} = \frac{1}{2\pi (10\text{K}) (0.01\mu)} = 1.59\text{K}\Omega$.

$$\therefore R = 1.59\text{K}\Omega \text{ for } 10\text{KHz}.$$

To get R_f , $R = 15.9\text{K}\Omega$ for 1KHz .

$$A_F = \left(1 + \frac{R_f}{R_i}\right) = 2.$$

$$\frac{R_f}{R_i} = 1$$

$$R_f = R_i$$

let us take $R_f = R_i = 1\text{K}\Omega$, $R = 20\text{K}\Omega \text{ POT}$ and $C = 0.01\mu\text{F}$.
 $f_H = 1\text{KHz}$

To get $f_H = 1.6\text{KHz}$

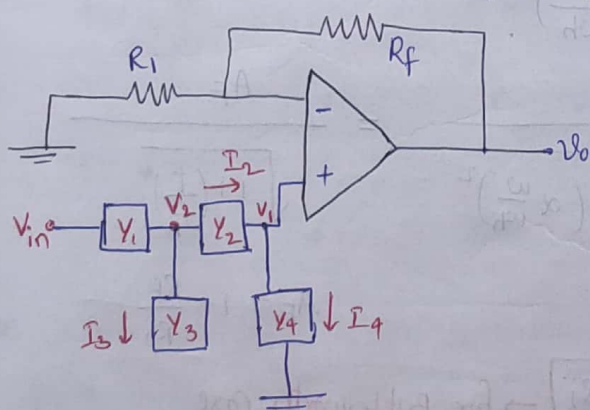
$$\text{factor} = \frac{\text{original } f_H}{\text{New } f_H} = \frac{1\text{KHz}}{1.6\text{KHz}} = 0.625$$

Now we have to multiply this factor to resistor value.

15/07/2021 $R \Rightarrow 0.625 \times 15.9\text{K}\Omega = 9.94\text{K}\Omega \approx 10\text{K}\Omega \text{ POT}$. (POT $\rightarrow$ potentiometer)

Second order low pass Butterworth filter :- -40dB/decade

* General second order lowpass filter is also called as "Sallen-Key".



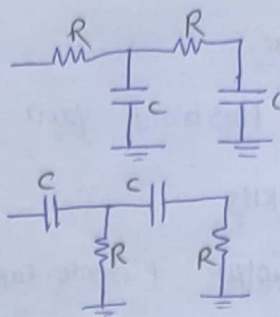
General formulas

$$A = \frac{A_F Y_1 Y_2}{Y_1 Y_2 + Y_2 Y_3 (1 - A_F) + Y_4 (Y_1 + Y_2 + Y_3)}$$

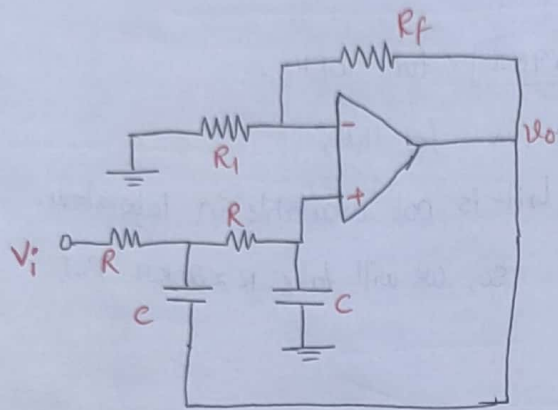
$$f = \frac{1}{2\pi RC}$$

$$f = \frac{1}{2\pi \sqrt{R_x R_y C_x C_y}}$$

	Y_1	Y_2	Y_3	Y_4
LPF	$\frac{1}{R}$	$\frac{1}{R}$	SC	SC
HPF	SC	SC	$\frac{1}{R}$	$\frac{1}{R}$



Second Order LPF :- Replace $Y_1 = Y_2 = \frac{1}{R}$ & $Y_3 = Y_4 = \text{SC}$



$$H(s) = \frac{V_o(s)}{V_i(s)} = \frac{A_o \times \frac{1}{R^2}}{\frac{1}{R^2} + \frac{SC}{R}(1+A_o) + SC(\frac{2}{R^2})}$$

$$H(s) = \frac{V_o(s)}{V_i(s)} = \frac{A_o \times \frac{1}{R^2} \times R^2}{R^2 \left(\frac{1}{R^2} + \frac{SC}{R}(1-A_o) + SC \left(\frac{2}{R^2} \right) \right)} \Rightarrow \frac{A_o}{1 + SC(3-A_o) + SC^2 R^2}$$

$$H(s) = \frac{A_o}{1 + SC(3-A_o) + SC^2 R^2}$$

$$H(s) = \frac{A_o \omega_h^2}{s^2 + \alpha \omega_h s + \omega_h^2} \rightarrow (2) \quad \alpha = \text{damping coefficient}$$

$$\omega_h = \frac{1}{RC}, \quad \alpha = 3 - A_o$$

$$s = j\omega \text{ in (2)}$$

$$H(j\omega) = \frac{A_o}{1 + j\alpha \left(\frac{\omega}{\omega_h} \right) + \left(\frac{j\omega}{\omega_h} \right)^2}$$

$$|H(j\omega)| = \frac{A_o}{\sqrt{\left(1 - \frac{\omega^2}{\omega_h^2} \right)^2 + \left(\alpha \frac{\omega}{\omega_h} \right)^2}}$$

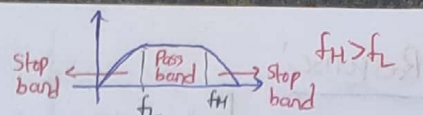
$$= \frac{A_F}{\sqrt{1 + \left(\frac{f}{f_h} \right)^2}}$$

$$A_F = 1 + \frac{R_F}{R_1}$$

$$R_2 = R_3 \text{ \& } C_2 = C_3, \quad R_F = 0.586 R_1 \rightarrow \text{for Butterworth case}$$

$$A_F = 1 + \frac{R_F}{R_1} = 1.586$$

Bandpass filters:-



(a) wide band pass filter

(b) Narrow band pass filter

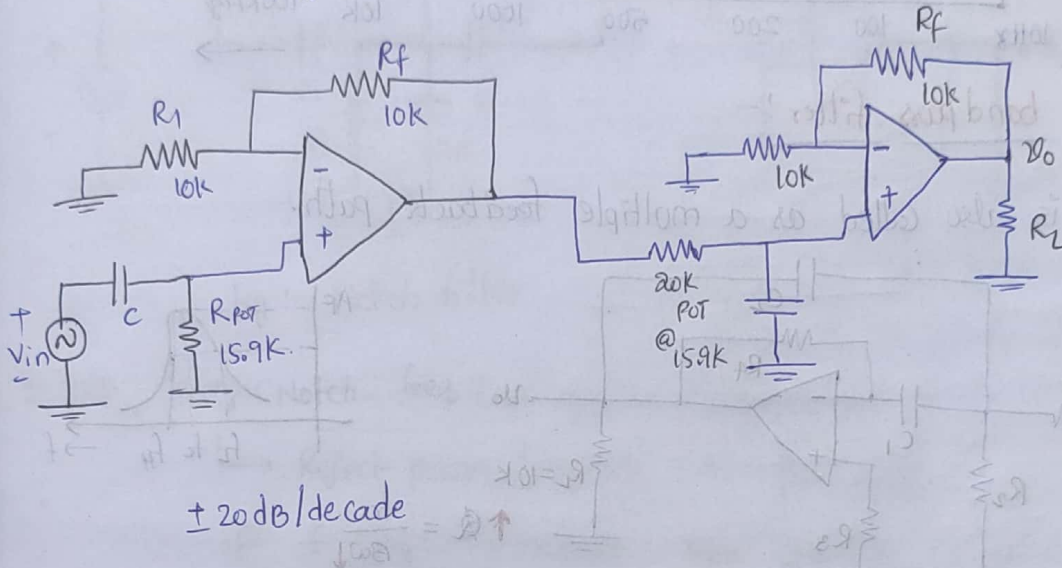
wide band filter $\rightarrow \phi < 10$

ϕ = Quality factor

Narrow band filter $\rightarrow \phi > 10$

$$\phi = \frac{f_c}{f_H - f_L}$$

$$f_c = \sqrt{f_H \cdot f_L}$$



$\pm 20 \text{ dB/decade}$

$$\left| \frac{V_o}{V_{in}} \right| = (\text{gain HPF}) \times (\text{gain of LPF})$$

$$\left| \frac{V_o}{V_{in}} \right| = \frac{A_{FT}(f/f_c)}{\sqrt{\left(1 + \frac{f}{f_L}\right)^2 \left(1 + \frac{f}{f_H}\right)^2}}$$

$$f_c = \sqrt{f_H \cdot f_L}$$

designing:-

if $f_L = 200 \text{ Hz}$

$f_H = 1 \text{ kHz}$

for $f_L \rightarrow R = 15.9 \text{ k}\Omega$
(HPF)

$C = 0.05 \mu\text{F}$

$$f_c = \sqrt{200 \times 1000}$$

$$= 500 \text{ Hz}$$

$$A_{FT} = (A_{HPF})(A_{LPF})$$

$$A_{FT} = 4$$

$$\phi = \frac{f_c}{1000 - 200}$$

$$= \frac{500}{800} = 0.6 < 10$$

wide band pass filter

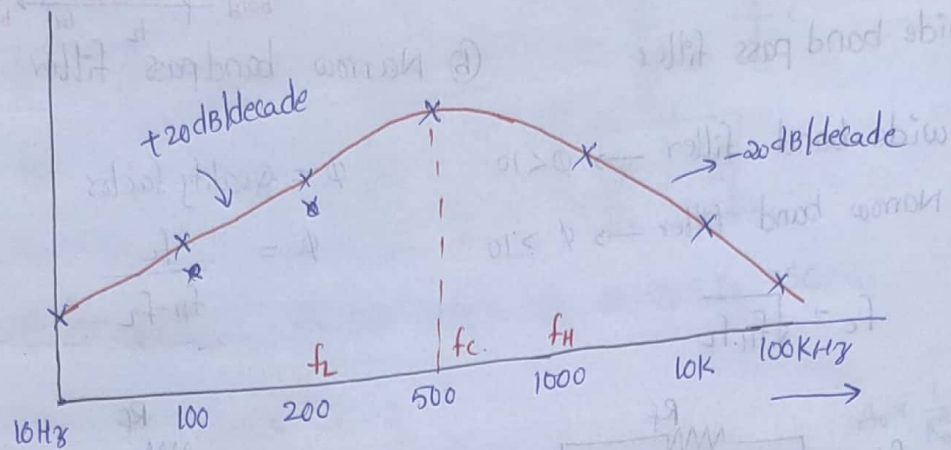
* if $\phi < 10$

it is wide band

pass filter

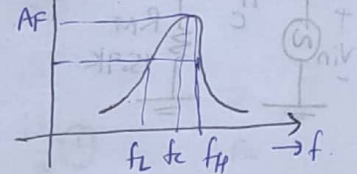
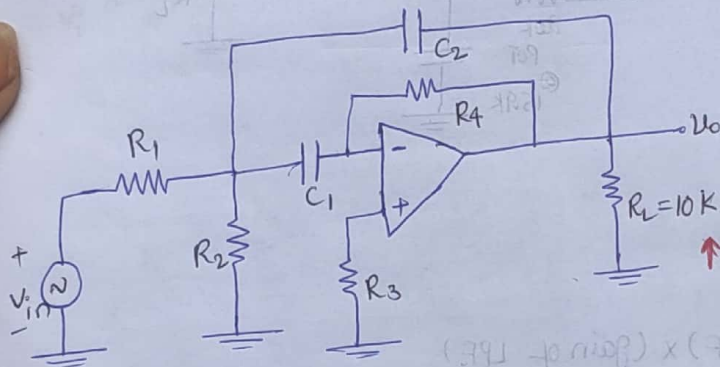
* Wide band pass filter is nothing but, quality factor is always less than 10. ($\phi < 10$)

Response:-



Narrow band pass filter:-

* It is also called as a multiple feedback path.



To design:- for specified f_c & Q

$$R_1 = \frac{Q}{2\pi f_c C A_F} \quad R_2 = \frac{Q}{2\pi f_c C (2Q^2 - A_F)}$$

$$R_3 = \frac{Q}{\pi f_c C}$$

$$A_F = \text{gain @ } f_c$$

$$A_F = \frac{R_3}{2R_1}$$

$$\therefore A_F < 2Q^2$$

$$R_2' = R_2 \left(\frac{f_c}{f_c'} \right)^2$$

f_c' = changed frequency.

$$f_c = 1 \text{ kHz} \quad Q = 3 \quad A_F = 10 \quad f_c' = 1.5 \text{ kHz}$$

* Band - Reject filters (Band stop filter):-



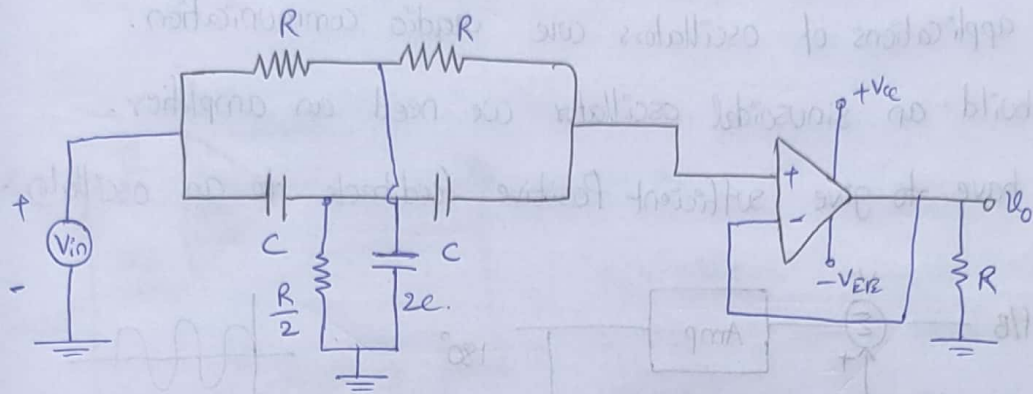
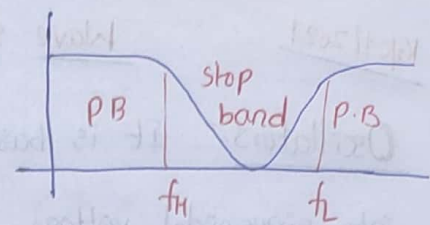
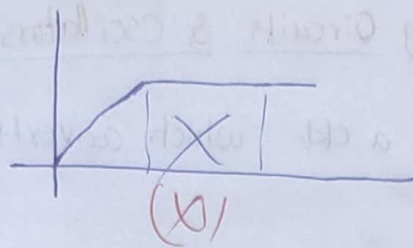


fig :- Notch filter.

* Here the notch frequency is, at which the maximum attenuation occurs. (f_N)

To get, 60KHz Notch freq

→ Refect power line hum * $f_N = \frac{1}{2\pi RC}$

if $f = 60KHz$ $C = 0.06\mu F$. then $R = \frac{1}{2\pi f C} = \frac{1}{2\pi(60)(0.06\mu)} =$

All pass filter: Delay / phase equalizers

* It passes all frequency components of input signal without attenuation, while providing the predictable phase shift, for a different frequency of input signal.

- * $f_1 \rightarrow$ has phase angle ϕ_1
- $f_2 \rightarrow \phi_2$
- $f_3 \rightarrow \phi_3$

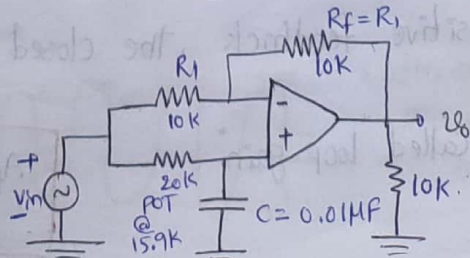
* we have to transmit all the signals, so the phase delay of signals transmitted through the telephone wires.

* The phase delay of signals transmitted through the telephone wires (or) transmission lines can be compensated by this filter.

* All pass filter is also called as "delay filter" or "Phase equalizer".

$$V_o = \left(\frac{1 - j2\pi f RC}{1 + j2\pi f RC} \right) V_{in}$$

$$\frac{V_o}{V_{in}} = \frac{1 - j2\pi f RC}{1 + j2\pi f RC} = 1$$



16/07/2021

Wave shaping Circuits & Oscillators

RKG → 279
book No.:-

Oscillators:- It is basically a ckt which converts dc voltage into sinusoidal voltage.

- * The applications of oscillators are radio communication.
- * To build an sinusoidal oscillator we need an amplifier.
- * we have to give sufficient Positive feedback to an oscillator.



Osc:- (Amp + +ve feedback)

- * "A circuit which produces ac o/p without using any ac i/p is called as "Oscillator".

- * Oscillator is a ckt which produces repetitive waveform with a fixed amplitude and frequency without ac i/p.

ex:- ~~Triangular wave~~ sin wave etc.

sinusoidal Oscillators

Audio (or) low frequency oscillator

- * RC phase shift oscillator
- * Wein bridge oscillator

Radio (or) high frequency oscillator (in MHz)

- LC osc
 - * Hartely osc
 - * Colpitts osc
- Crystal osc
- * clapp osc

Operation of Oscillator:-

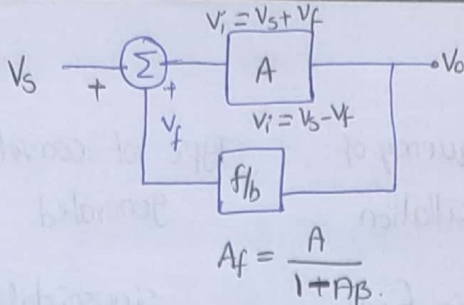
- * For positive feedback, the closed loop gain = $\frac{\text{open loop gain}}{1 + A\beta}$

$A\beta$ is called "loop gain"

$$A_f = \frac{A}{1 - A\beta}$$

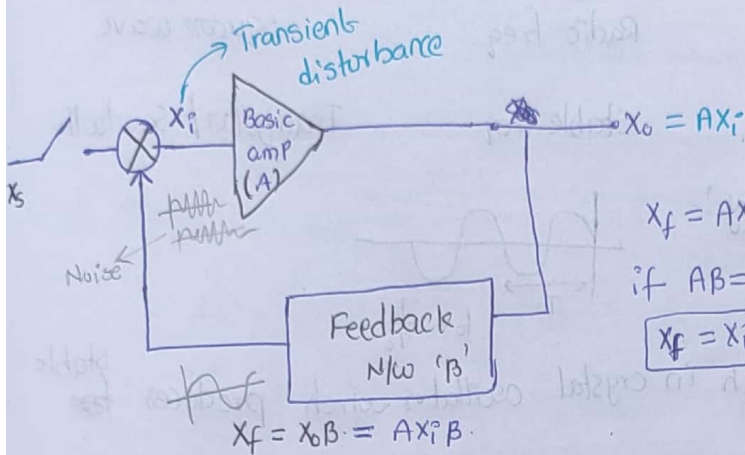
$$1 - A\beta = 0$$

$$A\beta = 1$$



$A\beta \rightarrow$ loop gain

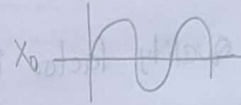
if $A\beta = 1$ $A_f = \infty$



$$X_f = AX_i\beta$$

if $A\beta = 1 \rightarrow$ This is satisfied at f_o .

$$X_f = X_i$$



* sudden change in de i/p the transient will occurs.

* In +ve feedback network we use combination of R, L, C components.

* In the case of +ve feedback β is dependent on frequency.

* if $|A\beta| = 1$ then it is called Barkhausen Criteria

Conditions for Barkhausen Criteria:-

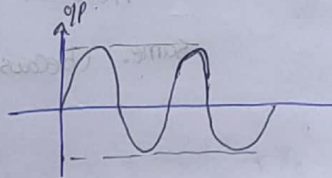
① $|A\beta| = 1$ (Unity)

② phase of loop gain $\angle A\beta = 0^\circ$ (or) 360° } @ $f = f_o$

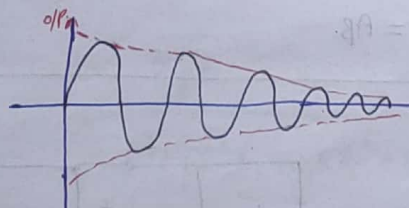
$f_o =$ frequency of oscillation.

Note:-

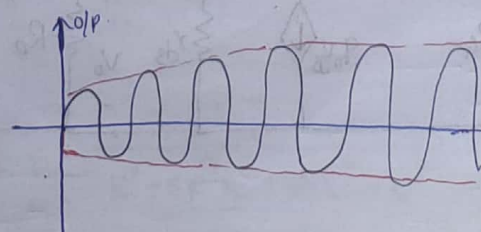
① If $|A\beta| = 1$



② If $|A\beta| < 1$



③ If $|A\beta| > 1$



→ after reaching the max value it is constant (amp)

17/10/2024

Types of Oscillators:-

Type of Components used
in the f/B N/w-

frequency of
oscillation

Type of waveform
generated

RC

Audio freq

Sinusoidal

LC

Radio freq

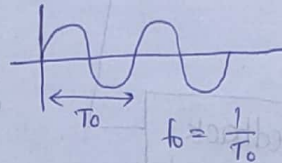
square wave

crystal

stable freq

Triangular / Sawtooth

Oscillator frequency stability:-



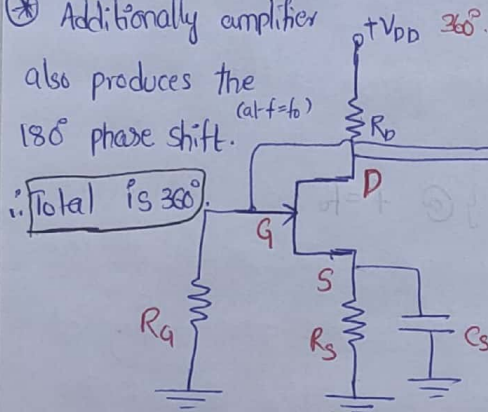
* The quality factor is high in crystal oscillator which produces ~~low~~ stable frequency.

RC phase shift Oscillator:-

* Here feedback network is RC phase shift network, it can deliver the phase shift of 180° by the three RC sections at a frequency of oscillation.

* The RC phase shift oscillator can be implemented by using

* Additionally amplifier also produces the 180° phase shift.

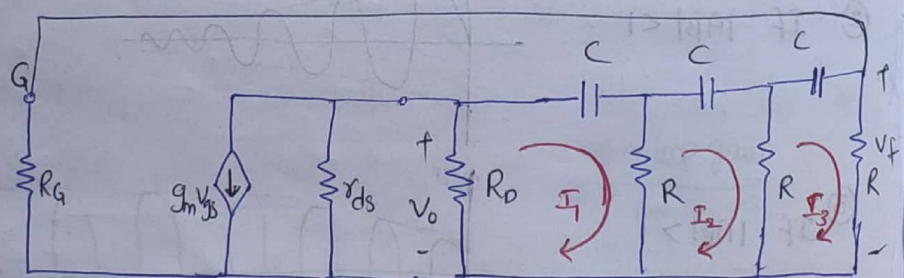


transistor,
mosfet,
Jfet
and
op-amp.

here we are taking RC values
same. (because to simplify the ckt).

Calculation of f_0 :-

here loop gain = AB



Apply KVL in loop ①

$$-V_0 + I_1 X_c + (I_1 - I_2)R = 0$$

$$I_1 (X_c + R) - I_2 R = V_0 \rightarrow \textcircled{1}$$

Apply KVL in loop ②

$$R(I_2 - I_1) + I_2 X_c + R(I_2 - I_3) = 0$$

$$-I_1 R + I_2 (2R + X_c) - I_3 R = 0 \rightarrow \textcircled{2}$$

Apply KVL in loop ③

$$R(I_3 - I_2) + I_3 X_c + I_3 R = 0$$

$$-I_2 R + I_3 (2R + X_c) = 0 \rightarrow \textcircled{3}$$

These equations are solved by using Cramer's method.

$$\begin{bmatrix} R+X_c & -R & 0 \\ -R & 2R+X_c & -R \\ 0 & -R & 2R+X_c \end{bmatrix} \begin{bmatrix} I_1 \\ I_2 \\ I_3 \end{bmatrix} = \begin{bmatrix} V_0 \\ 0 \\ 0 \end{bmatrix}$$

$$I_3 = \frac{\Delta_3}{\Delta}$$

$$\text{where } \Delta_3 = \begin{vmatrix} R+X_c & -R & V_0 \\ -R & 2R+X_c & 0 \\ 0 & -R & 0 \end{vmatrix} \Rightarrow \Delta_3 = V_0 R^2$$

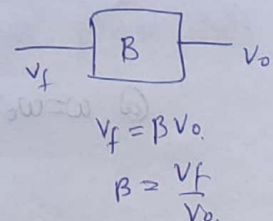
by solving

$$\Delta = R^3 + 6R^2 X_c + 5R X_c^2 + X_c^3$$

$$I_3 = \frac{\Delta_3}{\Delta} = \frac{V_0 R^2}{R^3 + 6R^2 X_c + 5R X_c^2 + X_c^3}$$

$$\text{from ckt } V_f = I_3 R$$

$$V_f = \frac{V_0 R^3}{R^3 + 6R^2 X_c + 5R X_c^2 + X_c^3}$$



$$V_f = \beta V_o$$

$$\beta = \frac{V_f}{V_o}$$

$$\frac{V_f}{V_o} = \beta = \frac{1}{1 + \frac{6X_c}{R} + \frac{5X_c^2}{R^2} + \frac{X_c^3}{R^3}}$$

$$\text{put } X_c = \frac{1}{j\omega C}$$

$$\beta = \frac{1}{1 - \frac{j6}{\omega CR} - \frac{5}{\omega^2 C^2 R^2} + \frac{j}{\omega^3 C^3 R^3}}$$

$$\beta = \frac{1}{1 - \frac{5}{\omega^2 C^2 R^2} - j \left(\frac{6}{\omega CR} - \frac{1}{\omega^3 C^3 R^3} \right)}$$

$$\text{let } \frac{1}{\omega RC} = \alpha$$

$$\beta = \frac{1}{1 - 5\alpha^2 - j(6\alpha - \alpha^3)}$$

$$\text{we know loop gain} = A\beta = \frac{A}{1 - 5\alpha^2 - j(6\alpha - \alpha^3)}$$

$$\text{at } \omega = \omega_0, \quad 360^\circ = \begin{bmatrix} 1 & 1 \\ -1 & 1 \\ 1 & 1 \end{bmatrix} \begin{bmatrix} 1 \\ 1 \\ 1 \end{bmatrix} \begin{bmatrix} 1 & 1 \\ 1 & 1 \\ 1 & 1 \end{bmatrix} \begin{bmatrix} 1 \\ 1 \\ 1 \end{bmatrix}$$

$$\alpha^3 - 6\alpha = 0$$

$$\alpha(\alpha^2 - 6) = 0$$

$$\alpha = 0, \quad \alpha^2 - 6 = 0$$

$$\alpha^2 = 6$$

$$\alpha = \pm \sqrt{6}$$

$$\frac{1}{\omega RC} = \sqrt{6}$$

$$\frac{1}{\omega} = RC\sqrt{6}$$

$$\omega = \frac{1}{RC\sqrt{6}}$$

$$2\pi f_0 = \frac{1}{RC\sqrt{6}}$$

$$f_0 = \frac{1}{2\pi RC\sqrt{6}}$$

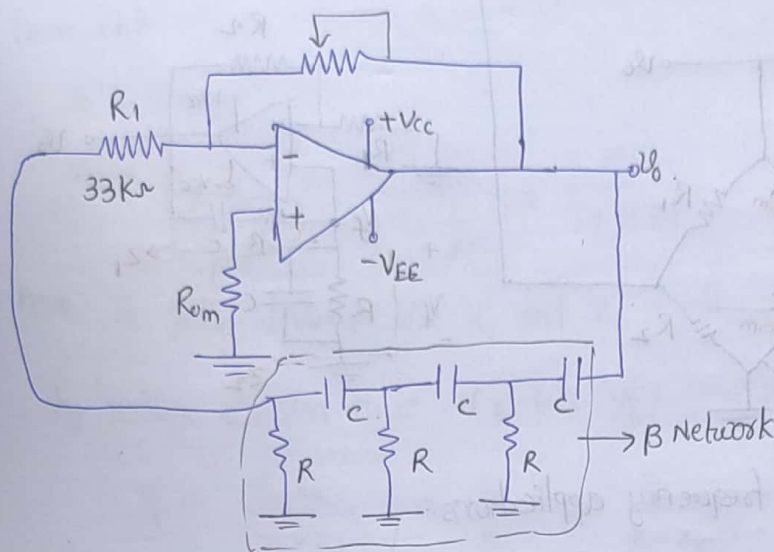
$$\text{@ } \omega = \omega_0 \quad \text{loop gain} = \frac{A}{1 - 5 \times 6 + j(0)}$$

$$\text{loop gain} = \frac{A}{1 - 30} = -\frac{A}{29}$$

$$|\text{loop gain}| \geq 1$$

$$\left| -\frac{A}{29} \right| \geq 1 \Rightarrow |A| > 29$$

$$|A| \geq 29$$



At ' f_0 ' $A_v = \frac{1}{\beta}$
 $\beta = \frac{1}{29}$

then $A_v = 29$

To make $A_v = 29 \Rightarrow \left| \frac{R_f}{R_i} \right| = 29$

$$R_f = 29 R_i$$

$$= 29 \times 33 \text{ k}\Omega$$

$$R_f = 957 \text{ k}\Omega \approx 1 \text{ M}\Omega$$

$$R_f = 1 \text{ M}\Omega$$

$$R_i = 33 \text{ k}\Omega$$

But in the case of JFET it is difficult to design $R_f = 1 \text{ M}\Omega$ and $R_i = 33 \text{ k}\Omega$

$$f_0 = \frac{1}{2\pi f \sqrt{6}} \text{ Hz}$$

$$f_0 = \frac{0.065}{RC}$$

$$360^\circ \text{ \& } 29$$

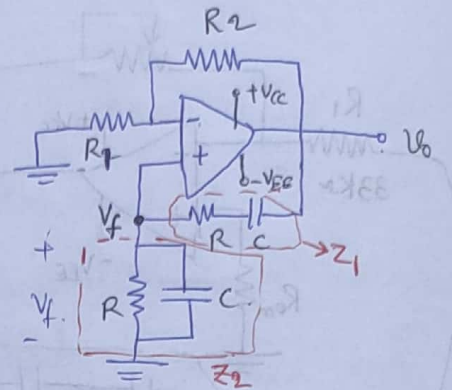
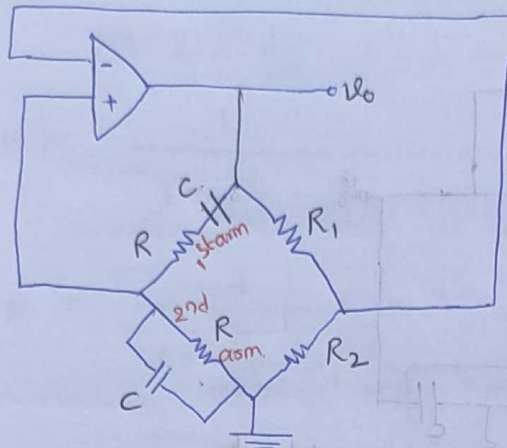
$$\text{@ } f_0$$

frequency of oscillation for RC phase shift oscillator.

* The RC phase shift oscillator ckt will produce 360° phase shift and 29 (gain), at $f = f_0$.

26/07/2021

Wein Bridge Oscillator - (Low frequency oscillator)



* It is used for audio frequency applications.

* The range for audio frequency is 20 to 20 kHz.

* In Wein bridge oscillator, both +ve and -ve feedbacks are present.

1st arm $\rightarrow$ Series RC ckt

2nd arm $\rightarrow$ parallel RC ckt

3, 4 arms $\rightarrow$ R_2, R_1 of op amp.

$\rightarrow 180^\circ$ phase shift
 $V_0 = -\frac{R_f}{R} V_i \rightarrow$ Inverting op amp

$V_0 = (1 + \frac{R_f}{R}) V_i \rightarrow$ Non-inverting op amp.
 $\downarrow$
 0° phase shift.

* RC feedback network produces
 0° phase shift at $f = f_0$.

* If bridge is balanced condition (at resonance condition)

$$f_0 = \frac{1}{2\pi RC} \quad \text{if } R_1 = R_2 = R \quad C_1 = C_2 = C.$$

* At this frequency, gain of op-amp at sustained condition is

$$A_v = \frac{1}{\beta} = 3$$

$$1 + \frac{R_2}{R_1} = 3$$

$$\therefore R_2 = 2R_1$$

$$\frac{R_2}{R_1} = 2$$

$\therefore$ if $R_1 = 2k\Omega$

$R_2 = 4k\Omega$

$\therefore$ if $R_1 = 4k\Omega$

$R_2 = 8k\Omega$

calculation of 'b':-

we know loop gain = $AB \rightarrow ①$

from ckt-

$$Z_1 = R + \frac{1}{j\omega C}$$

$$Z_2 = R \parallel \frac{1}{j\omega C} = \frac{R \times \frac{1}{j\omega C}}{R + \frac{1}{j\omega C}} = \frac{R}{1 + j\omega RC}$$

here V_0 gets divided b/w ' Z_1 ' and ' Z_2 ' (voltage division)

by voltage division rule (to find V_f)

$$V_f = \frac{V_0 \cdot Z_2}{Z_1 + Z_2} \Rightarrow \frac{V_f}{V_0} = \beta = \frac{Z_2}{Z_1 + Z_2}$$

$$\frac{V_f}{V_0} = \beta = \frac{\left(\frac{R}{1 + j\omega RC} \right)}{\left(\frac{R}{1 + j\omega RC} \right) + \left(\frac{R}{1 + j\omega RC} \right)} = \frac{R}{(1 + j\omega RC) \left[R + \frac{1}{j\omega C} + \frac{R}{1 + j\omega RC} \right]}$$

$$\beta = \frac{R}{(R + j\omega R^2 C + \frac{1}{j\omega C} + R + R)} = \frac{1}{3 + j\omega RC + \frac{1}{j\omega RC}}$$

$$\beta = \frac{1}{3 + j\omega RC + \frac{1}{j\omega RC}}$$

$$\therefore \beta = \frac{1}{3 + j\omega RC - \frac{j}{\omega RC}} \rightarrow ②$$

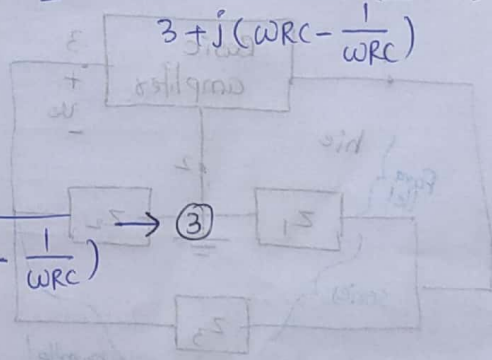
② in ①

$$\text{Loop gain} = AB = \frac{A}{3 + j\omega RC - \frac{j}{\omega RC}} \rightarrow ③$$

at $\omega = \omega_0$

In the capacitors frequency is dependent only on imaginary part.
so, to find frequency of oscillation we need to equal imaginary part to '0'.

$$\therefore \omega RC - \frac{1}{\omega RC} = 0$$



$$WRC = \frac{1}{WRC}$$

$$\omega_0^2 = \frac{1}{R^2 C^2}$$

$$\omega_0 = \frac{1}{RC}$$

$$2\pi f_0 = \frac{1}{RC}$$

$$\therefore f_0 = \frac{1}{2\pi RC} \quad (\text{if } R_1, R_2 \text{ and } C_1, C_2 \text{ are identical}).$$

If Non-identical R, C are used, then

$$f_0 = \frac{1}{2\pi \sqrt{R_1 R_2 C_1 C_2}}$$

at $\omega = \omega_0$ loop gain = $\frac{A}{3 + j(\omega_0)} = \frac{A}{3}$ $\text{Imag part} = 0$

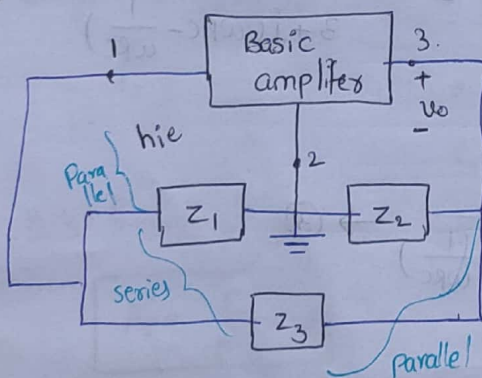
loop gain ≥ 1

$$\frac{A}{3} \geq 1$$

$$A \geq 3$$

LC Oscillators:-

* It consist of op-amp ckt- and feedback network.



$$Z_L = Z_2 \parallel (Z_3 + Z_1)$$

$$Z_L = Z_2 \parallel (Z_3 + (h_{ie} \parallel Z_1))$$

$$\beta = \frac{V_f}{V_o}$$

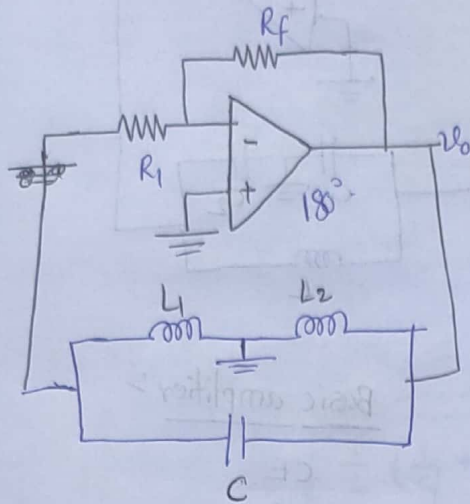
For CE amplifier $A_v = \frac{-h_{fe} Z_L}{h_{ie}}$

loop gain = $A\beta \geq 1$

$X_1 + X_2 + X_3 = 0$ for to find ' f_0 '. $|A| \geq \frac{X_2}{X_1}$ for FET (or) op-amp.

$$h_{fe} \geq \frac{X_1}{X_2} + \frac{X_2}{X_1} \cdot \frac{h_{ie}}{R_c} \text{ for BJT.}$$

* Hartley Oscillator



Calculation of 'fo' :-

at $\omega = \omega_0$

$$X_1 + X_2 + X_3 = 0$$

X_1, X_2, X_3 are reactances.

$$j\omega_0 L_1 + j\omega_0 L_2 - \frac{1}{j\omega_0 C} = 0$$

$$j\omega_0 L_1 + j\omega_0 L_2 - \frac{1}{\omega_0 C} = 0$$

$$\omega_0 (L_1 + L_2) = \frac{1}{\omega_0 C}$$

$$\omega_0^2 = \frac{1}{C(L_1 + L_2)}$$

$$\omega_0 = \frac{1}{\sqrt{C(L_1 + L_2)}}$$

$$2\pi f_0 = \frac{1}{\sqrt{(L_1 + L_2)C}}$$

$$f_0 = \frac{1}{2\pi \sqrt{L_{eq} C}}$$

where $L_{eq} = L_1 + L_2$

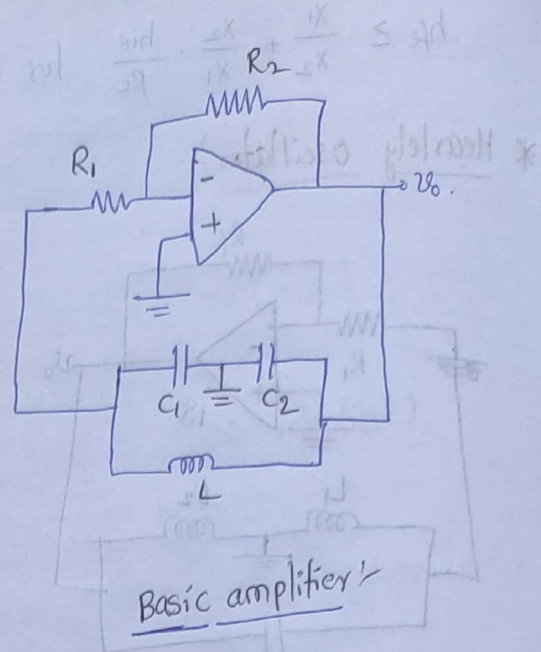
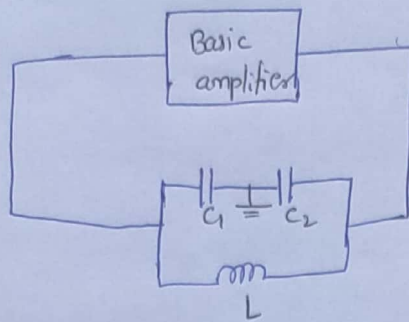
freq. of oscillation for Hartley oscillator for sustained output

$$A \geq \frac{X_2}{X_1}$$

$$A \geq \frac{\omega_0 L_2}{\omega_0 L_1}$$

$$A \geq \frac{L_2}{L_1}$$

Calpitt's oscillator



Calculation of f_0

$$X_1 + X_2 + X_3 = 0$$

$$-\frac{1}{\omega_0 C_1} - \frac{1}{\omega_0 C_2} + \omega_0 L = 0$$

$$\omega_0 L = \frac{1}{\omega_0 C_1} + \frac{1}{\omega_0 C_2}$$

$$\omega_0 L = \frac{1}{\omega_0} \left(\frac{1}{C_1} + \frac{1}{C_2} \right)$$

$$\omega_0^2 L = \frac{C_1 + C_2}{C_1 C_2}$$

$$\omega_0^2 L = \frac{1}{C_{eq}}$$

$$\omega_0^2 = \frac{1}{L C_{eq}}$$

$$\omega_0 = \frac{1}{\sqrt{L C_{eq}}}$$

$$2\pi f_0 = \frac{1}{\sqrt{L C_{eq}}}$$

$$f_0 = \frac{1}{2\pi \sqrt{L C_{eq}}}$$

$$C_{eq} = C_1 \parallel C_2$$

$$C_{eq} = \frac{C_1 C_2}{C_1 + C_2}$$

$$0 = \frac{1}{\omega_0 L} - \frac{1}{C_{eq}} = \frac{C_1 + C_2}{C_1 C_2}$$

$$\text{where } C_{eq} = \frac{C_1 C_2}{C_1 + C_2}$$

frequency of oscillation for Calpitt's oscillator for sustained output

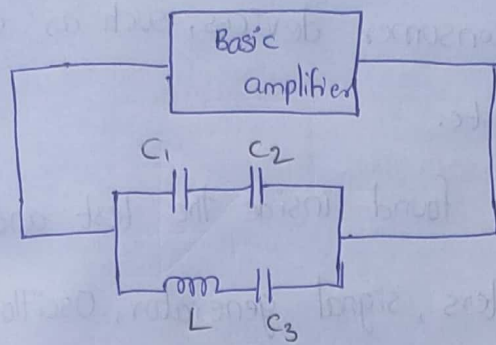
$$A \geq \frac{X_2}{X_1}$$

$$A \geq \frac{\frac{1}{\omega_0 C_2}}{\frac{1}{\omega_0 C_1}}$$

$$\therefore |A| \geq \frac{C_1}{C_2}$$

21/07/2021

Clamp Oscillator:-



frequency of oscillation is

$$f_0 = \frac{1}{2\pi} \sqrt{\frac{1}{L} \left(\frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3} \right)}$$

If C_3

$$\frac{1}{C_3} \gg \gg \frac{1}{C_1} + \frac{1}{C_2}$$

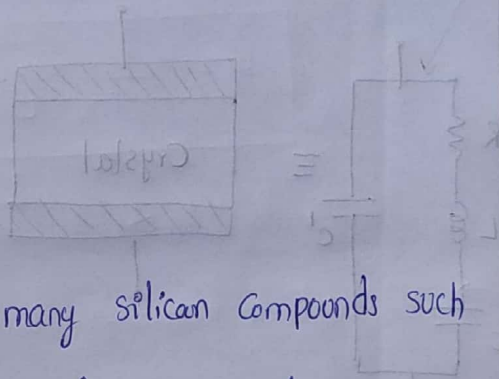
So, it is neglected.

$$\text{Now } f_0 \cong \frac{1}{2\pi} \sqrt{\frac{1}{L} \cdot \frac{1}{C_3}}$$

$$f_0 \cong \frac{1}{2\pi \sqrt{LC_3}}$$

Crystal Oscillator:-

- * Here we are using "quartz crystal".
- * The quartz is the source of the many silicon compounds such as silicones, the examples are high performance polymer.
- * Silicon is nothing but micro electronics.
- * Silicones are high performance polymers.
- * The major reason for the wide use of crystal oscillator is, it having higher quality factor (Q).
- * The range of Quartz oscillator is 10^4 to 10^6 . (Typical range)
Q-factor range
- * These quartz crystals are manufactured for frequencies.



* These frequencies are from a few tens of kHz to some tens of MHz.

* Mostly these are used for consumer devices, such as clocks, radios, computers, cell phones etc.

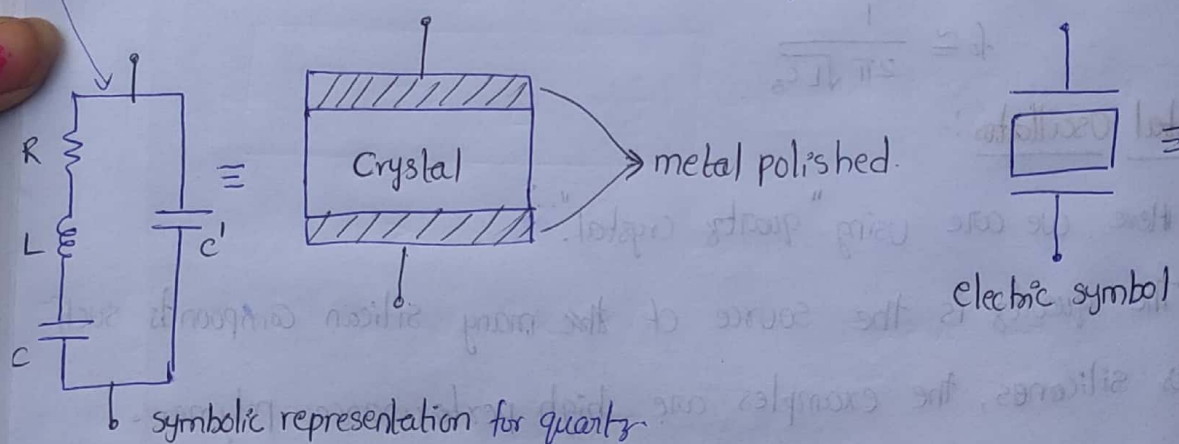
* These quartz crystals are also found inside the test and measurement equipments such as counters, signal generator, Oscilloscope.

* Generally these are used for generating the frequency or manufactured for the frequency only. (kHz to MHz)

* Here quartz is a piezo electrical material that converts a electrical into mechanical, mechanical into electrical vice versa.

* When a quartz crystal is used in electrical circuits, it will be polished with a metal on opposite faces.

In clamp oscillator $\Rightarrow$ inductor is replaced with crystal.



$R, L, C \rightarrow$ Representation of Resistance, inductance, Capacitance of the quartz material. (internal components)

$C' \rightarrow$ Parallel plate capacitor in which a quartz is a dielectric material. And two metal coatings are parallel plates.

To find impedance of the crystal is

$$Z = \left(r + j\omega L + \frac{1}{j\omega C} \right) \parallel \frac{1}{j\omega C'}$$

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$x \rightarrow$ very small (neglected)

$$Z \approx (j\omega L + \frac{1}{j\omega C}) \parallel \frac{1}{j\omega C'} \quad (\text{parallel})$$

$$Z = \frac{(j\omega L + \frac{1}{j\omega C}) \times \frac{1}{j\omega C'}}{j\omega L + \frac{1}{j\omega C} + \frac{1}{j\omega C'}} \Rightarrow \frac{j\omega L (1 + \frac{1}{j^2 \omega C \omega L}) \times \frac{1}{j\omega C'}}{j\omega L (1 + \frac{1}{j^2 \omega C \omega L} + \frac{1}{j^2 \omega C' \omega L})}$$

$$Z = \frac{j\omega L (1 - \frac{1}{\omega^2 LC}) \times \frac{1}{j\omega C'}}{j\omega L (1 - \frac{1}{\omega^2 LC} - \frac{1}{\omega^2 LC'})}$$

$$Z = \frac{(1 - \frac{1}{\omega^2 LC}) \times \frac{1}{j\omega C'}}{1 - \frac{1}{\omega^2 LC} - \frac{1}{\omega^2 LC'}} \Rightarrow \frac{1 - \frac{1}{\omega^2 \cdot \frac{1}{LC}}}{1 - \frac{1}{\omega^2 \cdot \frac{1}{L} (\frac{1}{C} + \frac{1}{C'})}} \times \frac{1}{j\omega C'}$$

replace $\frac{1}{LC}$ with ω_s^2

lly $\frac{1}{L} (\frac{1}{C} + \frac{1}{C'})$ with ω_p^2

$$\therefore Z = \frac{1 - \frac{\omega_s^2}{\omega^2}}{1 - \frac{\omega_p^2}{\omega^2}} \times \frac{-j}{\omega C'}$$

$$Z = \frac{-j}{\omega C'} \times \frac{\omega^2 - \omega_s^2}{\omega^2 - \omega_p^2}$$

we know $\omega_s = 2\pi f_s$

$\omega_p = 2\pi f_p$

$$Z = \frac{-j}{2\pi f C'} \times \frac{f^2 - f_s^2}{f^2 - f_p^2} \rightarrow \text{impedance of quartz material}$$

$$\Rightarrow \text{If } f = f_s \quad Z = \frac{-j}{2\pi f C'} \cdot \frac{f_s^2 - f_s^2}{f^2 - f_p^2} = 0$$

$\therefore [Z=0] \rightarrow$ quartz crystal goes to series resonance at f_s .

$\therefore f_s$ is known as 'series resonance frequency'.

$$\omega_s^2 = \frac{1}{LC}$$

$$\omega_s^2 = \frac{1}{LC}$$

$$(2\pi f_s)^2 = \frac{1}{LC}$$

$$2\pi f_s = \sqrt{\frac{1}{LC}}$$

$$f_s = \frac{1}{2\pi\sqrt{LC}} \rightarrow \text{series resonance frequency}$$

$\Rightarrow$ If $f = f_p$.

$$Z = \frac{-j}{\omega c'} \times \frac{f^2 - f_s^2}{f_p^2 - f_p^2} = \infty$$

$\therefore [Z = \infty] \rightarrow$ quartz crystal goes to parallel resonance at f_p .

$\therefore f_p$ is also called as parallel resonance frequency.

$$\omega_p^2 = \frac{1}{L} \left(\frac{1}{C} + \frac{1}{C'} \right)$$

$$(2\pi f_p)^2 = \frac{1}{L} \left(\frac{1}{C} + \frac{1}{C'} \right)$$

$$2\pi f_p = \sqrt{\frac{1}{L} \left(\frac{1}{C} + \frac{1}{C'} \right)}$$

$$f_p = \frac{1}{2\pi} \sqrt{\frac{1}{L} \left(\frac{1}{C} + \frac{1}{C'} \right)} \rightarrow \text{parallel resonance frequency}$$

Generally $f_p > f_s$

$\Rightarrow$ If applied frequency $f_s < f < f_p$ then $Z = +ve \rightarrow$ behaves like inductor.

* The quartz crystal is used as an inductor in LC oscillator such ckt will be crystal oscillator.

* Generally in this crystal oscillator, the frequency of oscillation is approximately equal to parallel resonance frequency.

$$f_p = \frac{1}{2\pi} \sqrt{\frac{1}{L} \left(\frac{1}{C} + \frac{1}{C'} \right)}$$

$\swarrow$
 $LC \rightarrow$ internal inductance, capacitance

$\rightarrow C' \rightarrow$ parallel plate capacitor

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* The properties of a quartz crystals are not effected by the temperature and aging process.

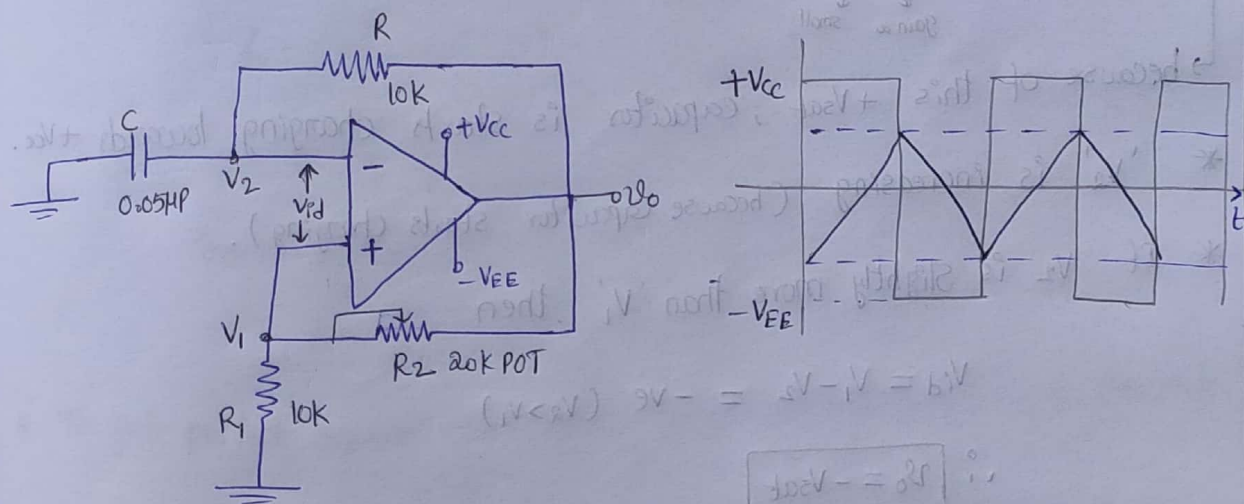
* The values of L, C, C' does not vary with time and temperature, so, we can say the crystal oscillator is a highly stable frequency of oscillation. That's why this crystal oscillator is used in many systems, computers etc.

* If the quartz crystal has resonance frequency $f_p = 2\text{MHz}$, this is called 2MHz crystal oscillator.

if $f_p = 1\text{MHz} \rightarrow 1\text{MHz}$ crystal oscillator

if $f_p = 10\text{MHz} \rightarrow 10\text{MHz}$ crystal oscillator

Square wave generator:-



* To get output as a square wave form

$\Rightarrow$ op-amp is forced to operate in the saturation region. Then

output is always $+V_{sat}^{(or)} -V_{sat}$.

Operation:-

* Assume voltage drop across capacitor is 0V.

$$\therefore V_2 = 0V$$

Voltage at non-inverting terminal $\Rightarrow V_1 = \text{small value}$ because of total o/p offset voltage.

$V_{OOT} \rightarrow$ Total output offset voltage (it is divided into 2 Resistors R_1 and R_2).

∴ by voltage division rule

$$V_1 = \frac{V_{OOT} \times R_1}{R_1 + R_2}$$

here $V_{OOT} \rightarrow$ is in mV (or) μV

So, $V_{OOT} \Rightarrow$ in mV (or μV) so $V_i = \text{small value}$. (multiplying)

Now

Let $V_{OOT} =$

$$V_{id} = V_1 - V_2 = V_1 - 0 = V_1 \rightarrow +ve \text{ value.}$$

$\therefore V_{id} = V_1 \rightarrow +ve \rightarrow$ capacitor (open ckt)

* when capacitor is open ckt, then the gain becomes ∞ .

i. The o/p of op-amp V_o goes to $+V_{sat}$.

$$\Rightarrow V_0 = +V_{sat}$$

$\Rightarrow$ Suppose $V_o = A \cdot V_i$ $= \pm V_{sat}$

 $\downarrow$ $\downarrow$
 gain ∞ small

↳ because of this $+V_{sat}$, capacitor is starts charging towards $+V_{cc}$.

* ' V_2 ' is increasing (because capacitor starts charging).

* If V_2 is slightly more than ' V_1 ' then

$$V_{id} = V_1 - V_2 = -ve \quad (V_2 > V_1)$$

$$v_i \quad v_o = -V_{sat}$$

$$\therefore V_1 = \frac{R_1}{R_1 + R_2} (-V_{sat})$$

* If the capacitor gets fully charged, then it will try to discharge.

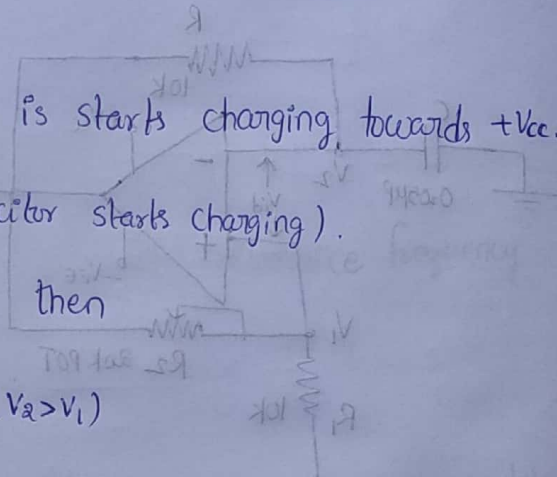
$C \rightarrow$ decreasing means $\rightarrow V_2$ decreasing ($V_2 \downarrow$)

⇒ If V_2 is slightly more -ve value, than ' V_1 '

Then $V_{id} = V_1 - V_2 = V_1 - (-V_2) = +ve$

$\therefore V_{p1} = +ve \text{ value}$

$$V_0 = +V_{sat}$$

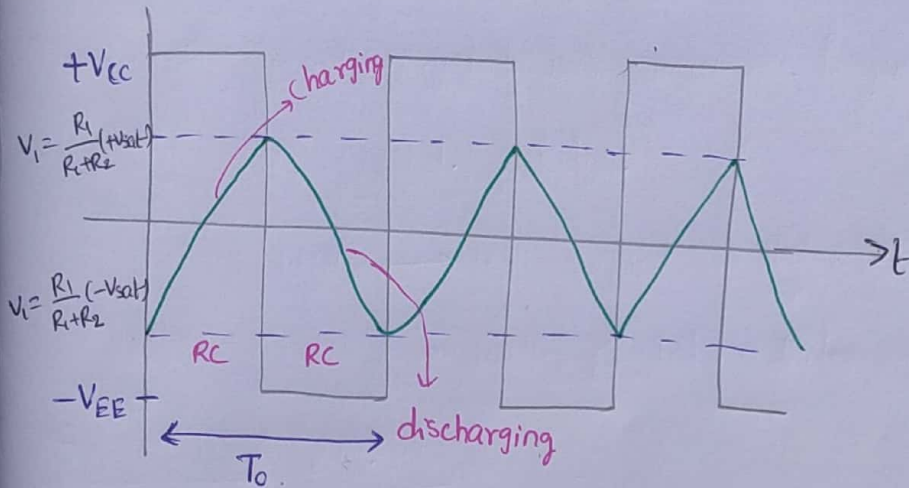


$$\therefore V_1 = \frac{R_1}{R_1 + R_2} (+V_{sat})$$

again capacitor gets charged then $V_o = -V_{sat}$, this cycle will repeats.

So, the time period of square wave generator is given by

$$T = 2RC \ln \left[\frac{2R_1 + R_2}{R_2} \right]$$



$$f_0 = \frac{1}{T} = \frac{1}{2RC \ln \left[\frac{2R_1 + R_2}{R_2} \right]}$$

$$\text{if } R_2 = 1.6R_1$$

$$\text{then } T = 2RC$$

$$f_0 = \frac{1}{2RC}$$

* To get perfect square wave, select the op-amp with high slewrate.