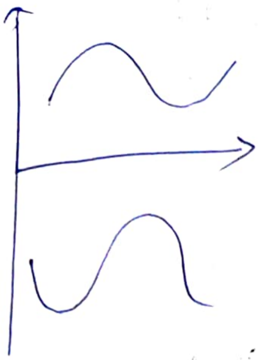
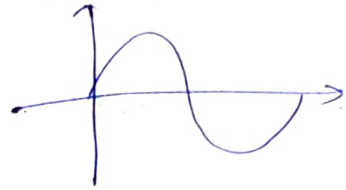
OP-AMP



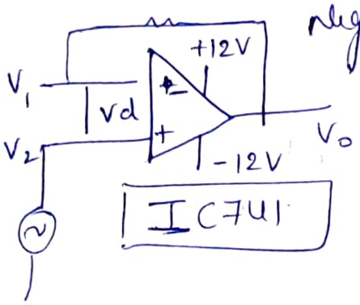
→ Unipolar signal



→ Bipolar signal

I/p of op Amp → 50 μ Amps

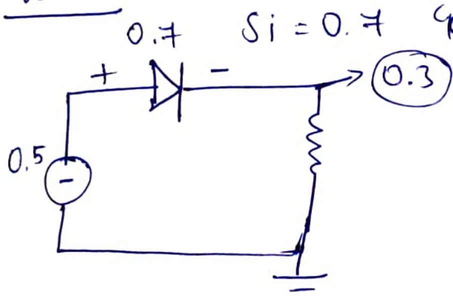
O/p voltage is managed at $\boxed{1\ 10^{-6}\ V}$



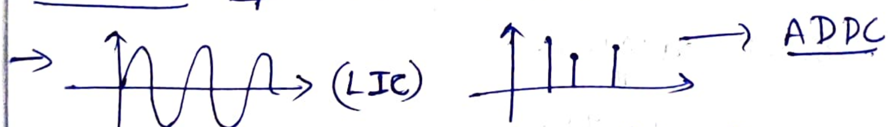
negative feed back for controlling stability of differential I/ps.

Diode

Si = 0.7 Ge = 0.3



Full wave precision rectifier



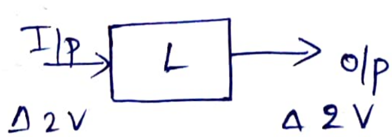
Ang

desired is dig

Basic signal is Ang

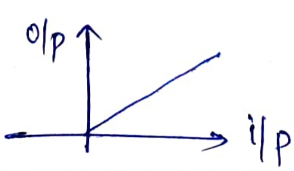
IC : Many components ~~using~~ combined to gather to form I Circu

Linear system :-



output always depends on I/p.

E.g:- or Application
Op AMP



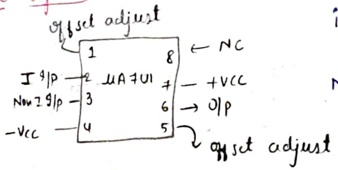
→ Op-AMP converts from Ang to Dig & Dig to Ang

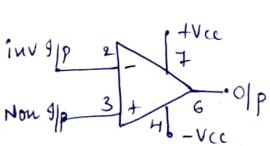
Major App of opAMP → Biomedical app

UNIT-1 CHARACTERICSTICS OF OP AMP.

Referance: S shaliva hanan, VS kanchema Bhaskaram.
Mc graw hill publication 2018

IC symbol





→ Practical features

(i) $A_v = \infty$ ⇒ Practically 2×10^5

$R_i = \infty$

$R_o = 0$

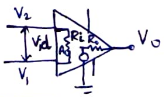
$BW = \infty$

$CMRR = \infty$

slew rate $= \infty$

$PSRR = 0$

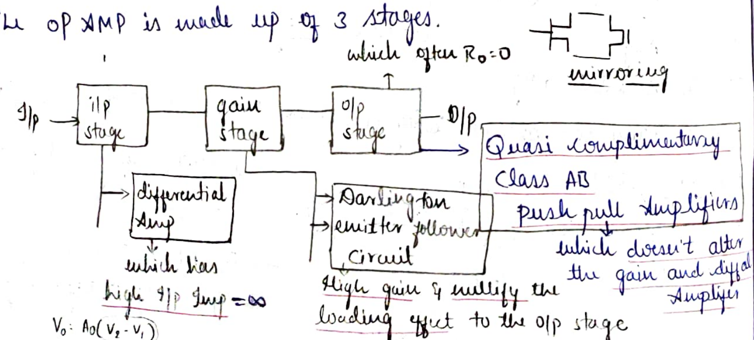
Practical circuit



$$\boxed{\begin{aligned} V_o &= A_o V_{id} \\ &= A_o (V_2 \sim V_1) \end{aligned}}$$

~~o/p~~ op AMP internal block diagram

The op AMP is made up of 3 stages.



Class A Amplifier = 90° → conduction angle

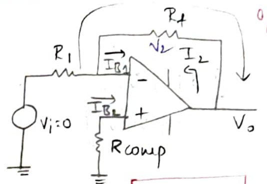
B → 180°

C → 180 - 270

AB → 90 + 180°

DC Performance

(i) I/p bias current : The avg current which is flowing into op amp ~~opm~~ is i/p bias current.



$$\boxed{\begin{aligned} I_i &= 0 \\ R_i &= \infty \end{aligned}}$$

If Rcomp is not present

$\boxed{V_o = I_B \cdot R_f}$ **

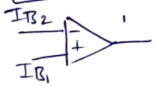
741 ⇒ 500 nA

$R_f = 1 M\Omega$

$\boxed{V_o = 500 mV}$

→ In order to compensate this we add R comp to reduce further more V_o

$\boxed{R_{comp} = R_1 || R_f}$ **



$\boxed{I_B = \dfrac{I_{B1} + I_{B2}}{2}}$ **

P 1 Assume an op Amp is having 400 and 300 nA of i/p bias currents. Calculate the i/p bias current and also compensation resistor value when $R_f = 100k\Omega$ and $R_1 = 1k\Omega$.

$$R_{comp} = \frac{R_1 R_f}{R_1 + R_f} = \frac{1K \times 100K}{(100+1)K} = 0.99K$$

$$I_B = \frac{(400 + 300)}{2} nA = 350 nA$$

(ii) i/p offset current and i/p offset voltage

op Amp - Active device

$\boxed{I_{os} = |I_{B1}| - |I_{B2}|}$ ** → Input offset current

i/p offset volt = $\boxed{V_o = \left(1 + \dfrac{R_f}{R_1}\right) V_{os}}$

Assume an OpAmp as 500 and 600nA of I/P currents determine the I/P offset current and V_{os} when the O/P reduces 200mV of O/P voltage to a resistance of 100kΩ & 1kΩ R_f and R_1 respectively.

$$\boxed{I_{os} = |I_{B1}| - |I_{B2}|}$$

$$I_{os} = |500| - |600| = 100nA$$

$$\boxed{V_o = \left(1 + \frac{R_f}{R_1}\right) V_{os}}$$

$$200mV = \left(1 + \frac{100K}{1K}\right) V_{os} \Rightarrow 200 = (101)\, V_{os}$$

$$= \boxed{V_{os} = 1.98\, mV}$$

Total offset voltage

$$\boxed{V_{OT} = \left(1 + \frac{R_f}{R_1}\right) V_{os} + R_f I_{os}}$$

we are studing all this to nullify the V_{OT}

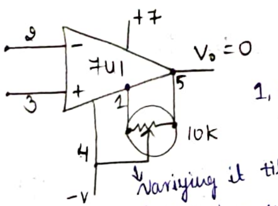
or

$$\boxed{V_{Bais} = \left(1 + \frac{R_f}{R_1}\right) V_{os} + R_f I_B}$$

Offset voltage compensation

(i) Op Amp with null terminals

(ii) Externally connected Networks.



1, 5 → External offset pins

Varying it till $V_o = 0$

(Nullifying the offset volt to zero)

Thermal drift: when Ic is ~~...~~ undergoing the temperature change it gives variation in characteristics.

$$\left\{\frac{\Delta V_{os}}{\Delta T}\right\} \mu V/°C \qquad \frac{\Delta I_{os}}{\Delta T}\ pA/°C \qquad \left\{\frac{\Delta I_B}{\Delta T}\right\} pA/°C$$

$$\boxed{\frac{1}{PSRR} = \frac{Max\ V_{os}}{Max\ supply}}$$

→ Assume $R_f = 10K\Omega$, $R_1 = 2K\Omega$, with an i/p offset volt of 5 mV, I/P offset current of 50nA, and a I/P bias current of 200nA at 25°C Determine the maximum o/p offset voltage of the circuit.

$$\boxed{V_{OT} = 30.5\, mV}$$

$$\boxed{V_{OT} = \left(1 + \frac{R_f}{R_1}\right) V_{os} + R_f I_{os}} = \left(1 + \frac{10K}{2K}\right) 5\times10^{-3} + 10\times10^{3}\times50\times10^{-9}$$

$$= 30.5\, mV$$

→ An op Amp connected & $R_1 = 100k$, $R_f = 1M\Omega$ with drift specification of $\frac{\Delta V_{os}}{\Delta t} = 30\, mV/°C$ & $\frac{\Delta I_{os}}{\Delta t} = 0.20\, nA/°C$, assume the o/p volt = 0 at 25°C. Cal the max change in o/p volt when the temp raise to 75°C with respect to drift in V_{os} and drift in I_{os}.

$$\Delta V_{os} = 30 \times (75 - 25) = 1500\, mV.$$

$$V_o = \left(1 + \frac{R_f}{R_1}\right) V_{os} = \left(1 + \frac{1M}{100K}\right)(1.5)$$

$$\boxed{V_o = 16.5}$$

$$\frac{\Delta I_o}{\Delta t} = 0.2 \Rightarrow \Delta I_o = 10nA$$

$$\boxed{\Delta V_{os} = \Delta I_{os} \times R_f}$$

$$= 0.01\, V.$$

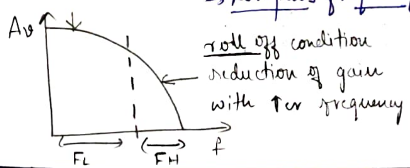
$$V_o = \left(1 + \frac{R_f}{R_1}\right)(0.01) = 0.11\, V.$$

Max change $V_o(75) - V_o(25) = 0.11 - 0 = 0.11V$

AC characteristics

(i) Frequency response. → high pass filter → which allows only high frequency.

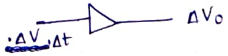
→ Lowpass frequency filter :- which allow only low frequency



(ii) Bandwidth :- The range of frequencies.

$$\boxed{BW = f_2 - f_1}$$ **

(iii) Slew rate : The maximum change of o/p voltage, when this is the slift change i/p voltage.



$$\boxed{\frac{dV_o}{dt} = \frac{I}{C}\ V/\mu sec}$$ *

* Noises in an op amp signal

2 types of noises 1) Internal noise
2) External noise.

in op amps:

1) Thermal noise
2) shot noise / discreate noise
3 1/f noise / flicking noise
4) Burst noise / perform noise

1. Thermal noise : It is due to increase in temperature of the system.

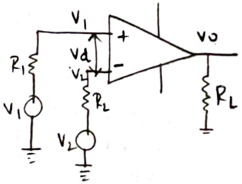
2. short noise : It is been generated due to current flow.

3

4.

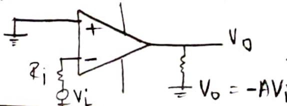
* open loop op-Amp configuration gain of the system is very high.

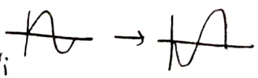
(i.) Differential amp



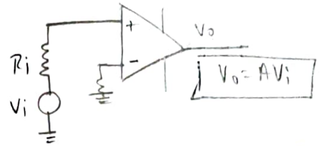
$$\boxed{V_o = A(V_1 \sim V_2)}$$

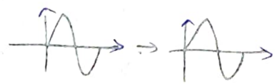
(ii) Inverting amp :- gives 180° phase shifting.





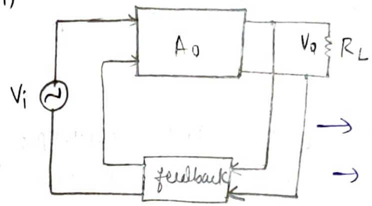
3. Non-inverting op amp





* closed loop op-amp system.

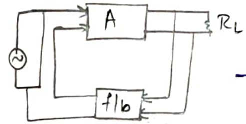
i)



→ voltage series system.

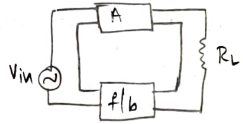
→ feed back is in series.

ii)



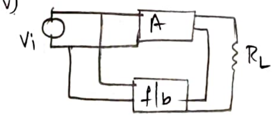
→ voltage shunt system

iii)



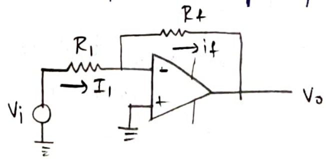
→ current series system.

(iv)



→ Current shunt system.

closed loop (Inverting amp),



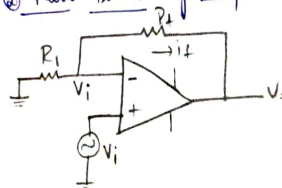
$I_1 = I_f$

$I_1 = \frac{V_i}{R_1}$

$$\boxed{V_o = -I_f \times R_f}$$ **

$V_o = -\frac{R_f}{R_1} \times V_i \Rightarrow$ $$\boxed{\frac{V_o}{V_i} = -\frac{R_f}{R_1}}$$ **

② Non-inverting amp

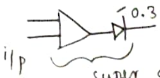


$$V_i = \frac{R_1}{R_1+R_f} \times V_o$$

$$\boxed{\frac{V_o}{V_i} = \frac{R_1+R_f}{R_1} = 1+\frac{R_f}{R_1}}$$ ★★

Circuits using diodes

op-amp does amplification of very low signals.

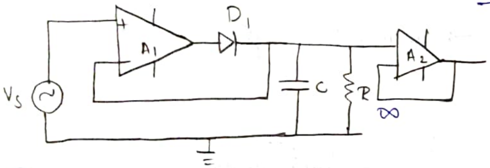


when an op-Amp is attached with diode. → super diode

diode only as 0.7 volt ~~to conduct~~ when it is attached with op-amp where op-amp as high voltage after amplification then diode as high voltage as compared to saturation voltage ⇒ (0.7)

Precision peak detector

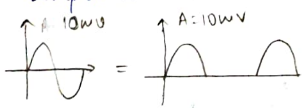
+ve peak detector



Application:-

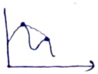
① Detecting the peak of the signal.

② → calculating or calibrating the temperature in boilers.



③ capacitor will be holding the gain

④ The i/p impedance at A_2 is ∞ so that capacitor won't discharge.

⑤ 

→ In this case capacitor should discharge so Resistor (R) is used.

To design an +ve peak detector.

Design $RC < 10\,(T)$ — Time period.

assume C = 0.01 μF

→ Assume, design an +ve peak detector circuit f = 10 KHz i/p volt = 25 mV.

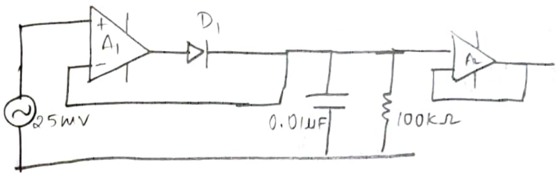
$V_s = 25\,mV$ $\quad T = 10^{-4}$ sec $\quad \leftarrow \frac{1}{2\pi}$

$C = 0.01\,\mu F$

$$R \times 0.01\times10^{-6} < 10\times10^{-4}$$

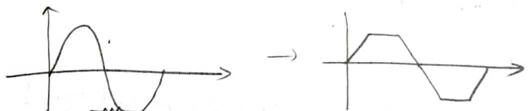
$$R < \frac{10^{-3}}{0.01\times10^{-6}}$$

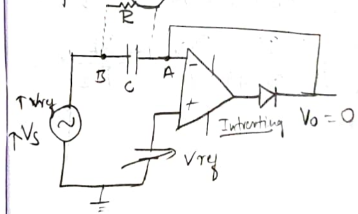
$$R < 1\times10^{5}\,\Omega = 100\,k\Omega$$



Precision Clamping

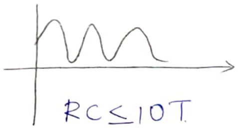
diodes are basically used for rectification other than that it is used for clamping or clipping.





Clamping circuit is the one which ~~shifts~~ shifts the signal by introducing DC voltage

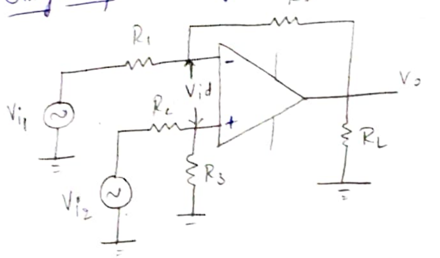
→ DC signal is introduced by ↑sing the Vref value.



$RC \leq 10T$

Differential Amplifier

Single opAMP design



Assuming all the resistors in the circuit to be equal to R, using superposition theorem the output V_{O1} due to the input V_{i1} equal.

$$V_{O1} = \frac{R_f}{R_1}(V_{i1})$$

$$V_o = \frac{R}{R}(V_{i1}) \Rightarrow V_{O1} = V_{i1}$$

By grounding input terminal V_{i1} the o/p V_{O2} due to i/p.

$$V_{O2} = -V_{i2}$$

$$V_o = V_{O1} + V_{O2} = V_{i1} - V_{i2}$$

$$\boxed{V_o = V_{i1} - V_{i2}}$$

If we have the variable resistance values are not equal the final output. $V_o = \left(1 + \frac{R_f}{R_1}\right)\left(\frac{R_3}{R_3 + R_2}\right)V_{i1} - \frac{R_f}{R_2}V_{i2}$

→ Calculate the

Diff Mode gain & Common mode gain

Same values are given to both the two i/p signals.

$$\boxed{V_{cm} = \frac{V_{i2} + V_{i1}}{2}}$$

→ Due to the symmetric property of the opAmp there ~~will~~ (should not) be any mismatch in the O/P voltage even though a common mode signal is given.

→ Since the system posess some abnormalities the response to the +ve and -ve terminals are found to be different.

→ The o/p is not zero even if the common mode signals are given.

→ ∴ $\boxed{V_o = A_1 V_{o1} + A_2 V_{o2}}$ then A_1 and A_2 are amplification factors with respect to i/p ① and ②

~~V_{+}~~ = The differential voltage V_{id} is given by $\boxed{V_{i1} - V_{i2}}$ where V_{i1} w.r.t common mode signal is given by.

$\boxed{V_{i1} = V_{cm} + \frac{1}{2}V_{id}}$ and $\boxed{V_{i2} = V_{cm} - \frac{1}{2}V_{id}}$

Substituting this to o/p eqn

$$\boxed{V_o = A_{dm}V_{id} + A_{cm}V_{cm}}$$

A_{dm} = diff mode gain $\quad$ A_{cm} = common mode gain.

$\boxed{A_{dm} = \frac{1}{2}(A_1 - A_2)}$ $\quad$ $\boxed{A_{cm} = A_1 + A_2}$

→ For a given CMRR of 10^5 a diff gain of 10^4. determine the common mode gain.

$$\boxed{CMRR = \frac{A_{dm}}{A_{cm}}}$$

$$10^5 = \frac{10^4}{A_{cm}} = 0.1 \Rightarrow A_{cm} = 0.1$$

→ The two i/p terminals of ~~o/p~~ op AMP are connected to voltage strength of 745 uV and 740 uV respectively. The differential mode gain of op AMP is 5×10^5, and CMRR is 80 dB. calculate the o/p voltage, a % error due to common mode signals.

$V_1 = 745\,\mu V$ $\quad A_d = 5 \times 10^5$

$V_2 = 740\,\mu V$ $\quad CMRR = 80\,dB$

$$\boxed{CMRR = 20 \log \frac{A_d}{A_c}}$$

$$80\,dB = 20 \log \frac{5 \times 10^5}{A_c}$$

$$10000 = \frac{5 \times 10^5}{A_c}$$

$$\boxed{A_{cm} = 50}$$

$$\boxed{V_o = A_{dm} V_{id} + A_{cm} V_{cm}}$$

$$\boxed{V_{id} = V_2 - V_1} = 5\,\mu V.$$

$$\boxed{V_{cm} = \frac{V_1 + V_2}{2}} = 742.5\,\mu V.$$

$$V_o = 5 \times 10^5 \times 5 \times 10^{-6} + 50 \times 742.5 \times 10^{-6}\,V.$$

$$= 25 \times 10^{-1} + 0.037125$$

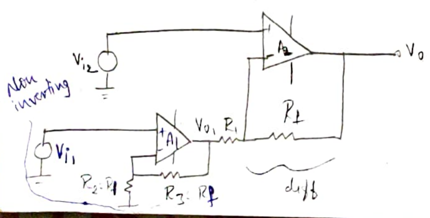
$$V_o = 2.537\,V.$$

$$\boxed{\text{Ideal voltage} : A_{dm} \cdot V_{dm}} = 2.5\,V$$

% Error :- $\dfrac{2.537 - 2.5}{2.5} \times 100 = 1.48\,\%.$

$$\boxed{\%\ \text{Error due to Common mode} = \frac{\text{o/p voltage} - \text{Ideal volt}}{\text{Ideal volt}} \times 100}$$ **

Dual op Amp



To increase the Z_i we are using dual op-Amp

→ Using dual op-Amp design the gain of the overall system can be ↑sed when compared to ~~signal~~ single op-Amp design. the above circuit is split into two parts with op-Amp A_1 acting as non-inverting amplifier and op-Amp A_2 ~~acting~~ acting as differential amplifier the o/p voltage ~~after~~ of amplifier A_1

$$\boxed{V_{o_1} = \left(1 + \frac{R_3}{R_2}\right) V_{i_1}}$$

The i/p voltage V_{i_2} appears on non-inverting terminal of op-AMP A_2 which posess gain of

$$\boxed{V_o = \left(1 + \frac{R_f}{R_1}\right) V_{i_2}}$$

V_{o_1} appears at the ~~non~~ inverting terminal with an input again of $\boxed{-\frac{R_f}{R_1} V_{o_1}}$

∴ By using superposition theorem the final o/p voltage

$$\boxed{V_o = -\left(\frac{R_f}{R_1}\right) V_{o_1} + \left(\frac{1 + R_f}{R_1}\right) V_{i_2}}$$

Substituting the value of V_{o_1} to the above equation

$$\boxed{V_o = -\left(\frac{R_f}{R_1}\right)\left(1 + \frac{R_3}{R_2}\right) V_{i_1} + \left(1 + \frac{R_f}{R_1}\right) V_{i_2}}$$ **

If we assume $R_3 = R_f$ and $R_1 = R_2$. final o/p equation.

$$V_o = -\left(\frac{R_f}{R_f}\right)\left(1 + \frac{R_f}{R_2}\right) V_{i_1} + \left(1 + \frac{R_f}{R_2}\right) V_{i_2}$$

$$\boxed{V_o = \left(1 + \frac{R_f}{R_1}\right)(V_{i_2} - V_{i_1})}$$ ***

i/p resistance of Dual op-Amp Differential amp

The i/p resistance of the overall system is found by measuring the i/p impedance of each system by considering the one i/p at a time. The i/p impedance for non inverting amplifier R_{i1} is given by $\boxed{R_{i1} = R_i(1 + A\beta_1)}$

where R_i is open loop resistance of the op-Amp

$$\boxed{\beta_1 = \frac{R_2}{R_2 + R_1}}$$

A - gain.

Similarly, shorting the i/p voltage V_{01} to ground and the second stage now behaves as non inverting amplifier which as the overall resistance given.

$$\boxed{R_{i2} = R_i(1 + A\beta_2)}$$

$$\boxed{\beta_2 = \frac{R_1}{R_1 + R_2}}$$

R_i - open loop resistance.

→ The overall resistance of the system will be combination of R_{i1} and R_{i2}.

The o/p resistance

The o/p impendance of the differential amplifier is same with a minor modification of β value

$$\boxed{\beta = 1/A_D}$$

where A_D is the closed loop gain of the differential amplifier

→ The overall output resistance.

$$\boxed{R_{of} = \frac{R_o}{1 + A/A_D}}$$

R_o - open loop resistance

A - open loop gain of op Amp

Similary we can calculate the band width of the differential amplifier which is given by BW_{CL} the ratio of unity gain band width to ~~gai~~ closed loop gain.

$$\boxed{BW_{CL} = \frac{A_0 \times f_1}{A_D}}$$

where f_1 is open loop break frequency

Assume $R_1 = R_3$ which is 560Ω, $R_f = R_2 = 5.6\,k\Omega$ and $V_{01} = -2V$. $R_i = 2M\Omega$. and gain $A = 2\times10^5$. Determine the voltage gain. i/p resistance and o/p voltage of the diff amp if input to the other terminal of the diff amp is -1V.

$V_{01} = 1+$

$R_{i1} = R_i(1 + A\beta_1)$

$$\beta_1 = \frac{R_2}{R_1 + R_2} = \frac{5.6K}{560 + 5.6K} = \cancel{5610}\ 0.909$$

$$R_{i1} = 2\times10^6(1 + 2\times10^5 \times \overset{0.909}{\cancel{5610}})$$

$$R_{i1} = 3.63602\times10^{11}$$

$$R_{i2} = R_i(1 + A\beta_2) \qquad \beta_2 = \frac{R_1}{R_1 + R_2}$$

$$= 2\times10^6(1 + 2\times10^5 \times 0.0909) \qquad = \frac{560}{560 + 5.6K} = 0.0909.$$

$$= 3.6362\times10^{10}$$

$$V_0 = A_D \times V_{id} \qquad A_D = 1 + \frac{R_f}{R_1} = 1 + \frac{5.6K}{560}$$

$$V_0 = -11V. \qquad = 11$$

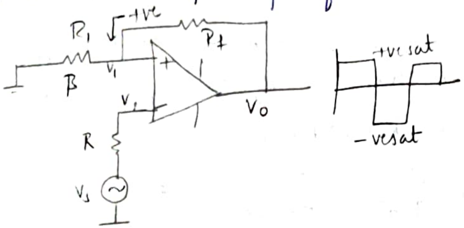
Schmitt trigger

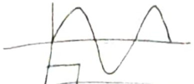
→ which converts the irregular signal to regular signal.
→ And compares the i/p ~~impedance~~ voltages.

$\beta V_o > V_s$ → op amp shifts to $+V_{sat}$

V_{sat} < source voltage (12V)

$\beta V_o < V_s$ → op amp shifts to $-ve$ sat.





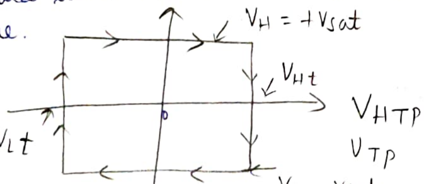
→ A schmitt trigger is basically a comparator circuit which produces a fixed square wave form which oscillates b/w +ve and -ve saturation.
→ At the non inverting terminal due to the presence of voltage divider circuit the feedback fraction of β which is voltage divider equal to $\boxed{\dfrac{R_1}{R_1+R_2}}$ is present with output voltage V_o in the non-inverting terminal.

$\therefore V_1 = \beta V_o$ when V_o = closed loop gain × input voltage

$\boxed{V_1 = \beta A_f V_s}$ $\boxed{V_o = A_f \cdot V_s}$

when $V_1 > V_s$ signal the output will continue to be +ve saturation value and when $V_1 < V_s$ the output falls to -ve saturation value.

Hysteresis curve

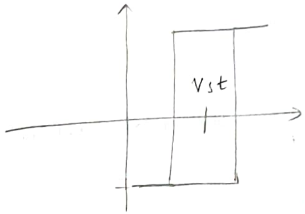


If the i/p exceeds V_{Ht} the o/p will be the V_{HT} which shifts from +ve to -ve V_{sat}.
→ Similarly if i/p goes below V_{LT} the o/p will be -V_{HT} which ~~shifts from~~ switch from $-V_{sat}$ to $+V_{sat}$.

Note :- positive voltage source H-curve shifts right.
-ve voltage source H-curve shifts lefts.

→ ~~Normal i/p and o/p characteristics~~ with practical analysis.

In op Amp which is designed as a smitt trigger with reference voltage the switching pot of the circuit changes from 0 to certain value.



$$\boxed{V_{st} = \frac{V_{UTP} + V_{LTP}}{2}}$$

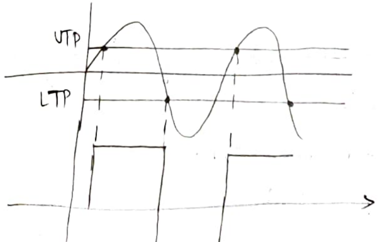
which as a relationship with respect to reference voltage which is unity but.

$$\boxed{V_{st} = \frac{R_f}{R_1+R_f} \times V_{ref}}$$

$$\boxed{V_{HT} = V_{ST} + \frac{R_1}{R+R_f}(+V_{sat})}$$

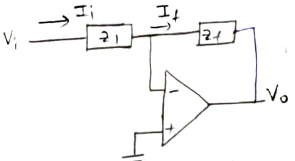
$$\boxed{V_{LT} = V_{st} + \frac{R_1}{R_1+R_f}(-V_{sat})}$$

→ Normal i/p and o/p characteristics.



UNIT-II APPLICATIONS OF OP-AMP

Sign changer / phase inverter.



closed loop gain $= -\frac{Z_f}{Z_1} = -1$

$Z_f = Z_1$

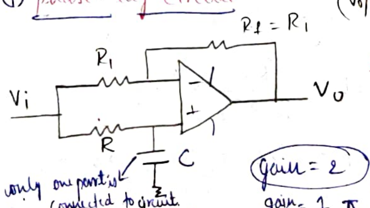
→ when ever an sign conversion is required do $R_1 = R_f \Rightarrow$ it will be -180° change

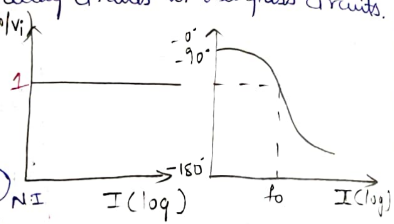
Scale changer

It doesn't bother on sign but only on the scale of $\boxed{\frac{Z_f}{Z_1}}$ where $\boxed{Z_f \neq Z_1}$

→ phase shift circuit

(i) phase lag circuit or Constant delay circuits or All pass circuits.





In phase circuits only imaginary part is considered.

→ Only phase of the signal is considered not magnitude.

→ All kinds of frequency is allowed. (Not like low pass or high pass)

→ When ever a signal reduces the phase of the signal is called as phase lag signal

→ To produce the lag we used RC circuit. which introduces the lag in the circuits.

→ RC as low pass filter.

$V_o(j\omega) = -V_i(j\omega) + 2\frac{1}{j\omega CR} V_i(j\omega)$ — 2 - gain of non-inverting terminal.

$= V_i(j\omega)\left(\frac{2}{j\omega CR} - 1\right)$

$= V_i(j\omega)\left(\frac{1 - j\omega CR}{1 + j\omega CR}\right)$

$$\boxed{\frac{V_o(j\omega)}{V_i(j\omega)} = \left(\frac{1 - j\omega CR}{1 + j\omega CR}\right)}$$

$\theta = -\tan^{-1}(\omega RC) - \tan^{-1}(\omega RC)$

$= -2\tan^{-1}(\omega RC)$

$\omega = 0 \Rightarrow \theta = 0^\circ$

$\omega = \infty \quad \theta = -180^\circ$

$$\boxed{\theta = 2\tan^{-1}(f/f_o)}$$

$$\boxed{f_o = \frac{1}{2\pi RC}}$$

→ Determine the angle, Output.

Assuming $R_1 = 20k\Omega$ $R = 39k\Omega$ $R_f = R_1$ &

$C = 1nF$, $f = 2KHz$

$f_o = \frac{1}{2\pi \times 39k \times 1\times10^{-9}}$

$f_o = 4080.89$

$\theta = 2\tan^{-1}(f/f_o)$

$\theta = 2\tan^{-1}\left(\frac{2k}{4080.89}\right)$

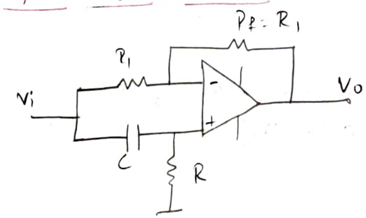
$\theta = -52^\circ.2^\circ$

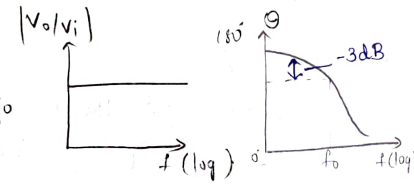
$td \longleftrightarrow T$

$$\boxed{\frac{\theta}{360^\circ} = \frac{td}{T}} \Rightarrow td = \frac{\theta T}{360^\circ} = \frac{(52.21)\times 5\times10^{-4}}{360^\circ}$$

$td = 7.2513\times10^{-5}$

→ Phase lead circuits





→ In phase lead circuit we use ~~phase~~ high pass filter to increase the angle.

→ with capacitor followed by resistor ⇒ high pass filter

→ Not bothered on magnitude and it is constant.

→ One RC component maximaly gives 180° phase shift.

→ phase shifts from 180° to 0° any where in b/w.

$$\boxed{V_o(j\omega) = -V_i(j\omega) + 2\left(\frac{j\omega RC}{1+j\omega RC}\right)V_i(j\omega)}$$

Inverting gain = 1

N I gain = 2

$$\boxed{\frac{V_o(j\omega)}{V_i(j\omega)} = \frac{-1 + j\omega RC}{1 + j\omega RC}} \quad ★★$$

when ever the difference in real parts phase addition. difference in imaginary part phase subtraction.

$$\theta = 180° - \tan^{-1}(\omega RC) - \tan^{-1}(\omega RC)$$

$$\boxed{\begin{aligned}\theta &= 180° - 2\tan^{-1}(\omega RC \\ \theta &= 180° - 2\tan^{-1}(f/f_0)\end{aligned}} \quad ★$$

P Determine a phase angle for phase lead circuit operating with $R_1 = 25\,k\Omega$, $R = 30\,k\Omega$, $C = 1\,nF$, $R_F = R_1$, frequency of $5\,k\Omega$

$$\theta = 180° - 2\tan^{-1}(f/f_0)$$

$$\theta = 180° - 86.60$$

$$\boxed{\theta = 93.39°}$$

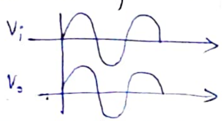
$$f_0 = \frac{1}{2\pi RC}$$

$$= \frac{1}{2\times\pi\times 30\times k\times 1\times 10^{-9}}$$

$$= 5305.164$$

→ Voltage follower

what ever the input the output should be of same.



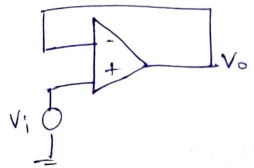
$$|v_i| = |v_o|$$

In voltage follower magnitude of the i/p and o/p should be same, so will get same phase angle.

→ To make ~~d~~ this possible we have to go through a non-inverting termal.

$$A_v = 1 + \frac{R_f}{R_1} \quad \text{where } R_1 \to \infty,\ R_f = 0$$

$$A_v = 1$$



Voltage controlled voltage source

when an output of the circuit depends on the i/p source → are dependent sources.

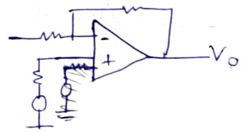
Design

(i) considering multiplication factor ⇒ (K) ⇒ times.

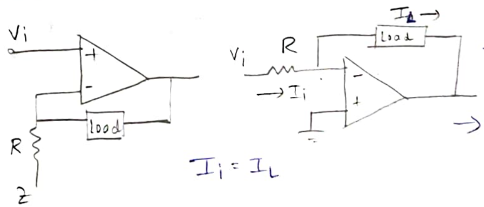
E.g:- $V_o = K V_i$ — Independent of current sources.

dependent

(ii) V_o is independent of I wheather it is inverting or non-inverting



Voltage controlled current source

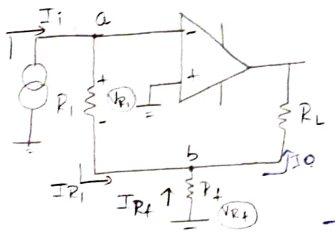


$$I_i = I_L$$

same current source is going through the circuit

→ fixed current source circuits.

Inverting Current amp



$V_{R_1} = V_{RF}$

$I_o = I_L = I_{R_1} + I_{RF}$

$A_i = \frac{I_o}{I_i} = \frac{I_{R_1} + I_{RF}}{I_i}$

$\boxed{I_{R_1} = I_i}$ **

$I_{RF} = \frac{V_{RF}}{R_F}$

$V_{RF} = V_{R_1}$

$I_{RF} = \frac{V_{Rf}}{R_f} = \frac{I_i R_1}{R_f}$

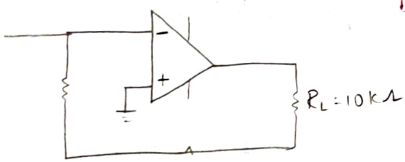
$I_o = I_i + \frac{I_i R_1}{R_f}$

$\boxed{I_o = I_i\left(1 + \frac{R_1}{R_f}\right)}$

$\boxed{A_i = 1 + \frac{R_1}{R_f}}$ **

Design an current amplifier for $R_1 = 22K\Omega$, $R_f = 1K\Omega$, and $R_L = 10K\Omega$, input current of $10\mu A$.

$\boxed{I_o = I_i\left(1 + \frac{R_1}{R_f}\right)}$

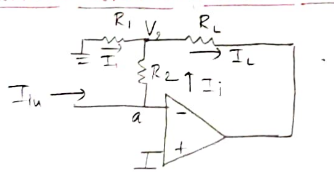


$10 \times 10^{-6}\left(1 + \frac{22k}{1K}\right)$

$10 \times 10^{-6} \times 23$

$I_o = 230\mu A$

Current controlled current source



(a) $I_o = K(I_i)$ constant

(b) I_i is always independent of load ~~current~~ resistance.

The current controlled current source, the o/p current will be equal to scale version of input current and it is also independent of the load present in the circuit

∴ the Iin current drawn into the op amp is zero

$I_{in} = I_i$

Node A is at virtual ground voltage at V_2 is given by $\boxed{V_2 = -I_i R_2}$

The current I_1 is calculated by

$I_1 = \frac{0 - V_2}{R_1} =$

$I_1 = \frac{I_i R_2}{R_1}$

applying KCL at V_2

$I_L = I_1 + I_i = \frac{I_i R_2}{R_1} + I_i$

$\boxed{I_L = I_i\left(1 + \frac{R_2}{R_1}\right)}$ **

→ Design an ~~cont~~ current controlled current source with node voltage $V_2 = 3V$, $R_1 = 10K$, $R_2 = 5K$.

$\boxed{V_2 = -I_i \times R_2}$

$3 = I_i \times 5k$

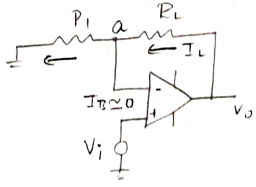
$\boxed{I_i = 0.6mA}$

$I_L = 0.6mA\left(1 + \frac{1}{2}\right)$

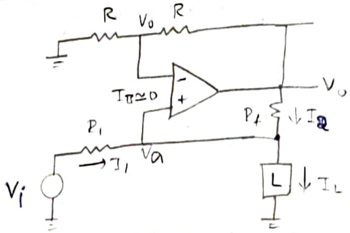
$\boxed{I_L = I_i\left(1 + \frac{R_2}{R_1}\right)}$

$\boxed{I_L = 0.9mA}$ //

Voltage to current converter (Transconductance Amplifier)



Floating loaded



Grounded load

A transconductance amplifier with floating node the output current is depending on the input voltage and which is independent of load present in the circuit since $I_B = 0$

The load current $\boxed{I_L = V_i / R_L}$ → floating load

In grounded load the anlysis slightly differs since the load is connected to ground directly

Applying KCL at node V_a and assuming $R = R_1 = R_f$

$$I_1 + I_2 = I_L$$

$$\frac{V_i - V_a}{R} + \frac{V_o - V_a}{R_f} = I_L$$

$$V_i - V_a + V_o - V_a = R I_L \Rightarrow V_i + V_o - 2V_a = I_L R$$

$$\boxed{V_a = \frac{V_i + V_o - I_L R}{2}}$$

The gain of the above non inverting amplifier.

$$1 + \frac{R_f}{R_1} = 1 + \frac{R}{R} = 2$$

The o/p of non inverting amplifier gain times i/p voltage

$$V_o = 2 \times V_a$$

$$\cancel{V_o} = V_i + \cancel{V_o} - I_L R$$

$$\boxed{V_i = I_L R} \qquad \boxed{I_L = \frac{V_i}{R}}$$

The transconductance factor $\boxed{g_m = \frac{I_L}{V_i} = \frac{1}{R}}$

$$\boxed{I_L = V_i \times g_m}$$

→ Design an transconductance amplifier with floating node having $R_f = 10\,k\Omega$, $R_L = 2\,k\Omega$, $V_i = 0.5\,V$.

$$I_L = \frac{V_i}{R_L} = \frac{\cancel{0.5}}{10k} = \cancel{5 \times 10^{-5} A} = \cancel{50\,\mu A}$$

$$= \frac{0.5}{2 \times k} = 0.25 \times 10^{-3} A = 250\,\mu A.$$

$$g_m = \frac{I_L}{V_i} = \frac{250\,\mu A}{0.5} = 500\,\mu A = 5 \times 10^{-4}\,\text{Siemens}.$$

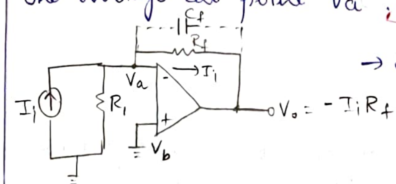
Current to voltage converter

The transresistance amplifier will convert the applied i/p current into a o/p voltage.

O/p voltage is the scaled factor of the input current and independent of the load present.

$\therefore V_o = K I_i$ ∴ where K is called as transresistance factor having a unit of ohms.

The voltage at point V_a ; $\boxed{V_a = -I_i R_f}$



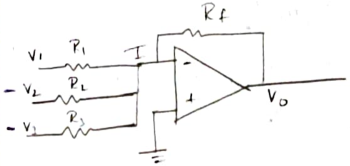
→ The o/p voltage $\boxed{V_o = K V_a}$

→ Design a trans resistance amplifier o/p volt = 5 V and $I_i = 10\,mA$

$$V_o = K I_i$$

$$5 = K\ 10\,mA \Rightarrow \boxed{K = 500\ \text{ohm}}$$

ADDER or Summing amplifier.



$$I = \frac{V_1}{R_1} + \frac{V_2}{R_2} + \cdots + \frac{V_n}{R_n}$$

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

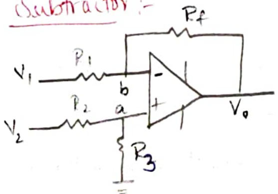
$$\boxed{V_o = A_1V_1 + A_2V_2 + \cdots + A_1V_1}$$

→ Design an summing amp for i/p voltage of 2, 3, 4 V with equal amount of resistance of 1kΩ.

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

$$= -\left[2 + 3 + 4\right] = -9V$$

Subtractor :-



$$V' = \frac{R_3}{R_2+R_3}V_2 = \frac{R}{R+R}V_2 = \frac{V_2}{2}$$

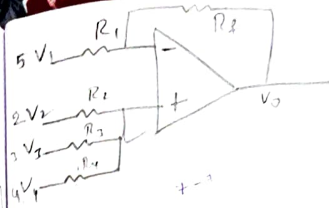
$$VO_2 = \left(1 + \frac{R_F}{R_1}\right)\frac{V_2}{2}$$

$$\boxed{VO_2 = V_2}$$

$$VO_1 = -\left(\frac{R_f}{R_1}\right)V_1$$

$$VO_1 = -V_1$$

→ Design a substractor and determine the output voltage with the help of superposition theorem with an input of 2 volts 3 volts, and 4 volts. all the 3 I/ps are given to Non-inverting terminal and I/p 5V is given to inverting terminal.



$$\frac{R \times R}{R+R} \quad \frac{R^2}{2R}$$

$$\boxed{VO_1 = -5V}$$

$$V' = \frac{R_4 \| R_3}{R_4 \| R_3 + R_2}(2) = \frac{R/2}{3\frac{R}{2}}(2)$$

$$= 2/3$$

$$V'' = \frac{R_2 \| R_4}{R_2 \| R_4 + R_3}(3)$$

$$= 3/3 = 1\,V.$$

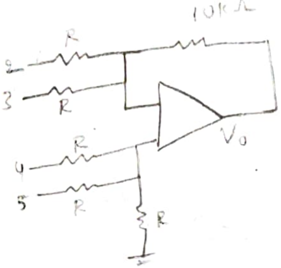
$$V''' = \frac{R/2}{3R/2}(4)$$

$$= 4/3\,V$$

$$VO_2 = \frac{2}{3} + 1 + \frac{4}{3} = 7/3\,V.$$

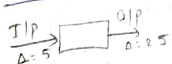
$$\frac{7}{3} \cdot 1.5$$

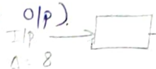
Calculate the output voltage of adder subtractor circuit with input voltage 2, 3, 4, 5, volts with a resistance value of 10 KΩ



OPAMP NON LINEAR CIRCUITS

Linear circuits :- Increament in I/p gives increament in O/p. (There will be a constant relation b/w i/p and o/p)



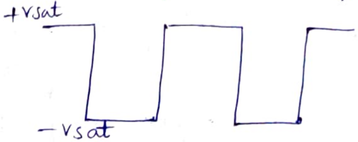


} Non linear circuits

Comparator's

These are also called as square wave generators.

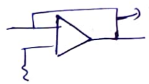
V_{ref} →
V_{in} → } I/p



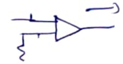
Here opamp as feedback or no feed back so it as only +Vsat or -Vsat

$V_{in} > V_{sat}$ → $+V_{sat}$

$V_{in} < V_{sat}$ → $-V_{sat}$

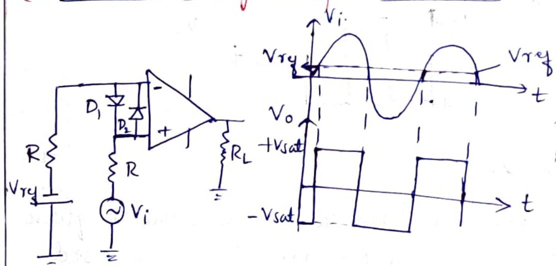


→ It doesn't undergo saturation



→ +Vsat or -Vsat

(i) Non inverting comparator circuit



Inverting

Same as Non-inverting but V_i to inverting terminal and V_{ref} to Non inverting terminal with V_{ref}

Comparator's circuits operates in non linear mode which produces Output which will be one of the saturation level depending on the comparision between input and referance voltage. The above fig shows the non inverting comparator which compares two input voltage V_{ref} and V_{in}

The reference voltage is always a +ve voltage and I/p voltage will be a AC signal. Here I/p voltage is sinusoidal AC signal.

- when input voltage V_i is less than V_{ref} then O/p of the op Amp will be at negative saturation, when the I/p voltage V_i greater than V_{ref} then O/p of the op Amp will be at +ve sat. This will continue since input voltage continues after every period.

D_1 and D_2 are used for protecting the op Amp from excessive voltage spikes ~~begin~~ being generated by reference source.

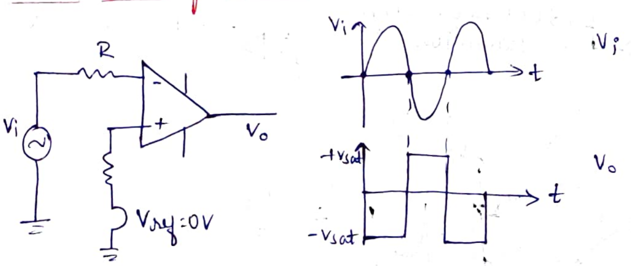
$V_i < V_{ref} \rightarrow V_o \rightarrow -V_{sat}$

$V_i > V_{ref} \rightarrow V_o \rightarrow +V_{sat}$

In inverting comparator V_i is connected to IN terminal and V_{ref} to NI terminal

V_{ref}

Zero crossing detector

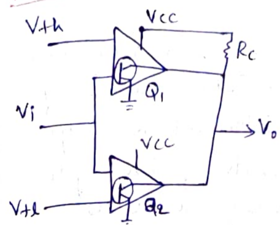


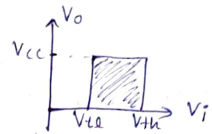
→ Detect only zero points.

→ Zero crossing detectors are also called as sine to square converters, Here the same comparator circuit is used by making reference voltage to zero.

→ This circuits will detect the zero points and shift the Output to Either +ve or -ve saturation voltages. Since the input is given to inverting terminal initially the first zero point will move the output voltage of the opamp to -ve saturation level. This continuous until the circuit detect next zero point which will shift the Output to +ve saturation this cycle continuous which makes the circuit to operates as sine to square converter.

Window detector





$\boxed{V_{+l} < V_i < V_{+h}}$

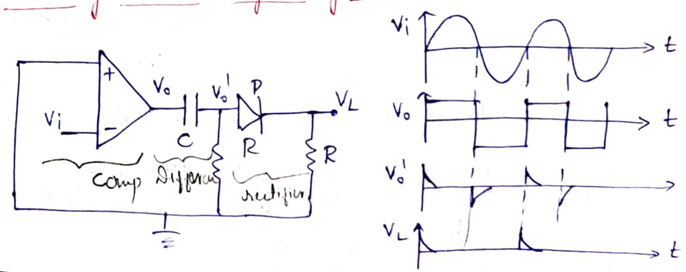
Window detector identifies the unknown input voltage b/w two threshold values V_{+l} and V_{+h}.

→ when the input voltage is b/w V_{+l} and V_{+h} both the transistor Q_1 and Q_2 are off and the resistor R_c pulls the voltage V_{cc} two the output making V_o to be high.

→ when $V_i > V_{+h}$ transistor Q_1 is ON which makes R_c to be pulled to ground which makes the output equal to zero.

→ Similary where $V_i < V_{+l}$ Q_2 is ON which makes the output equal to zero.

Timing Marker signal generator

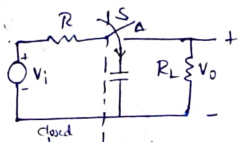


This are used for digital circuit.
→ Timing marker signal generator produces trigger pulses which consists of three parts having

(i) Comparator
(ii) Differentiator
(iii) Rectifier

The comparator operates as zero crossing detector, which converts sine wave into square wave, the output of the comparator is fed to a differentiator whose output is V_0', the differentiated output consists of two cycle in each period which is rectified using a diode rectifier which produces output V_L with a single position spike in each half of the cycle.

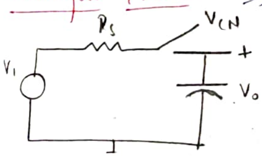
Analog switches

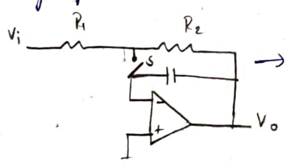


V_g Gating signal (Analog signal) ⇒ At switch.

Sample & hold

→ charging closed





→ For speed we use op amp circuit.

This are also called Analog to digital converters. (ADC)
→ Sample and hold circuits are used in ADC, the circuit is operated using a switch which is controlled by a voltage (V_{CN}). the amount of time duration decides the charging and discharging of the capacitor.
→ Sample and hold circuitries are two time period one is (i) aperture time that is maximum ~~time~~ amount of time for the switch to open.
(ii) Aquasition time which the minimum time required after the sample signal is applied and output reaching the input signal.
→ The opening and closing of the switch is controlled by a RC filter formed using an Op Amp for input voltage of V_i, the output voltage $V_0(t)$

$$\boxed{V_0(t) = -\frac{R_F}{R_1} V_i \left(1 - e^{-t/R_F C}\right)}$$

UNIT-2 — II part

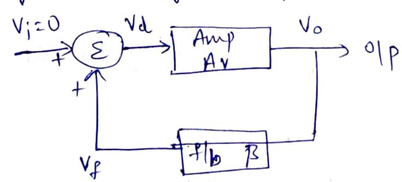
WAVE FORM GENERATOR'S

The oscillators which generates wave form without input.

– ve feed back → amplifiers   +ve feed back → wave form oscillation

(E.g: square form, triangle)

Oscillator is a feed back network consisting of an amplifier and the feed back circuit, the output of the amplifier is fed back to the input through a feed back network, the above fig shows the principle of oscillation with input = 0, the differential voltage V_d is given by summation of $V_i + V_f = V_d$



The output voltage V_o is given by voltage gain A_v into V_d

$\boxed{V_o = A_v \cdot V_d} = \boxed{A_v(V_i + V_f)}$

Feed back voltage V_f is given feed back factor β

$\boxed{V_f = \beta \cdot V_o = \beta \cdot A_v(V_i + V_f)}$

$$\boxed{\frac{V_o}{V_i} = \frac{A_v}{1-\beta A_v}}$$

The above shown circuit could work as an oscillator two conditions must be satisfied.

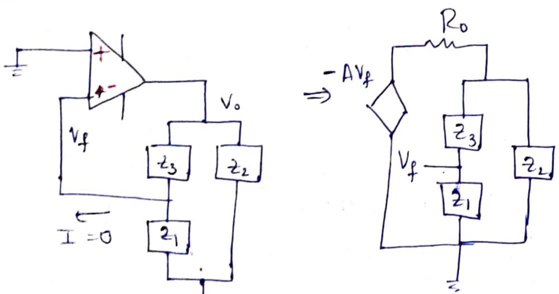
(i) Magnitude of open loop gain at feed back fraction should be equal to one ($|A_v\beta| = 1$)

(ii) The phase angle of open loop gain and feed back factor is 360 or 0 $\angle A_v\beta = 360°$ or $0°$

This above two condition is called as barkHausain criteria for sustained oscillation

Sine wave generators

LC - oscillators



$\Rightarrow$ F_o: operating frequency

LC oscillator is designed using an inverting amplifier and a feed back network which provides a feed back factor β which is equal to $\boxed{\beta = -\frac{V_f}{AV_f}}$

Considering the equivalent circuit having the dependent voltage source and equivalent resistance R_o of the op amp. Analysis is carried out for calculating the operating frequency.

Applying voltage divider rule to the equivalent circuit we can calculate f/b voltage V_f

$$\boxed{V_f = \frac{Z_1}{Z_1+Z_3} V_o}$$

Similarly the output voltage V_o can be calculated as $\boxed{\frac{Z}{Z+R_o}(-AV_f)}$ where Z is $\boxed{Z = Z_2 \| (Z_1+Z_3)}$

Taking the reciprocal of the overall gain of the system

$$\boxed{\frac{1}{AV_f} = -\frac{1}{V_o} \frac{Z}{Z+R_o}}$$

Substitute the value of Z

$$\frac{1}{AV_f} = -\frac{1}{V_o} \frac{Z_2 \times (Z_1+Z_2)}{(Z+R_o)(Z_2+Z_1+Z_2)}$$

$$\frac{1}{AV_f} = -\frac{1}{V_o} \frac{Z_1Z_2 + Z_2^2}{Z_2(Z_1+Z_3) + R_o(Z_1+Z_2+Z_3)}$$

Solving for β. , $\boxed{\beta = -\frac{V_f}{AV_f} = \frac{-Z_1Z_2}{R_o(Z_1+Z_2+Z_3) + Z_2(Z_1+Z_2)}}$

For an LC Quinable oscillator the 3 impedance Z_1, Z_2, Z_3 are purely reactive, that is the real part will be equal to zero, it can be written as.

$\boxed{Z_i = jX_i}$ $i = 1, 2, 3$

Substituting this to β equation β will become

$$\beta = \frac{X_1X_2}{jR_o(X_1+X_2+X_3) + X_2(X_1 * X_3)}$$

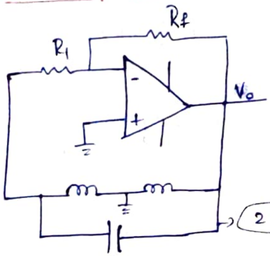
For β to be real the summation of real parts should be equal to zero, which is nothing but $X_1 + X_2 + X_3 = 0$

$\beta = \frac{X_1}{X_1 + X_3}$ $\quad$ $\beta(\omega_0) = \frac{X_1}{X_1 + X_3}$

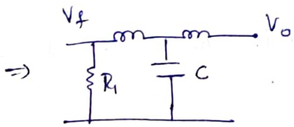
making X_3 a negligable component so that $X_1 + X_3$ is almost equal to X_2 $\therefore X_1 + X_3 = X_2$

$$\boxed{\beta(\omega_0) = \frac{X_1}{X_2}}$$

Hartley oscillator



$\Rightarrow$



2L, 1C

Hartley oscillators are sine wave generators which makes uses of 2 inductance and one capacitance in the feed back network the phase shift through the feed back network is 180° with an additional phase shift of 180° being provided by the ~~int~~ inverting amplifier.

Considering the feedback network the reactance X_1 is

$X_1 = j\omega L_1$ $\quad$ $X_2 = j\omega L_2$ $\quad$ $X_3 = -j/\omega C$

the operating frequency can be found out using ω_0 which is $\boxed{\omega_0 = \sqrt{\frac{1}{C(L_1+L_2)}}}$

$$\boxed{\beta(\omega_0) = \frac{L_1}{L_2}}$$

Finally the operating frequency f_0 is given by $\frac{1}{2\pi\sqrt{CL_T}}$

where, $\boxed{L_T \text{ is } L_1 + L_2}$ or $\boxed{L_T = L_1 + L_2 + 2M}$ where M = Mutual inductance of Coil L_1 and L_2

Colpitts oscillator

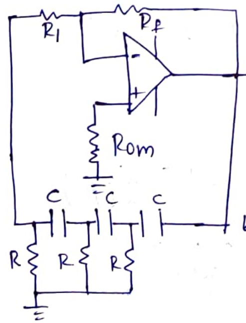
2C, 1L $\quad$ $\boxed{\frac{1}{2\pi\sqrt{C_T L}}}$

→ RC - phase shift oscillator.

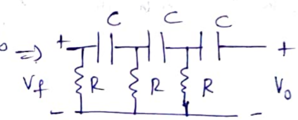
For smooth end wave form we will go with RC.

→ basically for sine wave only.

→ only one complex form is present that is C.



$\Rightarrow$



analysis

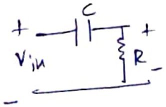
CR - high pass

RC - low pass

RC phase shift oscillators are used when an application involving low frequency signals are required, LC oscillators are not stable in low frequencies, due to which RC oscillators are used.

RC oscillator contains two stages feed back networks which provides 180° phase shift and an electrical system consisting of an inverting amplifier providing another 180° phase shift. The equivalent circuit for feed back network is as showned above consisting. of R and C components.

Taking a singled stage RC network, This behaves as an an high pass filter.



HPF

The Reactance of the network which contains a capacitor component which is given by $\boxed{X_C = \frac{1}{\omega C}}$

Calculating the gain of the network will get.

$$\boxed{\frac{V_o}{V_i} = \frac{R}{\left(R - \frac{j}{\omega C}\right)}}$$

Dividing both num and denominator by R we get.

$$\frac{V_o}{V_i} = \frac{1}{\left(1 - \frac{j}{\omega CR}\right)}$$

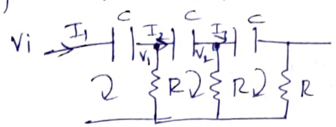
The phase angle is given by $\angle\phi = 0 - \tan^{-1}\left(-\frac{1}{\omega CR}\right)$.

$$\boxed{\phi = \tan^{-1}\left(\frac{X_C}{R}\right)} \Leftarrow \boxed{\phi = \tan^{-1}\left(\frac{1}{\omega CR}\right)}$$

If X_C = small componend then ϕ angle will be equal to zero ($\phi = 0$)

If R is very small ⇒ ($\phi = 90°$)

→ Theoretically by making $R = 0$ we achieve 90° of phase shift in each feed back stage, practically, since $R = 0$ sustained oscillation will not be achived, in orderd to overcome this third stage of RC component is added to feed back network each providing 60° of phase shift.



Considering the above 3 stage cascade network applying nodal analysis at point V_2

$$V_2 = (-jX_C I_3) + V_o$$

$$V_2 = \left(-jX_C \times \frac{V_o}{R}\right) + V_o \Rightarrow V_2 = \frac{V_o}{j\omega CR} + V_o$$

$$\boxed{V_2 = V_o\left[1 + \frac{1}{j\omega CR}\right]}$$

Applying KCL at load V_2

$$I_2 = \left(\frac{V_2}{R}\right) + I_3 \qquad I_2 = \frac{V_o}{R}\left(1 + \frac{1}{j\omega CR}\right) + \frac{V_o}{R}$$

$$\boxed{I_2 = \frac{V_o}{R}\left[2 + \frac{1}{j\omega CR}\right]}$$

Similarly applying nodal analysis at node V_1

$$V_1 = V_2 + \frac{I_2}{j\omega C}$$

$$= V_o\left[1 + \frac{1}{j\omega CR}\right] + \frac{V_o}{R}\left[2 + \frac{1}{j\omega CR}\right] \cdot \frac{1}{j\omega C}$$

$$= V_o\left[\left[\frac{1}{j\omega CR} + 1\right] + \frac{1}{\cancel{R}}\left[\frac{2}{j\omega CR} + \frac{1}{-1\omega^2 C^2 R^2}\right]\right]$$

$$V_1 = V_o\left[1 + \frac{3}{j\omega CR} - \frac{1}{\omega^2 C^2 R^2}\right]$$

Applying KCL at V_1 current $I_1 = \frac{V_1}{R} + I_2$

$$I_1 = \frac{V_0}{R}\left[1 + \frac{3}{j\omega CR} - \frac{1}{\omega^2 C^2 R^2}\right] + \frac{V_0}{R}\left[2 + \frac{1}{j\omega CR}\right]$$

$$I_1 = \frac{V_0}{R}\left[3 + \frac{4}{j\omega CR} - \frac{1}{\omega^2 C^2 R^2}\right]$$

Similarly applying nodal analysis for input node Vin is given by $V_{in} = V_1 + \frac{I_1}{j\omega C}$

$$V_{in} = \frac{V_0}{j\omega CR}\left[3 + \frac{4}{j\omega CR} - \frac{1}{\omega^2 C^2 R^2}\right] + V_0\left[1 + \frac{3}{j\omega CR} - \frac{1}{\omega^2 C^2 R^2}\right]$$

$$\cancel{V_{in} = V_0\left[\frac{4}{j\omega CR} - \frac{7}{\omega^2 C^2 R^2}\right]} \qquad \boxed{V_{in} = V_0\left[1 + \frac{6}{j\omega CR} - \frac{5}{\omega^2 C^2 R^2} - \frac{1}{j\omega^3 C^3 R^3}\right]}$$

The above equation contains both real part and img part the freq of oscillation is found by equating imaginary part to zero.

$$\frac{6}{j\omega CR} - \frac{1}{\omega^3 C^3 R^3} = 0$$

$$\frac{6}{\omega CR} = \frac{1}{\omega^3 C^3 R^3} = 6 = \frac{1}{\omega^2 C^2 R^2}$$

$$\boxed{f = \frac{1}{2\pi RC\sqrt{6}}} \qquad \boxed{\omega = \frac{1}{\sqrt{6}\,CR}}$$

In the input output relation substitute imaginary part as zero and ω as $\frac{1}{\sqrt{6}RC}$.

$$V_{in} = V_0\left[1 + \frac{-5\times 6 \cancel{C^2}\times \cancel{R^2}}{\cancel{C^2}\times\cancel{R^2}}\right] \qquad \omega^2 = \frac{1}{6C^2R^2}$$

$$V_{in} = V_0[1 - 30] \quad = \boxed{\frac{V_0}{V_{in}} = -\frac{1}{29}}$$

The gain of the feed back network is $-\frac{1}{29}$ which indicates the phase reversal of 180°, the same reciprocal gain should be provided by the electrical system inorder to make the overall gain of the oscillator to be equal to one ∴ The inverting amplifier should be designed we gain of $\boxed{\frac{R_F}{R_1} = +29}$

$$\cancel{\frac{V_0}{V_{in}} = -\frac{R_f}{R_1}} \qquad \cancel{-\frac{1}{29} =}$$

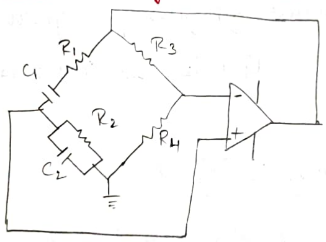
Design an RC phase shift oscillator for a $f_0 = 300$ Hz assuming $C = 0.1\mu F$

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

$$300 = \frac{1}{2\times 3.14\times R\times 0.1\times 10^{-6}\times\sqrt{6}}$$

$R = 2.1669 k\Omega$

Wiens Bridge oscillator



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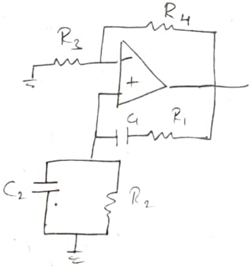

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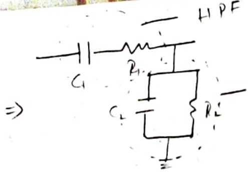
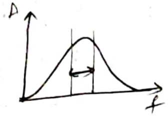




Weins bridge oscillator are circuits which generates frequ in the the range of audio signals.

The circuit consists of two parts the wein bridge feed back network and a non inverting amplifier.

Since, the electrical system doesn't provide any phaseshift the entire 360° phase shift is provided by the feed back network.

Analysing the feedback network it can be visualized as an notch filter whose frequency response is as shown in the fig.

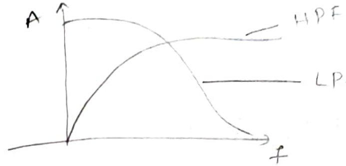
A notch filter allows a narrow frequency signals which is made up of combination of high pass filter and a low pass filter. During the resonate frequency the phase angle of the feed back network will be ($\phi = 0$) and the gain is fixed $\boxed{\frac{V_o}{V_i} = \frac{1}{3}}$ or ~~$A_v = \frac{1}{3}$~~

This value is called as the feed back factor. $\boxed{\frac{1}{3} = \beta}$

If $R_1 = R_2$ and $C_1 = C_2$ the Resonance frequency is given by $\boxed{f_r = \frac{1}{2\pi RC}}$ if $R_1 \neq R_2$ & $C_1 \neq C_2$ the Resonant frequency is given by $\boxed{f_r = \frac{1}{2\pi\sqrt{R_1 R_2 C_1 C_2}}}$

For sustained oscillations $\boxed{A\beta = 1}$ which tells us the gain of the op amp $\boxed{A = 3}$ Since the opamp is configured as non inverting amplifier $\boxed{A = 1 + \frac{R_4}{R_3}}$ which should be equal to 3.

$$\frac{R_4}{R_3} = 2 \qquad \therefore \boxed{R_4 = 2R_3}$$



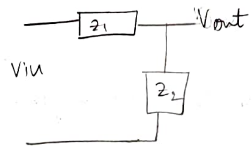
Calculate the resonant frequency of a weins bridge oscillator for an $R_1 = R_2 = 10k\Omega$, $C_1 = C_2 = 0.1\mu F$

$$f_r = \frac{1}{2\pi \times 10k \times 0.1\mu F} \qquad \boxed{f_r = \frac{1}{2\pi RC}}$$

$f_r = 159.23$ Hz

Analysing of feed back

Analysing the feedback network and representing it in terms of impedances the output voltage of the feedback network shown in the above fig can be written as



$$V_{out} = \frac{Z_2}{Z_1 + Z_2} V_{in}$$

$$\boxed{\frac{V_{out}}{V_{in}} = \frac{Z_2}{Z_1 + Z_2}}$$

$$Z_2 = R_2 \| C_2 = R_2 \| \frac{1}{j\omega C_2}$$

$$\boxed{Z_2 = \frac{R_2}{1 + j\omega C_2 R_2}} \qquad \boxed{Z_1 = R_1 + \frac{1}{j\omega C_1}}$$

$$A = 1 + \frac{R_4}{R_3}$$

$$= 1 + \frac{\frac{R_2}{1 + j\omega C_2 R_2}}{R_1 + \frac{1}{j\omega C_1}} = \frac{R_1 + j\omega C_1 + \frac{R_2}{1 + j\omega C_2 R_2}}{R_1 + \frac{1}{j\omega C_1}}$$

$$\frac{V_o}{V_i} = \frac{j\omega R_2 C_1}{1-\omega^2 R_1 R_2 C_1 C_2 + j\omega(R_1C_1+R_2C_2+R_2C_1)}$$

At Resonant frequency since the phase shift is equal to zero 0°, the real part of the above equation will be equal to one.

Equating Real part = 1 $\quad \omega^2 R_1 R_2 C_1 C_2 = 1$

$$\boxed{f_r = \frac{1}{2\pi\sqrt{R_1R_2C_1C_2}}}$$

Considering the imaginary part

$$\frac{V_o}{V_i} = \frac{R_2 C_1}{R_1C_1+R_2C_2+R_2C_1} = \beta \quad \text{since } R_1 = R_2,\ C_1 = C_2$$

$$\boxed{\frac{V_o}{V_i} = \frac{1}{3}}$$

Since the sustained oscillations $A\beta = 1$ so $A = \frac{1}{\beta}$

$$A = \frac{R_1C_1+R_2C_2+R_2C_1}{R_2C_1}$$

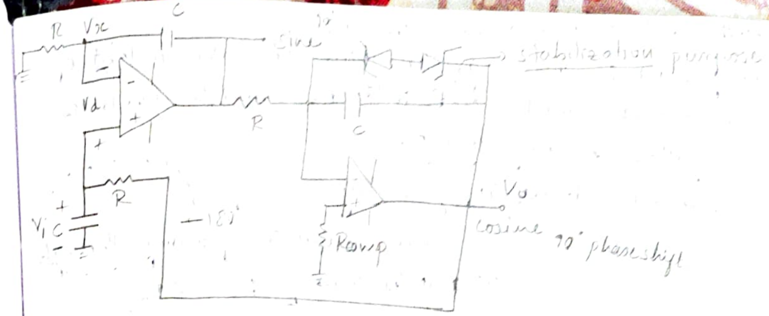
$$A = \frac{R_1}{R_2} + \frac{C_2}{C_1} + X = \frac{R_4}{R_3} + X$$

since it is an non inverting amplifier the gain is given by $A = \frac{R_1}{R_2} + \frac{C_2}{C_1} = \frac{R_4}{R_3}$

Assuming $R_1 = R_2 \quad C_1 = C_2$

$$\boxed{\frac{R_4}{R_3} = 3}$$

Quadrature Oscillations



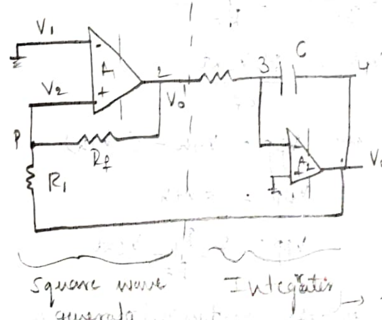
will get same frequency of oscillators with different phase shift.

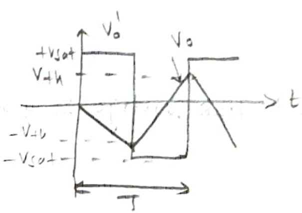
Sine wave gives 90° phase shift, cosine gives 90° phase shift. and RC gives 180° ~~give~~ phase shift.

The overall circuit gives 360° or 0° phaseshift.

water level controller Analog, Digital, Mathematical

Triangular wave generator



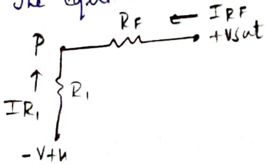


Vth → Voltage that capacitor can hold

triangular wave can be implemented by integrating square wave output generated by smitt trigger, in the above circuit op amp A_1 operates as smitt trigger and A_2 as an integrator A_1 compares V_1 and V_2 and produces square wave accordingly. the operation of overall circuit can be

splited into two modes. $V_+ > 0$
During mode 1. V_+ is greater than zero, the output of A_1 is $+V_{sat}$ which fed into A_2 which produces a negatives boaring ramp.

The equivalent circuit is given by

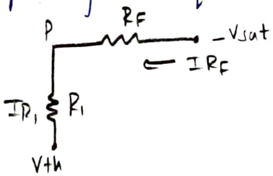


∴ Since current flowing through op amp is zero $\boxed{IR_1 = -I_{Rf}}$

$$-\frac{V_{th}}{R_1} = -\frac{V_{sat}}{R_F}$$

$$\boxed{-V_{th} = \frac{R_1(-V_{sat})}{R_F}}$$

During Mode 2 the $V_+ < 0$ A_1 will be at negative $-V_{sat}$ which makes the integrator to produce positive boaring ramp, the equivalent feed back network is given by



$$IR_1 = -IR_F$$

$$\frac{V_{th}}{R_1} = -\frac{(-V_{sat})}{R_F}$$

$$V_{th} = \frac{R_1 V_{sat}}{R_F}$$

Peak to Peak voltage is given by $V_{pp} = V_{th} - (-V_{th})$

$$V_{pp} = 2V_{th}$$

$$\boxed{V_{pp} = 2\frac{R_1}{R_F}V_{sat}}$$

The period and frequency of the rectangular wave is given by considering the capacitor voltage operating in mode 2 that is input to the integrator is $-V_{sat}$. The instantaneous voltage of capacitor. $\boxed{V_C(t) = \frac{-1}{RC}\int V_0'(t) - V_{th}}$

$$V_C(t) = \frac{-1}{RC}\int(-V_{sat})\,dt - V_{th}$$

$$V_C(t) = \frac{V_{sat}.t}{RC} - V_{th}$$

Considering the period (t) $t = (T/2)$

$$V_C(T/2) = \frac{V_{sat}.T/2}{RC} - \frac{R_1 V_{sat}}{R_F}$$

$$V_{th} = \cancel{V_{sat}}\left[\frac{T}{2RC} - \frac{R_1}{R_F}\right]$$

$$\Rightarrow V_{th} = \frac{V_{sat}.T/2}{RC} - V_{th}$$

$$\Rightarrow 2V_{th} = \frac{V_{sat}\,T/2}{RC}$$

$$2V_{th} = \frac{V_{sat}.T/2}{RC}$$

$$2\left(\frac{R_1 \cancel{V_{sat}}}{R_F}\right) = \frac{\cancel{V_{sat}}.T/2}{RC}$$

$T = 1/f$

$$\boxed{T = \frac{4RC.R_1}{R_F}} \qquad \boxed{f_0 = \frac{R_F}{4RCR_1}}$$

→ Calculate the time period for an triangular wave with feed back resistance of 10kΩ, V_{th} of 3 volts, R=150KΩ V_{sat} of 11 V,

$$T = \frac{4RC.R_1}{R_F} = \frac{4 \times 150K \times 0.1\mu \times 2.727K}{10K}$$

$$T = 1.636\,msec$$

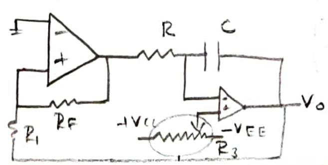
$$V_{th} = \frac{R_1 V_{sat}}{R_F}$$

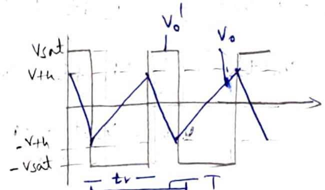
$$3 = \frac{R_1\,11}{10K\Omega}$$

$$\frac{30K}{11} = R_1$$

$$2.727K = R_1$$

Saw tooth ~~Square~~ wave generator

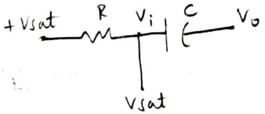




Saw tooth wave form is a modified triangular wave wh[illegible] as unequal raise and fall time.

The triangulare wave is ~~connect~~ converted into saw tooth by using variable voltage V_{ref} at the non inverting terminal of op amp A_2.

Mode 1 :- During mode 1 ($V_+ > 0$) output of the op amp A_1 is at positive saturation which is input to the op amp A_2, the equivalence circuit of the feedback network is given by



At the beginning the output voltage will be V_{th}

The non inverting terminal will be at V_{ref}, since, due to the presence of virtual ground concept the inverting terminal will also have same V_{ref} voltage

→ The ~~instate~~ instantaneous capacitive voltage $V_c(t=0)$.

$$V_c(t=0) = V_1 - V_o \qquad V_1 = V_{ref}$$

$$= V_{ref} - V_{th} \qquad V_o = V_{th}$$

→ The instantaneous capacitance voltage $V_c(t) = \frac{1}{C}\int i_c(t)\,dt + V_c(t=0)$

$$V_{ref} - V_o(t) = \frac{1}{C}\int i_c\,dt + V_c(t=0)$$

$$V_{ref} - V_o(t) = \frac{1}{C}\int i_c\,dt + V_{ref} - V_{th}. \qquad i_c = \frac{V_{sat} - V_{ref}}{R}$$

$$V_o(t) = -\left[\frac{1}{C}\int i_c\,dt - V_{th}\right]$$

$$= V_{th} - \frac{V_{sat} - V_{ref}}{RC}\cdot t$$

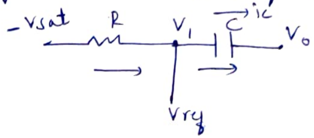
At end of this mode ∴ $t = t_1$ Output voltage will be at

$$V_o(t = t_1) = -V_{th}$$

$$-V_{th} = V_{th} - \frac{V_{sat} - V_{ref}}{RC}\cdot t_1$$

$$\boxed{t_1 = \frac{2RCV_{th}}{V_{sat} - V_{ref}}}$$ → doubt check in text

During mode 2 : $V_+ < 0$ output of A_1 will be at $-V_{sat}$ (negative saturation) & equivalence circuits is given by.



$$V_o = -V_{th}$$

$$V_c(t=0) = V_1 - V_o$$

$$= V_{ref} + V_{th}.$$

$$V_c(t) = \frac{1}{C}\int i_c(t)\,dt$$

$$\boxed{t_2 = \frac{2R_C V_{th}}{V_{sat} + V_{ref}}}$$

$$\boxed{T = t_1 + t_2 = \frac{4RCV_{th}V_{sat}}{V_{sat}^2 - V_{ref}^2}}$$

$$\boxed{f = \frac{1}{T} = \frac{V_{sat}^2 - V_{ref}^2}{4RCV_{th}V_{sat}}}$$

K (Duty cycle) $\boxed{= \frac{t_1}{T}} = \frac{\text{On period}}{\text{total period}}$

$$\boxed{K = \frac{1}{2}\left[1 + \frac{V_{ref}}{V_{sat}}\right]}$$