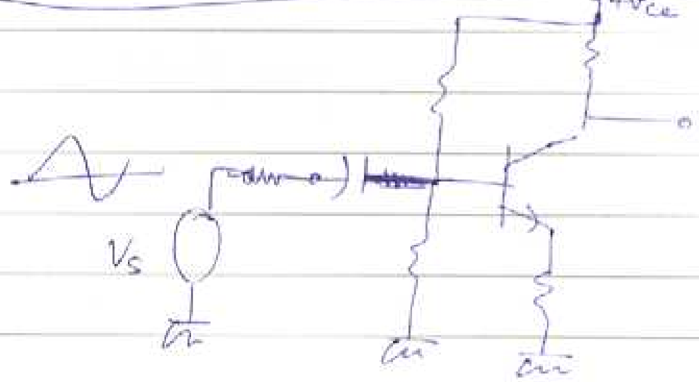
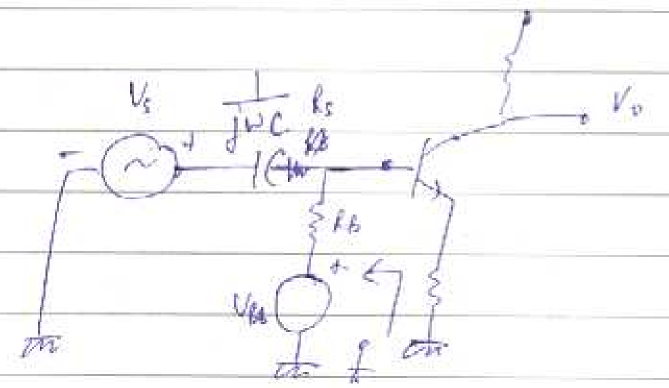
Max I_E $= 100 \times 7.5$ mAmp.
$= 0.75$ Amp.

Min ~~Max~~ $R_L = \dfrac{7.5 - 0.7}{0.75 \text{ Amp}} = 9.07\ \Omega$

Constant voltage source for $R_L > 9.07\ \Omega$





Around operating point if I_B is varied this will cause variation in I_C hence in V_{CE}

$$\frac{V_{S0} - V_{BB}}{R_S + R_S + \frac{1}{jwC}} \times R_B + V_{BB} = V_0 + V_S'$$

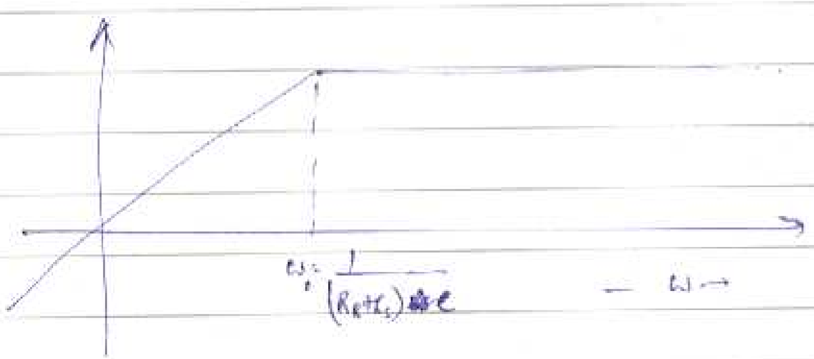
$$\frac{(V_S - V_{BB})\, jwC R_B}{jwC(R_S + R_B) + 1} + V_{BB} = V_0 + V_S'$$

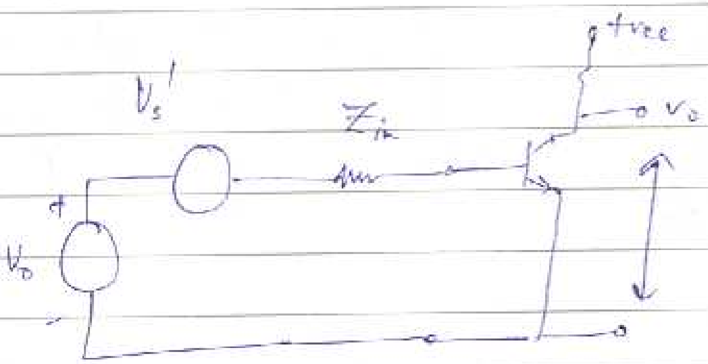
$$V_{BB}\left(\frac{\cancel{-jwR_BC} + 1 + jwCR_S + \cancel{jwR_BC}}{1 + jwC(R_S + R_B)}\right) = V_0 + V_S'$$

$$V_0 = \frac{V_{BB}\left(1 + j\omega C R_s\right)}{\left(1 + j\omega C(R_s + R_B)\right)}$$

$R_s \gg R_B$ then $V_0 = V_{BB}$

$$V_s' = \frac{V_s \cdot j\omega C R_B}{1 + j\omega C(R_B + R_s)}$$ high pass function





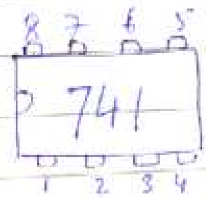
Operational amplifier.

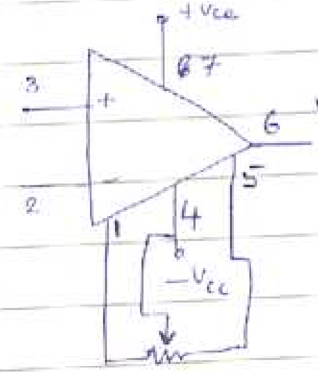
~~Commonly~~ Versatile ~~Integrat~~ Integrated device.

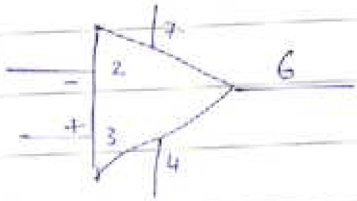
One get it in ~~IC 74~~ packaged IC form

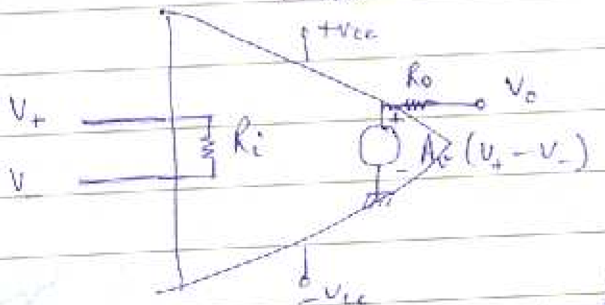
Example IC 741.

From Top







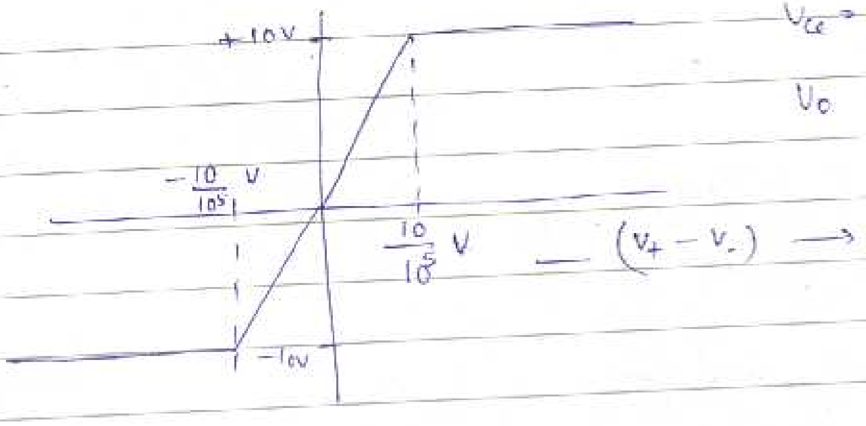


R_i is very large

For ideal op-amp (Can be assumed $\infty\ \Omega$. R_o is very small $\sim 0\ \Omega$.

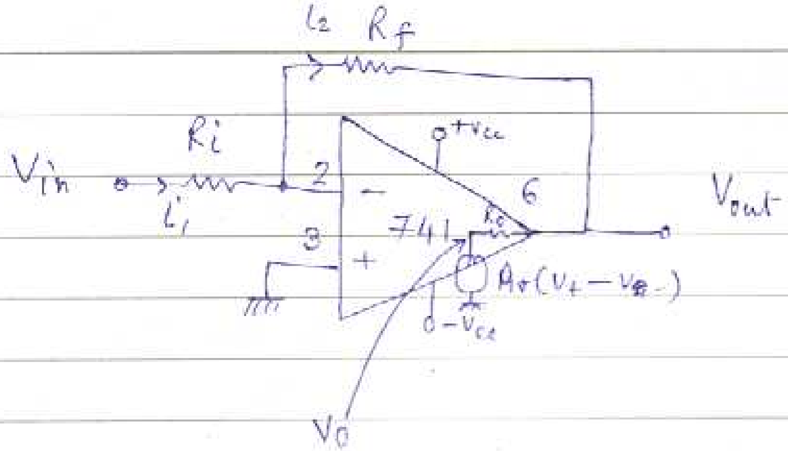
A_v is very large 100,000 (10^5 for 741).

$R_i = 2\ M\Omega$, $R_o = 75\ \Omega$



$V_{cc} = 10V$

V_o Cannot be $> 10V$



$$\frac{V_{in} - V_-}{R_i} = i_1 \quad \text{— (1)}$$

$$i_2' = \frac{V_- - \cancel{V_{out}}\,V_{out}}{\cancel{R_f}\,R_f'} \quad \text{— (2)}$$

i_1, V_-, i_2, V_{out}

$R_f' = R_f + R_0$

$$(0 - V_-)\,A_v = \cancel{V_{out}}\,{}_{out} \quad \text{— (3)}$$

$$i_1' - i_2' = \frac{V_-}{R_i} \quad \text{— (4)}$$

As R_i is very large

$$i_1' - i_2' \simeq 0$$

$$i_1 = i_2'$$

Assuming Op-amp operating in linear region

The above equations not valid in saturation ~~area~~ region.

$$-V_- A_v = V_{out} \quad \text{— (1)}$$

$$\frac{V_{in} - V_-}{R_i} = \frac{V_- - V_{out}}{R_f} \quad \text{— (2)}$$

$$\frac{V_{in} - V_-}{R_i} = i_1 \quad \text{— (3)}$$

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using (1) and (2)

$$\left(V_{in} + \frac{V_{out}}{A_v}\right)\frac{1}{R_i} = \left(-\frac{V_{out}}{A_v} - \cancel{V_f}\, V_{out}\right)\frac{1}{R_f}$$

$$\frac{V_{in}}{R_i} = \frac{-1}{R_f}\left(\frac{1}{A_v} + \frac{R_f}{R_i A_v} + 1\right) V_{out}$$

$$\frac{V_{out}}{V_{in}} = -\frac{R_f}{R_i}\left(\cancel{\frac{A_v+2}{A_v}}\right)\left(\cancel{\frac{A_v}{2+A_v}}\right)\left(\frac{A_v}{A_v + \left(1+\frac{R_f}{R_i}\right)}\right)$$

$$= -\frac{R_f}{R_i}\left(\frac{1}{1 + \frac{\left(1+\frac{R_f}{R_i}\right)}{A_v}}\right)$$

$A_v \sim$ large. (10^5)

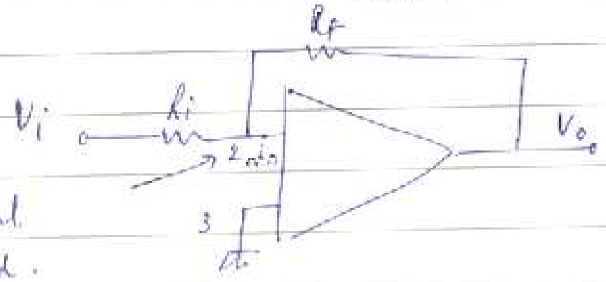
$A_v >> 1 + \frac{R_f}{R_i}$ Then $\Longrightarrow$ $\boxed{\frac{V_{out}}{V_{in}} \sim -\frac{R_f}{R_i}}$

$$V_- = V_{in}\left(-\frac{R_f}{R_i}\right)\frac{1}{A_v}$$

as A_v is very large $V_- \sim 0$.

In the above circuit

Potential at V_- and V_+ are almost same.



Virtual ground.

For most of the circuits this is true.

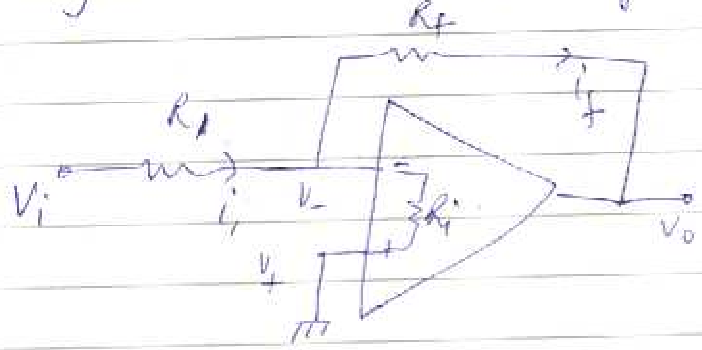
$R_i >> R_i, R_f$

$A_v >> 2$

$A_v >> R_f/R_i$

$R_f >> R_o$

Subjective understanding why this happens.



~~$V_i \uparrow \Rightarrow i_f \uparrow$~~

$V_- \uparrow$ $\quad$ $V_o \downarrow$

because $V_o = -A_v V_-$

$i_f \uparrow$ because $\dfrac{V_- - V_o}{R_f}$

$= \dfrac{V_- + A_v V_-}{R_f}$

$= (1 + A_v)\dfrac{V_-}{R_f}$

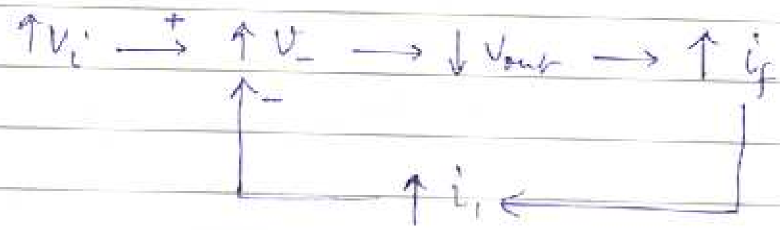
Current through $R_i \sim 0$ as R_i is very large.

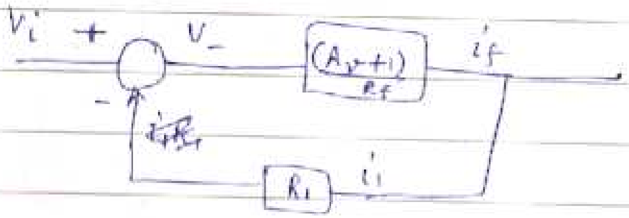
~~$\uparrow i_f \Rightarrow i_f \uparrow$ should increase~~

Change in V_i, i_1 is fixed ~~change~~ increases V_- leading to

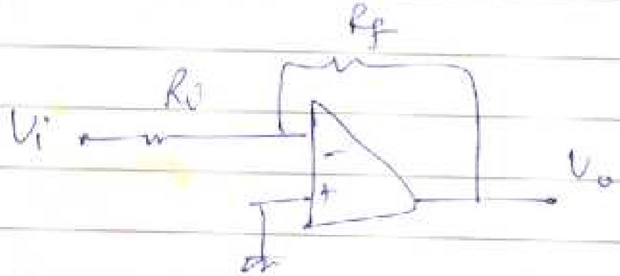
~~…~~ - change in i_f

This increase i_1 reducing V_-

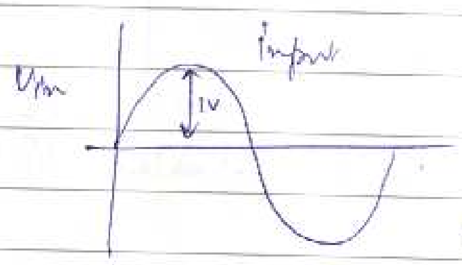




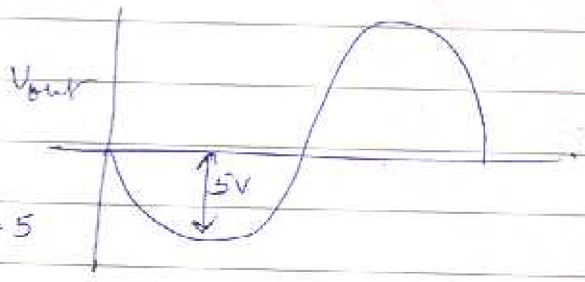
-ve feedback



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

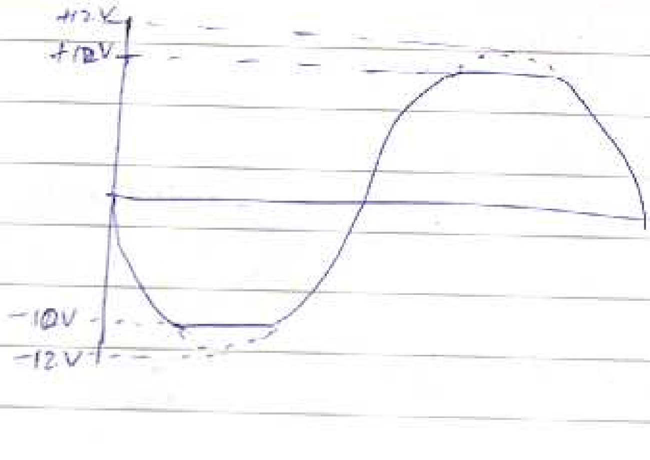


for $\frac{R_f}{R_i} = 5$

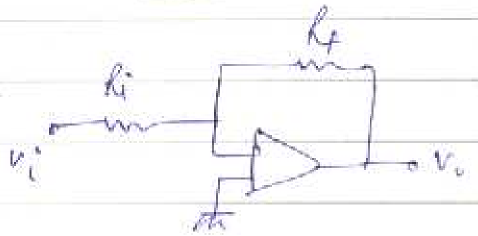


Always $\boxed{V_{out} \leq V_{cc}}$

for $\frac{R_f}{R_i} = 12$

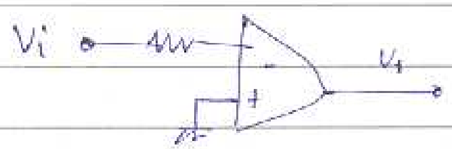


~~CMRR~~



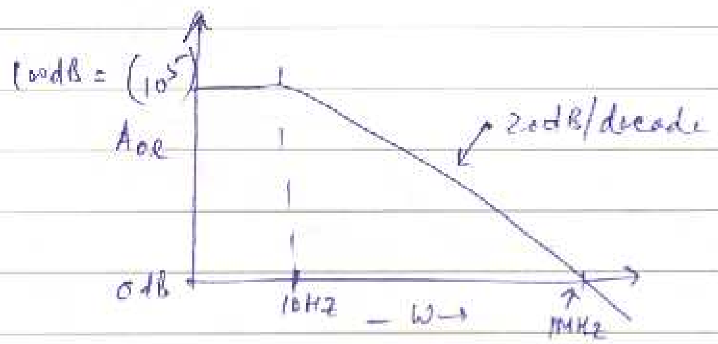
$V_i = V_p \sin(\omega t)$

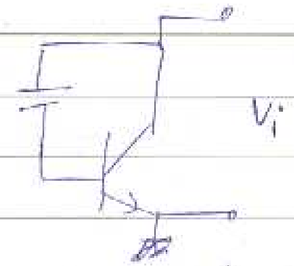
$V_o = V_p \boxed{A_{CL}} \sin(\omega t + \phi)$

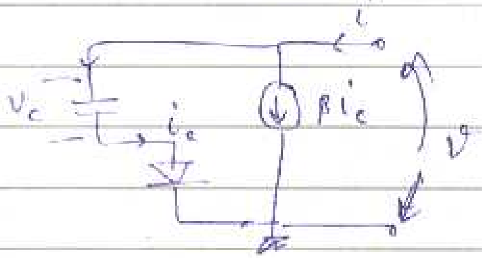


open loop

$$\frac{|V_o(\omega)|}{|V_i(\omega)|} = A_d$$







$$c\frac{dv_c}{dt} = i_c$$

$$i = i_c + \beta i_c$$
$$= (1+\beta)\, i_c$$

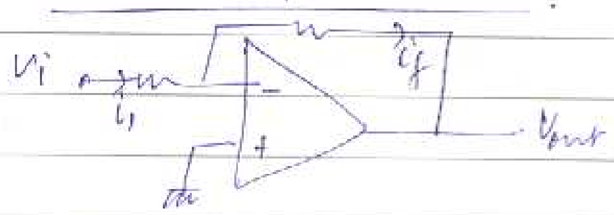
$$v_c + v_D = v$$

$$c\,\frac{d(\cancel{v_c + v_D}\; v - v_D)}{dt} = i_c$$

$$\boxed{i = (\beta+1)\, c\, \frac{dv}{dt}}$$

Effective capacitance $\boxed{(\beta+1)\, c}$

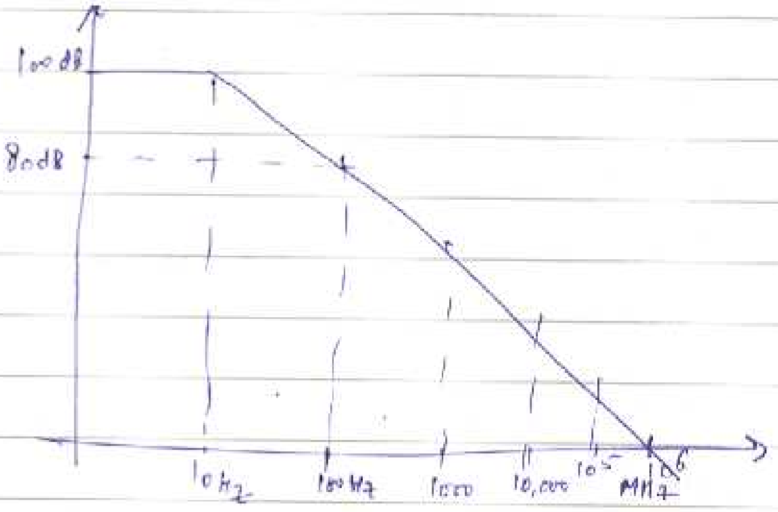
~~when -ve feedback exist.~~



V_1 is at w.f. $f_1 > 10$ Hz

say 100 Hz

A_{OL} is small.



$A_{OL} = 10^4$
$= 10^{(80/20)}$

due to smaller A_{OL}, $|V_{out}|$ is smaller hence it is higher (less -ve)

~~but~~
This causes drop in i_f. and thus drop in i_1

and hence increase in V_-, thus leading to increase in V_{out}.

-ve feedback compensates for reduction of A_{OL}.

$$\frac{V_{out}}{V_{in}} = -\frac{R_f}{R_i}\left(\cancel{\frac{A_V}{A_f}}\right)\left(\frac{1}{1+\frac{(1+R_f/R_i)}{A_V}}\right)$$

A_V is still much larger than

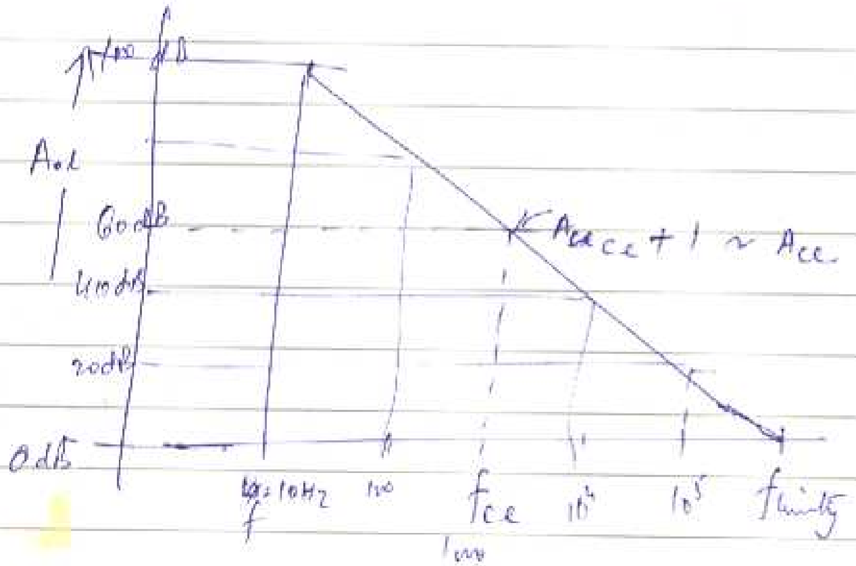
~~hence~~

~~$\frac{V_{out}}{V_{in}} \approx -\frac{R_f}{R_i}$~~

when $A_v = 1 + \frac{R_f}{R_{in}}$, then cut off for

A_{cl} happen

At f_{cl}, $A_{ol} = 1 + A_{cl}$



20 dB/decade

$$20 \log \frac{A_{cl}+1}{1} = 20 \log \left(\frac{f_{unity}}{f_{cl}} \right)$$

$$\boxed{\frac{f_{unity}}{A_{cl}+1} = f_{cl}}$$

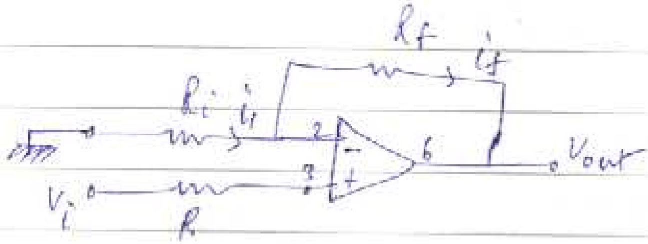
usually $A_{cl} > 10$ in practical cases.

$f_{unity} = 1 MHz$

with gain of 1000 $\quad f_{cl} = \frac{10^6}{10^3} = 10^3 Hz$

DATE.....................

Non inverting amplifier.



Since no current is flowing into pin 3,

R is immaterial ~~for~~ in the circuit.

$V_+ = V_i$

$-(V_- - V_+) = -(V_- - V_i) A_v = V_{out}$

$\Rightarrow \quad V_- = \dfrac{-V_{out} + A_v V_i}{A_v} = \dfrac{-V_{out}}{A_v} + V_i$

$i_1 = i_f$

$V_o = V_- - R_f i_f$

$0 - i_f R_i = V_-$

$V_{out} = -i_f R_i - R_f i_f$

$V_{out} = -(R_i + R_f) i_f$

$V_{out} = +(R_i + R_f) \dfrac{V_-}{R_i}$

$\cancel{V_{out}}\ \cancel{V_- = \dfrac{(R_i+R_f)}{R_i} \dfrac{V_-}{A_v} + V_i}$

$\dfrac{V_{out} R_i}{R_i + R_f} = \dfrac{-V_{out}}{A_v} + V_i$

$\cancel{V_-\left(1 - \dfrac{R_i + R_f}{R_i} \times \dfrac{1}{A_v}\right) = V_i}$

$$V_{out}\left(\frac{R_i}{R_i+R_f} + \frac{1}{A_v}\right) = V_i$$

$$\frac{V_{out}}{V_{in}} = \frac{R_i+R_f}{R_i\left(1+\frac{R_i+R_f}{R_i A_v}\right)}$$

when $A_v \gg \frac{R_i+R_f}{R_i}$

then $\boxed{\frac{V_{out}}{V_{in}} \simeq \frac{R_i+R_f}{R_i}}$

when $A_{ol} = A_{cl} = \frac{R_i+R_f}{R_i}$, There after the A_{cl} drops.

$$f_{cl} = \frac{f_{unity}}{A_{cl}}$$

$$f_{cl} \times A_{cl} = f_{unity}$$

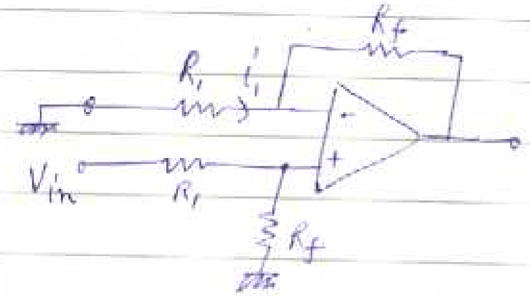
$$\frac{-V_{out}}{(R_f+R_i)} = I_f \qquad V_- = -I_f R_i = +\frac{V_{out} R_i}{R_f+R_i}$$

$$\boxed{V_- = V_{in}}$$

Both $-$ and $+$ terminals will have same voltage due to feedback.

Differential amplifier

$(V_{in1} - V_{in2})\, G = V_{out}$



$$V_+ = \frac{V_{in} R_f}{R_1 + R_f}$$

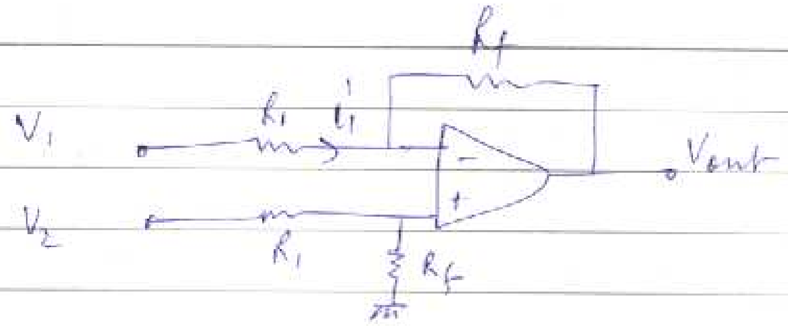
Due to -ve feedback V_- and V_+ will be same.

$$i_1 = -\frac{V_{in} R_f}{R_1 + R_f} \times \frac{1}{R_1}$$

$$V_{out} = 0 - \frac{V_{in} R_f}{R_1 + R_f} \times \cancel{\frac{R_f}{R_1}} - \frac{V_{in} R_f}{R_1 + R_f} \times \frac{1}{R_1} \times R_f$$

$$= -\frac{V_{in} R_f}{R_1 + R_f} \left(1 + \frac{R_f}{R_1}\right)$$

$$\boxed{V_{out} = -V_{in} \frac{R_f}{R_1}}$$



$$V_+ = \frac{V_2 R_f}{R_1 + R_f}$$

$$V_- = \frac{V_2 R_f}{R_1 + R_f} \Rightarrow i_1 = \left(V_1 - \frac{V_2 R_f}{R_1 + R_f}\right)\frac{1}{R_1}$$

$$V_{out} = V_1 - i_1 R_1 - i_1 R_f$$

$$= V_1 - i_1 (R_1 + R_f)$$

$$= V_1 - \left(V_1 - \frac{V_2 R_f}{R_1 + R_f}\right)\frac{(R_1 + R_f)}{R_1}$$

$$= V_1 - V_1\left(\frac{R_1 + R_f}{R_1}\right) + V_2 \frac{R_f}{R_1}$$

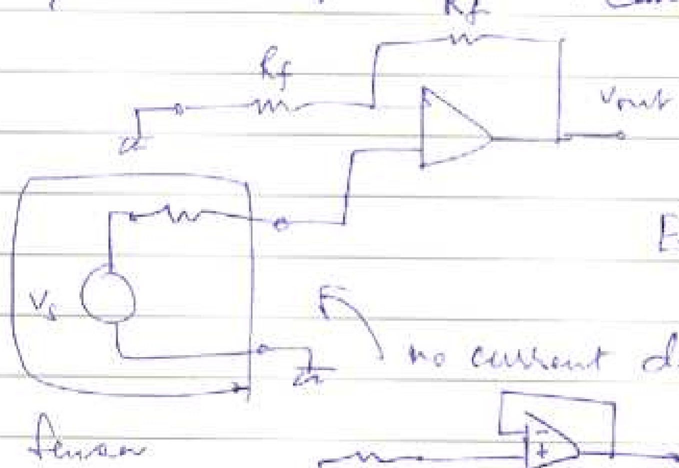
$$= -V_1 \frac{R_f}{R_1} + V_2 \frac{R_f}{R_1}$$

$$= (V_2 - V_1)\frac{R_f}{R_1}$$

Voltage source

Without drawing any current voltage need to be sensed

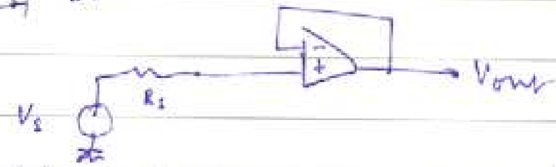
Can be made unity gain if $R_f = 0\,\Omega$, $R_1 = \infty$



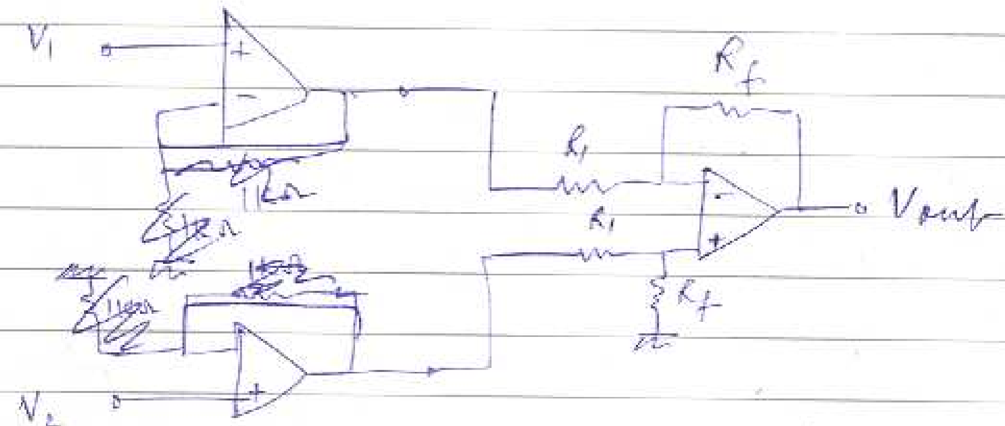
gain $\left(1+\frac{R_f}{R_1}\right) = 2$

Emitter follower

no current drawn from sensor



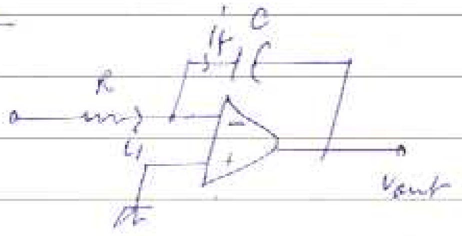
At output more current can be drawn out. ~~with~~



$$V_{out} = (V_2 - V_1)\frac{R_f}{R_1}$$

Instrumentation amplifier.

Integrator



V_- is virtually grounded.

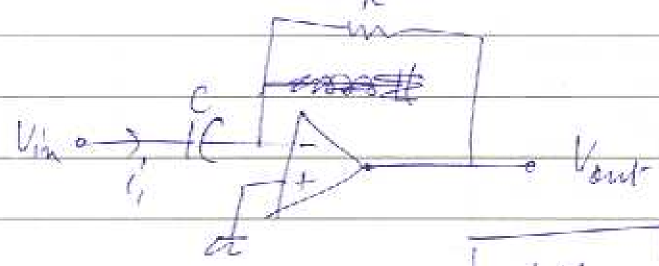
$$i_1 = \frac{V_{in}}{R} = i_f$$

$$-C\frac{dV_{out}}{dt} = i_f = \frac{V_{in}}{R}$$

$$V_{out} = -\int_0^t \frac{V_{in}}{RC}\,dt$$

$$\text{gain} = \frac{1}{RC}$$

Differentiator



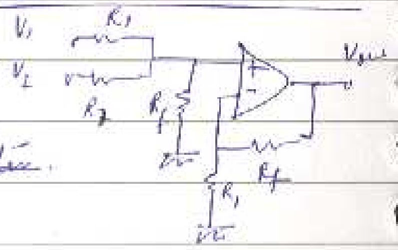
$$i_1 = C\frac{dv_{in}}{dt}$$

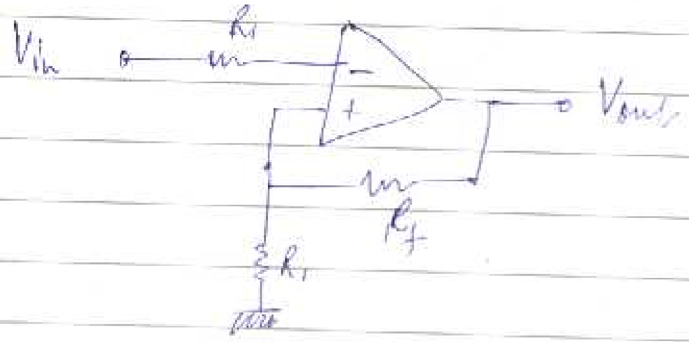
$$V_{out} = -i_1 R$$

$$\boxed{V_{out} = -RC\frac{dv_{in}}{dt}}$$

Adder

~~Subtraction~~





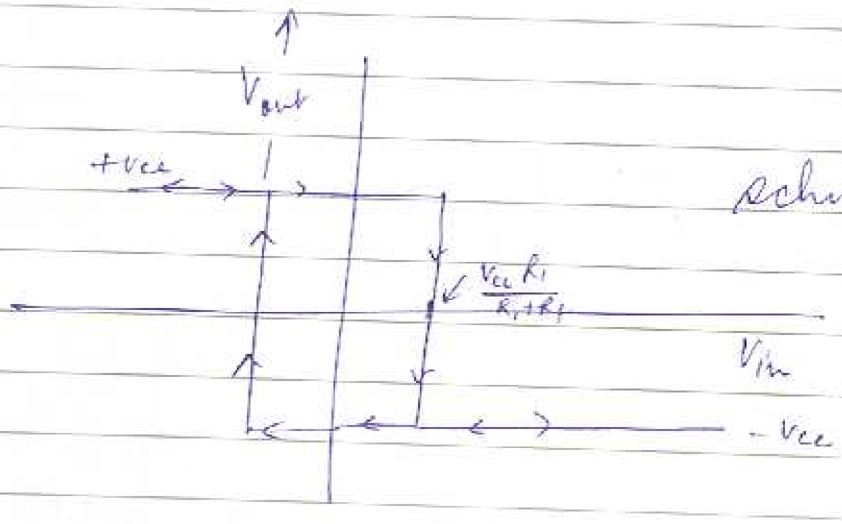
$$V_+ = \frac{V_{out}}{R_1+R_f} \times R_1$$

When $V_{in} < V_+$, $V_{out} = +V_{cc}$ and $V_+ = \frac{V_{cc} R_1}{R_1+R_f}$

when $V_{in} > \frac{V_{cc} R_1}{R_1+R_f}$, then $V_{out} = -V_{cc}$

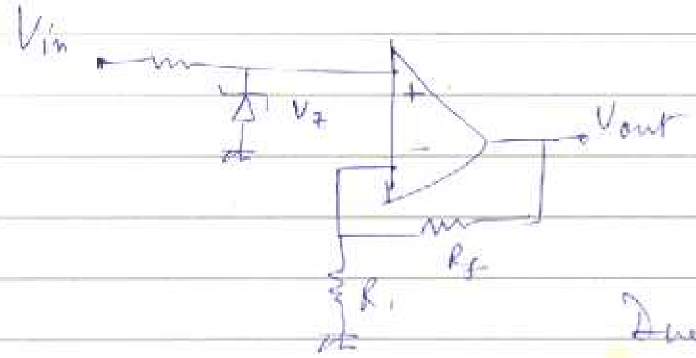
and V_+ changes to $\frac{-V_{cc} R_1}{R_1+R_f}$

Now any ~~further~~ decrease of V_{in} will not change the V_{out} till $V_{in} < \frac{-V_{cc} R_1}{R_1+R_f}$



Schmitt trigger.

Voltage Reference (typical for large voltage)



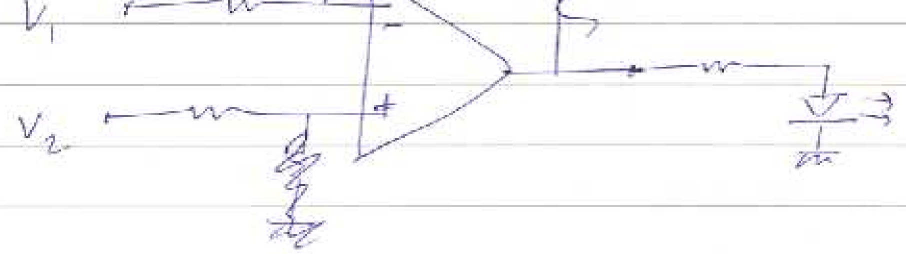
Due to negative feedback

$$V_- = V_Z$$

$$\frac{V_{out}}{R_1+R_f} \times R_1 = V_- = V_Z$$

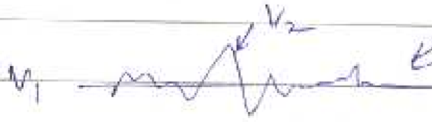
$$V_{out} = \left(\frac{R_1+R_f}{R_1}\right) V_Z$$

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



V_1 is Reference, when V_2 crosses V_1, LED "light" should glow.

DATE



This will cause flickering of LED.

If instead of LED a relay is used it will chatter.

To reduce this effect.

hysteresis is introduced (using +ve feedback).

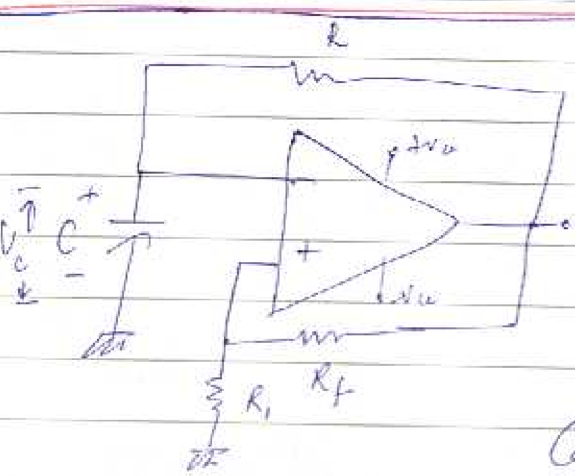
This is schmitt trigger

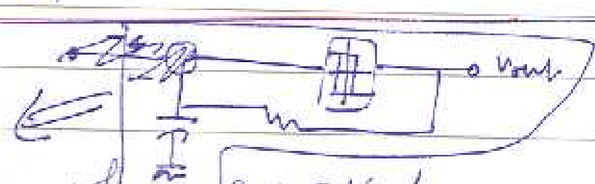
Closed loop gain Unity

phase shift = $2n\pi$

Barkhausen Criterion

Then oscillations will happen.





When Capacitor has no charge $V_c = 0$

$V_{out} = +V_{cc}$

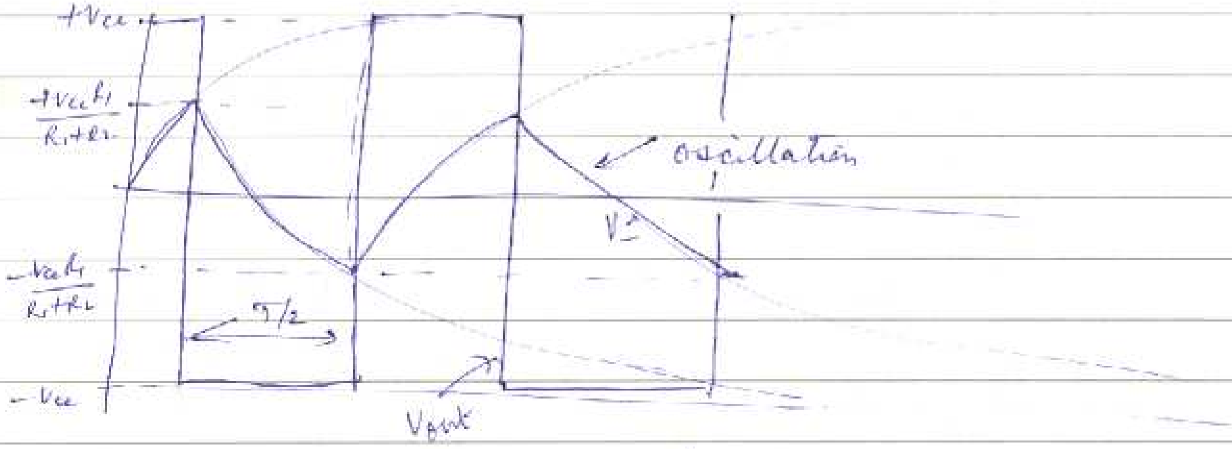
Capacitor will starting Charging.

When it is charged upto $\frac{V_{cc} R_1}{R_1 + R_f}$, then

$$V_{out} = \frac{V_{cc} R_1}{R_1+R_f} - V_{ce} \quad , \quad V_+ = \frac{-V_{ce} R_1}{R_1+R_f}$$

Now Capacitor will start discharg till it gets charged in Reverse direction to $\frac{-V_{ce} R_1}{R_1+R_2}$.

At that again Vout will change to +Vce.



⇒ astable multivibrator

⇒ Mono stable multivibrator

⇒ Bistable multivibrator.

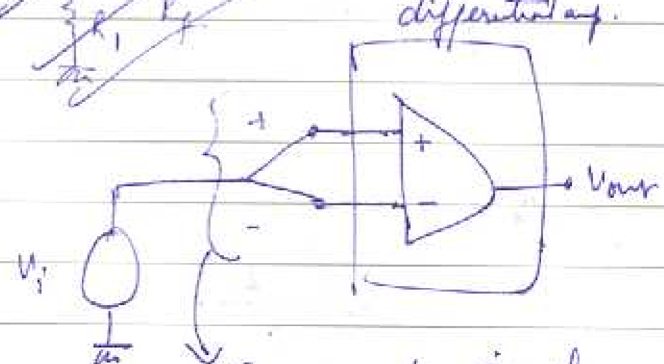
$$-\frac{V_{ce} R_1}{R_1+R_2} = -V_{ce} + \left(\frac{V_{ce} R_1}{R_1+R_2} + V_{ce}\right) e^{-t/RC}$$

$$\frac{\left(V_{ce} - \frac{V_{ce} R_1}{R_1+R_2}\right)}{\left(V_{ce} + \frac{V_{ce} R_1}{R_1+R_2}\right)} = e^{-t/RC}$$

$$\frac{V_{cc}R_2}{2V_{cc}R_1 + V_{cc}R_2} = \frac{R_2}{2R_1 + R_2} = e^{-t/RC}$$

$$\boxed{T/2 = RC \ln\left(\frac{2R_1 + R_2}{R_2}\right)}$$

$$\boxed{T = 2RC \ln\left(1 + \frac{2R_1}{R_2}\right)}$$



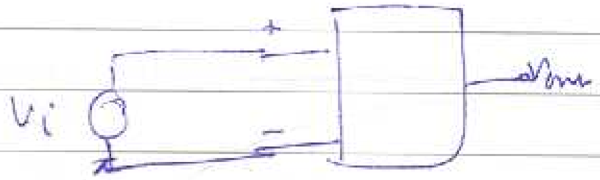
CMRR ⟹

$$\frac{V_{out}}{V_{in}} = A_{cm}$$ ← Common mode gain

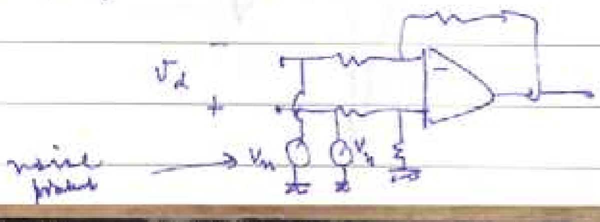
CMRR $= \dfrac{A_{dm}}{A_{cm}}$ ← differential mode gain

Common mode rejection ratio.

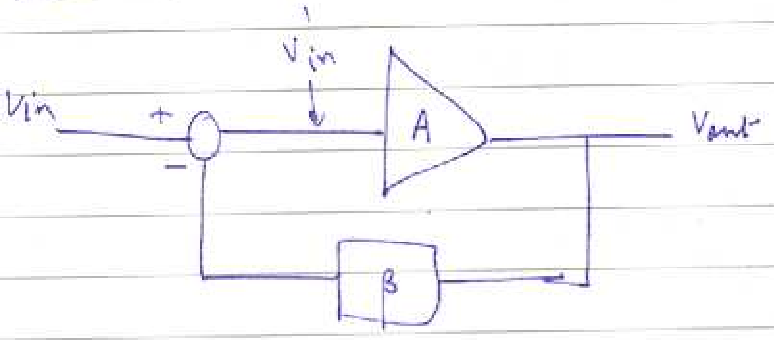
(Specified in dB).



$$\frac{V_{out}}{V_{in}} = A_{dm}$$



Oscillator



$$(V_{in} - V_{out}\beta)A = V_{out}$$

$$V_{in}A = V_{out}(1+\beta A)$$

$$G = \frac{V_{out}}{V_{in}} = \frac{A}{1+\beta A}$$

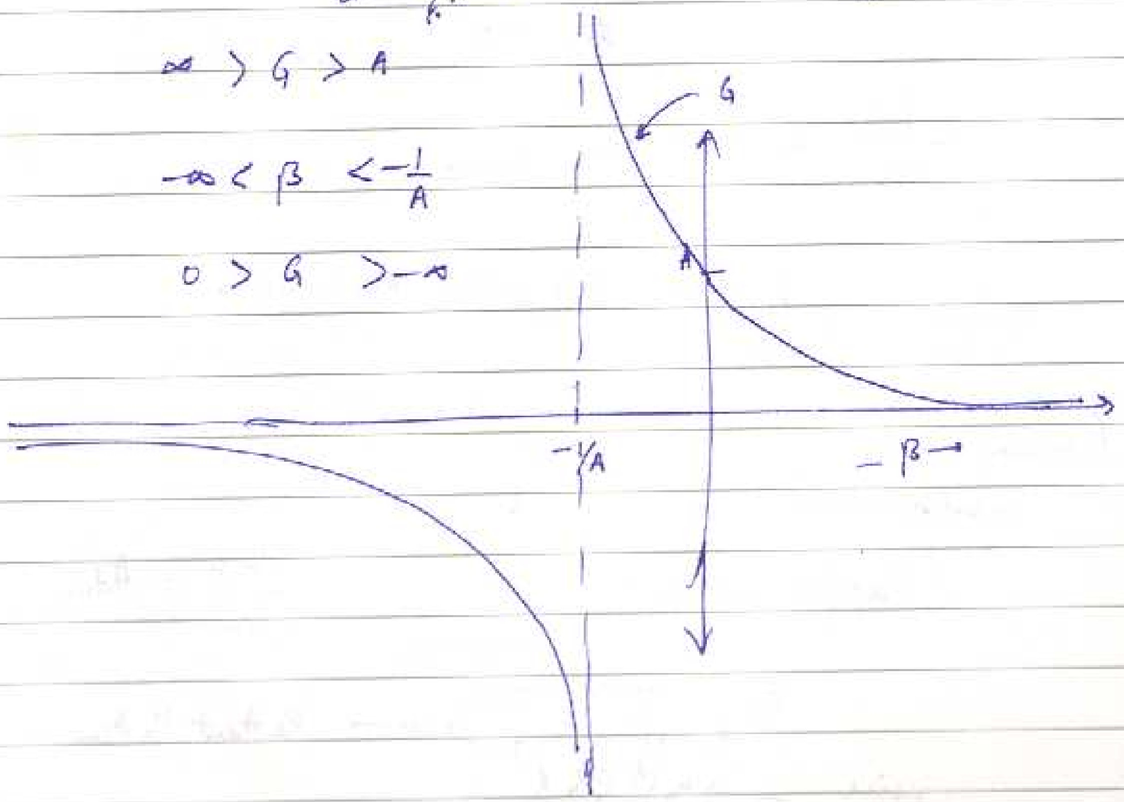
if $\beta > 0$ $\quad 0 < G < A$, $\infty > \beta > 0$ } −ve feedback

for $\frac{-1}{A} < \beta < 0$ } +ve feedback

$\infty > G > A$

$-\infty < \beta < -\frac{1}{A}$

$0 > G > -\infty$



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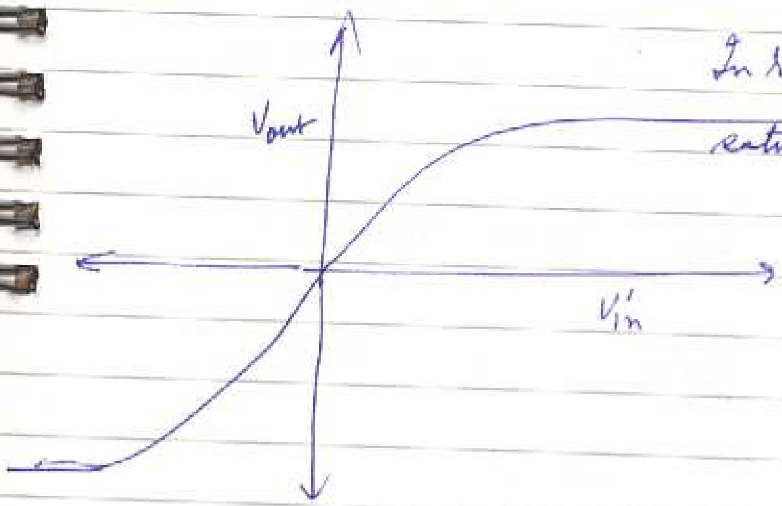
A is Constant with V_{in}'

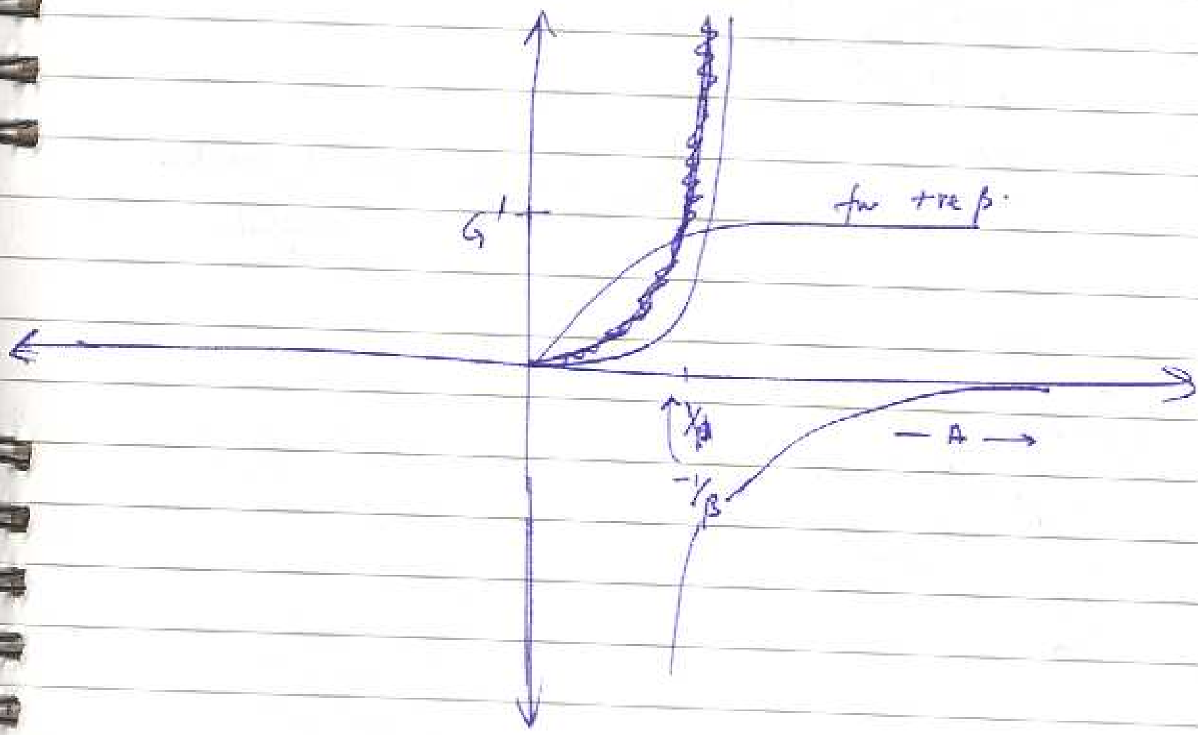


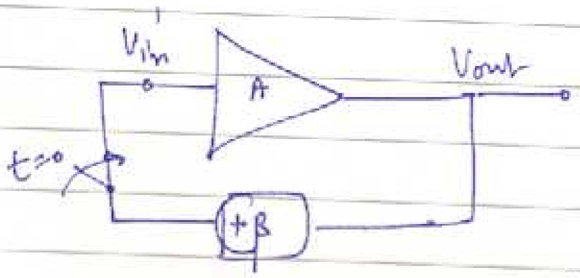
In real life. , β = Constant , A is variable with V_{in}'

saturation

~~when βA β is Constant.~~

~~and A is large in magn~~





$\forall\beta$ when $A > \frac{1}{\beta}$ at $t<0$

after $t \geq 0$

V_{out} will increase

and A will reduce till

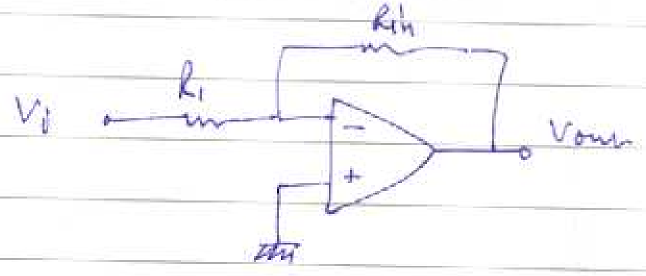
$$A = \frac{1}{\beta}.$$

Then ~~some~~ more increase is feasible.

~~A and~~ β is ~~are~~ frequency dependent.

$$A(\omega) = \frac{1}{\beta(\omega)}$$ ω's satisfying these can oscillate

phase shift in the loop should be $2m\pi$



V_{out} and V_{in} are π radians shifted.