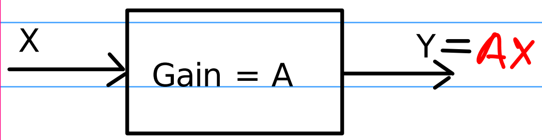
# Feedback

HW MOSFETs
Depletion
Enhancement

* When present output depends only on input and not on the past output, there is no feedback
* But when present output depends on past output as well, there is feedback.

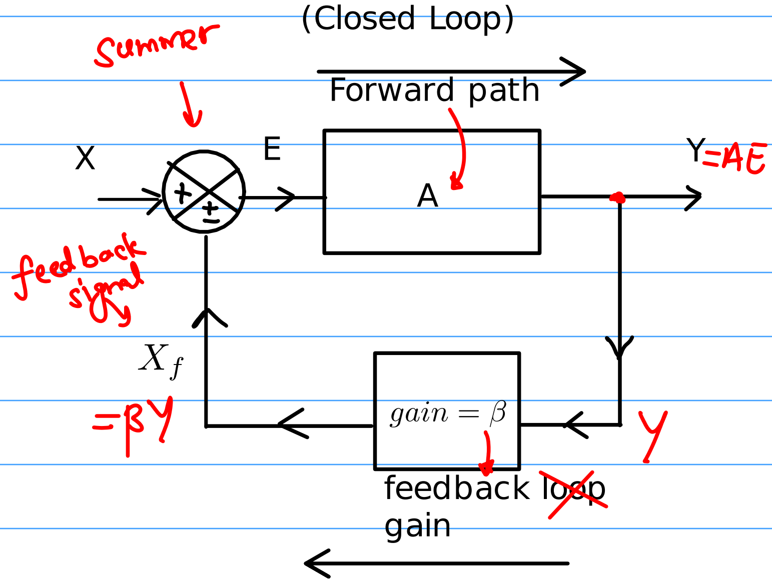
Basic Amplifier
(Open Loop)

No feedback




Open loop Gain = $\frac{Y}{X} = A$

Amp with feedback
(Closed Loop)




$A_f$ = Closed loop Gain = $\frac{Y}{X}$ = ?

## Closed loop Gain

(i) +ve feedback :

$$Y = AE$$
$$E = X + X_f$$
$$X_f = \beta Y$$
$$\Rightarrow E = X + \beta Y$$
$$\Rightarrow Y = A[X + \beta Y]$$
$$\Rightarrow \boxed{A_f = \frac{Y}{X} = \frac{A}{1 - A\beta}}$$

(ii) −ve feedback :

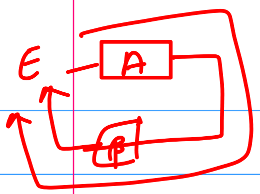
$$Y = AE$$
$$E = X - X_f$$
$$X_f = \beta Y$$
$$\Rightarrow E = X - \beta Y$$
$$\Rightarrow Y = A[X - \beta Y]$$
$$\Rightarrow \boxed{A_f = \frac{Y}{X} = \frac{A}{1 + A\beta}}$$

Compare with open loop gain $\frac{Y}{X} = A$

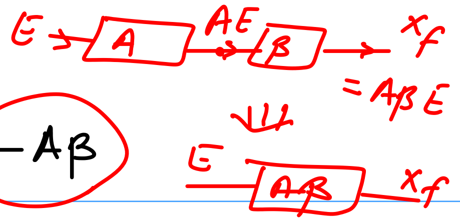
* if $A\beta > 0$ :

$|A_f| > |A|$ $\qquad$ $|A_f| < |A|$

* **Loop Gain :** for $-ve$ feedback :




$$\text{Loop Gain} = \frac{-x_f}{E} = -A\beta$$




for $+ve$ feedback :

$$\text{Loop Gain} = \frac{x_f}{E} = A\beta$$

* **Return Difference : (or Desensitivity, D)** **

$$\boxed{D = 1 - \text{Loop Gain}}$$

for $-ve$ feedback : $D = 1 + A\beta$

for $+ve$ feedback : $D = 1 - A\beta$

denominator of $A_f$ expression

* **Feedback Gain $\beta$ :**

'if 10% output is 'sampled' and fed-back, then

$$\beta = \frac{10}{100} = 0.1$$

* **Amount of feedback (N, in deciBels or dB) :**

$$N = 20 \log_{10} \left| \frac{A_f}{A} \right| \quad (dB)$$

for $-ve$ f.b. : $N = 20 \log_{10} \left( \frac{1}{1 + A\beta} \right) < 0$ ($-ve$)

$|(A_f| < |A|)$

for $+ve$ f.b. : $N = 20 \log_{10} \left( \frac{1}{1 - A\beta} \right) > 0$ ($+ve$)

$|A_f| > |A|$

Three conditions for feedback:
1. Basic amp should be unidirectional. $X \to \boxed{A} \to Y$
2. Feedback network (beta) should be unidirectional $X_f \leftarrow \boxed{\beta} \leftarrow Y$
3. Beta should be independent of the load and source resistances (RL and Rs)

feedback gain

$-$ve f.b. $A_f = \dfrac{A}{1+A\beta}$

O.L. gain (overall gain)

for C.E. amp, $A = \beta_T \dfrac{R_L}{R_i}$

$\beta_T = \dfrac{I_C}{I_B}$

So, $A_f$ depends on $R_L$ (Bad)

Loop Gain

But if $\boxed{A\beta >> 1}$, then

$$A_f \simeq \frac{A}{A\beta} \Rightarrow \boxed{A_f \simeq \frac{1}{\beta}}$$ ** feedback gain

So, if $\beta$ is independent of $R_L$ & $R_s$, $A_f$ also will be independent (good!)

## * Advantages of negative feedback:

1. Desensitivity of amplification :

* if $A$ can fluctuate due to environment or device variability, $A_f$ should be insensitive to that change.

* Measure : Sensitivity, $S = \dfrac{dA_f/A_f}{dA/A}$

* fractional change (% change) in $A_f$ should be less than that in $A$.

* So, $\boxed{S < 1 \text{ is desirable}}$ **

$$A_f = \frac{A}{1+A\beta}$$ (-ve f.b)

$$\frac{dA_f}{dA} = \frac{1+A\beta - A(\beta)}{(1+A\beta)^2}$$

$$dA_f = \frac{dA}{(1+A\beta)^2}$$

Divide by $A_f$

$$\Rightarrow \quad \frac{dA_f}{A_f} = \frac{dA}{(1+A\beta)^2} \times \frac{(1+A\beta)}{A} = \frac{(dA/A)}{(1+A\beta)}$$

$$\Rightarrow \quad \boxed{S = \frac{dA_f/A_f}{dA/A} = \frac{1}{1+A\beta} = \frac{1}{D}}$$

$S < 1$ [if $A\beta > 0$]

& $D > 1$ → % change in $A_f$ is less than that $A$

2. Improved Stability:

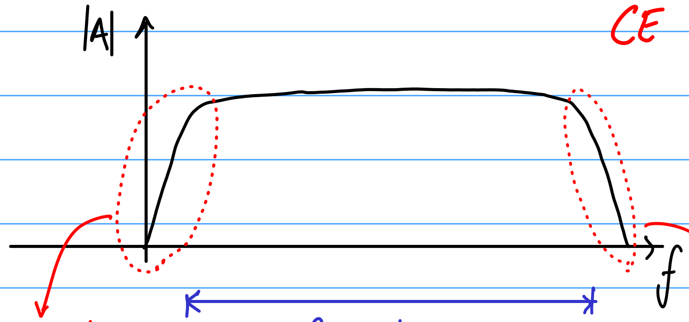
Stability: Bounded i/p ⇒ Bounded o/p (BIBO)

* -ve feedback reduces gain ($A_f < A$). That improves stability.

3. **Reduction in frequency Distortion :**

* Gain should stay constant for a very wide frequency range (called Band Width). Ideally, for all freq., gain should be constant.

* A depends on freq.




CE amp gain

Drop due to Coupling capacitors

Drop due to internal cap. (Junction capacitors)

$a_2 \sin 4\pi t$ → $(10) a_2 \sin 4\pi t$

$a_3 \sin 6\pi t$ → $(12) a_3 \sin 6\pi t$

* Closed loop Gain $\boxed{A_f \simeq \frac{1}{\beta}}$ ← $\frac{A}{1+A\beta}$

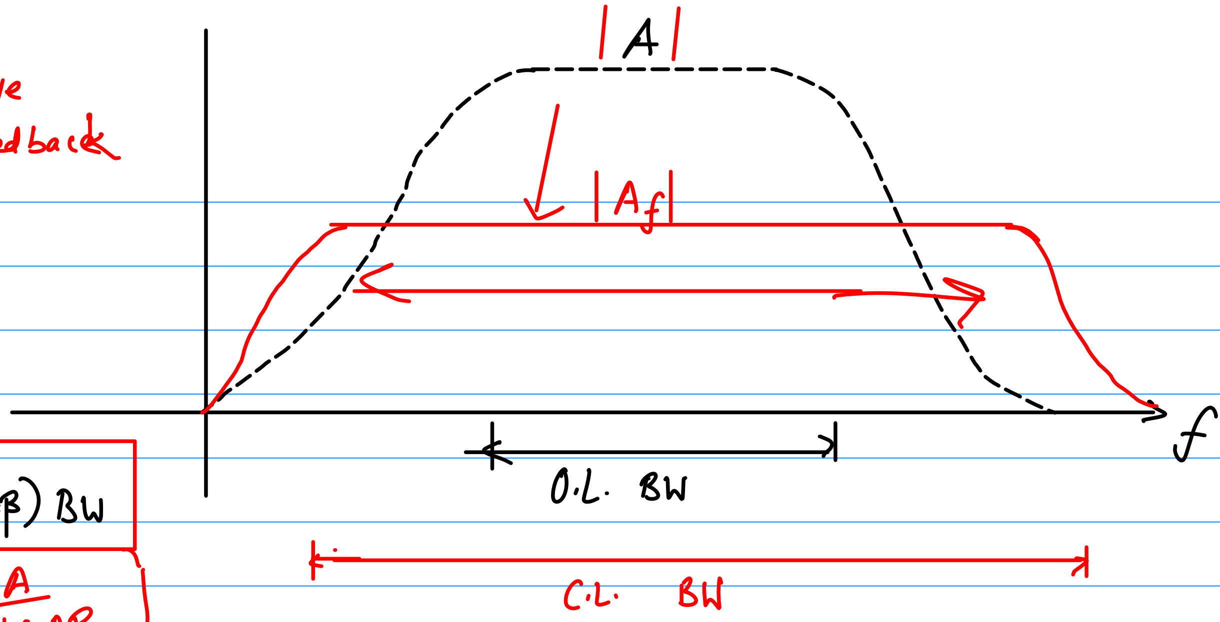
A depends on caps & hence freq.

if feedback network ($\beta$) is made of only resistances & no reactive components (like L & C) then $\beta$ & $A_f$ both will be independent (somewhat) of frequency.

* $\beta$ should also not have any active comp. (e.g BJT, JFET or MOS FET)
* This reduces freq. & phase distortion

* Reactance of inductor, $X_L = 2\pi f L$ (in Ohms)
* Reactance of capacitor, $X_C = \frac{1}{2\pi f C}$ (in Ohms)

−ve feedback




$$\boxed{BW_f = (1+A\beta)\, BW}$$

$\because A_f = \dfrac{A}{1+A\beta}$

* In any amp, Gain BW product = GBW = constant

## 4. Reduction in Non Linear Distortion :

**O.L. system :**

$$X = \sin\omega t \longrightarrow \boxed{\text{Amp.}} \longrightarrow Y = \underbrace{B_0}_{\text{unwanted DC}} + \underbrace{B_1 \sin\omega t}_{\text{Desired}} \underbrace{+ B_2 \sin 2\omega t + B_3 \sin 3\omega t + \cdots}_{\text{unwanted harmonics}}$$

unwanted harmonics → Non Linear Distortion

PN J^n → $I \propto e^{V}$

$\sin^2\theta = \dfrac{1-\cos 2\theta}{2}$

$RI = V_0 \propto e^{V} = 1 + V + \dfrac{V^2}{2!} + \cdots$

$B_1 > B_2 \gg B_3 \gg B_4 \; \cdots$

* 2nd harmonic Distortion, $D_2 = \left|\dfrac{B_2}{B_1}\right| < 1$

3rd harmonic Distortion, $D_3 = \left|\dfrac{B_3}{B_1}\right| < 1$

$\vdots$

** $D_2 \gg \underbrace{D_3 \gg D_4 \; \cdots}_{\text{neglected}}$

* So, 2nd harmonic distortion is the main (dominant) one.

* So, in general, $\text{Non-Lin. Distortion} \equiv D_2^{*} = \left|\dfrac{B_2}{B_1}\right| < 1$

* distortion with −ve f.b.,

C.L. O.L.

$$\downarrow D_{2f} = \frac{D_2}{(1+A\beta)} < D_2$$

5. Noise Reduction: Noise power without f.b. = $N_0$

with f.b.,
$$\boxed{N_{0f} = \frac{N_0}{1+A\beta}}$$ *

So, −ve f.b. increases signal to noise ratio.

→ Disadvantages : −ve f.b. Reduces Gain

→ Application : Good, Stable low noise amplifiers.

→ Positive feedback :

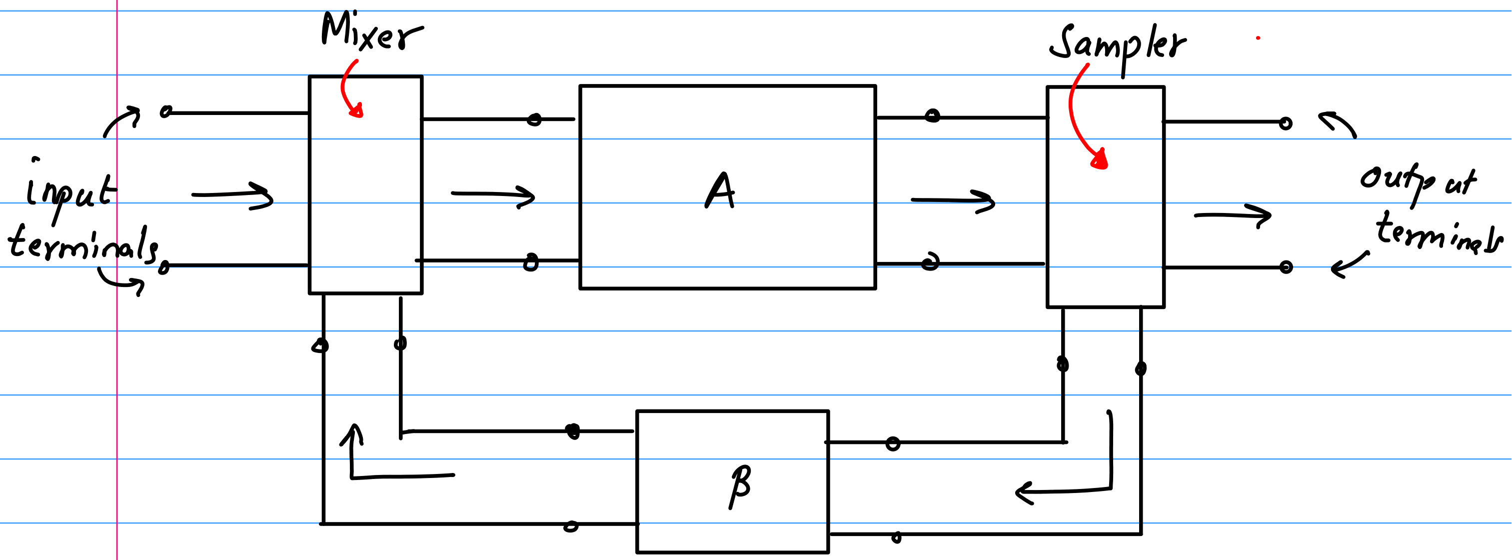
Advantages : Increases Gain. (Not really an adv.)

Disadvantages :

1. Reduces Band width (increases freq. distortion)
2. Increases noise, harmonic distortion.
3. Reduces stability.

Application : Oscillators.

# The 4 Feedback Topologies



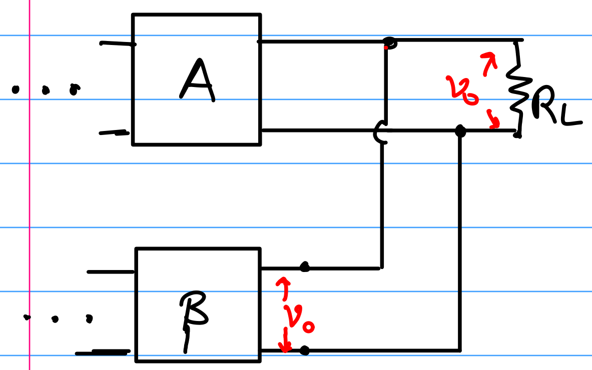

Sampler — vol. sampling / Current sampling

Mixer — vol. mixing / Current Mixing

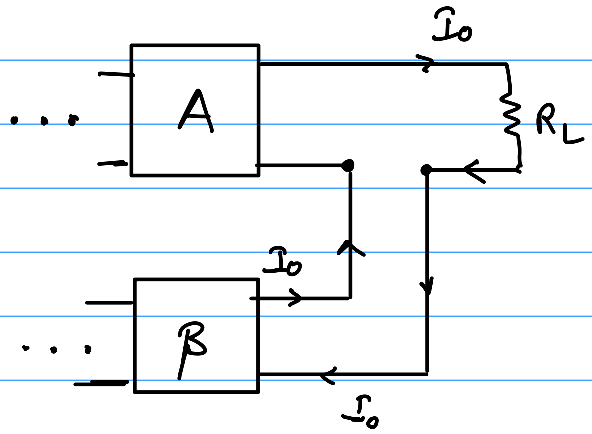
4 topologies

## → Sampling :

(1) Voltage Sampling or Shunt Sampling

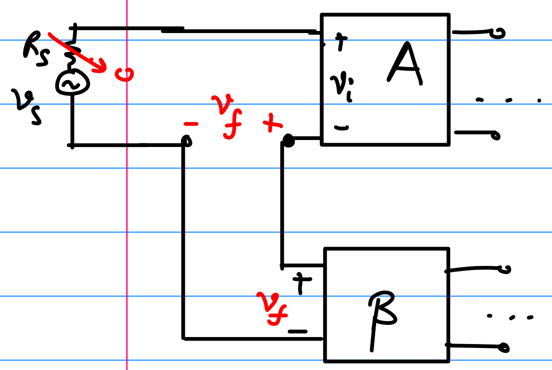



(2) Current Sampling or Series Sampling




## → Mixing :

(1) Voltage or Series Mixing




Assuming $R_s = 0$ (no vol. drop),

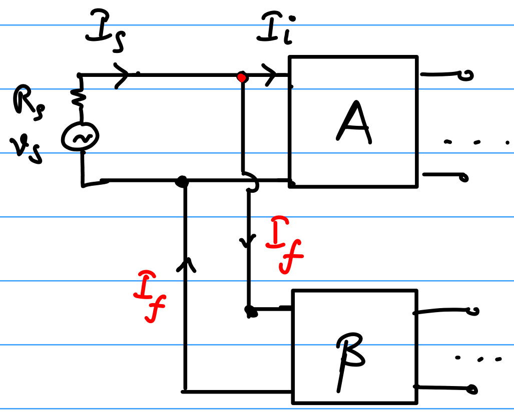
KVL: $v_i = v_s - v_f$

(−ve f.b.)

if polarities of $v_f$ flipped,

$v_i = v_s + v_f$ (+ve f.b.)

(2) Current or Shunt mixing




KCL: $I_i = I_s - I_f$

(−ve f.b.)

if direction of $I_f$ flipped,

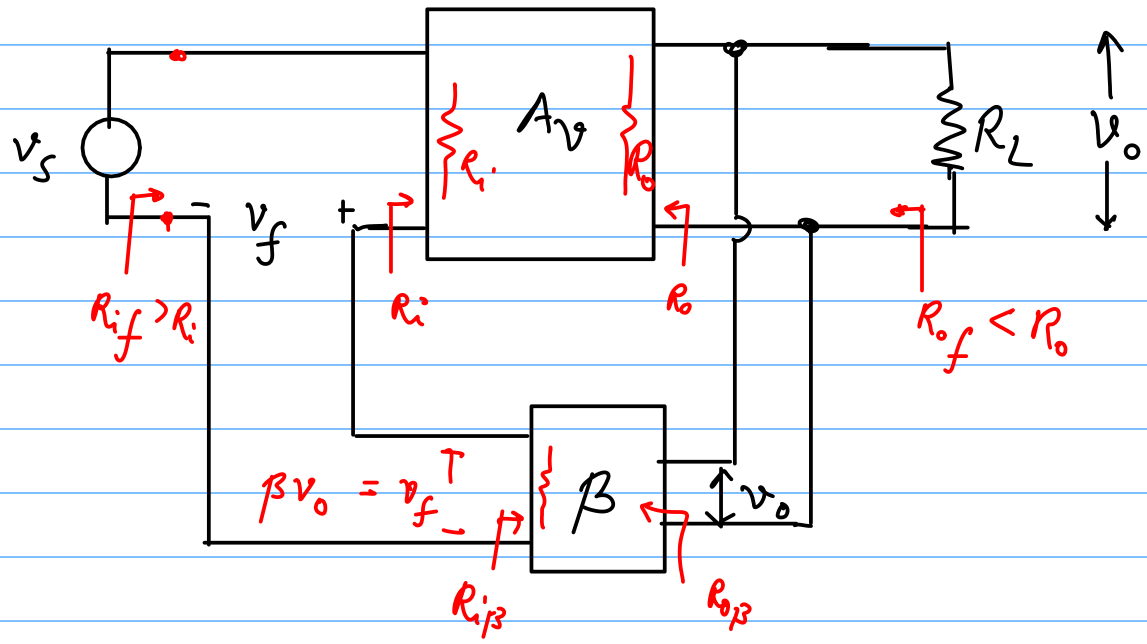
$I_i = I_s + I_f$

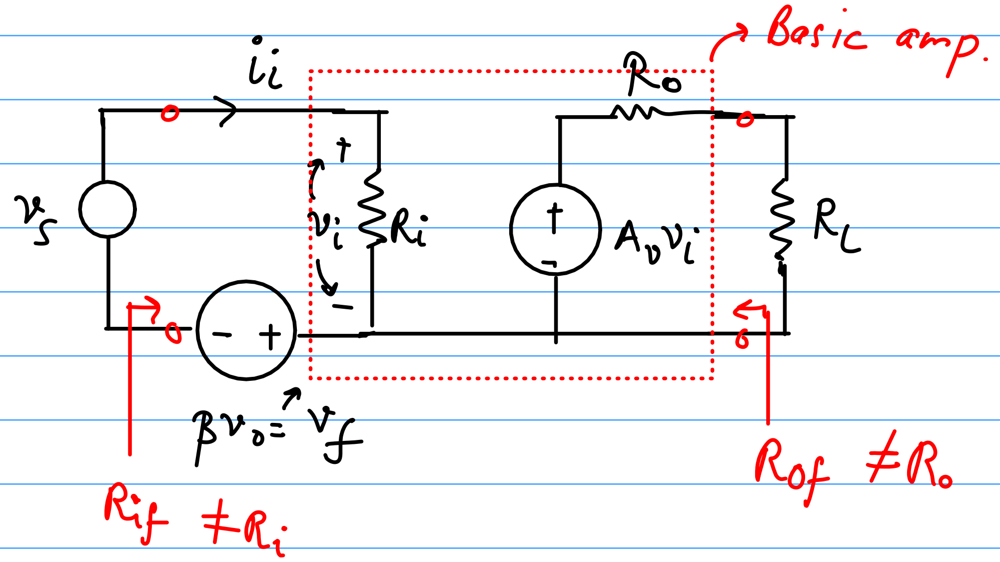
(+ve f.b.)

| Feedback Topology O/p (Sampling) | Feedback Topology I/p (Mixing) | Basic Amp | Closed loop stabilized Gain | unit of $\beta$ | Other name i/p | Other name o/p |
|---|---|---|---|---|---|---|
| 1) Voltage (V) | Series (V) | $A_v$ (Vol. Amp) | $A_{vf} \simeq \frac{1}{\beta}$ | unitless | series (V) | shunt (V) |
| 2) Current (I) o/p | Series (V) i/p | $G_m$ (Trans-Cond. Amp) | $G_{mf} \simeq \frac{1}{\beta}$ | Ohm | Series i/p | series o/p |
| 3) Voltage (V) o/p | Shunt (I) i/p | $R_m$ (Trans-Resistance Amp) | $R_{mf} \simeq \frac{1}{\beta}$ | mho | Shunt i/p | Shunt o/p |
| 4) Current (I) o/p | Shunt (I) i/p | $A_i$ (Current Amp) | $A_{if} \simeq \frac{1}{\beta}$ | unitless | Shunt i/p | Series o/p |

## → Voltage – Series f.b. :

o/p          i/p




$$\boxed{R_{if} = (1+\beta A_v) R_i}$$

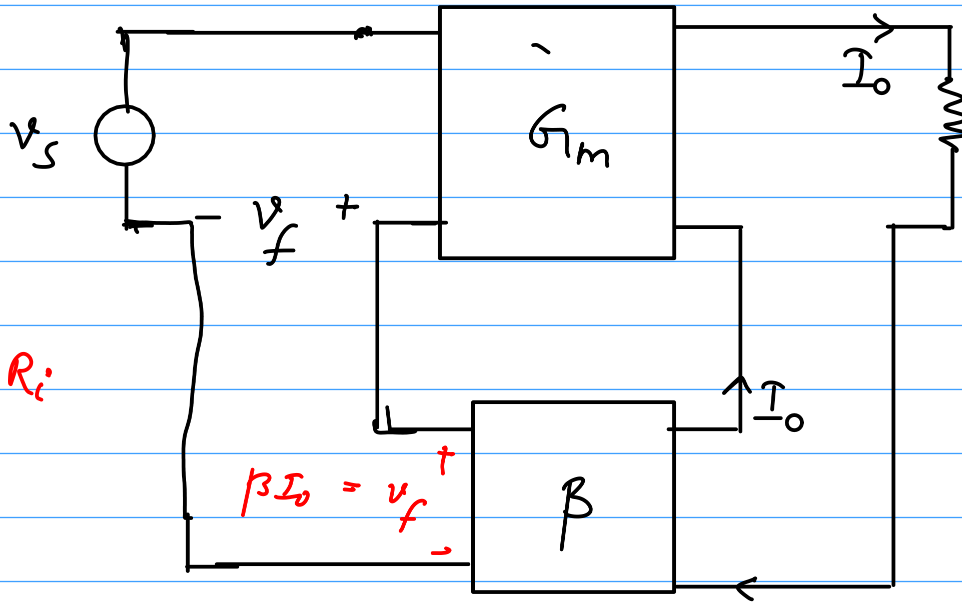
$$\boxed{R_{of} = \frac{R_o}{1+\beta A_v}}$$

<u>Examples</u>: Emitter follower (Common Collector) [BJT], Source follower (Common Drain), Voltage follower (Non-inverting OpAmp)

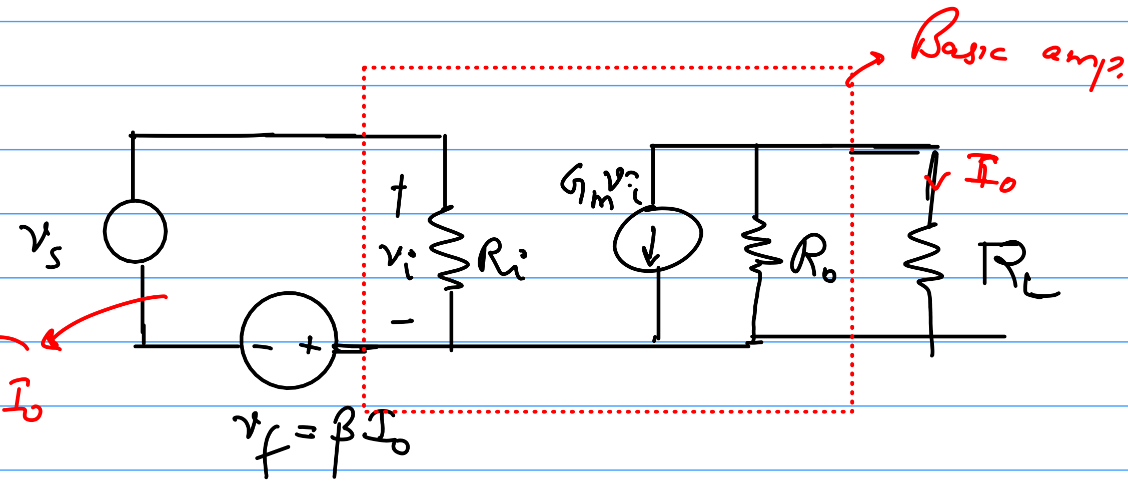
→ 2) Current series f.b. :

$\underbrace{\text{Current}}_{o/p}$ $\underbrace{\text{series}}_{i/p}$

$R_{if} > R_i$




$R_{of} > R_o$




$\underbrace{-ve\ f.b}$

$v_i = v_s - \beta I_o$

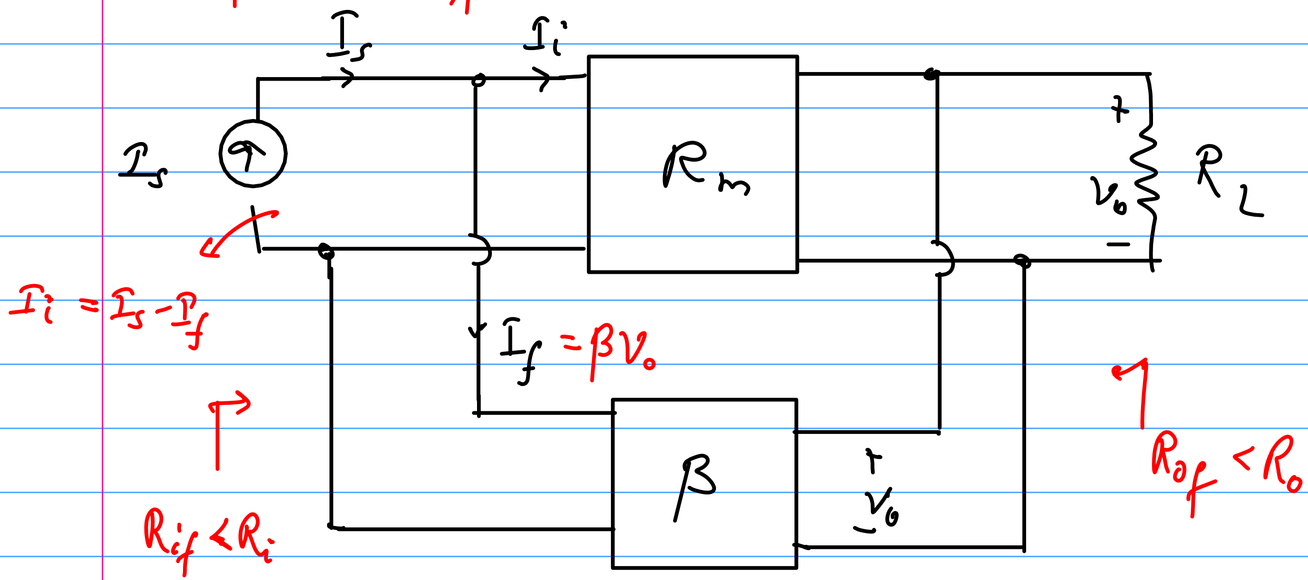
$$\boxed{R_{if} = (1+\beta G_m) R_i}$$

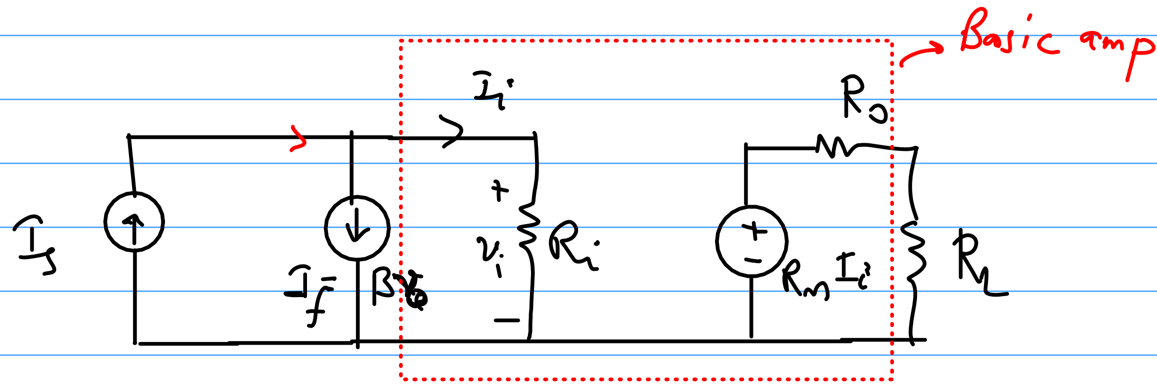
$$\boxed{R_{of} = (1+\beta G_m) R_o}$$

Better

→ 3) <u>Voltage - Shunt f.b:</u>

o/p  i/p



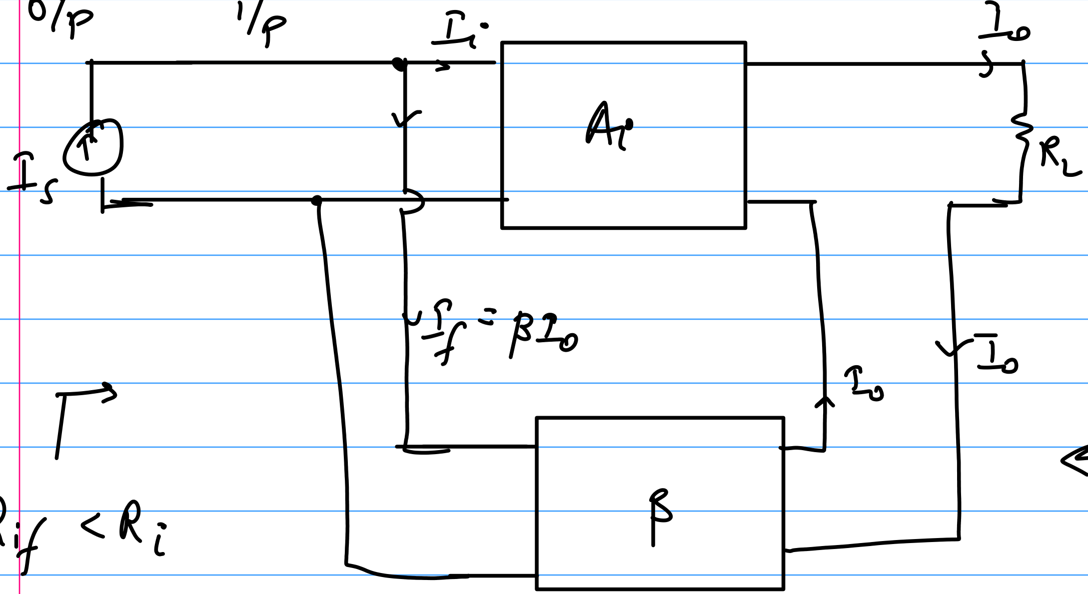




$$\boxed{R_{if} = \frac{R_i}{(1+\beta R_m)}}$$

$$\boxed{R_{of} = \frac{R_o}{(1+\beta R_m)}}$$

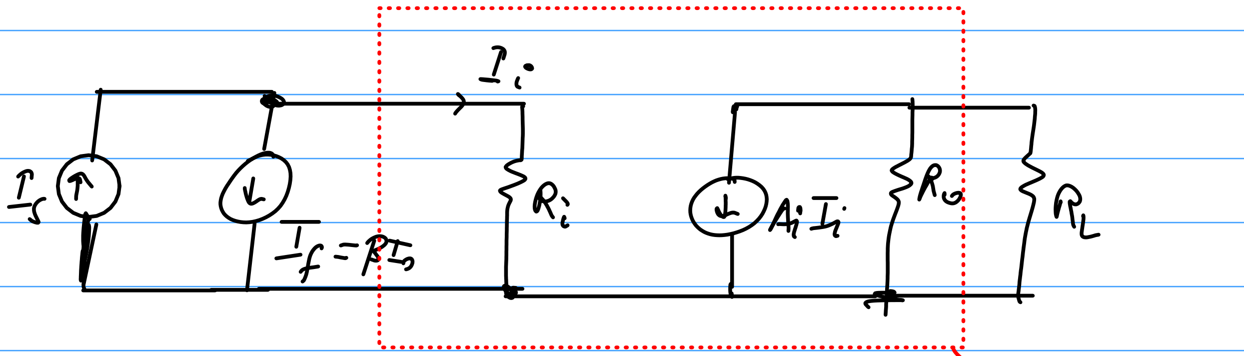
4) Current Shunt fb:

o/p i/p




$R_{if} < R_i$

$R_{of} > R_o$



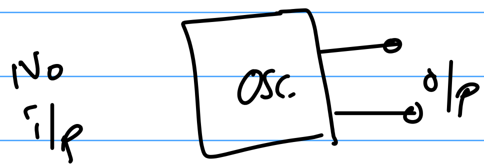

-ve f.b.

$$\boxed{R_{if} = \frac{R_i}{1+\beta A_i}}$$

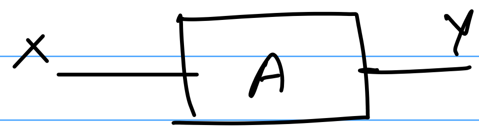
$$\boxed{R_{of} = (1+\beta A_i) R_o}$$

# Oscillators → o/p is periodic waveform (osc.)

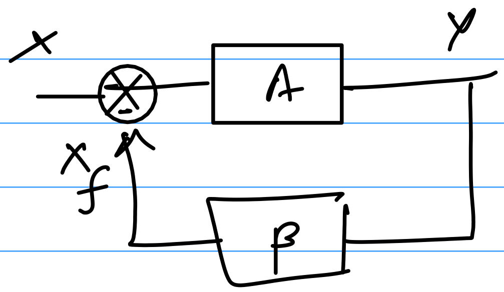
Generator → Generates an o/p without any i/p
(it does need power supply e.g. $V_{CC}$ or $V_{DD}$)




→ **Barkhausen's Criterion:** Some conditions for sustained oscillations




(Amp. no osc.)
∵ there is an input

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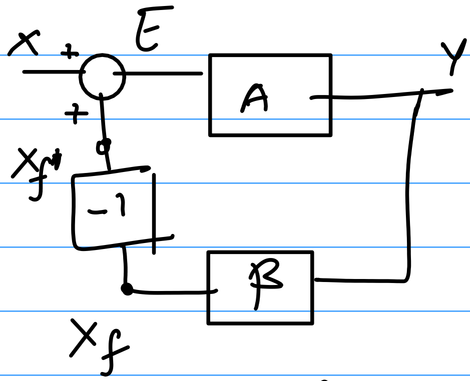
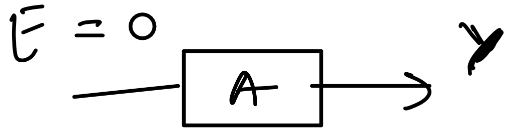



Negative feedback

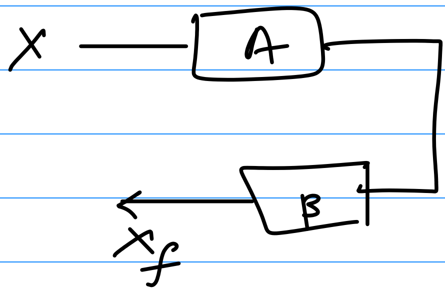
$$x_f' = -x_f$$

if $x_f = x_i$ then

$$E = x - x_f = 0$$




we get o/p $Y$ with no i/p $\because E=0$




to get $x_f = x_i$

$$\boxed{A\beta = 1} \;*$$

## Barkhausen's criterion :

1) $|A\beta| = 1$

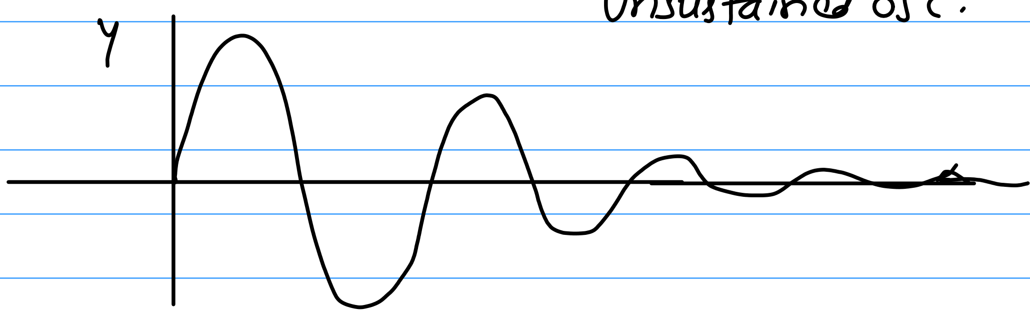
2) $\angle A\beta = 0°$, or $360°$ or $2n\pi$

for -ve f.b. system

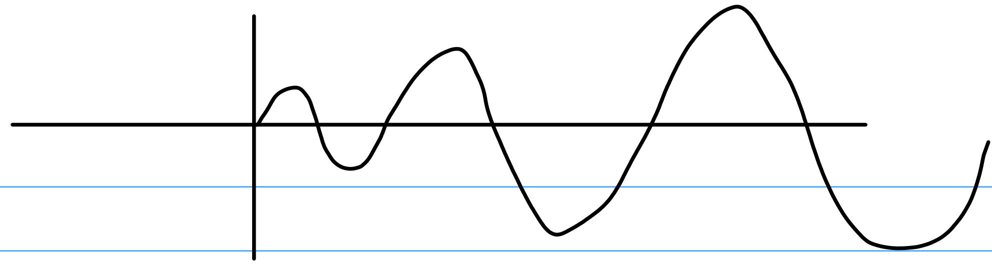
Then no i/p is needed to generate o/p

* if $|A\beta| < 1$ then

Unsustained osc.

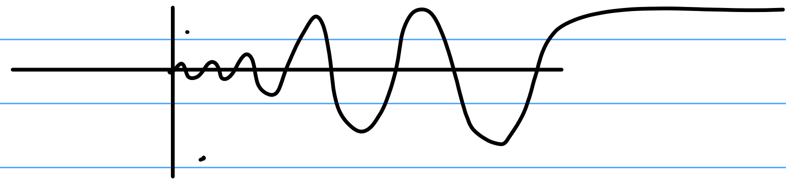


* if $|A\beta| > 1$

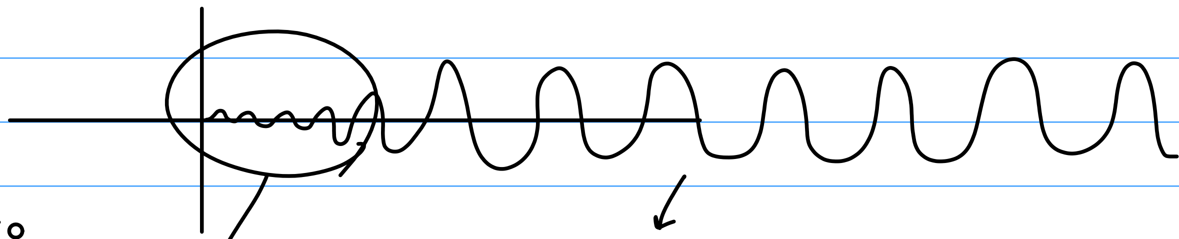


**Unstable system**

Osc. don't keep ↑ blindly. They are ultimately limited by supply vol, $V_{CC}$ or $V_{DD}$.

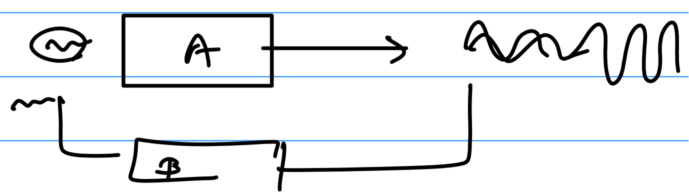


So, ideally we want $|A\beta| = 1$



No i/p, so, some noise gets amplified

sustained osc.



## Practical considerations :

The noise initially needs to be amplified,

so, $\boxed{|A\beta| \gtrsim 1}$ slightly

for sustained osc

* Also there are losses in the ckt so they prevent the o/p from keep increasing even if $|A\beta| > 1$

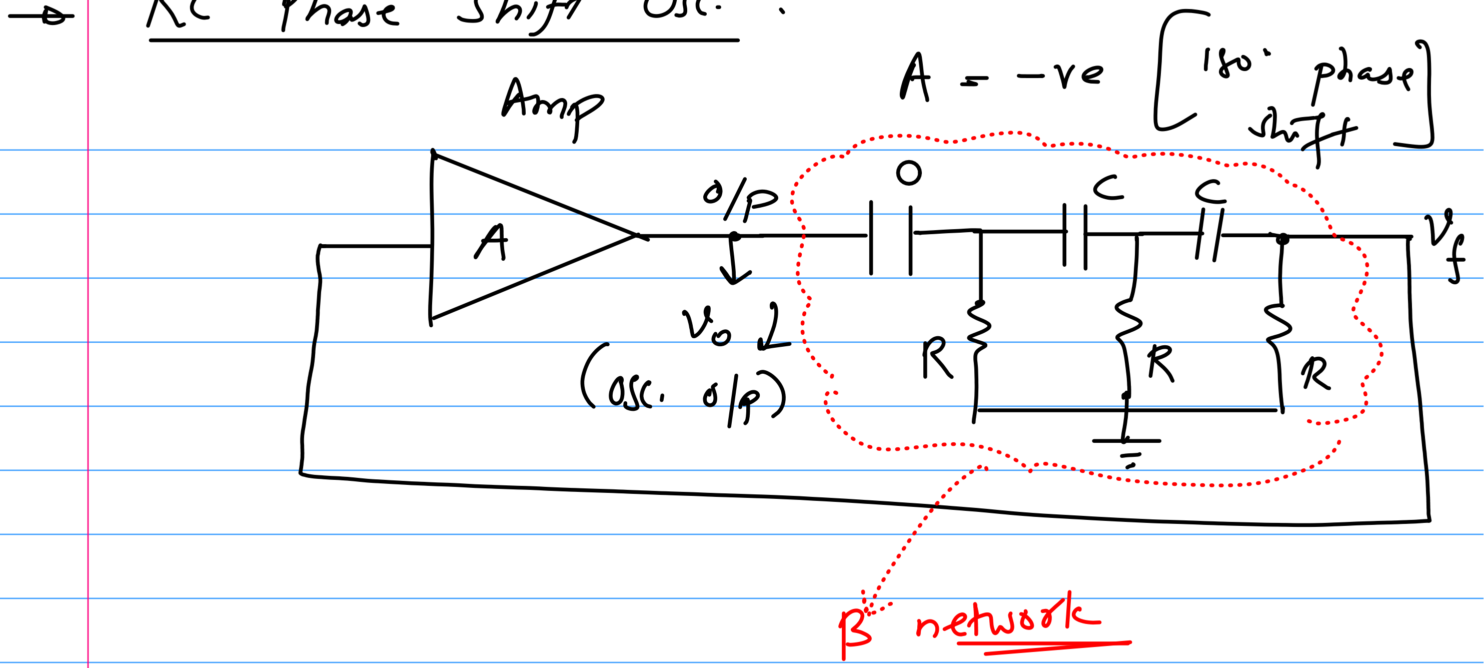
$\because$ $|A\beta|$ is only slightly bigger than 1 & that is compensated by losses in the ckt.

* Properties of Osc :

1. Gain is $\infty$ $(A_f)$ or v.large
2. +ve feed back $\because$ loop gain = $A\beta$ = +ve
3. System stability is less as compared to amplifier.
4. No i/p required externally.

The noise is sufficient to generate oscillations.

## RC Phase Shift Osc. :




A, e.g could be a CE amp, a CS amp or inverting Op-Amp.

* If A provides 180° phase shift to the signal then the R-C network (β) should also provide 180° phase shift

i.e. If A = −ve

then β = −ve should be

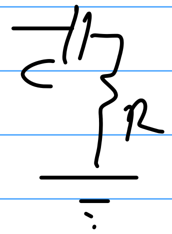
So, $\underbrace{A\beta}_{\text{the feedback}} = +ve$ = 360° phase shift

loop gain

also, $|\beta| \geq \frac{1}{|A|}$ so that $|A\beta| \geq 1$

* 3 RC stages give 180° phase shift

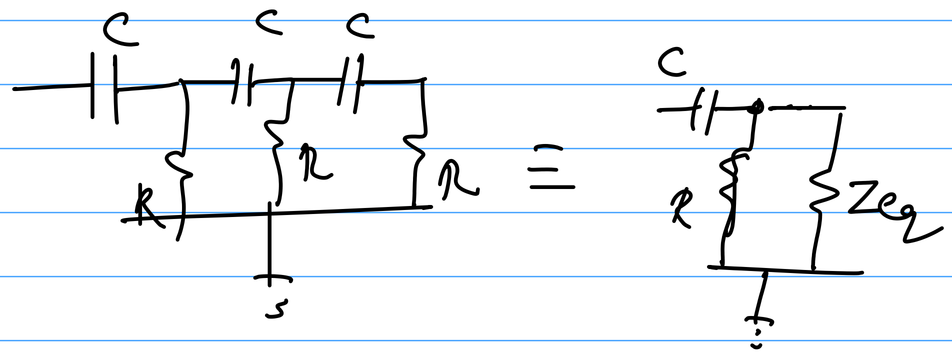
So,




single RC stage should give 60° phase.

* But if it is giving 60° then overall phase of 3 RC stages is bigger than 180°

∵




$\phi$ of first stage

$$= \phi_1 = \tan^{-1}\left(\frac{1}{\omega R_{eq} C}\right) > \tan^{-1}\left(\frac{1}{\omega RC}\right)$$

if $\tan^{-1}\left(\frac{1}{\omega RC}\right) = 60°$ (as per design)

$$R_{eq} = R \,||\, Z_{eq} < R$$

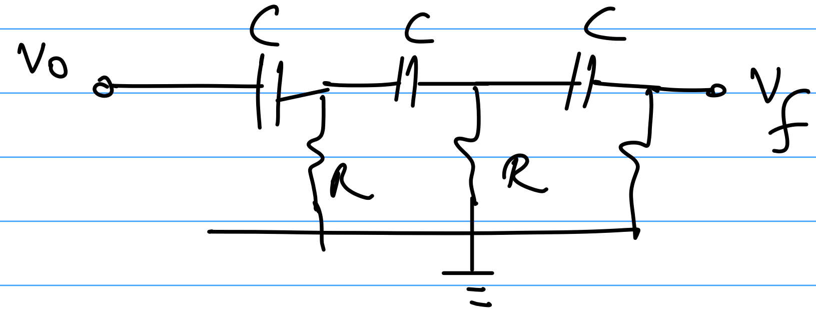
so, $\phi_1 > 60°$

* So, single RC stage phase, R & C should be designed such that

$$\tan^{-1}\left(\frac{1}{\omega CR}\right) < 60°$$

* Find Osc freq. :

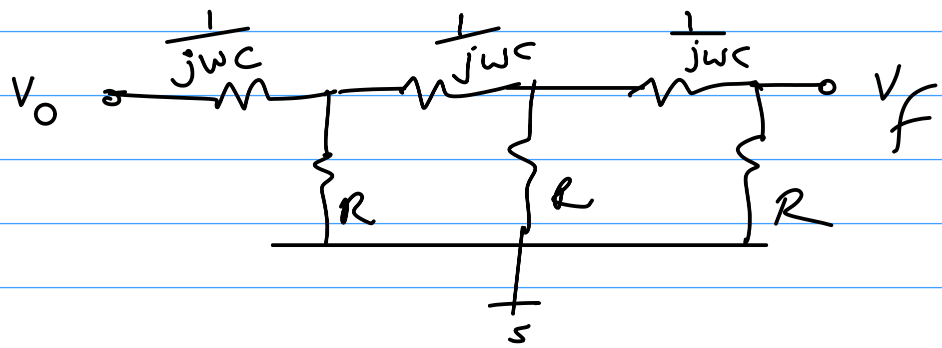
1) find $\beta$




$$\beta = \frac{v_f}{v_o}$$

Replace C by $\frac{1}{jwC} = X_C$ (Reactance)

$j = \sqrt{-1}$




find $\frac{V_f}{V_o}$ from KVL & KCL $= \beta$

So, $\beta$ will be a complex number.

$\beta = X + jY \qquad \angle\beta = \tan^{-1}\left(\frac{Y}{X}\right) = 180^\circ$

Since $A = -ve$, $\beta$ should be $-ve$

phase $= 180^\circ$

$\beta = -0.5$ e.g

real number (no imag. part)

$$\tan^{-1}\left(\frac{Y}{X}\right) = 180^\circ$$

if $Y = 0$ & $X = -ve$

2) Put $\text{Imag.}(\beta) = 0$ $\quad \because \beta = f(j\omega)$

that gives $\omega$

$$\omega = 2\pi f$$

rad/sec      Hz

This $f$ is the freq. of osc.

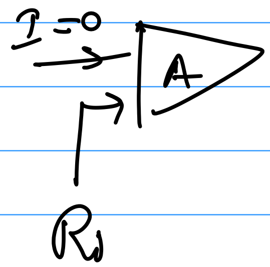
3) So, $\beta = X + j0 \Rightarrow \boxed{\beta = X}$

So, Amp gain $A$ should be

$$\boxed{A = \frac{1}{X}}$$

Then we have an osc.

if




is satisfied

$R_i = \infty$

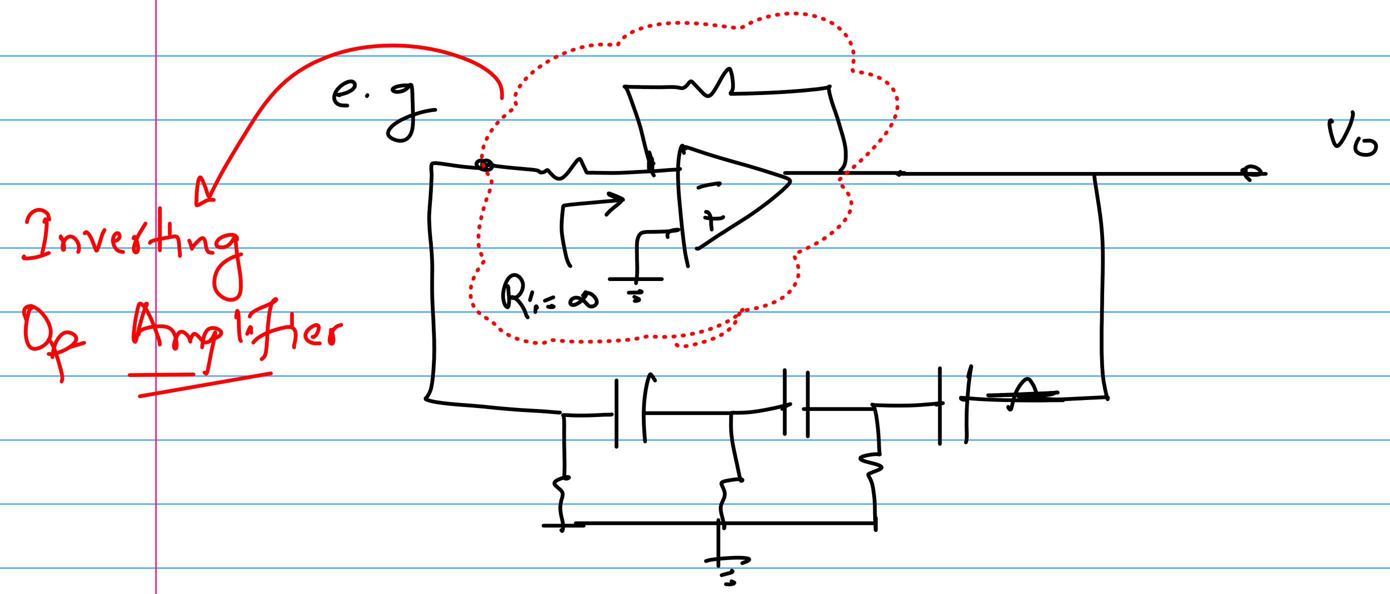
then $$\boxed{f_o = \frac{1}{2\pi(\sqrt{6})RC}}$$

osc. freq.

& in this case $\quad \beta = -\frac{1}{29}$

So, $A = -29$

or $|A| \geq 29$ slightly bigger




$|A| \gtrsim 29 \qquad f_0 = \frac{1}{2\pi RC\sqrt{6}}$