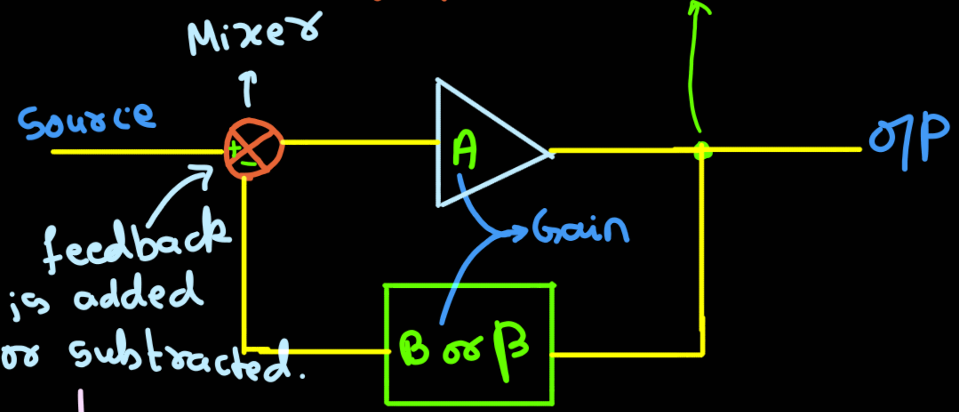
Feedback Amplifiers

Feedback :-

↳ Fraction of o/p is sampled & given back to i/p side.



↳ Based on this → 2 types of feedback.

- − → -ve feedback
- + → +ve feedback

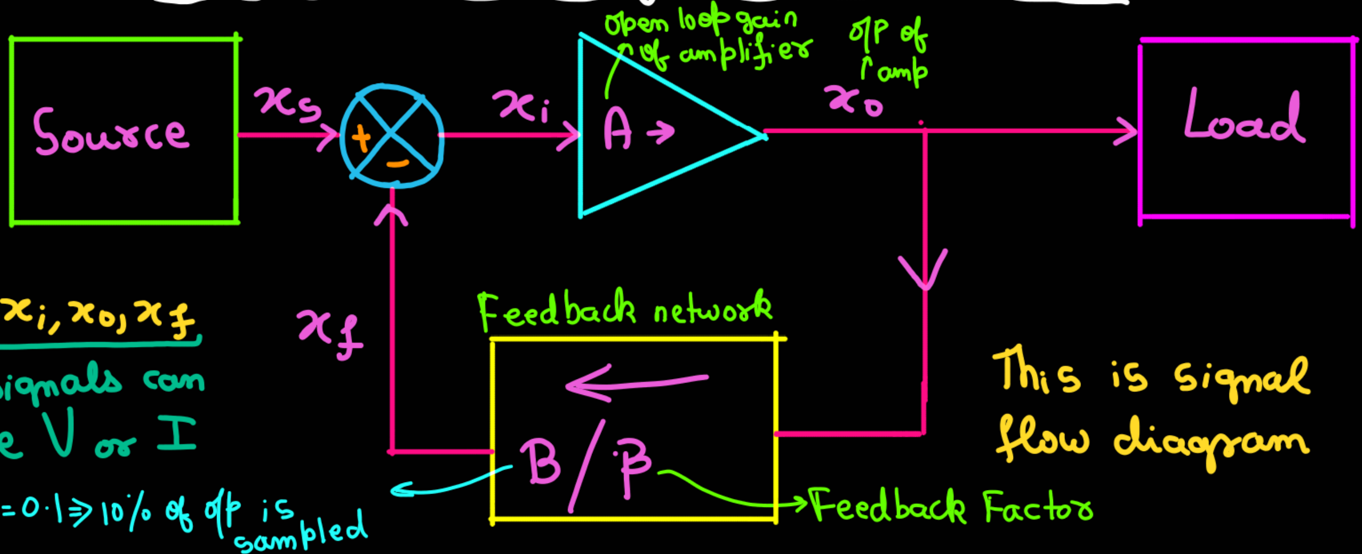
Why negative feedback ?

Adv :-

1. Desensitize the Gain
2. Reduces a non-linear distortion.
3. Reduces the effect of noise
4. Modifies the i/p & o/p impedence
5. Increases bandwidth

Dis adv :- All this is done at the cost of the reduction of overall gain

General structure of feedback amplifier :-



x_o, x_i, x_o, x_f
↳ signals can be V or I

If $\beta = 0.1 \Rightarrow 10\%$ of o/p is sampled

This is signal flow diagram

Mathematically $\Rightarrow$ $x_f = \beta x_o$, $x_o = A \cdot x_i$ $\Big\}$ $x_i = x_s - x_f$

We want to find overall gain $\Rightarrow$ $\dfrac{x_o}{x_s}$

$$\frac{x_o}{A} = x_s - \beta x_o \Rightarrow \frac{x_o}{A} + \beta x_o = x_s \Rightarrow \boxed{\frac{x_o}{x_s} = \frac{A}{1+A\beta} = A_f}$$

Gain of amplifier with feedback network.

$A\beta \Rightarrow$ Loop Gain

↳ for -ve feedback

↳ $A\beta$ must be +ve

Here, $1+A\beta$ = Amount of feedback.

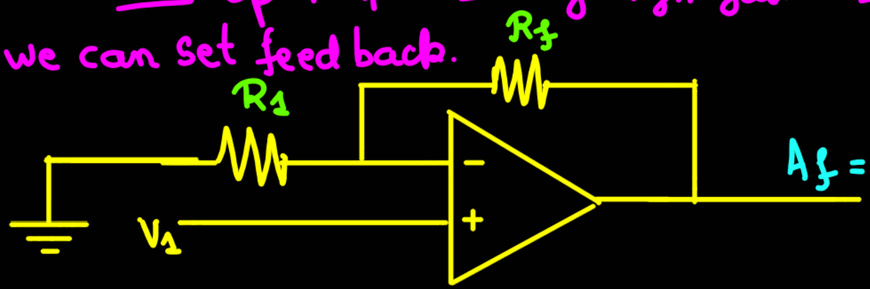
When $A\beta \gg 1 \Rightarrow A_f = \dfrac{A}{A\beta} \approx \dfrac{1}{\beta}$

Almost independent of the open loop gain

↳ determined entirely by feedback network.

★ Easy to set precise value of the gain of the feedback amplifier $\Rightarrow$ $\because$ made of passive elements

Ex: Op-Amp has very high gain. Using simple resistors, we can set feed back.



$A_f = 1 + \dfrac{R_2}{R_1}$

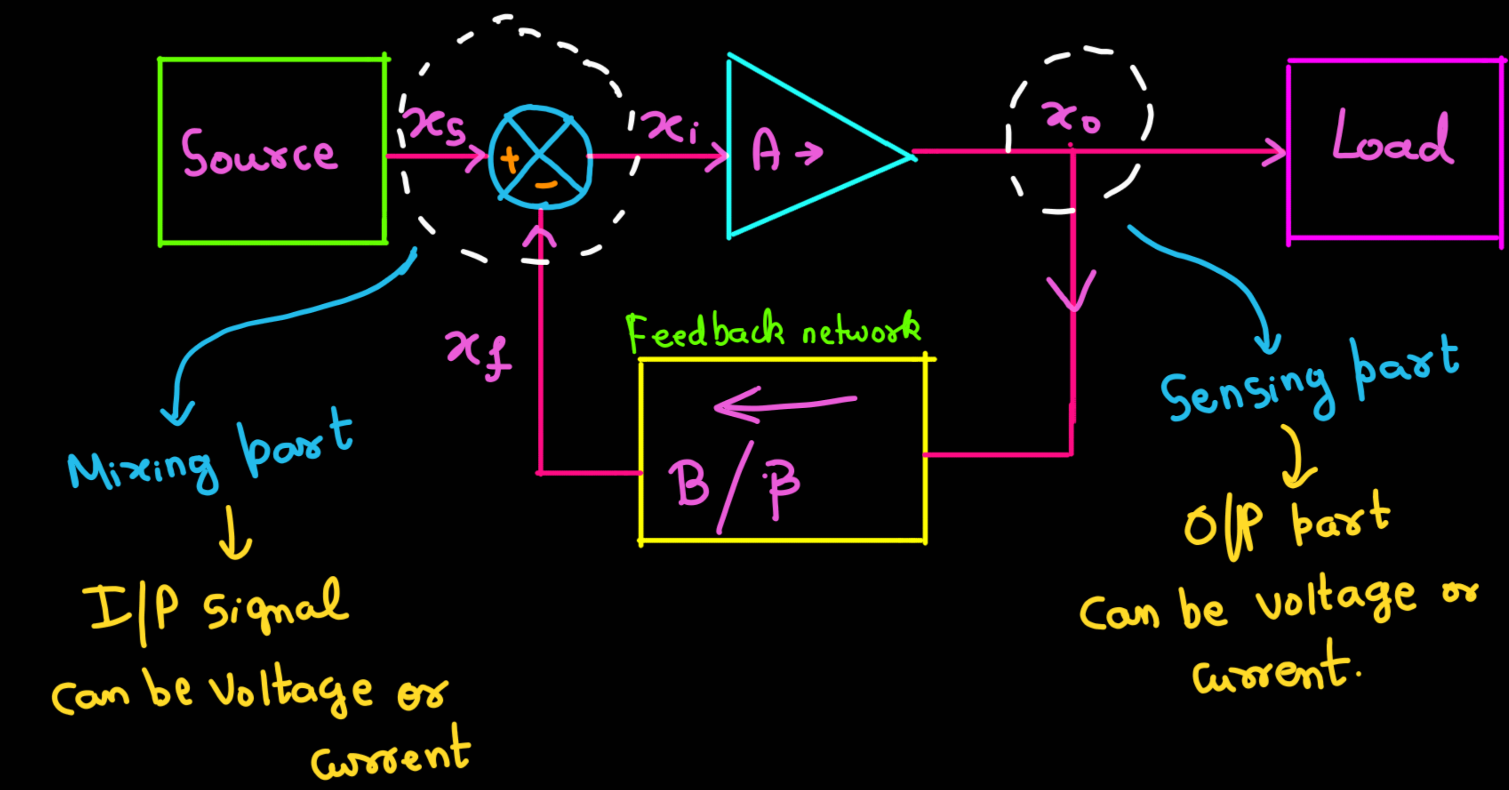
WKT, $x_o = \dfrac{A}{1+A\beta} x_s$ | WKT, $x_f = \beta x_o$

$$\therefore x_f = \frac{A\beta}{1+A\beta} x_s$$

If $A\beta \gg 1 \Rightarrow \boxed{x_f \approx x_s}$

#Feedback Topologies:-

Consider the general structure.

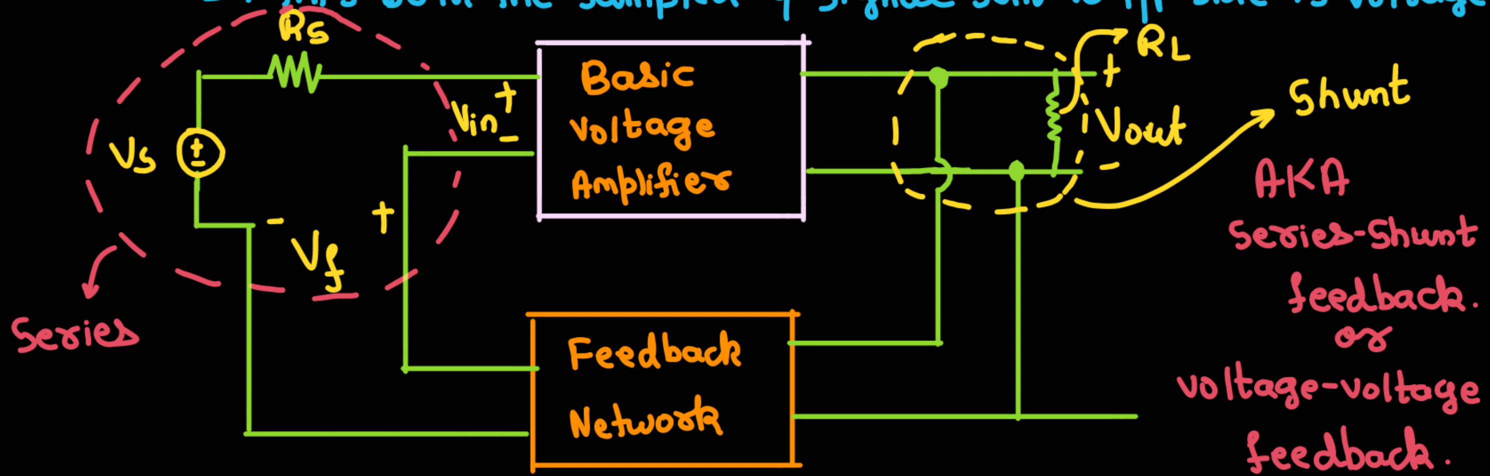


From the above, we have 4 topologies

1. Voltage Series Feedback
2. Voltage Shunt Feedback
3. Current Series Feedback
4. Current Shunt Feedback.

#Voltage Series Feedback:-

In this both the sampled & signal sent to i/p side is voltage.



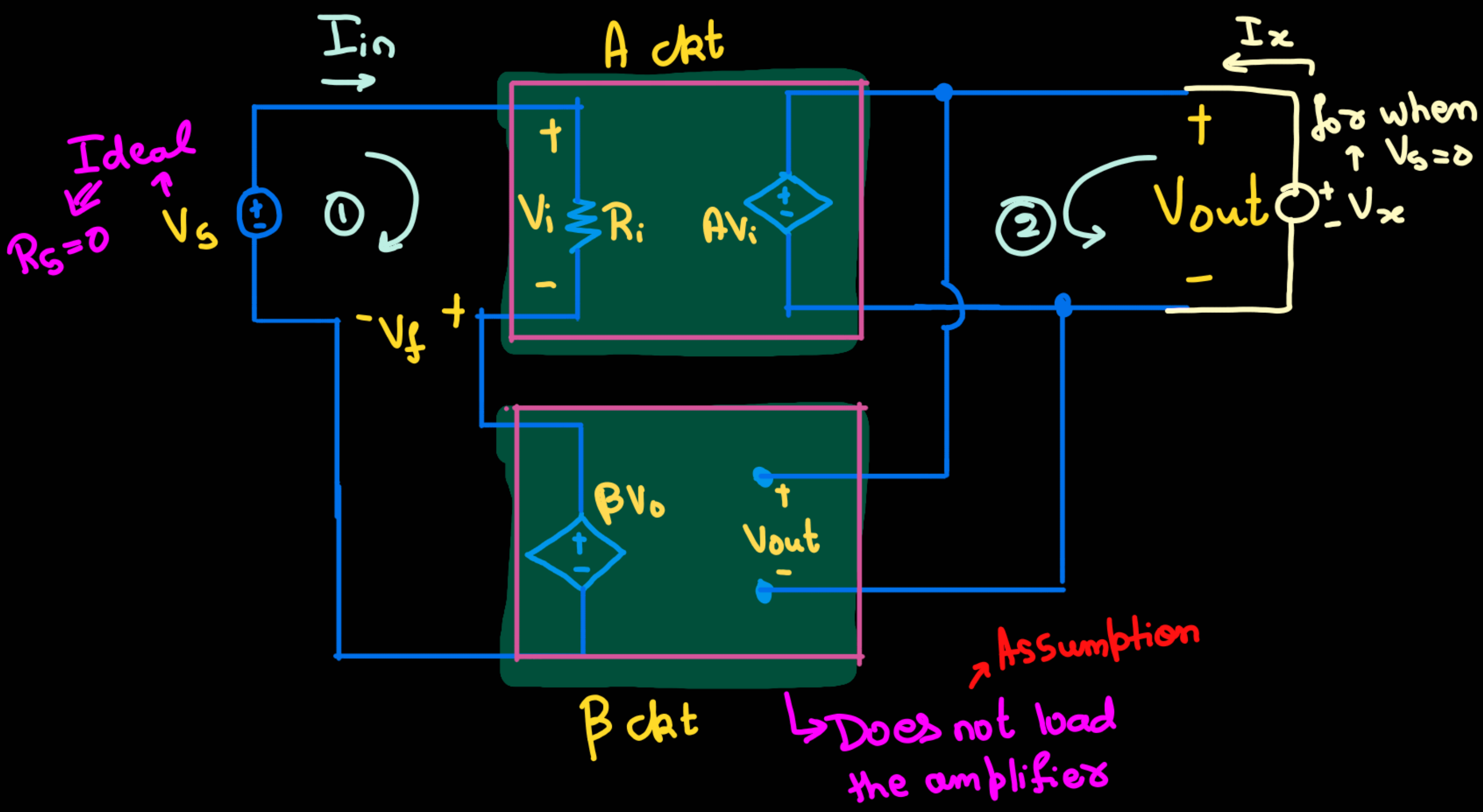
★ when we want to sample the voltage, then on o/p ⇒ shunt
i/p or mixing ⇒ series

★ All voltage amplifiers use this topology

★ **I/P & O/P impedences :-**

→ Due to series connection i/p impedance will increase
↳ $R_{if} = R_i(1 + A\beta)$

→ " " shunt " " o/p " " decrease
↳ $R_{of} = \frac{R_o}{1 + A\beta}$



★ **Effective I/P impedance :-**

As seen from source side $= R_{if} = \frac{V_s}{I_{in}}$

KVL in loop 1 :- $V_i = V_s - V_f = V_s - \beta V_o$

$I_{in} \times R_i = V_s - \beta V_o$

$\Rightarrow I_{in} R_i = V_s - A\beta V_{in}$

$$\Rightarrow I_{in}R_i = V_s - A\beta[I_{in} \times R_i]$$

$$(1+A\beta)I_{in} \times R_i = V_s$$

$$\Rightarrow \frac{V_s}{I_{in}} = R_i(1+A\beta)$$

$$\Rightarrow R_{if} = R_i(1+A\beta)$$

i/p impedence increases

For o/p impedance $\Rightarrow V_s = 0$ & apply test voltage to o/p side
↳ Say V_x

$$\boxed{R_{of} = \frac{V_x}{I_x}} \qquad V_f = \beta V_x$$

Applying KVL in loop 1 but with $V_s = 0$

$$\Rightarrow V_i = -V_f$$

Applying KVL in loop 2

$$\Rightarrow V_x = R_o I_x + A V_i$$

$$V_x = R_o I_x - A\beta V_x$$

$$V_x(1+A\beta) = R_o I_x$$

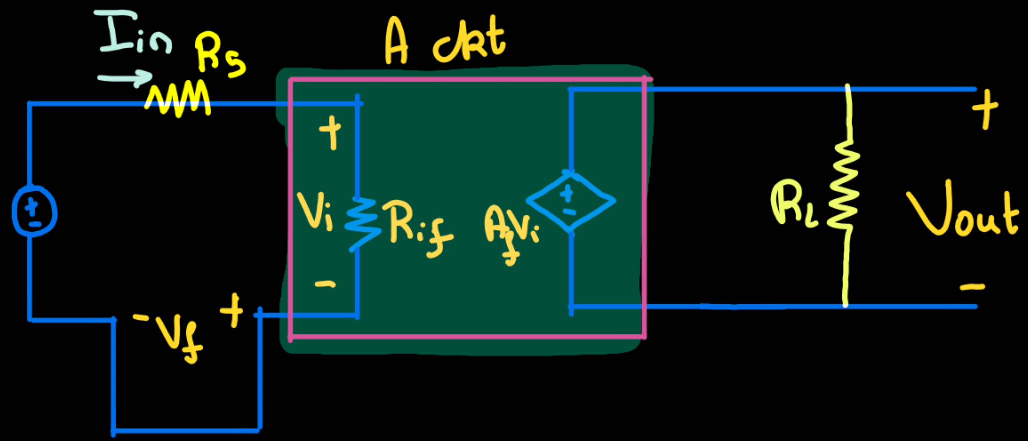
$$\frac{V_x}{I_x} = \frac{R_o}{(1+A\beta)} \Rightarrow R_{of} = \frac{R_o}{1+A\beta}$$

o/p impedence will reduce

This ↑ in i/p impedance & ↓ in o/p impedence is desired.

The actual / real amplifier ckt has R_s & R_L additionally.

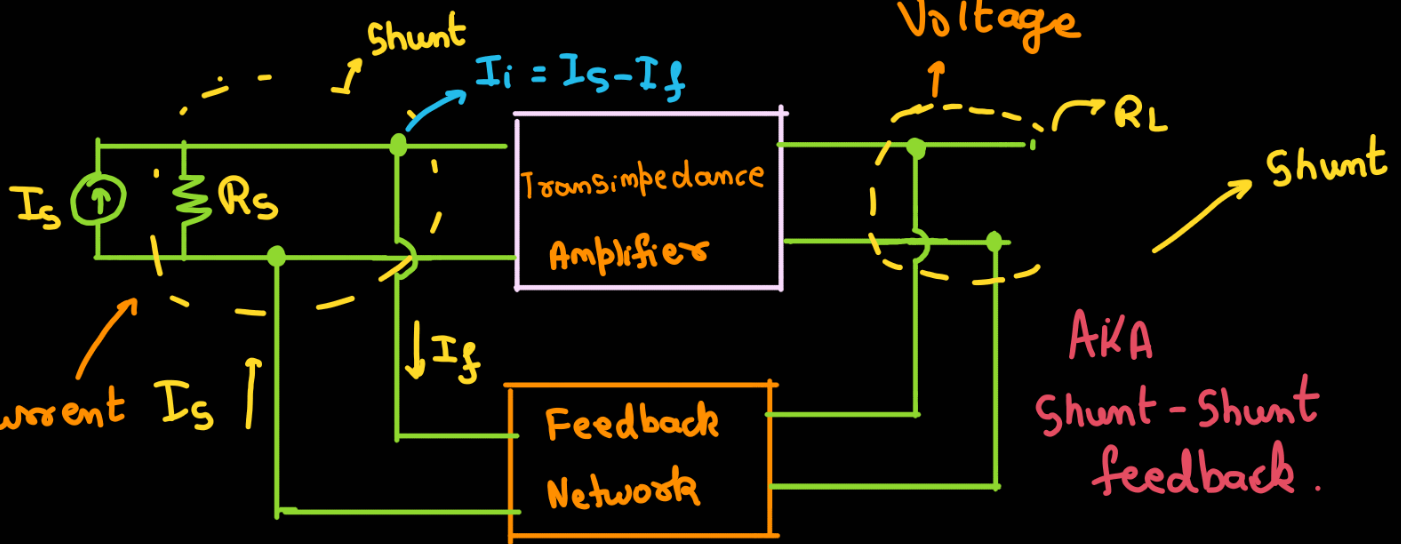
Equivalent feedback ckt



$$V_i = \frac{R_{if}}{R_{if}+R_s} \cdot V_s$$

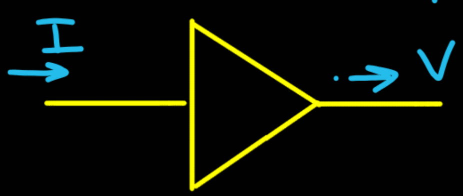
$$V_{oL} = \frac{R_L}{R_{of}+R_L} \times A_f V_i$$

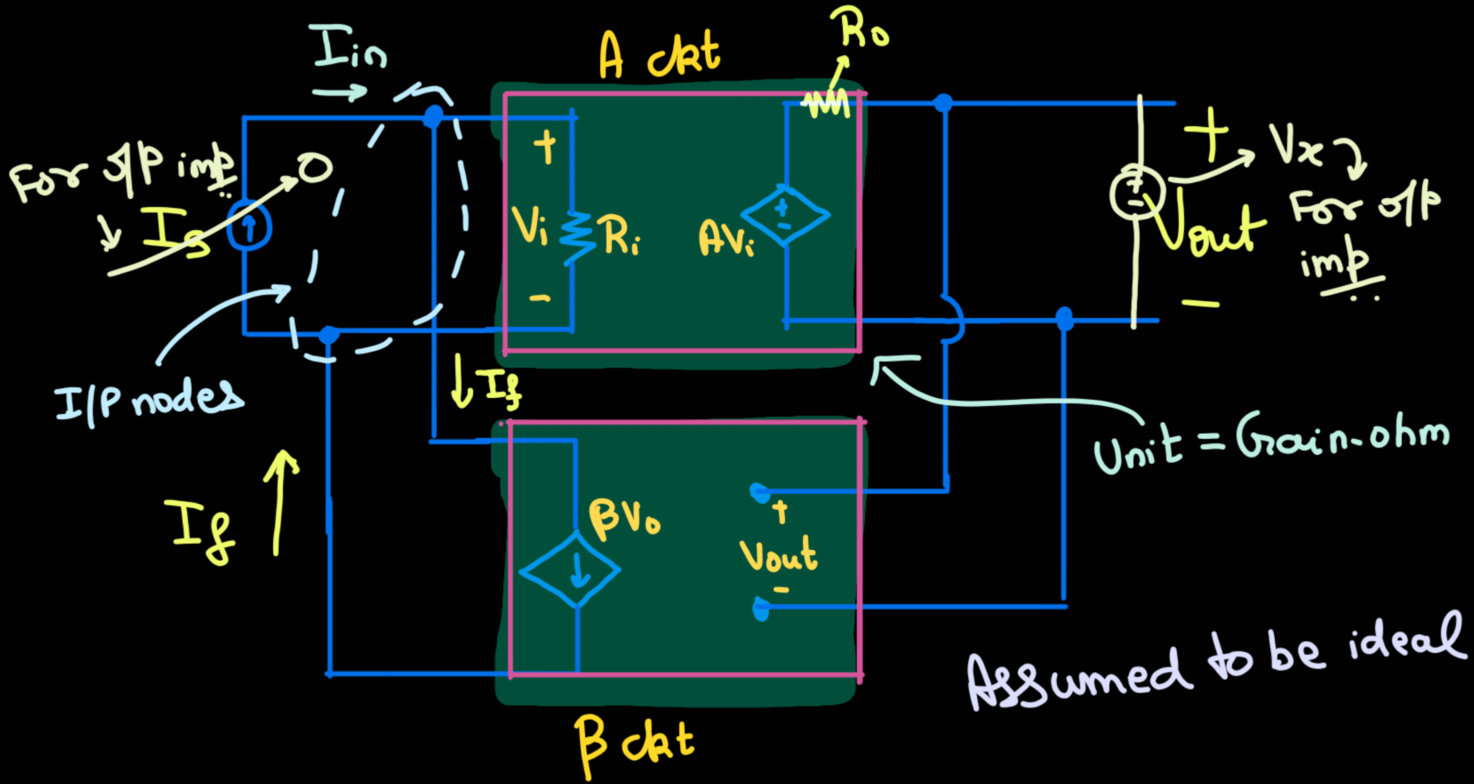
Voltage Shunt Feedback:-



AKA Shunt-Shunt feedback.

Transimpedance Amplifier





★ I/P & O/P impedances :-

Since both i/p & o/p ckts are shunt, the i/p & o/p impedences will both reduce by a factor of $1+A\beta$

→ I/P impedence :-

$$R_{if} = \frac{V_i}{I_S}$$

KCL to i/p node :-

$$I_S - I_f = I_i$$

$$\Rightarrow I_S - \beta V_o = I_i$$

$$\Rightarrow I_S = I_i + \beta V_o = I_i + A\beta I_i$$

$$I_s = I_i(1+A\beta)$$

$$I_s = \frac{V_i}{R_i}(1+A\beta) \Rightarrow \frac{V_i}{I_s} = \frac{R_i}{1+A\beta}$$

$$\Rightarrow R_{if} = \frac{R_i}{1+A\beta}$$

* o/p impedence :-

All independent sources are open ckt. Test voltage V_x applied on o/p side.

$$R_{of} = \frac{V_x}{I_x}$$

$I_f = \beta V_x$

Applying KCL to i/p node.

$I_f = -I_i \Rightarrow \beta V_x = -I_i$

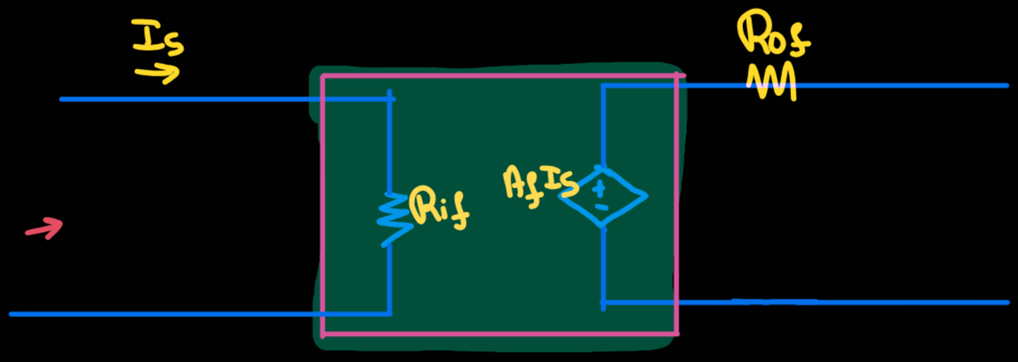
WKT,

$$V_x = R_o I_x + A I_i$$

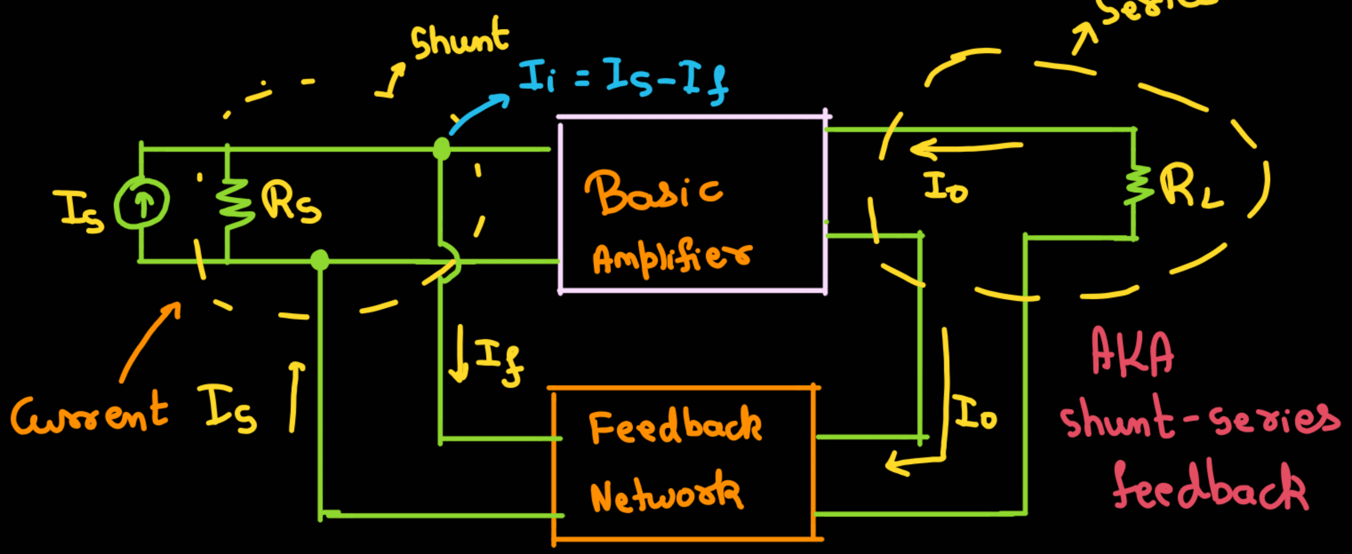
$$V_x = R_o I_x - A\beta V_x \Rightarrow V_x[1+A\beta] = R_o I_x$$

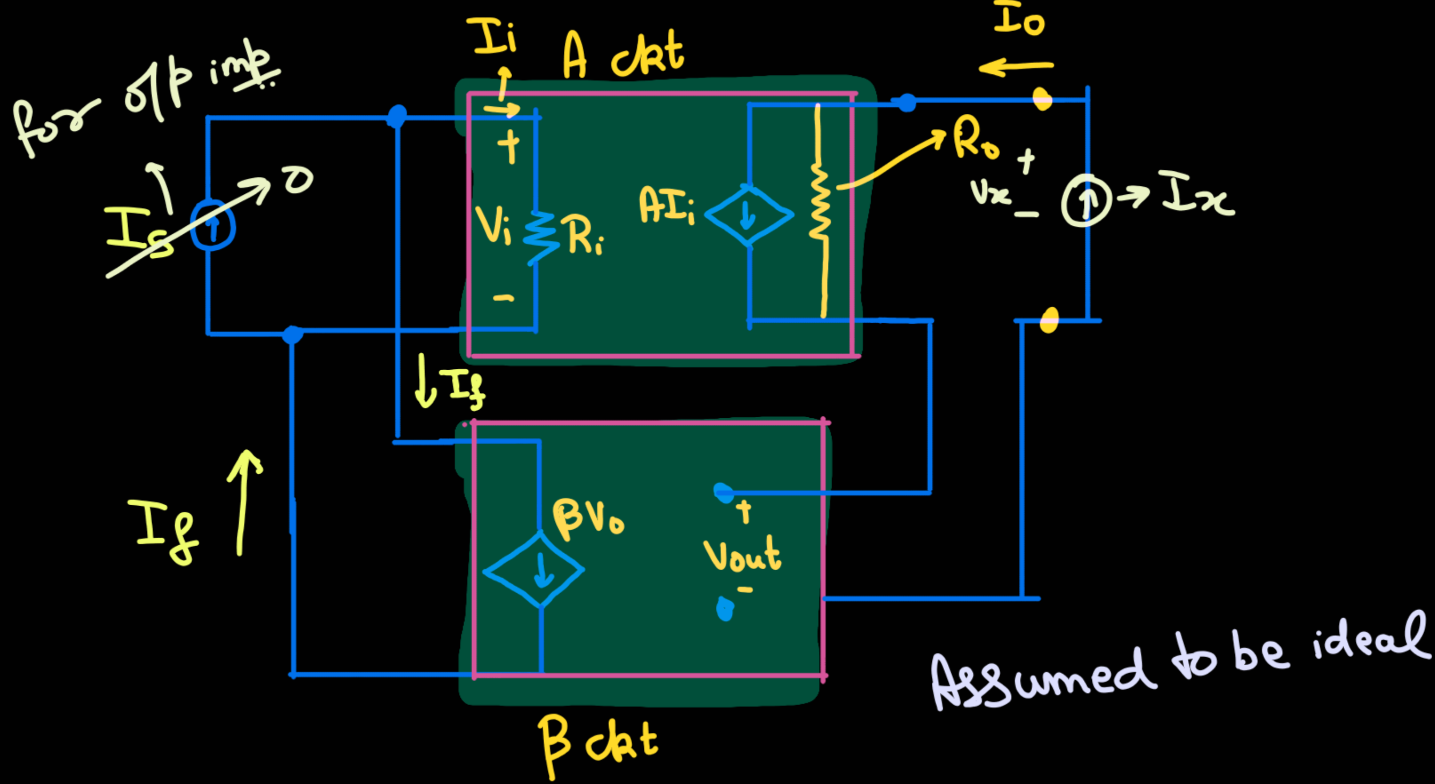
$$\Rightarrow \frac{V_x}{I_x} = \boxed{R_{of} = \frac{R_o}{1+A\beta}}$$

Equivalent ckt →



Current Shunt Feedback:-





★ Effective i/p impedance

$$R_{if} = \frac{V_i}{I_s}$$

Applying KCL to i/p nodes

$$I_s - I_f = I_i$$

$$\Rightarrow I_s - \beta I_o = I_i \Rightarrow I_s - A\beta I_i = I_i$$

$$I_s = I_i(1 + A\beta)$$

$$I_s = \frac{V_i}{R_i}(1 + A\beta)$$

$$\boxed{\frac{V_i}{I_s} = R_{if} = \frac{R_i}{1+A\beta}}$$

* Effective o/p impedance :-

All independent sources are open ckt. Test current I_x applied on o/p side.

$$R_{of} = \frac{V_x}{I_x}$$

$I_f = \beta I_x$

Applying KCL to i/p node

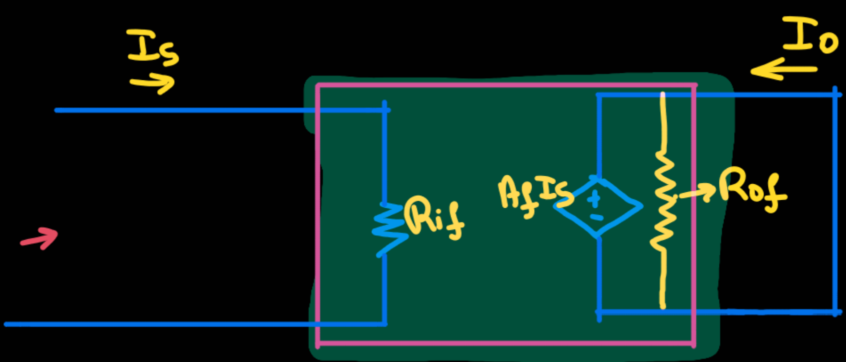
$\Rightarrow I_i = -I_f \Rightarrow I_i = -\beta I_x$

$$I_x = AI_i + \frac{V_x}{R_o} = -A\beta I_x + \frac{V_x}{R_o}$$

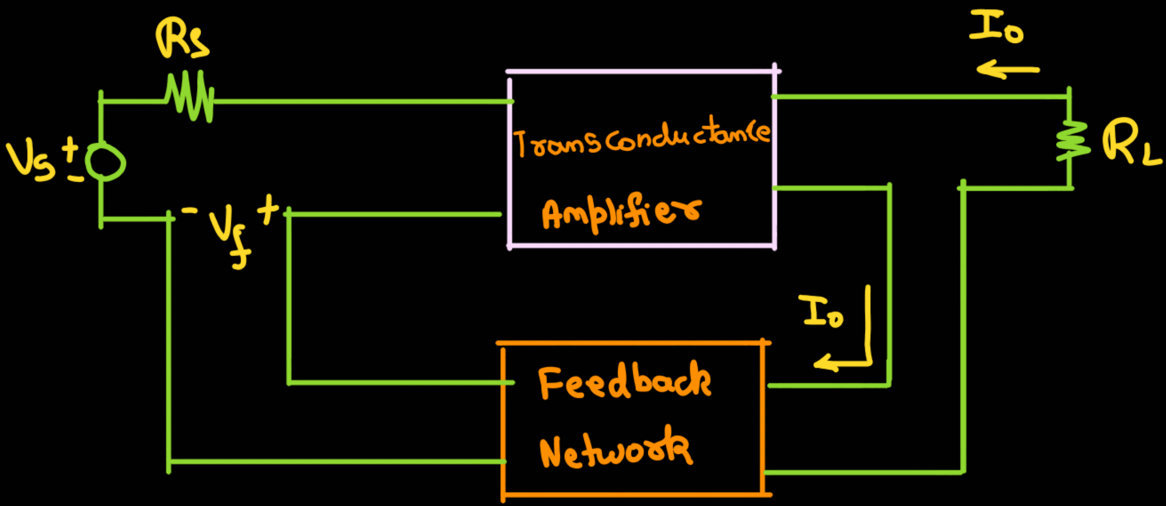
$$\frac{V_x}{R_o} = I_x[1+A\beta] \Rightarrow \frac{V_x}{I_x} = R_o[1+A\beta]$$

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

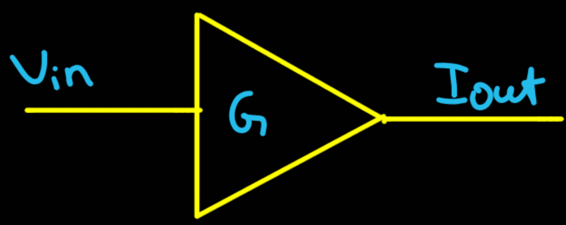
Equivalent ckt →

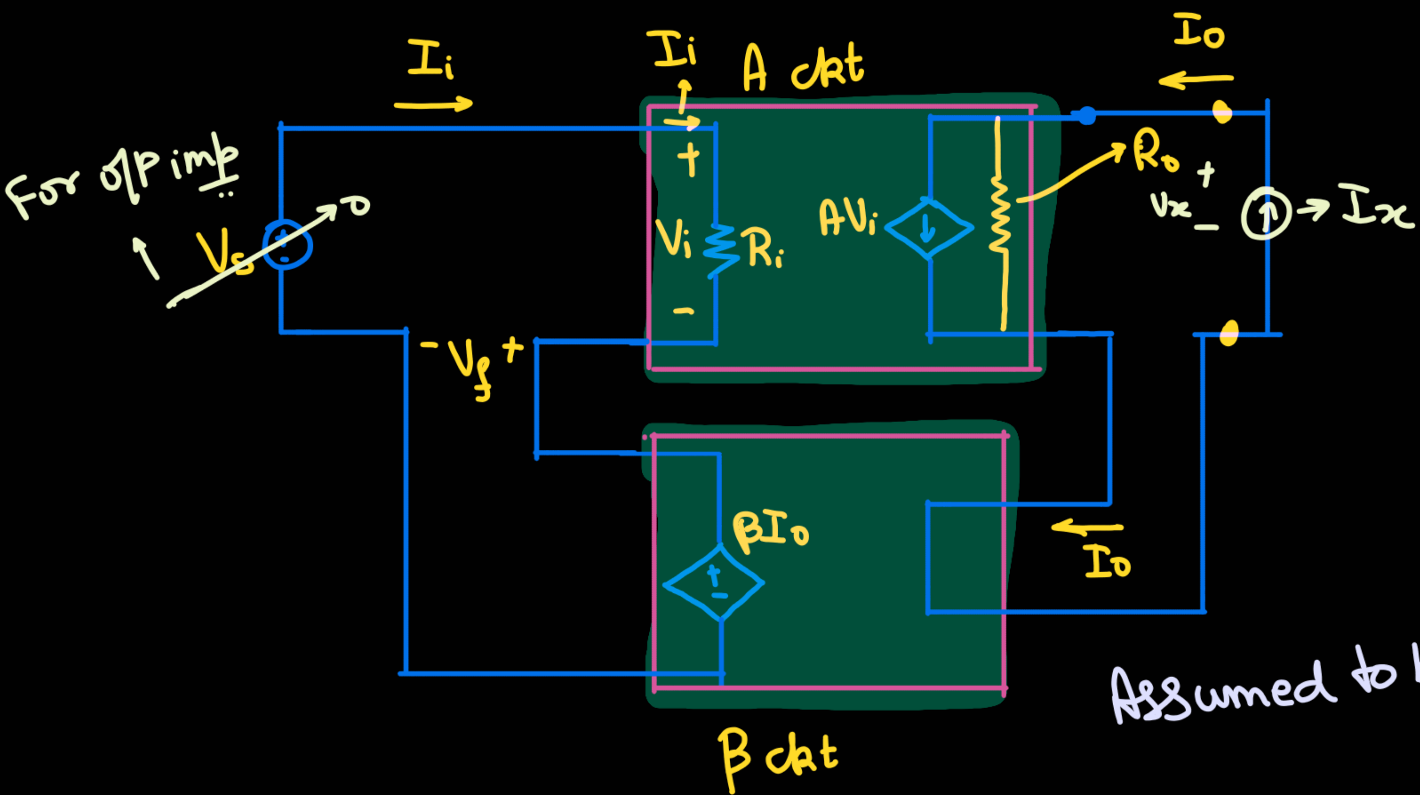


Current Series Feedback:-



Transconductance Amplifier





Assumed to be ideal

★ Effective I/P & O/P impedances:-

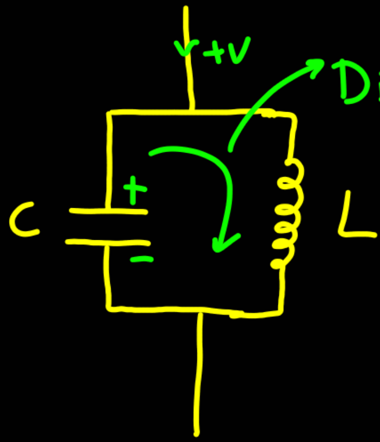
Use same logic as above 3.

$R_{if} = R_i[1+A\beta]$ | $R_{of} = R_o(1+A\beta)$

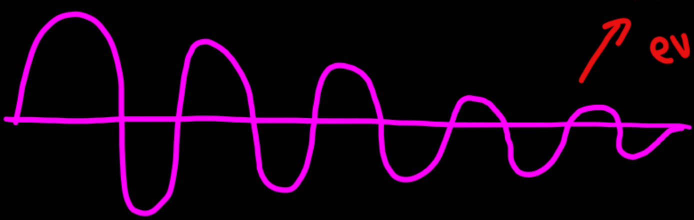
Oscillators

Tank Circuit:-

An LC parallel ckt is called Tank circuit



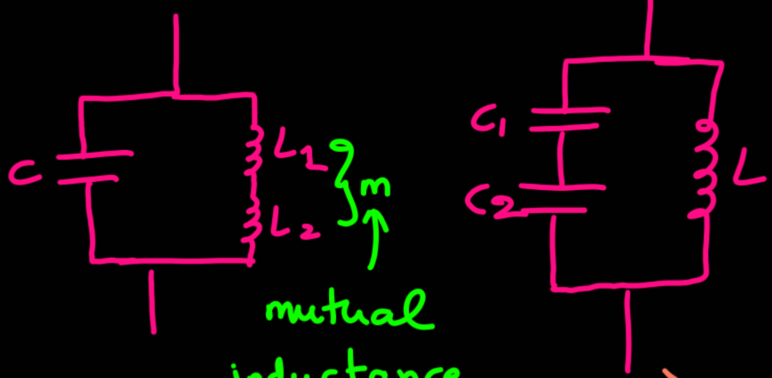
Dissipates in this direction then capcitor charges again



Will damp out eventually

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

This much voltage must be regularly supplied to sustain Output.

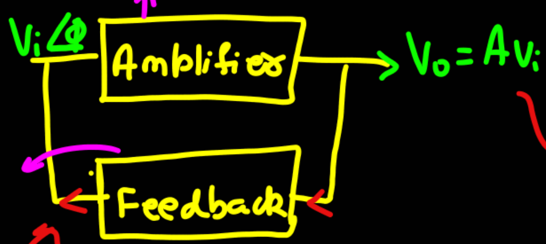


mutual inductance

We can split either C or L in Tank Ckt and get same freq.

$$f = \frac{1}{2\pi\sqrt{LC}} \qquad \boxed{L} = L_1 + L_2 + 2M$$

$$f = \frac{1}{2\pi\sqrt{LC}} \qquad \boxed{C} = \frac{C_1 C_2}{C_1 + C_2}$$



Output out of phase by 180°

Phase shift of additional 180° $\Rightarrow \therefore$ Total $\Delta\phi = 360°$

Overall Gain = Loop Gain $= A \times B = 1$

Gain

Always 1

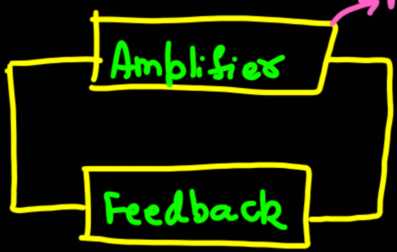
Conditions for sustained oscillations:-

These conditions are called Barkhausen's criteria

- Loop Gain = 1
- overall phase shift in the loop must be 0°/360°

Oscillator:-

An amplifier with +ve feedback network & that can sustain O/P based on Barkhausen's Criteria is called Oscillator



→ NPN/PNP
BJT, RC coupled amplifier

Types of oscillators:-

- Hartely oscillator
- Colpitts oscillator
- RC phase shift oscillator
- Crystal oscillator

⇒ These are Radio freq or high freq oscillators

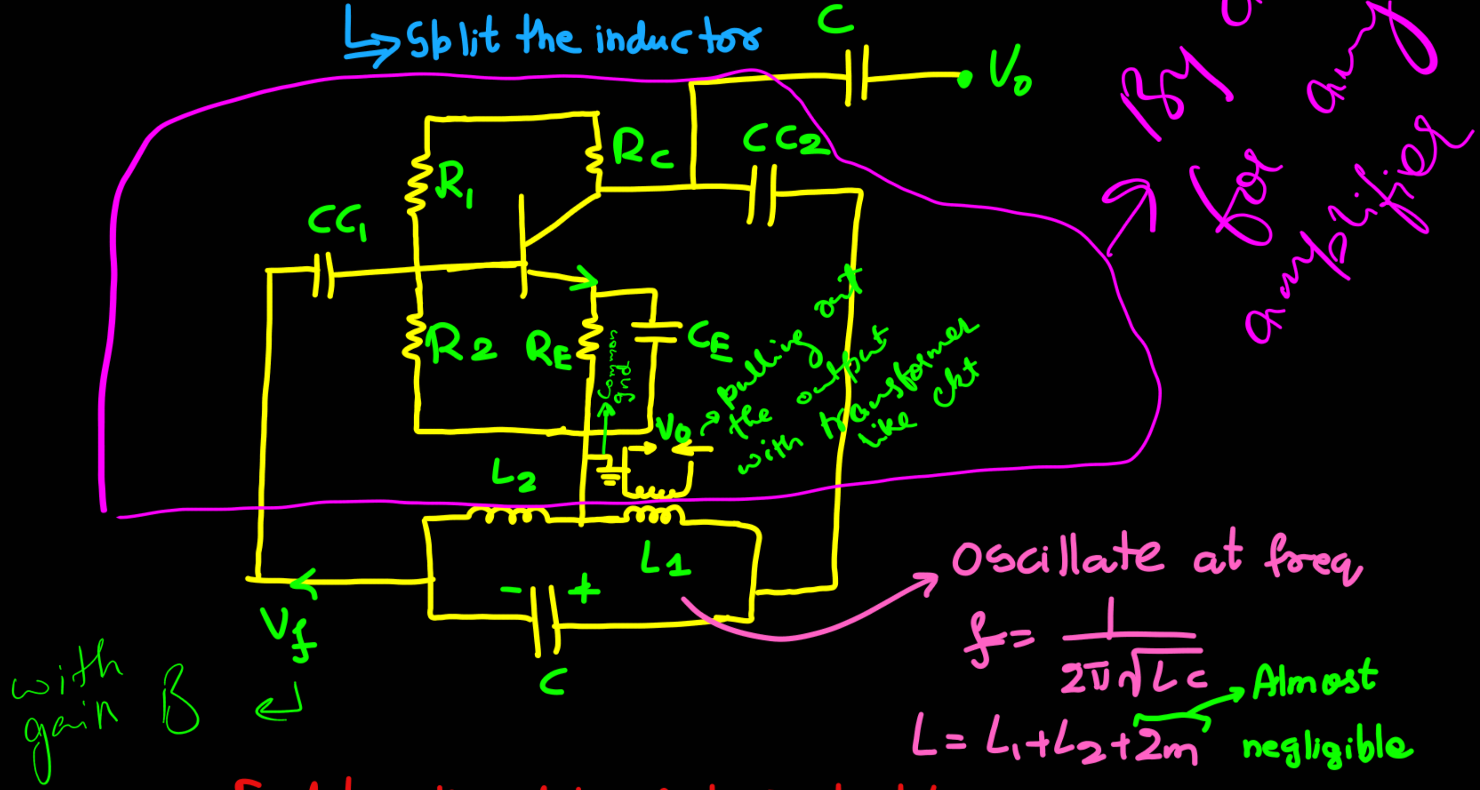
⇒ Audio freq or low freq oscillators

frequency
- High → Called Radio freq
- Low → Called Audio freq

L & C is not used for low frequency oscillations as the ckt will become lengthy.

Thus only R & C are used for AF

Hartely Oscillator :-
↳ H → Inductance
↳ Split the inductor



Oscillate at freq

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

$L = L_1 + L_2 + 2m$ → Almost negligible

Explain the ckt ⇒ Amp, Tank ckt, then output can be taken befor CC_2 or across L_1

To prove Barkhausen Criteria:-
1) $AB = 1$
2) overall phase shift = 0°/360°

$V_o = V_i \angle 180^\circ \ (A = 1)$

$V_f = V_o \angle 180^\circ \ (B = 1)$

Wkt, $V_i = V_f \angle \phi = V_o \angle 180^\circ$

but $V_o = V_i \angle 180^\circ$

$\therefore V_i = V_f \angle 180^\circ \angle 180^\circ \Rightarrow V_i = V_f \angle 360^\circ$ → Criteria 1

$$B = \frac{O/P \text{ voltage}}{I/P \text{ voltage}} = \frac{V_f}{V_o} = \frac{X_{L_1}}{X_{L_2}} = \frac{\omega L_1}{\omega L_2} = \frac{L_1}{L_2}$$

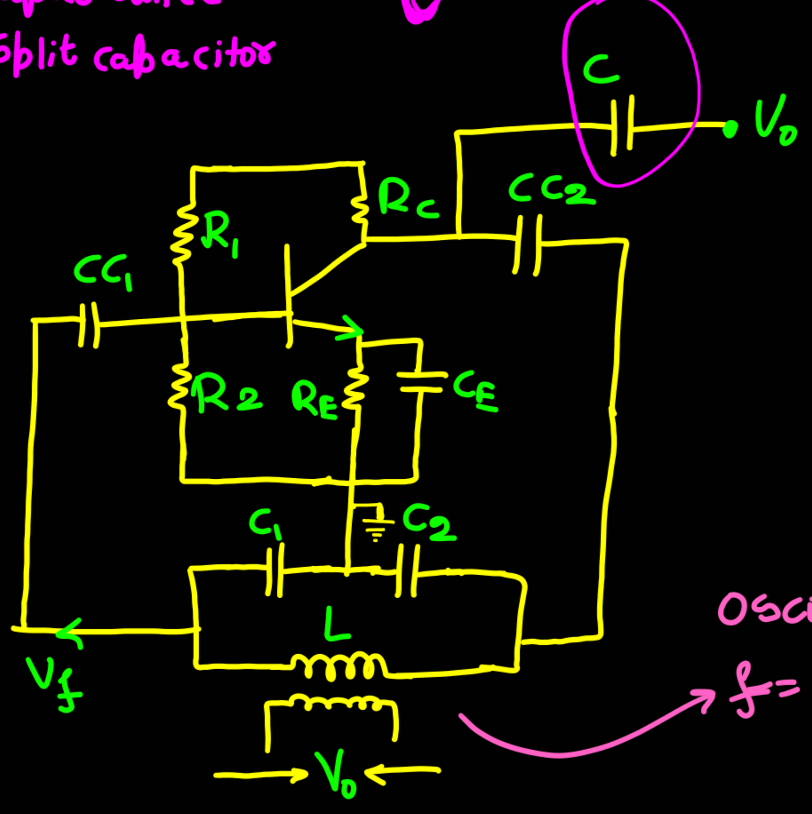
$A = \frac{L_2}{L_1} \Rightarrow A = \frac{1}{B} \Rightarrow \boxed{AB=1}$ 2nd Criteria

Colpitts oscillator:-

↳ C → capacitance

↳ Split capacitor

Use this 'C' for reducing noise ↓ i.e better output



Oscillate at freq

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

where $C = \frac{C_1 C_2}{C_1 + C_2}$

Explain the ckt ⇒ Amp, Tank ckt, then output can be taken befor CC_2 or across L

To prove Barkhausen Criteria:-

1) $AB = 1$
2) overall phase shift $= 0° / 360°$

$$V_f = iX_{C_1} = \frac{i}{\omega C_1}$$

$$V_0 = iX_{C_2} = \frac{i}{\omega C_2}$$

$$B = \frac{V_0}{V_f} = \frac{i}{\omega C_2} \cdot \frac{\omega C_1}{i} = \frac{C_1}{C_2}$$

If $A = \frac{C_2}{C_1}$ then oscillations will be sustained

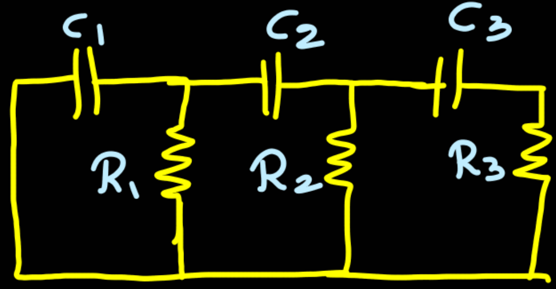
Phase diff expl^n same ⇒ ∴ Prove Barkhausen Criteria

RC phase shift oscillator :-

360° overall shift

Equilibrium

Feedback network



At eq^m frequency, phase shift is 60° in each loop.

$\Rightarrow$ Max phase shift = 180°

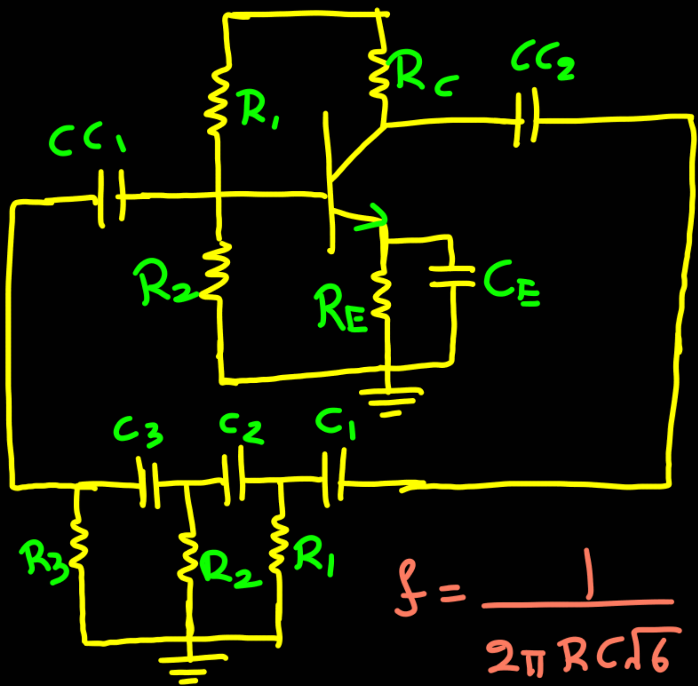
$R_1 = R_2 = R_3 = R$

$C_1 = C_2 = C_3 = C$

Eq^m frequency $= f = \dfrac{1}{2\pi RC\sqrt{6}}$

for other freq., the phase shift in each loop goes to 90°, so 90×3 $\Rightarrow$ 270

$\therefore$ freq. is maintained @ Equilibrium freq.



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

At $f \Rightarrow$ phase shift in each RC network is 60°, $\therefore$ Total feed back network phase shift is 180°

Amplifier ps = 180° $\Rightarrow$ $\boxed{\text{Total} = 360°}$ $\rightarrow$ Barkhausen Criteria 1 satisfied

The gain of the 3 RC network is $\dfrac{1}{29}$ $\Rightarrow B = \dfrac{1}{29}$

$\therefore$ If $A = 29$, then $\boxed{AB = 1}$ $\rightarrow$ B.C 2 satisfied

Crystal oscillator:-

→ Made of quartz → Property → Piezo electric property

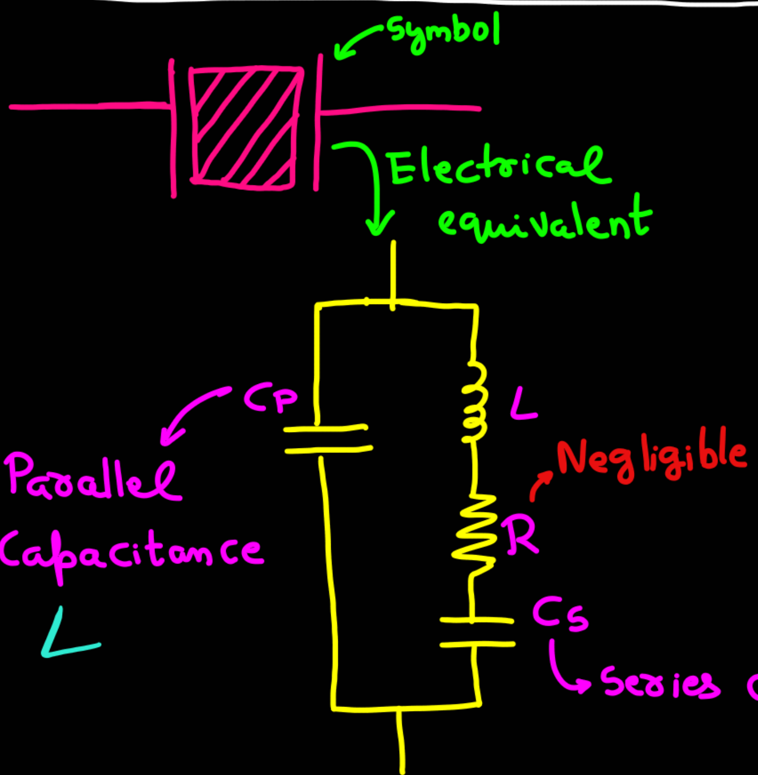
Application of pressure creates electrical energy

Mechanical energy is converted to electrical energy and vice-versa

We need the crystal to vibrate in order to generate oscillations.

We now apply variable voltage to the crystal, to produce vibrations, these vibrations then create oscillatory current!

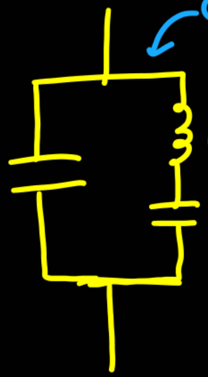
Electrical Equivalent ckt of crystal:-

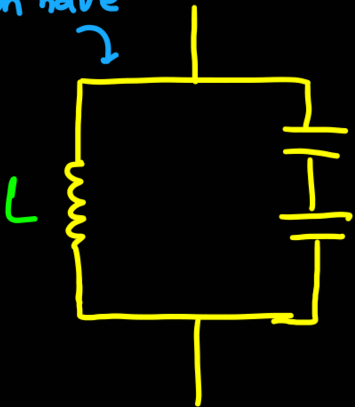


Parallel Capacitance to L

Series capacitance to L

Crystal can have 2 configs ∴



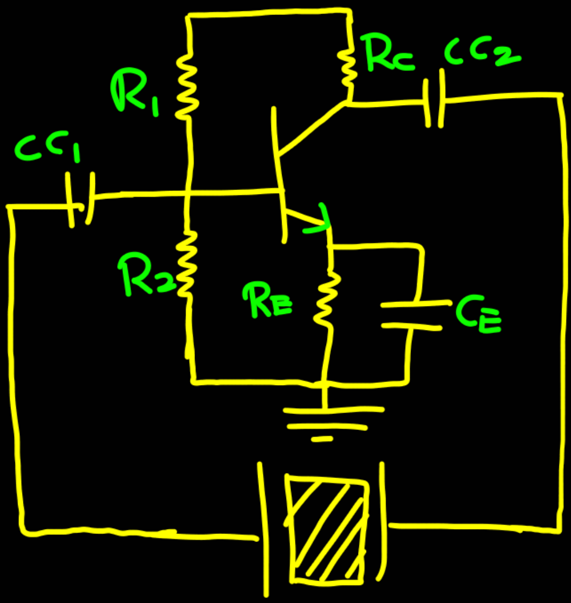


$$f_S = \frac{1}{2\pi\sqrt{LC_S}}$$

freq. for series config of crystals

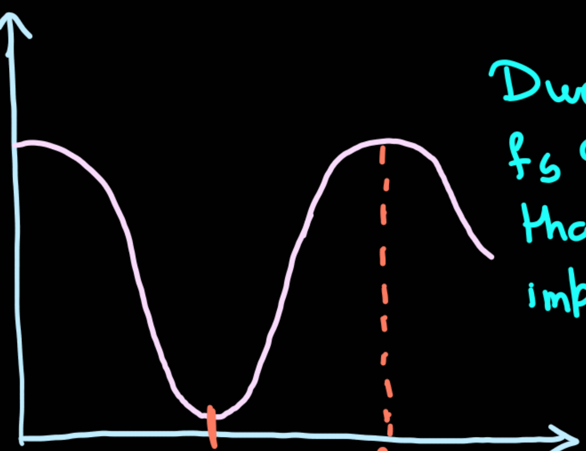
$$f_P = \frac{1}{2\pi\sqrt{\frac{1+C_S/C_P}{LC_S}}}$$

freq. for parallel config of crystals



crystal

Imbedence characteristics of crystals:-



Very close to each other

Series resonance frequency

Parallel resonance frequency

∴ We always prefer f_P as imp. is ↑,

Due to close values of f_S & f_P and the fact that f_P gives higher impedance → crystal oscillator always operated at f_P

* The material size is almost constant for variable app^n of temp., thus f is stable

Unlike in LC, in which L & C are likely to change, thus freq maybe unstable & need more economy to stabilise

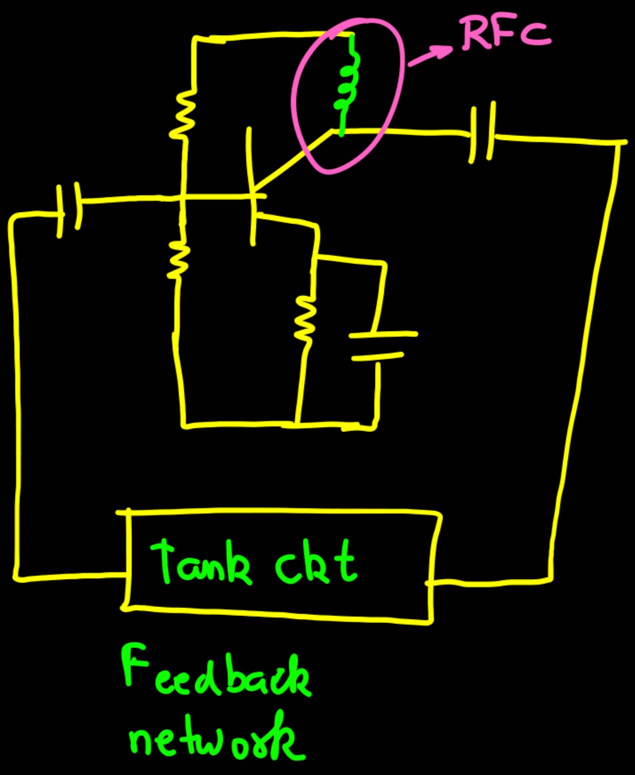
∴ Crystal oscillator is more stable

Additional points:-

* RC not preferred for high freq oscillator as RC becomes too low.

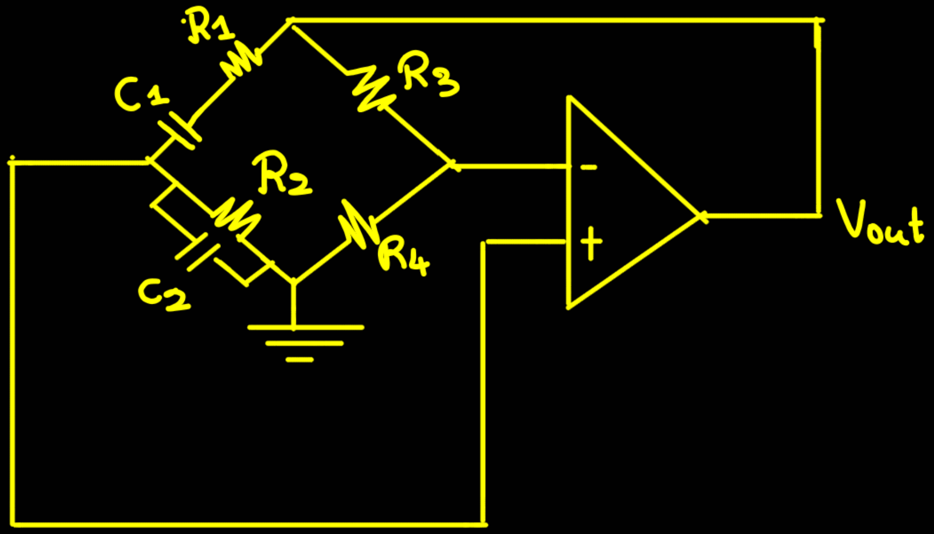
* To avoid power dissipation we replace R_c in amplifier with an inductor called Radio Frequency coil (RFC)

Advantage:- DC power in the collector resistor reduces, thus not draining input very quickly.

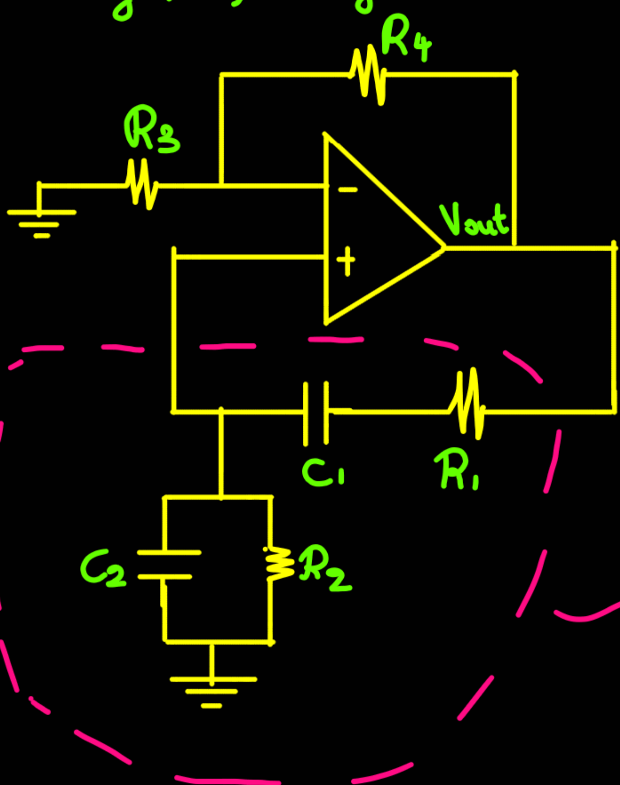


TO BE USED ONLY FOR RF OSCILLATORS!!!

Wein Bridge Oscillator:-

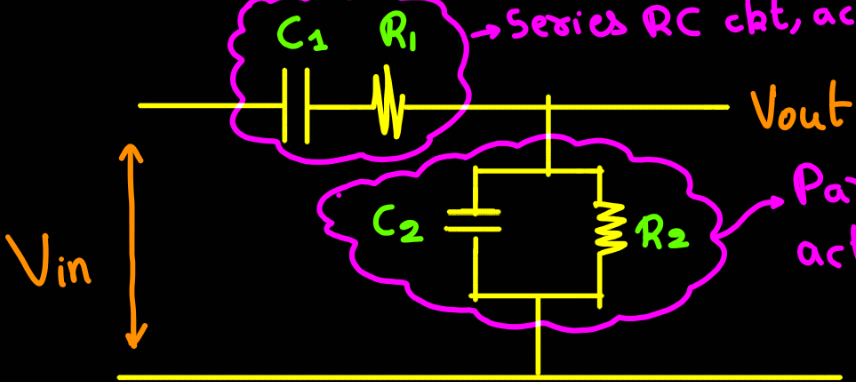


Redrawing this, we get



Feedback network
↳ provides +ve feedback

Consider the feedback network:-



→ Series RC ckt, acts as a high pass filter

Parallel RC ckt
acts as low pass frequency

$f_r \rightarrow$ resonant frequency

Response at $f_r \rightarrow$ 

At f_r, phase shift $\phi = 0$ & $\frac{V_o}{V_{in}} = \frac{1}{3}$

If $R_1 = R_2$ & $C_1 = C_2$, then:-

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