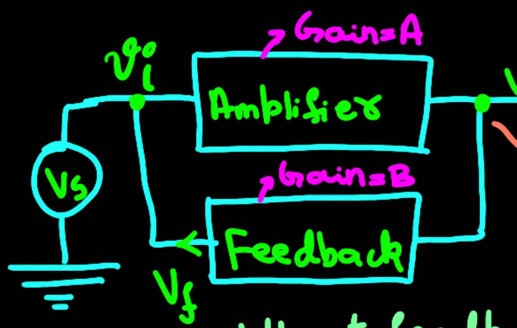
Feedback:-

↳ Return back



$V_o = AV_i$

↳ A part of amplifier output is fed into feedback network

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

$$V_i = \underbrace{\overbrace{V_s}^{\text{without feedback}} + V_f}_{\text{with feedback}}$$

$V_i = V_s + BV_o$

$V_o = A(V_s + BV_o)$

$$\Rightarrow \boxed{\frac{V_o}{V_s} = \frac{A}{1-AB} = A_{vf}}$$

⇒ Overall voltage gain of feedback amplifier

Shortcut to remember

$$\boxed{\frac{V_s}{V_o} = \frac{1}{A} - \frac{1}{B}}$$

Feedback amplifier

$V_i = V_s + V_f$ → Positive feedback → $A_{vf} = \frac{A}{1-AB}$

$V_i = V_s - V_f$ → Negative feedback → $A_{vf} = \frac{A}{1+AB}$

Types of feedback:-

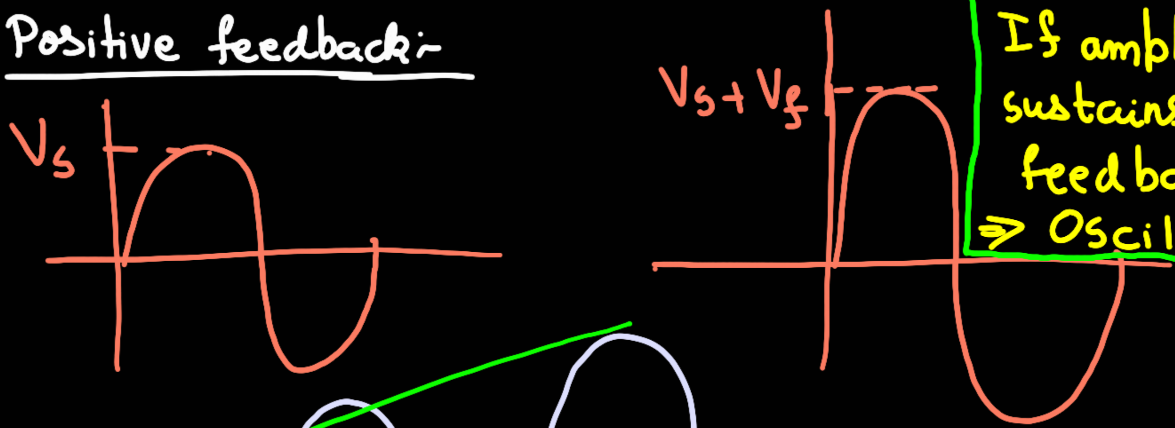
1. Negative feedback → Feed a -ve voltage
2. Positive feedback → Feed a +ve voltage

} without coupling capacitors in RC coupled amp.

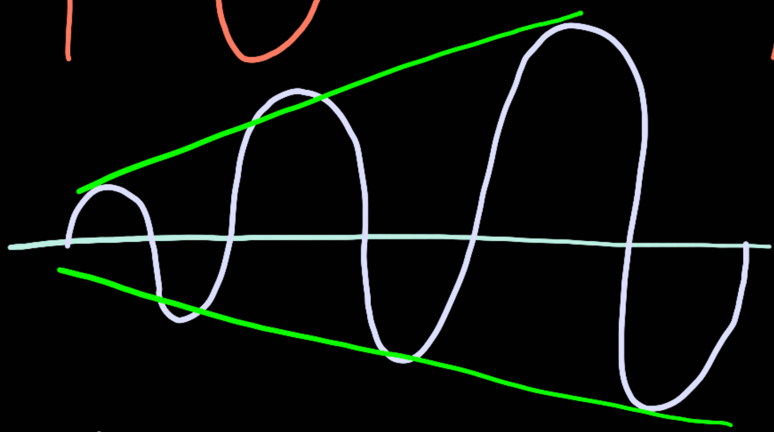
Negative feedback:-

- Feedback in which -ve voltage is fed
- Amplifier gain reduces
- Noise reduces due to reduction in amplifier gain
- Improves the bandwith
- Amplifier performance improves due to higher stability

Positive feedback:-

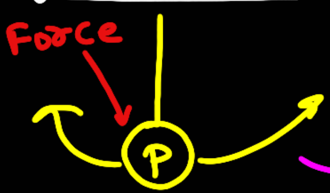


If amplifer sustains +ve feedback ⇒ Oscillator



Positive Feedback diverges & O/P becomes unstable

Principles of oscillator:-



→ Results in Sine wave
↳ oscillations reduce to zero at some point

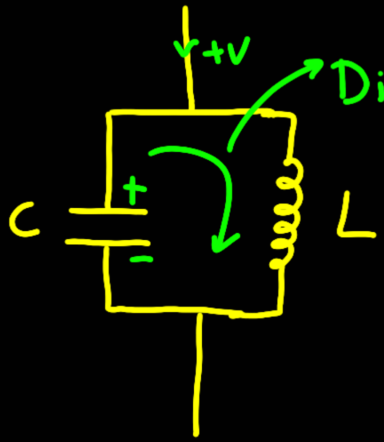
Period = $t = \frac{1}{f}$ ↗ frequency

As long as we supply energy regularly to the pendulum, the oscillations will fully continue till the energy supply lasts

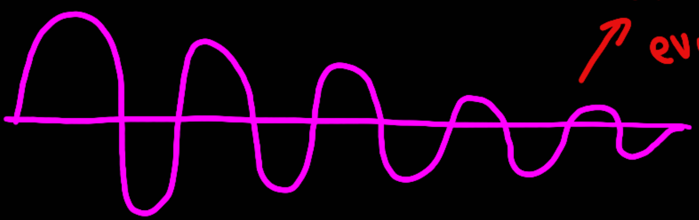
This can be achieved in Electronics with the help of a Tank circuit

Tank Circuit:

An LC parallel ckt is called Tank circuit



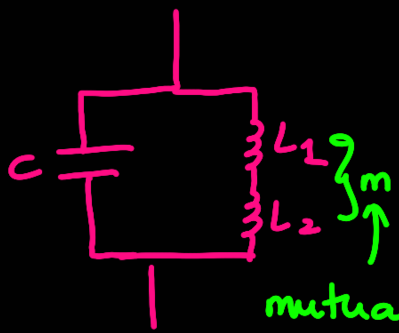
Dissipates in this direction then capcitor charges again



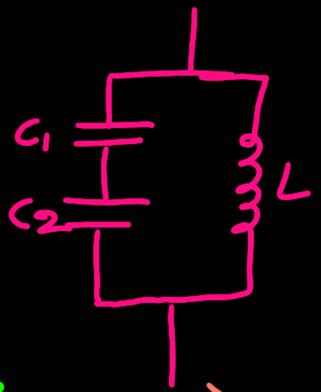
Will damp out eventually

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

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.

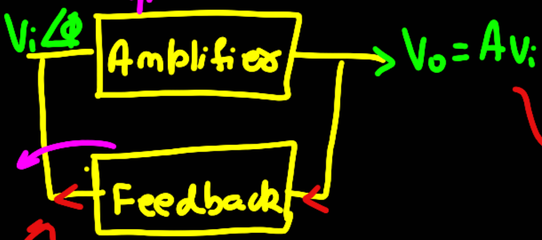
$f = \frac{1}{2\pi\sqrt{LC}}$

$\boxed{L} = L_1 + L_2 + 2M$

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

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

Gain = A



Gain = B

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

gain

Always 1

Output out of phase by 180°

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

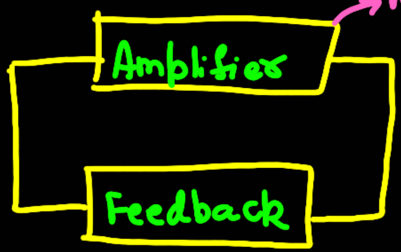
Conditions for sustained oscillations:-

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

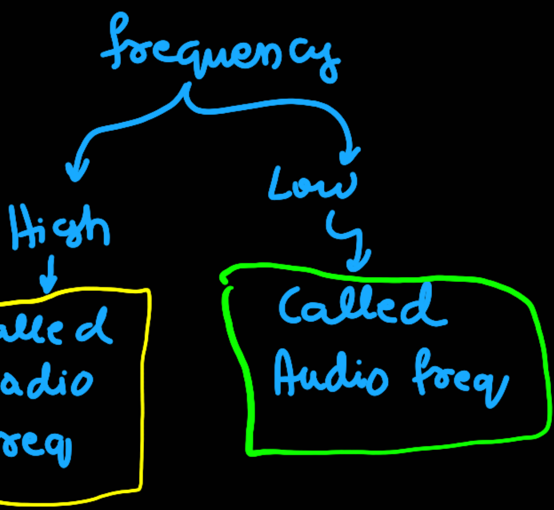


NPN/PNP

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

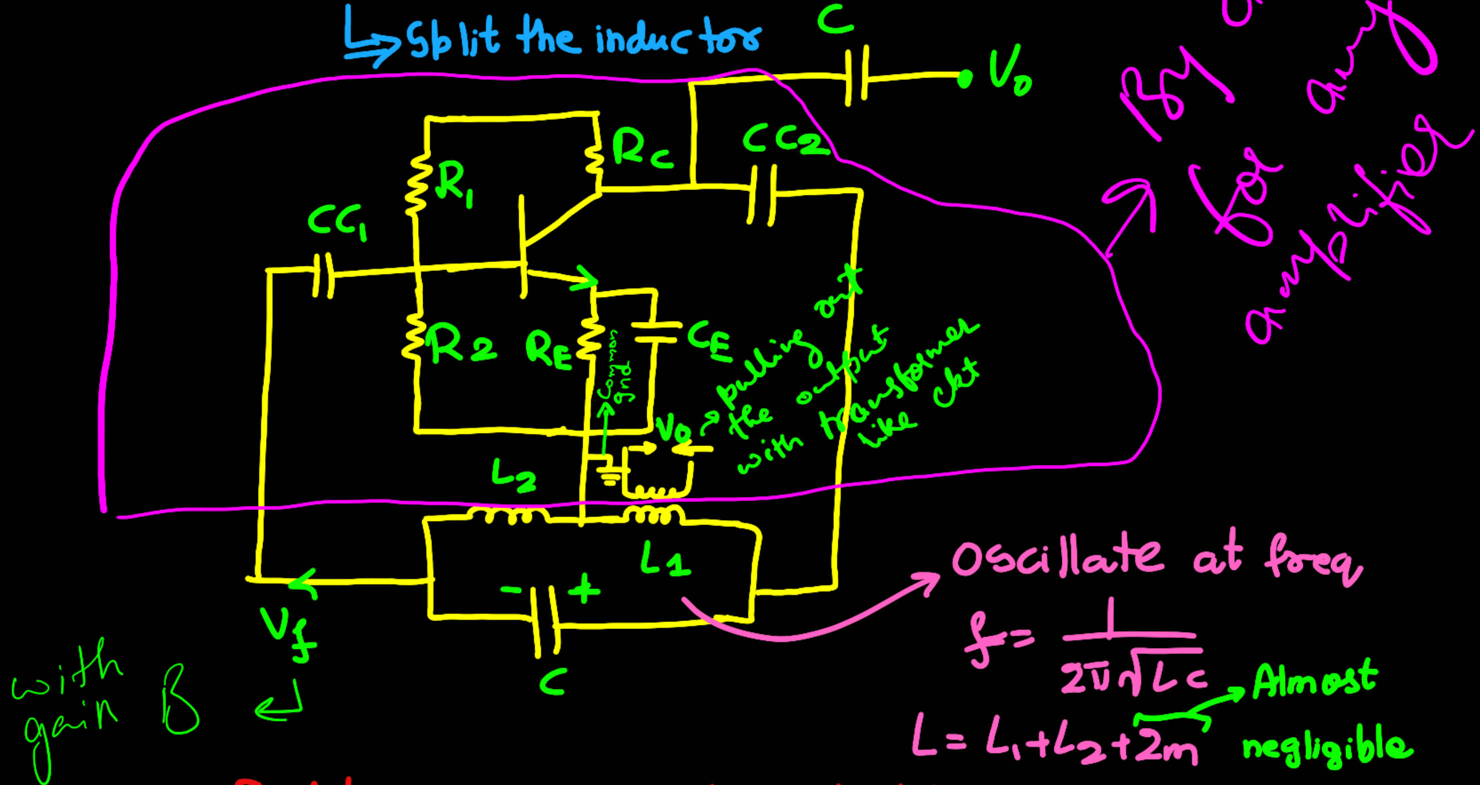
L & C is not used for low frequency oscillations as the ckt will become lengthy.

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°

$V_o = V_i \angle 180°$ $(A = 1)$

$V_f = V_o \angle 180°$ $(B = 1)$

wkt, $V_i = V_f \angle 0 = V_o \angle 180°$

but $V_o = V_i \angle 180°$

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

$$B = \frac{O/P \text{ voltage}}{I/P \text{ voltage}} = \frac{V_f}{V_o} = \frac{X_{L1}}{X_{L2}} = \frac{\omega L_1}{\omega L_2} = \frac{L_1}{L_2}$$

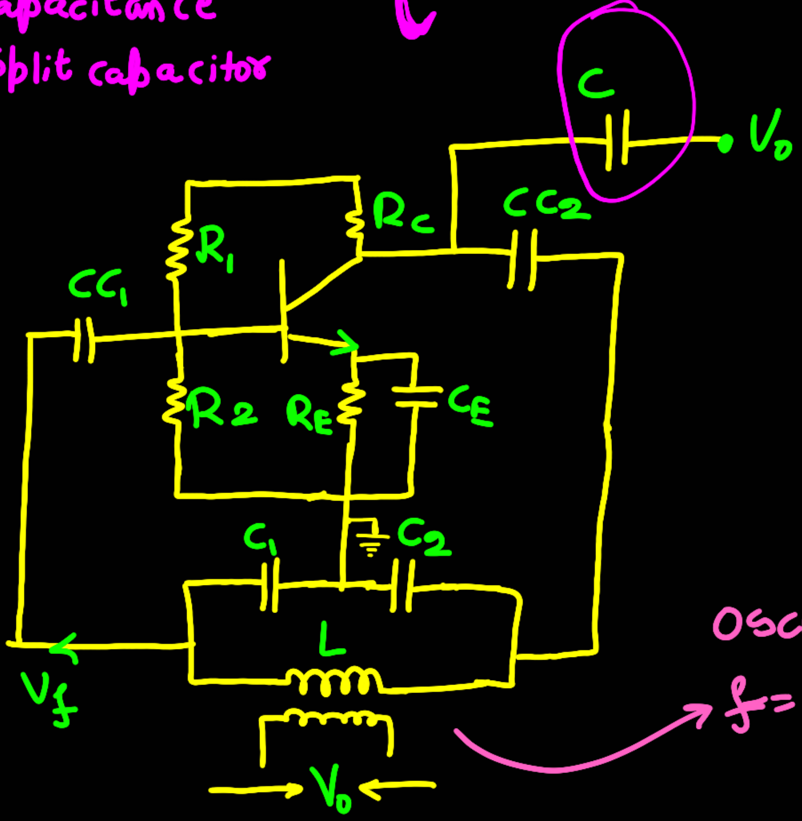
$A = \frac{L_2}{L_1} \Rightarrow A = \frac{1}{B} \Rightarrow \boxed{AB = 1}$ 2nd Criteria

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 before CC_2 or across L

To prove Barkhausen Criteria:-

1) $AB = 1$

2) overall phase shift = 0°/360°

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

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

$B = \frac{V_f}{V_o}$...

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

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

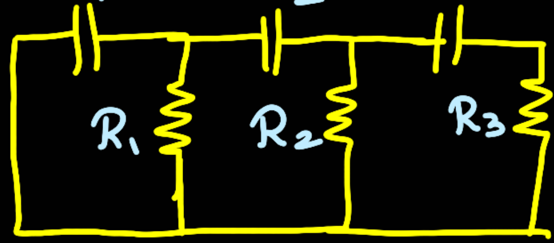
 Phase diff expl^n same ⇒ ∴ Prove Barkhausen Criteria

RC $\boxed{\text{phase shift}}$ oscillator :-

360° overall shift

Equilibrium

Feedback network



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

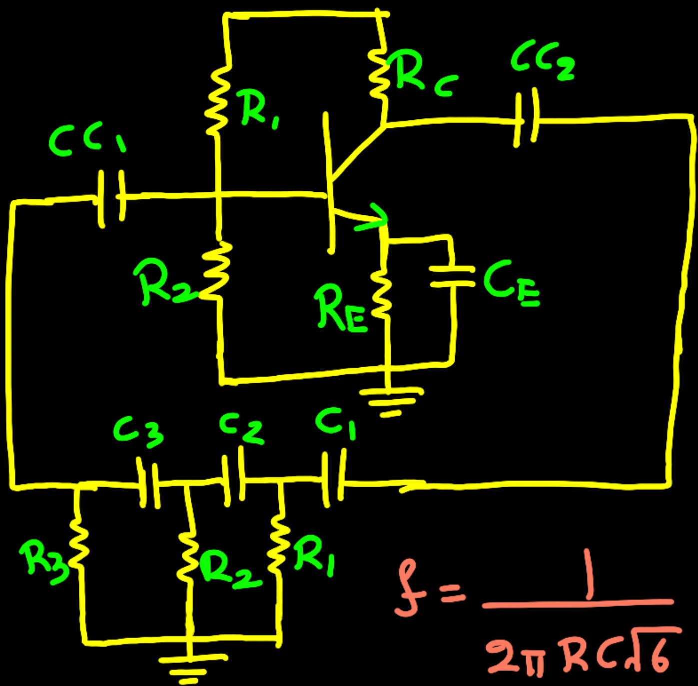
$\Rightarrow$ Max phase shift = 180°

$\Downarrow$

$R_1 = R_2 = R_3 = R$

$C_1 = C_2 = C_3 = C$

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

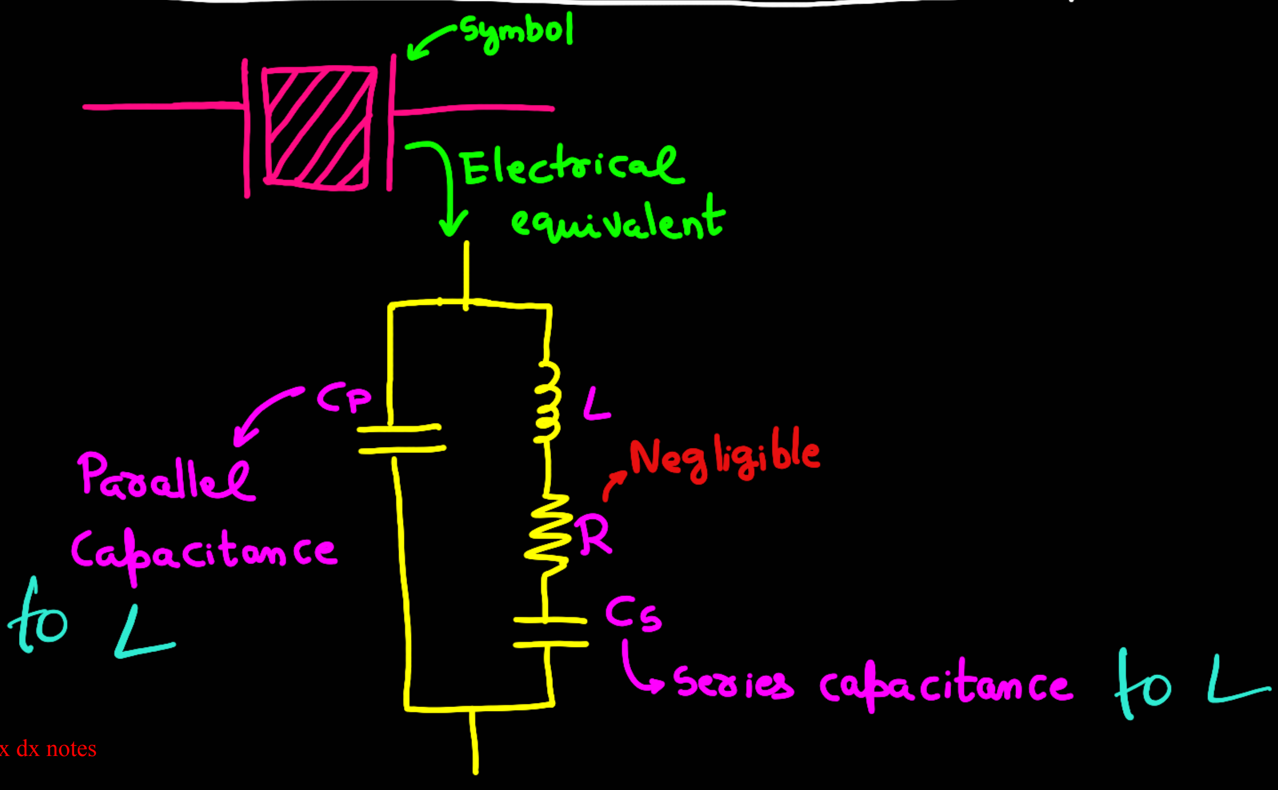
Application of pressure creates electrical energy

Mechanical energy is converted to electrical energy and vice-versa

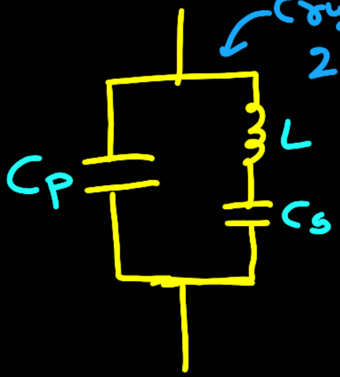
We need the crystal to vibrate in order to generate oscillations.

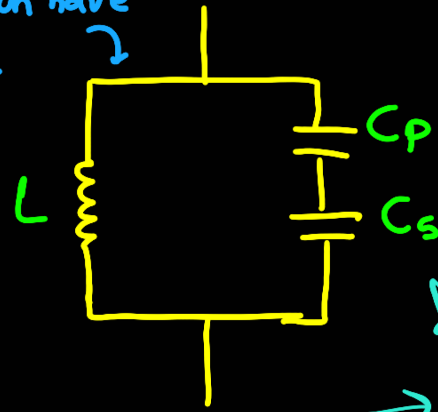
We now apply variable voltage to the crystal, to produce vibrations, these vibrations then create oscillatory current!

Electrical Equivalent ckt of crystal:-



Crystal can have 2 configs



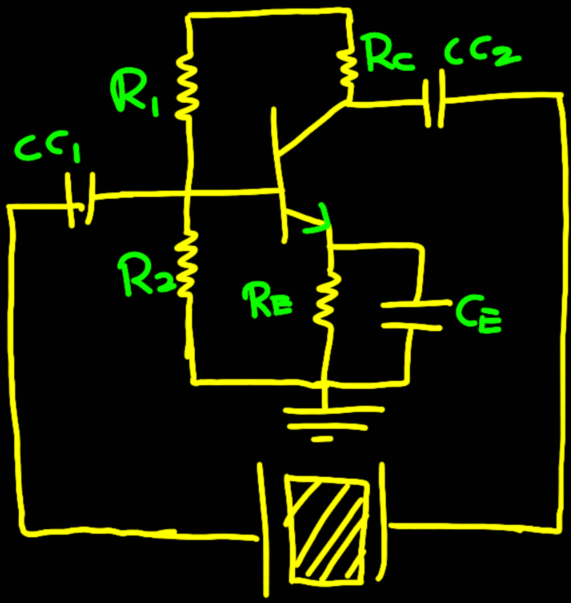


freq. for series config of crystals

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

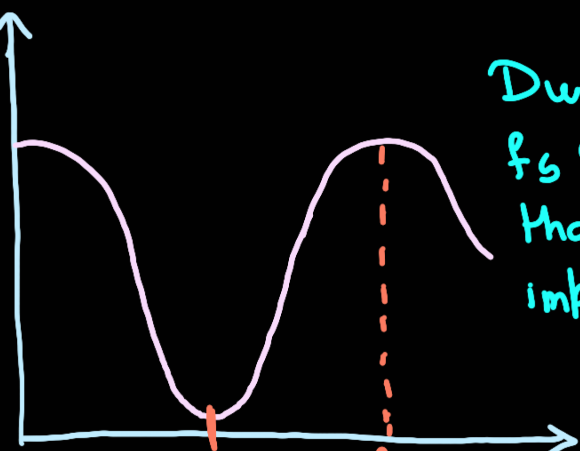
$$f_p = \frac{1}{2\pi\sqrt{\dfrac{1 + C_s/C_p}{LC_s}}}$$

freq. for parallel config of crystals



crystal

Impedence characteristics of crystals:-



f_s — f_p 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

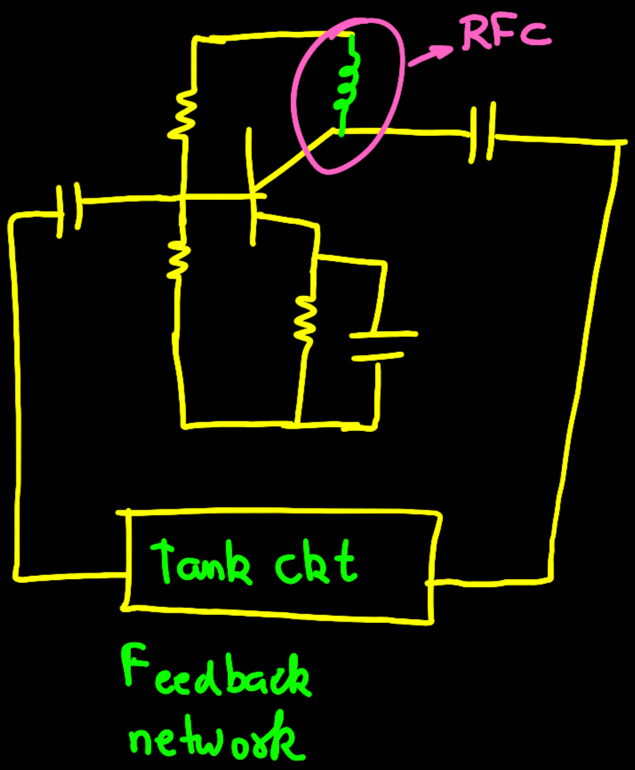
∴ Crystal oscillator is more stable

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!!!

Operational Amplifiers:-

Gives large output

↓

May not be enough

∴ Cascade multiple amplifiers together

$V_i \rightarrow \boxed{A_1} - \boxed{A_2} - \cdots - \boxed{A_n} - V_0 = A_1 A_2 \ldots A_n V_i$

↳ Too bulky

We need something just like this but a single integrated circuit

Op-Amp:-

↳ Has a very high gain integrated into a single ckt

Operations:-

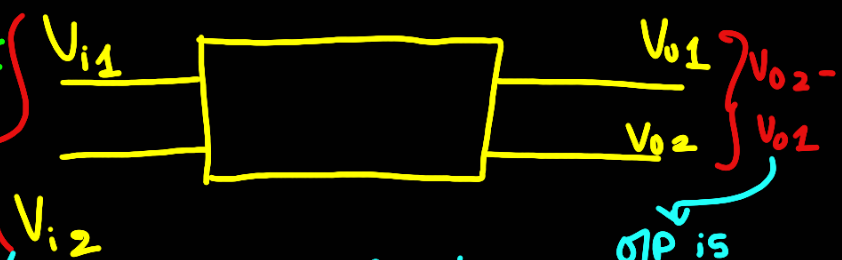
Mathematical (Arithmetic)
Logical
Relational

Has a very high gain & capable of performing certain operations like mathematical, logical & relational.

→ Analog Circuit

Coz its continuous

↳ Op-Amp is a linear Circuit

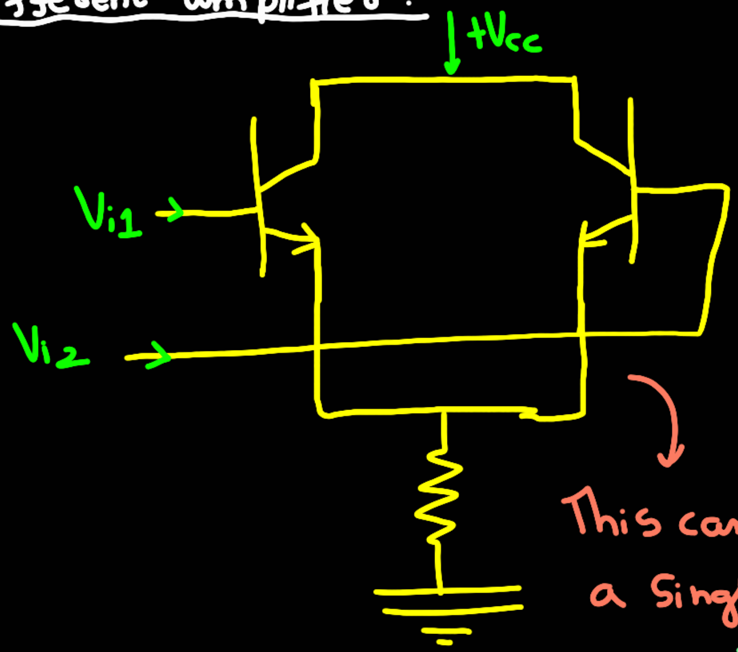


$V_{i2} - V_{i1}$ → Cancels the Common DC voltage

O/P is balanced

∴ Differential I/P & Differential O/P

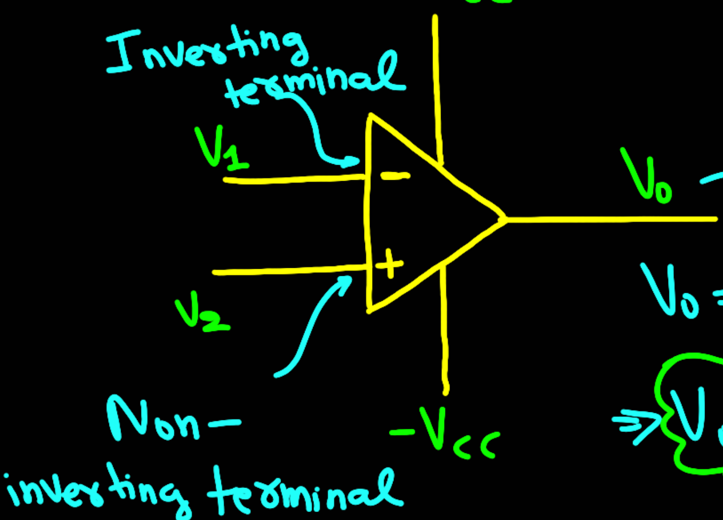
Different amplifier :-



Capacitors & Biasing resistors eliminated

This can be integrated into a single chip.
↓
Cascading

Symbol:-



V_0 → O/P terminal

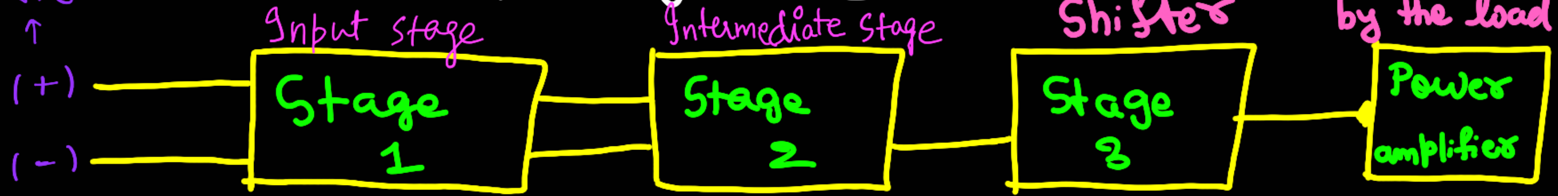
$V_0 = (V_2 \sim V_1) * \text{Gain}$

$\Rightarrow \boxed{V_0 = V_d A_v}$

→ Input signal to be amplified

Block diagram of op-Amp:-

Provides current & voltage req by the load



1. It's a differential amplifier
2. It's a dual input, balanced output Diff. Amp. (*DUAL O/P*)
3. Rejects noise
4. This stage also provides high I/P impedance
5. Provides high voltage gain

1. Dual I/P (balanced) and unbalanced O/P amplifier.
2. Provides very high voltage gain

1. The O/P of stage
2. i.e I/P of stage 3 is above GND as direct coupling is used.
2. Level 3 (level shifter) is used to sift the O/P of level 2 downwards (wrt GND)

1. Also called as push pull amplifier
2. Increase the O/P voltage swing
3. Improves current supplying capabilities
4. Provides Min. O/P impedance

Ideal Op-Amp VTC & its characteristics:-

→Voltage Transfer characteristics

✱ ∞ i/p impedance ⤵
Ideally no loading needed

✱ Zero o/p impedance ⤵
O/P can drive ∞ no. of other devices

✱ ∞ Bandwidth ⤵
So, that any freq. can be accepted by the ideal op-amp

✱ ∞ Voltage gain

✱ Perfect Balance, i.e input offset voltage = 0
(If no i/p no o/p at all IDEALLY)

✱ ∞ CMRR (Common Mode Rejection Ratio)

$$\frac{\text{Differential Gain}}{\text{Common Mode Gain}}$$

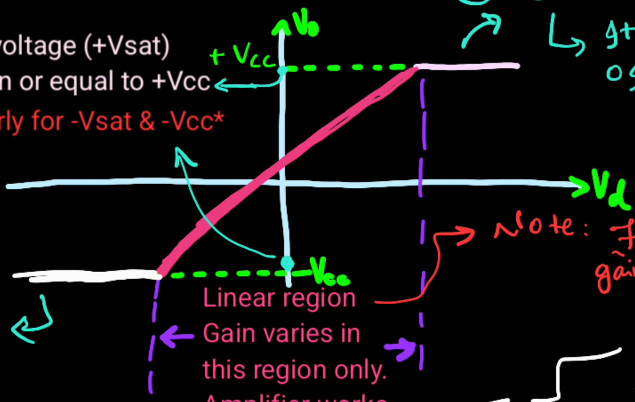
Normal Vout, When there is a difference in i/p voltage

Ratio of these 2 is CMRR

↳ If both the input signal are same or grounded, then diff. i/p is 0, ∴ the output is also 0 ideally, but ≠ 0, practically

✱ ∞ Slew rate → Rate of change of O/P voltage w.r.t time = $\frac{dV_o}{dt}$

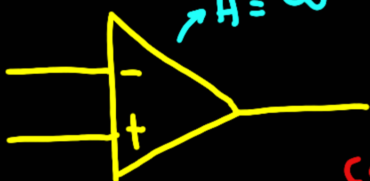
(Tells us how fast the amplificatⁿ process takes place)



@ Saturatⁿ region
↳ It becomes an oscillator ⤵ (constant gain)

Note: For an amplifier gain must keep on changing

@ Saturatⁿ region
↳ It becomes an oscillator (constant gain)

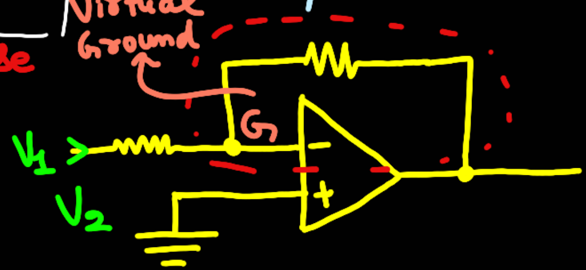


A = ∞ → Disadv:- No use

Gain can be reduced using -ve feedback ⟹

Virtual Ground

-ve feedback



✱ op-Amp is amplifier with -ve feedback

$\boxed{I_f = -I_1}$

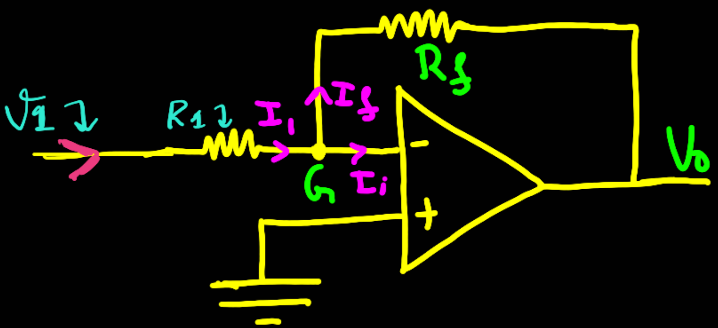
O/P = $-V_o$

O/P is always 180° out of phase

Applications of Op-Amp :-

① Inverting Amplifier :-

* R_f : feedback resistance
* I_i : Inverting current
* I_1 : Net current



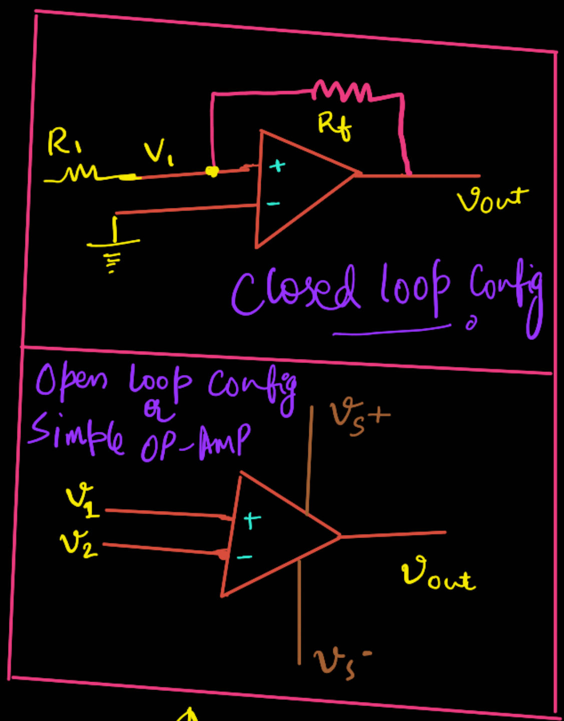
1. Does not exist in electrical ckts, it exists only in Electronic ckts (op-amps)
2. Node whose voltage is zero but not connected to GND physically or mechanically.

$$V_0 = A_v V_1$$

$$I_1 = \frac{V_1 - V_G}{R_1}$$

$$\boxed{V_G = 0}$$ Virtual Ground

$$\boxed{I_1 = \frac{V_1}{R_1}}$$



$$I_1 = \cancel{I_i}^{\,0} + I_f \Rightarrow I_1 = I_f$$

$$I_f = \frac{V_G - V_0}{R_f} = \frac{-V_0}{R_f}$$

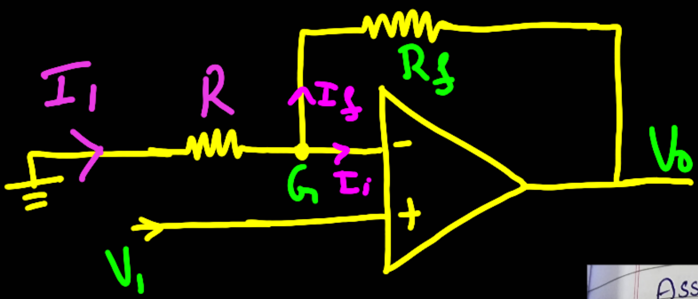
The open loop gain is extremely high, and because of such high gain The OP AMP becomes unstable, so inordered to avoid such conditions we connect a resistor (Rf) from output back to the input (closed loop OP AMP) to loose some gain, this helps us in reducing amd controlling the gain. It depends on the value of the resistor (Rf) .
Therfore, closed loop OP AMP is more controlled than open loop OP AMP

$$\frac{-V_0}{R_f} = \frac{V_1}{R_1} \Rightarrow \boxed{V_0 = -\frac{R_f}{R_1} V_1}$$ → o/p voltage

$$\boxed{A_V = -\frac{R_f}{R_1}}$$ → Gain

O/P is inverted by a phase shift of 180°

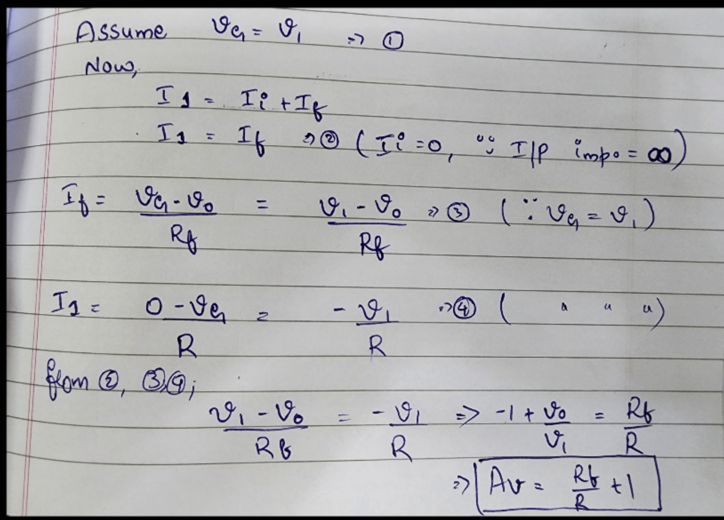
Non-inverted amplifier:-



Follow same procedure for V_o & A_v

$$V_o = \left(\frac{R_f}{R_1} + 1\right) V_1$$ → O/P voltage

$$A_v = \frac{R_f}{R_1} + 1$$ → Gain



Assume $v_G = v_1$ ⇒ ①

Now,

$I_1 = I_i + I_f$

$I_1 = I_f$ ⇒ ② ($I_i = 0$, ∵ I/P impe. = ∞)

$I_f = \frac{v_G - v_0}{R_f} = \frac{v_1 - v_0}{R_f}$ ⇒ ③ (∵ $v_G = v_1$)

$I_1 = \frac{0 - v_G}{R} = \frac{-v_1}{R}$ ⇒ ④ (" " ")

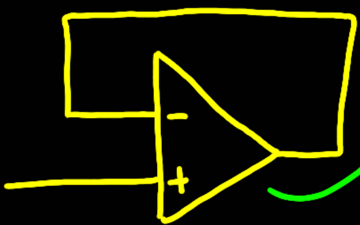
from ②, ③④;

$\frac{v_1 - v_0}{R_f} = \frac{-v_1}{R}$ ⇒ $-1 + \frac{v_0}{v_1} = \frac{R_f}{R}$

⇒ $\boxed{A_v = \frac{R_f}{R} + 1}$

**O/P phase shift is 0/360º

Voltage Follower/Unity Gain Amplifier/Buffer Amplifier:-



Gain = 1

Non-inverting amplifier gain $= \frac{R_f}{R_1} + 1$

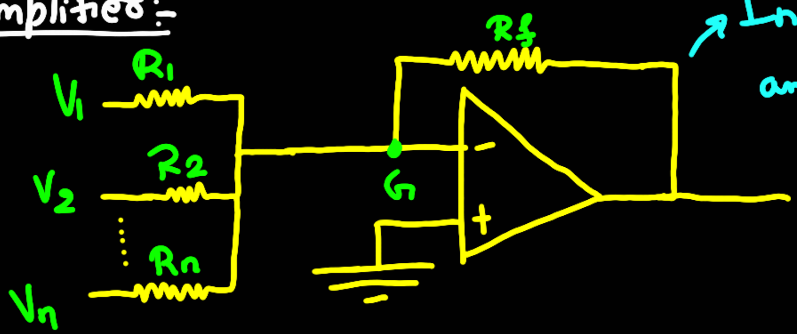
Eliminating R_f ⇒ $A_v = 1$

∴ $V_o = V_i$ → Thus, V_o follows V_i

1. In buffer amplifier the O/P voltage follows I/P voltage, i.e. Vout=Vin
2. Loop gain= 1
3. It's a special case of *Non-inverting (+ve)* amplifier so phase of O/P signal is 0/360º
4. Feedback resistance (Rf) =0
   R1=infinity

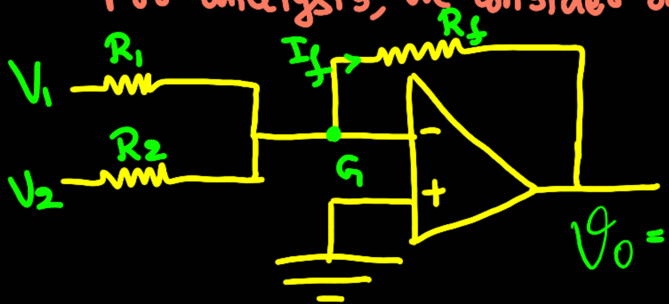
Application:
1. Adds buffer effect to the ckt
2. Used for impedance matching
3. Acts as an Isolator

Summing Amplifiers:-



Inverting amplifiers Configuration

For analysis, we consider only V_1 & V_2



$\vartheta_0 = V_1 + V_2$ To prove this

$$I_1 = \frac{V_1 - V_G}{R_1} = \frac{V_1}{R_1}$$

$$I_2 = \frac{V_2 - V_G}{R_2} = \frac{V_2}{R_2}$$

$$\left(V_G = 0 \right)$$

★ The sum of currents I_1 & I_2 enter node G

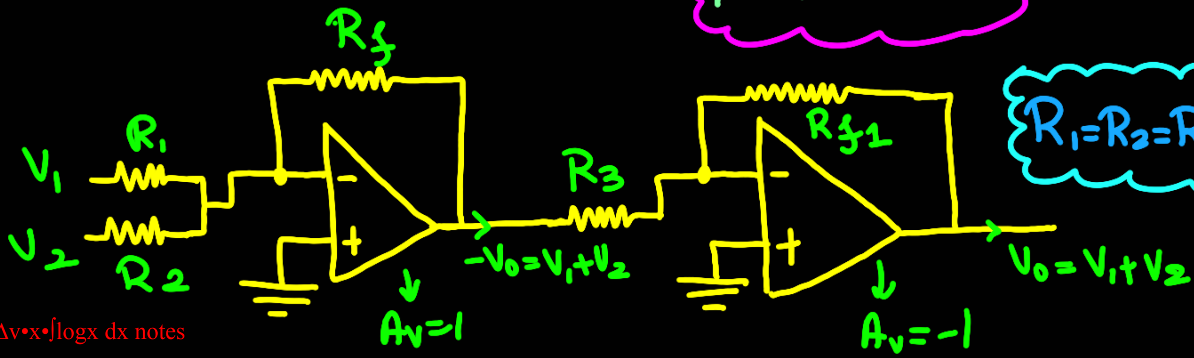
★ Since I_i (current into op-amp) is zero $\Rightarrow I_f = I_1 + I_2$

$$I_f = \frac{V_G - V_0}{R_f} = \frac{-V_0}{R_f}$$

$$\frac{-V_0}{R_f} = \frac{V_1}{R_1} + \frac{V_2}{R_2}$$

Let $R_f = R_1 = R_2 = R$

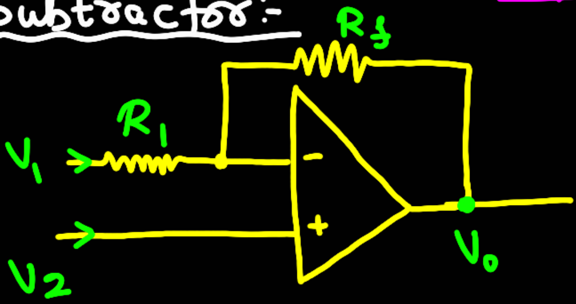
$\Rightarrow -V_0 = V_1 + V_2 \Rightarrow \boxed{|-V_0| = V_1 + V_2}$ Thus, it can be used as adder ckt



$\boxed{R_1 = R_2 = R_f = R_3 = R_{f1}}$

Subtractor:-

To prove:- $V_o = V_2 - V_1$



$$V_{o1} = -\frac{R_f}{R_1}(V_1)$$

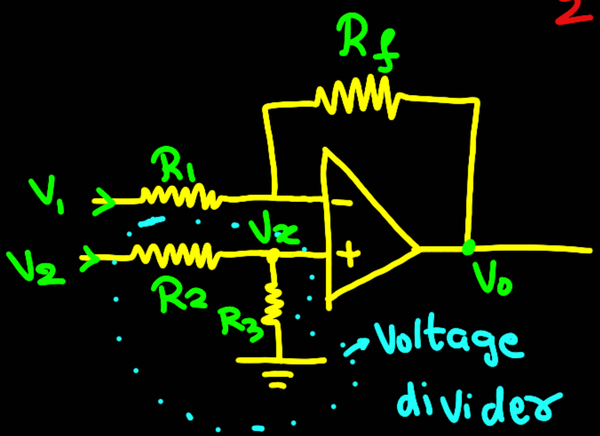
$$V_{o2} = \left(1+\frac{R_f}{R_1}\right)(V_2)$$

Taking $R_f = R_1 = 1$ ⇒ $V_{01} = -V_1$ → We need this

⇒ $V_{02} = 2V_2$ → We don't need this

$\overline{2}$ → Thus we need to divide!

Use a voltage divider



$$\boxed{V_x = \frac{V_2}{2}}$$

Expression for O/P voltage:-

O/P voltage due to V_1 is V_{o1} given by

$$V_{o1} = \frac{-R_f}{R_1} V_1 \rightarrow (1)$$

O/P voltage due to V_2 is V_{o2} given by

$$V_{o2} = \left(1+\frac{R_f}{R_1}\right)V_x \rightarrow (2)$$

$$V_x = R_3\left(\frac{V_2}{R_2+R_3}\right) \rightarrow (3)$$

Thus from (3), (2) now becomes

$$V_x = \left(1+\frac{R_f}{R_1}\right)\left(\frac{R_3V_2}{R_2+R_3}\right)$$

$$V_0 = V_{01} + V_{02}$$

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

Let $R_1 = R_2 = R_3 = R_f = R$

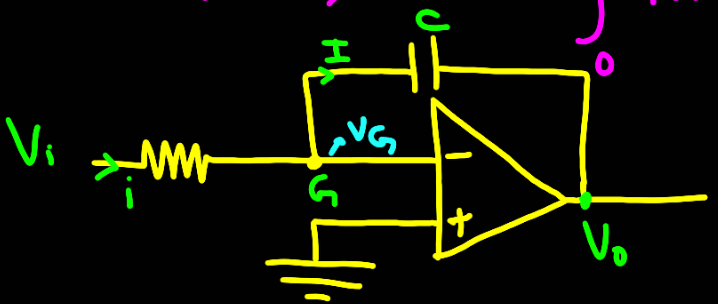
$$V_0 = \frac{-R}{R} V_1 + \left(1 + \frac{R}{R}\right)\left(\frac{R}{R+R}\right) V_2 = -V_1 + V_2$$

$\therefore V_0 = V_2 - V_1$ → Thus it is used as a subtractor

Integrator:-

↳ Op-amp is used for integration

Prove that ⇒ $V_0 \propto \int_0^t V_i \, dt$



Voltage across capacitor C is $V_G - V_0 = \frac{q}{C} \Rightarrow -V_0 = \frac{q}{C}$ ①

WKT ⇒ $q = \int_0^t i \, dt$ → ②

From the ckt $i = \frac{V_i - V_G}{R} = \frac{V_i}{R}$ ③ $(V_G = 0)$

Put ③ & ② in ①

$$-V_0 = \frac{1}{C}\int_0^t i \, dt = \frac{1}{C}\int_0^t \frac{V_i}{R} \, dt$$

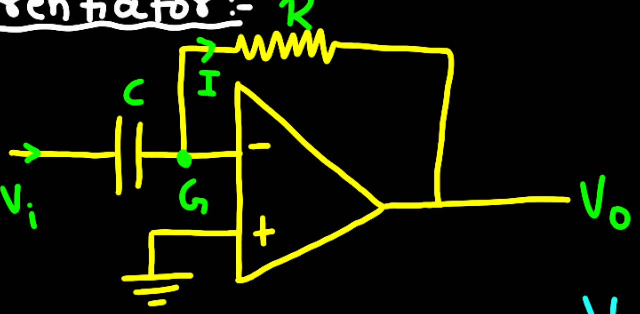
$$V_0 = \frac{-1}{RC}\int_0^t V_i\,dt$$

$$\Rightarrow \boxed{V_0 \propto \int_0^t V_i\,dt}$$

Thus, it can be used as integrator

Differentiator :-

Op-Amp used for differentiation



$$I = \frac{V_G - V_0}{R} = \frac{-V_0}{R} \rightarrow (1)$$

$$V_i - V_G = \frac{q}{C} \Rightarrow q = CV_i \rightarrow (2)$$

$V_G = 0$

Differentiating (2), we get

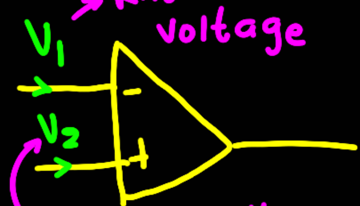
$$\frac{dq}{dt} = C\frac{dV_i}{dt} \Rightarrow \frac{-V_0}{R} = C\frac{dV_i}{dt}$$

$$-V_0 = RC\frac{dV_i}{dt}$$

$$V_0 = -RC\frac{dV_i}{dt} \Rightarrow \boxed{V_0 \propto \frac{dV_i}{dt}}$$

Thus it can be used as differentiator

Comparator :-



★ Compare V_2 with V_1

★ $V_2 < V_1 \Rightarrow$ O/P is −ve

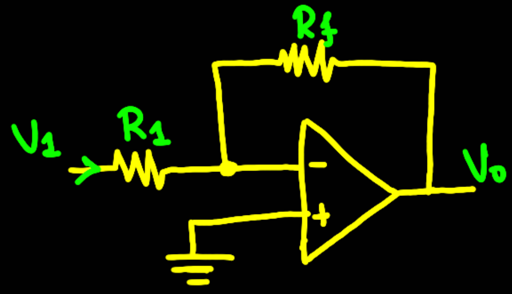
★ $V_2 > V_1 \Rightarrow$ O/P is +ve

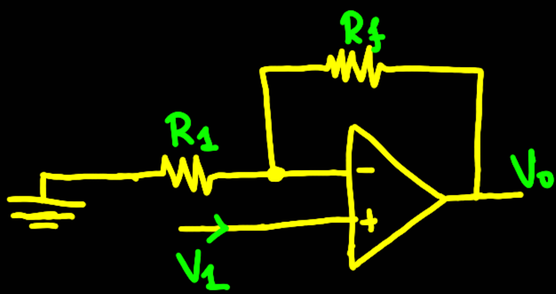
★ $V_2 = V_1 \Rightarrow$ O/P is Zero

Oscillators using OP Amps

★ We do not know how to design amplifiers using BJT yet but we do know how to make one using Op-Amps

Consider the following:-





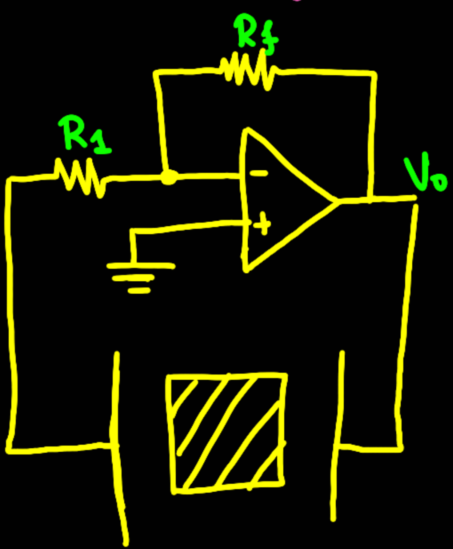
Inverting Amplifier
↓
Amplifier Gain $= -\frac{R_f}{R_1}$

Non-inverting Amplifier
↓
Amplifier Gain $= 1+\frac{R_f}{R_1}$

Example question:- Design Crystal oscillator using Op-Amp

We can use either of the 2 op-Amp amplifiers

Inverting amplifier



WKT, Gain of Crystal $= 1/29 = B$

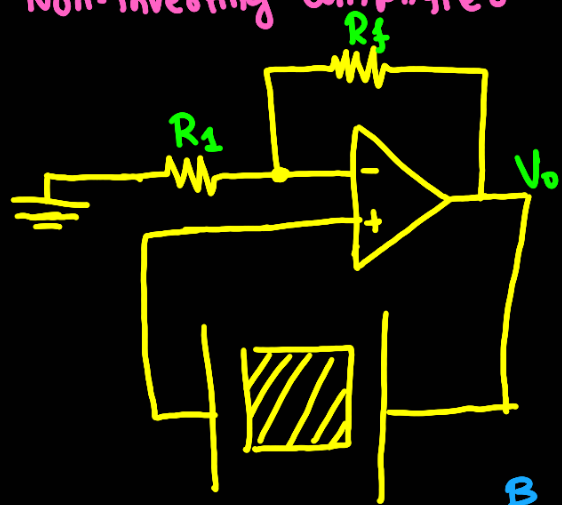
To satisfy Barkhousen Criteria

Amplifier Gain must be 29 $\therefore$ Let $R_f = 29\,k\Omega$

$R_1 = 1\,k\Omega$

$\therefore A = \frac{-R_f}{R_1} = \underbrace{-29}_{-ve}$

Non-inverting amplifier



WKT, Gain of Crystal $= \overset{B}{\overset{\shortparallel}{1/29}}$

To satisfy Barkhousen Criteria

Amplifier Gain must be 29. $R_f = 28\,k\Omega$

$R_1 = 1\,k\Omega$

$\therefore A = 1+\frac{R_f}{R_1} = 1+\frac{28}{1} = 29$ → +ve answer

MORE feasible

Thus we need to have another op-Amp for +ve answer → NOT feasible