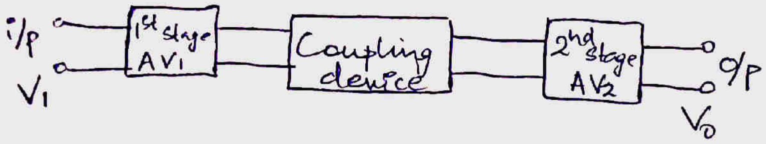
MODULE - 3

MULTISTAGE AMPLIFIERS



$AV_1 \rightarrow$ gain of 1st stage
$AV_2 \rightarrow$ gain of 2nd stage

- In practical applications, situations may occur where single-stage amplifier becomes insufficient, so multistage amplifiers are used.
- Here output of 1st stage is coupled to the input of next stage using a coupling device. (may be capacitor or transformer)
- The process of joining two amplifier stages using a coupling device is known as cascading.
- Overall gain = product of voltage gain of first & second stage.

$$\Rightarrow AV = AV_1 \times AV_2$$

→ Purpose of coupling device :-

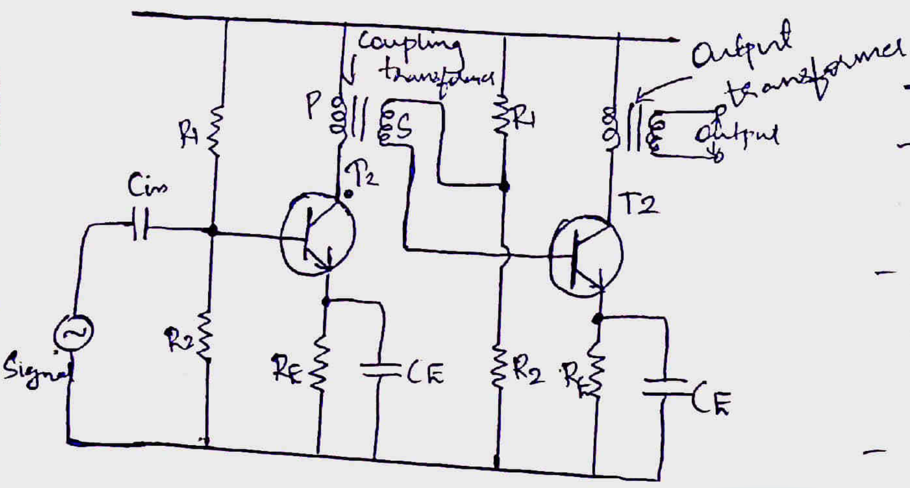
* To transfer the AC from the output of one stage to the input of next stage
* To block the dc to pass from the output of one stage to the input of next stage.

Types of coupling in multistage amplifier :-

- Transformer coupling - here transformer acts as coupling device
- RC coupling - resistors and capacitors used.
- Direct coupling - o/p of 1st directly connected to i/p of 2nd.

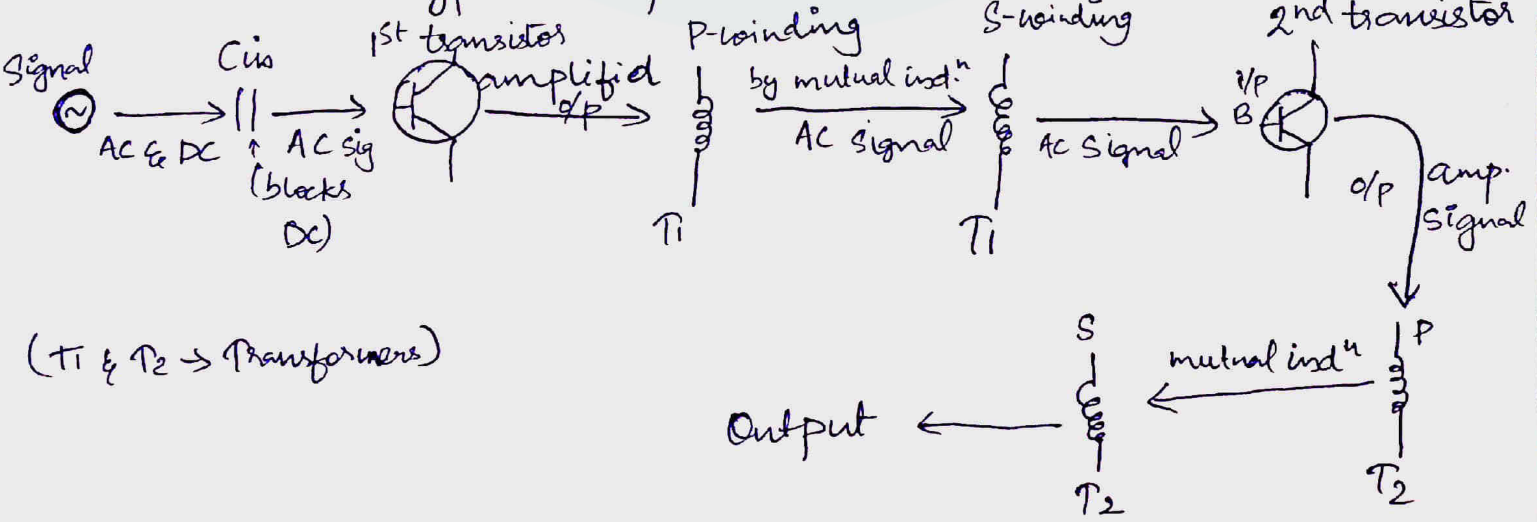
(Coupling - how we connect o/p of 1st to i/p of 2nd stage and so on.)

Transformer coupling Amplifiers



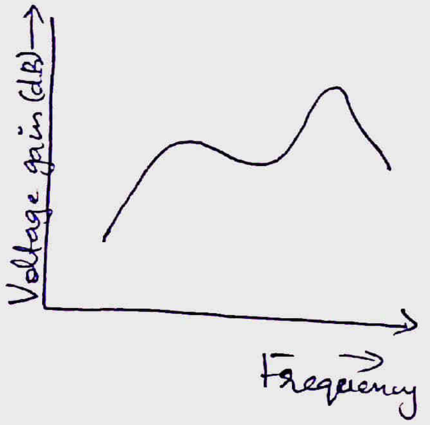
- 2 transistors are there.
- Resistor is not present here at collector side
- No capacitor also - to pass the signal from 1st to 2nd stage of transistors.
- Instead coupling transformer is placed there.

- Near output side also both collector resistor & capacitor is absent & the output is taken through output transformer.
- Transformer allows only ac to pass & blocks dc.
- It contains current carrying coils, 1° winding P & 2° winding S.
- In b/w 2 windings iron core is kept(||), when current passes through 1° coil, due to the changes there current induces in 2° coil by mutual induction.
- Mainly instead of capacitor, transformer is used (both blocks dc) and it brings singnal from 1st to 2nd stage
- R_1 & R_2 → used for biasing purpose
- R_E → for stabilization
- C_E → acts as bypass capacitor



(T1 & T2 → Transformers)

→ Frequency response curve of transformer coupled amplifier :-



- Voltage gain is not constant
- freqs are amplified in different ways.
- this freq. response curve is not good
- if RC coupled, its mid-freq range is constant.

→ Advantages of transformer coupled amplifier :-

- Excellent impedance matching is provided - so max power transfer occurs.
  (transferring power from one stage to next one)
- Since collector resistance is absent, the gain achieved is is higher (∵ there is no voltage drop).
- There will be no power loss in collector and base resistors
- Efficient in operation

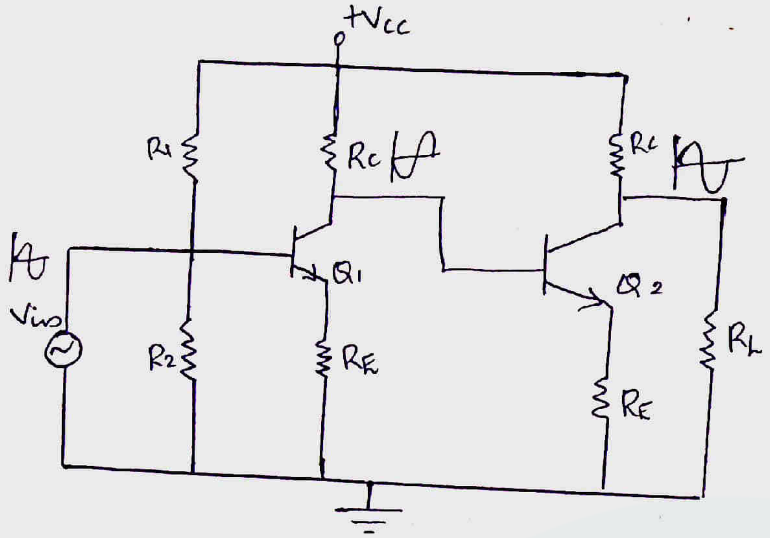
→ Disadvantages :-

- Poor frequency response (not const. voltage gain)
- Freq. distortion is higher
- Transformers tend to produce hum noise.
- Transformers are bulky & costly.

→ Applications :-

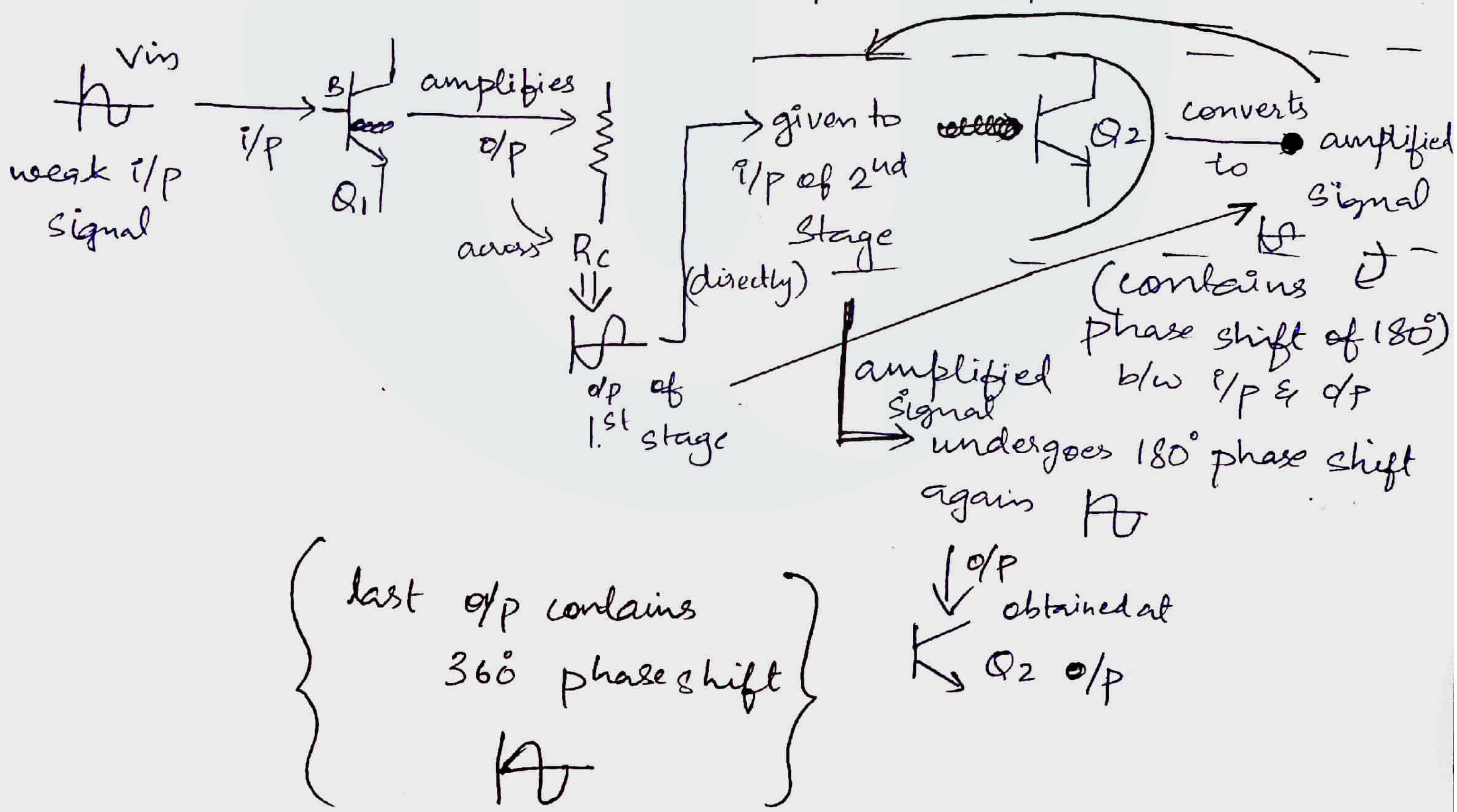
- Mostly used for impedance matching purposes.
- Used for power amplification.
- Used in applications where max. power transfer is needed
(for voltage amplification - RC coupled amplifiers are used)

2. Directly Coupled Amplifier



- capacitors are not at all used
- It is used to amplify low freq. signals.
  $f < 10Hz$
- ind., cap, transformers are not used b/c its electrical size is very larger when used at low freq. range.

- At first stage, voltage divider biasing is used (includes R_1, R_E, R_2)
- VD biasing is necessary to keep the Q point (operating pt) exactly at the centre of load-line so that transistor Q_1 will work as an amplifier.
- Output of 1st stage is directly coupled to i/p of next stage



Applications :

- Headphones, loud speakers.

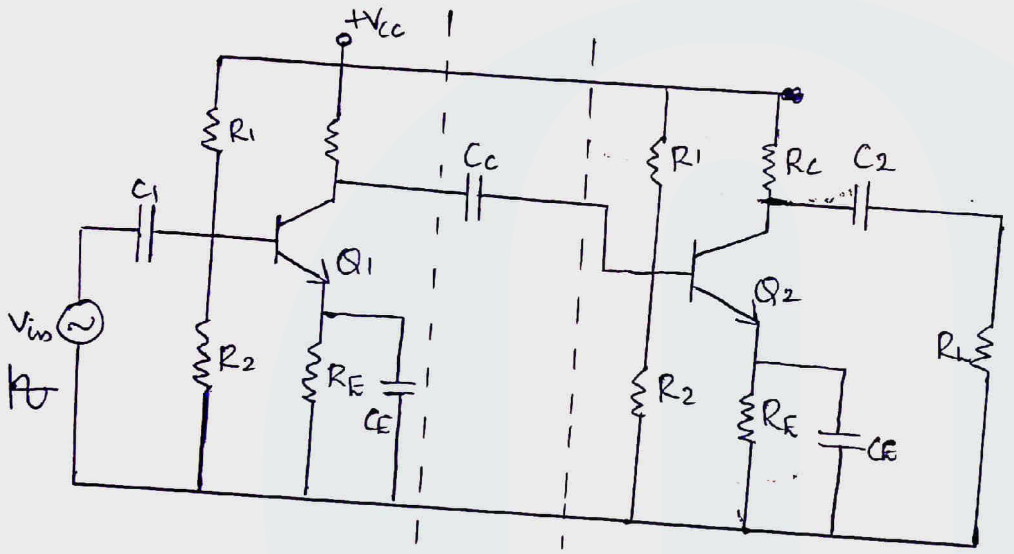
Advantages :-

- Excellent freq. response
- Low cost
- Simple circuit & min resistors are used
- Amplify very low freq. signals (both ac & dc)

Disadvantages :-

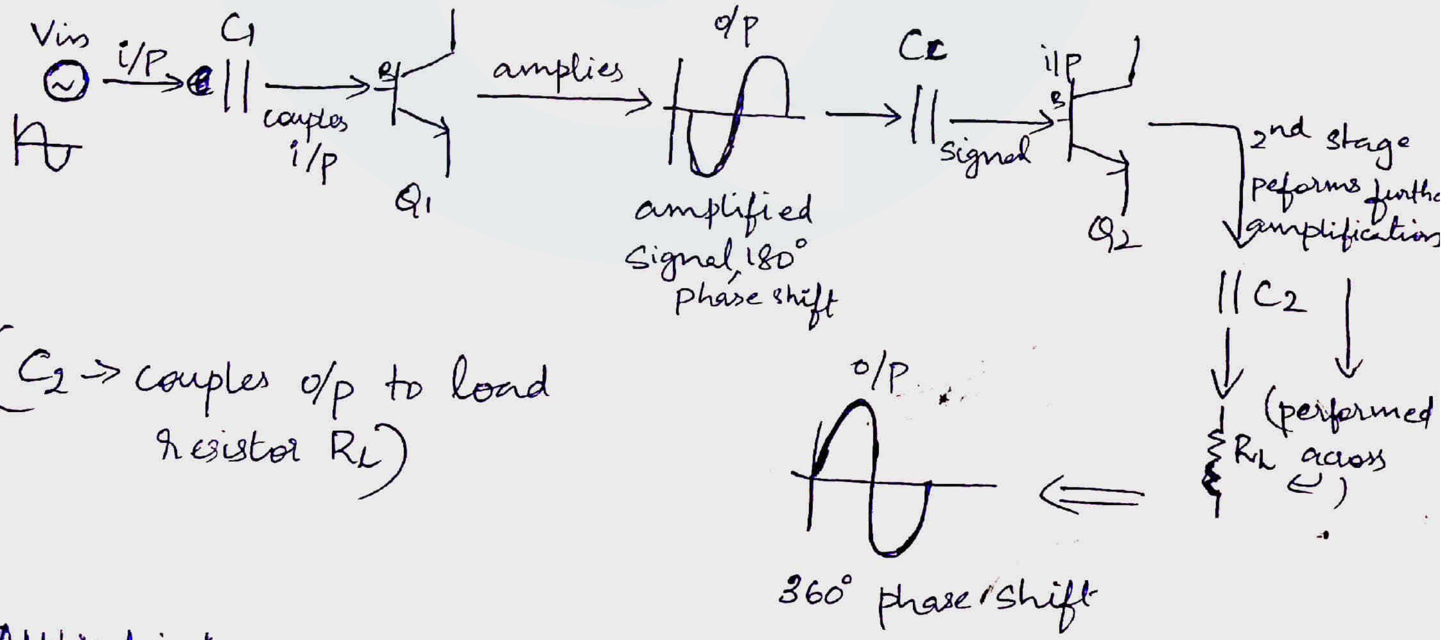
- Not suitable for high freq. signals
- No coupling capacitors (dc from 1st enter 2nd stage) so both ac & dc get coupled
- Output changes with temp.

③ RC Coupled Amplifier



- $R_1, R_2, R_E \rightarrow$ voltage divider biasing
- Q_1 & $Q_2 \rightarrow$ 2 stages
- $C_c \rightarrow$ coupling cap. which couples o/p of 1st to i/p of 2nd

- R_c & C_c present $\rightarrow$ RC Coupled Amplifier



($C_2 \rightarrow$ couples o/p to load resistor R_L)

Application:

- used for voltage amplification

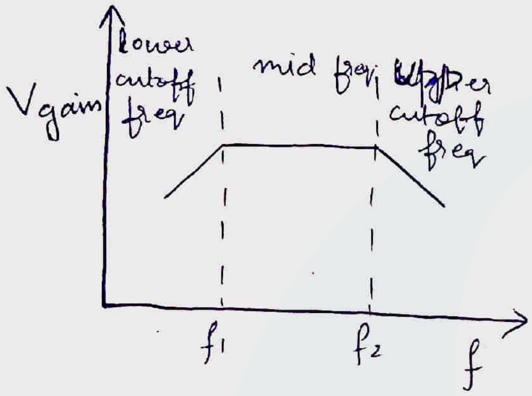
Advantages:

- Simple Network
- Cost effective
- req. less space & weight
- mostly used in audio freq. range

Disadvantages:

- Not used for impedance matching network
- Not having great gain
- Noise is high

→ Frequency response curve of RC coupled amplifier :-



- Voltage gain drops at low freq (<50Hz) and high freq (>20kHz)
- Voltage gain remains const. at mid freq. range

$$X_C = \frac{1}{2\pi f C}$$

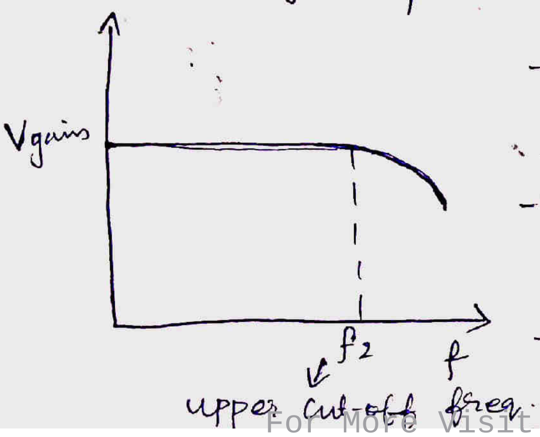
*- If $f \downarrow$, $X_C \uparrow$s so only small part of signal passes from 1st to 2nd stage.

- Emitter bypass capacitor cannot shunt emitter resistor effectively b/c of this large reactance at low freq.
- Thus voltage gain drops

*- If $f \uparrow$, $X_C \downarrow$s, so reactance of coupling capacitor will be very small, so it becomes like a short circuit.

- This low reactance affects the transistor i.e voltage gain drops.

→ Frequency response curve of Direct coupled amplifier :-



- no voltage drop at low freq (b/c coupling or bypass capacitors are absent), so constant
- After f_2, voltage gain reduces due to Inter-electrode cap. & wiring cap. (or stray cap)
- Inter electrode cap. causes undesirable effect on the funⁿ of electrical comp. & circuits.

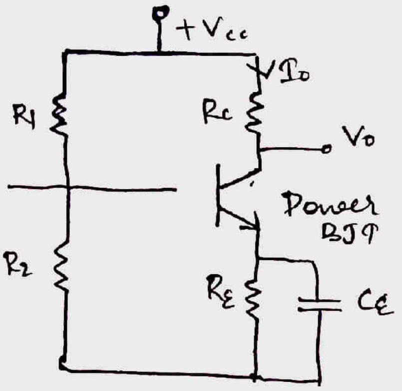
POWER AMPLIFIERS (Large Signal Amplifier)

- used when high power requirements are there
  eg: Audio amplifier, Antenna.
- Some BJT's have certain limitations, so power BJT's can be used ⇒ So power amplifiers are used. (less power dissipation) not wastage
- Parameters include distortion (linear)
- Depending on the rating of current & voltage, power BJT or Power Mosfet can be checked.
- Conventional BJT & JFET has limitations such as:
  * current handling capacity is not more than 0.8A.
  * cannot handle voltage more than 100V.
  * temp. " capacity is upto 150°C only.
- So power amplifiers are used.
- It is also called as large signal amplifier b/c conventional BJT & JFET uses only less current or voltage, so Q pt or operating pt. varies only in a small range of current or voltage. But in power amplifiers large amount is used so large signals are used or considered and there is the analysis of large signal, hence the name large signal amplifier.

→ It can be classified into:-
* Class A power amplifier
* Class B "
* Class AB "
* Class C "

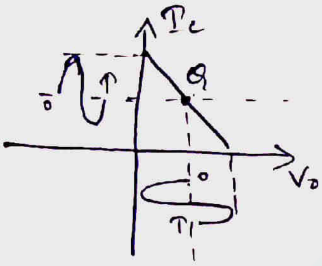
→ Classification is based on:-
- Angle of conduction
- Efficiency
- Position of operating pt
- Distortion
- Application

Class A power amplifier



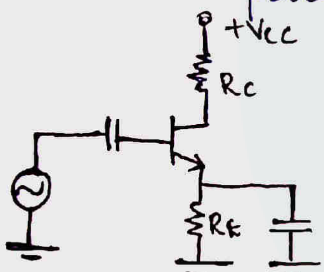
- low distortion
- Q pt. will be always in active regions
- conduction angle is from 0 - 2π (360°) for the signal (no clipping occurs)
- low efficient (25%)
- simple circuit

⇒

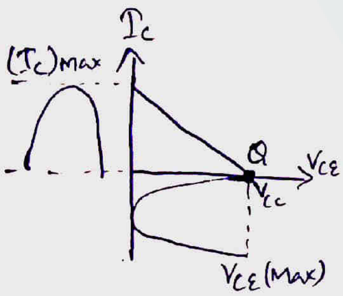


- It is used in 1st step amplification of outdoor communication circuits/systems
- eff. will not exceed 50%.

→ Class B power amplifier

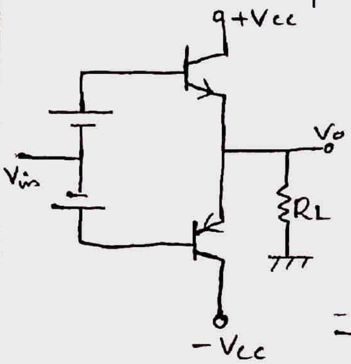


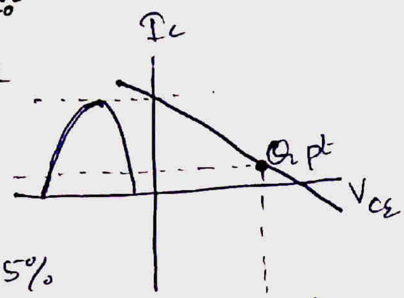
- conduction angle is 0-180°. (for half i/p cycle only)
- efficiency is about 78.5%
- Q pt. will be in cut-off region
- disadvantages of class A is solved here.



- distortions are more when compared to class A
- used in audio amplifiers.

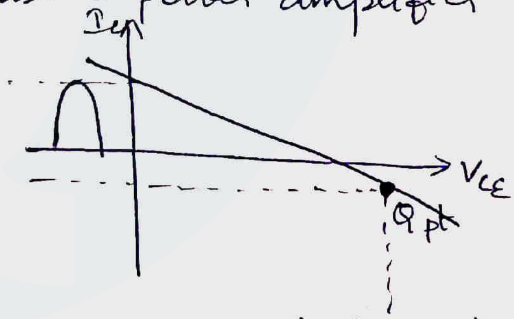
→ Class AB power amplifier





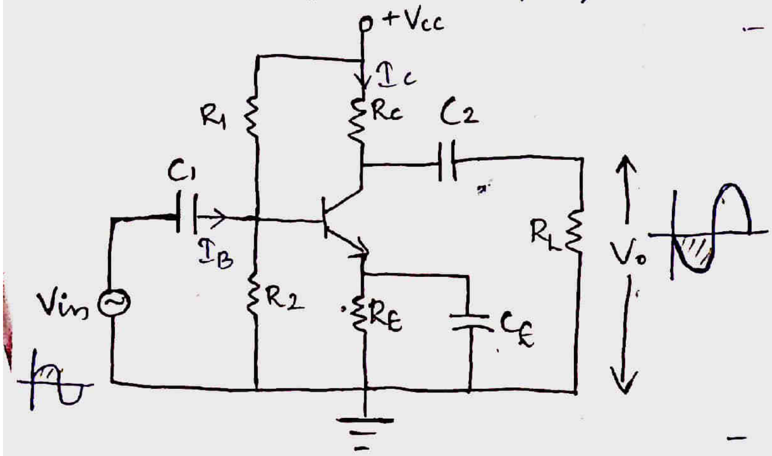
- efficiency 78.5%
- Q pt is near to & just below the active regions
- conduction angle is >180° but < 360°
- distortions are less but a cross over dist. will be present which can be solved by changing in the ckt. i.e Voltage is supplied for both both transistors.
- This amplifier ckt is called complimentary-symmetry power amplifier circuit b/c the transistors used are comp. in nature.
- radio-freq amplifiers uses this

→ Class C power amplifier



- Q pt is placed below the cutoff region
- Conduction angle is very low (≈60°) (<180°)
- efficiency is high, 95%
- maximum distortions
- audio power amplifiers used this class C.
- used in communication systems

Class A power amplifier



- ckt dgm is similar to single stage CE amplifier only diff. is power transistor is used here instead normal transistor and R_L is directly coupled to the transistor i.e directly coupled trans.
- only one transistor is used here in amplifier stage (singled ended)

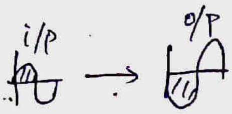
- This amplifier is also called as ~~sing~~ direct coupled - single ended - class A power amplifier.
- $R_1, R_2, R_E \rightarrow$ forms voltage divider biasing ckt
- C_1 & $C_2 \rightarrow$ coupling capacitors $C_1 \rightarrow$ couples i/p to base of trans. $C_2 \rightarrow$ connects o/p to R_L.
- $C_E \rightarrow$ bypass cap.
  - bypasses all emitter current to the ground hence voltage drop across R_E will be less, voltage gain ↑s.
- output current will flow for the entire cycle of i/p signal. & 180° phase shift b/w i/p & o/p signal & amplified o/p is obt.

Working:

- During the +ve half cycle, I_B flows through the base terminal of transistor, Vcc supplies collector current I_C

$$I_C = \beta \cdot I_B \qquad \beta \rightarrow \text{current gain}; \quad \text{as } I_B \uparrow s,\ I_C \uparrow$$

o/p voltage $V_{CE} = V_{CC} - I_C(R_C + R_E)$.



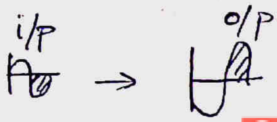
when ~~the~~ I_C ↑s & Vcc remains const $\Rightarrow V_{CE}$ ↓s.

due to V_{CE} ↓, we get a negative half cycle in the o/p

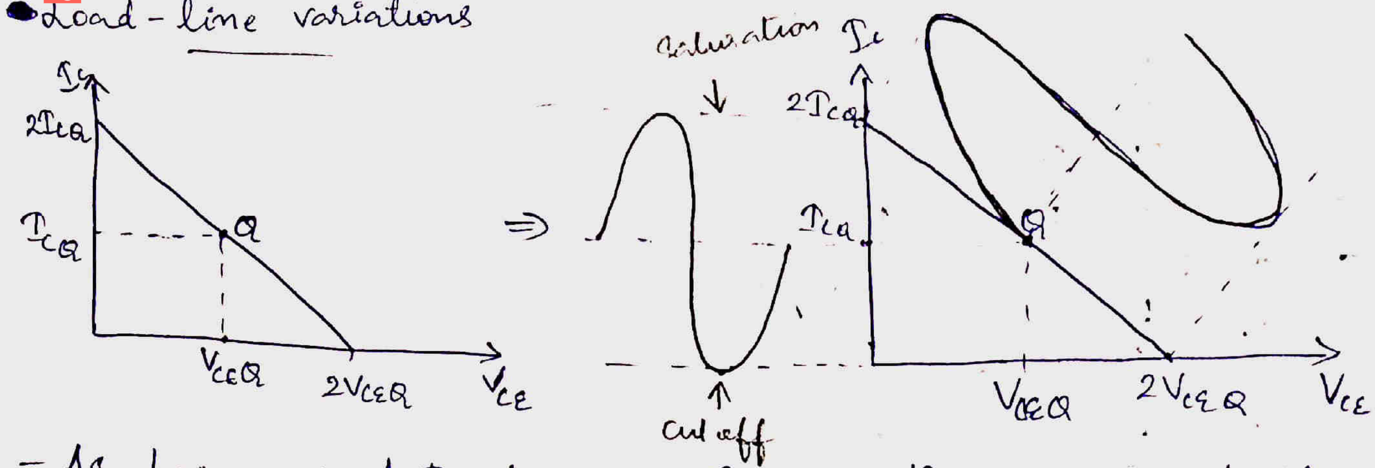
- During -ve half cycle, reverse happens.

I_B ↓s, I_C ↓s $\Rightarrow V_{CE}$ ↑s

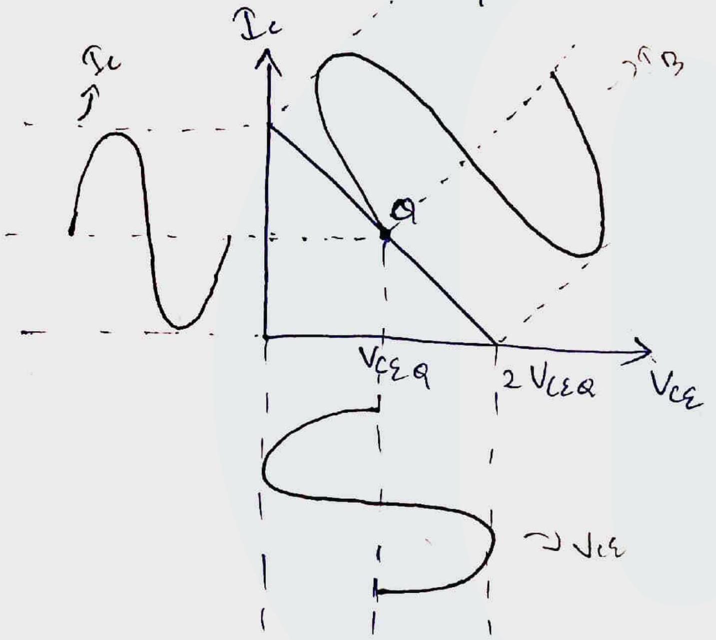
i.e we get a +ve half cycle in the o/p



- Load - line variations

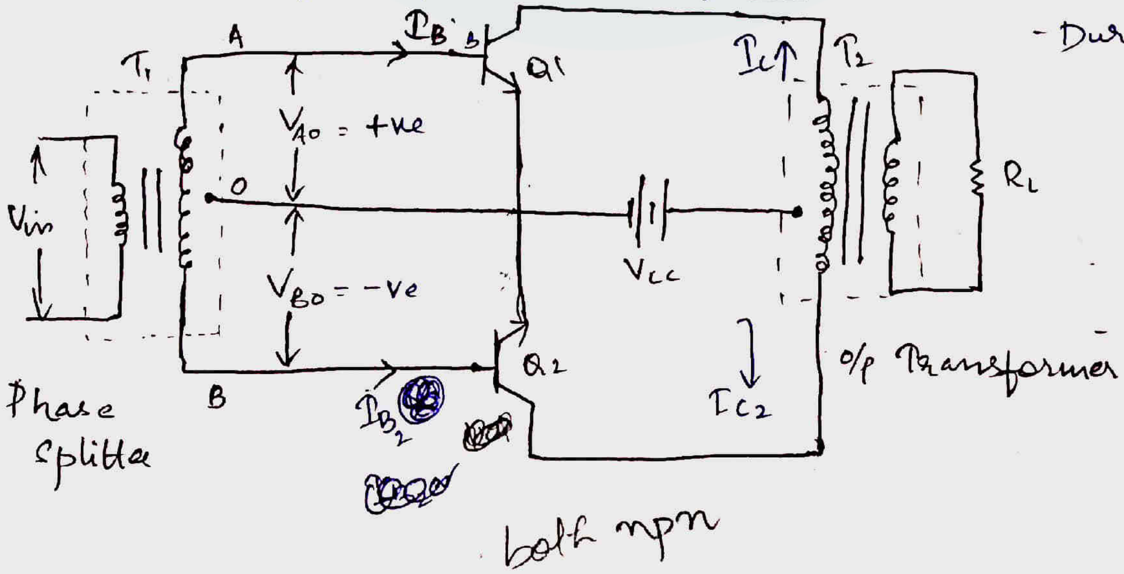


- As base current I_B ↑s from Q pt in the +ve & -ve half cycle, the output current I_c also changes from Q pt I_{CQ} to $2I_{CQ}$ & it attains min pt. at 0.



- Output voltage varies from V_{CEQ} to zero during the half cycle & from V_{EQ} to $2V_{EQ}$ during -ve half cycle.

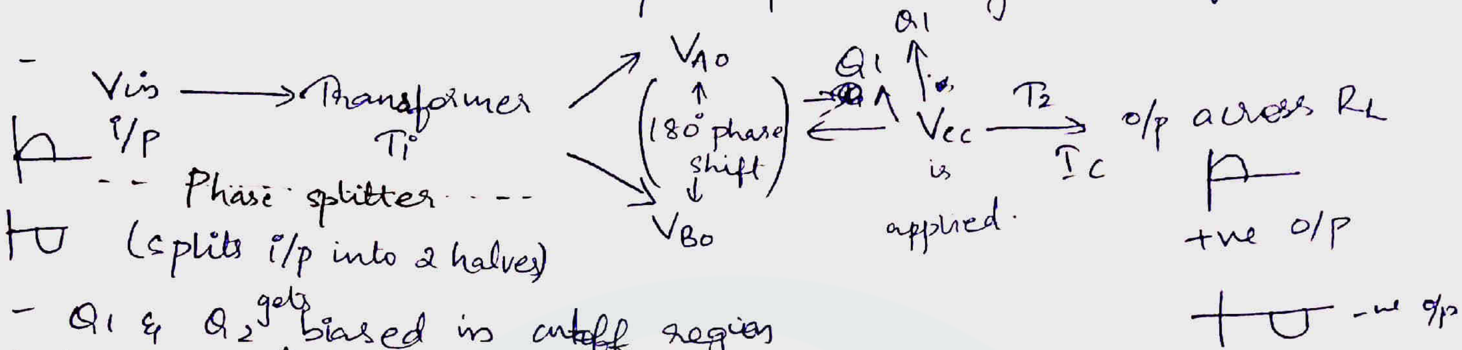
→ Class B push pull power amplifier



- During the half cycle:
  - I_B flows
  - I_{B_2} ✗
  - I_c flows
- -ve half cycle
  - I_B ✗
  - I_B ✓
  - I_{c_2} ✓

Here the transistor biasing & the input signal will flow in such a way that the output current is available only for the half input. (condⁿ angle → 0-180°)

- So 2 transistors are used to get the entire output (full range). and this is called as push pull arrangement of transistors



- Q_1 & Q_2 gets biased in cutoff region

Its Working:

- During +ve half cycle of i/p signal, V_{A0} will be +ve & V_{B0} will be -ve. the voltage is given to base-emitter junⁿ of transistor Q_1, so it undergoes forward biasing. -ve voltage to Q_2, undergoes reverse biasing.
- Since Q_1 is forward biased, it acts as a closed switch & Q_2 reverse biased, acts as open switch.
- So I_B flows through Q_1 & I_{B_2} will not flow through Q_2.
- As I_B flows through Q_1, I_C also flows through it and the 1° winding of transformer is coupled to 2° winding and we will get a positive half (o/p) cycle across R_L.

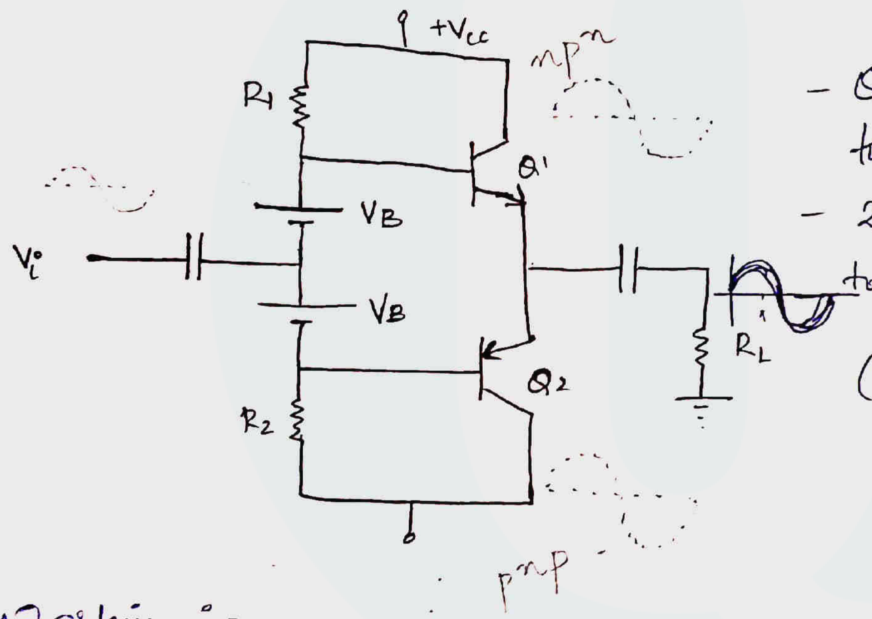
- During -ve half cycle, reverse happens,
  - I_{B_2} flows Q_2 & I_{C2} also flows through it.
- Thus we get -ve half cycle as output across R_L

⇒ During : +ve half cycle	-ve half cycle
Q_1 is on	Q_1 is off
Q_2 is off	Q_2 is on
⇒ +ve o/p	⇒ -ve o/p

 Hence during +ve & -ve half cycle, one transistor is pushed in to conduction & other one to pulled out of it which is referred to as push-pull method and called as push-pull amplifier.

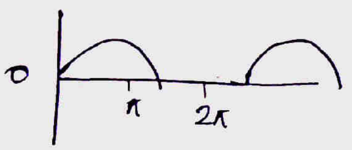
→ Advantages of Class B amplifier:-
- Efficiency = 78.5%
- Eliminates harmonic distortions at o/p
- It has maximum o/p

• Class AB power amplifier



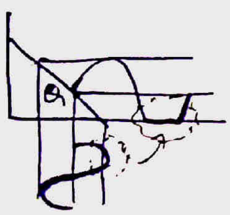
- Q1 & Q2 are complimentary to each other
- 2 VB voltages are used to avoid cross-over dist.
(when one signal is moved from one trans to another one, dist occurs in its o/p wave shape)

Working :-
- During +ve half cycle, Q1 conducts & Q2 is cutoff and in -ve half cycle, Q2 conducts & Q1 cutoff.



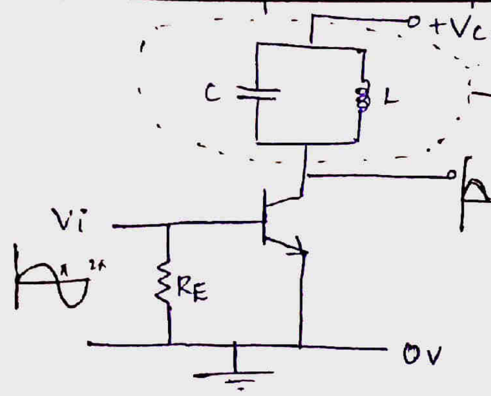
o/p wave form

→ o/p will be > ~~less~~ half cycle (π) but < ~~less~~ full cycle (2π)
→ condn angle > π, < 2π

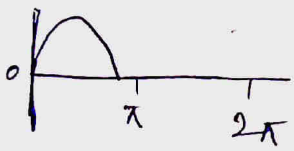


→ Q pt is placed b/w active & cutoff regions
- efficieny 50-60%

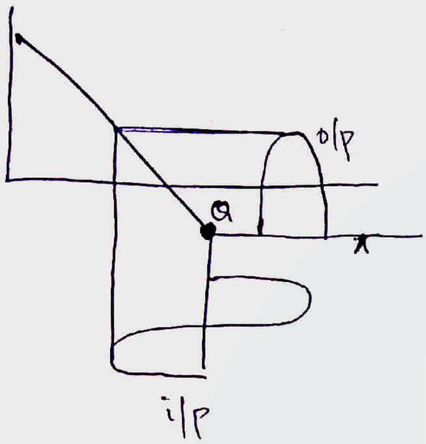
 C power amplifier



- used for high frequency purposed
→ tanked portion (combⁿ of C & L in parallel)
- due to this tanked circuit (class c), it is called as tuned power amplifier



→ o/p less than half cycle



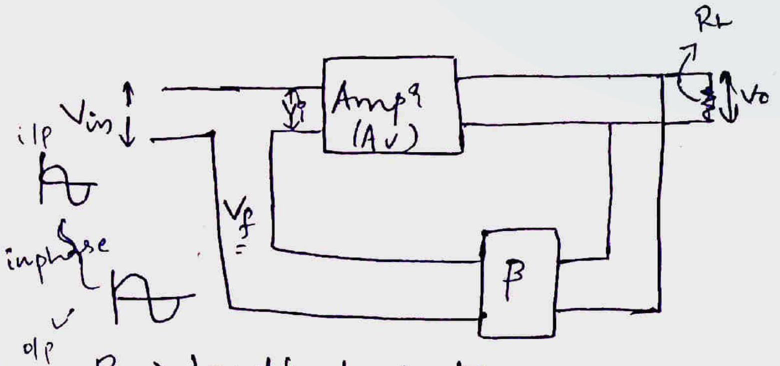
→ Q is below cutoff region
→ ~~disadvantage~~ : ~~dist.~~ condⁿ angle $\angle 120°$ (b/w 60° & 120°)
→ Operated in high freq region
→ used for analog applications (not digital)
→ efficiency > 90%
→ heavy distortion, not suitable for audio amp

→ Feedback :

- process of giving o/p back to i/p signal
- either full o/p or a part of signal is given

Two types -

• Positive feedback



- wave forms of Vin & Vf are in phase

Vf - feedback voltage

β → feedback factor

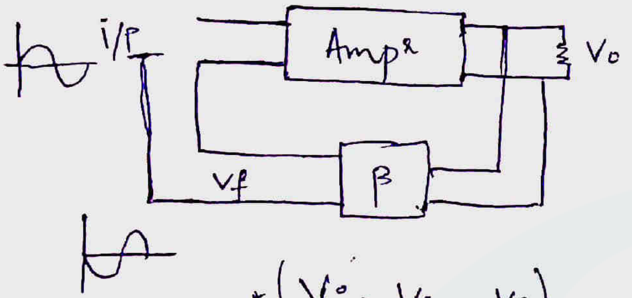
- here a part of o/p voltage which is applied back to i/p ~~during~~
- Both signals i/p signal & part of o/p given to i/p (V_f) gets added since they are in phase.

 V_i will be greater for +ve feedback ($V_{in} + V_f$ w.f) is given to amplifier

→ +ve feedback = regenerative feedbak

$$V_i = V_{in} + V_f$$

- Negative feedback



$*(V_i = V_{in} - V_f)$

- a part of o/p is given to i/p but less b/c both are out of phase i.e o/p & i/p signal are out of phase

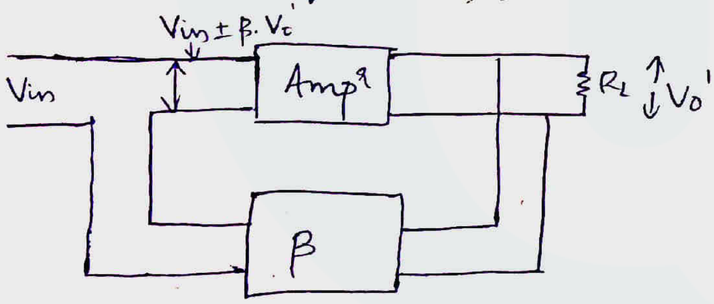
⇒ V_i ↓s since both gets substracted

- -ve feedback = degenerative feedback

→ Gain (without feedback):

$$A_V = \frac{V_o}{V_{in}} = \frac{\text{o/p voltage}}{\text{i/p voltage}}$$

→ Gain (with feedback):



- β - feedback factor
- output voltage with feedback V_o'
- V_i given = $V_{in} \pm \beta . V_o'$

$$\rightarrow A_V = \frac{V_o'}{V_{in} \pm \beta . V_o'}$$

$A_V = \dfrac{V_o'}{V_{in} + \beta . V_o'}$ - +ve fb.

$A_V = \dfrac{V_o'}{V_{in} - \beta V_o'}$ -ve fb.

Gain (for +ve f.b)

$$A_V = \frac{V_o'}{V_{in} + \beta . V_o'}$$

$$\Rightarrow \boxed{A_{Vf} = \frac{A_V}{1 - \beta . A_V}}$$

$\Rightarrow A_{Vf} > A_V$

for -ve f.b

$$\boxed{A_{Vf} = \frac{A_V}{1 + \beta . A_V}}$$

$\Rightarrow A_{Vf} < A_V$

Applications :

- +ve feedback where voltage gain ↑s is used in oscillator ckts.
- -ve " " ↓s " amplifier ckts.

vimp

★ BARKHAUSEN'S CRITERION (applicable for oscillators) (+ve ★ fb is used)

$A_{vf} = \dfrac{A_v}{1-\beta A_v}$ A_{vf} = V. gain with fb

A_v = V gain without fb/ open loop gain

- ★ If βA_v becomes 1,

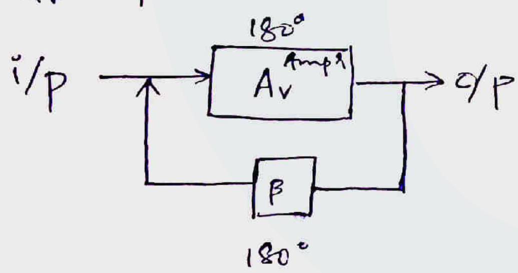
$A_{vf} = \dfrac{A_v}{0} \Rightarrow A_{vf} = \infty$

$A_{vf} = \dfrac{V_o}{V_{in}} \Rightarrow \boxed{V_{in} = 0}$

i.e the oscillators do not require input signal

- ★ So necessary condⁿ for producing oscillations is that input signal should not be given.

① $\beta A_v = 1$

② 

- 1st i/p is given ⇒ 180° phase shifted o/p
- 2nd part of this o/p again phase shifted 180° given as i/p. (feedback signal)
- both i/p & fd signal are in phase

- closed loop gain

$\angle \beta \cdot A_v = 0°$ or $360°$

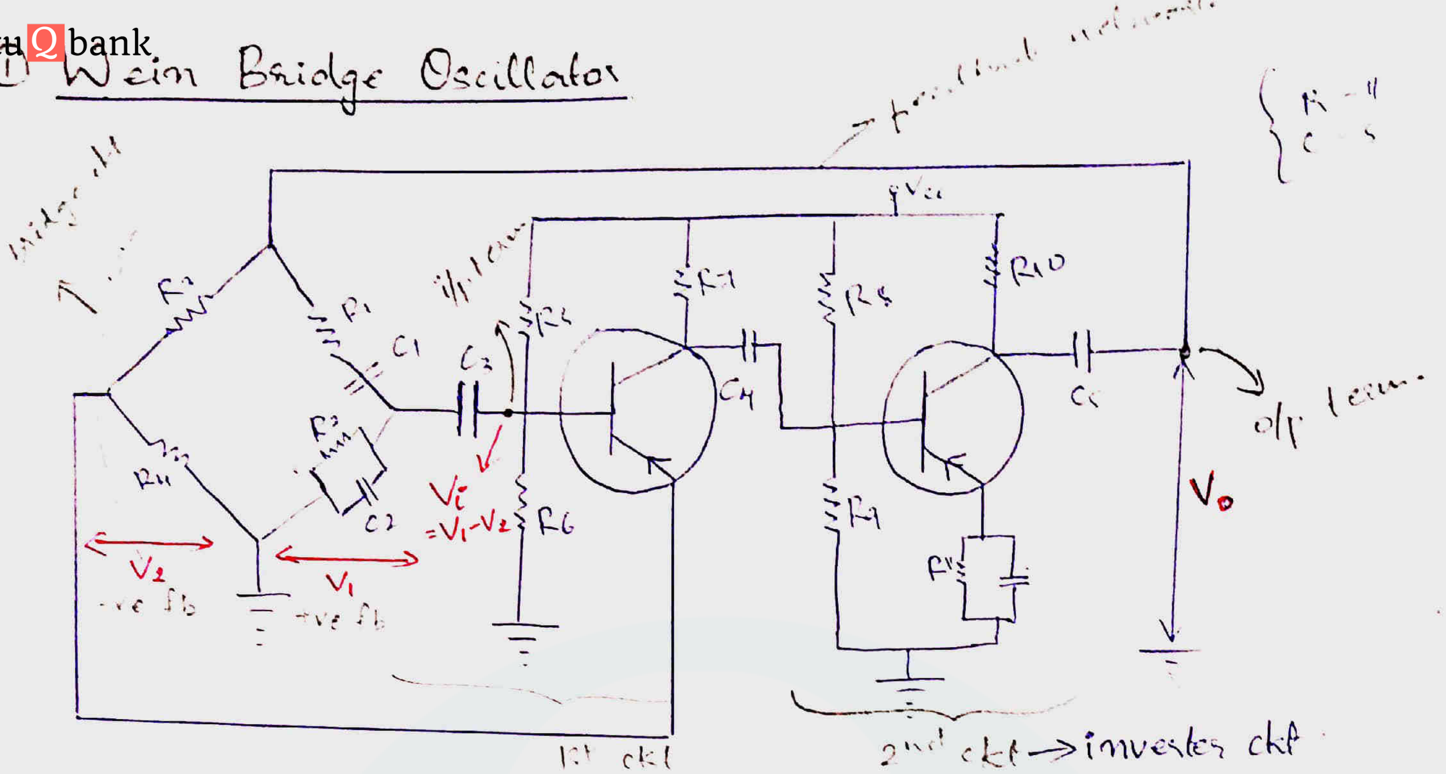
RC Oscillators

- → Wein Bridge Oscillator
- → RC Phase shift Oscillator

LC Tuned Oscillators

- → Hartley oscillator
- → Colpitts "
- → Tuned collector "

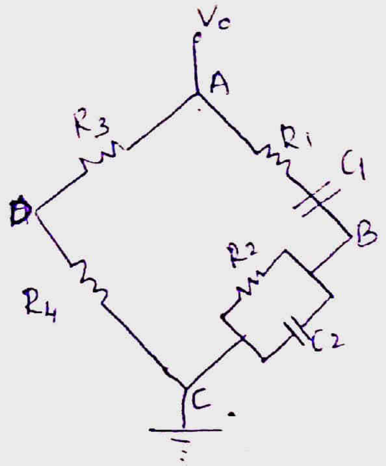
① Wein Bridge Oscillator



- 2 common emitter transistors are present - pnp. & connected in voltage divider biasing arrangement.
- from the o/p of 1st transistor it connected to next transistor by a coupling capacitor C_4
- C_5 – coupling cap., kept at o/p of 2nd transistor, and through this transistor is feedbacked to a bridge ckt
- C_3 – connects bridge ckt to base of 1st transistor
- we must get a phase shift of 360° so 2 transistors are kept (1st one only 180°) and 2nd portion of ckt is called inverter ckt (makes 180° phase shift again as we need 360°)
- 1st ckt acts as a oscillator & an amplifier
- oscillations from oscillators are damped so to make it undamped a feedback network is provided which connects to bridge ckt i.e used for stabilization

- Oscillator → dc to ac converter
- for an amplifier to act as an oscillator it should follow 3 criteria :-
  - +ve fb
  - $A_v \cdot \beta = 1$
  - $\angle \beta \cdot A_v = 360°$ or $0°$

Mathematical Analysis for Wein Bridge Oscillator :-



For Balanced bridge,

$$\frac{R_3}{R_4} = \frac{R_{AB}}{R_{BC}}$$

$$\frac{R_3}{R_4} = \frac{R_1 + X_{C_1}}{\frac{R_2 X_{C_2}}{R_2 + X_{C_2}}} = \frac{\left[R_1 + \frac{1}{i\omega C_1}\right]}{\frac{\left[R_2 \times \frac{1}{i\omega C_2}\right]}{\left[R_2 + \frac{1}{i\omega C_2}\right]}}$$

Suppose $R_1 = R_2 = R$

$C_1 = C_2 = C$

$$\Rightarrow \frac{R_3}{R_4} = \frac{\left[R + \frac{1}{i\omega C}\right]\left[R + \frac{1}{i\omega C}\right]}{\left[\frac{R}{i\omega C}\right]}$$

$$\Rightarrow \frac{R_3}{R_4} = \frac{i\omega C}{R}\left[R^2 + \frac{1}{i^2\omega^2 C^2} + \frac{2R}{i\omega C}\right]$$

$$\frac{R_3}{R_4} = \frac{i\omega C}{R}\left[R^2 - \frac{1}{\omega^2 C^2}\right] + 2$$

Compare real parts on both sides,

$$\Rightarrow \frac{R_3}{R_4} = 2 \quad \Rightarrow R_3 = 2R_4 \quad -(1)$$

Compare img parts,

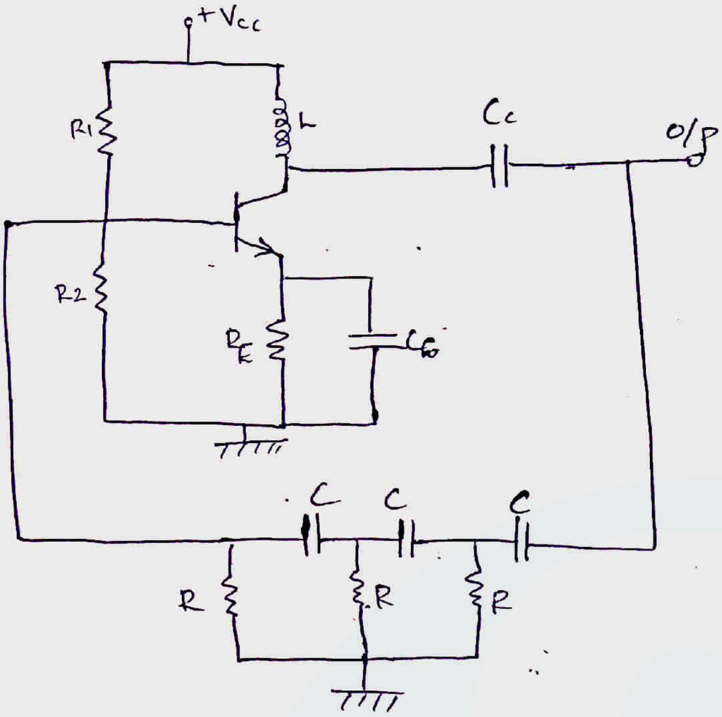
$$0 = \frac{\omega C}{R}\left[R^2 - \frac{1}{\omega^2 C^2}\right]$$

$$R^2 - \frac{1}{\omega^2 C^2} = 0 \rightarrow R = \frac{1}{\omega C} \quad \Rightarrow \omega = \frac{1}{RC}$$

also $\omega = 2\pi f \Rightarrow 2\pi f = \frac{1}{RC}$

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

② RC Phase Shift Oscillator



- Also called as RC sinusoidal oscillator. (prod. sine waves)
- used for producing audio-freq. signals (20Hz - 20kHz)
- (for high freq. LC osc used)
- upper part → CE amplifier
- lower " → RC components (3)
- Resonance freq,

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

- we know $A_V\beta = 1$

also gain $A_V = 29$

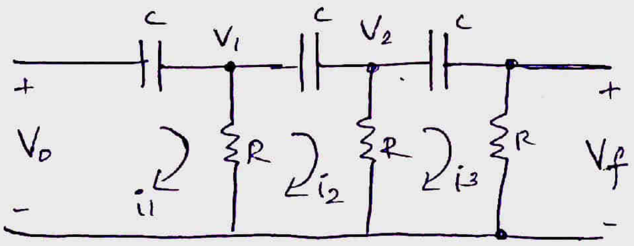
$$\Rightarrow \boxed{\beta = \frac{1}{29}}$$

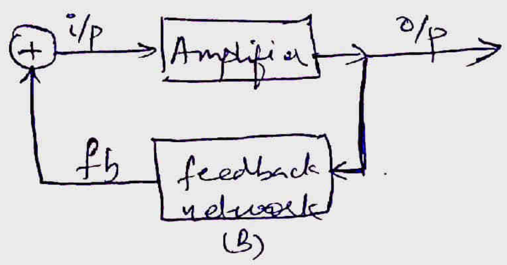
Working :-

- each RC produces 60° phase shift, total 180°
- CE amplifier also prod. 180°

} 360° ~~phase sh~~
⇓
condⁿ for <u>tue</u> fb
⇓
oscillator

Frequency of RC phase shift oscillator :-

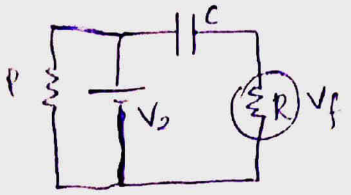




$$V_f = i_3 \cdot R$$

$$\Rightarrow i_3 = \frac{V_f}{R}$$

① At Node 2, apply KVL,



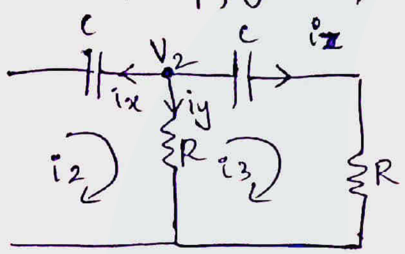
$$\Rightarrow V_2 = V_c + V_f$$

$$V_2 = V_f + I_3 \times X_c$$

$$V_2 = V_f + \frac{I_3}{j\omega c} = V_f + \frac{V_f}{j\omega RC}$$

$$\left\{ V_2 = V_f\left(1 + \frac{1}{j\omega RC}\right) \right\} - ①$$

② At Node 2, apply KCL,



$$i_x + i_y + i_z = 0 \qquad i_x = -i_2$$

$$-i_2 + i_y + i_3 = 0 \qquad i_z = i_3$$

$$i_2 = i_y + i_3$$

$$i_2 = \frac{V_2}{R} + \frac{V_f}{R}$$

Sub ① here,

$$i_2 = \frac{V_f}{R}\left(1 + \frac{1}{j\omega RC}\right) + \frac{V_f}{R}$$

$$\left\{ i_2 = \frac{V_f}{R}\left(2 + \frac{1}{j\omega RC}\right) \right\} - ②$$

③ At Node 1, apply KVL

$$V_1 = V_c + V_2 \qquad V_c = i_2 \cdot X_c$$

$$V_c = i_2 \times \frac{1}{j\omega c}$$

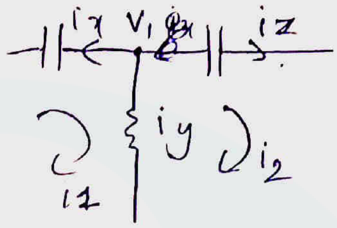
$$V_1 = V_2 + \frac{i_2}{j\omega c}$$

Sub. ② ,① here,

$$\Rightarrow V_1 = V_f\left(1 + \frac{1}{j\omega RC}\right) + \frac{1}{j\omega c}\left(\frac{V_f}{R}\left(2 + \frac{1}{j\omega RC}\right)\right)$$

$$\left\{ V_1 = \frac{V_f}{j\omega RC}\left(3 + j\omega RC + \frac{1}{j\omega RC}\right) \right\} - ③$$

④ Apply KCL at node 1,



$$i_x + i_y + i_z = 0$$

$$i_x = -i_1 \qquad i_z = i_2$$

$$\Rightarrow i_1 = i_y + i_2$$

$$i_1 = \frac{V_1}{R} + i_2$$

Subs. ② and ③ here,

$$i_1 = \frac{\frac{V_f}{j\omega RC}\left(3 + j\omega RC + \frac{1}{j\omega RC}\right)}{R} + \frac{V_f}{R}\left(2 + \frac{1}{j\omega RC}\right)$$

$$\Rightarrow i_1 = \frac{V_f}{R}\left(\frac{3}{j\omega RC} + 1 + \frac{1}{j^2\omega^2 R^2 C^2} + 2 + \frac{1}{j\omega RC}\right)$$

$$\left\{ i_1 = \frac{V_f}{R}\left[3 + \frac{4}{j\omega RC} - \frac{1}{\omega^2 R^2 C^2}\right] \right\} - ④$$

⑤ At node V_0:

$$V_0 = V_c + V_1 \qquad V_c = i_1 \times X_c$$

$$V_0 = \frac{i_1}{j\omega c} + V_1 \qquad V_c = i_1 \times \frac{1}{j\omega c}$$

Sub ③ & ④

$$V_0 = \frac{V_f}{j\omega RC}\left[3 + \frac{4}{j\omega RC} - \frac{1}{\omega^2 R^2 C^2}\right] + \frac{V_f}{j\omega RC}\left(3 + j\omega RC + \frac{1}{j\omega RC}\right)$$

$$V_o = \frac{V_f}{j\omega RC}\left(6 + j\omega RC + \frac{5}{j\omega RC} - \frac{1}{\omega^2 R^2 C^2}\right)$$

$$\Rightarrow \frac{V_f}{V_o} = j\omega RC \times \left(\frac{1}{6 + j\omega RC + \frac{5}{j\omega RC} - \frac{1}{\omega^2 R^2 C^2}}\right) = \frac{j\omega RC}{j\omega RC}\left(\frac{1}{\frac{6}{j\omega RC} + 1 + \frac{5}{j^2\omega^2R^2C^2} - \frac{1}{j^3\omega^3R^3C^3}}\right)$$

β

equating imag. parts,

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

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

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

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

→ LC Tuned Oscillator :

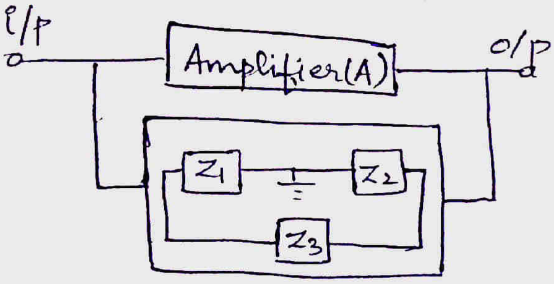
- oscillator connected with inductor & ~~collector~~ capacitor
- if L & C are connected //el, it is called as tank circuit.
- used for high freq applications (> 500mega Hz)
- It is of 3 types:-

① Tuned collector oscillator

- If the tank circuit (L & C are //el) is connected to collector side of voltage divider bias ckt, then it is called as a tuned collector oscillator

② Hartley oscillator

- If in the feedback network, considering 3 components, Z_1 & Z_2 are inductors & Z_3 is a capacitor, then it is a Hartley oscillator



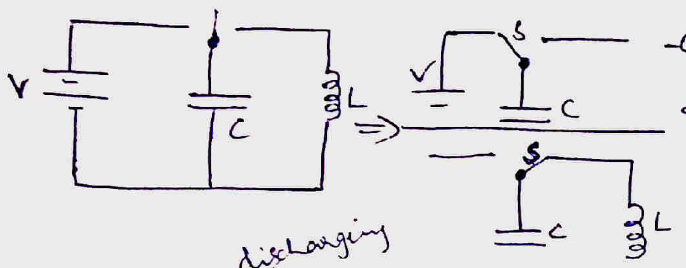
feedback network

③ Colpitts oscillator

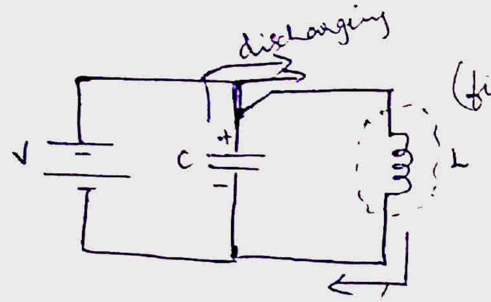
- if Z_1 & Z_2 are capacitors & Z_3 is an inductor, then Colpitts

Tank Circuit

working principle

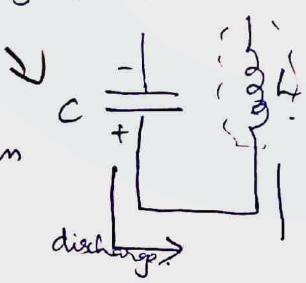


- during this posn the capacitor gets fully charged

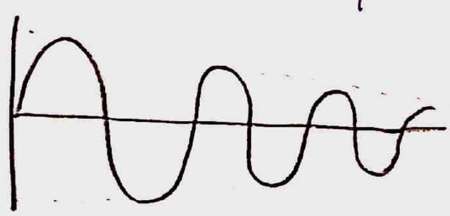


- presently cap. is full charged but when a potential diff. arises b/w two 2 plates of capacitor, charge will be stored in the form of an electrostatic field. But now when S is connected to L side, capacitor starts discharging to inductor. So when current passes through inductor, charge is stored as a magnetic field - also voltage of capacitor ↓s, current through inductor ↑s, magnetic field strength ↑s. Now when cap. gets fully discharged, maximum current flows through inductor, so no current from capacitor. Again then current of inductor reduces, mag. field ↓s, variations can be observed in inductor i.e a collapse happens in emf of magnetic field. The emf generated due to collapse is called back emf.

- Now the back emf which is formed in the inductor, starts flowing towards capacitor, this current flow again starts charging capacitor
- Thus capacitor again attains max. charged condition.
- The mag. field in inductor when current reaches capacitor changes to electrostatic field.
- Now when max, capacitor again starts discharging ~~(& goes on)~~ but in opposite dirn.
- Inductor gets a magnetic field again
- This goes on....



- We get an ~~ideal~~ output wave form as: (here)

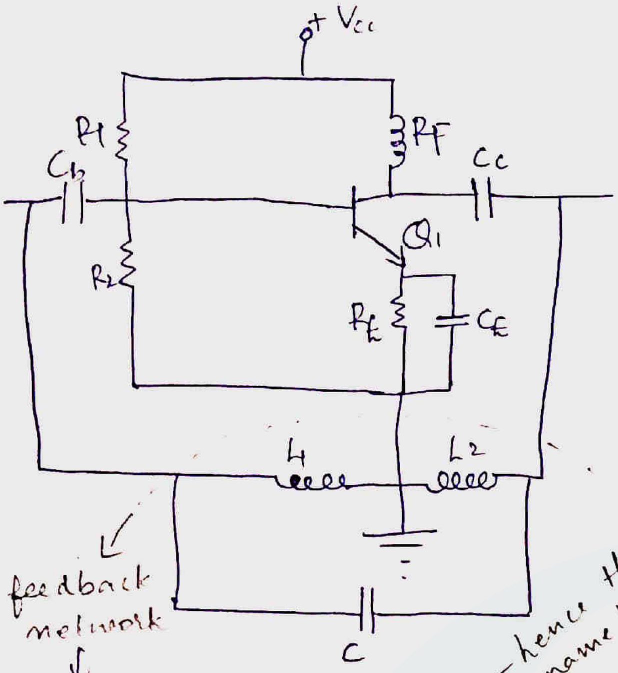


if an ideal inductor & capacitor was used, we get a perfect sine wave as output waveform

- Not perfect sine wave due to losses in L & C and thus after each cycle, the amplitude of the oscillations starts decreasing - we get damped oscillations

Ktu Q bank

Hartley Oscillator



- used in radio recievers.
- $R_F \to$ Radio freq. coil, used to give the V_{cc} (that we apply) to collector side smoothly.
- $C_b \to$ coupling cap at base } allows ac
- $C_C \to$ " collector } blocks dc
- $R_E \to$ used for thermal stability
- $C_E \to$ bypass capacitor, it prevents the bypassing through R_E which results in large voltage drop across it & affects the oscillations (variations) of the o/p.

- (L_1 & L_2 in series) //el with C. — hence the name Hartley
- Autotransformers can be used in case of inductors.

Working :-

- when supply is given, capacitor C starts charging.
- when it gets fully charged, it starts discharging the charge stored in the form of electrostatic field to inductor L_2 where charge is stored in the form of magnetic field.
- Now when C is fully discharged, there will be no current flow to L_2 which ↓s current value in L_2 ⇒ ↓s magnetic field strength ⇒ results in a collapse of mag. field. This variation induces an emf i.e back emf.
- This back emf again starts charging capacitor, mag. field in L_2 gets converted to electrostatic field again ⇒ oscillations are produced across L_2. These oscillations & our o/p are in phase.
- These osc. from L_2 is transferred to L_1 but undergoes a phase shift of 180° (due to the earthing provided b/w L_1 & L_2)
- This is given to the transistor where a phase shift of 180° again happens. (total 360° phase shift)
  i.e cond^n for an amplifier to work as an oscillator is satisfied in o/p
  ⇒ Thus oscillations are induced

$$f = \frac{1}{2\pi\sqrt{L_T C}}$$

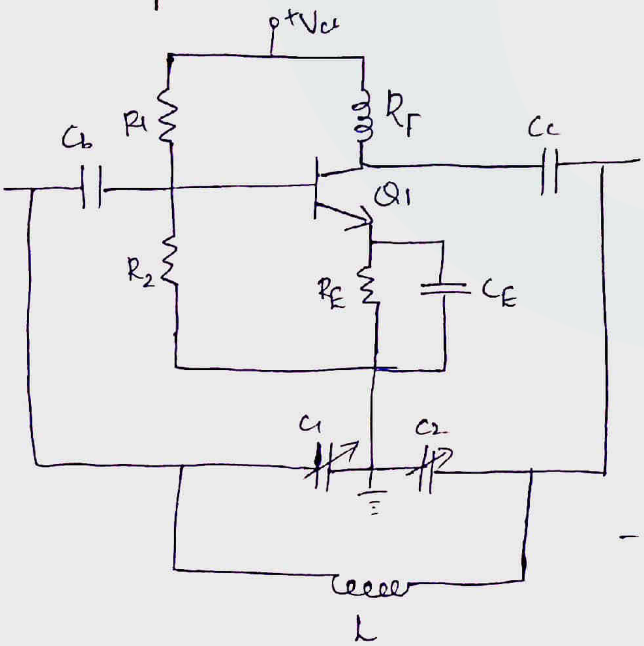
$$L_T = L_1 + L_2 + 2M$$

Applications:-
- used to produce a sinewave of desired freq.
- mostly used as a local oscillator in radio receivers
- used as R.F Oscillator.

Advantages:-
- Instead of using large transformer, a single coil can be used as an auto-transformer.
- Freq. can be varied by employing either a variable capacitor or a variable inductor.
- Less number of components are sufficient.
- The amplitude of o/p remains constant over a fixed freq. range.

Disadvantages:-
- It cannot be a low freq. oscillator
- Harmonic distortions are present.

② Colpitts Oscillator



- diff. from Hartley oscillator is that C_1 & C_2 are placed here instead of inductors & L inplace of C.
- Colpitts oscillator removes or clears the 2 disadvantages of Hartley

Working:

- when supply is given, C_1 & C_2 gets charged ⇒ when fully charged ⇒ gets discharged to inductor ⇒ gets stored in the form of mag field ⇒ when mag field reaches max. ⇒ its strength starts ↓s ⇒ collapse ⇒ emf generated (back emf) ⇒ earthing + transistor 180° 180° ⇒ phaseshift ⇒ works as an oscillator

$$\frac{1}{2\pi\sqrt{LC_T}} \qquad C_T = \frac{1}{C_1} + \frac{1}{C_2}$$

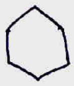
Advantages:-

- generate sinusoidal signals of very high freq.
- withstand high & low temp.
- frequency stability is high
- freq. can be varied by using both variable capacitors
- Less no. of components are sufficient
- Amplitude of o/p remains const. over a fixed freq. range.

Applications:-

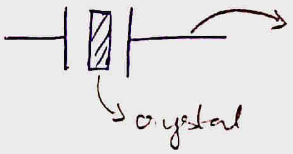
- can be used as High freq. sinewave generator
- " temp. sensor with some associated circuitry
- used as local oscillator in radio receivers.
- " R.F. oscillator
- used in mobile applications.

→ Crystal Oscillator

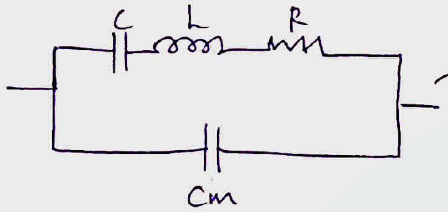
- when Hartley & Colpitts oscillators are used for a long time, its freq. stability of oscillator gets affected & results in some variations (power supply var./load var./temp var.), so inorder to avoid this crystal oscillator is used.
- crystal - hexagonal in shape 
- ~~It has~~ It has a property called piezoelectric property - if a mechanical stress is given to any one side/phase, a potential diff is developed across its opposite side
- If crystal is used as an oscillator, inverse piezoelectric effect is ~~caused~~ produced.

inverse piezoelectric effect : If we apply a potential diff, mechanical stress is developed on the opposite side which produces vibrations ⇒ changes into oscillations

- Crystals are Rochelle salt, Tourmaline, Quartz (mostly used)
  - naturally available
  - inexpensive
  - mech. strength



→ metallic plate } similar to capacitor



→ equivalent ckt. of crystal

value of C & R ↓, L ↑

- when ac voltage is applied across crystal, it starts vibrating i.e at supply freq. that we apply, oscillator vibrates.
- If supply freq = natural freq. of crystal or if they matches ⇒ it reaches its resonante condition i.e max. vibration is obtained in the crystal ⇒ oscillations are produced.

- Two condn → - crystal vibrates – series resonant freq f_s (impd. ↓, fb ↑) (Series RLC ckt)
  - do not vibrate – //el resonant freq condn, f_p (impedence ↑, feedback ↓)

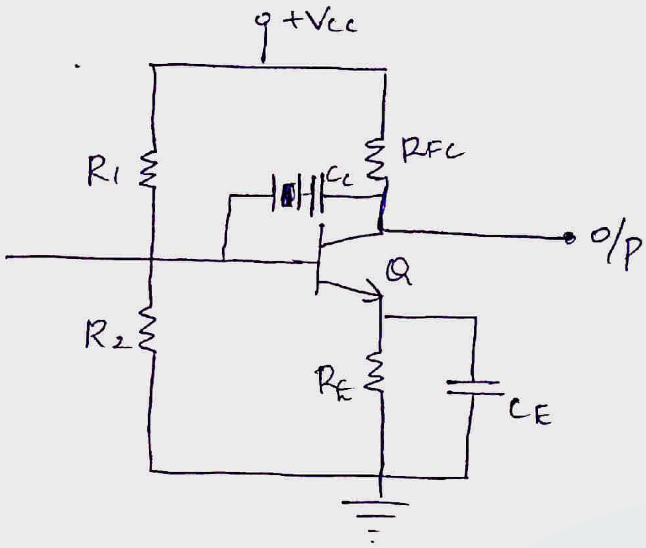
$$\left\{ f_p = \frac{1}{2\pi\sqrt{L\left(\frac{C_m \cdot C}{C_m + C}\right)}} \right\}, \left\{ f_s = \frac{1}{2\pi\sqrt{LC}} \right\}$$

- when crystall is used as an oscillator, it is used in both low impd. & high impd. mode

low impd. ↓ Series res.

high impd. ↓ //el res.

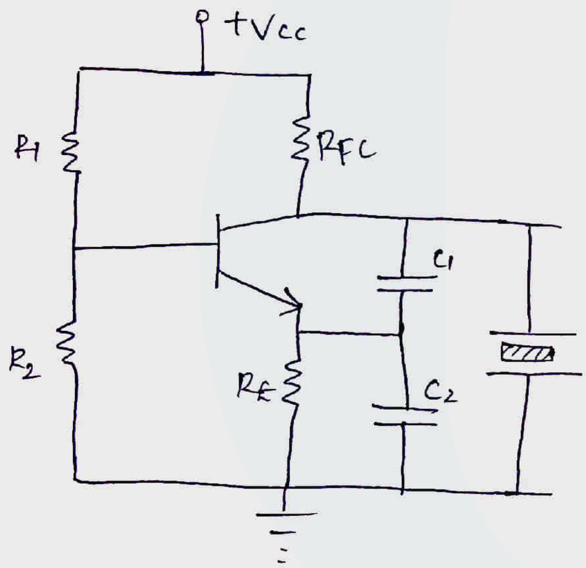
→ Series Resonant Mode :-



- RE for thermal stability
- CE - bypass cap.
- crystall is connected to Cc (coup. cap) & feedback is given (conn. in series)
- series resonant freq. is obtained,

$$\left\{ f_s = \frac{1}{2\pi\sqrt{LC}} \right\}$$

→ Parallel Resonant Mode :-



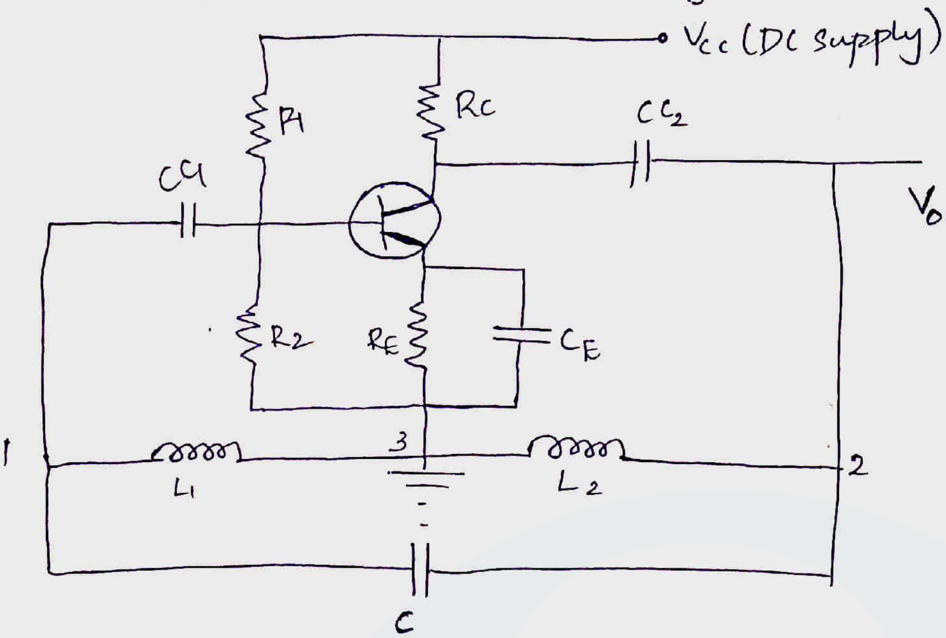
- here capacitive voltage divider C1 & C2 are used instead of CE
- crystall is connected // el to these
- thus //el resonant freq mode

$$\left\{ f_P = \frac{1}{2\pi\sqrt{L\left(\frac{C_m \cdot C}{C_m + C}\right)}} \right\}$$

- When compared to other oscillators, crystall oscillator will not affect frequency stability.

- Operating range : 40 KHz - 100MHz.
- Applications : Communication system
  Tracking system
  Video Gaming

Hartley Oscillator (Frequency derivation)



- R_1, R_2 & R_E provides necessary DC biasing to the transistor
- Z_1 & Z_2 -> ind. reactance
  Z_3 -> cap reactance

$$Z_1 = j\omega L_1 + j\omega M$$

$$Z_2 = j\omega L_2 + j\omega M$$

$$Z_3 = \frac{1}{j\omega C} = \frac{-j}{\omega C}$$

$$\left\{ h_{ie}[Z_1 + Z_2 + Z_3] + Z_1 Z_2 (1+h_{fe}) + Z_1 Z_3 = 0 \right\}$$ – Generalised eqn of oscillator

Subs. $\Rightarrow h_{ie}\left[j\omega L_1 + j\omega M + j\omega L_2 + j\omega M - \frac{j}{\omega C}\right] + (j\omega L_1 + j\omega M)(j\omega L_2 + j\omega M) \times (1+h_{fe})$

$$+ (j\omega L_1 + j\omega M)\left(\frac{-j}{\omega C}\right) = 0$$

$$\Rightarrow \omega j\, h_{ie}\left[L_1 + L_2 + 2M - \frac{1}{\omega^2 C}\right] - \omega^2 (L_1 + M)(L_2 + M)(1+h_{fe})$$

$$+ \left(\frac{L_1 + M}{C}\right) = 0$$

To find freq, equate imaginary part $= 0$

$$\omega j\, h_{ie}\left[L_1 + L_2 + 2M - \frac{1}{\omega^2 C}\right] = 0$$

$$\Rightarrow L_1 + L_2 + 2M = \frac{1}{\omega^2 C}$$

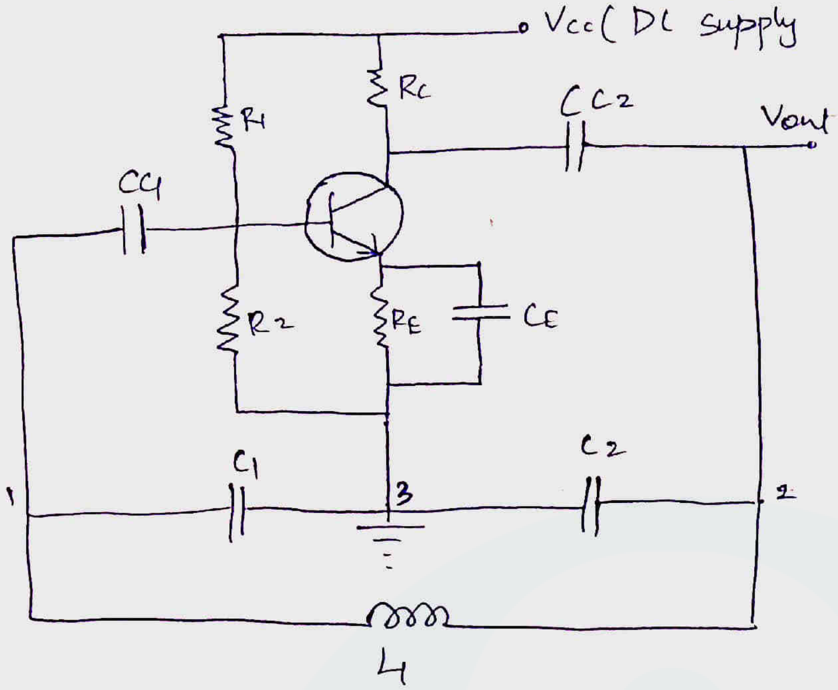
$\omega = 2\pi f$

$$\omega = \frac{1}{\sqrt{(L_1 + L_2 + 2M) \times C}}$$

(equate $L_1 + L_2 + 2M = L$)

$$\Rightarrow f = \frac{1}{2\pi\sqrt{(L_1 + L_2 + 2M)C}} \Rightarrow f = \frac{1}{2\pi\sqrt{LC}}$$

Colpitts Oscillator (Frequency derivation)



– no mutual ind. (only 1 L)

$$Z_1 = \frac{1}{j\omega C_1} = \frac{-j}{\omega C_1}$$

$$Z_2 = \frac{1}{j\omega C_2} = \frac{-j}{\omega C_2}$$

$$Z_3 = j\omega L$$

$$h_{ie}\left[Z_1 + Z_2 + Z_3\right] + Z_1 Z_2 (1 + h_{fe}) + Z_1 Z_3 = 0$$

$$\Rightarrow h_{ie}\left[\frac{-j}{\omega C_1} \frac{-j}{\omega C_2} + j\omega L\right] + (1+h_{fe})\left(\frac{-j}{\omega C_1}\right)\left(\frac{-j}{\omega C_2}\right) + \left(\frac{-j}{\omega C_1}\right)(j\omega L) = 0$$

$$\Rightarrow \frac{h_{ie} \cdot j}{\omega}\left[\frac{-1}{C_1} - \frac{1}{C_2} + \omega^2 L\right] + (1+h_{fe})\left(\frac{-1}{\omega^2 C_1 C_2}\right) + \frac{L}{C_1} = 0$$

eq. imaginary part $= 0$

i.e $\quad \frac{h_{ie}}{\omega}\left[\frac{-1}{C_1} - \frac{1}{C_2} + \omega^2 L\right] = 0$

$$\Rightarrow \omega^2 L = \frac{1}{C_1} + \frac{1}{C_2}$$

$$\Rightarrow \omega = \sqrt{\frac{1}{L}\left(\frac{1}{C_1} + \frac{1}{C_2}\right)}$$

$$\omega = 2\pi f \Rightarrow f = \frac{1}{2\pi}\sqrt{\frac{1}{L}\left(\frac{1}{C_1} + \frac{1}{C_2}\right)}$$

—×—