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Module - 3

POWER AMPLIFIERS

Power Amplifiers :-

→ It is used to raise the power level of the input signal.

→ In order to get large power at the output, it is necessary that the input voltage signal is large. That is the reason why power amplifiers are placed after voltage amplifiers in an electronic system. Hence power amplifiers are also called large signal amplifiers.

→ Power amplifier converts dc power into ac power.

Conditions Required for the operation of power amplifier

1. In power amplifier, i/p resistance of transistor is very large as compared to o/p resistance.
2. The current gain β of a transistor used in power amplifier is smaller compared to that of voltage amplifiers.
3. In power amplifiers transformer coupling for impedance matching is used.
4. Power amplifiers need large size, because a considerable amount of heat is dissipated within transistor and hence large surface area is required for heat dissipation.

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Classification of power amplifiers :-

→ **According to the frequency of operation**

(i) Audio power amplifiers :-

* Also called small signal power amplifiers
* Raise the power levels of signals that have audio frequency range [20 Hz - 20 KHz].

(ii) Radio power amplifiers :-

* Also called large signal power amplifiers.
* Raise the power levels of signals that have radio frequency range. [Above 20 KHz].

→ **According to mode of operation**

* This is based on the amount of transistor bias and amplitude of input signal.

They are classified as on the basis of Q point

(i) Class A amplifier :-

The operating point and magnitude of input signal is such that the o/p current flows for the entire cycle of the input signal. So o/p = i/p

(ii) Class B amplifier :-

The operating point and magnitude of i/p signal is such that the o/p current flows only

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during the positive half cycle of the input signal.

(iii) Class AB amplifier :-

o/p signal swing occurs between 180° and 360° and is neither class A nor class B operation.

(iv) Class C amplifier :-

The power amplifiers in which collector current flows for less than half cycle of the input signal.

(v) Class D amplifier :-

It operates with digital or pulse type signals.

→ According to deriving output

(i) Single ended power amplifiers :-

* Uses a single transistor and derives output power with respect to one end permanently grounded.

(ii) Double ended (push pull) amplifier :-

* This uses two transistor in a single stage. The collector current loops flows in opposite direction but add in the load.

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iii) Complementary symmetry push pull amplifier :-

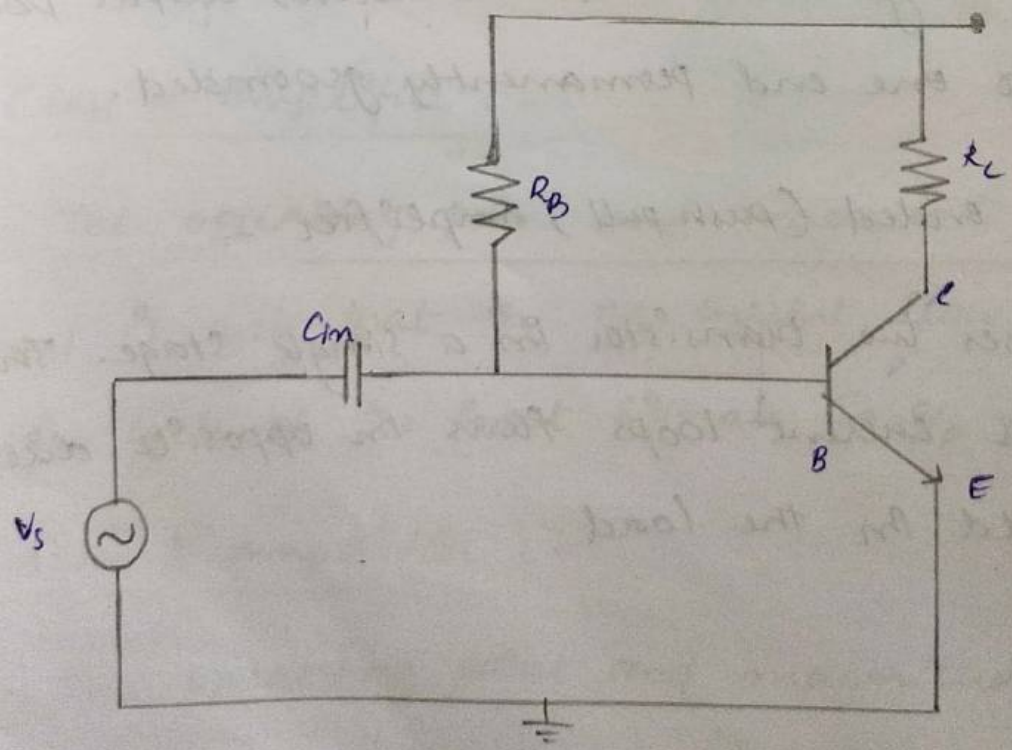
* This uses a two transistor in a single stage with complementary symmetry. i.e, if one transistor is PNP then the other one will be PNP.

Class A power amplifiers [Direct coupled] or Class A series fed amplifiers

* Class A series fed Amplifiers

→ Class A amplifier is a power amplifier in which output current flows for the full cycle (360°) of the input signal. In other words, the transistor remains forward biased throughout the input cycle.

→ A schematic circuit of a series fed class A large signal amplifier using resistive load R_C is shown



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→ Here fixed biasing is used.

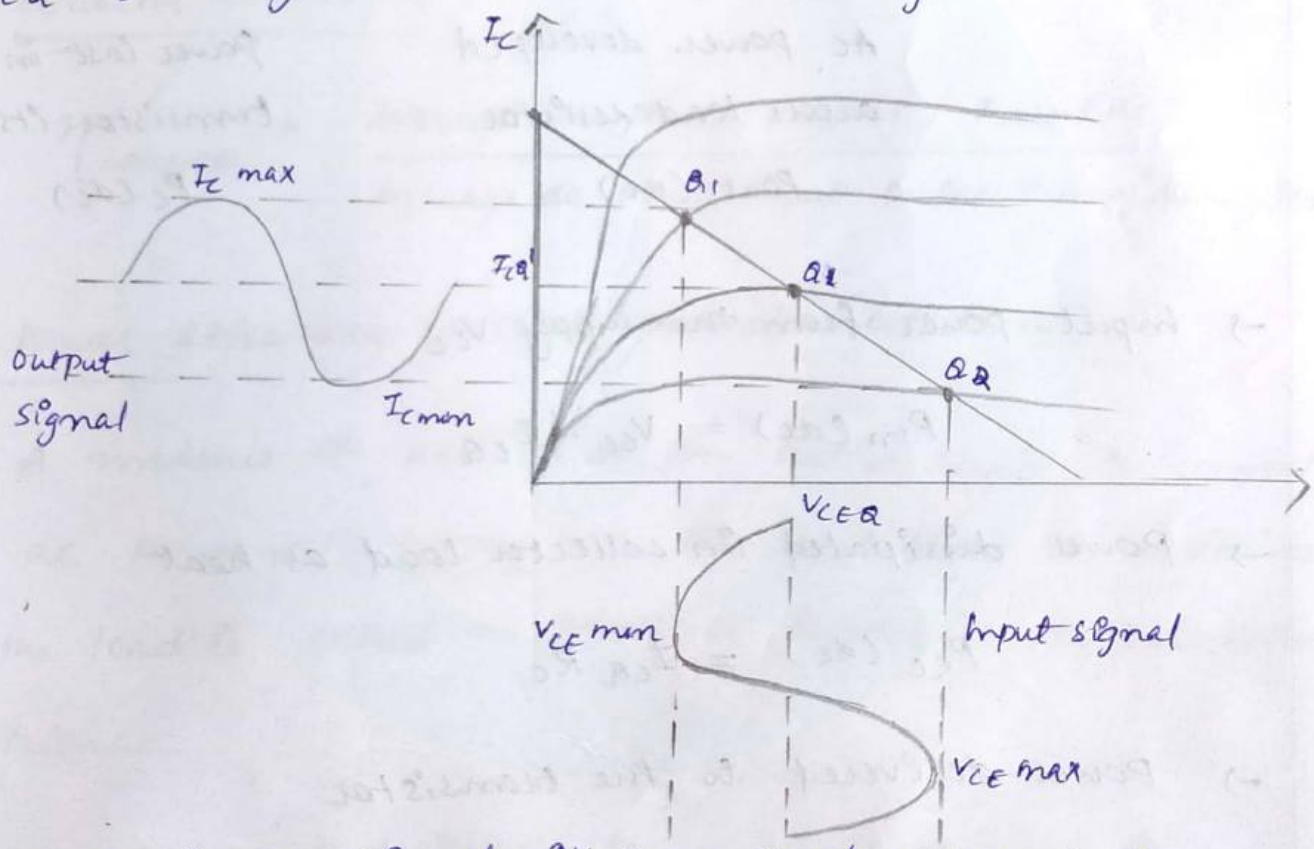
→ The term series fed is derived from the fact that the load R_C is connected in series to the transistor output.

→ This circuit is less used for power amplification because of its poor collector efficiency.

→ The output characteristic with operating point Q is as shown in figure.

I_{CQ} : zero signal collector current

V_{CEQ} : zero signal collector emitter voltage



→ A small input signal will cause the base current to vary above and below the dc bias point, which will cause the collector current to vary from the dc bias point

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Power distribution in class A amplifier

The power flow diagram of a transistor is given below

P_{in} (dc)

- Power lost in load resistor R_C — P_{RC} (dc)
- Power delivered to transistor — P_{tr} (dc)
  - AC power developed across load resistor — P_{out} (ac)
  - Power lost in transistor itself — P_C (dc)

→ Input power from the supply V_{CC}

$$P_{in}(dc) = V_{CC} \cdot I_{CQ}$$

→ Power dissipated in collector load as heat

$$P_{RC}(dc) = I_{CQ}^2 R_C$$

→ Power delivered to the transistor

$$P_{tr}(dc) = P_{in}(dc) - P_{RC}(dc)$$

$$= V_{CC} I_{CQ} - I_{CQ}^2 R_C$$

The power supplied to the transistor P_{tr} (dc) is further subdivided into.

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(a) AC power, $P_{out}(ac) = I_{c_{rms}} \cdot V_{ce_{rms}}$

$$= \frac{I_c \text{ (Peak to Peak)}}{2\sqrt{2}} \times \frac{V_{ce} \text{ (PP)}}{2\sqrt{2}}$$

$$= \frac{I_c \text{ (P-P)} \cdot V_{ce} \text{ (P-P)}}{8}$$

$$I_{rms} = \frac{I_m}{\sqrt{2}} = \frac{I_m \text{ (Peak to Peak)}}{2\sqrt{2}}$$

(b) power dissipated in the form of heat by transistor itself.

→ <u>collector efficiency</u> :

$$\eta_{collector} = \frac{\text{Average ac power output, } P_{out}(ac)}{\text{average dc power input to the transistor, } P_{tr}(dc)}$$

→ <u>power efficiency</u> (over all conversion efficiency) :

A measure of ability of an active device to convert the dc power of supply into the ac signal power delivered to the load is called the power or conversion or theoretical efficiency.

$$\eta = \frac{\text{AC power delivered to the load } P_{out}(ac)}{\text{total power drawn from dc supply } P_{in}(dc)}$$

Here $P_{out}(ac) = \frac{I_c \text{ (P-P)} \times V_{CE} \text{ (P-P)}}{8}$ —— (a)

$P_{in}(dc) = V_{cc} \cdot I_{CQ}$ —— (b)

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$$\therefore \eta = \frac{P_{out}(ac)}{P_{in}(dc)} = \frac{I_c(p\text{-}p) \times V_{ce}(p\text{-}p)}{8 V_{cc} I_{CQ}}$$

→ Maximum power efficiency :

Maximum power efficiency of an amplifier is given by

$$\eta_{max} = \frac{P_{out}(ac)\,max}{P_{in}(dc)\,max}$$

$$P_{out}(ac)\,max = \frac{V_{ce}^2}{8R_c}$$

$$P_{in}(dc)\,max = \frac{V_{cc}^2}{2R_c}$$

$$\eta_{max} = \frac{V_{cc}^2/8R_c}{V_{cc}^2/2R_c} = \frac{1}{4} = 0.25 = 25\%$$

Class A amplifier [Transformer coupled]

→ It is also known as single ended power amplifier single ended means circuit consists of only one transistor and output is taken with respect to a single ground.

→ In case of a direct coupled class A amplifier, the quiscent current flows through the collector resistor and cause large wastage of dc power in it.

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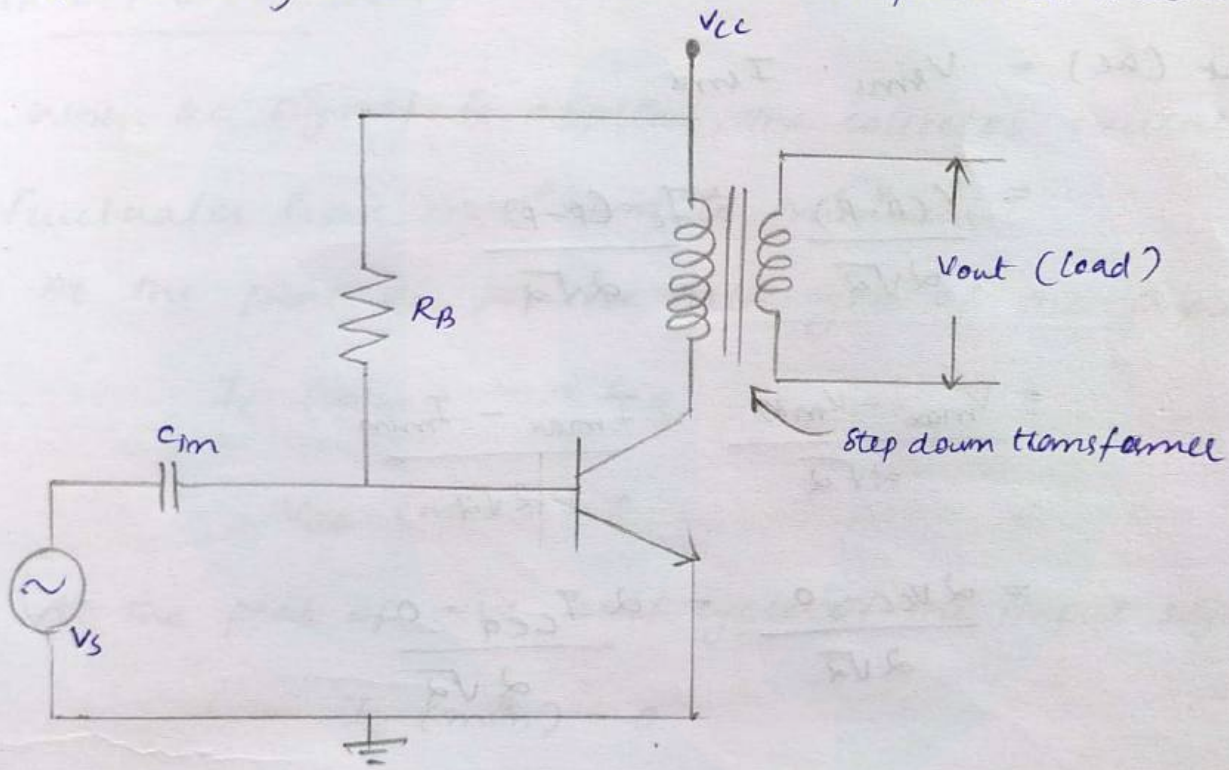
→ Here transformer is used for coupling the load to the amplifier. This enhances the efficiency by eliminating dc power dissipation in the load.

→ Primary winding of the transformer has low dc resistance hence power loss will be negligible

→ This also prevents a large dc current flowing through the load.

→ This arrangement also permits impedance matching.



Circuit Analysis

* In ideal transformer, there is no voltage drop in primary so $V_{CEQ} = V_{CC}$.

* Power input to the transistor ($P_{tr}(dc)$) is equal to the dc power drawn from the supply.

ie, $P_{tr}(dc) = P_{in}(dc) = V_{CC} I_{CQ}$

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We know that overall efficiency $= \eta = \frac{P_{out}(ac)}{P_{in}(dc)}$

But here $P_{in}(dc) = P_{tr}(dc)$

overall efficiency $= \frac{P_{out}(ac)}{P_{tr}(dc)}$ = Collector efficiency

$$= \frac{P_{out}(ac)}{V_{cc} \cdot I_{cq}}$$

$$P_{out}(ac) = V_{rms} \cdot I_{rms}$$

$$= \frac{V_{(p-p)}}{2\sqrt{2}} \quad \frac{I_{c}(p-p)}{2\sqrt{2}}$$

$$= \frac{V_{max} - V_{min}}{2\sqrt{2}} \cdot \frac{I_{max} - I_{min}}{2\sqrt{2}}$$

$$= \frac{2V_{cc} - 0}{2\sqrt{2}} - \frac{2I_{ceq} - 0}{2\sqrt{2}}$$

$$= \frac{V_{cc}}{\sqrt{2}} \cdot \frac{I_{cq}}{\sqrt{2}}$$

$$= \frac{V_{cc} I_{cq}}{2}$$

$$= \frac{1}{2} P_{in}(dc)$$

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$\therefore$ overall efficiency $= \frac{P_{out}(ac)}{P_{in}(dc)} = \frac{V_{CE} I_{CQ}}{2 \cdot V_{CE} I_{CQ}}$

$= \frac{1}{2}$ or 50%

$\therefore \eta = 50\%$

Thus for transformer coupled class A power amplifier the maximum theoretical efficiency is 50%.

CIRCUIT OPERATION

* When ac signal is applied, the collector current fluctuates from maximum to minimum
* At the peak of positive half cycle of the input signal,

$I_c(max) = 2 I_{CQ}$

$V_{CE}(min) = 0$

* At the peak of -ve half cycle of the input signal,

$I_c(min) = 0$

$V_{CE}(max) = 2 V_{CE}$

$I_c(min) = 0$

$V_{CE}(max) = 2 V_{CE}$

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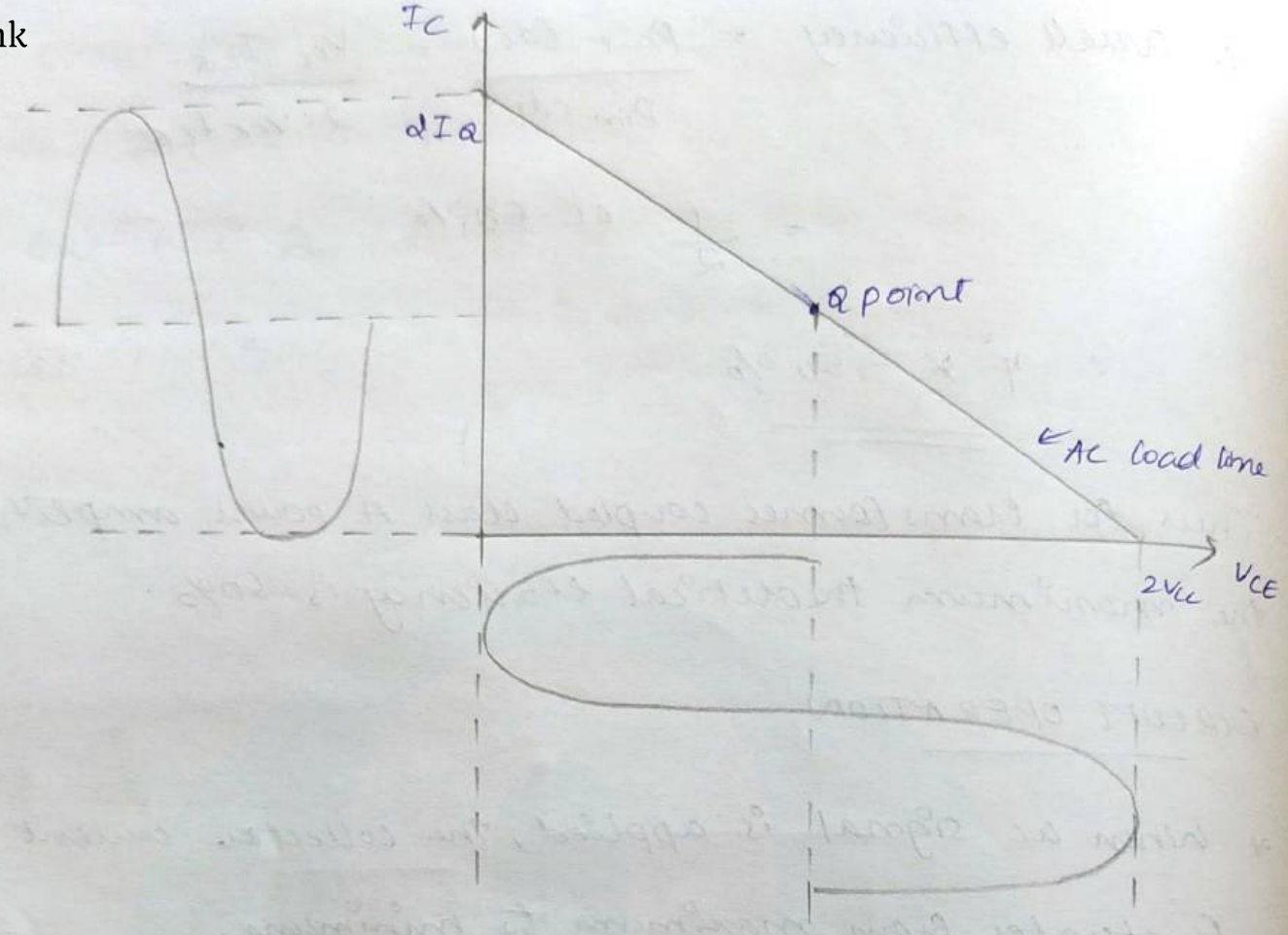

Distortion in class A amplifier

* Class A amplifier is a low distortion device, however a kind of distortion ~~of~~ is observed in this amplifier. This amplitude distortion.
* When the input signal is of high amplitude, +ve half or negative half of signal is clipped off, this cause a distortion in amplitude. This type of distortion is known as amplitude distortion.

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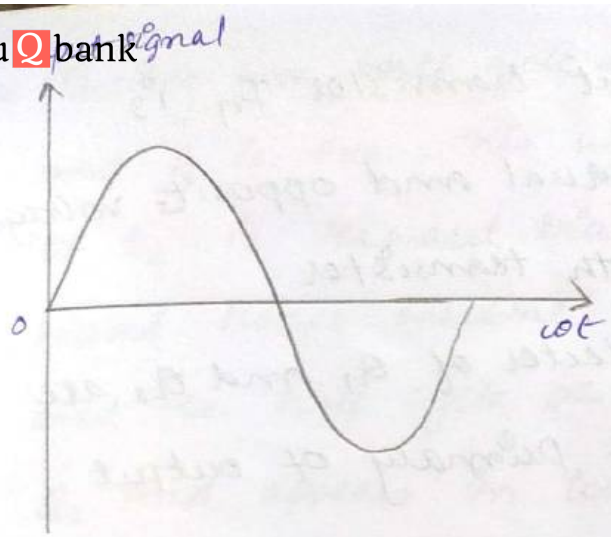
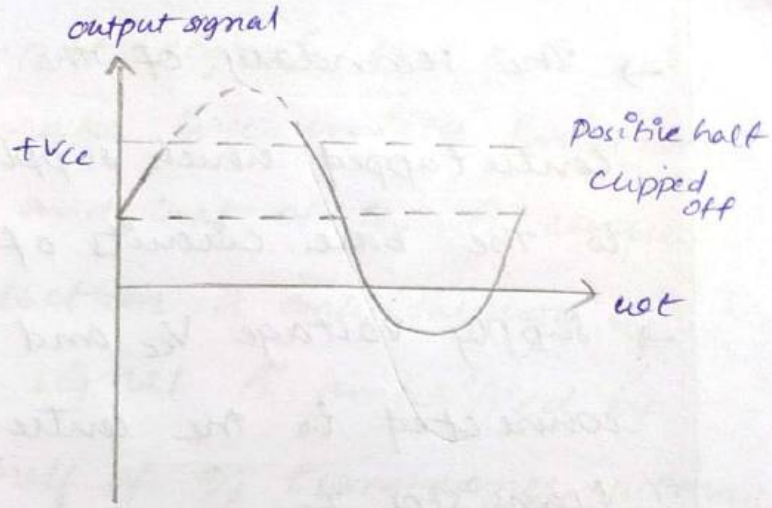
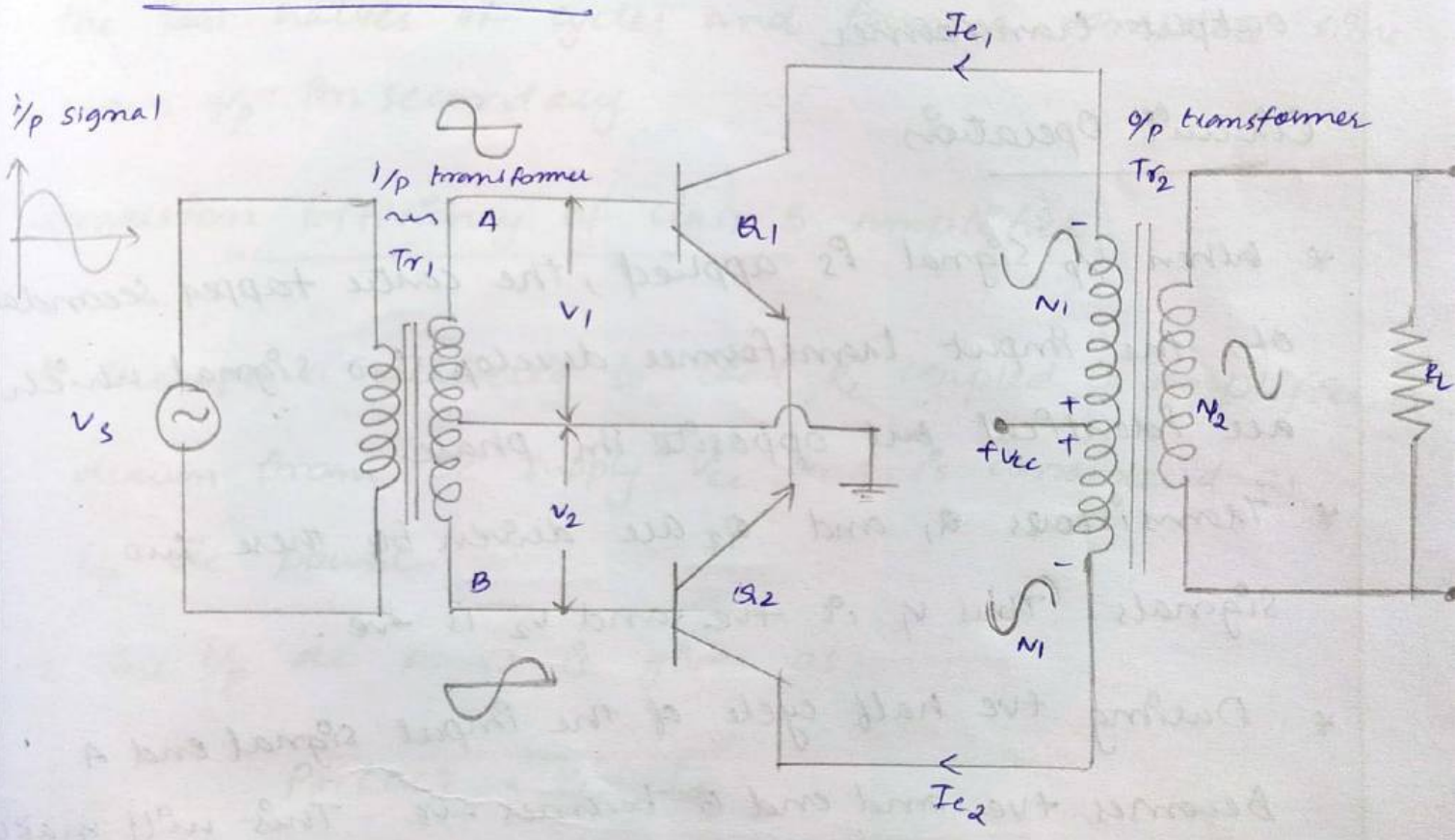




Class B push pull amplifiers



→ Here two identical transistors Q_1 and Q_2 are connected to the opposite ends of secondary of transformer Tr_1

→ Both transistors are connected back to back and they are operated in class B operation ie collector current is almost zero in the absence of signal.

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→ The secondary of the input transistor Tr_1 is centre tapped which supplies equal and opposite voltages to the base circuits of both transistor.

→ Supply voltage V_{cc} and collector of Q_1 and Q_2 are connected to the centre tap primary of output transistor Tr_2.

→ Load R_L is connected to the secondary of the output transformer.

Circuit Operation

* When i/p signal is applied, the centre tapped secondary of the input transformer develop two signal which are identical but opposite in phase.
* Transistors Q_1 and Q_2 are driven by these two signals. Thus v_1 is +ve and v_2 is -ve.
* During +ve half cycle of the input signal end A becomes +ve and end B becomes -ve. This will make base-emitter junction of transistor Q_1 forward biased and that of transistor Q_2 is reverse biased.

Thus current will be conducted only through Q_1 and not through Q_2. Therefore first half cycle of the signal is amplified by the transistor Q_1 and appears in the upper half of the primary of o/p transformer.

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* During -ve half cycle of input signal. end A is -ve and B is +ve, this will make base emitter junction of Q_2 is forward biased and that of Q_1 is reverse biased. Hence current conduction is only through Q_2. and -ve half cycle of the signal is amplified by Q_2 and appears in lower half of o/p transformer primary.

* The centre tapped primary of o/p transformer combines the two halves of cycles and forms a complete sine wave o/p in secondary.

Conversion Efficiency of Class B Amplifier

→ The power delivered to load R_L coupled to amplifier is drawn from DC supply V_{CC} and is considered as i/p dc power

→ The i/p dc power is given as

$$P_{in}(dc) = V_{CC} \cdot I_{dc}$$

where I_{dc} : avg or direct current taken from dc supply V_{CC}

→ In class B operation the current drawn from single power supply is full wave rectified signal, thus

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$$I_{dc} = \frac{1}{\pi}\int_0^{\pi} I_{c\,max} \sin\theta \, d\theta$$

$$= \frac{1}{\pi} I_{c\,max} \left[-\cos\theta\right]_0^{\pi}$$

$$= \frac{I_{c\,max}}{\pi}\left[-(\cos\pi - \cos 0)\right] = \frac{I_{c\,max}}{\pi}\left(-(-1-1)\right)$$

$$I_{dc} = \frac{2}{\pi} I_{c\,max}$$

$\therefore$ i/p power $P_{in}(dc) = V_{cc} \cdot I_{dc}$

$$P_{in}(dc) = \frac{2}{\pi} V_{cc} I_{c\,max}$$

→ AC o/p power, $P_{out}(ac) = V_{rms} \cdot I_{rms}$

$$= \frac{V_{cc}}{\sqrt{2}} \cdot \frac{I_{c\,max}}{\sqrt{2}}$$

$$\therefore P_{out}(ac) = \frac{V_{cc} I_{c\,max}}{2}$$

→ Overall efficiency $\eta = \dfrac{P_{out}(ac)}{P_{in}(dc)}$

$$= \frac{\frac{V_{cc} I_{c\,max}}{2}}{\frac{2}{\pi} V_{cc} I_{max}} = \frac{\pi}{4}$$

$$\eta = \pi/4 = 0.785 = 78.5\%$$

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→ Collector power dissipation for two transistors

$$P_d = P_{in}(dc) - P_{out}(ac)$$

$$= \frac{2}{\pi} V_{cc} I_{cmax} - \frac{V_{cc} I_{cmax}}{2}$$

$$P_d = 2 I_{c\,max} \left[\frac{V_{cc}}{\pi} - \frac{V_{cc}}{4} \right]$$

Cross Over Distortion

→ In class B amplifier distortions are due to

1) Non linearity of collector characteristics
2) Non matching of two transistors
3) Non linearity of i/p characteristics

→ The silicon transistors must have atleast 0.5 V or 0.6V at base for conduction.

→ In class B pushpull amplifiers, the forward bias is produced by the i/p signal, both of the transistors will be OFF, when the i/p signal is approximately ±0.5 V. This forms a dead band in the input and produced cross over distortion in the O/p.

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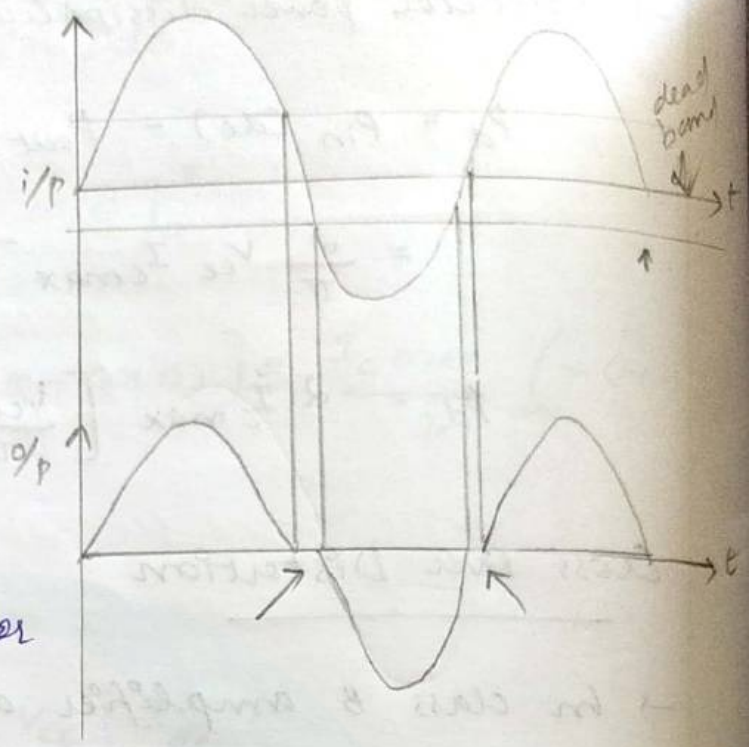
In simple words distortion occurs as a result of one transistor cutting off before the other begins conducting.

→ To eliminate cross over distortion it is necessary to add a small amount of forward bias to make transistor conducting.



PROBLEMS

1. A class B push pull amplifier is supplied with $V_{cc} = 50V$. The signal swings the collector voltage down to $V_{min} = 5V$. The total dissipation in both transistors is 40W. Find the total pressure and conversion efficiency.

Ans:- DC supply $= V_{cc} = 50\,V$

$V_{min} = 5\,V$

Total power dissipation $= 40\,W$

$$P_d = P_{in}(dc) - P_{out}(ac)$$

$$40 = \frac{2}{\pi} V_{cc} I_{max} - \frac{I_{cmax}}{2}(V_{cc} - V_{min})$$

$$= I_{c}max \left[\frac{2}{\pi} V_{cc} - \frac{V_{cc} - V_{min}}{2}\right]$$

$$= I_{cmax}\left[\frac{2}{\pi} \times 50 - \frac{45}{2}\right] = 9.33\ I_{cmax}$$

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$\therefore I_{cmax} = \frac{40}{9.33} = 4.287\ A$

Input power $P_{in}(dc) = \frac{2}{\pi} V_{cc} I_{cmax} = 136.45\ W$

AC o/p power $P_{out}(ac) = \frac{I_{cmax}}{2}[V_{cc} - V_{min}] = 96.46\ W$

Efficiency, $\eta = \frac{P_{out}(ac)}{P_{in}(dc)} = \frac{96.46}{136.45} = 0.707$

$\therefore \eta = 70\%$

2) Determine the input power, o/p power and efficiency resulting in class B pushpull amplifier providing a signal of 20V peak to 16 Ω load using a single supply $V_{cc} = 30V$.

Ans:- $I_{cmax} = \frac{V_{cc}}{R_L} = 1.875\ A$

$V_{cc} = 30V$

$R_L = 16\Omega$

i/p power, $P_{in}(dc) = \frac{2}{\pi} V_{cc} I_{cmax}$

$= \frac{2}{\pi} \times 30 \times 1.875 = 35.8\ W$

AC o/p power, $P_{out}(dc) = \frac{V_{cc} I_{cmax}}{2}$

$= \frac{30 \times 1.875}{2} = 28.125\ W$

Efficiency $\eta = \frac{P_{out}(ac)}{P_{in}(dc)}$

$= \frac{28.125}{35.8} = 0.785 \quad \therefore \eta = 78.5\%$

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3. A class B pushpull amplifier delivers 10W of audio power to o/p load.

(i) if o/p transformer is 80% efficient, what is minimum power drawn on the power supply.

(ii) what is minimum average dissipation rating required for each transistor.

Ans- power delivered to load = 10 W

AC o/p power of amp = $\frac{P_L}{\text{o/p transformer efficiency}}$

$= \frac{10W}{0.8} = 12.5W$

Efficiency of class B pushpull amp = 0.785

= 78.5%

(i) Minimum power drawn on power supply

$P_{in}(dc) = \frac{P_{out}(ac)}{\eta} = \frac{12.5}{0.785} = 15.9W$

(ii) Minimum average dissipation

$P_d = P_{in}(dc) - P_{out}(ac)$

$= 15.92 - 12.5$

$= 3.42W$

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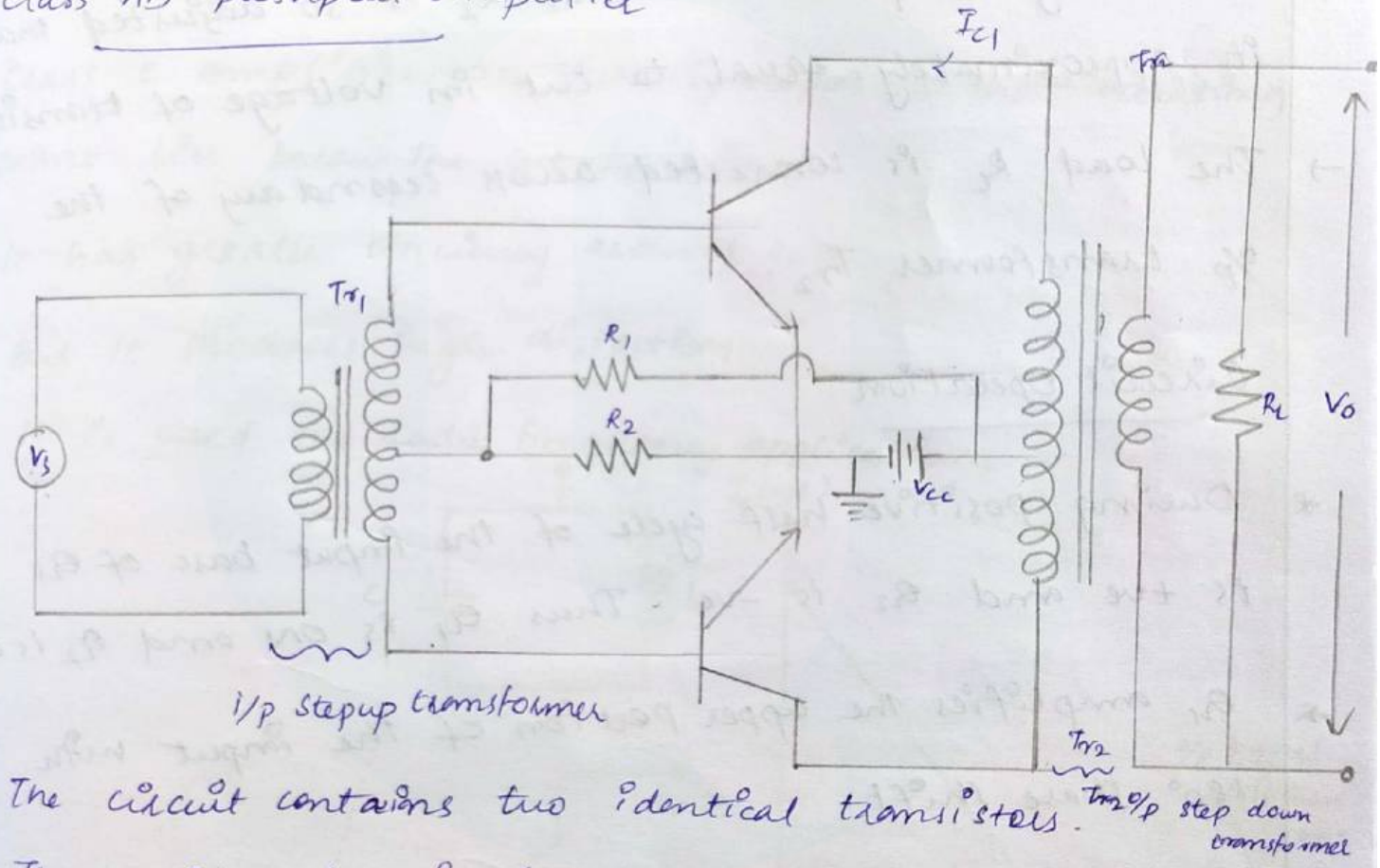
Class AB power amplifier

- It is a combination of class A and class B type amplifiers.
- Class AB amplifiers is the most commonly used audio power amplifier design.
- It has a conversion efficiency of 50–60%.

Class AB pushpull amplifier



- The circuit contains two identical transistors.
- The emitter terminals of Q_1 and Q_2 are connected together and input signal is applied to the i/p of two transistors through centre tapped step-up transformer T_{r1} which provides opposite polarity signals to two transistor inputs.
- The collector terminals of both transistors are connected

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* and terminals of centre tapped primary of o/p transformer Tr_2.

→ The power supply V_{cc} is connected between emitter terminals and centre tap of primary of o/p transformer

→ ~~Resistance~~ Resistors R_1 and R_2 are used to provide the proper bias for the circuit.

→ The voltage drop across resistor R_2 is so adjusted that it approximately equal to cut in voltage of transistor

→ The load R_L is connected across secondary of the o/p transformer Tr_2.

Circuit Operation

* During positive half cycle of the input base of Q_1 is +ve and Q_2 is -ve. Thus Q_1 is ON and Q_2 is OFF.

* Q_1 amplifies the upper portion of the input with 180° phase shift.

* During -ve half cycle, Q_1 turns OFF only after Q_2 is turned ON. Now Q_2 amplifies lower portion of input.

* Output transformer combines both outputs and a continuous ac signal is obtained at the output.

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Drawbacks

* Efficiency is less than class B.
* Wastage of power.

Class C Amplifiers

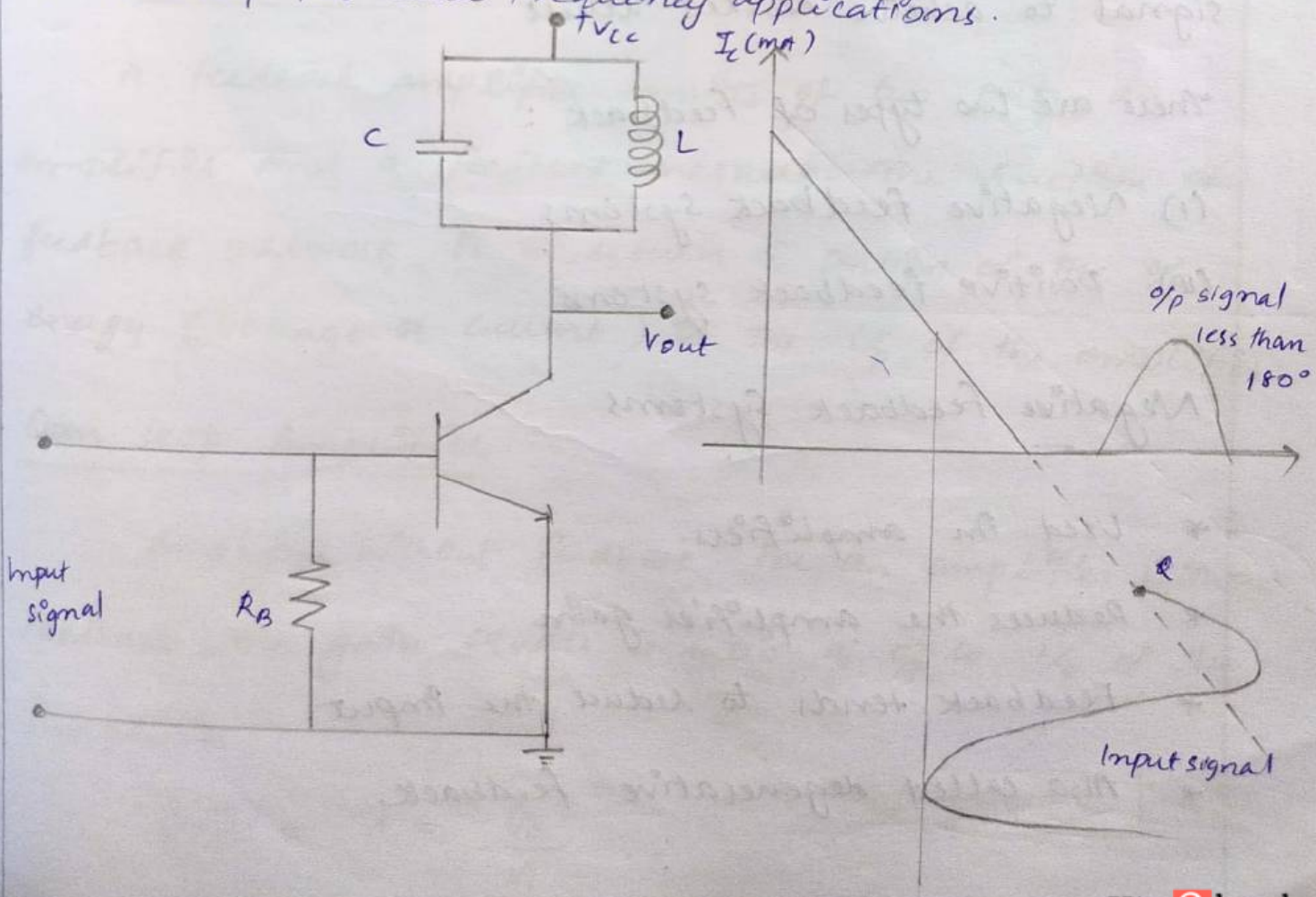
→ Transistor conducts for less than one half cycle of the input signal i.e less than 180°.

→ Class C amplifiers are heavily doped, so that operating point lies below the cutoff point.

→ It has greater efficiency around 80%.

→ But it produces high distortion.

→ It is used for radio frequency applications.



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→ Biasing is provided through the resistor R_B so that operating point lies below the cutoff point.

→ Inductor L_1 and C_1 forms a tank circuit which helps to obtain a complete sine wave from the collector current.

→ The values of L and C are ~~satisfied~~ selected such that resonant circuit oscillates in the frequency of the input signal.

Feedback Amplifiers

A feedback system is one in which a part or fraction of output is combined with the input. Feedback systems use the o/p information to modify the i/p signal to acheive desired result.

There are two types of feedback :

(i) Negative feedback systems

(ii) Positive feedback systems

Negative feedback systems

* Used in amplifiers.
* Reduces the amplifier gain
* Feedback tends to reduce the input.
* Also called degenerative feedback.

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Advantages ⇒ * Gain stability
* Reduction in distortion and noise
* Increase in bandwidth
* Increase in input impedance.
* Decrease in output impedance.

positive feedback System

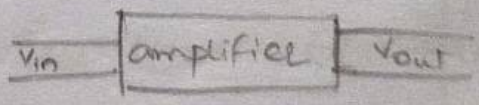
* Used in oscillators.
* Feedback tends to increase the i/p.
* Also known as Regenerative feedback.
* Disadvantages ⇒ Excessive distortion
Instability

Feedback in amplifiers

A feedback amplifier consists of two parts, an amplifier and a feedback network. The function of feedback network is to return a portion of the o/p energy (voltage or current) to the i/p of the amplifier.

→ Open loop Amplifier :

Amplifier without feedback. For an amplifier without feedback, the gain equals to ratio of o/p to i/p of the amplifier.



$$\text{Gain} = A = \frac{V_o}{V_i}$$

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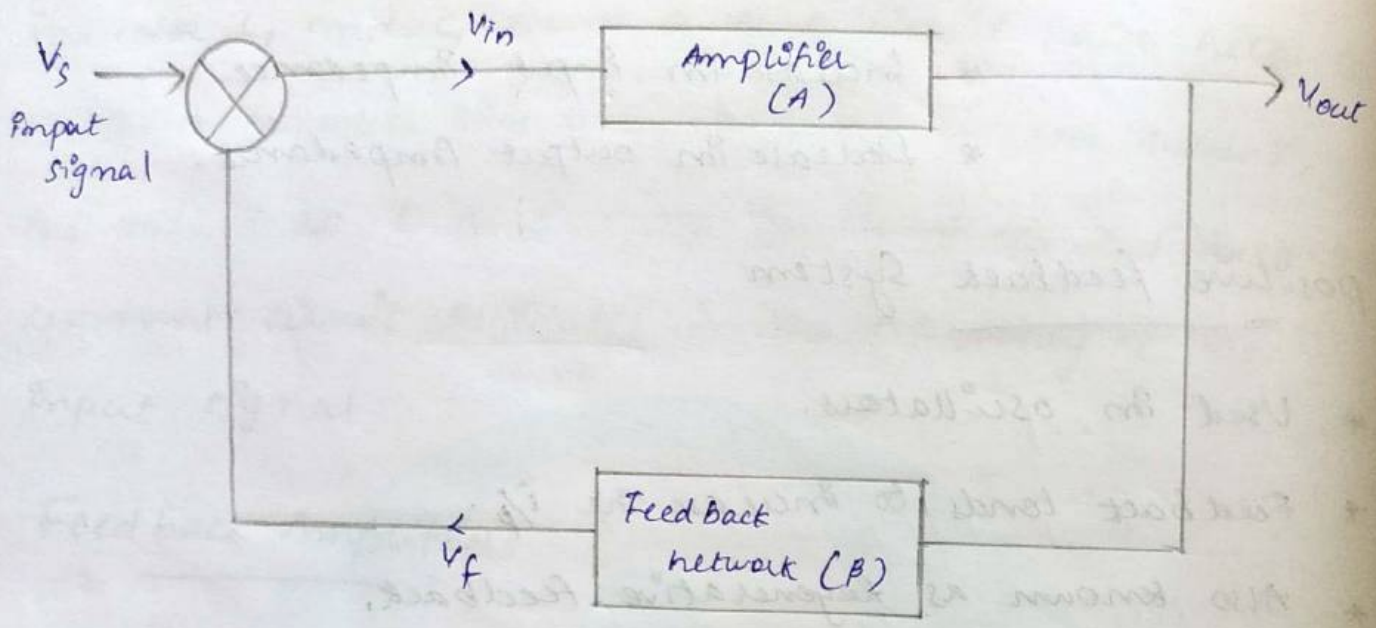
Closed loop amplifier :

Amplifier with feed back.



* Feedback signal $V_f = \beta V_{out}$
* V_{in} represents the input signal (may be voltage or current)
* For +ve feedback, $V_{in} = V_s + V_f$

$$= V_s + \beta V_{out}$$

* For -ve feedback, $V_{in} = V_s - V_f$

$$= V_s - \beta V_{out}$$

* Output voltage, $V_{out} = A V_{in}$
* For negative feedback $\Rightarrow$

$$V_{out} = A V_{in}$$

$$= A [V_s - \beta V_{out}]$$

$$= AV_s - A\beta V_{out}$$

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$$V_{out} + A\beta V_{out} = AV_s$$

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

$$\boxed{\frac{V_{out}}{V_s} = \frac{A}{1+A\beta} = A_f}$$

* For positive feedback $\Rightarrow$

$$V_{out} = A V_{in}$$

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

$$V_{out} - A\beta V_{out} = A V_s$$

$$V_{out}(1-A\beta) = A V_s$$

$$\boxed{\frac{V_{out}}{V_s} = A_f = \frac{A}{1-A\beta}}$$

* Amount of feedback (N) is usually expressed in decibels.

$$N = \text{dB of feedback} = 20\log_{10}\left|\frac{A_f}{A}\right|$$

$$= 20\log_{10}\left|\frac{A}{(1+A\beta)A}\right|$$

$$\boxed{N = 20\log_{10}\left|\frac{1}{1+A\beta}\right|}$$

* Also the input signal, $V_{in} = V_s - V_f$

= Source signal − f/b signal

It is also called error signal.

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Effects of Negative and positive feedback

(1) Effects on gain ⇒

(i) −ve feedback case :

Gain of amplifier with −ve f/b is given by

$$A_f = \frac{A}{1+A\beta}$$

The gain is decreased by a factor $(1+A\beta)$.

(ii) +ve feedback case :

$$A_f = \frac{A}{1-A\beta}$$

* If $A\beta$ is less than 1, A_f is greater than A, thus gain is increased.

* If $A\beta = 1$, $A_f = \infty$, ie gain of current is infinity. That means it can produce an output even in the absence of i/p. This make it used as an oscillator

(2) Effect on frequency response & bandwidth ⇒

(i) −ve feedback case :-

* Gain is reduced by a factor of $(1+A\beta)$. It also affects lower and upper half power frequencies.

* The lower frequency f_1 is reduced to f_1'.

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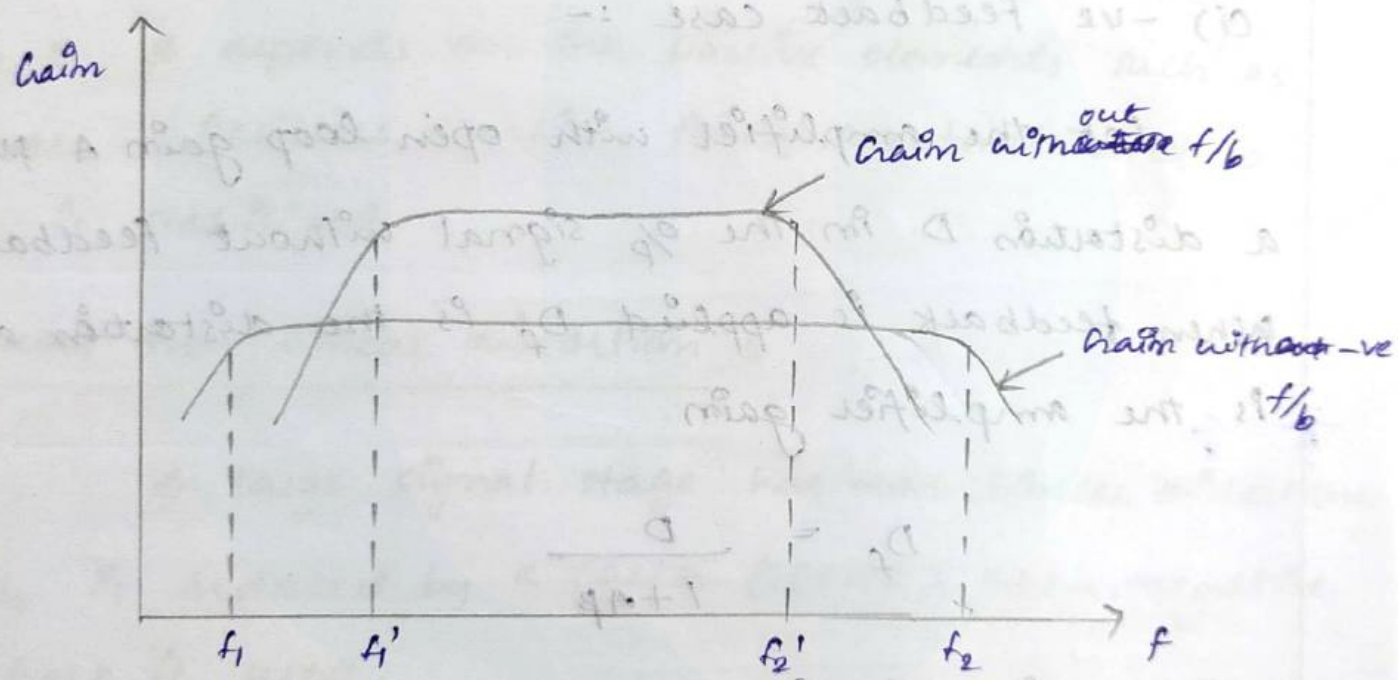
ie, $f_1' = \dfrac{f_1}{1+A\beta}$

The upper frequency f_2 is increased to f_2'.

ie, $f_2' = f_2(1+A\beta)$

* Thus bandwidth becomes $f_2' - f_1$ and it is greater than $f_2 - f_1$
* with -ve f/b, bandwidth increases gain decreases. But gain bandwidth product remains constant.



(ii) +ve feedback case :-

* Gain is increased by a factor $(1+A\beta)$.
* f_1 is increased to f_1' and f_2 is decreased to f_2'.
* Thus bandwidth decreases.

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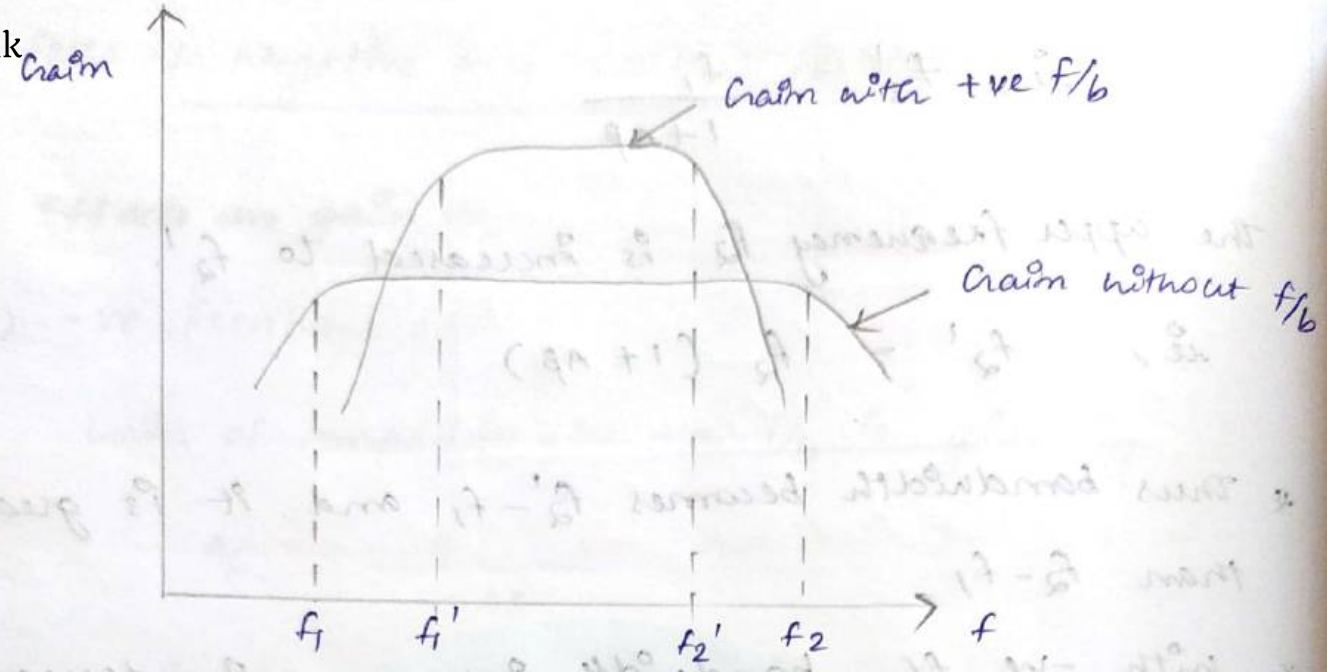

(3) Effects of feedbacks on distortion ⇒

(i) −ve feedback case :-

Let the amplifier with open loop gain A produces a distortion D in the o/p signal without feedback. When feedback is applied D_f is the distortion and A_f is the amplifier gain.

$$D_f = \frac{D}{1+A\beta}$$

Thus distortion is reduced by $(1+A\beta)$.

(ii) +ve feedback case :-

Net distortion $D_f = \dfrac{D}{1-A\beta}$

∴ Distortion is increased.

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Advantages of Negative feedback [effects of -ve feedback]

1. **Gain Stability :**

The voltage gain of the amplifier with negative feedback is given as $A_f = \frac{A}{1+A\beta}$

If $A\beta >> 1$, then $A_f = \frac{1}{\beta}$, that means the overall gain of the amplifier with feedback is independent of internal gain and depends only on feedback ratio β. β depends on the passive elements such as resistors. Resistors remains fairly constant and so gain is stabilized.

2. **Reduced non linear distortion :**

A large signal stage has non linear distortion which is reduced by a factor $(1+A\beta)$ when negative feedback is used.

3. **Reduced Noise :**

There is always a noise voltage in the amplifier which is reduced by a factor $(1+A\beta)$ when negative feedback is applied.

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4. Increased Bandwidth (improved frequency response) :

The bandwidth (BW) of an amplifier without feedback is equal to the seperation between 3dB frequencies f_1 and f_2. ie, $BW = f_2 - f_1$.

If A is the gain, then gain band width product is $A \times BW$. If negative feedback is applied to an amplifier. The amplifier gain is reduced since gain band width product has to remain constant, the bandwidth will increase to compensate for the reduction in gain.

5. Increased input impedance :

The input impedance of the amplifier with negative feedback is increased by a factor $(1+A\beta)$.

6. Reduced Output impedance :

The output impedance of the amplifier with negative feedback is reduced by a factor $(1+A\beta)$.

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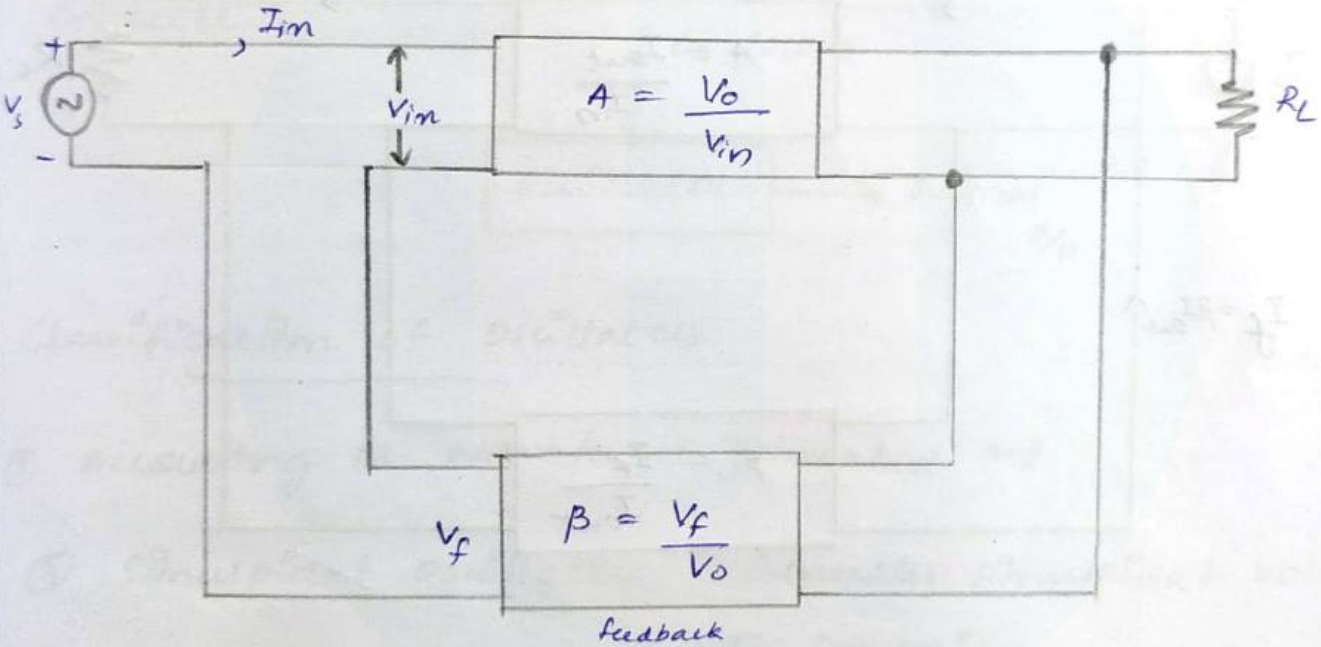
Feedback Topologies and Properties

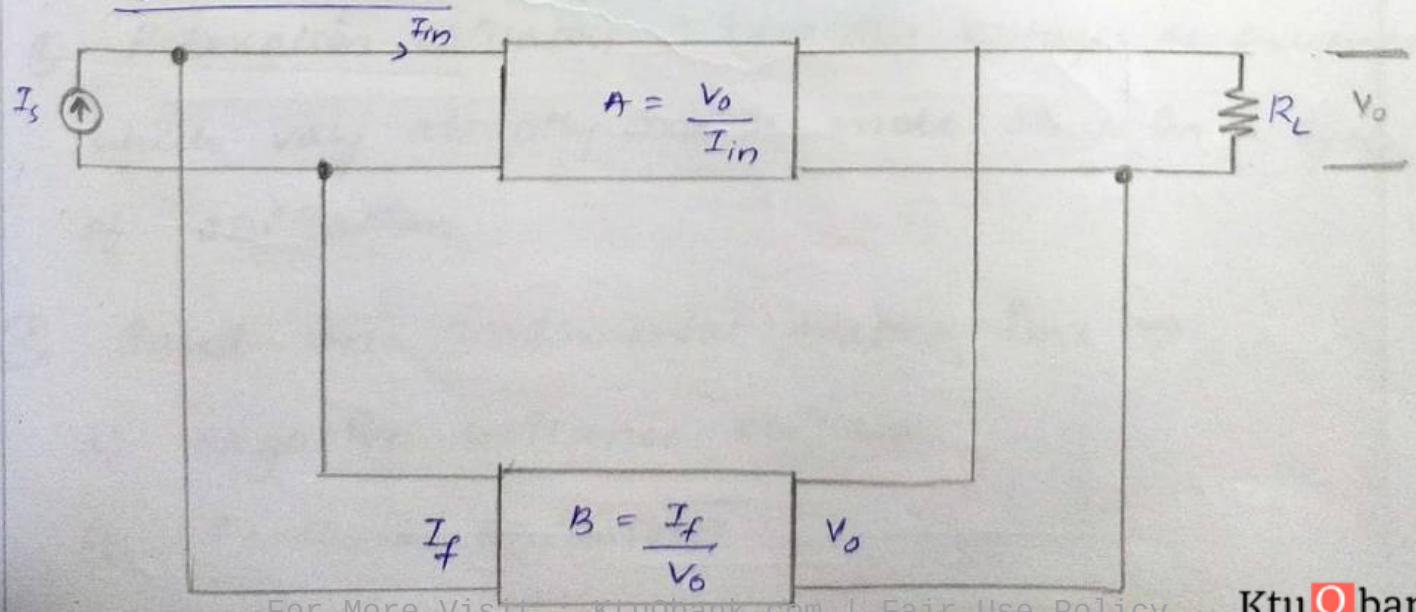
8) Based on the type of feedback, there are four apologies

① Voltage series feedback
② voltage shunt feedback
③ current series feedback
④ current shunt feedback

Voltage Series feedback Amplifier



Voltage Shunt feedback



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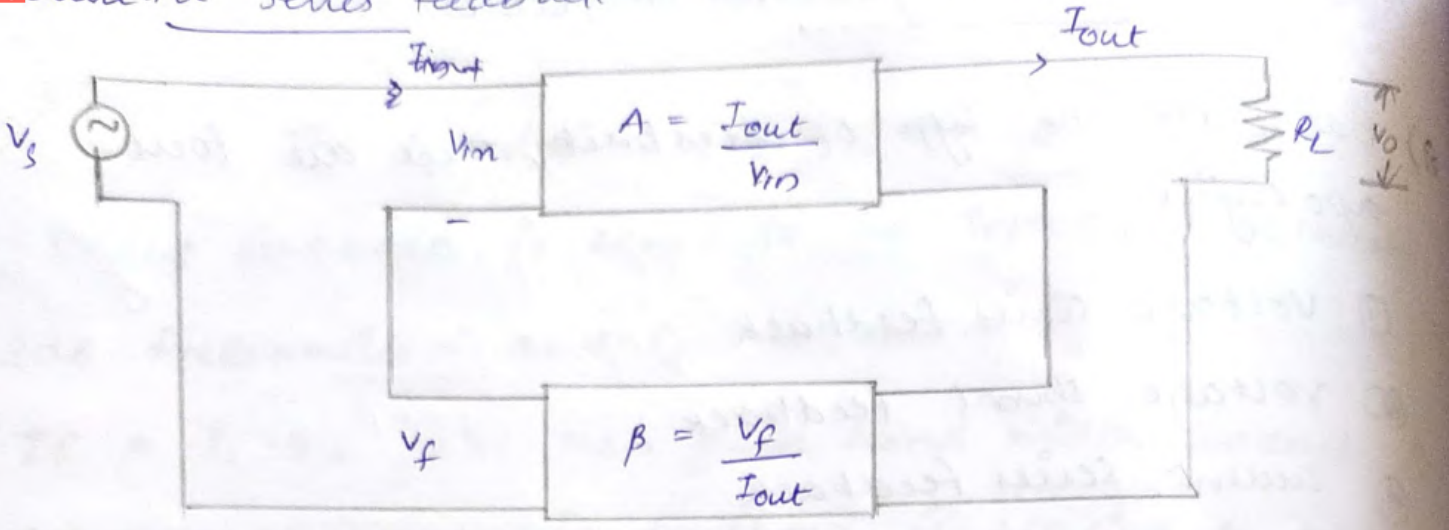
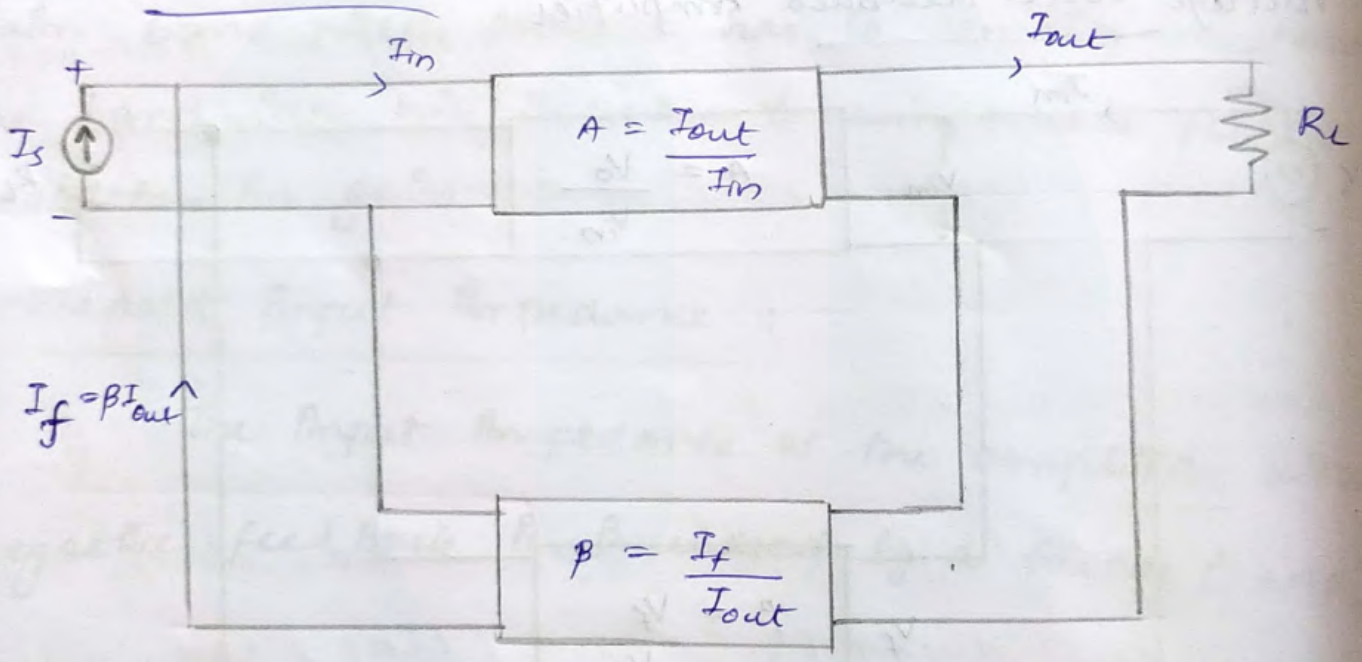
Current Series feedback



Current Shunt Feedback



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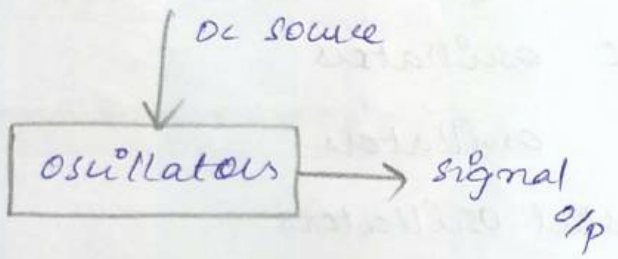
OSCILLATORS

* Any circuit which is used to generate a voltage (o/p) without an ac input signal is called an oscillator.
* To generate a voltage, the circuit is supplied with energy from a dc source.
* Oscillators are amplifiers with positive feedback.
* It simply converts unidirectional current from a dc source of supply into alternating current of desired frequency. Therefore it sometimes called an inverter



Classification of oscillators

① According to waveforms generated ⇒

ⓐ Sinusoidal oscillators : Generates sinusoidal voltages or currents.

ⓑ Relaxation oscillators : Generates voltages or currents which vary abruptly one or more times in a cycle of oscillation.

② Based on fundamental mechanisms ⇒

a) Negative resistance oscillators

b) Feedback Oscillators

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(B) According to the frequency generated ⇒

a) Audio frequency oscillator (AFO) : upto 20 KHZ

b) Radio frequency oscillator (RFO) : 20 KHZ to 30 MHZ

c) Very high frequency (VHF) oscillator : 30 MHZ to 300MHZ

d) Ultra high frequency (UHF) oscillator : 300 MHZ – 3GHZ

e) Microwave frequency oscillator : Above 3GHZ

(A) According to the type of circuits used, sinusoidal oscillators may be classified as

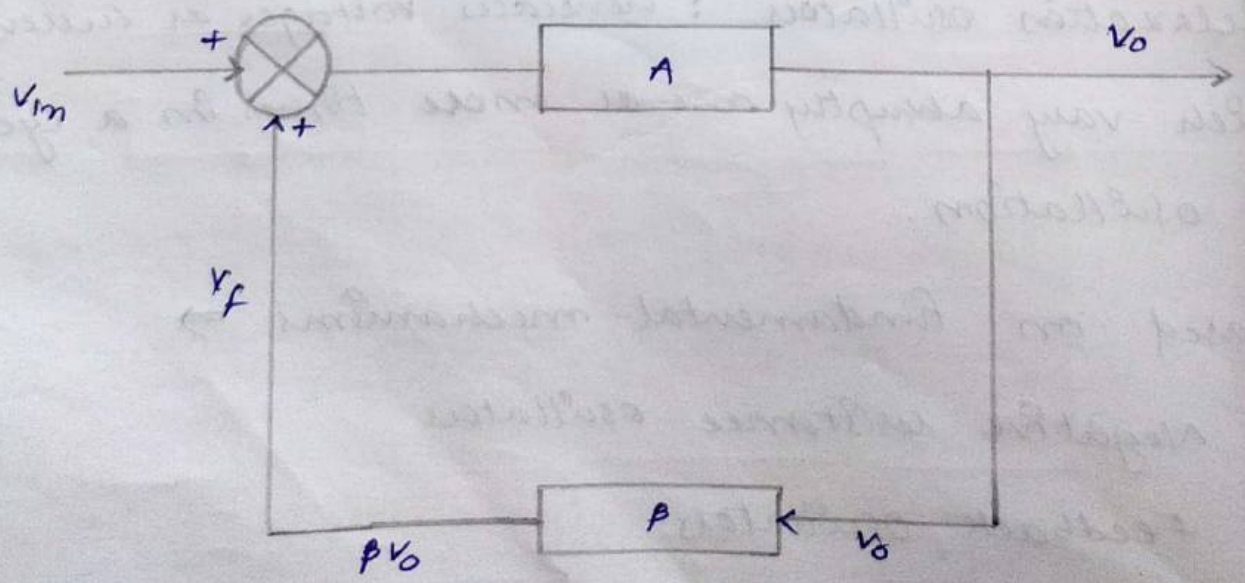
(a) LC oscillators

(b) RC oscillators

(c) Crystal oscillators

Principle of oscillators

* Oscillators are amplifiers with positive feedback.
* Consider a feedback amplifier with an input signal V_{in} and o/p V_o.



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* A is open loop gain of the amplifier

* Without feedback, the o/p voltage of the amplifier is $V_o = A V_{in}$

* When positive feedback is used, the feedback voltage V_f is added to the input signal V_{in}. Thus the input will become $V_f + V_{in}$

with f/b the o/p voltage $V_o = A\ (V_{in} + V_f)$

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

$$V_o - A\beta V_o = A V_{in}$$

$$V_o\ (1 - A\beta) = A V_{in}$$

$$\therefore \text{Gain} = \frac{V_o}{V_{in}} = \frac{A}{1 - A\beta}$$

Consider the case when input signal V_{in} is removed. so that feedback signal V_f is directly ~~proportional~~ connected to the amplifier. This is the case of the oscillator that no input signal is applied to it.

ie, If $V_{in} = 0$; $V_o\ (1 - A\beta) = 0$

$$A\beta = 1$$

$\therefore$ Loop gain $A\beta = 1 \Rightarrow |A\beta| = 1$ and $\angle A\beta = 0$

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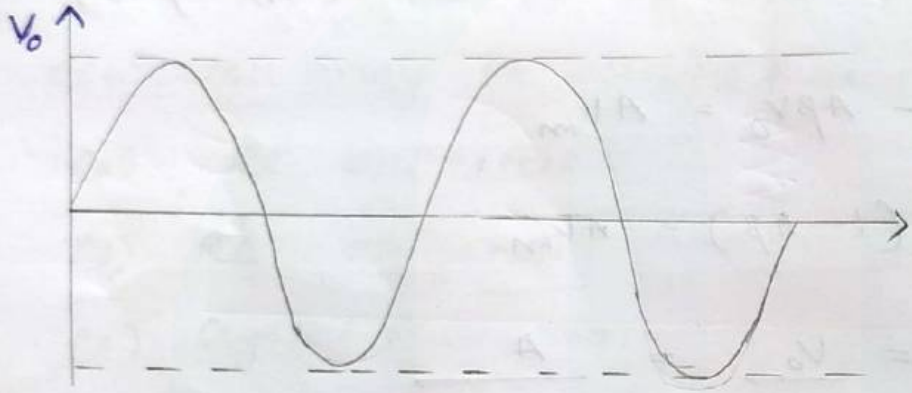
Thus the conditions for sustained oscillations are

1) The magnitude of the loop gain $A\beta$ of the circuit must be equal to unity (one) ie, $A\beta = 1$

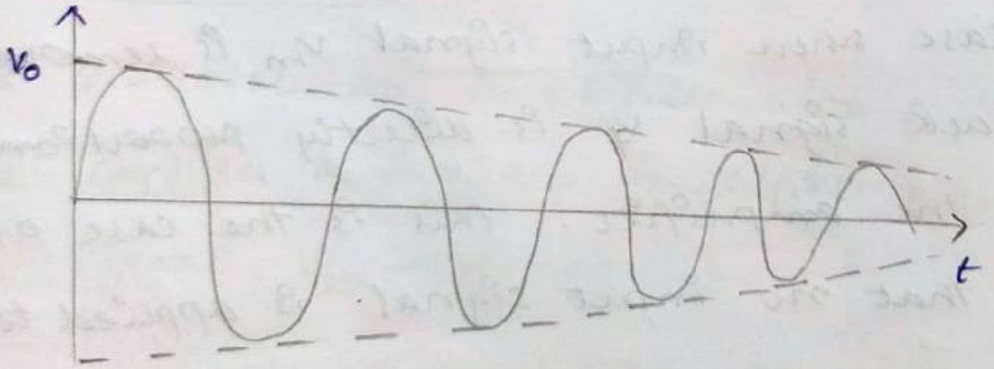
2) The Phase shift of the loop gain $A\beta$ around the circuit must be $0°$ or $360°$ ie $\angle A\beta = 0°, 2\pi, 4\pi$ –

These requirements are known as Barkhausen Criteria.

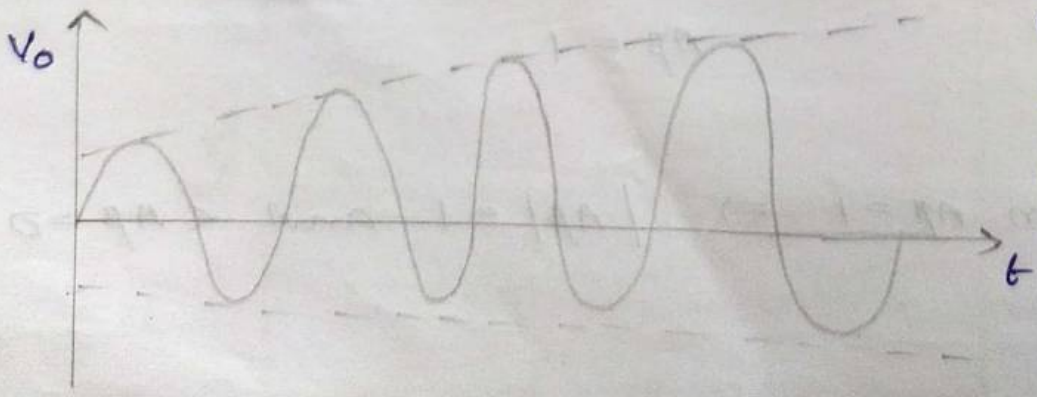
Oscillations will not be sustained if $A\beta < 1$ or $A\beta > 1$.



o/p waveform of oscillator if $A\beta = 1$ (sustained oscillations)



when $A\beta < 1$ the o/p signal will die out (damped oscillation)



when $A\beta > 1$, the o/p signal will builds up gradually (growing oscillator)

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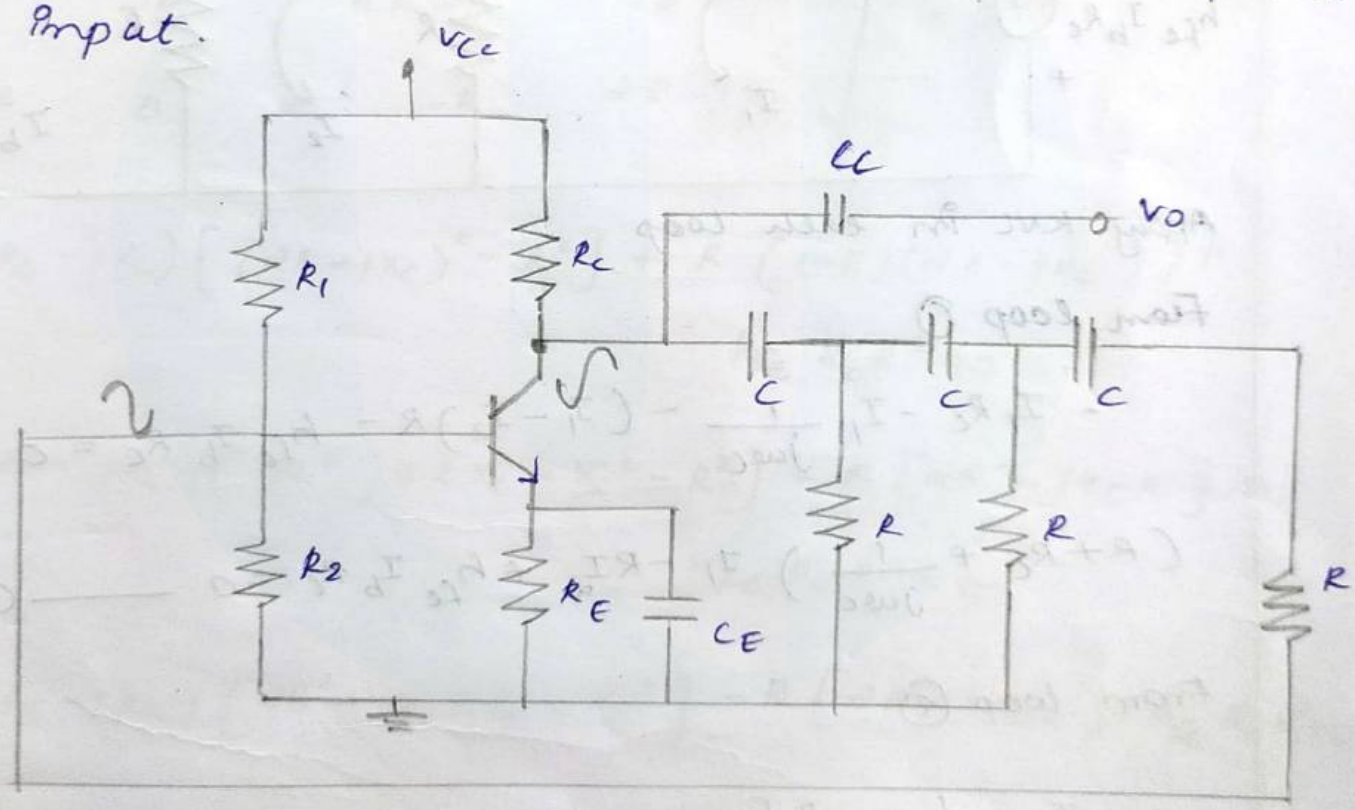
RC OSCILLATORS (Audio oscillators)

→ Employs resistors and capacitors to generate low or audio frequency signals.

→ Two types : ① RC phase shift oscillators
② Wein bridge oscillators

RC phase shift oscillators

In RC phase shift oscillators, an external resistor capacitor (RC) n/w feeds a portion of o/p of an amplifier to its input.



→ The amplifier used here is common emitter (CE) amplifier which produces a phase shift of 180° and the feedback b/w (RC phase shift b/w) produces a further phase shift of 180°. Therefore total phase shift becomes 0° or 360°, which is essential for

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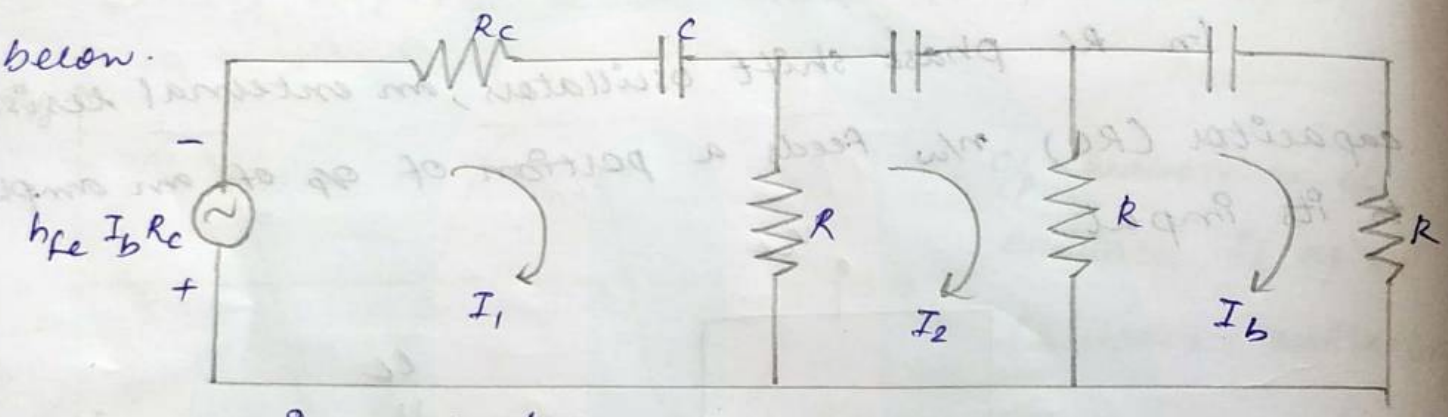
sustained oscillations.

→ The circuit is set into oscillations by any random or variation caused in base current, this variation in base current is amplified in the collector circuit. The o/p of amplifier is supplied to RC feedback n/w.

Frequency of oscillation

9) It is delivered from the equivalent circuit shown below.



Apply KVL in each loop

From loop ①

$$-I_1 R_c - I_1 \frac{1}{j\omega c} - (I_1 - I_2)R - h_{fe} I_b R_c = 0$$

$$\left(R + R_c + \frac{1}{j\omega c}\right) I_1 - R I_2 + h_{fe} I_b R_c = 0 \quad \text{——— ①}$$

from loop ②

$$-I_2 \frac{1}{j\omega c} - R[I_2 - I_b] - R[I_2 - I_1] = 0$$

$$-R I_1 + \left[2R + \frac{1}{j\omega c}\right] I_2 - R I_b = 0 \quad \text{——— ②}$$

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Ktu Q bank loop ③

$$-I_b \frac{1}{j\omega c} - RI_b - R[I_b - I_2] = 0$$

$$0 - RI_2 + \left[2R + \frac{1}{j\omega c}\right] I_b = 0 \quad \text{—— ③}$$

As the currents I_1, I_2 and I_b are non-vanishing. The determinant of coefficients of I_1, I_2 and I_b should be zero. Also substitute $X_c = \frac{1}{\omega c}$

$$\therefore \begin{vmatrix} R + R_c - jX_c & -R & h_{fe} R_c \\ -R & 2R - jX_c & -R \\ 0 & -R & 2R - jX_c \end{vmatrix} = 0$$

$$(R + R_c - jX_c)\left[(2R - jX_c)^2 - R^2\right] + R\left((-R)(2R - jX_c)\right) + h_{fe} R_c R^2 = 0$$

$$(R + R_c - jX_c)\left[4R^2 - j4RX_c - X_c^2 - R^2\right] - R\left[2R^2 - jX_cR\right] + h_{fe} R_c R^2 = 0$$

$$(R + R_c - jX_c)\left[3R^2 - 4jRX_c - X_c^2\right] - R\left[2R^2 - jX_cR\right] + h_{fe} R_c R^2 = 0$$

$$3R^3 - RX_c^2 - j4R^2X_c + 3R^2R_c - X_c^2R_c - j4RR_cX_c - jX_c3R^2 + jX_c^3 + j^2 4RX_c^2 - 2R^3 + jX_cR^2 + h_{fe} R_c R^2 = 0$$

$$R^3 - 5RX_c^2 - 6jX_cR^2 + R^2R_c[3 + h_{fe}] - R_cX_c^2 - j4RR_cX_c + jX_c^3 = 0$$

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Group real and imaginary parts together

$$R^3 - 5RX_c^2 - R_cX_c^2 + R^2R_c[3+h_{fe}] - j[6X_cR^2 + 4RR_cX_c - X_c^3] = 0$$

Equating imaginary components to zero

$$6R^2X_c + 4RR_cX_c - X_c^3 = 0$$

$\div$ by X_c

$$6R^2 + 4RR_c - X_c^2 = 0$$

$$X_c^2 = 6R^2 + 4RR_c$$

$$X_c = \sqrt{6R^2 + 4RR_c}$$

$$2\pi fC = \frac{1}{\sqrt{6R^2 + 4RR_c}}$$

$$f = \frac{1}{2\pi RC\sqrt{6 + 4\frac{R_c}{R}}}$$

If $R = R_c$ then

$$f = \frac{1}{2\pi RC\sqrt{10}}$$

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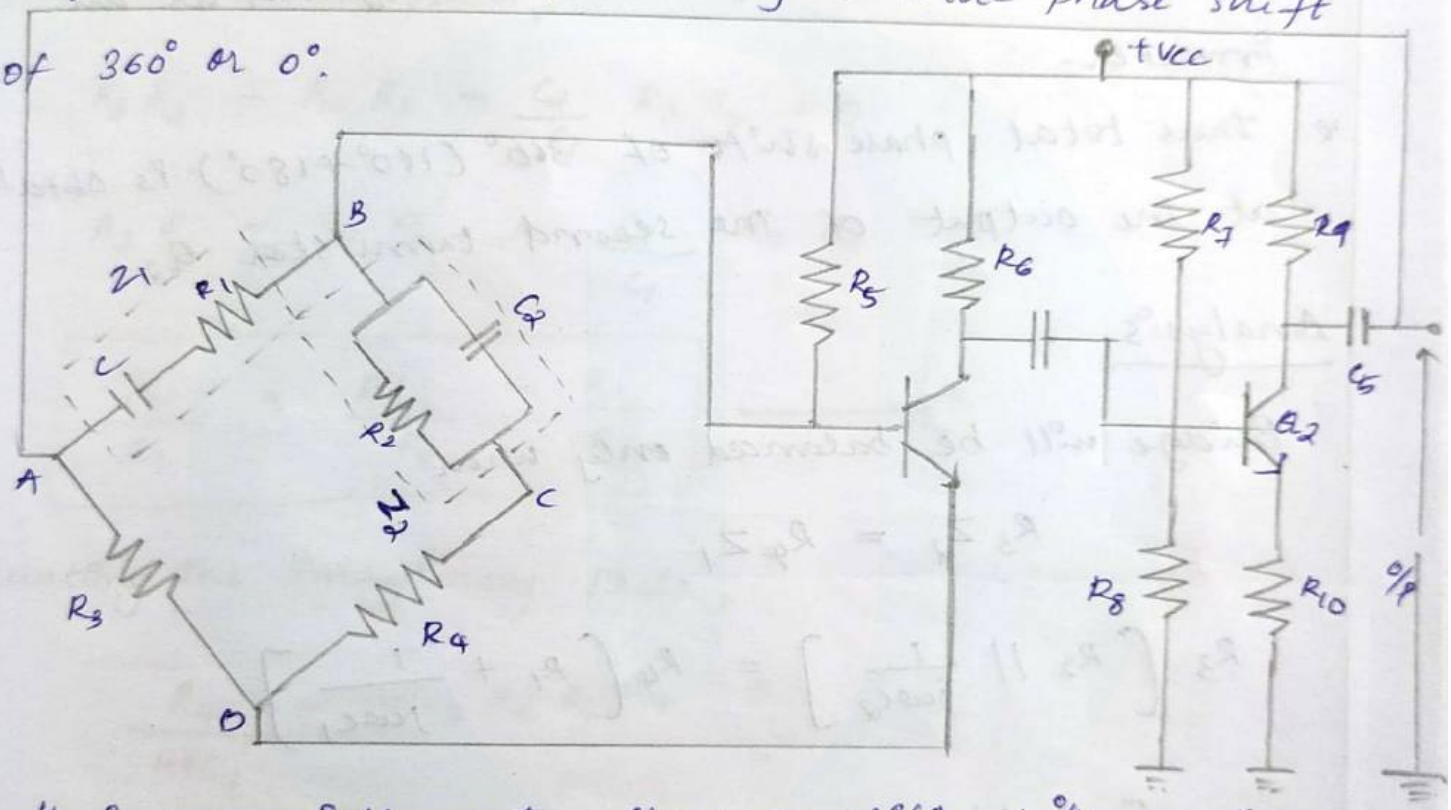
bridge oscillator

→ Most popular type of oscillators used in audio and subaudio frequency ranges ie (20 - 20 KHZ).

→ It is simple in design, compact in size and remarkable stable in its frequency o/p.

→ It employs two transistors, each producing a phase shift of 180°, thus producing a total phase shift of 360° or 0°.



→ It is essentially a two stage amplifier with an RC bridge circuit (wein bridge circuit).

→ RC bridge circuit is a lead - lag n/w. ie the bridge circuit has four arms each containing components ① R_1C_1 in series ② R_2C_2 in parallel ③ R_3 ④ R_4

→ The frequency of oscillation is provided by series elements R_1C_1 and parallel elements R_2C_2 of bridge n/w.

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Operation

* When dc power supply is switched ON, the bridge circuit produces the oscillations of certain frequency.
* These oscillations are fed to transistor Q_1. After amplification, these oscillations are fed to second transistor.
* Q_1 serves as an amplifier and Q_2 acts as an inverter.
* Thus total phase shift of 360° $(180^\circ + 180^\circ)$ is obtained at the output of the second transistor Q_2.

Analysis

Bridge will be balanced only when

$$R_3 Z_2 = R_4 Z_1$$

$$R_3 \left[R_2 \parallel \frac{1}{j\omega C_2} \right] = R_4 \left[R_1 + \frac{1}{j\omega C_1} \right]$$

$$R_3 \left[\frac{R_2 / j\omega C_2}{R_2 + \frac{1}{j\omega C_2}} \right] = R_4 \left[R_1 + \frac{1}{j\omega C_1} \right]$$

$$R_3 \left[\frac{R_2}{j\omega C_2 R_2 + 1} \right] = R_4 \left[R_1 - \frac{j}{\omega C_1} \right]$$

$$R_3 R_2 = R_4 \left[j\omega C_2 R_2 + 1 \right] \left[R_1 - \frac{j}{\omega C_1} \right]$$

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$$R_3 R_2 = R_4 \left[j\omega C_2 R_2 R_1 + \frac{C_2 R_2}{C_1} + R_1 - \frac{j}{\omega C_1} \right]$$

$$= j\omega C_2 R_2 R_1 R_4 + \frac{C_2 R_2 R_4}{C_1} + R_4 R_1 - \frac{j R_4}{\omega C_1}$$

$$R_3 R_2 - R_4 R_1 - \frac{C_2}{C_1} R_2 R_4 + \frac{j R_4}{\omega C_1} - j\omega C_2 R_2 R_1 R_4 = 0$$

Equating the real parts,

$$R_3 R_2 - R_4 R_1 - \frac{C_2}{C_1} R_2 R_4 = 0$$

$$R_3 R_2 - R_4 R_1 = \frac{C_2}{C_1} R_2 R_4$$

$$\boxed{\frac{C_2}{C_1} = \frac{R_3}{R_4} - \frac{R_1}{R_2}} \quad \text{——— (1)}$$

Equating the imaginary parts,

$$\frac{R_4}{\omega C_1} - \omega C_2 R_2 R_1 R_4 = 0$$

$$R_4 - \omega^2 C_1 C_2 R_1 R_4 R_2 = 0$$

$$\omega^2 C_1 C_2 R_1 R_4 R_2 = R_4$$

$$\omega^2 = \frac{\cancel{R_4}}{C_1 C_2 R_1 \cancel{R_4} R_2}$$

$$= \frac{1}{C_1 C_2 R_1 R_2}$$

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$$\omega = \frac{1}{\sqrt{C_1 C_2 R_1 R_2}}$$

$$2\pi f = \frac{1}{\sqrt{C_1 C_2 R_1 R_2}}$$

$$\boxed{f = \frac{1}{2\pi\sqrt{C_1 C_2 R_1 R_2}}}$$

If $C_1 = C_2 = C$ and $R_1 = R_2 = R$

then, $f = \dfrac{1}{2\pi\sqrt{R^2 C^2}}$

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

From equation ①,

$$1 = \frac{R_3}{R_4} - 1$$

$$2 = \frac{R_3}{R_4} \; ; \quad R_3 = 2R_4$$

∴ The amplifier voltage gain

$$A = \frac{R_3 + R_4}{R_4} = 1 + \frac{R_3}{R_4} = 1 + \frac{2R_4}{R_4}$$

$$\boxed{A = 3}$$

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Advantages of wein bridge oscillator

→ It gives constant output.

→ The circuit works quite easily.

→ The frequency of oscillations can be easily changed by using potentiometer.

Disadvantages

→ The circuit requires two transistors and a large no: of components.

→ It cannot generate very high frequencies.

PROBLEMS

) In a phase shift oscillator $R_1 = R_2 = R_3 = 800\ k\Omega$ and $C_1 = C_2 = C_3 = 100\ pF$. Determine the frequency of oscillation.

:- Frequency $f = \dfrac{1}{2\pi RC\sqrt{10}}$

$$= \frac{1}{2\pi \times 800 \times 10^3 \times 100 \times 10^{-12}\sqrt{10}}$$

$$= 629.115\ Hz$$

$R_1 = R_2 = R_3 = 800\ k\Omega$

$= 800 \times 10^3\ \Omega$

$C_1 = C_2 = C_3 = 100\ pF$

$= 100 \times 10^{-12}\ F$

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2) An RC phase shift oscillator has to be designed to provide a sine wave of frequency 1KHZ. If the value of frequency is 1KHZ. and c is 0.016 μF. Calculate the value of the resistances.

Ans.-

$$f = \frac{1}{2\pi RC\sqrt{10}}$$

$$R = \frac{1}{2\pi fC\sqrt{10}}$$

$$= \frac{1}{2\pi \times 1\times10^{3} \times 0.016\times10^{-6}\sqrt{10}}$$

$$R = 3.146\ K\Omega$$

$C_1 = C_2 = C_3 = 0.016\mu F$

$= 0.016 \times 10^{-6} F$

$f = 1KHZ$

$= 1\times10^{3}\ Hz$

3) A weinbridge oscillator has the following components $R_1 = R_2 = R_4 = 5.6\ K\Omega$, $R_3 = 12\ K\Omega$ and $C_1 = C_2 = 2000\ PF$ Calculate the value of frequency.

Ans.- $R_1 = R_2$ and $C_1 = C_2$

So $$f = \frac{1}{2\pi RC}$$

$$= \frac{1}{2\pi \times 5.6\times10^{3}\times2000\times10^{-12}}$$

$$f = 14.2\ KHZ$$

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A) Design the RC elements of a wein bridge oscillator for operation at $f = 10\,KHz$.

Ans:- Assume $R_1 = R_2 = 200\,k\Omega$ and $C_1 = C_2$

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

$$C = \frac{1}{2\pi R f} = \frac{1}{2\pi \times 200 \times 10^3 \times 10 \times 10^3}$$

$$C = 79.6\,pF$$

LC oscillators

* Oscillators which use inductance capacitance (LC) as the tank circuit are called L-C oscillators.
* LC oscillators are very popular for generating high frequency outputs (10 KHz to 100 MHz).
* LC oscillators are

(a) Hartley oscillator

(b) Colpitts oscillator

(c) Crystal oscillator

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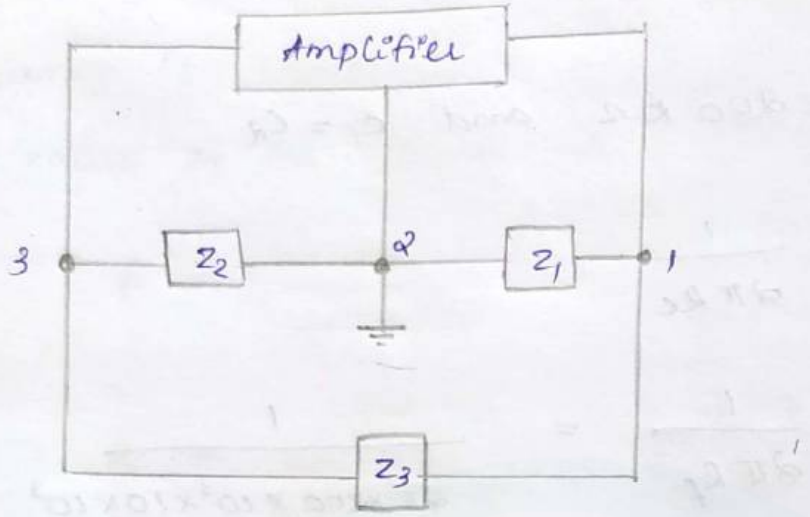
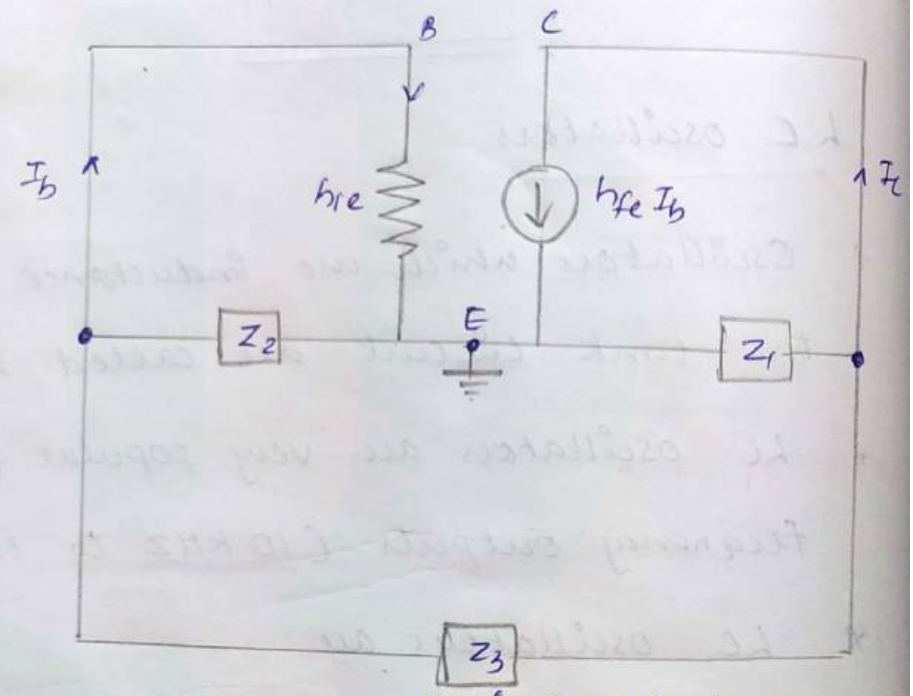
General form of an LC oscillator



General form of oscillator

⇒



equivalent circuit

* Z_1, Z_2 and Z_3 are reactive elements constituting the feedback tank circuit which determines frequency of oscillation.

* Here Z_1 and Z_2 serve as an ac voltage divider for the o/p voltage and feedback signal. Thus voltage across Z_2 is feedback signal.

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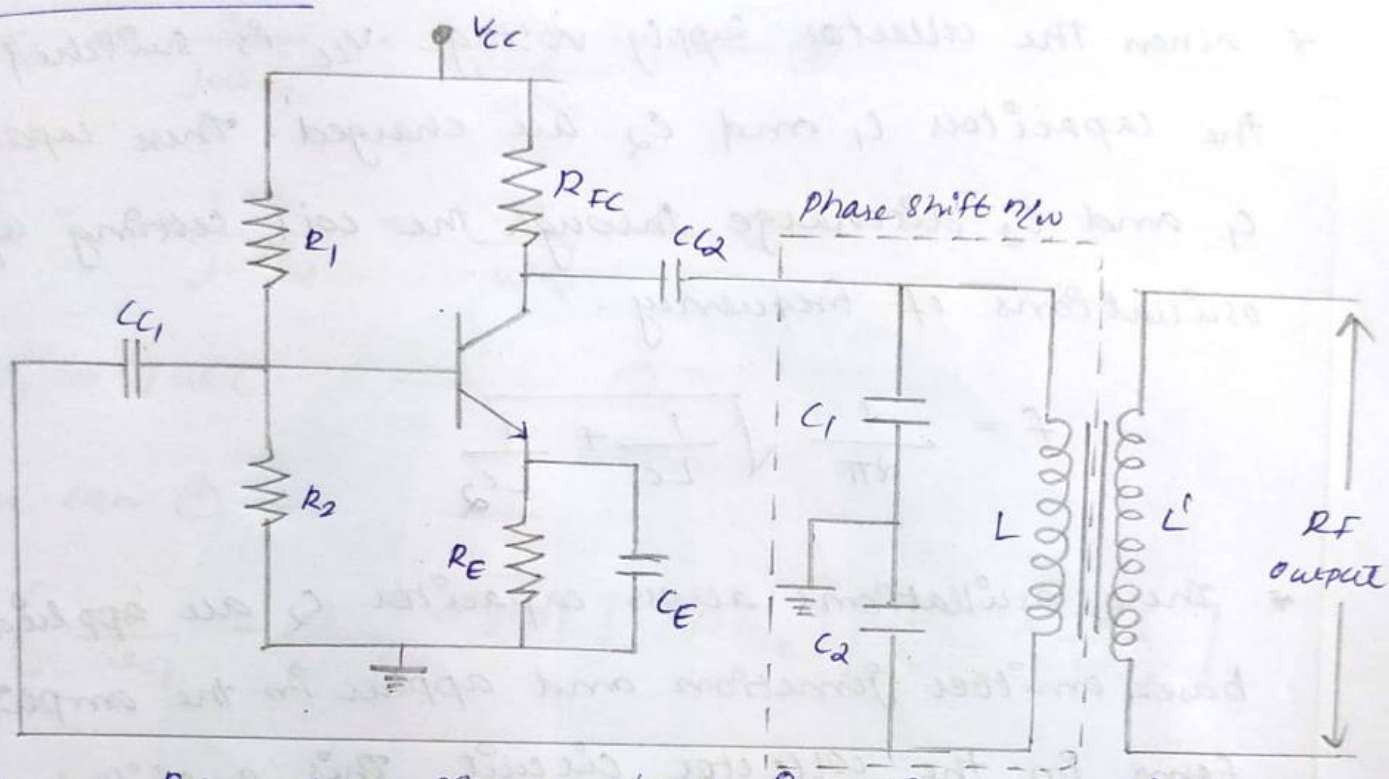
The general form equation of oscillator is

$$h_{ie}\left[(Z_1+Z_2+Z_3)\right]+(1+h_{fe})Z_1Z_2+Z_2Z_3=0$$

Colpitts Oscillator



* It consists of a single stage inverting amplifier and an LC phase shift n/w.
* Two series capacitors C_1 and C_2 from the potential divider used for providing the feedback voltage.
* Parallel combination of RE and CE along with resistors R_1 and R_2 provides the stabilised self bias.
* Transistor itself provides a phase shift of 180° and another phase shift of 180° is provided by capacitive feedback. Thus total phase shift of 360° is obtained which is a essential condition for developing oscillations.

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The o/p voltage is derived from secondary winding L_1' of the transformer.

Working

* When the collector supply voltage V_{CC} is switched ON, the capacitors C_1 and C_2 are charged. These capacitors C_1 and C_2 discharge through the coil setting up oscillations of frequency.

$$f = \frac{1}{2\pi}\sqrt{\frac{1}{LC_1} + \frac{1}{LC_2}}$$

* These oscillations across capacitor C_2 are applied to base-emitter junction and appear in the amplified form in the collector circuit. This amplified output in the collector circuit has same frequency as that of oscillatory circuit.
* The energy supplied to the tank circuit is of correct phase. If $A\beta > 1$, the oscillations are sustained in the circuit.
* The loop gain must be greater than 1 to ensure that circuit oscillates.

So $A\beta \geq 1$

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Frequency of oscillations

The general expression of oscillator is

$$h_{ie}\left[Z_1+Z_2+Z_3\right]+(1+h_{fe})Z_1Z_2+Z_2Z_3=0 \quad \text{——— (1)}$$

$$Z_1=\frac{1}{j\omega C_1}=\frac{-j}{\omega C_1} \quad \text{——— (a)}$$

$$Z_2=\frac{1}{j\omega C_2}=\frac{-j}{\omega C_2} \quad \text{——— (b)}$$

$$Z_3=j\omega L \quad \text{——— (c)}$$

Then eqn (1) $\Rightarrow$

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

$$+\left(\frac{-j}{\omega C_2}\right)j\omega L=0$$

$$-jh_{ie}\left[\frac{1}{\omega C_1}+\frac{1}{\omega C_2}-\omega L\right]-\frac{(1+h_{fe})}{\omega^2C_1C_2}+\frac{L}{C_2}=0$$

Equating imaginary components to zero

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

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

$$\frac{\omega C_1+\omega C_2}{\omega_a^2C_1C_2}=\omega L$$

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$$\frac{\omega(C_1+C_2)}{\omega^2 C_1 C_2} = \omega L$$

$$\frac{C_1+C_2}{\omega C_1 C_2} = \omega L$$

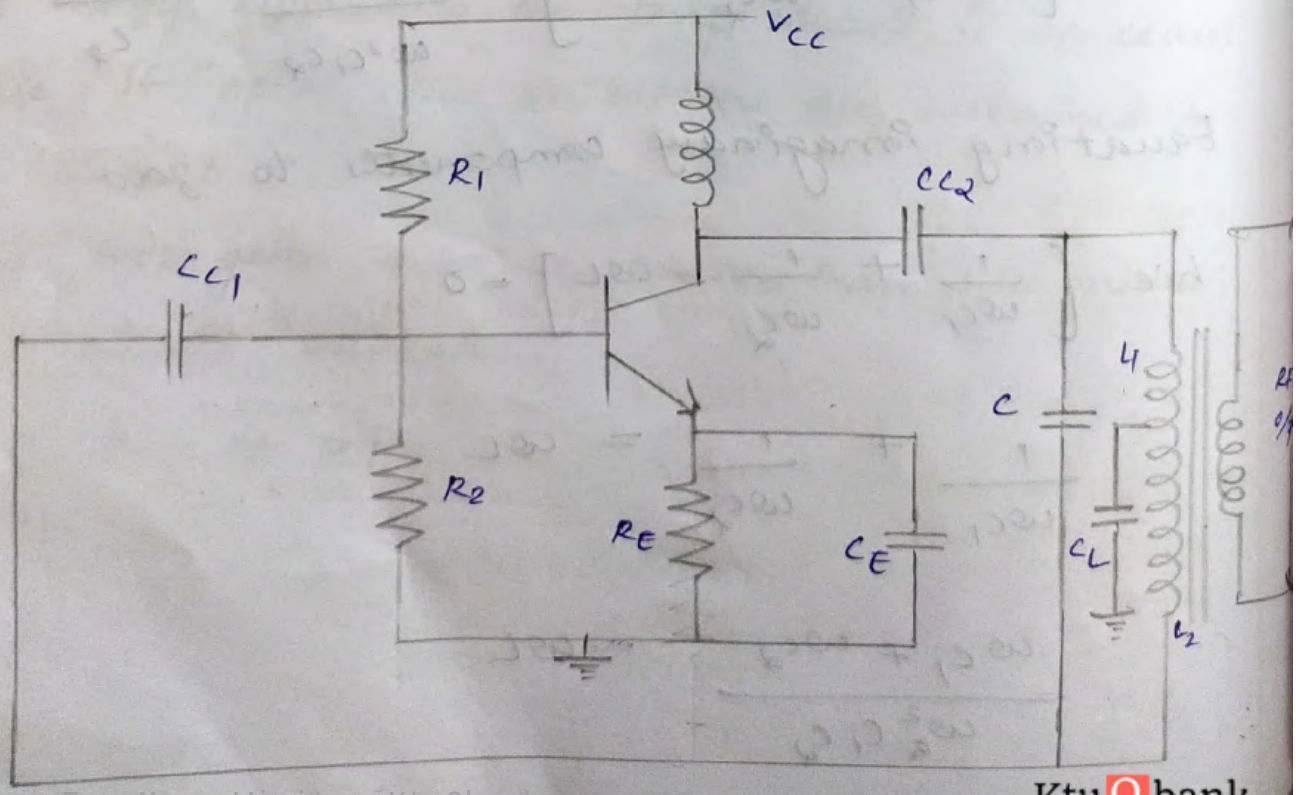
or $$\omega^2 = \frac{C_1+C_2}{LC_1C_2}$$

$$\omega = \sqrt{\frac{C_1+C_2}{LC_1C_2}} = \sqrt{\frac{1}{LC_2}+\frac{1}{LC_1}}$$

$$\therefore f = \frac{1}{2\pi}\sqrt{\frac{1}{LC_2}+\frac{1}{LC_1}}$$

$$f = \frac{1}{2\pi}\sqrt{\frac{1}{LC_1}+\frac{1}{LC_2}}$$

Hartley Oscillator



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In Hartley oscillator, the phase shift n/w consists of two inductors L_1 and L_2 and capacitor C.

* The o/p of amplifier is applied across inductor L_1 and the voltage across inductor L_2 forms the feedback voltage
* operation of the circuit is similar to that of colpitts oscillator.
* The junction between L_1 and L_2 cannot be directly grounded, instead capacitor C_L is used.
* There exists mutual inductance b/w coils L_1 and L_2 because the coils are wound on the same core

∴ Effective inductance $L = L_1 + L_2 + 2M$

* Frequency of oscillation (reasonant frequency) is given by

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

Frequency of oscillation

The general equation of oscillation is

$$h_{ie}(Z_1 + Z_2 + Z_3) + Z_1 Z_2 (1 + h_{fe}) + Z_2 Z_3 = 0 \quad \text{——— (1)}$$

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

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

$$\cancel{Z_3 = j\omega L_3 + j\omega M}$$

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

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(4) $\Rightarrow$

$$h_{ie}\left[\left(j\omega L_1 + j\omega M + j\omega L_2 + j\omega M - \frac{j}{\omega C}\right)\right] + (j\omega L_1 + j\omega M)$$

$$(j\omega L_2 + j\omega M)(1+h_{fe}) + (j\omega L_2 + j\omega M) - \frac{j}{\omega C} = 0$$

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

$$\left. - \omega^2 L_2 M - \omega^2 M^2\right](1+h_{fe}) + \frac{L_2}{C} + \frac{M}{C} = 0$$

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

$$(1+h_{fe}) + \frac{L_2 + M}{C} = 0$$

Equating imaginary parts to zero

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

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

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

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

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

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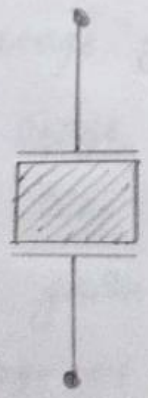
Crystal Oscillator

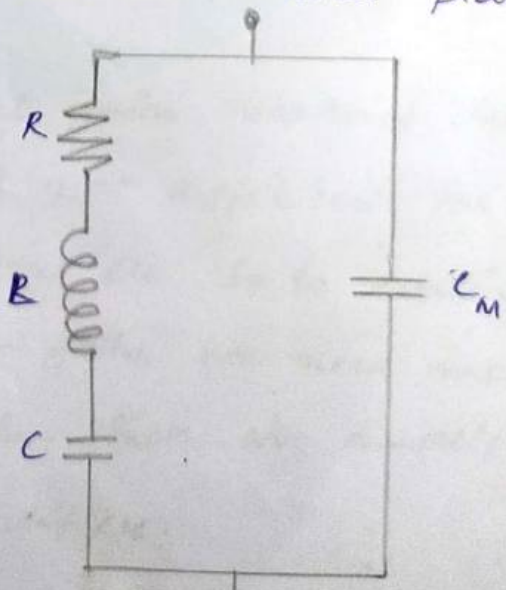
* In crystal oscillator, the electric resonant circuit is replaced by a mechanically vibrating crystal.
* The crystal (usually quartz) has a high degree of stability for holding constant frequency.
* A quartz crystal exhibits a very important property known as piezo electric effect.
* When an ac voltage is applied across a crystal, it starts vibrating at the frequency of supply voltage. Conversely when a mechanical pressure is applied across the face of the crystal, a voltage proportional to the applied mechanical pressure appears across the crystal. This effect is known as piezoelectric effect.

The crystals which exhibit this effect are known as piezoelectric crystals. eg:- quartz, Rochelle salt

* For use in electronic circuits, the crystal is suitably cut and then mounted between two metal plates.



crystal mounting



C_M = The capacitance of mounting electrodes

Electrical equivalent ckt of crystal

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Because of the presence of C_M, the crystal has two resonant frequencies.

(i) Series Resonant frequency (f_s):

It is due to RLC branch and is given by

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

(2) Parallel resonant frequency (f_p):

It is due to combined circuit of C_M in parallel with RLC branch

$$f_p = \frac{1}{2\pi\sqrt{LC_T}} \qquad C_T = \frac{C \cdot C_M}{C + C_M}$$

$$\boxed{f_p = \frac{1}{2\pi}\sqrt{\frac{C + C_M}{C + C_M}}}$$

$\Rightarrow f_p > f_s$

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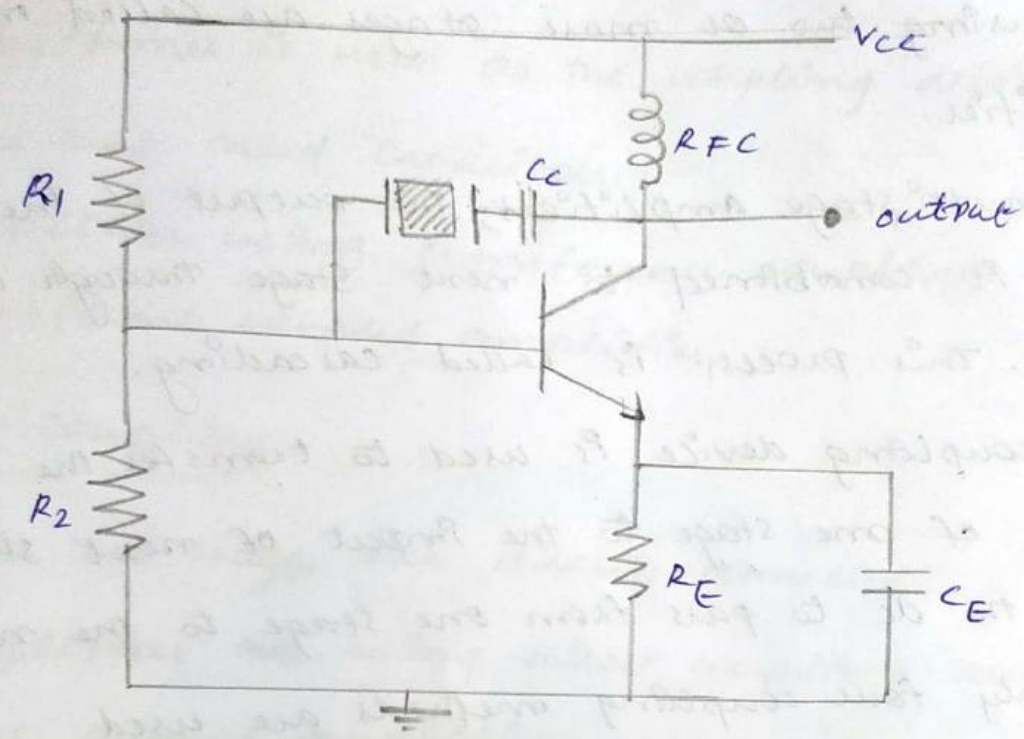
Series Crystal oscillator



* To excite a crystal for operation in series resonant mode, it may be connected as a series element in feedback path.

* R_1, R_2, R_E provides a voltage divider stabilised dc bias circuit, the capacitor C_E provides ac bypass of emitter resistor R_E and R_{FC} provides dc bias.

MULTISTAGE AMPLIFIERS

* The voltage gain or current gain obtained from a single stage amplifier is not sufficient for the devices like speakers, motors etc. So to acheive high voltage gain and current gain we need more than one stage of amplification. Such an amplifier is known as multistage amplifiers.

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* Amplifiers that produce voltage or current or power gain using two or more stages are called multistage amplifier.
* In multistage amplifiers, the output of the first stage is combined to next stage through a coupling device. This process is called cascading.
* The coupling device is used to transfer the ac output of one stage to the input of next stage. Block the dc to pass from one stage to the next stage
* Mainly four coupling methods are used

(1) RC coupling
(2) Direct coupling
(3) Transformer coupling
(4) Impedance coupling

RC coupling

* Resistors and capacitors are used for coupling.
* Most commonly used type
* It is cheap and have good frequency response
* Amplifier with RC coupling is called RC coupled amplifier.

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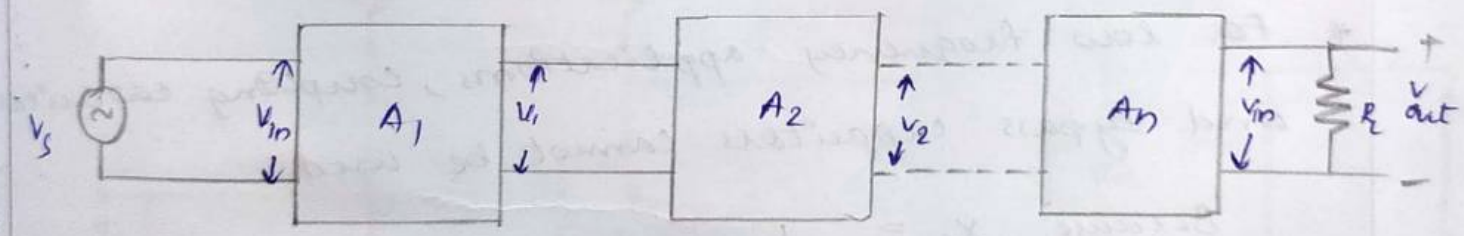
Transformer coupling

* Transformer is used as the coupling device.
* Does not need capacitors.
* Amplifier using transformer coupling is called transformer coupled amplifier.

Direct coupling

* Here two stages are directly connected
* Amplifiers ~~out~~ using direct coupling are called direct coupled amplifiers.
* Used for low frequency applications.

Multistage amplifier block diagram



* The output of the first stage makes the input for the second stage. The output of the second stage become input for the third stage and so on.
* The overall ~~gain~~ voltage gain of the amplifier

$$A = \frac{V_{out}}{V_{in}} = \frac{V_{out}}{V_s}$$

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$$= \frac{V_1}{V_{in}} \times \frac{V_2}{V_1} \times \frac{V_3}{V_2} \times \cdots \frac{V_n}{V_{n-1}}$$

$$A = A_1 \cdot A_2 \cdot A_3 \cdots A_n$$

∴ The overall gain of the multistage amplifiers is equal to the product of gains of individual stages.

When the gains are expressed in dB,

$$A_{(dB)} = A_{1(dB)} + A_{2(dB)} + \cdots + A_{n(dB)}$$

Direct coupled Transistor Amplifier

* Direct coupling is essential for very low frequency (below 10 Hz) applications such as photoelectric current, thermocouple current etc.
* For low frequency applications, coupling capacitors and bypass capacitors cannot be used.

Because $X_c = \frac{1}{2\pi f C}$

when frequency is low, X_c will become large

* If we include this capacitors, their values will be extremely large, large in size and are very expensive.
* To avoid this, one stage is directly connected to the next stage without using any coupling

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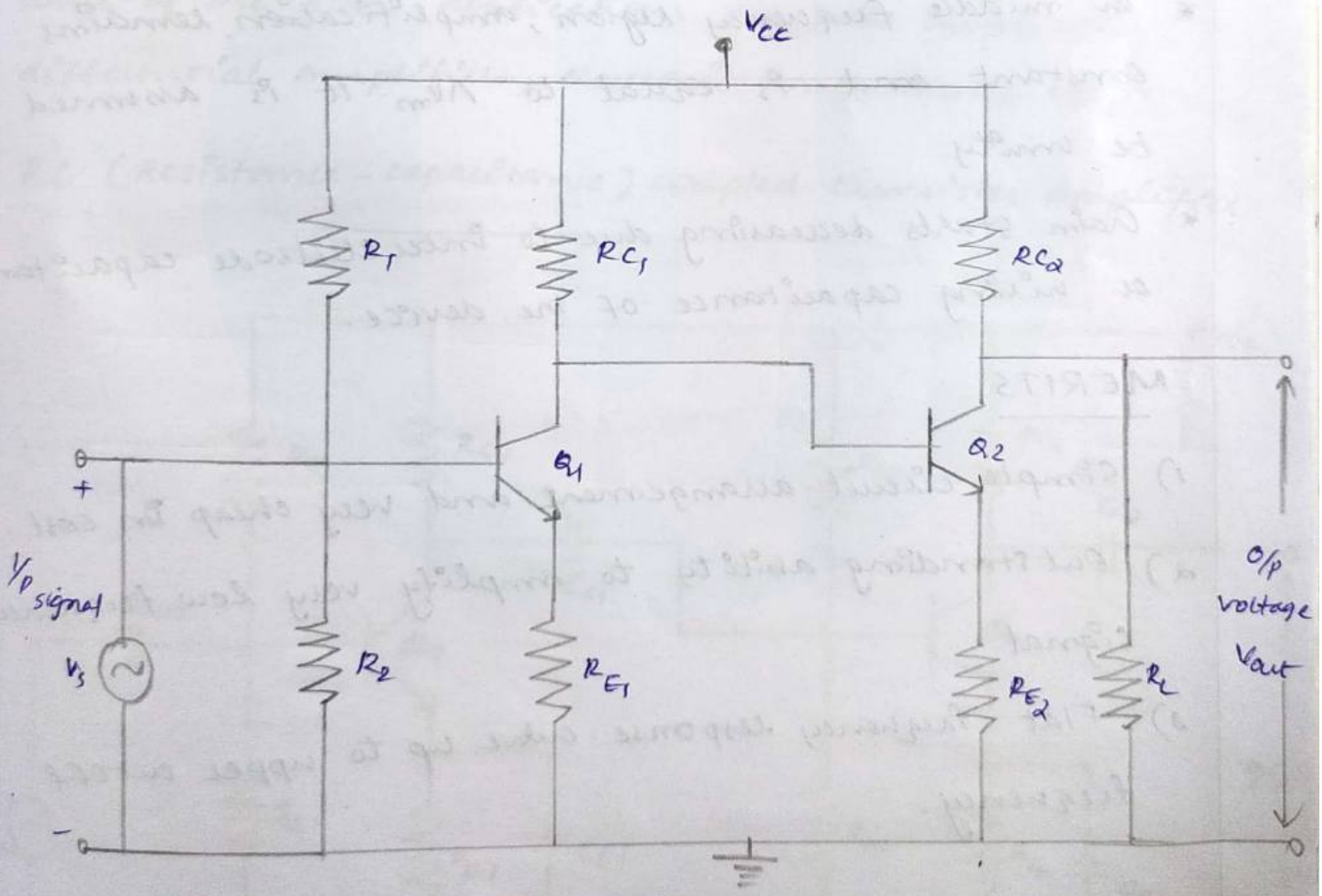
Hence the name direct coupled amplifier.

Operation

* A weak signal is applied to the base of the transistor.
* An amplified output is obtained across the collector resistor R_{C_1} of the transistor Q_1. This amplified signal is applied to the base of the next transistor.
* This is further amplified by the next stage and so on.
* Thus weak signal is amplified by a direct coupled amplifier.



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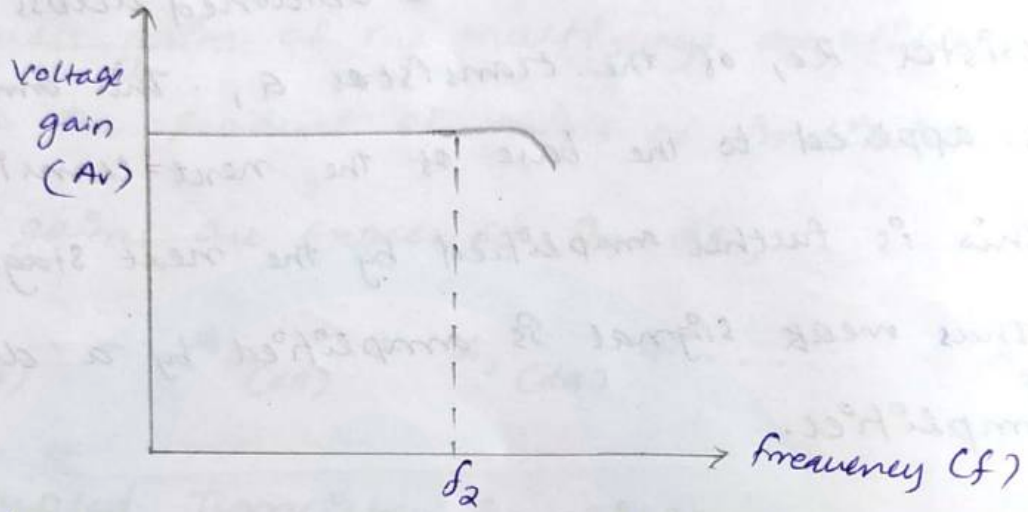
Typical Frequency Response

* The curve drawn between voltage gain and signal frequency of a amplifier is known as frequency response.



* In middle frequency region, amplification remains constant and is equal to A_{Vm}. It is assumed to be unity.

* Gain starts decreasing due to interelectrode capacitance or wiring capacitance of the device.

MERITS

1) Simple circuit arrangement and very cheap in cost.
2) Outstanding ability to amplify very low frequency signal.
3) Flat frequency response curve up to upper cutoff frequency.

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DEMERITS

1) It is not suitable for amplification of high frequency signals.

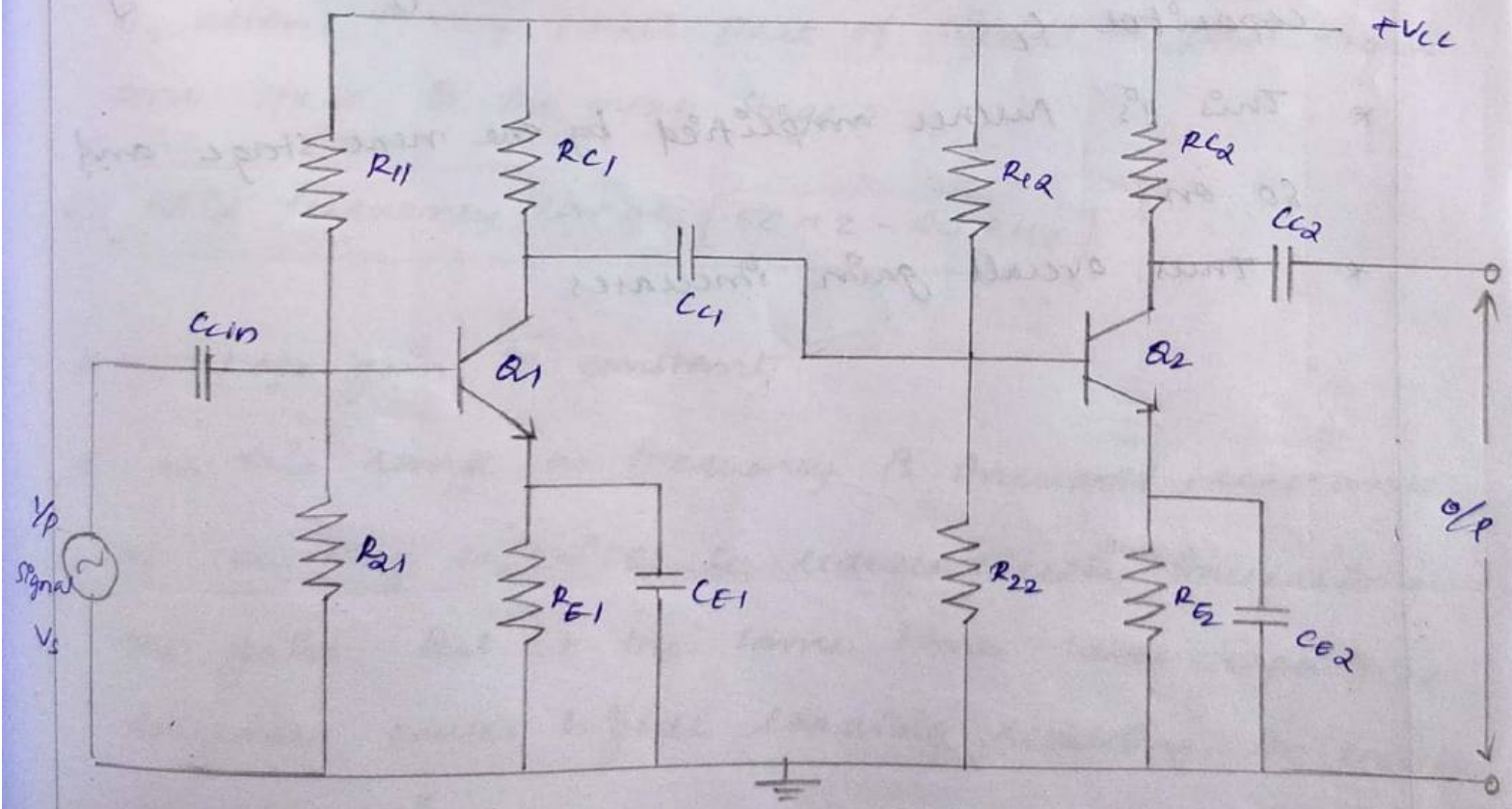
2) It has poor temperature stability.

APPLICATIONS

Direct coupled amplifiers are used when the load is directly in series with the output terminal of the active circuit element such as headphones, loudspeakers etc.

Some of the other applications are pulse amplifiers, differential amplifiers, electronic instruments etc.

RC (Resistance - capacitance) coupled transistor amplifier



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* Two transistors Q_1 and Q_2 are identical.
* Resistors R_1 R_2 and R_E form biasing and stabilization network.
* The function of input capacitor C_{in} is to allow only ac from signal source to the input.
* Emitter bypass capacitor C_E provides low reactance path to the signal. If CE is absent the gain reduces

Operation

* When ac signal is applied to the base of first amplifier, it appears in amplified form across collector resistor R_C.
* This amplified signal transmitted to the base of next stage of the amplifier through coupling capacitor C_C.
* This is further amplified by the next stage and so on.
* Thus overall gain increases.

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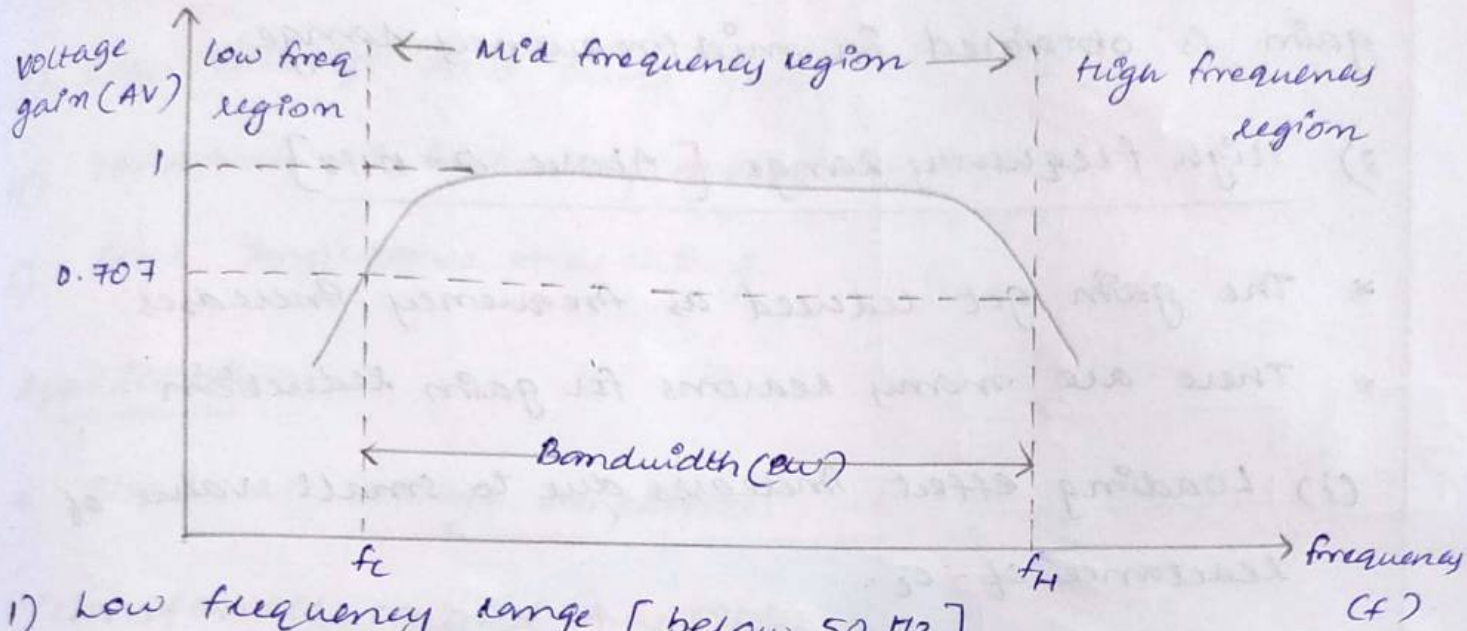
Frequency Response Curve



1) Low frequency range [below 50 Hz]

* At low frequencies, capacitive reactance is high

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

* Hence voltage gain falls at low frequencies.
* Higher capacitive reactance of coupling capacitor C_C allows a very small part of signal to pass from one stage to the next stage.

2) Mid frequency range [50 Hz - 20 kHz]

* voltage gain is constant.
* In this range as frequency is increased, reactance of coupling capacitor C_C reduces thereby increasing the gain. But at the same time lower capacitive reactance causes higher loading resulting in lower voltage gain.

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This two effects cancel each other and uniform gain is obtained in mid frequency range.

3) High frequency range [Above 20 KHz]

* The gain get reduced as frequency increases.
* There are many reasons for gain reduction.

(i) Loading effect increases due to small value of reactance of C_C.

(ii) The effect of stray capacitance, wiring capacitance and input capacitance of next stage reduces the gain.

(iii) At high frequencies, interelectrode capacitance connects the output circuit and gain is reduced.

BANDWIDTH

The difference between upper cutoff frequency (f_H) and lower cutoff frequency (f_L) is called bandwidth

$$BW = f_H - f_L$$

Advantages

1) Excellent frequency Response
2) Cheaper cost
3) very compact circuit.

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Disadvantages

1) Low voltage and power gain.
2) Tendency of becoming noisy by ages.
3) Poor impedance matching.

Applications

* Used as voltage amplifiers.

Transformer coupled Amplifier

* The main cause for low voltage and power gains of RC coupled amplifier is that the effective load of each stage is reduced due to low impedance presented by the input of each stage to the preceeding stage.
* This drawback has been overcome in a transformer coupled amplifier. By suitably selecting turns ratio of the transformer, the low resistance of a stage can be matched with the output impedance of the preceeding stage.
* Transformer coupled amplifier are used when load is small such as a loudspeaker

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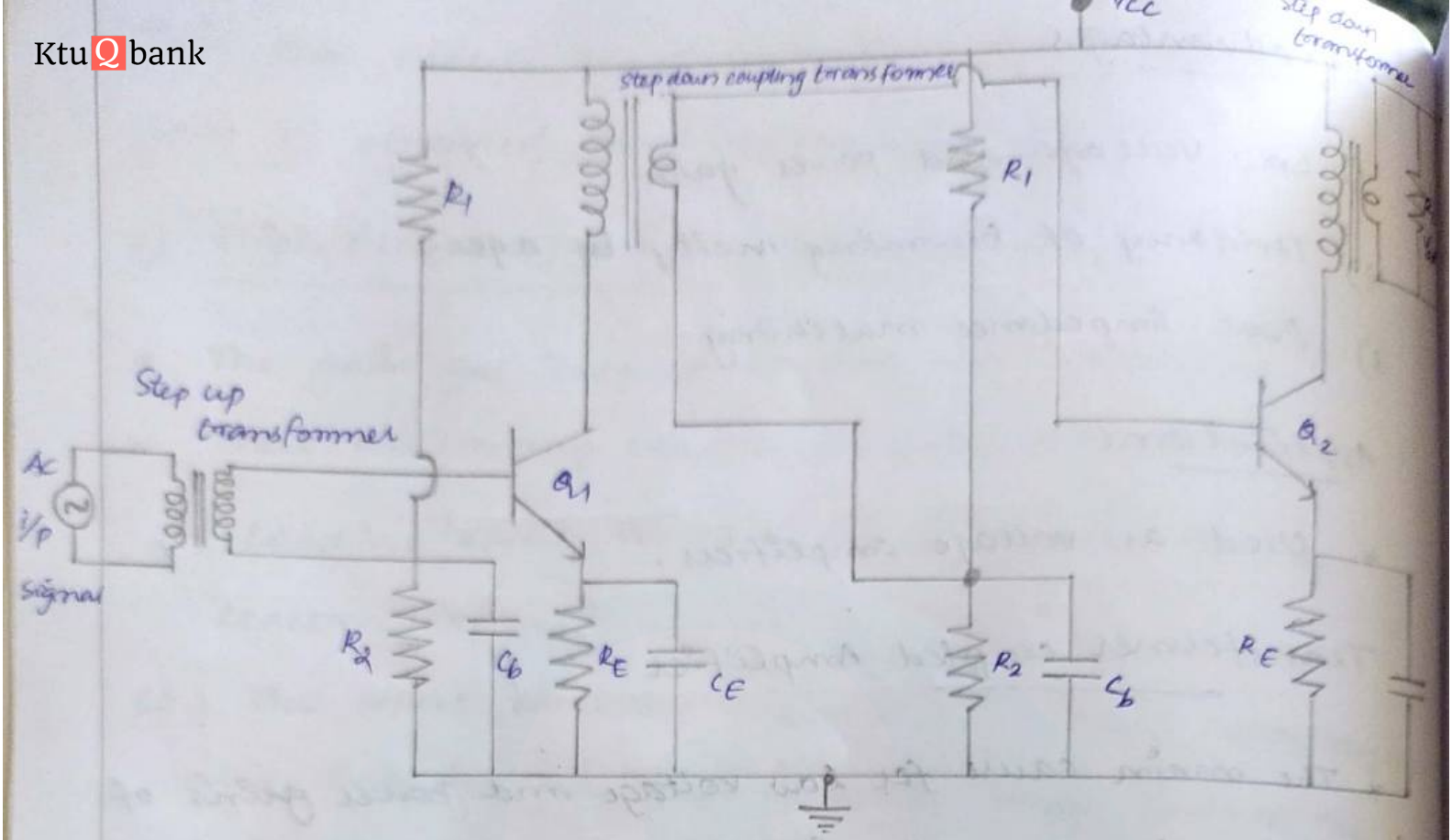

* No coupling capacitors are used in the circuit.
* A step up transformer is connected to the ac signal source as to increase the voltage level.
* A step down transformer is connected between stages of match each stages.
* A bypass capacitor (C_b) is used on the bottom of each secondary winding to get an ac ground. This prevents the loss of signal power in the biasing resistors.

Operation

* When the input ac signal is applied to the base of first transistor through a step up transformer, it gets amplified and appears across the primary

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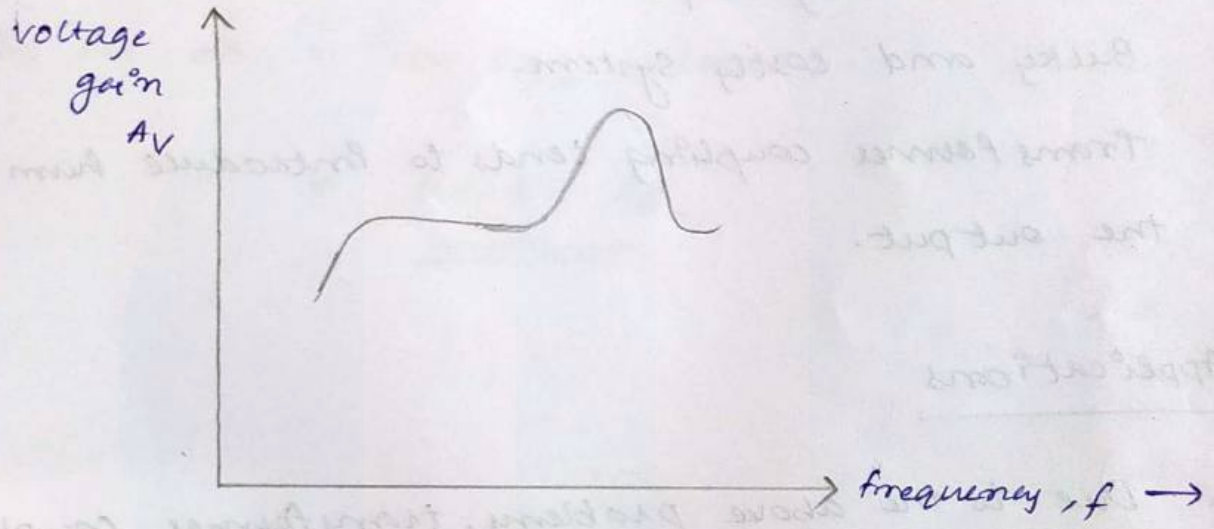
the coupling transformer.

* Voltage developed across the primary of coupling transformer is transferred to the input of next stage through secondary winding.
* The second stage further amplifies in exactly similar way and so on.

Frequency Response



* Frequency response of a transformer coupled amplifier is very poor.
* At low frequencies, the reactance decreases ($X_C = 2\pi fC$) and thus gain is reduced.
* At high frequencies, interwinding capacitance acts as bypass and reduces the output voltage and hence the gain reduces.
* Hence there will be irregular amplification over the complete range of signal frequency.

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Advantages

* More efficient than RC coupled amplifier.
* It provides excellent impedance matching which results in high gain.
* Coupling is effective.

Disadvantages

* Poor frequency response.
* Bulky and costly system.
* Transformer coupling tends to introduce hum in the output.

Applications

* Due to the above problems, transformer coupled amplifier are not used for amplifying low frequency signal.
* They are widely used for amplifying radio frequency signals.

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PROBLEM

1) The given multistage amplifier consists of three stages. The voltage gains of the stages are 30, 50 and 80. Determine the overall voltage gain in dB.

$A_1 = 30$, $A_2 = 50$, $A_3 = 80$

overall gain $= A_1 \times A_2 \times A_3$

$= 30 \times 50 \times 80 = 120000$

Gain in dB $= 20 \log_{10} (120000)$

$= 101.59$ dB

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