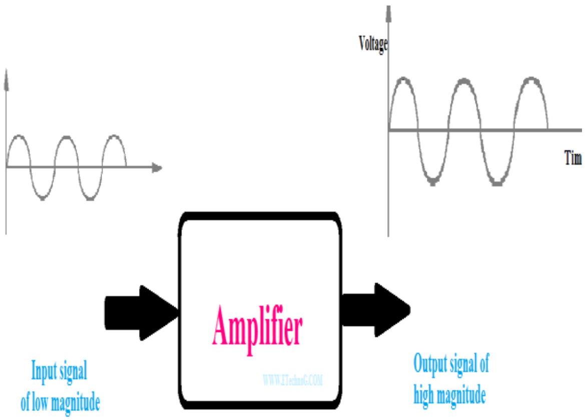
UNIT 4

Transistor Amplifiers and Oscillators

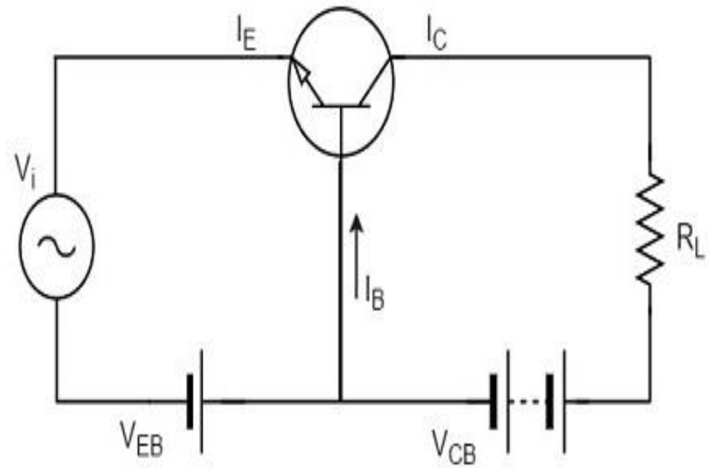
Transistor Amplifier

A transistor acts as an amplifier by raising the strength of a weak signal.



Any small change in input signal to result in an appreciable change in the output.

The emitter current caused by the input signal contributes the collector current, which when flows through the load resistor R_L, results in a large voltage drop across it.



Thus a small input voltage results in a large output voltage, which shows that the transistor works as an amplifier.

Let 0.1v is input voltage applied, which produces a change of 1mA in the emitter current.

This emitter current will produce a change in collector current of 1mA.

A load resistance of 5kΩ placed in the collector would produce a voltage of 5 kΩ × 1 mA = 5V

Hence it is observed that a change of 0.1v in the input gives a change of 5v in the output, which means the voltage level of the signal is amplified

Types of amplifiers

1. Based on the property of their output
   Voltage Amplifier
   Power Amplifier

2. Based on the number of stages
   Single stage Amplifier
   Multistage Amplifier

3. Based on the size of the input signals
   Small signal Amplifiers
   Large signal amplifiers

4. Based on the mode of operation
   Class A
   Class B
   Class AB
   Class C

5. Based on the operating frequency
   Audio frequency (AF) amplifier
   Radio Frequency (RF) amplifier

6. Based on coupling used
   RC coupled amplifier
   Transformer coupled Amplifier
   Direct coupled amplifier

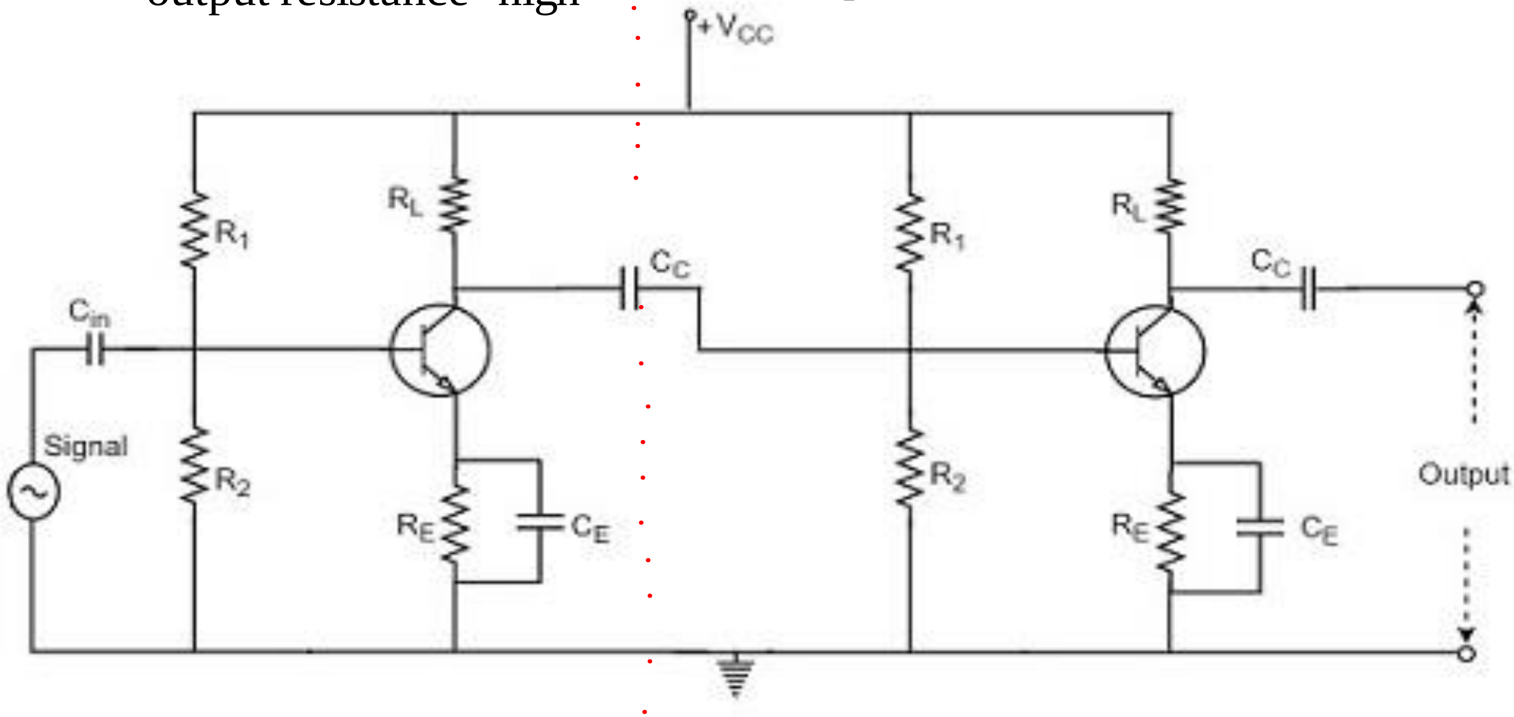
7. Based on configuration
   CB amplifier
   CE amplifier
   CC amplifier

Voltage Amplifier	Power Amplifier
In voltage amplifier the amplitude of input A.C signal is small.	In power amplifier the amplitude of input A.C signal is large.
In voltage amplifier the collector current is low, about 1 mA.	In power amplifier the collector current is very high above greater than 100mA.
The transistor used can dissipate less heat produced during its operation.	The transistor used can dissipate more heat produced as compared to voltage amplifier during its operation.
RC coupling is used in voltage amplifier.	In power amplifier invariably transformer coupling is used.
The transistor used has thin base to handle low current.	The transistor used has thick base to handle large current.
In voltage amplifier the A.C power output is low.	In power amplifier the A.C power output is high.
The physical size of transistor used is usually small and is known as low or medium power transistor.	The physical size of transistor used is usually large and is known as power transistor.
In voltage amplifier the collector load has high resistance, typically $4k\Omega$ to $10k\Omega$.	In power amplifier the collector load has low resistance, typically 5Ω to 20Ω.

RC coupled transistor Amplifier
RC பிணைப்பு பெருக்கி

output resistance=high

input resistance=less



The two stage amplifier circuit has two transistors connected in CE configuration

Power supply V_{CC} is used

R_1 and R_2 form the biasing

R_E stabilization network

Emitter by-pass capacitor C_E (capacitor allows ac blocks dc)

It offers a low reactance path to the signal

R_L - load impedance.

Input capacitor - C_{in} couples AC signal to the base of the transistor.

Capacitor C_C is the coupling capacitor - connects two stages

It prevents DC interference between the stages

Controls the shift of operating point

AC input signal is applied to the base of first transistor, it gets amplified and appears at the collector load R_L

Amplified signal is passed through the coupling capacitor C_C to the next stage.

This becomes the input of the next stage, whose amplified output again appears across its collector load.

Thus the signal is amplified in stage by stage action.

The total gain is less than the product of the gains of individual stages. $G < G1 \times G2 \times G3$

When a second stage is made to follow the first stage, the **effective load resistance** of the first stage is reduced due to the shunting effect of the input resistance of the second stage

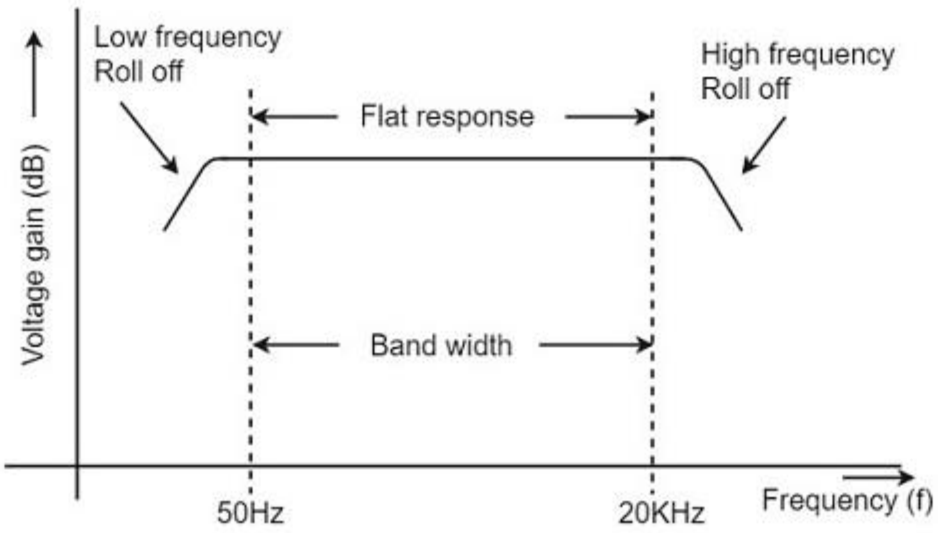
Only the gain of the last stage remains unchanged

In a two stage amplifier, the output phase is same as input.

The phase reversal is done two times by the two stage CE configured amplifier circuit

Frequency Response
அதிர்வெண் உணர்திறன் வரைபடம்

Frequency response curve is a graph that indicates the relationship between voltage gain and function of frequency.



The frequency decreases for the frequencies below 50Hz and for the frequencies above 20 KHz

voltage gain (frequencies between 50Hz and 20 KHz) is constant.

$X_C=1/\omega C=1/2\pi fc$
Capacitive reactance is inversely proportional to the frequency.

At Low frequencies (i.e. below 50 Hz)

At low frequencies, the reactance is quite high.

The reactance of C_{in} and C_C are so high and a small part of the input signal is allowed.

The reactance of C_E is also very high during low frequencies (cannot shunt the emitter resistance effectively)

Voltage gain decreases at low frequencies

At High frequencies (above 20 KHz)

Capacitive reactance is low at high frequencies ($X_C=1/\omega C=1/2\pi fc$)

Capacitor behaves as a short circuit, at high frequencies.

The loading effect of the next stage increases, which reduces the voltage gain.

Capacitance of emitter diode decreases, it increases the base current and the current gain ($\beta=I_C/I_B$) reduces

Hence the voltage gain decreases off at high frequencies

Mid-frequencies (i.e. 50 Hz to 20 KHz)

The voltage gain of the capacitors is maintained constant in this range of frequencies

If the frequency increases, the reactance of the capacitor C_C decreases which tends to increase the gain.

Lower capacitance reactive increases the loading effect of the next stage and is a reduction in gain.

Due to these two factors, the gain is maintained constant.

Advantages

- The frequency response of RC amplifier provides constant gain over a AUDIBLE frequency range
- Suitable for audio applications
- Circuit is simple
- Low cost (because it employs resistors and capacitors which are cheap)
- It becomes more compact

Disadvantages

The voltage and power gain are low because of the effective load resistance.

But many stages can be employed to increase the gain

They become noisy with age

Poor impedance matching so power transfer will be low

Applications

They have excellent audio fidelity over a wide range of frequency

Widely used as Voltage amplifiers

Due to poor impedance matching, RC coupling is rarely used in the final stages.

Transformer coupled amplifier
மின்மாற்றி பிணைப்பு பெருக்கி

The main drawback of RC coupled amplifier is that the effective load resistance gets reduced.

The input impedance of an amplifier is low, while its output impedance is high.

When they are coupled to make a multistage amplifier, the high output impedance of one stage comes in parallel with the low input impedance of next stage.

Hence, effective load resistance is decreased. This problem can be overcome by a **transformer coupled amplifier**.

Here the stages of amplifier are coupled using a transformer

Construction of Transformer Coupled Amplifier

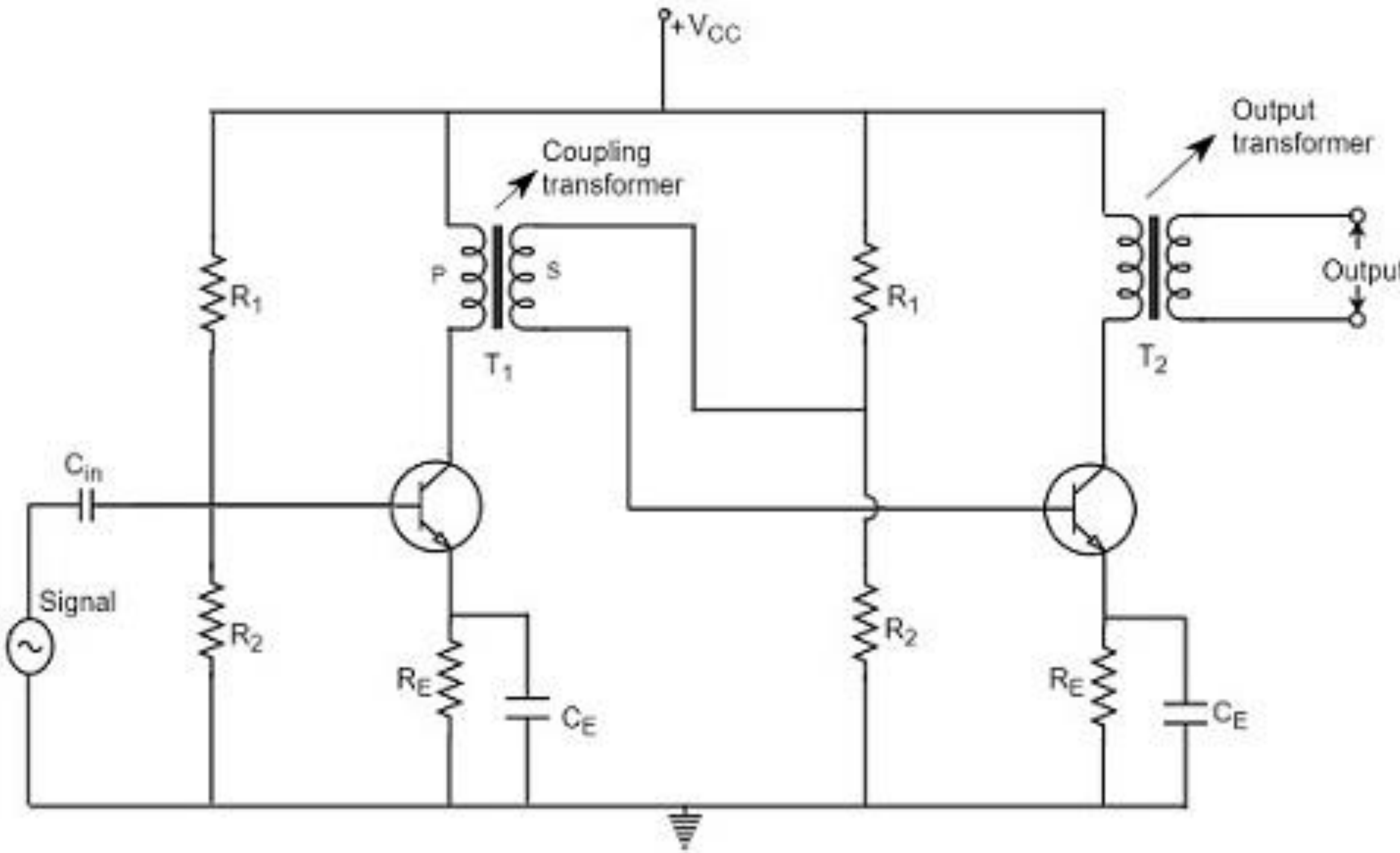
The previous stage is connected to the next stage using a coupling transformer

The coupling transformer T_1 is used to feed the output of 1^{st} stage to the input of 2^{nd} stage

The collector load is replaced by the primary winding of the transformer.

The secondary winding is connected between the potential divider and the base of 2^{nd} stage, which provides the input to the 2^{nd} stage.

A transformer is used for coupling any two stages, in the transformer coupled amplifier circuit



+V_CC
Coupling
transformer
P
S
T_1
R_1
R_2
C_in
Signal
R_E
C_E
R_1
R_2
R_E
C_E
Output
transformer
T_2
Output

The potential divider network R_1 and R_2 and the resistor R_E together form the biasing and stabilization network.

The emitter by-pass capacitor C_E offers a low reactance path to the signal.

The input capacitor C_{in} present at the initial stage of the amplifier couples AC signal to the base of the transistor.

It prevents DC interference between the stages and controls the shift of operating point.

Operation of Transformer Coupled Amplifier

When an AC signal is applied to the input at the base of the first transistor

It gets amplified by the transistor and appears at the collector to which the primary of the transformer is connected

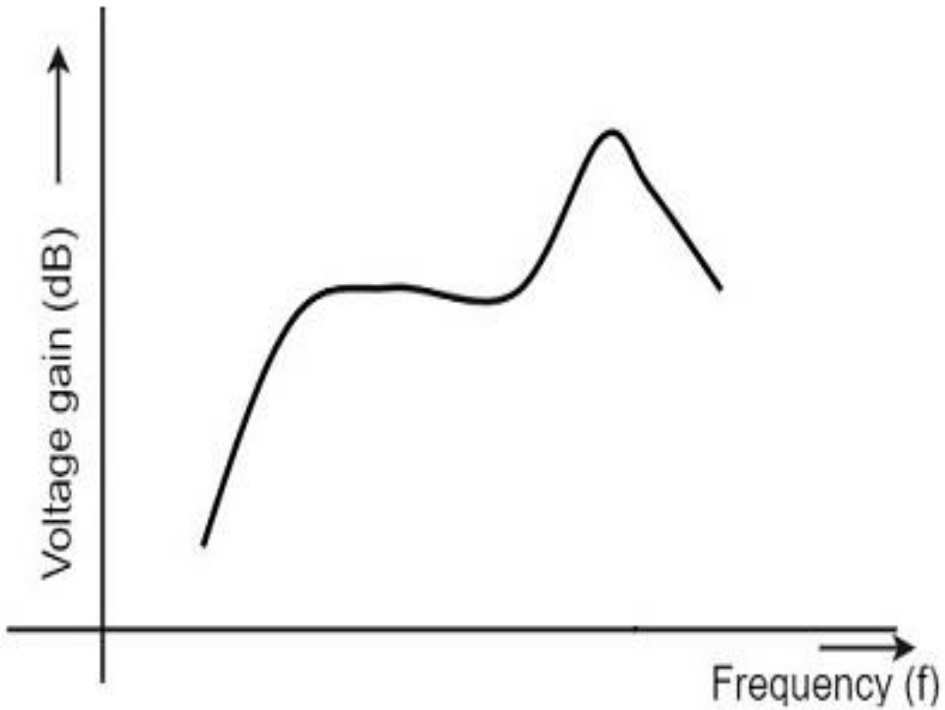
The transformer is a coupling device it has the property of impedance matching

The voltage at the primary is transferred according to the turns ratio of the secondary winding of the transformer

This transformer coupling provides good impedance matching between the stages of amplifier

The transformer coupled amplifier is generally used for power amplification.

Frequency Response of Transformer Coupled Amplifier



The gain of the amplifier is constant for a small range of frequencies

The output voltage is equal to the collector current multiplied by the reactance of primary $V_o=IX_L$

$V_o = IX_L$ ($X_L = \omega L = 2\pi fL$)

At **low frequencies,** the reactance of primary begins to fall, resulting in decreased gain. [Gain=Vo/Vi]

At **high frequencies**, the capacitance between turns of windings acts as a bypass condenser to reduce the output voltage and hence gain ($V_o = IX_C$) ($X_C = 1/\omega C = 1/2\pi fc$)

Amplification of audio signals will not be proportionate and some distortion- **Frequency distortion**

Reactance of primary=o/p impedence of transistor
Reactance of secondary= i/p impedence of transistor
Step down transformer
$R_L' = (Np/Ns)^2 R_L$
Np:Ns=10:1 , $R_L = 100\ \Omega$; $R_L' = (10/1)^2 100 = 10000 = 10\ k\Omega$

Advantages of Transformer Coupled Amplifier

- An excellent impedance matching is provided.
- Gain achieved is higher. (2RC)
- There will be no power loss in collector and base resistors.
- Efficient in operation.

Disadvantages of Transformer Coupled Amplifier

- Though the gain is high, it varies considerably with frequency.
- Poor frequency response.
- Frequency distortion is higher.
- Transformers tend to produce hum noise.
- Transformers are bulky and costly.

Applications

- Mostly used for impedance matching purposes.
- Used for Power amplification.
- Used in applications where maximum power transfer is needed

Direct coupled amplifier - நேர் பிணைப்பு பெருக்கி

Direct coupled amplifier is used to amplify lower frequency (<10Hz) signals

Amplifying photo-electric current ஒளிமின்னியமின்னோட்டம் or thermo-couple current வெப்ப மின்னிரட்டைமின்னோட்டம்

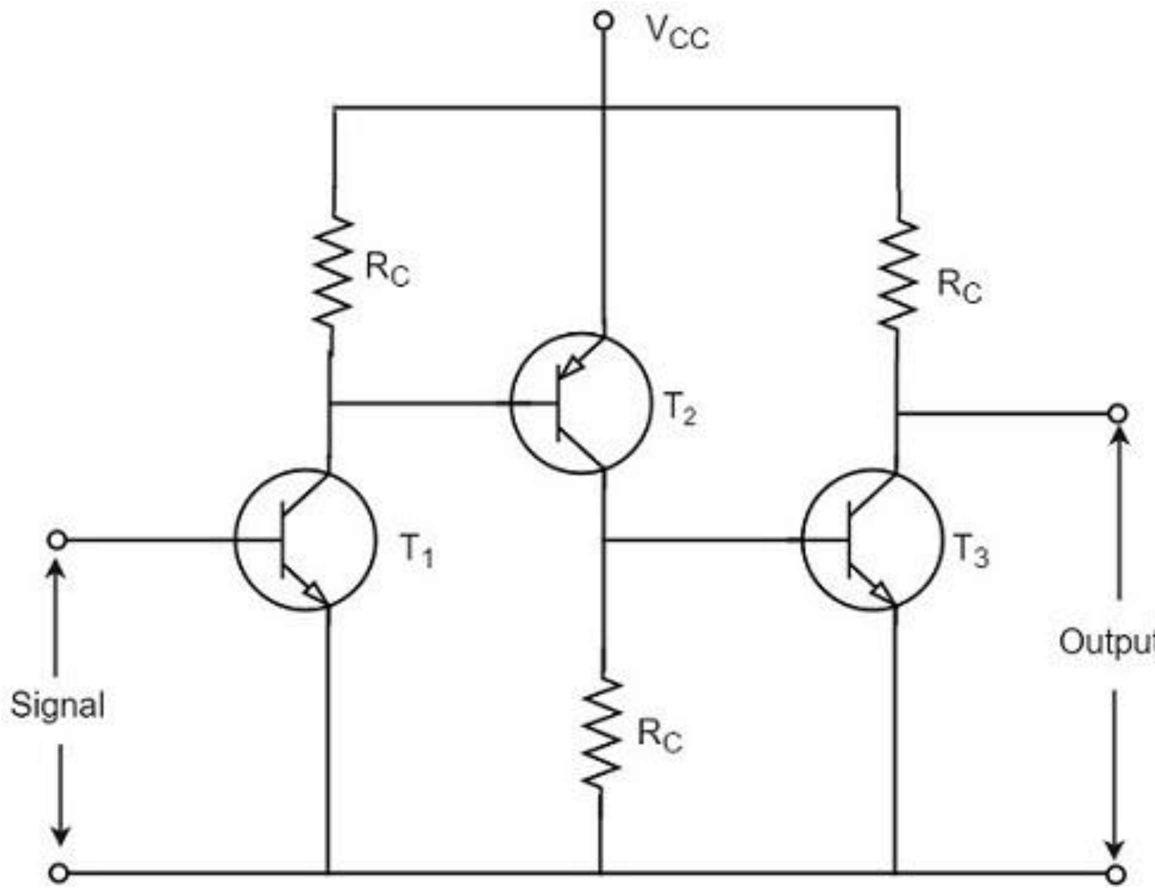
As no coupling devices are used

The coupling of the amplifier stages is done directly and hence called as **Direct coupled amplifier**

Construction

Complementary transistors are used

The output of first stage transistor T_1 is connected to the input of second stage transistor T_2.



V_{CC}
R_C
R_C
T_2
T_1
T_3
R_C
Signal
Output

The transistor in the first stage will be an NPN transistor

The transistor in the next stage will be a PNP transistor and so on.

The variations in one transistor tend to cancel the variations in the other.

The rise in the collector current and the variation in β of one transistor gets cancelled by the decrease in the other

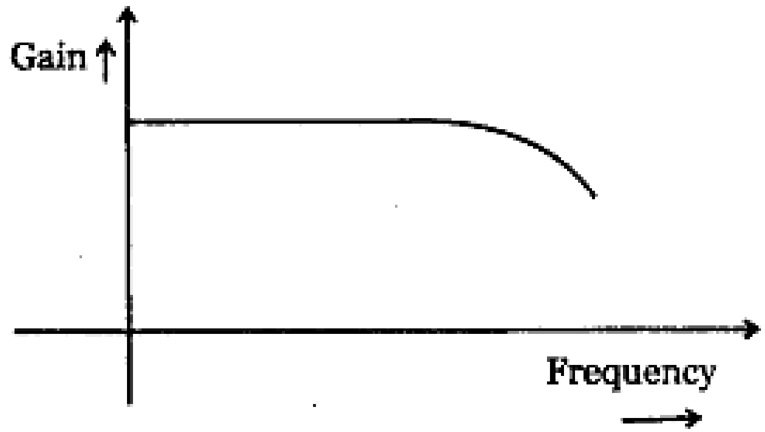
Operation

The input signal when applied at the base of transistor T_1, it gets amplified due to the transistor action

The amplified output appears at the collector resistor R_c of transistor T_1.

This output is applied to the base of transistor T_2 which further amplifies the signal.

In this way, a signal is amplified in a direct coupled amplifier circuit.



Advantages

•The circuit arrangement is simple because of minimum use of resistors.

• Impedence matching good

•The circuit is of low cost because of the absence of expensive coupling devices.

Disadvantages

•It cannot be used for amplifying high frequencies.

•The operating point is shifted due to temperature variations, No proper biasing

Applications

•Low frequency amplifications.

•Low current amplifications.

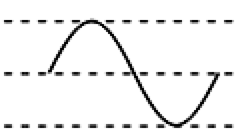
S.No	Particular	RC Coupling	Transformer Coupling	Direct Coupling
1	**Frequency response**	Excellent(AF)	Poor	Best
2	**Cost**	Less	More	Least
3	**Space and Weight**	Less	More	Least
4	**Impedance matching**	Not good	Excellent	Good
5	**Use**	For voltage amplification	For Power amplification	Amplify low frequencies

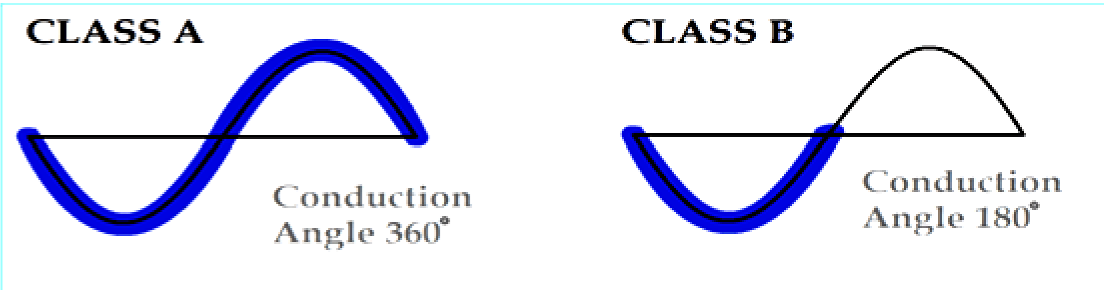
Classification of power amplifiers
திறன் பெருக்கி- வகைப்படுத்துதல்

On the basis of the mode of operation, i.e., **the portion of the input cycle during which collector current flows**

Class A Power amplifier (A-வகை திறன் பெருக்கி)
– When the collector current flows at all times during the full cycle of signal, the power amplifier is known as **class A power amplifier - Q point at centre of load line- efficiency** செயல்திறன் **=25%**

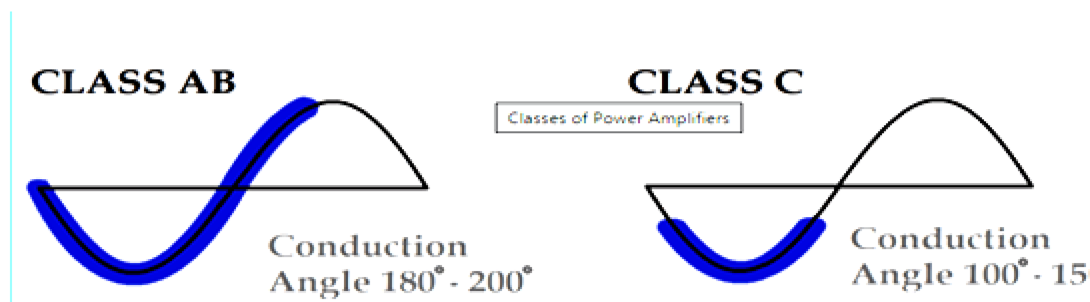
Class B Power amplifier (B-வகை திறன் பெருக்கி) – When the collector current flows only during the positive half cycle of the input signal, the power amplifier is known as **class B power amplifier - Q point-cutoff- efficiency=78%**





Class C Power amplifier (C-வகை திறன் பெருக்கி) – When the collector current flows for less than half cycle of the input signal, the power amplifier is known as **class C power amplifier – Q point – below cutoff- efficiency=100%**

Class AB amplifier (AB-வகை திறன் பெருக்கி) **:**if we combine the class A and class B amplifiers so as to utilize the advantages of both-Q point is between centre and cutoff-efficiency =between 25-75%



Class A	Class B	Class C
In this P.A the operating point of BJT is at centre of load line.	In this P.A operating point of BJT is in cut off region.	In this P.A the operating point of BJT is below the cut off region.
Under no signal condition TX is ON	Under no signal condition TX is OFF	Under no signal condition TX is OFF
Conduction angle $\theta = 0^\circ$ to 360°	Conduction angle $\theta = 0^\circ$ to 180°	Conduction angle $\theta < 180$
O/p signal is not distorted.	O/p is distorted i.e. o/p is just like rectified o/p.	O/p is distorted i.e. o/p current flows in the form of pulse.
$\eta = 50\%$	$\eta = 78.5\%$	$\eta \geq 95\%$

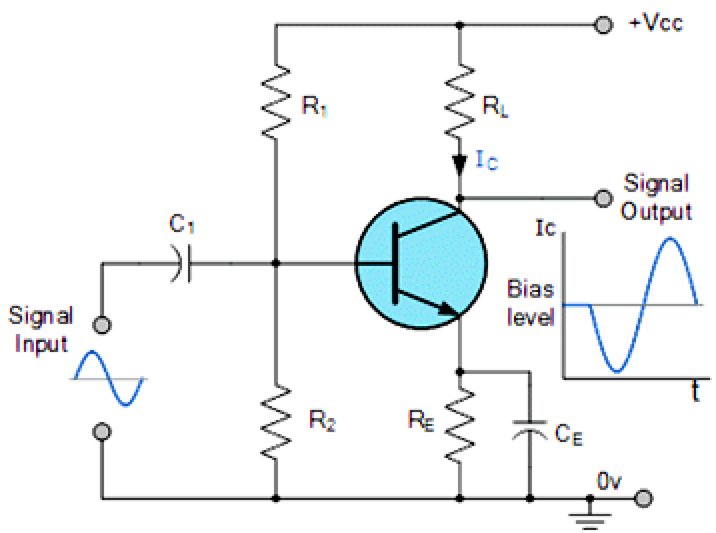
Class A Power Amplifier

- A **Class A power amplifier** is one in which the output current flows for the entire cycle of the AC input supply

- The complete signal present at the input is amplified at the output

- The operating point of this amplifier is present in the linear region
 (At the centre of the load line)

- It is so selected that the current flows for the entire ac input cycle



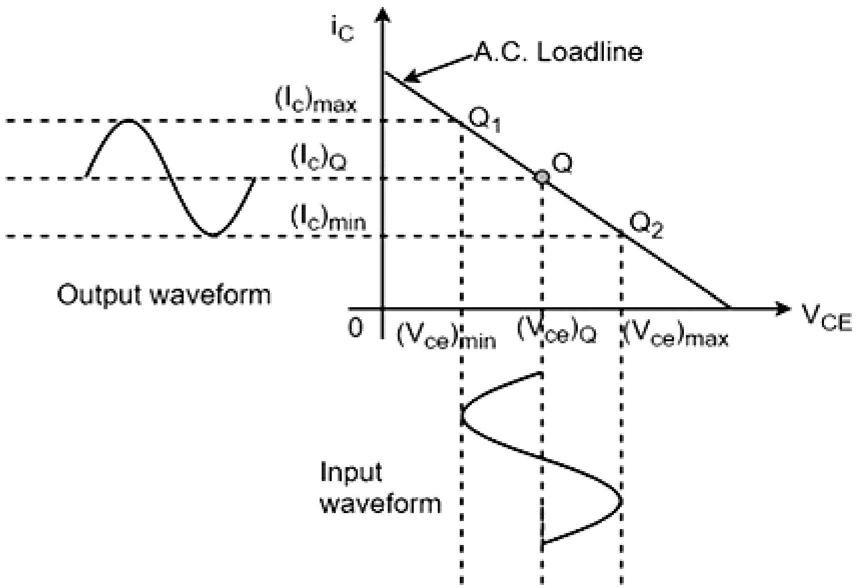
- The output characteristics with operating point Q is shown in the figure

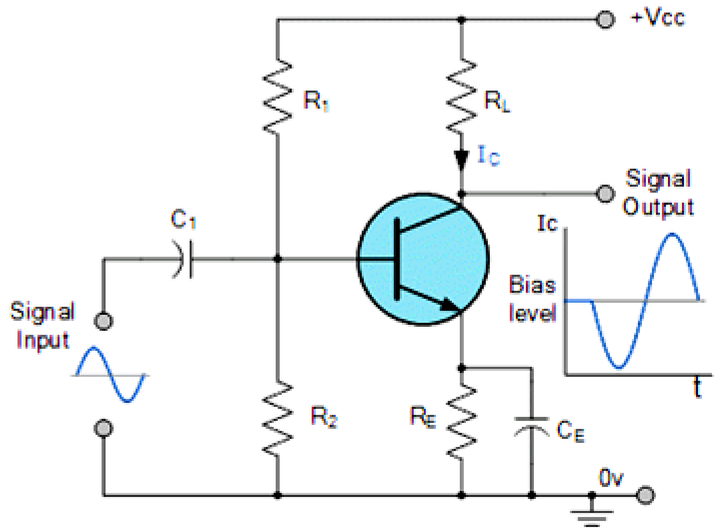
- Here $(I_C)_Q$ and $(V_{CE})_Q$ represent no signal collector current and voltage between collector and emitter respectively

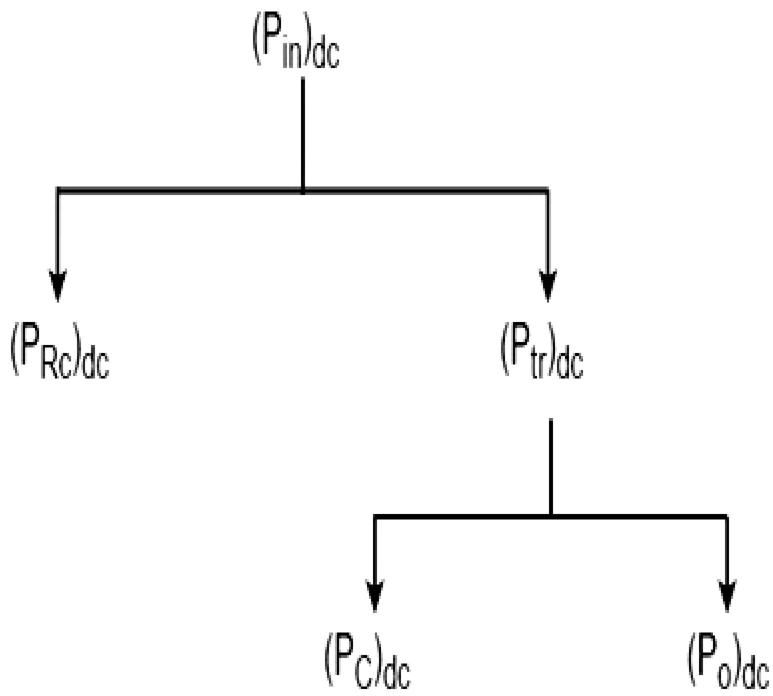
- When signal is applied, the Q-point shifts to Q_1 and Q_2

- The output current increases to $(I_C)_{max}$ and decreases to $(I_C)_{min}$

- Similarly, the collector-emitter voltage increases to $(V_{CE})_{max}$ and decreases to $(V_{CE})_{min}$




+Vcc
R1
RL
IC
Signal
Output
C1
Ic
Bias
level
Signal
Input
t
R2
RE
CE
0v


$(P_{in})_{dc}$
$(P_{Rc})_{dc}$
$(P_{tr})_{dc}$
$(P_C)_{dc}$
$(P_o)_{dc}$

D.C. Power drawn from collector battery V_{cc} is given by

$$P_{in} = voltage \times current = V_{CC}(I_C)_Q$$

This power is used in the following two parts –

- Power dissipated in the collector load as heat is given by

$$P_{RC} = (current)^2 \times resistance = (I_C)_Q^2 R_C$$

- Power given to transistor is given by

$$P_{tr} = P_{in} - P_{RC} = V_{CC}(I_C)_Q - (I_C)_Q^2 R_C$$

When signal is applied, the power given to transistor is used in the following two parts –

- A.C. Power developed across load resistors RC which constitutes the a.c. power output.

$$(P_O)_{ac} = I_{rms}^2 R_C = \frac{V_{rms}^2}{R_C} = \left(\frac{V_m}{\sqrt{2}}\right)^2 \frac{1}{R_C} = \frac{V_m^2}{2R_C}$$

Where **I** is the R.M.S. value of a.c. output current through load, **V** is the R.M.S. value of a.c. voltage, and $\mathbf{V_m}$ is the maximum value of V.

DC power dissipated in the collector region of the transistor in the form of heat $P_C(DC)$

Overall Efficiency

The overall efficiency of the amplifier circuit is given by

$$(\eta)_{overall} = \frac{a.c\ power\ delivered\ to\ the\ load}{total\ power\ delivered\ by\ d.c\ supply}$$

$$= \frac{(P_O)_{ac}}{(P_{in})_{dc}}$$

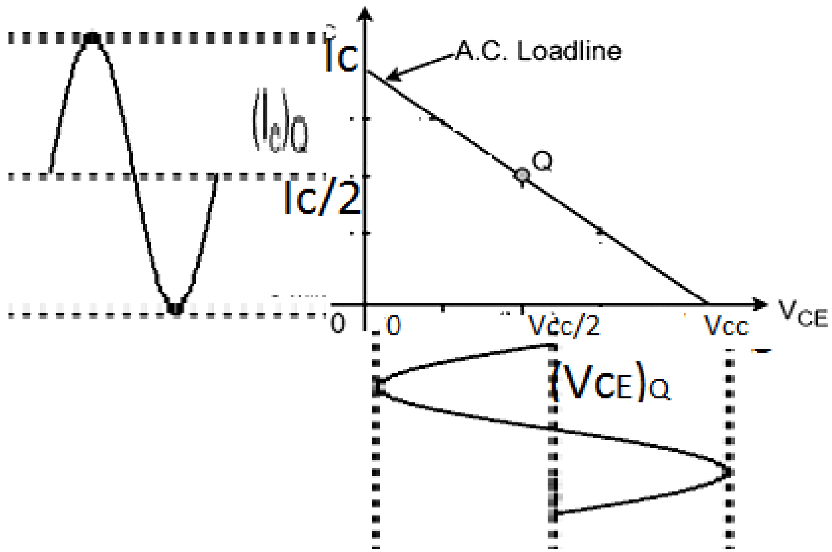
Collector Efficiency

The collector efficiency of the transistor is defined as

$$(\eta)_{collector} = \frac{average\ a.c\ power\ output}{average\ d.c\ power\ input\ to\ transistor}$$

$$= \frac{(P_O)_{ac}}{(P_{tr})_{dc}}$$

$$P_{in} = voltage \times current = V_{CC}(I_C)_Q$$



$$= \frac{V_{CC}(I_C)}{2}$$

$$(P_O)_{ac} = V_{rms} \times I_{rms}$$

$$V_{rms} = \frac{1}{\sqrt{2}}\left[\frac{(V_{ce})_{max} - (V_{ce})_{min}}{2}\right] = \frac{1}{\sqrt{2}}\left[\frac{(V_{ce})_{max}}{2}\right] = \frac{V_{CC}}{2\sqrt{2}}$$

$$I_{rms} = \frac{1}{\sqrt{2}}\left[\frac{(I_C)_{max} - (I_C)_{min}}{2}\right] = \frac{1}{\sqrt{2}}\left[\frac{(I_C)_{max}}{2}\right] = \frac{I_C}{2\sqrt{2}}$$

Therefore,

$$(P_O)_{ac} = V_{rms} \times I_{rms} = \frac{V_{CC}}{2\sqrt{2}} \times \frac{(I_C)}{2\sqrt{2}} = \frac{V_{CC} \times (I_C)}{8}$$

$$(\eta)_{overall} = \frac{a.c\ power\ delivered\ to\ the\ load}{total\ power\ delivered\ by\ d.c\ supply}$$

$$= \frac{(P_O)_{ac}}{(P_{in})_{dc}}$$

$$= \frac{\frac{V_{CC} \times (I_C)}{8}}{\frac{V_{CC}(I_C)}{2}}$$ = 1/4 = 0.25 or 25%

Advantages of Class A Amplifiers

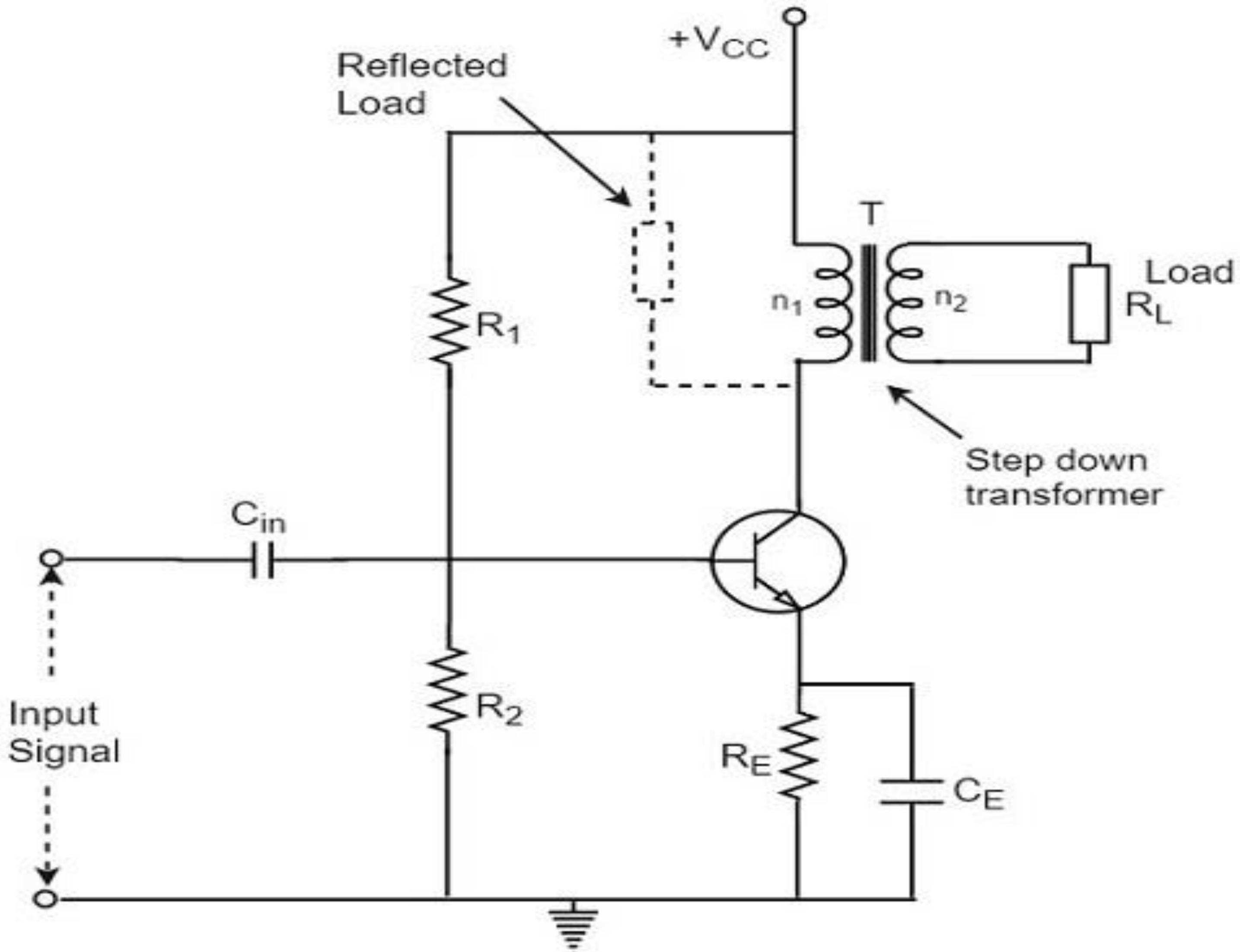
- The current flows for complete input cycle
- It can amplify small signals
- The output is same as input
- No distortion is present

Disadvantages of Class A Amplifiers

- Low power output
- Low collector efficiency

Class A power amplifier has low output power and low efficiency.
So, the transformer coupled class A power amplifier has been introduced.

Class A transformer coupled power amplifier



Class A transformer coupled power amplifier

- This is similar to the normal amplifier circuit but connected with a transformer in the collector load.

- Here R_1 and R_2 provide potential divider arrangement.

- The resistor R_E provides stabilization, C_E is the bypass capacitor

- The transformer used here is a step-down transformer.

- The high impedance primary of the transformer is connected to the high impedance collector circuit.

- The low impedance secondary is connected to the load (generally loud speaker).

Transformer Action

The transformer used in the collector circuit is for impedance matching.

R_L is the load connected in the secondary of a transformer.

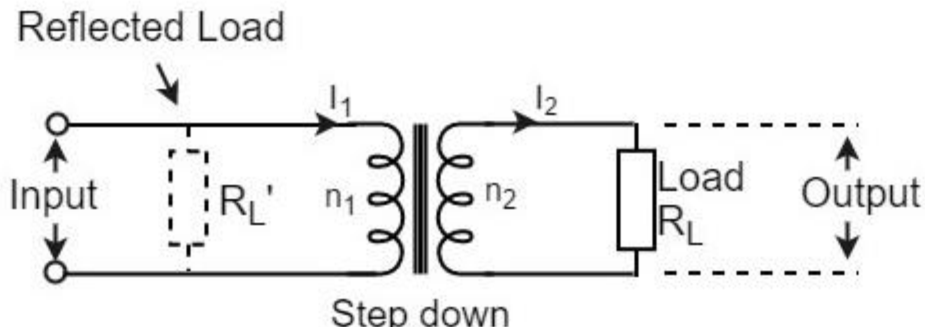
R_L' is the reflected load in the primary of the transformer.

The number of turns in the primary are n_1 and the secondary are n_2.

Let V_1 and V_2 be the primary and secondary voltages

I_1 and I_2 be the primary and secondary currents respectively.

A power amplifier may be matched by taking proper turns ratio in step down transformer.



$$n = \frac{\text{number of turns in primary}}{\text{number of turns in secondary}} = \frac{n_1}{n_2}$$

P1=P2

$V_1 I_1 = V_2 I_2$

$$\frac{V_1}{V_2} = \frac{n_1}{n_2} \; and \; \frac{I_2}{I_1} = \frac{n_1}{n_2}$$

Or

$$V_1 = \frac{n_1}{n_2} V_2 \; and \; I_1 = \frac{n_2}{n_1} I_2$$

Hence

$$\frac{V_1}{I_1} = \left(\frac{n_1}{n_2}\right)^2 \frac{V_2}{I_2}$$

But $V_1/I_1 = R_L'$ = effective input resistance

And $V_2/I_2 = R_L$ = effective output resistance

Therefore,

$$R'_L = \left(\frac{n_1}{n_2}\right)^2 R_L = n^2 R_L$$

Circuit Operation

In order to achieve complete amplification, the operating point should lie at the center of the load line.

The operating point obviously varies when the signal is applied. The collector voltage varies in opposite phase to the collector current.

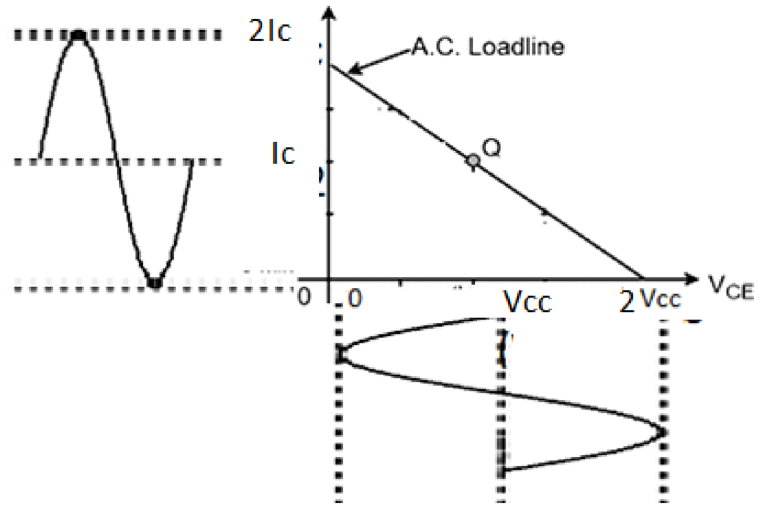
The variation of collector voltage appears across the primary of the transformer.

Circuit Analysis

The power loss in the primary is assumed to be negligible, as its resistance is very small.

Overall and collector efficiency are equal in this case.

$$(P_{in})_{dc} = (P_{tr})_{dc} = V_{CC} \times (I_C)_Q \quad = V_{CC} \times (I_C)$$



$$(P_O)_{ac} = V_{rms} \times I_{rms}$$

$$V_{rms} = \frac{1}{\sqrt{2}}\left[\frac{(V_{ce})_{max} - (V_{ce})_{min}}{2}\right] = \frac{1}{\sqrt{2}}\left[\frac{(V_{ce})_{max}}{2}\right] = \frac{1}{\sqrt{2}} \quad \frac{2Vcc}{2} = \frac{Vcc}{\sqrt{2}}$$

$$I_{rms} = \frac{1}{\sqrt{2}}\left[\frac{(I_C)_{max} - (I_C)_{min}}{2}\right] = \frac{1}{\sqrt{2}}\left[\frac{(I_C)_{max}}{2}\right] = \frac{1}{\sqrt{2}} \quad \frac{2\,I_C}{2} = \frac{Ic}{\sqrt{2}}$$

$$(P_O)_{ac} = V_{rms} \times I_{rms} = \frac{V_{CC}}{\sqrt{2}} \times \frac{I_C}{\sqrt{2}} = \frac{V_{CC} \times (I_C)}{2}$$

$$(\eta)_{\text{collector}} = \frac{a.c\ power\ delivered\ to\ the\ load}{total\ power\ delivered\ by\ d.c\ supply} = \frac{(P_O)_{ac}}{(P_{in})_{dc}}$$

$$= \frac{V_{CC} \times (I_C)}{2} \times \frac{1}{V_{CC} \times (I_C)} = \quad 1/2=0.5 \text{ or } 50\%$$

The efficiency of a class A power amplifier is nearly than 30% whereas it has got improved to 50% by using the transformer coupled class A power amplifier.

Advantages

- No loss of signal power in the base or collector resistors
- Excellent impedance matching is achieved
- Gain is high

Disadvantages

- Hum noise is introduced by transformers.
- Transformers are bulky and costly.
- Poor frequency response.

Applications

- This circuit is used where impedance matching is the main criterion.
- These are used as driver amplifiers and sometimes as output amplifiers

Class B Power Amplifier

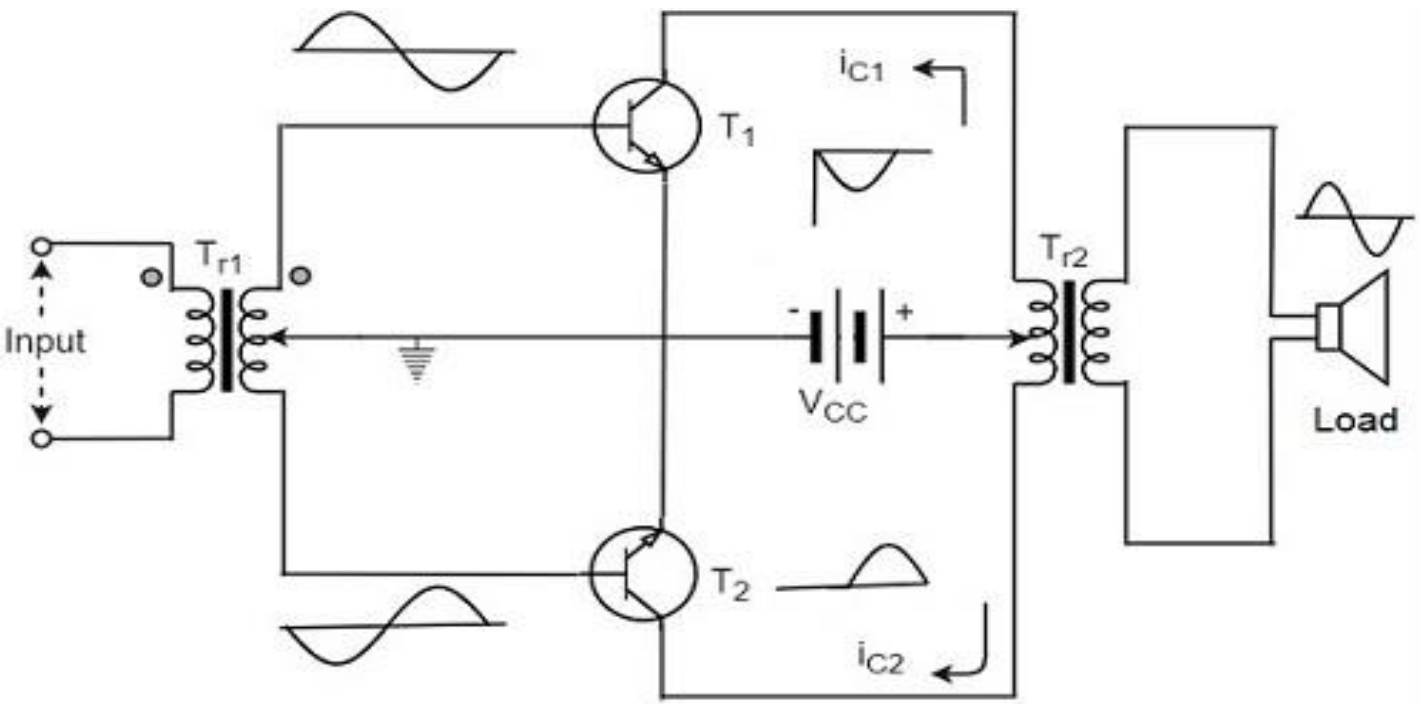
- When the collector current flows only during the positive half cycle of the input signal, the power amplifier is known as **class B power amplifier**.

- The biasing of the transistor in class B operation is in such a way that at zero signal condition, there will be no collector current.

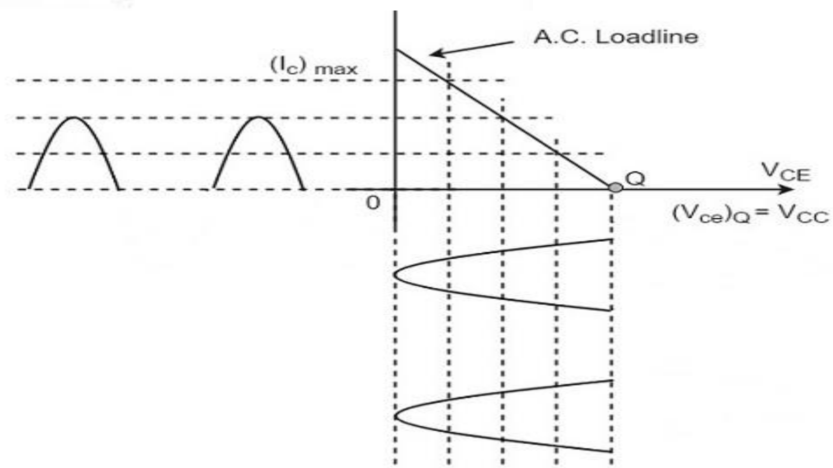
- The **operating point** is selected at cut off voltage.

- When the signal is applied, **only the positive half cycle** is amplified at the output

- The figure shows the input and output waveforms during class B operation.



i_{C1}
T_1
T_{r1}
T_{r2}
Input
V_{CC}
Load
T_2
i_{C2}



A.C. Loadline
$(I_c)_{max}$
V_{CE}
Q
0
$(V_{ce})_Q = V_{CC}$

When the signal is applied, the circuit is forward biased for the positive half cycle of the input and hence the collector current flows.

But during the negative half cycle of the input, the circuit is reverse biased and the collector current will be absent.

Hence **only the positive half cycle** is amplified at the output.

As the negative half cycle is completely absent, the signal **distortion will be high.**

Also, when the applied signal increases, the power dissipation will be more.

But when compared to class A power amplifier, the output efficiency is increased.

Class B - Push-Pull Amplifier - தள்ளு இழு பெருக்கி

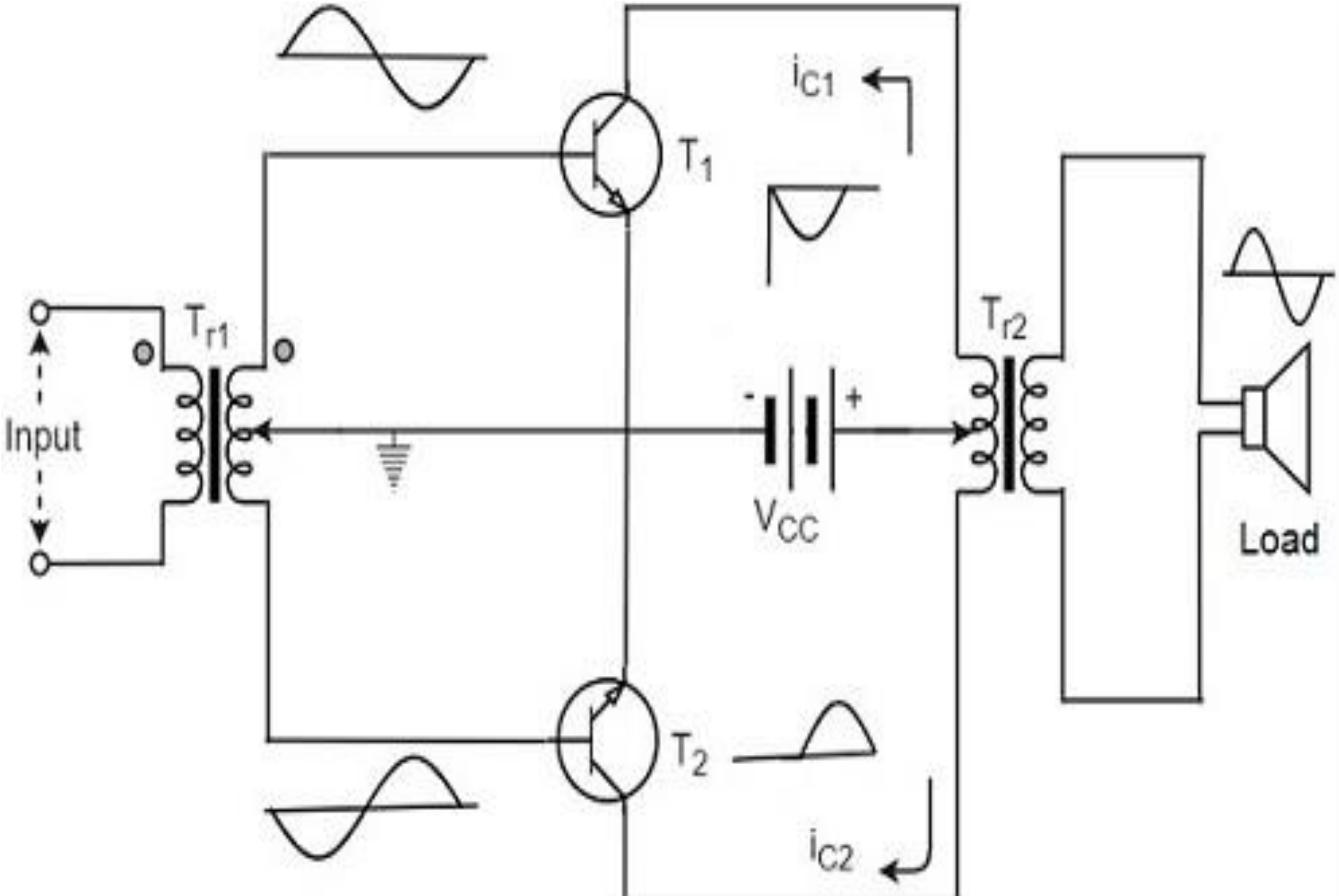
Though the efficiency of class B power amplifier is higher than class A, only one half cycle of the input is amplified, so the distortion is high.

Also, the input power is not completely utilized. So push-pull configuration is introduced in class B amplifier.

Construction

The circuit of a push-pull class B power amplifier consists of two identical transistors T_1 and T_2 whose bases are connected to the secondary of the center-tapped input transformer T_{r1}. The emitters are shorted and the collectors are given the V_{CC} supply through the primary of the output transformer T_{r2}.

In class B push-pull amplifier the transistors are biased at cut off, instead of using the biasing resistors



Input
T_{r1}
T_1
T_2
i_{C1}
i_{C2}
-
+
V_{CC}
T_{r2}
Load

Operation

The circuit of class B push-pull amplifier has two center-tapped transformers

When no signal is applied at the input, the transistors T_1 and T_2 are in cut off condition ; no collector currents flow.

As no current is drawn from V_{CC}, no power is wasted.

When input signal is given, it is applied to the input transformer T_{r1} which splits the signal into two signals that are 180^o out of phase with each other.

These two signals are given to the two identical transistors T_1 and T_2.

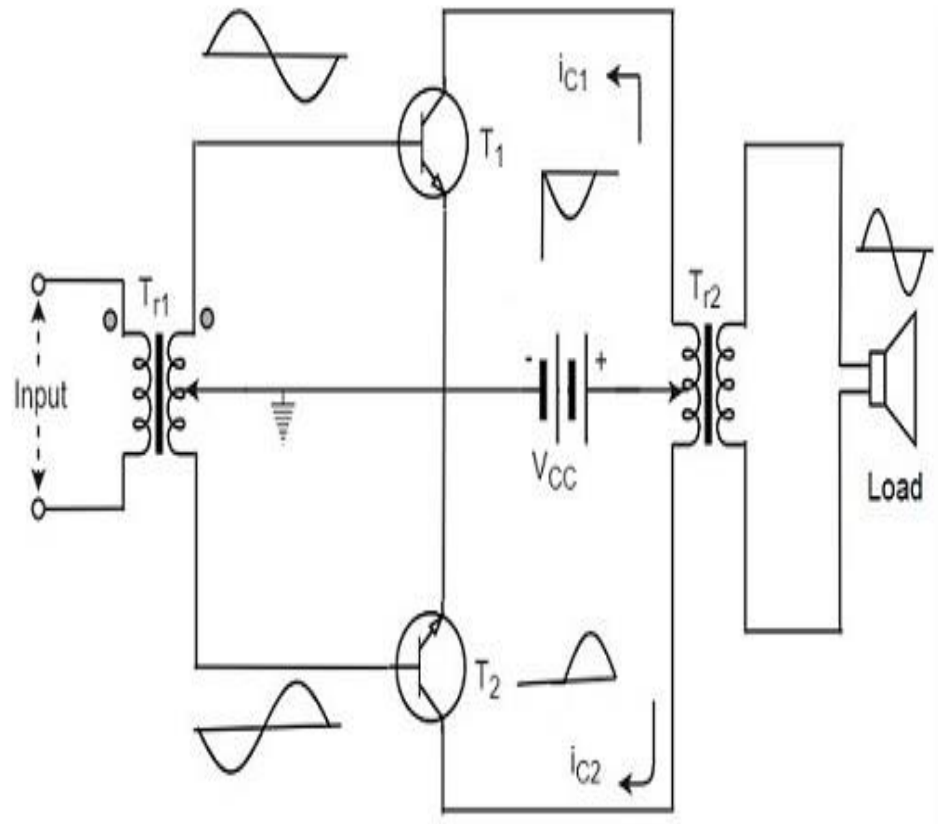
For the positive half cycle, the base of the transistor T_1 becomes positive and forward biased and

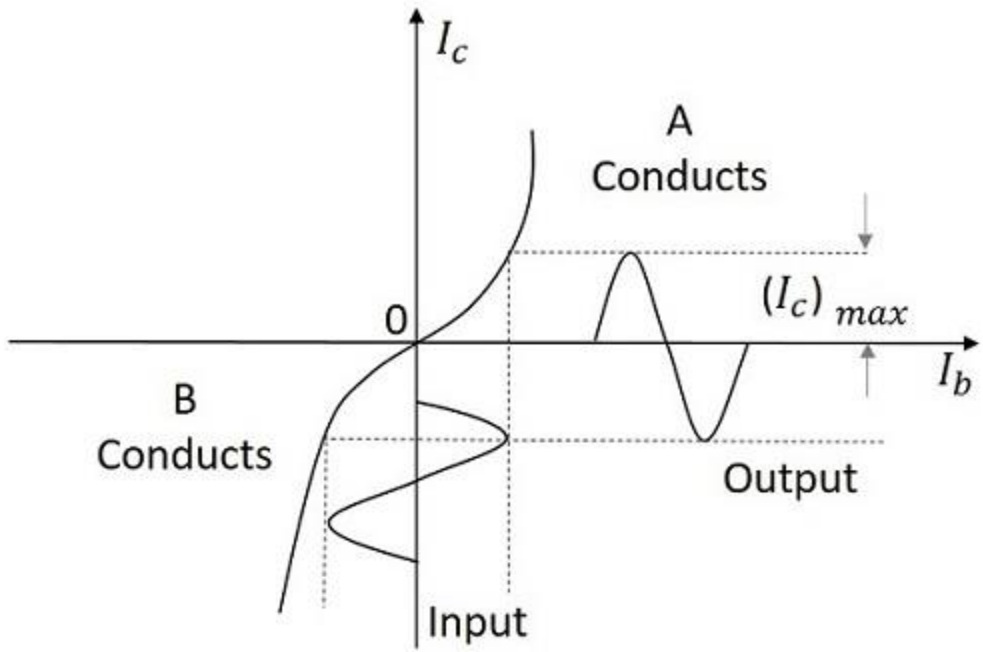
The transistor T_1 is in the ON state and collector current flows.

At the same time, the transistor T_2 has negative half cycle, and base of the transistor T_2 is negative and reverse biased

The transistor T_2 is in cutoff condition and hence no collector current flows.

The waveform is produced as shown in the following figure





For the next half cycle, the transistor T_1 gets into cut off condition and the transistor T_2 gets into conduction, to contribute the output.

Hence for both the cycles, each transistor conducts alternately.

The output transformer T_{r2} serves to join the two currents producing an almost undistorted output waveform.

Efficiency of Class B Push-Pull Amplifier

Current in each transistor is the average value of half sine loop.
For half sine loop, I_{dc} is given by

$$I_{dc} = \frac{(I_C)_{max}}{\pi}$$

Therefore,

$$(p_{in})_{dc} = 2 \times \left[\frac{(I_C)_{max}}{\pi} \times V_{CC}\right]$$

Here factor 2 is introduced as there are two transistors in push-pull amplifie

R.M.S. value of collector current = $I_{rms} = (I_C)_{max}/\sqrt{2}$

R.M.S. value of output voltage = $V_{rms} = V_{CC}/\sqrt{2}$

Under ideal conditions of maximum power

Therefore, $(P_O)_{ac} = V_{rms} \times I_{rms}$

$$(P_O)_{ac} = \frac{(I_C)_{max}}{\sqrt{2}} \times \frac{V_{CC}}{\sqrt{2}} = \frac{(I_C)_{max} \times V_{CC}}{2}$$

Now overall maximum efficiency

$$\eta_{overall} = \frac{(P_O)_{ac}}{(P_{in})_{dc}}$$

$$= \frac{(I_C)_{max} \times V_{CC}}{2} \times \frac{\pi}{2(I_C)_{max} \times V_{CC}}$$

$$= \frac{\pi}{4} = 0.785 = 78.5\%$$

Hence the class B push-pull amplifier improves the efficiency than the class A push-pull amplifier.

Advantages

- Output ac power and efficiency are high
- Distortion is reduced

Disadvantages

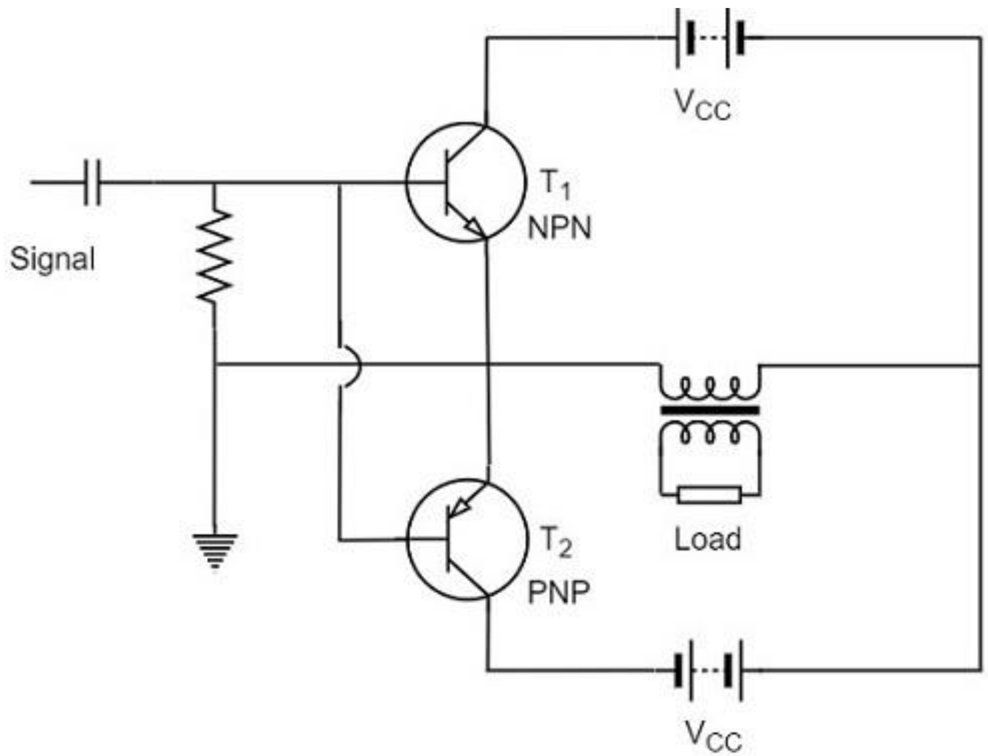
- Two center tapped transformers are needed, so circuit is costly and bulkier
- Equal and opposite input signal voltages are required
- Two identical transistors to be used
- If the parameters of the transistors are not the same; unequal amplification of the 2 halves of the signal

Complementary symmetry push pull class B amplifier

The push pull amplifier improves efficiency

But the usage of center-tapped transformers makes the circuit bulky, heavy and costly.

To make the circuit simple and to improve the efficiency, the transistors used can be complemented,



Thermal Runaway - வெப்ப ஓட்டம்

The self-destruction of such an unstabilized transistor is known as **Thermal run away**.

All semiconductors are sensitive to temperature; as temp increases, collector current increases and produces heat at collector junction and if not controlled , transistor gets damaged

Si transistor can withstand upto 230˚C and Ge transistor upto 100˚C

In order to avoid **thermal runaway** and the destruction of transistor, it is necessary to stabilize the operating point, i.e., to keep I_C constant.

Operating point depends on surrounding temp, power dissipated by the transistor

Heat sink- வெப்ப வாங்கி

A metal sheet that serves to dissipate heat from a transistor- protect transistor from thermal run away

Dissipation α material, volume, area, shape, contact between case and sink, movement of air around sink

To prevent thermal runaway:

1. Choice of Q point
2. Ambient temperature
3. Type of transistor(metal case / plastic case)
4. Circuit to compensate temp changes and stabilize Q point

Amplifier vs. Oscillator

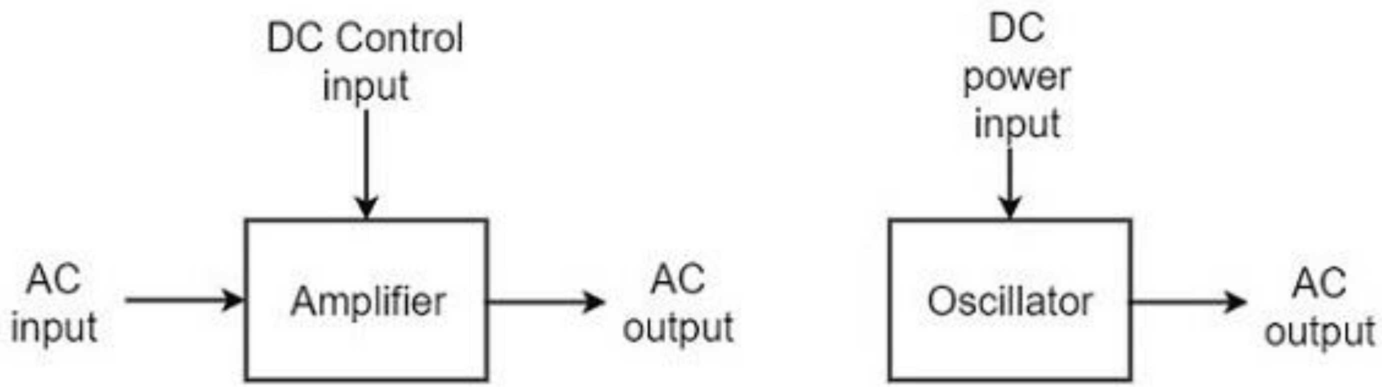
An **oscillator** generates AC output without any ac input signal.

An electronic oscillator is a circuit which converts dc energy into ac at a very high frequency.

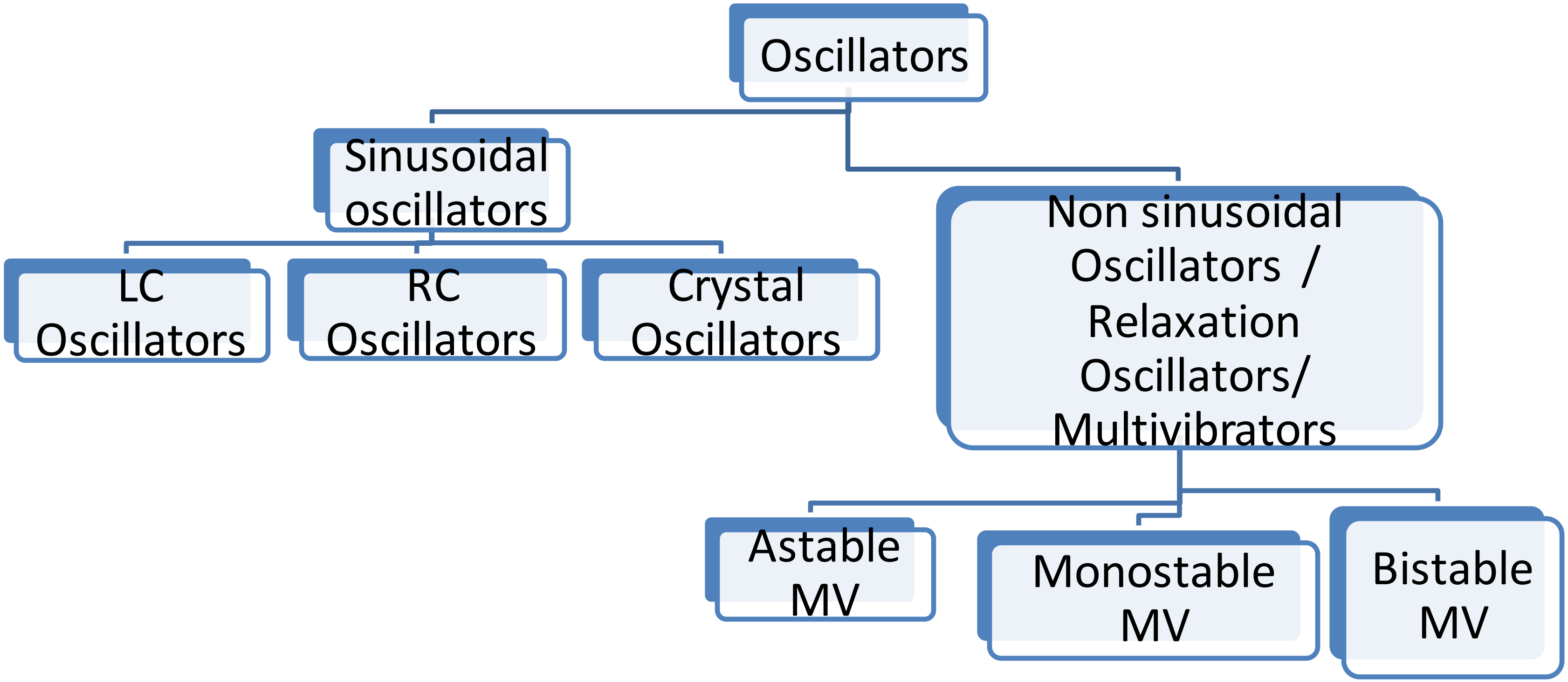
An amplifier with a positive feedback can be act as an oscillator.

An **amplifier** increases the signal strength of the input signal applied, whereas an **oscillator** generates a signal without that input signal

Both require dc for its operation.



Oscillator Types

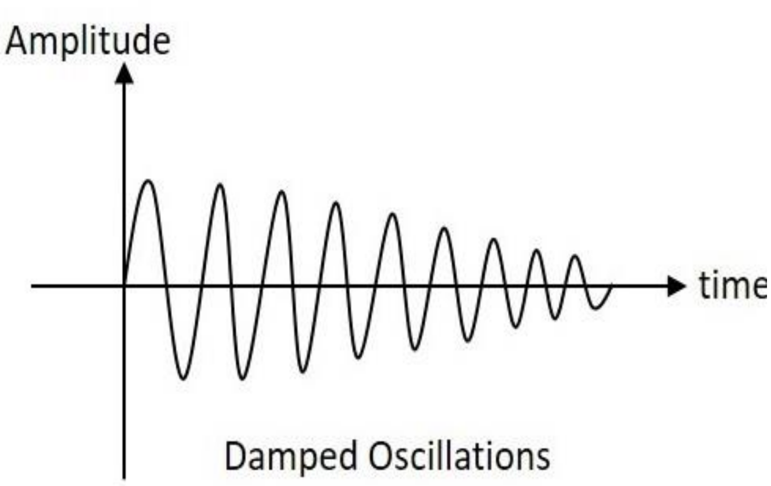


Nature of Sinusoidal Oscillation
சைன்வளைவோட்டம் அலைவு

The nature of oscillations in a sinusoidal wave are generally of two types. They are **damped** and **undamped oscillations**.

Damped Oscillations தடையுற்ற அலைவுகள்

The electrical oscillations whose amplitude goes on decreasing with time are called as **Damped Oscillations**. The frequency of the damped oscillations may remain constant depending upon the circuit parameters.

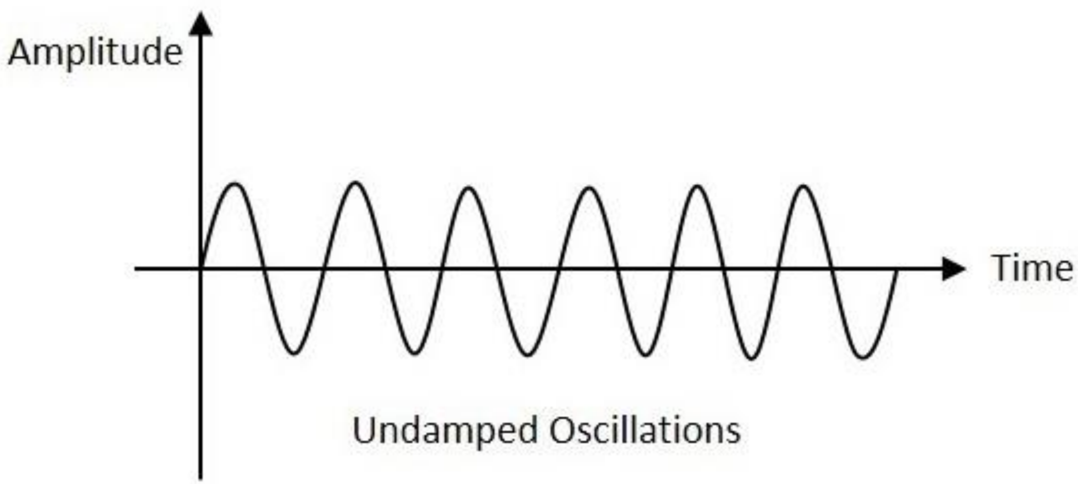


Damped oscillations are generally produced by the oscillatory circuits that produce power losses and doesn’t compensate if required

Undamped Oscillation-தடையற்ற அலைவு

The electrical oscillations whose amplitude remains constant with time are called as **Undamped Oscillations**. The frequency of the Undamped oscillations remains constant.

Undamped oscillations are generally produced by the oscillatory circuits that produce no power losses and follow compensation techniques if any power losses occur



An amplifier with positive feedback produces its output to be in phase with the input and increases the strength of the signal.

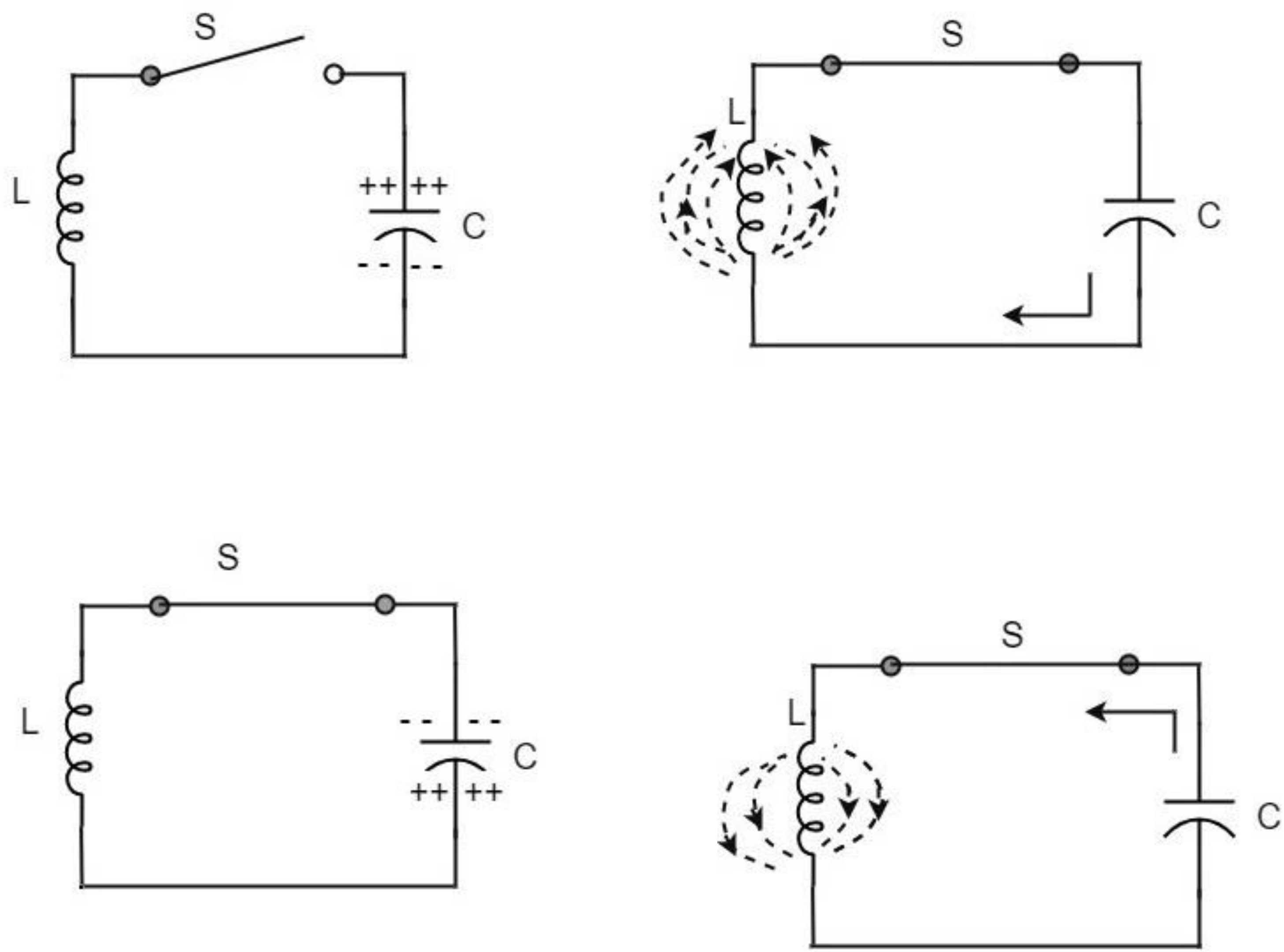
The Oscillatory Circuit - அலைவுச்சுற்று

An oscillatory circuit produces electrical oscillations of a desired frequency. They are also known as **tank circuits**.

A simple tank circuit comprises of an inductor L and a capacitor C which determine the oscillatory frequency of the circuit.

The capacitor in this circuit is already charged using a dc source. In this situation, the lower plate of the capacitor has excess of electrons whereas the upper plate has deficit of electrons. The capacitor holds some electrostatic energy and there is a voltage across the capacitor.

When the switch **S** is closed, the capacitor discharges and the current flows through the inductor. Due to the inductive effect, the current builds up slowly towards a maximum value. Once the capacitor discharges completely, the magnetic field around the coil is maximum.


S
L
C
++ ++
S
L
C
S
L
C
++ ++
S
L
C

Once the capacitor is discharged completely, the magnetic field begins to collapse and produces a counter EMF according to Lenz's law.

The capacitor is now charged with positive charge on the lower plate and negative charge on the upper plate.

Once the capacitor is fully charged, it starts to discharge to build up a magnetic field around the coil

Continuous charging and discharging results in alternating motion of electrons or an **oscillatory current**. The interchange of energy between L and C produce continuous **oscillations**.

In an ideal circuit, where there are no losses, the oscillations would continue indefinitely.

In a practical tank circuit, there occur losses such as **resistive** and **radiation losses** in the coil and **dielectric losses** in the capacitor. These losses result in damped oscillations.

Frequency of Oscillations - அலைவு அதிர்வெண்

The frequency of the oscillations produced by the tank circuit are determined by the components of the tank circuit, **L** and **C**.

The actual frequency of oscillations is the **resonant frequency** (or natural frequency) of the tank circuit which is given by

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

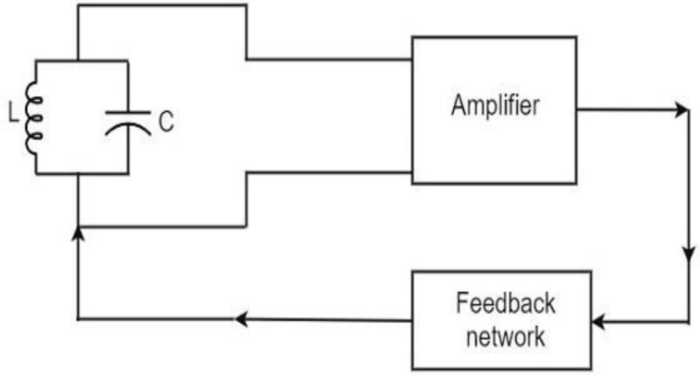
Essentials of an Oscillator circuit

Practical Oscillator circuit consists of a tank circuit, a transistor amplifier, and a feedback circuit.

•**Tank Circuit** − The tank circuit consists of an inductance L connected in parallel with capacitor **C**. The values of these two components determine the frequency of the oscillator circuit and hence this is called as **Frequency determining circuit**.

•**Transistor Amplifier** − The output of the tank circuit is connected to the amplifier circuit so that the oscillations produced by the tank circuit are amplified here. Hence the output of these oscillations are increased by the amplifier.

•**Feedback Circuit** − The function of feedback circuit is to transfer a part of the output energy to LC circuit in proper phase. This feedback is positive in oscillators while negative in amplifiers.



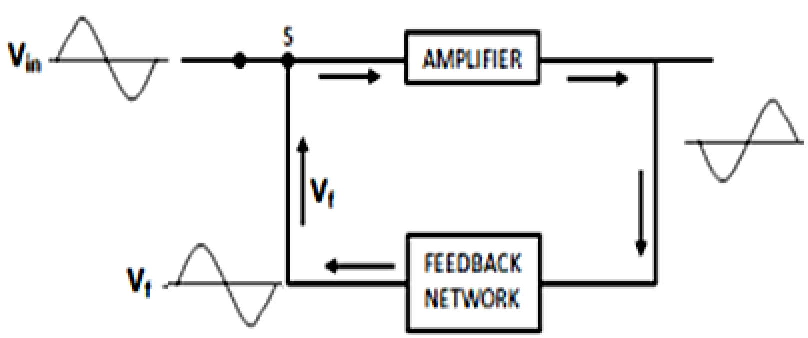
Positive Feedback- நேர் பின்னூட்டம்

The feedback in which the feedback energy i.e., either voltage or current is in phase with the input signal

The amplifier introduces a phase shift of 180^{o} into the circuit and the feedback network amplifier introduces a phase shift of 180^{o}. Total phase shift is 360^{o} around the loop, i.e, feed back signal is in phase with the input signal.

Advantage: **Increases the gain** of the amplifier
Disadvantages :Increasing distortion; Instability

If the positive feedback is sufficiently large, it leads to oscillations, by which oscillator circuits are formed

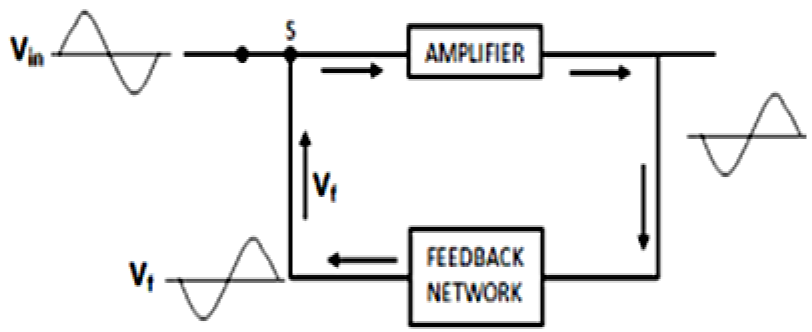


Negative Feedback-எதிர் பின்னூட்டம்

The feedback in which the feedback energy i.e., either voltage or current is out of phase with the input

The amplifier introduces a phase shift of 180^o into the circuit while the feedback network is so designed that it produces no phase shift or zero phase shift. Thus the resultant feedback voltage V_f is 180^o out of phase with the input signal V_{in}.

Disadvantage: **gain** of the amplifier is **reduced**,
Advantages :
Stability of gain is improved; Reduction in distortion
Reduction in noise; Increase in input impedance
Decrease in output impedance

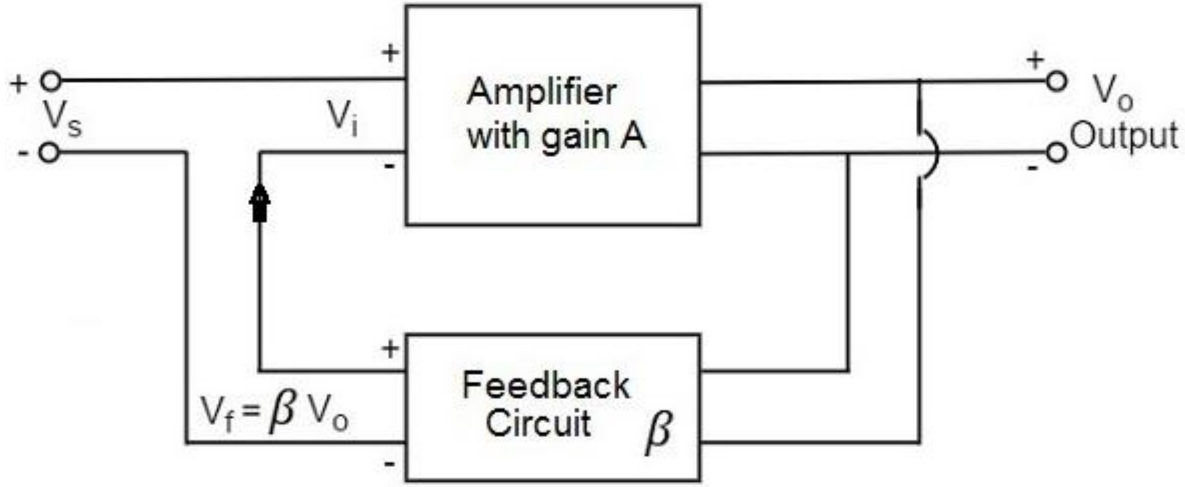


Principle of Feedback Amplifier- பின்னூட்ட தத்துவம்

A feedback amplifier generally consists of two parts. They are the **amplifier** and the **feedback circuit**.

The feedback circuit usually consists of resistors.

The concept of feedback amplifier can be understood from the following figure below.



The gain of the amplifier A is the ratio of output voltage Vo to the input voltage V_i.

A=Vo/Vi

The feedback network extracts a voltage $V_f = \beta V_o$ from the output V_o of the amplifier.(Feed fraction , **β**)

This voltage is added for positive feedback and subtracted for negative feedback, from the signal voltage V_s

So, for a positive feedback,

$V_i = V_s + V_f = V_s + \beta V_o$

The quantity **β** $= V_f/V_o$ is called as feedback ratio or feedback fraction.

The output V_o must be equal to the input voltage (V_s + βV_o) multiplied by the gain A of the amplifier. (A)= (V0) / (Vi)

$(Vs+\beta Vo)A=Vo$
$AVs+A\beta Vo=Vo$
$AVs=Vo(1-A\beta)$
$Vo / Vs = A /(1-A\beta)$

Let A_f be gain with the feedback of the amplifier.

A_f=Output Voltage/Input Signal Voltage=Vo/Vs

$A_f=A/(1-A\beta)$

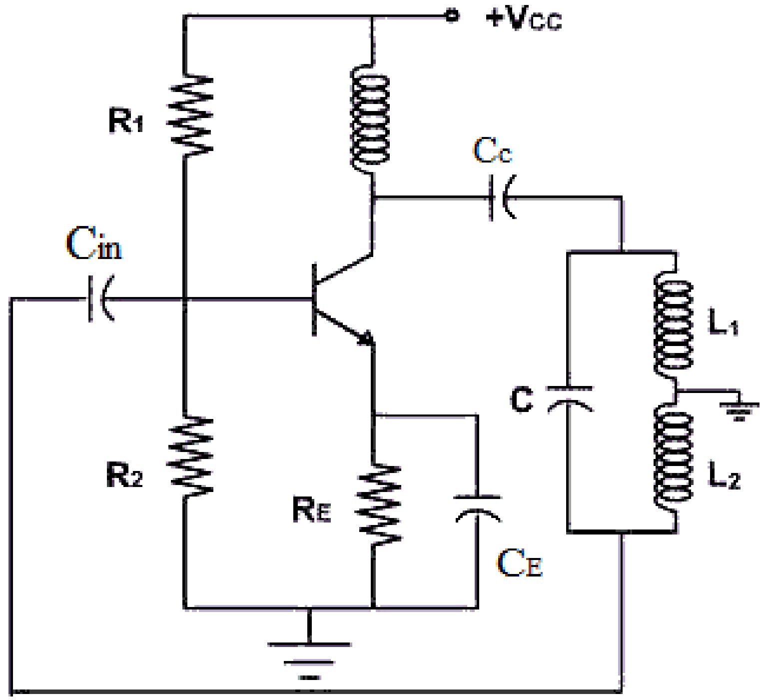
Where **Aβ** is the **feedback factor** or the **loop gain**.

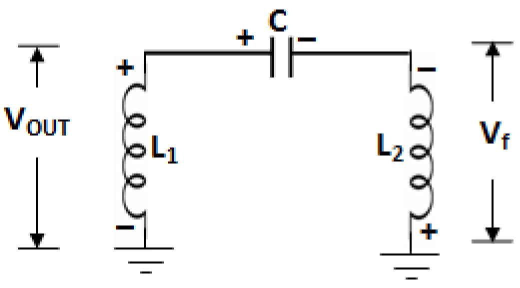
If $A\beta = 1$, $A_f = \infty$. Thus the gain becomes infinity, i.e., there is output without any input. In another words, the amplifier works as an Oscillator.

The condition $A\beta = 1$ is called as **Barkhausen Criterion of oscillations**.

Hartley Oscillator

ஹார்ட்லி அலையியற்றி





Construction

The resistors R_1, R_2 and R_e provide necessary bias condition for the circuit.
The capacitor C_E provides a.c. ground thereby providing any signal degeneration. This also provides temperature stabilization.

The capacitors C_c and C_B are employed to block d.c. and to provide an a.c. path.

The radio frequency choke (R.F.C) offers very high impedance to high frequency currents which means it shorts for d.c. and opens for a.c.

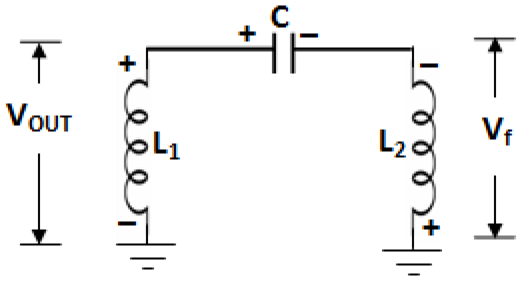
Hence it provides d.c. load for collector and keeps a.c. currents out of d.c. supply source

Tank Circuit- தொட்டி சுற்று

The frequency determining network is a parallel resonant circuit which consists of the inductors L_1 and L_2 along with a variable capacitor C.

The junction of L_1 and L_2 are earthed. The coil L_2 has its one end connected to base via C_{in} and the other to emitter via C_E.

So, L_1 is in the output circuit. Both the coils L_1 and L_2 are inductively coupled and together form an **Auto-transformer**.



Operation

When the collector supply is given, a transient current is produced in the oscillatory or tank circuit.

The oscillatory current in the tank circuit produces a.c. voltage across L_1.

The **auto-transformer** made by the inductive coupling of L_1 and L_2 helps in determining the frequency and establishes the feedback.

As the CE configured transistor provides 180^o phase shift, another 180^o phase shift is provided by the transformer, which makes 360^o phase shift between the input and output voltages.

This makes the feedback positive which is essential for the condition of oscillations.

When the **loop gain $|\beta A|$ of the amplifier is greater than one**, oscillations are sustained in the circuit.

The equation for **frequency of Hartley oscillator** is given as

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

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

Here, $\mathbf{L_T}$ is the total cumulatively coupled inductance; $\mathbf{L_1}$ and $\mathbf{L_2}$ represent inductances of 1 and 2nd coils; and **M** represents mutual inductance.

Mutual inductance is calculated when two windings are considered.

Feedback Fraction: In Hartley oscillator, the feedback voltage is across L2 and output voltage is across L1.

Feedback Fraction,

$$\beta = \frac{V_f}{V_{out}} = \frac{X_{L2}}{X_{L1}} = \frac{L_2}{L_1}$$

Or,

$$\beta = \frac{L_2}{L_1}$$

Advantages

The advantages of Hartley oscillator are

- Instead of using a large transformer, a single coil can be used as an auto-transformer.
- Frequency can be varied by employing either a variable capacitor or a variable inductor.
- Less number of components are sufficient.
- The amplitude of the output remains constant over a fixed frequency range.

Disadvantages

The disadvantages of Hartley oscillator are

- It cannot be a low frequency oscillator.
- Harmonic distortions are present.

Applications

The applications of Hartley oscillator are

- It is used to produce a sinewave of desired frequency.
- Mostly used as a local oscillator in radio receivers.
- It is also used as R.F. Oscillator.

Colpitts Oscillator- கால்பிட் அலையியற்றி

A Colpitts oscillator looks just like the Hartley oscillator but the inductors and capacitors are replaced with each other in the tank circuit

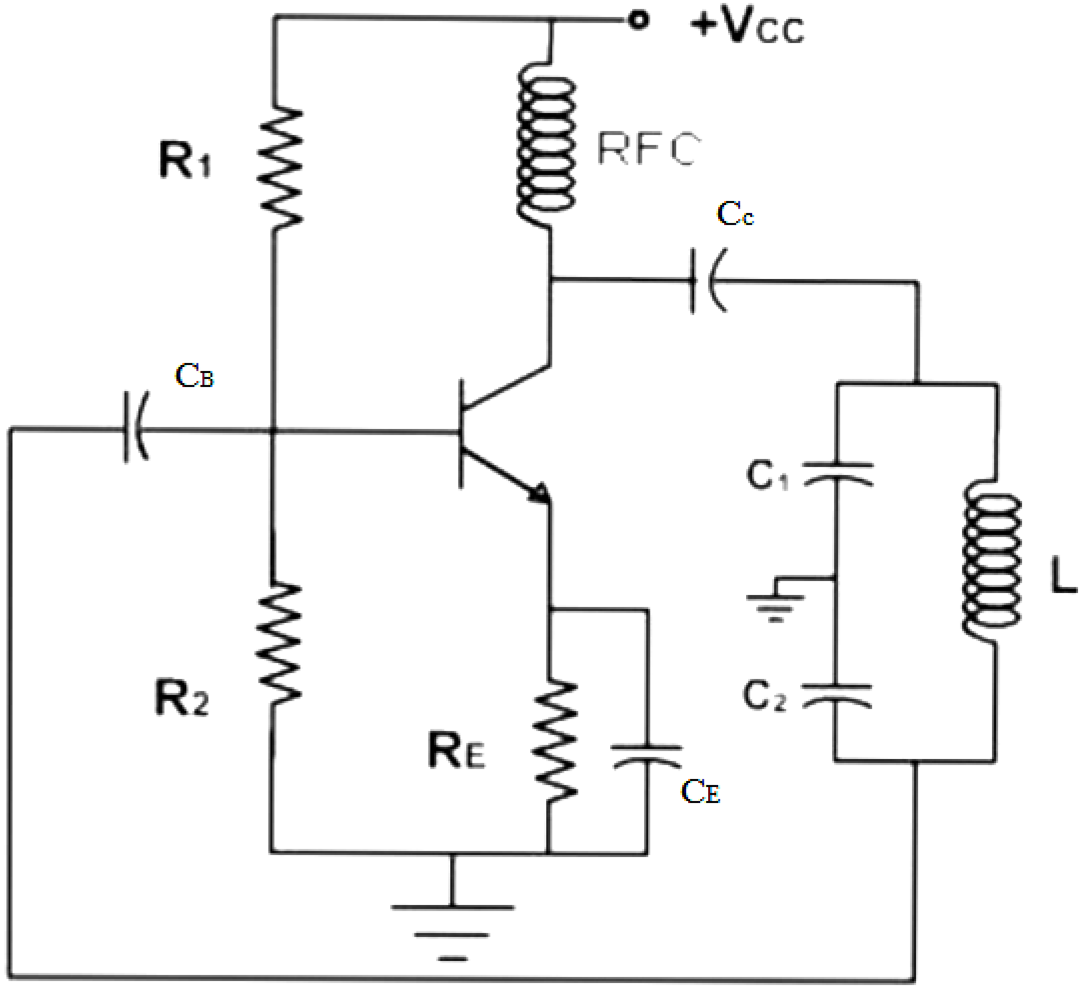
The resistors R_1, R_2 and R_E provide necessary bias condition for the circuit.

The capacitor C_E provides a.c. Ground; This also provides temperature stabilization.

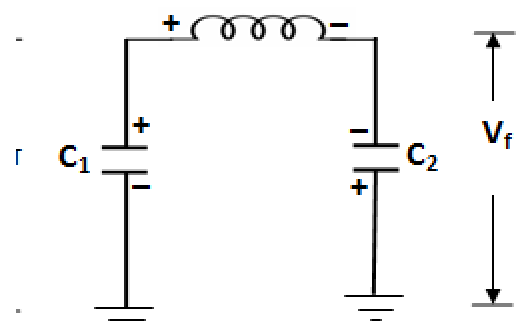
The capacitors C_c and C_B are employed to block d.c. and to provide an a.c. path.

The radio frequency choke (R.F.C) offers very high impedance to high frequency currents which means it shorts for d.c. and opens for a.c.

Hence it provides d.c. load for collector and keeps a.c. currents out of d.c. supply source.



+Vcc
RFC
R1
Cc
CB
C1
L
C2
R2
RE
CE



+
−
C1
+
−
C2
−
+
Vf

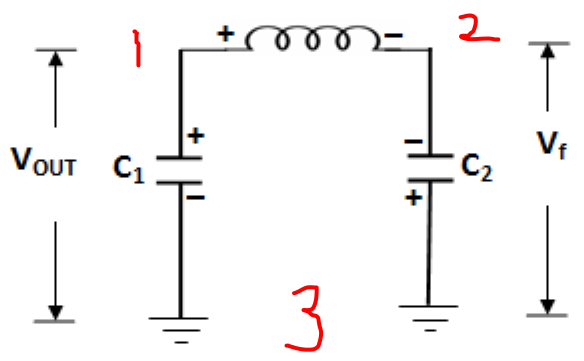
Tank Circuit

The frequency determining network is a parallel resonant circuit which consists of variable capacitors C_1 and C_2 along with an inductor L.

The junction of C_1 and C_2 are earthed.

The capacitor C_1 has its one end connected to collector via C_c and the other to emitter via C_E

Voltage developed across C_2 provides the regenerative feedback required for the sustained oscillations.



Operation

When the collector supply is given, a transient current is produced in the oscillatory or tank circuit.

The oscillatory current in the tank circuit produces a.c. voltage across C_1 which are applied to the base emitter junction and appear in the amplified form in the collector circuit and supply losses to the tank circuit.

If terminal 1 is at positive potential with respect to terminal 3 at any instant, then terminal 2 will be at negative potential with respect to 3 at that instant because terminal 3 is grounded. Therefore, points 1 and 2 are out of phase by 180^o.

As the CE configured transistor provides 180^o phase shift, it makes 360^o phase shift between the input and output voltages.

Hence, feedback is properly phased to produce continuous Undamped oscillations. When the **loop gain |βA| of the amplifier is greater than one, oscillations are sustained** in the circuit.

Frequency

The equation for **frequency of Colpitts oscillator** is given as

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

C_T is the total capacitance of C_1 and C_2 connected in series.

$$\frac{1}{C_T} = \frac{1}{C_1} + \frac{1}{C_2}$$

$$C_T = \frac{C_1 \times C_2}{C_1 + C_2}$$

Feedback Fraction: The amount of feedback voltage in Colpitt's oscillator depends upon feedback fraction mv of the circuit. For this circuit,

Feedback fraction,

$$\beta = \frac{V_f}{V_{out}} = \frac{X_{c2}}{X_{c1}} = \frac{C_1}{C_2}$$

ADVANTAGES

Sine waves of high frequency
Freq stability
Frequency can be varied by using both the variable capacitors.
Less number of components are sufficient.
The amplitude of the output remains constant over a fixed frequency range.

APPLICATIONS

High frequency sinewave generator.
Local oscillator in radio receivers.
R.F. Oscillator.
Mobile applications.

Drawbacks of LC circuits

LC circuits have few **drawback:**

Frequency instability

Waveform is poor

Cannot be used for low frequencies

Inductors are bulky and expensive

By replacing the inductors with resistors –RC oscillators

Frequency stability is improved

A good quality waveform is obtained

Can also produce lower frequencies.

The circuit is not bulky or expensive.

All the drawbacks of **LC** oscillator circuits are eliminated in **RC** oscillators.

Principle of Phase-shift oscillators
RC network- RC வலையமைப்பு

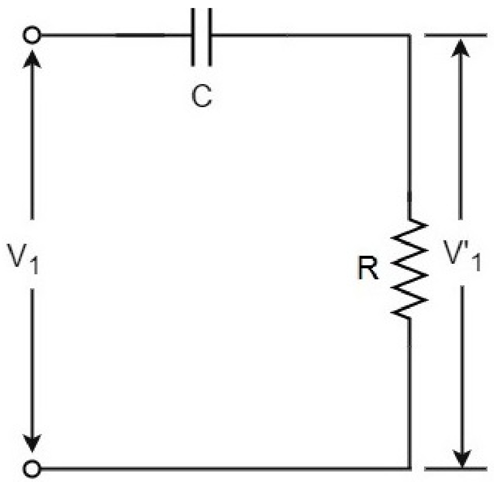
Output voltage of an RC circuit for a sinewave input leads the input voltage.

The phase angle by which it leads is determined by the value of RC components used in the circuit

The output voltage V_1' across the resistor R leads the input voltage applied input V_1 by some phase angle ϕ^o.

If R were reduced to zero, V_1' will lead the V_1 by 90^o i.e., $\phi^o = 90^o$.

However, adjusting R to zero would be impracticable, because it would lead to no voltage across R.

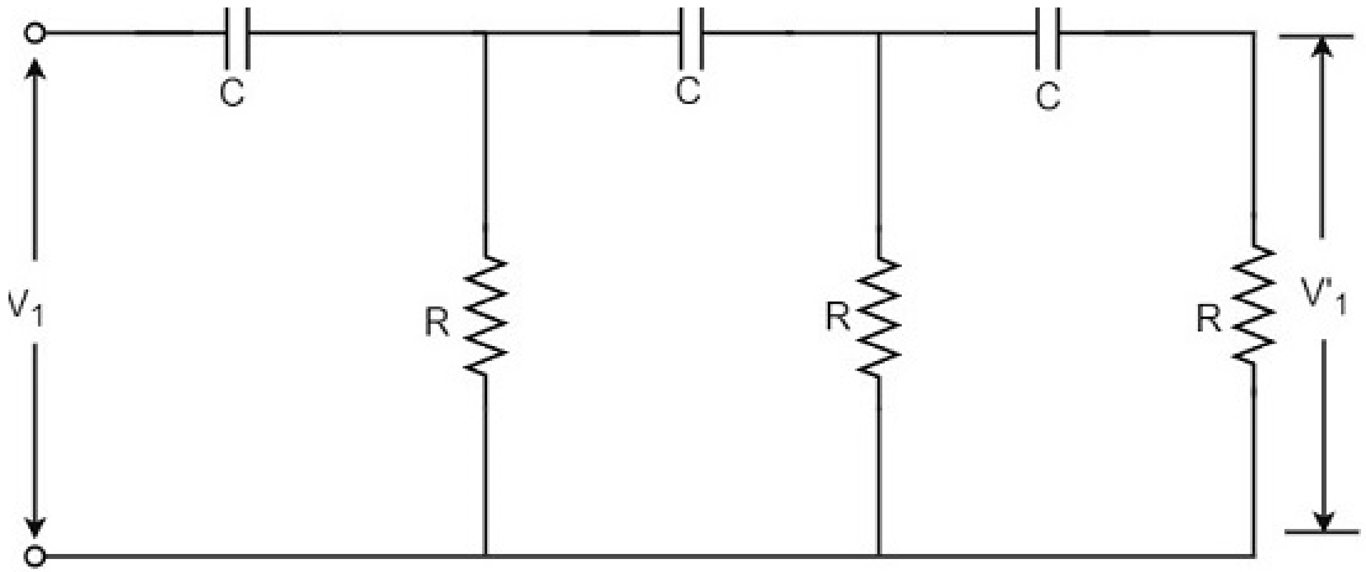


Therefore, in practice, R is varied to such a value that makes V_1' to lead V_1 by 60°.

The following circuit diagram shows the three sections of the RC network.

Each section produces a phase shift of 60°.

Consequently, a total phase shift of 180° is produced, i.e., voltage V_2 leads the voltage V_1 by 180°.



Phase-shift Oscillator - கட்டப் பெயர்ச்சி அலையியற்றி

The oscillator circuit that produces a sine wave using a RC network is called as a Phase-shift oscillator circuit.

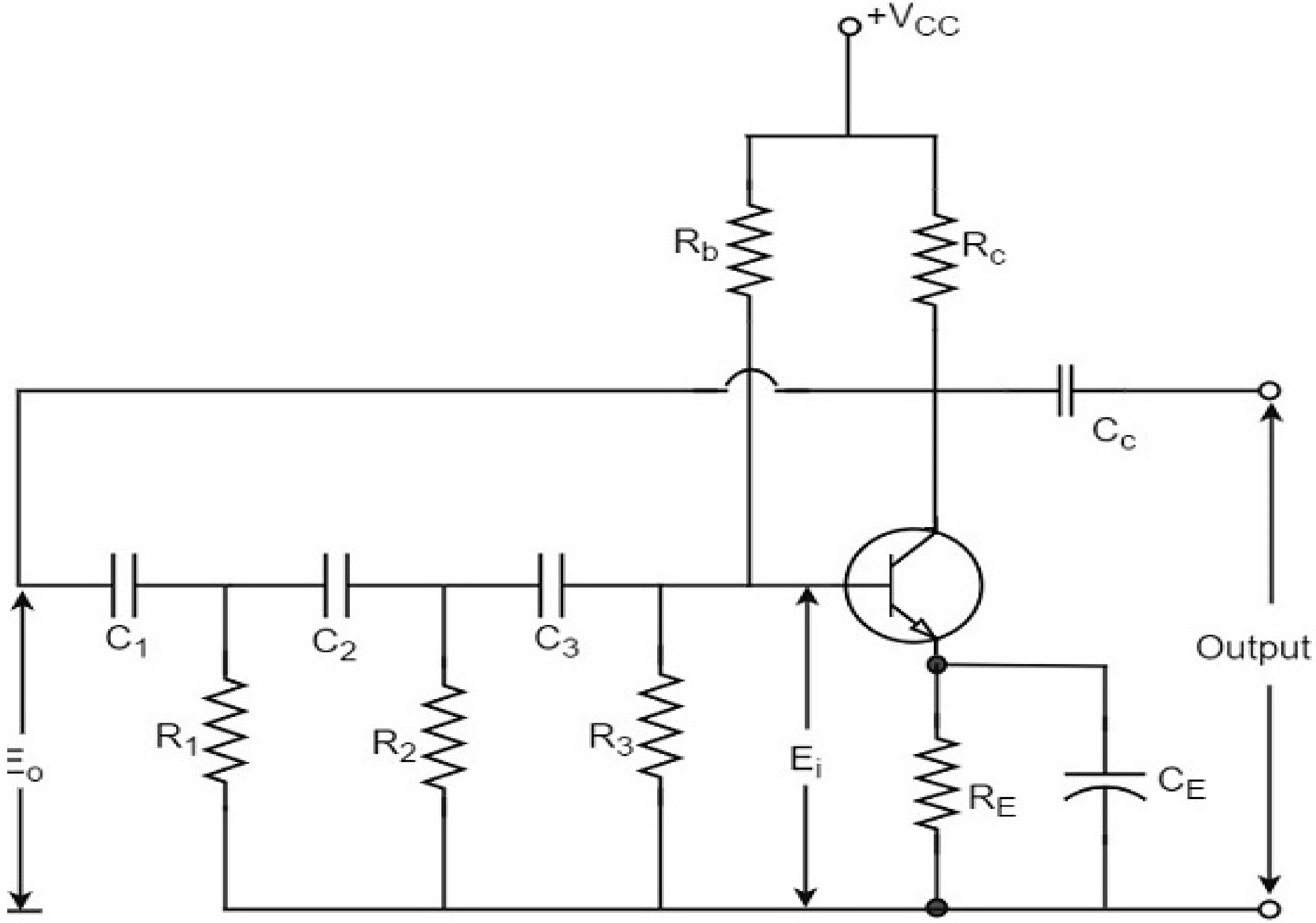
Construction

The phase-shift oscillator circuit consists of a single transistor amplifier section and a RC phase-shift network.

The phase shift network in this circuit, consists of three RC sections.

At the resonant frequency f_o, the phase shift in each RC section is 60^o so that the total phase shift produced by RC network is 180^o.

Freq below 10KHz - generated



+V_CC
R_b
R_c
C_c
C_1
C_2
C_3
R_1
R_2
R_3
E_i
R_E
C_E
Output
E_o

The frequency of oscillations is given by $$f_r = \frac{1}{2\pi RC\sqrt{2N}}$$

$$R_1 = R_2 = R_3 = R$$

$$C_1 = C_2 = C_3 = C$$

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

N- No. of RC networks

Operation

The circuit when switched ON oscillates at the resonant frequency f_o.

The output E_o of the amplifier is fed back to RC feedback network.

This network produces a phase shift of 180^o and a voltage E_i appears at its output.

This voltage is applied to the transistor amplifier.

The feedback applied will be β=Vf/Vo =Ei/Eo

The feedback is in correct phase, whereas the transistor amplifier, which is in CE configuration, produces a 180^{o} phase shift.

The phase shift produced by network and the transistor add to form a phase shift around the entire loop which is 360^{o}.

Thus the voltage gain of the amplifier must be sufficiently high enough to overcome these passive RC losses.

Advantages

It does not require transformers or inductors.
It can be used to produce very low frequencies.
The circuit provides good frequency stability.

Disadvantages

Starting the oscillations is difficult as the feedback is small.
The output produced is small.

Wien Bridge Oscillator
வியன் சமன சுற்று அலையியற்றி

Popular audio frequency oscillator

This circuit is free from the **circuit fluctuations** and the **ambient temperature**.

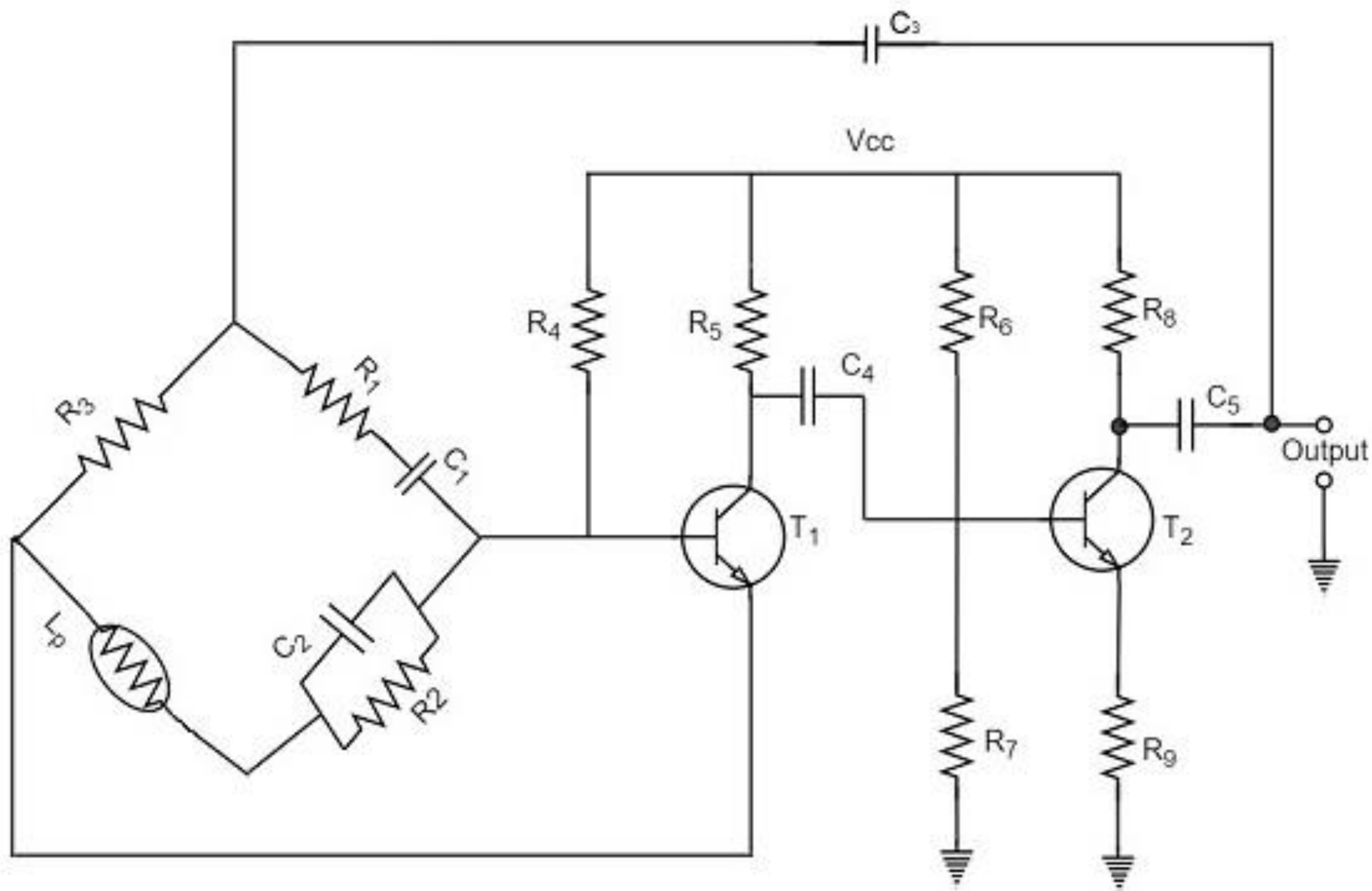
The main advantage of this oscillator is that the frequency can be varied in the range of 10Hz to about 1MHz

Construction

It is a two-stage amplifier with RC bridge circuit.

The bridge circuit has the arms R_1C_1, R_3, R_2C_2 and the tungsten lamp L_p.

Resistance R_3 and the lamp L_p are used to stabilize the amplitude of the output.



C3
Vcc
R4
R5
R6
R8
R3
R1
C4
C5
C1
Output
T1
T2
Lp
C2
R2
R7
R9

The transistor T_1 serves as an oscillator

The other transistor T_2 serves as an inverter.

The inverter operation provides a phase shift of 180^o.

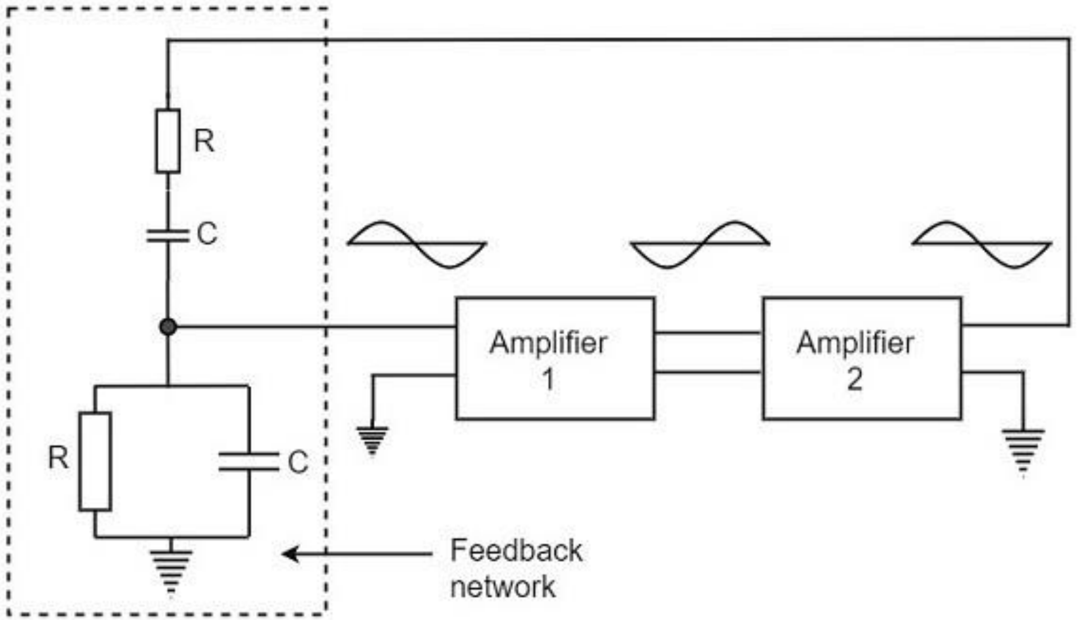
This circuit provides positive feedback to the transistor T_1 through R_1C_1, C_2R_2

Negative feedback - through the voltage divider to the input of transistor T_2

The frequency of oscillations is determined by the series element R_1C_1 and parallel element R_2C_2 of the bridge.

$$f = \frac{1}{2\pi\sqrt{R_1C_1R_2C_2}} \qquad = \frac{1}{2\pi RC}$$

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



The oscillator consists of two stages of RC coupled amplifier and a feedback network.

The voltage across the parallel combination of R and C is fed to the input of amplifier 1.

The net phase shift through the two amplifiers is zero.

Output of amplifier 2 is connected to amplifier 1 (to provide signal regeneration for oscillator)

Amplifier 1 will amplify signals over a wide range of frequencies

Direct coupling would result in poor frequency stability

By adding **Wien bridge feedback network**, the oscillator becomes sensitive to a particular frequency and hence frequency stability is achieved.

Operation

When the circuit is switched ON, the bridge circuit produces oscillations

The two transistors produce a total phase shift of 360° so that proper positive feedback is ensured.

The negative feedback in the circuit ensures constant output.

This is achieved by temperature sensitive tungsten lamp L_p.

Its resistance increases with current.

If the amplitude of the output increases, more current is produced and more negative feedback is achieved. Gain is low; o/p is decreased

Due to this, the output would return to the original value.

If the output tends to decrease, negative feedback is less ; Gain more ; O/P is increased to original value

Advantages

Good frequency stability.
Constant output.
The operation of circuit is quite easy.
The overall gain is high because of two transistors.
The frequency of oscillations can be changed easily.

Disadvantages

The circuit cannot generate very high frequencies.
Two transistors and number of components are required for the circuit construction