14. ASSIGNMENT TOPICS WITH MATERIALS

UNIT-1

1. CE amplifier with un bypassed emitter resistor
Consider the two-port network of CE amplifier. \( R_S \) is the source resistance and \( Z_L \) is the load impedance \( h \)-parameters are assumed to be constant over the operating range. The ac equivalent circuit is shown below figure. (Phasor notations are used assuming sinusoidal voltage input). The quantities of interest are the current gain, input impedance, voltage gain, and output impedance.

![CE Amplifier Diagram](image)

Current gain:
For the transistor amplifier stage, \( A_i \) is defined as the ratio of output to input currents.

\[
A_i = \frac{I_C}{I_B} = \frac{h_{fe}}{h_{be}} \quad (I_C + I_E = 0 \quad \therefore I_C = -I_E)
\]

\[
I_C = h_{re} I_B + h_{re} V_c
\]

\[
V_c = I_C Z_L = I_E Z_L
\]

\[
I_E = h_{re} I_B + h_{re} (I_C + Z_L)
\]

\[
A_i = \frac{h_{fe}}{h_{re} + h_{re} Z_L} Z_L
\]

Input Impedance:
The impedance looking into the amplifier input terminals (1,1') is the input impedance \( Z_i \)
Voltage gain:

The ratio of output voltage to input voltage gives the gain of the transistors.

\[ A_v = \frac{\frac{V_c}{V_b}}{\frac{I_c}{I_b}} = \frac{V_c}{V_b} \cdot \frac{I_b}{I_c} = \frac{A_i Y_L}{I_i} \]

Output Admittance:

It is defined as

\[ Y_0 = \left. \frac{I_b}{V_c} \right|_{V_b=0} = 0 \]

\[ I_c = h_{ie} I_b + h_{oe} V_c \]

\[ \frac{I_c}{V_c} = h_{ie} \frac{I_b}{V_c} + h_{oe} \]

when \( V_b = 0 \), \( R_s I_b + h_{oe} I_b + h_{oe} V_c = 0 \).

\[ b = \frac{h_{ie}}{R_s + h_{oe}} \]

\[ \therefore Y_0 = h_{ie} \frac{h_{re}}{R_s + h_{oe}} \]

Voltage amplification taking into account source impedance \( (R_s) \) is given by

\[ A_{vS} = \frac{\frac{V_c}{V_z}}{\frac{V_b}{V_S}} = \frac{V_b V_c}{V_S} \left( V_b - \frac{V_s}{R_s + Z_i} \right) \]

\[ = A_v \cdot \frac{Z_i}{Z_i + R_s} \]

\[ = \frac{A_i Z_L}{Z_i + R_s} \]

2. Types of distortions present in amplifiers?
Amplitude Distortion

Amplitude distortion occurs when the peak values of the frequency waveform are attenuated causing distortion due to a shift in the Q-point and amplification may not take place over the whole signal cycle. This non-linearity of the output waveform is shown below.

Amplitude Distortion greatly reduces the efficiency of an amplifier circuit. These “flat tops” of the distorted output waveform either due to incorrect biasing or over driving the input do not contribute anything to the strength of the output signal at the desired frequency.

Having said all that, some well known guitarist and rock bands actually prefer that their distinctive sound is highly distorted or “overdriven” by heavily clipping the output waveform to both the +ve and -ve power supply rails. Also, increasing the amounts of clipping on a sinusoid will produce so much amplifier distortion that it will eventually produce an output waveform which resembles that of a “square wave” shape which can then be used in electronic or digital synthesizer circuits.

Frequency Distortion

Frequency Distortion is another type of amplifier distortion which occurs in a transistor amplifier when the level of amplification varies with frequency. Many of the input signals that a practical amplifier will amplify consist of the required signal waveform called the “Fundamental Frequency” plus a number of different frequencies called “Harmonics” superimposed onto it.

Normally, the amplitude of these harmonics are a fraction of the fundamental amplitude and therefore have very little or no effect on the output waveform. However, the output waveform can become distorted if these harmonic frequencies increase in amplitude with regards to the fundamental frequency. For example, consider the waveform below:
In the example above, the input waveform consists of the fundamental frequency plus a second harmonic signal. The resultant output waveform is shown on the right-hand side. The frequency distortion occurs when the fundamental frequency combines with the second harmonic to distort the output signal. Harmonics are therefore multiples of the fundamental frequency and in our simple example a second harmonic was used.

Therefore, the frequency of the harmonic is twice the fundamental, 2 × f or 2f. Then a third harmonic would be 3f, a fourth, 4f, and so on. Frequency distortion due to harmonics is always a possibility in amplifier circuits containing reactive elements such as capacitance or inductance.

Phase Distortion

Phase Distortion or Delay Distortion is a type of amplifier distortion which occurs in a non-linear transistor amplifier when there is a time delay between the input signal and its appearance at the output.

If we say that the phase change between the input and the output is zero at the fundamental frequency, the resultant phase angle delay will be the difference between the harmonic and the fundamental. This time delay will depend on the construction of the amplifier and will increase progressively with frequency within the bandwidth of the amplifier. For example, consider the waveform below:

3. Different coupling schemes used in amplifiers
The coupling schemes used in amplifiers are
- RC coupling
- Direct coupling
- Transformer coupling

**RC COUPLING**

RC Coupling is the most Commonly used Coupling Between the two stages of a cascaded or multistage amplifier because it is cheaper in cost and Very compact circuit and provides excellent frequency response.

**DIRECT COUPLING**

Direct coupling is essential for Very low frequency applications Such as photoelectric current. It has got advantages of Simple and Very cheap circuit arrangement, outstanding ability to amplify low frequency signals. The Drawbacks of Direct Coupling includes Poor Temperature stability and unsuitability for amplification of high frequency signals. Direct coupled amplifiers are used when the load is directly in series with the Output terminal of the active circuit element.

**TRANSFORMER COUPLING**

Impedance Coupling results in more efficient amplification because no signal power is wasted in Inductor L. Such Coupling has the drawback of being larger, Heavier and Costlier than the RC COUPLING. Impedance Coupling is rarely used beyond audio range.
4. comparison of RC coupling, Direct coupling and Transformer coupling

Comparison of above coupling schemes is shown in below table.

<table>
<thead>
<tr>
<th>S.N</th>
<th>Particular</th>
<th>R-C Coupled Amplifier</th>
<th>Transformer Coupled Amplifier</th>
<th>Direct Coupled Amplifier</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Frequency Response</td>
<td>More</td>
<td>Poor</td>
<td>best</td>
</tr>
<tr>
<td>2.</td>
<td>Cost</td>
<td>Excellent</td>
<td>More</td>
<td>Least</td>
</tr>
<tr>
<td>3.</td>
<td>Space and Weight</td>
<td>Less</td>
<td></td>
<td>Least</td>
</tr>
<tr>
<td>4.</td>
<td>Impedance matching</td>
<td>Not good</td>
<td></td>
<td>Good</td>
</tr>
<tr>
<td>5.</td>
<td>Applications</td>
<td>Voltage amplification</td>
<td>Power amplification</td>
<td>Amplifying very low frequencies</td>
</tr>
</tbody>
</table>

5. Darlington pair

This is two transistors connected together so that the amplified current from the first is amplified further by the second transistor. This gives the Darlington pair a very high current gain such as 10000. Darlington pairs are sold as complete packages containing the two transistors. They have three leads (B, C and E) which are equivalent to the leads of a standard individual transistor.
The overall current gain is equal to the two individual gains multiplied together:
Darlington pair current gain, \( h_{FE} = h_{FE1} \times h_{FE2} \)

(h\(_{FE1}\) and \(h_{FE2}\) are the gains of the individual transistors)

This gives the Darlington pair a very high current gain, such as 10000, so that only a tiny base current is required to make the pair switch on.

Two transistors may be combined to form a configuration known as the Darlington pair which behaves like a single transistor with a current gain equivalent to the product of the current gain of the two transistors. This is especially useful where very high currents need to be controlled as in a power amplifier or power-regulator circuit. Darlington transistors are available whereby two transistors are combined in one single package. The base-emitter voltage drop is twice that of a small transistor.

\[
\begin{align*}
A_V &= \frac{V_o}{V_i} = \frac{R}{(R - jX_C)} = \frac{1}{1 - j\left(\frac{X_C}{R}\right)} = \frac{1}{1 - j\left(\frac{1}{\omega RC}\right)} = \frac{1}{1 - j\left(\frac{1}{2\pi f RC}\right)} \\
V_o &= \frac{RV_i}{R + X_C} \\
A_V &= \frac{1}{1 - j\left(\frac{f_1}{2}\right)}
\end{align*}
\]

Where \(f_1 = \frac{1}{2\pi RC}\)

In the magnitude and phase form,

\[
A_V = \frac{V_o}{V_i} = \frac{1}{\sqrt{1 + \left(\frac{f_1}{2}\right)^2}} \times \tan^{-1}\left(\frac{f_1}{2}\right)
\]

\[Atf = f_1, |A_V| = \frac{1}{\sqrt{2}} = 0.707 \rightarrow -3dB\]
UNIT-2

1. hybrid pi model

When input signal to an amplifier is in the range of ten to hundred Kilo Hertz, a small signal-low frequency model of the transistor can be used for analysis. But as the frequency increases, internal capacitance of the transistor will strongly effect its performance. A low frequency model cannot work well in this situation. To accommodate these performance changes of the transistor, a separate model is developed for high frequency operations. This high frequency model is given in Fig 1. A high frequency hybrid-pi model is also known as Giacoletto model.

1) Resistor $r_x$ is known as Base-spreading resistor

In Fig1, B' is a point internal to the transistor and is a part of base region. $r_x$ denotes the resistance of the silicon material between external base terminal B and internal base terminal B'. It's value is usually less than 100 ohms and has significant effect in high frequency response. It does not have any roll in low frequency analysis. $r_x \ll r_\pi$.

2) Base - Emitter capacitance $C_\pi$

This capacitance occurs due to the combined effect of emitter junction diffusion capacitance $C_{de}$ and emitter junction depletion capacitance $C_{je}$. (Diffusion and depletion capacitance are in your 'Solid State Devices' text book.) It's value is in between few pF to few tens of pF.

3) Collector - Base capacitance $C_{11}$

It is the capacitance of the Collector- Base junction of the transistor. It is ranging from fraction of pF to a few pF

2. CE short circuit current gain

an important high frequency characteristics of transistor is unity-gain bandwidth,($z_\pi$). this is defined as the frequency at which short-circuit current gain.
Figure 1: The hybrid-pi circuit for a single transistor with short circuit load

Applying KCL at collector terminal provides an equation for short circuit collector current

\[ I_C = g_m V_C - j\omega C_C V_C \]

At input terminal B, \( V_B = I_B, Z_{in} = I_B/V_B \) \( Z_{C_m} + Z_C \)

\[ V_C = I_B \left( \frac{1}{r_m} + j\omega (C_C + C_m) \right) \]

\[ I_C = (g_m - j\omega C_m) I_B \left( \frac{1}{r_m} + j\omega (C_C + C_m) \right) \]

\[ h_{fe} = \frac{I_C}{I_B} = \frac{(g_m - j\omega C_m)}{\left( \frac{1}{r_m} + j\omega (C_C + C_m) \right)} \]

as \( g_m \gg j\omega C_m \) therefore, \( h_{fe} \approx \frac{g_m r_m}{\left[ 1 + j\omega (C_C + C_m)r_m \right]} \)

The above frequency response \( h_{fe} \) is in the form of single pole low pass circuit.
3. gain bandwidth product of an amplifier

- For transistors, the current-gain–bandwidth product is known as the $f_T$ or transition frequency.

- It is calculated from the low-frequency current gain under specified test conditions, and the cutoff frequency at which the current gain drops by 3 decibels (70% amplitude);

4. common emitter current gain with load resistance

The hybrid pi model of common emitter amplifier with resistive load is shown in the below figure.
The current gain with resistive load is

$$f_T = f_b \cdot h_{re} = \frac{g_m}{2\pi(C_e + C_c)}$$

$$f_H = \frac{1}{2\pi C_s \left( \frac{1}{R_C} \ || \ R_L \right)}$$

UNIT-3

1. construction and characteristics of BJT

The BJT is a one type of transistor that uses both majority and minority charge carriers. These semiconductor devices are available in two types such as PNP and NPN. The main function of this transistor is to amplify current. These transistors can be used as switches and amplifiers. The applications of BJTs involve in a wide range that includes electronic devices like TVs, mobiles, computers, radio transmitters, audio amplifiers and industrial control.

**Construction of BJT**

A bipolar junction transistor comprises of two p-n junctions. Depending on the structure of the BJT, these are classified into two types such as PNP and NPN. In NPN transistor, lightly doped P-type semiconductor is placed between two heavily-doped N-type semiconductors. Equally, a PNP transistor is formed by placing an N-type semiconductor between P-type semiconductors. The construction of a BJT is shown below. The emitter and collector
terminals in the below structure are called n-type and p-type semiconductors which are denoted with ‘E’ and ‘C’. While the remaining collector terminal is called p-type semiconductor denoted with ‘B’.

2. construction and characteristics of FET

The term FET stands for Field effect transistor and it is also named as a Unipolar transistor. FET is a one type of transistor, where the o/p current is controlled by electric fields. The basic type of FET is totally dissimilar from BJT. FET consist of three terminals namely source, drain and gate terminals. The charge carriers of this transistor are holes or electrons, which flow from the source terminal to drain terminal via an active channel. This flow of charge carriers can be controlled by the voltage applied across the source and gate terminals.
Field effect transistors are classified into two types such as JFET and MOSFET. These two transistors have similar principles. The construction of p-channel JFET is shown below. In p-channel JFET, the majority charge carriers flow from the source to drain. Source and drain terminals are denoted by S and D.

3. Differences between BJT and FET

4. Bipolar junction transistors are bipolar devices, in this transistor there is a flow of both majority & minority charge carriers.

5. Field effect transistors are unipolar devices, in this transistor there are only the majority charge carriers flows.

6. Bipolar junction transistors are current controlled.

7. Field effect transistors are voltage controlled.

8. In many applications FETs are used than bipolar junction transistors.

9. Bipolar junction transistor consist of three terminals namely emitter, base and collector. These terminals are denoted by E, B and C.

10. Field effect transistor consist of three terminals namely source, drain and gate. These terminals are denoted by S, D and G.

11. The input impedance of field effect transistors has high compared with bipolar junction transistors.

12. A BJT needs a small amount of current to switch on the transistor. The heat dissipated on bipolar stops the total number of transistors that can be fabricated on the chip.

13. Whenever the ‘G’ terminal of the FET transistor has been charged, no more current is required to keep the transistor ON.

14. The BJT is responsible for overheating due to a negative temperature co-efficient.

FET has a +Ve temperature coefficient for stopping overheating.
15. BJTs are applicable for low current applications.

16. FETS are applicable for low voltage applications.

17. FETs have low to medium gain.

18. BJTs have a higher max frequency and a higher cutoff frequency.

4. characteristics of cascode amplifier

**Cascode amplifier**

While the C-B (common-base) amplifier is known for wider bandwidth than the C-E (common-emitter) configuration, the low input impedance (10s of Ω) of C-B is a limitation for many applications. The solution is to precede the C-B stage by a low gain C-E stage which has moderately high input impedance (kΩs). See Figure below. The stages are in a cascode configuration, stacked in series, as opposed to cascaded for a standard amplifier chain. See “Capacitor coupled three stage common-emitter amplifier” Capacitor coupled for a cascade example. The cascode amplifier configuration has both wide bandwidth and a moderately high input impedance.

![Common-base, Common-emitter, Cascode diagrams]

5. advantages of folded cascode amplifier over cascode amplifier

Compare to cascode amplifier, folded cascode amplifier consist following advantages

3. Easy to stabilize.
4. Output swing is much better than telescopic and slightly worse than common source output stage.
5. Input common mode is at least as good as two stage amplifier. There is a modified topology where input common mode can go close to rails on both sides.
6. Input referred noise and offset is worst among the three.
7. Static power consumption is worse than telescopic.
UNIT-4

1. classification of amplifiers

The classification of amplifiers are

- **Voltage Amplifier**: An amplifier provides a voltage output proportional to the voltage input and the proportionality factor does not depend on the magnitudes of the source and load resistance.
- **Current Amplifier**: An amplifier which provides an output current proportional to the signal current.
- **Transconductance Amplifier**: An amplifier in which, the output current is proportional to the signal voltage, independent of the magnitudes of source and load resistance.
- **Transresistance Amplifier**: An amplifier in which output voltage is proportional to the signal current of the magnitudes of source and load resistance.

2. series shunt feedback amplifier

1. In the series – shunt feedback amplifier shown in fig. calculate the voltage gains without feedback, \( A \), and with feedback \( A_{FB} \).
The open loop gain $A$, is defined as the ratio of output voltage, $v_o$, to the error voltage, $v_e$, which is input to the basic amplifier.

Therefore,

$$ A = \frac{v_o}{v_e} = \frac{IV}{5 \times 10^{-6}V} = 2 \times 10^3 $$

$A = 2 \times 10^3$

Voltage gain of feedback amplifier, $A_{FB}$, is expressed as,

$$ A_{FB} = \frac{A}{1 + AB} $$

Where $B$ is gain of the feedback network.

Since $AB >> 1$

$$ A_{FB} = \frac{A}{AB} = \frac{1}{B} $$

And $B$ is,

$$ B = \frac{P_1}{R_1 + R_2} = \frac{1k}{1k + 99k} = \frac{1}{100} = 0.01 $$

Therefore,

$$ A_{FB} = \frac{1}{B} = \frac{1}{0.01} = 100 $$

$A_{FB} = 100$

3. Hartley oscillator and colpitts oscillator

Hartley oscillator:

Hartley oscillator is a type of LC oscillator where the tank circuit consists of two inductors and one capacitor. The inductors are connected in series and the capacitor is connected in parallel to the series combination. It was invented by American scientist Ralph Hartley in 1915. Typical operating frequency of Hartley oscillator is from 20KHz to 20MHz and it can
be realized using BJT, FET or opamps. The circuit diagram of a Hartley oscillator is shown in the figure.

**Colpitts oscillator:**

Colpitts oscillator is another type of LC oscillator where the tank circuit consists of two capacitors and one inductor. The capacitors are connected in series and the inductor is connected in parallel to the series combination of the capacitors. It was invented by scientist Edwin Colpitts in the year 1918. Typical operating range of Colpitts oscillator is from 20KHz to MHz. The Colpitts oscillator has better frequency stability when compared to Hartley oscillator. Circuit diagram of a typical Colpitts oscillator is shown in the figure.

**4. Wien bridge oscillator**

It employs two transistors, each producing a phase shift of 180°, and thus producing a total phase-shift of 360° or 0°. The circuit diagram of Wien bridge oscillator is shown in the figure below. It is essentially a two-stage amplifier with an R-C bridge circuit.
In oscillators, RC phase-shift networks, each offering a definite phase-shift can be cascaded so as to satisfy the phase-shift condition led by the Barkhausen Criterion. One such example is the case in which RC phase-shift oscillator is formed by cascading three RC phase-shift networks, each offering a phase-shift of 60°, as shown by Figure.
Figure 2  RC Phase-Shift Oscillator Using BJT

Applying KVL,

\[
\begin{align*}
\eta_{0}R_{L} + R'_{L}I_{1} + X_{C}I_{2} + R(1 - I_{2}) &= 0 \\
R(1 - I_{2}) + X_{C}I_{2} + R(I_{2} - I_{3}) &= 0 \\
R(I_{3} - I_{2}) + X_{C}I_{3} + R'I_{3} &= 0
\end{align*}
\]

\[
I_{2} = \frac{1}{R}(2R + X_{C})I_{3}
\]

\[
I_{3} = \frac{1}{R}\left\{(2R + X_{C})^{2} - R\right\}I_{3}
\]

\[
\eta_{0} I_{1} + R'_{L}I_{1} + (R'_{L} + R + X_{C})\left\{\frac{3R^{2}X_{C}^{2} + 4RR'_{L}X_{C}}{R^{2}}\right\}I_{3} - (2R + X_{C})I_{3} = 0
\]

\[
\eta_{0} R'_{L} R^{2} > \left\{-R^{3} - 5RX_{C}^{2} - 3R'R_{L}R^{2} - R'_{L}X_{C}^{2}\right\}
\]

\[
> \left\{-R^{3} - 5R\left(-5R^{2} - 4RR'_{L}\right) - 3R'R_{L}R^{2} - R'_{L}\left(-5R^{2} - 4RR'_{L}\right)\right\}
\]

\[
\eta_{0} R'_{L} R^{2} > \left\{28R^{3} + 23R^{2}R'_{L} + 4RR'_{L}^{2}\right\}
\]

\[
\eta_{0} > \left\{\frac{29}{R'_{L}} + 23 + \frac{4R'R_{L}}{R}\right\}
\]

Therefore, the two conditions must be satisfied for oscillation to start and sustain.
1. Class A power amplifier

Class A power amplifier is the simplest type of power amplifier circuit. It uses a single-ended transistor for its output stage with the resistive load connected directly to the Collector terminal. When the transistor switches “ON” it sinks the output current through the Collector resulting in an inevitable voltage drop across the Emitter resistance thereby limiting the negative output capability.

The efficiency of this type of circuit is very low (less than 30%) and delivers small power outputs for a large drain on the DC power supply. A Class A amplifier stage passes the same load current even when no input signal is applied so large heat sinks are needed for the output transistors.

2. transformer coupled amplifier
As the Collector current, $I_C$ is reduced to below the quiescent Q-point set up by the base bias voltage, due to variations in the base current, the magnetic flux in the transformer core collapses causing an induced emf in the transformer primary windings. This causes an instantaneous collector voltage to rise to a value of twice the supply voltage $2V_{cc}$ giving a maximum collector current of twice $I_c$ when the Collector voltage is at its minimum. Then the efficiency of this type of Class A amplifier configuration can be calculated as follows.

The r.m.s. Collector voltage is given as

$$V_{CE} = \frac{V_C(\text{max}) - V_C(\text{min})}{2\sqrt{2}} = \frac{2V_{cc} - 0}{2\sqrt{2}}$$

The r.m.s. Collector current is given as:

$$I_{CE} = \frac{I_C(\text{max}) - I_C(\text{min})}{2\sqrt{2}} = \frac{2I_c - 0}{2\sqrt{2}}$$

The r.m.s. Power delivered to the load ($P_{ac}$) is therefore given as:

$$P_{ac} = V_{CE} \times I_{CE} = \frac{2V_{cc}}{2\sqrt{2}} \times \frac{2I_c}{2\sqrt{2}} = \frac{2V_{cc} \times 2I_c}{8}$$

The average power drawn from the supply ($P_{dc}$) is given by

$$P_{dc} = V_{cc} \times I_C$$

and therefore the efficiency of a Transformer-coupled Class A amplifier is given as:

$$\eta_{\text{max}} = \frac{P_{ac}}{P_{dc}} = \frac{2V_{cc} \times 2I_c}{8V_{cc}I_C} \times 100\%$$

3. cross over distortion

The main problem with class B push pull output stages is that each transistor conducts for NOT QUITE half a cycle. As shown in below figure distortion occurs on each cycle of the signal waveform as the input signal waveform passes through zero volts. Because the transistors have no base bias, they do not actually begin to conduct until their base/emitter voltage has risen to about 0.6V. As a result, there is a ‘Dead Zone’ of about 1.2V around the zero volts line (between $-0.6V$ and $+0.6V$) where the signal waveform is not amplified, causing a "missing" section from the output signal, resulting in unwanted distortion during the "crossover" from one transistor to the other.

The effect of this distortion on the output depends to some degree on the amplitude of the output signal, the larger the amplitude the less significant the missing 1.2 volts becomes. Also the distortion will be less severe at high frequencies where the rate of change of the wave, as it passes through zero is much faster, causing a shorter “step” in the waveform.

The large and varying current drawn by a powerful class B amplifier also puts considerable extra demand on the DC power supply and as the current drawn varies with the amount of signal applied, the smoothing capabilities of the power supply must be efficient enough to prevent this varying current from creating voltage changes at audio frequencies on the power.
supply lines. If these are not adequately removed, unintended audio feedback into earlier amplifier stages can occur and cause problems with instability. This extra demand on power supply complexity adds to the cost of class B power amplifiers.

![Graph showing input voltage, Tr1 collector current, Tr2 collector current, and output voltage](image)

4. Transistor power dissipation and heat sinks

**Transistor Power Dissipation**

- There is not a clear cut difference between ‘ordinary’ transistors used in voltage amplifiers and power transistors, but generally Power transistors can be categorised as those than can handle more than 1 Ampere of collector (or Drain in the case of FETs) current.
- Power transistors can handle larger currents and higher voltages.
- They have a different construction to small signal devices.
- They must have low output resistances so that they can deliver large currents to the load, a good junction insulation to withstand high voltages.
- They must also be able to dissipate heat very quickly so they do not overheat.

As most heat is generated at the collector/base junction, the area of this junction is made

**Heat Sinks**

![Heat sink image](image)
A heat-sink is designed to remove heat from a transistor and dissipate it into the surrounding air as efficiently as possible. Heat-sinks take many different forms, such as finned aluminium or copper sheets or blocks, often painted or anodised matt black to help dissipate heat more quickly. A selection of heat-sinks is illustrated in Figure. Good physical contact between the transistor and heat-sink is essential, and a heat transmitting grease (heat-sink compound) is smeared on the contact area before clamping the transistor to the heat-sink.

Where it is necessary to maintain electrical insulation between transistor and heat-sink a mica layer is used between the heat-sink and transistor. Mica has excellent insulation and very good heat conducting properties.

5. class C power amplifier

Class c power amplifier

Class C power amplifier is a type of amplifier where the active element (transistor) conduct for less than one half cycle of the input signal. Less than one half cycle means the conduction angle is less than 180° and its typical value is 80° to 120°. The reduced conduction angle improves the efficiency to a great extend but causes a lot of distortion. Theoretical maximum efficiency of a Class C amplifier is around 90%

Biasing resistor Rb pulls the base of Q1 further downwards and the Q-point will be set some way below the cut-off point in the DC load line. As a result the transistor will start
conducting only after the input signal amplitude has risen above the base emitter voltage \( (V_{be} \approx 0.7V) \) plus the downward bias voltage caused by \( R_b \). That is the reason why the major portion of the input signal is absent in the output signal.

Advantages of Class C power amplifier.
- High efficiency.
- Excellent in RF applications.
- Lowest physical size for a given power output.

Disadvantages of Class C power amplifier.
- Lowest linearity.
- Not suitable in audio applications.
- Creates a lot of RF interference.
- It is difficult to obtain ideal inductors and coupling transformers.
- Reduced dynamic range.

Applications of Class C power amplifier.
- RF oscillators.
- RF amplifier.
- FM transmitters.
- Booster amplifiers.
- High frequency repeaters.
- Tuned amplifiers etc
16. Unit wise-Question bank

UNIT-I

Two marks questions with answers

1. What is network and explain about two port network?

Network: A network is a collection of interconnected components. Network analysis is the process of finding the voltages across, and the currents through, every component in the network.

Two port network:

A transistor can be treated as a two part network. The terminal behavior of any two part network can be specified by the terminal voltages V1 & V2 at parts 1 & 2 respectively and current i1 and i2, entering parts 1 & 2, respectively, as shown in figure.

2. What are the advantages of h parameter model?

- Use of h – parameters to describe a transistor have the following advantages.
  - h – parameters are real numbers up to radio frequencies.
  - They are easy to measure
  - They can be determined from the transistor static characteristics curves.
  - They are convenient to use in circuit analysis and design.
  - Easily convert able from one configuration to other.
- Readily supplied by manufactories

3. What are is the advantage of emitter resistance in CE amplifier?

The voltage gain of a CE stage depends upon $h_{fe}$. This transistor parameter depends upon temperature, aging and the operating point. Moreover,
h_{fe} may vary widely from device to device, even for same type of transistor. To stabilize voltage gain $A_v$ of each stage, it should be independent of $h_{fe}$. A simple and effective way is to connect an emitter resistor $R_e$ as shown in Figure. The resistor provides negative feedback and provide stabilization.

**Figure: CE amplifier with $R_E$**

4. **Explain phase distortion?**
Phase Distortion or Delay Distortion is a type of amplifier distortion which occurs in a non-linear transistor amplifier when there is a time delay between the input signal and its appearance at the output.

If we say that the phase change between the input and the output is zero at the fundamental frequency, the resultant phase angle delay will be the difference between the harmonic and the fundamental. This time delay will depend on the construction of the amplifier and will increase progressively with frequency within the bandwidth of the amplifier. For example, consider the waveform below:

![Phase distortion](image)

5. **What is use of coupling capacitor and bypass capacitor?**

**Coupling capacitor:**
Coupling capacitors (or dc blocking capacitors) are used to decouple ac and dc signals so as not to disturb the quiescent point of the circuit when ac signals are injected at the input.

**Bypass capacitor:**
Bypass capacitors are used to force signal currents around elements by providing a low impedance path at the frequency.

**Three marks questions with answers**

1. **What are the advantages and disadvantages of transformer coupling?**
   1. Transformer Coupling results in more efficient amplification because no signal power is wasted in Inductor L.
   2. This Coupling has the drawback of being larger, Heavier and Costlier than the RC coupling.
3. Transformer Coupling is rarely used beyond audio range.

2. Draw the circuit of Darlington pair?

3. What is the advantages of Cascode Amplifier?
   - While the C-B (common-base) amplifier is known for wider bandwidth than the C-E (common-emitter) configuration, the low input impedance (10s of Ω) of C-B is a limitation for many applications.
   - The solution is to precede the C-B stage by a low gain C-E stage which has moderately high input impedance (kΩs).
   - The cascode amplifier configuration has both wide bandwidth and a moderately high input impedance.

4. Draw the common base amplifier circuit and it’s small signal equivalent model?

5. What are the coupling schemes used in amplifiers?
The coupling techniques used in amplifiers are
   - RC coupling
   - Direct coupling
   - Transformer coupling
Five marks questions with answers

1. Draw the circuit of CE amplifier with un bypassed emitter resistor and derive expressions for \( R_i \), \( R_o \), \( Av \) & \( Ai \) using approximate \( h \)-parameter model?

Consider the two-port network of CE amplifier. \( R_S \) is the source resistance and \( Z_L \) is the load impedance \( h \)-parameters are assumed to be constant over the operating range. The ac equivalent circuit is shown in below figure. (Phasor notations are used assuming sinusoidal voltage input). The quantities of interest are the current gain, input impedance, voltage gain, and output impedance.

**Current gain:**

For the transistor amplifier stage, \( A_i \) is defined as the ratio of output to input currents.

\[
A_i = \frac{I_c}{I_b} = \frac{I_c}{I_b} \quad (I_c + I_b = 0 \quad \therefore I_c = -I_b)
\]

\[
I_c = h_{fe} I_b + h_{re} V_c
\]

\[
V_c = I_c Z_L - I_b Z_L
\]

\[
\therefore I_c = h_{re} I_b + h_{re} (-I_b Z_L)
\]

or

\[
\frac{I_c}{I_b} = \frac{h_{fe}}{1 + h_{re} Z_L}
\]

\[
A_i = -\frac{h_{fe}}{1 + h_{re} Z_L}
\]

**Input Impedance:**

The impedance looking into the amplifier input terminals (\( 1,1' \)) is the input impedance \( Z_i \)
Voltage gain:

The ratio of output voltage to input voltage gives the gain of the transistors.

\[ A_v = \frac{V_o}{V_i} = -\frac{h_{fe} Z_L}{h_{ie}} \]

Output Admittance:

It is defined as

\[ Y_0 = \frac{b}{\frac{V_o}{V_i}} = 0 \]
\[ I_c = h_{fe} b + h_{re} V_c \]
\[ \frac{b}{V_c} = h_{re} \frac{b}{V_o} + h_{re} \]

when \( V_c = 0 \), \( R_e = R_e + h_{re} V_c = 0 \).
\[ b = h_{re} \]
\[ V_c = \frac{h_{re}}{R_e + h_{re}} \]

\[ Y_0 = h_{re} \frac{h_{fe}}{R_e + h_{re}} \]

Voltage amplification taking into account source impedance \( R_s \) is given by

\[ A_{VS} = \frac{V_o}{V_i} = \frac{V_o}{V_i} + \frac{V_o}{V_s} \left( V_o - \frac{V_s}{R_s + Z_l} \right) \]
\[ = A_v \frac{Z_l}{Z_l + R_s} \]
\[ = \frac{A_v Z_L}{Z_l + R_L} \]

2. Explain different types of distortions present in amplifiers?

Amplitude Distortion
Amplitude distortion occurs when the peak values of the frequency waveform are attenuated causing distortion due to a shift in the Q-point and amplification may not take place over the whole signal cycle. This non-linearity of the output waveform is shown below.

Amplitude Distortion greatly reduces the efficiency of an amplifier circuit. These “flat tops” of the distorted output waveform either due to incorrect biasing or over driving the input do not contribute anything to the strength of the output signal at the desired frequency. Having said all that, some well known guitarist and rock bands actually prefer that their distinctive sound is highly distorted or “overdriven” by heavily clipping the output waveform to both the +ve and -ve power supply rails. Also, increasing the amounts of clipping on a sinusoid will produce so much amplifier distortion that it will eventually produce an output waveform which resembles that of a “square wave” shape which can then be used in electronic or digital synthesizer circuits.

Frequency Distortion
Frequency Distortion is another type of amplifier distortion which occurs in a transistor amplifier when the level of amplification varies with frequency. Many of the input signals that a practical amplifier will amplify consist of the required signal waveform called the “Fundamental Frequency” plus a number of different frequencies called “Harmonics” superimposed onto it. Normally, the amplitude of these harmonics are a fraction of the fundamental amplitude and therefore have very little or no effect on the output waveform. However, the output waveform can become distorted if these harmonic frequencies increase in amplitude with regards to the fundamental frequency. For example, consider the waveform below:
In the example above, the input waveform consists of a fundamental frequency plus a second harmonic signal. The resultant output waveform is shown on the right hand side. The frequency distortion occurs when the fundamental frequency combines with the second harmonic to distort the output signal. Harmonics are therefore multiples of the fundamental frequency and in our simple example a second harmonic was used.

Therefore, the frequency of the harmonic is twice the fundamental, $2 \times f$ or $2f$. Then a third harmonic would be $3f$, a fourth, $4f$, and so on. Frequency distortion due to harmonics is always a possibility in amplifier circuits containing reactive elements such as capacitance or inductance.

**Phase Distortion**

Phase Distortion or Delay Distortion is a type of amplifier distortion which occurs in a nonlinear transistor amplifier when there is a time delay between the input signal and its appearance at the output.

If we say that the phase change between the input and the output is zero at the fundamental frequency, the resultant phase angle delay will be the difference between the harmonic and the fundamental. This time delay will depend on the construction of the amplifier and will increase progressively with frequency within the bandwidth of the amplifier. For example, consider the waveform below:

3. Explain Different coupling schemes used in amplifiers

The coupling schemes used in amplifiers are
RC COUPLING

RC Coupling is the most commonly used coupling between the two stages of a cascaded or multistage amplifier because it is cheaper in cost and very compact circuit and provides excellent frequency response.

DIRECT COUPLING

Direct coupling is essential for very low frequency applications such as photoelectric current. It has got advantages of simple and very cheap circuit arrangement, outstanding ability to amplify low frequency signals. The drawbacks of direct coupling include poor temperature stability and unsuitability for amplification of high frequency signals. Direct coupled amplifiers are used when the load is directly in series with the output terminal of the active circuit element.

TRANSFORMER COUPLING

Impedance coupling results in more efficient amplification because no signal power is wasted in inductor L. Such coupling has the drawback of being larger, heavier, and costlier than the RC COUPLING. Impedance coupling is rarely used beyond audio range.
4. Explain the comparison of RC coupling, Direct coupling and Transformer coupling?

Comparison of above coupling schemes is shown in below table.

<table>
<thead>
<tr>
<th>S.No</th>
<th>Particular</th>
<th>R-C Coupled Amplifier</th>
<th>Transformer Coupled Amplifier</th>
<th>Direct Coupled Amplifier</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Frequency Response</td>
<td>More</td>
<td>Poor</td>
<td>best</td>
</tr>
<tr>
<td>2.</td>
<td>Cost</td>
<td>Excellent</td>
<td>More</td>
<td>Least</td>
</tr>
<tr>
<td>3.</td>
<td>Space and Weight</td>
<td>Less</td>
<td></td>
<td>Least</td>
</tr>
<tr>
<td>4.</td>
<td>Impedance matching</td>
<td>Not good</td>
<td></td>
<td>Good</td>
</tr>
<tr>
<td>5.</td>
<td>Applications</td>
<td>Voltage amplification</td>
<td>Power amplification</td>
<td>Amplifying very low frequencies</td>
</tr>
</tbody>
</table>

5. Explain the operation of Darlington pair?

This is two transistors connected together so that the amplified current from the first is amplified further by the second transistor. This gives the Darlington pair a very high current gain such as 10000. Darlington pairs are sold as complete packages containing the two transistors. They have three leads (B, C and E) which are equivalent to the leads of a standard individual transistor.
The overall current gain is equal to the two individual gains multiplied together:
Darlington pair current gain, $h_{FE} = h_{FE1} \times h_{FE2}$
(h_{FE1} and h_{FE2} are the gains of the individual transistors)
This gives the Darlington pair a very high current gain, such as 10000, so that only a tiny base current is required to make the pair switch on.

Two transistors may be combined to form a configuration known as the Darlington pair which behaves like a single transistor with a current gain equivalent to the product of the current gain of the two transistors. This is especially useful where very high currents need to be controlled as in a power amplifier or power-regulator circuit. Darlington transistors are available whereby two transistors are combined in one single package. The base-emitter voltage drop is twice that of a small transistor.

**OBJECTIVE QUESTIONS**

1. Which of the following amplifier has high power gain
   a. CB                b. CE                      c. CC                            d. both CB and CE
   **Reason:** since CE amplifier has a moderate current gain and moderate voltage gain. Power gain is nothing but product of voltage gain and current gain.

2. In a RC coupled amplifier, which of the following component is mainly responsible for harmonic distortion of the signal
   a. Transistor       b. Biasing resistor     c. coupling capacitor    d. power supply
   **Reason:** Transistor is the mainly responsible for the harmonic distortion since harmonics are mainly due to the transistor.

3. Typical value of hie is
   a. 1k               b. 25k                c. 50k                 d. 100k
   **Reason:** The typical value of hie must be low.

4. Identify the incorrect statement
- Frequency distortion in an amplifier is mainly due to the reactive component circuit.
- Amplitude distortion is also referred to as non-linear distortion.
- Distortion in amplifier due to unequal phase shifts at different frequencies is called delay distortion.
- Phase shift distortion is same as frequency distortion.

**Reason:** Phase shift distortion is not same as frequency distortion.

5. Phase difference between o/p voltage & i/p voltage of a CC amplifier at mid band frequencies
   - a. 180°
   - b. 0°
   - c. 45°
   - d. 90°

**Reason:** There is no phase shift between input and output in CC amplifier.

6. Major drawback of Darlington transistor pair
   - Low current gain compared to single emitter follower.
   - Dependence of Av on transistor selected.
   - Low i/p impedance compared to single emitter follower.
   - Dependence of H-parameters on quiescent conditions.

**Reason:** The main drawback of darlington pair is dependence of h-parameter on quiescent conditions.

7. Resultant current gain of a Darlington pair individual current gain of hfe is
   - a. hfe/2
   - b. 2hfe
   - c. hfe
   - d. hfe²

**Reason:** The resultant current gain of a darlington pair is the product of two individual current gains.

8. 2-stage RC coupled amplifier is configured as
   - 2 capacitively coupled CE stages cascaded.
   - A CE stage capacitively coupled to a CC stage.
   - 2 capacitively coupled CB stages cascaded.
   - 2 capacitively coupled CC stages cascaded.

**Reason:** Two stage RC coupled amplifier is a combination of two capacitively coupled CE amplifier stages in cascade connection.

9. 2-transistor cascade with both collectors tied together & emitter of the transistor connected to the base of the transistor is referred to as
   - Darlington pair.
   - CE & CC cascade.
   - Cascade amplifier.
   - Differential pair.

**Reason:** In a darlington pair connection, the both collectors of tied together and one transistor emitter is connected to base of the another transistor.

10. The i/p impedance of cascade amplifier is
    - hic
Reason: The input impedance of a cascade amplifier is hie.

**FILL IN THE BLANKS**

1. The parameter h22 has units of __________

2. A CC Amplifier has highest __________ but lowest __________

3. The current gain of single stage CE amplifier is nearly equal to ________

4. The input impedance Ri of a CE amplifier in terms of hie, hoe, hre and load resistance. ______________.

5. The phase difference between output and input voltages of a CB amplifier is ________

6. Transformer coupling is generally used when RL is ________

7. In a two stage cascaded amplifier, each of two cascaded stages has a voltage gain of 30 then the overall gain is __________

8. The main advantage of multi stage amplifiers is ________

9. Cascode amplifier is a combination of ________

10. Darlington pair is combination of ________

<table>
<thead>
<tr>
<th>S.NO</th>
<th>PART-A KEY</th>
<th>PART-B KEY</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>B</td>
<td>seimens</td>
</tr>
<tr>
<td>2</td>
<td>A</td>
<td>Current gain, power gain</td>
</tr>
<tr>
<td>3</td>
<td>A</td>
<td>Beta</td>
</tr>
<tr>
<td>4</td>
<td>D</td>
<td>hie-(hrehfeRL)/(1+hoerL)</td>
</tr>
<tr>
<td>5</td>
<td>B</td>
<td>0</td>
</tr>
<tr>
<td>6</td>
<td>D</td>
<td>small</td>
</tr>
<tr>
<td>7</td>
<td>D</td>
<td>900</td>
</tr>
<tr>
<td>8</td>
<td>A</td>
<td>High gain</td>
</tr>
<tr>
<td>9</td>
<td>A</td>
<td>CE-CB</td>
</tr>
<tr>
<td>10</td>
<td>B</td>
<td>CC-CC</td>
</tr>
</tbody>
</table>
UNIT-2

Two marks questions with answers

1. What are the advantages of Hybrid pi model?

- The hybrid-pi model is a popular circuit model used for analyzing the small signal behavior of bipolar junction and field effect transistors.
- Sometimes it is also called Giacoletto model because it was introduced by L.J. Giacoletto in 1969.
- The model can be quite accurate for low-frequency circuits and
- It can easily be adapted for higher frequency circuits with the addition of appropriate inter-electrode capacitances and other parasitic elements.

2. Draw the hybrid pi model of CE amplifier?

![CE Amplifier Hybrid Pi Model Diagram]

3. Explain the parameters included in the hybrid pi model?

In high frequency model a resistor and two capacitors are added in addition to the components in low frequency model.

1) Resistor $r_x$ is known as Base-spreading resistor

In Fig1, B' is a point internal to the transistor and is a part of base region. $r_x$ denotes the resistance of the silicon material between external base terminal B and internal base terminal B'. It's value is usually less than 100 ohms and has significant effect in high frequency response. It does not have any roll in low frequency analysis. $r_x << r_\pi$.

2) Base - Emitter capacitance $C_\pi$

This capacitance occurs due to the combined effect of emitter junction diffusion capacitance $C_{de}$ and emitter junction depletion capacitance $C_{je}$. It's value is in between few pF to few tens of pF.
3) Collector - Base capacitance $C_{	ext{B}}$

It is the capacitance of the Collector-Base junction of the transistor. It is ranging from fraction of pF to a few pF.

4. Draw the graph between CE short circuit gain and frequency?

![Graph showing short-circuit CE current gain vs. frequency.]

5. What is gain bandwidth product?

- For transistors, the current-gain–bandwidth product is known as the $f_T$ or transition frequency.
- It is calculated from the low-frequency current gain under specified test conditions, and the cutoff frequency at which the current gain drops by 3 decibels (70% amplitude);
- the product of these two values can be thought of as the frequency at which the current gain would drop to 1, and the transistor current gain between the cutoff and transition frequency can be estimated by dividing $f_T$ by the frequency.

**Three marks questions with answers**

1. What is transconductance and write it's formula?

   the ratio of the change in current at the output terminal to the change in the voltage at the input terminal of an active device

   $$g_m = \frac{\text{change in output current}}{\text{change in input voltage}}$$

2. What is transresistance?

   **Transresistance** (for transfer resistance), also infrequently referred to as **mutual resistance**, is the dual of transconductance. It refers to the ratio between a change of the voltage at two output points and a related change of current through two input points.
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4. What is hybrid pi model?

When input signal to an amplifier is in the range of ten to hundred Kilo Hertz, a small signal-low frequency model of the transistor can be used for analysis. But as the frequency increases, internal capacitance of the transistor will strongly affect its performance. A low frequency model cannot work well in this situation. To accommodate these performance changes of the transistor, a separate model is developed for high frequency operations. This high frequency model is given in Fig 1. A high frequency hybrid-pi model is also known as Giacoletto model.

5. Explain the parameters included in the hybrid pi model?

In high frequency model a resistor and two capacitors are added in addition to the components in low frequency model.

1) Resistor $r_x$ is known as Base-spreading resistor
   
   In Fig1, $B'$ is a point internal to the transistor and is a part of base region. $r_x$ denotes the resistance of the silicon material between external base terminal $B$ and internal base terminal $B'$. It's value is usually less than 100 ohms and has significant effect in high frequency response. It does not have any roll in low frequency analysis. $r_x << r_\pi$.

2) Base - Emitter capacitance $C_\pi$
   
   This capacitance occurs due to the combined effect of emitter junction diffusion capacitance $C_{de}$ and emitter junction depletion capacitance $C_{je}$. It's value is in between few pF to few tens of pF.

3) Collector - Base capacitance $C_{\mu}$
   
   It is the capacitance of the Collector- Base junction of the transistor. It is ranging from fraction of pF to a few pF.
Five marks questions with answers

1. What is hybrid pi model and explain the parameters included?

When input signal to an amplifier is in the range of ten to hundred Kilo Hertz, a small signal-low frequency model of the transistor can be used for analysis. But as the frequency increases, internal capacitance of the transistor will strongly effect it's performance. A low frequency model cannot work well in this situation. To accommodate these performance changes of the transistor, a separate model is developed for high frequency operations. This high frequency model is given in Fig 1. A high frequency hybrid-pi model is also known as Giacoletto model.

In high frequency model a resistor and two capacitors are added in addition to the components in low frequency model.

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In Fig1, B' is a point internal to the transistor and is a part of base region. \( r_x \) denotes the resistance of the silicon material between external base terminal B and internal base terminal B'. It's value is usually less than 100 ohms and has significant effect in high frequency response. It does not have any roll in low frequency analysis. \( r_x \ll r_\pi \).

2) Base - Emitter capacitance \( C_\pi \)

This capacitance occurs due to the combined effect of emitter junction diffusion capacitance \( C_{de} \) and emitter junction depletion capacitance \( C_{je} \). (Diffusion and depletion capacitance are in your 'Solid State Devices' text book.) It's value is in between few pF to few tens of pF.
3) Collector - Base capacitance \( C_{\mu} \)

It is the capacitance of the Collector-Base junction of the transistor. It is ranging from fraction of pF to a few pF.

2. Find CE short circuit current gain formula?

An important high frequency characteristics of transistor is unity-gain bandwidth, \( f_\mu \). This is defined as the frequency at which short-circuit current gain.

\[
\eta_{fe} = \left. \frac{I_c}{I_b} \right|_{s.c.\, load}
\]

![Figure 1: The hybrid-pi circuit for a single transistor with short circuit load](image)

Applying KCL at collector terminal provides an equation for short circuit collector current

\[ I_c = g_m V_\pi - j \omega C_{\mu} V_\pi \]

At input terminal B,

\[
V_\pi = I_b Z_{in} = I_b r_n \left( Z_{C_n} + Z_{C_p} \right)
\]

\[
V_\pi = I_b \left[ \frac{1}{r_n} + j \omega (C_n + C_p) \right]^{-1}
\]

\[
I_c = (g_m - j \omega C_{\mu}) I_b \left[ \frac{1}{r_n} + j \omega (C_n + C_p) \right]^{-1}
\]

\[
\eta_{fe} = \left. \frac{I_c}{I_b} \right| = \left( g_m - j \omega C_{\mu} \right) \left[ \frac{1}{r_n} + j \omega (C_n + C_p) \right]^{-1}
\]

As \( g_m \gg j \omega C_{\mu} \) therefore, \( \eta_{fe} \approx g_m r_n \left[ 1 + j \omega (C_n + C_p) r_n \right]^{-1} \)

The above frequency response \( \eta_{fe} \) is in the form of single pole low pass circuit.
3. Explain gain bandwidth product of a amplifier?

- For transistors, the current-gain–bandwidth product is known as the $f_T$ or transition frequency.

- It is calculated from the low-frequency current gain under specified test conditions, and the cutoff frequency at which the current gain drops by 3 decibels (70% amplitude);

- the product of these two values can be thought of as the frequency at which the current gain would drop to 1, and the transistor current gain between the cutoff and transition frequency can be estimated by dividing $f_T$ by the frequency.

4. Draw and derive the common emitter current gain with load resistance?

The hybrid pi model of common emitter amplifier with resistive load is shown in below figure.
The 3db frequency $f_M = \frac{1}{2\pi r_x C} = \frac{g_{be}}{2\pi C}$

where $C = C_e + C_c (1 + g_m R_L)$

The current gain with resistive load is

$$f_T = f_\beta \cdot h_{re} = \frac{g_m}{2\pi \left(C_e + C_c\right)}$$

$$f_{H} = \frac{1}{2\pi C_s \left(R_C || R_L\right)}$$

5. Explain the parameters included in the hybrid pi model?

In high frequency model a resistor and two capacitors are added in addition to the components in low frequency model.

1) Resistor $r_x$ is known as Base-spreading resistor

In Fig1, B' is a point internal to the transistor and is a part of base region. $r_x$ denotes the resistance of the silicon material between external base terminal B and internal base terminal B'. It's value is usually less than 100 ohms and has significant effect in high frequency response. It does not have any roll in low frequency analysis. $r_x << r_\tau$.

2) Base - Emitter capacitance $C_{\pi}$

This capacitance occurs due to the combined effect of emitter junction diffusion capacitance $C_{de}$ and emitter junction depletion capacitance $C_{je}$. It's value is in between few pF to few tens of pF.

3) Collector - Base capacitance $C_{\mu}$

It is the capacitance of the Collector- Base junction of the transistor. It is ranging from fraction of pF to a few pF

**OBJECTIVE QUESTIONS**

1. Which capacitance/s in hybrid $\pi$ model represent/s the storage of excess minority carriers at the base emitter junction?
   a. Diffusion capacitance
   b. Transition capacitance
   c. Both a and b
   d. None of the above
The diffusion capacitances in hybrid pi model represents the storage of excess minority carriers at the base emitter junction.

2. What should be the value of unity gain frequency for a short circuit CE transistor with gain of 30 at 4MHz and cut-off frequency of about 100 kHz?
   a. 40 MHz  
   b. 80 MHz  
   c. 120 MHz  
   d. 150 MHz
   
   **Reason:** The relation between unity gain frequency, bandwidth and gain is
   \[ \text{Unity gain frequency} = \text{gain} \times \text{bandwidth} \]
   \[ \text{Unity gain frequency} = 30 \times 4\text{MHz} = 120\text{MHz} \]

3. Miller's theorem is applicable in a single stage CE hybrid π model in order to deal with
   a. Series combination of \( C_C \) and \( r_{bc} \)  
   b. Series combination of \( C_e \) and \( r_{be} \)  
   c. Parallel combination of \( C_C \) and \( r_{bc} \)  
   d. Parallel combination of \( C_e \) and \( r_{be} \)
   
   **Reason:** Miller's theorem is applicable in a single stage CE hybrid π model in order to deal with parallel combination of \( C_e \) and \( r_{be} \).

4. Which among the following will possess a higher bandwidth, if two transistors are provided with unity gain frequency?
   a. Transistor with lower \( h_{fe} \)  
   b. Transistor with higher \( h_{fe} \)  
   c. Transistor with lower \( h_{re} \)  
   d. Transistor with higher \( h_{re} \)
   
   **Reason:** The relation between unity gain frequency, bandwidth and gain is
   \[ \text{Unity gain frequency} = \text{gain} \times \text{bandwidth} = h_{fe} \times \text{bandwidth} \]
   Bandwidth inversely proportional to \( h_{fe} \).

5. Which among the following represents the frequency at which short circuit CE current gain acquires unit magnitude?
   a. \( f_i \)  
   b. \( f_{f3} \)  
   c. \( f_r \)  
   d. None of the above
   
   **Reason:** short circuit CE current gain acquires unit magnitude at \( f_T \).

6. The cut-off frequency (fβ) is basically the frequency at which the short circuit _________
   a. CB gain of transistor drops by 3 dB from its value at low frequency  
   b. CE gain of transistor drops by 3 dB from its value at low frequency  
   c. CC gain of transistor drops by 3 dB from its value at low frequency  
   d. None of the above
7. Which among the below specified parameters exhibit inverse relationship with an input conductance of hybrid π model?
   a. Temperature at constant $h_{fe}$
   b. Current at constant $h_{fe}$
   c. Voltage at constant $h_{re}$
   d. Resistivity at constant $h_{re}$

   **Reason:** The input conductance of hybrid π model is inversely proportional to the temperature at constant $h_{fe}$.

8. Which among the following plays a cardinal role in providing the transition capacitance in hybrid π model?
   a. Forward biased base-emitter junction
   b. Reverse-biased collector base junction
   c. Forward biased collector base junction
   d. Reverse-biased base-emitter junction

   **Reason:** Transition capacitance in hybrid π model is operated in reverse biased collector base junction.

9. Which resistance in hybrid π model of transistor represents the bulk resistance present between the external base terminal and the virtual base?
   a. Collector-to-emitter resistance ($r_{ce}$)
   b. Base spreading resistance ($r_{bb}$)
   c. Virtual base to emitter resistance ($r_{be}$)
   d. None of the above

   **Reason:** The resistance present between the external base terminal and the virtual base is base spreading resistance ($r_{bb}$).

10. Why do the internal capacitances of transistor at low frequencies treated as open circuits by completely neglecting their effects in analysis?
    a. Due to high reactance
    b. Due to low reactance
    c. Due to moderate reactance
    d. None of the above

   **Reason:** The internal capacitances effect is neglecting in analysis due to it’s high reactance.
FILL IN THE BLANKS

1. Hybrid pi model is also called as_________________

2. The gain is ______________ at high frequency.

3. Gain is decreases at high frequency due to____________

4. $R_{ce}$ is in the order of ______________

5. Forward transit time is defined as the average time the ________carrier spends in base.

6. The high frequency hybrid Pi or Giacoletto model of BJT is valid for frequencies ___________ than the unit gain frequency.

7. Gain band width product is denoted by___________

8. cutoff frequency is the frequency at which the current gain drops by _________ decibels.

9. ____________ capacitance in hybrid π model represent the storage of excess minority carriers at the base emitter junction.

10. Transistor with lower $h_{fe}$ and unity gain frequency will provide _______ bandwidth.

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<tr>
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UNIT-III
Two marks questions with answers

1. What is FET and what are the characteristics of FET?

- The **field-effect transistor (FET)** is a **transistor** that uses an electric field to control the electrical behaviour of the device.
- They are also known as **unipolar transistors** since they involve single-carrier-type operation.
- Field effect transistors generally display very high **input impedance** at low frequencies.
- Conductivity between the drain and source terminals is controlled by an electric field in the device, which is generated by the voltage difference between the body and the gate of the device.

2. Explain classification of FET?

![FET Classification Diagram]

3. What are the main differences between BJT and FET?

- Bipolar junction transistors are bipolar devices, in this transistor there is a flow of both majority & minority charge carriers.
- Field effect transistors are unipolar devices, in this transistor there are only the majority charge carriers flows.
- Bipolar junction transistors are current controlled.
- Field effect transistors are voltage controlled.
- In many applications FETs are used than bipolar junction transistors.
- Bipolar junction transistor consist of three terminals namely emitter, base and collector. These terminals are denoted by E, B and C.
Field effect transistor consist of three terminals namely source, drain and gate. These terminals are denoted by S, D and G.

The input impedance of field effect transistors has high compared with bipolar junction transistors.

4. What is the difference between MOSFET enhancement and depletion mode?

In case of depletion type there is a channel between source and drain terminals which is absent in case of enhancement type. The transfer function of depletion type MOSFET is same as the JFET transfer function. MOSFET can be operated with either a positive or a negative gate. When gate is positive with respect to the source it operates in the enhancement and when the gate is negative with respect to the source, it operates in depletion-mode.

5. Draw the circuit of JFET CD amplifier?

Three marks questions with answers

1. What is the need of folded cascode amplifier?

The gain from a single stage amplifier without cascoding is in the order of \( \text{gm} \times r_0 \) where \( \text{gm} \) is the transconductance and \( r_0 \) is the output impedance. With a folded cascode, the gain is in the order of \((\text{gm} \times r_0)^2\). It has

- Easy to stabilize.
- Output swing is much better than telescopic and slightly worse than common source output stage.
- Input common mode is at least as good as two stage amplifier. There is a modified topology where input common mode can go close to rails on both sides.
- Input referred noise and offset is worst among the three.
2. What are the characteristics of JFET?

- It is a kind of current-control device
- and its generating current includes electron flow and hole flow. The transistor is therefore referred to as bipolar junction transistor.
- FET has very high input impedance, typically around 100 MΩ

3. What are the applications of common gate stage?

- A common-gate amplifier is one of three basic single-stage field-effect transistor (FET) amplifier topologies, typically used as a current buffer or voltage amplifier.

   In this circuit the source terminal of the transistor serves as the input, the drain is the output and the gate is connected to ground, or "common," hence its name

4. What are the advantages of folded cascode amplifier over cascode amplifier?

   Compare to cascode amplifier, folded cascode amplifier consist following advantages

   2. Easy to stabilize.
   3. Output swing is much better than telescopic and slightly worse than common source output stage.
   4. Input common mode is at least as good as two stage amplifier. There is a modified topology where input common mode can go close to rails on both sides.
   5. Input referred noise and offset is worst among the three.
   6. Static power consumption is worse than telescopic.

5. Explain the characteristics of cascode amplifier?

   **Folded cascode amplifier**

   ![Folded cascode amplifier diagram]

   The gain from a single stage amplifier without cascoding is in the order of \( \text{gm} \times r_0 \) where \( \text{gm} \) is the transconductance and \( r_0 \) is the output impedance. With a folded cascode, the gain is in the order of \( (\text{gm} \times r_0)^2 \). For a fair comparison, let us compare with few other options that can give similar gains.
1) Telescopic amplifier - The input and output swing will be limited. Also, the negative output swing is a function of input common mode. However, there is only one dominant pole - relatively easy to stabilize.

2) Two-stages with a common source output stage - Output swing is the best among the three. However, it would be harder to stabilize due to two poles. One common technique is miller compensation.

**Five marks questions with answers**

**1. Explain the construction and characteristics of BJT?**

![Diagram of BJT types](image)

The BJT is a one type of transistor that uses both majority and minority charge carriers. These semiconductor devices are available in two types such as PNP and NPN. The main function of this transistor is to amplify current. These transistors can be used as switches and amplifiers. The applications of BJTs involve in a wide range that includes electronic devices like TVs, mobiles, computers, radio transmitters, audio amplifiers and industrial control.

**Construction of BJT**

A bipolar junction transistor comprises of two p-n junctions. Depending on the structure of the BJT, these are classified into two types such as PNP and NPN. In NPN transistor, lightly doped P-type semiconductor is placed between two heavily-doped N-type semiconductors. Equally, a PNP transistor is formed by placing an N-type semiconductor between P-type semiconductors. The construction of a BJT is shown below. The emitter and collector terminals in the below structure are called n-type and p-type semiconductors which are denoted with ‘E’ and ‘C’. While the remaining collector terminal is called p-type semiconductor denoted with ‘B’.

**P.USHA, ASSISTANT PROFESSOR**
2. Explain the construction and characteristics of FET?

The term FET stands for Field effect transistor and it is also named as a Unipolar transistor. FET is a one type of transistor, where the o/p current is controlled by electric fields. The basic type of FET is totally dissimilar from BJT. FET consist of three terminals namely source, drain and gate terminals. The charge carriers of this transistor are holes or electrons, which flow from the source terminal to drain terminal via an active channel. This flow of charge carriers can be controlled by the voltage applied across the source and gate terminals.

**Construction of FET**
Field effect transistors are classified into two types such as JFET and MOSFET. These two transistors have similar principles. The construction of p-channel JFET is shown below. In p-channel JFET, the majority charge carriers flow from the source to drain. Source and drain terminals are denoted by S and D.

3. Explain the Differences between BJT and FET?

- Bipolar junction transistors are bipolar devices, in this transistor there is a flow of both majority & minority charge carriers.
- Field effect transistors are unipolar devices, in this transistor there are only the majority charge carriers flows.
- Bipolar junction transistors are current controlled.
- Field effect transistors are voltage controlled.
- In many applications FETs are used than bipolar junction transistors.
- Bipolar junction transistor consist of three terminals namely emitter, base and collector. These terminals are denoted by E, B and C.
- Field effect transistor consist of three terminals namely source, drain and gate. These terminals are denoted by S, D and G.
- The input impedance of field effect transistors has high compared with bipolar junction transistors.
- A BJT needs a small amount of current to switch on the transistor. The heat dissipated on bipolar stops the total number of transistors that can be fabricated on the chip.
- Whenever the ‘G’ terminal of the FET transistor has been charged, no more current is required to keep the transistor ON.
- The BJT is responsible for overheating due to a negative temperature co-efficient.

FET has a +Ve temperature coefficient for stopping overheating.
- BJT's are applicable for low current applications.
- FETS are applicable for low voltage applications.
- FETs have low to medium gain.
- BJT's have a higher max frequency and a higher cutoff frequency.

4. Explain the characteristics of MOSFET of enhancement and depletion mode?

MOSFET (Metal Oxide Semiconductor Field Effect Transistor) is a unipolar, voltage
controlled current device and is a device in which current at two electrodes drain and source is controlled by the action of electric field at another electrode gate having in between a semiconductor very a thin metal oxide layer. MOSFET is classified into two types i.e. enhancement type and depletion type.

- There is no direct electrical connection between the gate terminal and the channel of a MOSFET. It is the insulating layer of n_o in the MOSFET construction that account for the very desirable high input impedance of the device.

Although there are some similarities in construction and mode of operation between depletion type and enhancement type but in case of depletion type there is a channel between source and drain terminals which is absent in case of enhancement type. The transfer function of depletion type MOSFET is same as the JFET transfer function. MOSFET can be operated with either a positive or a negative gate. When gate is positive with respect to the source it operates in the enhancement—or E-mode and when the gate is negative with respect to the source, it operates in depletion-mode.

5. Explain the characteristics of cascode amplifier in detail?

**Cascode amplifier**

While the C-B (common-base) amplifier is known for wider bandwidth than the C-E (common-emitter) configuration, the low input impedance (10s of $\Omega$) of C-B is a limitation for many applications. The solution is to precede the C-B stage by a low gain C-E stage which has moderately high input impedance (k$\Omega$s). See Figure below. The stages are in a cascode configuration, stacked in series, as opposed to cascaded for a standard amplifier chain. See “Capacitor coupled three stage common-emitter amplifier” Capacitor coupled for a cascade example. The cascode amplifier configuration has both wide bandwidth and a moderately high input impedance.
**OBJECTIVE QUESTIONS**

1. The phase relationship between output and input voltages of a CS amplifier for frequency above higher cut off frequency is
   7. both are 180 degrees out of phase
   8. output leads input
   9. both are in phase
   10. output lags input
   **Reason:** At higher frequency the output of CS amplifier lags the input.

2. Phase relationship between o/p and i/p voltage of a CS amplifier for frequency below lower cut-off frequency is
   11. both are in phase
   12. o/p lags i/p
   13. output leads i/p
   14. both are 180° out of phase
   **Reason:** At higher frequency the output of CS amplifier is leads the input.

3. Voltage gain of a given CS FET depends on its
   15. Dynamic drain resistance
   16. i/p impedance
   17. Amplification factor
   18. D rain load resistance
   **Reason:** The voltage gain of a CS FET depends on it’s drain load resistance

4. phase difference between o/p voltage & i/p voltage of a CG amplifier at mid band frequencies is
   19. 1800
   20. 00
   21. 450
   22. 90
5. FET amplifier configuration, which is similar to CC BJT is
   23. common gate amplifier
   24. common drain amplifier
   25. common source amplifier
   26. swamped source resistor amplifier
   **Reason:** Common drain amplifier is similar to common collector amplifier.

6. Phase reversal between i/p & o/p signal voltages occurs in
   27. common base amplifier
   28. common drain amplifier
   29. common gate amplifier
   30. common source amplifier
   **Reason:** The phase reversal between input and output voltages occurs in common source amplifier.

7. Which MOSFET allows the flow of drain current even with zero gate to source voltage just due to existence of channel between drain and source terminals?
   a. Depletion MOSFET
   b. Enhancement MOSFET
   c. Depletion-Enhancement MOSFET
   d. All of the above
   **Reason:** In depletion mode MOSFET allows the flow of drain current even with zero gate to source voltage.

8. Which property of MOSFET distinguishes it from JFET regarding to voltage application in addition to operational strategies and mechanisms?
   a. Provision of applying positive and negative voltages to gate being insulated from channel
   b. Provision of applying only positive voltage to gate to E-MOSFET
   c. Provision of applying only negative voltage to gate to DE-MOSFET
   d. All of the above
   **Reason:** All the options satisfies the MOSFET distinguishes from JFET.

9. A JFET has three terminals, namely ...........
   31. cathode, anode, grid
   32. emitter, base, collector
   33. source, gate, drain
   34. none of the above
   **Reason:** The terminals of JFET are source, gate and drain.

10. If the reverse bias on the gate of a JFET is increased, then width of the conducting channel ...........
    35. is decreased

**P. USHA, ASSISTANT PROFESSOR**
36. is increased
37. remains the same
38. none of the above
**Reason:** If the reverse bias on the gate of a JFET is increased, then width of the conducting channel is decreased.

**FILL IN THE BLANKS**

1. Resultant phase shift of even no of CG amplifier stages at higher cut off frequencies is ________________
2. JFET is also called as ______transistor
3. JFET is a ______ controlled device
4. the gate of JFET is ______ biased.
5. MOSFET is sometimes called as ______ JFET
6. The input impedance of a MOSFET is of the order of ______
7. A CS JFET amplifier has a load resistance of 10 kΩ, \( R_D = 820Ω \), \( I_{g_m} = 5mS \) and \( V_{in} = 500 \text{ mV} \), the output signal voltage is ______
8. Q10. A MOSFET has________ terminals
9. ______ has the lowest noise-level
10. ______ has the highest input impedance.

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<tr>
<td>3</td>
<td>D</td>
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<td>6</td>
<td>D</td>
<td>MΩ</td>
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**P. USHA, ASSISTANT PROFESSOR**
UNIT-IV

Two marks questions with answers

1. List the names of classification of amplifier based on feedback?
The amplifiers are divided into four types
1. voltage amplifiers
2. current amplifiers
3. transconductance amplifier
4. transresistance amplifier

2. What is feedback?
Feedback is defined as the process in which a part of output signal (voltage or current) is returned back to the input. The amplifier that operates on the principle of feedback is known as feedback amplifier.

3. What are the types of feedback?
The types of feedbacks are.
- Positive feedback
- Negative feedback.

Positive feedback: If the original input signal and the feedback signal are in phase, the feedback is called as positive feedback.

Negative feedback: However if these two signals are out of phase then the feedback is called as negative feedback.

4. What are the advantages and disadvantages of negative feedback?

**ADVANTAGES**
- Input resistance increases
- Output resistance decreases
- Bandwidth increases
- Non linear distortion decreases
- Frequency distortion decreases
- Sensitivity will be decreased
- Gain stability

**DISADVANTAGES**
- Decrease in gain

5. What is the effect of negative feedback on input-output resistance?
- **Input resistance**
  feedback amplifiers, series mixing at the input tends to increase the input resistance and shunt mixing tends to decrease the input resistance.

- **Output resistance**
  feedback amplifiers, voltage sampling at the output tends to decrease the output resistance and current sampling tends to increase the output resistance.
Three marks questions with answers

1. Draw the circuit of voltage shunt feedback amplifier?

![Circuit Diagram]

2. What are the condition for oscillations?
The use of positive feedback is useful for producing oscillators. The condition for positive feedback is that a portion of the output is combined in phase with the input. For an amplifier with positive feedback the gain is given by the expression below

The large open loop gain of an op-amp makes it inevitable that the condition

$$A_0B = 1$$

and the gain expression

$$A_f = \frac{V_{out}}{V_{in}} = \frac{A_0}{1 - A_0B}$$

becomes infinite

3. What are the advantages of RC phase shift oscillator

- This circuit is very simple and cheap as it comprises resistors and capacitors (not bulky and expensive high-value inductors).
- It provides good frequency stability.
- The output of this circuit is sinusoidal that is quite distortion free.
- The phase shift oscillator circuit is simpler than the Wein bridge oscillator circuit because it does not need negative feedback and the stabilization arrangements.
- They have a wide range of frequency (from a few Hz to several hundred of kHz).
- They are particularly apt for low frequencies, say of the order of 1 Hz, so these frequencies can be easily gained by using R and C of large values.

4. What is piezo electric effect?
When a voltage source is applied to a small thin piece of quartz crystal, it begins to change shape producing a characteristic known as the Piezo-electric effect. This Piezo-electric Effect is the property of a crystal by which an electrical charge produces a mechanical force by changing the shape of the crystal and vice versa, a mechanical force applied to the crystal produces an electrical charge.

5. What is de-sensitivity factor?

De sensitivity factor is defined as the factor with which the feedback desensitizes the gain. It is also called as return difference.

\\[ \text{De sensitivity factor} = \frac{dA_{fb}}{dA_{fb}} \times dA = \frac{1}{1+\alpha \beta} \]

Where \( A_{fb} \) is gain with feedback

\( A \) is gain without feedback

\( \beta \) is feedback factor.

Five marks questions with answers

1. Explain the classification of amplifiers?

The classification of amplifiers are

- Voltage Amplifier: An amplifier provides a voltage output proportional to the voltage input and the proportionality factor does not depend on the magnitudes of the source and load resistance

- Current Amplifier: An amplifier which provides an output current proportional to the signal current.

- Transconductance Amplifier: An amplifier in which the output current is proportional to the signal voltage, independent of the magnitudes of source and load resistance.

- Transresistance Amplifier: An amplifier in which output voltage is proportional to the signal current of the magnitudes of source and load resistance.

2. In a series shunt feedback amplifier shown in below figure calculate the voltage gain without feedback \( A \) and with feedback \( A_{FB} \).

![Diagram of series shunt feedback amplifier]
The open loop gain $A$, is defined as the ratio of output voltage, $v_o$, to the error voltage, $v_e$, which is input to the basic amplifier.

Therefore,

$$A = \frac{v_o}{v_e} = \frac{1V}{5 \times 10^{-6}V} = 2 \times 10^5$$

$$A = 2 \times 10^5$$

Voltage gain of feedback amplifier, $A_{FB}$, is expressed as,

$$A_{FB} = \frac{A}{1 + AB}$$

Where $B$ is gain of the feedback network.

Since $AB \gg 1$

$$A_{FB} = \frac{A}{AB} = \frac{1}{B}$$

And $B$ is,

$$B = \frac{R_1}{R_1 + R_2} = \frac{1k}{1k + 99k} = \frac{1}{100} = 0.01$$

Therefore,

$$A_{FB} = \frac{1}{B} = \frac{1}{0.01} = 100$$

$$A_{FB} = 100$$

3. Show that the gain of Wien bridge oscillator using BJT amplifier must be at least 3 for the oscillations to occur?

It employs two transistors, each producing a phase shift of $180^\circ$, and thus producing a total phase-shift of $360^\circ$ or $0^\circ$. The circuit diagram of Wien bridge oscillator is shown in the figure below. It is essentially a two-stage amplifier with an R-C bridge circuit.
4. Draw the circuit diagram of RC phase shift oscillator using BJT. Derive the expression for frequency of oscillations?

In oscillators, RC phase-shift networks, each offering a definite phase-shift can be cascaded so as to satisfy the phase-shift condition led by the Barkhausen Criterion. One such example is the case in which RC phase-shift oscillator is formed by cascading three RC phase-shift networks, each offering a phase-shift of 60°, as shown by Figure.
The simplified equivalent circuit is shown in Fig. 3.

Applying KVL:

\[
\begin{align*}
\text{hie} & = \frac{1}{R} (2R + X_C) L_3 \\
L_1 & = \frac{1}{R} \left\{ \frac{(2R + X_C)^2}{R} - R \right\} L_3 \\
\text{hie} L_b R' + R' (L_1 + X_C L_3 + R (L_2 - L_1)) & = 0 \\
R (L_2 - L_1) + X_C L_2 + R (L_2 - L_1) & = 0 \\
R (L_3 - L_2) + X_C L_3 + R L_3 & = 0
\end{align*}
\]

\[
\begin{align*}
\therefore I_2 & = \frac{1}{R} (2R + X_C) L_3 \\
I_1 & = \frac{1}{R} \left\{ \frac{(2R + X_C)^2}{R} - R \right\} L_3 \\
\therefore h_{ie} & = \frac{R'}{R} \left( R' L_1 + (R' + R + X_C) \left\{ \frac{3 R^2 + X_C^2 + 4 R X_C}{R^2} \right\} L_3 \cdot (2R + X_C) L_3 = 0 \right.
\end{align*}
\]
\[ h_{fe} R'_L R^2 > \left\{ -5 R X_C^2 - 3 R'_L R^2 - R'_L X_C^2 \right\} \]

\[ > \left\{ -5 R - 4R R'_L \right\} \]

\[ h_{fe} R'_L R^2 > \left\{ \frac{29 R^2 + 23 R R'_L + 4R R'_L}{R} \right\} \]

Therefore, the two conditions must be satisfied for oscillation to start and sustain.

5. Draw the feedback topologies?

- **Series voltage feedback**
- **Series current feedback**
- **Parallel voltage feedback**
- **Parallel current feedback**

**OBJECTIVE QUESTIONS**

1. Negative feedback in amplifier
   a. Improves SNR at the input
   b. Improves SNR at the output
   c. Increases distortion
   d. None of the above
   **Reason:** Negative feedback in amplifiers improves SNR at the output.

2. The gain of an amplifier with feedback is _______.
   a. \( A/1 + A\beta \)
   b. \( \beta /1 + \beta a \)
   c. \( \beta /1 - \beta a \)
   d. \( A/1 - A\beta \)
   **Reason:** The gain of the amplifier with feedback if \( A/1 + AB \).

3. In voltage shunt feedback, the input impedance
a. increases  
b. decreases  
c. depends on dc voltage applied  
d. depends on frequency of operation  

**Reason:** In voltage shunt feedback, the input impedance decreases due to shunt connection at the input.

4. An oscillator of LC type having a split capacitor in the tank circuit is  
a. Hartley  
b. Colpitts  
c. Tuned  
d. Wein Bridge  

**Reason:** The Colpitt’s oscillator consists of capacitors in the tank circuit.

5. In a Crystal oscillator the frequency is very stable due to _________ of the crystal  
a. rigidity  
b. high Q  
c. vibration  
d. none  

**Reason:** In crystal oscillator the frequency is very stable due to the vibration of the crystal.

6. For generating a sinusoidal wave of 1KHz frequency, the most suitable oscillator is ___  
a. Hartley  
b. Colpitts  
c. Wien bridge  
d. None of the above  

**Reason:** The Wien bridge oscillator is suitable at below the 20 KHz.

7. The frequency stability of LC oscillator is _______ than RC oscillators.  
a. less  
b. more  
c. either a or b  
d. None of the above  

**Reason:** The frequency stability of LC oscillators is less than the RC oscillators.

8. An important limitation of a crystal oscillator is ________  
a. its low output  
b. its high Q  
c. less availability of quartz crystal  
d. its high output  

**Reason:** One of the disadvantages of a crystal oscillator is its low output.

---

**FILL IN THE BLANKS**

1. The Trans conductance amplifier is also called as ____________

2. The ratio of input impedance with feedback to without feedback is _________

3. Non sinusoidal oscillators are also called ____________

4. The oscillator which uses inductive feedback is _________

5. In a RC phase shift oscillator, each RC section provides a phase shift of _________

6. An oscillator using LC tuned circuit has L= 58.6μH & C=300pF, then the frequency of oscillations will be ____________

7. Quartz crystal oscillators tend to operate towards their ____________.

---

*P. USHA, ASSISTANT PROFESSOR*
8. In current shunt feedback amplifier the output resistance is _________ by a factor of $1+A\beta$.

9. one of the effects of negative feedback in amplifier is to __________________

10. The voltage gain of an amplifier is 100. On applying negative feedback with $\beta=0.03$, it’s gain will reduce to_________

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<td>1</td>
<td>B</td>
<td>Series series amplifier or current series amplifier</td>
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<td>2</td>
<td>A</td>
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<td>3</td>
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<td>9</td>
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UNIT-V

Two marks questions with answers

1. What is power amplifier and list the types?
Amplifier circuits form the basis of most electronic systems, many of which need to produce high power to drive some output device.
Types:
   - Class A
   - Class B
   - Class AB
   - Class C

2. Define conduction angle in power amplifier?
The time during which the transistor conducts i.e. (the collector current is non zero) when an input sinusoidal signal is applied in a power amplifier is defined as Conduction angle.

3. What is class A, Class B, Class AB, Class C amplifiers?
Class A amplifier: In class A amplifiers the collector is biased at a value greater than the amplitude of AC signal current. Hence the conduction angle is 360 Degrees i.e. the class A stage conducts for the entire cycle for the input signal.
Class B amplifier: Class B amplifiers are biased at zero DC bias collector current. Hence it conducts only for half of the input signal cycle, so the conduction angle for class B amplifier is 180 Degrees.
Class AB amplifier: In class AB amplifiers the biasing current is non zero but much smaller than the peak current of the sine wave signal. As a result the transistor conducts for interval slightly greater than half a cycle. The conduction angle is slightly greater than 180 Degrees.
Class C amplifier: In class C amplifier the transistor conducts for an interval less than the half cycle. Hence the conduction angle is less than 180 Degrees.

4. What is push-pull amplifier?
A push pull amplifier is a special type of arrangement used in class B amplifiers where the active device pair push (supply) current and pull (absorb) current from load. Push pull amplifiers are more efficient than the single ended power amplifiers. Because of the symmetric construction of two sides of the amplifier the even harmonics are cancelled and output signal distortion can be minimized. Another advantage of the push pull amplifier is the effect of ripple voltage that may be contained in the power supply is balanced out. The main disadvantages of the push pull amplifier are the need for two identical transistors and the requirement of bulky and costly coupling transformers used for phase splitting.

5. What is complementary push-pull amplifier?
Complementary Push-pull amplifiers use two “complementary” or matching transistors, one being an NPN-type and the other being a PNP-type with both power transistors receiving the same input signal together that is equal in magnitude, but in opposite phase to each other.
This results in one transistor only amplifying one half of the input waveform cycle while the other transistor amplifies the other half of the input waveform cycle with the resulting “two-halves” being put back together again at the output terminal. In complementary push pull amplifier neither an input nor an output transformer is needed. The main difficulty with this circuit .if there is unbalance in the characteristic f the two transistors considerable distortion will be introduced.

Three marks questions with answers

1. Draw the circuit of class A power amplifier?

![Class A Amplifier](image)

2. What are the characteristics of Class B Amplifier?

The class B amplifiers are the positive and negative halves of the signals, that are allocated to the different parts of the circuits and the output device switched ON and OFF continuously. The basic class B amplifiers are used in two complementary transistors which are FET and bipolar. These two transistors of each half of the waveform with its output are configured in a push-pull type arrangement. Hence the each amplifier only half of the output waveform.

3. What is crossover distortion?

The main problem with class B push pull output stages is that each transistor conducts for NOT QUITE half a cycle. As shown in below figure distortion occurs on each cycle of the signal waveform as the input signal waveform passes through zero volts. Because the transistors have no base bias, they do not actually begin to conduct until their base/emitter voltage has risen to about 0.6V. As a result, there is a ‘Dead Zone’ of about 1.2V around the zero volts line (between −0.6V and +0.6V) where the signal waveform is not amplified, causing a "missing" section from the output signal, resulting in unwanted distortion during the "crossover" from one transistor to the other.
4. What is tuned amplifier and what are the types of tuned amplifier?

A tuned amplifier is an electronic amplifier which includes bandpass filtering components within the amplifier circuitry. They are widely used in all kinds of wireless applications. There are several tuning schemes in use,

(1) Small signal tuned amplifiers
   a. Single tuned amplifiers
      (i) Capacitive coupled
      (ii) Inductively coupled (or) Transformer coupled
   b. Double tuned amplifiers
   c. Stagger tuned amplifiers

(2) Large signal tuned amplifiers

5. Define Q factor of resonant circuit.

- It is the ratio of reactance to resistance.
- It also can be defined as the measure of efficiency with which inductor can store the energy.
- \[ Q = \frac{2\pi}{R} \times \left( \frac{\text{Maximum Energy Stored per cycle}}{\text{Energy dissipated per cycle}} \right) \]

Five marks questions with answers

1. Explain the operation of Class A power amplifier?

Class A power amplifier is the simplest type of power amplifier circuit. It uses a single-ended transistor for its output stage with the resistive load connected directly to the Collector terminal. When the transistor switches “ON” it sinks the output current through the Collector resulting in an inevitable voltage drop across the Emitter resistance thereby limiting the negative output capability.

The efficiency of this type of circuit is very low (less than 30%) and delivers small power outputs for a large drain on the DC power supply. A Class A amplifier stage passes the same...
load current even when no input signal is applied so large heat sinks are needed for the output transistors.

2. Calculate the efficiency of transformer coupled amplifier?

As the Collector current, $I_c$ is reduced to below the quiescent Q-point set up by the base bias voltage, due to variations in the base current, the magnetic flux in the transformer core collapses causing an induced emf in the transformer primary windings. This causes an instantaneous collector voltage to rise to a value of twice the supply voltage $2V_{cc}$ giving a maximum collector current of twice $I_c$ when the Collector voltage is at its minimum. Then the efficiency of this type of Class A amplifier configuration can be calculated as follows.

The r.m.s. Collector voltage is given as:

$$V_{CE} = \frac{V_{C(max)} - V_{C(min)}}{2\sqrt{2}} = \frac{2V_{CC} - 0}{2\sqrt{2}}$$

The r.m.s. Collector current is given as:

$$I_{CE} = \frac{I_{C(max)} - I_{C(min)}}{2\sqrt{2}} = \frac{2I_{C} - 0}{2\sqrt{2}}$$
The r.m.s. Power delivered to the load \( (P_{ac}) \) is therefore given as:

\[
P_{ac} = V_{CE} \times I_{CE} = \frac{2V_{CC}}{2\sqrt{2}} \times \frac{2I_C}{2\sqrt{2}} = \frac{2V_{CC} \times 2I_C}{8}
\]

The average power drawn from the supply \( (P_{dc}) \) is given by

\[
P_{dc} = V_{CC} \times I_C
\]

and therefore the efficiency of a Transformer-coupled Class A amplifier is given as:

\[
\eta_{\text{max}} = \frac{P_{ac}}{P_{dc}} = \frac{2V_{CC} \times 2I_C}{8V_{CC}I_C} \times 100\%
\]

3. Explain about cross over distortion present in class B power amplifier?

The main problem with class B push pull output stages is that each transistor conducts for NOT QUITE half a cycle. As shown in below figure, distortion occurs on each cycle of the signal waveform as the input signal waveform passes through zero volts. Because the transistors have no base bias, they do not actually begin to conduct until their base/emitter voltage has risen to about 0.6V. As a result, there is a ‘Dead Zone’ of about 1.2V around the zero volts line (between -0.6V and +0.6V) where the signal waveform is not amplified, causing a "missing" section from the output signal, resulting in unwanted distortion during the "crossover" from one transistor to the other.

The effect of this distortion on the output depends to some degree on the amplitude of the output signal, the larger the amplitude the less significant the missing 1.2 volts becomes. Also the distortion will be less severe at high frequencies where the rate of change of the wave, as it passes through zero is much faster, causing a shorter ‘step’ in the waveform.

The large and varying current drawn by a powerful class B amplifier also puts considerable extra demand on the DC power supply and as the current drawn varies with the amount of signal applied, the smoothing capabilities of the power supply must be efficient enough to prevent this varying current from creating voltage changes at audio frequencies on the power supply lines. If these are not adequately removed, unintended audio feedback into earlier amplifier stages can occur and cause problems with instability. This extra demand on power supply complexity adds to the cost of class B power amplifiers.
4. Explain about transistor power dissipation and heat sinks?

**TRANSISTOR POWER DISSIPATION**

- There is not a clear cut difference between ‘ordinary’ transistors used in voltage amplifiers and power transistors, but generally Power transistors can be categorised as those than can handle more than 1 Ampere of collector (or Drain in the case of FETs) current.
- Power transistors can handle larger currents and higher voltages.
- They have a different construction to small signal devices.
- They must have low output resistances so that they can deliver large currents to the load, a good junction insulation to withstand high voltages.
- They must also be able to dissipate heat very quickly so they do not overheat.

As most heat is generated at the collector/base junction, the area of this junction is made

**HEAT SINKS**

A heat-sink is designed to remove heat from a transistor and dissipate it into the surrounding air as efficiently as possible. Heat-sinks take many different forms, such as finned aluminium
or copper sheets or blocks, often painted or anodised matt black to help dissipate heat more quickly. A selection of heat-sinks is illustrated in Figure. Good physical contact between the transistor and heat-sink is essential, and a heat transmitting grease (heat-sink compound) is smeared on the contact area before clamping the transistor to the heat-sink.

Where it is necessary to maintain electrical insulation between transistor and heat-sink a mica layer is used between the heat-sink and transistor. Mica has excellent insulation and very good heat conducting properties

**Heat Sink Types**

- Active Heat Sinks. These are generally fan type and utilize power for cooling purpose. They can also be termed as Heat sink or fans. ...
- Passive Heat Sinks. ...
- Aluminum Heat Sink. ...
- Stamped Heat Sinks. ...
- Machining Heat Sinks. ...
- Bonded-Fin Heat Sinks. ...
- Folded-Fin Heat Sinks. ...
- Skived Heat Sinks.
- as large as possible

5. **Draw the circuit of class C power amplifier and explain it’s operation?**

**Class c power amplifier**

![Class C power amplifier diagram](www.circuitstoday.com)
Class C power amplifier is a type of amplifier where the active element (transistor) conduct for less than one half cycle of the input signal. Less than one half cycle means the conduction angle is less than 180° and its typical value is 80° to 120°. The reduced conduction angle improves the efficiency to a great extend but causes a lot of distortion. Theoretical maximum efficiency of a Class C amplifier is around 90%.

Biasing resistor $R_b$ pulls the base of Q1 further downwards and the Q-point will be set some way below the cut-off point in the DC load line. As a result the transistor will start conducting only after the input signal amplitude has risen above the base emitter voltage ($V_{be} \sim 0.7V$) plus the downward bias voltage caused by $R_b$. That is the reason why the major portion of the input signal is absent in the output signal.

Advantages of Class C power amplifier.
- High efficiency.
- Excellent in RF applications.
- Lowest physical size for a given power output.

Disadvantages of Class C power amplifier.
- Lowest linearity.
- Not suitable in audio applications.
- Creates a lot of RF interference.
- It is difficult to obtain ideal inductors and coupling transformers.
- Reduced dynamic range.

Applications of Class C power amplifier.
- RF oscillators.
- RF amplifier.
- FM transmitters.
- Booster amplifiers.
- High frequency repeaters.
- Tuned amplifiers etc.

**OBJECTIVE QUESTIONS**

1. With transformer connection to load the maximum efficiency of the class A amplifier will go up to a maximum of
   a. 78.5%  
   b. 25%  
   c. 50%  
   d. 66%
   **Reason:** By the transformer connection the efficiency of a class A power amplifier is increased to 50%.

2. In ____ power amplifier, the output signal varies for a full 360° of the cycle.
   a. Class A  
   b. Class B  
   c. Class AB  
   d. None of the above
   **Reason:** Class A power amplifier the conduction angle is 360 degrees.

3. Maximum theoretical efficiency of Class B push pull amplifier is ____.

_P. USHA, ASSISTANT PROFESSOR_
4. The purpose of resonant circuits in tuned circuits is
   a. To provide properly matching load impedance
   b. To reset unwanted harmonics
   c. To couple power to load
   d. All of the above
   **Reason:** The purpose of resonant circuit in tuned circuits is to provide a perfect matching, to remove unwanted harmonics and to couple the power to load.

5. To reduce further harmonic distortion in large signal tuned amplifiers_______ is used
   a. feedback configuration
   b. transformer coupling
   c. Push Pull configuration
   d. all of the can be used
   **Reason:** To reduce the harmonic distortion the push pull configuration is used. In this configuration two different types of transistors are used to provide the complementary symmetry.

6. In tuned amplifiers, harmonic distortion is ____________.
   a. Infinite          b. more            c. less            d. None
   **Reason:** In tuned amplifiers the harmonic distortion effect is very less.

7. Double tuned amplifier provides ____ bandwidth than single tuned amplifiers. ^a.
   a. larger        b. smaller        c. negligible       d. constant
   **Reason:** Double tuned amplifiers provides larger bandwidth than a single tuned amplifier.

8. Tuned amplifiers can be used in _____.
   a. Radar          b. IF amplifiers      c. both a and b    d. None
   **Reason:** Tuned amplifier can also used in Radar and IF amplifiers.

9. When either L or C is increased, the resonant frequency of LC circuit is............
   * remains the same
   * increases
   * decreases
   * insufficient data
   **Reason:** The resonant frequency of LC circuit is $f=1/(2\pi \sqrt{LC})^{(1/2)}$.

10. A push pull amplifier is used to balance out
    a. Even harmonics
    b. Odd harmonics
c. Both even and odd harmonics
d. Neither even nor odd harmonics

**Reason:** A push pull amplifier is used to balance out odd harmonics

---

**FILL IN THE BLANKS**

1. Thermal resistance of the heat sink will be typically ________
2. If output power = 20W and the input dc power = 60W, then the efficiency of power amplifier is ________
3. In Class B power amplifier, Q-point is set ______
4. The input transformer in push-pull power amplifier is ________
5. The output transformer in push pull power amplifier is ________
6. Small signal tuned amplifiers are operated in ________
7. Parallel tuned circuit is also known as ________
8. The Band width of an ideal tuned amplifier is ________
9. The value of quality factor if circuit is single tuned is ________
10. The value of quality factor if circuit is double tuned is ________

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17. Beyond syllabus topics with material

Beyond topic: application of amplifier in today's technology

Material:

An amplifier, electronic amplifier or (informally) amp is an electronic device that can increase the power of a signal (a time-varying voltage or current). An amplifier uses electric power from a power supply to increase the amplitude of a signal. The amount of amplification provided by an amplifier is measured by its gain: the ratio of output voltage, current, or power to input. An amplifier is a circuit that has a power gain greater than one.

An amplifier can either be a separate piece of equipment or an electrical circuit contained within another device. Amplification is fundamental to modern electronics, and amplifiers are widely used in almost all electronic equipment. Amplifiers can be categorized in different ways. One is by the frequency of the electronic signal being amplified. For example, audio amplifiers amplify signals in the audio (sound) range of less than 20 kHz, RF amplifiers amplify frequencies in the radio frequency range between 20 kHz and 300 GHz, and servo amplifiers and instrumentation amplifiers may work with very low frequencies down to direct current. Amplifiers can also be categorized by their physical placement in the signal chain; a preamplifier may precede other signal processing stages, for example. The first practical electrical device which could amplify was the triode vacuum tube, invented in 1906 by Lee De Forest, which led to the first amplifiers around 1912.

Amplifier properties are given by parameters that include:

- Gain, the ratio between the magnitude of output and input signals
- Bandwidth, the width of the useful frequency range
- Efficiency, the ratio between the power of the output and total power consumption
- Linearity, the extent to which the proportion between input and output amplitude is the same for high amplitude and low amplitude input
- Noise, a measure of undesired noise mixed into the output
- Output dynamic range, the ratio of the largest and the smallest useful output levels
- Slew rate, the maximum rate of change of the output
- Rise time, settling time, ringing and overshoot that characterize the step response
- Stability, the ability to avoid self-oscillation

Amplifiers are described according to the properties of their inputs, their outputs, and how they relate. All amplifiers have gain, a multiplication factor that relates the magnitude of some property of the output signal to a property of the input signal. The gain may be specified as the ratio of output voltage to input voltage (voltage gain), output power to input power (power gain), or some combination of current, voltage, and power. In many cases the property of the output that varies is dependent on the same property of the input, making the gain unitless (though often expressed in decibels (dB)).

Most amplifiers are designed to be linear. That is, they provide constant gain for any normal input level and output signal. If an amplifier's gain is not linear, the output signal can
become distorted. There are, however, cases where variable gain is useful. Certain signal
processing applications use exponential gain amplifiers.[4]

Amplifiers are usually designed to function well in a specific application, for
example: radio and television transmitters and receivers, high-fidelity ("hi-fi") stereo
equipment, microcomputers and other digital equipment, and guitar and other instrument
amplifiers. Every amplifier includes at least one active device, such as a vacuum
tube or transistor.

Negative feedback feeds the difference of the input and part of the output back to the input in
a way that cancels out part of the input. The main effect is to reduce the overall gain of the
system. However, the unwanted signals introduced by the amplifier are also fed back. Since
they are not part of the original input, they are added to the input in opposite phase,
subtracting them from the input. In this way, negative feedback acts as a technique to reduce
errors (at the expense of gain). Large amounts of negative feedback can reduce errors to the
point that the response of the amplifier itself becomes almost irrelevant as long as it has a
large gain, and the output performance of the system (the "closed loop performance") is
defined entirely by the components in the feedback loop.

Careful design of each stage of an open-loop (non-feedback) amplifier can achieve about 1%
distortion for audio-frequency signals. With negative feedback, 0.001% is typical. Noise,
even crossover distortion, can be practically eliminated. Negative feedback also compensates
for changing temperatures, and degrading or nonlinear components in the gain stage, but any
change or nonlinearity in the components in the feedback loop will affect the output. Indeed,
the ability of the feedback loop to define the output is used to make active filter circuits. The
concept of feedback is used in operational amplifiers to precisely define gain, bandwidth, and
other parameters entirely based on the components in the feedback loop.

Negative feedback can be applied at each stage of an amplifier to stabilize the operating
point of active devices against minor changes in power-supply voltage or device
characteristics.

Some feedback, positive or negative, is unavoidable and often undesirable—introduced, for
example, by parasitic elements, such as inherent capacitance between input and output of
deVICES such as transistors, and capacitive coupling of external wiring. Excessive frequency-
dependent positive feedback can produce parasitic oscillation and turn an amplifier into
an oscillator.
15. Tutorial topics and Outcomes

1. CE amplifier with un bypassed emitter resistor

Consider the two-port network of CE amplifier. $R_S$ is the source resistance and $Z_L$ is the load impedance $h$-parameters are assumed to be constant over the operating range. The ac equivalent circuit is shown in below figure. (Phasor notations are used assuming sinusoidal voltage input). The quantities of interest are the current gain, input impedance, voltage gain, and output impedance.

![CE Amplifier Circuit](image)

**Current gain:**

For the transistor amplifier stage, $A_i$ is defined as the ratio of output to input currents.

$$A_i = \frac{I_c}{I_b} = -\frac{I_c}{I_b}$$  \[1\]

\[I_c = h_{fe} \cdot I_b + h_{re} \cdot V_c\]

\[V_c = I_c \cdot Z_L = -I_b \cdot Z_L\]

\[\therefore I_c = h_{fe} \cdot I_b + h_{re} \cdot (-I_c \cdot Z_L)\]

or

$$\frac{I_c}{I_b} = \frac{h_{fe}}{1 + h_{re} \cdot Z_L}$$

\[\therefore A_i \approx \frac{h_{fe}}{1 + h_{re} \cdot Z_L}\]

**Input Impedance:**

The impedance looking into the amplifier input terminals (1,1') is the input impedance $Z_i$. 
Voltage gain:

The ratio of output voltage to input voltage gives the gain of the transistors.

$$A_v = \frac{\frac{V_c}{V_b}}{\frac{V_e}{V_b}} = \frac{V_c}{V_e}$$

$$A_v = \frac{I_e A_v Z_L}{V_e} = \frac{A_v Z_L}{I_e}$$

Output Admittance:

It is defined as

$$y_0 = \frac{b}{\frac{I_c}{\frac{V_e}{V_c}}} = 0$$

$$I_e = h_{fe} I_b + h_{oe} V_c$$

$$\frac{I_c}{V_c} = h_{re} I_b + h_{oe}$$

when $V_c = 0$, $R_e I_b + h_{oe} I_b + h_{oe} V_b = 0$.

$$\frac{b}{V_c} = \frac{h_{re}}{R_e + h_{oe}}$$

$$\therefore y_0 = h_{re} \frac{h_{re}}{R_e + h_{oe}}$$

Voltage amplification taking into account source impedance ($R_e$) is given by

$$A_{vS} = \frac{\frac{V_c}{V_e}}{\frac{V_b}{V_c}} = \frac{V_c}{V_e} + \frac{V_e}{V_c}$$

$$= A_v \frac{Z_L}{Z_L + R_e}$$

2. Types of distortions present in amplifiers?
Amplitude Distortion

Amplitude distortion occurs when the peak values of the frequency waveform are attenuated causing distortion due to a shift in the Q-point and amplification may not take place over the whole signal cycle. This non-linearity of the output waveform is shown below.

![Amplitude Distortion Diagram]

Amplitude Distortion greatly reduces the efficiency of an amplifier circuit. These “flat tops” of the distorted output waveform either due to incorrect biasing or over driving the input do not contribute anything to the strength of the output signal at the desired frequency.

Having said all that, some well known guitarist and rock bands actually prefer that their to both the +ve and -ve power supply rails. Also, increasing the amounts of clipping on a sinusoid will produce so much amplifier distortion that it will eventually produce an output waveform which resembles that of a “square wave” shape which can then be used in electronic or digital synthesizer circuits.

Frequency Distortion

Frequency Distortion is another type of amplifier distortion which occurs in a transistor amplifier when the level of amplification varies with frequency. Many of the input signals that a practical amplifier will amplify consist of the required signal waveform called the “Fundamental Frequency” plus a number of different frequencies called “Harmonics” superimposed onto it.

Normally, the amplitude of these harmonics are a fraction of the fundamental amplitude and therefore have very little or no effect on the output waveform. However, the output waveform can become distorted if these harmonic frequencies increase in amplitude with regards to the fundamental frequency. For example, consider the waveform below:
In the example above, the input waveform consists of the fundamental frequency plus a second harmonic signal. The resultant output waveform is shown on the right-hand side. The frequency distortion occurs when the fundamental frequency combines with the second harmonic to distort the output signal. Harmonics are therefore multiples of the fundamental frequency and in our simple example a second harmonic was used.

Therefore, the frequency of the harmonic is twice the fundamental, $2 \times f$ or $2f$. Then a third harmonic would be $3f$, a fourth, $4f$, and so on. Frequency distortion due to harmonics is always a possibility in amplifier circuits containing reactive elements such as capacitance or inductance.

**Phase Distortion**

Phase Distortion or Delay Distortion is a type of amplifier distortion which occurs in a non-linear transistor amplifier when there is a time delay between the input signal and its appearance at the output.

If we say that the phase change between the input and the output is zero at the fundamental frequency, the resultant phase angle delay will be the difference between the harmonic and the fundamental. This time delay will depend on the construction of the amplifier and will increase progressively with frequency within the bandwidth of the amplifier. For example, consider the waveform below:

3. hybrid pi model
When input signal to an amplifier is in the range of ten to hundred Kilo Hertz, a small signal-low frequency model of the transistor can be used for analysis. But as the frequency increases, internal capacitance of the transistor will strongly affect its performance. A low frequency model cannot work well in this situation. To accommodate these performance changes of the transistor, a separate model is developed for high frequency operations. This high frequency model is given in Fig 1. A high frequency hybrid-pi model is also known as Giacoletto model.

![Figure 1: High frequency model](image1)

![Figure 2: Low frequency model](image2)

In high frequency model a resistor and two capacitors are added in addition to the components in low frequency model.

1) Resistor $r_x$ is known as Base-spreading resistor

In Fig1, B' is a point internal to the transistor and is a part of base region. $r_x$ denotes the resistance of the silicon material between external base terminal B and internal base terminal B'. Its value is usually less than 100 ohms and has significant effect in high frequency response. It does not have any roll in low frequency analysis. $r_x \ll r_π$.

2) Base - Emitter capacitance $C_π$

This capacitance occurs due to the combined effect of emitter junction diffusion capacitance $C_{de}$ and emitter junction depletion capacitance $C_{je}$. (Diffusion and depletion capacitance are in your 'Solid State Devices' text book.) Its value is in between few pF to few tens of pF.

3) Collector - Base capacitance $C_{β1}$

It is the capacitance of the Collector- Base junction of the transistor. It is ranging from fraction of pF to a few pF

4. CE short circuit current gain

An important high frequency characteristics of transistor is unity-gain bandwidth, $\nu_0$. This is defined as the frequency at which short-circuit current gain.

$$h_{fe} = \left. \frac{I_c}{I_b} \right|_{\text{s.c.load}}$$
Figure 1: The hybrid-pi circuit for a single transistor with short circuit load

Applying KCL at collector terminal provides an equation for short circuit collector current

\[ I_c = g_m V_\pi - j\omega C_\mu V_\pi \]

At input terminal B,

\[ V_\pi = I_b Z_{\text{in}} = I_b r_\pi \left( Z_{C_\pi} + Z_{C_\rho} \right) \]

\[ V_\pi = I_b \left[ \frac{1}{r_{\pi}} + j\omega (C_\pi + C_\rho) \right]^{-1} \]

\[ I_c = (g_m - j\omega C_\mu) I_b \left[ \frac{1}{r_{\pi}} + j\omega (C_\pi + C_\rho) \right]^{-1} \]

\[ h_{fe} = \frac{I_c}{I_b} = \frac{(g_m - j\omega C_\mu)}{\left[ \frac{1}{r_{\pi}} + j\omega (C_\pi + C_\rho) \right]^{-1}} \]

as \( g_m \gg |j\omega C_\mu| \) therefore, \( h_{fe} \approx \frac{g_m r_{\pi}}{1 + j\omega (C_\pi + C_\rho) r_{\pi}} \)

The above frequency response \( h_{fe} \) is in the form of single pole low pass circuit.
5. Construction and characteristics of BJT and MOSFET

The BJT is a one type of transistor that uses both majority and minority charge carriers. These semiconductor devices are available in two types such as PNP and NPN. The main function of this transistor is to amplify current. These transistors can be used as switches and amplifiers. The applications of BJTs involve in a wide range that includes electronic devices like TVs, mobiles, computers, radio transmitters, audio amplifiers and industrial control.

Construction of BJT

A bipolar junction transistor comprises of two p-n junctions. Depending on the structure of the BJT, these are classified into two types such as PNP and NPN. In NPN transistor, lightly doped P-type semiconductor is placed between two heavily-doped N-type semiconductors. Equally, a PNP transistor is formed by placing an N-type semiconductor between P-type semiconductors. The construction of a BJT is shown below. The emitter and collector terminals in the below structure are called n-type and p-type semiconductors which are denoted with ‘E’ and ‘C’. While the remaining collector terminal is called p-type semiconductor denoted with ‘B’.
The term FET stands for Field effect transistor and it is also named as a Unipolar transistor. FET is a one type of transistor, where the o/p current is controlled by electric fields. The basic type of FET is totally dissimilar from BJT. FET consist of three terminals namely source, drain and gate terminals. The charge carriers of this transistor are holes or electrons, which flow from the source terminal to drain terminal via an active channel. This flow of charge carriers can be controlled by the voltage applied across the source and gate terminals.

**Construction of FET**
Field effect transistors are classified into two types such as JFET and MOSFET. These two transistors have similar principles. The construction of p-channel JFET is shown below. In p-channel JFET, the majority charge carriers flow from the source to drain. Source and drain terminals are denoted by S and D.

6. Differences between BJT and FET

Bipolar junction transistors are bipolar devices, in this transistor there is a flow of both majority & minority charge carriers.

1. Field effect transistors are unipolar devices, in this transistor there are only the majority charge carriers flows.

2. Bipolar junction transistors are current controlled.

3. Field effect transistors are voltage controlled.

4. In many applications FETs are used than bipolar junction transistors.

5. Bipolar junction transistor consist of three terminals namely emitter, base and collector. These terminals are denoted by E, B and C.

6. Field effect transistor consist of three terminals namely source, drain and gate. These terminals are denoted by S, D and G.

7. The input impedance of field effect transistors has high compared with bipolar junction transistors.

8. A BJT needs a small amount of current to switch on the transistor. The heat dissipated on bipolar stops the total number of transistors that can be fabricated on the chip.

9. Whenever the ‘G’ terminal of the FET transistor has been charged, no more current is required to keep the transistor ON.

10. The BJT is responsible for overheating due to a negative temperature co-efficient.

FET has a +Ve temperature coefficient for stopping overheating.

11. BJTs are applicable for low current applications.

12. FETS are applicable for low voltage applications.

13. FETs have low to medium gain.

BJTs have a higher max frequency and a higher cutoff frequency

7. classification of amplifiers

The classification of amplifiers are
• **Voltage Amplifier** - An amplifier provides a voltage output proportional to the voltage input and the proportionality factor does not depend on the magnitudes of the source and load resistance.

• **Current Amplifier** - An amplifier which provides an output current proportional to the signal current.

• **Transconductance Amplifier** - An amplifier in which, the output current is proportional to the signal voltage, independent of the magnitudes of source and load resistance.

• **Transresistance Amplifier** - An amplifier in which output voltage is proportional to the signal current of the magnitudes of source and load resistance.

8. **series shunt feedback amplifier**

1. In the series shunt feedback amplifier shown in fig. calculate the voltage gains without feedback, $A$, and with feedback $A_{FB}$.
Class A power amplifier is the simplest type of power amplifier circuit. It uses a single-ended transistor for its output stage with the resistive load connected directly to the Collector terminal. When the transistor switches “ON” it sinks the output current through the Collector resulting in an inevitable voltage drop across the Emitter resistance thereby limiting the negative output capability.

The efficiency of this type of circuit is very low (less than 30%) and delivers small power outputs for a large drain on the DC power supply. A Class A amplifier stage passes the same load current even when no input signal is applied so large heat sinks are needed for the output transistors.
10. transformer coupled amplifier

As the Collector current, $I_c$ is reduced to below the quiescent Q-point set up by the base bias voltage, due to variations in the base current, the magnetic flux in the transformer core collapses causing an induced emf in the transformer primary windings. This causes an instantaneous collector voltage to rise to a value of twice the supply voltage $2V_{cc}$ giving a maximum collector current of twice $I_c$ when the Collector voltage is at its minimum. Then the efficiency of this type of Class A amplifier configuration can be calculated as follows.

The r.m.s. Collector voltage is given as:

$$V_{CE} = \frac{V_{C(max)} - V_{C(min)}}{2\sqrt{2}} - \frac{2V_{cc} - 0}{2\sqrt{2}}$$

The r.m.s. Collector current is given as:

$$I_{CE} = \frac{I_{C(max)} - I_{C(min)}}{2\sqrt{2}} - \frac{2I_c - 0}{2\sqrt{2}}$$

The r.m.s. Power delivered to the load ($P_{ac}$) is therefore given as:
The average power drawn from the supply \( P_{dc} \) is given by
\[
P_{dc} = V_{CC} \times I_C
\]
and therefore the efficiency of a Transformer-coupled Class A amplifier is given as:
\[
\eta_{max} = \frac{P_{ac}}{P_{dc}} = \frac{2V_{CC} \times 2I_C}{8V_{CC}I_C} \times 100\%
\]

3. **Cross Over Distortion**

The main problem with class B push pull output stages is that each transistor conducts for **NOT QUITE** half a cycle. As shown in below figure distortion occurs on each cycle of the signal waveform as the input signal waveform passes through zero volts. Because the transistors have no base bias, they do not actually begin to conduct until their base/emitter voltage has risen to about 0.6V. As a result, there is a 'Dead Zone' of about 1.2V around the zero volts line (between −0.6V and +0.6V) where the signal waveform is not amplified, causing a "missing" section from the output signal, resulting in unwanted distortion during the "crossover" from one transistor to the other.

The effect of this distortion on the output depends to some degree on the amplitude of the output signal, the larger the amplitude the less significant the missing 1.2 volts becomes. Also the distortion will be less severe at high frequencies where the rate of change of the wave, as it passes through zero is much faster, causing a shorter 'step' in the waveform.

The large and varying current drawn by a powerful class B amplifier also puts considerable extra demand on the DC power supply and as the current drawn varies with the amount of signal applied, the smoothing capabilities of the power supply must be efficient enough to prevent this varying current from creating voltage changes at audio frequencies on the power supply lines. If these are not adequately removed, unintended audio feedback into earlier amplifier stages can occur and cause problems with instability. This extra demand on power supply complexity adds to the cost of class B power amplifiers.
Input Voltage 0V

Tr1 collector current
+0.6V
-0.6V

Tr2 collector current

Dead zone Tr1 & Tr2 turned off

Output Voltage

Crossover Distortion

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