CHAPTER - 4

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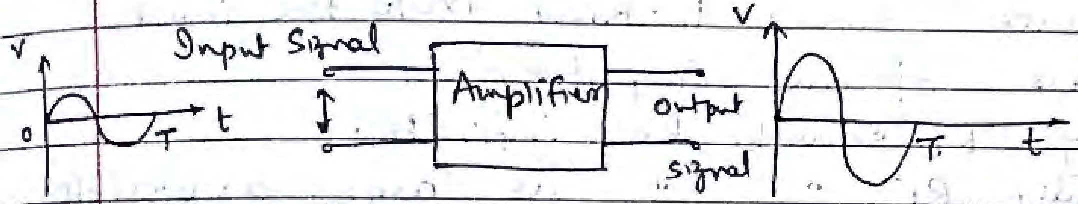
AC Analysis of BJT Circuits & Small Signal Amplifier.

Amplification:

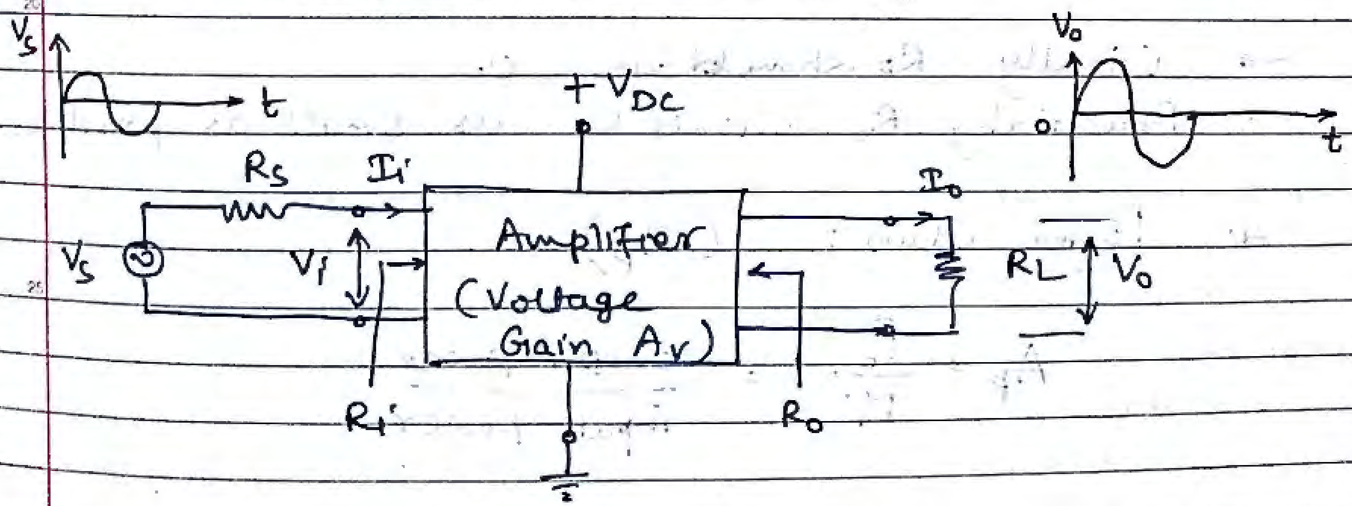
It is a process of adding strength to signal or magnifying the input signal without changing its shape.

Amplifier: It is a electronics circuit which amplifies small input signal.



Load: Output load can be loud speaker in an audio amplifier.

Block Diagram of an Amplifier:



Amplifier Characteristics Parameters:

1. Voltage Gain A_V & Current Gain A_I

→ Gain of an amplifier is ratio of output quantity to the input quantity.

Voltage Gain $A_V = \frac{V_o}{V_i}$

Current Gain $A_I = \frac{I_o}{I_i}$

2. Input Resistance : (R_i)

→ Resistance seen looking into the input terminals of an Amplifier.

→ ideally R_i should be infinite,
Practically R_i " " as large as possible.

3. Output Resistance : (R_o)

→ Resistance seen looking into output terminals of an amplifier when $V_i = 0$.

→ ideally R_o should be 0.

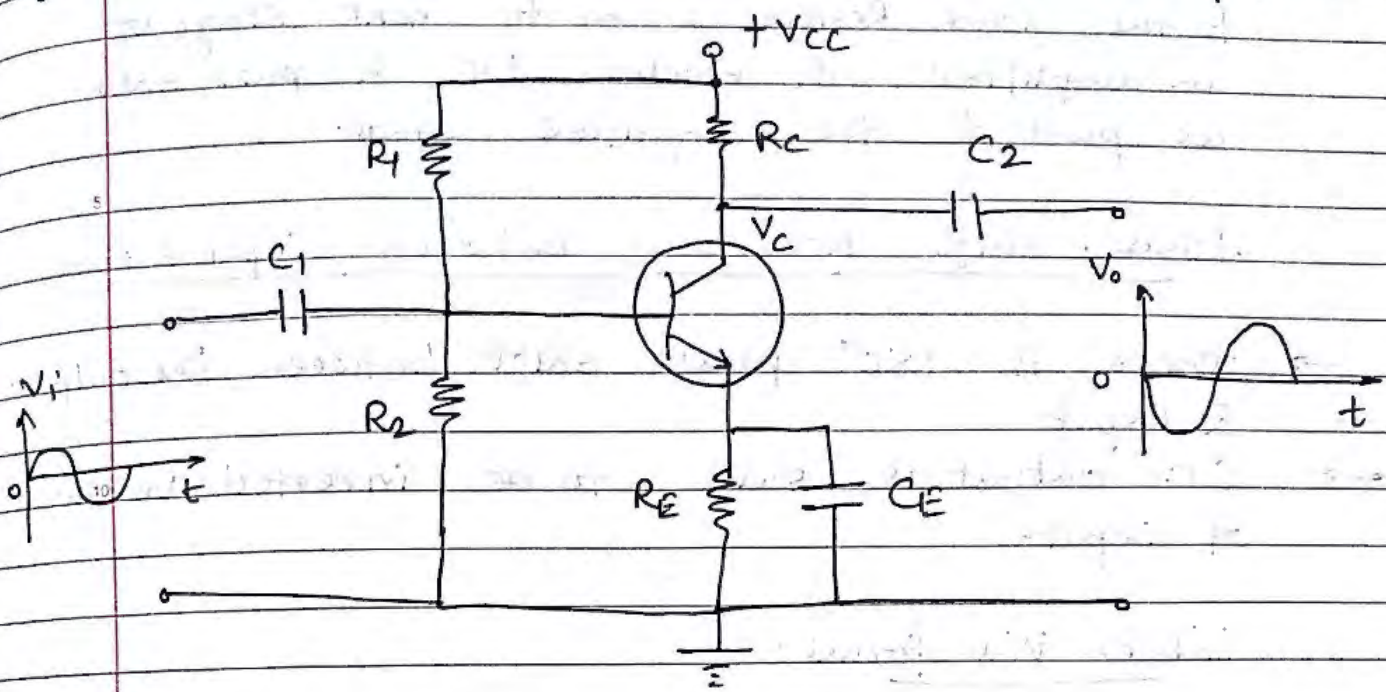
→ Practically R_o should be as small as possible

4. Power Gain : (A_p)

$$A_p = \frac{P_o}{P_i} = \frac{\text{output power}}{\text{input power}}$$

Explain

Q. Amplification Process in VDB C.E. Amplifier.



→ C_1 & C_2 are coupling capacitors.

→ C_E is bypass capacitor.

→ R_1 & R_2 are used for biasing.

→ R_C is collector resistor used for controlling collector current.

→ input coupling capacitor is used for coupling the AC input voltage V_i to the base of transistor. It blocks dc & allow ac signal to pass through.

→ Bypass capacitor C_E offers low reactance to the amplified ac signal. So R_E gets bypassed through C_E for only ac signals. This will increase voltage Gain of an amplifier.

→ C_E acts as open circuit for DC. But as R_E is present in circuit for DC conditions, high Q-point stability is obtained.

→ Presence of C_E doesn't alter DC biasing.

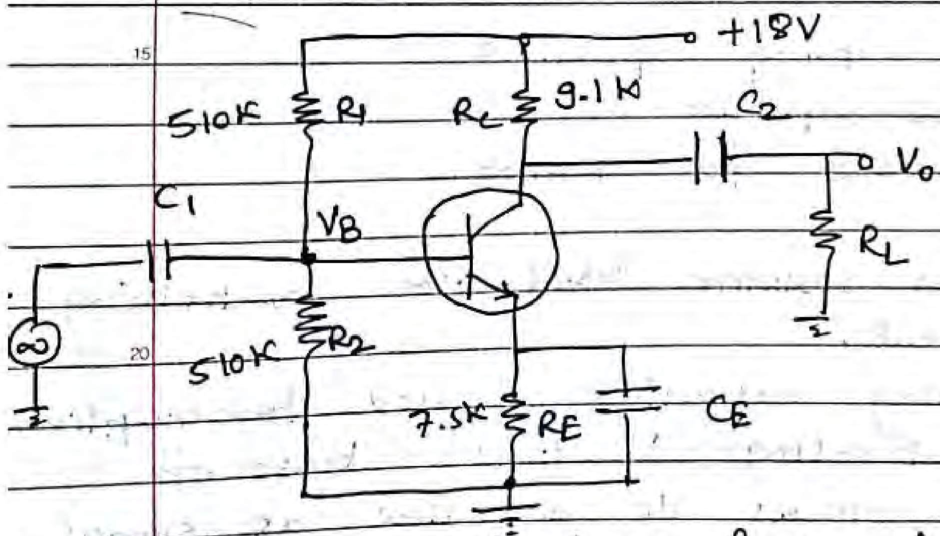
→ Capacitor C_2 couples the amplifier output to the load Resistance or to next stage of an amplifier. It blocks DC & pass only ac part of the amplified signal.

Phase shift Relation between input & output:

→ there is 180° phase shift between the output & input.

→ Or output is said to be inverted version of input.

VDB Waveforms:



Approximate Analysis of an Amplifier:

$$V_B = \frac{R_2}{R_1+R_2} \times 18 = 9V$$

$$V_E = V_B - V_{BE} = 9 - 0.7 = 8.3V.$$

$$I_E = \frac{V_E}{R_E} = \frac{8.3}{7.5k\Omega} = 1.1\,mA.$$

$$I_C \approx I_E = 1.1\,mA$$

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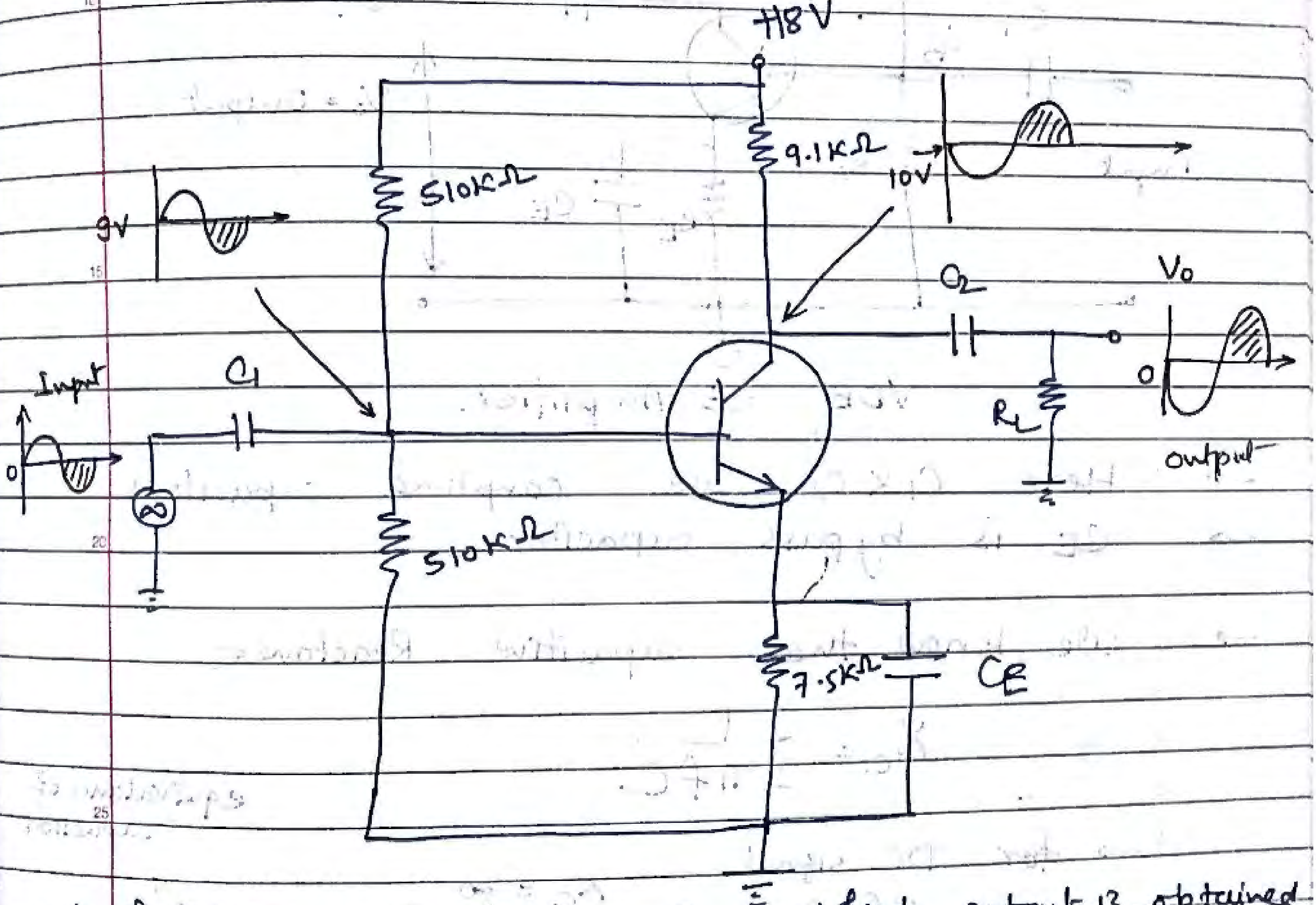
$V_C = 18 - I_C \cdot R_C$

$= 18 - [(1.1 \times 10^{-3}) \times (9.1 \times 10^{3})]$

$= 18 - 10.01 = 7.99\,V$

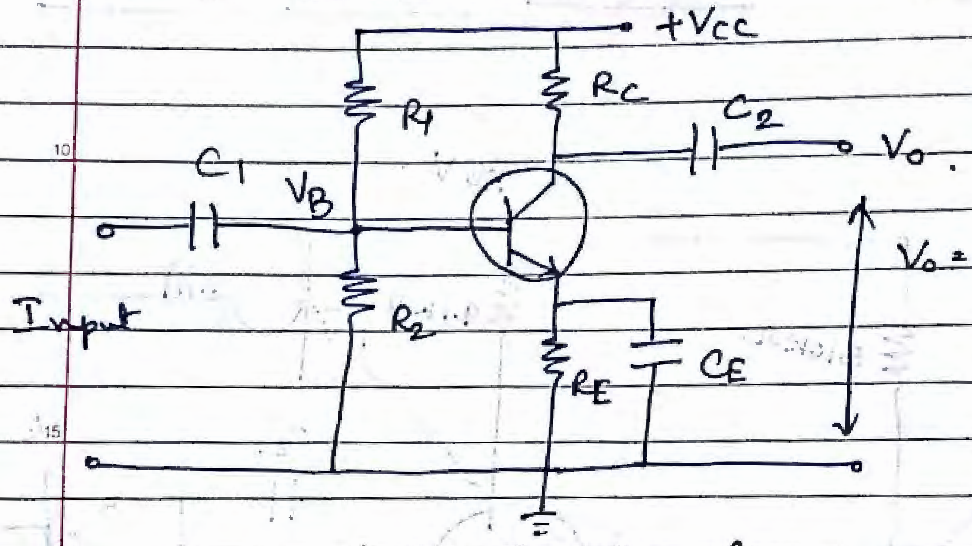
CE Amplifier Voltage waveforms at various point.



→ Input applied to base & amplified output is obtained at the collector.
→ Voltage Gain is high. Current Gain is high.
→ i/p impedance is moderately high.
→ o/p " " " "
→ 180° phase shift between input & output.

Q. Explain use of coupling & bypass capacitor in amplifier.

→ Here to understand coupling & bypass capacitor we consider voltage divider bias common emitter Amplifier.



VDB CE Amplifier.

→ Here C_1 & C_2 are coupling capacitors.
→ C_E is bypass capacitor.

→ We know that capacitive Reactance

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

∴

equivalance of capacitor

→ for DC signal (f=0) $X_C = \infty$

for DC

→ for AC signal (with sufficient high f) X_C is low.

for AC.

Coupling Capacitor C_1:

It couples the signal to the base of transistor. It blocks DC component present in the signal & passes only AC signal for amplification.

→ C_1 is required to maintain biasing conditions.

→ If input is connected directly, V_B is altered due to input signal's dc component & Biasing condition of circuit is being altered.

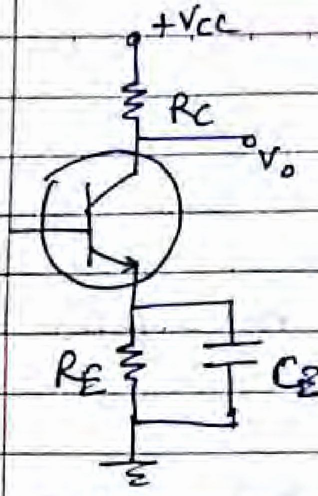
Coupling capacitor C_2:

It couples output of an amplifier to load or next stage of the amplifier. It also blocks DC & passes only AC signal.

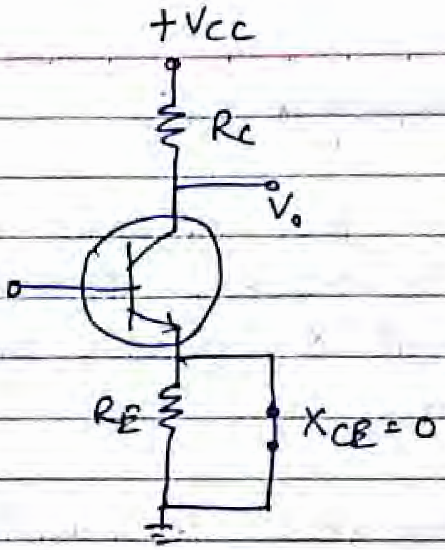
Bypass Capacitor C_E:

C_E is connected in parallel with R_E to provide low reactance path to amplified ac signal. If C_E is not present, the amplified ac signal passing through R_E will cause a voltage drop across it. This will reduce o/p voltage, which reducing gain of the amplifier.

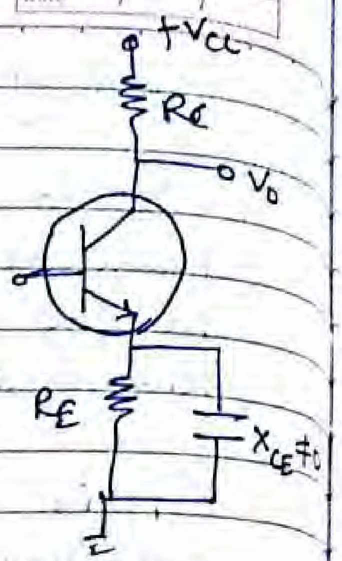
→ C_E bypass R_E for AC signal (with medium & high freq. signal)



Bypass capacitor



C_E acts as short circuit at medium & high freq.



At low freq. X_{CE} is compara. to R_E

→ Bypass capacitor will work properly if its reactance is very small as compared to R_E at lowest operating freq.

→ Condition for Good bypass capacitor.

$$X_{CE} < 0.1\, R_E \quad \text{at lowest freq.}$$

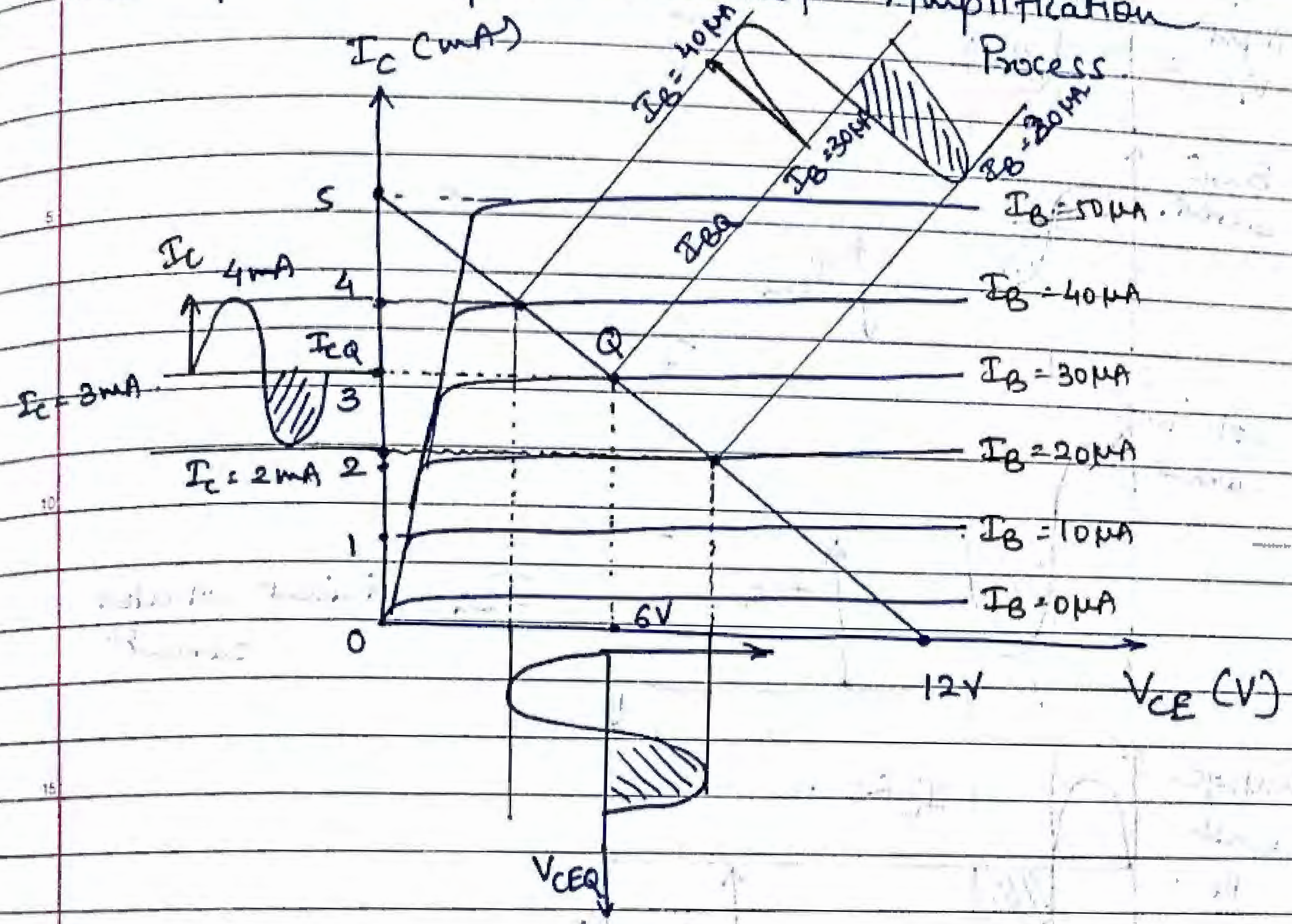
Q. Explain Amplification process
(Voltage Divider Common Emitter Amplifier

→ To understand amplification process let us consider common Emitter amplifier with voltage Divider bias.

→ As input signal is applied to amplifier, alternating base current starts flowing. AC base current varies above & below Q-point value of base current (I_{BQ})

→ Due to this variation in I_B proportional variations takes place in I_C, b'cos $I_C = \beta I_B$

Graphical Representation of Amplification Process



→ I_C & I_B are in phas with each other. I_C also varies above its Q-point I_{CQ}.

→ I_C passes through R_C to produce $I_C R_C$ across it.

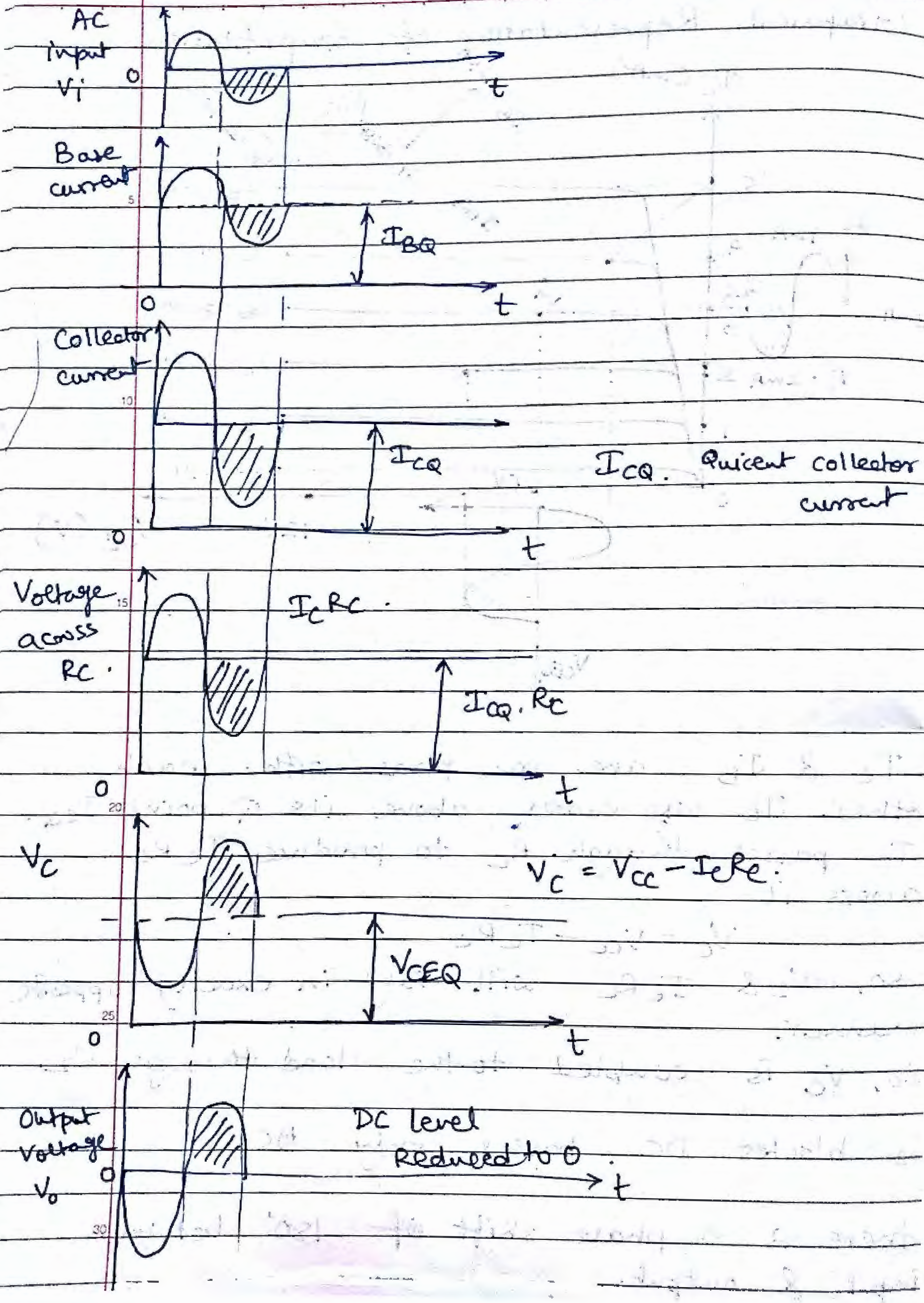
$$V_C = V_{CC} - I_C R_C$$

→ So, V_C & $I_C R_C$ will vary in exactly opposite manner.

→ So, V_C is coupled to the load through C_2.

→ C_2 blocks DC passes only AC.

→ there is a phase shift of 180° between input & output.



AC input V_i
0
t
Base current
0
I_{BQ}
t
Collector current
0
I_{CQ}
t
I_{CQ}. Quicent collector current
Voltage across R_C.
$I_C R_C$.
$I_{CQ} . R_C$
0
t
V_C
$V_C = V_{CC} - I_C R_C$.
V_{CEQ}
0
t
Output voltage V_o
0
DC level Reduced to 0.
t

Amplification Process

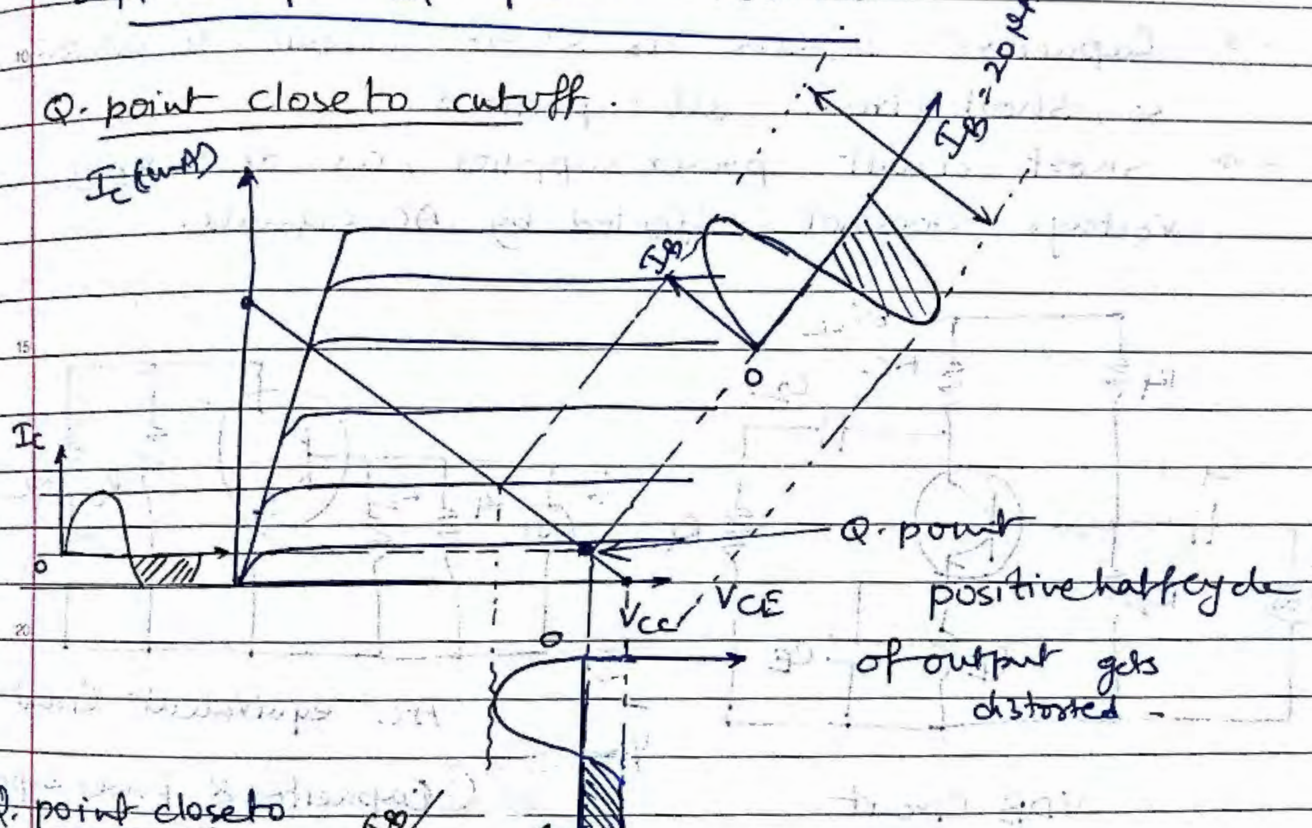
$$\Delta I_B = I_{B(max)} - I_{B(min)}$$

$$\Delta I_B = 40\mu A - 20\mu A = 20\mu A$$

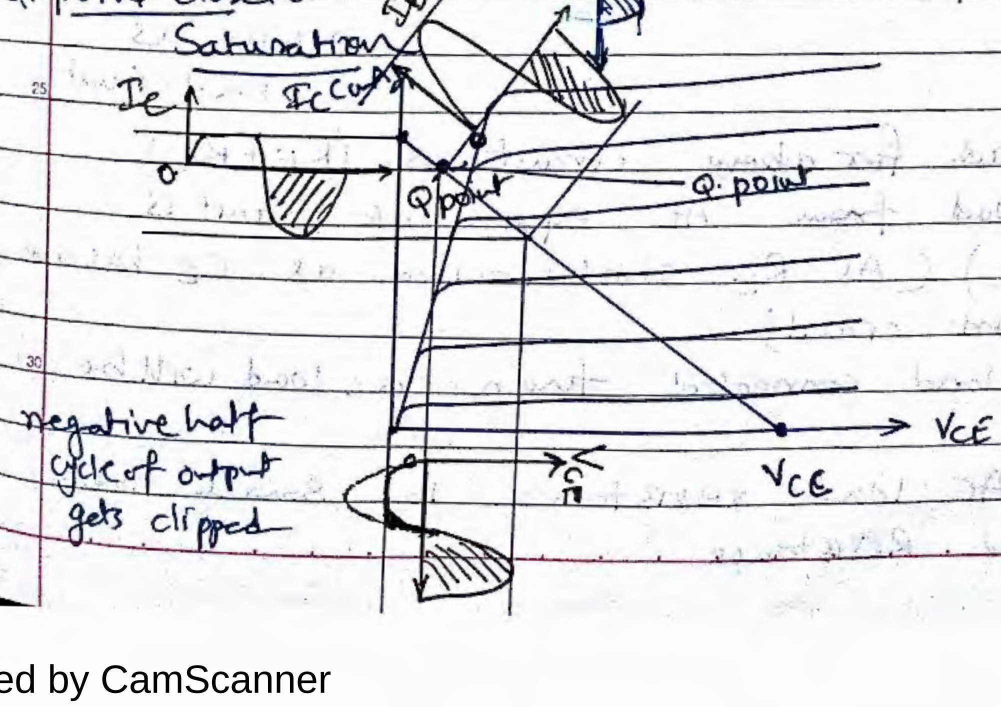
$$\Delta I_C = \beta \Delta I_B = 2 mA.$$

Effect of Q-point Position:

Q-point close to cutoff.



Q-point close to
Saturation



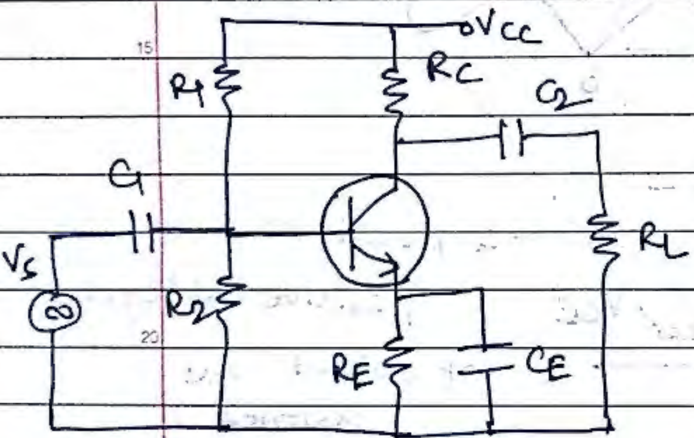
Q. What is AC Loadline?

Every amplifier has two equivalent Circuits:
1) DC equivalent Circuit
2) AC " "

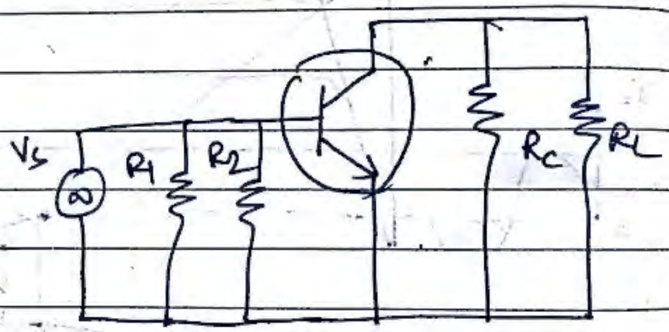
→ So they have two load lines.

AC equivalent Circuit:

→ Capacitor behave as short circuit to ac signals so, short circuit all capacitors.
→ short circuit power supplies, as dc supply voltage doesnot affected by AC signals.



VDB Circuit



AC equivalent Circuit
(Capacitor & power supply behave as ac short-circuit)

→ DC load for above circuit is $(R_E + R_C)$
→ AC load from AC equivalent circuit is $(R_C \| R_L)$ (As R_E short circuited as C_E behave as short circuit)
→ if no load connected then ac load will be R_C.
→ So, AC load resistance is small then DC load Resistance.

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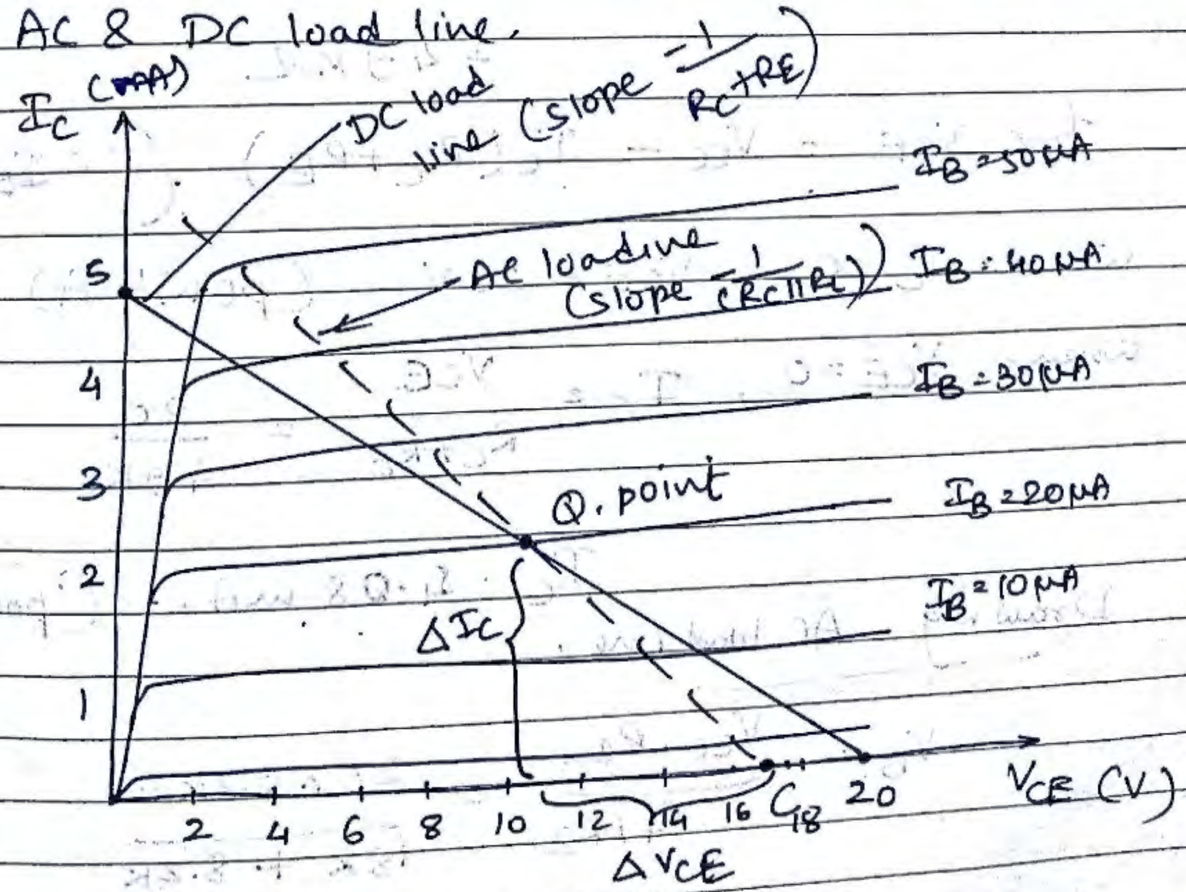
slope of DC load line $-\dfrac{1}{R_C + R_E}$

Slope of A C load line $-\dfrac{1}{(R_C \| R_L)}$

→ slope of AC load line is higher than DC load line.

→ when there is no input signal, the transistor voltage & current conditions are exactly as indicated by Q-point on DC load line.

→ An ac signal cause transistor current & voltage levels to vary above & below Q-point. Therefore Q. point is common to both AC & DC load line.



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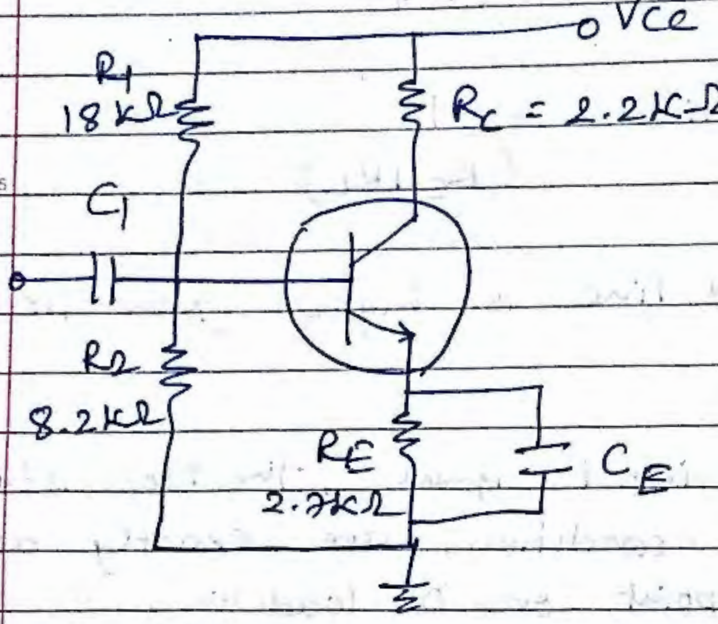
Q. Draw AC & DC load line for following Circuit



→ Drawing of DC load line

$$R_{L(dc)} = R_C + R_E = 2.2K\Omega + 2.7K\Omega$$

$$= 4.9K\Omega$$

for $V_{CE} = V_{CC} - I_C(R_C + R_E)$ $(\because I_E \simeq I_C)$

When I_C 20, $V_{CE} = 20V$ (point A)

when $V_{CE} = 0$, $I_C = \frac{V_{CE}}{R_C + R_E} = \frac{20}{4.9K}$

$I_C = 4.08\ mA.$ (point B)

→ Drawing AC load line,

$$V_B = \frac{V_{CC} \cdot R_2}{R_1 + R_2} = \frac{20 \times 8.2K\Omega}{18K + 8.2K}$$

$$= 6.3V$$

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$V_E = V_B - V_{BE} \quad = 6.3V - 0.7V$

$$\boxed{V_E = 5.6V}$$

$$I_C \simeq I_E = \frac{V_E}{R_E} = \frac{5.6V}{2.7k\Omega}$$

$$I_C = 2.07mA$$

mark Q. point on DC loadline at $I_C = 2.07mA$

→ Drawing AC loadline

AC load $R_{L(AC)} = R_C = 2.2k\Omega$

$\Delta I_C = 2.07mA$.

Corresponding $\Delta V_{CE} = \Delta I_C \cdot R_C$

$= 4.55V$.

mark point C by ΔV_{CE}.

→ Draw AC load line through point C & Q.

Q. Give Difference between DC Load line & AC load line.

Sr. No	Parameters	DC loadline	AC loadline
1.	Slope	$-1/R_C$	$-\frac{1}{(R_C \parallel R_L)}$
2.	To be used when	Biasing a transistor	Transistor is used as an Amplifier
3.	Slope	Less than AC load line	Higher than DC load line
4.	equivalent ckt. of the Amplifier	Use DC equivalent circuit	Use AC equivalent circuit

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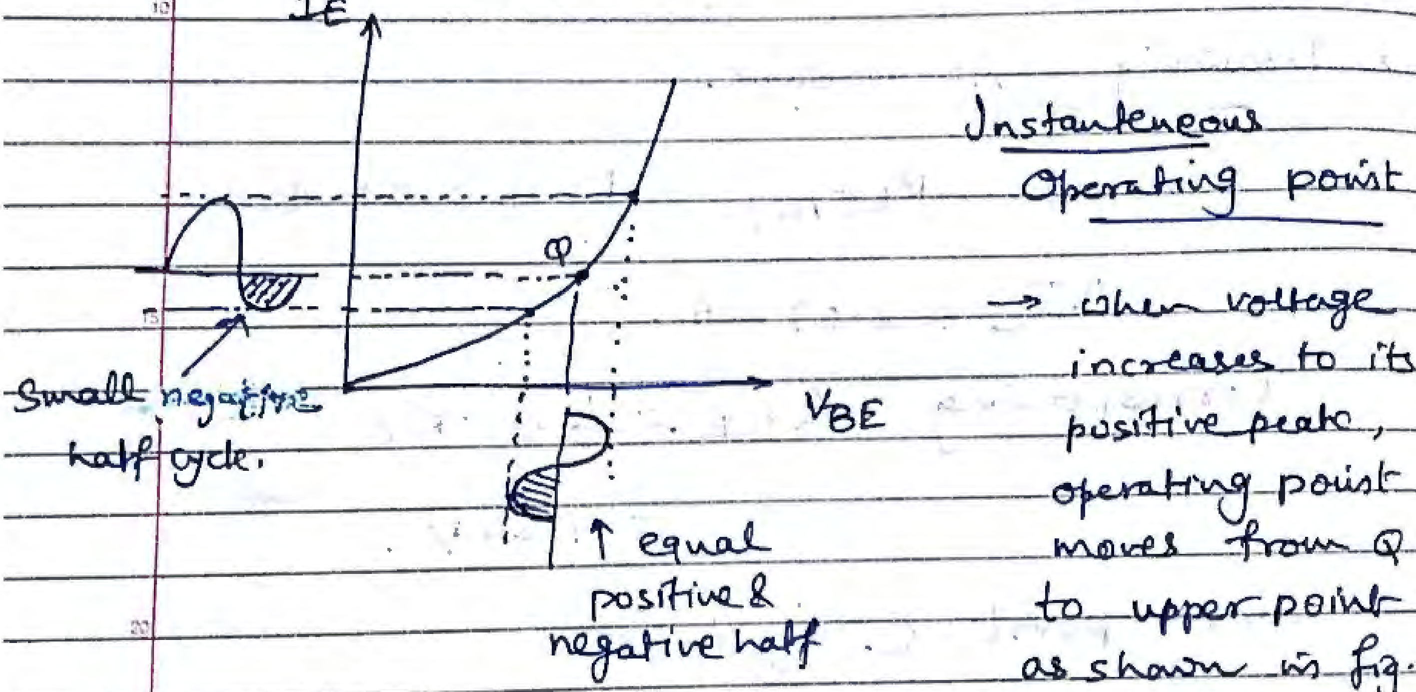
Q. Explain Small signal operation & the 10 percent Rule

→ Following figure shows graph of current versus voltage for Base-emitter diode.
→ when AC voltage applied to base of transistor, an AC voltage appears across base emitter diode, this produces sinusoidal variation in V_{BE}.



→ when voltage increases to its positive peak, operating point moves from Q to upper point as shown in fig.

→ When sine wave decreases to negative peak, operating point moves away from Q point.
→ Size of AC voltage signal decides how far instanteneous Q-point moves away from Q-point.
→ large AC base voltages produce large variations, where as small AC base voltages produces small variations.

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Distortion

→ AC voltage on base produces AC emitter current. Both emitter current & base voltage has same freq.
→ AC emitter current is not a perfect replica of the ac base voltage because of the curvature of the Graph.
→ Since graph is curved upward positive half cycle of emitter current is stretched & negative half cycle is compressed.
→ stretching & compressing of half-cycles is called distortion.

Reducing distortion:

→ one way to reduce distortion is keep base voltage small. small base voltage, small peak & it reduce much movement of instantaneous operating point.
→ small swing, means less curvature in graph.

10 percent Rule:

→ Emitter current consist of a dc component & an ac component

$$I_E = I_{EQ} + i_e.$$

I_{EQ} ↑ DC emitter current

i_e ↑ Ac emitter current

→ To minimise distortion, peak to peak ac emitter current is Less than 10% of the dc emitter current

$i_{e(pp)} < 0.1\, I_{EQ}$.

AC Resistance of Emitter diode :

→ for Base emitter diode

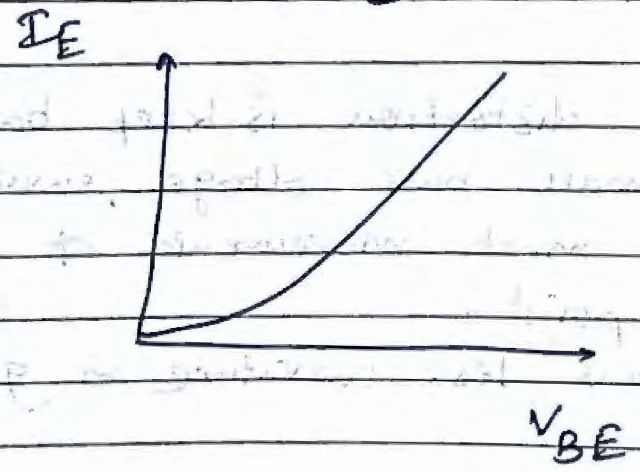
→ $I_E = I_{EQ} + i_e$

→ $V_{BE} = V_{BEQ} + V_{be}$

V_{BEQ} → DC part, V_{be} → AC part

→ AC emitter resistance is r_e' defined as follows:

$$r_e' = \frac{V_{be}}{i_e}$$



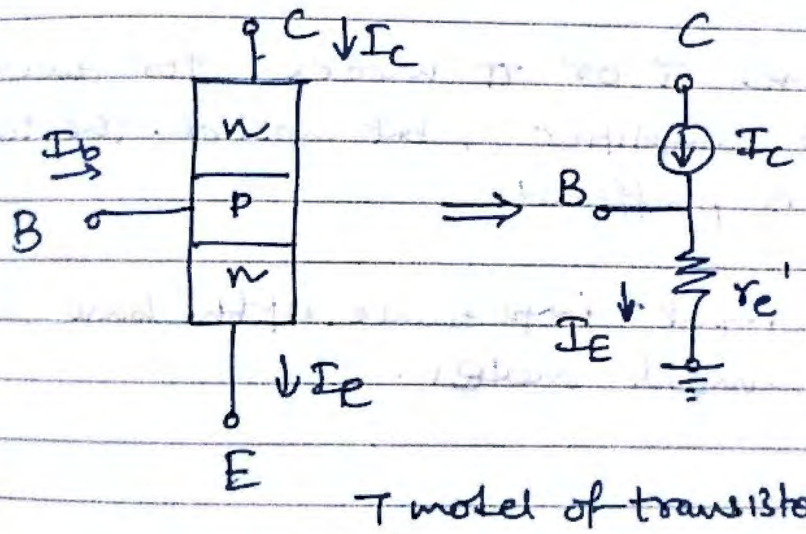
Q. Draw & explain two models of transistor.

→ AC Analysis of an amplifier can be carried out by ac equivalent circuit. We need model of transistor in order to simulate behaviour of BJT. (Under AC operating conditions)

→ Two models that we will discuss are

1) The T model
2) The π model.

1) The T- model.

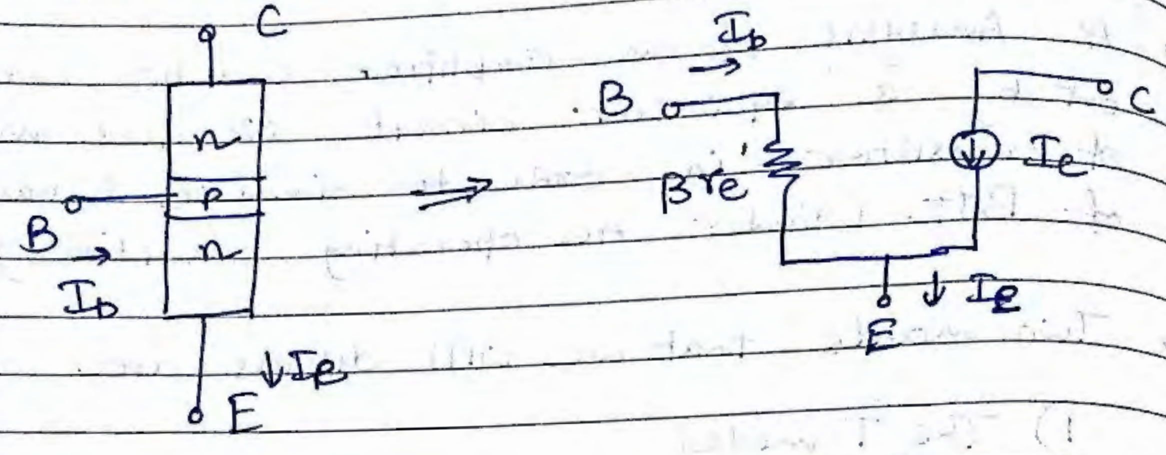


T model of transistor

→ T model is one of the oldest ac model i.e. Ebers-moll model, as it looks like "T", it is called T model.

→ for small AC signals applied at the input, emitter diode of the transistor is equivalent to resistance r_e', & collector diode is equivalent to current source I_c.

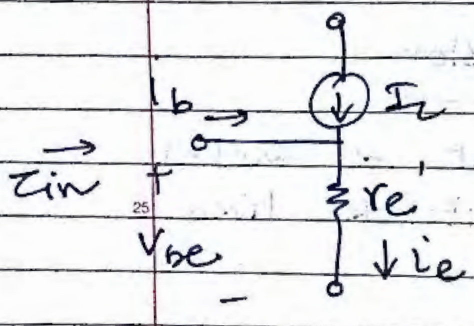
The π model:



→ for a π model the input impedance i.e. impedance measured at base terminal is equal to $\beta r_e'$.

→ We can use T or π model for analysis of transistor amplifier, but most of the time π model is preffered.

→ Defining input impedance of the base in Eber's moll model.



$$V_{be} = i_e r_e'$$

$$Z_{in(base)} = \frac{V_{be}}{i_b}$$

$$= \frac{i_e \cdot r_e'}{i_b}$$

$$= \beta r_e'$$

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So, input impedance in π model is $\beta r_e'$

Analysing an amplifier:

→ Amplifier Analysis

1) DC Analysis: All capacitors open circuited & then we calculate dc voltages & currents

2) AC Analysis: Draw AC equivalent circuit.

→ for ac equivalent circuit All capacitors are replaced by short circuit

→ Replace all dc power supplies by short circuit

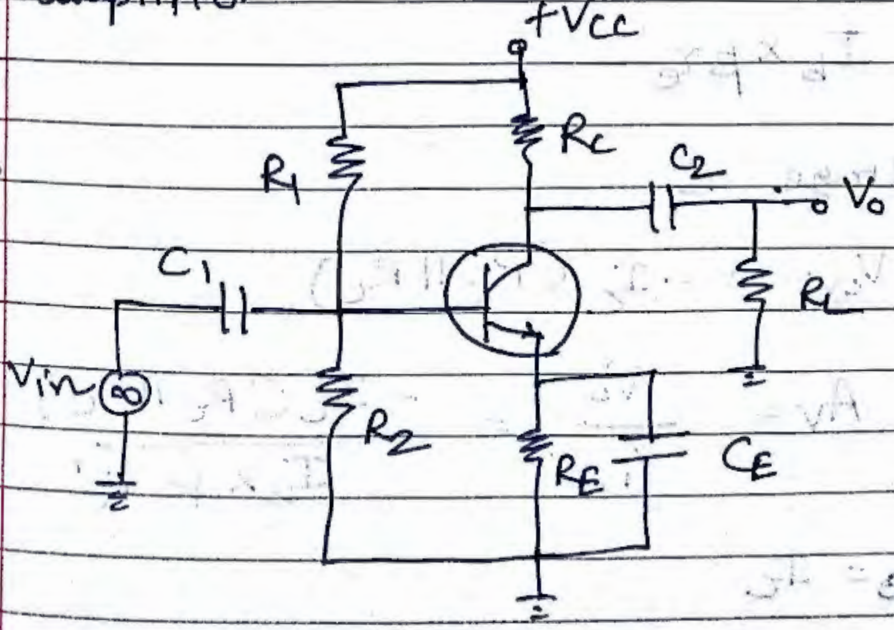
→ Replace transistor by π or T model.

Q. Draw and explain AC Analysis of common emitter amplifier.

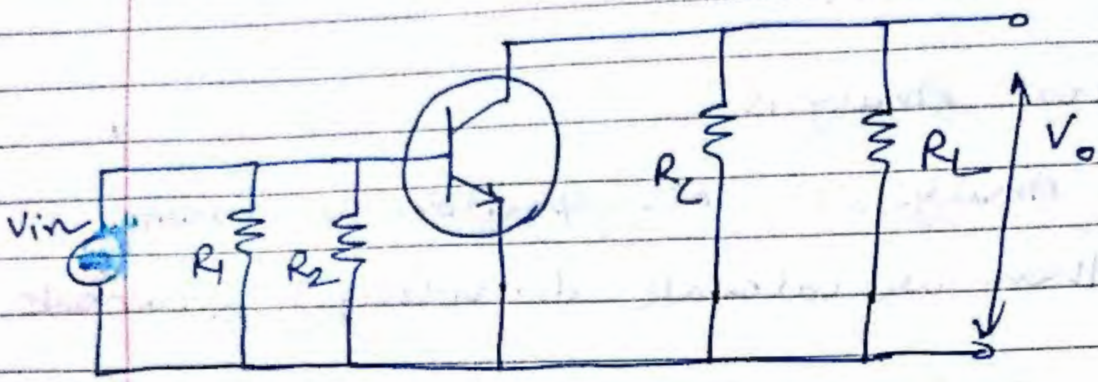
OR

Explain small signal Analysis of CE amplifier

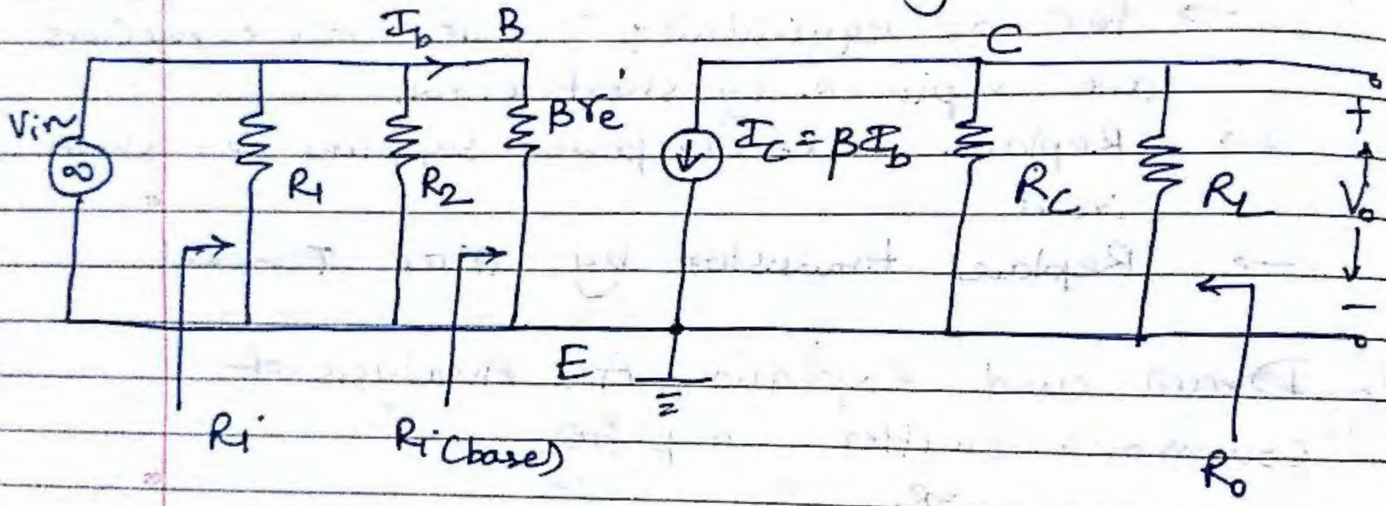
A,



AC equivalent Circuit of Voltage Divider CE Amplifier.



AC equivalent circuit using π model.



1. <u>Voltage Gain</u>:

$$V_{in} = I_b \times \beta r_e'$$

→ output voltage is

$$V_{out} = -I_c (R_C \parallel R_L)$$

$$A_V = \frac{V_o}{V_{in}} = \frac{-I_C (R_C \parallel R_L)}{I_b \times \beta r_e'}$$

But $\beta I_B = I_C$

$$A_V = \frac{-(R_C \parallel R_L)}{r_e'}$$

AC collector Resistance: Total ac load resistance seen by collector is parallel combination of R_C & R_L

$$r_c = R_C \parallel R_L$$

so, $$A_V = \frac{-r_c}{r_e'}$$ (negative sign indicate output voltage is 180° out of phase with input)

2. Input Resistance:

Resistance measured between the input terminals of an amplifier.

→ R_i is resistance measured between base & ground terminals.

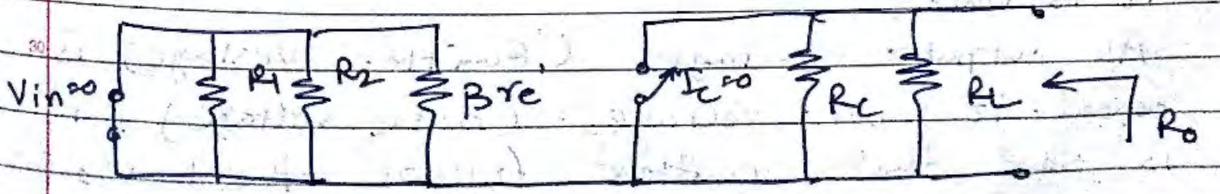
→ $$R_i(\text{base}) = \beta r_e'$$

→ input resistance of entire amplifier is given by

$$R_i = R_1 \parallel R_2 \parallel \beta r_e'$$

3. Output Resistance:

→ output resistance is measured between output terminals when input voltage is short circuited ($V_{in} = 0V$)



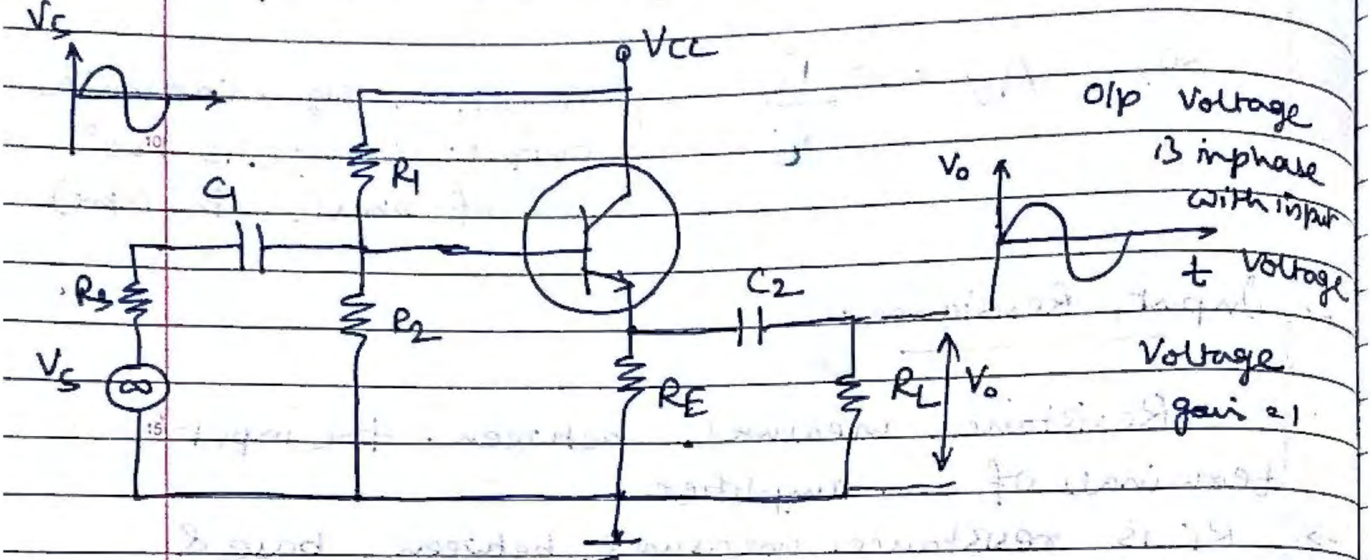
$V_{in} = 0$, $I_C = 0A$ (so open circuit)

$$R_o = R_C \parallel R_L = r_C .$$

Q. Explain the operation of Emitter follower amplifier. why is it named as emitter follower.

OR

Explain common collector amplifier.



→ input voltage is applied at the base of the transistor with respect to ground & the output of amplifier is taken from emitter with respect to ground.

→ As emitter voltage follows the base voltage the gain of this amplifier is approximately is equal to 1.

→ Input & output voltage waveforms are in phase with each other, no phase shift.

→ Input Impedance of common collector amplifier is high & output impedance of it is low.

→ As output voltage (Emitter Voltage) is equal to input voltage (base voltage), it is said that emitter follows the base, so name given is emitter follower.

Negative feedback:

→ Due to negative feedback voltage gain is extremely stable. input impedance is large & distortion doesnot exist.

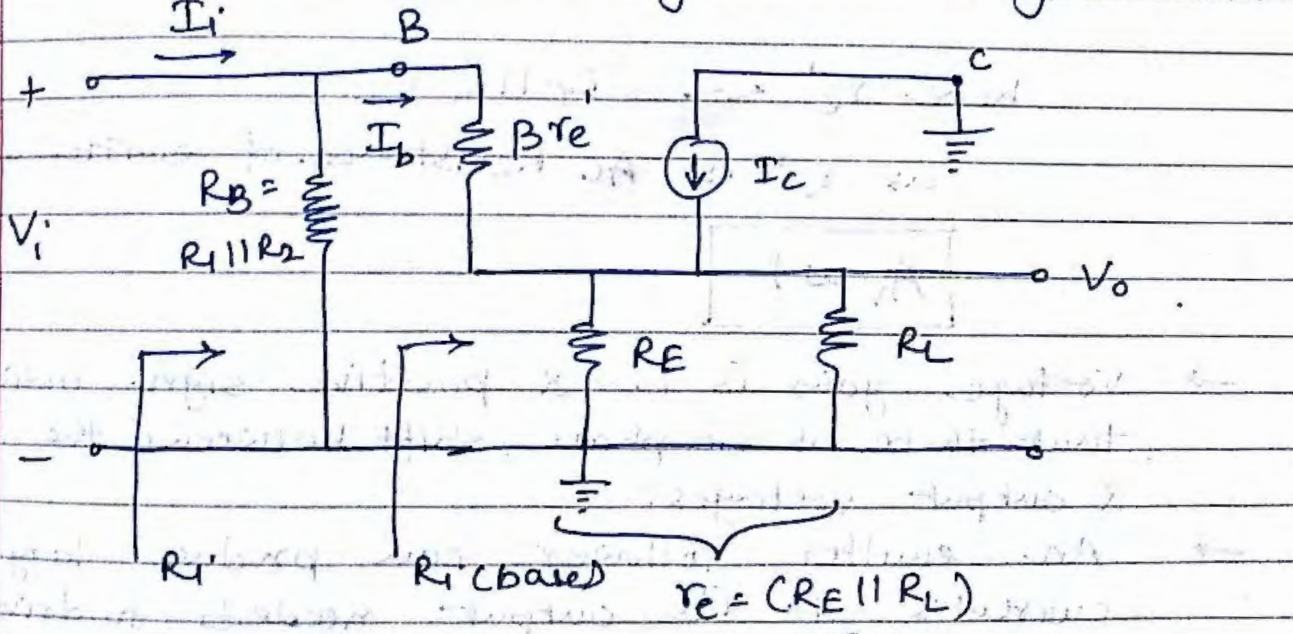
→ This is achieved at the cost of reduced voltage gain.

Q. AC Analysis of CC Configuration:

OR

Q. Small signal Analysis of CE configuration

→ Approximate π model of emitter follower i.e. common collector configuration is given below.

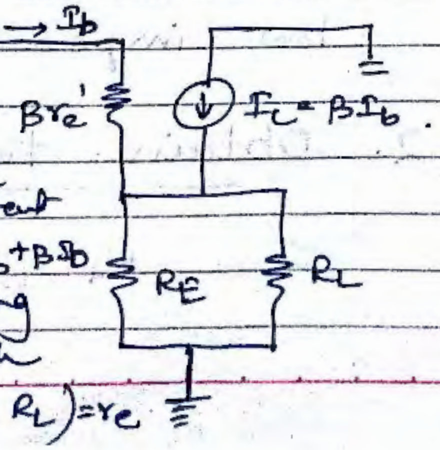


1. Voltage Gain:

→ $r_e = (R_E || R_L)$

$V_o = (1+\beta) I_B (R_E || R_L)$

Total current is $I_b + \beta I_b$ flowing through $(R_E || R_L) = r_e$



$V_i = I_b \cdot \beta r_e' + V_o$

$V_i = I_b \beta r_e' + I_c r_e$

$= I_c r_e' + I_c r_e$

$V_i = I_c (r_e' + r_e)$

Voltage Gain $A_V = \frac{V_o}{V_i} = \frac{I_e (R_E || R_L)}{I_c (r_e' + r_e)}$

$I_e \approx I_c$

So, $A_V = \frac{(R_E || R_L)}{(r_e' + r_e)} = \frac{r_e}{r_e' + r_e}$

here $r_e' << (R_E || R_L)$

as r_e' is AC Resistance of emitter diode

$$\boxed{A_V \approx 1}$$

→ Voltage gain is 1. & positive sign indicates that there is no phase shift between the input & output voltages.

→ An emitter follower can produce large currents at its output needed to drive low impedance loads.

2. Obtain the Input Impedance

$R_i (base) = \frac{V_i}{I_b}$

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$$V_i = I_b \beta r_e' + I_e (R_E || R_L)$$

$$I_e = (1+\beta) I_b$$

$$V_i = I_b \beta r_e' + (1+\beta) I_b (R_E || R_L)$$

$$(1+\beta) \approx \beta \quad (\text{as } \beta \text{ is high})$$

$$V_i = I_b [\beta (r_e' + (R_E || R_L))]$$

$$R_{i(base)} = \frac{I_b [\beta (r_e' + (R_E || R_L))]}{I_b}$$

$$= \beta (r_e' + (R_E || R_L))$$

$$R_{i(base)} = \beta (r_e' + r_e)$$

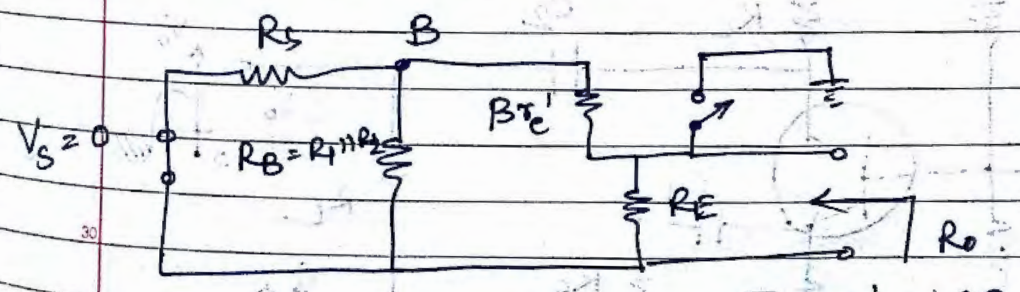
$$R_i = R_{i(base)} || R_B$$

$$R_B = (R_1 || R_2)$$

$$R_i = \beta (r_e' + r_e) || R_1 || R_2$$

3) Output Resistance (R_o)

→ ac equivalent circuit of emitter follower with $V_s = 0$



$$R_o = R_E || \left[\frac{\beta r_e' + (R_S || R_1 || R_2)}{\beta} \right]$$

Resistance transferred from base to emitter

Camlin Page
Date / /

Features of CC Amplifier:

→ Input signal is applied at base and output is obtained at emitter.
→ Voltage gain is less than 1 but very close to 1. current gain is high $(1+\beta)$

$$I_e = (1+\beta) I_b$$

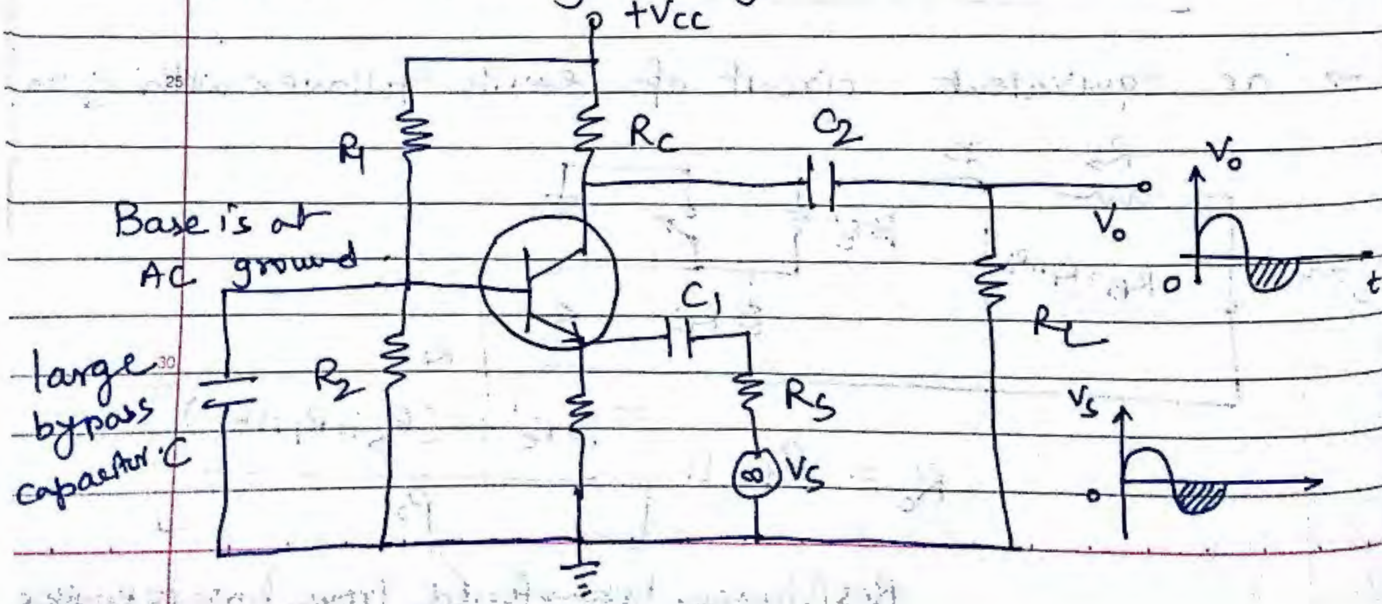
→ Input Impedance is high; output impedance is low.
→ Input & outputs are in phase, there is no phase reversal.

Applications.

→ CC amplifier is used as buffer stage that can increase the current sourcing capacity.
→ It is also used for impedance matching.

Q. Write short Note on Common Base Amplifier. Give AC analysis of Circuit.

→ Common base Amplifier with voltage divider biasing is given below.



→ R_1 & R_2 are biasing resistors, C_1 & C_2 are coupling capacitors.

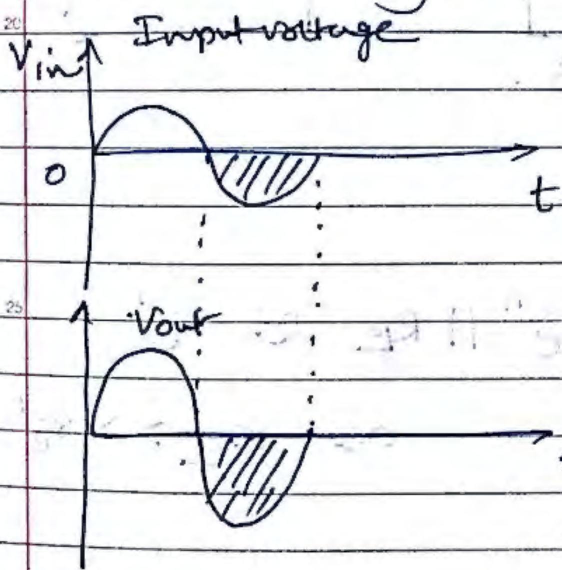
→ Base is connected to ground (for ac signals only) via large capacitor C, which acts as short circuit for ac signals & Thus base terminal is common between input & output.

→ when positive half cycle of input signal, the emitter voltage varies sinusoidally above its Q. point.

→ As emitter voltage increases, $V_{be}\downarrow$, so, $I_b\downarrow$ & I_c also $\downarrow$, so voltage drop across $R_C\downarrow$.

→ As voltage drop across $R_C\downarrow$, collector voltage increases above Q-point.

→ Thus we get positive half cycle at output for correspoing positive halfcycle of input.



* **Features of CB Amplifier.**

→ Input signal applied at emitter & o/p taken at collector. Base is common between i/p & o/p.

→ Base is connected to ground via capacitor C only for ac signals.

→ Input Resistance is low.

→ Output " is very high.

→ Current Gain is approximately equal to 1. no, current Amplification.

→ Voltage Gain is high.

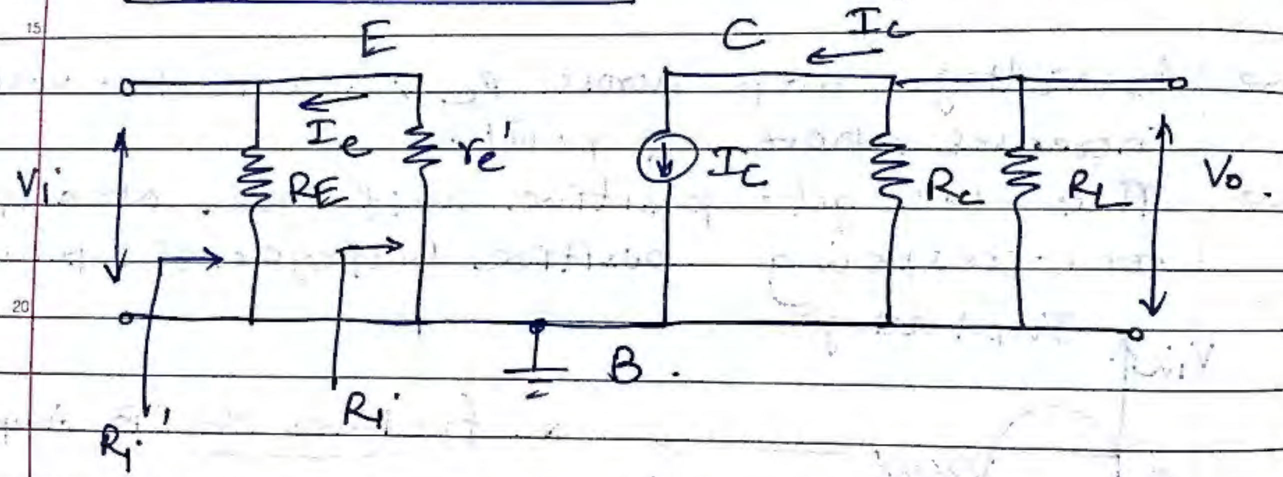
Applications:

→ As high freq. amplifier having large band-width.

→ For impedance matching.

AC Analysis of Common Base Amplifier:

1) AC equivalent circuit with π model is shown.



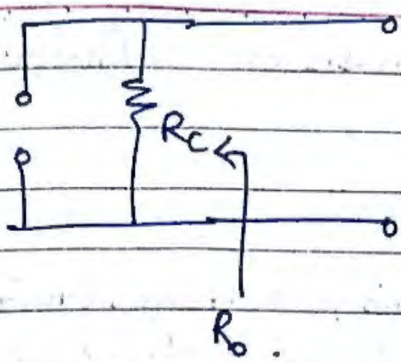
2) Input Resistances R_i & R_i'. $R_i' = r_e'$

$$R_i' = r_e'' \| R_E \approx r_e'$$

as $R_E >> r_e'$

3) Output Resistance:

To calculate output Resistance V_i is reduced to 0. so, $I_e = 0$



$$\boxed{R_o = R_C}$$

4) Voltage Gain:

$$A_V = \frac{V_o}{V_i} = \frac{-I_C (R_C \| R_L)}{-I_e r_e'}$$

$$\frac{I_C}{I_e} = \alpha_{ac}.$$

$$A_V = \alpha_{ac} \frac{(R_C \| R_L)}{r_e'}$$

$(R_C \| R_L)$ = collector ac Resistance

$$\boxed{A_V = \alpha_{ac} \cdot \frac{r_c}{r_e'}}$$

+ve gain so no phase shift between input & output.

Give

Q. Comparision of transistor Amplifier configurations.

OR

Compare current Gain, voltage Gain, i/p impedance & output impedence of CC & CB, CE configurations.

Sr. No.	Quantity/ Parameter.	CE	CB	CC
1.	Input terminal	Base	Emitter	Base
2.	Output terminal	collector	collector	Emitter
3.	Common terminal	Emitter	Base	collector
4.	Input Resistance (R_i)	Medium	Low	High
5.	Output Resistance (R_o)	Medium	High	Low
6.	Current Gain (A_I)	High	Less than 1	High
7.	Voltage Gain (A_V)	High	High	Less than 1
8.	Applications	Af voltage Amplifiers	Low noise pre-amplifier	Buffer Amplifier.