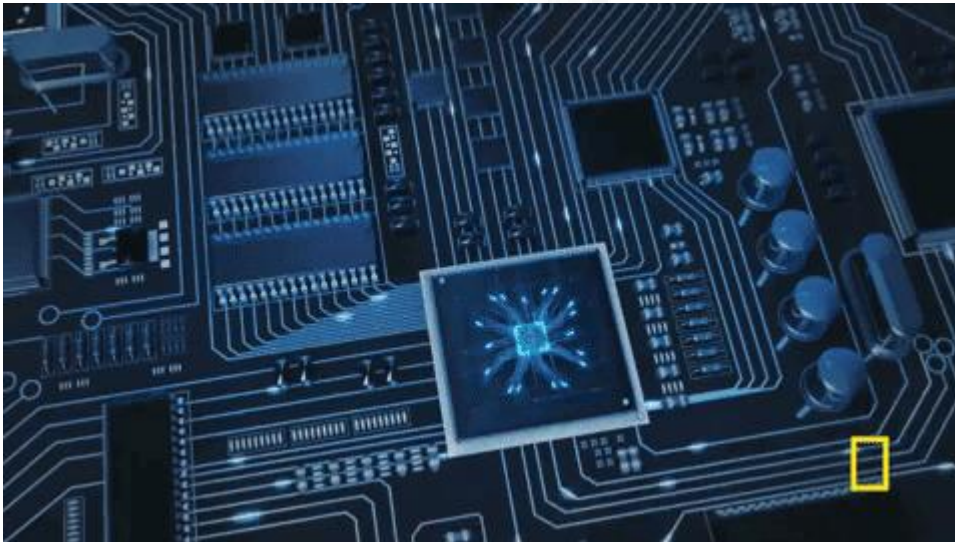


Course Code:1BEE302

Course: Analog Electronic Circuits



Presented by,
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Assistant Professor
Electrical and Electronics Engineering
ATME College of Engineering, Mysuru



Course Details

Module-2 Syllabus

2 a) BJT Biasing

Introduction to biasing, operating point, bias configurations; fixed-bias, emitter bias, voltage divider bias, DC bias with voltage feedback, design of bias circuits, effect of temperature on bias; thermal runaway, bias stabilization, stability, stability factors of bias circuits.

2 b) BJT AC Analysis

Amplification in AC domain, Transistor modelling for small signal analysis; resistance (r_e) model of CB, CE, and CC configurations, hybrid equivalent model CB, CE, and CC configurations, hybrid π model. Low frequency analysis, high frequency analysis.

Biasing Configurations of BJT

1. Fixed bias configuration
2. Emitter stabilized bias configuration
3. Voltage divider bias configuration

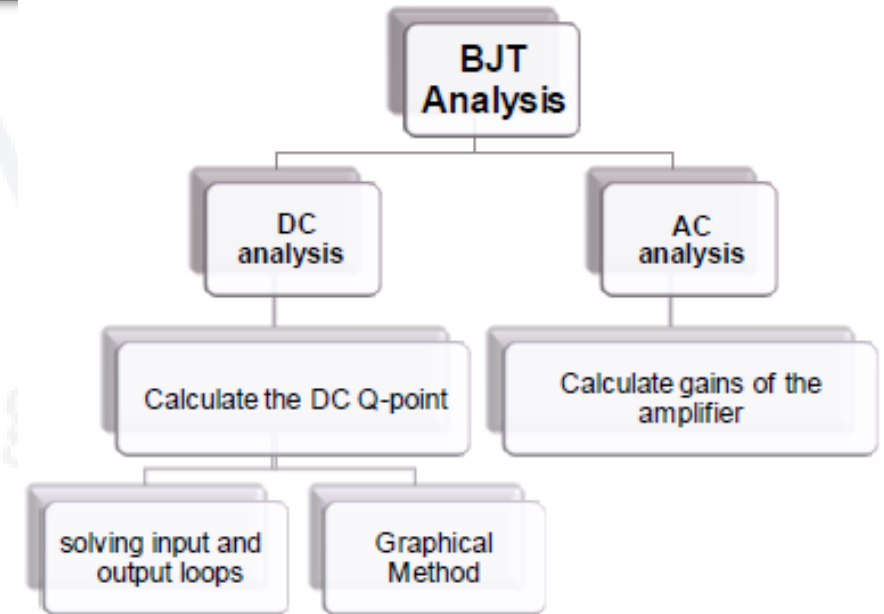
Parameters of BJT

1. Gain
2. Input Impedance
3. Output Impedance

DC current gain (β_{DC}) and DC Alpha (α_{DC})

The dc current **gain** of a transistor is the ratio of the dc collector current (I_C) to the dc base current (I_B) and is designated dc **beta** (β_{DC}).

The ratio of the dc collector current (I_C) to the dc emitter current (I_E) is the dc **alpha** (α_{DC}). The alpha is a less-used parameter than beta in transistor circuits



The biasing of a bipolar junction transistor is to establish the desired value of **collector to emitter voltage V_{CE} and Collector current I_C** .

The values of V_{CE} and I_C together are known as **operating point or quiescent point (Q-point)**

Need for Bias Stabilization:

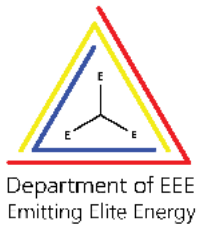
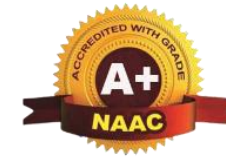
To maintain a stable operating point (Q-point) by minimizing variations in collector current due to temperature changes or transistor parameter (β) variations.

Applications of Different Types of Bias (Practical):

- **Fixed Bias:** Used in simple amplifier circuits for **low-cost and experimental setups**.
- **Collector-to-Base Bias:** Applied in **improved amplifier stages** where moderate stability is required.
- **Emitter Bias:** Commonly used in **medium-gain amplifiers** for enhanced thermal stability.
- **Voltage Divider Bias:** Widely used in **practical amplifier and transistor circuit designs** due to its excellent stability and predictable performance.



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Bias Stabilization

Stability:

It is the measure of the sensitivity of the circuit to variation in the external parameters.

As **Temperature** ↑

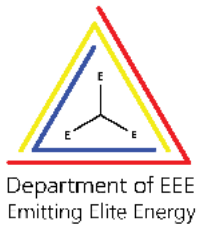
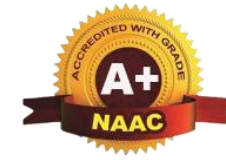
→ β ↑

→ V_{BE} ↓

→ I_{CO} ↑ (Reverse saturation current)



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Fixed Bias and Stabilization

At **T = 25°C**

Q Point is stable

At **T = 100°C**

At this temperature, there will be **distortion** in the output as Q-point has shifted.

Definition: Stability Factor

The rate of change of **collector current (I_C)** with respect to **leakage current (I_{CO})** at **constant base-emitter voltage (V_{BE})** and **amplification factor (β)** is called the **Stability Factor**.

$$S(I_{CO}) = \frac{\Delta I_C}{\Delta I_{CO}} \quad (V_{BE}, \beta \text{ constant})$$

$$S(V_{BE}) = \frac{\Delta I_C}{\Delta V_{BE}} \quad (I_{CO}, \beta \text{ constant})$$

$$S(\beta) = \frac{\Delta I_C}{\Delta \beta} \quad (I_{CO}, V_{BE} \text{ constant})$$

Method - 1

$$S = \left. \frac{dI_C}{dI_{CBO}} \right|_{V_{BE}, \beta}$$

Step-1: Input Current

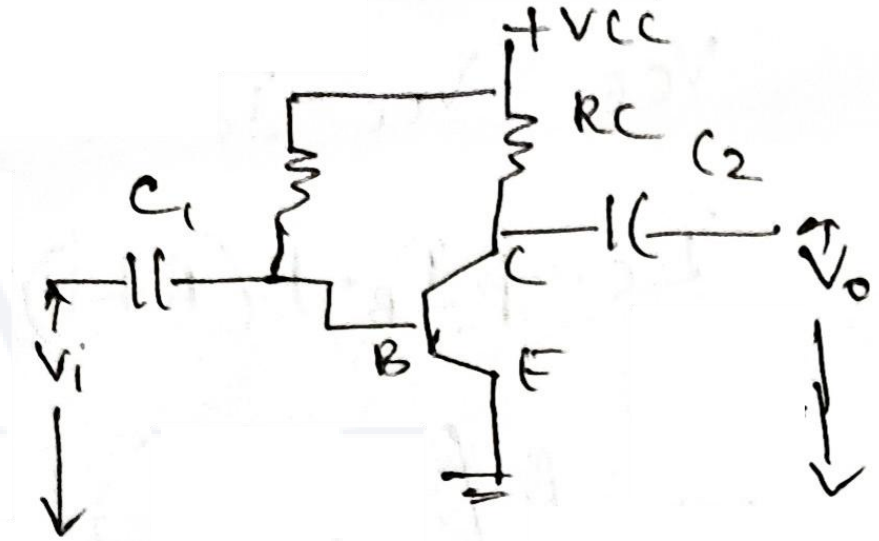
$$I_B = \frac{V_{CC} - V_{BE}}{R_B}$$

Step-2: Differentiate w.r.t I_C

$$\frac{dI_B}{dI_C} = 0 \quad \text{since } I_C \text{ not present}$$

Step-3: Stability Factor Equation

$$S = \frac{1 + \beta}{1 - \beta \frac{dI_B}{dI_C}}$$



Step-4: Substitute Eqn 2 in 3 Stability Factor

$$S = \frac{1 + \beta}{1 - 0} = 1 + \beta$$

Method - 2

$$S(V_{BE}) = \frac{dI_C}{dV_{BE}} \quad (\text{with } I_{CBO} \text{ and } \beta \text{ constant})$$

Step-1

$$I_B = \frac{V_{CC} - V_{BE}}{R_B} \quad (1)$$

$$I_C = \beta I_B \quad (2)$$

Step-2: Substitute 1 in 2

$$I_C = \beta \frac{(V_{CC} - V_{BE})}{R_B}$$

$$I_C = \frac{\beta V_{CC}}{R_B} - \frac{\beta V_{BE}}{R_B} \quad (3)$$

Step-3: Differentiate Eq. (3) w.r.t V_{BE}

$$\frac{dI_C}{dV_{BE}} = 0 - \frac{\beta}{R_B}$$

$$\therefore S(V_{BE}) = -\frac{\beta}{R_B}$$

Method – 3

$$S = \frac{dI_C}{d\beta}$$

Step-1

$$I_B = \frac{V_{CC} - V_{BE}}{R_B} \quad (1)$$

$$I_C = \beta I_B$$

$$I_B = \frac{I_C}{\beta} \quad (2)$$

$$\frac{I_C}{\beta} = \frac{V_{CC} - V_{BE}}{R_B}$$

Step-2

$$I_C = \beta \left(\frac{V_{CC} - V_{BE}}{R_B} \right) \quad (3)$$

Step-3

At temperature T_1 :

$$\beta = \beta_1, \quad I_C = I_{C1}$$

$$I_{C1} = \beta_1 \left(\frac{V_{CC} - V_{BE}}{R_B} \right) \quad (4)$$

At temperature T_2 :

$$\beta = \beta_2, \quad I_C = I_{C2}$$

$$I_{C2} = \beta_2 \left(\frac{V_{CC} - V_{BE}}{R_B} \right) \quad (5)$$

Step-4

Dividing Eq. (5) by Eq. (4):

$$\frac{I_{C2}}{I_{C1}} = \frac{\beta_2}{\beta_1} \quad (6)$$

Step-5

Subtracting Eq. (6) by 1:

$$\begin{aligned} \frac{I_{C2}}{I_{C1}} - 1 &= \frac{\beta_2 - \beta_1}{\beta_1} \\ \frac{I_{C2} - I_{C1}}{I_{C1}} &= \frac{\beta_2 - \beta_1}{\beta_1} \end{aligned}$$

Step-6

$$\Delta I_C = I_{C2} - I_{C1}$$

$$\Delta \beta = \beta_2 - \beta_1$$

$$\therefore \frac{\Delta I_C}{I_{C1}} = \frac{\Delta \beta}{\beta_1}$$

$$\Rightarrow \frac{\Delta I_C}{\Delta \beta} = \frac{I_{C1}}{\beta_1}$$



Inference:

Fixed Bias Stabilization:

The stability factor $S=1+\beta$ is high, indicating **poor stability**, as collector current I_C varies significantly with changes in transistor gain (β) or temperature.

Emitter Bias and Stabilization

Method – 1

$$S = \frac{dI_B}{dI_C}$$

Step-1

From emitter-stabilized bias circuit:

$$V_{CC} = I_B R_B + V_{BE} + I_E R_E \quad (1)$$

Step-2

Since $I_E = I_C + I_B$:

$$V_{CC} = I_B R_B + V_{BE} + (I_C + I_B) R_E$$

$$V_{CC} = I_B (R_B + R_E) + V_{BE} + I_C R_E \quad (2)$$

$$I_B (R_B + R_E) = V_{CC} - V_{BE} - I_C R_E$$

Step-3

Differentiate Eq. (2) w.r.t I_C

$$0 = \frac{dI_B}{dI_C}(R_B + R_E) + \frac{dV_{BE}}{dI_C} + R_E$$

Since $\frac{dV_{BE}}{dI_C} \approx 0$:

Step-4

$$0 = \frac{dI_B}{dI_C}(R_B + R_E) + R_E$$

Step-5

$$\frac{dI_B}{dI_C}(R_B + R_E) = -R_E$$

$$\frac{dI_B}{dI_C} = -\frac{R_E}{R_B + R_E}$$

Step-6**Step-3: Stability Factor Equation**

$$S = \frac{1 + \beta}{1 - \beta \frac{dI_B}{dI_C}}$$

Step-7

$$S = \frac{1 + \beta}{1 - \beta \left(-\frac{R_E}{R_B + R_E} \right)}$$

Method – 2

$$S_{V_{BE}} = \frac{dI_C}{dV_{BE}}$$

$$\frac{dI_C}{dV_{BE}} = \frac{-\beta}{R_B + (1 + \beta)R_E}$$

Method – 3

$$S = \frac{dI_C}{d\beta}$$

$$\frac{\Delta I_C}{\Delta \beta} = \frac{I_{C1}(R_B + R_E)}{\beta_1(R_B + R_E(1 + \beta_2))}$$

Inference:

The stability factor $S = \frac{1 + \beta}{1 + \beta \frac{R_E}{R_B + R_E}}$ is lower, indicating **better stability**, as the emitter resistor

R_E provides negative feedback that minimizes variations in I_C .

Voltage Divider Bias Stabilisation

Method – 1

$$S_{I_{C0}} = \frac{1 + \beta}{1 + \beta \left(\frac{R_E}{R_E + R_B} \right)}$$

Method – 2

$$S_{V_{BE}} = \frac{-\beta}{R_B + (1 + \beta)R_E}$$

(where $R_B = R_{TH}$)

Method – 3

$$S_{\beta} = \frac{I_{C1}(R_B + R_E)}{\beta_1(R_B + R_E(1 + \beta_2))}$$

(with $R_B = R_{TH}$)

Inference:

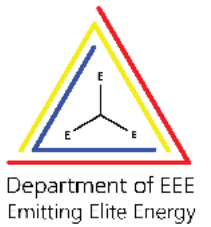
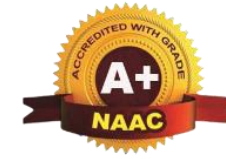
The stabilization equation shows that adding an emitter resistor R_E reduces the stability factor S , thereby making the collector current I_C less sensitive to variations in transistor gain (β) and temperature, resulting in improved bias stability.

Course Details

Hybrid Parameter	General Parameter	Transistor configuration		
		Common Emitter	Common Base	Common collector
h_i	h_{11}	h_{ie}	h_{ib}	h_{ic}
h_r	h_{12}	h_{re}	h_{rb}	h_{rc}
h_f	h_{21}	h_{fe}	h_{fb}	h_{fc}
h_o	h_{22}	h_{oe}	h_{ob}	h_{oc}



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Course Details

- Current gain
- Input resistance
- Voltage gain
- Output resistance

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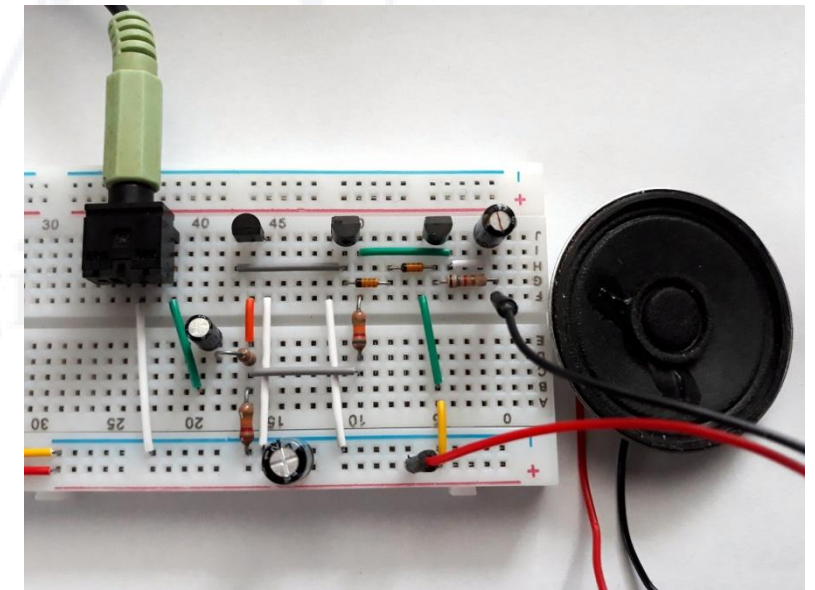
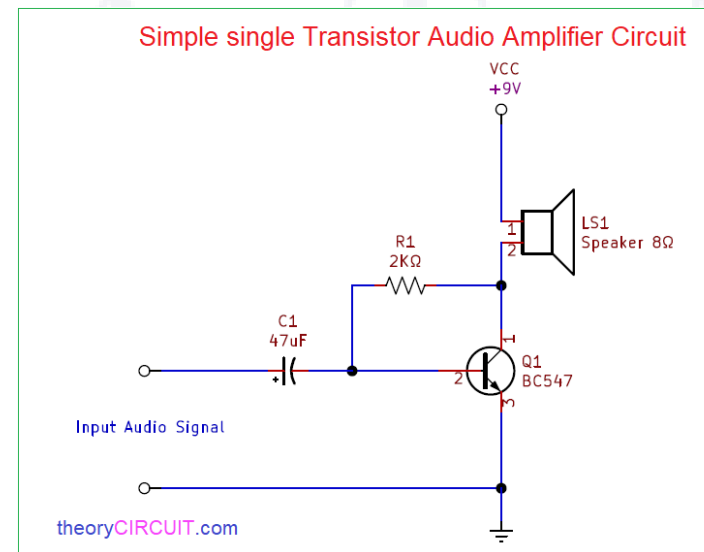
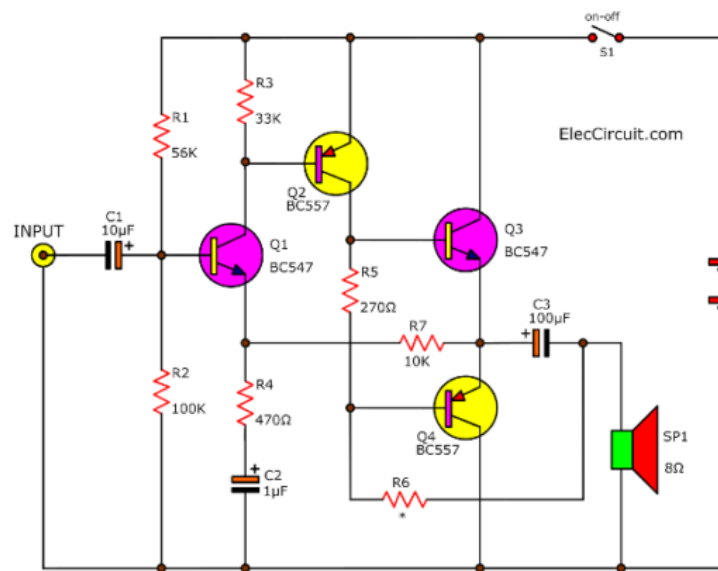
Course Details

Practical Application – Transistor Amplifier Using h-Model

Application	Description
Audio Amplifiers	Small microphones → transistor CE stage using h-model for gain design
Signal Conditioning	Used in sensors where weak analog signals are amplified
Radio Frequency Amplifiers	High-frequency transistors analyzed using h-parameter models
Switching Circuits	The hybrid model helps predict cutoff and saturation points
Pre-Amplifiers in Medical Instruments	For ECG, EEG, and sensor signal amplification

Course Details

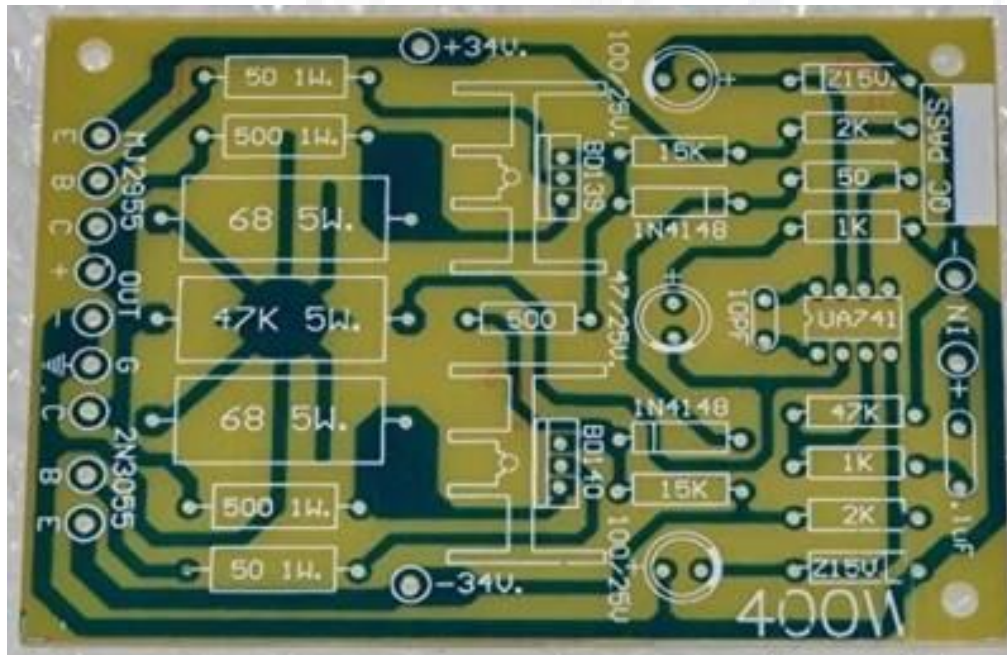
Practical Application – Audio Amplifier



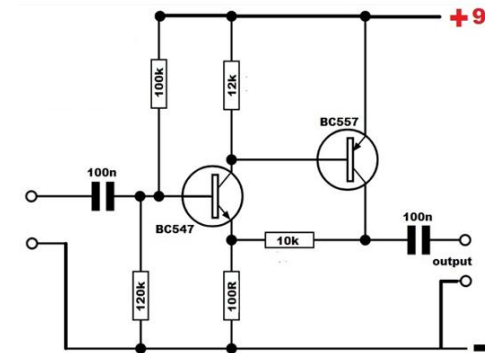
Transistor in a **common-emitter (or similar)** configuration amplifies small audio signals (eg microphone outputs) into loudspeakers or headphones.

Course Details

Audio Amplifier



Two Transistor Audio Amplifier



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Course Details

Signal Conditioning

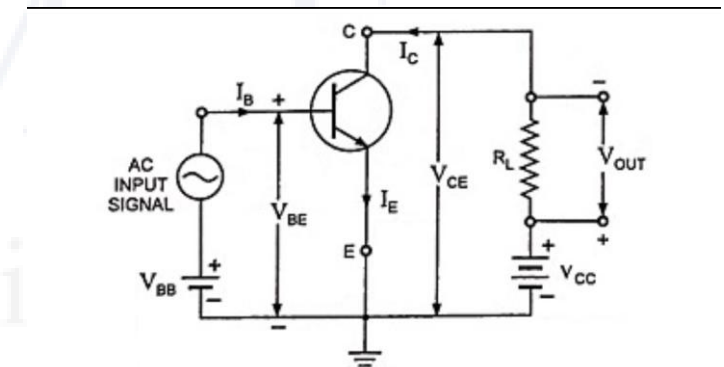
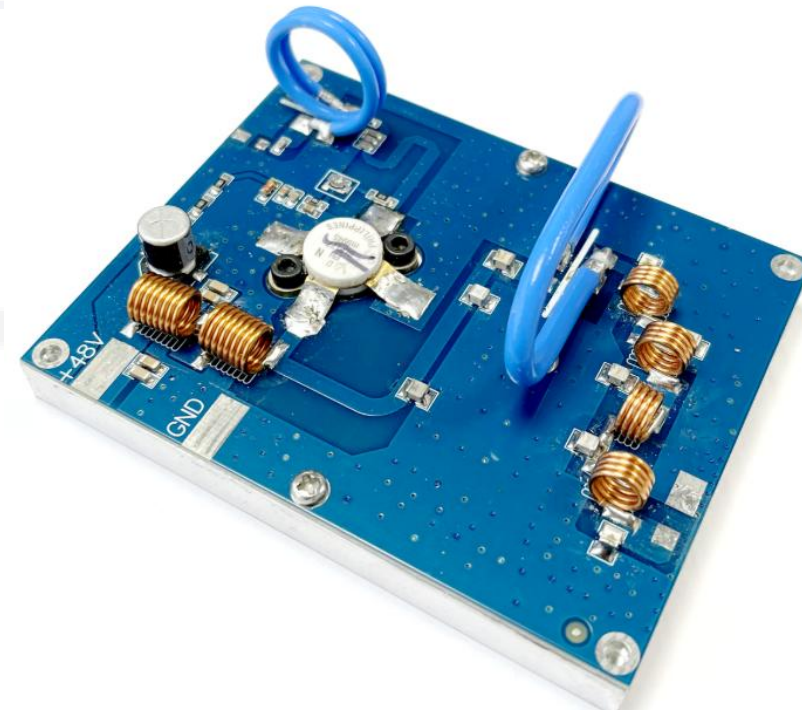
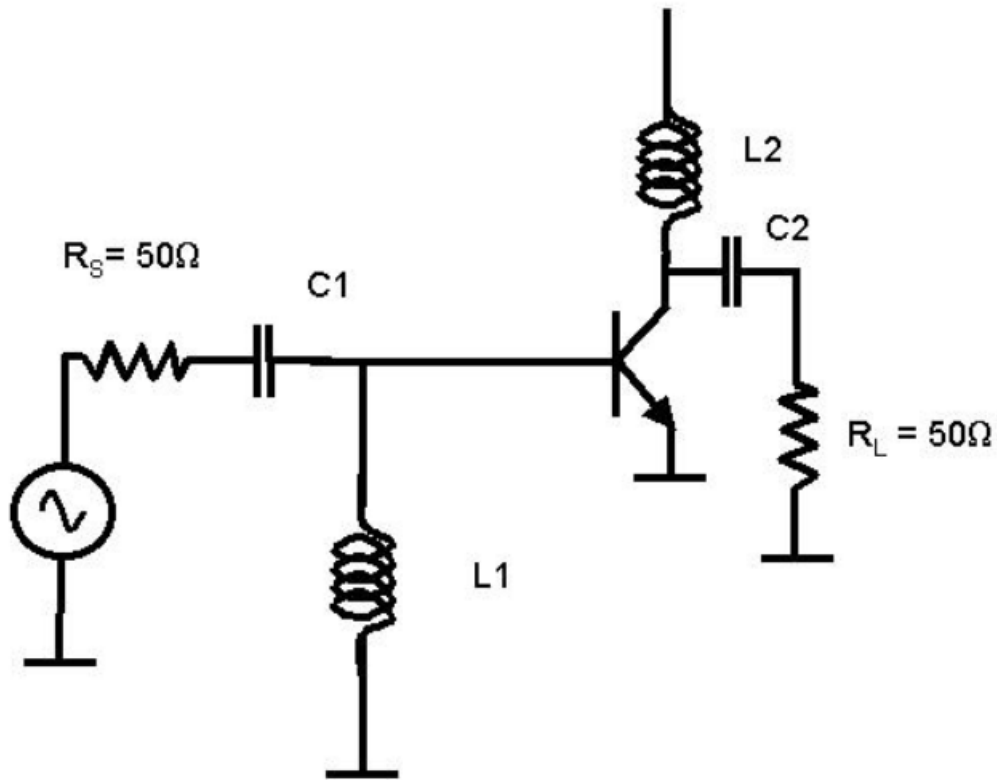


Fig. 10.32 Common Emitter NPN Transistor Amplifier Circuit

Course Details

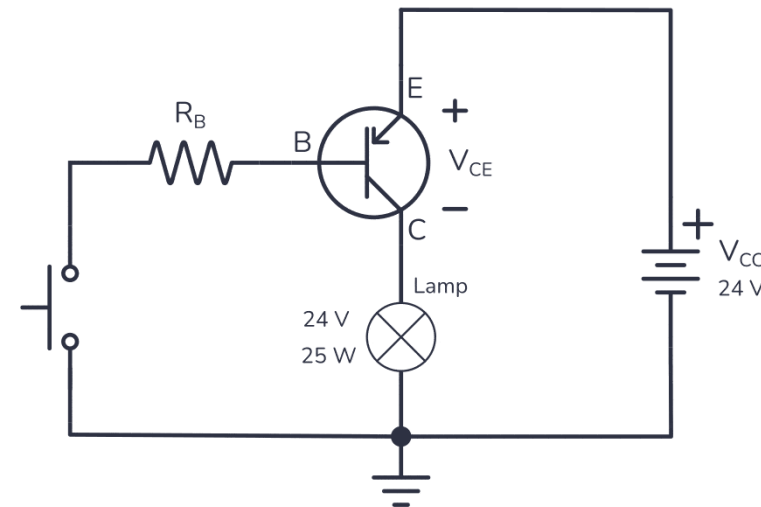
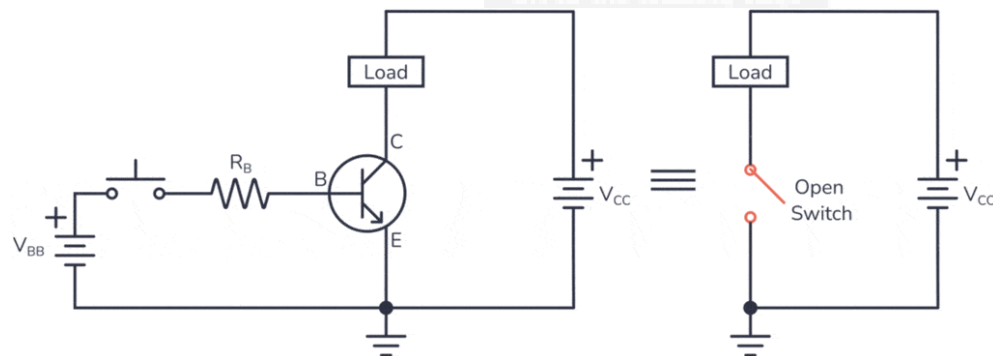
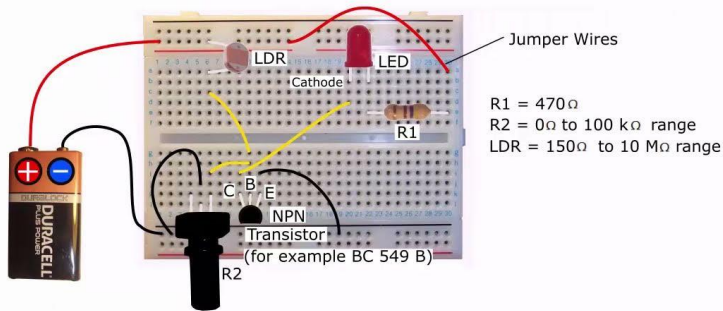
RF Circuits



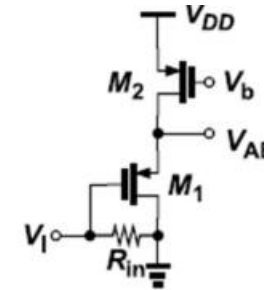
Course Details

Switching Circuits

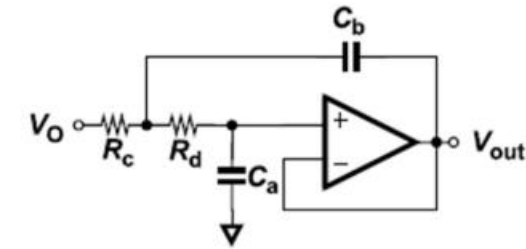
4 - Day Light



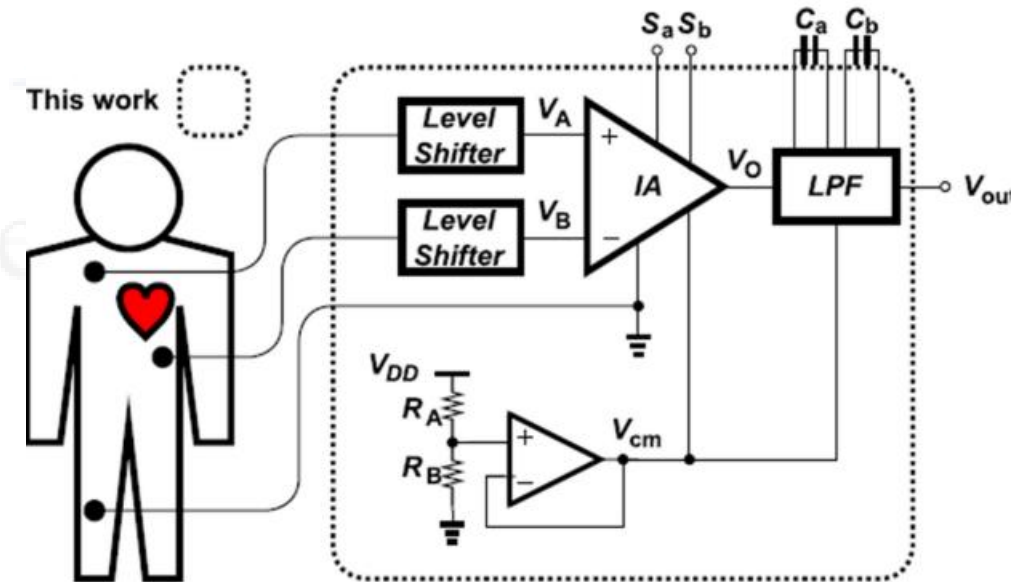
Pre-Amplifiers in Medical Instruments



(a)



(b)



(c)

Hybrid Equivalent Model of Transistor

To develop hybrid equivalent circuit we consider;

I_i and V_o as independent variables.

V_i and I_o as dependant variables

Step-1:

$$V_i = f(I_i, V_o) ; V_i = h_{11} * I_i + h_{12} * V_o ; V_i = h_i * I_i + h_r * V_o \text{ ----- (1)}$$

Step-2:

$$I_o = f(I_i, V_o) ; I_o = h_{21} * I_i + h_{22} * V_o ; I_o = h_f * I_i + h_o * V_o \text{ ----- (2)}$$

$h_i = h_{11}$ = Input impedance with output short circuited, unit is ohm

$h_{12} = h_r$ = reverse voltage gain with input open circuit, no unit.

$$h_r = \frac{V_i}{V_o} \text{ at } I_i = 0$$

$h_{21} = h_f$ = forward current gain with output short circuited, no unit.

$$h_f = \frac{I_o}{I_i} \text{ at } V_o = 0$$

$h_{22} = h_o$ = output admittance with input open circuit, unit is per ohms. $h_o = \frac{I_o}{V_o} \text{ at } I_i = 0$



Hybrid Equivalent Model of Transistor



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$$V_i = h_{11} * I_i + h_{12} * V_o$$

$$I_o = h_{21} * I_i + h_{22} * V_o$$

$$V_i = h_i * I_i + h_r * V_o \text{ ----- (1)}$$

$$I_o = h_f * I_i + h_o * V_o \text{ ----- (2)}$$

Step-3:

From equation (1);

$h_i * I_i$ = Voltage drop across the impedance h_i

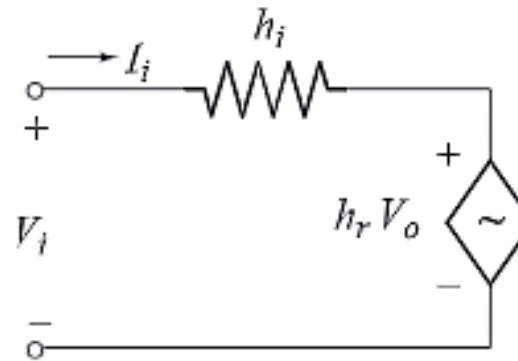
$h_r * V_o$ = Controlled voltage source

Step-4:

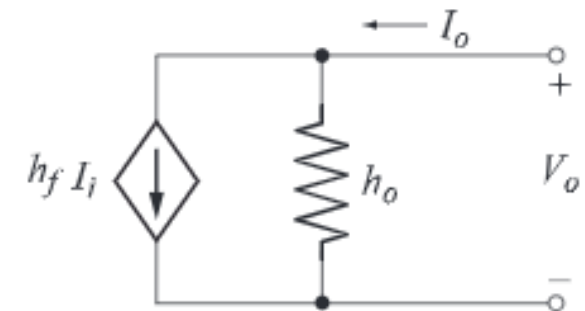
From equation (2);

$h_f * I_i$ = Controlled current source

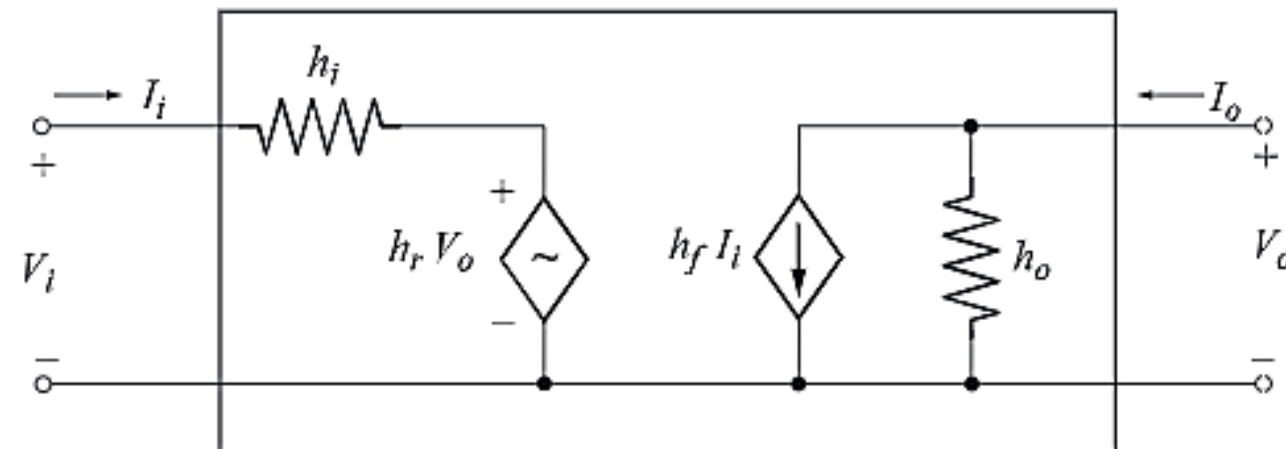
$h_o * V_o$ = Current through admittance h_o



Circuit model of $V_i = h_i I_i + h_r V_o$



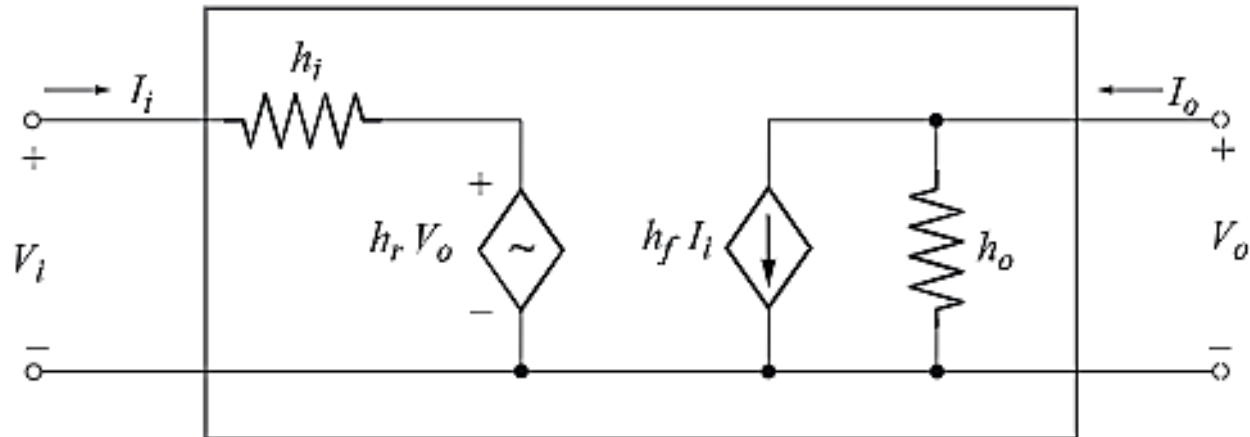
Circuit model of $I_o = h_f I_i + h_o V_o$



Hybrid equivalent circuit of Transistor

Hybrid Equivalent Model of Transistor

Step-5:



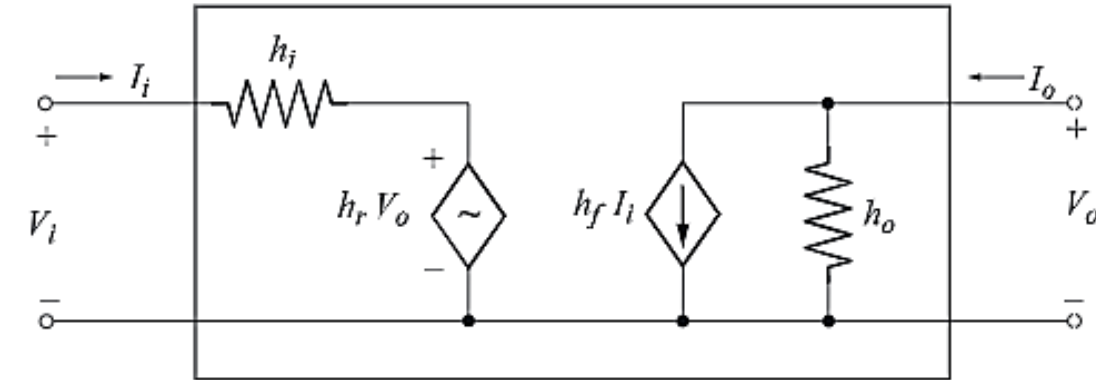
Hybrid equivalent circuit of Transistor

$$V_I = h_{11} * I_I + h_{12} * V_O$$

$$I_O = h_{21} * I_I + h_{22} * V_O$$

$$V_i = h_i * I_i + h_r * V_o \text{ ----- (1)}$$

$$I_o = h_f * I_i + h_o * V_o \text{ ----- (2)}$$



Hybrid equivalent circuit of Transistor

Step-6:

Hybrid Parameters Nomenclature

$h_i = h_{11}$ = Input resistance with output shorted

$h_r = h_{12}$ = Reverse voltage gain with input open

$h_f = h_{21}$ = Forward current gain with output shorted

$h_o = h_{22}$ = Output conductance with input open.

Hybrid Parameter	General Parameter	Transistor configuration		
		Common Emitter	Common Base	Common collector
h_i	h_{11}	h_{ie}	h_{ib}	h_{ie}
h_r	h_{12}	h_{re}	h_{rb}	h_{re}
h_i	h_{21}	h_{ic}	h_{fb}	h_{fe}
h_o	h_{22}	h_{oe}	h_{ob}	h_{oe}

Hybrid Parameters	Configuration		
	CE	CB	CC
h_i	h_{ie}	h_{ib}	h_{ic}
h_f	h_{fe}	h_{fb}	h_{fc}
h_r	h_{re}	h_{rb}	h_{rc}
h_o	h_{oe}	h_{ob}	h_{oc}

Hybrid Model of Common Emitter Configuration

Basic equations:

$$V_i = h_i * I_i + h_r * V_o \text{ ---- (1)}$$

$$I_o = h_f * I_i + h_o * V_o \text{ ----- (2)}$$

$$V_i = V_{be}$$

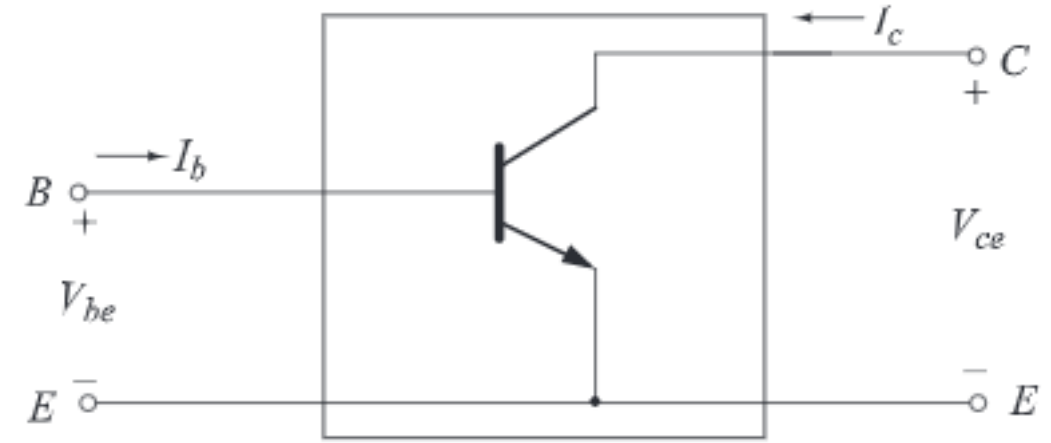
$$I_i = I_b$$

$$V_o = V_{ce}$$

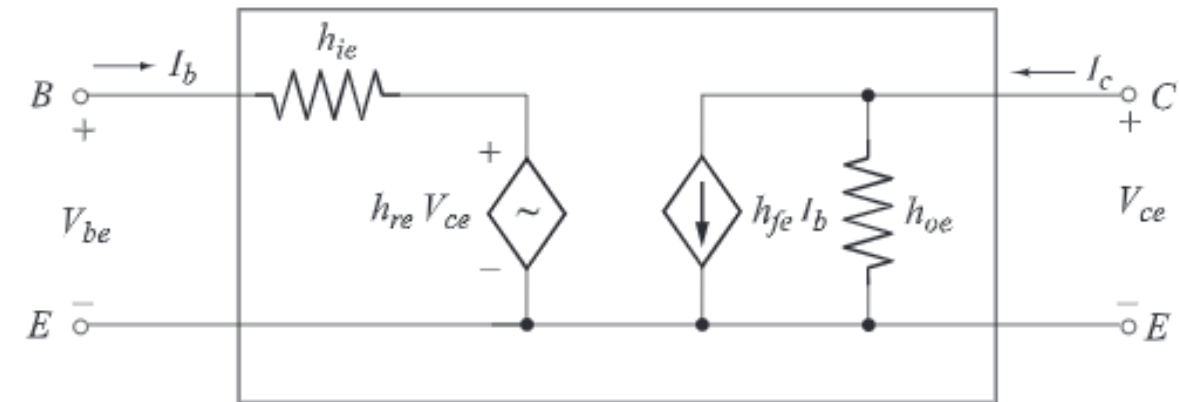
$$I_o = I_c$$

$$V_{be} = h_{ie} * I_b + h_{re} * V_{ce}$$

$$I_c = h_{fe} * I_b + h_{oe} * V_{ce}$$



Two port network of CE configuration



Hybrid equivalent circuit of CE configuration

Hybrid Model of Common Base Configuration

Basic equations:

$$V_i = h_i * I_i + h_r * V_o \text{ ----- (1)}$$

$$I_o = h_f * I_i + h_o * V_o \text{ ----- (2)}$$

$$V_i = V_{eb}$$

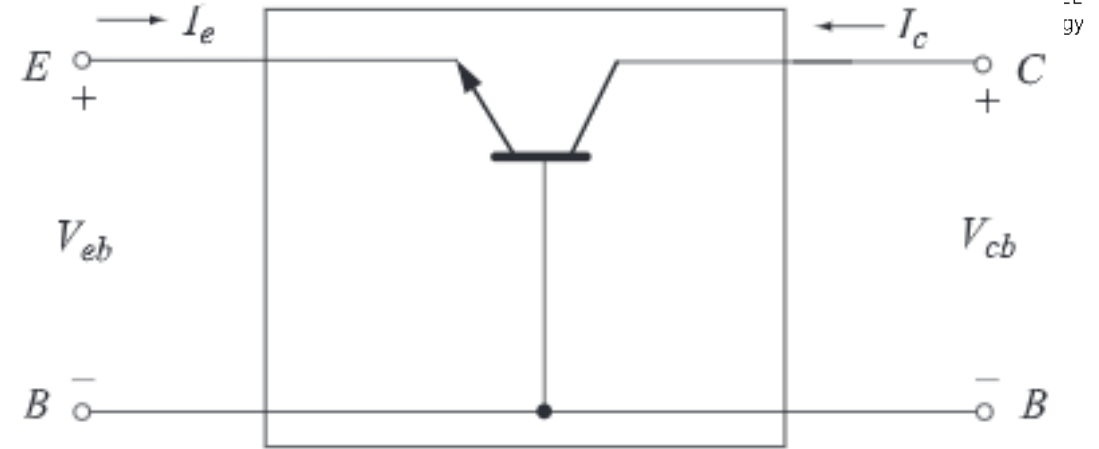
$$I_i = I_e$$

$$V_o = V_{cb}$$

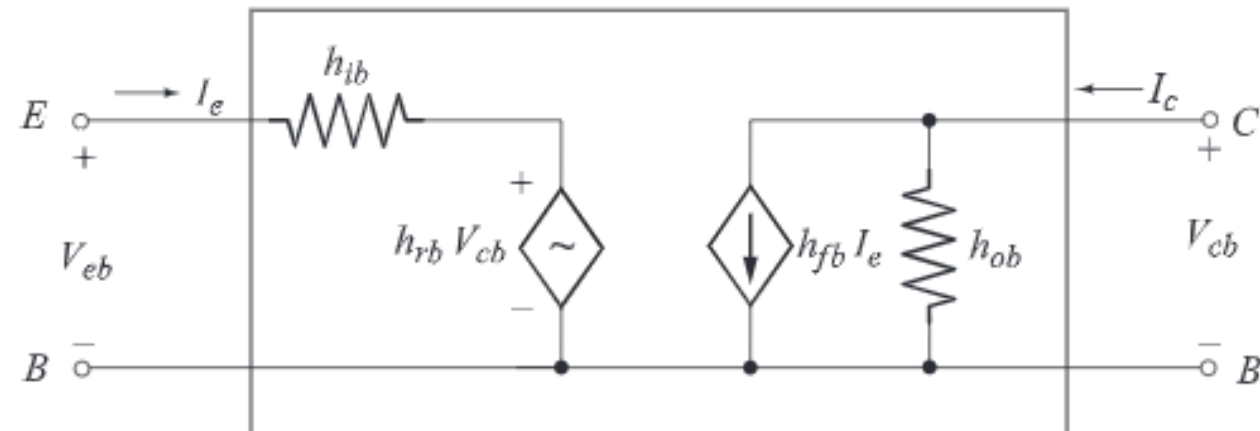
$$I_o = I_c$$

$$V_{eb} = h_{ib} * I_e + h_{rb} * V_{cb}$$

$$I_c = h_{fb} * I_e + h_{ob} * V_{cb}$$



Two port network of CB configuration



Hybrid equivalent circuit of CB configuration

Hybrid Model of Common Collector Configuration

Basic equations:

$$V_i = h_i * I_i + h_r * V_o \text{ ----- (1)}$$

$$I_o = h_f * I_i + h_o * V_o \text{ ----- (2)}$$

$$V_i = V_{bc}$$

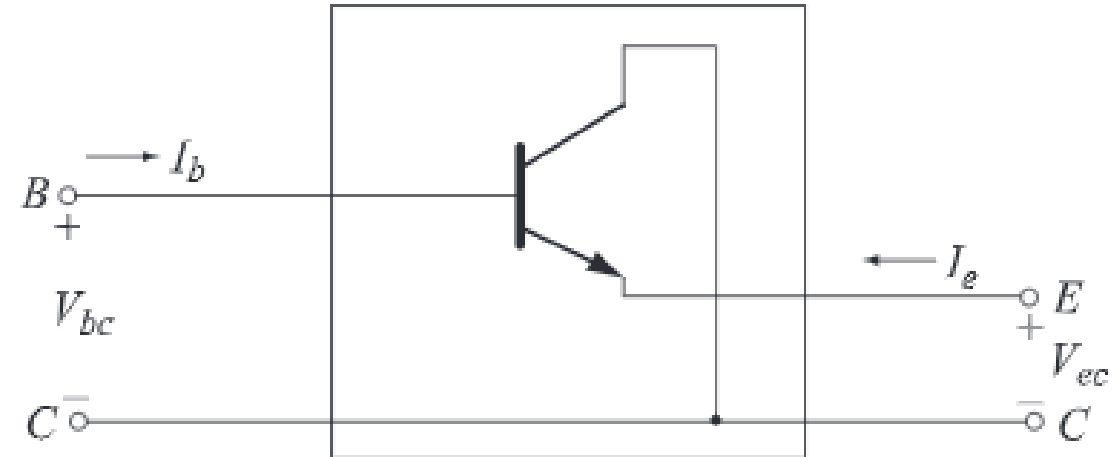
$$I_i = I_b$$

$$V_o = V_{ec}$$

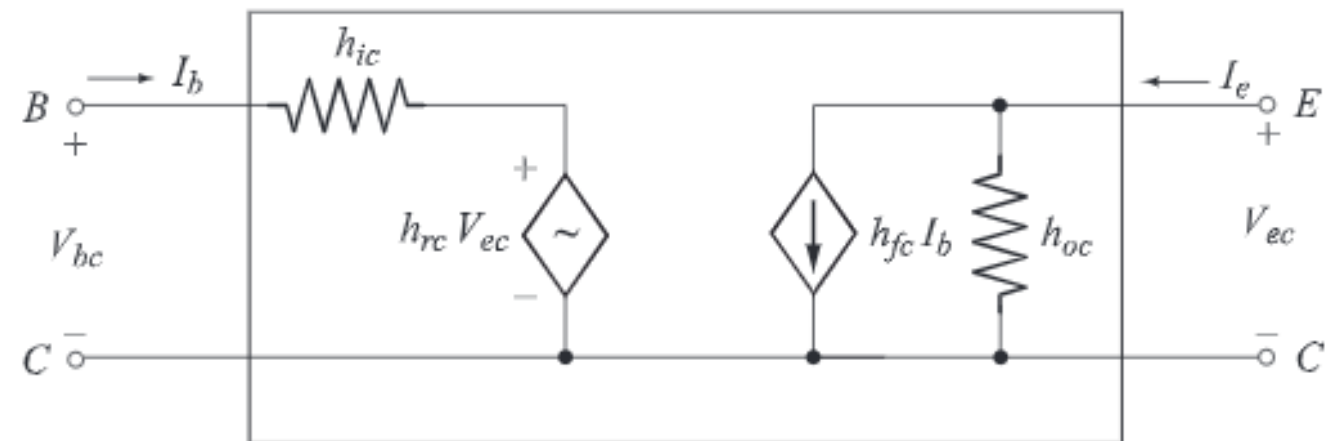
$$I_o = I_e$$

$$V_{bc} = h_{ic} * I_b + h_{rc} * V_{ec}$$

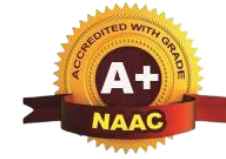
$$I_e = h_{fc} * I_b + h_{oc} * V_{ec}$$



Two port network of CC configuration



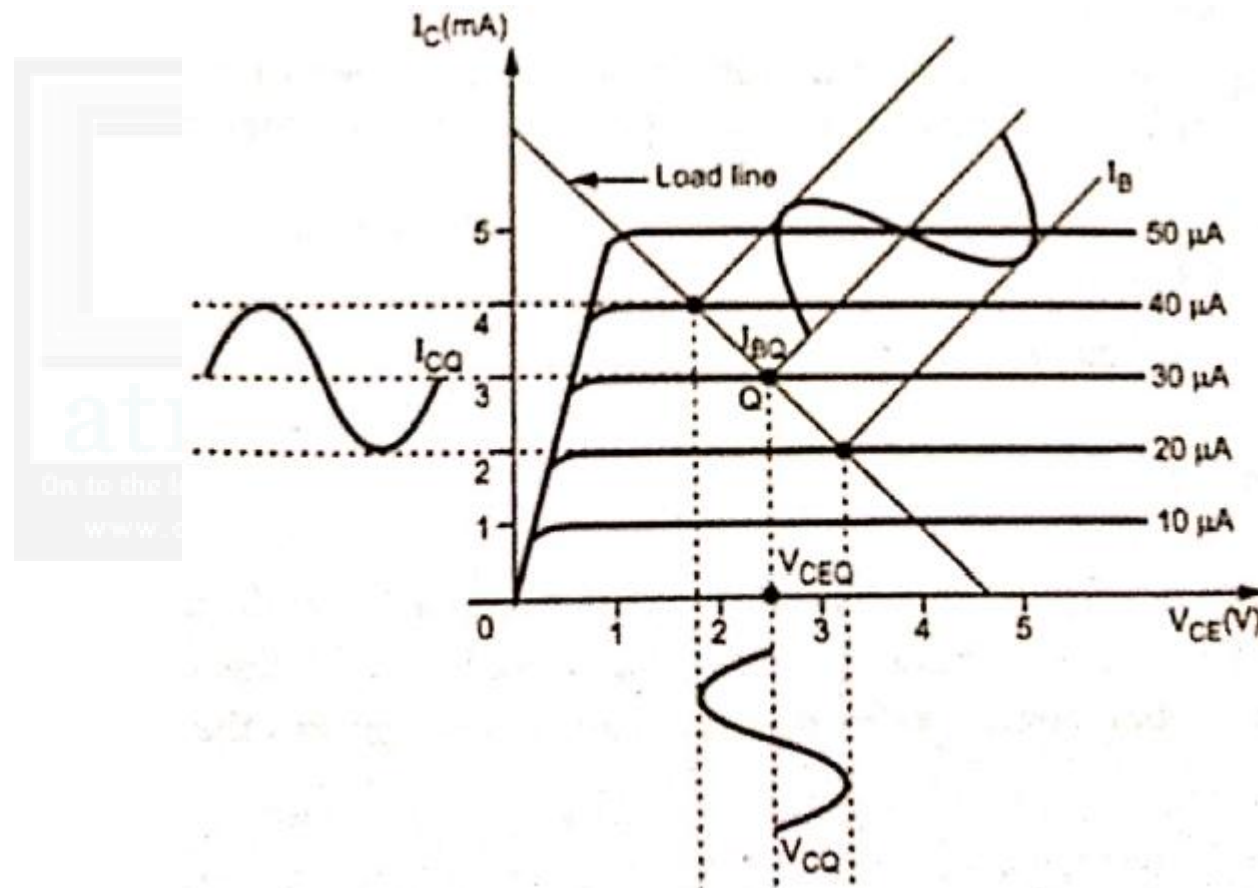
Hybrid equivalent circuit of CC configuration

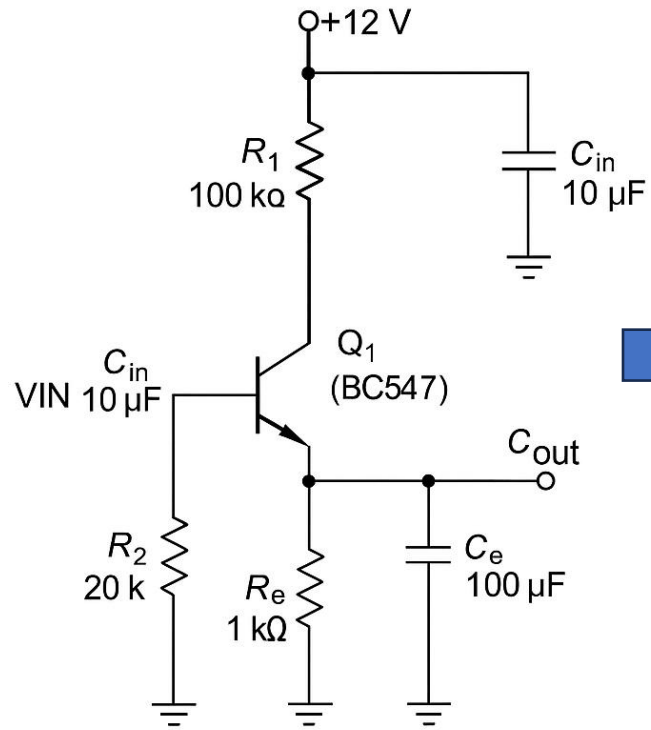


- Mid-band analysis of single stage amplifier,
- Simplified hybrid model,
- Analysis for CE, CB and CC(emitter voltage follower circuit) modes

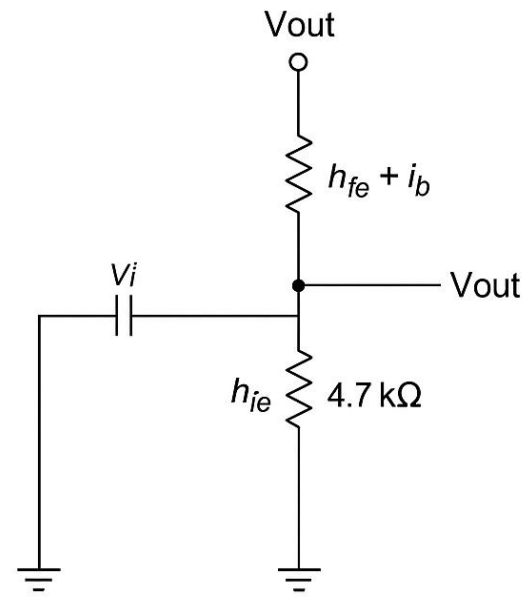
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Mid-band analysis of single stage amplifier





Practical single-stage
Common-Emitter amplifier
(before)



Mid-band small-signal
equivalent (after)

Mid-band analysis of single stage amplifier

Meaning

The **mid-band region** of a single-stage amplifier is the frequency range where:

- The **coupling** and **bypass capacitors** act like short circuits, and
- The **internal transistor capacitances** act like open circuits.

Hence, the **gain remains almost constant** (flat region of the frequency response).

Mid-band analysis of single stage amplifier

1. Coupling & Bypass Capacitors → Short Circuits:

At mid frequencies, their reactance $X_C = \frac{1}{2\pi fC}$ is very small, so they freely pass AC signals and don't affect gain.

2. Internal Transistor Capacitances → Open Circuits:

Their values are very small (pF range), so at mid frequencies their reactance is very high, making them ineffective (open) in the circuit.

Mid-band analysis of single stage amplifier

Component Type	Behavior in Mid-Band
Coupling Capacitors (C_{in} , C_{out})	Short circuit (no signal loss)
Bypass Capacitor (C_e)	Short circuit (emitter at AC ground)
Transistor Capacitances (C_{bc} , C_{be})	Open circuit (negligible effect)

Mid-band analysis of single stage amplifier

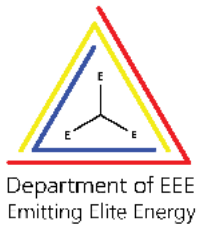
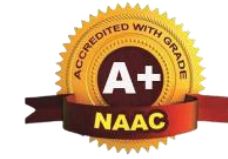
Equivalent AC Circuit

In the mid-frequency range:

- Capacitors are shorted,
- DC sources are grounded,
- The transistor is replaced by its small-signal hybrid- π or h-parameter model.



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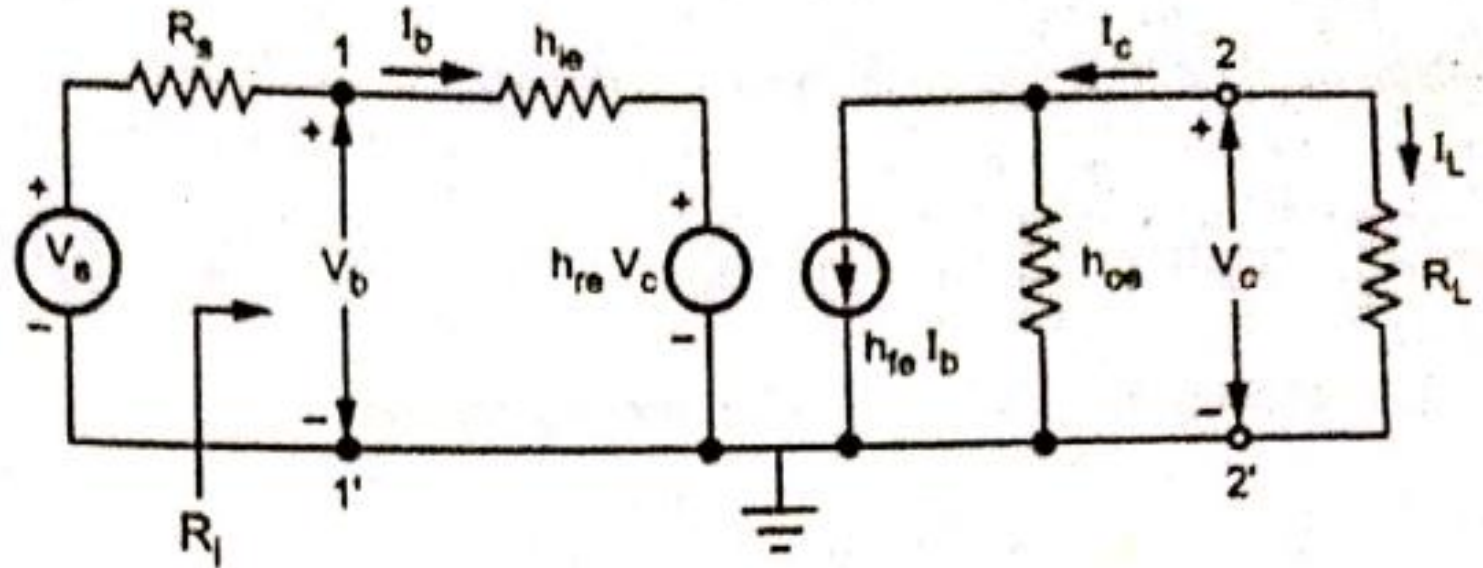
Hybrid model to find

- Current gain
- Input resistance
- Voltage gain
- Output resistance.

Common-Emitter using the **h-parameter model**

Current Gain

$$A_i = I_L / I_b$$



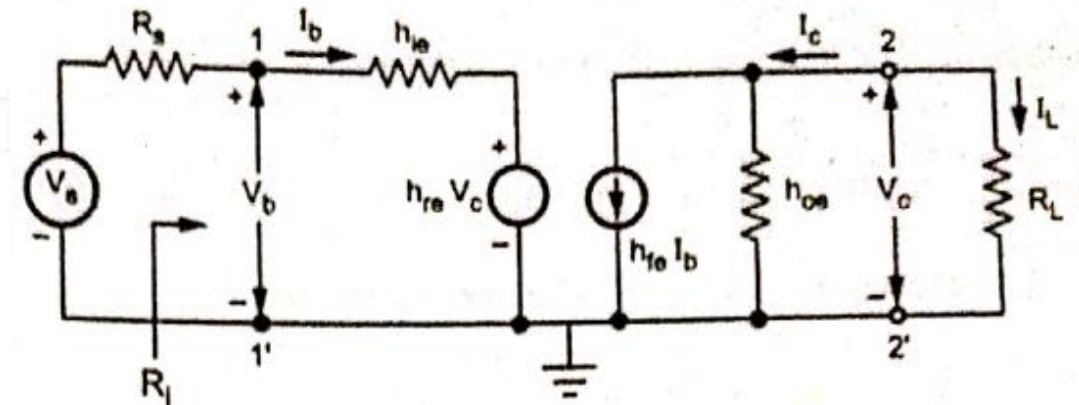
Common-Emitter using the **h-parameter model**

Current Gain

Step 1 — Write the small-signal h-parameter equations (two-port)

$$v_1 = h_{11} i_1 + h_{12} v_2,$$

$$i_2 = h_{21} i_1 + h_{22} v_2.$$



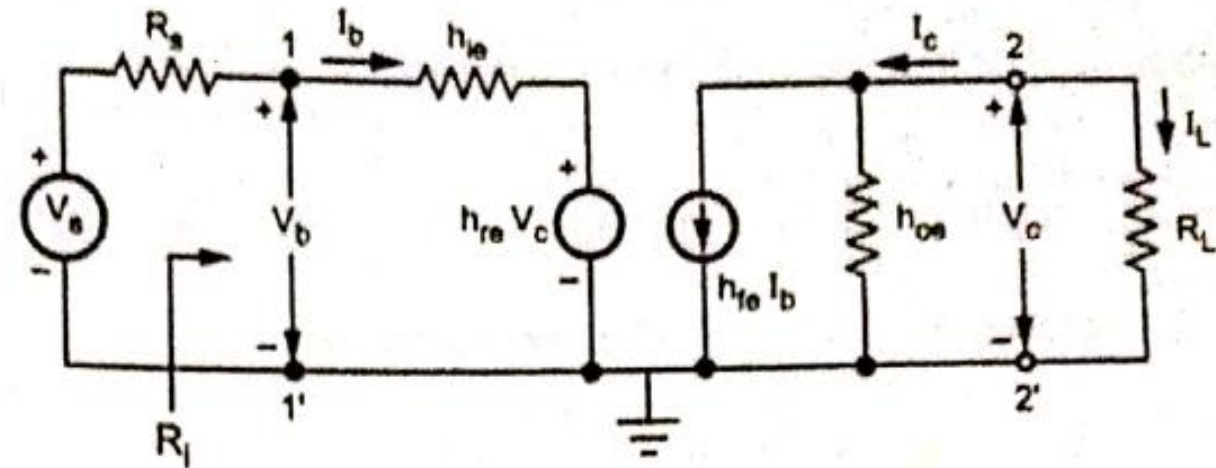
Common-Emitter using the **h-parameter model**

Current Gain

Step 2 — Express V_2 in terms of I_c using the load

By the chosen sign convention,

$$v_2 = V_C = -I_c R_L$$



Common-Emitter using the **h-parameter model**

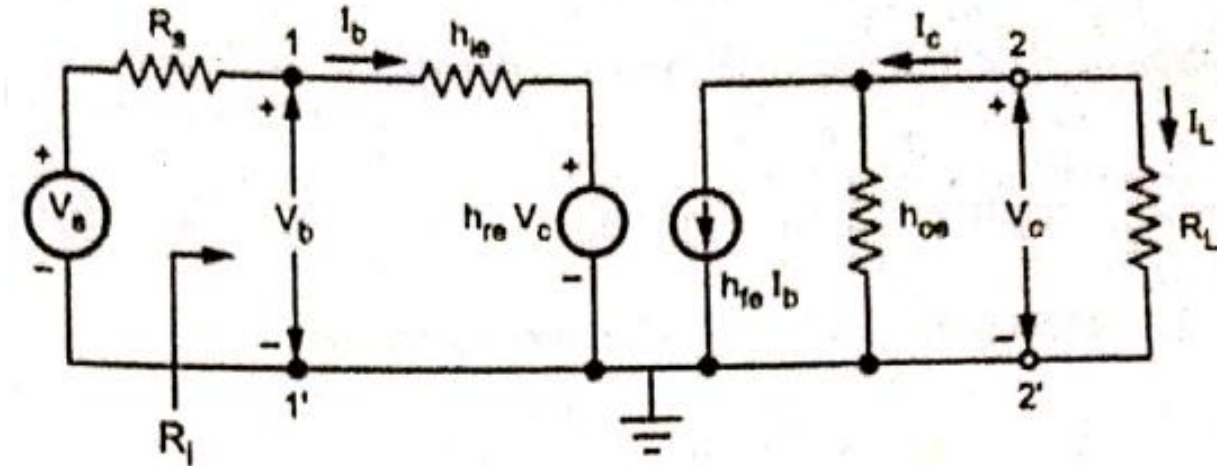
Current Gain

Step 3 — Substitute V_2 into the i_2 equation

$$I_c = h_{fe} I_b + h_{oe} v_2.$$

Substitute $v_2 = -I_c R_L$: to the leading edge
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$$I_c = h_{fe} I_b + h_{oe} (-I_c R_L).$$



Common-Emitter using the **h-parameter model**

Current Gain

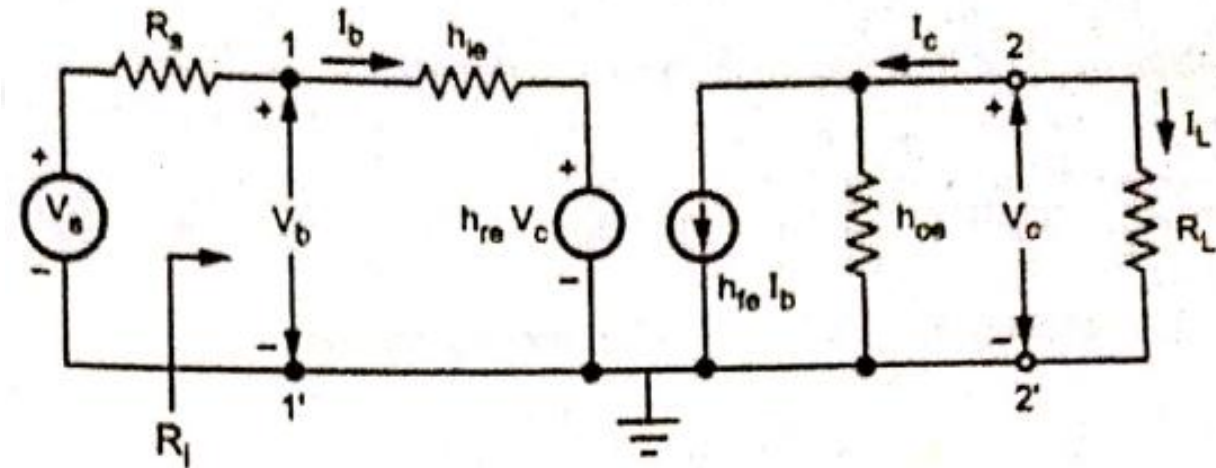
Step 4 — Rearrange to solve for $\frac{I_c}{I_b}$

Bring the I_c -terms to one side:

$$I_c + h_{oe} I_c R_L = h_{fe} I_b,$$

$$I_c (1 + h_{oe} R_L) = h_{fe} I_b.$$

$$\boxed{\frac{I_c}{I_b} = \frac{h_{fe}}{1 + h_{oe} R_L}}.$$



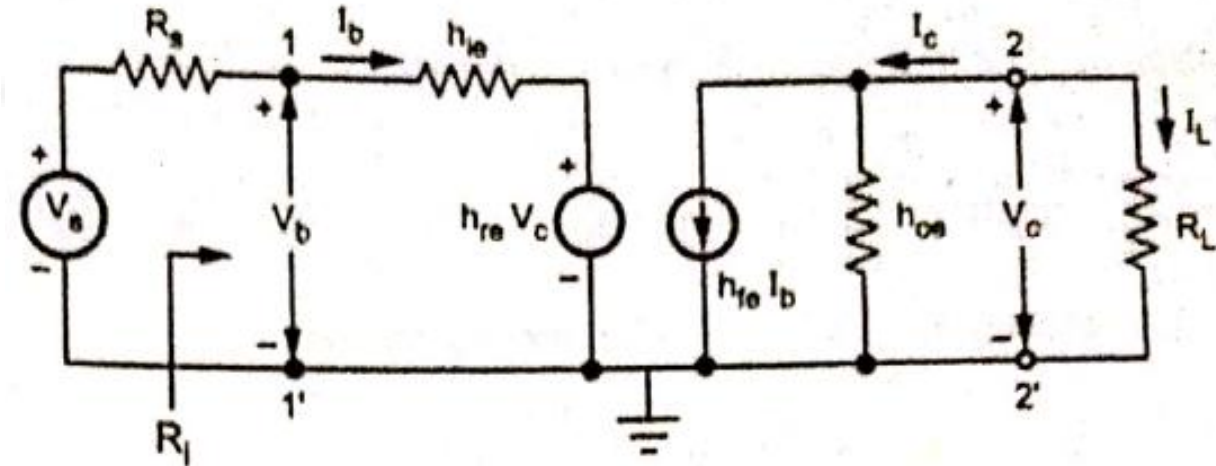
Common-Emitter using the **h-parameter model**

Current Gain

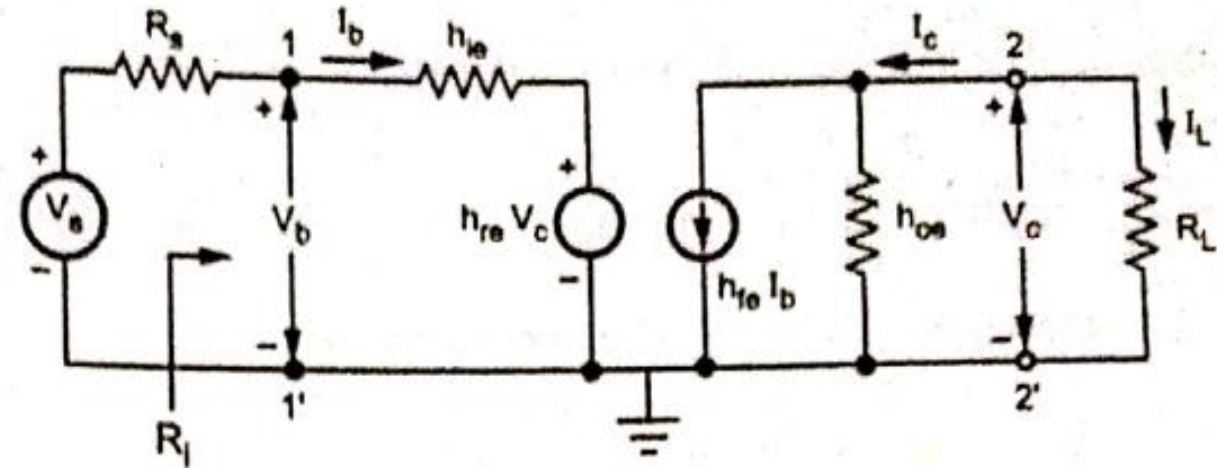
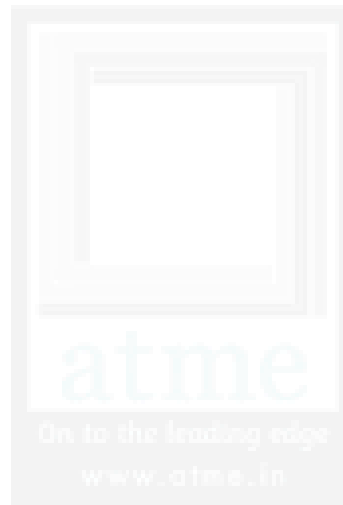
Step 5 — Relate load current I_L to I_c and get A_i

$$I_L = -I_c.$$

$$A_i = \frac{I_L}{I_b} = -\frac{I_c}{I_b} = -\frac{h_{fe}}{1 + h_{oe}R_L}$$



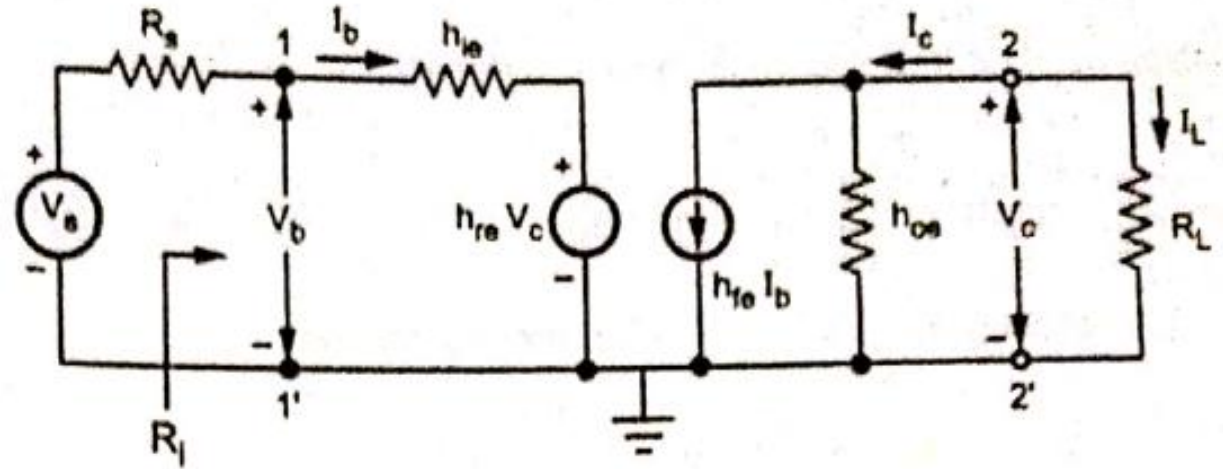
Input Resistance



Input Resistance

Step 1 — write v_1 in terms of i_1 and v_2

$$v_1 = h_{11}i_1 + h_{12}v_2$$



Step 2 — express v_2 in terms of i_1 using output equation + load

From $i_2 = h_{21}i_1 + h_{22}v_2$ and $v_2 = -R_L i_2$:

$$i_2(1 + h_{22}R_L) = h_{21}i_1 \Rightarrow i_2 = \frac{h_{21}}{1 + h_{22}R_L} i_1.$$

$$v_2 = -R_L i_2 = -\frac{h_{21} R_L}{1 + h_{22} R_L} i_1.$$

Step 3 — substitute v_2 into v_1 and form $Z_{\text{in}} = v_1 / i_1$

$$v_1 = h_{11} i_1 + h_{12} \left(-\frac{h_{21} R_L}{1 + h_{22} R_L} i_1 \right) = \left(h_{11} - \frac{h_{12} h_{21} R_L}{1 + h_{22} R_L} \right) i_1.$$

Thus

$$Z_{\text{in}} = \frac{v_1}{i_1} = h_{11} - \frac{h_{12} h_{21} R_L}{1 + h_{22} R_L}.$$

Voltage gain A_v

(A) Derive intrinsic gain $A_v = v_2/v_1$

Step 1 — solve for i_1 from the input equation

From $v_1 = h_{11}i_1 + h_{12}v_2$,

$$i_1 = \frac{v_1 - h_{12}v_2}{h_{11}}.$$

Step 2 — substitute i_1 into the output equation

$i_2 = h_{21}i_1 + h_{22}v_2$ so

$$i_2 = h_{21}\left(\frac{v_1 - h_{12}v_2}{h_{11}}\right) + h_{22}v_2 = \frac{h_{21}}{h_{11}}v_1 + \left(h_{22} - \frac{h_{12}h_{21}}{h_{11}}\right)v_2.$$

Voltage gain A_v

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$i_2 = h_{21}i_1 + h_{22}v_2$ so

$$i_2 = h_{21}\left(\frac{v_1 - h_{12}v_2}{h_{11}}\right) + h_{22}v_2 = \frac{h_{21}}{h_{11}}v_1 + \left(h_{22} - \frac{h_{12}h_{21}}{h_{11}}\right)v_2.$$

Step 3 — relate v_2 and i_2 through load

$v_2 = -R_L i_2$. Substitute the expression for i_2 :

$$v_2 = -R_L \left(\frac{h_{21}}{h_{11}} v_1 + \left(h_{22} - \frac{h_{12}h_{21}}{h_{11}} \right) v_2 \right).$$

Step 4 — collect v_2 -terms and solve for v_2/v_1

Bring the v_2 term on left:

$$v_2 \left[1 + R_L \left(h_{22} - \frac{h_{12}h_{21}}{h_{11}} \right) \right] = -R_L \frac{h_{21}}{h_{11}} v_1.$$

$$A_v = \frac{v_2}{v_1} = - \frac{\frac{h_{21}}{h_{11}} R_L}{1 + R_L \left(h_{22} - \frac{h_{12} h_{21}}{h_{11}} \right)}.$$

Step 5 — algebraically equivalent compact form

Multiply numerator and denominator by h_{11} to get another common form:

$$A_v = - \frac{h_{21} R_L}{h_{11} (1 + h_{22} R_L) - h_{12} h_{21} R_L}.$$

$$Y_o = \frac{i_2}{v_2} \text{ with } v_1 = 0$$

Step 1 — set $v_1 = 0$ in the input equation

From $0 = h_{11}i_1 + h_{12}v_2$,

$$i_1 = -\frac{h_{12}}{h_{11}} v_2.$$

Step 2 — substitute i_1 into i_2

From $i_2 = h_{21}i_1 + h_{22}v_2$,

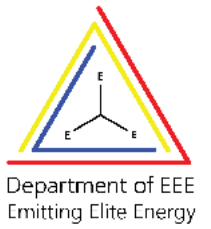
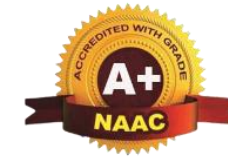
$$i_2 = h_{21} \left(-\frac{h_{12}}{h_{11}} v_2 \right) + h_{22} v_2 = \left(h_{22} - \frac{h_{12}h_{21}}{h_{11}} \right) v_2.$$

Step 3 — form Y_o and R_o

$$Y_o = \frac{i_2}{v_2} = h_{22} - \frac{h_{12}h_{21}}{h_{11}}.$$



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And the corresponding output resistance

$$R_o = \frac{1}{Y_o} = \frac{1}{h_{22} - \frac{h_{12}h_{21}}{h_{11}}}.$$



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$$A_i = -\frac{h_{fe}}{1 + h_{oe}R_L}$$

Current gain of CE amplifier

$$Z_{in} = h_{ie} - \frac{h_{re}h_{fe}R_L}{1 + h_{oe}R_L}$$

Input resistance looking into base of CE

$$A_v = -\frac{h_{fe}R_L}{h_{ie}(1 + h_{oe}R_L) - h_{re}h_{fe}R_L}$$

Voltage gain between collector and base

$$Y_o = h_{oe} - \frac{h_{re}h_{fe}}{h_{ie}}$$

Output admittance seen at collector with input shorted

Parameter

Common Emitter (CE)

Current Gain A_i

$$A_i = \frac{-h_{fe}}{1 + h_{oe}R_L}$$

Input Resistance Z_{in}

$$Z_{in} = h_{ie} - \frac{h_{re}h_{fe}R_L}{1 + h_{oe}R_L}$$

Voltage Gain A_v

$$A_v = \frac{-h_{fe}R_L}{h_{ie}(1 + h_{oe}R_L) - h_{re}h_{fe}R_L}$$

Output Admittance Y_o

$$Y_o = h_{oe} - \frac{h_{re}h_{fe}}{h_{ie}}$$

Common Base (CB)

$$A_i = \frac{1 + h_{fe}}{1 + h_{oe}R_L}$$

$$Z_{in} = \frac{h_{ie}(1 + h_{oe}R_L) - h_{re}h_{fe}R_L}{(1 + h_{fe})(1 + h_{oe}R_L)}$$

$$A_v = \frac{(1 + h_{fe})R_L}{h_{ie}(1 + h_{oe}R_L) - h_{re}(1 + h_{fe})R_L}$$

$$Y_o = h_{oe} - \frac{h_{re}(1 + h_{fe})}{h_{ie}}$$

Common Collector (CC)

$$A_i = \frac{h_{fe}}{1 + h_{oe}R_L}$$

$$Z_{in} = h_{ie}(1 + h_{fe})$$

$$A_v = \frac{R_L}{R_L + h_{ie}(1 + h_{fe})}$$

$$Y_o = h_{oe}$$

Advantages of h-parameters

1. Universally applicable:

The h-parameter model can represent any transistor configuration — Common Emitter (CE), Common Base (CB), or Common Collector (CC) — simply by changing the parameter subscripts.

2. Experimentally measurable:

Each h-parameter can be directly obtained from input/output voltage and current measurements without knowing the internal transistor structure.

3. Linear two-port representation:

Transistors are nonlinear devices, but h-parameters allow a linear small-signal equivalent around the operating (Q) point, making analysis much easier.

4. Simplifies AC analysis:

The model converts the transistor into a standard two-port network, enabling use of circuit analysis techniques like Thevenin, Norton, and superposition.



5. Requires few parameters:

Only four parameters (h_{ie} , h_{re} , h_{fe} , h_{oe}) are needed, reducing complexity while providing accurate small-signal behavior.

6. Relates directly to measurable quantities:

h -parameters are defined in terms of terminal voltages and currents, so they correspond to real, measurable circuit values.

7. Convenient for amplifier design and comparison:

Amplifiers using different transistors or configurations can be easily compared in terms of gain, input, and output resistance using the same framework.

8. Useful for hybrid and simulation models:

Forms the basis for modern small-signal models (like hybrid- π and T-models) and is compatible with circuit simulation programs.

1. For the transistor connected in CE configuration, determine A_v , A_i , R_i & R_o using complete hybrid equivalent model.

$R_L = R_S = 1k\Omega$, $h_{ie} = 1k\Omega$, $h_{re} = 2 \times 10^{-4}$, $h_{fe} = 100$, $h_{oe} = 20 \mu A/V$.

1. Current Gain

$$A_i = \frac{-h_{fe}}{1 + h_{oe} * R_L}$$

$$A_i = \frac{-100}{1 + 20 * 10^{-6} * 1k} = -98$$

2. Input resistance

$$R_i = h_{ie} + h_{re} * A_i * R_L$$

$$R_i = 1k + 2 \times 10^{-4} * -98 * 1k = 980.4 \Omega$$

3. Voltage Gain

$$A_v = \frac{A_i R_L}{R_i}$$

$$A_v = \frac{-98 * 1k}{980.4} = -99.9$$

4. Output resistance

$$Y_O = h_{oe} - \frac{h_{fe}h_{re}}{R_S + h_{ie}}$$

$$Y_O = 20\mu - \frac{100 * 2 * 10^{-4}}{1k + 1k} = 1 \times 10^{-5}$$

$$R_O = \frac{1}{Y_O}$$

$$R_O = \frac{1}{1 \times 10^{-5}} = 100k\Omega$$

2. A voltage source of negligible internal resistance drives a common collector transistor amplifier. The load resistance is $2.5k\Omega$. Determine A_v , A_i , R_i & R_o using complete hybrid equivalent model. $h_{ic} = 1k\Omega$, $h_{rc} = 1$, $h_{fc} = -50$, $h_{oc} = 25 \mu A/V$.

1. Current Gain

$$A_i = \frac{-h_{fc}}{1 + h_{oc} * R_L}$$

$$A_i = \frac{-(-50)}{1 + 25 * 10^{-6} * 2.5k} = 47$$

2. Input resistance

$$R_i = h_{ic} + h_{rc} * A_i * R_L$$

$$R_i = 1k + 1 * 47 * 2.5k = 118.5k\Omega$$

3. Voltage Gain

$$A_v = \frac{A_i R_L}{R_i}$$

$$A_v = \frac{47 * 2.5k}{118.5k} = 0.99156$$

4. Output resistance

$$Y_o = h_{oc} - \frac{h_{fc}h_{rc}}{R_S + h_{ie}}$$

$$Y_o = 25\mu - \frac{-50 * 1}{1k} = 0.050025$$

$$R_o = \frac{1}{Y_o}$$

$$R_o = \frac{1}{0.050025} = 19.99\Omega$$

3. Consider a single stage CE amplifier with $R_L = 1.2 \text{ k}\Omega$ and $R_S = 1 \text{ k}\Omega$. Calculate A_i , R_i , A_v , A_{vs} , A_{is} and R_o if, $h_{ie} = 1.1 \text{ k}\Omega$, $h_{re} = 2.5 \times 10^{-4}$, $h_{fe} = 50$, $h_{oe} = 25 \text{ }\mu\text{A/V}$.

1. Current Gain

$$A_i = \frac{-h_{fe}}{1 + h_{oe} * R_L}$$

$$A_i = \frac{-50}{1 + 25 * 10^{-6} * 1.2k} = -48.54$$

2. Input resistance

$$R_i = h_{ie} + h_{re} * A_i * R_L$$

$$R_i = 1.1k + 2.5 * 10^{-4} * -48 * 54 * 1.2k = 1085.44 \text{ }\Omega$$

3. Voltage Gain

$$A_v = \frac{A_i R_L}{R_i}$$

$$A_v = \frac{-48.54 * 1.2k}{1085.44} = -53.663$$

$$A_{vs} = \frac{A_v R_i}{R_i + R_S}$$

$$A_{vs} = \frac{-53.663 * 1085.44}{1085.44 + 1000} = -27.93$$

$$A_{is} = \frac{A_i R_S}{R_i + R_S}$$

$$A_{is} = \frac{-48.54 * 1000}{1085.44 + 1000} = -23.28$$

Output resistance

$$Y_o = h_{oe} - \frac{h_{fe} h_{re}}{R_S + h_{ie}}$$

$$Y_o = 25\mu - \frac{50 * 2.5 * 10^{-4}}{1k + 1.2k} = 19 * 10^{-6}$$

$$R_o = \frac{1}{Y_o}$$

$$R_o = \frac{1}{19 * 10^{-6}} = 52.6 k\Omega$$

4. For the common base circuit shown, the transistor parameters are $h_{ib} = 22 \Omega$, $h_{rb} = 2.9 \times 10^{-4}$, $h_{fb} = -0.98$, $h_{oe} = 0.49 \mu A/V$. Calculate A_i , R_i , A_v , and R_o .

1. Current Gain

$$A_i = \frac{-h_{fb}}{1 + h_{ob} * R_L^1}$$

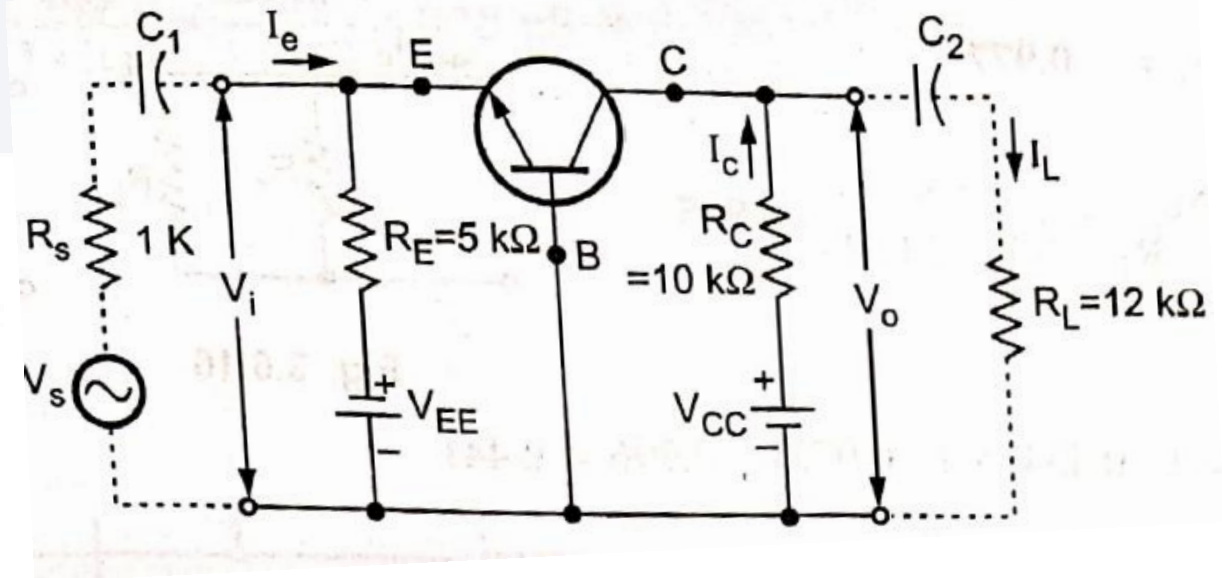
$$R_L^1 = R_C \parallel R_L = 10k \parallel 12k = 5.45 k\Omega.$$

$$A_i = \frac{-(-0.98)}{1 + 0.49 * 10^{-6} * 5.45k} = 0.977$$

2. Input resistance

$$R_i = h_{ib} + h_{rb} * A_i * R_L^1$$

$$R_i = 22 + 2.9 * 10^{-4} * 0.977 * 5.45k = 23.54 \Omega$$



$$R_i^1 = R_i \parallel R_S = 23.54 \parallel 5k = 23.43 \Omega.$$

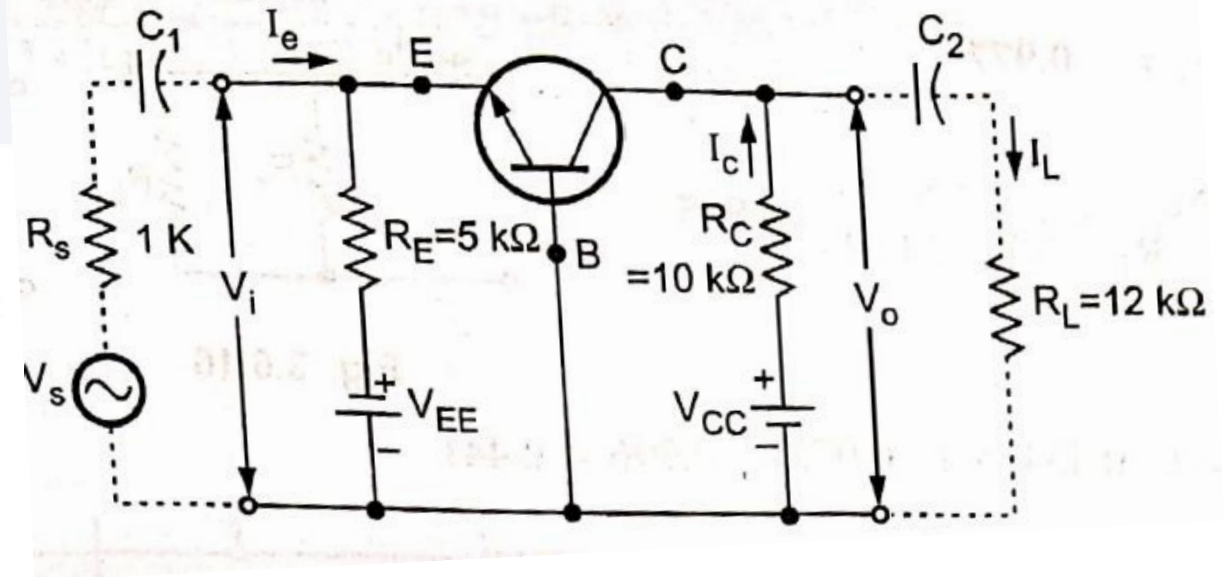
3. Voltage Gain

$$A_V = \frac{A_i R_L^1}{R_i}$$

$$A_V = \frac{0.977 * (5.45k)}{23.54} = 226$$

$$A_{VS} = \frac{V_o}{V_s} = \frac{V_o}{V_e} * \frac{V_e}{V_s}$$

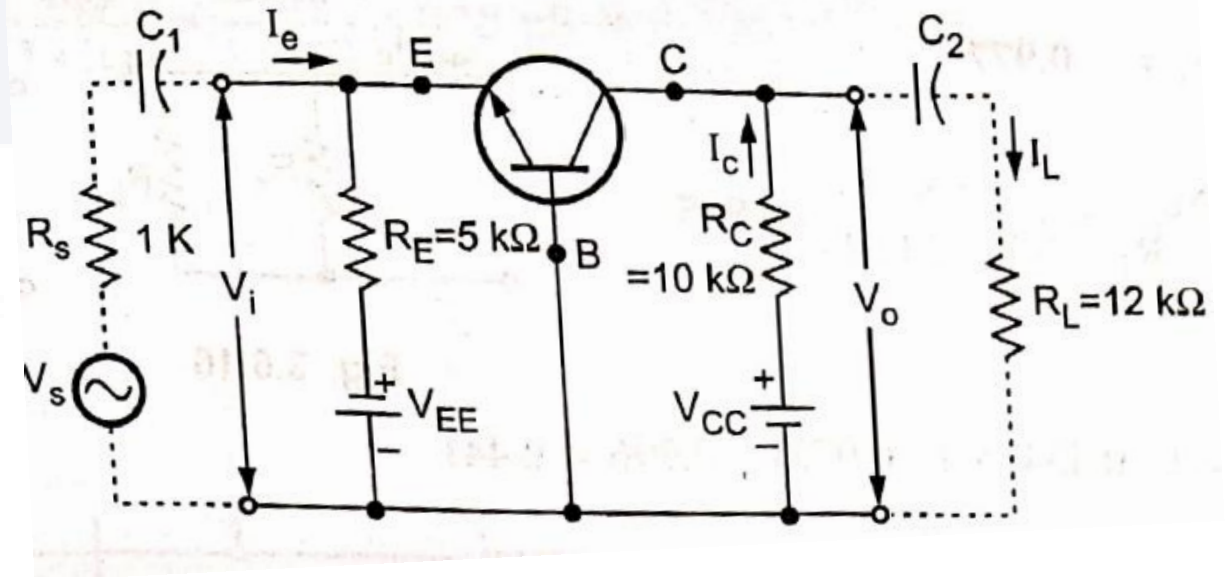
$$\frac{V_o}{V_e} = A_V \quad \frac{V_e}{V_s} = \frac{R_i^1}{R_i^1 + R_s}$$



3. Voltage Gain

$$A_{VS} = \frac{V_o}{V_s} = A_V * \frac{R_i^1}{R_i^1 + R_s}$$

$$A_{VS} = \frac{V_o}{V_s} = 226 * \frac{23.43}{23.43 + 1k} = 5.174$$



4. Overall Current Gain

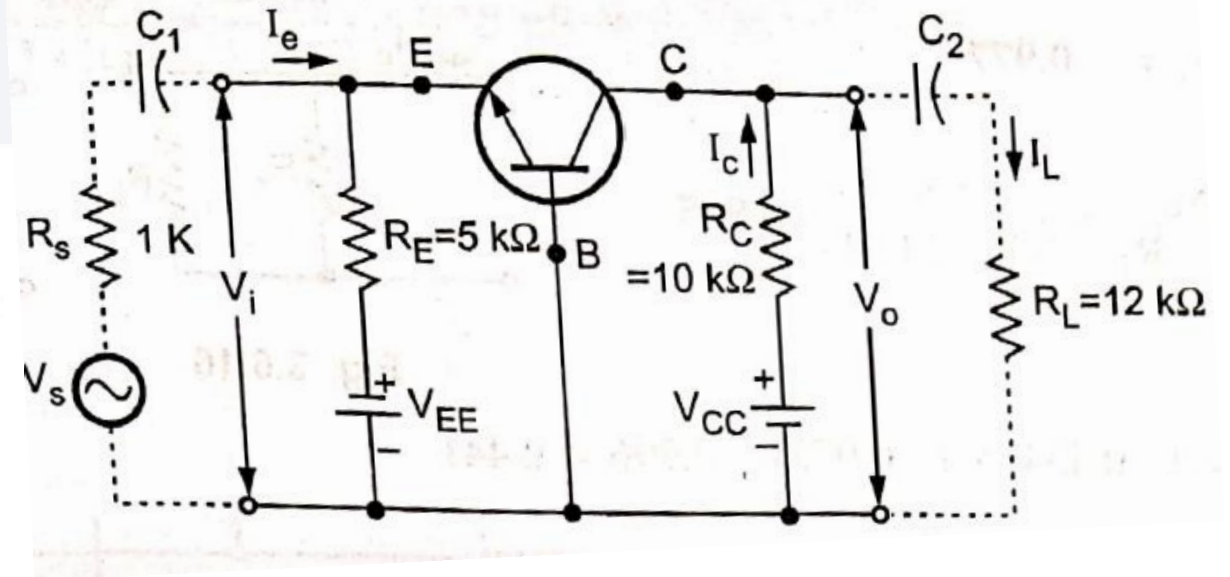
$$A_{iS} = \frac{I_L}{I_S} = \frac{I_L}{I_C} * \frac{I_C}{I_e} * \frac{I_e}{I_S}$$

$$\frac{I_L}{I_C} = -\frac{R_C}{R_C + R_L} = -\frac{10k}{10k + 12k} = -0.454$$

$$\frac{I_C}{I_e} = -A_i = -0.977$$

$$\frac{I_e}{I_S} = \frac{R_E}{R_E + R_i} = \frac{5k}{5k + 23.54} = 0.995$$

$$A_{iS} = (-0.454) * (-0.977) * (0.995) = 0.441$$



Output resistance

$$Y_O = h_{ob} - \frac{h_{fb}h_{rb}}{R_S^1 + h_{ib}}$$

$$R_S^1 = R_S \parallel R_E = 1k \parallel 5k = 833.33$$

$$Y_O = 0.49\mu - \frac{-0.98 * 2.9 * 10^{-4}}{833.33 + 22} = 0.826\mu$$

$$R_O = \frac{1}{Y_O}$$

$$R_O = \frac{1}{0.826\mu} = 1.21 M\Omega$$

$$R_O^1 = R_O \parallel R_L^1 = 1.21 M \parallel 5.45k = 5.425k\Omega$$