IIT ROORKEE

NPTEL ONLINE CERTIFICATION COURSE

# Microelectronics: Devices to Circuits

## BJT as an Amplifier, small circuit Model

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# Outline

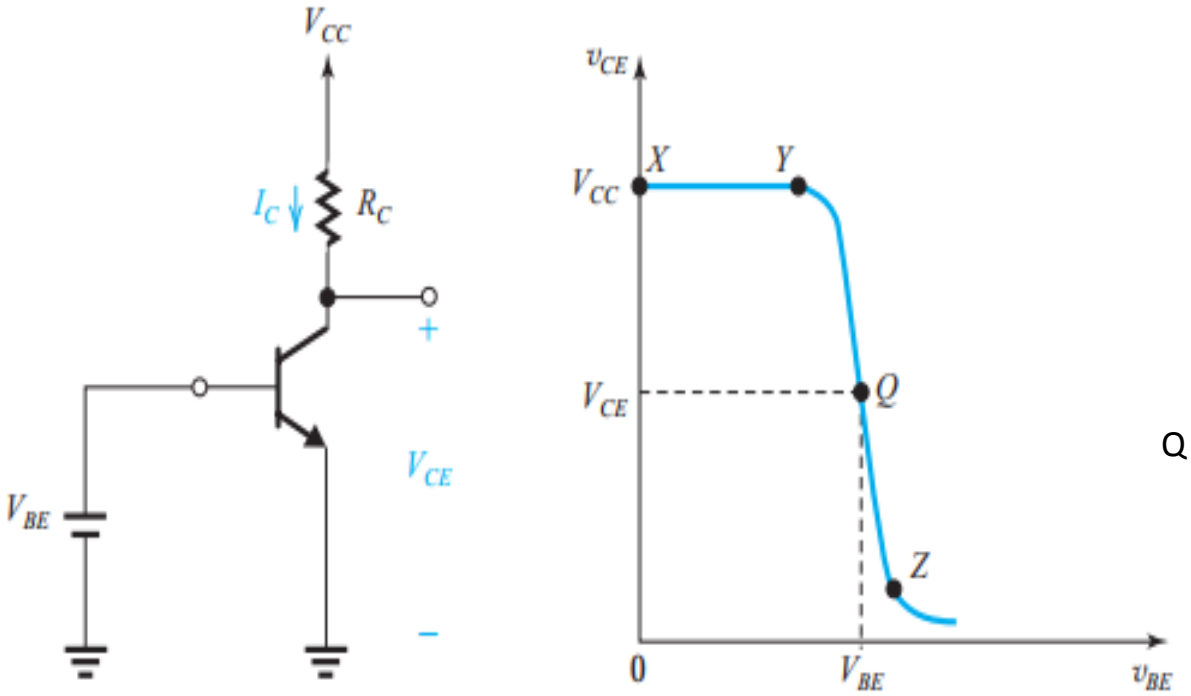
- BJT as an Amplifier
- Biasing of the BJT to obtain linear amplification
- Determining the VTC by graphical analysis
- Amplifier gain
- Small-signal operation and Model
- Hybrid-π Model
- T Model
- Common –emitter configuration
- Common –emitter configuration with emitter resistance
- Common –base Amplifier
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- Recapitulation

# BJT as an amplifier

- BJT acts as an amplifier in active mode.
- BJT acts as a voltage –controlled current source .
- Changes in the base-emitter voltage $v_{BE}$ give rise to changes in the collector current $i_C$.
- The active mode of BJT can be used to implement a trans-conductance amplifier.
- Voltage amplification can be obtained simply by passing the collector current through a resistance $R_C$.

Source: Microelectronics Circuits, Sedra and Smith, Fifth edition

# Biasing of the BJT to obtain linear amplification

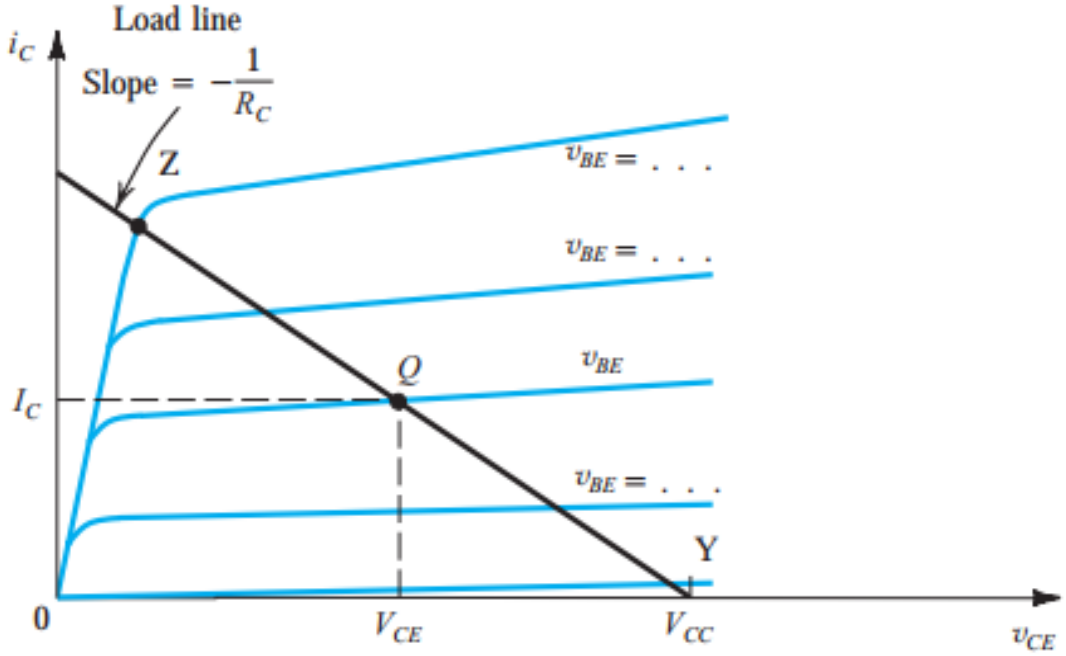



Q is the bias point

Fig.1. Biasing the BJT amplifier at a point Q located on the active mode segment on the VTC

Source: Microelectronics Circuits, Sedra and Smith, Fifth edition

# Determining the VTC by graphical analysis




$$i_C = \frac{V_{CC}}{R_C} - \frac{1}{R_c} v_{CE}$$

Fig.2. Graphical construction for determining the VTC of the amplifier circuit

Source: Microelectronics Circuits, Sedra and Smith, Fifth edition

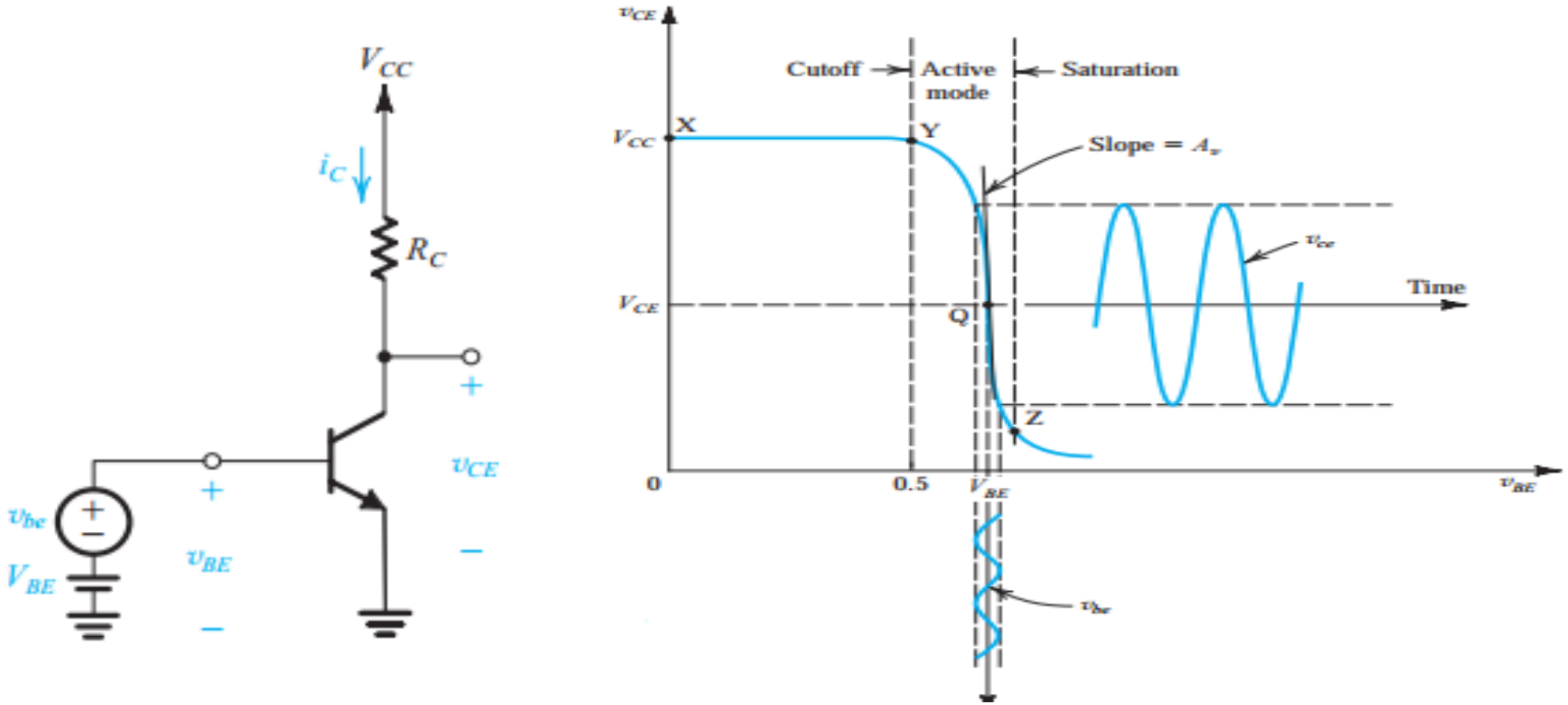



Fig.3. Basic common –emitter amplifier circuit and transfer characteristics of the circuit

Source: Microelectronics Circuits, Sedra and Smith, Fifth edition

- The most commonly used BJT amplifier is common- emitter circuit.
- The total input voltage $v_I$ (bias+ signal) is applied between base and emitter $v_{BE} = v_I$ .
- The output voltage $v_0$ (bias + signal) is taken between collector and ground $v_0 = v_{CE}$ .
- The resistor $R_C$ has two functions.
  1) Establish dc bias voltage at the collector.
  2) Convert the collector signal current $i_C$ to an output voltage $v_0$.

Source: Microelectronics Circuits, Sedra and Smith, Fifth edition

$$v_0 = v_{CE} = V_{CC} - R_C i_C$$

$$i_C = I_S e^{\frac{v_{BE}}{v_T}}$$

$$I_{Csat} = \frac{V_{CC} - V_{CEsat}}{R_C}$$

$$i_C = I_S e^{\frac{v_I}{v_T}} \qquad v_{BE} = v_I$$

$$v_0 = V_{CC} - R_C I_S e^{\frac{v_I}{v_T}}$$

- In saturation region $v_{CE} = V_{CEsat}$, falls in the range of 0.1 V to 0.2 V.

Source: Microelectronics Circuits, Sedra and Smith, Fifth edition

# Amplifier Gain

- To operate the BJT as a linear amplifier, it must be biased at a point in the active region.
- The signal to be amplified, Vi is superimposed on $V_{BE}$ .

$$I_C = I_S e^{\frac{v_{BE}}{v_T}} \qquad v_{BE} = v_I$$

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

$$A_v = \frac{d v_o}{d v_I} \Big| v_I = V_{BE}$$

$$A_v = -\frac{1}{V_T} I_S e^{\frac{V_{BE}}{V_T}} R_C$$

Source: Microelectronics Circuits, Sedra and Smith, Fifth edition

$$A_v = -\frac{I_C R_C}{V_T} = -\frac{V_{RC}}{V_T}$$

$$V_{RC} = V_{CC} - V_{CE}$$

$V_{RC}$ Is the dc voltage drop across $R_C$

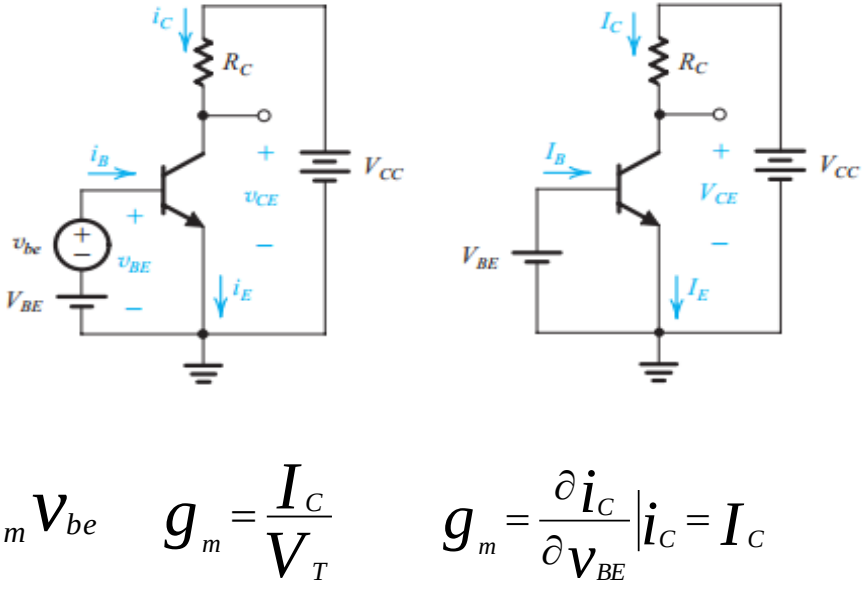
- Maximum gain at the edge of saturation.

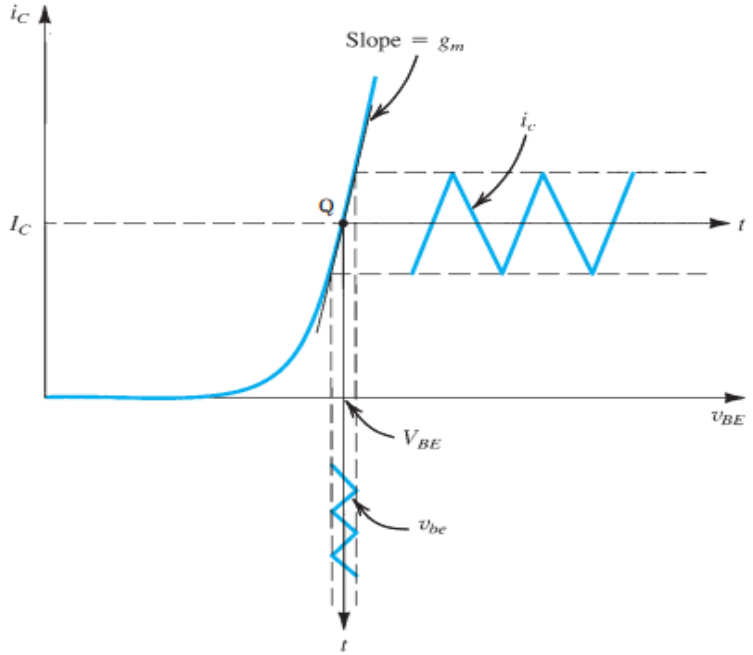
$$A_v = -\frac{V_{CC} - V_{CEsat}}{V_T} \qquad A_{v\max} = -\frac{V_{CC}}{V_T}$$

- The gain is negative, which signifies that the amplifier is inverting.
- The gain is proportional to the collector bias current $I_C$ and the load resistance $R_C$.

Source: Microelectronics Circuits, Sedra and Smith, Fifth edition

# Small-signal operation and Model




$$i_C = g_m v_{be} \qquad g_m = \frac{I_C}{V_T} \qquad g_m = \frac{\partial i_C}{\partial v_{BE}} \Big| i_C = I_C$$

gm is the trans-conductance of the amplifier

Fig.4. Operation of transistor as an amplifier and linear operation of amplifier under the small signal - condition

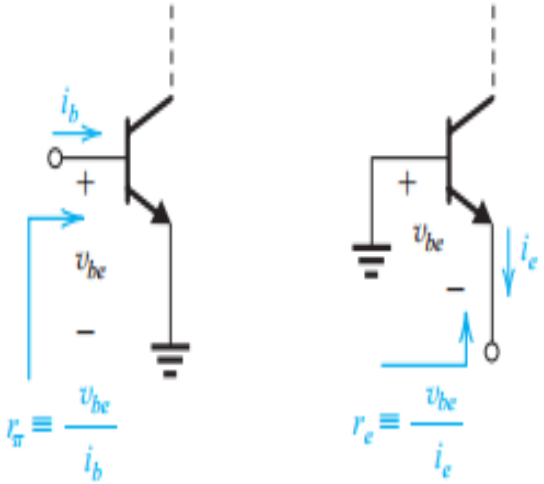
Source: Microelectronics Circuits, Sedra and Smith, Fifth edition

- Small-signal input resistance between base and emitter, looking into the base denoted by $r_\pi$ .
- Small-signal input resistance between base and emitter, looking into the emitter denoted by $r_e$ .

$$r_\pi = \frac{v_{be}}{i_b} \qquad r_e = \frac{v_{be}}{i_e}$$

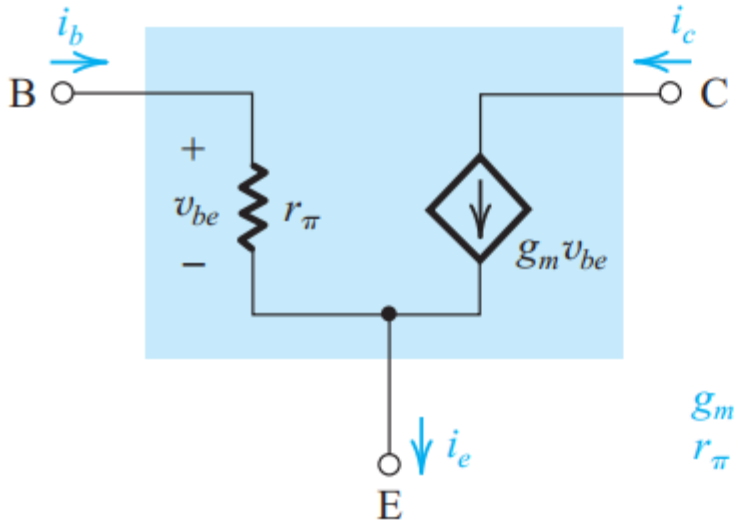
$$r_\pi = \frac{\beta}{g_m} \qquad r_e = \frac{V_T}{I_E} \qquad r_\pi = (\beta+1) r_e$$

$$r_\pi = \frac{V_T}{I_B} \qquad r_e = \frac{1}{g_m}$$




Source: Microelectronics Circuits, Sedra and Smith, Fifth edition

# Hybrid-π Model




$$g_m = I_C / V_T$$
$$r_\pi = \beta / g_m$$

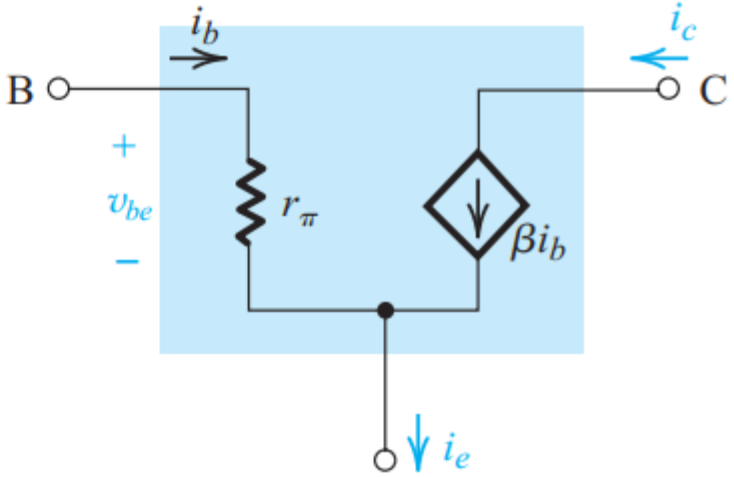
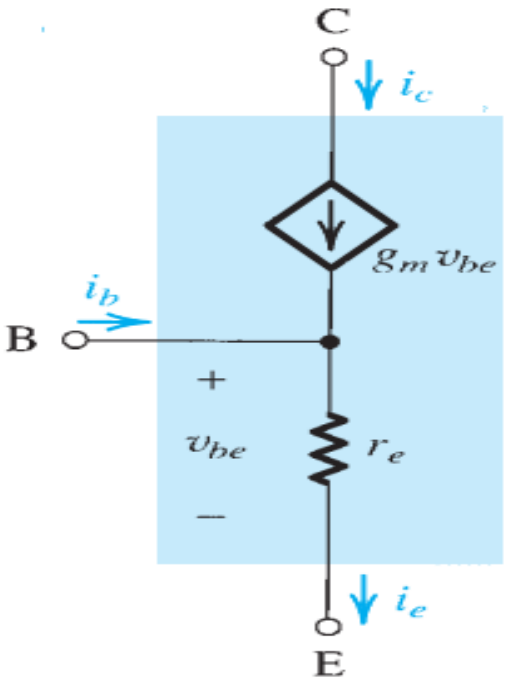



Fig.5. Hybrid –π model for the small signal operation of BJT.

Source: Microelectronics Circuits, Sedra and Smith, Fifth edition

# T- Model




$$g_m = I_C / V_T$$

$$r_e = \frac{V_T}{I_E} = \frac{\alpha}{g_m}$$

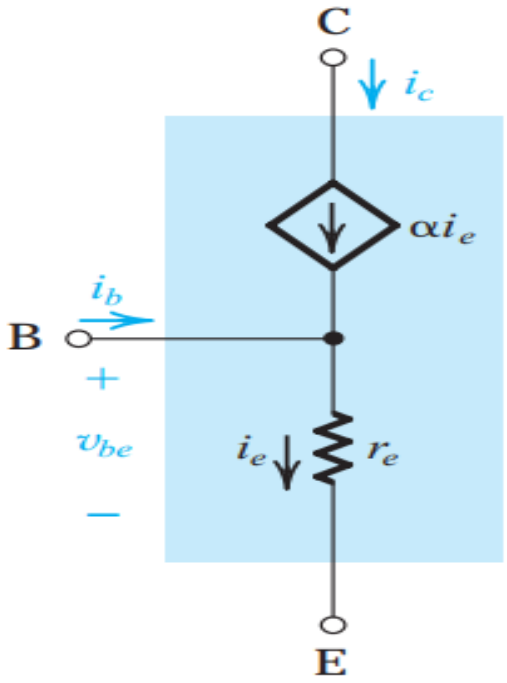
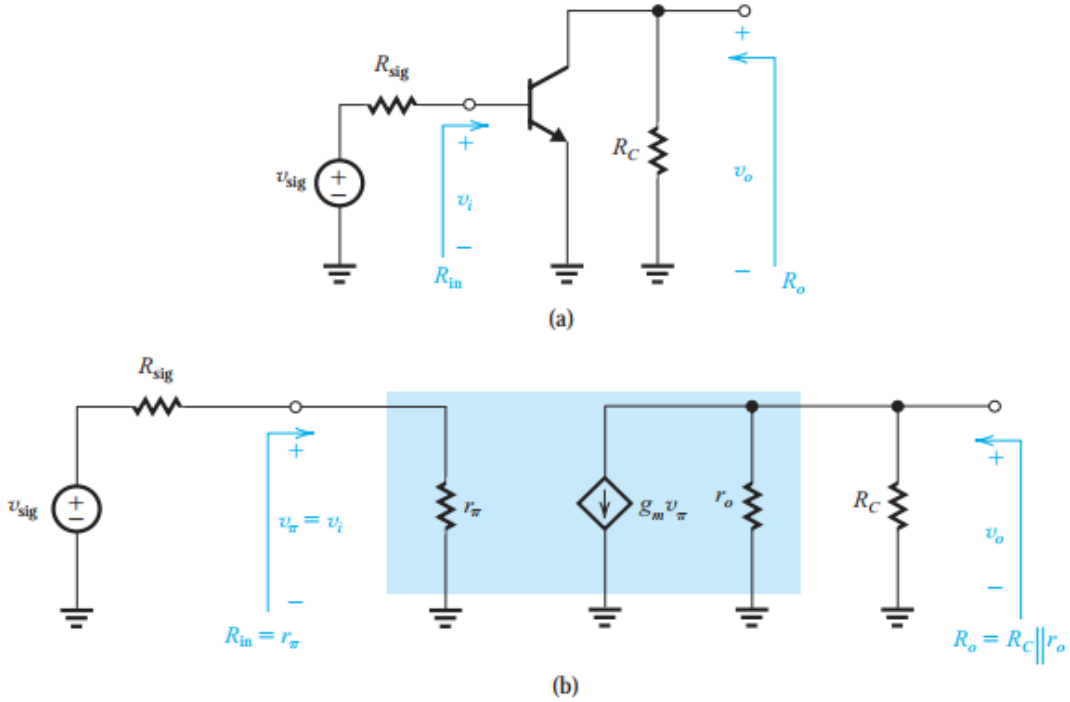



Fig.6. T model for the small signal operation of BJT.

Source: Microelectronics Circuits, Sedra and Smith, Fifth edition

# Common –emitter configuration




$$R_{in} = r_\pi$$

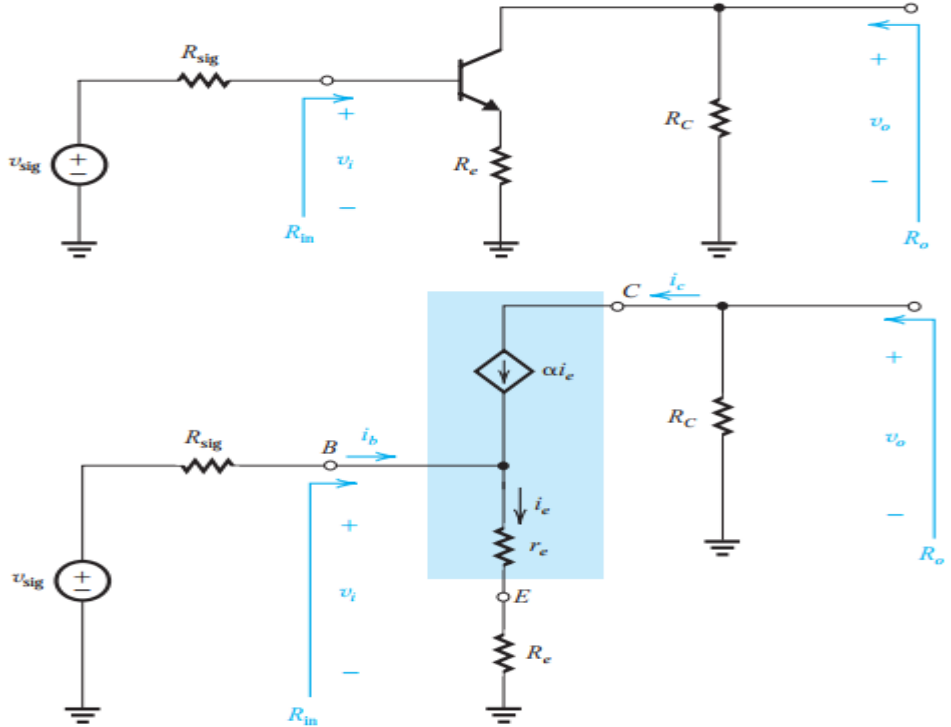
$$v_o = -(g_m v_\pi)(R_C \| r_o)$$

$$R_0 = (R_C \| r_o)$$

Fig.7. Common –emitter amplifier

Source: Microelectronics Circuits, Sedra and Smith, Fifth edition

# Common –emitter configuration with emitter resistance




$$R_{in} = (\beta + 1)(r_e + R_e)$$

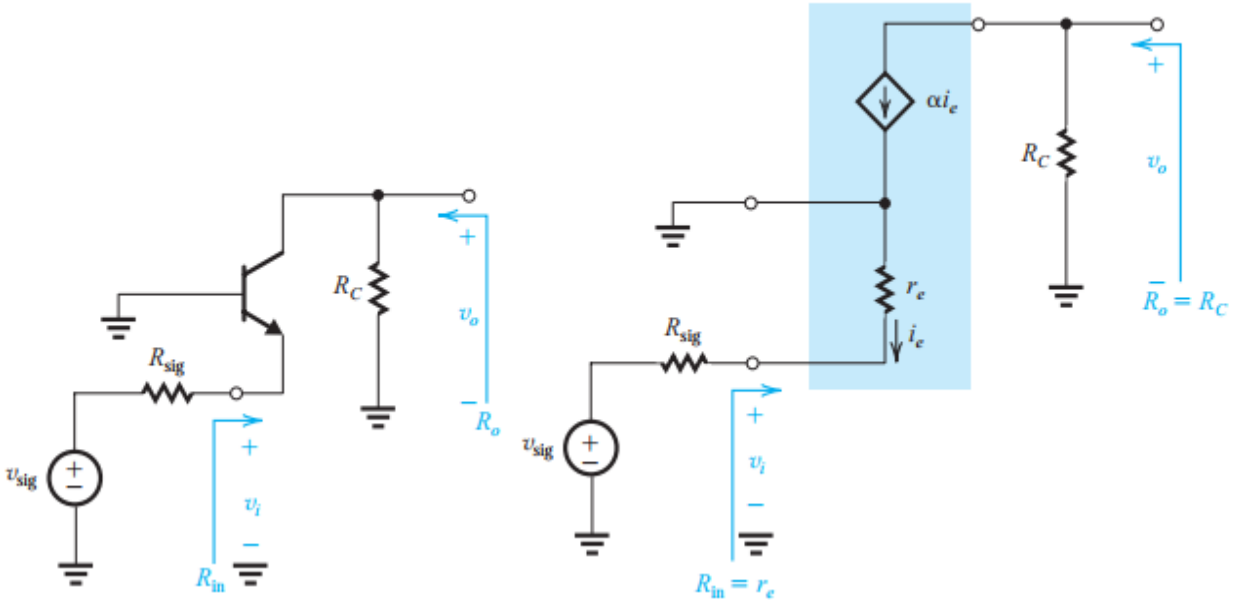
$$A_{vo} = -\frac{g_m R_C}{1 + g_m R_e}$$

$$R_0 = R_C$$

Fig.7. Common –emitter amplifier with emitter resistance

Source: Microelectronics Circuits, Sedra and Smith, Fifth edition

# Common –base Amplifier




$$R_{in} = r_e$$

$$A_{vo} = g_m R_C$$

$$R_o = R_C$$

Fig.7. Common –base amplifier

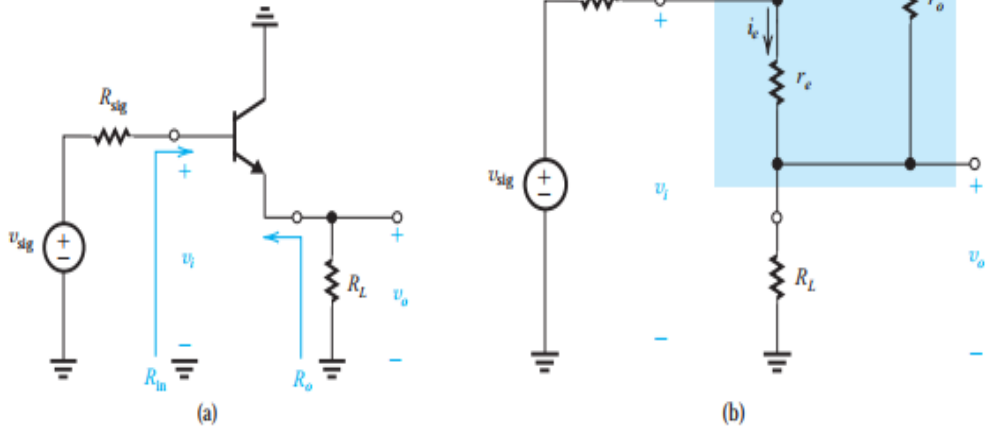
Source: Microelectronics Circuits, Sedra and Smith, Fifth edition

# Common –collector Amplifier or emitter follower

$$R_{in} = (\beta + 1)(r_e + R_L)$$

$$R_o = r_e$$

$$A_{vo} = 1$$



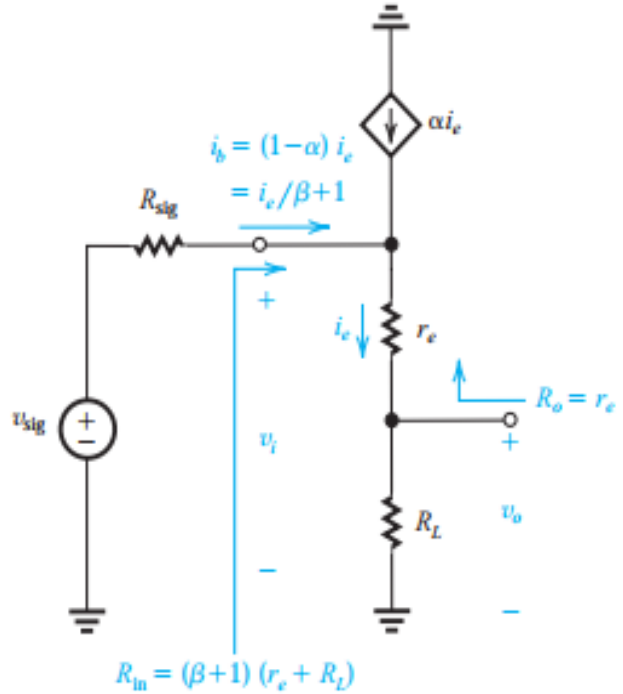




Fig.7. Common –collector amplifier

Source: Microelectronics Circuits, Sedra and Smith, Fifth edition

# Recapitulation

- The CE configuration is the one best suited for realizing the bulk of gain required in an amplifier.
- The CB amplifier use as a high frequency amplifier due to low input resistance.
- The emitter follower finds application as a voltage buffer for connecting a high source to a low-resistance load.

Source: Microelectronics Circuits, Sedra and Smith, Fifth edition

# Thank You