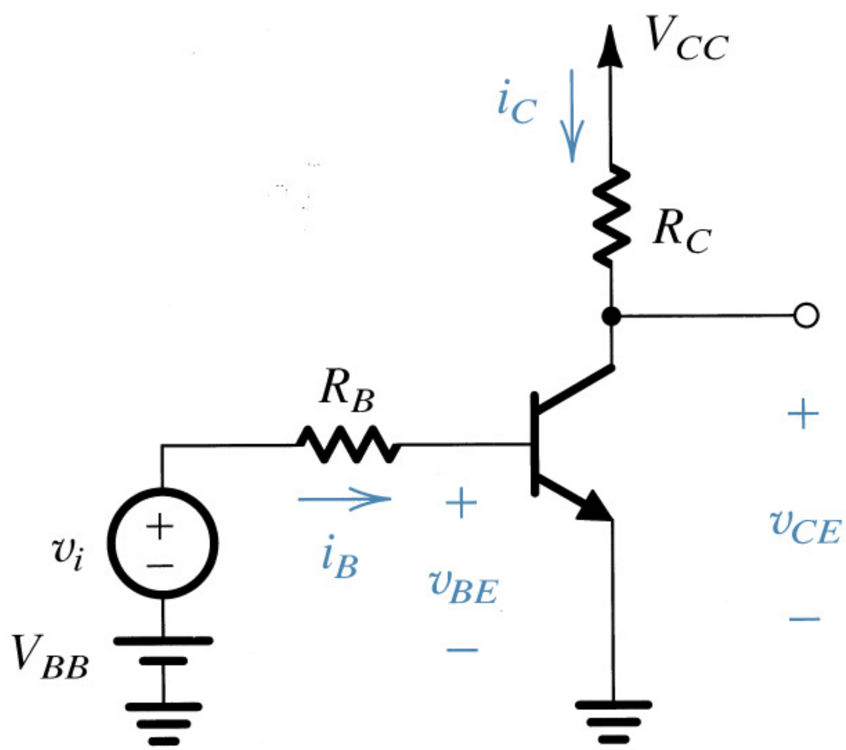
Faculty of Engineering

ECE 334: Electronic Circuits

Lecture 4:
BJT Small Signal Analysis

Example: Graphical Analysis



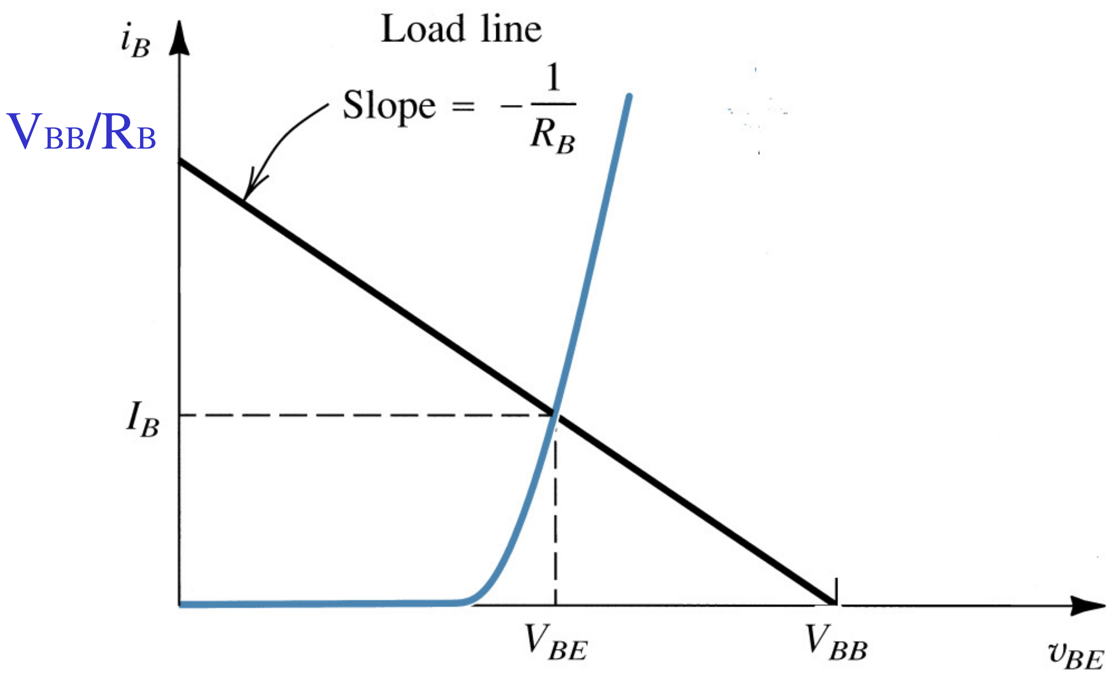
Input circuit

B-E voltage loop

$V_{BB} = I_B R_B + V_{BE}$

$I_B = (V_{BB} - V_{BE})/R_B$

Graphical construction of I_B and V_{BE}

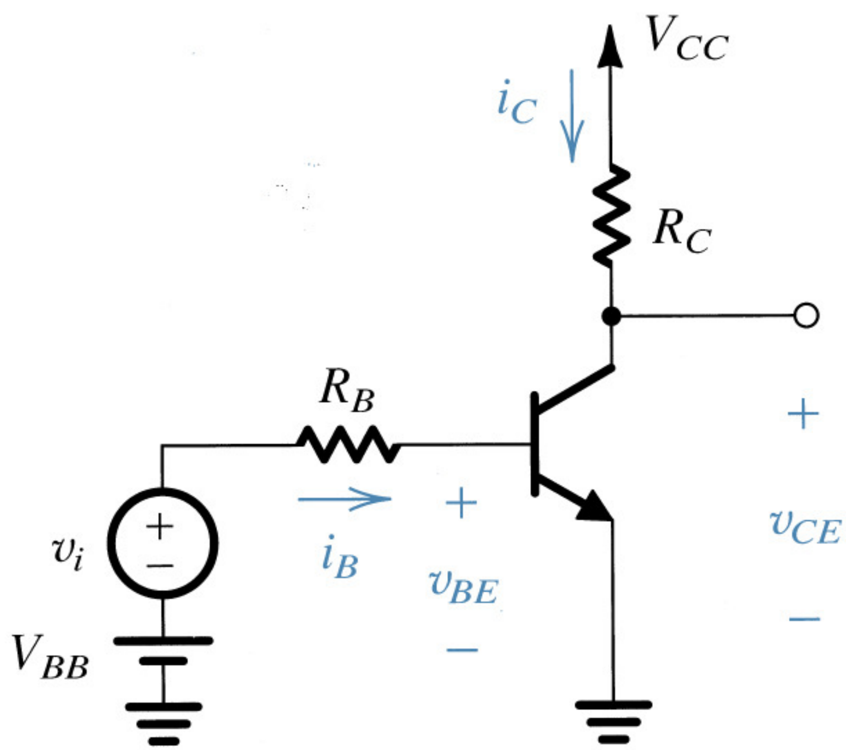


$I_B = (V_{BB} - V_{BE})/R_B$

If $V_{BE} = 0$, $I_B = V_{BB}/R_B$

If $I_B = 0$, $V_{BE} = V_{BB}$

Load Line



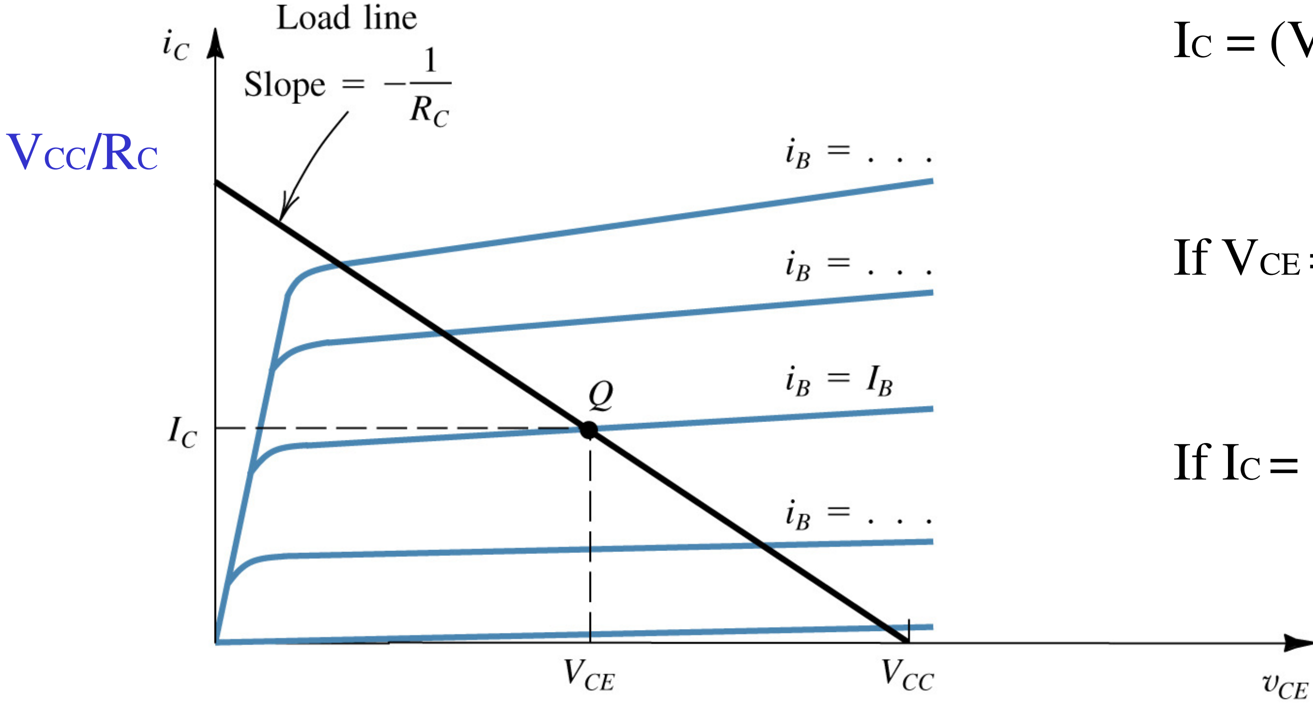
<u>Output circuit</u>

C-E voltage loop

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

$I_C = (V_{CC} - V_{CE})/R_C$

Graphical Construction of I_C and V_{CE}

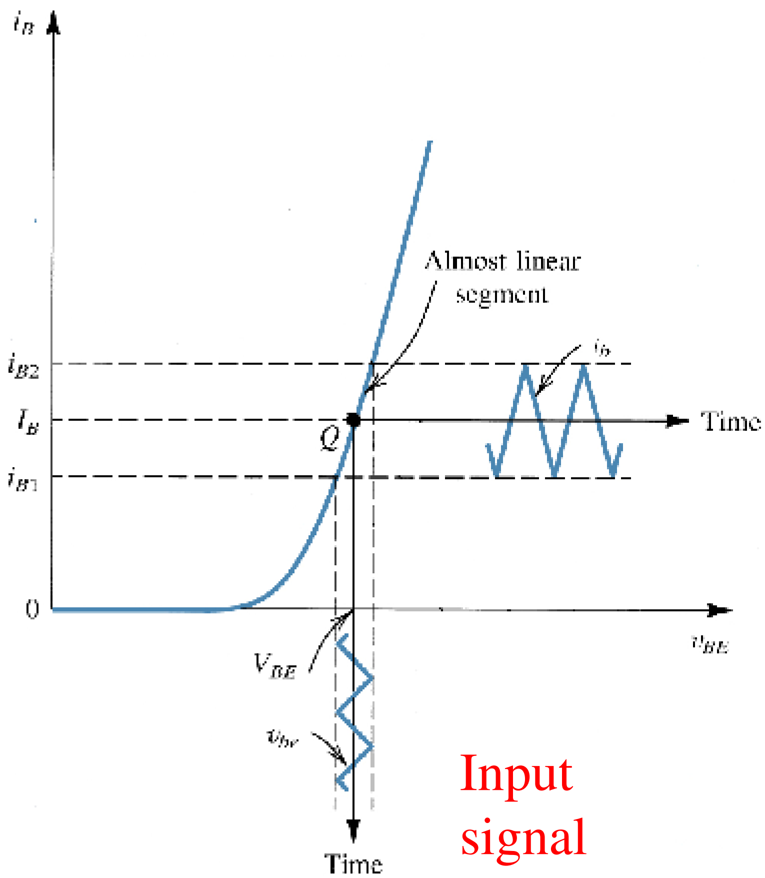


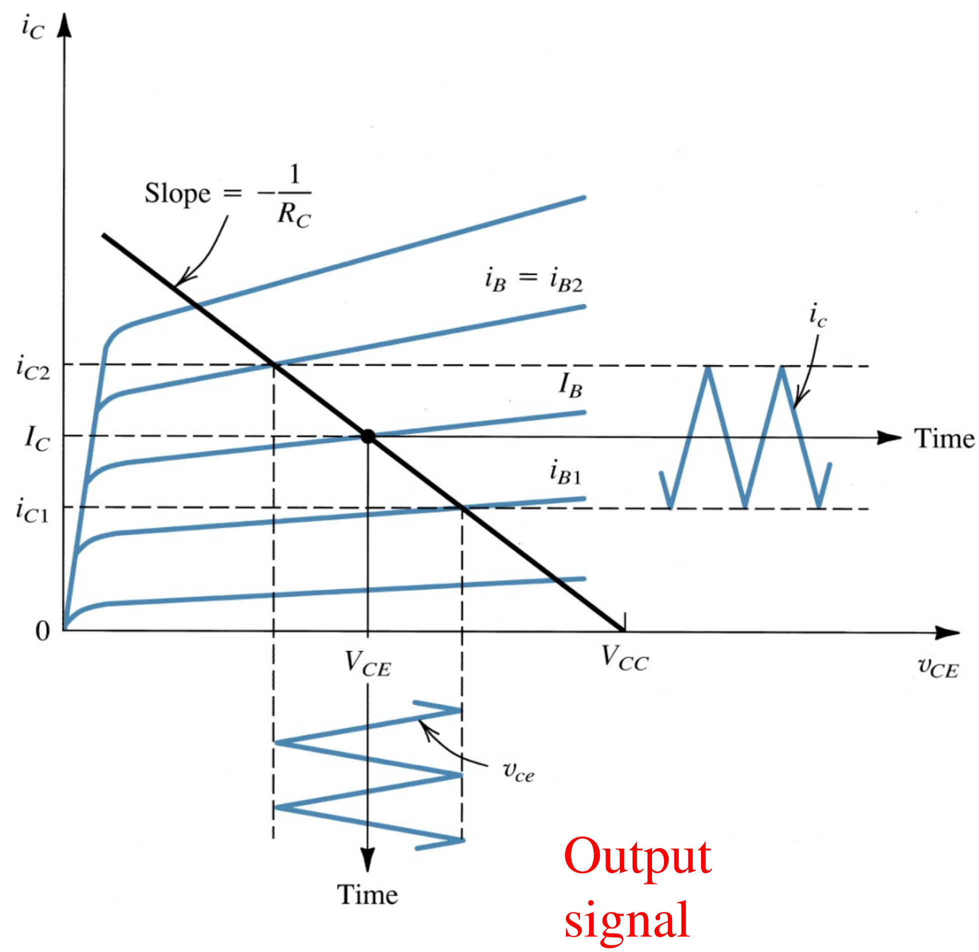
$I_C = (V_{CC} - V_{CE})/R_C$

If $V_{CE} = 0$, $I_C = V_{CC}/R_C$

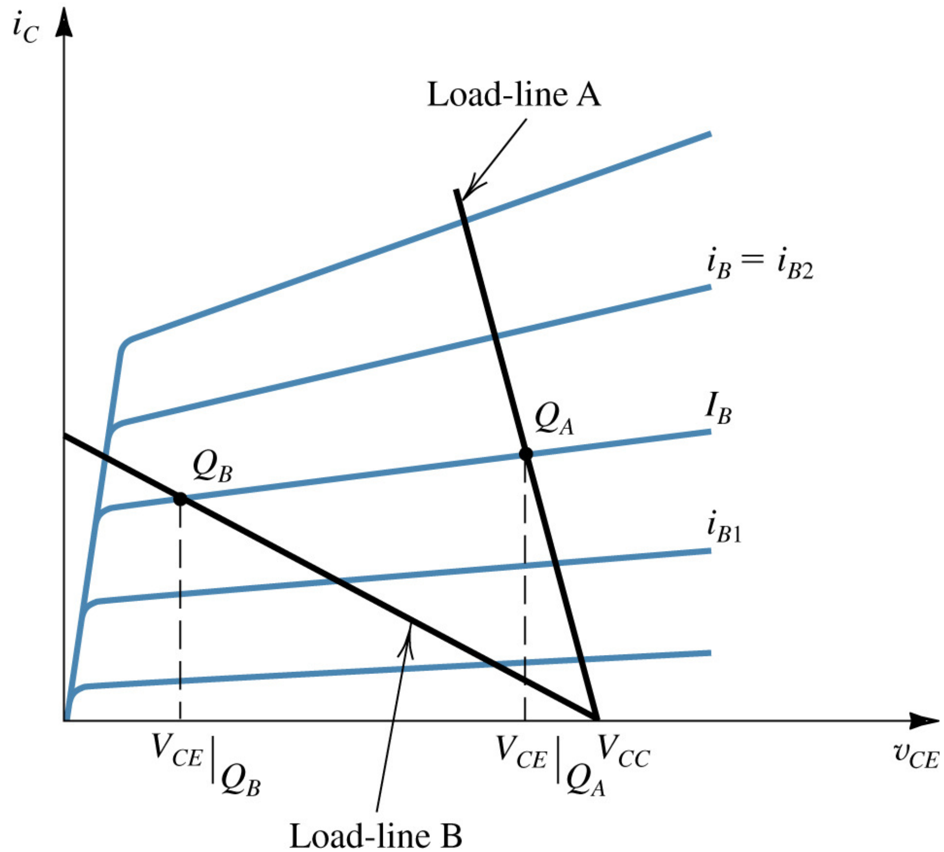
If $I_C = 0$, $V_{CE} = V_{CC}$

Graphical Analysis





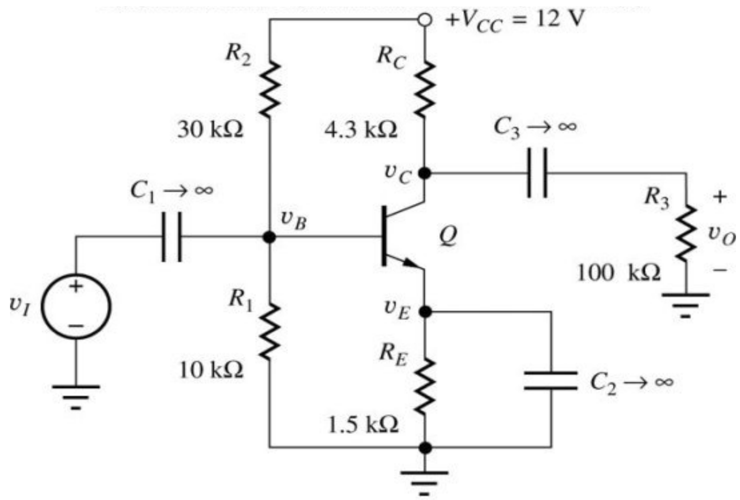
Bias Point Location Effects



•Load-line A results in bias point Q_A which is too close to V_{CC} and thus limits the positive swing of v_{CE}.

•Load-line B results in an operating point too close to the saturation region, thus limiting the negative swing of v_{CE}.

A Practical BJT Amplifier using Coupling and Bypass Capacitors



In a practical amplifier design, C_1 and C_3 are large coupling capacitors or dc blocking capacitors, their reactance ($X_C = |Z_C| = 1/\omega C$) at signal frequency is negligible. They are effective open circuits for the circuit when DC bias is considered.

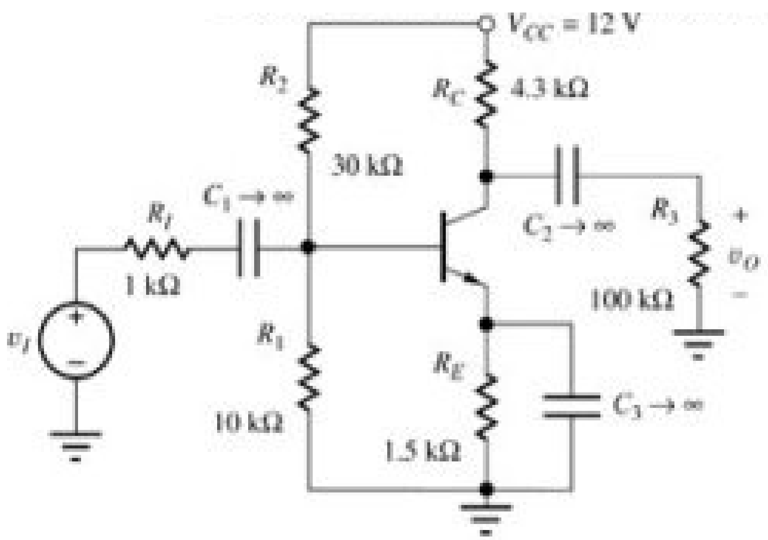
- AC coupling through capacitors is used to inject an ac input signal and extract the ac output signal without disturbing the DC Q-point
- Capacitors provide negligible impedance at frequencies of interest and provide open circuits at dc.

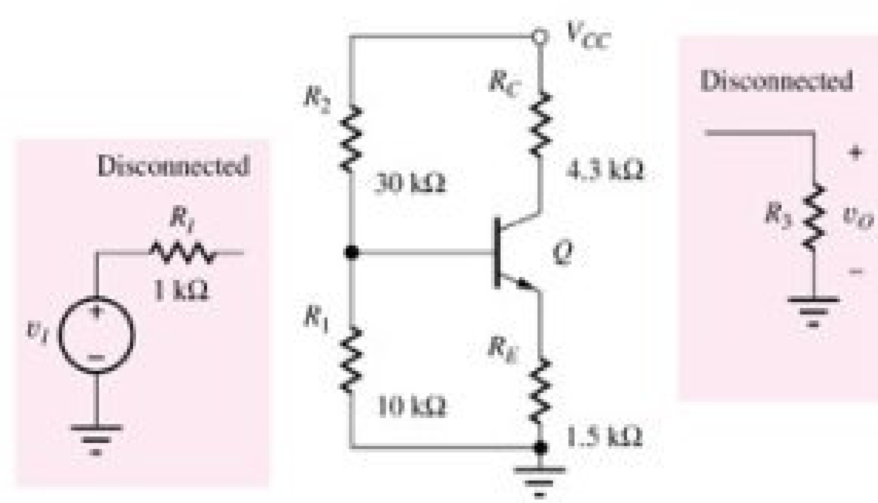
C_2 is a bypass capacitor. It provides a low impedance path for ac current from emitter to ground. It effectively removes R_E (required for good Q-point stability) from the circuit when ac signals are considered.

DC and AC Analysis -- Application of Superposition

- DC analysis:
  - Find the DC equivalent circuit by replacing all capacitors by open circuits and inductors (if any) by short circuits.
  - Find the DC Q-point from the equivalent circuit by using the appropriate large-signal transistor model.
- AC analysis:
  - Find the AC equivalent circuit by replacing all capacitors by short circuits, inductors (if any) by open circuits, dc voltage sources by ground connections and dc current sources by open circuits.
  - Replace the transistor by its small-signal model (to be developed).
  - Use this equivalent circuit to analyze the AC characteristics of the amplifier.
  - Combine the results of dc and ac analysis (superposition) to yield the total voltages and currents in the circuit.

DC Equivalent for the BJT Amplifier

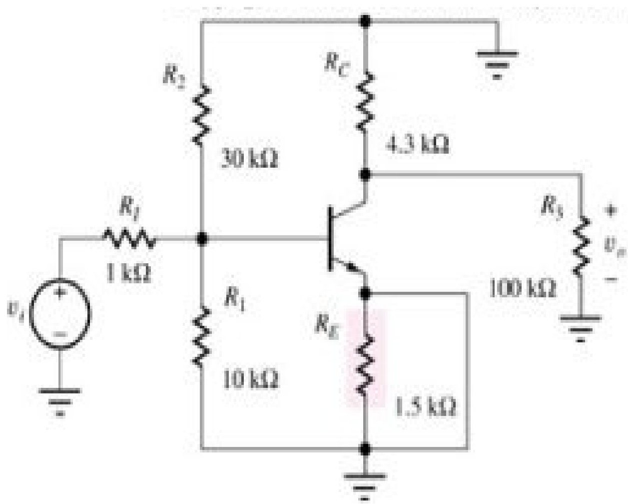


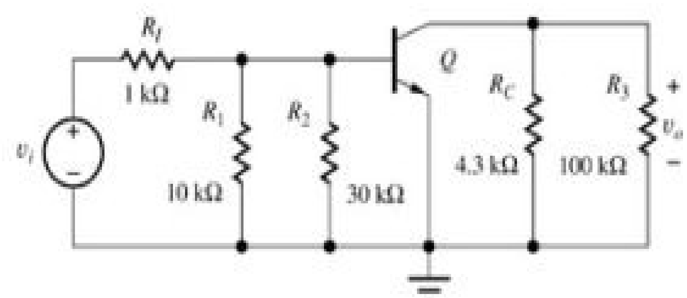


DC Equivalent Circuit

- All capacitors in the original amplifier circuit are replaced by open circuits, disconnecting v_I, R_I, and R_3 from the circuit and leaving R_E intact. The the transistor Q will be replaced by its DC model.

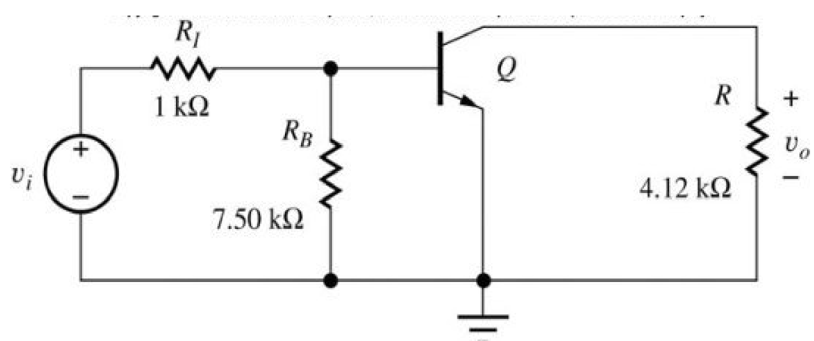
AC Equivalent for the BJT Amplifier





- The coupling and bypass capacitors are replaced by short circuits. The DC voltage supplies are replaced with short circuits, which in this case connect to ground.

AC Equivalent for the BJT Amplifier (contd.)

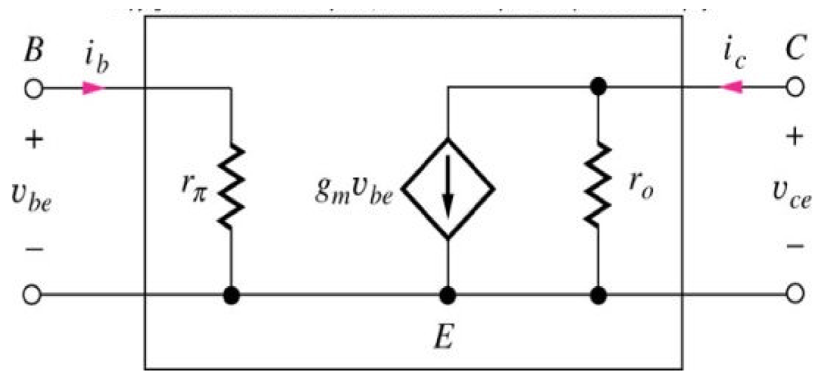


$$R_B = R_1 \| R_2 = 10\text{k}\Omega \| 30\text{k}\Omega$$

$$R = R_C \| R_3 = 4.3\text{k}\Omega \| 100\text{k}\Omega$$

- By combining parallel resistors into equivalent R_B and R, the equivalent AC circuit above is constructed. Here, the transistor will be replaced by its equivalent small-signal AC model (to be developed).

Hybrid-Pi Small-Signal AC Model for the BJT



- The hybrid-pi small-signal model is the intrinsic low-frequency representation of the BJT.
- The small-signal parameters are controlled by the Q-point and are independent of the geometry of the BJT.

Transconductance:

$$g_m = \frac{I_C}{V_T} \cong 40 I_C$$

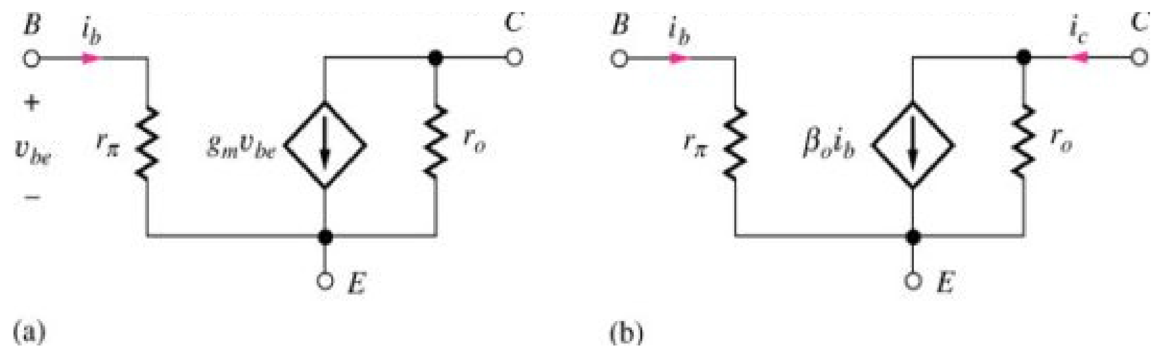
Input resistance:

$$r_\pi = \frac{\beta_o V_T}{I_C} = \frac{\beta_o}{g_m}$$

Output resistance:

$$r_o = \frac{V_A + V_{CE}}{I_C}$$

Equivalent Forms of the Small-signal Model for the BJT



- The voltage-controlled current source $g_m v_{be}$ can be transformed into a current-controlled current source,

$$v_{be} = i_b r_\pi = i_b \frac{\beta_o}{g_m}$$

$$\therefore g_m v_{be} = g_m i_b r_\pi = \beta_o i_b$$

$$i_c = g_m v_{be} + \frac{v_{ce}}{r_o} \cong g_m v_{be} = \beta_o i_b$$

- The basic relationship $i_c = \beta i_b$ is useful in both dc and ac analysis when the BJT is biased in the forward-active region.

Examples

- On the Board