48521 FUNDAMENTALS of ELECTRICAL ENGINEERING

LECTURE 11A

The BJT

(Bipolar Junction Transistor)

N-P-N Bipolar Junction Transistor

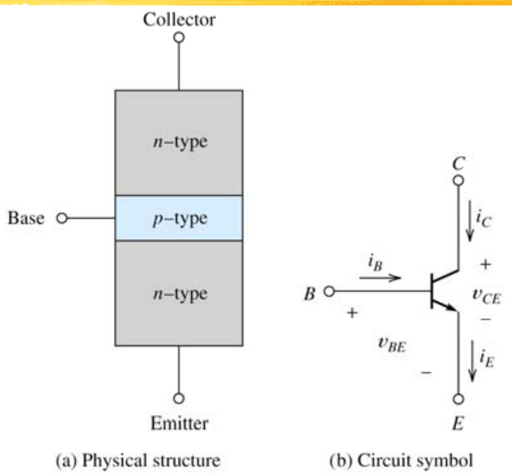


Figure 13.1 The *npn* BJT.

N-P-N Bipolar Junction Transistor

- In ***normal*** operation, B-E junction is biased in forward and B-C junction is biased in reverse.
- Emitter current i_E is given by Shockley's equation:

$$i_E = I_{ES}\left[\exp\left(\frac{v_{BE}}{V_T}\right) - 1\right]$$

N-P-N Bipolar Junction Transistor

- The KCL requires that $i_E = i_C + i_B$
- Introducing the parameter $\alpha = i_C / i_E$ we can write:

$$i_C = \alpha I_{ES}\left[\exp\left(\frac{v_{BE}}{V_T}\right) - 1\right]$$

and:

$$i_B = (1-\alpha) i_E \qquad i_B = (1-\alpha) I_{ES}\left[\exp\left(\frac{v_{BE}}{V_T}\right) - 1\right]$$

N-P-N Bipolar Junction Transistor

- Defining the parameter $\beta = i_C / i_B = \alpha/(1-\alpha)$, we have: $i_C = \beta i_B$

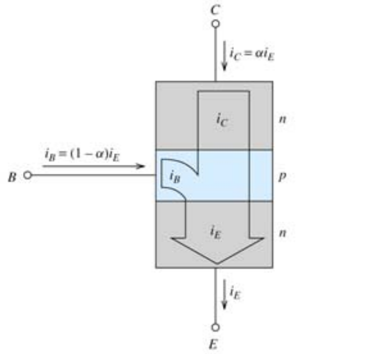


Figure 13.3 Only a small fraction of the emitter current flows into the base (provided that the collector–base junction is reverse biased and the base–emitter junction is forward biased).

Common-Emitter Characteristics

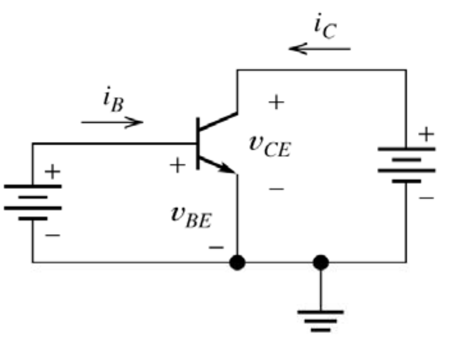


Figure 13.4 Common-emitter circuit configuration for the *npn* BJT.

Common-Emitter Characteristics

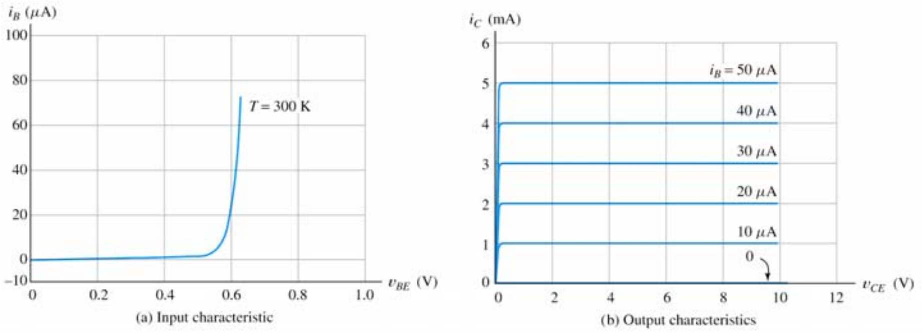
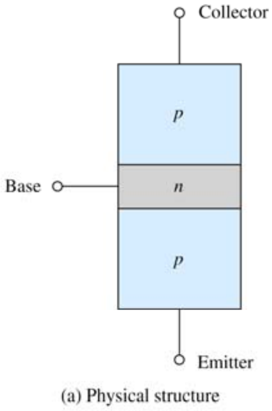


Figure 13.5 Common-emitter characteristics of a typical *npn* BJT.

P-N-P Device



All equations are the same as for p-n-p device if we reverse the polarity of v_{BE} and v_{BC}

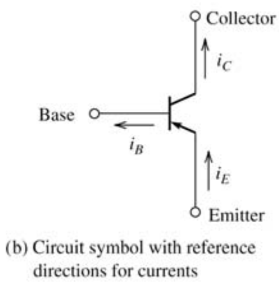


Figure 13.13 The *pnp* BJT.

BJT: Regions of Operation

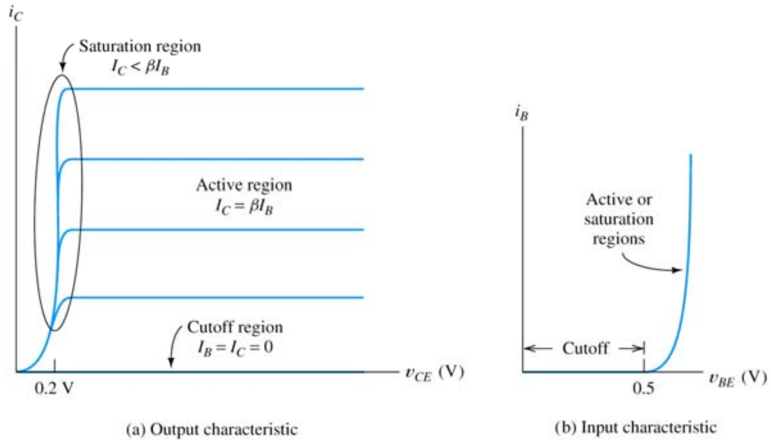
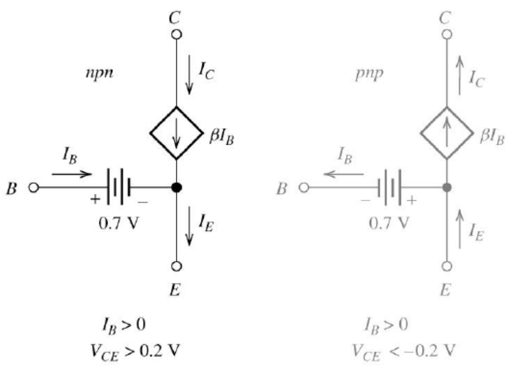


Figure 13.17 Regions of operation on the characteristics of an *npn* BJT.

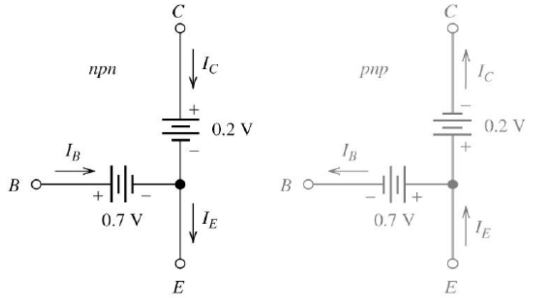
Large-Signal Models

- Normal Active Region: **B-E - fwd, B-C - rev.**



Large-Signal Models

- Saturation Region: **B-E - fwd, B-C - fwd**

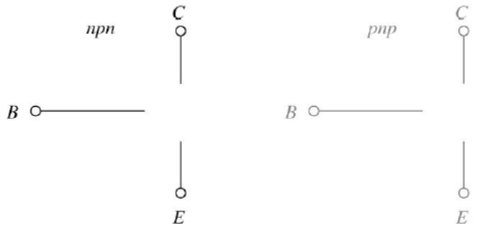


$I_B > 0$
$\beta I_B > I_C > 0$

$I_B > 0$
$\beta I_B > I_C > 0$

Large-Signal Models

- Cut-off Region: **B-E - rev., B-C – rev.**



$V_{BE} < 0.5$ V
$V_{BC} < 0.5$ V

$V_{BE} > -0.5$ V
$V_{BC} > -0.5$ V

DC Analysis of BJT Circuits

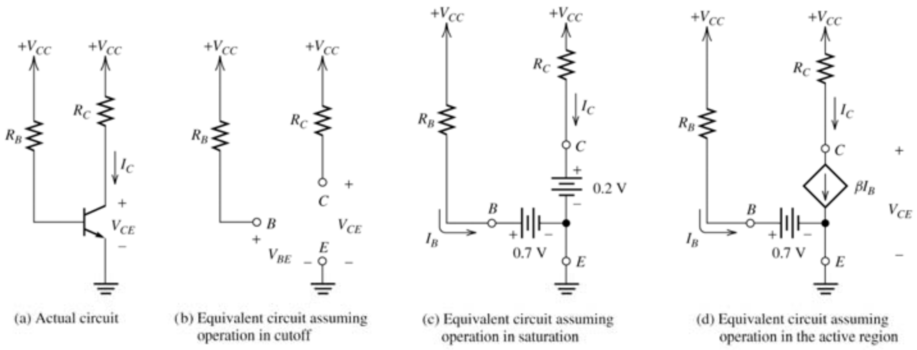
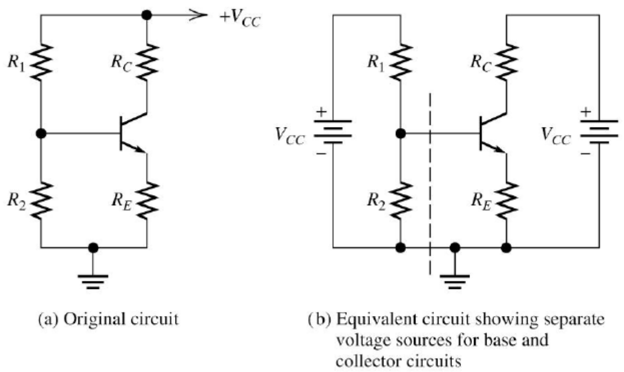
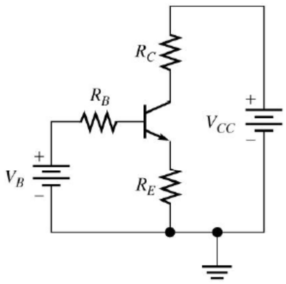


Figure 13.18 Bias circuit of Examples 13.4 and 13.5.

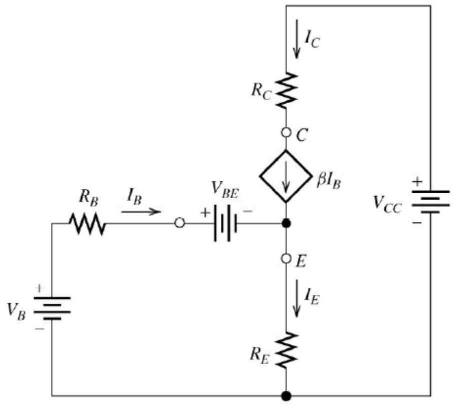
DC Analysis of BJT Circuits



DC Analysis of BJT Circuits

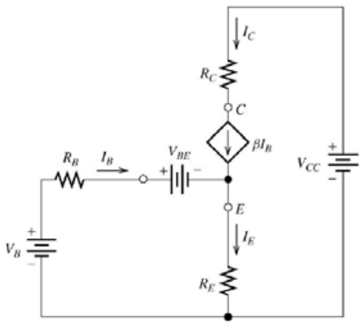


(c) Circuit using Thévenin equivalent in place of V_{CC}, R_1, and R_2



(d) Equivalent to part (c) with active-region transistor model

DC Analysis of BJT Circuits



(d) Equivalent to part (c) with active-region transistor model

KVL in a B-E loop gives:

$$V_B = I_B R_B + V_{BE} + I_E R_E$$

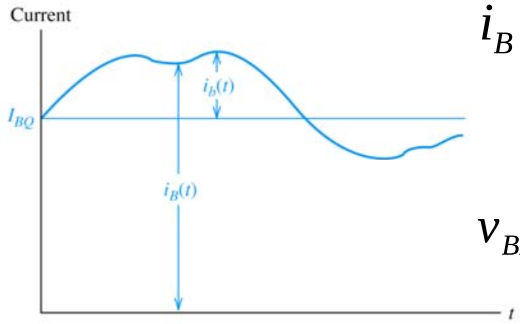
But $I_E = (\beta+1) I_B$, so:

$$V_B = I_B R_B + V_{BE} + (\beta + 1) I_B R_E$$

$$V_{BE} + [R_B + (\beta + 1) R_E] I_B$$

$$\boxed{V_{CE} = V_{CC} - R_C I_C - R_E I_E}$$

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



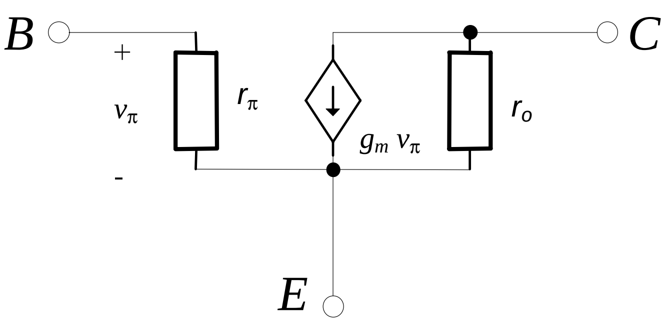
$$i_B(t) = I_{BQ} + i_b(t)$$

$$v_{BE}(t) = V_{BEQ} + v_{be}(t)$$

$i_b(t)$ denotes the signal current flowing into the base, I_{BQ} is the dc current that flows when the signal is absent, and *$i_B(t)$* is the total base current. Similar notation is used for the other currents and voltages.

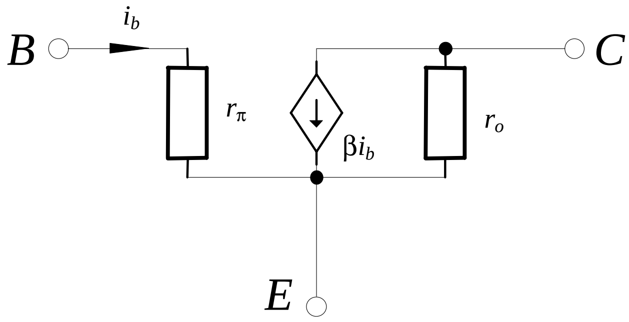
BJT: Small-Signal Model (hybrid-π)

There are three mathematically identical models with different topology. Model 1 (with transconductance g_m):



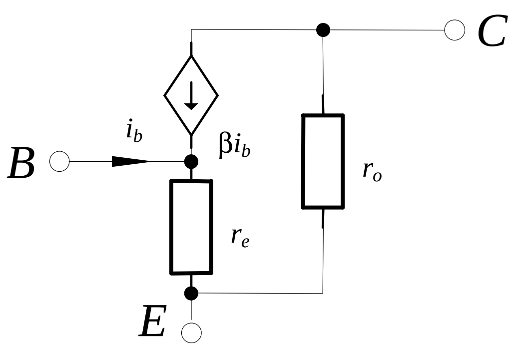
BJT: Small-Signal Model

There are three mathematically identical models with different topology. Model 2 (with CCCS βi_b):



BJT: Small-Signal Model

There are three mathematically identical models with different topology. Model 3 (with emitter resistance r_e):



BJT: Small-Signal Model (hybrid-π)

The values of the basic elements of the these models depend on the BJT parameters and the operating point.

$$g_m = \frac{I_{CQ}}{V_T} \qquad r_\pi = \frac{\beta}{g_m} \qquad r_e = \frac{\alpha}{g_m} \qquad r_o = \frac{V_A}{I_{CQ}}$$

Where: I_{CQ} – quiescent collector current

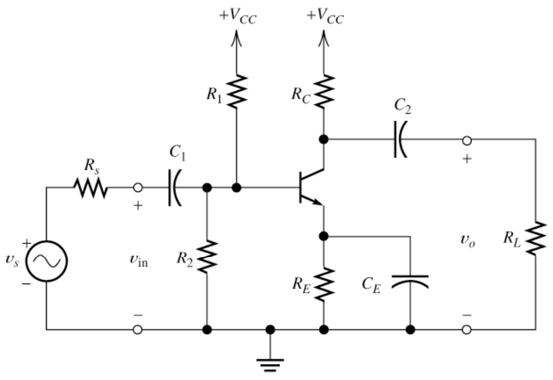
V_T – thermal voltage (~ 26 mV)

V_A – Early voltage (~ 100 V)

β – transistor's current gain

$\alpha = \beta/(\beta+1)$

Basic BJT Amplifiers
Common Emitter

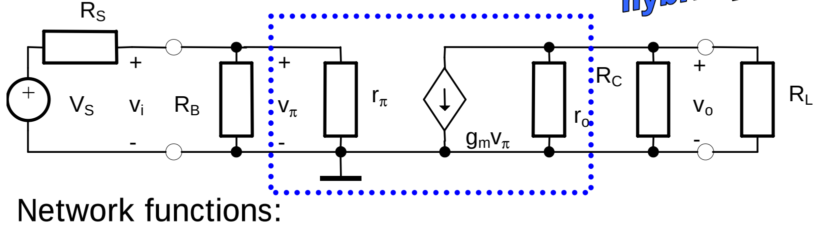


$$R_B = R_1 \| R_2 = \frac{R_1 R_2}{R_1 + R_2}$$

Basic BJT Amplifiers
Common Emitter

Small-signal mid-band equivalent circuit:

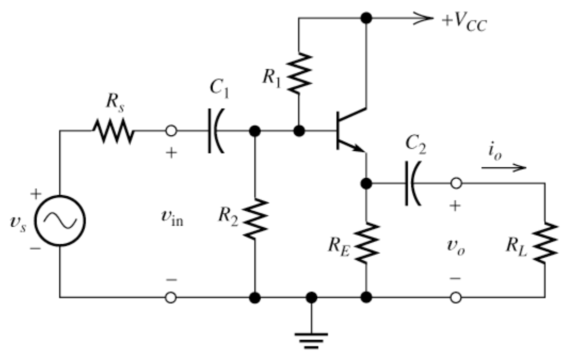
hybrid-pi model



Network functions:

$$A_V = \frac{v_o}{v_i} = \frac{-g_m}{G_C + g_o + G_L} \qquad Z_{in} = \frac{1}{G_B + g_\pi} \qquad Z_{out} = \frac{1}{G_C + g_o}$$

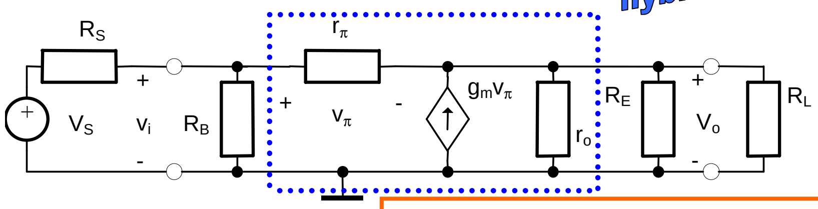
Basic BJT Amplifiers
Common Collector (Emitter Follower)



$$R_B = R_1 \parallel R_2 = \frac{R_1 R_2}{R_1 + R_2}$$

Basic BJT Amplifiers
Common Collector (Emitter Follower)

Small-signal mid-band equivalent circuit: *hybrid-pi model*

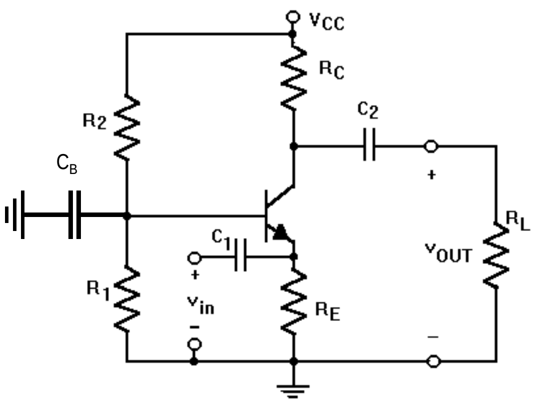


Network functions:

$$\boxed{A_V = \frac{v_o}{v_i} = \frac{g_m + g_\pi}{g_m + g_\pi + G_E + g_o + G_L} \approx 1}$$

$$Z_{in} = \frac{1}{G_B + g_\pi(1 - A_V)} \approx \frac{1}{G_B} \qquad Z_{out} = \frac{1}{G_E + g_o + (g_m + g_\pi)\left(1 - \dfrac{g_\pi}{g_\pi + G_S + G_B}\right)}$$

Basic BJT Amplifiers
Common Base

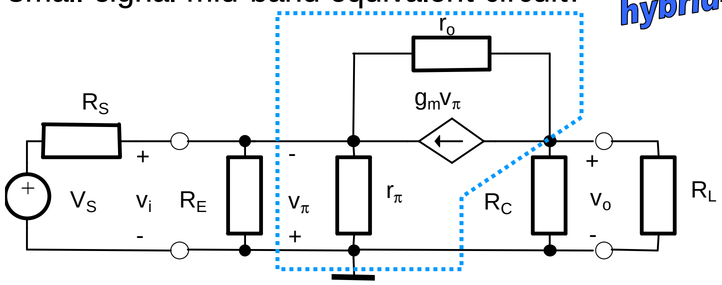


Common Base Amplifier

Basic BJT Amplifiers
Common Base

Small-signal mid-band equivalent circuit:

hybrid-pi model



$$A_V = \frac{v_o}{v_i} = \frac{g_m + g_o}{G_C + g_o + G_L} \qquad Z_{in} = \frac{1}{G_E + g_\pi + g_o(1 - A_V) - g_m}$$