Chapter 6 - BJTs

Threshold voltage: $V_T \approx 25.9$ mV.

Two junctions in BJT, EBJ (Emitter Base Junction) and CBJ (Collector Base Junction).

Mode	EBJ	CBJ
Cutoff	Reverse	Reverse
Active	Forward	Reverse
Saturation	Forward	Forward

NPN TRANSISTOR:

In the cutoff mode:

$V_{BC} < 0.4$ V | $V_{BE} < 0.5$ V |

$I_C = 0$ | $I_B = 0$

In the active mode:

$V_{BC} < 0.4$ V | $V_{BE} \approx 0.7$ V | $V_{CE} > 0.3$ V

$I_C = \beta I_B$ | $I_B > 0$

In the saturation mode:

$V_{BC} \approx 0.5$ V | $V_{BE} \approx 0.7$ V | $V_{CE_{SAT}} \approx 0.2$ V

$I_C = \beta_{forced} I_B$ | $I_B > 0$

PNP TRANSISTOR:

In the cutoff mode:

$V_{CB} < 0.4$ V | $V_{EB} < 0.5$ V |

$I_C = 0$ | $I_B = 0$

In the active mode:

$V_{CB} < 0.4$ V | $V_{EB} \approx 0.7$ V | $V_{EC} > 0.3$ V

$I_C = \beta I_B$ | $I_B > 0$

In the saturation mode:

$V_{CB} \approx 0.5$ V | $V_{EB} \approx 0.7$ V | $V_{EC_{SAT}} \approx 0.2$ V

$I_C = \beta_{forced} I_B$ | $I_B > 0$

Current relationships in a BJT transistor.

I_S is known as Saturation Current

$i_E = i_C + i_B$ | $i_E = \frac{\beta+1}{\beta} i_C$ | $i_C = \alpha i_E$ | $\alpha = \frac{\beta}{\beta+1}$ | $\beta = \frac{\alpha}{1-\alpha}$

α is the **common-base current gain**.

A BJT is in the Saturation Region if - The CBJ is Forward biased by more than 0.4V - The Ratio of i_C/i_B is lower than β

$$i_C = I_s e^{v_{BE}/V_T}$$

Considering the Early voltage

$$i_C = I_s e^{v_{BE}/V_T} \left(1 + \frac{v_{CE}}{V_A}\right)$$

$$r_o = \left[\frac{\delta i_c}{\delta v_{CE}} \Big|_{V_{BE}=\text{constant}} \right]^{-1}$$

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

$$r_o = \frac{V_A}{I'_C}$$

Where $I'_C = I_s e^{V_{BE}/V_T}$

$$R_{CE_{\text{SAT}}} \equiv \frac{\delta v_{CE}}{\delta i_C}\Big|_{i_B = I_B | i_C = I_{C_{\text{SAT}}}}$$

Amplifier stuff

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

Operating point Q occurs at (V_{BE}, V_{CE}).

$$A_v = -\left(\frac{I_C}{V_T}\right) R_C = -\frac{V_{RC}}{V_T}$$

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

$$A_{vmax} \approx \frac{V_{CC}}{V_T}$$

Small signal stuff

$i_C = I_C + \frac{I_C}{V_T} v_{be}$

$i_C = I_C + i_c$

$i_c = \frac{I_C}{V_T} v_{be}$

$i_c = g_m v_{be}$

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

Base current:

$i_B = \frac{i_C}{\beta} = \frac{I_C}{\beta} + \frac{1}{\beta} \frac{I_C}{V_T} v_{be}$

$i_B = I_B + i_b$

$i_b = \frac{1}{\beta} \frac{I_C}{V_T} v_{be}$

We know that $I_C/V_T = g_m$ so

$i_b = \frac{g_m}{\beta} v_{be}$

The small-signal input resistance looking into the base, is denoted by r_π and is defined as

$r_\pi \equiv \frac{v_{be}}{i_b} = \frac{\beta}{g_m} = \frac{V_T}{I_B}$

Emitter current:

$i_E = \frac{i_C}{\alpha} = \frac{I_C}{\alpha} + \frac{i_c}{\alpha}$

$i_E = I_E + i_e$

$i_e = \frac{i_c}{\alpha} = \frac{I_C}{\alpha V_T} v_{be} = \frac{I_E}{V_T} v_{be}$

Small-signal resistance looking into the emitter is

$r_e \equiv \frac{v_{be}}{i_e}$

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

$r_e = \frac{\alpha}{g_m} \approx \frac{1}{g_m}$

Relationship between r_π and r_e:

$v_{be} = i_b r_\pi = i_e r_\pi$

$r_\pi = (i_e/i_b) r_e$

$r_\pi = (\beta + 1) r_e$

Voltage gain of the amplifier:

$A_v \equiv \frac{v_{ce}}{v_{be}} = -g_m R_C$

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

Hybrid-π model includes the r_π resistor:

$i_e = \frac{v_{be}}{r_\pi} + g_m v_{be}$

$\frac{v_{be}}{r_\pi}(1 + g_m r_\pi)$

$g_m v_{be} = g_m (i_b r_\pi)$

T-model includes the r_e resistor:

$g_m = I_C/V_T$

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

If we include r_o, the output voltage becomes:

$v_o = -g_m v_{be} (R_C \parallel r_0)$

Three different amplifier configurations:

Common-emitter

Common-base

Common-collector (also known as **emitter follower**)

But first, for all amplifier configurations:

$R_{in} \equiv \frac{v_i}{i_i}$

$v_i = \frac{R_{in}}{R_{in} + R_{sig}} v_{sig}$

$A_{vo} \equiv \frac{v_o}{v_i}\Big|_{R_L = \infty}$

$R_x = \frac{v_x}{i_x}$