Important formulae and device models for you to prepare for ELE2110A test 2

Prof. KP Pun, 13 March 2008

BJT collector current in active mode: $i_C = I_S e^{v_{BE}/V_T}$

BJT collector current in active mode (including Early effect): $i_C = I_S e^{v_{BE}/V_T}(1+\frac{v_{CE}}{V_A})$

Relationship between base and collector currents for BJT in active mode: $i_B = \frac{i_C}{\beta}$

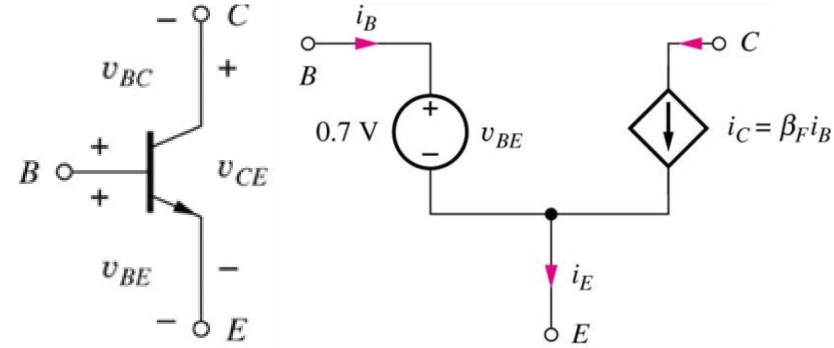
Relationship between emitter and collector currents for BJT in active mode: $i_C = \alpha\, i_E$

Relationship between α and β: $\alpha = \frac{\beta}{1+\beta}$

Single stage BJT amplifier properties:

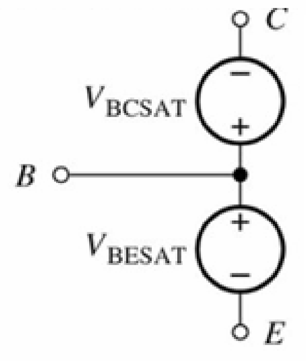
	C-E (R_E=0)	Emitter Degenerated C-E	C-C	C-B
Terminal Voltage Gain	Inverting & large	Inverting & moderate	1	Non-inverting & Large
Input Resistance	Moderate	Large	Large	Low
Output Resistance	Moderate	Large	Low	Large
Input Voltage Range	Small	Moderate	Large	Moderate
Terminal Current Gain	Inverting & Large	Inverting & Large	Non-inverting & Large	1

Simplified DC model for *npn* transistor in active mode:



(β_F is another notation for β).

Simplified DC model for *npn* transistor in saturation mode:

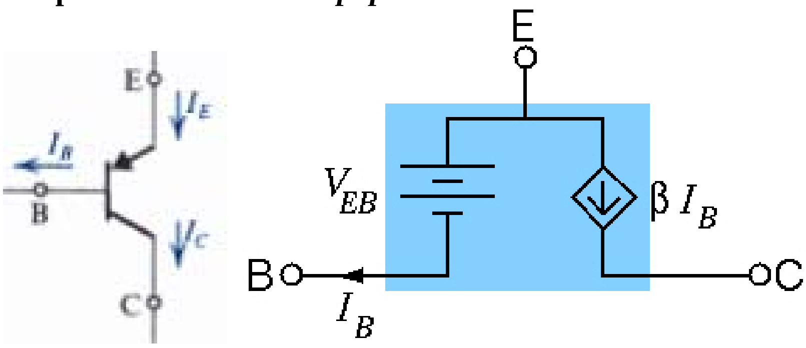


+

V_{CEsat}
(typically 0.2V)

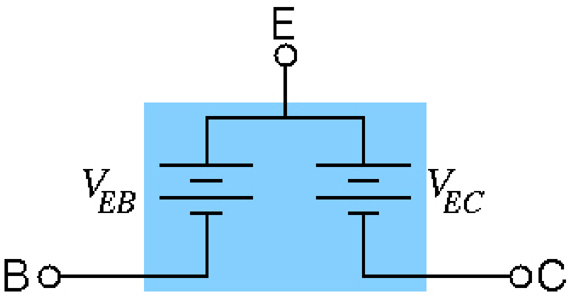
-

Simplified DC model for *pnp* transistor in active mode:



$$V_{EB} \cong 0.7\text{ V}$$

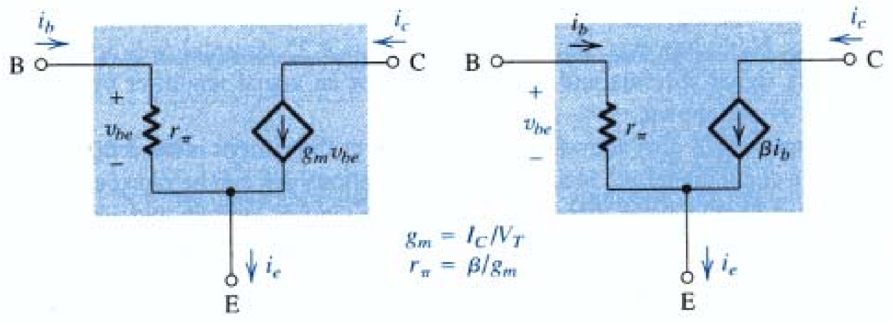
Simplified DC model for *pnp* transistor in saturation mode:



$$V_{EB} \cong 0.7\text{ V}$$

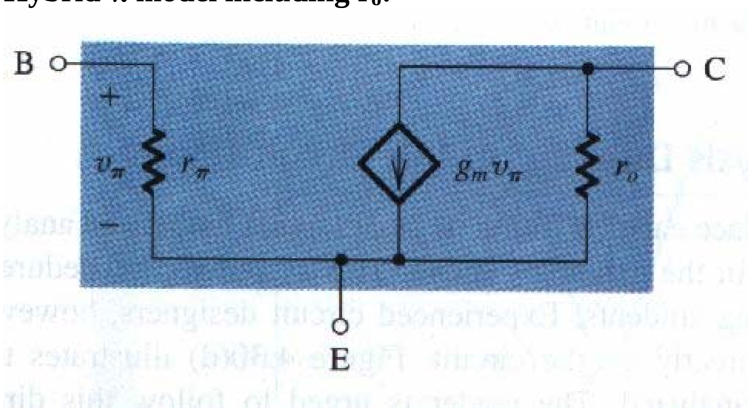
$$V_{EC} \cong 0.2\text{ V}$$

Small signal AC model for BJT (both *npn* and *pnp*) in active mode (Hybrid-π model):



Constraint on v_{be} for BJT small signal models to be valid: $v_{be} << V_T$ (thermal voltage)

Hybrid-π model including r_o:

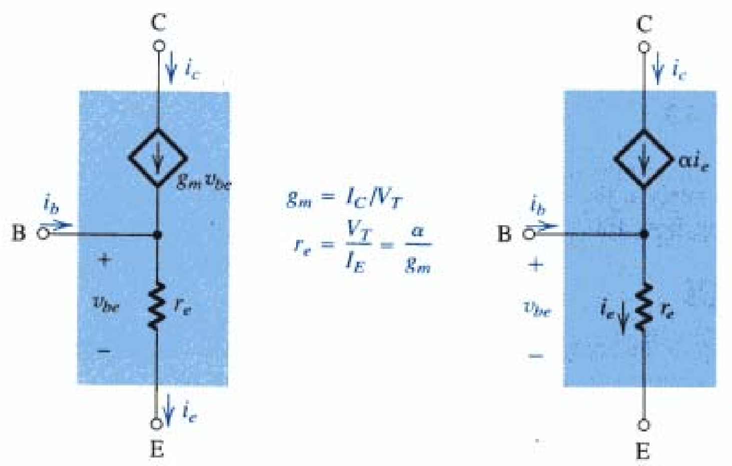


$$g_m = \frac{I_C}{V_T},$$

$$r_\pi = \frac{V_T}{I_B},$$

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

Small signal AC model for BJT (both *npn* and *pnp*) in active mode (T-model):



n-channel MOSFET I-V equations in different modes:

Region	Cutoff	Triode	Saturation
Conditions	$v_{GS} < V_t$	$v_{GS} \geq V_t$	
		$v_{DS} < v_{GS} - V_t$	$v_{DS} \geq v_{GS} - V_t$
I-V relation	$i_D = 0$	$i_D = K'_n \frac{W}{L}\left[(v_{GS} - V_t)v_{DS} - \frac{1}{2}v_{DS}^2\right]$	$i_D = \frac{1}{2}K'_n \frac{W}{L}(v_{GS} - V_t)^2$

where $K_n' = \mu_n C_{ox}$, V_t is the threshold voltage (sometimes denoted as V_{TN} for nmos).

Saturation mode equation including the channel length modulation effect:

$$i_D = \frac{K_n'}{2}\frac{W}{L}\left(v_{GS} - V_t\right)^2\left(1 + \lambda v_{DS}\right)$$

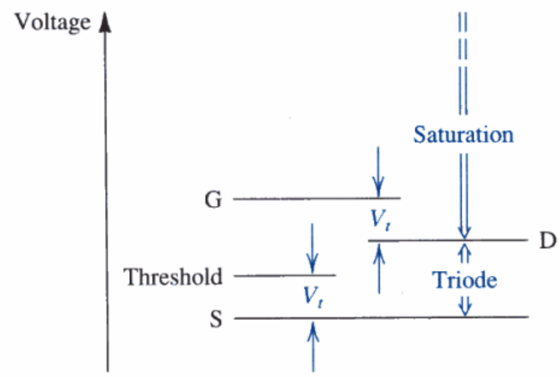
p-channel MOSFET I-V equations in different modes:

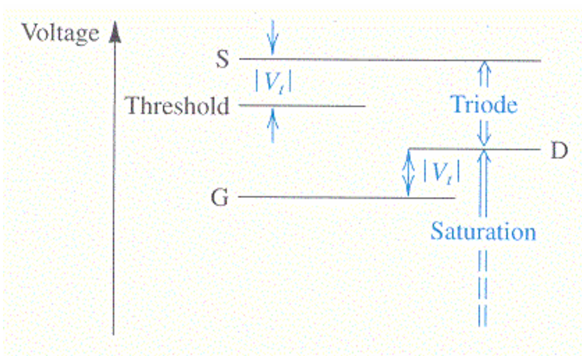
Cutoff	Triode/Linear	Saturation
$i_D = 0$	$i_D = K_p\left[(v_{GS} - V_t)v_{DS} - \frac{1}{2}v_{DS}^2\right]$	$i_D = \frac{1}{2}K_p(v_{GS} - V_t)^2$

where $K_p = K_p'\frac{W}{L}$, $K_p' = \mu_p C_{ox}$

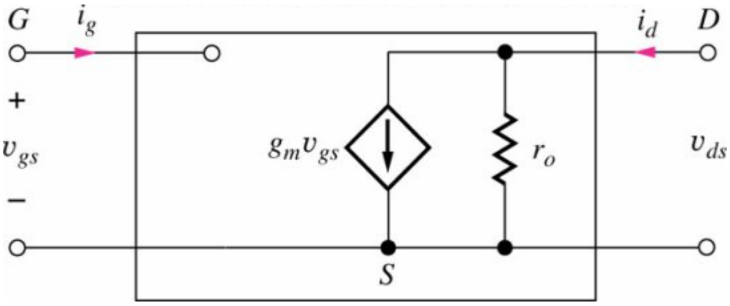
V_t, v_{GS} and v_{DS} are negative for pmos.

Charts helping you to judge the operational mode of nmos (left) and pmos (right):





MOSFET small signal model (for both nmos and pmos):



$g_m = k_n' \frac{W}{L}(V_{GS} - V_t)$, $g_m = \sqrt{2k_n'}\sqrt{\frac{W}{L}}\sqrt{I_D}$, or $g_m = \frac{I_D}{(V_{GS} - V_t)/2}$

$r_0 = \frac{1 + \lambda V_{DS}}{\lambda I_D} \cong \frac{1}{\lambda I_D}$

Constraint on v_{gs} for the small signal model to be valid: $v_{gs} << 2(V_{GS} - V_t)$, or $v_{gs} < 0.2(V_{GS} - V_t)$.