

# ECE 342 – Equations for Exam 3

## 1. MOSFETs

|            | NMOS  | PMOS   |
|------------|---|--|
|            | $I_D, V_{GS}, V_{DS}, V_{t_n} > 0$  | $I_D, V_{GS}, V_{DS}, V_{t_p} < 0$   |
|            | $k'_n = \mu_n C_{ox}$   | $k'_p = \mu_p C_{ox}$  |
|            | $V_{t_n} = V_{t_{0n}} + \gamma_n (\sqrt{2\phi_f + V_{SB}} - \sqrt{2\phi_f})$  | $V_{t_p} = V_{t_{0p}} + \gamma_p (\sqrt{2\phi_f +  V_{SB} } - \sqrt{2\phi_f})$   |
| Cutoff     | $V_{GS} < V_{t_n}$<br>$I_D = 0$   | $V_{GS} > V_{t_p}$<br>$I_D = 0$  |
| Triode     | $V_{GS} > V_{t_n}, V_{DS} < V_{GS} - V_{t_n}$<br>$I_D = k'_n \frac{W_n}{L_n} \left( V_{GS} - V_{t_n} - \frac{V_{DS}}{2} \right) V_{DS}$ | $V_{GS} < V_{t_p}, V_{DS} > V_{GS} - V_{t_p}$<br>$I_D = -k'_p \frac{W_p}{L_p} \left( V_{GS} - V_{t_p} - \frac{V_{DS}}{2} \right) V_{DS}$ |
| Saturation | $V_{GS} > V_{t_n}, V_{DS} > V_{GS} - V_{t_n}$<br>$I_D = \frac{k'_n}{2} \frac{W_n}{L_n} (V_{GS} - V_{t_n})^2 (1 + \lambda_n V_{DS})$     | $V_{GS} < V_{t_p}, V_{DS} < V_{GS} - V_{t_p}$<br>$I_D = -\frac{k'_p}{2} \frac{W_p}{L_p} (V_{GS} - V_{t_p})^2 (1 + \lambda_p V_{DS})$     |

## 2. BJTs

|            | NPN   | PNP   |
|------------|---|---|
| Cutoff     | $V_{BE} < 0.4 \text{ V}, V_{BC} < 0.4 \text{ V}$<br>$I_C = I_E = I_B = 0$   | $V_{EB} < 0.4 \text{ V}, V_{CB} < 0.4 \text{ V}$<br>$I_C = I_E = I_B = 0$   |
| Saturation | $V_{BE} = 0.7 \text{ V}, V_{CE} = V_{CE_{sat}} = 0.3 \text{ V}$<br>$I_C = I_S e^{(V_{BE}/V_T)} - I_{SC} e^{(V_{BC}/V_T)}$<br>$\beta_{forced} = \frac{I_C}{I_B} \Big _{saturation} < \beta$  | $V_{EB} = 0.7 \text{ V}, V_{EC} = V_{EC_{sat}} = 0.3 \text{ V}$<br>$I_C = I_S e^{(V_{EB}/V_T)} - I_{SC} e^{(V_{CB}/V_T)}$<br>$\beta_{forced} = \frac{I_C}{I_B} \Big _{saturation} < \beta$  |
| Active     | $V_{BE} = 0.7 \text{ V}, V_{BC} < 0.4 \text{ V}$<br>$I_C = I_S e^{(V_{BE}/V_T)} (1 + \frac{V_{CE}}{V_A})$<br>$I_B = I_C / \beta, \quad \beta = \frac{\alpha}{(1-\alpha)}$<br>$I_E = I_C / \alpha, \quad \alpha = \frac{\beta}{1+\beta}$ | $V_{EB} = 0.7 \text{ V}, V_{EC} < 0.4 \text{ V}$<br>$I_C = I_S e^{(V_{EB}/V_T)} (1 + \frac{V_{EC}}{V_A})$<br>$I_B = I_C / \beta, \quad \beta = \frac{\alpha}{(1-\alpha)}$<br>$I_E = I_C / \alpha, \quad \alpha = \frac{\beta}{1+\beta}$ |