

MOSFET Large Signal Model (NMOS)

Cut-off: $V_{GS} < V_T$, $I_D = 0$

Triode: $V_{GS} > V_T$, $V_{DS} < V_{GS} - V_T$, $I_D = \frac{1}{2} k_n' \frac{W}{L} [2V_{DS}(V_{GS} - V_T) - V_{DS}^2]$

Saturation: $V_{GS} > V_T$, $V_{DS} > V_{GS} - V_T$, $I_D = \frac{1}{2} k_n' \frac{W}{L} (V_{GS} - V_T)^2 (1 + \lambda V_{DS})$

- $k_n' = \mu_n C_{ox}$
- λ is for channel length modulation effect
sometimes quoted as $V_A = 1/\lambda$, similar to Early effect
- some books use $k_n = \mu_n C_{ox} \frac{W}{L}$ or $K_n = \frac{1}{2} \mu_n C_{ox} \frac{W}{L}$
- we use k_n' , consistent with Sedra & Smith
- in triode region, behaves as variable resistor

$$r_{DS} = \frac{V_{DS}}{I_D} \approx \frac{1}{k_n' \frac{W}{L} (V_{GS} - V_T)}$$

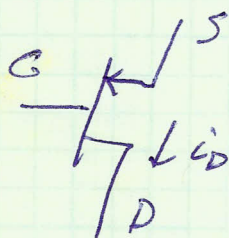
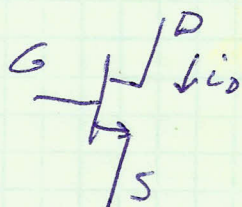
- For PMOS, everything is the same, but reverse all voltages

$$V_{GS} \rightarrow V_{SG}, \quad V_{DS} \rightarrow V_{SD}, \quad V_{TN} \rightarrow |V_{TP}|$$

(note V_{TP} is negative)

NMOS

PMOS



Important points:

- no current flows into gate - $i_G = 0$
- in cut-off, $i_D = 0$ (however $i_D = 0$ does not mean cutoff, it could just be because $V_{DS} = 0$)
- saturation mode - called because i_D is saturated
- equivalent to BJT active mode
- behavior of BJTs + FETs are similar
- both are off when input is below threshold (V_{DS} or V_T)
- BJT requires i_B to work, FET has $i_G = 0$

Recipe for solving MOSFET circuits

- 1) write down GS-KVL and DS-KVL
 - 2) from GS-KVL, calculate V_{GS}
 - if $V_{GS} < V_T \rightarrow$ cutoff, $i_D = 0$, solve for V_{DS} with DS-KVL
 - if $V_{GS} > V_T \rightarrow$ not cutoff → Done
 - 3) assume saturation
 - calculate i_D from device equation for saturation
 - find V_{DS} from DS-KVL, if $V_{DS} > V_{GS} - V_T \rightarrow$ Done
 - 4) if $V_{DS} < V_{GS} - V_T$, in triode mode
 - ~~- calculate i_D from triode equation~~
 - ~~- find V_{DS}~~
 - substitute i_D from triode equation into DS-KVL
 - calculate V_{DS} (one of two roots will be unphysical)
 - check that $V_{DS} < V_{GS} - V_T$
 - substitute V_{DS} in DS-KVL to find i_D
- * Check examples in notes page 3-25