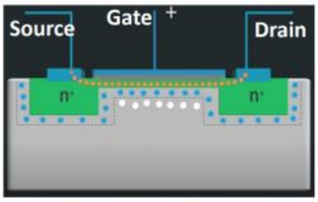
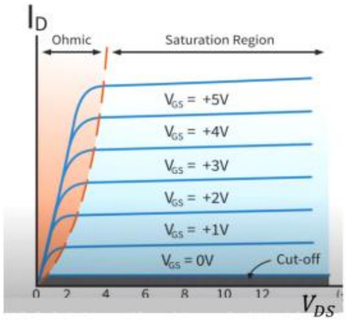
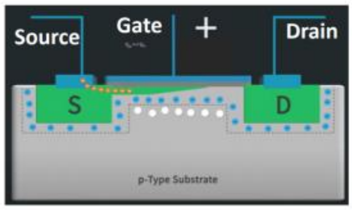
Operation regions of MOSFET



Triode or ohmic region: $V_{GD} > V_{TH}$

$$I_D = k_n[(V_{GS} - V_{TH})V_{DS} - \frac{1}{2}V_{DS}^2]$$

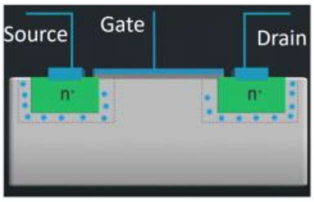




Saturation region: $V_{GD} < V_{TH}$

$$I_D = \frac{1}{2}k_n\,(V_{GS} - V_{TH})^2(1 + \lambda V_{DS})$$

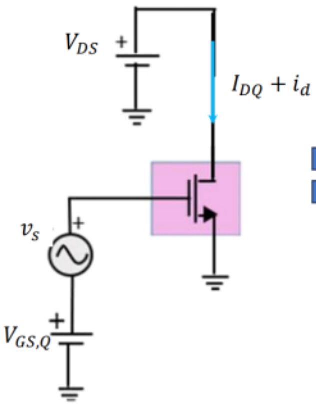
- $\lambda = \frac{L-L'}{V_{DS}L}$: channel length modulation coefficient
- L': actual channel length



Cut-off region: $V_{GS} < V_{TH}$
$I_D = 0$

Triode and cut-off region: switching devices
Saturation region: amplifier

MOSFET—small-signal model



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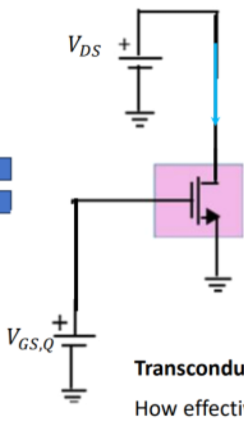

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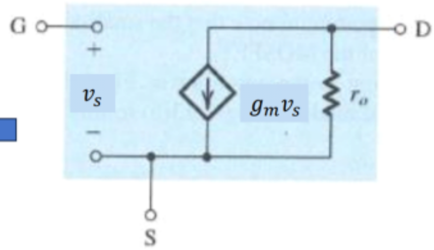
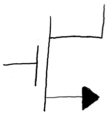
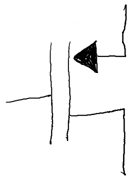
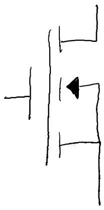
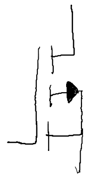


$V_{GS,Q} + v_s - V_{DS} \le V_{TH}$
In saturation region

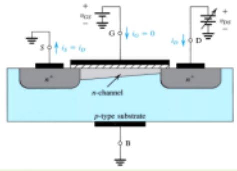
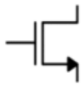
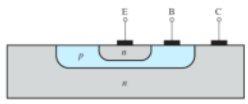
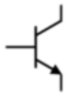
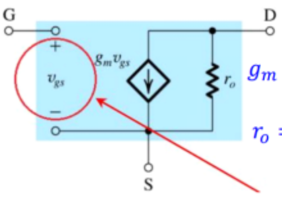
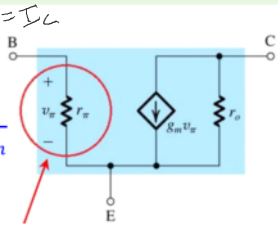
Transconductance $g_m = \frac{\Delta I_D}{\Delta V_{GS}} = \frac{2I_{DQ}}{V_{GS,Q} - V_{TH}} = k_n(V_{GS,Q} - V_{TH})$

How effectively the MOSFET converts a change in V_{GS} into a change in I_D.

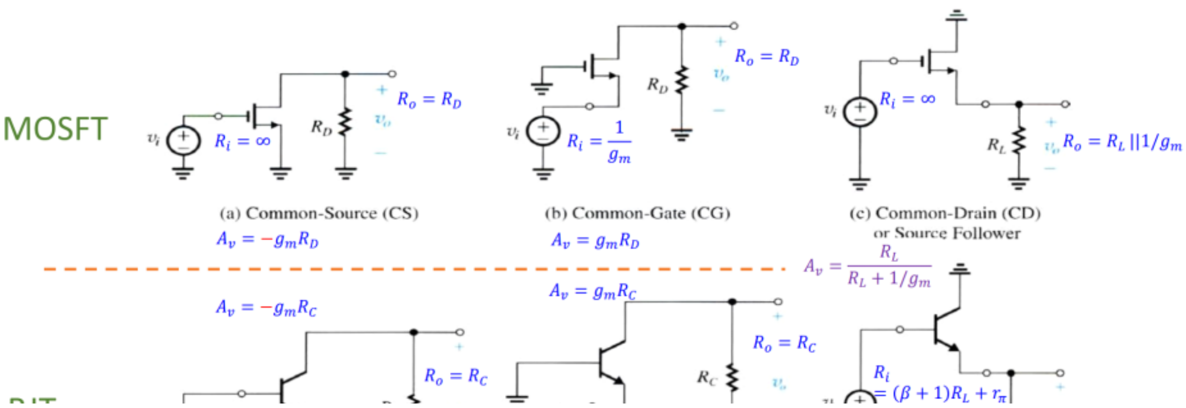
Output resistance: $r_o = \frac{\Delta V_{DS}}{\Delta I_D} = \frac{v_s}{i_d} = \frac{1}{I_{DQ}\lambda}$

Nmos	Pmos
N-depletion  $V_{GS} = +Ve \to ON$ $V_{GS} = 0 \to ON$ $V_{GS} = -Ve \to OFF$	P-depletion  $V_{GS} = +Ve \to OFF$ $V_{GS} = 0 \to ON$ $V_{GS} = -Ve \to ON$
N-enhancment  $V_{GS} = +Ve \to ON$ $V_{GS} = 0 \to OFF$ $V_{GS} = -Ve \to OFF$	P-enhancment  $V_{GS} = +Ve \to OFF$ $V_{GS} = 0 \to OFF$ $V_{GS} = -Ve \to ON$

MOSFT VS. BJT

	MOSFT	BJT
Structure	 N-type or P-type 	 NPN or PNP 
Symmetric fabrication	Yes	No
Dominant I-V characteristics	$I_D = \frac{1}{2}k_n(V_{GS} - V_{TH})^2(1 + \lambda V_{DS})$ – Saturation	$I_C = I_s(e^{\frac{V_{BE}}{V_T}} - 1)$ — forward active
Current control	No current flowing through G and S. The voltage of GS that controls the current through D and S.	A small current flowing through B and E controls a much larger current through C and E.
Small-signal model	 $g_m = \frac{2I_{DQ}}{V_{GS,Q} - V_{TH}}$ $r_o = \frac{1}{I_{DQ}\lambda}$ $V_{GSQ} = V_{GS}$ we think	$g_m = \frac{\overbrace{I_{CQ}}^{=I_C}}{V_T}$ $r_\pi = \frac{V_T}{I_B} = \frac{\beta}{g_m}$ $r_o = \frac{V_A}{I_{CQ}}$  early votage effect mcllem 15 og 200

Three basic configurations: MOSFT VS. BJT



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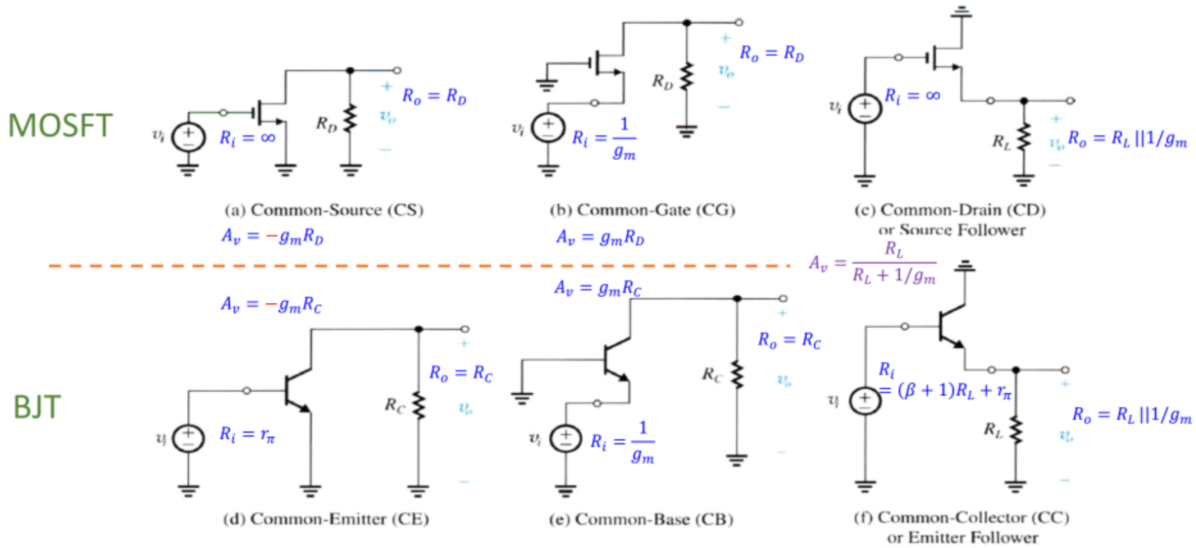
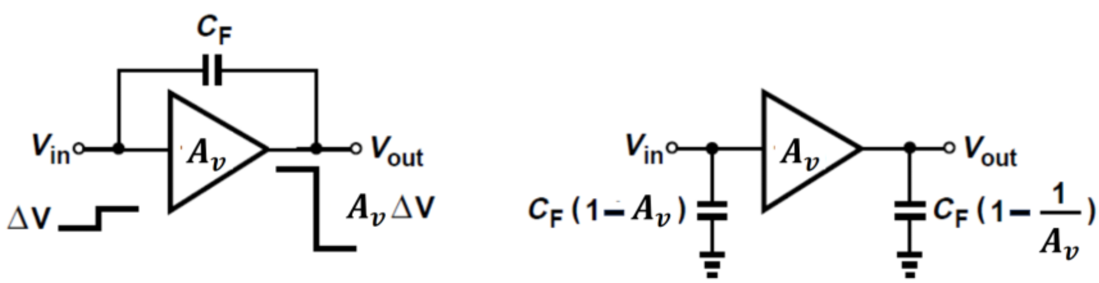
Three basic configurations: MOSFT VS. BJT



Example



$A_v = V_{out}/V_{in}$

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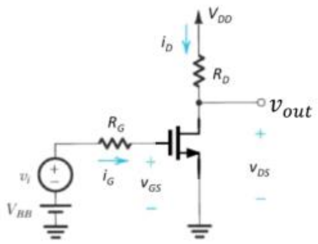
Assignments:

8.1:

A MOSFET circuit is shown in Fig. 1. It is assumed that: $V_{DD} = 10$ V, $R_G = 33\ K\Omega$, $R_D = 5.6\ K\Omega$ and the channel length modulation coefficient $\lambda = 0$. Furthermore, we assume that $V_{TH} = 2\ V$ and $k_n = 0.9 * 10^{-3}\ A/V^2$.

(a) To achieve $I_D = 1\ mA$, $V_{GS} = ?$
(b) To have V_{GS} obtained in (a), V_{BB} =? Explain why.
(c) To ensure the MOSFET operating in saturation, how large is the output signal swing?
(d) Setup a small signal circuit and calculate the component values and voltage gain A_v.
(e) To achieve a maximum output signal swing for $I_D = 1\ mA$, R_D =?
(f) If the channel length modulation coefficient $\lambda = 0.5$ and $R_D = 5.6\ K\Omega$ are considered, the output resistance r_o =? The voltage gain A_v =?



Solution:

$I_D = \frac{1}{2} k_n (V_{GS} - V_{TH})$

(a) $I_D = \frac{1}{2} k_n (V_{GS} - V_{TH})^2 \rightarrow V_{GS} = \sqrt{\frac{2I_D}{k_n}} + V_{TH} \approx 3.5\ V$

2. (b) Since $I_G = 0 \rightarrow V_{R_G} = 0 \rightarrow V_{BB} = V_{GS} = 3.5\ V$

(c) $V_{DS} = V_{DD} - R_D I_D = 10 - 5.6K\Omega * 1mA$ = 4.4 V

To ensure the MOSFET working in saturation, $V_{DS} \geq V_{GS} - V_{TH} = 1.5\ V$, i.e., $V_{DS,min} = 1.5\ V$. In addition, $V_{DS} \leq V_{DD} = 10\ V$. Thus, the swing of the output signal = min{4.4 − 1.5, 10 − 4.4} = 2.9 V.

$\rightarrow (V_{DS} - V_{DSmin}), (V_{DD} - V_{DS})$

(d) $g_m = \frac{2I_D}{V_{GS} - V_{TH}} = 1.3\ mS \rightarrow A_v = -g_m R_D \approx -7.5$

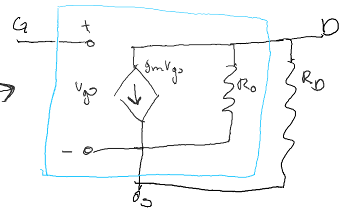
(e) To achieve a maximum output signal swing, we need to ensure the $V_{DS,Q}$ is located in the middle of the available range:

$V_{range} = V_{DD} - V_{DS,min} = 10 - 1.5 = 8.5\ V \rightarrow V_{DS,Q} = \frac{V_{range}}{2} + V_{DS,min} =$ 5.75 $V \rightarrow V_{R_D} = V_{DD} - V_{DS,Q} = 4.25$

$\rightarrow R_D = \frac{V_{R_D}}{I_D} = \frac{4.25V}{1\ mA} = 4.25\ K\Omega$

(f) $r_o = \frac{1}{I_D \lambda} = \frac{1}{1mA * 0.5} = 2\ K\Omega$

$A_v = -g_m * (R_D || r_o) = -1.3\ mS * (5.6K\Omega || 2K\Omega) = 1.9$

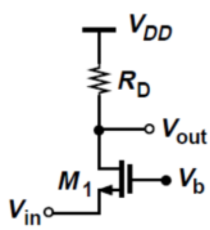


Very similar to BJT analysis

8.2:

A common gate amplifier is given in Fig.2.

(a) Draw the internal capacitors of the circuit.
(b) Simplify the circuit by merging the capacitors.
(c) Is there any floating capacitor in the circuit?
(d) If yes, how to decompose the floating capacitor into two capacitors connected to AC ground by using Millers theorem?

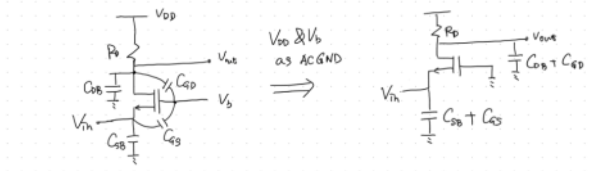


Rember that:

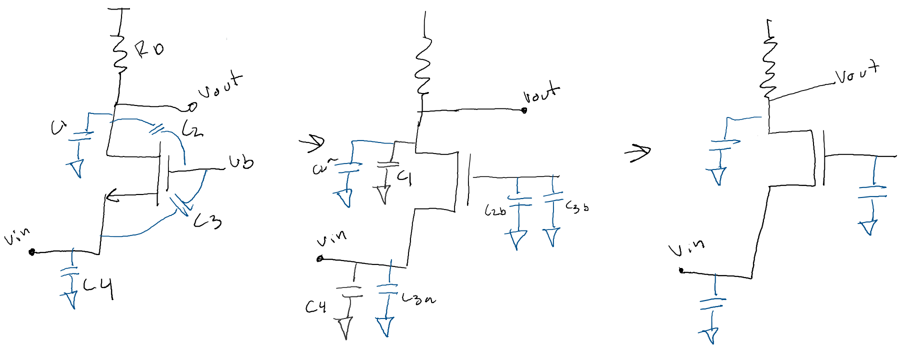
$C_{inMiller} = C_f (1 - A_v)$

$C_{outMiller} = C_f (1 - \frac{1}{A_v})$

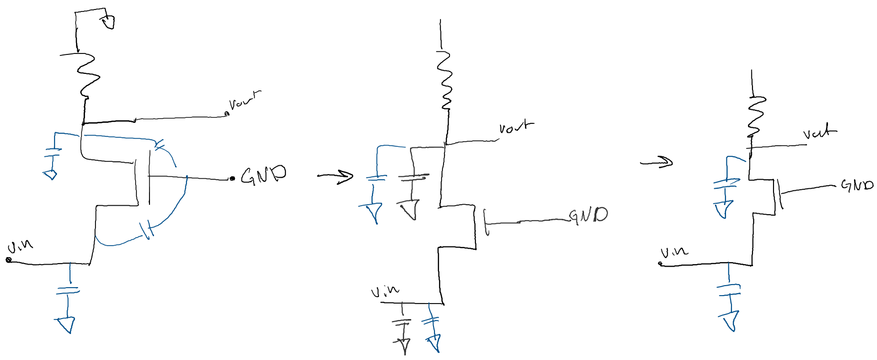
Solution:



No floating capacitor in the circuit.



BUT AS VB is ACGND



And the Miller becomes irrelevant!