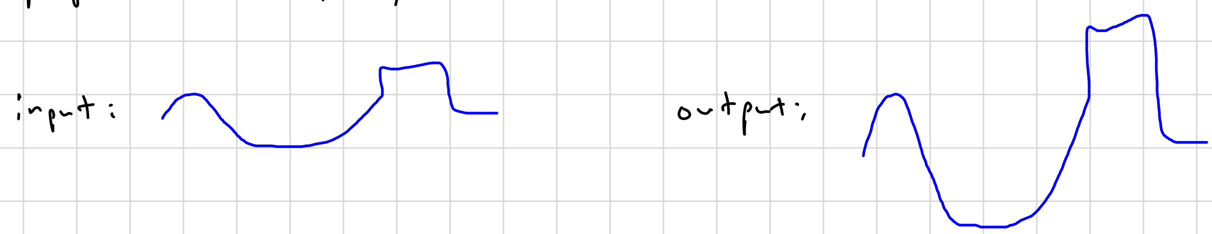
Lecture #19

Common-Source MOSFET Amplifier

Linear Amplifier: magnifies input signal with output signal of larger magnitude but directly proportional to input; hence "linear"



current/voltage notations:

i_D, v_{GS} — Total instantaneous values (at a specific instance of time)

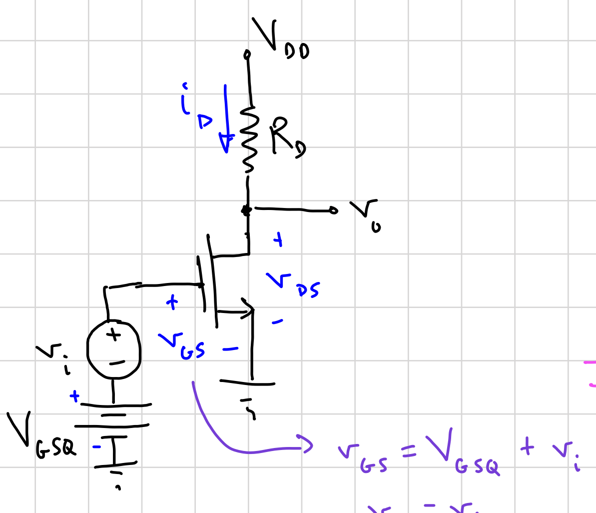
I_D, V_{GS} — DC values

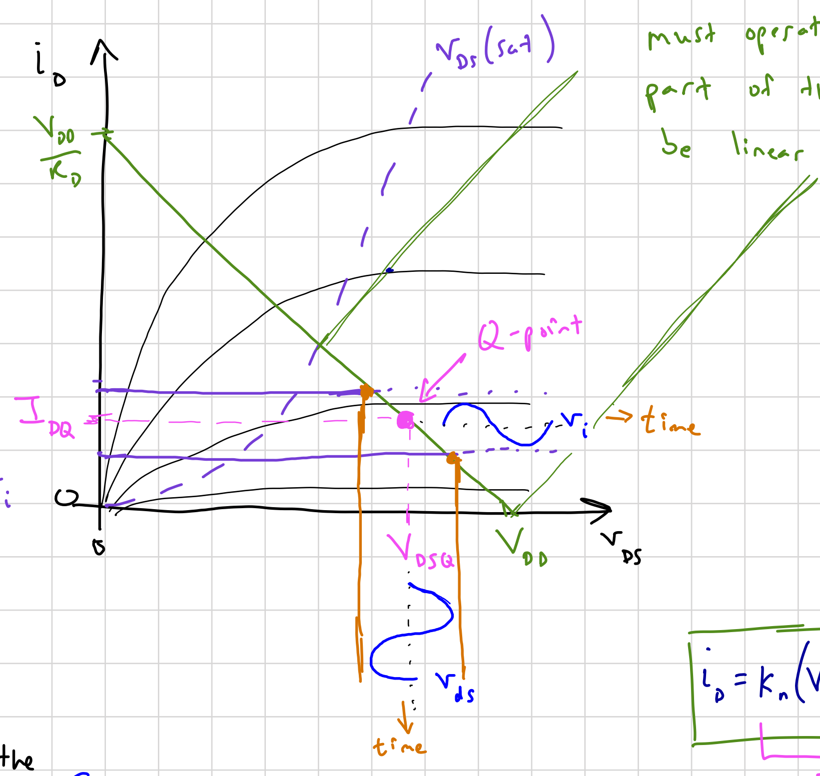
i_d, v_{gs} — Instantaneous AC values

I_d, V_{gs} — Phasor values (we will not use these, just replace with the instantaneous ac values instead)

"small signal": able to linearize the ac equivalent circuit

- Simple NMOS Common-Source Circuit with ac signal in series





must operate within the saturation on this part of the load line, otherwise will not be linear amplification!

$$v_{GS} = V_{GSQ} + v_i = V_{GSQ} + v_{gs}$$

$$i_D = K_n (v_{GS} - V_{TN})^2$$

$$i_D = K_n ((V_{GSQ} - V_{TN}) + v_{gs})^2$$

OR

$$\boxed{i_D = \underbrace{K_n (V_{GSQ} - V_{TN})^2}_{I_{DQ}} + \underbrace{2K_n (V_{GSQ} - V_{TN}) v_{gs}}_{i_d} + K_n v_{gs}^2}$$

produces distortion in amplification

So: $v_{gs} \ll 2(V_{GSQ} - V_{TN})$

condition must be satisfied to be a small-signal linear amplifier

$\therefore$ neglect this term and get: $\boxed{i_D = I_{DQ} + i_d}$

$$v_o = v_{DS} = V_{DD} - i_D R_D$$

transconductance relates the small-signal i_d and v_{gs}:

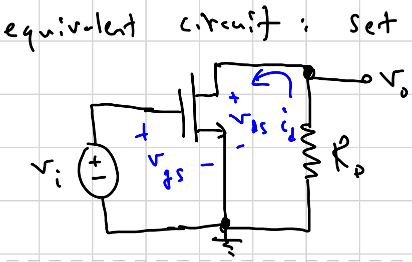
$$g_m = \frac{i_d}{v_{gs}} = 2K_n (V_{GSQ} - V_{TN}) = \left.\frac{\partial i_D}{\partial v_{GS}}\right|_{v_{GS} = V_{GSQ}}$$

→ represents the gain of the MOSFET

$$g_m = 2\sqrt{K_n I_{DQ}}$$

$\Rightarrow$ Part of being a linear circuit is that we can analyze the ac & dc parts separately and then add!

→ AC equivalent circuit: set DC sources to zero:

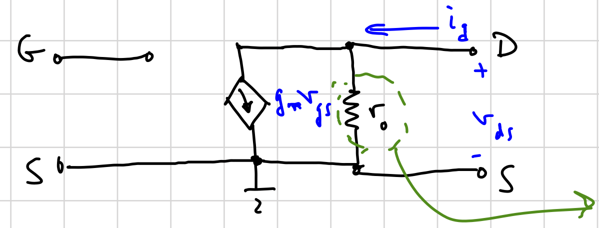


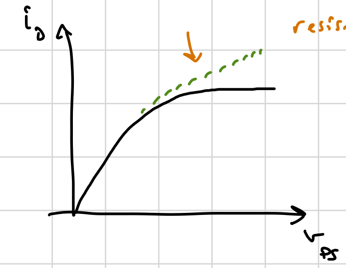
$$v_{ds} = -i_d R_D$$

$$i_d = g_m v_{gs}$$

$$v_{gs} = v_i$$

→ one step further for ac equiv. circuit is to include the small-signal equiv. circuit for the MOSFET (assuming low frequency)





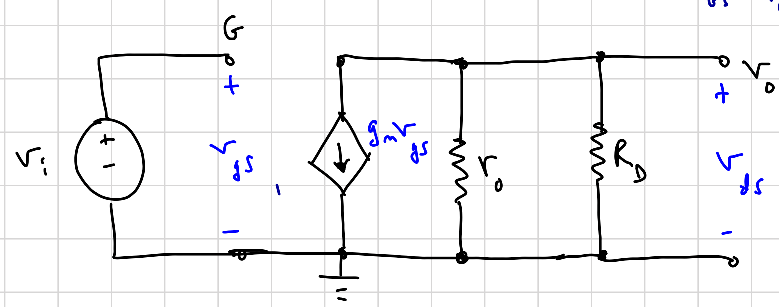
$$i_D = K_n\left[(v_{GS}-V_{TN})^2(1+\lambda v_{DS})\right]$$

λ: channel length modulation parameter

$$r_o = \left(\frac{\partial i_D}{\partial v_{DS}}\right)^{-1}\Bigg|_{v_{GS}=V_{GSQ}=\text{constant}} = \left[\lambda I_{DQ}\right]^{-1}$$

Bringing these together:

ac equiv. circuit:

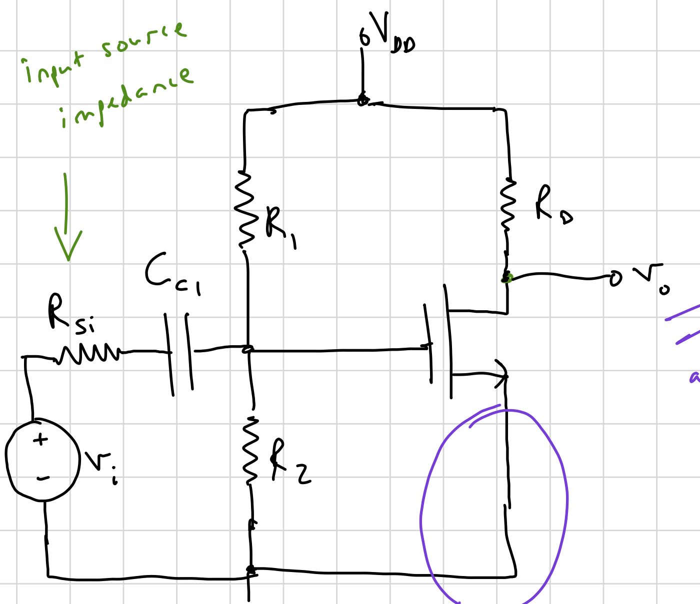


Look at steps in book on pg. 594 (E-book)

Small-signal voltage gain:

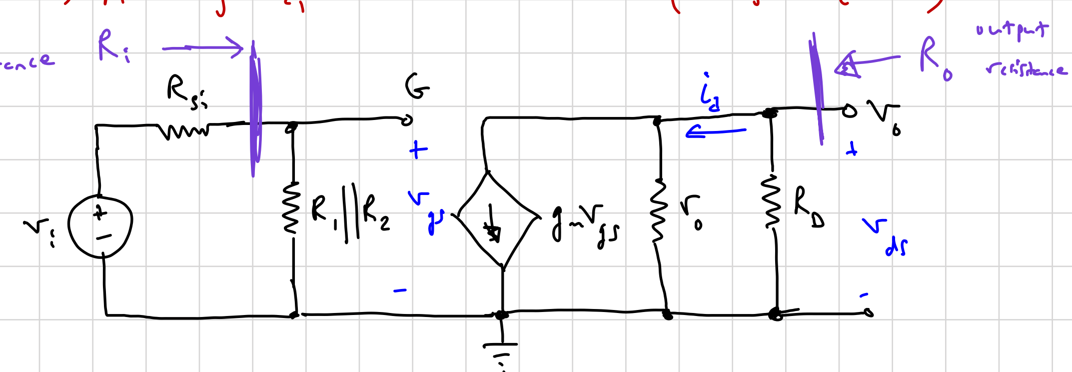
$$\boxed{A_v = \frac{v_o}{v_i} = -g_m\underbrace{(r_o \| R_D)}_{\frac{r_o R_D}{r_o + R_D}}}$$

- Common-Source Amplifier



ac equiv. circuit

→ ignoring capacitor effects in MOSFET
→ Assuming C_{C1} is like a short (~high frequencies)



Find R_o by setting $v_i = 0$, $v_{gs} = 0$: $R_o = R_D \| r_o$

$$v_o = -g_m v_{gs}(r_o \| R_D) \quad , \quad v_{gs} = \left(\frac{R_i}{R_i + R_{Si}}\right)v_i$$

$\hookrightarrow R_{Si} << R_i$

$$\therefore \boxed{A_v = \frac{v_o}{v_i} = -g_m(r_o \| R_D)\left(\frac{R_i}{R_i + R_{Si}}\right)}$$

Options: ① Add source resistor (R_S) to make Q-point more consistent from transistor to transistor
→ loose some A_v
→ more stable Q-point

② Add bypass capacitor and constant current source
→ lessen A_v loss
→ further stabilize Q-point
→ increased complexity