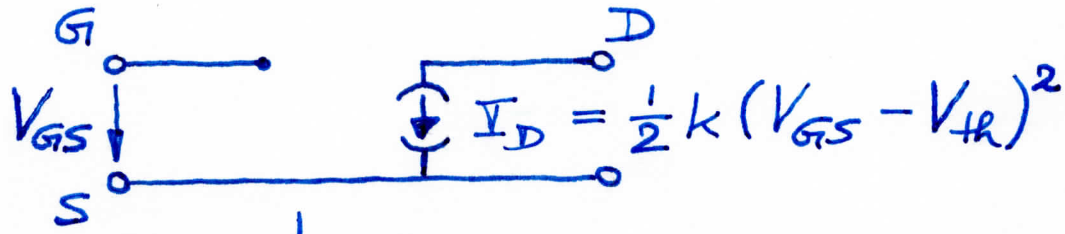
Equivalent circuit of FET

Recall: $I_D = \frac{1}{2} k \, (V_{GS} - V_{th})^2$

↳ this was shown above

Equivalent circuit (n-channel FET)



↳ Large-signal equivalent circuit

Example: Consider FET with $V_{th} = 2V$ and $k = 10 \frac{mA}{V^2}$

↳ n-channel FET

Q: $V_{GS} = 0V \Rightarrow I_D = ?$

$\Rightarrow I_D = 0$

Q: $V_{GS} = 2V \Rightarrow I_D = ?$

$I_D = \frac{1}{2} k \, (V_{GS} - V_{th})^2 = 0$

Q: $V_{GS} = 4V \Rightarrow I_D = ?$

$$I_D = \frac{1}{2} k \, (V_{GS} - V_{th})^2 = \frac{1}{2} \, 10 \frac{mA}{V^2} \, (4V - 2V)^2$$

$$= \frac{1}{2} \, 10 \frac{mA}{V^2} (2V)^2 = \frac{1}{2} \, 10 \, mA \; 4 = 20 \, mA$$

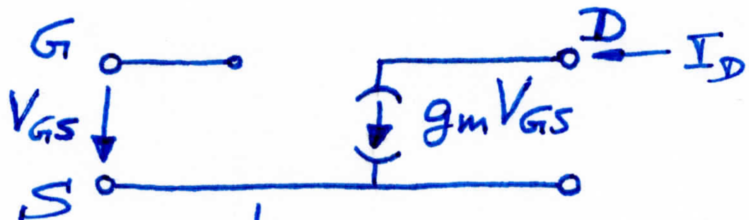
Q: I_D - vs - V_{GS} curve. Linear or non-linear?

⇒ **Non-linear** (parabola)

Q: In the small-signal regime, is I_D-vs-V_{GS} linear or nonlinear?

⇒ In small-signal regime, we can linearize the I_D-vs-V_{GS} curve.

Small-signal equivalent circuit



↳ small signal equivalent circuit

$$g_m = \frac{dI_D}{dV_{GS}} = \frac{d\,(\text{Output current})}{d\,(\text{Input voltage})}$$

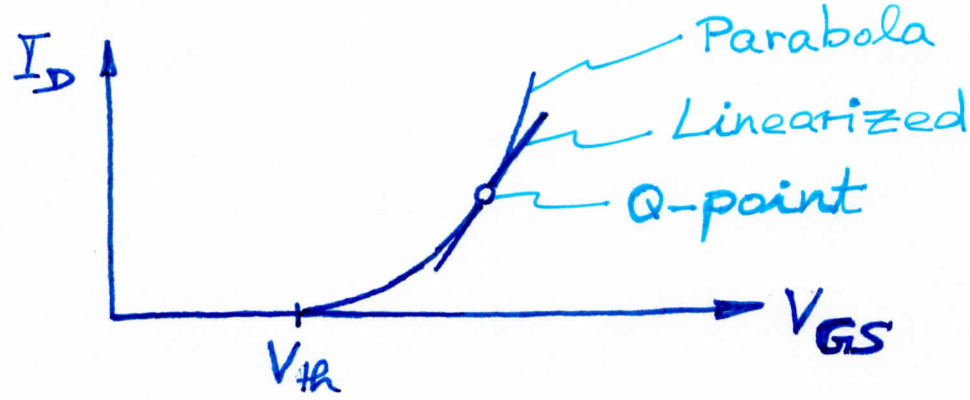
$$= \underbrace{\text{Trans}}_{\frac{\text{Output}}{\text{Input}}}\underbrace{\text{conductance}}_{I/V}$$

Units $\{g_m\}$ = A/V = S

↳ Siemens (e.g. 200mS)

Dependence of g_m on k

Recall $I_D = \frac{1}{2} k \left(V_{GS} - V_{th}\right)^2$



$$g_m = \left.\frac{dI_D}{dV_{GS}}\right|_{Q\text{-point}} = \frac{d}{dV_{GS}} \frac{1}{2} k \left(V_{GS} - V_{th}\right)^2$$

$$= \frac{1}{2} k \, 2 \left(V_{GS} - V_{th}\right) = k \left(V_{GS} - V_{th}\right)$$

$$\boxed{g_m = k\left(V_{GS} - V_{th}\right)}$$

$\rightarrow$ V_{GS} of Q-point (Quiescent point)

Example: Consider n-channel FET with $k = 50 \frac{mA}{V^2}$ and $V_{th} = 0.5V$. Determine Q-point at which $g_m = 100\ mS$ (milli siemens).

Transconductance $= g_m = k(V_{GS} - V_{th})$

$\Rightarrow$ Solve for $V_{GS} \Rightarrow V_{GS} = \frac{g_m}{k} + V_{th} =$

$$= \frac{100\ mA/V}{50\ mA/V^2} + 0.5V = 2V + 0.5V = 2.5V$$

FET input is capacitor-like $\Rightarrow$ No input current (DC) $\Rightarrow$ No input power!

Q: Is zero input power good or bad for an amplifier?

$\Rightarrow$ Very good (especially for low-power signals that are to be amplified)

Small-signal regime $\Rightarrow$ Use lower-case i and v

$$\Rightarrow \quad \boxed{i_D = g_m\, v_{GS}}$$

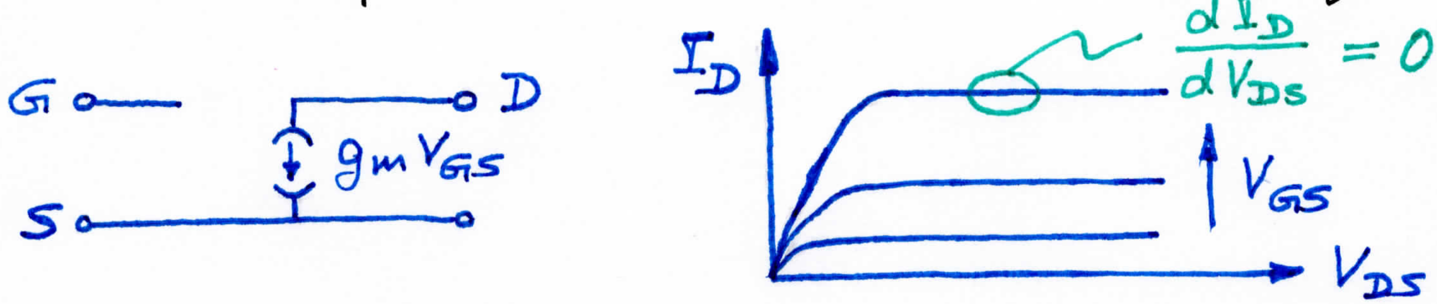
Input voltage

Transconductance

Output current

FET : Non-ideal output impedance

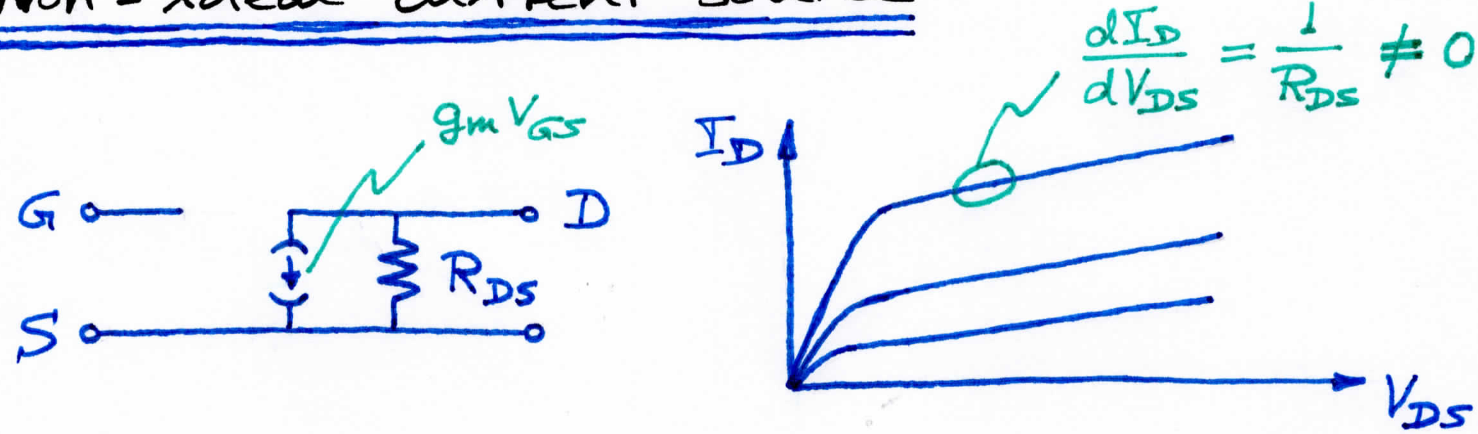
Recall : Equivalent circuit (small signal)



$\Rightarrow \frac{dI_D}{dV_{DS}} = 0 \Rightarrow$ Ideal current source

$\Rightarrow$ Infinite output impedance

Non-ideal current source



$\Rightarrow \frac{dI_D}{dV_{DS}} \neq 0 \Rightarrow$ Non-ideal current source

$\Rightarrow$ FET has finite output impedance ($= R_{DS}$)