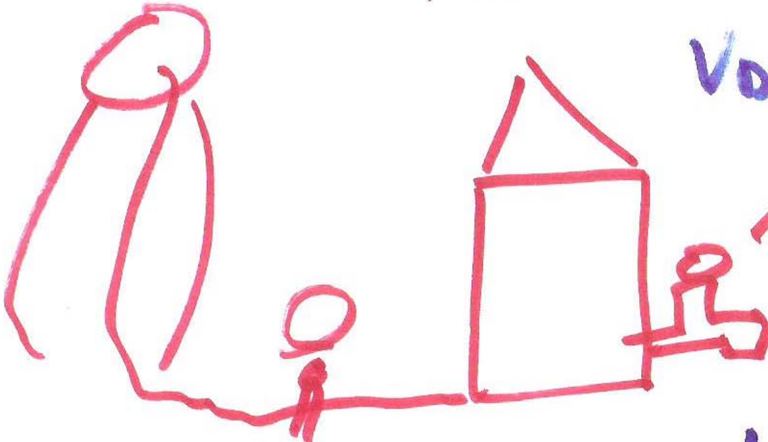
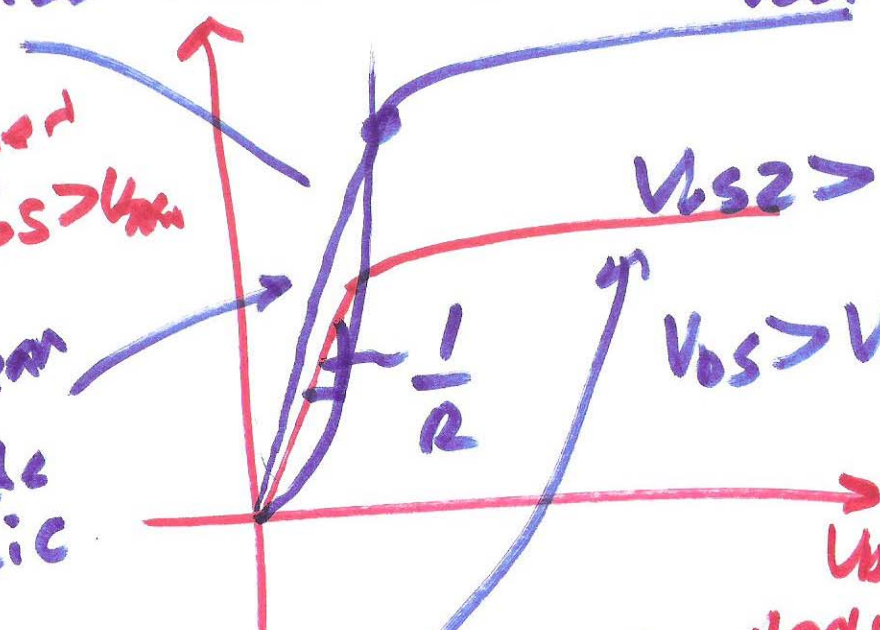
EE 320 Electronics

Lecture 14, 3/15/2013

MOSFET Operation





Linear
triode
ohmic

Saturation, Apply water pressure

$$I_D = \mu_n C'_{ox}\frac{W}{L}\left((V_{GS}-V_{THN})V_{DS} - \frac{V_{DS}^2}{2}\right)$$

$V_{GS}>V_{THN}$

$$K'_n = \mu_n C'_{ox} = KP$$

$$\beta = KP\cdot\frac{W}{L} = \mu_n C'_{ox}\cdot\frac{W}{L}$$

$$I_D = \frac{\mu_n C'_{ox}}{2}\cdot\frac{W}{L}\left(V_{GS}-V_{THN}\right)^2$$

Saturation

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1)

$$i_D = I_D + i_d = \frac{W}{L}\mu_n C'_{ox}\left((v_{GS} - V_{THN})v_{DS} - \frac{v_{DS}^2}{2}\right)$$

triode equation in triode

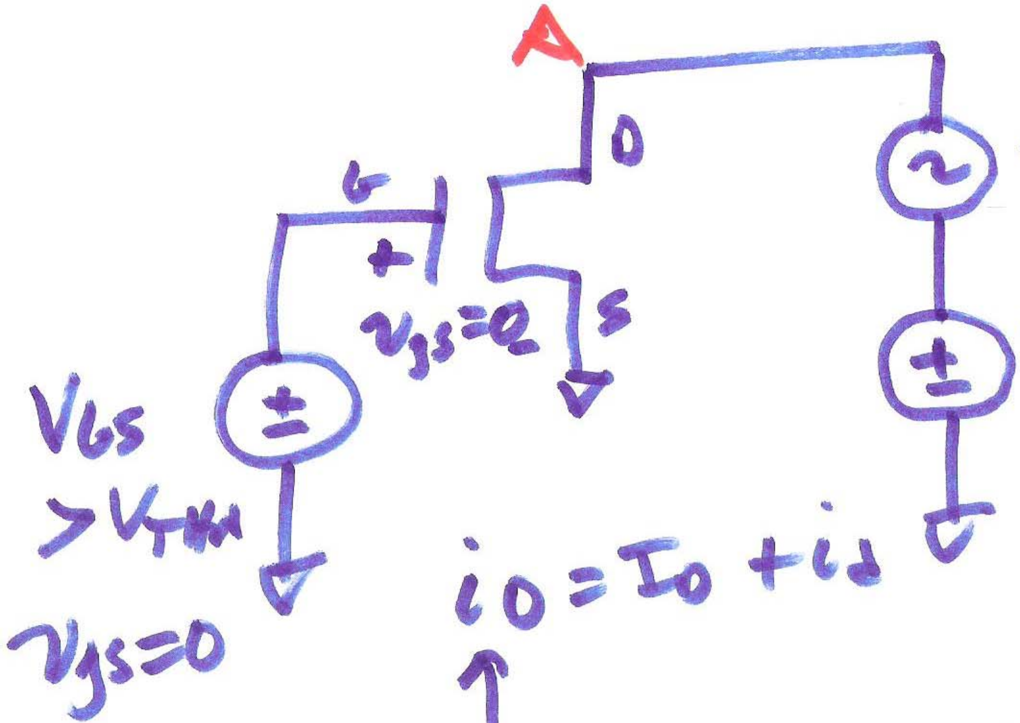
$$v_{GS} = V_{GS} + v_{gs}$$
$$v_{DS} = V_{DS} + v_{ds}$$

$$V_{GS} > V_{THN}$$
$$V_{DS} < V_{GS} - V_{THN}$$

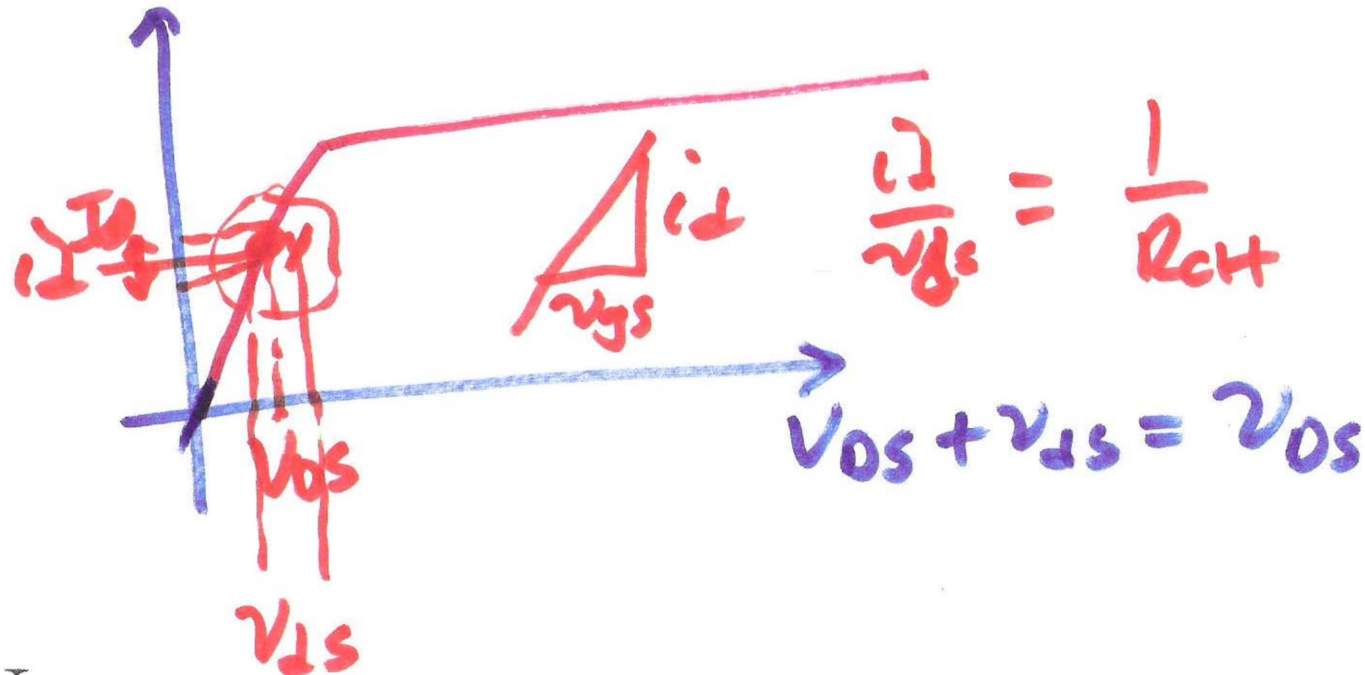
$$i_D = I_D + i_d = \frac{W}{L}\mu_n C'_{ox}\left((v_{GS} - V_{THN})v_{DS} - \frac{v_{DS}^2}{2}\right)$$

$F/\text{AREA} \leftarrow C'_{ox} = \frac{\epsilon_{ox}}{t_{ox}}$

$C_{ox} = C'_{ox} \cdot W \cdot L \rightarrow$ AREA



$i_D = I_D + i_d$



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$$R_{CH}^{-1} = \frac{\delta i_D}{\delta v_{DS}}\Bigg|_{\substack{I_D = CONST \\ V_{DS} = CONST}} = \frac{\delta}{\delta v_{DS}} \frac{W}{L}\mu_n C'_{ox} \cdot \left((V_{GS} - V_{THN}) \cdot v_{DS} - \frac{v_{DS}^2}{2} \right)$$

$$R_{CH}^{-1} = \frac{W}{L}\mu_n C'_{ox}\left((V_{GS} - V_{THN}) - V_{DS} \right)$$

$V_{DS} >> v_{ds}$ (small-signal approximation)

$$R_{CH} \approx \frac{1}{\frac{W}{L}\mu_n C'_{ox}\left((V_{GS} - V_{THN}) - V_{DS} \right)}$$

$V_{GS} > V_{THN}$

$V_{DS} < V_{GS} - V_{THN}$

if V_{DS} is small $\quad R_{CH} \approx \dfrac{1}{\frac{W}{L}\mu_n C'_{ox}(V_{GS} - V_{THN})}$

4.9) $I_D = ?$

$V_{GS} = 0, 1, 2, 3$

$V_{DS} = 0.25$

$V_{TN} = 800mV$

$W = 5\mu$ $\quad L = 0.5\mu$

$K_n' = 200\mu A/V^2$ $\quad K_n = ?$

$K_n = K_n' \cdot \frac{W}{L}$

$= \frac{200\mu A}{V^2} \cdot \frac{5\mu}{.5\mu}$

$K_n = 2\, mA/V^2$

$V_{GS} = 0, \ I_D = 0$

$V_{GS} < V_{THN}$

$V_{GS} = 1V \quad I_D \neq 0$

SAT.

$V_{DS} \geq V_{GS} - V_{THN}$

$0.25 \overset{?}{\geq} 1 - .8 = 0.2$

$I_D = \frac{K_n}{2}(V_{GS} - V_{THN})^2 = \frac{2mA}{2}(1 - .8)^2$

5)

$V_{GS} = 2V \quad I_D \neq 0$

$V_{DS} \geq V_{GS} - V_{THN}$ (for saturation)

$0.25 \overset{?}{\geq} 2 - .8 = 1.2$

NO, MUST be in triode

$$I_D = K_N\left((V_{GS}-V_{THN})V_{DS} - \frac{V_{DS}^2}{2}\right)$$

$$I_D = \frac{2\,\mu A}{V^2}\left((2-.8).25 - \frac{.25^2}{2}\right)$$

$V_{DS} = V_{GS} - V_{THN}$ triode or saturation?

$$I_D = K_N\left((V_{GS}-V_{THN})\underbrace{(V_{GS}-V_{THN})}_{} - \frac{\overbrace{(V_{GS}-V_{THN})}^{V_{DS}}{}^2}{2}\right)$$

$$= K_N\left((V_{GS}-V_{THN})^2 - \frac{(\overbrace{V_{GS}}^{V_{DS}} - V_{THN})^2}{2}\right)$$

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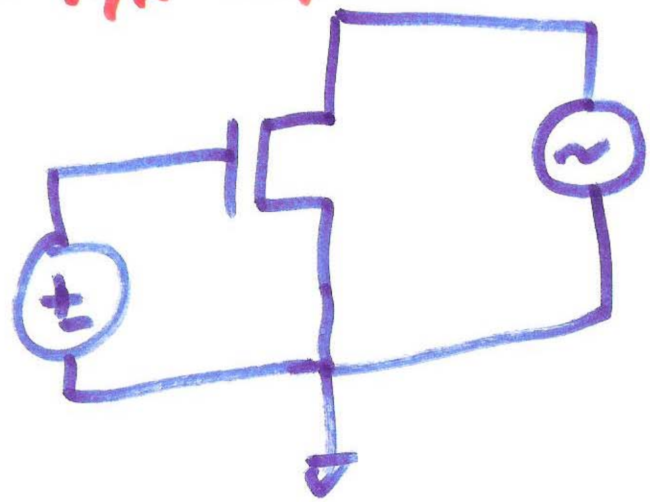
4.16) $V_{TN} = 0.75$

$K' = 100\mu A/V$

$= \mu_n \cdot C'_{ox}$



$$R_{CH} = \frac{1}{K' \cdot \frac{W}{L} \cdot (V_{GS} - V_{THN})}$$

$$500 = \frac{1}{100\mu \cdot \frac{W}{L} \cdot (5 - .8)}$$

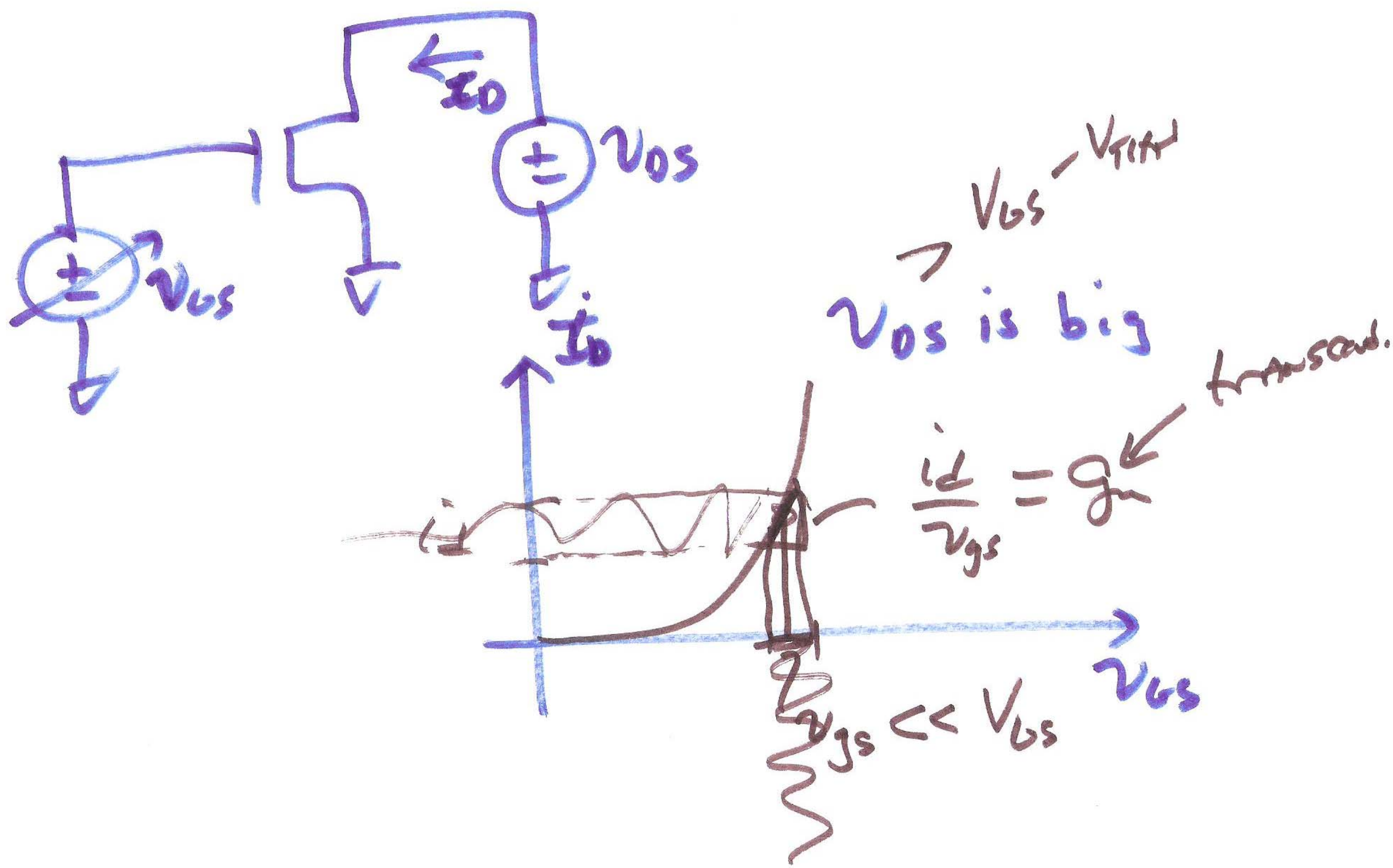
.75

$$\frac{W}{L} = \frac{1}{500 \cdot 100\mu \cdot 4.25}$$

$= 4.7$

$W = 47\mu$

$L = 10\mu$



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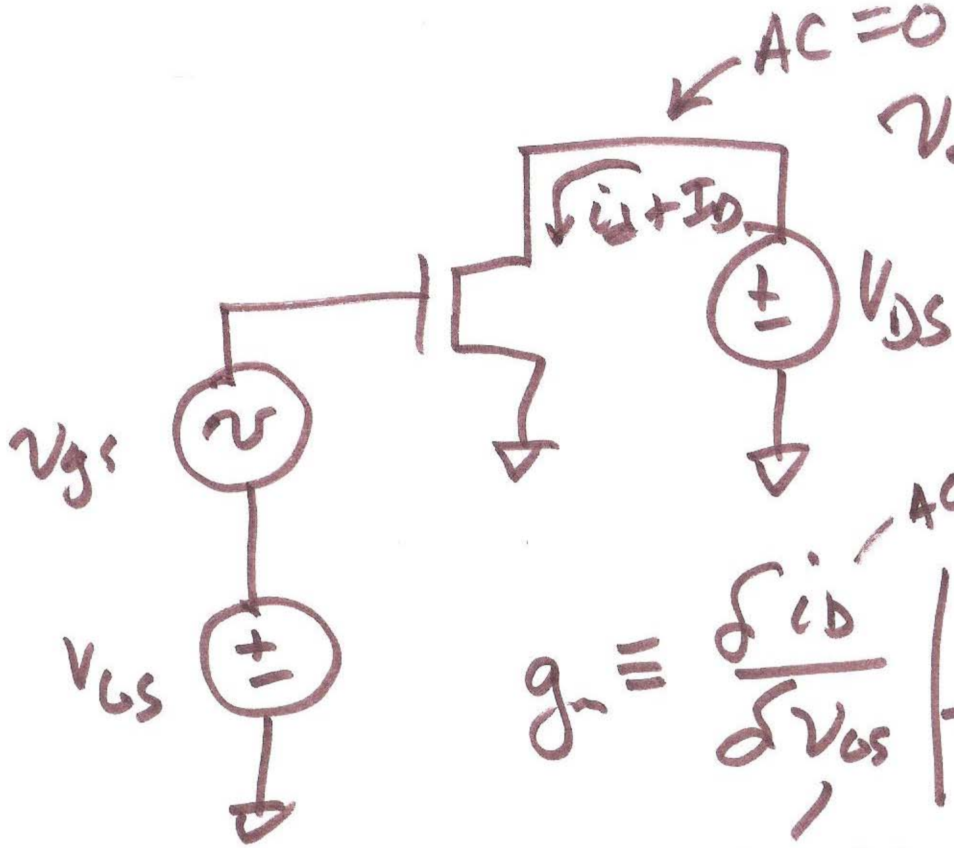

$v_{ds} = 0$

$$g_m \equiv \frac{\partial \overbrace{i_D}^{AC+DC}}{\partial \underbrace{v_{GS}}_{AC+DC}}\Bigg|_{\substack{I_D = CONST \\ V_{GS} = CONST}} = \frac{i_d^{\;AC}}{v_{gs_{AC}}}$$

$$= \frac{\partial \frac{K'W}{2L}\left(v_{GS} - V_{THN}\right)^2}{\partial v_{GS}}$$

$$\boxed{K'\cdot\frac{W}{L}\left(V_{GS} + v_{gs} - V_{THN}\right) = g_m} \Longleftarrow \equiv \frac{\partial}{\partial v_{GS}}\Bigg|\frac{K'}{2}\cdot\frac{W}{L}\left(V_{GS} + v_{gs} - V_{THN}\right)^2\Bigg|_{\substack{I_D = CONST \\ V_{GS} = CONST}}$$

$V_{GS} \gg v_{gs}$

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$I_D = \frac{K'}{2}\cdot\frac{W}{L}(V_{GS}-V_{THN})^2$

$= \frac{100\mu}{2}\cdot 5\cdot 1^2$

$= 250\mu A$

$$\boxed{g_m = K'\cdot\frac{W}{L}\left(V_{GS}-V_{THN}\right)}$$

Made-up example

$v_{ds}=0$

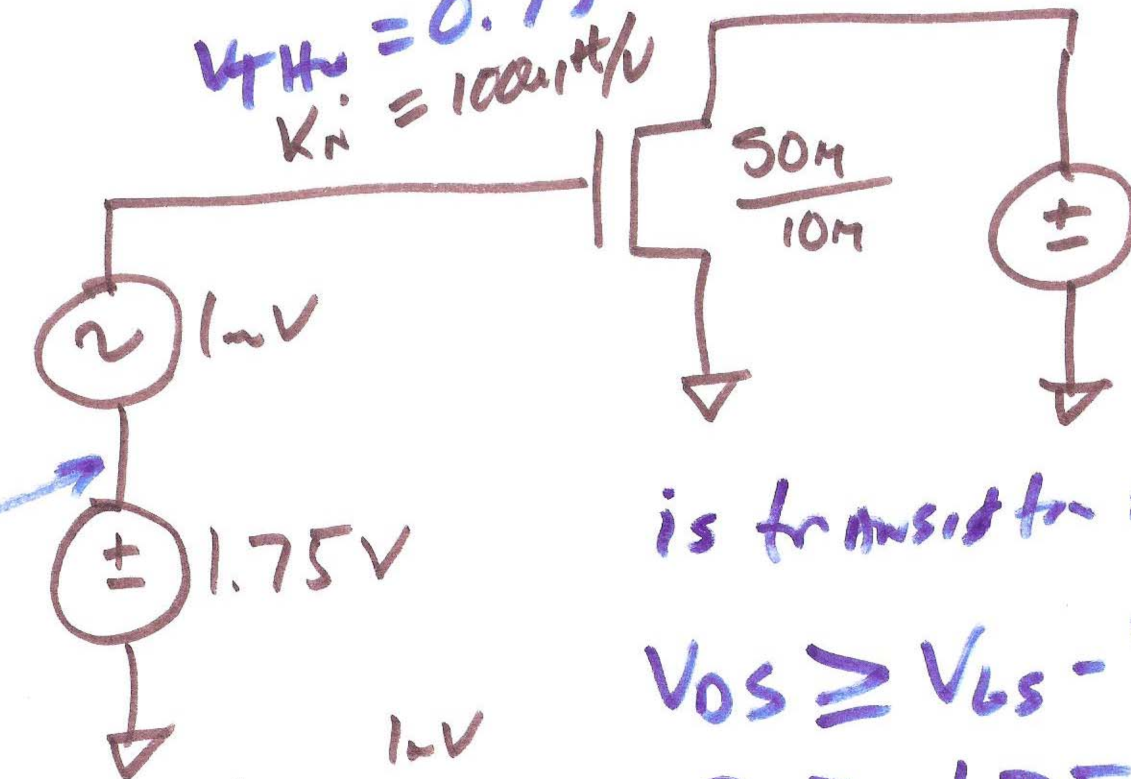
$V_{DS}=3$

$V_{THN}=0.75$

$K_n'=100\mu A/V$

$v_{gs}=1mV$

$V_{GS}=1.75$



AC = 0

is transistor in SAT?

$V_{DS} \geq V_{GS} - V_{THN}$

$3 \overset{?}{\geq} 1.75 - .75$

yes, in SAT!

$i_d = \underbrace{g_m}_{500\mu A/V}\,\overbrace{v_{gs}}^{1mV} \Rightarrow i_d = 500nA$

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