Unit 6. Transconductances of MOSFET and BJT

Voltage gain of amplifier stages

MOSFET voltage amplifier stage

MOSFET transconductance

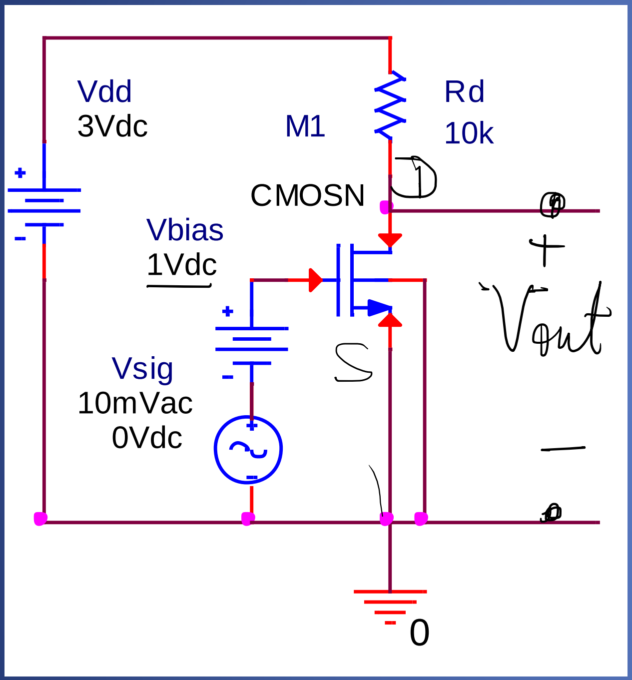
Small-signal equivalents:
π-model vs T-model

Load line

Voltage gain of a common-source amplifier stage with resistive load

BJT transconductance

Example: Voltage Amplifier with Common Source



$$A_v = \frac{v_{out}}{v_{in}} - ?$$

$W = 10\,\mu m \quad L = 0.5\,\mu m$

$k_n' = 200\,\mu A/V^2 \quad V_{bias} = 1V$

1) $V_{ov} = V_{bias} - V_{tn} = 1 - 0.7 = 0.3V$

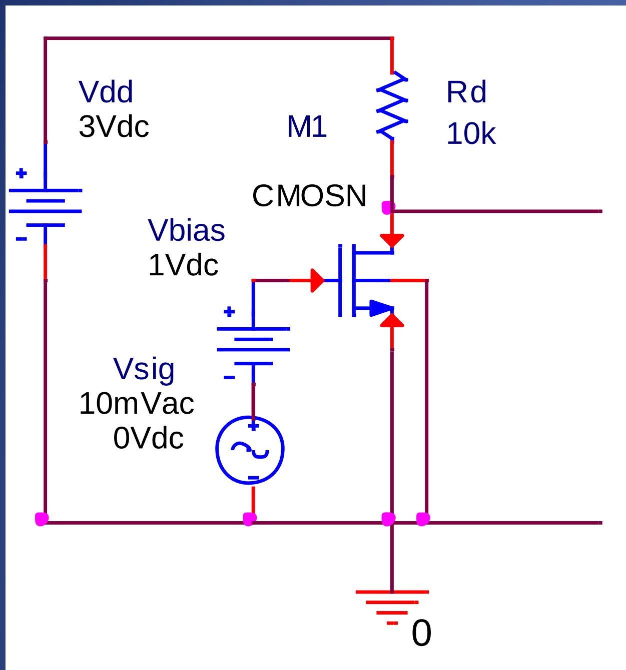
2) $I_{D\,sat} = \frac{1}{2} k_n' \frac{W}{L} V_{ov}^2 = \frac{200}{2} \cdot 20 \cdot 0.09 = 180\,\mu A$

One can estimate the drain current with this expression only In the saturation region:
it is required to have V_DS > Vov = 0.3 V.   Indeed, V_DS = Vdd-Id*Rd= 3 – 0.18mA*10k = 1.2 V $> 0.3V$

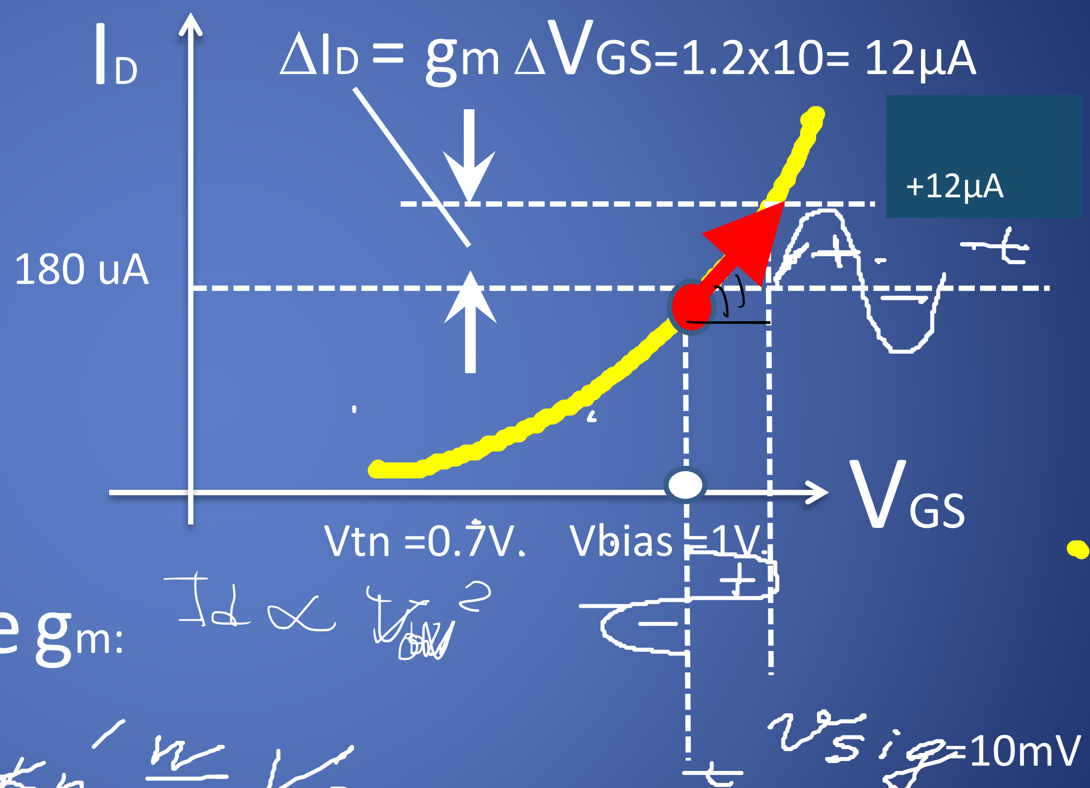
2

1.8V

Common-Source Gain Stage



TRANSFER CHARACTERISTIC: I_D VS V_{GS}



Transconductance g_m:

$I_d \propto V_{ov}^2$

$$g_m = \frac{\Delta I_D}{\Delta V_{GS}} = k_n' \frac{W}{L} V_{ov}$$

$$g_m = 200 \frac{\mu A}{V^2} \cdot 20 \cdot 0.3 = 1.2 \frac{mA}{V}$$

Estimation of the MOSFET transconductance from operating point (DC) parameters

$$g_m = k_n' \frac{W}{L} \cdot V_{ov}$$

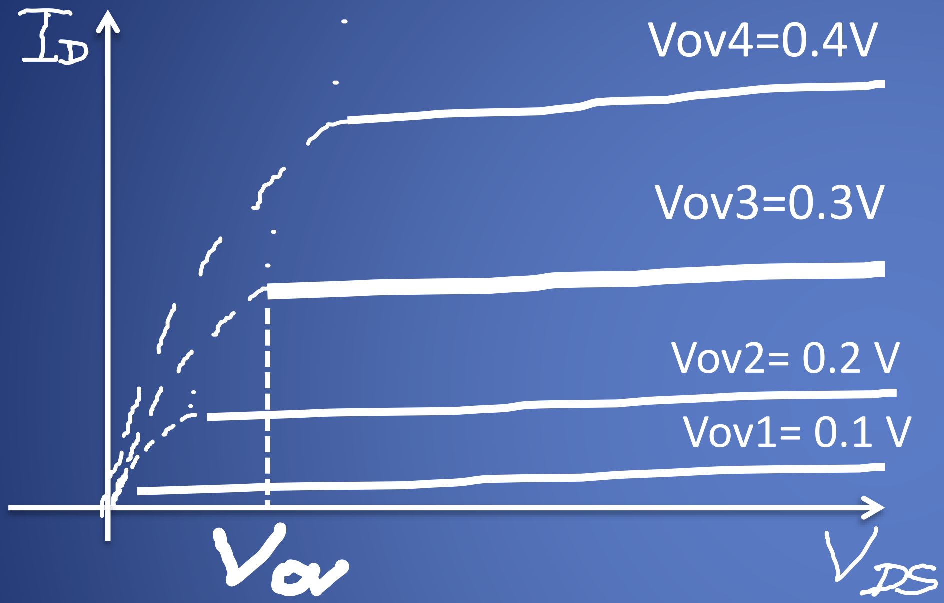
$$I_D = \frac{1}{2} k_n' \frac{W}{L} V_{ov} \cdot V_{ov}$$

$$I_D = \frac{1}{2} g_m V_{ov}$$

$$\boxed{g_m = \frac{2 I_D}{V_{ov}}}$$

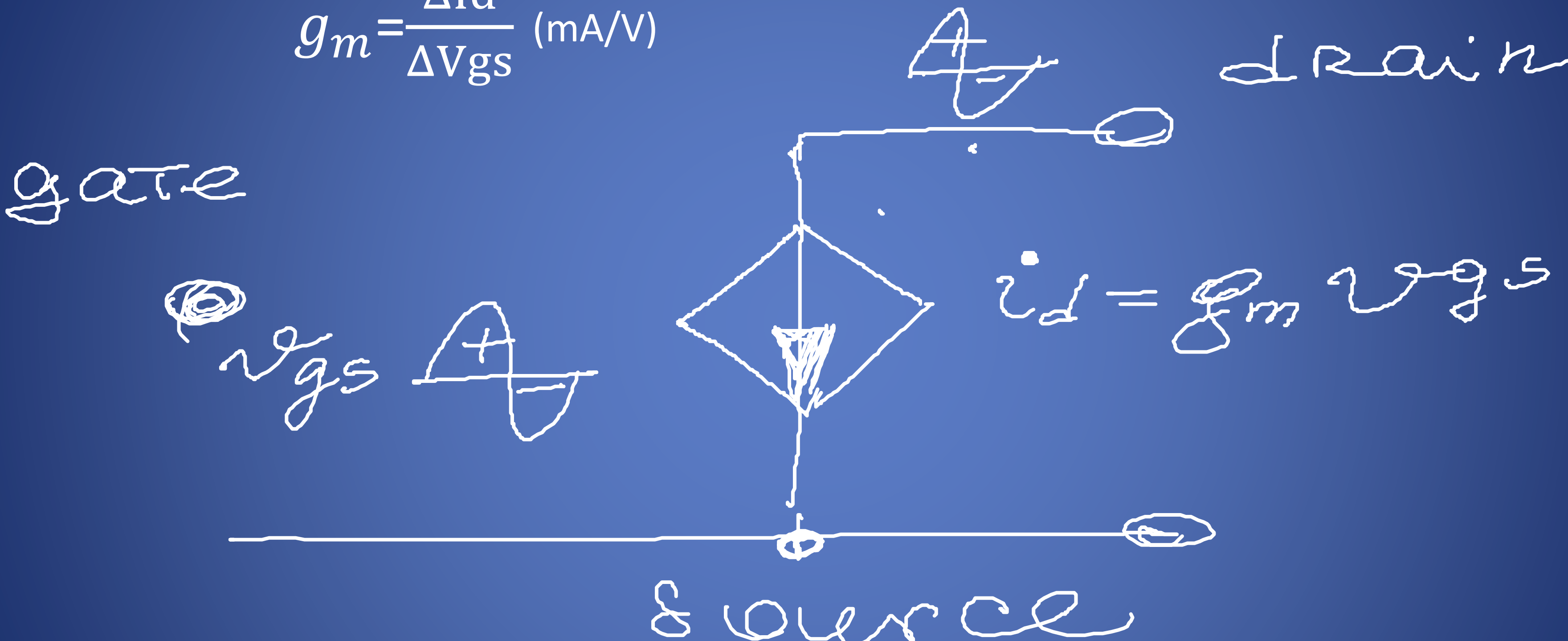
$$g_m = \frac{2 \cdot 0.18\,mA}{0.3\,V} = \frac{0.36}{0.3} = 1.2\,\frac{mA}{V}$$

MOSFET output characteristics

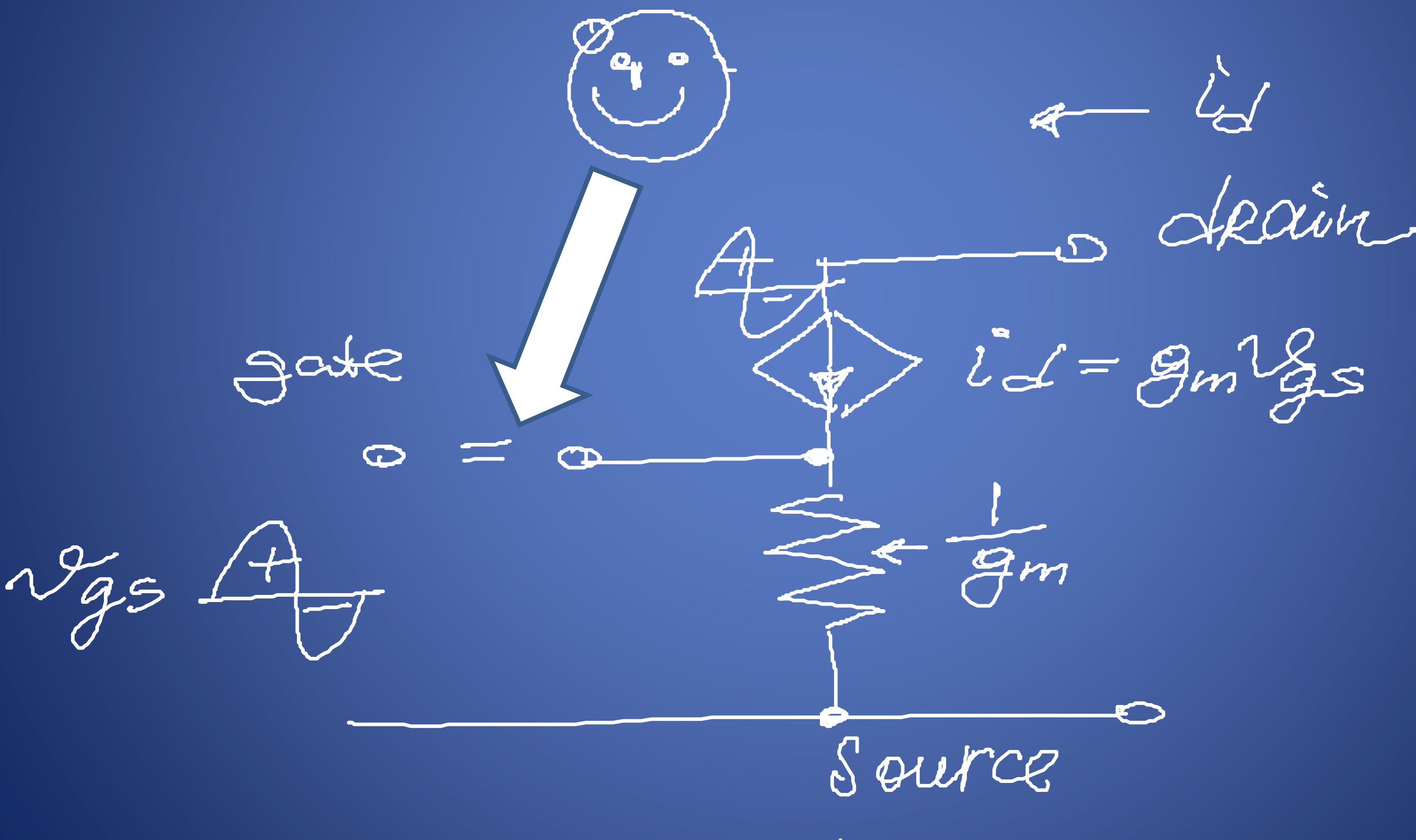


Small-signal model of the MOSFET: π-model

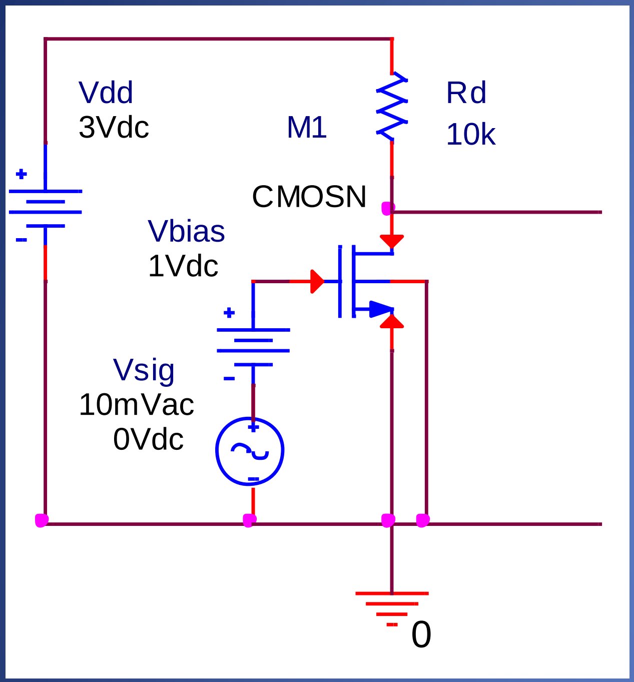
$g_m = \frac{\Delta Id}{\Delta Vgs}$ (mA/V)



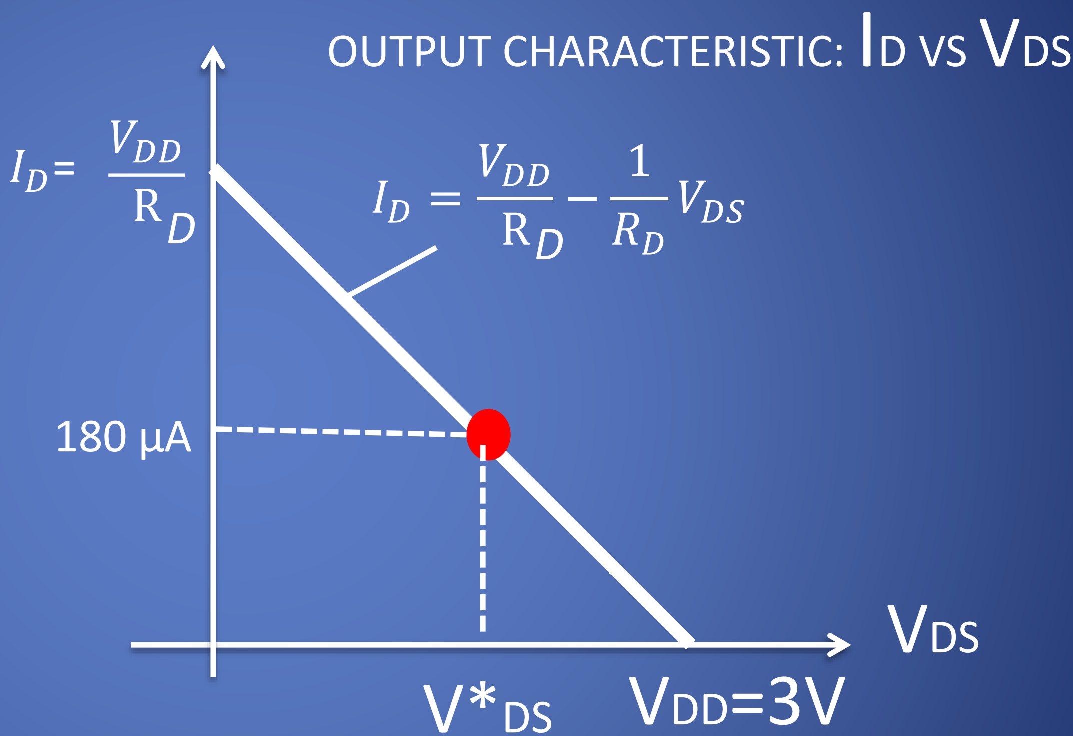
Alternative small-signal model of the MOSFET: T-model



Load Line equation: $V_{DD} = V_{DS} + I_D R_D$



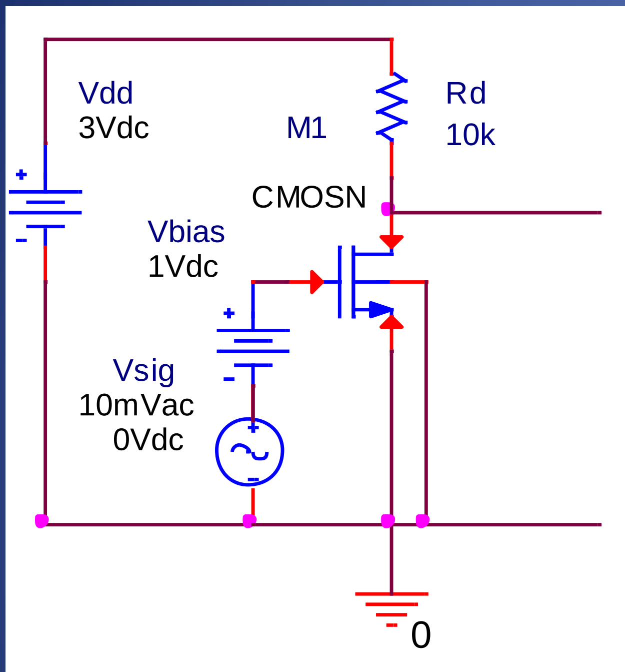
R_D converts change of I_D into change of V_{DS}:



$V^*_{DS} = V_{DD} - I_D R_D$ = 3- 0.18 mA x10k = 1.2 V > V_{ov} = 0.3 V

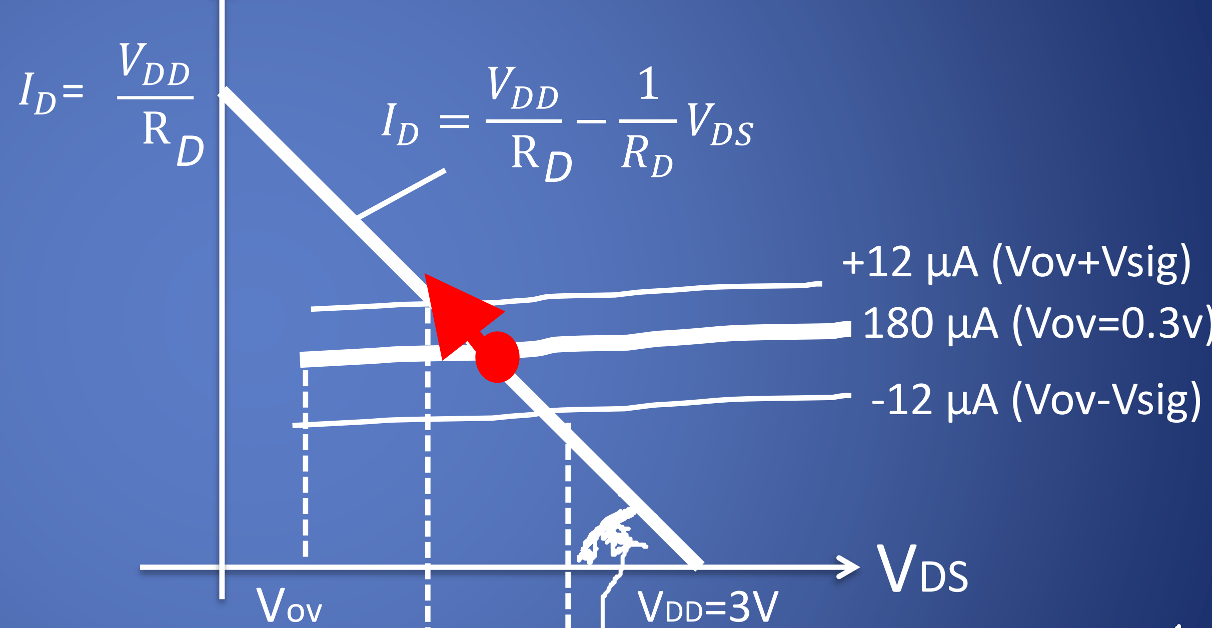
Indeed, MOSFET operates in the saturation mode and use of the square low for estimation of the drain current was adequate

Load Line equation: $V_{DD} = V_{DS} + I_D R_D$



R_D converts change of I_D into change of V_{DS}:

OUTPUT CHARACTERISTIC: I_D vs V_{DS}



$\Delta V_{DS} = -\Delta I_D R_D = g_m R_D \Delta V_{GS}$

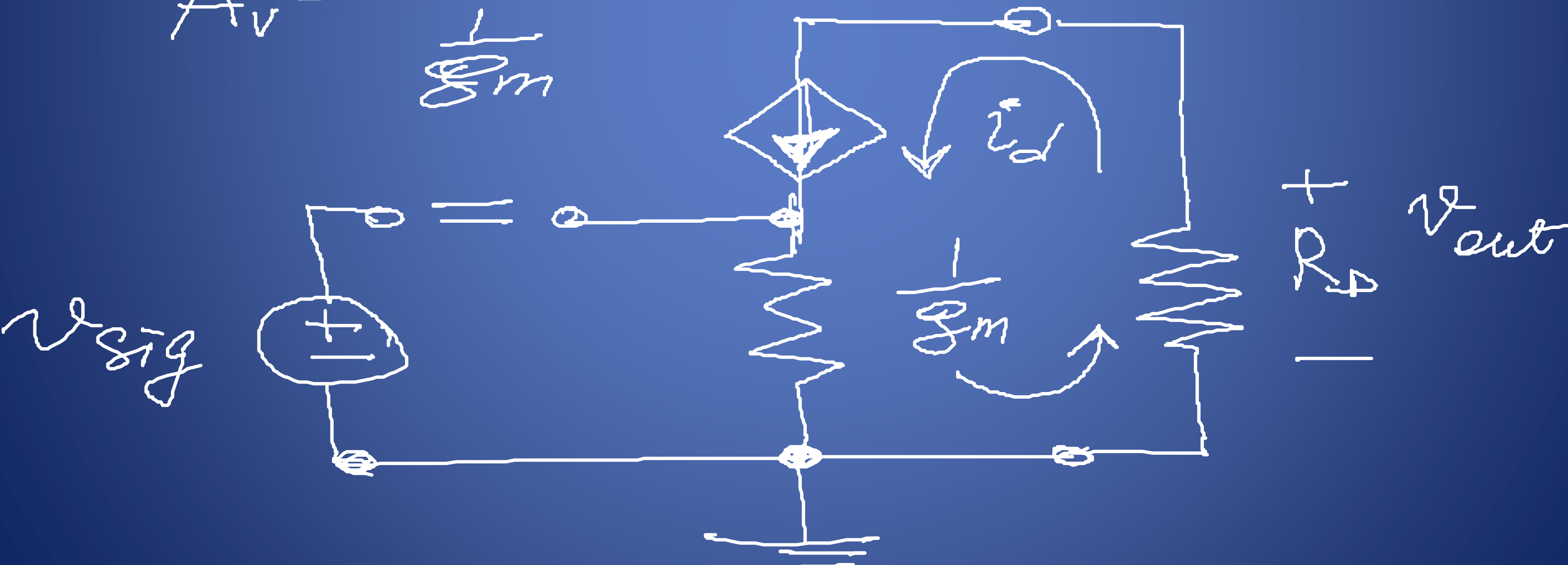
slope $= -\frac{1}{R_D}$

$|A_v| = g_m R_D = 1.2 \frac{mA}{V} \cdot 10 k\Omega = 12$ times only

Small signal model of the MOSFET amplifier stage with Common Source configuration

Voltage gain is defined by RATIO of the EQUIVALENT resistances in the DRAIN and SOURCE networks

$$A_v = -\frac{R_d}{\frac{1}{g_m}}$$



BJT transcoductance

$$g_m = \frac{\partial I_C}{\partial V_{BE}} = \frac{I_S}{V_T} \exp\left(\frac{V_{BE}}{V_T}\right) = \frac{I_C}{V_T}$$

$$g_m = \frac{I_C}{V_T}$$

$$g_m = \frac{180\mu A}{26mV} \simeq 7\frac{mA}{V}$$

At the same bias current
the BJT has much greater gm
compared to the MOSFET

TRANSFER CHARACTERISTIC: I_C VS V_{BE}