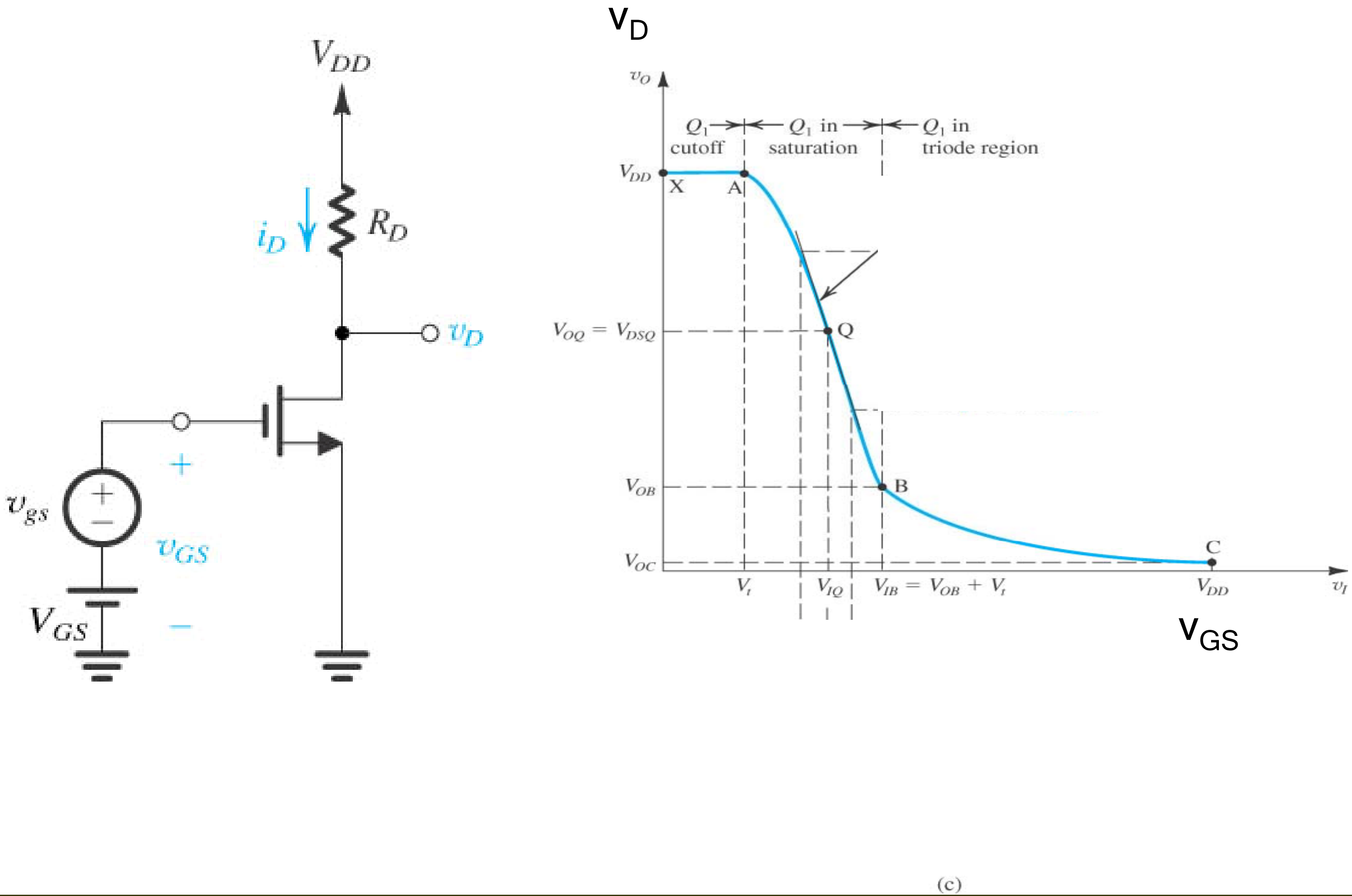
Lect. 21: MOSFET Small-signal Model

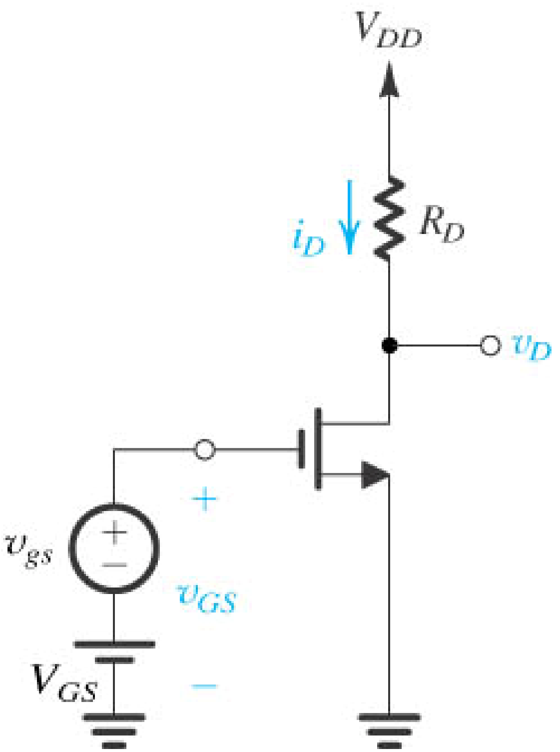
(Razavi 6.3.1)



Lect. 21: MOSFET Small-signal Model

(Razavi 6.3.1)

Decompose all signals into Large Signals and Small Signals

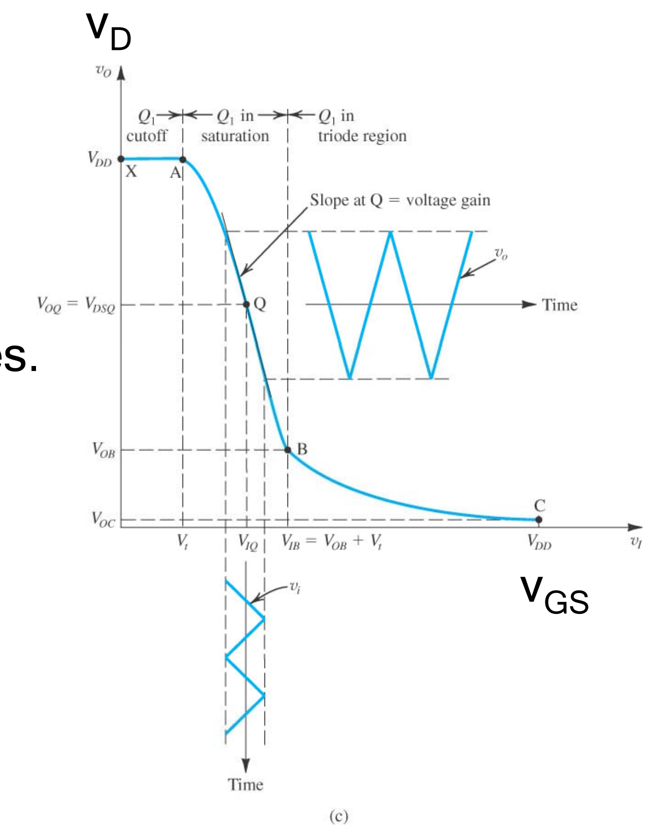


$v_{GS} = V_{GS} + v_{gs}$
$i_D = I_D + i_d$
$v_D = V_D + v_d$

Large signals provide biases.

Small signals are amplified.
($v_d = A_v v_{gs}$).

What is $A_v = v_d/v_{gs}$?



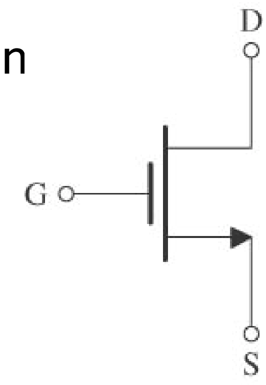
Lect. 21: MOSFET Small-signal Model

Small signal model for NMOS in saturation

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

$i_G = I_G + i_g$, $i_D=I_D + i_d$

➔ i_g, i_d as functions of v_{gs}, d_{vs}



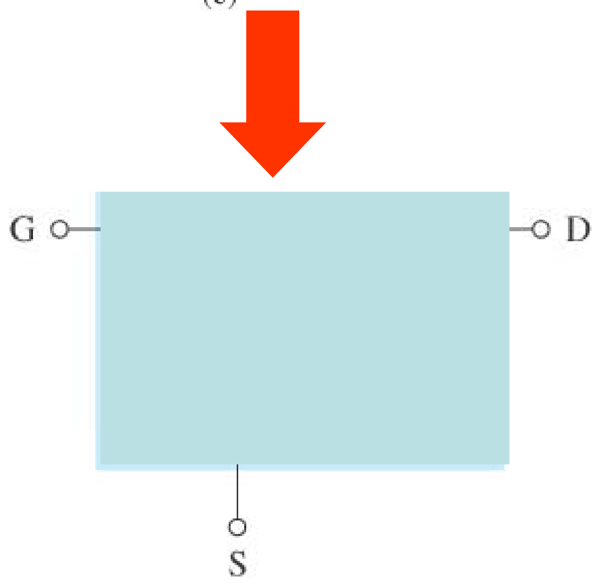
(c)

$$i_g = 0$$

From $i_D = \frac{1}{2}\mu_n C_{ox}\frac{W}{L}(v_{GS}-V_T)^2$ with $v_{GS}=V_{GS}+v_{gs}$

$$i_d = \frac{di_D}{dv_{GS}}\Big|_{V_{GS}} \cdot v_{gs} = \mu_n C_{ox}\frac{W}{L}(V_{GS}-V_T)\cdot v_{gs}$$

$$= g_m \cdot v_{gs}$$



(a)

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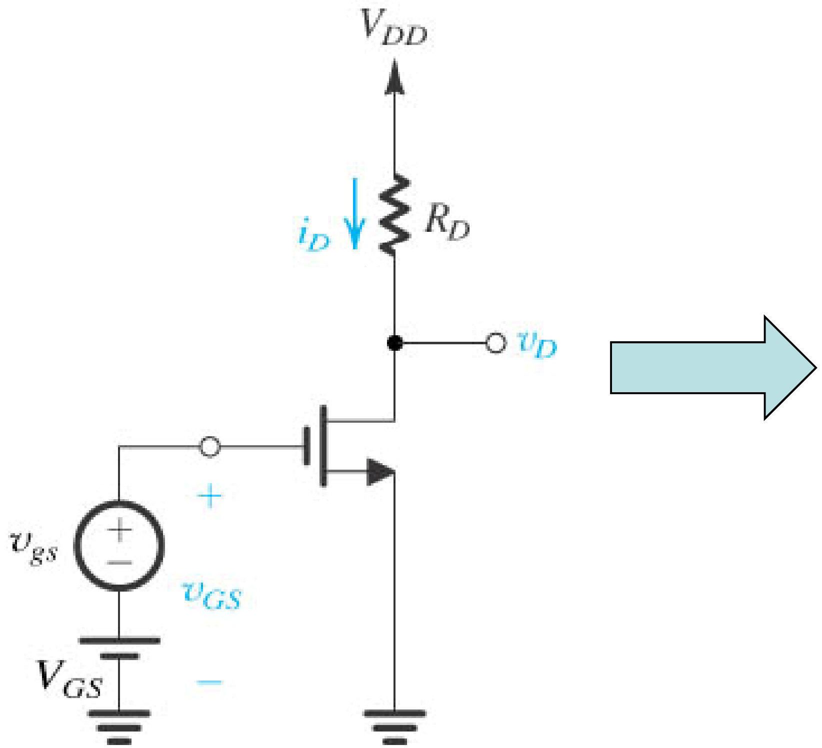

Small signal circuit

$$v_d = -g_m v_{gs} R_D$$

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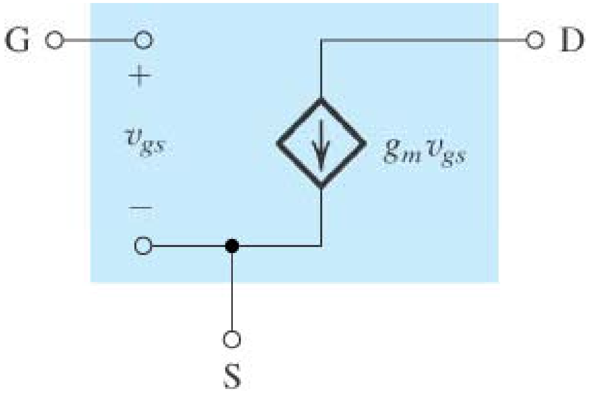


(a)

Various expressions for g_m

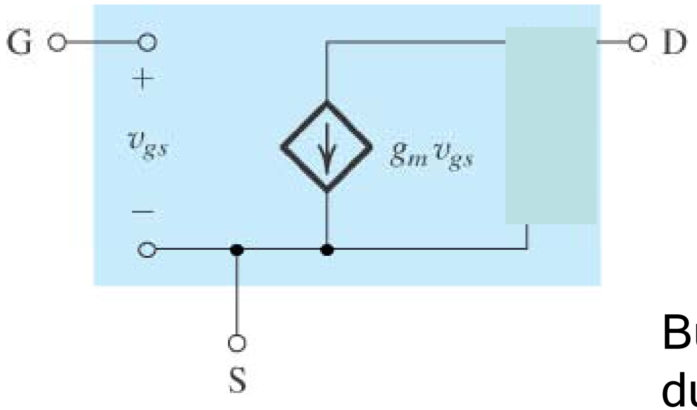
$$\text{From } i_D = \frac{1}{2}\mu_n C_{ox}\frac{W}{L}(v_{GS} - V_T)^2$$

$$g_m = \frac{di_D}{dv_{GS}}\Big|_{V_{GS}} = \mu_n C_{ox}\frac{W}{L}(V_{GS} - V_T)$$

$$= \frac{2I_D}{V_{GS} - V_T}$$

$$= \sqrt{2\mu_n C_{ox}\cdot\frac{W}{L}\cdot I_D}$$

Lect. 21: MOSFET Small-signal Model



(b)

➔ No change in i_d with v_{ds}

$$i_D = \frac{1}{2}\mu_n C_{ox}\frac{W}{L}(v_{GS} - V_T)^2$$

But in real MOSFET devices i_D increases due to channel length modulation

$$i_D = \frac{1}{2}k'\frac{W}{L}(1 + \lambda \cdot v_{DS})(v_{GS} - V_t)^2$$

$$\Delta i_D = \frac{\partial i_D}{\partial v_{GS}} \cdot \Delta v_{GS} + \frac{\partial i_D}{\partial v_{DS}} \cdot \Delta v_{DS}$$

$$\frac{\partial i_D}{\partial v_{GS}} = k'\frac{W}{L}(1 + \lambda \cdot v_{DS})(v_{GS} - V_t) = \frac{2i_D}{v_{GS} - V_t} = g_m$$

$$\frac{\partial i_D}{\partial v_{DS}} = \frac{1}{2}k'\frac{W}{L}\lambda(v_{GS} - V_t)^2 = \frac{1}{r_0}$$

$$i_d = g_m \cdot v_{gs} + \frac{v_{ds}}{r_0}$$

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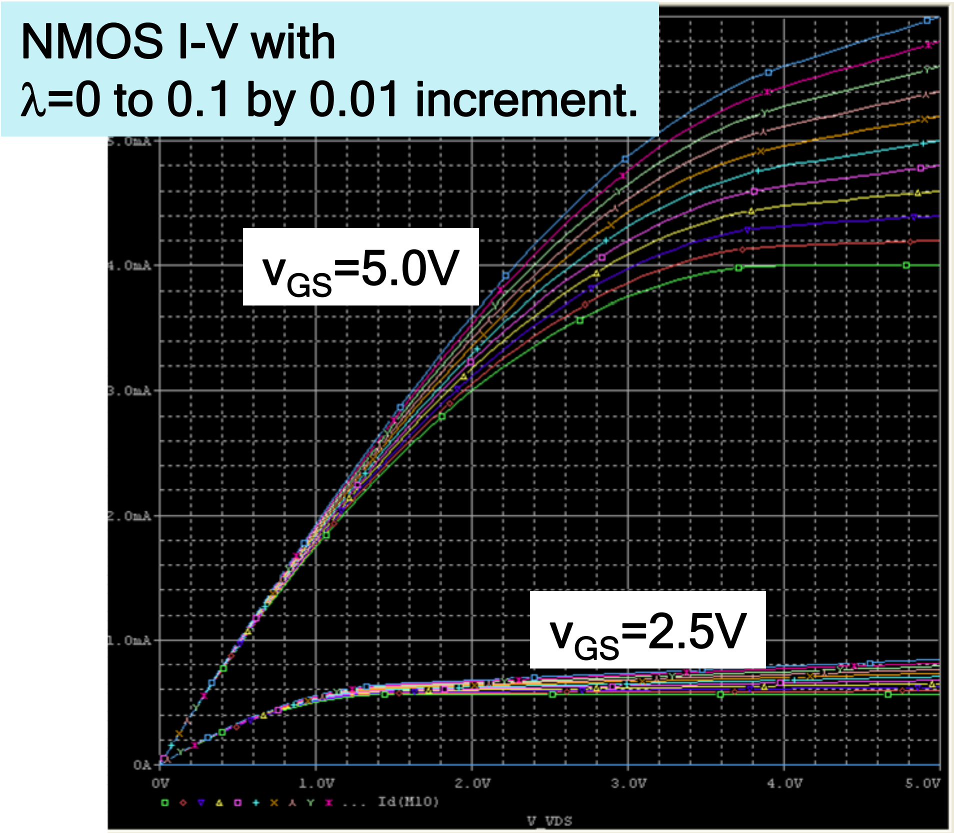
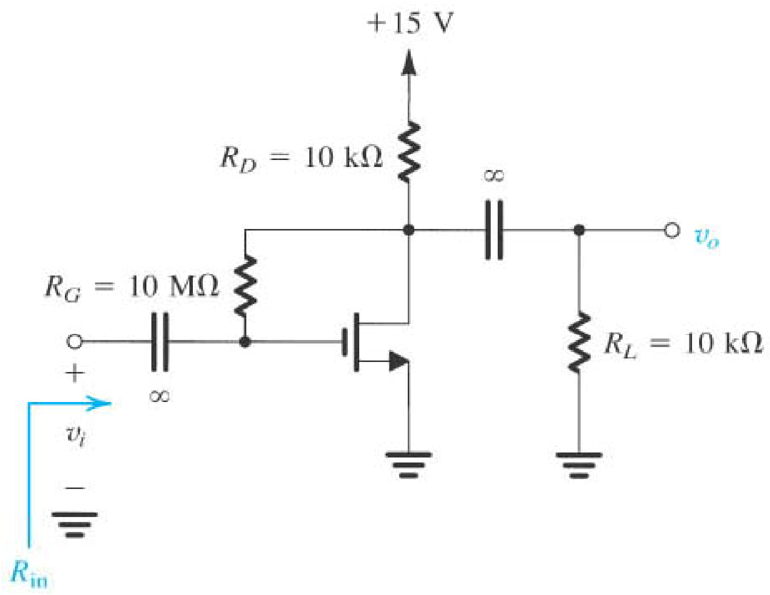
Small signal model for NMOS with channel-length modulation



$$i_D = \frac{1}{2} k' \frac{W}{L} (1 + \lambda \cdot v_{DS})(v_{GS} - V_t)^2$$



(a)

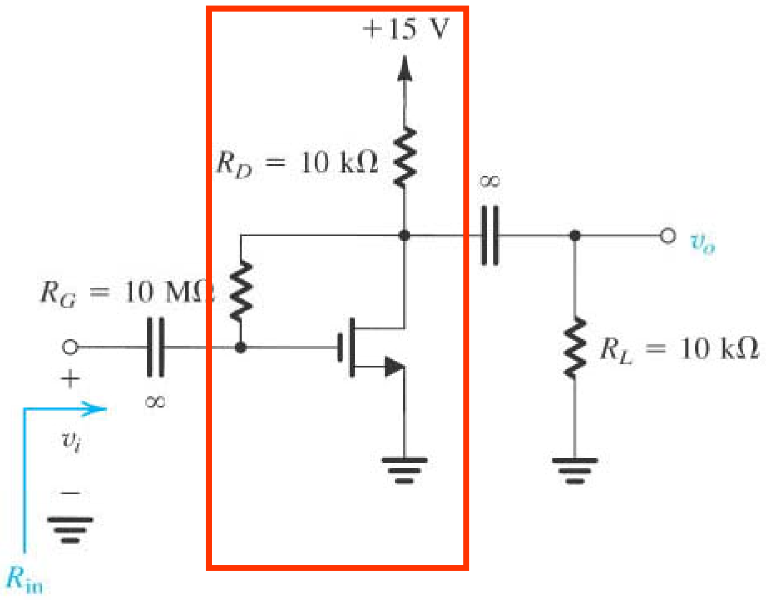
Ex. 4.10

V_t=1.5V, k' (W/L)=0.25mA/V^2

1. Determine bias conditions.
2. Derive small signal circuit model.
3. Voltage gain?
4. Input resistance?
5. Max. v_i?

Lect. 21: MOSFET Small-signal Model

1. Determine bias conditions.



(a)

V_t=1.5V, k' (W/L)=0.25mA/V^2

I_D=0.5X0.25 (V_D-1.5)^2

V_D=15-$R_D I_D$

I_D=1.06mA, V_D=4.4V

In saturation?

g_m= k' (W/L) (V_{GS}-V_t) = 0.725mA/V

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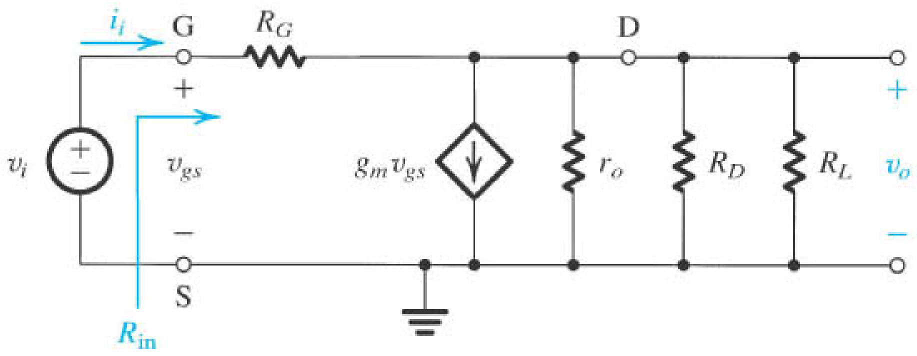
Voltage Gain

Small-Signal model



(b)

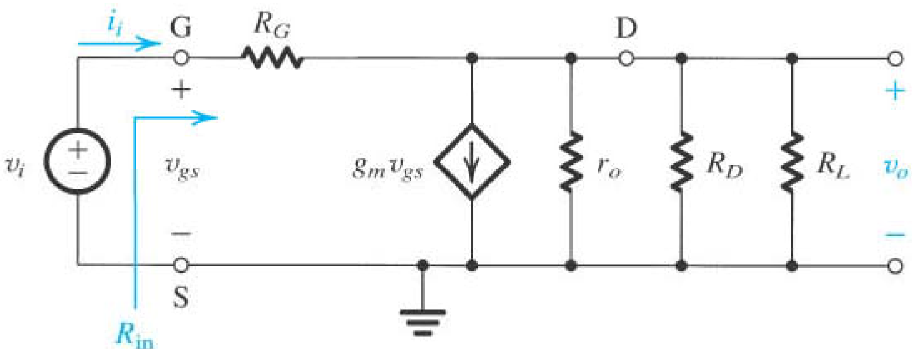
$$v_o = -g_m \cdot v_i \cdot (R_D \,||\, R_L \,||\, r_0)$$

$$A_v = \frac{v_o}{v_i} = -g_m \cdot (R_D \,||\, R_L \,||\, r_0) = -3.3$$

R_D=10KΩ, R_L=10KΩ, R_G=10MΩ, r_o = 47kΩ

Lect. 21: MOSFET Small-signal Model

R_D=10KΩ, R_L=10KΩ, R_G=10MΩ



(b)

Input Resistance

$$R_{in} = \frac{v_i}{i_i}$$

$$i_i = \frac{v_i - v_o}{R_G} = \frac{v_i}{R_G}(1 - \frac{v_o}{v_i})$$

$$\therefore R_{in} = \frac{v_i}{i_i} = \frac{R_G}{1 - A_v} = 2.33 \text{ M}\Omega$$

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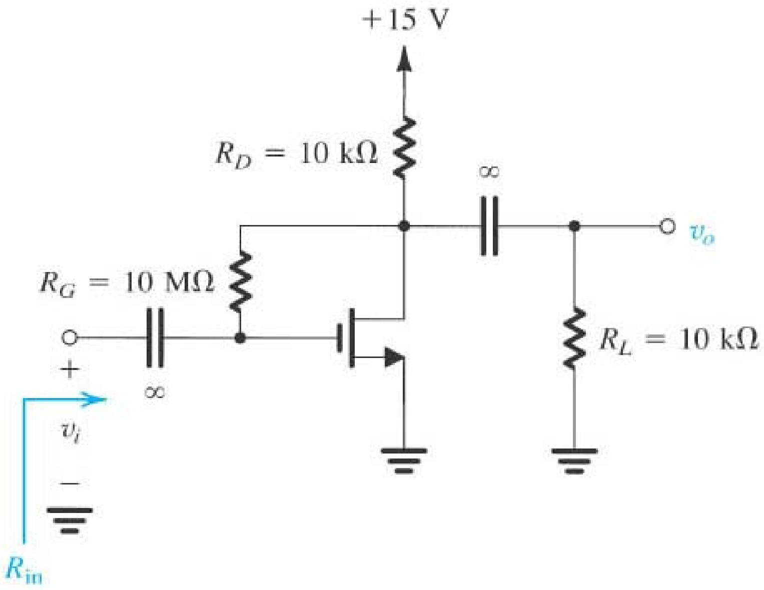

(a)

For Max. v_i, $v_{DS} > v_{GS} - V_t$ (saturation)

$$V_{DS} - |A_V| v_{i,\max} = V_{GS} + v_{i,\max} - V_t$$

$$v_{i,\max} = 0.34\text{V}$$

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Small signal model for PMOS ?

Identical to NMOS small signal model!

Homework: Due before Tutorial on 11/9

Determine small-signal resistance R_x and R_y in the following circuits.
Assuming M_1 and M_2 are in saturation.
Consider the channel length modulation but not body effect.