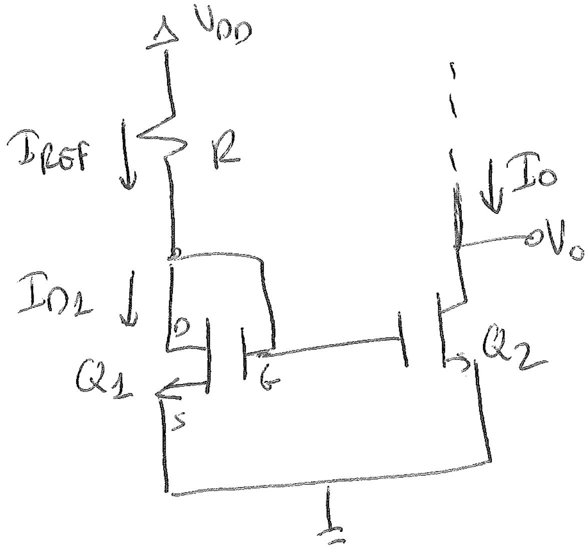
9/29/2016

8.2.1 – Current Sources, current Mirrors,

Basic MOSFET current source.



$Q_1 \rightarrow$ "Heart" of circuit.
Diode connected → always sat.

$$I_{D1} = \frac{1}{2} k_n' \left(\frac{W}{L}\right)_1 (V_{GS} - V_{TN})^2 \quad (1)$$

(assume $\lambda_0 \rightarrow 0$)

Drain current supplied thru V_{DD} and Resistor R (external to circuit)

Gate current → 0

$$\therefore I_{D1} = I_{REF} = \frac{V_{DD} - V_{GS}}{R} \quad (2)$$

→ Equations (1) + (2) used to determine ~~I_{REF}~~ R for a set I_{REF}.

→ Q_2 → has same V_{GS} as Q_1 (also in saturation)

$$\therefore I_O = I_{D2} = \frac{1}{2} k_n' \left(\frac{W}{L}\right)_2 (V_{GS} - V_{TN})^2 \rightarrow (3)$$

From (1) and (3)
$$\frac{I_O}{I_{REF}} = \frac{\frac{1}{2} k_n' \left(\frac{W}{L}\right)_2 (V_{GS} - V_{TN})^2}{\frac{1}{2} k_n' \left(\frac{W}{L}\right)_1 (V_{GS} - V_{TN})^2} = \frac{\left(\frac{W}{L}\right)_2}{\left(\frac{W}{L}\right)_1}$$

→ If $\left(\frac{W}{L}\right)_1 = \left(\frac{W}{L}\right)_2$ then $I_{REF} = I_O$ → "current mirror"

→ Scaling $\left(\frac{W}{L}\right)_1$ to $\left(\frac{W}{L}\right)_2$ scales I_O to I_{REF} → current gain or current transfer ratio.

Effect of V_o and I_o

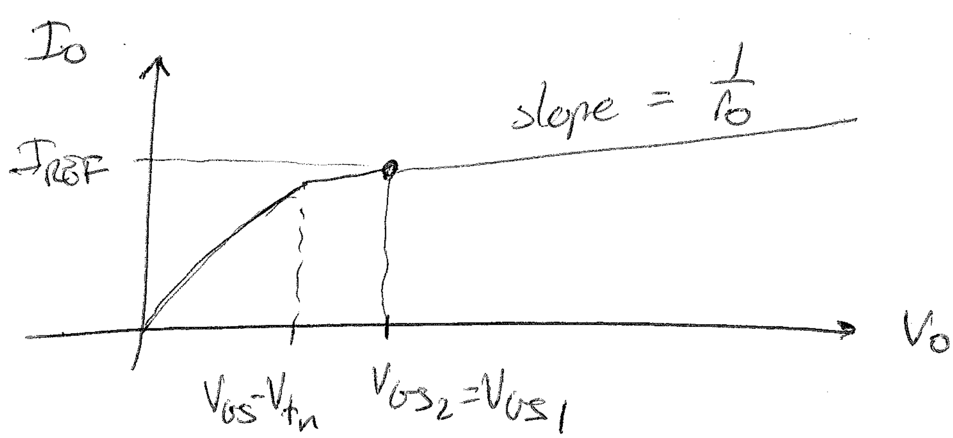
→ Q_2 must remain in saturation.

$\therefore \quad V_o = V_{DS_2} \geq V_{GS_2} - V_{tn} \quad$ or $\quad V_o \geq V_{OV}$

V_{OV} generally a few tenths of volts.

→ Also channel-length modulation λ can have significant effect on the operation of the current source.

$\therefore$ As V_o increases beyond initial value of V_{GS_1}, I_o increases according to r_{o_2} of Q_2.



$\therefore$ Output resistance of current source

$$R_o = \frac{\Delta V_o}{\Delta I_o} = r_{o2} = \frac{V_{A2}}{I_o} = \frac{1}{\lambda_2 I_o}$$

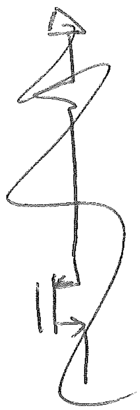
→ use long channel trans. to get high R.

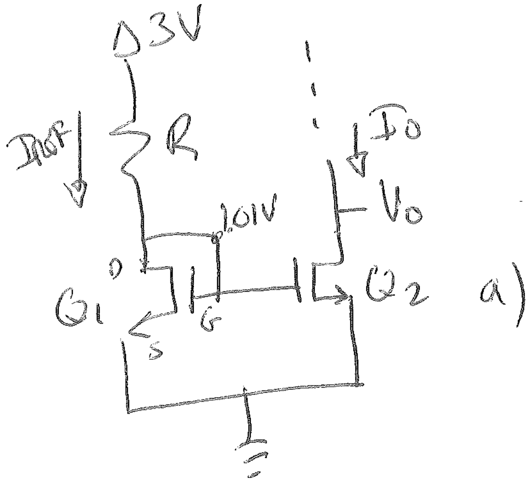
Also $\quad I_o = \dfrac{(W/L)_2}{(W/L)_1} I_{REF}\left(1 + \dfrac{V_o - V_{GS}}{V_{A2}}\right)$ take into account channel length mod.

Ex. 8.1 – Current mirror example:

9/29/2016 (2)

lec 15 ↑
lec 16 ↓





$V_{DD} = 3V$

$I_{REF} = 100\mu A$

Design circuit for $I_O = 100\mu A$.
Find R for $Q_1 = Q_2$ and
$L = 1\mu m$, $W = 10\mu m$, $V_{t_n} = 0.7V$
$k_n' = 200\ \mu A/V^2$.

a) $Q_1 = Q_2$ in saturation $V_O = V_G$

$$\therefore \quad I_{D1} = I_{REF} = \frac{1}{2} k_n' \left(\frac{W}{L}\right)_1 \underbrace{(V_{GS} - V_T)^2}_{(V_{OV})^2}$$

$$100\times10^{-6} A = \frac{1}{2}\, 200\times10^{-6} A/V^2 \left(\frac{10}{1}\right) V_{OV}^2$$

$$V_{OV}^2 = \cancel{0.316V} = \frac{2 \cdot 100\times10^{-6}}{200\times10^{-6}} \frac{1}{10}$$

$$\sqrt{(V_{OV})^2} = \sqrt{0.2}$$

$$V_{OV} = V_{GS} - V_T = 0.316V$$

$$V_{GS} = 0.316V + 0.7V = 1.01 \text{ Volt.}$$

$$\boxed{R = \frac{3V - 1.01V}{100\times10^{-6}A} = 19.83\ k\Omega}$$

b) Find lowest possible value of V_O?

$$\boxed{V_{Omin} = V_{GS} - V_T = V_{OV} = 0.316V}$$

c) Assuming $V_A' = 20V/\mu m$ (length dependent early voltage) find output resistance of the current source.

$$R_o = r_{o2} = \frac{V_{A2}}{I_{D2}}$$

$$V_{A2} = V_A' \times (\text{length})$$

$$V_{A2} = 20V/\mu m \times 1\mu m = 20V$$

$$\boxed{R_o = \frac{20V}{100\mu A} = 200\,k\Omega}$$

d) Find change in output current resulting from a + 1-V change in V_o.

$$\Delta V_o = \Delta I_o \cdot r_o \longrightarrow \Delta V_o = 1V,\ r_o = 200\,k\Omega.$$

$$\boxed{\Delta I_o = \frac{1V}{200k\Omega} = 5\mu A}$$

HW #4:

5.46, 5.50, 5.61

↳ sol: (a) $R = 24\,k\Omega$ (b) $W_2 = 14.4\mu m$ $R_2 = 3.1\,k\Omega$

$V_{DS} = V_{GS} - V_T = 0.25V$

10/3/2016

Electronics 1

Chapter 7 - MOSFET as transistor amplifiers

→ Study models used to represent MOSFETs in the analysis and design of small-signal linear amplifiers.

→ Three basic configurations of single-MOSFET amplifiers.

7.1 - Basic principles

MOSFETs operated in saturation (also called active region).

$$\therefore \; i_D = \frac{1}{2} k_n (V_{GS} - V_{tn})^2$$

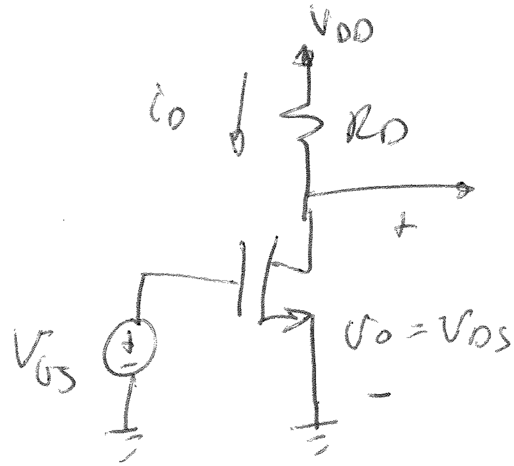
Implies
$v_{GD} \leq V_{tn}$
$v_{DS} \geq V_{GS} - V_{tn}$

→ ~~Voltage amplifier.~~

→ Equation above describes a transconductance amplifier: Amplifier with a voltage input and current output.

→ We want voltage amplifier.

→ pass the output current through a resistor and take voltage across it as the output.



← Voltage amplifier.

→ R_D → load resistance.

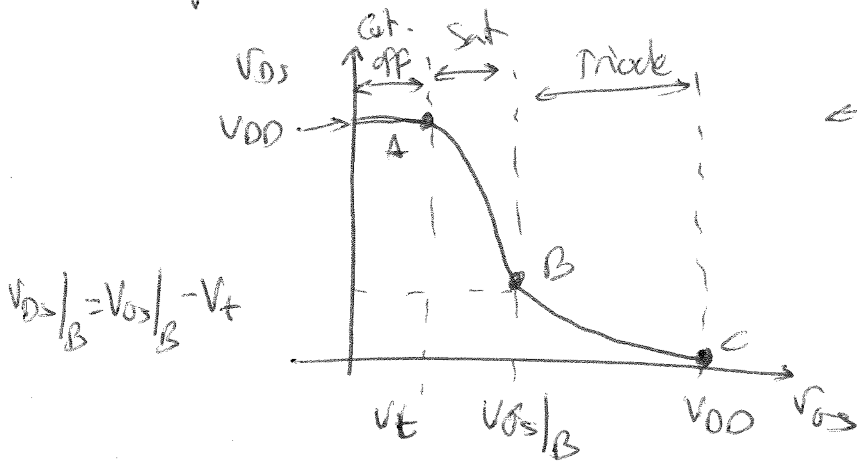
→ $v_O = v_{DS}$ in order to have a common ground.

→ R_D, V_{DD} bias NMOS in saturation.

$$\boxed{v_O = v_{DS} = V_{DD} - i_D R_D}$$

→ which is inverted value of $i_D R_D$ shifted by a constant value V_{DD}

→ Keep MOSFET in sat./active region.



← Voltage transfer characteristic

← VTC

For $v_{GS} < V_t$ → NMOS cut-off. $i_D = 0A$ and $v_{DS} = V_{DD}$

→ As v_{GS} increases, NMOS turns on and $i_D \neq 0$ and v_{DS} decreases.

→ When $v_{DS} = v_{GS} - V_t$, NMOS in triode region.

→ For segment AB:

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

$$v_{DS} = V_{DD} - \frac{1}{2} k_n R_D (v_{GS} - V_t)^2$$

$v_{GS} = v_{GS}|_B$

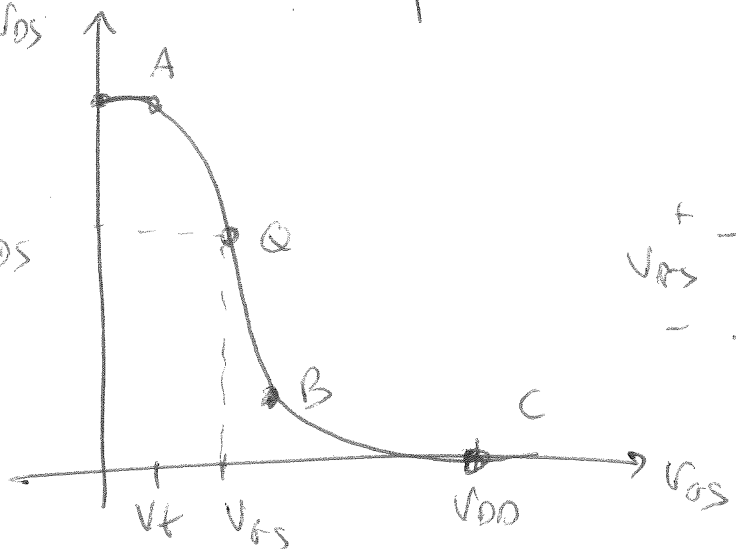
$v_{DS} = v_{GS}|_B - V_T$

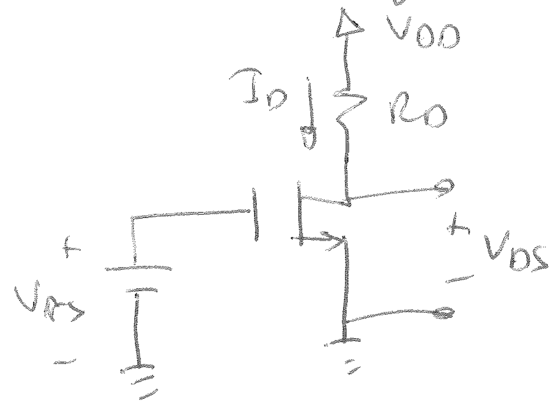
and $$v_{GS}|_B = V_t + \frac{\sqrt{2 k_n R_D V_{DD} + 1} - 1}{k_n R_D}$$

7.1.4. Biasing transistor for linear amplification
(or ~~small~~ almost linear)

→ Want to bias transistor in <u>linear region</u> of VTC.

Q-point.

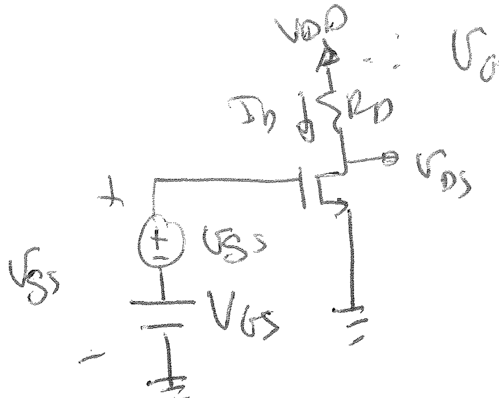


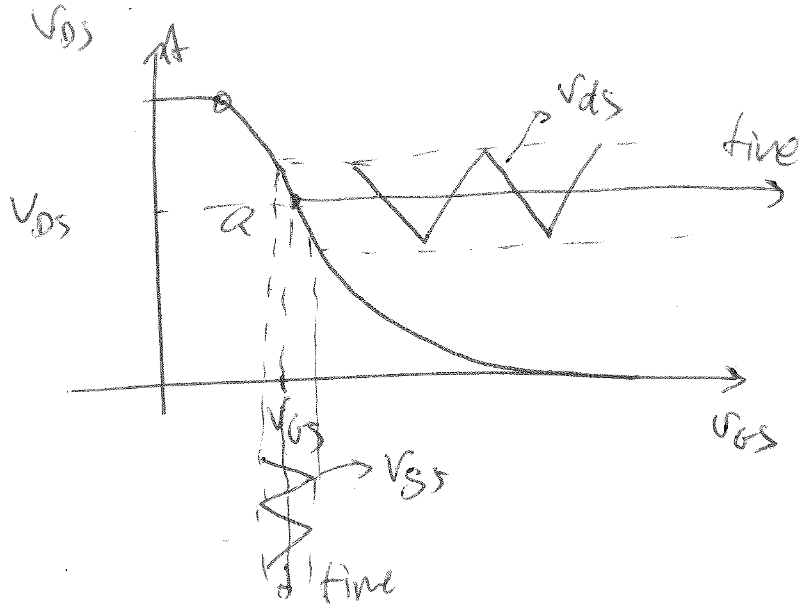


→ Point Q is known as <u>bias point</u> or <u>dc operating point</u> or <u>quiescent point</u> ≡ Q-point (how to bias at this point next class)

→ Next superimpose signal to be amplified $v_{gs}(t)$.

$$v_{GS}(t) = V_{GS} + v_{gs}(t)$$





The ~~closer~~ shorter the segment ←
the ~~larger the~~ greater the linearity achieved.

→ large v_{gs} swing lead to non-linear amplification → distortion and turning off of MOSFET → "clipped off" clipping.

→ "Allowable signal swing at output."

lec 16 ↑
lec 17 ↓

7.15. Small-signal voltage gain.

$$A_v = \left.\frac{dv_{DS}}{dv_{GS}}\right|_{v_{GS}=V_{GS}} \leftarrow \text{at Q-point}$$

$$v_{DS} = V_{DD} - \frac{1}{2} k_n R_D (v_{GS} - V_t)^2$$

$$\left.\frac{dv_{DS}}{\partial v_{GS}}\right|_{v_{GS}=V_{GS}} = -k_n R_D \underbrace{(V_{GS} - V_t)}_{V_{ov}} = -k_n R_D V_{ov} = A_v$$

→ gain is negative (inverting)

→ proportional to R_D and k_n and V_{ov}.

Also $A_v = -\frac{I_D R_D}{V_{ov}/2}$ ← from $I_D = \frac{1}{2} k_n V_{ov}^2$

$$V_{ov}^2 = \frac{2 I_D}{k_n}$$

$$k_n = \frac{2 I_D}{V_{ov}}$$

$$A_v = -\frac{V_{DD} - V_{DS}}{V_{ov}/2}$$

move to After small signal gain analysis

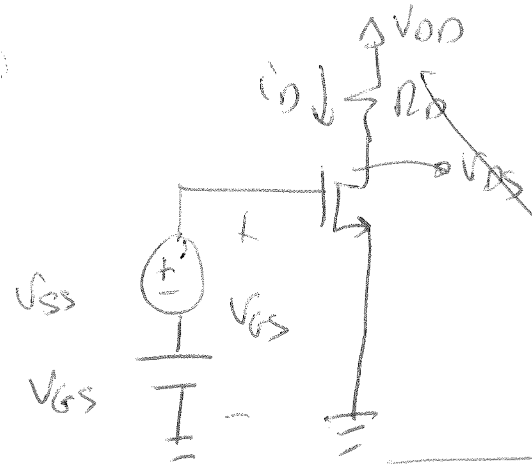
at point B

$$|A_v|_{max} \Big|_B = \frac{V_{DD} - V_{DS}|_B}{V_{ov}|_B/2} = \frac{V_{DD} - V_{ov}|_B}{V_{ov}|_B/2}$$

$$V_{DS}|_B = V_{ov}|_B$$

7.2. SMALL-SIGNAL OPERATION and MODELS

10/5/2016
Electronics 1.



→ DC voltage V_{GS}

→ Input signal to be applied → v_{gs}

→ Output ~~at~~ voltage at drain.

→ Separate DC Analysis and signal analysis

→ DC. Bias Point:

→ $I_D = \frac{1}{2} k_n (V_{GS} - V_t)^2 = \frac{1}{2} k_n V_{ov}^2$ $(\lambda \to 0)$

V_t

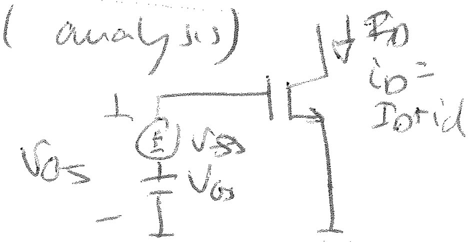
→ at drain voltage $V_{DS} = V_{DD} - I_D R_D$

$V_{DS} > V_{ov}$ (sat.)

↳ large enough to allow for voltage swing.

move to after model introduction

→ Signal current in Drain terminal. (signal analysis)



total → $v_{GS} = \underset{\to DC}{V_{GS}} + \underset{\to \text{small signal}}{v_{gs}}$

→ $i_D = \frac{1}{2} k_n (V_{GS} + v_{gs} - V_t)^2$

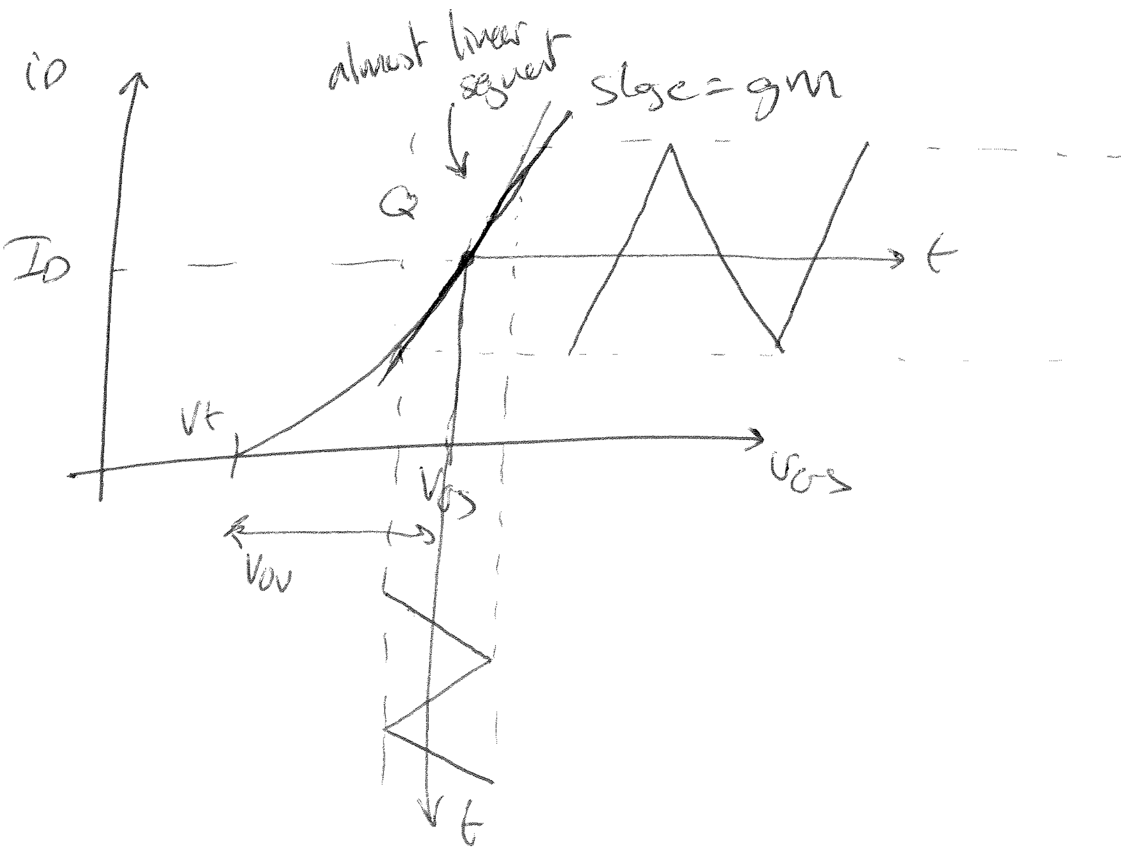
$$i_D = \underbrace{\frac{1}{2} k_n (V_{GS} - V_t)^2}_{\text{D.C. } I_D} + \underbrace{k_n (V_{GS} - V_t) v_{gs}}_{\text{proportional small-signal } v_{gs} \; i_d} + \underbrace{\frac{1}{2} k_n v_{gs}^2}_{\text{small (ignore) } v_{gs} \text{ neglect}}$$

→ $i_D \simeq I_D + i_d$

where $\boxed{i_d = k_n (V_{GS} - V_t) v_{gs}}$

and $\frac{i_d}{v_{gs}} = k_n (V_{GS} - V_t) \equiv g_m$ → MOSFET transconductance

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



→ $g_m = \left.\frac{\partial i_D}{\partial v_{GS}}\right|_{v_{GS}=V_{GS}} = k_n(V_{GS}-V_T) = k_n'\left(\frac{W}{L}\right)(V_{GS}-V_T) = k_n'\left(\frac{W}{L}\right)V_{ov}$

→ Also $g_m = \sqrt{2k_n'}\,\sqrt{W/L}\,\sqrt{I_D}$

if $V_{ov} = \sqrt{\frac{2I_D}{k_n}} = \sqrt{\frac{2I_D}{k_n'\left(\frac{W}{L}\right)}}$

from $I_D = \frac{1}{2}k_n V_{ov}^2$

→ And $g_m = \frac{2I_D}{V_{GS}-V_T} = \frac{2I_D}{V_{ov}}$

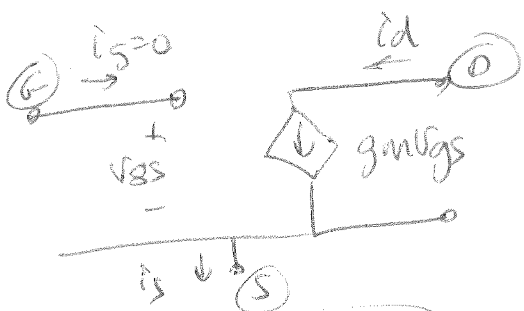
$\frac{\text{lec 17} \uparrow}{\text{lec 18} \downarrow}$

6/6/2016

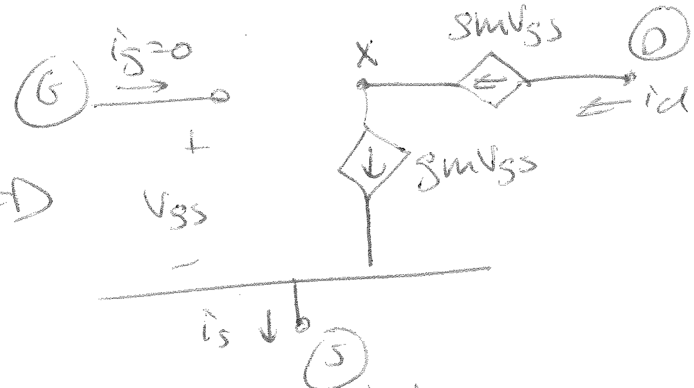
Other small-signal equivalent circuits:

T equivalent - circuit model:

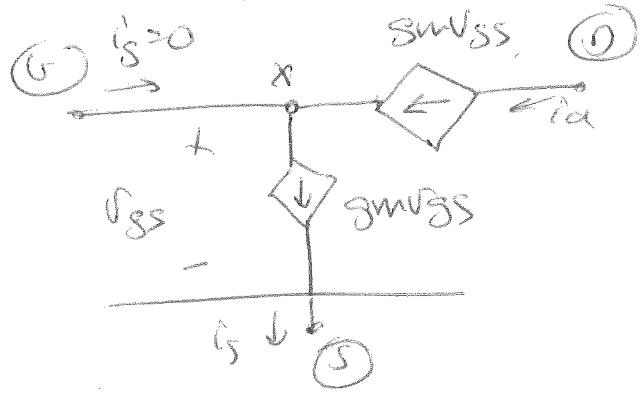
($\lambda \to 0$)



$\boxed{\text{hybrid } \pi\text{-model}}$

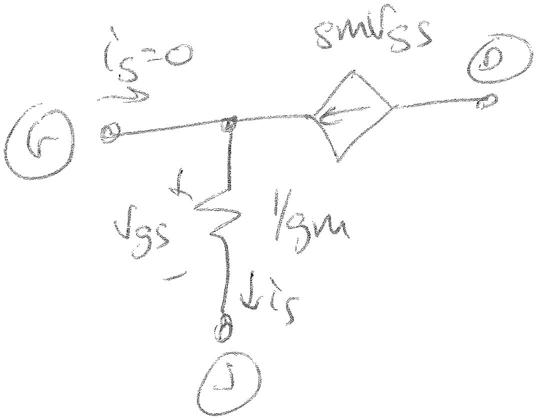


X-node created



i_g still $=0$

current $g_m v_{gs}$ has v_{gs} drop across it



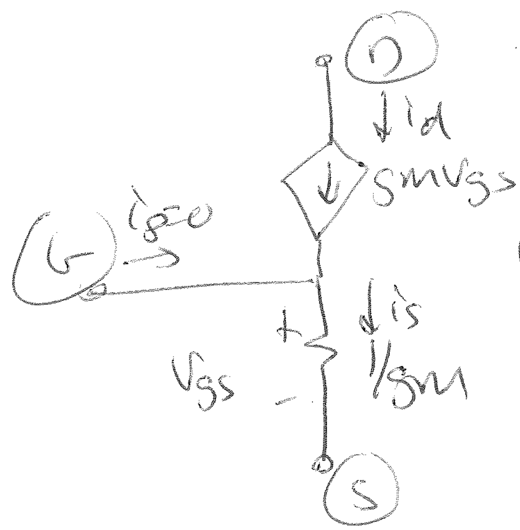
$v_{gs} = g_m v_{gs} R$

$\boxed{R = \frac{1}{g_m}}$

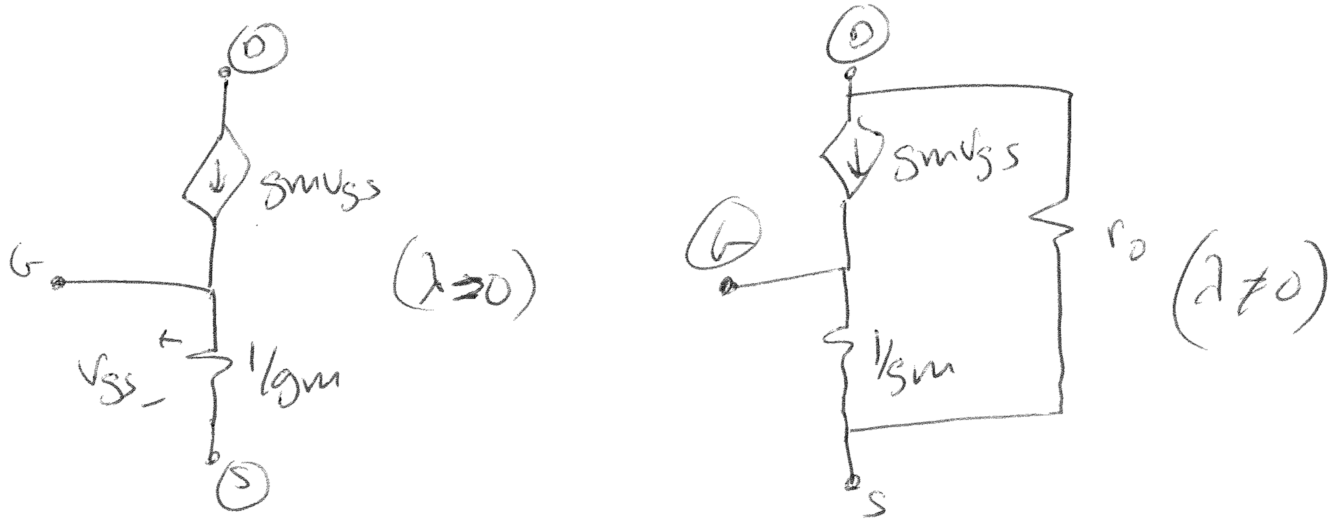
Replace current source w/ equivalent resistance to obtain v_{gs} drop across it w/ $i = g_m \cdot v_{gs}$

$\therefore \boxed{R = \frac{1}{g_m}}$

T-equivalent circuit



($\lambda \to 0$)

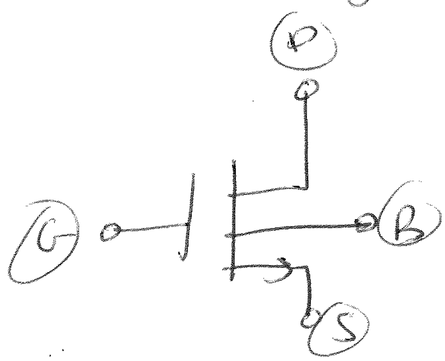


T- model

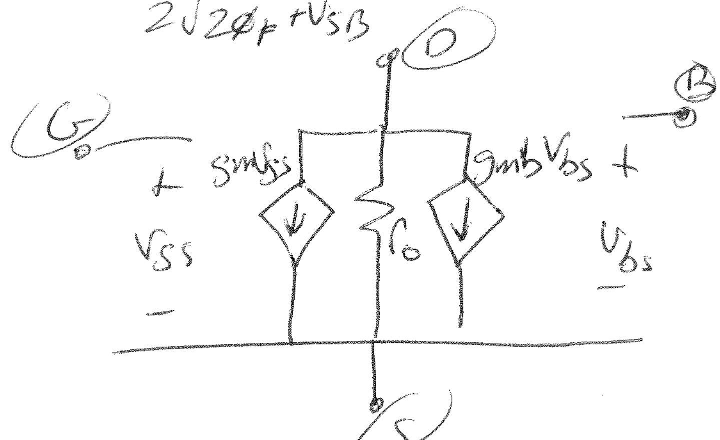
<u>Modeling the body effect:</u>

$$g_{mb} \equiv \left.\frac{\partial i_D}{\partial v_{BS}}\right|_{\substack{v_{GS} = \text{constant} \\ v_{DS} = \text{constant}}}$$

$$g_{mb} = \chi g_m \qquad \chi = \frac{\gamma}{2\sqrt{2\phi_F + V_{SB}}}$$



$\Longleftrightarrow$

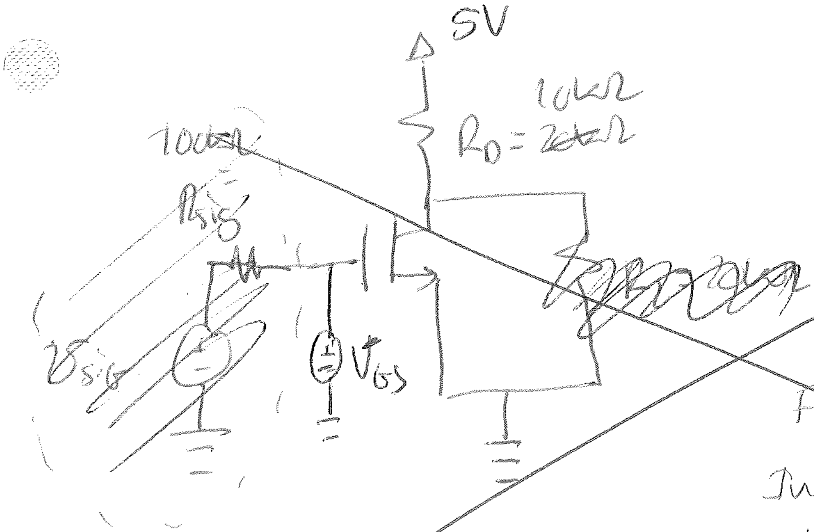


→ ~~Systematic Procedure for analysis of transistor amplifier circuits.~~

~~1. Eliminate~~ signal source + determine DC operating point.

~~2. Calculate~~

7.33 - Common-source (CS) amplifier - example.



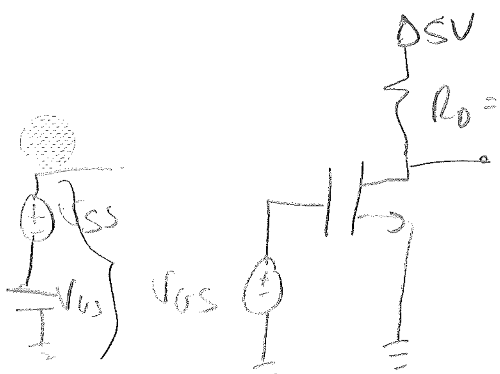
~~$I_D = 0.25$ mA~~

~~$V_{OV} = 0.25$ V~~

~~Find R_{in}, A_{vo}, R_o, A_v, and G_v.~~

~~Input sine-wave limited to 10% of $2V_{OV}$, what is peak of sine-wave voltage of input?~~

~~DC Analysis~~ ~~$I_D = \frac{1}{2} k_n (V_{GS} - V_T)^2 =$~~



$V_t = 1V$, $k_n' = 20\mu A/V^2$, $\frac{W}{L} = 20$, $V_{GS} = 2V$, $\lambda = 0$

$v_{gs} = 0.2 \sin \omega t$ volts.

(a) Find V_{DS} (DC) and I_D (DC)

(b) Find voltage gain $\frac{v_{ds}}{v_{gs}}$

1st - DC analysis.

(a) $$I_D = \frac{1}{2} k_n' \left(\frac{W}{L}\right)(V_{GS} - V_T)^2 = \frac{1}{2}\, 20\times10^{-6} \tfrac{A}{V^2} (20)(2-1)^2 = 200\mu A$$

$$V_{DS} = V_{DD} - I_D R_D = 5V - (200\mu A)(10k\Omega) = 3V$$

(b) Small-signal analysis (w/o) model:

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

$$v_{DS} = V_{DD} - R_D(I_D + i_d)$$

$$v_{ds} = -i_d R_D = -g_m v_{gs} R_D \longrightarrow \frac{v_{ds}}{v_{gs}} = -g_m R_D$$

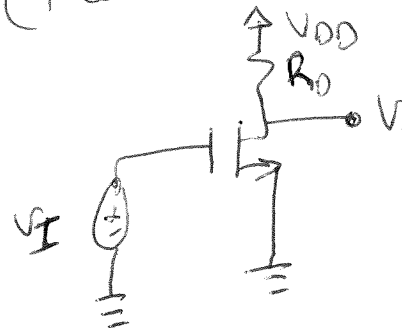
$$g_m = \frac{i_d}{v_{gs}} = k_n' \frac{W}{L}(V_{GS} - V_T) = 20\times10^{-6}(20)(2-1) = 400\times10^{-6} \frac{A}{V}$$

$$\boxed{\frac{v_{ds}}{v_{gs}} = -400\times10^{-6} A/V \cdot 10k\Omega = -4 V/V}$$

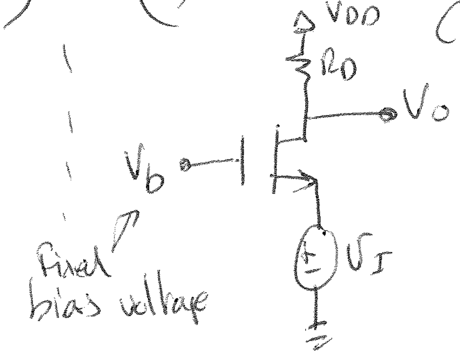
20/6/2016
2

7.3.1. – Three basic configurations of single MOSFET amplifiers:

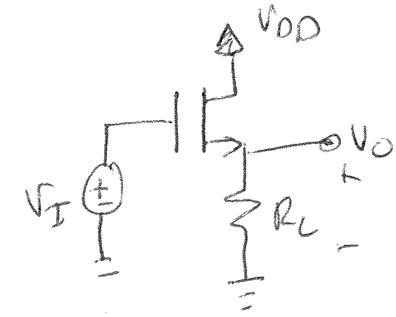
(a) Common source (CS)



(b) Common-Gate (CG)

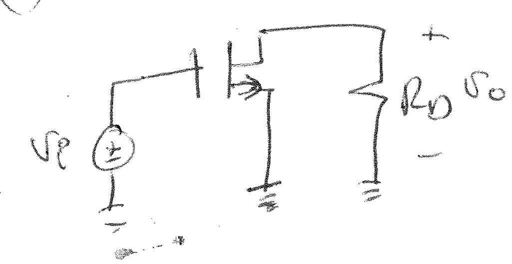


(c) Common-~~source~~ drain (CD) /source follower.

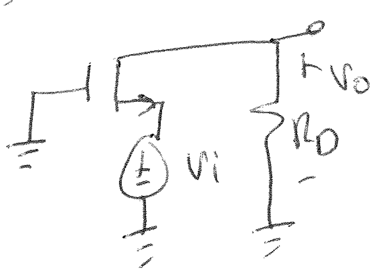


signal-analysis circuits: $V_{source} \to 0V$, $I_{source} \to 0A$ | leave small signal sources on.

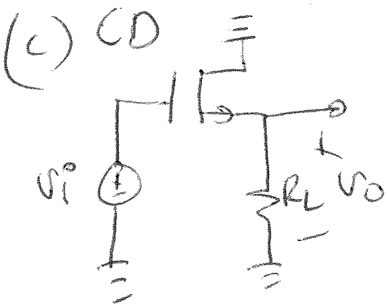
(a) Common source (CS)



(b) CG



(c) CD



(a) (CS) Most common amplifier. Cascoded to obtain large amplification values

(b) CG – Gate voltage is fixed! Grounded for small signal analysis. Signal applied to source

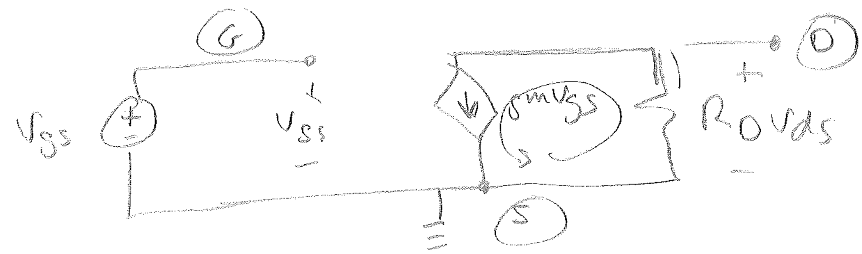
(c) CD – Drain is grounded for small signal analysis. Signal applied to gate. Also known as source follower.

10/6/2016

(3)

FRONT

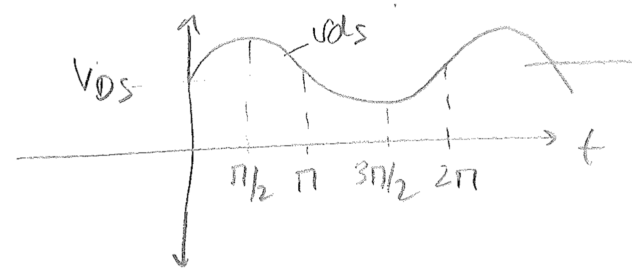
w/ model



$$v_{ds} = -g_m \cdot v_{gs} \cdot R_O$$

$$\frac{v_{ds}}{v_{gs}} = -4\,V/V \quad \text{(same as before)}$$

(c) If $v_{gs} = 0.2 \sin \omega t$ volts, what are minimum and maximum values of v_{DS}.



$$v_{ds} = 0.8 \sin \omega t$$

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

$$v_{DS_{max}} = 3V + 0.8V = 3.8V$$

$$v_{DS_{min}} = 3V - 0.8V = 2.2V$$

Systematic procedure for analysis of transistor amplifier circuits

1. Eliminate signal source + determine DC operating point.
2. Calculate values of small-signal model parameters
3. Eliminate DC sources. $V_S \to 0V$ (short-circuit), $I_S \to 0A$ (open-circuit).
4. Replace transistors w/ small-signal model. Choose more appropriate one.
5. Analyze resulting circuit for required quantities (voltage gain, input resistance, etc?)

lec 18 ↑

lec 19 ↓ A more realistic CS example.

10/6/2016

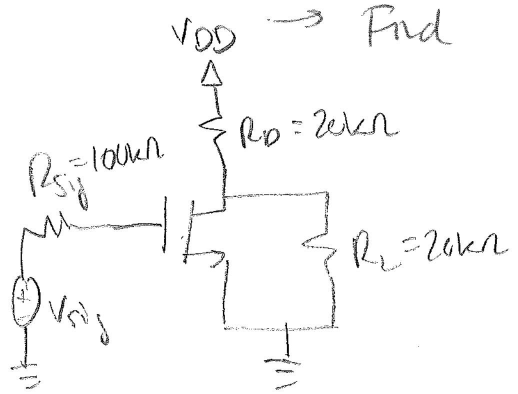
BACK.

7.21 A CS w/ MOSFET $I_D = 0.25\,mA$ with $V_{ov} = 0.25\,V$

$R_D = 20\,k\Omega$. Amplifier signal $R_{sig} = 100\,k\Omega$

and output load $= 20\,k\Omega$.

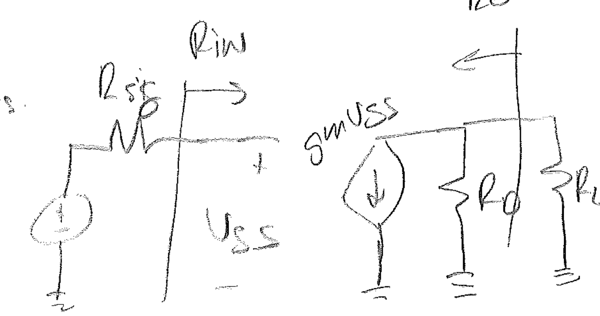
→ Find $R_{in}, A_{vo}, R_o, A_v, G_v$.



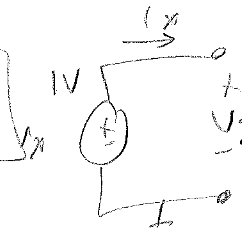
→ DC given.

→ Do ac analysis.

$v_i = v_{sig}$

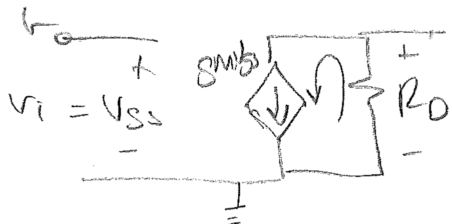


$$\boxed{R_{in} = \frac{v_x}{i_x} = \frac{1}{0} = \infty}$$



v_{ss} ∴ $v_i = v_{sig} = v_{ss}$

A_{vo} → open circuit voltage gain



$v_o = -g_m v_{ss} \cdot R_D$

$v_i = v_{ss}$

$v_o = -g_m v_i \cdot R_D$

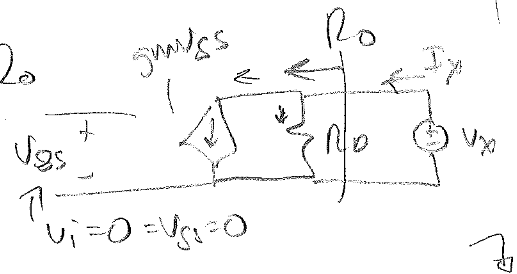
$$A_{vo} = \frac{v_o}{v_i} = -g_m R_D$$

$$g_m = \frac{2 I_D}{V_{ov}} = \frac{2 \times 0.25 \times 10^{-3} A}{0.25\,V}$$

$g_m = 2\,mA/V$

$$\boxed{A_{vo} = -(2\,mA/V)(20\,k\Omega) = -40\,V/V}$$

R_o



$I_x = \frac{v_x}{R_D}$

$R_o = \frac{v_x}{I_x}$

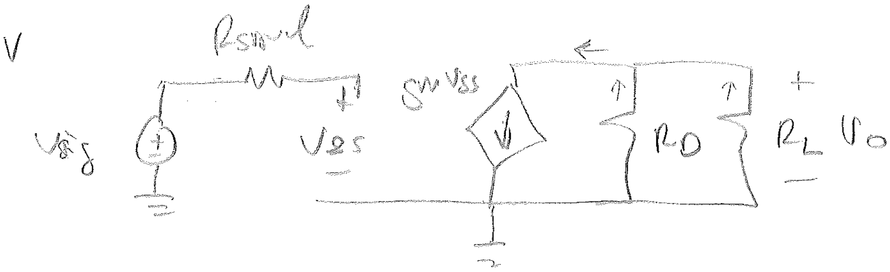
∴ $\boxed{R_o = \frac{v_x}{v_x/R_D} = R_D = 20\,k\Omega}$

→ cont's

↑ cont'd

10/6/2016
(4)

Av



$v_{gs} = v_i$

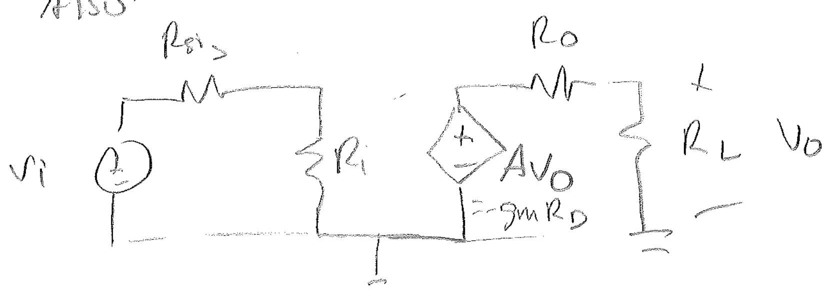
$R_o = 20k\Omega$

$v_o = -g_m v_{gs}(R_D \| R_L)$

$A_v = \frac{v_o}{v_i} = -g_m(R_D \| R_L) = -g_m\left(\frac{R_D R_L}{R_D + R_L}\right)$

$= -2mA/V(10k\Omega) = \boxed{-20\ V/V}$

Also:



same.

$R_{sig} = 100k\Omega$
$R_i = \infty$
$R_o = 20k\Omega$
$R_L = 20k\Omega$

$A_{vo} = -g_m R_D$

$g_m = 2mA/V$

$v_o = -g_m R_D\left(\frac{R_L}{R_o + R_L}\right) = -40\left(\frac{20}{20+20}\right) = -20 V/V$

Also known as:

Overall voltage gain $= \frac{v_o}{v_{sig}} \approx -20 V/V$

v_i

To maintain linearity peak of input is limited to 10% of $2V_{ov}$. What is peak of sine-wave voltage at output.

peak of v_i → $\hat{v}_i = 0.1 \cdot 2(0.25V) = 0.05V$

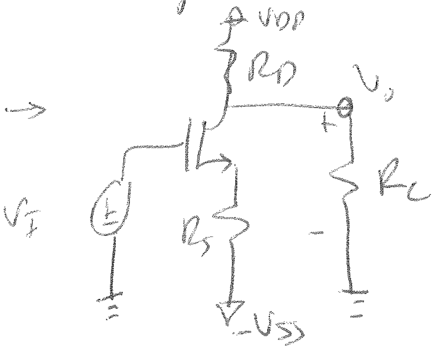
$\hat{v}_o = 0.05 \cdot |(-20)| = 1V$ ✓

10/11/2016

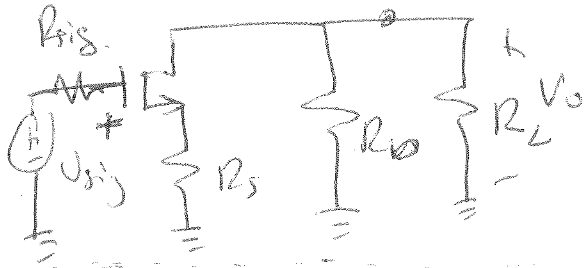
Electronics I.

7.3.4. Common-source (CS) amplifier w/ a source resistance.

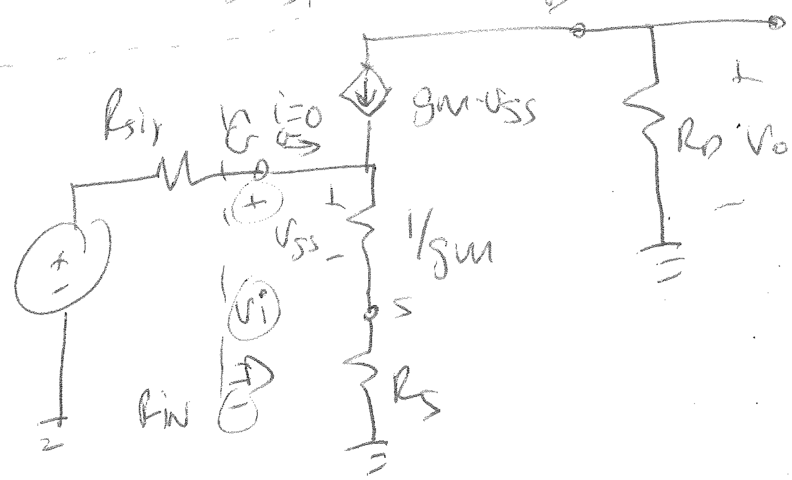
→ Beneficial to insert a resistance R_S in source lead.

→ 

⟹ w/o bias,



⟹ small signal:



⊘ T-model used: whenever a resistance is connected in the source lead, the T-model is preferred.

$R_{in} = \infty$ since $i_G = 0$ ∴ $v_i = v_{sig}$

→ but $v_i \neq v_{gs}$

$$v_{gs} = v_i \frac{1/g_m}{1/g_m + R_s} = v_i \frac{1/g_m}{1/g_m} \frac{1}{1 + R_s g_m}$$

$$v_{gs} = v_i \frac{1}{1 + R_s g_m}$$

⟹ Magnitude of ∴ v_{gs} can be controlled by value of R_s and make sure it is not too large → output distortion.

⟹ Also: Extended bandwidth of amplifier + negative feedback.

→ Negative feedback →

If v_{gs} and v_i constant and drain current increases, source current also increases and voltage drop accross R_s also increases. Then V_{gs} decreases and drain current decreases, which counteracts initial change.

→ Output voltage $v_o = \cancel{-iR_D} = -g_m v_{gs} R_D$

and $$g_m v_{gs} = \frac{v_i}{1/g_m + R_s} = v_i \frac{\cancel{1/g_m}}{\cancel{1/g_m}} \left(\frac{1}{1/g_m + R_s} \right)$$

$$g_m v_{gs} = v_i \left(\frac{g_m}{1 + g_m R_s} \right)$$

$$v_i = g_m \cdot v_{gs} \left(\frac{1 + g_m R_s}{g_m} \right)$$

∴

$$\frac{v_o}{v_i} = \frac{-g_m \cdot v_{gs} R_D}{g_m v_{gs} \left(\frac{1 + g_m R_s}{g_m} \right)} = \frac{-R_D}{\frac{1 + g_m R_s}{g_m}} = \frac{-g_m R_D}{1 + g_m R_s}$$

$$\boxed{A_{vo} = \frac{-g_m R_D}{1 + g_m R_s} = -\frac{\cancel{g_m}}{\cancel{g_m}} \left(\frac{R_D}{\frac{1}{g_m} + R_s} \right) = -\frac{R_D}{1/g_m + R_s}}$$

Compared to CS $\boxed{A_{vo} = -g_m R_D}$

∴ Decreases gain.

Known as source-degeneration resistance

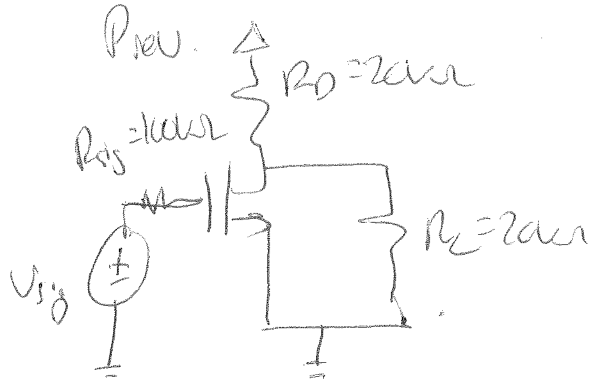
Also w/ load. ⇒ $$\boxed{A_v = \frac{-g_m (R_D \| R_L)}{1 + g_m R_s} = -\frac{R_D \| R_L}{1/g_m + R_s}}$$

lec 19 ↑
lec 20 ↓

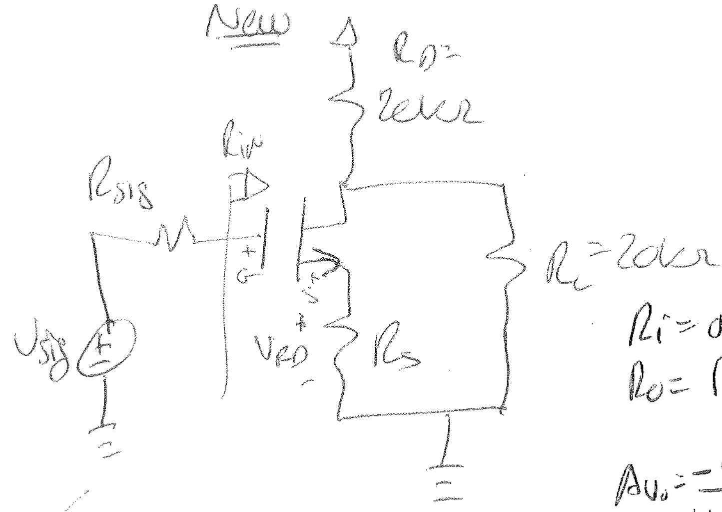
Ex. 7.23 — 10/11/2016 — (2)

Same as previous example but $v_{sig} = 0.2V$ peak ~~and want~~ instead of 50mV peak.
and want to modify circuit (by adding R_s) to keep v_{gs} unchanged and prevent ~~linear~~ nonlinear distortion.
Value of R_s? What is voltage gain? Peak output voltage?

Prev.



New



$R_i = \infty$
$R_o = R_D$

$A_{v_o} = \frac{-g_m R_D}{1 + g_m R_s}$

$A_v = \frac{-g_m R_D \| R_L}{1 + g_m R_s}$

$I_D = 0.25mA$, $V_{ov} = 0.25V$

$R_i = \infty$
$R_o = R_D$
$A_{v_o} = -g_m R_D$
$A_v = -g_m(R_D \| R_L)$

$\hat{v}_{sig} = v_{gs} = 50mV$

$\rightarrow \hat{v}_{sig} = 0.2V \neq v_{gs}$

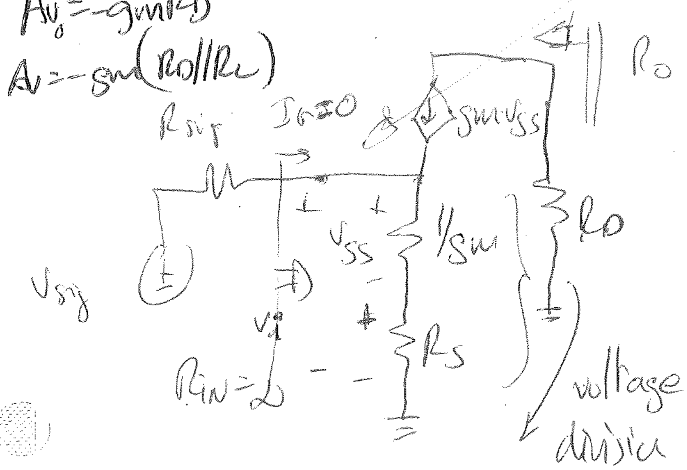
$\rightarrow$ want $\hat{v}_{gs} = 50mV$

R_i still ∞ since $I_G = 0$

$\therefore$ ~~$v_{gs} =$~~ $v_i = v_{gs} + \cancel{I_D R_s}\ g_m v_{gs} R_s$

$v_i = v_{gs}(1 + g_m R_s)$

$$\boxed{v_{gs} = v_i \left(\frac{1}{1 + g_m R_s}\right)}$$ ✓



voltage division

same.

~~$v_{gs} = v_i \frac{1/g_m}{1/g_m} \left(\frac{1}{1+g_m R_s}\right)$~~

$v_{gs} = v_i \frac{1/g_m}{1/g_m + R_s} = \cancel{v_i} \ v_i \left(\frac{1/g_m}{\cancel{1/g_m}\ \cancel{1/g_m + R_s}}\right)$ ~~$v_{gs} = v_i \left(\frac{1/g_m}{1/g_m + R_s}\right)$~~

cancels

7 cont'd

$\therefore$ ~~wait~~ $\cancel{v_{gs} = \frac{v_{signal}}{\quad}} \rightarrow$

$$v_{gs} = \frac{v_i}{1 + g_m R_s} \rightarrow \text{wait}$$

$v_{gs} = 50mV$
when $v_i = 0.2V$
then
$$v_{gs} = 50mV = \frac{0.2V}{1 + g_m R_s}$$

$\therefore g_m R_s = 3$

$$\rightarrow \boxed{\cancel{R_s = \frac{g_m}{3}} \quad R_s = \frac{3}{g_m}}$$

$$g_m = \frac{2I_D}{V_{OV}} = \frac{2 \times 0.25 \times 10^{-3} A}{0.25V} = 2mA/V$$

$$\rightarrow R_s = \cancel{\frac{2 \times 10^{-3} A/V}{3}} = \frac{3}{2 \times 10^{-3} A/V} = 1.5k\Omega.$$

$$G_v = A_v = \frac{-R_D \| R_L}{1/g_m + R_s} = -\frac{(20 \| 20) \times 10^3}{0.5 \times 10^3 + 1.5 \times 10^3} = -5 V/V$$

$$\hat{v}_o = G_v \cdot \hat{v}_{sig} = 5 \times 0.2 = 1V \quad \text{(unchanged)}$$

HWA5 7.25, 7.30, 7.32, 7.59, 7.64, 7.71