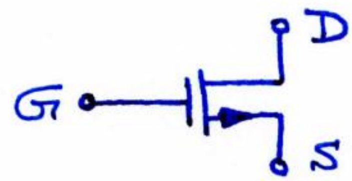
ITE – Homework 10 – Solution

Problem 1 FET linear amplifier circuits

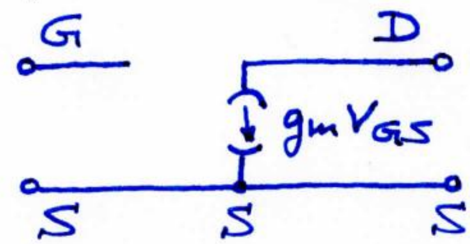
(a) n-channel FET

Source = Source of electrons

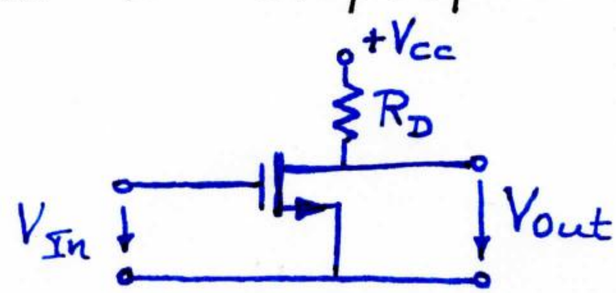


⇒ Current flows out of the source

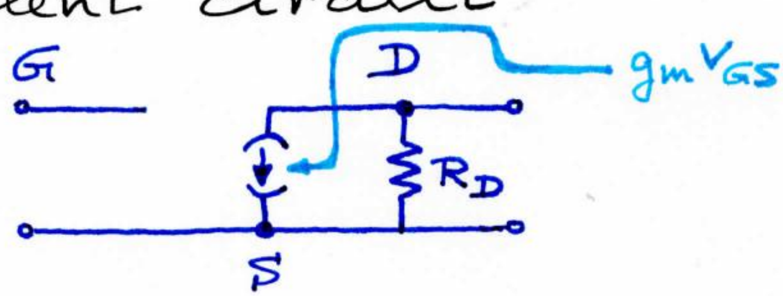
Small-signal equivalent circuit



(b) Common-S amplifier



Equivalent circuit



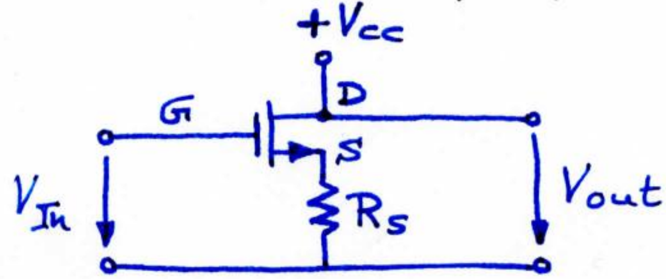
$$Z_{in} = \frac{V_{in}}{i_{in}} = \frac{V_{in}}{0} = \underline{\underline{\infty}}$$

$$Z_{out} = \frac{V_{out}}{i_{out}} = \underline{\underline{R_D}}$$

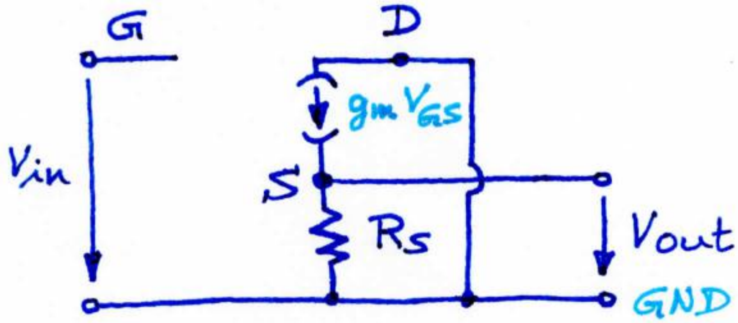
$$A_{voc} = \frac{V_{out}}{V_{in}} = \frac{-g_m V_{GS} R_D}{V_{GS}} = \underline{\underline{-g_m R_D}}$$

$$A_{ISC} = \frac{i_{out}}{i_{in}} = \frac{g_m V_{GS}}{0} = \underline{\underline{\infty}}$$

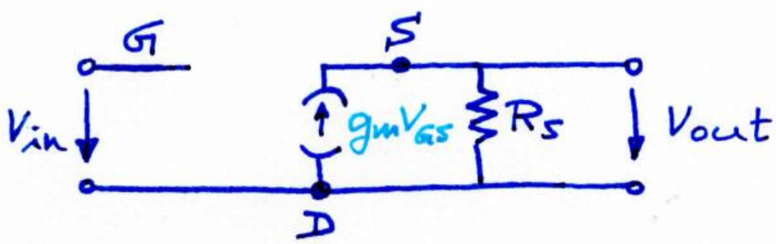
(c) Common - D amplifier



Equivalent circuit



Redraw equivalent circuit



$$Z_{in} = \frac{V_{in}}{i_{in}} = \frac{V_{in}}{0} = \underline{\underline{\infty}}$$

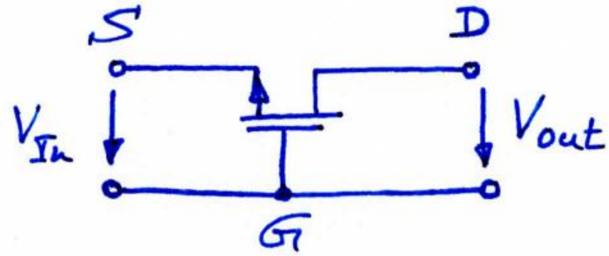
$$Z_{out} = \frac{V_{out}}{i_{out}} = \underline{\underline{R_S}}$$

$$A_{VOC} = \frac{V_{out}}{V_{in}} = \frac{g_m V_{GS} R_S}{V_{GS} + g_m V_{GS} R_S} = \frac{g_m R_S}{1 + g_m R_S} \approx \underline{\underline{1}}$$

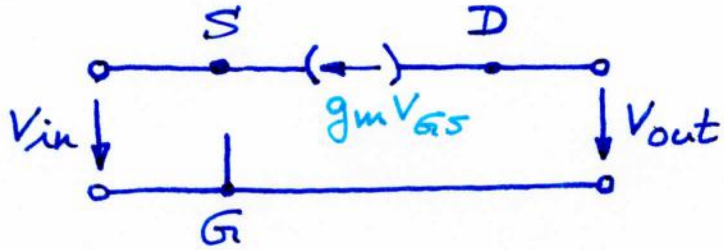
For large g_m or R_S

$$A_{ISC} = \frac{i_{out}}{i_{in}} = \frac{i_{out}}{0} = \underline{\underline{\infty}}$$

(d) Common – G amplifier



Equivalent circuit



$$Z_{in} = \frac{V_{in}}{i_{in}} = \frac{V_{in}}{g_m V_{GS}} = \frac{V_{GS}}{g_m V_{GS}} = \underline{\underline{\frac{1}{g_m}}}$$

$$Z_{out} = \frac{V_{out}}{i_{out}} = \frac{\infty}{g_m V_{GS}} = \underline{\underline{\infty}}$$

Why is $V_{out} = \infty$? Circuit has an ∞ load resistance ($R_{Load} = \infty$). The voltag across the load is $g_m V_{GS} R_{Load} = \infty$

$$A_{VOC} = \frac{V_{out}}{V_{in}} = \frac{\infty}{V_{in}} = \underline{\underline{\infty}}$$

$$A_{ISC} = \frac{i_{out}}{i_{in}} = \frac{i_D}{i_S} = \underline{\underline{1}}$$

(e) Table

	Common-S	Common-D	Common-G
Z_{in}	∞	∞	$1/g_m$
Z_{out}	R_D	R_S	∞
A_{voc}	$-g_m R_D$	1	∞
A_{ISC}	∞	∞	1

(f) Lowest output impedance:

Common-S and common-D

$\hookrightarrow R_D$ $\hookrightarrow R_S$

Yes, low output impedance is **desirable**

(g) Lowest input impedance:

Common-G

$\hookrightarrow 1/g_m$

No, low input impedance is **not desirable**

(h) $A_{voc} \approx 1$

$\Rightarrow$ Common-D configuration

$\hookrightarrow$ = S follower

(i) Common-S and common-D configurations are the most useful ones.

They have no undesirable characteristics.

Problem 2 Miller capacitance

FET $k = 20 \frac{mA}{V^2}$ $V_{th} = 1.0V$ n-channel FET

(a) This is a common-source amplifier

Voltage at G $V_G = V_{GS} = V_{CC} \frac{R_2}{R_1 + R_2}$

$$= 10V \frac{20k\Omega}{20k\Omega + 80k\Omega} = 10V \frac{20}{100} = 2V$$

Drain current

$$I_D = \frac{1}{2} k (V_{GS} - V_{th})^2 = \frac{1}{2} 20 \frac{mA}{V^2} (2V - 1V)^2$$

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

(b) Choice of R_D

$$V_{RD} = V_{CC} - V_{DS} = 10V - 5V = 5V$$

$$R_D = \frac{V_{RD}}{I_{RD}} = \frac{5V}{10mA} = 0.5k\Omega = 500\Omega$$

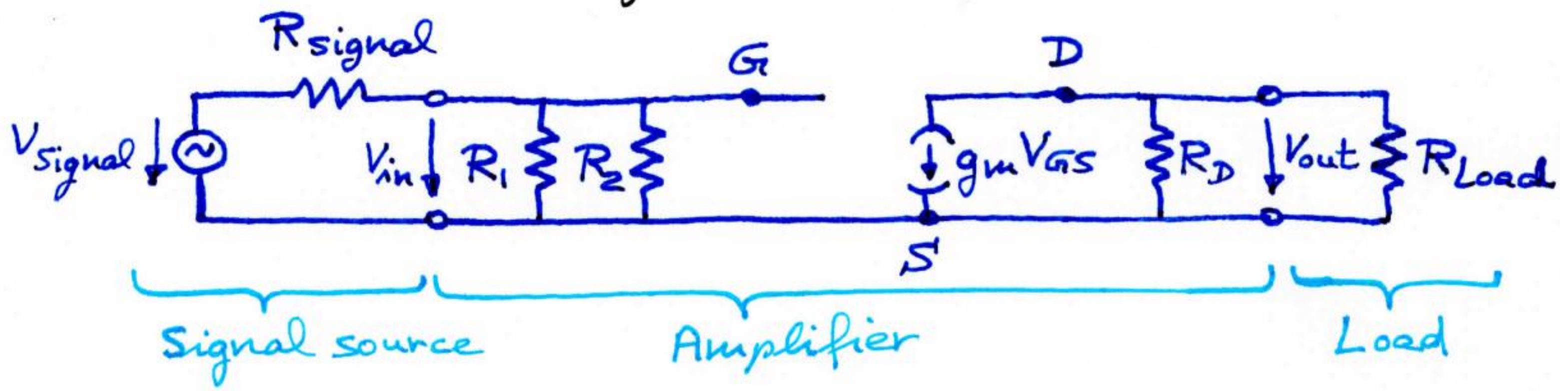
(c) Transconductance

Recall $g_m = k (V_{GS} - V_{th}) = 20 \frac{mA}{V^2} (2V - 1V)$

$$= 20 \, mA/V = 20 \, mS$$

$\hookrightarrow$ S = Siemens

(d) AC small-signal circuit



(e) Calculate A_{VOC} and A_V

$$A_{VOC} = \frac{V_{out}}{V_{in}} = \frac{g_m V_{GS} R_D}{V_{GS}} = \underline{\underline{g_m R_D}}$$

$$= 20\,mS \times 500\,\Omega = \underline{\underline{10}}$$

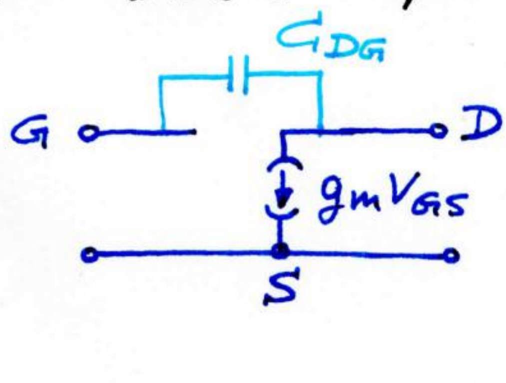
$$R_{Load} = 1\,k\Omega$$

$$A_V = \frac{V_{out}}{V_{in}} = \frac{g_m V_{GS} (R_D \parallel R_{Load})}{V_{GS}} = \underline{\underline{g_m (R_D \parallel R_{Load})}}$$

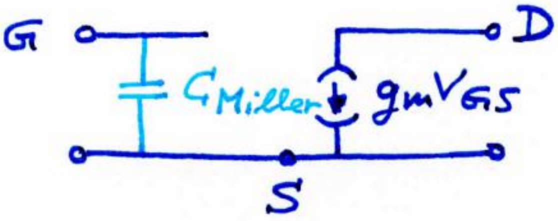
$$= g_m (500\,\Omega \parallel 1\,k\Omega) = 20\,mS \times 333\,\Omega = \underline{\underline{6.66}}$$

(f) $C_{DG} \Rightarrow$ Physical capacitance between D & G.

This is a capacitance we can measure with a capacitance meter

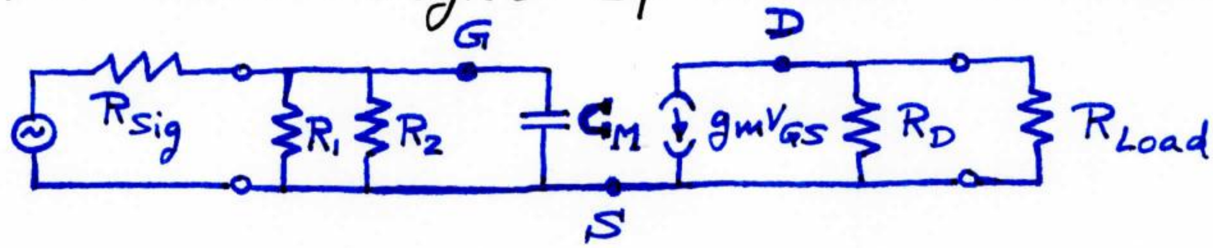


C_{Miller} ⇒ Equivalent capacitance relevant ("seen") at the input terminals of the FET.



(g) Cutoff frequency = 20 MHz

AC small-signal equivalent circuit



RC time constant. What is the relevant R? Through which resistors will C_M discharge?

$$R = R_1 \parallel R_2 \parallel R_{signal} = 80\,k\Omega \parallel 20\,k\Omega \parallel 5\,k\Omega$$

└ Relevant R

$$= \underline{3.81\,k\Omega}$$

Recall $\omega_{cutoff} = \frac{1}{RC} = \frac{1}{\tau}$

$$\Rightarrow \tau = RC = 1/\omega_{cutoff} = \frac{1}{2\pi f_{cutoff}} = \frac{1}{2\pi\, 20\,MHz}$$

$$= \frac{1}{126 \times 10^6 \frac{1}{s}} = \underline{7.94\,ns}$$

(h) $\tau = RC_M \Rightarrow C_M = \frac{\tau}{R} = \frac{7.94\,ns}{3.81\,k\Omega} = \underline{2.08\,pF}$

Recall $C_M = (1 + A_V)\, C_{DG}$

$$\Rightarrow C_{DG} = \frac{C_M}{1+A_V} = \frac{2.08\,pF}{1+6.66} = \underline{\underline{0.272\,pF}}$$

(i) Yes. The common-D configuration does not suffer from the limitations of the Miller capacitance.