L19 - part 2

ENEE2360 Analog Electronics

T10:
FET Amplifiers
ac small signal analysis

Instructor : Nasser Ismail

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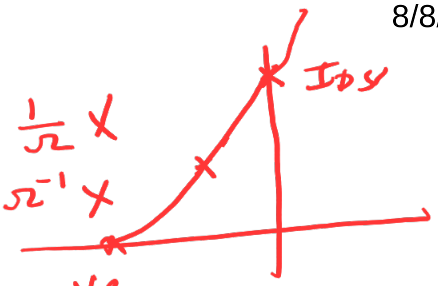
$g_m = \frac{\partial I_D}{\partial V_{gs}} \rightarrow \frac{A}{V} = \frac{1}{\Omega}$ ✗

$= \Omega^{-1}$ ✗

= mho ✗ ohm

= Siemens ✓



JFET DMOSFET $I_D = I_{DSS}\left(1 - \frac{V_{GS}}{V_P}\right)^2$

EMOSFET → $I_D = K_n (V_{GS} - V_T)^2$

Definition: Transconductance g_m

always positive

For JFETs and DMOSFETs

$$g_m = \frac{\partial I_D}{\partial V_{GS}} = \frac{2I_{DSS}}{|V_P|}\left[1 - \frac{V_{GS}}{V_P}\right]$$

$$g_m = g_{m0}\left[1 - \frac{V_{GS}}{V_P}\right] = g_{m0}\sqrt{\frac{I_D}{I_{DSS}}}$$

✓ $g_{m0} = \frac{2I_{DSS}}{|V_P|} = g_m\big|_{V_{GS}=0}$

For EMOSFET

$$I_D = K\left(V_{GS} - V_{GS(TH)}\right)^2$$

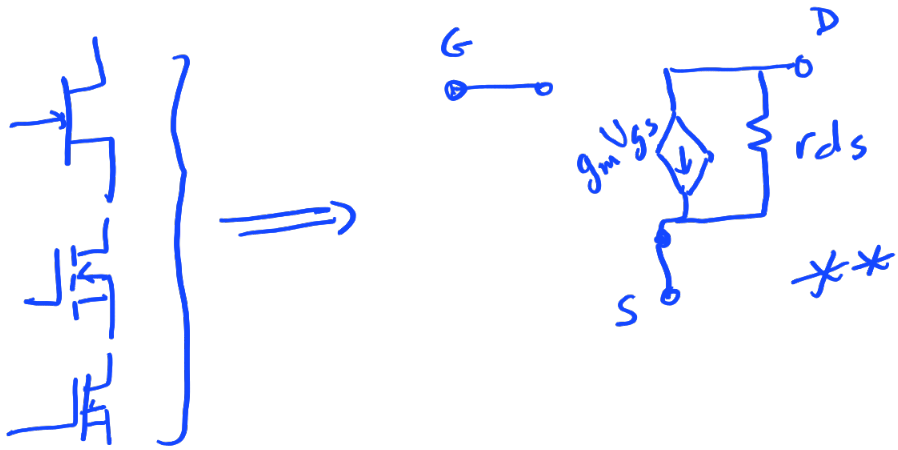
✓ $K = \frac{I_{D(ON)}}{\left(V_{GS(ON)} - V_{GS(TH)}\right)^2}$

$$g_m = \frac{\partial I_D}{\partial V_{GS}} = 2\overset{K_n}{K}\left(V_{GS} - \underset{V_T}{V_{GS(TH)}}\right)$$

$$\left(V_{GS} - V_{GS(TH)}\right) = \sqrt{\frac{I_D}{K}}$$

$$\therefore g_m = 2K\sqrt{\frac{I_D}{K}} = 2\sqrt{\frac{I_D K^2}{\cancel{K}}} = 2\sqrt{I_D K}$$

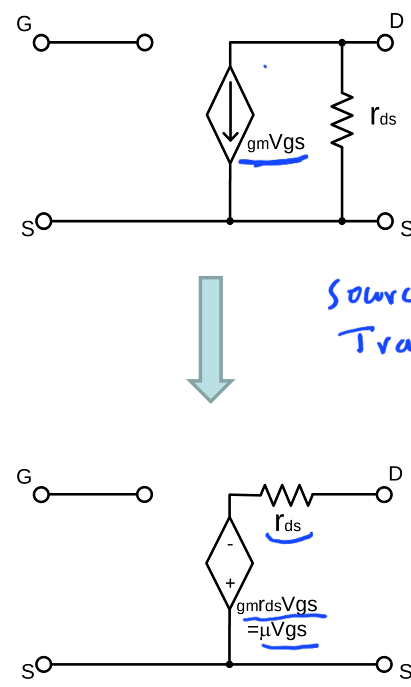
operating point



AC Small Signal Equivalent Circuit (MODEL Valid for all FET Types)

- In ac

$$\underline{g_m} = \frac{i_d}{\underline{v_{gs}}} \Rightarrow \underline{i_d} = \underline{g_m v_{gs}}$$



Source Transformation

- Or

$$\underline{\mu} = \underline{g_m r_{ds}} \quad \text{- \underline{amplification factor}}$$

unitless

$$g_m v_{gs} r_{ds} = \underbrace{g_m r_{ds}}_{\mu} v_{gs}$$

FET amplifiers

BJT

same ac eq. circuit

1. Common Source (CS) ⇒ CE
2. " Drain (CD) ⇒ CC
3. " Gate (CG) ⇒ CB

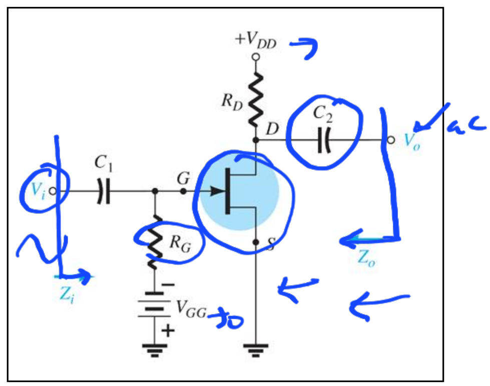
Common-Source (CS) Fixed-Bias

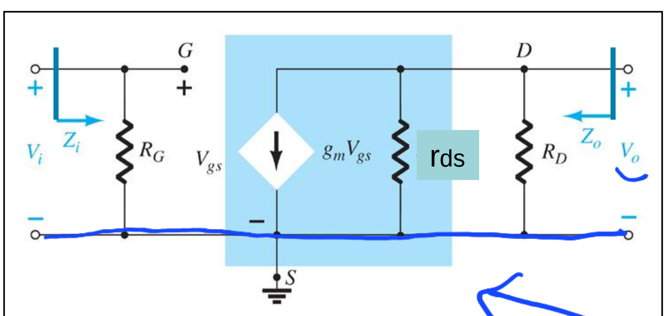
The input is applied to the gate and the output is taken from the drain

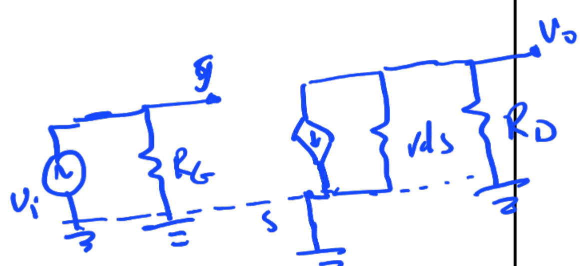
There is a 180° phase shift between the circuit input and output

To construct ac ss equivalent circuit

1) C1 & C2 are replaced by short
2) V_{DD}=0 V (short) , $V_{GG}=0 \rightarrow$ short
3) FET ac ss MODEL







Calculations

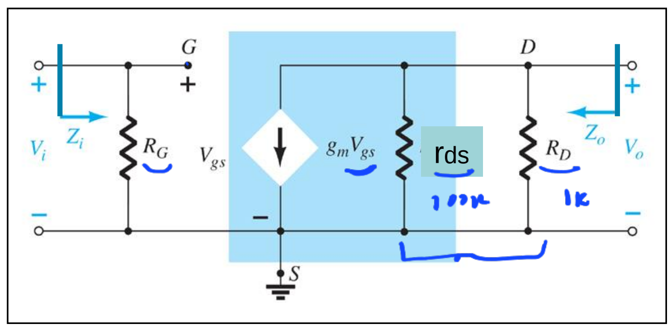
Input impedance:

$$Z_i = R_G$$

Output impedance:

$$Z_o\Big|_{Vi=0} = R_D || r_{ds}$$

$$Z_o\Big|_{Vi=0} \cong R_D \Big|_{r_{ds} \geq 10 R_D}$$



Voltage gain:

$$V_i = V_{gs}$$

$$V_o = V_{ds}$$

not important

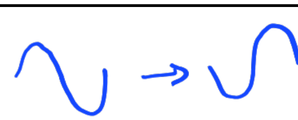
$$A_v = \frac{V_o}{V_i} = \frac{V_{ds}}{V_{gs}}$$

$$V_{ds} = -g_m V_{gs} (r_{ds} || R_D)$$, $V_{gs} = V_i$

$A_v = \frac{V_o}{V_i}$; $V_o = (R_D || r_{ds}) - g_m V_{gs}$

$$A_v = \frac{V_{ds}}{V_{gs}} = -g_m (r_{ds} || R_D)$$

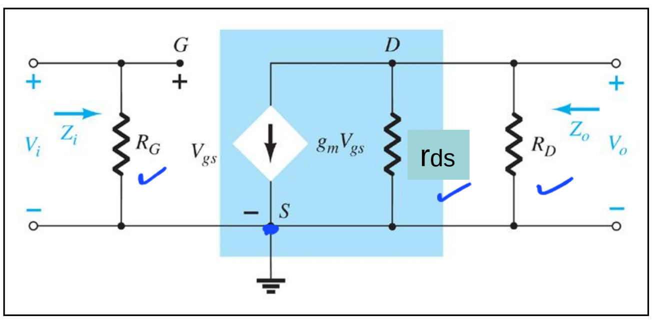
$$A_v = \frac{V_o}{V_i} = -g_m R_D \Big|_{r_{ds} \geq 10 R_D}$$

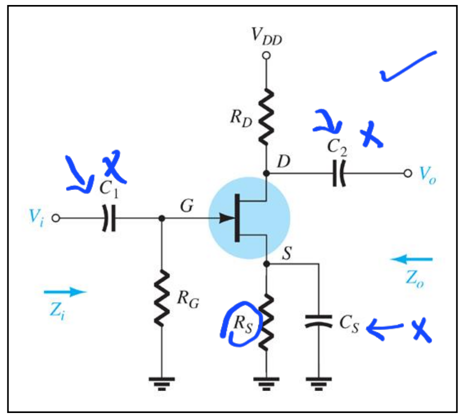


180° shift → or × −1

Common-Source (CS) Self-Bias

This is a common-source amplifier configuration, so the input is applied to the gate and the output is taken from the drain.





There is a 180° phase shift between input and output.

Calculations

Input impedance:

$$Z_i = R_G$$

Output impedance:

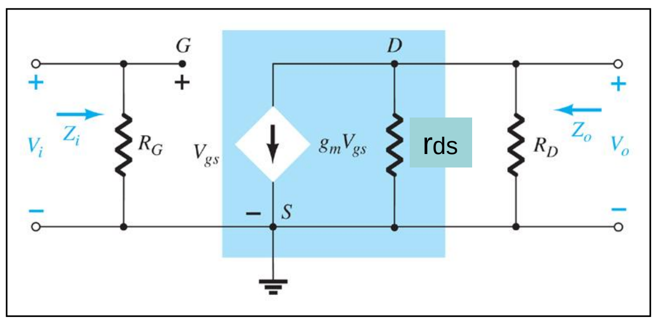
$$Z_o = r_{ds} || R_D$$

$$Z_o \cong R_D \Big|_{r_{ds} \geq 10 R_D}$$

Voltage gain:

$$A_v = -g_m (r_{ds} || R_D)$$

$$A_v = -g_m R_D \Big|_{r_{ds} \geq 10 R_D}$$



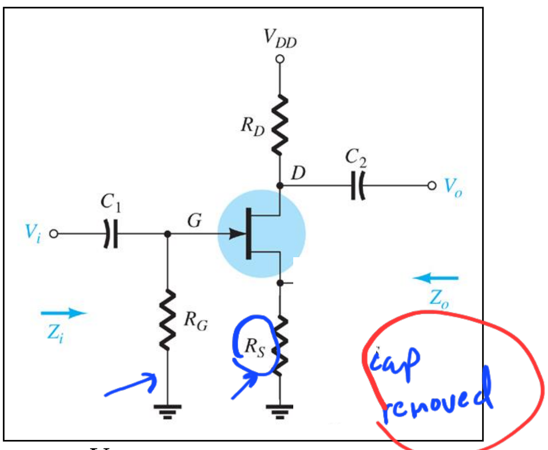
same as previous circuit

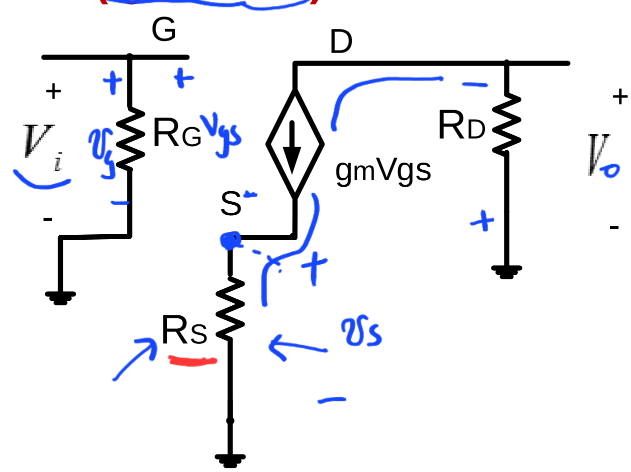
$v_o = -g_m v_{gs} R_D \quad \cdots (1) \quad \rightarrow \quad \frac{v_o}{v_{gs}} = -g_m R_D$ ✗

$v_{gs} = v_g - v_s$; $v_g = v_i$, $v_s = g_m v_{gs} R_s$ $\qquad \frac{v_{gs}}{v_i} = \frac{1}{1+g_m R_s}$

$v_{gs} = v_i - g_m v_{gs} R_s \Rightarrow v_i = v_{gs}(1+g_m R_s) \quad \cdots (2)$

Common-Source (CS) Self-Bias
Effect of Rs (ignore rds) → $r_{ds} = \infty$





$$A_v = \frac{V_o}{V_i}$$

$$V_o = -g_m V_{gs}(R_D)$$

$$V_s = g_m V_{gs}(R_S)$$

$$V_g = V_i$$

$$V_{gs} = V_g - V_S = V_i - g_m V_{gs} R_S$$

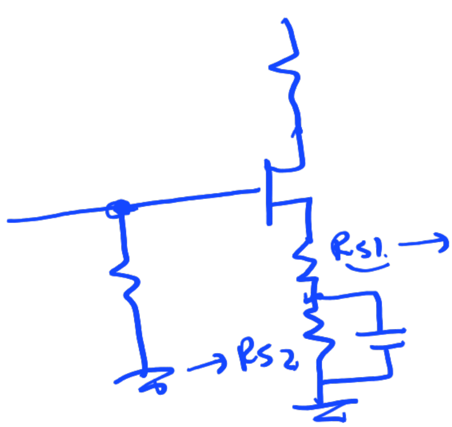
$$\Rightarrow V_i = V_{gs} + g_m V_{gs} R_S$$

$$A_v = \frac{V_o}{V_i} = \frac{-g_m V_{gs} R_D}{V_{gs} + g_m V_{gs} R_S}$$

$$A_v = \frac{-g_m R_D}{1+g_m R_S} \Leftrightarrow -g_m R_D \leftarrow \text{without } R_S$$

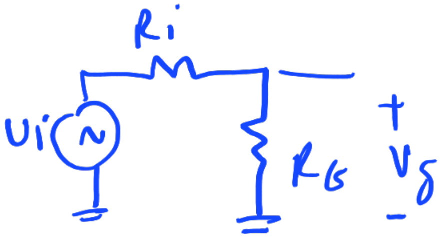
previous circuit

Gain is reduced due to R_S



$R_{S1} + R_{S2} = R_S$

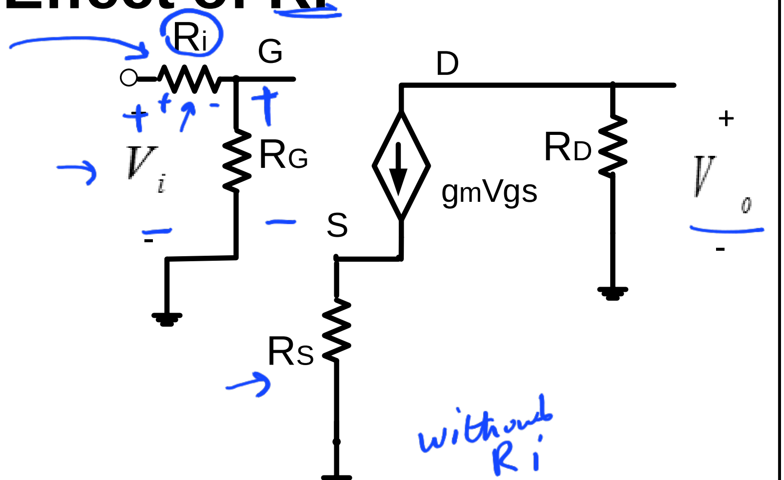
dc



$v_i = v_g$ → without Ri

$v_g = v_i \frac{R_G}{R_G + R_i}$ *

Common-Source (CS) Self-Bias
Effect of Ri



$$A_v = \frac{V_o}{V_i}$$

$$V_o = -g_m V_{gs}(R_D)$$

$$V_s = g_m V_{gs}(R_S)$$

$$V_g = \frac{R_G}{R_G + R_i} V_i$$

$$V_{gs} = V_g - V_S = \frac{R_G}{R_G + R_i} V_i - g_m V_{gs} R_S$$

$$\Rightarrow V_i = V_{gs}(1 + g_m R_S)\frac{R_G + R_i}{R_G}$$

without Ri

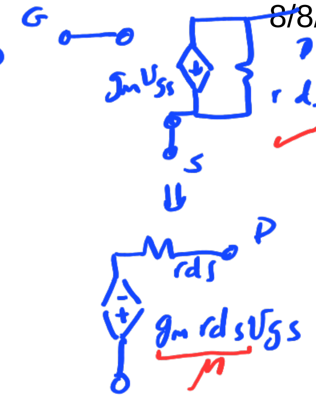
$$A_v = \frac{V_o}{V_i} = \boxed{\frac{-g_m R_D}{1 + g_m R_S}} \frac{R_G}{R_G + R_i}$$

→ < 1

Gain is reduced more due to R_i

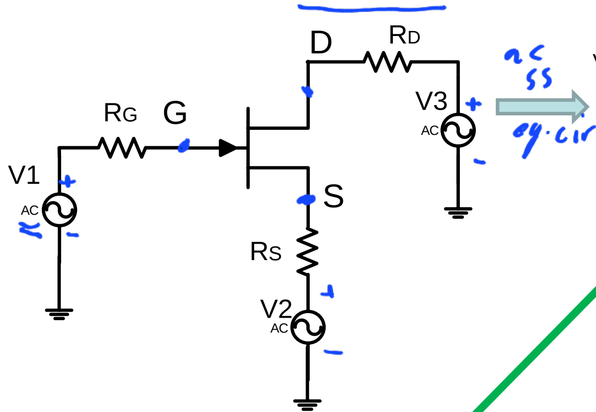
End of L19
12/8/2021

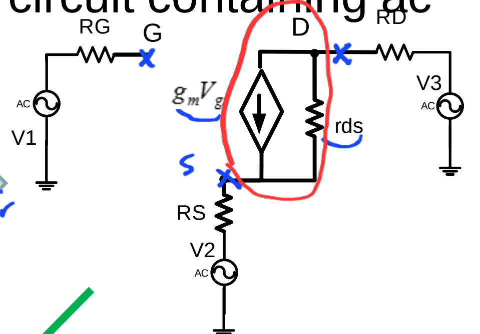
FET's → ss equivalent circuit →



Impedance Reflection

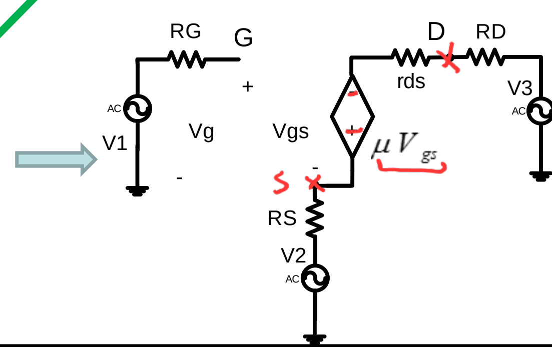
- Consider the following circuit containing ac sources V1,V2,V3



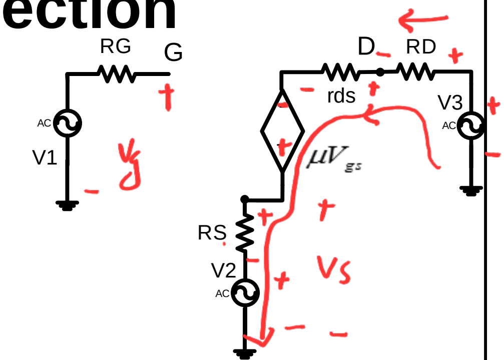


with source transformation

$\mu = g_m r_{ds}$ - amplification factor



Impedance Reflection



KVL for the drain - source loop

$$V_3 - i_D R_D - i_D r_{ds} - i_D R_S + \mu V_{gs} - V_2 = 0 \ldots\ldots\ldots\ldots\ldots\ldots(1)$$

but

$$V_{gs} = V_g - V_S = V_g - \overbrace{\left(i_D R_S + V_2\right)}^{V_s} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(2)$$

substituting (2) in (1) yields:

$$V_3 - i_D R_D - i_D r_{ds} - i_D R_S + \mu\left(V_g - \left(i_D R_S + V_2\right)\right) - V_2 = 0$$

$$V_3 - i_D R_D - i_D r_{ds} - i_D R_S + \mu V_g - \mu i_D R_S - \mu V_2 - V_2 = 0$$

$\rightarrow i_D$?

$$V_3 - i_D R_D - i_D r_{ds} - i_D R_S\left(\mu + 1\right) + \mu V_g - V_2\left(\mu + 1\right) = 0$$

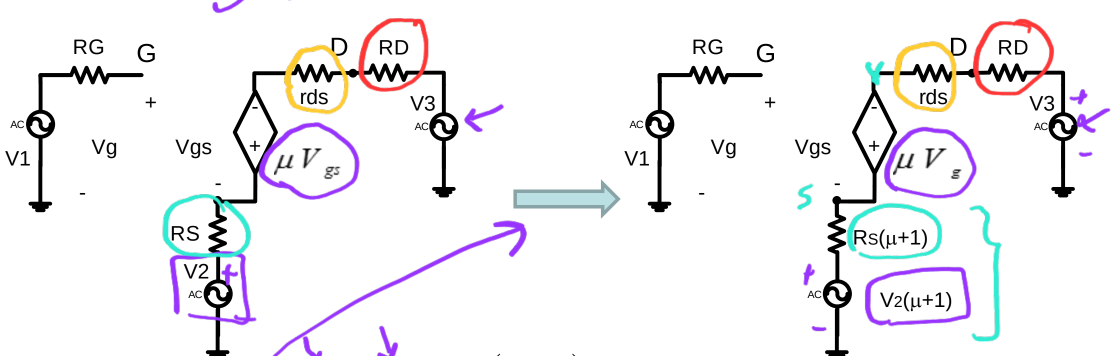
$$i_D R_D + i_D r_{ds} + i_D R_S\left(\mu + 1\right) = V_3 + \mu V_g - V_2\left(\mu + 1\right)$$

$$V_3 - i_D R_D - i_D r_{ds} - i_D R_S + \mu\left(V_g - \left(i_D R_S + V_2\right)\right) - V_2 = 0$$

$$i_D = \frac{V_3 + \mu V_g - V_2\left(\mu + 1\right)}{R_D + r_{ds} + R_S\left(\mu + 1\right)} \ldots\ldots\ldots\ldots\ldots\ldots(3) \quad *$$

(3) is the drain Equivalent circuit equation

original circuit



$$i_D = \frac{V_3 + \mu V_g - V_2(\mu+1)}{R_D + r_{ds} + R_S(\mu+1)} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots(3)$$

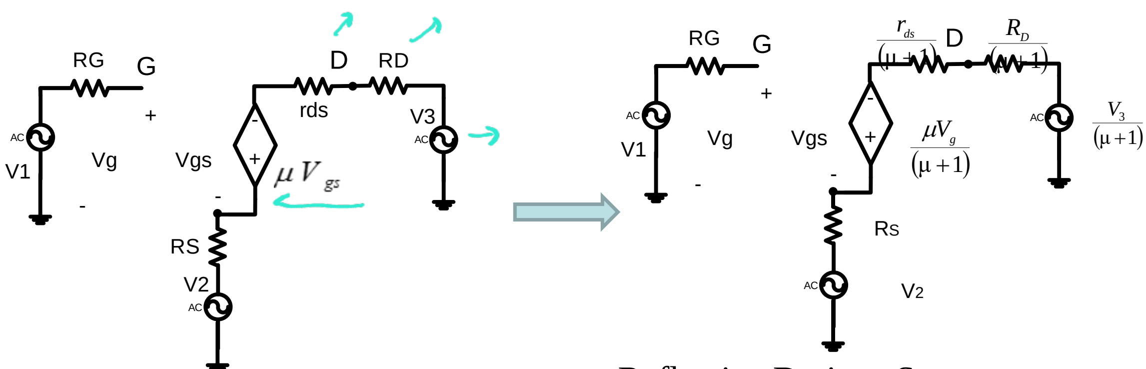
(3) is the drain Equivalent circuit equation

Reflection from Source to Drain

$\mu V_{gs} \Rightarrow \mu V_g$

$R_S \Rightarrow R_S(\mu+1)$

$V_2 \Rightarrow V_2(\mu+1)$



divide eq. (3) by $(\mu+1)$

$$i_D = \frac{\frac{V_3}{(\mu+1)} + \frac{\mu V_g}{(\mu+1)} - V_2}{\frac{R_D}{(\mu+1)} + \frac{r_{ds}}{(\mu+1)} + R_S} \quad \ldots\ldots\ldots\ldots\ldots\ldots(4)$$

(4) is the source equivalent circuit equation

Reflection Drain to Source

$$\mu V_{gs} \Rightarrow \frac{\mu V_g}{(\mu+1)}$$

$$R_D \Rightarrow \frac{R_D}{(\mu+1)}$$

$$r_{ds} \Rightarrow \frac{r_{ds}}{(\mu+1)}$$

$$v_3 \Rightarrow \frac{v_3}{(\mu+1)}$$

Example: Phase Splitting circuit

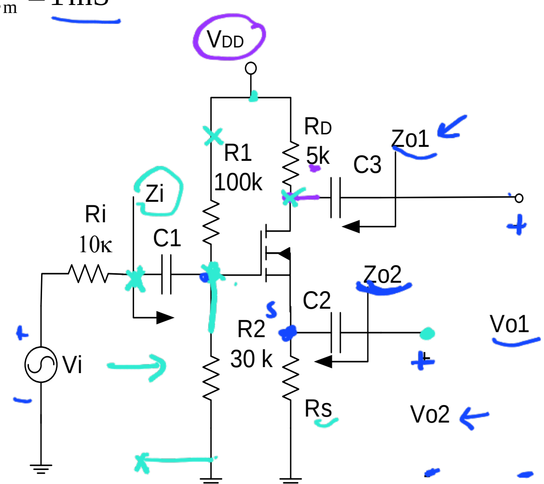
→ two outputs

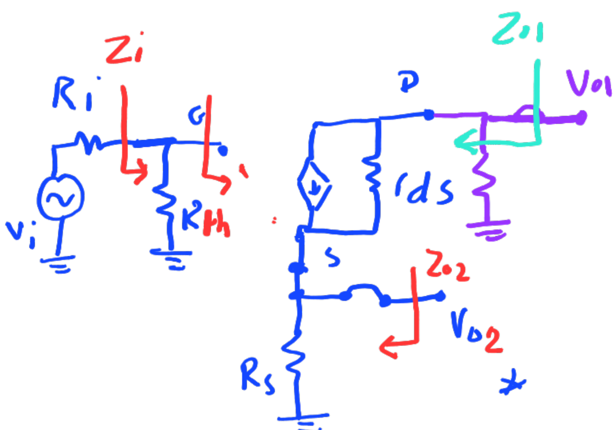
- Two outputs:
  - Vo1 from drain
  - Vo2 from source

$r_{ds} = 100\,k\Omega$

$g_m = 1\,mS$

Find A_V, A_I, Z_{O1}, Z_{O2} and Z_I



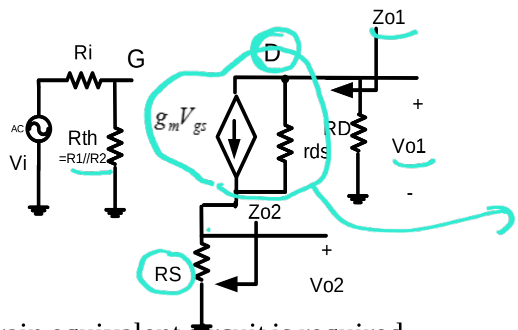


$R_{th} = R_1 \parallel R_2$

no V_o ?

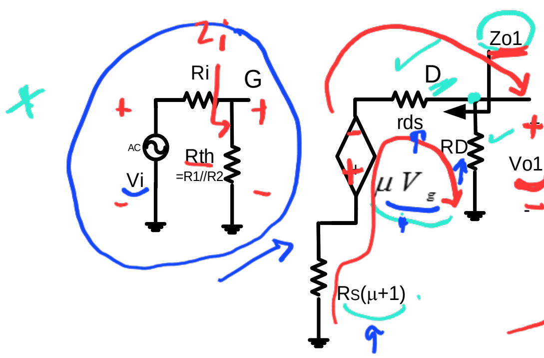
$\boxed{Z_{in} = R_{th}}$

Solution: ac ss equivalent circuit



1) To Find Z_{O1}, V_{O1} Drain equivalent circuit is required since both of these quantities are seen from the drain

Voltage Divider

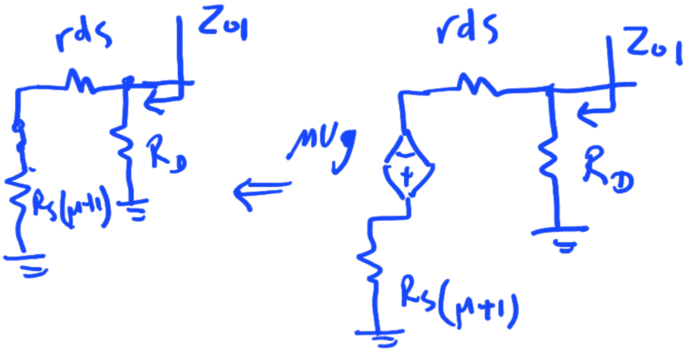


$$\rightarrow V_{o1} = \frac{R_D}{R_D + r_{ds} + R_S(\mu+1)}(-\mu V_g) \rightarrow \frac{V_{o1}}{V_g}$$

$$\rightarrow V_g = V_i \frac{R_{th}}{R_{th} + R_i} \rightarrow \frac{V_g}{V_i}$$

$$Av = \frac{V_{o1}}{V_i} = (-\mu)\frac{R_D}{R_D + r_{ds} + R_S(\mu+1)} \times \frac{R_{th}}{R_{th} + R_i}$$

$$Av = \frac{V_{o1}}{\cancel{V_g}} \times \frac{\cancel{V_g}}{V_i}$$



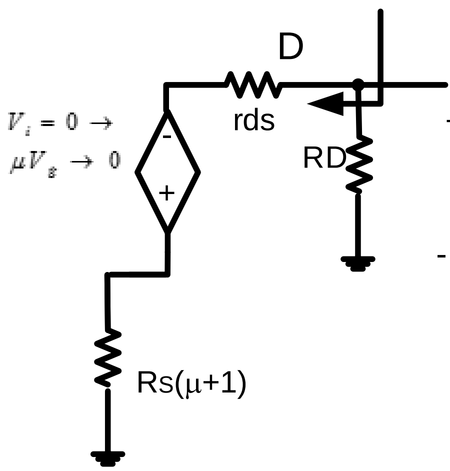
$$Z_{o1}\Big| = R_D // (r_{ds} + R_S(\mu+1))$$

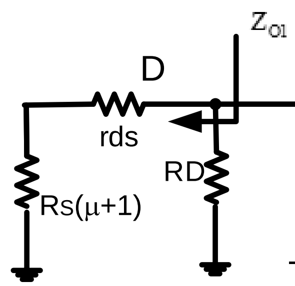
$V_i = 0$

$V_g = 0$

$\mu V_g = 0$ (short)

2) To Find $Z_{O1}\Big|_{\substack{Vi=0\\Vg=0}}$

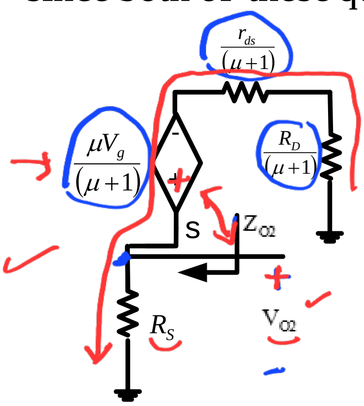




$$Z_{O1}\Big|_{\substack{Vi=0\\Vg=0}} = R_D // \left[r_{ds} + R_s(\mu+1) \right]$$

Solution: continued

3) To Find Z_{O2}, V_{O2} Source equivalent circuit is required since both of these quantities are seen from the source

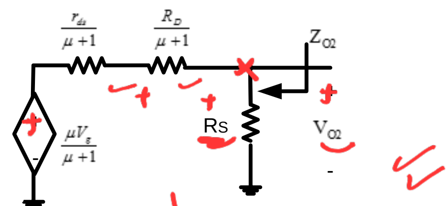


Reflection Drain to Source

$$\mu V_{gs} \Rightarrow \frac{\mu V_g}{(\mu+1)}$$

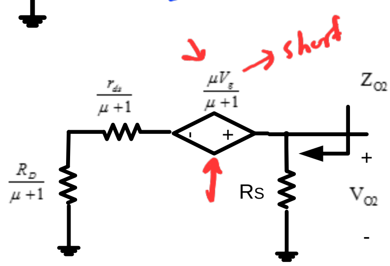
$$R_D \Rightarrow \frac{R_D}{(\mu+1)}$$

$$r_{ds} \Rightarrow \frac{r_{ds}}{(\mu+1)}$$

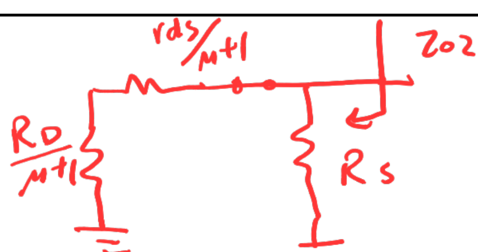


$$V_{o2} = \frac{R_S}{\frac{R_D + r_{ds}}{(\mu+1)} + R_S}\left(\frac{\mu V_g}{(\mu+1)}\right)$$

$$V_g = V_i \frac{R_{th}}{R_{th} + R_i}$$



$$A_{v2} = \frac{V_{o2}}{V_i} = \frac{\mu}{(\mu+1)} \frac{R_S}{\frac{R_D + r_{ds}}{(\mu+1)} + R_S} \times \frac{R_{th}}{R_{th} + R_i}$$



$Z_{o2} = R_S \,//\, \left(\frac{r_{ds}+R_D}{\mu+1}\right)$

$v_i = 0$
$v_s = 0$
$\frac{\mu v_s}{\mu+1} = 0$

if $rds \rightarrow \infty$

$$\boxed{Z_{o2}\Big|_{rds\to\infty} = R_s \,//\, \frac{1}{g_m}} \; ***$$

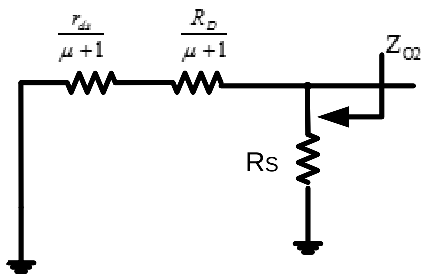
$$Z_{o2} = R_s \,//\, \frac{rds+R_D}{\mu+1}$$

$$\lim_{rds\to\infty} \frac{rds+R_D}{\underbrace{\mu+1}_{g_m rds}} = \lim_{rds} \frac{rds+R_D}{g_m rds+1} = \lim_{rds\to\infty} \frac{1+\cancel{\frac{R_D}{rds}}^{\,0}}{g_m+\cancel{\frac{1}{rds}}^{\,0}}$$

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

Solution: continued

4) To Find $Z_{O2}\Big|_{\substack{Vi=0\\Vg=0}}$



$$Z_{O2}\Big|_{\substack{Vi=0\\Vg=0}} = R_S \,//\left[\frac{r_{ds}+R_D}{(\mu+1)}\right]$$

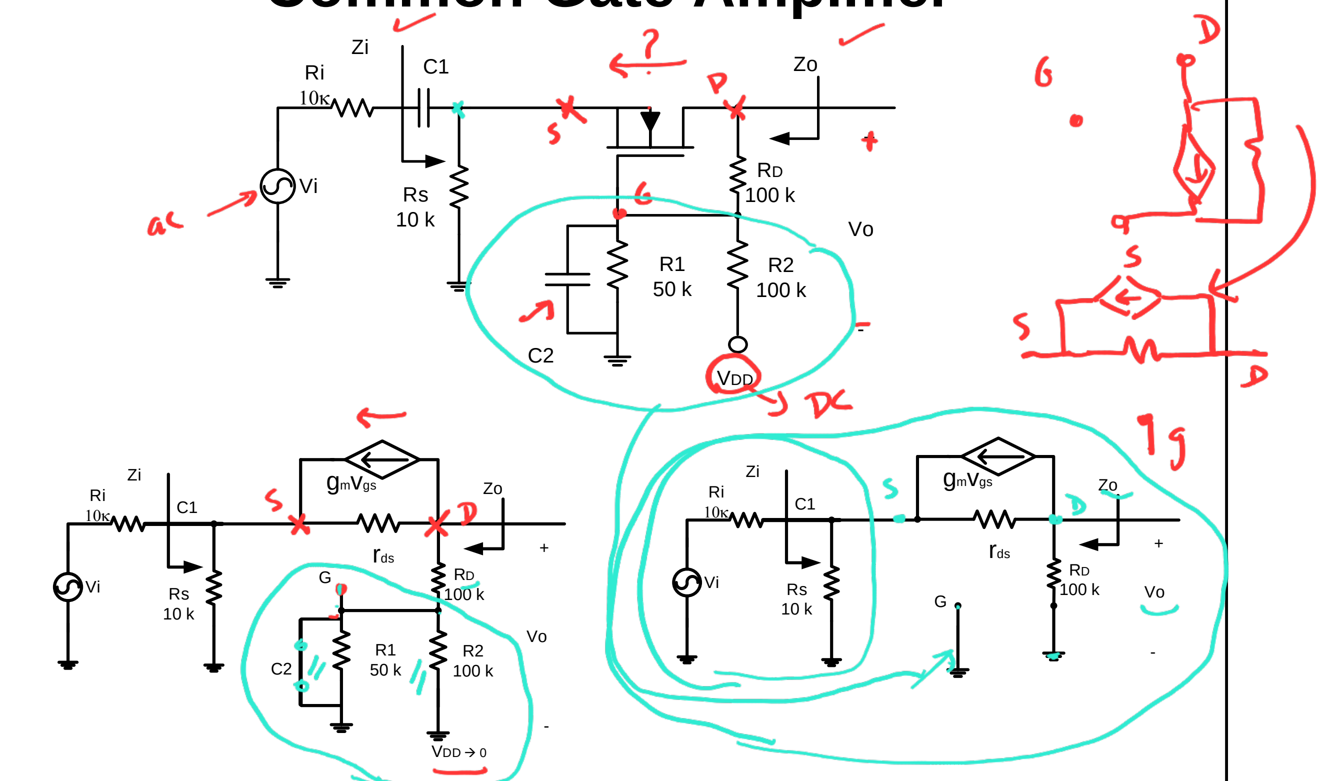
$$Z_{O2}\Big|_{\substack{Vi=0\\Vg=0}}\Big|_{r_{ds}\to\infty} = R_S \,//\, \frac{1}{g_m}$$

$$\text{since } \lim_{rds\to\infty} \frac{rds+R_D}{\mu+1} = \lim \frac{\frac{rds}{rds}+\frac{R_D}{rds}}{\frac{g_m rds}{rds}+\frac{1}{rds}}$$

$$= \lim_{rds\to\infty} \frac{1+\frac{R_D}{rds}}{g_m+\frac{1}{rds}} = \frac{1}{g_m} \checkmark$$

$$Z_i = R_{th} = R_1 \,//\, R_2$$

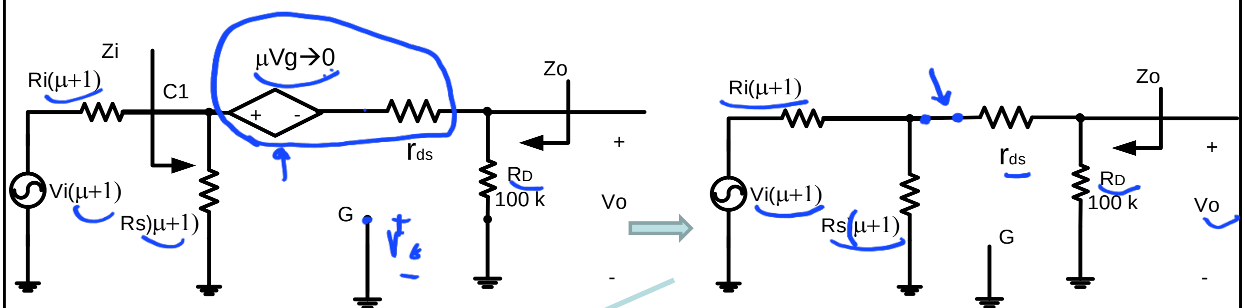
Common Gate Amplifier

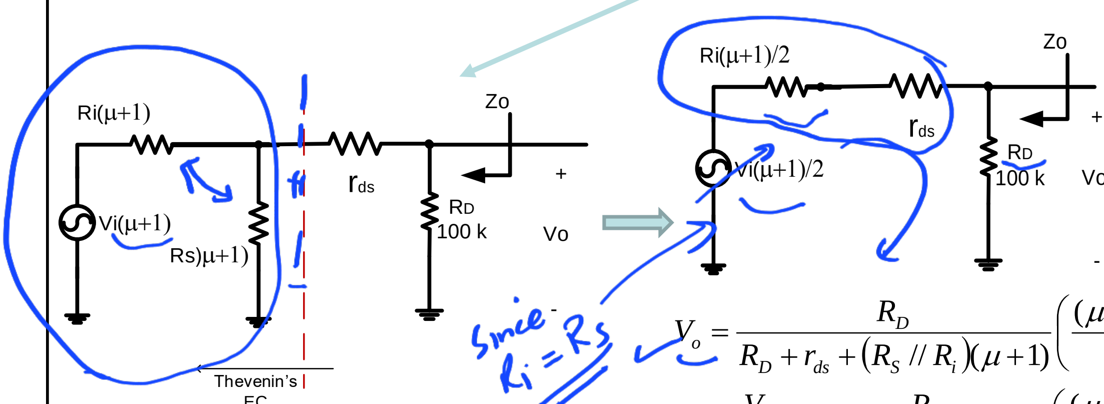


$\mu v_{GS} \rightarrow \mu v_g \rightarrow$

$R_i = R_S \leftarrow$ in this example

Drain Equivalent circuit to find Vo and Zo



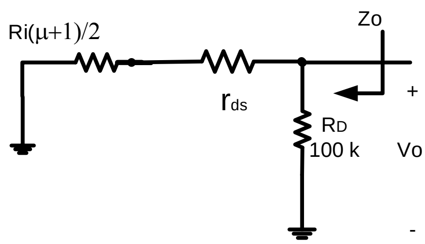


Since $R_i = R_S$

$$V_o = \frac{R_D}{R_D + r_{ds} + (R_S \,//\, R_i)(\mu+1)} \left(\frac{(\mu+1)}{2} V_i \right)$$

$$Av = \frac{V_o}{V_i} = \frac{R_D}{R_D + r_{ds} + 5k(\mu+1)} \left(\frac{(\mu+1)}{2} \right)$$

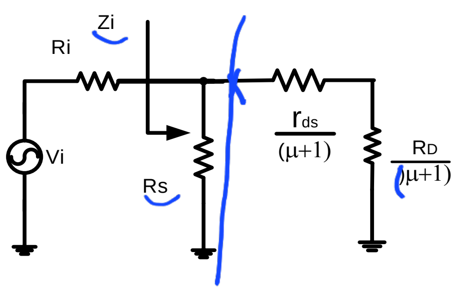
- Drain Equivalent circuit to find Vo and Zo



$$Z_O\Big|_{Vi=0} = R_D // \left(r_{ds} + \frac{R_i(\mu+1)}{2} \right)$$

ENEE236

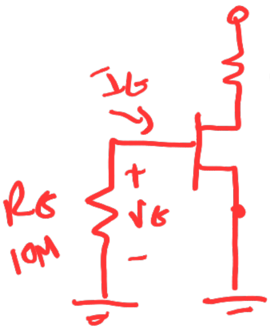
- To find Zi source equivalent circuit is needed



$$Z_i = R_S \, // \left[\frac{r_{ds} + R_D}{(\mu + 1)} \right]$$

$$Z_i \Big|_{r_{ds} \to \infty} = R_S \, // \frac{1}{g_m}$$

End of L20



$\to V_{GS} = V_G - V_S = 0$

$V_G = 0$

$V_S = 0$

L21
16-8-2021

$$g_m = \frac{2 I_{DSS}}{|V_P|}\left(1 - \frac{\cancel{V_{GS}}^{\,0}}{V_P}\right) = \frac{2 \times 10\,mA}{4} = 5\,mS$$

FET Amplifier Design (Important)

- Design a fixed bias network such that the ac voltage gain $|Av| = 10$, i.e. find value of R_D

DC analysis

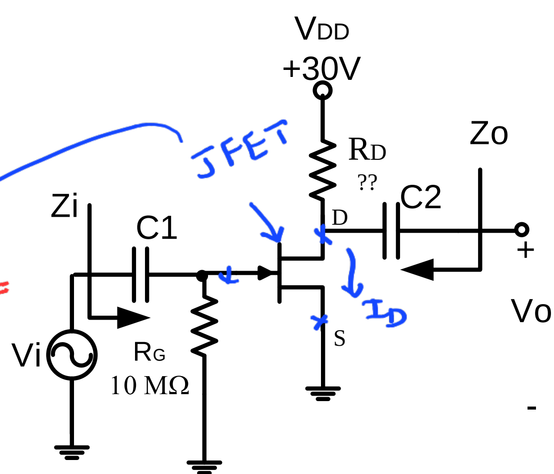
AC analysis

$A_v = f(g_m, r_{ds})$

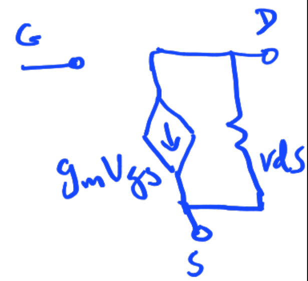
$V_P = -4\text{ V}$

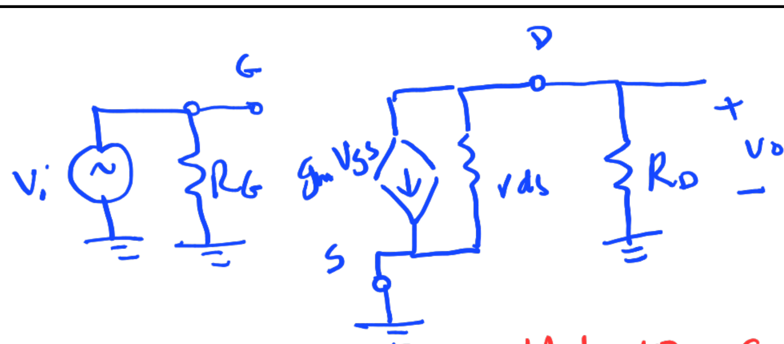
$I_{DSS} = 10\text{ mA}$

$r_{ds} = 50\text{ k}\Omega$



$$g_m = \frac{\partial I_D}{\partial V_{GS}} = \frac{2 I_{DSS}}{|V_P|}\left(1 - \frac{V_{GS}}{V_P}\right)$$





$A_v = \frac{V_o}{V_i}$

$V_o = -g_m V_{gs} (r_{ds} \| R_D)$

$V_{gs} = V_i$

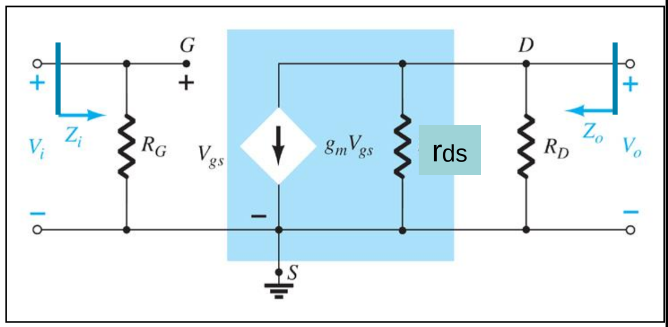
$A_v = -g_m (r_{ds} \| R_D)$?

$|A_v| = 10 = g_m \frac{r_{ds} \cdot R_D}{r_{ds} + R_D}$

$\therefore R_D =$

Solution

ac ss equivalent circuit



$$V_{GS} = V_G - V_S = 0V$$

$$I_D = I_{DSS}\left(1 - \frac{0}{-4}\right)^2 = I_{DSS} = 10mA$$

For JFETs

$$g_m = \frac{2I_{DSS}}{|V_P|}\left[1 - \frac{V_{GS}}{V_P}\right]$$

$$= \frac{2(10mA)}{|-4|}\left[1 - \frac{0}{-4}\right] = 5\,mS$$

$$V_{gs} = V_i$$

$$A_v = \frac{V_o}{V_i}$$

$$V_o = -g_m V_{gs}(r_{ds}||R_D)$$

$$V_o = -g_m V_i (r_{ds}||R_D)$$

$$|A_v| = \left|\frac{V_o}{V_i}\right| = |-g_m(r_{ds}||R_D)|$$

Since Av & gm are known , then

$$|A_v| = \left|\frac{V_o}{V_i}\right| = |-g_m(r_{ds}||R_D)| = 10$$

$$\therefore (r_{ds}||R_D) = \frac{10}{g_m} = \frac{10}{5\,mS} = 2\,k\Omega$$

Substitute $r_{ds} = 50\,k\Omega$

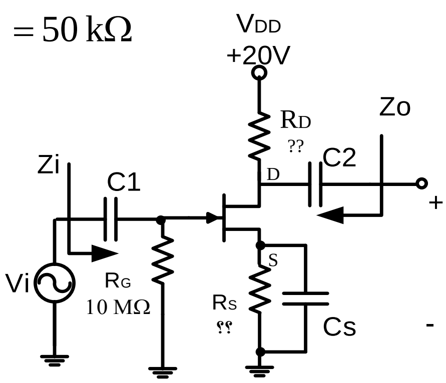
$$(r_{ds}||R_D) = \frac{r_{ds}.R_D}{r_{ds} + R_D} = \frac{50\,k\Omega.R_D}{50\,k\Omega + R_D} = 2\,k\Omega$$

$$\rightarrow R_D = \frac{2\,k\Omega\ .50\,k\Omega}{48\,k\Omega} = 2.08\,k\Omega$$

Design Example 2 (Important)

Choose the values of R_D and R_S that will result in voltage gain $|Av| = 8$ using the value of g_m defined at $V_{GSQ} = \frac{1}{4}V_p$

$V_P = -4\text{ V}$
$I_{DSS} = 10\text{ mA}$
$r_{ds} = 50\text{ k}\Omega$



$$g_m = \frac{2I_{DSS}}{|V_P|}\left(1 - \frac{V_{GS}}{V_P}\right)$$

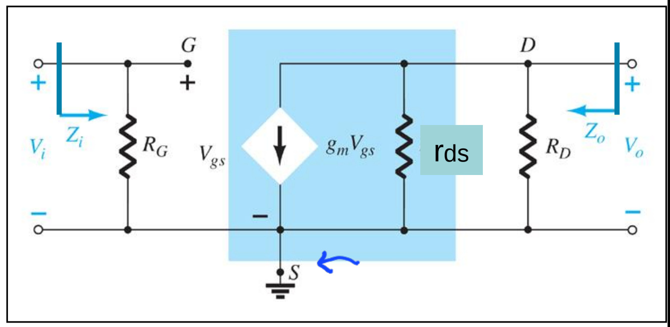
$$g_m\Big|_{V_{GS}=\frac{1}{4}V_P} = \frac{2I_{DSS}}{4}\left(1 - \frac{-1}{-4}\right)$$

$$= \frac{2 \times 10\text{mA}}{4}\left(1 - \frac{1}{4}\right)$$

$$= 3.75\text{ mS}$$

Solution (value of RD?)

ac ss equivalent circuit



$$g_m = \frac{2I_{DSS}}{|V_P|}\left[1-\frac{V_{GS}}{V_P}\right]$$

$$= \frac{2(10mA)}{|-4|}\left[1-\frac{-1}{-4}\right] = 3.75\,mS$$

$$V_{gs} = V_i$$

$$A_v = \frac{V_o}{V_i}$$

$$V_o = -g_m V_{gs}(r_{ds}||R_D)$$

$$V_o = -g_m V_i (r_{ds}||R_D)$$

$$|A_v| = \left|\frac{V_o}{V_i}\right| = |-g_m(r_{ds}||R_D)|$$

Since Av & gm are known , then

$$|A_v| = \left|\frac{V_o}{V_i}\right| = |-g_m(r_{ds}||R_D)| = 8$$

?

$$\therefore (r_{ds}||R_D) = \frac{8}{g_m} = \frac{8}{3.75\,mS} = 2.133\,k\Omega$$

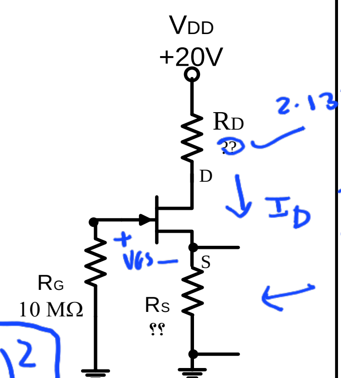
$$\text{Substitute } r_{ds} = 50\,k\Omega$$

$$(r_{ds}||R_D) = \frac{r_{ds}.R_D}{r_{ds}+R_D} = \frac{50\,k\Omega.R_D}{50\,k\Omega + R_D} = 2.133\,k\Omega$$

$$\rightarrow R_D = \frac{2.133\,k\Omega\ .50\,k\Omega}{47.867\,k\Omega} = 2.22\,k\Omega$$

Value of Rs?

The value of R_S is determined from DC analysis



Given

$$V_{GS} = V_G - V_S = \frac{1}{4} V_p = -1$$

$V_G = 0$?

$V_S = I_D R_S = 1$

0.75

$$\boxed{I_D = I_{DSS}\left(1 - \frac{V_{GS}}{V_P}\right)^2}$$

$$but\ I_D = I_{DSS}\left(1 - \frac{-1}{-4}\right)^2 = I_{DSS}.0.5625 = 5.625 mA$$

$$\therefore R_S = \frac{V_S}{I_D} = \frac{1\ \text{V}}{5.625\ \text{mA}} = 177.8\ \Omega$$

Resistor standard Values

160
→ 180
200
± 5%

Design Example 3

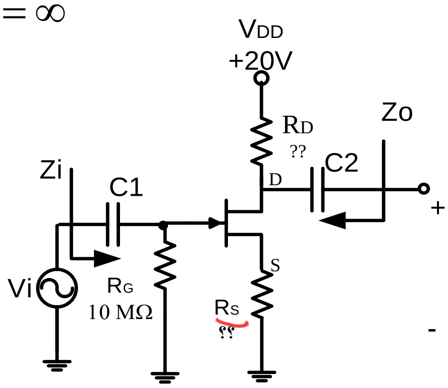
Choose the values of R_D and R_S that will result in

voltage gain $|Av| = 8$ using the value of g_m defined at $\underbrace{V_{GSQ} = \frac{1}{4} V_p}$ $= -1\,V$

$V_P = -4\text{ V}$

$I_{DSS} = 10\text{ mA}$

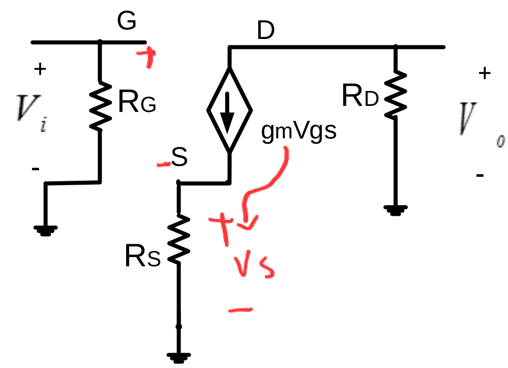
$r_{ds} = \infty$



Note: This is the same previous example except that no Cs (source capacitor)

Solution

ac ss equivalent circuit



$V_{GS} = -1\,\mathrm{V}$

$I_D = 5.625mA$

$\mathrm{g_m} = 3.75\,\mathrm{m}S$ (from previous example)

$$A_v = \frac{V_o}{V_i}$$

$$V_o = -g_m V_{gs}(r_{ds} \| R_D)$$

RD

$$V_{gs} = V_g - g_m V_{gs} R_S$$

$$V_g = V_i$$

$$V_{gs} = V_i - g_m V_{gs} R_S$$

$$V_i = V_{gs} + g_m V_{gs} R_S$$

$$A_v = \frac{V_o}{V_i} = \frac{-g_m V_{gs}(R_D)}{V_{gs} + g_m V_{gs} R_S} = \frac{-g_m R_D}{1 + g_m R_S}$$

$$|A_v| = \left|\frac{V_o}{V_i}\right| = \left|\frac{-g_m R_D}{1 + g_m R_S}\right| = 8$$

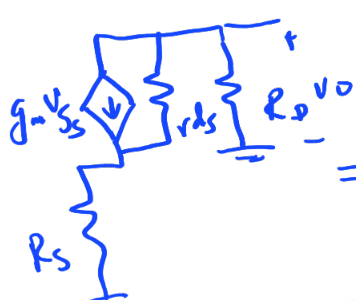
Since Av & gm and $\mathrm{R_S}$ are known, then

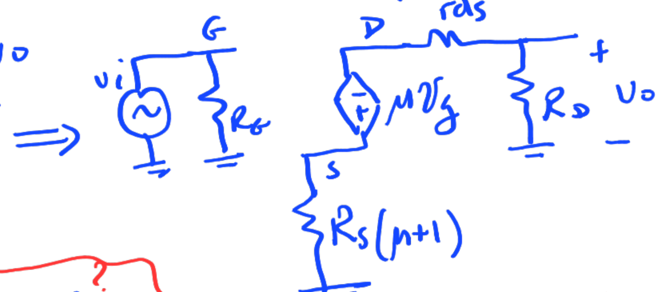
$\mathrm{R_S} = 180\,\Omega$ (based on DC analysis)

$\therefore R_D = 3.573\,\mathrm{k}\Omega$

if rds $\neq \infty$

Drain eq. circuit



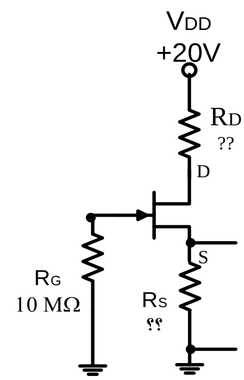


$$\frac{v_o}{v_i} = \frac{-\mu R_D}{R_D + r_{ds} + R_S(\mu+1)}$$

$\mu = g_m r_{ds}$

Value of Rs?

The value of R_S is determined from DC analysis



Given

$$V_{GS} = V_G - V_S = \frac{1}{4} V_p = -1$$

$$V_G = 0$$

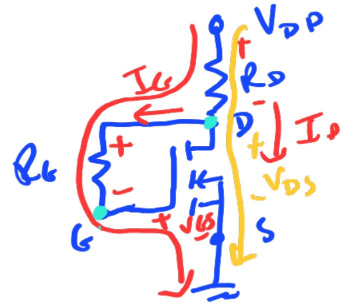
$$V_S = I_D R_S = -1$$

$$but\ I_D = I_{DSS}\left(1 - \frac{-1}{-4}\right)^2 = I_{DSS}.0.5625 = 5.625mA$$

$$\therefore R_S = \frac{V_S}{I_D} = \frac{1\ \text{V}}{5.625\ \text{mA}} = 177.8\ \Omega$$

choose standard value 180Ω

DC analysis



$V_{GS} = V_G - V_S = V_{DD} - I_D R_D$

$V_S = 0$

$V_G =$

$V_{DD} - I_D R_D - \cancel{I_G} R_G - V_{GS} = 0$

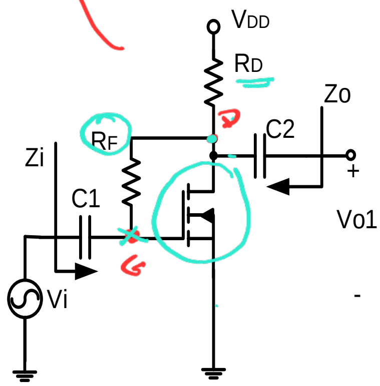
$V_{DD} - I_D R_D - V_{DS} = 0 \Rightarrow$

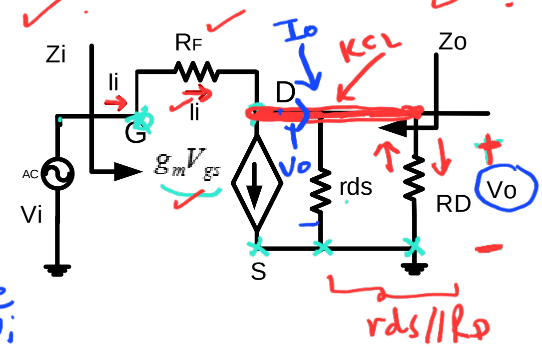
$V_{DS} = V_{DD} - I_D R_S$

$V_{GS} = V_{DS}$ OR $V_G = V_D$

Drain Feedback Configuration (self study)

Av ?





$A_v = \frac{v_o}{v_i}$

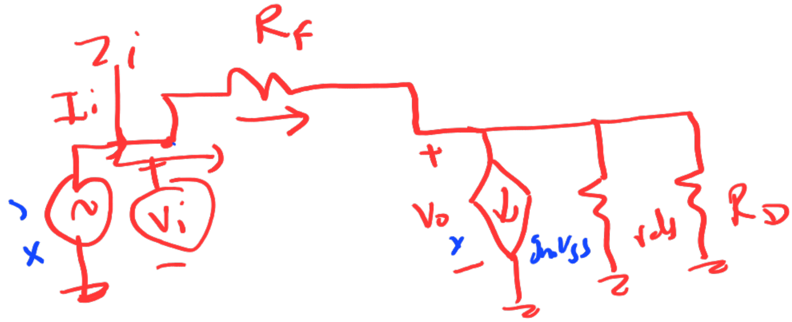
KCL

$$I_i = g_m V_{gs} + \frac{V_o}{R_D // r_{ds}}$$

$$V_{gs} = V_i$$

$$I_i = g_m V_i + \frac{V_o}{R_D // r_{ds}}$$

$$I_i - g_m V_i = \frac{V_o}{R_D // r_{ds}}$$



$$V_o = (I_i - g_m V_i)(R_D // r_{ds}) \quad \cdots (1)$$

also

$$I_i = \frac{V_i - V_O}{R_F} \quad \cdots (2)$$

$$I_i = \frac{V_i - ((I_i - g_m V_i)(R_D // r_{ds}))}{R_F}$$

$$I_i R_F = V_i - ((I_i - g_m V_i)(R_D // r_{ds}))$$

$$V_i[1 + g_m(R_D // r_{ds})] = I_i[R_F + (R_D // r_{ds})]$$

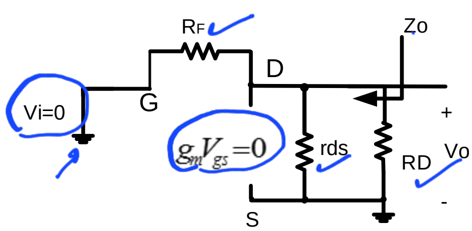
$\therefore$

$$Z_i = \frac{V_i}{I_i} = \frac{[R_F + (R_D // r_{ds})]}{[1 + g_m(R_D // r_{ds})]}$$

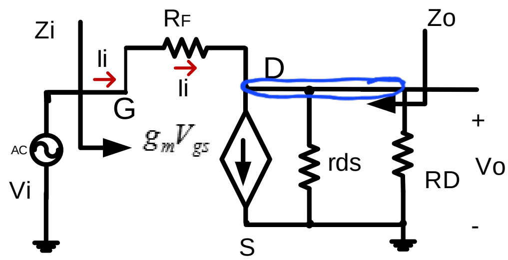
Av ✓

Zi

$$Z_i = \frac{V_i}{I_i}$$



$$Z_o\big|_{vi=0} = R_D // r_{ds} // R_F$$



$$I_i = g_m V_{gs} + \frac{V_o}{(R_D // r_{ds})}$$

$$V_{gs} = V_i \quad also \quad I_i = \frac{V_i - V_O}{R_F}$$

$=V_i$

$$\frac{V_i - V_O}{R_F} = g_m V_{gs} + \frac{V_o}{(R_D // r_{ds})}$$

$$\frac{V_i}{R_F} - \frac{V_O}{R_F} = g_m V_i + \frac{V_o}{(R_D // r_{ds})}$$

$$\frac{V_i}{R_F} - g_m V_i = \frac{V_o}{(R_D // r_{ds})} + \frac{V_O}{R_F}$$

$$V_i\left(\frac{1}{R_F} - g_m\right) = V_o\left(\frac{1}{(R_D // r_{ds})} + \frac{1}{R_F}\right)$$

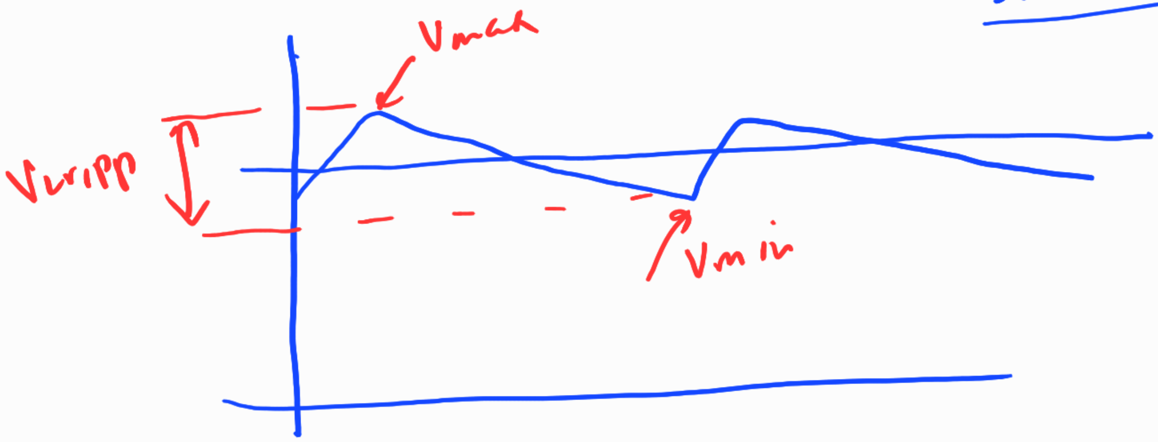
$$A_V = \frac{V_o}{V_i} = \frac{\left(\frac{1}{R_F} - g_m\right)}{\left(\frac{1}{(R_D // r_{ds})} + \frac{1}{R_F}\right)}$$

Best 3 of 4 Quizes will be counted

End of T10 FET TOPIC

Monday 23/8 Quiz #4 T9+T10

From Simulation



$70V$ مطلوب

$80V$? ليش

تغيير

C ?

N_1/N_2

error $80-70=10$

$\boxed{\%\,\text{error} \;\; \frac{10}{70}\times 100\% \le 2\%}$

$V_{avg} =$

$V_{Lripp} =$

$V_{Lrirms} = \frac{V_{Lripp}}{2\sqrt{3}}$

$r\% = ?$

$5V \rightarrow 4V$

$10\% \rightarrow 7\%$