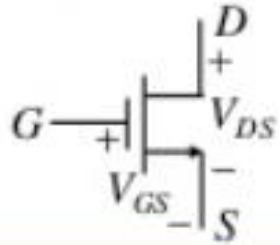
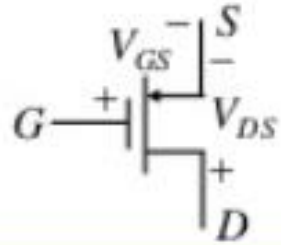
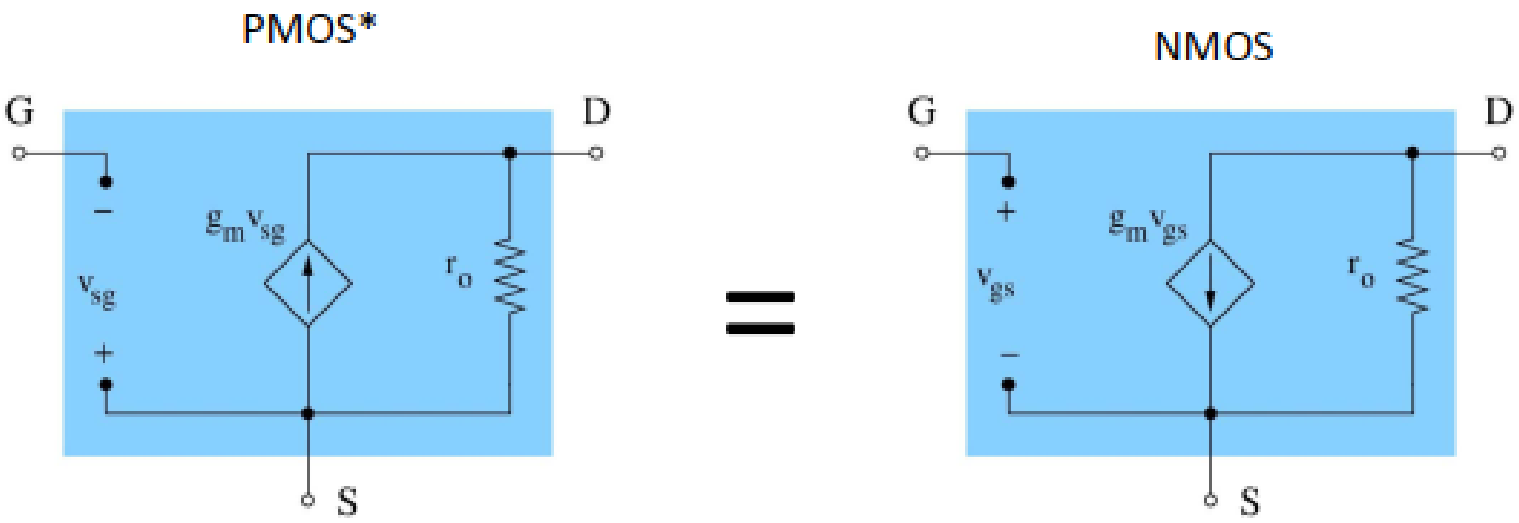


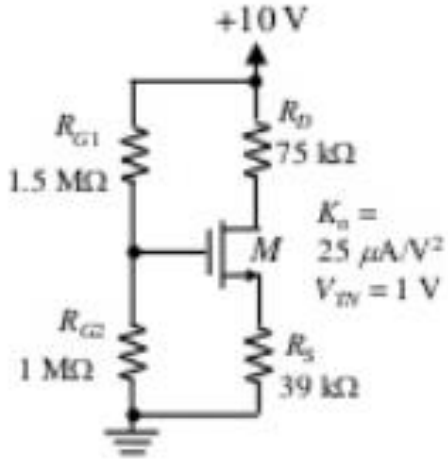

$V_{TN} > 0$

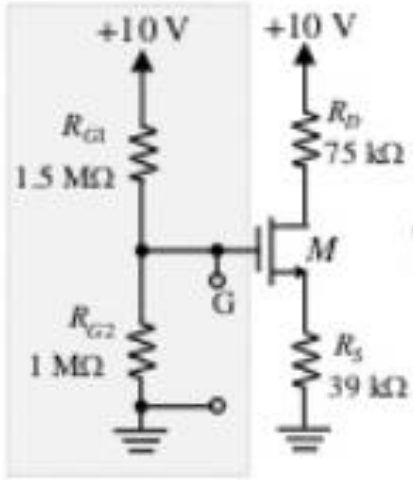


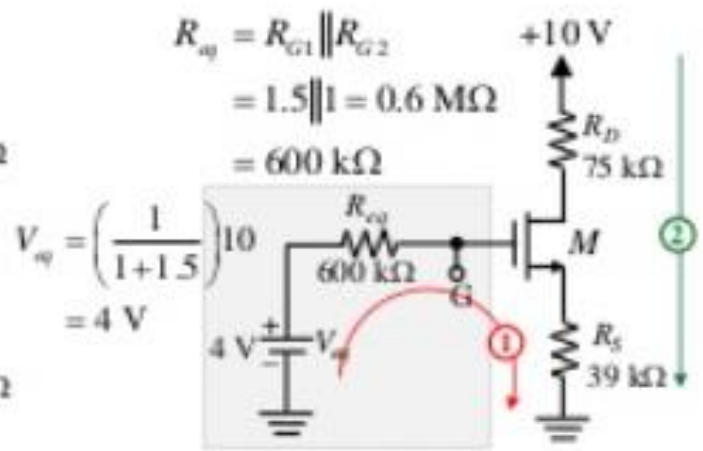

$V_{TP} < 0$

| Region | NMOS | PMOS |
|---|---|---|
| Cutoff | $V_{GS} < V_{TN}$<br>$I_D = 0$ | $\lvert V_{GS}\rvert < \lvert V_{TP}\rvert$<br>$I_D = 0$ |
| Triode | $V_{GS} \geq V_{TN}$ and $V_{DS} < V_{GS} - V_{TN}$<br>$I_D = K_n\left(V_{GS} - V_{TN} - \frac{V_{DS}}{2}\right)V_{DS}$ | $\lvert V_{GS}\rvert \geq \lvert V_{TP}\rvert$ and $\lvert V_{DS}\rvert < \lvert V_{GS}\rvert - \lvert V_{TP}\rvert$<br>$I_D = K_p\left(\lvert V_{GS}\rvert - \lvert V_{TP}\rvert - \frac{\lvert V_{DS}\rvert}{2}\right)\lvert V_{DS}\rvert$ |
| Saturation | $V_{GS} \geq V_{TN}$ and $V_{DS} \geq V_{GS} - V_{TN}$<br>$I_D = \frac{K_n}{2}(V_{GS} - V_{TN})^2$ | $\lvert V_{GS}\rvert \geq \lvert V_{TP}\rvert$ and $\lvert V_{DS}\rvert \geq \lvert V_{GS}\rvert - \lvert V_{TP}\rvert$<br>$I_D = \frac{K_p}{2}(\lvert V_{GS}\rvert - \lvert V_{TP}\rvert)^2$ |


PMOS*
G
D
S
$v_{sg}$
$g_m v_{sg}$
$r_o$
=
NMOS
G
D
S
$v_{gs}$
$g_m v_{gs}$
$r_o$




KVL 1: Since $I_G = 0$, $V_{eq} = V_{GS} + I_D R_S$

$4 = V_{GS} + 0.5 \times 25\mu\,(V_{GS} - 1)^2 \times 39\text{ k}$

$V_{GS}^2 + 0.05\,V_{GS} - 7.21 = 0$

$V_{GS} = -2.71$ or $2.66$ V

Since $V_{GS} = -2.71 < V_{TN} = 1$, $V_{GS} = 2.66$ V.

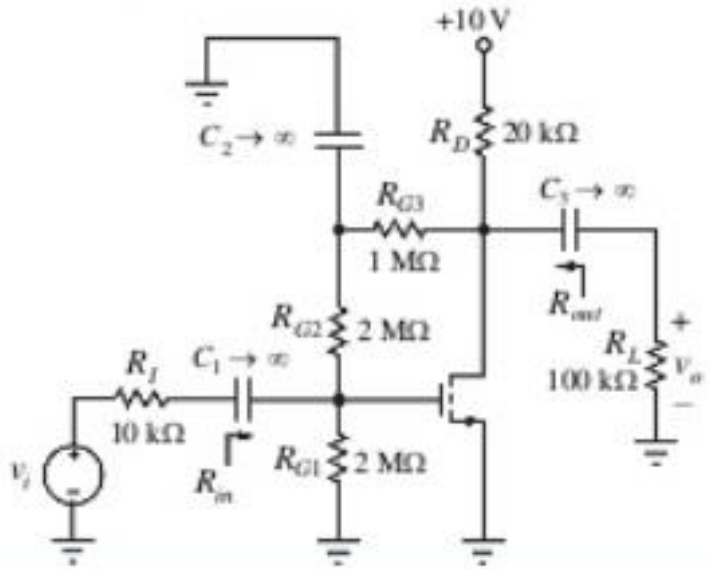
$I_D = (4 - 2.66)/39\text{k} = \mathbf{34.4\ \mu A}$

KVL 2: $V_{DS} = 10 - I_D R_D - I_D R_S$

$V_{DS} = 10 - 0.0344 \times (75 + 39) = \mathbf{6.08\ V}$

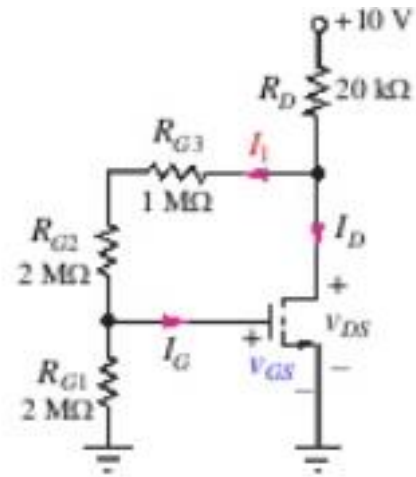
Since $V_{DS} > V_{GS} - V_{TN} = 1.66$,

***M* is in saturation region.**




**Problem:** Find voltage gain, input and output resistances.

**Given:** $K_n = 500\ \mu A/V^2, V_{TN} = 1V,$




DC Analysis:

$$I_1 = \frac{V_{DS}}{5\times10^6}$$

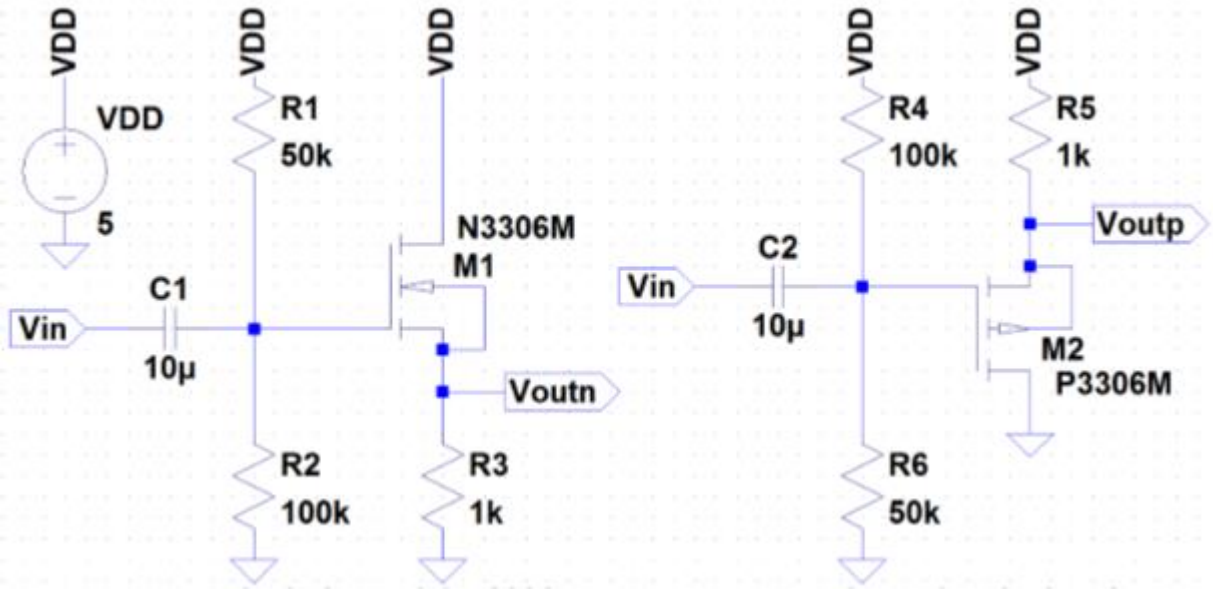
$$V_{GS} = I_1 \times 2\times10^6$$

$$= 0.4V_{DS}$$

$$I_D = \frac{500\ \mu}{2}(V_{GS} - 1)^2 \text{ —— (1)}$$

$$V_{DS} = 10 - 20\times10^3(I_D + I_1) \text{ ——(2)}$$

$$\therefore\ V_{DS} = 5V, V_{GS} = 2V, I_D = 250\ \mu A$$




**NMOS**: ZVN3306A

$KP_n = 0.1233A/V^2 \quad V_{THN} = 1.824v$

**DC Bias Point**

$$V_G = 5 * \frac{100k}{100k + 50k} = 3.33V$$

$$V_s = I_D * 1k$$

$$I_D = \frac{0.1233}{2} * \frac{1}{1} * (3.33 - I_D * 1k - 1.824)^2$$

$$I_D = 0.06165 * (1.506 - I_D * 1k)^2$$

$$16.2 * I_D = 2.26 - 3012I_D + 1MEG * I_D^2$$

$$1MEG * I_D^2 - 3028.2 * I_D + 2.26 = 0$$

$$I_D = 1.36mA$$

$$V_{GS} = 3.33 - 1.36 = 2.03V$$

**AC analysis**

$$gmn = \sqrt{2 * KP_n * I_D}$$

$$gmn = \sqrt{2 * (0.1233) * (0.00136)} = \frac{18.3mA}{v}$$

$$v_{gs} = v_{in} - v_{out}$$

$$i_d = v_{gs} * gmn$$

$$v_{out} = i_d * 1k$$

$$\frac{v_{out}}{v_{in}} = \frac{gmn}{\frac{1}{1k} + gmn} = 0.948v/V$$

**Output and Input Resistance**

$R_{in} = 50k \parallel 100k =$ **33.3kΩ**

$R_{out} = \frac{1}{gmn} \parallel 1k =$ **51.8Ω**

**PMOS**: ZVP3306A

$KP_p = 0.145\ A/V\text{^}2 \quad V_{THP} = 2.875v$

**DC Bias Point**

$$V_G = 5 * \frac{50k}{100k + 50k} = 1.66V$$

$$V_s = (5 - I_D) * 1k$$

$$I_D = \frac{0.145}{2} * \frac{1}{1} * (5 - 1.66 - I_D * 1k - 2.875)^2$$

$$I_D = 0.0725 * (0.465 - I_D * 1k)^2$$

$$13.8 * I_D = 1.216 - 930 * I_D + 1MEG * I_D^2$$

$$1MEG * I_D^2 - 943.8 * I_D + 0.216 = 0$$

$$I_D = 433\mu A$$

$$V_{SG} = 5 - 0.39 - 1.66 = 2.95V$$

**AC analysis**

$$gmp = \sqrt{2 * KP_p * I_D}$$

$$gmp = \sqrt{2 * (0.145) * (0.000433)} = \frac{11.2mA}{v}$$

$$v_{sg} = v_{out} - v_{in}$$

$$i_d = v_{sg} * gmp$$

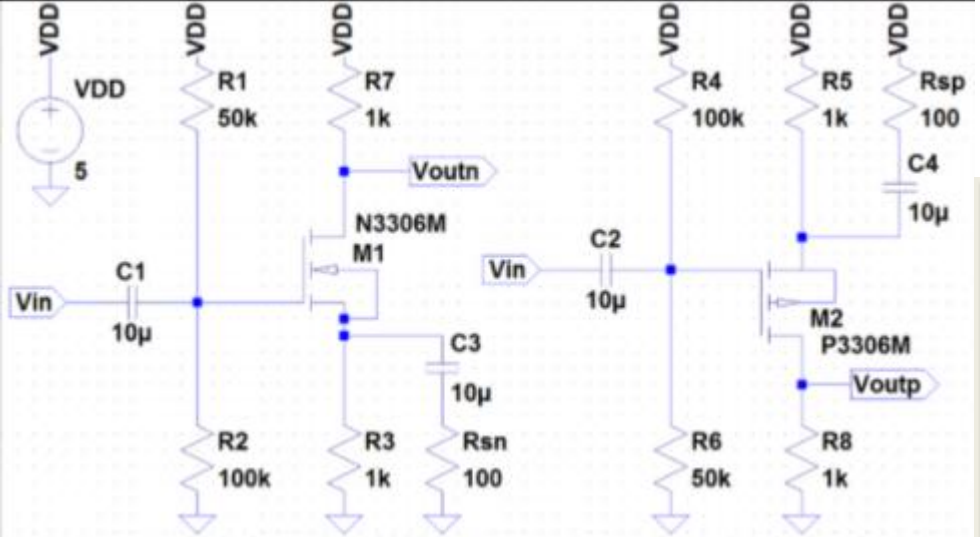
$$v_{out} = -i_d * 1k$$

$$\frac{v_{out}}{v_{in}} = \frac{gmp}{\frac{1}{1k} + gmp} = 0.918v/V$$

**Output and Input Resistance**

$R_{in} = 50k \parallel 100k =$ **33.3kΩ**

$R_{out} = \frac{1}{gmp} \parallel 1k =$ **81.97Ω**




**NMOS**: ZVN3306A

$KP_n = \frac{0.1233A}{V^2}$ $V_{THN} = 1.824v$ $gmn = \frac{18.3mA}{v}$

***NOTE:** Amplifier operating with the same DC Bias

## AC Analysis

$v_{gs} = v_{in} - v_s$

$i_d = v_{gs} * gmn$

$v_s = (1k \parallel 100) * i_d$

$i_d = -\frac{v_{out}}{1k}$

$$-\frac{v_{out}}{1k} = \left(v_{in} - \left(90.9 * -\left(-\frac{v_{out}}{1k}\right)\right)\right) gmn$$

$$-\frac{v_{out}}{1k} = gmn * v_{in} + 90.9 * gmn * \frac{v_{out}}{1k}$$

$$v_{out}\left(-\frac{1}{1k} - \frac{90.9gmn}{1k}\right) = gmn * v_{in}$$

$$\frac{v_{out}}{v_{in}} = -6.87$$

## Output and Input Resistance

$R_{in} = 50k \parallel 100k = 33.3k\Omega$

$R_{out} = 1k\Omega$

**PMOS**: ZVP3306A

$KP_p = \frac{0.145A}{V^2}$ $V_{THp} = 2.875v$ $gmp = \frac{11.2mA}{v}$

***NOTE:** Amplifier operating with the same DC Bias

## AC Analysis

$v_{sg} = v_s - v_{in}$

$i_d = v_{sg} * gmp$

$v_s = -(1k \parallel 100) * i_d$

$i_d = \frac{v_{out}}{1k}$

$$\frac{v_{out}}{1k} = \left(\left(-90.9 * \left(\frac{v_{out}}{1k}\right)\right) - v_{in}\right) gmp$$

$$\frac{v_{out}}{1k} = -90.9 * gmp * \frac{v_{out}}{1k} - gmp * v_{in}$$

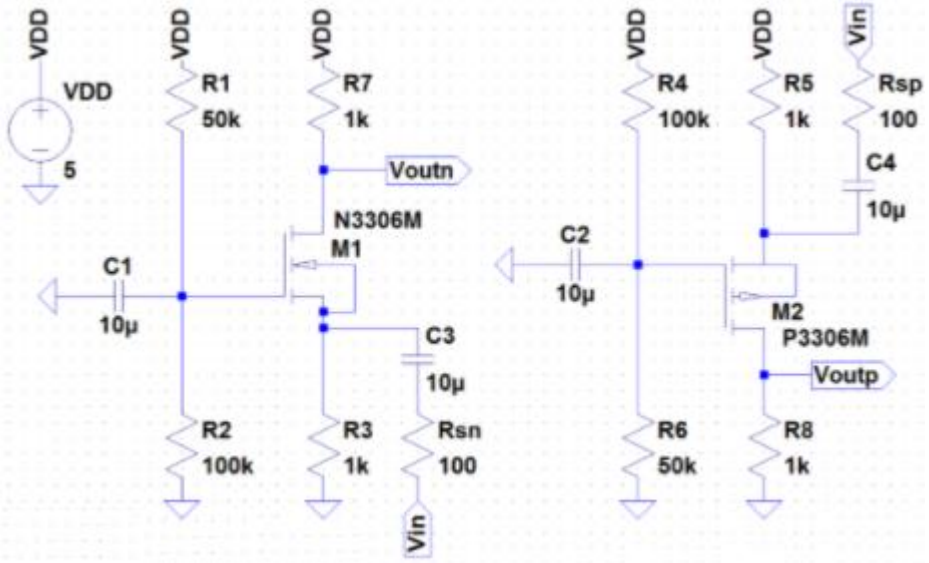
$$v_{out}\left(\frac{1}{1k} - \frac{90.9gmp}{1k}\right) = gmp * v_{in}$$

$$\frac{v_{out}}{v_{in}} = -5.55$$

## Output and Input Resistance

$R_{in} = 50k \parallel 100k = 33.3k\Omega$

$R_{out} = 1k\Omega$




**NMOS**: ZVN3306A

$KP_n = \frac{0.1233A}{V^2}$ $V_{THN} = 1.824v$ $gmn = \frac{18.3mA}{v}$

***NOTE:** Amplifier operating with the same DC Bias

**AC Analysis**

$v_{out} = -i_d * 1k$

$v_{gs} = 0 - v_s$

$$v_s = \frac{v_{in}\left(\frac{1}{gmn} \parallel 1k\right)}{\frac{1}{gmn} \parallel 1k + 100}$$

$v_s = -0.341 * v_{in}$

$i_d = v_{gs} gmn = -0.341 gmn * v_{in}$

$v_{out} = -id * 1k$

$v_{out} = 346 gmn * v_{in}$

$\frac{v_{out}}{v_{in}} = 6.33$

**Output and Input Resistance**

$R_{in} = 100 + 51.8 = 151.8\Omega$

$R_{out} = 1k\Omega$

**PMOS**: ZVP3306A

$KP_n = \frac{0.145A}{V^2}$ $V_{THN} = 2.875v$ $gmn = \frac{11.2mA}{v}$

***NOTE:** Amplifier operating with the same DC Bias

**AC Analysis**

$v_{out} = i_d * 1k$

$v_{sg} = v_s$

$$v_s = \frac{v_{in}\left(\frac{1}{gmp} \parallel 1k\right)}{\frac{1}{gmp} \parallel 1k + 100}$$

$v_s = 0.45 * v_{in}$

$i_d = v_{sg} gmp = 0.45 gmp * v_{in}$

$v_{out} = -id * 1k$

$v_{out} = 450 gmn * v_{in}$

$\frac{v_{out}}{v_{in}} = 5.04$

**Output and Input Resistance**

$R_{in} = 100 + 81.2 = 182\Omega$

$R_{out} = 1k\Omega$

در مدار شکل زیر ترانزیستورها در ناحیه اشباع بایاس شده‌اند. مقدار بهره ولتاژ $V_{out}/V_{in}$ را بدست آورید.

$$g_{m1} = 10\ mA/V \quad , \quad g_{m2} = 5\ mA/V$$