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DEPARTMENT OF ELECTRONICS ENGINEERING
ELECTRONIC CIRCUITS
Single Stage FET Amplifier

Numerical 1:
For the circuit shown below in figure 1, find A_V, R_1 and R_0

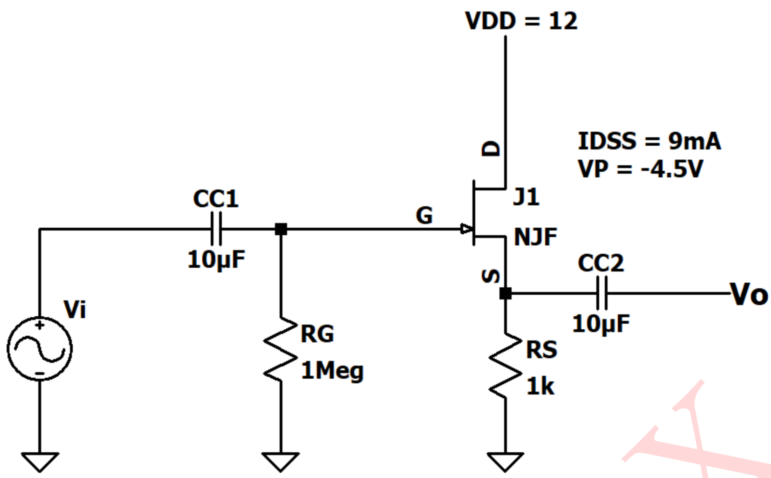

Figure 1: Circuit 1

Solution:

DC analysis:
$\because$ We are performing DC analysis all capacitors are open circuitted

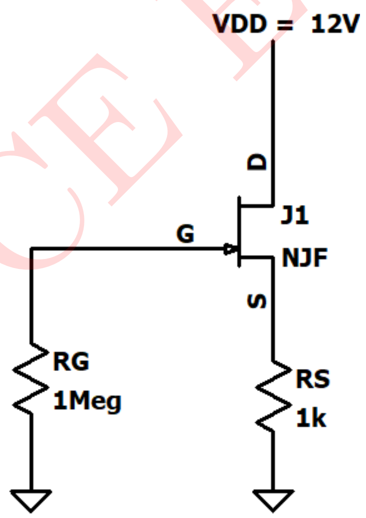

Figure 2: DC equivalent circuit

Applying KVL to gate-source loop,

$I_g R_G - V_{GS} - I_D R_S = 0$

$0 - V_{GS} - I_D R_S = 0 \qquad (\because I_g = 0, I_g R_G = 0)$

$\therefore V_{GS} = -I_D R_S$

$\therefore V_{GS} = -I_D (1k\Omega)$

$\therefore I_D = \dfrac{-V_{GS}}{1k\Omega} \qquad .....(1)$

Assuming JFET is working in saturation region,

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

$$I_D = 9mA\left(1-\frac{V_{GS}}{-4.5}\right)^2$$

$$\frac{-V_{GS}}{1k\Omega} = 9mA\left(1+\frac{V_{GS}}{4.5}\right)^2 \qquad \text{...[from (1)]}$$

$$-V_{GS} = 1k\Omega \times 9mA\left(1+\frac{V_{GS}}{4.5}\right)^2$$

$$-V_{GS} = 9\left(1+2\left(\frac{V_{GS}}{4.5}\right)+\frac{{V_{GS}}^2}{20.25}\right)$$

$$-V_{GS} = 9+18\left(\frac{V_{GS}}{4.5}\right)+9\times\frac{{V_{GS}}^2}{20.25}$$

$$-V_{GS} = 9+4V_{GS}+0.44{V_{GS}}^2$$

$$0 = 9+5V_{GS}+0.44{V_{GS}}^2$$

$V_{GS} = -2.242V$ or $V_{GS} = -9.121V$

We reject the value $V_{GS} = -9.121V$ $\qquad (\because |V_P| > |V_{GS}|)$

$\therefore V_{GS} = \mathbf{-2.242V}$

$\because I_D = \dfrac{-V_{GS}}{1k\Omega} = \dfrac{2.24V}{1k\Omega} = \mathbf{2.24mA}$

Small signal parameters:

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

$$= \frac{2\times 9mA}{4.5V}\left[1-\frac{(-2.24V)}{(-4.5V)}\right]$$

$$= 4mA/V\left[1-\frac{2.24V}{4.5V}\right]$$

$$= 4mA/V\,[1-0.49] = \mathbf{2mA/V}$$

ii) $r_d = \infty$

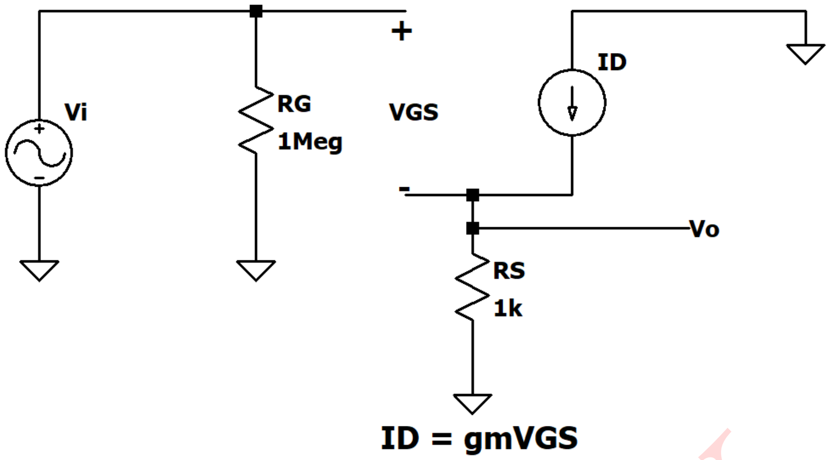

Figure 3: Small signal equivalent circuit

Input resistance,

$Z_i = R_G = \mathbf{1M\Omega}$

Output resistance,

$$
\begin{aligned}
Z_o &= \frac{1}{g_m} \parallel R_S \\
&= \frac{1}{2mA/V} \parallel 1k\Omega \\
&= 0.5k\Omega \parallel 1k\Omega \\
&= \frac{0.5k\Omega \times 1k\Omega}{0.5k\Omega + 1k\Omega} = \mathbf{0.333k\Omega}
\end{aligned}
$$

Voltage gain,

$$
\begin{aligned}
A_V &= \frac{V_o}{V_{in}} \\
&= \frac{(g_m V_{GS})(R_S)}{V_{GS} + V_{RS}} \\
&= \frac{(g_m V_{GS})(R_S)}{V_{GS} + g_m V_{GS} R_S} \\
&= \frac{(g_m V_{GS})(R_S)}{(V_{GS})[1 + g_m R_S]} \\
&= \frac{g_m R_S}{1 + g_m R_S} = \frac{2mA/V \times 1k\Omega}{1 + (2mA/V \times 1k\Omega)} = \frac{2}{1+2} = \mathbf{0.666}
\end{aligned}
$$

SIMULATED RESULTS:
Above circuit is simulated in LTspice and results are as follows:

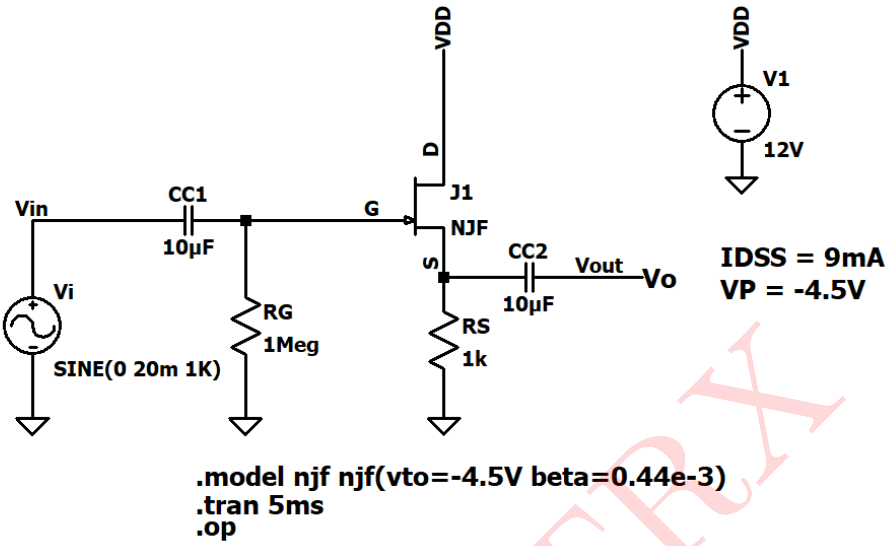

Figure 4: Circuit Schematic 1

The input and output waveforms are shown in figure 5.

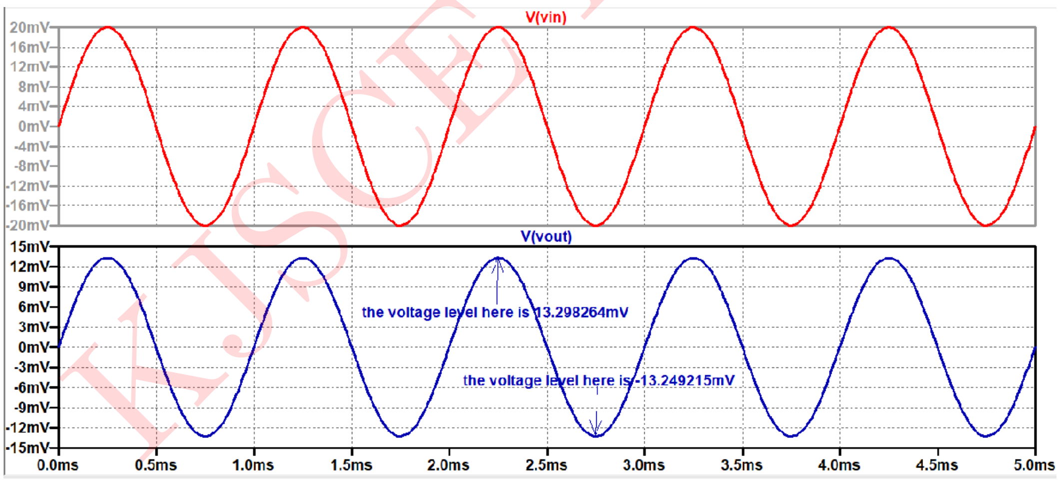

Figure 5: Input-Output waveforms

Comparison between theoretical and simulated values:

Parameters	Theoretical values	Simulated values
I_D	2.24mA	2.24247mA
V_{GS}	-2.242V	-2.242455V
A_V	0.666	0.6636

Table 1: Numerical 1

Numerical 2:
Determine V_o, Z_i, Z_o and A_V for the circuit given below in figure 6, if $V_i = 20mV$

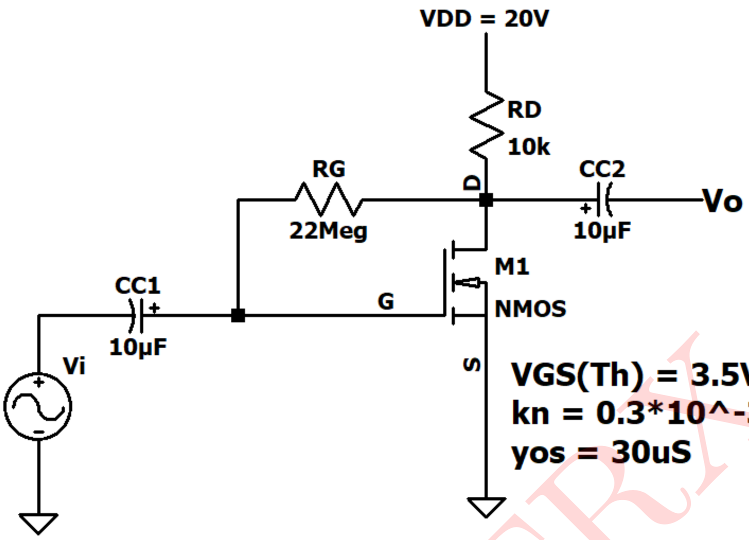

Figure 6: Circuit 2

Solution:

The above circuit is drain feedback bias consisting of N-channel E-MOSFET
DC analysis:

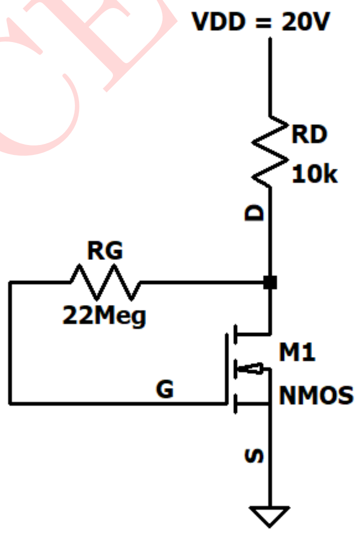

Figure 7: DC equivalent circuit

Since $I_g = 0, V_{GS} \approx V_{DS}$

Applying KVL to drain source loop,

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

$\therefore V_{DS} = V_{DD} - I_D R_D$

$V_{GS} = V_{DD} - I_D R_D \qquad ....(1)$

In MOSFET,

$I_{DQ} = k_n \left[V_{GSQ} - V_{GS_{(TH)}}\right]^2$

$\therefore I_D = 0.3 \times 10^{-3} mA/V^2 [V_{GS} - 3.5V]^2$

Substituting the value of I_D in equation (1),

$\because V_{GS} = V_{DD} - I_D R_D$

$\therefore V_{GS} = 20V - (0.3 \times 10^{-3}[V_{GS} - 3.5V]^2)(10k\Omega)$

$\therefore V_{GS} = 20V - 3[V_{GS} - 3.5V]^2$

$\therefore V_{GS} = 20V - 3\left({V_{GS}}^2 - 7V_{GS} + 12.25\right)$

$\therefore V_{GS} = 20V - \left(3{V_{GS}}^2 - 21V_{GS} + 36.75\right)$

$\therefore V_{GS} = 20V - 3{V_{GS}}^2 + 21V_{GS} - 36.75$

$\therefore V_{GS} = -3{V_{GS}}^2 + 21V_{GS} - 16.75$

$\therefore 0 = -3{V_{GS}}^2 + 20V_{GS} - 16.75$

$\therefore V_{GS} = 5.68V$ or $V_{GS} = 0.982V$

We reject the value $V_{GS} = 0.982V$ $\quad (\because |V_{GS}| > |V_{GS_{(TH)}}|)$

$\therefore V_{GS} = \mathbf{5.68V}$

$\because I_D = 0.3 \times 10^{-3}[V_{GS} - 3.5V]^2$

$= 0.3 \times 10^{-3}[5.68V - 3.5V]^2$

$= 0.3 \times 10^{-3}[2.18]^2 = \mathbf{1.425mA}$

$\because V_{GS} \approx V_{DS}$

$\therefore V_{DS} = \mathbf{5.68V}$

Small signal parameters:

i) $g_m = 2k_n \left(V_{GSQ} - V_{GS_{(TH)}}\right)$

$= 2 \times 0.3 \times 10^{-3} mA/V^2 (5.68 - 3.5.)$

$= 0.6 \times 10^{-3}(2.18) = \mathbf{1.308mA/V}$

ii) $r_d = \dfrac{1}{y_{OS}} = \dfrac{1}{30\mu s} = \mathbf{33.33k\Omega}$

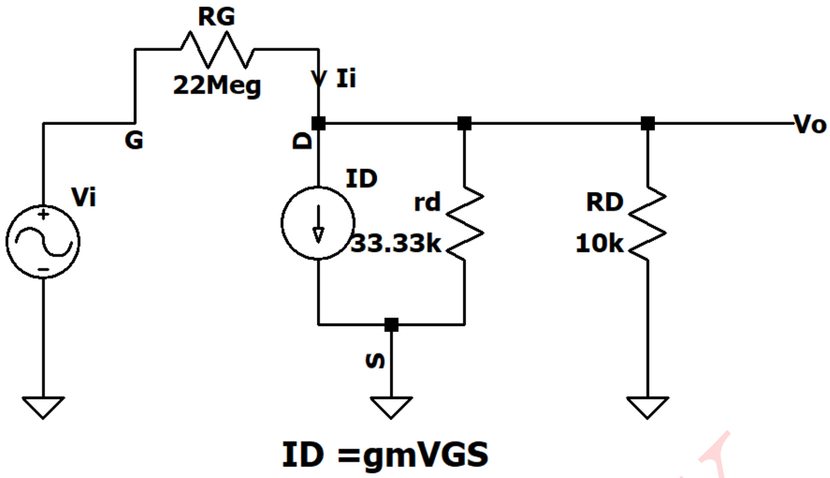

Figure 8: AC equivalent circuit

Applying KCL at D,

$$I_i = g_m V_{GS} + \frac{V_o}{r_d \parallel R_D}$$

Also, $I_i = \dfrac{V_i - V_o}{R_G}$

$$\therefore \frac{V_i - V_o}{R_G} = g_m V_i + \frac{V_o}{r_d \parallel R_D}$$

$$\therefore \frac{V_i}{R_G} - g_m V_i = \frac{V_o}{R_G} + \frac{V_o}{r_d \parallel R_D}$$

$$\therefore V_i\left[\frac{1}{R_G} - g_m\right] = V_o\left[\frac{1}{R_G} + \frac{1}{r_d \parallel R_D}\right]$$

$$\because \frac{1}{R_G} \approx \text{very small}$$

$$\therefore \frac{1}{R_G} - g_m \approx -g_m$$

$$\therefore V_i(-g_m) = V_o\left[\frac{1}{R_G} + \frac{1}{r_d \parallel R_D}\right]$$

$$\therefore \frac{V_o}{V_i} = -g_m(R_G \parallel r_d \parallel R_D)$$

$$\therefore A_V = -g_m(R_G \parallel r_d \parallel R_D)$$

$$\therefore A_V = -1.308mA/V(22M\Omega \parallel 33.33k\Omega \parallel 10k\Omega)$$

$$= -1.308mA/V\left(22M\Omega \parallel \left(\frac{33.33k\Omega \times 10k\Omega}{33.33k\Omega + 10k\Omega}\right)\right)$$

$$= -1.308mA/V(22M\Omega \parallel 7.69k\Omega)$$

$$= -1.308mA/V\left(\frac{22M\Omega \times 7.69k\Omega}{22M\Omega + 7.69k\Omega}\right)$$

$$= -1.308mA/V\,(7.687k\Omega) = \mathbf{-10.05}$$

Input impedance,

$$Z_i = \frac{R_G + (r_d \parallel R_D)}{1 + g_m(r_d \parallel R_D)}$$

$$= \frac{22M\Omega + (33.33k\Omega \parallel 10k\Omega)}{1 + 1.308mA/V(33.33k\Omega \parallel 10k\Omega)}$$

$$= \frac{22M\Omega + \left(\dfrac{33.33k\Omega \times 10k\Omega}{33.33k\Omega + 10k\Omega}\right)}{1 + 1.308mA/V\left(\dfrac{33.33k\Omega \times 10k\Omega}{33.33k\Omega + 10k\Omega}\right)}$$

$$= \frac{22M\Omega + 7.69k\Omega}{1 + 1.308mA/V(7.69k\Omega)} = \mathbf{216.642k\Omega}$$

Output impedance,

$$Z_o = R_G \parallel r_d \parallel R_D$$

$$= 22M\Omega \parallel 33.33k\Omega \parallel 10k\Omega$$

$$= 22M\Omega \parallel \left(\frac{33.33k\Omega \times 10k\Omega}{33.33k\Omega + 10k\Omega}\right)$$

$$= 22M\Omega \parallel 7.69k\Omega$$

$$= \frac{22M\Omega \times 7.69k\Omega}{22M\Omega + 7.69k\Omega} = \mathbf{7.687k\Omega}$$

SIMULATED RESULTS:

Above circuit is simulated in LTspice and results are as follows:

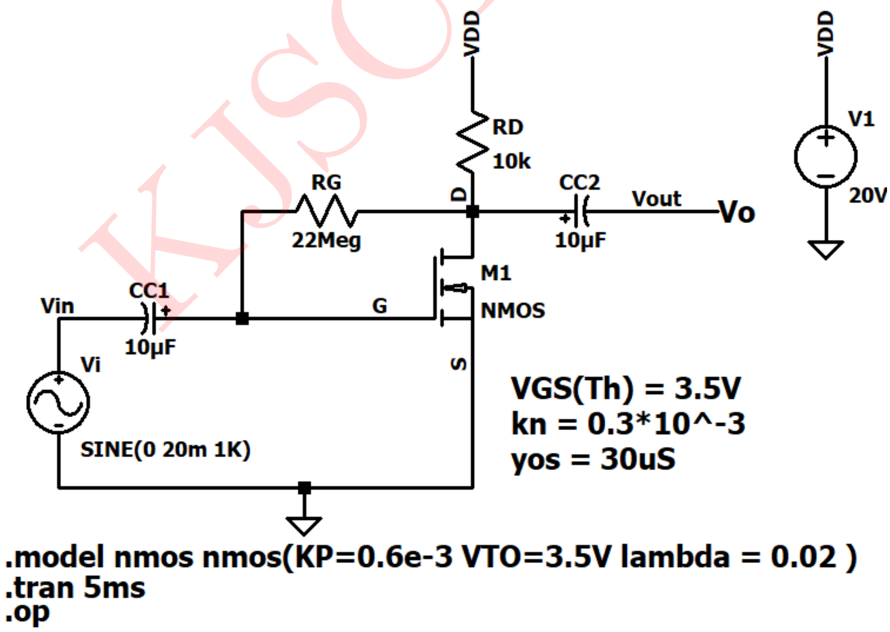

Figure 9: Circuit Schematic

The input and output waveforms are shown in figure 10.

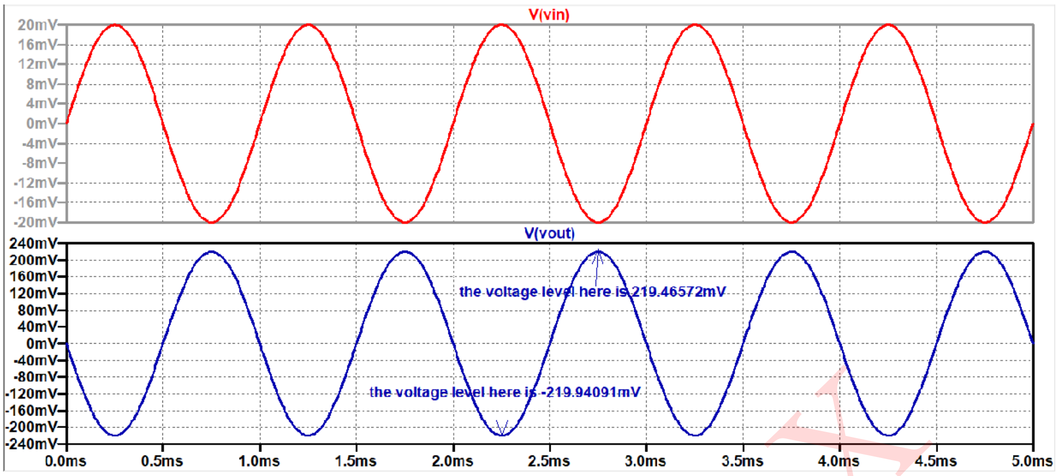

Figure 10: Input-Output waveforms

Comparison between theoretical and simulated values:

Parameters	Theoretical values	Simulated values
I_D	1.425mA	1.43155mA
V_{GS}	5.68V	5.68446V
A_V	-10.05	-10.985

Table 2: Numerical 2

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