Design Project 4: FET

11/20/19
Jaeha Huh

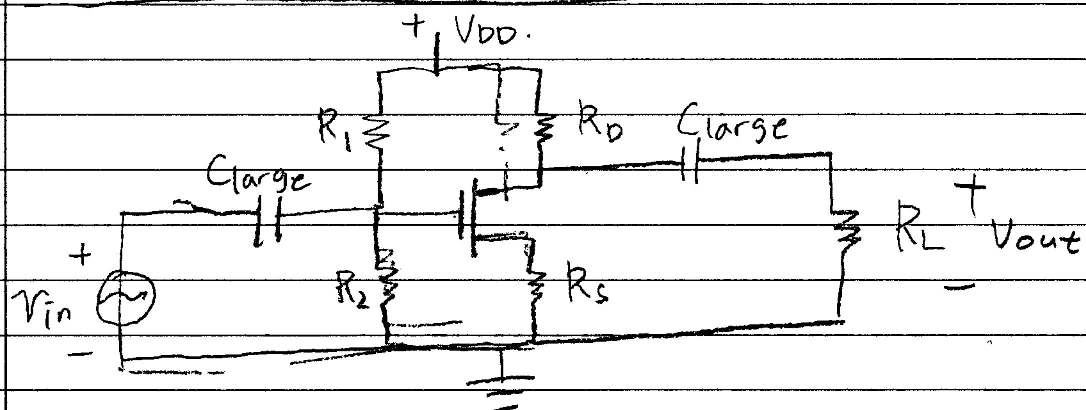
Given

$k_n = 0.06\ A/V^2$, $V_{TN} = +2.6V$, r_o = large (open)
$R_L = 500\Omega$

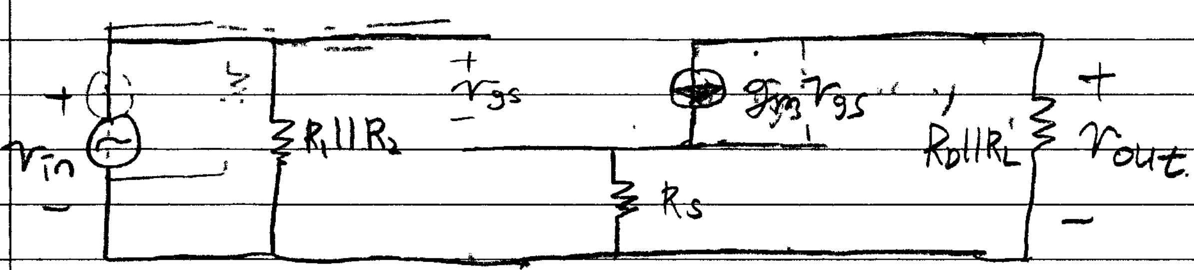
1. Hard Calculations:

a) Small signal voltage gain, $|A_v| = \left|\frac{V_{out}}{V_{in}}\right| = 14 + 2 = 16$.
So let find $|A_v|$ (range 14 to 25)

Use Common Source Amplifier with R_s



Small signal model



r_o is large so it is open.

$V_{out} = -(g_m V_{gs})(R_D \| R_L)$

$V_{in} = V_{gs} + (g_m V_{gs}) R_s = V_{gs} + V_{gs}(g_m R_s)$

$= V_{gs}(1 + g_m R_s)$

$A_v = \frac{V_{out}}{V_{in}} = \frac{-g_m \cancel{V_{gs}} (R_D \| R_L)}{\cancel{V_{gs}}(1 + g_m R_s)} = \frac{-g_m (R_D \| R_L)}{(1 + g_m R_s)}$

Since $|A_v| = 16$ (find value between $16 \sim 17$)
We need value of g_m, R_D, R_S

Assume $\boxed{R_D = 1k\Omega,\ R_S = 5\Omega,\ I_D = 19mA = 0.019A}$

$$g_m = 2\sqrt{k_n I_D} = 2\sqrt{(0.06)(0.019)} = 0.06753$$

$$A_v = \frac{-g_m'(R_D \| R_L)}{1 + g_m R_S} = \frac{-0.06753\,(1000 \| 500)}{1 + 0.06753\,(5)}$$

$$= \frac{-22.509}{1.3377} = -16.83$$

So $\boxed{|A_v| = 16.83 \cong 16}$

$\therefore$ the assumption is right.

- DC part:

- Assume FET is saturated, So $I_D = k_n(V_{GS} - V_{TN})^2$

$$0.019 = 0.06\,(V_{GS} - 2.6)^2$$

$$\frac{0.019}{0.06} = (V_{GS} - 2.6)^2$$

$$V_{GS} = \sqrt{\frac{0.019}{0.06}} + 2.6 = 3.1627V \quad \text{or}$$

$$V_{GS} = -\sqrt{\frac{0.019}{0.06}} + 2.6 = 2.0373\,V$$

Since $V_{GS} \geq V_{TN}$ for transistor on,

$\boxed{\therefore V_{GS} = 3.1627\,V}$

- Check the saturation

let $V_{DD} = 30\,V$.

$V_D = V_{DD} - I_D R_D = 30 - (0.019)(1000) = 30 - 19 = 11V$

$V_S = I_D R_S = (0.019)(5) = 0.095$

$V_{DS} = V_D - V_S = 11 - 0.095 = 10.905\,V$

$V_{DS,sat} = V_{GS} - V_{TN} = 3.1627 - 2.6 = 0.5627\,V$

$V_{DS} \overset{?}{\geq} V_{DS,sat} \qquad 10.905 > 0.5627$

$\therefore$ $V_{DS} \geq V_{DS,sat}$

So FET is Saturated.

- Now, find R_1 and R_2

$V_{GS} = 3.16273V \quad V_S = 0.095$

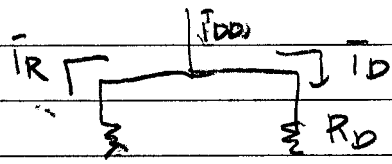
$V_G = V_{GS} + V_S = 3.16273 + 0.095 = 3.25773$

$V_G = V_{DD}\left(\frac{R_2}{R_2+R_1}\right)$ let $\boxed{R_2 = 20k}$

$3.25773 = 30\left(\frac{20k}{20k+R_1}\right) \quad 0.10859 = \frac{20k}{20k+R_1}$

$\boxed{\therefore R_1 = 164177\ \Omega = 164.177\ k\Omega}$

- find I_{DD}



$I_R = \frac{V_{DD}}{R_1+R_2}$

$= \frac{30}{164.177k+20k} = 0.1629mA$

$I_{DD} = I_D + I_R = 19mA + 0.1629mA$

$\boxed{\therefore I_{DD} = 19.1629\ mA}$

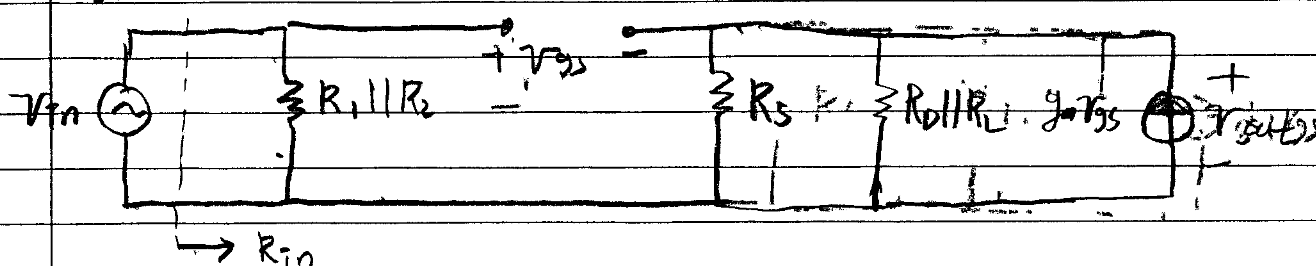
- find P_D

$P_D = V_{DS}(I_D) = (10.905V)(0.019A) = 207.2\ mW$

$P_D < 500mW$

So, it is correct. $\boxed{P_D = 207.2mW}$

- AC part
- find R_{in}

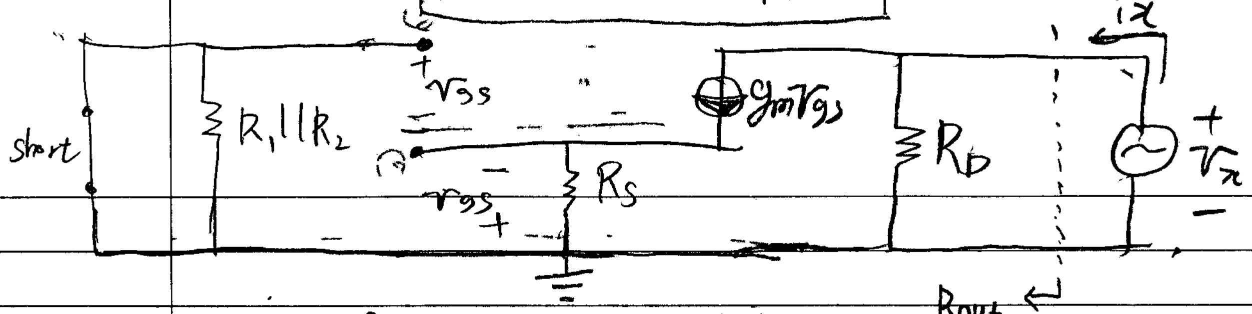


$R_{in} = R_1 \| R_2 = 164.177k \| 20k$

$= 17828.176\Omega = 17.828\ k\Omega$

$\boxed{\therefore R_{in} = 17.828\ k\Omega}$

- Find Rout $\boxed{R_{out} = \frac{v_x}{i_x} \Big| v_{in}=0}$



$(g_m v_{gs})(R_S) = -v_{gs}$ (1)

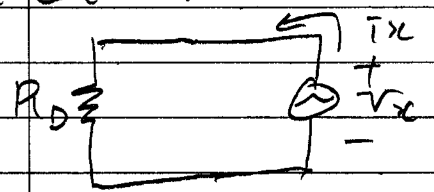
$i_x = \frac{v_x}{R_D} + g_m v_{gs}$ (2)

Use equation (1) divided by v_{gs}

$g_m R_S = -1$, So it is not vaild.

$v_{gs} = 0$

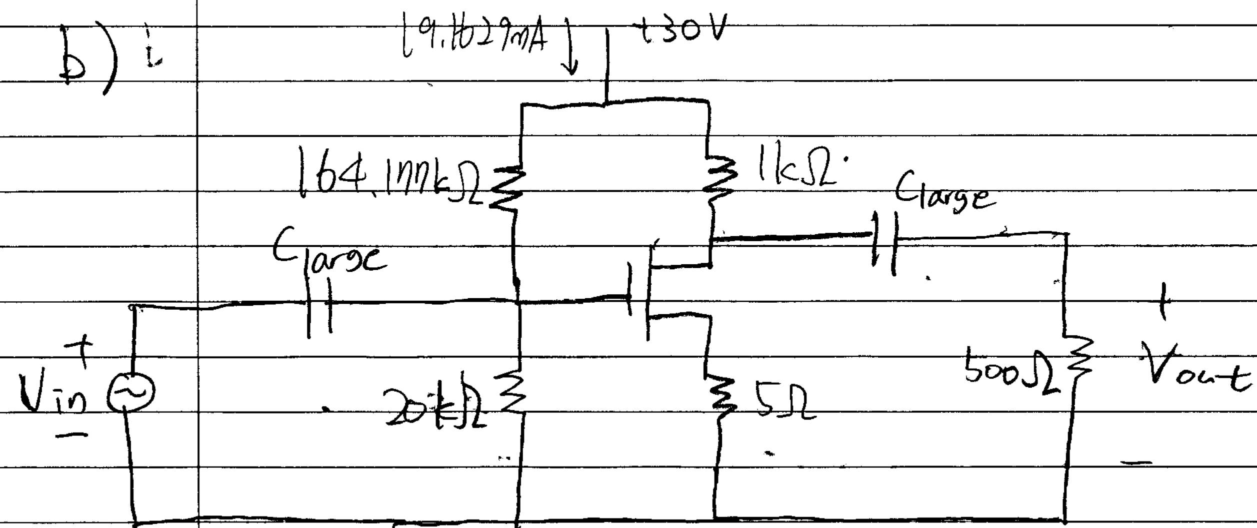
$\Rightarrow$ equivalent circuit



$\therefore R_{out} = R_D$

$\boxed{\therefore R_{out} = 1k\Omega}$

b) i.



c) c) Table of selected/Calculated parameters

A_v	-16.83
V_{DD}	$30V$
I_{DD}	$19.1629mA$
R_{in}	$17.828 k\Omega$
R_{out}	$1k\Omega$
P_D	$207.2mW$

d) Small signal condition valid for $v_{gs} \ll 2(V_{GS} - V_{TN})$

$v_{gs} \ll 2(3.1627 - 2.6) = 2(0.5627)$

$v_{gs} \ll 1.1254$

$v_{gs} \leq 10\% \; (1.1254) = 0.11254$

$v_{gs} = 0.11254$

$v_{in} = v_{gs}(1 + g_m R_s) \quad g_m = 0.06753 \;\&\; R_s = 5$

$= (0.11254)(1 + 0.06753 \times 5)$

$\approx (0.11254)(1.33765)$

$= 0.1505 V$

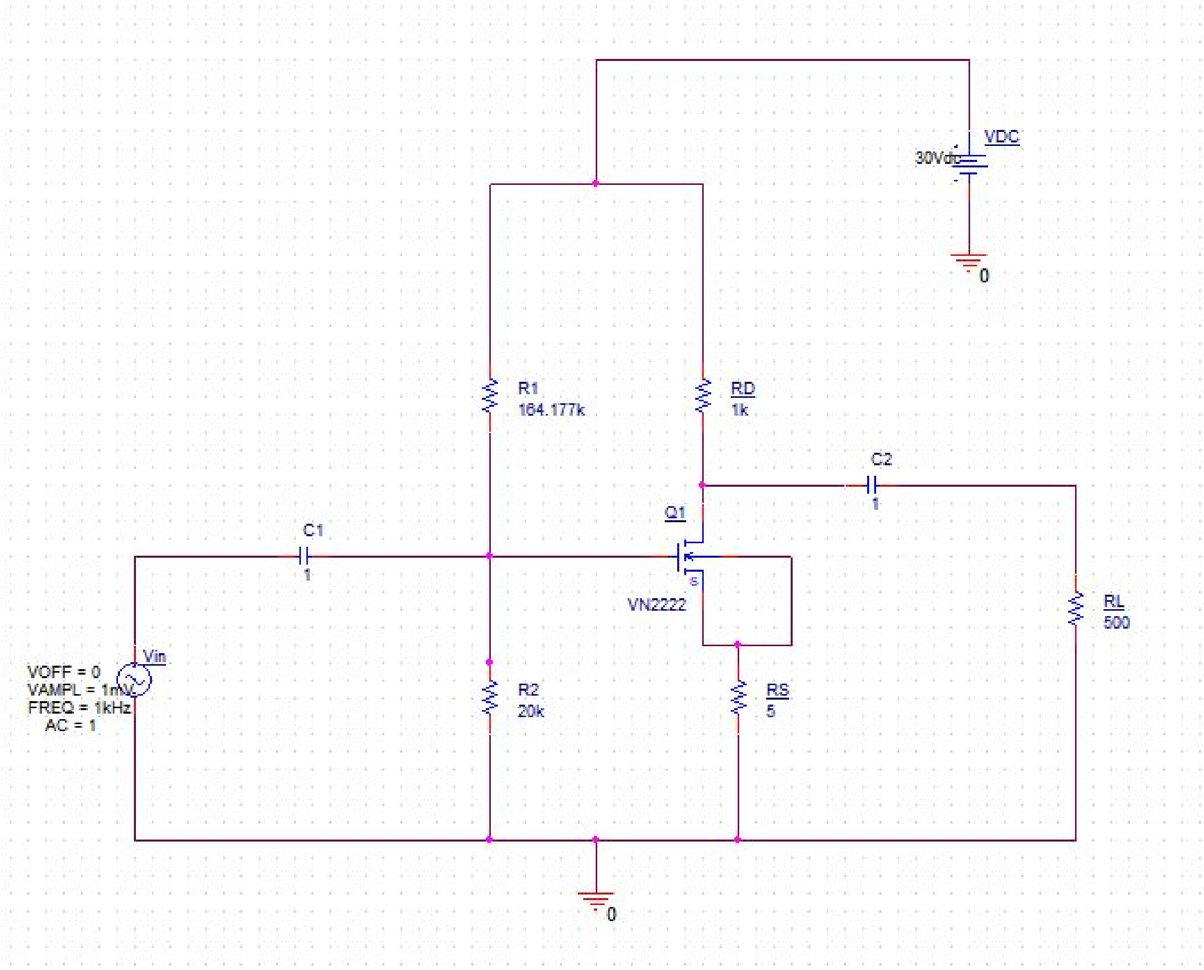
$\boxed{\therefore \text{ Amplitude for } v_{in} = 0.1505V}$

Design Project 4: FET

Jaeha Huh

2. PSPICE

a, b)



c)

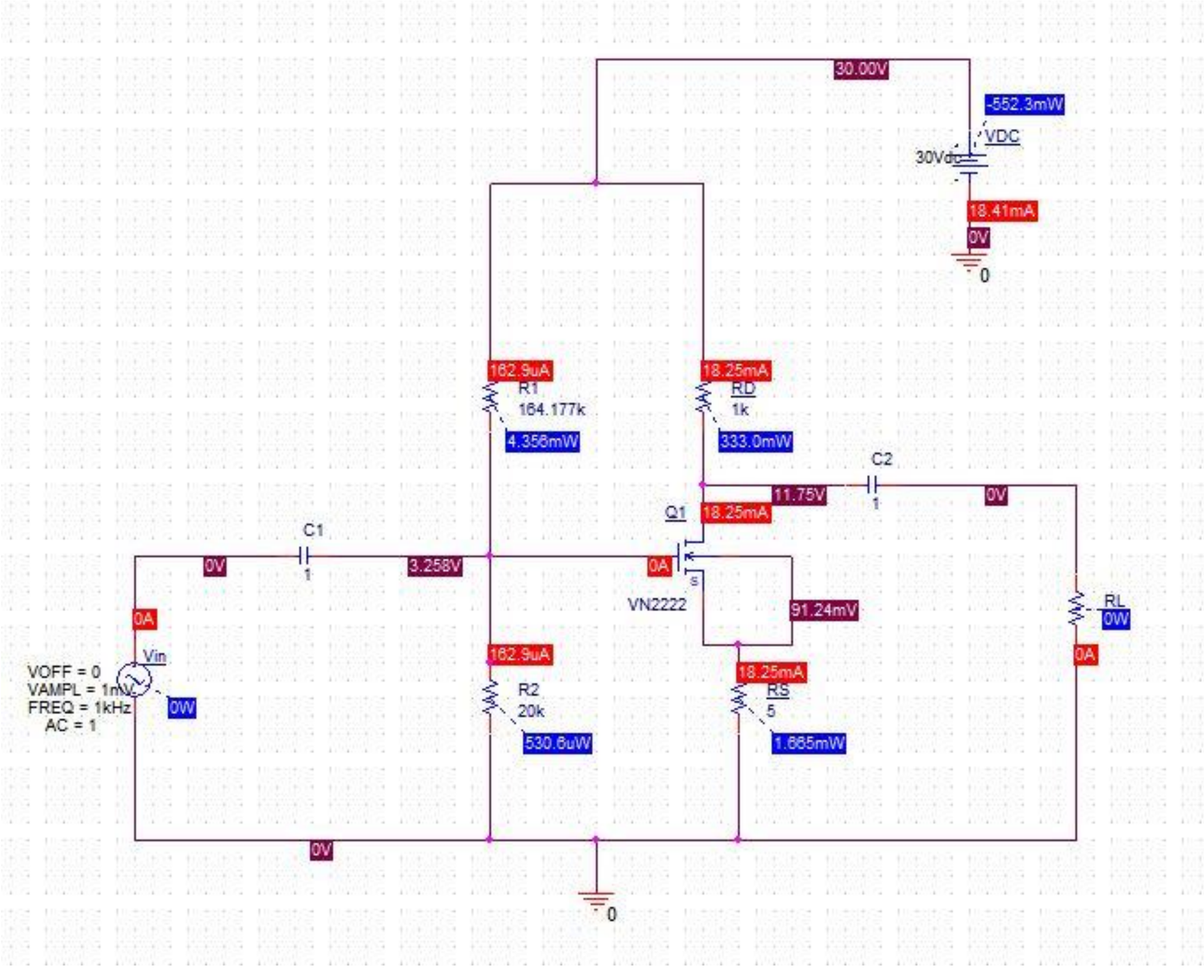


Table of simulated values

I_{DD}	18.41mA
I_{DQ}	18.25mA
V_{GSQ}	3.258V
V_{DSQ}	11.659V
P_D	333mW

For transistor on: $V_{GS} \geq V_{TN}$

In this circuit, $V_{GS} = 3.258V$ and $V_{TN} = 2.6V$ $(3.258V \geq 2.6V)$ so transistor is on.

Check the circuit operating the “saturated” region

$V_{DS} \geq V_{DS,sat} = V_{GS} - V_{TN}$

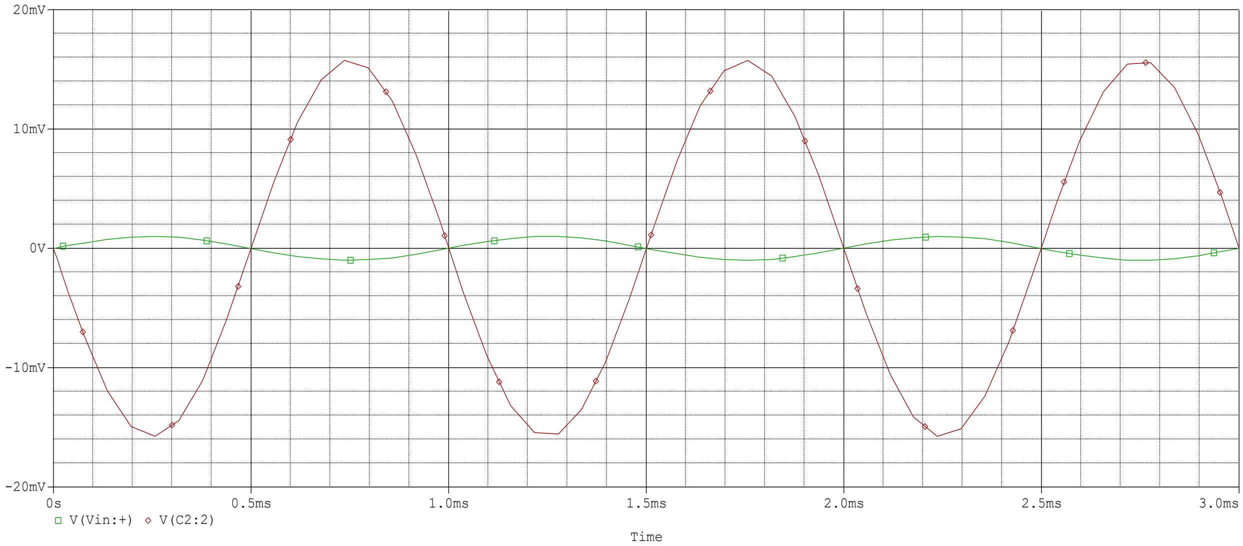
$V_{DS,sat} = 3.258 - 2.6 = 0.658V$ and $V_{DS} = 11.659V$

Since $11.75V \geq 0.658V$, the transistor is saturated.

$I_{DD} = 18.41mA \leq I_{DD}$, max $= 75mA$; the maximum power supply current is not exceeded.

$P_D = 333mW \leq P_D$, max $= 500mW$; the maximum power dissipation rating is not exceeded.

d) Simulated Gain



d.1) Two waves are completely out of phase. (180° out of phase)

d.2) There is a minimal distortion.

d.3) $v_{out,peak} = 15.775\text{mV}$

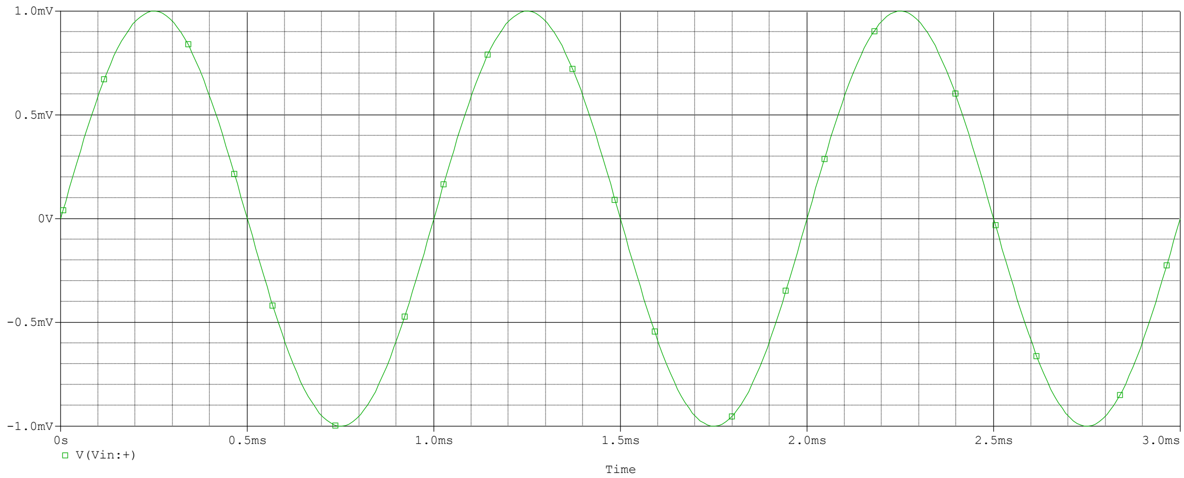
$v_{in,peak} = 0.9998\text{mV}$

Voltage gain, $A_v = \frac{v_{out}}{v_{in}} = \frac{15.775mV}{0.9998mV} = 15.7781$

d.4) The calculated value of A_v is 16.83; Thus, the percent difference is $\frac{15.7781-16.83}{16.83} * 100 =$ 6.25%

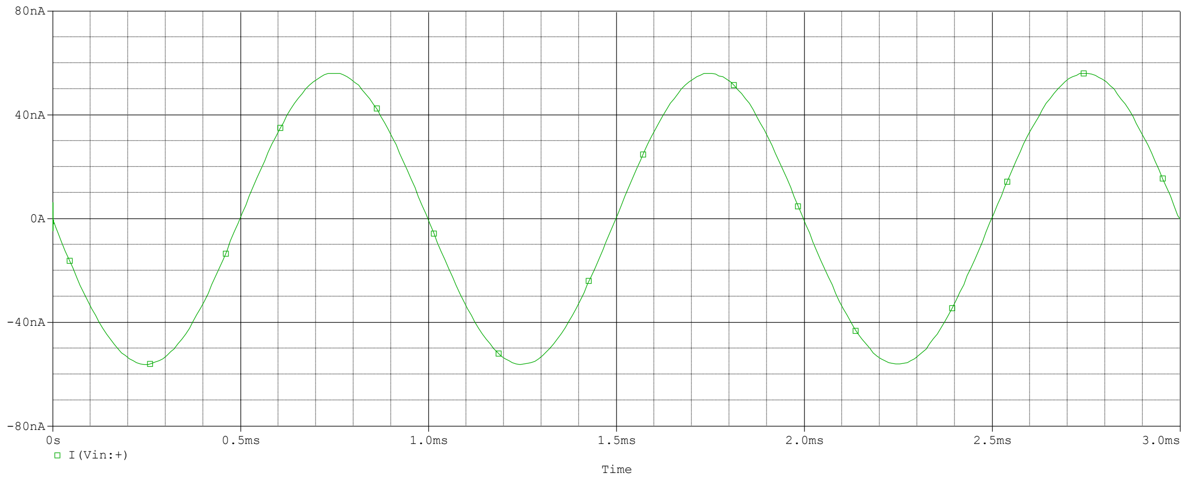
e) Simulated Input Resistance

v_{in} versus time



$v_{in,peak} = 0.9998mV$

i_{in} versus time



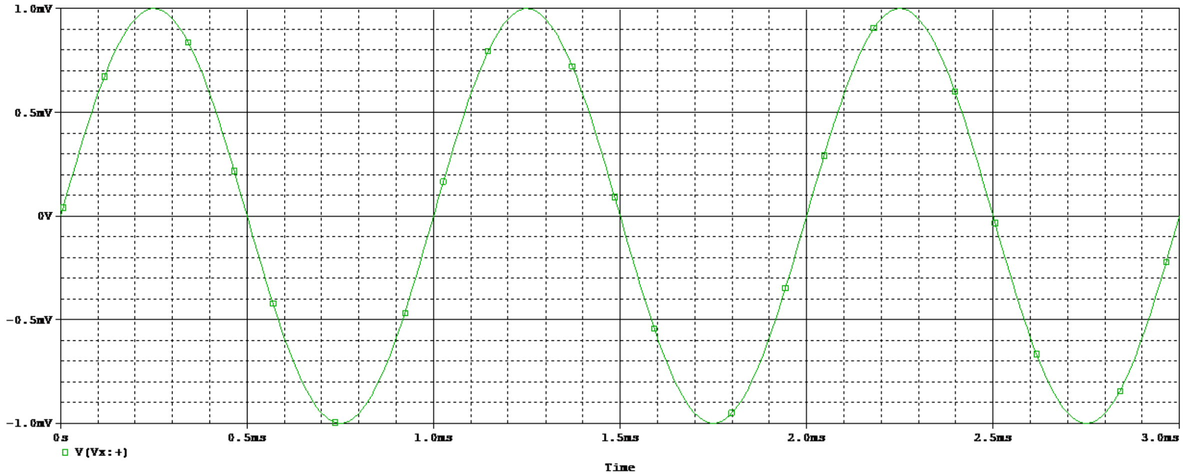
$i_{in,peak} = 55.973nA$

$$R_{in} = \frac{v_{in}}{i_{in}} = \frac{0.9998mV}{55.973nA} = \frac{0.9998 * 10^{-3}}{55.973 * 10^{-9}} = 17862.184\Omega$$

The calculated value of R_{in} is 17828.176Ω; Thus, the percent difference is $\frac{17862.187-17828.176}{17828.176} * 100 = 0.19\%$.

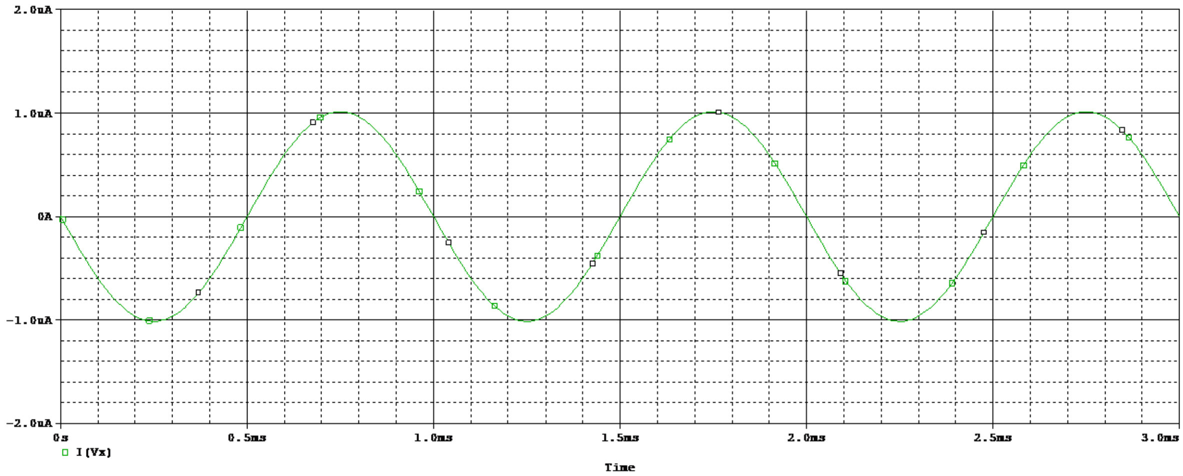
f) Simulated Output Resistance

v_x versus time



$v_{x,peak} = 0.9998mV$

i_x versus time

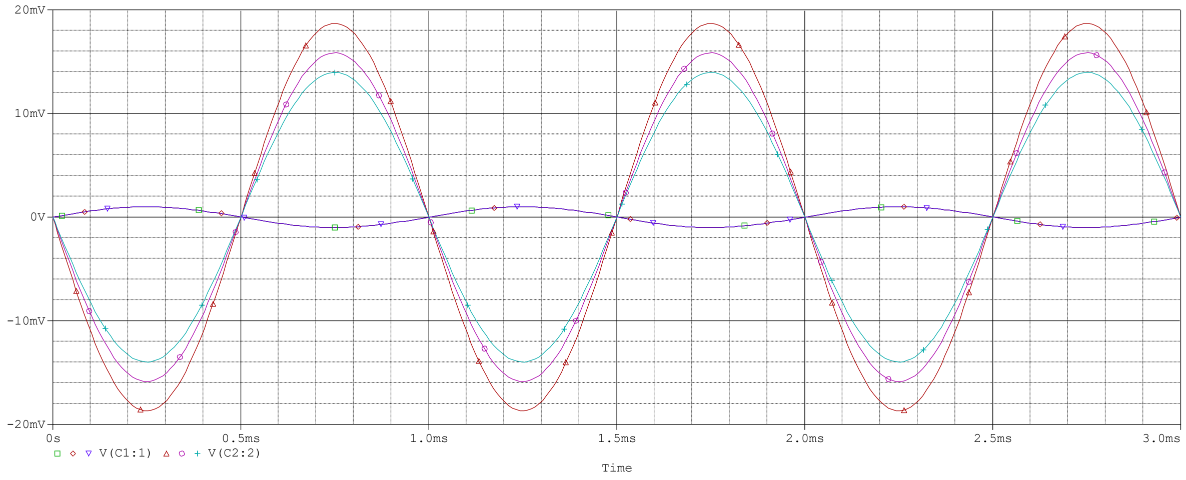


$i_{x,peak} = 1.0130uA$

$$R_{out} = \frac{v_x}{i_x} = \frac{0.9998mV}{1.0130uA} = 986.97\Omega$$

The calculated value of R_{out} is 1kΩ; Thus, the percent difference is $\frac{986.97-1000}{1000} * 100 = 1.3\%$.

g) Extra Credit: Simulated Gain Over Temperature



$v_{in,peak} = 0.9998mV$

$v_{out(-40℃),peak} = 18.682mV$

$$A_{v,-40℃} = \frac{v_{out}}{v_{in}} = \frac{18.682mV}{0.9998mV} = 18.6857$$

$v_{out(+25℃),peak} = 15.848mV$

$$A_{v,+25℃} = \frac{v_{out}}{v_{in}} = \frac{15.848mV}{0.9998mV} = 15.8512$$

$v_{out(+85℃),peak} = 13.964mV$

$$A_{v,+85℃} = \frac{v_{out}}{v_{in}} = \frac{13.964mV}{0.9998mV} = 13.9668$$

Table of simulated gain over temperature

	$-40℃$	$25℃$	$80℃$
$v_{out,peak}$	$18.682mV$	$15.848mV$	$13.964mV$
$v_{in,peak}$	$0.9998mV$	$0.9998mV$	$0.9998mV$
A_v	18.6857	15.8512	13.9668
Percentage change in gain over temperature	15.17%	0% (reference)	13.5%

The gain can be considered unstable under changing temperature because it has max 15.17% deviation from reference temperature.