Name Solution

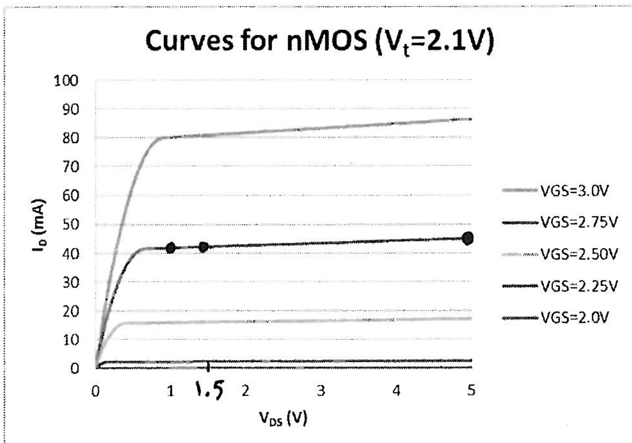
Section ________

1. (50 points) You wanted to characterize your BS170 nMOS transistor (V_t=2.1V) using the curve tracer and generated the family of curves and data points below. Using the trace corresponding to an overdrive voltage (V_{ov}) of 650 mV when V_{DS}=1.5V, determine (in no particular order) the

   a. transconductance parameter (k)
   b. channel length modulation (λ)
   c. channel length resistance (r_o)
   d. early voltage (V_A)
   e. transconductance gain (g_m)

$V_{GS} - V_t = V_{ov} = 650\ mV \quad \therefore V_{GS} = 2.75\ V$

$V_{DS} = 1.50\ V$



	I_D (mA)				
V_{DS} (V)	V_{GS}=3.0V	V_{GS}=2.75V	V_{GS}=2.50V	V_{GS}=2.25V	V_{GS}=2.0V
0	0	0	0	0	0
0.5	63.68	39.19	15.68	2.20	5.1E-10
1	80.14	41.80	15.83	2.23	1.01E-09
1.5	80.93	42.21	15.99	2.25	1.51E-09
2	81.71	42.62	16.14	2.27	2.01E-09
2.5	82.50	43.03	16.30	2.29	2.51E-09
3	83.28	43.44	16.45	2.31	3.01E-09
3.5	84.07	43.85	16.61	2.34	3.51E-09
4	84.86	44.26	16.76	2.36	4.01E-09
4.5	85.64	44.67	16.92	2.38	4.51E-09
5	86.43	45.08	17.07	2.40	5.01E-09

You may find the following equations useful. Write your final answers below.

$V_A = \frac{1}{\lambda}$	$g_m = kV_{OV} = 2\frac{I_D}{V_{OV}}$	$r_o = \frac{1}{\lambda I_D}$	$g_m = \left.\frac{dI_D}{dV_{GS}}\right\vert_{V_{DS}}$	$\text{slope} = \frac{1}{r_o} = \left.\frac{dI_D}{dV_{DS}}\right\vert_{V_{GS}}$

k 200 $mA\cdot V^{-2}$	λ 0.0197 V^{-1}	r_o 1.2 KΩ	V_A 51.5 V	g_m 129.9 $mA\cdot V^{-1}$

$$\frac{1}{r_o} = \left.\frac{dI_D}{dV_{DS}}\right\vert_{V_{GS}} = \frac{(45.08 - 41.8)\ mA}{(5-1)\ V} = 0.82\ mS \quad \therefore r_o = 1.2\ k\Omega$$

$$r_o = 1/\lambda I_D, \quad \lambda = \frac{1}{r_o I_D} = \frac{1}{(1.2k)(42.21mA)} = 0.0197 \approx 0.02\ V^{-1}$$

$$V_A = 1/\lambda = 1/0.0197 = 51.5V$$

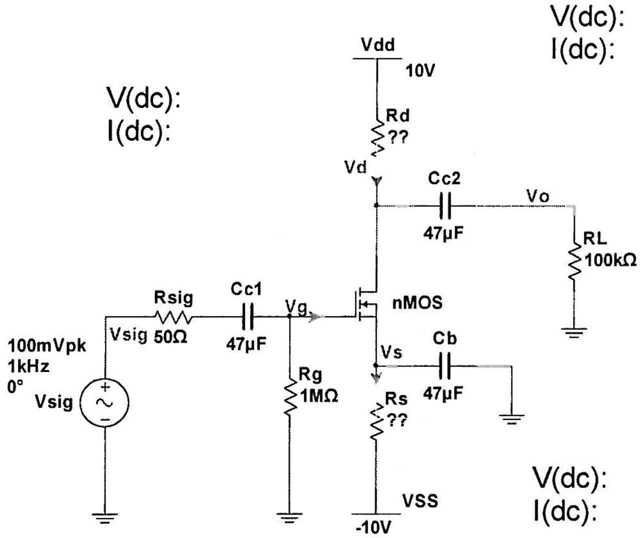
$$g_m = \frac{2 I_D}{V_{ov}} = \frac{2(42.21mA)}{0.650V} = 129.9\ mA/V$$

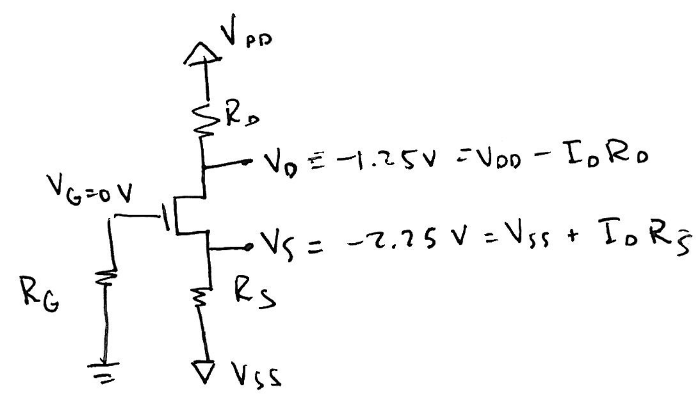
$$K = g_m / V_{ov} = 200\ mA/V^2$$

2. (50 points) Assume you found λ=0.02 V^{-1} and k=200 $mA{\cdot}V^{-2}$ from part 1 where V_t = 2.1 V. You then biased your transistor using the 2-supply biasing scheme below for V_{OV} = 650 mV and V_{DS} = 1.5V.

2a. (10 points) Draw the large signal model and determine the required R_d and R_s.

Disconnect the capacitors





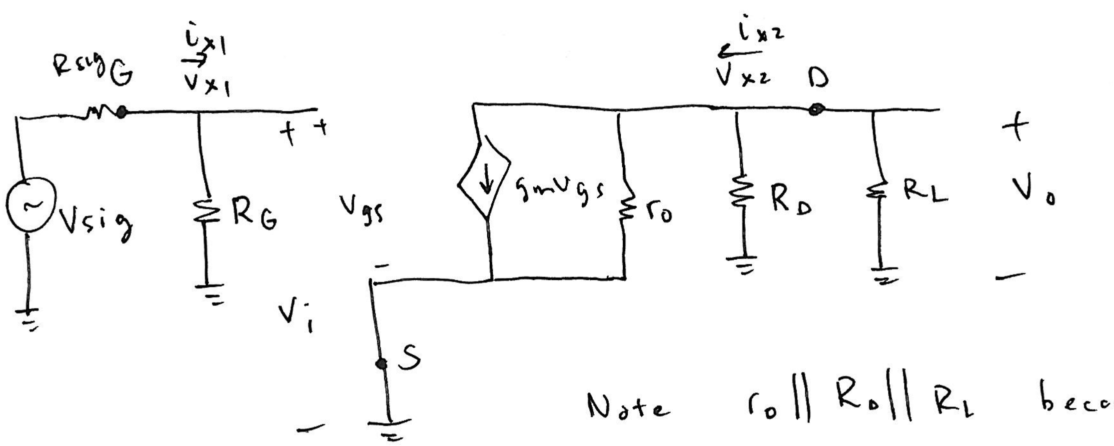
$V_{GS} = 2.75\ V \Rightarrow V_S = -2.75V$

$V_{DS} = 1.5V \Rightarrow V_D = -2.75 + 1.5 = -1.25V$

$R_D = \dfrac{V_{dd} - V_D}{I_D} = \dfrac{10 - (-1.25)}{42.21mA} = \boxed{266.5\Omega = R_D}$

$R_S = \dfrac{V_S - V_{SS}}{I_D} = \dfrac{-2.75 - (-10)}{42.21mA} = \boxed{171.8\ \Omega = R_S}$

2b. (10 points) Draw the hybrid-π small signal model. Ensure you account for r_o.



Note $r_o \| R_o \| R_L$ because source to ground

2c. (20 points) Determine relationships for A_{vo}, A_v, R_i, and R_o.

$$A_{vo} = \left.\frac{V_o}{V_i}\right|_{R_L=\infty} = \frac{-g_m v_{gs}\, r_o \| R_D}{v_{gs}} = -g_m\, r_o \| R_D$$

$$A_v = \left.\frac{V_o}{V_i}\right|_{R_L} = \frac{-g_m v_{gs}\, r_o \| R_D \| R_L}{v_{gs}} = -g_m\, r_o \| R_D \| R_L$$

$$R_i = \frac{V_{x1}}{i_{x1}} = R_G$$

$$R_o = \frac{V_{x2}}{i_{x2}} = r_o \| R_D$$

2d. (10 points) Calculate A_{vo}, A_v, R_i, and R_o from your relationships above.

$$A_{vo} = -(129.9\ mA/V)(1.2K \| 266.5) = -28.32\ V/V$$

$$A_v = -(129.9\ mA/V)(1.2K \| 266.5 \| 100K) = -28.26\ V/V$$

Note $A_v \approx A_{vo}$ because $R_L \gg R_D, r_o$

$$R_i = 1M\Omega$$

$$R_o = (1.2K \| 266.5) = 218.1\ \Omega$$

ECE 321 – Quiz 4 (part 2)

MOSFET Characterization

Fall 2015

Name Solution **Section** ________

ACADEMIC SECURITY. This Quiz is released at the beginning of the next lesson.

INTEGRITY: Your honor is extremely important. This academic security policy is designed to help you succeed in meeting academic requirements while practicing the honorable behavior our country rightfully demands of its military. Do not compromise your integrity by violating academic security or by taking unfair advantage of your classmates.

Collaboration Policy: No collaboration allowed. This is individual effort. You may not seek help from other cadets, nor from any faculty members. All help must be properly documented.

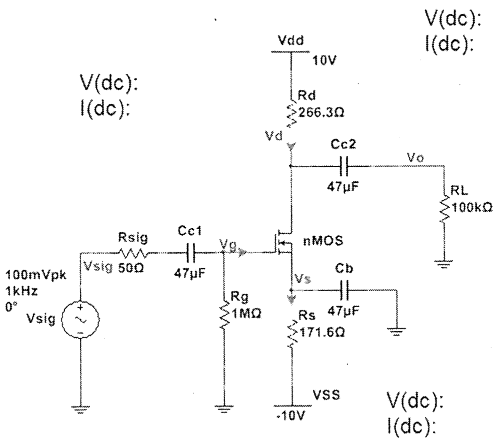
Permissible References: Any texts or online resources.

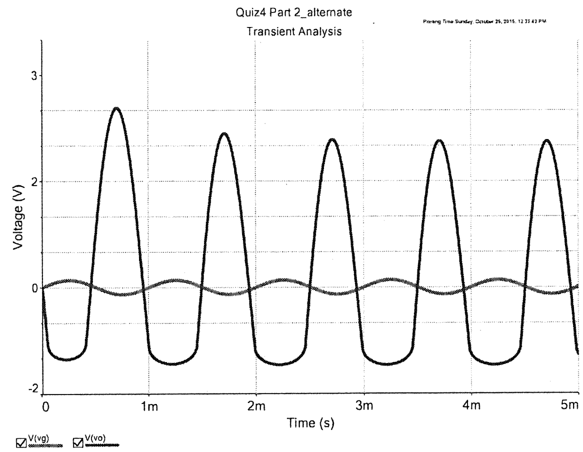
Grading: This is part 2 of the quiz.

Total ______ **Grade** _______

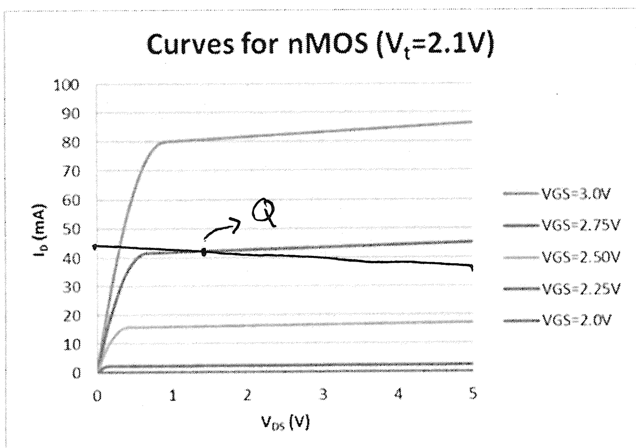
Documentation:

3. (50 points) Assume you found the correct bias point and simulated your circuit with below results showing v_o and v_i (i.e. v_g). Comment on the appropriateness of the bias point and the measures you would take to ensure undistorted voltage swing in both directions.



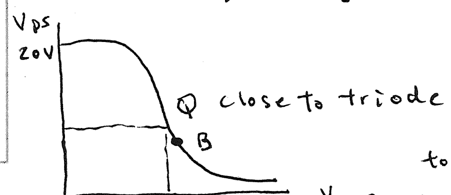


See load line at Q close to triode



You may find the figure to the left helpful in your analysis and explanation.

the output is swinging too low into triode. See that $V_{DS} = 1.5\text{V}$ which is a small fraction of the total supply voltage $(V_{DD} - V_{SS} = 20\text{v})$.



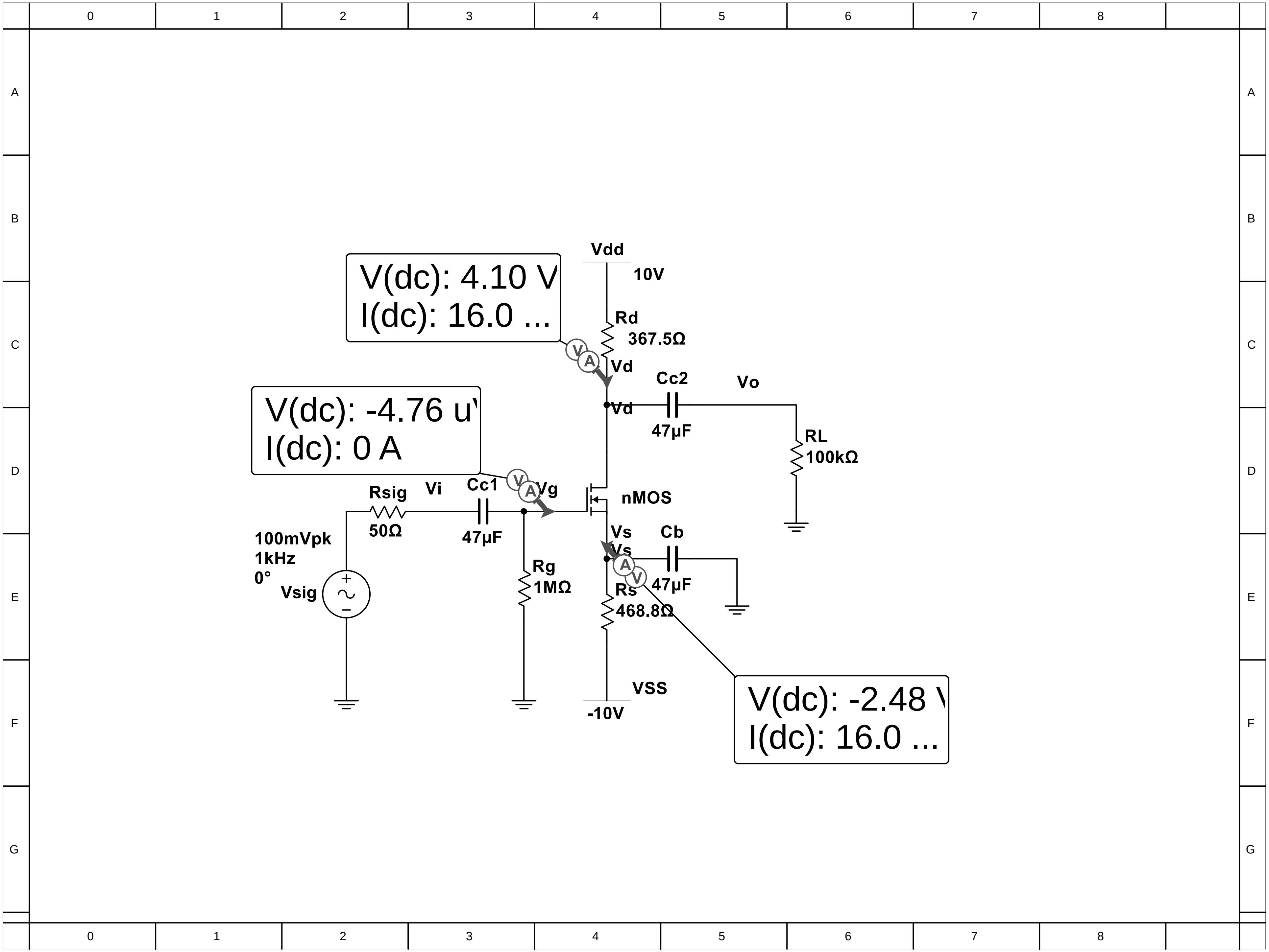
So we need to raise V_{DS} to allow our output to swing both ways.

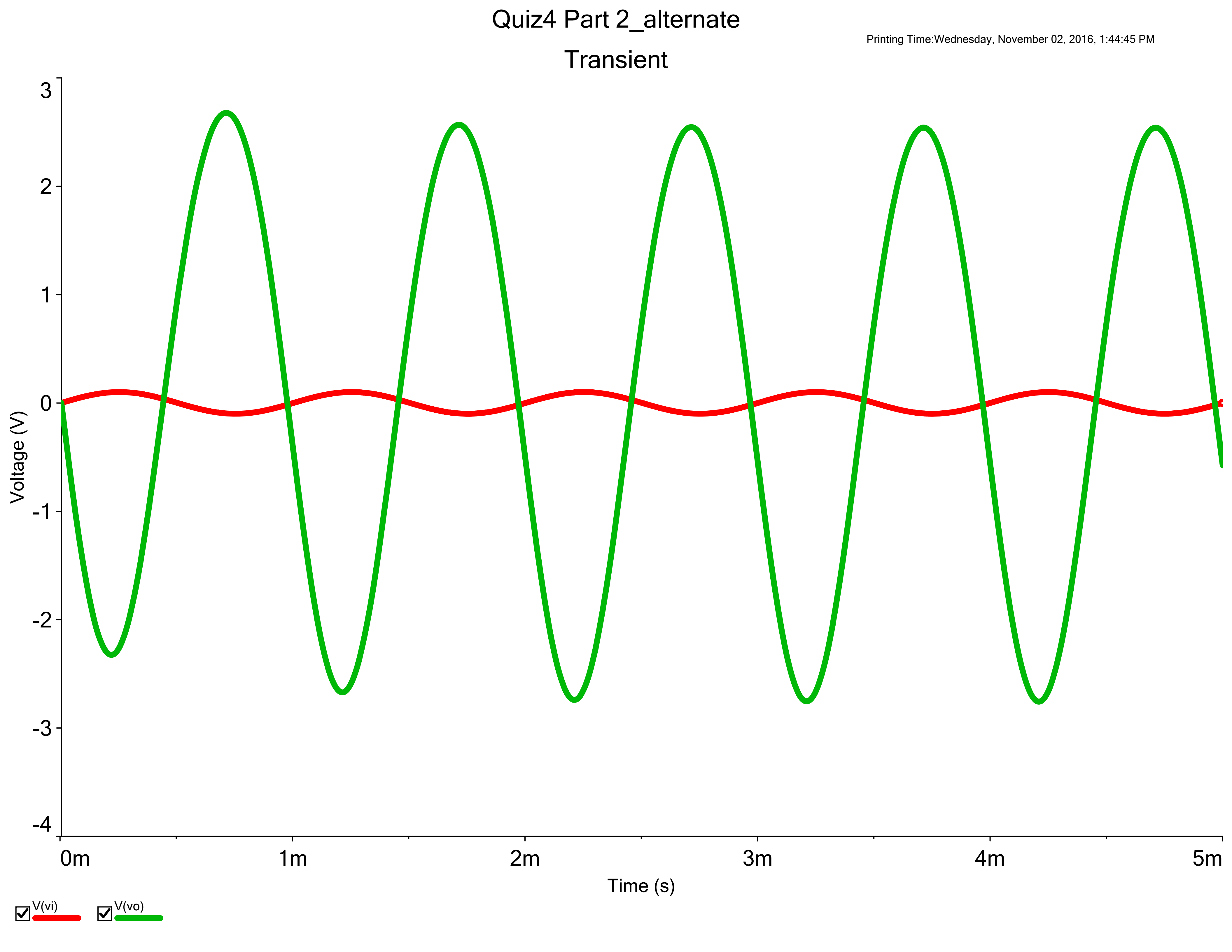
You could raise V_D by lowering R_D but this may adversely affect your gain remember $A_v = -g_m R_D \| R_L \| r_o = -28.3\ \text{V/V}$ from part 2d. Alternatively you could lower I_D so less voltage drop across R_D, R_S resulting in a bigger V_{DS}. Suppose we use the $V_{GS} = 2.5\text{V}$ curve. This is a $V_{OV} = 0.4\text{V}$ giving $I_D = \frac{1}{2}(200)(0.4)^2 = 16\text{mA}$. Then $R_S = \frac{-2.5 - (-10)}{16\text{mA}} = 468.8\,\Omega$

now $g_m = 200(0.4) = 80\ \text{mA/V}$ which is a 38% reduction so would anticipate A_v to also drop by ~38%. So we could now raise R_D by 38% giving $R_D = 266.3 \times 1.38 = 367.5\,\Omega$ so now $V_{DS} = 6.62\text{V}$

$V_D = V_{DD} - I_D R_D = 4.12\text{V}$ $\quad V_S = V_{SS} + I_D R_S = -2.5\text{V}$

$V_{DS} = 6.62\text{V}$ which is now a bigger fraction of the total supply and we preserved our gain A_v


V(dc): 4.10 V
I(dc): 16.0 ...
Vdd
10V
Rd
367.5Ω
Vd
Cc2
Vo
Vd
47μF
RL
100kΩ
V(dc): -4.76 u
I(dc): 0 A
Rsig
Vi
Cc1
Vg
nMOS
50Ω
47μF
100mVpk
1kHz
0°
Vsig
Rg
1MΩ
Vs
Vs
Cb
47μF
Rs
468.8Ω
VSS
-10V
V(dc): -2.48 V
I(dc): 16.0 ...


Quiz4 Part 2_alternate
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Transient
3
2
1
0
-1
-2
-3
-4
Voltage (V)
0m
1m
2m
3m
4m
5m
Time (s)
V(vi)
V(vo)