# ECE 3040 Microelectronic Circuits

*Exam 3*

*April 18, 2014*

*Dr. W. Alan Doolittle*

Print your name clearly and largely: Solutions

**Instructions:**
***DO NOT TAKE APART ANY PAGES OF THIS EXAM AND SHOW ALL WORK ON THE PROVIDED PAGES.*** Read all the problems carefully and thoroughly before you begin working. You are allowed to use 1 new sheet of notes (1 page front and back), your two note sheets from the previous exams as well as a calculator. There are 100 total points in this exam. Observe the point value of each problem and allocate your time accordingly. SHOW ALL WORK AND CIRCLE YOUR FINAL ANSWER WITH THE PROPER UNITS INDICATED. Write legibly. If I cannot read it, it will be considered a wrong answer. Do all work on the paper provided. Turn in all scratch paper, even if it did not lead to an answer. Report any and all ethics violations to the instructor. Good luck!

Sign your name on **ONE** of the two following cases:

I DID NOT observe any ethical violations during this exam:

I observed an ethical violation during this exam:

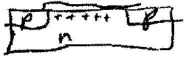
***First 20%*** **Multiple Choice and True/False (Select the most correct answer)**

1.) (2-points) [✓ True] / False: The voltage at the end of the pinched off channel of a MOSFET biased into Saturation is always $V_{D\text{-}SAT} = V_{GS}\text{-}V_T$.

2.) (2-points) [✓ True] / False: The effective mobility is lower than the bulk mobility because the gate's electric field forces carriers to interact with the defective $SiO_2$/Si interface.

3.) (2-points) True / [✓ False]: The MOSFET's transconductance, $g_m$, is determined by the slope of the $I_{DS}$-$V_{DS}$ curve and only is non-zero if λ, the channel length modulation parameter, is non-zero. $= V_{GS}$ $r_o$

4.) (2-points) [✓ True] / False: For a PMOSFET a negative gate voltage is needed to drive the mos capacitor into inversion.



5.) (2-points) [✓ True] / False: A current amplifier should ideally have zero input impedance.

6.) (2-points) True / [✓ False]: For a MOSFET amplifier, clipping occurs when the output is large enough to drive the transistor into ~~saturation~~ linear and cutoff.

7.) (2-points) True / [✓ False]: With every new generation that shrinks proportionally in size, Intel must redesign every old circuit to account for different $I_{DS}$ values. Scaling!

8.) (2-points) True / [✓ False]: Common ~~source~~ amplifiers have a gain of ~1, a very high input impedance and low output impedance. CO

9.) (2-points) [✓ True] / False: If amplifying a voltage from a signal with a very high source impedance like a pH meter, the voltage amplifier should also have a very high input impedance, possibly even amplified by using feedback.

10.) (2-points) [✓ True] / ____: (In honor of April 15th that just passed☺ ) Currently in America, the lower 50% of income earners in America pay less than 3% of Federal Income tax while the top 5% of income earners pay ~57% of all taxes. In other words, ~1/2 of Americans can vote higher taxes on others but do not pay any federal taxes themselves – astounding!
Reference http://taxfoundation.org/article/summary-latest-federal-income-tax-data

$\nearrow A_{open}$ $\nearrow \frac{\omega_B}{2\pi}$

11.) (10-points) An amplifier has an open loop gain of 200 V/V, a open loop bandwidth of 100 Hz, and an input impedance of 100K ohms and an Output impedance of 100 ohms. Show work:

$\uparrow R_{in}$ $\uparrow R_{out}$

a) Determine a percentage of the output voltage that can be fed back to the negative terminal to result in a closed loop bandwidth of 3 KHz.

$A_{open} = 200\ V/V$

$\% = \beta$

Gain Band Width Product is Constant:

$(200\ V/V)(100\ Hz) = (A_{closed})(3000) \Rightarrow \boxed{A_{closed} = 6.\overline{66}\ v/v}$

$6.\overline{66} = \frac{A_{open}}{1 + \beta A_{open}} = \frac{200}{1 + \beta 200} \Rightarrow 6.\overline{66} + \beta 200(6.\overline{66}) = 200$

$\beta = \frac{200 - 6.\overline{66}}{200(6.66)} \Rightarrow \boxed{\beta = 0.145 \text{ or } 14.5\%}$

b) For your answer in part a), what is the new closed loop gain?

$A_{closed} = 6.\overline{66}\ v/v$

c) For your answer in part a), what is the new input impedance (at DC – i.e. do not worry about the frequency response)?

$R_{in_{closed}} = (1 + \beta A_{open}) R_{in_{open}}$

$= [1 + 0.145(200)]\,100K$

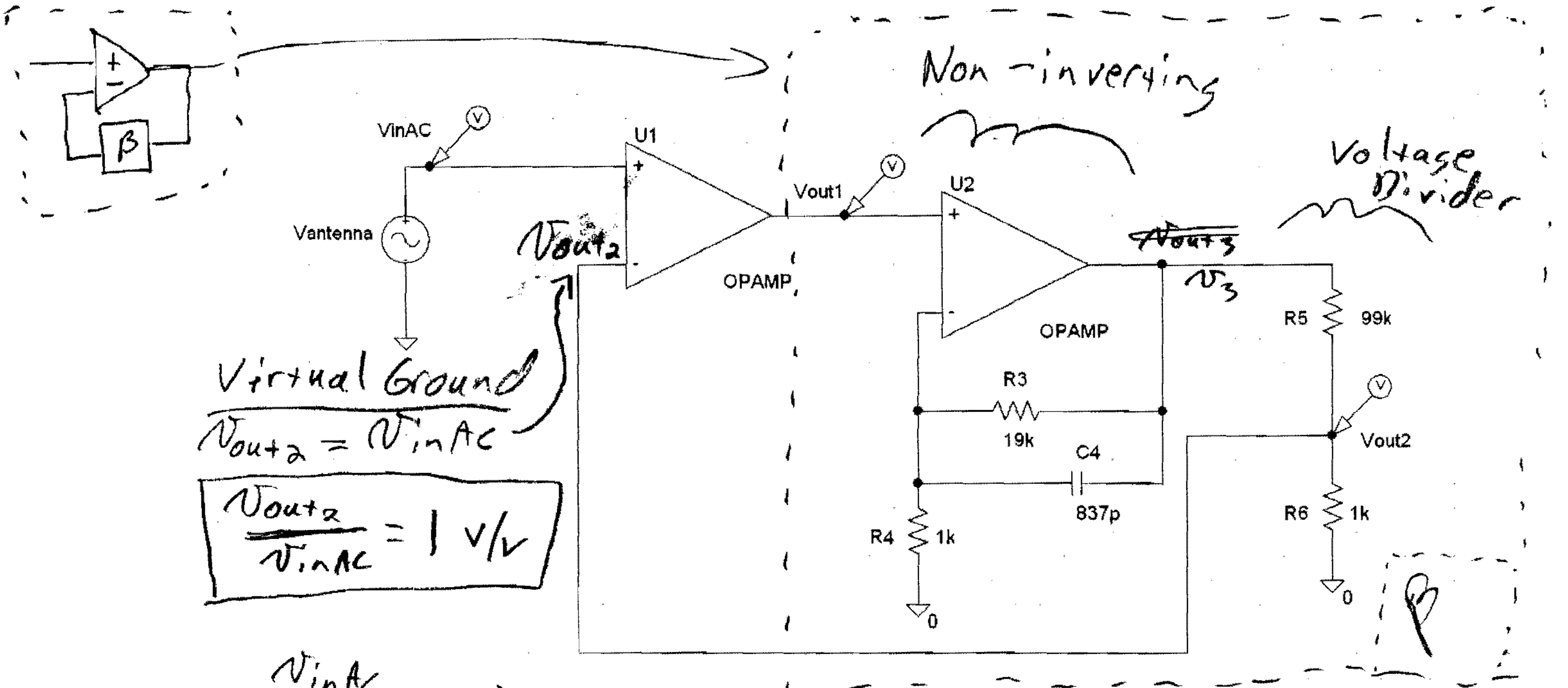
$\boxed{R_{in_{closed}} = 3\ Meg\ \Omega}$

d) For your answer in part a), what is the new output impedance (at DC – i.e. do not worry about the frequency response)?

$R_{out_{closed}} = \frac{R_{out_{open}}}{1 + \beta A_{open}}$

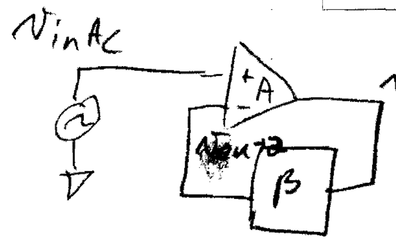
$\boxed{R_{out_{closed}} = \frac{100}{30} = 3.\overline{33}\ \Omega}$

11.)(20-points) Because your professor is so nice, the opamps used in the circuit below can be considered ideal. There are two outputs Vout1 and Vout2 and one input VinAC. Determine the closed loop gains Vout1/VinAC and Vout2/VinAC and plot both gains on a Bode plot.



$$V_{out2} = V_{inAC}$$

$$\boxed{\frac{V_{out2}}{V_{inAC}} = 1\ V/V}$$



$$\frac{V_{out1}}{V_{inAC}} = \frac{A}{1+\beta A} \longrightarrow \frac{1}{\beta} \text{ as } A \to \infty$$

$$\beta = \frac{V_{out2}}{V_{out1}} = \left(\frac{V_{out2}}{V_3}\right)\left(\frac{V_3}{V_{out1}}\right)$$

$$\frac{V_3}{V_{out1}} = \left(1 + \frac{R_3 \| \frac{1}{C_4 s}}{R_4}\right)$$

$$= 1 + \left(\frac{R_3 \frac{1}{C_4 s}}{R_3 + \frac{1}{C_4 s}}\right)\left(\frac{1}{R_4}\right)$$

$$= 1 + \frac{R_3}{1 + R_3 C_4 s}\left(\frac{1}{R_4}\right)$$

$$= \frac{1 + R_3 C_4 s + \frac{R_3}{R_4}}{1 + R_3 C_4 s}$$

$$= \frac{\left(1 + \frac{R_3}{R_4}\right) + R_3 C_4 s}{1 + R_3 C_4 s}$$

$$= \underbrace{\left(1 + \frac{R_3}{R_4}\right)}_{DC\ gain} \frac{1 + \frac{R_3 C_4 s}{(1 + R_3/R_4)}}{1 + R_3 C_4 s}\ V/V$$

$$\frac{V_{out2}}{V_3} = \frac{1k}{1k + 99k} = \frac{1}{100}\ V/V$$

$$\frac{1}{\beta} = \frac{V_{out1}}{V_{inAC}}$$

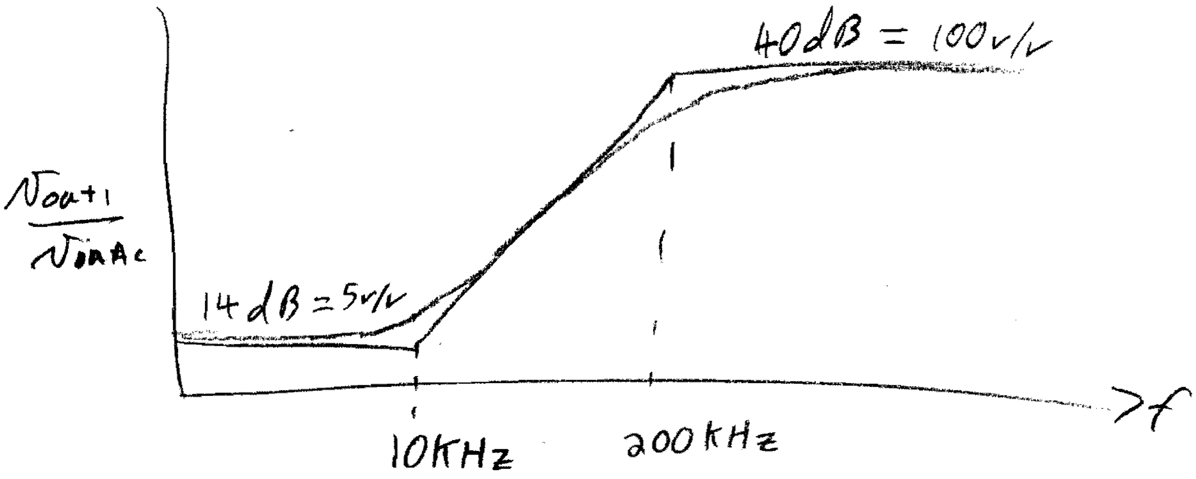
$$\frac{1}{\beta} = \frac{(100)}{\left(1 + \frac{R_3}{R_4}\right)}\left[\frac{1 + R_3 C_4 s}{1 + \frac{R_3 C_4 s}{(1 + R_3/R_4)}}\right]$$

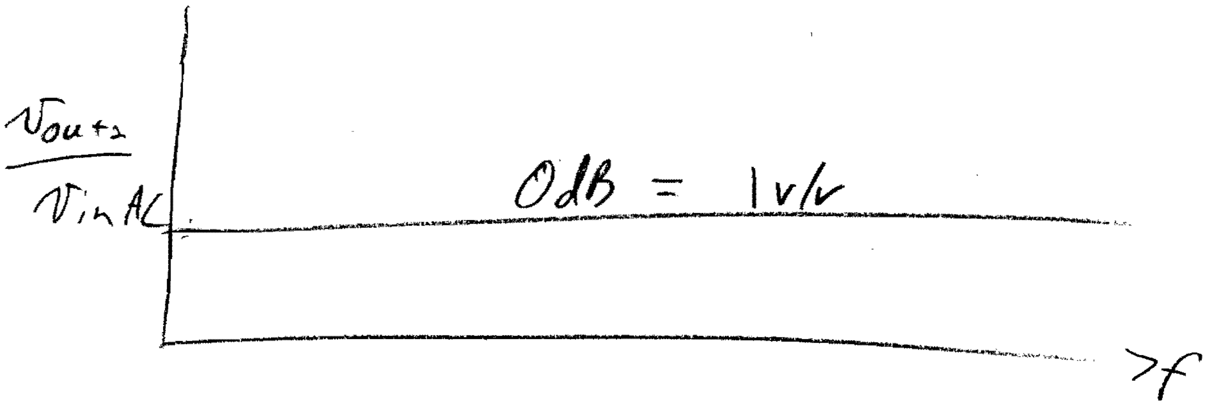
$$= \left(\frac{100}{20}\right)\left[\frac{1 + (1.6e\text{-}5)s}{1 + \left(\frac{1.6e\text{-}5}{20}\right)s}\right]$$

$$= 5\left[\frac{1 + \frac{jf}{10000}}{1 + \frac{jf}{200{,}000}}\right]\ V/V$$

@ DC $\frac{V_{out1}}{V_{inAC}} = 5\ V/V = 14\ dB$

@ $f \to \infty$ $\frac{V_{out1}}{V_{inAC}} = 5 \left[\frac{\frac{1}{10,000}}{\frac{1}{200,000}}\right] = 100\ V/V = 40dB$

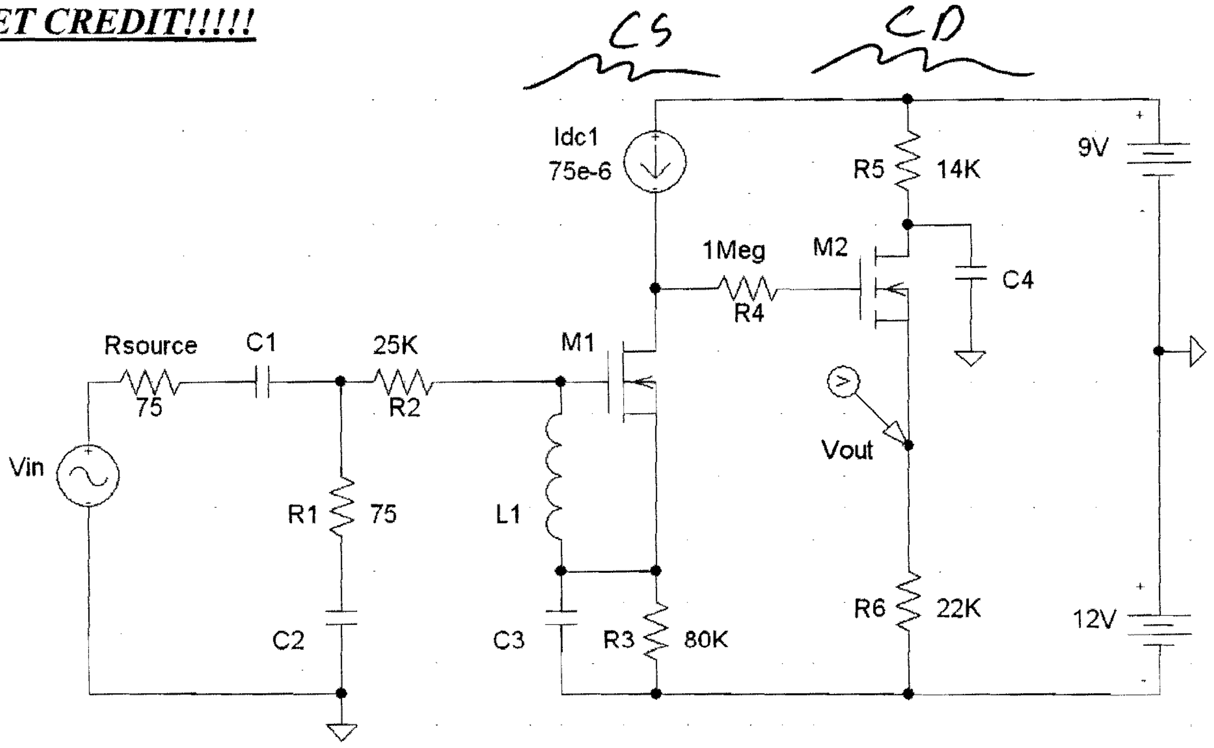




Pulling all the concepts together for a useful purpose:

***10) (50-points)*** Given the following amplifier circuit, (a) Identify the configuration of the stage (common ____). (b) What is the AC voltage gain, $v_{out}/v_{in}$? You may assume all capacitors have infinite capacitance and all inductors have infinite inductance. Additionally consider the circuit to be operated at low frequencies where you can neglect all small signal capacitances.

Grading will be based as such: part a=5 points, part b=18 points for DC solution (gate, source and drain voltages along with drain currents), 12 points for the conversion to the small signal model and 15 points for small signal analysis. ***SHOW ALL WORK TO GET CREDIT!!!!!***



Use the following parameters (note that K, $V_T$ and $\lambda$ vary with transistor type):

For PMOS Depletion Transistors:
$K_p$'=40 uA/$V^2$ **$V_T$= +3.0V** **$\lambda$=0.0 $V^{-1}$** Length (L)=10 um Width (W)=10 um

For PMOS Enhancement Transistors:
$K_p$'=30 uA/$V^2$ **$V_T$= -1.75V** **$\lambda$=0.1 $V^{-1}$** Length (L)=10 um Width (W)=10 um

M1: For NMOS Depletion Transistors:
$K_n$'=1 uA/$V^2$ **$V_T$= -1.0V** **$\lambda$=0.1 $V^{-1}$** Length (L)=0.18 um Width (W)=18 um

M2: For NMOS Enhancement Transistors:
$K_n$'=50 uA/$V^2$ **$V_T$= +1.0V** **$\lambda$=0.0 $V^{-1}$** Length (L)=1.8 um Width (W)=18 um

Extra work can be done here, but clearly indicate with problem you are solving.

$0.1\,V^{-1}$

DC:

Assume Saturation

M1: $V_{GS_1} = 0$ $\quad I_{DS} = 75uA = \frac{1}{2}(1e{-6})\left(\frac{18}{0.18}\right)(0-(-1))^2(1+\overset{\downarrow}{\lambda} V_{DS})$

↑ Inductor

$$\left(\frac{75e{-6}}{50e{-6}}\right) = 1 + 0.1\,V_{DS}$$

$$V_{DS} = 5\,V$$

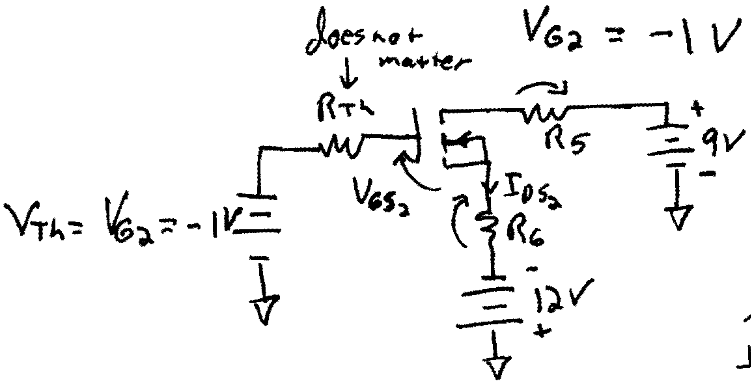
$$\underset{5V}{\overset{\uparrow}{V_{DS}}} > \underset{0}{\overset{\uparrow}{V_{GS}}} - \underset{-1V}{\overset{\uparrow}{V_T}}$$

Assumption Verified

M2: $V_{D1} = V_{G2} = V_{[illegible]S} + I_{DC1}R_3 - 12\,V$

$$= 5 + (75uA)\,80k - 12\,V$$

$V_{G2} = -1\,V$



$$\underbrace{250e{-6}}_{10} \times R6 = 5.5$$

$$\frac{1}{2}(50e{-6})\left(\frac{18}{1.8}\right)(V_{GS_2} - V_{T_2})^2$$

$$V_{Th} - V_{GS_2} - I_{DS_2}R_6 + 12\,V = 0$$

$$-V_{GS_2} - 5.5\left(V_{GS_2}-1\right)^2 + 11 = 0$$

$$-5.5V_{GS_2}^2 + 11V_{GS_2} - 5.5 - V_{GS_2} + 11 = 0$$

$$-5.5V_{GS_2}^2 + 10V_{GS_2} + 5.5 = 0$$

$$\boxed{V_{gs_2} = 2.26\ V} \Rightarrow I_{DS} = 250e\text{-}6\left(2.26-1\right)^2 \qquad \boxed{I_{DS} = 396.9\ \mu A}$$

or

$$-0.44\ V \Longrightarrow \text{cutoff}$$

Check:

$$-12 + I_{DS_2}R_6 + V_{DS} + I_{DS_2}R_5 - 9 = 0$$

$$V_{DS} = 21 - 396.9\,\mu A\,(22k + 14k)$$

$$V_{DS} = 6.711\ V$$

$$V_{DS} > V_{GS} - V_T \ \checkmark$$

---

Conversion:

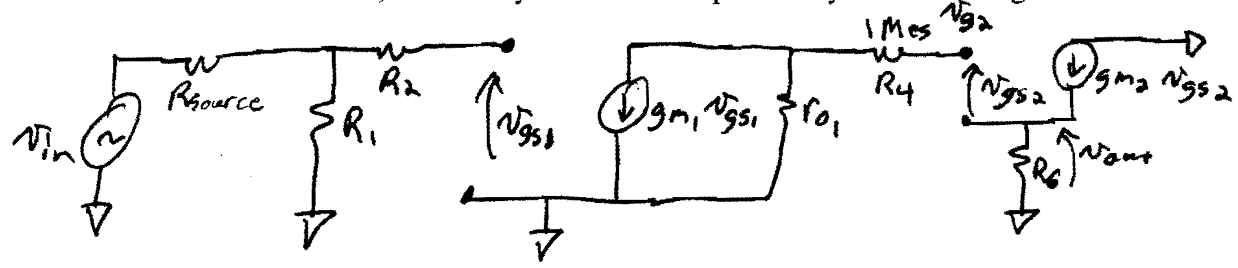
$$g_{m_1} = \frac{I_{DS_1}(2)}{\left(V_{GS_1} - V_{T_2}\right)} = 150\,\mu S$$

$$r_{o_1} = \frac{V_{DS_1} + \frac{1}{\lambda}}{I_{DS_1}} = 200K$$

$$g_{m_2} = \frac{I_{DS_2}(2)}{V_{GS_2} - V_T} = 630\,\mu S$$

$$r_{o_2} = \frac{V_{DS_2} + 1/\lambda \swarrow 0}{I_{DS_2}} = \infty\ .$$

Extra work can be done here, but clearly indicate with problem you are solving.



AC:

(1) $v_{gs1} = v_{in} \dfrac{R_1}{R_1 + R_{source}}$

(2) $v_{g2} = (-g_{m1} v_{gs1}) r_{o1}$

$v_{g2} = v_{gs2} + v_{out} \Rightarrow$ (3) $v_{g2} = v_{gs2}(1 + g_{m2} R_6)$

(4) $v_{out} = (g_{m2} v_{gs2}) R_6$

$$\frac{v_{out}}{v_{in}} = \overset{(1)}{\left(\frac{v_{gs1}}{v_{in}}\right)} \overset{(2)}{\left(\frac{v_{g2}}{v_{gs1}}\right)} \overset{(3)}{\left(\frac{v_{gs2}}{v_{g2}}\right)} \overset{(4)}{\left(\frac{v_{out}}{v_{gs2}}\right)}$$

$$= \left(\frac{R_1}{R_1 + R_{source}}\right)(-g_{m1} r_{o1}) \left(\frac{1}{1 + g_{m2} R_6}\right)(g_{m2} R_6)$$

$$= (0.5)(-30)\left[\left(\frac{13.86}{1 + 13.86}\right) \cancel{(0.933)}\right]$$

$$\boxed{A_v = -13.99 \text{ V/V}}$$