Name SOLUTIONS

ECE Box # ____________

A	90 - 100
B	76 - 89
C	60 - 75

μ 79.9

σ 14.5

MED 82

Problem	Average Score	Points
1	9.7	10
2	27.0	30
3	24.2	30
4	19.0	30

ECE3204 D2009

Microelectronics II

Exam 1

- This is a **closed book, closed notes test**! Use of calculators is allowed. No pre-stored formulas or outside resource access!
- Show **all** your work. Partial credit may be given. If you think you need something that you can't remember, write down what you need and what you'd do if you remembered it.
- Look for the simple, straightforward way to solve the problem for the level of accuracy required. **Don't get entangled in unnecessary algebra**.
- As in real life, some problems may give you more information than you need. Don't assume that all information must be used! It's your job to decide what's relevant to the solution.
- Unless otherwise indicated or implied, you may assume all op-amps to be ideal.
- You will have 50 minutes to complete this exam. There are four problems on a total of 9 pages.

1) State the Microelectronics II Mantra:

[10]

IF AN OP-AMP IS CONNECTED WITH NEGATIVE FEEDBACK

AND THE OPEN LOOP GAIN A IS SUFFICIENTLY HIGH

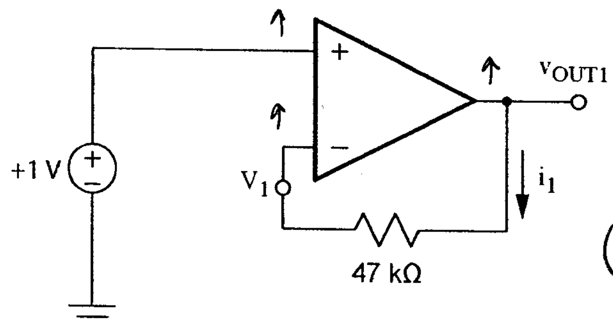
THEN THE OP-AMP INPUTS $V_- \approx V_+$ ARE APPROXIMATELY EQUAL

2) For each of the op-amp circuits in this problem, you may assume the op-amps to be ideal. For each circuit:

i) First, circle one choice to indicate whether the circuit is configured for positive or negative feedback. Then,

ii) **ONLY FOR THE CIRCUITS THAT HAVE NEGATIVE FEEDBACK**, determine the indicated voltages/currents.

[30]



POSITIVE FEEDBACK

NEGATIVE FEEDBACK ⇨

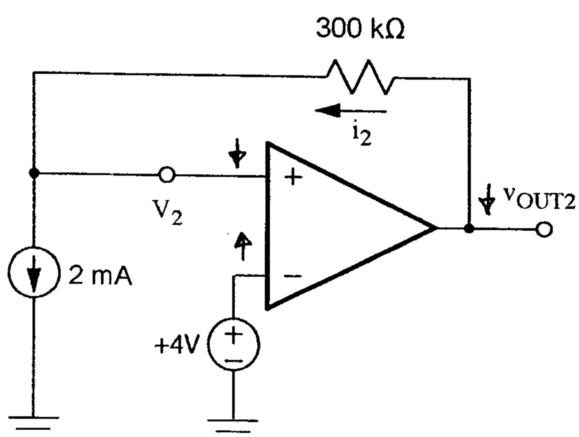
v_{OUT1} = +1V

v_1 = +1V

i_1 = 0

$i_1 = 0 \quad (i_- = 0)$

$V_1 = +1V \quad (V_- \approx V_+)$



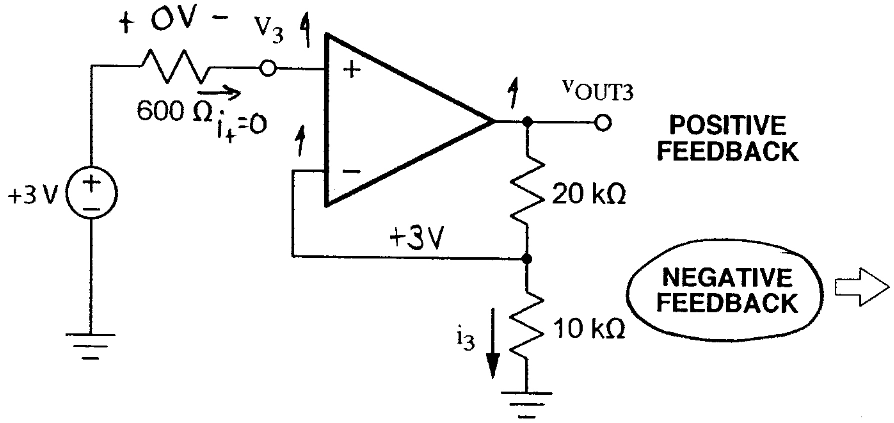
POSITIVE FEEDBACK

NEGATIVE FEEDBACK ⇨

v_{OUT2} = ______

v_2 = ______

i_2 = ______



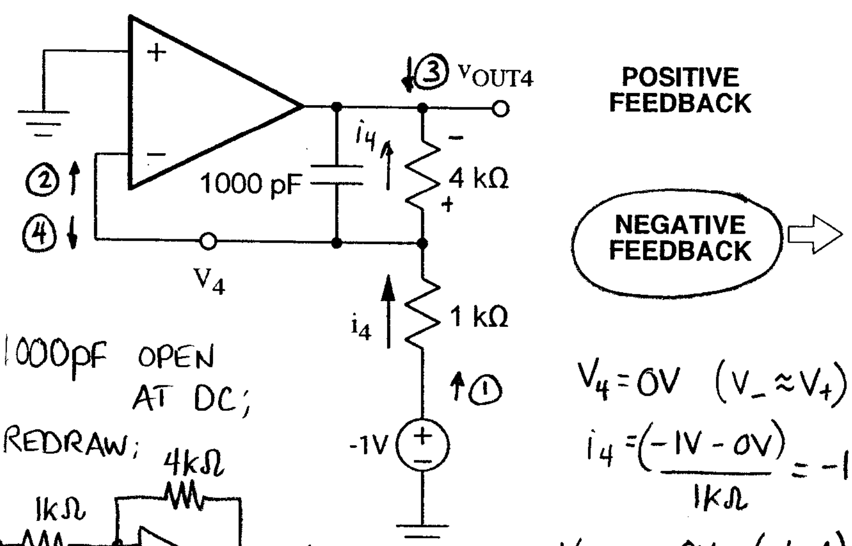
v_{OUT3} = +9V

v_3 = +3V

i_3 = 0.3 mA

$$\frac{V_{OUT3}}{V_3} = \frac{10k + 20k}{10K} = 3$$

$$i_3 = \frac{3V}{10k\Omega}$$



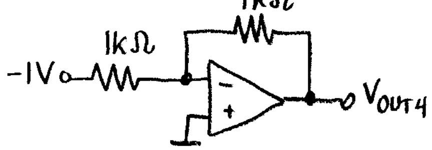
v_{OUT4} = +4V

v_4 = 0V

i_4 = -1mA

1000pF OPEN AT DC;

REDRAW;



$V_4 = 0V \quad (V_- \approx V_+)$

$$i_4 = \frac{(-1V - 0V)}{1k\Omega} = -1\ mA$$

$$V_{OUT4} = 0V - (-1mA)\,4k\Omega = +4V$$

3) For the circuit shown on the opposite page, you may assume the op-amp to be ideal except for finite open-loop gain A. The open-loop DC gain is $A_0 = 50{,}000$ and the unity gain frequency is $f_T = 10$ MHz.

a) Using the space on the opposite page, carefully plot |A| as a magnitude Bode plot over a frequency range from 1 Hz to 100 MHz. Be sure to label any interesting asymptotic values, intersection points, and/or slopes in your plot.

[6]

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b) It is desired that the closed loop DC gain of the amplifier be +50. Find the required value of R_F. Nonstandard value is OK.

NONINVERTING GAIN CONFIGURATION **[6]**

R_F = 490 kΩ

$$\frac{R_F + 10\text{k}\Omega}{10\text{k}\Omega} = 50 \rightarrow R_F = 490\text{k}\Omega$$

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c) Given the choice of R_F in (b), what will the 3-dB bandwidth $f_{3\text{-dB}}$ of the closed loop transfer function v_{out}/v_{in} ?

GAIN - BANDWIDTH RELATIONSHIP **[6]**

$f_{3\text{-dB}}$ = 200kHz

$$50 \times f_{3dB} = f_T = 10\text{MHz}$$

$$f_{3dB} = \frac{10\text{MHz}}{50} = 200\text{kHz}$$

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d) Using the same space on the opposite page, carefully superimpose a magnitude plot of the closed loop transfer function $|v_{out}/v_{in}|$ over a frequency range from 1 Hz to 100 MHz. Be sure to label any interesting asymptotic values, intersection points, and/or slopes in your plot

CLOSED LOOP DC GAIN : $20 \log(50) = 34\text{dB}$ **[6]**

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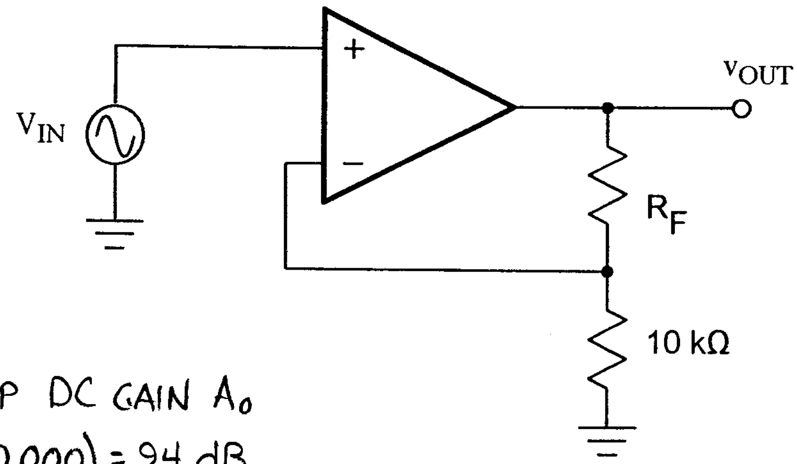
e) If a sine wave input of 1MHz is applied to the closed loop amplifier, what will be the magnitude of the closed loop gain $|v_{out}/v_{in}|$? (Accuracy ±10%; either a number or in dB is OK, just specify which)

[6]

$$\left|\frac{v_{out}}{v_{in}}\right|_{f=1MHz} = +20\text{dB}$$ GRAPHICALLY

OR FROM TRANSFER FUNCTION

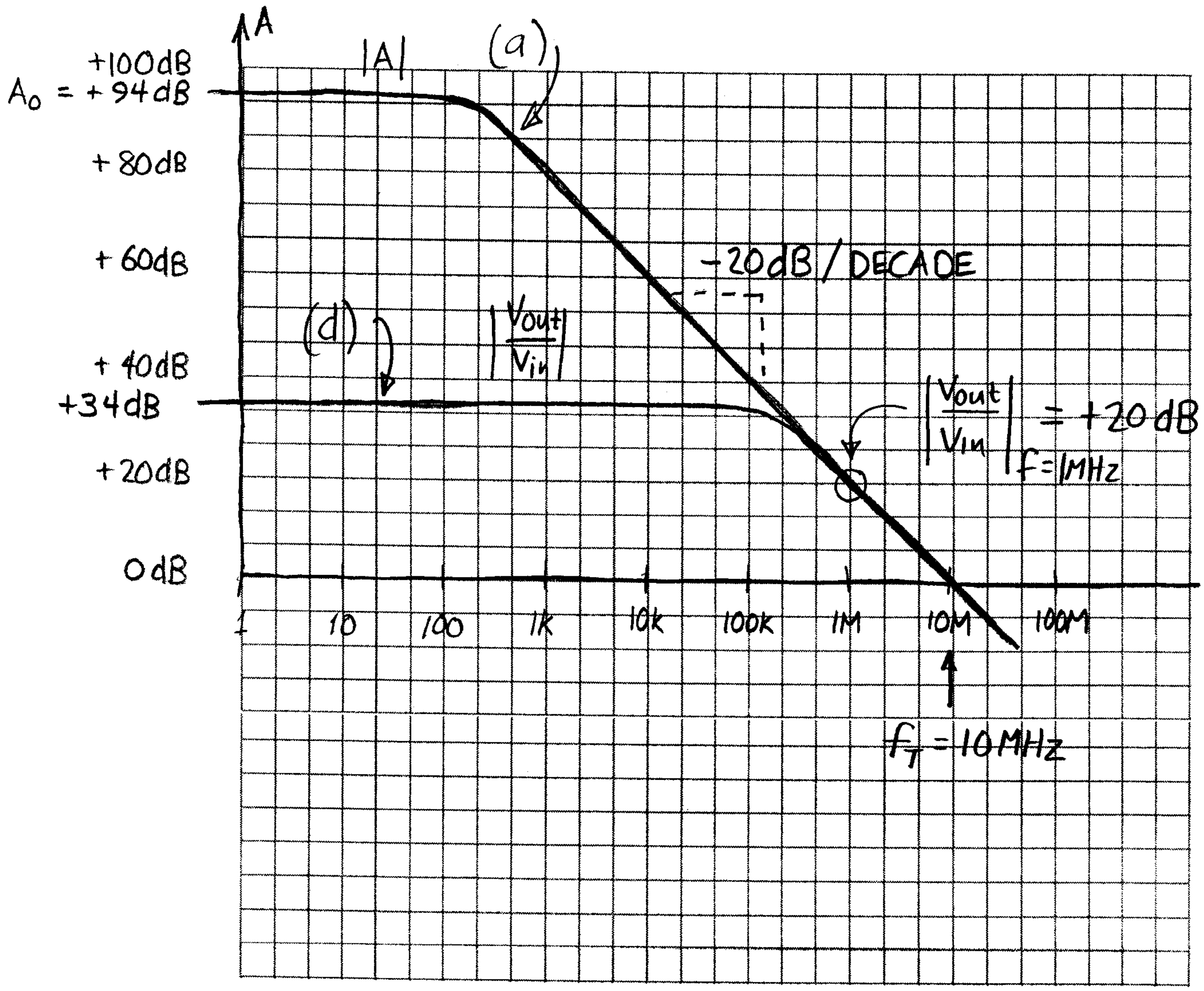
$$\frac{50}{\sqrt{1 + \left(\frac{1E+6}{200E+3}\right)^2}} = 9.8$$



OPEN LOOP DC GAIN A_o

$20 \log (50\,000) = 94$ dB

Axes for (a,d):



4) In this problem, the circuit on the opposite page is used as a microphone amplifier in an audio application. The input is modeled as a pure sine wave (zero DC component) which can range in frequency from 20Hz to 20kHz.

Assume the op-amp to be ideal except for the following:

- Input offset voltage V_{OS}
- Output voltage limt V_{OMAX}
- Output slew rate limit SR

Performance specifications for a range of op-amps are given below:

Op-amp	V_{OS}	V_{OMAX}	**SR**	**Cost**
LM741	± 6.0 mV	± 12 V	0.5 V / μs	$ 0.47
LF356	± 1.0 mV	± 13 V	12.0 V / μs	$ 1.10
LM318	± 2.0 mV	± 13 V	70.0 V / μs	$ 2.55
UO9661	± 0.1 mV	± 14 V	75.0 V / μs	$ 5.40

For parts (a) and (b), you use the LM741 (from your lab kit) in the circuit.

a) Given a 20 mV peak sine wave input at a low frequency of 20 Hz: Use the area on the following page to plot the resulting output voltage. *Assume the worst-case combination of maximum error sources.* Be sure to indicate any interesting values of amplitude or other waveform characteristics.

CLIPPING DUE TO OUTPUT DC OFFSET **[10]**

b) Given a 20 mV peak sine wave input at the a frequency of 20 kHz: Use the area on the following page to plot the resulting output voltage. *Assume the worst-case combination of maximum error sources.* Be sure to indicate any interesting values of amplitude or other waveform characteristics.

[10]

c) Given the choices from the table above, what is the lowest cost op-amp that would provide undistorted output waveforms for both (a) and (b)? Circle one: **[2]**

✗	✓	✓	✓	
LM741	(LF356)	LM318	UO9661	NONE OF THE ABOVE
		TOO EXPENSIVE	TOO EXPENSIVE	

Explain! **[8]**

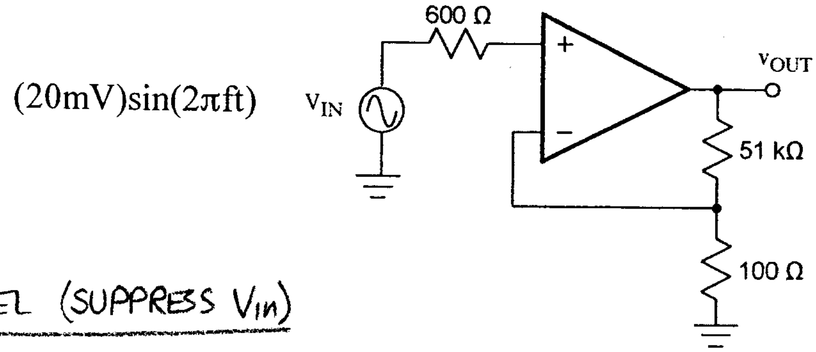
NEED SR > 1.28 V/μsec

AND $10.22V + (511)V_{OS} < V_{OMAX}$

V_{OS} = 1mV, V_{OMAX} = +13V } LF356

10.731 V < +13V ✓

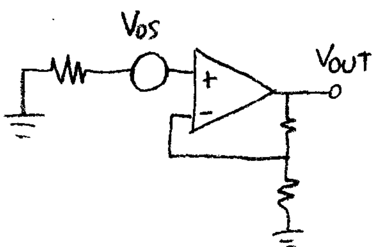
8



$$V_{OUT} = \left(\frac{51k + 100\Omega}{100\Omega}\right) V_{in} = 511\, V_{in}$$

$$= (10.22\text{ V}) \sin(2\pi f t)$$

V_{OS} MODEL (SUPPRESS V_{in})



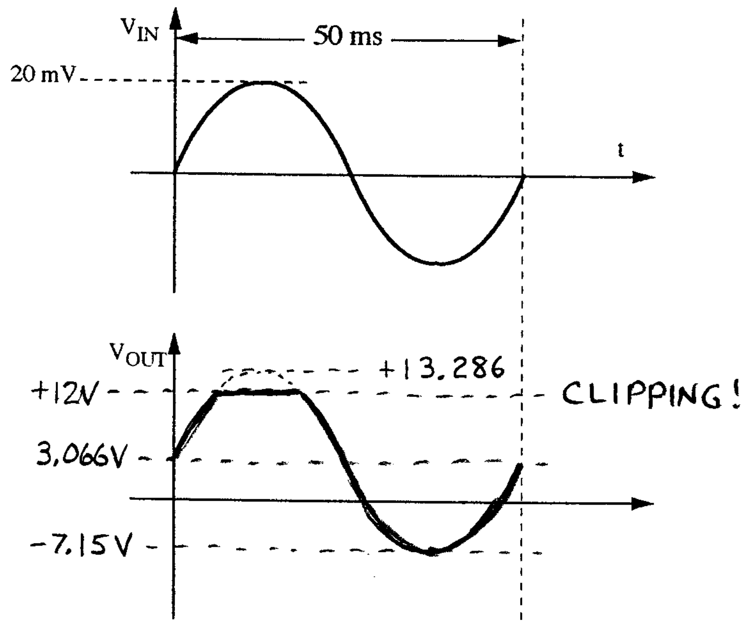
$V_{OUT} = 511\, V_{OS} = 3.066\text{V}$

741 WORST CASE: 6mV

ADD BY SUPERPOSITION:

$(10.22\text{V}) \sin(2\pi f t) + 3.066$

Axes for (a):



CHECK MAX $\frac{dV}{dt}$

$$\left.\frac{dV_{OUT}}{dt}\right|_{MAX} = (10.22\text{V})\, 2\pi f$$

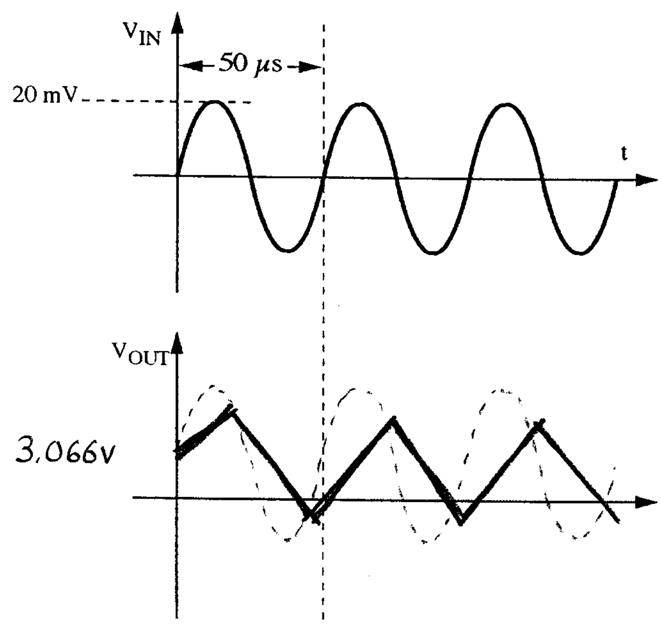
$= (10.22\text{V})\, 2\pi\, (20\text{Hz})$

$= 1.28\text{E}{+}3\ \text{V/sec}$

$\ll 0.5\ \text{V}/\mu\text{sec}$

NO SLEW RATE LIMITING

Axes for (b):



SAME DC OFFSET ERROR AS (a)

CHECK MAX $\frac{dV}{dt}$

$(10.22\text{V})\, 2\pi\, (20\text{kHz})$

$= 1.28\text{E}{+}6\ \text{V/sec}$

$= 1.28\ \text{V}/\mu\text{sec}$

$> 0.5\ \text{V}/\mu\text{sec}$

OUTPUT WILL BE SLEW RATE LIMITED