Name SOLUTIONS

ECE Box # ____________

A	86 - 100
B	70 - 85
C	55 - 69

μ 74.7

σ 14.7

MED 76

Problem	Average Score	Points
1	10.0	10
2	18.8	25
3	20.4	25
4	18.0	25
5	7.5	15

ECE3204 D2015
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 55 minutes to complete this exam. There are five problems on a total of 11 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

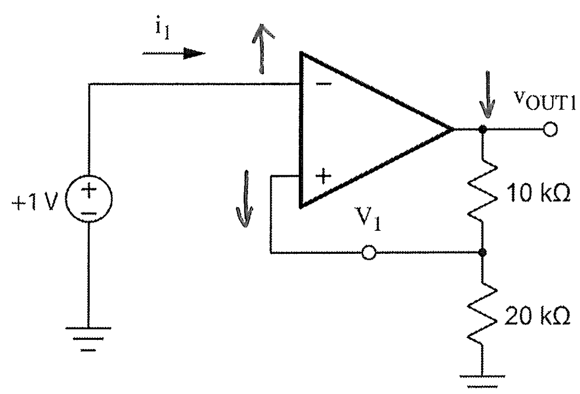
THEN THE OP-AMP INPUTS $V_- \approx V_+$ ARE
APPROXIMATELY EQUAL

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.

[25]



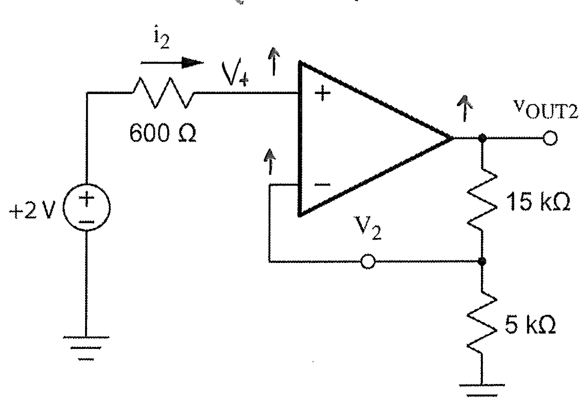
POSITIVE FEEDBACK

NEGATIVE FEEDBACK ⇨ v_{OUT1} = ________

v_1 = ________

i_1 = ________

$V_{OUT2} = \left(\frac{15k+5k}{5k}\right)V_+$

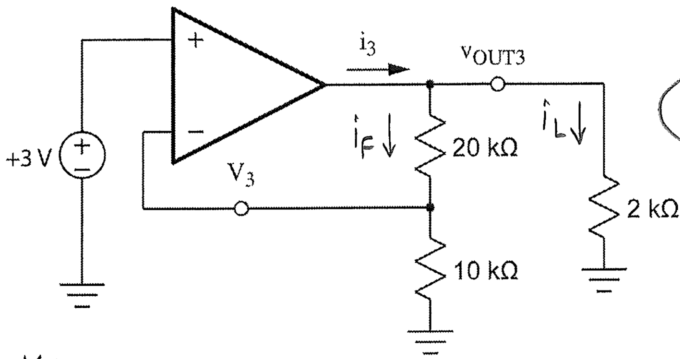


POSITIVE FEEDBACK

NEGATIVE FEEDBACK ⇨ v_{OUT2} = +8V

v_2 = +2V

i_2 = 0



POSITIVE FEEDBACK

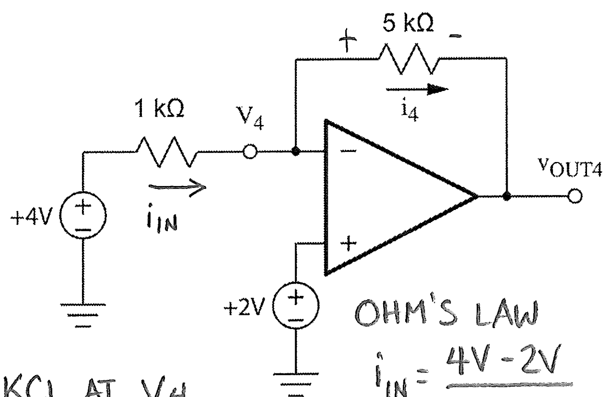
NEGATIVE FEEDBACK ⇨ v_{OUT3} = +9V

v_3 = +3V

i_3 = 4.8mA

KCL

$i_3 = i_F + i_L = \frac{9V}{30K} + \frac{9V}{2K}$



POSITIVE FEEDBACK

NEGATIVE FEEDBACK ⇨ v_{OUT4} = -8V

KVL TO V_{OUT4}

v_4 = +2V

$V_{OUT4} = 2V - (2mA)(5k\Omega)$

$= -8V$

i_4 = 2mA

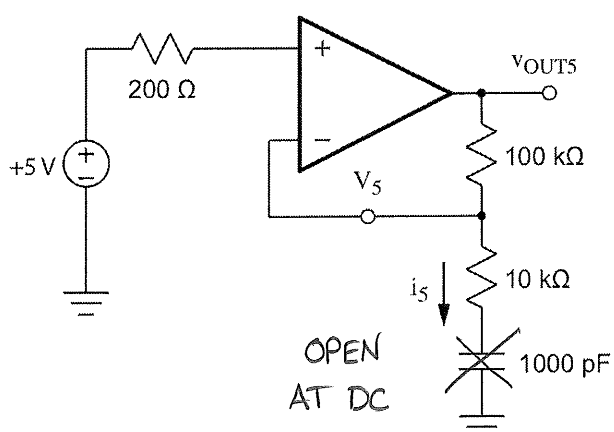
OHM'S LAW

$i_{IN} = \frac{4V - 2V}{1K\Omega}$

$= 2\ mA$

KCL AT V_4

$i_{IN} = i_4$



OPEN AT DC

POSITIVE FEEDBACK

NEGATIVE FEEDBACK ⇨ v_{OUT5} = +5V

v_5 = +5V

i_5 = 0

3) The first task you are assigned on your summer internship is design of the circuit shown on the opposite page. The application is a battery powered system with ±9V power supplies. Output swing is limited to approximately ±7V so it is desired that the circuit have a closed loop DC gain magnitude of 60. To save power, it is required that the amplifier circuit draw a maximum of 5μA peak from the input signal source.

a) Find the required numerical values of R_A and R_B. Nonstandard value is OK. **[10]**

R_A = 20kΩ R_B = 1.2MΩ = 60 R_A

Your design is built with an LM741 op-amp with gain-bandwidth product (unity gain frequency) f_T = 1MHz.

b) Determine the resulting closed loop 3dB bandwidth f_{3dB} . **[5]**

f_{3dB} = 16.4 kHz $\frac{1\text{MHz}}{61}$ GAIN-BW PRODUCT RELATIONSHIP

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c) Write the equation of the resulting transfer function, in a form showing numerical values for the DC gain and bandwidth. Either f or ω is OK. **[5]**

$$\frac{v_{out}}{v_{in}} = \frac{-60}{1 + j\left(\frac{f}{16.4\text{kHz}}\right)}$$

GENERAL FORM: $\frac{[\text{DC GAIN}]}{1 + j\left(\frac{f}{f_{3dB}}\right)}$

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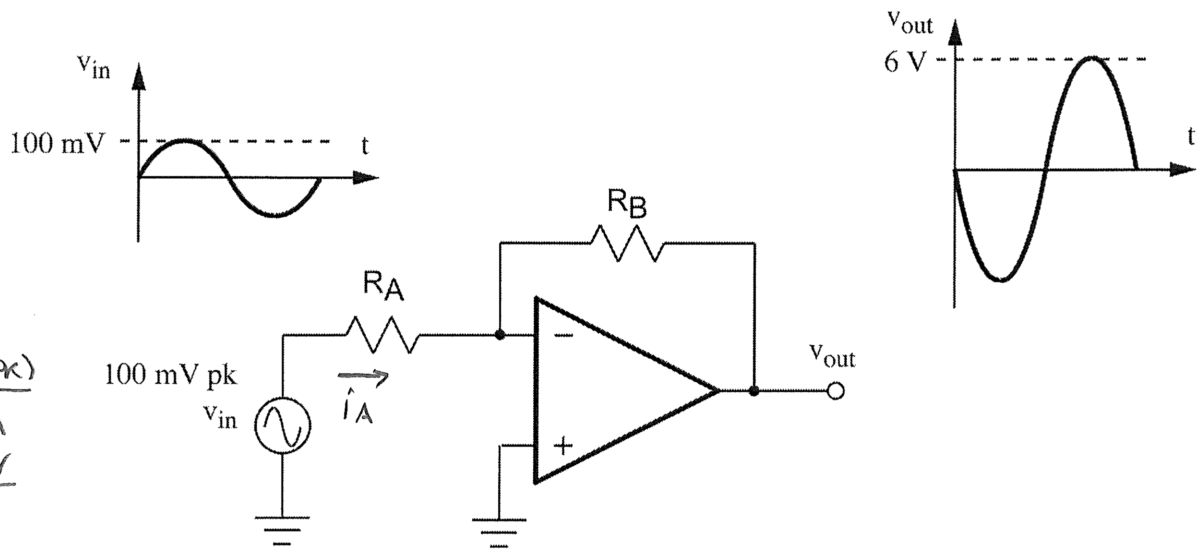
d) In the space on the opposite page, CAREFULLY draw the magnitude Bode plot of the resulting closed loop transfer function over a frequency range of 1Hz to 10MHz. Be sure to indicate accurate numerical values for any interesting features of your plot. **[5]**

60 : 20 log(60) = 35.5 dB

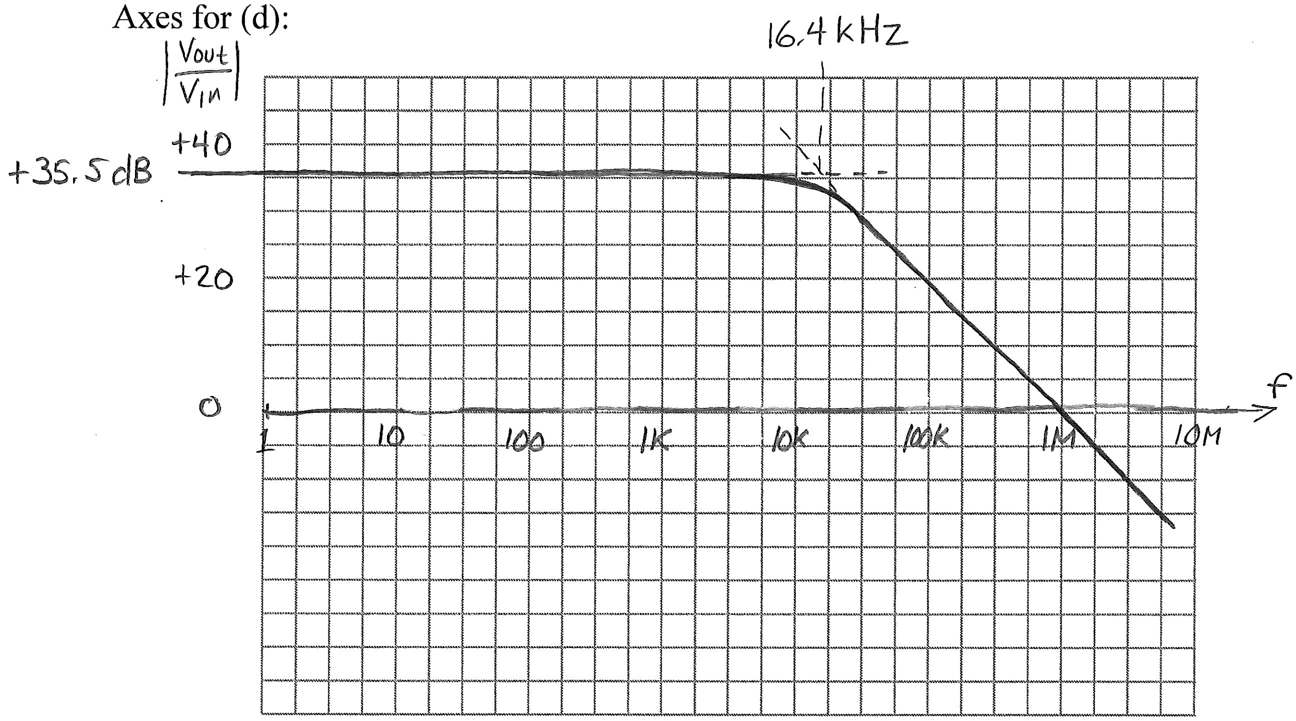


$i_{A(PK)} = \frac{V_{in\,(PK)}}{R_A}$

$5\mu A = \frac{0.1V}{R_A}$

$R_A = 20K\Omega$

Axes for (d):



4) In this problem, the circuit on the opposite page is used as a voltage buffer in a medical ultrasound application. The input is modeled as a pure sine wave (zero DC component) that can range in frequency from DC to 1 MHz.

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

- Unity gain frequency f_T
- Output current limit I_{OMAX}
- Output slew rate limit SR

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

Op-amp	f_T	I_{OMAX}	SR	Cost
LM741	1 MHz	30 mA	0.7 V / μs	$ 0.47
LF356	4 MHz	30 mA	12.0 V / μs	$ 1.10
LM318	15 MHz	20 mA	70.0 V / μs	$ 2.55
UO9661	80 MHz	80 mA	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 100 mV peak sine wave input at a frequency of 1 MHz: 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.

AT f_{3dB}: $\frac{V_{out}}{V_{in}} = 0.707$, 45° PHASE LAG **[8]**

b) Given a 5V peak sine wave input at a frequency of 1 MHz: 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.

SLEW RATE LIMITED **[8]**

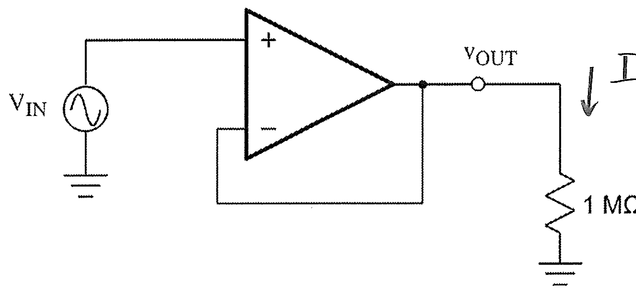
c) Given the choices from the table above, what is the lowest cost op-amp that would provide undistorted output waveforms for both (a) and (b)? Circle one: **[2]**

$\underbrace{\cancel{\text{LM741}} \quad \cancel{\text{LF356}}}_{\text{SR TOO SLOW}}$ $\underbrace{\text{LM318} \quad \cancel{\text{UO9661}}}_{\text{SR FAST ENOUGH}}$ NONE OF THE ABOVE

Explain! SR TOO SLOW SR FAST ENOUGH COSTS MORE **[7]**

FOR LM318 $V_{d(PK)} \approx 5V$

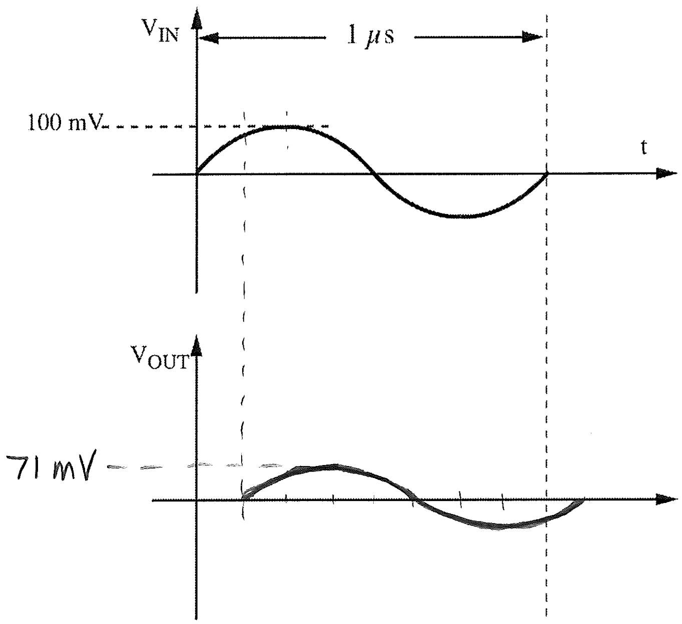
$$\left.\frac{dV_o}{dt}\right|_{MAX} = (5V)\, 2\pi\, (1E{+}6) = 31\ V/\mu sec$$



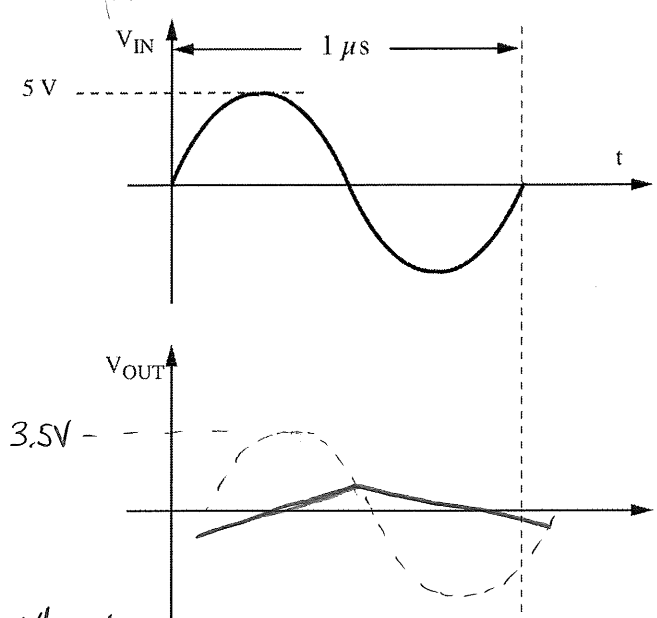
$\downarrow I_{OMAX} = \frac{5V}{1M\Omega} = 5\mu A$

I_O NEVER A PROBLEM

Axes for (a):



Axes for (b):



IF NO SLEW LIMIT:

3.5V pk

$$\left.\frac{dV_o}{dt}\right|_{MAX} = (3.5V)2\pi(1E+6)$$

$= 22\ V/\mu sec > 0.7\ V/\mu sec!$

5) This problem involves measurement of op-amp DC errors for a particular op-amp. For the three circuit configurations shown on the opposite page, the indicated DC output voltages are measured.

Determine the values of the input bias current I_{B+} and I_{B-} and the op-amp DC offset error V_{OS}. Required accuracy for full credit ±1% on currents, ±10μV on voltages.

[15]

I_{B+} = 951 nA I_{B-} = 840 nA V_{OS} = +1.58mV

FOR EXACT SOLUTION, SUBTRACT $\frac{1}{47}$ OF [2] FROM [3]

$$(100k\Omega)I_{B-} + 1001\ V_{OS} = +1.67\,V$$

$$(100k\Omega)I_{B-} + .021\ V_{OS} = +0.084\,V$$

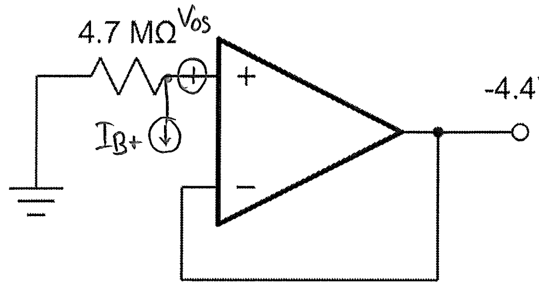
$$1001\ V_{OS} = 1.586\,V$$

$$V_{OS} = 1.58\ mV$$

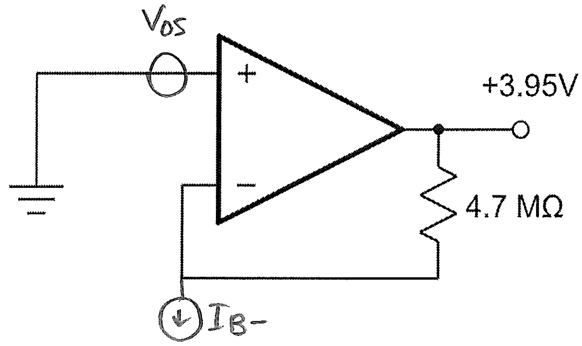
USING THIS IN [1], [2] GIVES

$$I_{B+} = \frac{-4.47V - 1.58\,mV}{-4.7M\Omega} = 951\,nA$$

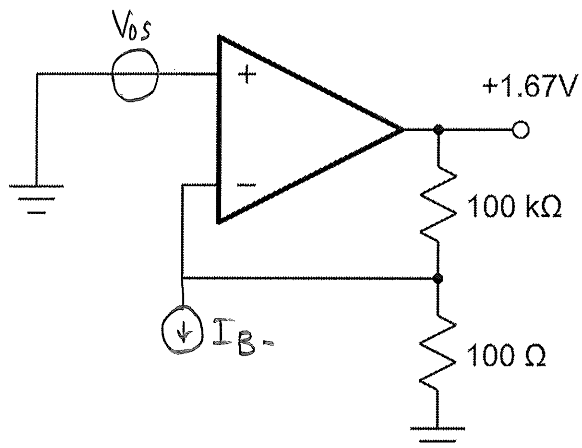
$$I_{B-} = \frac{3.95V - 1.58\,mV}{4.7\,M\Omega} = 840\,nA$$



$$-4.47V = (-4.7M\Omega) I_{B+} + V_{os} \quad [1]$$



$$+3.95V = (4.7M\Omega) I_{B-} + V_{os} \quad [2]$$



$$+1.67V = (100k\Omega) I_{B-} + 1001 V_{os} \quad [3]$$