**Name**: ______________________________________________

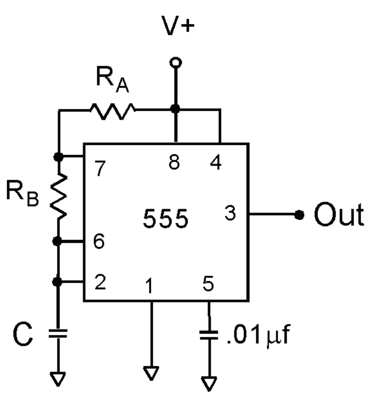
# BENG 186B Winter 2011

## Final

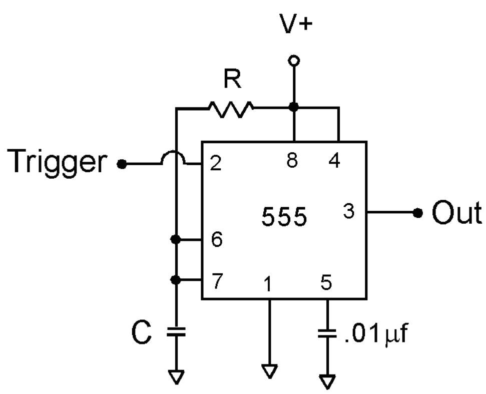
- This exam is closed book, closed note, calculators are OK.
- Circle and put your final answers in the space provided; show your work only on the pages provided. Include units.
- Do not attach separate sheets. If you need more space, use the back of the pages.
- Points for each problem are given in [brackets], 100 points total.

| | |
|---|---|
| 1 | /10 |
| 2 | /16 |
| 3 | /8 |
| 4 | /8 |
| 5 | /8 |
| 6 | /10 |
| 7 | /10 |
| 8 | /8 |
| 9 | /10 |
| 10 | /8 |
| 11 | /4 |
| Total | /100 |

Useful schematics and equations




Oscillator




One-shot

Nernst Equation:

$$E = \frac{RT}{zF} \ln \frac{C_1}{C_2}$$

$R$ = 8.3 J/(°K · mol)
$T$ = temperature (°K)
$F$ = 96,500 C/mol
$z$ = valence (unitless)

Common mode gain and differential gain:

$v_o = A_d v_d + A_c v_{cm}$
$v_d = v_a - v_b$
$v_{cm} = (v_a + v_b) / 2$

1. Circle the letter of the best (one and only one) answer for each. [10 pts; 1 pt each]

A) Resolution of an instrument is:

a) the difference between its true output and its measured value
b) the standard deviation of its measured output
c) the largest signal that it can measure without distortion
d) the measure it takes in calibrating itself
e) the smallest measurable increment in its output

B) The damping ratio of a second-order system should be:

a) as small as possible to avoid an oscillatory system response
b) as large as possible to produce a fast system response
c) zero for a critically damped response
d) one for a critically dampled response
e) negative for an overdamped response

C) Poisson's ratio for a strain gauge relates:

a) change in resistance to change in diameter
b) change in resistance to change in length
c) change in diameter to change in length
d) strain to change in length
e) strain to resistance

D) A 2P3T (two-pole, three-throw) switch allows to connect: (*Hint*: it helps to draw the switch)

a) three inputs to any of six outputs
b) two inputs to any of six outputs
c) three inputs to either of two sets of three outputs
d) two inputs to either of three sets of two outputs
e) neither of the above

E) At high frequencies the gain of an opamp is

a) zero
b) equal to the gain-bandwidth product
c) the gain-bandwidth product divided by frequency
d) increasing with frequency
e) independent of frequency

F) A hysteretic comparator uses

a) capacitive feedback
b) negative feedback
c) positive feedback
d) unity-gain feedback
e) neither of the above

G) The concentration overpotential of an electrode depends on:

a) temperature
b) valence of the cation
c) activity of the cation
d) all of the above
e) none of the above

H) Compliance of the diaphragm and air bubbles in a catheter tube can be modeled electrically as:

a) capacitance
b) inductance
c) inertance
d) resistance
e) constant current

I) Pulse oxymetry directly measures:

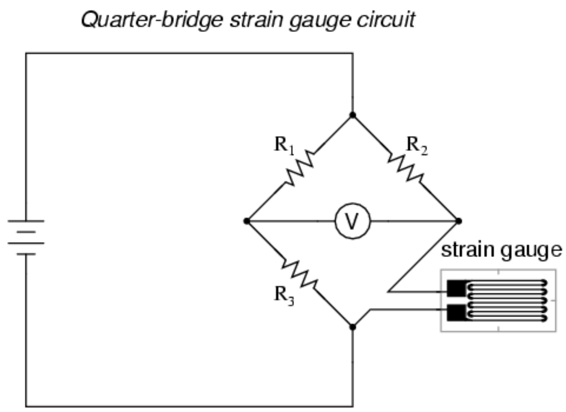
a) PO2 with an electrochemical sensor
b) SO2 with an electrochemical sensor
c) SO2 with an optical sensor
d) PO2 with an optical sensor
e) Neither of the above

J) Macroshock is:

a) A massive electrical shock with severe damage or fatality
c) An electrical shock caused by currents through a catheter
b) An electrical shock where all current passes through the heart
d) An electrical shock where part of the current passes through the heart
e) A massive disruption of electrical activity in the brain

2) Short answer, write your answer only in the space provided. [16 pts; 2 pts each]

(a) Find the precision of the voltage output in the following strain gauge circuit. All resistances are nominally 100 kΩ, but the strain gauge resistance is found to be 96 kΩ at zero strain. The supply voltage is 5 V. [2 pts]




(b) List the parameters that describe non-ideal opamp characteristics. [2 pts]

(c) What is the difference between EEG and ECoG? [2 pts]

(d) What determines the voltage measured between two electrodes immersed in a uniform ionic solution? [2 pts]

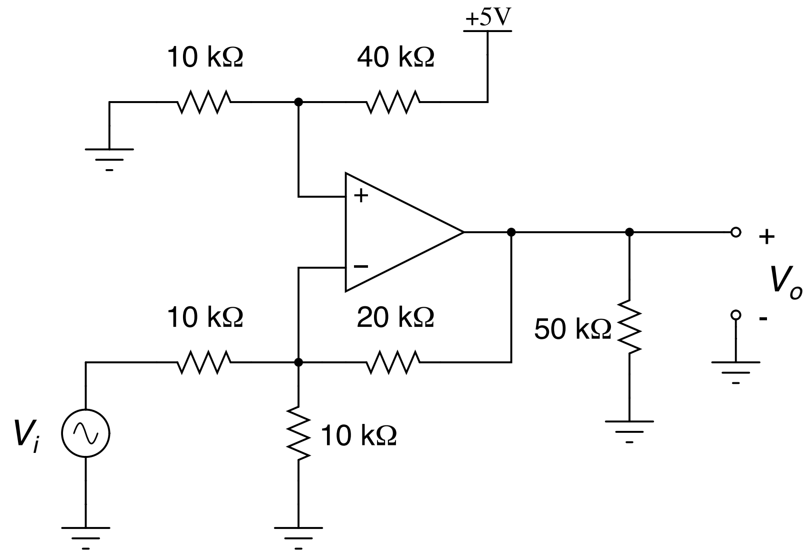
(e) Sketch the Einthoven triangle with 6 ECG lead vectors in the frontal plane. [2 pts]

(f) What is the Doppler frequency shift for blood moving with velocity $v$ towards the instrument containing both ultrasonic transmitter and receiver, with ultrasonic waves of frequency $f$ and speed $c$? [2 pts]

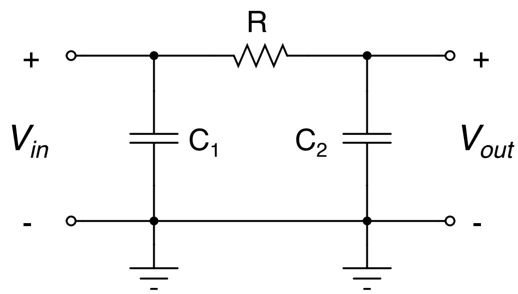
(g) What is $SO_2$? [2 pts]

(h) Why is it safer to operate an instrument with a grounded rather than an ungrounded plug? [2 pts]

3) Find the Thevenin equivalent at the $V_o$ terminals in terms of the input voltage signal $V_i$ [8 pts].



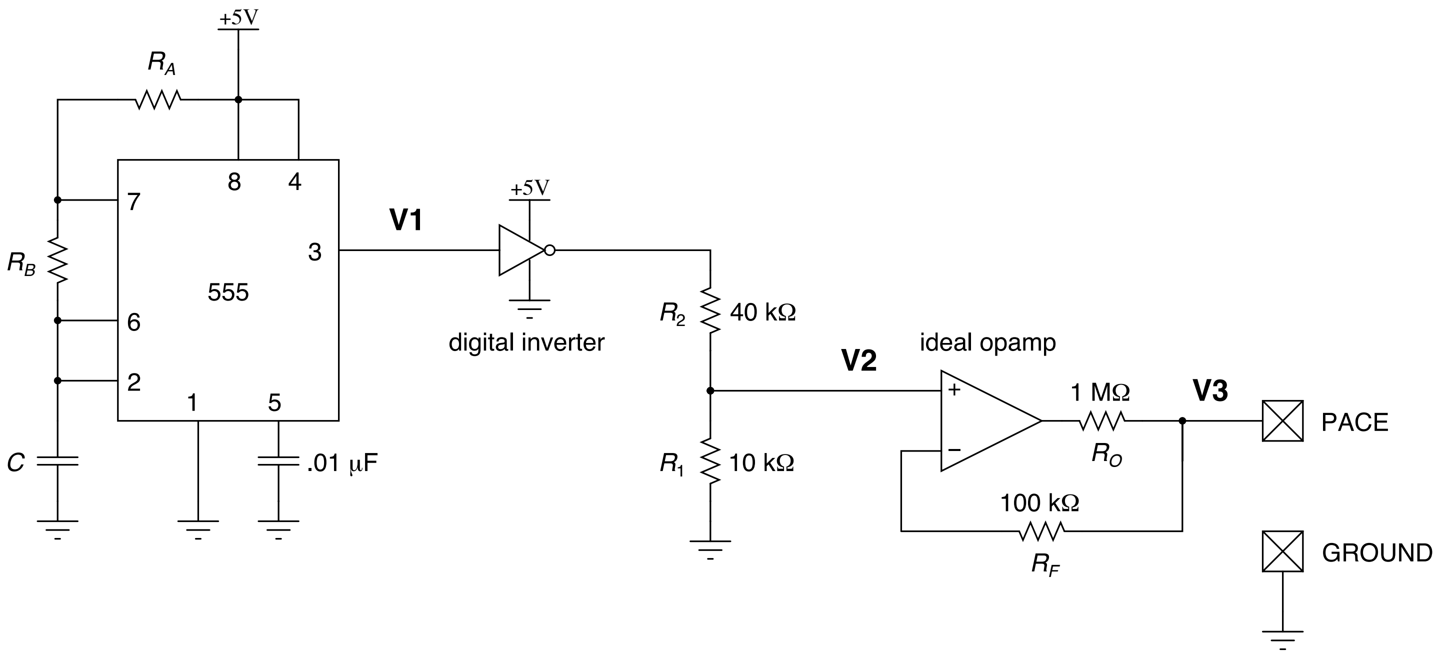
4a) Find the input impedance $Z_{in}(j\omega)$ as seen at the $V_{in}$ terminal for the following filter circuit. [2 pts]




b) Find the output impedance $Z_{out}(j\omega)$ as seen at the $V_{out}$ terminal. [2 pts]

c) Find the transfer function $H(j\omega) = V_{out}(j\omega) / V_{in}(j\omega)$. What type of filter is it? Sketch the magnitude of the transfer function, as function of frequency $f$, for $R$ = 100 kΩ, $C_1$ = 1.6 nF, and $C_2$ = 16 nF. Indicate numerical values of the filter parameters. [4 pts]

5a) Sketch the voltage waveforms **V1**, **V2**, and **V3** over time for the pacemaker circuit shown below. Indicate the time and voltage scale on the waveforms. The equations for the 555 timer circuit are $T_{low} = 0.7\ R_b\ C$, and $T_{high} = 0.7\ (R_a + R_b)\ C$, where $R_a$ = 1.3 MΩ, $R_b$ = 1.3 kΩ, and $C$ = 1 μF. [6 pts]




**V1**

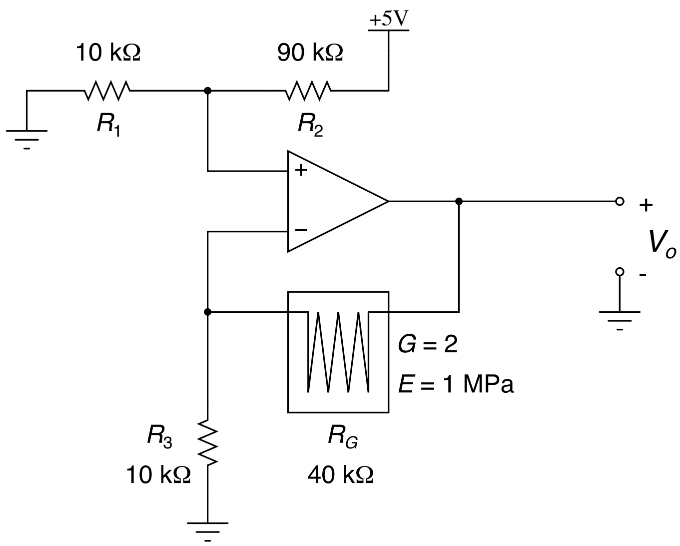
**V2**

**V3**

b) Explain the function of the $R_O$ and $R_F$ resistors in protecting the patient, and in protecting the circuit. [2 pts]

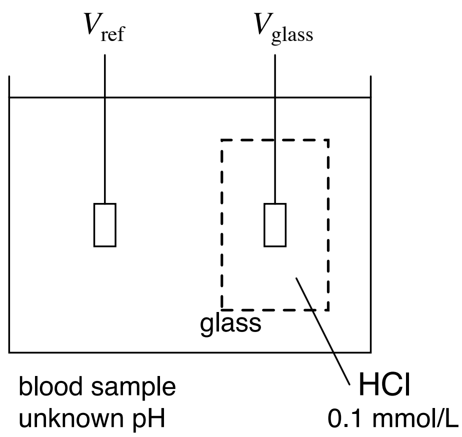
c) *BONUS* (only do this after you have completed everything else):
Extend the pacemaker circuit so that the “PACE” output is only driven when no heartbeat is detected for at least five seconds. For this a third electrode “ECG” is connected to the heart and produces a voltage that is greater than 50mV during the QRS complex. Note: once your circuit starts pacing, it should not stop until a heartbeat is detected *outside* of the pace pulse. [extra 6 points, no partial credit!]

6a) Find the voltage $V_o$ as a function of tensile stress $\sigma$ for the following stress transducer circuit. $R_G$ is the resistance of the strain gauge at zero strain, G is the gauge factor, and E is the Young's modulus of the strain gauge under tensile stress, as given below. [8 pts]

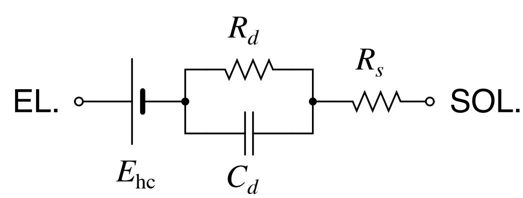



b) Find the sensitivity of the stress transducer, and indicate the units. [2 pts]

7) A blood pH reader is shown below, with one Ag/AgCl electrode immersed in the blood sample at room temperature, and a second Ag/AgCl electrode inside a glass bulb containing a solution of 0.1 mmol/L HCl in water. The glass membrane is permeable to $H^+$ only. For each Ag/Ag/Cl electrode, the half cell potential is $E_{hc} = 0.223$ V, and the impedance parameters are $R_d = 320$ kΩ, $C_d = 1$ pF, and $R_s = 1$ kΩ.




Each Ag/AgCl electrode:




a) Find the pH of the HCl solution inside the glass bulb. [2 pts]

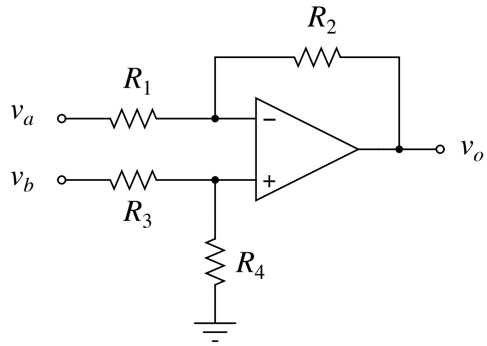
b) The voltage on the glass electrode relative to the reference electrode measures -186 mV. Find the pH of the blood sample. [4 pts]

c) Assuming that the electrical resistance between the solutions for transport of hydrogen through the thin glass membrane is $R_{mem} = 260$ kΩ, find the equivalent impedance between the two electrodes. Sketch the magnitude of the impedance as a function of frequency. On your graph denote and quantify the corner frequency $f_c$, and the value of effective resistance at zero and infinite frequencies. [4 pts]

8a) Sketch the time waveform of a typical ECG voltage signal measured across lead II in the frontal plane. Indicate P, Q, R, S, and T on the waveform, and indicate the time and voltage scales on the axes. [4 pts]

b) It is generally observed that the T wave is zero for the aVL lead, and is maximally positive for the II lead. Based on this, sketch a typical direction of the cardiac vector for the T wave in the frontal plane, in relation to the 6 lead vectors. *Hint*: You may assume that for each of the leads the corresponding ECG signal is $V_{\mathbf{a}} = \mathbf{M} \cdot \mathbf{a}$, where **M** is the cardiac vector, and **a** is the lead vector. [4 pts]

9) Consider the differential biopotential amplifier below, with resistance values $R_1 = R_3 = 100$ kΩ, and $R_2 = R_4 = 10$ MΩ.

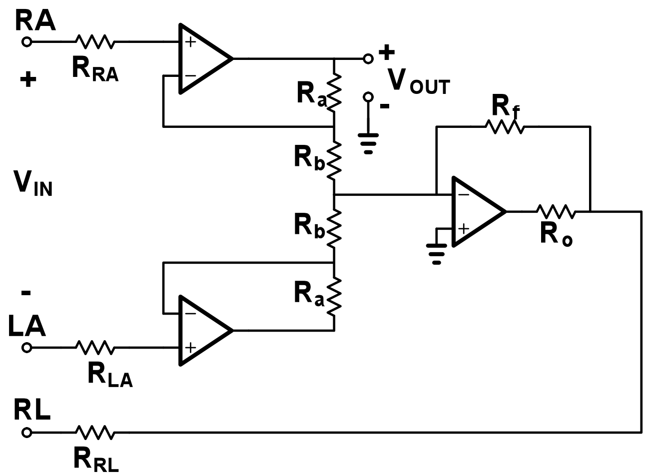



a) Find the input impedance on the $v_a$ node to ground, the input impedance on the $v_b$ node to ground, and the output impedance on the $v_o$ node to ground. [3 pts]

b) Find the differential gain $A_d$, common gain $A_c$, and common mode rejection ratio CMRR of the bioamplifier. [3 pts]

c) The bioamplifier is now connected to the body through electrodes with impedance $R_a = 110$ kΩ on the $v_a$ terminal, and $R_b = 90$ kΩ on the $v_b$ terminal. Find the resulting changes in differential gain $A_d$, common gain $A_c$, and common mode rejection ratio CMRR. Explain what happened. [4 pts]

10) Consider the DRL system below, with electrode resistances $R_{RA} = R_{LA} = R_{RL} = 130\ \text{k}\Omega$, and with circuit resistances $R_a = 1\ \text{M}\Omega$, $R_b = 1\ \text{k}\Omega$, and $R_f = 1\ \text{M}\Omega$.




a) Find the effective resistance between the RL terminal and ground. Assume the entire body is at common mode potential $v_{cm}$, and an external displacement current $i_d$ enters the body. [5 pts]

b) Find the value of the resistance $R_o$ such that no more than 10 μA can flow to or from the body through the RL terminal. You may assume the body is near ground potential, and the opamp is powered with +5 V and -5 V. [3 pts]

11) Questions from 2 guest lectures as promised. Please write answer only in the space provided.

Wireless Non-contact ECG and EEG [2 pts]

a) Why is it necessary for a non-contact capacitive electrode to have a build-in amplifier?

b) How does the impedance of a capacitive electrode depend on the distance from the skin? Does it matter what material is in between the skin and electrode?

Wireless and Global Health Care [2 pts]

a) Which country has the highest infant mortality rate in the developed world?

b) What does Dr. Saldivar mean by “reverse tropicalization”?