# BENG 186B Winter 2013

Quiz 2

February 15, 2013

NAME (Last, First):

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- This quiz is closed book and closed notes. You may use a calculator for algebra.

- Circle your final answers in the space provided; show your work only on the pages provided.

- 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. The quiz is 50 minutes long.

1	/25
2	/25
3	/20
4	/30
Total	/100

1. [**25 pts**] Consider the following active circuit with voltage input V_{in} and voltage output V_{out}. You may assume that the op-amp is ideal.
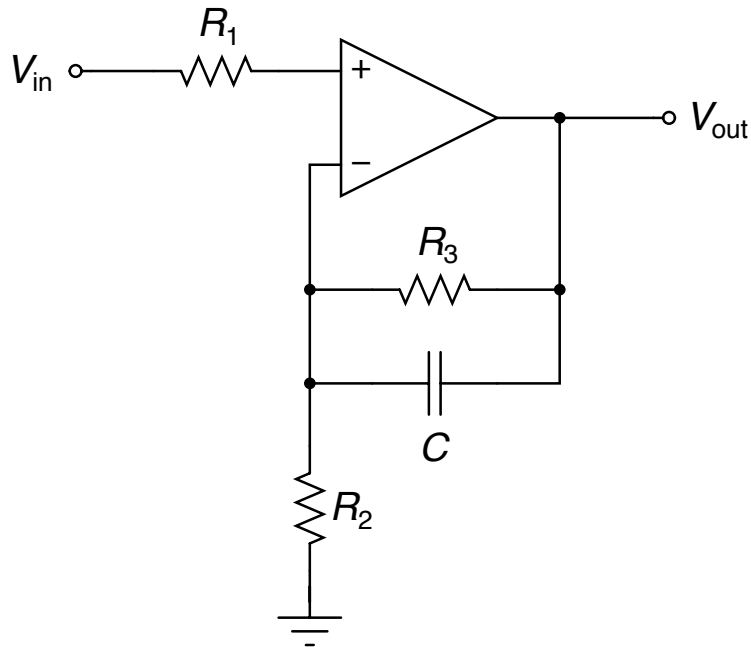

a. Derive the transfer function $H(j\omega) = V_{out}(j\omega)/V_{in}(j\omega)$. [10 pts]

b. Identify the pole(s) and/or the zero(s) of the transfer function $H(j\omega)$, and sketch the Bode plot (log amplitude and phase of $H(j\omega)$ as a function of log radial frequency ω). [8 pts]

c. Derive the input impedance $Z_{in}(j\omega)$. [4 pts]

d. Derive the output impedance $Z_{out}(j\omega)$. [3 pts]

2. **[25 pts]** The following circuit generates a voltage output V_{out} as shown below. The components OP27, LM311, 555 are assumed ideal, each with positive supply at +5 V and negative supply at GND (0 V). $R_1 = 2\ M\Omega$, $R_2 = 1\ M\Omega$, and $C = 100\ nF$. The equations for the 555 are: $T_{high} = 0.7\ (R_1 + R_2)\ C$ and $T_{low} = 0.7\ R_2\ C$.
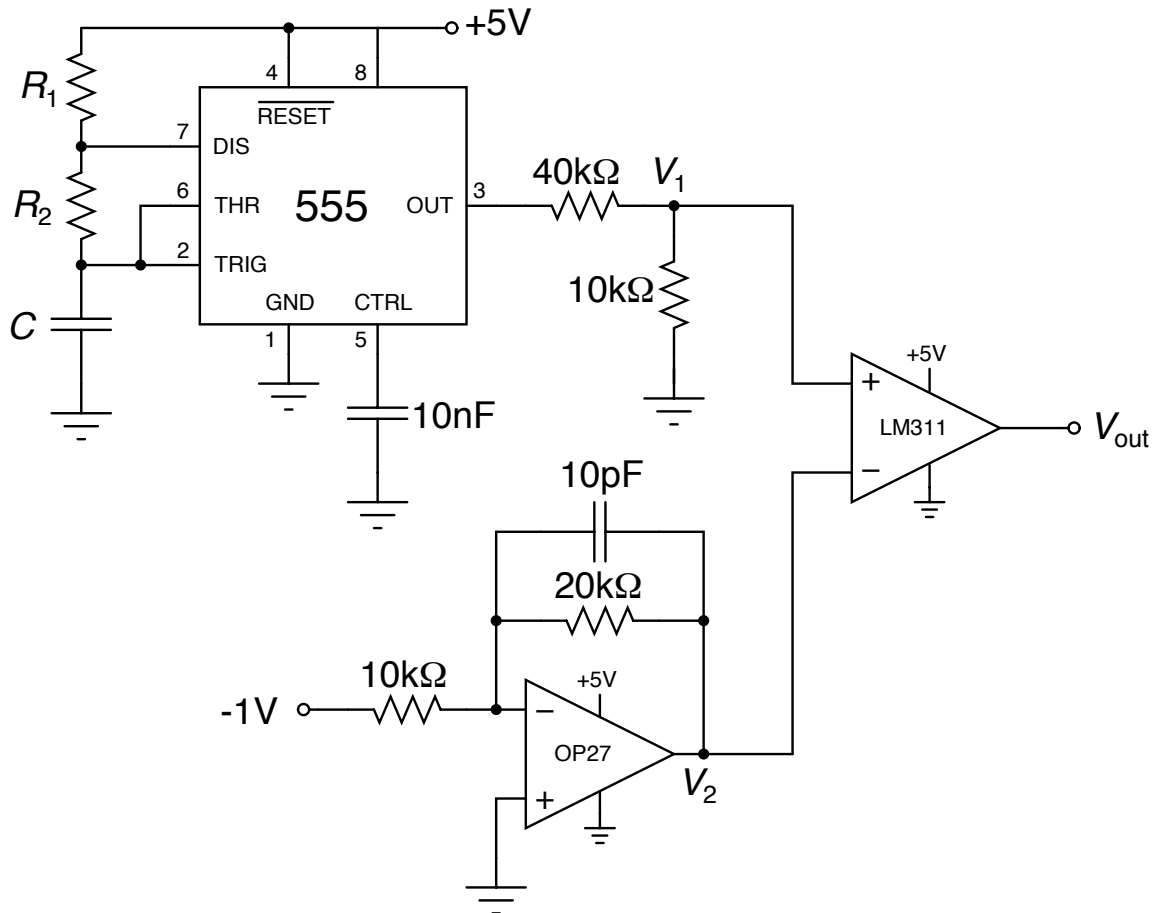
Sketch the waveforms for the voltages V_1, V_2 and V_{out} on the diagrams on the next page. Show your work below.
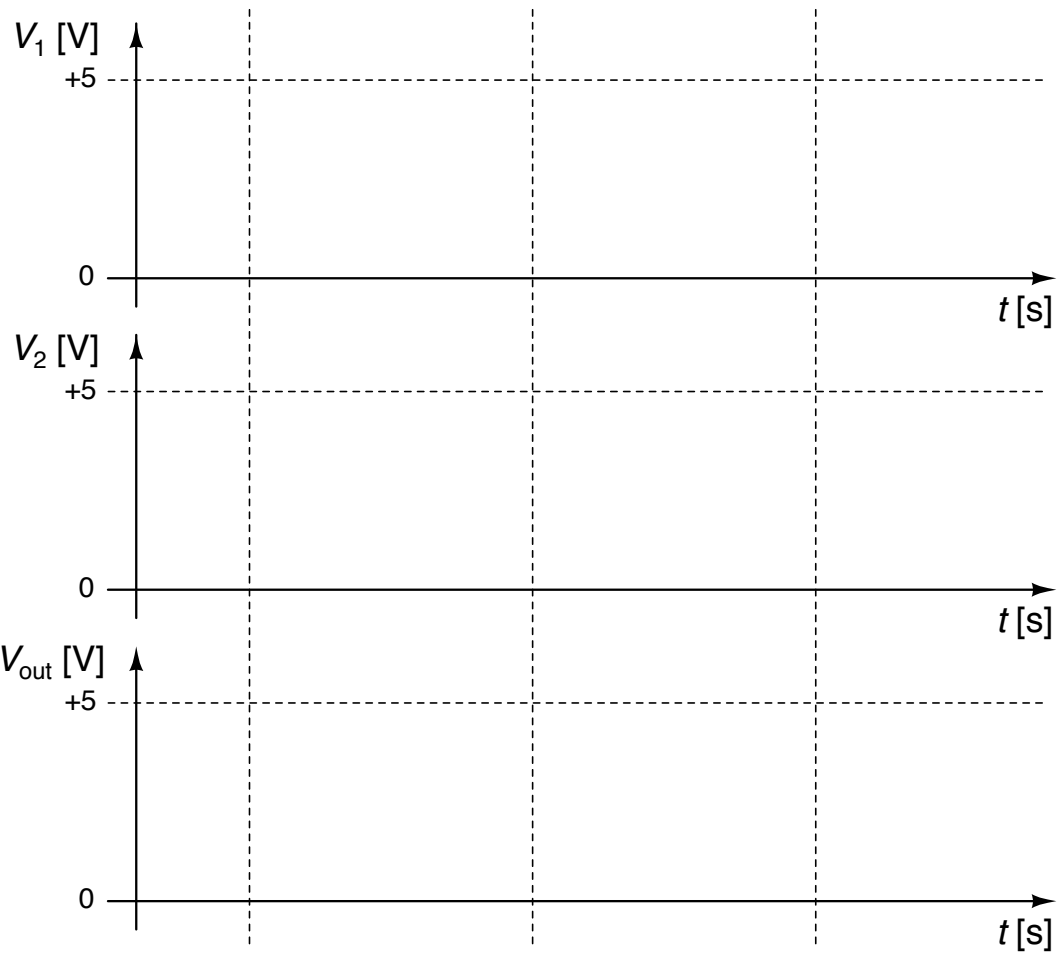
3. **[20 pts]** Circle the best answer (circle only one choice for each question a. and b., and circle TRUE or FALSE for each part of question c. and d.).

   a. [4 pts] In an active circuit using an ideal opamp, the voltage at the non-inverting input can be considered virtually identical to the voltage at the inverting input:
      i. When there is no feedback
      ii. When there is positive feedback
      iii. When there is negative feedback
      iv. When the output is saturated
      v. Through hysteresis

   b. [4 pts] The following digital circuit comprised of only NAND gates is functionally equivalent to the following gate:
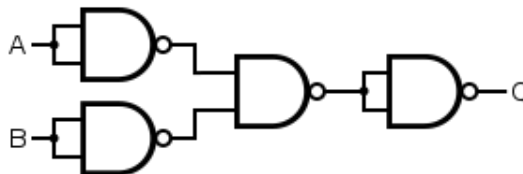
      i. AND
      ii. OR
      iii. NOR
      iv. XOR
      v. XNOR

   c. [6 pts] Indicate whether each of the following statements regarding electrocardiography are true or false:
      [TRUE / FALSE] Atrial depolarization occurs before ventricular depolarization in the ECG cycle.
      [TRUE / FALSE] The AV node triggers the onset of ECG cycle.
      [TRUE / FALSE] Ventricular repolarization produces the highest voltage amplitude in a typical ECG.

   d. [6 pts] Indicate whether each of the following statements regarding half-cell potentials are true or false:
      [TRUE / FALSE] The Ag/AgCl electrode is polarizable.
      [TRUE / FALSE] The half-cell potential is independent of ionic concentrations in the solution.
      [TRUE / FALSE] In a passive electrical circuit connected to two electrodes immersed in ionic solution, current flows from the electrode with highest half-cell potential to that with lowest.

4. [**30 pts**] Consider the circuit model for the electrode-skin interface below. The Ag/AgCl electrode has a half cell potential of +223 mV, and the ion concentrations in the gel and epidermis are given in the following table:

	Gel (outside skin)	Epidermis (inside skin)
$[Na^+]$	10 mmol/L	10 mmol/L
$[K^+]$	100 mmol/L	1 mmol/L
$[Cl^-]$	110 mmol/L	11 mmol/L
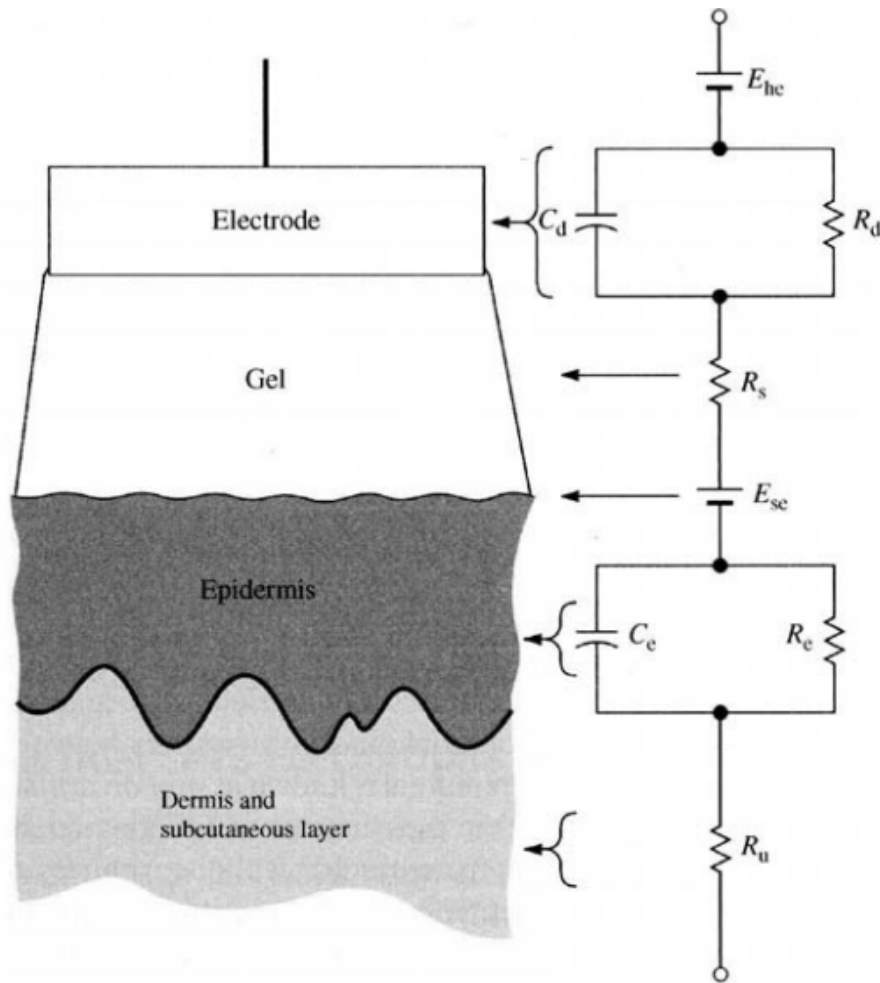
The Goldman-Hodgkin-Katz (GHK) equation:

$$E = (60mV) \cdot \log_{10} \frac{P_K[K^+]_o + P_{Na}[Na^+]_o + P_{Cl}[Cl^-]_i}{P_K[K^+]_i + P_{Na}[Na^+]_i + P_{Cl}[Cl^-]_o}$$

a. Find the Nernst potentials for Na^+, K^+ and Cl^- across the gel-epidermis interface. [4 pts]

b. Find the equilibrium potential E_{sc} across the gel-epidermis interface, assuming the boundary separating the epidermis from the gel is equally permeable to all ion types. [4 pts]

c. Derive the voltage between the electrode and the subcutaneous body at rest. [4 pts]

d. Find the general expression for the impedance $Z(j\omega)$ of the electrode-skin interface, based on the AC equivalent circuit. What is the order of the system? Identify all poles and zeros. [10 pts]

e. Sketch the Bode plot of the impedance $Z(j\omega)$ (log amplitude and phase as a function of log radial frequency ω) for $R_s = R_u = 1\ k\Omega$, $R_d = 10\ k\Omega$, $R_e = 1\ M\Omega$, $C_d = 100\ pF$, and $C_e = 1\ nF$. Indicate units and key values on your axes. [8 pts]