Neuromorphic Integrated Bioelectronics - Fall 2025

BENG 216, UC San Diego

Midterm

Due Friday November 7, 2025

- Open book, open notes. *It will be helpful to review the material covered in homework 1 through 4.* You do not need access to Cadence, Matlab, or other computational tool to complete this midterm.
- Take the midterm wherever and whenever is most convenient to you. No communication except with the instructor and TAs.
- Submit a single PDF file with all your solutions by 11:59pm on the due date on Canvas/Gradescope.

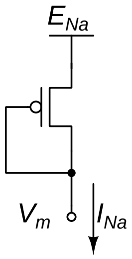
1. *Project proposal* [10 points].

   Identify a topic and formulate a proposal for a potential design project in this course. No diagrams or equations are necessary; just list the title of a proposed project for the full-custom design of a neuromorphic or bioelectronic integrated circuit and a brief (200 words or less) paragraph of text describing the problem that your proposed circuit addresses, the objective(s) to be met in the design, and your proposed approach to achieve the objective(s).

   If you have already formed a group and are proceeding with your final project, your proposal may be closely related, but formulate your project in your own words and no not copy or communicate material with your group mates. If you are not part of a group or haven't yet formulated a project, this is your opportunity to express what you would like to get out of the design experience in this course culminating in the final project.

2. *Ion channel conductance* [20 points].

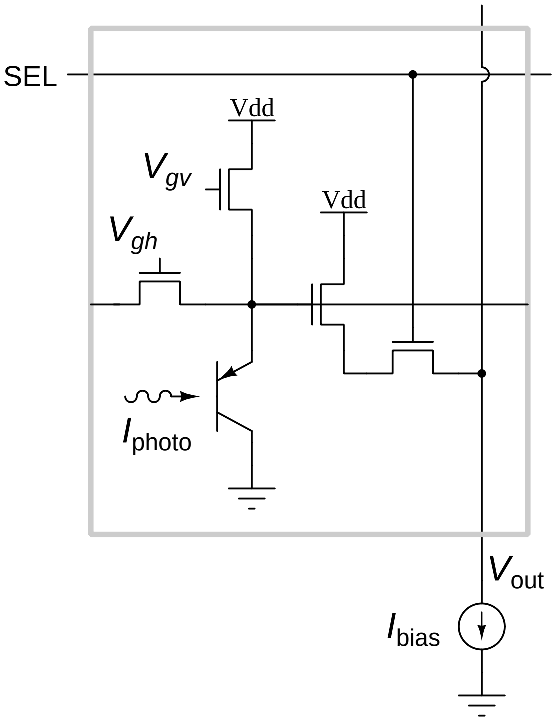
   (a) [10 points] Consider a pMOS transistor with source connected to E_{Na}, modeling a sodium ion channel with reversal potential E_{Na}. Both the drain and gate connect to the membrane. Find the subthreshold slope of the small-signal membrane conductance $g_m = dI_{Na} \,/\, dV_m$ as a function of the membrane voltage V_m for $\kappa_p = 0.6$ at room temperature, and compare with a typical subthreshold slope for a biophysical sodium ion channel conductance.

   (b) [10 points] How would you change the circuit to implement a more biophysically realistic model of a slow inactivation sodium ion channel?

3. *Contrast-sensitive silicon retina* [40 points].

   Consider the silicon retina circuit shown in the diagram below. The pixel is activated by a logic high voltage on the SEL row select line, producing an output voltage V_{out} measured on the output column line in response to light illuminating the pixel generating a photocurrent I_{photo}. The pixel connects to its left and right neighbor pixels through horizontal conductances set by V_{gh}, whereas the bipolar cell vertical conductance is set by V_{gv}.



(a) [10 points] Show that the output voltage $V_{\text{out, filtered}}$ measured when the activated pixel is illuminated at an intensity generating a photocurrent I_{photo} is given by

$$V_{\text{out, filtered}} = V_{\text{out, ref}} - \kappa_n V_{th} \ln\left(\frac{I_{\text{photo, filtered}}}{I_{\text{photo, ref}}}\right)$$

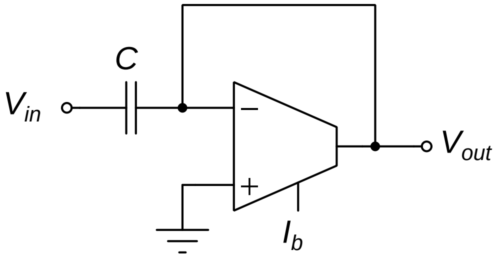
where $V_{\text{out, ref}}$ is the reference output voltage measured when the array of pixels is uniformly illuminated at a reference intensity generating a reference photocurrent $I_{\text{photo, ref}}$, and $V_{th} = kT/q$ is the thermal voltage, and $I_{\text{photo, filtered}}$ represents a spatially filtered version of the intensity.

(b) [10 points] Define the filtering characteristic in terms of the intensity profile as a function of pixel index along the horizontal axis, and the bias voltages V_{gh} and V_{gv}.

(c) [10 points] Show how to obtain a contrast sensitive image from two measurements at differing spatial filtering settings, *i.e.*, at two different sets of bias voltages V_{gh} and V_{gv}. Explain the operation of the contrast-sensitive imager based on the sequence of measurements and the combining of the results, and quantify the contrast kernel obtained.

(d) [10 points] How is the output affected by transistor mismatch caused by imprecision in the fabrication process? How is it affected by variations in temperature? Explain.

4. *Gm-C highpass filter* [30 points].



(a) [10 points] Consider the Gm-C first-order highpass filter circuit shown to the right. Draw the transistor-level circuit schematic of a differential-input, single-ended output operational transconductance amplifier (OTA) that implements the Gm cell with a bias current I_b as shown.

(b) [10 points] Using your OTA design, find the DC gain and the cut-off frequency of the highpass filter.

(c) [10 points] Estimate the power consumption of the highpass filter using your design. What is the ratio of the power over the bandwidth? Interpret what you find.