Neuromorphic Integrated Bioelectronics - Fall 2026

BENG 216, UC San Diego

Midterm

Due Friday November 6, 2026

- 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.

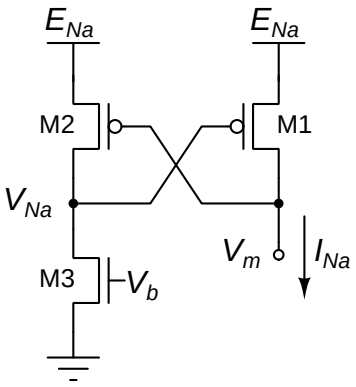
1. *Project proposal* [10 points].

   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).

   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. What you propose here may be closely related to the final design project you will be doing with your group; however, you must formulate your project in your own words and not copy or communicate material with your group mates. And you are free to propose something here entirely different from your group's final project.

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

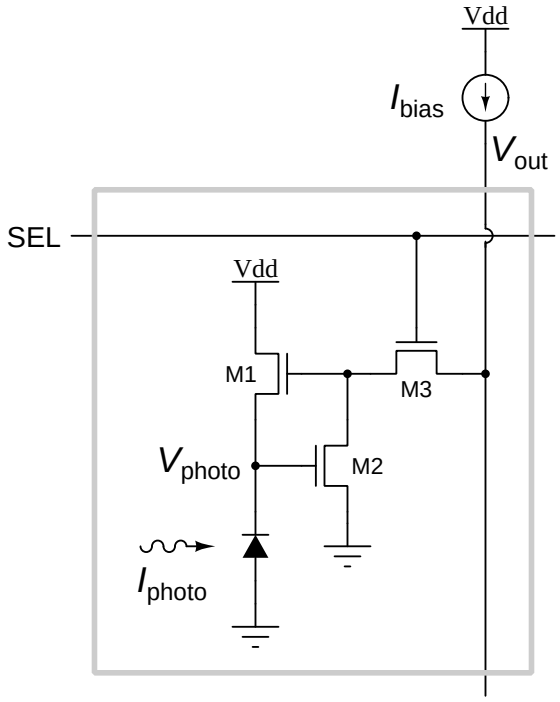
   (a) [10 points] Consider the circuit shown on the right implementing a sodium ion channel with reversal potential E_{Na}. Transistors M2 and M3 form a pMOS inverting amplifier with input at membrane potential V_m and with output on the gate of transistor M1 at potential V_{Na}. Does this provide activation or inactivation of sodium current I_{Na} with rising membrane potential? With identical sizing W/L of all transistors, find the threshold of the membrane potential V_m at which the sodium current gets activated/deactivated in terms of the amplifier bias voltage V_b. Here you may assume all transistors have zero drain conductance in saturation, so that the pMOS inverting amplifier M2-M3 has infinite voltage gain.



   (b) [10 points] Now consider that the pMOS inverting amplifier M2-M3 has a finite voltage gain A. 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 at room temperature for $\kappa_p = 0.6$ and $A = -10$. Compare with a typical subthreshold slope for a biophysical sodium ion channel conductance.

3. *Active pixel sensor* [40 points].

Consider the active pixel sensor (APS) circuit shown in the diagram below, implementing a simplified silicon model of the retina with with logarithmic encoding of light intensity. 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}.



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

$$V_{\text{out}} = \frac{1}{\kappa_n}\left(V_{\text{photo}} + V_{th}\,\ln\left(\frac{I_{\text{photo}}}{I_n\frac{W}{L}}\right)\right)$$

where V_{photo} is the voltage across the photodiode, $V_{th} = kT/q$ is the thermal voltage, and κ_n, I_n, W and L are the usual process and layout dependent parameters which are assumed identical for all nMOS transistors.

(b) [10 points] Show that the voltage across the photodiode V_{photo} is independent of the photocurrent I_{photo}. Write V_{photo} in terms of the bias current I_{bias}.

(c) [10 points] Now consider that the pixel is deactivated by a logic low voltage on the SEL row select line. What happens to V_{photo}? Do the unselected rows of pixels consume power? Explain.

(d) [10 points] Sketch the cross-section through the silicon wafer for a possible realization of part of the circuit showing the photodiode and the nMOS transistor M1 connected to it, along with the GND and Vdd supplies. Could the anode of the photodiode be merged with the source of M1? Explain the merits of doing so.

4. *Source follower G_m-C filter* [30 points].

   (a) [10 points] Consider the G_m-C filter circuit shown to the right, where the transconductance G_m is realized by an nMOS source follower driven with constant bias current I_b. Show that the small-signal response of the filter circuit, for small variations v_{in} and v_{out} in input and output voltage, is given by

   $$C\frac{dv_{out}}{dt} = G_m\left(\kappa_n v_{in} - v_{out}\right)$$

   Find the transconductance G_m as a function of the bias current I_b and the thermal voltage V_{th}.

   (b) [10 points] What type of filter is this? Find the DC gain and the cut-off frequency of the filter.

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

