

EE 591L – Neuromorphic Analog VLSI

Project 4 – Differential Pairs and OTAs

Objective

To understand the operation of differential pairs and how they are used to construct operational transconductance amplifiers.

Simulation Models

As will be standard with all projects involving circuit simulations, we will be using the 0.5 μm EKV model for MOSFETs because it correctly handles both subthreshold and above threshold currents very well. With a 0.5 μm process, the supply voltage (V_{dd}) is 3.3V.

Part 1 – Differential Pair

Simulate a standard nFET differential pair. You may use any transistor sizes you desire as long as the maximum dimension does not exceed 100 μm (and may be much smaller) and $W > L$. The input transistors must be symmetric, but the current-sink transistor may have different dimensions. For all parts of this project, the input transistors must have a larger W/L ratio than any other transistors in the circuits you are analyzing (this will become important for the following project). Connect the drains of the input transistors to V_{dd} .

Simulate input voltage sweeps ($V_{in} = V_1 - V_2$) of the differential pair for three different values of subthreshold bias/tail currents. You may use either a current source that is mirrored into the current sink of the differential pair or simply a voltage on the gate of the current sink.

Plot all the drain currents of the two input transistors for each of the three bias currents on the same plot. Also, plot all three differential output currents ($I_{out} = I_1 - I_2$), on a separate plot.

- What is the transconductance for each of the three bias currents?
- What is the range of input voltages over which the transconductance stays approximately linear? Does this change with bias current? Why or why not?
- When changing the bias current, specifically what changes in the output current, and what stays the same.
- What is the maximum current that the differential pair can source/sink?
- Comment on anything else that seems interesting.

Part 2 – Operational Transconductance Amplifier

Simulate a standard five-transistor operational transconductance amplifier (OTA) using the differential pair from the previous section as a basis for the OTA. Simulate the DC characteristics of the OTA in two ways.

- Current output
- Voltage output

For the current-output simulation, measure the current through a DC voltage source at the output. Symmetrically sweep $V_{in} = V_1 - V_2$ with a subthreshold bias/tail current.

- What voltages can the output voltage have?
- What is the G_m of this device? Does it agree with what you would expect?
- How does the G_m change with respect to changing the bias current?

For the voltage-output simulation, let the output node float (do not connect it to anything) and measure the output voltage while sweeping V_1 and holding V_2 constant. Repeat for two more values of V_2 such that the V_{\min} effect is clearly demonstrated.

Part 3 – Wide-Range OTA

Create a SPICE subcircuit (.SUBCKT) for a wide-range OTA. The gain of this OTA must be at least 1000. You will use this OTA subcircuit in subsequent projects.

Repeat the current-output and voltage-output simulations from Part 2. How does this wide-range OTA differ from the five-transistor version?

Turn in an electronic copy of this subcircuit (it can be included in a SPICE deck). Also, print out a copy of JUST the .subckt. This does not count towards your four-page limit on the reports (you can put this in an appendix).

Part 4 – Unity-Gain Follower

Use your wide-range OTA subcircuit to create a unity-gain follower circuit. Perform a DC sweep of the input voltage and measure the output voltage. What is the exact gain of this circuit, and how closely does it agree with the theoretical value of the gain (remember, the gain of this buffer will be dependent on the gain of the OTA).