Lab 3 – Digital-to-Analog Conversion

CSE 3323 – Electronics for Computer Engineering

In this lab, we will design and build a **DAC Converter** (4-bit input, 0-5V output) standing alone, directly connected to a load, using an Op-Amp voltage follower, and then finally "combining" the output with a signal generator. First built on the **breadboard** and then each student will **solder** a working prototype PCB (protoboard).

Students work in pairs (except one group of 3) during lab time.

Each student will submit a PDF lab report (due by one week) regarding the lab measurements and the circuits built. Other required files are detailed on the last page.

What you specifically should include in your lab report is indicated in RED throughout this document. You should also elaborate to discuss the procedure of each individual circuit AND discuss your results/measurements/thoughts.

Lab reports are **individual work** but include your lab partner's name in your report.

Tools Used:

- **Digital Multimeters**
  - Thsinde 18B+ (yellow)
  - Mastech MS8268 (green)
- **Current-Limited Power Supplies**
  - DC Power Supply, Yihua YH-302D
  - DC Regulated Power Supply, Tekpower TP3005T
- **Digital Oscilloscope**
  - Siglent SDS 1202X-E, 200MHz
- **Signal Generator**
  - Siglent SDG1025, 25MHz, 125 MSa/s
- **Wire cutters/strippers, probes, banana connectors, alligator clips, jumper wires, etc.**

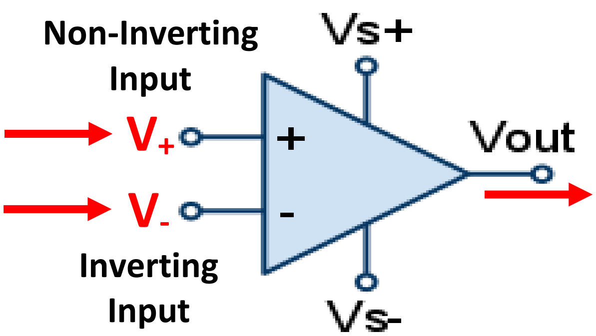
Components Used:

Note: Mouser part numbers below link to their datasheets and specs

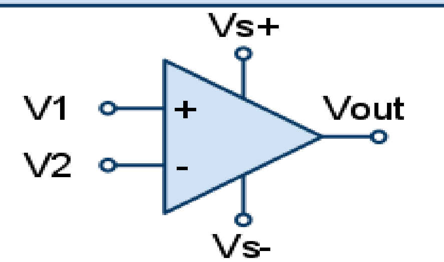
- 100kΩ Resistor: 660-MF1/4CC1003F
- 200kΩ Resistor: 660-MF1/4CC2003F
- Operational Amplifier IC (2-channel Op-Amp): 579-MCP6002-I/P
- DIP Socket (8 pin): Amazon Link
- Screw Terminal (2-Pole Connector): Amazon Link
- SPDT Slide Switch: Amazon Link
- Prototyping PCB (Solderable Circuit Board): Amazon Link

Directed Part of Lab:

1. **Op-Amp Review and Discussion** (no breadboarding, only whiteboard/discussion)

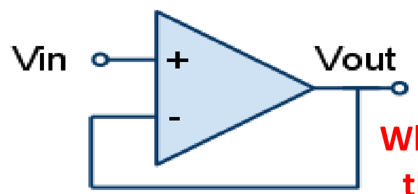


Voltage Comparator



$$V_{out} = \begin{cases} V_{s+} & V1 > V2 \\ V_{s-} & V1 < V2 \end{cases}$$

Voltage Follower



Why do this?

Vout = Vin

TWO BIG RULES (LAWS)

1. **No current flows into the inputs**
2. **With feedback (loop) the Op-Amp <u>tries</u> to make the two inputs equal to each other**

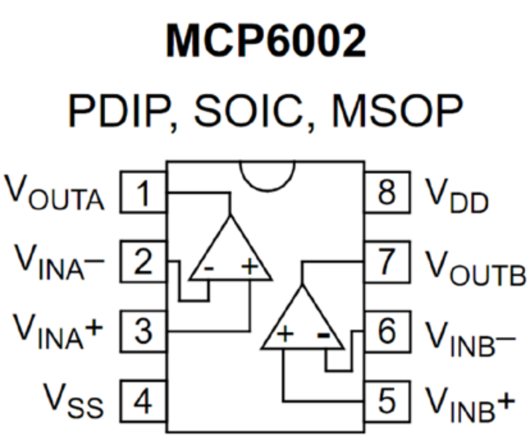
$$V_+ = V_-$$

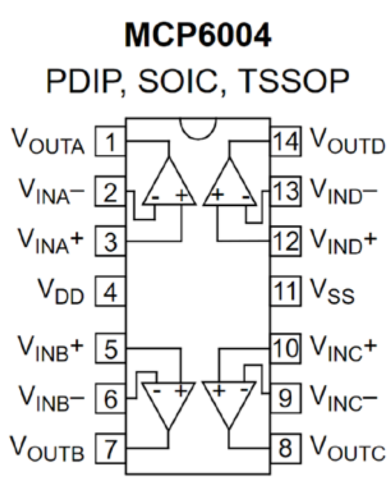
$$\Delta V = V_+ - V_- = 0$$

No Loop (no feedback) → $V_{out} = A_{OL}(V_+ - V_-)$

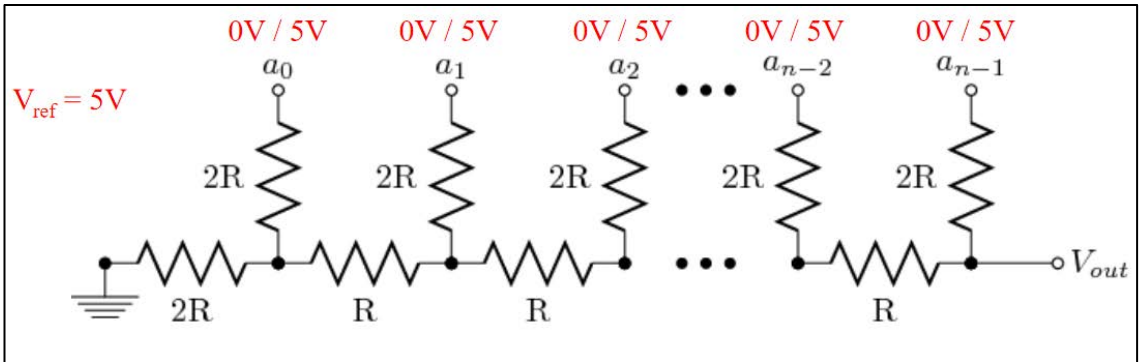
A_{OL} = Open Loop Gain

A_{OL} >> 100k (Ideally ∞)





2. **Digital-to-Analog Converter** (no load)
   a. Build a 4-bit **R-2R Resistor Ladder DAC** using bit switches as the "$\mathbf{a_n}$" inputs (use slide switches to create your own bit switches, 0V or 5V)
   b. Measure the $\mathbf{V_{out}}$ for all 16 input combinations (0b0000 → 0b1111)
      i. Table and graph all of these measurements
   c. Using the theoretical equation for a DAC R-2R Ladder do the following:
      i. Table the **Calculated Ideal** $\mathbf{V_{outs}}$ vs. the **Actual Measured** $\mathbf{V_{outs}}$
      ii. Also calculate overall error using 2 different measures of difference:
         1. Mean Absolute Error $MAE = \frac{\sum_{i=1}^{n} |V\_Calc_i - V\_Meas_i|}{n}$
         2. Root-Mean-Square Error $RMSE = \sqrt{\frac{\sum_{i=1}^{n} (V\_Calc_i - V\_Meas_i)^2}{n}}$
         3. What do these error values indicate to you?
   d. Draw your circuit (SCH in EAGLE) to include in your report and describe in your report how this circuits operates (how do all of the "$\mathbf{a_n}$" inputs influence the value of the voltage output?)



$$\mathbf{V_{out} = V_{ref} \times \frac{\mathit{VAL}}{2^N}}$$

Individual Part of Lab:

3. **Digital-to-Analog Converter** (with load)
   a. Repeat parts (2: a, b, c) with a 100kΩ resistor load connected between $\mathbf{V_{out}}$ and **0V**
   b. Are your measurements different now? Why or why not?
   c. Now use an Op-Amp as a "voltage follower" placed between the $\mathbf{V_{out}}$ and the 100kΩ resistor load and repeat parts (2: a, b, c) again
   d. Are these measurements different now? Why or why not?
   e. Draw these new circuits (SCH in EAGLE) to include in your report

4. **Digital-to-Analog Converter** (with the signal generator)
   a. Using the signal generator, generate a **1kHz** sine wave with a **V_{PP} = 4V**
   b. Take your DAC with the new voltage follower **V_{out}** and "sum it" with the output waveform from the signal generator
   c. Use two 100kΩ resistors for the simple summing circuit
   d. The "combined" output should then be fed into its own voltage follower (the Op-Amp IC has two separate Op-Amps inside, MCP600**2**)
   e. Observe and record the DAC's direct **V_{out}** with a multimeter and observe the combined summed voltage output (offset sinewave) on the oscilloscope
   f. Discuss your observations and discuss how this circuit operates
   g. Draw this circuit (SCH in EAGLE) to include in your report

5. **Soldering a Prototype of the Full DAC Circuit** (Individual Work, not pairs)
   a. You will solder a prototype of the same circuit built in part (4). After it is completely finished and demoed successfully to the TA or instructor, you will submit the soldered board so the layout and soldering work can be graded later. You may include photos of your board in your report, however it is not required. You will be given back the soldered board to keep once it's graded.
   b. Total Number of Components for this Soldered Circuit:

1: Prototyping PCB	4: Pin Headers
5: 100 kΩ Resistors	1: Screw Terminal Connector Pair
5: 200 kΩ Resistors	1: MCP6002 Op-Amp
4: SPDT Switches	1: 8-Pin DIP Socket

   c. Use the **Screw Terminal Pair** for you +5V and 0V power connections
   d. Use the **4 Pin Headers** for:
      i. Signal Generator IN
      ii. Signal Generator GND
      iii. Oscilloscope Vout
      iv. Oscilloscope GND

Additional Submission Details:

ZIP up all 3 of these files into a single zip file and upload to Blackboard

1. **Lab Report (.pdf)**
   a. Include all of the details indicated above in RED
2. **Schematic File (.sch)**
   a. Using EAGLE, draw the final full circuit from **Part (4)**
   b. Including all the resistors, power/input/output connections, slide switches, etc.
   c. Include part numbers and component values if applicable
   d. Include text labels to help explain and indicate "what your circuit does"
3. **PCB File (.brd)**
   a. Convert your .SCH file into a PCB
   b. Arrange all the components in a logical and efficient manner
   c. Keep the overall blueprint (size) of the board small and tight
   d. You may use either single or double layer routing