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**Online Lab 5: Operational Amplifier**

**INTRODUCTION:**

The purpose of this lab is to familiarize you with the properties and operations of the operational amplifier. You will use the 741 op amp to first implement an inverting amplifier. Based on a summing amplifier (which has a very similar working principle as the inverting amplifier), you will build a 4-bit digital-to-analogue converter (DAC). The DAC converts a binary input into an analogue output. In the final, stage will add a comparator using the remaining op amp to drive an LED at the output when the DAC input exceeds a minimum value.

**Note that you will be writing your lab report based on this lab experiment.**

**Learning Outcomes:**

* Simulate the implementation of a inverting op amp circuit on a breadboard
* Relate the theory of an ideal op amp to real op amp circuits
* Implement a DAC using op amps on a breadboard
* Implement a comparator using op amps to drive an LED at the output

**REQUIRED MATERIALS IN TINKERCAD:**

Hardware:

1. Digital multimeter
2. Power supply

Components:

1. 741 operational amplifier
2. Resistors
3. DIP Switch SPST x 4
4. LED
5. Breadboard

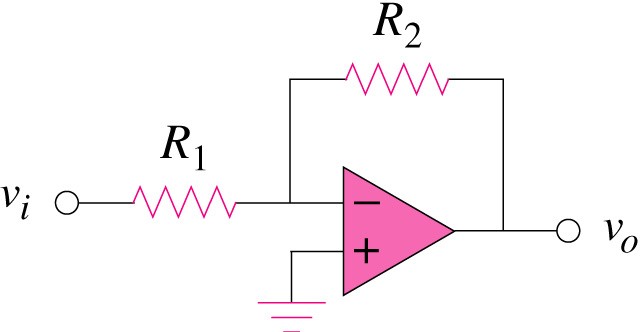
**LAB TASK 1: Basic Inverting Amplifier**

Write down the closed-loop gain expression of a inverting amplifier (Fig 1) in the space below:

**Inverting amplifier:** Closed-loop Gain

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Fig 1: Circuit schematic of a inverting amplifier Pin diagram of 741 op amp

* 1. Choose two resistors to achieve a gain of about 4.

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* 1. Build the inverting amplifier circuit on your breadboard using 741 op amp.
  2. Use ±5V as the supply voltages to the operational amplifier.
  3. Simulate voltage output *v*o as you increase *v*i from – 1.8V to 1.8V in steps of 0.2V.
  4. Record your data in **Table 1**. **/ 1**

Shape

Description automatically generated**Table 1:** Record of measurements for inverting amplifier with gain of around 4

|  |  |
| --- | --- |
| ***v*i** | ***v*o** |
| -1.8V | **4.90V** |
| -1.6V | **4.90V** |
| -1.4V | **4.91V** |
| -1.2V | **4.80V** |
| -1.0V | **4.00V** |
| -0.8V | **3.20V** |
| -0.6V | **2.40V** |
| -0.4V | **1.60V** |
| -0.2V | **0.80V** |
| 0 | **0** |
| 0.2V | **-0.80V** |
| 0.4V | **-1.60V** |
| 0.6V | **-2.40V** |
| 0.8V | **-3.20V** |
| 1.0V | **-4.00V** |
| 1.2V | **-4.80V** |
| 1.4V | **-4.91V** |
| 1.6V | **-4.90V** |
| 1.8V | **-4.90V** |

* 1. Simulate the current from the input source using the multimeter when *v*i = 0.2V, and hence determine the input resistance of the circuit.

Input current when *v*i = 0.2V: *i*in =

Input resistance (of circuit): *v*i/*i*in = **\_\_\_\_\_\_\_ / 1**

* 1. Plot your recorded data in Table 1 on Excel.
  2. Determine the measured gain from the slope of the linear best fit line for *v*o vs. *v*i.

Slope of the linear best fit line: -**3.3416**

Is it similar to the gain estimated in task 1.1? ☑ **Similar** ☐ Different **\_\_\_\_\_\_\_ / 1**

* 1. The reason that the graph is flat close to +5V and -5V is due to: **\_\_\_\_\_\_\_ / 1**

cannot exceed either of the supply voltages which is +5V and -5V in this task.

Hence if and , cannot be higher than 5V or lower than -5V.

* 1. Explain by using a sketch how the *v*o vs. *v*i graph will change if the value of R1 is halved while R2 is kept the same. Use the blank space beside Table 1 to sketch your curve.

Slope will be ☐same ☑ **double** ☐ half

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**LAB TASK 2: Digital-to-Analogue Converter (DAC) based on Op Amp**

* 1. **Switch off** the voltage supply to the op amp first. Then begin to build the circuit in Fig 2. We will use a 4-channel SPST switch to provide us with the 24 = 16 different input binary combinations.

In this lab task, you have full freedom in the choice of resistor values (based on the lecture notes). The only recommendation is to choose Rf = R1 which might help to simplify your solution.

Diagram, engineering drawing

Description automatically generated

Fig 3: Schematic of DAC for Lab Task 2

Table 2: Selected values of resistors for proposed DAC

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Rf** | **R1** | **R2** | **R3** | **R4** |
|  |  |  |  |  |

**/ 1**

* 1. Set Vh to -1V. This value represents logic high in the input combination. Use ±Vs values similar to Lab Task 1.
  2. Measure Vo for all 16 input combinations allowed by the switch. Record your readings in Table 3.

|  |  |  |
| --- | --- | --- |
| **Binary combo** | **Value in decimal** | **Measured Vo** |
| 0000 | 0 | 0 |
| 0001 | 1 | 0.125V |
| 0010 | 2 | 0.250V |
| 0011 | 3 | 0.375V |
| 0100 | 4 | 0.500V |
| 0101 | 5 | 0.625V |
| 0110 | 6 | 0.750V |
| 0111 | 7 | 0.875V |
| 1000 | 8 | 1.00V |
| 1001 | 9 | 1.13V |
| 1010 | 10 | 1.25V |
| 1011 | 11 | 1.37V |
| 1100 | 12 | 1.50V |
| 1101 | 13 | 1.62V |
| 1110 | 14 | 1.75V |
| 1111 | 15 | 1.87V |

**Table 3: Digital-to-analogue conversion measurement results**

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**LAB TASK 3: DAC with Comparator Output**

In this final part of the lab, you will extend the circuit from Lab Task 2 to have an LED alarm that lights up when the input combination exceeds a minimum set value. This can be achieved using a comparator which compares the output of the DAC in Fig 2 to a reference voltage (Vref). The output of the comparator saturates either towards the negative or positive supply depending on the relative voltage difference between the inverting and non-inverting terminals.

Your task here is to add an additional stage to your DAC circuit from Lab Task 2 with the function of driving an LED when the input combination of the DAC ***reaches/exceeds*** a binary value of 1-0-0-0.

A suggested solution is shown in Fig 3. You will need to decide on the required value of Vref and how to apply it. Use the other op amp that is unused to implement the comparator. This is an extension of the Lab Task 2 and should not need to dismantle the DAC you have built in Lab Task 2.

# Vref =

Diagram

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Fig 3: Suggested comparator circuit and LED connection with respect to DAC output (Vo)

**TinkerCAD links:**

**Task 1:**

<https://www.tinkercad.com/things/gMHu6DYLe6b-task-1/editel?sharecode=BW9zwigGJtuJxtNx31WzWHVRRTTruhs315anFu0VQQM>

**Task 2:**

<https://www.tinkercad.com/things/3ELv1AIn38B-task-2/editel?sharecode=Efe515y7Hw5tHIu3XoravoLHpd5H7VesUm__rty09N4>

**Task 3:**

<https://www.tinkercad.com/things/e0wpygE4tU7-task-3/editel?sharecode=Xra8jbMVs7CMkQMTDeipFBFOIy5lCk8vsl0lU1-jLg>

## Upload the solution to the CANVAS submission link on time

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