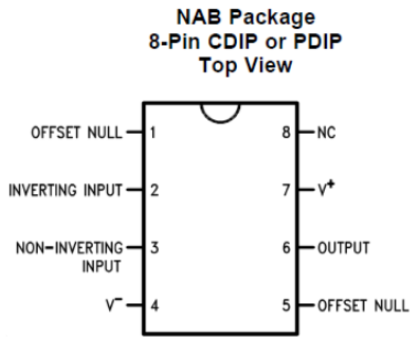
EE 230 – Analog Lab - 2021-22/I (Autumn)

Experiment 6: Opamp Amplifiers

(Ver 2, Aug 30,2021)

Part A – LM 741 Operational Amplifier



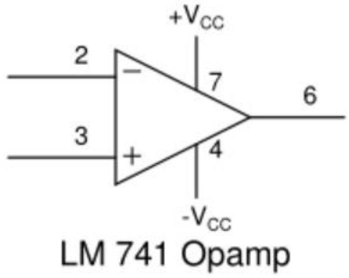


Fig.1 Pinout diagram of the LM 741 Opamp

Pin out of the LM 741 general purpose opamp is shown in Fig.1. All the experiments in this handout will performed using LM741.
Basic parameters (nominal values) of the LM741 Opamp:

DC Open-loop gain : 2×10^5 V/V	Open-loop cut-off frequency : 5 Hz
Open-loop input resistance : 2 MΩ	Open-loop Output resistance : 75 Ω
Slew rate : 0.5 V/μs	CMRR (= A_d/A_{cm}) : 90 dB

In this experiment we shall study the major single-opamp amplifier configurations, viz. inverting amplifier, non-inverting amplifier and the difference amplifier. We shall use LM 741 general purpose opamp for these amplifier configurations and their applications.

Part B - Inverting Amplifier

2.1 Inverting Amplifier Configuration

The inverting amplifier configuration is possibly the simplest amplifier configuration and is used in a number of applications. We shall study a few examples to bring out its uniqueness.

2.2 Inverting Amplifier (as a Voltage Amplifier)

Circuit Values: +Vcc = +12 V, - Vcc = -12 V; R_1 = 10 kΩ, R_F = 100 kΩ

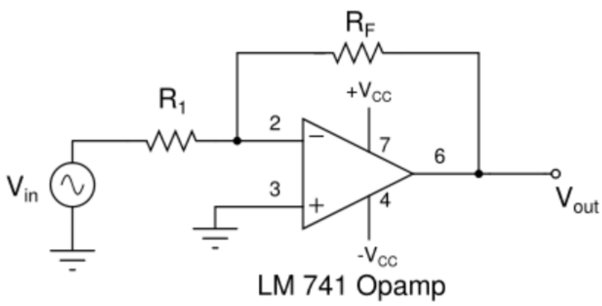


Fig.2 Inverting amplifier

Questions:

i) What are the unique features of the inverting amplifier as a voltage amplifier (other than the phase inversion between input and output signals)?

ii) What are the limitations of the inverting amplifier configuration when used as a voltage amplifier?

iii) For what type of applications are the inverting amplifier configuration well suited? Justify your answer.

2.3 A Special Inverting Amplifier (with Higher Input Resistance and Voltage Gain)

Circuit diagram of a special type of inverting amplifier is shown in Fig.3. The voltage gain expression is given by: $\frac{V_{out}}{V_{in}} = \frac{-R_2}{R_1}\left(1 + \frac{R_4}{R_2} + \frac{R_4}{R_3}\right)$

(Ref: Sedra & Smith: Microelectronic Circuits, Chap 2, page 70).

Circuit values: +Vcc = +12 V, - Vcc = -12 V; $R_1 = R_2 = R_4$ =1 MΩ, R_3 = 120 kΩ

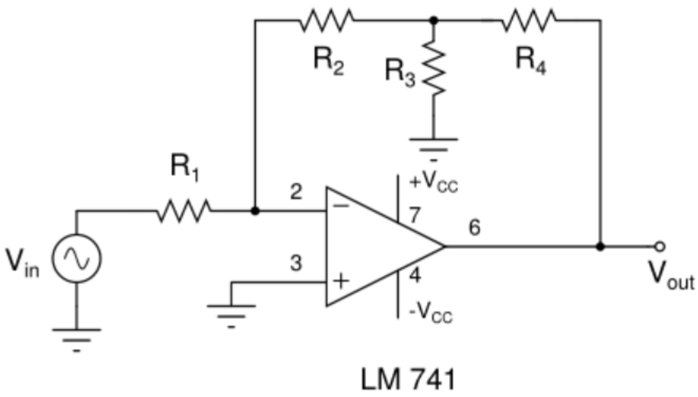


Fig.3 A special type of inverting amplifier

Questions:

i) What are the advantages of the above amplifier circuit (name two major advantages) over the standard inverting amplifier?

2.4 The Weighted Summer

Another useful application of the inverting amplifier configuration is the weighted summer, shown in Fig. 4. The weighted summer output can be written as: $V_{out} = -\left(\frac{R_F}{R_1}V_1 + \frac{R_F}{R_2}V_2 + \frac{R_F}{R_3}V_3\right)$.

Circuit values: +Vcc = +12 V, - Vcc = -12 V; $R_1 = R_2$ = 6.8 kΩ, R_F = (6.8 kΩ+ 6.8 kΩ)

(Expt circuit used only V_1 and V_2, where V_1 = a unipolar sinewave (Max 5 V and Min 0 V); V_2 = -2.5 V dc)

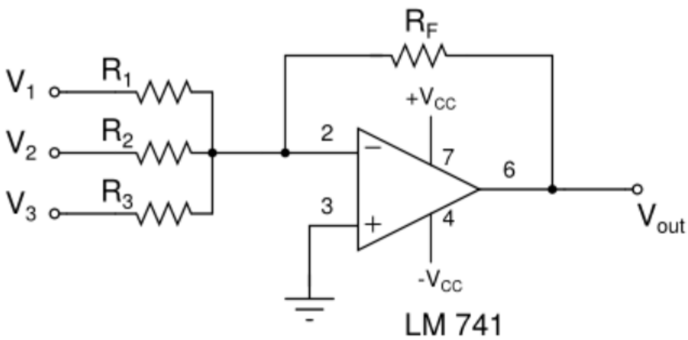


Fig.4 The weighted-summer circuit

The weighted summer is very useful in combining different signals, say for example to add dc offset to a signal. Resistors R_1, R_2 and R_3 can be chosen as required. For a given V_1, V_2 or V_3, their individual weightages can be increased by decreasing the corresponding resistor values.

Part C – Non-inverting Amplifier

3.1 Non-inverting Voltage Amplifier

Circuit diagram of the non-inverting voltage amplifier is given in Fig. 5. This circuit is the most preferred one and commonly used in voltage amplifier circuits.

Circuit Values: +Vcc = +12 V, - Vcc = -12 V; R_1 = 10 kΩ, R_F = 100 kΩ

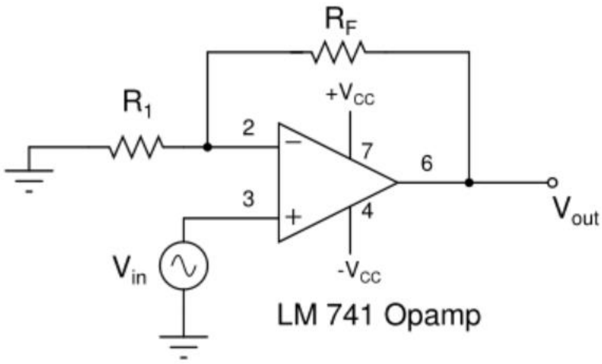


Fig.5 The non-inverting voltage amplifier

This circuit is quite different from the inverting amplifier. For the same values of R_1 and R_F, the magnitude of the voltage gain is marginally higher compared to the inverting amplifier.

Questions:

i) What are the unique features of the non-inverting amplifier (other than input and output waveforms having the same phase)?

ii) For what application is the non-inverting amplifier configuration best suited? Justify your answer.

iii) What are the limitations of the non-inverting amplifier configuration?

Part D – Difference Amplifier

4.1 Difference Amplifier

The third major single opamp amplifier configuration is the difference amplifier. In order for the circuit to work as a difference amplifier with a differential gain, $A_d = R_4/R_3$, the following condition has to be satisfied: $(R_4/R_3) = (R_2/R_1)$.

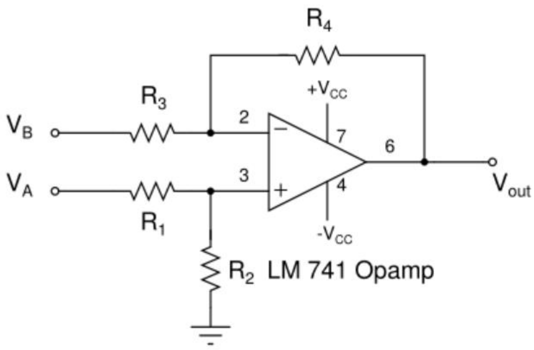


Fig. 6 Single-opamp difference amplifier

4.1.1 Measurement of Common-mode Gain A_{cm}

A very important parameter of the difference amplifier is its common-mode gain, A_{cm}.

Circuit values: +Vcc = +12 V, -Vcc = -12 V; $R_1 = R_3 = 10$ kΩ, $R_4 = 100$ kΩ, R_2 = (68 kΩ + 50 kΩ pot).

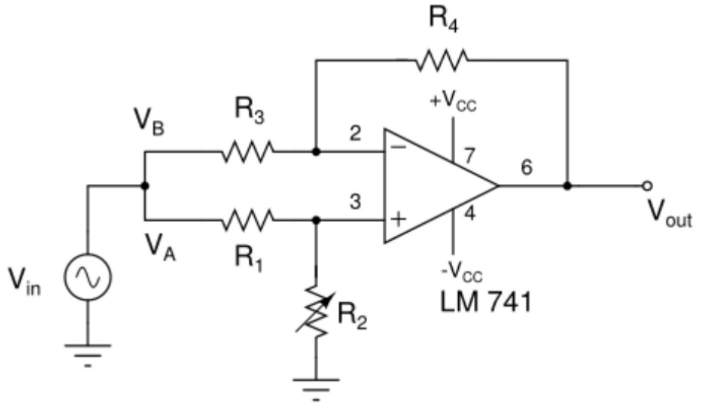


Fig.7 Setup for measuring A_{cm} of the difference amplifier

<u>Measurement of A_{cm}</u>:

A_{cm} being a very small quantity, special care must be exercised to measure it. Connect V_A and V_B inputs to a mid-frequency sinusoidal signal with the largest possible amplitude, for example 10 sin ωt V (f = 1 kHz). Assuming $(R_4/R_3) = (R_2/R_1)$, V_{out} should have been ideally zero (i.e. $A_{cm} = 0$). However, due to non-zero A_{cm}, V_{out} will be very small, but not zero. Adjust R_2 (the 50 kΩ pot) till V_{out} reaches the lowest possible value. At this point, measure V_{out} and calculate: $A_{cm} = V_{out}/V_{in}$.

<u>Questions:</u>

i) What are the unique features of the difference amplifier which are useful in field applications?
ii) What are the limitations of the single-opamp difference amplifier? Name two such limitations.

4.2.1 Application 1 – I-V Characteristics of a Zener Diode

We shall use the difference amplifier circuit for a very useful application, viz. to measure the i-v characteristics of Zener and other types of diodes.

<u>Circuit values</u>: +Vcc = +12 V, -Vcc = -12 V; $R_1 = R_2 = R_3 = R_4 = 10$ kΩ, R = 1 kΩ.
Zener diodes: 3.6 V and 5.6 V

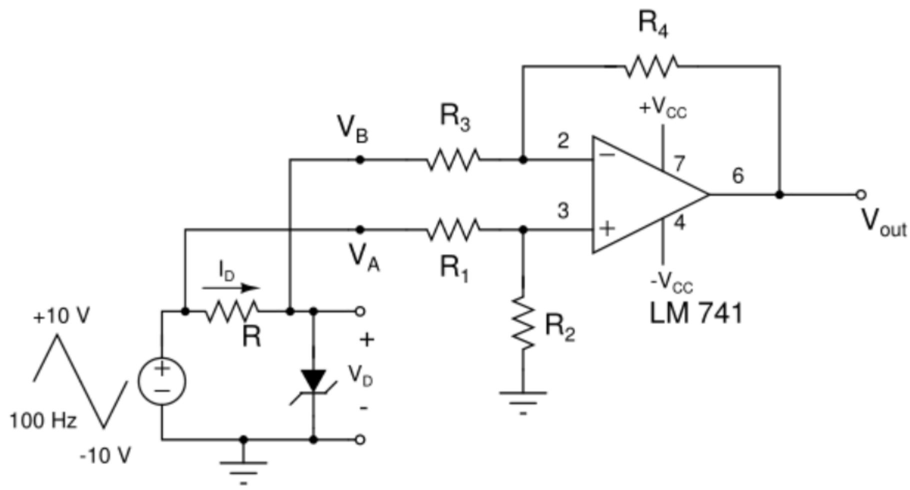


Fig. 8 Setup for measuring the i-v characteristic of the Zener diode

With the circuit values as given above, the difference amplifier output $V_{out} = (V_A - V_B) = I_D.R$. Since $R = 1\ k\Omega$, the magnitude of V_{out} (in volts) will be the same as I_D (in mA). We shall use the DSO in the XY mode with the Zener diode voltage V_D connected as X and V_{out} ($=I_D$) connected as Y.

4.2.2 Application 2 – I-V Characteristics of Silicon and Ge Diodes

Replace the Zener diode in Fig.8 with silicon (IN4007 and IN914) and Ge diodes so as to obtain their i-v characteristics.

4.2.3 Application 3 – I-V Characteristics of LEDs (Red, Yellow, Green, and Blue)

Replace the Zener diode in Fig.8 with different LEDs and obtain their i-v characteristics.

<u>Questions:</u>

i) Explain why a triangular (ramp) signal is used in the diode circuit. What would happen, if instead of the triangular signal a sinusoidal waveform or a square waveform (with the same peak amplitude) is used?

ii) Why is the frequency of the triangular wave kept between 100 Hz to 1 kHz? What would happen if the frequency is made 10 kHz or 20 kHz?

iii) Why are the cut-in voltages of the LEDs very different from that of a Si/Ge diodes, and also different for each different LED?

4.3 Application 4 – Interfacing Circuits for the LM35 Temperature Sensor

LM 35 is a popular temperature sensor giving a voltage output proportional to the temperature in ºC (i.e. output = 10 mV/ºC). Since the LM35 output is lower than a volt normally, an analog interfacing circuit (amplifier) is required before further processing/display. LM35 output can get corrupted if the sensor is located far away from the rest of the interface circuitry. We shall study three interface circuit solutions, viz. an inverting amplifier, a non-inverting amplifier and a difference amplifier, with the LM35 sensor located a few meters away and connected to the amplifier circuit through ordinary (unshielded) wires.

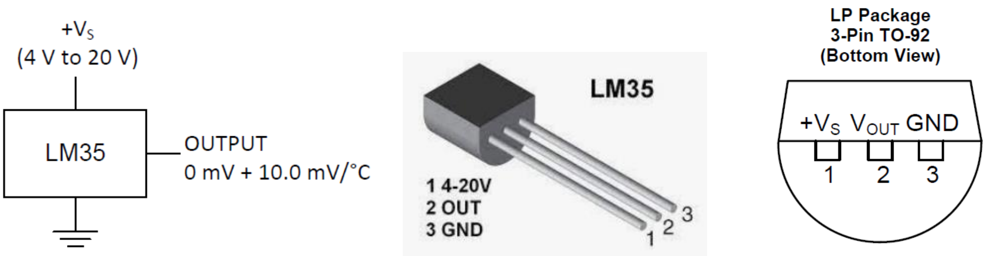


Fig. 9 LM35 Temperature sensor

4.3.1 Interfacing Circuit 1: Non-inverting Amplifier (with gain 10)

<u>Circuit values</u>: +Vcc = +12 V, -Vcc = -12 V; $R_1 = 1\ k\Omega$, $R_F = 9\ k\Omega$.

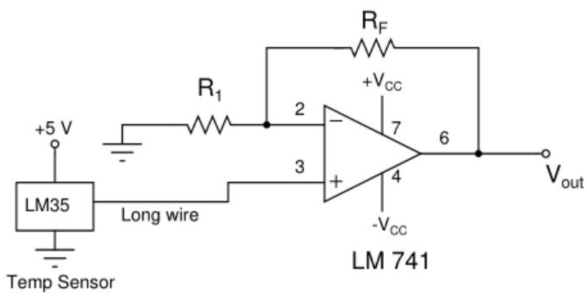


Fig. 10 Interfacing circuit 1 for LM35 – Non-inverting amplifier

4.3.2 Interfacing Circuit 2: Inverting Amplifiers (with gain 10)

Circuit values: +Vcc = +12 V, -Vcc = -12 V; $R_1 = R_F = 10\ k\Omega$, $R_2 = 1\ k\Omega$, $R_3 = 10\ k\Omega$.

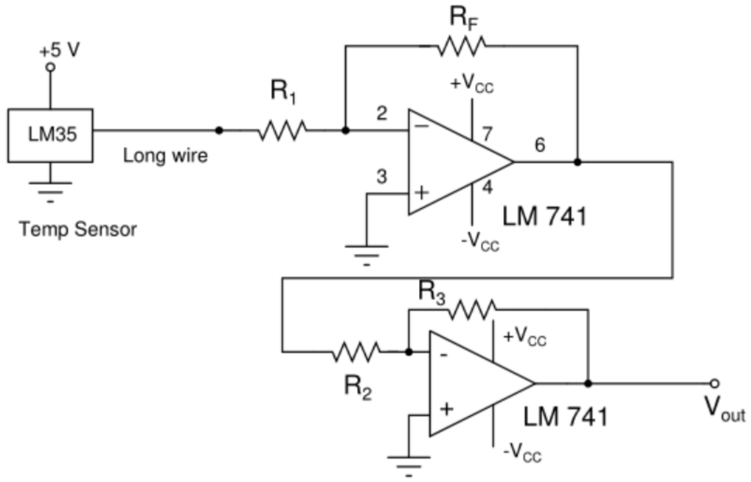


Fig. 11 Interfacing circuit 2 for LM35 – inverting amplifiers

4.3.3 Interfacing Circuit 3: Difference Amplifier (with A_d = 10)

Circuit values: +Vcc = +12 V, -Vcc = -12 V; $R_1 = R_3 = 10\ k\Omega$, $R_2 = R_4 = 100\ k\Omega$

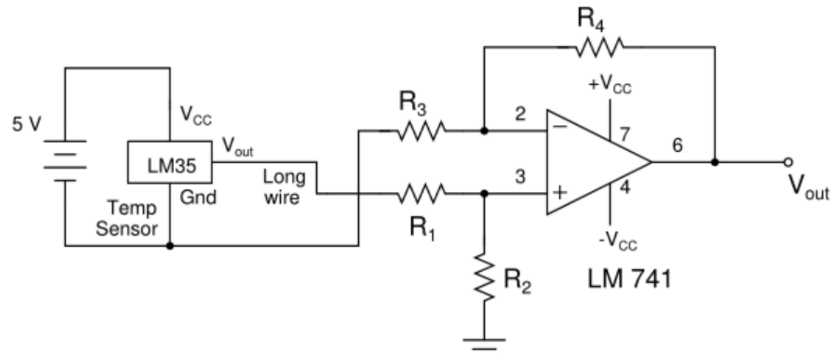


Fig. 12 Interfacing circuit 3 for LM35 – inverting amplifiers

Lab Report

1. For Experiment 6, please limit your Lab report to just 4 pages – one page for the inverting amplifier, one page for the non-inverting amplifier and two pages for the difference amplifier and its applications. No NGSPICE simulations required.
2. In each page, please include the amplifier circuit diagram and answers to the questions. Please also add one line of what you learned.
3. Deadline for Lab Report 6: Sep 5, 2021 (Sunday), 11pm.
4. Please do not email the Lab instructor with late submission requests of Lab Reports. Instead, you may write to your Tutor, who would assess your request, and might allow late submission (by say a maximum of 12 hours) as a one-time concession.

Note: Request all students to refrain from any unfair means, such as copying Lab Reports of others, in part or in full. Defaulters (both parties) will attract very severe punishment – including negative marks (i.e. -5 marks, instead of 0 marks for non-submission), and grade penalty. Your names will also be reported to your Faculty Advisor and to Head, EE dept for further action against you.