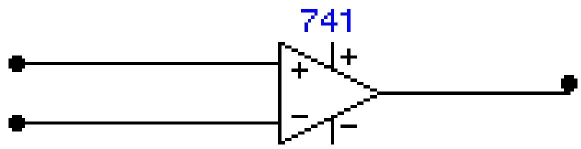
Section 2 - Operational Amplifiers

Introduction

The 741 Operational Amplifier (opamp) is a high gain voltage amplifier. The inputs to the amplifier consist of V_+ (non-inverting input) and a V_- (inverting input). The electronic symbol for the 741 is shown below.



Properties

The main properties of the 741 op amp are:

- High open-loop gain: $A_o \approx 2 \times 10^5$
- Unity gain bandwidth: $B \approx 2 \times 10^6$ Hz
- High input impedance: $Z_i \approx 10^6\ \Omega$
- Low output impedance: $Z_o \approx 100\ \Omega$

Action and Characteristics

The output voltage of the op-amp is given by the equation:

$$V_o = A_o(V_+ - V_-) = A_o V_d$$

where:

V_+ is the voltage at the non-inverting terminal,
V_- is the voltage at the inverting terminal
A_o is the open-loop gain of the amplifier
V_d is the differential input (i.e. $V_+ - V_-$)
V_{cc_+} is +12V power input
V_{cc_-} is -12V power input

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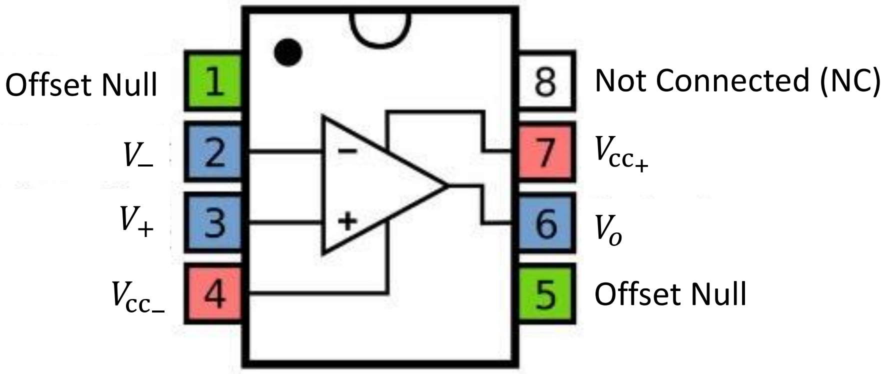
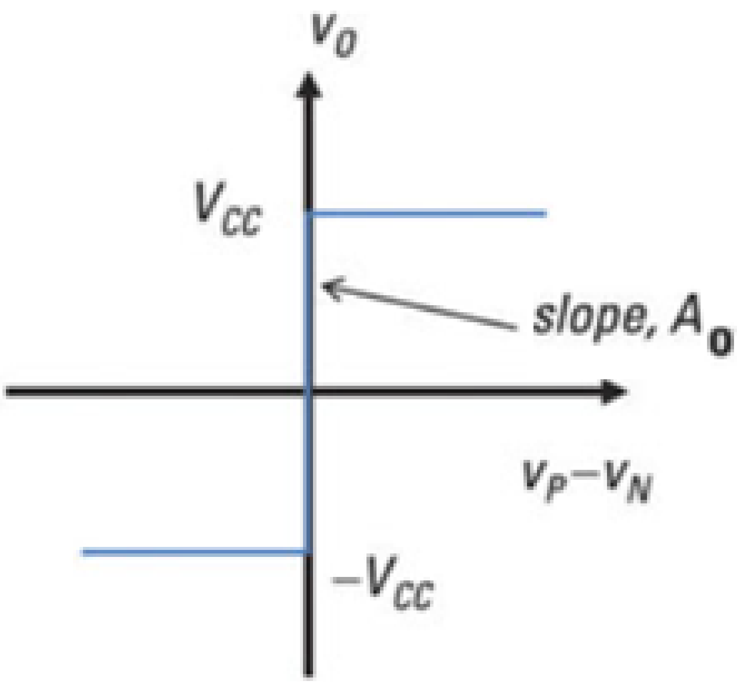
Part 1: Non-inverting operational amplifier in open loop configuration

The pinout schematic for the 741 is as shown below.



Voltage Transfer Characteristic
When the op-amp is on open-loop configuration, due to the very high open loop gain of the amplifier there is a very limited linear region. The higher the gain of the amplifier, the larger the slope of the linear region and the closer the line becomes to a vertical as shown below.



At positive saturation the output voltage produce approaches the maximum positive supply voltage V_{cc_+}. At negative saturation the output voltage produce is close to the maximum negative voltage V_{cc_-}.

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Procedure:

1. Connect a 12V DC power supply to Pin 7 (+) and Pin 4 (-) to power the op amp.

2. Connect the op amp in an open-loop configuration, as shown in Figure 1 below using a DC power supply to provide +5 volts and ground the circuit as appropriate.

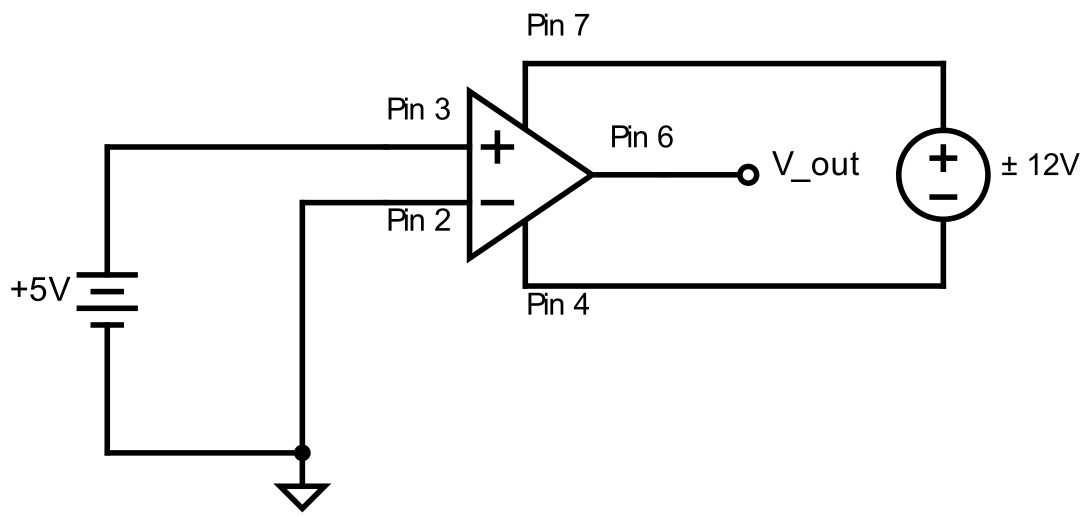

Figure 1: A 741 op amp in open loop configuration.

3. Measure and record in the values of the input voltage V_{cc_+} and $V_{cc\_}$.

4. Record the value of positive saturation voltage.

5. Change the input on Pin 3 to $-5\ \mathrm{V}$ and record the negative saturation voltage.

6. Compare the saturation values to V_{cc_+} and $V_{cc\_}$ and comment on the result.

Part 2: Negative feedback non-inverting voltage amplifier

Negative feedback is a fundamental concept in operational amplifier (op amp) circuits that enhances stability, precision, and bandwidth. In a non-inverting voltage amplifier, negative feedback ensures that the output voltage closely tracks the input signal while maintaining high gain and minimal distortion. This configuration amplifies the input without inverting its phase and provides advantages such as reduced sensitivity to component variations, improved linearity, and controlled gain. By applying feedback, the amplifier becomes more stable, with predictable behaviour, and operates effectively across a wide range of frequencies, making it ideal for signal amplification in precision applications.

The voltage transfer characteristic (V_o versus V_i) for a negative feedback non-inverting op amp is shown below in Figure 2. It shows an increased linear region due to the reduction in gain. The feedback section consists of R_f a fixed resistor in series with a variable resistor R_g. The addition of the variable resistor in series with the fixed resistor allows the feedback section to be varied between and thus allow control over the gain of the amplifier.

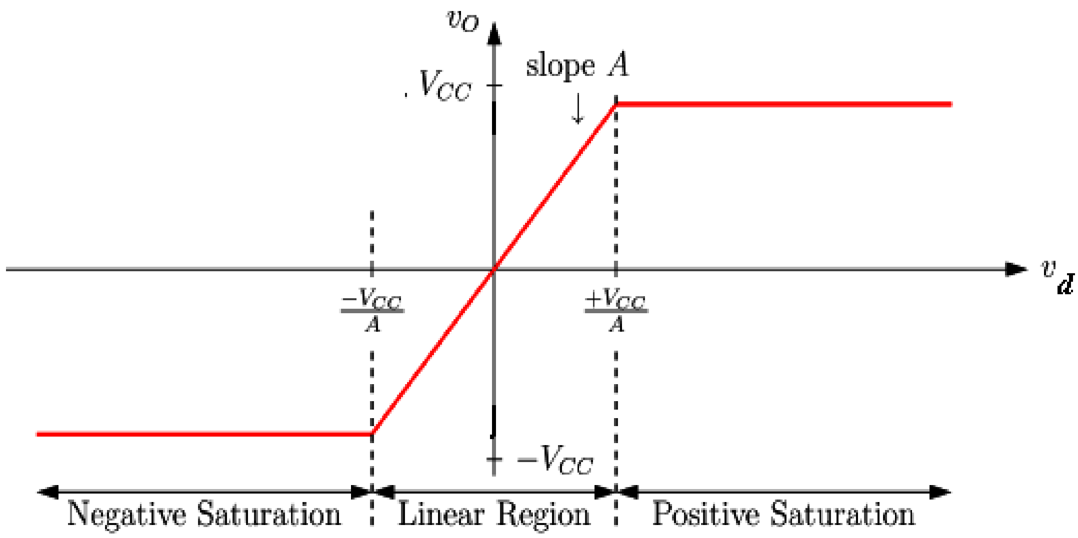

Figure 2: Transfer characteristic of the 741 op amp.

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Procedure:

1. Set up the negative feedback non-inverting voltage amplifier circuit as shown in Figure 3.

Note: For simplicity and clarity, normally the power lines for the op amp (Pin 4 and Pin 7) are excluded from the circuit diagram, but the amplifier must be powered to be function.

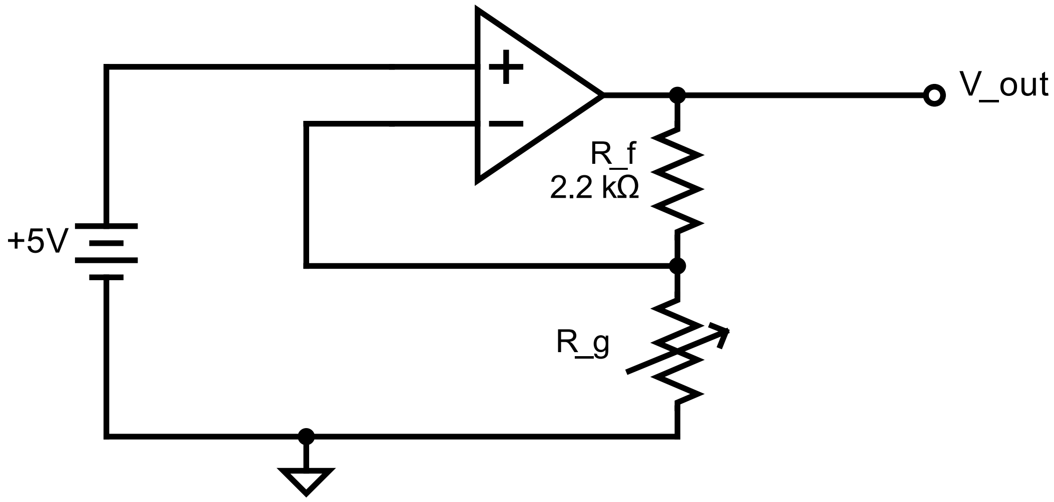

Figure 3: Non-inverting feedback operational amplifier circuit.

2. Set the input voltage from the DC Source to 5V.

3. Set the R_g to $500\ \Omega$ and measure V_o and $V\_$, and record all three measurements.

4. Vary R_g between $500\ \Omega$ and $100\ k\Omega$, ensuring that you have a range of readings to clearly show both the linear and saturation regions of the transfer characteristic.

5. Plot a graph of R_i versus $\mathrm{V_{out}}$.

6. Using the formula $A_v = \frac{V_{out}}{V_{in}}$, calculate the gain, A_v, of the amplifier.

Part 3: Design of a 40 dB non-inverting amplifier

In this experiment, we aim to design and analyse a non-inverting amplifier with a fixed gain. The primary objective is to achieve precise voltage amplification while maintaining signal integrity and minimizing distortion. By using operational amplifiers in a non-inverting configuration, the circuit amplifies the input signal without altering its phase. This experiment will focus on selecting appropriate resistor values, testing the frequency response, and ensuring stable operation within the designed gain range.

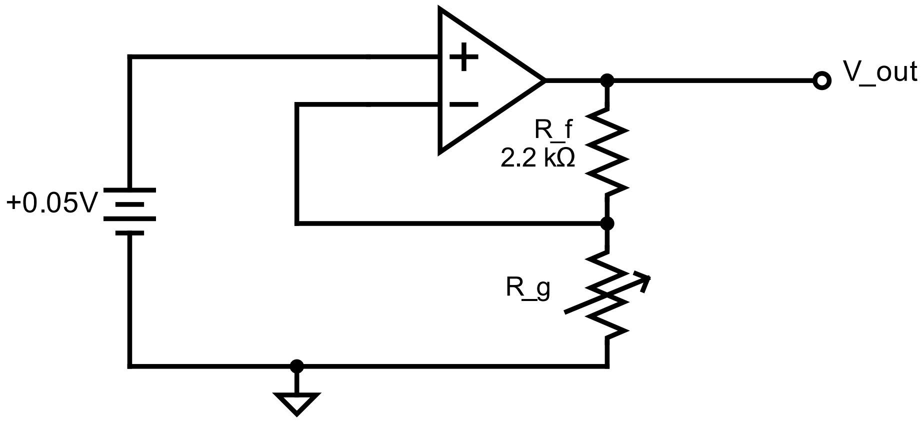

Figure 4: Circuit diagram for a non-inverting op-amp with 50 mV input.

Procedure:

1. Set up the circuit as shown in Figure 4.

2. Using a DC power supply or signal generator, set the input voltage V_i to 50 mV, vary R_g until the gain of the amplifier is 40 dB i.e. until the measured value of $V_{out} = 5\text{ V}$.

3. Measure and record a range of V_i and V_o and as in the Part 2, ensure that you have a range of readings to clearly showing both the linear and saturation regions of the transfer characteristic.

Note: As the op amp approaches saturation, be sure to use smaller voltage increases to properly map the curve of the transfer characteristic.

4. Set the input voltage to $-50\ \mathrm{mV}$ by swapping the leads on the power supply.

5. Plot a graph of V_i versus V_o.

Part 4: 40 dB Non-Inverting Amplifier Offset Nulling

The graph above did not give a zero output for a zero input and so we must provide the amplifier with a null offset. Offset voltage, caused by imperfections in the operational amplifier, can lead to inaccuracies in signal amplification. The goal of this section is to minimize or eliminate this offset using offset nulling techniques. By carefully adjusting the circuit, we aim to achieve high precision and accurate amplification, ensuring the output signal remains faithful to the input, free from unwanted DC bias or drift.

For an input of 0 V the output voltage value should also be zero, however, the circuit does not give a zero output because of input offset voltages i.e. the gain of the non-inverting terminal may not be exactly equal to the gain of the inverting terminal. The 741 operational amplifier has internal circuitry to balance out this offset (null offset circuitry) which is set up as follows:

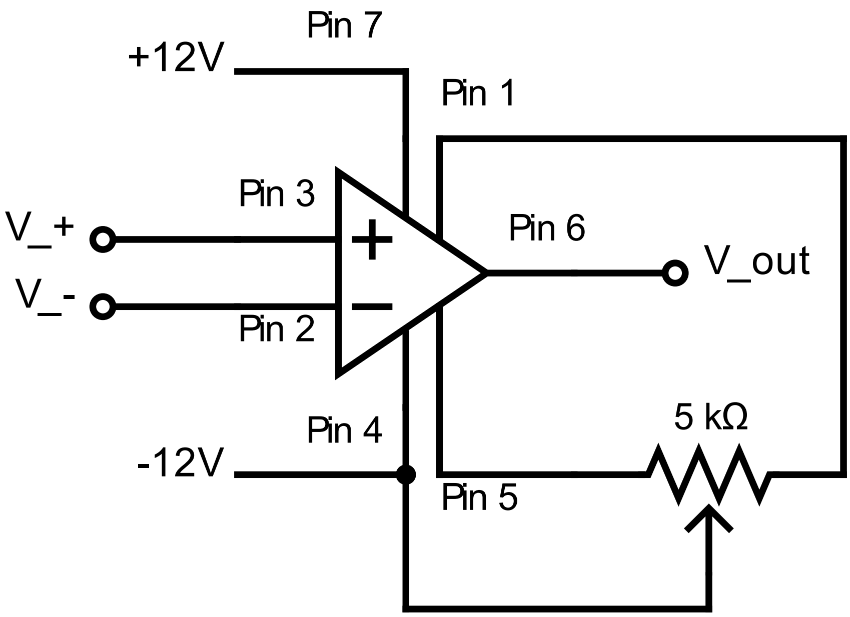

Figure 5: Op amp with null offset connected.

Procedure:

1. Using the circuit from Part 3, connect a $10\ k\Omega$ potentiometer across Pin 1 and Pin 5 of op-amp and the centre point (Pin 2) of the potentiometer to $V_{cc\_}$, as shown in Figure 5.

2. With $\mathrm{V_i}$ to $0\ \mathrm{V}$, vary the $10\ \mathrm{k\Omega}$ potentiometer until $\mathrm{V_o} = 0\ \mathrm{V}$.

3. Remove the input terminal from ground and reconnect it to the voltage input arrangement. Vary the potentiometer to set V_i to $50\ \mathrm{mV}$ and verify that $V_o = 5\ \mathrm{V}$ (i.e. a gain of 100).

4. As in Part 3, vary the potentiometer, and measure V_o for a range of V_i and record the results

5. Set the input voltage to $-50\ \mathrm{mV}$ by swapping the leads on the power supply.

6. Plot a graph of V_i versus V_o.

Part 5: Frequency Response of an Amplifier with a gain of 100

In this experiment, we explore the frequency response of an amplifier with a gain of 100, with a focus on the gain-bandwidth product (GBW). As we transition from DC to AC signals, it is essential to understand how the amplifier’s gain diminishes as frequency increases, as shown in Figure 6. This experiment will analyse the amplifier’s performance across a range of frequencies, determining its bandwidth and the frequency at which the gain begins to roll off. By examining the relationship between gain and bandwidth, we aim to assess the trade-offs involved and ensure optimal performance within the amplifier's GBW limits.

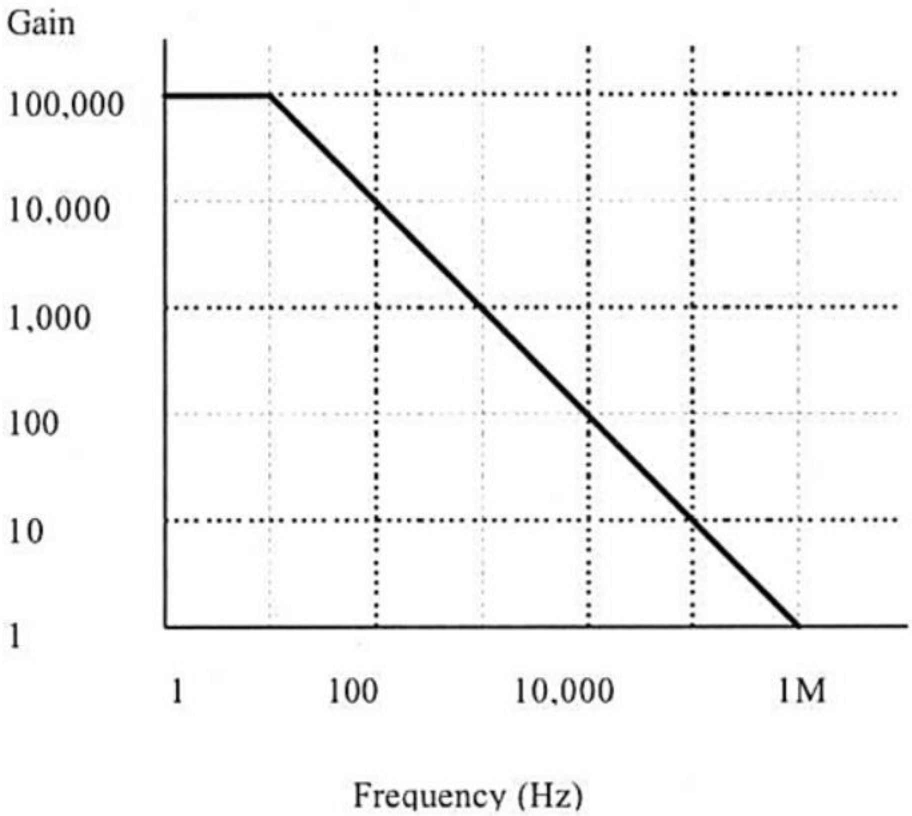

Figure 6: Frequency vs. gain response of a 741 op amp in open loop configuration.

Procedure:

1. Maintaining the 40 dB gain, substitute a function generator to drive the input using sine wave.

2. Set $V_i = 50$ mV and measure V_o range 50 Hz to 100 kHz. For each datapoint, also calculate the gain, A_v.

3. Plot a graph of f versus A_v

4. Determine the bandwidth of the amplifier given that for a 741 op amp:

$$\text{Gain} \times \text{Bandwidth} = 10^6$$

5. Reduce the gain of the amplifier to 10 and repeat the measurements.

Part 6: Simulation of the Frequency Response of an Amplifier

1. Simulate a 40 dB gain amplifier circuit, using an AC input on Multisim.

Note: You should use the 3-terminal Op Amp component for simplicity. The 5-terminal (i.e. with V_{cc_+} and $V_{cc\_}$) can also be simulated.

2. Double-click on the op-amp component to view the model settings. Set the following parameters:
   a. $A_{VOL} = 10\text{k}$
   b. $BW = 10$ MHz
   c. $R_I = 10\text{M}\Omega$
   d. $R_O = 100\Omega$

3. Set V_{OMP} and V_{OMN} to equal the V_{CC_+} and $V_{CC\_}$ respectively as per Part 5.

4. Using an AC Sweep, plot a graph of f versus A_v

5. Compare the results to those experimentally determined in Part 5

6. Reduce the gain of the amplifier to 10 and repeat the simulation.

Part 8: Simulation of Differentiation of a Sinusoidal Wave

1. Using Multisim, solve the following equation.

$$2.9x - \int_{0}^{5} (0.1x + 9x^2)\,dx$$