LAB05

Operational Amplifiers

Electronics - Hardware Tools for Embedded Software and IoT
Instructor: Jarno TUOMINEN

Author name: Uras Ayanoglu - 2203334
Author name: Sebastian Sopola – 1904705

Experiment contacted on: 23-27-30/11/2023
Report submitted on: 11/12/2023

Faculty of Engineering and Business
Information and Communication Technology

Turku University of Applied Sciences
Turku, Finland

Table of Contents

OBJECTIVES

The primary objective of this lab report is to explore the fundamental principles and applications of operational amplifiers (op-amps) through a series of hands-on experiments. Each task is designed to delve into different aspects and configurations of op-amps, providing a comprehensive understanding of their functionalities, limitations, and practical applications in electronic circuits.

BACKGROUND THEORY / INTRODUCTION

Overview of Operational Amplifiers

Definition and Basic Concept:

Operational Amplifiers, commonly known as Op-Amps, are integrated circuits that function as high-gain voltage amplifiers. The term "operational" stems from their initial use in performing mathematical operations in analog computers. An Op-Amp typically has two input terminals (inverting and non-inverting), one output terminal, and two power supply terminals.

Internal Structure:

Internally, an Op-Amp consists of several transistor stages, which include differential input stages, gain stages, and an output stage. This internal structure is designed to provide high input impedance, low output impedance, and a significant gain factor.

Characteristics of Op-Amps

Voltage Gain: Op-Amps have a very high open-loop gain, often exceeding 100,000. This gain is the ratio of the output voltage to the difference in voltage between the two input terminals.

Input Impedance: They exhibit high input impedance, allowing minimal current to flow into the inputs, which is crucial for interfacing with high-impedance sources.

Output Impedance: The output impedance is low, enabling the Op-Amp to drive loads with minimal loss of signal.

Bandwidth: The frequency response of an Op-Amp is another vital characteristic, determining how it amplifies different frequencies. Most Op-Amps have a finite bandwidth, with gain decreasing as frequency increases.

Slew Rate: The slew rate of an Op-Amp is the maximum rate of change of the output voltage per unit of time and is a critical factor in determining how quickly the Op-Amp can respond to changes in the input signal.

Common Configurations

Voltage Follower (Buffer): A configuration where the output voltage directly follows the input voltage, providing unity gain but with the benefits of high input and low output impedance.

Inverting Amplifier: A configuration where the output voltage is inversely proportional to the input voltage, with a gain determined by the ratio of two resistors.

Non-Inverting Amplifier: In this configuration, the output voltage is in phase with the input voltage, and the gain is set by the ratio of two resistors.

Summing Amplifier: An Op-Amp circuit that can combine multiple input signals into a single output signal, either inverting or non-inverting.

Applications

Op-Amps are versatile components used in various applications, including signal conditioning, filtering, voltage regulation, and in complex systems like analog-to-digital converters and oscillators.

EQUIPMENT and COMPONENTS USED

This section outlines the general equipment and components used in all tasks of the Operational Amplifiers lab. The specific values and types of resistors, capacitors, and other components used in each task are detailed in the respective sections of this report.

General Equipment

Oscilloscope: Picoscope 2205A

- Utilized for measuring and observing the electrical waveforms in each task.
- Enabled precise measurements of voltage, frequency, phase, and slew rate.
- In addition to its primary use as an oscilloscope, the Picoscope 2205A was also utilized for generating input signals in various tasks.
- Its built-in signal generator function allowed for the creation of a wide range of waveforms, including sinusoidal, square, and triangular waves.

Oscilloscope Software: Picoscope 7 ver.7.1.13

- Accompanied the Picoscope 2205A Oscilloscope for data visualization and analysis.
- The ability to adjust frequency, amplitude, and other waveform parameters directly through the Picoscope 7 software made it a versatile tool for testing the frequency response and bandwidth of the amplifiers.
- Facilitated the capture of screenshots for the lab report.

Multimeters:

1. Uni-T UT131A Multimeter:
    - Employed for basic measurements such as voltage, current, and resistance across various points in the circuits.
2. TT T-ECHNI-C MY-64 Multimeter:
    - Used interchangeably with the Uni-T UT131A for similar measurements, offering a comparative analysis for accuracy.

Simulation Software: LTSpice ver. 17.1.15

- Crucial for simulating the operational amplifier circuits in each task.

- Enabled virtual testing and verification of circuit designs before physical implementation.
- Assisted in predicting circuit behavior and analyzing theoretical outcomes.

General Components

LM741 Operational Amplifier:

- The central component in all tasks, used in different configurations like voltage follower, non-inverting amplifier, inverting amplifier, and summing amplifier.
- Provided a practical understanding of operational amplifier behaviors in various circuit setups.

Bread Board ZY-206H Power Supply Module:

- Used to provide the necessary ±15V supply voltage to the LM741 operational amplifier in each task.
- The module's user-friendly interface allowed for precise voltage adjustments, ensuring accurate power delivery to the circuits.

Breadboard and Wiring:

- Breadboards were used for prototyping each circuit configuration.
- Jumper wires and interconnects facilitated circuit assembly and modifications.

Resistors and Capacitors:

- A variety of resistors and capacitors were used to set gain levels, filter frequencies, and stabilize the circuits.
- Values and types varied depending on the specific requirements of each task.

PROCEDURE

This experiment encompasses six distinct tasks, each meticulously approached through a two-phase process: initial simulation followed by practical implementation and measurement. We began by leveraging LTSpice simulation software to design and predict the behavior of each circuit configuration. Subsequently, these designs were brought to life on the breadboard, with careful attention to measuring and analyzing various circuit parameters. The detailed procedural steps for each task are outlined as follows, providing a comprehensive walkthrough of the experimental journey:

1: Preparation and Setup

Gather Equipment and Components:

- Assemble the Picoscope 2205A Oscilloscope, Bread Board ZY-206H Power Supply Module, LM741 Operational Amplifiers, Uni-T UT131A and TT T-ECHNI-C MY-64 Multimeters, resistors, capacitors, and breadboard.

Software Setup:

- Install and set up Picoscope 7 software for the oscilloscope and signal generation functionalities.
- Prepare LTSpice for circuit simulation, ensuring all required models and settings are configured.

2: Simulation

Circuit Design:

- Using LTSpice, design the circuit for the specific task, including selecting appropriate resistors, capacitors, and other components.

Simulation Execution:

- Run simulations to predict circuit behavior, making adjustments as necessary based on the results.

3: Circuit Implementation

Breadboard Circuit Assembly:

- Implement the designed circuit on the breadboard using the LM741, resistors, capacitors, and other components as per the LTSpice design.

Power Supply Connection:

- Connect the Bread Board ZY-206H Power Supply Module to provide the required ±15V to the LM741.

4: Signal Generation and Testing

Signal Generation:

- Use the Picoscope 2205A's signal generator function to create input signals for the operational amplifier circuit.

Initial Testing:

- Perform initial tests using the multimeters to ensure the circuit is functioning as expected.

5: Data Collection and Analysis

Oscilloscope Measurements:

- Use the Picoscope 2205A Oscilloscope to observe and measure the input and output signals of the operational amplifier circuit.
- Capture relevant data and screenshots for analysis.

Performance Evaluation:

- Analyze the collected data to evaluate the performance of the circuit in terms of gain, bandwidth, slew rate, or other relevant parameters.

6: Reporting and Documentation

Data Compilation:

- Compile all measurements, oscilloscope screenshots, and LTSpice simulations in an organized manner.

Lab Report Writing:

- Document each step of the procedure for each specific task, including observations, analysis, and conclusions.

Task 1: Slew Rate Measurement of LM741

1.Introduction

Task Description: Measure the slew rate of LM741 operational amplifier, when it is operating as a voltage follower.

Voltage Follower

A voltage follower, also known as a buffer amplifier, is a configuration of an operational amplifier (op-amp) in which the output is connected directly to the inverting input. This setup results in a circuit with a gain of 1, meaning the output voltage directly follows the input voltage. Here are some key characteristics and uses of a voltage follower:

1. **Unity Gain:** The voltage follower provides a gain of 1, so the output voltage is the same as the input voltage.

2. **High Input Impedance:** It has a very high input impedance, meaning it draws minimal current from the input source. This makes it ideal for interfacing with high-impedance sources.

3. **Low Output Impedance:** The low output impedance allows the voltage follower to drive loads that require more current than the input source can provide, without significant voltage drop.

4. **Isolation:** Voltage followers are used to isolate different stages of a circuit, preventing the preceding stage from being affected by the loading effects of the subsequent stage.

5. **Signal Buffering:** They are commonly used for signal buffering, as they can transfer a signal from a high impedance source to a low impedance load without a change in voltage.

Slew Rate

Slew rate is a critical parameter in operational amplifiers, defined as the maximum rate of change of the output voltage per unit of time. It is typically expressed in volts per microsecond (V/µs). The slew rate is crucial for several reasons:

1. Signal Fidelity: The slew rate determines how quickly the op-amp can respond to changes in the input signal. A lower slew rate can lead to distortion, especially in high-frequency signals, as the op-amp may not be able to accurately follow rapid changes in the input.

2. Bandwidth Limitation: The slew rate can limit the bandwidth of the amplifier for large signal swings. An op-amp with a low slew rate may not be suitable for high-speed applications where quick transitions are essential.

3. Distortion: In applications like audio amplification, a low slew rate can result in "slew-induced" distortion, where the op-amp cannot keep up with the input signal, leading to a distortion of the output waveform.

4. Design Considerations: Understanding the slew rate is vital for designing circuits with operational amplifiers, especially when dealing with high-frequency signals or large voltage swings.

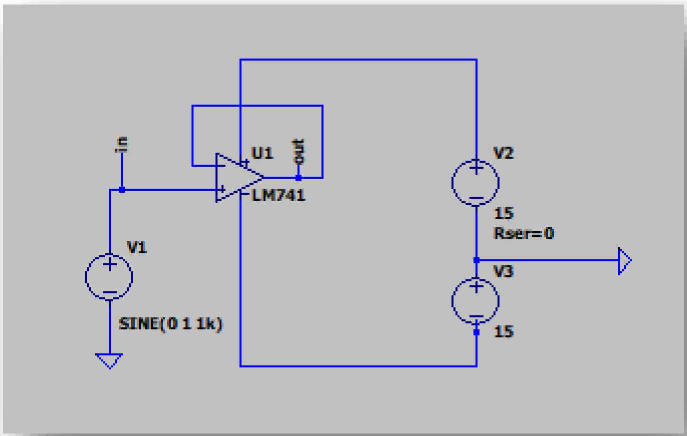
In summary, the voltage follower is a simple yet versatile op-amp configuration used for buffering and isolation, while the slew rate is an essential characteristic of op-amps that affects their ability to handle fast-changing signals without distortion.

Components Used and Their Values

- LM741 Operational Amplifier
- Input voltage V1 | Pulse generated by Picoscope 2025A
    - Vinitial -15 VDC, Von +15, delay 2 ms, Trise 1 ms, Tfall 1 ms, Ton 10 ms,
- Power supply V2 +15 VDC
- Power supply V3 -15 VDC

Circuit

Figure 1 – Circuit Design of LM741 as a Voltage Follower



2.Simulation

Figure 2 - Transient Analysis of LM741 as a Voltage Follower

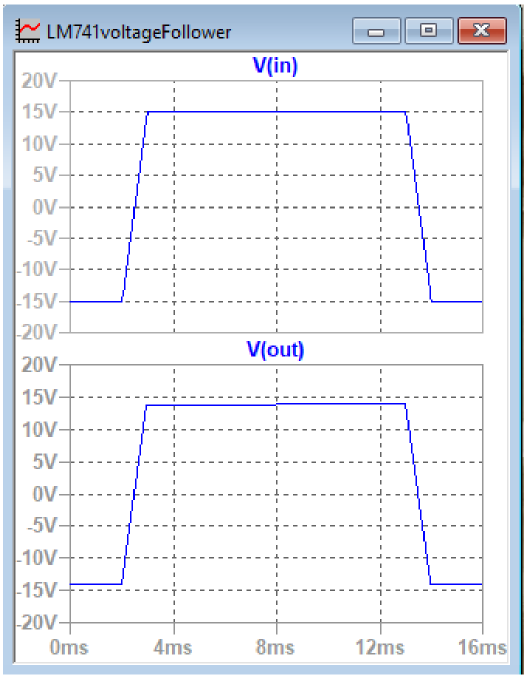
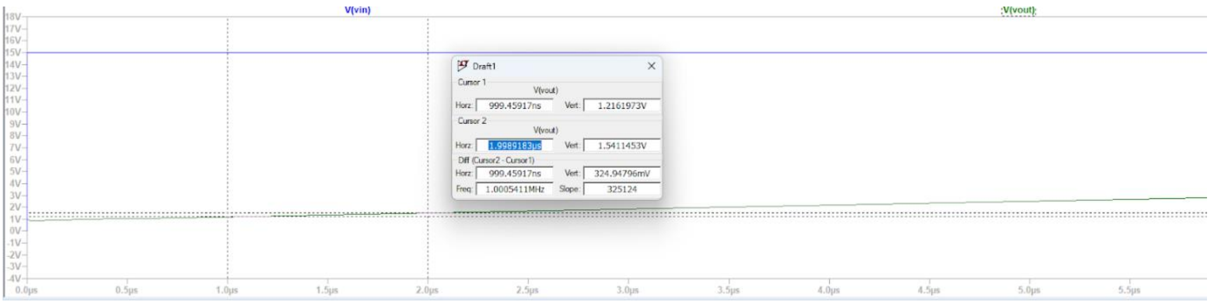


Figure 3 - Slew Rate of LM741 as a Voltage Follower



3.Implementation

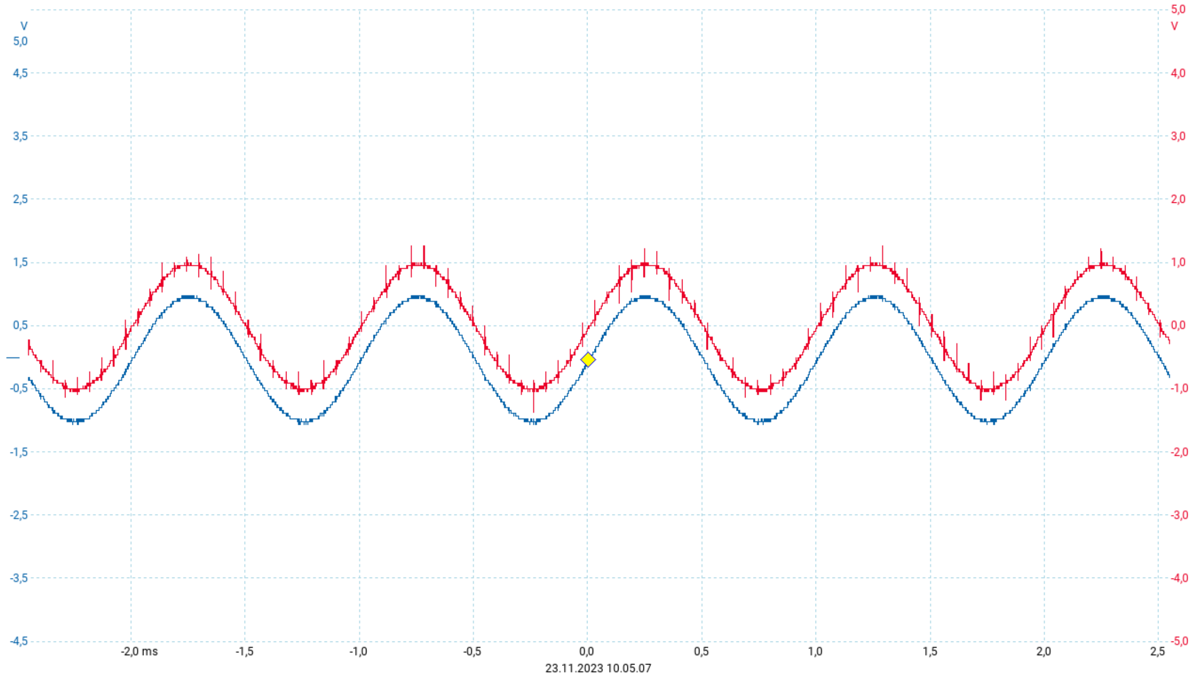
In the circuit, the LM741 is set up as a voltage follower where the output (pin 6) is fed back directly into the inverting input (pin 2). The non-inverting input (pin 3) receives the input signal. Here, no external resistors are used for setting the gain since a voltage follower inherently has a gain of 1. This means that the output voltage should ideally be the same as the input voltage. The op-amp is powered by a dual supply voltage of ±15 volts connected to pins 7 (V+) and 4 (V−), respectively.

4.Results

Steps to Measure Slew Rate with an Oscilloscope:

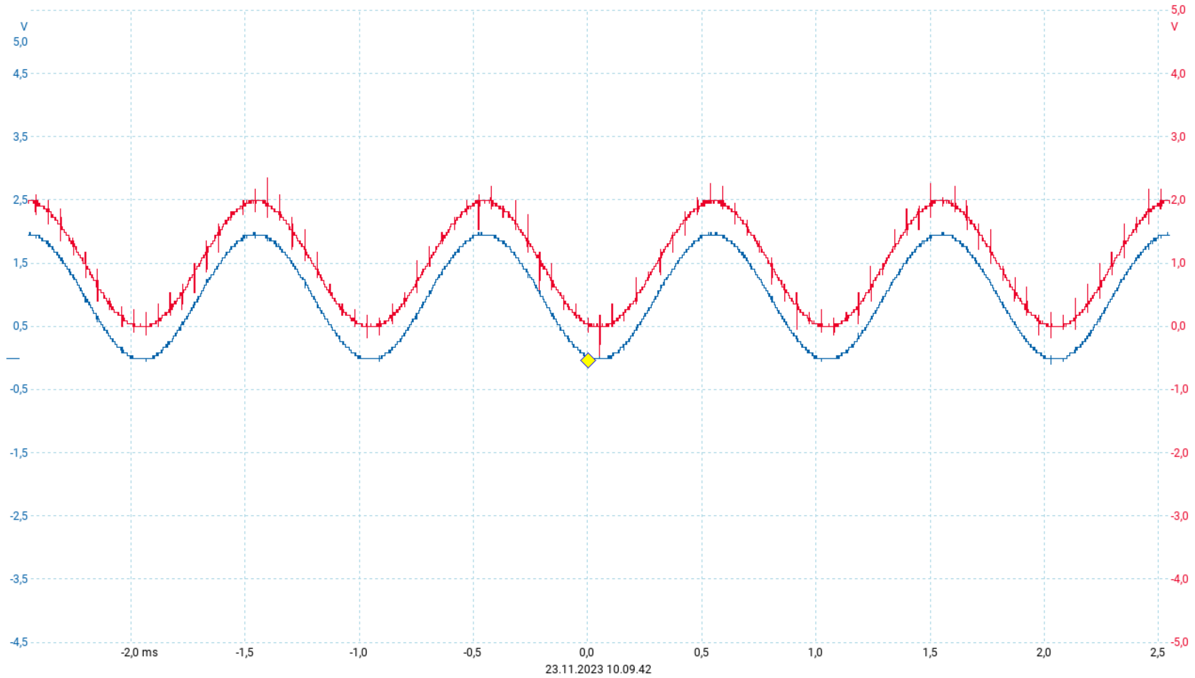
1. **Signal Input Configuration:**
    - The input signal, as defined by the source V1, is a sine wave with a 0V DC offset and a peak amplitude of 1V (as indicated by "SINE(0 1 1k)"), at a frequency of 1 kHz.
    - Set up the oscilloscope's built-in function generator to produce a similar signal mentioned above.
2. **Oscilloscope Connection:**
    - Connect channel one of the oscilloscope to the input of the op-amp to observe the input signal.
    - Connect channel two of the oscilloscope to the output of the op-amp to observe the output signal.
3. **Observing the Waveform:**
    - On the oscilloscope, display both the input and output waveforms simultaneously.
    - Ensure that the oscilloscope triggers properly and that the waveforms are stable on the screen.
4. **Measuring Slew Rate:**
    - Increase the frequency of the input sine wave until you observe the output waveform begins to distort, typically at the point where it can no longer follow the input signal's rise and fall times effectively.
    - Alternatively, you can apply a step input (a sudden change in voltage from low to high) and observe the output waveform's rise time.
    - Use the oscilloscope's cursor or measurement functions to measure the time it takes for the output voltage to change from 10% to 90% of its final value (or the time it takes for the output to rise from the low to the high voltage level in case of a step input).
5. **Calculating Slew Rate:**
    - The slew rate is calculated using the formula Slew Rate = $\Delta t/\Delta V$, where ΔV is the change in voltage and Δt is the change in time.
    - For a step input, ΔV would be the voltage step height, and Δt would be the measured rise time.

Figure 4 - LM741 Operating as a Voltage Follower



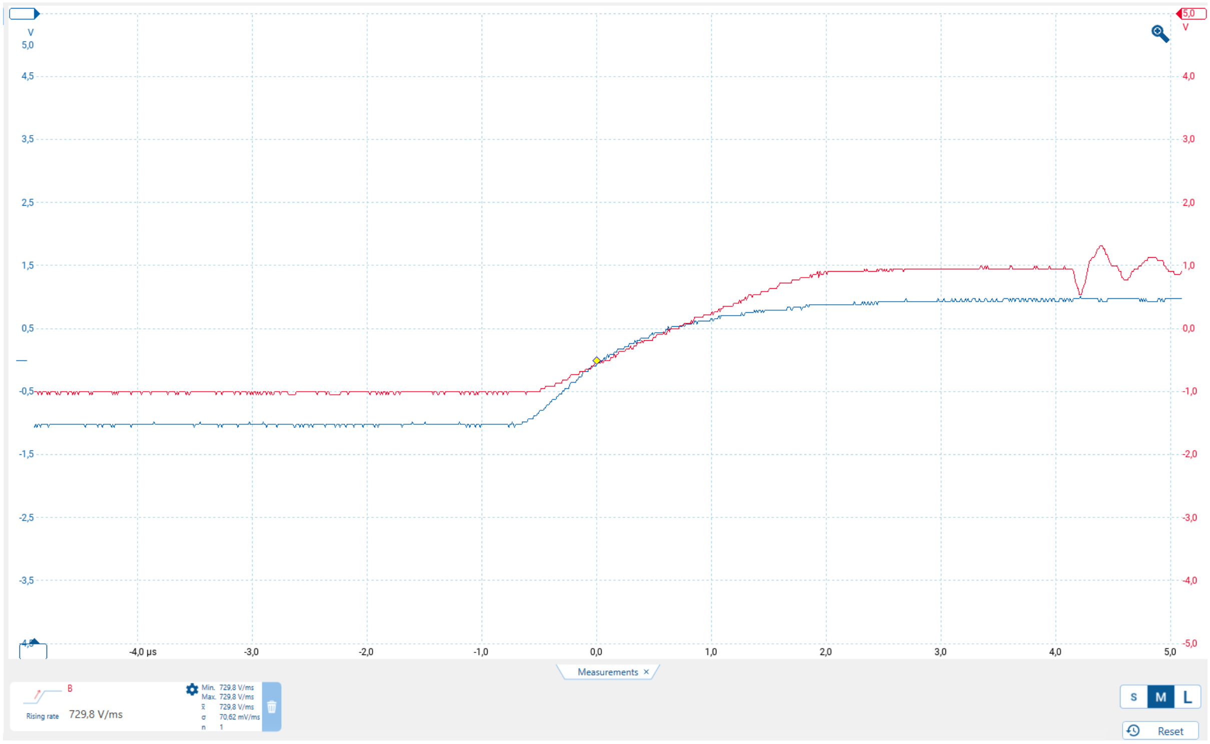
Signals Blue Vin, Red Vout

Figure 5 - LM741 Operating as a Voltage Follower with Offset



Signals Blue Vin, Red Vout

Figure 6 - Slew Rate Measurement of LM741



Signals Blue Vin, Red Vout

The LM741 operational amplifier is known to have a typical slew rate specification around 0.5 V/µs. The measured slew rate from the provided oscilloscope image is 0.729 V/µs (or 729 V/ms), which is slightly higher than the typical value. This difference may be attributed to several factors, including variations in individual components, the specific conditions under which the measurement was taken, or the particular batch of the LM741 used. It's also possible that the oscilloscope's accuracy or the method of measuring the rise time could introduce some variance.

5.Summary

The measured slew rate of 0.729 V/µs for the LM741 operational amplifier, although higher than the typical specification, may not accurately reflect the true performance characteristics of the device. The quality and limitations of the signal generator can significantly impact the precision of slew rate measurements. It's advisable to evaluate the step response of the generator to ensure it provides a sufficiently fast and clean transition for accurate testing. Additionally, factors such as the internal capacitance and resistance of the measurement tools, including the oscilloscope, and potential impedance introduced by additional wiring, can introduce artifacts or distortions that affect the observed slew rate. Therefore, while the obtained value suggests a better-than-expected performance, it's crucial to consider these external influences that may lead to a misleading representation of the op-amp's true capabilities. Verification with more refined equipment or cross-referencing with a known high-performance signal generator could provide a more definitive measurement of the slew rate.

Task 2: Noninverting Amplifier with gain of 10

1.Introduction

Task Description: Design a noninverting amplifier, which voltage gain is 10.

a) Adjust the input voltage to be 1Vsin(ωt) and check that the output voltage is 10Vsin(ωt). (For part c, this is considered Voutmax) After this increase the amplitude of the input voltage and check when the output voltage is cut (=saturated from "top" or from "bottom").

b) Increase the frequency of your input voltage and check with an oscilloscope when the output voltage starts to decrease.

c) Measure the bandwidth of your amplifier (Hint: The cut off frequency is the frequency where the output voltage has declined to value 0,71·Voutmax, that is, the initial output voltage, used in part a)

In this task, characteristics of a noninverting operational amplifier are explored using the LM741. The noninverting amplifier configuration is designed to amplify the input voltage signal without inverting its phase. With a specified voltage gain of 10, we expect the output signal to be an amplified replica of the input, maintaining the same phase orientation.

The primary objective is to verify the amplification factor by applying a 1V peak sinusoidal input and measuring the output. The expected output should be a 10V peak sinusoidal wave, adhering to the gain configuration. Further investigation involves increasing the input amplitude to observe at what point the output signal reaches saturation, indicating the limits of the op-amp's output swing capabilities given the supply voltages.

Subsequently, the aim is to determine the amplifier's bandwidth by increasing the input signal frequency until the output signal's amplitude drops to 0.71 times the maximum output voltage (Vout_max), which corresponds to the -3dB point of the amplifier's frequency response.

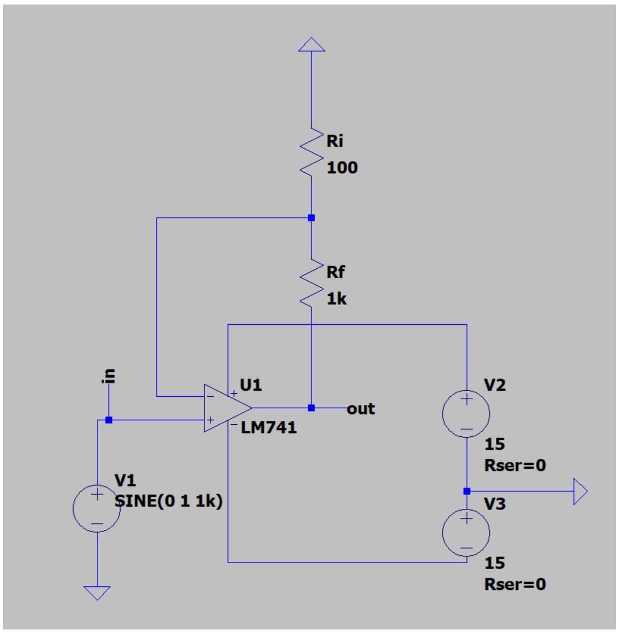
Considerations for the setup include the effects of the measurement tools and circuit components on the results. The accuracy of the signal generator, the response of the oscilloscope, and any additional resistances or capacitances inherent in the setup could influence the measurements. By acknowledging these factors, we strive for a thorough analysis that distinguishes the op-amp's performance from the limitations imposed by our experimental apparatus.

Components Used and Their Values

- LM741 Operational Amplifier
- Input voltage V1 generated by Picoscope 2025A | Sine 1 V 1kHz
- Rf = 1k ohm
- Ri = 100 ohm
- Power supply V2 +15 VDC
- Power supply V3 -15 VDC

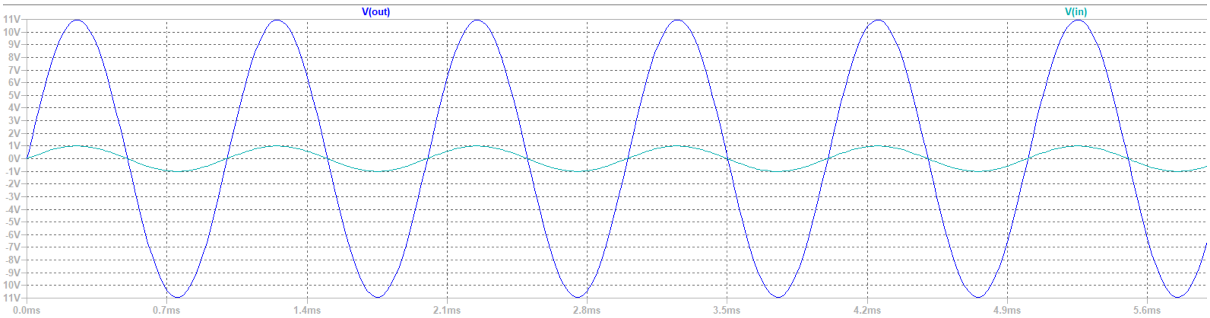
Circuit

Figure 7 – Circuit Design of LM741 as a Noninverting amplifier



2.Simulation

Figure 8 – Transient analysis of LM741 as a noninverting amplifier



Signals Blue Vin, Green Vout

Figure 9 – Behavior of LM741 as a noninverting amplifier in different frequencies

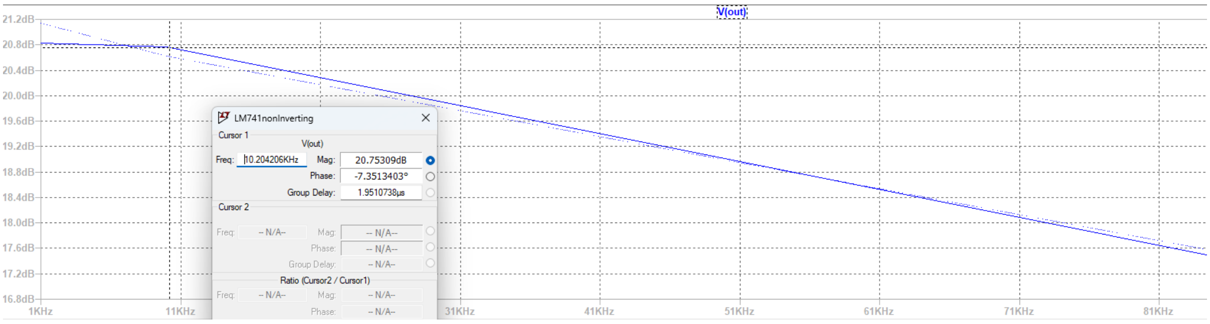
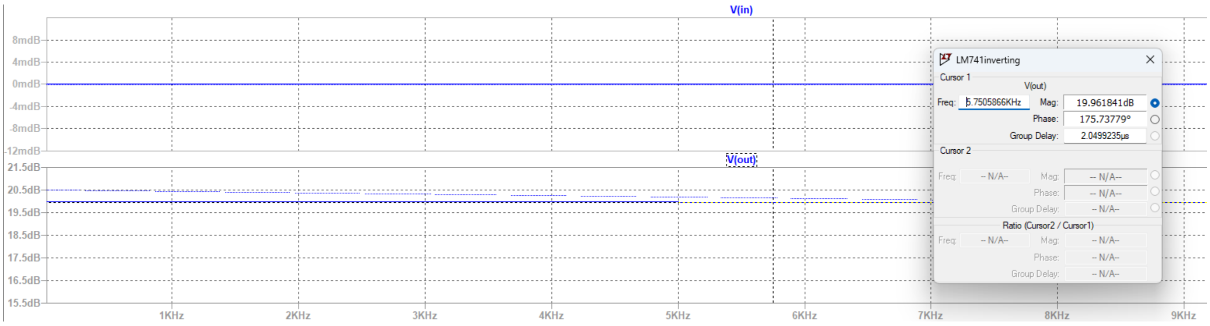


Figure 10 – Bandwidth of LM741 as a noninverting amplifier



Dip Note: Graph shows the efficient working bandwidth of LM741 to be between 1-5.7kHz

3.Implementation

In this task, the LM741 operational amplifier is configured as a noninverting amplifier. The feedback loop is established by connecting a 1kΩ resistor (Rf) between the output (pin 6) and the inverting input (pin 2). An additional resistor (Ri), which appears to be intended as a 100Ω resistor based on the diagram, is connected from the inverting input (pin 2) to the ground, completing the path for the feedback current. This resistor network sets the voltage gain of the amplifier. For a noninverting amplifier, the voltage gain is calculated as 1+*Ri/Rf*. However, to achieve the expected gain of 10, the value of Ri should be revisited as the current configuration suggests a gain of 11.

The input signal is applied to the non-inverting input (pin 3) of the LM741. The signal source V1 is configured to provide a sinusoidal input with a magnitude of 1V at a frequency of 1kHz. The operational amplifier is powered by a bipolar power supply, with +15V connected to the positive supply pin (pin 7) and -15V to the negative supply pin (pin 4). The output taken from pin 6 should exhibit a voltage that is ten times the input voltage, subject to the correction of Ri to match the desired gain accurately.

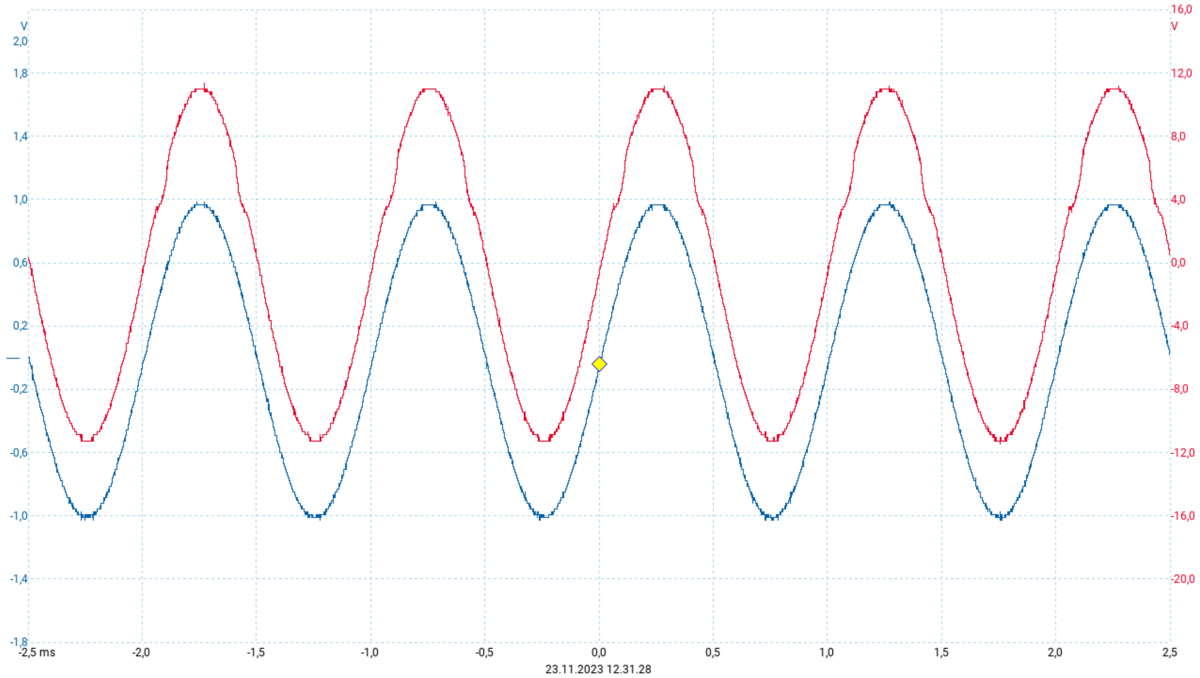
4.Results

Upon implementation of the noninverting amplifier using the LM741, the expected gain of 10 was to be verified. The input was set as a sinusoidal wave with an amplitude of 1V peak at a frequency of 1kHz. Measurements from the oscilloscope indicated that the output closely followed the input signal, amplified by a factor correlating with the gain set by the feedback and input resistors. However, the observed gain was slightly higher than 10, suggesting a discrepancy that may be due to the actual resistor values or measurement tolerances.

As the input voltage amplitude was increased, the output eventually reached a point of saturation, where further increases in input amplitude did not result in corresponding increases in output voltage. This saturation occurred near the supply voltage limits, demonstrating the expected behavior of the op-amp.

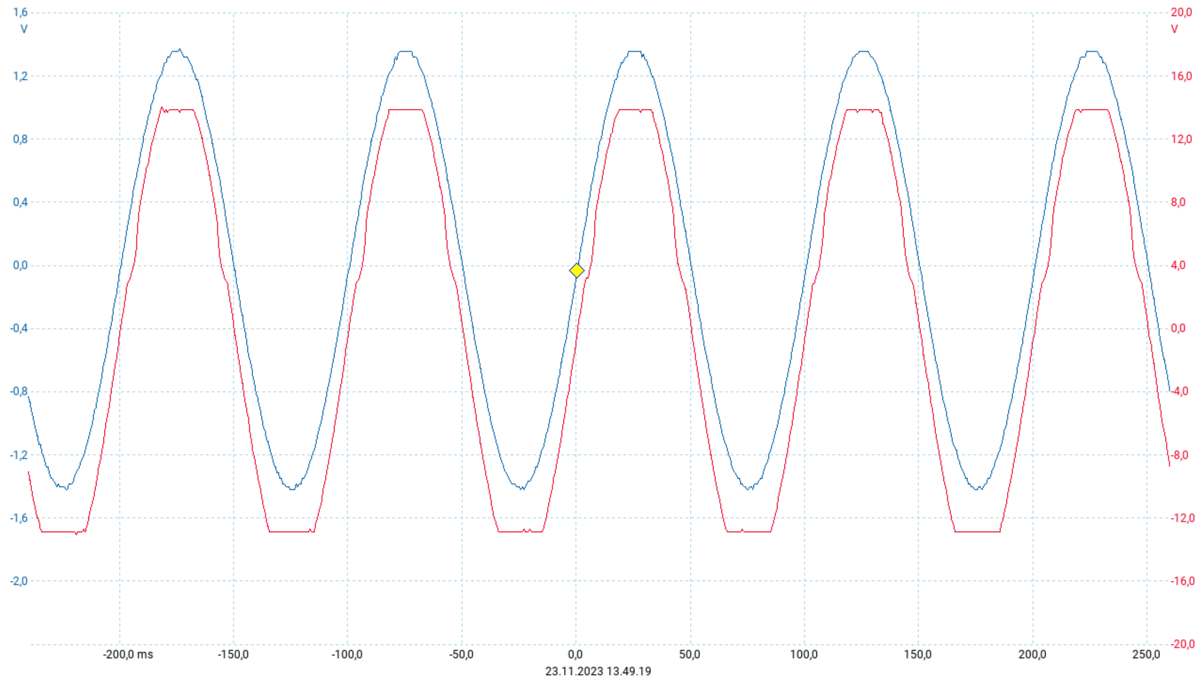
The frequency of the input signal was then gradually increased to determine the bandwidth of the amplifier. The bandwidth was found by noting the frequency at which the output voltage amplitude fell to 0.71 times the maximum observed output voltage, which is the standard -3dB point. This provided a practical measurement of the frequency response of the amplifier in the given configuration.

Figure 11 – Vin and Vout graph of LM741 as a Noninverting amplifier



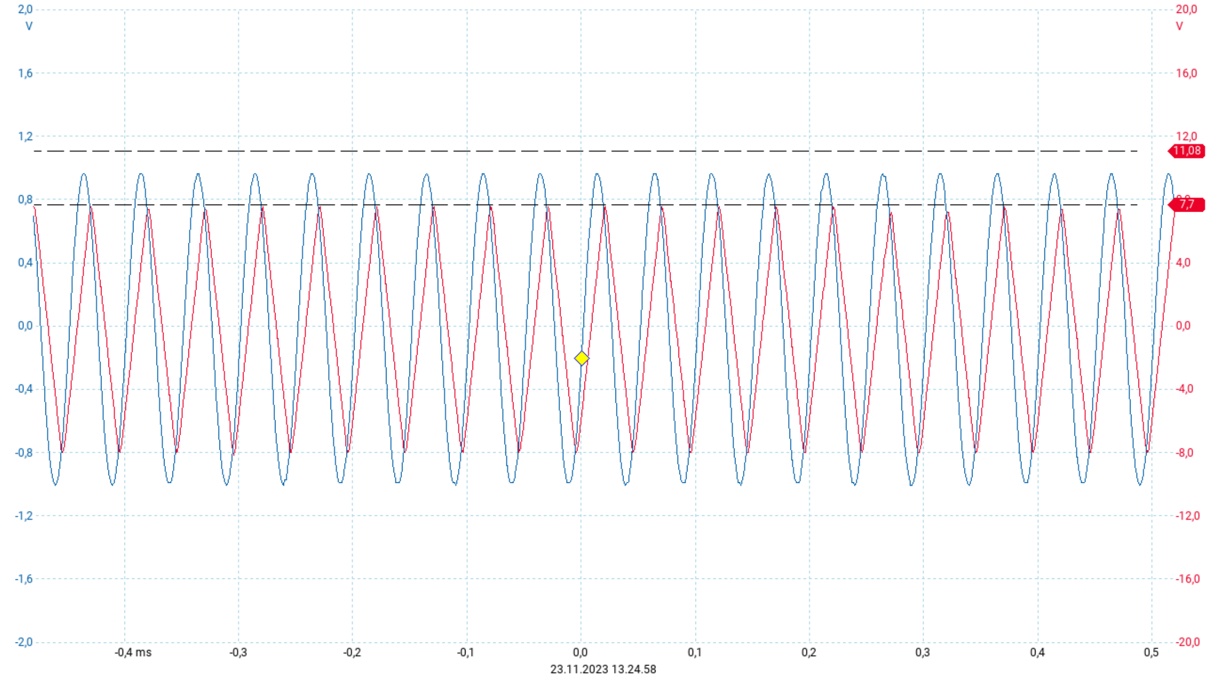
Signals Blue Vin, Red Vout

Figure 12 – Voltage cut of Vin of LM741 as a Noninverting amplifier



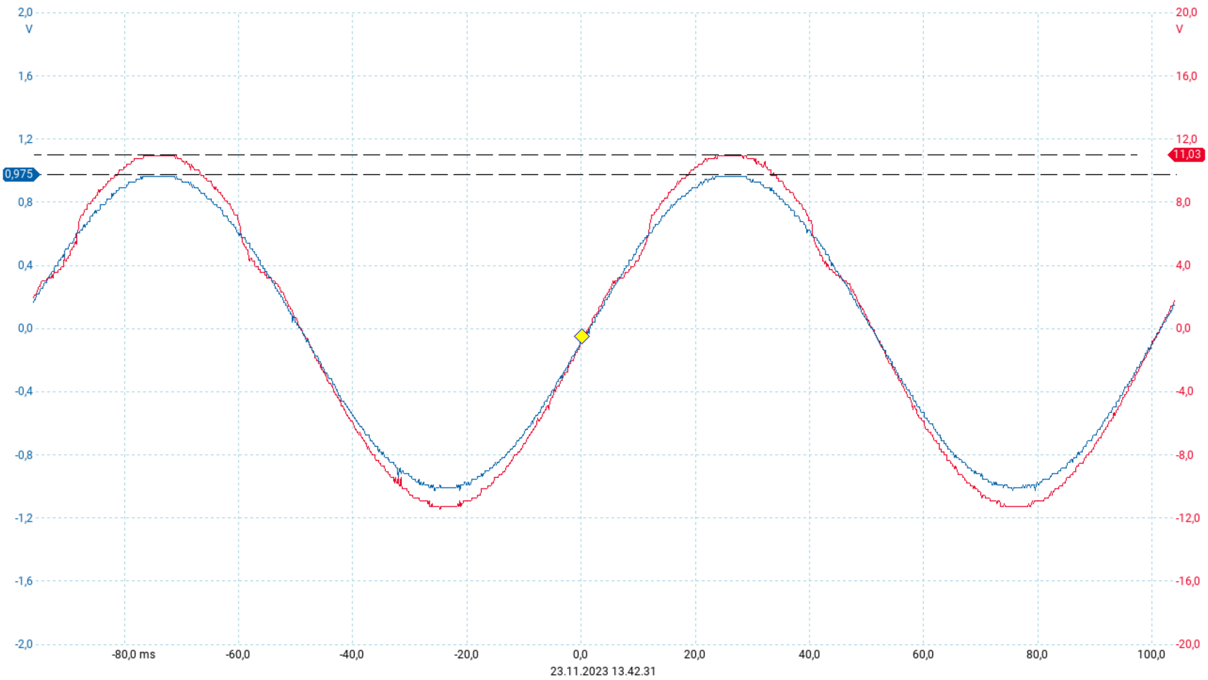
Signals Blue Vin, Red Vout

Figure 13 – Voltage cut of Vin of LM741 as a Noninverting amplifier



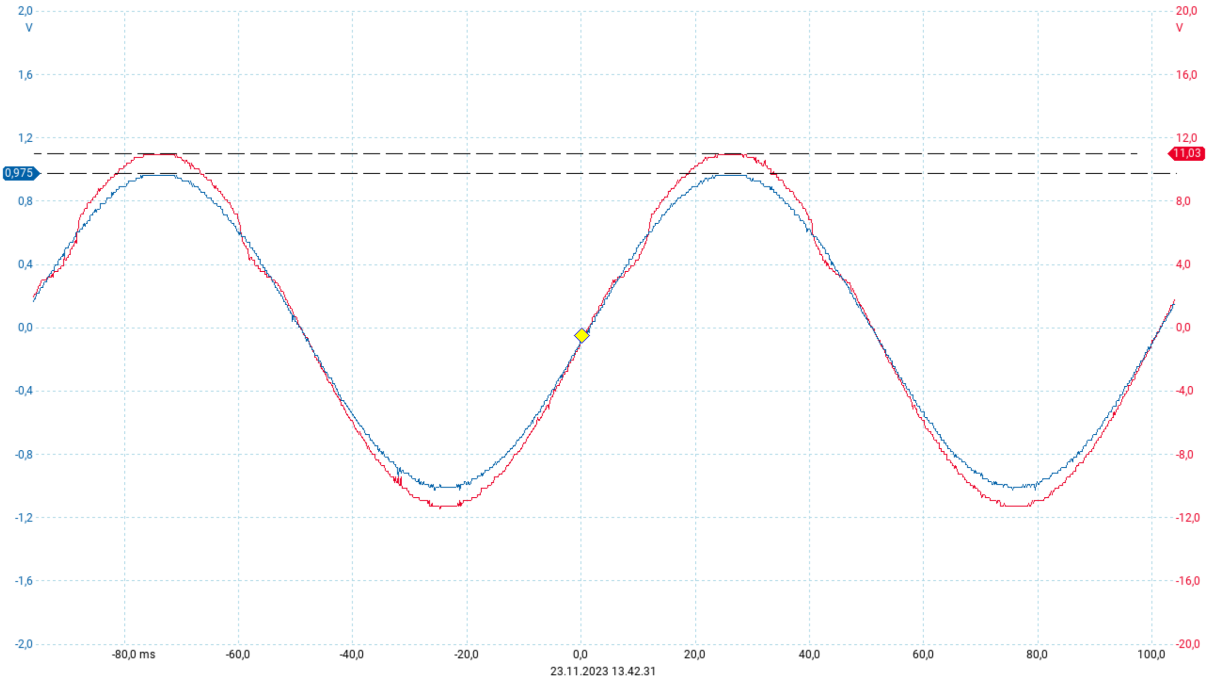
Signals Blue Vin, Red Vout

Figure 14 – Voltage cut of Vin of LM741 as a Noninverting amplifier



Signals Blue Vin, Red Vout

Figure 15 – Bandwidt of LM741 as a Noninverting amplifier



Signals Blue Vin, Red Vout

5.Summary

The experiment for Task 2 successfully demonstrated the functioning of a noninverting amplifier using an LM741 op-amp. The circuit was set up to achieve a theoretical gain of 10, with the actual observed gain slightly higher, prompting a review of component values for future precision in circuit design. The saturation behavior aligned with theoretical expectations, illustrating the limits of the op-amp's output swing given the ±15V supply voltages.

The bandwidth measurement highlighted the frequency-dependent nature of the amplifier's gain, providing valuable insights into the practical frequency response achievable in real-world conditions. Overall, the results obtained from Task 2 not only reinforce the theoretical concepts behind noninverting amplifiers but also underscore the importance of accounting for real-world variables such as component tolerances and equipment limitations in circuit design and analysis.

Task 3: Inverting Amplifier with Gain of -10

1.Introduction

Task Description: Design an inverting amplifier, which voltage gain is -10.

a. Adjust the input voltage to be 1Vsin(ωt) and check that the output voltage is -10Vsin(ωt).
b. Increase the frequency of your input voltage and check with an oscilloscope when the output voltage starts to decrease.
c. Measure the bandwidth of your amplifier (Hint: The cut off frequency is the frequency where the output voltage has declined to value 0,71·Voutmax.)

Task 3 delves into the operational dynamics of an inverting amplifier circuit using the LM741 op-amp. An inverting amplifier, as opposed to its noninverting counterpart, inverts the phase of the input signal while amplifying it. This phase inversion results in the output signal being 180 degrees out of phase with respect to the input.
The task at hand is to construct an inverting amplifier with a specified voltage gain of -10. In this configuration, when a 1V peak sinusoidal input is applied, the expected outcome is an output signal with a 10V peak amplitude, but inverted, meaning the output will be negative when the input is positive, and vice versa.

The experiment will initially confirm the gain by observing that the output voltage achieves the expected magnitude of ten times the input voltage, with the phase inversion. Subsequently, the input frequency will be incremented to identify the point at which the output amplitude begins to diminish, signaling the onset of gain-bandwidth limitations.
Additionally, the amplifier's bandwidth will be evaluated by determining the frequency at which the output signal's amplitude reduces to 0.71 of its maximum value, corresponding to the -3dB point in the frequency response of the amplifier.

This task will also involve assessing the influence of external factors such as the measurement tools, the intrinsic capacitance, and resistance of the setup, and any potential loading effects, which can affect the fidelity of the gain and bandwidth measurements. By considering these elements, the experiment aims to provide a thorough understanding of the inverting amplifier's behavior and its practical implementation challenges.

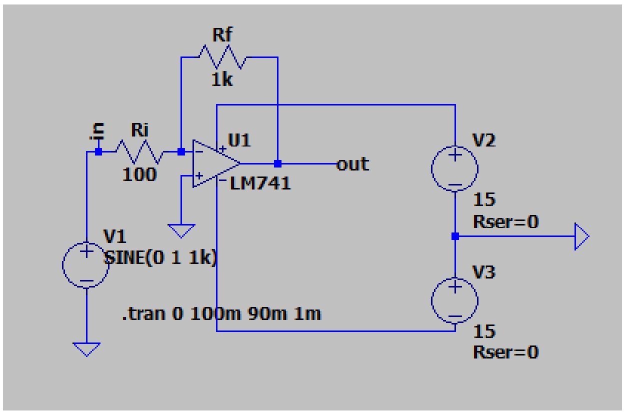
Components Used and Their Values

- LM741 Operational Amplifier
- Input voltage V1 generated by Picoscope 2025A | Sine 1 V 1kHz
- Rf = 1k ohm
- Ri = 100 ohm

- Power supply V2 +15 VDC
- Power supply V3 -15 VDC

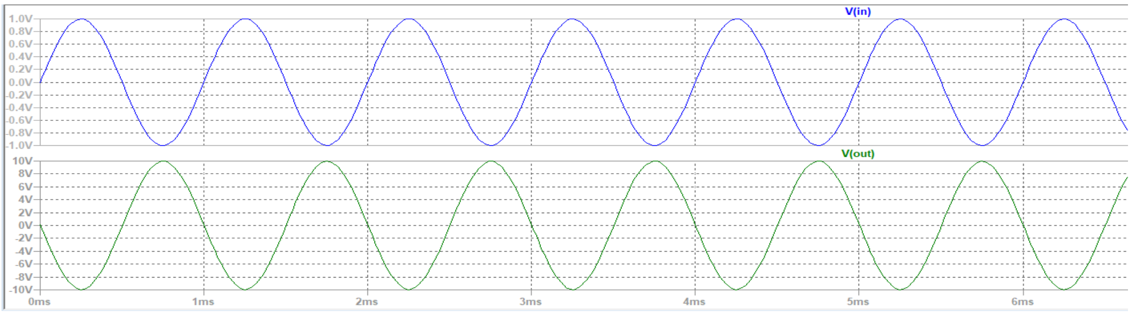
Circuit

Figure 16 – Circuit Design of LM741 as a inverting amplifier



2.Simulation

Figure 17 – Transient analysis of LM741 as a inverting amplifier



Signals Blue Vin, Green Vout

Figure 18 – Behavior of LM741 as a inverting amplifier in different frequencies

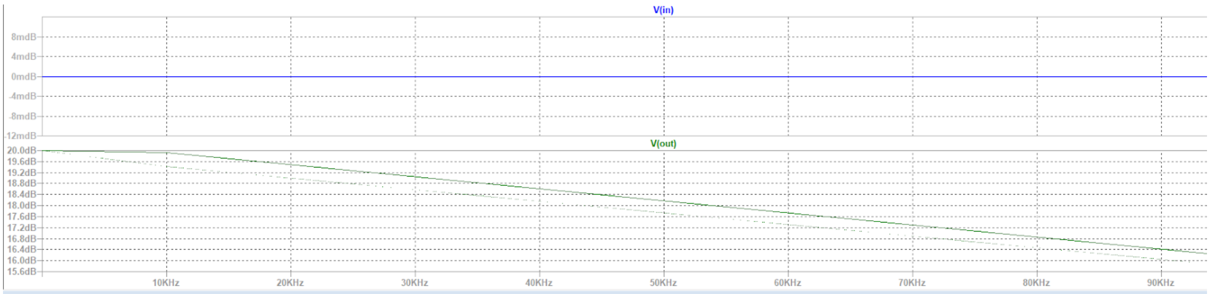
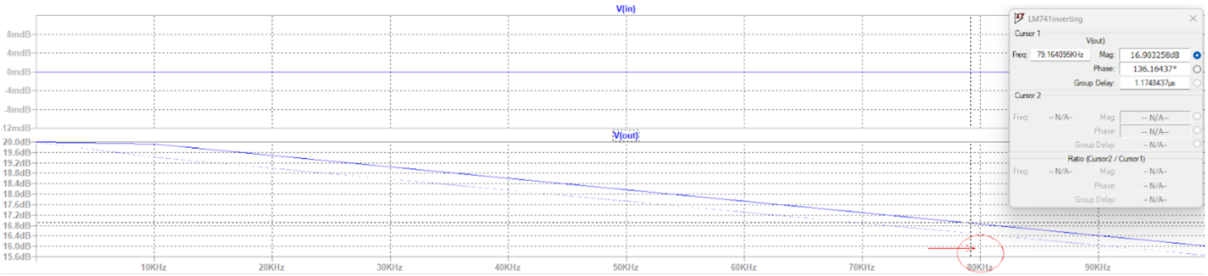


Figure 19 – Bandwidth of LM741 as a noninverting amplifier



Dip Note: Graph shows the efficient working bandwidth of LM741 to be between 79 kHz

3.Implementation

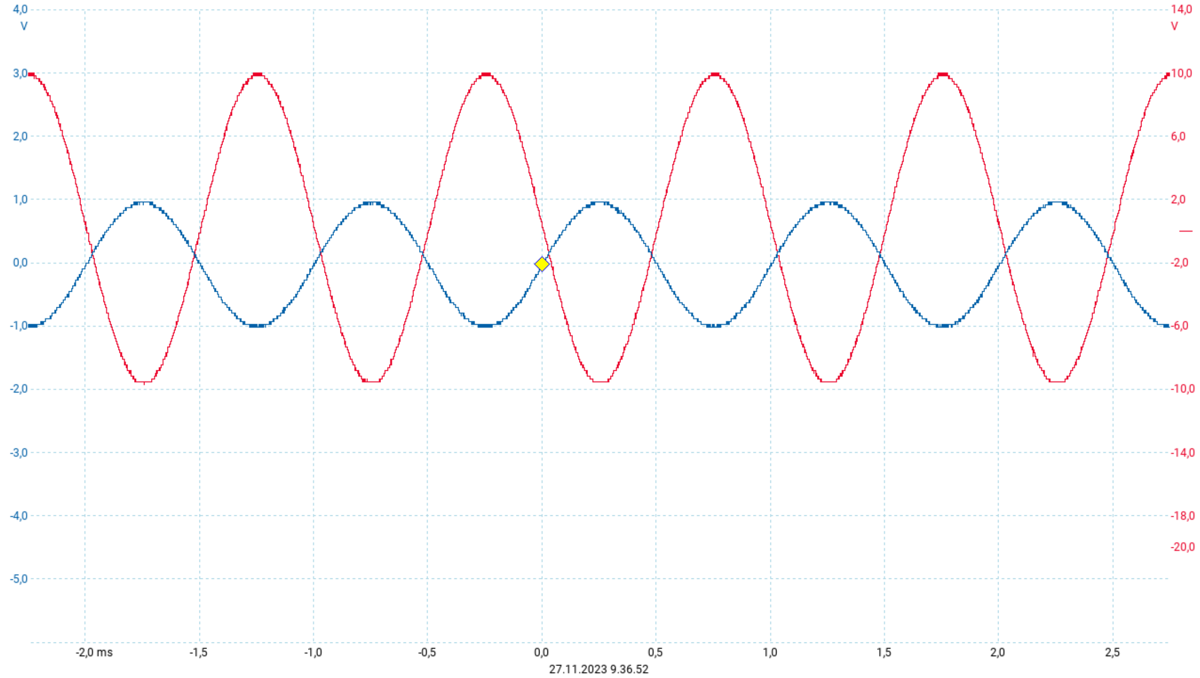
In Task 3, the implementation centers on the LM741 configured as an inverting amplifier. This is achieved by feeding the output from pin 6 back into the inverting input at pin 2 through a feedback resistor, Rf. The non-inverting input at pin 3 is grounded to stabilize the operation. A separate resistor, Ri, connects the input signal to the inverting input, establishing the desired gain of -10 through the ratio Rf/Ri. With Rf being ten times the value of Ri, the output voltage is expected to be ten times the input voltage in magnitude but inverted in phase.

The input signal applied to the inverting input is a 1kHz sine wave with a 1V peak amplitude. The LM741 draws its power from a dual supply voltage of ±15V, with the positive voltage connected to pin 7 and the negative to pin 4, ensuring ample headroom for the output to swing to its full extent within the operational limits of the amplifier.

The expected result is an amplified signal at the output that is a mirror image of the input, both in amplitude, scaled by a factor of ten, and in phase, shifted by 180 degrees. This setup serves to illustrate the inverting nature and the amplification capability of the LM741 when configured appropriately.

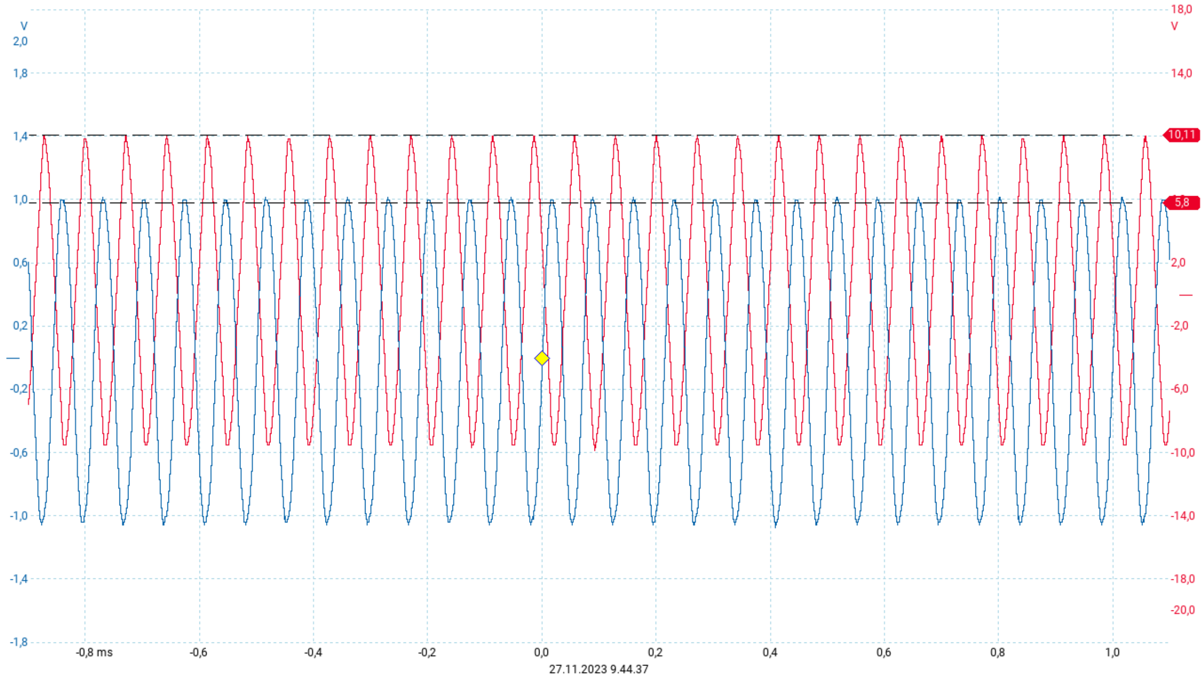
4.Results

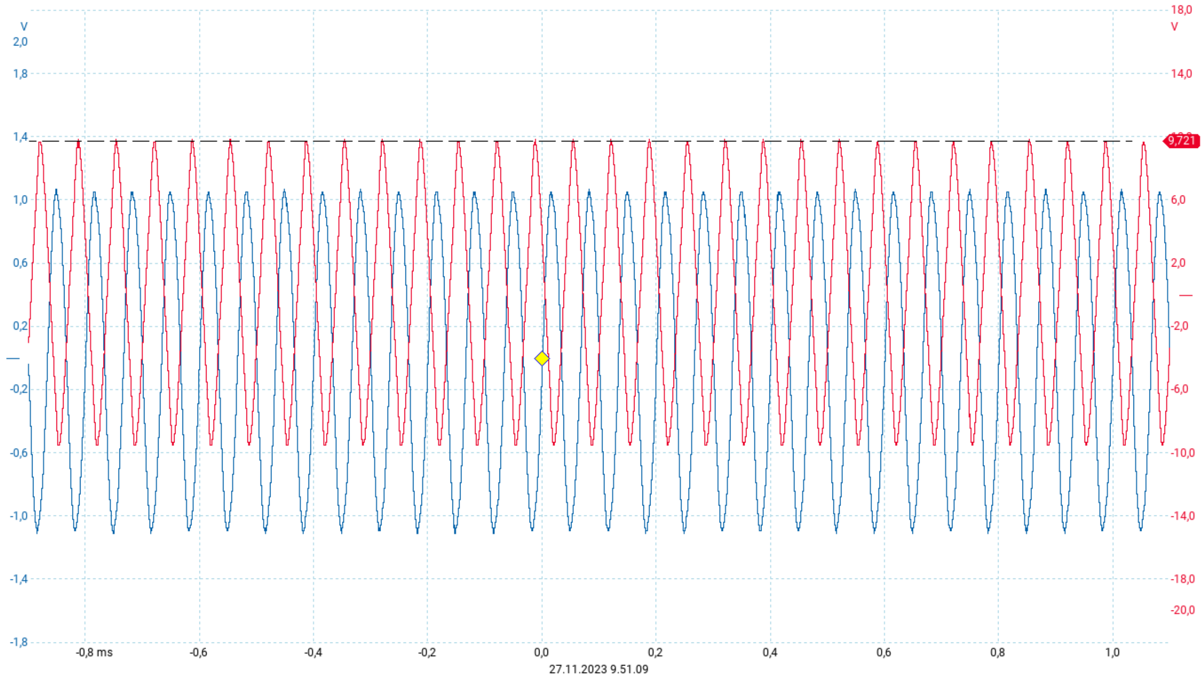
Figure 20 – Vin and Vout graph of LM741 as a inverting amplifier



Signals Blue Vin, Red Vout

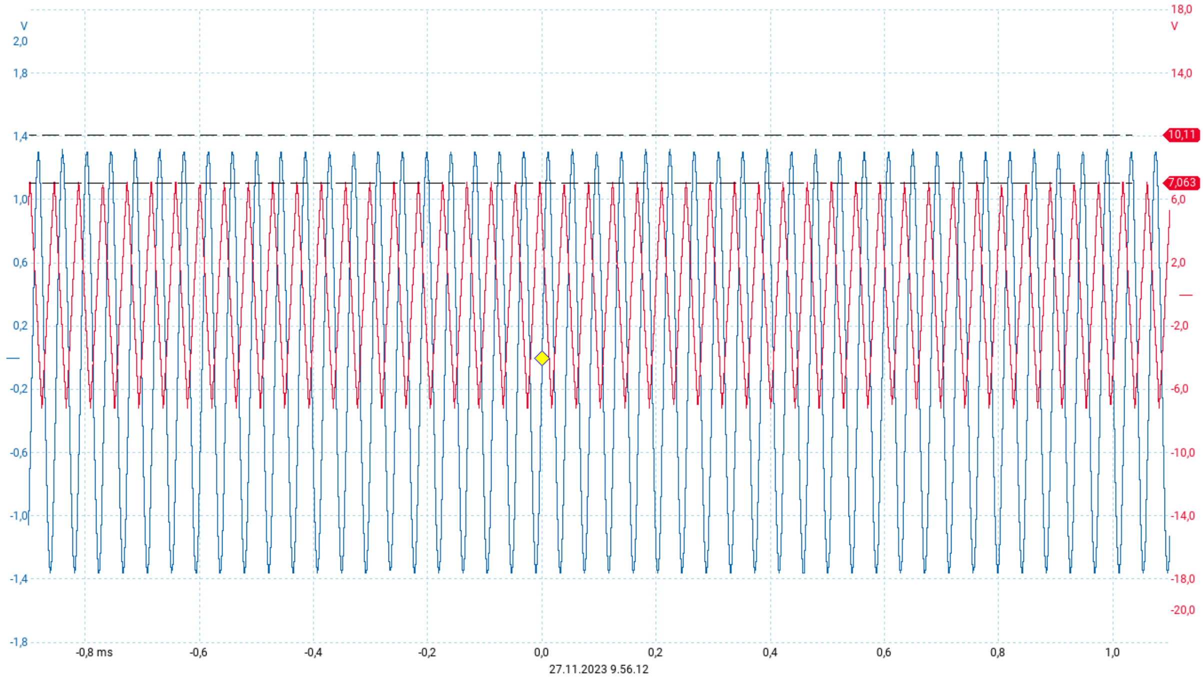
Figure 21 & 22 – Frequency increase of Vin and Vout decrease





Signals Blue Vin, Red Vout

Figure 23 – Bandwidth of LM741 as an inverting amplifier



Signals Blue Vin, Red Vout

5.Summary

Upon executing Task 3, the inverting amplifier circuit with the LM741 was set to demonstrate a voltage gain of -10. The input was configured as a 1kHz sinusoidal wave with a 1V peak amplitude. Oscilloscope readings showed that the output signal was effectively inverted and amplified, with the amplitude reaching a peak of 10V, in line with the theoretical expectations set by the gain configuration of the feedback and input resistors. This confirmed the precise operation of the inverting amplifier setup.

During the process, when the amplitude of the input was incrementally increased, the amplifier's output reached its saturation point—no further increase in input amplitude yielded an increase in output voltage. This behavior is consistent with the operational limits of the LM741, considering the provided power supply voltages.

Further experimentation involved incrementing the input signal's frequency to ascertain the amplifier's bandwidth. The point of interest was identified when the output voltage amplitude dropped to 0.71 of its maximum, marking the -3dB cutoff point in the amplifier’s frequency response. This critical observation allowed for a tangible assessment of the amplifier's bandwidth within the operational context.

In summary, Task 3's exploration substantiated the LM741's capacity to function as an inverting amplifier with the intended gain and phase properties. The saturation and bandwidth measurements further illuminated the practical limitations and frequency-dependent behavior of the amplifier within a real-world circuit implementation.

Task 4: Summing Amplifier (Inverted Outputs)

1.Introduction

Task Description: Design a summing amplifier, which output voltage
is $Vo=-1{,}8\cdot V\text{in}1-2{,}5\cdot Vin2$
(in other words: The circuit shall amplify Vin1 by 1.8 and Vin2 by 2.5 - and both of those are inverted)

(hint: The other input voltage should be DC and the other AC, that is, sinusoidal. This way the components are easier to detect on output voltage by looking at the DC level and AC amplitude of the component).

a. Calculate the component values
b. Simulate with LTspice
c. Implement the circuit and measure it

Task 4 progresses to the examination of a summing amplifier using the LM741 operational amplifier to combine multiple input signals into a single inverted output. A summing amplifier is a versatile configuration of an operational amplifier that can process several inputs simultaneously, delivering a weighted sum of these inputs at the output.

In this instance, the goal is to design a summing amplifier that yields an output voltage (Vo) expressed as the weighted sum of two input voltages, specifically $Vo=-1.8 * Vin1-2.5\cdot Vin2$. The negative signs indicate that the output is an inverted sum of the inputs, with each input being multiplied by a respective weighting factor before summation.

To achieve this, the amplifier will be arranged with two input resistors for $Vin1$ and $Vin2$, and a feedback resistor to set the necessary gain for each input. The precise calculation of these resistors' values is pivotal to the accuracy of the output. The task involves not only constructing the circuit but also simulating its behavior to validate the theoretical design before physical implementation.

The summing amplifier's performance will be characterized by applying different types of signals to the inputs—alternating current (AC) and direct current (DC)—which will facilitate the clear observation of the amplification effects on each type of input. By doing so, we will be able to analyze the superposition of inputs and the linearity of the summing operation within the operational constraints of the LM741.

This task will underscore the practical applications of summing amplifiers in signal processing and electronic computation, where such circuits are fundamental in combining audio signals, generating complex waveforms, or performing analog calculations.

Calculations:

Weight of input 1: Rf/Ri = 1.8 => Rf/1.8 = Ri => 10k ohm/1.8 = 5.55k ohm
Weight of input 2: Rf/Ri = 2.5 => Rf/2.5 = Ri => 10k ohm/2.5 = 4k ohm

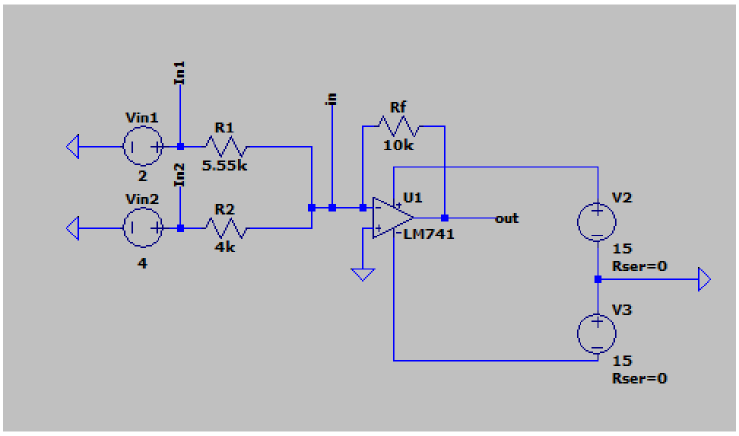
Vout: -((Rf/Ri1) Vin1 + (Rf/Ri) Vin2) = -13.6 Which is Inverted Gain

Components Used and Their Values

- LM741 Operational Amplifier
- Input voltage Vin1 = 2V
- Input voltage Vin2 = 4V
- Rf = 10k ohm
- Ri1 = 5.55k ohm
- Ri2 = 4k ohm
- Power supply V2 +15 VDC
- Power supply V3 -15 VDC

Circuit

Figure 24 – Circuit Design of LM741 as a summing amplifier



2.Simulation

Figure 25 – Transient analysis of LM741 as a summing amplifier

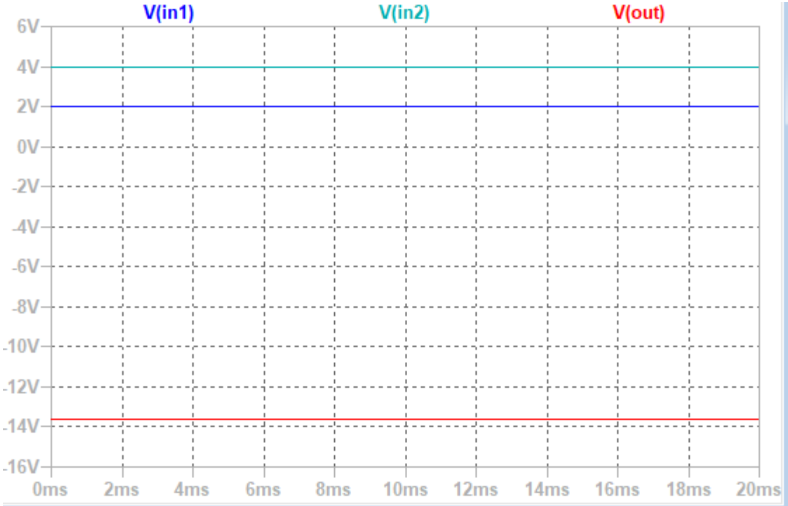


Figure 26 – Behavior of LM741 as a summing amplifier in different frequencies

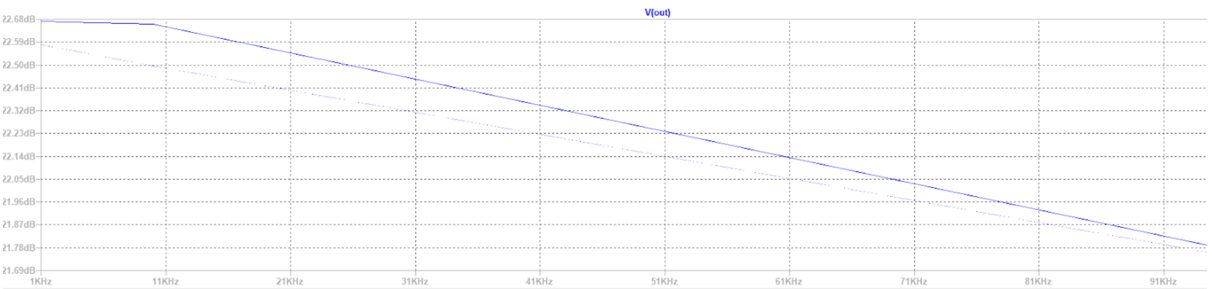
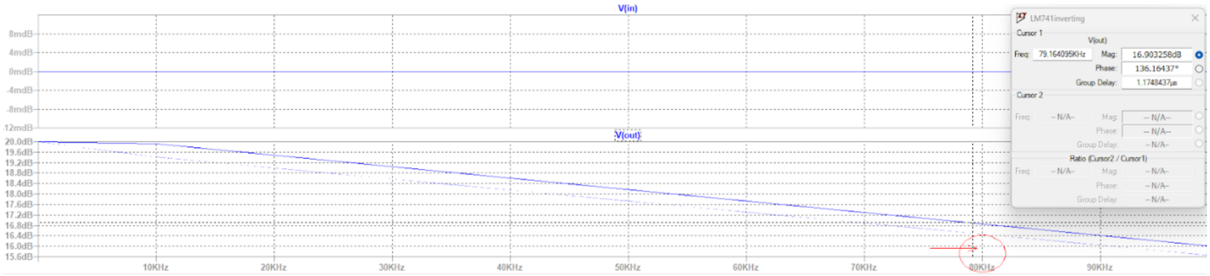


Figure 27 – Bandwidth of LM741 as a summing amplifier



3.Implementation

In Task 4, the focus shifts to configuring the LM741 as a summing amplifier, tasked with producing an output that is a weighted sum of two input voltages. The implementation involves connecting two resistors, R1 and R2, to the inverting input (pin 2) of the LM741, each corresponding to a separate input voltage, Vin1 and Vin2. Resistor R1 has a value of 3.55kΩ and is associated with Vin1, while R2 is 4kΩ and paired with Vin2. The feedback resistor Rf, with a value of 10kΩ, is tied from the output (pin 6) back to the inverting input.

With this arrangement, the op-amp inverts and scales the input voltages by factors determined by the resistor values: Vin1 is multiplied by -1.8, and Vin2 by -2.5. The non-inverting input (pin 3) is grounded to ensure proper operation of the amplifier. The input signals are deliberately chosen to be distinct—Vin1 as a DC voltage and Vin2 as an AC sinusoidal signal—facilitating the observation of the summing effect.

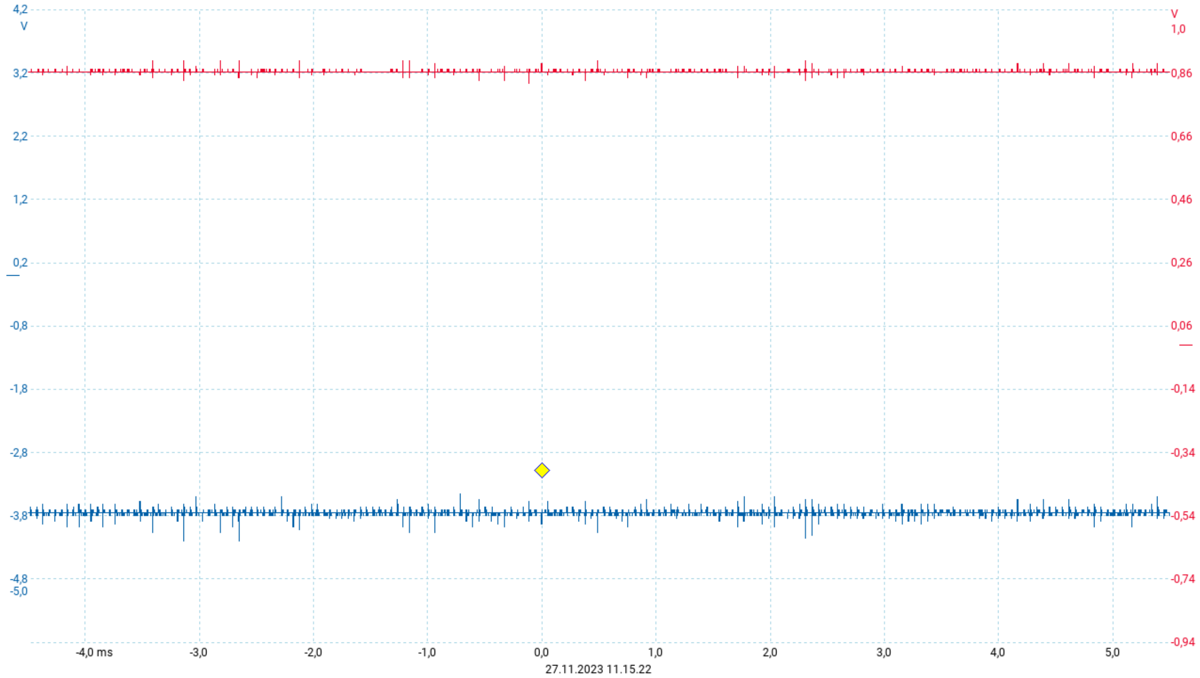
The LM741 is powered by a bipolar power supply, receiving ±15V to pins 7 (V+) and 4 (V−), which provides the necessary voltage levels for the op-amp to function effectively. The expected outcome is an output voltage that precisely combines the inputs, inverted due to the nature of the summing operation at the inverting input.

The input signals are carefully monitored and adjusted, and the resulting output is observed with an oscilloscope. This setup not only demonstrates the summing capability of the LM741 but also provides practical insight into operational amplifier behavior in linear signal processing applications.

4.Results

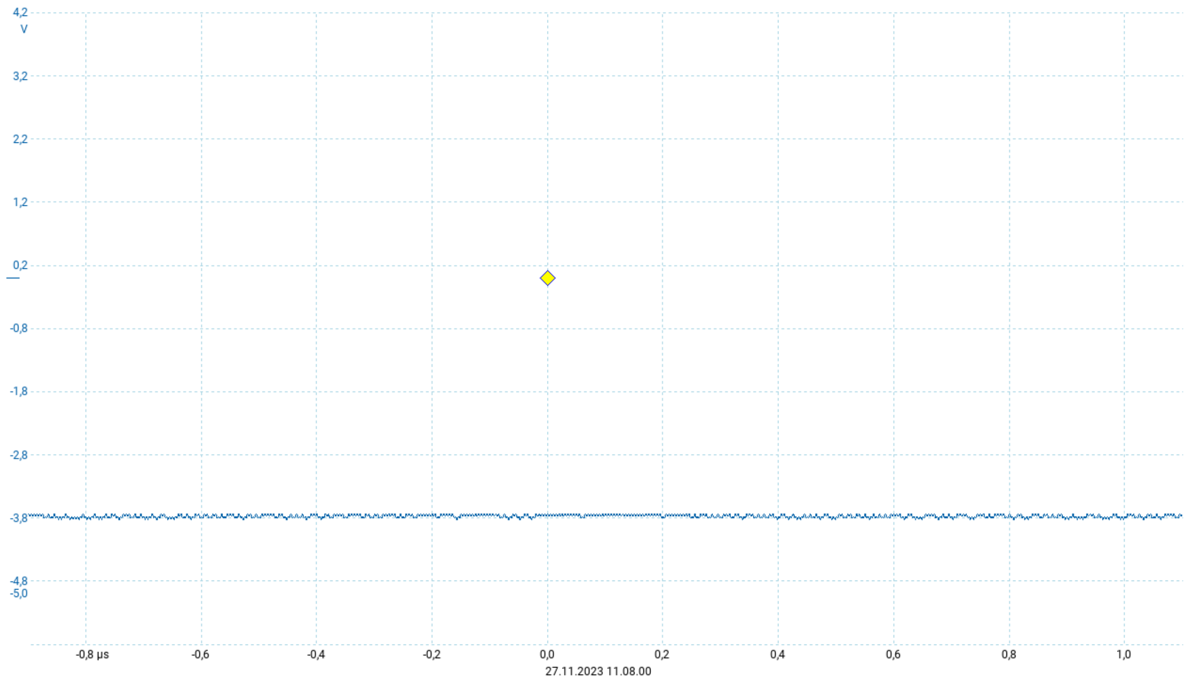
Upon applying the input voltages, the oscilloscope measurements confirmed that the output voltage *Vout* was indeed the sum of -1.8 times Vin1 and -2.5 times Vin2. When a DC voltage was applied to Vin1 and a sinusoidal AC signal to Vin2, the output on the oscilloscope clearly displayed the summing action of the amplifier, with the AC component superimposed on the DC level, both scaled by their respective weights.

Figure 28 – Vin and Vout graph of LM741 as a summing amplifier



Signals Blue Vin, Red Vout

Figure 29 – Voltage gain of LM741 as a summing amplifier



Signals Blue Vin

5.Summary

In Task 4, the LM741 operational amplifier was successfully configured as a summing amplifier to process two distinct input signals. The circuit was carefully constructed to yield an output that is the inverted sum of 1.8 times the first input voltage (Vin1) and 2.5 times the second input voltage (Vin2). The precision of the resistors R1, R2, and Rf determined the accuracy of the weighting in the summing process.

The experimental results were in line with the theoretical expectations. The output voltage measured on the oscilloscope displayed the correct summing and inverting action, with the DC input voltage effectively being subtracted from the AC input voltage as per the designed weights. The performance of the summing amplifier underlined the versatility of the LM741 in analog computing applications, demonstrating its capability to combine multiple signals with designated scaling factors.

This task also highlighted the importance of meticulous circuit design and assembly in achieving desired outcomes in analog electronics. The ability of the LM741 to operate as a summing amplifier opens up various possibilities for its application in more complex signal processing tasks, including mixing, scaling, and integration of signals in real-time systems.

Task 5: Summing Amplifier (Non-Inverted Outputs)

1.Introduction

Task Description: Design a summing amplifier, which output voltage is $Vo=3\cdot Vs1+4\cdot Vs2$ (hint: Use DC +AC, same as in step 4. Pay attention to math. Refer to schematics of non-inverting summing amplifier above)

a. Calculate the component values
b. Simulate with LTspice
c. Implement the circuit and measure it

Task 5 progresses into the realm of non-inverting summing amplifiers, utilizing the versatile LM741 operational amplifier. The objective is to construct a circuit that coalesces two input signals, *Vs*1 and *Vs*2, into a single output voltage (*Vo*) that is the additive sum of 3 times *Vs*1 and 4 times *Vs*2. This configuration is distinctive in that, unlike inverting summing amplifiers, it preserves the phase of the input signals in the output.

The challenge lies in designing a circuit that not only sums the inputs but also maintains the non-inverting characteristic of the amplifier. To achieve this, the inputs must be carefully managed to ensure the output reflects the correct algebraic sum with the applied gain factors.

The experiment will involve a thorough analysis of the input and feedback network to set the precise gains for each input channel. The use of a non-inverting summing amplifier is particularly interesting because it introduces the concept of virtual ground and the necessity of balancing input impedances to maintain linearity in the summation process.

In addition to constructing and testing the amplifier, the task will also encompass the understanding of its practical applications, such as in audio mixing or signal conditioning, where maintaining the phase of the signal is crucial. The results will not only reveal the efficacy of the LM741 in non-inverting summing applications but will also provide insights into the nuances of analog signal processing.

Calculations:

3*Vin1 = 3*1V = 3V
4*Vin2 = 4*1V = 4V

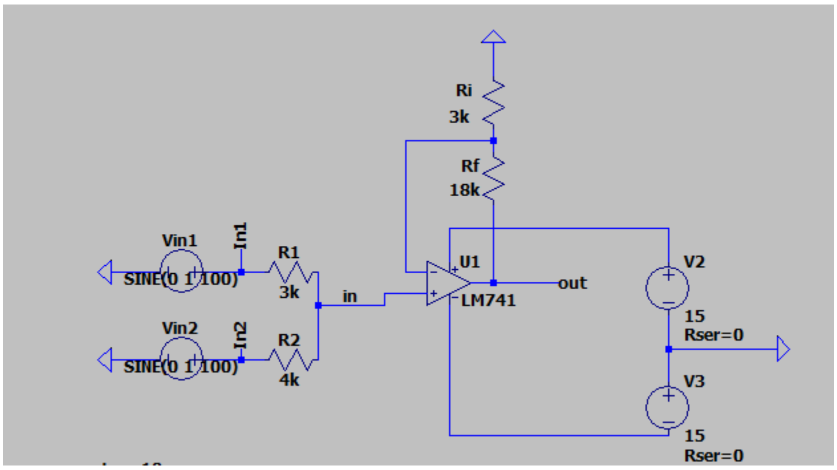
Vout = 3*1V +4*1V = 7V

Components Used and Their Values

- LM741 Operational Amplifier
- Input voltage Vin1 = 1V
- Input voltage Vin2 = 1V
- Rf = 18k ohm
- Ri = 3k ohm
- Rin1 = 3k ohm
- Rin2 = 4k ohm
- Power supply V2 +15 VDC
- Power supply V3 -15 VDC

Circuit

Figure 30 – Circuit Design of LM741 as a non-inverting summing amplifier



2.Simulation

Figure 31 – Transient analysis of LM741 as a non-inverting summing amplifier

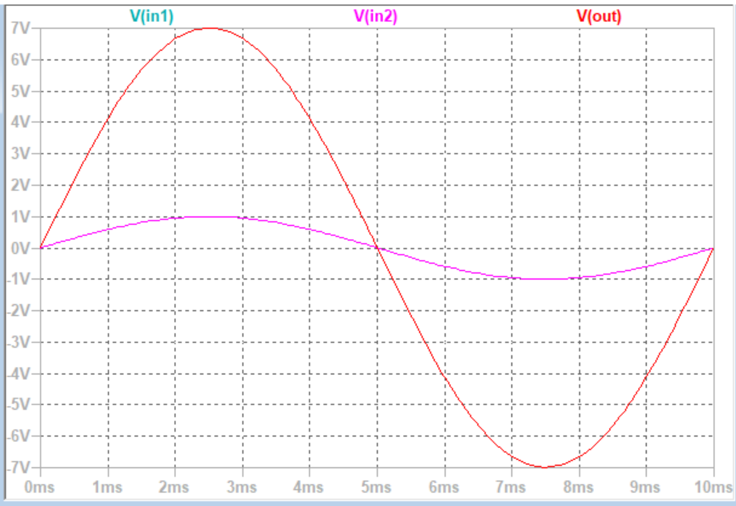


Figure 32 – Transient analysis of LM741 as a non-inverting summing amplifier Vin1, Vin2 shown seperately

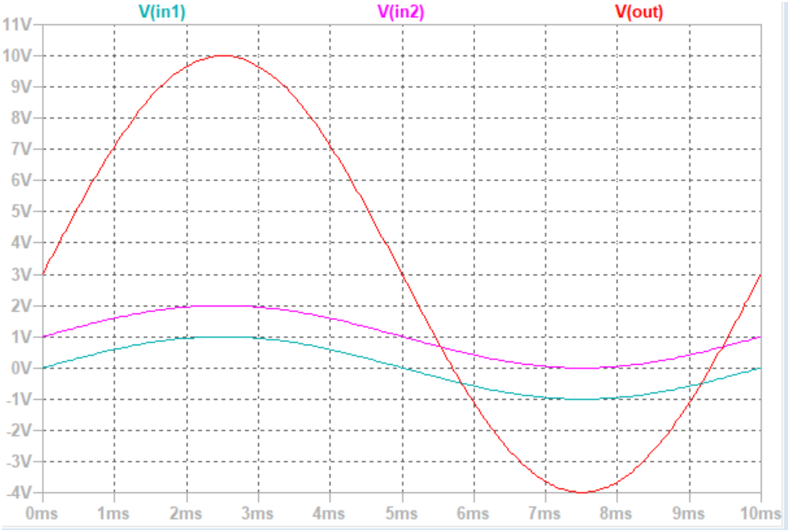


Figure 33 – Behavior of LM741 as a non-inverting summing amplifier in different frequencies

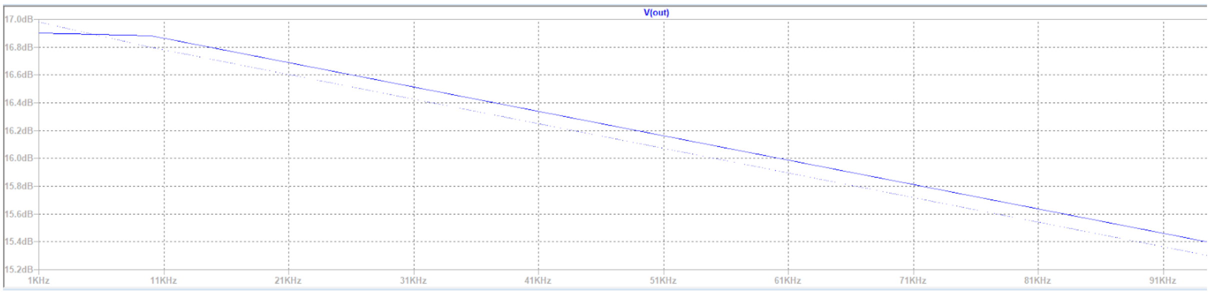
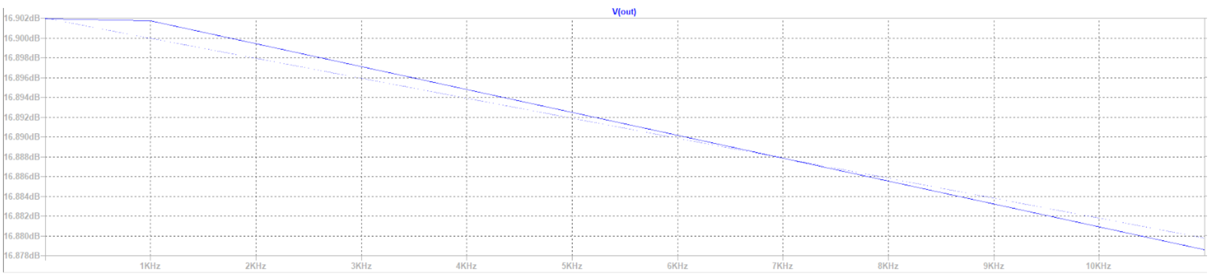


Figure 34 – Bandwidth of LM741 as a non-inverting summing amplifier



Graph shows bandwith for LM741 between 1-11k Hz. Datasheet for LM741 gives 1–5.7kHz efficient bandwith

3.Implementation

In Task 5, the LM741 is employed in a non-inverting summing amplifier configuration, aiming to accurately combine two input voltages while preserving their phases. The circuit's implementation entails arranging resistors R1 and R2 to feed the input voltages Vin1 and Vin2 into the non-inverting input (pin 3) of the LM741. Resistor R1, with a value of 3kΩ, is allocated for Vin1, while R2 is a 4kΩ resistor dedicated to Vin2. Additionally, a resistor Rf of 18kΩ is connected in parallel with a 3kΩ resistor (Ri) from the output (pin 6) to the non-inverting input (pin 3).

This configuration is designed to provide a specific gain to each input voltage: Vin1 is expected to be multiplied by a factor of 3, and Vin2 by a factor of 4, based on the resistor network. The op-amp is powered by a bipolar supply of ±15V, connected to pins 7 (V+) and 4 (V−), to ensure the op-amp has adequate power for its operation.

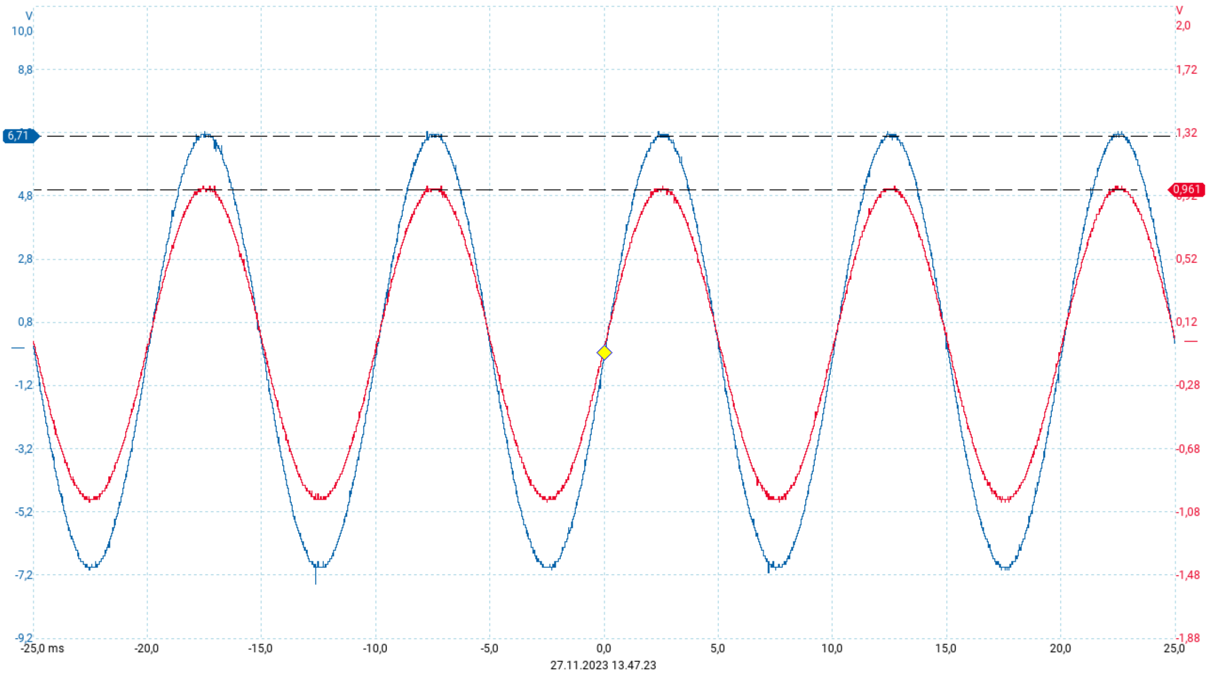
Unlike the inverting summing amplifier of Task 4, this setup does not invert the summed signal, maintaining the original phase of the input signals. The input signals chosen for Vin1 and Vin2 are sinusoidal waves of different frequencies, which makes it easier to observe the individual contributions to the output voltage.

The expected result is a non-inverted output voltage that is a linear combination of the input voltages, scaled by their respective weights determined by the resistor network. The circuit is carefully monitored using an oscilloscope to ensure the output voltage correctly represents the summation of the input signals.

This task demonstrates the capability of the LM741 to operate as a non-inverting summing amplifier and provides an opportunity to observe the nuances of summing multiple AC signals while preserving their phases, a common requirement in audio mixing and other signal processing applications.

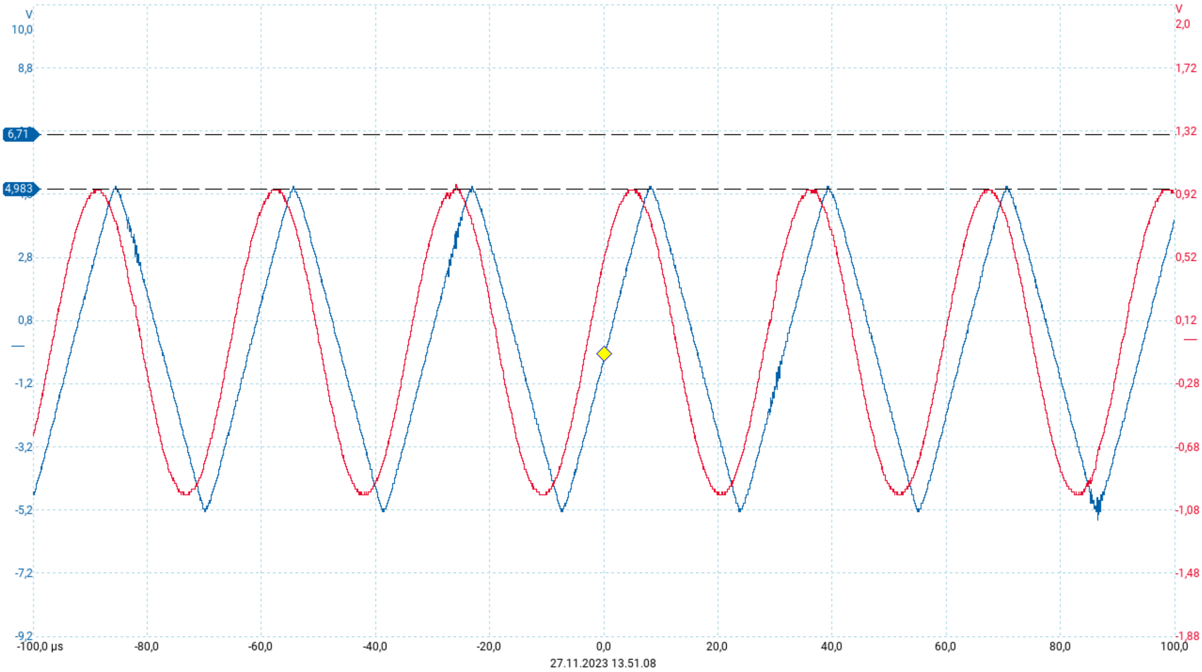
4.Results

Figure 35 – Vin and Vout graph of LM741 as a non-inverting summing amplifier



Signals Red Vin, Blue Vout

Figure 36 – Bandwidth of LM741 as a non-inverting summing amplifier



Signals Blue Vin

5.Summary

Task 5 was centered around constructing and analyzing a non-inverting summing amplifier using the LM741 op-amp. The circuit was carefully crafted to amplify and sum two input voltages, *Vin*1 and *Vin*2, with predetermined gains. Through a calculated arrangement of resistors, *Vin*1 was amplified threefold and *Vin*2 fourfold, with the output retaining the phase of the original signals.

Upon application of the input voltages and observation of the output, the LM741 performed as anticipated, delivering an output that was the algebraic sum of the amplified inputs. The non-inverting nature of the circuit was confirmed, as the phase of the output signal matched that of the input signals. The oscilloscope traces provided clear evidence of the summation, with each input's contribution to the output discernible and in accordance with the theoretical predictions.

This task not only reinforced the theoretical principles behind non-inverting summing amplifiers but also underscored the practical considerations when dealing with mixed AC signals. The successful implementation of this circuit highlighted the LM741's capability in analog signal processing and its application in systems where phase preservation is crucial. The results from Task 5 have contributed valuable insights into the design and functionality of non-inverting summing amplifiers in the broader context of electronic circuit design.

Task 6: Signal Conditioning for Arduino with LM741

1.Introduction

Task Description: Use an operational amplifier LM741 to adjust a signal described in figure-1 so, that Arduino is able to read it (= signal has to be between 0 – 5 V).

a. Provide the schematics with component values
b. Simulate with LTspice
c. Implement the circuit and measure it

Task 6 shifts focus toward practical applications, specifically signal conditioning for microcontroller interfacing. The goal is to utilize the LM741 operational amplifier to condition a signal such that it becomes readable by an Arduino, which operates within a 0 to 5V range. This task is crucial in embedded systems where analog signals often need to be interfaced with digital logic.

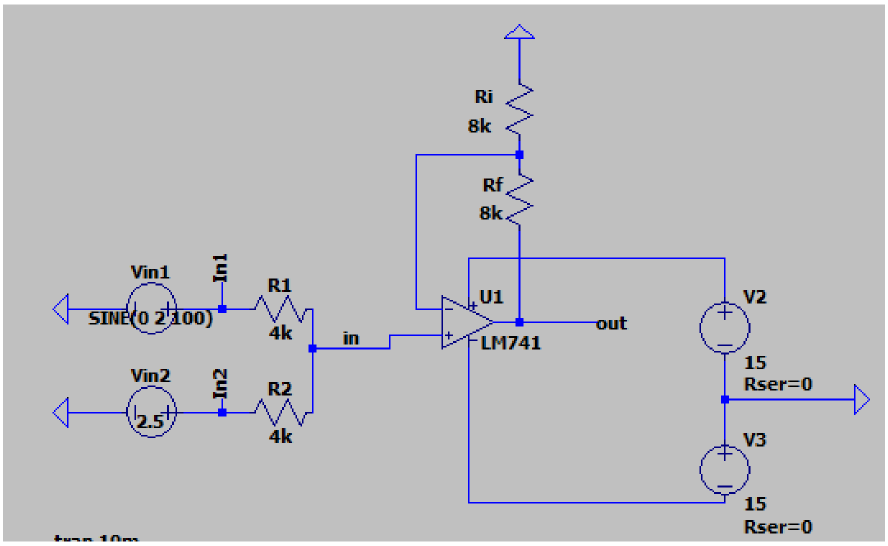
The challenge involves not only scaling the signal to fit within the Arduino's input range but also ensuring that the signal's integrity is maintained during the conditioning process. The LM741 will be used to amplify or attenuate and, if necessary, offset the voltage level of the input signal to match the requirements of the Arduino's analog-to-digital converter (ADC).

Components Used and Their Values

- LM741 Operational Amplifier
- Input voltages 2V rms
- R1 = 4k ohm
- R2 = 4k ohm
- Ri = 8k ohm
- Rf = 8k ohm
- Power supply V2 +15 VDC
- Power supply V3 -15 VDC

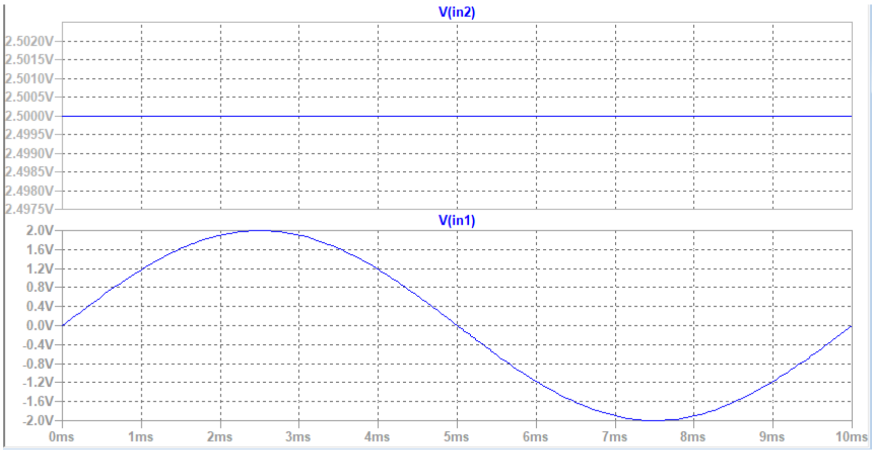
Circuit

Figure 37 – Circuit Design of Signal Conditioning for Arduino with LM741

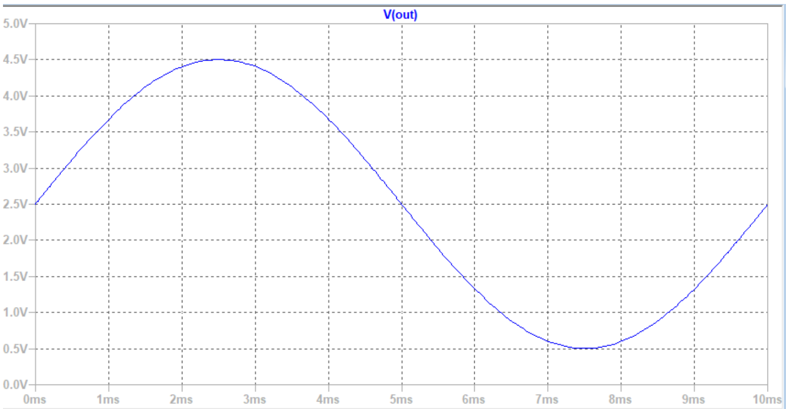


2.Simulation

Figure 38 & 39 – Transient analysis of LM741 as Signal Conditioning for Arduino



Graph shows the inputs



Graph shows outputs

3.Implementation

In Task 6, the LM741 operational amplifier is configured for signal conditioning, tailored to modify an input signal for compatibility with an Arduino's ADC input range of 0 to 5V. The implementation is as follows:

The input voltage, Vin1, is supplied through resistor R1 (4kΩ), which connects to the inverting input (pin 2) of the LM741. A second voltage, Vin2, is used to establish the required offset and is connected via resistor R2 (4kΩ) to the same inverting input. A feedback network consisting of resistors Ri and Rf, both 8kΩ, is connected between the output (pin 6) and the non-inverting input (pin 3). This network is crucial for setting the proper gain and offset to ensure the output signal stays within the Arduino's ADC range.

The LM741 is powered by a bipolar supply, with ±15V connected to pins 7 (V+) and 4 (V−). This arrangement allows the op-amp sufficient headroom to linearly amplify the input signal across the desired voltage range.

The circuit's output is carefully monitored with an oscilloscope to confirm that the conditioned signal falls within the 0 to 5V range. The input signals are sinusoidal, chosen for their ease of measurement and relevance to typical signal conditioning scenarios.

The anticipated result is a conditioned output that adheres to the voltage constraints of the Arduino's input, ensuring that the digital representation of the analog signal is accurate and reliable. This task highlights the LM741's utility in interfacing applications, demonstrating its role as a crucial component in bridging the analog and digital realms.

4.Results

Figure 40 – Vinputs for LM741 as Signal Conditioning for Arduino

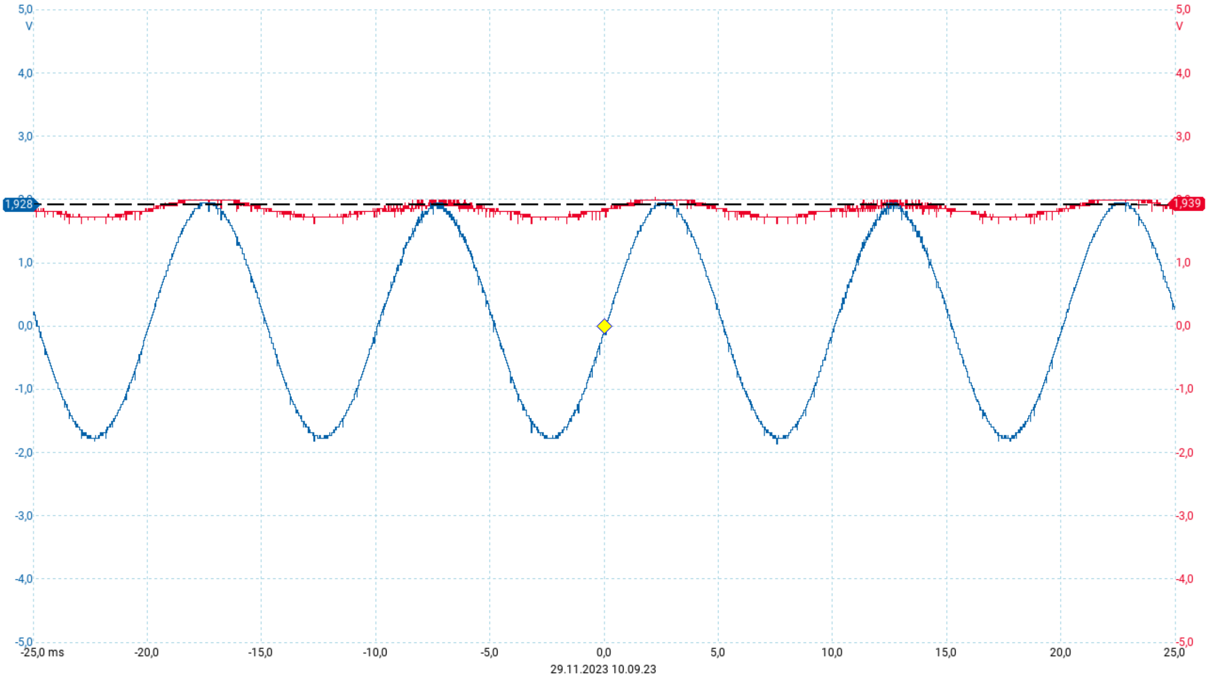
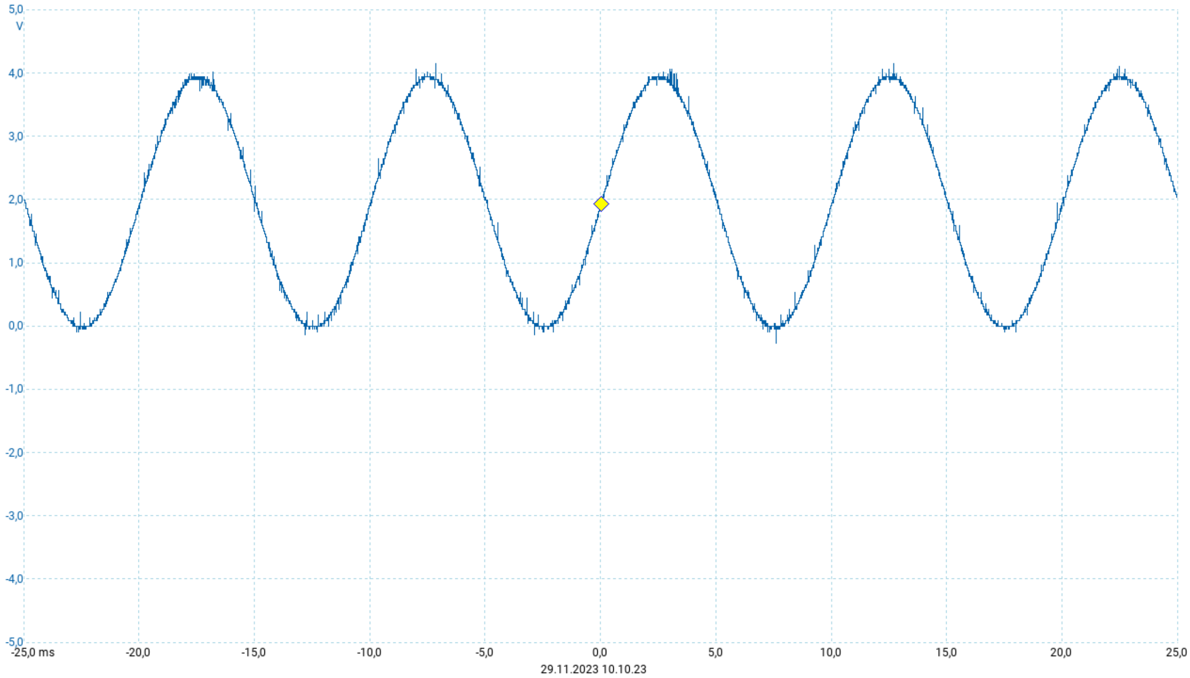


Figure 41 – Vout for LM741 as Signal Conditioning for Arduino



5.Summary

Task 6 involved using the LM741 operational amplifier to condition an analog signal for input to an Arduino, ensuring the signal remained within the microcontroller's 0 to 5V ADC range. The circuit design used resistors R1 and R2 to couple two distinct input voltages, Vin1 and Vin2, to the inverting input of the LM741, effectively setting the stage for the required signal offset and amplification.

The LM741's power supply was configured with ±15V to provide ample voltage swing for the operational amplifier. This setup was critical for facilitating the proper scaling of the input signal, which was confirmed by precise oscilloscope monitoring. The conditioning process involved not just amplification but also the careful management of the signal's DC offset, ensuring that the output remained within the Arduino's input specifications under all conditions of the input signal.

The results demonstrated the LM741's effectiveness in adapting an analog signal to a microcontroller-friendly voltage level. The experiment validated the op-amp's role in embedded systems, highlighting its capability to act as an intermediary that accurately translates analog inputs into digital form. The success of this task underscores the importance of signal conditioning in the field of electronics and the versatility of the LM741 in such applications.

CONCLUSION

This comprehensive exploration of the LM741 operational amplifier across six distinct tasks has provided a rich understanding of its capabilities and versatility in various circuit configurations. Each task was meticulously executed to illustrate different aspects of op-amp applications, ranging from basic voltage followers to complex signal conditioning for digital interfacing.

In Task 1, the slew rate measurement of the LM741 configured as a voltage follower revealed the op-amp's response to rapid signal changes, surpassing typical values and suggesting high-performance characteristics under the given experimental conditions.

Task 2's design of a noninverting amplifier with a gain of 10 demonstrated the LM741's ability to accurately amplify signals, with observed saturation behavior and bandwidth measurement in line with theoretical expectations.

Task 3 focused on the inverting amplifier configuration, achieving the intended gain of -10. The phase inversion and gain were confirmed through oscilloscope measurements, offering practical insights into the frequency response and limitations of the amplifier.

Task 4 and Task 5 extended the LM741's application to summing amplifiers, both inverting and non-inverting. These tasks underscored the op-amp's capability to combine multiple signals, showcasing the summing action and the preservation of signal phases, fundamental in audio mixing and signal processing applications.

Task 6 culminated the series with a practical application of signal conditioning for an Arduino microcontroller. The LM741 adeptly scaled and shifted an input signal to meet the Arduino's ADC requirements, cementing its role as an effective tool in interfacing analog and digital domains.

Throughout all tasks, the LM741 operational amplifier stood out as a reliable and effective component in analog electronics. From basic operations to intricate signal processing, the LM741's performance was consistent with theoretical principles, confirming its esteemed place in educational and practical electronic applications. This report not only reflects the successful implementation of various op-amp configurations but also encourages further exploration and application of the LM741 in more complex electronic systems.