**Op-amp as a differential amplifier**

Here we will learn how an operational amplifier can be used to measure voltage differences.

## Introduction to operational amplifiers

An operational amplifier is a high-grade DC amplifier with special properties. Originally designed for mathematical operations and control engineering applications, operational amplifiers (op-amps) are now used increasingly in analog circuits. Modern operational amplifiers integrating numerous transistors and resistors into a single, small housing offer significant advantages over amplifiers made up of discrete components:

- Compact
- More economical than many separate parts
- Easy to use and develop in terms of circuitry
- Excellent properties and technical specifications

These advantages have allowed the operational amplifier to pervade all areas of electronics in many variations available at reasonable prices from different manufacturers.

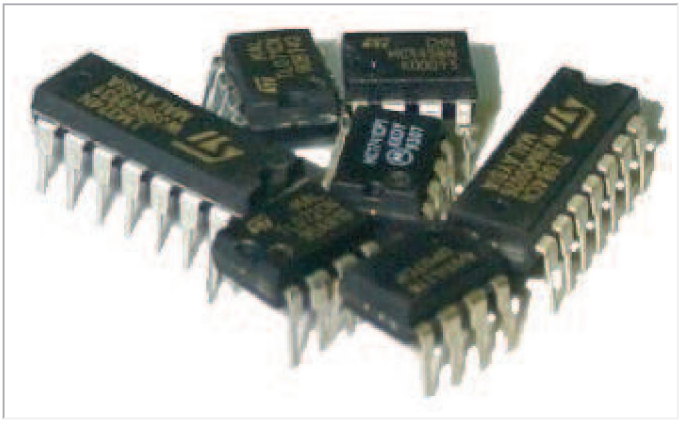
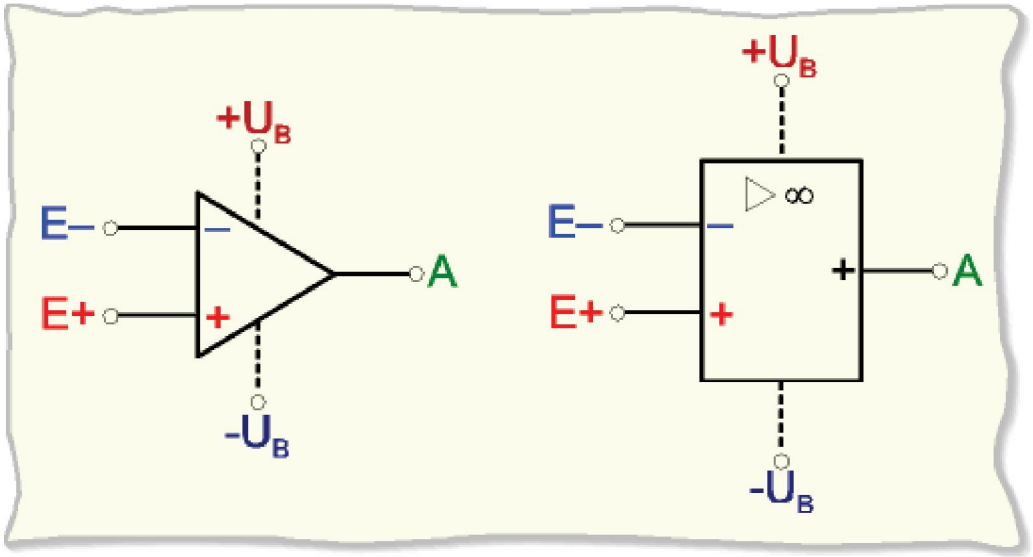


**Figure 1:**
Though operational amplifiers come in housings of various types, they usually have a DIL-housing.
In this age of miniaturization, however, many amplifiers are now being furnished with newer SMD housings.

## Circuit diagram

Although a variety of circuit symbols are used to represent this component, a common one among them is still the relatively old one consisting of a triangle with two inputs and one output. The inverting input is marked with a minus sign, the non-inverting input with a plus sign. The output is not furnished with any markings. In some cases, two further inputs for the positive and negative voltage supply are included.
A newer symbol replacing the triangle with a rectangle has not yet proliferated very widely in practice.




Common representation (similar to DIN 40 900 T10)

Representation according to DIN 40 900 T13

Illustrated above are some of an op-amp's circuit symbols.
We will use the more common, left-hand representation.

## Functional description

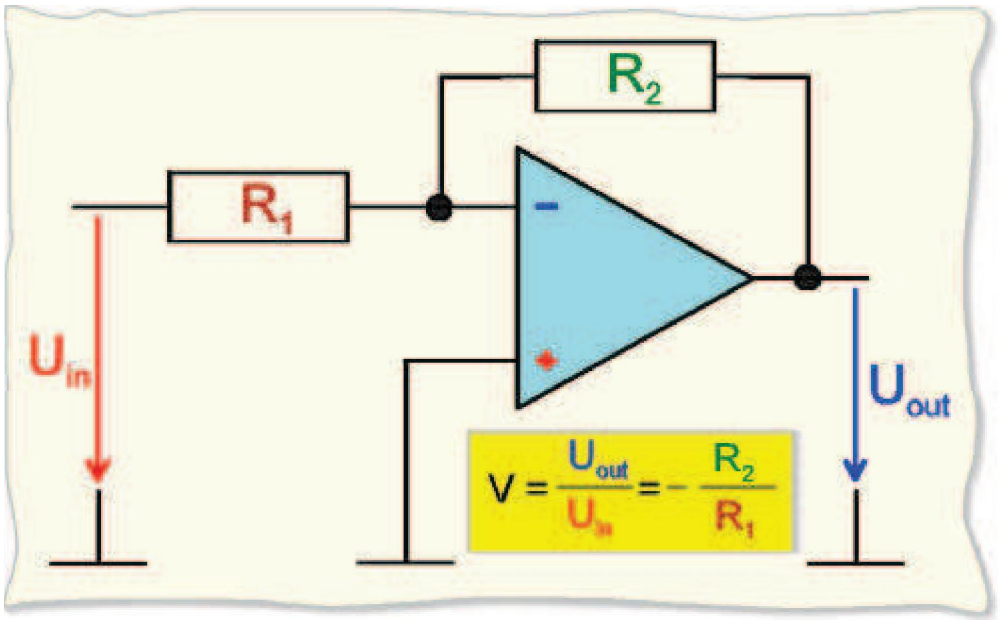
An **ideal** op-amp has an infinite gain independent of the frequency. The amplified parameter is the voltage difference between the op-amp's two inputs, which is why one also speaks of a *differential amplifier*.
The component has one inverting input (E– ) and one non-inverting input (E+). If the voltage at the inverting input is higher than the voltage at the non-inverting input, the op-amp amplifies the difference to output a negative voltage. If the non-inverting input's voltage is higher, then the output voltage is positive.
Ideal op-amps do not exist in practice, these components being subject to limits which can vary considerably depending on design.

Typical values are listed below.

| | |
|---|---|
| Operating voltage: | 3V ... +/-30 V |
| Voltage gain: | $10^3$ ... $10^8$ |
| Input resistance: | $10^5$ ... $10^{15}$ ohms |
| Output resistance: | 15 ... 3000 ohms |
| Frequency range: | 0 Hz ... 100 MHz |

An operational amplifier's functionality ultimately depends on its external circuitry. Many variants are possible here, all of them being employed in circuit technology and described in relevant literature. This introduction deals with three basic circuits which are of special importance and examined in the subsequent experiments.

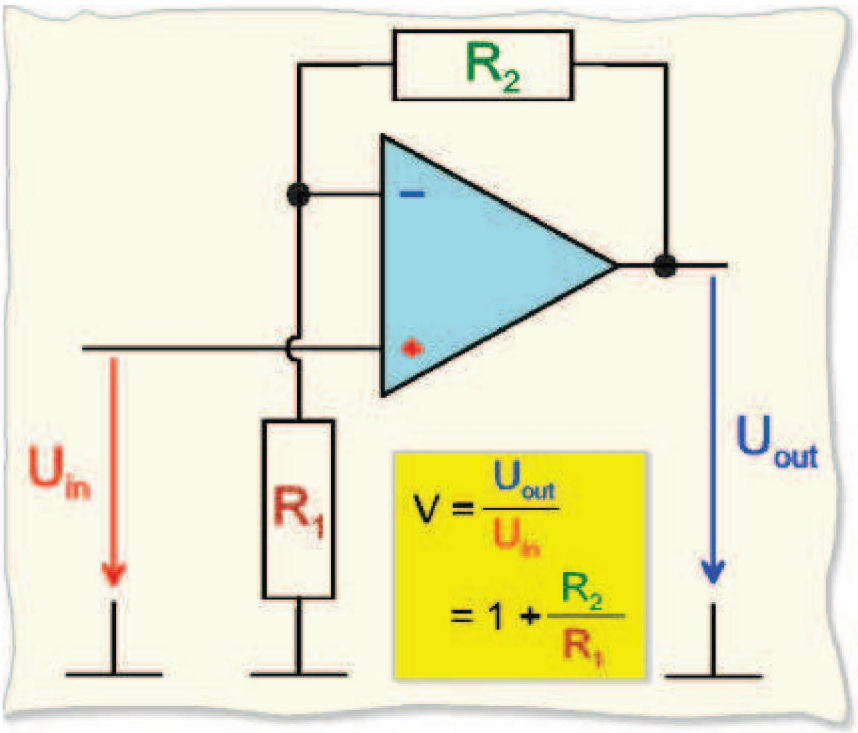
## Inverting amplifier



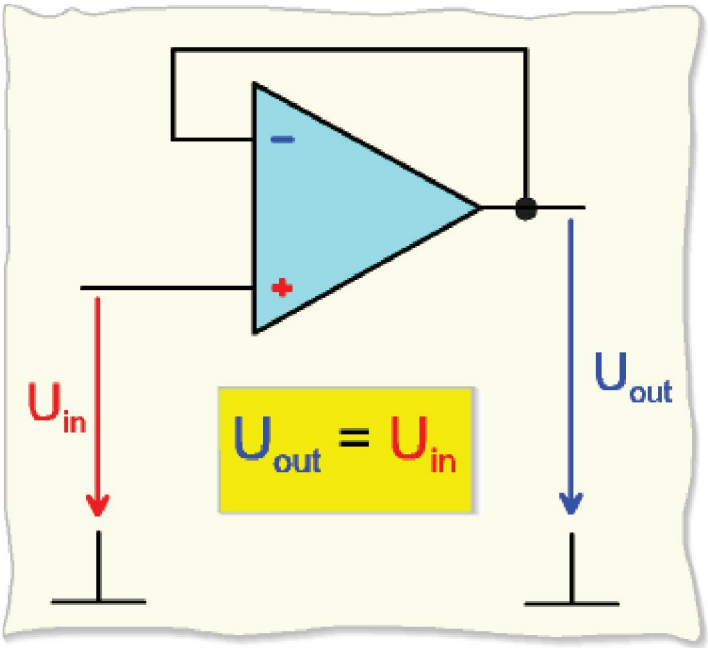

The **inverting** amplifier illustrated above is one of the operational amplifier's standard circuits. Its gain is determined exclusively by the ratio between the two resistors $\mathbf{R_1}$ and $\mathbf{R_2}$.
The output signal $\mathbf{U_{out}}$ is phase-shifted by 180° with respect to the input signal $\mathbf{U_{in}}$. This inversion is reflected in the negative value of the gain **V**.
If $\mathbf{R_1}$ is greater than $\mathbf{R_2}$, the gain $\mathbf{V} < 1$, resulting in attenuation.

The circuit's input resistance is determined by resistor $\mathbf{R_1}$.

## Non-inverting amplifier




An amplifier circuit whose output signal is in phase with the input signal **(i.e. not inverted)** is achieved by wiring an op-amp as shown here. The gain depends on the ratio between resistors $R_2$ and $R_1$, and is always larger than 1. The circuit's input resistance is very high and determined by the op-amp's input resistance. Depending on the amplifier's design, this resistance lies in the range of $10^5$ ... $10^{15}$ ohms.

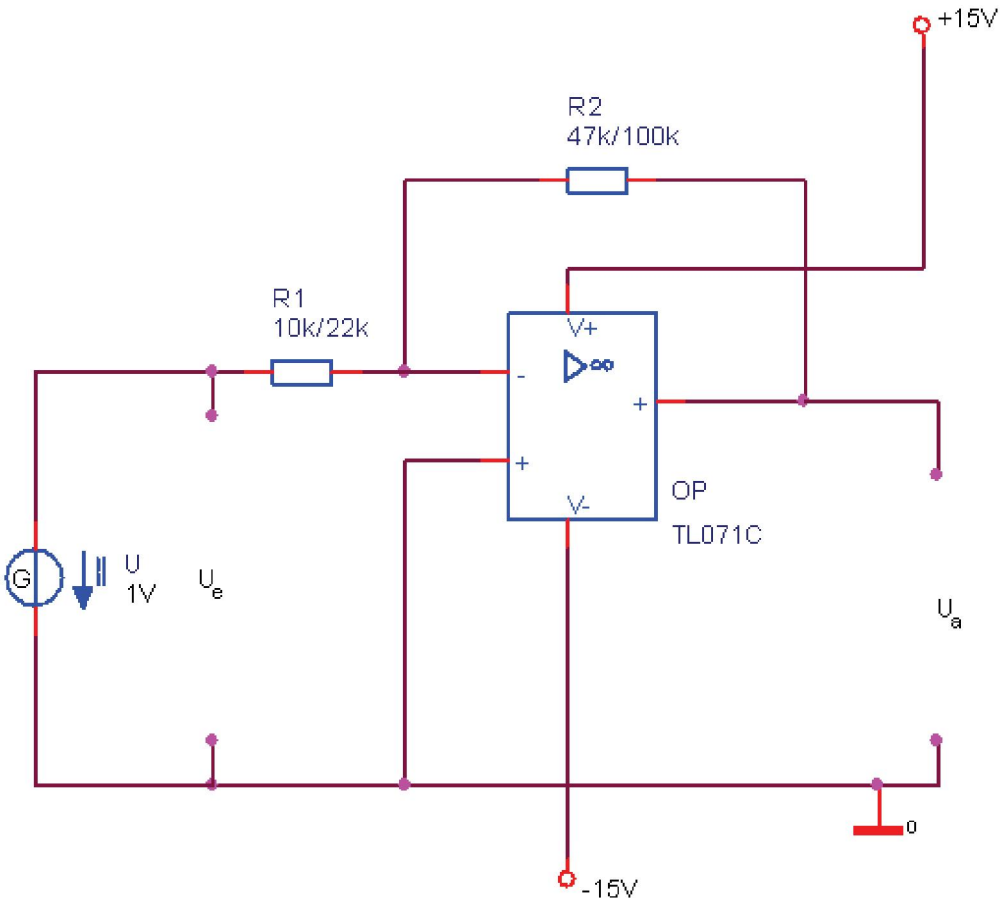



A special form of the non-inverting amplifier is the voltage follower with a gain of 1. The

voltage follower is also known as an impedance converter, due to its relatively high input resistance and relatively low output resistance.

## Circuit diagram

This experiment is configured according to the circuit diagram shown next.



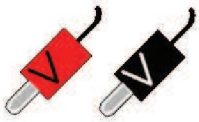
## Components

The components listed below are needed here.

| Quantity | ID | Designation |
|---|---|---|
| 2 | PS4124-01 | Cable |
| 4 | PS4124-02 | Large bridge |
| 24 | PS4124-03 | Small bridge |
| 1 | PS4121-3Q | R 10k |
| 1 | PS4121-3U | R 22k |
| 1 | PS4121-4A | R 47k |
| 1 | PS4121-4E | R 100k |
| 1 | PS4123-2V | OP 741 |

## Instruments

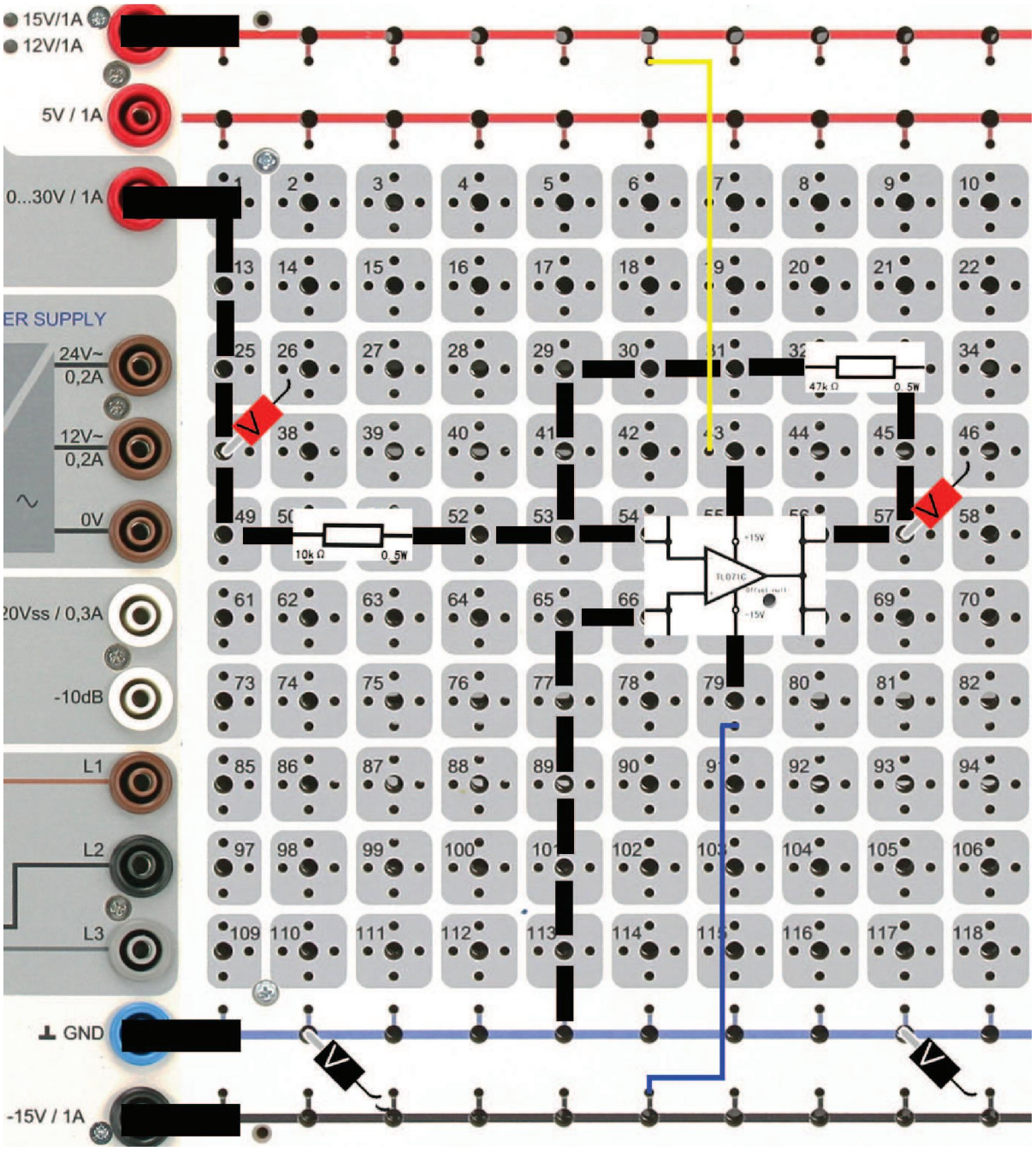
The instruments and related settings indicated below are needed here.

| Instrument | Settings | |
|---|---|---|
|  | Black cable | Ground |
| | Red cable | V/ohm input |
| | Adjustment knob | V = |
| |  | Insert the red and black probes into the marked points. |

## Experiment setup

Set up the experiment on the patch panel in the sequence mentioned next.

- Bridging plugs, starting with pad 110
- Electronic modules
- Measuring devices and cables



## Procedure and exercises

Insert $R_1$ = 10 kohms and $R_2$ = 47 kohms into the circuit. Set the adjustable voltage source to 1V and connect it to the circuit.

31.1 Measure the output voltage and enter the result in the field provided below.

Output voltage $U_a$ = _____ V

Perform the measurement with the multimeter set to its DC mode.

31.2 Determine the circuit's gain:

Gain = _____

Gain = $U_a$ / $U_e$

Set the voltage $U_e$ to 2 V.

31.3 Measure the output voltage and enter the result in the field provided below.

Output voltage $U_a$ = _____ V

Perform the measurement with the multimeter set to its DC mode.

31.4 Determine the circuit's gain:

Gain = _____

Gain = $U_a$ / $U_e$

31.5 Compare the results from 31.2 and 31.4. How does the gain respond to the change in input voltage?

- ○ The gain decreases.
- ○ The gain remains constant.
- ○ The gain increases.

Only one answer is correct.

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Switch off the direct voltage supply and replace feedback resistor $R_2$= 47 kohms with one rated at 100 kohms.

31.6 Set the input voltage $U_e$ = 1 V and measure the output voltage.

Output voltage $U_a$ = _____ V

Perform the measurement with the multimeter set to its DC mode.

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31.7 Determine the circuit's gain:

Gain = _____

Gain = $U_a$ / $U_e$

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31.8 Compare the results from 31.2 and 31.7. What is the relationship between the input voltage, feedback resistance and gain?

- ☐ The gain changes in dependence on the input resistance.
- ☐ The gain changes in dependence on the input voltage.
- ☐ The gain changes in dependence on the feedback resistance.
- ☐ The gain changes in dependence on the ratio between the output and input resistances.
- ☐ The gain changes in dependence on the ratio between the output voltage's feedback component and input voltage.
- ☐ The gain changes in dependence on the ratio between the output and input voltages.

Several answers may be correct.

Switch off the direct voltage supply and replace series resistor $R_1$= 10 kohms with one rated at 22 kohms.

31.9 Set the input voltage $U_e$= 1 V and measure the output voltage.

Output voltage $U_a$ = _____ V

Perform the measurement with the multimeter set to its DC mode.

31.10 Determine the circuit's gain:

Gain = _____

Gain = $U_a$ / $U_e$

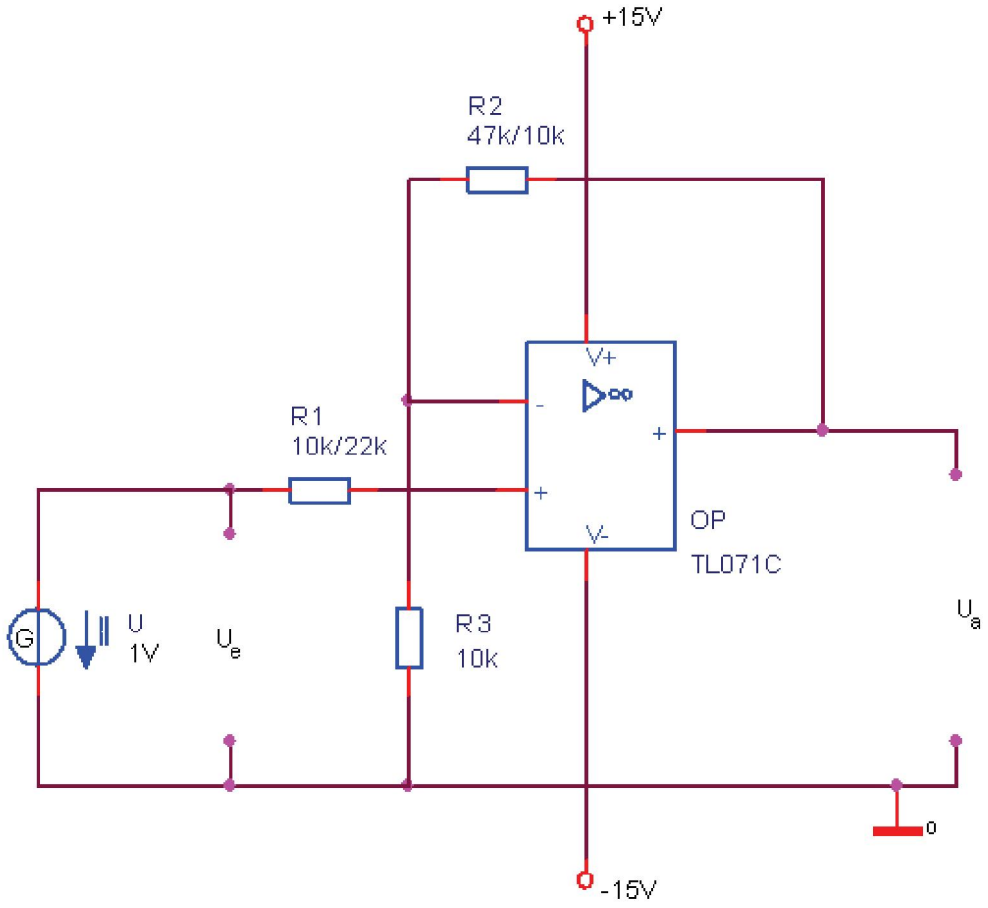
31.11 Compare the results from 31.7 and 31.10. How is the gain influenced by the input and output voltages, input and output resistances, and feedback resistance?

- The gain depends on the input resistance.
- The gain depends on the input voltage.
- The gain depends on the output resistance.
- The gain depends on the output voltage.
- The gain depends on the feedback resistance.

Only one answer is correct.

## Circuit diagram

This experiment is configured according to the circuit diagram shown next.




## Components

The components listed below are needed here.

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|---|---|---|
| 3 | PS4124-01 | Cable |
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| 3 | PS4121-3Q | R 10k |
| 1 | PS4121-4A | R 47k |
| 1 | PS4123-2V | OP 741 |

## Instruments

The instruments and related settings indicated below are needed here.

| Instrument | Settings | |
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|  | Black cable | Ground |
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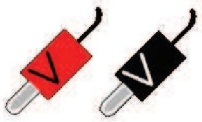
| |  | Insert the red and black probes into the marked points. |

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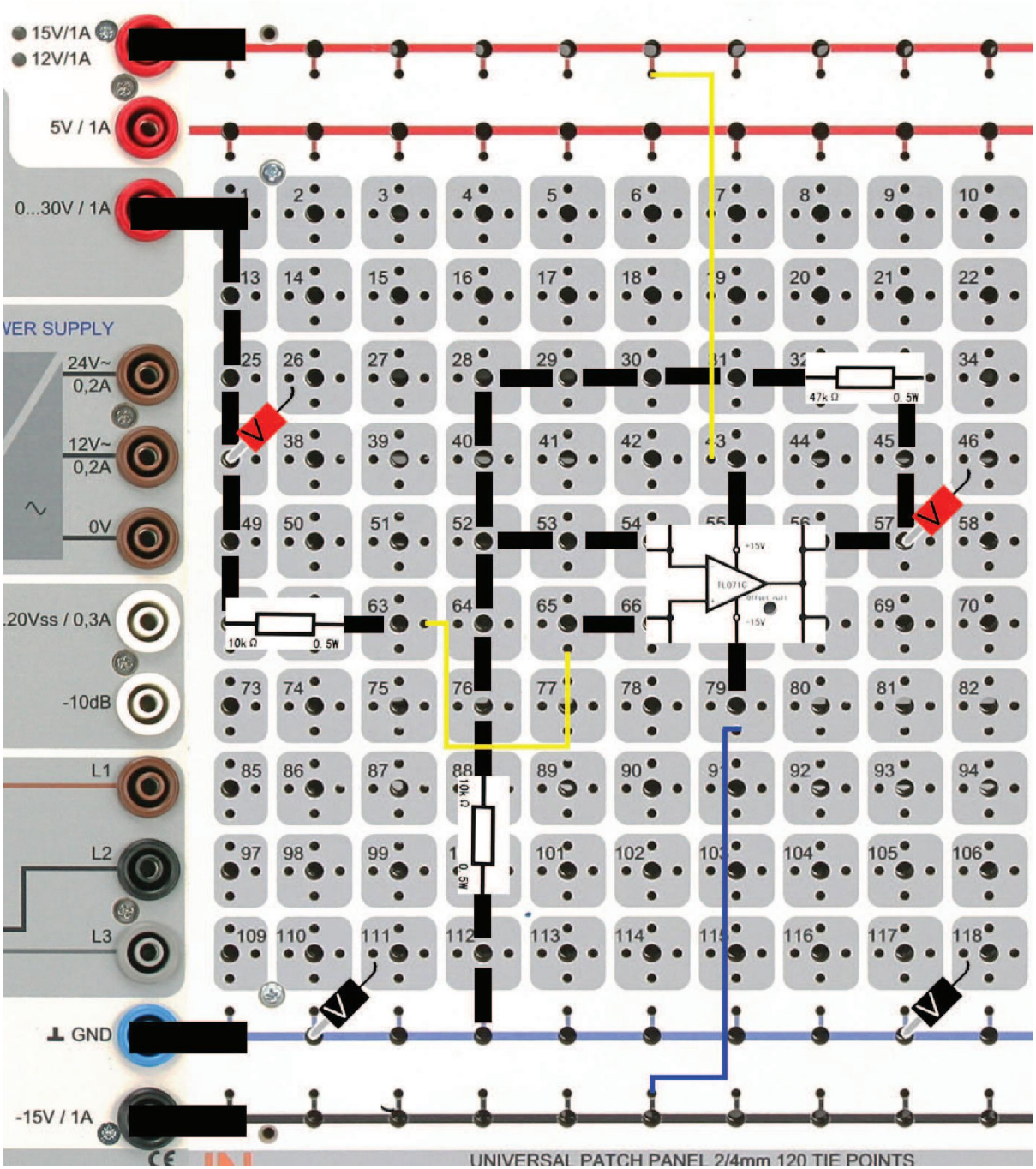

## Procedure and exercises

Insert $R_1$ = 10 kohms and $R_2$ 47 kohms into the circuit. Set the adjustable direct voltage source to 1V and connect it to the circuit.

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Perform the measurement with the multimeter set to its DC mode.

32.2 Determine the circuit's gain:

Gain = _____

Gain = $U_a$ / $U_e$

Set the input voltage $U_e$ to 2V.

32.3 Measure the output voltage and enter the result in the field provided below.

Output voltage $U_a$ = _____ V

Perform the measurement with the multimeter set to its DC mode.

32.4 Determine the circuit's gain:

Gain = _____

Gain = $U_a$ / $U_e$

32.5 Compare the results from 32.2 und 32.4. How does the gain respond to the change in the input voltage?

- ○ The gain increases.
- ○ The gain decreases.
- ○ The gain remains constant.

Only one answer is correct.

Switch off the direct voltage supply and replace feedback resistor $R_2$= 47 kohms with one rated at 10 kohms.

32.6 Set the input voltage $U_e$ = 1V and measure the output voltage.

Output voltage $U_a$ = _____ V

Perform the measurement with the multimeter set to its DC mode.

32.7 Determine the circuit's gain:

Gain = _____

Gain = $U_a$ / $U_e$

32.8 Compare the results from 32.2 and 32.7. What is the relationship between the input voltage, feedback resistance and gain?

- ☐ The gain changes in dependence on the input voltage.
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- ☐ The gain changes in dependence on the ratio between the output and input resistances.
- ☐ The gain changes in dependence on the ratio between the output voltage's feedback component and input voltage.

Several answers may be correct.