FUNDAMENTALS OF ELECTRONICS

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Operational Amplifiers

LAB 11
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1. OPERATIONAL AMPLIFIERS BASICS

Operational amplifiers are linear devices that have all the properties required for nearly ideal DC amplification and are therefore used extensively in signal conditioning, filtering or to perform mathematical operations such as add, subtract, integration and differentiation [5]. An operational amplifier almost always works with an external feedback loop, which determines the main parameters of the circuit. It is built as a multi-stage differential amplifier with very high gain (several hundred decibels / several hundred thousand).

An Operational Amplifier (Fig. 1) is basically a three-terminal device which consists of two high impedance inputs (of course, the additional inputs are the power terminals). One of the inputs is called the Inverting Input, marked with a negative or "minus" sign, (–). The other input is called the Non-inverting Input, marked with a positive or "plus" sign (+). A third terminal represents the operational amplifiers output port. The input voltage difference is called the differential voltage ($V_{DIF} = V_+ - V_-$). The output voltage is the product of the differential voltage and a very large gain.

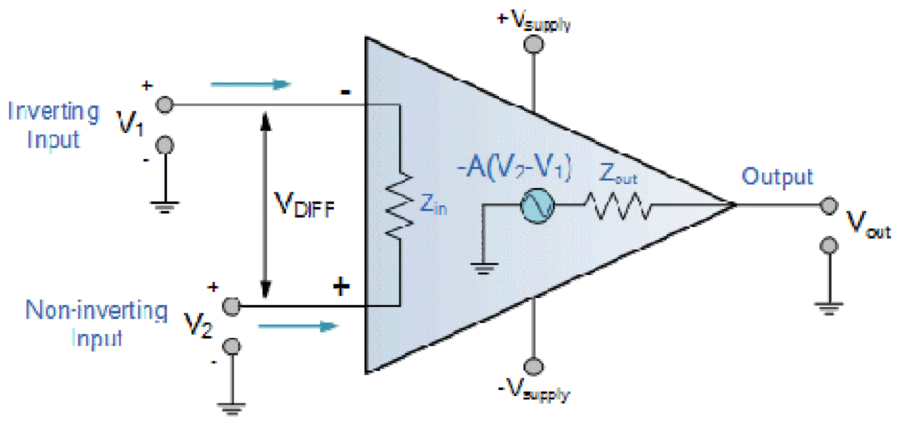


Fig. 1: Schematic diagram of the operational amplifier [5]

An ideal operational amplifier should have the following features:

- infinitely high gain in open loop feedback ($K \to \infty$);
- infinitely bandwidth;
- infinitely high input impedance, both between the inputs and between each input and ground;
- output impedance equal to zero;
- output voltage equal to zero for equal input voltages ($V_{out} = 0$ when $V_+ = V_-$);
- infinitely high output current;
- input current equal to zero;
- perfectly differential gain, means an infinitely high damping for the common (non-differential) signal;
- maintaining the above properties with temperature changes.

2. BASIC PARAMETERS OF THE OPERATIONAL AMPLIFIER

Open Loop Gain ***(pl. Wzmocnienie w pętli otwartej)*** – The main function of an operational amplifier is to amplify the differential input signal. The more open loop gain it has the better. Open-loop gain is the gain of the op-amp without positive or negative feedback. Typical real values range from about 10 000 to 500 000.

Input impedance ***(pl. Impedancja wejściowa)*** – Input impedance is the ratio of the input voltage to the input current. An ideal op-amp has an infinite input impedance. Real op amps have input leakage currents ranging from a few picoamperes to a few microamperes.

Output impedance ***(pl. Impedancja wyjściowa)*** – The output impedance of the ideal operational amplifier is assumed to be zero. Op-amp work as a perfect internal voltage source with no internal resistance. This internal resistance is effectively in series with the load thereby reducing the output voltage available to the load. Real op-amps have output impedances in the 100 Ω – 20 kΩ range [5].

Bandwidth ***(pl. Pasmo przenoszenia)*** – An ideal operational amplifier has an infinite frequency response and can amplify any frequency signal from DC to the highest AC frequencies so it is therefore assumed to have an infinite bandwidth. With real op-amps, the bandwidth is limited by the Gain-Bandwidth product (GB), which is equal to the frequency where the amplifiers gain becomes unity [5].

Common Mode Reject Ratio CMRR ***(pl. Współczynnik Tłumienia Sygnału Wspólnego)*** – An ideal amplifier should only amplify the voltage difference between the inputs (inverting and non-inverting). It should remove all common components of the input signals. However, if the same signal is applied to both inputs of the amplifier, a small part of it will appear at the output. The CMMR factor indicates what part of the input signal will go to the output. It is the ratio of the differential to common-mode gain [4].

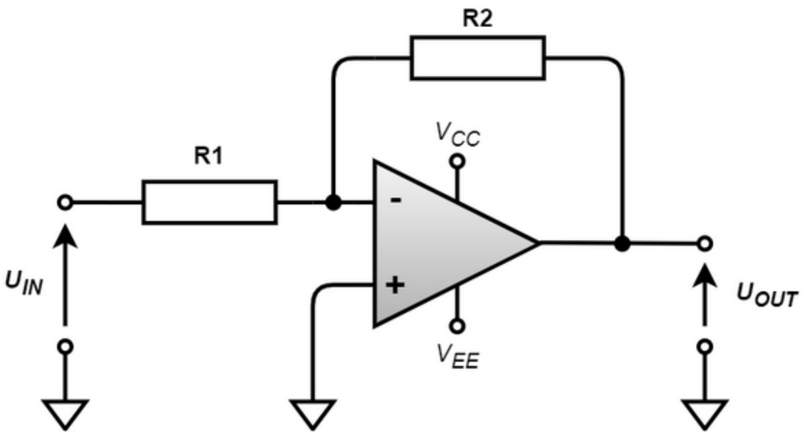
Slew Rate SR ***(pl. Szybkość narastania zbocza)*** – It is a parameter given in units of V/µs and determines how quickly the voltage at the amplifier's output can change.

Offset Voltage ***(pl. Napięcie niezrównoważenia)*** – The amplifiers output will be zero when the voltage difference between the inverting and the non-inverting inputs is zero, the same or when both inputs are grounded. Real op-amps have some amount of output offset voltage [5].

3. BASIC APPLICATIONS

3.1 Inverting Operational Amplifier

It is one of the simplest applications using an operational amplifier (fig. 2). The gain can be greater than one (the output signal will have a greater amplitude than the input signal) or smaller than one (the output signal will have a lower amplitude than the input signal). This configuration cause an inversion of the output signal with respect to the input as it is 180° out of phase. This is due to the feedback being negative in value. The gain in this configuration is obtained by changing the value (ratio) of the resistors R1 and R2 (usually their values are in the range 1 k – 100 k).



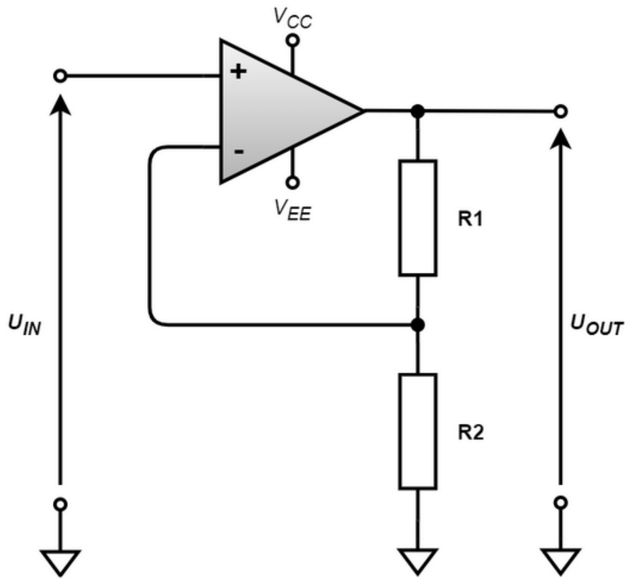
$$Gain: k = -\frac{R2}{R1}$$

$$U_{OUT} = k \cdot U_{IN} = -\frac{R2}{R1} \cdot U_{IN}$$

Fig. 2: Inverting Operational Amplifier

3.2 Non-inverting Operational Amplifier

In this configuration, the achieved gain can only be greater than one. This configuration don't cause an inversion of the output signal with respect to the input signal. As in the previous case, the gain is obtained by changing the value (ratio) of the resistors R1 and R2 (usually their values are in the range 1 k – 100 k). A circuit with the operational amplifier in a non-inverting configuration is shown in Fig. 3.



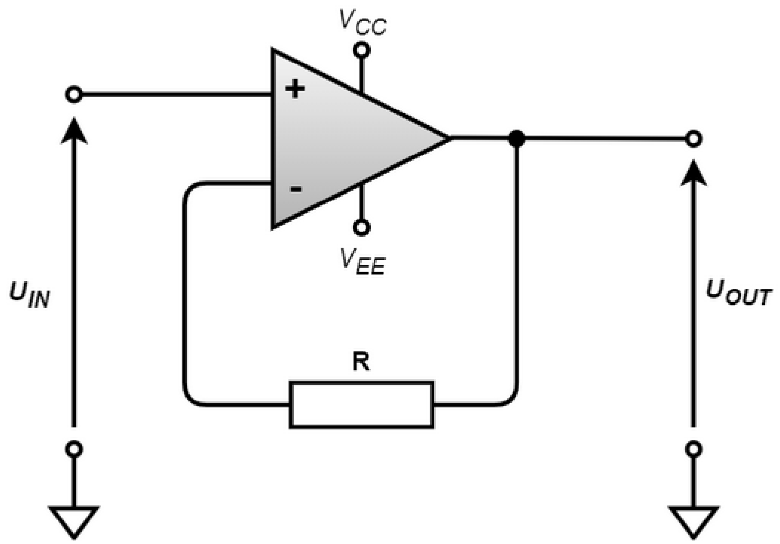
$$Gain : k = 1 + \frac{R1}{R2}$$

$$U_{OUT} = k \cdot U_{IN} = 1 + \frac{R1}{R2} \cdot U_{IN}$$

Fig. 3: Non-inverting Operational Amplifier

3.3 Op-amp Voltage Follower (Buffer)

The voltage follower (Fig. 4), based on the Op-amp is a simplified version of a non-inverting amplifier with a gain equal 1. Voltage followers are used to increase the current efficiency of the signal and/or to protect sensitive conversion circuits (ADCs) from interference and damage. In this case, the voltage follower is used as separating element.



$$Gain : k = +1$$

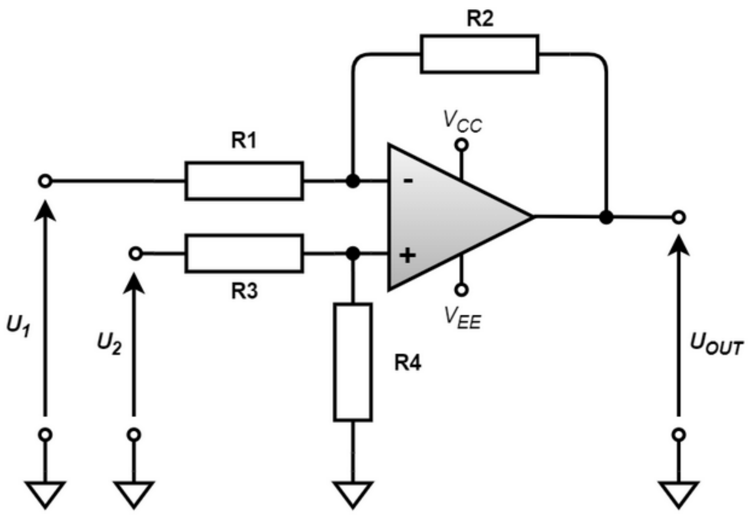
$$U_{OUT} = U_{IN}$$

Fig. 4: Operational Amplifier as Voltage Follower

3.4 The Differential Amplifier

Another application that can be built on the basis of an operational amplifier is a differential amplifier. In this configuration, circuit amplifies signal that is the difference between two input signals. This configuration is very often used to work with Resistive Bridges where the useful signal is the difference between the branches of the bridges.

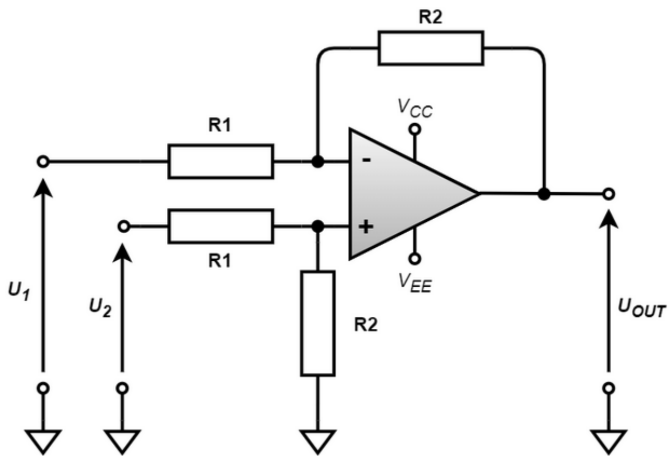
In general, the output voltage is given by the formula shown in Figure 5.



$$U_{OUT} = \frac{(R_1 + R2) \cdot R4}{(R_3 + R4) \cdot R1} \cdot U_2 - \frac{R2}{R1} \cdot U_1$$

Fig. 5: The Differential Amplifier (the general case)

Assuming that the resistance values R1 = R3 and R2 = R4, the formula is simplified to the equation shown in Fig. 6.



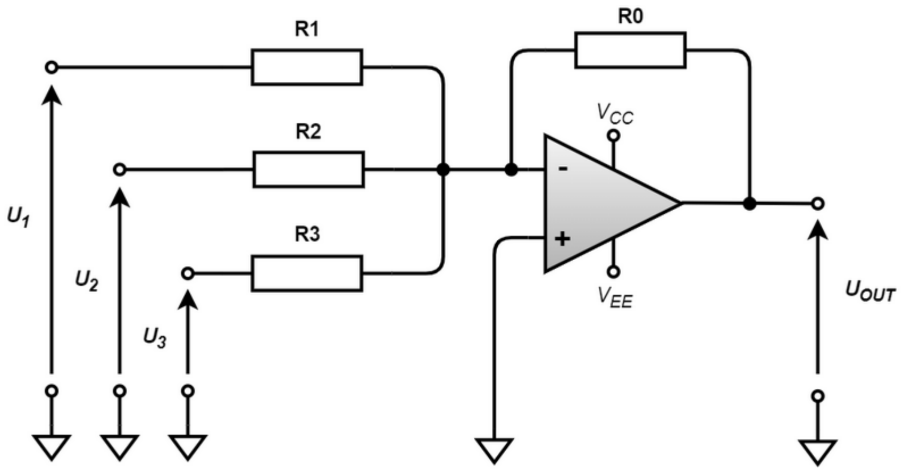
$$U_{OUT} = \frac{R2}{R1} \cdot (U_2 - U_1)$$

Fig. 6: The Differential Amplifier (the simplified case)

If all resistance values are identical (R1 = R2 = R3 = R4), the output voltage is equal to the input voltage difference $U_{OUT} = U_2 - U_1$.

3.5 The Summing Amplifier

Next application is the voltage adder, shown in Fig. 7. The same figure also shows the output voltage equations in the general case and for identical resistance values. Note that this circuit also cause an inversion of the output signal with respect to the input signal.



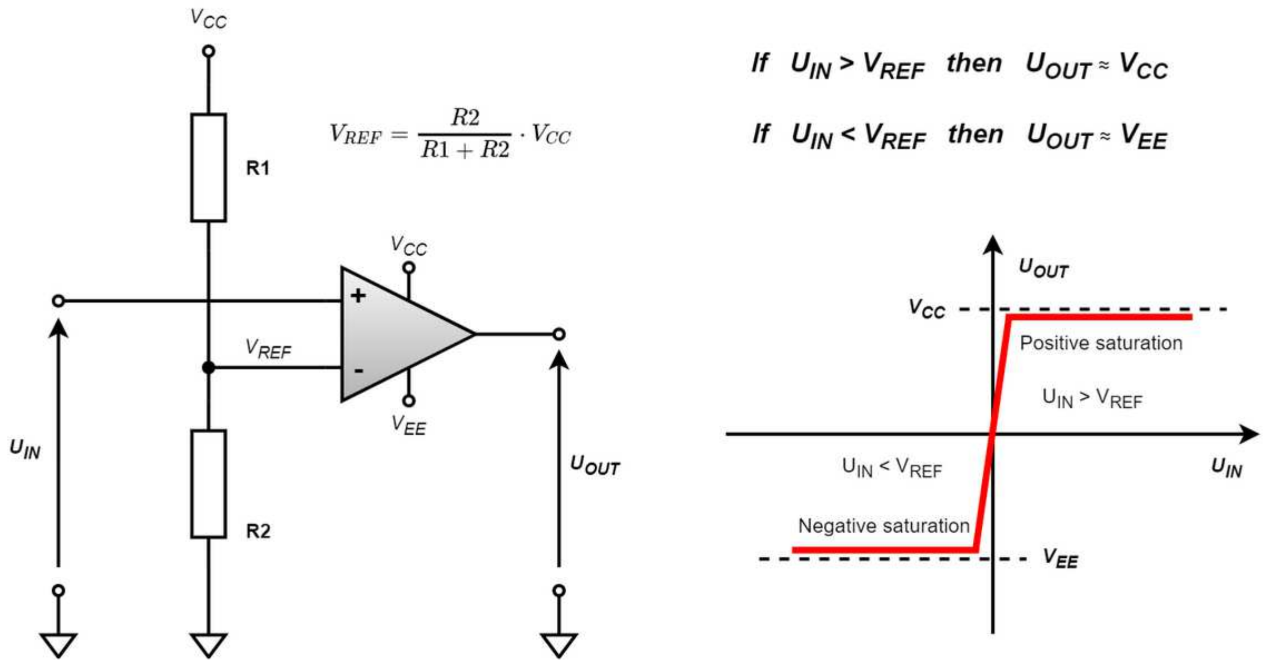
$$U_{OUT} = -R0 \cdot \left(\frac{U_1}{R1} + \frac{U_2}{R2} + \frac{U_3}{R3}\right)$$

If: $R1 = R2 = R3 = R$

$$U_{OUT} = -\frac{R0}{R} \cdot (U_1 + U_2 + U_3)$$

Fig. 7: The Summing Amplifier

3.6 Op-amp Comparator



$$V_{REF} = \frac{R2}{R1 + R2} \cdot V_{CC}$$

If $U_{IN} > V_{REF}$ *then* $U_{OUT} \approx V_{CC}$

If $U_{IN} < V_{REF}$ *then* $U_{OUT} \approx V_{EE}$

Fig. 8: Operational Amplifier as Voltage Comparator

The Op-amp Comparator (fig. 8) compares one analogue voltage level with another analogue voltage level (or some reference voltage V_{REF}) and produces an output signal based on this voltage comparison. In other words, the op-amp voltage comparator compares the magnitudes of two voltage inputs and determines which is the largest of the two[5]. The output voltage is close to one of the voltages supplying the amplifier, depending on which of the input voltages (inverting and non-inverting) is greater. In this application the amplifier operates in an open feedback loop in its nonlinear (saturation) range. The open-loop op-amp comparator is an analogue circuit that operates in its non-linear region as changes in the two analogue inputs, V+ and V- causes it to behave like a digital bitable device as triggering causes it to have two possible output states, +Vcc or -Vcc. Then we can say that the voltage comparator is essentially a 1-bit analogue to digital converter, as the input signal is analogue but the output behaves digitally [5].

Fig. 9 shows the different ways to obtain the reference voltage.

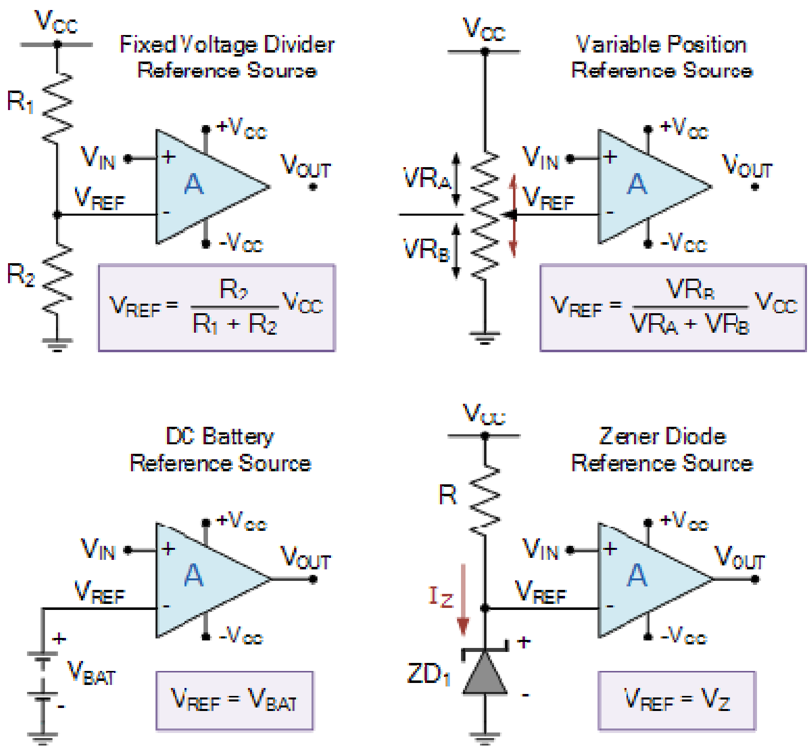


Fig. 9: Different ways to get a reference voltage for the comparator [5]

4. REFERENCES

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