EP03 Operational Amplifier

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1.1 Aim of the experiment

Understanding and applying the op-amp as a universal component in analog electronics.

1.1.1 Tasks

To apply the op-amp as

- comparator
- inverting amplifier
- non-inverting amplifier
- differential amplifier
- differentiator
- integrator

1.1.2 Note

1. The double rows of sockets along the sides of the breadboard are connected parallel to the red and blue lines. They are intended for use as power supply buses. All other sockets are connected crosswise in groups of five between the supply buses and the groove in the middle of the board (columns a-e and f-j).
2. While assembling a circuit and taking measurements take care to make all connections between the components and to the supply buses correctly.
3. The supply voltages must be stabilized with capacitors on the breadboard. Without them the circuit tends to oscillate, especially when strong negative feedback is used, due to the high open loop gain.

1.1.3 Equipment and components

Power supplies for positive and negative supply voltages and two variable input voltages, breadboard, operational amplifier, resistors, two 100 nF capacitors, jumpers, multimeter, oscilloscope

1.1.4 Key topics

Basic laws of DC circuits, voltage measurement with multimeter and oscilloscope, bipolar transistor and FET, negative feedback, op-amp function and internal circuit concept, setting the open circuit gain with external components.

1.2 Theory

1.2.1 Principle of the operational amplifier

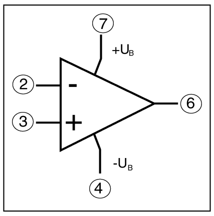

Figure 1.1: Op-amp pinout

The transistors used in amplifiers (whether a.c. or d.c.) must be operated within the linear region of their characteristic curves, i.e. it is necessary to set an operating point. With a.c. amplifiers this is very simple, due to the d.c. decoupling between the signal source or load and the amplifier. With a common emitter amplifier for example, the operating point can be set by means of a simple voltage divider. D.c. amplifiers, however, require a different approach, because d.c. decoupling cannot be used. Instead, the input stage of an op-amp uses two common emitter configured transistors with a common relatively large negative feedback emitter resistor. The current through this resistor is shared between the transistors in proportion to their input signals. Because the current should be as constant as possible, the resistor is often replaced by a constant current source. Instead of two separate input signals, the input stage can also be driven by a difference signal. The signal from the input stage is strongly amplified (e.g. open loop gain 10^4) before being fed to the output. Because of the input stage symmetry, common mode input signals (equal voltage on both inputs relative to ground) are not amplified. The operational amplifier is a differential amplifier.

1.2.2 Modifying the function with external components

Comparator

Without external components the op-amp functions as a comparator. This is because of the high open loop gain, due to which very small input signal differences are sufficient to drive the output stage into saturation (positive or negative). The maximum output voltage range is determined by the supply voltages, which can be unipolar ($+U_B$ relative to Ground) or bipolar ($+U_B$ and $-U_B$ relative to Ground). A real op-amp has a switching threshold of a few millivolts, compared with the theoretical value of zero differential input voltage. This value is called the offset voltage.

Inverting amplifier

When configured as an inverting amplifier, the op-amp has it's positive input connected to ground. The input signal is fed through a resistor to the op-amp's negative input. The op-amp's output is connected to the negative input by a negative feedback resistor. Because of the op-amp's very high input resistance, practically all of the input current flows through the negative feedback resistor to the output. The almost equal currents in the two resistors and the high open loop gain result in an output voltage that produces a very small input voltage difference (practically 0 V). The inverting input is a virtual ground. The op-amp's high open loop gain is reduced by the negative feedback. The actual gain is equal to the quotient of the negative feedback resistance divided by the resistance between the signal input and the op-amp's inverting input, with a minus sign indicating the inversion, i.e. the 180^0 phase difference between input and output.

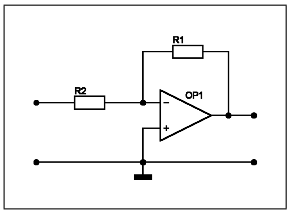

Figure 1.2: Inverting amplifier

Non-inverting amplifier

The non-inverting or U/U-amplifier is obtained when a voltage divider feeds part of the output voltage to the op-amp's inverting input and the input voltage is fed to the non-inverting input. Because the input currents and the op-amp's input voltage difference are very small, the voltage divider may be regarded as being unloaded. The circuit gain is obtained by dividing the sum of the two resistances by the resistance to ground.

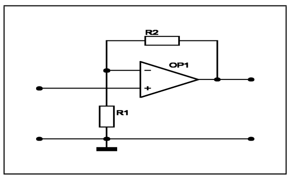

Figure 1.3: Non-inverting amplifier

Differential amplifier

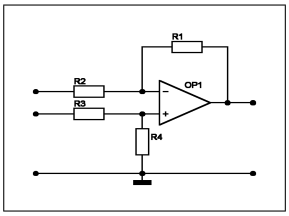

Figure 1.4: Differential amplifier

If the inverting amplifier's positive input is disconnected from ground and fed a second input voltage, one obtains a differential amplifier. This circuit's gain is different for each input and can be calculated through superposition of the inverting and non-inverting amplifier's gains. To obtain a symmetrical amplifier with equal gain for both inputs, the voltage reaching the positive input has to be reduced by a voltage divider. The input voltages are amplified equally when the values of the four resistors satisfy the balance condition for a Wheatstone bridge. It is for this reason that the differential amplifier is also called a bridging amplifier.

Differentiator and Integrator

If the inverting amplifier is fed it's input voltage through a capacitor instead of a resistor, it becomes a differentiator. It's function can be explained by the differential relationship between current and voltage in a capacitor ($I = C \cdot \frac{dU}{dt}$). Any change in the input voltage results in a charge or discharge current through the capacitor, which produces a proportional voltage change over the negative feedback resistor.

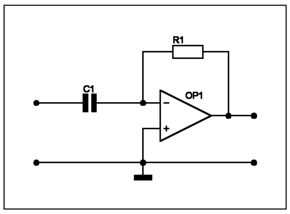

Figure 1.5: Differentiator

The required output voltage is delivered by the op-amp's output. By exchanging the resistor and capacitor one obtains an integrator. Any input voltage other than 0V causes the op-amp's output voltage to change continually, so that the (dis-)charge current through the capacitor is always equal to the input current. Before each measurement the capacitor must be discharged, so that integration begins at zero.

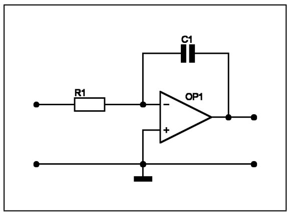

Figure 1.6: Integrator

1.3 Experiment

1.3.1 Procedure

1. Set up a comparator and determine it's characteristic curve.
2. Set up a non-inverting amplifier and determine it's characteristic curve.
3. Set up an inverting Amplifier and determine it's characteristic curve.
4. Disconnect the op-amp's positive input from ground and connect it to a variable voltage source. Determine the characteristic curves for one input voltage while the other input is held at fixed voltages.
5. Extend the circuit to a symmetrical differential or bridging amplifier and repeat the measurements in item 4.
6. Set up a differentiator with R=10 kΩ and C=100 nF and test the circuit with sine and square wave signals at different frequencies.
7. Repeat the measurements in item 6 for an integrator with R=10 kΩ and C=100 nF

Documents: data sheet for op-amp LF356