Laboratory Electronics 2

Task 4: Operational Amplifier

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Learning Objectives

The objective of the fourth lab task is the design of an amplifier for a high-frequency application. We take one of the base circuits of an operational amplifier and implement it with the correct component values. This time, we consider the limiting parameters which are caused by the selected components for the amplifier. Due to the fact that the signal frequency can become high, we will focus on the limiting parameters for the AC behavior of the system. During the first task, the input system will be defined and explained. Subsequently, a suitable base circuit for the operational amplifier must be selected. During the verification, the limits of the circuit are determined.

- Analysis of a technical problem and conclusion of the input and output signals
- Use of a basic operational amplifier circuit for a technical problem
- Determination of the technical limits in theory and in practice
- Signal analysis using FFT

Lab Devices

You will find the following devices in the lab. Please make sure that you have the manuals ready. We also provide a breadboard with all required components and wires to setup your electrical circuit.

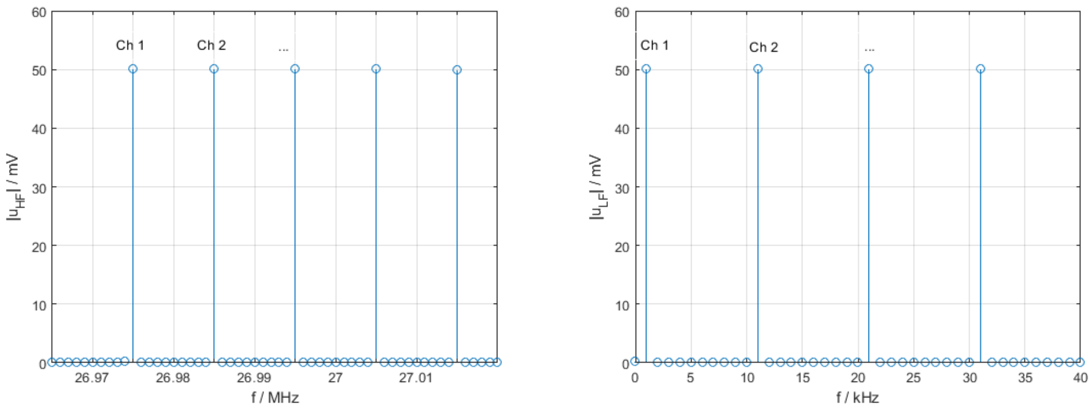
- **Digital Multimeter** Fluke 8808A
- **Oscilloscope** Tektronix MDO3034
- **Frequency Generator** Rohde & Schwarz HMF2550
- **DC Power Supply** Toellner TOE 8735

1 Input / Output

In this laboratory experiment we use an operational amplifier to amplify a *Citizens band radio* (CB radio) signal. This signal is usually used to enable truck drivers to communicate or to transmit the sound of a baby monitor. A typical CB radio receiver is shown in figure 1.

Figure 1: CB radio receiver

For the transmission of data or sound, the useful signal is modulated with a high-frequency carrier signal (frequency or amplitude modulation). The frequency of the carrier signals are standardized according to CEPT and are in a range from 26.965 MHz to 27.405 MHz. In this range are 40 different channels that are 10 kHz apart. Due to the fact that the carrier frequencies are sinusoidal oscillations, the individual channels appear as lines in the magnitude spectrum. This can be seen in figure 2(a).



(a) CB radio magnitude spectrum in high frequency range (ideal)

(b) CB radio magnitude spectrum in low frequency range (ideal)

Figure 2: CB radio magnitude spectrum

Some simplifications are assumed for the laboratory test. For example, there is no noise and the amplitude of the carrier signals is 50 mV. Furthermore, only the carrier signals are considered without a useful signal modulated on them. After the signal from an antenna has been converted from a wireless signal into a voltage, the signal is filtered with a band pass and mixed down into a low frequency range. Mixing is done by multiplying the antenna signal with a sinusoidal signal with a frequency of a little less than the frequency of the first channel. The output signal of the filter and mixer can be seen in figure 2(b). Mathematically, the signal in the low frequency range corresponds to the following equation:

$$v_{\mathrm{LF}}(t) \quad = \quad \sum_{c\,=\,0}^{39} \alpha \sin(2\pi t \cdot (f_1 + c \cdot f_c)) \tag{1}$$

Here c describes a counting variable, α the amplitude of the channel, f_1 the frequency of the first channel and f_c the distance between the individual channels. Behind the planned amplifier circuit, the signal is transferred to software-based signal processing by an ADC. The ADC has an input voltage range of 0...1 V.

- Find the signals of the first three and last three channels as separate equations.
- Find the bandwidth of the low frequency signal.
- Due to the fact that the individual carrier frequencies do not overlap, they can be considered separately. Find a way to create a signal source in the simulation which automatically sweeps through all channels. Only use one voltage source for this.
- There is only one frequency generator available in the lab. Find a way to generate the signal for all channels.

2 Operational Amplifier Circuit Design

One possible implementation of the adaptation of the low-frequency antenna signal to the ADC input is the operational amplifier as a summing amplifier. The advantage of this basic circuit is the fact that an offset can be added. This basic circuit can be seen in figure 3. Keep in mind that this is the general base circuit and it is not adjusted for a specific application.

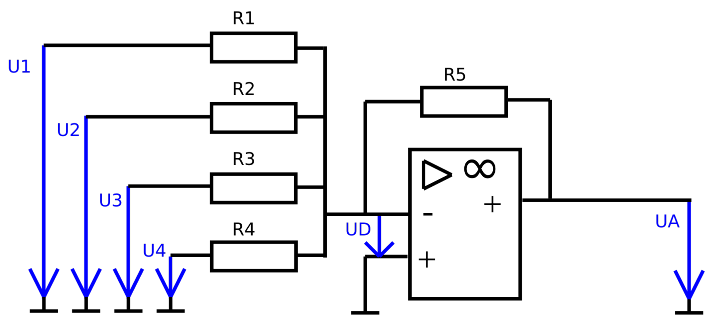


Figure 3: Summing amplifier base circuit [1]

The output voltage u_A can be calculated by [1]:

$$u_A = -R_5 \cdot \left(\frac{U_1}{R_1} + \frac{U_2}{R_2} + \frac{U_3}{R_3} + \frac{U_4}{R_4} \right) \quad (2)$$

- We use the operational amplifier UA741CP in the lab. Set up a circuit which matches the low frequency antenna signal to the ADC input range. Define the required amplification, number of inputs for the amplifier, resistor values and potential additional signal inputs (e.g. offset voltages). For the calculation of the resistances, low frequencies should first be considered.
- Define the power source/s you need for the operational amplifier.
- Use equation 2 to prove mathematically that the calculated resistances are correct for the limits of the input and output signals.
- Simulate the circuit and verify the desired functionality.

3 Limits

- Find the most important parameters of the operational amplifier regarding the amplification of high frequencies. One of these parameters is the slew rate. Calculate the maximum output frequency if you just consider the slew rate and find the corresponding CB radio channel number.
- Find the channel number where the magnitude of the output signal gets reduced by 50% compared to the output signal of a low frequency input. Compare the resulting channel numbers of the simulation and the measurement.
- Measure the amplification of the last channel. Compare the signal shape and magnitude of the first, the last and the "50%"-channel between simulation and measurement.
- Describe the characteristic of the circuit (low pass, high pass or band pass filter). Measure the cut-off frequency or frequencies within the bandwidth of our application. Explain the reason for this behavior.
- A different way to compare the shape of the signals is the usage of the fast fourier transformation (fft) to transform the time domain signal into the frequency domain. As previously mentioned, a sine wave appears there as a single line at the frequency of it. The oscilloscope has the option to create an fft of a signal by using the math channel. Compare the magnitude spectrum for the first, the last and the "50%"-channel to each other and between simulation and measurement.
- As you can see, the selected operational amplifier UA741 is not suitable for the given application. Replace the operational amplifier UA741 by the TL072. Measure the amplification again with the new operational amplifier and rate its functionality for our given scenario.
- Recommend a different operational amplifier which can amplify every CB radio channel in the same way. You can find electronic components online. (https://ie.rs-online.com/web/, https://www.farnell.com/, Amazon...)

References

[1] Wikibooks, *Interessante messungen/ da-wandler*, `https://de.wikibooks.org/wiki/Interessante_Messungen/_DA-Wandler`.