Laboratory Electronics 2

Task 3: Differential Amplifier

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Learning Objectives

The objective of the third lab task is the entire development of a signal processing circuit for a given application. This application is related to a real existing problem. For the solution of the problem, a differential amplifier will be used. This lab task describes the typical way to find a possible solution for such a problem. At the beginning, it is important to understand the problem and the input / output values. After that, the generic circuit of a possible solution can be found in the literature. This circuit needs to be modified to fulfill the requirements. Finally, the developed circuit can be tested as a simulation and built up. Please work on all of the tasks and develop a circuit for a given application. You must only set up your final result of the circuit of your preparation during the lab!

- Understanding of the typical way to handle a given problem
- Definition of required input and output characteristics of an amplifier circuit
- Transfer of the generic description of a differential amplifier from the literature to a given problem
- Finding ways to optimize a functional circuit

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** GOSSEN METRAWATT METRA HIT 26S
- **Oscilloscope** Tektronix MDO3012
- **Frequency Generator** Agilent 33210A
- **DC Power Supply** Rohde & Schwarz NGT 20

1 Application

The given situation is the development of an analog circuit for a fever thermometer as shown in figure 1. It is planned to use a Pt100 (platin thermistor) as temperature sensor and an internal

Figure 1: Example of a fever thermometer [1]

ADC (analog-to-digital converter) of a microcontroller to convert the sampled temperature value to a displayed value. A Pt100 changes its resistance value in proportion to the temperature. The circuit gets powered by four batteries in series with a voltage of 1.5 V each. We assume, that the supply voltage is constant. A common way to convert the resistance change of the Pt100 to a voltage change is by using a wheatstone measuring bridge as shown in figure 2.

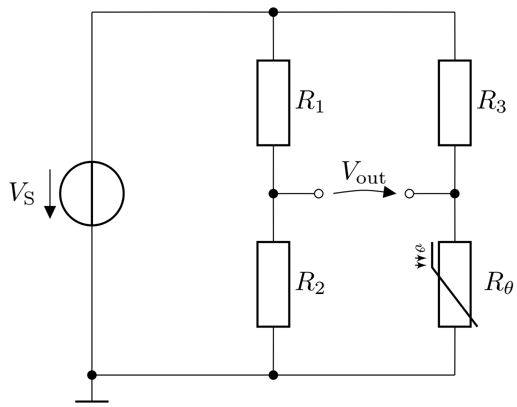

Figure 2: Generic Differential Amplifier [2]

The resistors are defined as $R_1 = R_2 = R_3 = 110\,\Omega$. The desired temperature measurement range for the thermometer is $T_M = 25...45\,°C$. In this range, the Pt100 changes its resistance in the range between $R_\theta = 110...117.5\,\Omega$. The supply voltage is $V_S = 3\,V$.

- Find the generic function $V_{out} = f(R_\theta)$.
- Calculate the range of the output voltage V_{out} for the specified temperature range.
- The input range of the ADC is set to $V_{ADC} = 1\,V$. Additionally, the ADC works with an differential input signal. Calculate the required differential amplification A_D to match V_{out} and V_{ADC}.

2 Generic Differential Amplifier

The signal V_{out} is a differential signal, because it appears independent of the system ground potential. Therefore, a single-ended amplifier cannot be used. For the amplification of differential signals, a differential amplifier must be used. The generic differential amplifier is defined in the literature as shown in figure 3.

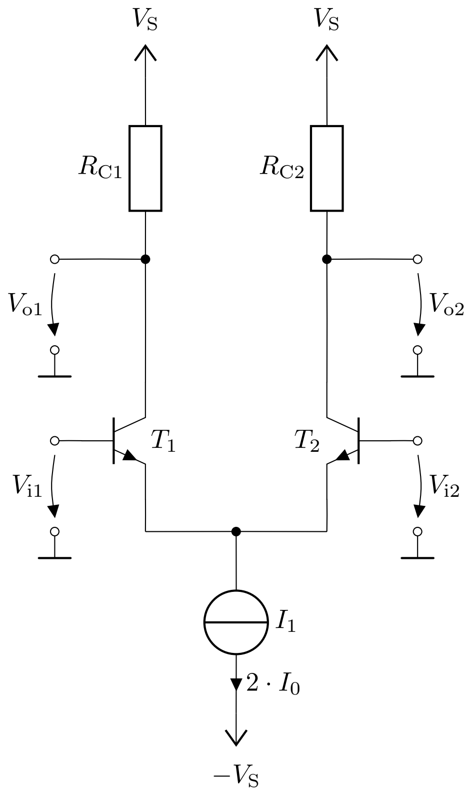

Figure 3: Generic Differential Amplifier [2]

The equations for calculating V_{ox} as a function of the input differential voltage V_{D} are as following:

$$V_{\text{o1}} = V_{\text{S}} - I_0 R_{\mathbf{C}} \left(1 + \tanh \frac{V_{\text{D}}}{2V_{\text{T}}}\right) \tag{1}$$

$$V_{\text{o2}} = V_{\text{S}} - I_0 R_{\mathbf{C}} \left(1 - \tanh \frac{V_{\text{D}}}{2V_{\text{T}}}\right) \tag{2}$$

We assume $R_{\text{C1}} = R_{\text{C2}} = R_{\text{C}}$ and $V_{\text{D}} = V_{\text{BE1}} - V_{\text{BE2}}$. The thermal voltage V_{T} can be assumed as $25\,\text{mV}$.

- Define V_{out} from the circuit 2 and the input signal of the ADC V_{ADC} as functions of the given signals in circuit 3.
- Find $V_{\text{ADC}} = f(V_{\text{out}})$. Explain the influence of V_{S} in that function.
- Define the parameters of the components in the differential amplifier in a way that it works for the desired amplification A_{D}. We use the transistor BC546A in the lab.
- Verify the function of your setup with a simulation. Find the maximum input range of the circuit.

3 Specific Differential Amplifier

After the verification of the general function of the amplifier, there must be some adjustments of the circuit. These modifications are necessary, because some of the circuit details don't fit to a setup in reality.

- The current source I_1 describes an ideal current source with an infinite inner resistance Ri. There can't be a ideal current source in reality. Find options for replacing that current source to get a circuit which can be used for a setup in reality.
- Compare the options for an alternative current source.
- Create a circuit diagram of the entire setup, including the Pt100-circuit and the ADC. Make sure that it is complete with all sources and relevant designators for voltages and currents.
- You must only set up the differential amplifier in the lab. Find a way to emulate the Wheatstone bridge in the defined temperature range with the given lab equipment. The input signal must vary in the entire temperature range. Find a way to emulate the ADC.
- Measure the input and output signals of the differential amplifier WITHOUT a differential probe.
- Measure $A_\mathrm{D} = f(V_\mathrm{D})$ and analyze this function.
- Overlap the input and output signal and explain the reason for the different shapes.
- The differential mode amplification A_D is generally defined as:

  $$A_\mathrm{D} \quad = \quad \frac{\mathrm{d}V_\mathrm{o1}}{\mathrm{d}V_\mathrm{D}} = -\frac{\mathrm{d}V_\mathrm{o2}}{\mathrm{d}V_\mathrm{D}} \tag{3}$$

  if the common mode voltage is constant.
  The common mode amplification is defined as:

  $$A_\mathrm{C} \quad = \quad \frac{\mathrm{d}V_\mathrm{o1}}{\mathrm{d}V_\mathrm{C}} = \frac{\mathrm{d}V_\mathrm{o2}}{\mathrm{d}V_\mathrm{C}} \tag{4}$$

  if the differential mode voltage is zero. Find the desired values of A_D and A_C for your application. Measure the two different amplifications.

References

[1] TURN-ON, *Fieberthermometer: 5 geräte zur zuverlässigen temperaturmessung*, `https://www.turn-on.de/article/fieberthermometer-5-geraete-zur-zuverlaessigen-temperaturmessung-564755`.

[2] U. Tietze, C. Schenk, and E. Gamm, *Electronic Circuits: Handbook for Design and Application* (Electronic Circuits). Springer Berlin Heidelberg, 2015, ISBN: 9783540786559.