Chapter 1

System design

1.1. System overview

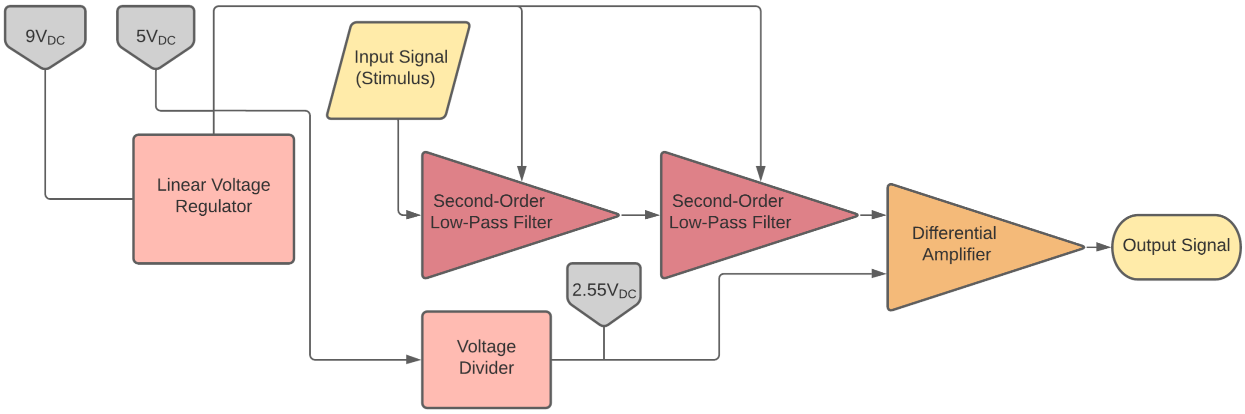

Figure 1.1: System Block Diagram

As part of the health monitoring system, which consists of an analogue temperature sensor and optic heart rate monitor, a voltage regulation circuit is required, as well as a signal conditioning and amplification system. This report focuses on the design and implementation of the latter components. Figure 1.1 gives an overview of the combined system, where the voltage regulator supplies power to the circuital components responsible for filtering the signal, removing its offset, and then amplifying the signal, which is received from a analog temperature sensor.

Two second-order low-pass filters were cascaded to clear the signal of noise. This may seem excessive at first, but the cascaded setup allows for the use of less costly components (see Section **??**), as well as producing an output signal subject to very low noise (see Section **??**). Since the filtered signal still has a DC offset, the voltage divider connects to the differential amplifier in such a way as to simultaneously remove the input DC offset, and to add the virtual ground needed for the amplifier to produce an output signal with the correct DC offset. Finally, the differential amplifier increases the magnitude of the input signal to the degree needed at the input of a microcontroller ADC, which is to be used to interpret the temperature sensor output. Note that this circuit design does not include a voltage buffer, as it was decided against upon noting that the desired output was easily obtained without a buffer, and omitting the buffer resulted in much lower current drawn from the battery (see Section **??**), as well as resulting in lower total cost due to less components present in the circuit. Analysis and simulation of all circuits was done with the simulation software LTSpice.

Chapter 2

Voltage regulation

2.1. Introduction

Given a 9 V_{DC} battery, a voltage regulator is required to reduce the voltage level to 5 V_{DC}, as this is the level required by the operational amplifiers used in the rest of the circuit. Two voltage regulators were considered: the LM7805 linear regulator as well as the LM2595 switchmode regulator, which were both analysed with regards to efficiency and noise by means of calculations and simulations. According to the literature, the linear regulator does not really output noise, but has low power efficiency of around 50% for input-output of 9 V_{DC} and 5 V_{DC} [?]. The switchmode regulator can provide power efficiency of around 85%, but outputs a considerable amount of noise [?]. With the aforementioned in mind, both of the regulators were simulated (Section 2.2 to determine the best trade-off between low noise and efficiency. Resistor and capacitor configurations were determined according to the respective datasheets [?] [?].

2.2. Design

2.2.1. Linear Regulator

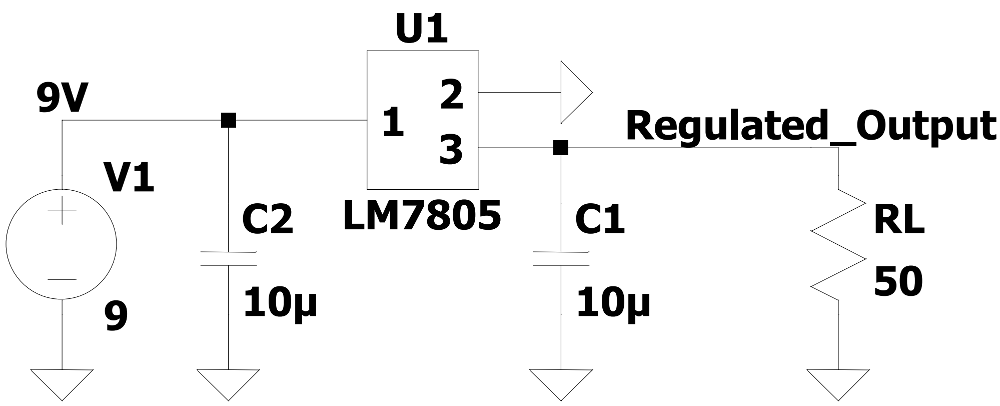

Figure 2.1: Linear Voltage Regulator

The LM7805 chip is shown in Figure 2.1, as well as the required peripheral circuit, which was obtained from the datasheet [?]. For testing purposes, a 50 Ω load was connected to the regulator, drawing 100 mA. Measurements are discussed in section 2.2.3.

2.2.2. Switchmode Regulator

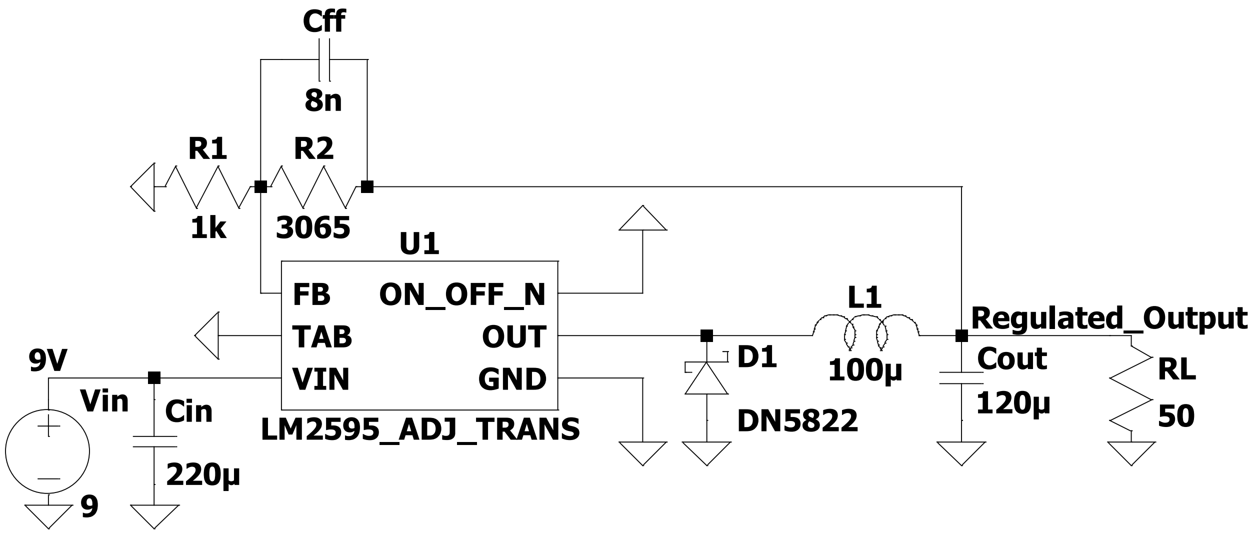

Figure 2.2: Switchmode Voltage Regulator

The LM2595 chip is shown in Figure 2.2, built into the required peripheral circuit. Capacitor and inductor values are as shown, and were obtained from the datasheet [?]. Resistor values were calculated as follows:

$$\mathrm{V_{OUT}} = \mathrm{V_{REF}}\left(1 + \frac{\mathrm{R_2}}{\mathrm{R_1}}\right) \qquad \text{where } \mathrm{V_{REF}} = 1.23\mathrm{V}$$

Selecting $\mathrm{R_1}$ as $1\,\mathrm{k\Omega}$, with $\mathrm{V_{out}}$ as $5\,\mathrm{V}$ gives $\mathrm{R_2}$ as $3065\,\Omega$. For testing purposes, a $50\,\Omega$ load was connected to the regulator, drawing $100\,\mathrm{mA}$. Measurements are discussed in section 2.2.3.

2.2.3. Voltage Regulator Comparison

The input and output power measurements are displayed in table 2.1.

Table 2.1: Comparison of Voltage Regulators

	I_{in} [mA]	I_{out} [mA]	P_{in} [mW]	P_{out} [mW]	η [%]
LM7805	105.06	100.05	945.54	500.55	52.93
LM2595	57.54	99.65	517.86	496.6	95.89

Comparing the efficiency of the respective regulators, it is clear that the switchmode regulator is considerably more efficient. However, simulation results in a settling time of 1.24 ms, which is quite slow. Furthermore, the switchmode regulator creates noise levels of up to 950 $\mathrm{mV_{pp}}$ in the output, as can be seen in figure 2.3. This is a problem, as the large gain of the differential amplifier, which is fed by the voltage regulator, will result in the noise levels to increase in magnitude and become prevalent in the output. Considering all of the above, the linear regulator was selected for the design, despite being less efficient, as it provides an almost instantaneous settling time, coupled with negligible amounts of noise.

More vreg calcs, Voltage reg power calcs before sim?

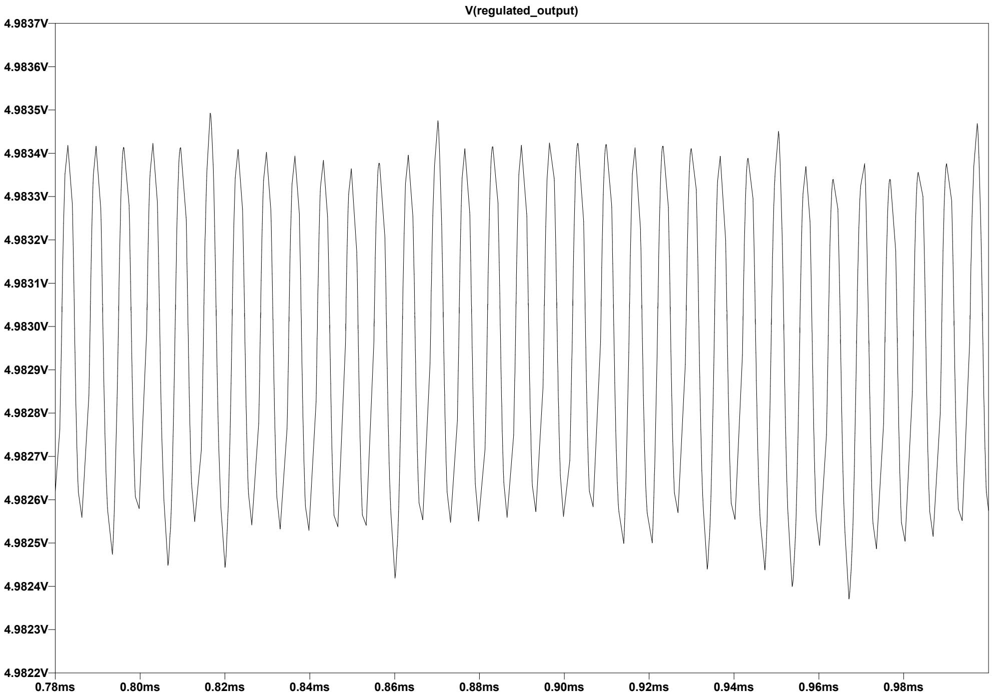

Figure 2.3: Switchmode Voltage Regulator Output

Table 2.2: Example of a simple table.

	2017	2018	Δ_{Abs}	Δ_{DiD}
A	9,868	10,399	+5	-11
B	10,191	10,590	+4	-12

2.3. Results

In this section, you want to demonstrate, by means of referring to simulation results, using the designed circuit, how your circuit behaves as you designed it in Section 2.2. Present and report on your simulated results in Figure **??** Be absolutely sure that the text and information in your report are readable.

You can use screengrabs or photos of the oscilloscope, or download the CSVs and plot them as PDFs using Matlab, Excel or similar. You can also use tables, example of which are presented in Tables 2.2 and 2.3.

Table 2.3: Example of another table.

Schools	Total energy used		Change	
	2017 [kWh]	2018 [kWh]	Δ_{Abs} [%]	Δ_{DiD} [%]
A	9,868	10,399	+5	-11
B	10,191	10,590	+4	-12

2.4. Summary

Concluding, it has been shown that both regulators behave as expected, but that the levels of noise present in the switchmode regulator make it unsuitable for the design at hand, as input signals, and thus the noise as well, will be amplified to levels of noise in the output signal that are unacceptable for an ADC input. This choice was made despite the fact that the switchmode regulator is approximately 40% more efficient than the linear regulator, influenced thereby that the total current drawn is still very low. However, it should be noted that the current drawn should be re-evaluated after the rest of the components have been connected to the regulator, in order to make sure that the current draw requirement still is met.

Chapter 3

Temperature sensor conditioning circuit

3.1. Intro

The signal obtained from the temperature sensor presents as DC, with a 35 mV, 50 Hz AC signal superimposed, which serves no purpose, but creates noise. The DC component increases linearly with respect to the temperature measured by the sensor. However, the sensor outputs a voltage of 440 mV at 0°C, which increases by 35 mV for every 1°C. These voltage levels are too small for a microcontroller ADC to take as input. Furthermore, as the sensor is only meant to measure human body temperature, the applicable range is only from 34°C to 42°C. The two aforementioned considerations necessitate amplification of the relevant part of the temperature sensor signal to occupy as much of a 0 to 5 V range as possible, as this is the voltage range used by the ADC. To this end, a temperature sensor conditioning circuit is required to transform the given input into the desired output. This conditioning circuit consists of a filter, an offset removing subcircuit, as well as an amplifier. The filter attenuates the AC signal present in the input signal in order to obtain an output signal with a minimal amount of noise. The offset removing subcircuit removes enough of the DC offset to ensure that the output signal is centered around 2.5 V, which is necessary to obtain the largest possible output swing as discussed previously. Finally, the amplifier increases the magnitude of the input signal in order to be suitable as input for an ADC.

3.2. Design

The amplifier was designed first, as its gain serves as the determining factor for the amount of noise reduction that is required from the filter. Since the output signal has to be centered around 2.5 V, a differential amplifier was decided upon, as the negative input can be used to adjust the offset present in the output. Given a zero-reference temperature sensor voltage ($\mathrm{V_{zero}}$) of 440 mV, with an increase ($\mathrm{V_{\Delta}}$) of 35 mV for every 1°C. Therefore, temperature sensor voltage levels are calculated as follows:

$$V_{temp} = V_{zero} + V_{\Delta} \times$$

Temp

According to table 3.1, the maximum input voltage swing equals $1.91 - 163 = 0.28\text{V}$, and has a DC offset of 1.77 V. Amplification is needed to reach an output voltage swing of 5 V.

Table 3.1: Temperatures and Corresponding Voltage Levels

Temperature [°C]	32	38	42
Voltage [V]	1.63	1.77	1.91

Therefore:

$$A_v = \frac{V_{out}}{V_{in}} = \frac{5}{0.28} = 17.86$$

Now, R is selected as $10\,\text{k}\Omega$, to prevent a large current from being drawn. This gives $\text{R}_{\text{feedback}} = 178.6\text{k}\Omega$.
Two points need to be considered:

1. The DC offset of the input signal is undesired and has to be removed in order to obtain a zero-mean input signal. This can be achieved by designing another subcircuit that makes use of another op-amp, for example. However, this adds to the cost and complexity of the circuit.

2. The output signal has to be centered around 2.5 V. This means that DC offset has to be added in the form of a virtual ground, as the op-amp has rails at 0 and 5 V.

When considered in conjunction with each other, the DC offset alteration can be resolved in one step, thereby reducing cost and complexity significantly. The decision was therefore made to use a differential amplifier, with the input signal connected to the positive input, after which the voltage required at the negative input can be calculated in such a way as to simultaneously subtract the offset and add the virtual ground in one step, thereby producing an output DC offset of 2.5 V (the lecturer mentions that this is an acceptable approach in Lecture Video 2). This approach also simplifies the design procedure, as it becomes unnecessary to calculate the virtual ground separately. The differential amplifier, however, has to be non-inverting. The calculation thus reduces to a simple differential amplifier gain formula [?]:

$$\text{V}_{OUT} = \frac{\text{R}_{feedback}}{\text{R}} (\text{V}_{in+} - \text{V}_{in-})$$

Taking V_{OUT} as 2.5 V, $\text{V}_{\text{in}+}$ as 1.77 V and the resistor values as calculated previously:

$$2.5 = \frac{178600}{10000} (1.77 - \text{V}_{in-})$$
$$\text{V}_{in-} = 1.63 \text{ V}$$

Under most circumstances, it is a good design practice to include a unity gain op-amp at the input of the op-amp responsible for the correct offset, as it acts as a voltage buffer, thereby clamping the voltage against fluctuations caused by the differential amplifier's other input. This design practice was considered, but ultimately decided against, as tests with and without the buffer provided outputs of equal quality (similar to the output shown in section 3.3. The only notable differences resulting from the inclusion of a buffer were an increase in current drawn, as well as an increase in cost for the circuit components, as another op-amp is required. Therefore, in order to keep the current consumption below 15 mA, as well as to use reduce cost by only using three op-amps, the voltage buffer was omitted in the final design.

3.3. Results

3.4. Summary

Chapter 4

System and conclusion

4.1. System

Report on the integration of the voltage regulator and temperature sensing circuitry. Report on noise levels and how the temperature sensor will fit into the system (E.g. what the calibration will look like and what the the measurement error will be given the range, quantisation error and noise).

4.2. Lessons learnt

Write down at least three of the most important things you have learnt in Assignment 1.

Bibliography

Appendix A

Social contract

Sign and inlcude.

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jou kennisvennoot • your knowledge partner

E-design 344 Social Contract

2020

The purpose of this document is to establish commitment between the student and the organisers of E344. Beyond the commitment made here, it is not binding.

In the months preceeding the term, the lecturer (Thinus Booysen) and the Teaching Assistant (Michael Ritchie) spent countless hours to prepare for E344 to ensure that you get your money's worth and that you are enabled to learn from the module and demonstrate and be assessed on your skills. We commit to prepare for the module, to set the tests and assessments fairly, to be reasonably available, and to provide feedback and support as best and fast we can. We will work hard to give you the best opportunity to learn from and pass analogue electronic design E344.

Signature: .... Date: 13 July 2020

....

I, ... have registered for E344 of my own volition with the intention to learn of and be assessed on the principals of analogue electronic design. Despite the potential publication of supplementary videos on specific topics, I acknowledge that I am expected to attend the lectures and lab sessions to make the most of these appointments and learning opportunities. Moreover, I realise I am expected to spend the additional requisite number of hours on E344 as specified in the yearbook.

I acknowledge that E344 is an important part of my journey to becoming a professional engineer, and that my conduct should be reflective thereof. This includes doing and submitting my own work, working hard, starting on time, and assimilating as much information as possible. It also includes showing respect towards the University's equipment, staff, and their time.

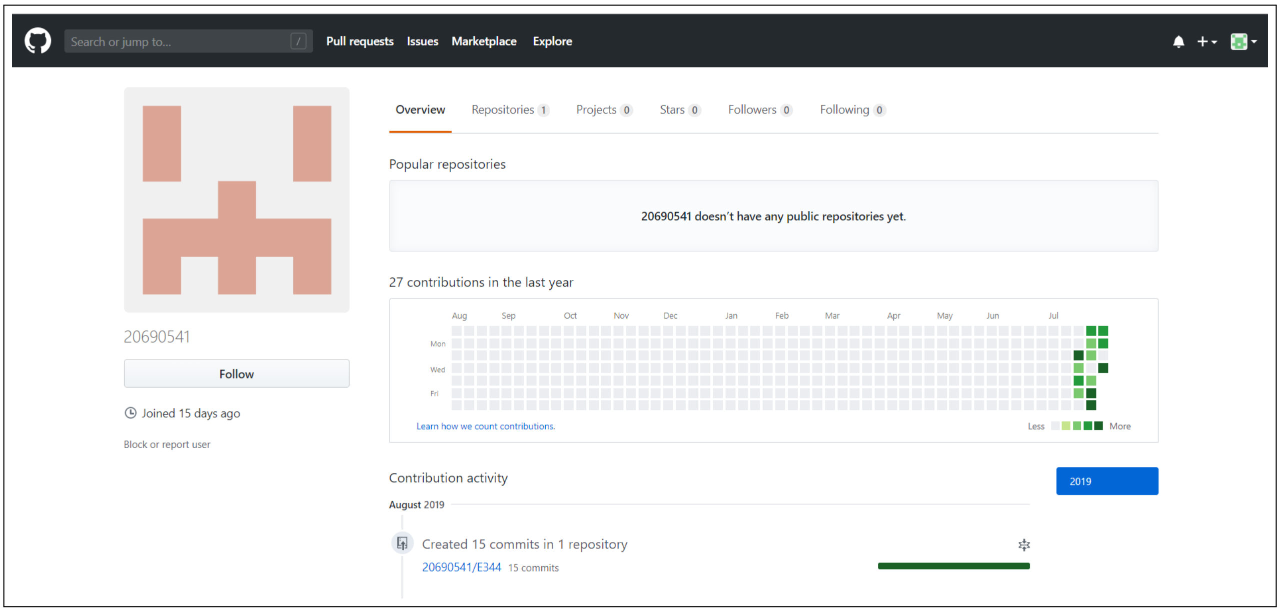
Signature: .... Date: ....

1

Appendix B

GitHub Activity Heatmap

Take a screenshot of your github version control activity heatmap and insert here.



Appendix C

Stuff you want to include

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