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E344 Assignment 2

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Report submitted in partial fulfilment of the requirements of the module Design (E) 344 for the degree Baccalaureus in Engineering in the Department of Electrical and Electronic Engineering at Stellenbosch University.

September 23, 2020

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   I declare that the work contained in this assignment, except where otherwise stated, is my original work and that I have not previously (in its entirety or in part) submitted it for grading in this module/assignment or another module/assignment.

21905541 Studentenommer / *Student number*	Handtekening / *Signature*
E. Gouws Voorletters en van / *Initials and surname*	September 23, 2020 Datum / *Date*

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Nomenclature

Variables and functions

$p(x)$	Probability density function with respect to variable x.
$P(A)$	Probability of event A occurring.
ε	The Bayes error.
ε_u	The Bhattacharyya bound.
B	The Bhattacharyya distance.
s	An HMM state. A subscript is used to refer to a particular state, e.g. s_i refers to the i^{th} state of an HMM.
$\mathbf{S}$	A set of HMM states.
$\mathbf{F}$	A set of frames.
$\mathbf{o}_f$	Observation (feature) vector associated with frame f.
$\gamma_s(\mathbf{o}_f)$	A posteriori probability of the observation vector $\mathbf{o}_f$ being generated by HMM state s.
μ	Statistical mean vector.
Σ	Statistical covariance matrix.
$L(\mathbf{S})$	Log likelihood of the set of HMM states $\mathbf{S}$ generating the training set observation vectors assigned to the states in that set.
$\mathcal{N}(\mathbf{x}\|\mu, \Sigma)$	Multivariate Gaussian PDF with mean μ and covariance matrix Σ.
a_{ij}	The probability of a transition from HMM state s_i to state s_j.
N	Total number of frames or number of tokens, depending on the context.
D	Number of deletion errors.
I	Number of insertion errors.
S	Number of substitution errors.

Acronyms and abbreviations

AE	Afrikaans English
AID	accent identification
ASR	automatic speech recognition
AST	African Speech Technology
CE	Cape Flats English
DCD	dialect-context-dependent
DNN	deep neural network
G2P	grapheme-to-phoneme
GMM	Gaussian mixture model
HMM	hidden Markov model
HTK	Hidden Markov Model Toolkit
IE	Indian South African English
IPA	International Phonetic Alphabet
LM	language model
LMS	language model scaling factor
MFCC	Mel-frequency cepstral coefficient
MLLR	maximum likelihood linear regression
OOV	out-of-vocabulary
PD	pronunciation dictionary
PDF	probability density function
SAE	South African English
SAMPA	Speech Assessment Methods Phonetic Alphabet
PWM	Pulse Width Modulation LPF
Low Pass Filter HPF	High Pass Filter

Chapter 1

System design

1.1. System overview

This report will encompasses the design and analysis of a signal conditioning system for a heart rate monitor. This forms part of the bigger system which also includes a temperature sensor and voltage regulator as designed in Report 1 [1]. The retrieved signal from the heart rate monitor is first passed through a second order low pass filter to remove noise followed by a second order high pass filter to stabilise the peaks of the heart beats in the signal. The signal is then amplified via an inverting amplifier to allow improved accuracy when placing a threshold. A comparitor is used to trigger pulses when the incoming signal exceeds the predetermined threshold/peaks aka an incoming heartbeat. These pulses are then extended to meet the delay requirement of 150ms using a mono stable multi-vibrator. Depending on the rate of the incoming heartbeat the frequency of the outputting pulses will increase/decrease. In turn this will cause a correlated increase/decrease in the average voltage outputted. Therefore by passing the output from the mono stable multi-vibrator through a sufficiently designed low pass filter we can obtain this average DC output voltage and transform it with differential amplifier to a corresponding analogue output voltage between 0 to 5 V.

The available current for the device in is specified as 100 mA. In the previous report [1] the current draw was found to be 10 mA therefore the remaining current is 90 mA. This is still a small current margin therefore we will opt for large resistances to limit our current use.

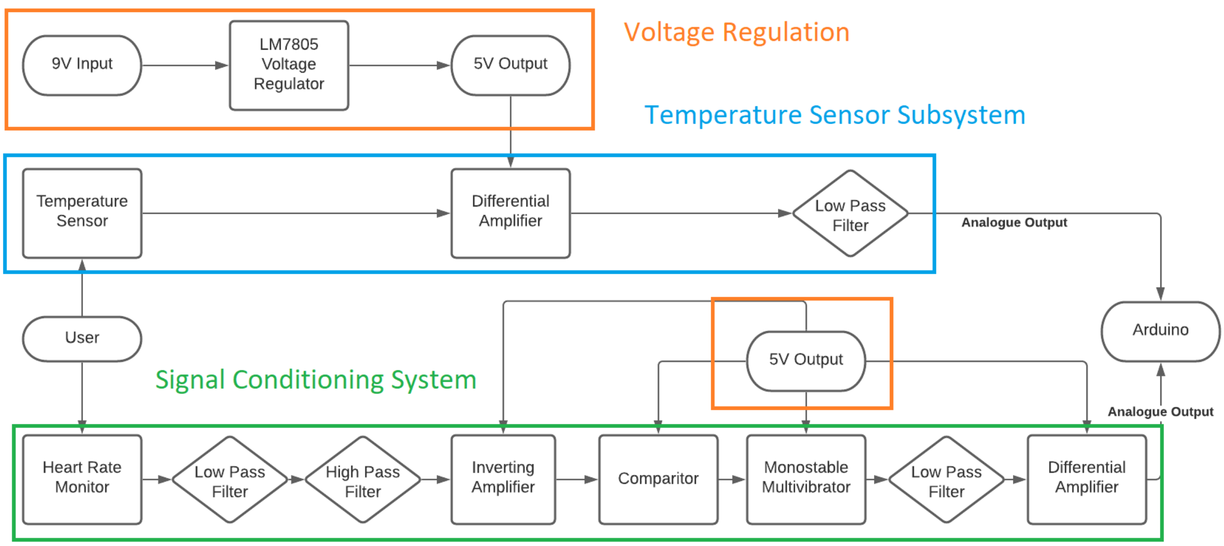


Figure 1.1: System diagram

Chapter 2

Heart rate sensor

2.1. Introduction

For the heart rate monitor the incoming signal requires noise conditioning via both a high pass filter [2], low pass filter [3] and amplifier [4] before being converted into finite pulses [5]. These pulses must adhere to a time delay greater than 150ms. The signal also needs to be converted into a correlating analogue output of between 0 to 5 V [6]- compatible for further Arduino processing. In this section we will design, implement and analyse each of these elements.We will also make use of some previously designed elements such as the virtual ground and voltage regulator as designed in Assignment 1. [1]

2.2. Design

Evaluating the frequency spectrum shown in Figure 2.1 of a given heartbeat signal we notice that the fundamental frequency of a heartbeat should lie between 50 to 150 rpm thus 1 to 2.5 kHz. Therefore the lower frequency peaks accounts for the slow changing sinus wave seen in the variation of incoming signal peaks with the higher frequency peaks resulting due to noise. Filters rid the incoming signal of these discrepancies to obtain a much neater output.

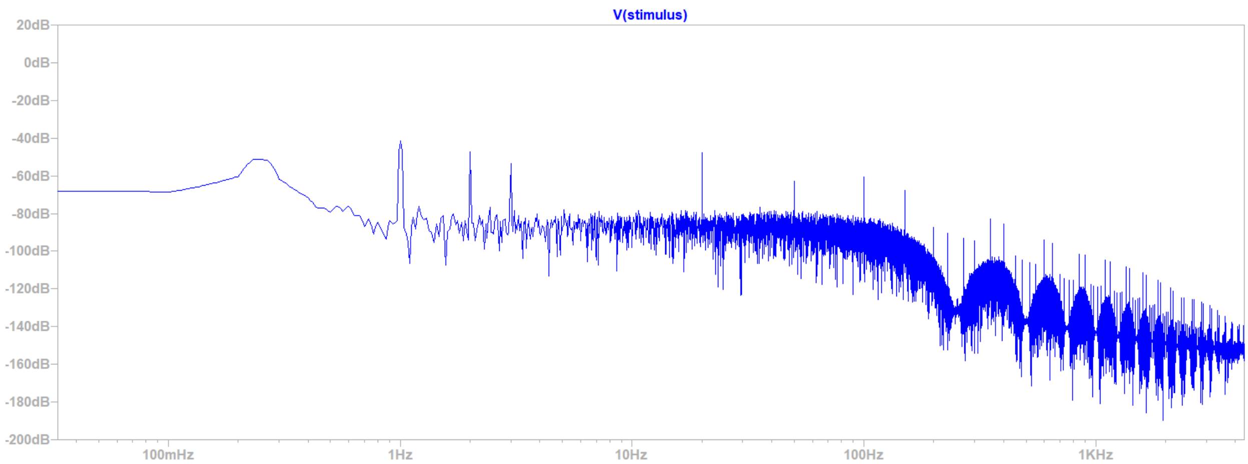


Figure 2.1: Frequency domain of unfiltered signal

2.2.1. Third Order Passive Low Pass Filter

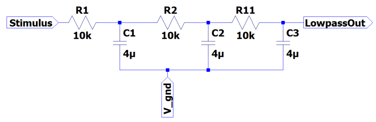


Figure 2.2: Third Order Passive Low Pass Filter

Choosing $R_1 = R_2 = R_3$ and $C_1 = C_2 = C_3$ $4\,\mu$F in Figure 2.2 with a cut-off frequency (f_c) at 4 Hz.

$$f_c = \frac{1}{2\pi\sqrt[3]{R_1C_1R_2C_2R_3C_3}} = \frac{1}{2\pi RC}. \tag{2.1}$$

We find R = $9.95\,\mathrm{k}\Omega = 10\,\mathrm{k}\Omega$.

2.2.2. Third Order Passive High Pass Filter

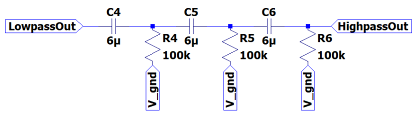


Figure 2.3: Third Order Passive High Pass Filter

Choosing $R_4 = R_5 = R_6$ and $C_4 = C_5 = C_6 = 2\,\mu$F in Figure 2.3 with a cut-off frequency (f_c) at 0.8 Hz.

$$f_c = \frac{1}{2\pi\sqrt[3]{R_4C_4R_5C_5R_6C_6}} = \frac{1}{2\pi RC}. \tag{2.2}$$

We find R = $99.5\,\mathrm{k}\Omega = 100\,\mathrm{k}\Omega$.After analyzing the bode plot the capacitance was adjusted to $6\,\mu$F to achieve the desired cut-off frequency.Thereafter the signal is amplified using a simple non-inverting amplifier to increase accuracy when placing a threshold. More information on how this was designed can be found in Appendix C - B.

2.2.3. Voltage Comparator

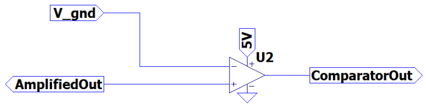


Figure 2.4: Voltage Comparator

Using the amplified signal centred around 2.5V / virtual ground at V_{in} and a threshold voltage (V_{ref}) placed at the centre (2.5V) the comparator will deliver a high/pulse at the start of an upward peak aka a heartbeat.The threshold is chosen in the centre due to the small pk-pk amplitude (100 mA) meaning that slight displacement of the threshold voltage could result in little to no tolerance of noise or deviation.

2.2.4. Monostable Multi-Vibrator

2.2.5. Transducer

Noting that as with PWM a higher frequency of pulses will result higher average DC output we wish to produce the required analogue voltage output by scaling and amplifying the DC output obtained from the monostable multivibrator. A second order Butterworth filter is used to obtain the DC value of the input which design can be found in Appendix C - B. To scale the correlated DC output we use a differential amplifier with a similar design as that seen in Report 1 [1] section 3.2.1. The differential amplifier is designed to ensure an output range of larger than 3.5V.

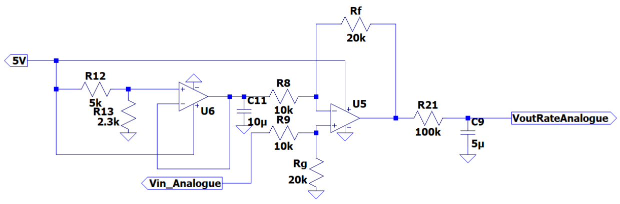


Figure 2.5: Differential Amplifier Circuit

Finding V_{out} at 50 bpm as 1.65V and V_{out} at 150 bpm as 4V we derive a midpoint voltage as

$$V_{mid} = \frac{V_{150} - V_{50}}{2} + V_{50} = 2.825. \tag{2.3}$$

Choosing $R_f = R_g$ and $R_1 = R_2$ we get

$$V_{out} = \frac{R_f}{R_1} \times (V2 - V1). \tag{2.4}$$

for the midpoint:

$$\frac{V_{max}}{2} = \alpha \times (V_{150} - V_{mid}). \tag{2.5}$$

$$2.5 = \alpha \times (1.175). \tag{2.6}$$

Choosing a gain of 2 will result in a swing of 2.35V. Therefore we choose Rf = 20 kΩ and R1 = 10 kΩ.

$V_1 = V_mid$ will be a constant offset value to linearize the midpoint around 2.5V. Using equation 3.6.

$$V_{midpoint} = \frac{R_f}{R_1} \times (V_{38^\circ} - V1). \tag{2.7}$$

We calculate $V_1 = 2.07$. Since we only have access to 5V voltage supply we will have to make use of voltage division methods to obtain this (2.07V) value.

$$V_o = (\frac{R_a}{R_a + R_b}) \times V_s. \tag{2.8}$$

Choosing R_a as 3.3 kΩ we find $R_b = 4.671$ kΩ We also add a unity gain buffer to stabilise our

2.07V required input from the voltage divider. We expect the TLC2272 to draw about 3 mA and and the TL081 buffer 2.8 mA.Along with the resistors a small current aswell. This should lead to a total current usage of about 9 mA. See circuit in appendix C.

In this section, you need to capture your design, which should include the following:

- Design rationale, i.e. what your thinking was behind the design. For example, explain that you had to first analyse the heart beat signals before you could design the filtering.
- References to literature/sources as appropriate [7].
- You can assume the reader has an E&E degree, and will not need detail explanations of trivial information (e.g. what a resistor is, or what Ohm's law is).
- Design calculations, for example to determine resistor values and capacitor values, or to check for allowed voltage and current ranges and levels. These calculations should also give expected outputs, which hopefully matches the simulated values. Importantly, they are based on maths, and not on simulation - there is a difference.
- Analysis of given or expected input conditions.
- Expected values and ranges based on your design.
- Explain your choice of supply buy referring to the advantages and disadvantages of each.
- Circuit diagram like the one in Figure 2.6. I used "print to PDF" from LTSpice, but feel free to use a cropped screengrab if you are PDF-challenged and do not have a PDF printer (there are some free PDF creators online). Also have a look at the demo video on SUNLearn.

For your benefit, here is how to write values with units: 150 mΩ or 199 myUnits, and this is how we write ranges: 2 to 5 kV.

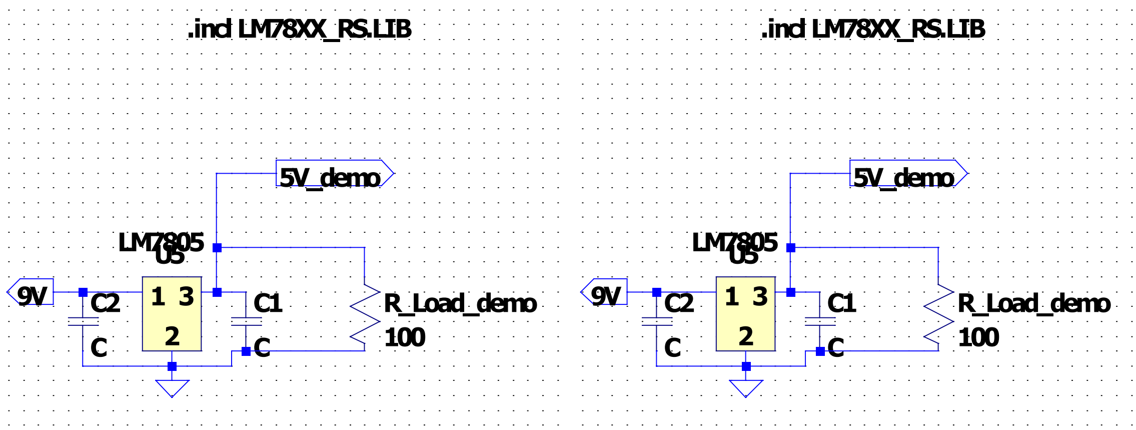
Here is an inline equation $\frac{55}{45+3}$. Here is a numbered equation in Eq. 2.9.

$$a = \frac{55}{45+3}. \tag{2.9}$$

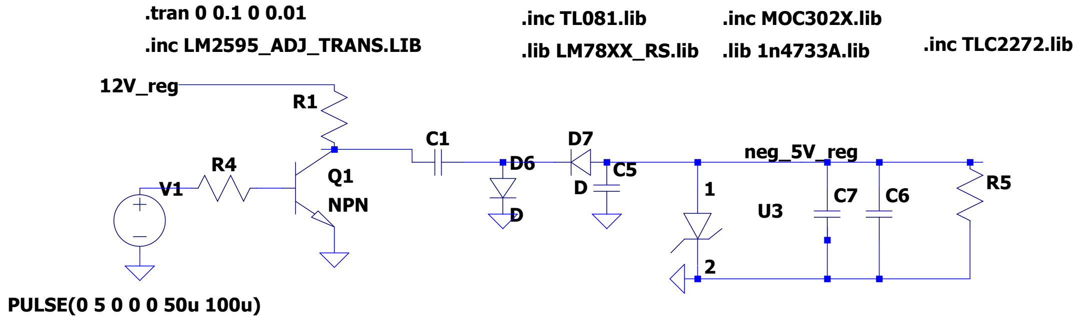
.

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 2.7. Be absolutely sure that the text and information in your report are readable.



(a) Linear voltage regulator. **(b)** Switchmode voltage regulator.



(c) Chargepump voltage regulator.

Figure 2.6: Circuit diagrams of the two voltage regulators, and another irrelevant one
.

Table 2.1: 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

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 2.1 and 2.2.

2.4. Summary

State whether your design performs as expected and what the limitations are or things to keep in mind are.

Table 2.2: 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

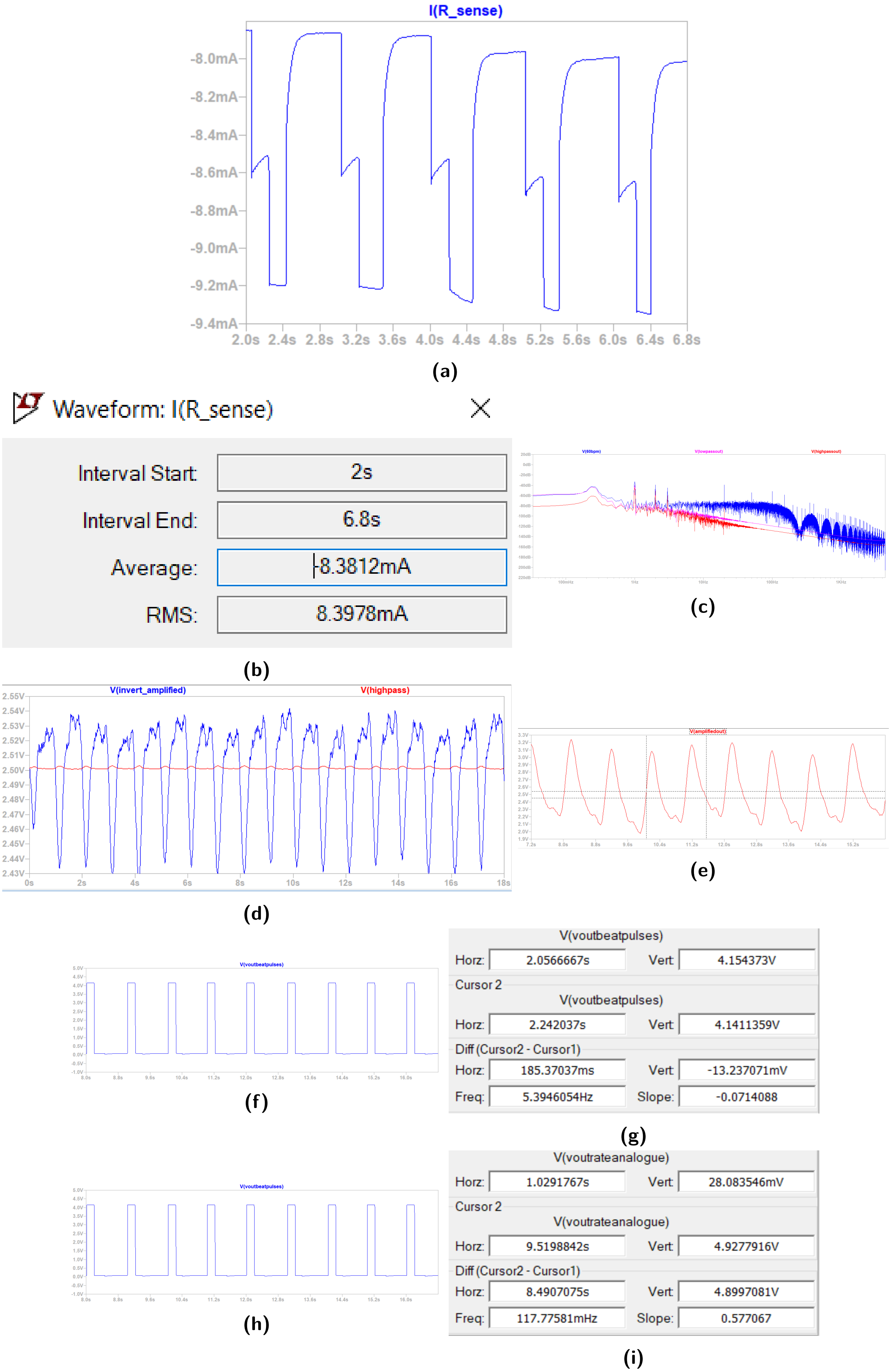


Figure 2.7: Voltage regulation, comparing the linear and switchmode regulators... (a) Blah blah. (b) Blah blah. (c) Blah blah. (d) Blah blah. As far as possible, please put input(s) and output(s) on the same plot rather than on separate plots. Based on the datasheet of XXXX in [7]

Chapter 3

System and conclusion

3.1. System

Report on the "so what" or the take-away of the ciruit you designed in this report. Report on noise levels and how the Heart rate 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).

3.2. Lessons learnt

Write down at least three of the most important things you have learnt in Assignment 2, and state what you would have done differently if you had another chance.

Bibliography

[1] E. Gouws, "Temperature Sensor," in *E344 Assignment 1 (ITSC 2020)*, Oct 2020, pp. 1–14.

[2] Electronics Tutorials, "Passive high pass filter," 2018. [Online]. Available: https://www.electronics-tutorials.ws/filter/filter_3.html

[3] ——, "Passive low pass filter," 2018. [Online]. Available: https://www.electronics-tutorials.ws/filter/filter_2.html

[4] CircuitsToday, "Butterworth filter design," 2010. [Online]. Available: https://www.circuitstoday.com/inverting-amplifier-using-opamp

[5] Doug Lowe, "Electronics components: How to use an op amp as a voltage comparator," 2010. [Online]. Available: https://www.dummies.com/programming/electronics/components/electronics-components-how-to-use-an-op-amp-as-a-voltage-comparator/

[6] Electronics Tutorials, "The differential amplifier," 2018. [Online]. Available: https://www.electronics-tutorials.ws/filter/filter_5.html

[7] BBC, "How to make opamps amp op," 2018. [Online]. Available: www.electronics-tutorials.ws

Appendix A

Social contract

Sign and inlcude.

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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.

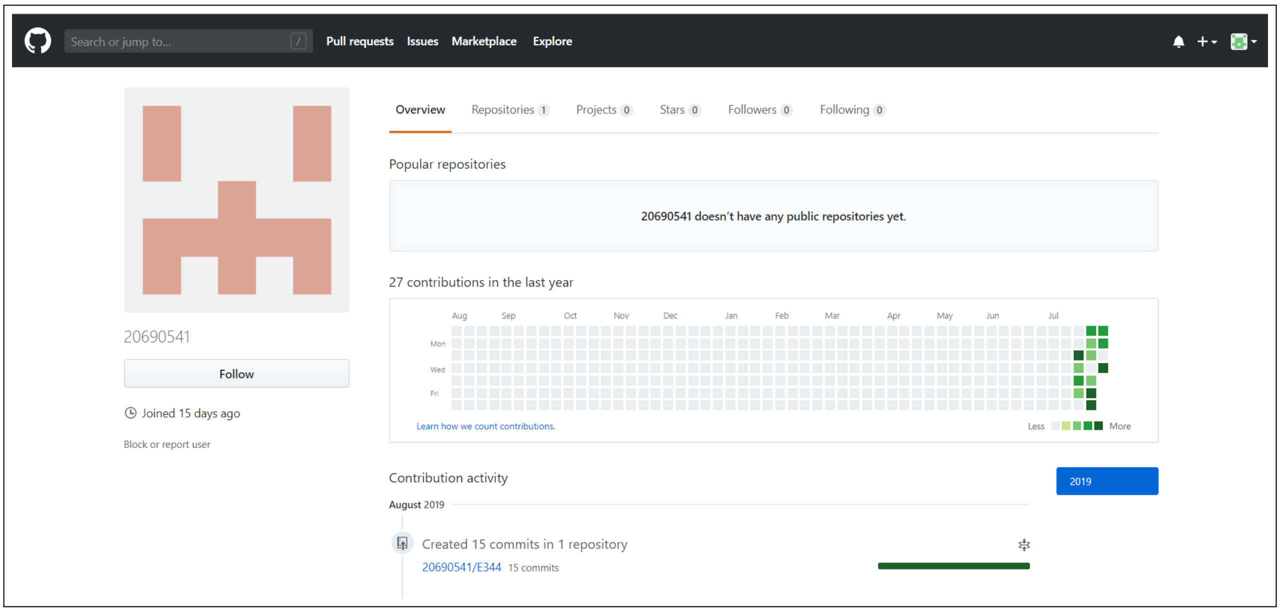
Signature: .... Date: ....

1

Appendix B

GitHub Activity Heatmap

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



Appendix C

A. Non-Inverting Amplifier

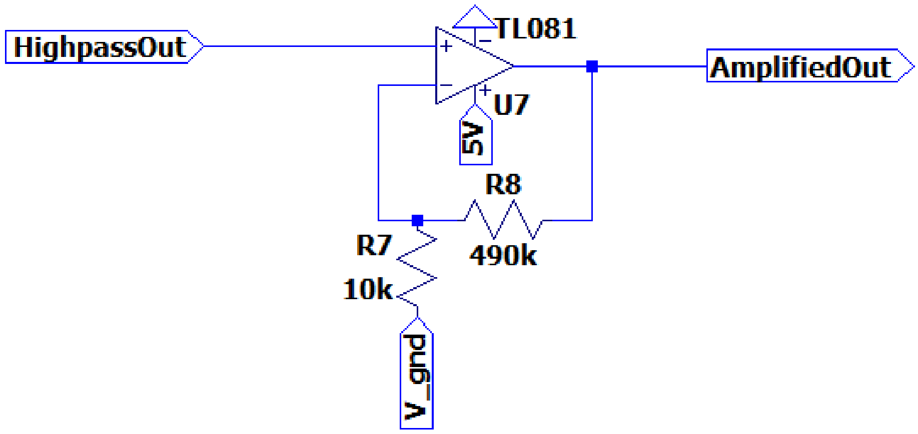


Figure 1: Non-Inverting Amplifier

Since the current pk-pk of the signal is 2 mV we wish to increase this quite significantly, opting for a gain (A_v) of 50.

$$A_v = 1 + \frac{R_8}{R_7} = 1 + \frac{490\,\text{k}\Omega}{10\,\text{k}\Omega} = 50 \tag{1}$$

B. Second Order Butterworth Filter

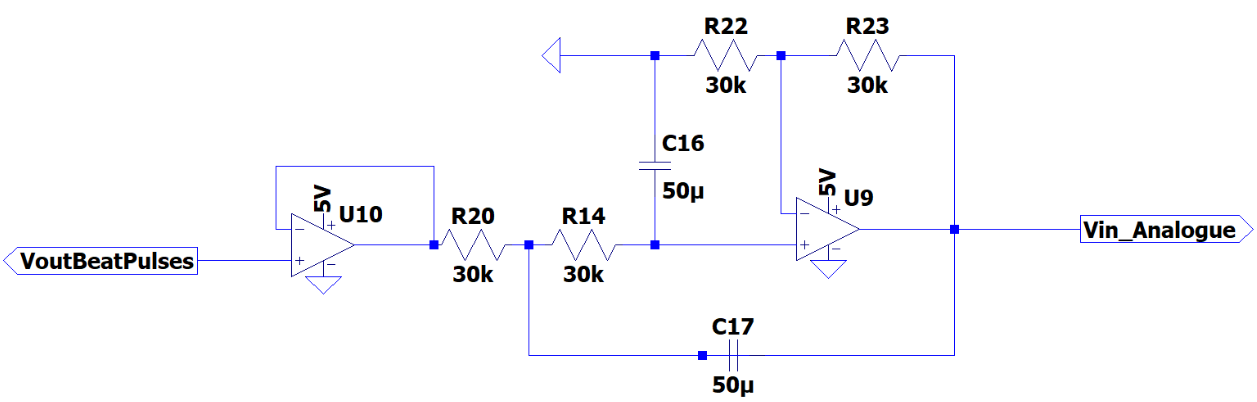


Figure 2: Second Order Butterworth Filter

$$f_c = \frac{1}{2\pi RC}. \tag{2}$$

With C $= 50\,\mu$F and a cutt- off frequency of 0.1 we find R $= 31.8\,\text{k}\Omega = 32\,\text{k}\Omega$