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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 29, 2020

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E. Gouws Voorletters en van / *Initials and surname*	September 29, 2020 Datum / *Date*

Contents

List of Figures

List of Tables

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
BPM	Beats Per Minute

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.

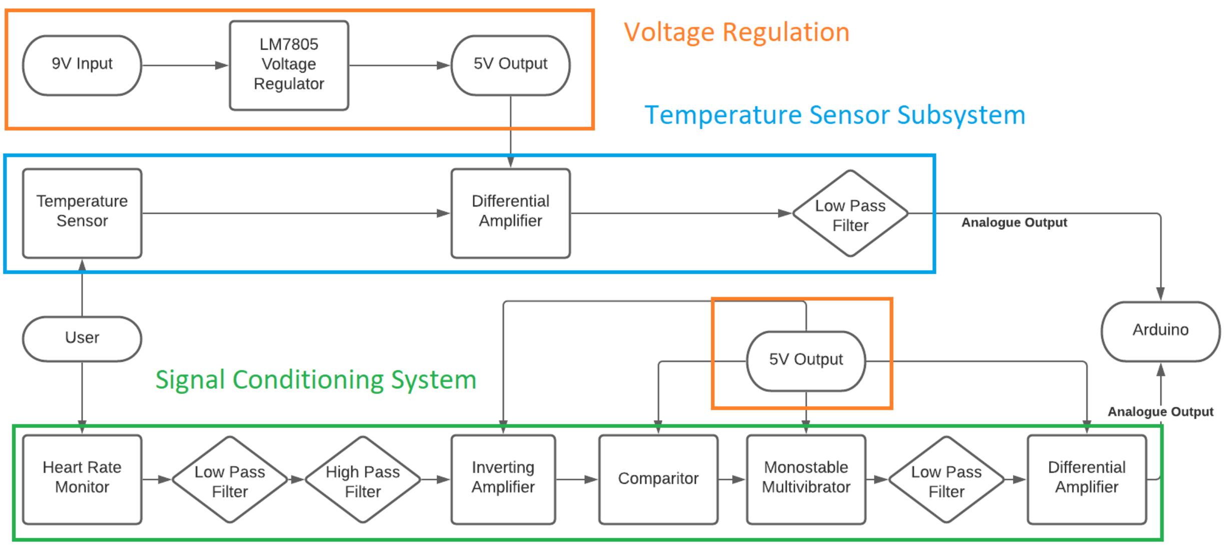


Figure 1.1: System diagram

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.

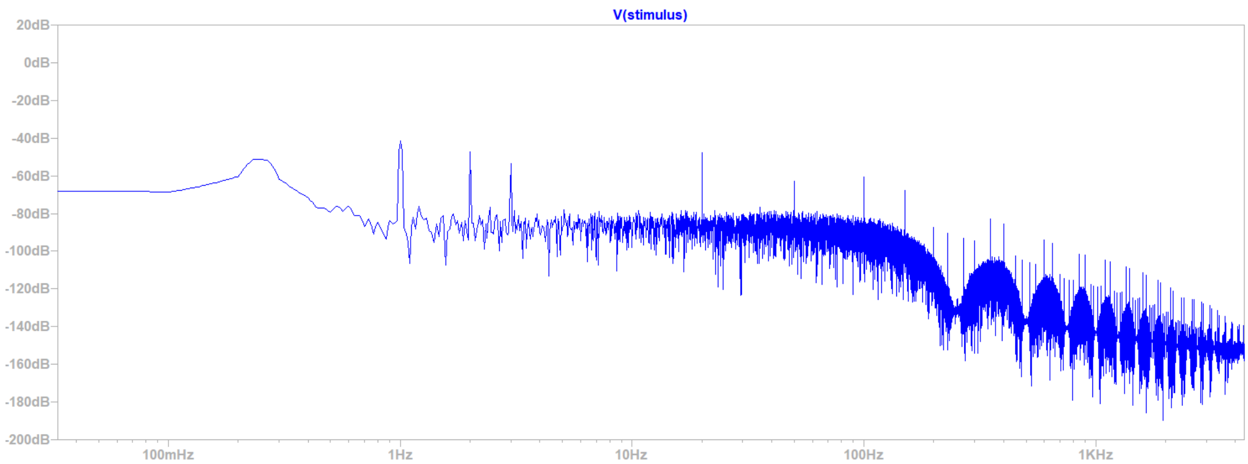


Figure 2.1: Frequency domain of unfiltered signal

2.2.1. Signal Conditioning

Third Order Passive Low Pass Filter

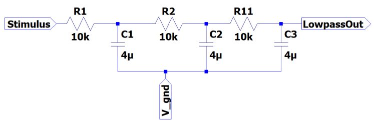


Figure 2.2: Third Order Passive Low Pass Filter

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 $= 9.95\,\text{k}\Omega = 10\,\text{k}\Omega$.

Third Order Passive High Pass Filter

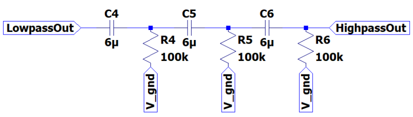


Figure 2.3: Third Order Passive High Pass Filter

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 $= 99.5\,\text{k}\Omega = 100\,\text{k}\Omega$.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 TL081 amplifier with a $VIN_{min} =??$ $VIN_{max} = 15$V ; $V_{dif} = 30$V placed in a non-inverting amplifier circuit to increase accuracy when placing a threshold. More information on how the non-inverting amplifier circuit was designed can be found in Appendix C - B.

2.2.2. Thresholding and Pulsed Output

Voltage Comparator

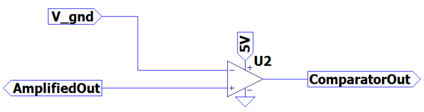


Figure 2.4: Voltage Comparator

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. We do however ensure that our amplification is adequate to allow for a 40 mV deviation around this point (2.5V) without any loss in accuracy.For input values > 2.5 V the comparator will output the top rail (5V) and for values < 2.5 V the bottom rail (0V).

Monostable Multi-Vibrator

Due to noise and variations the pulsed output produced by the comparator will not be identical but vary in duration.To ensure a uniform final output we make use a monostable multi-vibrator to extend all pulsed time frames to a duration of our desire.

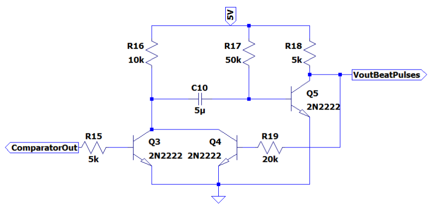


Figure 2.5: Monostable multi-vibrator

For the circuit seen in Figure 2.5 we chose $R_{15} = 5$k to ensure the BJT saturation.We make use of 2N2222 NPN transistors as these are easily accessible in the labs. For $V_{out} = V_{cc}$ I_{CQ2} R_{18} we choose $R_{18} = 5$k to ensure $V_{out} > 4$V yet minimizing current consumption. The resistor values of R_{16} and R_{19} are of little significance and therefore chosen as 10k and 20k respectively.

$$\tau = \frac{R_{12}C_{10}}{1.37} > 150ms. \tag{2.3}$$

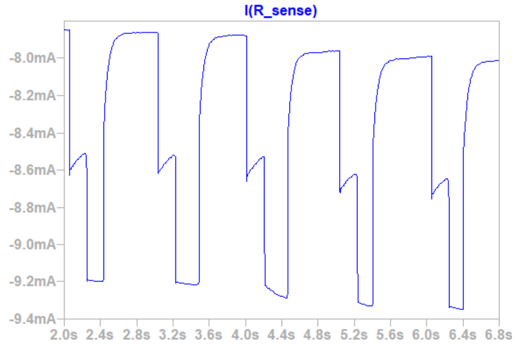
Choosing R_{12} as 50k and $\tau = 180$ ms we find C_{10} 5F.

2.2.3. Transducer

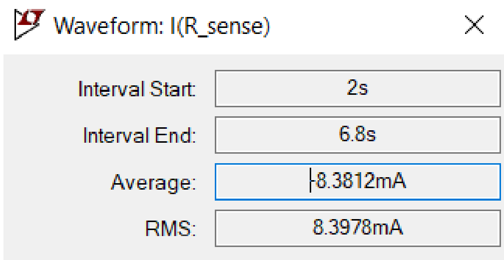
Noting that as with PWM a higher frequency of pulses will result higher average DC output we wish to produce the required analogue voltage output by scaling and amplifying the DC output obtained from the monostable multivibrator. A second order Butterworth filter is used to obtain the DC value of the input which design can be found in Appendix C - B. To scale the correlated DC output we use a differential amplifier with the same design process as used in Report 1 [1] section 3.2.1. Specific design for Assignment 2 can be viewed in Appendix C - B. The differential amplifier is designed to ensure an output range of larger than 3.5V centered around 2.5V for optimal swing. From the design We expect to see output values of 4.85V @ 150 bpm ; 2,5V @ 100 bpm ; 150 mV @ 50 bpm.

!!! 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.

2.3. Results



(a)



(b) Current Draw of Circuit

From this the current draw measured in Figure 2.6b can be seen as well below the assignment current specification of 50mA and the voltage regulator maximum output current requirement of 100mA.

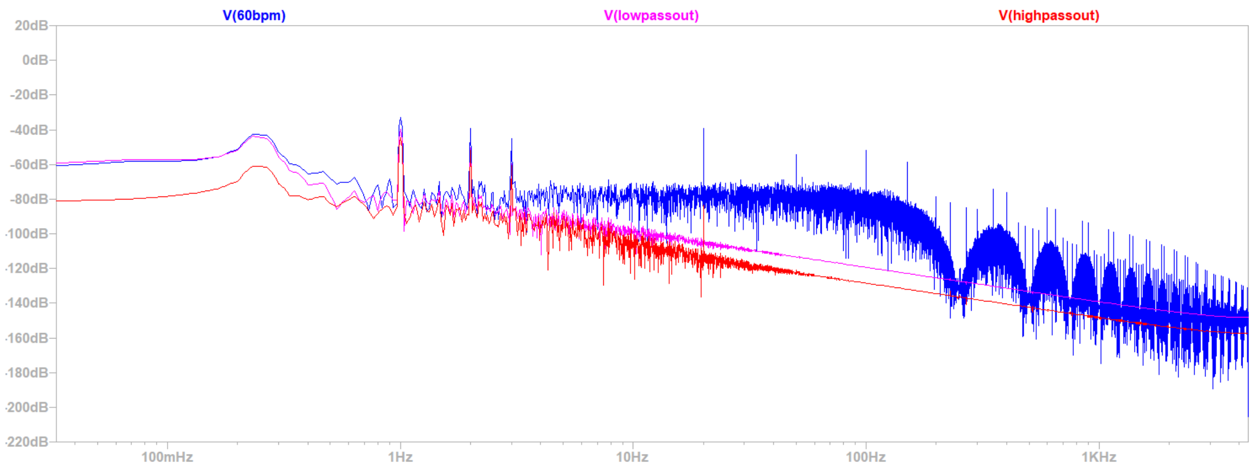


Figure 2.7: Frequency Response of Filter Output

Analysing the output in Figure 2.7 we can clearly see the suppression the higher noise frequency due to the LPF (pink graph) and the dampened curve at +– 0.8 Hz due to the HPF (red graph).

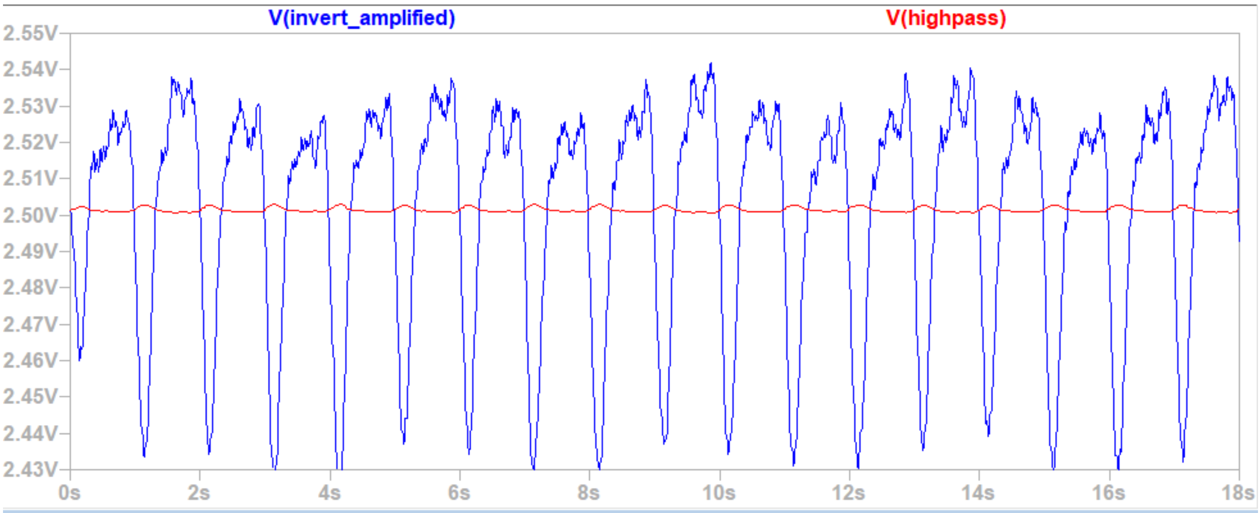
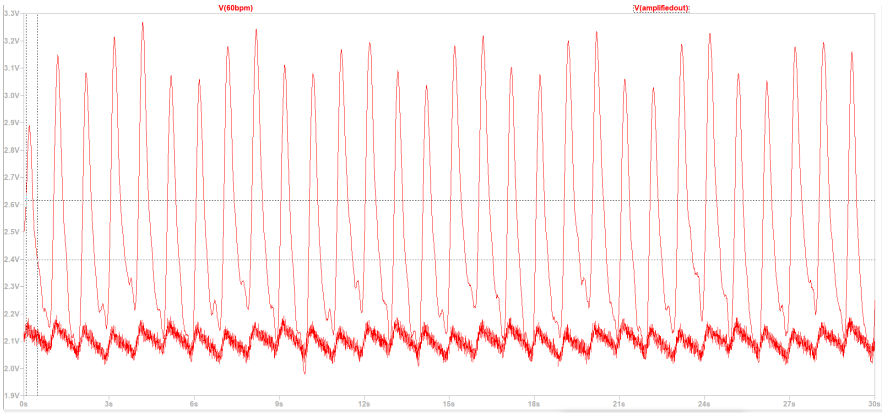
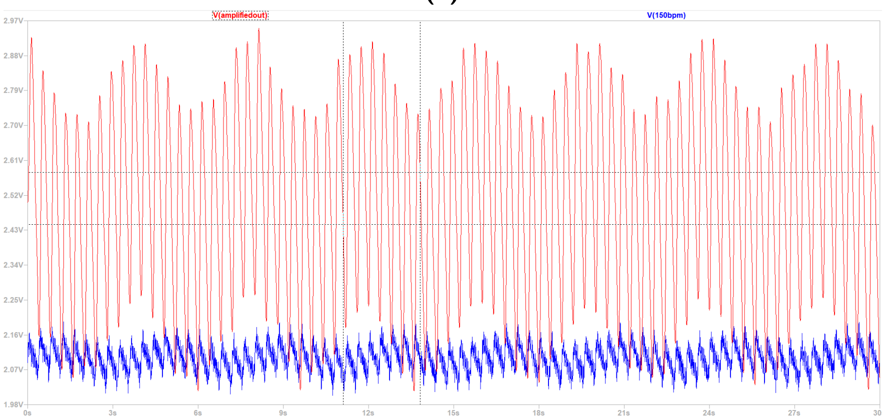


Figure 2.8



(a)



(b)

Figure 2.9: (a) 60 bpm threshold placement and variation. (b) 150 bpm threshold placement and variation.

Figure 2.9a and Figure 2.9b show the conditioned incoming signal for ranges 60 bpm and 150 bpm prior to thresholding. The cursors indicate a 10 percent pk-pk deviation allowable to showing that even with these deviations accurate pulses will still be generated.

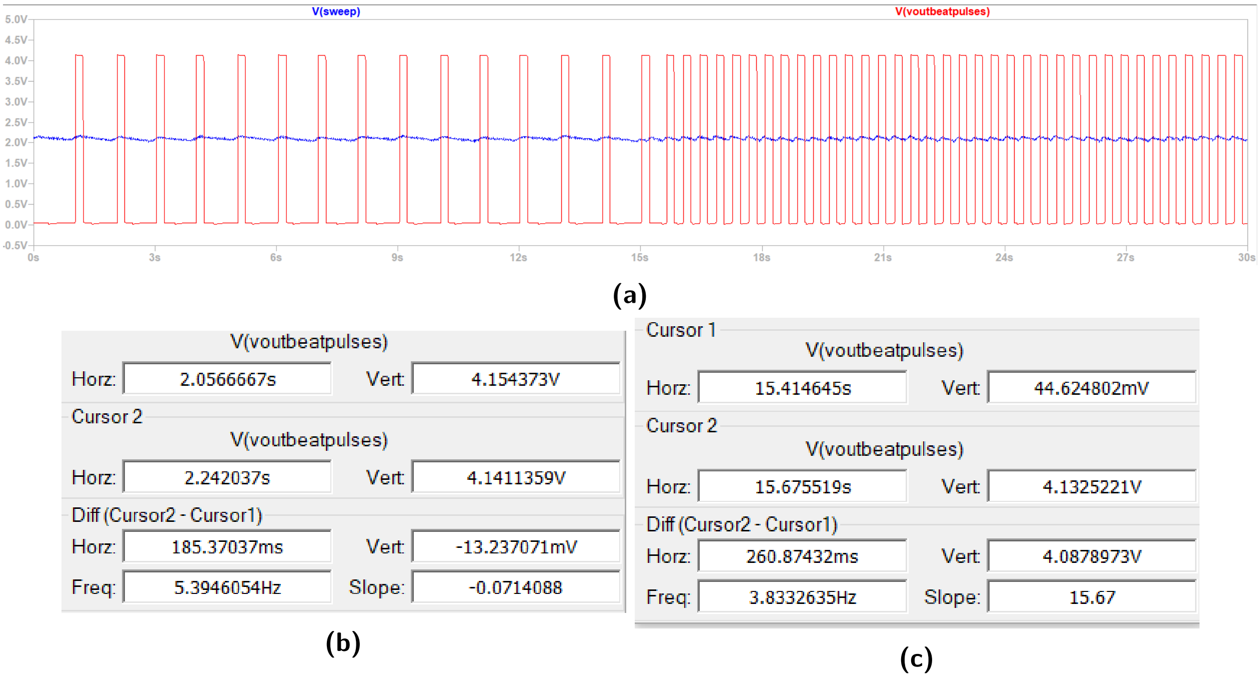


Figure 2.10: (a) Pulsed input VS output for 60 - 150 bpm (b) Measured output voltage range. (c)Measured output duration.

Therefore measured output meets the design requirement of high > 4V , low < 0.1 V and duration > 150 ms.

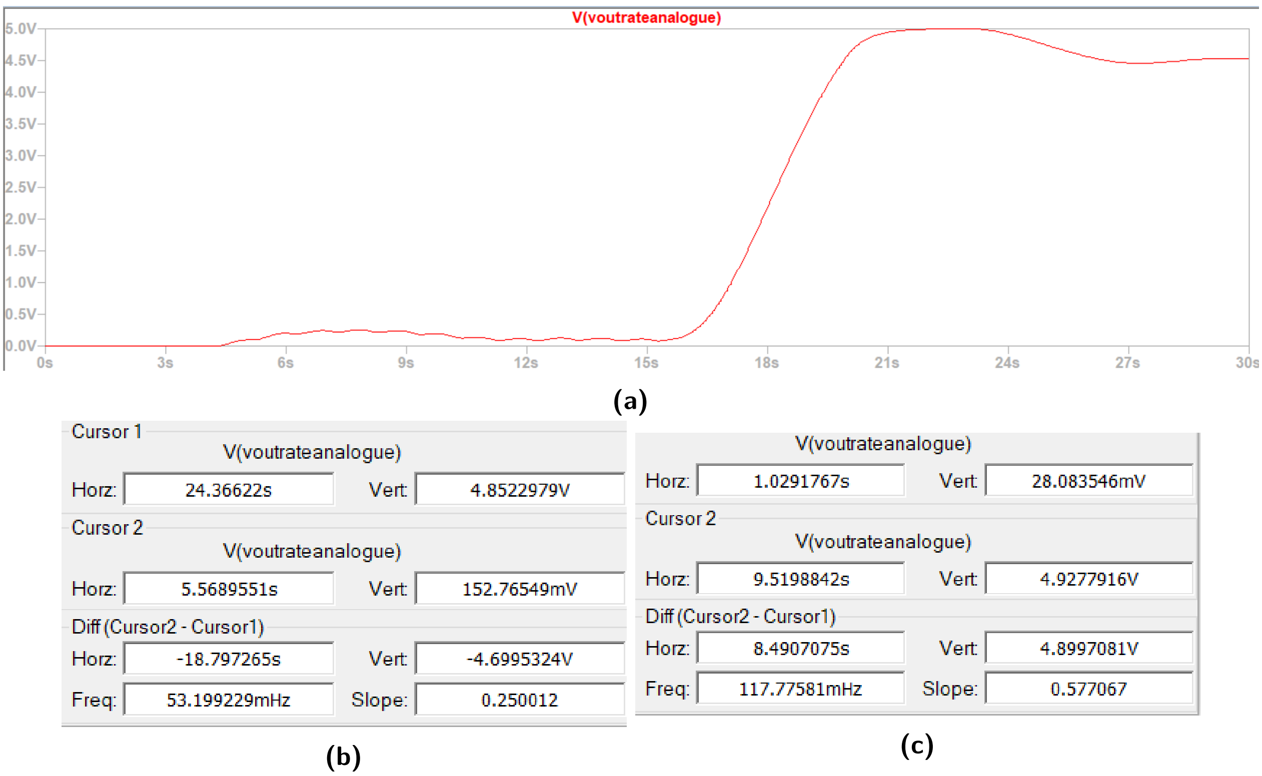


Figure 2.11: (a) Analog output from 50 bmp and to 150 bpm (b) Measured analogue output voltage range. (c)Measured analogue 5 persent settling time.

The circuit meets the requirement of $V_{range} > 3.5$V and a response time of no more than 10s.

2.4. Summary

The circuit performs very much as expected and meets all necessary requirements.

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).

Calibration Constant

From our design we know:

Table 3.1: Comparison of voltage regulators.

Heart Rate [bpm]	Input Voltage [V]	Output Voltage [V]
50	1.65	0.15
100	2.825	2.5
150	4	4.85

From this we can construct a linear equation (y = ax + b) such that:

$$V_{out} = a \times HeartRate + b. \tag{3.1}$$

Where a = $\frac{\delta y}{\delta x}$ = 0.047 and b = -2.2 (calculated using the gradient and V_{out} at 50 bpm).

$$V_{out} = 0.047 \times HeartRate - 2.2. \tag{3.2}$$

$$HeartRate = \frac{V_{out} + 2.2}{0.047}. \tag{3.3}$$

Remaining Current

$$I_{remain} = I_{total} - I_{temp} - I_{heart} = 100m - 11m - 9m = 80mA. \tag{3.4}$$

3.2. Lessons learnt

1. Latex margins are way too big.There is also no explicit penalty stated for changing them.
2. If you know of anyone in the professional industry, it's worth there your time to pick their

brain about ideas of implementations.
3. Stick to the rubric, else you'll do too much and end up having to delete most of your hard work the morning of to adhere to the page limit.

Bibliography

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

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

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[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

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.

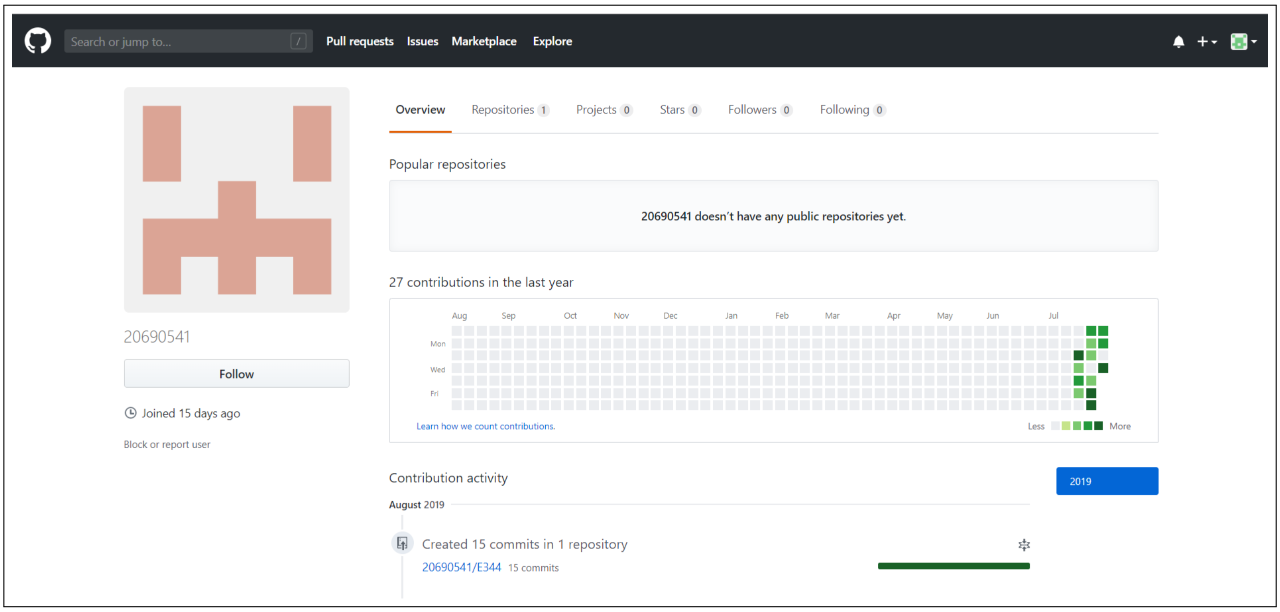
Signature: .... Date: ....

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

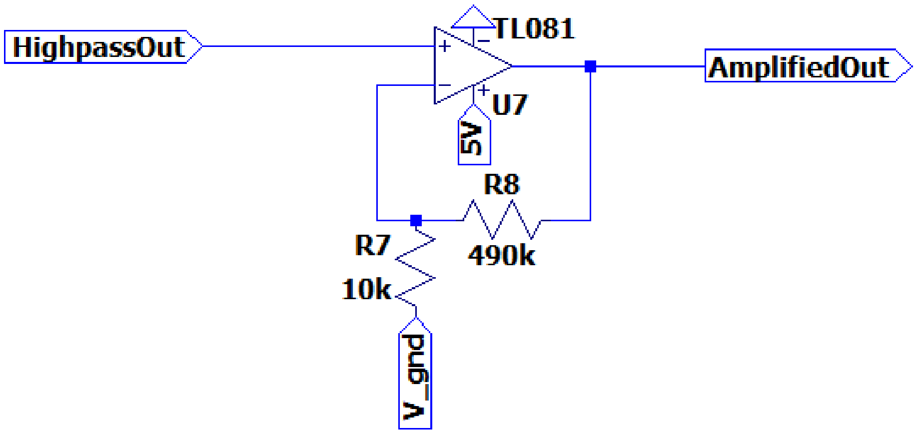


Figure 1: Non-Inverting Amplifier

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.

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

B. Second Order Butterworth Filter

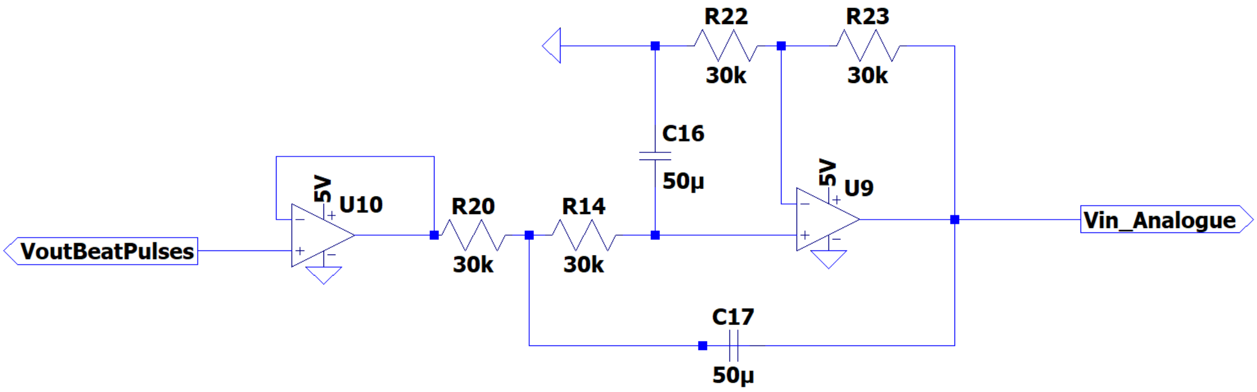


Figure 2: Second Order Butterworth Filter

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

With C = 50 μF and a cutt- off frequency of 0.1 we find R = 31.8 kΩ = 32 kΩ

C. Differential Amplifier

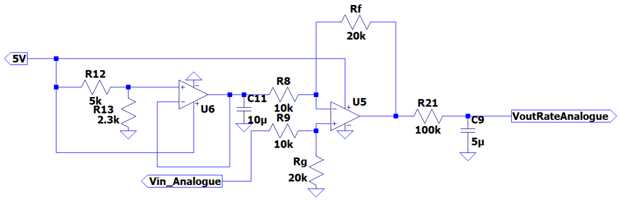


Figure 3: Differential Amplifier Circuit

Finding V_{out} at 50 bpm as 1.65V and V_{out} at 150 bpm as 4V we derive a midpoint voltage as 2.825V. Choosing $R_f = R_g$ and $R_1 = R_2$ we get

$$V_{out} = \frac{R_f}{R_1} \times (V2 - V1). \tag{3}$$

$$\frac{V_{max}}{2} = \alpha \times (V_{150} - V_{mid}). \tag{4}$$

$$2.5 = \alpha \times (1.175). \tag{5}$$

Choosing a gain of 2 will result in a swing of 2.35V. Therefore we choose Rf $= 20\,\mathrm{k\Omega}$ and R1 $= 10\,\mathrm{k\Omega}$.

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

$$V_{midpoint} = \frac{R_f}{R_1} \times (V_{150} - V1). \tag{6}$$

We calculate $V_1 = 1.575$. We make use of a 5V supply and voltage division to achieve this value. A unity buffer is added for further stability around this point.

Based our final formula of

$$V_{out} = 2 \times (V_{in} - 1.575). \tag{7}$$

From the design We expect to see output values of 4.85V @ 150 bpm ; 2,5V @ 100 bpm ; 150 mV @ 50 bpm.