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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 24, 2020

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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

Chapter 1

System design

1.1. System overview

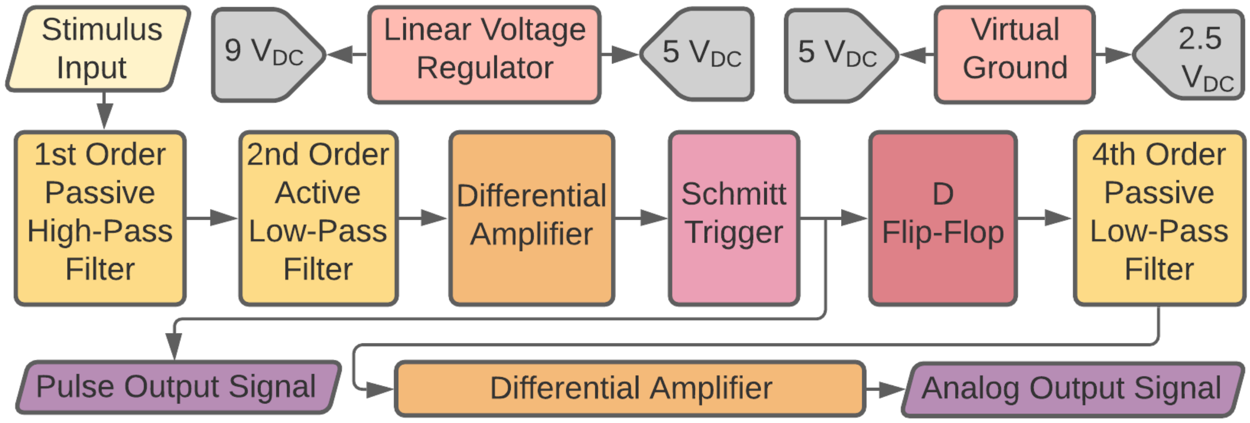


Figure 1.1: System Diagram

A heart-rate sensor is designed to receive an input signal from which pulses and analogue values are generated, corresponding to heart-beats and the heart-rate respectively. The aforementioned is achieved by voltage regulation, signal conditioning, pulse generation and conversion to analogue, as shown in figure 1.1. The circuit is powered by a voltage regulator [1] which can supply 100 mA, of which 12.8 mA is used for the temperature sensor - see E344 Assigment 1 [1] - leaving 87.2 mA at 5 V. The input signal has an amplitude of insufficient magnitude for conversion, and is subject to noise, necessitating signal conditioning: a first order passive high-pass filter and a second order active low-pass filter attenuate both high- and low-frequencies. Chosen with maximal simplicity in mind to reduce cost and complexity, the filters still performing adequately. Thereafter, a differential amplifier produces a signal with a large amplitude and little noise. A Schmitt Trigger then outputs a pulse signal with a frequency corresponding to the heart-rate. The Schmitt Trigger was chosen as it provides a noise margin via hysteresis. An analogue voltage output is required for the microcontroller - filtering and peak detection using diodes was considered but discarded, as non-linear diodes result in extremely slow simulation. Rather, the pulse output signal was converted to a pulse-width modulated signal, where the frequency of the former determines the duty cycle of the latter. This was done as PWM signals lend themselves to conversion-to-analogue by simple filtering. The PWM signal was obtained by using a D Flip-Flop and a RC-circuit (see section **??**). A third order passive RC filter is then used - passive components reduce current usage and simulation time. The filter is of high order as to minimize noise, while meeting the settling time requirement. Finally, the signal was amplified to achieve the required range.

Chapter 2

Heart rate sensor

2.1. Introduction

Circuits pertaining to signal conditioning, pulse signal and analogue output generation will be discussed. Conditioning is done via filtering and amplification; active filters provide high input and low output impedance, and a large Q-factor [2]. A differential amplifier is suitable for amplification, as the gain is referenced against a customizable voltage [3]. A Schmitt Trigger is well-suited for pulse generation, as it provides a noise margin [4]. PWM signals can be converted to analogue using filtering [5]. **check template at end to make sure everything is included**

2.2. Design

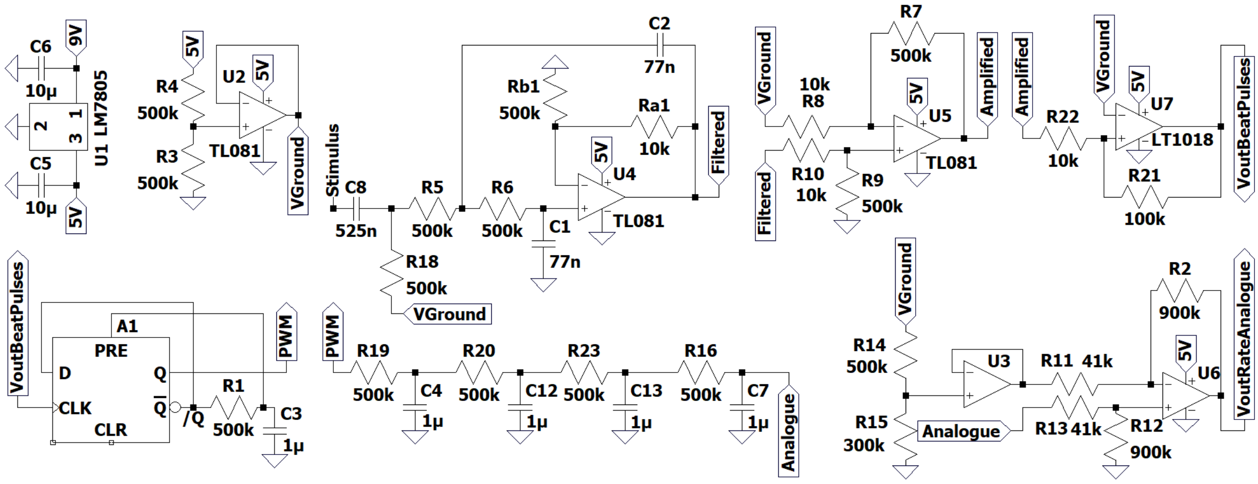


Figure 2.1: Complete Circuit **enlarge this**

The complete circuit is shown upfront in figure 2.1 in order to aid with explanation. Note that when resistor values are selected at random, the largest resistor in the sub-circuit is always chosen to be 500 kΩ, as to reduce current usage. The design process now follows.
The stimulus input signal contains noise at 0.25 Hz and at 5 Hz and higher. The information in the signal resides between 0.8 to 2.5 Hz, corresponding to 50 and 150 BPM respectively. Noise results in distorted square wave output, necessitating filtering. A first order passive high-pass filter, cutoff frequency 0.606 Hz, attenuates the low frequency noise. With R18 = 500 kΩ, C8 = 525 nF according to $f_c = \frac{1}{2\pi RC}$. The capacitor is connected to a virtual ground of 2.5 V, thus centering the signal around 2.5 V. A second order active low-pass

filter, cutoff frequency 4.1 Hz, filters out high frequency noise. R5 = R6 = 500 kΩ, C1 = C2 = 77 nF - see aforementioned formula. Cutoff frequencies were selected to remove noise maximally while minimally affecting heart-rate data. The signal should reside slightly above 2.5 V to facilitate amplification (to be discussed). Thus, Rb1 = 500 kΩ and Ra1 = 10 kΩ since $A_v = 1 + \frac{R_A}{R_B}$ [?]. The TL081 op-amp is used, as it is less expensive than the TLC2272 [?]. A filter output with DC offset slightly above 2.5 V allows for the use of a differential amplifier with the existing virtual ground connected to the negative input, thus removing the need for additional circuitry otherwise required to provide a voltage level at the negative input. The signal is amplified according to $\mathrm{V_{OUT}} = \frac{\mathrm{R}_a}{\mathrm{R}_b}(\mathrm{V_2} - \mathrm{V_1})$ [3], where $\mathrm{R_a}$ corresponds to R7 and R9, and $\mathrm{R_b}$ to R8 and R10. The gain of 50 was selected to again provide a DC offset of 2.5 V, as it facilitates implementation of the comparator (to be discussed). Since the amplified signal has an amplitude of only 1.66 V, the inexpensive TL081 was chosen despite having a smaller output range. Next, the signal is fed into a Schmitt Trigger comparator, which produces 5 V if the input exceeds the upper trip point (UTP) and 0 V if the input falls below the lower trip point (LTP) [4]. The range between the UTP and LTP is referred to as the hysteresis width and serves as a noise margin [4] around the reference voltage, V_{REF}. The hysteresis width was chosen as 0.5 V as to be an order of magnitude larger than the highest levels of noise present on the signal serving as input to the comparator. As mentioned previously, the amplified signal has a DC offset of 2.5 V, which was chosen as to require $\mathrm{V_{REF}} = 2.5$ V, once again allowing for the use of the existing virtual ground (instead of additional circuitry) at the negative input of the LT1018 comparator, which was chosen as it allows for output very close to 0 and 5V, and has a high gain. Now, UTP = 2.75 V, LTP = 2.25 V, UTP = $V_{REF} + \beta Vcc$ and LTP = $V_{REF} - \beta Vcc$, thus $\beta = 0.05$ [4]. Further, $\beta = \frac{\mathrm{R_{22}}}{\mathrm{R_{22}+R_{21}}}$. Thus R21 = 190 kΩ and R22 = 10 kΩ. (R21 was later adjusted to 100 kΩ to account for loading effects). The design specifications require a pulse width of at least 150 ms. A one-shot was considered to extend the pulses, but was omitted as the requirement could be met without it. All of the aforementioned thus produces a square wave output, where the frequency of the pulses directly relates to the heart-rate.

Obtaining an output suitable for a microcontroller presents itself as a problem of converting frequency to analogue. The decision was made to obtain a PWM signal from the FM pulse signal, as PWM signals lend themselves more readily to conversion-to-analogue using a simple low-pass RC filter. Pulse-width modulation was achieved by means of a D flip-flop. The essence of the design is to firstly keep the output high continually, but to then drive the output low for a fixed time, once per period. Since the period of the clock signal varies against BPM, driving low for a fixed amount of time results in a different ratio of the pulse being low at different frequencies, producing a varying duty cycle. Specifically, the previously generated pulse signal is used as a clock signal for the D flip-flop, and the not-Q output is fed back into the data line. This would normally drive the output high for all time t; thus a RC circuit is added of which the capacitor is charged by the not-Q output, and connected to the SET-line

of the flip-flop. Once the capacitor charges to 2.5 V, Q is pulled high and not-Q low until the next rising edge of the clock input inverts Q and not-Q. The result is a slightly delayed PWM signal, with a large duty cycle at high frequencies, and vice-versa. This configuration was preferred above the standard one-shot setup, as it results in a linear and consistent PWM output, as long as the capacitor charge time is selected to be shorter than the narrowest pulse of the clock signal. See section 2.3, figure 2.6 for output graphs. The calculations follow.
Select R1 = 500 kΩ. The capacitor charge oscillates between V_L and V_H. $V_H = 2.5\,\mathrm{V}$. V_L is reached for the first time at t_{L_1} and V_H at t_{H_1}. V_L is then reached at t_{L_2}. For 150 BPM (or 2.5 Hz), the pulse drives high for 0.2 ms. Since the capacitor has to charge faster than 0.2 ms, a charge time of 0.16 ms was selected to add a 20% margin, accounting for noise. Thus $t_{H_1} - t_{L_1} = 0.16$ and $t_{L_2} = 0.4 - 0.16 = 0.24$ for the 150 BPM signal. Finally,

$$V_L = 5\left(1 - e^{\frac{t_{L_1}}{\tau}}\right)$$

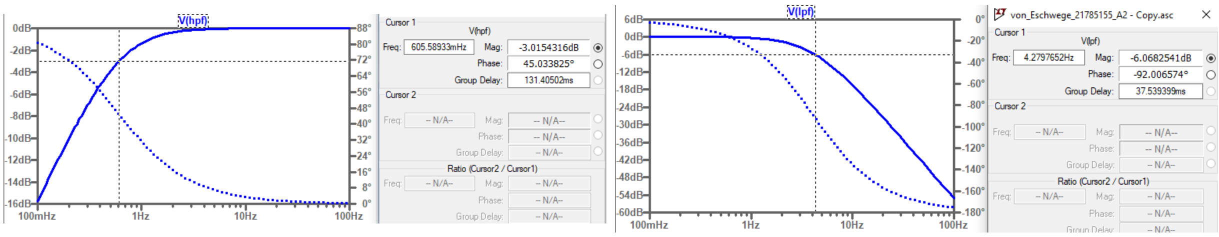
$$V_H = 5\left(1 - e^{\frac{-t_{H_1}}{\tau}}\right)$$

$$V_L = V_H\left(e^{\frac{t_{L_1}}{\tau}}\right)$$

giving $C = 1\mu$. Solving of equations is omitted here for the sake of brevity. See Appendix C for the relevant Matlab script.
Having obtained a PWM signal, a fourth order passive low-pass filter produces analogue values in the range of 0.95 to 1.2 V. A cutoff frequency of 0.5 Hz ensures maximal attenuation of noise while maintaining a 5% settling time of 10 seconds. Therefore resistor values are 500 kΩ and capacitor values are 1 μ. Finally, the analogue output is amplified by means of a differential amplifier with a negative input at 0.938 V. A gain of 20 produces a sufficient output range. Resistor values were chosen to be large as to minimize loading effects. Thus, R2 = R12 = 900 kΩ and R11 = R13 = 45 kΩ according to $\mathrm{V_{OUT}} = \frac{\mathrm{R}_a}{\mathrm{R}_b}(\mathrm{V}_2 - \mathrm{V}_1)$ [3]. Loading effects still had a slight effect, and required adapting R11 and R13 to 41 kΩ. An analogue transducer is thus designed, and can be connected to a microcontroller.

2.3. Results

The frequency response of both the high- and low-pass filters are $-3dB$ at 0.606 Hz and $-6dB$ at 4.3 Hz respectively, as shown in figures 2.2a and 2.2b, thus matching the design calculations almost perfectly. **current!!!!!!!**
The filtered signal is passed through a differential amplifier; the input is shown in blue and the output in red in figure 2.3. The filtered signal has a 50 mV amplitude (peak-to-peak), and the output 1.747 V. Therefore $A_v \approx 35$, which, although smaller than calculated, is to be expected due to non-linear behaviour for high amplification factors.
Following amplification, the signal is passed into a LT1018 comparator. Input and output thereof is shown in figure 2.4. Measurements yielded UTP = 2.75 V and LTP = 2.25V, giving



(a) High-pass filter

(b) Second-order low-pass filter

Figure 2.2: Frequency response of filters

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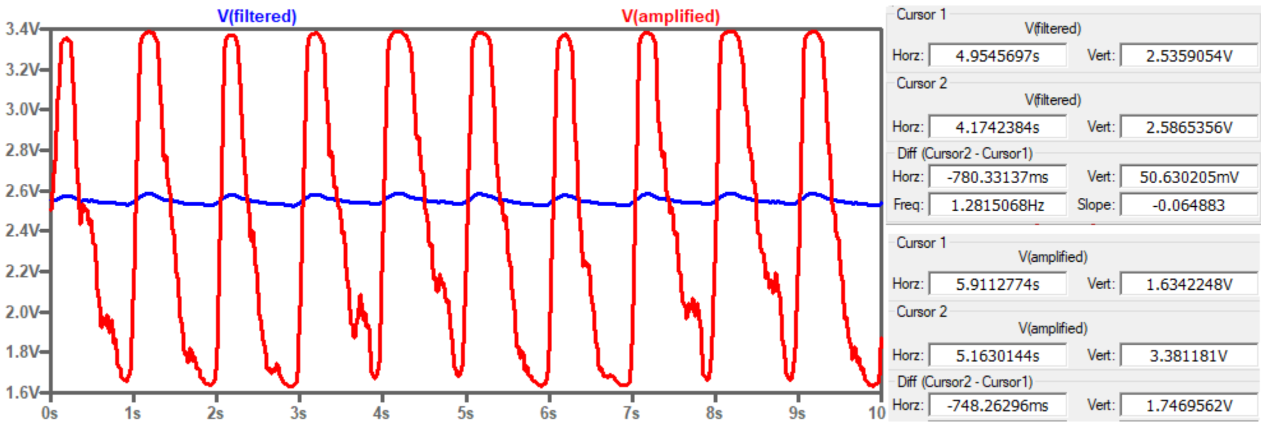


Figure 2.3: Amplification of filtered signal

a hysteresis width of 0.5 V, exactly as calculated. The cursor at the top right in figure 2.4 measures the narrowest pulse at 150 BPM as to demonstrate compliance with the 150 ms requirement, and the lower right gives the values of the tip points.

For the analogue transducer, a PWM signal is obtained as in figure 2.6. Section 2.2 explains tne interrelation of the signals, where `voutbeatpulses`, `pwm`, `/q` and `rc` correspond to the clock signal, Q, not-Q and the charging capacitor voltage respectively. As shown, the pulse is high for about 730 ms of every 1 s period in the case of 60 beats per minute. A duty cycle of 73% is thus obtained, and decreases to 56% for 0.223 s of 0.4 s at 150 beats per minute - see

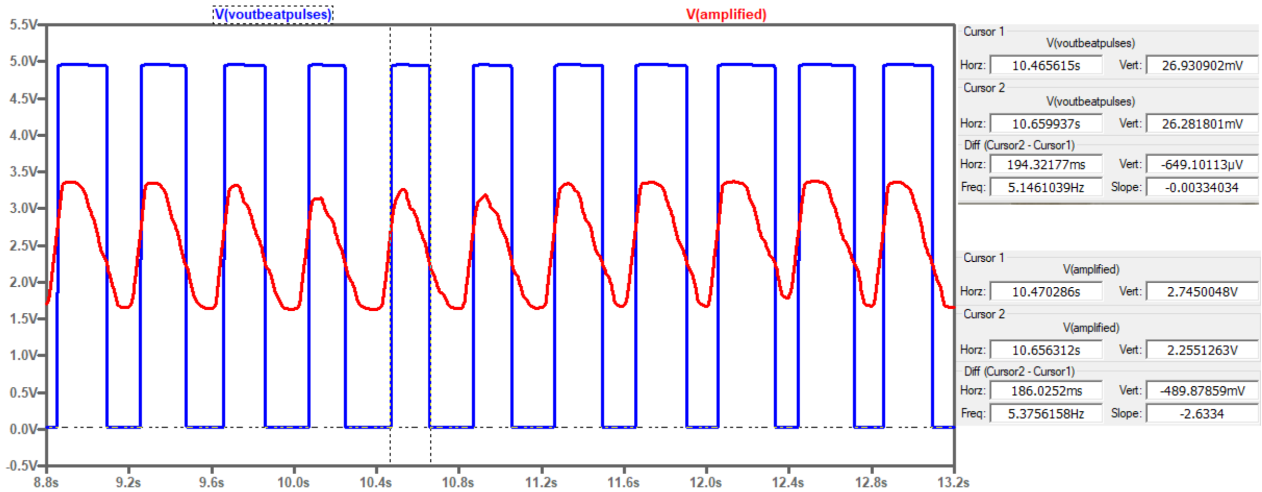


Figure 2.4: Pulse width modulation - 60 BPM

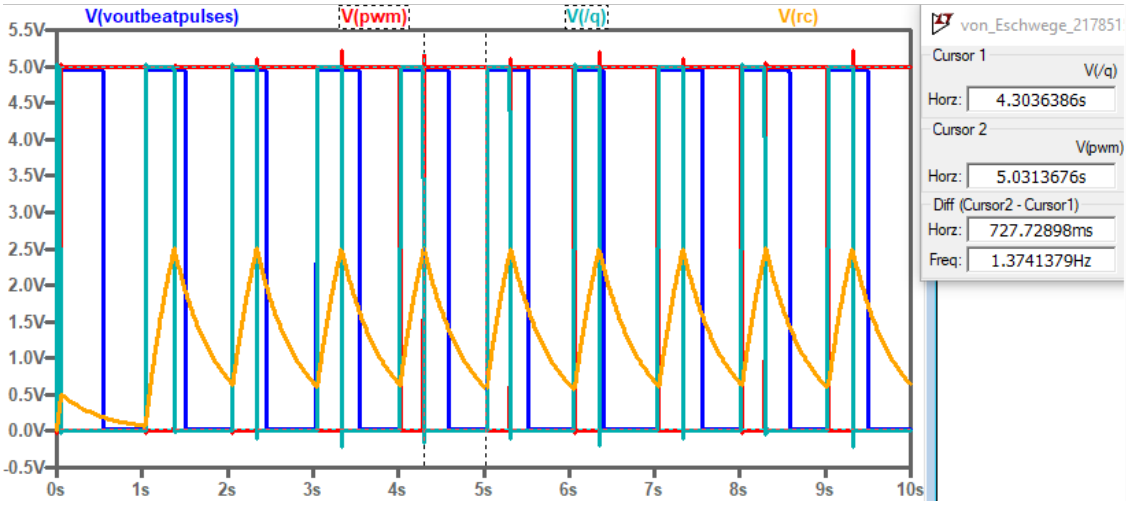


Figure 2.6: Pulse width modulation - 60 BPM

figure 2.5.

Finally, amplification and filtering of the PWM signal produces the output shown in figure ??, demonstrating an output range of 4.2 V.

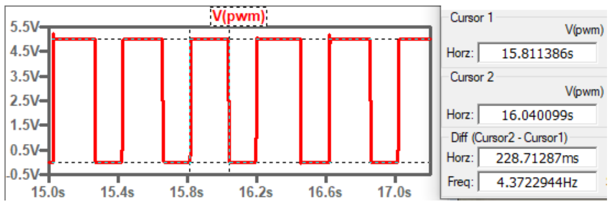


Figure 2.5: Pulse width modulation - 150 BPM

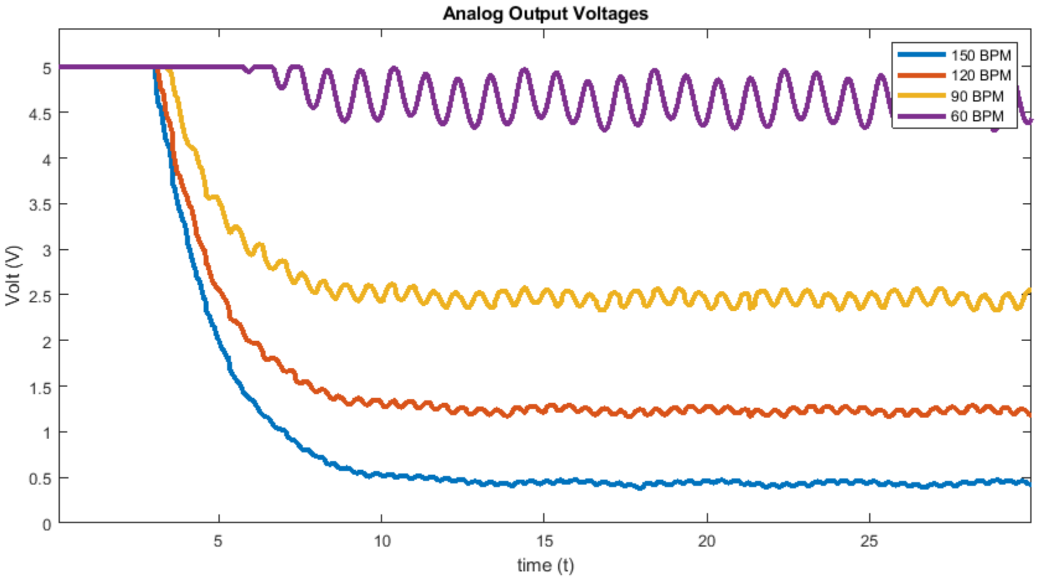


Figure 2.7: Analogue Voltage Output

Table 2.1: Example of a simple table.

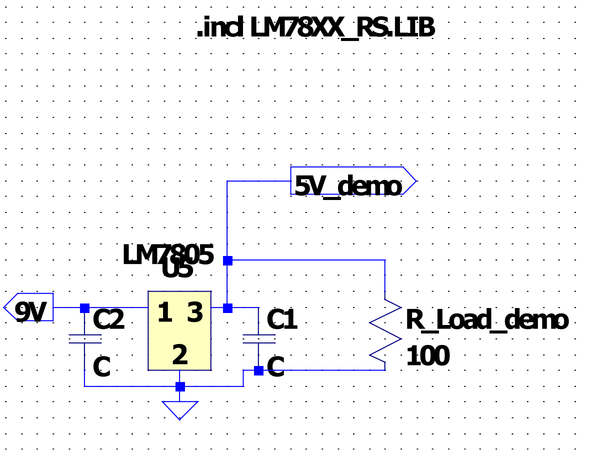
	2017	2018	Δ_{Abs}	Δ_{DiD}
A	9,868	10,399	+5	-11
B	10,191	10,590	+4	-12

2.4. Summary

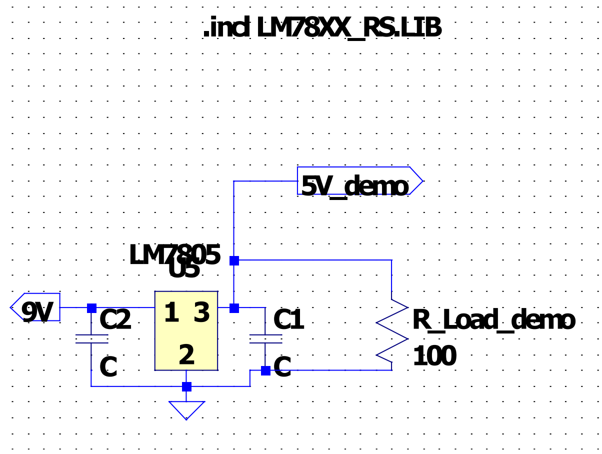
State whether your design performs as expected and what the limitations are or things to keep in mind are.

Table 2.2: Example of another table.

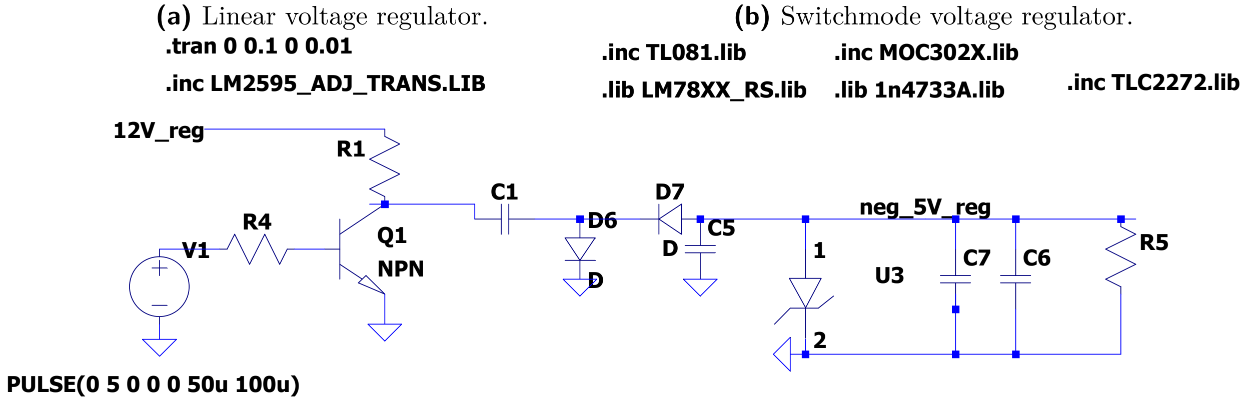
Schools	Total energy used		Change	
	2017 [kWh]	2018 [kWh]	Δ_{Abs} [%]	Δ_{DiD} [%]
A	9,868	10,399	+5	-11
B	10,191	10,590	+4	-12



(a) Linear voltage regulator.

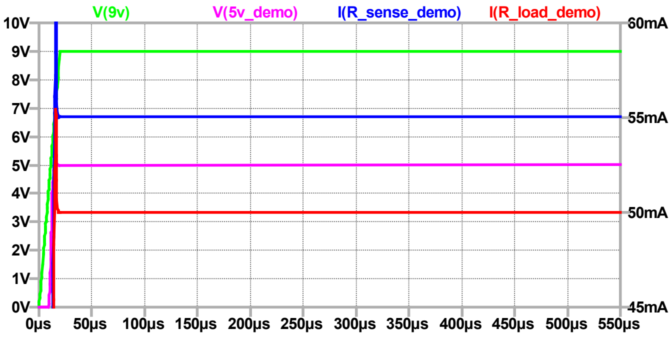


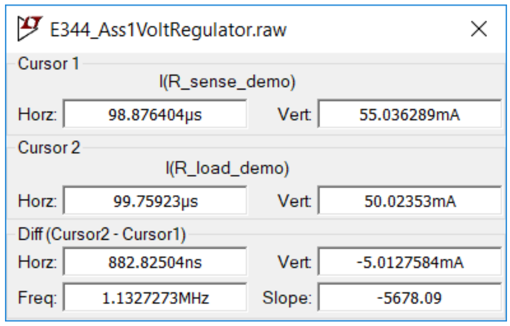
(b) Switchmode voltage regulator.



(c) Chargepump voltage regulator.

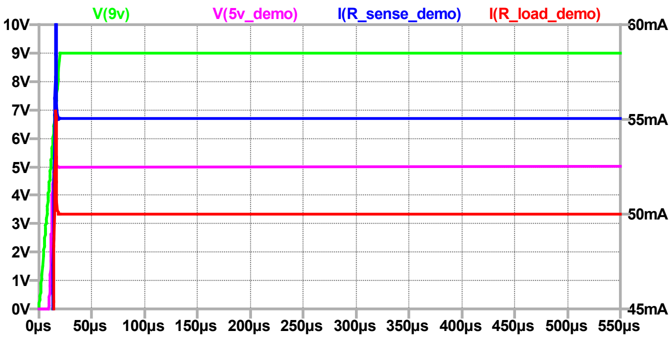
Figure 2.8: Circuit diagrams of the two voltage regulators, and another irrelevant one .

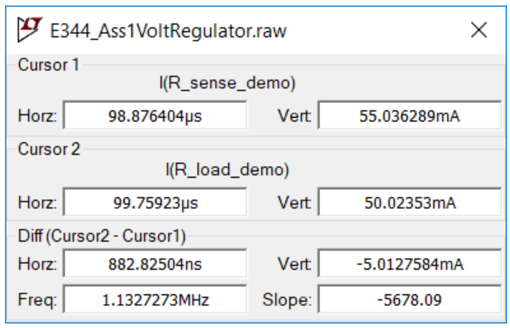




(b)

(a)





(d)

(c)

Figure 2.9: 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 [?]

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] "E344 assignment 1."

[2] "Difference between active and passive filter."

[3] W. Storr, "Operational amplifiers," 2018. [Online]. Available: https://www.electronics-tutorials.ws/opamp

[4] ——, "Op-amp comparator," 2018. [Online]. Available: https://www.electronics-tutorials.ws/opamp/op-amp-comparator.html

[5] "Analog output - convert pwm to voltage."

Appendix A

Social contract

Sign and inlcude.

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