Design Report – Team 04

ELETENG209: Analogue & Digital Design

Design of a Smart Energy Monitor

Anthony White
Hrichik Sircar
Logan Brighouse
Akash Pai
Department of Electrical, Computer, & Software Engineering

Abstract

This report details the analogue and digital design process of our smart energy monitor. For the analogue design, we designed a schematic in LTSpice and calculated the component values based on the design specifications. This design was then modelled in Altium. For the digital design, we used Microchip Studio to write our code that we would use to program the ATMega328P and validated the design using a simulation on Proteus. We then discussed the results obtained from our model.

Introduction

In the second year of our Bachelor of Engineering (Honours) degrees, and the first year in our respective specialisations, we took the compulsory project-based course COMPSYS/ELECTENG 209. The primary objective of this course was for us to design and engineer a system with a specific functionality by applying the concepts learnt in both analogue electronics and embedded software development. But we also had other goals including gaining the fundamental knowledge, experience, skill-set and professional behaviour needed to succeed in the more challenging design projects we would engage in the future as engineers.

We were tasked with designing a smart energy monitor that measures and displays the amount of energy consumed by a household appliance. Using the conceptual system diagram [1], we created a model of this system. Our model includes analogue circuitry consisting of sensors, amplifiers, and filters through which the input voltage and current signals can be measured by our microcontroller. This microcontroller is programmed by an embedded software program that converts the analogue signals to digital form and calculates the energy consumption together with other important information. The information is then transmitted to a local LCD display. This report documents the design process of our model. This includes our design specifications, analogue design that was created and validated in LTSpice, PCB design created in Altium designer, and our embedded software design that was coded in Microchip Studio (to run on a ATMega328PB microcontroller) and then validated in Proteus. We then discuss the overall performance of our model.

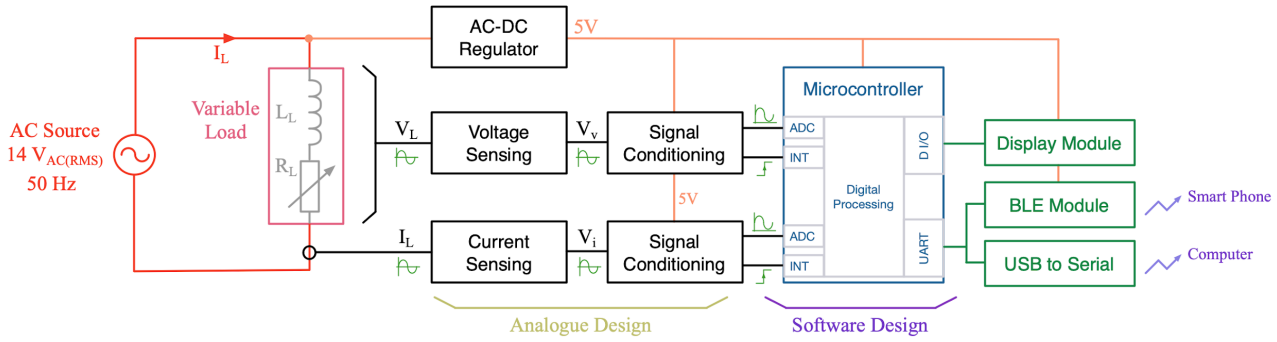


Fig. 1: A conceptual system diagram [1]

Literature Research

Table I: A Comparison of existing energy meters

Parameter	Neurio Sensor	Efergy
Operating voltage range	120 - 240V	110 - 300V AC
Power consumption	< 2W	-
Measurement accuracy	99%	98%
Operating Temperature	5 - 50 degrees	5 - 45 degrees
USB Port	No	No
Dimensions	-	78x117x32mm

Design Specifications

Table II: Key system specifications

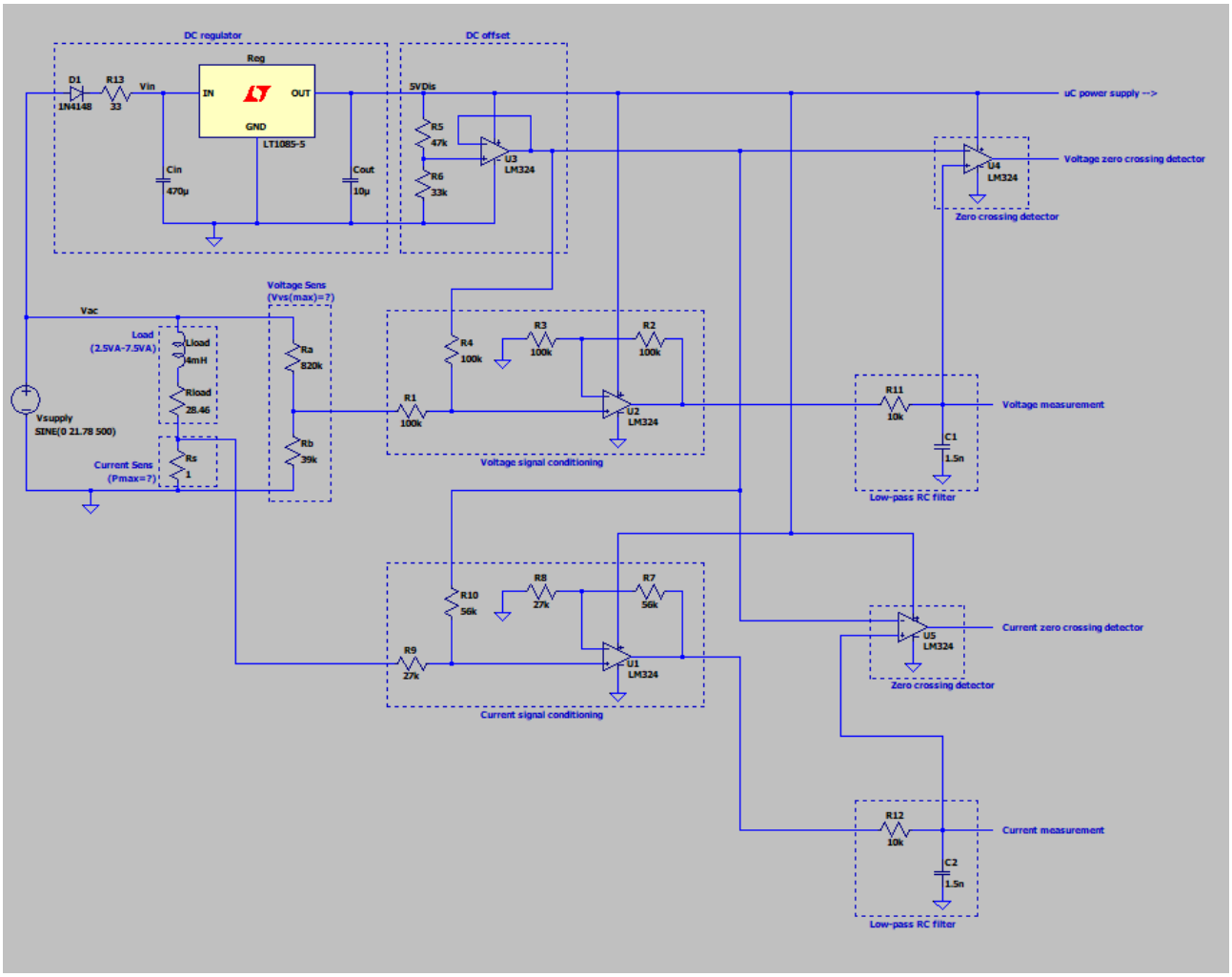
Parameter	Value
Source Voltage	14 VRMS ± 10%
Source Frequency	500 Hz ± 2%
Load Range	2.5 VA to 7.5 VA
Load Power Factor	0.6 to 0.99
Measurement Accuracy	±5% of full-scale reading
ADC Conversion Rate	10 kHz
MCU System Clock	2 MHz
LCD Display Information	Voltage, Current and Power
LCD Display Units	Vpk, Arms, and W
LCD Scroll Rate	1 s
UART Baud Rate	9600 Baud
Information Transferred Via UART	Voltage, Current and Power
PCB Size	10000 mm²
PCB Technology	Double Layer with PTH

Device Technology	TH

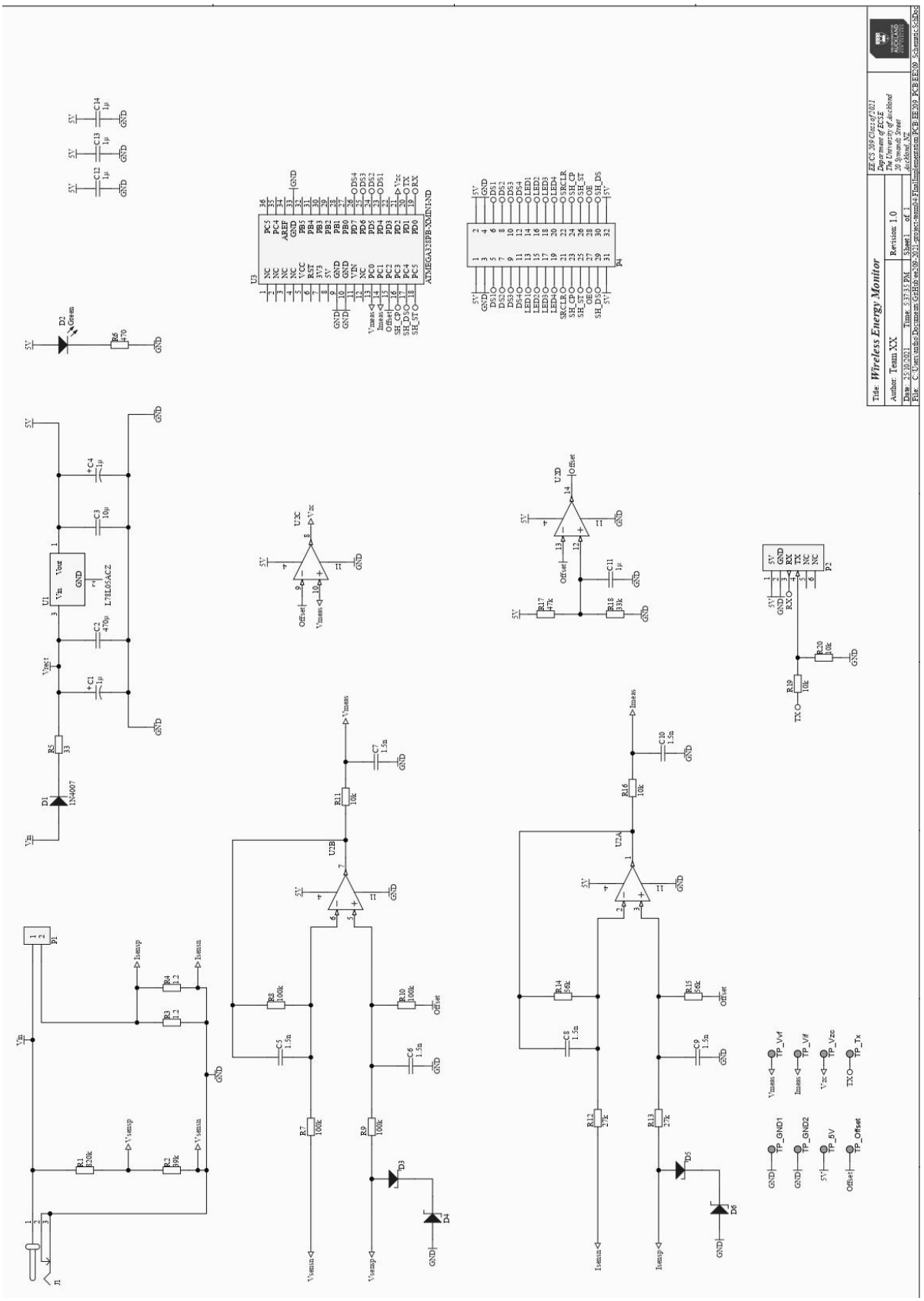
The commercial designs have a much greater operating voltage range than our design and can operate in a greater temperature range. They also have a greater measurement accuracy. This is attributed to the more expensive and higher quality resources they are using as well the large team of professionals implementing the design.

The Analogue Design

The Schematic

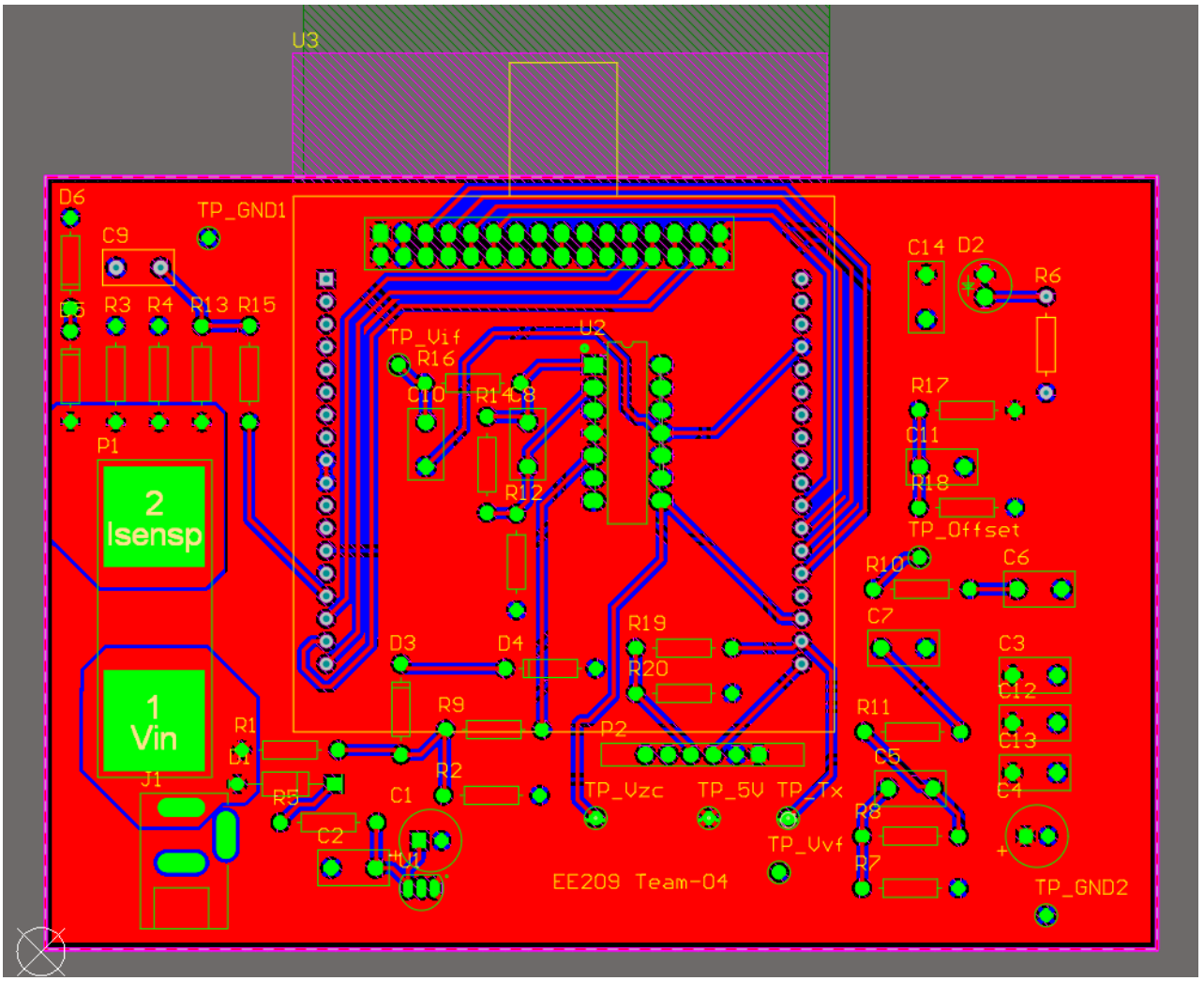


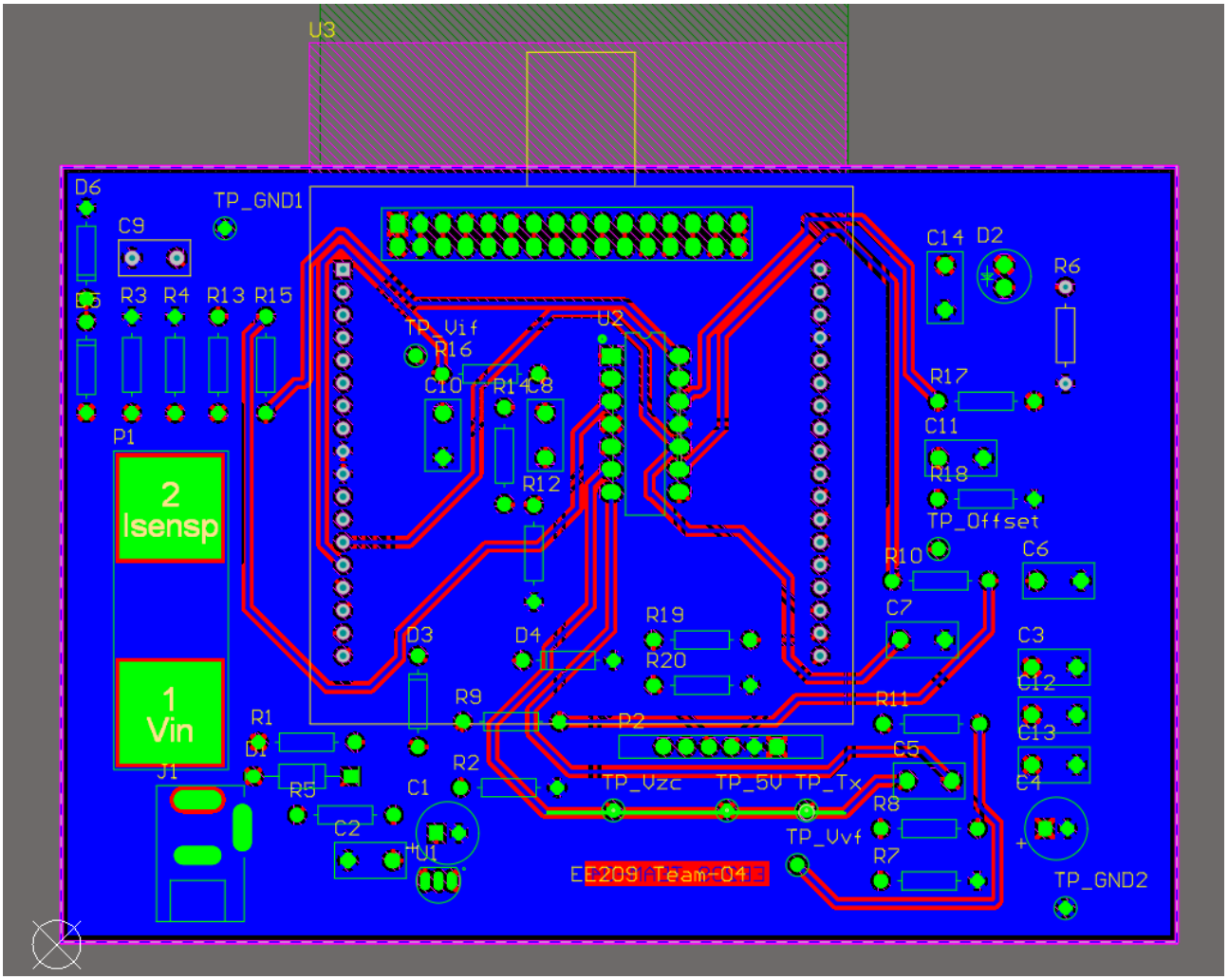
LTSpice Schematic of the Analogue Design



Altium Schematic of the Analogue Design

The PCB


U3
D6
TP_GND1
C9
R3
R4
R13
R15
TP_Vif
R16
C10
R14
U2
P1
2
Isensp
1
Vin
J1
R12
D3
D4
R19
R20
R9
R1
D1
R5
C1
R2
C2
P2
TP_Vzc
TP_5V
TP_Tx
TP_Uvf
EE209 Team-04
C14
D2
R6
R17
C11
R18
TP_Offset
R10
C6
C7
C3
C12
C13
R11
C5
C4
R8
R7
TP_GND2


U3
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C9
R3 R4 R13 R15
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1
Vin
J1
TP_Vif
R16
C10
R14
C8
U2
R12
C14
D2
R6
R17
C11
R18
TP_Offset
R10
C6
C7
C3
C12
C13
C4
R19
R20
D3
D4
R9
P2
R11
C5
R8
R7
TP_GND2
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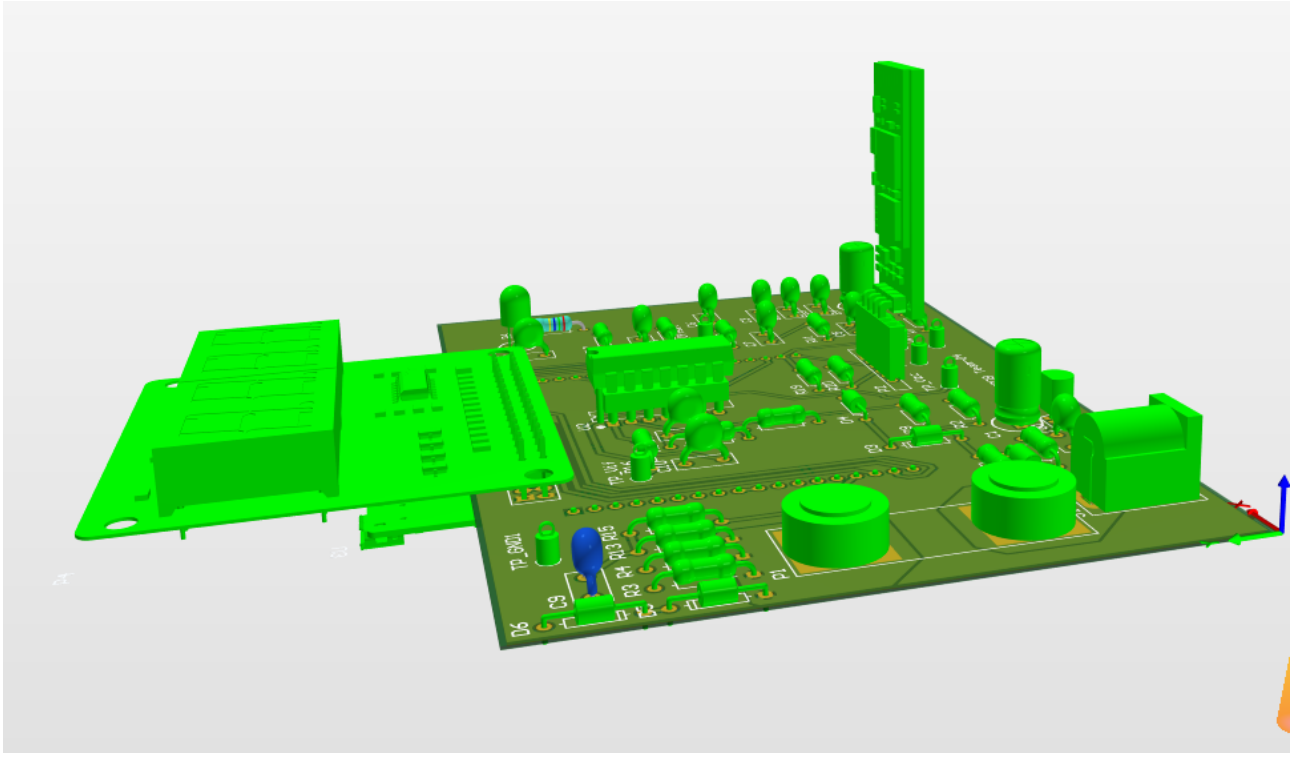


This PCB is designed so that all access ports are at the edge of the board, where they are easily accessible. Polygonal pours were used for connecting large surface mount pads, the 5V power source and the ground. This allows a better flow of current through the board.

Design Validation

Table III: Key design parameters

Parameter	Calculated (Peak)	Simulated (Peak)
G_{vs}	0.0454	
V_{vs} when V_{AC} is 15.4 V_{rms}	0.98V	1.15V
V_{vs} when V_{AC} is 12.6 V_{rms}	0.81V	1V
G_{is}	1	
V_{is} when I_{AC} is 0.60 A_{rms}	743mV	743.06mV
V_{is} when I_{AC} is 0.16 A_{rms}	160mV	160.12mV
G_{vo}	1	
V_{vo} when V_{AC} is 15.4 V_{rms}	3.04V	3.21V
V_{vo} when V_{AC} is 12.6 V_{rms}	2.87V	3.07V
G_{io}	2.07	
V_{io} when I_{AC} is 0.60 A_{rms}	3.60V	3.47V
V_{io} when I_{AC} is 0.16 A_{rms}	2.39V	2.39V
G_{vf}	1	
V_{vf} when V_{AC} is 15.4 V_{rms}	3.04V	3.21V
V_{vf} when V_{AC} is 12.6 V_{rms}	2.87V	3.07V
G_{if}	1	
V_{if} when I_{AC} is 0.60 A_{rms}	3.60V	3.47V
V_{if} when I_{AC} is 0.16 A_{rms}	2.39V	2.39V
ΔV_{in} of 5V regulator	0.2mV	146mV
ΔV_{5V} of 5V regulator	0.001mV	0.73mV

The Embedded Software Design

Flowchart

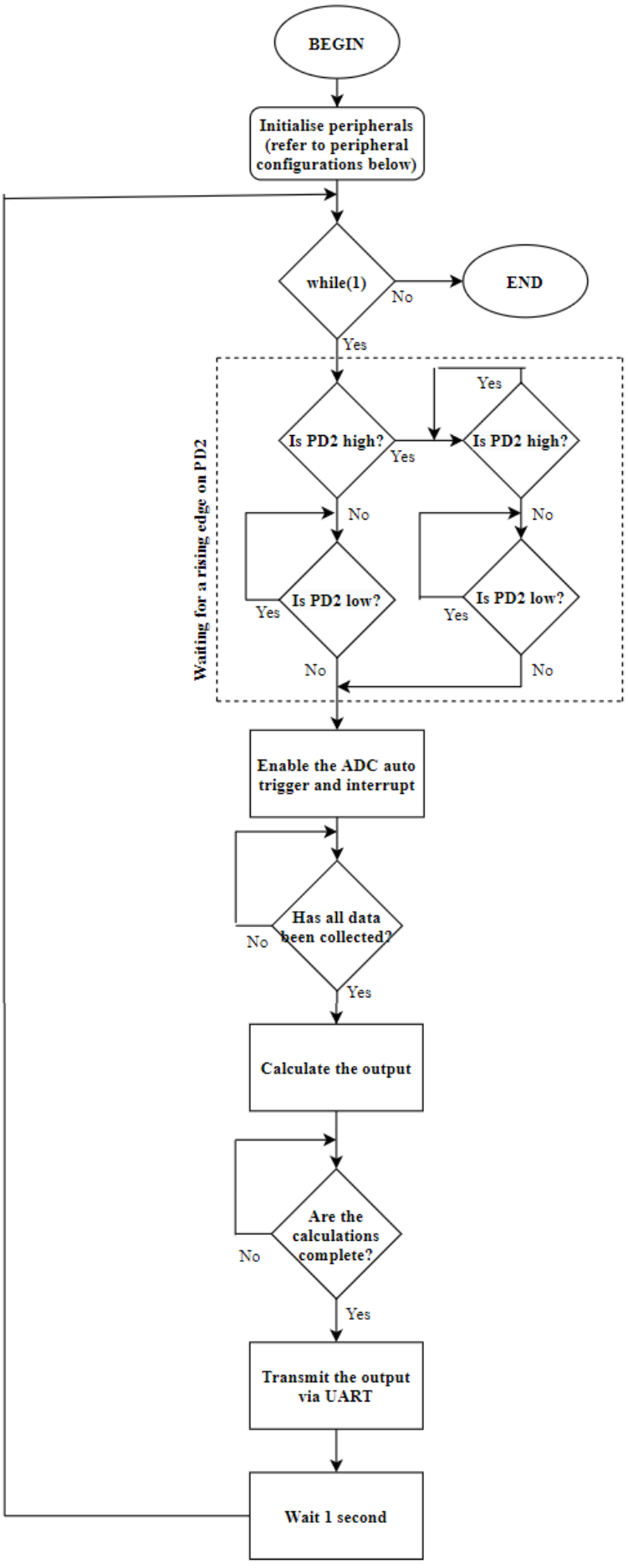
The main program flowchart executes upon startup, and includes code that controls the data collection and processing. When the ADC is enabled, 80 samples of current and voltage are collected via ADC readings and linear approximations. Following that, the data is processed, and the results are stored in global variables to be displayed. The outputs of the program are transmitted via UART, which can be used to output to a bluetooth module to be displayed on a computer or smartphone. Also, the output is displayed on a four digit seven segment display which scrolls every second.

The second flowchart shows the events that take place on the overflow to TCNT0, which is used to control the ADC. Voltage and current readings are taken, alternating between the two, until the sample size is reached. Then, the ADC is disabled and additional data points are calculated using a linear approximation, and then a flag is set indicating that the data is ready to be processed.

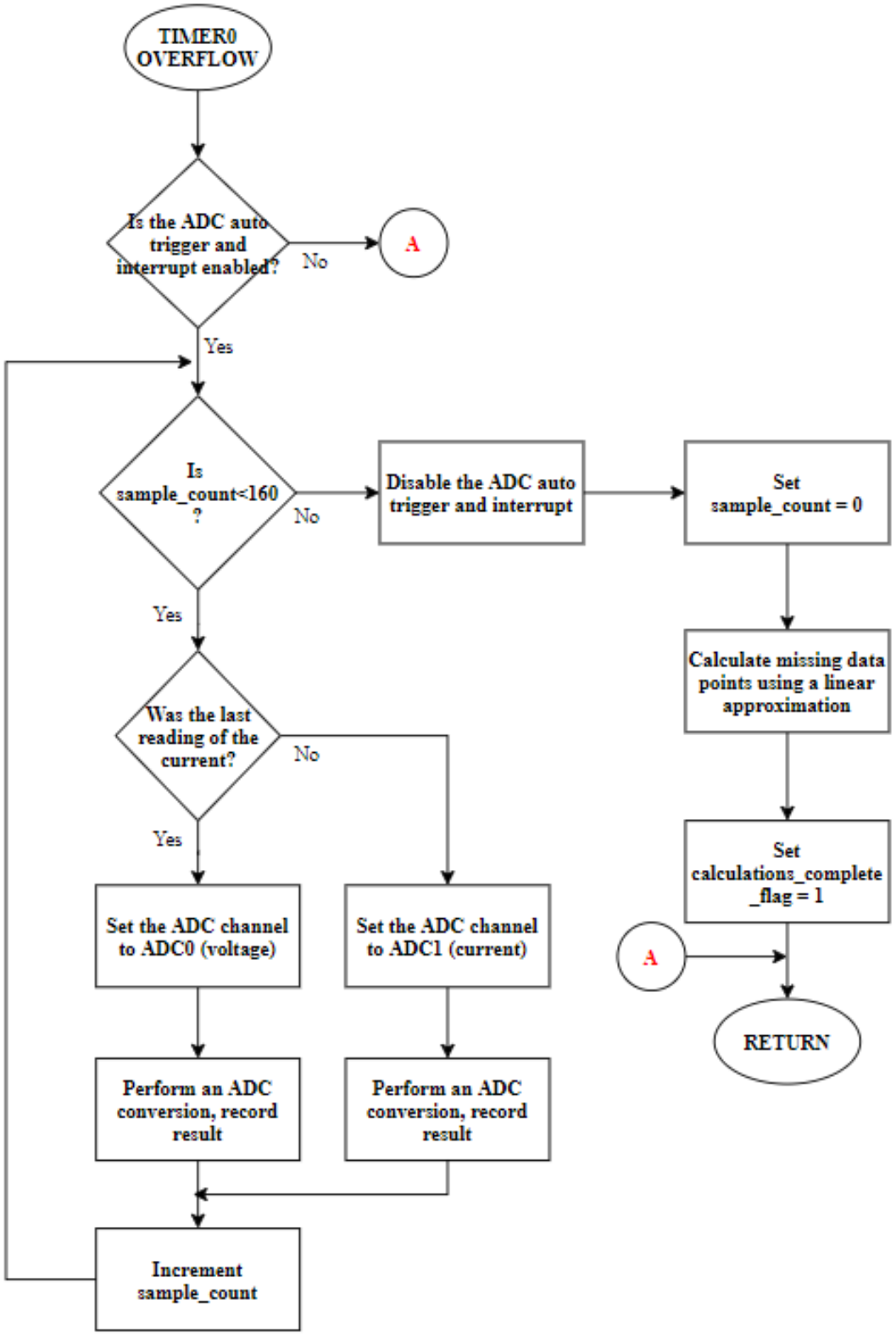
The third flowchart shows the events that take place on the overflow of TCNT2, which controls the seven segment display. Every 100 overflows, the data displayed changes, so that we have a scroll rate of one second. Also, every overflow the digit/character is changed, so that each digit flashes on after each other, every 10ms. This gives the user the impression that all four digits are on at the same time.

The fourth flowchart shows a routine that is called in the third flowchart, and details the process undergone to operate the seven segment display.

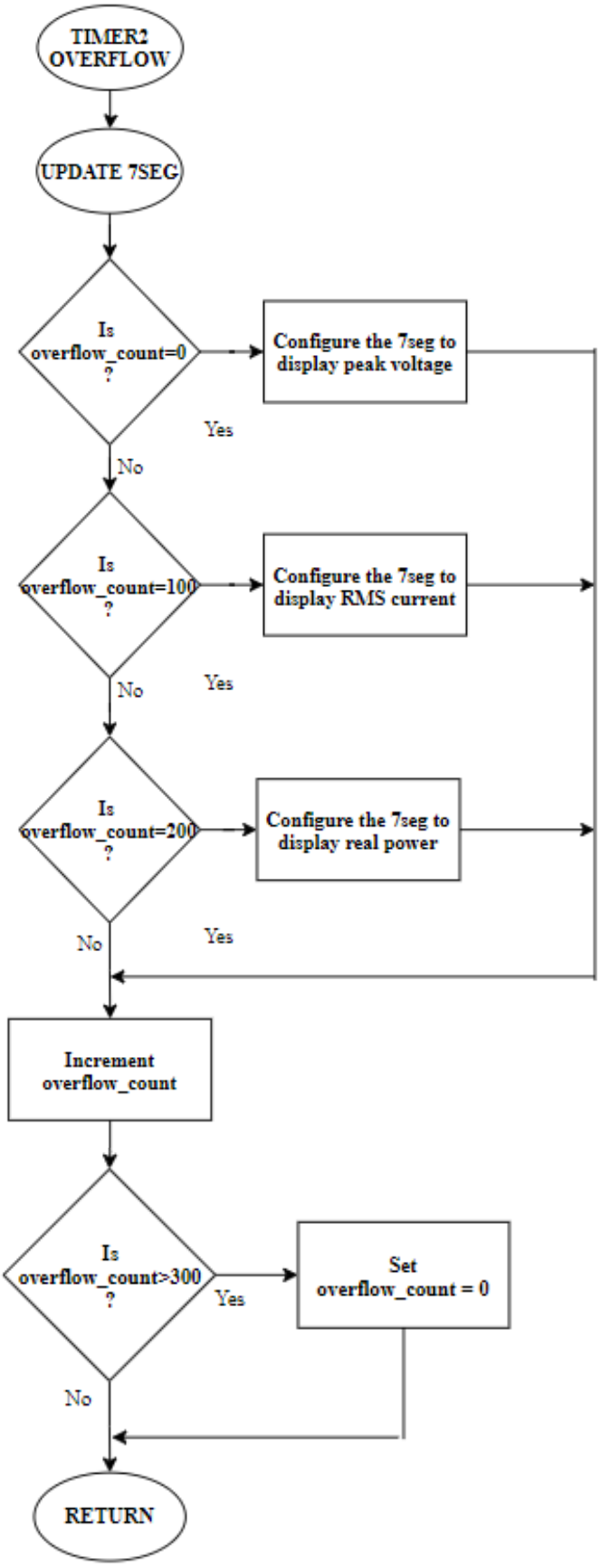
Main Program



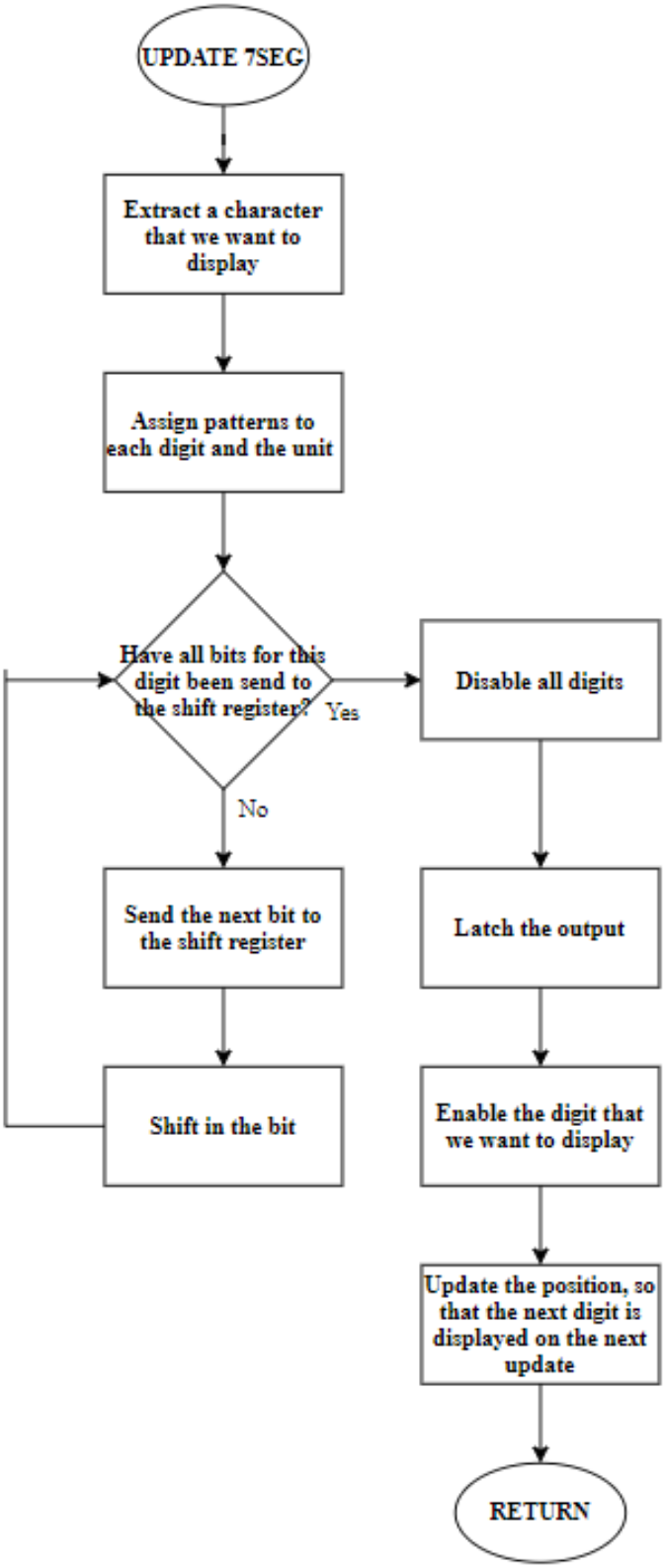
Timer/Counter0 Overflow



Timer/Counter2 Overflow



Update 7seg


UPDATE 7SEG
Extract a character that we want to display
Assign patterns to each digit and the unit
Have all bits for this digit been send to the shift register?
Yes
No
Disable all digits
Send the next bit to the shift register
Latch the output
Shift in the bit
Enable the digit that we want to display
Update the position, so that the next digit is displayed on the next update
RETURN

Peripheral Configurations

Table IV: UART configuration

Parameter	Configuration
Number of data bits	8
Number of stop bits	1
Baud rate	9600
Parity mode	None
Transmission mode	Simplex (transmit)
Transmit mode	Polling (UDRE0)
Transmit voltage	5 V

Table V: ADC configuration

Parameter	Configuration
Reference Voltage	AVCC (5V)
Left adjusted?	No
Trigger mode	Auto trigger
Auto trigger source	Timer0 overflow
Prescaler	8
Input channel	ADC0(V) and ADC1(I)
Interrupt enabled?	Yes

Table VI: Timer/Counter0 configuration

Parameter	Configuration
Timer Mode	Fast PWM w/ OCR0A as top
Prescaler	8
Top (OCR0A)	24
Interrupt enabled?	No

Table VII: Timer/Counter2 configuration

Parameter	Configuration
Timer Mode	CTC w/ OCR2A
Prescaler	256
Compare value (OCR2A)	78
Interrupt enabled?	Yes

Design Validation

UART

The baud rate of the UART peripheral is 9600, therefore the time per bit transmitted should be 1/9600 s, or approximately 0.1 ms. In Fig. 3, we can observe the time per bit on the oscilloscope , and clearly the time per bit is 0.1 ms. In addition, Fig. 4 shows the output, which is displaying the correct output.

ADC

When we apply a DC voltage to the input of the ADC, we get a constant ADC value, as expected. In Fig. 5, a 1V DC voltage is applied to ADC0 and a 3V DC source is applied to ADC1. The resulting ADC values are 205 on ADC0 and 614 on ADC2, which are consistent with the ADC settings used.

Timers

Timer0 is designed to overflow every 0.1ms and Timer2 is designed to overflow every 10ms. We can test this by using an LED to toggle overy time the overflow occurs and observe the results with the oscilloscope on Proteus. Fig. 6 and Fig. 7 show the operation of Timer0 and Fig. 8 and Fig. 9 show the operation of Timer2.

Seven Segment Display

The seven segment display is operated through the use of a shift register. We can validate this design easily by observing the inputs and outputs of the shift register, as well as the display itself. This is shown in Fig.10, Fig.11 and Fig. 12.

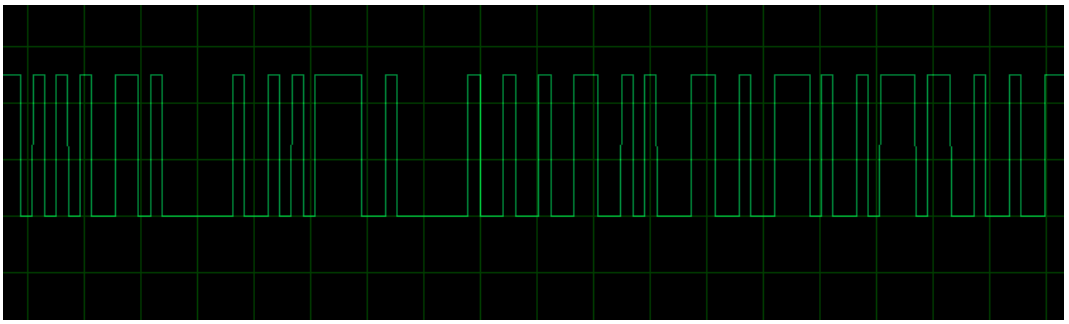


Fig. 2: UART transmission pin on Proteus oscilloscope

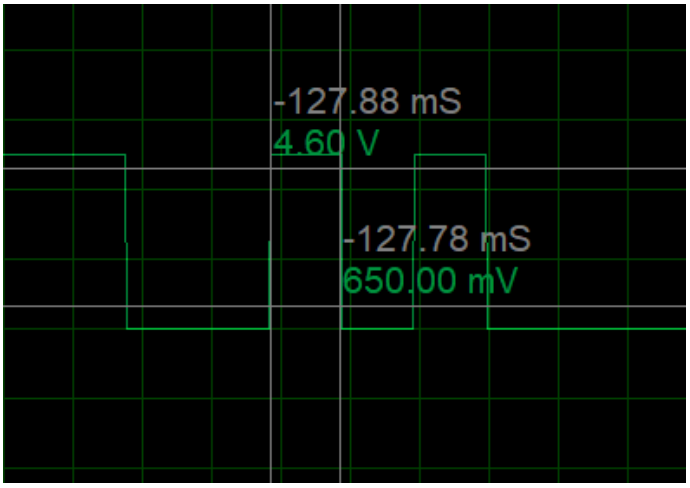


Fig. 3: Time per bit is 0.1ms, so the baud rate is 9600

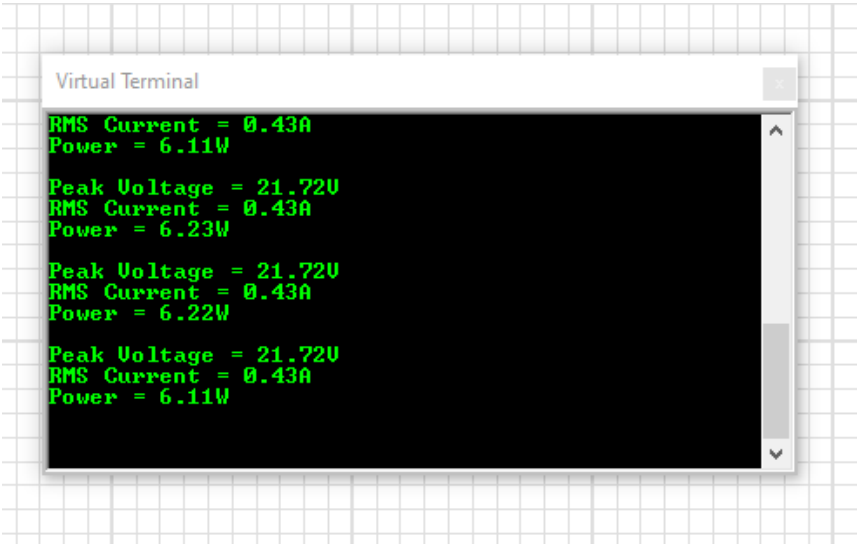


Fig. 4: UART transmission output

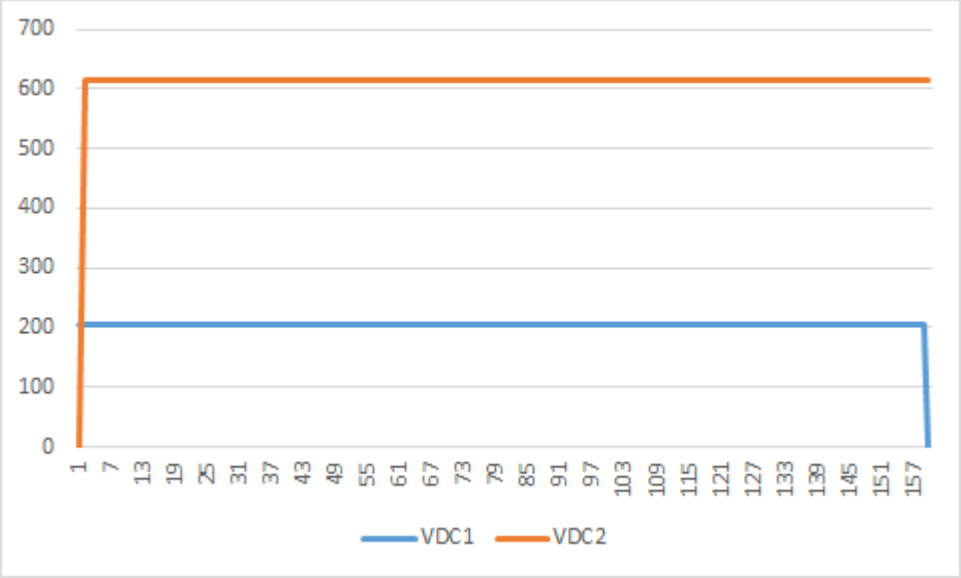


Fig. 5: Applying a DC voltage to the ADC channels

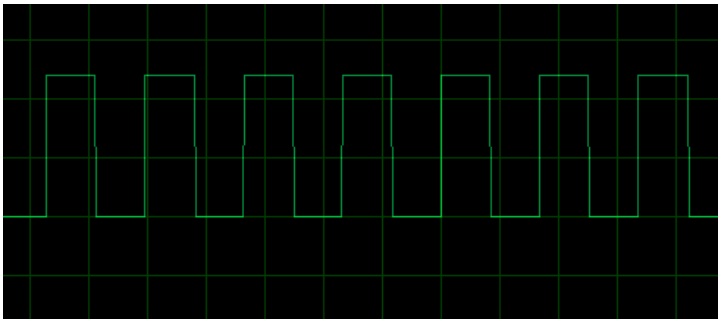


Fig. 6: Using Timer/Counter0 to toggle an LED

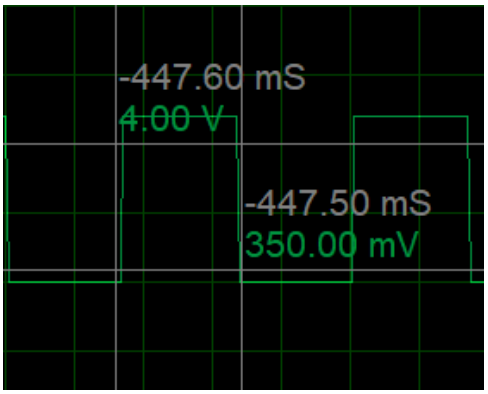


Fig. 7: Timer/Counter0 - time between counts

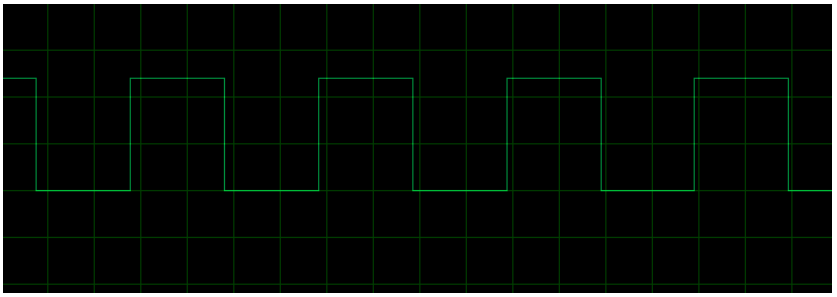


Fig. 8: Using Timer/Counter2 to toggle an LED

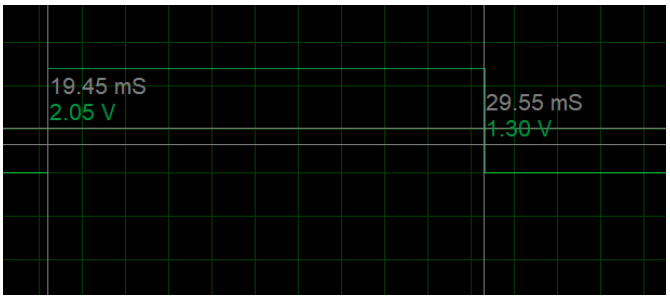


Fig. 9: Timer/Counter2 - time between counts

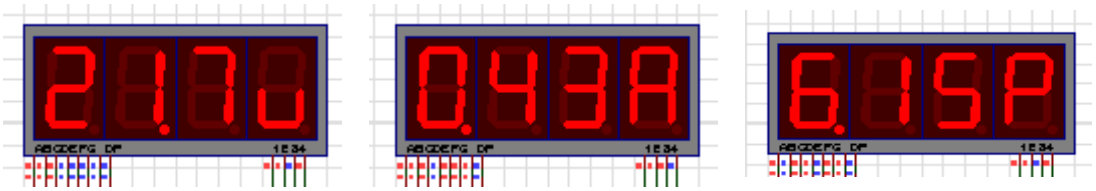


Fig. 10: Seven segment display output

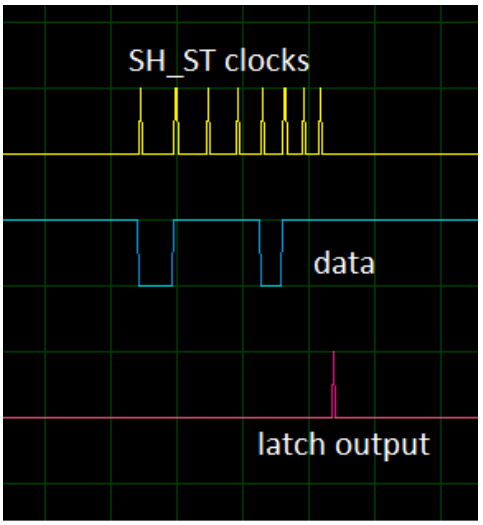


Fig. 11: Data going into the shift register

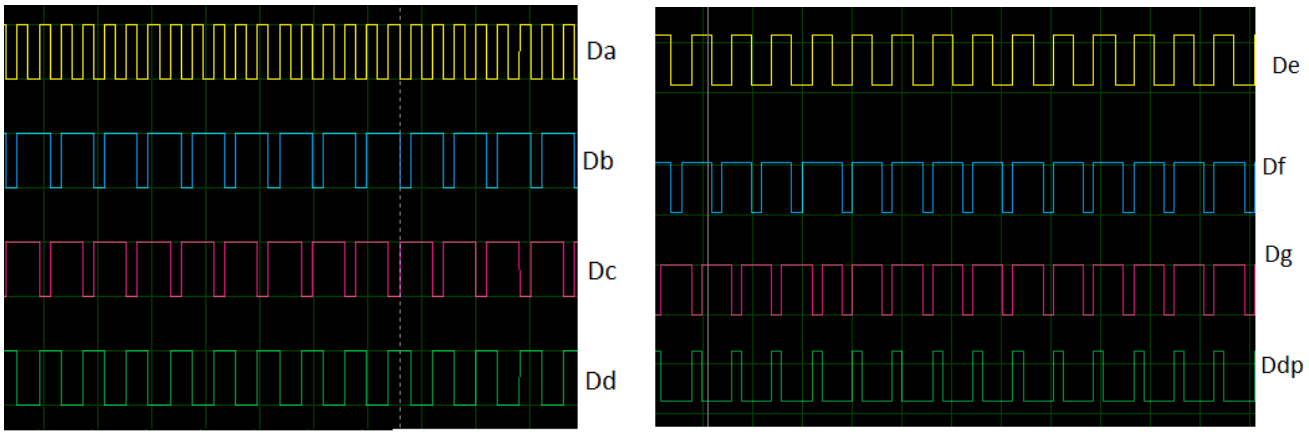


Fig. 12: Data going out of the shift register

Performance of the Energy Monitor

Design Validation

The ADC readings of the voltage and current measurements are shown in Fig. 15 and Fig. 16. Comparing them to the emulated waveforms generated in the analogue circuit, shown in Fig. 13 and Fig. 14, they are as expected. The voltage waveform shows the ADC values vary from around 230 - 630, which corresponds to a range of 1.1V to 3.1V. The current waveform shows the ADC values vary from around 170 - 700, which corresponds to a range of 0.8V to 3.4V.

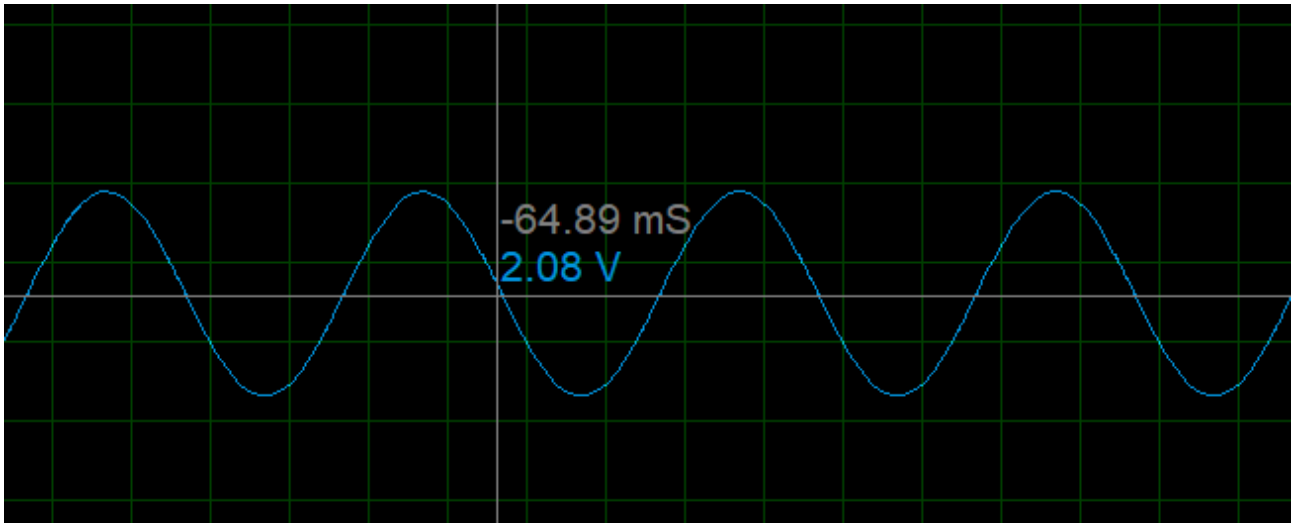


Fig. 13: Current waveform on Proteus (1V, 0.5 ms per division)

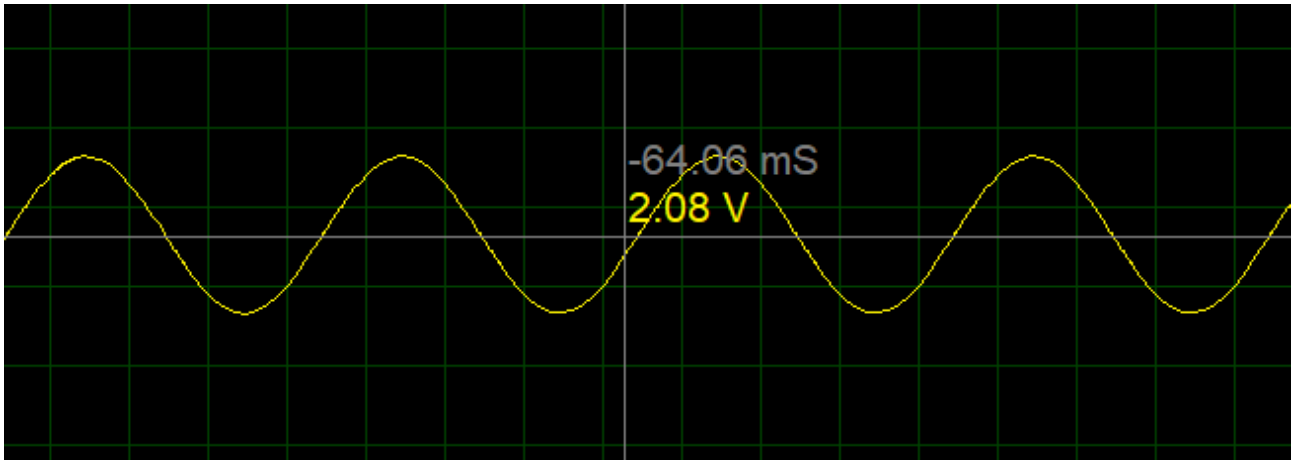


Fig. 14: Voltage waveform of Proteus (1V, 0.5 ms per division)

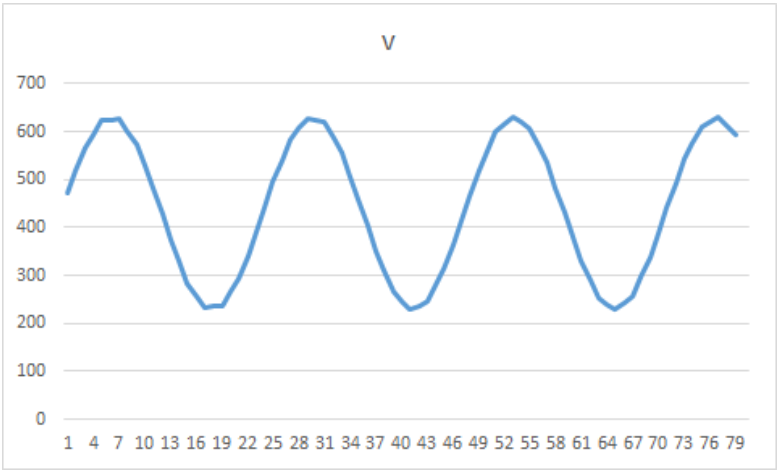


Fig. 15: Voltage ADC Values

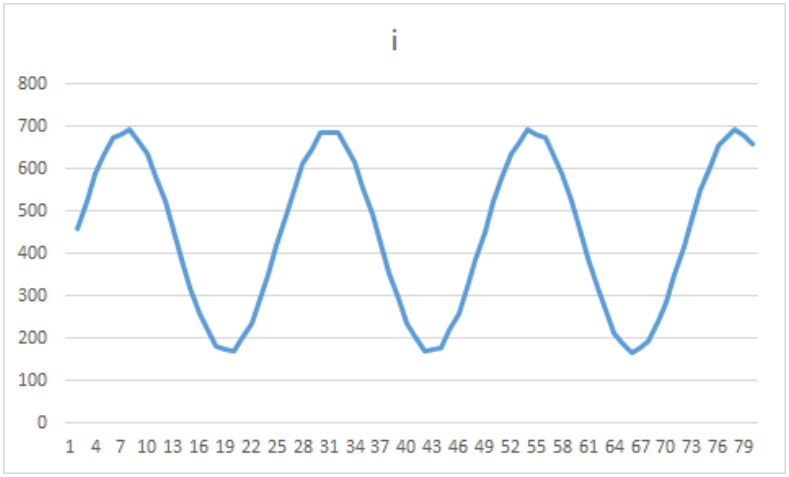
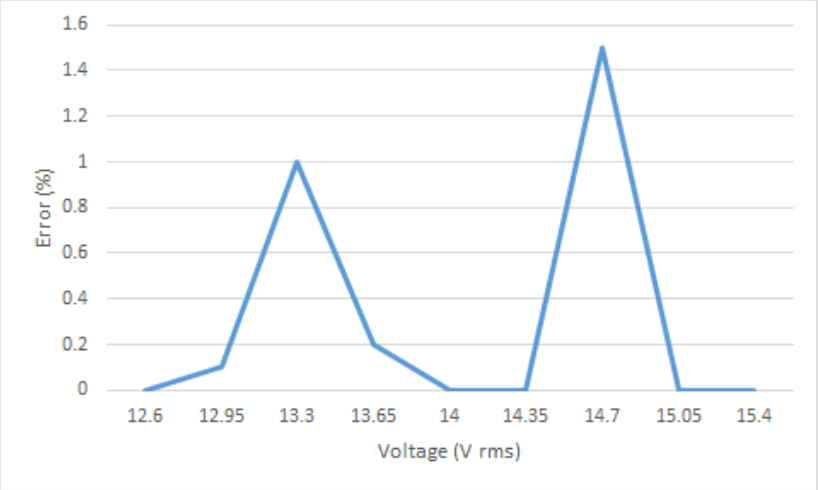


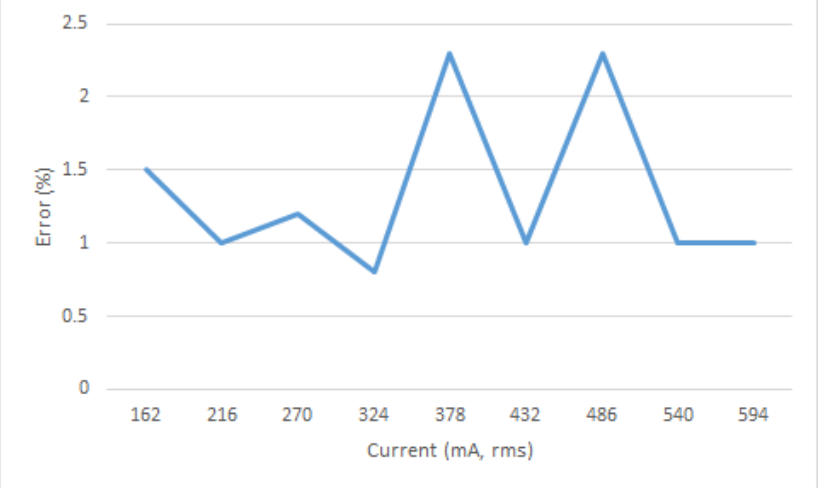
Fig. 16: Current ADC Values

The Accuracy

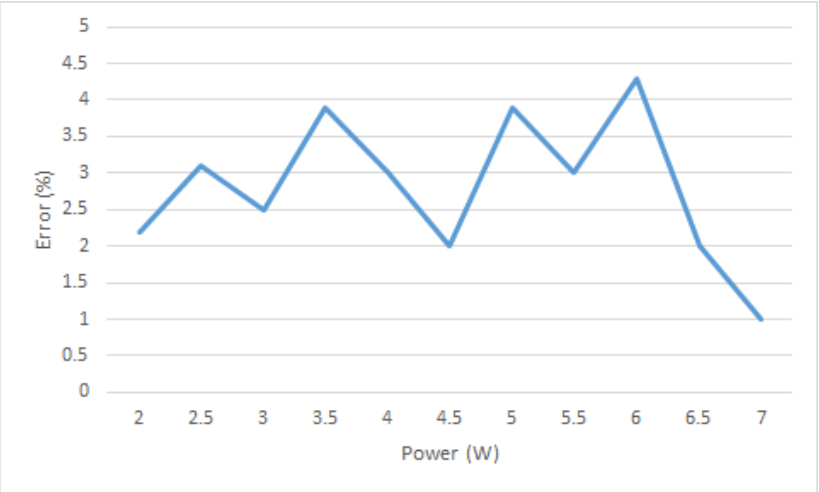
According to the below graphs, we can clearly see that the error in the results displayed vary a bit, however each measurement is within the 5% error allowed according to the specifications. Out of the three quantities displayed, the voltage is the most accurate and produces the most consistent output, followed by the current and finally the power. It is expected that power has the most variation, as it is calculated by the program using current and voltage measurements.



Voltage error measurements



Current error measurements



Power error measurements

Conclusions

The design of our Smart Energy Monitor was mostly a success, and the final product provides a reasonably accurate power reading. Improvements could be made with the general accuracy and consistency of the output, however the power meter complies with the given specifications, according to simulations carried out in LTSpice and Proteus. In addition, the power meter has been tested with varying resistive and inductive load components, and has shown that the power reading remains within the desired accuracy range.

References

[1] D. J. Thrimawithana, Class Lecture, Topic: "Analogue & Embedded Software Design: An Introduction to the Course" ELECTENG 209, Department of Electrical, Computer, and Software Engineering, The University of Auckland, Auckland, October 2020.

[2] Neurio-Sensor W1™ Specifications https://d1819pwkf4ncw.cloudfront.net/files/documents/neurio-sensor-w1-spec-sheet032715-1-271710.pdf

[3] Efergy energy monitor specifications https://efergy.com/elite-classic-specs/

Dep. of Electrical, Computer, & Software Engineering
The University of Auckland
20, Symonds Street
Auckland, New Zealand
T +64 9 373 7599
W auckland.ac.nz