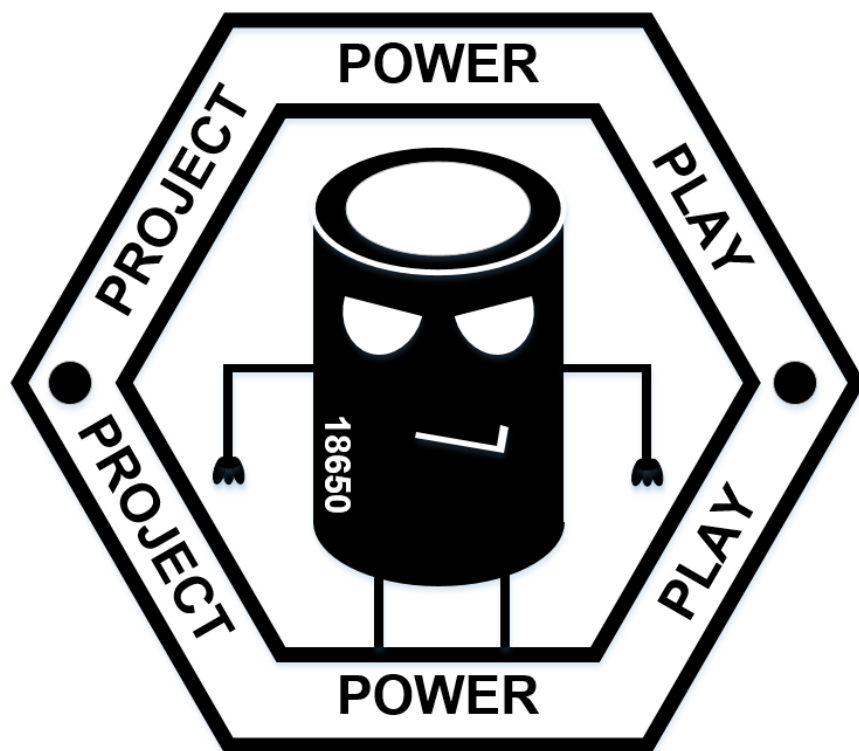




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ACDA5017: Group Project

Project Power Play

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Introduction

The fast pace of technology in the digital age results in increased demands for tools and equipment to be smaller or resilient to fluctuations in power supplies. As a result of these requirements, research and development of battery technology has seen a surge in the past decade as companies and institutions seek to develop ever smaller batteries, capable of sourcing higher currents and greater capacities. [MP]

A requirement has been identified to be able to identify the chemistry, capacity and nominal voltage of a given battery. [MP]

Understanding the chemistry, capacity and nominal voltage of a battery is key to its safe storage. For example Nickel Metal Hydride (NiMH) batteries should be stored at temperatures below 30°C and power-cycled (discharging and recharging the battery) on a regular schedule [1]. Meanwhile Lithium Ion (Li-Ion) and Lithium-Polymer (Li-Po) batteries should be stored at 20°C or lower and an individual cell voltage of 3.7V. [MP]

The goal of this project is to reduce fire risk to building 500 by assisting in the safe storage of batteries that have unknown properties. In this specific situation, it is not possible to contact the manufacturer or check a datasheet for these batteries. Subsequently, the goal is to figure out as much about each battery as possible. Examples include chemistry, nominal voltage, and state of charge (SOC). We will attempt to figure out these properties by running the battery through a charge-discharge cycle and analyse the results. When complete, it will be possible to provide recommendations on what SOC the batteries should be stored at, and the corresponding voltage. [JL]

Literature Review

We initially split up the research into a number of different areas; chemistry identification, charging, discharging and safety considerations. We each took responsibility for researching individual elements, while also supporting each other to ensure we all maintained a good working knowledge of the project. [MP]

Battery Characterisation [TR]

For this area of research, I focussed on methods for identifying battery chemistry, capacity, and state of charge. As well as key safety measures that need to be considered when charging batteries. [TR]

One of the methods for identifying battery characteristics is called electrochemical impedance spectroscopy which involves injecting an ac signal across a range of frequencies and measures the response values [2]. These values can be used to determine a range of characteristics such as state of charge, capacity as well as battery ageing [3]. However, the issue with this method is that it requires a lot of previously captured data and data processing. Existing products such as Cadex [4] use this method, but they already have the vast amount of data acquired to achieve this. For this project we decided that this method would take too much time and should not be a priority. [TR]

Another example is to monitor the electrochemical dynamic response to determine capacity of a battery [3]. This is done by applying brief load pulses and monitoring the voltage recovery [5]. The speed at which the battery recovers within a period can be used to determine the capacity [5]. There are multiple patents and papers on this method of battery analysis as well as custom algorithms made to interpret the data. The project was designed to have all the sensors required to achieve this method of analysis using voltage and current monitoring circuits. [TR]

Charging and Discharging Lit Review [JL]

Electric batteries are an indispensable part of modern society, wherever an electrical device is used and not expected to remain stationary, a battery is required to provide it with power. Designing our own infrastructure for charging and discharging batteries will be essential for this task. [JL]

When charging, most battery chemistries have two main phases: constant current, (CC, where the charger will alter the voltage supplied to maintain the specified current consistently) and constant voltage (CV, where a charger will maintain the specified voltage, with reducing current as the battery fills) [6]. In a lead-acid battery, these are called bulk and absorption [7]. [JL]

Constant current is used to restore the state of charge (SOC) of the battery quickly, then constant voltage charging is used to fill the remainder of the battery capacity, ensuring that a constant-current method does not damage the battery attempting to induce a current when the battery is at capacity. Finally, some battery chargers will also “trickle” charge when the battery is at full capacity [6], to maintain its health. In lead-acid batteries this is known as “float” charging [7]. [JL]

All batteries will have specified voltages to switch over from CC to CV, and from CV to trickle charge. However, if not known, it is possible to detect a full charge using a negative delta voltage (NDV) [8], where the change in voltage drops off as SOC nears 100%. Such signatures vary depending on the chemistry of the battery. [JL]

When discharging, a load must be able to alter its resistance such that it can draw whatever current specified. Most battery dischargers bias a MOSFET in the linear triode region, allowing it to behave as a voltage-controlled resistor [9]. Unlike most chargers, a discharger is always set based on the current draw, and only stops when it has reached the under-voltage protection (UVP). [JL]

Safety [TR] [MP]

The main concern regarding safety when charging batteries is to make sure the battery itself is protected from over voltage, over current, temperatures, shock, fault detection, electrical isolation [10] [11] [12]. [TR] To ensure that any batteries connected to the device remain in a safe condition it's important for the user to visual inspect batteries prior to connecting it to the system, and for the system to monitor current source/sink, cell voltage and cell temperature. [TR] Simple thermistors are ideal for monitoring battery temperature due to the ease of interfacing it

with a microcontroller Analog Digital Convertor (ADC) input, and the same is true for monitoring the voltage of the cell/battery. **[MP]**

Current monitoring can be achieved by use of current clamps mounted onto, or integrated into a PCB, surrounding a track or wire; alternatively a current can be passed through a low resistance shunt resistor and the current calculated by the voltage drop across the shunt. Both methods rely on the use of an ADC input to measure a change in voltage, however there are standalone devices that can be used which then interface with a microcontroller. **[MP]**

Development Methodology [JL]

For this research, quantitative methods will be used. In this situation, it is possible to empirically prove that the modules designed to charge, discharge, and control batteries are working properly. The advantage of this is the innate ability to provide the customer with a completed project that has verifiable functionality. [JL]

Regarding hardware usage, bench power supplies will be invaluable in this project, acting as any battery that could be needed simply by changing the voltage. Since controlling the charger and discharger modules will require Pulse Width Modulation (PWM), a signal generator (and oscilloscope to verify output) will also be needed. [JL]

Proteus circuit simulator will be used to design and test the circuits that go into the charging, discharging, and control of the microcontroller. This is due to several factors: licenses are already available (reducing project costs), we have built up competency in using this software (something that would be difficult to do in the allocated project time for other software), and we know the model for the PIC16F877A simulates correctly. [JL]

MPLab will be used to program the IC, as Microchip designed this software, and the PIC chip we will be using, ensuring compatibility. [JL]

The project will be tested by using batteries of known characteristics, hooking them up to the box, and comparing the “measured” characteristics to those on the datasheet. [JL]

Design & Implementation

Requirements:

The requirements for the charger and discharger are as follows:

- Can charge and Discharge batteries from 0V - 30V
- Can charge and discharge up to 2A
- Can charge and discharge most main battery chemistries (Lead-acid, Li-Ion, Ni-Cd, Ni-Mh)

Implementation:

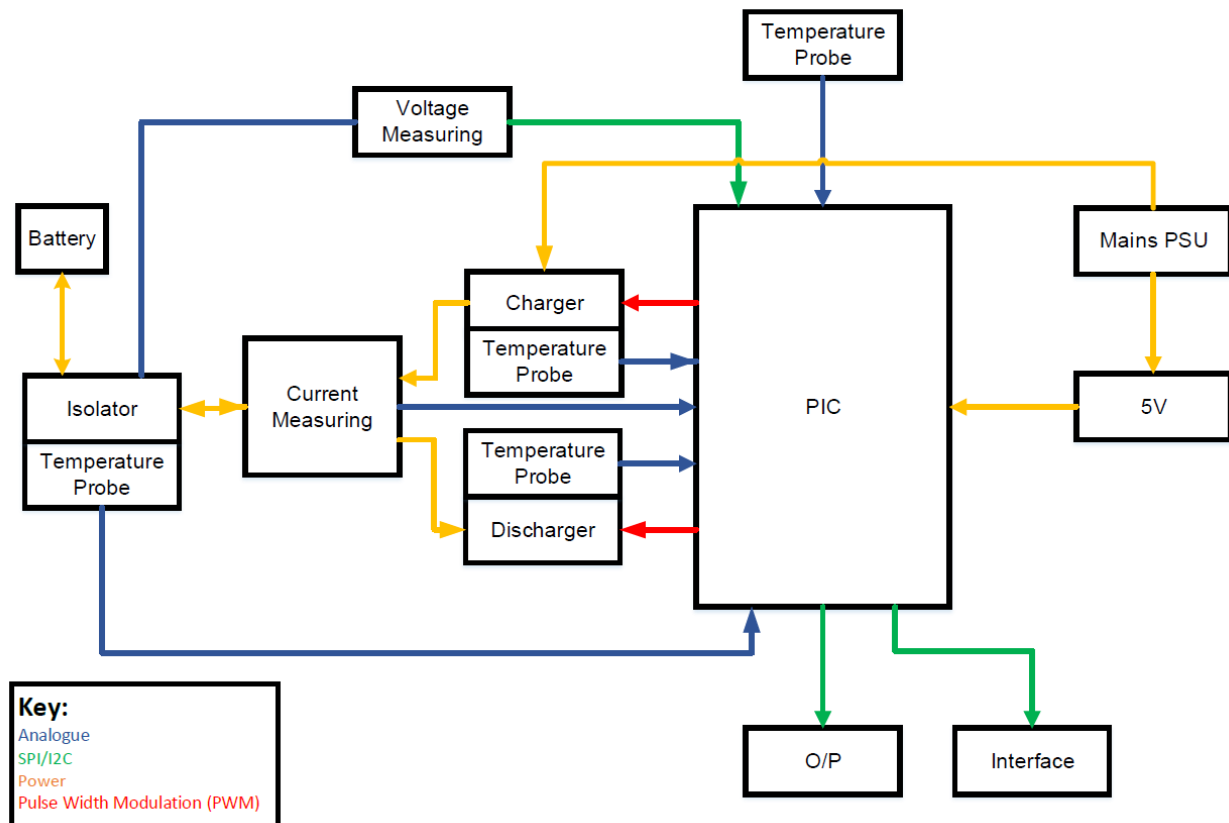


Figure 1 - Initial design system overview

Charger Design and Implementation [TR]

The charging circuit of choice for the power supply was a buck converter. This was initially designed in proteus, and this is where most of the testing was done to determine if it would work. The final circuit decided by the group is shown below: [TR]

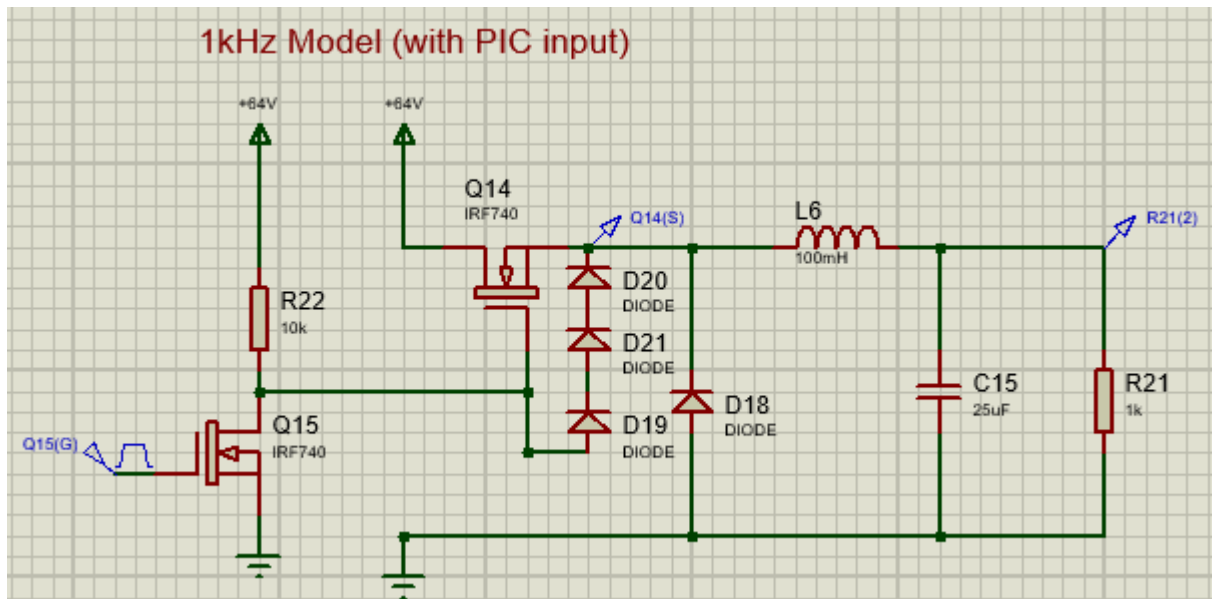


Figure 2 - Charging Circuit Proteus Schematic

The circuit has an input of 64V and will be able to adjust the voltage to a desired level so that we can charge the batteries at a range of voltages. The circuit itself is based on a buck converter and it requires two MOSFETS an inductor and a capacitor. The inductor and capacitor's values are determined by the frequency of the PWM signal from the PIC using the equation: [TR]

$$J\omega L = \frac{1}{J\omega C} \quad \text{where } \omega = 2\pi f$$

Equation 1 – Relationship between frequency and the impedance/inductance.

The higher the frequency of the PWM signal the lower the resolution of the adjustable voltage. Therefore, it was important to test multiple frequencies to see which provided the best results we opted for the 100Hz for our PWM frequency. [TR]

After deciding on the circuit of choice the next step is to determine the best suited components and the values needed to be used for our circuit. To determine the inductor and capacitor values we need to ensure that they both have equal impedance to smooth the output DC voltage. The MOSFETS used must be suitable for the input voltage and be capable of switching at the rate of the duty cycle of the PWM signal. They also need to be able to dissipate the heat generated so a sufficient heatsink will be required. The diode/diodes will also need to be rated for a greater voltage than the input voltage. [TR]

After purchasing the correct parts, the circuit can now be built onto a breadboard for preliminary testing. This is to make sure that the circuit operates as intended and all the parts are sufficient and produce the correct output. The completed breadboard is shown below: [TR]

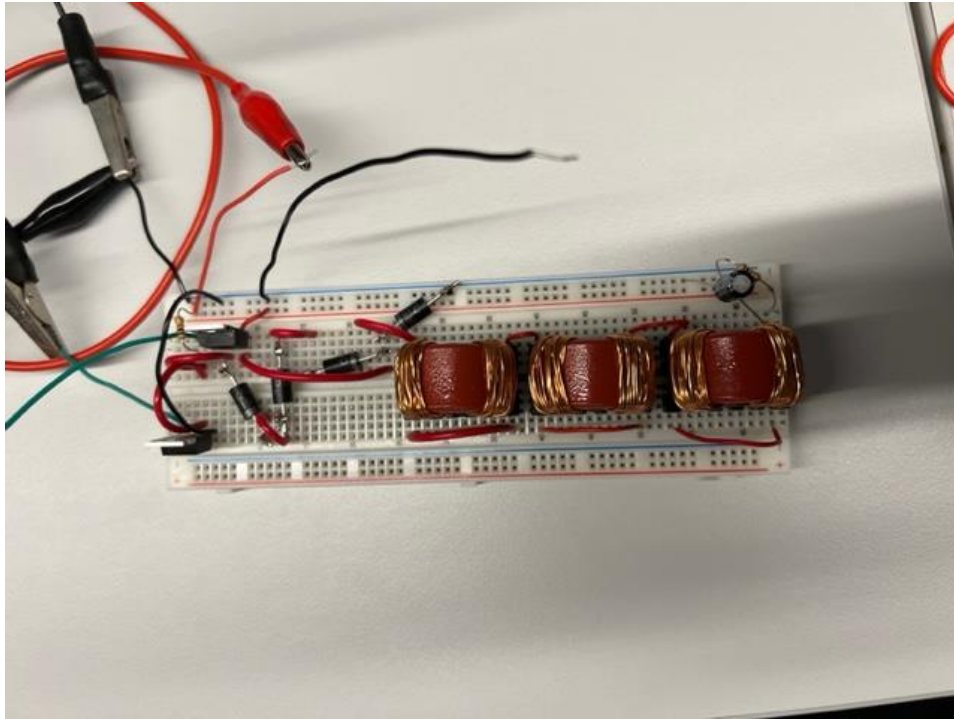


Figure 3 - Charging Circuit on Breadboard

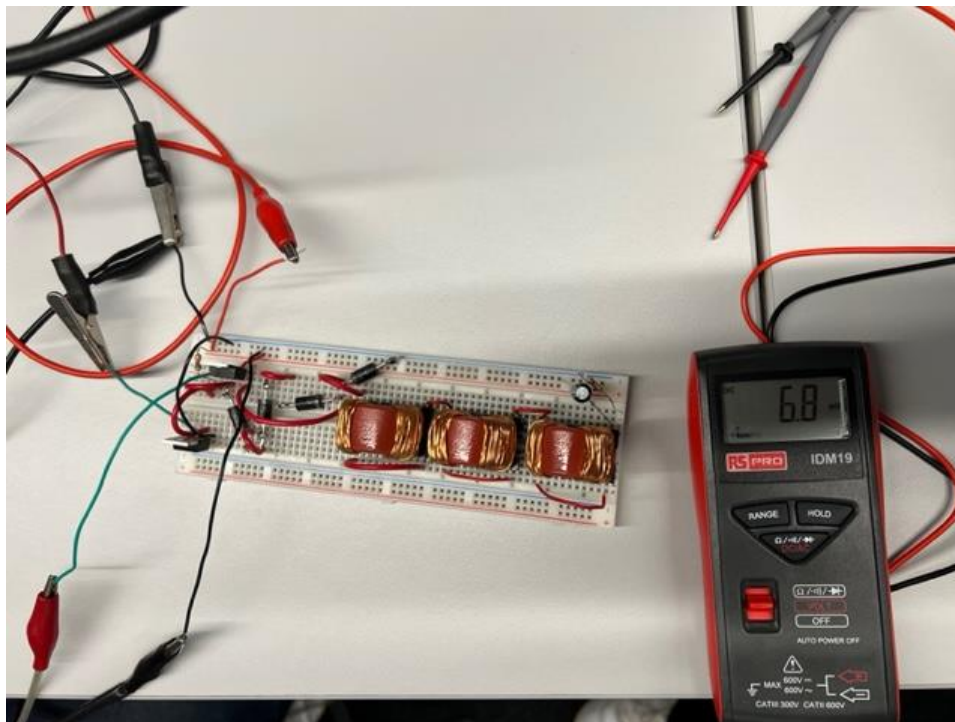


Figure 4 - Testing Charging Circuit Outputs

After building a stable and adjustable power supply on the breadboard the next step is to build it on stripboard as a more permanent solution. This required soldering each individual component onto the board in specific places. The orientation and location of the component is important as it reduces the amount of copper that needs scratching off as well as the overall size of the circuit board. The final stripboard circuit is shown below: [TR]

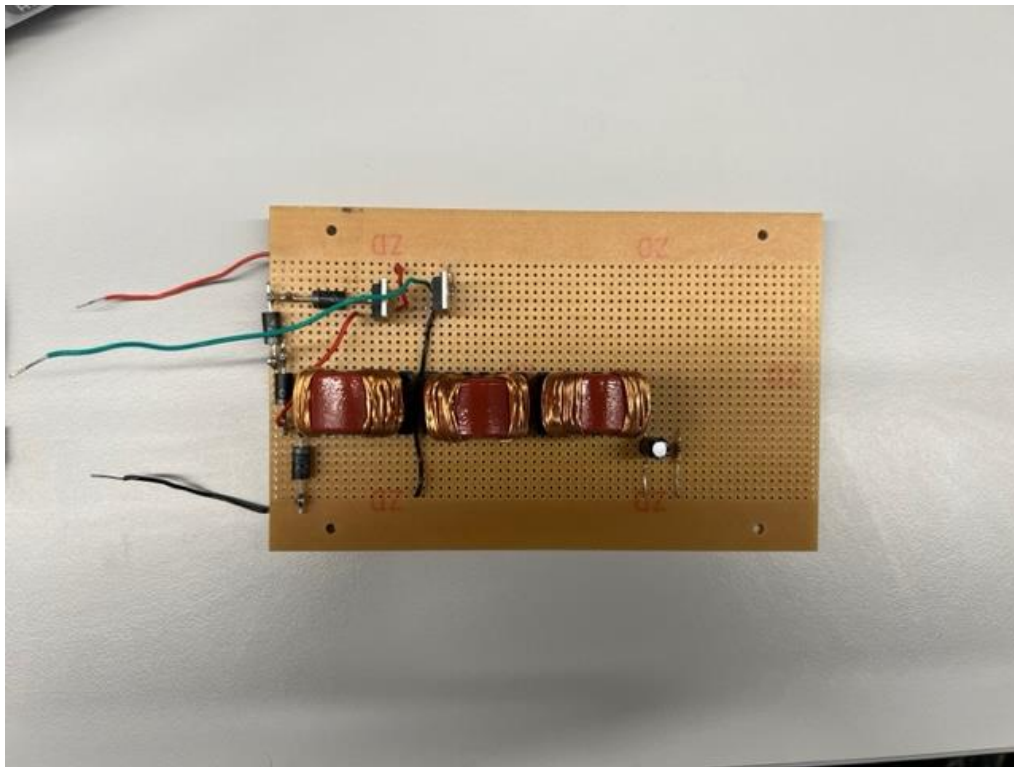


Figure 5 - Top view of stripboard circuit

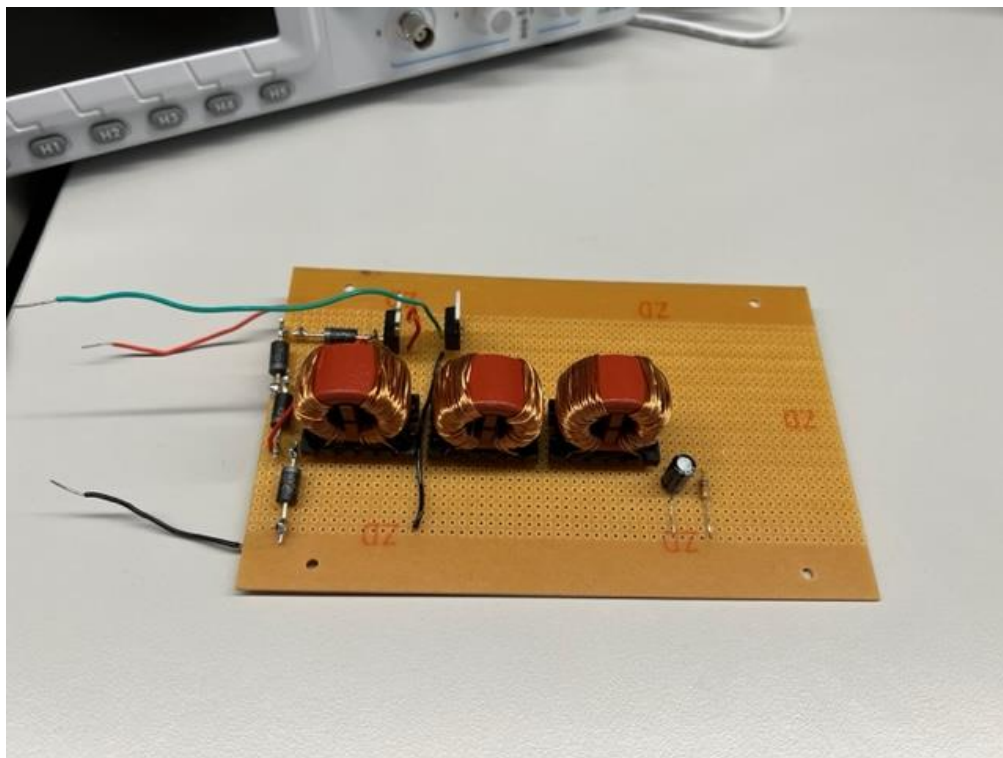


Figure 6 - Side view of stripboard circuit

The final stage is to then retest the new circuit on the stripboard to validate that the output is the same as the breadboard and that the circuit is operating correctly. [TR]

Discharger Design and Development [JL]

To discharge batteries, a dynamic threshold voltage was used to bias a MOSFET in the linear/triode region. Enabling the MOSFET to behave as a voltage-controlled resistor, this altered the current flowing through it based on a pulse width modulation (PWM). [JL]

To provide the threshold voltage, an operational amplifier (Op-Amp) was used, similarly to the below design:

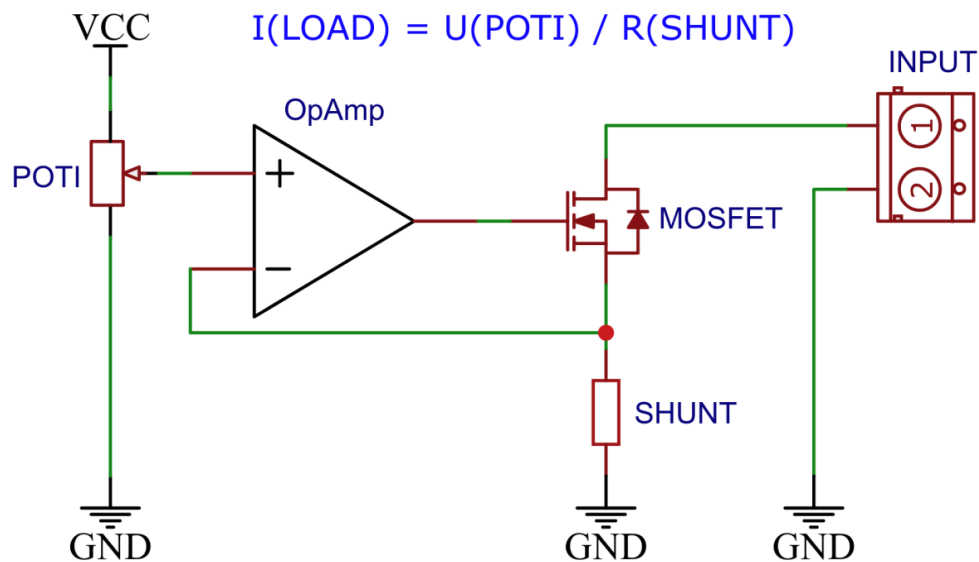


Figure 7: MOSFET driven artificial load for discharging a battery . [13]

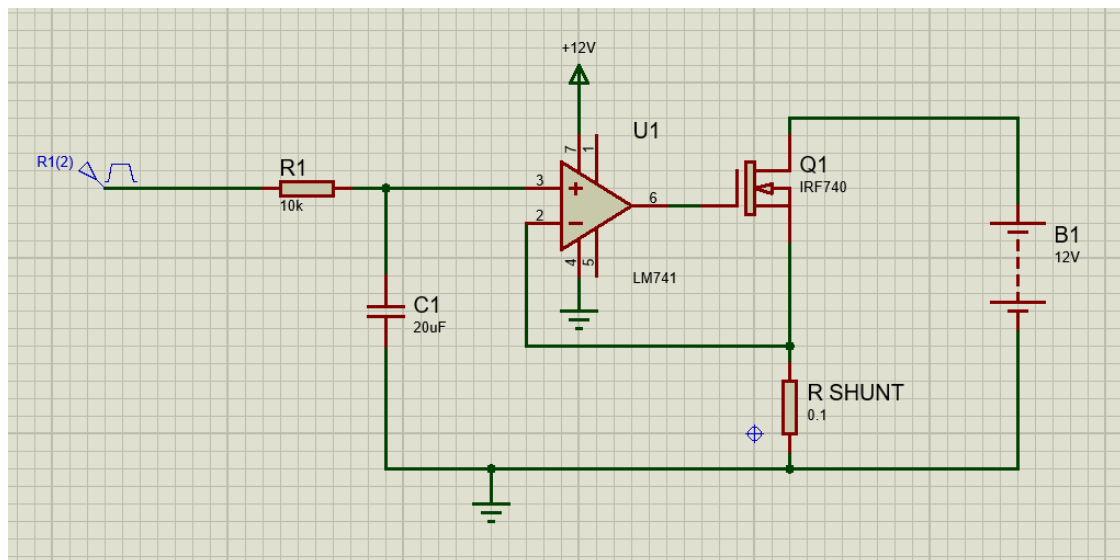


Figure 8: Above: A Proteus circuit Simulation of a design like the one shown above

R1 and C1 take the PWM output of the PIC and smooth it to a consistent DC voltage. The values were selected so that the time-constant was 0.2 seconds. After five time-constants, this capacitor charging circuit is considered “fully charged”. The larger the values, the smaller the ripple when it has found the right voltage, however it will take longer to reach that value. [JL]

The Op-Amp in the circuit above takes the smoothed PWM as input, and outputs a voltage controlling the gate, such that the drain-gate voltage across the MOSFET matches the smoothed PWM signal from the pic. [JL]

However, when this circuit was assembled on a veroboard, the Op-Amp outputted a 12V signal, differing from the proteus simulation (even though correct input was confirmed). With not enough time to fully investigate and fault-find, the op-amp was removed, and the MOSFET was controlled directly by the RC circuit. [JL]

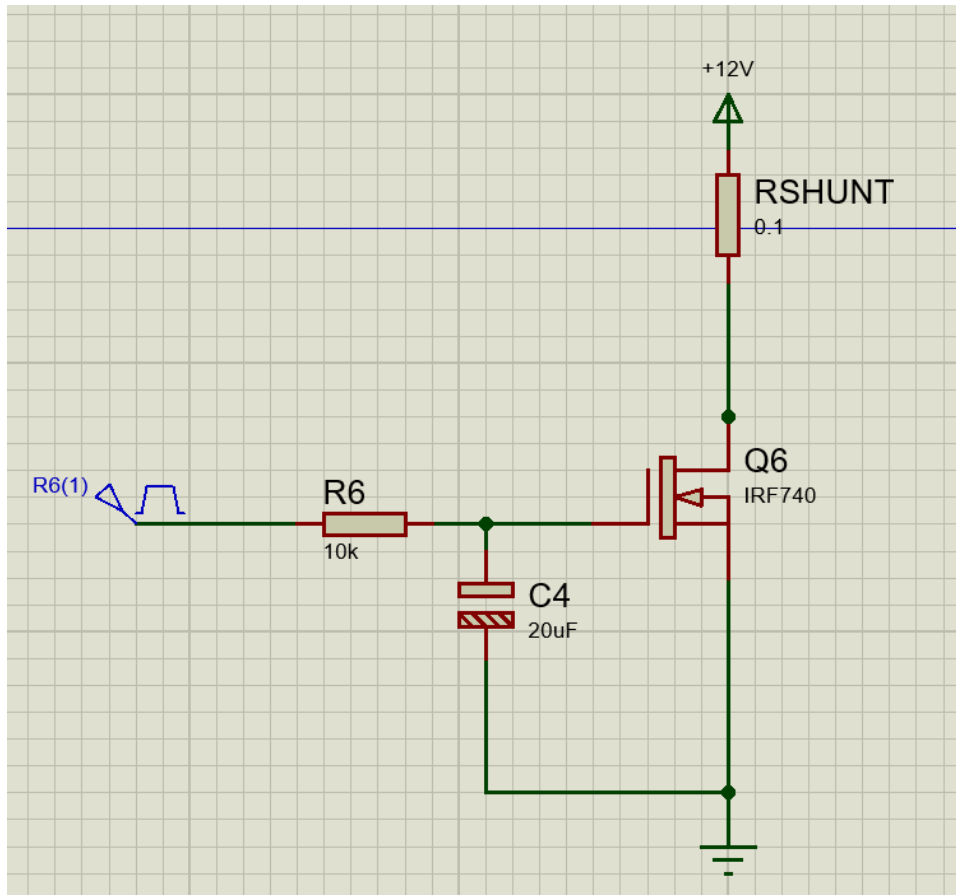


Figure 9 **Above:** An alternative discharger design, avoiding the use of an Op-Amp.

Shunt Resistor, MOSFET and Heat-Sink Selection:

At 64V and 2A, a total of 128W needs to be dissipated. The selected heat-sink has a thermal resistance of 0.6°C/W [14], rising a maximum of 76.8°C. When accounting for natural air-cooling and power dissipated by other components, this will be acceptable. [JL]

The MOSFET selected for this circuit is the IRF740, and has a maximum continuous power dissipation of 125W, so the circuit was altered to include three [15]. [JL]

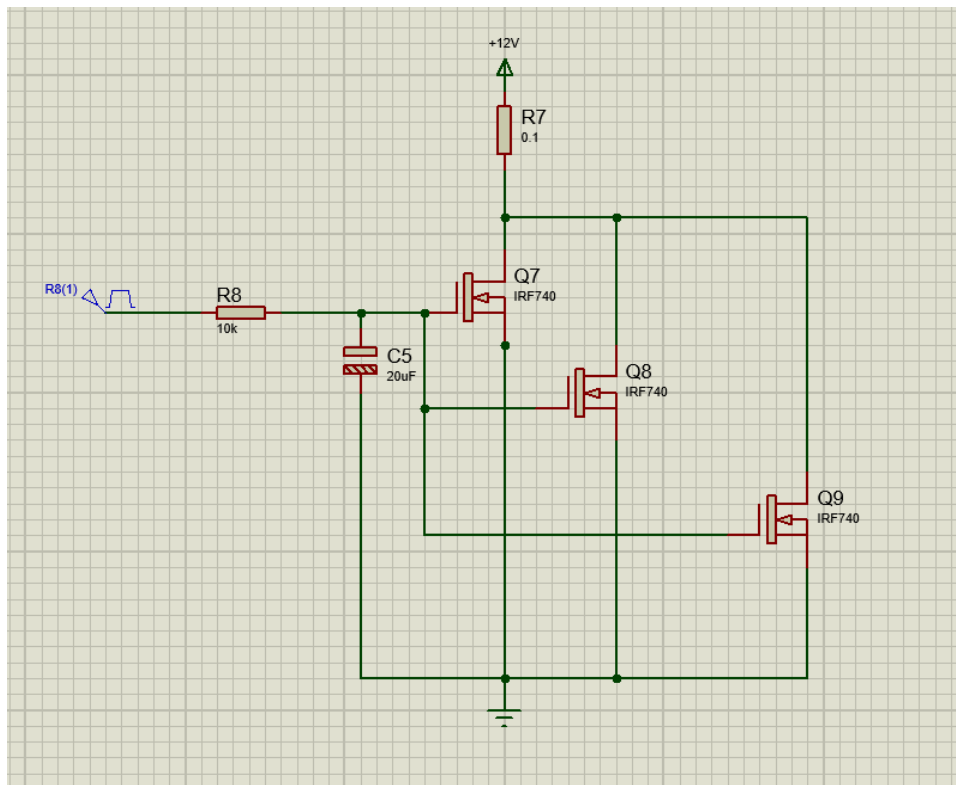


Figure 10: Discharger modified to use three MOSFETs..

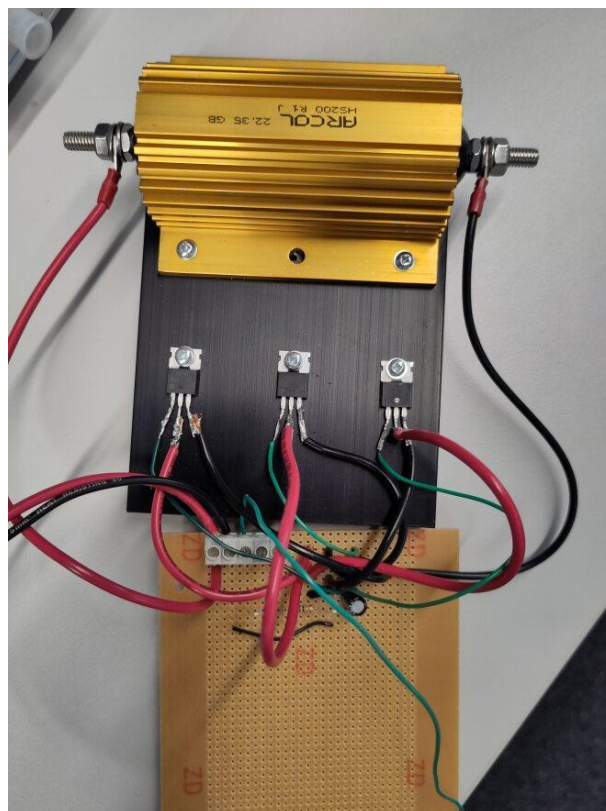


Figure 11: Finished Discharger Module on Veroboard

Current Sense Module [MP]

The current sense module was developed around the INA225 [16], a programmable current monitor from Texas Instruments which was chosen for its low part count, and wide input range.

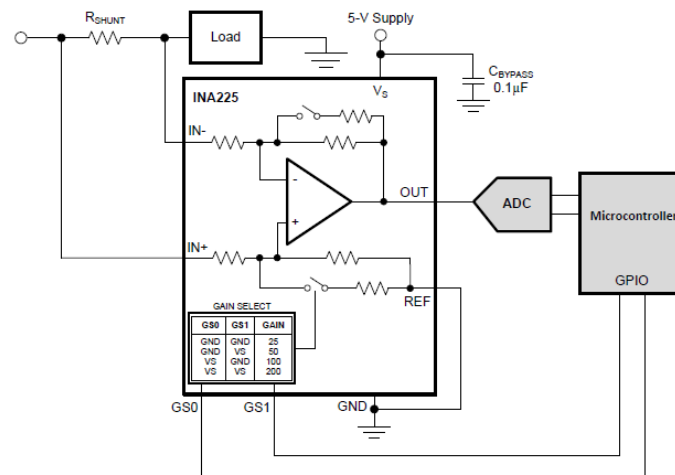


Figure 12 - INA225 suggested typical application

The operation of the INA225 utilises a low value shunt resistor through which the monitored current flow passes. The value of the current shunt resistor must be chosen carefully to ensure a large enough voltage drop occurs across the resistor while not loosing too much power over the resistor.

$$I_{MAX} = 2 \quad V_{OUT} = 5 \quad GAIN = 100$$

$$V_{DIFF} = V_{OUT} / GAIN = 5 / 100 = 0.05$$

$$R_{SHUNT} = V_{DIFF} / I_{MAX} = 0.05 / 2 = 0.025\Omega$$

Based on guidance from the INA225 Datasheet [16], the ideal value for the shunt resistor can be calculated as 25Ω for a full deflection at 2 Amperes. This was incorporated into the schematic design based on recommended typical application and then sent to JLCpcb for manufacture.

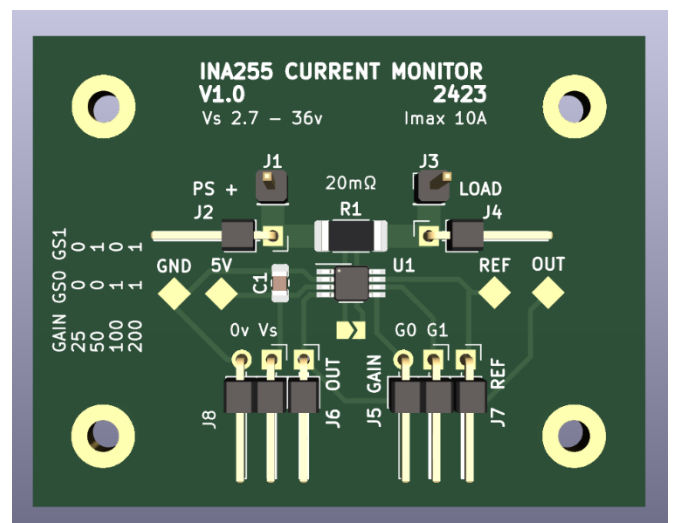
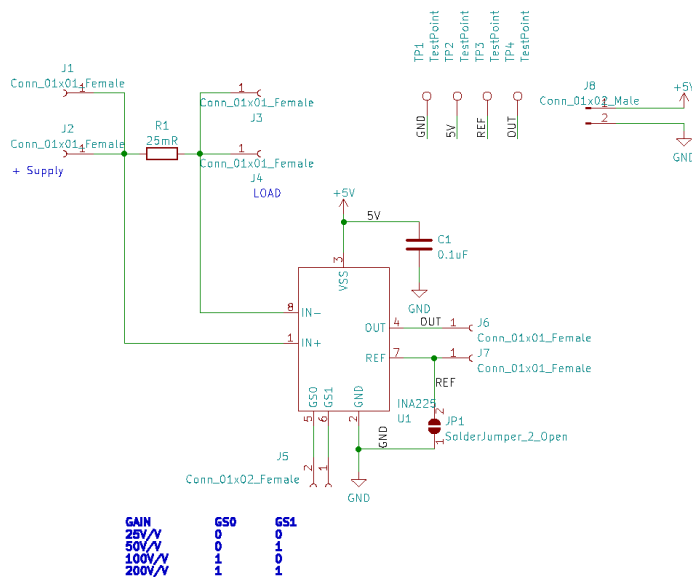


Figure 13 - INA225 Schematic drawn in KiCAD 6.0 [LEFT] and PCB design [RIGHT]

Evaluation

Discharging [JL]

The shunt resistor and MOSFETs were soldered to fly leads, and bolted onto the heat sink to ensure maximum thermal conduction. M3x16 Pan-Head machine screws were used for the mounting, with 2.5mm holes drilled, then tapped with a 0.5mm pitch. [JL]

Two cables were made up to connect the shunt resistor to the circuit, using 16AWG (10A rating, more than sufficient), and red fork terminals adjusted to fit with a mallet. [JL]

Since all three MOSFETs were in parallel, this made for easy soldering of the rest of the components on the Veroboard. [JL]

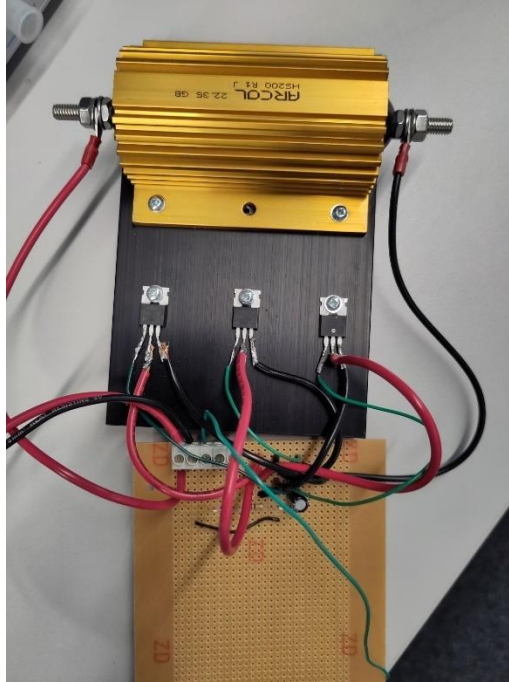


Figure 14: Completed discharger module

In future, it would be best to insulate the legs of each MOSFET with potting compound to prevent any short-circuiting and provide mechanical support. For further design revisions, it would also be best to fix inside of an earthed metal enclosure for safety reasons. [JL]

Results:

The discharger was tested using a benchtop power supply acting as a battery. The supply voltage was changed to simulate different batteries, and the PWM was altered, with the change in current measured. [Please see appendices 1-5 for results] [JL]

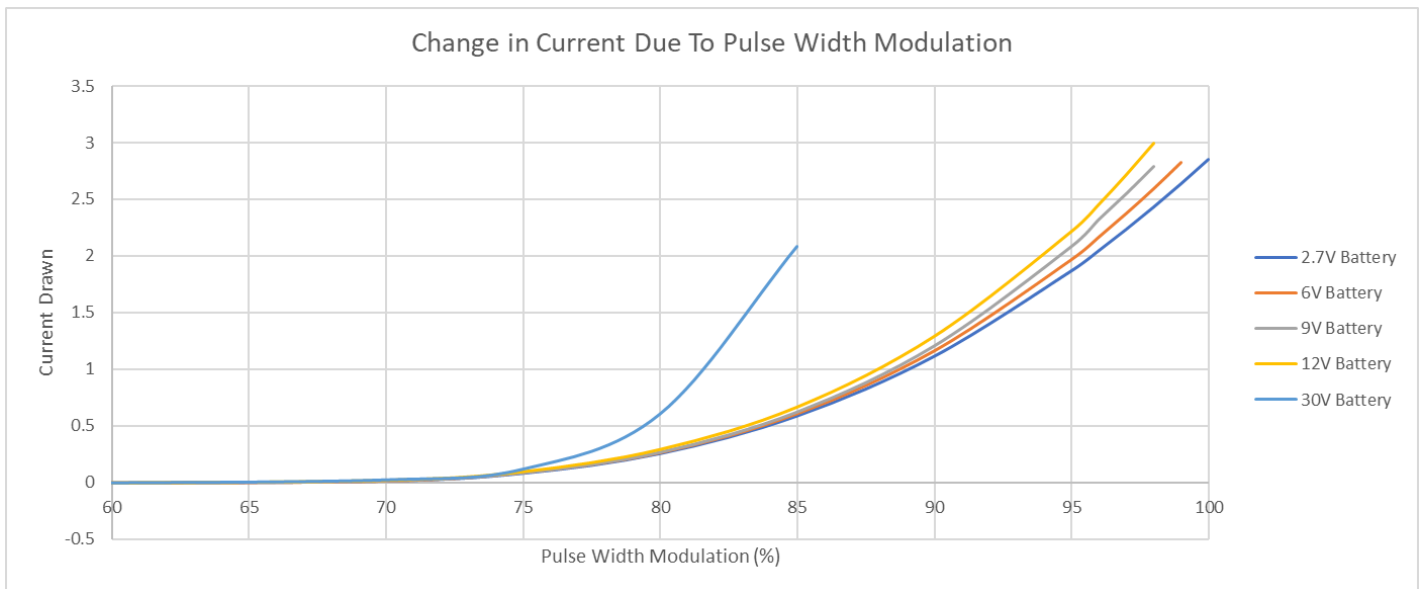


Figure 15: The alteration in drain current caused by Pulse Width Modulation for different battery voltages.

As can be seen above, there is an exponential relationship between the PWM and current drawn. There is no significant drain current until a PWM > 70% is reached for all battery voltages. The lower voltage batteries reach higher drain currents with a lower PWM. Please note that a 3A limit was set on the power supply, so any points that would go above 3A have not been recorded. [JL]

Discussion: [JL]

Non-linear relationship: [JL]

When a threshold voltage is applied to the gate of the MOSFETs, the holes supplied form a conductive channel across the P-Si substrate. The larger the threshold voltage, the higher the conductance between drain and source. This is a non-linear relationship, and typical curves illustrating gate voltage and drain current for a given voltage will look like this: [JL]

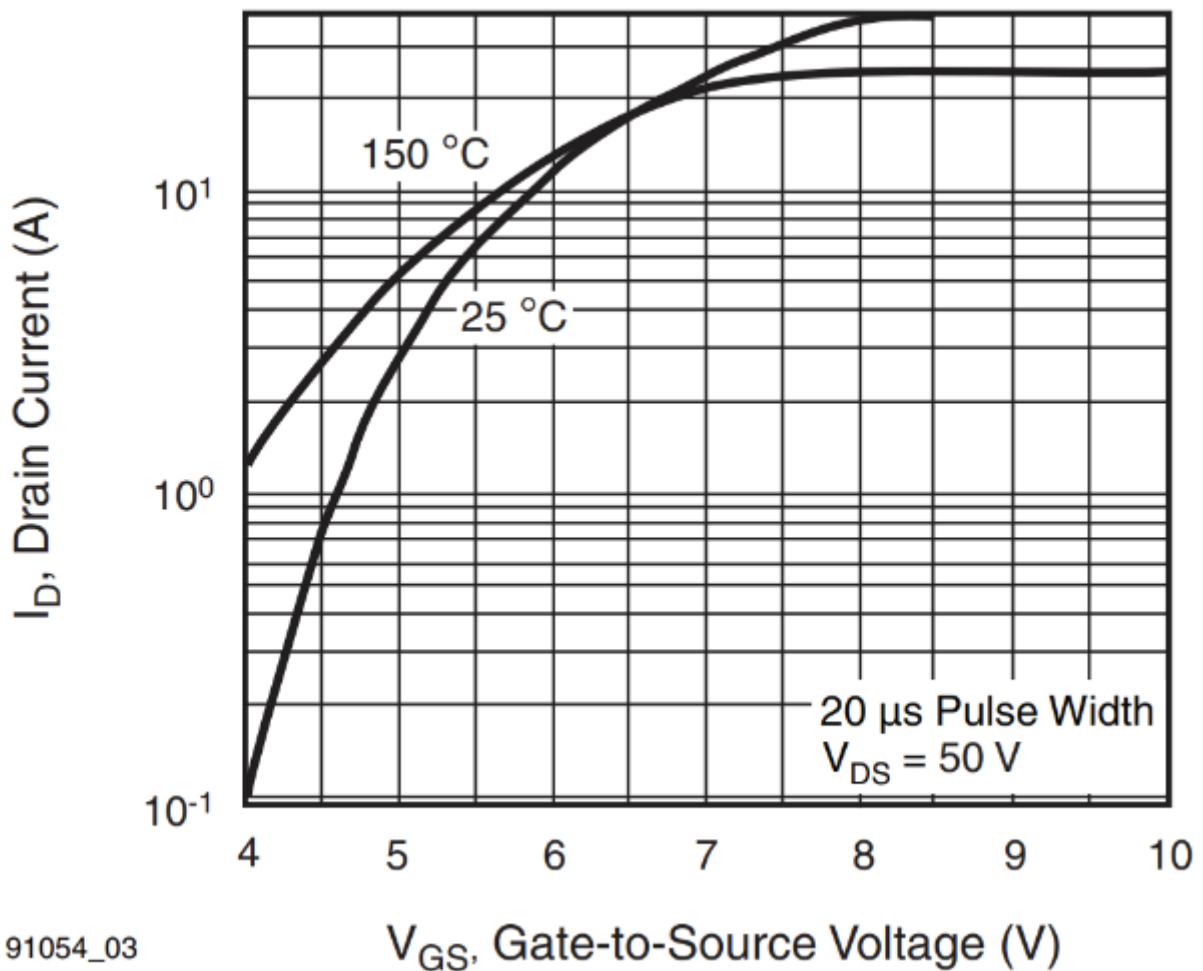


Figure 16: A graph showing the non-linear relationship between gate-source voltage and drain current for the IRF740 MOSFET. [14]

Of course, the relationship shown in the figure above and in the excel graph are positive and negative exponentials, the reason for this is that the gate voltage for the transistor is below 5V for the curve, and therefore is an expansion of the very left side (that is a positive exponential). [JL]

Evaluation Conclusion: [JL]

These results confirm that the discharging circuit was working as expected, and suitable for purpose. fulfilling our criteria for use discharging batteries from 0-30V, and 0-2A, being controlled by a 5V PWM cycle. [JL]

Although electrically sound, this module required further design work to be suitable to hand to a user. Specifically, heat-sink or potting compound on the MOSFET legs, as this currently risks a short-circuit. Some additional mechanical support would also help, ensuring they do not snap or break off, this materialise as a strain-relief hole that the wires are fed through before soldering to the Veroboard and MOSFET legs. [JL]

Charging [TR]

After building the circuit on the breadboard the next stage is to test and validate the output of the power supply. By connecting it to a bench power supply and function generator we can simulate the incoming 64V as the circuit input voltage as well as changing the duty cycle to regulate the voltage. [TR]



Figure 17 – Function Generator and Power Supply

Using an oscilloscope, the output of the function generator and power supply can be analysed to make sure it is functioning properly. The circuit itself can also be probed at specific points to validate the outputs. For instance, a probe was placed at the output of the power supply to monitor the PWM output, stability, ramp-up and ramp-down times of the power supply. It is important to note that the time it takes to reach the desired voltage is as small as possible to avoid damaging the batteries. The stability of the power supply also needs to be considered as it needs to be able to output a stable constant voltage that is as smooth as possible. [TR]



Figure 18 - Oscilloscope Capture when adjusting the duty cycle from 0% to 100%

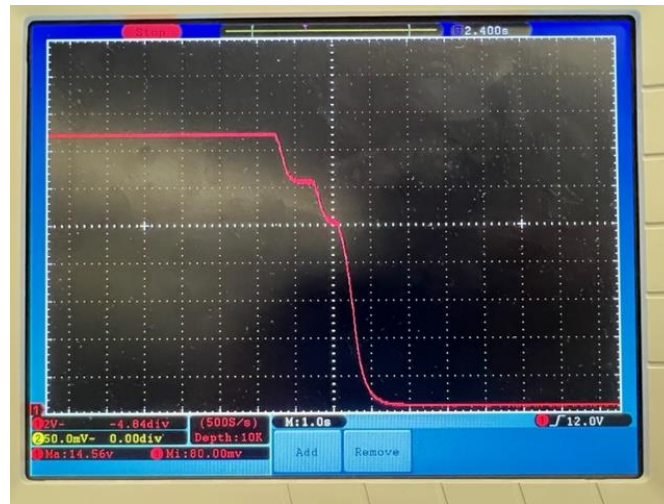


Figure 19 - Oscilloscope capture of the power supply operating at the peak and minimum voltage

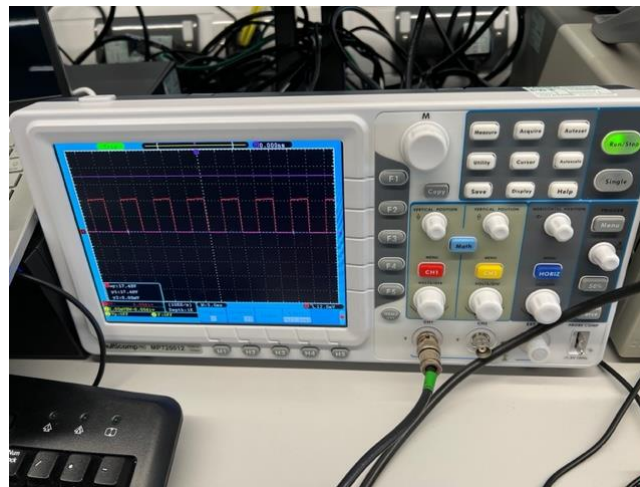


Figure 20 - Oscilloscope capture to validate the output of the PWM signal

As seen above, the power supply is very stable and even performs really well when adjusting the duty cycle to alter the voltage. The power supply ranges from a maximum value of 14.56V and a minimum value of 80mV as seen in Figure 19. **[TR]**

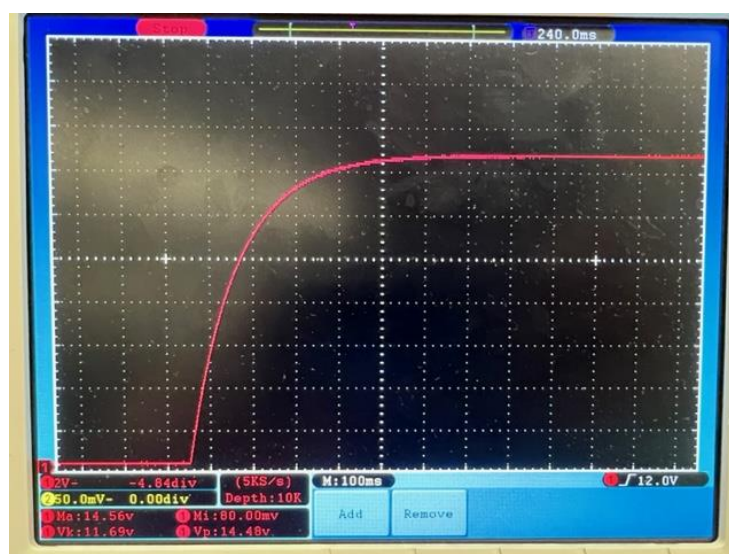


Figure 21 - Oscilloscope capture the ramp up of the power supply



Figure 22 - Oscilloscope capture ramp down of the power supply

Figure 21 shows the power supply voltage ramp up when initially powering the circuit. The ramp up/down of the power supply is approximately 500 milliseconds according to the oscilloscope captures. This isn't a bad time but it can be improved through better component selection, by creating a more complex circuit that operates with different input voltages to shorten the time needed for the power supply to ramp up. It can also be reduced by increasing the PWM signal frequency. For this project this power supply is perfectly suitable as it provides a constant stable voltage that can be finely tuned by altering the duty cycle of the PWM signal. [TR]

Current Sense Module Testing [MP]

One of the current sense modules was assembled at DstI then tested at UWTSD. The test was conducted in stages, initially an adjustable power supply was hooked up with a load resistor inline across the shunt resistor and an oscilloscope connected to the output to monitor. The current limit on the adjustable power supply was set at 3A and the voltage stepped up 1 volt at a time. A table of results can be found in Appendix 6. The results provided a linear result between the INA225's output voltage and the current drawn by the resistor load as the supply voltage increased. Due to the low power level of the load resistor, the test had to be stopped long before we reached the upper limits of our design requirements. [MP]

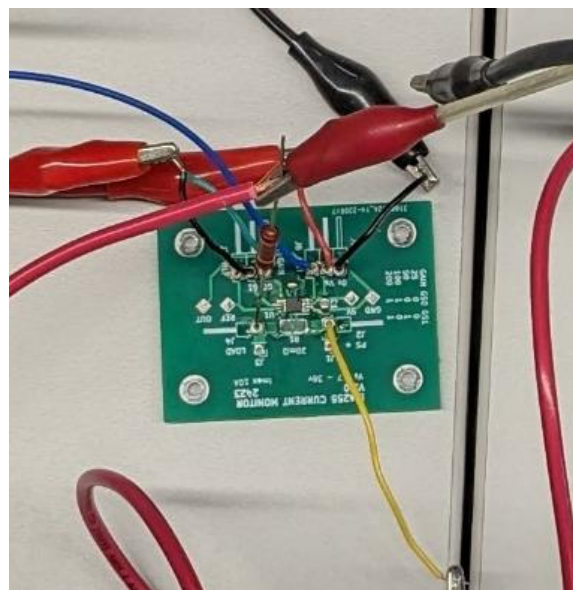


Figure 23 - INA225 PCB in place testing its output

Testing then progressed to reading the output of the current monitor into the PIC development board, and fine-tuning the values used in Ohms Law to provide an accurate output. The display output seen in Figure 24 shows the

calculated V_{DIFF} across the shunt resistor (labelled as Sense V on the display) and the raw ADC input reading (labelled as Current on the display) being incorrectly formatted. [MP]

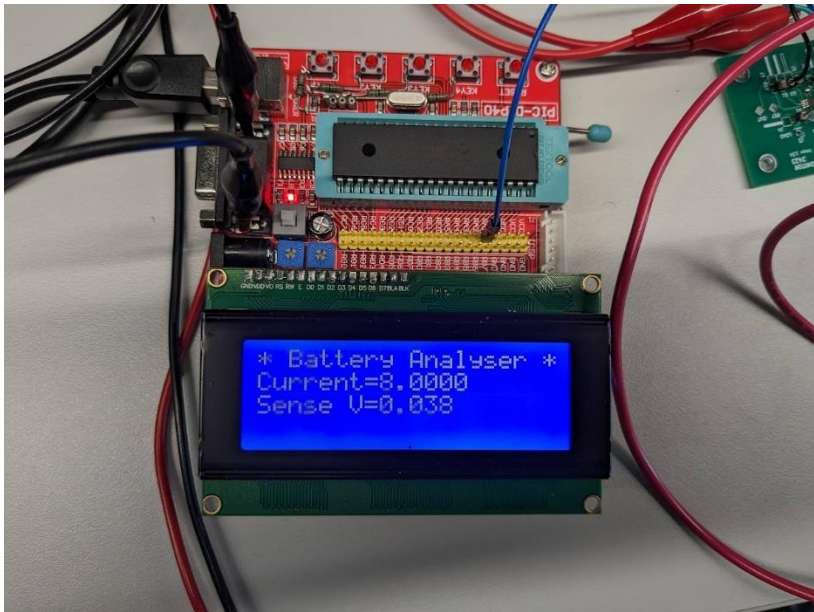
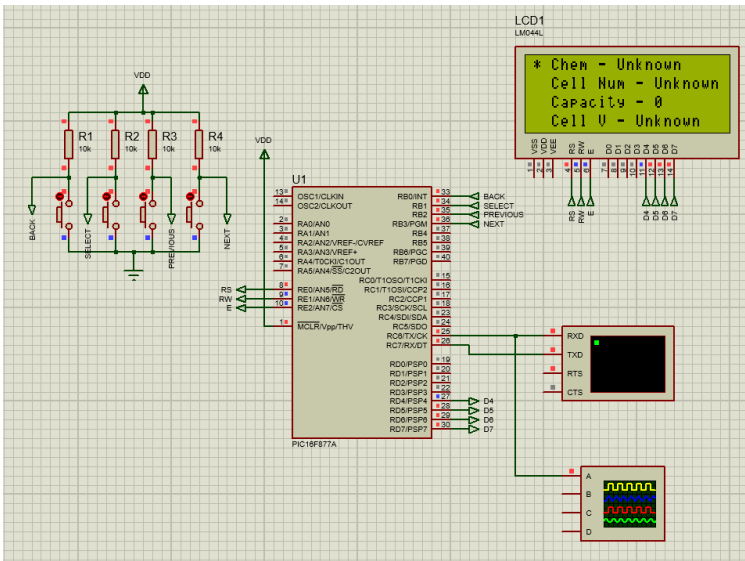


Figure 24 - PIC Development Board reading output of Current Sense Module

PIC User Interface [TR]



involved troubleshooting the drivers used with the specific LCD screen purchased as well as the PIC programmer itself. [TR]

This UI lets the user enter any of the known characteristics of the battery they wish to identify. This includes battery cell voltage, cell count, chemistry, and the capacity. The code was then tested for bugs and peer reviewed for any suggestions. I received feedback to add an indicator to show the user which line they are currently editing. The final look for the user interface is shown below: [TR]



Figure 26 - User interface on PIC development board

Conclusion & Recommendation

Techniques for characterising batteries are heavily dependent on prior data being captured and analysed. This would require too much time to achieve in the time frame given. The data itself would also need computing and algorithms need to be created to extract any meaningful results from the data. Without that prior data it is not possible to implement the chemistry identification feature. **[TR]**

The charging circuit operated well and was very stable even when changing the duty cycle to alter the voltage. The output of the power supply was a smoothed DC signal and could be adjusted from 80mV to around 14V which was validated by checking the output on an oscilloscope shown in Figure 19. The ramp up/down time of 500 milliseconds can be reduced by using different values for the inductor and capacitor which depends on the frequency of the PWM signal used from the PIC. **[TR]**

I also managed to produce a successfully working user interface that made use of 4 push buttons and an LCD screen. However, without much experience with programming PICs a lot of the time was wasted troubleshooting issues rather than progressing with the code. **[TR]**

Development of prototype solutions of each module worked well individually, future work should look at finalising the designs of each module and building them up on PCB's for further development and integration. The software on the microcontroller would need to be developed further and the user interface tested against a group of users to gain feedback and inform the development. **[MP]**

Charging and discharging batteries by designing your own charger and discharger is a difficult and potentially unsafe thing to do and is best to avoid wherever possible. Although some signatures exist to identify and categorize different battery chemistries (temperature, negative voltage gradient etc...), they are hard to spot and vary between specific make and models of battery. **[JL]**

Because of this, I recommend that these batteries are profiled manually and considered on a case-by-case basis, or more development goes into safety measures for the project (e.g., insulated metal enclosure, automatic fire alarm, greater temperature sensing capability). It is likely that the solution will never be "plug and play" and will always require at least some degree of careful consideration from the user. **[JL]**

As a recommendation for the next step we should integrate all the separate modules together to create a device that can charge and discharge basic batteries whilst monitoring the outputs. As well as creating the circuits on PCBs and developing the code further so all the modules work. **[TR]**

Reflection

Theo

This project provided me with a greater insight into charging and characterising batteries. It also highlighted the importance of battery safety and what protection features you need to consider when using batteries. The project provided lots of hands-on experience with building circuits on proteus and breadboards as well as soldering components on stripboard. I also got to familiarise myself with using PIC programming software and hardware as well as using lab equipment to validate the outputs of my circuits. The project itself was successful, even though it isn't finished, as we still built a solid foundation for the additional tests and hardware to be implemented. [TR]

The next step for me in this project will be to continue developing the code so all the separate modules can be integrated with the PIC and to include charging curves. To achieve the battery characterisation for this project the methods used in the research papers need to be trialled using the lab equipment and some batteries before implementing it with the PIC. Due to the amount of research and preparation that this project required it wasn't possible to achieve everything within this timescale. [TR]

Matthew

This project has helped me develop an appreciation for active research, by which I mean developing simulations & hardware in tandem with research, in the early stages of a project to help fully understand techniques or technologies. Without such an approach it is easy to get stuck researching without making any progress forwards. This approach could also be considered as a "failing fast" approach where you don't expect everything to work, but you learn from the results of each test and move forwards. [MP]

I've also gained a better appreciation for prioritization and time management of a project and work overall. As a team we started strong with a team meeting in the first week of the Group Project, however with our individual priorities being with other work, little progress was made in researching the problem. As a result we spent most of our first dedicated week at UWTSD reading up and researching the problems, rather than working through prototypes and simulations. This had a knock-on effect to future weeks as we ran out of time to develop our hardware solution. [MP]

Jack

This project has been an excellent opportunity to develop my skills in embedded software, and hardware design, alongside project management and problem-solving. [JL]

Although we did not fully finish all the battery categorisation tasking, we have a good prototype of the charging, discharging, and control modules that are required, and thus forms the completion of the first generation of hardware. Continuing with this project, the next step will be to put everything inside of an enclosure, and code safety features such as overvoltage or overcurrent protections, alongside temperature considerations to prevent thermal runaway. [JL]

We will also want to spend more time delving into the safe storage guidelines, ensuring that we can charge or discharge batteries to the appropriate SOC (state of charge), completing the project. Additionally, we should also investigate the design of the charging module, and why it will only output half the input voltage when a low-resistance load is applied. [JL]

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Appendices

[1] PWM-Current Table for a 2.7V battery:

PWM (%)	Current Drawn (A):
0	0
10	0
20	0
30	0
40	0
50	0
60	0
70	0.017
75	0.085
80	0.259
85	0.591
90	1.117
95	1.87
96	2.048
97	2.236
98	2.432
99	2.638
100	2.853

Above: Table ###, Output current of a 2.7V "battery", changed by differing Pulse width modulation.

[2] PWM-Current Table for a 6V battery:

PWM (%)	Current Drawn (A):
0	0
10	0
20	0
30	0
40	0
50	0
60	0
70	0.017
75	0.091
80	0.267
85	0.611
90	1.165
95	1.969
96	2.168
97	2.376
98	2.594
99	2.826
100	(3A current limit reached)

Above: Table ###, Output current of a 6V "battery", changed by differing Pulse width modulation

[3] PWM-Current Table for a 9V battery:

PWM (%)	Current Drawn (A):
0	0
10	0
20	0
30	0
40	0
50	0
60	0
70	0.019
75	0.09
80	0.271
85	0.626
90	1.209
95	2.086
96	2.325
97	2.552
98	2.791
99	(3A current limit reached)
100	(3A current limit reached)

Above: Table ###, Output current of a 9V “battery”, changed by differing Pulse width modulation

[4] PWM-Current Table for a 12V battery:

PWM (%)	Current Drawn (A):
0	0
10	0
20	0
30	0
40	0
50	0
60	0
70	0.023
75	0.099
80	0.295
85	0.67
90	1.294
95	2.22
96	2.459
97	2.721
98	2.998
99	(3A current limit reached)
100	(3A current limit reached)

Above: Table ###, Output current of a 12V “battery”, changed by differing Pulse width modulation

[5] PWM-Current Table for a 30V battery:

PWM (%)	Current Drawn (A):
0	0
10	0
20	0
30	0
40	0
50	0
60	0
70	0.026
75	0.12
80	0.605
85	2.08
90	(3A current limit reached)
95	(3A current limit reached)
96	(3A current limit reached)
97	(3A current limit reached)
98	(3A current limit reached)
99	(3A current limit reached)
100	(3A current limit reached)

Above: Table ###, Output current of a 30V “battery”, changed by differing Pulse width modulation

[6] Current Monitor testing code – C [MP]

```
#include <main.h>
#include <16F877A.h>

#define LCD_ENABLE_PIN PIN_E2
#define LCD_RS_PIN PIN_E0
#define LCD_RW_PIN PIN_E1
#define LCD_DATA4 PIN_D4
#define LCD_DATA5 PIN_D5
#define LCD_DATA6 PIN_D6
#define LCD_DATA7 PIN_D7

#include <lcd.c>

// Variable Prototypes
float currentADC, AvgADC[5], sum, currentVoltage, currentAmp;
unsigned int x;
//

// Function Prototypes
long analog(unsigned int);
//

void main()
{

    setup_adc_ports(AN0_AN1_AN2_AN3_AN4);
    setup_adc(ADC_CLOCK_INTERNAL);
    lcd_init();
    delay_ms(20);

    lcd_gotoxy(1,1);
    printf(lcd_putc, "\f* *SETUP COMPLETE* *");
    delay_ms(1000);
    lcd_gotoxy(1,1);
    printf(lcd_putc, "* Battery Analyser *");
    lcd_gotoxy(1,2);
    printf(lcd_putc, "Current=");
    lcd_gotoxy(21,1);
    printf(lcd_putc, "Sense V=");

    while(TRUE)
    {
        lcd_gotoxy(9,2);
        printf(lcd_putc, "    "); // clear 5 spaces
        lcd_gotoxy(29,1);
        printf(lcd_putc, "    "); // clear 5 spaces
        for(x=0; x<5; x++){           // Take an average of 5 ADC readings to mitigate some odd results
            AvgADC[x]=analog(1);      // ADC reads a 10bit value into float array
            sum=sum+AvgADC[x];
        }
    }
}
```

```

currentADC=sum/5;           // Calculate the average
sum=0;
currentVoltage=currentADC/209; // Calculate the sensed voltage div/1024 multiplied by 5
currentAmp=currentVoltage/0.020; // Apply Ohms Law – divide by 20mR
lcd_gotoxy(9,2);
printf(lcd_putc,"%1.4g",currentAmp); // Print values to LCD
lcd_gotoxy(29,1);
printf(lcd_putc,"%2.3g",currentVoltage);
delay_ms(1000);
}

}

long analog(unsigned int chan)
{
    set_adc_channel(chan); //set adc channel
    delay_us(20);           // wait 20uS
    return(read_adc());     // store value in variable ADC
}

```

[7] Current Sensing and Discharger testing data

Voltage Supplied:	Oscilloscope Reading:	Current Board measurement:	Difference:	Corrected Current Board:
1	0.018	0	0.018	
2	0.03	0	0.028	
3	0.04	0	0.042	
4	0.06	0	0.058	
5	0.07	0	0.072	
6	0.09	0.01	0.078	0.083667
7	0.10	0.023	0.081	0.096667
8	0.12	0.043	0.073	0.116667
9	0.13	0.052	0.08	0.125667
10	0.15	0.072	0.076	0.145667
11	0.16	0.091	0.069	0.164667
12	0.18	0.101	0.075	0.174667
13	0.19	0.125	0.067	0.198667
14	0.21	0.135	0.075	0.208667
15	0.22	0.154	0.07	0.227667
16	0.24	0.168	0.074	0.241667
17	0.26	0.192	0.066	0.265667

[8] User Interface PIC C code

```
8 #include <main.h>
9 #include <16F877A.h>
10 #include <string.h>
11
12 #define LCD_ENABLE_PIN PIN_E2
13 #define LCD_RS_PIN PIN_E0
14 #define LCD_RW_PIN PIN_E1
15 #define LCD_DATA4 PIN_D4
16 #define LCD_DATA5 PIN_D5
17 #define LCD_DATA6 PIN_D6
18 #define LCD_DATA7 PIN_D7
19
20 #include <lcd.c>
21
22 // Define Prototypes:
23
24 void batt_config();
25 void chem_setup();
26 void cap_setup();
27 void cell_volt_setup();
28 void cell_setup();
29 void lcd_setup();
30 void setup();
31
32 // Define Variables
33
34 char const input_cell_voltage[5][8] = {"", "Unknown", "1.2V", "3.6V", "3.7V"}; // Using arrays to store values for voltage
35 char const input_chemistry[6][8] = {"", "Unknown", "Lion", "LiPo", "NiMh", "NiCd"}; // Using arrays to store values for chemistry
36 unsigned long input_capacity=0;
37 char const input_cells[18][8] = {"", "Unknown", "1", "2", "3", "4", "5", "6", "7", "8", "9", "10", "11", "12", "13", "14", "15", "16"}; // Using arrays to store values for cell count
38 int chem=1; // This variable is used to cycle through the positions in the array
39 int cell=1; // This variable is used to cycle through the positions in the array
40 int cap=1; // This variable is used to cycle through the positions in the array
41 int volt=1; // This variable is used to cycle through the positions in the array
42 int step=1; // This variable is used to cycle through the steps in the setup
43 unsigned int but[4] = {0,0,0,0};
44
45 // Interrupt using TIMER0 - To check the input of the switches
46
47 #INT_TIMER0
48 void TIMER0_isr(void)
49 {
50     if(input(PIN_B0)) but[0] = 1;
51     if(input(PIN_B1)) but[1] = 1;
52     if(input(PIN_B2)) but[2] = 1;
53     if(input(PIN_B3)) but[3] = 1;
54 }
55
56
57 int main (void)
58 {
59     setup_timer_0(RTCC_INTERNAL|RTCC_DIV_1|RTCC_8_BIT); //256 us overflow
60     enable_interrupts(INT_TIMER0); // Enables interrupts
61     enable_interrupts(GLOBAL);
62
63     lcd_init(); // Initialise
64     lcd_setup(); // Initialise LCD
65
66     while (TRUE)
67     {
68         batt_config(); // Run the subroutine batt_config()
69         step=0; // Set "step" to 0
70     }
71 }
72
73 void batt_config()
74 {
75     while(TRUE)
76     {
77         if(input(PIN_B1)) // If select key is pressed increase step by 1.
78         {
79             step++;
80             lcd_setup(); // Run subroutine lcd_setup()
81             delay_ms(100); // Delay
82
83             if(step==1) chem_setup(); // If step = 1 run subroutine chem_setup();
84             if(step==2) cell_setup(); // If step = 2 run subroutine cell_setup();
85             if(step==3) cap_setup(); // If step = 3 run subroutine cap_setup();
86             if(step==4) cell_volt_setup(); // If step = 4 run subroutine cell_volt_setup();
87             if(step==5) break; // If step = 5 break from while loop;
88         }
89     }
90 }
91
92 void lcd_setup() // This subroutine will print the 4 battery characteristics(Chemistry, Cell count, Capacity, Cell Voltage)
93 // Onto the LCD screen. As the user cycles through the selection it will constantly update.
94 {
95     printf(lcd_putc, "\f");
96     if(step==1) // If statement to make sure the marker/indicator is placed on the current line the user is editing.
97     {
98         lcd_gotoxy(1,1);
99         printf(lcd_putc, "*"); // This is used as a marker/indicator for the user to see which line they are editing.
100     }
101     lcd_gotoxy(3,1); // This tells the lcd screen where to put the text in x, y coords. (3,1) means 3 on the X axis and 1 on the y axis.
102     printf(lcd_putc, "Chem - %s", input_chemistry[chem]); // This will output "Chem - " The value of the variable that the user has chosen.
103     if(step==2)
104     {
105         lcd_gotoxy(1,2);
106         printf(lcd_putc, "*");
107     }
108     lcd_gotoxy(3,2);
109     printf(lcd_putc, "Cell Num - %s", input_cells[cell]);
110     if(step==3)
111     {
112         lcd_gotoxy(21,1);
113         printf(lcd_putc, "*");
114     }
115     lcd_gotoxy(23,1);
116     printf(lcd_putc, "Capacity - %Lu", input_capacity);
117     if(step==4)
118     {
119         lcd_gotoxy(21,2);
120         printf(lcd_putc, "*");
121     }
122     lcd_gotoxy(23,2);
123     printf(lcd_putc, "Cell V - %s", input_cell_voltage[volt]);
124 }
125
126
```

```

126
127 void chem_setup()                // Subroutine that takes the input of the "next" and "previous" buttons to cycle through the values in the arrays
128 {
129     if(but[3]==1)                // if next button is pressed
130     {
131         chem++;
132
133         if(chem==6)   chem=1;          // if it reaches max value of elements in the array then reset to the first
134
135         delay_ms(100);
136         lcd_setup();                // update display
137     }
138     if(but[2]==1)                // if previous button is pressed
139     {
140         chem--;
141
142         if(chem==0)   chem=5;          // if it reaches the min valyue of elements in the array then go to the last
143
144         delay_ms(100);
145         lcd_setup();                // update display
146     }
147     delay_ms(5);
148     but[3]=0;                    // reset button flags
149     but[2]=0;
150     delay_ms(20);
151 }
152

```

```

152
153 void cell_setup()                // Subroutine that takes the input of the "next" and "previous" buttons to cycle through the values in the arrays
154 {
155     if(but[3]==1)                // if next button is pressed
156     {
157         cell++;
158         if(cell==18)   cell=1;          // if it reaches max value of elements in the array then reset to the first
159
160         delay_ms(100);
161         lcd_setup();                // update display
162     }
163     if(but[2]==1)                // if previous button is pressed
164     {
165         cell--;
166         if(cell==0) cell=18;          // if it reaches the min valyue of elements in the array then go to the last
167
168         delay_ms(100);
169         lcd_setup();                // update display
170     }
171     delay_ms(5);
172     but[3]=0;
173     but[2]=0;
174     delay_ms(20);
175 }
176
177 void cell_volt_setup()           // Subroutine that takes the input of the "next" and "previous" buttons to cycle through the values in the arrays
178 {
179     if(but[3]==1)                // if next button is pressed
180     {
181         volt++;
182         if(volt==5) volt=1;          // if it reaches max value of elements in the array then reset to the first
183
184         delay_ms(100);
185         lcd_setup();                // update display
186     }
187     if(but[2]==1)                // if previous button is pressed
188     {
189         cap--;
190         if(volt==0) volt=5;          // if it reaches the min valyue of elements in the array then go to the last
191
192         delay_ms(100);
193         lcd_setup();                // update display
194     }
195     delay_ms(5);
196     but[3]=0;
197     but[2]=0;
198     delay_ms(20);
199 }
200

```

```

200
201 void cap_setup()                // Subroutine that takes the input of the "next" and "previous" buttons and increases/decreases capacity by 10 each time
202 {
203     if(but[3]==1)                // if next button is pressed
204     {
205         input_capacity= input_capacity+10;    // increament input_capacity by 10.
206
207         delay_ms(100);
208         lcd_setup();                // update display
209     }
210     if(but[2]==1 && input_capacity!=0)        // if previous button is pressed
211     {
212         input_capacity= input_capacity-10;    // decreament input_capacity by 10.
213
214         delay_ms(100);
215         lcd_setup();                // update display
216     }
217     delay_ms(5);
218     but[3]=0;
219     but[2]=0;
220     delay_ms(20);
221 }
222

```