Automated AA Battery Health Assessment Device Prototype Design

Victoria Bench - 1611349, Blake Denham - 1714988, Jonathan Taylor - 1665909

***Abstract*—This prototype for an automated AA battery health assessment device focuses primarily on a circuit design for determining the voltage and internal resistance over a AA battery. The prototype addresses automating a controllable voltage over a load resistor, PWM to DC voltage rectification and internal resistance calculation using an Arduino Uno. In the future designs, the prototype will utilise a stand alone ATMEGA328P microcontroller and a visual display of results, as well as potentially provide additional information such as the state of capacitance of the battery.**

***Index Terms*—AA Battery, Voltage, Internal Resistance, PWM to DC, Arduino**

I. INTRODUCTION

A BATTERY'S STATE OF HEALTH is determined by several parameters including voltage, internal resistance, capacitance and self discharge. Internal resistance provides valuable information about a battery's SoH as a high reading indicates end-of-life. The device prototype discussed in this report measures the internal resistance and voltage across a AA battery, giving the user a rough idea of the battery's state of health.

Section II provides insight into the method used to calculate internal resistance as well as information about the automation of the circuit. Section III provides and validates prototype test results. Section IV discusses further project plans and milestone distribution. Section V summarizes and concludes the report. The Appendix provides circuit diagrams, simulation results and a project timeline to referred to in the report.

II. MATERIALS AND METHODS

The open circuit voltage over the battery is read directly into the microcontroller. Internal resistance is calculated using a dual-pulse test [1]. Two sequential discharge loads of different currents and time durations are applied to the battery. The battery first discharges and stabilizes at a low load current of $\pm 5mA$, followed by a higher current of $\pm 505mA$ for $100ms$. Ohm's law is used to calculate the internal resistance by dividing the change in voltage by the change in current. These values are strictly resistive and do not reveal SoC or capacity estimations. This method is appropriate for testing AA batteries because these batteries are normally used to power DC loads [2].

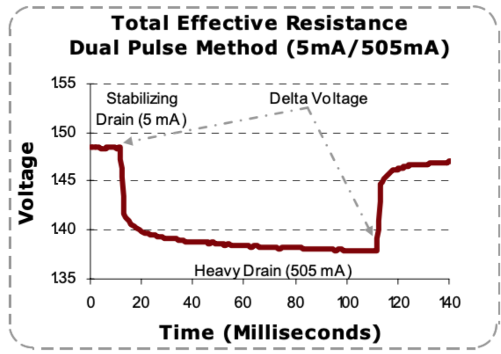


Fig. 1: Example pulse test conducted by Energizer [1]. A $5mA$ stabilizer load current is used with a $505mA$ pulse current , giving a delta of $5mA$. If the voltage changes form $1.485V$ to $1.378V$, the delta would be $0.107V$, giving an effective resistance of $0.107/500 = 214m\Omega$.

Circuit Automation

The following units were considered in automating the device. Refer to Figure 4 in Appendix A for the full circuit diagram and component values:

- Controllable voltage source to change the load current
- Electronic switch to open and close the current sink circuit
- Internal Resistance Calculation

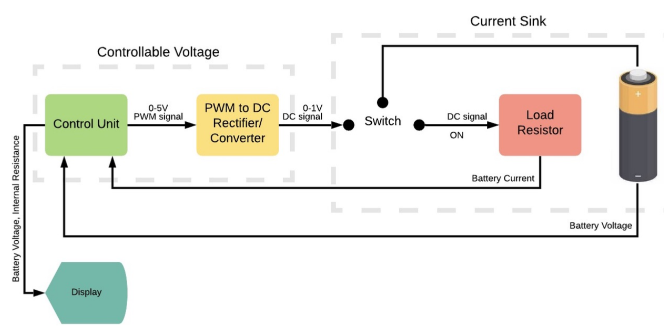


Fig. 2: Block diagram showing prototype system

Controllable Voltage Source The dual-pulse test requires two different load currents, so two different voltages must be applied over a 1Ω load resistor. *See Figure 4a) in the Appendix for the circuit diagram.*

The ATMEGA328P first outputs a PWM signal with a low duty cycle (representing a low load current), followed by a shorter pulse of PWM with high duty cycle (representing a load high current). The outputted PWM is rectified to DC using a second order low pass filter. A rail-to-rail operational amplifier voltage follower is used in the filter to ensure no saturation occurs within the $0V - 5V$ range. This also means that only one $5V$ power supply is required to power all the circuit components.

To ensure no more than $1A$ is being drawn from the battery, a voltage divider is used to reduce the voltage to a range of $0V - 1V$. This voltage is then applied over the 1Ω resistor through a second rail-to-rail voltage follower. This voltage determines the amount of current being drawn from the battery.

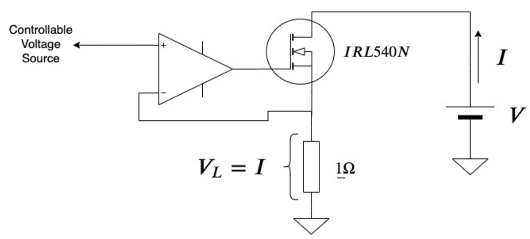


Fig. 3: Diagram of Current Sink circuit

Electronic Switch A switch between the battery and load resistor is necessary to ensure no current is being drawn before and after the short test to avoid draining the battery. This design uses an IRL540N MOSFET. This is an appropriate MOSFET as it is a logic level transistor and therefore can turn on fully from the logic level of a microprocessor. The power dissipated over the transistor would be no more than $2.3W$ (testing a $3.7V$ battery) for a very short period.

Internal Resistance Calculation The ATMEGA328P calculates the average of 1000 current and voltage samples for the stabilizer load and battery respectively to reduce the effect of any noise. This is repeated for the pulse load and the deltas are divided to calculate approximate internal resistance. For the first prototype,the results are displayed on the Arduino IDE Serial Monitor, however a considerations for final display include a LCD screen or a series of seven segment displays.

III. Results

The following tables show the results of a built prototype testing the SoH of a new and an old battery respectively. The tests aim for a stabilizer load current of $5mA$ and a pulse current of $505mA$, so as to align with the example provided by Energizer [1]. Since we do not have access to a tool that gives a 100% accurate reading of internal resistance, assumptions are made about the validity of the results based on relativity and manual calculations. A manual test resulted in an internal resistance of $291m\Omega$ for the new battery and $987.52m\Omega$ for the old battery. Simulation results are shown in Appendix.

TABLE I: Testing a New Battery

Init. Duty Cycle	V_1	I_1	V_2	I_2	r
1	1.52V	0.00A	1.34V	511.06mA	$335.35m\Omega$
2	1.51V	5.15mA	1.34V	511.03mA	$331.65m\Omega$
4	1.51V	5.12mA	1.34V	503.41mA	$333.32m\Omega$

Analysis of results

TABLE II: Testing an Old Battery

Init. Duty Cycle	V_1	I_2	V_2	I_2	r
4	1.14V	7.93A	0.55V	496.23mA	$1210.14m\Omega$

The internal resistance test results line up with the expectation with an approximate error of 15%. This error is due to the difference in conditions between the manual and automated test. The manual test took place over a longer time than the automatic test and used different load currents. A duty cycle of 4 gives load currents closest to the desired $5mA$ and $500mA$ for a new battery, however does not produce the same results when testing an older battery. It is clear that code needs to be produced to make the duty cycle adapt automatically in order to produce consistent stabilizer and pulse currents and furthermore, produce more consistent results.

The simulation results reinforce the design decisions as the voltage rectifier circuit produces a smooth enough DC signal within the range of $0V - 1V$ proportional to the duty cycle of the PWM wave. Figure 6 in the Appendix shows that no more than $2.3W$ will be dissipated over the MOSFET, which would increase its temperature by $1.15°$ with a heat sink. Power over the load resistor does not exceed $1W$ and therefore a $5W$ resistor will be more than sufficient.

IV. Implementation Plan

A time table showing the tasks and milestones is included in Figure 8 of the Appendix. Tuesday and Friday afternoons will be dedicated to optimizing and designing for the project. At least 3.5 hours a week should be set aside on average, giving the group of three a total of 21 hours each over the next six weeks. The minimum viable product should be complete before the study break ends, as there is a higher deadline and test concentration in the second term and there will be less time to work on the project.

V. Conclusion

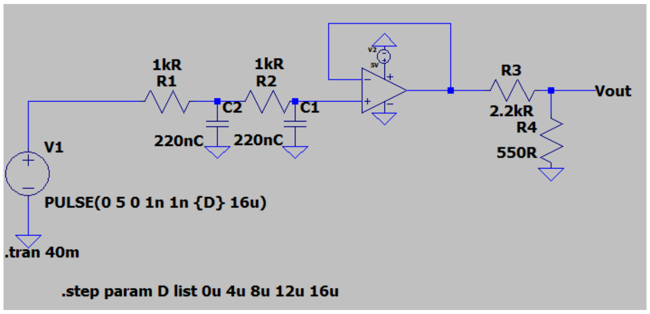
The prototype can successfully calculates an internal resistance that makes relative sense using the dual pulse method. The next iteration will incorporate a power source, stand alone ATMEGA328P , some form of digital display and more finely tuned load currents. State of capacitance will be further researched and considered as an additional function of the device if it fits with the current design.

References

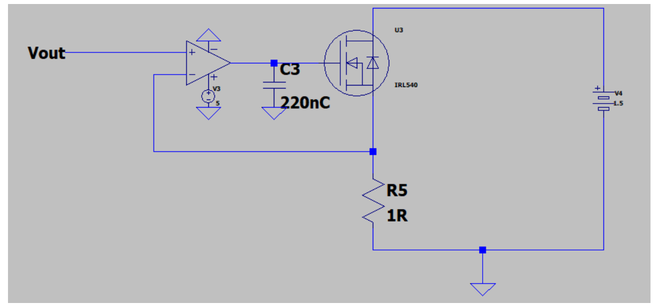
[1] Battery Internal Resistance. Energizer Technical Bulletin. vol. 1.1.0 , 2005.

[2] BU-902: How to Measure Internal Resistance. Isidor Buchmann. web site URL: https://batteryuniversity.com/learn/article/how_to_measure_internal_resista downloaded 8 March, 2020.

APPENDIX



(a) Controllable Voltage Source



(b) Switch and Current Sinking Circuit

Fig. 4: Prototype Circuit Diagram

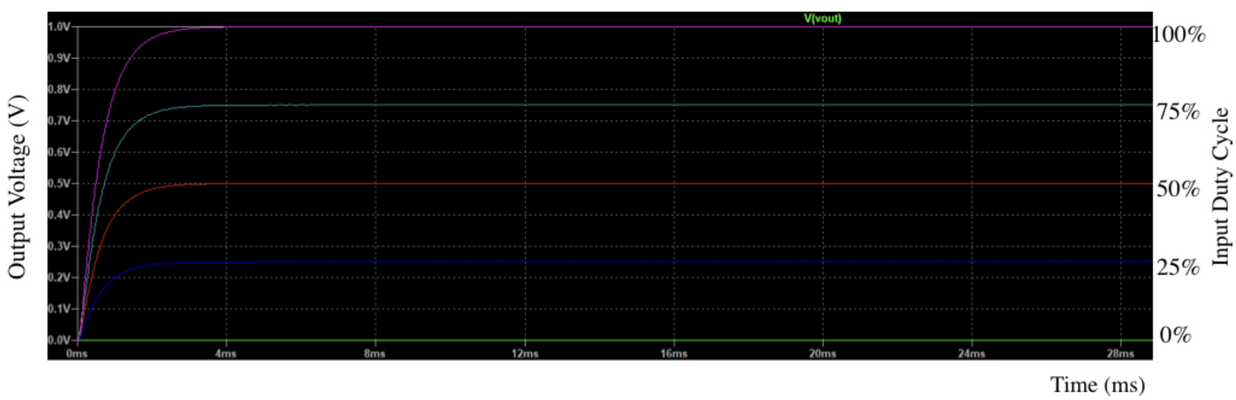


Fig. 5: Output DC signal of Controllable Voltage Source circuit over time

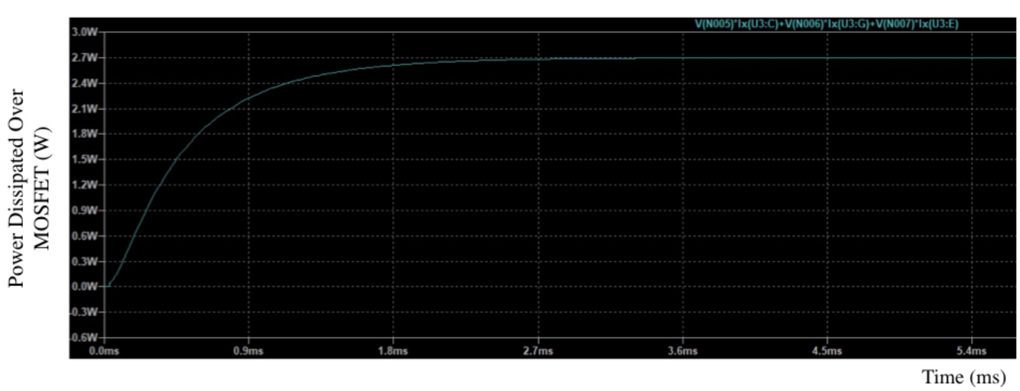


Fig. 6: Power over MOSFET over time while testing a 3.7V AA Li-ion Battery (Worst Case)

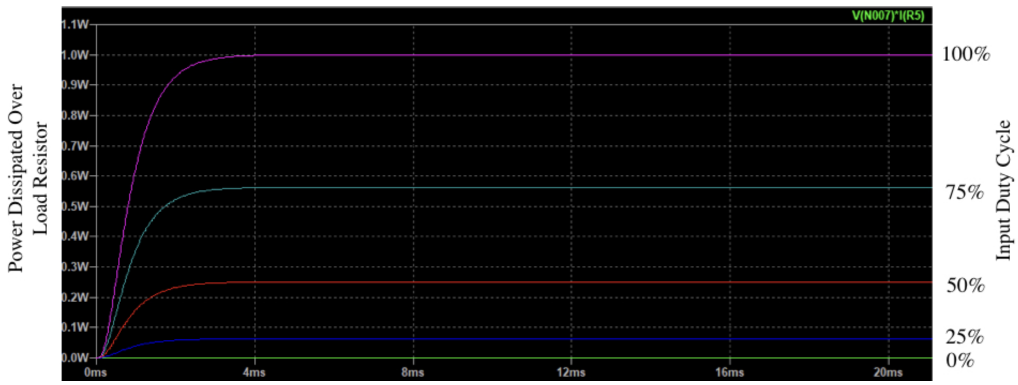


Fig. 7: Power dissipated 1Ω load resistor over time while testing a 3.7V AA Li-ion Battery (Worst Case)

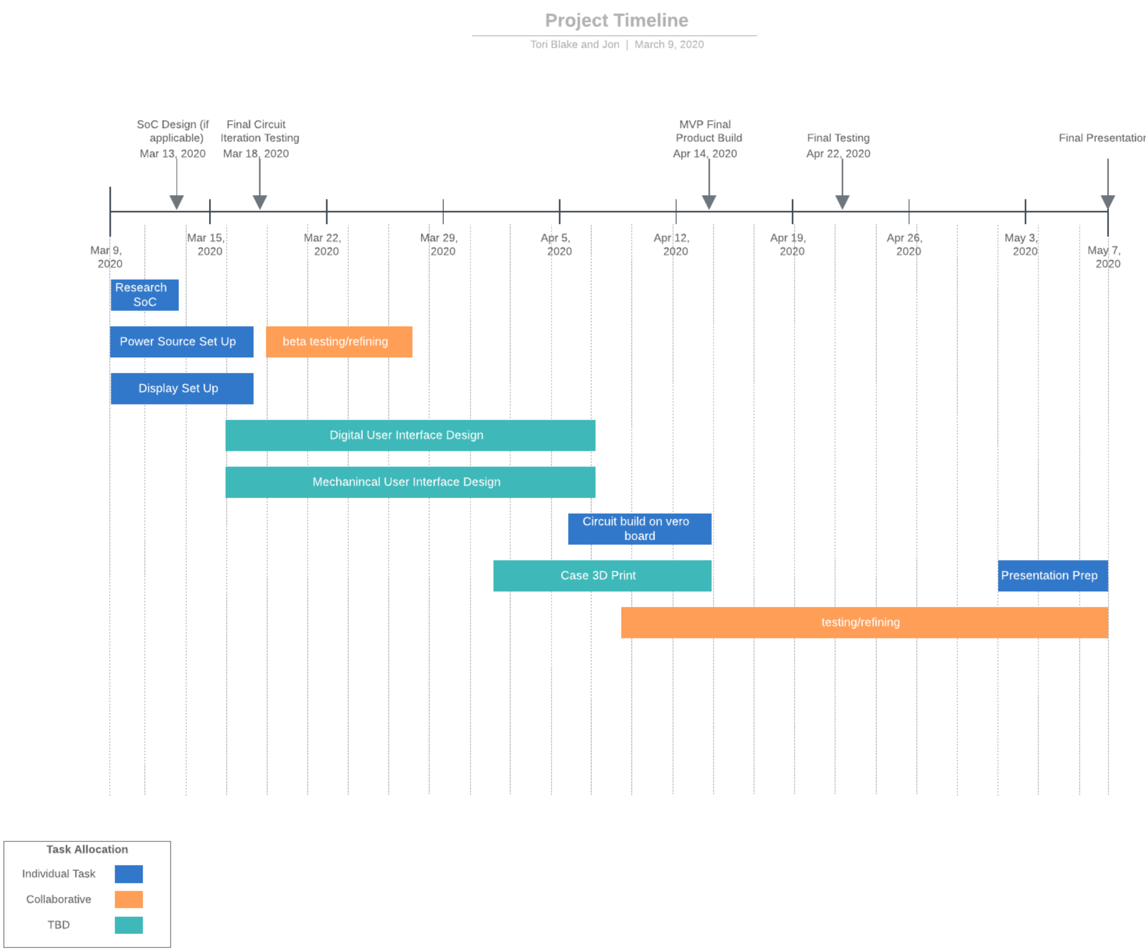


Fig. 8: Project timeline showing dates of deadlines and listing tasks