ELECTROCHEMICAL IMPEDANCE SPECTROSCOPY BOARD

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AGENDA

- Introduction
- Problem Statement
- Engineering Efforts
- Future Work
- Questions
- References

INTRODUCTION

PROBLEM BACKGROUND

- Battery dependency at an all-time high
- Need to use batteries at maximum efficiency
- Two most common battery capability metrics:
  - State of Charge (SOC)
  - State of Health (SOH)

PROBLEM BACKGROUND

- State of Charge (SOC):
  - A metric that reports percentage of energy remaining as compared to maximum energy[1]
  - Multiple established methods of calculating SOC:
    - Coulomb Counting
    - Open Circuit Voltage lookup table

PROBLEM BACKGROUND

- State of Health (SOH):
  - Currently a more complex and uncertain method
  - Goal is to inform the user of overall condition and performance capabilities, and to warn of catastrophic failure
  - Many proposed SOH solutions require bulky and expensive equipment
  - Not viable for most Battery Management Systems

PROBLEM STATEMENT

A lightweight, compact, low power, and inexpensive solution must be found for a real-time SOH monitor to be attached to a deployable battery

REVIEW OF EXISTING LITERATURE

- Potential SOH Methods[2]:
  - Linear Approximation
  - Single Cell Impedance
  - Weighted Average
  - Log Book Function
  - Electrochemical Impedance Spectroscopy (EIS)

REVIEW OF EXISTING LITERATURE

- EIS:
  - Established for laboratory experiments[3]
  - Basic Principle[4] is to excite electrochemical cell with sinusoidal signal and measure the response
  - Linearity of the system means sinusoidal input will yield approximately sinusoidal output

REVIEW OF EXISTING LITERATURE

- EIS offers wealth of battery information[5]:
  - Reaction mechanisms
  - Change of active surface area during operation
  - Separator Evaluation
  - Possible corrosion processes
- Our use is to generate frequency response and Nyquist plots

REVIEW OF EXISTING LITERATURE

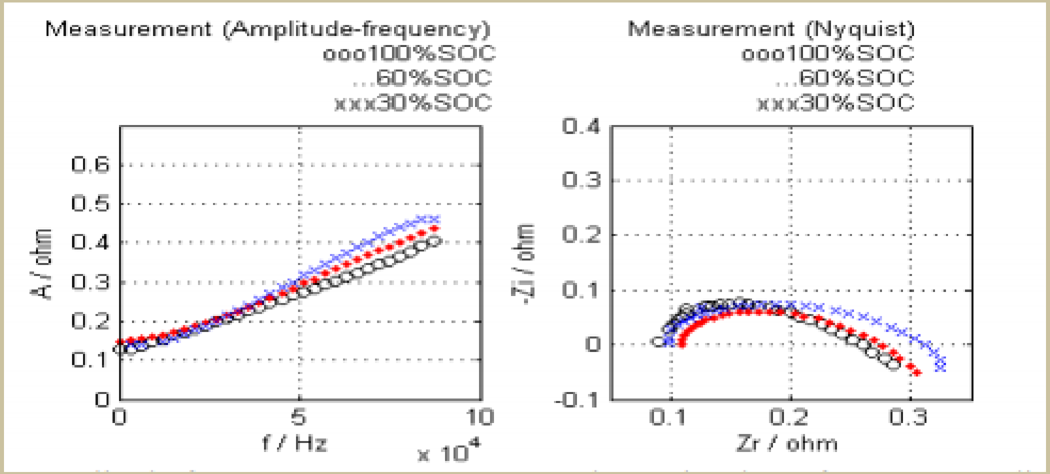


Figure 1: Frequency Response and Nyquist Plots [4]

- Battery health degradation tracked by outward shifts in the curvature over time

PROBLEM SOLUTION

- EIS determined to be most effective solution
- Proper implementation aims to[6]:
  - Enhance accuracy of SOC and SOH measurements
  - Fine tune individual cell balancing
  - Extend discharge and shorten charge cycles
  - Provide second life benefits

PROBLEM SOLUTION

- Sandia National Laboratories (SNL) has developed "EIS Board"
- Capable of performing two different EIS Techniques

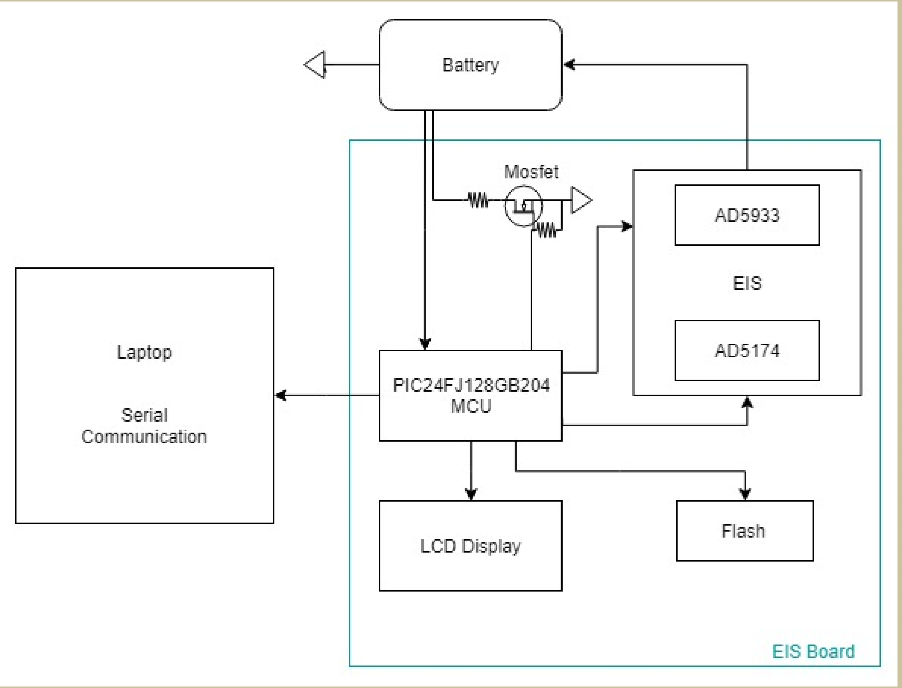


Figure 2: High Level EIS Board Block Diagram

ENGINEERING EFFORTS

Design

DESIGN GOALS

- EIS Board intended to be capable of implementing two different EIS techniques
  - Method 1: “Pseudo EIS”
  - Method 2: “True Impedance Spectroscopy”
- My goal was to write all of the firmware for these methods
- Current board hardware is only capable of Method 1

DESIGN GOALS

- Efficient firmware was written for:
  - UART Communication to Laptop
  - ADC, LCD, Timer, GPIOs
  - Initial SPI and I2C Communication to EIS Hardware

EIS METHOD 1: "PSEUDO EIS"

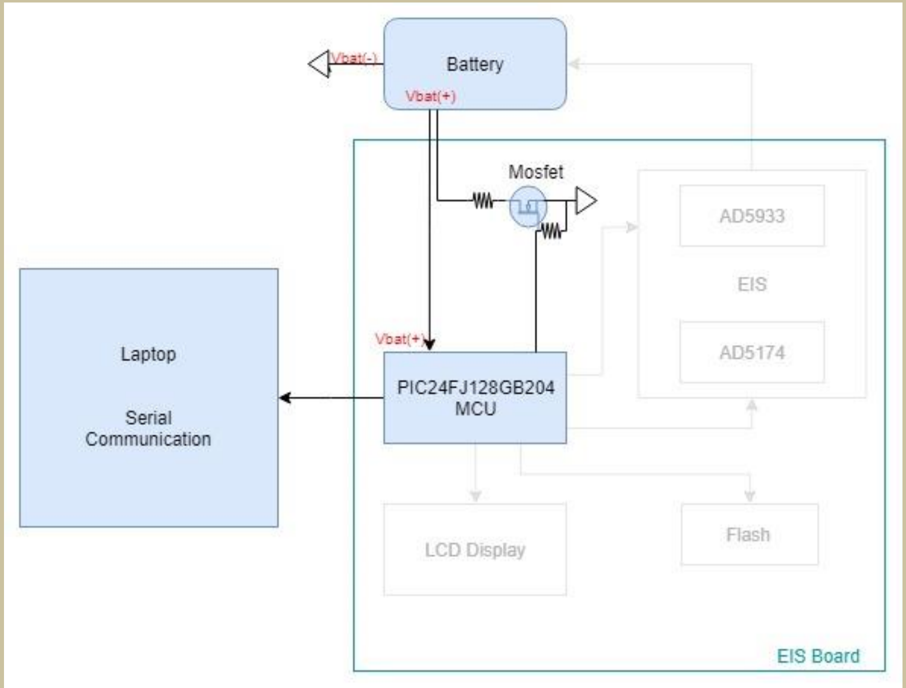


Figure 3: EIS Board Block Diagram for EIS Method 1

EIS METHOD 1: "PSEUDO EIS"

- Battery excited by square-wave current pulse
- Voltage response is measured
- Fourier Transform of both waveforms
- Complex impedance response calculated
- Filtering by digital signal processing
- Nyquist Plot graphed
- Track deviations over time

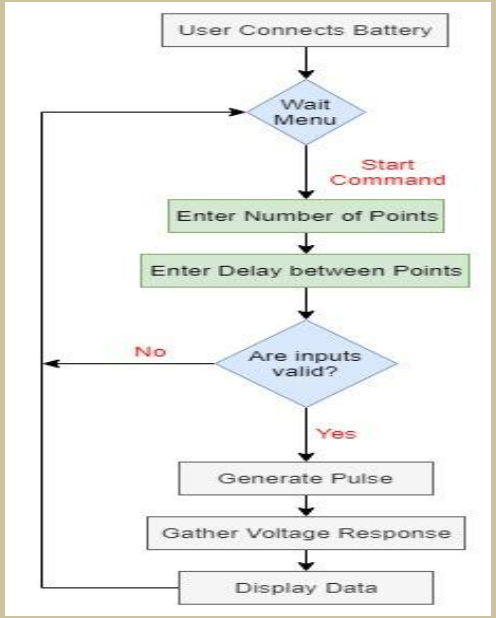


Figure 4: EIS Method 1 Software Flow Chart

EIS METHOD 2: "TRUE IMPEDANCE SPECTROSCOPY"

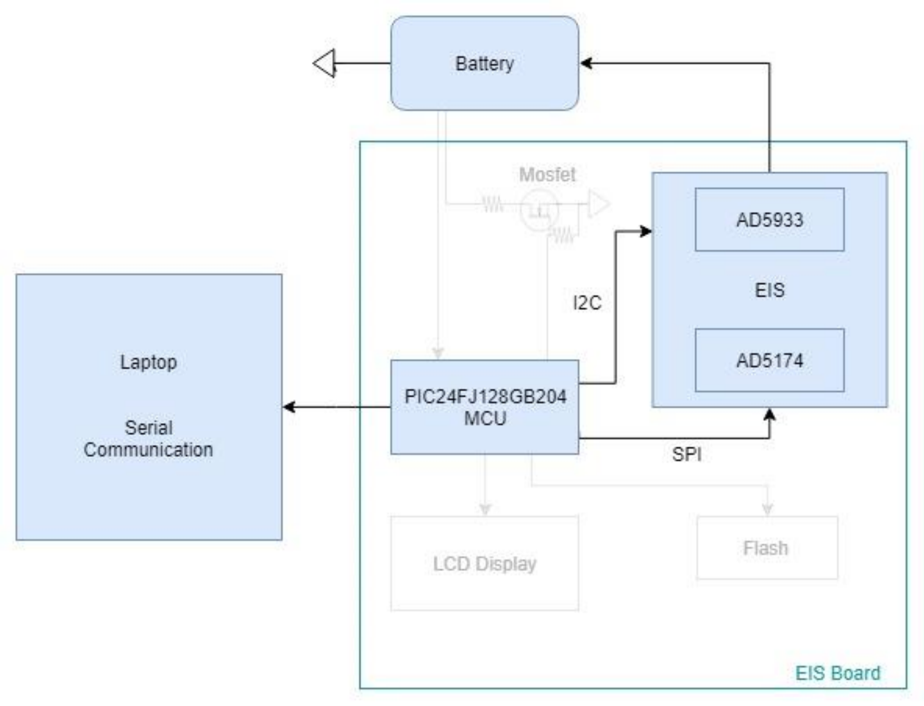


Figure 5: EIS Board Block Diagram for EIS Method 2

EIS METHOD 2: "TRUE IMPEDANCE SPECTROSCOPY"

- Utilizes impedance converter/network analyzer AD5933 [7]
  - With help from the AD5174 digital rheostat [8]
- Allows for excitation of load by sinusoidal voltage at known frequencies
- Performs on-board Fourier transform with DSP engine
- Returns real and imaginary impedance values at known frequency

AD5933

- Impedance Converter
- Network Analyzer
- Frequency Sweep Generator
- 12 bit ADC
- DSP Engine

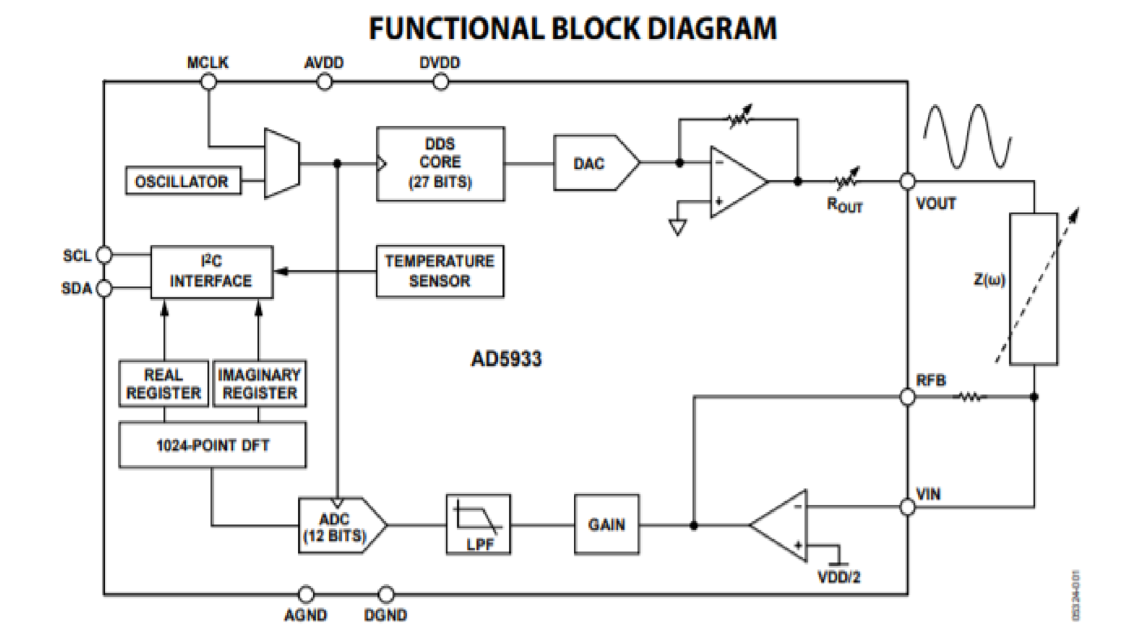


Figure 6: Functional Block Diagram of AD5933 [7]

EIS METHOD 2: "TRUE IMPEDANCE SPECTROSCOPY"

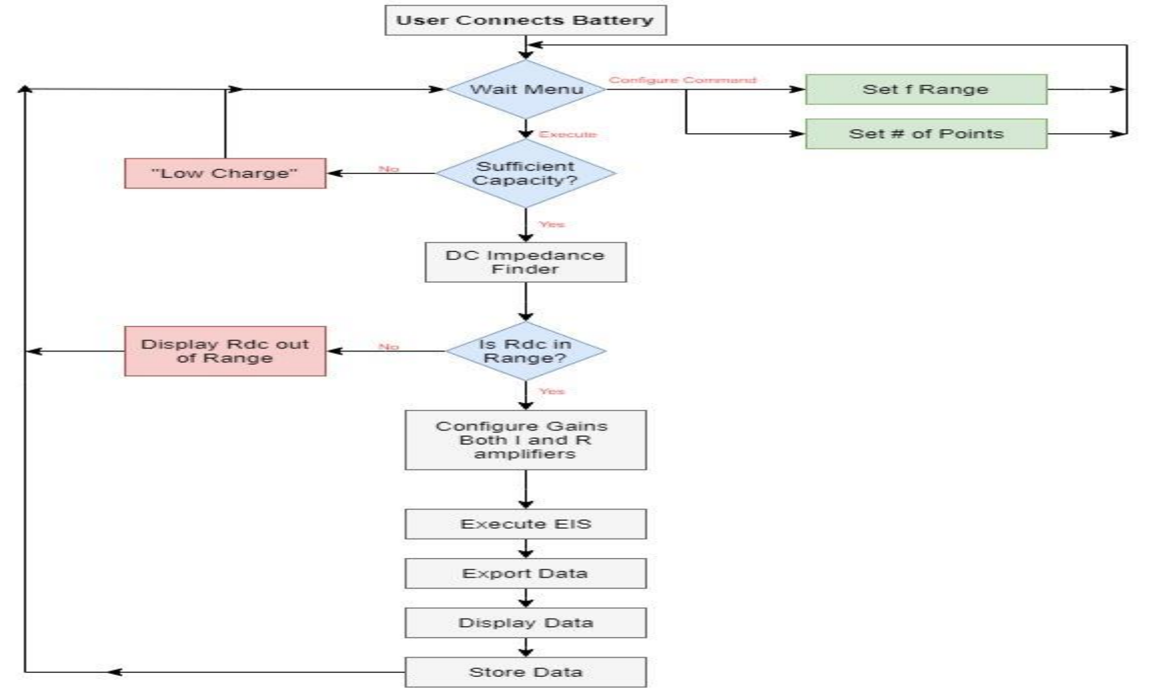
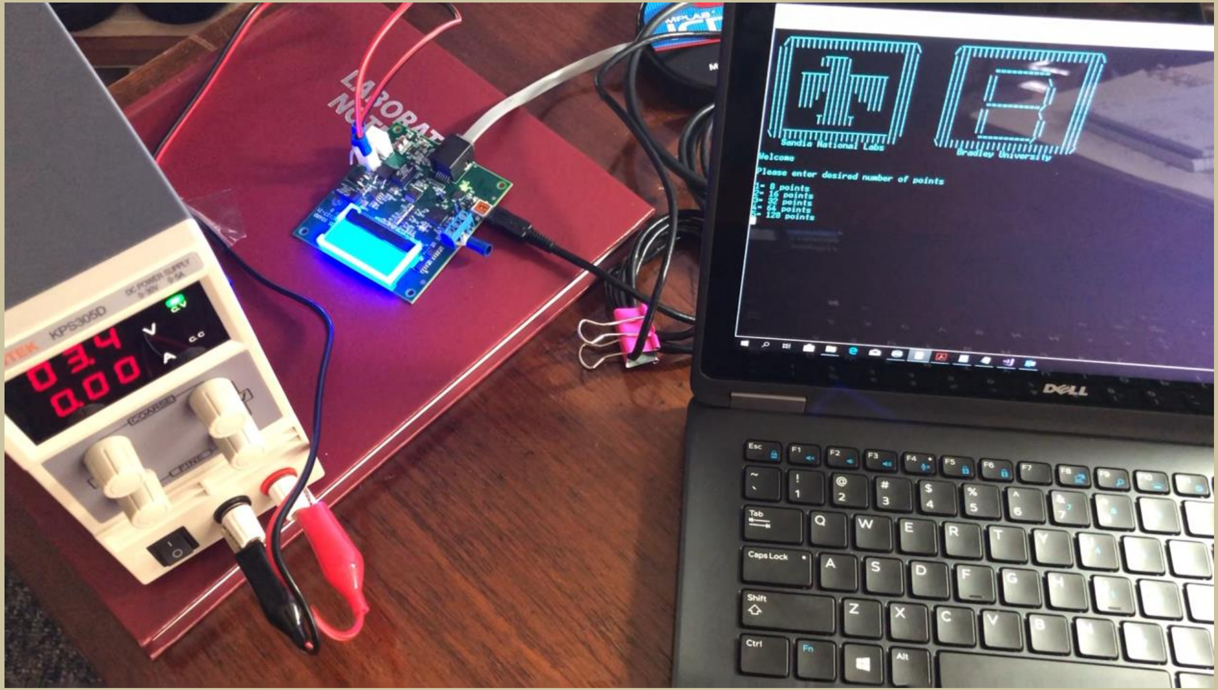


Figure 7: EIS Method 2 Software Flow Chart

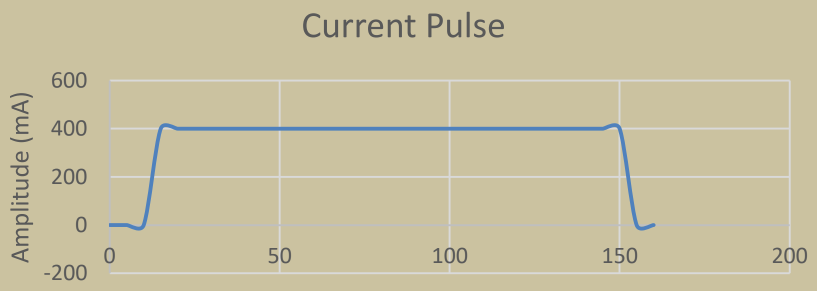
ENGINEERING EFFORTS

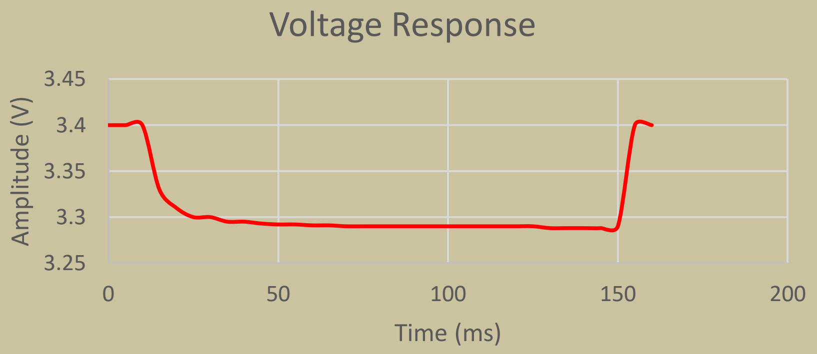
Experimental Results

EIS METHOD 1 RESULTS



EIS Method 1 Results





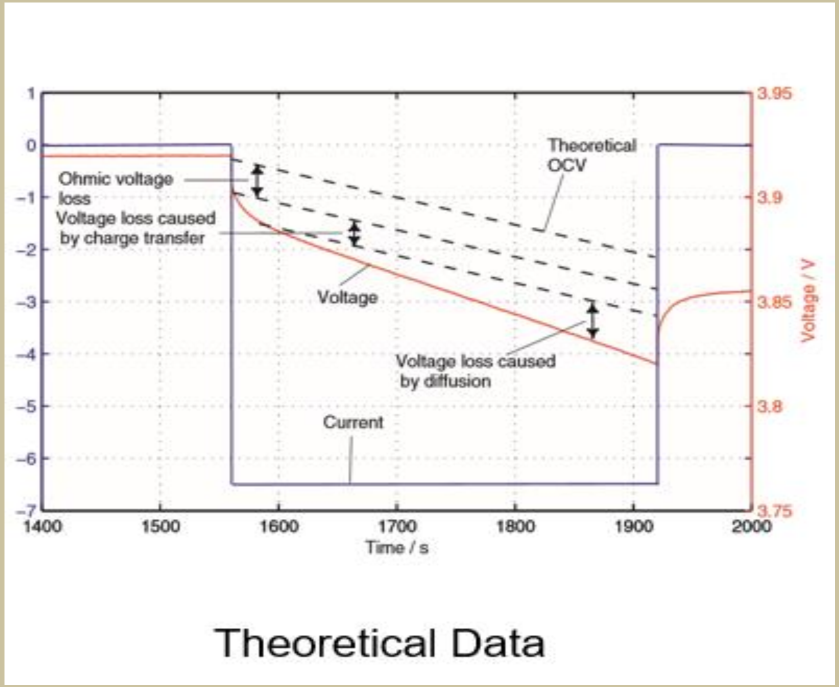
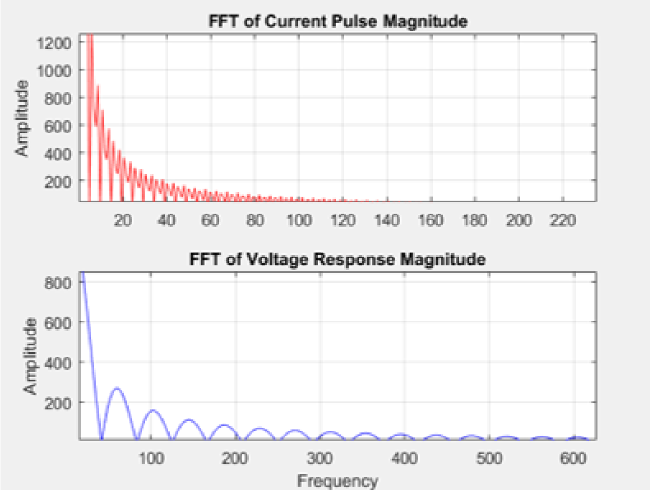


Figure 8: Experimental vs Theoretical Data [9]

EIS METHOD 1 RESULTS



$$Z(\omega) = \frac{U(\omega)}{I(\omega)} = \frac{U_0}{I_0} \cdot e^{j\phi}$$

$$Z(\omega) = |Z| \cdot e^{j\phi} = R_{real} + j \cdot R_{img}$$

Where:

- U represents the FT of voltage response
- I represents the FT of excitation current
- Z represents impedance response

Figure 9: Fourier Transform of Experimental Data [4]

FUTURE WORK

FUTURE WORK

- Further research and testing on DSP algorithms for EIS Method 1
- Second version of EIS Board needed
- Firmware for EIS Method 2 completion
- Test EIS Method 2 on power supply for proof of concept
- Test EIS Method 2 functionality on batteries
- Collect data and analyze the results

FUTURE WORK

- Create database of battery health "fingerprints" to track changes in health over time

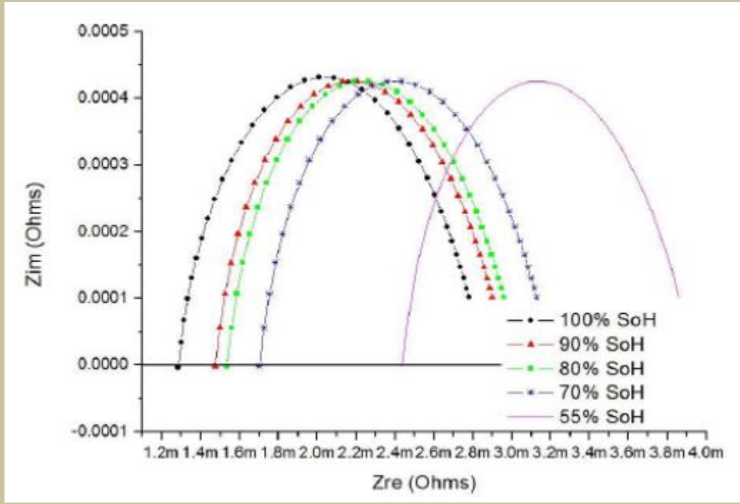


Figure 10: Estimated Nyquist Plot for Varying SOH [10]

QUESTIONS?

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