Electrochemical Impedance Spectroscopy Board

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Introduction

Problem Background

- Battery dependency and need for efficient usage are at all all-time high.
- Two most common battery capability metrics are State of Charge (SOC) and State of Health[6] (SOH)
- SOC is an established method that reports percentage of energy remaining as compared to maximum energy [4]
- SOH is currently a more complex method capable of informing user of battery condition but existing methods are associated with great deal of uncertainty
- Common implementations are also found to be too large or require external hardware

Problem Overview

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

Problem Solution

- Electrochemical Impedance Spectroscopy (EIS) determined to be most effective SOH solution
- The basic principle of EIS is to input an excitation signal to a load and observe the characteristic response of the system at many frequencies.
- An impedance spectrum is obtained by calculating the complex impedance at varying frequencies and can be used to produce frequency response and Nyquist plots

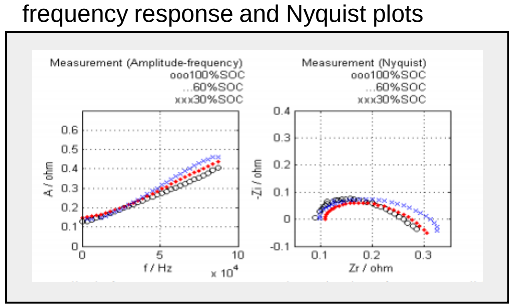

Figure 1: Frequency Response and Nyquist Plots [1]

- Battery health degradation can be tracked by observing outward shifts in the curvature over time[4]
- Proper implementation of EIS hopes to: enhance accuracy of SOC and SOH measurements, fine tune individual cell balancing, extend discharge and shorten charge cycles, and provide second life benefits[3]

EIS Method 1

Pseudo EIS by Current Pulse

- Battery is excited by a square-wave current pulse
- Voltage response then measured
- Fourier Transform taken on both waveforms
- Impedance response calculated
- Impedance data filtered by digital signal processing
- Plot Nyquist graph
- Track deviations over time and alert user of degradation or signs of impending failure

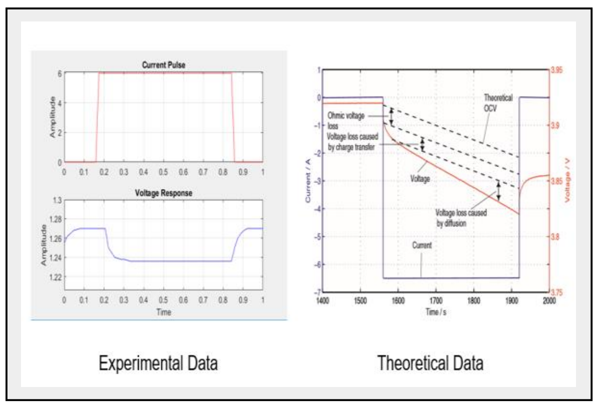

Figure 2:Experimental vs Theoretical Data [7]

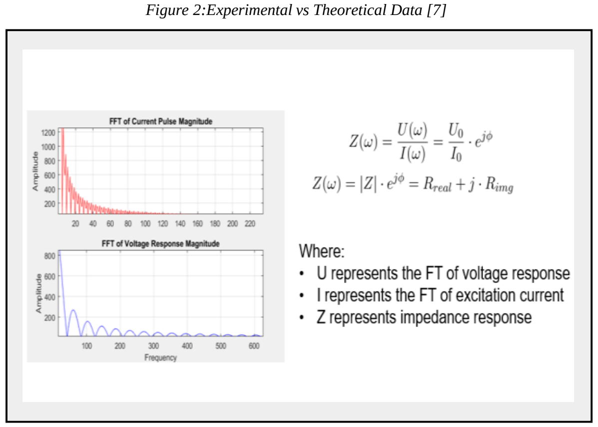

Figure 3: Experimental Data after Fourier Transform[5]

- Key Advantage: No additional hardware required
- Key Disadvantage: Very complex series of DSP algorithms needed in order to translate the impedance data into a proper Nyquist plot

EIS Method 2

True Impedance Spectroscopy

- Battery is excited by small sinusoidal voltage
- Linearity yields sinusoidal current response
- Complex impedance can then be calculated
- Sandia National Labs has developed "EIS Board" that utilizes Analog Device AD5933[2] to excite a load by a sweep of known frequencies, sampling the responses, performing DFT, and finding complex impedances all on-board and in real-time

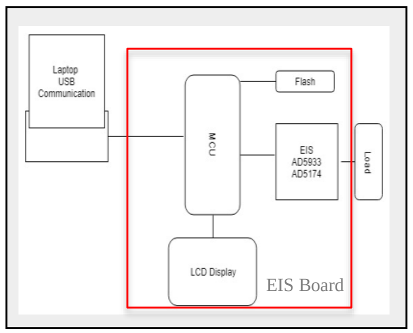

Figure 4: High Level EIS Board Block Diagram

- Key Disadvantage: Additional hardware required, but still very small and inexpensive
- Key Advantage: Having real and imaginary impedance data points at known frequencies is very valuable for easily producing Nyquist plots

Project Progress

- Implementation of EIS Method 1 function
- Firmware has been written and implemented for ADC, UART, LCD, and Timer
- Initial firmware written for SPI and I2C communication to EIS block on board

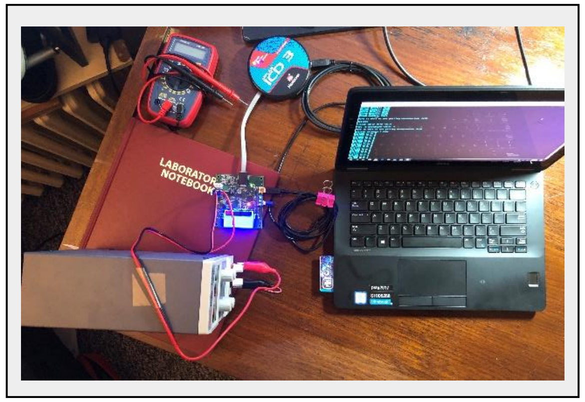

Figure 5: Laboratory Set-Up

Future Work

- A second version of the EIS Board needs to be developed in order to correct a couple hardware mistakes on the current model
- Firmware completion and implementation of I2C and SPI communication to the EIS block
- Test EIS Method 2 functionality on power supply for proof of concept
- Test EIS Method 2 functionality on batteries
- Collect data and analyze the results
- Create database of individual battery health "fingerprints" to track changes in health over time

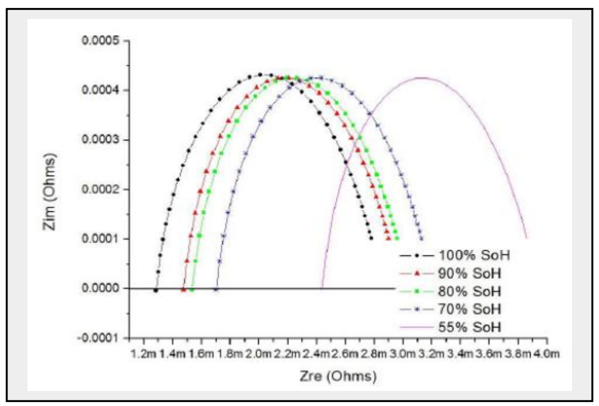

Figure 5: Estimated Nyquist Plot for Varying SOH [8]

References

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