# Testing Batteries for Optimal Robot Performance (revised)

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www.the-charge.com

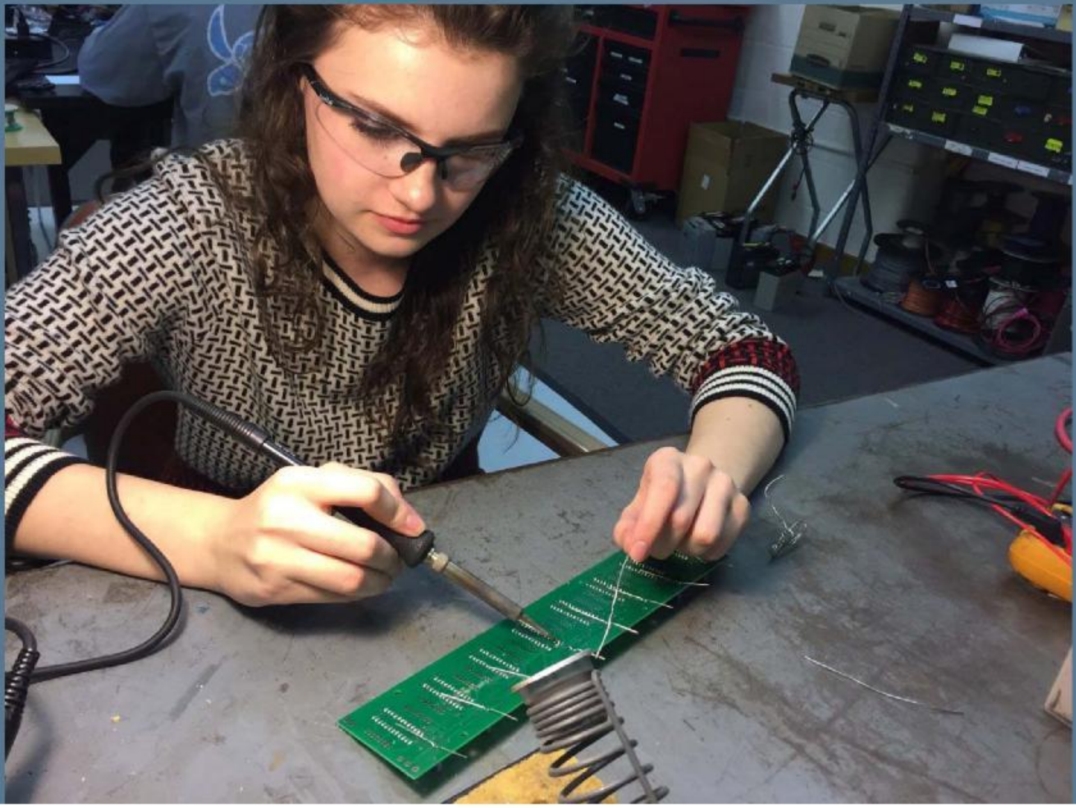
## FIRST Worlds Seminar
## April 26, 2018

# Introduction

**Presenters:**

– Isabel Chaput

- Junior at H.H. Dow High School Midland, MI
- Leader of Electrical Team: FRC-2619



# Presenters:

– **Michael Most**

- Senior at H.H. Dow High School Midland, MI
- One of Three Team Directors: FRC-2619

# Introduction

**Presenters:**

- **Robert Most**
  - Professor/Electrical Engineering Ferris State University
  - Mentor: FRC-2619

# Presentation Outline

- Goals & Background
  - Robert Most
- History and Research
  - Michael Most
- The Battery Test Kiosk Concept
  - Isabel Chaput
- Data Analysis and Findings
  - Michael Most
- Improvements and Future Goals
  - Isabel Chaput
- Conclusions / Q & A
  - Robert Most

# About Team 2619

- H.H. Dow High School, Midland Michigan USA
- Founded in 2007
- Strong STEM Background
- Great Students and Mentors

# Team 2619 Electrical Team

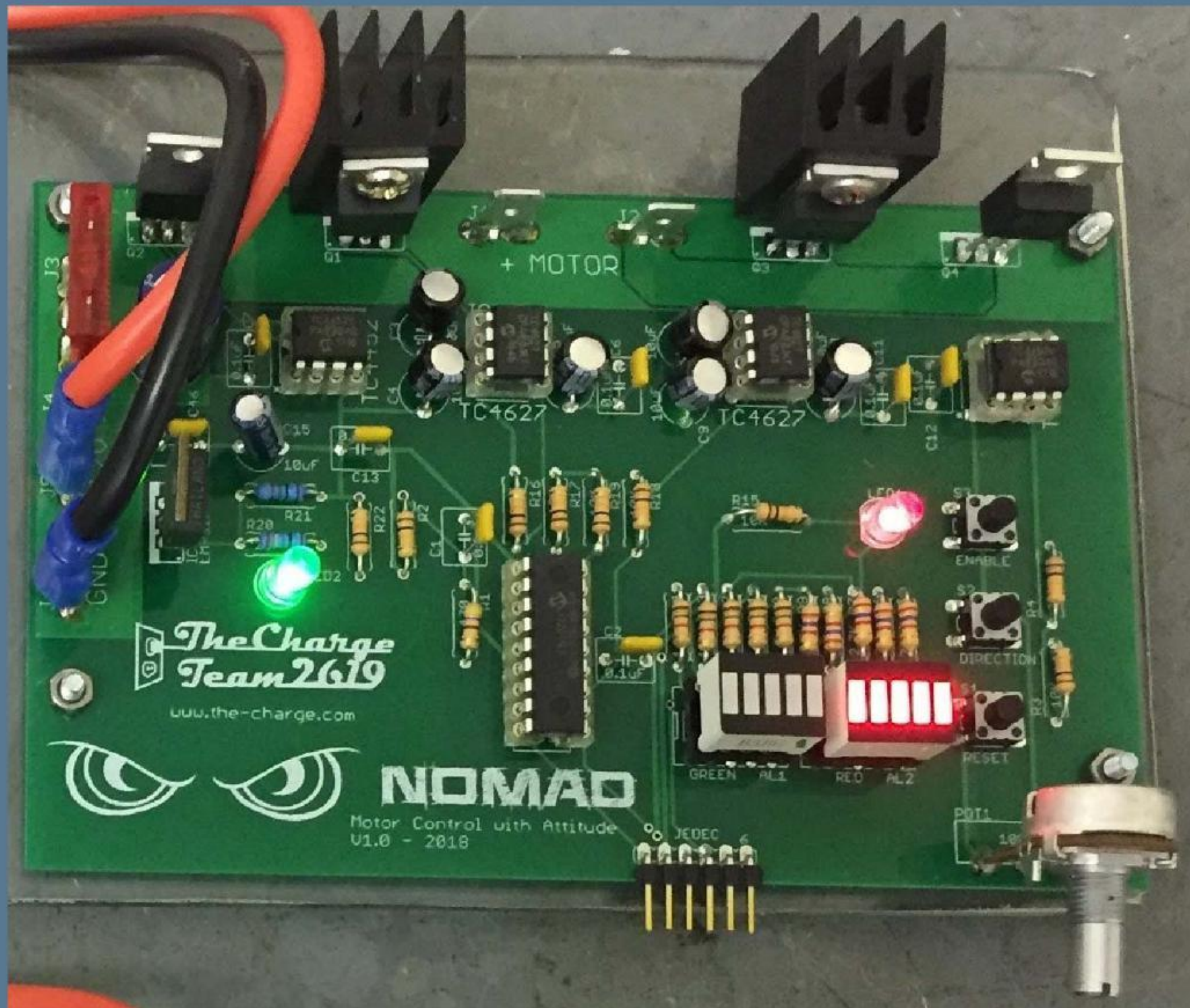
- Provide Students Opportunities in Building Electronic Projects
- Some Examples Include:
  - Star Ornament Project
  - 1300 LED Sound Meter
  - RADD Scrolling Displays
  - Nomad Motor Controller

# Animated Star



# 1300 LED Sound Meter


# Scrolling LED Signs




# Motor Controller

# Importance of Battery Performance

- Poor Robot Functionality
- 2014 “Good” Battery Failure
- Opportunity
  - Research Batteries
  - Understand Performance
- 100% != ☺

# Project Goals

- Understand Battery Performance
- Provide Students with Engineering Research
  - Explore Industry Standards
  - Learn about Battery Technologies
  - Provide a Means for Research / Data Analysis
  - Provide Experience in Technical Writing
  - Create a Workflow for Testing
- Create a Device that other FRC Teams can build
- Create a Kiosk that can be taken to FRC Competitions

# History and Research

**Questions That Need to be Addressed:**

- **What are the Industry Standards in Battery Testing?**
- **What are the Characteristics of FIRST Robotics Batteries?**
- **Can we Create a Testing Procedure to Accurately Rank our Batteries?**

# Teams Accumulate Batteries...


- But which ones are can we rely on when we go to competition??

# Battery Testing Standards

We Researched Battery Standards in Industry to Understand How Batteries are Tested:

- SAE J240 – Life Test for Automotive Storage Batteries
- SAE J537 – Automotive Storage Battery Testing
- UL 2054 – Household and Commercial Batteries
- 60254-1 – British Standard for Traction Battery Testing
- IEC 61982-3 Secondary batteries for the Propulsion of Electric Road Vehicles

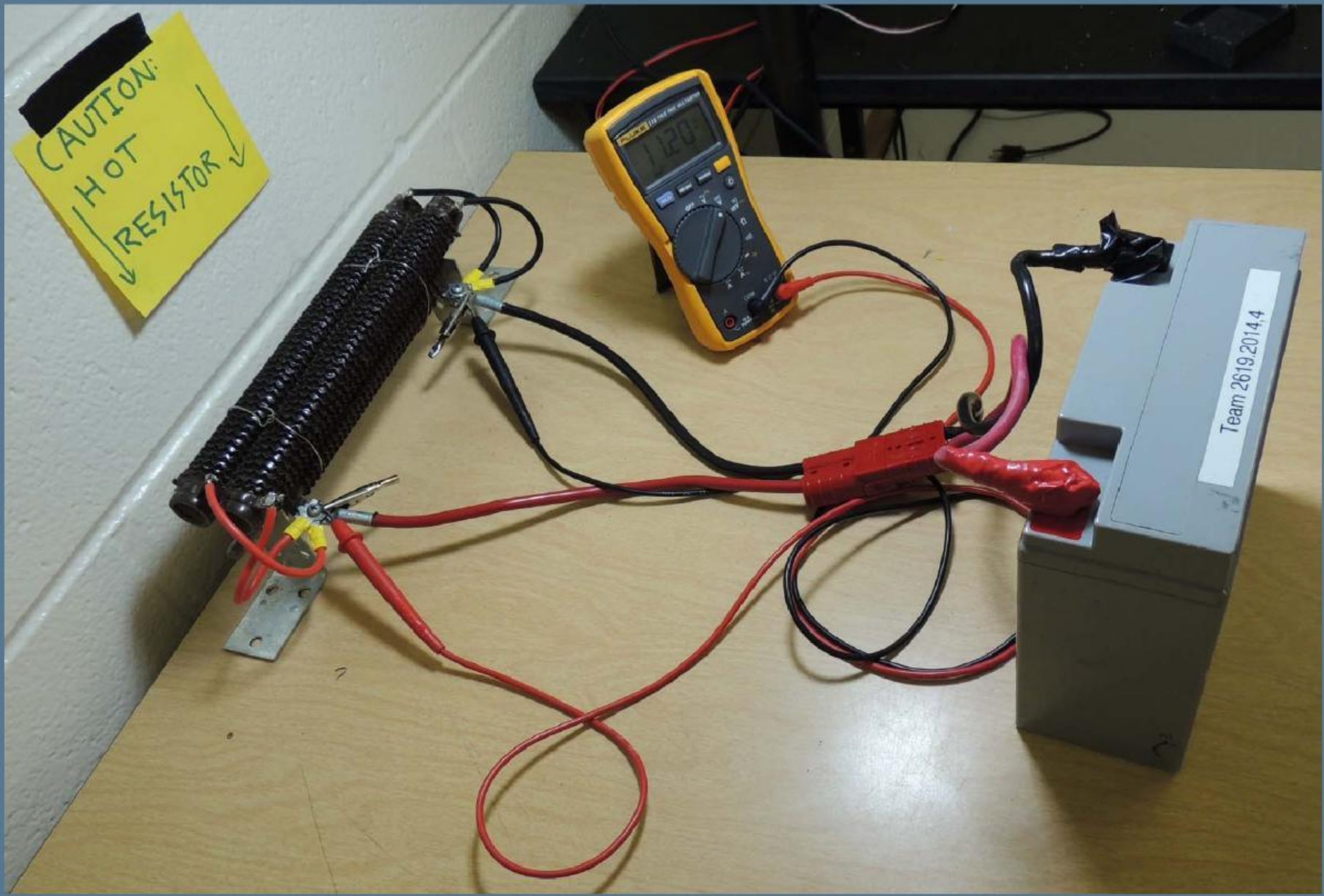
# Characteristics of FIRST Batteries Researched:


- Sealed Lead-Acid Battery Properties
- Internal Resistance Measurement
- Power Output Characteristic
- Effects of Age on Battery Performance

# General Procedure to Gauge Performance

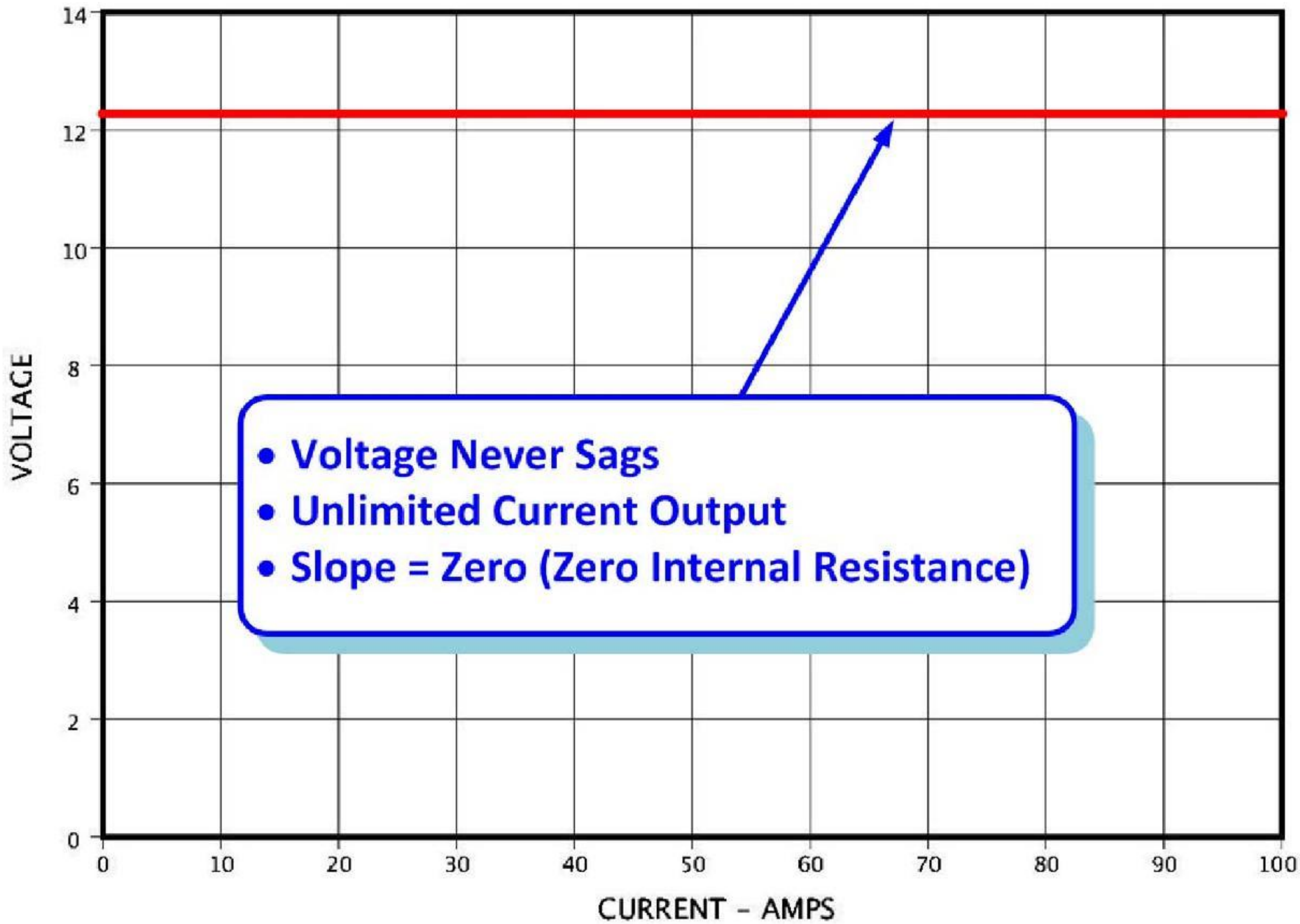
- Testing Procedure that...
  - Safe, Accurate, Consistent
  - Key Battery Parameters
  - Ranks Batteries
  - Use the Best Ones

# Past Testing Procedure Done Manually



# Student Testing a Battery Manually

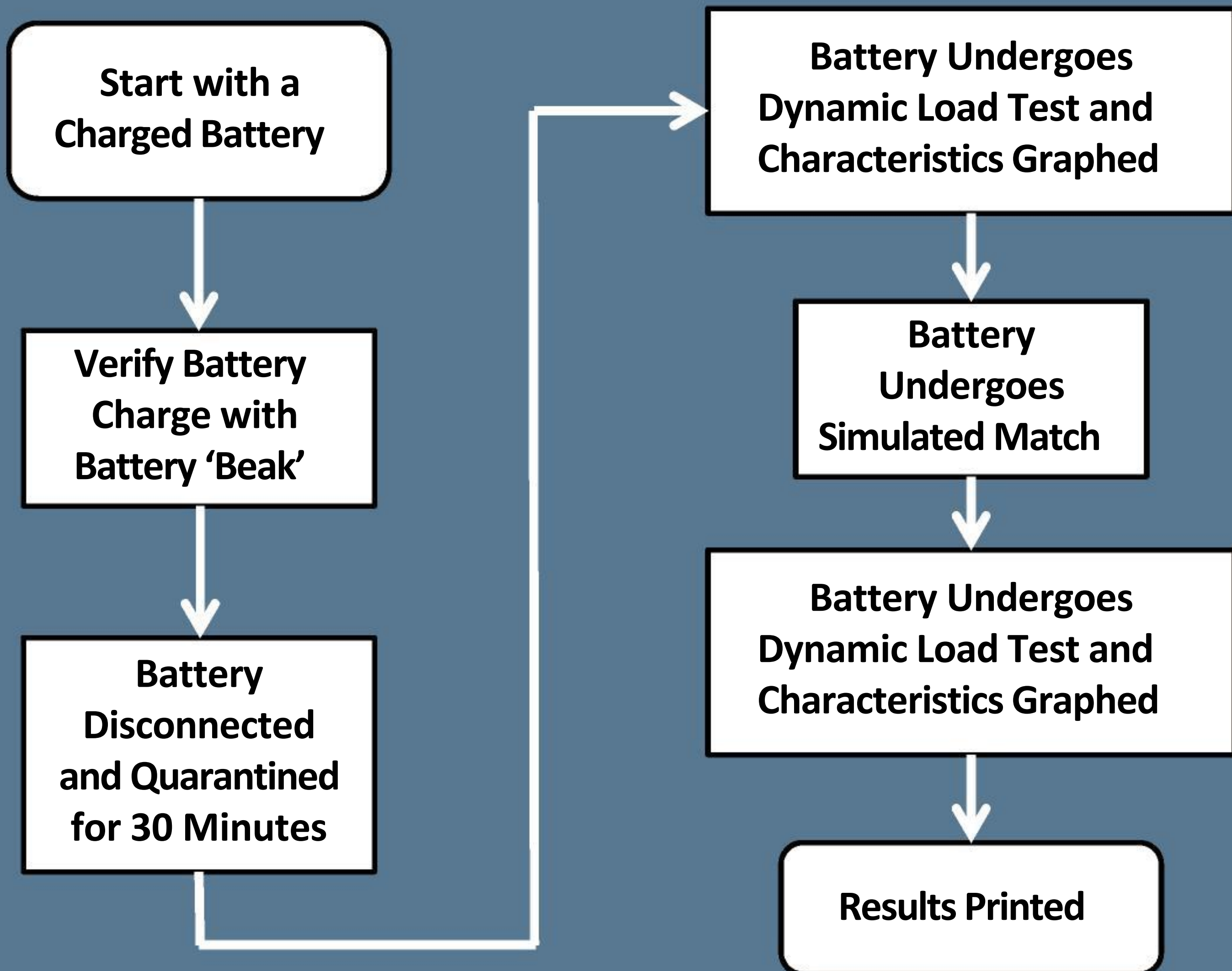
# A "Perfect Battery" Characteristic



# How Would FIRST Batteries Perform on a Characteristic Graph?

- FIRST Batteries are not "Perfect"...
- Can a Test Platform be Developed to Quickly and Accurately Create a Characteristic Graph?
- What Information Can Such a Graph Provide?

# New Battery Test Procedure Flowchart

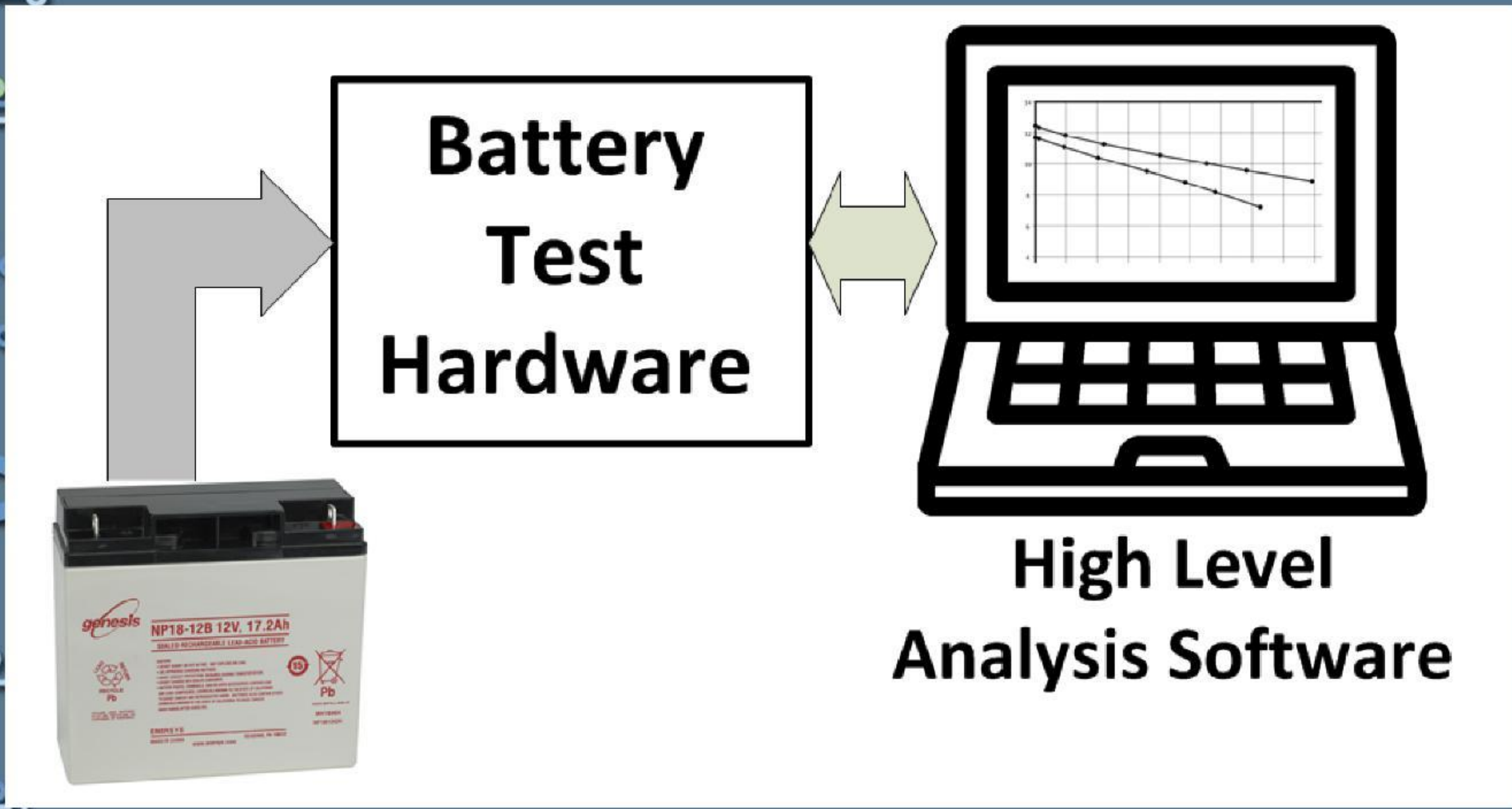


# New Testing Procedure In Action!

# The Battery Test Kiosk Concept

- Provide a Rapid Means of Battery Testing
  - Ease of Hardware & Software Use
- Automate the Test Procedure
  - Avoid Introducing Human Errors
  - Provide Consistency in Results
- Ability to Simulate a Robot Match Through Software
  - Recipe Based Testing Gathered From a Real Match

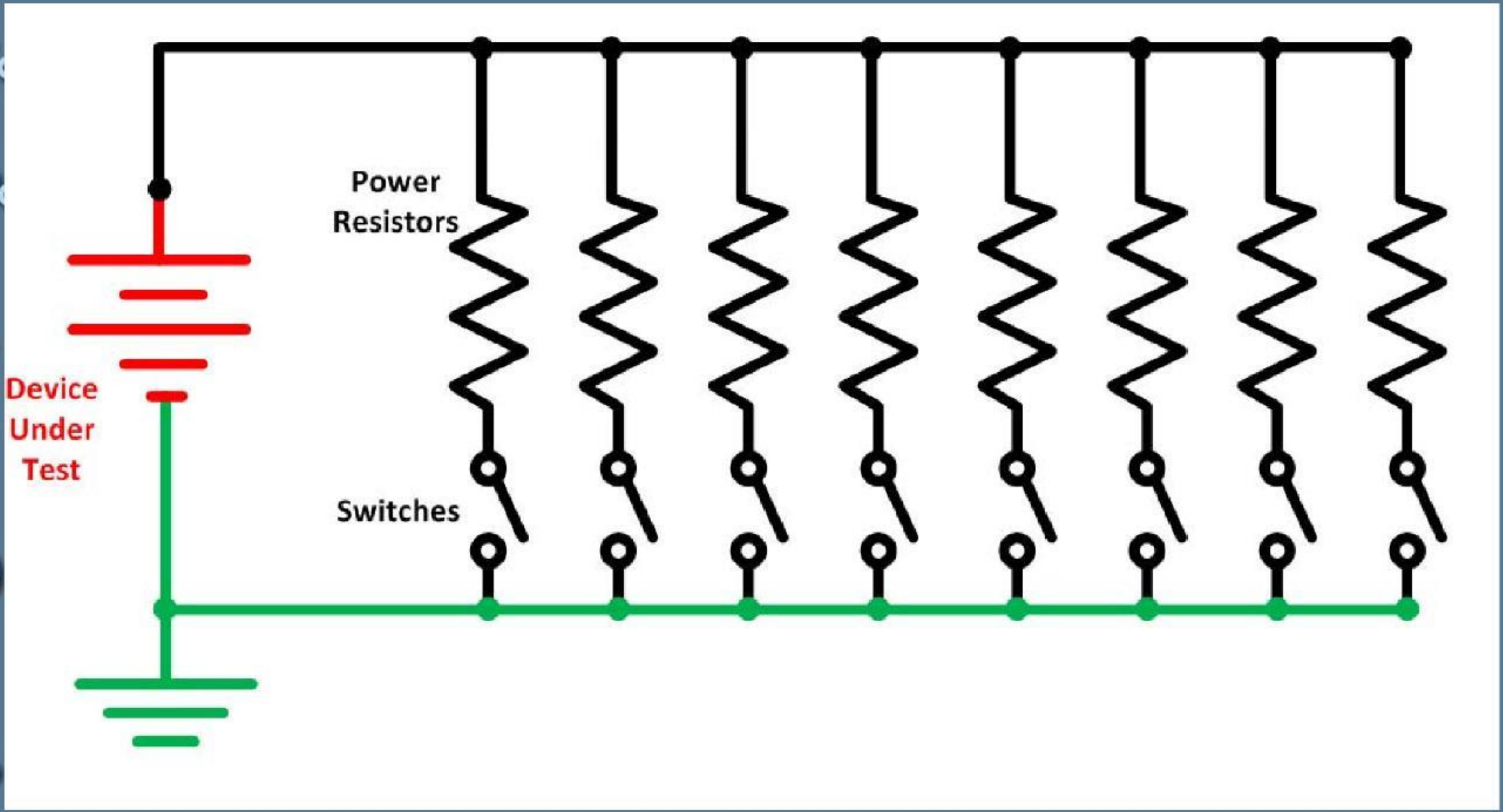
# Conceptual Block Diagram



# Battery Test Hardware

- A Bank of Power Resistors Can Vary a Load on the Battery Being Tested
- The Power Resistors are Switched On and Off as Directed by a Microcontroller
- The Microcontroller Measures the Battery Voltage and Current and Sends Data to High Level Software on the Host PC

# Varying Battery Load



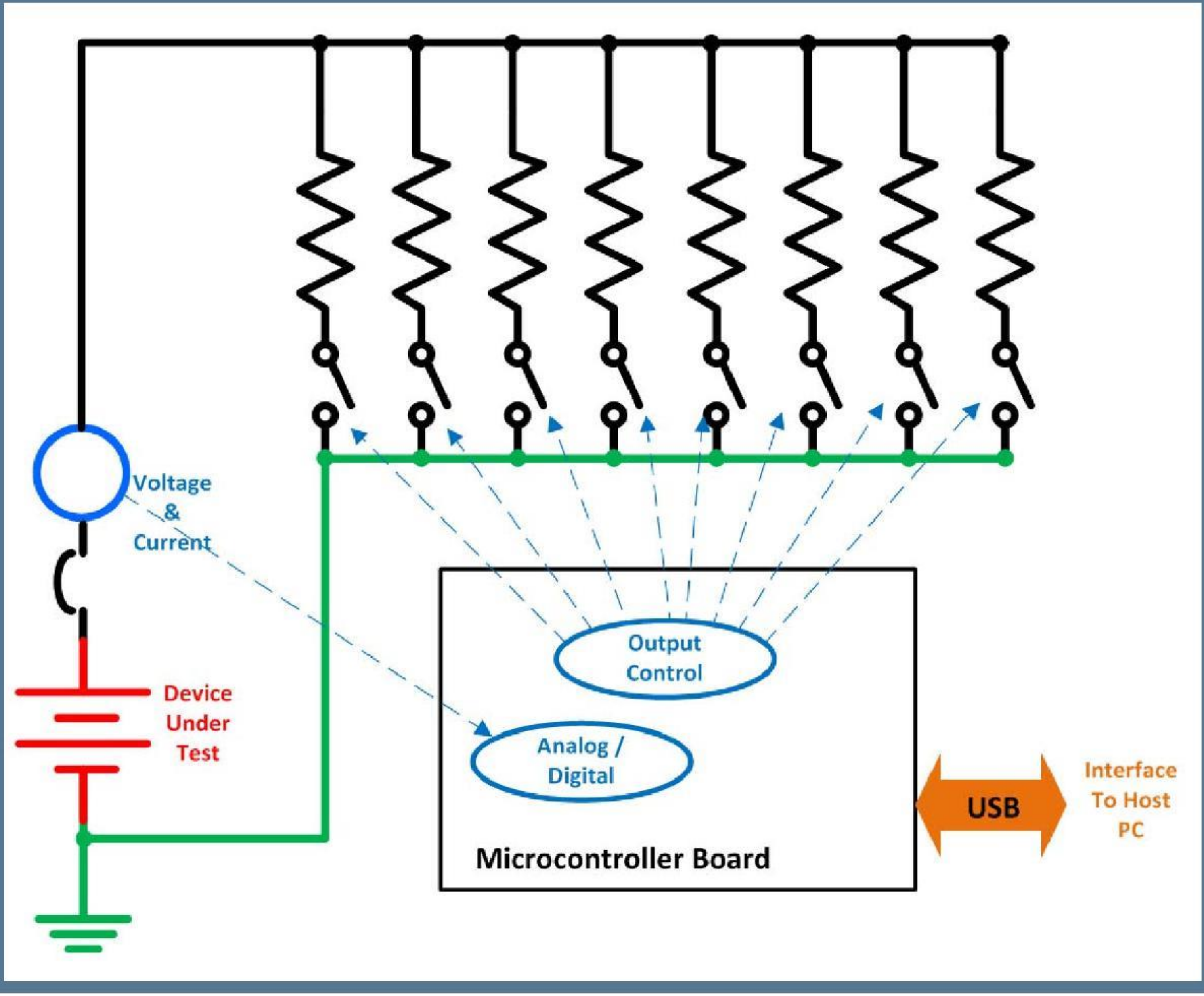

A Varying Load is Achieved by Rapidly Switching Power Resistors According to a Pre-Defined Recipe.

# Battery Test Hardware

- **The Hardware is Directed by the Host PC Software to Execute Two Functions:**

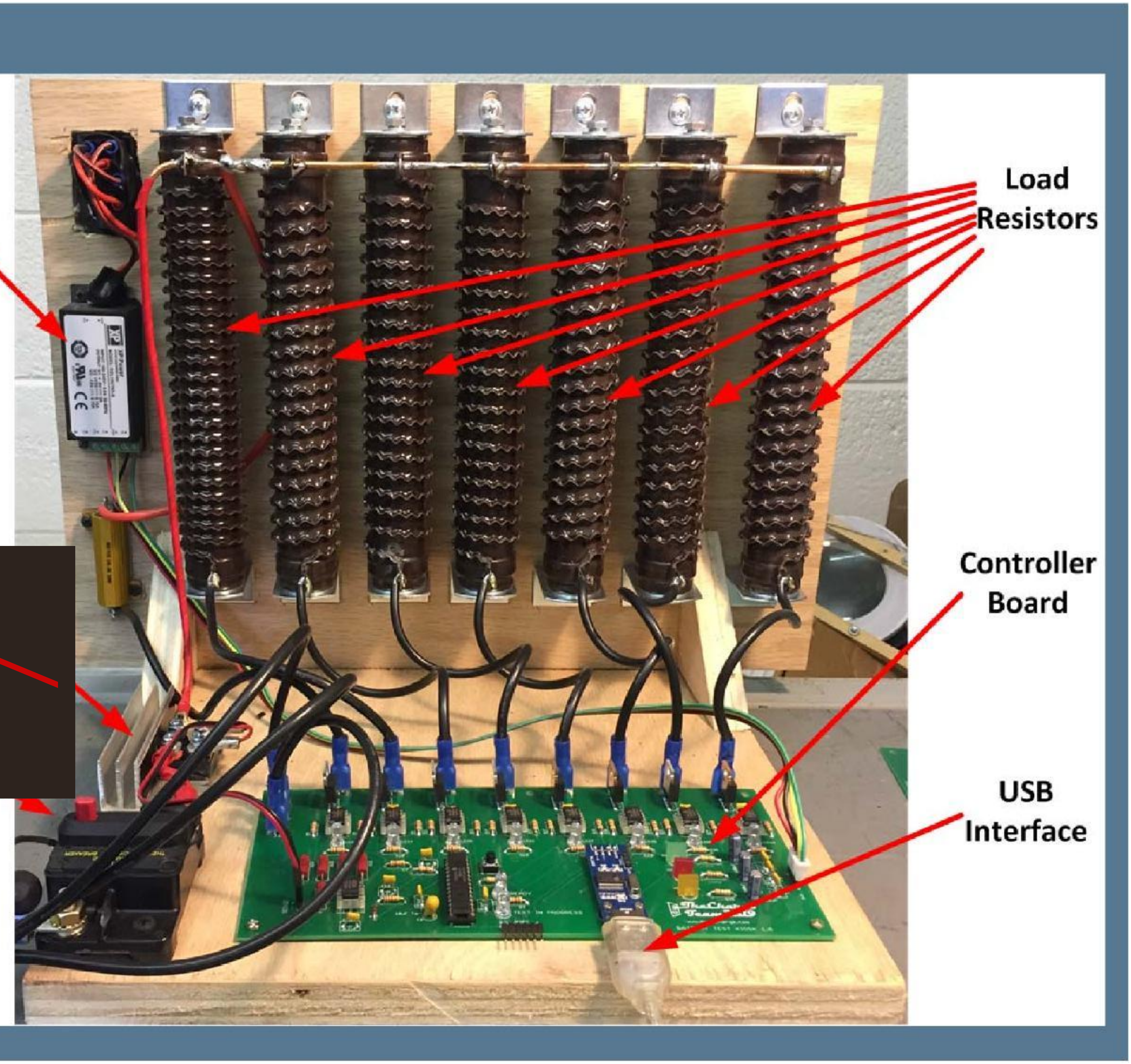
  1. **Provide a Varying Load Battery Test Profile.**
     - ➢ This Test Executes in Less than 10 Seconds
     - ➢ Loads the Battery From 0A to a Possible 125A
     - ➢ Sends Data to the Host PC for Graphing
  2. **Execute a Match Load Simulation.**
     - ➢ This Test Simulates a Predefined 2 Minute Match Complete with Autonomous and Tele-Operated Modes

# Battery Test Hardware Block Diagram

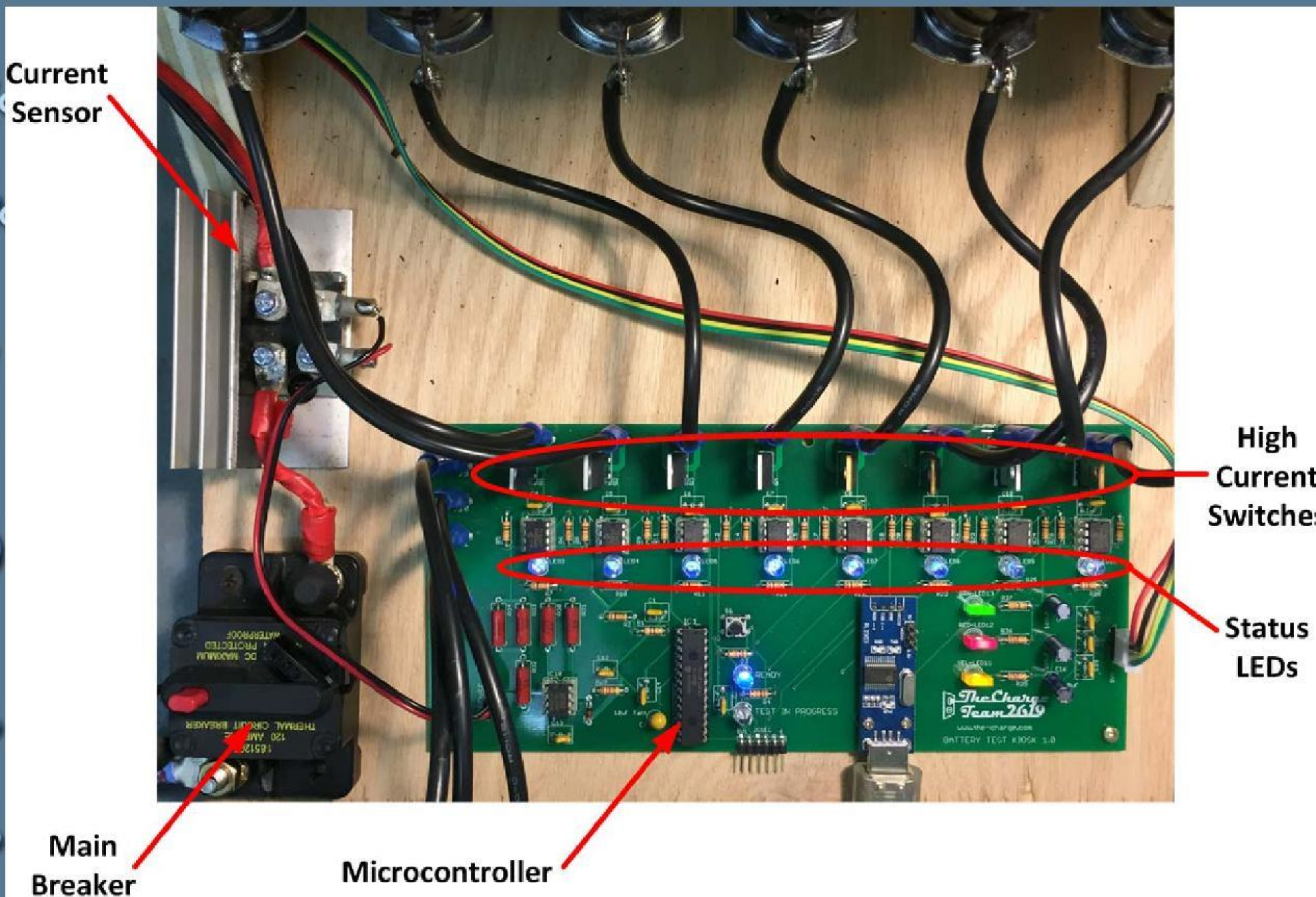


# Major Hardware Components

- 120A FIRST Robotics Main Breaker
- Eight power resistors
- Eight High Current Switches (MOSFETs)
- Current Sensor
- 12 Bit Analog to Digital Conversion
- USB Interface to Host PC

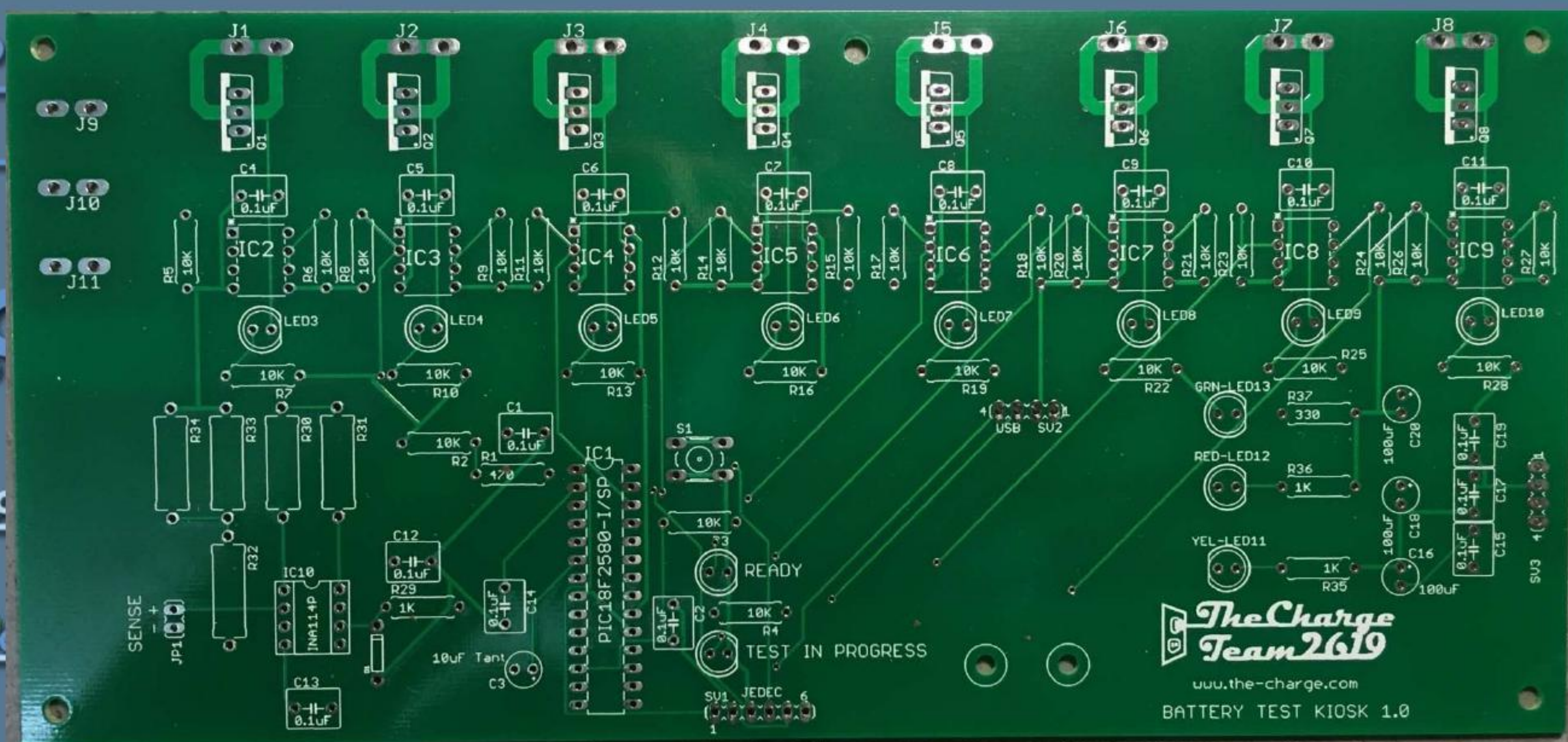

Load
Resistors
Controller
Board
USB
Interface

# Hardware Top View

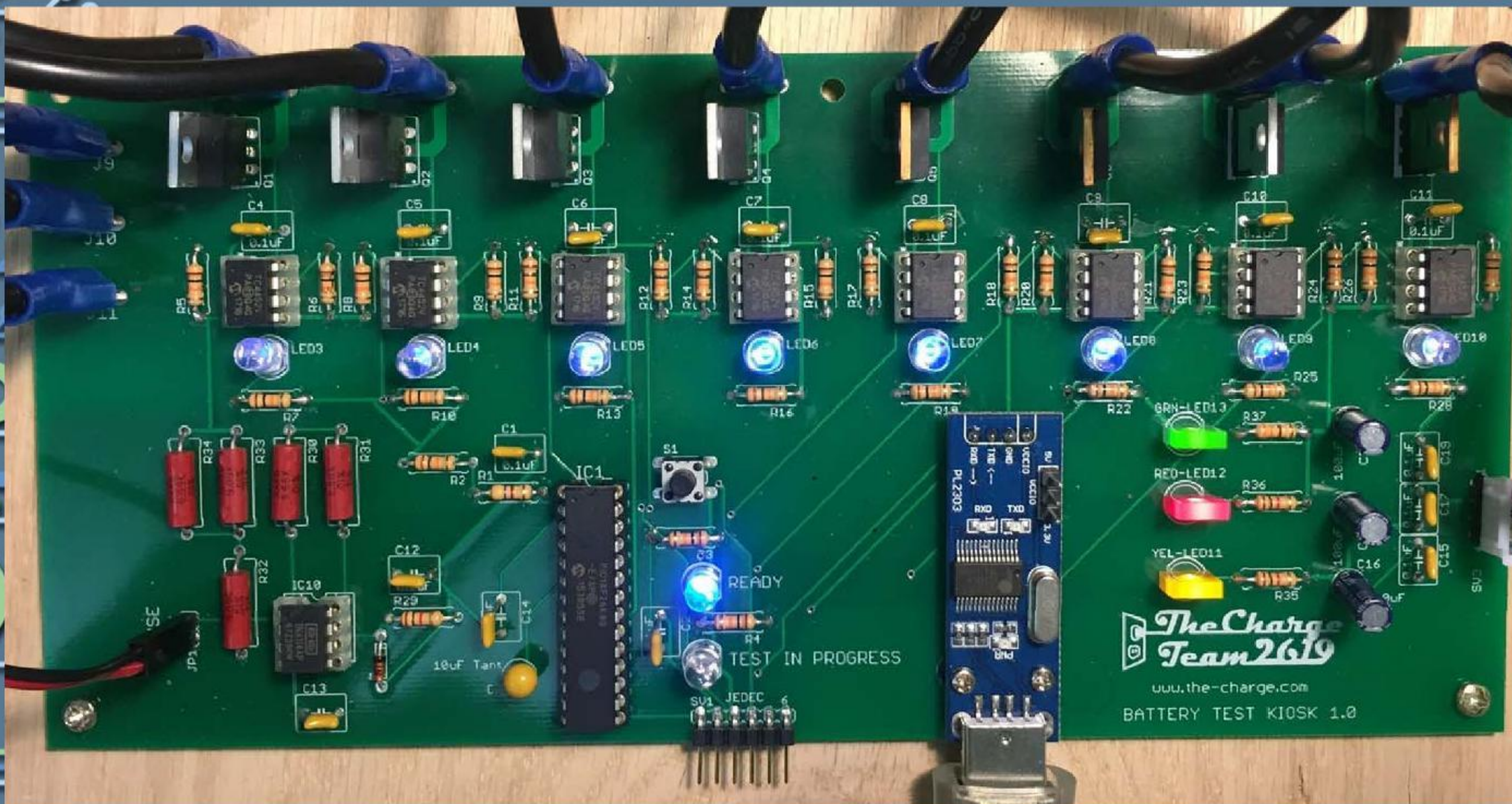


# Hardware Controller Board

- Custom Circuit Design
- Use of Standard Industry Parts



# Fully Populated Board



# Battery Test Software

- Written in Open-Source Java-Like Language called 'Processing 3.0'
- Developed in the Aesthetics and Computation Group at the MIT Media Lab in 2012

# Processing 3.0 Environment

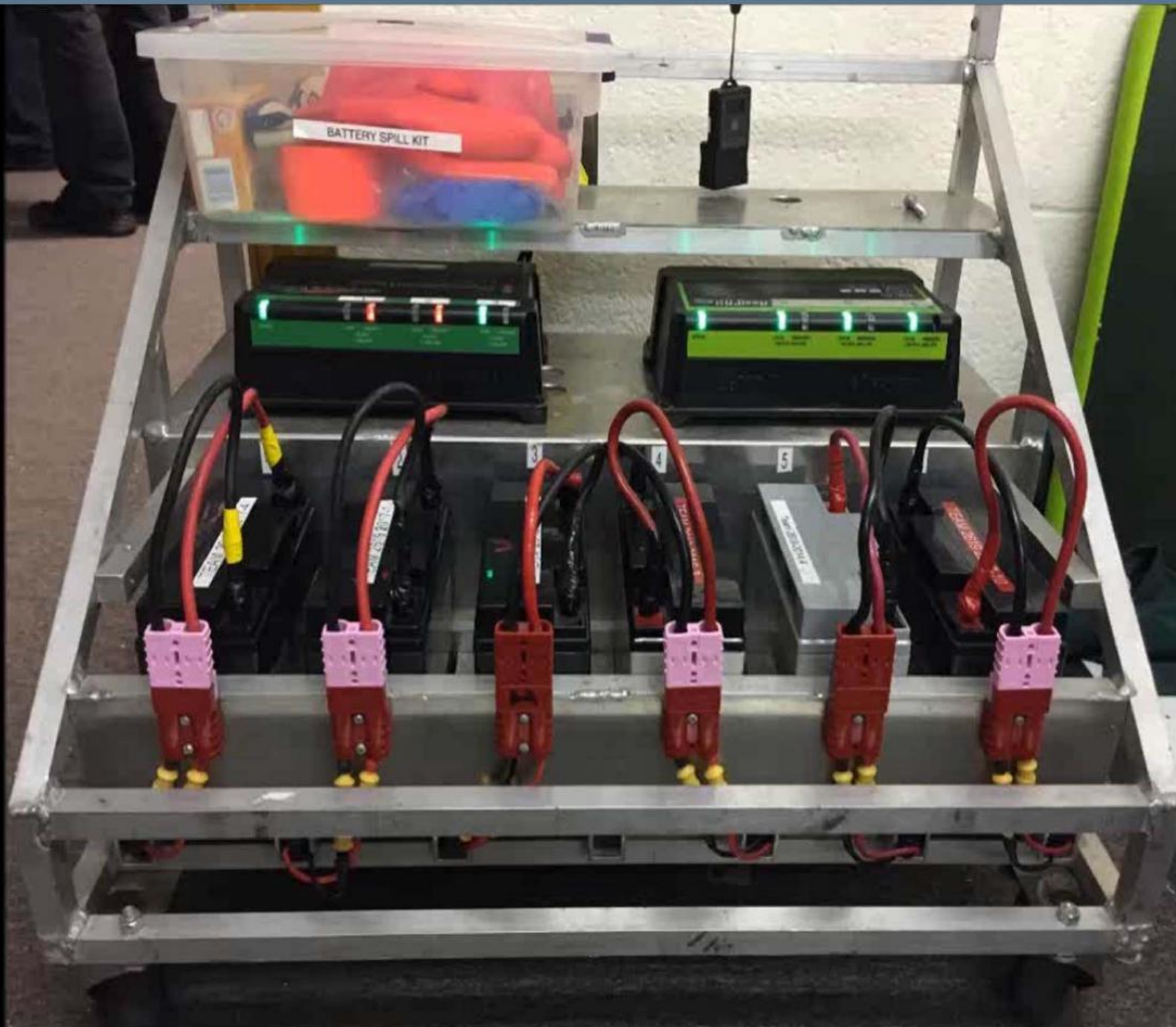
Battery_Test_Kiosk_Production_pdf | Processing 3.1.1

File Edit Sketch Debug Tools Help

Battery_Test_Kiosk_Production_pdf

```
  text("Load #5 Current:", 50,580);

  text("Load #6 Voltage:", 50,620);
  text("Load #6 Current:", 50,650);

  text("Load #7 Voltage:", 50,690);
  text("Load #7 Current:", 50,720);

  fill(0,255,0);    // color of fill for button
  stroke(127);       // color of lines below
  strokeWeight(5);   // Thickness of line around buttons below
  rect(50, 100, 200, 50, 100);    // Define Button 1 [ start horiz, start vert, width, height, radius on corners ]
  fill(0);  // Color of text to fill as defined below; 0 = black, 255 = white
  textSize(18);
  text("Click To Start Test",70, 130);    // text + X/Y coordinate of where to start - center is +30 from the rect defined above

  fill(0,255,0);     // color of fill for button
  stroke(127);       // color of lines below
  strokeWeight(5);   // Thickness of line around buttons below
  rect(50, 760, 200, 50, 100);    // Define Button 2 [ start horiz, start vert, width, height, radius on corners ]
  fill(0);  // Color of text to fill as defined below; 0 = black, 255 = white
  textSize(18);
  text("Match Simulator",76, 792);    // text + X/Y coordinate of where to start - center is +30 from the rect defined above

  fill(0,255,0);     // color of fill for button
  stroke(127);       // color of lines below
  strokeWeight(5);   // Thickness of line around buttons below
  rect(1525, 760, 200, 50, 100);    // Define Button 3 [ start horiz, start vert, width, height, radius on corners ]
  fill(0);  // Color of text to fill as defined below; 0 = black, 255 = white
  textSize(18);
  text("Print Results",1570, 792);    // text + X/Y coordinate of where to start - center is +30 from the rect defined above

  myPort = new Serial(this, "COM5", 19200); // Starts the serial communication
  myPort.bufferUntil('\n'); // Defines up to which character the data from the serial port will be read. The character '\n' or 'New Line'
}
```

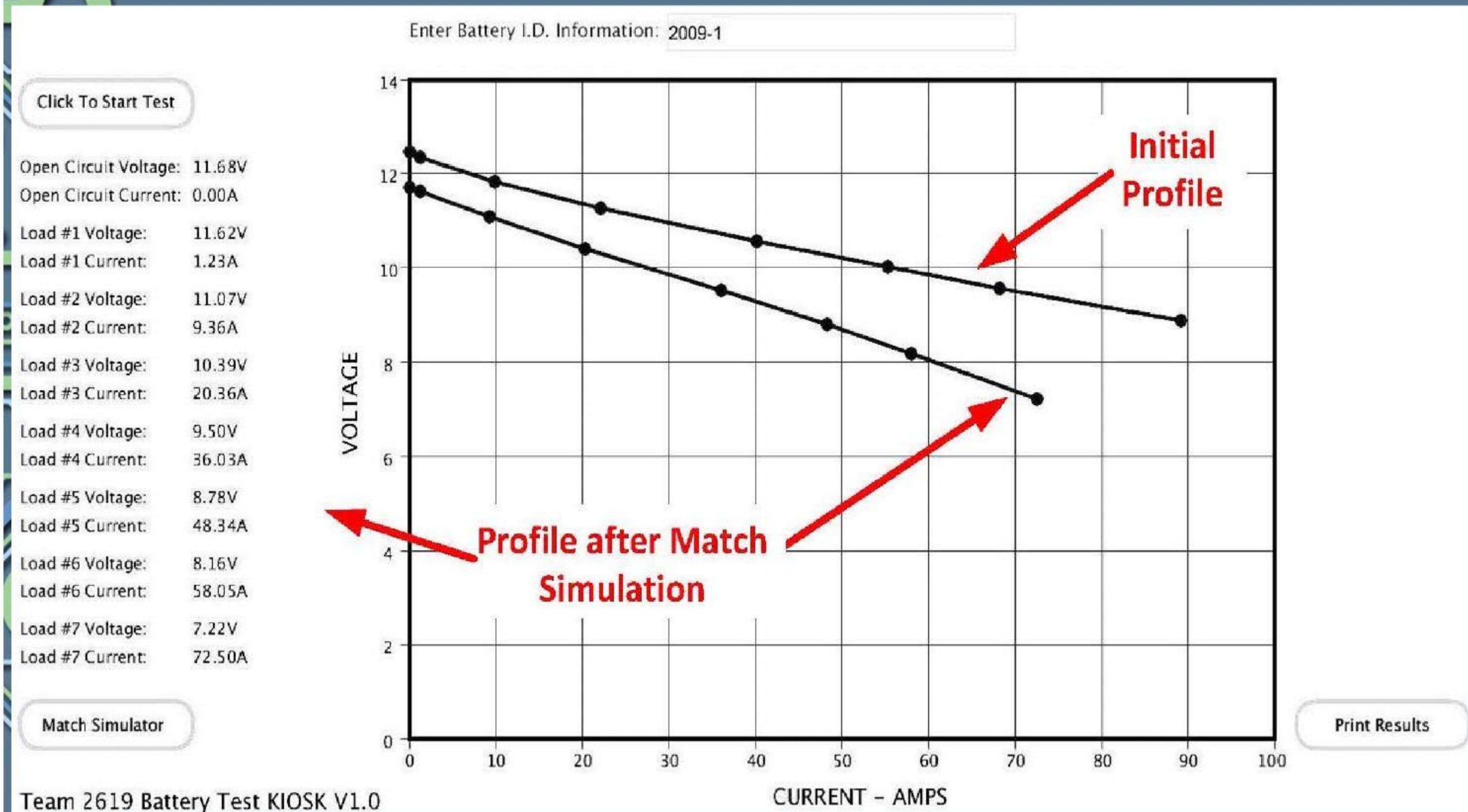
# Video of Test Procedure



# Data Output and Analysis

- Examples of Characterization Graphs
- How Data was Analyzed
- Ranking Criteria
- Data Analysis Graphs

# Typical Output After Complete Test



# How Data was Analyzed

- "Loads" of Information
  - Battery Resiliency through Disparity
  - Slope of Line is the Battery Internal Resistance
    - Slope is Sometimes Non-Linear!
  - Maximum Power Output After Simulation is Easily Determined
- Performance Over Time

# Excellent Battery Characteristic Graph

Enter Battery I.D. Information: 2017-9

Click To Start Test

Open Circuit Voltage: 12.68V
Open Circuit Current: 0.00A

Load #1 Voltage: 12.66V
Load #1 Current: 1.32A

Load #2 Voltage: 12.41V
Load #2 Current: 10.46A

Load #3 Voltage: 12.11V
Load #3 Current: 23.62A

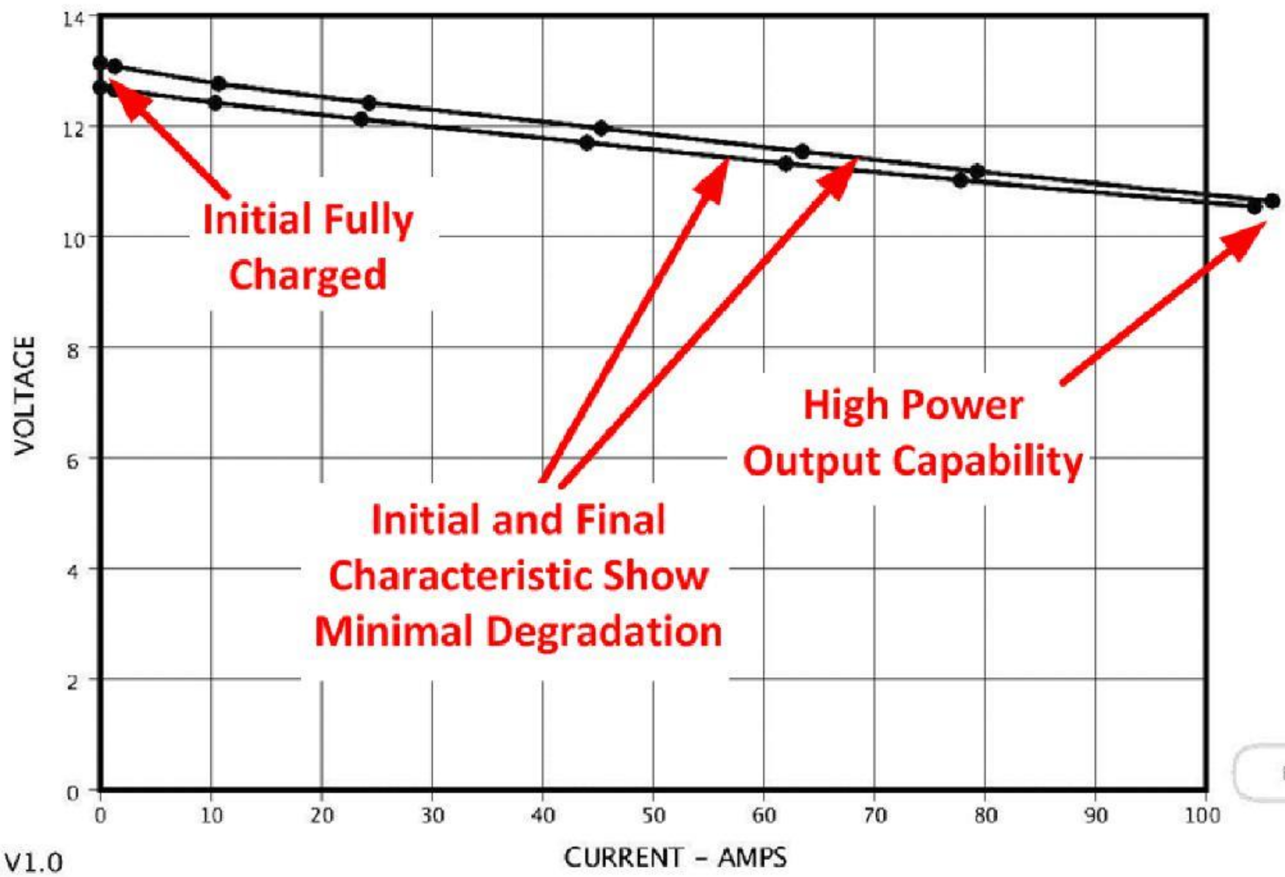
Load #4 Voltage: 11.68V
Load #4 Current: 44.07A

Load #5 Voltage: 11.32V
Load #5 Current: 62.01A

Load #6 Voltage: 11.00V
Load #6 Current: 77.84A

Load #7 Voltage: 10.52V
Load #7 Current: 104.42A

Match Simulator




Print Results

Team 2619 Battery Test KIOSK V1.0

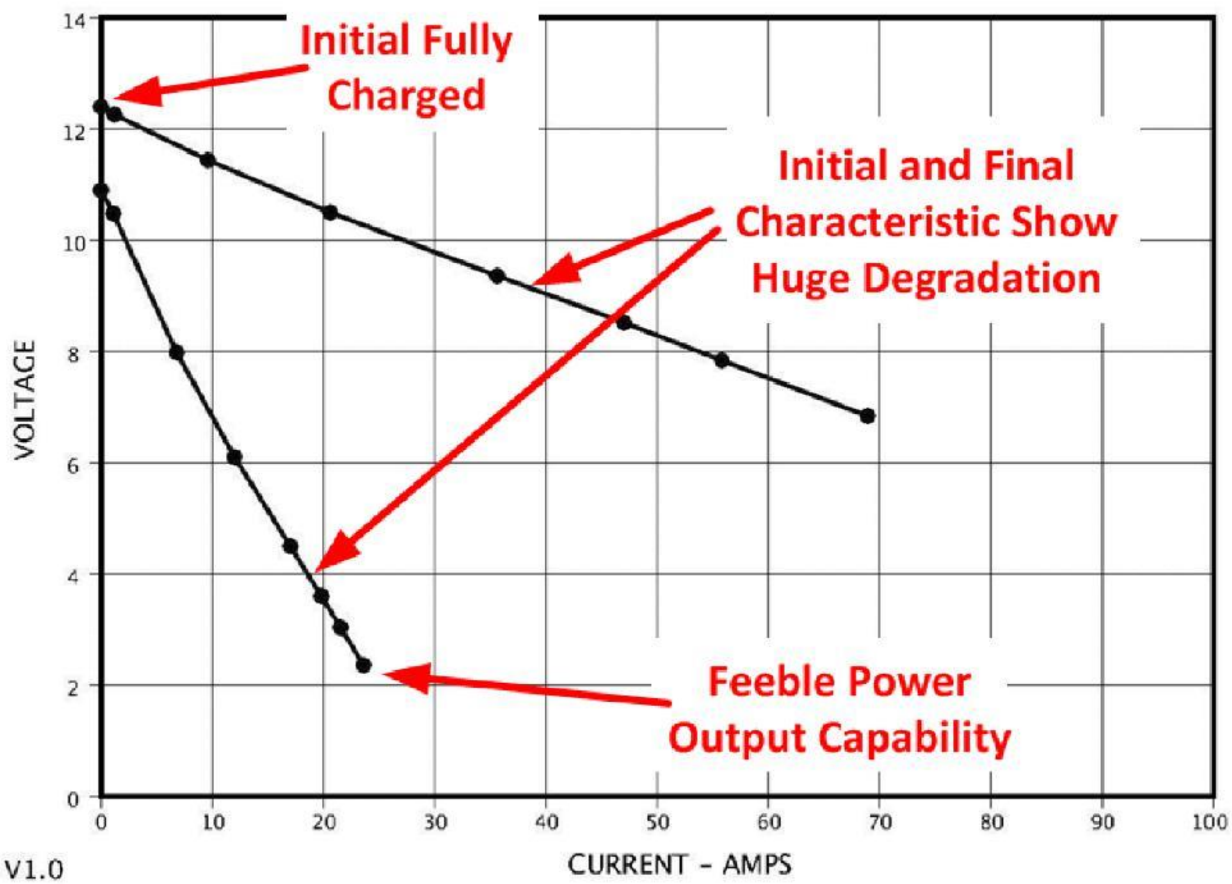
# Poor Battery Characteristic Graph

Enter Battery I.D. Information: 2010-2

Click To Start Test

| | |
|---|---|
| Open Circuit Voltage: | 10.89V |
| Open Circuit Current: | 0.00A |
| Load #1 Voltage: | 10.47V |
| Load #1 Current: | 1.13A |
| Load #2 Voltage: | 7.97V |
| Load #2 Current: | 6.82A |
| Load #3 Voltage: | 6.10V |
| Load #3 Current: | 12.03A |
| Load #4 Voltage: | 4.49V |
| Load #4 Current: | 17.09A |
| Load #5 Voltage: | 3.60V |
| Load #5 Current: | 19.88A |
| Load #6 Voltage: | 3.02V |
| Load #6 Current: | 21.58A |
| Load #7 Voltage: | 2.35V |
| Load #7 Current: | 23.69A |

Match Simulator




Print Results

Team 2619 Battery Test KIOSK V1.0

# Ranking Criteria

- Max. Power Output after Simulation
  - Resiliency Results in Higher Value
- Battery Internal Resistance
  - Slope of the *Curve*
  - Non-Sagging Voltage Results in Lower Value
- Strong Negative Correlation
  - They are Related!

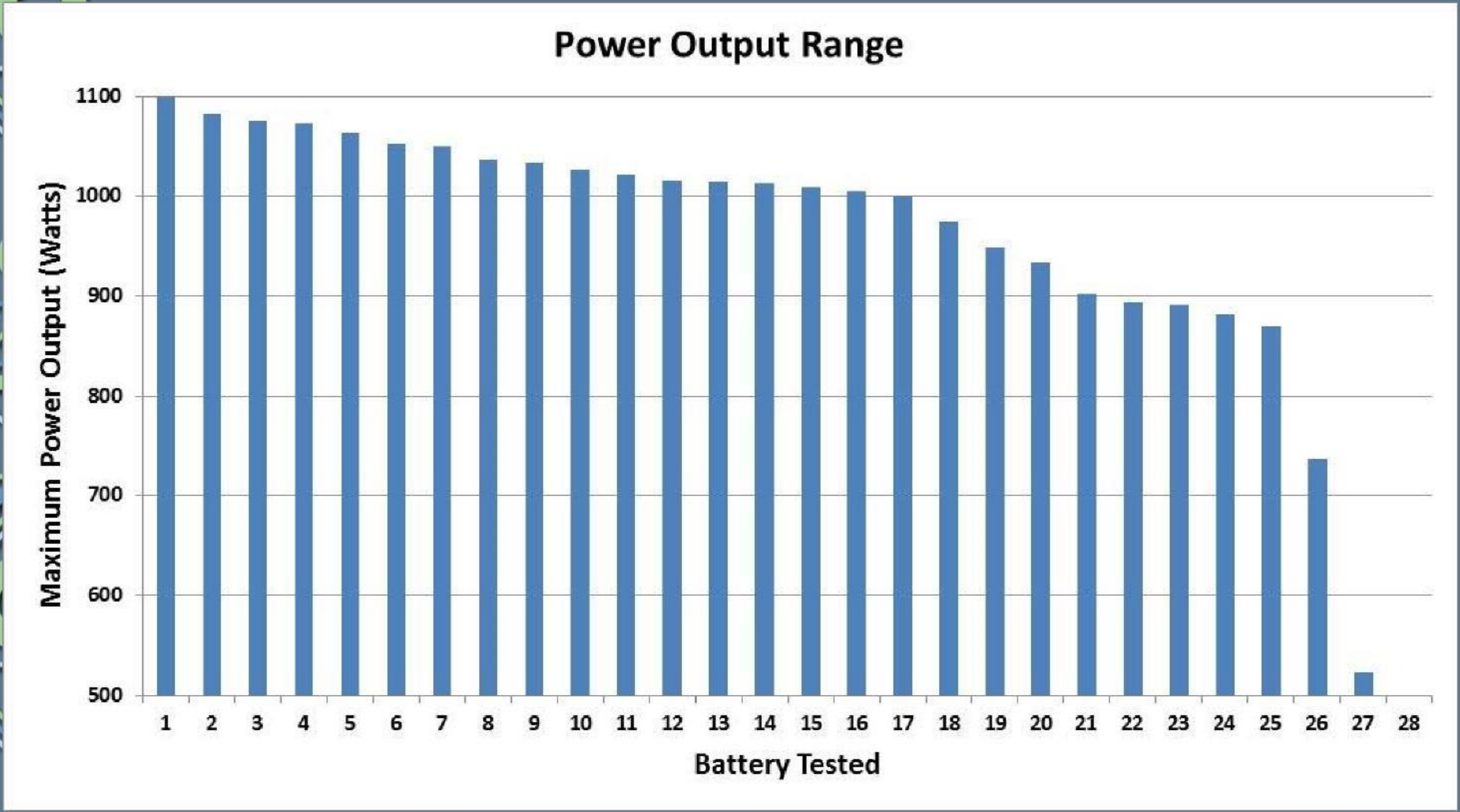
# Performance Range of Batteries Tested

- 28 Batteries Were Tested
  - Five Different Manufacturers
  - Age Range 0 – 9 Years
  - Number of Charge Cycles Unknown
- All Indicated “Fully Charged”
  - Confirmed by Hand-Held Device
- Batteries Were Ranked by Performance Criteria

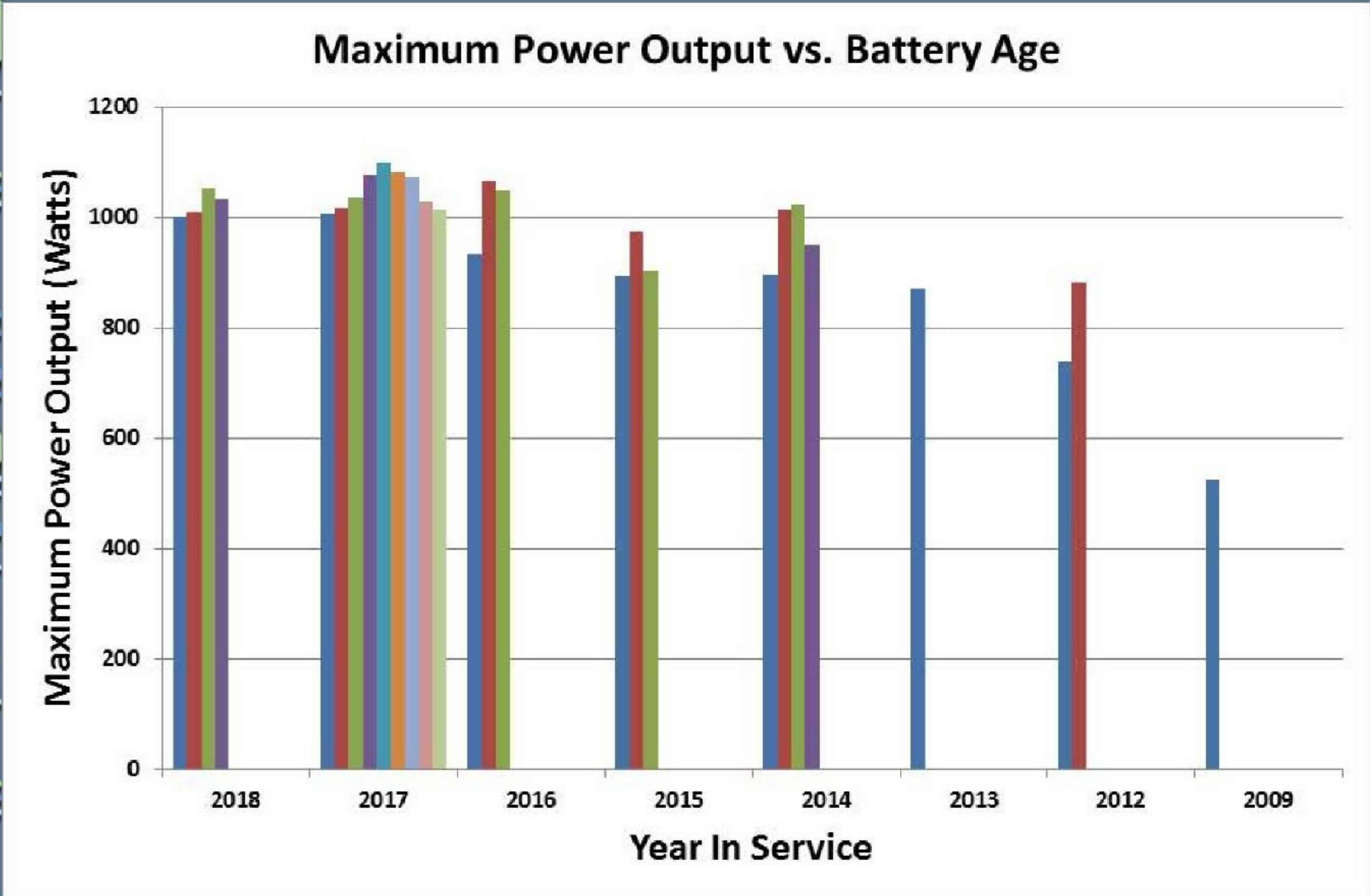
# Data Analysis Spreadsheet

| Battery ID | Year | Manufacturer | Mfg Type | Internal Res. Initial mΩ | Internal Res. Final mΩ | Internal Res. Rank | Final $I_O$ | Final $V_O$ | Final $P_O$ (Watts) | Final $P_O$ Rank | Average Rank |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 2017-10 | 2017 | Duracell DURA12-18NB | 1 | 14.86 | 14.80 | 1 | 103.76 | 10.43 | 1082.2 | 2 | 1.5 |
| 2017-9 | 2017 | Duracell DURA12-18NB | 1 | 15.62 | 15.20 | 2 | 104.42 | 10.52 | 1098.5 | 1 | 1.5 |
| 2017-7 | 2017 | Duracell DURA12-18NB | 1 | 16.19 | 15.74 | 4 | 103.32 | 10.41 | 1075.6 | 3 | 3.5 |
| 2016-2 | 2016 | Power Patrol SLA1116 | 5 | 15.23 | 15.39 | 3 | 102.91 | 10.34 | 1064.1 | 5 | 4 |
| 2018-1 | 2018 | Genesis NP18-12B | 2 | 17.47 | 17.23 | 5 | 102.31 | 10.29 | 1052.8 | 6 | 5.5 |
| 2017-3 | 2017 | Power Patrol SLA1116 | 5 | 17.95 | 18.15 | 9 | 103.35 | 10.38 | 1072.8 | 4 | 6.5 |
| 2016-3 | 2016 | Genesis NP18-12B | 2 | 17.92 | 17.90 | 7 | 102.19 | 10.27 | 1049.5 | 7 | 7 |
| 2018-2 | 2018 | KEYO KT-12180 HRT GEL | 3 | 19.94 | 18.14 | 8 | 101.40 | 10.19 | 1033.3 | 9 | 8.5 |
| 2014-2 | 2014 | MKPowered ES17-12 | 4 | 17.30 | 18.43 | 10 | 100.96 | 10.12 | 1021.7 | 11 | 10.5 |
| 2017-2 | 2017 | Power Patrol SLA1116 | 5 | 18.21 | 19.74 | 13 | 101.46 | 10.21 | 1035.9 | 8 | 10.5 |
| 2018-3 | 2018 | KEYO KT-12180 HRT GEL | 3 | 17.70 | 17.74 | 6 | 100.21 | 10.07 | 1009.1 | 15 | 10.5 |
| 2017-5 | 2017 | Genesis NP18-12B | 2 | 19.67 | 19.34 | 12 | 101.12 | 10.16 | 1027.4 | 10 | 11 |
| 2014-1 | 2014 | Genesis NP18-12B | 2 | 19.52 | 18.85 | 11 | 100.49 | 10.10 | 1014.9 | 13 | 12 |
| 2017-4 | 2017 | Power Patrol SLA1116 | 5 | 19.11 | 19.89 | 15 | 100.62 | 10.07 | 1013.2 | 14 | 14.5 |
| 2017-6 | 2017 | KEYO KT-12180 HRT | 3 | 19.77 | 21.20 | 18 | 100.62 | 10.10 | 1016.3 | 12 | 15 |
| 2017-8 | 2017 | KEYO KT-12180 HRT | 3 | 19.70 | 19.76 | 14 | 99.92 | 10.00 | 999.2 | 17 | 15.5 |
| 2017-1 | 2017 | Power Patrol SLA1116 | 5 | 19.77 | 19.97 | 16 | 100.02 | 10.05 | 1005.2 | 16 | 16 |
| 2014-3 | 2014 | MKPowered ES17-12 | 4 | 22.02 | 20.86 | 17 | 97.35 | 9.74 | 948.2 | 19 | 18 |
| 2015-1 | 2015 | Genesis NP18-12B | 2 | 22.60 | 21.53 | 20 | 98.45 | 9.89 | 973.7 | 18 | 19 |
| 2014-4 | 2014 | MKPowered ES17-12 | 4 | 22.14 | 21.28 | 19 | 94.43 | 9.47 | 894.3 | 22 | 20.5 |
| 2016-1 | 2016 | Power Patrol SLA1116 | 5 | 24.44 | 21.89 | 21 | 96.47 | 9.68 | 933.8 | 20 | 20.5 |
| 2015-3 | 2015 | Genesis NP18-12B | 2 | 23.90 | 23.53 | 22 | 94.74 | 9.52 | 901.9 | 21 | 21.5 |
| 2015-2 | 2015 | Genesis NP18-12B | 2 | 22.78 | 24.48 | 24 | 94.36 | 9.45 | 891.7 | 23 | 23.5 |
| 2013-3 | 2013 | Genesis NP18-12B | 2 | 24.38 | 24.01 | 23 | 93.23 | 9.33 | 869.8 | 25 | 24 |
| 2012-4 | 2012 | MKPowered ES17-12 | 4 | 23.35 | 26.04 | 25 | 93.74 | 9.41 | 882.1 | 24 | 24.5 |
| 2012-1 | 2012 | Genesis NP18-12B | 2 | 32.12 | 28.55 | 26 | 85.79 | 8.59 | 736.9 | 26 | 26 |
| 2009-1 | 2009 | MKPowered ES17-12 | 4 | 27.62 | 34.98 | 27 | 72.50 | 7.22 | 523.5 | 27 | 27 |
| 2010-2 | 2010 | MKPowered ES17-12 | 4 | 57.82 | 151.30 | 28 | 23.69 | 2.35 | 55.7 | 28 | 28 |

# Data Analysis Graph



# Other Interesting Outcomes



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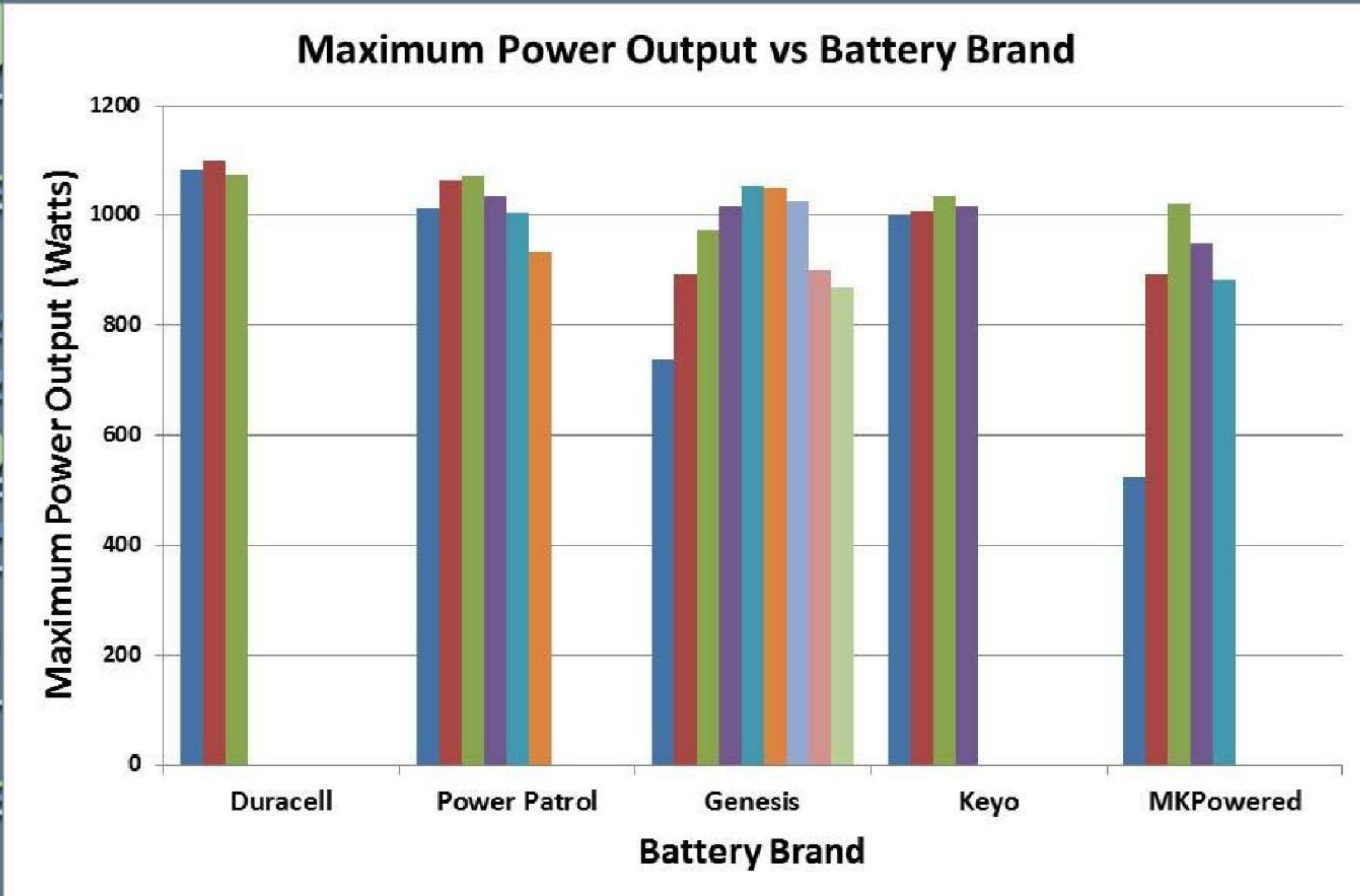


# Improvements and Future Goals

- Logging Battery Charging Cycles
- Other FIRST Teams Building the Kiosk
- Collective Database for Battery Performance

# Logging Battery Charging Cycles

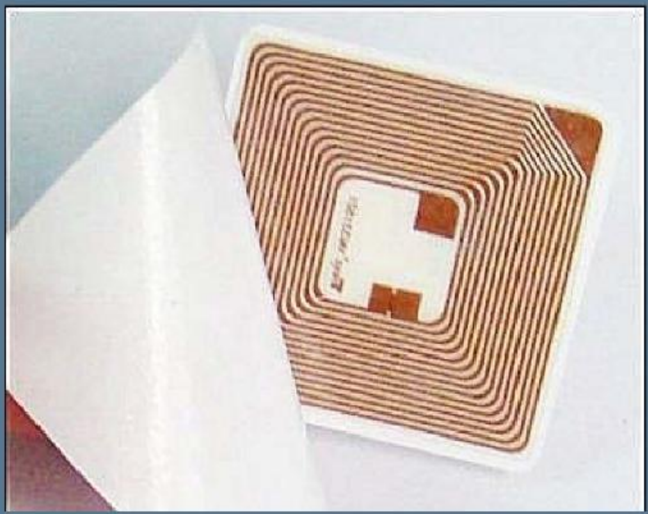
- Outfit Each Battery With an RFID Tag

- Create a Mobile Application that a Pit Crew Uses to Track Charging Cycles

- Track Charging Cycles to Correlate with Battery Performance Curves

# Mobile App Using RFID Technology

- An RFID Tag Affixed to each Battery
- An Application Could be Developed to Log the Battery Each Time it is Charged

# Smartphone RFID Reader Example

# Battery Test Kiosk Cost Breakdown

- A Total of 130 Individual Parts
- Majority of Cost in Power Resistors

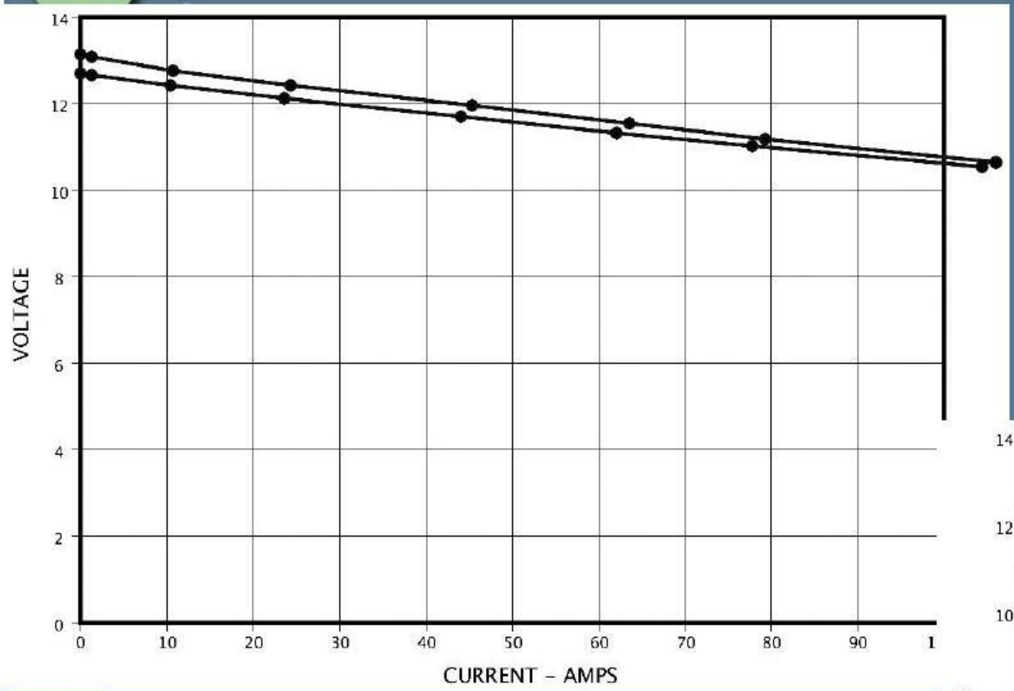
| Component / Assembly | Cost |
|---|---|
| Power Resistors | $220 |
| Power Supply Components | $65 |
| PC Board and Components | $102 |
| Software | $0 |
| Total Cost | $387 |

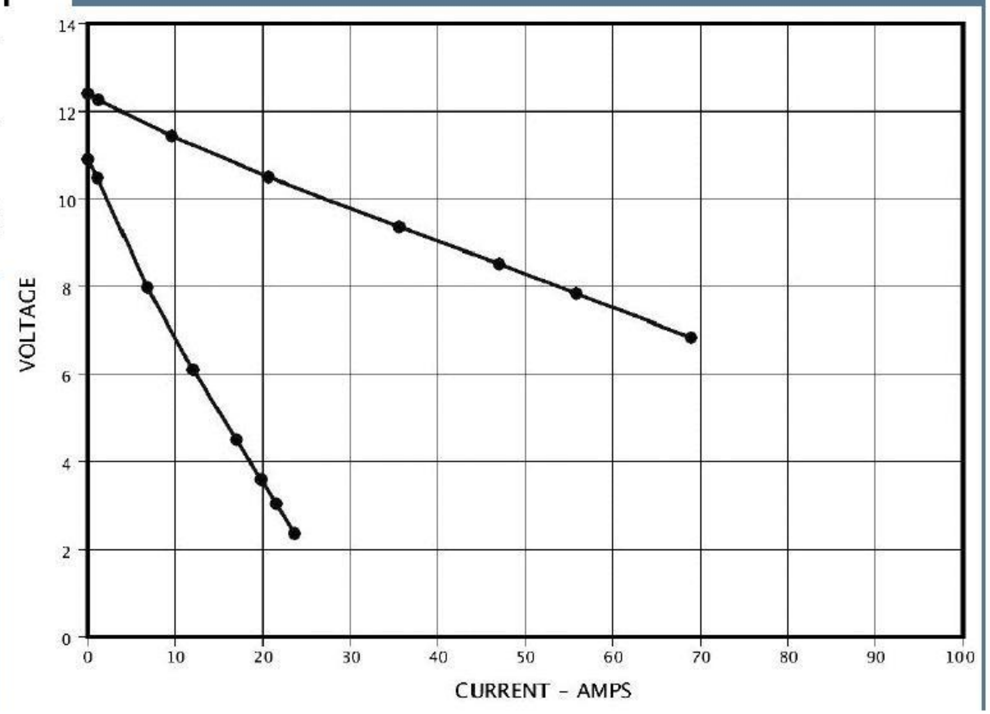
# Acknowledgements

- Amelia Mylvaganam (Student – Team 2619)
  - Data Analysis
  - Battery Testing
  - Video Demonstration Participant
- Josh Kline (Student – Team 2619)
  - Battery Testing
  - Battery Test Kiosk Cost Breakdown
- Team 2619
  - Unwavering Commitment to STEM
- FIRST Robotics
  - Opportunity to Present This Seminar

# Conclusions / Q & A

- **A 2-D Line Graph Characterization Curve Provides Insight in Battery Performance.**



# Conclusions / Q & A

- **A Match Simulator Allows a Battery to be Tested Without A Robot!**
- **Data Can be Stored and Shared.**
- **More Information in Our Battery Report:**
  - **Download pdf at www.the-charge.com**

# Questions?

DOW HIGH'S

THE CHARGE

FIRST ROBOTICS TEAM FRC #2619

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