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## Revision History

| Date       | Author     | Notes  |
|------------|------------|--|
| 10/30/2025 | J. Leonard | Initial revision   |
| 12/21/2025 | J. Leonard | Updated home screen; added 'Initial Setup' and 'Battery Manufacturer Selection' sections |
| 2/27/2026  | J. Leonard | Added CAN message definitions; added RoboRIO web interface description                   |

## Glossary

|     |  |
|-----|--|
| BFG | Battery Fuel Gauge   |
| CAN | Controller Area Network  |
| DLC | Data Length Code; The number of data bytes present in CAN message (0-8)  |
| DOD | Depth of Discharge; Charge (Coulombs or Amp-hours) and Energy (Joules or Watt-hours) extracted from a battery since it was fully charged. This quantity increases as the battery is discharged. Negative values indicate more charge/energy was put into the battery while charging than was extracted during discharge. |
| PbA | Lead-Acid  |
| SOC | State of Charge  |
| SOH | State of Health; Ratio of the current battery capacity to the capacity of a new battery  |

## Introduction

The BFG (Battery Fuel Gauge) is a simple and effective way for FRC teams to manage their collection of lead-acid (PbA) batteries. The BFG not only tracks battery state of charge, but also the health of the battery. It monitors discharge current, current spikes, voltage dips, depth of discharge and more to estimate the overall health of the battery. Since the BFG is always connected, it knows how hard each battery was used, how it was cared for, and can compile all that data into a simple health metric that you can instantly view from the onboard OLED display.

The BFG draws ultralow standby current and is designed to be left connected to a battery all season for the life of the battery. When the battery is worn out, the BFG may be reset and moved to a new battery.

The onboard OLED display turns off when the battery is inactive (neither charging or discharging). The display will turn on anytime electrical current is measured, CAN traffic is detected, or after the 'Wake' button is pressed. Pressing the 'Wake' button again will cycle the display through various pages



## Initial Setup

Each BFG includes a 6-inch CAN (Controller Area Network) pigtail. A CAN connection is not required for day-to-day operation, but it is required for firmware updates, resetting BFG battery statistics (when connected to a different battery), and monitoring battery health statistics from the RoboRIO.

The BFG is intended to be semi-permanently connected to a battery using the pre-crimped 90-degree lugs. Most new batteries include bolts, screws, and nuts. The BFG battery lugs are sized for #10 screws. Ensure the battery terminals and BFG lugs are electrically insulated. Often the best way to do this is by using heat shrink over the terminal/lug after the two are securely screwed together.

**Optional:** Remove the protective plastic film over the OLED display on the BFG connector body.

When shipped, the BFG expects to be connected to a new 18Ah battery. The battery capacity and state of health are preset full/100%. However, the BFG may also be connected to a 'used' battery. The BFG will slowly learn the battery capacity each charge discharge cycle. To accelerate this learning process, fully charge then discharge the battery at a low discharge current (1.8A or less). The capacity may also be explicitly set using the RoboRIO web interface. See the Battery Capacity Estimation and BFG Live Dashboard sections for more information.

The BFG contains models of several common FRC batteries (Duracell, Energizer, Interstate, MK Powered, Mighty Max, and PowerSonic). The BFG may be used with other batteries from other manufacturers, however the battery health and capacity estimates may be less accurate.

The battery manufacturer may be specified through the OLED display. See the BFG and Battery Configuration

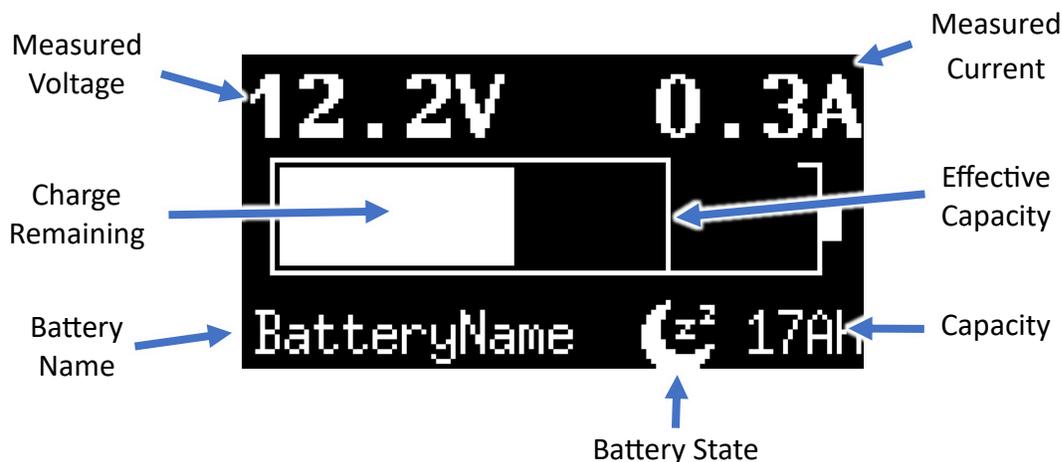
Battery Manufacturer Selection section.

## Display Pages

### Home

The default page when the OLED display wakes up is 'Home'. This page is designed to summarize the state of the battery at a glance. It reports the measured battery voltage and current along with battery-shaped Charge Indicator.

The Battery Name in the lower left corner is user-configurable and can be used to uniquely identify each battery.



| Parameter        | Meaning  |
|------------------|--|
| Measured Voltage | The instantaneous measured battery voltage   |
| Measured Current | The instantaneous measured battery current. Positive numbers indicate discharge and negative numbers indicate charging.  |
| Charge Remaining | How much usable charge (Coulombs or Ah) is left in the battery considering the current RMS discharge rate. When this number reaches zero the battery may have some chemical potential energy remaining, but it will be unable to continue delivering the same discharge current. |

|                 |   |
|-----------------|---|
| Capacity        | How much charge (Coulombs or Ah) a fully charged battery could deliver in Amp-hours. This number is often larger than 18Ah for a brand-new battery and will decrease as the battery wears out. Capacity divided by design-capacity is commonly referred to as State-of-Health (SOH) |
| Design Capacity | How much charge a brand new, fully charged battery could deliver in Amp-hours   |
| Battery Name    | User-definable name used to identify the battery  |

| Battery State Image   | Meaning   |
|---|---|
|  | The battery is actively charging  |
|  | The battery has completely charged and may be removed from the charger. The charger is either trickle charging or has entered a 'float' mode.   |
|  | The battery has not charged or discharged for a long period of time (10+ hours). The state of charge is estimated using the open circuit voltage and will update as the battery self-discharges |

The 'Home' page charge indicator packs a lot of information in a small area. It primarily displays two values: the Effective Capacity (how much energy could a fully charged battery deliver) and the Charge Remaining (how much useful energy is available).

Charge Remaining is represented but the solid filled white box within the Charge Indicator and it is an absolute value (Amp-hours, not percent). The relative strength of any two batteries may be compared simply by looking at the length of this solid white box. Whichever battery has the longest white box is the battery that should be used in competition.

The second half of the Charge Indicator is the Effective Capacity. This is the white outline which surrounds the Charge Remaining box. When a battery is fully charged (or when it hasn't been used for many hours) the Effective Capacity box describes the current battery capacity – how much energy the battery could hold if it were fully charged. This capacity starts out somewhere near 18Ah and slowly gets smaller each time the battery is charged and discharged. As the battery is discharged the BFG watches the discharge rate. As the average discharge rate increases the Effective Capacity will also decrease. What this is really saying is that the faster you discharge a PbA battery, the less energy it will be able to deliver before falling below its minimum cell voltage.

Again, Effective Capacity is an absolute value (Amp-hours, not percent) and can be used to compare the relative health of multiple batteries. This become particularly useful when there is a mix of new and used batteries. When choosing a battery for a robot match, first choose the

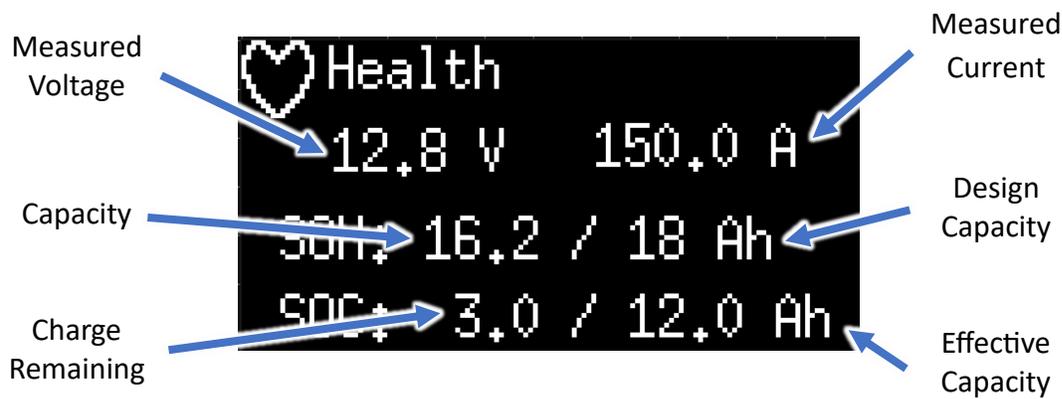
battery with the longest solid white line (Remaining Charge). If multiple batteries have the same Remaining Charge, select the battery with the longest white outline (Effective Capacity)

The following table provides examples and explanations of various Charge Indicator displays:

| Charge Indicator  | Meaning  |
|---|--|
|    | The battery is fully charged and the battery can deliver at least 18Ah. In other words, it is a new battery and can deliver the full design capacity charge if the battery is discharged over a 20-hour period (0.05C).  |
|    | The battery is fully charged (because the filled rectangle is the same width of the Effective-Capacity box), but the Effective Capacity is reduced. This could be because this is an old battery and it can only store a fraction of its original design capacity, or it can mean the discharge current is high and the battery can only deliver a fraction of what it could at a slow discharge rate. |
|    | Battery is 75% discharged. The Effective Capacity is high (this is a new battery and it is being discharged slowly), but the Charge Remaining (the filled white box) only occupies about 25% of the Effective Capacity (the white box). About 4.5Ah (25% of 18Ah) is available for useful work   |
|  | Charge remaining (filled white box) is the same as the previous example, meaning this battery can still deliver close to 4.5Ah, but the effective capacity is much lower. This is an older battery or the discharge current is high.   |
|  | Battery is about half full and could deliver about 9Ah   |
|  | Battery is empty and should be charged.  |

## Health Page

The 'Health' page describes the instantaneous state of the battery including the measured voltage, current and estimated capacity. It provides the numeric values represented by the Charge Indicator on the 'Home' page.

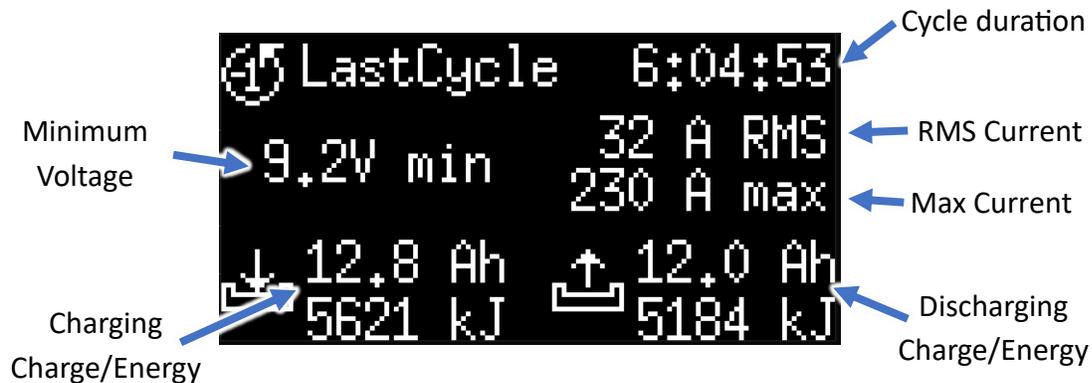


| Parameter          | Meaning  |
|--------------------|--|
| Measured Voltage   | The instantaneous measured battery voltage   |
| Measured Current   | The instantaneous measured battery current. Positive numbers indicate discharge and negative numbers indicate charging.  |
| Capacity           | How much charge a fully charged battery could deliver in Amp-hours. This number is often larger than 18Ah for a brand-new battery and will decrease as the battery wears out. Capacity divided by design-capacity is commonly referred to as State-of-Health (SOH)   |
| Design Capacity    | How much charge a brand new, fully charged battery could deliver over a 20-hour discharge (0.05C) in Amp-hours   |
| Charge Remaining   | How much charge/energy is left in the battery considering the current RMS discharge rate. When this number reaches zero the battery may have some chemical protentional energy remaining, but it will be unable to continue delivering the same discharge current without the cell voltage falling below the lower limit.<br><br>Charge Remaining divided by Capacity is commonly referred to as State-of-Charge (SOC) |
| Effective Capacity | Composite value that takes into account the battery's capacity (which changes over time) and the discharge rate. The amount of energy that can be extracted from a lead-acid battery goes down as discharge current increases.<br><br>This number describes how many Ah/Joules a used, but fully charged battery could deliver at the current RMS current. Effective Capacity is always less than or equal to Capacity |

## Last Cycle Statistics

The 'LastCycle' page describes battery statistics since the last time the battery was charged. A cycle begins when the battery is removed from a charger and begins discharging. The cycle ends when the battery is reconnected to a charger and is fully recharged.

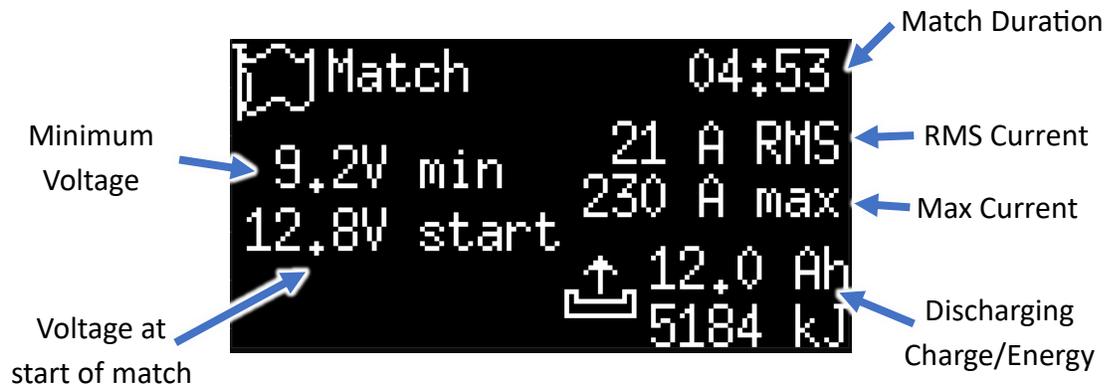
The BFG resets each of the last cycle statistics each time a new cycle begins.



| Parameter                 | Meaning  |
|---------------------------|--|
| Cycle duration            | Time in hh:mm:ss since the battery began discharging this cycle. In other words, if the battery was fully charged and then set on a shelf for a week, this number will not begin increasing until the battery is connected to a robot and begins discharging.  |
| Minimum Voltage           | Minimum battery voltage since the start of the cycle (since the battery was last fully charged). This number is useful for diagnosing brown-outs.  |
| RMS Current               | RMS average of the measured current since the battery first began discharging. The RMS current takes the square of the measured current, then integrates it. This means this average is weighted more heavily to large current spikes and can be used as an approximation for how 'hard' the battery was discharged. |
| Max Current               | Maximum discharge current measured since the start of the cycle  |
| Charging Charge/Energy    | How much energy was put into the battery since the start of the cycle  |
| Discharging Charge/Energy | How much charge (Ah) and energy (kJ) was extracted from the battery since the start of the cycle   |

## Last Match Statistics

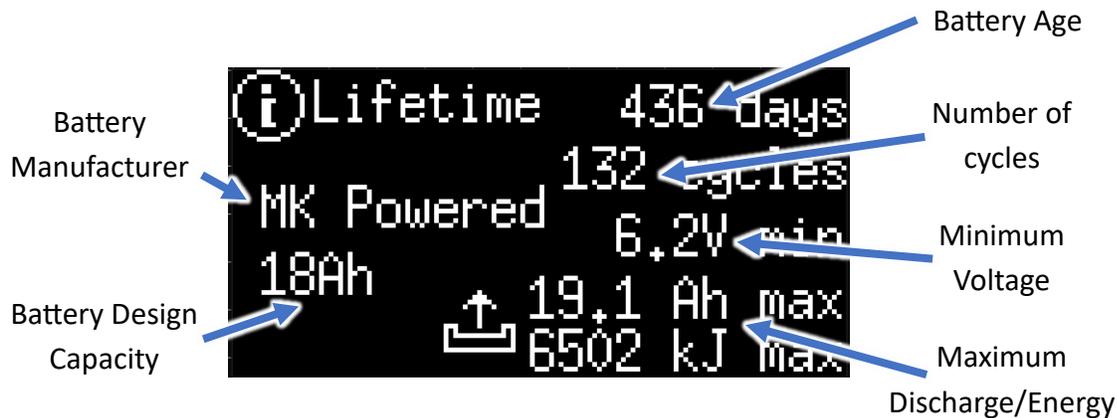
The 'Match' page describes battery statistics during the last robot match. The match start and end times are estimated by monitoring the battery discharge current. Matches begin when the discharge current exceeds 1A. Matches end when the discharge current is less than 1A continuously for two minutes.



| Parameter                 | Meaning  |
|---------------------------|--|
| Match duration            | Time in hh:mm:ss since the match began.  |
| Minimum Voltage           | Minimum battery voltage since the start of the match. This number is useful for diagnosing brown outs. |
| Voltage at start of match | Measured battery voltage when the match started  |
| RMS Current               | RMS average of the measured current since start of the match.  |
| Max Current               | Maximum discharge current measured since the start of the match.                                       |
| Discharging Charge/Energy | How much charge (Ah) and energy (kJ) was extracted from the battery since the start of the cycle       |

## Battery Lifetime Statistics

The battery 'Lifetime' summarizes the battery history. It describes the battery age in days, number of charge/discharge cycles, as well as the minimum battery voltage. Each of these numbers can help in determining when it is time to recycle and replace a used battery.



| Parameter                | Meaning   |
|--------------------------|---|
| Battery Age              | Time in days since the battery  |
| Number of cycles         | Number of complete charge/discharge cycles since the battery was new. This number does not necessarily increase for partial charges. The battery must be fully charged to increment this count. |
| Battery Manufacturer     | Selected battery manufacturer. Used to fine tune the state estimation model for a particular battery  |
| Battery Design Capacity  | Battery design capacity for a new battery. This number is always 18Ah for FRC legal batteries.  |
| Minimum Voltage          | Minimum battery voltage over the life of the battery  |
| Maximum Discharge/Energy | Maximum charge (Ah) and energy (kJ) which was extracted from the battery during any cycle   |

## BFG and Battery Configuration

### Battery Manufacturer Selection

The battery manufacturer is stored in the BFG's non-volatile memory and is used to tune the battery capacity/health models.

The manufacturer can be specified without a CAN connection to a PC or RoboRIO through the built in OLED screen. To specify the battery manufacturer:

1. Navigate to the 'Lifetime' page using short button presses.
2. Press and hold the button for two seconds (then release). The Battery Manufacturer field should begin blinking.
3. Press and release the button (hold less than a second) to change the manufacturer selection.

4. Press and hold the button for two seconds (then release). To commit the new manufacturer to memory. The manufacturer will stop blinking.
5. Or, to abort and leave the battery manufacturer unchanged, do not press the button for ten seconds. After the ten second timeout the manufacturer field will stop blinking and the BFG will revert to the previous manufacturer.

The battery manufacturer may also be modified through the RoboRIO web interface or through the CAN interface. See the BFG Live Dashboard and Set Nickname 2 sections for details.

The initial capacity of a new battery varies among manufacturers. If the manufacturer is changed during the first 10 charge/discharge cycles, the BFG will reset the battery capacity to the default initial capacity for the new manufacturer. If the manufacturer is changed after 10 charge/discharge cycles, the BFG will still use the battery health model constants for the new manufacturer, but it will not change the battery capacity.

## Battery Nickname Selection

The battery nickname may be modified through the RoboRIO web interface or through the CAN interface. See the BFG Live Dashboard and Set Nickname 2 sections for details.

## Reset Battery Statistics

BFG battery statistics should be reset when a BFG is moved from one battery onto another. Min/max depth of discharge, minimum battery voltage, battery age, and capacity are reset to 'new' values. Battery nickname, manufacturer and BFG CAN device ID are not modified by this operation.

The battery statistics may be modified through the RoboRIO web interface or through the CAN interface. See the BFG Live Dashboard and Set Nickname 2 sections for details.

## Battery Capacity Estimation

Each time the battery is fully charged the BFG attempts to update the battery capacity estimate. The BFG determines when a battery is charging by looking for specific events. First the battery must be charged at a constant rate – generally 5.4A for 18Ah FRC batteries. Next, the battery must be charged at a constant voltage, once the voltage reaches around 13.5-14.6 V. Finally,

the charger must enter a 'trickle-charge' mode where it applies a small (few hundred mA) current for a period.

Most modern chargers perform the sequence. Even ancient linear chargers will charge at a fixed current followed by a period of constant voltage charging. If the battery capacity reported by the BFG does not seem correct, the first step is to look at the number of battery charge/discharge cycles on the 'Lifetime' page and ensure this number increments every time the battery is fully charged.

Every charger is different. If the battery cycle count does not increase after charging, please reach out to [TechnicalSupport@PlayingWithFusion.com](mailto:TechnicalSupport@PlayingWithFusion.com) and help us to understand your setup and equipment.

## Partial Discharge Capacity Estimation

One of the best ways to prolong battery life is to limit the depth-of-discharge each cycle, IE to use partial discharges as much as possible rather than completely depleting the battery.

There are several mechanisms at work to estimate capacity. The first (and slowest to converge) simply compares the energy discharged from the battery and the energy put back by the charger. This mechanism works for full and partial discharges; however, it is susceptible to drift over time. If no other capacity estimation method is used, it may take up to 20 charge/discharge cycles for the BFG to 'learn' a 'used' battery.

## Full Discharge Capacity Estimation

The most accurate way for the BFG to learn a batteries capacity is to completely discharge the battery. When this happens the BFG has a very good idea of the capacity by watching how much energy is put back in by the charger.

The downside is that the deeper a battery is discharged the more damage occurs within the battery and fewer cycles that battery can achieve before it loses significant capacity. In fact, most manufacturers recommend not fully discharging a new battery for the first few cycles as the battery 'breaks in'.

If the battery is fully discharged and reaches a voltage between 9.6 and 10.5V (dependent on average load), the BFG will use the Full-Discharge Capacity Estimation method. This method can converge on the correct battery capacity of a 'used' battery in as few as 3 charge/discharge cycles.

How fast the estimated capacity will converge with the true value is dependent on the average discharge current during that cycle. The estimated capacity will converge the fastest (and be the most accurate) if a fully-charged battery is discharged at 1.8A or less until it reaches 10.5V, and is then immediately recharged. This discharge profile can be achieved using battery profiles such as the AndyMark CBA.

## Open Circuit Capacity Estimation

Another capacity estimation method relies on evaluating the open circuit battery voltage. Unlike lithium chemistry batteries, it is relatively accurate and straight forward to estimate the state of charge for lead-acid batteries by measuring the open circuit voltage after the battery has sat for a sufficient period.

Any time a battery sits for more than 10 hours without any load or charger connected, the BFG will correct drift in its internal depth-of-discharge value, and then use that updated value to update the battery capacity the next time the battery is full charged.

This mechanism is primarily used when a battery sits for months unused (IE during the off-season) to track state of charge as the battery self-discharges.

Never allow a fully-discharged lead-acid battery to sit for an extended period of time. The longer it sits discharged, the greater the risk of permanently damaging the battery. Best practice is to connect a full discharged battery into a charger immediately after discharge.

## RoboRIO Driver Installation

The BFG is designed work stand-alone and does not require a connection to other CAN devices. However, a RoboRIO driver is available to provide measured BFG values to a robot program as well as provide a web interface to monitor parameters and change BFG settings.

The easiest way to include the Playing With Fusion driver into a robot program is through the Dependency Manager in VS Code (See <https://docs.wpilib.org/en/stable/docs/software/vscode-overview/3rd-party-libraries.html> for more information). Search for the latest version of 'PlayingWithFusion' and then click install. Driver updates may also be performed through the VS Code Vendor Dependencies tab.

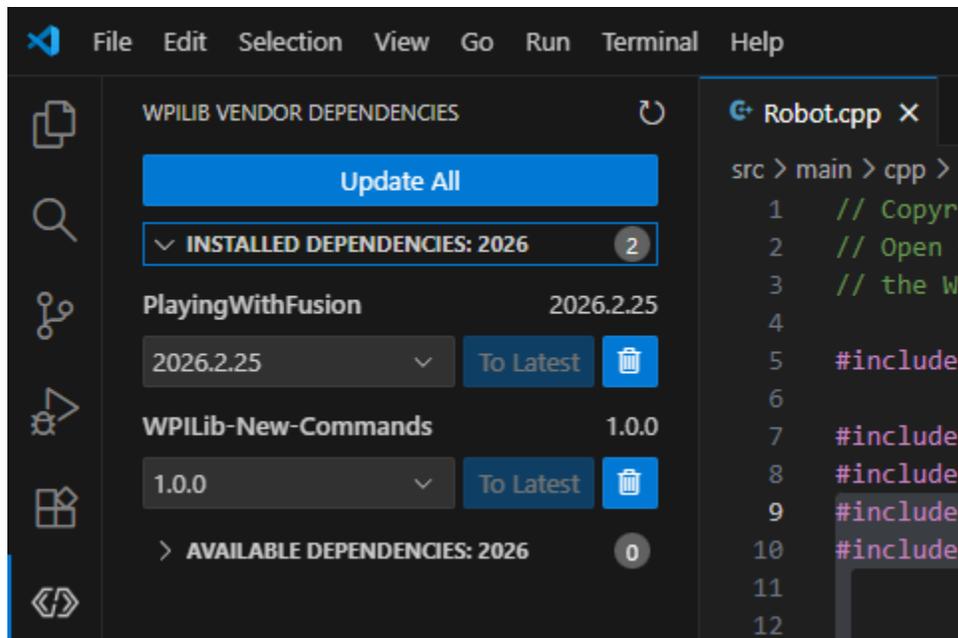


Figure 1 - VS Code Vendor Dependencies Tab

## BFG Web Configuration

The libPlayingWithFusion RoboRIO library includes a web interface to manage all Playing with Fusion CAN devices

Each device must be assigned an ID that is unique for all other devices of the same type. For example, only one motor controller may use ID 0. It is perfectly acceptable to also configure a time of flight sensor as ID 0 because it is a different device type than the Venom motor.

The configuration interfaces may be accessed by typing in the IP address of the RoboRIO into a web browser followed by :5812.

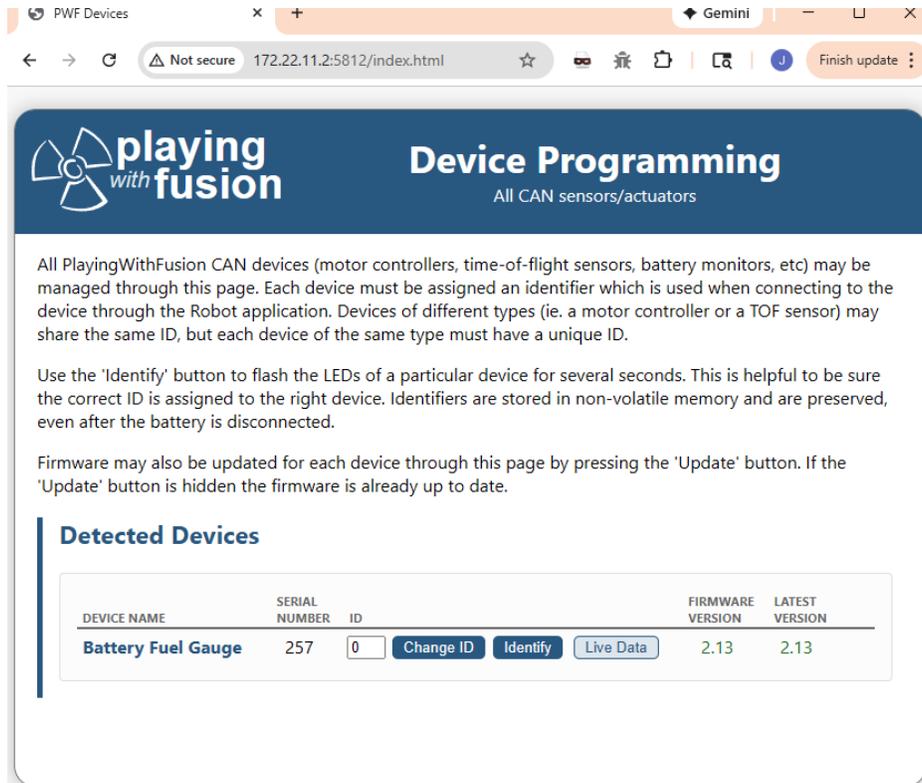


Figure 2 - PWF Device Configuration Page

Each Playing with Fusion device will be listed on the configuration page. If a device is missing, check power to the device and verify the CAN bus connections.

Device IDs may be changed by entering the desired device ID into text box on the corresponding row then pressing the Change ID button. The change will take effect immediately and will be stored across power cycles.

The Identify button is a useful tool to determine which physical device is associated with each ID. The BFG OLED display will change to an identification page for a short period when 'Identify' is pressed.

## BFG Firmware Update

If new firmware is available for any device, an Update button will appear in the right most column for that device. Firmware is included as part of the PlayingWithFusionDriver and cannot

be downloaded separately from the Playing with Fusion website. The Update button is hidden when the 'Firmware Version' and 'Latest Version' are the same

To update device firmware:

- Disable the robot using the driver station
- Ensure the robot battery is fully charged
- Press the Update button.
- Do not initiate another firmware update or remove power from the roboRIO until the update process is complete.
- A message will appear above the device list which will display whether or not the reprogramming attempt was successful.
- If you have difficulties reprogramming contact Playing With Fusion technical support at [TechnicalSupport@PlayingWithFusion.com](mailto:TechnicalSupport@PlayingWithFusion.com)

## BFG Live Dashboard

Live battery measurements and statistics can be monitored through the BFG Live Data Dashboard. Click the 'Live Data' button next to a BFG on the Device Programming page.

The Dashboard values are updated once a second.

Battery nickname and battery manufacturer may be changed by pressing the respective 'Edit' buttons.

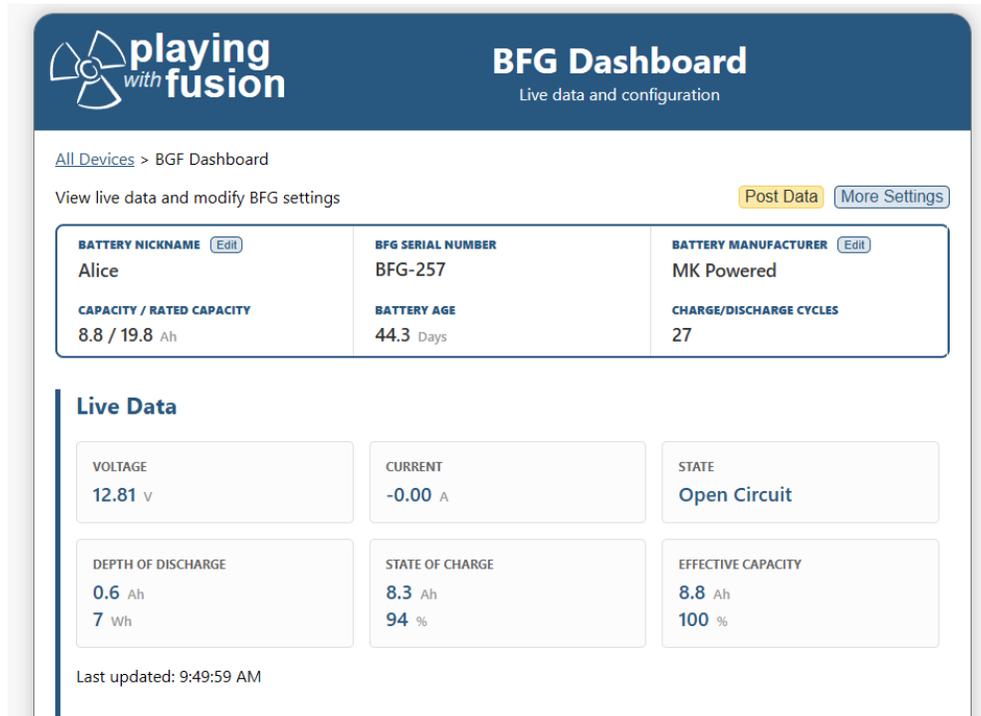


Figure 3 - BFG Live Data Dashboard

Additional battery parameters may be modified by pressing the 'More Settings' button on the top right of the BFG Dashboard.

BFG OLED display orientation may be modified by pressing the 'Normal' and 'Flipped/Inverted' buttons.

The battery age (time), number of charge/discharge cycles, and capacity (in Ah) can be modified through the 'Edit Battery Age/Capacity' button. This can be helpful when a BFG is installed onto an 'used' battery. Although the BFG capacity estimate will converge on the true battery capacity each time the battery is charged, this process can take many cycles (depending on how deeply the battery is discharged). Manually setting the battery capacity can give this process a head start.

The 'Reset BFG' button is used to reset battery statistics when a BFG is moved from one battery onto another. Min/max discharge, minimum battery voltage, battery age, and capacity are reset to 'new' values. Battery nickname, manufacturer and BFG CAN device ID are not modified by this operation.

Warning: the 'Reset BFG' operation cannot be undone.

Similarly, changes to calibration values cannot be undone and these values should not be modified without first contacting Playing With Fusion technical support at [TechnicalSupport@PlayingWithFusion.com](mailto:TechnicalSupport@PlayingWithFusion.com)

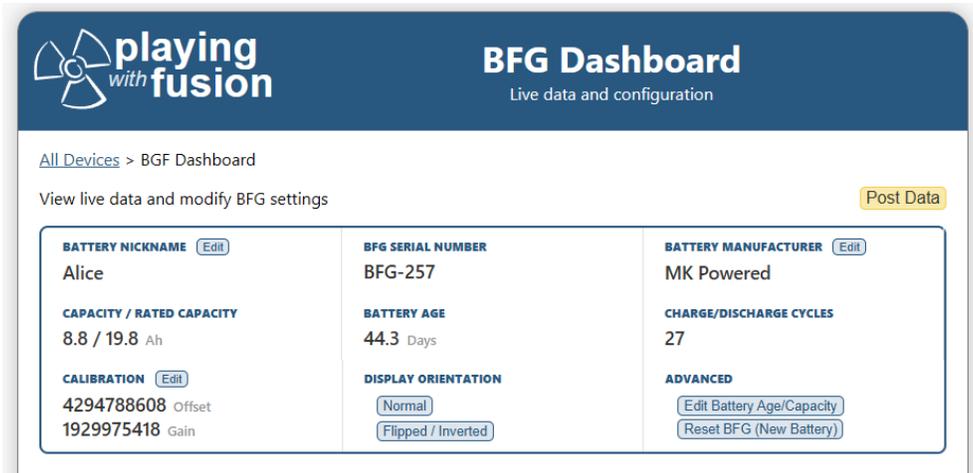


Figure 4 - Additional settings within BFG Dashboard

## BFG Cloud Backup

BFG measurements may be sent to Playing With Fusion servers by pressing the 'Post Data' button. This serves two purposes. First, it serves as a backup. If calibration values are lost or unintentionally modified in the future, Playing With Fusion can provide the most recent values so they can be restored. Second, this data will be used to improve the battery degradation model in future BFG firmware versions.

Playing with Fusion also reserves the right to share portions of this dataset publicly with other FRC teams. Email addresses will never be shared publicly or with third parties.

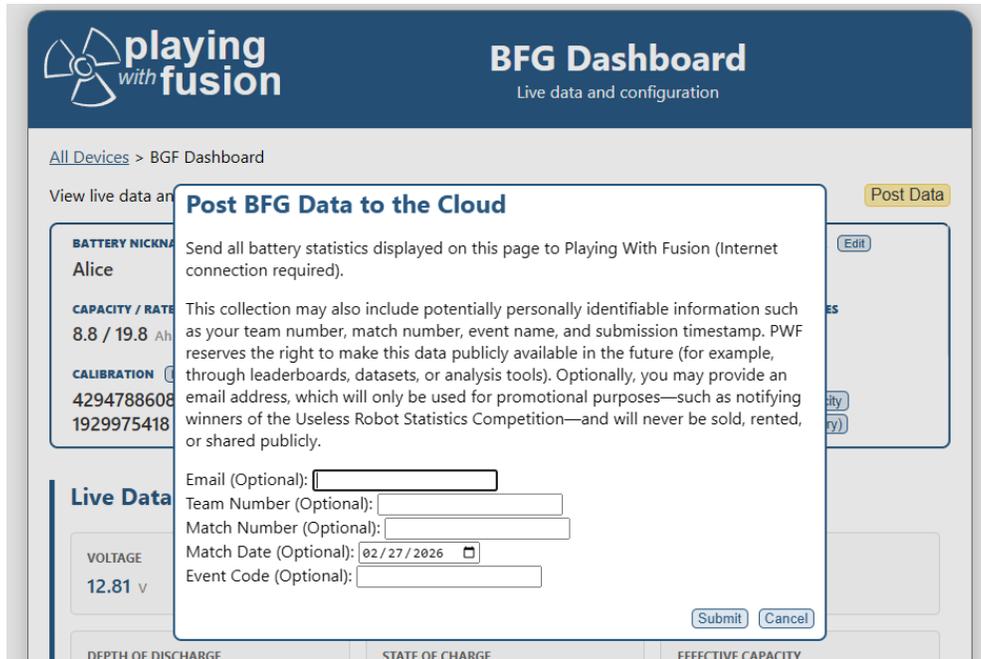


Figure 5 - BFG Post Data dialog

## CAN Messages

All messages use extended (29-bit) CAN identifiers.

Multi-byte data fields are little endian (least significant byte first). The number 0x1234 in hexadecimal is encoded in two bytes. The first byte is 0x34 and the second byte is 0x12.

Many messages include a 'Device ID' as the least significant byte of the CAN message identifier. This device ID is programmed into each BFG by the end user and is used to identify individual devices on a CAN bus. All sensors ship with a default device ID of zero.

## Transmitted CAN Messages

### Heartbeat

Heartbeat message is transmitted once a second and provides the sensor firmware version and hardware serial number

|                    |  |
|--------------------|--|
| <b>Message ID:</b> | 0x1F0B01ss (where ss = device ID)      |
| <b>DLC:</b>        | 8                                      |
| <b>Byte 0:</b>     | Reserved, always 0                     |
| <b>Bytes 1-3:</b>  | Hardware serial number                 |
| <b>Bytes 4-5:</b>  | Manufacturer part number, always 0x130 |
| <b>Bytes 6-7:</b>  | Firmware version                       |

### Battery Power

Measured battery voltage and discharge rate. Transmitted every 10 milliseconds.

|                    |  |
|--------------------|--|
| <b>Message ID:</b> | 0x0A0B00ss (where ss = device ID)  |
| <b>DLC:</b>        | 8  |
| <b>Bytes 0-3:</b>  | Signed discharge current in milliamps. Positive numbers represent discharge.           |
| <b>Bytes 4-5:</b>  | Unsigned battery voltage in millivolts.  |
| <b>Bytes 6-7:</b>  | Signed depth of discharge in milliamp-hours. Value increases as battery is discharged. |

### State of Charge

Estimated battery state of charge in charge (Ah) and energy (Wh / Joules) as well as the estimated battery charge/discharge state. Transmitted every 10 milliseconds.

|                    |                                   |
|--------------------|-----------------------------------|
| <b>Message ID:</b> | 0x0A0B07ss (where ss = device ID) |
| <b>DLC:</b>        | 8                                 |

|                   |  |
|-------------------|--|
| <b>Bytes 0-1:</b> | Estimated state of charge in milliamp-hours  |
| <b>Bytes 2-3:</b> | Estimated effective capacity in milliamp-hours   |
| <b>Byte 4:</b>    | Battery charge state: 0=Init/Unknown; 1=Discharge; 2=Charging (Constant Current); 3=Charging (Constant Voltage); 4=Charging (Trickle); 5=Charging Complete; 6=Open Circuit |
| <b>Bytes 5-7:</b> | Estimated depth of discharge in Joules (Wh / 3600)   |

## Battery Health

Estimated battery age and health. Transmitted once per second.

|                    |                                    |
|--------------------|------------------------------------|
| <b>Message ID:</b> | 0x0A0B01ss (where ss = device ID)  |
| <b>DLC:</b>        | 8                                  |
| <b>Bytes 0-3:</b>  | Battery age in seconds             |
| <b>Bytes 4-6:</b>  | Battery capacity in milliamp-hours |
| <b>Bytes 6-7:</b>  | Number of charge/discharge cycles  |

## Match Current

Min/max battery discharge current during the last robot match. Positive numbers represent discharge, negative represent charging. Transmitted once per second.

|                    |  |
|--------------------|--|
| <b>Message ID:</b> | 0x0A0B02ss (where ss = device ID)                  |
| <b>DLC:</b>        | 8  |
| <b>Bytes 0-3:</b>  | Minimum current during the last match in milliamps |
| <b>Bytes 4-7:</b>  | Maximum current during the last match in milliamps |

## Match Charge

Min/max battery voltage and depth of discharge during the last robot match. The higher the depth of discharge, the more charge was delivered by the battery during the match.

Transmitted once per second.

|                    |  |
|--------------------|--|
| <b>Message ID:</b> | 0x0A0B03ss (where ss = device ID)  |
| <b>DLC:</b>        | 8  |
| <b>Bytes 0-1:</b>  | Minimum voltage during the last match in millivolts                        |
| <b>Bytes 2-3:</b>  | Maximum voltage during the last match in millivolts                        |
| <b>Bytes 4-5:</b>  | Minimum battery depth of discharge during the last cycle in milliamp-hours |
| <b>Bytes 6-7:</b>  | Max depth of discharge during the last cycle in milliamp-hours             |

## Match Time

Time spent charging and discharging the battery during the last robot match. Transmitted once per second.

**Message ID:** 0x0A0B05ss (where ss = device ID)  
**DLC:** 8  
**Bytes 0-3:** Charging time during the last match in seconds  
**Bytes 4-7:** Discharging time during the last match in seconds

## Match Delta Energy

Battery depth of discharge (energy) at the start and end of the last robot match. Total energy consumed during the match may be calculated by subtracting the starting depth of discharge from the final value. Transmitted once per second.

**Message ID:** 0x0A0B0Dss (where ss = device ID)  
**DLC:** 8  
**Bytes 0-1:** Depth of discharge at the start of the robot match in Joules. 128 Joules per bit. Multiply the CAN value by 128 to decode the depth of discharge in Joules.  
**Bytes 2-3:** Depth of discharge at the end of the robot match in Joules. 128 Joules per bit.  
**Bytes 4-5:** Battery voltage at the start of the robot match in millivolts  
**Byte 6:** Battery manufacturer: 0=Duracell; 1=Energizer; 2=Interstate; 3=Mighty Max; 4=MK Powered; 5=Power Sonic

## Match Delta Charge

Battery depth of discharge at the start and end of the last robot match. Transmitted once per second.

**Message ID:** 0x0A0B0Ess (where ss = device ID)  
**DLC:** 8  
**Bytes 0-1:** Depth of discharge at the start of the robot match in milliamp-hours  
**Bytes 2-3:** Depth of discharge at the end of the robot match in milliamp-hours  
**Bytes 4-7:** Duration of the last robot match (Estimated by monitoring battery current)

## RMS Current

RMS discharge current during the last robot match and charge/discharge cycle. RMS current is defined as the square of measured current, summed over time, divided by the number of samples. It can be thought of as a weighted average that favors current spikes. Transmitted once per second.

**Message ID:** 0x0A0B06ss (where ss = device ID)  
**DLC:** 8  
**Bytes 0-3:** RMS discharge current during the last match in milliamps  
**Bytes 4-7:** RMS discharge current during the last charge/discharge in milliamps

## Last Cycle Current

Min/max battery discharge current during the last charge/discharge cycle. Positive numbers represent discharge, negative represent charging. Transmitted once per second.

|                    |  |
|--------------------|--|
| <b>Message ID:</b> | 0x0A0B08ss (where ss = device ID)                  |
| <b>DLC:</b>        | 8  |
| <b>Bytes 0-3:</b>  | Minimum current during the last cycle in milliamps |
| <b>Bytes 4-7:</b>  | Maximum current during the last cycle in milliamps |

## Last Cycle Charge

Min/max battery voltage and depth of discharge during the last charge/discharge cycle. The higher the depth of discharge, the more charge was delivered by the battery during the cycle. Transmitted once per second.

|                    |  |
|--------------------|--|
| <b>Message ID:</b> | 0x0A0B09ss (where ss = device ID)  |
| <b>DLC:</b>        | 8  |
| <b>Bytes 0-1:</b>  | Minimum voltage during the last cycle in millivolts                        |
| <b>Bytes 2-3:</b>  | Maximum voltage during the last cycle in millivolts                        |
| <b>Bytes 4-5:</b>  | Minimum battery depth of discharge during the last cycle in milliamp-hours |
| <b>Bytes 6-7:</b>  | Max depth of discharge during the last cycle in milliamp-hours             |

## Last Cycle Time

Time spent charging and discharging the battery during the last charge/discharge cycle. Transmitted once per second.

|                    |   |
|--------------------|---|
| <b>Message ID:</b> | 0x0A0B0Ass (where ss = device ID)                 |
| <b>DLC:</b>        | 8   |
| <b>Bytes 0-3:</b>  | Charging time during the last cycle in seconds    |
| <b>Bytes 4-7:</b>  | Discharging time during the last cycle in seconds |

## Last Cycle Energy

Min and max battery depth of discharge (energy) during the last charge/discharge cycle. Total energy consumed during the cycle may be calculated by subtracting the starting depth of discharge from the final value. Transmitted once per second.

|                    |  |
|--------------------|--|
| <b>Message ID:</b> | 0x0A0B0Css (where ss = device ID)  |
| <b>DLC:</b>        | 8  |
| <b>Bytes 0-1:</b>  | Minimum depth of discharge during the last cycle in Joules. 128 Joules per bit. Multiply the CAN value by 128 to |
| <b>Bytes 2-3:</b>  | Max depth of discharge during the last cycle in Joules. 128 Joules per bit.                                      |

- Bytes 4-5:** Battery voltage at the start of the cycle in millivolts
- Bytes 6-7:** Battery design capacity – capacity of a new battery for the selected manufacturer

## Calibration

BFG current measurement factory calibration values. Transmitted once per second.

- Message ID:** 0x0A0B0Bss (where ss = device ID)
- DLC:** 8
- Bytes 0-3:** Current measurement offset
- Bytes 4-7:** Current measurement gain

## Nickname 1

First half of battery nickname

- Message ID:** 0x0A0B0Fss (where ss = device ID)
- DLC:** 8
- Bytes 0-7:** First eight bytes of the battery nickname (ASCII). Terminate string with 0/NULL.

## Nickname 2

Second half of battery nickname

- Message ID:** 0x0A0B10ss (where ss = device ID)
- DLC:** 8
- Bytes 0-2:** Last three bytes of the battery nickname (ASCII). Terminate string with 0/NULL.

## Received CAN Messages

### Device Configuration

The Device Configuration message primarily used to initiate internal calibration routines and initiate firmware updated. This message is unique in that the message ID is fixed. Since the device ID is not part of the CAN ID, the specific device is specified by the serial number and manufacturer part number (available from the Heartbeat message) in bytes 1-5.

Byte 0 is a 'command byte'. It specifies which behavior is commanded as well as the meaning of data bytes 6 and 7.

- Message ID:** 0x1F0B03FF

|                   |  |
|-------------------|--|
| <b>DLC:</b>       | 8                                      |
| <b>Byte 0:</b>    | Command byte                           |
| <b>Bytes 1-3:</b> | Hardware serial number                 |
| <b>Bytes 4-5:</b> | Manufacturer part number, always 0x130 |
| <b>Bytes 6-7:</b> | Optional arguments – see command byte  |

#### *Unlock (CommandByte=0xA)*

The Unlock command is used to ‘unlock’ non-volatile memory within the BFG and allow other operations such as calibration routines or modifying battery parameters. The BFG must be unlocked each time non-volatile parameters are defined.

#### *Set Device ID (CommandByte=0xC)*

The Set Device ID command is used to specify the device id (least significant byte of CAN ID). Data byte 6 specifies the new device ID.

#### *Identify (CommandByte=0xD)*

Command used to identify an individual device when multiple devices are present on the CAN bus. When an Identify message is received, the BFG OLED display will briefly change and show an identification page.

#### *Calibrate (CommandByte=0xB)*

Initiate internal BFG current measurement calibration routines. BFG must be unlocked before the Calibrate command is issued. BFG will be re-lock after the Calibrate command is received.

Byte 6 specifies the calibration mode (1=zero current calibration; 2=10A current calibration).

### Set Nickname 1

Specifies the battery nickname. BFG must be unlocked prior to sending the Set Nickname 1 message.

|                    |  |
|--------------------|--|
| <b>Message ID:</b> | 0x0A0B20ss (where ss = device ID)  |
| <b>DLC:</b>        | 8  |
| <b>Bytes 0-7:</b>  | First eight bytes of the new battery nickname (ASCII). Terminate string with 0/NULL. |

### Set Nickname 2

Specifies the battery nickname and other BFG parameters. Set data bytes to 0xFF to leave parameters unchanged.

This message works in conjunction with the Set Nickname 1 message. To change the battery nickname, first unlock the BFG (Device Configuration message). Then send the Set Nickname 1 message, and then send the Set Nickname 2 message. These three messages must be received by the BFG in that order. Set data bytes 0-2 to 0xFF to change other BFG parameters but leave the battery nickname unchanged.

To change the battery manufacturer, unlock the BFG and then send this message with data byte 3 set to a value other than 0xFF.

To reset all battery statistics, unlock the BFG and then send this message with data byte 4 equal to 0x69. The reset command clears all non-volatile BFG memory except for the factory calibration values, battery nickname and manufacturer.

- Message ID:** 0x0A0B21ss (where ss = device ID)
- DLC:** 8
- Bytes 0-2:** Last three bytes of the new battery nickname (ASCII). Terminate string with 0/NULL.
- Byte 3:** New battery manufacturer: 0=Duracell; 1=Energizer; 2=Interstate; 3=Mighty Max; 4=MK Powered; 5=Power Sonic. Set to 0xFF to leave manufacturer unchanged
- Byte 4:** Reset all BFG battery statistics. Set to 0x69 to reset statistics, otherwise set to 0xFF
- Byte 5:** Invert/flip BFG OLED display. Set to 0x00 to set display to normal. Set to 0x01 to flip OLED screen 180 degrees. Set to 0xFF to leave display orientation unchanged.

## Set Health

Message used to set the battery age and capacity. The BFG must be unlocked prior to sending the Set Health message. Set data bytes to 0xFF to leave parameters unchanged.

- Message ID:** 0x0A0B22ss (where ss = device ID)
- DLC:** 8
- Bytes 0-3:** New battery age in seconds. Set all four bytes to 0xFF to leave age unchanged
- Bytes 4-5:** New battery capacity in milliamp-hours. Set both bytes to 0xFF to leave capacity unchanged
- Bytes 6-7:** New number of battery charge/discharge cycles. Set both bytes to 0xFF to leave cycle count unchanged