ROB-70001: Battery Fuel Gauge

User Manual

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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

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 the health of the battery as well. 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 any time 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 the BFG 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). See the Battery Capacity Estimation section for mor 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.

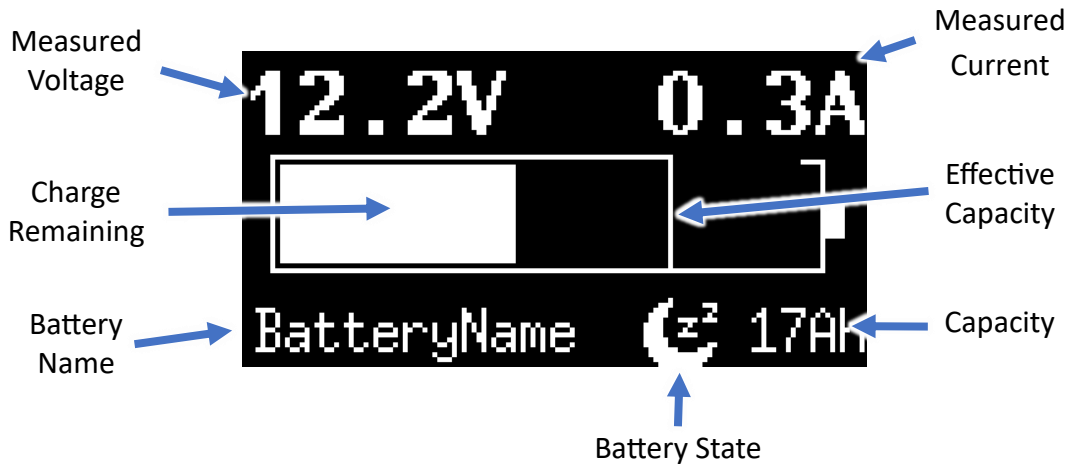
The battery manufacturer may be specified through the OLED display. See the Battery Manufacturer Selection section.

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 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
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 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

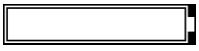
The 'Home' page charge indicator packs a lot of information in a small area. It primarily displays two values: the Effective Capacity (how much energy could a fully charged battery deliver) and the Charge Remaining (how much useful energy is available).

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 bellow 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)

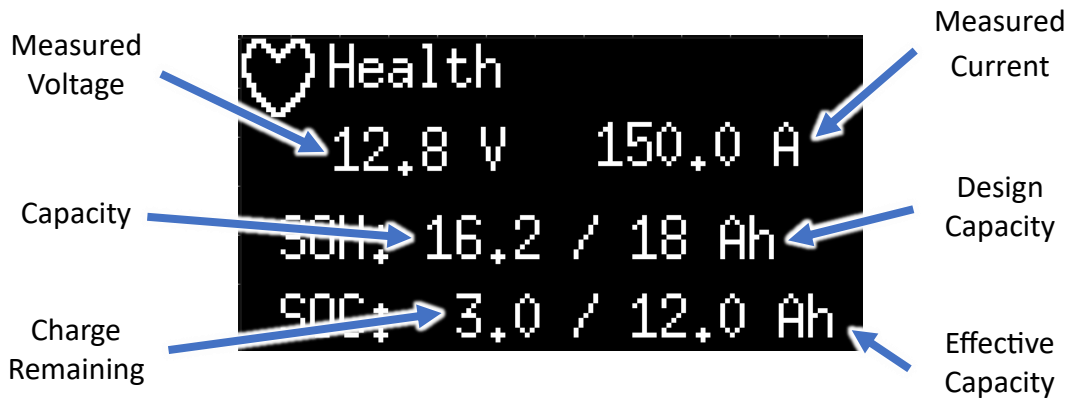
The following table provides examples and explanations of various Charge Indicator displays:

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.



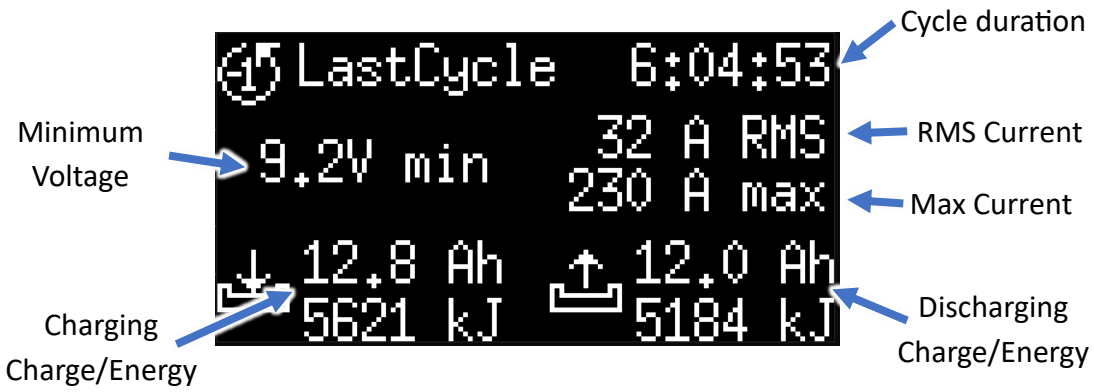
Parameter	Meaning
Measured Voltage	The instantaneous measured battery voltage
Measured Current	The instantaneous measured battery current. Positive numbers indicate discharge and negative numbers indicate charging.
Capacity	How much charge a fully charged battery could deliver in Amp-hours. This number 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 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.

	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. 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.

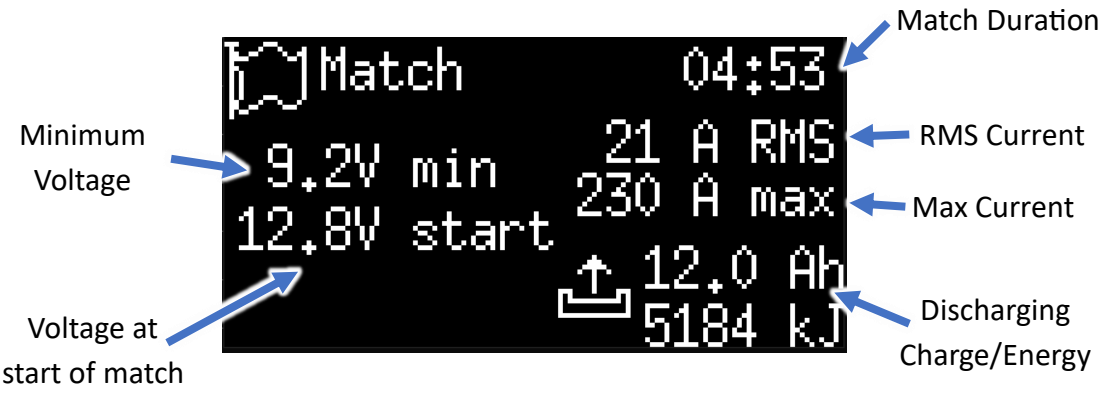


Parameter	Meaning
Cycle duration	Time in hh:mm:ss since the battery began discharging this cycle. In other words, if the battery was fully charged and then set on a shelf for a week, this number will not begin increasing until the battery is connected to a robot and begins discharging.
Minimum Voltage	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 energy 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 energy 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 energy which was extracted from the battery during any cycle

Battery Manufacturer Selection

The battery manufacturer is stored in the BFG's 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 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 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 preform 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 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 fulling discharging a new battery for the first few cycles as the battery 'breaks in'.

If the battery if 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' batter 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.