

How to Evaluate Battery Test Equipment

Batteries are a critical component of many products, and energy storage plays a very active role in our lives even outside of the research/industry setting. Therefore, selecting the right battery test equipment is an important decision for companies and the individual researchers who are responsible for producing results, whether they are starting small, or at massive scale.

The expert engineers at Arbin have been advancing the benchmark of “state-of-the-art” battery test equipment for over 27 years. We are defined by innovation, from being the first to apply multiple current ranges on a single test channel to more recently being the only company to offer true high-precision testing for high current applications, and supporting “Turbo Mode” with smart battery modules. We continue to learn from our industry partners and work with them on key technology breakthroughs.



The following report shares some of this knowledge using plain terminology and illustrations. Here are five key topics to consider when choosing battery test equipment:

1. **Hardware** - Specifications & Quality of Materials [\[page 2 - 6\]](#)
2. **Software** - Usability and Features [\[page 7\]](#)
3. **Data** - Logging, Management, and Analysis [\[page 8 - 9\]](#)
4. **Options** - Auxiliary Features and Accessories [\[page 10 - 11\]](#)
5. **Support** - Product Safety and Support [\[page 12\]](#)



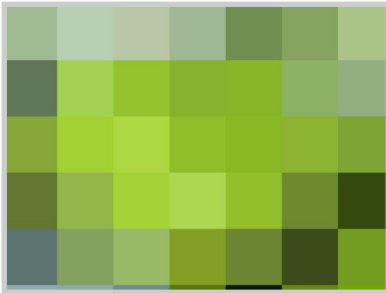
Why We Are Passionate

At Arbin, we understand the vital role energy storage plays in our everyday life and its importance to our future. This is why we work hard to provide the best service and testing equipment as a tool for both researchers and industry.

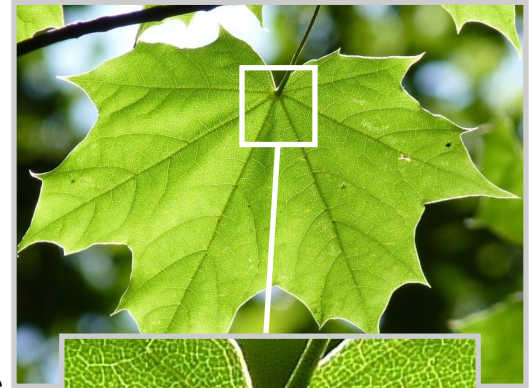
How to Evaluate Battery Test Equipment

1. Hardware - Specifications and Quality of Materials

Resolution indicates the smallest change in measurement that can be detected by the instrument's sense and control circuitry. Typically referred to in "bits" of resolution or an absolute unit of measurement such as μV or μA .



These images illustrate a 256x difference in resolution. The same difference as Arbin's test equipment compared to the industry standard.

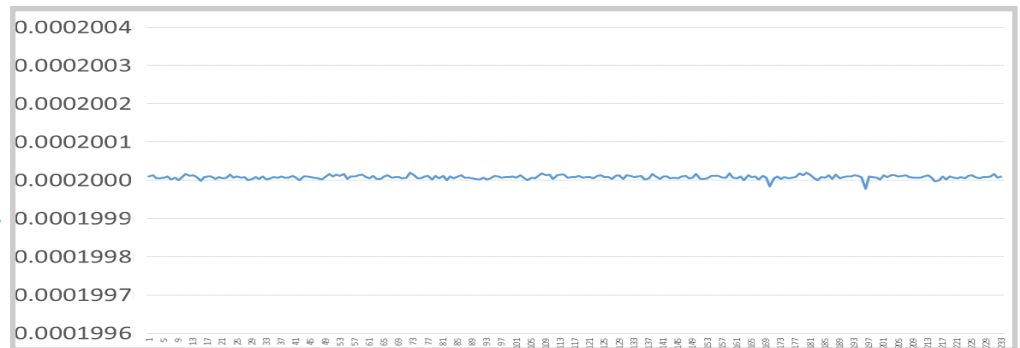


For battery test equipment, *resolution* is determined by the analog to digital and digital to analog conversion, commonly known as ADC and DAC, of the sense circuitry and control system. Analog signals vary at a continuous (near infinite) rate while a digital signal varies by a discrete rate that is measured in bits. When zooming in to look at current/voltage/time measurement data, the bits of resolution are the smallest changes that can be detected, and while capacity, energy, internal resistance, etc. are not *direct* measurements, they are all calculated from the same data.

Translating this into test results...

Arbin's 24-bit resolution means its circuitry can sense 1 part in 16,777,216 (2^{24}). This is a **256x** improvement over 16-bit resolution (1 part in 65,526), which is the industry standard. Greater resolution produces greater clarity with more significant digits.

Note the zoomed scale of plot at right. 24-bit resolution allows researchers to detect the smallest changes in voltage/current.



Higher resolution test equipment, when combined with high precision measurements, has the sensitivity to detect changes in voltage & current (as well as capacity, energy, IR, etc.) that would otherwise be missed, such as detecting a small spike in resistance as a battery approaches end of life, or a slight dip in coulombic efficiency that indicates end of life. Many academic papers have been published by scientists who look for trends and identifying test metrics that can reduce the test time required during battery material development. An upgraded tool with better resolution and overall performance should expedite this process even more.

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1. Hardware - Specifications and Quality of Materials

Precision determines the level of noise/fluctuation present in the test equipment's measurement. Precision also indicates the consistency and repeatability of the instrument's measurement circuitry. A measurement with very little noise/fluctuation is considered to be precise. Measurement precision at "100ppm" indicates it will vary by no more than 0.01% (100/1,000,000).

Noise in a high resolution image illustrates how poor precision can obscure the fine details.



Many instruments will not specify their precision, which is a warning sign, or will improperly report precision through multiple averaged calculations or very slow frequency data logging that hides the noise. Another common tactic is to report precision of battery coulombic efficiency calculations instead of hardware specification. These practices are misleading and reflect negatively on the company's reputation. [Ask to learn more.]

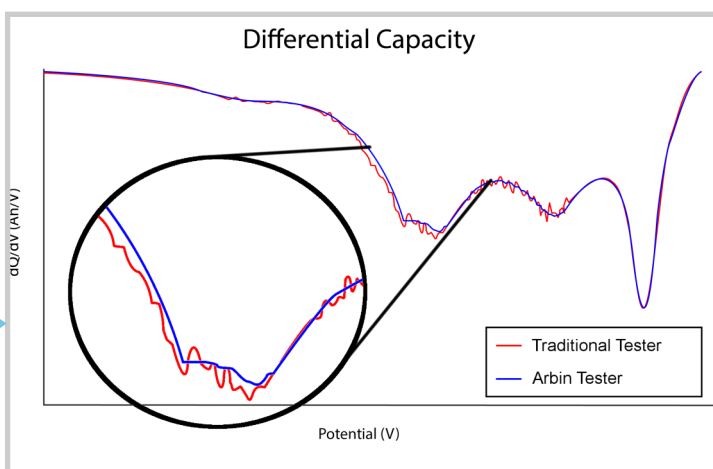
The test equipment resolution, quality of materials, and thermal management all play a significant role to provide superior precision. Precision should be specified *directly* for the voltage, current, time, and sometimes temperature measurement of the test equipment.

Translating this into test results...

Arbin defines the measurement precision for *voltage*, *current*, and *time* for each class of test equipment. These are the three parameters measured by the test equipment that define its performance. Quartz timing crystals are used by each microcontroller for measurement and timestamp; representing the state-of-the-art method for such measurements. The benefits of high-precision measurements during battery research have been widely discussed in academia for almost a decade. *Coulombic efficiency* and *differential capacity* are two battery metrics that have been shown to require incredibly high precision test equipment to be meaningful and draw confident conclusions.

These analytical techniques can miss or obscure signatures in the data if experiments are conducted with low precision test equipment that will generate noisy and inconsistent (unrepeatable) results.

Benefit of high precision seen in dQ/dV plot. The first event shown is clear with a high-precision tester like Arbin, but would easily be overlooked with traditional battery test equipment.

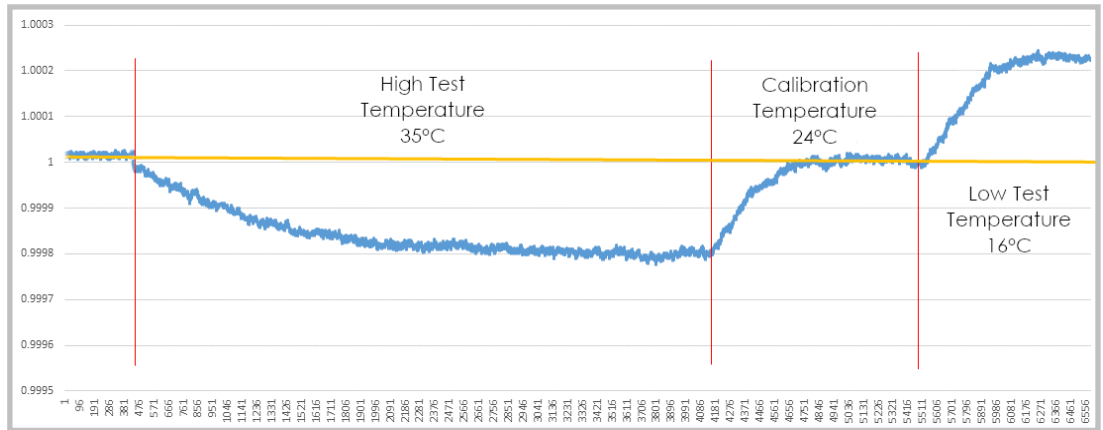


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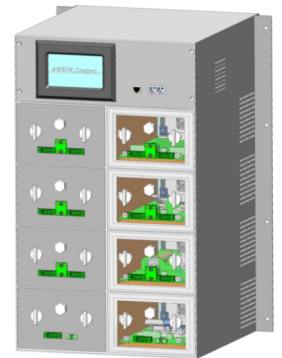
1. Hardware - Specifications and Quality of Materials

Temperature variance of the test equipment and the device under test will always affect the measurement. This is a physical property that cannot be escaped, but it can be minimized.

Plot shows the affect of temperature variance on current measurement.



Knowing how temperature affects the measurement empowers the researcher when determining the experimental error. When test equipment resolution and precision are sufficient, measurement fluctuation due to temperature will be seen. *Gradual* temperature changes will *gradually* skew results data [above], and sudden temperature changes can cause jumps in the data as seen [below]. It is important to use test equipment that is resistant to temperature changes with proper thermal control mechanisms and to control temperature of the test environment.

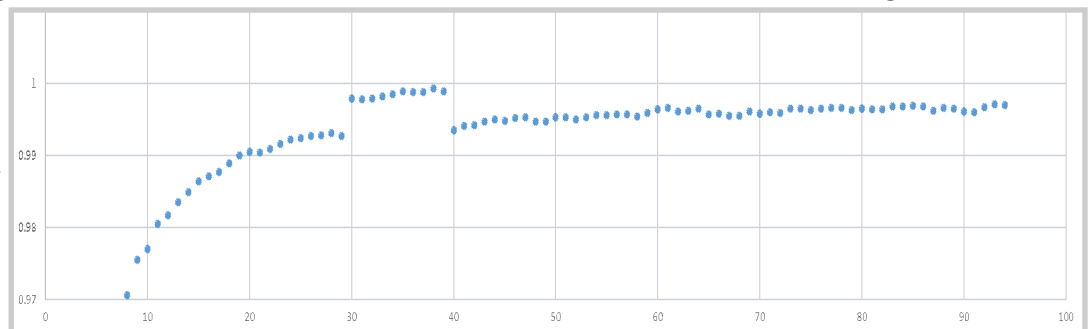


NOTE: For the most precise results possible, Arbin offers a multi-chambered temperature chamber (MZTC) to maintain constant temperature of cells under test. The MZTC also provides a safe testing environment by isolating cells to prevent cascading failures. [Learn more under Topic #4; Options]

Translating this into test results...

Arbin defines the affect of temperature on the instrument accuracy as $\sim 0.000185\% / 1^\circ\text{C}$, by using patented shunt designs and high-quality materials that are resistant to temperature fluctuations. Additionally, some of Arbin's test equipment uses internal thermal control mechanisms that isolate sensitive components and tightly regulate the temperature using techniques developed during a multi-year investigation with partners Ford Motor Company and Sandia National Lab's metrology department; regarded as one of the best in the world. This technology allows the test equipment to maintain incredibly high precision measurements.

Plot shows the affect of sudden temperature change



How to Evaluate Battery Test Equipment

1. Hardware - Specifications and Quality of Materials

Robustness; the quality of materials and quality of construction have a major impact on how long the test equipment lasts and how long it will hold calibration. Resistance to corrosion and temperature fluctuations are significant attributes of high-quality test equipment. The instruments duty cycle and the maximum power rating also heavily contribute to the usefulness and longevity of the equipment.



Long-term battery testing requires test equipment to run continuously. Modern batteries are designed to run for thousands of cycles at a minimum, while xEV and grid storage applications require batteries to last 10's or even 100's of thousands of cycles. High-quality test equipment that can operate without interruption is necessary for such applications. Likewise, the power demands for modern batteries make it important to verify the max power rating of test equipment. Many will not be rated to operate at a maximum calculated power (max voltage x max current), especially with a 100% duty cycle.

Low quality equipment is known to have a high failure rate and may not hold calibration. Frequent calibration checks and re-calibration will be required, which affects the validity of results data. Replacing failed test equipment on a regular basis also affects the validity of test results across this period.



Arbin 96-channel cycler using bipolar circuitry and designed for continuous operation.

Translating this into test results...

Arbin testers have corrosion resistant coatings on all circuitry. The high-quality materials offer better natural resistance to temperature fluctuations and some products have special thermal management technology inside for sensitive components (ask your Arbin sales rep for more information). Arbin test equipment is also engineered to run *continuously* on a 100% duty cycle and is rated to operate at maximum power (full voltage, full current output).

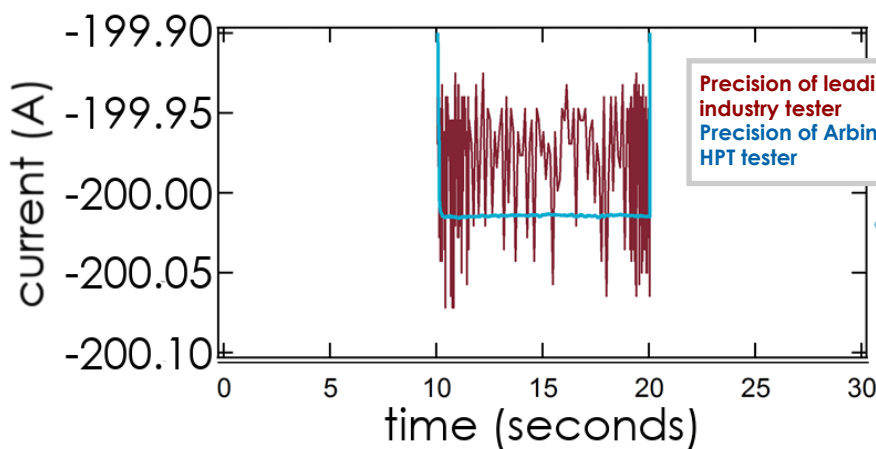
The **true bipolar circuitry** used by Arbin eliminates the switching time between charge and discharge. It also increases the longevity of equipment since relays are not switching during test profiles with frequent charge/discharge such as drive profile simulations.

How to Evaluate Battery Test Equipment

1. Hardware - Specifications and Quality of Materials

Accuracy represents the trueness of test equipment measurement; the closeness of average sample to its true value. Specifying this metric requires comparison to a known source such as a high-performance meter.

Accuracy should not be confused with noise. The relationship between “accuracy” and “precision” relates to the measurement noise. As stated above, accuracy is how close the average measurement is to the true value largely ignoring noise. Precision specifies to the amount of noise that will be present. Therefore, an instrument with good accuracy can still have a noisy measurement if it has poor precision and can be affected by temperature fluctuations.



Red plot is noisy (poor precision) with average sampling slightly less than -200A representing accuracy.

Blue plot has low noise (high precision) with average sampling slightly greater than -200A also representing accuracy.

Both plots have similar accuracy specification, but very *different* measurement precision as seen by the noise.

Plot of -200A discharge pulse on two different testers.

Translating this into test results...

Note the plot and description above. Many types of battery test equipment will have similar accuracy specifications, and while this is important, it should be evaluated in combination with the instrument's resolution and precision. The accuracy metric alone can hide the true performance difference of the equipment.

Calibration is another related factor to question during evaluation. Battery test equipment that is sufficient to use a simple hand-held meter during calibration will not produce results any better than the meter. Arbin calibration requires a 6.5 digit or better digital multi-meter and some equipment will require 8.5 digit or better. NIST-traceability is maintained for meters used in all factory calibrations.



Inadequate meter for calibration

Arbin Instruments



6.5 digit (or better) meter should be used for calibration

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2. Software - Usability and Features

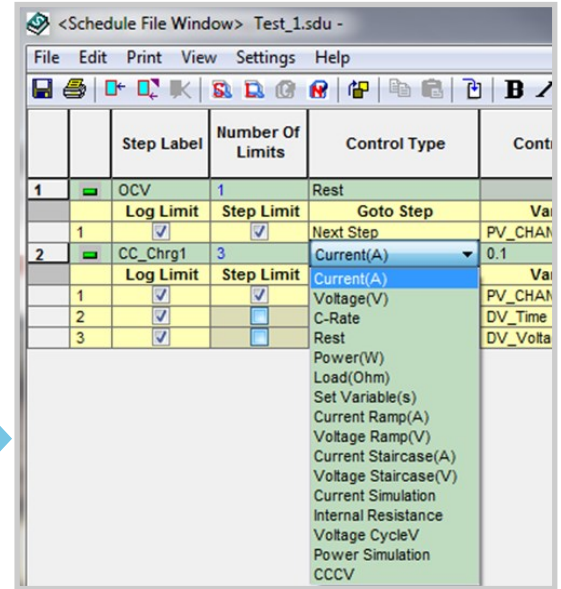
All battery test equipment requires software to operate the instrument. The software interface can be one of the main differentiating points besides hardware performance. It is important to confirm the software communicates using a modern high-speed standard such as TCP/IP (Ethernet) protocol and whether high-performance microcontrollers are used internally. This helps future-proof the system as well as meet the bandwidth necessary for fast data logging.

A software user interface should use familiar commands and follow a logical process to create tests, but also needs the flexibility to control advanced test protocols. The best software will not restrict the researcher to pre-defined test parameters, but will give full authority over the equipment's voltage and current control. The following questions will help identify a complete feature-set:

- Are capacity and energy calculations made at the micro-controller level or post-processed data?
- Is there a limit on the number of steps per test?
- How can an EV drive profile be performed?
- Do tests utilize branching and looping conditions?
- Can tests utilize multiple condition like this for each step and combine logical functions?
- Can tests use mathematical functions?
- Can the software use meta-variables instead of numeric values only, such as stopping a test based on "80% discharge capacity" instead of only a numeric value?
- How many of these meta-variables are offered?
- Can tests be controlled using C-rate values instead of amperage if the cells under test vary in capacity?
- Can channels be connected in parallel to increase the current capability? If yes, then how many?

Arbin allows all these methods and more to apply dynamic and complete control of voltage, current, power, & load, and offers user-defined variables in addition to the 90+ standard meta-variables.

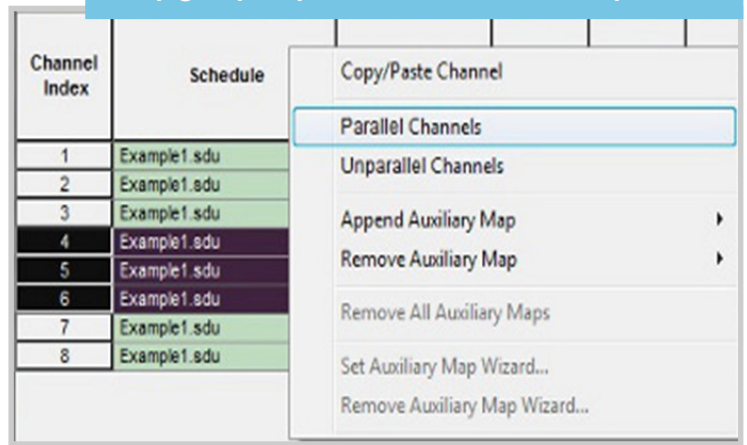
Easy to use dropdown lists to build test profiles.



Control Type	Control Value	Extra Control Value 1
Rest		
Goto Step	Variable1	Operator1
Next Step	PV_CHAN_Step_Time	>=
	DV_Time	>=
Current Simulation		
Goto Step		
Next Step	PV_	
	DV_	

Simple method to implement drive cycle or other simulation.

Easily group any number of channels in parallel.



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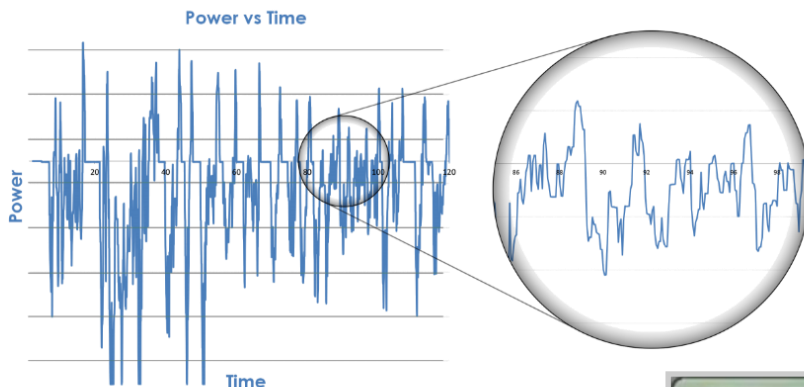
3. Data - Logging, Management, and Analysis

Logging and analyzing results data is the ultimate purpose of battery test equipment. Researchers must have the ability to record results from the tests and experiments performed. In addition to the test equipment resolution, precision, and accuracy described in the *hardware* section, the test equipment must be able to capture the resulting data at a sufficient rate and be able to manage the potentially large volumes of data through a professional database format.



Arbin's MITS Pro Software

Arbin's standard logging rate is **2000 pts/sec**, per system. Special hardware is available for high speed pulse applications that log as fast as **0.05ms**. This rate of logging is possible since all Arbin testers use Ethernet-based communication. A high-bandwidth method of communication like Ethernet is an important feature to compliment the instrument performance. In addition to the fast logging rate, Arbin systems automatically calculate charge/discharge capacity and energy values directly from the microcontroller sampling, which creates the most accurate calculations possible. Many other testers will calculate these values based on logged or post-processed data, which will be less accurate than the internal microcontrollers can generate.



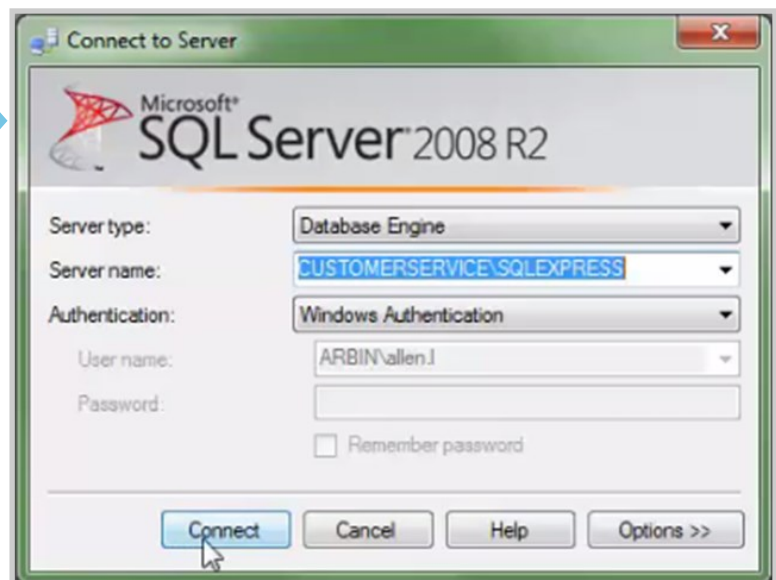
Drive profile simulation with high rate data logging.

Large volumes of data can be generated relatively quickly with fast logging, many test

channels, and/or long-term operation. It is common for drive profile simulations to log 100k datapoints or more.

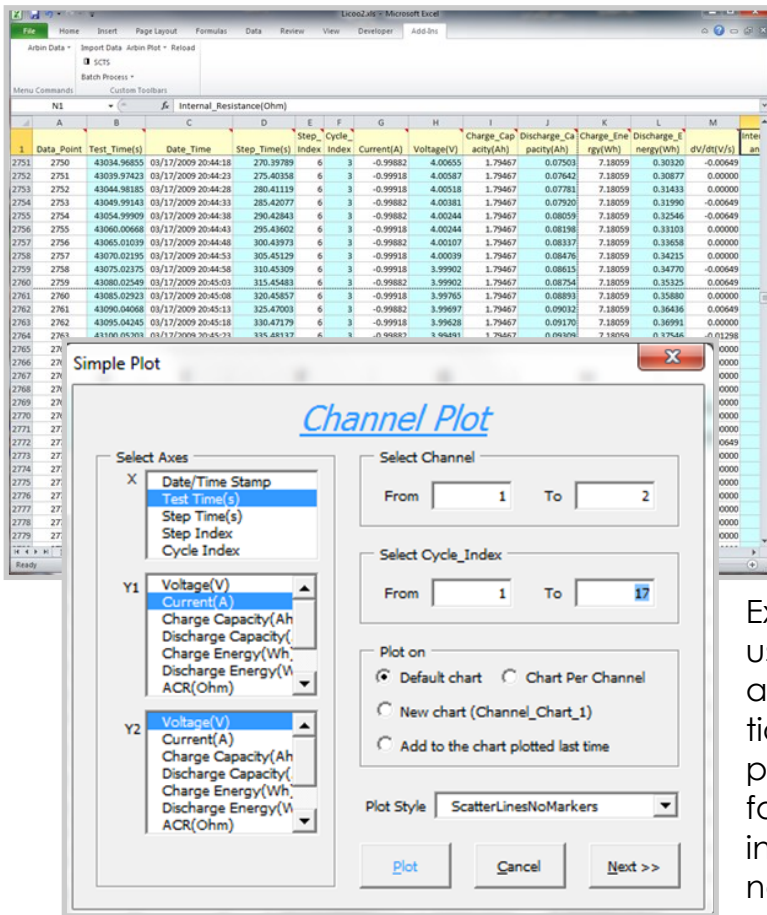
A professional and non-proprietary database format is required to manage data. The database should have backup and mirror capabilities and be network-friendly. **SQL** represents the industry standard for such a database and is used by Arbin for all results data. IT professionals across industry rely on SQL as their "big data" solution for security and management.

SQL is the industry-leading database format preferred by professionals.



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3. Data - Logging, Management, and Analysis



While SQL is an incredibly powerful database for large sets of data, we realize it may not be user-friendly for everyone, therefore Arbin provides tools to automatically import data into Excel format with our **DataPro** macro including analysis and plotting tools. A real-time graphing program (**DataWatcher**) is also provided to view results while tests are running.

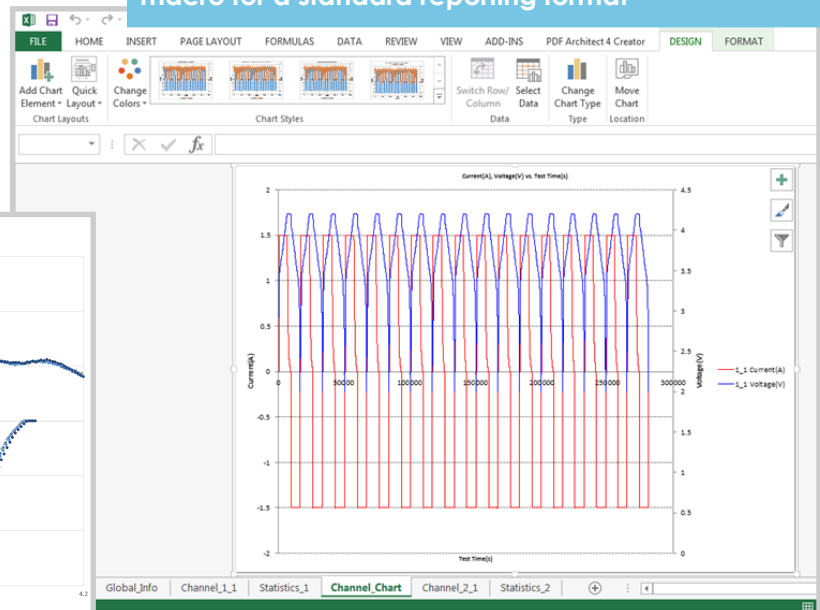
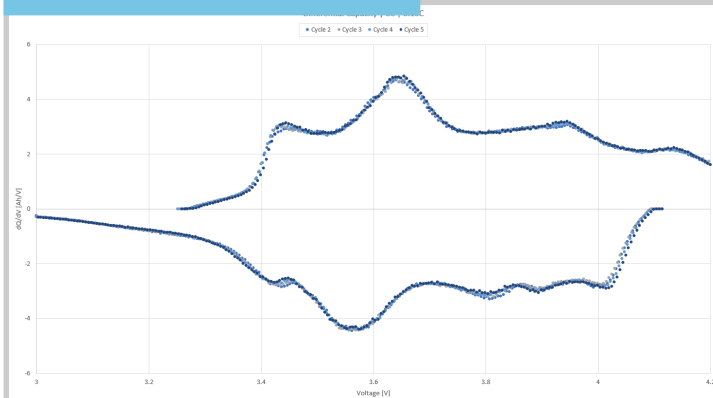
[TOP] Raw data imported into Excel using Arbin's DataPro macro.
[MIDDLE] Use Arbin's DataPro macro to easily create custom plots.

Excel provides the user-friendly interface all users can apply to analyze results and create reports for internal or external publication. Arbin's DataPro macro in Excel makes plotting and customizing data for reports effortless, and users are granted the license to install these tools on as many facility PC's as needed.

DataPro can automatically plot per-cycle data, view most recent 10% of data, import specific cycles of data, and much more. It includes auxiliary data such as additional reference electrodes and temperature measurement when present.

[BELOW] Users have Excel's full capability to further customize plots generated by Arbin's DataPro macro for a standard reporting format

[BELOW] Differential Capacity (dQ/dV) plot.



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4. Options and Accessories

Battery test equipment is a key piece of hardware for an researcher working on energy storage, but the charge/discharge electronics are only part of the solution. There are many additional features and accessories that are required for various battery test applications.

Measurement Auxiliaries add additional measurement capability to the test equipment.

- **Secondary voltage sense** leads can be added to any Arbin system to provide additional reference electrodes in a multi-electrode experiment or to monitor cell or module voltages within a pack.
- **Auxiliary temperature measurement** can be used as a safety limit and to control the test. Inputs are offered for T & K-type Thermocouple and PT100 or 10kOhm thermistor.
- **Electrochemical Impedance Spectroscopy (EIS) Interface** allows an EIS module to be connected and multiplexed across up to 32 Arbin channels. Multiple EIS modules may be used with higher channel-count systems. The EIS module is internally shared by the Arbin test channels so no change of connection is required, and data is automatically merged together.



External Control Auxiliaries add ability to control or interface with external hardware or smart circuitry inside a battery pack.

- **Analog** and **Digital Input/Output** channels allow the Arbin system to interact with external hardware and devices through a digital on/off relay signal, or an analog 0-10V signal. Typical uses include pumps, flow meters, valves, etc. for flow battery applications.
- **3rd Party Chamber Interface (TCI)** allows the Arbin system to communicate with an approved 3rd party temperature chamber. Arbin's software can turn the chamber on and off and adjust temperature during the test.
- **CANBus** and **SMBus** option allow the Arbin system to communicate with a battery management system inside a battery pack. It will both send and receive CAN and SMBus messages to the device under test. There are no 3rd party DLL packages or licenses required.



Meta Variable Name	Meta Name	Enable	Data Log	CAN Message ID	DLL
1 CAN_MV_001	BCU_hardware_number	✓	✓	0x002	0
2 CAN_MV_002	BCU_software_version	✓	✓	0x002	0
3 CAN_MV_003	BCU_manufacture_code	✓	✓	0x002	0
4 CAN_MV_004	BCU_error_memory	✓	✓	0x002	0
5 CAN_MV_005	HCU_SOC	✓	✓	0x038	0
6 CAN_MV_006	EMU_status	✓	✓	0x281	17
7 CAN_MV_007	BCU_CAN_error	✓	✓	0x331	4
8 CAN_MV_008	BCU_general_error	✓	✓	0x331	4
9 CAN_MV_009	SOC	✓	✓	0x251	0
10 CAN_MV_010	SOCmin	✓	✓	0x251	0
11 CAN_MV_011	SOCmax	✓	✓	0x251	0
12 CAN_MV_012	SOC_warn	✓	✓	0x251	0
13 CAN_MV_013	Cap_actual	✓	✓	0x251	0
14 CAN_MV_014	Umax	✓	✓	0x241	0
15 CAN_MV_015	min_voltage_module_number	✓	✓	0x241	0
16 CAN_MV_016	max_voltage_module_number	✓	✓	0x241	0
17 CAN_MV_017	min_battery_temperature	✓	✓	0x241	0
18 CAN_MV_018	Target_battery_temperature	✓	✓	0x241	0
19 CAN_MV_019	min_battery_temperature	✓	✓	0x241	0
20 CAN_MV_020	max_battery_temperature	✓	✓	0x241	0

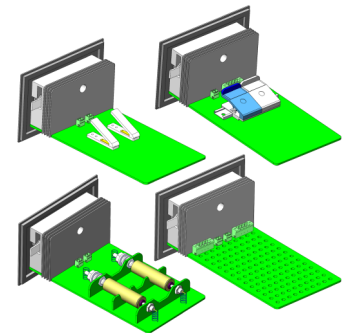
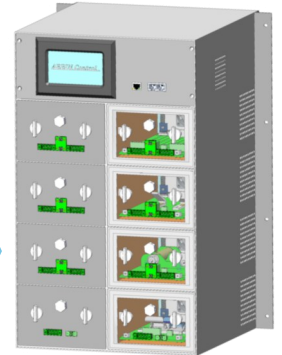
How to Evaluate Battery Test Equipment

4. Options and Accessories

Optional Modules and Accessories can complement the main test equipment.

- **Auto-Calibration** module enables the Arbin system to self-calibrate when connected to a compatible meter.
- **Arbin Multi-Chamber (MZTC)** is a temperature chamber with 8 independent chambers that isolate cells to provide the best temperature stability and to isolate cells
- **Uninterruptable Power Supply (UPS)** option provides a 1500Wh UPS designed to support the PC and detect a power outage. The software will stop tests if power is lost and then resume automatically if power is restored quickly or else safely shut down the PC to help protect data. 1 UPS provides backup power for 1 PC.
- **Battery Holders** of all sizes ranging from coin cells, up to 300A (pouch cell) or 200A (cylindrical cell). Trays that hold groups of 4-8 batteries are also offered.
- **Battery Racks** are available for coin cells, cylindrical cells, pouch cells, and universal trays with positions for up to 192 cells on the rack.
- **High Precision Shunts** were developed by Arbin during our 3-years ARPA-E project with industry partners, Ford Motors and Sandia National Lab. These are available for calibration of relatively high currents greater than the limit of most digital multi-meters.

Arbin Multi-Chamber with trays for each cell type below



largest

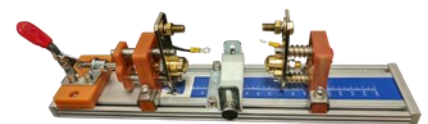
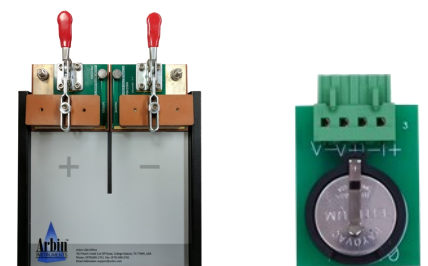


Choose from 4 sizes of Rack and choose battery trays for coin cells, cylindrical cells, pouch cells. High amperage available.

Choose from dozens of battery holders and cables for:

- Coin cells (4 sizes available)
- Cylindrical cells (<10A, up to 200A)
- Pouch/Flat cells (<10A, up to 300A)
- Cables with alligator clips, ring terminals, or other

NOTE: More details are available in our separate catalog of all connection options to interface between Arbin tester and battery under test.



How to Evaluate Battery Test Equipment

5. Support and Safety

Battery test equipment is a significant investment for companies large and small, so supporting this investment is equally important. Support should include the initial setup and training, eventual maintenance that may be necessary, and how safe the equipment is to use.



The following questions will help determine whether a manufacturer can effectively provide support:

- Is a local representative available to provide training and answer questions?
- Are there other training materials and resources available?
- How easy is it to contact support?
- Are there regional personnel available to help?
- Is test equipment modular allowing easy repair or replacement of parts?



Most battery researchers are familiar with the catastrophic failures possible with even relatively small cells. Low capacity cells can still release a significant amount of energy if a failure event occurs. Thermal runaway is especially dangerous in a testing environment since a large quantity of cells may be kept in a small space, and safety equipment may be lacking. Safety of the testing environment can be addressed both through **prevention** and



containment.

The test equipment should provide multiple layers of safety limits when creating and running test profiles. It should also have redundant internal mechanisms to monitor safety limits. Arbin systems do this by providing a redundant microcontroller that is dedicated to watching safety limits in the case that a primary microcontroller on a board fails. Likewise, all internal communication is continually monitored and will stop a test if a loss of communication is detected.

Containment of failure propagation can be achieved with Arbin's new Multi-Chamber (MZTC). This is an innovative temperature chamber design with 8 fully independent chambers that allow more stable thermal control and isolates cells from each other in the case of a battery failure. Each of the 8 chamber can hold between 1 and 4 cells, depending on the size and amperage, and provides a pressure relief valve. This comprehensive approach to safety has built Arbin's reputation as a trusted partner.

How to Evaluate Battery Test Equipment

Contact us today to learn more about test equipment and accessories from Arbin. We offer everything from multi-channel potentiostat/galvanostats, up to pack testers at 1MW; including specialty applications such as smart battery packs, high speed telecom pulses, and temperature chambers.

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