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 whether they are starting small, or at massive scale. Here are five key topics to consider when choosing battery test equipment:

1. Hardware - Specifications and Quality of Materials
2. Software - Usability and Features
3. Data - Logging, Management, and Analysis
4. Options - Auxiliary Features and Accessories
5. Support - Product Safety and Support

1. Hardware - Specifications and Quality of Materials

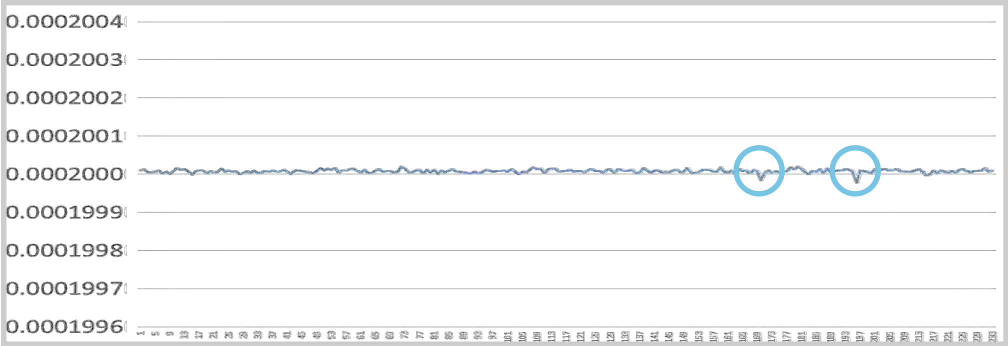
Resolution indicates the smallest change in measurement that can be detected by the instrument's sense circuitry. Typically referred to in "bits" of resolution or an absolute unit of measurement such as µV or µA.

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

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. 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.

The plot at right shows even the smallest change in current, which would be invisible on a lower resolution instrument.



How to Evaluate Battery Test Equipment

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.

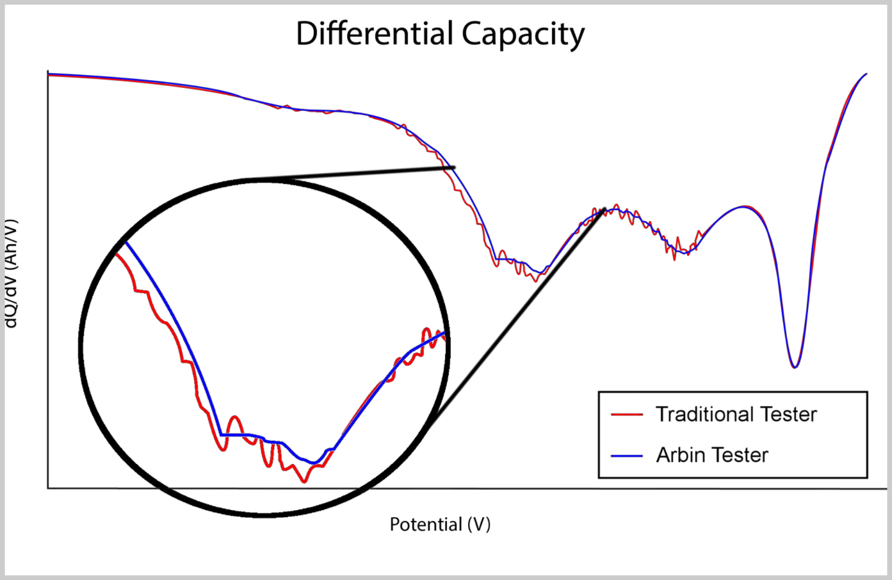
Many instruments will not specify their precision, which is a warning sign, or will improperly report precision though multiple averaged calculations or very slow frequency data logging that hides the noise. Another common tactic is to report precision of battery coulombic efficiency calculations instead 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 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 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.



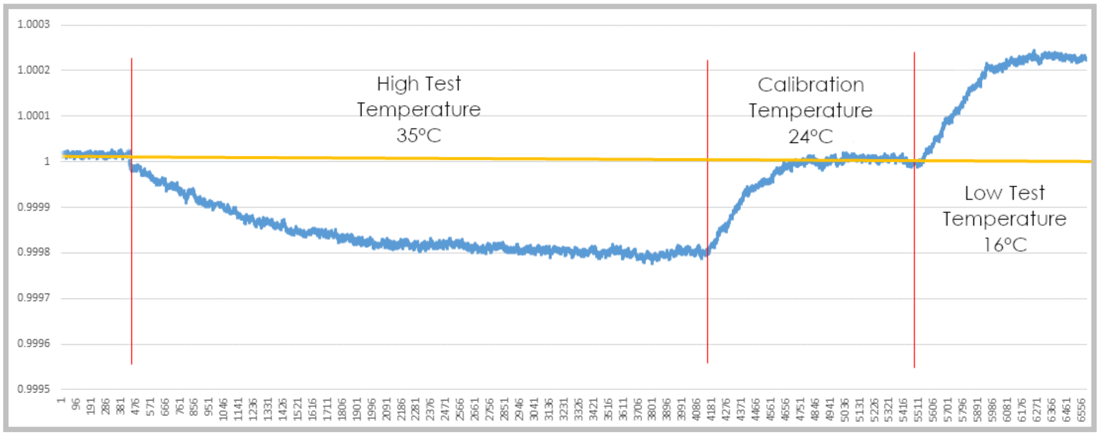
Benefits of high-precision seen in dQ/dV curve. Note the first event in the zoomed in portion likely would have been missed with an instrument with poor precision.

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.



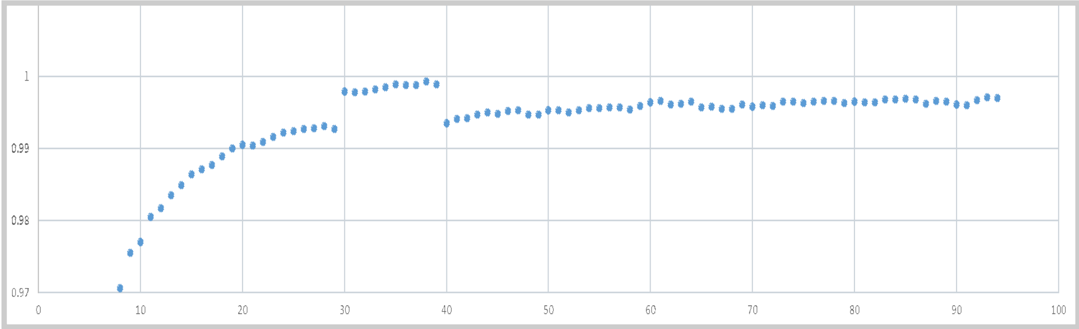
Knowing how temperature affects the measurement empowers the researcher when determining the experimental error. When test equipment resolution and precision are sufficient, measurement fluctuation due to temperature will be seen. *Gradual* temperature changes will *gradually* skew results data [above], 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 (MTC) to maintain constant temperature of cells under test. The MTC 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 ~0.000185% / 1°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



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 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.

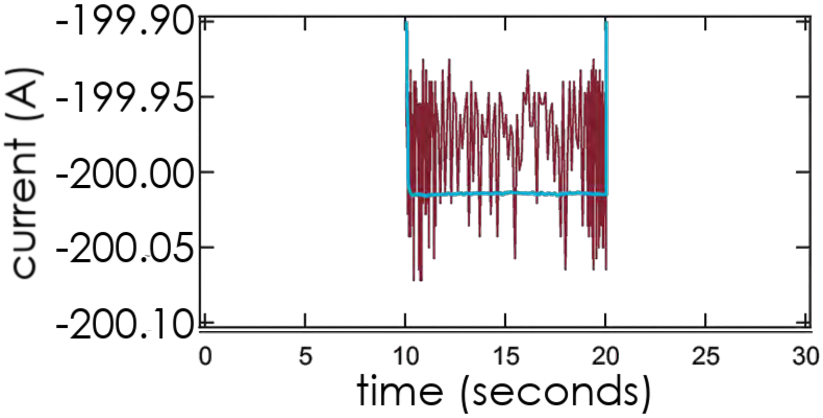
Translating this into test results...
Arbin testers have corrosion resistant coatings on all circuitry. The high-quality materials offer better natural resistance to temperature fluctuations and some products have special thermal management technology inside for sensitive components (ask your Arbin sales 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.

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 shows noisy measurement with average sampling slightly less than -200A representing accuracy.
Blue plot shows measurement sampling with almost no noise and 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.
Blue is Arbin LBT generation; Red **is previous industry "state**-of-the-**art."**

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.

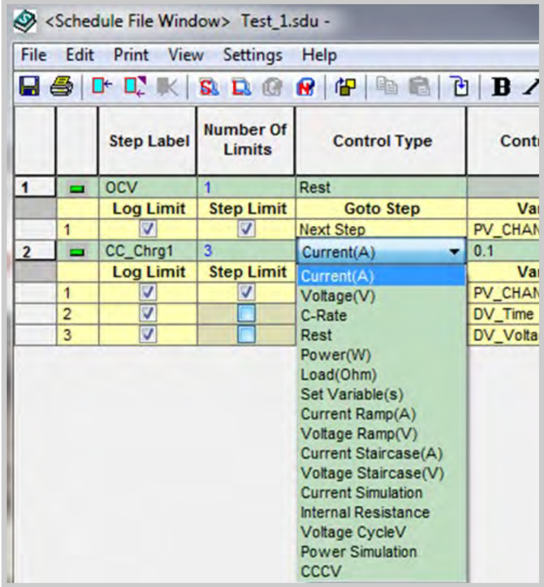
Calibration is another related factor to question during evaluation. Battery test equipment that is sufficient to use a simple hand-held meter during calibration will not produce results any better than the meter. Arbin calibration requires a 6.5 digit or better digital multi-meter and some equipment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

Inadequate meter for calibration

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

2. Software - Usability and Features

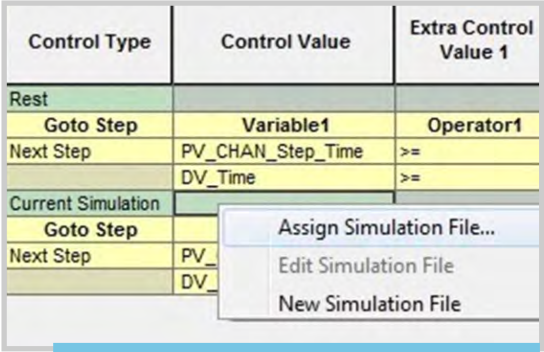
All battery test equipment requires software to operate the instrument. The software interface can be one of the main differentiating points besides hardware performance. It is important to confirm the software communicates using a modern high-speed standard such as TCP/IP (Ethernet) protocol and whether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



Easy to use dropdown lists to build test profiles.

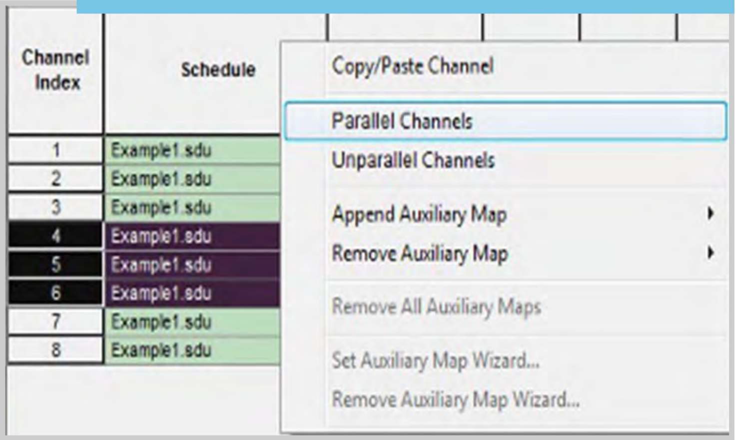
A software user interface should use familiar commands and follow a logical process to create tests, but also needs the flexibility to control advanced test protocols. The best software will not restrict the researcher to pre-defined test parameters, but will give full authority over the equipment's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



Simple method to implement drive cycle or other simulation.

Easily group any number of channels in parallel.



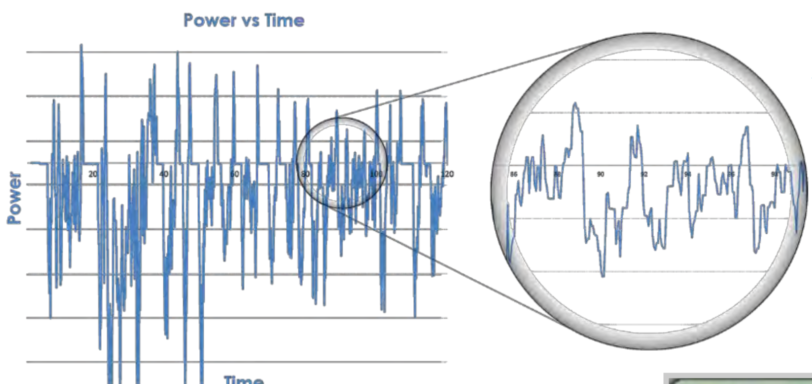
Arbin allows all these methods and more to apply dynamic and complete control of voltage, current, power, & load, and offers user-defined variables in addition to the 90+ standard meta-variables.

3. Data - Logging, Management, and Analysis

Arbin's MITS Pro Software

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 though a professional database format.

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.



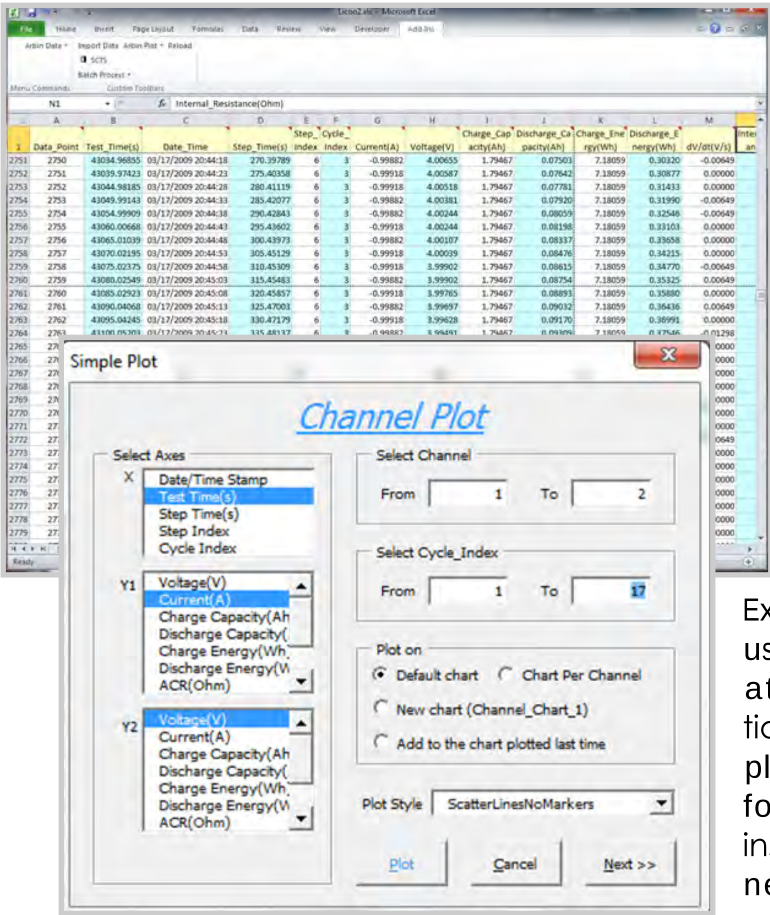
Drive profile simulation with high rate data logging.

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 of SQL as their "big data" solution for security and management.

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

3. Data - Logging, Management, and Analysis



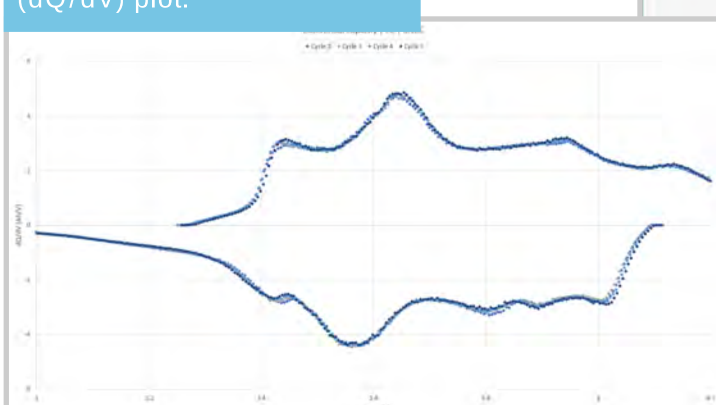
While SQL is an incredibly powerful database for large sets of data, we realize it may not be user-friendly for everyone, therefore Arbin provides tools to automatically import data into Excel format with our DataPro macro including analysis and plotting tools. A real-time graphing program (DataWatcher)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

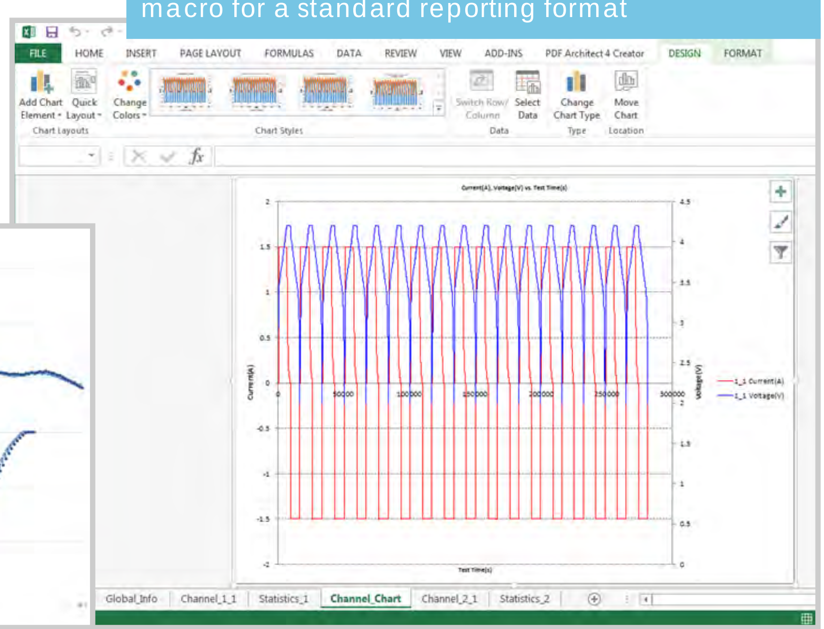
Excel provides the user-friendly interface all users can apply to analyze results and create reports for internal or external publication. Arbin's DataPro macro in Excel makes plotting and customizing data for reports effortless, and users are granted the license to install these tools on as many facility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



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



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.

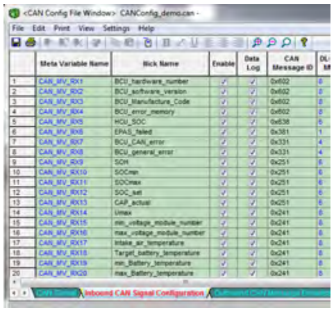
Measurement Auxiliaries

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 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 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.



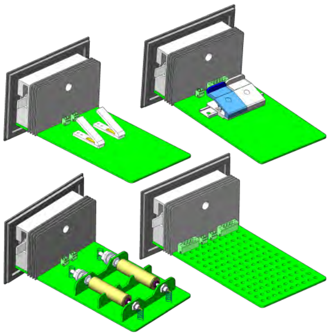
- Analog and Digital Input/Output channels allow the Arbin system to interact with ex-ternal hardware and devices through a digital on/off relay signal, or an analog 0-10V signal. Typical uses include pumps, flow meters, valves, etc. for flow battery applications.
- 3rd Party Chamber Interface (TCI) 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.

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 (MTC) 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 coincells, 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 coincells, cylindrical cells, pouch cells, and universal trays with positions for up to 192 cells on the largest 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.

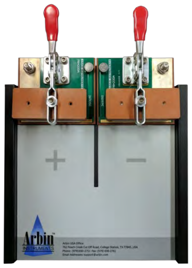
Arbin Multi-Chamber with trays for each cell type below

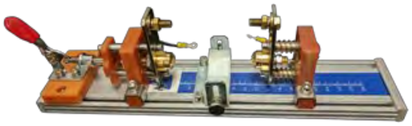


Choose from 4 sizes of Rack and choose battery trays for coin cells, cylindrical cells, pouch cells. High amperage available.

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





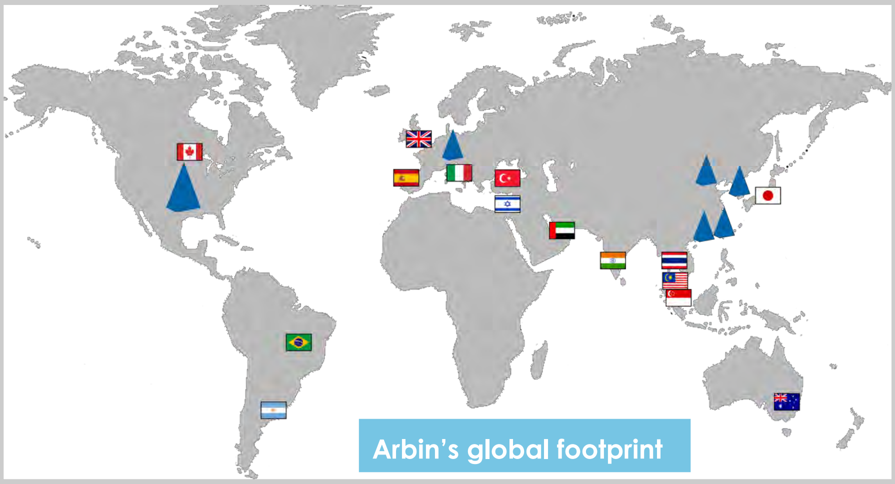
NOTE: More details are available in our separate catalog of all connection options to interface between Arbin tester and battery under test.

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?


Arbin's global footprint

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 (MTC). 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.