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Hioki Solutions for battery industry

Testing → Control → Product development

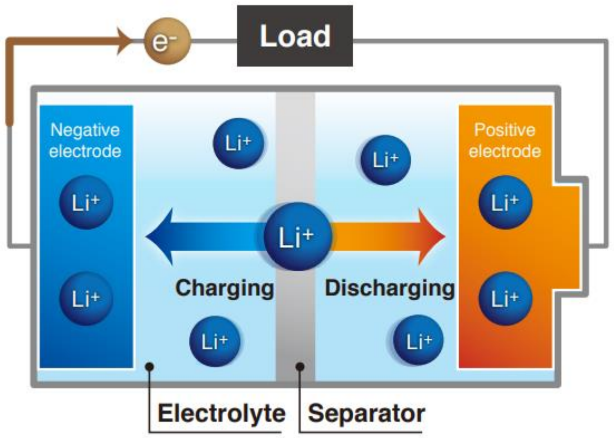
1. Introduction

Lithium-ion batteries (LIBs)

Lithium-ion batteries (LIBs) is a rechargeable battery that is charged and discharged by lithium ions moving between the positive (anode) and negative (cathode) electrodes.

Because LIBs are suitable for storing high-capacity power, they are used in a wide range of applications.

- Past to present:
  - Power supply for portable devices
- Present:
  - Stationary energy storage systems (ESS/BESS)
  - Electric vehicles (EVs, HEVs and PHEVs)

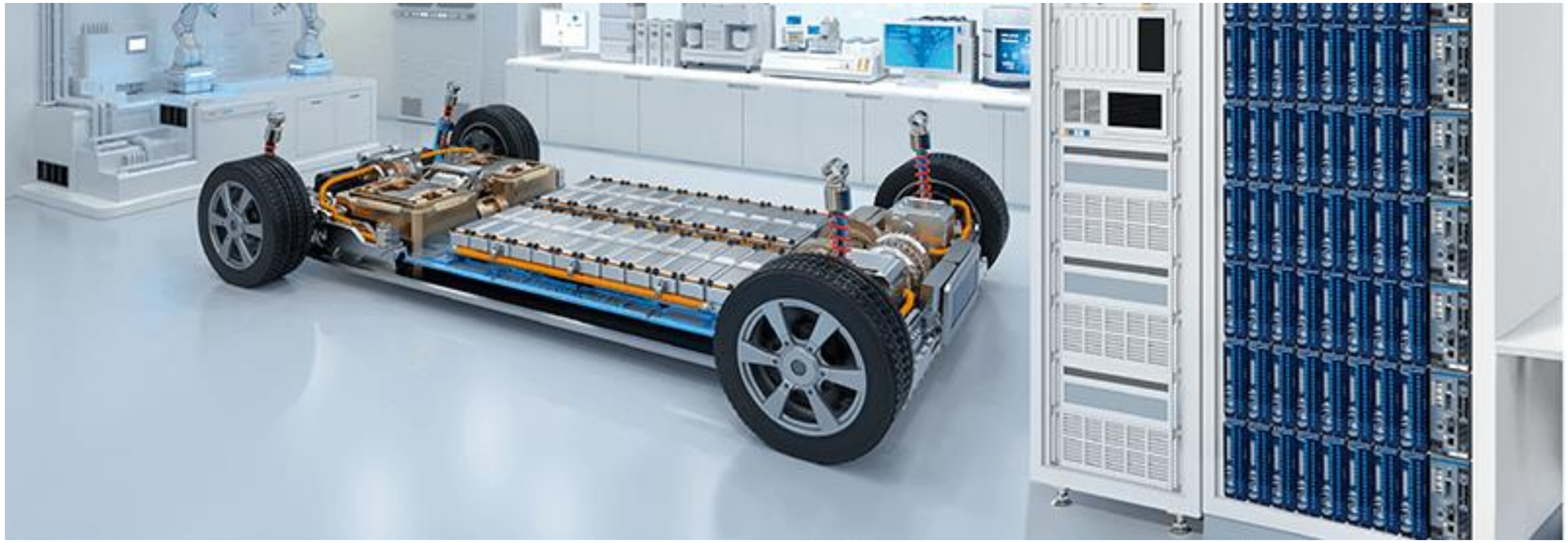


Lithium-ion batteries (LIBs)

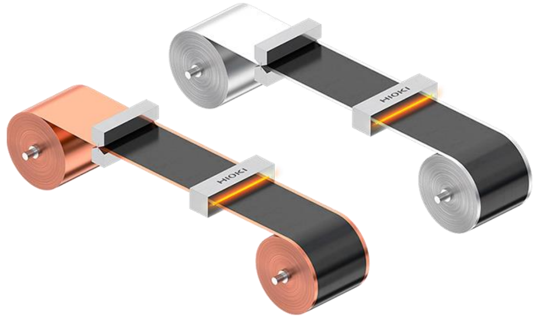
Key battery characteristics (EV as an example):

- High energy density -> Long-distance driving
- The ability to charge using large currents -> Fast charging
- Long battery service life (improved performance of repeated charge/discharge cycles) -> Extended use
- Protective functionality provided by prevention of internal battery short-circuits -> Improved safety
- Limitations on material prices and high productivity -> Lower vehicle cost

To achieve battery characteristics shown above, many different measurements and tests are necessary at each state of the battery manufacturing process to assure the quality of each process!



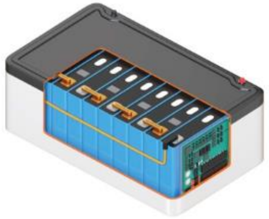
Overview of the Lithium-Ion Battery Production Process



Manufacturing of Materials (slurry) and Electrodes

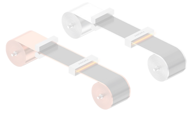
Assembly of Battery Cells

Performance testing of finished Battery Cells



Assembly of Modules and Packs

Overview of the Lithium-Ion Battery Production Process



Manufacturing of
Materials and Electrodes

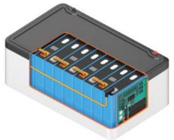
- Slurry production
- Electrode fabrication
- Quality testing of electrode sheets

Assembly of
Battery Cells

- Slitting & Final Drying
- Winding / (or) Stacking
- Tab welding
- Terminal welding
- Assembly & case closing
- Insulation resistance safety tests

Performance testing of
finished Battery Cells

- Electrolyte Filling
- Formation & Sealing
- Pre-shipments inspection



Assembly of
Modules and Packs

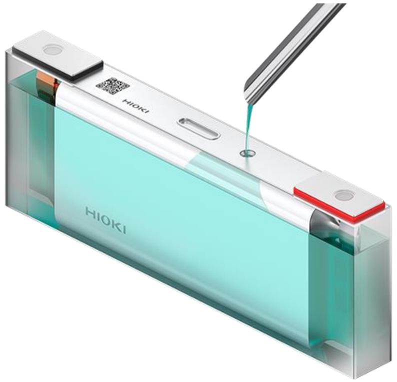
- Total resistance testing of battery modules and battery packs
- Testing of BMS boards
- Pre-shipment inspections of modules and packs
- Actual-load testing of batteries in EVs

2. Performance testing of finished Battery Cells

Initial charging of LIB cell / pre-charging

- Dry cell is now filled with electrolyte.
- A partial vacuum is created in the cell and a pre-determined quantity of electrolyte is delivered to the cell.
- Cell is sealed after the electrolyte filling and vacuuming process and before any first charging

- It is necessary to pre-charge the cell immediately after electrolyte filling in order to prevent elution of the negative electrode’s collector
- The charge/discharge system used to pre-charge the cell



- Formation process of a LIB starts with the initial charging of the cell. This first charge is an essential part of the formation process because it triggers the development of the solid electrolyte interphase (SEI) layer on the anode

Charge/discharge characteristics testing

- The cells are repeatedly charged and discharged.
- Specialized battery cyclers and environmental chambers are used for precise control over the charge/discharge parameters:
  - current
  - voltage
  - temperature
- Data is recorded over multiple cycles to assess degradation and overall battery health

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Modular Data Logger for Battery Charge/Discharge Testing

- Monitoring cell voltage and temperature during charge/discharge testing, is essential.
- As EV battery voltages rise from 400V, 800V, or even 1000V and more, instruments must handle higher terminal-to-ground and module-to-module voltages for safe measurements.

M7100

LR8101

NEW

M7102

LR8102

Hioki Data Loggers: Voltage/Temp. Module M710x series

NEW

Max. 1500 V

Voltage / Temp. Module

M7100

- terminal-to-ground voltage 1500V DC / 1000V AC category II
- 15 channel
- max. input Voltage: 100 VDC
- 5 ms max. sampling rate

Voltage

Temperature

Max. 600 V

Voltage / Temp. Module

M7102

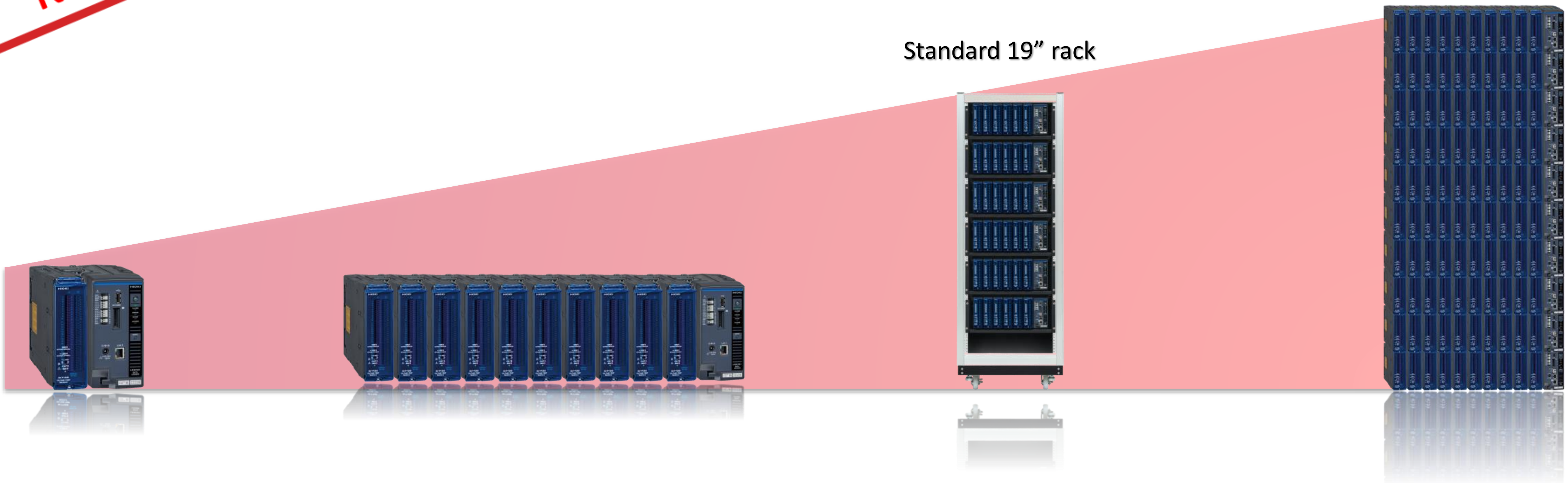
- terminal-to-ground voltage 600 V AC/DC, measurement category II
- 30 channels
- max. input Voltage: 100 VDC
- 10 ms max. sampling rate

Voltage

Temperature

NEW

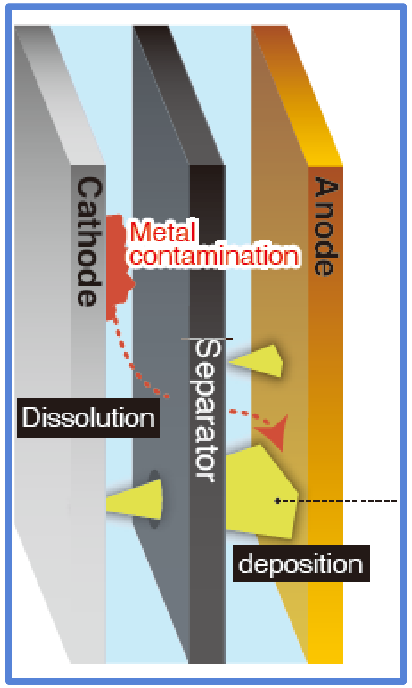
Hioki Data Loggers: Scale up

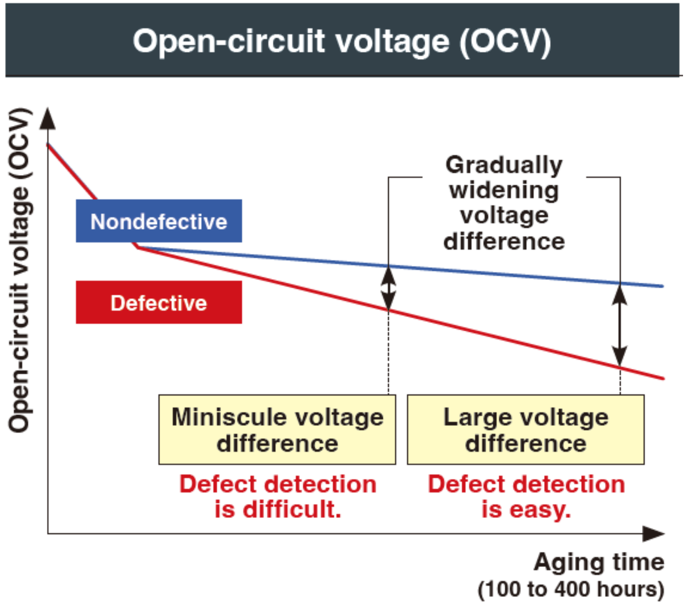


M7100: 15 channels M7102: 30 channels	M7100: 150 channels M7102: 300 channels	M7100: 540 channels M7102: 1080 channels	M7100: 1500 channels M7102: 3000 channels
1 logger 1 module	1 logger 10 modules	6 loggers 36 modules	10 loggers 100 modules

Aging process: OCV measurement

- Open-Circuit Voltage (OCV) refers to the voltage of the battery when it is not under any load (no current flowing).
- Monitoring OCV over time is a key method for understanding and predicting battery aging.
- When an insulation defect such an internal short occurs inside the battery, self-discharge causes the open-circuit voltage to decrease

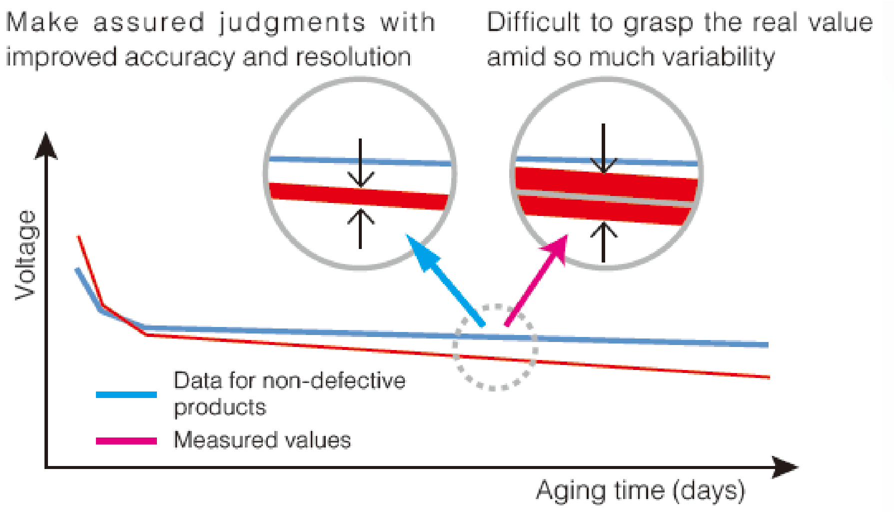




OCV measurement and key considerations

- High Input Impedance
  To avoid drawing current from the battery, input impedance should be 10 MΩ or higher for accurate OCV readings.

- Resolution & Accuracy
  High resolution (millivolt or microvolt) and accuracy within ±0.01% are critical for detecting small voltage changes, especially in battery packs.



- Temperature Compensation
  This feature ensures consistent readings despite temperature fluctuations.

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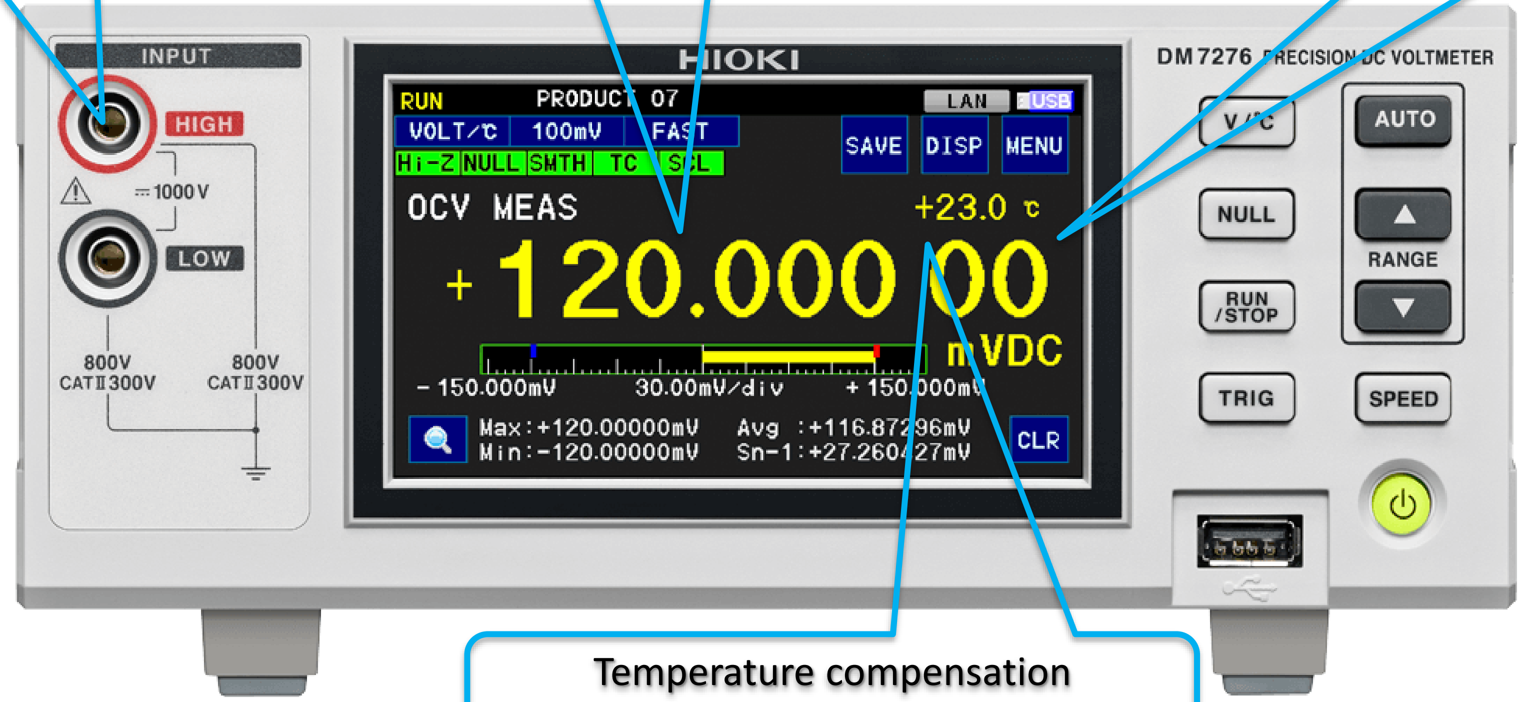
OCV measurement: DM7275/DM7276 series

Input resistance 10 MΩ ±1% (impedance)

7-1/2 Digit and 1 µV resolution

Measurement accuracy ±0.0009% rdg. ±12 µV



Temperature compensation
(Z2001 Temperature Sensor needed)

OCV measurement and Hioki DM7276

- Hioki has multiple solutions to measure OCV
- For OCV measurement during Aging process it is recommended to use DM7276 (why? check Aging measurement Key considerations slide)

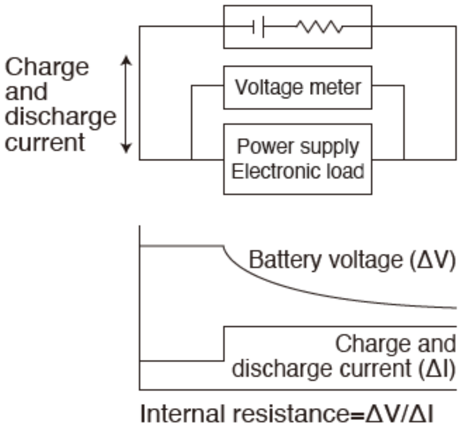
High-accuracy

Model	BT356x series	BT4560	DM7276 (DC VOLTMETER)
Appearance			
Recommended range for 4 V measurement	6 V range	5 V range	10 V range
Number of digit, Max. Display	5 1/2 digit, 6.000 00	5 1/2 digit, 5.100 00	7 1/2 digit, 12.000 000
Resolution*1	10 μV	10 μV	1 μV
Basic accuracy*1	±0.01% rdg ±3 dgt	±0.0035% rdg ±5 dgt	±0.0009% rdg ±12 μV
Measurement error*1 *2	±430 μV	±190 μV	±48 μV
Period of accuracy guarantee	1 year	1 year	1 year
Temperature measurement	N/A	YES	YES
Temperature Compensation Function	N/A	N/A	YES

Pre-shipment Inspection DC-IR and AC-IR

- Internal resistance testing is common and there are two methods of measurement:

DC method (DC-IR)



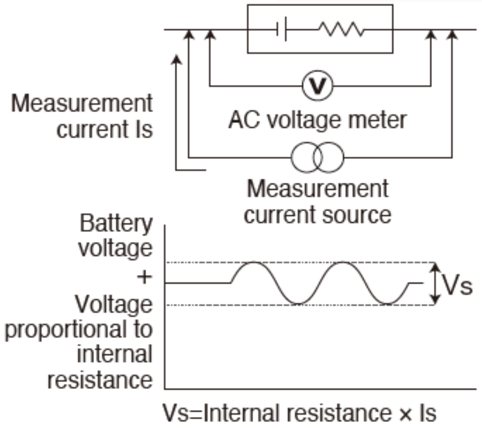
When you want to check battery performance under conditions close to actual operation

Issues with DC-IR

- Measurement takes more time.
- Measurements are less reproducible.
- Battery charges rate changes.
- Large charging and discharging equipment is required.
- The line must be capable of supplying large amounts of power.

Connect a load and measure the resistance value based on the change in voltage and current.

AC method (AC-IR)



When you wish to identify defective products quickly and accurately, for example during shipping or acceptance inspections

Issues resolved by AC-IR measurement

- Quickly measurement with milliseconds.
- Measurements are highly reproducible.
- Battery charges rate not changes.
- Testing can be carried out with compact equipment in an energy-saving manner.

Apply the measurement current at a measurement frequency of 1 kHz and calculate the battery's internal resistance from an AC voltmeter's voltage value.

AC-IR and IEC 61960-3:2017

IEC 61960-3:2017 provides detailed guidelines for performance testing of secondary li-ion batteries used in portable applications / Part 3: Prismatic and cylindrical lithium secondary cells and batteries made from them.

The standard:

The alternating RMS voltage, U_a, shall be measured while applying an alternating RMS current, I_a, at the frequency of 1,0 kHz ± 0,1 kHz, to the battery, for a period of 1 s to 5 s.

All voltage measurements shall be made at the terminals of the battery independently of the contacts used to carry current.

The internal AC resistance, R_{ac}, is given by:

$$R_{ac} = \frac{U_a}{I_a}$$

where

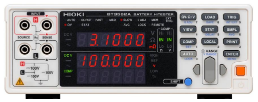
U_a is the alternating RMS voltage;

I_a is the alternating RMS current.

Considerations when selecting the AC-IR instrument

Quality testing / acceptance / shipping inspections

BT3561A Small Cells / packs up to 60V



BT3562A Large Cells for xEVs or *Mid-sized Packs* of up to 100 V

BT3563A Large Packs for xEVs or Large Packs of up to 300 V

BT3564 High-Voltage *EV and PHEV Battery Packs* up to 1000V

BT4560-50 Small Cells up to 5V

R&D

BT4560 battery characteristics analysis by frequency sweep impedance measurement and equivalent circuit analysis.

IM3590 chemical impedance analyzer

Maintenance

BT3554-50 UPS and *lead-acid* battery diagnostics up to 60V

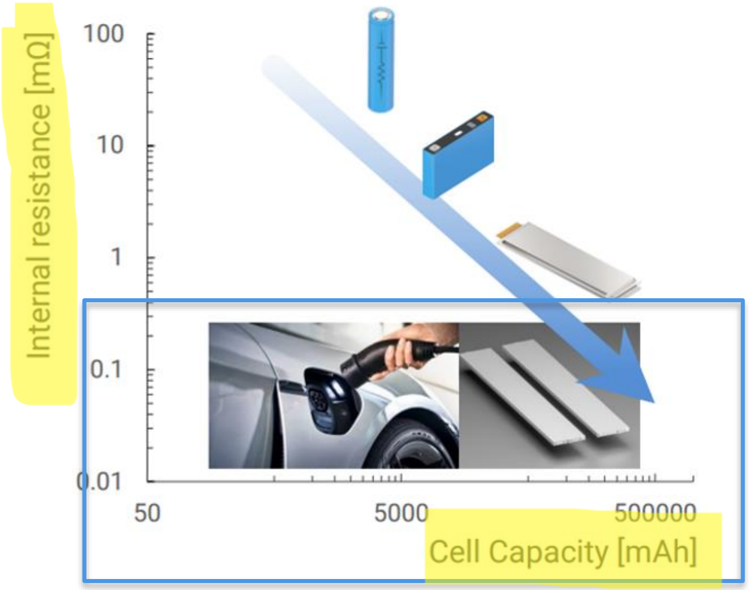
On the picture you will can see the most popular instruments used by end-customers. Optional equipment to be included when ordering (test fixtures, probes, or software).

Requirements for AC-IR measurement of a high-capacity LIB cell

1. *Frequency of Measurement*: ACIR is typically measured at 1 kHz (IEC 61960-3:2017) to avoid electrochemical interference.

2. *Input Impedance & Sensitivity*: The meter should be sensitive enough to detect small resistance changes in the milliohm or micro-ohm range.

3. *Accuracy & Resolution*: Look for ±0.1% accuracy and micro-ohm resolution to measure low internal resistance, especially in Li-ion batteries.



Requirements for AC-IR measurement of a high-capacity LIB cell

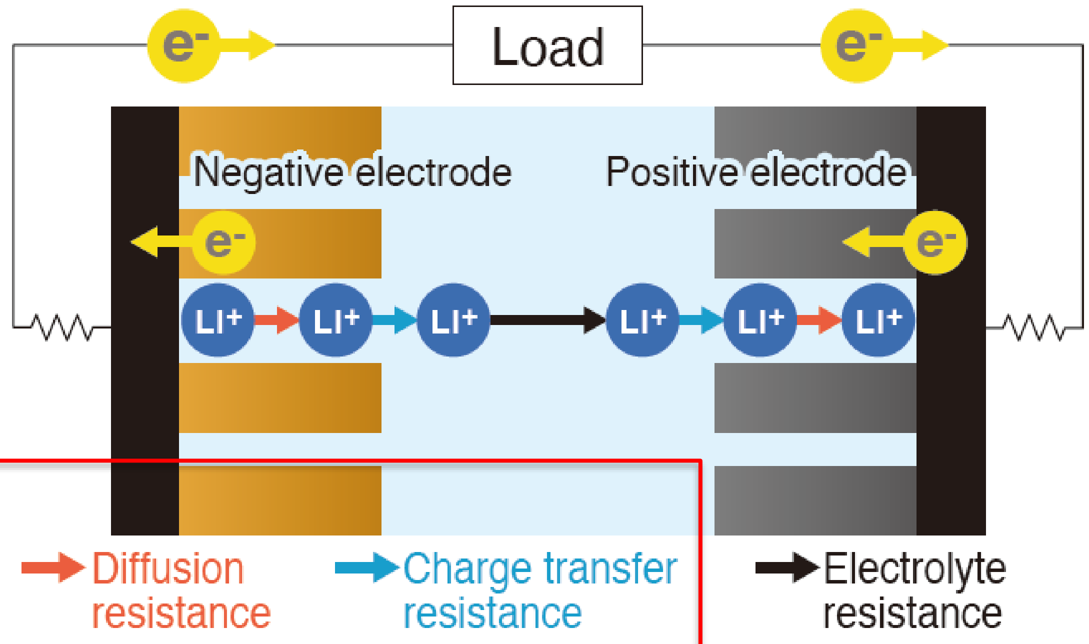
- When measuring AC-IR of high-capacity EV battery cells under1 mΩ IR it is crucial is to have extremely high resolution
- High resolution enables these models to perform advance cell-grading

NEW BT6075

	BT3562A	5.5 digit (Hi-Resolution) BT6065, BT6075	
Display range	3.1000 mΩ	5.10000 mΩ	5.10000 mΩ
Resolution	100 nΩ	10 nΩ	10 nΩ
Test current	100 mA	**100 mA** for long test leads	**300 mA** for more accurate
Accuracy	±0.5 % rdg. ±1 μΩ	±0.08 % rdg. ±0.50 μΩ	±0.08 % rdg. ±0.08 μΩ

Advanced Capabilities in Battery Testing

Low-frequency impedance measurement is crucial for assessing battery health, especially in large EV and energy storage batteries.



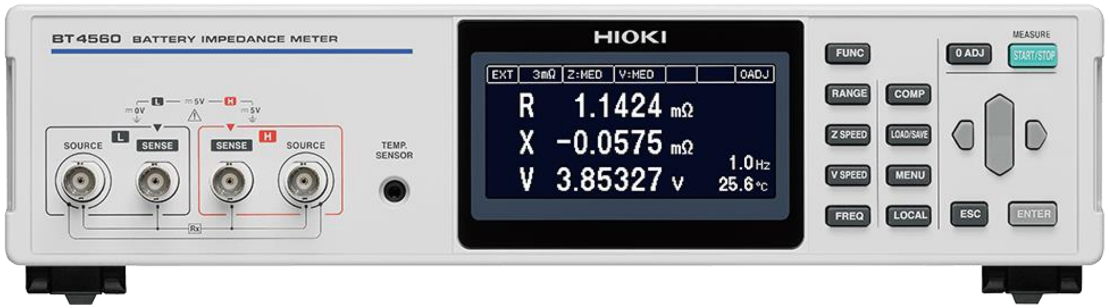
less than 1 Hz	Low frequencies	Li-ion diffusion in the electrode (Diffusion resistance)
1 Hz to several hundred Hz	Intermediate frequencies	Li-ion transfer (Charge transfer resistance)
About 1 kHz	High frequencies	Li-ion transport in electrolyte (electrolyte resistance)

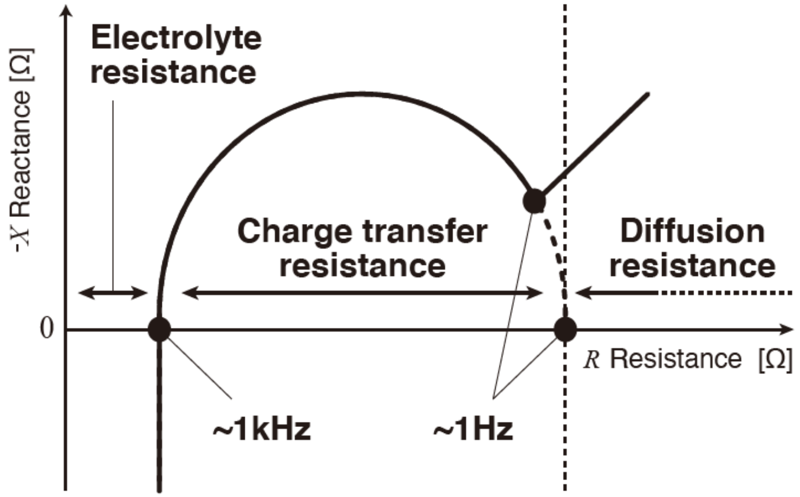
Importance of EIS in Battery Testing and BT4560 -50

Hioki BT4560-50 is a high-precision battery impedance meter designed to measure the internal impedance and voltage of batteries

Electrochemical Impedance Spectroscopy EIS is an analytical technique used to measure the impedance of a battery over a range of frequencies.

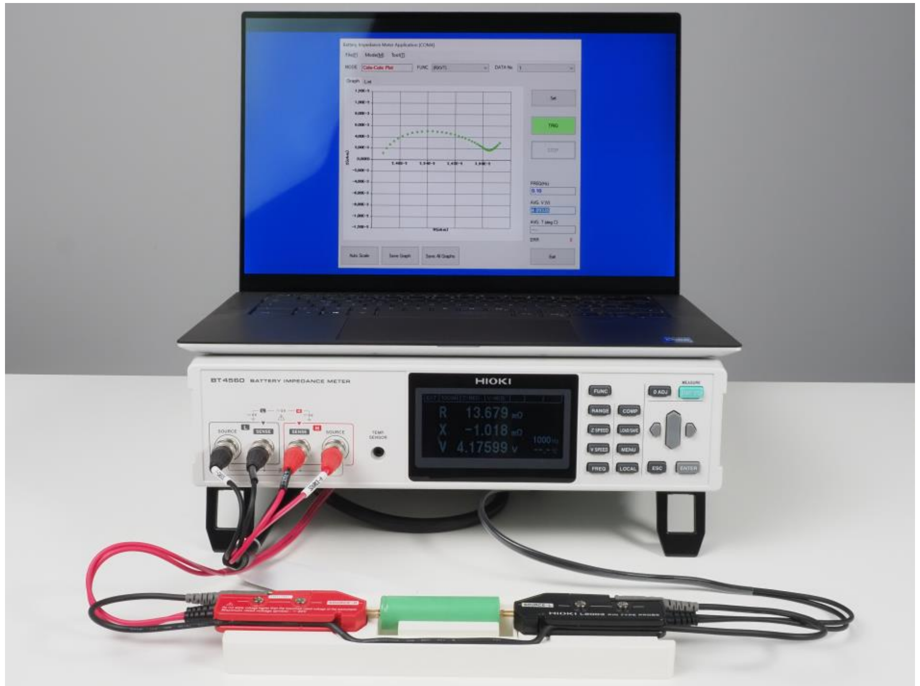
It provides detailed information about the electrochemical processes occurring within the battery, such as charge transfer, double-layer formation, and diffusion.





BT4560 Battery Impedance Meter

- Frequency Range: Typically operates at 1 kHz for standard ACIR tests, but can also perform measurements at lower frequencies (down to 0.01 Hz) for more detailed analysis.
- Accurate IR Measurement: Measures AC – IR with high precision, detecting milliohm level resistance changes, crucial for ensuring battery performance and detecting early-stage failures.



BT4560 basic performance	
Impedance	Maximum resolution: 0.1 μΩ
Voltage range	±5 V, resolution of 10 μV
Measurement current	Max. 1.5 A rms
EIS measurement frequency	10 mHz to 1050 Hz

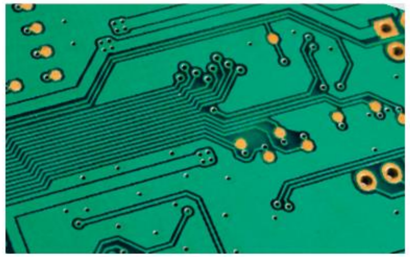
2. Assembly of Modules and Packs

Importance of Welding Quality Verification

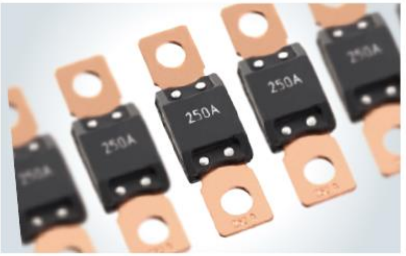
Batteries, motors, electronic components, and other parts accommodate increasingly large currents and high voltages. Since even minuscule amounts of resistance can have a significant impact on energy efficiency and safety, high accuracy quality control focusing on resistance is required.

For the motor transformer Coil resistance

For the charging connector Connection resistance



Printed circuit boards Pattern resistance



DC resistance of the fuse-shunt resistor

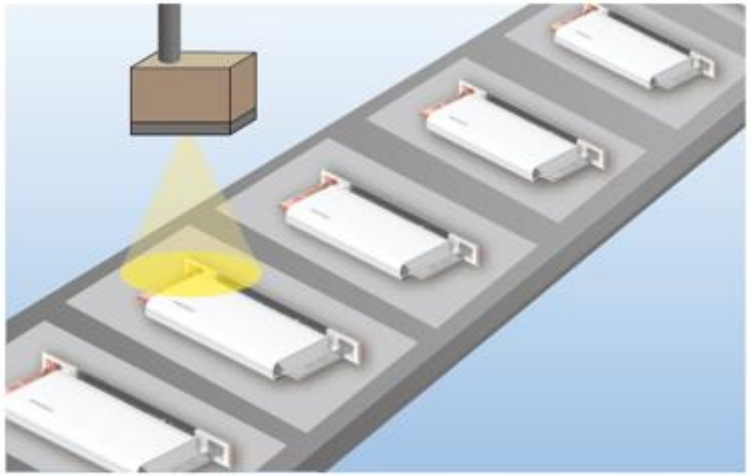
On the battery bus bar Connection resistance

Weld Quality traditional testing

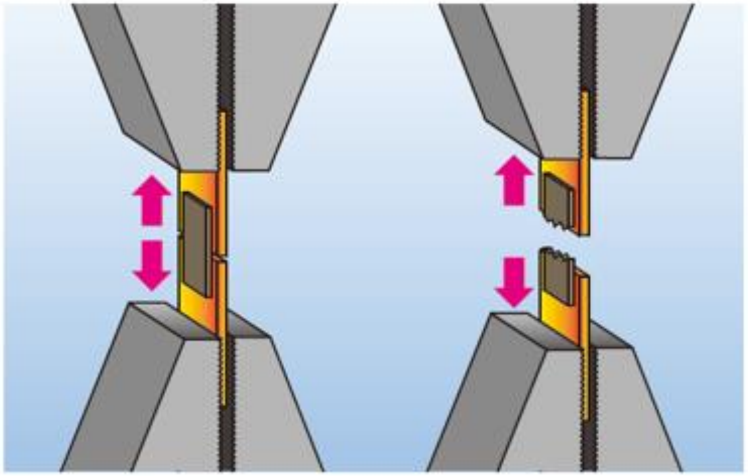
Complete non-destructive inspection of weld quality is difficult.

Different type of testing:

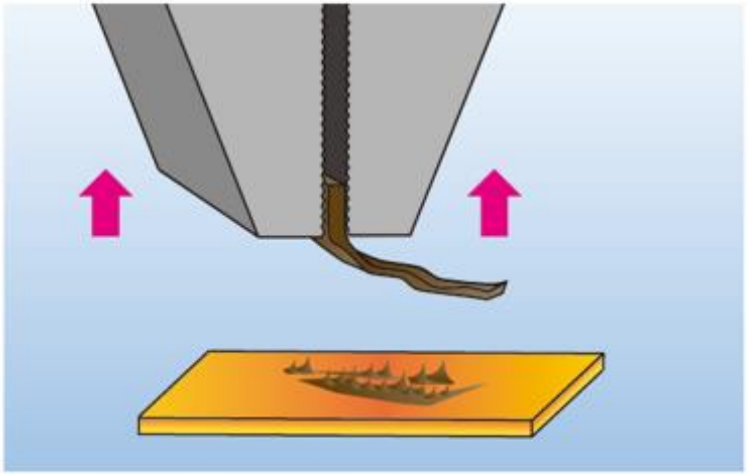
- Camera on pic 1 used to test battery tab quality welding (economic solution) it can only check surface not under weld surface (the welds should look uniform)
- Mechanical test on pic 2 and 3 are some of common methods to used to test/inspect spot weld quality



Visual inspection



Tensile strength testing



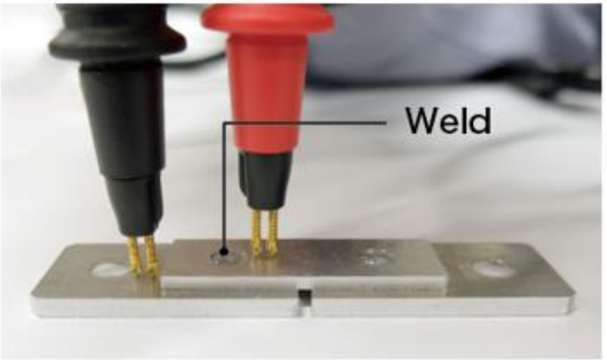
Checking whether welds were made properly based on marks left after one side is peeled off

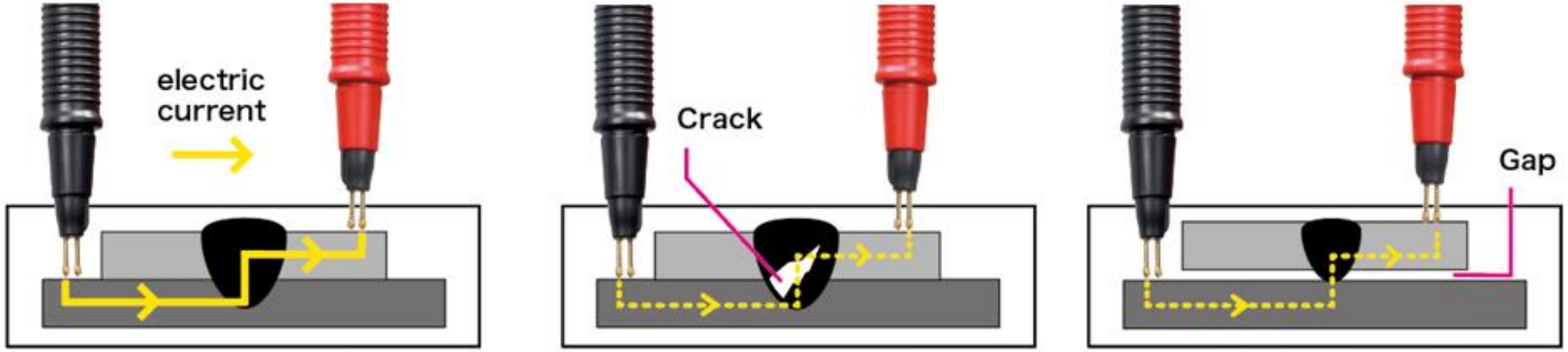
New solution of Weld Quality Testing

Instead of traditional methods, more accurate quality control focusing on low DC resistance measurement is required low resistance values at high precision and high resolution; in case of RM3545A with 1 nΩ resolution.

This is important, because a typical low-resistance weld can have resistance ranging from 10 µΩ to 100 µΩ.
RM3545A provides a 1000 µΩ range and 1 nΩ resolution, allowing it to measure low resistance values with a high degree of precision.

If a weld is insufficient (defective), its resistance value will exceed that of a non-defective:





Because of electrical inspection,
It is non-destructive, high-speed

Internal defects
can be inspected

Connection failure
can be inspected

Resistance meter RM3545A

Weld resistance testing

If welds connecting tabs or other battery components, resistance between components will increase significantly, resulting in electrical energy loss and battery overheating.

How it works?

High accuracy DC resistance meter apply a constant DC current (100nA to max 1A) to the testing point.

The meter then detects a minuscule voltage generated by the applied current and calculates the resistance value.

High-precision, low-resistance measurement

Resistance measurement

- Measurable range: **1 nΩ to 1200 MΩ**
- Max. resolution: **1 nΩ (1000 μΩ range)**
- Min. measurement range: **1000 μΩ**
- Min. measurement range accuracy: **0.045% rdg.**
- Max. measurement current: **1 A**

Conclusion

- ✓ ***LR8101/LR8102**: **Real-time voltage and temperature monitoring** during charge/discharge testing*
- ✓ ***DM7276**: **Accurate OCV measurement** for aging process analysis*
- ✓ ***BT6065/BT6075**: **ACIR testing** for pre-shipment inspection, meeting IEC standards*
- ✓ ***BT4560-50**: **Low-frequency ACIR and EIS** for in-depth battery health analysis and diagnostics*
- ✓ ***RM3545A**: **Weld resistance testing** in EV power cables and bus bars for quality assurance*

***Precision Matters**:*
*Precise and reliable testing is essential throughout battery production to ensure **safety** and **performance***

***Key to Quality**:*
*Accurate measurement of **voltage**, **temperature**, and **internal resistance** ensures high-quality, long-lasting batteries*

Supporting Innovation
*Advanced testing supports **innovation** and **sustainability** in the growing battery industry*

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Thank you for your attention!

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