Manage Electrode Reaction Resistance, Electrolyte Resistance, and Welding Resistance

The Ultimate Instrument for Measuring Large-Capacity Li-ion Batteries for EVs
Improve the quality of battery cell inspections

- Set your own measurement frequency between 100 mHz and 1.05 kHz
- Use low frequencies to measure electrode reaction resistance
- Use high frequencies to measure electrolyte resistance and welding resistance
- Create Cole-Cole plots (with bundled application program)
- Use equivalent circuit analytic software to analyze internal battery defects

Use the BT4560 for impedance measurement... To isolate defective factors in battery cells

Conceptual diagram of a battery

Battery equivalence circuit

When $R_1$ is larger... Electrolyte concentration might be reduced, or the electrode might have poor welding
When $R_2$ is larger... A failure might have occurred during the electrode production process, or the electrode might react poorly on its surface

DC-IR measurement using a charging/discharging tester

DC-IR measurement passes electric currents into $R_1$ and $R_2$, which makes it difficult to measure electrolyte resistance and reaction resistance separately.

(See the equivalent circuit diagram shown above)
**Exceptional Accuracy**

**Unsurpassed Stability**

**Measure very low impedances of 1mΩ or less**

Some high-capacity Li-ion batteries have an internal impedance less than 1 mΩ. The BT4560 can measure very low impedances of 1mΩ or less, stably and with high reproducibility.

**Measure DC voltage with high accuracy**

Accuracy: ±0.0035% rdg.  ±5 dgt.

The BT4560 achieves an accuracy comparable to a 6.5-digit DMM. It can be used to measure both OCV and impedance in batteries.

![Graph showing impedance measurement](image)

**Four-terminal pair measurement resolves system construction problems**

The four-terminal pair method reduces various effects of induced magnetic fields, such as cabling influence, eddy-current influence due to surrounding metals, and interference when multiple devices are used simultaneously. When compared to the conventional four-terminal method, the BT4560 controls magnetic fluxes generated by the measurement current. This significantly reduces the impact on the measured value when cabling for measurements is changed, improving stability when the measurement instrument is embedded within the production line.

**Magnetic flux influence using the conventional four-terminal method**

1. The magnetic flux generated by the measurement current generates induced voltage in the voltage terminal.

2. The magnetic flux generated by the eddy current generates induced voltage in the voltage terminal.

3. External magnetic flux (interference when multiple devices are used simultaneously).

**Impedance measurement using the four-terminal pair method**

Passing a current in the direction opposite to the measurement current controls the magnetic flux generated.

Through the return wire at the measurement target, passing a current in the direction opposite to the measurement current controls the magnetic flux generated.

**Dedicated probes for four-terminal pair measurement reduce the magnetic flux generated**

Dedicated probes with the four-terminal pair structure provide stable measurement less affected by environmental noise or cabling.

**CLIP TYPE PROBE L2002**

For measuring laminated sheet batteries

Adjust the point of contact by sliding a stopper.

**PIN TYPE PROBE L2003**

For line-embedded applications and various other types of batteries

Threaded holes are provided to secure the probe on an inspection fixture.

* Contact your local Hioki distributor for details of the probe tip shapes.
Battery cell selection extends the battery pack service life

Battery pack deterioration factors
Heat reduces or deterioriates the battery capacity. Large-capacity batteries for EVs that charge/discharge with large currents generate significant amounts of heat.

Selection is necessary for extending battery pack service life
Combining cells with the same battery capacity and internal resistance equalizes heat generated, extending the service life.

Checking the battery deterioration level

Compare measured data for new and deteriorated batteries
Here, Cole-Cole plot data is compared for new Li-ion battery cells (upper-left plot) and deteriorated Li-ion battery cells of the same kind (lower-left plot).

R1: Electrolyte resistance and welding resistance
R2: Reaction resistance
(Reaction resistance of positive/negative electrodes)

Comparing the new Li-ion battery with the deteriorated one confirms significant changes in the reaction resistance value. Although much depends on the deterioration factors, in addition to heat effects, the deterioration of the electrode reactive portion appears on a graph as reaction resistance for particular applications, such as repeated charging/discharging at low temperature and repeated deep charging/discharging (SOC: Between 0 and 100%).
To assess Li-on battery deterioration levels and select batteries for inclusion in manufacturing and production lines

### Isolate battery deterioration factors

Cole-Cole plot data obtained by using the BT4560 and commercially-available equivalent circuit analysis software, such as "ZView®", can be used to analyze deterioration factors.

The impedance characteristics of a Cole-Cole plot are generally expressed as a pseudo equivalent circuit.

A pseudo equivalent circuit is expressed by:

- **Resistance in the electrolyte and tab welding portions** \( (R_1) \)
- **Positive/negative electrode reactions within the battery** \( (R_2/C_2, R_3/C_3) \)
- **Lead and other inductance** \( (L) \)

... to give just a few examples.

Once a pseudo equivalent circuit is constructed, equivalent circuit analysis software (ZView®) can provide the circuit constant of each element by means of curve fitting. Quantifying the changes in each element’s constant when a battery is new and when it deteriorates allows analysis of which portions within the battery have changed. This serves to isolate battery deterioration factors.

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### Create Cole-Cole plots using bundled software

A free PC application that comes with the BT4560 can conduct measurement and draw Cole-Cole plots. Additionally, "ZView®" from Scribner Associates Inc. also provides detailed analysis based on equivalent circuit analysis.

![Image of Cole-Cole plot](image)

**1. Bundled PC application**

Creates Cole-Cole plots. Measurement results can also be output in Excel and CSV files.

**2. Application bundled with LabView driver**

Compares multiple overlaid graphs. Equipped with a simple equivalent circuit analysis function, this application also gives insight into electrolyte resistance and reaction resistance.

**3. AC impedance analysis software "ZView®"**

"ZView®" creates certain equivalent circuits based on CSV files output from the above application while quantifying each element, to analyze deteriorated portions in a battery.
Characteristics and features of BT4560

All-in-one compact unit
The BT4560 requires no loading devices and provides measurements simply as a stand-alone unit, without having to establish a complicated measurement system.

Self-calibration
Correct any offset voltage and gain drift that may be present in the circuit to improve the accuracy of voltage measurement.

Sample delay*
Specify a delay between AC voltage being applied and sampling being started so that measurement can start after the response stabilizes.

Prevent charging or discharging when AC voltage is applied*
To prevent the battery that is being measured from charging or discharging, the battery impedance meter terminates the applied measurement signal when zero is crossed.

Simultaneous measurement of impedance and voltage
Reduce tact time by testing both impedance and high accuracy DC voltage at the same time.

Slope correction function*
If measurement signals drift due to the battery characteristics or the input impedance of measurement instrument, the BT4560 applies correction to the linear drift.

Temperature measurement
Reaction resistance measured at low frequency is sensitive to temperature. An optional temperature sensor measures the temperature around the battery and associates the results with data, thereby improving the reliability of the measurements.

*Functions available during impedance measurement

Functions to accommodate automated machines

Contact check
Monitor the contact resistance of the probe before and after measurement so that the measurement will only start when the measuring electrode on the probe is in contact with the object to be measured.

Comparator
- Simultaneously measure impedance and voltage
- Output overall determination results
- Use the two-tone buzzer to indicate determination results

NPN/PNP switch
Switch the input/output circuits for EXT. I/O according to the type of output: current sink output (NPN) or current source output (PNP).

Panel saving and loading
Store up to 126 sets of measurement conditions in internal memory so that they can be called through EXT. I/O for future measurements.
Accuracy specifications

Impedance measurement accuracy

○ 3 mΩ range (0.1 Hz to 100 Hz), 10 mΩ range, 100 mΩ range

R accuracy = ± (0.004 |R| + 0.0017 |X|) [mΩ] ± α
X accuracy = ± (0.004 |X| + 0.0017 |R|) [mΩ] ± α
Z accuracy = ± 0.4% rdg. ± α (|sinθ| + |cosθ|)
θ accuracy = ± 0.1° ± 57.3 (|sinθ| + |cosθ|) (α is as shown in the table below.)

○ 3 mΩ range (110 Hz to 1050 Hz)

R accuracy = ± (0.004 |R| + 0.0052 |X|) [mΩ] ± α
X accuracy = ± (0.004 |X| + 0.0052 |R|) [mΩ] ± α
Z accuracy = ± 0.4% rdg. ± α (|sinθ| + |cosθ|)
θ accuracy = ± 0.3° ± 57.3 (|sinθ| + |cosθ|) (α is as shown in the table below.)

Temperature measurement accuracy

<table>
<thead>
<tr>
<th>α</th>
<th>Resolution</th>
<th>3 mΩ range</th>
<th>10 mΩ range</th>
<th>100 mΩ range</th>
</tr>
</thead>
<tbody>
<tr>
<td>FAST</td>
<td>25 dgt.</td>
<td>60 dgt.</td>
<td>60 dgt.</td>
<td></td>
</tr>
<tr>
<td>MED</td>
<td>15 dgt.</td>
<td>30 dgt.</td>
<td>30 dgt.</td>
<td></td>
</tr>
<tr>
<td>SLOW</td>
<td>8 dgt.</td>
<td>15 dgt.</td>
<td>15 dgt.</td>
<td></td>
</tr>
</tbody>
</table>

Temperature coefficient

R: ± R accuracy × 0.1 / °C, X: ± X accuracy × 0.1 / °C, Z: ± Z accuracy × 0.1 / °C, θ: ± θ accuracy × 0.1 / °C,

Voltage measurement accuracy

V display range −5.00000 V to 5.10000 V
Resolution 10 μV
Voltage accuracy ±0.0035% rdg. ±5 dgt.

Temperature measurement accuracy

Accuracy ±0.0035% rdg. ±5 dgt. ± α

BT4560 specifications

Accuracy specifications

<table>
<thead>
<tr>
<th>Resolution</th>
<th>Measurement range</th>
<th>3 mΩ range</th>
<th>10 mΩ range</th>
<th>100 mΩ range</th>
</tr>
</thead>
<tbody>
<tr>
<td>FAST</td>
<td>25 dgt.</td>
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<td>60 dgt.</td>
<td></td>
</tr>
<tr>
<td>MED</td>
<td>15 dgt.</td>
<td>30 dgt.</td>
<td>30 dgt.</td>
<td></td>
</tr>
<tr>
<td>SLOW</td>
<td>8 dgt.</td>
<td>15 dgt.</td>
<td>15 dgt.</td>
<td></td>
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</tbody>
</table>

Temperature coefficient ±0.0035% rdg. ±5 dgt. ± α (applied in the ranges of 0°C to 18°C and 28°C to 40°C)

Impedance measurement

Measurement functions (R,X,V,T) / (Z,θ,V,T) / (R,X,T) / (Z,θ,T) / (V,T)

Function Comparator, self-calibration, sample delay, average, voltage limit, potential gradient compensation for impedance measurement, charge/discharge prevention during AC signal application, key lock, system test, panel saving and loading (up to 128 condition sets)

Measurement error detection Contact check, measurement current error, voltage drift on measured object, overvoltage input, voltage limit, measurement range, measurement time, memory full, contact check, memory full, key lock, panel lock, system test, panel lock, interface

Interface RS-232C/USB (virtual COM port) * Cannot be used simultaneously

BT4560 + Z2005 temperature sensor

Accuracy ±0.5°C (measurement temperature: 10.0°C to 40.0°C)
±1.0°C (measurement temperature: -10.0°C to 9.9°C, 40.1°C to 60.0°C)

Temperature measurement

Extinction temperature ±0.01°C (applied in the ranges of 0°C to 18°C and 28°C to 40°C)

Specifications

<table>
<thead>
<tr>
<th>Measured signals</th>
<th>Impedance, voltage, temperature</th>
</tr>
</thead>
<tbody>
<tr>
<td>Impedance, voltage, temperature</td>
<td></td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th>Impedance measurement</th>
</tr>
</thead>
<tbody>
<tr>
<td>Measurement parameters</td>
</tr>
<tr>
<td>Measurement frequency</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Frequency setting resolution</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.10 Hz to 0.99 Hz in 0.1-Hz increments</td>
</tr>
<tr>
<td>1.0 Hz to 9.9 Hz in 0.1-Hz increments</td>
</tr>
<tr>
<td>10.0 Hz to 99.9 Hz in 1-Hz increments</td>
</tr>
<tr>
<td>100 Hz to 1050 Hz in 10-Hz increments</td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th>Measurement ranges</th>
</tr>
</thead>
<tbody>
<tr>
<td>3.0000 mΩ, 10.0000 mΩ, 100.0000 mΩ</td>
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</table>

<table>
<thead>
<tr>
<th>Measurement current/DC load</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.5 Arms ±10%</td>
</tr>
<tr>
<td>500 mA Arms ±10%</td>
</tr>
<tr>
<td>50 mArms ±10%</td>
</tr>
<tr>
<td>DC load current</td>
</tr>
<tr>
<td>0 mA or less</td>
</tr>
<tr>
<td>0.35 mA or less</td>
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<tr>
<td>0.035 mA or less</td>
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<table>
<thead>
<tr>
<th>Measurement wave number</th>
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</thead>
<tbody>
<tr>
<td>FAST</td>
</tr>
<tr>
<td>MED</td>
</tr>
<tr>
<td>SLOW</td>
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</table>

<table>
<thead>
<tr>
<th>Voltage measurement</th>
</tr>
</thead>
<tbody>
<tr>
<td>Measurement range</td>
</tr>
<tr>
<td>5.00000 V (single range)</td>
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</table>

<table>
<thead>
<tr>
<th>Resolution</th>
<th>10 μV</th>
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</thead>
</table>

<table>
<thead>
<tr>
<th>Measurement time</th>
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</thead>
<tbody>
<tr>
<td>FAST : 0.1 s</td>
</tr>
<tr>
<td>MED : 0.4 s</td>
</tr>
<tr>
<td>SLOW : 1.0 s</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Temperature measurement</th>
</tr>
</thead>
<tbody>
<tr>
<td>Display range</td>
</tr>
<tr>
<td>10.0°C to 60.0°C</td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th>Resolution</th>
<th>0.1°C</th>
</tr>
</thead>
</table>

<table>
<thead>
<tr>
<th>Measurement time</th>
<th>2.3 s</th>
</tr>
</thead>
</table>
### Options

**CLIP TYPE PROBE L2002**
- Cable length: 1.5 m (4.92 ft)

**PIN TYPE PROBE L2003**
- Cable length: 1.5 m (4.92 ft)

**TEMPERATURE SENSOR Z2005**
- Cable length: 1 m (3.28 ft)

**RS-232C CABLE 9637**
- For the PC, 9 pins - 9 pins, cross, Cable length: 1.8 m (5.91 ft)

### Custom specification line-up

<table>
<thead>
<tr>
<th>Measurement voltage</th>
<th>Standard 5 V (±5.10000 V)</th>
<th>Measuring range: 3mΩ/10mΩ/100mΩ</th>
<th>Measurement current: 1.5 A/500 mA/50 mA</th>
</tr>
</thead>
<tbody>
<tr>
<td>Custom 10 V (±9.99999 V)</td>
<td>Measuring range: 30 mΩ/300 mΩ</td>
<td>Measurement current: 500 mA/50 mA</td>
<td></td>
</tr>
<tr>
<td>Custom 20 V (-10.0000 V to 20.40000 V)</td>
<td>Measuring range: 30 mΩ/300 mΩ</td>
<td>Measurement current: 150 mA/50 mA/5 mA</td>
<td></td>
</tr>
</tbody>
</table>

### Measurement frequency

- **Standard 0.10 Hz to 1050 Hz**
- **Custom 0.01 Hz to 1050 Hz**

### Probe tip shape

- 9770
- 9771
- 9772

### Measure electrochemical parts and materials

**Model: CHEMICAL IMPEDANCE ANALYZER IM3590**

**Model No. (Order Code)**
- IM3590

**Measurement range**: 100 mΩ to 100 MΩ
**Measurement frequency**: 1 mHz to 200 kHz

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