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Making High Quality Open Circuit Voltage Measurements on Battery Cells

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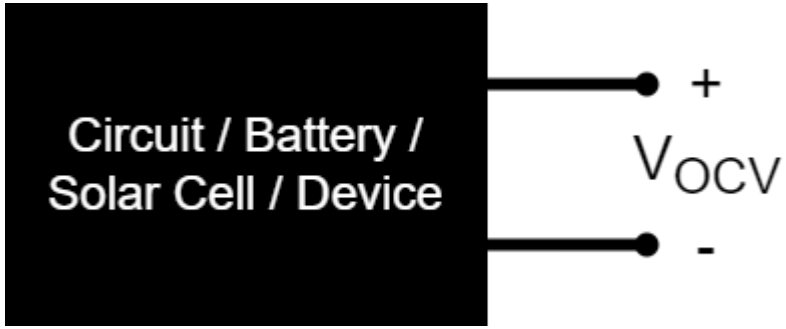
Agenda

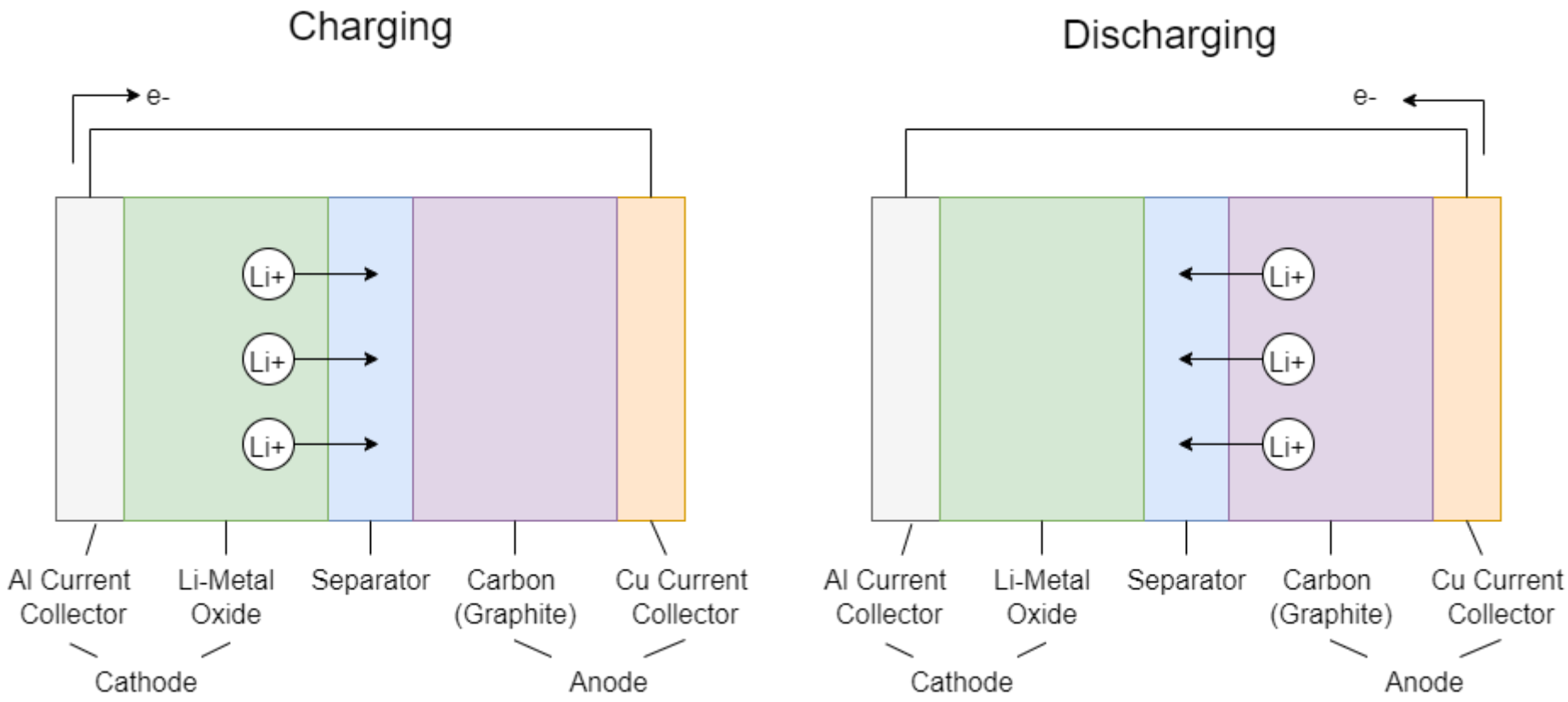
- What is OCV?
- Uses for battery OCV
- Measuring OCV
- Using the DMM7510
- Improving the measurement

What is Open Circuit Voltage (OCV)?

- Open circuit voltage is the difference in potential between two terminals when no load is connected between them
- There should be no current in the cell
- Indicator of the max voltage potential that would be available in a particular circuit



Battery Cell Construction



Battery Cell Open Circuit Voltage

- Batteries store and release energy, converting between electrical and chemical energy
- How do we measure the energy stored in the battery? Use OCV!
- The OCV of a battery cell changes with the energy stored in the cell
- Lithium ion batteries can range from 2 V to 5 V during cycling
- Other chemistries (like lead acid or alkaline) and smaller form factors can cause batteries to have smaller ranges of voltages

Battery Voltage Terminology

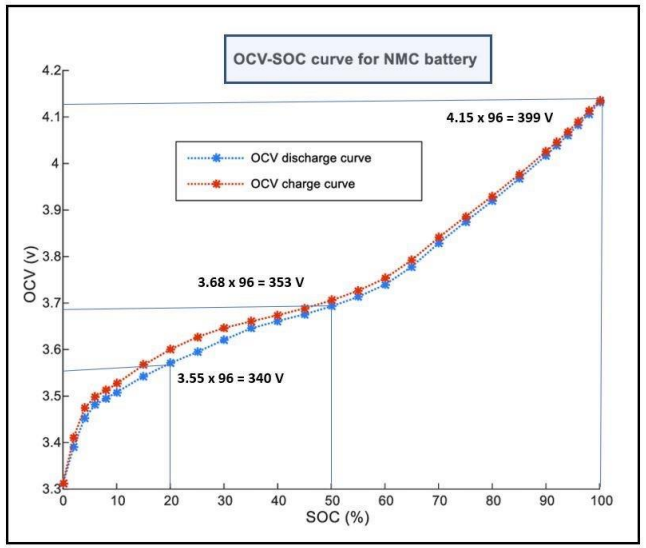
- Open Circuit Voltage: Voltage with no load
- Terminal Voltage: Voltage with load
- Nominal Voltage: The average or standard open circuit voltage of the battery when fully charged
  - Nominal voltage is the “specified” voltage of the battery and the term we use to refer to the battery’s capability
  - In practice, the battery voltage at full charge is higher than the nominal voltage and then voltage at full discharge is much less
- Charge Voltage: The OCV of the battery when fully charged
- Cut-off Voltage: The OCV of the battery when fully discharged
- Float Voltage: The OCV to maintain when testing for self-discharge of the battery

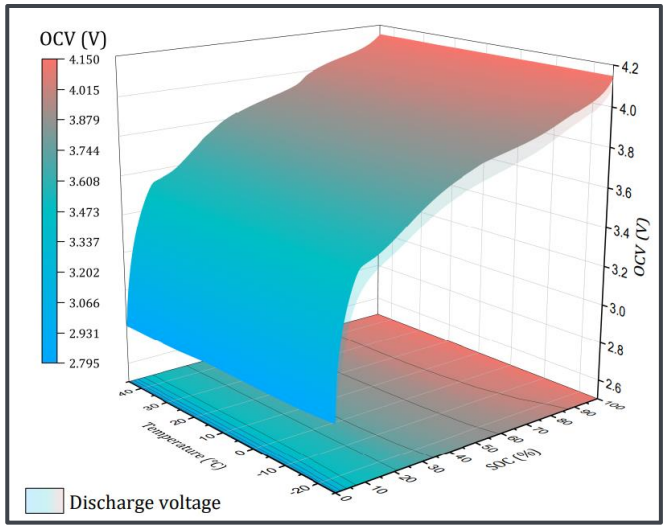
OCV During Charging and Discharging

- Battery charging includes 2 steps
  - Constant Current (CC): Battery is charged with a constant current rate defined by the C-rate
  - Constant Voltage (CV): Battery voltage is held constant and the current drops off until a desired cutoff (i.e. 10% of rate, 0.05C). May also be called saturation charge.
- Open circuit voltage can be used to judge the capacity of the battery during charging and discharging
- Lithium ion batteries don’t take well to overcharging so we need to know when the battery is full
- Over discharging causes damage to the SEI layer and reduces performance and lifespan

Battery Modeling and Degradation

- OCV measurements can be used to generate a full relationship between the OCV and the SOC
  - Can be used for battery simulation
  - Can be used to understand hysteresis effects
- OCV-SOC relationship is temperature dependent – thermal characterization is involved here
- Open circuit voltage can also relate to SOH and degradation
  - There are lots of ways battery functionality can degrade over time
  - Some mechanisms can cause changes in the OCV-SOC relationship
  - We can also use models as prediction mechanisms





Battery Self-Discharge

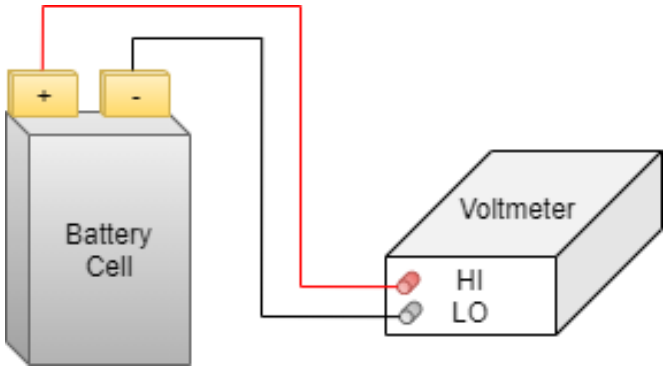
- All batteries have small internal discharge currents
- Defects in the batteries (i.e. microshorts, pinholes in the separator, contaminants) make the battery discharge faster
- OCV is one way to measure the self-discharge behavior of the battery
  - Measure the OCV at full to establish baseline
  - Periodically measure the OCV over a period of time as the cell rests
  - Calculate the change in the OCV over time
- Batteries with significant changes may have defects and could be pulled from the line for further testing and analysis

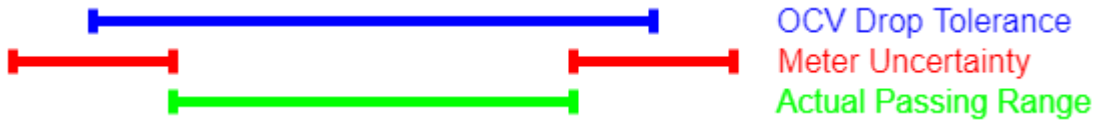
Battery Grading

- We can use the measure of the self-discharge to bin the batteries into different quality grades
- Grade A batteries have the longest lifespans, lower internal impedance and better overall performance. They are usually used in high power applications or applications that require fast charging such as EV applications
- Grade B batteries have lesser performance and lesser lifespans, and are more common in applications like energy storage, where the performance and life span aren’t as critical
- Grade C batteries are the worst performing and are mostly used for single cell portable applications

Measuring the Open Circuit Voltage

- Connect the battery cell directly to the DMM's voltmeter input
- DMM or voltmeter should have good input impedance
- Resolution ensures that the DMM can measure very small changes in the battery voltage – ultimately saving time for longer term tests
- Accuracy ensures that the digits you measure can be trusted
- For battery quality and other binning applications, higher accuracy means a larger target to hit for the highest quality products since there's less instrument accuracy to be accounted for.
- Battery must settle if measuring during charge or discharge





Using the DMM7510

- Our most popular solution!
- Accuracy at 1 year on 10 V range: 14 ppm Reading + 1.2 ppm Range
  - For a battery cell at 3.7 V (10 V range):
    $14 \times 10^{-6} * 3.7 + 1.2 \times 10^{-6} * 10 = 63.8\ \mu V$
- 7.5 Digit resolution: 1 µV on the 10 V range
- Large touch screen and user friendly interface is perfect for R&D benchtop users
- TSP and SCPI Language Modes and standard communication options (GPIB, USB, Ethernet) make test automation easy

Using the DMM6500

- 6.5 Digits of Resolution (10 µV on 10 V range)
- Accuracy: 0.0025% reading + 0.0005% range
  - (142.5 µV uncertainty for the 3.7 V cell)
- Great solution for verification of OCV at the OEM/End Use Application level

Multichannel OCV Testing: 3706A

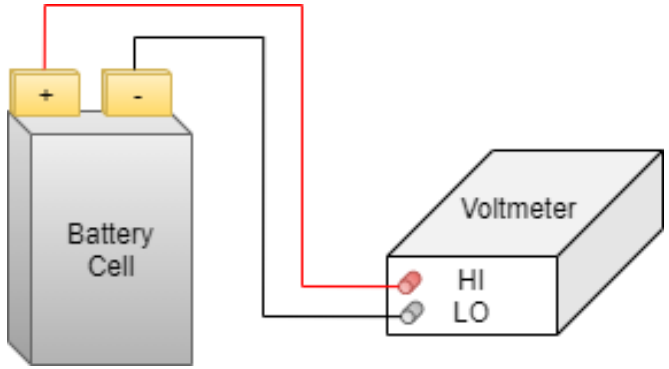
- **3706A System Switch and Multimeter**
  - 7.5 Digits of Resolution (1 µV on 10 V range)
  - Accuracy: 25 ppm reading + 2 ppm range
    - (112.5 µV uncertainty for the 3.7 V cell)
- **3724 High Speed Solid State Card**
  - 60 channels / card, 360 channels / mainframe
  - At 1 NPLC, AZERO OFF, 1 reading per channel into buffer: Approx. 60 channels / second
  - Solid state relays = unlimited relay life for production facilities
- **3722 High Density Card**
  - 96 channels / card, 576 channels / mainframe
  - At 1 NPLC, AZERO OFF, 1 reading per channel into buffer: Approx. 40 channels / second

Methods to Improve the Measurement

- Every test system has some inherent offsets
  - Internal offsets from the instrument
  - Thermal offsets due to dissimilar metal connections
- Remove constant offsets by using the REL function
  - Short leads together (for 0 V)
  - Enable REL function
  - Connect leads to battery
- Use connections with the same metals to avoid voltage offsets from the Seebeck effect

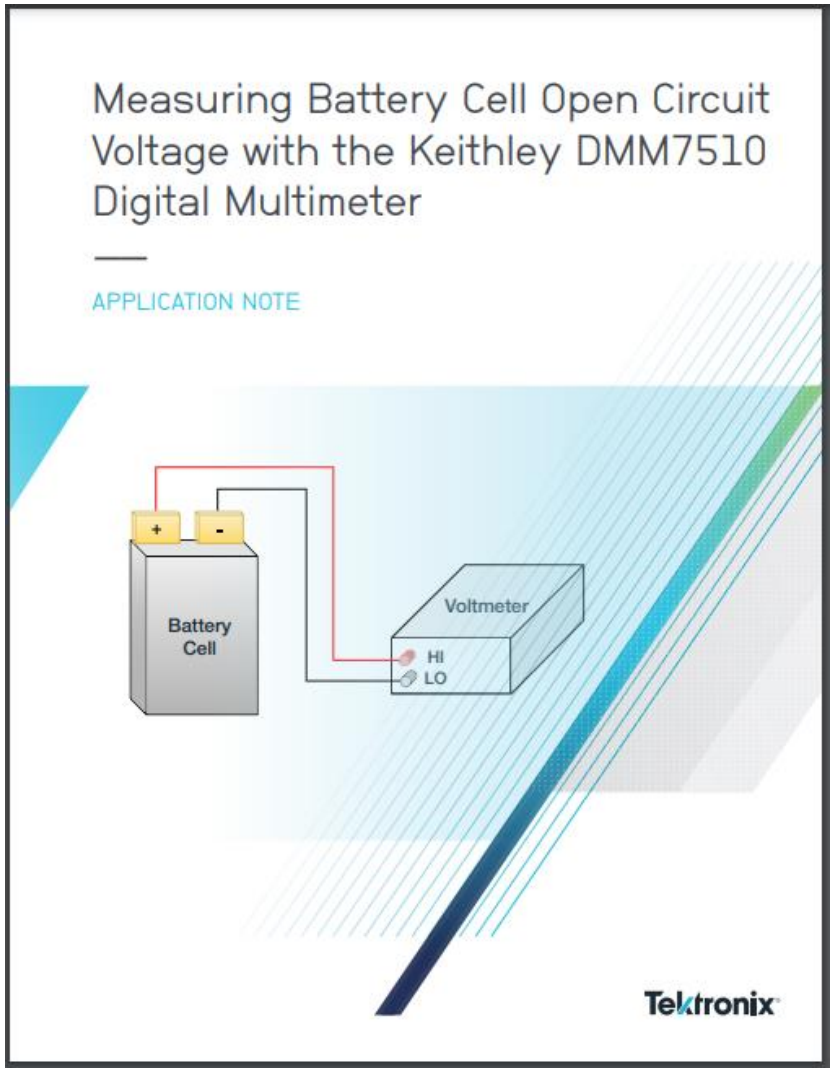
Summary

- Battery open circuit voltage is the voltage on the battery with no load connected
- Open circuit voltage is a result of the chemistry of the battery and changes during charging and discharging
- The OCV-SOC relationship is important for battery modeling
- The OCV can also be used to judge the quality of the battery
- OCV should be measured using an accurate, high resolution DMM connected directly to the battery
- Beware of instrument and thermal voltage offsets in the measurement



More Information and Resources

- Product Pages:
  - DMM7510 7.5 Digit DMM
  - DMM6500 6.5 Digit DMM
  - 3706A System Switch and 7.5 Digit DMM
- Application Note: Measuring Battery Cell Open Circuit Voltage with the Keithley DMM7510 Digital Multimeter



Q&A

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