APPLICATION NOTE

Battery Temperature Testing

Evaluating the effects of temperature

Mess- und Prüftechnik. Die Experten.

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E36731A - Battery emulator and profiler

DAQ973A - Data acquisition system

BV9210B - PathWave BenchVue advanced battery emulation software

Introduction

The invention of smartphone technology has enabled us to be more connected and productive in our busy daily lives. The technology has received incremental new features and updates year-over-year, which makes it more capable beyond a communication and computing device.

As the usage trend and demand increase, it puts pressure on the smartphone device manufacturer to increase the device power-on time to serve its user. While increasing battery capacity does help to prolong device power-on time, it negatively impacts device charging time and takes up valuable space for the electronics.

To overcome this challenge, more and more smartphone device manufacturers are pushing high currents and power to charge their devices. This technique is proven effective in reducing battery charging time and indirectly aids in prolonging device power-on time. However, the shortcoming of this technique is that it generates a lot of heat because of the energy transfer loss. The effect is more prominent when using a low-efficiency wireless charger, an aging smartphone battery, or a low-quality battery due to the increase of battery internal resistance.

While high current charging increases battery temperature, other factors also contribute to the increase in battery temperature, such as performing extensive CPU data payload processing or using the smartphone in hot ambient temperatures.

When the battery has been exposed beyond its allowable temperature range for an extended time, it suffers an accelerated capacity, performance, and life span degradation as the long-term effect. The smartphone device manufacturer commonly introduces a precautional technique by adding a temperature sensor within the device to continuously monitor the battery temperature when the device is charging or discharging and will stop the operation when it exceeds certain temperature limits.

Advanced software control is usually in place and running in parallel to control the voltage and current of the smartphone device during the charging and discharging operations. Other known technique includes using a more sophisticated temperature absorption or cooling technique to dispel the heat generated or received from the environment.

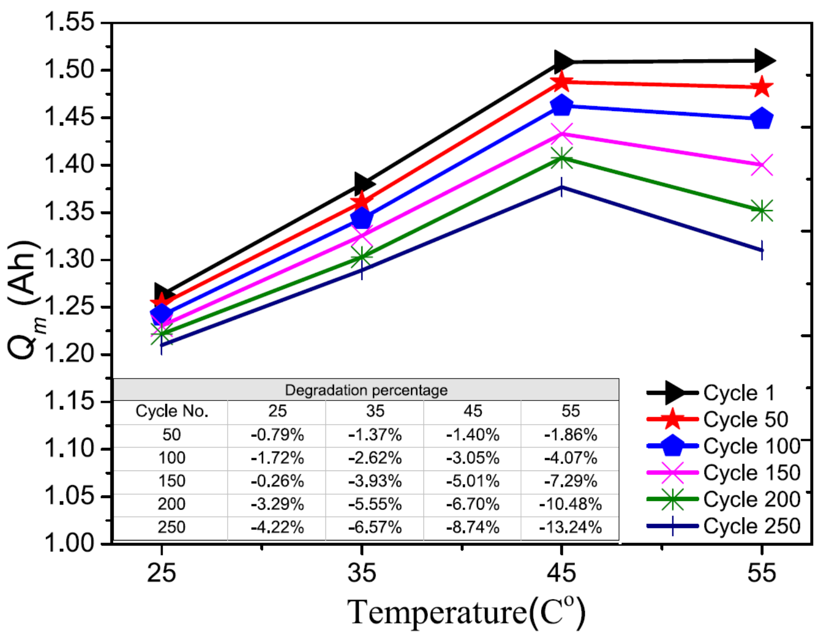
Having said that, it is evident that temperature has a significant effect on battery performance. Smartphone device manufacturers constantly innovate to develop new techniques to protect the battery from degradation. This application note explains the general temperature effect on the battery while utilizing our cost-efficient Keysight E36731A Battery Emulator and Profiler, Keysight DAQ973A Data Acquisition System, together with Keysight BV9210B PathWave BenchVue Advanced Battery Emulation software for comprehensive and seamless data collection.

How Does Temperature Affect Battery Capacity, Performance, and Life Span?

Effects of high temperature

While operating the device in a hot environment increases the battery temperature, force charging the battery with high current and wattage can further increase the battery temperature. This is because the energy loss during the charging process dissipates as heat, and the heat generation will worsen when charging with a low-efficiency wireless charger. During the operation, poor thermal, current, and voltage control would result in thermal runaway and will cause a fire.

Charging or discharging a battery at a high temperature can accelerate the chemical reactions within the battery, reduce its internal resistance, and increase its performance and storage capacity. However, prolonged exposure to high temperatures causes accelerated aging and reduces the battery's lifespan. Researchers have conducted studies on the degradation of Li-Ion batteries. The figure below illustrates the effect of temperature on battery degradation. Batteries with different chemistry may also exhibit similar effects with some degree of variation.



Degradation percentage				
Cycle No.	25	35	45	55
50	-0.79%	-1.37%	-1.40%	-1.86%
100	-1.72%	-2.62%	-3.05%	-4.07%
150	-0.26%	-3.93%	-5.01%	-7.29%
200	-3.29%	-5.55%	-6.70%	-10.48%
250	-4.22%	-6.57%	-8.74%	-13.24%

Figure 1. Maximum charge storage capacity as a function of temperature & charging cycle[1].

1. Leng, Feng & Tan, Cher & Pecht, Michael. (2015). Effect of Temperature on the Aging rate of Li-Ion Battery Operating above Room Temperature. Scientific reports. 5. 12967. 10.1038/srep12967.

Effects of low temperature

In general, the drop in battery temperature increases battery internal resistance. This is because the movement of ions, their transfer rate, and the overall chemical reactions between the electrodes and electrolytes within the battery are reduced at cold temperatures. This translates to higher internal resistance, making charging and discharging difficult. This, in turn, reduces the amount of energy that the battery can produce or store.

Figure 2 explains the relationship between battery internal resistance and temperature across batteries with different chemistry. It is also crucial for the end user to charge or discharge their battery within the allowable temperature range per battery specification. When operated outside the allowable temperature range, such as in an extremely cold environment, charge acceptance will be reduced due to the slower ion combination. In this condition, forcing a high current can be dangerous as it can build up pressure and lead to thermal runaway.

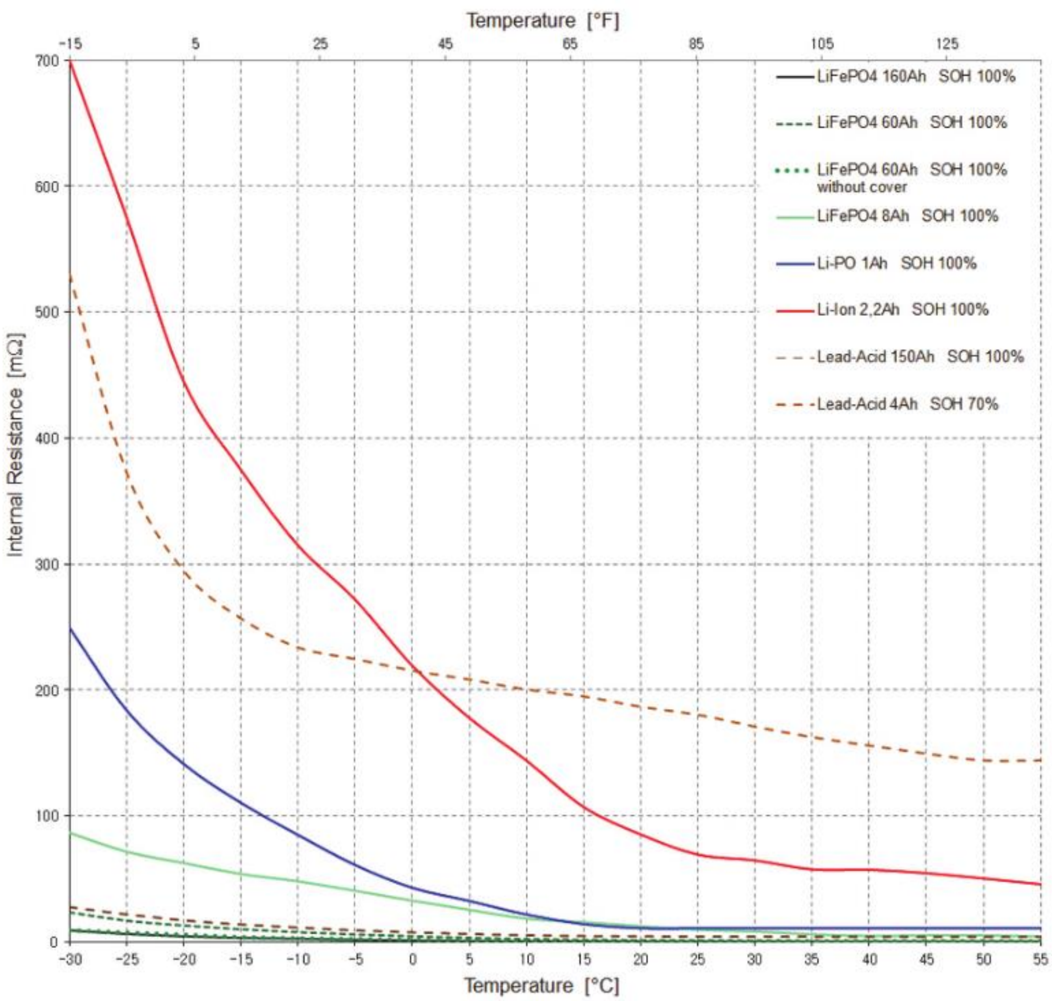


Figure 2. Battery internal resistance against temperature[2]

2. Łebkowski, Andrzej. (2017). Temperature, Overcharge and Short-Circuit Studies of Batteries used in Electric Vehicles. Przeglad Elektrotechniczny. 1. 10.15199/48.2017.05.13.

Keysight Integrated Solution

To observe the effect of temperature on the battery, we will be primarily using Keysight E36731A Battery Emulator and Profiler together with Keysight BV9210B PathWave BenchVue Advanced Battery Emulation software for the test. The Keysight E36731A Battery Emulator and Profiler and Keysight BV9210B PathWave BenchVue Advanced Battery Emulation software is a complete, easy-to-use, cost-efficient hardware and software solution that helps you to run a variety of battery tests for your project.

Figure 3. Keysight BV9210B PathWave BenchVue Advanced Battery Emulation user interface

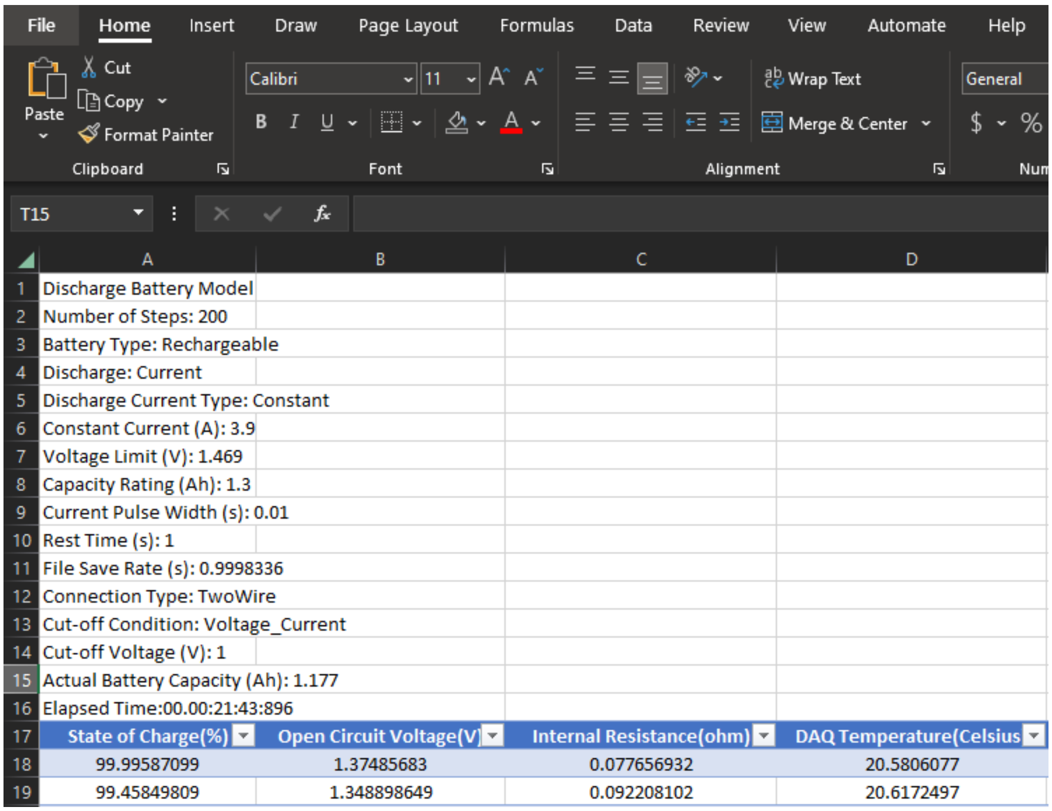
The Keysight BV9210B PathWave BenchVue Advanced Battery Emulation software offered a few useful modes for the battery test, namely:

- **Profile Mode –** Create a battery model from a physical battery by dynamically or constantly charging/discharging the physical battery. The profiler will map out the internal resistance, voltage, and current of the battery and tie it with the State of Charge (SoC) of the battery.
- **Emulate Mode –** Keysight E36731A Battery Emulator and Profiler will act as a source and mimic battery operation according to the selected profile. It also allows you to run battery tests at a specific SoC, reducing test time, improving safety, and increasing test repeatability.
- **Charge/Discharge Mode –** Charge/discharge the physical battery to track the performance and capacity of the battery over time.
- **Cycler Mode –** Create a repetitive sequence of charging, resting, and discharging the battery to monitor the performance and capacity degradation over time.

Using these modes allows you to run battery tests up to 200W, 30V, and 20A, which is ideal for testing low-power or embedded electronic devices such as IoT devices, mobile devices, and medical devices.

On top of that, Keysight E36731A Battery Emulator and Profiler hardware can also be configured as an independent external power supply or electronic load to fulfill your test requirement. This configuration can power up your Device Under Test (DUT) with up to 250W, 60V, and 40A while offering advanced features such as scope function, data logging, dynamic load profiles, and many more.

To achieve greater accuracy, you can monitor the battery temperature in real time during the test using the Keysight BV9210B PathWave BenchVue Advanced Battery Emulation software. You can input the temperature information manually or retrieve it from the Keysight DAQ973A Data Acquisition System, which is connected to a temperature sensor. The software allows you to export the recorded test data to CSV format for further analysis.



	A	B	C	D
1	Discharge Battery Model			
2	Number of Steps: 200			
3	Battery Type: Rechargeable			
4	Discharge: Current			
5	Discharge Current Type: Constant			
6	Constant Current (A): 3.9			
7	Voltage Limit (V): 1.469			
8	Capacity Rating (Ah): 1.3			
9	Current Pulse Width (s): 0.01			
10	Rest Time (s): 1			
11	File Save Rate (s): 0.9998336			
12	Connection Type: TwoWire			
13	Cut-off Condition: Voltage_Current			
14	Cut-off Voltage (V): 1			
15	Actual Battery Capacity (Ah): 1.177			
16	Elapsed Time:00.00:21:43:896			
17	State of Charge(%)	Open Circuit Voltage(V)	Internal Resistance(ohm)	DAQ Temperature(Celsius
18	99.99587099	1.37485683	0.077656932	20.5806077
19	99.45849809	1.348898649	0.092208102	20.6172497

Figure 4. The recorded test data, including data pulled from the Keysight DAQ973A Data Acquisition System, can be exported to a CSV file for easy data analysis.

Measuring the Temperature Effect on Battery

Design Under Test (DUT)

For our battery rundown test, a consumer-grade rechargeable battery has been selected as DUT, and it has the following specification:

DUT feature	Description
Chemical System	Nickel-Metal Hydride (NiMH) battery
Nominal Voltage	1.2 V
Cut-off Voltage	1.0 V
Rated Capacity	1.3 Ah

Test setup

Below test condition and configuration have been used throughout the battery rundown test:

Test parameter	Description
Battery Discharge Temperature (Temperature Chamber)	-2 °C, 20 °C, 50 °C ***Note:*** *The temperature range above simulates battery discharge in the room, cold and hot ambient temperatures.*
Keysight BV9210B Battery Emulator Mode	Profiler (Discharge)
Constant-Current Discharge Value	3.9 A (C-rate: 3.0C) ***Note****: Higher C-rate has been used in the test to accelerate the battery rundown test and to observe the effect of a high discharge current on battery temperature.*

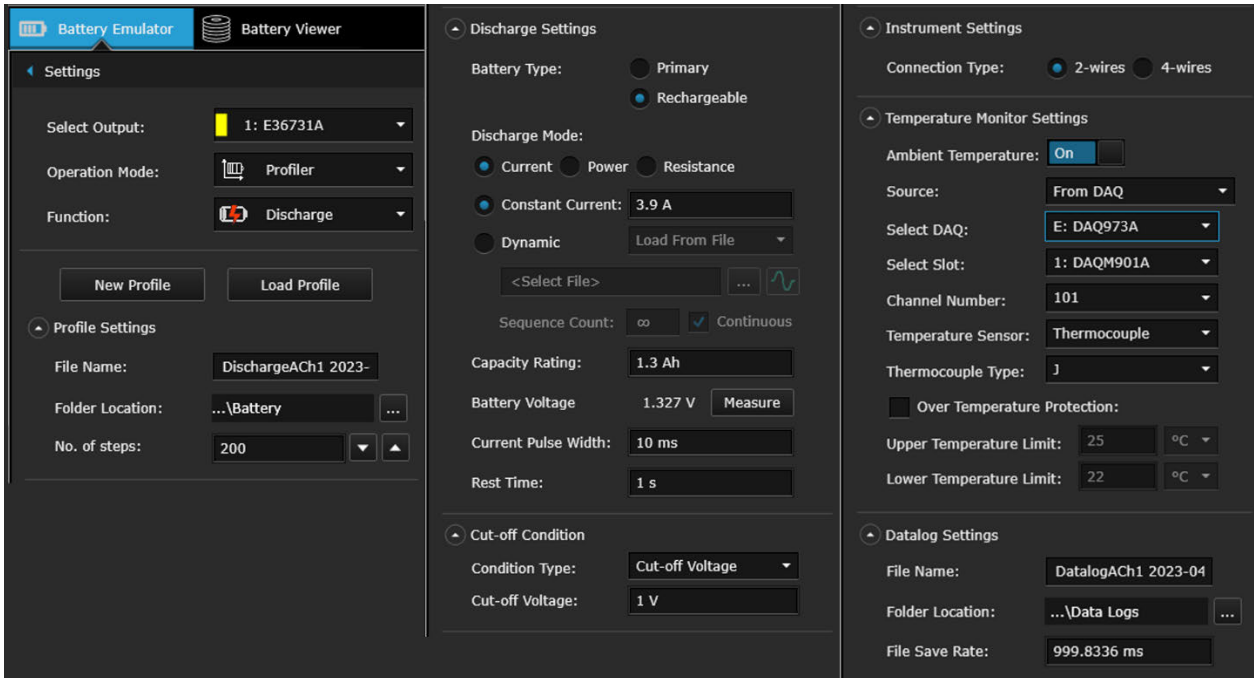


Figure 5. Configuration used within Keysight BV9210B Pathwave BenchVue Advanced Battery Emulation software

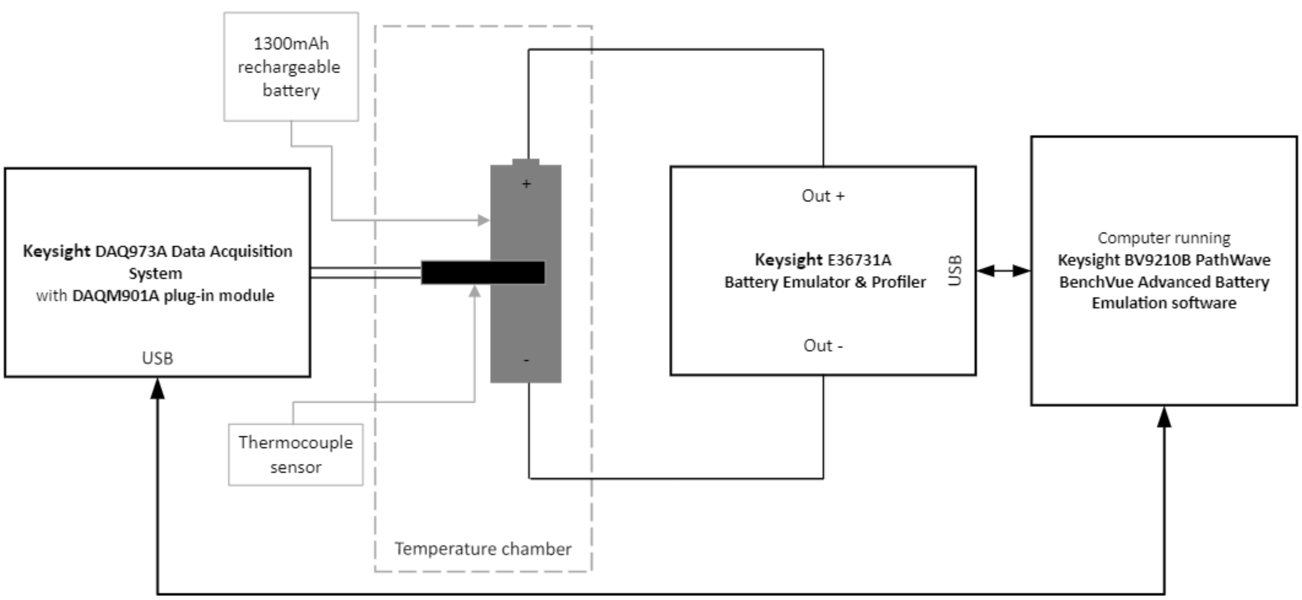


Figure 6. Hardware connection diagram

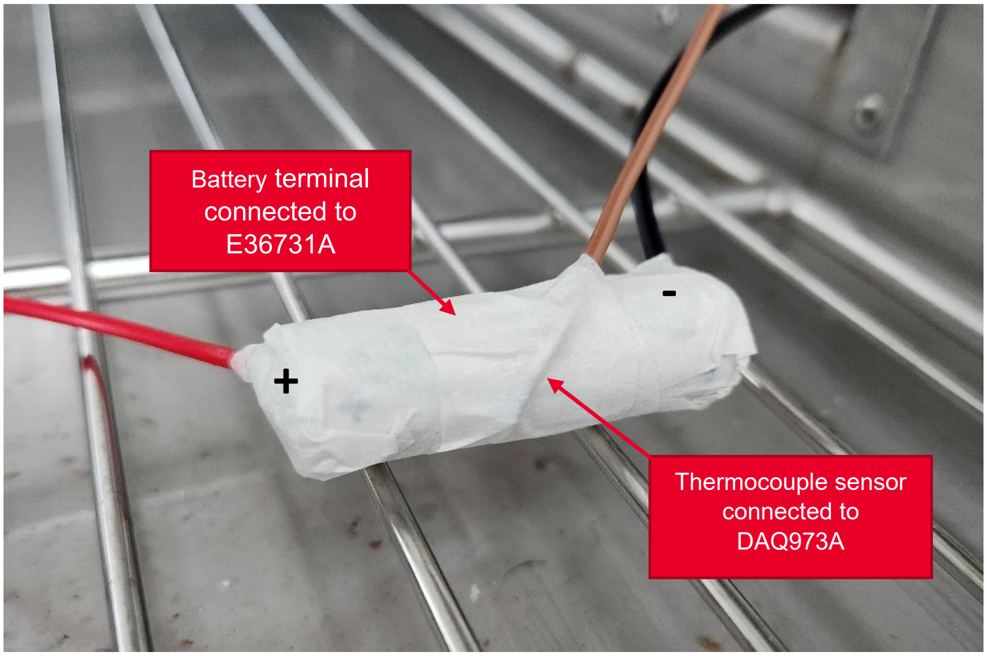


Figure 7. Battery placed in the temperature-controlled chamber.

Results and observation

Figure 8 - 10 shows the precise NiMH battery discharge profile data, rundown from 1.3 V to 1 V against various temperature points that have been captured via the Keysight BV9210B PathWave BenchVue Advanced Battery Emulation software with Keysight E36731A Battery Emulator and Profiler hardware. Note that the X-axis of the graph represents the remaining battery discharge capacity (Ah) while the Y-axis represents Open Circuit Voltage (Voc) and battery internal resistance (Ri).

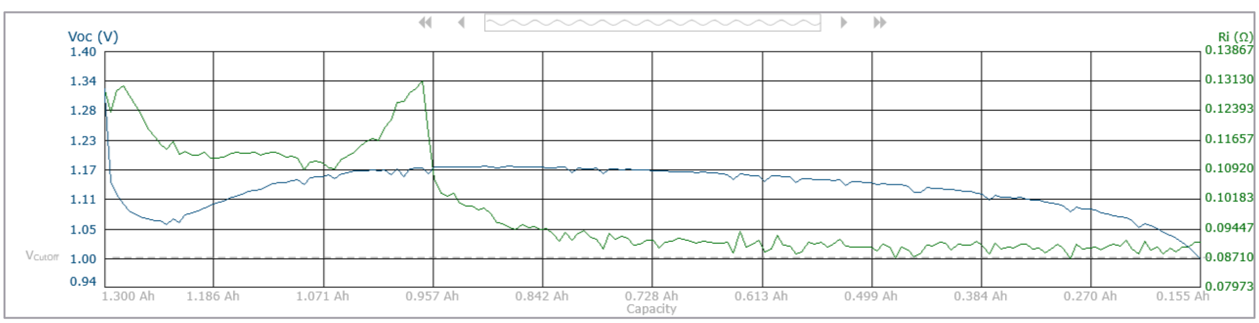


Figure 8. Recorded battery discharge profile at -2 °C

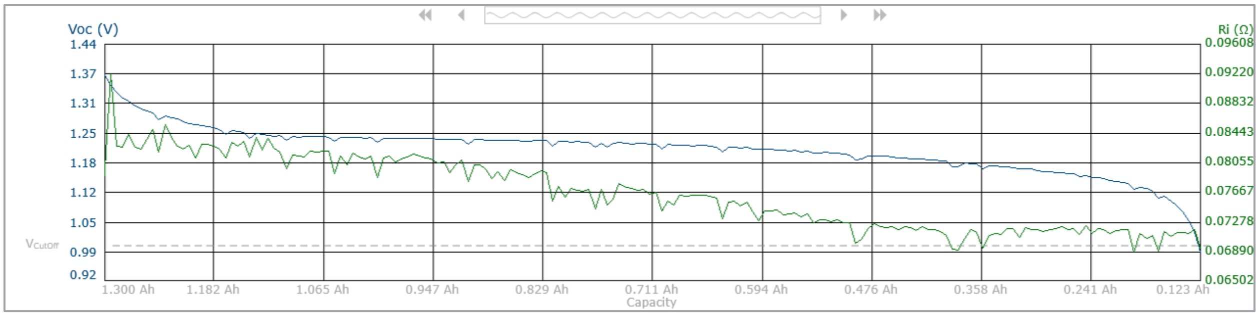


Figure 9. Recorded battery discharge profile at 20 °C

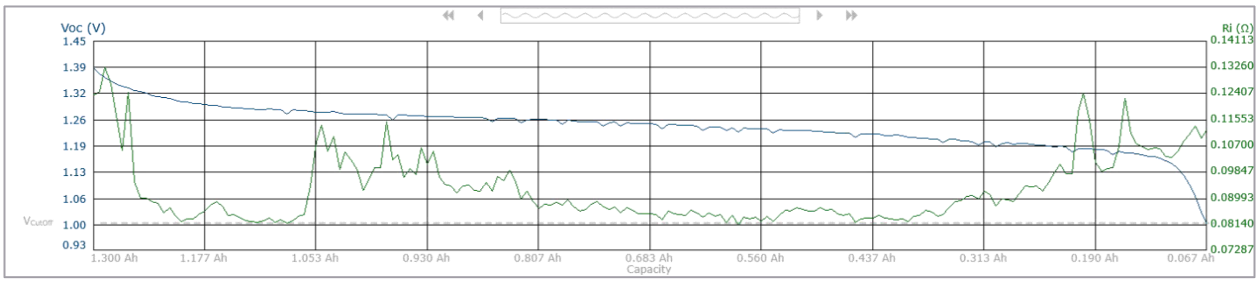


Figure 10. Recorded battery discharge profile at 50 °C

Figure 11 shows the superimposed data set from Figures 8 - 10 created for our analysis. It is known that a higher discharge current or higher discharge C-rate will cause the battery temperature to be elevated beyond ambient temperature and reduce battery capacity. As observed in Figure 11 and the table below, the final battery temperature increased by a few degrees, and the discharge capacity of the battery running at 20 °C (room temperature) was reduced to 1.177 Ah instead of 1.3 Ah, due to the effect of a higher discharge current. This effect can be diminished with a lower discharge current or with a lower discharge C-rate.

We can also see the effect of temperature on the battery as predicted, in which we have 4.7% more capacity when discharged at 50 °C versus 20 °C. The high temperature also improved the battery performance, which helps the battery stay above 1V for an extended period before it drops to 1 V. Likewise, a 2.8% capacity reduction can be seen at -2 °C versus 20 °C, with a voltage undershoots at the beginning of the discharge phase. The voltage undershoots behavior is known in cold temperatures due to the slower electrochemical reaction and an increase in the battery's internal resistance.

Chamber temperature	Initial battery temperature	Final battery temperature	Discharged capacity
-2 °C	-1.94 °C	8.72 °C	1.1446 Ah
20 °C	20.58 °C	26.81 °C	1.1770 Ah
50 °C	49.65 °C	58.59 °C	1.2334 Ah

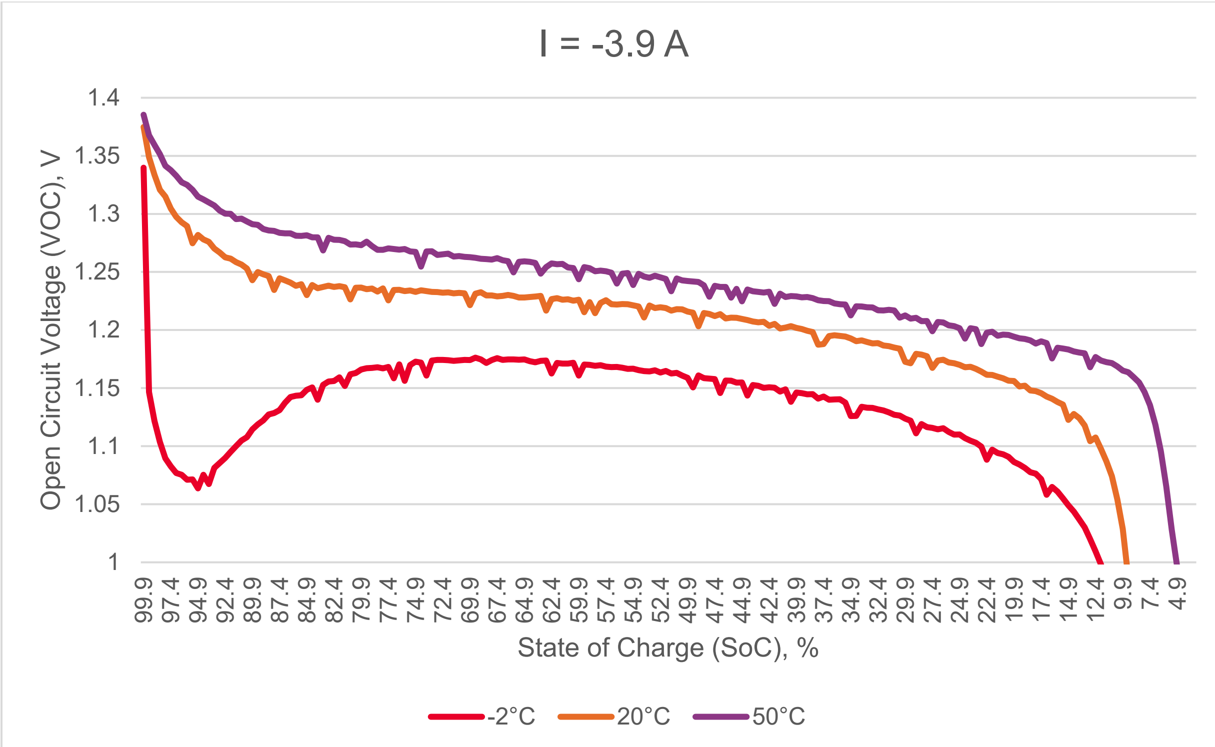


Figure 11. Battery State of Charge (SoC) vs Open Circuit Voltage (VOC) at various temperature points

Conclusion

The effect of temperature on the battery, specifically on the battery's discharge capacity, has been observed from the battery rundown test using Keysight E36731A Battery Emulator and Profiler, Keysight DAQ973A Data Acquisition System, together with Keysight BV9210B PathWave BenchVue Advanced Battery Emulation software. The observation aligns with recent research findings.

Beyond this battery rundown test, the Keysight hardware and software solution provides more flexibility and allows you to run various other battery tests configurations such as battery rundown test with a DUT connected, battery emulation test, dynamic battery charge test, battery cycling test, and many other test configurations, making it ideal for testing low-power or battery-powered embedded electronic devices such as IoT devices, mobile devices, and medical devices.

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