Keysight Technologies
Evaluating Adaptive Fast USB Battery Charging of Mobile Devices

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Application Note

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Overview

Today's mobile devices, including smart phones, phablets, and tablets have a phenomenal amount of capabilities to perform all kinds of innovative applications. However their power consumption has grown considerably as a result. They now utilize much larger lithium ion batteries in order to maintain acceptable run-time while supporting this greater power consumption. As one example battery capacities well over 9,000 mAh are now commonplace in tablets.

Even with their larger batteries devices often need recharging before the end of the day. And the dilemma with such large batteries is they take overnight to charge, due to the marginal power delivery of USB adapters. This dilemma is now being addressed with two new innovations; specifications for higher power delivery over USB and adaptive fast charging battery management systems. Together, these can charge a battery typically up to 80% of its capacity within an hour. This calls for using the maximum charging rate or C-rate, which is usually 1C maximum for lithium ion batteries. To put things in perspective, a 1C rate equates to 9 amps of current for charging a 9,000 mAh battery.

Adaptive fast USB charging is considerably more complex and must carefully manage battery charging to assure safety and reliability. A consequence of this for the design engineer of the charging system is all aspects of its operation need to be thoroughly validated during development. This process is greatly simplified using specialized test solutions tailored for the job. In this application note we will show how the Keysight N6781A 20W and N6785A 80W 2-quadrant source-measure units, together with the N6705C DC Power Analyzer mainframe and 14585A control and analysis software can be used to greatly simplify evaluating and validating adaptive fast-charging battery management operation; a task that is difficult at best with more traditional test equipment.

Legacy and Adaptive Fast USB Charging Technologies

To understand the advantages of adaptive fast USB charging technology it is helpful to first understand the basics of legacy USB battery charging, shown in Figure 1, along with its inherent limitations.

Most all mobile devices incorporate a single-cell lithium ion battery. Using a single-cell strikes a good balance between cost effectiveness and having sufficient voltage to power the electronics within the device. Most lithium ion cells used in mobile devices have an average rated voltage of 3.7 to 3.8 volts, with the maximum reaching 4.2 volts at completion of charging.

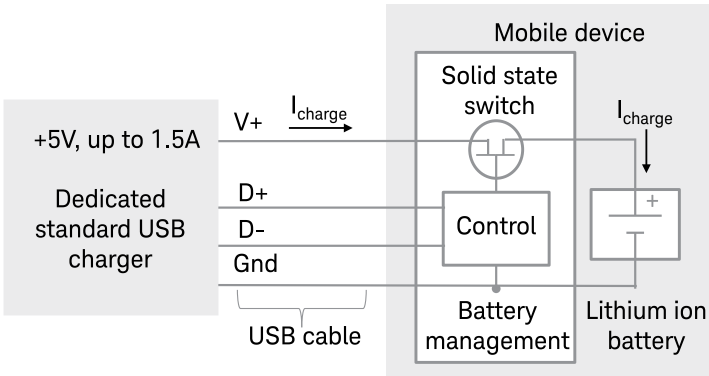

Figure 1. Legacy USB battery charging system

When first connected, the mobile device validates what type of USB port it is connected to, in order to determine how much current it can draw from the port. The mobile device then channels the +5 volt USB power to the battery through a solid state switch within its battery management system. While effective, there are a number of inherent limitations that impede faster charging, especially for larger capacity batteries:

– Version 1.2 of the USB battery charging specification increased charging current up to 0.9 amps from a non-dedicated charging port and up to 1.5 amps from a dedicated charging port. Even then this is a small fraction of current compared to what is needed to charge today's large lithium ion batteries at their maximum rates.
– The existing USB connectors are typically rated for a maximum of 1.5 amps.
– There is not a lot of potential difference between the USB's +5 volts and a lithium ion battery's 4.2 volt charging float voltage, making it difficult for the device's battery management circuitry to charge the battery at the USB rated current. This is further hampered when the acceptable USB voltage can be as low as 4.75 volts.
– The resistances in the USB cable and connectors contribute to additional voltage drops at higher currents, also impeding the maximum possible charging rate.

The power and current limitations of these previous USB power delivery specifications for charging purposes were well recognized. USB power delivery 2.0 and USB Type-C specifications have been established to resolve these limitations. Together they define an infrastructure to deliver much higher power of up to 100 watts, both through greater currents of up to 5 amps, and greater voltage of up to 20 volts. USB power is no longer a limiting factor for faster charging of larger batteries.

Many devices have alternately incorporated proprietary adaptive fast USB charging technology, independent of the updated USB specifications. While similar in operation, they instead make use of the existing legacy USB infrastructure. They maintain backward compatibility by keeping the charging adapter's output at the USB default 5 volt level when connected to a non-compatible device and maintain current within acceptable levels. When connected to a compatible adaptive fast charge-capable device, higher power is delivered primarily through increasing the voltage to a higher level, up to 20 volts. This adaptive fast USB charging system is depicted in Figure 2.

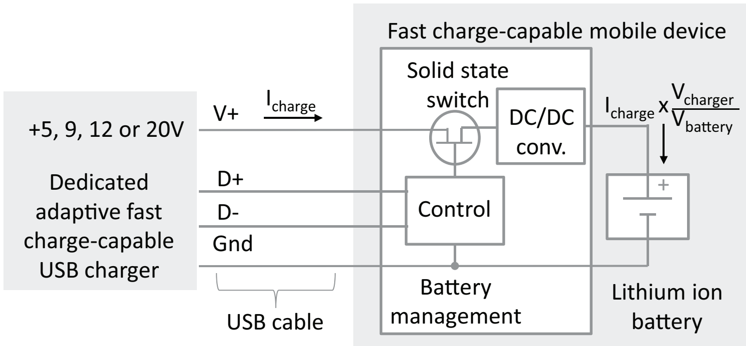

Figure 2: Example of an adaptive fast USB charging system

This adaptive fast USB charging first starts out at USB's default 5 volt level. The adaptive fast charge-capable device then negotiates one of a few higher output voltage levels from the charger power source, potentially up to 20 volts. DC-to-DC conversion within the mobile device efficiently converts the higher voltage, lower current charging power into a lower voltage, higher current power suited for charging the lithium ion battery. This technology resolves the inherent power limitations of legacy USB charging, allowing fast charging of large mobile device batteries at up to their maximum acceptable C-rates, greatly reducing the charging time.

Validating Adaptive Fast USB Charging Performance

Due to higher power, greater dissipation, and using maximum battery C-rates, it is vital to fully validate an adaptive fast USB charging system design to assure safety and reliability. This requires validating a number of aspects including:

- USB default +5 volt operation
- The adaptive fast charge negotiation process
- Maximum C-rate achieved together with losses and efficiency
- % of charge reached for fixed durations, such as 30 and 60 minutes
- Total time to 100% charge
- Correct charge termination

To fully validate the performance of an adaptive fast USB charging system it is necessary to be able to simultaneously measure both the adapter's voltage and current being sourced to the mobile device, together with the voltage and current directly charging the battery. These measurements need to be continually logged over the duration of the charging cycle. Of utmost importance is the current measurements must have negligible burden or they will alter the results, such as producing lower than expected charging rates as well as other issues. Once the measurements are captured the data then needs to be analyzed for the above list of aspects. To accomplish this task an N6705C DC Power Analyzer with N6781A 20V, 3A, 20W and N6785A 20V, 8A, 80W source-measure units and 14585A Control and Analysis software were set up together with an adaptive fast-charge capable mobile device, as shown in Figure 3.

In this setup the N6781A and N6785A source-measure units are operated in their current measure-only mode, acting as zero-burden ammeters. Unlike a traditional approach using shunts they are able to measure current ranging from nanoamps to amps without introducing any voltage drop, assuring accurate test results. The N6781A and N6785A also feature an auxiliary DVM input so that voltage can be logged simultaneously with current, providing accurate voltage, power, and energy measurements as well. The N6785A was selected for measuring the charging current of the device's 3,300 mAh battery, as it would exceed the N6781A's 3 amp maximum capability in order at up to a 1C rate. The 8 amp, 80 watt capability of the N6785A is an excellent match for the current, power, and voltage levels that will be encountered in testing adaptive fast USB charging systems, as well as powering today's higher-power mobile devices in general.

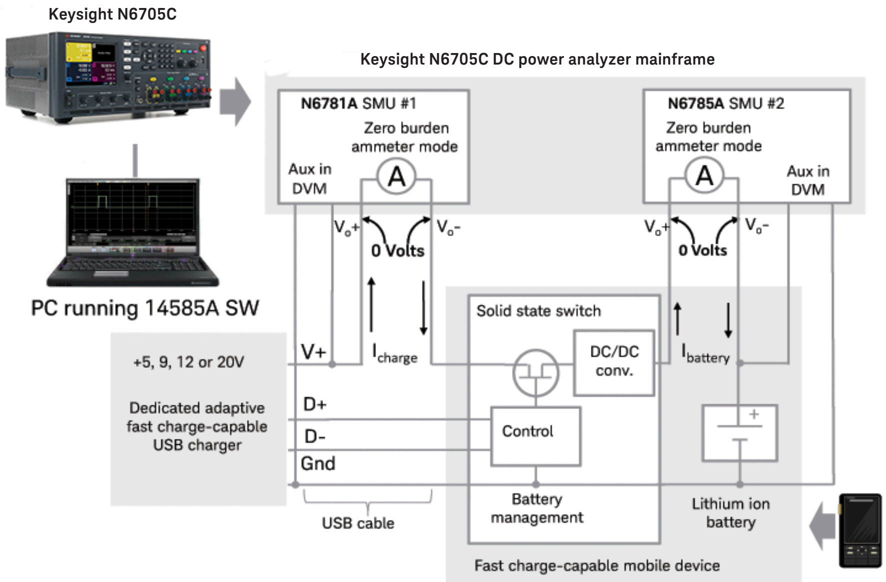

Figure 3: Setup for validating a device's adaptive fast USB charging performance

The 14585A Control and Analysis software provided a simple way to quickly set up and run, and then capture, display, and analyze the results of the adaptive fast charge performance. The data log operating mode was used to provide a long-term capture, as it takes up to several hours to fully charge a lithium ion battery. While the logging was set up to capture the hours-long overall charge cycle, it was also set up to sample at a sufficiently high rate so that details of short-term activities can be examined as well. This includes the initial fast charge negotiation process as shown in Figure 4. Here the adapter's voltage, current, and power are the yellow and orange traces on the bottom of the graph, while the battery's charging voltage, current, and power are the blue traces at the top. By analyzing the startup portion of the fast charge process, the following aspects were validated:

- When the adapter is first connected to the DUT, it outputs the default 5V level.
- As can be seen in the graph a negotiation between the adapter and DUT then takes place over 7.6 seconds, after which the adapter increases its output from 5V to 9V.
- It was validated that whenever the adapter was disconnected it would immediately drop back down to the default 5V level and the negotiation would have to take place again for the output to increase to a higher level. This assures backward compatibility when connected to legacy mobile devices.
- At 9V out, the adapter is able to deliver 80% more charging power for the same level of charging current as a result. This is because the DUT incorporates a DC to DC converter that converts the adapter's +9V output down to the battery voltage, but at greater charging current.
- It was found the charging current quickly reaches a maximum level of 3.02 amps. This is 0.9C for a 3,300 mAh battery. This is consistent with applying the recommended 1C maximum charge rate for standard lithium ion batteries.
- At maximum charging the adapter's output power was 14.54W while the battery's charging power was 11.59W. This equates to 80% power conversion efficiency with 2.95W of losses to contend with inside the mobile device.

Figure 4: Adaptive fast USB charging startup details

Looking at the overall charge cycle in Figure 5, there are two main phases to lithium ion battery charging. The first phase is constant current (CC) charging, where the battery is most readily able to absorb charge, as it rises to its maximum safe charging float voltage level limited by the device's battery management system. At this point the charging transitions over to the constant voltage (CV) float phase. Here the voltage remains constant while the charging current tapers off to nearly zero, as the battery accumulates the rest of its charge. From analyzing the data log of the overall charge cycle the following aspects were validated:

- By placing measurement markers at the start and end points it took a total of 2 hours and 24 minutes for the fully-discharged battery to reach 100% charge. This is relatively very fast for lithium ion battery charging. During this period the battery accumulated 3,200 mAh of charge.
- The CC phase took 54 minutes, just 38% of the total time, for the battery to accumulate 2,359 mAh, which is 73% of its charge. Fast charging takes advantage of the battery being able to accept a greater C-rate during the CC phase.
- It was found that the battery reached 43% charge in 30 minutes and 81% charge in 60 minutes. This makes fast charging practical for adequately recharging device to get it through the day!
- In contrast to the CC phase, CV float phase took 130 minutes, or 62% of the total time, but the battery accumulated only 850 mAh, or 27% more of its total charge.
- The final float voltage level was 4.386V for the 4.4V rated battery. Charging was terminated when charge current fell below 94.5 mA, which is 2.9% of the 1C charge rate. Both values are within acceptable ranges.

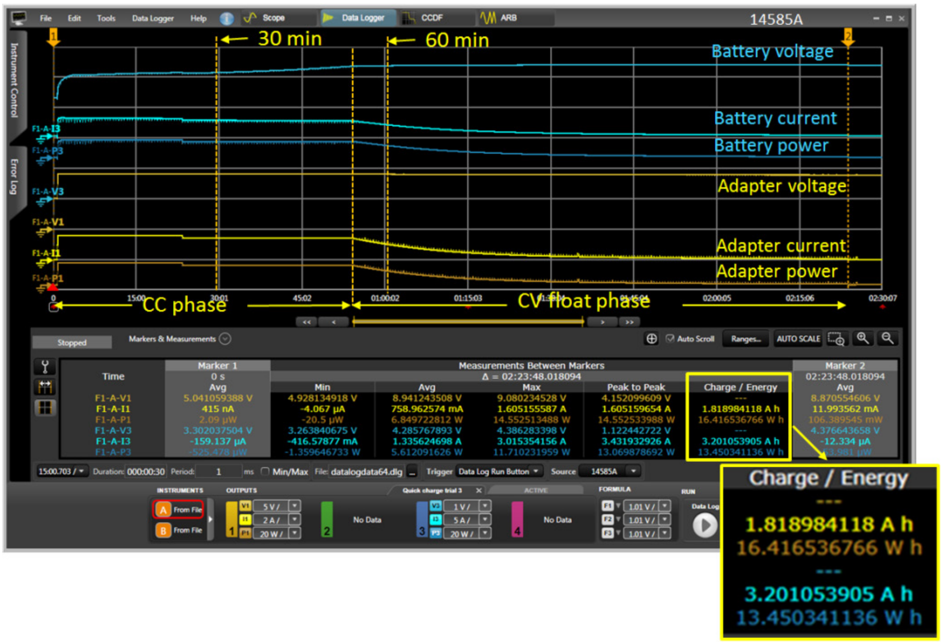

Figure 5: Adaptive fast USB charging overall results

Validating Performance For Worst-Case Conditions

It is important to perform tests for various worst-case conditions, in addition to nominal conditions, when validating the performance of adaptive fast charging systems. One example of this is validating the performance for the battery's expected range of equivalent series resistance (ESR).

To do this the test setup in Figure 3 was altered slightly. The device's battery was removed altogether. The N6785A serving as SMU#2, previously operating in zero-burden measurement mode, now directly replaces and emulates the battery under charge. This updated setup is depicted in Figure 6.

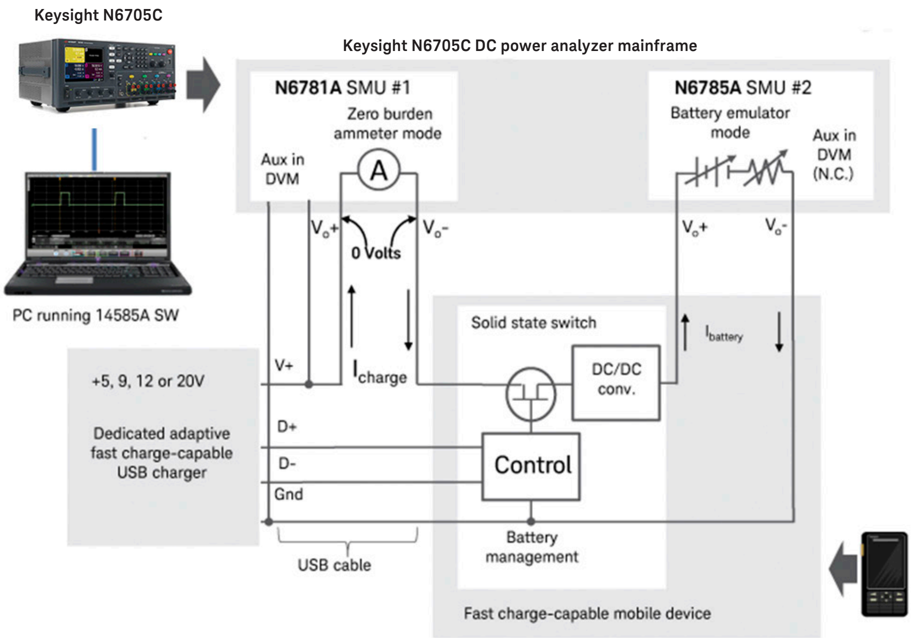

Figure 6: Setup for validating adaptive fast USB charging for a high ESR battery condition

The N6785A operating as a battery emulator provides programmable ESR so that the adaptive fast charging can be tested over the range of expected battery ESR. The following aspects were validated:

– When the programmable ESR was set to emulate the actual battery's ESR of 115 mΩ, results matched that of using the actual battery.
– When the programmable ESR was increased to 215 mΩ, charging current was reduced by 20%, significantly increasing charging time.

Not only does this show that the battery's ESR has a significant impact on charging, but this also emphasizes that current measurements made between the DUT and its battery need to have negligible burden or they will similarly alter the test results.

Summary

To offset their greater power consumption, today's mobile devices are now incorporating larger batteries. However, the consequence of this is that it takes a lot longer to recharge due to the marginal power delivery of USB. This dilemma has now been addressed with new USB standards for higher power delivery and adaptive fast charging systems. Together they can recharge large batteries up to typically 80% of their capacity within an hour.

Adaptive fast USB charging is considerably more complex and must carefully manage battery charging to assure safety and reliability. As a result all aspects of adaptive fast USB charging operation need to be thoroughly validated during development. This process is greatly simplified using specialized test solutions tailored for the job. The Keysight N6781A 20W and N6785A 80W 2-quadrant source-measure units, together with the N6705C DC Power Analyzer mainframe and 14585A control and analysis software, can be used to greatly simplify evaluating and validating adaptive fast-charging battery management operation; a task that is difficult at best with more traditional test equipment.

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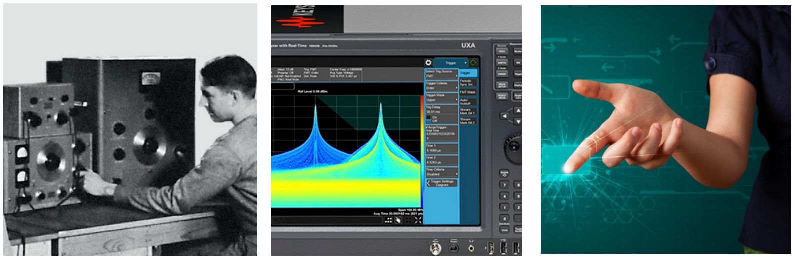

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