Application Note

How to Quickly and Safely Charge Supercapacitors

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ABSTRACT

This application note provides a design for charging supercapacitors using either dedicated supercapacitor chargers or simple modifications to Li-ion battery chargers.

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1 Introduction

Most super capacitors (supercaps) can be discharged down to 0 V and recharged to their maximum voltage with the manufacturer recommended charge current. A simple voltage regulating LED driver with constant current, usually regulated by sensing a low side, series current sense resistor, then a voltage clamp can be used to charge a super capacitor. However, using a dedicated charging IC that provides both output voltage and current regulation, as well as input power regulation, temperature sensing, thermal regulation and other safety features allows for more precise and safer charging. Also, there is no series sense resistor creating an undesirable voltage drop, especially during discharge. This application note provides a design for charging supercaps using either dedicated supercap chargers or simple modifications to Li-ion battery chargers.

2 Supercapacitors Charging Key Care-Abouts and Implementations

2.1 Supercap Charge Profile

A typical supercap charge profile is shown in Figure 2-1.

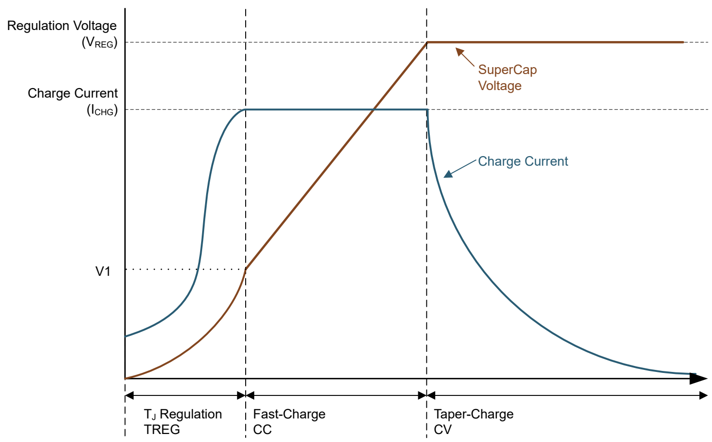

Figure 2-1. Supercap Charging Profile

With a fully discharged supercap, the charging circuit initially sends current directly to ground. The charging circuit operates at a much-reduced, slowly increasing current due to the converter die temperature reaching thermal regulation. Alternatively, the charging circuit may turn on and off due to a die temperature fault at changing duty cycle. Eventually, the super capacitor voltage, and therefore the charging circuit's operating efficiency, increases so the capacitor charges at the desired constant (fast or max) charge current, I_{CHG}, until it reaches and remains at constant voltage (CV) regulation voltage, V_{REG}. Having CV regulation allows for total utilization of the supercap's capacity.

The charge time in CC mode can be estimated rearranging $i = C \times dv/dt$ to get $dt = C \times (V_{REG}-V1)/I_{CHG}$. Charge time can be difficult to predict if the initial, reduced charge current is unknown or slowly increases out of thermal regulation up to voltage V1, as shown above.

2.2 Linear Based Supercap Charger

A step-down only linear regulator-based charger is best for applications where

- The input voltage is higher than V_{REG}.
- I_{CHG} is low, typically < 1.0A
- The supercap's capacitance is low or charging time is not critical
- The system load can be connected directly to the supercap

The BQ25173 is a linear regulator based supercap charger. The FB pin resistors set the CV voltage, V_{REG}, and the ISET resistor sets the CC current, I_{CHG}.

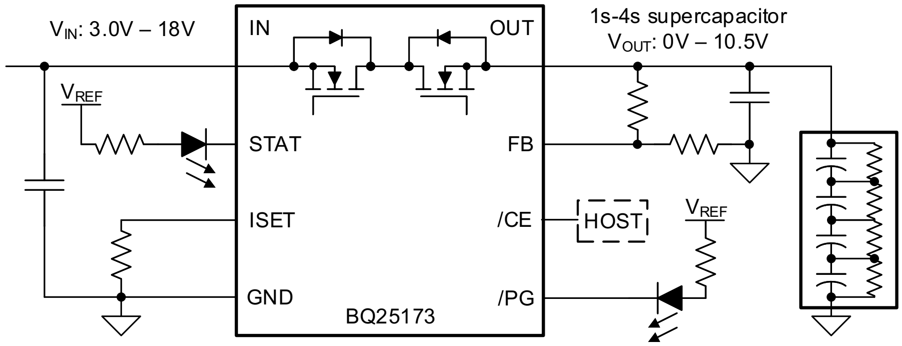

Figure 2-2. BQ25173 Supercap Charger Block Diagram

A complete charge cycle of the BQ25173 charging a 10F supercap to 5 V with I_{CHG}=800mA and V(IN)=5.5 V is shown in Figure 2-3.

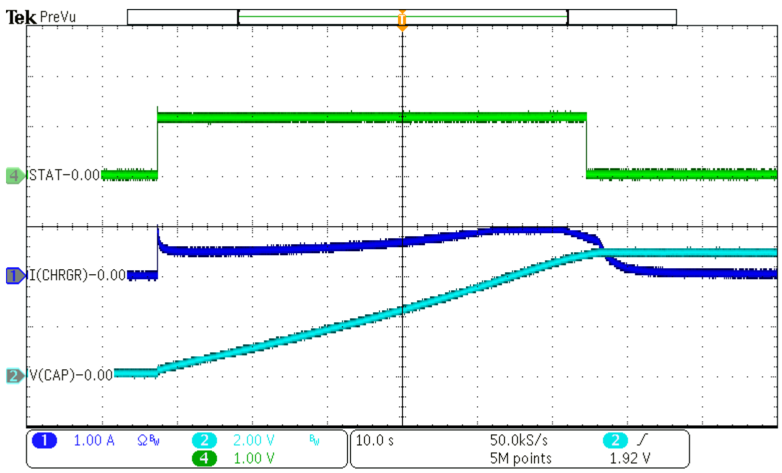

Figure 2-3. BQ25173 Charge Cycle of a 10 F Supercap to 5.5 V with 800 mA Charge Current

Note the thermally reduced charge current at the beginning of the cycle. The STAT pin goes low when the supercap voltage reaches 98% of the regulation voltage. The charger stays in CV to maintain the supercap voltage at 5 V.

2.3 Switch-Mode Buck Converter Based Supercap Charger

A buck switch mode supercap charger is needed when the

- The input voltage is higher than V_{REG}.
- I_{CHG} is high, typically > 1.0A
- The supercap's capacitance is high or fast charging time is required
- The system load can be connected directly to the supercap

The BQ24640 is a supercap charge controller with external FETs as shown below. The VFB pin resistors set the CV voltage, V_{REG}, and the ISET resistors set the CC current, I_{CHG}. The optional TS pin senses the supercap temperature from a NTC thermistor placed on the supercap and disables charge if the supercap temperature is outside a set window.

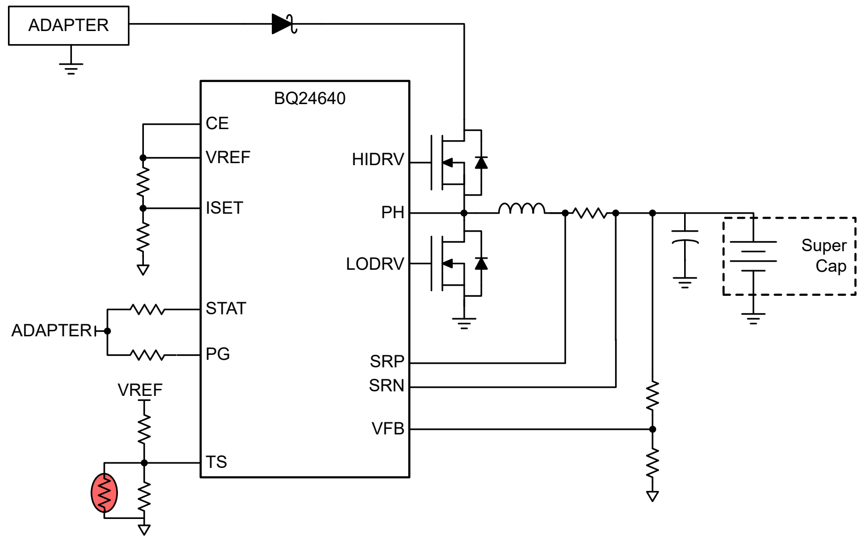

Figure 2-4. BQ24640 Supercap Charger Block Diagram

A complete charge cycle using the BQ24640 to charge a 10 F supercapacitor to 5 V with I_{CHG}=4A and V (adapter) = 24 V is shown in Figure 2-5.

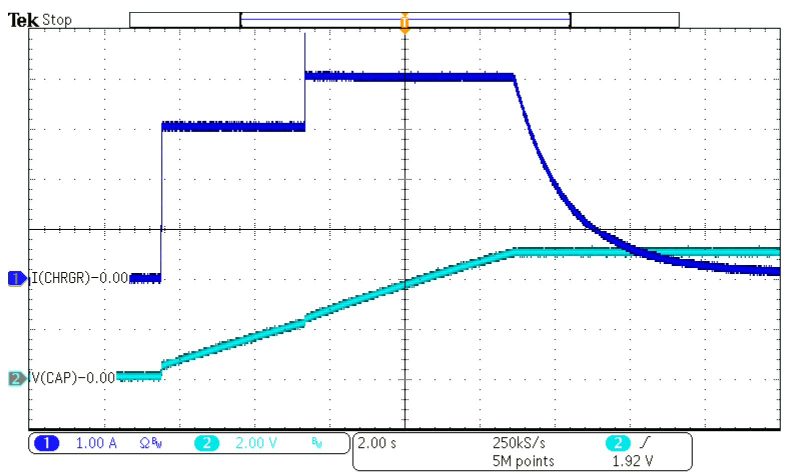

Figure 2-5. BQ24640 Charge Cycle of a 10 F Supercap with ICHG = 4 A

Note that to protect the power FETs, while the supercap voltage is less than 2.1 V, the ISET pin is clamped to 600 mV. For a 10 m ohm current sense resistor (the resistor between SRP and SRN pins), this clamp limits the max charge current to 3 A even if the ISET pin sets I_{CHG} higher. Termination is disabled on the BQ24640 so the STAT pin (not shown above) does not change state when the supercap reaches full charge. The converter operates in CV mode indefinitely to keep the supercap charged to 5 V.

2.4 Modifying Li-ion Chargers to Charge Supercaps

Due to large selection of Li-ion chargers on the market, it seems reasonable to use a Li-ion charger to charge a supercapacitor. A Li-ion charge profile is show in Figure 2-6.

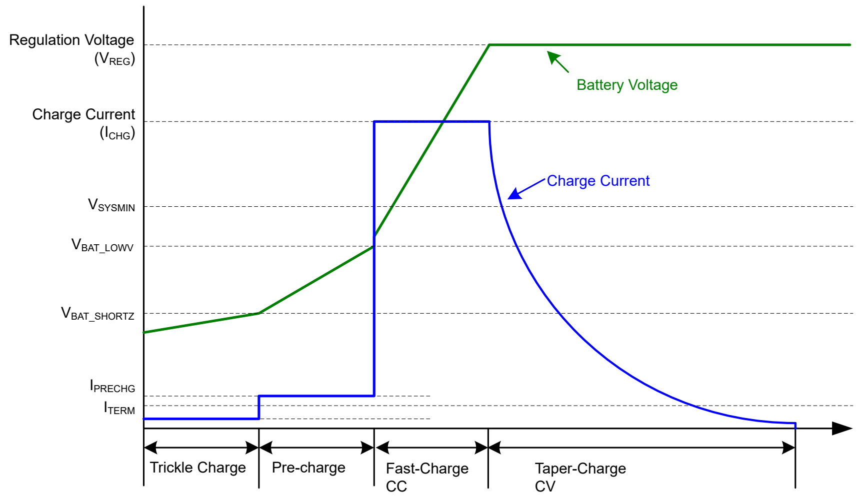

Figure 2-6. Li-ion Charge Profile

To prevent damage and increase battery lifetime, Li-ion battery pack protectors prevent the cells from being discharged below approximately 2.5 V cell. If the pack protector is open due to deeply discharged cells or there is no storage element at the BAT pin, the BAT voltage is <= 2.0 V (VBAT_SHORTZ) and the charger provides a small trickle charge in the 100 mA range to slowly raise the pack cell voltage. Then the charger must charge at a low pre-charge current in the 100 mA to 800 mA range until the battery reaches 2.6-3.0 V typically (VBAT_LOWV). After those two stages, the CC and CV stages are the same for supercap charging as previously discussed. Li-ion batteries are recommended to have charge termination and not be continuously topped off, for example, not be recharged until the battery discharges by a nominal amount (at least 200 mV). Supercapacitors typically do not need trickle charge or pre-charge, do not require charge termination and can be constantly topped off. Luckily, most chargers allow termination to be disabled. But only a few Li-ion chargers allow trickle charge to be disabled. Therefore, some modification from default settings and/or additional circuitry is required for a Li-ion battery charger to charge a supercap.

2.5 Using a Li-ion Buck-Boost Integrate FET Charger to Charge a Supercap or Li-ion Battery

Modifying an integrated FET, host controlled buck-buck boost charger to charge a supercap is best if

- There is a need to switch between Li-ion battery and supercap charging with a single charger IC (using host software to change the charge settings).
- The input voltage to the charger can be higher or lower than V_{REG}.
- 1.0 A < I_{CHG} < 5.0 A
- The supercap’s capacitance is medium to high or fast charging time is required

The BQ25798 is a buck-boost charger with integrated FETs capable of providing up to 5-A. It is a narrow voltage dc (NVDC) charger that can provide a minimum system voltage. The charger's I^2C registers allow its VBAT_LOWV threshold to be reduced to 15% of VBATREG. With BATREG = 5.0 V, VBAT_LOWV is then 0.75 V which is below VBAT_SHORTZ = 2.5 V. Therefore, the charger bypasses pre-charge and transitions directly from trickle charge to fast charge. To assist with the charger's 100 mA trickle charge current while V(BAT) =V(CAP) < 2.5V, a current limited switch with thermal regulation, the TPS25221, is added between SYS and BAT to speed up capacitor charging. Since the TPS25221 minimum input voltage is 2.5 V, the BQ25798 minimum system voltage must be set to at least 2.5 Vminimum value. Higher minimum system voltage settings result in more losses across the switch. The host can disable the switch after the supercap voltage reaches 2.5 V.

The BQ25798 + TPS25221 reference design block diagram is shown below. In this configuration, the charger can be used in a cradle to charge either a supercap or a LiIon battery pack. A mechanical switch is likely required to inform the host, and therefore the charger, which storage element is being charged and how to reset the charger's registers.

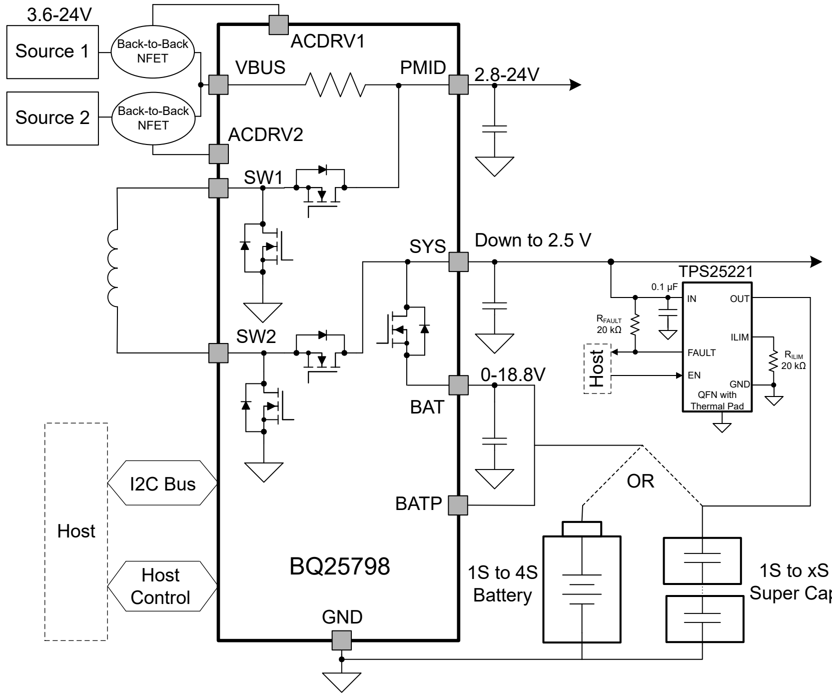

Figure 2-7. BQ25798 Plus TPS25221 Supercap and Li-ion charging Reference Design Block Diagram

A complete charge cycle using the BQ25798 and TPS25221 to charge a 10F supercapacitor to 5 V with I_{CHG}=2 A and VBUS = 5 V is shown in Figure 2-8.

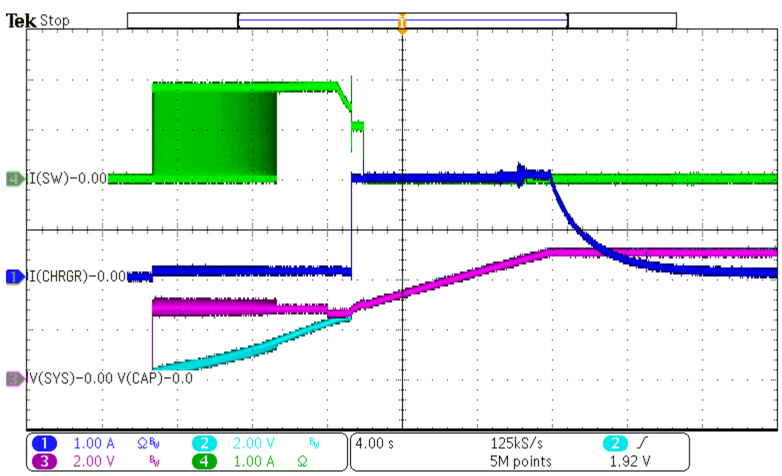

Figure 2-8. BQ25798 Plus TPS25221 Charge Cycle of a 10 F Supercap with ICHG=2 A

The pink trace is V(SYS) and blue trace is V(CAP). While V(CAP) < 2.5 V, the charger provides 100 mA trickle charge and the switch provides 1.9 A, after exiting the thermal fault duty cycle phase. Then the host turns off the switch and the charger provides the entire 2 A fast charge current. It is possible to parallel multiple switches to share the losses, reduce their time in thermal fault and allow for higher charge current. In this example, the host disabled charge termination so the STAT pin (not shown) never changes state and the converter operates in CV mode indefinitely to keep the supercap at 5 V.

2.6 Using a Buck-Boost Controller with External FETs to Charge a Supercap

Modifying an integrated FET, host controlled buck-buck boost charger to charge a supercap is best if

- The input voltage to the charger can be higher or lower than V_{REG}.
- I_{CHG} is high, typically $\geq$ 3.0A
- The supercap's capacitance is very high or very fast charging time is required

Unlike many chargers, the BQ25713/30 family of buck-boost charge controllers with external FETs does not provide trickle charge. Also, even though it is an NVDC charger, the BQ25713/30 has I^2C registers that allow the user to disable the minimum system voltage, and therefore precharge phase, and BAT pin short circuit protection. With the minimum system voltage disabled, the voltage across the BATFET during initial charge is minimized.

If a minimum system voltage is needed, the controller's minimum system voltage can be enabled and set to the lowest acceptable value for the system, to minimize losses across the BATFET.

The BQ25713 block diagram is shown below. The host sets the charge current and supercap voltage regulation, as well as the other settings previously mentioned, in the charger's I^2C registers.

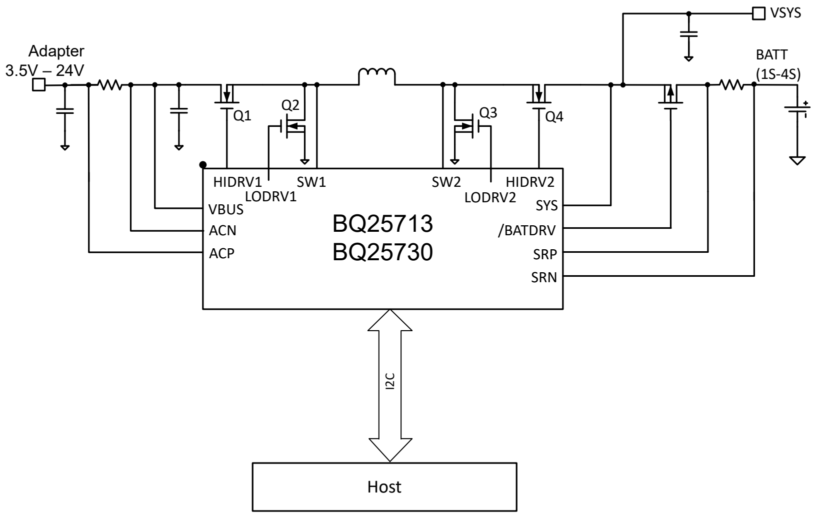

Figure 2-9. BQ25713 Charger Block Diagram

A complete charge cycle using the BQ25713 to charge a 5 F supercap to 5.2 V with I_{CHG} = 3 A from VBUS = 20 V is shown in Figure 2-10.

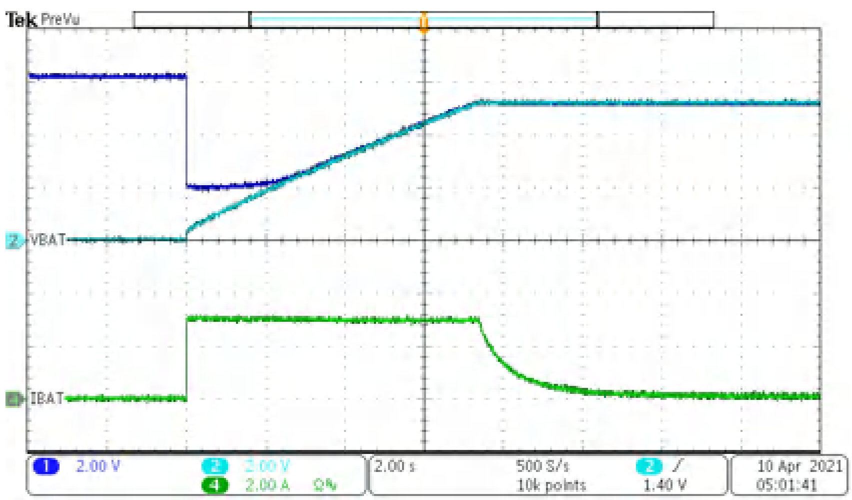

Figure 2-10. BQ25713 Charge Cycle of a 5 F Supercap with ICHG = 3 A

As shown in the curve in Figure 2-10, the charger requires a minimum output voltage (approximately 2 V) to supply a given charge current, so V(SYS) is maintained at this level until V(BAT) = V(CAP) rises up to V(SYS). Initially, there is high but slowly decreasing power loss ($P_{L(MAX)}$ = 2 V * ICHG) in the BATFET. The user must select a BATFET which can safely handle this power dissipation, especially if their charge current is high.

3 Summary

This application note's supercap charging designs can be easily scaled to fit larger or higher voltage supercaps by changing the charge voltages and or charge currents. The key concern, and charge time variable, is how the charging circuit manages its high power losses and heat dissipation until the supercap voltage reaches a manageable voltage level. Table 3-1 compares the options,

Table 3-1. Supercap Charging Design Options

Design	Input Power Voltage	Capacitance	Charge Current	Charge Time	Other features
BQ25173 linear charger	> V(REG)	Low	< 1 A	long	Small size
BQ24640 buck charger	> V(REG)	Med-High	>1 A but < 10 A	Short - medium	
BQ25798 b-b charger plus TPS25221 switch	<or > V(REG)	Med-High	>1 A but <5 A	medium	LiIon or supercap charging with host software
BQ25713/30 b-b controller	<or > V(REG)	High	>2 A but < 20 A	short	

4 References

- Texas Instruments, *BQ25173: 800-mA Linear Charger for 1- to 4-Cell Super Capacitor*, data sheet.
- Texas Instruments, *bq24640 High-Efficiency Synchronous Switched-Mode Super Capacitor Charger*, data sheet.
- Texas Instruments,*BQ25798 I2C Controlled, 1- to 4-Cell, 5-A Buck-Boost Battery Charger with Dual-Input Selector, MPPT for Solar Panels and Fast Backup Mode*, data sheet.
- Texas Instruments,*TPS25221 2.5-V to 5.5-V, 2-A Continuous Current Limited Switch*, data sheet.
- Texas Instruments,*BQ25730 I2C 1- to 5-Cell Buck-Boost Narrow VDC Battery Charge Controller with Power Path Control and USB-C PD 3.0 OTG Output*, data sheet.