Application Note
Capacitor Backup Circuits with the BQ25856-Q1

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ABSTRACT

A capacitor backup or *last gasp* circuit provides a short boost of backup power for when the main power fails. A capacitor backup is a common requirement across a wide variety of applications. This is a critical need to make sure MCUs can shut down safely, volatile memory can be stored, safety doors can open, or to provide a small boost of power during a blip in the main power. The BQ25856-Q1 can charge both super capacitors and normal capacitors to work in this application.

Table of Contents

List of Figures

List of Tables

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1 Introduction

The BQ25856-Q1 provides automatic reverse mode operation for when the main power fails when auto reverse mode is enabled. As the input voltage, or VAC, falls below the set undervoltage threshold, the BQ25856-Q1 can automatically enter reverse operation and regulate the VAC voltage to a set voltage target. The BQ25856-Q1 also provides reverse blocking protection, adjustable charge voltage and charge current. The BQ25856-Q1 has a wide input range of 4.4V to 70V, a wide output voltage of up to 70V, and a maximum charge current of 20A.

There are two paths for the backup capacitors. The first path is to use electrolytic capacitors. Electrolytic capacitors can be charged to high voltages and store a decent amount of power cheaply in a small board size. The second path is to use supercapacitors. Supercapacitors have large amounts of capacitance, but a single-cell supercapacitor can have an operating voltage of around 2.1V to 3.5V. Using two supercapacitors in series to get a higher voltage can be necessary.

Figure 1-1 shows a simplified block diagram of the BQ25856-Q1 circuit.

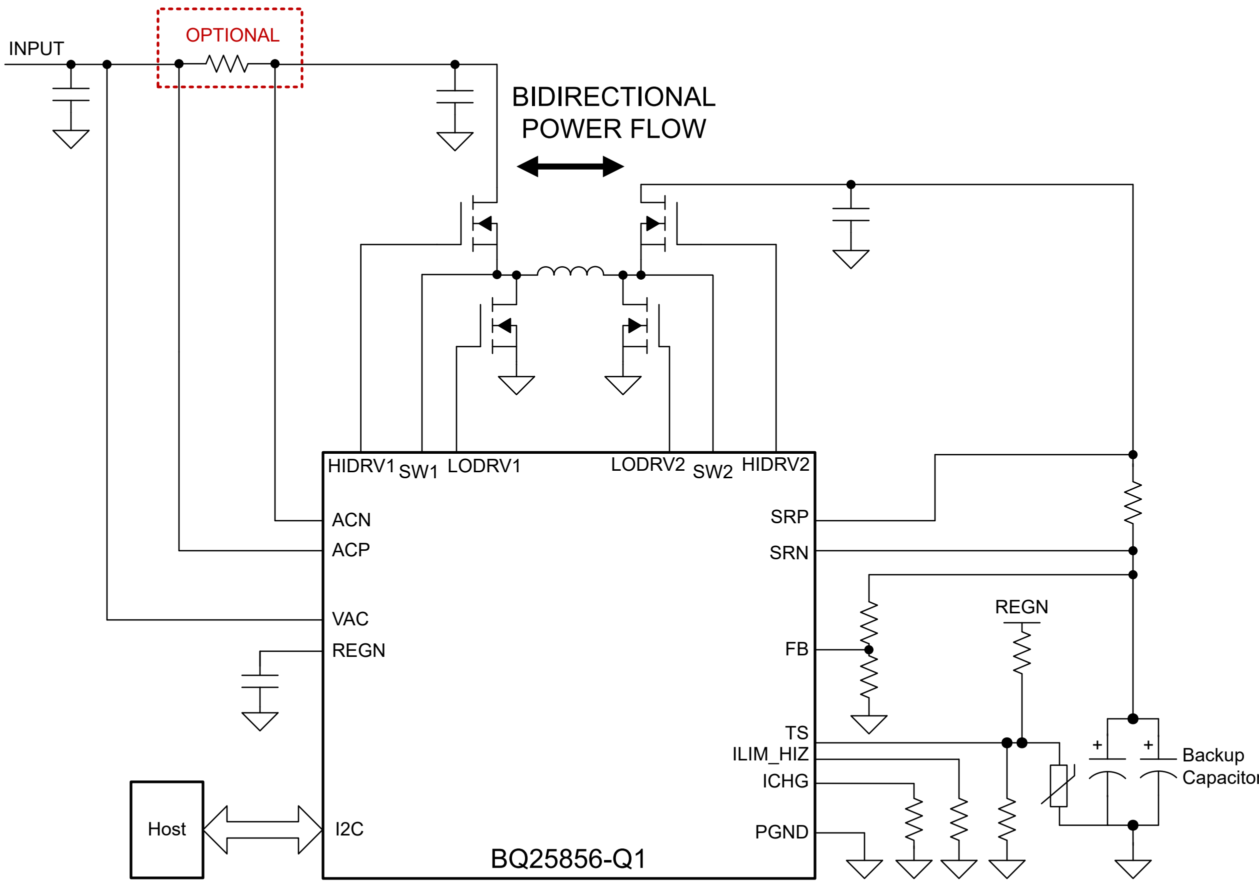

Figure 1-1. BQ25856-Q1 Capacitor Backup Block Diagram

2 ACUV and ACOV Settings

The BQ25856-Q1's VAC undervoltage threshold is set by the ACOV/ACUV voltage divider. The BQ25856-Q1 enters into auto reverse mode as soon as the power drops below the ACUV setting with the EN_AUTO_REV set to 1. The ACUV setting is set by a resistor voltage divider on the VAC, ACUV, and ACOV pins. These pins also control the ACOV setting and ACUV_DPM voltage. The ACOV pin detects when the VAC voltage is above a certain value. The ACUV_DPM voltage limits the output charge current of the BQ25856-Q1 to prevent the input power supply from being overwhelmed. The resistor divider is shown in Figure 2-1.

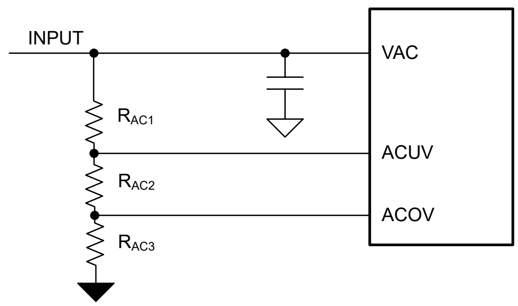

Figure 2-1. ACOV and ACUV Resistor Divider

The ACUV/ACOV settings are set by the following equations.

$$V_{VACOVP} = \frac{1.2(R_{AC1} + R_{AC2} + R_{AC3})}{R_{AC3}} \quad (1)$$

$$V_{ACUV\_DPM} = \frac{1.2(R_{AC1} + R_{AC2} + R_{AC3})}{R_{AC2} + R_{AC3}} \quad (2)$$

$$V_{VACUVP} = \frac{1.1(R_{AC1} + R_{AC2} + R_{AC3})}{R_{AC2} + R_{AC3}} \quad (3)$$

Setting the ACUV voltage correctly is critical for a fast transition time. A smaller difference between the minimum VAC voltage and the ACUVP threshold results in the reverse mode being triggered faster. A faster transition time gives less time for the system voltage to drop below critical levels.

3 Derivation

The math behind how much capacitance is needed to support the backup power is described in this section. The BQ25856-Q1 converter turns off once the capacitor voltage falls below 2.5V on the SRN pin. The amount of usable energy that can be stored in a capacitor is calculated by using Equation 4:

$$E_{Cap} = \frac{1}{2}C\left({V_{Cap}}^2 - 2.5^2V\right) \tag{4}$$

The total energy required by the circuit is set by the system voltage, the needed current, and the how long system needs to stay working can be calculated by using Equation 5:

$$E_{Load} = I_{Load}V_{Load}\Delta t_{Load} \tag{5}$$

Now, the two equations can be combined to calculate the total capacitance or charge voltage needed by using Equation 6:

$$2\Delta t_{Load}I_{Load}V_{Load} = C\left({V^2}_{Cap} - 6.25V\right) \tag{6}$$

Note, these equations are only an estimation of the total energy required by the system. Switching losses, conduction and the equivalent series resistance (ESR) of the capacitor losses from the converter reduces the usable power from the backup capacitor.

For backup energies of 10J or less, electrolytic capacitors can be used. For higher energy demands, supercapacitors work better because of the much greater capacitance.

4 Application Diagram

The application diagram with the measurement points for the following example electrolytic and supercapacitor backup circuits is shown in the Figure 4-1.

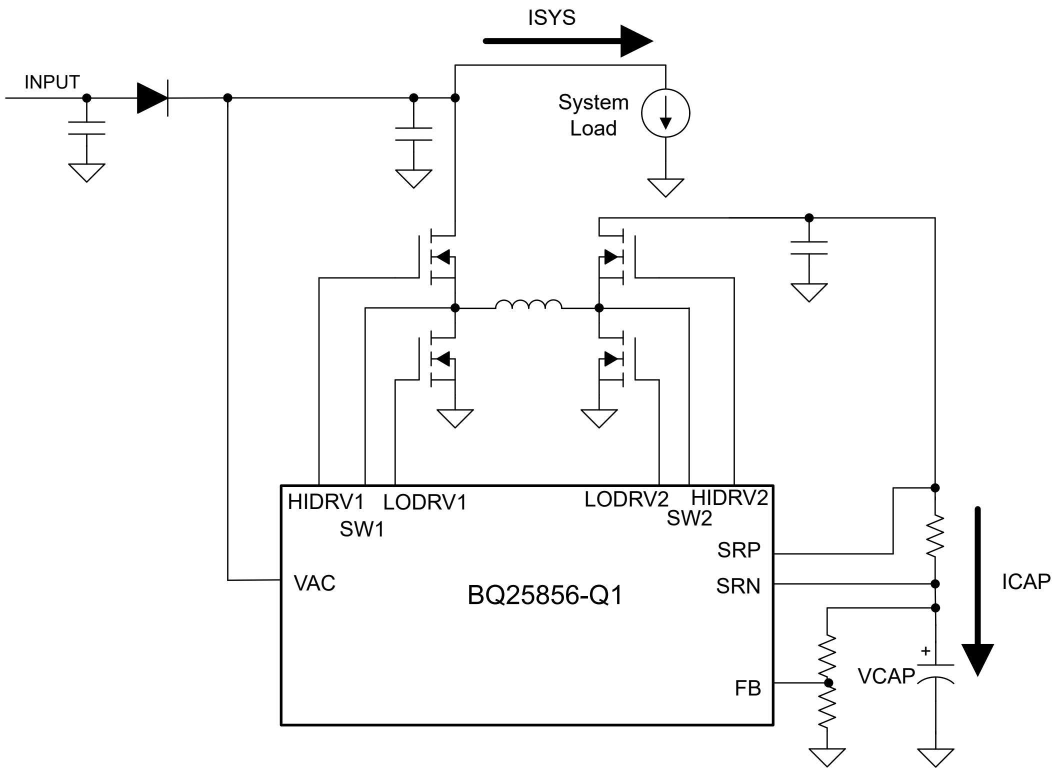

Figure 4-1. Application Block Diagram

In Figure 4-1, the input voltage is separated from the system voltage by a diode. As can be seen, VAC is approximately equal to VSYS when VAC is high. When the input voltage turns-off, the VAC voltage drops and the BQ25856-Q1 enters into reverse mode. At this moment, the capacitor current flips from positive to negative during the transition and begins to source power. The VSYS voltage then falls to the reverse voltage setting.

5 Application Example - Electrolytic Capacitor Backup

In the following scenario, there is a car battery powering a 1.4A system load. This system needs to maintain the 1.4A system load for 600ms at 5V. The backup power allows the car systems to safely shut down. The requirements are summarized in Table 5-1.

Table 5-1. Design Requirements

Parameter	Value
Input voltage	12V
System load	1.4A
Reverse voltage needed	5V
Load hold time needed	600ms
Total energy needed	4.9J

Because the energy needed is 4.9J, an electrolytic capacitor can be used for the backup capacitor. If board space is constrained, then the high voltage electrolytic capacitors can hold more energy compared to increasing the capacitance. 58V can be used for the capacitor. Equation 7 is used to calculate the needed capacitance.

$$\frac{2I_{Load}V_{Load}\Delta t_{Load}}{{V_{Cap}}^2 - 6.25V} = C \quad (7)$$

The capacitance needed is 2,502µF. This number is rounded up to 3000µF. The total capacitance is 3160µF once the EVM output capacitors are included.

Table 5-2. Hardware Setup

Parameter	Value
Output capacitor	3160µF (3x1000µF +160µF)
Output voltage	58V
ACUV setting	6.2V

Table 5-3. Register Settings

Register	Description
REG0x14[0]=0	Sets EN_PRECHG=0 and sets the charger to skip the trickle charge and precharge modes. This sets the BQ25856-Q1 to only be in fast charge mode or taper charge mode.
REG0x14[3]=0	Sets EN_TERM = 0 and makes sure the charger doesn't stop charging while VIN is good. This makes sure that the capacitor always has the max possible charge.
REG0x02=0x0A0	Sets ICHG_REG = 2000mA.
REG0x06=0x01E0	Sets IAC_DPM=15000mA. The input supply has a max current output of 15A. This makes sure the input doesn't crash.
REG0x19[1]=1	Sets EN_AUTO_REV=1 and this enables auto reverse mode.
REG0x0C=0x03E8	Sets VAC_REV = 5000mV and sets the voltage that the BQ25856-Q1 regulates VAC too while in reverse mode.
REG0x1E[5]=1	Sets SYSREV_UV=1. By default, reverse mode turns OFF if VAC is below 80% of the reverse voltage target. SYSREV_UV=1 fixes the undervoltage setting to 3.3V. This makes sure reverse mode turns ON even if VAC has dropped below the reverse voltage target.

Figure 5-1 shows a full cycle of charging and discharging. The BQ25856-Q1 takes around 100ms to charge the output capacitors from 0V to 60V at a charge current of 2A. For reference, channel 1 is the input source and is colored blue. Channel 2 is the capacitor voltage and is colored teal. Channel 3 is the system current. Channel 4 is the current out of the capacitor. Current into the capacitor is negative. When the input voltage drops out, the BQ25856-Q1 goes into reverse mode and the system load current stays constant.

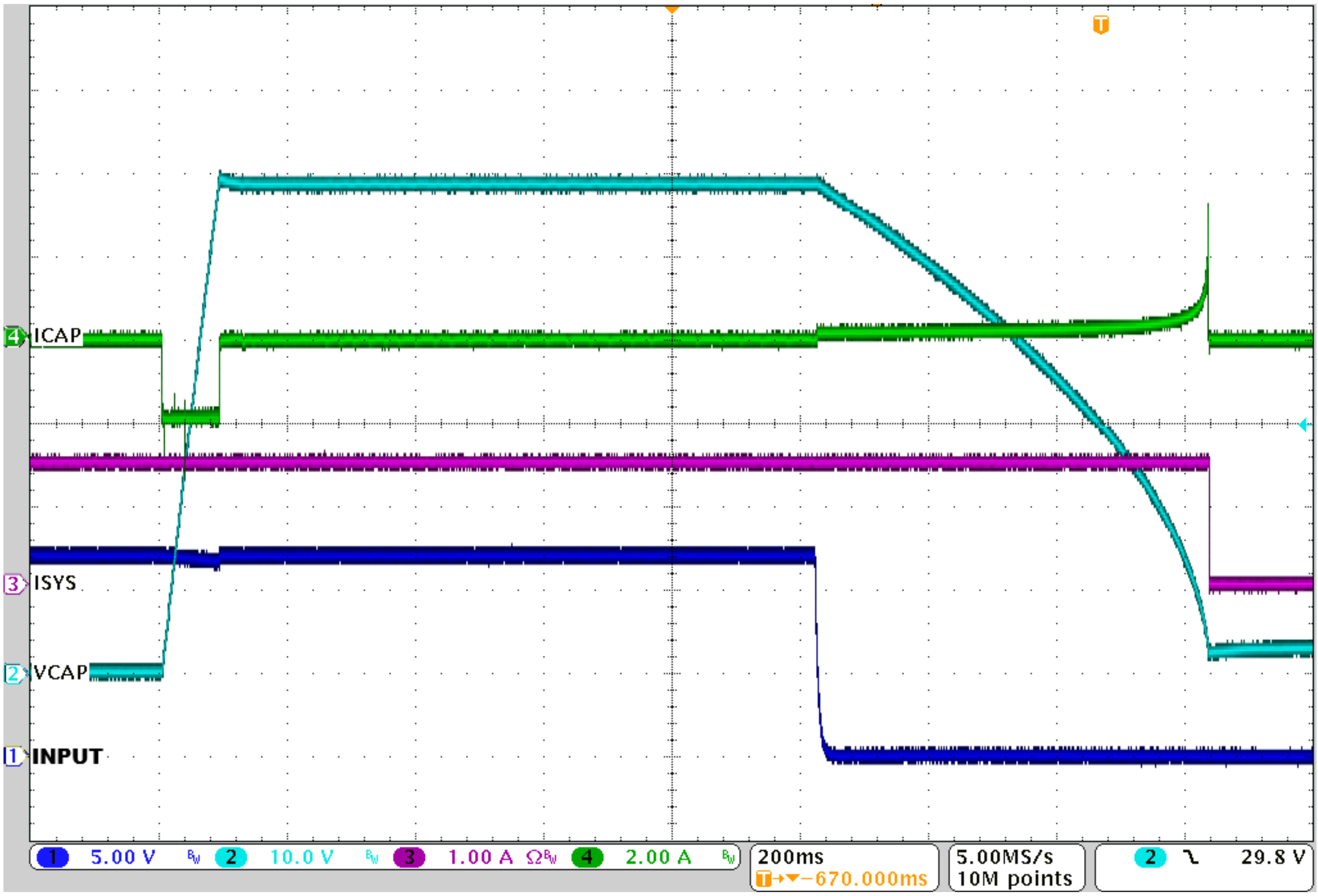

Figure 5-1. BQ25856-Q1 Full Charging And Discharge Cycle

Figure 5-2 zooms in on the output capacitor charge speed.

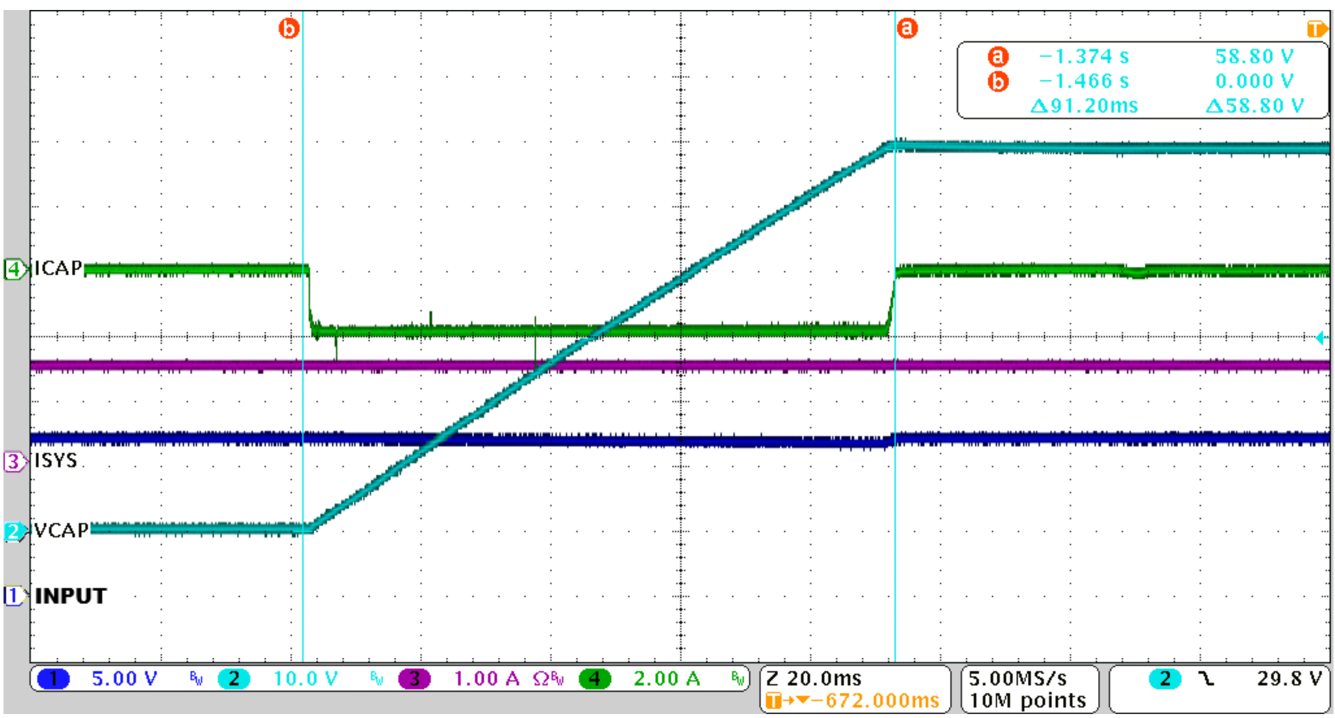

Figure 5-2. BQ25856-Q1 Electrolytic Capacitor Charging Speed

Figure 5-3 zooms in on the capacitor discharge. The BQ25856-Q1 provides backup power to a 1.4A system load for 610ms.

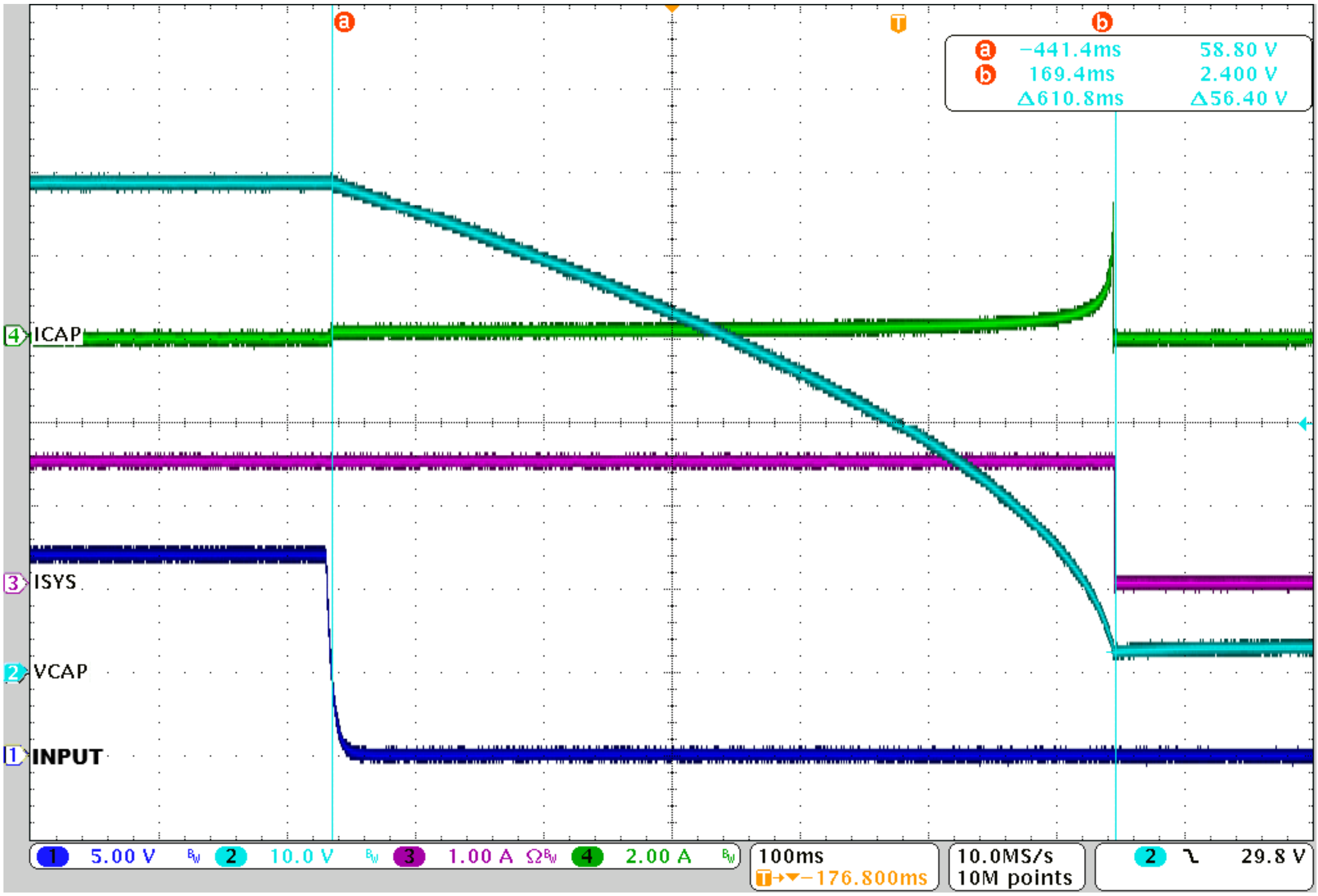

Figure 5-3. BQ25856-Q1 Provides Backup Power with a 1.4A Load

Figure 5-4 shows how fast reverse mode activates. As soon as the VAC voltage crosses the ACUV threshold, the BQ25856-Q1 takes an average of 100µs to activate reverse mode and begin sourcing power. The exact time depends on the load current and voltages. In Figure 5-4 from the same circuit as above, the switchover time is about 50µs to transition from charging to discharging. For reference, Channel 1 is VAC and is colored blue. Channel 3 is switch node 2 and is colored magenta. Channel 4 is the current into the capacitors and is colored green. Current into the capacitors is assigned a negative value. The capacitor current goes from negative to positive as the BQ25856-Q1 goes from charging to discharging.

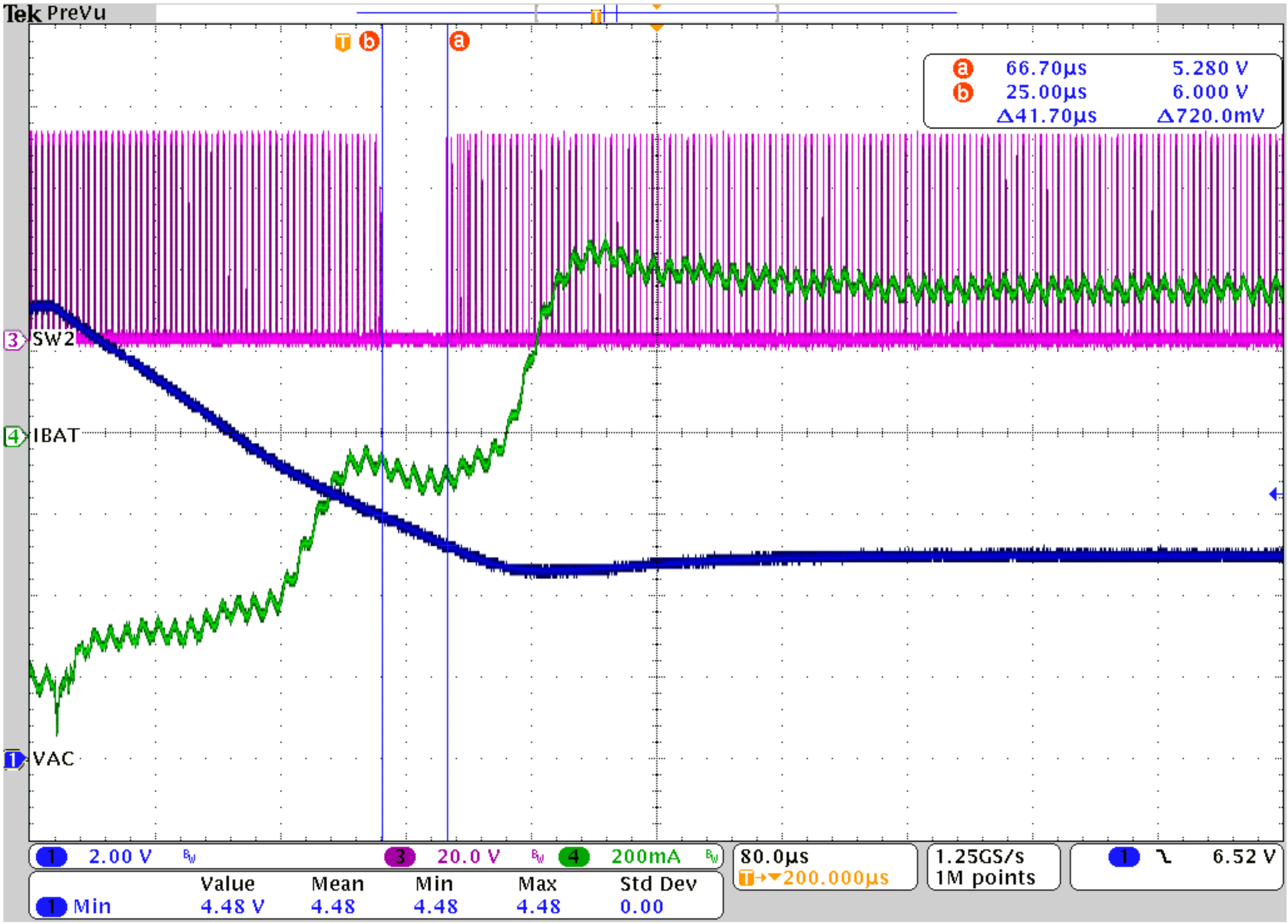

Figure 5-4. BQ25856-Q1 Auto Reverse Mode Response Time

6 Application Example - Super Capacitor Backup

The BQ25856-Q1 also works with super capacitor backup systems. In the following example, the backup capacitor circuits needs to maintain a 10V system load at 4A for 0.9 seconds. This is an extreme case for the BQ25856-Q1 because the maximum discharge current from the capacitors is greater than 15A once the capacitor voltage falls to 2.5V. The design requirements are summarized in Table 6-1.

Table 6-1. Design Requirements

Parameter	Value
Input voltage	12V
System load	4A
Reverse voltage needed	10V
Load hold time needed	0.9s
Total energy needed	36J

Supercapacitors offer the best storage for these high energy backup systems. A single cell supercapacitors has a low maximum charge voltage of around 2.5-3.7V. To get a higher voltage and more usable power, multiple supercapacitors have to be used in a series configuration. Two supercapacitors in series allows for a charge voltage of 5V. The equations above can be used to calculate the needed capacitance as 3.84F. Because of the extreme current being pulled from the capacitor, this number is multiplied by 4 to get 11.52F. Two 25F capacitors in series can be used to get a total capacitance of 12.5F with a total voltage rating of 5V.

Table 6-2. Hardware

Parameter	Value
Output capacitor	12.5F (2x25F capacitors in series)
Output voltage setting	5V
ACUV setting	10V

Table 6-3. Register Settings

Register	Description
REG0x02=0x0640	Sets ICHG_REG to the maximum of 20A to charge the capacitor as fast as possible.
REG0x06=0x01E0	Sets IAC_DPM to 15A to prevent the charger from crashing the input power supply.
REG0x0C=0x07D0	Sets VAC_REV = 10000mV and this sets the reverse mode voltage.
REG0x14[3]=0	Sets EN_TERM = 0.
REG0x14[0]=0	Sets EN_PRECHG=0 and sets the charger to skip the trickle charge and precharge modes.
REG0x18[6]=0	Sets EN_ILIM_HIZ_PIN=0. This disables the input current hardware limitation on the EVM. Now, the IC only uses the IAC_DPM register to regulate the input current.
REG0x1E[5]=1	Sets SYSREV_UV=1. By default, reverse mode turns OFF if VAC is below 80% of the reverse voltage target. SYSREV_UV=1 fixes the undervoltage setting to 3.3V. This makes sure reverse mode turns ON even if VAC has dropped below the reverse voltage target.

In Figure 6-1, the BQ25856-Q1 EVM takes 6.78 seconds to charge the capacitors completely. Channel 1 is the input voltage and is blue. Channel 2 is the capacitor voltage and is teal. Channel 3 is the system voltage and is magenta. Channel 4 is the capacitor current and is green. Current into the capacitor is positive.

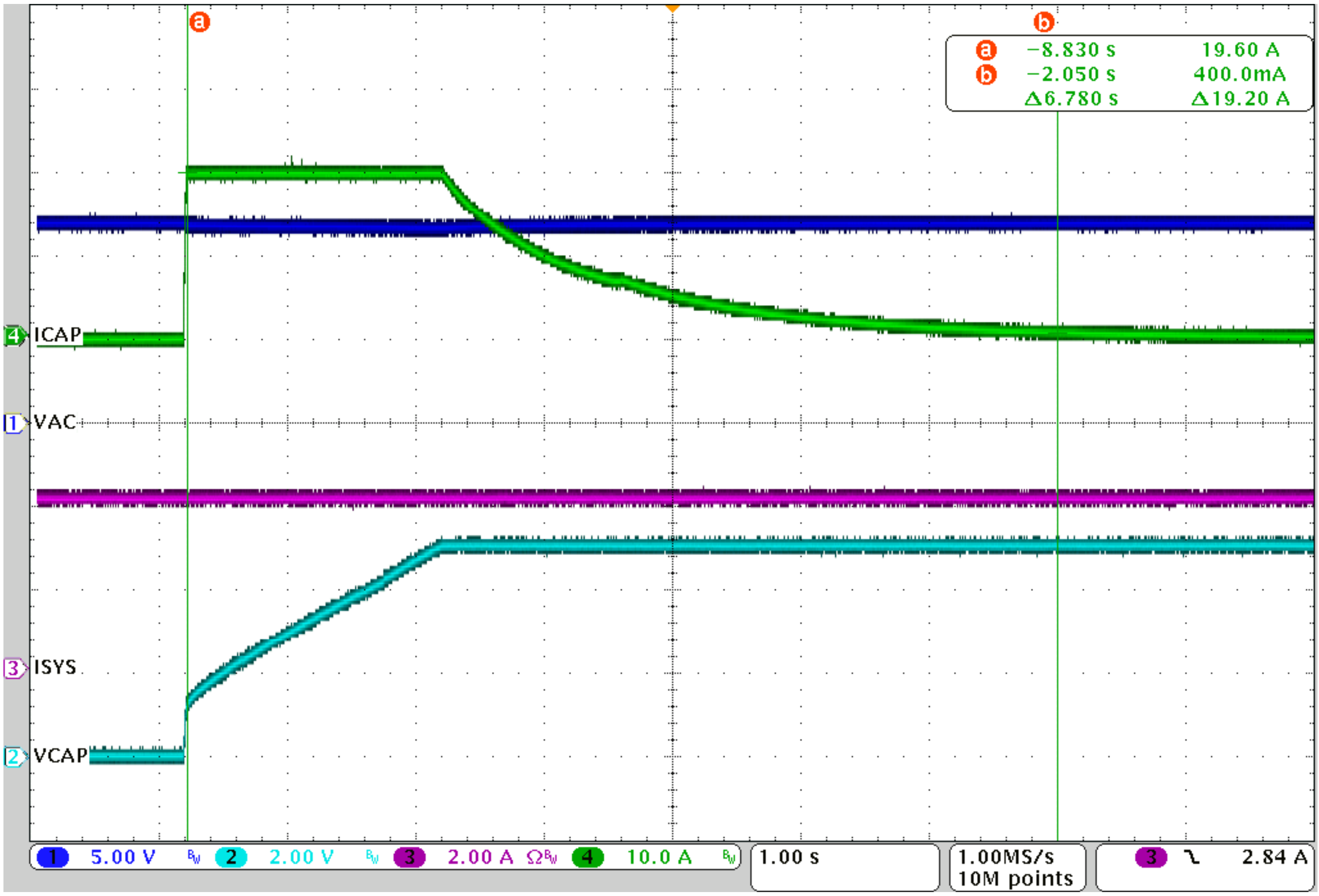

Figure 6-1. BQ25856-Q1 Charging Up Supercapacitors

In Figure 6-2, the BQ25856-Q1 provides a 4A system load at 10V for 900 milliseconds. Channel 1 is the VAC voltage seen at the charger. Channel 2 is the voltage on the backup capacitors. Channel 3 is the system load current. Channel 4 is current into the capacitor. The capacitor current turns negative as the BQ25856-Q1 begins sourcing power. Note that VAC begins to fall, but VAC stabilizes at 10V.

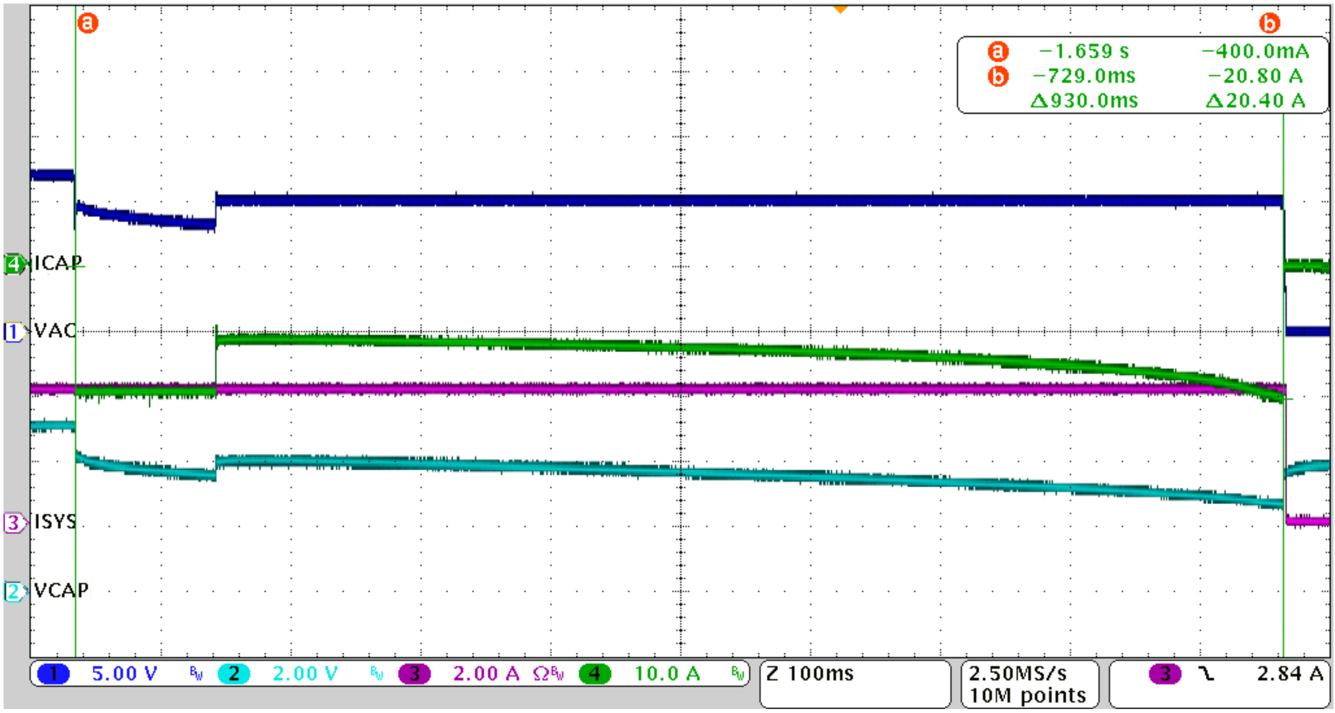

Figure 6-2. BQ25856-Q1 Provides Backup Power with a 4A Load

Note, that the capacitor voltage comes up after reverse mode turns-off and this indicates that ESR losses present. To maintain a current output of 4A at 10V, the BQ25856-Q1 needs 20A from the capacitor when the capacitor voltage is at 2.5V. This is causing a voltage drop of 1.28V at the capacitor. The ESR of the supercapacitors can be calculated to be 64mΩ and the ESR is dissipating 25.6W at the very end of the discharge. At these large currents, the ESR of the capacitors and IR drop of the wires plays a big role. The available power can be increased by using capacitors with lower a ESR and larger wires. Note, that the maximum discharge current is set by the BQ25856-Q1 to be 20A. This value can be decreased by using the IBAT_REV bits.

Note, that operating the supercapacitors at these high loads decreases the effective capacitance, increases the ESR over time, and reduces the operating lifetime. The lifespan of the supercapacitors can be increased by using supercapacitors with a low ESR to reduce the internal heating. Supercapacitors can also be used in parallel to reduce the current load on each capacitor. An in-depth analysis of these effects is outside the scope of this application note. A few useful research papers are listed in Section 8.

In Figure 6-3, the BQ25856-Q1 takes around 60µs to transfer from charging to discharging when the input power is disconnected. Channel 1 is the current into the 4A system load and is blue. Channel 2 is the /INT pin on the BQ25856-Q1 and is teal. The /INT pin generates an interrupt pulse when the BQ25856-Q1 changes states. Channel 3 is the voltage measured at the 4A system load and is magenta. Channel 4 is switch node 1 and is green. The /INT pin is going low from VAC going low and auto reverse mode turning ON.

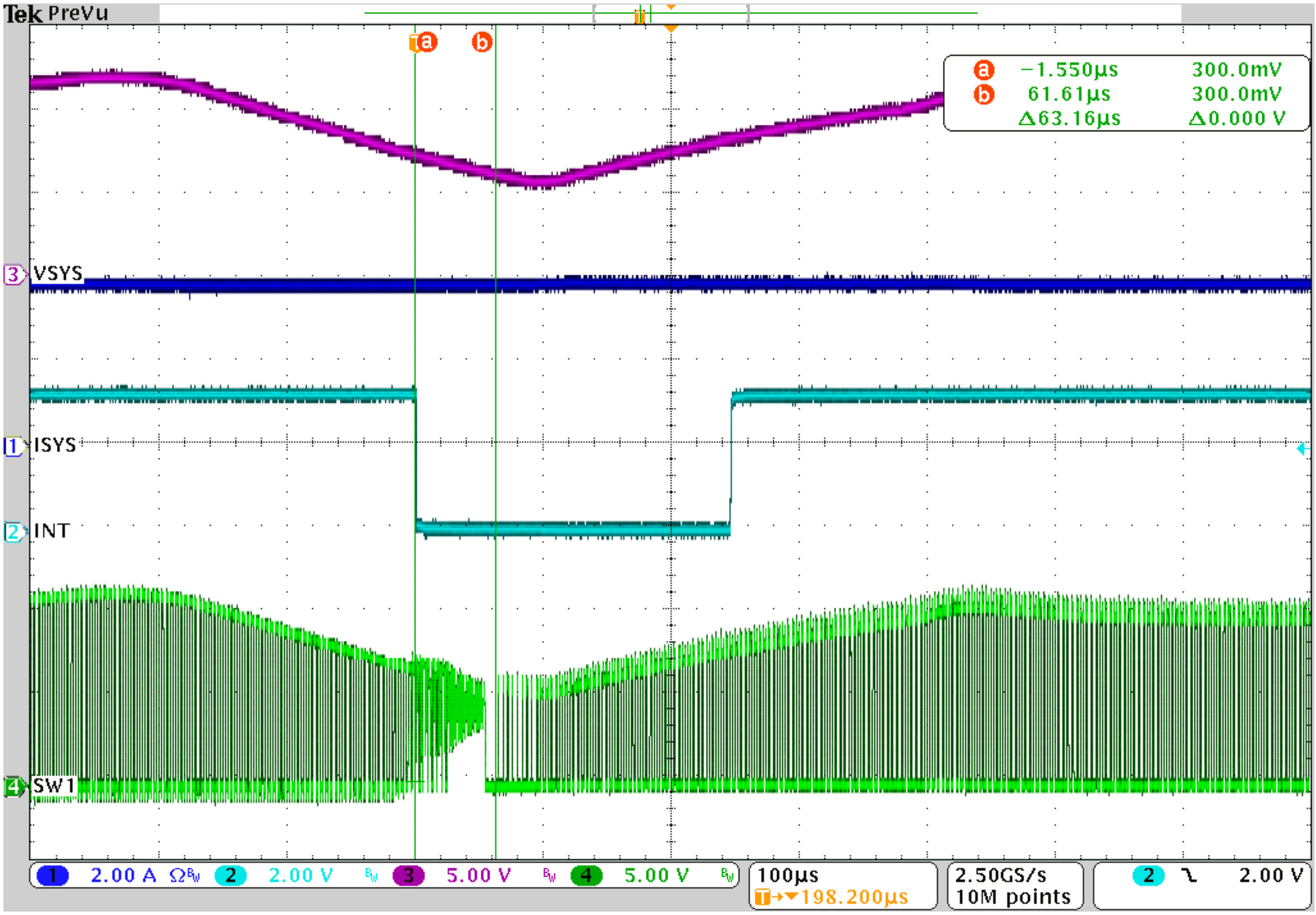

Figure 6-3. BQ25856-Q1 Auto Reverse Time with Supercapacitors

7 Summary

The BQ25856-Q1 is designed to work in industrial or automotive backup applications. The BQ25856-Q1 is able to handle wide input and output ranges. The IC is durable and can survive transient voltages of up to 80V. The response time is incredibly fast and the IC can work with both electrolytic and super capacitor circuits. These features allow the BQ25856_Q1 IC to provide reliable backup functionality.

8 References

- Texas Instruments, BQ25856-Q1: Automotive, Standalone/I2C Controlled, 1- to 14-Cell Bidirectional Buck-Boost Battery Charge Controller, data sheet
- Texas Instruments, [FAQ] BQ2575X FAQ Page, E2E FAQ page.
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- Sedlakova V, Sikula J., Majzner J., Sedlak P., Kuparowitz T., Buergler B., Vasina P. (2016), Supercapacitor Degradation Assessment By Power Cycling And Calendar Life Tests, Wrocław, Poland; Committee on Metrology and Scientific Instrumentation of the Polish Academy of Sciences

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