

High-Efficiency Backup Power Supply

Michael Helmlinger

ABSTRACT

A backup power supply is an electrical system that provides emergency power to a load when the main power source fails. An appropriate backup power supply provides instantaneous protection from main power interruptions without glitches, by supplying energy which is stored in backup capacitors or batteries. Such backup power supplies are typically used to protect hardware such as solid state drives (SSDs), storage systems, telecommunication equipment, industrial equipment, or other electrical equipment, where an unexpected power disruption can cause malfunction or data loss.

This application report describes a circuit which addresses instantaneous protection of main power interruptions by using a buck-boost converter and a backup capacitor. It also provides the design, schematic, key components, and measurement results showing the performance of the circuit.

1 System Design Overview

In this design, the backup power circuit is based on the TPS63060, a highly-efficient, synchronous, single-inductor, buck-boost converter. [Figure 1](#) shows a simplified block diagram of the circuit.

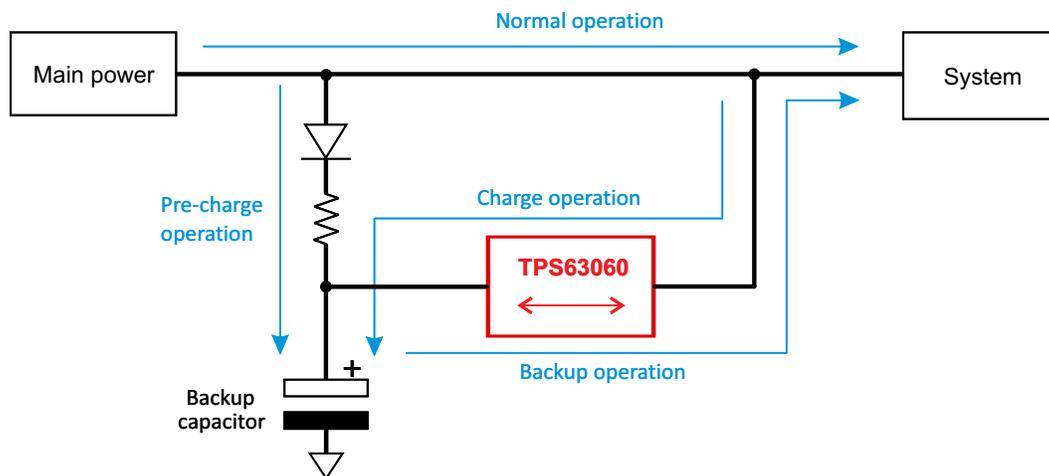


Figure 1. Simplified Block Diagram of the Backup Power System

During normal operation, the main power is directly connected to the system and the backup capacitor is charged using the TPS63060 buck-boost converter. During backup operation, the buck-boost converter supplies the system directly from the backup capacitor. The TPS63060 buck-boost converter supports energy transfer from the input to the output, as well as from the output to the input. With this bidirectional operation functionality, the TPS63060 charges and discharges the backup capacitor in a very efficient and controlled way. Charging the backup capacitor to a voltage level higher than the main power voltage results in a smaller backup capacitor value and smaller solution size to store the same amount of energy. The usable energy stored in the backup capacitor is only limited by the input voltage range of the buck-boost converter, which is 12 V for the TPS63060.

The objective of the circuit is to charge the backup capacitor to a programmed voltage level and provide instantaneous backup power in case of a main power interruption for a load up to 10 W. Typically, this circuit can be used for a SSD system to enable a controlled shutdown to prevent data loss in case of a main power loss. See the [TI reference designs library](#) for an example implementation.

2 Schematic

This design example is focused on a SSD backup power application. [Figure 2](#) illustrates the circuit of the design, which consists of a buck-boost converter (TPS63060) and an eFuse (TPS25940A). The buck-boost converter is used for charging and discharging the backup capacitor, C_1 . The smart eFuse has integrated back-to-back FETs and enhanced built-in protection circuitry for SSD applications. The TPS25940A is not required for this high-efficiency backup power supply design, but is generally used in these applications to provide protection for the system. More details can be found in the [TPS25940A data sheet](#). The detailed operation description in the next section is focused on the TPS63060 buck-boost converter.

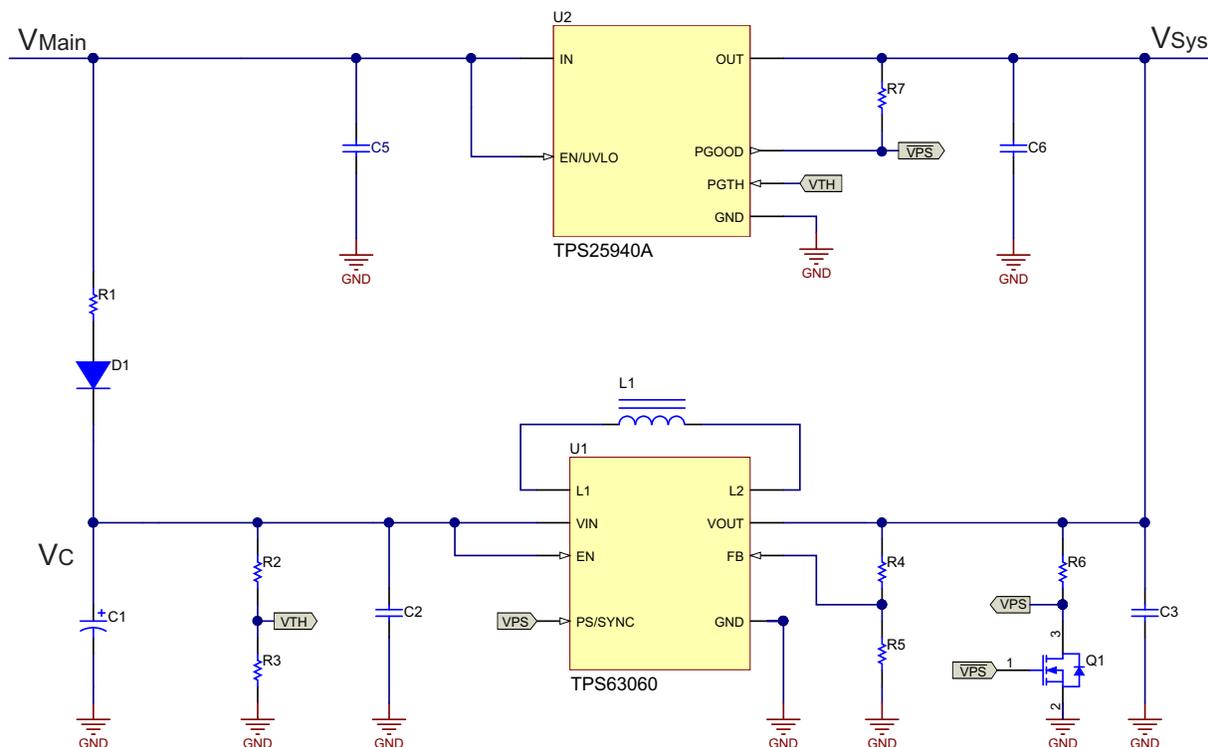


Figure 2. SSD Backup Power Application Schematic

3 Detailed Operation Description

3.1 Backup Capacitor Pre-Charging Operation

The first time main power is available, there is no voltage on the backup capacitor, and thus no voltage on the input of the TPS63060. Therefore, the backup capacitor must be pre-charged via a diode to the minimum operating input voltage level of the TPS63060 (typical 2.2 V). At this input voltage level, the buck-boost converter starts operating. A series resistor, R_1 , is used to program the maximum pre-charge current into the backup capacitor. The pre-charging current linearly decreases with the increase of the backup capacitor voltage, V_C . Equation 1 defines the pre-charging current.

$$I_{PCH} = \frac{V_{Main} - V_{D1} - V_C}{R_1}$$

where

- V_{Main} : Main power voltage
- V_{D1} : Forward voltage of diode D1
- V_C : Backup capacitor voltage
- R_1 : Resistor to set the pre-charging current
- I_{PCH} : Pre-charge current

(1)

3.2 Backup Capacitor Charging Operation

The TPS63060 buck-boost converter operates bidirectionally and is able to transfer energy from the input to the output as well as from the output to the input. The latter is used to charge the backup capacitor, connected to the converter's input. Transferring energy from the output to the input in order to charge the backup capacitor, two items have to be fulfilled.

First, the converter must be in forced PWM mode. The converter is able to operate in the reverse direction (only in this mode). To enable the forced PWM mode, the PS/SYNC pin must be programmed to a logic high level. The [TPS63060 data sheet](#) shows a detailed description of this mode pin.

Secondly, the output voltage of the TPS63060 must be programmed lower than the system voltage.

As long as these two items are fulfilled, the TPS63060 sinks current from the system voltage V_{sys} . This way, the converter transfers energy from output to input and charges the backup capacitor. The charge current is defined by the negative current limit of the TPS63060 buck-boost converter. Depending on the converter operating mode, either in buck mode or in boost mode, the negative current limit is typically between 0.2 A and 0.4 A, which is ideal because it does not add a high load to the main power.

With the feedback resistor divider consisting of R_4 and R_5 , the output voltage of the buck-boost converter must be programmed to a level below the system voltage in normal operation. Ensure that the programmed voltage is below the system voltage including all tolerances of the main power source and the buck-boost converter. Equation 2 defines the programmed output voltage.

$$V_{OUT} = \left(\frac{R_4}{R_5} + 1 \right) \times V_{FB}$$

where

- V_{OUT} : Output voltage of TPS63060
- V_{FB} : Feedback voltage of TPS63060 (500 mV typical)
- R_4, R_5 : Resistors of the output voltage divider

(2)

When operating in forced PWM mode in a reverse direction, the TPS63060 charges the backup capacitor. As the TPS63060 has no input overvoltage protection, the PS/SYNC pin must be used to stop the charging. Setting the PS/SYNC pin to a logic low level enables power save mode and stops the charging of the backup capacitor. In the power save mode, the reverse direction is blocked.

Figure 3 shows the basic circuit implementation consisting of a resistor divider and a comparator with an integrated reference voltage source, V_{REF} . When the voltage of the resistor divider reaches the reference voltage, the PS/SYNC pin is set to a logic low level. Alternatively, the designer can use a supply voltage supervisor (SVS) device instead of a comparator.

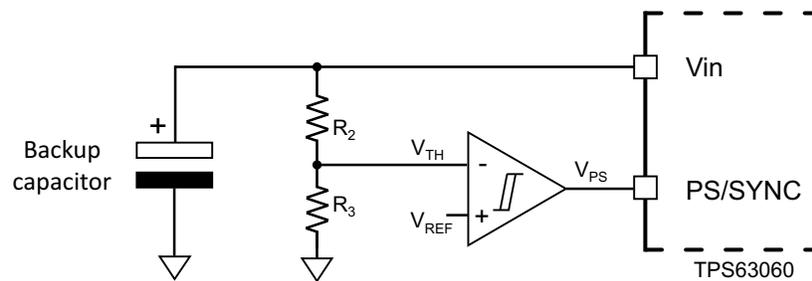


Figure 3. General Implementation to Stop Charging the Backup Capacitor

When the voltage V_{TH} reaches the level of the rising threshold voltage V_{THR} of the comparator, the PS/SYNC signal goes low and the TPS63060 converter stops charging the backup capacitor. Equation 3 defines the backup capacitor voltage when V_{TH} reaches the level of the rising comparator threshold voltage.

$$V_{CR} = \left(\frac{R_2}{R_3} + 1 \right) \times V_{THR}$$

where

- V_{CR} : Backup capacitor voltage at comparator rising threshold
 - V_{THR} : Comparator rising threshold voltage
 - R_2, R_3 : Resistors of the voltage divider at the backup capacitor
- (3)

Due to the leakage current of the backup capacitors, the quiescent current of the TPS63060 and the current of the resistor divider (R_2, R_3), the backup capacitor is slowly discharged. When the voltage V_{TH} reaches the level of the falling threshold voltage V_{THF} , the PS/SYNC pin is pulled to a high level and the TPS63060 converter starts charging the backup capacitor again. In normal steady-state operation, this is an iterative process. The recharge cycle time depends on the leakage currents and on the hysteresis of the comparator. Figure 4 shows the voltage at the charged backup capacitor in normal operation.



Figure 4. Backup Capacitor Voltage in Steady State

Equation 4 defines the backup capacitor voltage when the resistor divider reaches the level of the falling comparator threshold voltage.

$$V_{CF} = \left(\frac{R_2}{R_3} + 1 \right) \times V_{THF}$$

where

- V_{CF} : Backup capacitor voltage at comparator falling threshold
 - V_{THF} : Comparator falling threshold voltage
 - R_2, R_3 : Resistors of the voltage divider at the backup capacitor
- (4)

The design in this document, as shown in Figure 2, uses a comparator which is integrated in the TPS25940A device. Because the comparator output of the TPS25940A is inverted, an additional inversion of the signal is necessary, which is achieved by R_6 and Q_1 . See the [TPS25940A data sheet](#) for a more detailed description.

Moreover, the comparator in the TPS25940A has a deglitch time of 0.5 ms incorporated. During this time, the backup capacitor voltage continues to rise, according to [Equation 5](#), before the PS/SYNC pin goes low and charging is stopped. Take this into account for small backup capacitor values.

$$\Delta V_C = \frac{I_{ch} \times t_{de}}{C}$$

where

- V_C : Voltage rise at the backup capacitor during the deglitch time
 - I_{ch} : Charge current (200 mA typical)
 - t_{de} : Deglitch time (0.5 ms typical)
 - C : Value of the backup capacitor
- (5)

Combining [Equation 3](#) and [Equation 5](#), the maximum voltage at the backup capacitor must be lower than the maximum input voltage rating of the buck-boost converter and within the voltage rating of the backup capacitor.

3.3 Backup Operation

In the backup case, when the main power is shorted, a reverse current flows from the system to the main power. This adds additional load to the backup power system. To prevent reverse current in case of a main power loss event, a TPS25940A device is used in the example to disconnect the main power from the system. This device is a smart eFuse with integrated back-to-back FETs and enhanced built-in protection circuitry for SSD applications. The TPS25940A provides true reverse current blocking when a main power fail condition is detected. See the [TPS25940A data sheet](#) for more details. If these features are not required, a diode or a MOSFET can prevent reverse current.

In case of a main power loss when the system voltage drops below the programmed output voltage level of the TPS63060, the buck-boost converter immediately starts regulating the system voltage. Depending on the required backup time and backup power, [Equation 6](#) calculates the minimum required value of the backup capacitor. V_{CL} is the lowest level the backup capacitor can be discharged to, which is the minimum operating input voltage of the TPS63060 buck-boost converter. V_{CF} is the voltage level of the backup capacitor where it reaches the falling comparator threshold voltage. This voltage is the worst case value for the charged backup capacitor in normal operation.

$$C_{min} = \frac{2 \times T \times P}{\eta \times (V_{CF}^2 - V_{CL}^2)}$$

where

- C_{min} : Minimum value of the required backup capacitor
 - V_{CF} : Backup capacitor voltage at comparator falling threshold
 - V_{CL} : Minimum discharge voltage of the backup capacitor, defined by the minimum input voltage of the TPS63060
 - η : Efficiency of the TPS63060
 - T : Backup time
 - P : Backup power
- (6)

4 Example

In the example, the TPS63060 provides instantaneous backup power of a SSD system in case of a main power interruption to prevent data loss. Ensure that the programmed output voltage of the TPS63060 is below the system voltage including all tolerances of the main power source and the buck-boost converter. In the example, the main power voltage is 5 V. With an estimated 7% total tolerance, the converter output voltage is programmed to 4.6 V. A constant system power of 5 W is provided for backup time of 4 ms.

Calculations:

The resistor R_1 sets the pre-charge current flowing through the diode. With a resistance of 27 Ω and a diode voltage drop of 1 V, the maximum pre-charge current was calculated:

- $I_{PCH} = 150$ mA (Equation 1)

The output resistor divider is used to program the output voltage of the TPS63060 converter. With given values of $R_4 = 90.9$ k Ω and $R_5 = 11$ k Ω , the output voltage was calculated:

- $V_{OUT} = 4.6$ V (Equation 2)

The resistor divider at the converter input is used to program the maximum voltage level of the backup capacitor. With values of $R_2 = 1$ M Ω , $R_3 = 110$ k Ω , $V_{THR} = 0.99$ V, and $V_{THF} = 0.92$ V (see [TPS25940A data sheet](#)), V_{CR} and V_{CF} were calculated:

- $V_{CR} = 10$ V (Equation 3)
- $V_{CF} = 9.3$ V (Equation 4)

With a buck-boost converter efficiency of 90% and a minimum backup capacitor voltage of 2.5 V, the value of the required backup capacitor was calculated:

- $C_{min} = 550$ μ F (Equation 6)

In this design example, four 150- μ F capacitors were selected to achieve the required backup power. Equation 5 was not taken into account because the influence of the deglitch time is negligible in this example.

5 Test Results

The following tests were performed with the same conditions and values as shown in the example in [Figure 2](#). The load is represented by an electronic load, which draws 5 W constantly. The following plots show the main power voltage, the system voltage, the voltage at the PS/SYNC pin of the buck-boost converter, and the voltage at the backup capacitor.

5.1 Backup Capacitor Pre-Charging and Charging Operation

[Figure 5](#) shows the pre-charging and charging of the backup capacitor. As soon as the main power is present, the capacitor starts being pre-charged. After the backup capacitor voltage reaches the minimum operating input voltage level of the TPS63060 (typical 2.2 V), the converter starts operating and charges up the backup capacitor. At the programmed voltage level of 10 V, the PS/SYNC signal goes low and the buck-boost converter stops charging the backup capacitor.

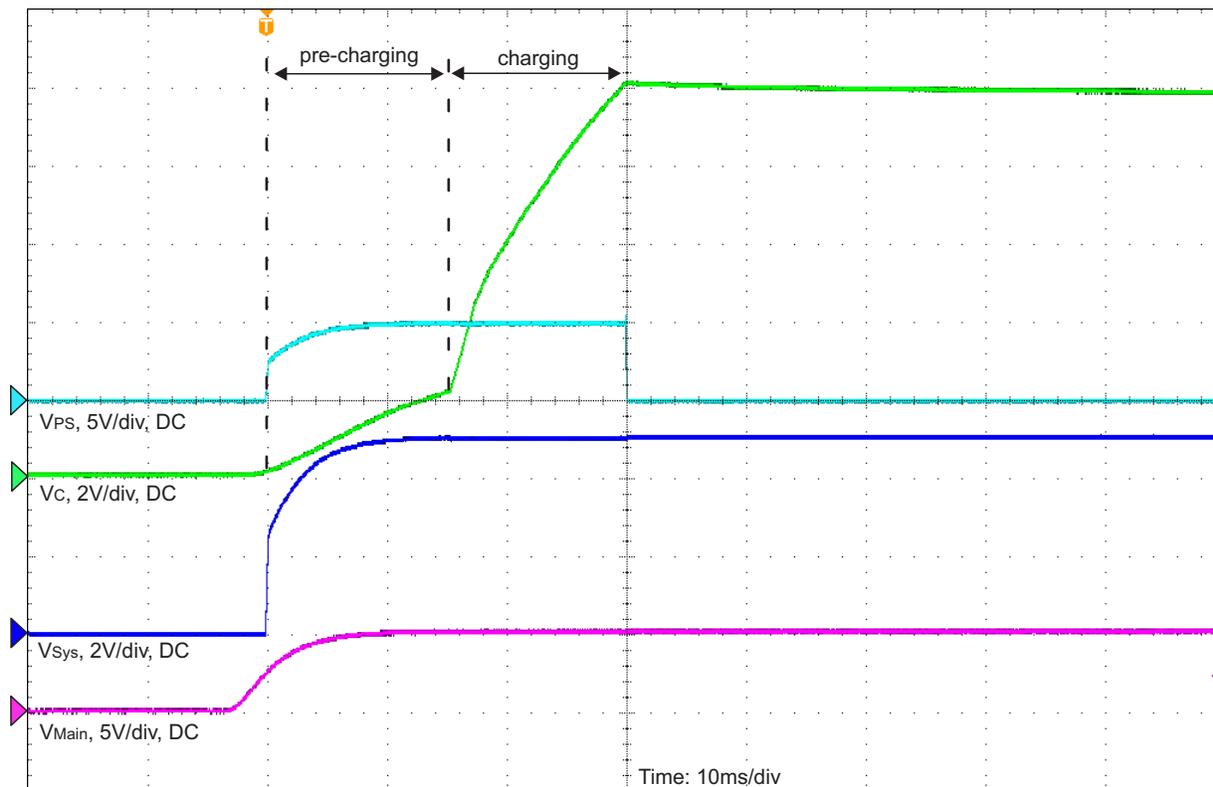


Figure 5. Pre-Charging and Charging of the Backup Capacitor

5.2 Backup Operation

Figure 6 shows the backup operation. If the main power fails, the TPS63060 converter immediately starts regulating the system voltage to its programmed output voltage. The backup capacitor is discharged and its voltage decreases slowly. When the backup capacitor voltage reaches the minimum operating voltage of the TPS63060, the converter stops operating and the system voltage decreases. In this scope plot, the backup time is about 4.5 ms. Larger backup capacitor value results in a longer backup time referring to Equation 6.

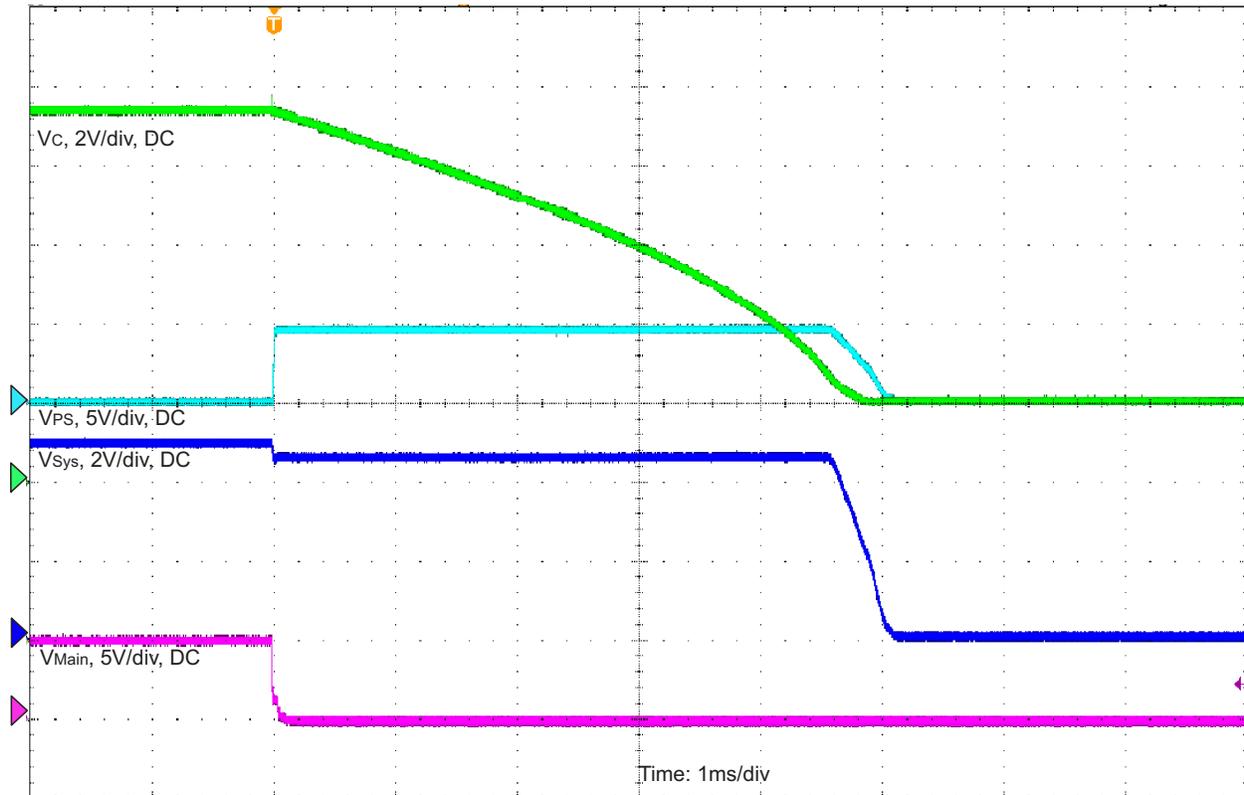


Figure 6. Backup Operation

5.3 Normal Operation

Figure 7 shows the backup power supply in normal, steady state operation. The main power is directly connected to the system and both have the same voltage level. The capacitor slowly discharges through leakage currents. After the backup capacitor voltage level reaches the comparator threshold voltage, the PS/SYNC signal goes high and the backup capacitor is charged again. In this design, the recharge period is 9 s.

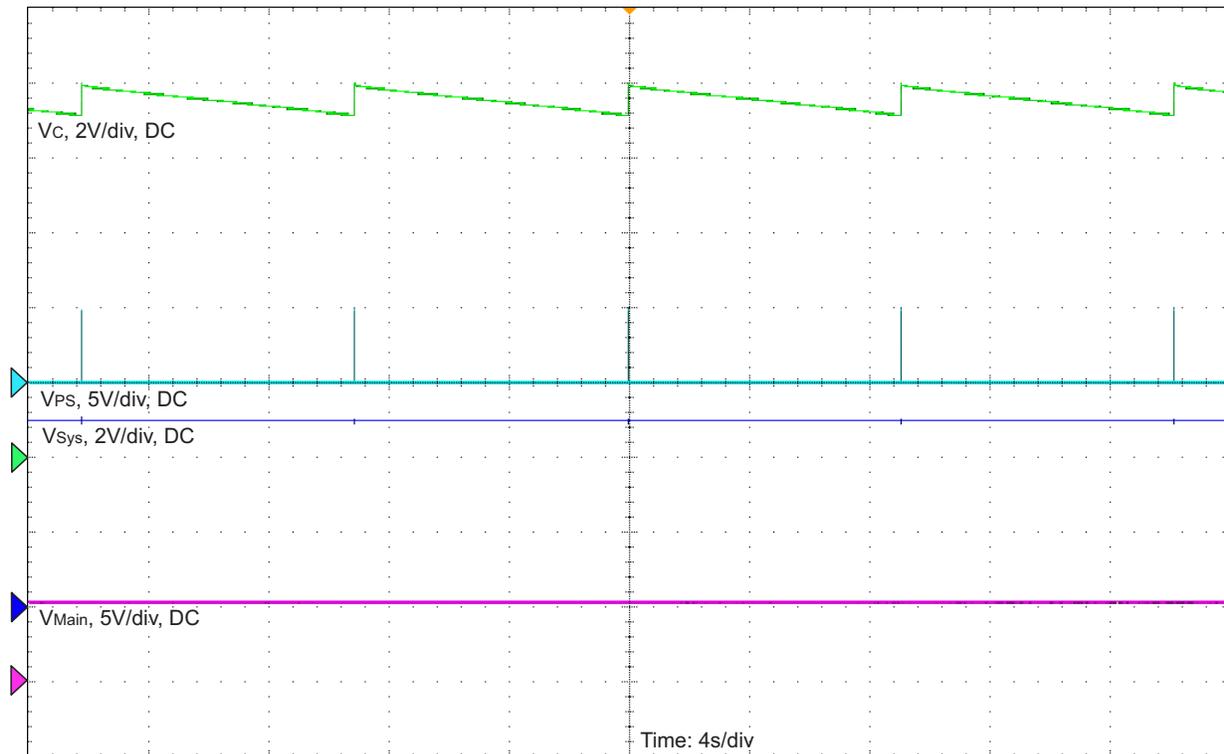


Figure 7. Normal Operation (Recharge Cycles)

6 Conclusion

Using the TPS63060 buck-boost converter for a backup power system brings some major advantages:

- Wide useable backup-capacitor voltage range (2.2 to 12 V) results in smaller backup capacitance and solution size
- Up to 10-W output power
- Small and high efficiency single converter solution
- No glitches at the transition from main power to backup power operation
- Backup-capacitor type and size are selectable to meet backup power needs
- Support of pulsed loads connected to a weak supply

This design fits in enterprise and industrial SSD applications. It helps that critical user data is not lost during a power-failure to the drive. In an industrial PLC application, it supports a secure power down.

IMPORTANT NOTICE

Texas Instruments Incorporated and its subsidiaries (TI) reserve the right to make corrections, enhancements, improvements and other changes to its semiconductor products and services per JESD46, latest issue, and to discontinue any product or service per JESD48, latest issue. Buyers should obtain the latest relevant information before placing orders and should verify that such information is current and complete. All semiconductor products (also referred to herein as "components") are sold subject to TI's terms and conditions of sale supplied at the time of order acknowledgment.

TI warrants performance of its components to the specifications applicable at the time of sale, in accordance with the warranty in TI's terms and conditions of sale of semiconductor products. Testing and other quality control techniques are used to the extent TI deems necessary to support this warranty. Except where mandated by applicable law, testing of all parameters of each component is not necessarily performed.

TI assumes no liability for applications assistance or the design of Buyers' products. Buyers are responsible for their products and applications using TI components. To minimize the risks associated with Buyers' products and applications, Buyers should provide adequate design and operating safeguards.

TI does not warrant or represent that any license, either express or implied, is granted under any patent right, copyright, mask work right, or other intellectual property right relating to any combination, machine, or process in which TI components or services are used. Information published by TI regarding third-party products or services does not constitute a license to use such products or services or a warranty or endorsement thereof. Use of such information may require a license from a third party under the patents or other intellectual property of the third party, or a license from TI under the patents or other intellectual property of TI.

Reproduction of significant portions of TI information in TI data books or data sheets is permissible only if reproduction is without alteration and is accompanied by all associated warranties, conditions, limitations, and notices. TI is not responsible or liable for such altered documentation. Information of third parties may be subject to additional restrictions.

Resale of TI components or services with statements different from or beyond the parameters stated by TI for that component or service voids all express and any implied warranties for the associated TI component or service and is an unfair and deceptive business practice. TI is not responsible or liable for any such statements.

Buyer acknowledges and agrees that it is solely responsible for compliance with all legal, regulatory and safety-related requirements concerning its products, and any use of TI components in its applications, notwithstanding any applications-related information or support that may be provided by TI. Buyer represents and agrees that it has all the necessary expertise to create and implement safeguards which anticipate dangerous consequences of failures, monitor failures and their consequences, lessen the likelihood of failures that might cause harm and take appropriate remedial actions. Buyer will fully indemnify TI and its representatives against any damages arising out of the use of any TI components in safety-critical applications.

In some cases, TI components may be promoted specifically to facilitate safety-related applications. With such components, TI's goal is to help enable customers to design and create their own end-product solutions that meet applicable functional safety standards and requirements. Nonetheless, such components are subject to these terms.

No TI components are authorized for use in FDA Class III (or similar life-critical medical equipment) unless authorized officers of the parties have executed a special agreement specifically governing such use.

Only those TI components which TI has specifically designated as military grade or "enhanced plastic" are designed and intended for use in military/aerospace applications or environments. Buyer acknowledges and agrees that any military or aerospace use of TI components which have **not** been so designated is solely at the Buyer's risk, and that Buyer is solely responsible for compliance with all legal and regulatory requirements in connection with such use.

TI has specifically designated certain components as meeting ISO/TS16949 requirements, mainly for automotive use. In any case of use of non-designated products, TI will not be responsible for any failure to meet ISO/TS16949.

Products

Audio	www.ti.com/audio
Amplifiers	amplifier.ti.com
Data Converters	dataconverter.ti.com
DLP® Products	www.dlp.com
DSP	dsp.ti.com
Clocks and Timers	www.ti.com/clocks
Interface	interface.ti.com
Logic	logic.ti.com
Power Mgmt	power.ti.com
Microcontrollers	microcontroller.ti.com
RFID	www.ti-rfid.com
OMAP Applications Processors	www.ti.com/omap
Wireless Connectivity	www.ti.com/wirelessconnectivity

Applications

Automotive and Transportation	www.ti.com/automotive
Communications and Telecom	www.ti.com/communications
Computers and Peripherals	www.ti.com/computers
Consumer Electronics	www.ti.com/consumer-apps
Energy and Lighting	www.ti.com/energy
Industrial	www.ti.com/industrial
Medical	www.ti.com/medical
Security	www.ti.com/security
Space, Avionics and Defense	www.ti.com/space-avionics-defense
Video and Imaging	www.ti.com/video

TI E2E Community

e2e.ti.com