

Basic Concepts for Energy Delivery with S6AE101A, S6AE102A, and S6AE103A

Author: Hiroyuki Takada

Associated Part Family: S6AE101A, S6AE102A, S6AE103A

Related Application Note: AN210772

Related Documents: S6AE101A, S6AE102A, S6AE103A Datasheets

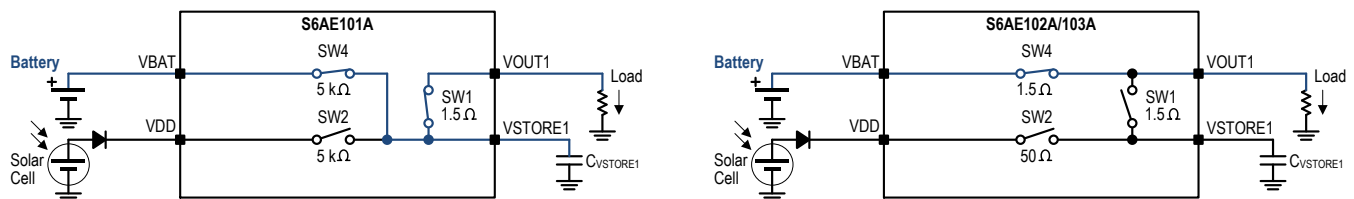
This application note describes the difference in energy delivery between S6AE101A and S6AE102A/103A for hybrid operation and discusses S6AE102A/103A energy delivery with the surplus power of a solar cell.

1 Introduction

S6AE101A/102A/103A is an energy harvesting power management IC (PMIC) that includes an energy delivery circuit for hybrid operation capable of switching its power source between a solar cell and a battery. As shown in Figure 1, S6AE101A and S6AE102A/103A have different energy delivery circuits when operating with both the solar cell and the battery (hybrid operation). S6AE101A charges the capacitor $C_{VSTORE1}$ from the battery initially and then outputs voltage to VOUT1 on the basis of the VSTORE1 voltage level. In contrast, S6AE102A/103A outputs voltage directly from the battery. Also, S6AE101A is designed to deliver energy mainly generated by the solar cell to minimize battery consumption, and S6AE102A/103A provides seamless energy delivery between the solar cell and the battery (see Figure 5).

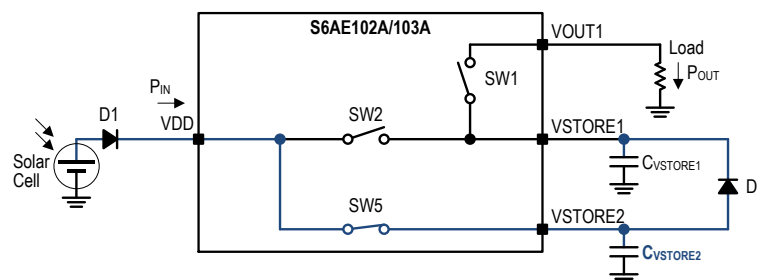
S6AE101A integrates the 5-k Ω switches (SW2 and SW4) to limit input currents, which optimizes this IC to acquire the microampere (μ A) of current output from the solar cell. S6AE102A/103A lowers the value of resistance (SW2 and SW4) to cover the range from microampere (μ A) to milliampere (mA) of current output from the solar cell.

Figure 1. Energy Delivery Circuit Difference in S6AE101A and S6AE102A/103A



S6AE102A/103A integrates an additional energy delivery circuit. When there is a surplus ($P_{IN} \gg P_{OUT}$) in the amount of power generated by the solar cell (P_{IN}) with respect to load power (P_{OUT}), the surplus power is charged in $C_{VSTORE2}$ via SW5 (see Figure 2).

Figure 2. Circuit to Be Charged with Surplus Power



Notes:

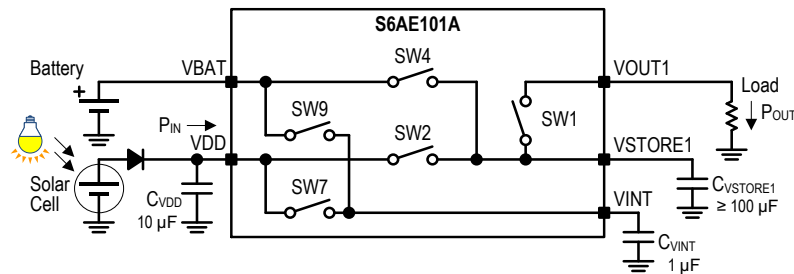
Both $C_{VSTORE1}$ and $C_{VSTORE2}$ are storage capacitors for charging the energy supplied from the solar cell. In particular, $C_{VSTORE2}$ is used when there is a surplus energy generated by the solar cell with respect to load. The size of $C_{VSTORE2}$ should be larger than 2 mF (see the [S6AE102A/103A](#) datasheet). For the capacitance value of these capacitors and the calculation of the charging/discharging time, see the application note [AN210772](#).

2 Energy Delivery Circuit

2.1 S6AE101A

S6AE101A integrates a power gating switch (SW1), a power storage switch (SW2), and a solar cell/battery changeover switch (SW4). Switches SW7 and SW9 are used to charge a capacitor (C_{VINT}) that drives the internal circuit (see [Figure 3](#)). SW7 turns ON when operating with the power source of the solar cell. SW9 turns ON when operating with the power source of the battery (see [Figure 5](#)). Power provided by a solar cell is charged in $C_{VSTORE1}$ via SW2. Then SW1 is turned on when the $VSTORE1$ voltage is within the range of the VOUT maximum voltage (V_{VOUTH}) to VOUT minimum voltage (V_{VOUTL}), and the power is applied to a load. When power is not generated by a solar cell, power from the connected battery is supplied to $C_{VSTORE1}$ via SW4. For more information, see the [S6AE101A](#) datasheet.

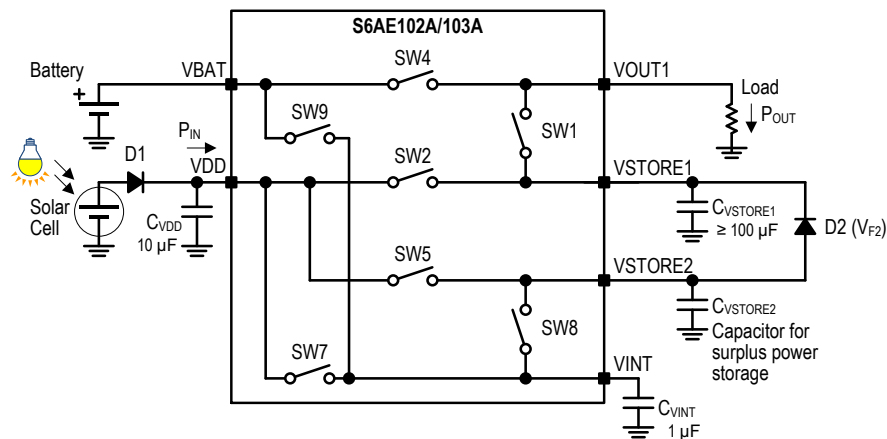
Figure 3. S6AE101A Energy Delivery Circuit



2.2 S6AE102A/103A

In addition to the S6AE101A circuit, S6AE102A/103A integrates a surplus power storage switch (SW5) and a switch (SW8) used to charge a capacitor (C_{VINT}) that drives the internal circuit (C_{VINT}) (see [Figure 4](#)). SW8 turns ON only when operating with the power source of $C_{VSTORE2}$. When there is a surplus ($P_{IN} \gg P_{OUT}$) in the generated power of the solar cell (P_{IN}) with respect to the load power (P_{OUT}), the surplus power is charged in $C_{VSTORE2}$ via SW5. When power is not generated by a solar cell, then the charged power in $C_{VSTORE2}$ is supplied to $C_{VSTORE1}$ via an external diode (D2). Using a low forward voltage (V_{F2}) of D2 is recommended. For more information, see the [S6AE102A/103A](#) datasheet.

Figure 4. S6AE102A/103A Energy Delivery Circuit



3 Energy Delivery for Hybrid Operation

As mentioned in the introduction, S6AE101A and S6AE102A/103A have different energy delivery circuits when operating with the power sources, both the solar cell and the battery (hybrid operation), as shown in Figure 5. S6AE101A charges the capacitor $C_{VSTORE1}$ from the battery initially and then outputs voltage to V_{OUT1} on the basis of the V_{STORE1} voltage level. In contrast, S6AE102A/103A outputs voltage directly from the battery. Figure 5 shows the energy delivery sequence of hybrid operation with S6AE101A and S6AE102A/103A. Table 1 provides a description of Figure 5. A constant load P_{OUT} is provided when voltage is being output at V_{OUT1} . “ $P_{IN} > P_{OUT}$ ” means that the power generated by a solar cell (P_{IN}) is greater than the load power (P_{OUT}). “ $P_{IN} = 0W$ ” means that power is not generated by a solar cell.

Notes:

- The voltage of solar cell, open voltage (V_{OPEN}) minus forward voltage (V_{F1}) will be more than the V_{OUT} maximum voltage (V_{VOUTH}) and less than the minimum value of the over voltage protection voltage (V_{OVPH}) that is 5.2V.
- The range of the V_{BAT} input voltage in S6AE101A will be $5.5V \geq V_{BAT} \geq V_{VOUTH}$, and $V_{BAT} \geq 2V$.
- The range of the V_{BAT} input voltage in S6AE102A/103A will be $5.5V \geq V_{BAT} \geq 2V$.

Figure 5. Energy Delivery Sequence in Hybrid Operation

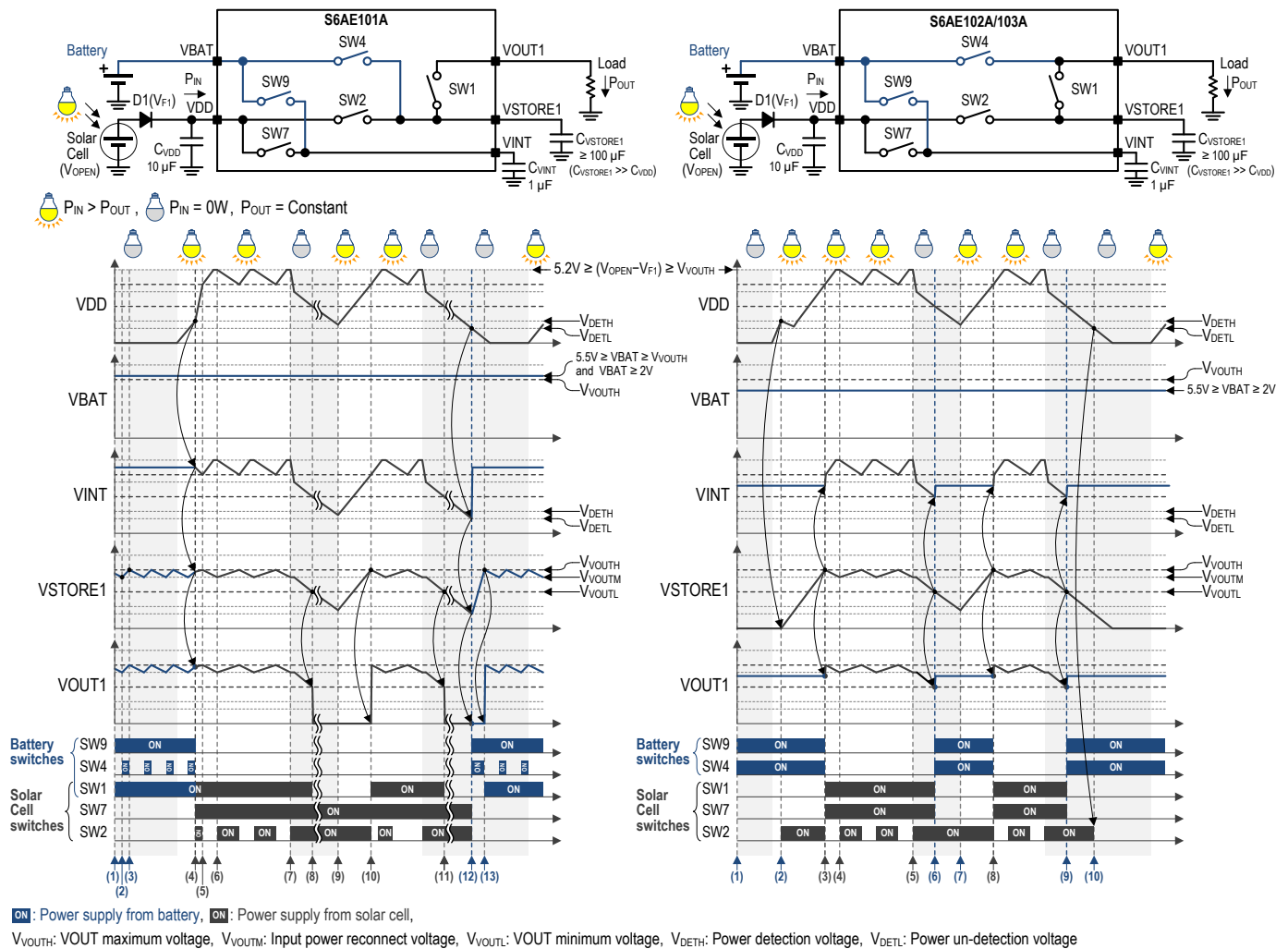


Table 1. Description of Figure 5: Difference between S6AE101A and S6AE102A/103A

Power Balance	S6AE101A		S6AE102A/103A	
	No.	Description	No.	Description
$P_{IN} = 0W$	(1)	Under battery power operation: SW9 and SW1 are ON. Power is supplied from battery and output to VOUT1.	(1)	Under battery power operation: SW9 and SW4 are ON. Power is supplied from battery and output to VOUT1.
	(2)	$V_{STORE1} \leq V_{VOUTM} \rightarrow$ SW4 turns ON.		
	(3)	$V_{STORE1} \geq V_{VOUTH} \rightarrow$ SW4 turns OFF.		
$P_{IN} > P_{OUT}$	(4)	Solar cell power operation starts: $V_{DD} \geq V_{DETH} \rightarrow$ SW9 and SW4 turn OFF, SW7 and SW2 turn ON. Power is supplied from solar cell and output to VOUT1.	(2)	$V_{DD} \geq V_{DETH} \rightarrow$ SW2 turns ON.
	(5)	$V_{STORE1} \geq V_{VOUTH} \rightarrow$ SW2 turns OFF.	(3)	Solar cell power operation starts: $V_{STORE1} \geq V_{VOUTH} \rightarrow$ SW9, SW4, and SW2 turn OFF and SW7 and SW1 turn ON. Power is supplied from solar cell ($C_{VSTORE1}$) and output to VOUT1.
	(6)	$V_{STORE1} \leq V_{VOUTM} \rightarrow$ SW2 turns ON.	(4)	$V_{STORE1} \leq V_{VOUTM} \rightarrow$ SW2 turns ON.
$P_{IN} = 0W$	(7)	$V_{STORE1} \leq V_{VOUTM} \rightarrow$ SW2 turns ON, but enough power is not supplied from solar cell. Then VSTORE1 starts to drop.	(5)	$V_{STORE1} \leq V_{VOUTM} \rightarrow$ SW2 turns ON, but enough power is not supplied from solar cell. Then VSTORE1 starts to drop.
	(8)	$V_{STORE1} \leq V_{VOUTL} \rightarrow$ SW1 turns OFF Power is not supplied to VOUT1. Note. It may take a while to move to the next stage, depending on the size of $C_{VSTORE1}$.	(6)	Battery power operation starts: $V_{STORE1} \leq V_{VOUTL} \rightarrow$ SW7 and SW1 turn OFF, SW9 and SW4 turn ON. Power is supplied from battery and output to VOUT1.
$P_{IN} > P_{OUT}$	(9)	$V_{STORE1} \geq V_{DETL}$ and enough power is supplied from solar cell. Then VDD starts to rise.	(7)	$V_{STORE1} \geq V_{DETL}$ and enough power is supplied from solar cell. Then VDD starts to rise.
	(10)	$V_{STORE1} \geq V_{VOUTH} \rightarrow$ SW2 turns OFF, SW1 turns ON Power starts output to VOUT1.	(8)	Same as (3).
	(11)	Same as (8).		
$P_{IN} = 0W$	(12)	Battery power operation starts: $V_{DD} \leq V_{DETL} \rightarrow$ SW9 and SW4 turn ON, SW7 and SW2 turn OFF.	(9)	Same as (6).
	(13)	$V_{STORE1} \geq V_{VOUTH} \rightarrow$ SW4 turns OFF, SW1 turns ON Power is supplied from battery and output to VOUT1.	(10)	$V_{DD} \leq V_{DETL} \rightarrow$ SW2 turns OFF.

4 Additional Energy Delivery Circuit of S6AE102A/103A with Surplus Power

This section describes the energy delivery of S6AE102A/103A with surplus power from a solar cell. When there is a surplus ($P_{IN} \gg P_{OUT}$) in the amount of power generated by the solar cell (P_{IN}) with respect to load power (P_{OUT}), S6AE102A/103A detects the surplus power state automatically, and then the power is charged in $C_{VSTORE2}$ via SW5. When power is not generated by a solar cell, the charged power in $C_{VSTORE2}$ is supplied to $C_{VSTORE1}$ via an external diode (D2).

Figure 6 shows the energy delivery sequence of S6AE102A/103A with the surplus power of a solar cell. Table 2 provides a description of the figure. As a premise, while voltage is being output to VOUT1, a constant load is given (P_{OUT}). " $P_{IN} \gg P_{OUT}$ " means that the power generated by a solar cell (P_{IN}) is much greater than the load power (P_{OUT}). " $P_{IN} = 0W$ " means that power is not generated by a solar cell.

Figure 6. Energy Delivery Sequence of S6AE102A/103A with Surplus Power

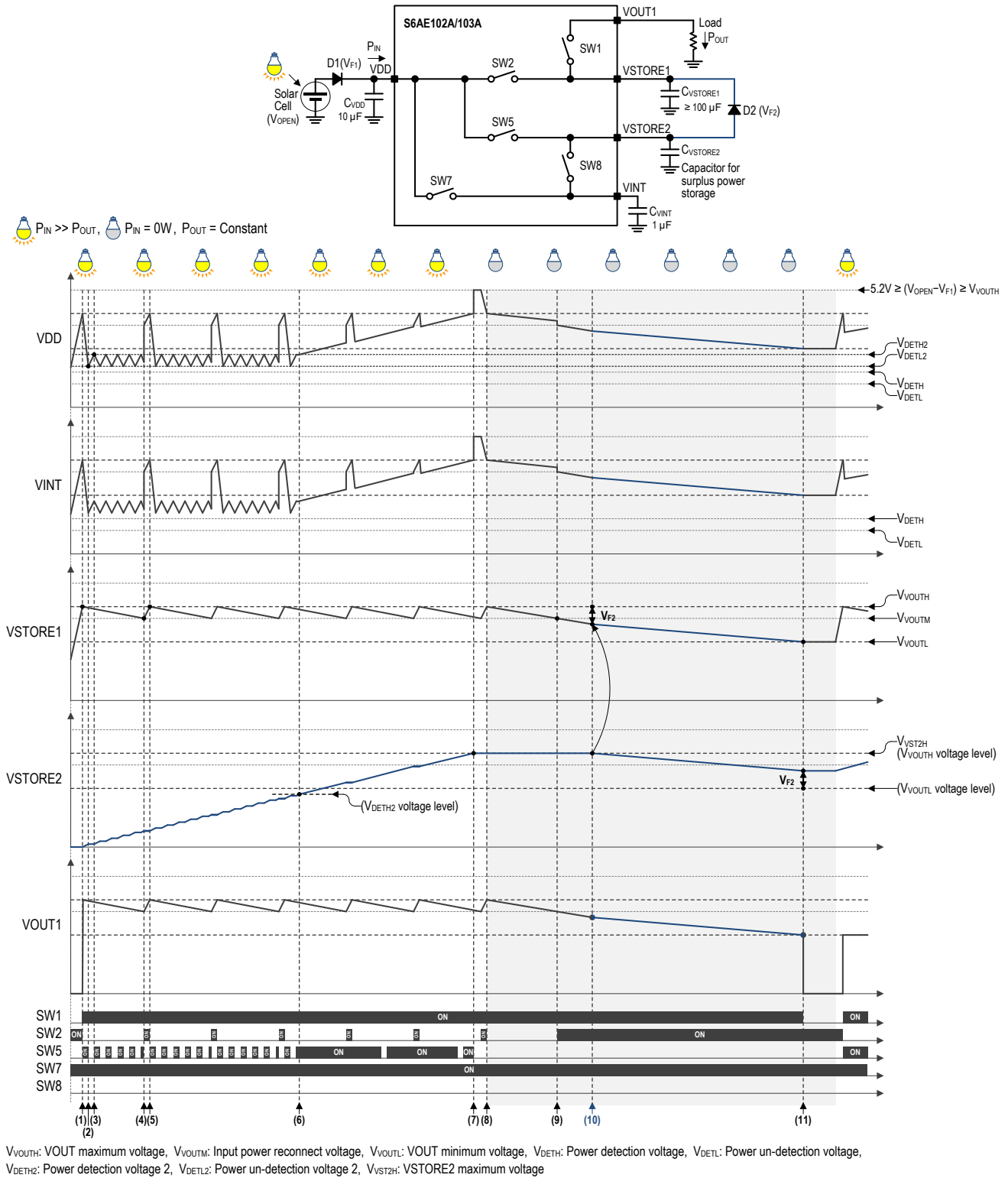


Table 2. Description of Figure 6: Charge / Discharge of $C_{VSTORE1}$ and $C_{VSTORE2}$

Power Balance	No.	Charge / Discharge	
		$C_{VSTORE1}$	$C_{VSTORE2}$
$P_{IN} \gg P_{OUT}$ (Surplus power)	(1)	When starting up: $V_{STORE1} \geq V_{VOUTH} \rightarrow$ SW2 turns OFF, SW1 turns ON. Power is supplied from $C_{VSTORE1}$ and output to VOUT1.	When starting up: $V_{STORE1} \geq V_{VOUTH} \rightarrow$ SW5 turns ON. Charging of $C_{VSTORE2}$ starts.
	(2)	–	$VDD \leq V_{DETL2} \rightarrow$ SW5 turns OFF. Charging of $C_{VSTORE2}$ stops.
	(3)	–	$VDD \geq V_{DETH2} \rightarrow$ SW5 turns ON. Charging of $C_{VSTORE2}$ starts.
	(4)	$V_{STORE1} \leq V_{VOUTH} \rightarrow$ SW2 turns ON. $C_{VSTORE1}$ starts being charged.	$V_{STORE1} \leq V_{VOUTH} \rightarrow$ SW5 turns OFF. Charging of $C_{VSTORE2}$ stops.
	(5)	$V_{STORE1} \geq V_{VOUTH} \rightarrow$ SW2 turns OFF. $C_{VSTORE1}$ stops being charged.	$V_{STORE1} \geq V_{VOUTH} \rightarrow$ SW5 turns ON. Charging of $C_{VSTORE2}$ starts.
	(6)	–	SW5 is ON and $V_{STORE2} \geq V_{DETL2}$. (VDD and VINT start rising.)
	(7)	–	$V_{STORE2} \geq V_{VST2H} \rightarrow$ SW5 turns OFF; full charge.
$P_{IN} = 0W$ (No power)	(8)	V_{STORE1} falls because there is no power. (VDD and VINT start falling.)	(VDD and VINT start falling.)
	(9)	$V_{STORE1} \leq V_{VOUTM} \rightarrow$ SW2 turns ON.	–
	(10)	$V_{STORE1} \leq (V_{VST2H} - V_{F2}) \rightarrow$ D2 turns ON. $C_{VSTORE1}$ starts being charged by $C_{VSTORE2}$.	($V_{STORE2} \geq (V_{STORE1} + V_{F2}) \rightarrow$ D2 turns ON.)
	(11)	$V_{STORE1} \leq V_{VOUTL} \rightarrow$ SW1 turns OFF. Power is not supplied to VOUT1.	–

5 Summary

This application note described the energy delivery behavior of an energy harvesting application based on Cypress's S6AE101A/102A/103A PMIC. S6AE101A is used mainly for solar-powered beacon, and S6AE102A/103A is used for solar-powered wireless sensor nodes. The most important understanding to be gained from this application note is that the energy delivery features of the S6AE101A/102A/103A lead to the effective use of energy and energy saving in a system.

S6AE101A/102A/103A has a set of documentation such as application notes, development tools, and online resources to assist you during your development process. Visit www.cypress.com/energy-harvesting to find out more.

Document History

Document Title: AN213948 - Basic Concepts for Energy Delivery with S6AE101A, S6AE102A, and S6AE103A

Document Number: 002-13948

Revision	ECN	Orig. of Change	Submission Date	Description of Change
**	5327130	HIXT	07/11/2016	New application note.
*A	5789124	AESATMP8	06/28/2017	Updated logo and Copyright.

Worldwide Sales and Design Support

Cypress maintains a worldwide network of offices, solution centers, manufacturer's representatives, and distributors. To find the office closest to you, visit us at [Cypress Locations](#).

Products

ARM® Cortex® Microcontrollers	cypress.com/arm
Automotive	cypress.com/automotive
Clocks & Buffers	cypress.com/clocks
Interface	cypress.com/interface
Internet of Things	cypress.com/iot
Memory	cypress.com/memory
Microcontrollers	cypress.com/mcu
PSoC	cypress.com/psoc
Power Management ICs	cypress.com/pmic
Touch Sensing	cypress.com/touch
USB Controllers	cypress.com/usb
Wireless Connectivity	cypress.com/wireless

PSoC® Solutions

[PSoC 1](#) | [PSoC 3](#) | [PSoC 4](#) | [PSoC 5LP](#) | [PSoC 6](#)

Cypress Developer Community

[Forums](#) | [WICED IOT Forums](#) | [Projects](#) | [Videos](#) | [Blogs](#) | [Training](#) | [Components](#)

Technical Support

cypress.com/support

All other trademarks or registered trademarks referenced herein are the property of their respective owners.



Cypress Semiconductor
198 Champion Court
San Jose, CA 95134-1709

© Cypress Semiconductor Corporation, 2016-2017. This document is the property of Cypress Semiconductor Corporation and its subsidiaries, including Spansion LLC ("Cypress"). This document, including any software or firmware included or referenced in this document ("Software"), is owned by Cypress under the intellectual property laws and treaties of the United States and other countries worldwide. Cypress reserves all rights under such laws and treaties and does not, except as specifically stated in this paragraph, grant any license under its patents, copyrights, trademarks, or other intellectual property rights. If the Software is not accompanied by a license agreement and you do not otherwise have a written agreement with Cypress governing the use of the Software, then Cypress hereby grants you a personal, non-exclusive, nontransferable license (without the right to sublicense) (1) under its copyright rights in the Software (a) for Software provided in source code form, to modify and reproduce the Software solely for use with Cypress hardware products, only internally within your organization, and (b) to distribute the Software in binary code form externally to end users (either directly or indirectly through resellers and distributors), solely for use on Cypress hardware product units, and (2) under those claims of Cypress's patents that are infringed by the Software (as provided by Cypress, unmodified) to make, use, distribute, and import the Software solely for use with Cypress hardware products. Any other use, reproduction, modification, translation, or compilation of the Software is prohibited.

TO THE EXTENT PERMITTED BY APPLICABLE LAW, CYPRESS MAKES NO WARRANTY OF ANY KIND, EXPRESS OR IMPLIED, WITH REGARD TO THIS DOCUMENT OR ANY SOFTWARE OR ACCOMPANYING HARDWARE, INCLUDING, BUT NOT LIMITED TO, THE IMPLIED WARRANTIES OF MERCHANTABILITY AND FITNESS FOR A PARTICULAR PURPOSE. To the extent permitted by applicable law, Cypress reserves the right to make changes to this document without further notice. Cypress does not assume any liability arising out of the application or use of any product or circuit described in this document. Any information provided in this document, including any sample design information or programming code, is provided only for reference purposes. It is the responsibility of the user of this document to properly design, program, and test the functionality and safety of any application made of this information and any resulting product. Cypress products are not designed, intended, or authorized for use as critical components in systems designed or intended for the operation of weapons, weapons systems, nuclear installations, life-support devices or systems, other medical devices or systems (including resuscitation equipment and surgical implants), pollution control or hazardous substances management, or other uses where the failure of the device or system could cause personal injury, death, or property damage ("Unintended Uses"). A critical component is any component of a device or system whose failure to perform can be reasonably expected to cause the failure of the device or system, or to affect its safety or effectiveness. Cypress is not liable, in whole or in part, and you shall and hereby do release Cypress from any claim, damage, or other liability arising from or related to all Unintended Uses of Cypress products. You shall indemnify and hold Cypress harmless from and against all claims, costs, damages, and other liabilities, including claims for personal injury or death, arising from or related to any Unintended Uses of Cypress products.

Cypress, the Cypress logo, Spansion, the Spansion logo, and combinations thereof, WICED, PSoC, CapSense, EZ-USB, F-RAM, and Traveo are trademarks or registered trademarks of Cypress in the United States and other countries. For a more complete list of Cypress trademarks, visit cypress.com. Other names and brands may be claimed as property of their respective owners.