AN213948

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

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Associated Part Family:S6AE101A, S6AE102A, S6AE103A

Related Application Note: AN210772

Related Documents: S6AE101A, S6AE102A, S6AE103A Datasheets

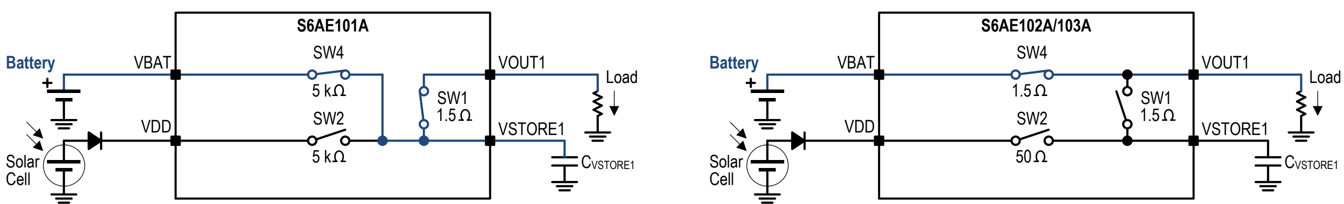
This application note describes the difference in energy delivery between S6AE101A and S6AE102A/103A for hybrid operation and discusses S6AE102A/103A energy delivery with the surplus power of a solar cell.

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).

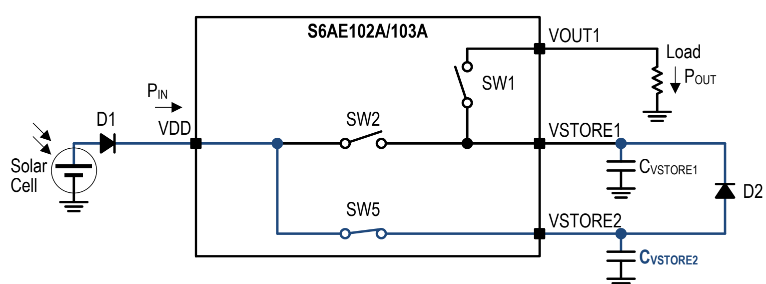
S6AE101A integrates the 5-kΩ switches (SW2 and SW4) to limit input currents, which optimizes this IC to acquire the microampere (µA) of current output from the solar cell. S6AE102A/103A lowers the value of resistance (SW2 and SW4) to cover the range from microampere (µA) to milliampere (mA) of current 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 ($P_{IN} >> P_{OUT}$) 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:

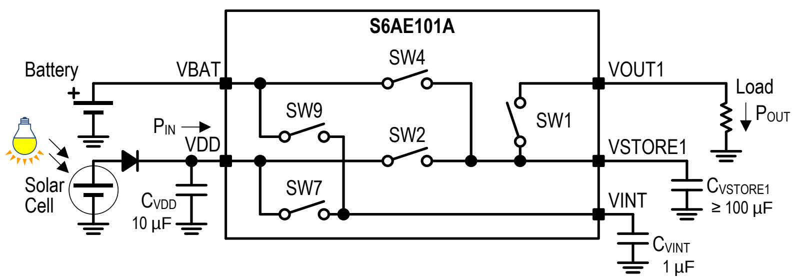
Both $C_{VSTORE1}$ and $C_{VSTORE2}$ are storage capacitors for charging the energy supplied from the solar cell. In particular, $C_{VSTORE2}$ is used when there is a surplus energy generated by the solar cell with respect to load. The size of $C_{VSTORE2}$ should be larger than 2 mF (see the S6AE102A/103A 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.

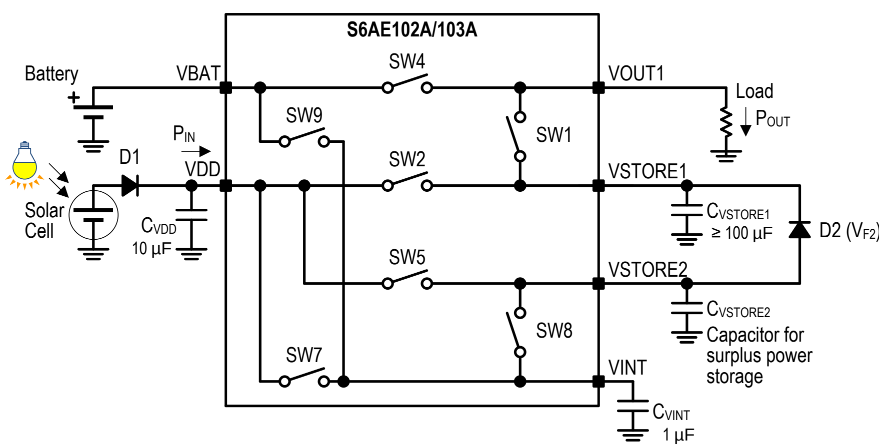
Figure 3. S6AE101A Energy Delivery Circuit



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} >> 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 VOUT1 on the basis of the VSTORE1 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 VOUT1. "$P_{IN} > P_{OUT}$" 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 VOUT 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 VBAT input voltage in S6AE101A will be 5.5V ≥ VBAT ≥ V_{VOUTH}, and VBAT ≥ 2V.
- The range of the VBAT input voltage in S6AE102A/103A will be 5.5V ≥ VBAT ≥ 2V.

Figure 5. Energy Delivery Sequence in Hybrid Operation

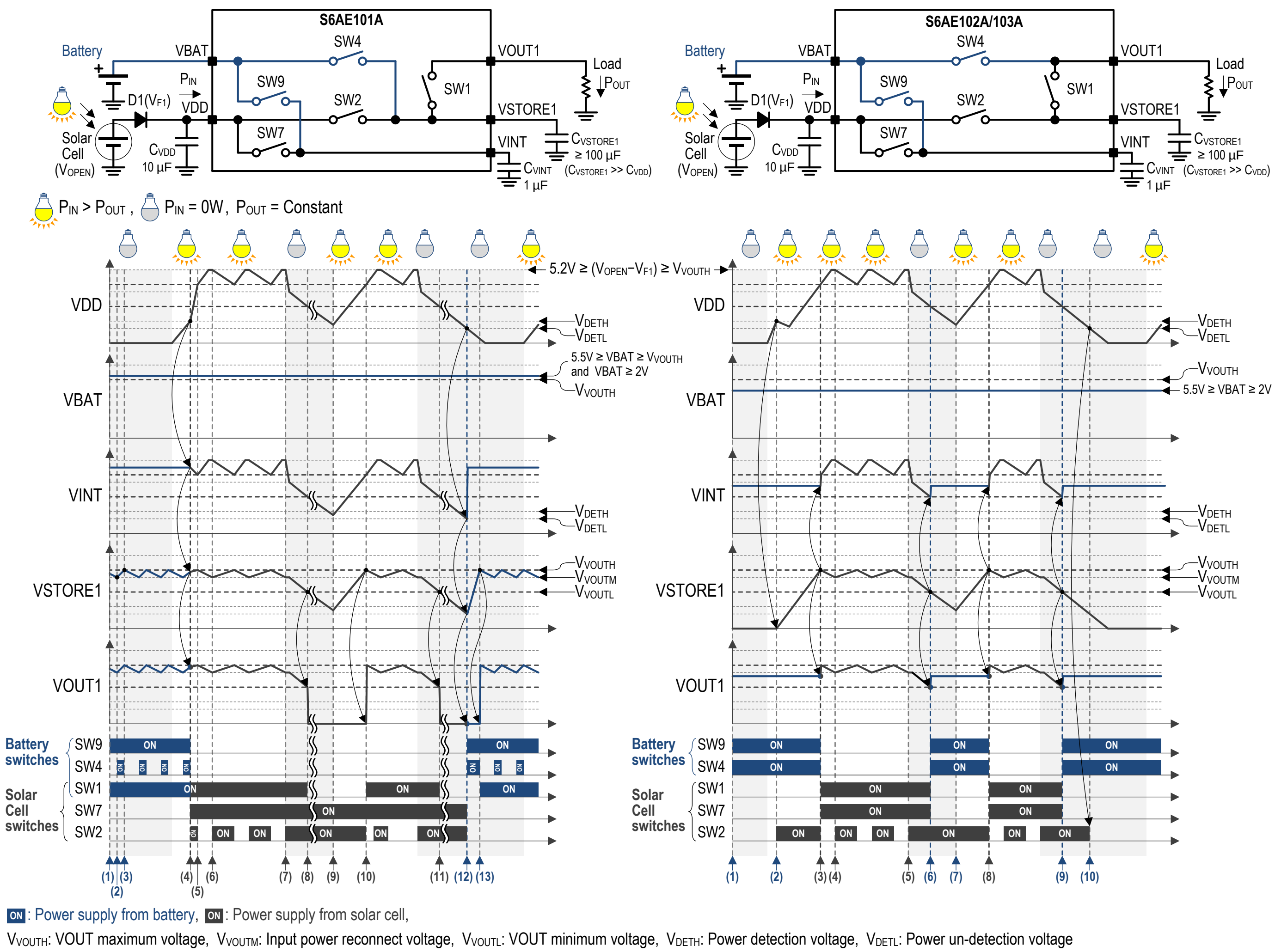


Table 1. Description of Figure 5: Difference between S6AE101A and S6AE102A/103A

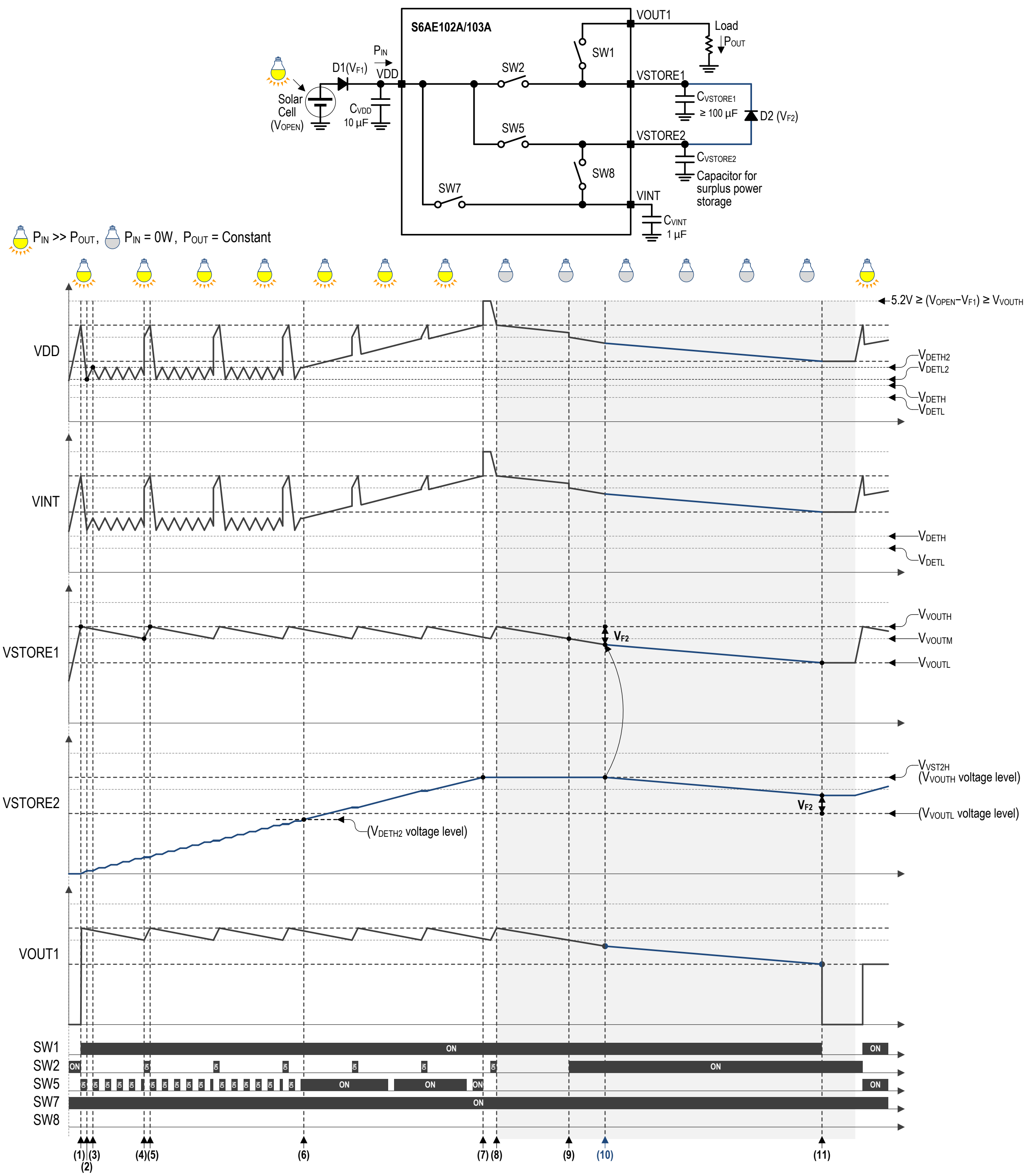
Power Balance	S6AE101A		S6AE102A/103A	
	No.	Description	No.	Description
P_{IN} = 0W	(1)	**Under battery power operation:** SW9 and SW1 are ON. Power is supplied from battery and output to VOUT1.	(1)	**Under battery power operation:** SW9 and SW4 are ON. Power is supplied from battery and output to VOUT1.
	(2)	VSTORE1 ≤ V_{VOUTM} → SW4 turns ON.		
	(3)	VSTORE1 ≥ V_{VOUTH} →SW4 turns OFF.		
P_{IN} > P_{OUT}	(4)	**Solar cell power operation starts:** VDD ≥ V_{DETH} → SW9 and SW4 turn OFF, SW7 and SW2 turn ON. Power is supplied from solar cell and output to VOUT1.	(2)	VDD ≥ V_{DETH} → SW2 turns ON.
	(5)	VSTORE1 ≥ V_{VOUTH} → SW2 turns OFF.	(3)	**Solar cell power operation starts:** VSTORE1 ≥ V_{VOUTH} → 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)	VSTORE1 ≤ V_{VOUTM} → SW2 turns ON.	(4)	VSTORE1 ≤ V_{VOUTM} → SW2 turns ON.
P_{IN} = 0W	(7)	VSTORE1 ≤ V_{VOUTM} → SW2 turns ON, but enough power is not supplied from solar cell. Then VSTORE1 starts to drop.	(5)	VSTORE1 ≤ V_{VOUTM} → SW2 turns ON, but enough power is not supplied from solar cell. Then VSTORE1 starts to drop.
	(8)	VSTORE1 ≤ V_{VOUTL} → 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:** VSTORE1 ≤ V_{VOUTL} → SW7 and SW1 turn OFF, SW9 and SW4 turn ON. Power is supplied from battery and output to VOUT1.
P_{IN} > P_{OUT}	(9)	VSTORE1 ≥ V_{DETL} and enough power is supplied from solar cell. Then VDD starts to rise.	(7)	VSTORE1 ≥ V_{DETL} and enough power is supplied from solar cell. Then VDD starts to rise.
	(10)	VSTORE1 ≥ V_{VOUTH} → 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:** VDD ≤ V_{DETL}→ SW9 and SW4 turn ON, SW7 and SW2 turn OFF.	(9)	Same as (6).
	(13)	VSTORE1 ≥ V_{VOUTH} → SW4 turns OFF, SW1 turns ON Power is supplied from battery and output to VOUT1.	(10)	VDD ≤ V_{DETL} → 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} >> 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} >> 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



VVOUTH: VOUT maximum voltage, VVOUTM: Input power reconnect voltage, VVOUTL: VOUT minimum voltage, VDETH: Power detection voltage, VDETL: Power un-detection voltage, VDETH2: Power detection voltage 2, VDETL2: Power un-detection voltage 2, VVST2H: VSTORE2 maximum voltage

Table 2. Description of Figure 6: Charge / Discharge of $C_{VSTORE1}$ and CVSTORE2

Power Balance	No.	Charge / Discharge	
		$C_{VSTORE1}$	$C_{VSTORE2}$
P_{IN} >> P_{OUT} (Surplus power)	(1)	When starting up: VSTORE1 ≥ V_{VOUTH} → SW2 turns OFF, SW1 turns ON. Power is supplied from $C_{VSTORE1}$ and output to VOUT1.	When starting up: VSTORE1 ≥ V_{VOUTH} → SW5 turns ON. Charging of $C_{VSTORE2}$ starts.
	(2)	–	VDD ≤ V_{DETL2} → SW5 turns OFF. Charging of $C_{VSTORE2}$ stops.
	(3)	–	VDD ≥ V_{DETH2} → SW5 turns ON. Charging of $C_{VSTORE2}$ starts.
	(4)	VSTORE1 ≤ V_{VOUTH} → SW2 turns ON. $C_{VSTORE1}$ starts being charged.	VSTORE1 ≤ V_{VOUTH} → SW5 turns OFF. Charging of $C_{VSTORE2}$ stops.
	(5)	VSTORE1 ≥ V_{VOUTH} → SW2 turns OFF. $C_{VSTORE1}$ stops being charged.	VSTORE1 ≥ V_{VOUTH} → SW5 turns ON. Charging of $C_{VSTORE2}$ starts.
	(6)	–	SW5 is ON and VSTORE2 ≥ V_{DETL2}. (VDD and VINT start rising.)
	(7)	–	VSTORE2 ≥ V_{VST2H} → SW5 turns OFF; full charge.
P_{IN} = 0W (No power)	(8)	VSTORE1 falls because there is no power. (VDD and VINT start falling.)	(VDD and VINT start falling.)
	(9)	VSTORE1 ≤ V_{VOUTM} → SW2 turns ON.	–
	(10)	VSTORE1 ≤ (V_{VST2H} – V_{F2}) → D2 turns ON. $C_{VSTORE1}$ starts being charged by $C_{VSTORE2}$.	(VSTORE2 ≥ (VSTORE1 + V_{F2}) → D2 turns ON.)
	(11)	VSTORE1 ≤ V_{VOUTL} → 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

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**	5327130	HIXT	07/11/2016	New application note.
*A	5789124	AESATMP8	06/28/2017	Updated logo and Copyright.

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