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Energy Calculation for Energy Harvesting with S6AE101A, S6AE102A, and S6AE103A

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Associated Part Family:S6AE101A, S6AE102A, S6AE103A

Related Documents: S6AE101A, S6AE102A, S6AE103A Datasheets

This application note describes system energy calculations for an energy harvesting system where the amount of energy from an energy harvester is very small.

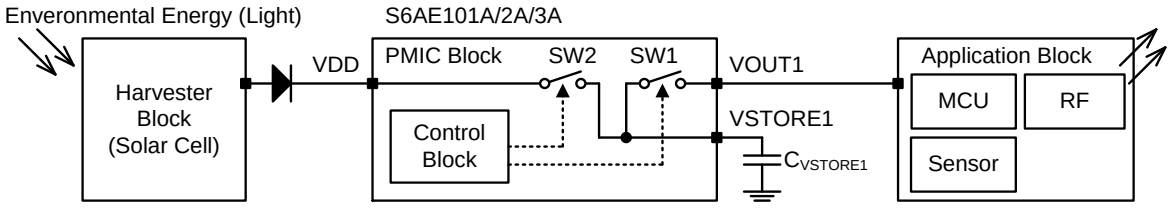
1 Introduction

Systems that are dependent on an energy harvesting solution must be designed for a low-power operation based on an energy budget calculation because the amount of energy from the energy harvester such as indoor solar cell is very small.

1.1 Energy Harvesting System

S6AE101A/2A/3A is a power management IC (PMIC) for energy harvesting operated with super-compact solar cells. Figure 1 shows an example of an energy harvesting system with S6AE101A/2A/3A.

Figure 1. Example of Energy Harvesting System with S6AE101A/2A/3A



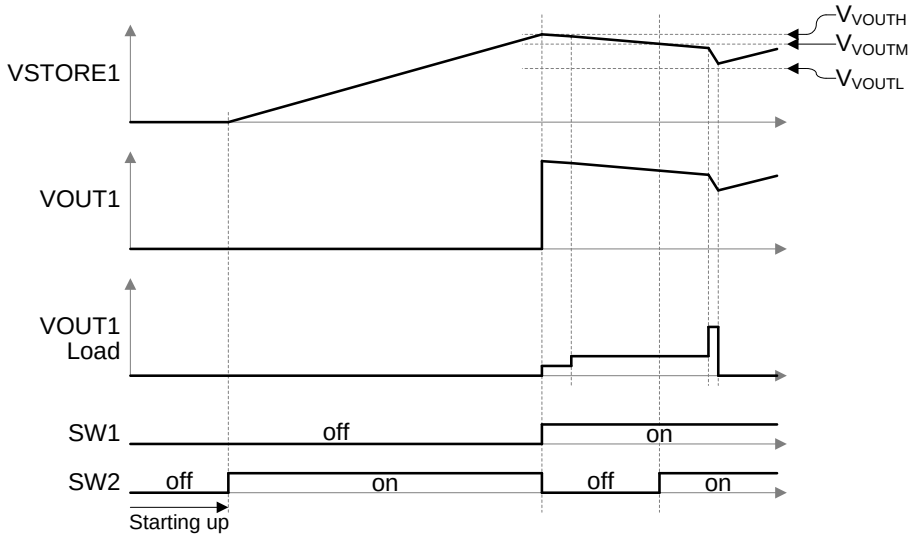
Because the energy from a harvester is limited, it should be stored in a capacitor ($C_{VSTORE1}$). A large-value capacitor would take too much time to store the energy into the capacitor; this means that the system cannot be operated frequently. On the other hand, if the capacitor were too small, enough energy cannot be stored on the capacitor for the application block. Therefore, the sizing of the capacitor is very important.

This PMIC has a power gating switch, SW1, for the application block. Once the VSTORE1 pin voltage reaches the VOUT maximum voltage (V_{VOUTH}), the path between the VSTORE1 pin and the VOUT1 pin is connected by the SW1 until the VSTORE1 pin voltage reaches the VOUT minimum voltage (V_{VOUTL}) (see Figure 2).

This PMIC has a switch, SW2, for charging the capacitor efficiently. After starting up the internal circuit of the PMIC, the path between the VDD pin and the VSTORE1 pin is connected by the SW2. When the VSTORE1 pin voltage reaches the V_{VOUTH}, the SW2 disconnects the path. When the VSTORE1 pin voltage reaches the input power reconnect voltage (V_{VOUTM}), the SW2 reconnects the path (see Figure 2).

For more information, see S6AE101A, S6AE102A, and S6AE103A datasheets.

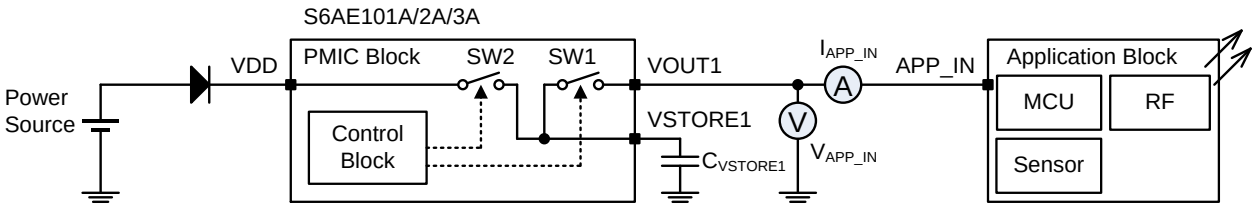
Figure 2. Relationship between SW1, SW2 and VSTORE1 Pin



2 Energy Calculation for Energy Harvesting

2.1 Calculation of Energy Consumption

Figure 3. Measurements of Voltage, Current, and Operation Time



First of all, the voltage (V_{APP_IN}), the current (I_{APP_IN}), and the operation time (t_{APP_IN}) of APP_IN pin in the application block are measured (see Figure 3 and Figure 4). The energy consumption in the application is calculated from Equation 1.

Equation 1 $$E_{APP\_IN}\,[J] = V_{APP\_IN} \times I_{APP\_IN} \times t_{APP\_IN}$$

However, when checking the waveform of V_{APP_IN} and I_{APP_IN} in the Figure 4, the waveform is divided into three parts, (1), (2), and (3). Therefore, the energy consumptions of each part should be calculated, and then three energy consumptions are added together.

$$E_{(1)} = V_{(1)} \times I_{(1)} \times t_{(1)} = 3.28\,[V] \times 1\,[mA] \times 5\,[ms] = 16.4\,[\mu J]$$

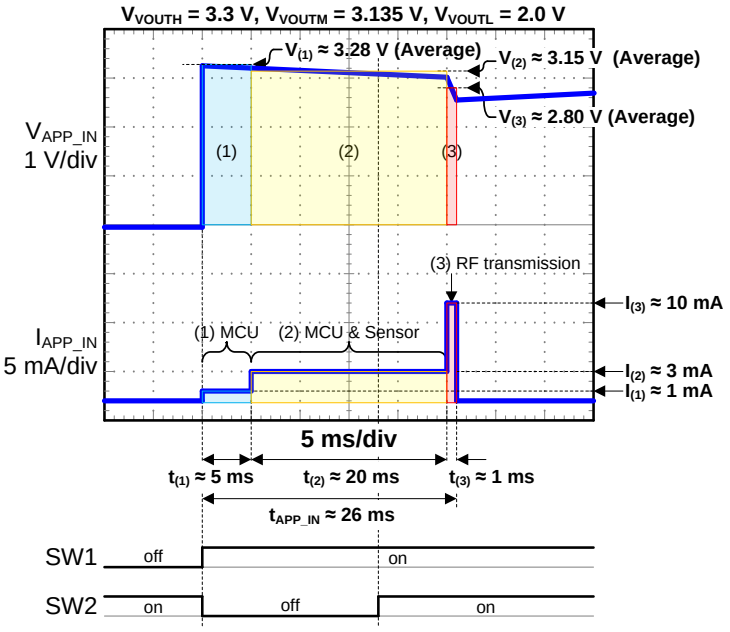
$$E_{(2)} = V_{(2)} \times I_{(2)} \times t_{(2)} = 3.15\,[V] \times 3\,[mA] \times 20\,[ms] = 189.0\,[\mu J]$$

$$E_{(3)} = V_{(3)} \times I_{(3)} \times t_{(3)} = 2.80\,[V] \times 10\,[mA] \times 1\,[ms] = 28.0\,[\mu J]$$

In this example, the energy consumption for the application block is calculated as 233.4 µJ.

$$E_{APP\_IN} = E_{(1)} + E_{(2)} + E_{(3)} = 16.4\,[\mu J] + 189.0\,[\mu J] + 28.0\,[\mu J] = 233.4\,[\mu J]$$

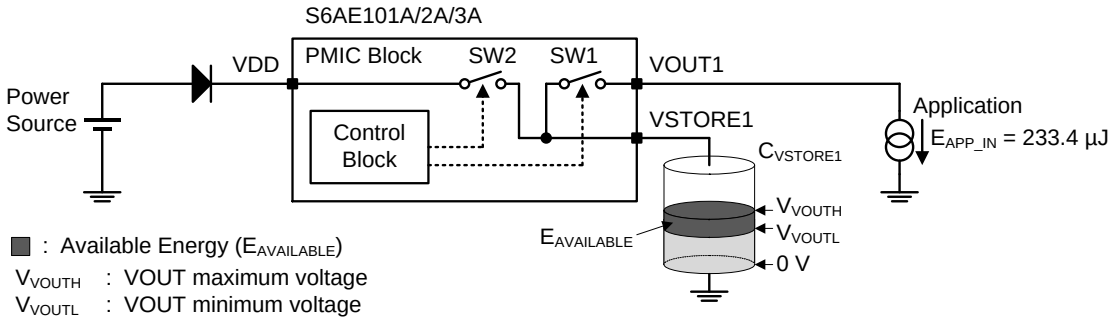
Figure 4. Waveform of V_{APP_IN}, I_{APP_IN}, and t_{APP_IN}



2.2 Calculation of Capacitance

Next, the capacitance is calculated based on the energy consumption of the application. Figure 5 shows the capacitor in the system.

Figure 5. Capacitor in the System



The energy stored on a capacitor is calculated by Equation 2 (E: Energy [J], C: capacitance [F], V: Voltage [V]).

Equation 2 $$E = \frac{1}{2}CV^2$$

Calculation of $C_{VSTORE1}$

The VOUT maximum voltage (V_{VOUTH}) and the VOUT minimum voltage (V_{VOUTL}) of S6AE101A/2A/3A are set by changing the external resistances. As a premise, the recommended operating voltage range for the application block is set from 1.8 V to 3.6 V. Then, V_{VOUTH} is set to 3.3 V and V_{VOUTL} is set to 2.0 V within the range. The stored energy from V_{VOUTL} to V_{VOUTH} is the available energy for the application. ($E_{AVAILABLE}$: Available energy, see Figure 5). $E_{AVAILABLE}$ should be larger than the E_{APP_IN} (233.4 µJ). (Equation 3 is derived from Equation 2)

Equation 3 $$E_{AVAILABLE} = \frac{1}{2} \times C_{VSTORE1} \times \left(V_{VOUTH}{}^2 - V_{VOUTL}{}^2\right)$$

$$233.4\ [\mu J] = \frac{1}{2} \times C_{VSTORE1} \times (3.3\ [V]^2 - 2.0\ [V]^2)$$

$$C_{VSTORE1} = 67.8\ [\mu F] \rightarrow 100\ [\mu F]$$

In this example, the capacitance of $C_{VSTORE1}$ should be larger than 67.8 µF. Moreover, at least 100-µF or larger capacitor is required for this PMIC (see the recommended operating conditions in S6AE101A, S6AE102A, and S6AE103A datasheets). The capacitance is set to 100 µF in this example.

Note:

The calculated capacitance in this example is the ideal value. There is a wide difference between an actual capacitance and a capacitance described in a datasheet. Also, there is a potential for a decrease in a capacitance by DC bias characteristics and temperature characteristics. When selecting a capacitor, please check datasheets for each manufacturer and check the actual capacitances under actual use conditions.

The type of capacitors and the characteristics for the energy harvesting are shown in Table 1. Ceramic capacitors with low leakage current are suitable for energy the harvesting.

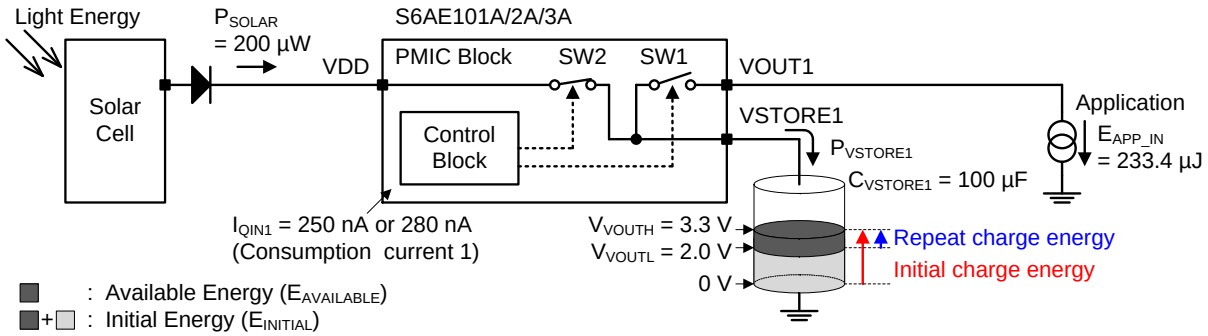
Table 1. Capacitor Characteristics

Type of Capacitor	Capacitance Range	Benefit	Drawback
Ceramic capacitor	0.1 µF to 470 µF	Low leakage current (nA), Small size, Low cost	Small capacitance
Aluminum electrolytic capacitor	0.1 µF to 1.5 F	High capacitance, Low cost	High leakage current (µA)
Tantalum electrolytic capacitor	33 nF to 6 mF	Low leakage current (nA), High capacitance	High cost
Electric double-layer capacitor (e.g., Supercapacitor)	Up to 50 F	Ultrahigh capacitance	High leakage current (µA) High cost

2.3 Calculation of Charging Time

The parameters for calculating charging time for the capacitor are shown in Figure 6.

Figure 6. Calculating the Parameters for Charging Time



This calculation assumes that the power from a solar cell (P_{SOLAR}) is 200 µW. The charge power ($P_{VSTORE1}$) to be supplied to the VSTORE1 pin capacitor ($C_{VSTORE1}$) is the value P_{SOLAR} minus the power consumption ($V_{VOUTH} \times I_{QIN1}$) of the PMIC (Equation 4) Values of consumption current 1 (I_{QIN1}) of S6AE101A/2A/3A are shown in Table 2. In this example, the value of S6AE101A is used.

Equation 4 $$P_{VSTORE1} = P_{SOLAR} - (V_{VOUTH} \times I_{QIN1}) = 200\ [\mu W] - (3.3\ [V] \times 0.25\ [\mu A]) = 199.2\ [\mu W]$$

Table 2. Consumption Current 1 (I_{QIN1})

Product Name	Consumption Current 1 (I_{QIN1})
S6AE101A	250nA
S6AE102A	280nA
S6AE103A	

Calculation of Initial Charging Time (t_{CHARGE})

The capacitor is charged from 0 V to V_{VOUTH} at the time of initial charging. The initial energy ($E_{INITIAL}$) is calculated by Equation 2.

$$E_{INITIAL} = \frac{1}{2} \times C_{VSTORE1} \times {V_{VOUTH}}^2$$

$$E_{INITIAL} = \frac{1}{2} \times 100\ [\mu F] \times 3.3\ [V]^2$$

$$E_{INITIAL} = 544.5\ [\mu J]$$

Equation 5 is derived from Equation 1 (E: Energy [J], P: Power [W], and t: time [s]). Equation 6 for the charging time is derived from Equation 5.

Equation 5 $$E = (V \times I) \times t = P \times t$$

Equation 6 $$t_{CHARGE} = \frac{E}{P_{VSTORE1}}$$

$$t_{CHARGE} = \frac{E_{INITIAL}}{P_{VSTORE1}} = \frac{544.5\ [\mu J]}{199.2\ [\mu W]} = 2.73[s]$$

Calculation of Repeat Charging Time (t_{CHARGE_R})

$$t_{CHARGE\_R} = \frac{E_{AVAILABLE}}{P_{VSTORE1}} = \frac{233.4\ [\mu J]}{199.2\ [\mu W]} = 1.17[s]$$

In this example, the initial charging time is 2.73 s, and the repeat charging time is 1.17 s. The repeat charging time is shorter than the initial one.

3 Summary

This application note explored the basic calculation of energy, capacitance, and charging time for an energy harvesting application based on Cypress's S6AE101A/2A/3A PMIC. The most important concept to be gained from this application note is to figure out a balance of charged energy with energy consumption.

S6AE101A/2A/3A has a set of documentation such as other 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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Revision	ECN	Orig. of Change	Submission Date	Description of Change
**	5099308	HIXT	02/17/2016	New application note
*A	5273891	HIXT	05/17/2016	Added the following sentences on page 4. Moreover, at least 100-µF or larger capacitor is required for this PMIC (see the recommended operating conditions in S6AE101A, S6AE102A, and S6AE103A datasheets). The capacitance is set to 100 µF in this example. Corrected typo error
*B	5690448	AESATMP8	04/10/2017	Updated logo, and Copyright.

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