High efficiency solar battery charger with embedded MPPT

Datasheet - production data

TSSOP8

Features

- 0.3 V to 5.5 V operating input voltage
- 140 mΩ internal synchronous rectifier
- 120 mΩ internal power active switch
- 100 kHz fixed PWM frequency
- Duty cycle controlled by MPPT algorithm
- Output voltage regulation, overcurrent and overtemperature protection
- Input source reverse polarity protection
- Built-in soft-start
- Up to 95% efficiency
- 3 mm x 4.4 mm TSSOP8 package

Applications

- Smart phones and GPS systems
- Wireless headsets
- Small appliances, sensors
- Portable media players
- Digital still cameras
- Toys and portable healthcare

Description

The SPV1040 device is a low power, low voltage, monolithic step-up converter with an input voltage range from 0.3 V to 5.5 V, and is capable of maximizing the energy generated by even a single solar cell (or fuel cell), where low input voltage handling capability is extremely important.

Thanks to the embedded MPPT algorithm, even under varying environmental conditions (such as irradiation, dirt, temperature) the SPV1040 offers maximum efficiency in terms of power harvested from the cells and transferred to the output.

The device employs an input voltage regulation loop, which fixes the charging battery voltage via a resistor divider. The maximum output current is set with a current sense resistor according to charging current requirements.

The SPV1040 protects itself and other application devices by stopping the PWM switching if either the maximum current threshold (up to 1.8 A) is reached or the maximum temperature limit (up to 155 °C) is exceeded.

An additional built-in feature of the SPV1040 is the input source reverse polarity protection, which prevents damage in case of reverse connection of the solar panel at the input.

Table 1. Device summary

Order code	Package	Packaging
SPV1040T	TSSOP8	Tube
SPV1040TTR		Tape and reel

Contents

1 Block diagram

Figure 1. Block diagram

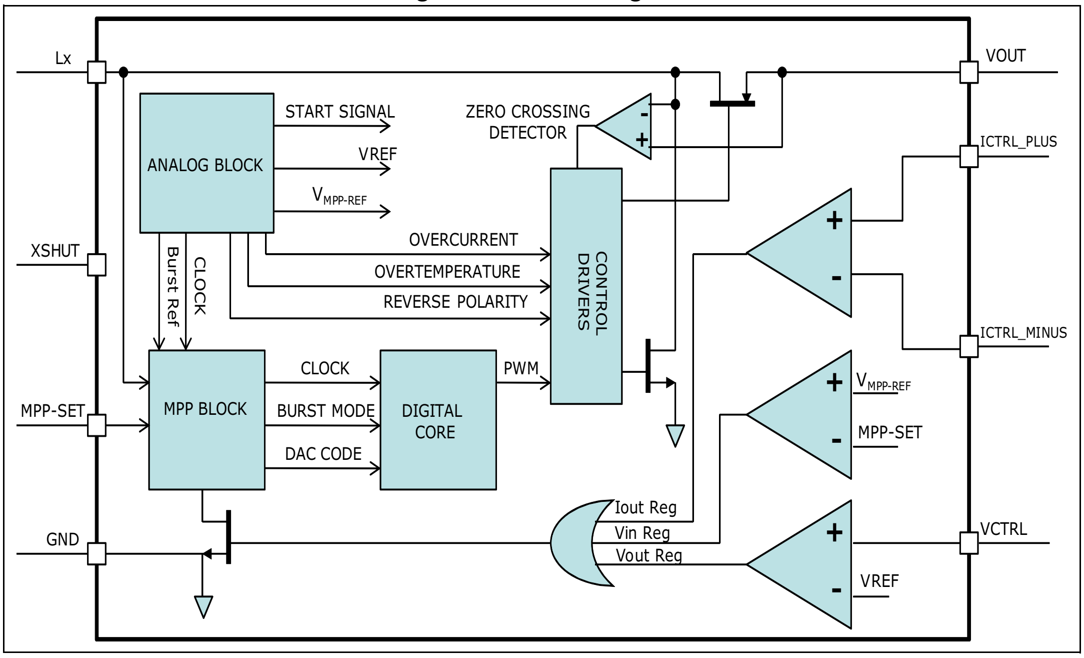
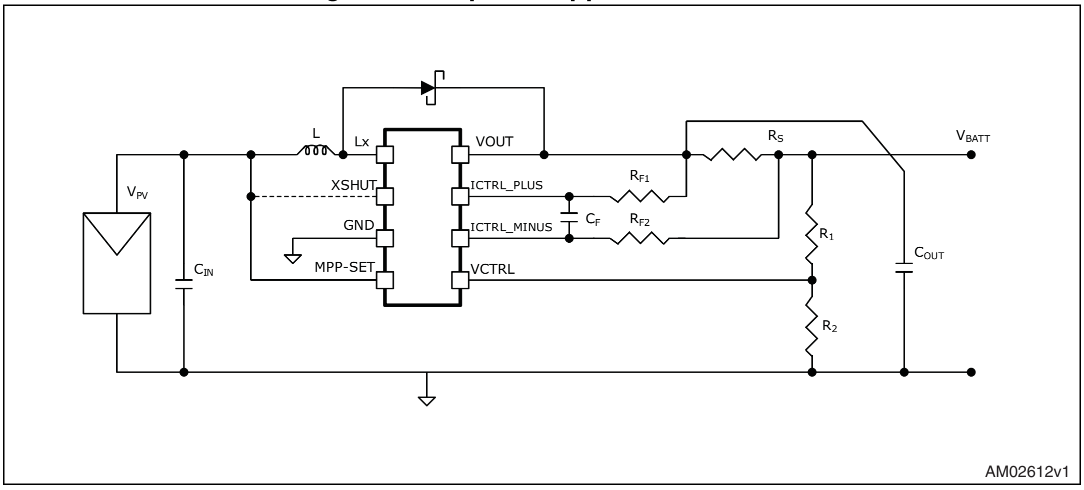


Figure 2. Simplified application circuit



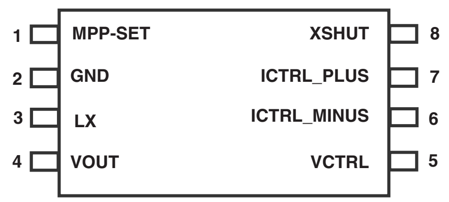
For setting up the application and simulating the related test results please go to www.st.com/edesignstudio

2 Pin description

Table 2. Pin description

Pin	Name	Type	Description
1	MPP-SET	I	Non-inverting input to sense the PV cell voltage. It cannot be left floating.
2	GND	Ground	Power ground reference.
8	XSHUT	I	Shutdown input pin: XSHUT = LOW: device in *Power Off* mode XSHUT = HIGH: device enabled for *Operating* mode This pin cannot be left floating.
3	LX	I	Booster inductor connection.
7	ICTRL_PLUS	I	Non-inverting input of constant current control loop. It cannot be left floating.
6	ICTRL_MINUS	I	Inverting input of constant current control loop. It cannot be left floating.
5	VCTRL	I	Non-inverting input of constant voltage control loop. It cannot be left floating.
4	VOUT	O	Booster output voltage.

Figure 3. Pin connection (top view)



3 Maximum ratings

3.1 Absolute maximum ratings

Table 3. Absolute maximum ratings

Symbol	Parameter	Range [min, max]	Unit
MPP-SET	Analog input	[-5.5, VOUT]	V
GND	Ground	0	V
XSHUT	Analog input	[-5.5, VOUT]	V
LX	Analog input	[-5.5, VOUT]	V
ICTRL_PLUS	Analog input	[-0.3, VOUT]	V
ICTRL_MINUS	Analog input	[-0.3, VOUT]	V
VCTRL	Analog input	[-0.3, VOUT]	V
VOUT	Analog output	[-0.3, 5.5]	V

3.2 Thermal data

Table 4. TSSOP8 thermal data

Symbol	Parameter	Value	Unit
$R_{th\ j\text{-}amb}$	Thermal resistance, junction-to-ambient	135	°C/W
Tj_{op}	Junction operating temperature	-40 to 125	°C
Tstg	Storage temperature	-40 to 150	°C

Note: *R_{thJA} was measured on a 2-layer PCB: FR4, 35 µm Cu thickness, 2.8 cm^2*

4 Electrical characteristics

VMPP-SET = 0.5 V, V_{CTRL} = I_{ctrl+} = I_{ctrl-} = GND, XSHUT = 0.5 V, T_J = -40 °C to 125 °C, unless otherwise specified.

Table 5. Electrical characteristics

Symbol	Parameter	Test condition	Min.	Typ.	Max.	Unit
Input source section						
$V_{MPP-SET}$	Low boost voltage threshold	V_{OUT} = 3.3V	0.4	0.45	0.50	V
I_q	Quiescent current	I_{LOAD}=0mA, V_{CTRL}=2V, V_{OUT}=3.3V,		60	80	µA
I_{SD}	Shutdown current	V_{OUT} = 3.3V, V_{CTRL}=2V, I_{LOAD} = 0mA, XSHUT = GND		0.7	5	µA
I_{rev}	Reverse input source current	$V_{MPP-SET}$=-4V, V_{OUT} = 1.5V		1	5	µA
V_{UVLO}	Undervoltage lockout threshold for turn ON @V_{OUT} = 3.3V	$V_{MPP-SET}$ increasing		0.27	0.34	V
	Undervoltage lockout threshold for turn OFF @V_{OUT} = 3.3V	$V_{MPP-SET}$ decreasing	0.14	0.24		V
Power section						
R_{DS_ON-N}	N-channel power switch ON resistance				120	mΩ
R_{DS_ON-P}	P-channel synchronous rectifier ON resistance	V_{CTRL}=2V			140	mΩ
Control section						
$V_{MPPT-THR}$	MPPT-mode threshold	Vout increasing, $V_{MPP-SET}$ = 1.5V	1.7	1.8	2	V
V_{OUT}	Output voltage range	$V_{MPP-SET} \geq 1.5V$	2		5.2(1)	V
P_{OUT} (2)	Maximum output power	$V_{MPP-SET} \geq 1.5V$			3	W
I_{Lx}	Maximum inductor current peak		1.5	1.65	1.8	A
F_{PWM}	PWM signal frequency		70	100	130	kHz
V_{REF}	Internal V_{CTRL} reference voltage	$V_{OUT} \geq 1.8V$, V_{CTRL} increasing	1.2	1.25	1.3	V
V_{Ictrl}	Sensing current offset	I_{CTRL}+ - I_{CTRL}- decreasing	40	50	60	mV
XSHUT	XSHUT logic LOW	XSHUT increasing		0.27	0.34	V
	XSHUT logic HIGH	XSHUT decreasing	0.14	0.24		V
Thermal shutdown						

Table 5. Electrical characteristics (continued)

Symbol	Parameter	Test condition	Min.	Typ.	Max.	Unit
$T_{shutdown}$	Overtemperature threshold for turn OFF	Temperature increasing		155		°C
	Overtemperature threshold for turn ON	Temperature decreasing		130		°C

1. According to the absolute maximum ratings the output charge voltage cannot be above 4.8 V but if an higher Vout up to 5.2 V is needed, a Schottky diode must be placed between the Lx and Vout pins as shown in *Figure 2*. In such way the Schottky diode in parallel to the embedded P-channel MOSFET will reduce the voltage drop between the VLX pin and the VOUT pin determined by the body diode when the internal PMOS is OFF from 0.7 V down to 0.3 V.

2. Given $T_j = T_a + R_{thJA} \times P_D$, and assuming R_{thJA} = 135°C/W, and that in order to avoid device destruction Tjmax must be ≤ 125 °C, and that in the worst conditions T_A = 85 °C, the power dissipated inside the device is given by:

$$P_D \le \frac{T_j - T_a}{R_{thJA}} = 295 mW$$

Therefore, if in the worst case the efficiency is assumed to be 90%, then $P_{IN\text{-}MAX}$ = 3.3 W and $P_{OUT\text{-}MAX}$ = 3 W.

5 Typical characteristics

Figure 4. Efficiency vs output voltage 3 PV cells - V_{mp} = 1.5 V, L_X = 33 µH

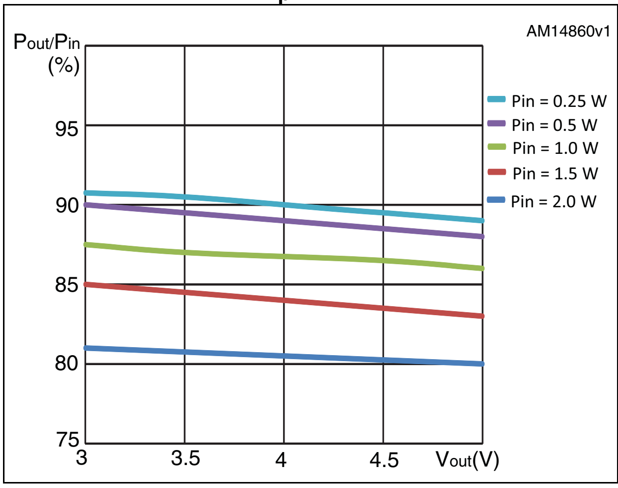


Figure 5. MPPT efficiency vs output voltage 3 PV cells - V_{mp} = 1.5 V, L_X = 33 µH

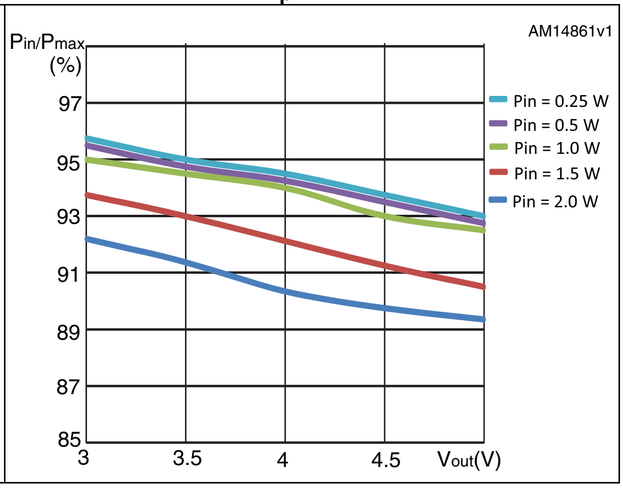


Figure 6. Efficiency vs output voltage 4 PV cells - V_{mp} = 2 V, L_X = 33 µH

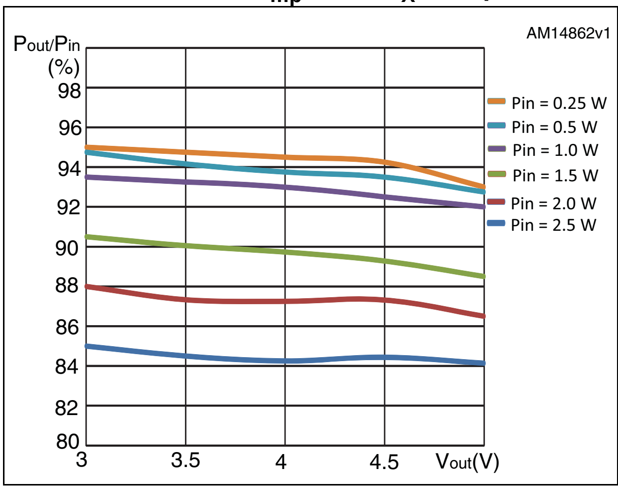


Figure 7. MPPT efficiency vs output voltage 4 PV cells - V_{mp} = 2 V, L_X = 33 µH

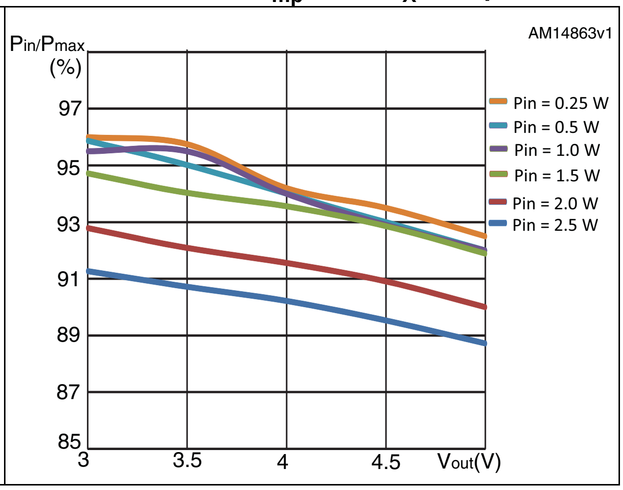


Figure 8. Efficiency vs output voltage 5 PV cells - V_{mp} = 2.5 V, L_X = 33 µH

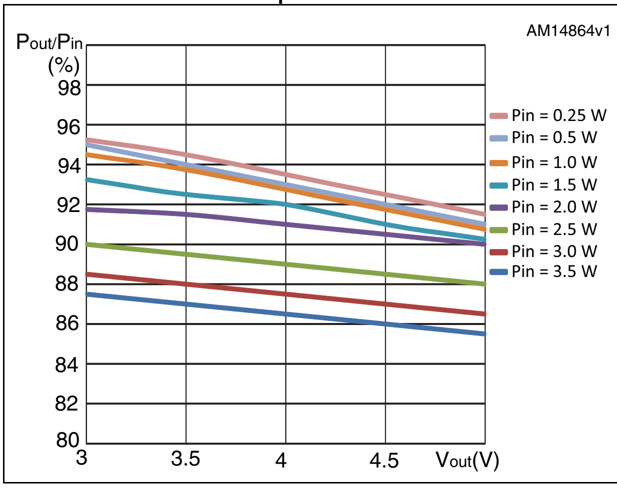


Figure 9. MPPT efficiency vs output voltage 5 PV cells - V_{mp} = 2.5 V, L_X = 33 µH

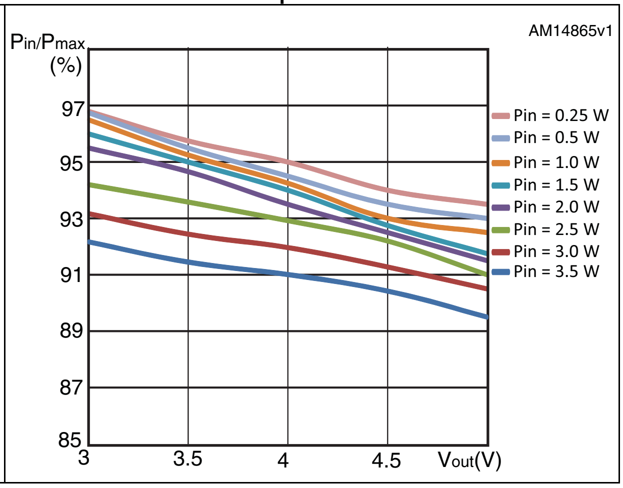


Figure 10. V_{LX} and I_{LX} waveforms - D = 39%

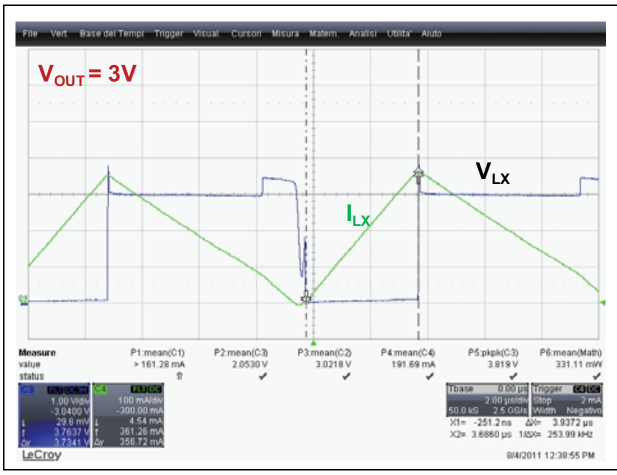
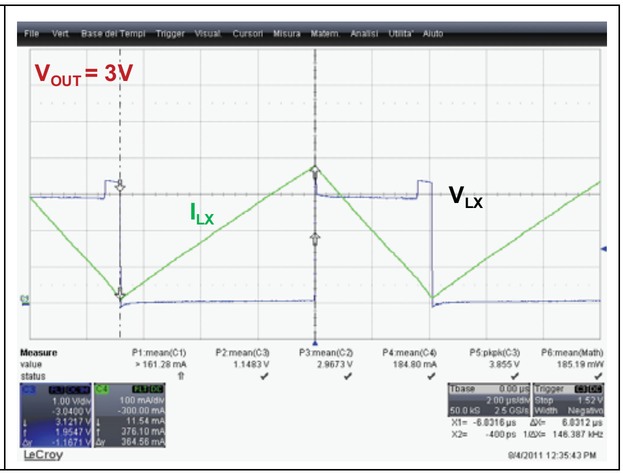


Figure 11. V_{LX} and I_{LX} waveforms - D = 68%



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6 Detailed description

The SPV1040 is a monolithic, high efficiency, low voltage, self-powered DC-DC converter that operates over a 0.3 V to 5.5 V DC input voltage range and provides a single output voltage.

The device provides regulated output voltage and current by sensing the VCTRL feedback of the external resistor divider and the voltage drop on the external sense resistor Rs, respectively.

High efficiency is ensured by low power consumption in any working mode and by the embedded *Perturb & Observe* MPPT algorithm.

The SPV1040 guarantees its own safety and application safety by stopping the N-channel power switch in case of overcurrent or overtemperature conditions.

6.1 Soft-start mode

In order to guarantee powerup even when V_{OUT} is very low (battery completely discharged), a proper startup strategy has been implemented.

Taking into account that the device is powered by the V_{OUT} voltage, If V_{OUT} is lower than 0.8 V, the device moves from power off to soft-start mode and the current flows from the input to output through the intrinsic body diode of the synchronous rectifier. In this condition V_{OUT} follows the LX voltage. The IC exits Startup mode when V_{OUT} reaches 0.8 V.

6.2 Startup mode

When V_{OUT} goes above 0.8 V but it is still lower than 2 V, a proper biasing of both MOSFETs is not yet guaranteed. In such conditions, the N-channel power switch is forced ON with a fixed duty cycle and the energy is transferred to the load via the intrinsic body diode of the P-channel synchronous switch. If the shutdown overcurrent limit is exceeded, the power switch is immediately turned OFF. The SPV1040 leaves Startup mode as soon as V_{OUT} goes above 2 V.

6.3 MPPT mode

Once the device has exited Startup mode, the SPV1040 enters MPPT mode to search for the maximum power point. The *Perturb & Observe* algorithm is based on monitoring either the voltage or the current supplied by the DC power source unit so that the PWM signal duty cycle is increased or decreased step by step according to the input power trend. Refer to *Figure 12*, which illustrates the MPPT working principle.

6.4 Constant voltage regulation

The constant voltage control loop consists of an internal voltage reference, an op amp and an external resistor divider that senses the battery voltage and fixes the voltage regulation set-point at the value specified by the user.

6.5 Constant current regulation

The constant current control loop consists of an op amp and an external sense resistor that feeds the current sensing circuit with a voltage proportional to the DC output current. This resistor determines the current regulation set-point and must be adequately rated in terms of power dissipation. It provides the capability to fix the maximum output current to protect the battery.

6.6 Overcurrent protection (OVC)

When the current that flows through the inductor reaches 1.8 A (overcurrent shutdown limit), the N-channel power switch is immediately forced OFF and the P-channel synchronous rectifier is switched ON. Once the overcurrent condition has expired (the inductor current goes below 1.8 A) the N-channel power switch is turned back ON.

6.7 Overtemperature protection (OVT)

When the temperature sensed at silicon level reaches 155 °C (overtemperature shutdown limit), the N-channel power switch is immediately forced OFF and the P-channel synchronous rectifier is switched ON. The device becomes operative again as soon as the silicon temperature goes below 130 °C.

6.8 Shutdown mode

The XSHUT pin low shuts OFF all internal circuitry, achieving the lowest power consumption mode.

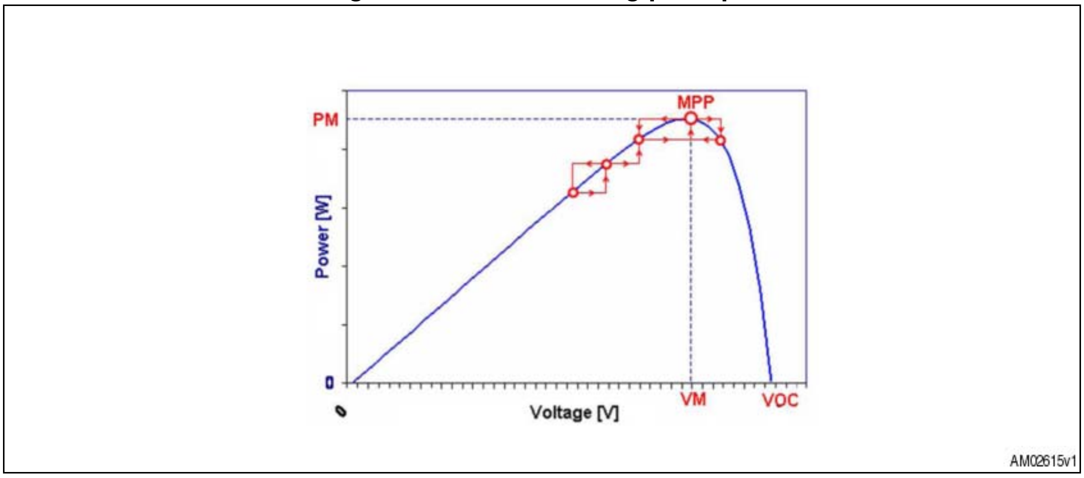
6.9 Undervoltage lockout (UVLO)

In order to prevent batteries from over-discharging, the device turns OFF in case of MPP-SET voltage lower than 0.24 V (no irradiation). A hysteresis has been implemented to avoid unpredictable ON-OFF switching.

6.10 Reverse polarity

In order to avoid damage to the device and battery discharge when the solar panel connection is reverse-inserted, a dedicated protection circuit has been implemented. In such condition, the SPV1040 stays OFF until the panel is inserted correctly.

Figure 12. MPPT working principle



6.11 Burst mode

When the output voltage reaches the battery charge voltage, the MPP-SET voltage drops below 450 mV, or the output current reaches the output maximum current limit, the duty cycle D drops down to 10% and the device evolves from Operating mode to Burst mode. The converter no longer works at constant frequency, but at frequencies gradually lower (1 T_{ON} over 1 PWM cycle, 1 T_{ON} over 2 PWM cycles, …,1 T_{ON} over 16 PWM cycles) prior to entering Sleep-IN mode.

6.12 Sleep-IN mode

Once Sleep-IN mode has been entered, no current is provided to the load. The device exits this mode once the cause which forced it into this state is no longer present.

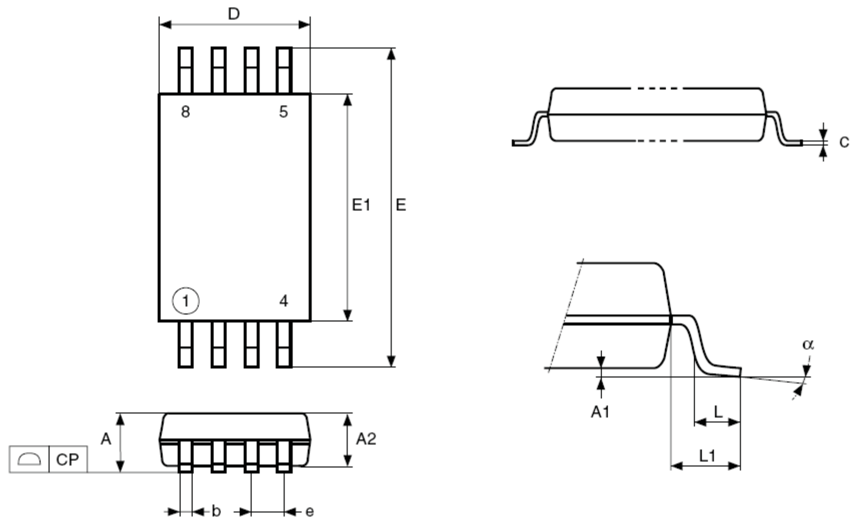
7 Package mechanical data

In order to meet environmental requirements, ST offers these devices in different grades of ECOPACK® packages, depending on their level of environmental compliance. ECOPACK® specifications, grade definitions and product status are available at: www.st.com. ECOPACK® is an ST trademark.

Table 6. TSSOP8 package mechanical data

Symbol	mm		
	Min.	**Typ.**	**Max.**
A			1.200
A1	0.050		0.150
A2	0.800	1.000	1.050
b	0.190		0.300
c	0.090		0.200
CP			0.100
D	2.900	3.000	3.100
e	–	0.650	–
E	6.200	6.400	6.600
E1	4.300	4.400	4.500
L	0.450	0.600	0.750
L1		1.000	
	0		8

Figure 13. TSSOP8 package mechanical drawing



8 Revision history

Table 7. Document revision history

Date	Revision	Changes
08-Oct-2010	1	Initial release
06-Apr-2011	2	Updated cover page, DFN8 information deleted, *Chapter 3*, *Chapter 4* and *Chapter 6*
04-Oct-2011	3	– Updated *Figure 1*, *Figure 2*, *Table 2* and *Table 5* – Minor text changes
25-Jul-2012	4	Updated *Figure 4*, *Figure 5*, *Figure 6*, *Figure 7*, *Figure 8*, and *Figure 9*.
21-Mar-2013	5	Updated *Figure 1* and note *1* in *Table 5*.