AN4050
Application note

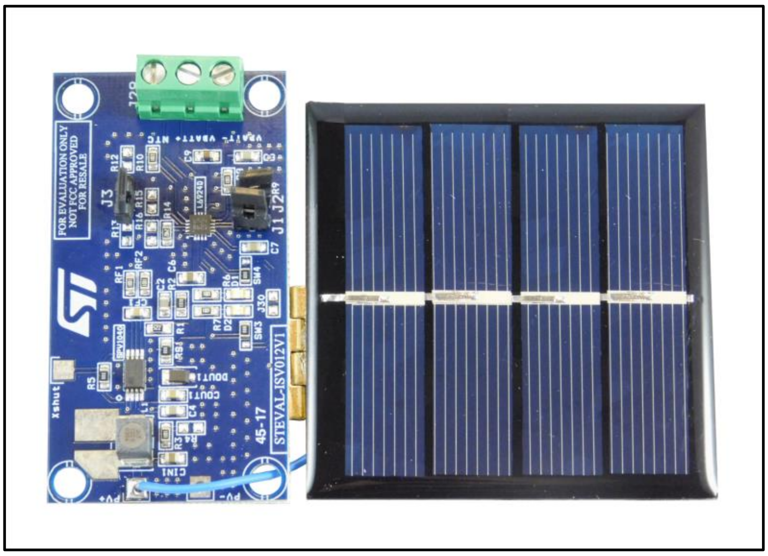
STEVAL-ISV012V1 lithium-ion solar battery charger

Domenico Ragonese; Alessandro Nicosia; Giovanni Conti

Introduction

The STEVAL-ISV012V1 evaluation board mounts an *SPV1040* (solar energy harvester) for the input stage and an *L6924D* (Li-Ion battery charger) as the output stage. It targets any portable application powered by lithium-ion batteries and merges the SPV1040 power extraction capacity of the solar module with the linear regulation of the L6924D for optimum battery charging load protection while reducing the power dissipation at the bottom.

Figure 1: STEVAL-ISV012V1 evaluation board



The board is designed to charge lithium-ion and lithium-polymer batteries with V_{BATT_max} = 4.1 or 4.2 V and it includes a 400 mWpk polycrystalline PV panel (SZGD6060-4P from NBSZGD) with V_{OC} = 2.2 V and I_{SC} = 220 mA.

According to specific application requirements, some components may be replaced[a]:

- The PV panel can be replaced as long as $V_{OC} < V_{BATT\_max}$ and $I_S < 1.65$ A.
- The inductor L1 can be replaced, but consider its effect on the maximum peak current to ensure that the input overcurrent limit is not triggered.
- The maximum output current can be limited by replacing the current sensing resistor R_S (0 0Ω by default).
- Resistor R14, which limits the charge current threshold (500 mA by default).

[a] For more details on component selection, refer to Application note AN3319, section “external component selection”

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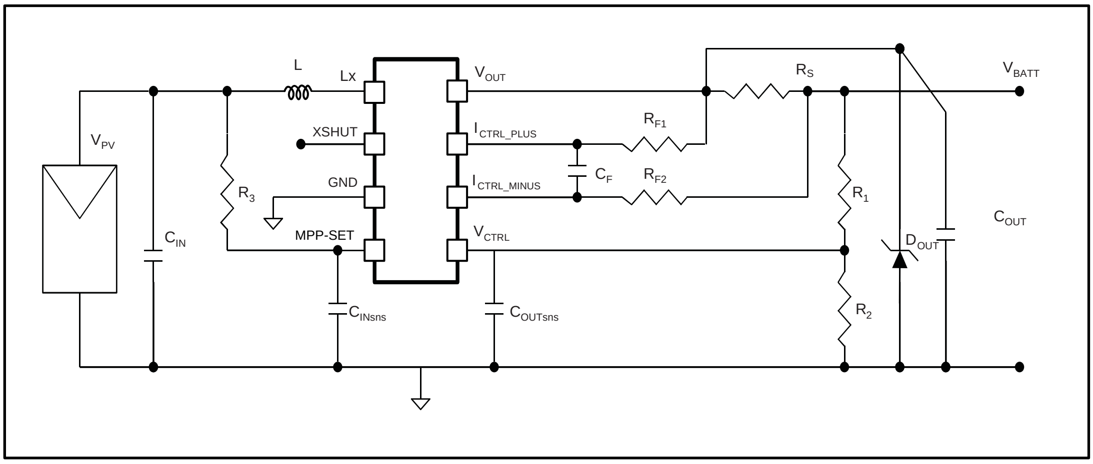
1 SPV1040 operation

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, capable of maximizing the energy generated by a single solar cell (or fuel cell), where low input voltage handling capability is important. When combined with the *L6924D*, it provides an ideal solution for charging lithium battery packs with energy harvested from a very small solar panel.

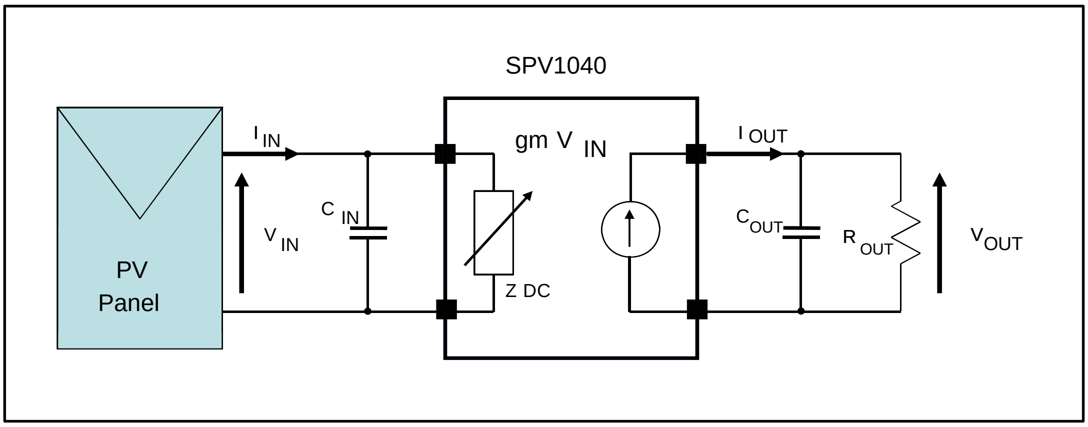
The SPV1040 is a 100 kHz, fixed-frequency pulse width modulation (PWM) step-up converter able to maximize the energy harvested by a few solar cells. It employs a maximum power point tracking (MPPT) algorithm which continuously tracks its output voltage and current. The converter guarantees the safety of the overall application and its own by stopping PWM switching in case of an overvoltage, overcurrent or overtemperature condition. The IC integrates a 120 mΩ N-channel MOSFET power switch and a 140 mΩ P-channel MOSFET synchronous rectifier.

Figure 2: Typical application circuit



The SPV1040 acts as an impedance adapter between the PV module and the output load. The equivalent circuit is shown below.

Figure 3: SPV1040 equivalent circuit



The MPPT algorithm sets up the correct DC working point by ensuring $Z_{in} = Z_m$ (assuming Z_m is the impedance of the supply source). In this way, the power extracted from the supply source ($P_{in} = V_{in} * I_{in}$) is maximum ($P_m = V_m * I_m$).

The voltage-current curve shows all the available working points of the PV panel at a given solar irradiation. The voltage-power curve is derived from the voltage-current curve by plotting the product V*I for each voltage generated[a].

Figure 4: MPPT working principle

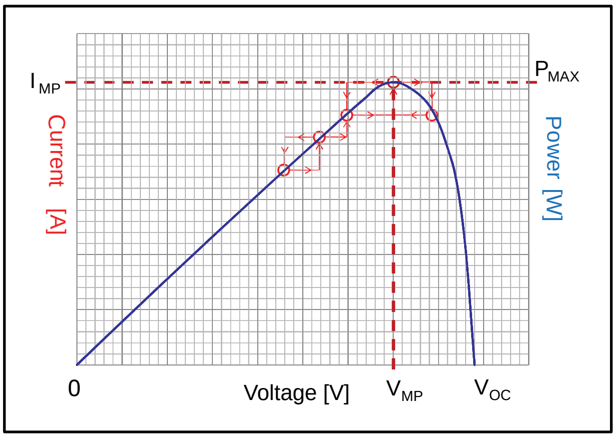
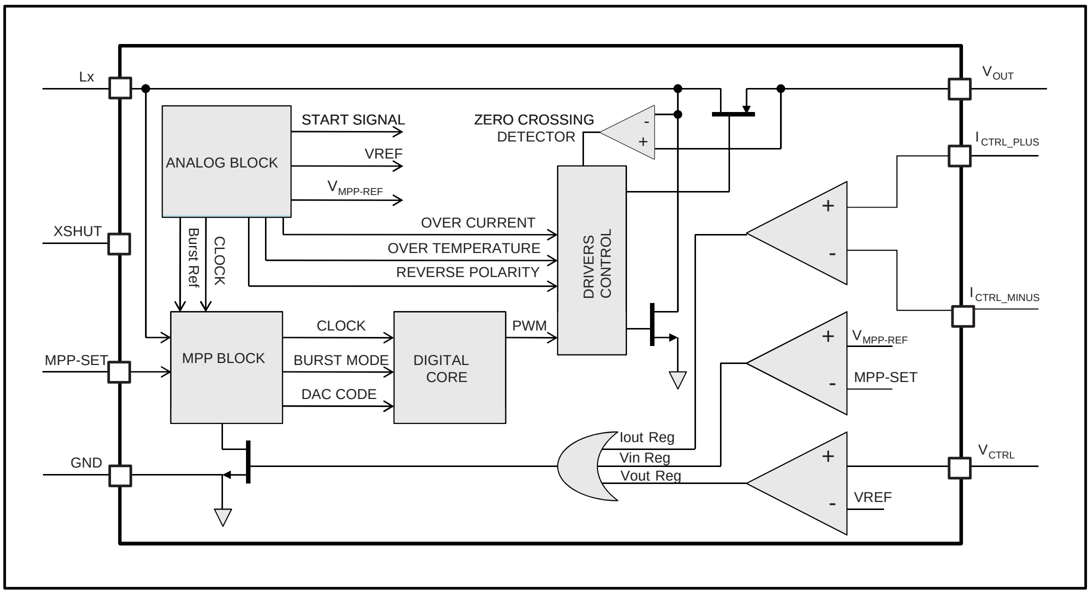


Figure 5: SPV1040 internal block diagram



The duty cycle set by the MPPT algorithm can be overwritten if one of the following events is triggered:

- Input overcurrent protection (OVC): inductor peak current ≤ 1.65 A
- Overtemperature protection (OVT): internal temperature ≤ 155 °C
- Output voltage regulation: VCTRL pin triggers the 1.25 V internal reference
- Output current limitation: R_S * (ICTRL_PLUS - ICTRL_MINUS) ≤ 50 mV
- MPP-SET voltage VMPP-SET ≤ 300 mV at startup and VMPP-SET ≤ 450 mV in running mode.

Application components must be carefully selected to avoid any undesired triggering of the above thresholds.

[a] For more details regarding the MPPT algorithm, refer to the SPV1040 datasheet.

2 L6924D operation

The *L6924D* is a fully monolithic battery charger dedicated to single-cell Li-Ion/polymer battery packs. It is designed with BCD6 technology and integrates all of the power elements (Power MOSFET, reverse blocking diode and sense resistor) in a small VFQFPN16 3 mm x 3 mm package.

It normally works as a linear charger when powered from an external voltage regulated adapter. However, thanks to its very low minimum input voltage (down to 2.5 V) the L6924D can also work as a quasi-pulse charger when powered from a current limited adapter, dramatically reducing the power dissipation.

The L6924D charges the battery in three phases:

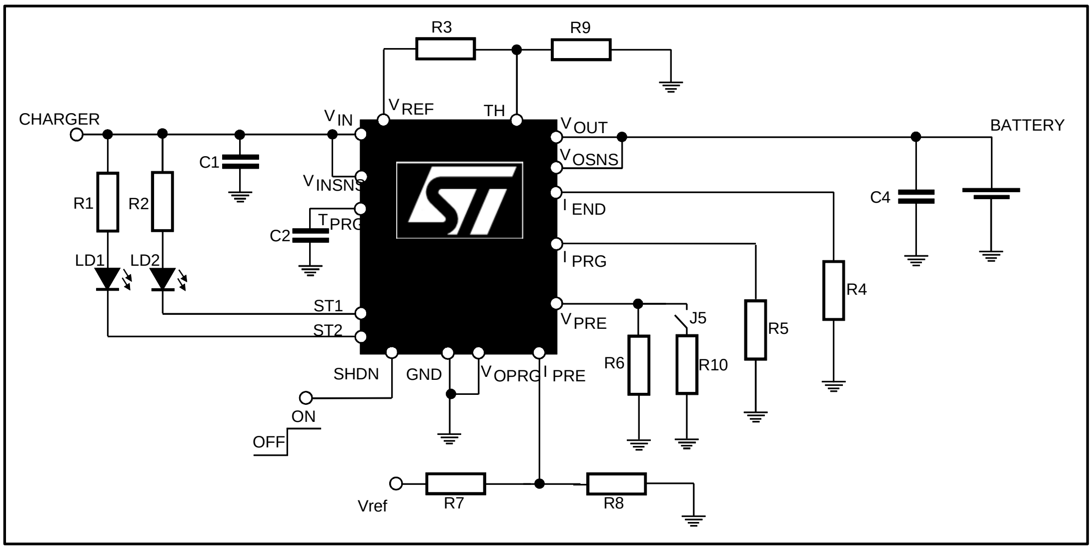
- Pre-charge constant current: a deeply discharged battery is charged with a low current.
- Fast-charge constant current: the device charges the battery with the maximum current.
- Constant voltage: when the battery voltage is close to the selected output voltage, the device starts to reduce the current until the charge termination has completed.

Regardless of the charging approach, a closed loop thermal control features protects the device from overheating. The L6924D allows the user to program many parameters, such as pre-charge current, fast-charge current, pre-charge voltage threshold, end-of-charge current threshold and charge timer.

The L6924D offers two open collector outputs for diagnostic purposes, which can be used to either drive two external LEDs or communicate with a host microcontroller.

Finally, the L6924D also provides other battery related functions, such as checking for battery presence, monitoring and protection from unsafe thermal conditions.

Figure 6: Basic application schematic



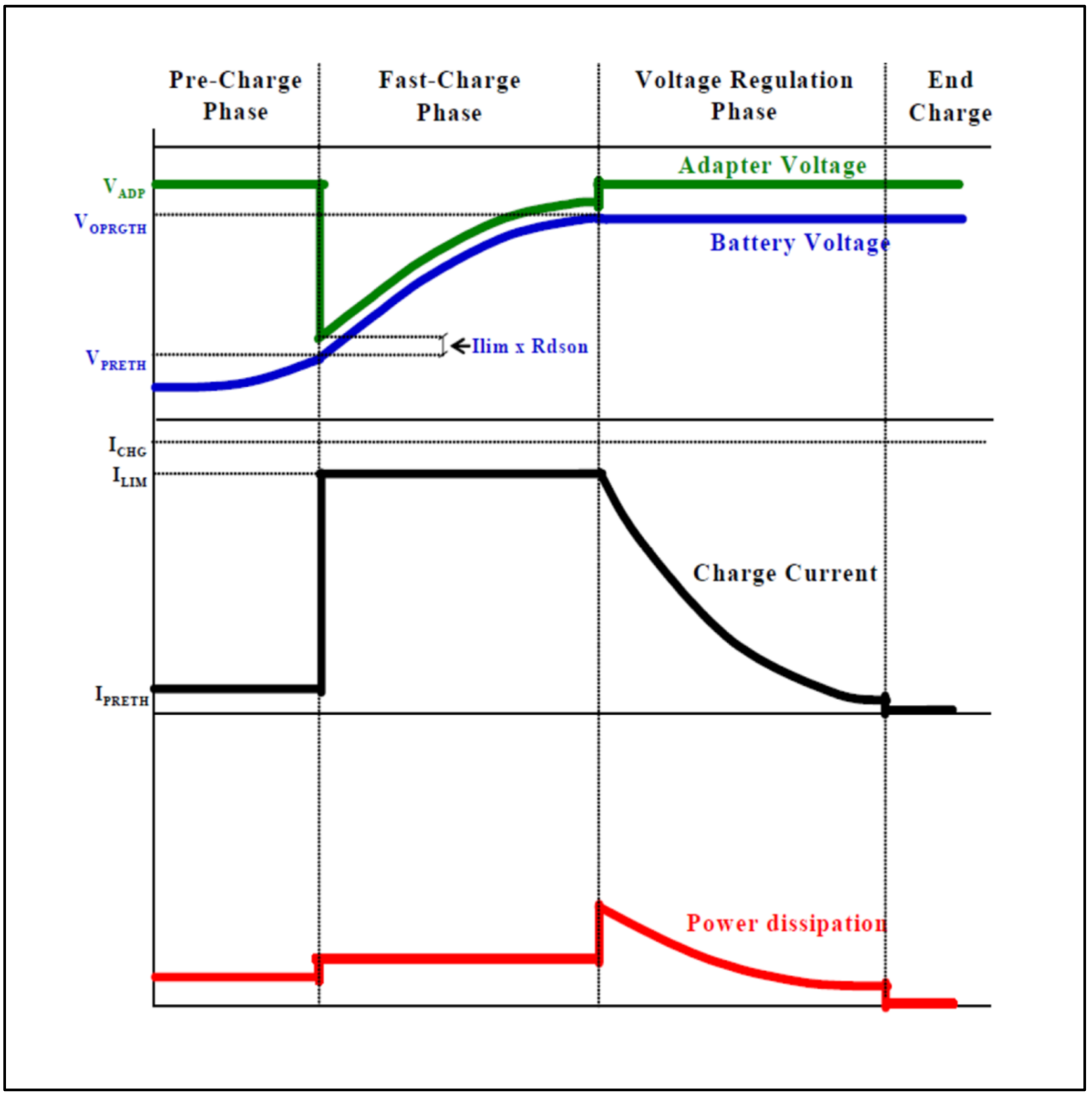
2.1 L6924D operation in solar powered applications

Thanks to its very low minimum input voltage (down to 2.5 V), the L6924D can also work as a quasi-pulse charger when powered from a current limited adapter such as a PV panel or a current limiting device such as the *SPV1040* step-up.

To work in this condition, set the device charging current (with R14) higher than the maximum peak current of the PV panel. During the fast-charge phase, the output voltage of the SPV1040 that supplies the L6924D drops down to the battery voltage plus the voltage drop across the power MOSFET of the charger.

In this mode, the L6924D charges the battery with the same three phases as in linear mode, but power dissipation is greatly reduced, as shown in the following figure.

Figure 7: Typical charge curve in Quasi-pulse mode



During the fast-charge phase, the output voltage of the SPV1040 (VIN of L6924D) drops down to the battery voltage (V_{BAT}) plus the voltage drop across the Power MOSFET (ΔV_{MOS}) of the charger.

Consequently, the internal MOSFET works in saturation mode with a voltage drop given by:

Equation 1

$$V_{IN} = V_{ADP} = V_{BAT} + \Delta V_{MOS}$$

where

Equation 2

$$\Delta V_{MOS} = R_{DS(on)} \times I_{LIM}$$

I_{LIM} is the current limit of the SPV1040, which depends on solar irradiation.

Neglecting the voltage drop across the charger (ΔVMOS) when the device operates in this condition, its input voltage is equal to the battery's, and therefore a very low operating input voltage (down to 2.5 V) is required. The power dissipated by the device during this phase is:

Equation 3

$$P_{CH} = R_{DS(on)} \times I_{LIM}^2$$

The advantage of the quasi-pulse charging method allows the energy harvested by few solar cells to be maximized.

The STEVAL-ISV0012V1 LEDs D1 and D2 indicate (when ON) whether the charge is in progress or is completed, respectively.

R14, and consequently I_{LIM}, must be set up according to the power provided by the PV panel at the maximum irradiation, but it is possible that D1 starts flickering (or appearing ON) at lower irradiation levels, while D2 is ON as well.

This is due to the battery charger, which tries to charge the battery at 4.2 V (or 4.1 V, depending on the V_{OPRG} setting) and I_{LIM}, but the required power can only be sustained if enough irradiation is available on the PV panel side. If the irradiation is not sufficient, the input voltage of the L6924D drops down to the battery voltage, causing battery charging to stop and D1 to turn ON. Shortly after, the voltage rises back to 4.2 V (or 4.1 V) and the battery charge starts again (D1 turns OFF).

In these low irradiation conditions the battery is charged by current packets anyway.

The plots below demonstrate the behavior in the event of low irradiation.

Figure 8: Battery charging at low irradiation

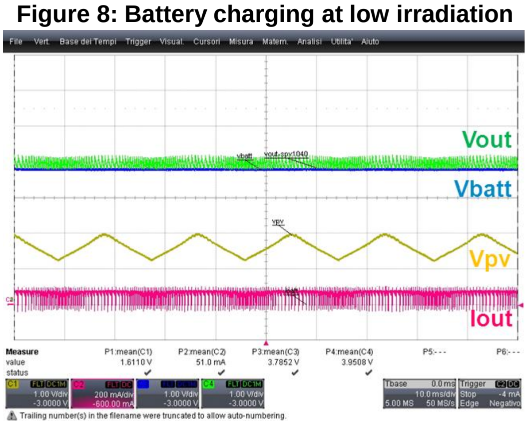
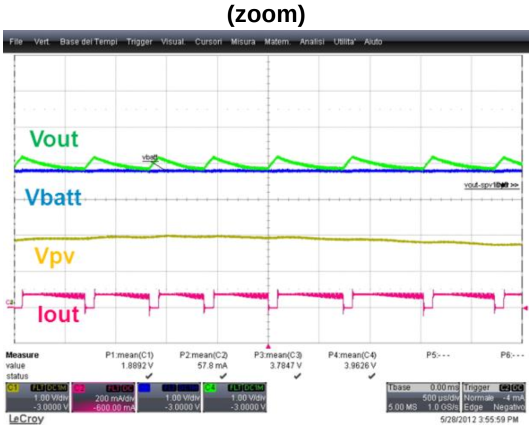


Figure 9: Battery charging at low irradiation (zoom)



The plots below show the maximum available current that can be provided to the battery charger according to the input power.

Figure 10: Maximum available current vs. Pin, 200 mW peak PV panel

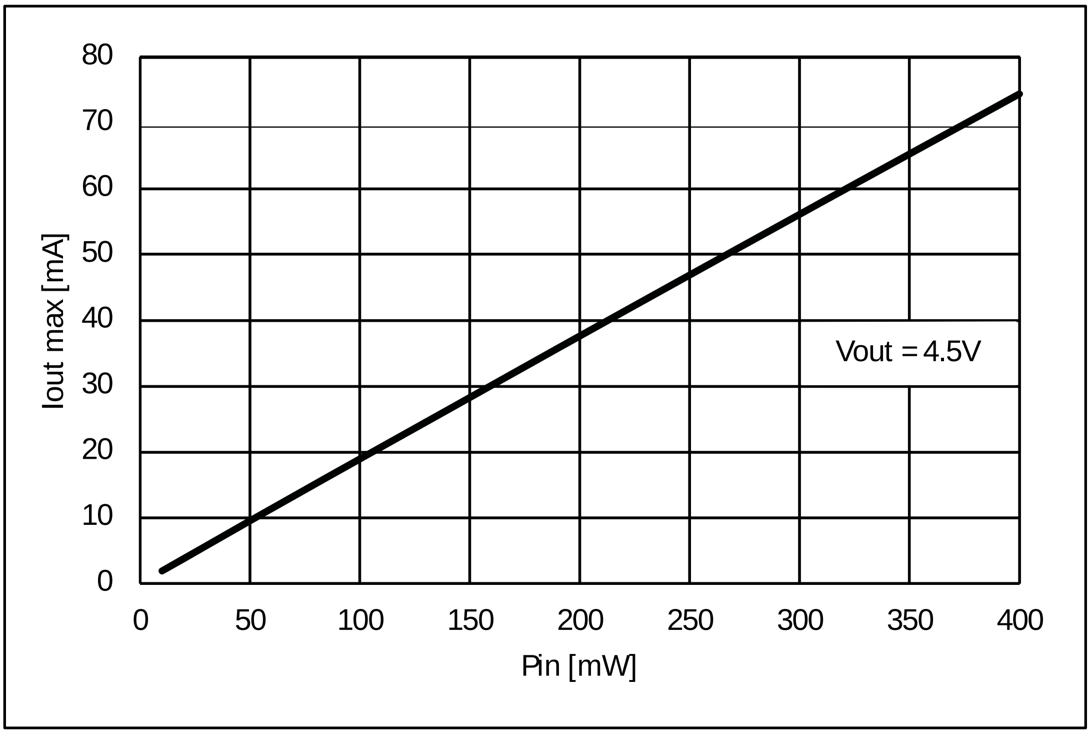
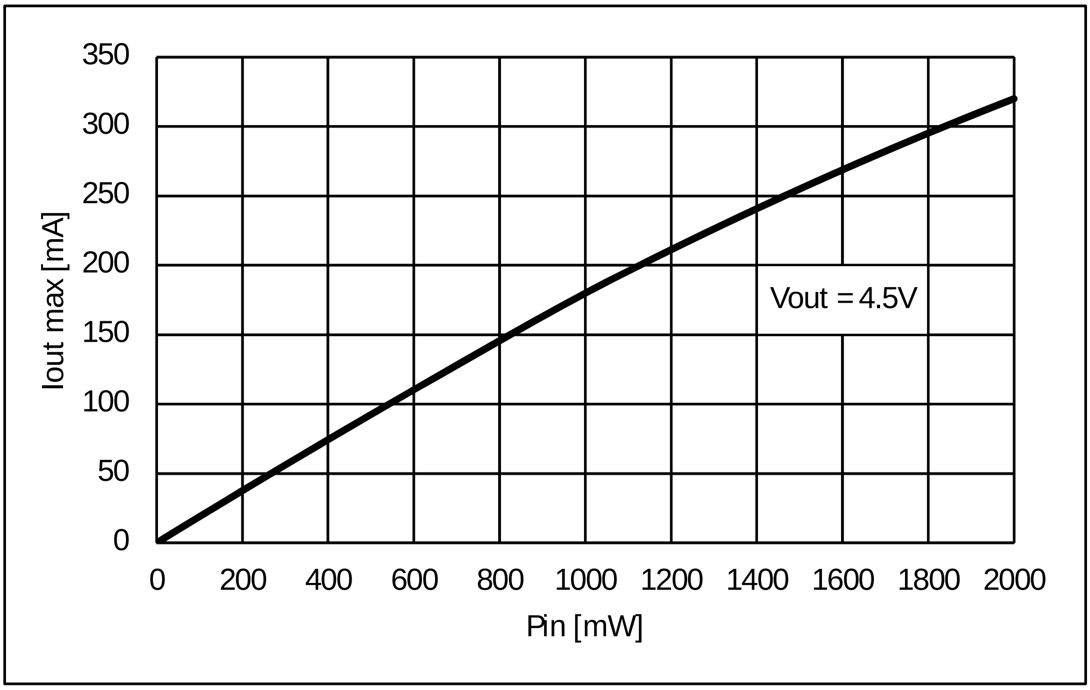


Figure 11: Maximum available current vs. Pin, 2 W peak PV panel



3 Reference design description

The set-up used for measurements is shown below.

Figure 12: Application set-up

A solar array simulator (SAS, SAS-FL05/01 from CBL Electronics) to simulate the PV module with V_{OC} = 2.5 V, I_{SC} = 210 mA, V_{mp} = 2.0 V, I_{mp} = 200 mA (@ 1000 W/m²irradiance) and a Li-Ion battery 3.7 V-700 mAh, are used. *Figure 13: "V-I and P-V plot diagrams"* shows the I-V and P-V curves generated by the SAS, obtained using a PV module analyzer (ISM490 from ISOTECH).

Figure 13: V-I and P-V plot diagrams

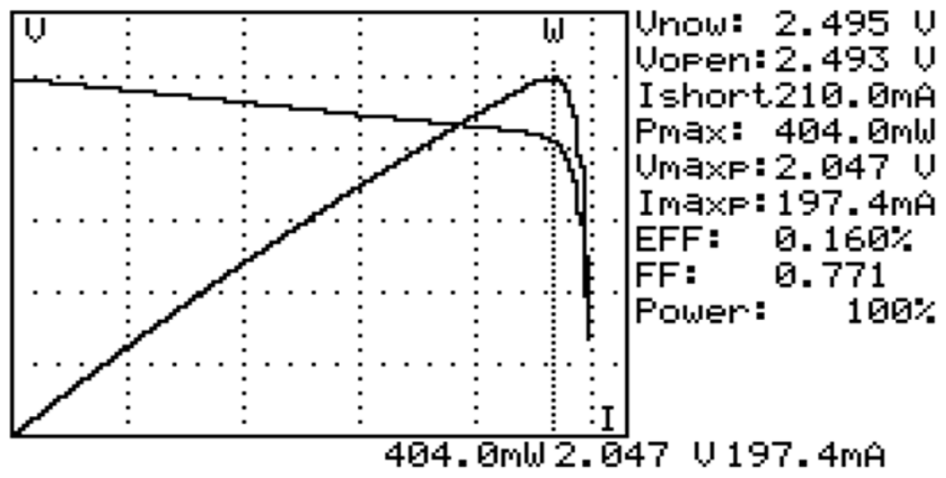


Figure 14: "Partial charge" and *Figure 15: "Full charge"* show the partial and full charge curves respectively. The partial charge curve shows charge current and voltage within a one hour time frame at full irradiation starting from a 3.4 V condition. The full charge curve shows charge current and voltage until the fully charged status is triggered, starting from a 3.4 V condition. After the one hour charge period time, the battery voltage reaches 3.8 V.

Different results can be obtained if a different PV panel and/or battery are used[a].

[a] Visit the support section on www.st.com if you require help regarding the use of different PV panels or batteries.

The average overall power efficiency is approximately 85% (94% for *SPV1040* and 90% for *L6924D*).

Figure 14: Partial charge

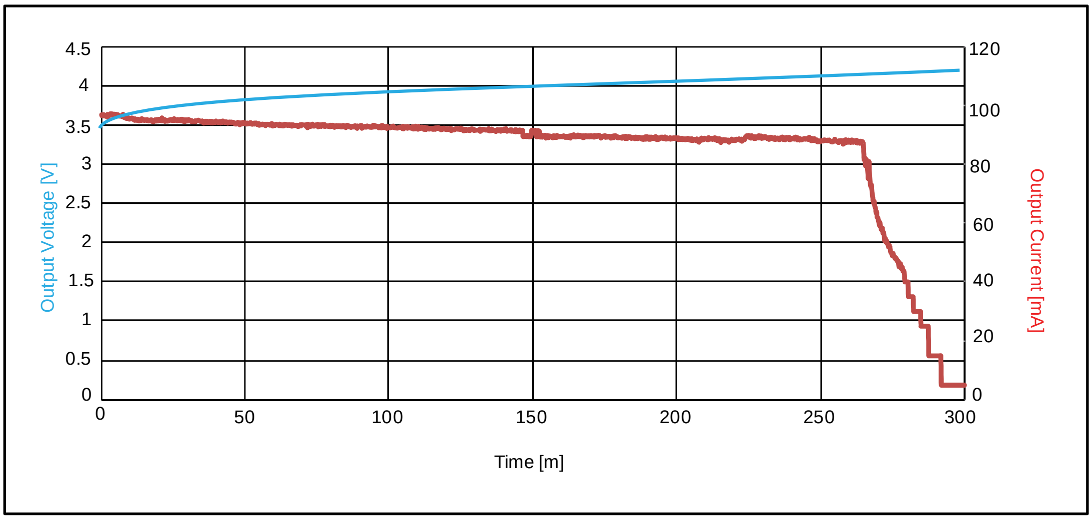
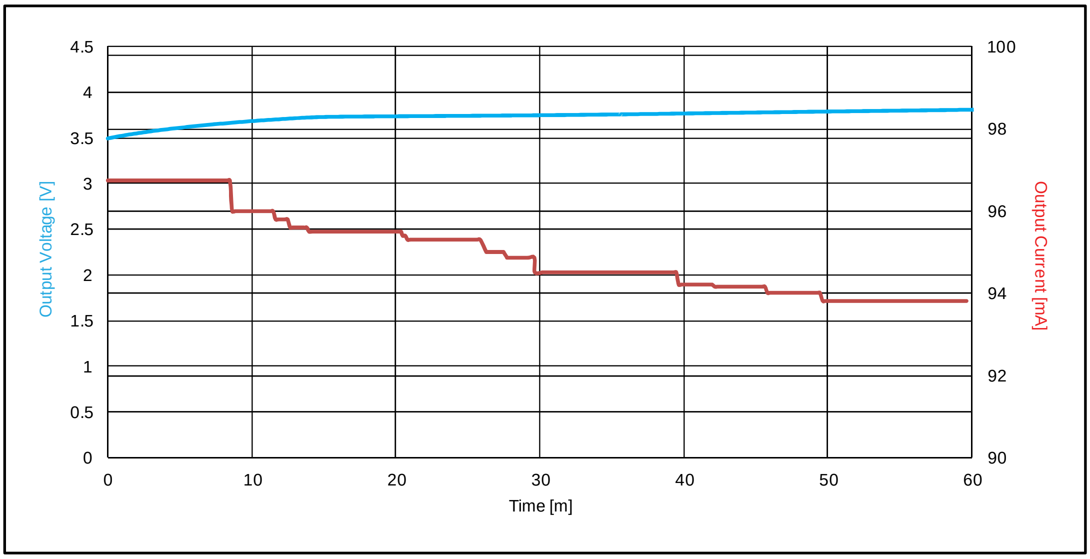


Figure 15: Full charge



4 Schematic diagrams

Figure 16: STEVAL-ISV012V1 schematic, battery charge section

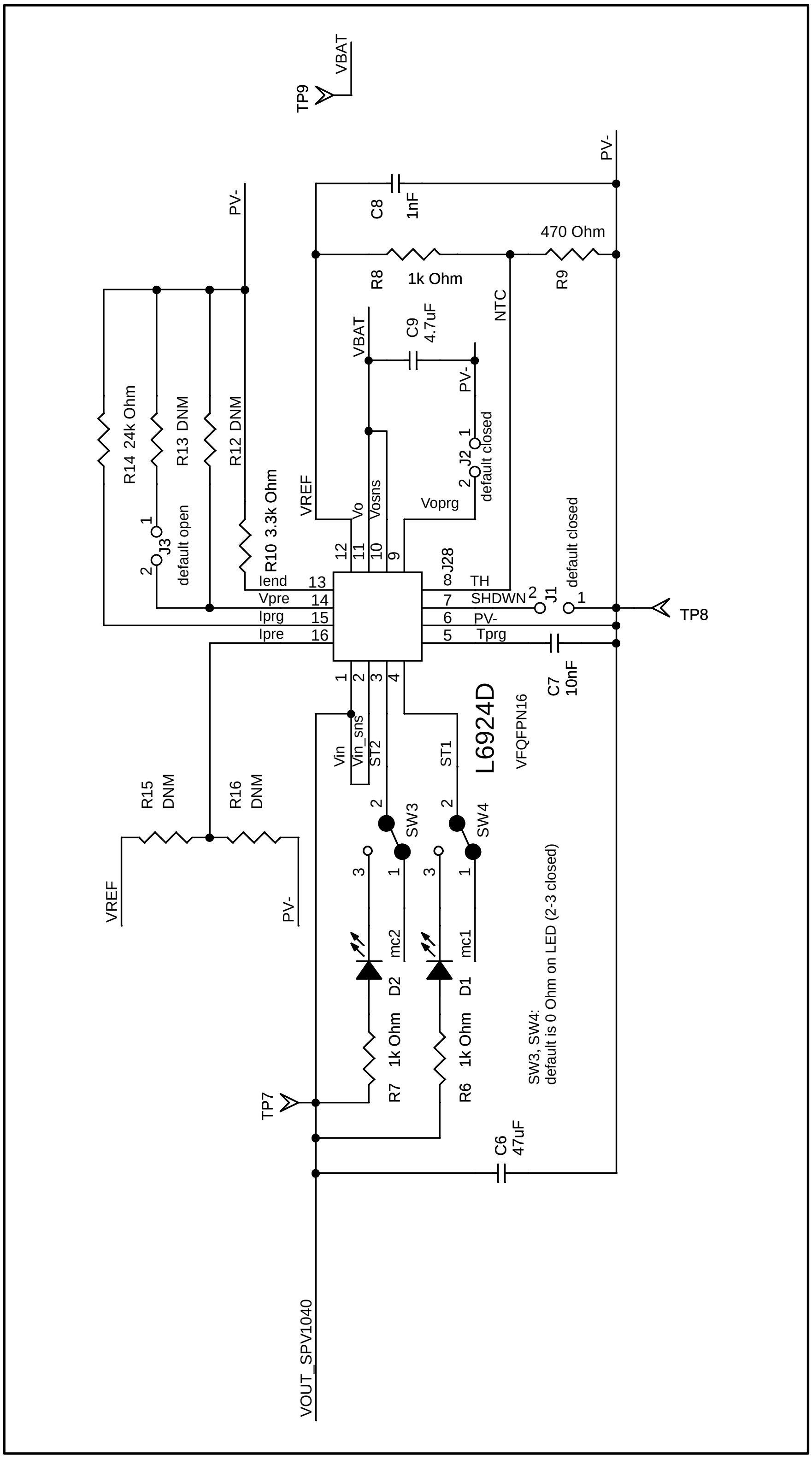
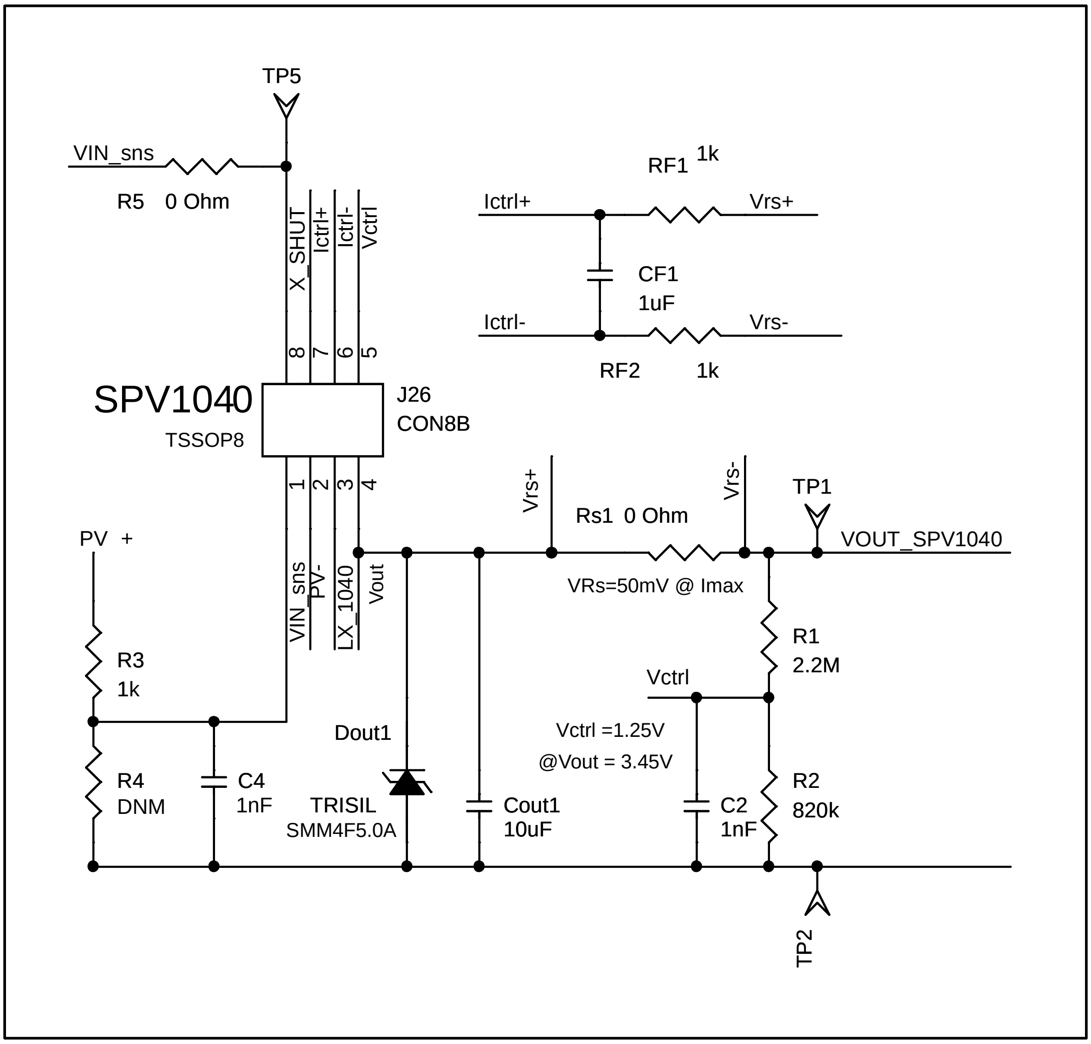


Figure 17: STEVAL-ISV012V1 schematic, solar power optimizer section



5 Bill of materials

Table 1: STEVAL-ISV012V1 bill of materials

Item	Q.ty	Ref.	Part/Value	Description	Manufacturer	Order code
1	1	PV1 (polycristalline)	400 mW, Vmp = 1.92 V; Imp = 200 mA; Voc = 2.2 V; Isc = 220 mA	Solar panel	NBSZGD	SZGD6060-4P
2	1	Cin1	47 µF, 6.3 V, 0805	Multilayer ceramic capacitor	Kemet	C0805C476M9PAC7800
3	2	C2, C4	1 nF, 50 V, 0805	Ceramic capacitors	Kemet	C0805C102K5RAC
4	1	Cout1	10 µF, 16 V, 0805	Multilayer ceramic capacitor	Kemet	C0805C106K4PAC7800
5	1	R3	1 kΩ, 0805	Resistor	Vishay	CRCW08051K00FKEA
6	1	R4	3.3 mΩ, 63M	Resistor		DNM
7	1	L1	10 µH, Isat > 1.5 A at vmp = 2 V, 2220(EIA)	Power inductor	Coilcraft	MSS7341-103ML
					EPCOS	B82442T1103K050
8	1	VRS	50 mV at Iout_max, 0805	Thick film resistor	Vishay	CRCW08050000Z0EA
9	1	R1	2.2 mΩ, 0805	Resistor	Multicomp	MCHV05WAJ0225T5E
10	1	R2	820 kΩ, 0805	Resistor	Vishay	CRCW0805820KFKEA
11	1	R5	0805	Resistor	Vishay	CRCW08050000Z0EA
12	1	J26	SPV1040, TSSOP8	High efficiency solar battery charger with embedded MPPT	ST	*SPV1040T*
13	1	Dout1	Vbr = 5 V, Vcl = 9 V, STmite Flat, SMM4F	400 W Transil™	ST	*SMM4F5.0*
14	1	J28	L6924D, VFQFPN16	Battery charger system with integrated power switch for Li-Ion/Li-Polymer	ST	*L6924D*

Item	Q.ty	Ref.	Part/Value	Description	Manufacturer	Order code
15	2	RF1, RF2	1 kΩ, 0805	Thick film resistors	Vishay	CRCW08051 K00FKEA
16	1	CF1	1 µF, 10 V, 0805	Multilayer ceramic capacitor	Murata	GRM21BR71 C105KA01L
17	2	D1, D2	SMD, 2.5 V, 25 mA, 0805	Green LED	Kingbright	KP-2012SGC
18	3	R6, R7, R8	1 kΩ, 0805	Resistors	Vishay	CRCW08051 K00FKEA
19	1	C6	47 µF, 6.3 V, 0805	Ceramic capacitors	Kemet	C0805C476M 9PAC7800
20	1	C7	10 nF, 50 V, 0805	Ceramic capacitors	Kemet	C0805C103K 5RAC
21	1	C8	1 nF, 50 V, 0805	Multilayer ceramic capacitor	Kemet	C0805C102K 5RAC
22	1	C9	4.7 µF, 0805	Ceramic capacitor	Murata	GRM21BF51 A475ZA01L
23	1	R10	3.3 kΩ	Resistor	Bourns	CR0805-FX-3301GLF
24	1	R9	470 Ω, 0805	Resistor	Bourns	CR0805-FX-4700GLF
25	1	R14	24 kΩ, 0.1 W, 0805, ± 1%	Resistor	Multicomp	C2012C0G2A 103J125AA
26	3	J1, J2, J3	Jumper100	Jumpers	Any	
27	2	SW3, SW4	0 Ω, 0805, SMD, 1/8 W	Thick film resistors	Vishay	CRCW08050 000Z0EA
28	2	J29		3-position wire to board terminal block	Phoenix Contact	1935174

6 Revision history

Table 2: Document revision history

Date	Version	Changes
11-Jun-2012	1	Initial release.
21-Mar-2013	2	Updated Figure 5: SPV1040 internal block diagram.
05-Dec-2017	3	Text and formatting changes throughout document. Updated *Section 5: "Bill of materials"*