

## STEVAL-ISV012V1: lithium-ion solar battery charger

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### Introduction

The STEVAL-ISV012V1 is a demonstration board that mounts the SPV1040 (solar energy harvester) as the input stage and the L6924D (Li-Ion battery charger) as the output stage. It targets any portable application powered by lithium-ion batteries and merges the capability of the SPV1040 to maximize the power extraction from the solar module with the linear regulation of the L6924D, to optimize the battery charge and to protect the load while reducing the power dissipation at the bottom. It is shown in [Figure 1](#).

**Figure 1. STEVAL-ISV012V1 demonstration board**



The board has been designed to charge lithium-ion and lithium-polymer batteries with  $V_{BATT\_max} = 4.1$  or  $4.2$  V and it includes a  $400\text{ mW}_{pk}$  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 as per the following guidelines:

- The PV panel can be replaced by a different one as long as  $V_{oc} < V_{BATT\_max}$  and  $I_{sc} < 1.65$  A.
- The inductor L1 can be replaced by considering that it affects the maximum peak current and that an input overcurrent limit must not be triggered.
- The maximum output current can be limited by replacing the current sensing resistor  $R_s$  ( $0\ \Omega$  by default).
- The resistor R14, which limits the charge current threshold, by default is set to 500 mA.

For further details on component selection, please refer to the section “external component selection” of the AN3319 application note. For details about SPV1040 and L6924D features please refer to the related datasheets.

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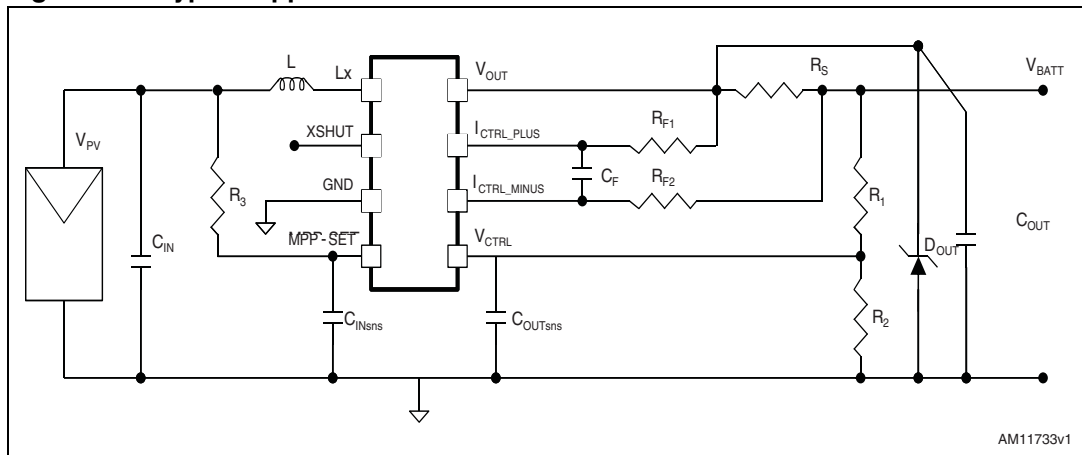
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# 1 SPV1040 operation description

The SPV1040 is a high efficiency, low power and low voltage DC-DC converter that provides a single output voltage up to 5.2 V. If combined with the L6924D, it provides the ideal solution for charging lithium battery packs by harvesting energy from a very small solar panel.

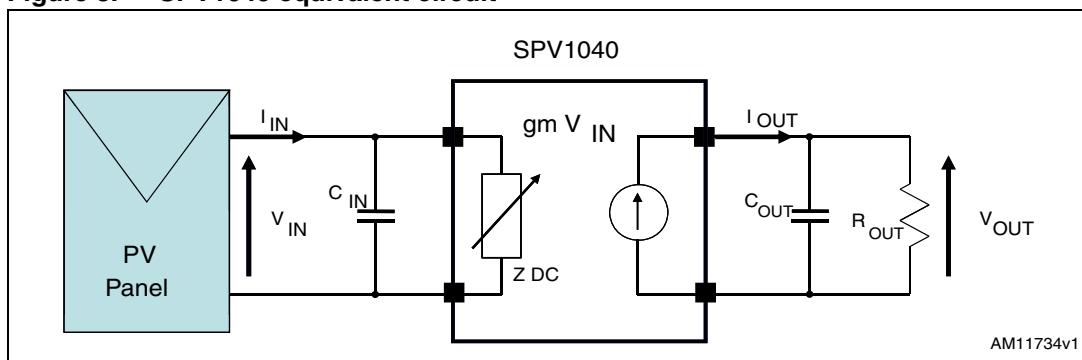
The SPV1040 is a 100 kHz fixed frequency PWM step-up converter able to maximize the energy harvested by few solar cells. thanks to the embedded MPPT algorithm which maximizes the power generated from the panel by continuously tracking its output voltage and current. The converter guarantees the safety of the overall application and its own by stopping the 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. In fact, the equivalent circuit can be seen below:

**Figure 3. SPV1040 equivalent circuit**

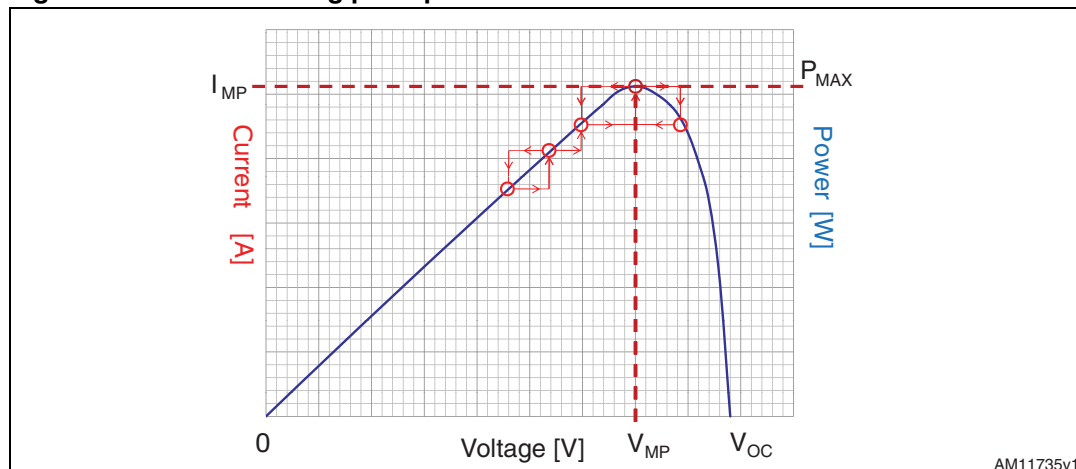


The MPPT algorithm properly sets up the DC working point by guaranteeing  $Z_{in} = Z_m$  (assuming  $Z_m$  is the impedance of the supply source). In this way, the power extracted from the supply source ( $P_{in} = V_{in} * I_{in}$ ) is maximum ( $P_m = V_m * I_m$ ).

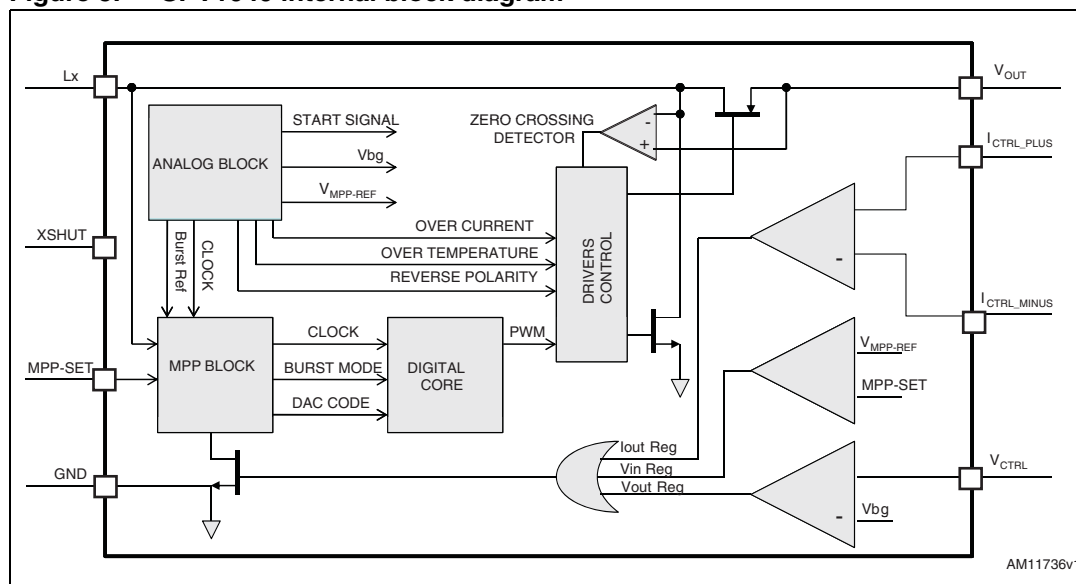
The voltage-current curve shows all the available working points of the PV panel at a given solar irradiation. The voltage-power curve is derived from the voltage-current curve by

plotting the product  $V \cdot I$  for each voltage generated. For further details of the MPPT algorithm, please refer to the SPV1040 datasheet.

**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 conditions is triggered:

- Input overcurrent protection (OVC): inductor peak current  $\leq 1.65$  A
- Overtemperature protection (OVT): internal temperature  $\leq 155$  °C
- Output voltage regulation:  $V_{CTRL}$  pin triggers the 1.25 V internal reference
- Output current limitation:  $R_s \cdot (I_{CTRL\_PLUS} - I_{CTRL\_MINUS}) \leq 50$  mV
- MPP-SET voltage  $V_{MPP\_SET} \leq 300$  mV at the startup and  $V_{MPP\_SET} \leq 450$  mV in running mode.

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

## 2 L6924D operation description

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 (the Power MOSFET, reverse blocking diode and the sense resistor) in a small VFQFPN16 3 mm x 3 mm package.

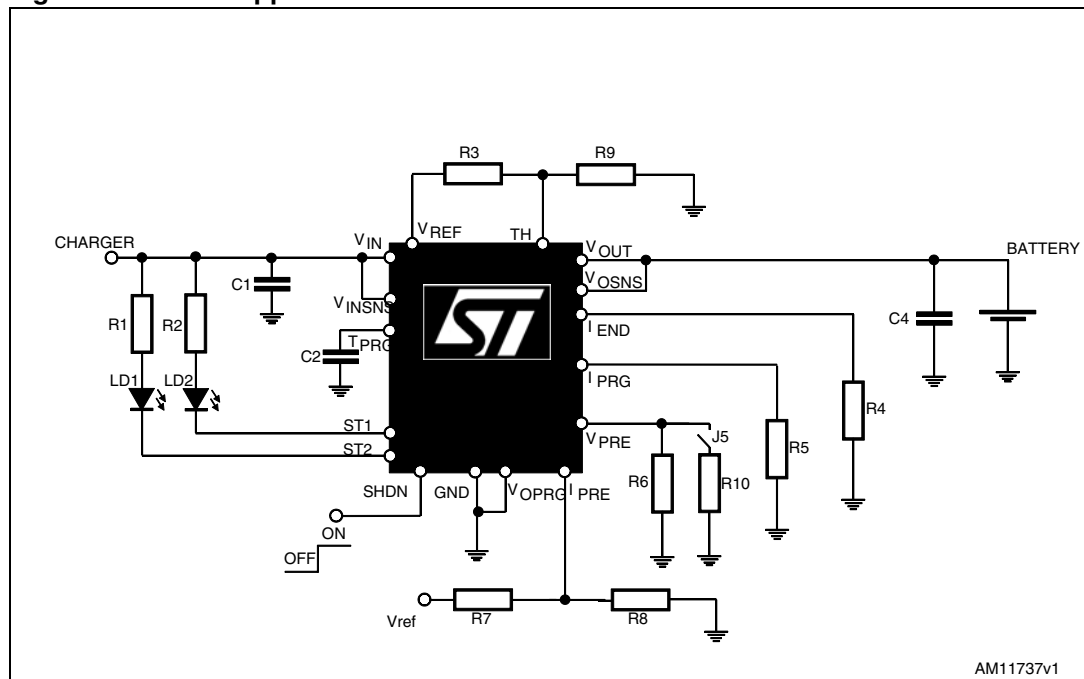
It normally works as a linear charger when powered from an external voltage regulated adapter. However, thanks to its very low minimum input voltage (down to 2.5 V) the L6924D can also work as a quasi-pulse charger when powered from a current limited adapter, dramatically reducing the power dissipation.

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 is completed.

Regardless of the charging approach, a closed loop thermal control avoids device 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



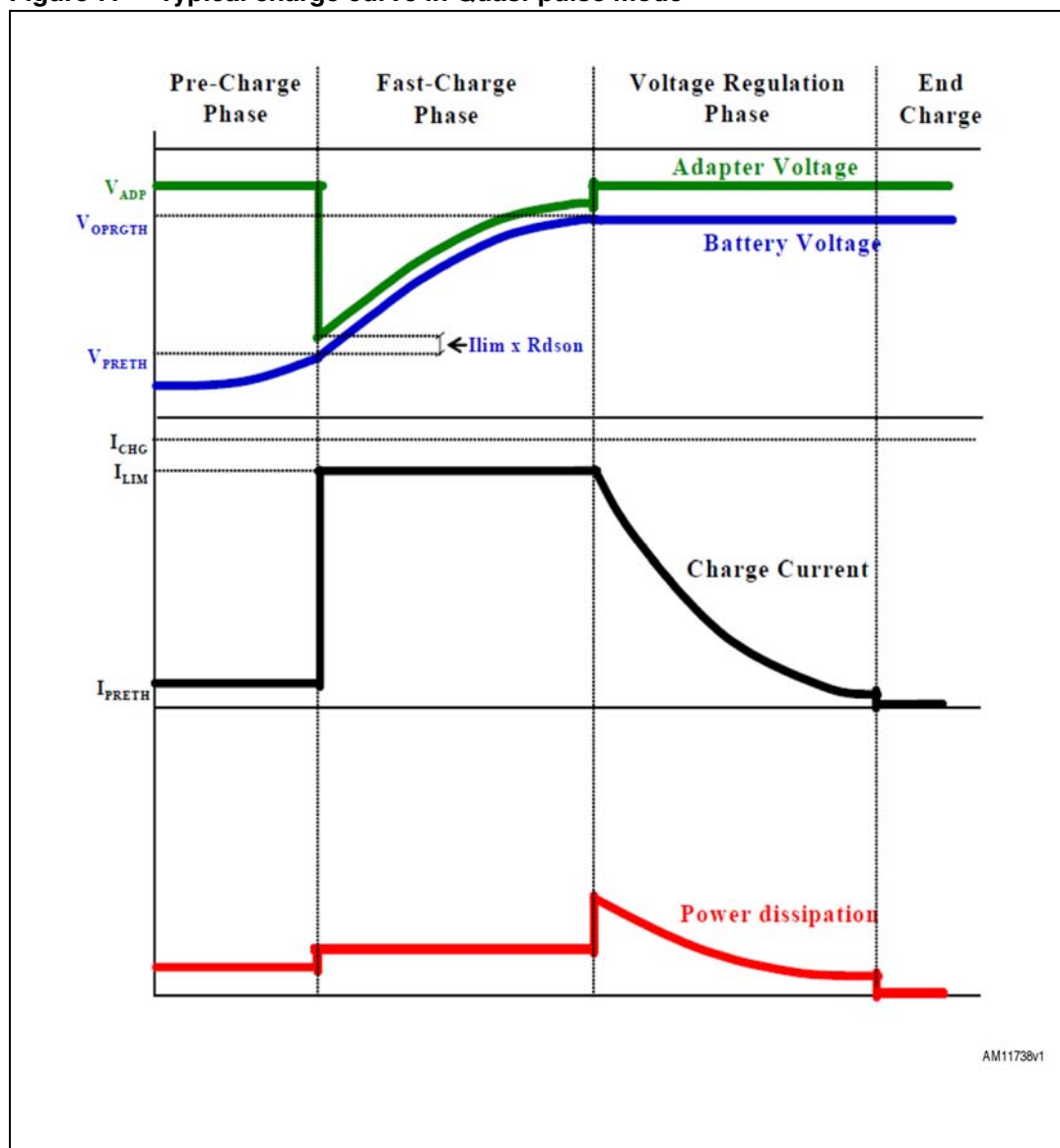
### 3 L6924D operation in solar powered applications

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 limit device such as the SPV1040 step-up.

To work in this condition, it is enough to set the device's charging current (by 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 goes 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 the power dissipation is greatly reduced, as shown in [Figure 7](#).

Figure 7. Typical charge curve in Quasi-pulse mode



During the fast-charge phase, the output voltage of the SPV1040 ( $V_{IN}$  of L6924D) goes down to the battery voltage ( $V_{BAT}$ ) plus the voltage drop across the Power MOSFET ( $\Delta V_{MOS}$ ) of the charger.

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

#### 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 ( $\Delta V_{MOS}$ ) when the device operates in this condition, its input voltage is equal to the battery one, and so 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.

Note that the STEVAL-ISV0012V1 mounts two LEDs, D1 and D2, which 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 at lower irradiances D1 starts flickering (or appearing ON), 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 be sustained only if enough irradiation is available at the PV panel side. If the irradiation is not sufficient, the input voltage of the L6924D drops down to the battery voltage, causing the battery charging to stop and D1 turns 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 show behavior in the case of low irradiation:



Figure 8. Battery charging at low irradiation

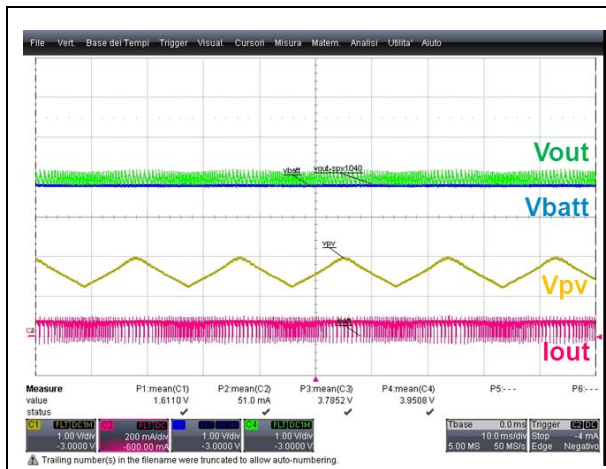
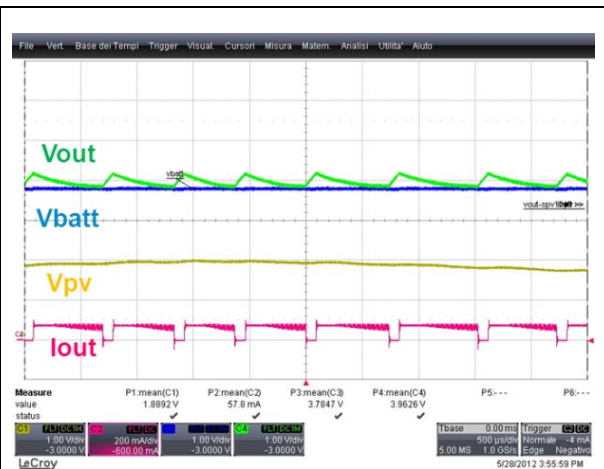


Figure 9. Battery charging at low irradiation, zoomed in



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

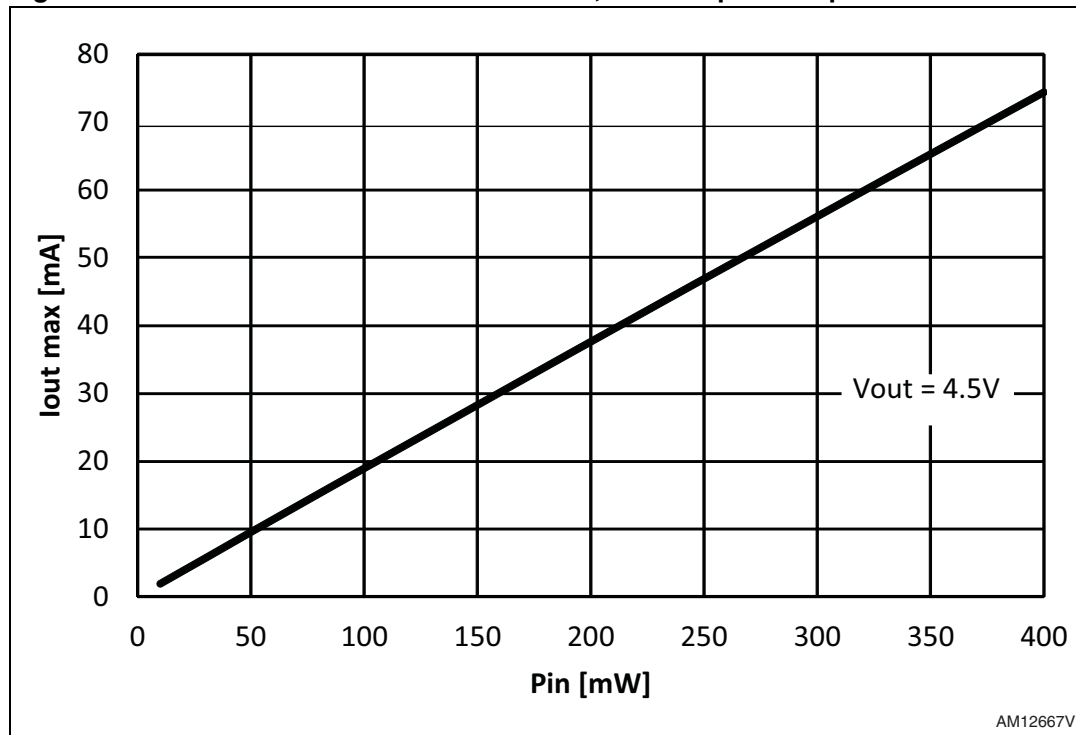
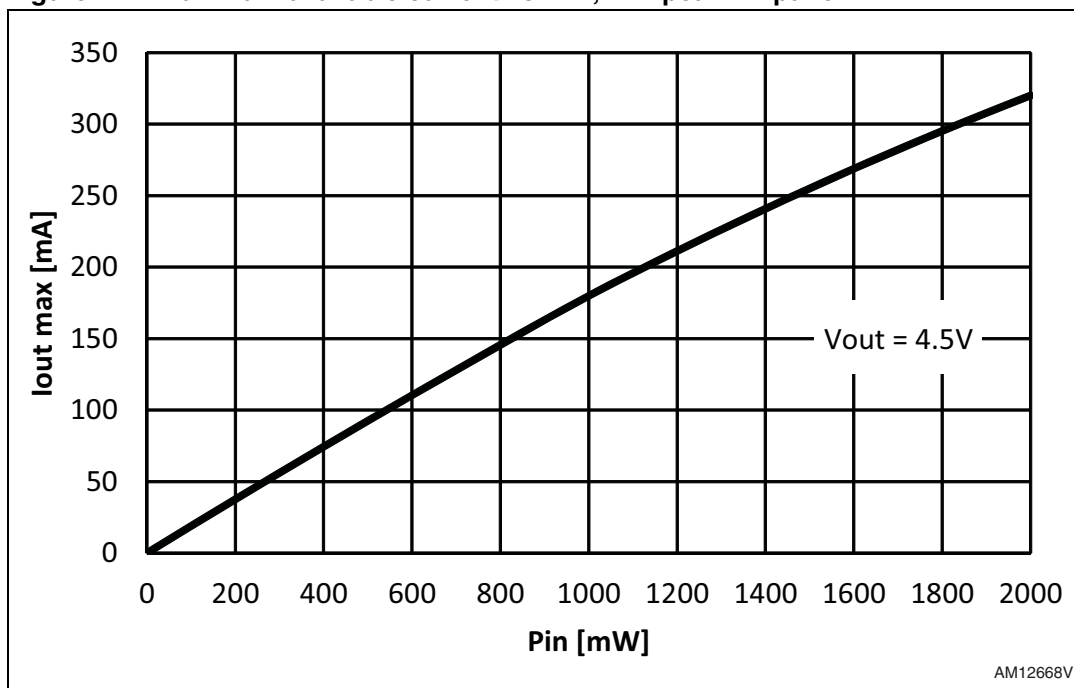


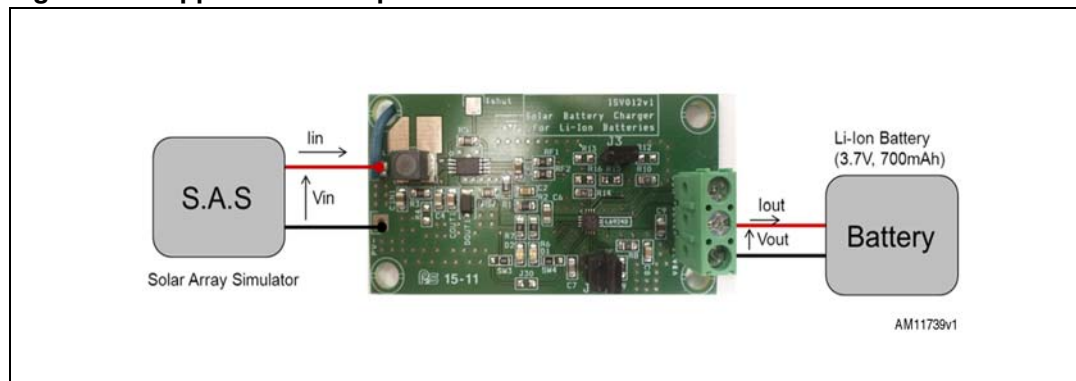
Figure 11. Maximum available current vs. Pin, 2 W peak PV panel



## 4 Reference design description

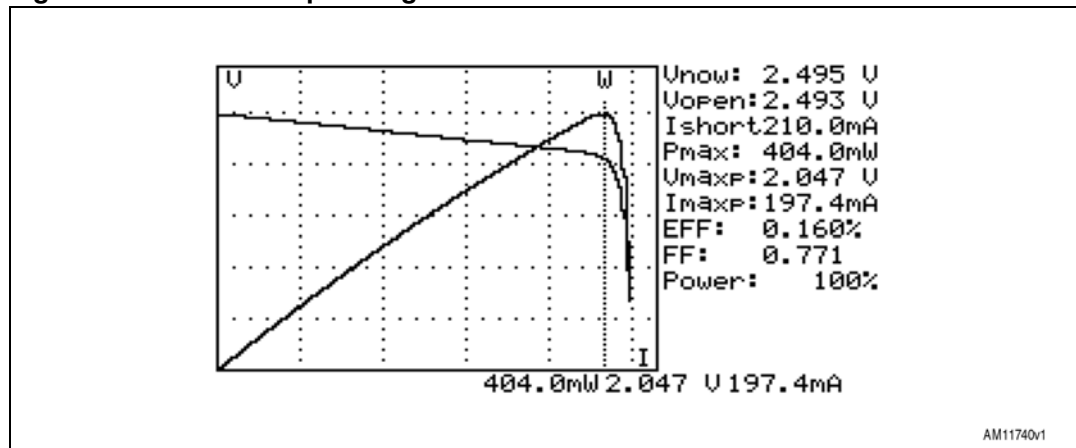
The set-up environment used for the measurement campaign is shown below.

**Figure 12. Application set-up**



A solar array simulator (SAS, SAS-FL05/01 from CBL Electronics) to simulate the PV module with  $V_{oc} = 2.5\text{ V}$ ,  $I_{sc} = 210\text{ mA}$ ,  $V_{mp} = 2.0\text{ V}$ ,  $I_{mp} = 200\text{ mA}$  (@  $1000\text{ W/m}^2$  irradiance) and a Li-Ion battery 3.7 V-700 mAh, are used. *Figure 13* shows the I-V and P-V curves generated by the SAS, obtained using a PV module analyzer (ISM490 from ISO-TECH):

**Figure 13. V-I and P-V plot diagrams**



*Figure 14* and *15* 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 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. If any help is required regarding the use of different PV panels and/or batteries, please go to the support area at [www.st.com](http://www.st.com).

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

Figure 14. Partial charge

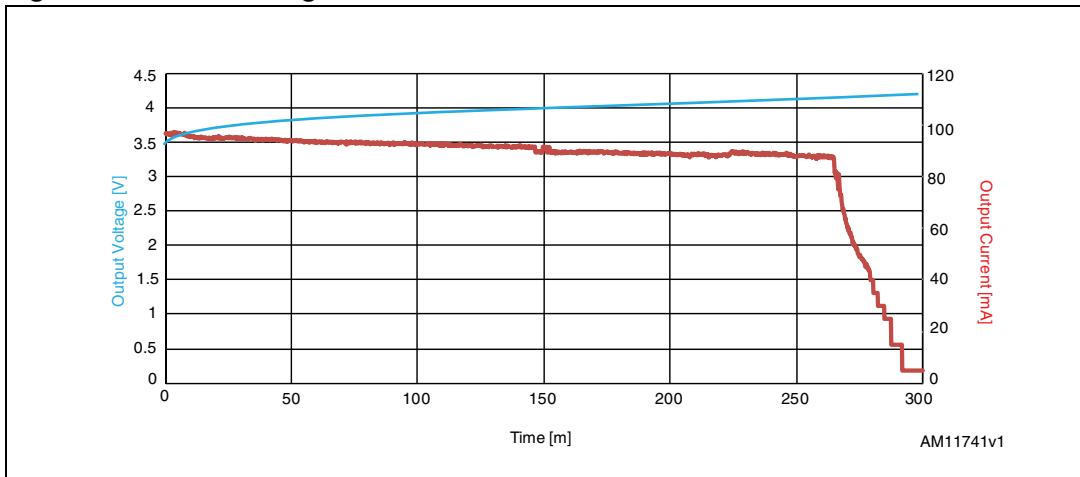
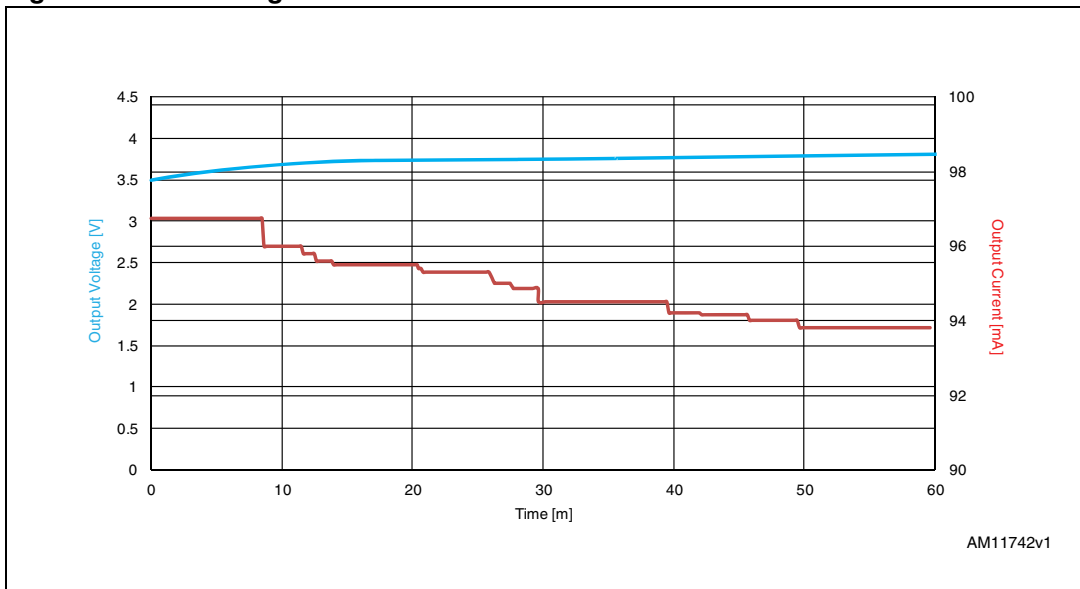


Figure 15. Full charge



# 5 Schematic and bill of material

The schematic, bill of material and Gerber files can be downloaded from [www.st.com](http://www.st.com).

**Figure 16. STEVAL-ISV012V1 schematic, battery charge section**

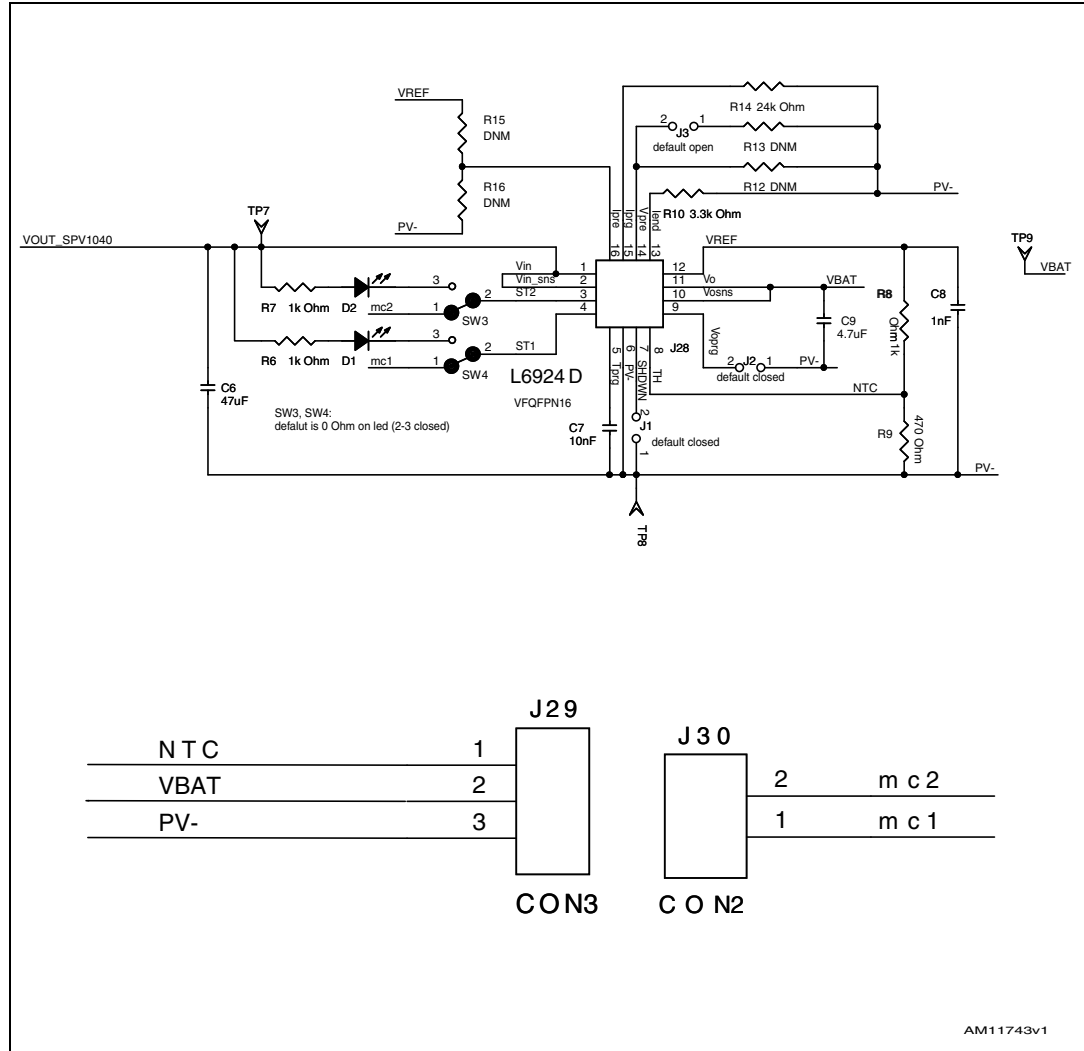


Figure 17. STEVAL-ISV012V1 schematic, solar power optimizer section

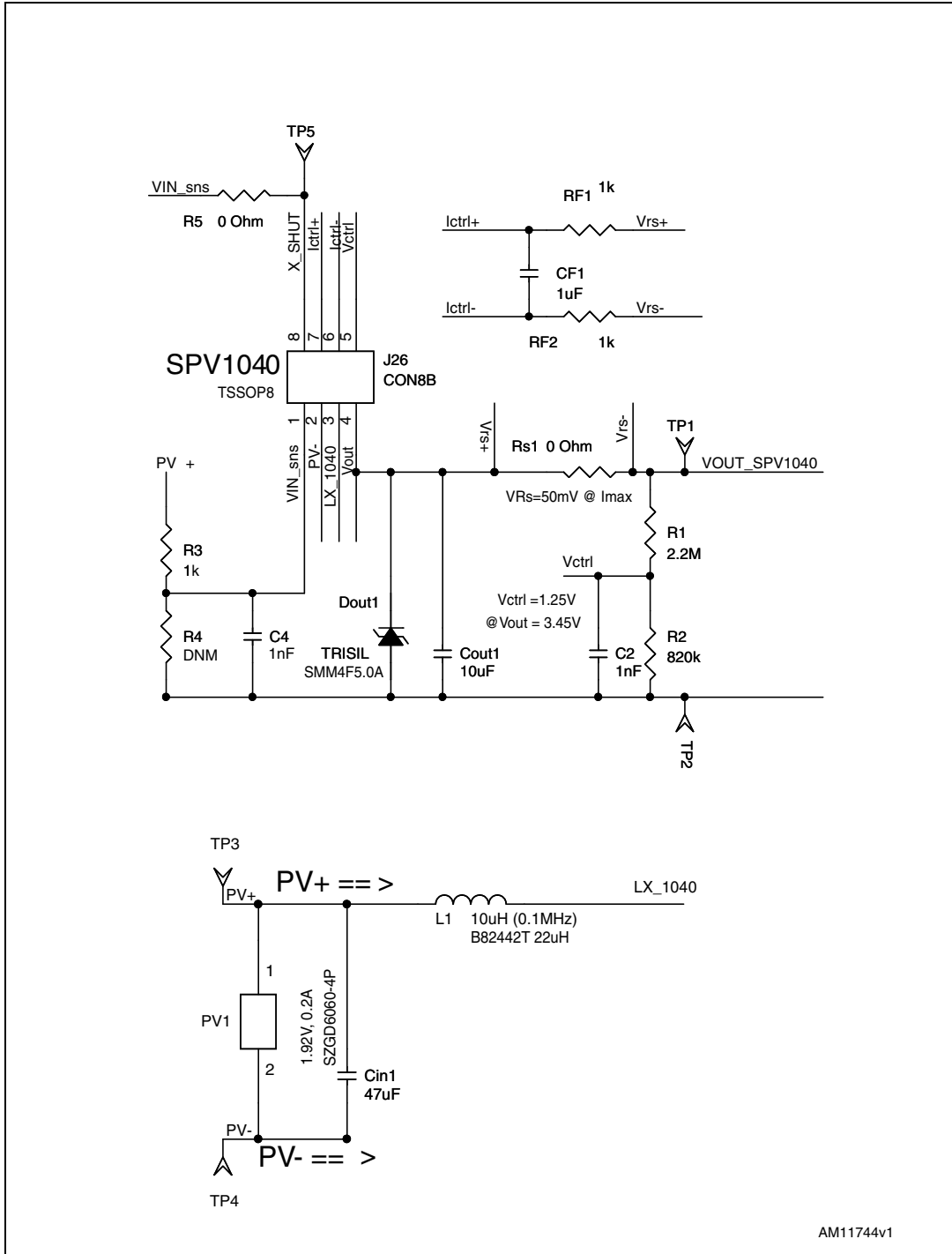


Table 1 shows the STEVAL-ISV012V1 list of components.

Table 1. BOM

Item	Quantity	Reference	Value	Voltage current	Package	Manufacturer	Manufacturer code
1	1	PV1 <sup>(1)</sup>	400 mW	Vmp:1.92 V; Imp:200 mA; Voc:2.2 V; Isc:220 mA		NBSZGD	SZGD6060-4P
2	1	Cin1	47 $\mu$ F	6.3 V	0805	KEMET	C0805C476M9PAC7800
3	1	C2	1 nF	50 V	0805	KEMET	C0805C102K5RAC
4	1	C4	1 nF	50 V	0805	KEMET	C0805C102K5RAC
5	1	Cout1	10 $\mu$ F	16 V	0805	KEMET	C0805C106K4PAC7800
6	1	R3	1 k $\Omega$		0805	VISHAY	CRCW08051K00FKEA
7	1	R4	DNM (3.3 M $\Omega$ )		63M		
8	1	L1	10 $\mu$ H	Isat > 1.5 A @vmp =2 V	2220(EIA)	Coilcraft EPCOS	MSS7341-103ML_ B82442T1103K050
9	1	VRS	0	50 mV @Iout_max	0805	VISHAY	CRCW08050000Z0EA
10	1	R1	2.2 M $\Omega$		0805	MULTICOMP	MCHV05WAJ0225T5E
11	1	R2	820 k $\Omega$		0805	VISHAY	CRCW0805820KFKEA
12	1	R5	0		0805	VISHAY	CRCW08050000Z0EA
13	1	J26	SPV1040		TSSOP8	STM	SPV1040T
14	1	Dout1	SMM4F5.0	Vbr = 5 V, Vcl = 9 V	STmite flat	STM	SMM4F5.0
15	1	J28	L6924D		MLPD 4x4	STM	L6934D
15	2	RF1, RF2	1 k $\Omega$		0805	VISHAY	CRCW08051K00FKEA
17	1	CF1	1 $\mu$ F	10 V	0805	Murata	GRM21BR71C105KA01L
18	2	D1, D2	SMD LED	2.5 V, 25 mA	0805	Kingbright	KP-2012SGC
20	3	R6, R7, R8	1 k $\Omega$		0805	VISHAY	CRCW08051K00FKEA
23	1	C6	47 $\mu$ F	6.3 V	0805	KEMET	C0805C476M9PAC7800
24	1	C7	10 nF	50 V	0805	KEMET	C0805C103K5RAC
25	1	C8	1 nF	50 V	0805	KEMET	C0805C102K5RAC
26	1	C9	4.7 $\mu$ F		0805	Murata	GRM21BF51A475ZA01L
27	1	R10	3.3 k $\Omega$		0805	BOURNS	CR0805-FX-3301GLF
28	1	R9	470 $\Omega$		0805	BOURNS	CR0805-FX-4700GLF
29	1	R14	24 k $\Omega$		0805	MULTICOMP	MC 0.1W 0805 1% 24K

Table 1. BOM (continued)

Item	Quantity	Reference	Value	Voltage current	Package	Manufacturer	Manufacturer code
30	3	J1, J2, J3			Jumper100		
33	2	SW3; SW4	0 Ohm		0805	VISHAY	CRCW08050000Z0EA
34	1	J29	3-pole connectors		Phoenix Contact	1935174	

1. Polycrystalline.



# 6 Layout

Figure 18. STEVAL-ISV012V1 PCB top view

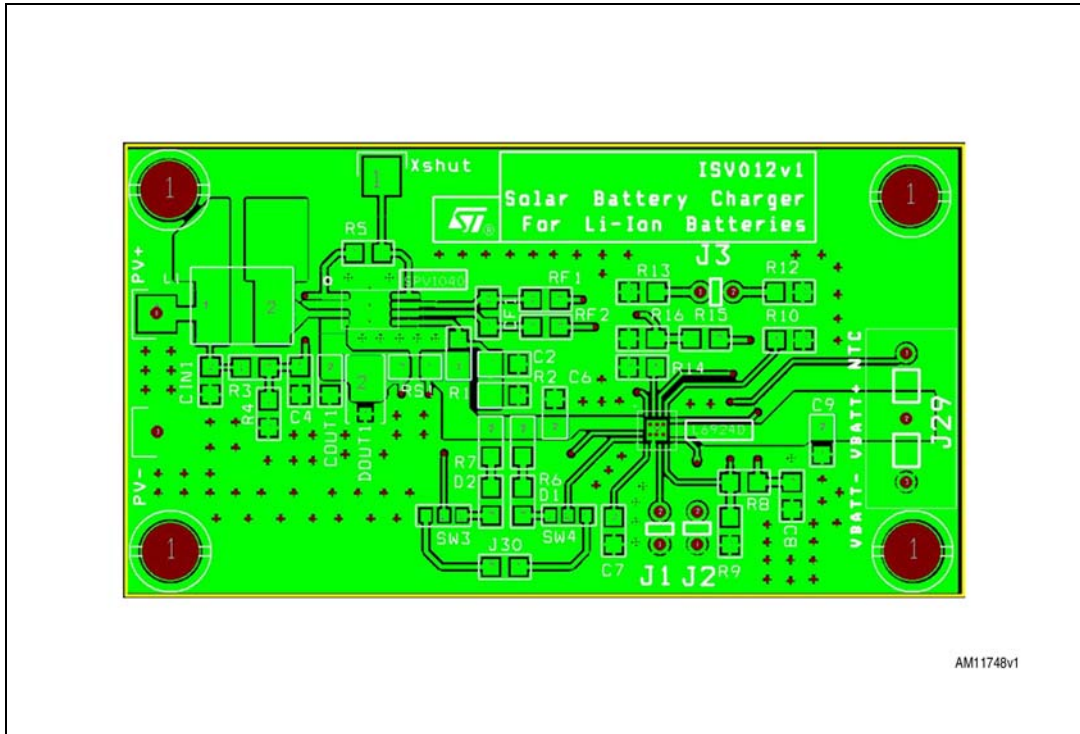
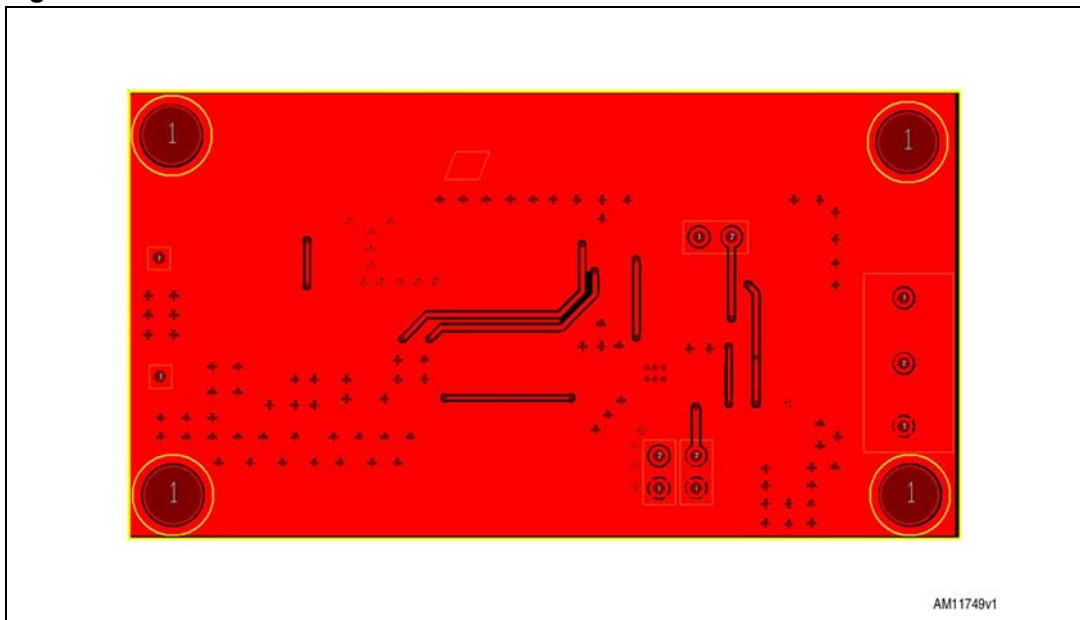


Figure 19. STEVAL-ISV012V1 PCB bottom view



## 7 Revision history

**Table 2. Document revision history**

Date	Revision	Changes
11-Jun-2012	1	Initial release.

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