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](image)

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

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

- The PV panel can be replaced as long as $V_{\text{OC}} < V_{\text{BATT, max}}$ and $I_{S} < 1.65$ A.
- The inductor $L_1$ 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 $R_{14}$, which limits the charge current threshold (500 mA by default).

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*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.

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

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 \( (P_{in} = V_{in} \times I_{in}) \) is maximum \( (P_m = V_m \times I_m) \).
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.

Figure 4: MPPT working principle

![MPPT working principle diagram]

Figure 5: SPV1040 internal block diagram

![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: Rs * (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.

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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 (\Delta V_{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**

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

$L_{LIM}$ 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'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.

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/m² irradiance) 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.

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* 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

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<td>CON8B</td>
</tr>
<tr>
<td>R5</td>
<td>0 Ohm</td>
</tr>
<tr>
<td>R3</td>
<td>1k</td>
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<td>1nF</td>
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<td>R1</td>
<td>2.2M</td>
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<tr>
<td>R2</td>
<td>820k</td>
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<tr>
<td>C2</td>
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<td>VRs</td>
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Notes:
- VIN_sns: Input voltage
- TP5: Test point
- X Shock: Shock test point
- RS: Resistance
- VOUT_SPV1040: Output voltage
- TRISIL: Tristate output
- SMM4F5.0A: Package type
- Dout1: Diode output
- Cout1: Capacitor output
- RS1: Resistance
- VRs: Voltage regulator
- RF1: Resistor
- CF1: Capacitor
- RF2: Resistor
- TP1, TP2: Test points
- TRIP: Test point
- Ohm: Ohm symbol
- mV: Millivolt symbol
- uF: Microfarad symbol
- nF: Nanofarad symbol
- k: Kilohm symbol
- M: Megohm symbol

Legend:
- ( ) : Element symbol
- ( ) : Element value
- ( ) : Element symbol
- ( ) : Element value
## 5 Bill of materials

Table 1: STEVAL-ISV012V1 bill of materials

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<th>Description</th>
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<th>Order code</th>
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<td>PV1</td>
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<td>400 mW, Vmp = 1.92 V; Imp = 200 mA; Voc = 2.2 V; Isc = 220 mA</td>
<td>Solar panel</td>
<td>NBSZGD</td>
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<td>2</td>
<td>1</td>
<td>Cin1</td>
<td>47 µF, 6.3 V, 0805</td>
<td>Multilayer ceramic capacitor</td>
<td>Kemet</td>
<td>C0805C476M9PAC7800</td>
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<tr>
<td>3</td>
<td>2</td>
<td>C2, C4</td>
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<td>Ceramic capacitors</td>
<td>Kemet</td>
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<td>SPV1040T</td>
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## 6 Revision history

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