AN3401
Application Note

SPV1001/SPV1002 performance evaluation in a typical photovoltaic application

Introduction

The SPV1001 and SPV1002 are system-in-package solutions for photovoltaic applications, designed to increase system efficiency by implementing a bypass function through a power MOSFET transistor instead of a conventional Schottky diode.

The SPV1002 differs from the SPV1001 in having a lower R_{DSon}.

This application note provides an evaluation of the performance comparison between the SPV100x and two standard Schottky diodes, in order to supply proper guidelines for the correct use of both devices.

Contents

1 Application overview

The photovoltaic effect allows each PV cell to generate current once irradiated. Therefore, the PV cell can be represented as a current generator, whose voltage and current generated depend on the cell technology, cell size, and irradiation level.

Typically, the voltage provided by a single PV cell is too low for most of the applications; so far, their connection in series is preferred. For this reason, PV panels are assembled by connecting in series a proper number of PV cells.

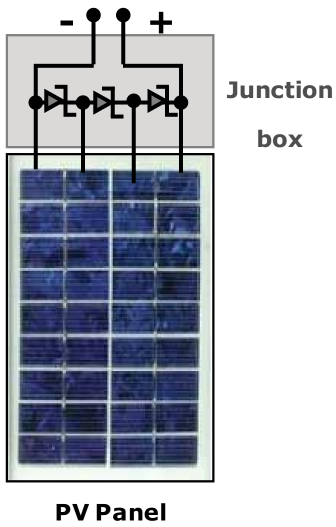
In optimal conditions the PV cells of a PV panel are equally irradiated and generate the same current, assuming negligible the spread among each PV cell.

Due to topological constraints, even if only one PV cell on the panel is partially shaded, the whole series operates at the lowest current level forced by the shaded PV cell.

Therefore, shaded cells behave like a load and the current generated from the fully irradiated cells can cause them to overheat (Hot spot) or in some cases, also lead to permanent damage.

In order to prevent these events, the series of cells of a PV panel are arranged in strings and a bypass device is connected in parallel to each string, as shown in *Figure 1*.

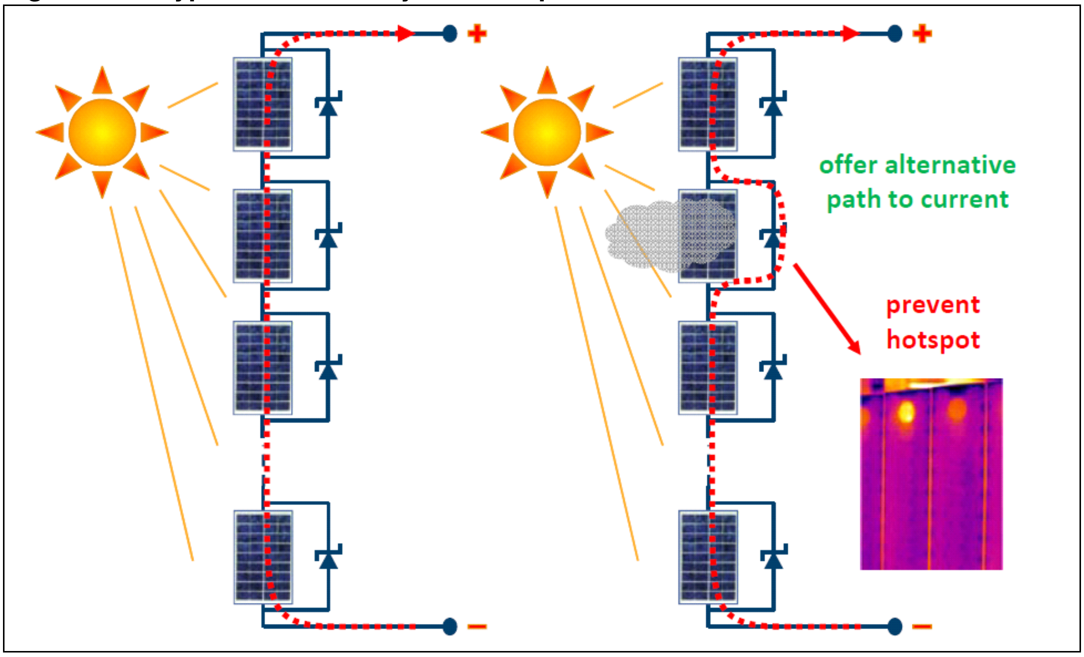
Figure 1. Bypass diodes internal connection



The following is a brief list of the main requirements of the bypass devices:

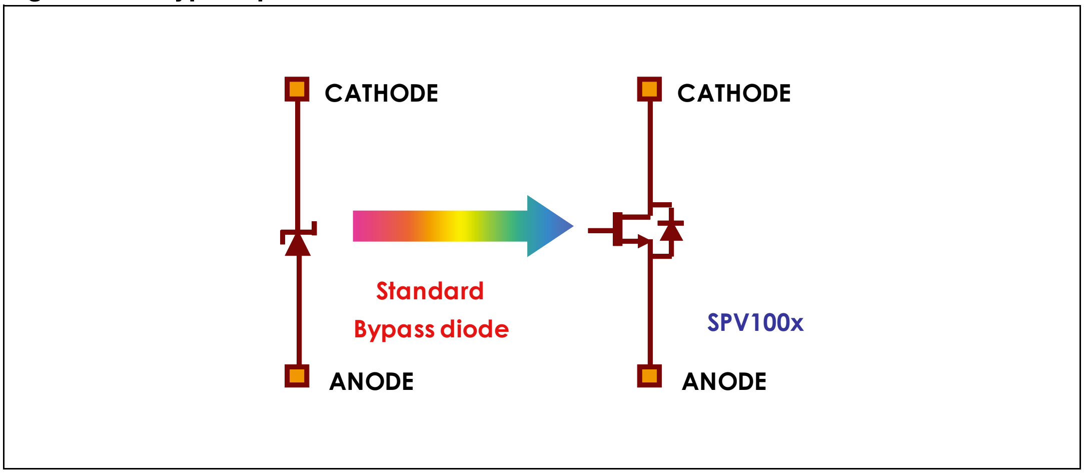
- To prevent the hot spot issue, bypass devices are connected in parallel to the cell string
- During normal operation (no shadows) the reverse leakage current must be very low
- When the cells are shaded the voltage drop must be very low.

Figure 2. Bypass functionality in series panels



The SPV100x is a two-pin device like a standard diode which, being based on power MOSFET technology, has very low reverse leakage current and very low forward voltage drop. Details on the operating mode of the SPV100x can be found in the related datasheet.

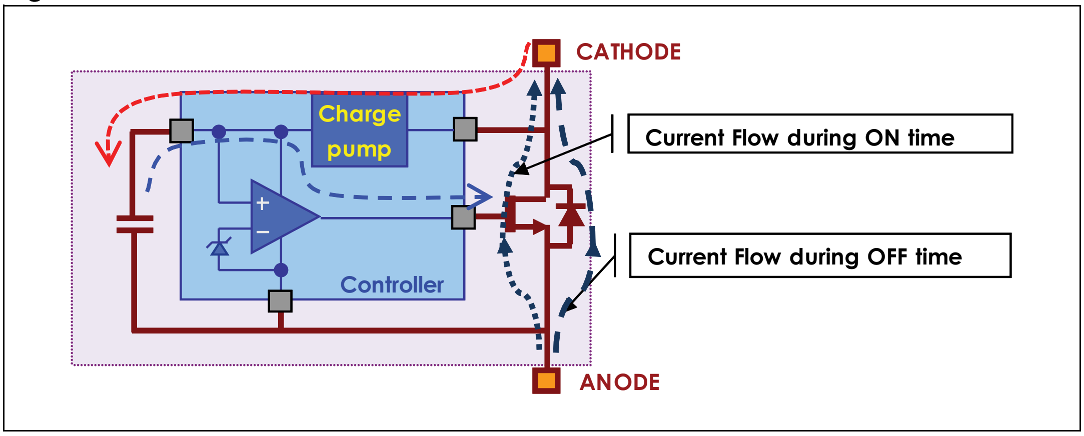
Figure 3. Bypass pin connection



2 SPV100x functionalities

The SPV100x consists of a power MOSFET transistor properly controlled by a gate driver + charge pump + tank capacitor system, such as that explained in *Figure 4*:

Figure 4. SPV100x internal architecture

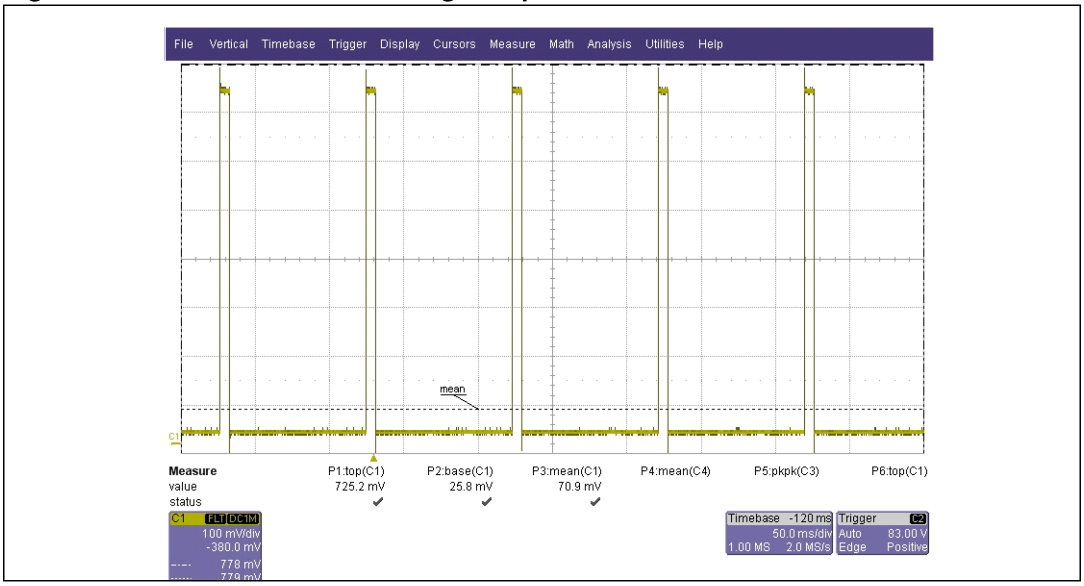


This architecture allows the following functionalities to be performed:

- To charge the integrated tank capacitor during the power MOSFET OFF time (T_{off}), boosting, with a charge pump, the voltage drop on the body diode of the power MOSFET itself.
- To drive the gate of the power MOSFET with the charge previously stored in the tank capacitor during the ON time (T_{on}).

So, the forward voltage drop between anode (source) and cathode (drain) terminals during the MOSFET switching, is shown in *Figure 5* below:

Figure 5. SPV100x forward voltage drop



3 Operating modes: forward and reverse

In forward mode the average voltage drop between anode (source) and cathode (drain) (V_{ak}) is:

Equation 1

$$V_{ak} = \frac{V_{ak_{off}} \cdot T_{off} + V_{ak_{on}} \cdot T_{on}}{T}$$

with $T = T_{on} + T_{off}$.

During the ON time the voltage drop is:

Equation 2

$$V_{ak_{on}} = R_{ds_{ON}} \cdot I_{ak}$$

While in the OFF time the voltage drop is equal to the MOSFET body diode voltage drop.

The average power is calculated using the relation:

Equation 3

$$P_{ak} = V_{ak} \cdot I_{ak}$$

In reverse mode the leakage current results from the standard MOSFET value:

$I_r < 1\ \mu A$ @ $T_j = 25\ °C$

$I_r < 10\ \mu A$ @ $T_j = 125\ °C$

4 Thermal runaway

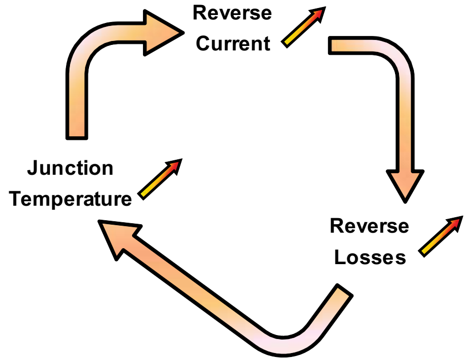
If the application is not properly designed in terms of heat dissipation, Schottky diodes can go into thermal runaway. This phenomenon permanently damages the diode, which works like short-circuit. As the SPV100x is based on MOSFET technology, it is free from the above mentioned phenomenon.

Normally, Schottky diodes with lower forward losses, have higher leakage current and so they are more sensitive to thermal runaway; for this reason the correct design of the application comes also from a trade-off between forward voltage drop and leakage current.

When the diode is in forward mode the temperature increases due to the high power dissipation, while, when it goes into reverse polarity it can have a relatively high leakage current due to the high temperature coming from the previous condition.

If the power losses generated from the leakage current are higher than those in forward mode, then the diode goes into thermal runaway until permanent damage occurs.

Figure 6. Thermal runaway positive loop



Therefore, in all the photovoltaic applications, the use of Schottky diodes, as the bypass device, may be dangerous because of the risk of thermal runaway.

During forward mode, the forward current (I_{ak}) and the forward voltage (V_{ak}) define the junction temperature (T_j):

Equation 4

$$T_j = T_a + R_{thJA} \cdot (V_{ak} \cdot I_{ak})$$

where R_{thJA} is the junction to ambient thermal resistance.

During the fast switching of the diode from forward to reverse mode, the junction temperature, due to the preceding forward mode, stays continuos and determines the leakage current (I_{rev}) related to the reverse voltage V_{rev}. This leakage current determines the new junction temperature trend.

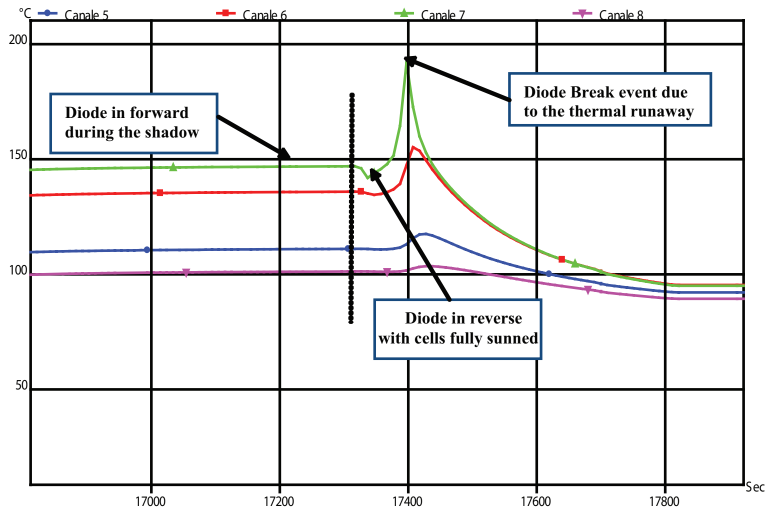
This variation trend, between the initial junction temperature (due to forward mode) and the new one (due to reverse mode), gives the Tj variation and the rotation sense that can be seen in *Figure 6.*

Experimental results can confirm that:

The stability can be guaranteed only if P_forward > P_reverse @ t_change

In *Figure 7* the details for the temperature increase that destroys the device is shown.

Figure 7. Thermal runaway detail



5 Application information

Typically, standard panels are split into three different cell groups (strings) and each one needs a bypass device.

In order to test the devices, such as they are already used in the field application, a dedicated PCB has been realized. Its size is suitable for many junction box dimensions, with three separated heat sinkers for each bypass device, and thermal vias through the two layers. Layer thickness is 35 µm.

The PCB image is shown in *Figure 4* and the sizes for the 3 heat sinkers are:

Left --> 10.0 cm^2;

Central --> 12.5 cm^2;

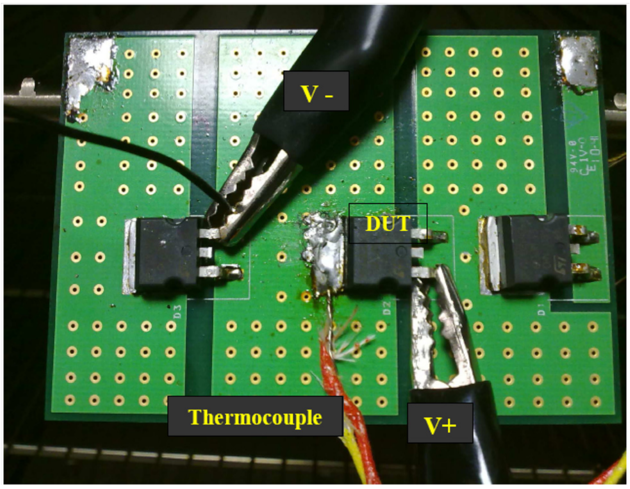
Right --> 10.5 cm^2

Different characterizations have been carried out in order to evaluate the device performance in terms of current capabilities, heat power dissipation, and average voltage drop, in four different operative conditions.

1. Device only, without any heat sinker @ oven temperature.
2. Just one device soldered on the PCB @ ambient temperature.
3. Three devices soldered on the PCB, at the temperature defined by IEC 61215 procedures (@ 85 °C).
4. The same as point 3 but at a different temperature (105 °C, to emulate the temperature inside a junction box when ambient temperature is 85 °C).

This analysis tries to evaluate the thermal performance of all devices in the conditions mentioned above. But note that the performances are strictly related to the PCB design. Also, performances can be affected by how the PCB is placed inside the junction box, and by the junction box material itself. Each of these elements can create an important bottleneck in the correct heat dissipation that must be guaranteed for every device used in this application field.

Figure 8. Typical junction box PCB to solder and connect the devices on PANEL



6 SPV100x test description

6.1 Purpose

To assess the device thermal performance, checking the adequacy of the PCB thermal design and relative long-term reliability of the SPV100x diodes versus two standard Schottky diodes with comparable current capability (20 A and 30 A) and reverse voltage (40 V).

6.2 Instrumentation used

- Thermal chamber MAZZALI SYSTEM model TESYS 1200h.
- Data Logging PicoLog, high resolution until 1/100 °C
- Thermocouples interconnected with PicoLog.
- Power supply and current probe.

6.3 Procedure

Set up the environment in order to measure the following parameters:

- For free devices: The Tj (junction devices temperatures), and power in forward mode
- For the devices soldered in the PCB: The Tj and power in forward mode
- For the devices soldered in the PCB in the heat chamber @ 85 °C and @105 °C: The Tj and power in forward mode.

All of the current values are checked in order to keep the SPV100x T_j temperature below its maximum operative value (150 °C).

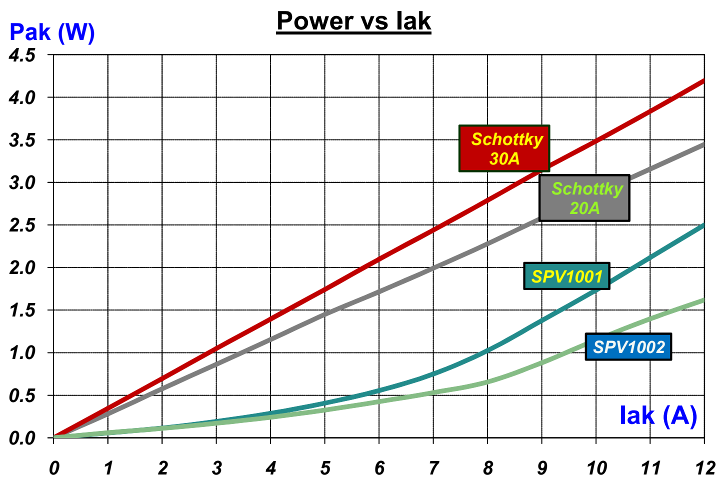
7 Test results and device comparison

For every device and temperature condition an analysis has been done in terms of, power dissipation and junction temperature.

7.1 Free devices at ambient temperature

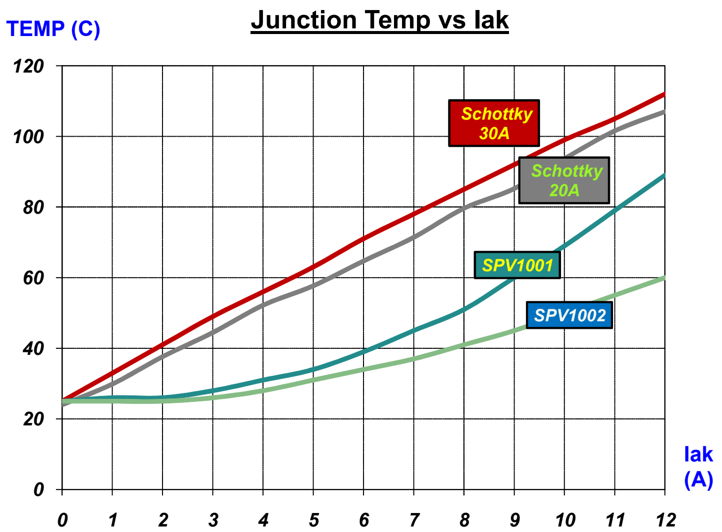
For the average power the values are calculated using *Equation 2*.

Figure 9. Power vs. Iak



In the same condition the measured junction temperatures are:

Figure 10. Junction temp. vs. Iak



7.2 Devices soldered on the PCB at ambient temperature

Figure 11. Power dissipation vs. Iak

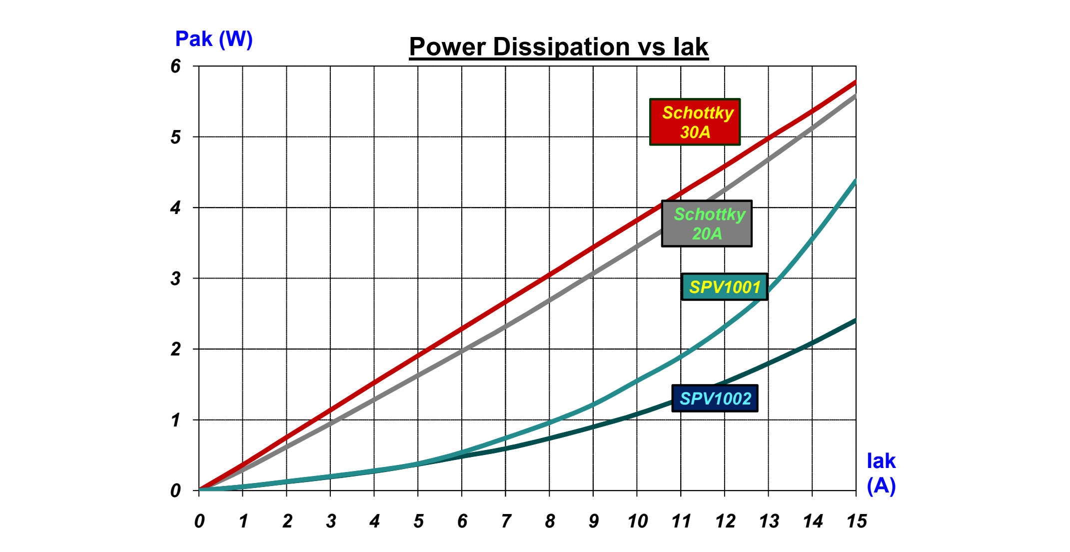
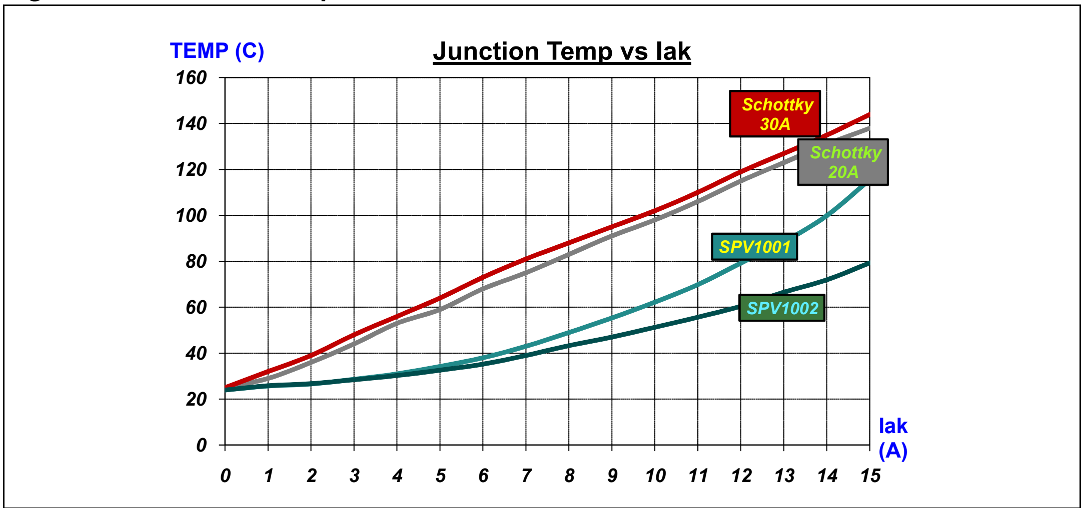


Figure 12. Junction temp vs. Iak



7.3 Devices soldered on the PCB at 85 °C chamber temperature

Figure 13. Power dissipation @ 85 °C vs. Iak

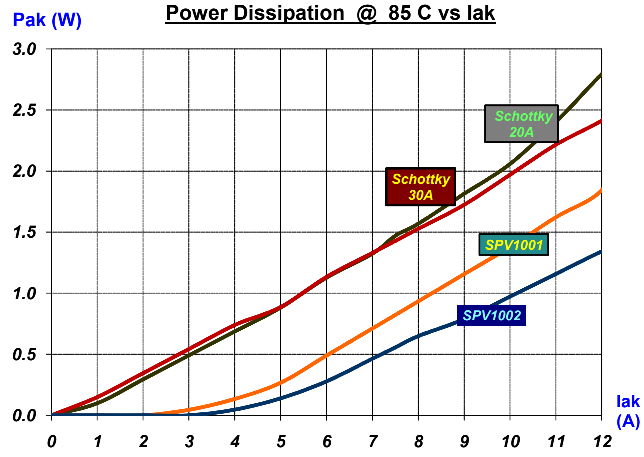
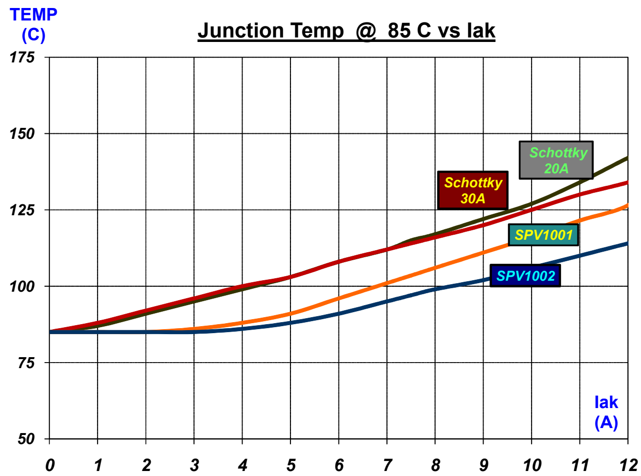


Figure 14. Junction temp @ 85 °C vs. Iak



7.4 Devices soldered on the PCB at 105 °C chamber temperature (junction box)

Figure 15. Power dissipation @ 105 °C vs. Iak

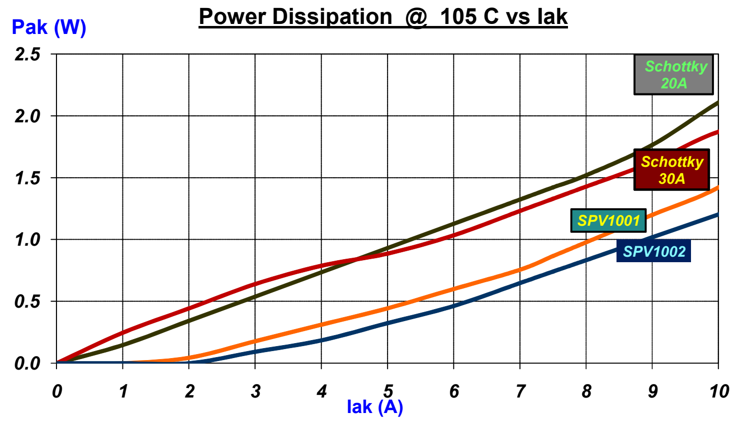
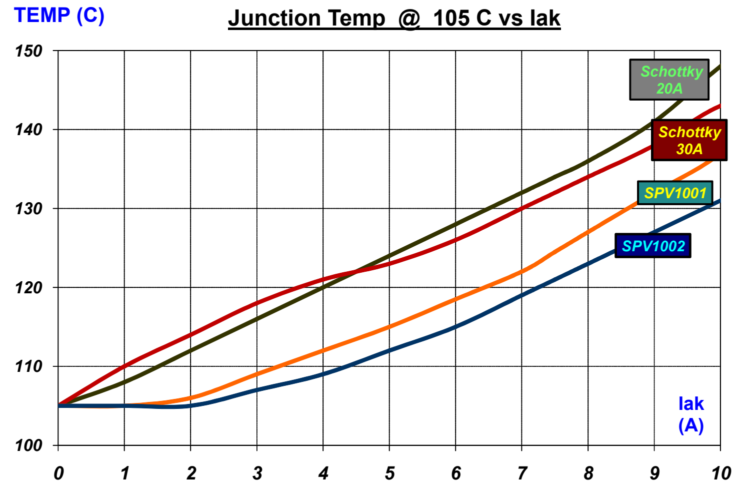


Figure 16. Junction temp. @ 105 °C vs. Iak



8 Conclusion

According to the results shown in the plots, the thermal and power performances of the SPV1001 and SPV1002 are better than the standard Shottky diodes.

The above results can be improved by changing the PCB heat-sinking characteristics (increasing size, increasing thickness, increasing copper layers, changing number and size of thermal vias).

Finally, from the application point of view it should be noted that the performance is strongly influenced by the specific junction box where the devices are placed.

So, for every panel, device integration in the junction box, the material and the internal PCB design, is an important key to reaching the target current capability.

9 References

1. CEI EN 61215-2006/08
2. SPV1001/SPV1002 datasheet
3. AN1542 application note
4. AN836 application note
5. AN869 application note

10 Revision history

Table 1. Document revision history

Date	Revision	Changes
05-Dec-2011	1	Initial release