

Solar Cell Bypass Diodes in Silicon Crystalline Photovoltaic Panels

IMPORTANT CHARACTERISTICS OF BYPASS DIODES FOR PHOTOVOLTAIC SOLAR CELLS

1. Forward Voltage Drop (V_F) at Bypass

The basic function of bypass diodes in solar cells is to protect against hot spot damage when the photovoltaic panel is partially shaded by snow, fallen leaves, or other obstructions, as shown in Fig. 1.

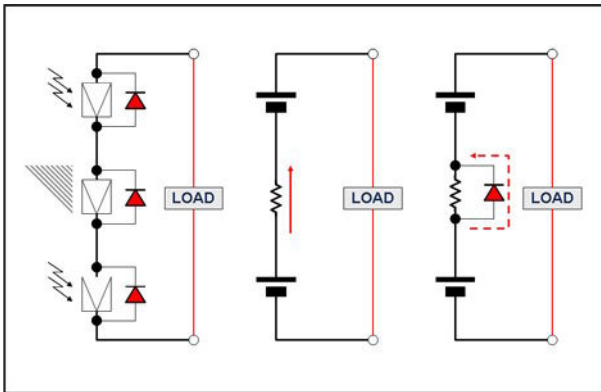


Fig. 1 - Bypass Operation

In this bypass operation, the forward voltage drop of the diode is similar to its internal resistance in operation, and is relative to the power loss of the diode and system efficiency. The equation for power loss of a diode in bypass operation is

$$P_d = V_F \text{ (at rated current and temperature)} \times I_F$$

This dissipated energy is a result of a change in temperature, and the definition of this change is $R_{\theta JC}$, $R_{\theta JL}$, or $R_{\theta JA}$.

The maximum junction temperature of most Schottky rectifiers being used as bypass diodes is 200 °C for one hour, and this limitation determines their maximum operating current capability.

The maximum condition for one hour of the rectifier is determined by

$$200 \text{ }^\circ\text{C} = (P_d \times R_{\theta JC}, R_{\theta JL}, \text{ or } R_{\theta JA}) + \text{ambient temperature.}$$

The continuous mode is determined by

$$\text{Max. } T_J = (P_d \times R_{\theta JC}, R_{\theta JL}, \text{ or } R_{\theta JA}) + \text{ambient temperature.}$$

2. Breakdown Voltage

Bypass diodes are in reverse biased mode (Fig. 2) during normal operation in solar cell panels, and are engaged by the output voltage of solar cell blocks. Fig. 2 shows the

typical operation of a diode in both forward (quadrant 1) and reverse (quadrant 3) polarity of operation. When the diode is in forward biased (conduction mode - turned-on) a small drop across the device occurs and does not change much as the forward current changes (quadrant 1). Now the device can carry a large amount of current as long as the temperature of its junction does not exceed $T_J \text{ max}$. The device turns on when the panel is fully or partially shaded thereby bypassing the panel. In regular operation the diode is reverse biased with a small amount of leakage current (Fig. 2 - quadrant 3). In the solar cell bypass function, the breakdown voltage of the diode is always higher than the total output voltage in V_{OC} of the solar cell in the string which is paralleled with the bypass diode.

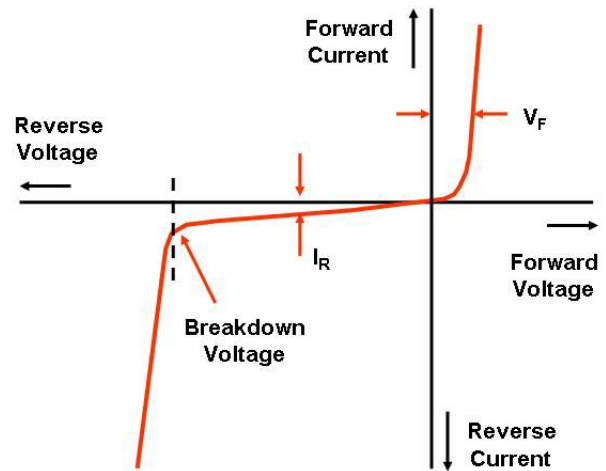


Fig. 2 - Voltage-to-Current Curve of Diode

Another consideration in the breakdown voltage specifications for bypass diodes is the maximum output voltage of solar cells in the flash condition, which simulates the voltage rush of lightning. This breakdown voltage is different than the isolation voltage of the photovoltaic solar panel or the solar power system, which is specified at IEC 61215-10-3. The bypass diode can possibly be damaged when the output voltage of the solar cell block is greater than the breakdown voltage from power dissipation.

The equation for power dissipation is $P_d = V_{BR} \times I_{BR}$, where V_{BR} = breakdown voltage, and I_{BR} = current at breakdown status.

APPLICATION NOTE

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3. Reverse Leakage Current

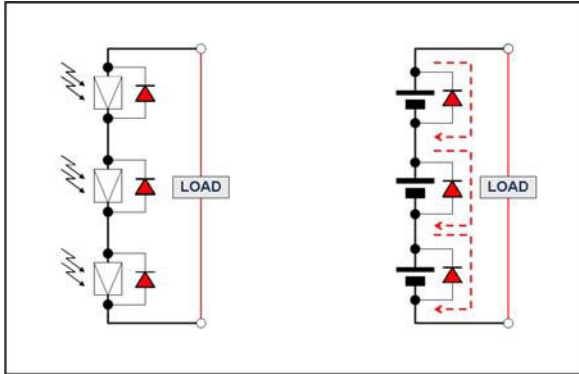


Fig. 3 - Reverse Leakage Current in Operation

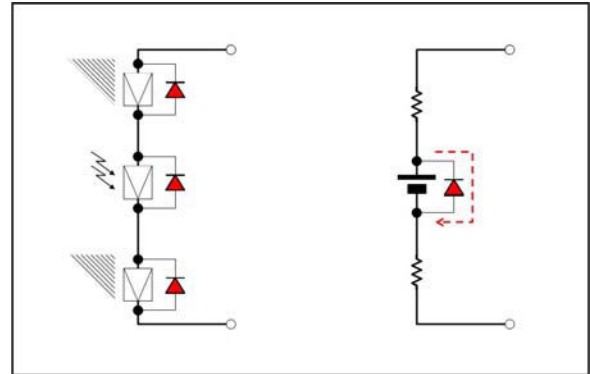


Fig. 4 - Reverse Leakage Current in Open Circuit

The reverse leakage current of a diode is related to its reverse biased voltage and junction temperature. Schottky rectifiers are generally used in bypass diodes for monocrystalline silicon and polycrystalline photovoltaic solar panels. Schottky rectifiers feature low forward voltage drop, offering higher efficiency and current density than traditional P-N junction diodes. However, they also have high a leakage (Fig. 3) reverse leakage current inoperation reliability of bypass diodes in solar panel applications. In normal solar panel operation, the bypass diode is reverse biased and the leakage current is constantly passing through it, as shown in Fig. 3.

The two worst cases in solar cell operation are high current exposure in the unloaded status during installation or repair, and the rush current exposure during lightning. In solar cell specifications, the highest output voltage is at the open circuit condition. The output voltage of a solar cell in the loaded condition is lower than in the open circuit condition and when the panel is flash tested (a technique used to avoid defects in the field). The reverse leakage current of bypass diodes is increased in this condition and will cause diode failures.

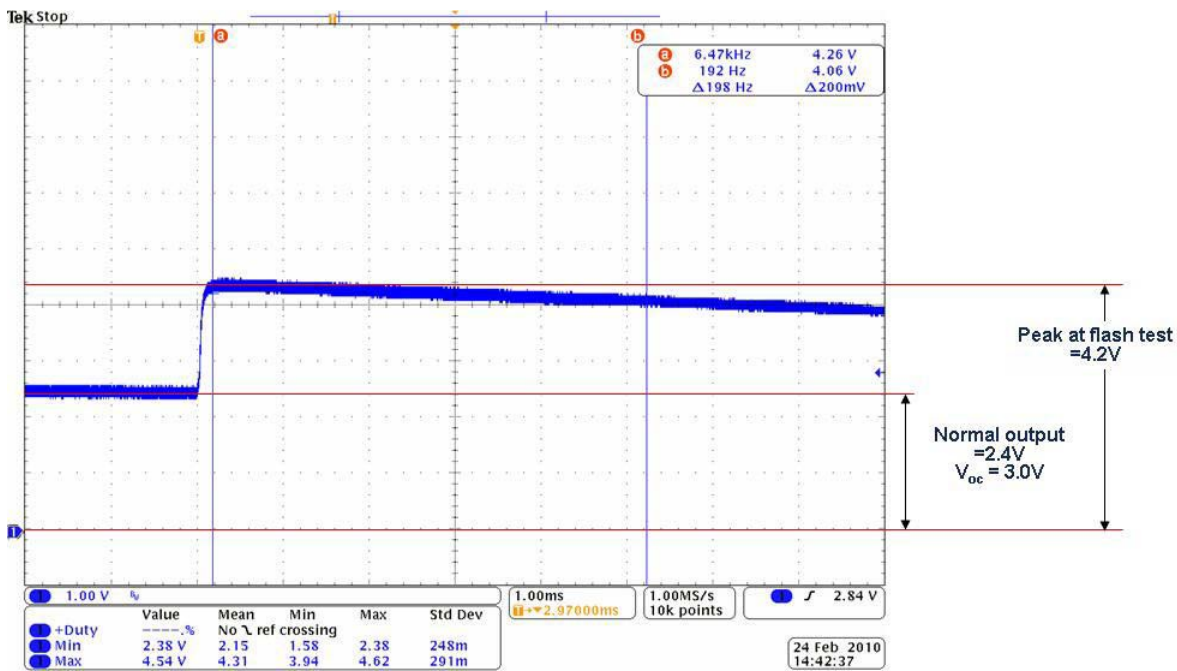


Fig. 5 - Output Voltage Form of Solar Cell at Flash Test

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TMBS® (TRENCH MOS BARRIER SCHOTTKY) RECTIFIERS FOR BYPASS DIODES

A new series of Vishay diodes applies new technology for low leakage at high temperatures and low forward voltage drop, thus improving on the disadvantages of low- and high-barrier conventional planar Schottky rectifiers.

Axial TMBS Rectifiers for Solar Cell Bypass Diodes

Axial-type packages are commonly used in bypass diodes, but their current capability is limited by their chip size and leads, which act as a heat sink in diodes.

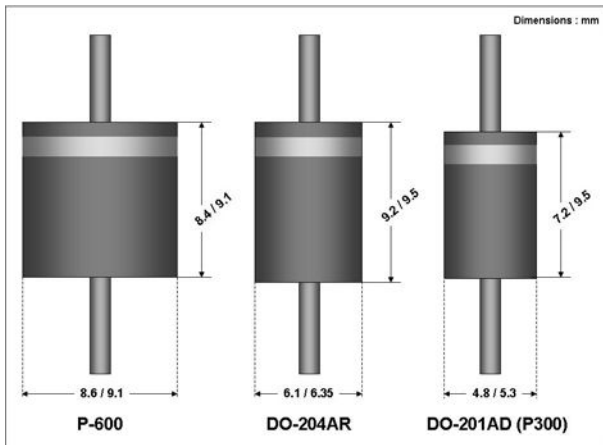


Fig. 6 - Power Axial Packages

Current bypass diodes from Vishay include the SB15H45 high-barrier type Schottky rectifier with very low leakage at high temperatures, and the 150SQ045 low-barrier type Schottky rectifier with very low forward voltage drop.

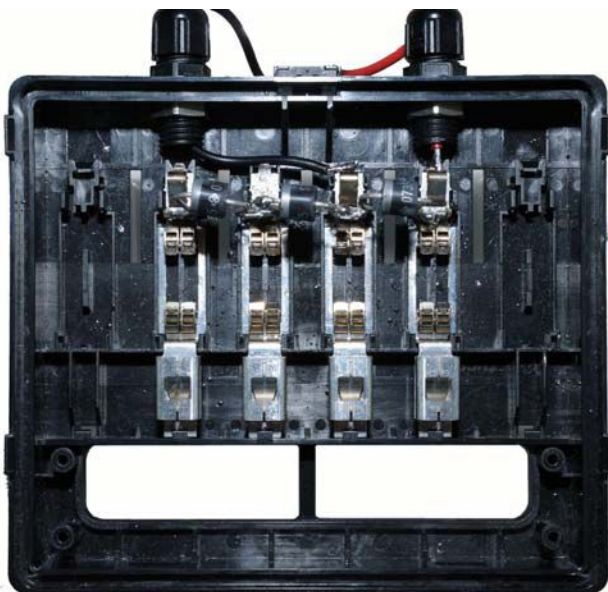


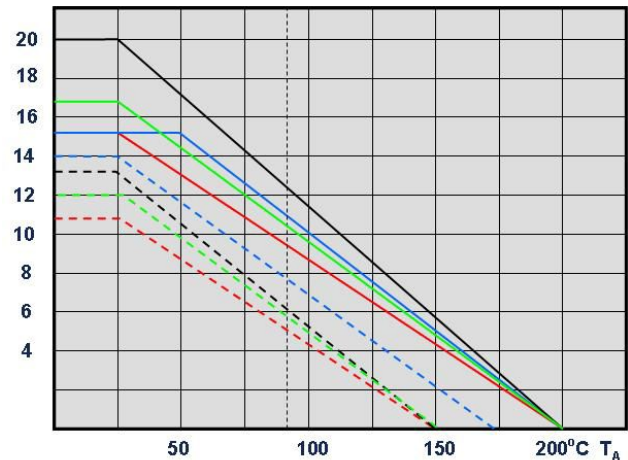
Fig. 7 - Axial Rectifier in Junction Box

The new Vishay TMBS axial-type Schottky rectifiers reach a 15 A current capability in the DO-201AD (P300) package, and a 20 A current capability in the P600 package without a heatsink.

Bypass diodes in solar junction boxes experience harsh conditions due to the poor ventilation of the enclosure and heat radiation from a limited heatsink.

Low forward voltage drop is a critical characteristic of bypass diodes because of the heat they generate by power dissipation. Low leakage current at high temperatures is also important when bypass diodes in solar panels go to normal mode operation from shaded mode.

VSB2045 and VSB1545



Mode	Continuous	200°C 1Hour
Conventional 15A Low barrier Schottky P600 package	-----	-----
SB15H45	-----	-----
VSB1545	-----	-----
VSB2045	-----	-----

Fig. 8 - Current Derating Curves of the P600 Package

Increasing the current rating of a solar cell through enhanced technology or by enlarging the cell size requires a bypass diode with a higher current rating. The VSB2045 has a large current capability of 20 A for enhanced high-power solar panel junction boxes.

The leakage current characteristics of TMBS rectifiers are improved over conventional planar low-barrier Schottky rectifiers.

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Fig. 9 shows the reverse leakage current of devices at low voltages under various temperature conditions. The SB15H45 has the very low leakage current characteristics of high-barrier Schottky rectifiers, while conventional

low-barrier devices have high leakage current characteristics at high temperatures. TMBS rectifiers also have low leakage current characteristics at high-temperature conditions.

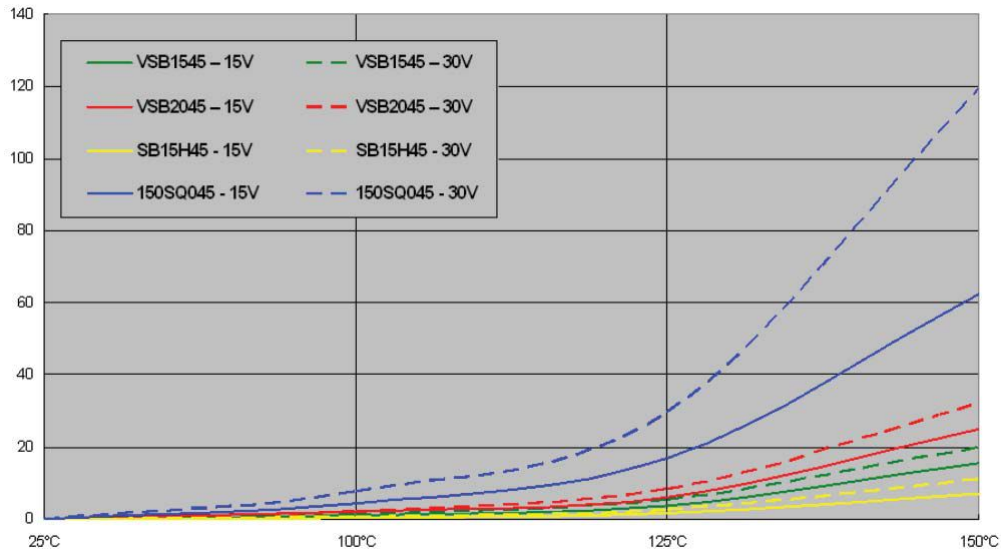


Fig. 9 - Leakage Current at Low Voltages

TO-220 and TO-263 Power Package TMBS Rectifiers for Solar Panels

The TO-220 and TO-263 power packages have high current capability up to 60 A and are optimized for PCB assembly.

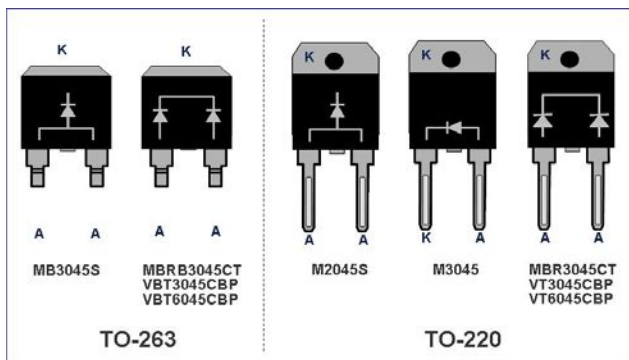


Fig. 10 - Power Package Types and Pin Configurations

Fig. 10 shows the pin configurations and packages of Vishay planar and TMBS Schottky rectifiers for bypass diodes.

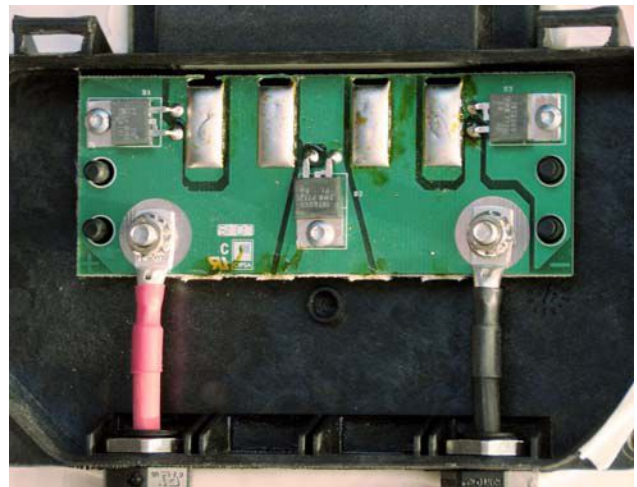
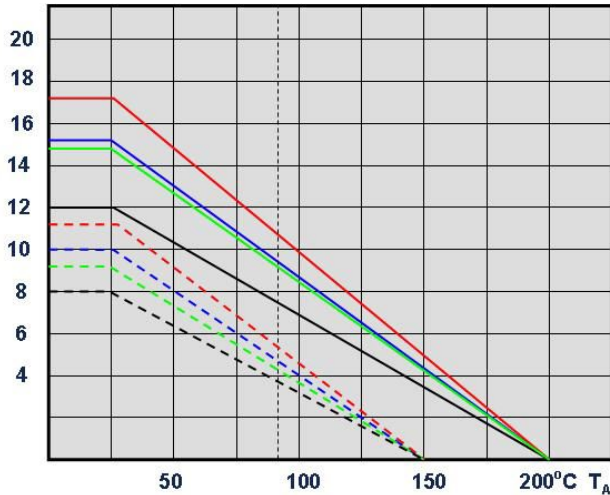


Fig. 11 - TO-220 Bypass Diodes in a Junction Box

Fig. 11 shows a PCB assembly with a TO-220 type rectifier in a junction box. The current capabilities of these power packages given in their datasheets are conditional on heatsink and PCB pad size and air ventilation.

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	Continuous	200°C 1Hour
VBT6045CBP	-----	-----
VBT3045CBP	-----	-----
MBRB3045CT	-----	-----
MB3045S	-----	-----

Fig. 12 - Current Capability of TO-263 Schottky Rectifiers

Fig. 12 shows the current capability of several kinds of Vishay TO-263 package type Schottky rectifiers, including the MB3045S single planar type, MBRB3045CT dual planar type, VBT3045CBP dual TMBS, and VBT6045CBP for solar cell bypass applications.

The actual current capability differs from this graph depending on the PCB pad and heat sink size of the junction box.

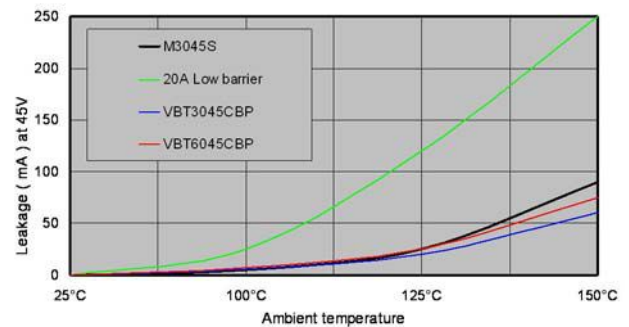


Fig. 13 - Current Capability of TO-263 TMBS Schottky Rectifiers

Fig. 13 shows the reverse leakage currents of Vishay TMBS Schottky rectifiers and conventional low-barrier Schottky rectifiers under different temperature conditions.