Selecting a Schottky Barrier Diode for Voltage Boost Circuits

Outline:

This document explains how to select a diode that can maximize the power supply efficiency of the step-up switching regulator of the asynchronous (diode) rectification method used in LED drive circuitry, etc.

Compare switching losses (efficiency) using CUHS20F40 of low forward voltage type and UHS20S40 of low leakage current type as an examples.

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1. Introduction

Notebook PCs, tablets, cell phones, and other mobile devices and consumer electronics contain many types of components operating at different voltages such as CPUs, memory devices, and displays. Figure 1.1 shows a 3.6-V battery power supply. The internal components of an electronic system operate at different voltages. For example, the battery voltage is stepped up from 3.6 V to 30 V for a string of series-connected backlight LEDs while it is stepped down from 3.6 V to 3.5 V for a Wi-Fi module and to 1.2 V for a camera module. It is therefore necessary to step up and down the voltage level from a DC power supply using DC-DC converters and LDO regulators.

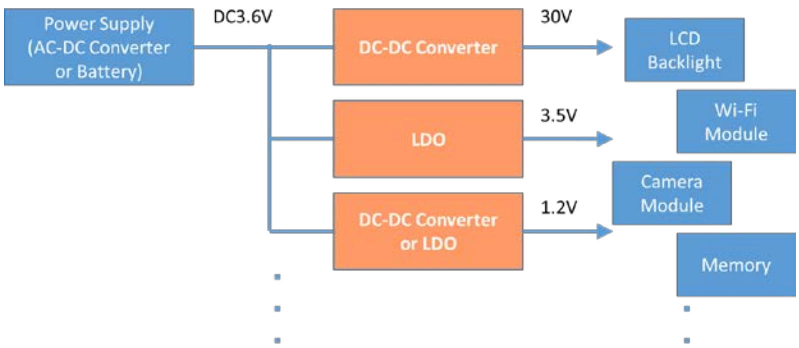


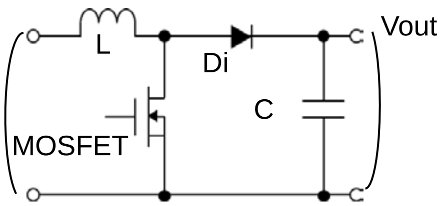
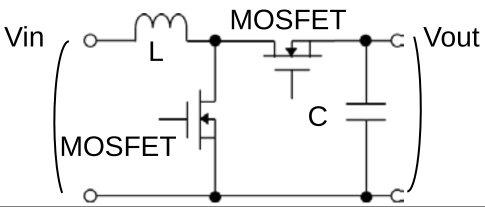
Figure 1.1 An example of voltage supply to various applications from a power supply unit

Nowadays, demand is growing for ever-smaller power supply units with higher power efficiency. To help reduce the board size, system manufacturers often rely on ICs that integrate diodes, transistors, and other discrete devices on the same chip. However, not all devices are integrated in ICs because integrating the devices that tolerate high voltage and current needed for step-up DC-DC converters results in an increase in the IC price. Therefore, asynchronous (diode) rectification is commonly used for DC-DC converters for LED backlight drive that provide relatively high voltage (on the order of 30 V). The next section describes the basic operation of asynchronous (diode) rectification and how to select a Schottky barrier diode (SBD) for asynchronous rectification.

2. Voltage boost circuits for DC-DC converters

Table 2.1 compares two types of voltage boost circuits for DC-DC converters.

Table 2.1 Comparison of voltage boost circuits

	Asynchronous (Diode) Rectification	Synchronous Rectification
Basic circuit		
Advantages	Inexpensive and simple circuit	High efficiency
Disadvantages	Low efficiency	Complicated circuit and expensive

In the case of voltage boost circuits for liquid crystal displays (LCDs), asynchronous (diode) rectification is commonly used because it is less costly and more straightforward than synchronous rectification. In an asynchronous rectification circuit, the VOUT output is preceded by a rectification diode. To minimize the power loss incurred by the diode, an SBD with low forward voltage is generally used.

2.1. Basic operation of a voltage boost circuit using asynchronous (diode) rectification

This subsection describes the principle of operation of asynchronous rectification using the circuit shown in Figure 2.1. When the MOSFET is on, current flows from VIN to GND via the MOSFET. At this time, inductor L stores the energy of an electric current. When the MOSFET turns off, inductor L tries to maintain the current at the same level by generating a voltage across its terminals. A voltage boost circuit steps up voltage by adding the voltage generated by inductor L to the voltage from VIN. Since the energy released from inductor L decreases over time, a step-up operation is repeated by turning on and off the MOSFET periodically. The stepped-up voltage is smoothed by capacitor C before it comes out of VOUT. Figure 2.2 shows the voltage (Vtr) and current (ID) waveforms of the diode.

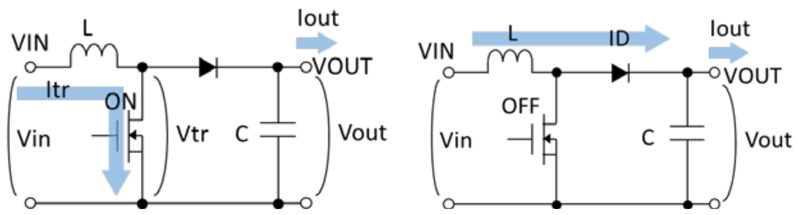


Figure 2.1 Current path through an asynchronous rectification voltage boost circuit

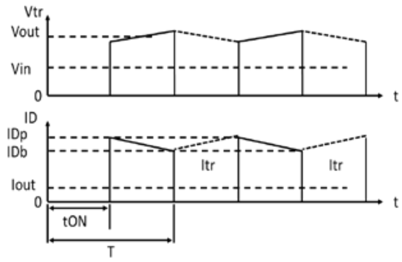


Figure 2.2 Waveforms of the ideal voltage boost circuit

When the load connected to VOUT is constant, the output voltage (Vout) is dependent on the turn-on time (tON) and the cycle period (T) of the MOSFET. Therefore, Vout can be calculated as follows:

$$\mathrm{Vout} = \frac{T}{(T-tON)} * Vin \qquad \text{... Equation 2.1}$$

Next, let’s consider the output current (Iout) based on the current flowing through the diode (ID). Let the instantaneous current due to the discharging of inductor L and the charging of the smoothing capacitor be IDp and the minimum current during the off state of the MOSFET be IDb. Then, ID can be expressed as follows:

$$\mathrm{Iout} = \frac{(T-tON)}{T} * \frac{(IDp+IDb)}{2} = \frac{(T-tON)}{T} * ID \qquad \text{... Equation 2.2}$$

Equation 2.1 and Equation 2.2 provide the output voltage and current for the ideal voltage boost circuit. In reality, however, Vout and Iout are affected by the power losses of the constituent components. It is therefore necessary to select the optimal components that help reduce power losses.

Dedicated step-up DC-DC converter ICs for LCD backlight applications are commercially available that incorporate control circuitry, a MOSFET, and an SBD. Since these ICs are expensive, there are also dedicated ICs with a good performance/cost balance that integrate only a MOSFET and control circuitry as shown in Figure 2.3.These ICs allow you to improve power efficiency by selecting an optimal SBD. The next section discusses how to select an SBD.

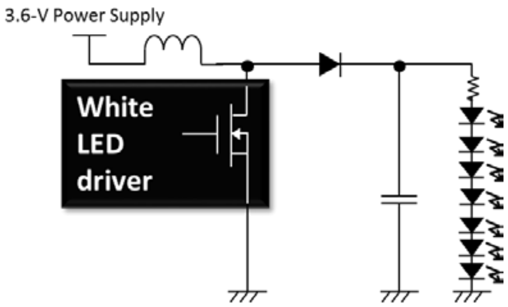


Figure 2.3 MOSFET integrated in a white LED driver IC

3. Considerations in selecting an SBD for a voltage boost circuit

It is necessary to select an SBD with absolute maximum ratings higher than the voltage and current at which the SBD will be used and to consider its losses that could affect the power efficiency of the voltage boost circuit.

3.1. Absolute maximum ratings

In selecting an SBD, allow for margins for the absolute maximum rated voltage and current, considering the number of LEDs connected as a load as well as its peak current and noise voltage during switching.

3.2. Switching loss

When a diode switches from the forward-biased conducting mode to the reverse-biased blocking mode, switching loss (PSW) might occur because the diode briefly remains conductive owing to the accumulated minority carriers (Figure3.1). Because the diode bias direction changes periodically in the asynchronous rectification voltage boost circuit, its PSW increases as the operating frequency increases. An SBD is generally used in the asynchronous rectification voltage boost circuit because the SBD, which has no carrier accumulation, ideally provides almost zero reverse recovery time (trr), eliminating the need to take PSW into consideration. When a PN-junction diode with long reverse recovery time must be used, it is necessary to consider PSW, which can be calculated as follows:

$$\mathrm{PSW(W)} \fallingdotseq 0.5 * VR(V) * IR(PEAK)(A) * trr(s) * f(Hz) \quad \text{... Equation 3.1}$$

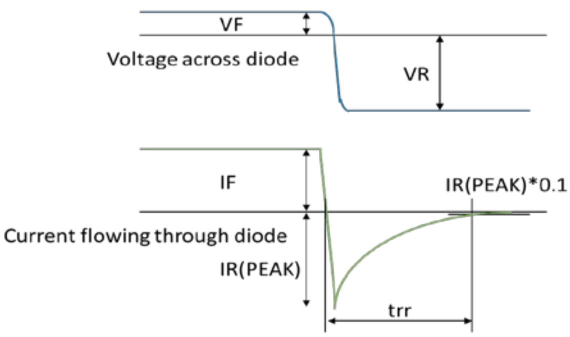


Figure 3.1 Diode's voltage and current waveforms during switching

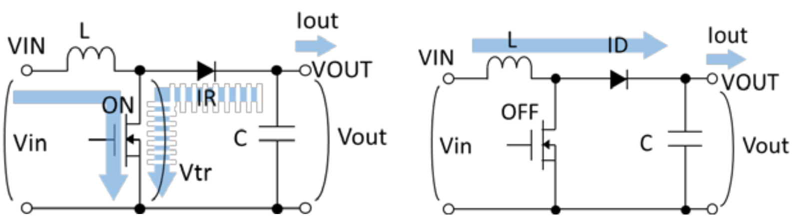
3.3. Thermal loss

The thermal loss of a diode should be considered separately for the forward- and reverse-bias modes. When the MOSFET is off, the SBD is forward-biased by Vin and L. As a result, current (ID) flows through the SBD, causing thermal loss, PF (forward loss). Figure 3.3 shows the VOUT voltage and current waveforms. PF can be calculated as follows from the turn-on time (tON) and the cycle period (T) of the MOSFET. Therefore, SBDs with lower forward voltage (VF) provide higher power efficiency.

$$\mathrm{PF(W)} = \frac{(T(s)-tON(s))}{T(s)} * \frac{(IDp(A)*VFd(V)+IDb(A)*VFp(V))}{2} \fallingdotseq \frac{(T(s)-tON(s))}{T(s)} * (ID(A)*VF(V)) \quad \text{… Equation 3.2}$$

Next, as shown in Figure 3.2, when the MOSFET is on, the SBD is reverse-biased by VOUT and C. As a result, current flows through the SBD in the reverse direction, causing thermal loss, PR (reverse loss). The reverse bias voltage of the SBD is equal to Vout. PR can be calculated from the turn-on time (tON) and the cycle period (T) of the MOSFET as follows. Therefore, PR is dependent on the IR of the SBD.

$$\mathrm{PR(W)} = \mathrm{VR(V)} * \mathrm{IR(A)} * \frac{tON(s)}{T(s)} = \mathrm{Vout(V)} * IR(A) * \frac{tON(s)}{T(s)} \quad \text{… Equation 3.3}$$



When the MOSFET is on When the MOSFET is off

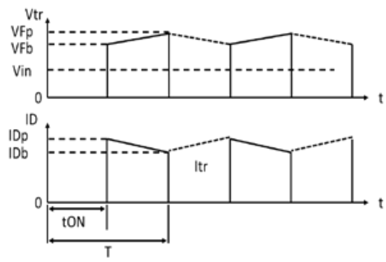


Figure 3.2 Current path through an asynchronous rectification voltage boost circuit

Figure 3.3 Current and voltage waveforms of a voltage boost circuit

From Equation 3.2 and Equation 3.3, the total thermal loss can be calculated as follows:

$$\mathrm{P(W)} = \mathrm{PF(W)} + \mathrm{PR(W)} = \frac{(T(s)-tON(s))}{T(s)} * \big(ID(A)*VF(V)\big) + Vout(V)*IR(A)*\frac{tON(s)}{T(s)} \text{… Equation 3.4}$$

Since forward voltage (VF) and reverse current (IR) affect PF and PR respectively, it is ideal to select an SBD with low VF and IR. However, there is a trade-off between VF and IR as shown in Figure 3.4. Therefore, either a low-VF or low-IR SBD should be selected according to the load in order to reduce thermal loss.

Toshiba provides an extensive lineup of SBDs. For example, typical low-VF and low-IR SBDs include the CUHS20F40 and CUHS20S40 (Table 3.1).

Table 3.1 SBD application examples

Load condition	Important characteristics	Example of Toshiba's SBD
Heavy	Low VF	CUHS20S40
Light	Low-IR	CUHS20F40

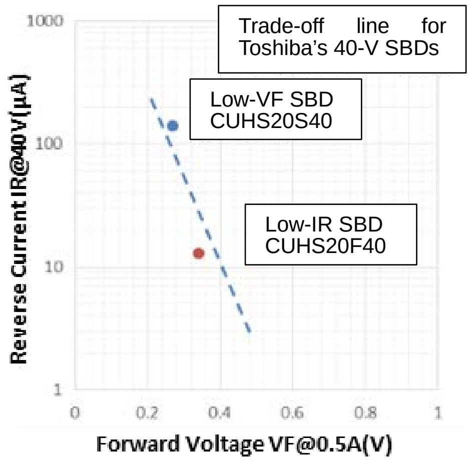
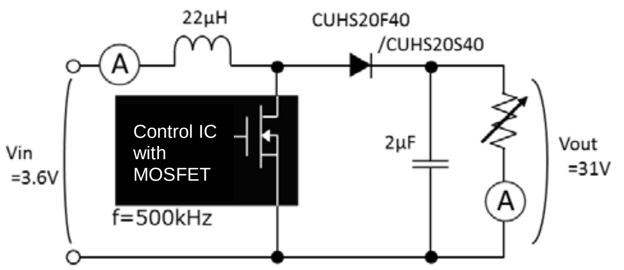


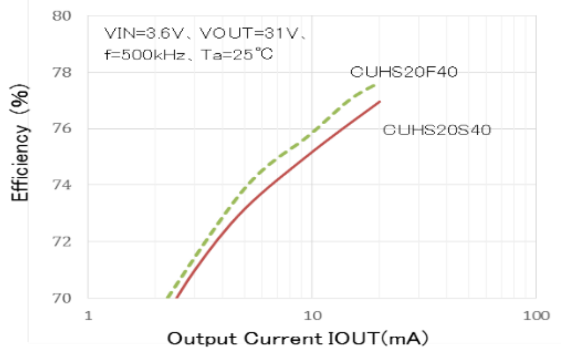
Figure 3.4
Trade-off line for Toshiba's 40-V SBDs

3.4. Power efficiencies of different SBDs

Suppose that we need to design a voltage boost circuit for an LED backlight consisting of eight series-connected white LEDs. Figure 3.5 shows efficiency curves of the voltage boost circuit using different SBDs. White LEDs should be driven at 3.0 to 3.8 V, considering the variations in their forward voltage (VF). Therefore, the assumption here is that we need to step up Vin to 31 V (see the evaluation circuit shown in Figure 3.5). Figure 3.5 compares the power efficiency of this evaluation circuit using 40-V low-VF and low-IR SBDs. In the case of a light load condition with an LED drive current of 10 to 20 mA, PR (reverse loss) is dominant in Equation 3.4. Therefore, the low-IR CUHS20F40 provides higher efficiency than the CUHS20S40.

Suppose the white LEDs are connected in parallel. This means the voltage boost circuit needs to drive a heavier load. In this case, using the low-VF CUHS20S40 helps improve power efficiency because PF (forward loss) is dominant in Equation 3.4.





Evaluation circuit Power efficiency curves

Figure 3.5 Power efficiency comparison of a voltage boost circuit using different SBDs

* Ratio of the output power to the input power supplied to the voltage boost circuit

4. Conclusion

Inexpensive and straightforward asynchronous (diode) rectification is widely used for voltage boost circuits for LED backlights for LCDs. The characteristics required for a rectification SBD depend on the load conditions. A low-VF SBD helps improve power efficiency in the case of a heavy load whereas a low-IR SBD is more beneficial in the case of a light load. Toshiba provides an extensive portfolio of easy-to-use SBDs, including low-VF and low-IR SBDs. See data sheets for detailed electrical characteristics.

SBDs suitable for realizing a high-efficiency voltage boost circuit

40-V/2-A low-VF SBD: **CUHS20F40** → Click Here

40-V/2-A low-IR SBD: **CUHS20S40** → Click Here

Lineup of other Toshiba SBDs → Click Here

Toshiba also provides an extensive portfolio of MOSFETs.

Toshiba's MOSFET lineup → Click Here

5. Related Links

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