Application Report

SNVA083B–May 2004–Revised May 2018

Reducing Losses in Your Internal Bootstrap Diode

ABSTRACT

Many half-bridge gate drivers incorporate a bootstrap diode to generate high-side bias, reducing the board space and component count for designers. In high frequency and capacitive load applications, it is often beneficial to add an external bootstrap diode to reduce losses associated with the diode. This report discusses the power dissipation within gate drivers with an integrated bootstrap diode and further discusses the selection of the external bootstrap diode.

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1 Introduction

The gate drive requirements for power MOSFETs, IGBTs, and SiCs used as high-side switches in applications, like half-bridge converters or synchronous buck converters, can be summarized as follows:

- Gate voltage must be 6 to 12 V higher than the source voltage. To fully enhance a high-side switch and reduce switching losses, the gate-to-source voltage must be higher than the threshold voltage, plus the minimum necessary voltage.
- Gate voltage must be controllable from the logic level, which is normally referenced to ground. Thus, the control signals must be level shifted to the source terminal of the high-side MOSFET (HS node), which in most applications, swings between ground and the high voltage rail.
- Power dissipation of the gate driver must remain within the package thermal limitations.

Highly integrated gate-driver ICs include the following blocks:

- Low-side gate driver
- High-side level shifter
- High-side gate driver
- Undervoltage lockout protection for both the high- and low-side drive
- Bootstrap diode

Figure 1 shows a typical gate drive using a simplified schematic of the LM510x family of devices from TI. The bootstrap circuit requires a high-voltage and high-speed diode with a low ESR/ESL capacitor.

The internal bootstrap diode charges the bootstrap capacitor ($C_{BOOTSTRAP}$) every cycle when the low-side MOSFET turns on. The charging of the capacitor involves high-peak currents, and therefore, transient power dissipation in the internal bootstrap diode may be significant and dependent on the forward voltage drop of the internal diode. The reverse recovery time of the bootstrap diode must be very small, to achieve a reduction in reverse recovery losses. Both the diode conduction losses and reverse recovery losses contribute to the total losses in the gate driver and must be considered in calculating the gate driver IC power dissipation.

For high-frequency and high-capacitive loads, it may be necessary to consider using an external bootstrap diode placed in parallel with the internal bootstrap diode, to reduce power dissipation. The location of the external bootstrap diode must be very close to the gate-driver IC. This application note quantifies the losses in the internal bootstrap diode at various external capacitive loads and supply rail voltages and provides the remedies to overcome those losses.

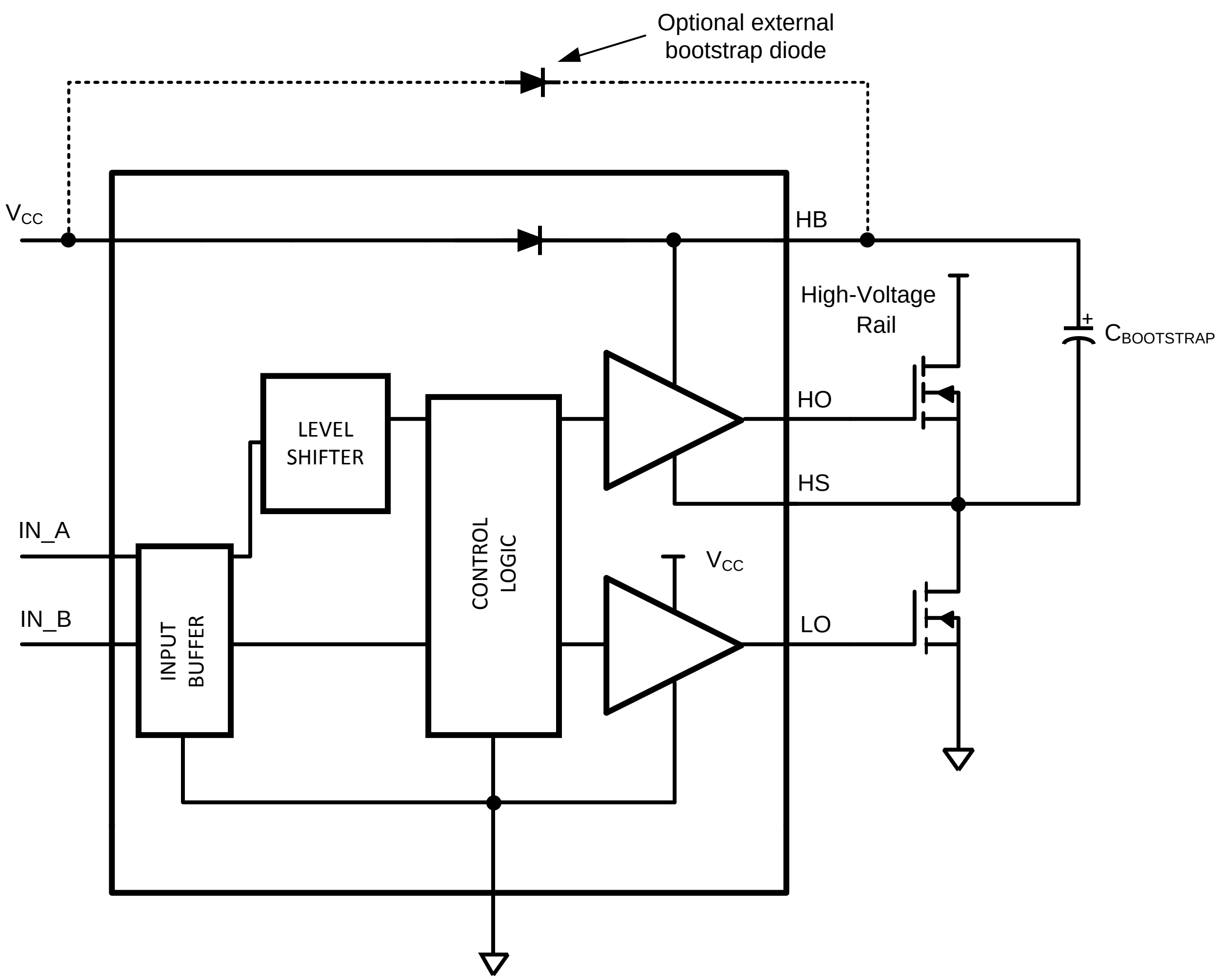

Figure 1. Simplified Schematic of High- and Low-Side Driver

2 Theory of Operation

2.1 Power Dissipation

The total IC power dissipation is the sum of the gate driver losses and the bootstrap diode losses. The gate driver losses are related to the switching frequency (f), output load capacitance (C_L) on LO and HO, and supply voltage (V_{DD}). The power dissipation is roughly calculated as follows in Equation 1:

$$P_{DGATES} = 2 \times f \times C_L \times V_{DD}{}^2 = 2 \times f \times Qg \times V_{DD}$$

where

- Qg is the total gate charge of the external MOSFET in coulombs. (1)

There are some additional losses in the gate drivers due to the internal CMOS stages used to buffer the LO and HO outputs. Figure 2 shows the measured gate driver power dissipation versus frequency and total gate charge of external MOSFET in coulombs. At higher frequencies and load capacitance values, the power dissipation is dominated by the power losses driving the output loads and agrees with Equation 1. Figure 2 shows the approximate power losses due to the LM510x gate drivers. This data was taken by connecting external capacitive loads on both outputs of the LM510X driver.

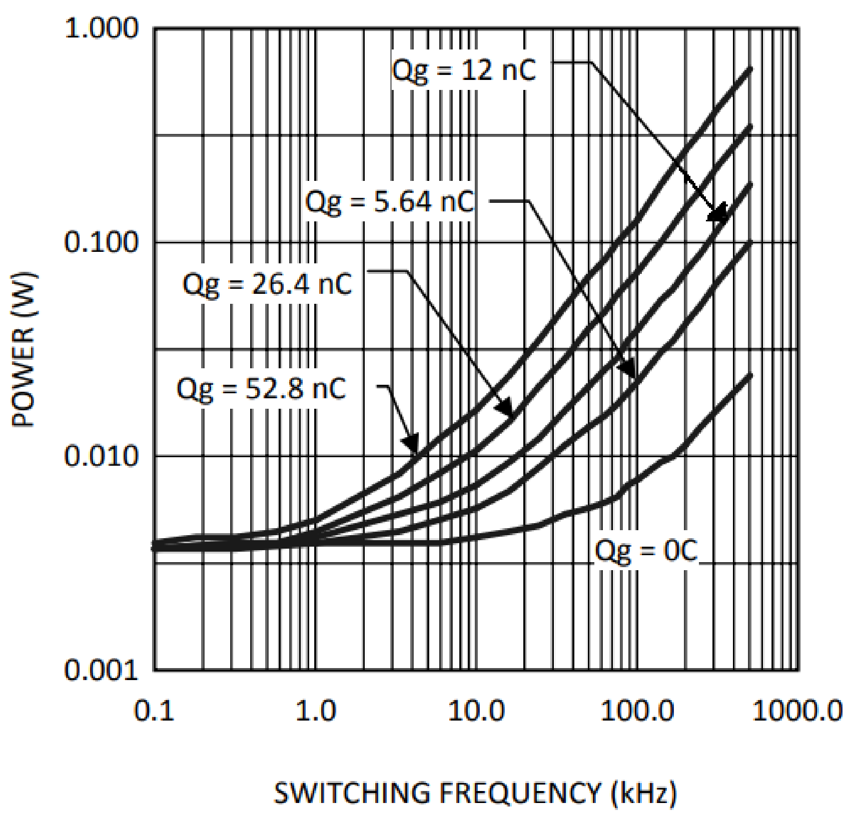

Figure 2. Gate -Driver Power Dissipation (LO and HO)
V_{CC} = 12 V, Neglecting Diode Losses

The bootstrap diode power loss is the sum of the forward-bias power loss that occurs while charging the bootstrap capacitor and the reverse-bias power loss that occurs during reverse recovery. Because each of these events occurs once per cycle, the diode power loss is proportional to the frequency. Larger capacitive loads require more current to recharge the boot capacitor, resulting in more losses. Higher input voltages (V_{IN}) to the half bridge result in higher reverse-recovery losses. Figure 3 and Figure 4 were generated based on calculations and lab measurements of the diode recovery time and current, under several operating conditions. This method can be useful for approximating the diode power dissipation.

The total IC power dissipation can be estimated from the plots shown in Figure 2, Figure 3, and Figure 4, by summing the gate-drive losses with the bootstrap-diode losses for the intended application. Because the diode losses can be significant, an external diode placed in parallel with the internal bootstrap diode can be helpful in removing power from the IC. For this method to be effective, the external diode must be placed close to the IC, to minimize series inductance and produce a significantly lower forward-voltage drop than the internal diode (see the LM510X data sheet).

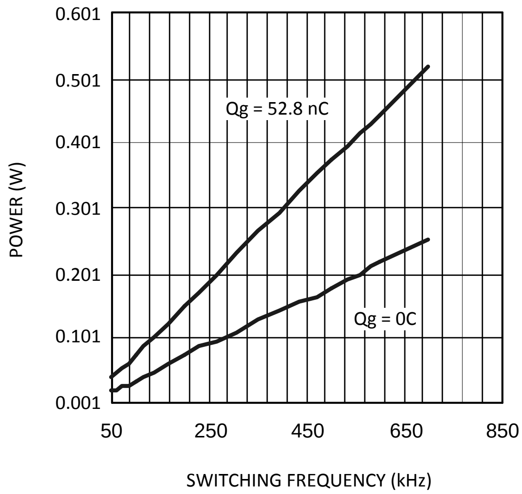

Figure 3. Internal-Diode Power Dissipation
V_{IN} = 40 V

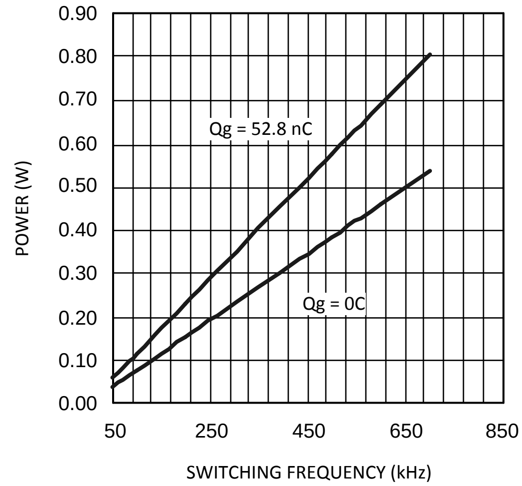

Figure 4. Internal-Diode Power Dissipation
V_{IN} = 80 V

3 Recommended External Bootstrap Diodes

Table 1. Recommended External Bootstrap Diodes

ITEM	DIODE PART NUMBER	MANUFACTURER	REMARKS
1	CRH01	Toshiba	S-FLATTM Package (3.5 mm x 1.6 mm)
2	Mura110T3	ONSEMI	SMA Package. (5.5 mm x 2.9 mm)
3	BYV40E	PHILIPS SEMI	SOT223 Package. (6.7mm x 6.7mm)
4	MA2YD1700L	PANASONIC	Schottky diode. High leakage current at high temperatures. Mini2-F1 package. (3.5mm x 1.6mm)

4 Conclusion

In high frequency and high capacitive load applications, it is beneficial to use an external bootstrap diode to reduce power dissipated within the IC.This application report quantified the losses in the internal bootstrap diode of LM510X high and low side gate driver. This application report is not limited to the LM510X family devices, it extends to other TI half bridge gate drivers with a built-in bootstrap diode.

Revision History

NOTE: Page numbers for previous revisions may differ from page numbers in the current version.

Changes from A Revision (May 2013) to B Revision	Page
• Changed app note title from AN-1317 Selection of External Bootstrap Diode for LM510X Devices to Selection of External Bootstrap Diode for Half-Bridge Gate Drivers	1
• Added IGBTs and SiCs to Introduction	2
• Deleted Removed approximate cost/unit column from Recommended External Bootstrap Diodes table	6