High-Side MOSFET Bootstrap Driver

Sufiyan Shaikh
Dept. of Electronics and Telecommunication
Pune Institute of Computer Technology

Abstract

The high-side MOSFET bootstrap driver circuit is a crucial component in power electronics applications, enabling efficient switching in environments where direct gate control is challenging. This document explores the theoretical foundations behind the design and optimization of such circuits, highlighting how a bootstrap capacitor and associated components can enhance the performance of high-side switches. The analysis emphasizes the importance of component selection, particularly the bootstrap capacitor, diode, and resistors, in achieving continuous current flow, reduced conduction losses, and improved dynamic operation. Through simulation and experimental validation, the effectiveness of the bootstrap driver in providing reliable operation under varying load conditions is demonstrated.

I. Introduction

High-side MOSFETs are widely used in circuits like DC converters, motor controllers, and power management because they handle high currents while keeping switching losses low. The problem is that driving them is not so straightforward. The source of the MOSFET is not fixed at a constant voltage but keeps moving depending on the load. To fully turn the device on, the gate voltage must be higher than the source by a threshold amount, and when the source voltage keeps changing, this becomes a real challenge. The bootstrap driver solves this problem in a clever way by using a capacitor and diode to temporarily boost the gate voltage. This eliminates the need for a separate isolated supply and makes the circuit more efficient and compact while still handling dynamic load changes smoothly. The design and optimization of such a circuit depend heavily on choosing the right values for the capacitor, diode, and resistances to ensure stability and reliability under varying conditions.

II. Objective

The primary objective of this work is to design and optimize a high-side MOSFET bootstrap driver that ensures reliable switching while maintaining continuous current flow in inductive loads. It aims to evaluate how the selection of bootstrap circuit elements influences the system's performance in terms of gate drive stability, voltage ripple, and harmonic distortion. Furthermore, the work intends to investigate the impact of operating conditions such as frequency, duty cycle, and load parameters on the bootstrap circuit's ability to maintain proper charge levels and avoid undesirable discontinuities.

III. Working Principle

The high-side MOSFET bootstrap driver is implemented using a high-side MOSFET, a low-side MOSFET, a bootstrap diode, a bootstrap capacitor, and a gate resistor. The high-side MOSFET controls the load connected to the supply, but to fully turn it on, its gate needs a voltage higher than its source. The low-side MOSFET connects the switching node to ground, which allows the bootstrap capacitor to charge through the diode from the supply voltage. When the low-side MOSFET is on, the capacitor charges up to nearly the supply voltage, minus the diode drop, storing enough energy to drive the high-side MOSFET.

When the high-side MOSFET turns on, its source rises toward the supply voltage, and the bootstrap capacitor provides the extra voltage needed to keep the gate sufficiently above the source. This ensures full conduction of the MOSFET. During this phase, the capacitor slowly discharges depending on the gate charge required and any leakage paths. The diode prevents the capacitor from discharging back into the supply. The gate resistor limits the inrush current when charging the MOSFET gate, controlling the switching speed. Proper selection of the bootstrap capacitor and diode is critical, as it directly affects voltage stability and reliable switching.

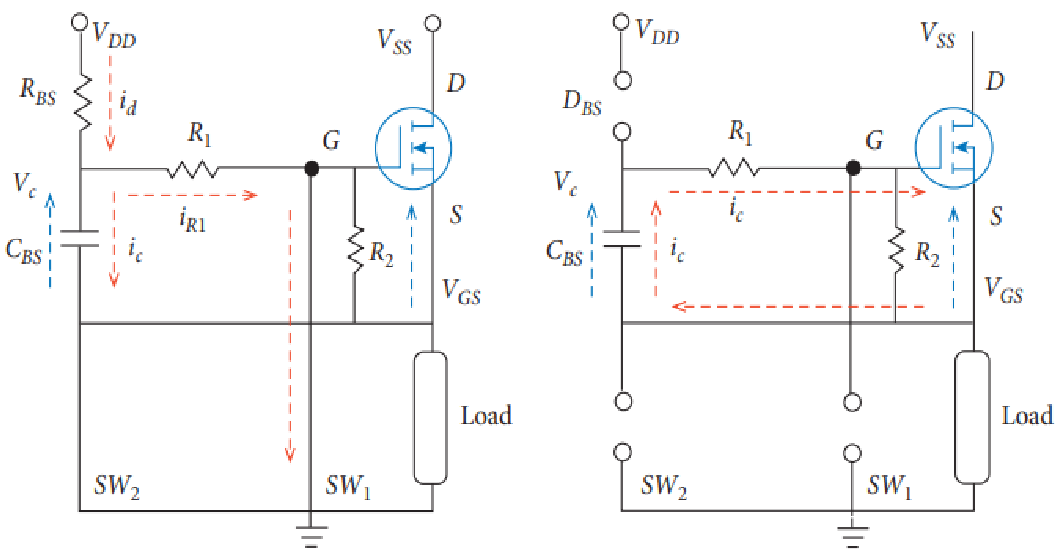


Fig. 1 Charging and discharging modes of the bootstrap capacitor

IV. Implementation

The high-side MOSFET bootstrap driver was implemented as shown in the schematic. The high-side MOSFET, labelled X1 (BUK7M6R3-40E), controls the load connected to the drain.

Its source connects to the switching node, which is also tied to a small series resistor R1 and the source of the low-side MOSFETs M1 and M2 (BSS123).

The bootstrap capacitor, Cbs1, is connected between the high-side gate and source, with a diode D1 (1N4148) providing a charging path from the supply voltage VDD1. A gate resistor RG1 limits the inrush current into the high-side MOSFET during switching.

The low-side MOSFETs M1 and M2 are driven by the PWM signal (V1), which pulls the switching node to ground during the low phase. During this phase, the bootstrap capacitor charges through the diode. When the PWM signal goes high, the low-side MOSFETs turn off, and the high-side MOSFET turns on. The charged bootstrap capacitor then provides the additional voltage above VDD needed to fully enhance the high-side MOSFET gate.

The circuit includes an external gate-source capacitor, Cgs_Ext1 which models gate charge effects and smooths voltage spikes. The transient response of the circuit can be observed at the high-side gate, low-side gate, and switching node, confirming that the bootstrap capacitor charges and discharges correctly, ensuring reliable high-side MOSFET conduction.

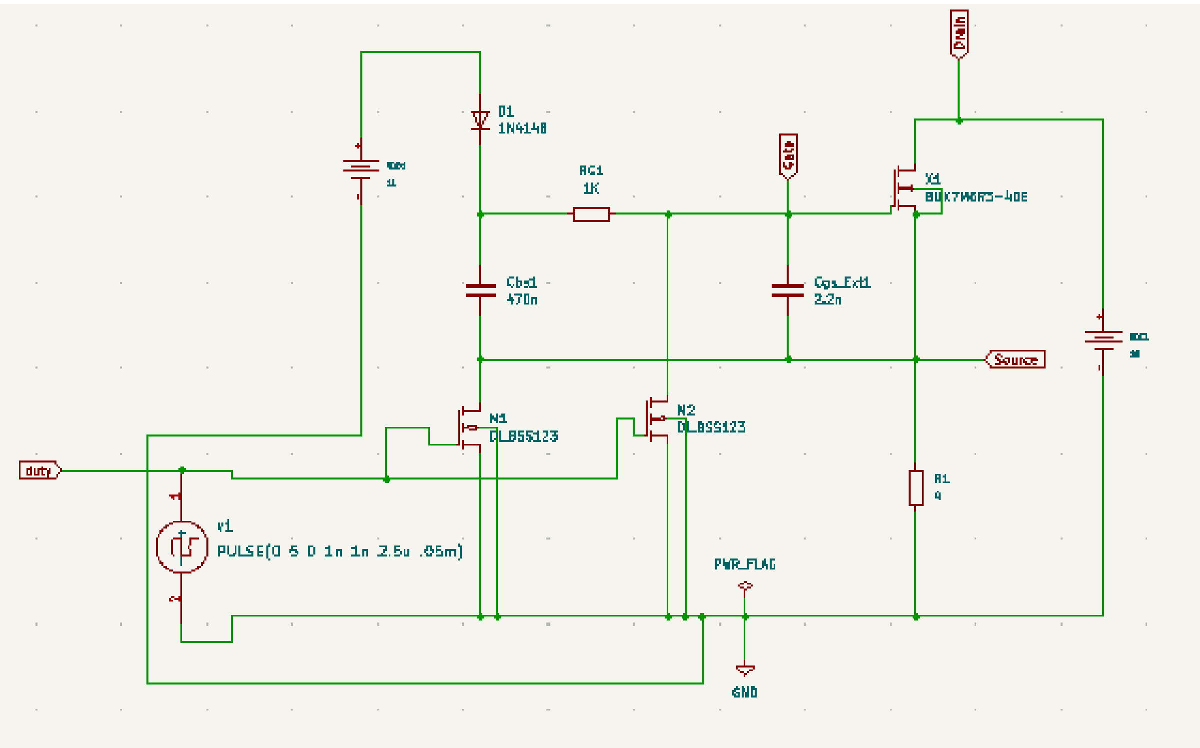


Fig. 2 eSim schematic

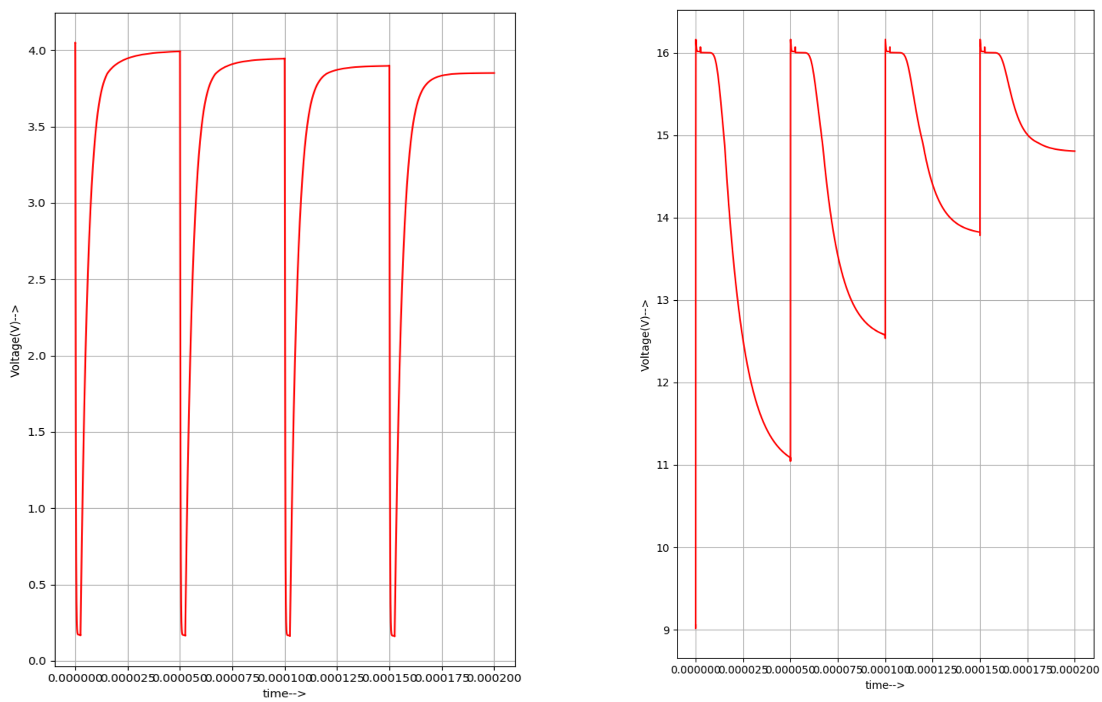
V. Analysis

The gate-source voltage of the high-side MOSFET rises to approximately 11 V while the source node simultaneously floats around 7 V, resulting in a gate-to-source voltage (Vgs) of roughly 4 V. This behavior is entirely expected in a bootstrap high-side driver configuration, as the source of the high-side MOSFET is not tied directly to ground but instead rises with the switch node. Although this Vgs is lower than the nominal full turn-on voltage of the MOSFET, it is sufficient to allow partial conduction, which effectively switches the load.

The drain-source voltage, representing the switch node, exhibits a characteristic transient waveform. It initially sits at the supply voltage and then drops as the high-side MOSFET turns on. The subsequent rise occurs when the MOSFET turns off, and the gradual decrease in the peak voltages over successive cycles is indicative of the natural charging and discharging behavior of the bootstrap capacitor. This interplay ensures that the gate receives enough voltage to keep the MOSFET switching correctly, even if it does not reach full saturation. Overall, the two waveforms collectively demonstrate that the bootstrap driver is operating as intended, with the switch node and gate voltages behaving in accordance with the expected dynamic response of the circuit.

Fig. 3 Gate-source and drain-source waveforms of the high-side MOSFET during operation

VI. Applications



The high-side MOSFET bootstrap driver is widely used in circuits that require efficient high-side switching. Key applications include:

- Half-bridge and full-bridge DC-DC converters, where precise switching of the high-side MOSFET is essential for energy transfer.

- Motor driver circuits, enabling control of high-side switches in H-bridge configurations for driving DC and stepper motors.
- Power management circuits, including load switches and high-side switching for battery-powered devices.
- Any system requiring isolated or floating high-side control, where a bootstrap approach simplifies gate driving without additional isolated supplies.

VII. Conclusion

The simulation results confirm that the high-side MOSFET bootstrap driver operates as intended. The gate-source voltage rises sufficiently relative to the floating source node to allow effective switching, while the drain-source (switch node) waveform exhibits the expected transient behavior, reflecting the charging and discharging of the bootstrap capacitor. Despite the MOSFET not fully reaching saturation, the circuit successfully drives the load and demonstrates proper dynamic response, validating the design and functionality of the bootstrap driver.

References

Abd El-Halim, H., Soliman, E.S. and Refky, A., 2022. Performance of MOSFET driven via a bootstrap capacitor for dynamic load continuity enhancement. Journal of Engineering, 2022(1), p.2273819