
Buck-Boost converter with STSPIN32G4

Introduction

The STSPIN32G4 is an advanced controller for driving three-phase brushless motors that integrates a triple half-bridge gate driver, one high performance STM32G431 microcontroller and a flexible power management circuitry. In particular, one Buck converter is available to efficiently generate gate driver supply voltage, VCC, starting from motor supply VM.

When VM voltage is reduced approaching target VCC voltage, the Buck converter is not able to properly regulate its output voltage that is consequently lower than input supply level. A reduction of system performance could arise during these low supply voltage operations since power MOSFETs of the motor inverter might be turned on with a not optimal gate voltage providing increased channel resistance and power losses.

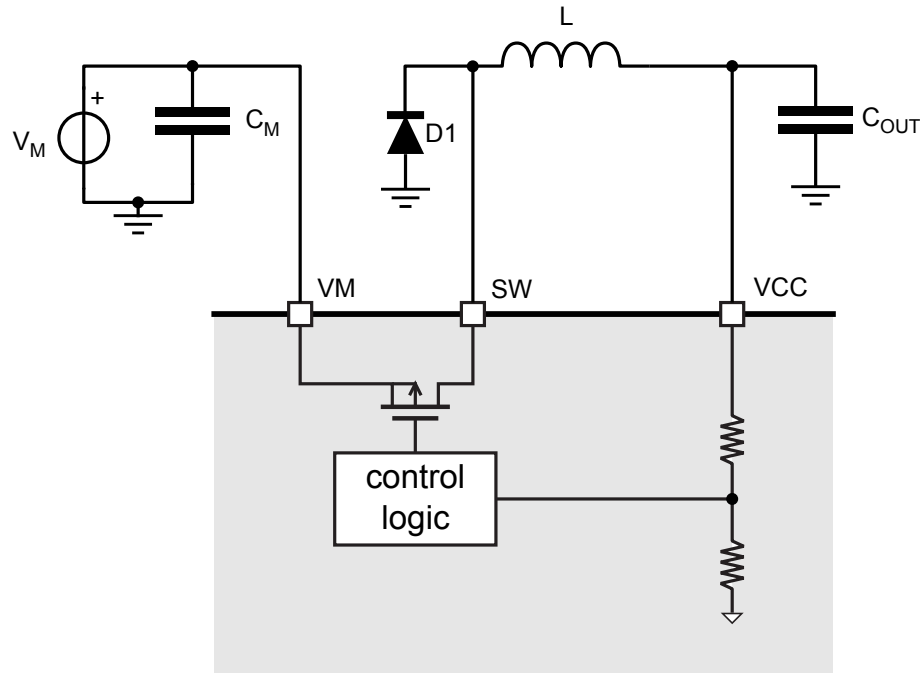
This application note describes how to convert the Buck regulator integrated inside STSPIN32G4 into a Buck-Boost regulator with few external components.

The presented solution can be beneficial for battery powered applications to achieve best system efficiency.

1 Overview of Buck regulator

The STSPIN32G4 Buck regulator is presented in Figure 1. The regulator has a current capability of 200 mA (typical value) and provides a configurable VCC output to 8 V (default), 10 V, 12 V and 15 V, soft-start, overcurrent protection and thermal shutdown.

Figure 1. Buck regulator



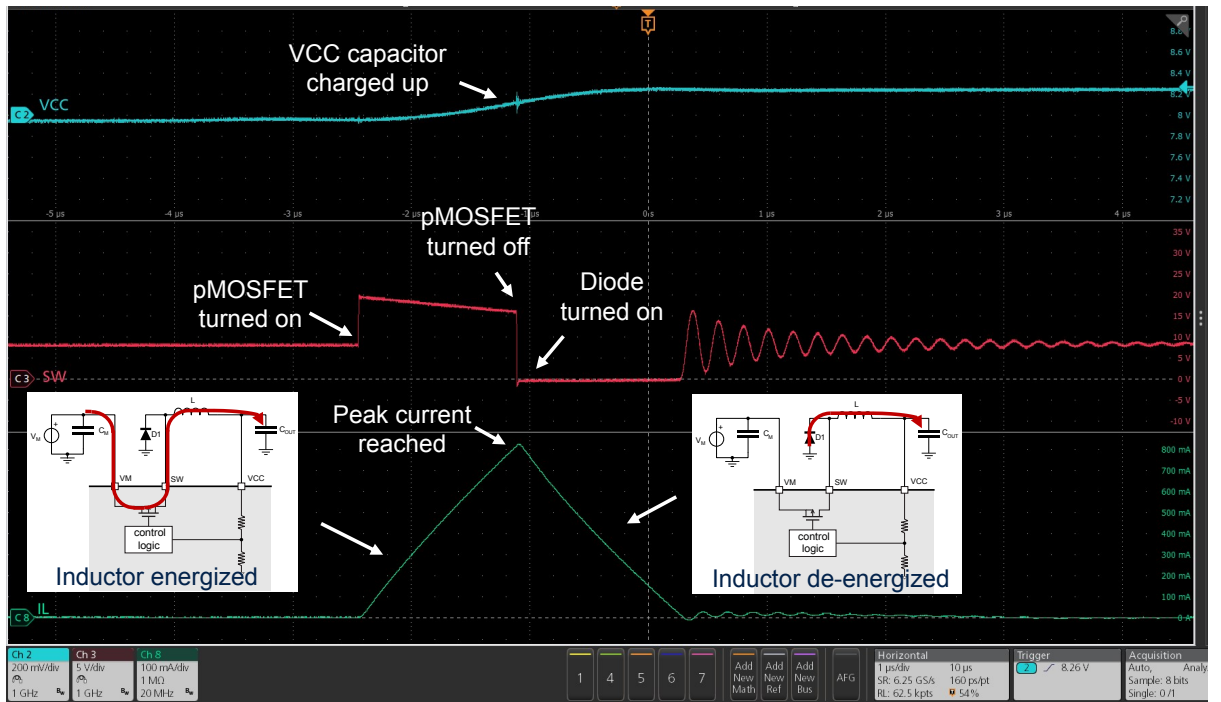
1.1 Operating principle

The operating principle of the Buck regulator is based on hysteretic control as detailed below with reference to Figure 2.

When VCC voltage becomes lower than the target value, the control logic of the Buck regulator turns on the integrated p-channel MOSFET connecting SW pin to VM supply. In this phase the inductor L is energized and the output capacitor C_{OUT} is charged. The current flowing out the SW pin is sensed by control logic and the MOSFET is turned off reaching $I_{peak,Buck}$ (750 mA typical value). At this moment, the inductor current recirculates through the diode D1 and continues to charge the output capacitor. Depending on operating conditions and selected components, the de-energization of the inductor can complete before a new energization phase begins or not. Indeed, the controller generates a new SW pulse with a frequency of $f_{SW,Buck}$ (500 kHz typical value) until the VCC voltage reaches the target value. When target has been reached, no more pulses are generated until the VCC voltage drops below the hysteresis of an internal feedback comparator. A minimum off-time $t_{OFF,Buck\ min}$ (220 ns typical value) for the MOSFET is guaranteed between consecutive SW pulses.

Given the operating principle of the Buck regulator it results that output voltage VCC can be regulated only with VM sufficiently greater than the target VCC set point since a minimum drop between input and output voltages is needed to produce a current flow across the inductor. Below a certain supply level the VCC output voltage is lower than VM depending on load condition and selected inductor.

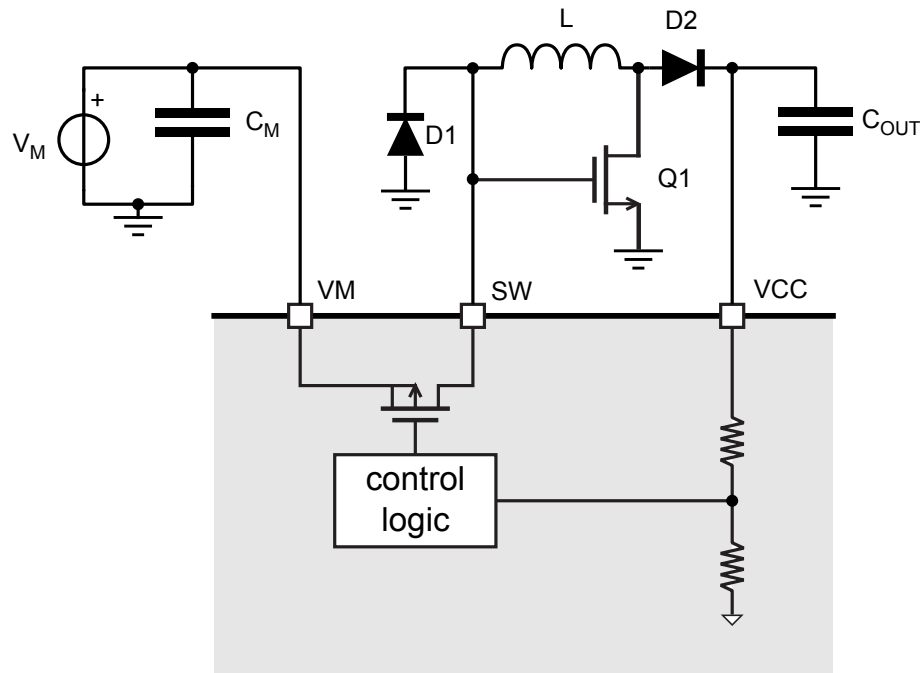
Figure 2. Buck converter switching



2 Buck-Boost regulator

The circuitry of the Buck regulator inside the STSPIN32G4 can be used to implement a Buck-Boost regulator as presented in [Figure 3](#). The Buck-Boost regulator requires only one diode and one n-channel MOSFET more compared to the Buck regulator. The Buck-Boost provides the selected VCC output voltage starting with a VM supply voltage between 5.5 V and 15 V.

Figure 3. Buck-Boost regulator



2.1 Operating principle

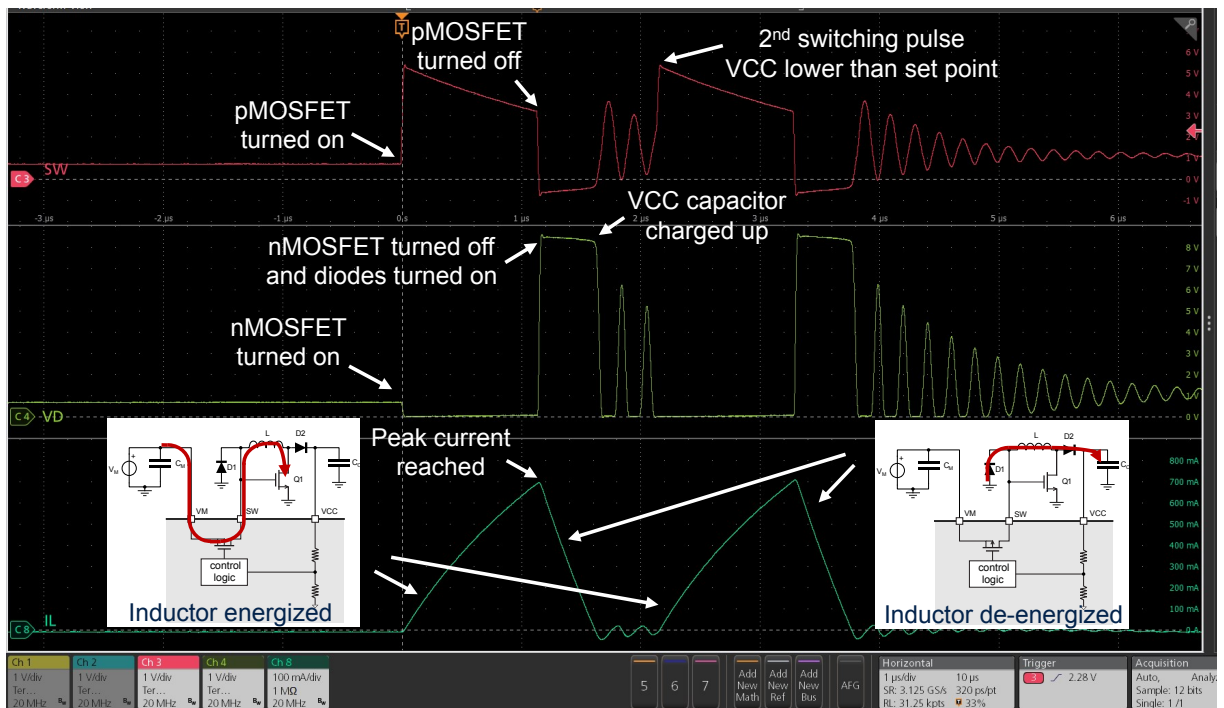
The presented circuit is a variant of a typical Buck-Boost converter where the turn-on/off signal of the n-channel MOSFET is derived from the SW pin instead of being provided by a dedicated control logic circuitry.

The converter behavior is shown in [Figure 4](#). When the VCC voltage goes below the set point the p-channel MOSFET inside the STSPIN32G4 is turned on and the SW pin is pulled high to VM supply (SW voltage in [Figure 4](#)).

Consequently, the external n-channel MOSFET Q1 gets turned on (MOSFET drain voltage V_D in [Figure 4](#)) and the inductor starts to be energized (I_L current in [Figure 4](#)) while diodes D1 and D2 are off. The control logic inside the STSPIN32G4 turns off the p-channel MOSFET as soon as the current flowing through the SW pin exceeds the peak threshold or if the maximum on-time expires without reaching the threshold.

In both cases, the inductor current starts flowing through diode D1, forcing the SW node below ground and turning off Q1 MOSFET. The inductor current flows into the output capacitor C_{OUT} through D1 and D2 diodes: the inductor is de-energized and capacitor C_{OUT} is re-charged increasing VCC voltage. Equivalent to the operation of the Buck converter (see [Section 1.1](#)), no more pulses are generated for the time VCC voltage remains greater than its set point.

Figure 4. Buck-Boost converter switching



2.2 Component selection

The reference part numbers of the Buck-Boost regulator can be seen in Table 1.

Table 1. Buck-Boost regulator - Reference part numbers

Part name	Part value / description	Part reference	Manufacturer
L	6.8 μ H SMT power inductor	74438323068	Würth Elektronik.
D1, D2	Schottky diodes	STPS0530Z	STMicroelectronics
Q1	n-channel MOSFET	STT6N3LLH6	STMicroelectronics
C _{OUT}	10 μ F low ESR SMT ceramic capacitor	-	-

The selected inductor should have a saturation current of at least 1 A and rating for continuous current greater than 500 mA.

Schottky diodes with maximum reverse voltage greater than 25 V and repetitive peak current higher than 1 A should be used.

Pay attention to n-channel MOSFET selection since this component may affect maximum and minimum operating voltages of the regulator. It is recommended to select a MOSFET with 20 V Absolute Maximum Rating (AMR) for gate voltage and a threshold voltage lower than 2.5 V to guarantee proper turning-on with minimum supply voltage. The typical on resistance should be lower than 100 m Ω to not significantly reduce the voltage drop applied to the inductor during energization phase.

A generic ceramic capacitor with low ESR can be selected for the output capacitor of the converter with a value of 10 μ F.

2.3 Performance

The Buck-Boost regulator provides reduced current capability compared to the Buck regulator since during the energization phase the inductor current is not provided to the output capacitor. The output current corresponds to the average current of diode D2 and mainly depends on VCC set point and inductor value. Table 2 reports the maximum output current of the regulator using recommended components. Higher VCC set point provides reduced current capability since the inductor takes less time to de-energize and D2 average current reduces consequently.

Table 2. Maximum output current of Buck-Boost regulator

VCC	ICC _{MAX}
8 V	70 mA
10 V	60 mA
12 V	50 mA
15 V	40 mA

The efficiency of the converter was measured in different operating conditions using recommended components. Figure 5 shows the Buck-Boost efficiency in the whole range of input and output voltages with the regulator loaded at 40 mA, i.e. the maximum output current allowed for all output voltages.

Figure 5. Efficiency of Buck-Boost regulator vs. VM supply voltage

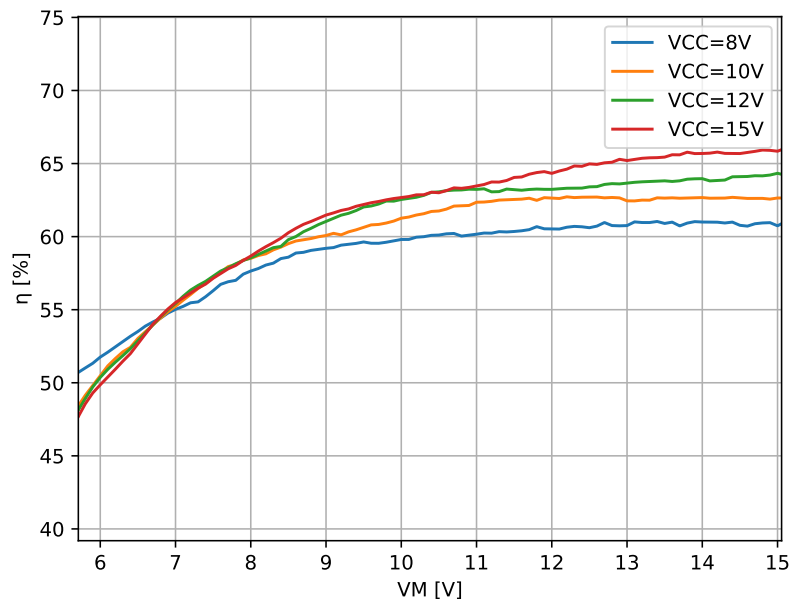
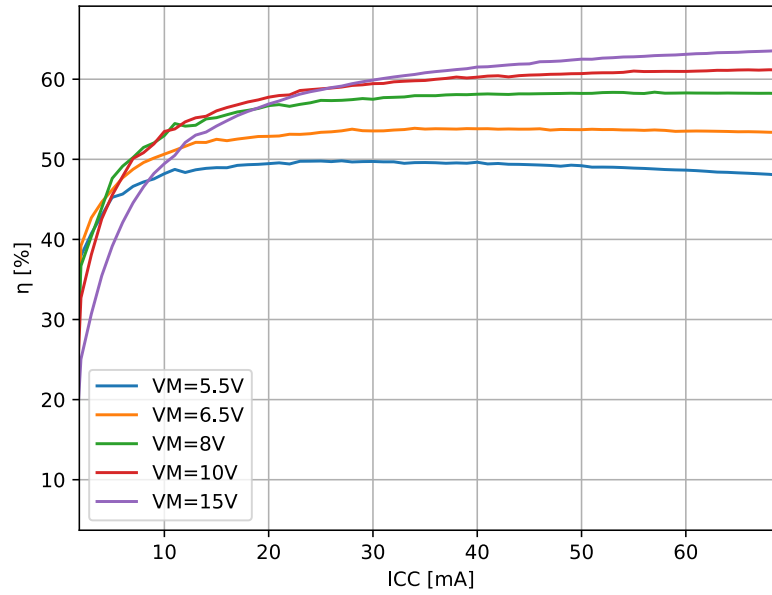


Figure 6 shows the converter efficiency changing the loading current. The measures are at several input voltages for an output voltage of 8 V. Efficiency for the other output voltages is equivalent.

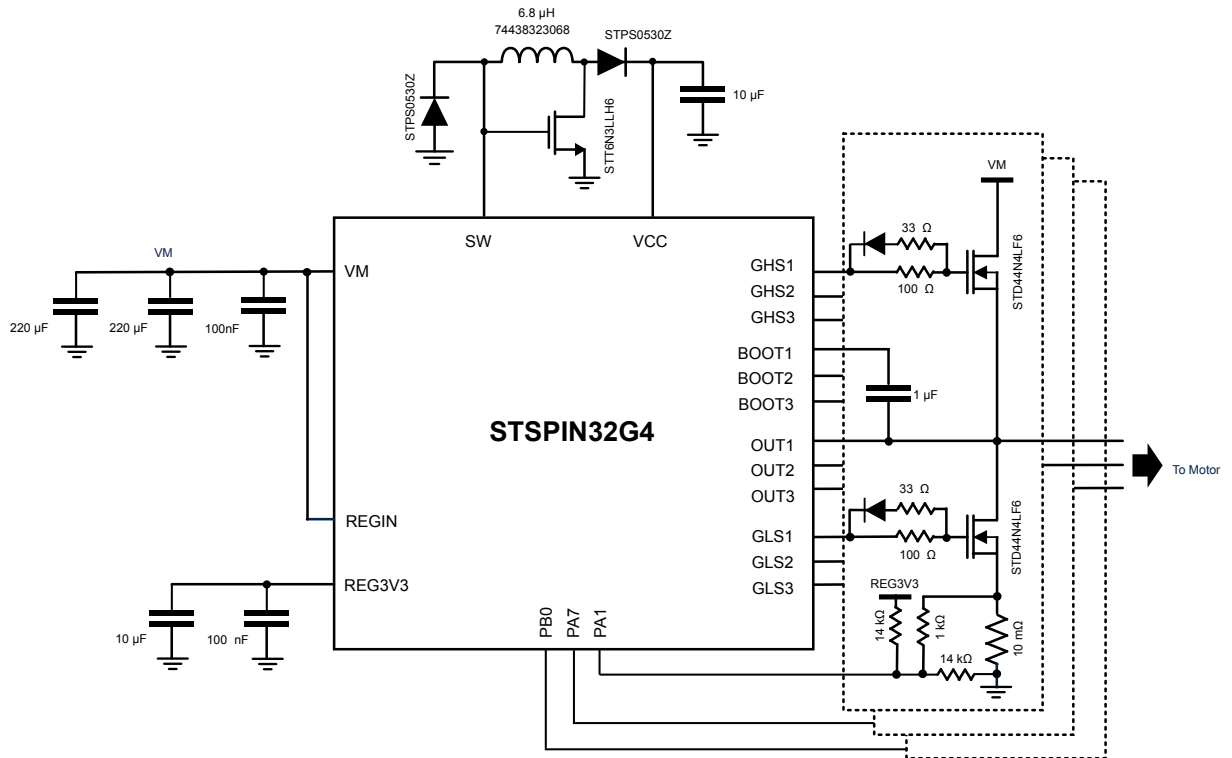
Figure 6. Efficiency of Buck-Boost regulator vs. ICC output current (VCC = 8 V)



3 Application example

To evaluate the performance of the Buck-Boost converter in an applicative scenario, a board for driving three-phase brushless motors was designed as shown in Figure 7. This board implements a basic Buck-Boost powered inverter using the STSPIN32G4.

Figure 7. Simplified schematic of Buck-Boost board



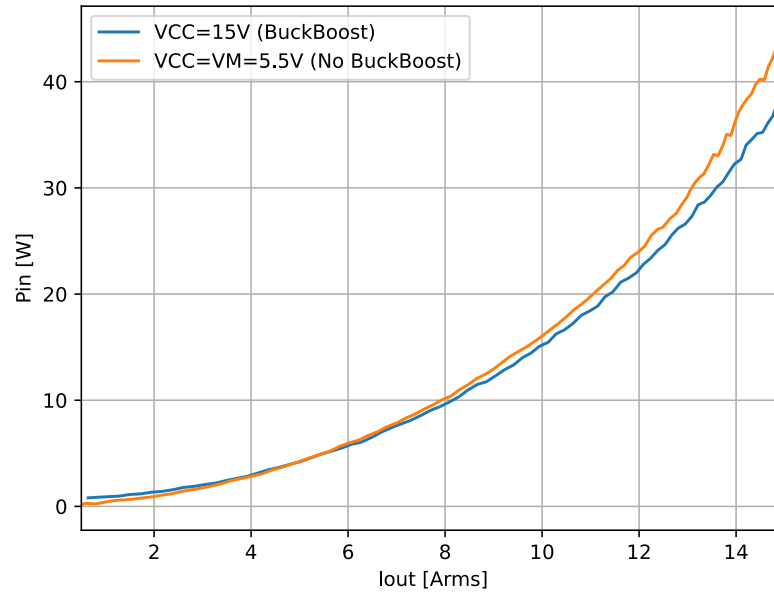
The input of the 3.3 V linear regulator, RGIN pin, was connected to main voltage VM conversely to a typical application of the STSPIN32G4 where the regulator is usually cascaded to the Buck converter. This is the recommended configuration so that current capability of the Buck-Boost regulator is entirely available for the driving of power MOSFETs. Using this topology, the standby feature of the STSPIN32G4 with the integrated low power regulator is available but the maximum VM voltage should never exceed the ratings of the RGIN pin whatever n-channel MOSFET is used for Buck-Boost implementation.

The power stage of the board is based on six STD44N4LF6 n-channel power MOSFETs that were selected for their very good performance when turned on at gate voltage as low as 5 V. However, even these MOSFETs that are optimized for low driving voltage shows a not negligible variation of their channel resistance with gate voltage. This drift directly influences inverter efficiency as evident from Figure 8.

The input power to the board was measured at the minimum supply voltage of 5.5 V and increasing the output current flowing into a three-phase load up to the maximum board rating. In the first condition the Buck-Boost converter was enabled to generate a VCC voltage of 15 V, while in the second condition the converter was disabled and VCC shorted to VM.

Focusing on the crossing of the two curves in Figure 8, the Buck-Boost solution reduces the overall power losses of the inverter when operated with currents above roughly 5 A_{rms} . Notably for this board, a power saving of more than 5 W was achieved at the maximum current rating of 15 A_{rms} .

Figure 8. Input power vs. output current of the board with and without Buck-Boost converter



Besides efficiency improvement, the use of Buck-Boost converter:

- Simplify the tuning of MOSFETs gate network obtaining a stable switching performance of the inverter to variations of main supply voltage as in the case of battery powered systems.
- Allow using MOSFETs not specifically designed for low voltage driving.

4 Conclusion

This application note described how to implement a Buck-Boost regulator using the STSPIN32G4 and few external components. This implementation represents a cheap and quick solution to obtain a stable and configurable voltage that can be higher or lower than the main supply voltage of the system. The current capability of the converter can be used to power small loads in the system while driving the gates of power MOSFETs.

Finally, using the STSPIN32G4 with a Buck-Boost converter, the efficiency of motor inverter can be significantly improved in those applications targeting high output currents with low supply voltages.

Revision history

Table 3. Document revision history

Date	Version	Changes
03-Nov-2021	1	Initial release.

Contents

1	Overview of Buck regulator	2
1.1	Operating principle	2
2	Buck-Boost regulator	4
2.1	Operating principle	4
2.2	Component selection	5
2.3	Performance	6
3	Application example	8
4	Conclusion	10
	Revision history	11
	Contents	12
	List of tables	13
	List of figures	14

List of tables

Table 1.	Buck-Boost regulator - Reference part numbers	5
Table 2.	Maximum output current of Buck-Boost regulator	6
Table 3.	Document revision history	11

List of figures

Figure 1.	Buck regulator	2
Figure 2.	Buck converter switching	3
Figure 3.	Buck-Boost regulator	4
Figure 4.	Buck-Boost converter switching	5
Figure 5.	Efficiency of Buck-Boost regulator vs. VM supply voltage	6
Figure 6.	Efficiency of Buck-Boost regulator vs. ICC output current (VCC = 8 V)	7
Figure 7.	Simplified schematic of Buck-Boost board	8
Figure 8.	Input power vs. output current of the board with and without Buck-Boost converter	9

IMPORTANT NOTICE – PLEASE READ CAREFULLY

STMicroelectronics NV and its subsidiaries (“ST”) reserve the right to make changes, corrections, enhancements, modifications, and improvements to ST products and/or to this document at any time without notice. Purchasers should obtain the latest relevant information on ST products before placing orders. ST products are sold pursuant to ST’s terms and conditions of sale in place at the time of order acknowledgement.

Purchasers are solely responsible for the choice, selection, and use of ST products and ST assumes no liability for application assistance or the design of Purchasers’ products.

No license, express or implied, to any intellectual property right is granted by ST herein.

Resale of ST products with provisions different from the information set forth herein shall void any warranty granted by ST for such product.

ST and the ST logo are trademarks of ST. For additional information about ST trademarks, please refer to www.st.com/trademarks. All other product or service names are the property of their respective owners.

Information in this document supersedes and replaces information previously supplied in any prior versions of this document.

© 2021 STMicroelectronics – All rights reserved