Application Note

DRV8662, DRV2700, DRV2665, and DRV2667 Configuration Guide

Brian Burk *Haptic and Piezo Products*

ABSTRACT

The DRV8662, DRV2700, DRV2665, and DRV2667 are high-voltage, Piezo drivers each with an integrated boost converter and amplifier. The integrated high-voltage solution eliminates design complexities and reduces the overall solution size for driving Piezos.

These devices have been designed for simplicity and are easy to configure; however, there are some common design issues that should be avoided. This application note discusses boost converter basics, hysteretic boost operation, and describes the proper steps for configuring the boost converter including calculating the load requirements, selecting the inductor, current limit resistor, input capacitor, and output capacitor.

Table of Contents

1 Boost Converter Basics ... 3
2 DRV8662, DRV2700, DRV2665, and DRV2667 Boost Converter ... 4
2.1 DRV8662, DRV2700, DRV2665, and DRV2667 Boost Converter Efficiency ... 5
2.2 DRV8662, DRV2700, DRV2665, and DRV2667 Boost Converter Load Regulation ... 6
3 Configuring the Boost Converter ... 7
4 Boost Converter Output Voltage ... 7
5 Calculating the Load Current ... 8
6 Selecting an Inductor ... 8
6.1 Inductance Rating ... 9
6.2 Saturation Current Rating ... 9
6.3 Thermal Current Rating ... 10
6.4 Choosing R_{EXT} ... 11
6.5 What to Avoid: Using Incorrect Inductor Current Ratings ... 11
7 Calculate the Maximum Boost Current ... 13
8 Output Capacitor Selection ... 13
9 Input Capacitor Selection ... 14
10 PCB Layout ... 16
10.1 What to Avoid: Incorrect Inductor Placement ... 17
11 Examples ... 19
11.1 Example: Based on the DRV8662EVM ... 19
11.2 Example: Based on the DRV2667EVM-CT with 25-nF Piezo Module ... 23
12 Revision History ... 27

List of Figures

Figure 2-1. Efficiency with V_{BST} = 30 V ... 5
Figure 2-2. Efficiency with V_{BST} = 55 V ... 5
Figure 2-3. Efficiency with V_{BST} = 80 V ... 5
Figure 2-4. Efficiency with V_{BST} = 105 V ... 5
Figure 2-5. Load Regulation with V_{BST} = 30 V ... 6
Figure 2-6. Load Regulation with V_{BST} = 55 V ... 6
Figure 2-7. Load Regulation with V_{BST} = 80 V ... 6
Figure 2-8. Load Regulation with V_{BST} = 105 V ... 6
Figure 6-1. Inductance vs DC Current ... 10
Figure 10-1. SW Node Parasitic Capacitance ... 17
Figure 10-2. Inductor Charging with Parasitic Capacitance ... 17

Copyright © 2021 Texas Instruments Incorporated

Figure 11-1. Simplified Version of the DRV8662EVM....19
Figure 11-2. Actual Load Regulation and Boost Efficiency....22
Figure 11-3. Boost Efficiency....22
Figure 11-4. Simplified Version of the DRV2667EVM-CT Schematic....23
Figure 11-5. Boost Voltage vs Boost Current - DRV2667EVM-CT-80 V....26
Figure 11-6. Efficiency vs Boost Current - V_{BST} = 80 V....26

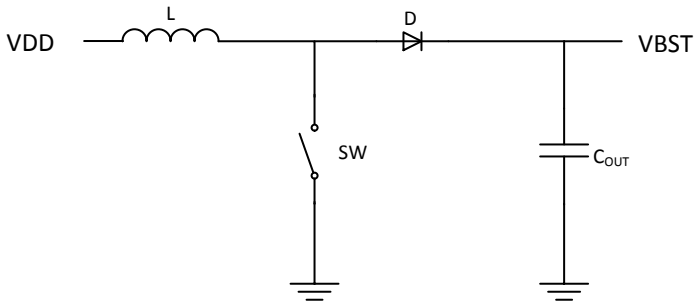
Trademarks

All trademarks are the property of their respective owners.

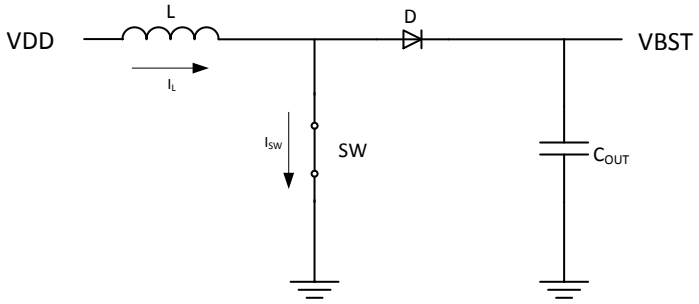
Copyright © 2021 Texas Instruments Incorporated

1 Boost Converter Basics

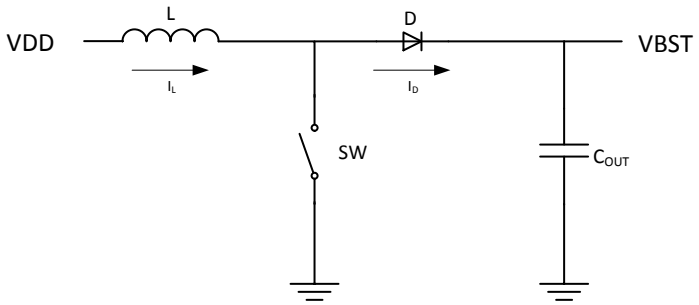
A boost converter, as the name implies, converts a low voltage power rail and boosts it to a higher voltage. A boost converter consists of three main components: an inductor, a switch (MOSFET), and a diode. The basic boost converter schematic is shown in the following figure.



To convert the low voltage to a high voltage, the boost converter operates in two phases. In the first phase the inductor is charged by closing the switch and forcing current through the inductor to ground. During this period the current through the inductor increases allowing the inductor to store charge.



Once the inductor current reaches a maximum threshold, the switch opens and forces the inductor to dump the stored charge through the diode and onto the output capacitor and load.



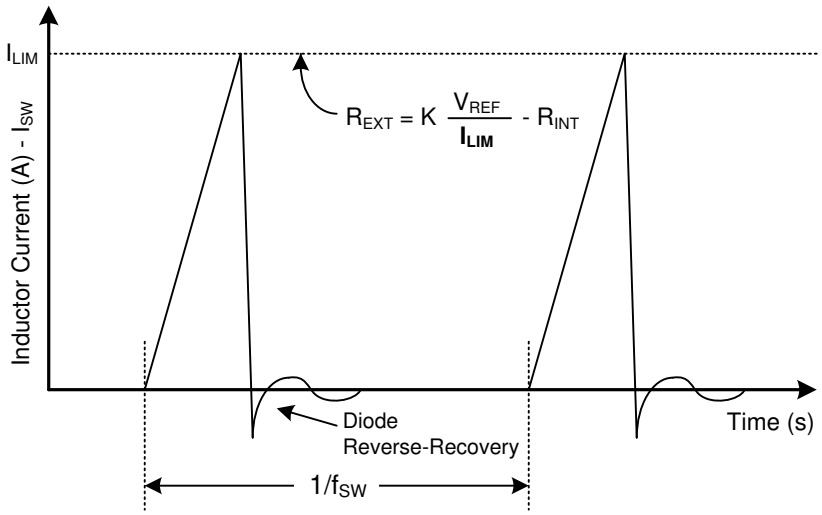
By repeating this charge and dump process, the boost converter is able to increase the output voltage.

Copyright © 2021 Texas Instruments Incorporated

2 DRV8662, DRV2700, DRV2665, and DRV2667 Boost Converter

The DRV8662, DRV2700, DRV2665, and DRV2667 use a hysteretic boost converter design to generate the high voltage needed to drive Piezos. This section describes the basic operating principle of the hysteretic boost converter.

The hysteretic boost converter uses fairly simple feedback to control the timing and frequency of the switch. The I_{LIM} value in the following figure is the peak current through the inductor every time the switch turns on. Once the peak current is reached, the switch opens. The peak inductor current of the DRV8662, DRV2665, and DRV2667 is set by the resistor on the REXT pin (pin 15).



The boost converter only switches when the output voltage (V_{BST}) is below the final target value, meaning that it will only switch when it needs to. Unlike a fixed-frequency boost converter design, the hysteretic boost converter design has a continually varying switching frequency and is load-dependent. Note that the DRV8662, DRV2665, and DRV2667 have forced switching at approximately 37 kHz.

Copyright © 2021 Texas Instruments Incorporated

2.1 DRV8662, DRV2700, DRV2665, and DRV2667 Boost Converter Efficiency

The boost converter efficiency for the DRV8662, DRV2700, DRV2665, and DRV2667 is shown in Figure 2-1 through Figure 2-4. The measurements were taken using the DRV8662EVM.

2.1.1 Boost Efficiency vs Boost Current

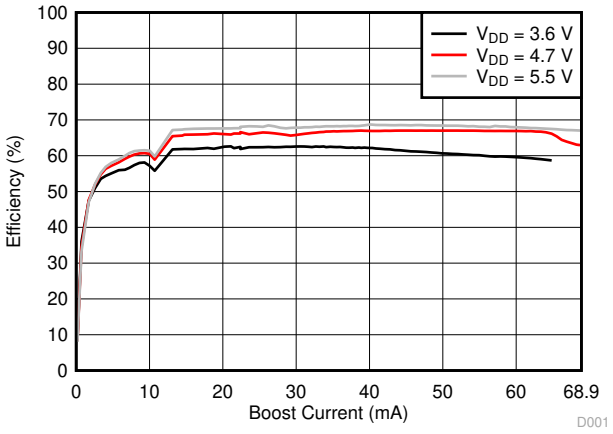


Figure 2-1. Efficiency with V_{BST} = 30 V

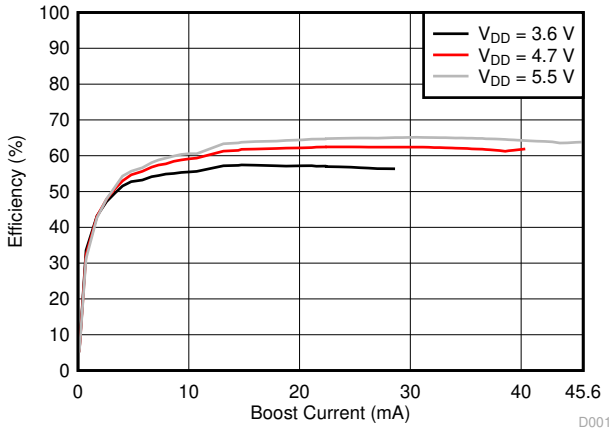


Figure 2-2. Efficiency with V_{BST} = 55 V

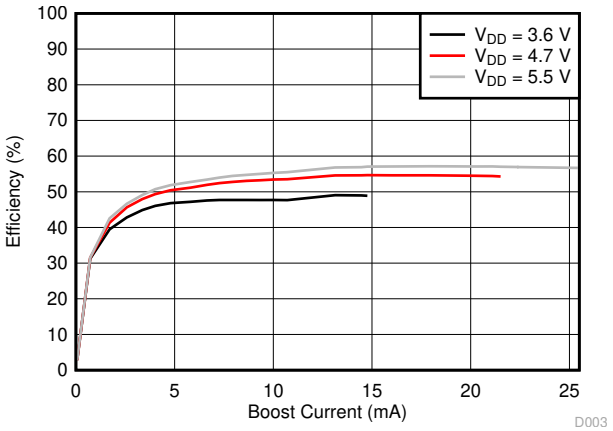


Figure 2-3. Efficiency with V_{BST} = 80 V

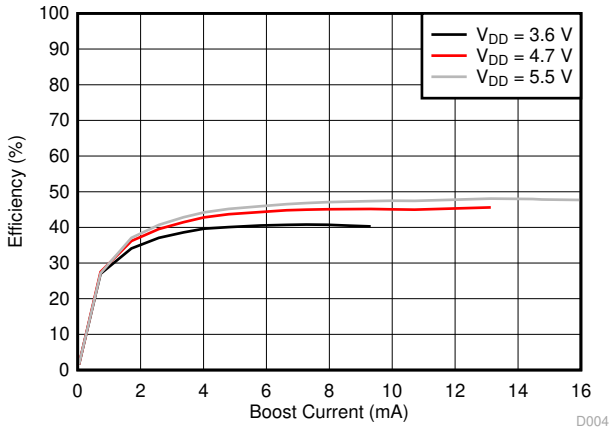


Figure 2-4. Efficiency with V_{BST} = 105 V

Copyright © 2021 Texas Instruments Incorporated

2.2 DRV8662, DRV2700, DRV2665, and DRV2667 Boost Converter Load Regulation

The boost converter load regulation for the DRV8662, DRV2700, DRV2665, and DRV2667 is shown in Figure 2-5 through Figure 2-8. The measurements were taken using the DRV8662EVM.

2.2.1 Boost Regulation vs Current

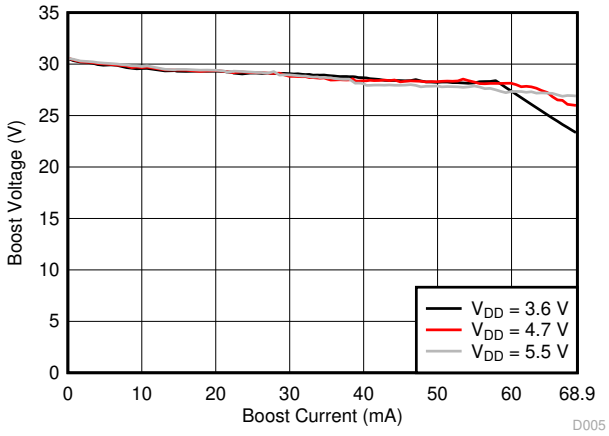


Figure 2-5. Load Regulation with V_{BST} = 30 V

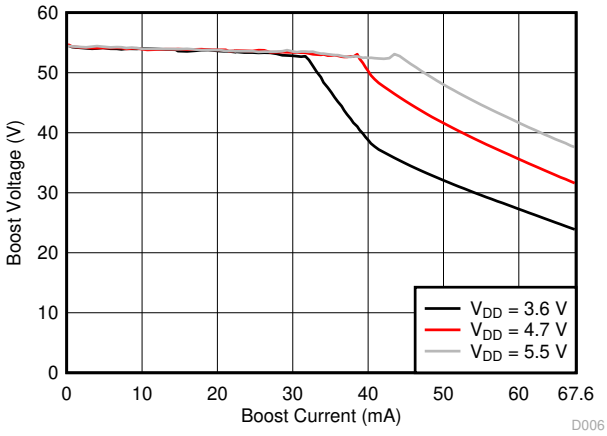


Figure 2-6. Load Regulation with V_{BST} = 55 V

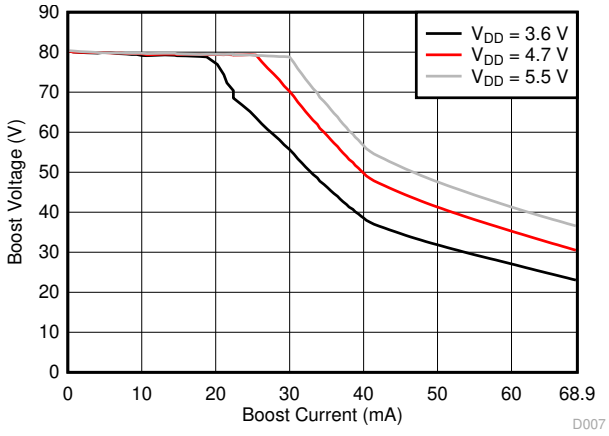


Figure 2-7. Load Regulation with V_{BST} = 80 V

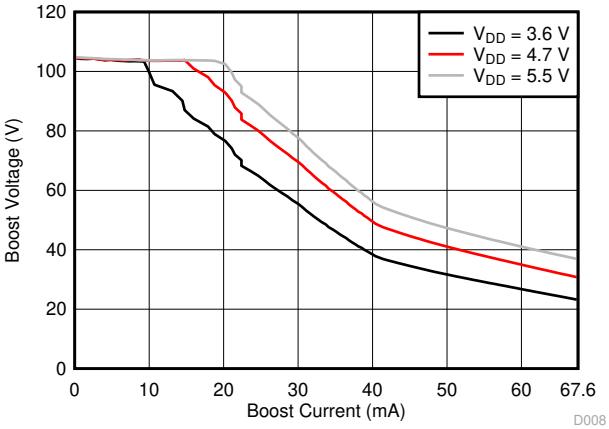


Figure 2-8. Load Regulation with V_{BST} = 105 V

Copyright © 2021 Texas Instruments Incorporated

3 Configuring the Boost Converter

This section describes the basic steps for configuring the boost converter. See the following sections for more details.

1. **Select the boost voltage.**
   Based on the rated voltage of the load, set the feedback resistors to the appropriate boost voltage (Section 4).
2. **Calculate the load current.**
   Estimate the maximum required load current to support the voltage, capacitance, and frequency of the load (Section 5).
3. **Select an inductor.**
   Choose an inductor with an inductance value between 3.3 µH and 22 µH, and a saturation current rating more than 1 A (Section 6).
4. **Set the current limit and R_{EXT} resistor.**
   Calculate the R_{EXT} resistor based on the saturation current of the inductor (Section 6.4).
5. **Compare the maximum boost current.**
   Compare the maximum boost current with the required load current calculated in step 2 (Section 7).
6. **Choose an input and output capacitor.**
   Input and output capacitors help reduce the effects of ripple and transient load currents on the supply and output voltages (Section 8).
7. **Verify performance.**
   Verify the performance of the components selected.

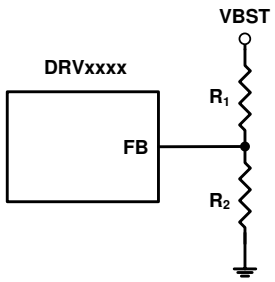
4 Boost Converter Output Voltage

Set the boost converter based on the rated or maximum voltage required by the load. Add an additional 5 V to provide headroom when using the amplifier. Use Equation 1 to calculate the boost voltage.

$$V_{BOOST} = V_{PEAK} + 5\ V \quad (1)$$

Symbol	Description	Value	Unit
V_{BOOST}	Boost output voltage	-	V
V_{PEAK}	Peak amplifier output voltage	-	V

The boost output voltage is programmed by two external resistors shown in the following diagram:



The boost feedback resistors can be calculated using equation Equation 2:

$$V_{BOOST} = V_{FB}\left(1 + \frac{R_1}{R_2}\right) \quad (2)$$

Note

Ensure that the sum of R_1 and R_2 is greater than 400 kΩ to prevent large leakage currents due to high voltages on V_{BOOST}.

Copyright © 2021 Texas Instruments Incorporated

5 Calculating the Load Current

The peak load current of the DRV8662, DRV2700, DRV2665, or DRV2667 on the OUT+ and OUT– terminals can be approximated using Equation 3.

$$I_{(load\text{-}peak)} = 2\pi \times C_{LOAD} \times V_{BOOST} \times f_{MAX} \quad (3)$$

Symbol	Description	Value	Unit
C_{LOAD}	Load capacitance	–	F
V_{BOOST}	Boost voltage	–	V
f_{MAX}	Maximum output frequency	–	f

Use the load parameters capacitance, boost voltage (peak output voltage), and maximum output frequency to estimate the peak current required at the load. This provides a rough current approximation that can be used to estimate the inductor size for the boost design.

6 Selecting an Inductor

The inductor plays a critical role in the performance of the DRV8662, DRV2700, DRV2665, and DRV2667, so selecting and testing a suitable inductor is important to ensure the best performance.

An inductor can be described with relatively few parameters. The following table shows the typical parameters listed in an inductor datasheet:

Part Number	Inductance (µH)	DC Resistance (Ω)	$I_{SATURATION}$ (A)	I_{RMS}	SRF (MHz)
CIG22E3R3SNE	3.3	0.200	1.1	1.30	42

DEFINITIONS
Inductance – the primary functional parameter of an inductor.
DC Resistance (DCR) – the resistance in the inductor due to the wire
$I_{SATURATION}$ or Saturation Current – the peak current flowing through the inductor that causes the inductance to drop due to core saturation.
IRMS or RMS Current or Thermal Current – the amount of continuous RMS current flowing through the inductor that causes the maximum allowable temperature rise.
SRF or Self Resonant Frequency – the frequency at which the inductance of the inductor winding resonates with the capacitance of the inductor winding.

To help narrow the number of inductors quickly, begin by looking at these three parameters:

1. Inductance – the range of recommend inductances is from 3.3 µH to 22 µH.
2. Saturation Current (I_{SAT}, 30% decrease in inductance due to DC current) – saturation current should typically be above 1 A for most applications, but will vary depending on the load. Use the examples at the end of this document as a reference for choosing an inductor.
3. RMS Current or Thermal Limit – the RMS current is less of an issue for haptic applications because of the low duty cycle of operation; however, in other applications where continuous operation is likely, be sure to select an appropriate RMS current rating.

Inductor current ratings are always the biggest source of confusion when selecting an inductor, because there are multiple, non-standardized current ratings to look for. See Section 6.5 for more information on inductor current ratings.

Copyright © 2021 Texas Instruments Incorporated

See the following sections for more information on each parameter.

Note

The inductor will see high voltages ($V_{BST} – V_{DD}$) during normal operation. Ideal inductors do not have a voltage rating and thus most manufacturers will not publish a voltage rating; however, certain inductor core materials have voltage limitations. Please contact the manufacturer and ensure that the inductor material can operate at high voltages.

6.1 Inductance Rating

The inductance sets the maximum switching frequency of the boost converter. The general trade off with inductances between 3.3 µH and 22 µH are:

- **Larger inductances (10 µH or greater)**
  - *Advantage:* Cause the boost converter to run at a lower switching frequency meaning less switching losses.
  - *Disadvantage:* Larger values typically have higher series resistance and lower saturation currents, requiring physically larger inductors.
- **Smaller inductances (Less than 10 µH)**
  - *Advantage:* Typically have higher saturation currents and are a better choice for maximizing output current of the boost converter per inductor area.
  - *Disadvantage:* Higher switching frequencies can lead to more losses. Switching losses are not a major concern in most applications, but if thermal dissipation is a concern because of a small PCB or extreme temperatures, then consider using a larger inductance.

The approximate switching frequency can be calculated using Equation 4:

$$f_{switching} = I_{LIMIT} \times L \left(\frac{1}{V_{IN}} + \frac{1}{V_{IN} - V_{BOOST}} \right) \quad (4)$$

Symbol	Description	Value	Unit
$f_{switching}$	DRVxxx switching frequency	–	Hz
V_{IN}	Minimum V_{DD} voltage applied to the DRVxxxx	–	V
V_{BOOST}	Maximum boost output voltage	–	V
I_{LIMIT}	Current limit set by the DRVxxxx REXT resistor	–	A_p

Tip
Smaller inductances (3.3 – 4.7 µH) are often preferred in space-constrained applications because of their size, higher saturation current, and ability to deliver more charge to the load.

6.2 Saturation Current Rating

Saturation current is the second-most important parameter of an inductor when using a hysteretic boost converter. Inductor saturation current is typically measured as the peak current that causes the inductance to decrease by 30%. This is the maximum operating current of the inductor.

In Figure 6-1, the saturation current for the 3.3-µH inductor is approximately 400 mA, which is the current that causes the inductance to reduce to 2 µH or by about 30%. A graph like Figure 6-1 can be used to determine and verify the saturation current rating of a specific inductor.

Copyright © 2021 Texas Instruments Incorporated

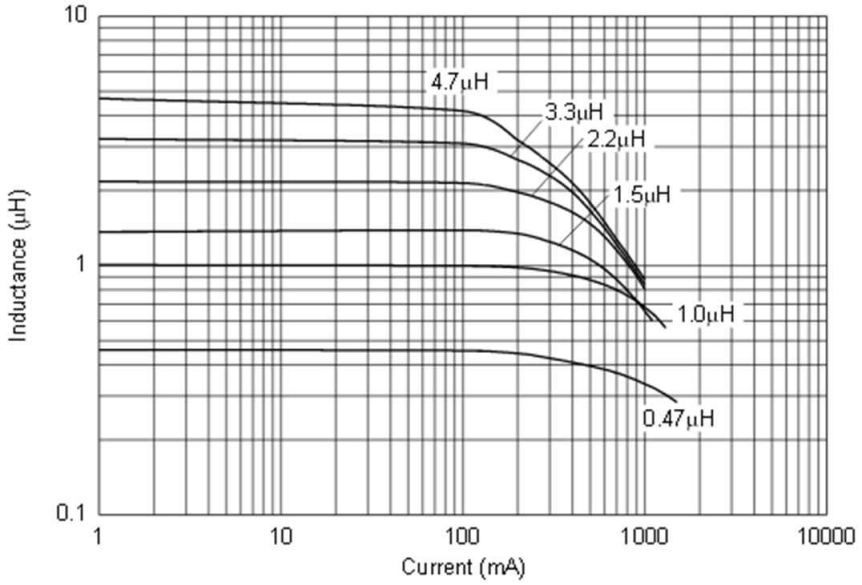


Figure 6-1. Inductance vs DC Current

The inductor saturation current value affects two things in the DRV8662, DRV2700, DRV2665, and DRV2667 boost design:

1. The amount of current that can be delivered to the load; the larger the saturation current, the larger amount of current can be delivered to the load.
2. The value of the current limit resistor (R_{EXT}) for the DRV8662, DRV2665, and DRV2667. It should be set equal to or less than the saturation current of the inductor. Section 6.4 describes how to choose the correct current limit resistor.

$$I_{LIM_DRVxxxx} \leq I_{Saturation_inductor} \quad (5)$$

Remember that the current limit on the DRV8662, DRV2665, and DRV2667 is not a safety mechanism, but a threshold to signal when the boost switch should open.

Tip
Often the saturation current is listed on the front page of an inductor datasheet; however, it is good practice to verify this value using an "Inductance vs DC Current" graph similar to Figure 6-1.

6.3 Thermal Current Rating

The thermal current rating is typically measured as the RMS current that causes some fixed rise in temperature (typically 20 – 30°C). Do not exceed this RMS current value.

Calculate the RMS current through the inductor using Equation 6. This is an approximation based on a triangular RMS waveform.

$$I_{RMS} = \frac{I_{LIMIT}}{\sqrt{3}} \quad (6)$$

Symbol	Description	Value	Unit
I_{RMS}	Inductor RMS Current	–	A_{RMS}
I_{LIMIT}	Peak current limit set by the DRVxxxx REXT resistor	–	A_p

Copyright © 2021 Texas Instruments Incorporated

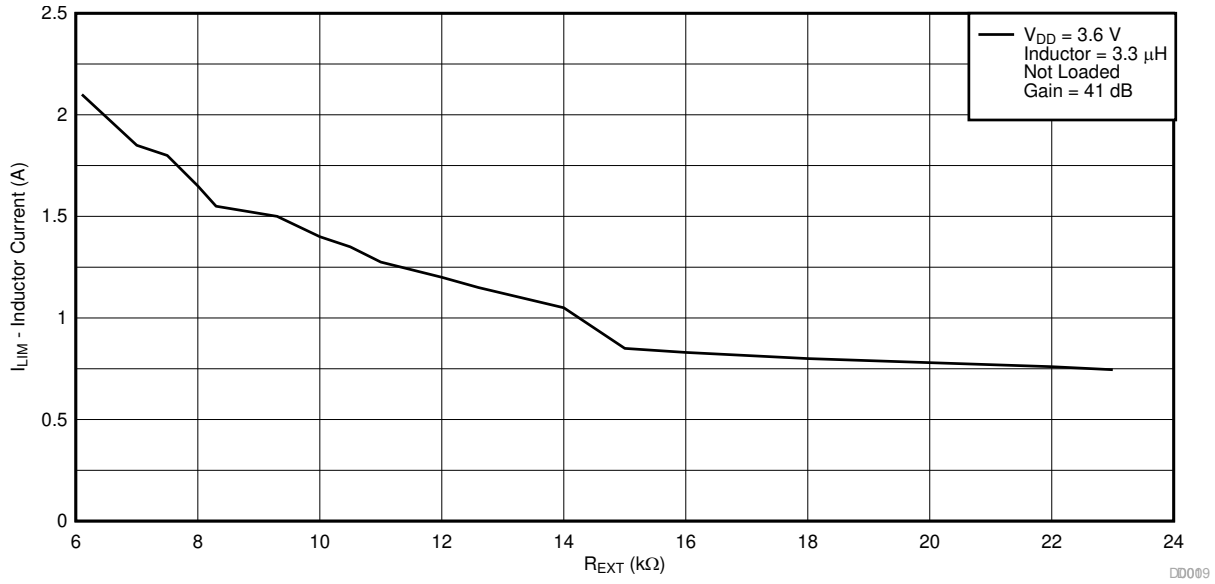
6.4 Choosing R_{EXT}

The resistor on the R_{EXT} pin is found using Equation 7:

$$R_{EXT} = \left(K \frac{V_{REF}}{I_{LIM}} \right) - R_{INT} \quad (7)$$

Symbol	Description	Value	Unit
K		10500	
V_{REF}	Internal reference voltage on REXT	1.35	V
R_{INT}	Internal resistance	60	Ω
I_{LIMIT}	Inductor current limit from inductor datasheet	–	A_p

The following graph shows the relationship between R_{EXT} and the current limit.



Use the R_{EXT} resistor to set the current limit for the inductor. This can serve two purposes:

1. **Prevent Inductor Saturation –** the current limit must be set equal to or lower than the inductor saturation current. If the inductance were to drop below 2.2 µH because of saturation, the boost converter may have difficulty regulating the output voltage.
2. **Limit Peak Battery Current –** the resistor can help limit the maximum current from the battery; however, a lower current limit decreases the amount of current delivered to the load each switch cycle.

Tip
The best way to lower peak battery currents is by adding a bulk input capacitor.

6.5 What to Avoid: Using Incorrect Inductor Current Ratings

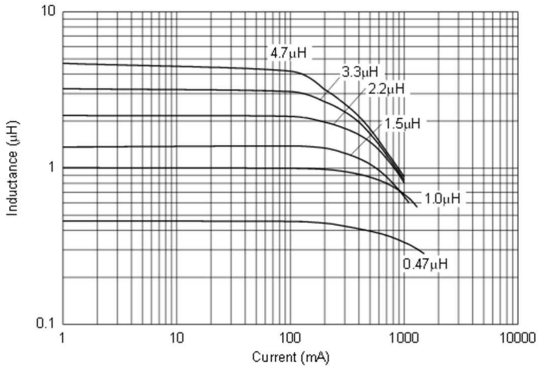
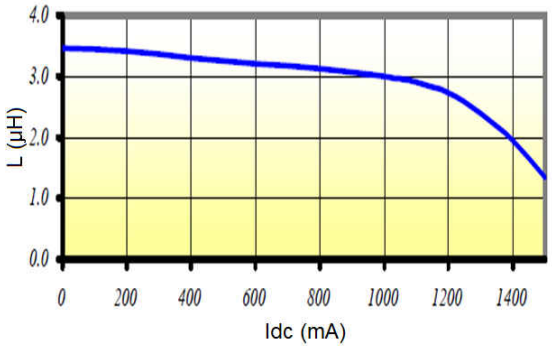
Manufacturers provide multiple current ratings, because boost converters typically operate with a very high peak-to-average ratio. This means there are very large current spikes, but the average current flowing through the inductor is very low. Because these are very different current operating points, the inductor manufacturers provide two current ratings to help make inductor selection easier: one for peak currents and one for RMS currents. The thermal current rating indicates maximum RMS currents, while the saturation current rating indicates maximum peak currents that could cause core saturation.

While inductor saturation current and thermal rating are readily available in most inductor datasheets, they are often obscured by manufacturer operating conditions and nomenclature. In some cases, one manufacturer may refer to one parameter as the *rated current* and another manufacturer may refer to a completely different

Copyright © 2021 Texas Instruments Incorporated

parameter as the *rated current*. The point of this section is to dispel any confusion and clarify what to look for when choosing the saturation current and thermal rating.

The following parameters are taken from two different inductor datasheets compared side-by-side. Both are good inductors, but only one has sufficient current ratings for a 1-A boost design.

Inductor 1 Murata – LQM2MPN3R3MG0L	**Inductor 2** TDK – VLS3010
Datasheet Front Page "Rated DC Current" Rated DC Current: 1.2 A	**Datasheet Front Page "Rated DC Current"** Rated DC Current: 1.1-1.3 A
Datasheet Graph Data I_{SAT} : 400 mA $I_{THERMAL}$: 1.2 A	**Datasheet Graph Data** I_{SAT} : 1.1–1.3 A $I_{THERMAL}$: 1.5 A
Inductance vs Peak Current	**Inductance vs Peak Current**
	

Inductor 1 (on the left) has a *Rated DC Current* of 1.2 A and Inductor 2 has a *Rated DC Current* between 1.1–1.3 A. Initially, both seem to work if our boost configuration requires 1 A; however, they are not equal.

If you notice the two parameters underneath "Rated DC Current" labeled I_{SAT} and $I_{THERMAL}$ are different. You can see that Inductor 1 has a thermal rating of 1.2 A, but only a 400 mA saturation current. Inductor 2 has a rated current of 1.1–1.3 A and a saturation current of 1.1–1.3 A and a thermal rating of 1.5 A. It is apparent from this comparison that "Rated DC Current" does not always refer to the same parameter, so be careful when choosing an inductor based on its current ratings.

Copyright © 2021 Texas Instruments Incorporated

7 Calculate the Maximum Boost Current

The maximum support boost current is estimated using Equation 8 and Equation 9.

First calculate the maximum duty cycle of the hysteretic converter. Equation 8 assumes worst-case duty cycle during maximum current.

$$D = 1 - \frac{V_{in_min} \times \eta}{V_{boost}} \tag{8}$$

Symbol	Description	Value	Unit
D	Boost Duty Cycle	–	–
V_{in_min}	Minimum V_{DD}	–	V
ETA (η)	Boost Efficiency	60	%
V_{boost}	Boost Voltage	–	V

If the approximate and the actual measurements do not align perfectly, then you can adjust η, which is the efficiency of the boost converter.

$$I_{boost_max} = \left(I_{limit} - \frac{I_{limit}}{2} \right) \times (1 - D) \tag{9}$$

Symbol	Description	Value	Unit
I_{boost_max}	Maximum boost current	–	A
I_{limit}	Boost current limit (R_{EXT})	–	A
D	Boost duty cycle	–	–

I_{boost_max} is the maximum boost current the boost can deliver to the amplifier. Compare this current to the current calculated for the load current. The boost current should be higher than the load current.

8 Output Capacitor Selection

The output capacitor is important for decreasing output voltage ripple and reducing the effects of load transients on the boost voltage. The boost output voltage can be configured from 20 V up to 105 V, so the boost output capacitor must have a voltage rating equivalent to the boost output voltage or higher. A 250-V rated, 100-nF capacitor of X5R or X7R type is recommended for a boost converter voltage of 105 V. The selected capacitor should have a minimum working capacitance of 50 nF.

To estimate the absolute minimum capacitance required, use Equation 10. Typically the DRVxxxx devices operate with a switching frequency between 800 kHz to 1 MHz. To include additional margin for the device loop response, it is best to use one-sixth of the switching frequency (f).

$$C = \frac{\Delta I}{2 \times f_{SW} \times V_{DROOP}} \tag{10}$$

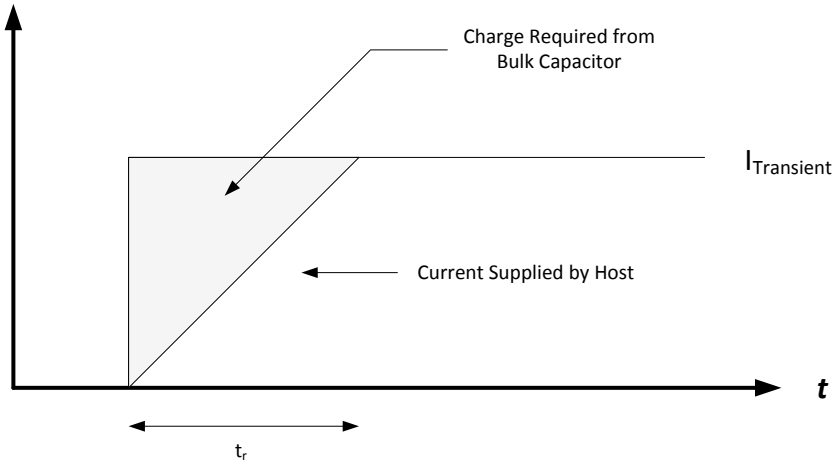
Symbol	Description	Value	Unit
DELTA I	Boost transient current	0 – 0.070	mA
V_{DROOP}	Maximum boost output voltage droop	–	V
f_{SW}	Boost switching frequency	Typically 800kHz-1MHz	Hz
C	Output capacitor	–	F

Copyright © 2021 Texas Instruments Incorporated

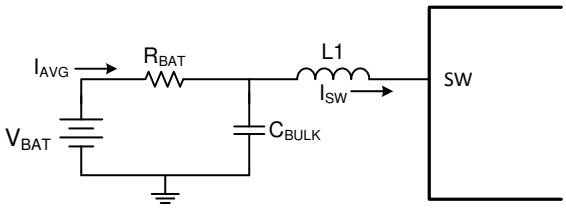
Tip
A guideline for ceramic capacitors: the de-rated capacitance is approximately equal to the rated capacitance multiplied by one minus the applied voltage over the rated voltage. $C_{de\text{-}rated} = C_{rated} (1 – V_{applied}/V_{rated})$ For example, when 50 V is applied to a 100-V rated capacitor, the capacitance will decrease by about 50%. Most capacitor vendors provide a capacitance versus voltage curve for reference.

9 Input Capacitor Selection

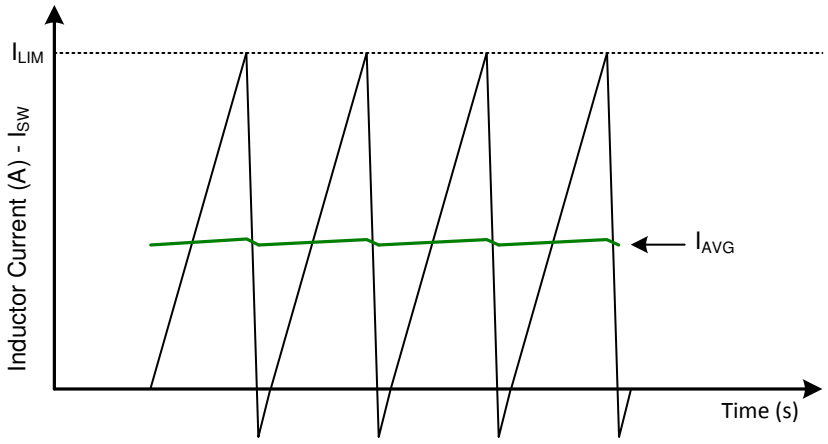
The input capacitor provides current to the DRVxxxx when there are large current transients during startup and heavy load periods.



When a bulk input capacitor is included, the following diagram shows that the battery actually sees a filtered version of I_{LIM}.



When the boost converter enters a heavy load condition or during a startup sequence, the switching frequency reaches a maximum value set by the slope of the charge/discharge curve and the I_{LIM} value.



Calculating the exact I_{AVG} value is rather difficult, but as long as the bulk decoupling capacitance in the system is sufficiently high, the average current drawn from the battery will be less than one-half of I_{LIM} as a general guideline.

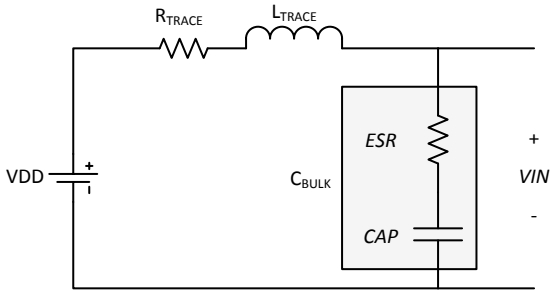
Copyright © 2021 Texas Instruments Incorporated

To estimate the bulk input capacitor value, use Equation 11.

$$C_{BULK} = \frac{1.21 \times I_{TR}^{2} \times L_{Trace}}{V_{DROOP}^{2}} \quad (11)$$

Symbol	Description	Value	Unit
C_{BULK}	Minimum V_{DD} bulk capacitance required	–	F
I_{TR}	Input transient current (maximum is I_{LIMIT})	–	A
L_{Trace}	Input trace inductance (estimate 50 nH, if unknown)	–	H
V_{DROOP}	Maximum boost output voltage droop (Ex.: 3.6 V – 0.1 V = 3.5 V, 0.1 V is the allowable droop)	–	V

This equation was derived from the RLC circuit formed by the trace resistance and inductance combined with the bulk capacitance and capacitor ESR.

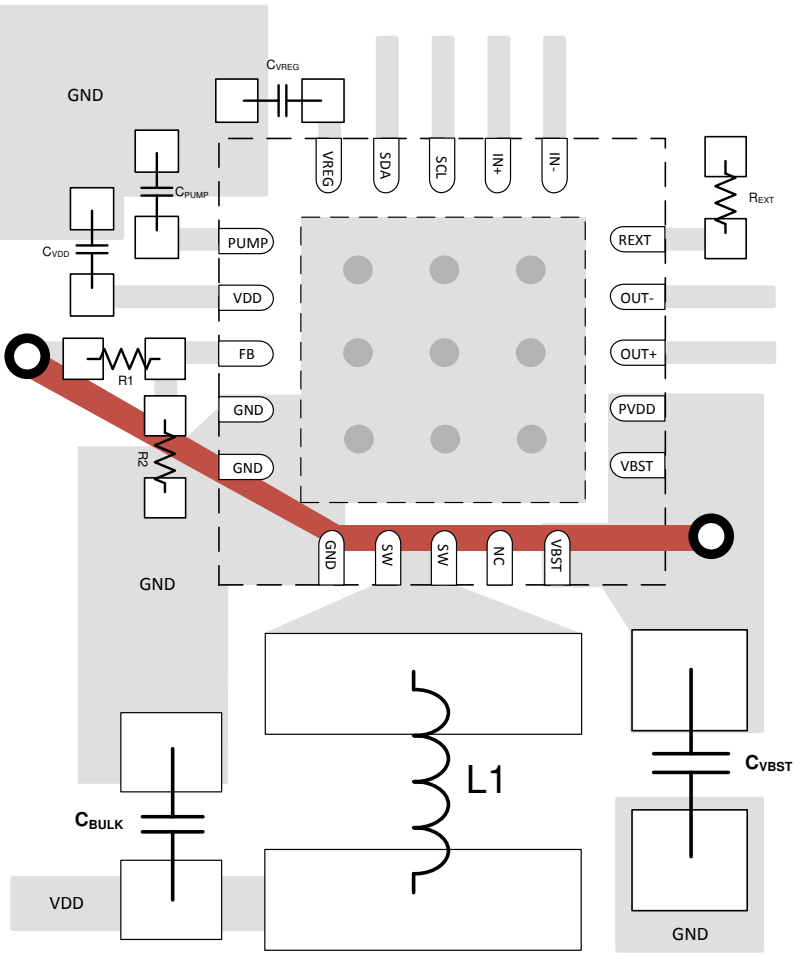


Keep in mind that it is difficult to calculate the exact input current required for the DRVxxxx, so a minimum capacitance between 22 µF and 47 µF is recommend.

Copyright © 2021 Texas Instruments Incorporated

10 PCB Layout

Use the following guidelines for PCB layout.



1. **Place the feedback resistors, R1 and R2, close to the FB pin.** If the resistors are placed far from the FB pin, then noise can enter the FB trace and causes instability or unwanted ripple.
2. **Protect the feedback trace (Red trace).** Isolate the feedback trace on a different layer and shield from the SW node using a ground plane.
3. **Minimize the size of SW node trace.** The trace between the SW pins and the inductor terminal should be as physically small as possible. A large switch node can add parasitic capacitance and slow the switching frequency of the boost converter, preventing it from delivering the required current. A small SW node also helps prevent radiated emissions.
4. **Place the bulk input capacitor near the inductor.** The bulk input capacitor provides the current during quick transient current spikes. Closer means less resistance between the bulk capacitor and inductor.
5. **Place the output capacitor near the VBST pin.**

Copyright © 2021 Texas Instruments Incorporated

10.1 What to Avoid: Incorrect Inductor Placement

In space-constrained applications, PCB *real estate* often trumps correct component placement. While layout guidelines were provided in the previous section, this section specifically covers inductor placement in more detail. The inductor should be placed as close to the SW node as possible; this helps reduce parasitic resistances, inductances, and most importantly, parasitic capacitances.

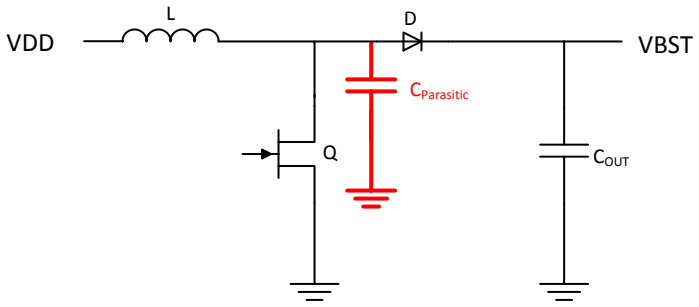


Figure 10-1. SW Node Parasitic Capacitance

What happens if the SW node has too much parasitic capacitance? Two things:

1. The switching frequency decreases due to a higher RC constant, resulting in less current delivery to the load
2. The SW node stores charge in the parasitic capacitor, resulting in less current delivery to the load

The switching frequency changes as a result of the charging and discharging of the parasitic capacitor each cycle. Figure 10-2 shows how the current charge cycle of the inductor changes when parasitic capacitance is present.

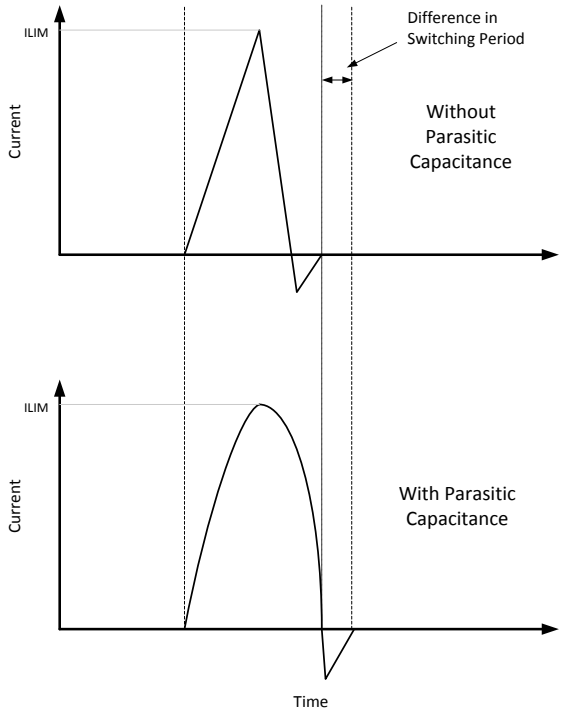
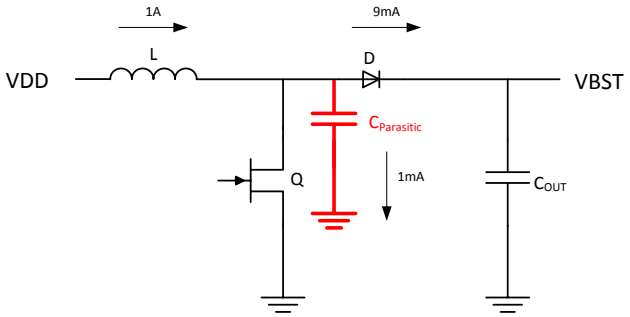


Figure 10-2. Inductor Charging with Parasitic Capacitance

Figure 10-2 shows that the period of the inductor charge cycle increases with parasitic capacitance. This longer charge cycle results in a slower boost-switching frequency.

Copyright © 2021 Texas Instruments Incorporated

In addition to a slower switching frequency, the parasitic capacitance on the SW node consumes charge. If, for example, the DRVxxxx boost design normally supports 10-mA current and there is parasitic capacitance present, a significant portion – sometimes up to 1 mA of the current – can be consumed by the parasitic capacitance. This means that 10% of the current intended for the load is being consumed by the parasitic capacitance.



Both of these issues can have drastic effects on the output waveform. To identify switch node parasitic capacitance, look for continuous switching on the SW pin. During normal operation, the switching turns on and off depending on the current required; however, with parasitic capacitance the SW node often continuously switches to recover for lost switch cycles and current.

Copyright © 2021 Texas Instruments Incorporated

11 Examples

This section provides two examples based on the DRV8662EVM and DRV2667EVM-CT and a 25-nF Piezo actuator.

11.1 Example: Based on the DRV8662EVM

The DRV8662EVM is the evaluation module for the DRV8662 analog high-voltage Piezo haptic driver. The board includes a MSP430 to control the DRV8662.

Figure 11-1 illustrates a simplified version of the DRV8662EVM.

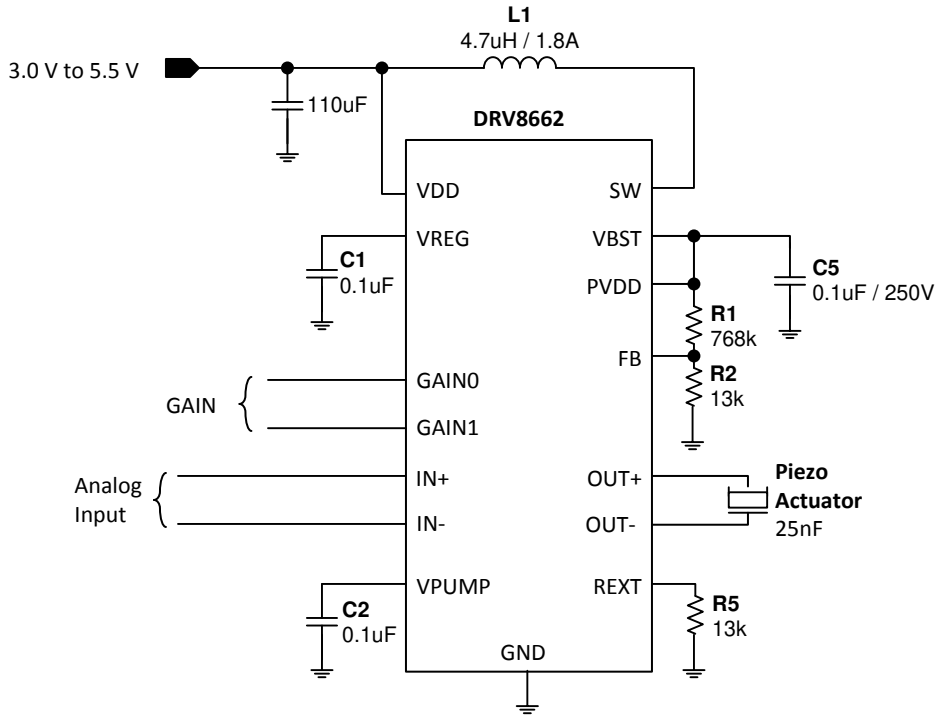


Figure 11-1. Simplified Version of the DRV8662EVM

The following table contains the primary components of the design. The board was configured for a SEMCO Piezo actuator.

Reference Designator	Value	Manufacturer Part #	Manufacturer
L1	4.7 µH / 1.8 A_{SAT}	LPS4018-472MLB	Coilcraft
Piezo Actuator	25 nF at 150 V, 200 Hz	PHAT423535XX	SEMCO

The full design documents including the schematic, layout, and BOM are found in the DRV2667EVM-CT User's Guide.

11.1.1 Configure the Boost Voltage

The values in this section were calculated using the DRV Design Equations excel file available on www.ti.com.

The SEMCO actuator has a rated voltage of 150 Vpp, which is defined as the voltage required for 100% vibration. The following values were entered into the design equation spreadsheet:

Actuator Properties	
Actuator Model: SEMCO 42mm	
$C_{actuator}$ = 25 nF	$V_{actuator}$ = 150 V_{pp}

Copyright © 2021 Texas Instruments Incorporated

Next, the settings section was completed to reflect a typical board environment. V_{boost} was set to 80 V using Equation 12. The additional 5 V provides headroom for the amplifier.

$$V_{boost} = \frac{V_{actuator}}{2} + 5V \quad (12)$$

Settings		
V_{in} = 3.6 V	V_{in_min} = 3 V	V_{in_max} = 5 V
V_{boost} = 80 V	$V_{forward}$ = 0.7 V	μ_{boost} = 70% (efficiency)
f_{in_min} = 100 Hz	f_{in_max} = 300 Hz	$I_{ripple_\%}$ = 20%

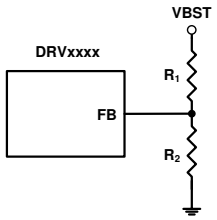
To configure the boost voltage, R_1 and R_2 must be set so that the voltage divider equals 1.32 V. The values are calculated using the *Feedback Resistors* section of the design equations excel file. R_1 was selected to be 768 kΩ so that the total resistance of the resistor divider is large, preventing high leakage currents. R_2 is calculated automatically and then R_{2_actual} is the closest standard resistor value. Finally, the boost voltage is back-calculated to show the expected boost voltage.

Feedback Resistors

$V_{feedback}$ = 132 V

$$R_2 = \frac{R_1 \times V_{feedback}}{V_{boost} - V_{feedback}}$$

R_1 = 768 kΩ
R_2 = 12.885 kΩ
R_{2_actual} = 13 kΩ



$$V_{boost_actual} = V_{feedback}\left(1 + \frac{R_1}{R_{2_actual}}\right)$$

V_{boost_actual} = 79.302 V

11.1.2 Configure the Inductor Current

The Piezo load requires approximately 1.88 mA of average current based on the following equation:

Piezo Actuator Current Requirements (Approximate)

$I_{out_max} = 2\pi \times C_{actuator} \times V_{boost} \times f_{in_max}$

I_{out_max} = 1.884956 mA
Maximum required amplifier current (estimate)

$$I_{bat_max} = 2\pi \times f_{in_max} \times C_{actuator} \times V_{boost}\left(\frac{V_{boost}}{V_{in} \times \mu_{boost}}\right)$$

I_{bat_max} = 139.626 mA
Maximum V_{BAT} current

This means that the inductor current limit (R_{EXT}) must be sufficiently large to support 1.88 mA.

The DRV8662EVM inductor is already fixed, but from here forward you may choose a different inductor that fits your load requirements. The maximum boost current with 80 Vp boost voltage is 20.3 mA based on the 4.7 µH / 1.8 A Coilcraft inductor selected using the following equations:

Boost Converter Current Capacity (Approximate)

$$D = 1 - \frac{V_{in_min} \times \eta}{V_{boost}}$$

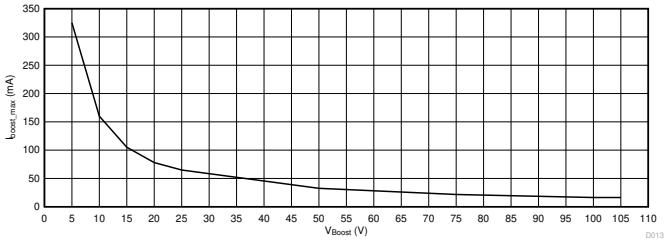
D = 0.978
Estimated duty cycle at maximum frequency

$$V_{boost_max} = \left(I_{limit} - \frac{I_{limit}}{2}\right) \times (1 - D)$$

I_{boost_max} = 20.289 mA
Maximum boost output current estimate

Copyright © 2021 Texas Instruments Incorporated

Boost Converter Current Capacity (Approximate)



V_{boost} (V)	I_{OUT} (mA)
25	64.92
50	32.46
75	21.64
100	16.23

The inductor on the DRV8662 is the LPS4018-472MLB from Coilcraft. The saturation current is 1.8 A and the current limit due to continuous current is 1.8 A. Enter these values into the *Boost Current Limit Resistor* section of the design equations excel file.

Boost Current Limit Resistor

Inductor Model Coilcraft LPS4018-472MLB

L = 4.7 µH	I_{sat} = 1.8 A	$I_{thermal}$ = 1.8 A
I_{min} = min (I_{SAT}, $I_{thermal}$)	I_{min} = 1.8 A	
I_{limit} = I_{min}	I_{limit} = 1.8 A	
$R_{ext} = \left(k \times \frac{V_{ref}}{I_{limit}} \right) - R_{int}$	R_{ext} = 7.815 kΩ	R_{ext_actual} = 7.87 kΩ
$I_{limit_actual} = k \times \frac{V_{ref}}{I_{ext_actual} + R_{int}}$		I_{limit_actual} = 1.788 A

The resulting current-limit resistor is calculated as 7.815 kΩ in R_{ext}. The nearest standard resistor value is 7.87 kΩ shown in the $R_{ext+actual}$ box. The current limit was then back-calculated to show the expected current limit, which is less than the saturation current.

Copyright © 2021 Texas Instruments Incorporated

11.1.3 Boost Performance Results

The actual load regulation and boost efficiency for the DRV8662EVM are shown in Figure 11-2. The load regulation is a measure of the boost voltage versus the boost output current. In Figure 11-2, the voltage regulation begins to drop above approximately 31 mA of boost output current.

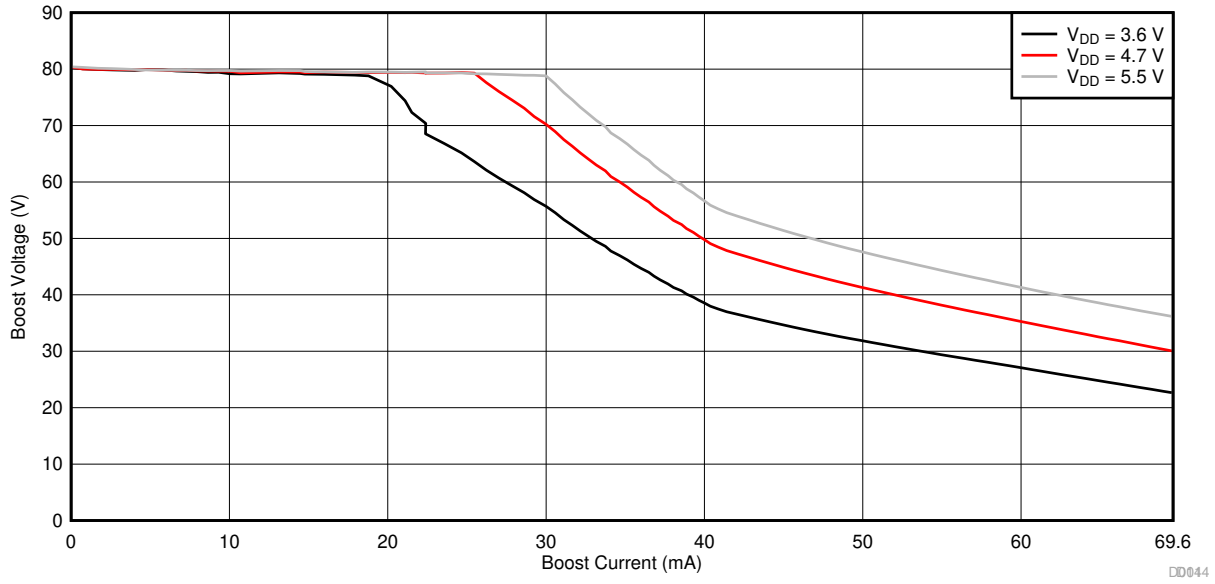


Figure 11-2. Actual Load Regulation and Boost Efficiency

The boost efficiency is shown in Figure 11-3. The efficiency data was removed after the boost voltage decreased by more than 5 V.

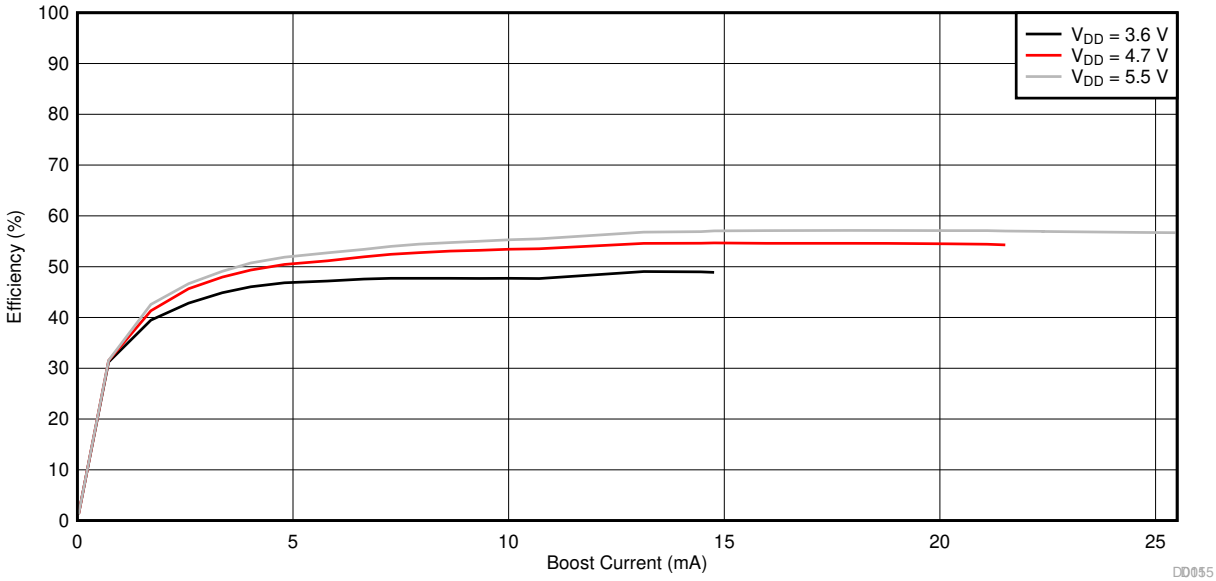


Figure 11-3. Boost Efficiency

Copyright © 2021 Texas Instruments Incorporated

11.2 Example: Based on the DRV2667EVM-CT with 25-nF Piezo Module

The DRV2667EVM-CT is the evaluation module for the DRV2667 high-voltage piezo haptic driver with digital front-end. The kit includes all the components to evaluate and test the DRV2667 including a Piezo haptics module manufactured by Samsung Electric and Mechanical.

Figure 11-4 is a simplified version of the DRV2667EVM-CT schematic.

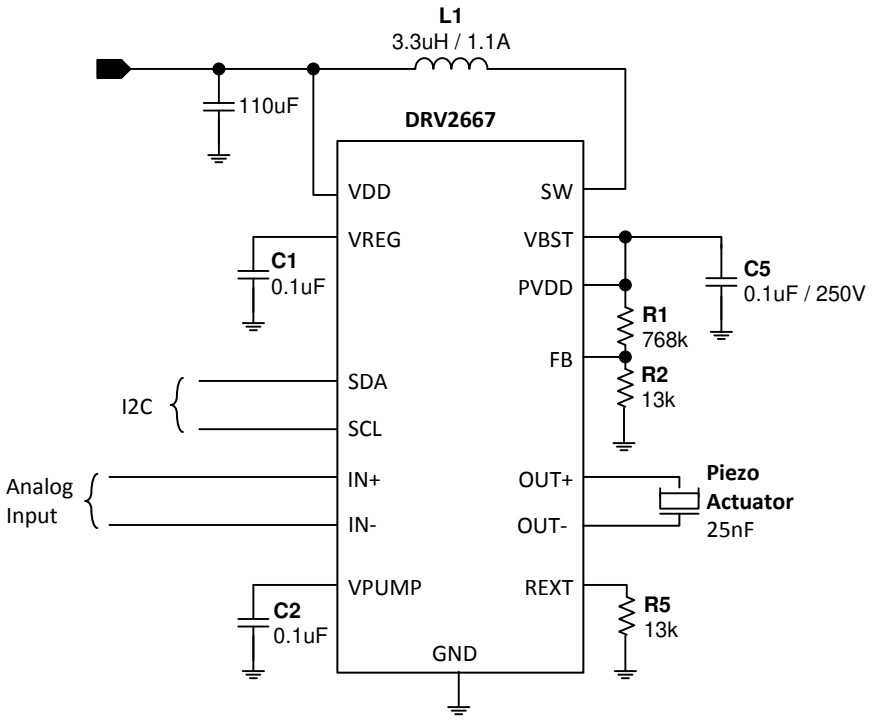


Figure 11-4. Simplified Version of the DRV2667EVM-CT Schematic

The following table contains the primary components of the design:

Reference Designator	Value	Manufacturer Part #	Manufacturer
L1	3.3 µH / 1.1 A_{SAT}	VLS3010ET-3R3M	TDK
Piezo Actuator	25 nF at 150 V, 200 Hz	PHAT423535XX	SEMCO

The full design documents including the schematic, layout, and BOM, can be found in the DRV2667EVM-CT User's Guide (SLOU323).

11.2.1 Configure the Boost Voltage

The values in this section were calculated using the DRV2667 Design Equations excel file available on www.ti.com.

The SEMCO actuator has a rated voltage of 150 Vpp, which is defined as the voltage required for 100% vibration. The following values were entered into the design equation spreadsheet:

Actuator Properties	
Actuator Model: SEMCO 42mm	
$C_{actuator}$ = 25 nF	$V_{actuator}$ = 150 V_{pp}

Next, the settings section was completed to reflect a typical board environment. V_{boost} was set to 80 V using Equation 13. The additional 5 V provides headroom for the amplifier.

$$V_{boost} = \frac{V_{actuator}}{2} + 5V \quad (13)$$

Copyright © 2021 Texas Instruments Incorporated

Settings		
V_{in} = 3.6 V	V_{in_min} = 3 V	V_{in_max} = 5 V
V_{boost} = 80 V	$V_{forward}$ = 0.7 V	μ_{boost}= 70% (efficiency)
f_{in_min} = 100 Hz	f_{in_max} = 300 Hz	$I_{ripple_\%}$ = 20%

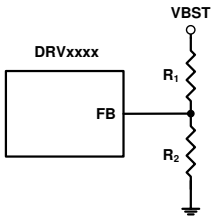
To configure the boost voltage, R_1 and R_2 must be set so that the voltage divider equals 1.32 V. The values are calculated using the *Feedback Resistors* section of the design equations excel file. R_1 was selected to be 768 kΩ so that the total resistance of the resistor divider is large, preventing high leakage currents. R_2 is calculated automatically and then R_{2_actual} is the closest standard resistor value. Finally, the boost voltage is back-calculated to show the expected boost voltage.

Feedback Resistors

$V_{feedback}$ = 1.32 V

$$R_2 = \frac{R_1 \times V_{feedback}}{V_{boost} - V_{feedback}}$$

R_1 = 768 kΩ
R_2 = 12.885 kΩ
R_{2_actual} = 13 kΩ



$$V_{boost_actual} = V_{feedback}\left(1 + \frac{R_1}{R_{2_actual}}\right)$$

V_{boost_actual} = 79.302 V

11.2.2 Configure the Inductor Current

The Piezo load requires approximately 1.88 mA of average current based on the following equation:

Piezo Actuator Current Requirements (Approximate)

$I_{out_max} = 2\pi \times C_{actuator} \times V_{boost} \times f_{in_max}$

I_{out_max} = 1.884956 mA
Maximum required amplifier current (estimate)

$$I_{bat_max} = 2\pi \times f_{in_max} \times C_{actuator} \times V_{boost}\left(\frac{V_{boost}}{V_{in} \times \mu_{boost}}\right)$$

I_{bat_max} = 139.626 mA
Maximum V_{BAT} current

This means that the inductor current limit (R_{EXT}) needs to be sufficiently large to support 1.88 mA.

Copyright © 2021 Texas Instruments Incorporated

The DRV2667EVM-CT inductor is already fixed, but from here forward you may choose a different inductor that fits your load requirements. The maximum boost current with 80 Vp boost voltage is 12.4 mA, based on the 3.3-µH /1.1-A TDK inductor selected using the following equations:

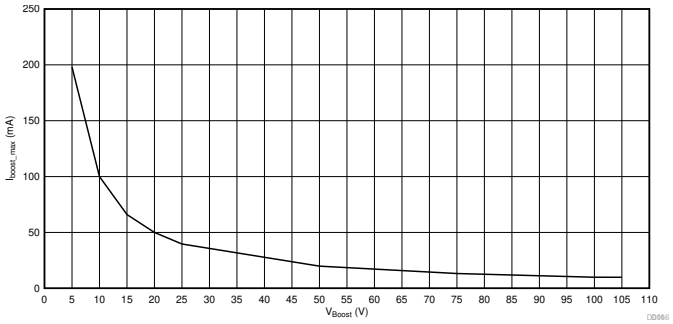
Boost Converter Current Capacity (Approximate)

$$D = 1 - \frac{V_{in_min} \times \eta}{V_{boost}}$$

D = 0.978
Estimated duty cycle at maximum frequency

$$I_{boost_max} = \left(I_{limit} - \frac{I_{limit}}{2} \right) \times (1 - D)$$

I_{boost_max} = 12.400 mA
Maximum boost output current estimate



V_{boost} (V)	I_{OUT} (mA)
25	39.68
50	19.84
75	13.23
100	9.92

The inductor on the DRV2667EVM-CT is the VLS3010ET-3R3M from TDK. The saturation current is 1.1 A and the current limit due to continuous current is 1.5 A. Enter these values into the *Boost Current Limit Resistor* section of the design equations excel file.

Boost Current Limit Resistor

Inductor model VLS3010ET-3R3M

L = 3.3 µH

I_{sat} = 1.1 A

$I_{thermal}$ = 1.5 A

I_{min} = min (I_{SAT}, $I_{thermal}$)

I_{min} = 1.1 A

I_{limit} = I_{min}

I_{limit} = 1.1 A

$$R_{ext} = \left(k \times \frac{V_{ref}}{I_{limit}} \right) - R_{int}$$

R_{ext} = 12.83 kΩ

R_{ext_actual} = 13 kΩ

$$I_{limit_actual} = k \times \frac{V_{ref}}{I_{ext_actual} + R_{int}}$$

I_{limit_actual} = 1.085 A

The resulting current limit resistor is calculated as 12.83 kΩ in R_{ext}. The nearest standard resistor value is 13 kΩ shown in the $R_{ext+actual}$ box. The current limit was then back-calculated to show the expected current limit, which is less than the saturation current.

Copyright © 2021 Texas Instruments Incorporated

11.2.3 Boost Performance Results

The actual load regulation and boost efficiency for the DRV2667EVM-CT are shown in Figure 11-5. The load regulation is a measure of the boost voltage versus the boost output current. In Figure 11-5, the voltage regulation begins to drop above approximately 10 mA of boost output current. Comparing the voltage regulation of the DRV2667EVM-CT to the DRV8662EVM, the DRV2667EVM-CT boost has much less current capacity because of the smaller inductor and current limit resistor settings.

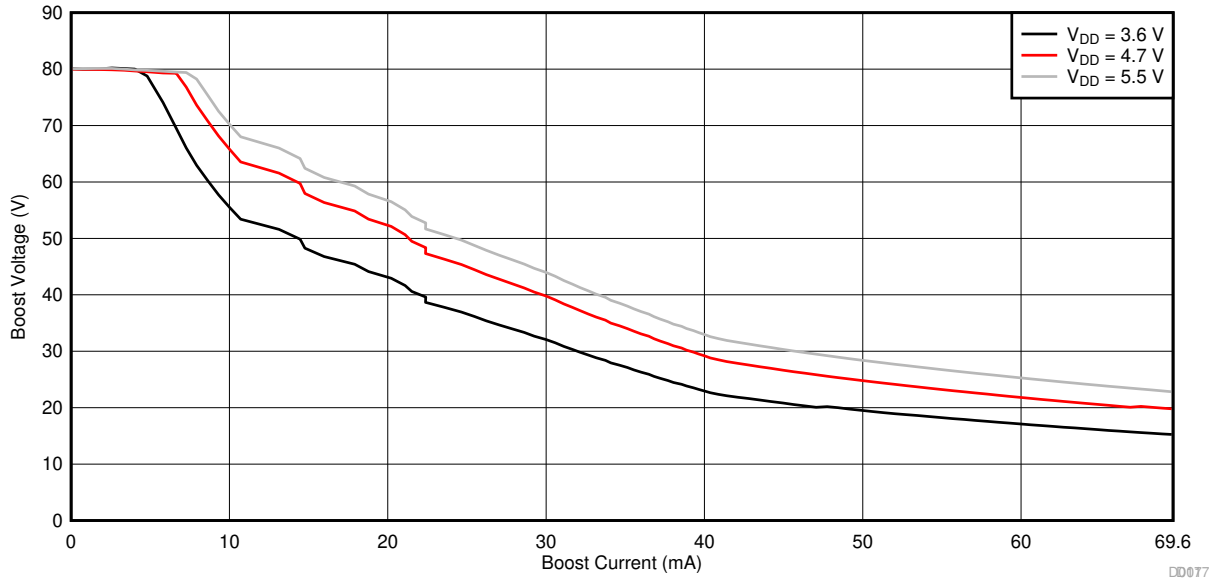


Figure 11-5. Boost Voltage vs Boost Current - DRV2667EVM-CT-80 V

The boost efficiency is shown in Figure 11-6. The efficiency data was removed after the boost voltage decreased by more than 5 V.

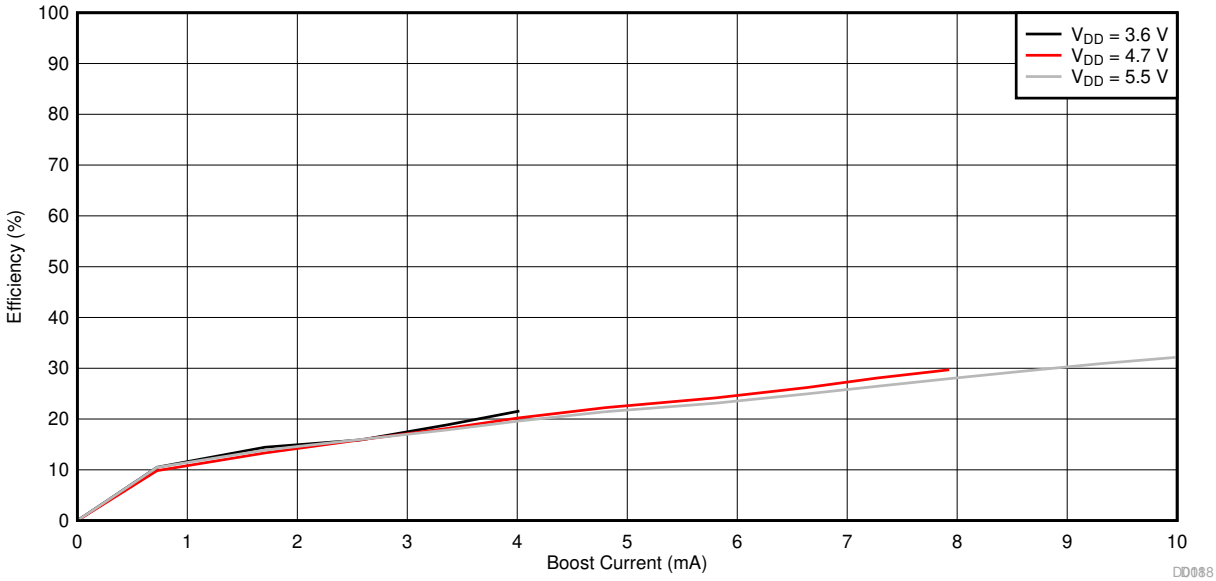


Figure 11-6. Efficiency vs Boost Current - V_{BST} = 80 V

Copyright © 2021 Texas Instruments Incorporated

12 Revision History

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

Changes from Revision * (September 2014) to Revision A (December 2021)	Page
• Updated the numbering format for tables, figures, and cross-references throughout the document.	1
• Added *DRV2700* as additional available device throughout the document.	1

Copyright © 2021 Texas Instruments Incorporated

IMPORTANT NOTICE AND DISCLAIMER

TI PROVIDES TECHNICAL AND RELIABILITY DATA (INCLUDING DATA SHEETS), DESIGN RESOURCES (INCLUDING REFERENCE DESIGNS), APPLICATION OR OTHER DESIGN ADVICE, WEB TOOLS, SAFETY INFORMATION, AND OTHER RESOURCES “AS IS” AND WITH ALL FAULTS, AND DISCLAIMS ALL WARRANTIES, EXPRESS AND IMPLIED, INCLUDING WITHOUT LIMITATION ANY IMPLIED WARRANTIES OF MERCHANTABILITY, FITNESS FOR A PARTICULAR PURPOSE OR NON-INFRINGEMENT OF THIRD PARTY INTELLECTUAL PROPERTY RIGHTS.

These resources are intended for skilled developers designing with TI products. You are solely responsible for (1) selecting the appropriate TI products for your application, (2) designing, validating and testing your application, and (3) ensuring your application meets applicable standards, and any other safety, security, regulatory or other requirements.

These resources are subject to change without notice. TI grants you permission to use these resources only for development of an application that uses the TI products described in the resource. Other reproduction and display of these resources is prohibited. No license is granted to any other TI intellectual property right or to any third party intellectual property right. TI disclaims responsibility for, and you will fully indemnify TI and its representatives against, any claims, damages, costs, losses, and liabilities arising out of your use of these resources.

TI’s products are provided subject to TI’s Terms of Sale or other applicable terms available either on ti.com or provided in conjunction with such TI products. TI’s provision of these resources does not expand or otherwise alter TI’s applicable warranties or warranty disclaimers for TI products.

TI objects to and rejects any additional or different terms you may have proposed.

Mailing Address: Texas Instruments, Post Office Box 655303, Dallas, Texas 75265
Copyright © 2022, Texas Instruments Incorporated