

Science Education Collection

DC/DC Boost Converter

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Overview

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Boost converters provide a versatile solution to stepping up DC voltages in many applications where a DC voltage needs to be increased without the need to convert it to AC, using a transformer, and then rectifying the transformer output. Boost converters are step-up converters that use an inductor as an energy storage device that supports the output with additional energy in addition to the DC input source. This causes the output voltage to boost.

The objective of this experiment is to study different characteristics of a boost converter. The step-up capability of the converter will be observed under continuous conduction mode (CCM) where the inductor current is non-zero. Open-loop operation with a manually-set duty ratio will be used. An approximation of the input-output relationship will be observed.

Principles

A boost converter relies on energy stored in the inductor, L , to supply energy to the output side where the load is supported, in addition to a DC source being the main energy source. The main concept behind boost converter operation is that an inductor will flip its voltage polarity to maintain current flow. As shown in Fig. 1(a) for a simple boost converter circuit, when the switch is on for a duty cycle D of the switching period T , inductor voltage V_L builds up. When the switch is off, the inductor current has to continue flowing and therefore the inductor's voltage polarity will flip to add to the input voltage V_{in} .

However, when the switch is on, the load is short-circuited and the output voltage is zero, which is not desired. Therefore, a blocking diode is added at the output side as shown in Fig. 1(b) to prevent the load from being short-circuited. This diode still does not solve the issue of the load seeing no voltage when the switch is on, so a capacitor is added as shown in Fig. 1(c) to provide the load with necessary current during the period when the switch is on. Note that when the switch is on, the diode is off (reverse biased), and vice versa. The average output voltage is thus related to the input voltage as: $\langle V_{out} \rangle = V_{in} / (1-D)$.

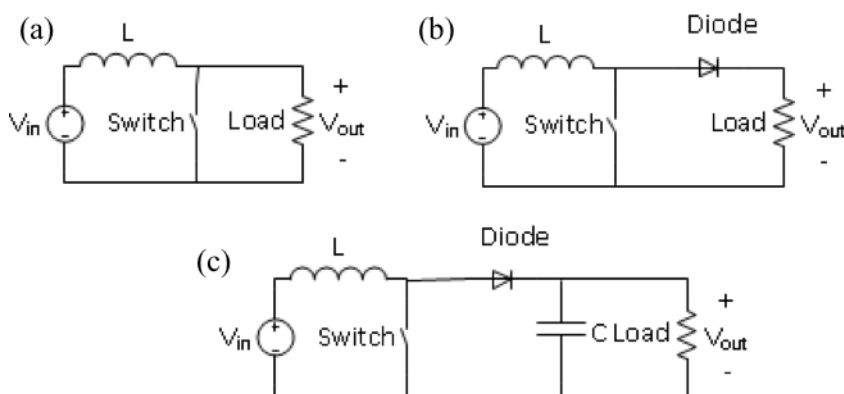


Figure 1. Steps to building a boost converter

As this experiment proceeds, it will be shown that the average output voltage increases as the duty cycle, D , increases. This is true since the output voltage to input voltage relationship is inversely proportional to $1-D$, and thus the output voltage and D have a positive correlation.

Note that the equation presented is for an ideal boost converter, and may seem as if a $D=1$ will yield infinite output voltage, but that is not true. In reality, parasitic elements and resistances in the boost converter cause D to be limited to around 70-80% after which parasitic effects start to dominate circuit operation and cause significant voltage drops. At such a point, the output voltage starts to decrease as D increases. With higher switching frequencies, the voltage ripple at the output will decrease since the voltage charging and discharging times at the capacitor become significantly shorter with a decreased switching frequency.

Procedure

ATTENTION: This experiment is designed to limit the output voltage to be less than 50V DC. Only use duty ratios, frequencies, input voltage, or loads that are given here.

This experiment will utilize the DC-DC converter board provided by HiRel Systems. <http://www.hirelsystems.com/shop/Power-Pole-Board.html>

Information about the board operation can be found in this collections video "Introduction to the HiRel Board."

The procedure shown here applies to any simple boost converter circuit that can be built on proto boards, bread boards, or printed circuit boards.

1. Board setup:

1. Connect the ± 12 signal supply at the "DIN" connector but keep "S90" OFF.
2. Make sure that the PWM control selector is in the open-loop position.
3. Set the DC power supply at 10 V.
 1. Keep the output disconnected from the board for now.
4. Before connecting the load resistor, adjust it to 20 Ω .
5. Build the circuit shown in Fig. 2 by using the lower MOSFET, upper diode, and BB magnetic board.
 1. Note the inductance value shown on the board.
6. Connect " R_L " across "V1+" and "COM."
 1. Note that the input and output connections are flipped compared to those in the buck converter experiment.
 2. NEVER Disconnect the load during the experiment as the boost converter can become unstable and cause damage to the board.
 3. Make sure the switch array for MOSFET selection (lower MOSFET), PWM selection, and other settings are correct to achieve a functional circuit as in Fig. 2.

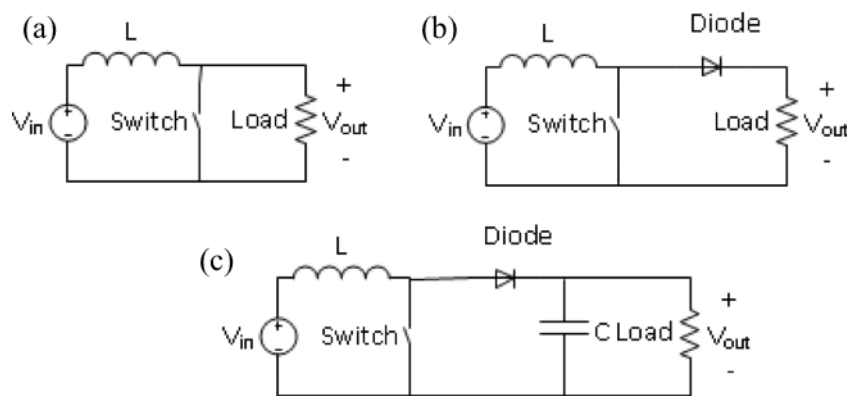


Figure 2. Boost converter circuit

2. Adjusting the Duty Ratio and Switching Frequency

1. Connect the differential probe across the gate-to-source of the lower MOSFET.
2. Turn ON "S90." A switching signal should appear on the scope screen.
 1. Adjust the signal time axis to see two or three periods.
 2. Adjust the frequency potentiometer to achieve a frequency of 100 kHz (period of 10 μ s).
3. Adjust the duty ratio potentiometer to achieve a 10% duty ratio (on-time of 1 μ s).

3. Boost Converter Testing for Variable Input

1. Connect the input DC power supply, which is already set at 10 V, to "V2+" and "COM."
2. Connect the differential probe to measure the inductor current at "CS5."
 1. Connect the other probe across the load. Make sure the ground connector is connected to "COM."
 2. Capture the waveforms and measure the output voltage mean, inductor current ripple, and inductor current mean.
 3. Record the input current and voltage readings on the DC power supply.
3. Adjust the input voltage to 8 V, 12 V and 14 V, and repeat the above steps for each of these voltages.
4. Disconnect the input DC supply and adjust its output to 10 V.

4. Boost Converter Testing for Variable Duty Ratio

1. Connect the differential probe across the gate to source of the lower MOSFET.
 1. Connect the other probe across the load. Make sure the ground connector is connected to "COM."
2. Connect the input DC supply to "V2+" and "COM."
3. Capture the waveforms and measure the output voltage mean and on-time of the gate-to-source voltage (also the duty ratio).
4. Record the input current and voltage readings on the DC power supply.

2. Adjust the duty ratio to 20%, 40%, and 60%. Repeat the above steps for each of these three duty ratios.
3. Reset the duty ratio to 10%.
4. Disconnect the input DC supply.

5. Boost Converter Testing for Variable Switching Frequency

1. Connect the differential probe across the gate to source of the lower MOSFET.
2. Connect the other probe across the load with the ground connector connected to "COM."
3. Connect the input DC supply to "V2+" and "COM."
4. Adjust the switching frequency to 70 kHz.
5. Capture the waveforms and measure the output voltage mean and on-time of the gate-to-source voltage (also the duty ratio).
6. Record the input current and voltage reading on the DC power supply.
7. Adjust the switching frequency to 40 kHz, 20 kHz, and 10 kHz (or minimum possible if 10 kHz cannot be reached).
8. Repeat the above steps for each of these three switching frequencies.
9. Turn OFF the input DC supply and "S90," and then disassemble the circuit.

Results

The boost converter output-input voltage relationship is proportional to the duty cycle in the sense that higher D will yield higher output voltages for a given input voltage. If the input voltage is V_{in} and the output voltage is V_{out} , $V_{out}/V_{in} = 1/(1-D)$, where $0 \leq D \leq 100\%$. Therefore, for an input voltage of 10 V, $V_{out} \approx 12.5$ V for $D = 20\%$, $V_{out} \approx 16.67$ V for $D = 40\%$, and $V_{out} \approx 25$ V for $D = 60\%$.

Nevertheless, the output voltage will be lower than expected from the ideal relationship, which is linear with the duty ratio. The main reason is that the ideal converter model from which the V_{out}/V_{in} relationship can be derived does not account for non-idealities and voltage drops in the converter. Theoretically, as $D \rightarrow 100\%$, $V_{out} \rightarrow \infty$; practically, a theoretical limit on the boosting capability is around 3-4x the input voltage, and after a certain level of D , the output voltage of the converter starts to drop rather than being boosted due to parasitic and non-ideal elements in a real converter.

Applications and Summary

Boost converters are very common in solar photovoltaic applications where the input voltage from the solar panel varies with weather conditions and available solar energy, and a boost converter can always boost from the PV panel voltage. Power factor correction to improve power quality as seen from the utility grid with power electronic loads which may require significant reactive power, e.g. motors, is another major application of boost converters.