LABORATORY 9

Boost Converters

Guide

Boost Converters

We have tried to use resistors (voltage dividers) to transform voltages but found that these solutions suffer from very poor efficiency: A significant fraction of the total power is dissipated in the resistors and not available for the load. Moreover, dividers are limited to lower the voltage. This is problematic in many applications such as micro electro mechanical systems (MEMS) which often require high voltages for operation.

We can overcome both problems by using inductors and capacitors. Since these elements (ideally) only store but do not dissipate power, much higher transformation efficiencies are attainable.

In this laboratory we design and test a special kind of switching power supply called boost converter that boosts the input voltage to a higher value and configure the circuit to generate 15V from a 5V input. Figure 1 shows the schematic diagram. The device labeled IRF510 is a transistor. The diode conducts current only in the direction of the arrow.

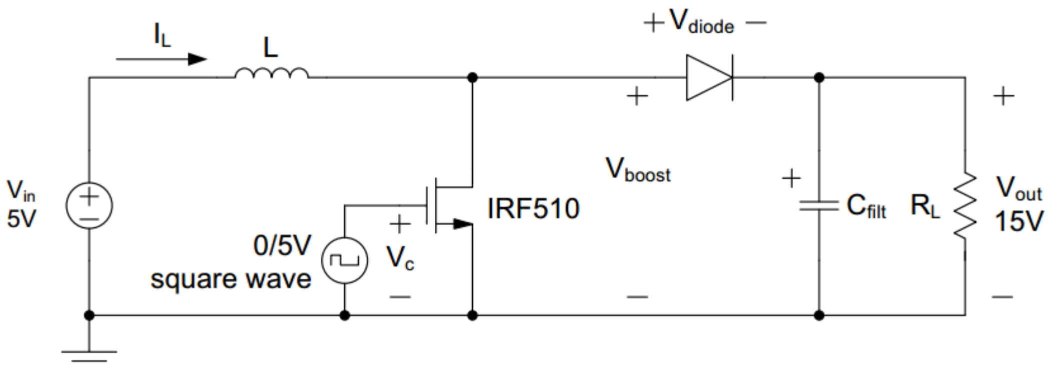


Fig. 1 Boost Converter

Before this lab, you are supposed to have read all the given materials and have the basic concepts and strict derivation about this circuit. Here we will give a simple analyze of it. To analyze the circuit we assume first that it works correctly, and the output voltage is 15V. The voltage V_c is a pulse train and changes between 0V and 5V.

- When $V_c = 5V$ the transistor (IRF510) is on and behaves essentially like a short circuit. Then $V_{boost} = 0\text{V}$ and $V_{diode} = V_{boost} - V_{out} = -15\text{V}$. Since V_{diode} is negative, the diode does not conduct any current, i.e. it behaves like an open circuit.
- With $V_c = 0V$ the situation reverses: now the transistor is off and the diode conducts.

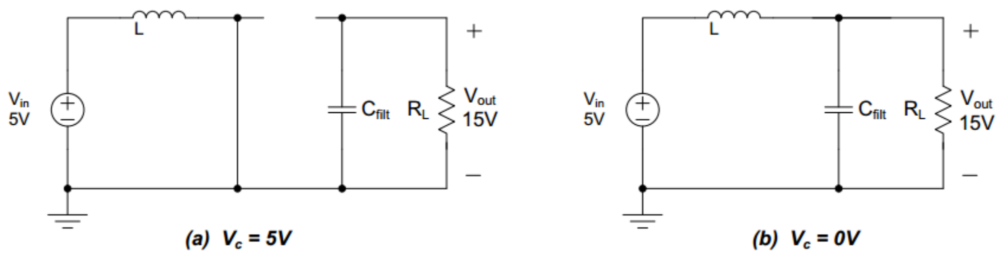


Fig. 2 Boost converter operating principle with the switch closed (a) and open (b).

Fig. 2 illustrates both situations: In situation (a), $V_c = 5V$ the supply voltage appears across the inductor. From the differential equation for inductance we observe that inductors integrate voltage. Therefore the inductor current is a ramp with slope determined by the value of $V_{in}$and L; In situation (b) the inductor again integrates the voltage $V_{in} - V_{out} = -10\text{V}$ that appears across it. In steady state the current increase and decrease must be identical as otherwise the average current would continually increase or decrease. Since it is negative the current through the inductor decreases, as shown in Fig. 3.

Since voltage is proportional to the slope of the current, we note intuitively that reducing the ratio of T_{off}/T_{on} results in higher output voltage V_{out}. This is because the positive slope is proportional to V_{in} and the negative slope of the decreasing current is proportional to V_{out}-V_{in}. In the laboratory we will analyze this relationship quantitatively.

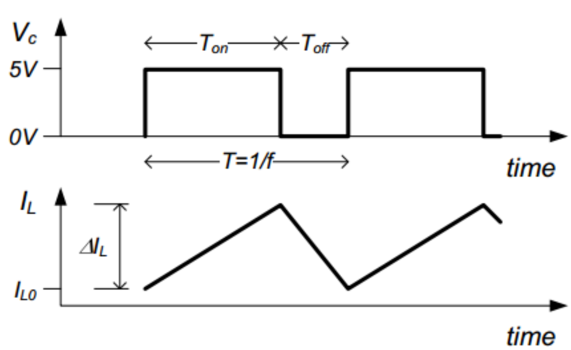


Fig 3. Boost converter timing diagram.

Reference

[1] UC Berkeley, course EECS100, Fall 2009.
[2] UC Berkeley, course EE40, Fall 2011.

Lab 9 Prelab

Name ___________ TA ______________________

Teammate ___________ Score ______________________

You are required to simulate, build and analyze the aforementioned boost converter circuits. **Note**: you are suggested to finish the report part (especially part four) in simulation software **before class**. Otherwise, it may be difficult for your group to finish all tasks in 3 hours.

TASK 1

(THIS TASK IS DESIGNED TO HELP YOU UNDERSTAND THE PRINCIPLES OF BOOST CONVERTER. IF YOU ARE UNFAMILIAR WITH THIS, PLEASE PAY ENOUGH ATTENTION TO THIS TASK.)

Let's first derive an expression for the voltage boost factor V_{out}/V_{in}. We start with writing expressions for ΔI_L during T_{on} and T_{off}. At this point, enter only the expressions. Once you have determined the value of L (see below) you can solve for and enter the numerical answer. Same for the simulation result.

During T_{on} ΔI_L =_____________

During T_{off} ΔI_L =_____________

Once reaching the steady state, the sum of ΔI_L during T_{on} and T_{off} is zero. Equate the equations above and solve for the voltage boost factor.

V_{out} / V_{in} =_____________

Remarkably this result depends only on T_{on} and T_{off} and is independent of the value of the inductance. Calculate T_{on} / T_{off} for V_{in} = 5V and V_{out} = 15V.

T_{on} / T_{off} =_____________

For simplicity, in this laboratory we will generate T_{on} and T_{off} with the pulse generator. More practical implementations adjust this ratio dynamically to keep the value of constant in the presence of variations of V_{in} and the load current. Calculate the value of T_{on} / T_{off} that keeps V_{out} constant despite varying V_{in}.

V_{in} =3V T_{on} / T_{off} =______________

V_{in} =10V T_{on} / T_{off} =______________

Since the expression of T_{on} / T_{off} is too inconvenient, positive duty cycle D, $T_{on} /(T_{on} + T_{off})$, can be introduced to express of voltage gain, V_{out}/V_{in}. What's the relationship between voltage gain and D ?

V_{out}/V_{in} =______________

To finalize the design of the boost converter we must determine the operating frequency $f = 1 / T$ with $T = T_{on} + T_{off}$, and the values of L and C_{filt}. We pick f = 100 kHz to account for the frequency limitation of solderless breadboards. From this we can calculate T_{on} and T_{off} and then solve for L from one of the equations for ΔI_L. Keeping this variation to ΔI_L = 5 mA. Round L to the nearest available value (use the resistor scale, i.e. multiples of 10, 12, 15, etc).

L =______________

During T_{on} the diode is not conducting and the entire current to the load comes from C_{filt}. Because of this the output voltage will drop. Keeping this drop to ΔV_{out} = 28 mV for R_L =1 kΩ determines the value of C_{filt} (use the next larger available value in the lab). Realizing that $\Delta V_{out} << V_{out}$ we conclude that the current through transistor is approximately constant, $I_{RL} = V_{out} / R_L$.

C_{filt} =______________

TASK 2

ALL DETAILS OF THIS PART ARE REQUIRED TO BE COMPLETED IN SIMULATION SOFTWARE

If the value of selected inductor is small enough, a novel waveform of i_L that's different from the one in Fig. 3 can be observed. In this novel waveform, i_L will decrease to zero and last for a certain time. Choose an appropriate resistance (maybe 1k or 10k), change the inductor in your boost converter to observe this phenomenon and draw the waveform of i_L below.

Does the magnitude of V_{out} vary? ______________

In this condition, which parameter(s) is (are) related to the magnitude of V_{out}? (such as load, T_{on}/T_{off}, capacitance)

____

2. Attach your simulation schematics diagram and results here. **___/ 13pt**

Lab 9 Report

Name ____________ TA Checkoff ____________

Teammate ____________ Score ____________

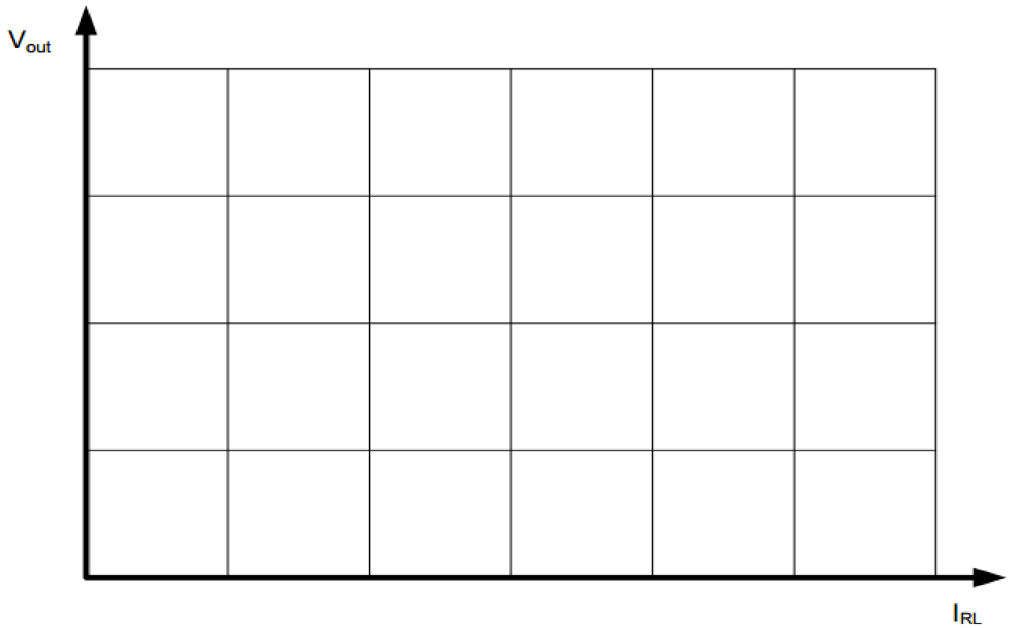
TASK 3

Now you are ready to test the boost converter in the laboratory. Although it is designed to generate 15V, it can produce voltages in excess of 30V e.g. when the input voltage is chosen higher than 5V. Also, complete the entire circuit before turning on power. Especially do not omit the diode and load resistor. Measure $\boldsymbol{V_{in}}$, $\boldsymbol{D}$ and $\boldsymbol{V_{out}}$ with the oscilloscope and compare your result to simulation result.

Complete the sheet below. TA CHECKOFF ____________

V_{in}/V	D	V_{out}/V	**THEORY**
3		15	
5		15	
10		15	
	0.5	20	
	0.75	20	
	0.8	20	
5	0.3		
5	0.5		
5	0.75		

In actual circuit, 5 V input and 15V output, vary the load resistor R from 1kΩ to 20 kΩ and graph both sets of results on the graph below. Label the axes!



TA CHECKOFF ___________________

TASK 4

Ideally the voltage gain should be independent of V_{in} and the current I_{RL} through the resistor. In practice it drops because of the constant boost factor and the series resistance of the inductor and diode, and the finite on-resistance of the transistor. Practical implementations of boost converters include additional circuitry that monitors the output voltage and dynamically adjusts T_{on} / T_{off} to ensure a constant V_{out}.

Give an 5 V input, and the calculated T_{on} / T_{off} to get a calculated output of 15V.

	Measured	Simulated
V_{out} =	______________	________________

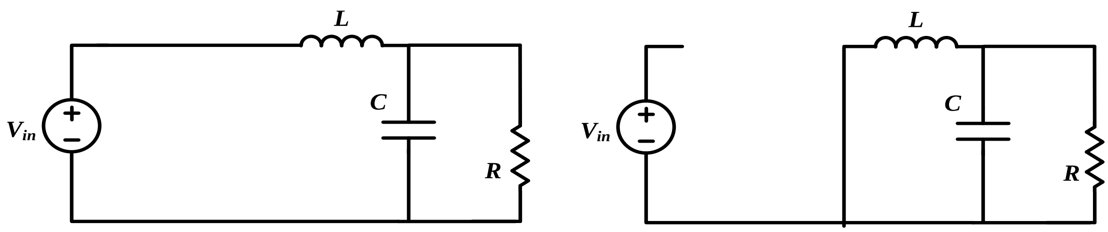
Now vary T_{on} (without changing the frequency f) to adjust measured Vout back to 15V. Compare measurement results with your understanding of the circuit. Fill in the calculated, simulated, and measured values of T_{on} and T_{off} that restore V_{out} to its design value while keeping f constant.

	Measured	Simulated	Calculated
During $\boldsymbol{T_{on}}$ $\boldsymbol{\Delta I_L}$ =	______________	_______________	______________
During $\boldsymbol{T_{off}}$ $\boldsymbol{\Delta I_L}$ =	______________	_______________	______________

Explain discrepancies between measured, simulated, and calculated results for above all.

EXTRA TASK

Boost converter is a very basic and classical converter with the advantage of high efficiency, few components and easy understanding. However, its drawback is obvious, it is unable to reduce input voltage. Buck converter is classical step-down converter. Its operating modes are shown as follow. Its components are the same with boost converter. Built a buck converter with the components for boost converter and draw buck converter's topology in the box. Also, show the step-down ability of your circuit to your TA.



(a) (a)

Fig 2. Buck converter operating principle with the switch closed (a) and open (b).

TA CHECKOFF ____________

Prelab : ____of 40 Pt.

Report : ____of 70 Pt.

Total： ____of 110 Pt