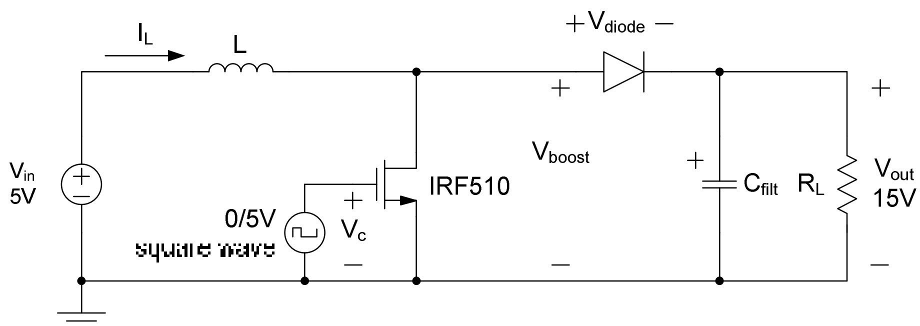
University of California Berkeley
Department of Electrical Engineering and Computer Sciences
EECS 100, Professor Leon Chua

LABORATORY 7 v3

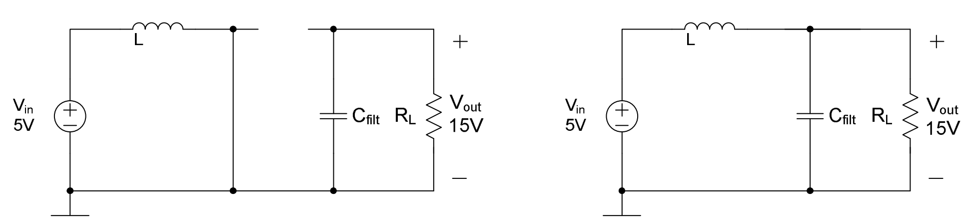
BOOST CONVERTER

In many situations circuits require a different supply voltage than that provided by the power supply. In battery operated systems it is often necessary to boost the voltage to the circuit's needs. Examples are circuits that require 110V but must be run from a car battery. Many hybrid cars use electric motors needing several hundred volts (these motors are smaller and more efficient), more than the battery or generator supply.

In this laboratory we will design and test a boost converter to produce 15V from a 5V input. Here is the schematic diagram:



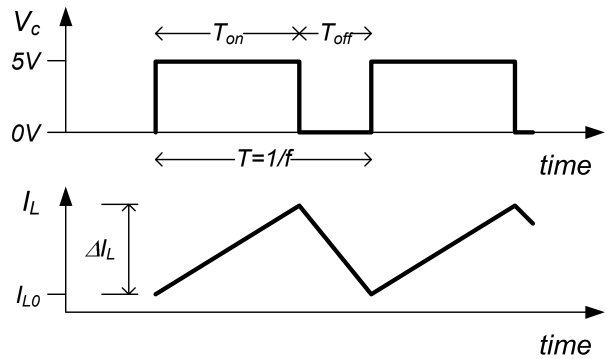
To analyze the circuit we assume first that it is working correctly, in particular that the output voltage is 15V. We will later verify of course that this is indeed the case. The voltage V_c is a pulse train and changes between 0V and 5V. For V_c=5V the transistor (IRF510) is on, i.e. essentially a short circuit. Then V_{boost}=0V and $V_{diode}=V_{boost}-V_{out}$=-15V. 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. The diagram below illustrates the two situations.



(a) V_c = 5V ***(b) V_c = 0V***

In situation (a), V_c=5V, the supply voltage V_{in} appears across the inductor. From the differential equation for inductance we observe that inductors integrate voltage. Therefore the inductor current I_L is a ramp with slope determined by V_{in} and L. In situation (b) the inductor again integrates the voltage

V_{in} -V_{out}=-10V 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 the following timing diagram:



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.

If you want more information about Boost Converters, please check out the website:

http://en.wikipedia.org/wiki/Boost_converter

LAB REPORT

Lab Session:

Name 1: SID:

Name 2: SID:

Let's first derive an expression for the voltage boost factor, V_{out}/V_{in}. We start by writing expressions for ΔI_L during T_{on} and T_{off}. Hint: set up the differential equation for current and voltage in the inductor during the two phases.

During T_{on}, ΔI_L = ___ of 2 **P**

During T_{off}, ΔI_L = ___ of 2 **P**

From the timing diagram shown in the guide we know that the magnitude of ΔI_L is the same during T_{on} and T_{off}. Equate the equations above and solve for the voltage boost factor V_{out}/V_{in}.

V_{out}/V_{in} = ___ of 2 **P**

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_{out}=15V and V_{in}=5V.

T_{on}/T_{off} = ___ of 2 **P**

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 will pick f=100kHz 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=6mA. Round L to the nearest available value (use the resistor scale, i.e. multiples of 10, 12, 15, etc).

L = _______ mH ___ of 2 **P**

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}=100mV for R_L=1kΩ determines the value of C_{filt}. Realizing that $\Delta V_{out} << V_{out}$ we conclude that the current through the is approximately constant, $I_R= V_{out} / R_L$. From this we can calculate ΔV_{out} and solve for C_{filt}.

C_{filt} = _______ μF ___ of 2 **P**

Verify your result with Multisim. For simulation only, **add a 6Ω resistor in series with the inductor to account for the winding resistance (do not add this resistor in the actual circuit you will be building)**. Hand in a transient simulation showing V_c, V_{boost}, V_{diode}, V_{out} and the current through the inductor (note it's the same as the current through V_{in} and computed automatically by Multisim) for 3 cycles in steady state.

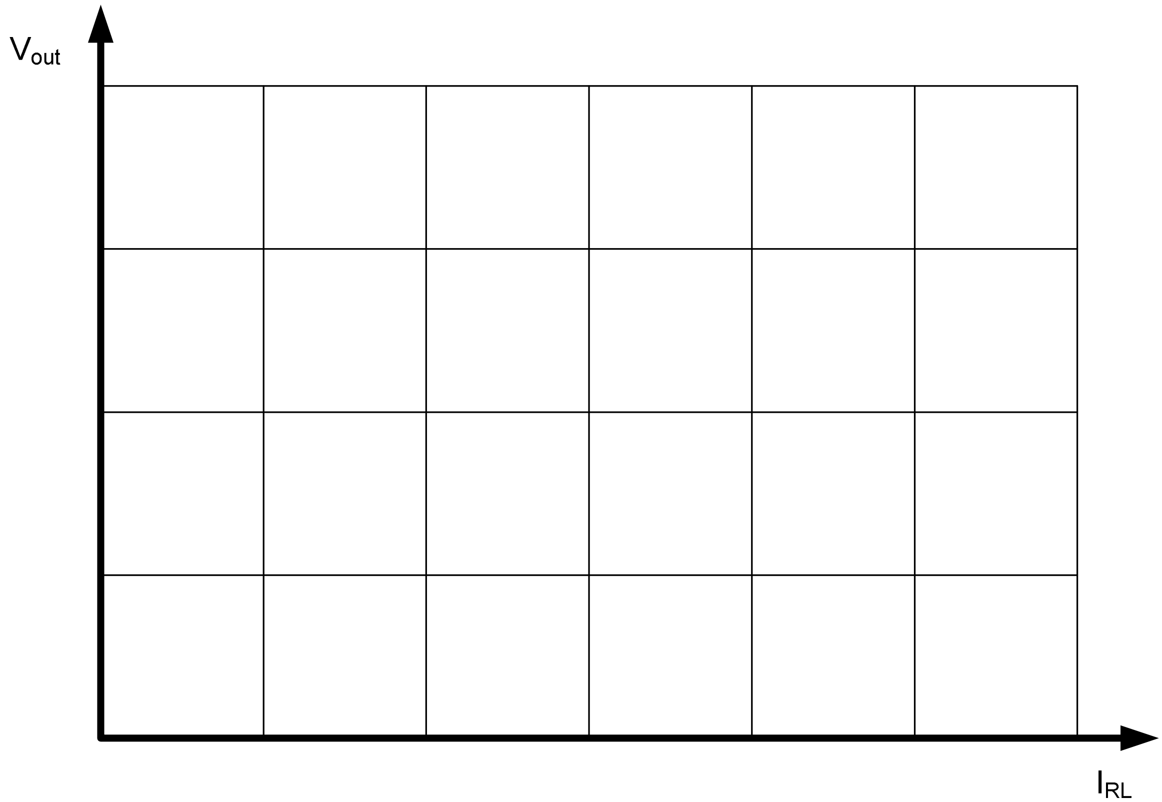
Simulation result: ______ V ___ of 10 **P**

Now you are ready to test the boost converter in the laboratory. Although it is designed to generate only 15V, it can produce voltages in excess of 25V e.g. when the input voltage is chosen higher than 5V. **Because of this exert extra caution and touch circuit nodes only after having determined (e.g. with the oscilloscope) that voltage levels agree with your simulation results and are below 20V.** Also, complete the entire circuit before turning on power. Especially do not omit the diode and load resistor. Measure V_c, V_{boost}, V_{diode}, V_{out} with the oscilloscope and compare your result to Multisim. Comment on any discrepancies (hint: consider the assumptions made for the calculations).

Oscilloscope printout: ___ of 10 **M**

Explanation of differences: ___ of 5 **M**

In Multisim and the actual circuit, vary the load resistor R_L from 100Ω to 20kΩ and graph your result. Label the axes!



Simulation: ___ of 5 **P**

Experiment: ___ of 5 **M**

Ideally the voltage should be independent of the current I_{RL} through the resistor. In practice it drops because of the series resistance of the inductor and diode, and the finite on-resistance of the transistor. Practical implementations of boost converter contain additional circuitry that monitor the output voltage and dynamically adjust T_{on} and T_{off} to ensure a constant V_{out}.

SUGGESTIONS AND FEEDBACK

Time for completing prelab:

Time for completing lab:

Please explain difficulties you had and suggestions for improving this laboratory. Be specific, e.g. refer to paragraphs or figures in the write-up. Explain what experiments should be added, modified (how?), or dropped.

PRELAB SUMMARY

Lab Session:

Name 1: SID:

Summarize your prelab (P) results here and turn this in at the beginning of the lab session.

Turn in a copy of the pages with prelab results at the beginning of the lab.

During T_{on}, ΔI_L = ___ of 2 P

During T_{off}, ΔI_L = ___ of 2 P

V_{out}/V_{in} = ___ of 2 P

T_{on}/T_{off} = ___ of 2 P

L = ___ of 2 P

C_{filt} = ___ of 2 P

Simulation result: ___ of 10 P