ECE 214 - Lab #8 — Boost Converter

5 April 2016

Introduction: This is the second of four labs that will culminate in a DC–DC converter circuit that will convert a 9 volt DC source into a 50 volt DC source. A block diagram of the final system you will design is shown in Figure 1 below.

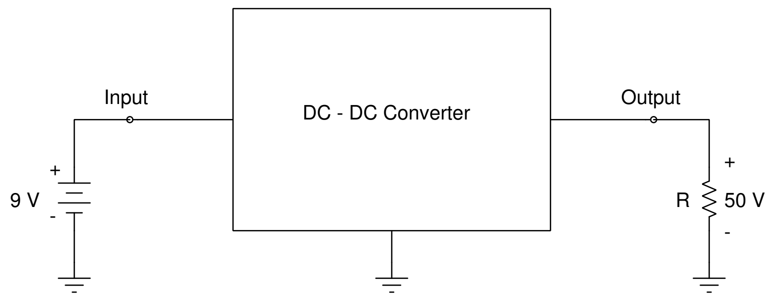

Figure 1: Block diagram of the DC–DC converter.

It is important that you understand how the DC–DC converter works, and are able to explain and describe how the various sub-circuits function. The final design will be up to you using the various circuits designed and tested in labs 7, 8 and 9. You will write a detailed lab report describing: how the circuits function, the theory of operation, the design of the DC–DC converter, the simulation results and the experimental results. Details of the report will be provided in ECP 214 and the report must be submitted electronically, in PDF format, to kotecki@maine.edu by 5:00pm on Tuesday 3 May 2016.

In Lab 7 you desinged, built and tested a Villard boost circuit. In this lab, you will design, build and test a second type of boost-circuit. The boost-circuit is one sub–circuit of the DC–DC converter. Boost circuits are used in many applications to produce a higher DC voltage from a low voltage source such as a battery. The boost circuit for Lab 8 is shown in Figure 2.

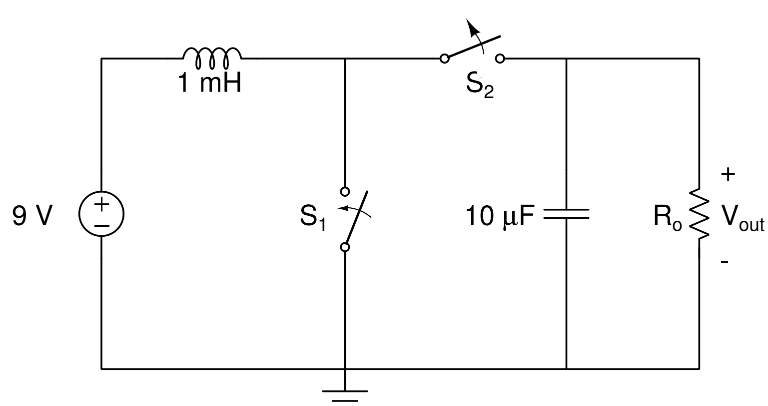

Figure 2: A basic boost circuit implemented with two synchronized switches.

A brief description of this circuit follows. In this circuit, the two switches operate simultaneously and in opposite directions. When switch S_1 closes, switch S_2 opens; when switch S_1 opens, switch S_2 closes. Switches S_1 and S_2 are never both open or both closed at the same time. Switches S_1 and S_2 are continuously opened and closed by an oscillator circuit that is not shown. (The oscillator circuit is the subject of Lab 9.)

When switch S_1 is closed and S_2 is open, the 9 V supply voltage and the inductor form one circuit, and the capacitor and the resistor form a second circuit. These circuits are isolated and not connected to each other. The voltage across the capacitor when switch S_2 opens will begin to decrease as the capacitor is discharged through resistor R_0. This decrease in voltage will depend on how long the switch is open and the value of the resistor R_0. At the same time, current through the inductor increases. The maximum current flow will depend on how long switch S_1 is closed and on the series resistance of the inductor and the switch S_1. The maximum current through the inductor should never be more than 0.5 A.

When switch S_1 is opened and S_2 is closed, the two circuits are connected and the energy in the inductor will pass through switch S_2 and be supplied to the 10μF capacitor. The voltage on the capacitor will increase and drive current through the resistor R_o.

A steady–state output voltage is reached when the energy transferred from the inductor to the capacitor when switch S_1 is open and switch S_2 is closed equals the energy lost from the capacitor when switch S_1 is closed and switch S_2 is open.

Rather than implement this circuit with two switches, you will design the boost circuit using diode in place of switch S_2 as shown in Figure 3. When the switch S_1 is opened, the energy in the inductor is released and charge passes through the diode D_1 and is supplied to the capacitor. The diode allows current to pass in only one direction. Once charge has passed through the diode onto the capacitor it can not return to the inductor side of the circuit. Hence, it only allows current to pass when switch S_1 is open and functions as an open circuit when switch S_1 closes.

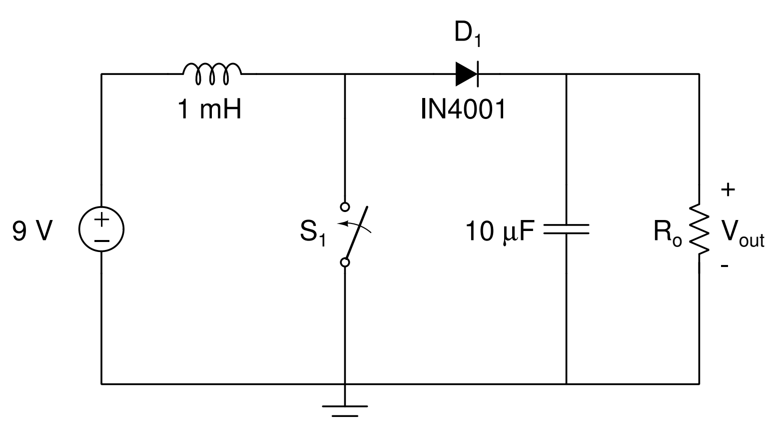

Figure 3: A basic boost circuit using a diode to replace switch S_2.

Pre–Lab: Design a boost–circuit which takes an input voltage of 9 VDC and produce an output voltage of 20 VDC with a peak–to–peak ripple of less than 0.1 V.

Record all hand–calculations and answers to the following questions in your notebook.

1. If V_{out} decreases from 20 V to 19.9 V when switch S_1 is closed, how much energy must be supplied to the capacitor when switch S_1 is open to bring the voltage back to 20 V?
2. Let t_1 be the duration that switch S_1 is closed. What is the value of t_1 to allow the inductor to absorb this much energy? Assume the inductor has a series resistance of 0.5 Ω and the switch has a resistance when closed of 1 Ω.
3. What is the maximum current through the inductor just before switch S_1 opens?
4. What value of R_o is required such that the capacitor voltage drops from 20 V to 19.9V during time t_1.
5. How much energy is lost in the resistor R_o when switch S_1 is closed?
6. Let t_2 be the amount of time it will take for the current to stop flowing from the inductor to the capacitor after switch S_1 is open. Approximate the value of t_2.
7. The period of the square wave used to drive switch S_1 is $T = t_1 + t_2$. What is T?
8. Using the above values for T, C, and R_o, how much current can the boost–circuit deliver?
9. Use Micro-Cap to simulate the boost–circuit shown in Figure 4. This circuit represents an approximation of what you will build in the lab. The switch is modeled in Micro–Cap as a voltage controlled switch S(V-Switch). This switch is available in Micro–Cap under `menus` → `Components` → `Analog Primitive` → `Special Purpose`. Choose the SBREAK2 model for this circuit. Set the "on resistance" of the switch to 1 Ω and the "off resistance" to 10^6 Ω. The switch is closed when the control voltage is 5 V and the switch is open when the control voltage is 0 V.

   (a) Set the value of R_o to what you calculated above.

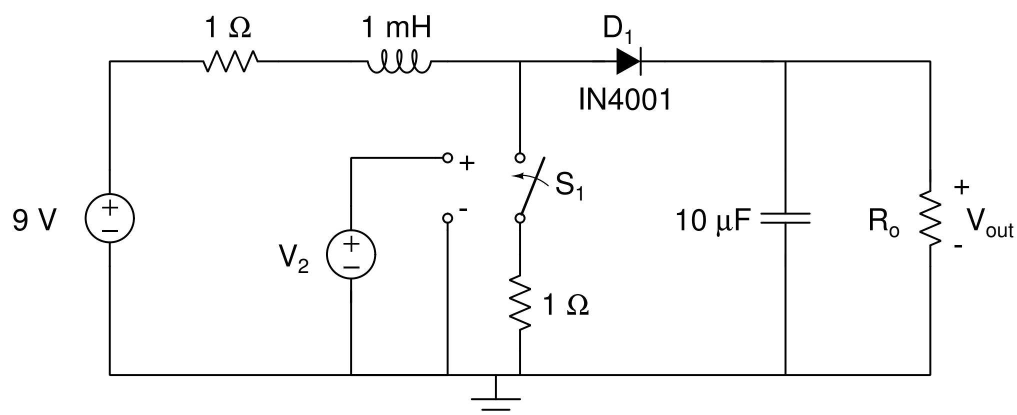

Figure 4: Test circuit representation of the boost circuit for Micro–Cap simulation.

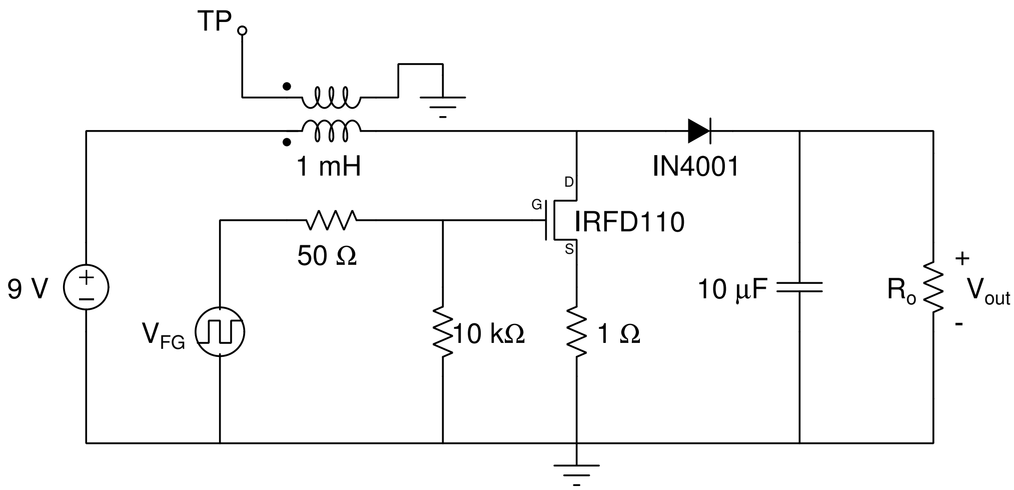

Figure 5: Boost circuit.

(b) Set V_2 to a square wave from 0 to 5 V with a period of T and the pulse width of t_1 calculated above.

(c) Plot the voltage across the capacitor and the current through the inductor for a time duration of 5 ms. This will show the continuous running state of the circuit.

(d) What is the output voltage V_{out}?

(e) How much ripple do you observe?

(f) If the values of t_1, t_2, and R_O are correct, you should see an output voltage of 20 V with a ripple of 0.1 V.

(g) Redesign the circuit if necessary to meet the specification. If the output voltage and ripple are close to the specification, you can adjust the output voltage by making small changes to the values of t_1, t_2 and R_o. Make sure the plot of your output voltage shows that your design meets the specification .

(h) Have a table listing the final values of t_1, t_2 and R_o and a plot of the output voltage in your notebook and reference the table and plot in the table of contents.

Lab Procedure:

Build and test the boost–circuit. The schematic is shown in Figure 5. A MOSFET transistor (IRFD110) is used as a solid–state voltage–controlled switch. You will determine the voltage V_{GS} needed to control this switch in lab.

Try and place the circuit near the end of your breadboard. You will eventually need two boost–circuits on the breadboard to meet the specifications in Lab 10. Record all results in your laboratory notebook.

1. Build the boost–circuit shown in Figure 5 but do not apply the 9 volt power supply.

2. Make sure you have a resistor bank for the load resistor R_o with the resistance value calculated in the pre–lab. Make sure your resistor bank can handle the power you will be supplying to these resistors.

3. Set the Function Generator to produce a square wave signal from 0 volts to 5 volts with a period of Ts and duty cycle of $\frac{t_1}{T}$. Check the signal on the scope to make sure it is correct before applying it to the circuit.

4. Attach one channel of the the scope across the capacitor and the second channel across the 1 Ω resistor in series with the transistor. Monitor these voltages carefully when powering up the circuit. Make sure the maximum current through the transistor never exceed 0.5A and the voltage across the capacitor does not exceed 25 V.

5. Turn the 20 V DC supply voltage down to zero and then connect it to the inductor where the +9 volts is indicated.

6. Slowly turn up the DC supply voltage until it reaches 9 V. If the voltage across the capacitor goes above 25 V, or the current through the transistor exceeds 0.5 A, immediately reduce the supply voltage. Adjust the magnitude of the load resistor or change the period and/or pulse width of the function generator to correct the problem. If either signal can't be kept within limits check your circuit.

7. Record the voltage across the capacitor in your notebook. Measure the average DC value using your DVM and the ripple using the scope. Ripple is the AC signal riding on the DC part. Does it meet the 0.1 Vp ripple limit?

8. Record the current in the transistor. Does it ever exceed 0.5 amps? Record all results in your notebook.

9. If the circuit does not meet the specification, redesign and retest the circuit. If you can not meet the specification, state the best results you were able to obtain. Take a photograph showing your final circuit connected to a 9V battery with the output displayed on a DVM. Also include a photograph showing the AC ripple on an oscilloscope. Include these photos in your notebook and reference them in the table of contents.

10. Wind a coil on the toroidal inductor used in this lab. This turns the inductor into a transformer and will allow you to look at the voltage across the inductor without connecting to the inductor windings. Connect one end of your coil to ground in the circuit and leave the other end TP (Test Point) free. Use the TP winding on the coil to look at the voltage that appears across the transformer. This is a transformer in action. Record in your notebook the signal at TP.