ECE 214 - Lab #7 — Boost Converter

27 March 2018

Introduction: In this lab, you will design, simulate, build, and test a boost converter based on the switched capacitor circuit shown in Figure 1.

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. In the ideal circuit, 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 a function generator (FG), or oscillator circuit, not shown in the figure.

When switch S_1 is closed and S_2 is open, the 12 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 exceed 0.6 A.

When switch S_1 is opened and S_2 is closed, the two circuits are connected, and the energy in the inductor will flow 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, with switch S_1 open and switch S_2 closed, is equal to the energy lost from the capacitor, with switch S_1 closed and switch S_2 open.

Rather than use two switches, you will implement the boost converter circuit using an NMOS transistor to represent switch S_1 and a diode to represent switch S_2. The schematic of the actual circuit is shown in Figure 2.

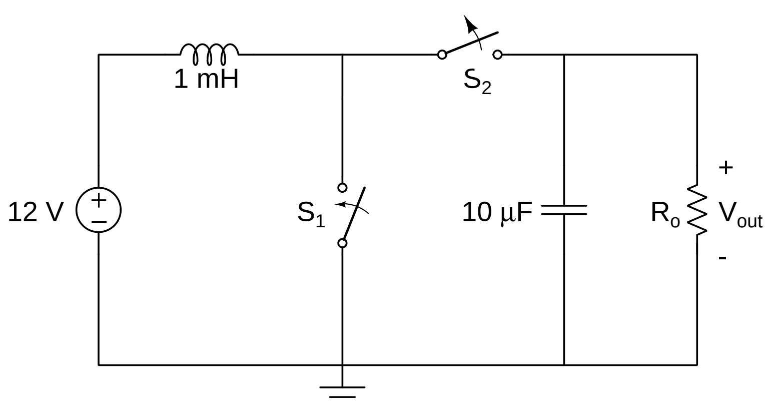

Figure 1: A boost converter circuit containing two synchronized switches.

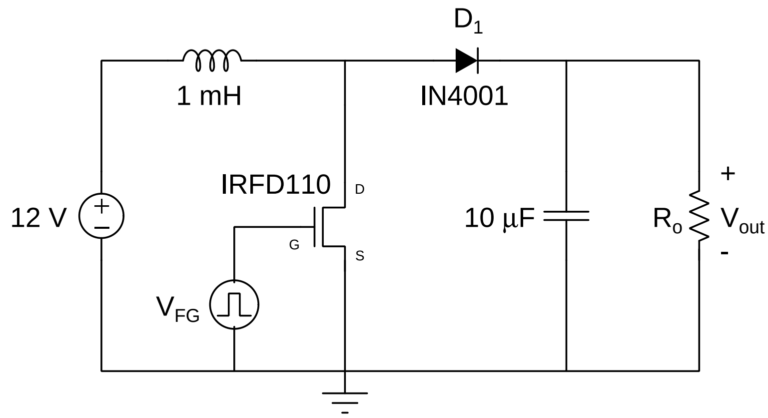

Figure 2: Boost converter circuit implemented with an NMOS transistor driven with a function generator (FG) to represent the switch S_1 and a diode to represent the switch S_2 in Figure 1.

The NMOS transistor acts as a voltage controlled switch. When V_{GS}, the voltage between the gate (G) terminal and the source (S) terminal, is 5 V, the drain (D) and source (S) terminals are effectively shorted, and current flows between the drain (D) terminal and the source (S) terminal of the transistor. When $V_{GS} = 0$, the connection between the D and S terminals of the transistor is open, and no current flows between the D and S terminals.

When the D and S terminals of the NMOS are open (switch S_1 open), the energy in the inductor causes charge to flow through the diode (D_1) to the capacitor. A diode allows current to flow in only one direction. Hence, the diode only allows current to flow from the inductor to the capacitor. Once the charge flows through the diode and onto the capacitor, it can not return back to the inductor side of the circuit.

The diode functions as an open circuit when the D and S terminals of the transistor are shorted (switch S_1 closed). Thus, anytime switch S_1 is closed, switch S_2 is open. The diode ensures that switches S_1 and S_2 are never both closed at the same time.

When the frequency of the FG is properly adjusted, switch S_1 will close when the maximum amount of energy is transferred from the inductor to the capacitor. By properly setting the FG frequency as described below, switches S_1 and S_2 are never both open at the same time.

Design Specification:

1. Inputs: +12 V_{DC} and a 5 V square wave from the FG with frequency f and duty cycle δ
2. Output: $V_{OUT} = 25 \pm 0.5\ V_{DC}$ and a ripple ≤ 300 mVpp

Pre-Lab:

1. Follow the steps below to estimate the frequency, duty cycle, and value of R_O which will be used as a starting point for the boost converter simulation.
   (a) Let V_{OUT} decrease from 25.05 V to 24.95 V when switch S_1 is closed. This 100 mV

decrease in V_{OUT} is half of the maximum allowed ripple. How much energy must be supplied to the capacitor when switch S_1 opens to bring the voltage back to 25.05 V?

(b) Let t_1 be the time duration that switch S_1 is closed. What is the value of t_1 that will allow the inductor to absorb this much energy?

(c) What is the maximum current through the inductor just before switch S_1 opens?

(d) What value of R_O is required such that the capacitor voltage drops from 25.05 V to 24.95 V during time t_1.

(e) Let t_2 be the amount of time it takes for the current to stop flowing from the inductor to the capacitor after switch S_1 opens. Approximate the value of t_2 by considering the series RLC circuit where R is the ESR of the inductor determined in Lab #6. Ignore the output resistance R_O in this calculation.

(f) The period of the square wave (T) used to drive switch S_1 is $t_1 + t_2$; the frequency (f) is $1/T$ and the duty cycle (δ) is t_1/T. What are T, f, and δ for the FG?

2. Use NGspice to simulate the boost converter circuit shown in Figure 3. Include the ESR of the inductor. Also include a 1 Ω resistor between the S terminal of the transistor and ground to allow for the simulation of the current through the transistor.

(a) Set the value of R_O to the value calculated in step 1d.

(b) Set V_{FG} to a square wave from 0 to 5 V with a period of T and the pulse width of t_1 calculated in steps 1e and 1f. Make the rise time and fall times $\ll$ pulse width.

(c) Plot the voltage across the capacitor as a function of time.

(d) Calculate the maximum current through the inductor.

(e) What is the steady-state output voltage V_{out}?

(f) What is the peak-to-peak ripple?

(g) Does the circuit satisfy the design specifications?

(h) Adjust the duty cycle and frequency of the FG, if necessary to meet the specification.

(i) Record the final values of R_O, f and δ for the design.

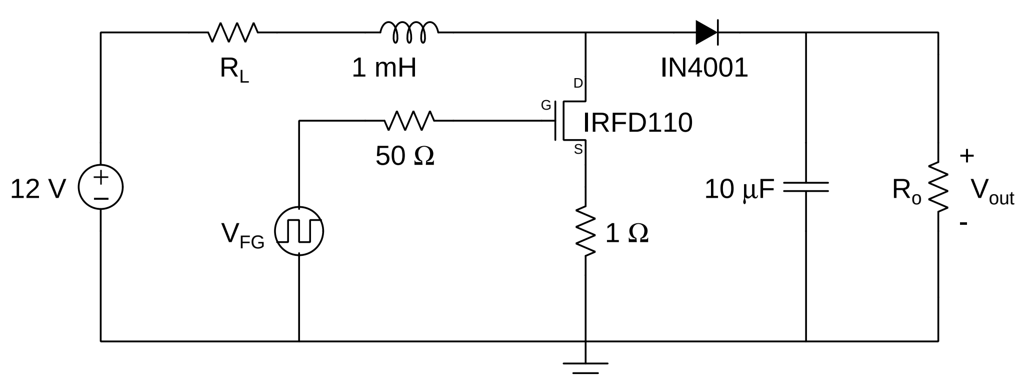

Figure 3: Boost converter circuit for NGspice simulation and for implementation.

Lab Procedure:

1. Build and test the boost converter circuit shown in Figure 3 using the component values and FG settings determined in step 2i of the Pre-Lab.

2. Set the FG to produce a square wave signal from 0 volts to 5 volts with a frequency fs and duty cycle δ. Check the signal on the scope to make sure it is correct before applying it to the circuit.

3. Attach one channel of the the scope across the capacitor and the second channel across the 1 Ω resistor in series with the transistor. Attach the DVM across the capacitor and set it to measure the DC voltage. Monitor these voltages carefully when powering up the circuit. Make sure the maximum current through the transistor is less than 0.5 A and the voltage across the capacitor remains less than 30V.

4. Slowly turn up the DC supply voltage until it reaches 12 V. If the voltage across the capacitor goes above 30 V, or the current through the transistor exceeds 0.6 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 these limits check your circuit.

5. 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?

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

7. If the circuit does not meet the specification, redesign and retest the circuit. Add a low pass filter if necessary. 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 the 10 V power supply 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.

8. Do not disassemble the circuit. You will need this circuit in Lab #9.

Post-Lab

1. Include a table in your notebook listing the final values of t_1, t_2 and R_o.

2. Use NGspice to simulate your final boost converter circuit using the measured values of the components you used in lab including the equivalent series resistance of the inductor. Plot the output voltage as a function of time.

3. Discuss your results and compare the simulated results to the measurements you made in lab.

4. Reference this Post Lab in the table of contents of your notebook.