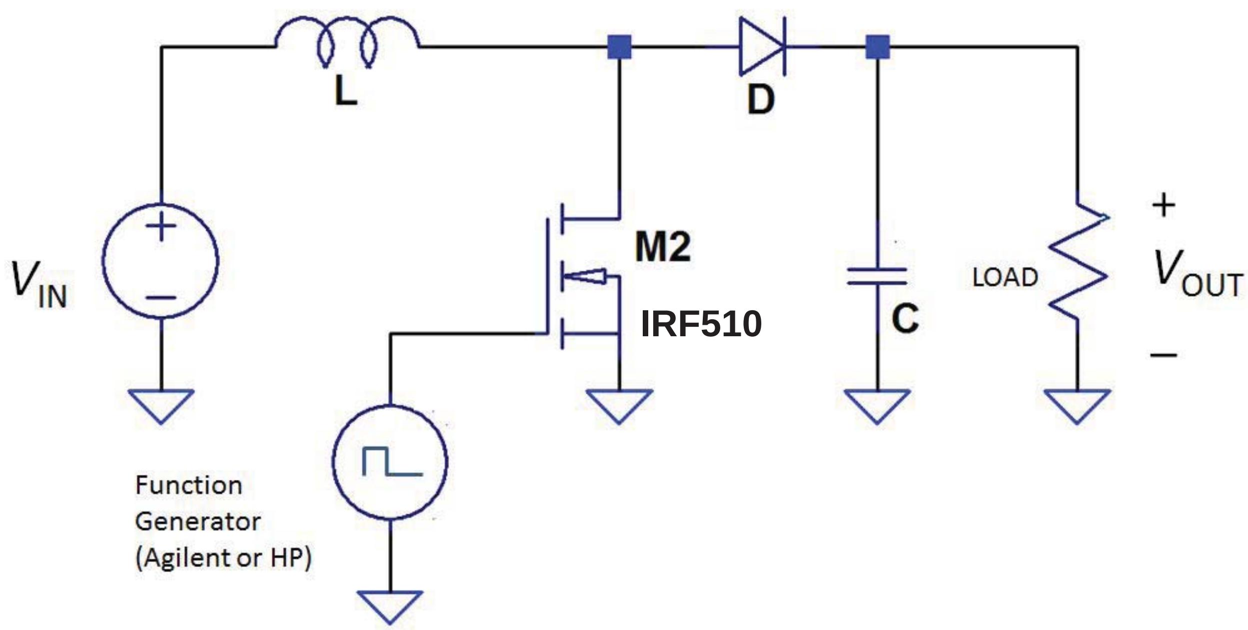
EC583 – Power Electronics for Energy Systems
DC-DC Boost Converter

Background:

This experiment focuses on the DC-DC *boost* converter that we studied in class. The word "boost" means to "raise" or "lift up"; indeed, the boost converter accepts raw voltage from a DC energy store, then uses inductive storage to provide a DC output at higher voltage. Thus one of the key characteristics of the boost converter is that its output voltage is larger than its input voltage. This type of controller is often found in energy systems in which lower voltages – for example, energy derived from a photovoltaic solar array – must be increased to 170 VDC so that it can then converted into 120 VAC *rms* by a circuit called an *inverter.* In this context, the switching inverter is a circuit that converts DC to AC; it should not be confused with the "transistor inverter" circuit – a form of amplifier – that you studied in electronics class.

The circuit shown below is a generic version of the boost converter. It's output will be unregulated; that is, you will set the duty cycle to produce a desired V_{OUT}, but the actual output will be different due to the forward diode drop (V_f = 0.7 V), the effect of the load, and losses in the MOSFET. In a later lab, we will learn how to build a controller that compares V_{OUT} to a reference voltage V_{REF} and then continually adjusts the duty cycle so that $V_{OUT} = V_{REF}$.
For this experiment, we will simulate the load by using a resistor equal to V_{OUT}/(Required Load Current)



Assignment Part 1

Write a spreadsheet (or MATLAB) program that will allow you to do the following:

- Specify desired V_{DC}, V_{OUT}, I_{LOAD}, and switching frequency f_{sw}
- Calculate required D, and find L_{min}
- Choose an appropriate L larger than L_{min}, and choose a value for C_1
- Calculate i_{MIN}, i_{MAX} and V_{rip}

Here are some of the relevant formulas for the boost converter as found in the Class Notes:

- ☞ $\dfrac{V_{OUT}}{V_{DC}} = \dfrac{1}{1-D}$ (See footnote**)
- ☞ $i_{\mathrm{MAX}} = I_{\mathrm{LOAD}} + V_{\mathrm{DC}} \dfrac{DT}{2L}$ and $i_{\mathrm{MIN}} = I_{\mathrm{LOAD}} - V_{\mathrm{DC}} \dfrac{DT}{2L}$
- ☞ $L_{\mathrm{min}} = V_{\mathrm{DC}} \dfrac{DT}{2I_{LOAD}}$
- ☞ $V_{\mathrm{rip}} = \hat{i}_{\mathrm{LOAD}} D/fC$

Assignment Part 2

Use your spreadsheet (or MATLAB program) to design and test a PWM DC-DC boost converter that has the following specifications:

- *Input voltage*: 3.0 V DC (This is the voltage of two AA batteries.)
- *Target Output voltage*: 5.0 V (This is the voltage needed to charge many cell phones.)
- *Switching frequency*: In the 5-20 kHz range.
- *Load current*: Some value between 0.5 and 1 A .

For now, use the HP/Agilent waveform generator to produce a 0 to 8-V square-wave with variable duty cycle as the gate drive signal.

a) Set the duty cycle to your calculated value and observe the output voltage. Then find the *actual* duty cycle, if it's different, that is needed to produce the desired V_{OUT}.
b) Measure the output voltage ripple V_{rip} at the duty cycle needed to produce the desired V_{OUT}.
c) Find the values of D required to change V_{OUT} by about $\pm 20\%$.
d) Verify that your converter operates in continuous conduction mode in at least 2 of 3 ways: a) Measure the inductor current; b) Measure the voltage across diode D_1. It should conduct the entire time that the MOSFET is off. You will need to use two probes in differential mode to make this measurement; c) Measure the voltage across Rds-on when the MOSFET is on.)

Note: Use the B-K Precision CP62 clamp-on current probe to measure inductor current.

** Inverting this formula: $D = \dfrac{V_{OUT} - V_{DC}}{V_{OUT}}$ provides the duty cycle D needed to obtain a desired $V_{\mathrm{OUT}}/V_{\mathrm{DC}}$.

Assignment Part 3

In real life, you can't carry around a function generator to produce the PWM duty-cycle signal required of the converter. Replace the function generator with the self-contained 555-timer circuit shown below. It provides two separate pathways for the charging/discharging of the timing capacitor C_T, one via D_1 and R_1, and the other via D_2 and R_2. The duty cycle can be adjusted using the potentiometer control R_3 to change the value of resistance connected to C_T for each pathway.

- Build the 555-timer circuit
- Find the minimum and maximum values of D that you can obtain using this circuit.
- Replace the function generator in your boost converter with this timer circuit.
- With V_{IN} = 1.5 V, vary (measure and record) the duty cycle, and find the minimum and maximum possible values of V_{OUT}. Compare with theoretical values predicted by $V_{OUT} = V_{IN}/(1 - D)$.