Lab 4 – Buck Converter

• GOAL

The goal of Lab 4 is to demonstrate a buck converter to drive a 5V DC brushless fan (e.g. a computer fan).

Fig. 1: 5V DC brushless fan.

• OBJECTIVES

1) Observe MOSFET gate charging effects (e.g. Miller Plateau)
2) Observe the benefit of using a totem-pole MOSFET gate driver
3) Measure the buck converter efficiency

• INTRODUCTION

Fig. 2 is a simplified schematic of a buck converter ($V_{OUT} < V_{IN}$). The inductor acts as a "current storage" element, the diode acts as a voltage clamp for the inductor, while a capacitor smooths the output voltage and current. Q1 is a p-channel power MOSFET, so a logic level shifter Q2 is needed to provide enough gate voltage. A detailed understanding of buck converters is beyond the scope of this course, but this lab will cover some basic concepts.

The design specs fall into two categories.

- For the output: $V_{OUT} = 5V$, $I_{OUT} = 0.22A$, $V_{OUT,RIPPLE} < 5\%$.
- For inside the buck converter: $\Delta I/I_{OUT} = 30\%$ and switching frequency $f_{SW} = 50$ kHz

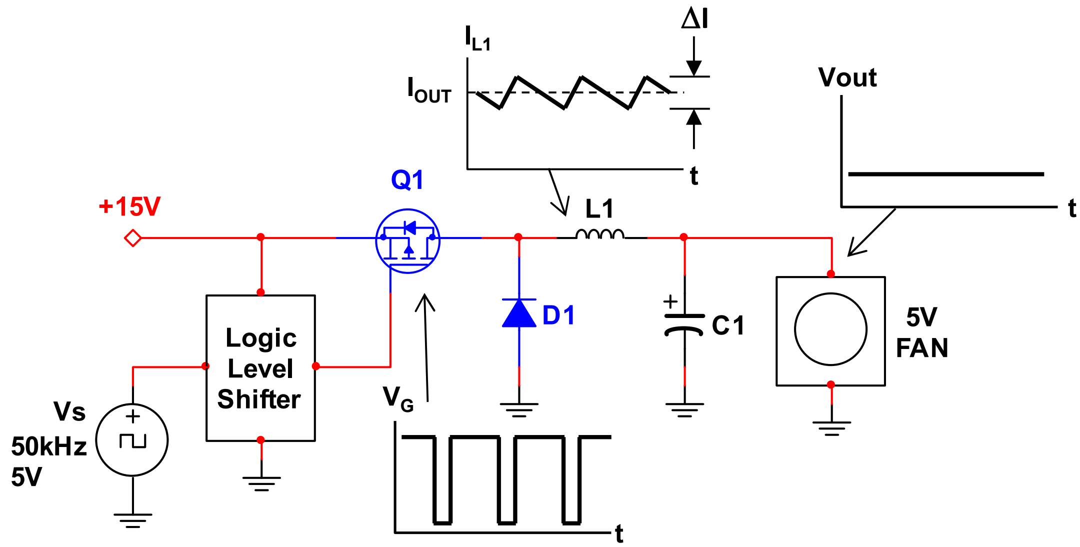

Fig. 2: Simplified schematic of a buck converter. Q1 is the FET switch that is rapidly turned on and off. The inductor current ramps up when Q1 is ON and ramps down while Q1 is off. The capacitor smooths out the voltage and current output.

- **PART 1: MOSFET GATE CHARGE EFFECTS**

Parts and Materials:

- Lab kit, benchtop power supply, function generator, scope, and probe box (contains banana cables, multimeter probes, etc.)
- 2N7000 MOSFET (n-ch), IRF9520 MOSFET (p-ch)
- Two 1 kohm resistors (brown/black/red), one 10 kohm resistor (brown/black/orange)

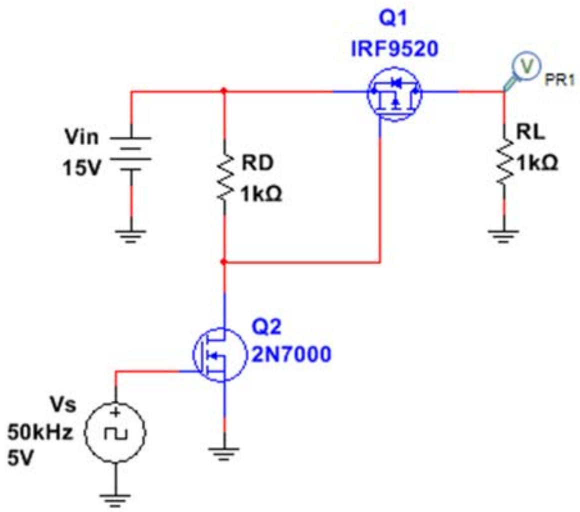

Fig. 3: Initial logic level shifting circuit to observe MOSFET gate charge effects.

➢ **<u>Task 1a: Build the logical level shifter in Fig. 3</u>**.

- You must use NEAT and COLOR-CODED wiring:
  - RED = +15V
  - BLACK = GND
  - YELLOW = everything else
- Component pin diagrams are in the data sheets on the course website.

➢ <u>**Task 1b**: Configure the function generator</u>.

➢ ***If you have the newer Agilent function generator (<u>Model 33220A</u>)*:**

1) Set the generator to "High Z" output.
   - Press "Utility", then select "Output Setup", then "High Z", and finally select "Done".
2) The waveform settings should be:
   - Square wave; Amplitude = $5V_{PP}$; Offset = 2.5V
   - Press "Duty Cycle" and then enter 33%.
3) Press the "Output" button on the waveform generator to turn on the output.
4) Connect the function generator output to the circuit's Vin using the coaxial cable with alligator clips.

➢ ***If you have the older Agilent function generator (<u>Model 33120A</u>)*:**

1) Set the Agilent generator to "High Z" output.
   - Press "Shift" and "Enter".
   - Press ">" three times until "D:SYS MENU" appears.
   - Press "∨" once to obtain "1: OUT TERM".
   - Press "∨" again to obtain "50 OHM"
   - Press ">" to make "High Z" appear and press "Enter" to finish.

2) The waveform settings should be:
   - Square wave; Amplitude = 5V_{PP}; Offset = 2.5V
   - Press "Shift" >> "% Duty", and then enter 33%.
3) Connect the function generator output to the circuit's Vin using the coaxial cable with alligator clips.

- **Task 1c: Measure the load voltage and Q1 gate voltage for R_D = 1 kohm and 10 kohm**.
  - Configure the scope trigger in the following manner:
    - Use a coaxial cable to connect the function generator's SYNC output to the scope's EXT input.
    - Set the scope to "External Trigger" by using TRIG MENU >> SOURCE >> EXT
    - Adjust the TRIG LEVEL to about 1V
  - Manually adjust the vertical and horizontal scales of the scope to show a couple cycles of the load voltage.
    - Do NOT press the Autoscale button! Buma will deduct 5000 points from your grade!
    - You should see waveforms that look something like Fig. 4a and 4b.
      - Fig. 4 shows Multisim traces, so your measured waveforms will not be identical.
    - **Save these traces for the lab demo** (e.g. use the "swave" command in MATLAB).
  - Replace R_D with a 10 kohm resistor, repeat the measurements, and SAVE THE TRACES.
    - Question: Why is the load voltage always 15V when RD = 10 kohm?
    - Write down your answer here:

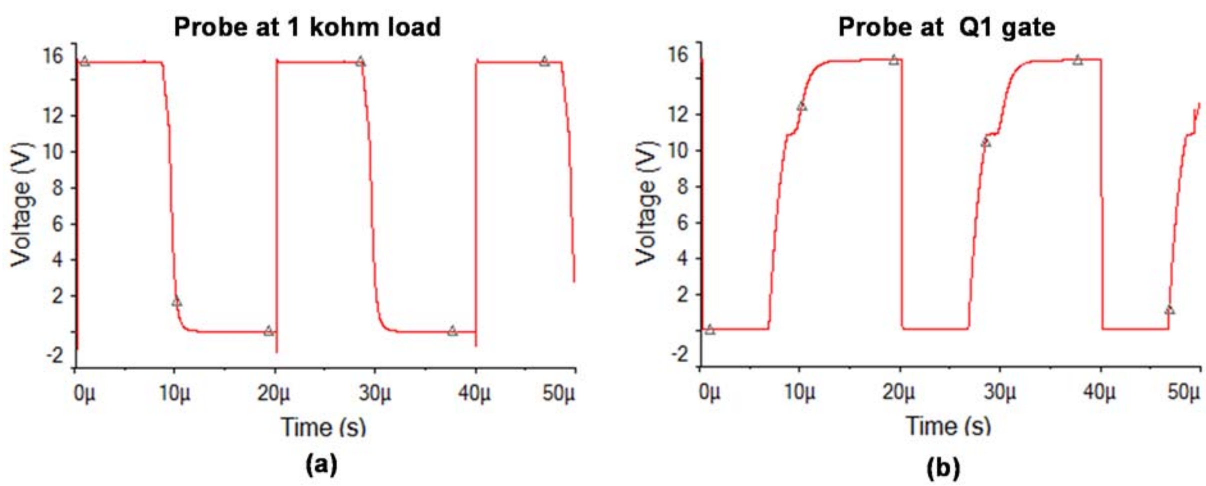

Fig. 4: Simulated waveforms for (a) load voltage (b) Q1 gate voltage. The little "kink" in the rising edge of the Q1 gate is the Miller plateau.

• PART 2: TOTEM-POLE GATE DRIVER

Parts and Materials:

- 2N3904 (npn) and 2N3906 (pnp) transistor

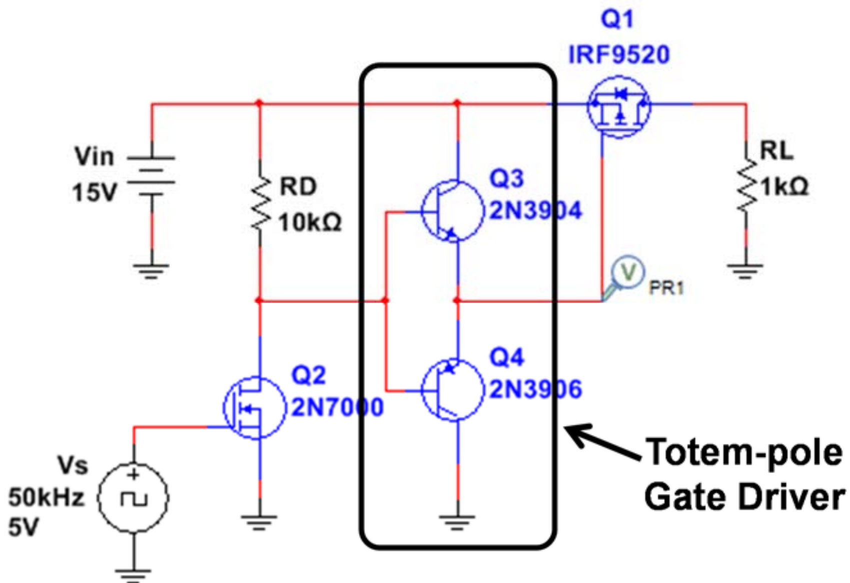

Fig. 5 Add the totem-pole gate driver to your circuit.

➢ **Task 2a: Add the totem-pole gate driver to your circuit (see Fig. 5)**.

  - Pin diagrams are in the datasheets on the course website.

➢ **Task 2b: Measure the load voltage and Q1 gate voltage**.

  - You should observe MUCH nicer waveforms!
  - ***Save these waveforms for your lab demo***.

• PART 3: BUCK CONVERTER EFFICIENCY

Parts and Materials:

- 1 mH inductor (it's pretty large)
- 1 uF electrolytic capacitor
- 1N4148 diode
- 22 ohm, 2W resistor (same as the really thick resistor used in Lab 1) (red/red/black)
- 5V fan

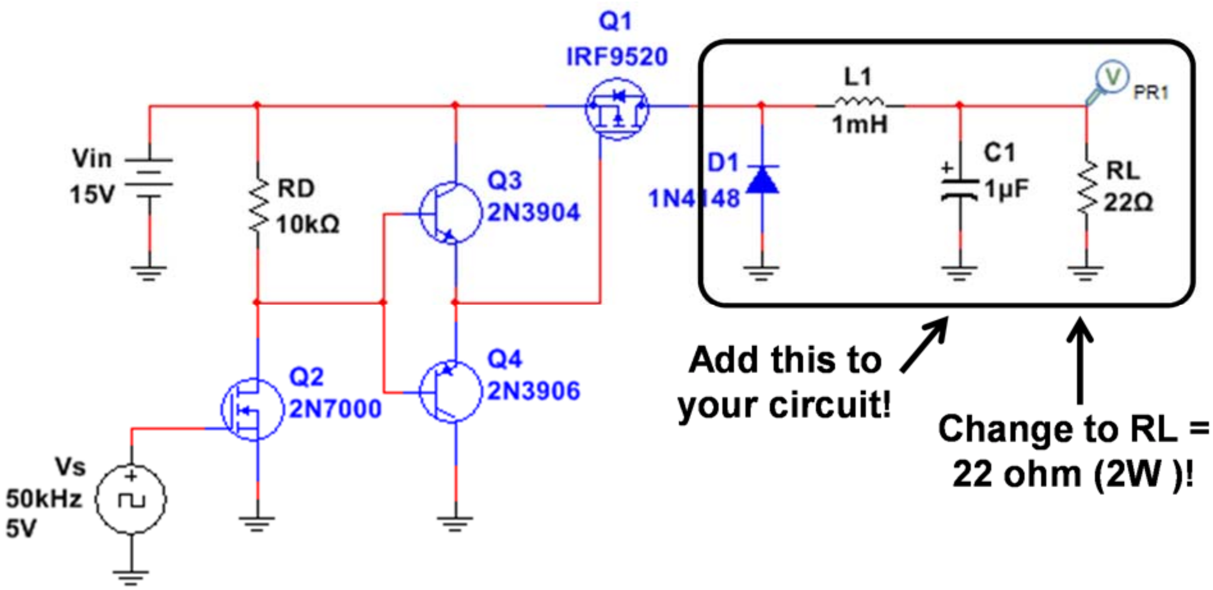

Fig. 6: Add the inductor, diode, and capacitor to your circuit. Change the load resistance to RL = 22 ohm!

- **<u>Task 3a: Add the inductor components to your circuit (see Fig. 6)</u>**.
  - The 22 ohm resistor is meant to mimic the 5V fan (at least for initial testing purposes).

- **<u>Task 3b: Measure the load voltage</u>**.
  - If your ripple is too big (see design specs), then you should increase the capacitor.
    - Available values are: 1, 4.7, 10, 47, 100, 330, and 470 uF.
    - ***Measure your output ripple and record this value for your lab demo***.
  - The average (or DC) value of the load voltage is probably a little different from 5V.
    - Adjust the function generator's duty cycle to get an output voltage close to 5V.
  - ***Save the final Vout waveform for your lab demo***.

- **<u>Step 3c: Measure the buck converter efficiency</u>**:
  - Replace the 22 ohm resistor with the 5V fan.
  - Use the multimeter to make the necessary measurements to compute the buck converter efficiency.
    - ***Save this result for your lab demo***!

- **<u>Step 3d: Lab Demo</u>**.
  - Buma will reset the scope and ask you to show the Q1 gate voltage.
  - Show Buma your MATLAB plots, measured voltage ripple and efficiency. (End of Lab 4)