Lab 7: MOSFET Switches (Week of May 25th)

GOAL

The overall goal of this lab is to better understand how MOSFETs are used in buck converters and H-bridges.

OBJECTIVES

To build, test, and understand the following circuits:

1) Buck converter
2) H-Bridge

GENERAL GUIDELINES

You should know the guidelines by this point in the course …

PARTS AND MATERIALS

- Lab kit (breadboard, wire stripper, wire)
- Digital oscilloscope, scope probes, function generator, coaxial cable (with alligator clips), benchtop power supply
- Fan
- Switch
- Npn transistor: 2N4401 (1)
- Power MOSFET: IRF9520 (p-channel) (2)
  IRF520 (n-channel) (2)
- Diode: 1N4002 rectifier (1)
- Resistors: 1 kΩ (brown/black/red) (2)
  10 kohm (brown/black/orange) (1)
- Capacitor: 100 μF electrolytic (1)
- Inductor: 1 mH (1)
- IC CD4011 quad NAND gate (1)

PART 1: POWER SUPPLY FOR A COMPUTER FAN

In this section you will build a buck converter (step-down DC-DC converter) driver a computer fan.

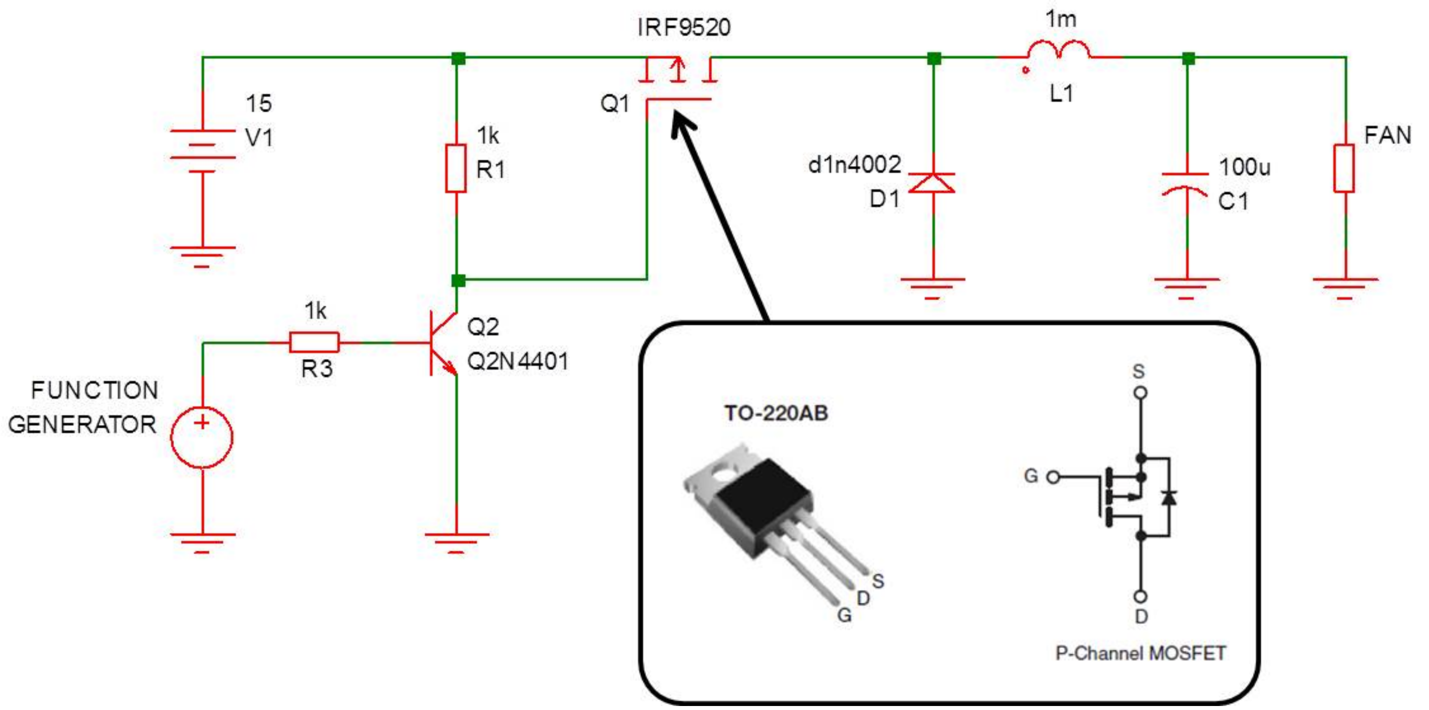


Fig. 1: Buck converter used to drive a 5V computer fan. The function generator is a 0-to-5V pulse train at 10 kHz and 33.3% duty cycle. The pin diagram for the IRF9520 p-channel MOSFET is shown in the inset.

- Step 1a: Build the buck converter shown in Fig. 1.
  - The input DC voltage is 15V from the benchtop supply (e.g. use the RED terminal of your breadboard).
  - The pin diagram for the IRF9520 (p-channel) MOSFET is in the figure as well as on the course website.
  - The PWM input comes from the Agilent function generator (see Step 1b).

- Step 1b: Test the buck converter.
  - Configure the Agilent "Pulse" waveform (Lo = 0V, Hi = 5V) to a 10 kHz frequency and 33.3% duty cycle.
  - Use alligator clips to apply the function generator output to the circuit.
  - Your circuit works if the motor is happily blowing air.

- Step 1c: DC measurements, scope snapshots, and calculations.
  - Use the multimeter to measure the AVERAGE voltage of the fan.
  - Adjust the Agilent duty cycle to make the average motor voltage be 5.0 V.
  - Record the duty cycle for your lab report.

- Use the scope to measure the gate voltage of the p-channel MOSFET (same as the collector voltage of the 2N4401 switch).
  NOTE: You should see a 0-to-15V pulse train with about 66% duty cycle.
- Use “swave” to record a few cycles of the scope waveform.
- Use the multimeter to record the DC current going into the fan.
- Use the multimeter to measure the DC current coming from the 15V benchtop supply.
- Computer P_{LOAD}, P_{IN}, and your buck converter efficiency. You should get between 70 and 80% efficiency

DO NOT DISSASSEMBLE THIS CIRCUIT UNTIL I HAVE SEEN IT WORK!

PART 2: H-BRIDGE MOTOR DRIVER

In this section you will build a full H-bridge motor driver using MOSFETs.

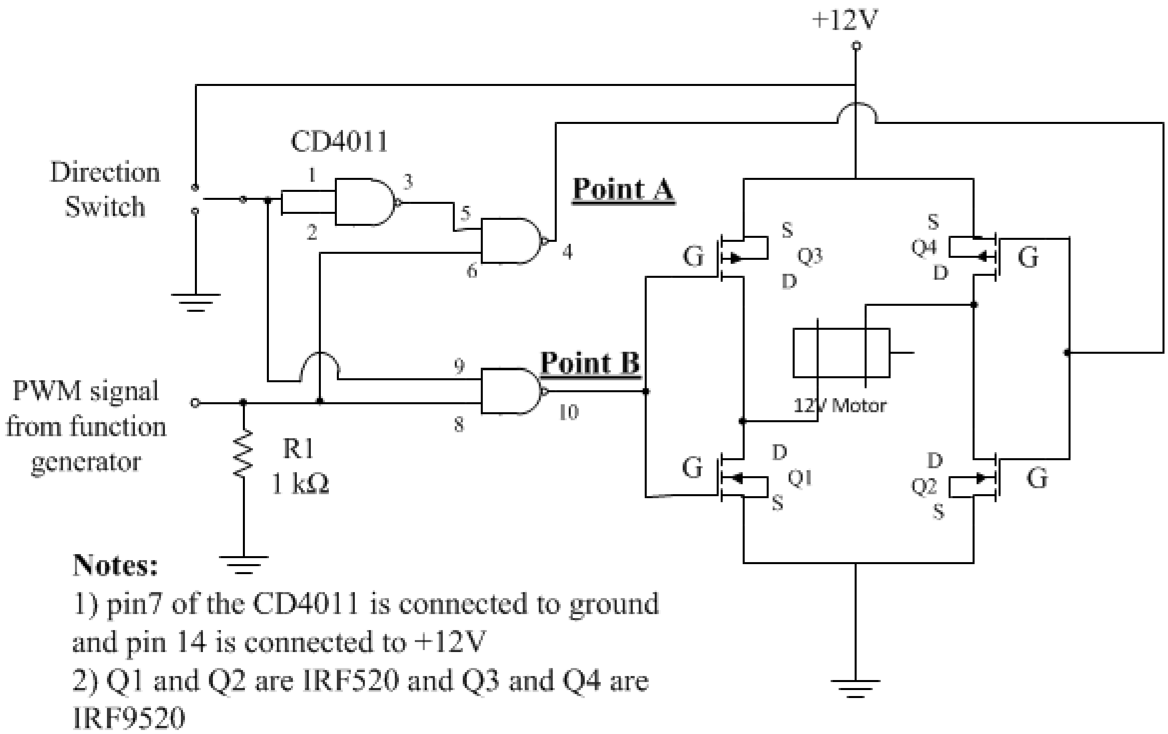
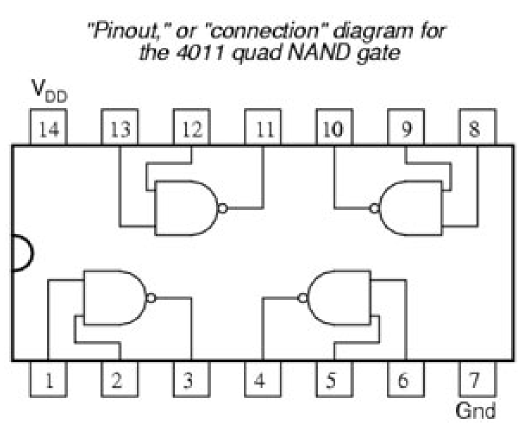


Fig. 2: H-bridge motor driver using four MOSFETs. The remaining components are the control logic.



This circuit looks pretty crazy, but it really is not that bad.

- Note that ONLY one P-FET and one N-FET in the circuit can be on at a time or there will be a short from VCC to ground.
- Remember that an N-FET is ON (conducting) when its gate is at +12 V and off (cutoff) when its gate is at 0V. A P-FET is ON (conducting) when its gate is 0 V and off (cutoff) when its gate is at +12V.
- When Q1 and Q4 are on the motor turns in the forward direction and when Q2 and Q3 are the motor turns in the reverse direction.
- Speed control is achieved by pulse width modulation (PWM).
- We have two digital inputs: PWM – the motor is on when the PWM signal is on and off otherwise; the direction signal is a 1 for forward and a 0 for.
- Our circuit uses three NAND gates to provide the logic to control the motor direction and speed.
- The following is a logic table for the circuit. Notice that there are four possible combinations for the two inputs but only three states: off, forward, and reverse. Thus two combinations result in the motor off state.

Direction	**PWM**	**Point A**	**POINT B**	**Q1**	**Q2**	**Q3**	**Q4**	**Motor**
0	0	1 (12 V)	1 (12V)	ON	ON	OFF	OFF	OFF
0	1	0 (0V)	1 (12V)	ON	OFF	OFF	ON	Forward
1	0	1 (12 V)	1 (12V)	ON	ON	OFF	OFF	OFF
1	1	1 (12V)	0 (0V)	OFF	ON	OFF	ON	Reverse

- Step 2a: Test the circuit.

  - Configure the Agilent "Pulse" waveform (Lo = 0V, Hi = 10V) to a 25 kHz frequency and 80% duty cycle.
  - Use alligator clips to apply the function generator output to the circuit.
  - Your circuit works if the motor speed can be controlled by the PWM duty cycle (vary from 20 to 95%).
  - Does the motor move faster or slower when the duty cycle is high or low (e.g. 80% vs 20%)?
  - Your circuit really really works if the motor DIRECTION changes by flipping the toggle switch.
  - When the Agilent duty cycle is 80%, use "swave" to record scope traces of:
    - The PWM input (from function generator)
    - The voltage at the motor's RED wire
    - The voltage at the motor's BLACK wire.
  - Flip the toggle switch in order to change the motor direction, and use "swave" to record scope traces of:
    - The voltage at the motor's RED wire
    - The voltage at the motor's BLACK wire.

PART 3: CIRCUIT DEMOS

As always, Professor Hedrick will reset the scope and function generator. -3000 pts if you hit Autoscale on the scope.

1) **Circuit #1: Buck Converter** (15 pts of lab demo grade)

- Configure the function generator.
  - HighZ output
  - Waveform = PULSE
  - Low Level = 0V High Level = 10V
  - Frequency = 10 kHz
  - Duty cycle = whatever you found in Part 1c

- Multimeter displays the motor voltage (the red wire).
- The motor should be happily blowing air.

2) **Circuit #2: H-Bridge motor driver**. (15 pts of lab demo grade)

- Configure the function generator.
  - HighZ output
  - Waveform = PULSE
  - Low Level = 0V High Level = 5V
  - Frequency = 25 kHz
  - Duty cycle = 80%

- CH1 displays the voltage of the motor's red wire.
- CH 2 displays the voltage of the motor's black wire.
- The motor speed should depend on the PWM duty cycle, and the direction should depend on the switch.

(End of Lab 7)