Homework #4
ECE 363 (F19)
8 problems for 100 pts
Due Oct 25

A. BJT switch analysis (all data sheets on course website)

1) Consider the LED driver shown in Fig. 1. The input comes from a SPDT switch. Assume the LED has a forward voltage drop V_F = 2V @ 10 mA. Perform a "typical" analysis.

   (a) Compute the base current and LED current when the switch is connected to GND.

   (b) Repeat when the switch is connected to +9V.

   (c) When the BJT is on, is it properly saturated? Hint: You should find that I_C/I_B is very close to 10.

2) A flexible heating element is a device that conforms to the surface an object requiring heat. It is basically a resistor that consists of a metal foil pattern on a flexible polymer substrate (e.g. silicone or polyimide). This substrate has an adhesive for attachment to the object.

   Consider the Darlington switch shown in Fig. 2. The heater is rated at 12V @ 20W. The control comes from a microcontroller with 5V logic output and 20 mA maximum current. Perform a typical analysis.

   (a) Is the microcontroller capable of driving Q2 under typical Q2 conditions?

   (b) Does Q2 need a heat sink?

   (c) If Q2 needs a heat sink, will a 28 °C/W heat sink be adequate? Assume T_A = 25°C and θ_{CS} = 0.5 °C/W.

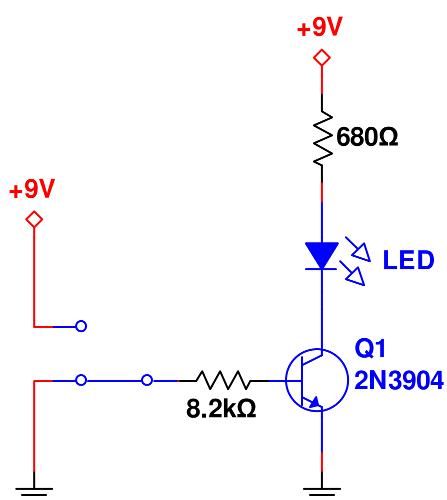

Fig. 1

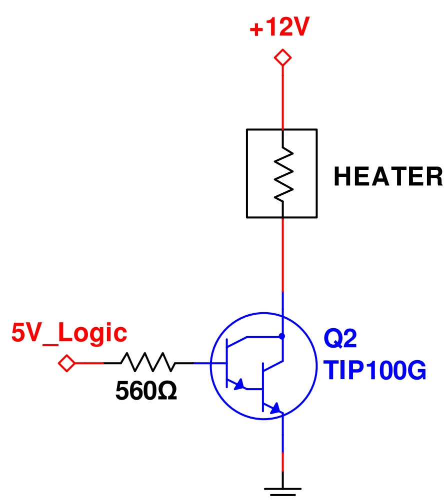

Fig. 2

B. BJT switch design (all data sheets on course website)

3) Solenoids are a common actuator found in pneumatic valves, automated door locks, etc. When a DC voltage is applied to a solenoid, the resulting current only depends on the coil resistance. Consider the solenoid driver shown in Fig. 3. The design constraints are shown below:

- The solenoid is rated at 24V and 6W and the power supply is +24V.
- The control comes from a microcontroller with 5V logic output and 40 mA current limit.
- You must choose between a BC546 and 2N2222A transistor.
- Choose between a 1N4148 and 1N4001 diode.

(a) Choose the transistor and diode. Make sure you analyze the important specs!
(b) Compute the minimum (e.g. worst case) solenoid voltage and current when Q3 is on.
(c) Choose the appropriate 5% value for R_B to ensure proper saturation under typical Q3 parameters.
(d) Based on your value for R_B, compute I_B and I_C/I_B for typical AND worst-case Q3 parameters.
(e) Can your microcontroller provide the required current under typical and worst-case Q3 parameters? NOTE: In general, it is a good idea to stay below 50% of the microcontroller current limit. For this problem, a Darlington transistor would have been better.

4) Suppose you want to operate a 12V DC motor that is part of a mechanical pump. Motors are typically specified by a "no-load" current and much larger "stall" current. The no-load or "free running" current is not useful because it means nothing is attached to the motor shaft. The stall current is when the motor is working as hard as it can, but the shaft won't move due to excessive mechanical load. **A reasonable rule of thumb is to design a motor driver to handle 50 % of the "stall" current**. Consider the motor driver shown in Fig. 4. The design constraints are shown below:

- The motor is rated at 12V (I_{NO_LOAD} = 100 mA, I_{STALL} = 1.7A) and the power supply is +12V.
- The control comes from a microcontroller with 5V logic output and 10 mA current limit.
- You must choose between a MPSA29 and TIP110.
- Choose between a 1N4148 and 1N4002 diode.

(a) Choose the transistor and diode. Make sure you analyze the important specs!
(b) Compute the worst-case (e.g. minimum) motor voltage when Q4 is on. NOTE: The motor still works if the voltage is less than the rated value. However, the maximum shaft speed and torque will be lower. Whether this matters or not depends on the anticipated mechanical load.
(c) Assuming the motor draws up to 0.85A of current, choose the appropriate 5% value for R_B to ensure proper saturation of Q4 (typical conditions).
(d) Assuming I_C = 0.85A, will a 25 °C/W heat sink keep Q4 happy, even under worst-case Q4 parameters?

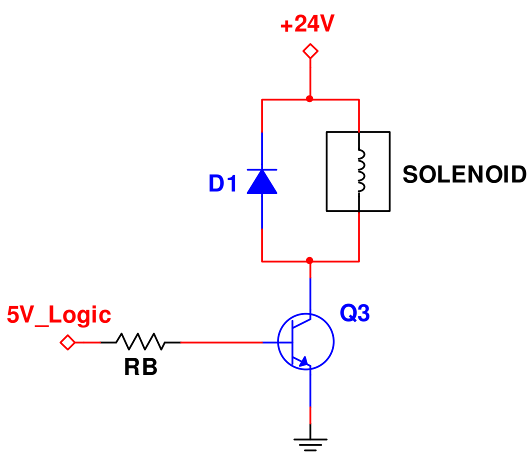

Fig. 3

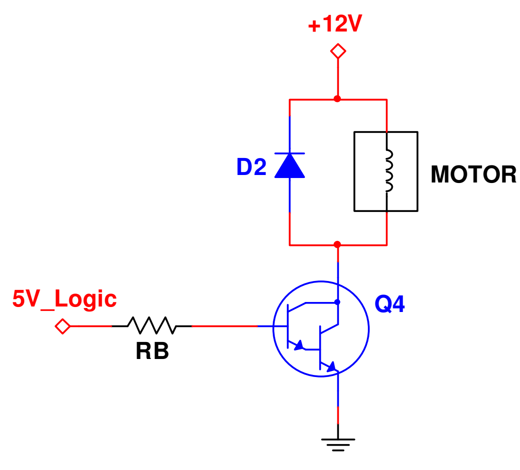

Fig. 4

C. MOSFET switch analysis (all data sheets on course website)

5) Consider the LED driver shown in Fig. 5. Assume the LED has a forward voltage drop $V_F = 2.2V$ at 20 mA (typical green LED). Perform a typical analysis.

(a) What is Q5's max threshold voltage?

(b) Determine $R_{DS,ON}$ and drain current when the control voltage is 5V. Is Q5 in the ohmic region?

(c) Suppose the input is a 5V pulse train at 200 Hz with 40% duty cycle. Sketch V_{IN} and I_{LED} from t = 0 to 15 ms. Label important features (e.g. time points, voltages)!

(d) Compute the average power dissipation in Q5 and the LED for the 40% duty cycle input.

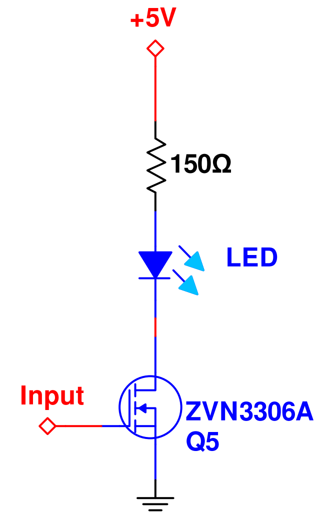

Fig. 5

6) Power switching often uses a high-side MOSFET switch, as shown in Fig. 6. A 5V CMOS NAND gate provides the control signal. Q2 is the logic level shifter, and Q3 is the high-side switch. The load is a light bulb rated at 15V @ 12W.

(a) For Q2, what is the maximum threshold V_{GS}?

(b) Based on your answer to (a), explain why the CMOS logic gate will properly turn Q2 off and on.

(c) When Q2 is on, explain why it is indeed in the ohmic region.

(d) For Q3, what is the maximum threshold V_{GS}?

(e) Based on your answer to (d), explain why Q2 can properly turn Q3 off and on.

(f) When Q3 is on, explain why it is indeed in the ohmic region.

(g) When the NAND gate output is 5V, compute Q3's $R_{DS,ON}$ and the light bulb's power dissipation. Assume typical Q3 parameters. Hint: You should get around 11.8W.

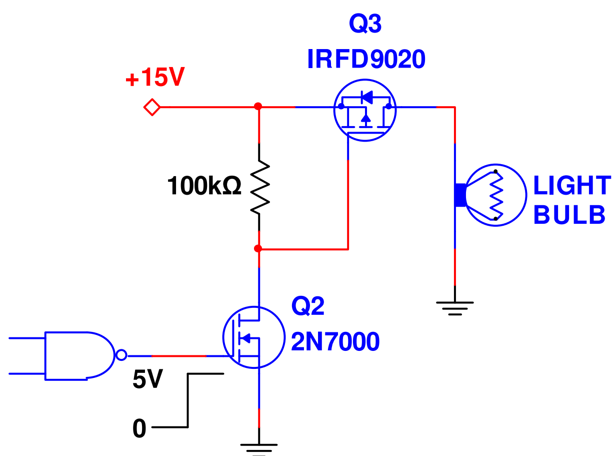

Fig. 6

D. <u>MOSFET switch design (all data sheets on course website)</u>

7) Consider the LED driver shown in Fig. 7. The design constraints are shown below.

- The red LED (see course website) should operate at 10 mA.
- The control input comes from a CMOS AND gate.
- You must choose between a ZVN3306A, ZVN2106A, and IRFD9020.

(a) Choose the appropriate MOSFET for Q6. Also confirm that Q6 is in the ohmic region!

(b) Choose the appropriate 5% standard value for R to ensure the LED current is 10 mA under "typical" conditions (for both MOSFET and LED). Hint: Somewhere around 300 ohm.

(c) Based on your choice of R, compute the "worst-case" LED current, which we'll interpret as the MINIMUM current. Hint: Roughly 8 mA.

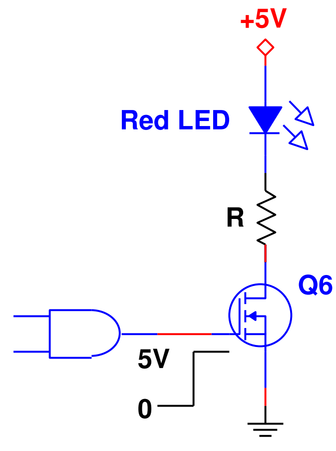

Fig. 7

8) High-side switches are commonly found in automotive applications, particularly when a grounded load is required for safety reasons. Consider a fluid pump based on a 12V DC motor. As shown in Fig. 8, the electronic control unit (ECU) provides 0-to-5V digital logic levels. The design constraints are below:

- 12V DC motor draws up to 1.5A of current.
- Your available MOSFETs are:
  - N-channel: 2N7000, ZVN2106, IRF520
  - P-channel: ZVP3310, ZVP2106, IRF9520
- The MOSFETs use a +12V supply (e.g. car battery).
- Minimize the number of MOSFETs.
- Fast switching (e.g. microsecond) is not necessary, so logic shifters can use large resistors (e.g. 100 kohm).

(a) Sketch your MOSFET circuit.

(b) Choose the high-side MOSFET. Include a table showing important specs to justify your choice.

(c) Choose the MOSFET logic level shifter. Justify your MOSFET and resistor choices!

(d) When the pump is on, does the high-side MOSFET switch need a heat sink under worst-case conditions? Show all work!

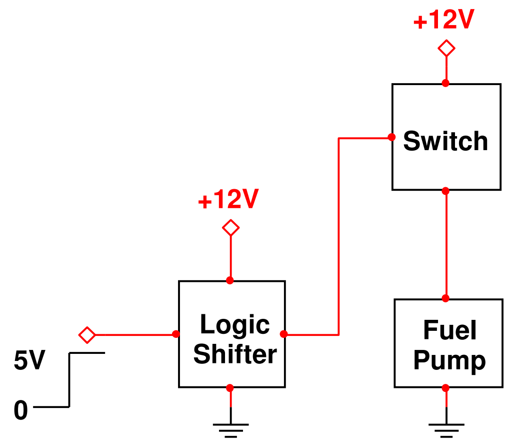

Fig. 8