

## Lab 6: BJT Switches and Inductive Loads (The week of May 18)

### GOAL

The overall goal of this lab is to understand how to use BJT switches with inductive loads.

### OBJECTIVES

To build, test, simulate, and understand the following circuits:

- 1) Relay controller
- 2) DC motor driver using pulse width modulation

### 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
- Miniature relay
- DC motor
- NPN transistor:     2N4401                             (2)
- Resistors:           1 kohm (brown/black/red)     (1)  
                          1.5 kohm (brown/green/red)     (1)
- Diode                1N4448 (similar to a 1N914)     (2)
- SPDT switch

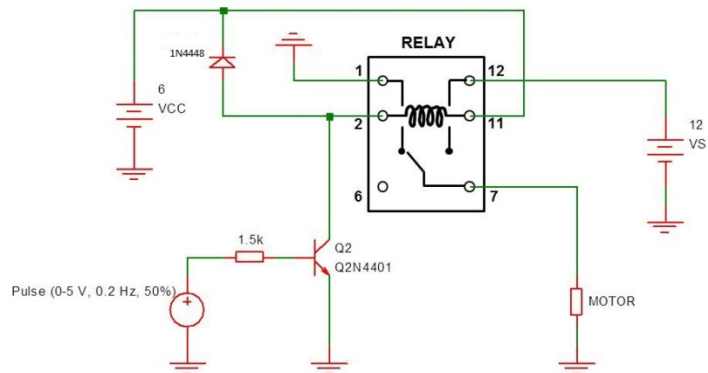
**NOTE: BUILD AND TEST THE CIRCUITS IN PARTS 1 AND 2 FIRST. IF YOU HAVE TIME YOU MAY COMPLETE THE SIMULATION DURING THE LAB PERIOD OTHERWISE COMPLETE IT ON YOUR OWN. INCLUDE THE RESULTS OF THE SIMULATION WITH THE LAB REPORT.**

## PART 1: RELAY CONTROL

In this section you will use BJT switch is used to control a relay that powers a DC motor. Notice the 1N4448 diode in parallel with the relay coil. This diode is a “fast switching diode”. This “flyback diode” suppresses the huge reverse voltage spike that occurs when switching an inductive load such as a relay. Otherwise, this “inductive kick” can potentially cause sparks or damage to components.

- Step 1a: Build the relay circuit in Fig. 1.

- **USE NEAT WIRING!**
- Wire the bench-top power supply properly!
  - Unlike other labs, you need the supply to provide two POSITIVE voltages (+6V and +12 V).
- The colored terminals on your breadboard should be the following:
  - RED terminal = 12V.
  - YELLOW terminal = 6V.
  - Black terminal = GND.
- Insert the relay across the breadboard “gap”, similar to the way you connect an op amp.
- The relay connections are the following:
  - Pin 1 = GND      Pin 2 = Collector of transistor      Pin 7 = Motor
  - Pin 11 = 6V      Pin 12 = 12V
- The 2N4401 pin diagram is on the course website.
- Remember the “black band” of the diode is the cathode.



**Fig. 1: Using a relay to turn a motor on and off. The 1N4448 diode acts as a voltage clamp. Otherwise, the inductive kick from the relay may wreak havoc with your electronics!**

- Step 1b: Test the relay circuit.

- The control signal is the Agilent function generator with the following settings:
  - HighZ output
  - Waveform = SQUARE WAVE
  - Low Level = 0V      High Level = 5V
  - Frequency = 0.2 Hz
- **Your circuit is working properly if the relay is clicking and the motor turns on and off.**

- Step 1c: Transient measurements of the relay turning off.

- Press “Default” to reset the scope.
- Use the following trigger settings:
  - Trigger mode = NORMAL (instead of auto)
  - Trigger edge = FALLING EDGE (instead of rising)
  - Trigger level = 2.5 V
- Go to the Acquire menu and set acquisition to Peak Detect.
- Use Ch1 of the scope to measure the input voltage to the circuit (e.g. from Agilent function generator).
- Use Ch2 of the scope to measure the voltage at the collector of the transistor.
  - You may need something like 2 V/div and 1 ms/div.
  - Use “swave” to record a snapshot of ONLY CH2 (the inductive “bump”) for your report.
- Remove the flyback diode and adjust the scope to about 20 V/div to see the inductive kick!
  - Use “swave” to record a scope snapshot of ONLY CH2 (the inductive kick) for your report.
  - **DO NOT DISASSEMBLE THIS CIRCUIT!**

## PART 2: MOTOR SPEED CONTROL USING PULSE WIDTH MODULATION (PWM)

PWM is a common technique used to control the speed of a motor. The basic idea is to power the motor with a series of PULSES rather than a DC voltage.

How does this affect speed? The duty cycle (% of on-time) affects the average voltage seen by the motor. For example, a DC voltage of +12V is basically a 100% duty cycle waveform. Therefore, the motor sees an average of +12 V (full speed). A 0-to-12 V square wave with a 50% duty cycle results in an average voltage of only +6V (about half speed). The pulse frequency must be fairly high (> kHz) to ensure the motor does not respond to individual pulses – remember that it is the AVERAGE value that we want! Our function generators will not provide a 0% duty cycle to turn the motor off and we will be using a toggle switch for this.

- Step 2a: Build the motor control circuit shown in Fig. 3.
  - Insert the SPDT power switch across the breadboard gap, similar to how you use an op amp.
    - The center pin of the switch is attached to the motor and flyback diode.
    - Connect one of the other pins (does not matter which one) to +12V.
    - Connect the remaining pin to GND.
  - The PWM signal comes from the Agilent function generator.
- Step 2b: Configure the Agilent function generator.
  - Choose the “Pulse” waveform with a 25 kHz frequency.
  - Set the LOW amplitude to 0 V and HIGH amplitude to +5 V.
  - Use alligator clips to attach the function generator output to the “PWM” input of the circuit.
- Step 2c: Test the circuit.
  - Your circuit works if:
    - The motor speed can be controlled by the PWM duty cycle (vary from 10 to 90%).
    - The motor turns on and off with the toggle switch.
  - Does the motor move faster or slower when the duty cycle is high (e.g. 80%)?
  - When the Agilent duty cycle is 80%, record scope traces of the PWM input (from function generator) and the transistor’s collector voltage. Try to record a few cycles for each trace.

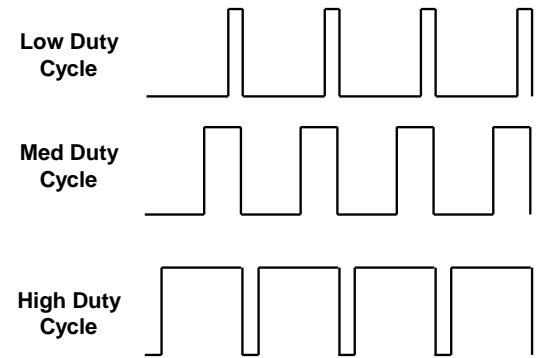


Fig. 2: Schematic of voltage pulses with different duty cycles.

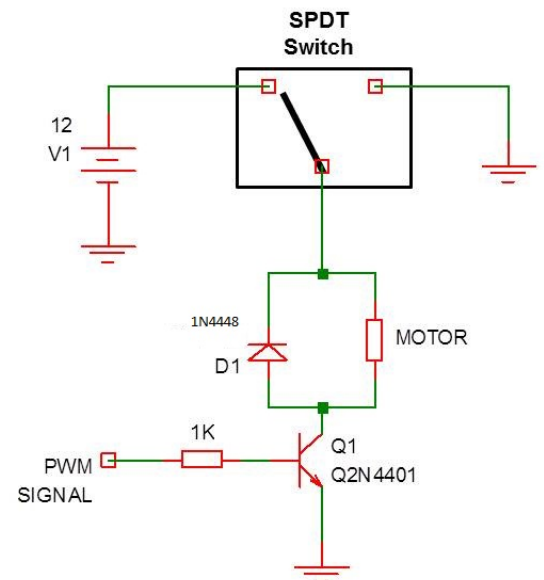


Fig. 3: PWM-driven transistor switch to control the speed of a DC motor.

**PART 3: CIRCUIT DEMOS**

As always, Professor Hedrick will reset the scope and function generator.

**1) Circuit #1: Relay with diode (inductive “bump”)**

(20 pts of lab demo grade)

- Put the diode back in the circuit.
- Configure the function generator.
  - HighZ output
  - Waveform = SQUARE WAVE
  - Low Level = 0V                      High Level = 5V
  - Frequency = 0.2 Hz
- Configure the scope.
  - Trigger mode            = NORMAL (instead of auto)
  - Trigger edge            = FALLING EDGE (instead of rising)
  - Trigger level            = 2.5 V
- CH1 displays the falling edge of the input square wave.
- CH2 displays the collector voltage of the transistor.
- Relay should be clicking, the motor should be turning on and off, and you should see the inductive “bump”.

**2) Circuit #2: PWM driver for DC motor.**

(10 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%
- Motor speed should depend on the PWM duty cycle.

The circuit demo is worth 30 pts. If ANY of your circuits are messy, it will cost you 10 pts. If you hit AutoScale on the scope, it will cost you 2030 pts.

## PART 4: SIMULATE THE BJT MOTOR CONTROL CIRCUIT

- Step 3a: Simulate the circuit in Fig. 4 which has no inductive spike damping diode
  - To place the relay coil: Place | Component | Electro-mechanical | Coils-Relays| ENERGIZING\_COIL
  - Place the component on your diagram and then right click on it. Set the coil parameters as you see in Figure 5 below.

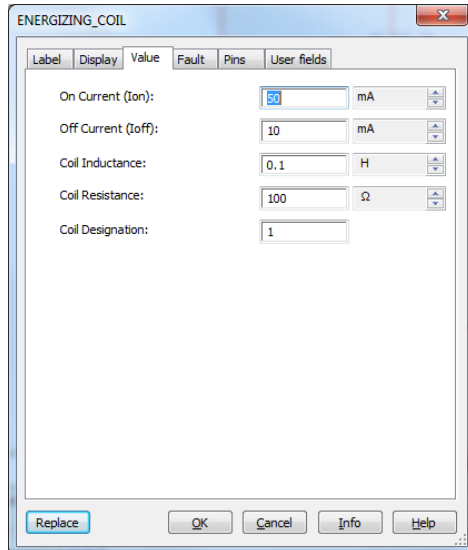


Figure 5: configure the relay coil model

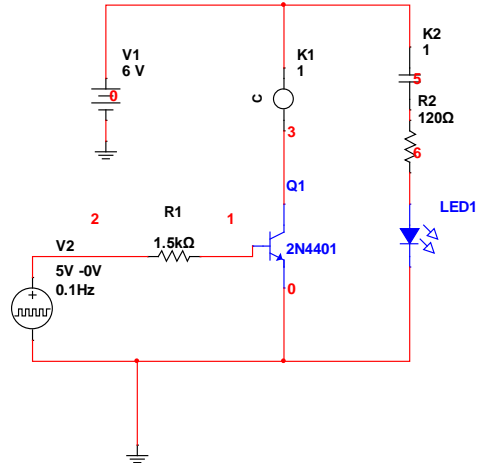


Fig. 4: Schematic for 2N4401 transistor switch and relay coil.

- Add a normally open relay contact: Place | Component | Electro-mechanical | Coils-Relays | NO\_CONTACT.
- Add the LED and current limiting resistor so that the LED will blink as the relay is opened and closed when you run the simulation using the simulation ON/OFF switch.
- The signal source is configured to produce a square-wave. Select: Place | Component | Sources | SIGNAL\_VOLTAGE\_SOURCE | BIPOLAR\_VOLTAGE. After you place the component on your diagram right click on it, select properties and set the model up as in Figure 6. Below.

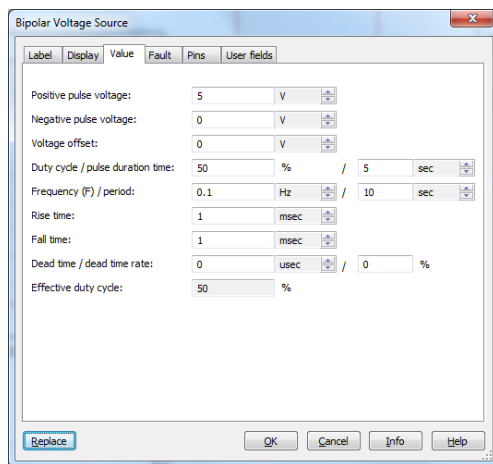


Figure 6  
Parameters for the input signal

- Run a transient analysis and set the start time to 2.5 seconds the end time to 2.51 seconds, and the minimum number of points to 1000. Run the simulation for the input and collector waveforms separately and then cut and paste into a single graph. Your final graph should look something like the one in Fihure 7 below.

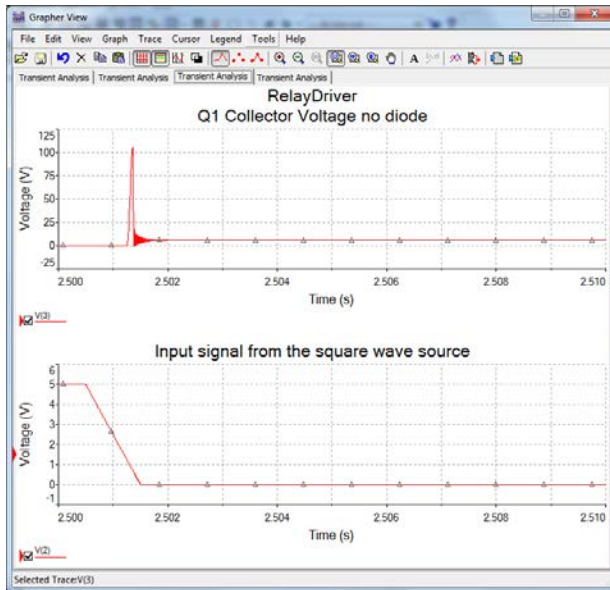


Figure 7  
Output of simulation with no diode

- Add the clamping diode to your circuit as in Figure 8 below. You should see about a .5 V bump when the clamping diode turns on to eliminate the inductive spike. The result of your simulation should be similar to Figure 9.

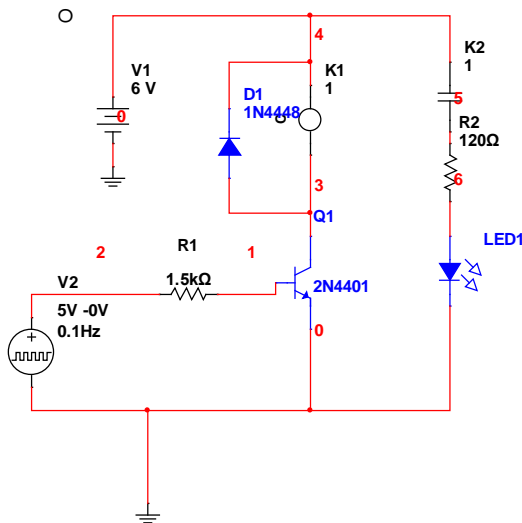


Figure 8  
Circuit with Clamp diode

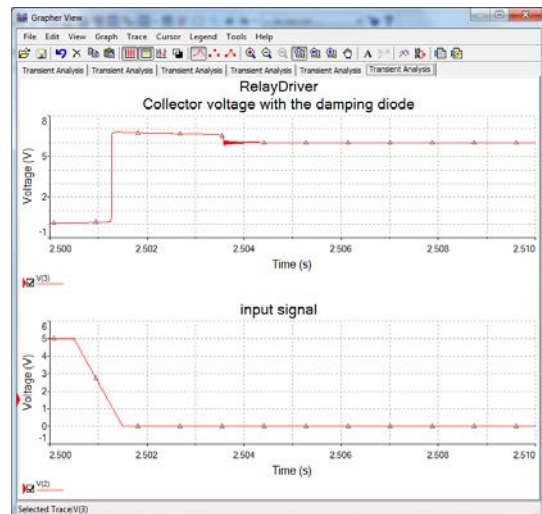


Figure 10  
Simulation output with diode

- Submit both the circuits and the waveforms, for the circuit with and without the diode, in your lab report. NOTE: You should see a roughly 0.5 V “bump” that occurs when the input voltage changes from +5 to 0 V in the circuit with the diode that is the voltage drop across the diode when it is forward biased by the inductive spike.

**(End of Lab 6)**