Engineers today, like Galileo three and a half centuries ago, are not superhuman. They make mistakes in their assumptions, in their calculations, in their conclusions. That they make mistakes is forgivable; that they catch them is imperative. Thus, it is the essence of modern engineering not only to be able to check one’s own work but also to have one’s work checked and to be able to check the work of others.

- Henry Petroski

Revised: Dan Wolf, 2/21/2018
OBJECTIVES:
• Relay types: SPST, SPDT, DPDT.
• Relay Construction
• Time-Delay Relays
• Protective Relays
• Solid State Relays
• Use of transistors as relay drivers
• Motor control for On/Off and Forward/Reverse
• “Back-EMF” Diode

DELIVERABLES THAT YOU MUST SUBMIT

1. Figure 3 as it will appear in your Hardware Interface Document (which will be due at the end of the course).
2. Practice Problems

On-Line Reading Material:
Required:
  b) https://learn.sparkfun.com/tutorials/transistors
  c) https://learn.sparkfun.com/tutorials/transistors/applications-i-switches

Optional:

INTRODUCTION:
A relay switch often opens and closes circuits via electromechanical or electronic means. They control one electrical circuit or output device by opening and closing the contacts on another circuit. Relay contacts are identified as normally open (NO) or normally closed (NC). NO contacts are open when they are not energized and NC contacts are closed when they are not energized.
Relays allow a low-voltage/current circuit to control a high-voltage/current circuit and they come in two different forms:
   1) Electromechanical
   2) Solid state (SSR)

An electromechanical relay (EMR) use magnets to open and close the circuits while solid state (SSR) relays use electronics. Additionally, protective relays help guard against damage within equipment and components through the identification of electrical abnormalities like reverse currents and overloads. Relays are used in a wide variety of applications such as to start heating elements, pilot lights, alarms, motors.

**Figure 1 – Basic Switch-Relay-Load Circuit**

**EQUIPMENT REQUIRED:**
1. Two BTA1-2C 12V coil relays with data sheet.
2. Two sockets for the relays.
3. Two SPST switches.
4. Misc. wire, LEDs, resisters, 9V battery
5. Two 1N4001 or equal diodes
6. Two 2N2222 transistors
7. +12 and +5 Volt power supply
8. 330Ω resister
9. Two 1KΩ resisters
10. Two 2KΩ resistors
11. Two LEDs
12. DC Motor

**Experiment #1 - Basic Switch-Relay-Load Circuit:**
1. The circuit in Figure #1 uses a Double-Pole-Double-Throw (DPDT) relay with a +12V coil to control a +5V LED. This represents a circuit where two different voltages are involved, specifically a +12V switch/signal that must control an +5V LED (output).

2. Connect the circuit shown in Figure #1. Ask the instructor to check the circuit before you apply power!
   a) Note that there are two sets of contacts on the relay and that each set of contacts has a Normally Open (N.O.) and a Normally Closed (N.C.) contact:
      - Pins 1, 3 (N.O.), and 4 (N.C.)
      - Pins 8, 6 (N.O.), and 5 (N.C.)

   b) Apply power then press and release the switch.

   c) Note that energizing the relay coil will turn on or off the LED depending on whether you used the N.C. Pin#5 of the relay (as shown) or to N.O. Pin 6 of the relay.

3. Complete Table #1
   a) Wire a second LED to the second set of contacts on Pins 1, 3, and 4 then test.

4. Ask the instructor to explain if you have any questions about how the relay operates.

<table>
<thead>
<tr>
<th>Switch Status</th>
<th>Coil Energized? Yes/No</th>
<th>LED Status on N.C. Pin 5? On/Off</th>
<th>LED Status on N.O. Pin 6? On/Off</th>
</tr>
</thead>
<tbody>
<tr>
<td>Open</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Closed</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

5. Include this circuit in your Hardware Interface Document which is due at the end of the course. Make sure it is neat and clearly labeled.
Experiment #2 - Motor On/Off Circuit:

1. Figure #2 shows a circuit has a low voltage signal driving the +12V relay coil. In this example, we use a 2N2222 transistor to amplify the +5V signal up to the required +12V relay coil voltage. This method is common whenever a low voltage device (such as a microcontroller) must control a high voltage device such as a motor.

2. Connect the circuit shown in Figure #2. Ask the instructor to check the circuit before you apply power!

3. The transistor and 2K ohm resistor provide the buffer and amplification required to convert a low voltage and low current digital output (typically +5V and 2mA) to a high voltage, high current relay coil (+12V at 100mA). The relay, in turn, drives a much higher load where the voltage and current can be even higher, easily up to 250Vac and 20A.

4. An explanation for the diode:

   When the transistor in the circuit is switched on, the +12V is applied across the coil (inductance) and the current through it increases. As it does so, a magnetic field is created around the coil.

   When the transistor is switched off, the coil is disconnected from ground. The current through it is interrupted and is no longer able to maintain the field. The field which has been established collapses very rapidly. In doing so it causes a voltage to be induced across the coil and this voltage can be very high.

   Since the direction of the field is changing in the opposite direction to that which caused it, the voltage induced across the coil is opposite in polarity too. The end of the coil connected to the collector of the transistor will be positive with respect to the coil's other end.

   Unless something were done about it, the collector voltage could rise so far above the +12V that the transistor may be damaged.

   The incorporation of the diode clamps the collector voltage to about +12.7V ($V_{\text{supply}} + V_{\text{diode}} = 12.7V$).
6. Include this circuit in your Hardware Interface Document which is due at the end of the course. Make sure it is neat and clearly labeled.

**Experiment #3 - Motor Control On/Off/Direction Circuit:**

1. Figure #3 shows a relay circuit that will both turn the motor on/off and reverse the voltage on the DC motor so that it will turn either forward or reverse.

2. Connect the circuit shown in Figure #3. **Ask the instructor to check the circuit before you apply power!**

3. Note that we are using a relay to drive the motor and that the relay is also capable of switching 120Vac (instead of 12Vdc). So, we could modify the wiring to control a much larger motor like the one on a 240Vac motorized lift crane.

4. Include this circuit in your Hardware Interface Document which is due at the end of the course. Make sure it is neat and clearly labeled.

**Optional Experiment #1 - Control of 120Vac:**

1. Ask your instructor for a blue 120Vac relay box. Design the interface and control a 120Vac device of your choosing (heat gun, electric drill, etc.).

**Optional Experiment #2 - Motor Speed Control:**

1. Figure #4 shows a motor speed control circuit where changing the variable resistor will result in a different motor speed. You are only asked to review this circuit and ask questions if you have them. No lab construction is required.

**Optional Experiment #3 - Status Indicator:**

1. Add an LED Status light as per Figure #1 to the circuit in either Figure #2 or #3.
Figure 2 - Motor On/Off Control
Figure 3 – Motor Control

Figure 4 – Motor Speed Control
PRACTICE PROBLEMS:

1. Sketch a schematic that shows a SPST switch connected to a +12Volt relay coil. The relay SPDT contacts should drive two 120V lights, one red and one green. The red light should turn on when the switch is closed and the green light should turn on when the switch is open.

2. Sketch a schematic which turns on an LED when a SPST switch is closed.

3. Sketch a schematic which turns on an LED when a SPST switch is open.

4. Sketch a schematic which shows a standard digital output energizing a relay coil. The +5volt digital output is capable of sinking or sourcing 40mA. The relay coil requires +12volt at 100mA.