

**EE 255**  
**ELECTRONICS I LABORATORY**  
**EXPERIMENT 6**  
**APPLICATIONS OF TRANSISTOR SWITCHES**

**OBJECTIVES**

In this experiment, you will

- Learn how to use transistors as power switches for controlling dc devices and
- Gain experience in interpreting manufacturer's data sheets.

**INTRODUCTION**

Quite often we need to electronically switch a device on and off. Good examples include dc motors, electromagnets, lamps or LEDs, relays and mechanical actuators. Transistors can provide this switching, as long as certain precautions are taken in the design.

Figure 1 shows how a Transistor-transistor logic (TTL) gate can be configured to drive an LED. Since TTL gates are able to sink much more current than they can source, we plan for the device to be energized when the output is in the LOW state. If we must supply more current to a device than the gate can safely sink, a transistor can be used, as shown in Fig. 2. Resistor  $R_1$  in this circuit limits the gates sink current to what is required to fully saturate the transistor. Resistor  $R_2$  helps turn the transistor off quickly and ensures that the base-emitter of the transistor is held in the OFF state, should the HIGH output of the gate be as low as  $V_{OH_{min}}$ .

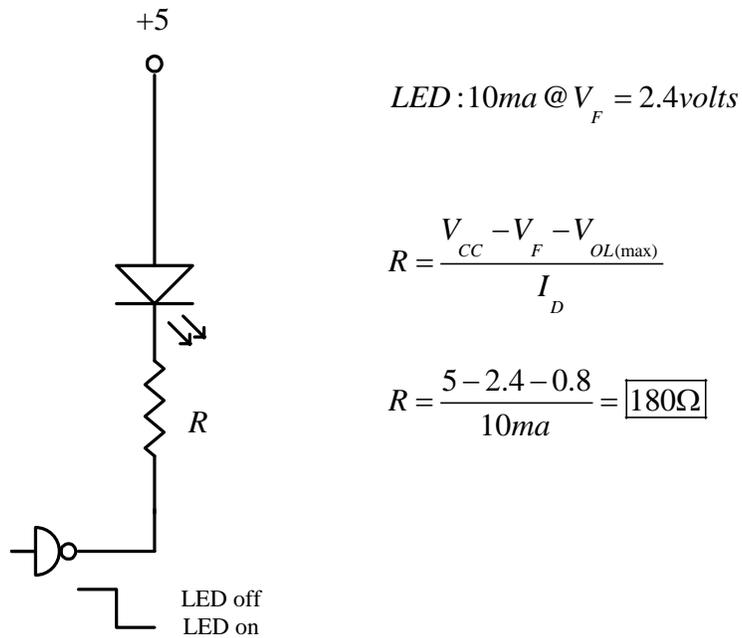


Fig. 1. Using the TTL gate to drive a 10ma LED.

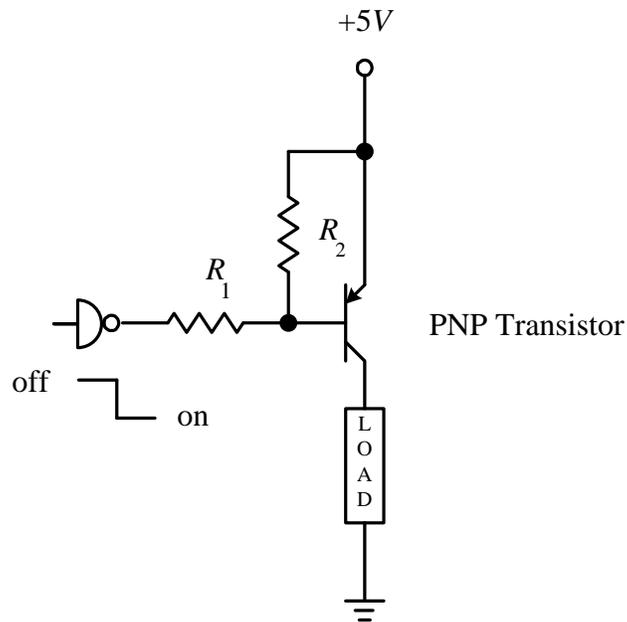


Fig. 2. Using a BJT to increase the current drive of a TTL gate.

In Part A of this experiment, we will use a small switching transistor to drive a relay coil. This circuit, shown in Fig. 3, is useful for controlling high-current or high-voltage devices as well as circuits.

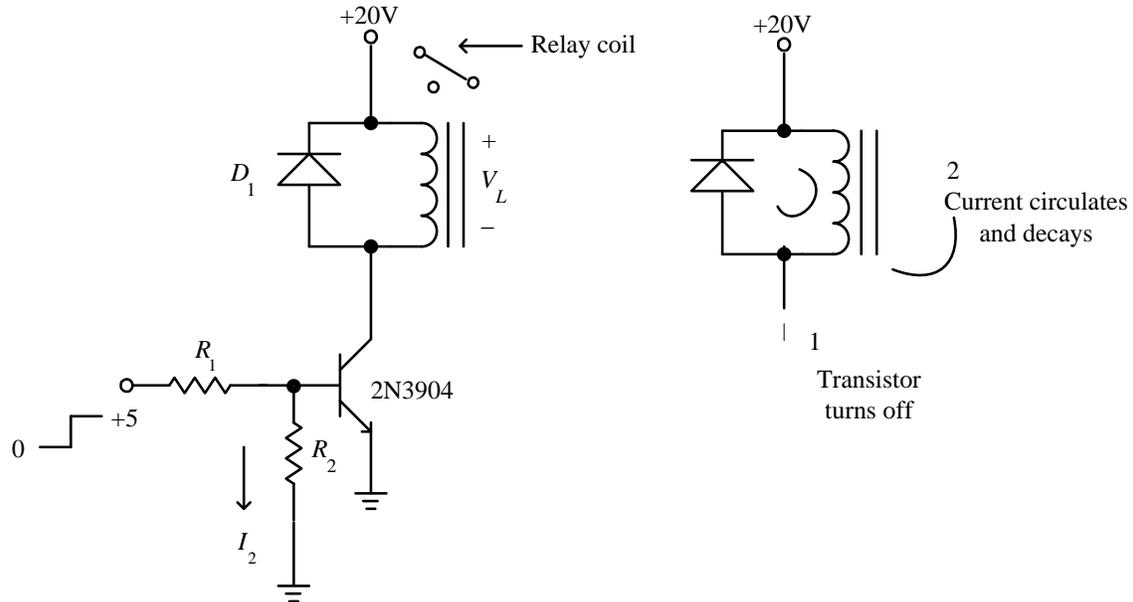


Fig. 3. Using a BJT to control a relay.

An important consideration when driving any inductive load is to provide a current path for the inductor, as the transistor turns off. This is accomplished in Fig. 3 with diode  $D_1$ . When the transistor is turned on, the inductance of the relay coil slows the rise in current. Being reverse-biased, the diode does not conduct. When the transistor turns off, the inductor voltage reverses polarity and becomes a source in order to maintain inductor current flow. If the diode were not present,  $V_L$  would increase to whatever voltage is necessary to maintain the current. This could be hundreds or *thousands* of volts! The transistor would not survive. With a suitable diode in place, the current can continue to circulate until the inductive energy is dissipated. These two cases are shown on the V-I plane in Fig. 4. To guarantee survivability, we must confine operation to the safe operation area (SOA).

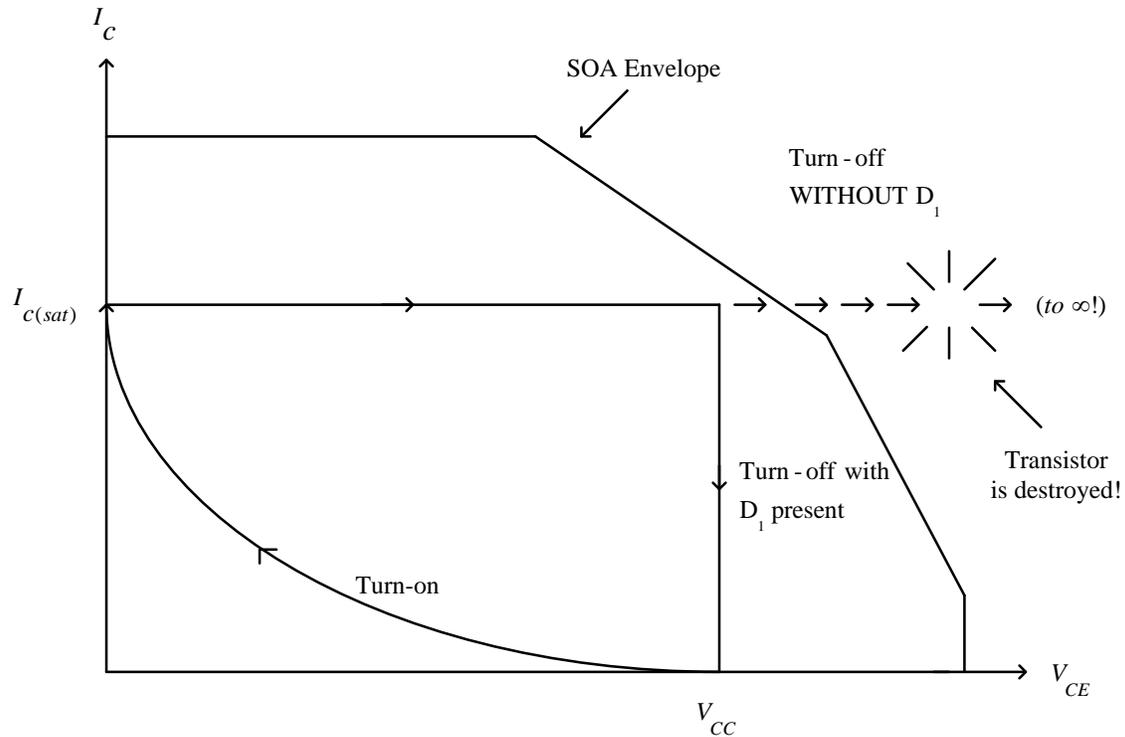


Fig. 4. Switch trajectory with and without  $D_1$ .

### EXPERIMENT – PART A

1. First, we will design the switching circuit of Fig. 3 to drive a small relay that will be provided for you in the lab. Relay coils sometimes give the nominal voltage and current required for the coil. In other cases (such as ours), the manufacturer provides the nominal coil voltage along with the approximate coil resistance. To ensure that the transistor will always be saturated when ON, perform the following calculations:

$$I_{C\max} = \frac{V_{CC} - V_{CE(sat)\min}}{R_{coil}} \quad (\text{since a minimum } V_{CE(sat)\min} \text{ is not given, use } V_{CE} = 0)$$

$$I_{B\max} = \frac{I_{C\max}}{h_{FE(\min)}}$$

$$R_{1(\max)} = \frac{V_{in} - V_{BE(\max)}}{I_{B(\max)} + I_2}$$

where  $I_2$  is the current through  $R_2$  (for our purposes, here, set  $R_2 = 2K$ ).

It is not unusual to overdrive the transistor switch by a factor of 4 to 10 to provide a safety margin and to speed up the switching process. After you determine the maximum value that  $R_1$  can be, divide this value by about 4. Consult the 2N3904 data sheet for the parameters you need in the equations above.

2. Next, calculate how much power will be dissipated in the relay coil. Also, calculate the power that will be dissipated in the transistor when the switch is ON> consult the 2N3904 data sheet. Will this transistor be able to perform within its limits? Will it need a heat sink? Why?
3. Carefully, breadboard your circuit, making sure that the relay's "freewheeling" diode is configured with its polarity correct. (the diode is already soldered in to prevent a disaster, should a breadboard contact become intermittent.)
4. When you apply the 20 volt power supply, the relay should not close. If it does, recheck your circuit.
5. Carefully set the function generator for a 0 to +5 volt square wave and a frequency of about 1Hz. When you now connect the generator to the circuit, the relay should begin turning on and off reliably. Look at the collector voltage with the scope and confirm that the diode is doing its job of suppressing any inductive overshoot on turn-off.
6. Allow the circuit to operate for a few minutes. Feel the transistor. No temperature rise should be detected.
7. If you had been required to specify the diode, what voltage and current rating would you have specified? Why?

## **EXPERIMENT – PART B**

1. Using an *RFPI4N05 MOSFET*, construct the circuit of Fig. 5. (the instructor will have the *MOSFET*'s data sheet.) **CAUTION!** These transistors are vulnerable to static charges. Discharge yourself before handling the device! Also, NEVER apply power to a *MOSFET* before the gate is properly terminated. If the gate is left open, it will turn on when the power supply is connected to the circuit!

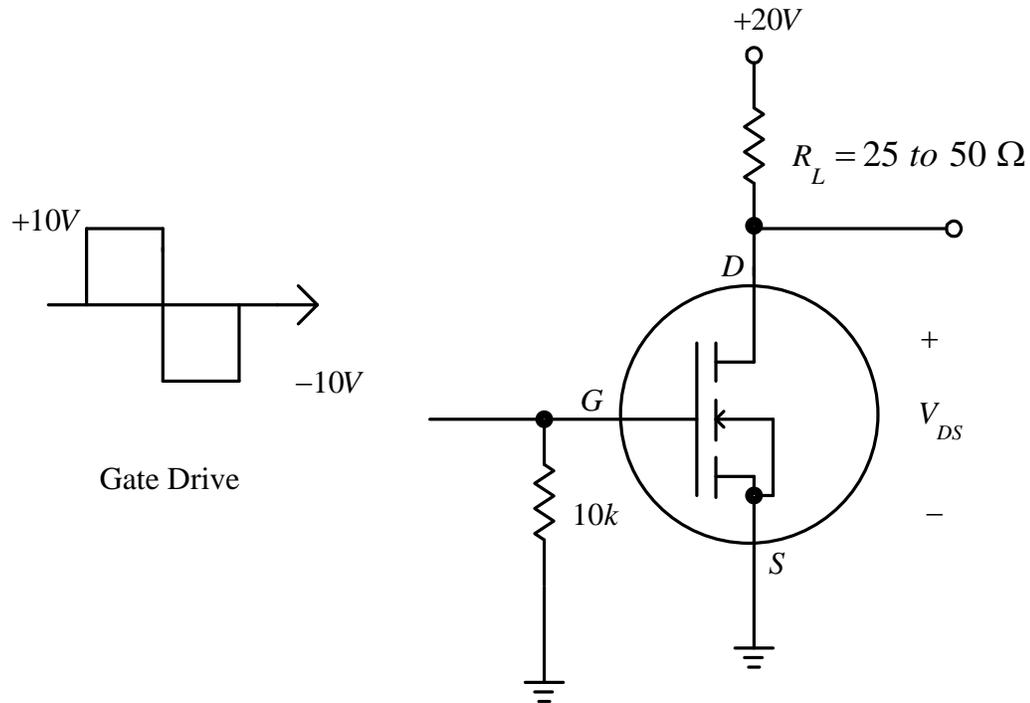


Fig. 5. Driving a resistive load with a power *MOSFET*.

2. Before energizing the circuit, calculate how much power you will be dissipating in the load resistor. Next, calculate the amount of power you expect to dissipate in the *MOSFET*:

$$P_D = I_D^2 R_{DS(on)}$$

3. Apply a +/-10 volt p-p square wave as the drive signal (you can start again at 1Hz). With the oscilloscope, observe  $V_{DS}$  to ensure that the *MOSFET* is switching the load as intended. Increase the frequency and look at the waveform during turn-off (that is, when  $V_{DS}$  goes HIGH). Do you see a turn-off transient? Why is this present with a resistive load? Why does it have this particular peak voltage?
4. Allow the circuit to operate for a few minutes. With your finger, feel the *MOSFET* for any temperature rise. Now, feel the resistive load. What does this tell you? Would the *MOSFET* need a heat sink?

## COMMENTARY:

With such a high input impedance, it would seem obvious that the *MOSFET* could be driven by a lower-power CMOS gate or similar circuit. However, consider the following:

1. The lower value of  $R_{DS(ON)}$  is achieved by having the large gate voltage swing. If you use a *MOSFET* that is specifically designed for the 5 volt logic devices,  $R_{DS(ON)}$  will be larger.
2. Although not mentioned in the data sheet, the power *MOSFET*'s input capacitance is in thousands of picofarads. Since a low-power circuit cannot supply such drive current, the switching time will be extended accordingly. This leads to very high switching losses as well as other problems.
3. We did not consider the drive power needed to switch the *MOSFET*. Essentially, the driver injects charge into the gate capacitance, and then, removes it. Some power is dissipated in this process. As the switching frequency increases, driver losses increase proportionally as does the *MOSFET* switching losses.