

EE 3101 ELECTRONICS I LABORATORY

EXPERIMENT 6 LAB MANUAL

APPLICATIONS OF TRANSISTOR SWITCHES

OBJECTIVES

In this experiment you will

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

LAB NOTEBOOKS

The format of lab notebooks should be such that the information can be used to reproduce the lab, including what values were used in a circuit, why the values were used, how the values were determined, and any results and observations made. This lab manual will be used as a guide for what calculations need to be made, what values need to be recorded, and various other questions. The lab notebook does not need to repeat everything from the manual verbatim, but it does need to include enough information for a 3rd party to be able to use the notebook to obtain the same observations and answers. In the following numbered sections there are **bolded words and/or lines**. These bolded words and/or lines are statements and/or questions that the lab TA will be looking for an answer either in the lab preliminary, or lab notebook.

INTRODUCTION

Quite often there is a 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, circuit designs should ensure the device is to be energized when the output is in the LOW state. If there is a need to supply more current to a device than the gate can safely sink, a transistor can be used, as shown in Figure 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 $V_{OH(min)}$.

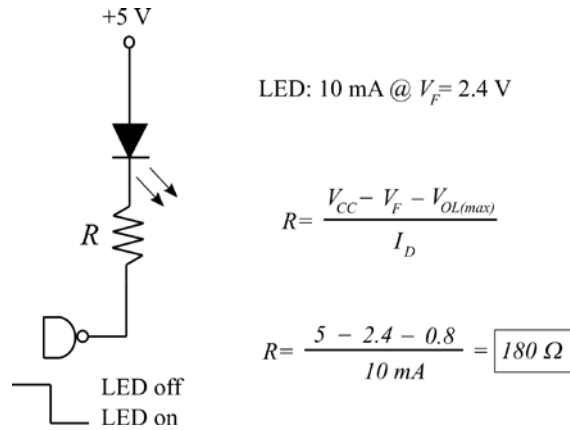


Figure 1: Using a TTL gate to drive a 10 mA LED.

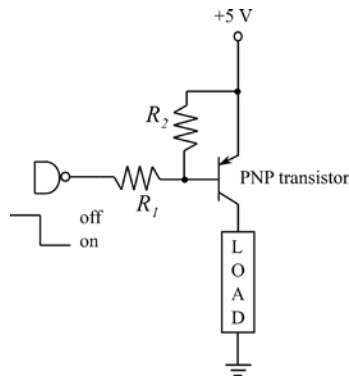


Figure 2: Using a BJT to increase the current drive of a TTL gate.

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

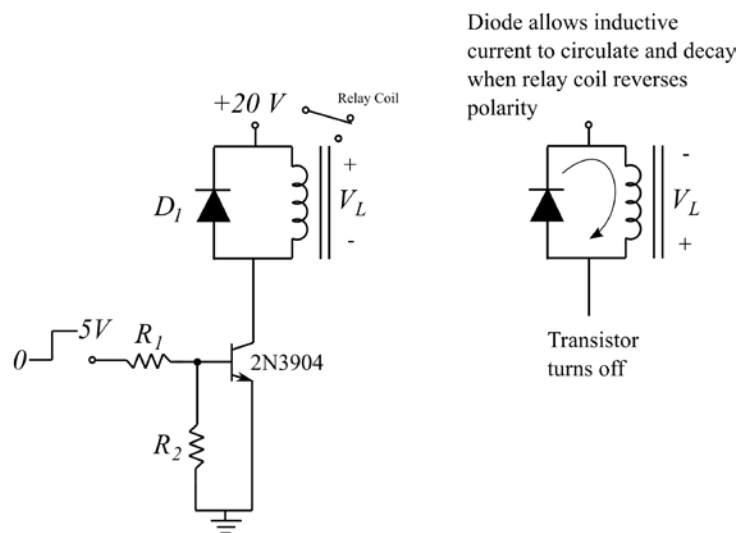


Figure 3: Using a BJT to control a relay.

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 Figure 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 Figure 4. To guarantee survivability, we must confine operation to the safe operation area (SOA).

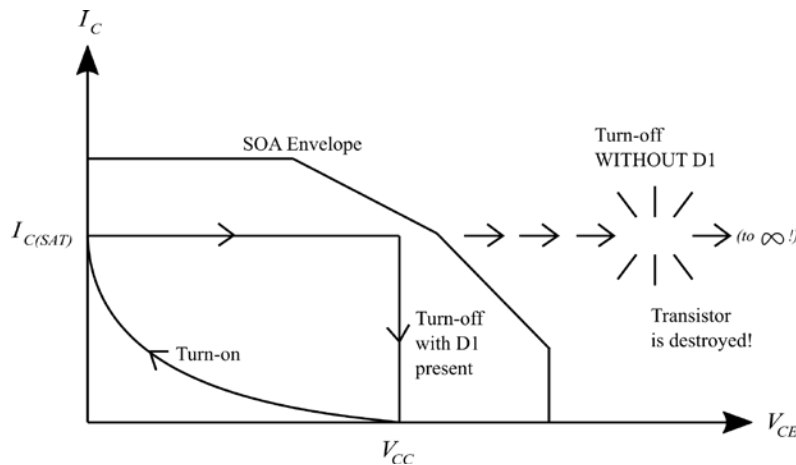


Figure 4: Switch trajectory with and without D_1 .

PRELIMINARY

1. Design the switching circuit of Figure 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 and write the values in your lab notebook:** (since a minimum $V_{CE(SAT)min}$ is not given, use 0).

$$I_{Cmax} = \frac{V_{CC} - V_{CE(SAT)min}}{R_{Coil}}$$

$$I_{Bmax} = \frac{I_{Cmax}}{h_{FEmin}}$$

$$R_{1max} = \frac{V_{in} - V_{BEmax}}{I_{Bmax} + I_2}$$

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 determining 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. **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).

Q1. Will this transistor be able to perform within its limits?

Q2. Will it need a heat sink? Why?

EXPERIMENT

Part A

1. Carefully, breadboard your circuit, making sure that the relay's freewheeling diode, D_1 , is configured with its polarity correct. (*The diode is already soldered in to prevent a disaster, should a breadboard contact become intermittent.*)
2. When V_{CC} is applied, the relay should not close. If it does, recheck your circuit.
3. Connect the function generator to the oscilloscope and carefully set the output for a 0 to +5 V square wave with a frequency of about 1 Hz. Next, connect the generator output to the circuit, and 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 (sketch the waveform).**
4. Allow the circuit to operate for a few minutes. **Carefully feel the transistor (*comment your observation*).** No temperature rise should be detected.

Q3. If you had been required to specify the diode, what voltage and current rating would you have specified? Why?

Part B

1. Using an *RFPI4N05 MOSFET*, construct the circuit of Figure 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!

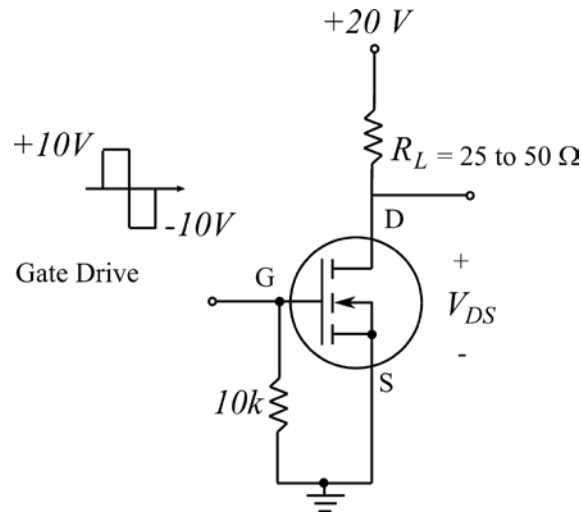


Figure 5: Driving a resistive load with a power MOSFET.

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 V_{p-p} square wave as the drive signal (start again at 1 Hz). 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).

Q4. Is there a turn-off transient?

Q5. Why is this present with a resistive load?

Q6. Why does it have this particular peak voltage?

4. Allow the circuit to operate for a few minutes. With your finger, **carefully feel the MOSFET for any temperature rise (comment your observation)**. **Carefully feel the resistive load (comment your observation)**.

Q7. 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 a *MOSFET* is used, that is specifically designed for the 5 V 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 pico-farads. 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. The drive power needed to switch the *MOSFET* was not considered. 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.