Lab 5: Water Sensor (Week of May 11)

GOAL

This lab has two primary goals. The first is to gain some soldering experience! You will solder a simple transistor-based circuit that turns on an LED when water is detected. The second goal is to understand the operation of a transistor switch, which operates in “saturated mode” rather than “active mode”.

OBJECTIVES

1) Build and test the water sensor circuit on a breadboard.
2) Solder and test the circuit.

GENERAL GUIDELINES

1) Each student must build, test, and demo all circuits.
2) During the lab session, students may need to share test stations.
3) Students are allowed (even encouraged) to help each other. Of course, Professor Hedrick will be around to provide assistance as well. Use neat wiring for your circuits! A messy circuit will cost you 10 pts from your lab demo grade.
4) Do not worry if you need lots of help during the lab. Just make sure you know your stuff for the exams. **In addition to the written exams, there will be one lab practical where each student is tested on basic skills in circuit construction and simulation.**
5) Ask questions! The more questions you ask, the more you learn (assuming Professor Hedrick can provide adequate answers ☺).
6) Build your circuits with neat wiring! Messy circuits will result in a 10 pt deduction from your lab demo grade.
7) Please keep your lab kit and work area organized.

PARTS AND MATERIALS

- Lab kit (breadboard, wire stripper, wire)
- Digital oscilloscope, scope probes, benchtop power supply
- Transistors: 2N4401 (2)
- Resistors: 330 ohm (orange/orange/brown) (1)
  10 kohm (brown/black/orange) (1)
- Green LED (1)
- 9V battery + connector
- Perfboard
- Soldering iron + tools

• PART 0: TRANSISTOR SWITCH

Basic Idea

A simple water sensor circuit can be made with a transistor switch, as shown in Fig. 1. Here's how it works.

- Water has some electrical conductivity, depending on the concentration of ions (e.g. sodium).
- When both probe tips are in contact with water, a small current flows into the transistor base.
- The very high current gain of the Darlington transistor pair produces a large collector current that turns on the LED.

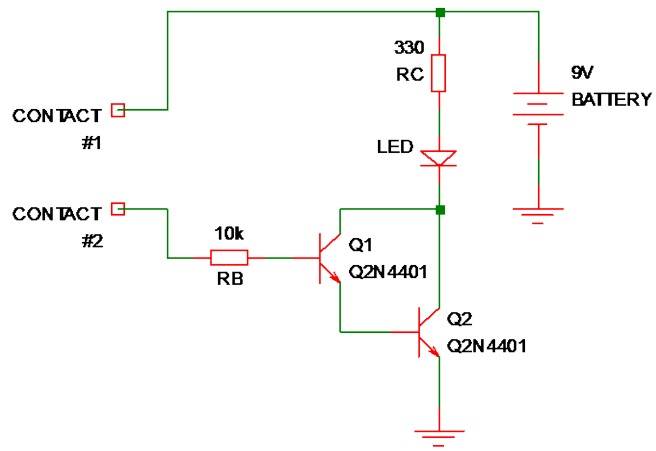

Fig. 1: Water sensor circuit based on a Darlington transistor switch.

Saturation Mode

Our transistor actually operates in "saturation mode" rather than "active mode". Consider the following example.

- Suppose the water resistance is about 10 kohm.
- The base current is $I_B = (9 – 1.4)/20k = 0.38$ mA.
- If the Darlington pair is in active mode and $\beta = 10000$, the collector current would be $I_C = \beta\ I_B = 3800$ mA.
- The collector-emitter voltage is $V_{CE} = V_C – V_E = (V_{CC} – I_CR_C – V_{LED}) – 0 = 9 – (3.8A)*330 – 2 = -1247$ V!!!
- Clearly, the transistor is not in active mode due to the ridiculously negative value of V_{CE}.
- Therefore, the transistor is in SATURATION mode.

Analyzing a Saturated Transistor

When a transistor is in saturation mode, we must use a different set of rules to analyze the circuit.

- In saturation mode, $V_{CE} = 0$V always.
- The collector current is $I_C = (V_{CC} – V_{LED} – V_{CE})/R_C = (9 – 2 – 0)/330 = 21.2$ mA.
- Notice that the current gain I_C/I_B is MUCH LESS than $\beta = 10000$!

  NOTE: In reality, V_{CE} is about 0.3V for a single saturated transistor and 1 V for a Darlington pair. But approximating $V_{CE} = 0$V is fine for this course.

• PART 1: BREADBOARD PROTOTYPE

In practical applications, it is important to first build a prototype of your circuit on a breadboard.

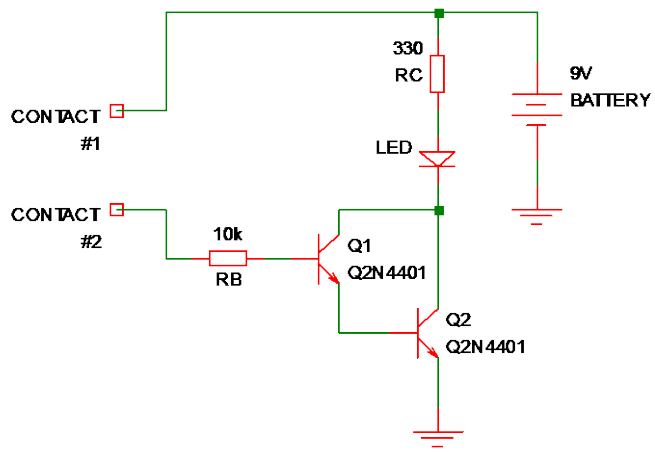

Fig. 2: Build this circuit on your breadboard.

- <u>Step 1a: Build the Darlington switch shown in Fig. 1</u>.
  - The 2N4401 transistors have the same "E-B-C" pin diagram as the 2N3904.
  - The "flat" side of the LED is the cathode ("-" end).
  - Use the exposed end of two short wires as "Contact #1" and "Contact #2".
  - The +9V comes from the breadboard's RED terminal.
  - The GND comes from the breadboard's BLACK terminal.
  - Wire the benchtop supply properly!
    - The (+) output should go to your board's RED terminal.
    - The (-) output should go to your board's BLACK terminal.
  - Turn on the power supply.
  - Use your finger tips to pinch the two metal contacts, but do not let the contacts directly touch each other. The LED should turn on.

    NOTE: If you have very dry finger tips, the LED may not turn on. A damp paper towel (or licking your finger tip) should turn on the LED.

- <u>Step 1b: Use the scope to measure the probe voltage.</u>
  - Press the "Default" button on the scope. This resets the scope.
  - Make sure your scope probe is set to 10X.
  - Use the scope probe to measure the voltage at "Contact #2".
  - When you pinch the metal contacts, the voltage should jump to a couple of volts. If you have very conductive finger tips (e.g. sweaty), then the voltage may jump to several volts!
  - You do NOT need to record any scope snapshots.

- **<u>Step 1c: Demo your breadboard circuit to Professor Hedrick (10 out of 30 pts of lab demo grade)</u>**.

(see next page for Part 2)

- **PART 2: SOLDERING PRACTICE**

Producing a neat properly soldered circuit is rewarding! Excellent soldering takes practice. Your finished circuit should look something like the figure below.

- o The circuit is soldered onto a “protoboard” (described below).
- o Power is provided by one 9V battery.
- o Two wires (each about 3 inches long) serve as the “water probe” tips.
- o It helps to twist the wires together, but obviously keep the tips separate (see figure).

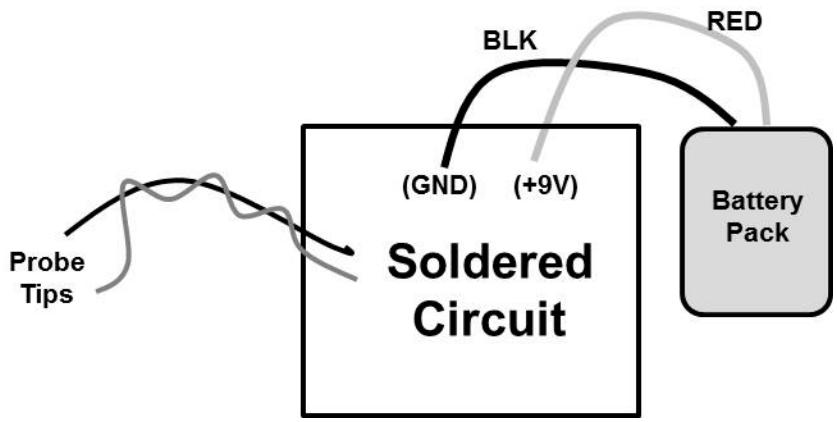

Fig. 3: Simplified schematic of your final circuit.

The “perfboard”:

- o Each hole on the perfboard is isolated! This is different from the breadboard, where all five holes in a row are connected.
- o There are NO bus lines to deliver power or ground but you will be using copper foil tape to create them.
- o The soldering pads are on ONE side of the perfboard.
- o You place components on the NON-metallized side of the perfboard.

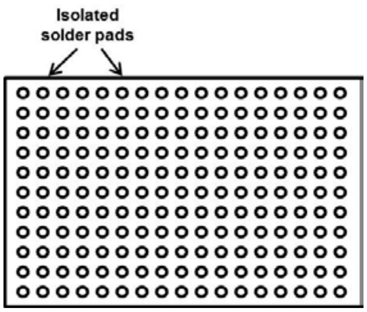

Fig. 4: The perfboard for soldering.

- ➢ Read the soldering and soldering safety handouts. You must use a fan and wear safety glasses.
- ➢ Always wet the sponge, clean the soldering iron tip, and tin the soldering iron tip before soldering.
- ➢ Make sure you melt the solder on the joint. Do NOT melt the solder on the soldering iron tip and dab the solder on the joint.
- ➢ If you have never soldered before, or would like a refresher, there are many soldering tutorial videos on the web. YouTube has countless videos. One example (a version is also on YouTube) is from: http://store.curiousinventor.com/guides/How_To_Solder/

- Step 2a: Practice soldering some resistors on a scrap piece of perfboard. Hand in your practice board at the end of lab so that they can be used in other lab sections.

- Step 2b: Demo to Professor Hedrick your soldered resistors. (5 out of 30 pts of lab demo grade).

• PART 3: SOLDERING

When you solder your circuit, you should do the following:

- Use copper foil tape to create VCC and ground/common buses.
  - Cut two pieces of copper foil tape about 1 ½ inches long using flush cutters. Remove the paper backing from the back of the tape and place on the perfboard. Use your finger to smooth the tape. Don't be concerned if tape is a little loose because the glue gets stronger when you heat it to solder components to it. See Figure 5. Below.

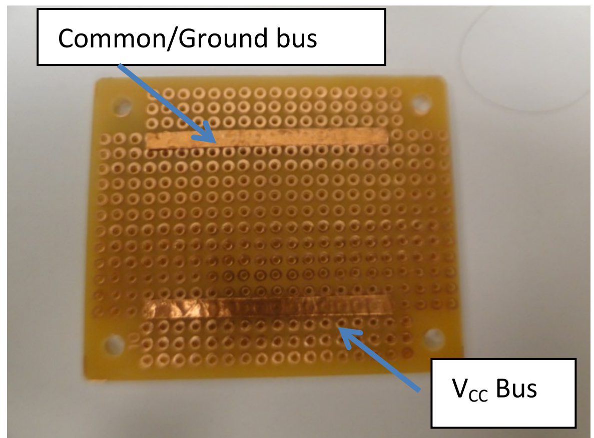

Figure 5

- Soldering components leads to the busses.
  - Push the component lead through one of the holes in the perfboard, bend it over, clip off the excess component lead and solder to the copper foil tape.

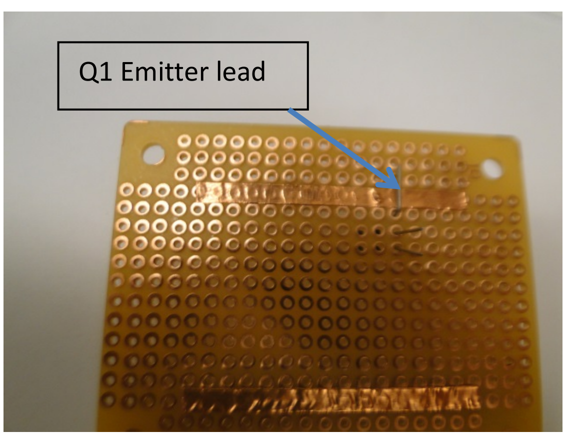

Figure 6
Emitter lead of Q_2 through hole and bent over

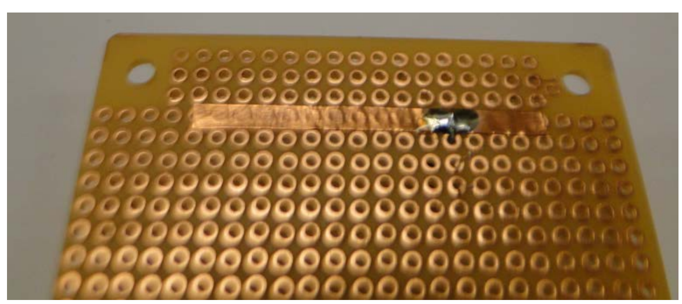

Figure 7
Emitter lead of Q_2 soldered to common bus

- Soldering component leads together.
  - Push leads to be connected through the top of the perfboard and bend them parallel to each other using needle-nose-pliers to form the leads, clip the excess using flush cutters, and solder the leads. Solder the leads to each other and to the copper pads to ensure maximum physical strength. See figures 8, 9, and 10 below for details.

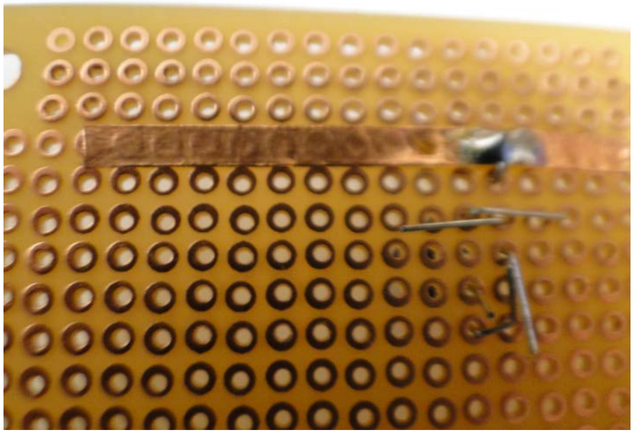

Figure 8
Emitter lead of Q1 connected to the base lead of Q2. And Collector lead of Q1 connected to the collector lead of Q2.

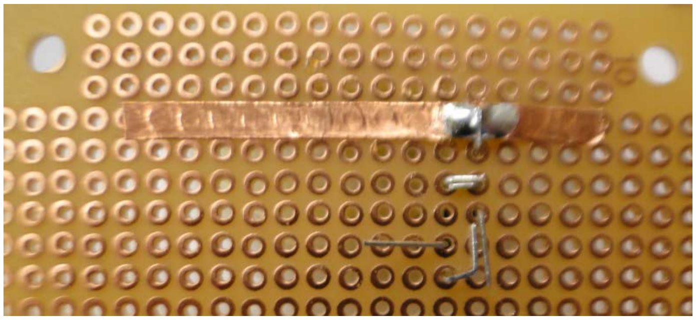

Figure 9
Leads formed and excess removed

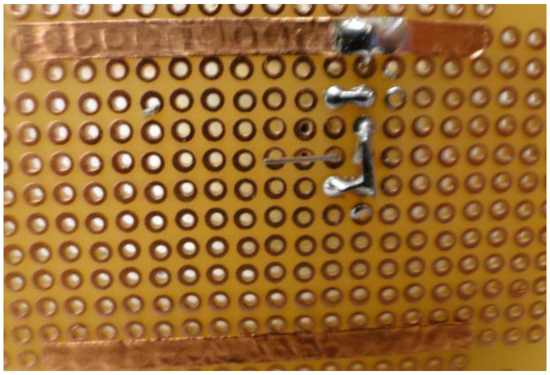

Figure 10
Leads soldered to each other and copper pads

- To connect widely separated holes.
  - just use a wire. This wire can run on either side of the board. It's up to you!

- You may use a "helping hand" to hold the perfboard while you are working on it.
  - See Figure 11 below for details.

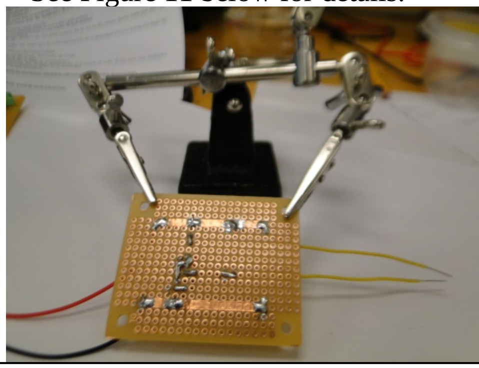

Figure 11 "Helping Hand"

- Your breadboard circuit is a blueprint. However, the breadboard and perfboard have different hole layouts. Therefore, your soldered circuit may look a little different than your breadboard.

- For an initial test of your circuit use the benchtop supply to power your circuit (see below).
  - The hexagonal socket on the battery connector is +9V.
  - The small round socket on the battery connector is GND.
  - You can use wires, or the banana cables, to provide power to the battery connector.

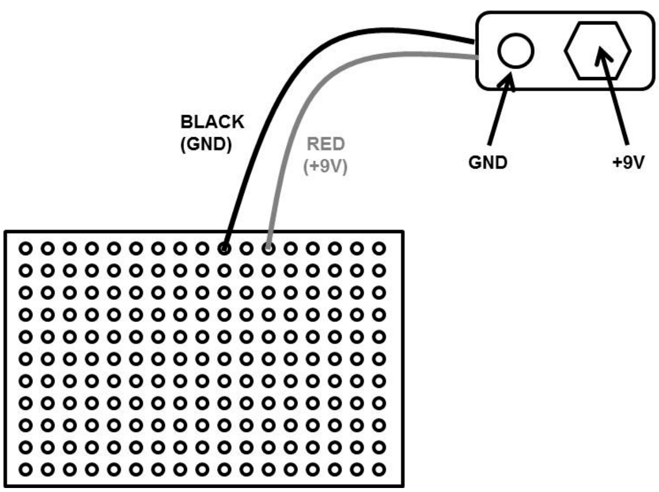

Fig. 12: BEFORE attaching the actual 9V battery, you should test your soldered circuit with the power supply. Connect +9V to the hexagonal socket in the battery connector. Connect GND to the smaller round socket. AFTER you have confirmed that everything works, replace the benchtop supply with the 9V battery.

- Make sure your LED turns on when the wires are squeezed between your fingers.
- Once you have confirmed a working circuit, insert the actual 9V battery into the connector.
- Make sure your circuit worksby putting the leads in a beaker with water in it.
- **Demo your working circuit (15 out of 30 pts of lab demo grade)**.
- **Take a photo of your finished circuit (e.g. with your camera phone) for your lab report.**

(End of Lab 5)