These are pages from my computer organization and architecture laboratory manual, from 1996.

Note, that the exact voltage readings that you will get, will depend upon the transistor that you implement your circuits with. The three transistor types described in the RadioShack page, all work correctly in this lab experiment.

Transistors have some internal resistance, and also are constructed internally between the base and emitter as a diode. Diodes cause a voltage drop, and are often called “watt-less resistors”, because they require a minimum level of voltage before conducting. Different transistors will have different electrical characteristics, which will result in different exact voltage levels being measured. In any case, if you use the transistors that have been tested, the experiments have been designed to demonstrate the logic as well as the “transistor bleed-through” effect. The “transistor bleed-through” effect can result in sufficiently high voltages in some cases, to be detected as a “1”, rather than a “0” as expected – watch out for that when building the AND circuit.

A variety of transistors will work fine. For instance the MPS2222A (Motorola) is rated at 40V collector-emitter, and 6V base to emitter.

-Dr. Hoganson

# LAB 2

**OBJECTIVE:** To construct logic gates using transistors

**PREPARATION:** Read the following material and complete steps 1 and 2 prior to the lab period.

The basic logic operations that are required to be implemented are AND, OR and NOT. These three basic operations allow boolean values to be combined in meaningful ways. Larger structures can then be constructed from these primitive devices. Figure 1 shows a transistor being used as a switch. The value of the input is passed though to the output. When the input is low, the voltage sampled at OUT is low, since it is connected to ground. When IN is high, the transistor conducts and OUT is connected to + voltage and so is high. The resistor is required to limit the amount of current passing through the transistor.

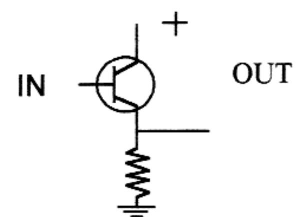


FIGURE 1

This simple device can be used to construct AND and OR gates. A two-input AND gate can be built by connecting two transistors in series (fig 2.a). The output will be high only

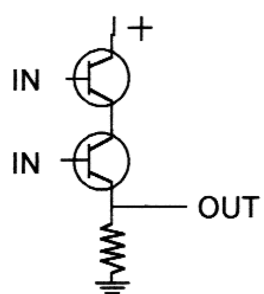


FIGURE 2.a

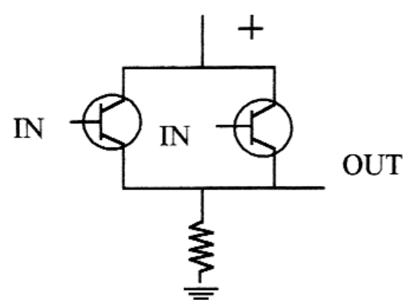


FIGURE 2.b

when both transistors are conducting. When both inputs are high, the output is connected through both transistors to the power source. Thus, the voltage difference measured between the output and ground will be high. If either transistor input is low, the transistor will not conduct, and the voltage difference measured between the output and the ground will be low. To construct a two-input OR gate (fig 2.b), two transistors wired in parallel will suffice. If either or both inputs to the transistors are high, the output will be connected to the power supply yeilding a large voltage differential between the output and ground. Only when BOTH inputs are low will the voltage measured at the output be low.

A NOT or INVERTOR cannot be implemented in the same way as the AND and OR above, where the output is the voltage sampled between OUT and ground. However, simply sampling the output before the transistor instead of after the transistor constructs the required gate. Figure 3 is a single transitor implementation of an invertor. When the input to the transistor is low, the transistor does not conduct and the output is connected to the voltage source. Measuring the voltage difference between the output and ground shows a large difference. That is, when the input is low, the output is high. When the input to the transistor is high, the transistor conducts, connecting the output through the transistor to ground. The voltage differential measured between the output and ground is now small (the small resistance of the tranistor ensures that there will be some measurable voltage differential).

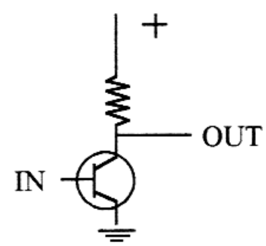
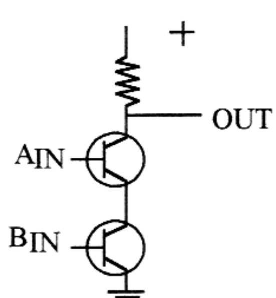


FIGURE 3

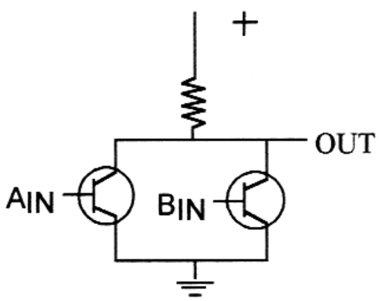
For ease in manufacturing and cost control it is desirable that a single consistent arrangement of transistors, resistors and power connections be used. Since the straightorward scheme of sampling the output after the transistors as in the AND and OR gates is unable to implement invertors, perhaps the alternate arangement can build useful devices besides the invertor. Consider Figure 5 where a circuit similar to the AND circuit




| AIN | BIN | OUTPUT |
|---|---|---|
| 0 | 0 | 1 |
| 0 | 1 | 1 |
| 1 | 0 | 1 |
| 1 | 1 | 0 |

FIGURE 5

is illustrated, except the output connection is before the transistors and the resistor is between the power and the transistor, as in the invertor. If either input is low, the output is connected directly to the power and so is high. Only when BOTH inputs are high does the output go low. The output from this circuit is the oposite of an AND gate and so is a




| AIN | BIN | OUTPUT |
|---|---|---|
| 0 | 0 | 1 |
| 0 | 1 | 0 |
| 1 | 0 | 0 |
| 1 | 1 | 0 |

FIGURE 6

NOT AND gate or NAND gate. Figure 6 illustrates a circuit similar to the OR gate except that the output is sampled before the transistors. When both inputs are low the output is high, but if either input is high, then the output is low. This circuit generates a function that is the opposite of an OR GATE and is called a NOR gate.

DeMorgan's Theorem can be used to convert AND logic to NOR logic and OR logic to

NAND logic. Logic circuits are then implemented in silicon using NAND, NOR and NOT gates. AND and OR gates if required can be implemented by adding an invertor to the NAND and NOR gates at the output.

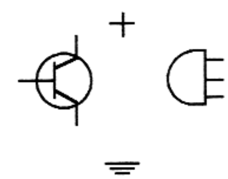
**Materials required:**

Three transistors (NPN 2SC945) (Radio Shack 276-2009)
Two resistors (1K ohm) (Radio Shack 271-1118)
IDL-800
Assorted wires

1. In your notebook draw a circuit to build a three input AND gate as in figure 2.a.

2. In your notebook draw a circuit to build a two input OR gate using a NOR and an invertor.

3. Using the lab equipement, construct your circuit from step 1. Figure 7 illustrates how to orient the transistors. Carefully spread the wire legs of the transistors as in Figure 8. Connect the inputs to your circuits to logic switches. Test the output voltages for each combination of inputs and record your data in your notebook. Use a table to record your observations allong with your expected results.




Transistor, top view

FIGURE 7

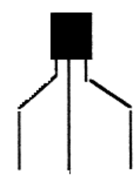


FIGURE 8

4. Next, instead of measuring the voltage difference from output to ground use one of the lights on the powerboard. Experiment with the positions of the input values, observing the effects on the light, recording your results in your notebook.

5. Construct your circuit from step 2, connecting the inputs to logic switches. Experiment with the switch positions while testing the output voltage. Record the results of your experiments in your notebook along with your expected results.

6. Connect an LED to the output. Experiment with the switch positions recording the results in your notebook.

You conclusion should explain any differences between expected results and observed results.