

Laboratory V: Switches

Reading: Simpson Chapter 5.11 (Transistor Switch), 10.19 (Schmitt Trigger), 12.7.8 (CMOS)

Optional reading: P. Horowitz and W. Hill, *The Art of Electronics* (Cambridge University Press, Cambridge, 1989), pp. 113 - 117, pp. 154 - 158, pp. 471 - 474.

1 Introduction

In this lab we focus on switches. This is obviously an important topic because we want to turn on and off our devices when we do physics experiments. Implementing a good switch is far more difficult than one might initially anticipate. Also, in this lab we will introduce the first example of circuits used in digital electronics, namely CMOS inverters. CMOS stands for Complementary Metaloxide Semiconductor and the CMOS gates are mainly made from MOSFETs (Metal Oxide Semiconductor Field Effect Transistors).

2 Laboratory Exercises

2.1 Handling CMOS

MOSFET devices, such as CMOS inverters, are very susceptible to being ruined by the static electricity which you build up by walking across the floor – despite the antistatic wax coating on the floor. Therefore, pick up the MOSFET device on the plastic part only, and discharge your electrical energy by touching the bread-board with your other hand before inserting the chip.

When connecting the CMOS logic, it is good policy to ground all of the unused INPUTS (e.g. of the 4069) before you start. [Do NOT ground outputs]. Connect V_{DD} to +5 volts and V_{SS} to ground. (D and S represent drain and source, respectively.)

NEGATIVE VOLTAGES DESTROY CMOS DEVICES

2.2 Function Generator Offset

In the following exercises, you will be inputting waveforms from your function generator into various switching-type circuits. Since these circuits operate between +VDD and 0 Volts, it is important that the input waveforms remain positive at all times. Such waveforms can be produced by simply implementing the DC OFFSET option on your Tektronix CFG280 Function Generator. Feeding the Function Generators output directly into your scope (using a BNC cable), find the proper adjustments that result in a triangle wave oscillating between 0 and +5 Volts. In the menu for the scope-channel that you are using, be sure that Coupling is selected to be DC.

2.3 Bipolar Transistor Switch

Build the circuit shown below (Fig. 1) which is a transistor switch, *i.e.*, the transistor is either saturated (on) or cutoff (off), for $V_{in} = +5\text{ V}$ and 0 V , respectively. As a consequence, the LED should switch between dark and bright. When does the LED light up? Now take out the LED and replace it by an Ampere-meter to measure the current when $V_{in} = +5\text{ V}$ and when $V_{in} = 0\text{ V}$. Does the result agree with your expectation? Also, verify that the V_{CE} voltage is as expected.

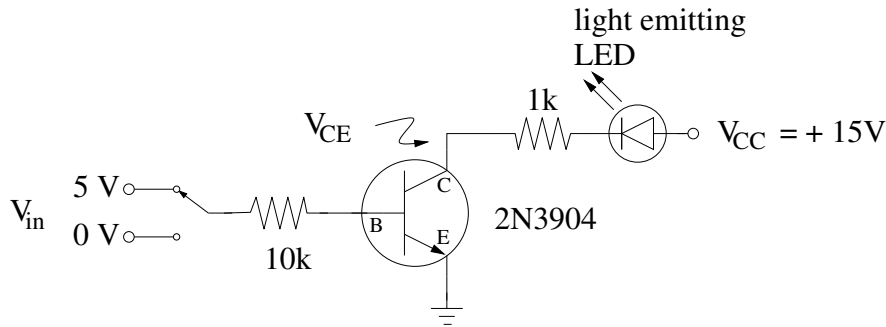


Figure 1: Bipolar transistor switch with LED

2.4 CMOS Inverter

The CMOS inverter is a basic building block of digital logic circuits. In such circuits, its role is to take a “logical 1” input ($+5\text{ V}$) and convert it to a “logical 0” output (0 V) and vice-versa. For the moment however, we will view it as an analog device and analyze its characteristics. The 4069 consists of six independent CMOS inverters, packaged together for convenience. Build the circuit below and verify its inverting ability by observing the output when inputting first 0 V , and then $+5\text{ DC Volts}$. Then input a triangle wave oscillating between 0 and $+5\text{ Volts}$ and simultaneously observe this input and the inverters output using your scope. At what input-voltage threshold does the inverters output make the transition to the opposite state? In the scope’s DISPLAY menu, switch Format to the XY option. The transition-voltage should now be easy to measure. Do you see any evidence of hysteresis, *i.e.*, does the low-to-high transition occur at the same input-voltage threshold as the high-to-low transition?

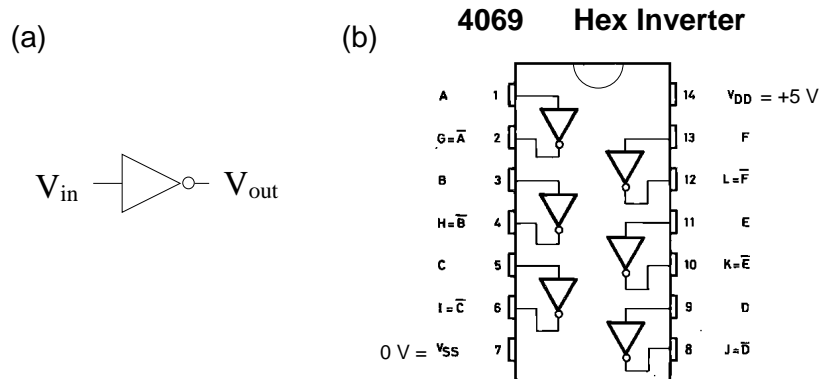


Figure 2: (a) Inverter schematic (b) pinout diagram for the 4069 hex inverter

2.5 Debouncing a Switch using the Schmitt Trigger

We will use a Schmitt trigger to debounce a data switch.

a) Build a Schmitt Trigger using two inverters as shown in Fig. 3. Use a triangle wave oscillating between 0 and +5 Volts as input and simultaneously observe this input and the Schmitt Trigger's output using the oscilloscope. Is the hysteresis voltage ΔV the value you expect? Can you change ΔV to half its value?

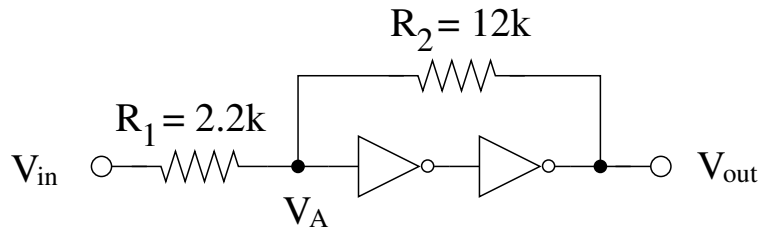


Figure 3: Schmitt Trigger

b) Figure 4a shows a “bit data switch” circuit in which a mechanical switch is used to produce two possible values for V_{out} : 0 V (switch closed) and +5 V (switch open). In this circuit, the $1k\Omega$ resistor protects the +5 V power supply by limiting the maximum current. Construct the circuit and switch between its two output states while monitoring V_{out} on your scope. Describe any bouncing you observe as V_{out} transitions between 0 V and +5 V (e.g., how many bounces, time scale of bouncing). To do this measurement it is helpful to utilize the option to take a single time trace (“Single Seq” - button on the oscilloscope) in concert with appropriately chosen trigger options (“Trig Menu”).

c) Next, build the “debouncer” circuit that is shown in Fig. 4b. It consists of an RC low-pass filter plus Schmitt Trigger. See if the output is clean. What determines the particular choice for the resistor and capacitance values in this circuit? If you need more cleaning power, should you increase or decrease the value of the capacitance?

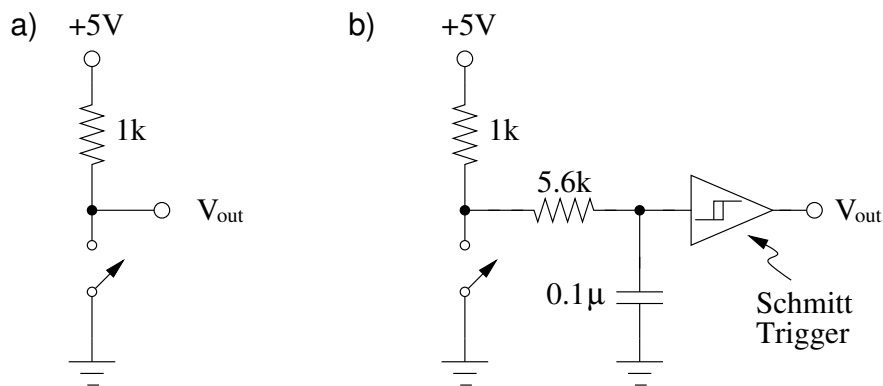


Figure 4: (a) Bit Data Switch (b) Debounced Switch using the Schmitt trigger from Fig. 3

2.6 Analog Switch

The 4066 contains four “analog transmission gates” each of which acts as a bi-directional switch as shown in Fig. 5a. Each switch acts as a small resistance when the control input is at V_{DD} (5 V) and as an open circuit when the control is at V_{SS} (ground). (The “D” subscripts indicate drain, and the “S” subscripts indicate source.) The input and output must be between these two voltages.

(a) Set up the circuit shown below in Fig. 5b. Measure the ON resistance, treating the circuit as a voltage divider. [If you decide to use a sine-wave input, a 1 kHz signal of about $1 V_{p-p}$ (V_{p-p} – peak-to-peak voltage) is suggested and the D.C. offset should be adjusted to ensure that the maximum and minimum voltages lie between 0 and 5 volts.]

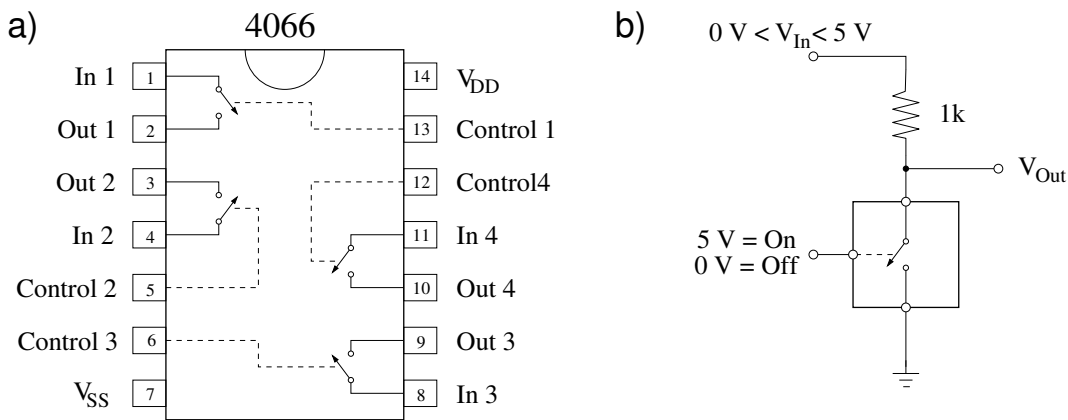


Figure 5: (a) The 4066 pinout schematic (b) Circuit for measuring the ON resistance

(b) Now rewire your switch to obtain the standard configuration, which is shown in Fig. 6b. (We previously used 1 k Ω merely to be able to measure the ON resistance). You should find that this switch works much cleaner, *i.e.* approximates an ideal switch much more closely. (Quantify this statement in your report).

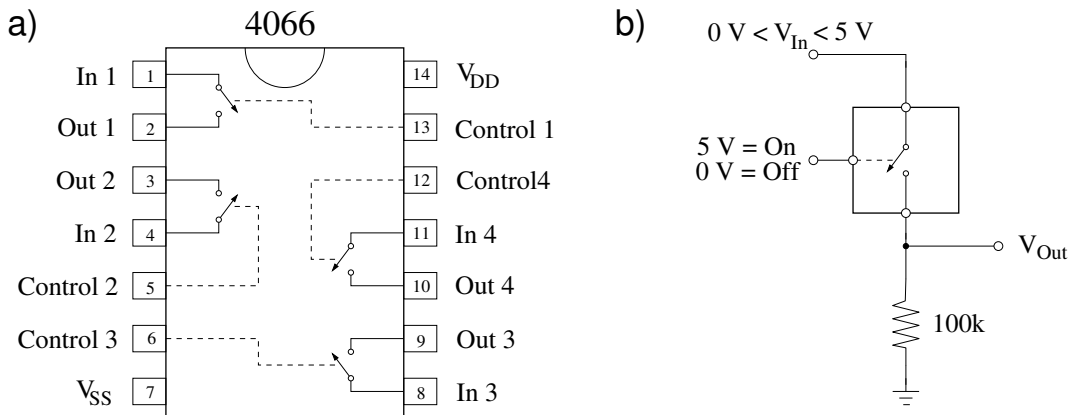


Figure 6: (a) The 4066 pinout schematic (b) Switch in the normal setup