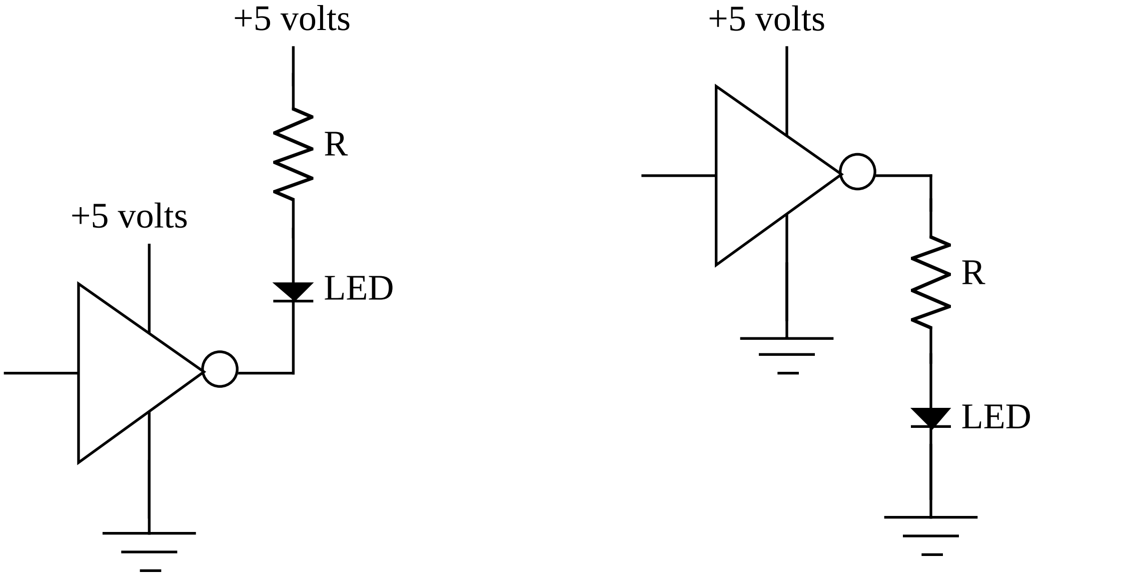
ENGR 210
Lab 11: Analog to Digital Conversion

In this lab you will first investigate the operation and the quantization effects of an A/D converter.

A. BACKGROUND

1. LED Displays

We have been using LEDs as indicators in the EWB simulations. There are two ways to use LEDs as indicators as shown in Figure 1. Note that these circuits do not work with all logic families — many times the logic gates cannot supply the current which the LED needs. In these cases you have to use an external transistor to supply extra current. The technique of using an external transistors can also be used to operate relays and lights from a logic gate. Although only an inverter is shown in Figure 1 you can use any logic gate which has the necessary current output. The actual current is dependent upon the particular LED used. If we assume a current of 10 mA and a typical voltage across the LED of about 1.7 volts, we can calculate R=(5-1.7)/0.01 mA = 3.3/0.1=330Ω. Using resistors which are much smaller than this can burn out the output of the integrated circuit and larger values are better.



(a) Using TTL output as a current sink.   (b) Using TTL output as a current source

Figure 1. LED driver circuits

2. Analog to Digital (A/D) and Digital to Analog (D/A) conversion

Data that is obtained from a physical system is generally in analog form, i.e., it varies in time and can have any voltage between some maximum and minimum value.

In order to do computer-based processing of that data it is necessary to first convert the information from analog to digital form. This is done by quantizing, or subdividing, the voltage range into a number of finite-size steps. The number of steps is usually $2^n - 1$, where n is the number of bits available for the binary word that will represent each level. An example of this quantization is shown in

Figure 2, where n = 3 has been chosen. As can be seen by comparing the two columns at the right of the figure, there is always some error introduced in the conversion since no matter how many bits are chosen, there is always a step between levels.

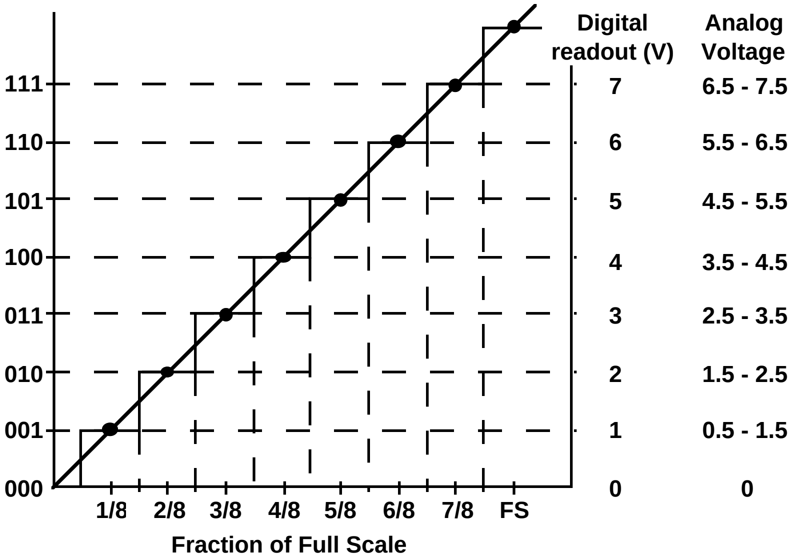


Figure 2. Three bit A/D quantization effect.

There are various approaches to the implementation of an A/D converter. One of these makes use of a set of comparators whose inputs are referenced to the quantized voltage levels. This is the fastest type of A/D converter available and is often called a "flash: converter. To demonstrate the quantization effect we will again use a Electronics Workbench simulation. (It's a bit complicated to build and test in one lab period.) The fabricated circuit consists, in part, of a 3-bit, comparator-based A/D converter, complete with a digital display. The output of the converter is connected to the input of an op amp-based D/A converter whose output can, in turn, be displayed on a scope or a DMM. The complete simulation circuit is shown in Figure 3.

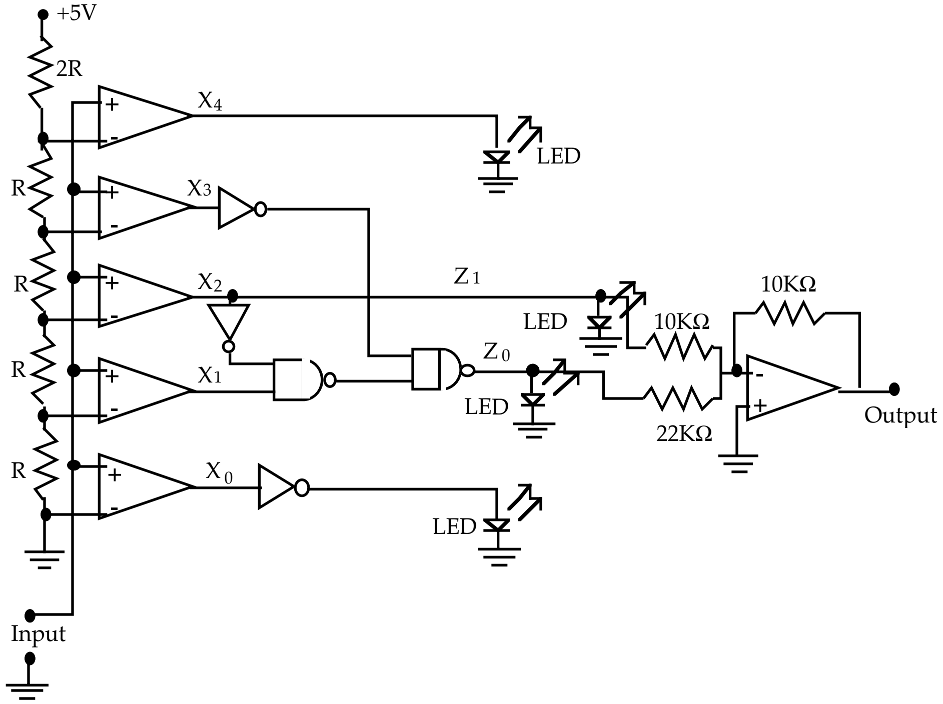


Figure 3. A/D, D/A demonstration circuit.

There are many other approaches to converting analog numbers to digital representations.

2. You have already seen one other type of A/D converter in the 555 timer lab — this is a V/F converter where an analog voltage can be used to control the frequency of a 555 timer. If a computer counts the number of output pulses over a fixed period of time, this count is a digital representation of the analog input quantity.

3. Another common type of A/D converter uses an input voltage to charge up a capacitor. The time that it takes to discharge this voltage is timed by a computer or a digital counter. This is the type most often found in digital instruments such as a DMM and, depending upon the exact details of the implementation, is called a single or dual slope integrating A/D.

4. Yet another common A/D called the successive approximation A/D uses a computer to generate a digital code which is sent to a D/A converter. This digitally generated voltage is compared to the input voltage with a comparator. If the input voltage is higher than the generated voltage the code number is increased, if the input voltage is less than the generated voltage the code number is decreased. The computer typically uses a binary search technique to rapidly find the largest code number which will generate the largest voltage less than or equal to the input voltage.

The difference between these converters lies in the details of how they work. The so-called "flash" A/D converter is the fastest. The dual slope integrating A/D converter is among the most accurate (especially using inexpensive components) and is among the slowest. The V/F converter is often the cheapest and is found in systems which already have a microprocessor, such as a computer controlled appliance.

B. LAB PREPARATION

1. Complete the truth table for the A/D section of the circuit in Figure 3. You can use the supplied Electronics Workbench simulation for this — you do not need to build the circuit. Record your results in Data Table 1.

C. LAB INSTRUCTIONS

Part 1: More logic circuits

1. You will use a single 7400 logic gate to determine the actual LOW and HIGH logic levels of a logic gate. Select a single gate from the 7400. Tie its two inputs together. Connect these inputs to the positive adjustable power supply output using a 10k resistor. Make sure the adjustable power supply is set to zero volts. Measure the output of your selected gate with a DMM. It should be near +5 volts if the input is zero. Remember that you have it connected essentially as an inverter. Now slowly increase the power supply voltage while monitoring the Q output with a DMM. Record the voltage at which the output goes high in Data Table 2.
2. Repeat Step 1 except now start the input voltage at +5 volts and decrease the input voltage. Since the input is initially HIGH the output should be LOW. At some value of the input voltage, the output will change. Record this voltage in Data Table 2.
3. Add the circuit of Figure 1(a) to the output of your 7400 gate. Use the variable power supply to vary the input voltage to the 7400 gate between 0 and +5 volts. Does the LED function to indicate the output state of the gate? Measure the voltage drop across the LED and the resistor. Compute the current through the diode. Record these measurements in Data Table 3.
4. Using the gates on a 7400, build the circuit shown in Figure 4.

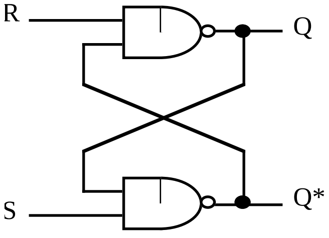


Figure 4. R-S Flip-flop

Determine the truth table for this circuit and record your measurements in Data Table 4. This is actually a R-S flip flop and can have very perplexing behavior. Unlike the combinational logic discussed in class it works based upon the two inputs (R and S) AND the current output. To help you understand this circuit the theoretical behavior of an R-S flip-flop is shown in Figure 5. Notice that the new output (Q_{n+1}) is described in terms of R, S and the previous value of Q (called Q_n). DO NOT CONFUSE Qn+1 with the Q* shown in Figure 4 — Q_{n+1} is the NEXT state (value) of the Q output of Figure 4. The actual operation of the R-S flip-flop can be more easily understood by a simple explanation. The R (also called the RESET) will always reset the Q output to zero (LOW) irregardless of the previous state of the output. The S (also called the SET) will always set the Q output to one (HIGH) irregardless of the previous state of the output. There will be no change in the Q output if both R and S inputs are zero (LOW). However, there is a problem if both R and S inputs are one (HIGH). Technically, you are trying to SET and RESET the output at the same time. As a result the output will be random and, consequently, undefined. During all of this time we are not concerned with the Q* output of Figure 4 and, in fact, it does not really behave as the NOT of Q.

S	R	Q_n (previous state)	Q_{n+1} (new state)
0	0	0	0
0	0	1	1
0	1	0	0
0	1	1	0
1	0	0	1
1	0	1	1
1	1	0	undefined
1	1	1	undefined

Figure 5. Theoretical operation of R-S Flip-flop

Your final objective is to use the EWB simulation to observe and understand the operation of the A/D and D/A converters and the quantization effect that is produced by the A/D converter. The circuit diagram of the simulated circuit is shown in Figure 3. Note that the EWB simulation may take a long time to converge for some of the input values.

1. A voltage divider which can go from -5 volts to +5 volts is used to generate an input for the A/D converter. It can be made to increase the input voltage 1% by typing a “R” on the keyboard; it can decrease 1% by typing “r” on the keyboard. Using the EWB simulation verify the truth table you constructed in Data Table 1.

2. There is also a D/A converter connected to the outputs of the A/D converter, i.e., the LEDs. This is only a two bit converter. Determine the truth table for the D/A converter, i.e. what combination of input bits produces what output voltage? Record your results in Data Table 5.

DATA AND REPORT SHEETS FOR LAB 11

Student Name (Print): ______________ Student ID: ____________________

Student Signature: _________________ Date: __________________________

Student Name (Print): ______________ Student ID: ____________________

Student Signature: _________________ Date: __________________________

Lab Group: ________________________

Data Table 1. Truth table for A/D converter

	X_4	X_3	X_2	X_1	X_0	Z_1	Z_0
$V_{in} < 0V$						x	x
$0 < V_{in} < 0.5$							
$0.5 < V_{in} < 1.5$							
$1.5 < V_{in} < 2.5$							
$2.5 < V_{in} < 3.5$							
$V_{in} > 4V$							

Data Table 2. Voltage at which digital logic switches

	Input voltage at which output switches	Initial Measured V_{out}	Measured V_{out} after switch
Increasing V_{in} from 0 volts			
Decreasing V_{in} from +5			

volts			

Data Table 3. LED indicator characteristics (for LED illuminated)

	Measured	**Calculated**
Voltage across R		▨
Voltage across LED		▨
Current through LED	▨	

Data Table 4. Truth table for R-S flip-flop

R	**S**	**Q_n**	**Q_{n+1}**
0	0		
0	1		
1	0		
1	1		

Data Table 5. D/A Converter Characteristics

X_4	X_3	X_2	X_1	X_0	V_{out}
0	0	0	0	0	
0	0	0	0	1	
0	0	0	1	1	
0	0	1	1	1	
0	1	1	1	1	
1	1	1	1	1	

Questions

2. Why does Data Table 5 only show five input codes? HINT: Can the A/D converter generate a an output code $X_0X_1X_2X_3X_4$=00010?

3. Using Data Table 1 and Data Table 5 explain how the digital logic converts the A/D converter outs $X_0X_1X_2X_3X_4$ into the two-bit code Z_0Z_1 used by the D/A converter?

4. What are the voltage levels at the output of the D/A converter? What range of voltage does each level of the input code Z_0Z_1 represent?

5. If we were to have a 3-bit A/D converter operating over the same voltage range as the 2-bit, what would be the new voltage levels?