

## PURPOSE

The purpose of this lab is to design and build a simple Analog-to-Digital (ADC) converter using OpAmp circuits and resistors. You will apply Thévenin's theorem to analyze an R-2R ladder network. This is a 2 week lab. In first week, you are expected to finish building the ADC. In week 2 you will build a Digital-to-Analog converter (DAC) and connect the ADC to the DAC. You will compare the input signal to the reconstructed output signal. Please refer to this video ([http://www.youtube.com/watch?feature=player\\_embedded&v=EoZ4n6323F4](http://www.youtube.com/watch?feature=player_embedded&v=EoZ4n6323F4)) to see an example of the circuit that you will be building for this lab.

## BACKGROUND

Digital-to-Analog converters (DACs) and Analog-to-Digital converters (ADC) are important building blocks which interface sensors (e.g. temperature, pressure, light, sound, cruising speed of a car) to digital systems such as microcontrollers or PCs. An ADC takes an analog signal and converts it into a binary one, while a DAC converts a binary signal into an analog value. Figure 1 gives a block diagram of such a system. An example of such a system is a PC sound card.

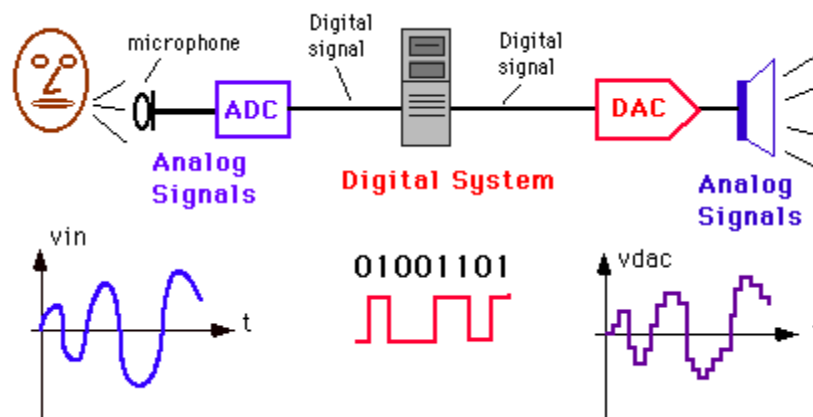


Figure 1 – Digital processing system with an ADC at the input and a DAC at the output

### **Analog-to-Digital Converter**

An ADC takes an analog input and generates a digital output as shown in Figure 2a. The more bits the output word has the better the resolution. For a 3-bit ADC, the number of steps will be 8 ( $=2^3$ ) while a 10-bit ADC will divide the analog signal up into 1024 ( $=2^{10}$ ) steps.

The input-output relationship of an ADC is shown in Figure 2b for a 3-bit converter. Notice that when the analog input signal (on the horizontal axis) reaches a certain level, a new digital code will be generated (see vertical axis in Figure 2b) which represents the digital output of the ADC as a function of the analog input. The maximum analog signal the ADC can accommodate is called the Full Scale (FS) as is shown in Fig. 2b. As an example, if the analog input is equal to  $\frac{4}{8} \times FS$  (Full Scale), the output code for the example of Figure 2b will be (100). However, if one increases the magnitude of the input signal above  $\frac{4.5}{8} \times FS$ , the new digital output code will be (101).

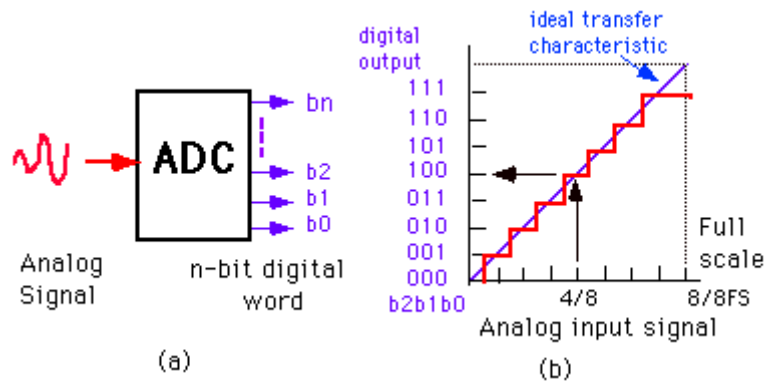


Figure 2 – (a) ADC; (b) input-output characteristic of an Analog-to-Digital Converter

### PRE-LAB ASSIGNMENT

Figure 3 shows a circuit that implements an Analog-to-Digital Converter (ADC). This circuit takes an analog signal and gives a digital output.

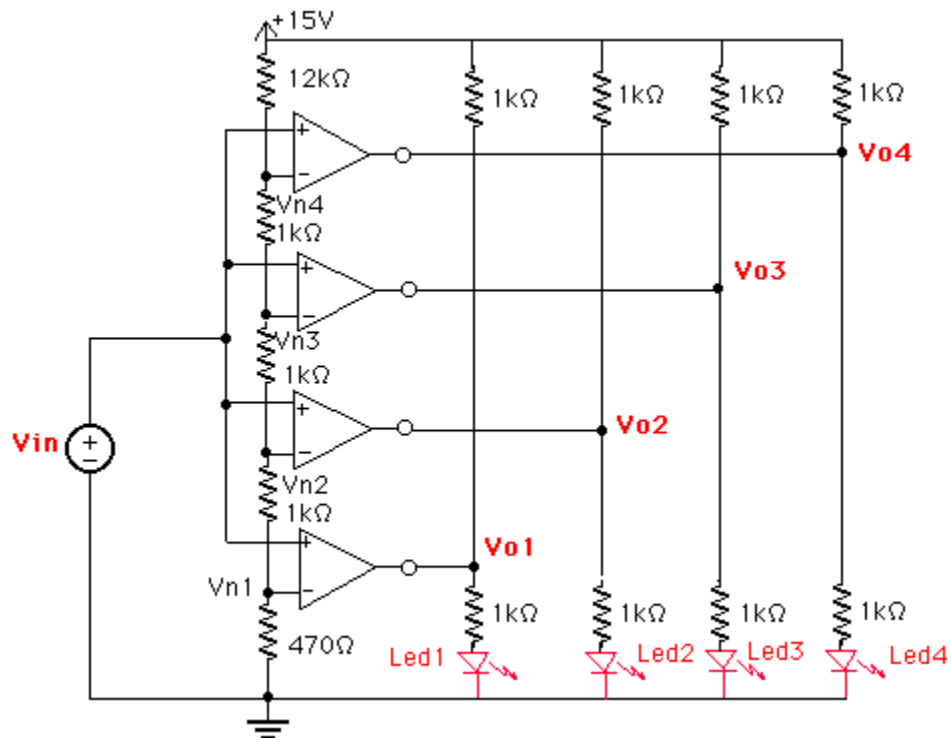


Figure 3 – Flash Analog-to-Digital Converter

The circuit consists of 4 comparators whose inverting inputs are connected to a voltage divider. A comparator is basically an operational amplifier used without feedback. The outputs of the comparators in Figure 3 correspond to a digital word. When the input rises above  $V_{N1}$ , the first comparator will switch to a high output voltage (positive rail), causing the LED to light up, indicating a (0001). For larger input voltages the output of other comparators will switch high as well. For large input voltages (above  $V_{N3}$ ) all comparators will be high corresponding to (1111) digital output. Thus the comparators encode the analog input as a digital word on a thermometer scale.

All comparators work in parallel which makes this ADC very fast. For that reason it is called a Flash Converter.

Notice that a 1 kOhm resistor has been added between the power supply and the output of the comparators. This has been done to ensure that the output voltage of the comparators is high enough (the comparators have an open collector - don't worry what that means at this point).

**Calculate and record in your notebook the values of  $V_{Ni}$  when each comparator will switch.**

## **IN LAB ASSIGNMENT**

### **A. Equipment**

1. Digital multimeter (HP34401A)
2. Triple output programmable power supply (HP E3631A): 5V, -5V
3. Protoboard
4. Blue box with cables and connectors
5. Resistors: 1kOhm, 3kOhm
6. Potentiometer
7. Ten LEDs
8. Quad Comparator LM 339 (quad=four devices in one package)

### **B. Procedure**

The final circuit that we will be building is shown in figure 4. However, we will be building that circuit by parts.

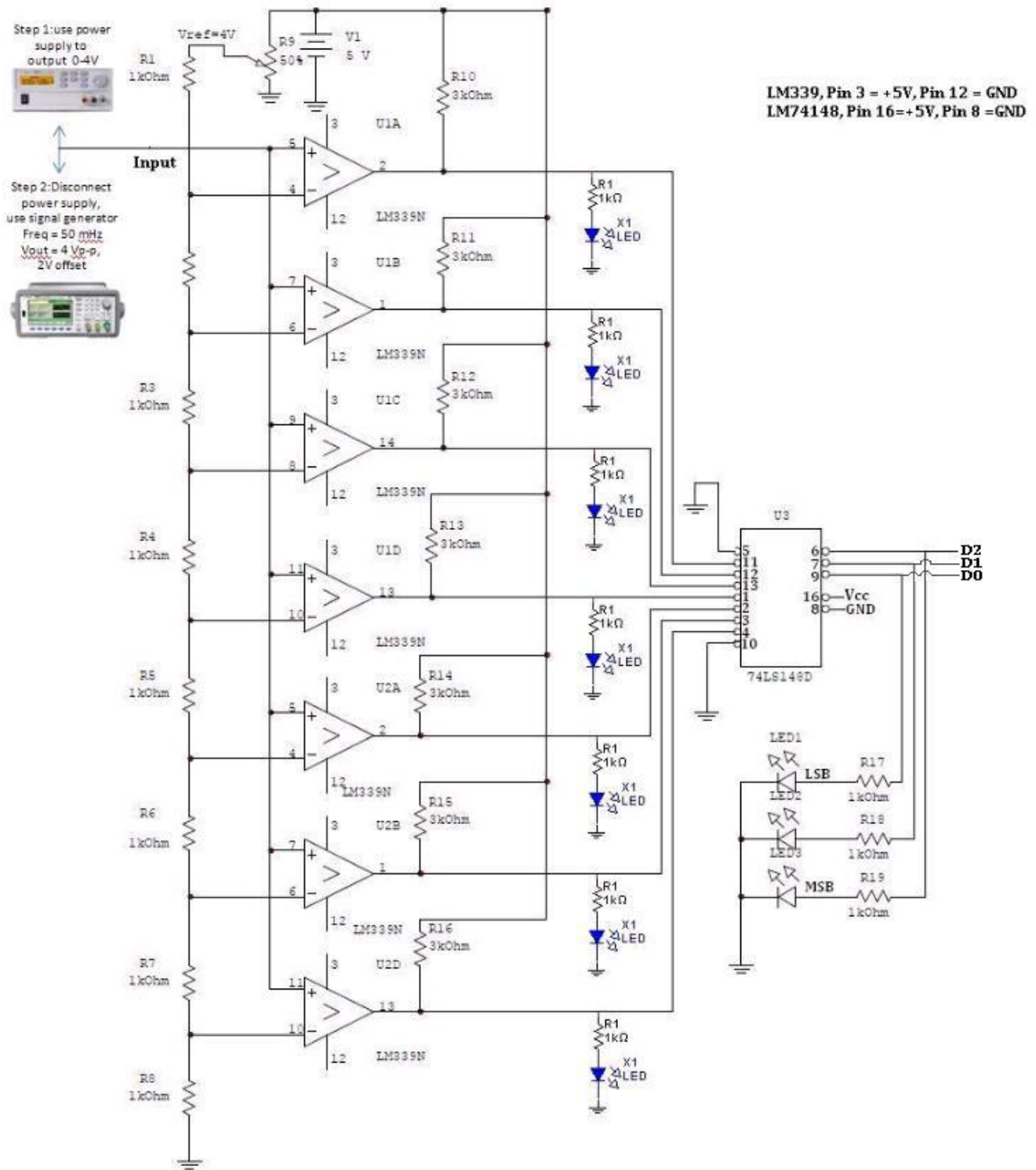


Figure 4 – Design, flash ADC using LM339 and Priority Encoder

Build the resistor ladder network shown in figure 5. Since the final circuit will be really large, we recommend you starting this circuit at the corner of your protoboard so that you have the space to add the extra parts on the following steps. Vary the potentiometer R9 such that the voltage V1 is as close as possible to 4V. Calculate what the voltages V1 through V8 should be. Now, measure and record the voltages at V1 through V8. Do these agree

with your calculated values? If not, check your circuits for mistakes. Show your voltage values to your TA before proceeding.

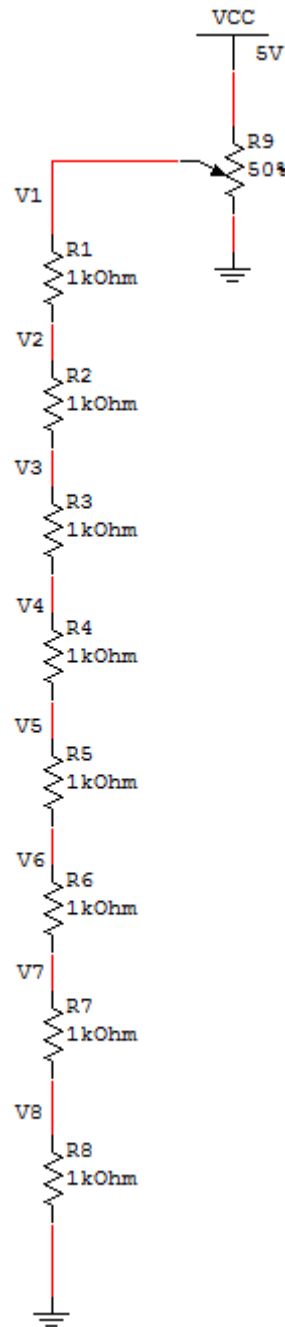


Figure 5 – Resistor ladder network

Next, you will be using the LM339 Quad Comparator to add the comparators to your circuit. Click [here](#) to see the specs of this comparator. The pin-out configuration for this part can be seen in Figure 6.

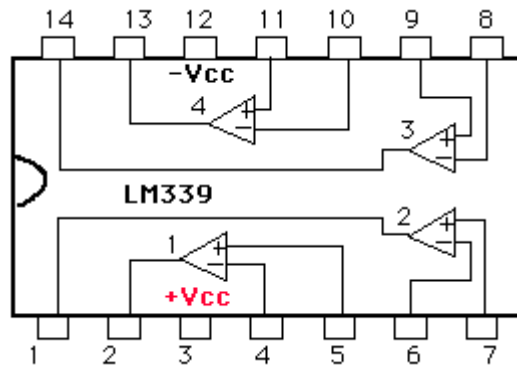


Figure 6 – Pin-out of the LM339 quad comparator

You can see that the LM339 has four comparators packed together. These comparators need pull-up resistors to enable the output voltage. You can read [this](#) to find out more about pull-up resistors. Modify your circuit to look like the one shown in figure 7. The comparators 1 through 4 shown in the image are the same as the ones that you saw on figure 6. In the circuit, pin 3 is the positive rail and should be connected to 5V. Pin 12 is the negative rail and should be connected to -5V.

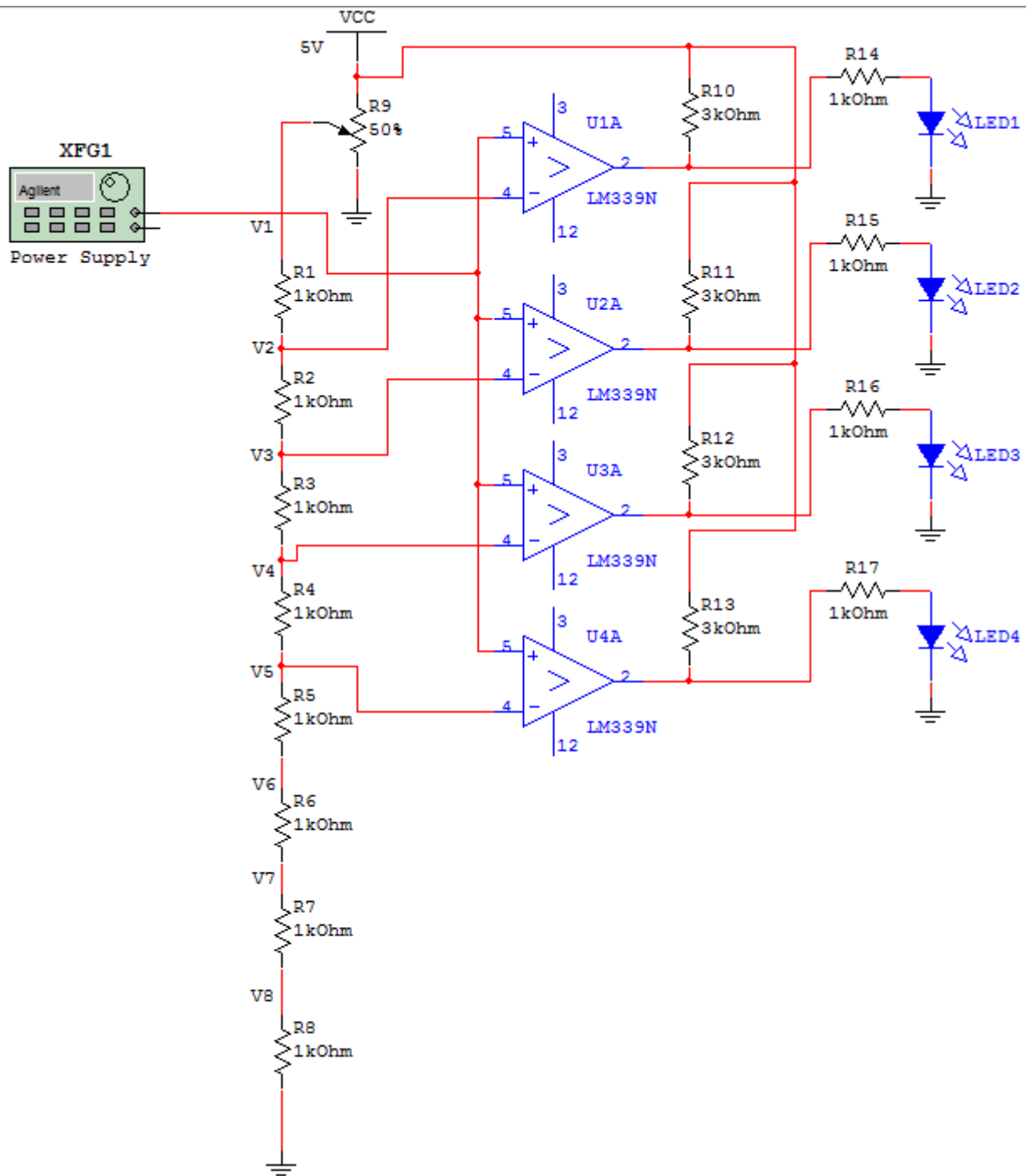


Figure 7 – ADC Circuit with one LM339

From your power supply, slowly vary the input voltage to the non-inverting pins of the comparators between 0 and 4V. Record the voltages at which the op-amps 1 through 4 switch high. Are these in line with the theory that you have learned? Show your circuit behavior to your TA.

Next, modify your circuit to look like the one shown in figure 8. For this circuit, we have added another LM339 to be able to have a total of 7 comparators. The first LM339 that you had on your circuit has the comparators 1 through 4. We now added a second LM339 with comparators 5 though 7.

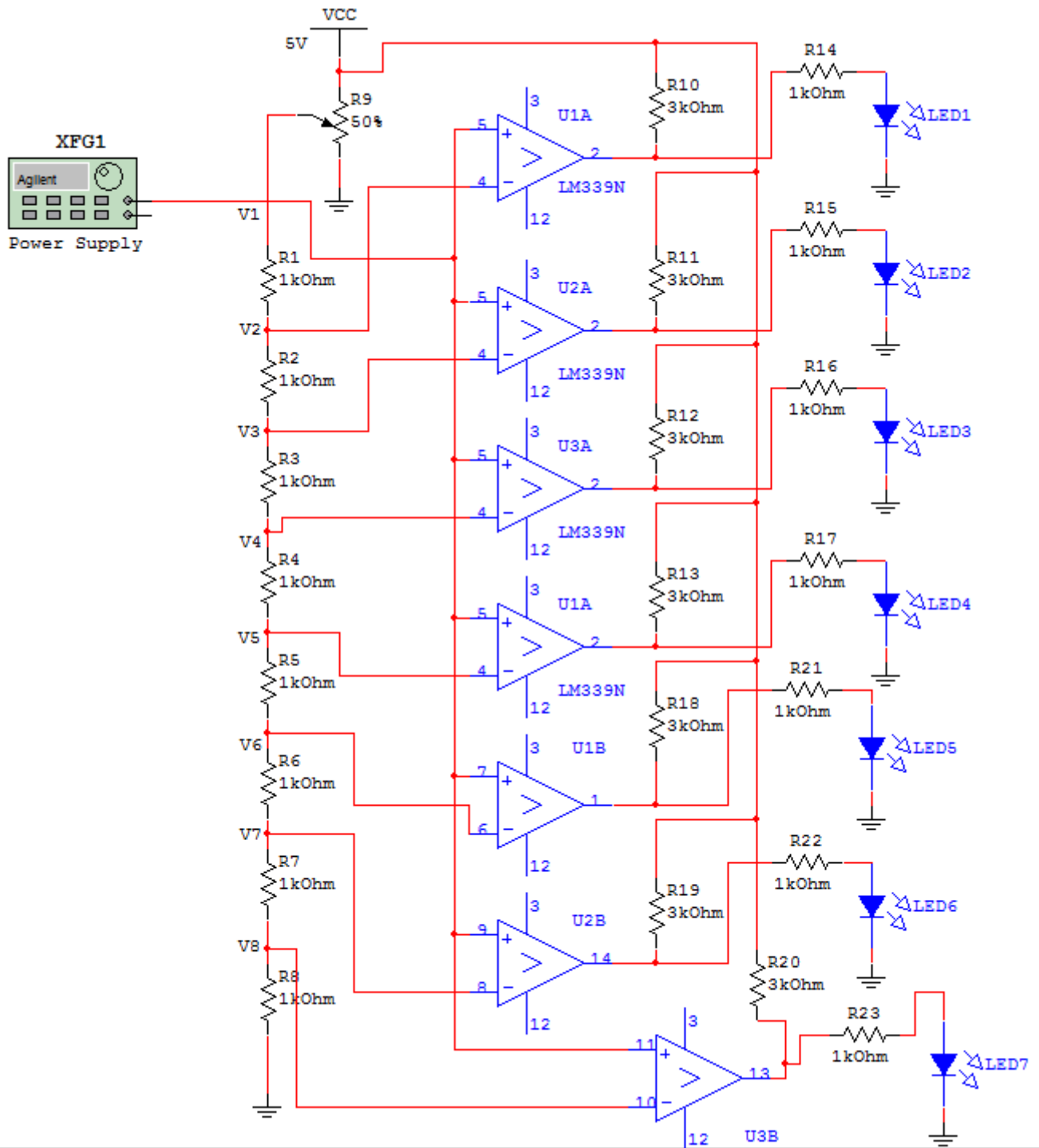


Figure 8 – ADC Circuit with all comparators

Once again, slowly vary the input voltage to the non-inverting pins of the comparators between 0 and 4V. Record the voltages at which the op-amps 5 through 7 switch high. Make sure that these values make sense based on the theory that you have learned. Show this step to your TA.

Now you have a circuit that is capable of indicating how many comparators are high at the same time. Next, we would like to translate this count value into its 3-bit representation. To accomplish this task, we will be using the



74148 priority encoder. You can see the specs for this encoder [here](#). The pin-out configurations for this part can be seen in figure 9.

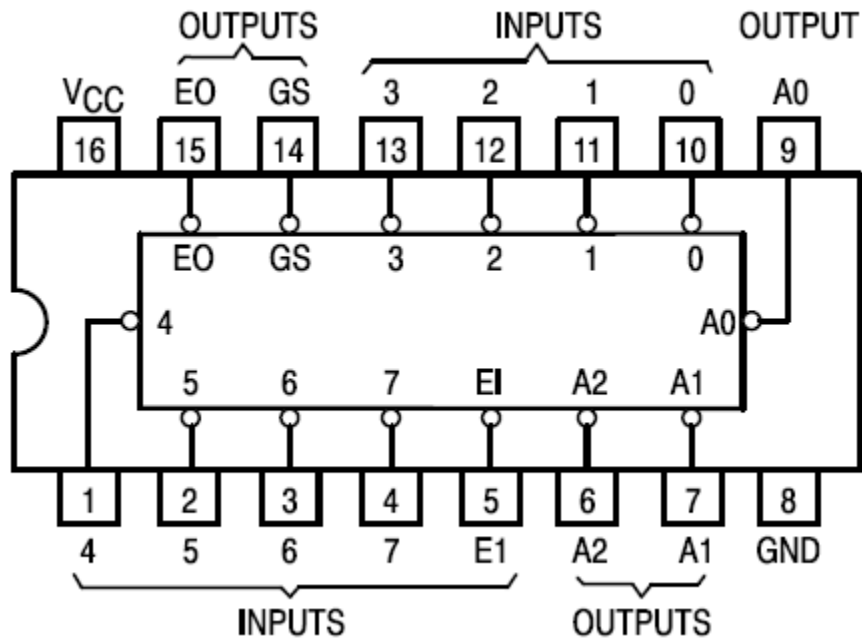


Figure 9 – Pin-out for the 74148 priority encoder

Modify your circuit to look like the one shown in Figure 10.

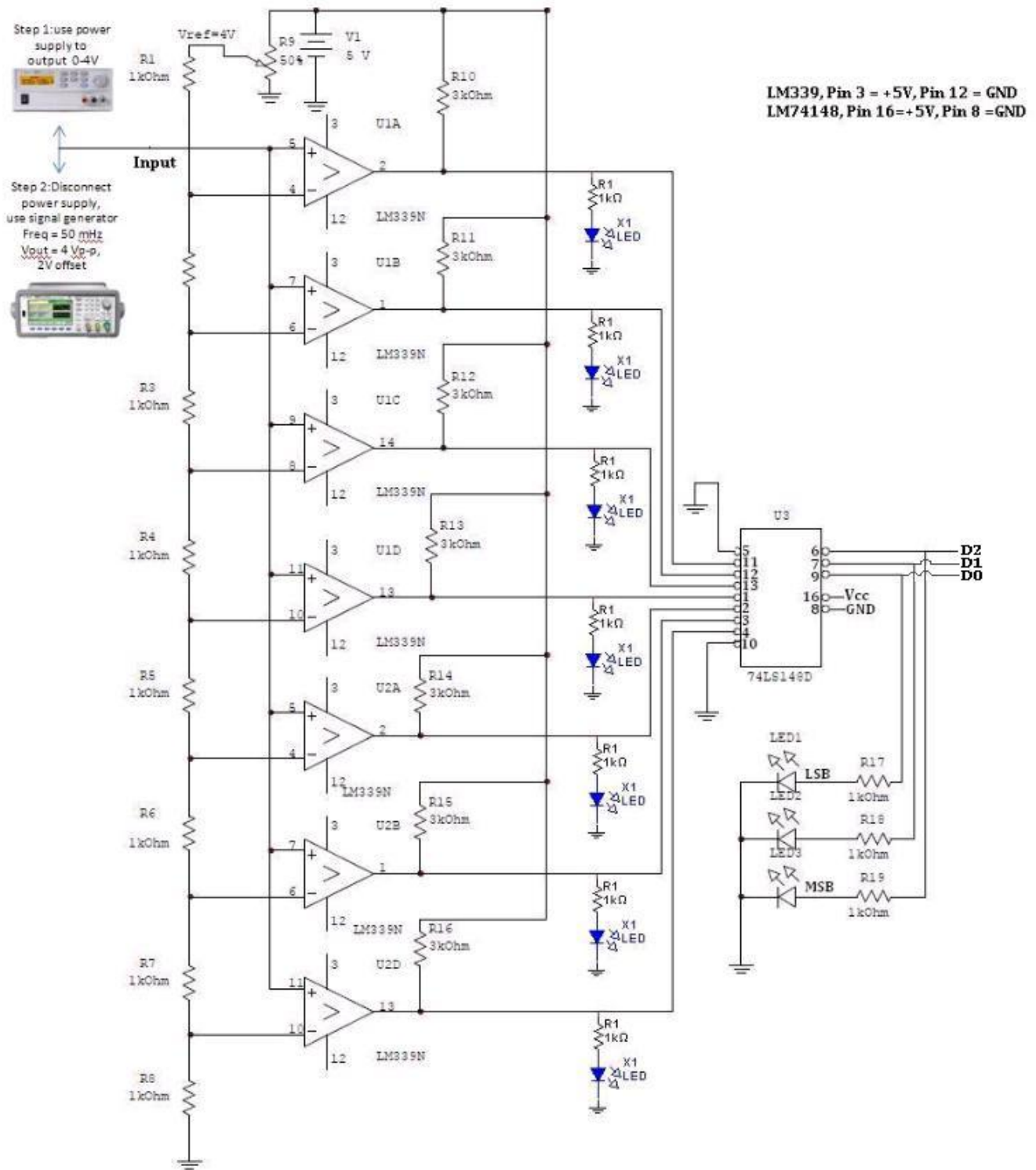


Figure 10 – Full ADC circuit

Slowly vary the input from the power supply and observe if your circuit is functioning correctly. Show this to your TA. Now, substitute the power supply by the function generator and supply to your circuit a sine wave with 4Vpp, 2V offset and 50mHz. Check if your circuit still behaves as it should. Document the behavior of the three output LED's. Show this to your TA.

Table 1 summarizes all the data that you should be collected from this lab. This table is your exit ticket.

Item	Value (V)
V1	
V2	
V3	
V4	
V5	
V6	
V7	
V8	
Voltage at which comparator 1 turns on	
Voltage at which comparator 2 turns on	
Voltage at which comparator 3 turns on	
Voltage at which comparator 4 turns on	
Voltage at which comparator 5 turns on	
Voltage at which comparator 6 turns on	
Voltage at which comparator 7 turns on	

Table 1 – Data Summary