Chapter 5

Comparators

5.1 Section Overview

Comparators are used to compare two voltage levels and typically provide a logic level output indicating the result of the comparison. One confusing aspect of comparators is the open collector output that can pull the output to ground but cannot drive it to a high voltage level. In this Lab, we will examine the behavior of the comparator.

5.2 Preparation

Make sure that the batteries are charged. Obtain either a printed or electronic copy of the datasheet for the LM339 Quad Comparator chip, from an On-line source, or from the TekBots Web-page (under the 'Reference' section).

5.3 Procedure

In the first part of this Lab, a test comparator circuit is constructed and analyzed. Later, there is a description of the operation, construction of an analog control board and an oscilloscope task. Finally, after assembling and testing the entire system, there is a challenge problem to perform with the newly-constructed TekBot.

5.3.1 Test Comparator Circuit

Construct the circuit, as shown in Figure 5.1. (Most of these parts will be used later on the analog control board: so, please be careful and gentle with them).

> The comparator in the schematic (Figure 5.1), is inside a dual in-line package (DIP) package. Physically, the comparator has very little resemblance to the schematic symbol. In order to understand what leads connect to what components, use a datasheet for the parts being used.
> The important section is the 'Pin Diagram' section.

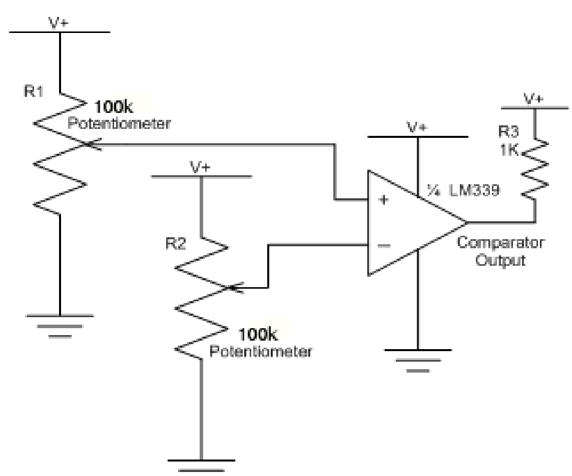

Figure 5.1: Schematic of the comparator test circuit

5.3.2 Circuit Description

R1 and R2 are used as voltage dividers to provide a variable input voltage to the inputs of the comparator. The position of the "slider" in the pot is adjusted with a screwdriver. R3 is a 1K resistor connected from the comparator output to the supply voltage. This resistor allows the comparator output to go to the supply voltage level when the comparison is true. Therefore, when the non-inverting input (+) is higher than the inverting input (-), the output will be driven by the resistor to the supply voltage. However, when the non-inverting input (+) is lower than the inverting input (-), the comparator output will go to ground.

To implement this circuit, follow these steps:

1. Apply power to the circuit from your battery pack. Apply the given comparator input levels and then fill in the corresponding output levels. (It is not necessary to set the input voltages exactly) For each voltage setting, record the comparator output voltage. Indicate the logical output level with a "1" if the output is near the supply voltage, and with a "0" if the output is near ground.

> The annotations 2+ and 2- indicate that the voltage is set to just above or just below 2V respectively. For example, 2- could be 1.9. This is done to make the comparator output decisive for our settings. The comparator could resolve between 2.0 volts and 2.000001 volts, but it is not possible to set the potentiometers to such precise readings.

ENTER THE VALUES:

Inverting "-" Terminal	**2V**	**2^+ V**	**2V**	**0V**	**1V**	**2^- V**	**3V**
Non-inverting "+" Terminal	**1V**	**2V**	**3V**	**2V**	**2V**	**2V**	**2V**
Comparator Output (volts)							
Comparator Logic Output (1 or 0)							

2. Using the table as a guide, describe in your own words a rule that describes as to when the comparator logic output is "high".

3. Remove the resistor between the comparator output and the supply voltage. Set the potentiometers using the table you just filled in, so that the output should be logic high. What voltage do you read? Explain the result of the readings.

4. In step 1, at what point did we measure the V_{ce} of the output transistor?

5.4 Operation of the Analog Control Board

The analog control board is used to control the forward, backward, and turning behavior of the TekBot. The robot goes forward until either one or both of the buttons on the sensor board strikes an object. Depending upon which button is depressed, the robot first backs up. It then turns towards the opposite side at which the button was struck, and proceeds forward again. This is referred to as *bumpbot* behavior.

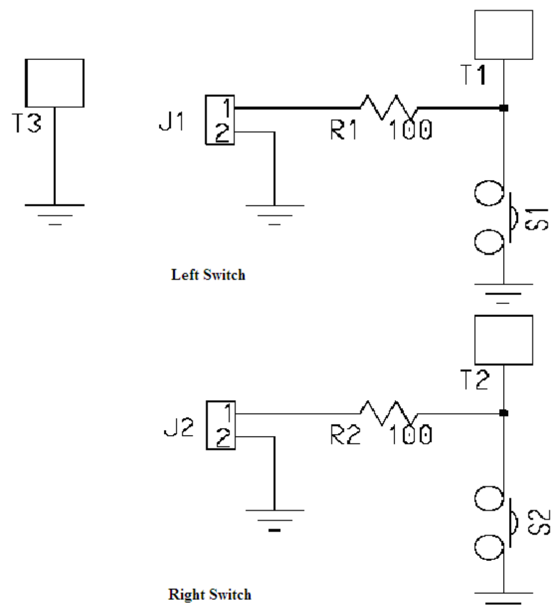

Figure 5.2: Schematic for the sensor board

Refer to figure 5.2 in order to understand the following example:

- If a button on the sensor board hits a wall, it connects pin 1 of J1 or J2 to ground through a 100Ω resistor.
- J1 and J2 are connected to J1 and J2 of the analog control board. When the button is depressed, the $10\mu F$ capacitor of the ramp generator is discharged and the non-inverting input to the comparators are brought to a ground potential. The comparators signal a low voltage output indicating the non-inverting inputs are lower than the inverting.
- This signal is passed to the motor control board which interprets the low voltage signal (logic '0') as an indication to reverse the motors.
- Once the robot has reversed its direction, and the sensor switch no longer is depressed by the obstacle, the switch opens again. This allows the $10\mu F$ capacitor to be charged again by the $100K$ resistor.
- However, the large resistor makes the capacitor charge slowly. The charging of the capacitor through the resistor forms a voltage ramp with an exponential curve.

  Refer to Figures 5.3 and 5.4 for an illustration of the following Ramp Generator behavior:
- The slowly changing voltage ramp provides a way to create the turning action. The robot turns by running one motor in reverse while the other is going forward.
- The amount of time spent in turning is determined by the difference in the voltage comparison points of two comparators and the slope of the ramp. The slope of the ramp is fixed by the $100K$ resistor and $10\mu F$ capacitor, but the comparison points of the comparators is set by two potentiometers.

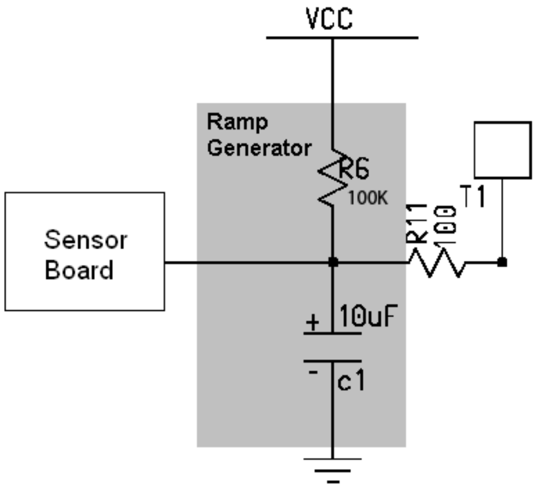

Figure 5.3: Schematic of Ramp Generator Behavior

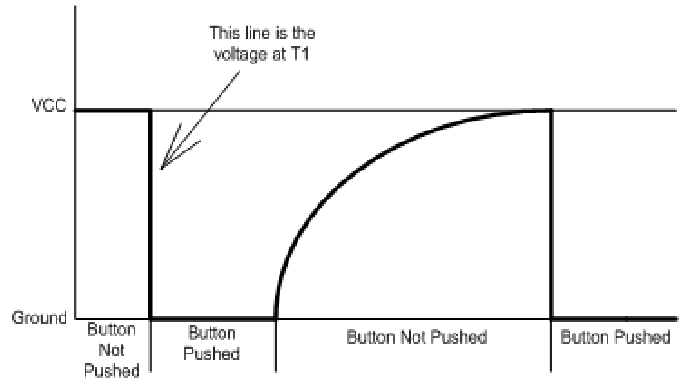

Figure 5.4: The exponential curve of the voltage ramp

See Figure 5.5 for a description of how the ramp and voltage decision points create the turning bumpbot behavior.

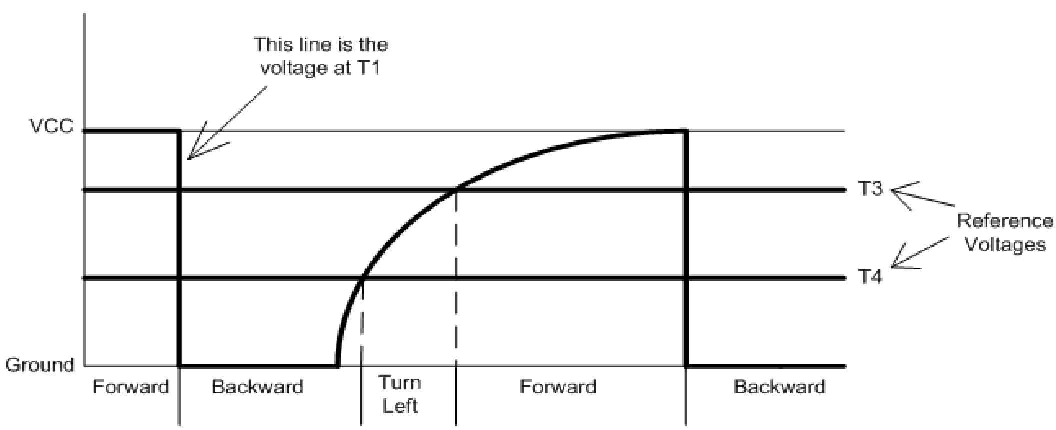

Figure 5.5: Voltage ramp creates bumpbot behavior

See Figure 5.6, for a schematic illustration of the left-sensor half.

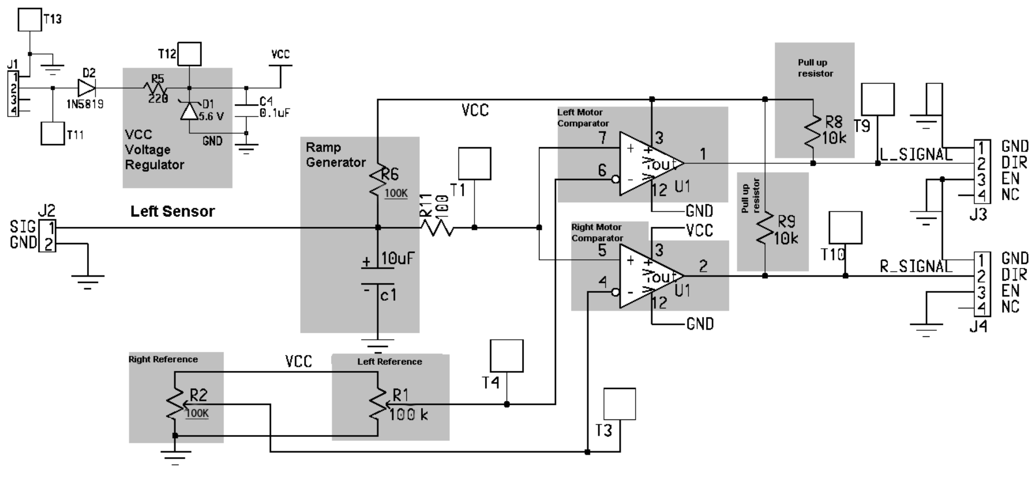

Figure 5.6: Schematic of the left sensor half

5.5 Building the Analog Control Board

This section describes the purpose, build and test processes for the various parts that make up the analog control board. They are the Voltage Regulator, the Reference Voltage Potentiometers, the Ramp Generator, and the Comparators and Pull-up Resistors.

5.5.1 Voltage Regulator

Purpose: This block sets the supply voltage for the board at approximately 4.7V.

Build: Build the VCC voltage regulator. Also put in J1, D2, and C4.

Test: Apply an input voltage from the charger board at J1. T11 is the input and should be close to 8V. T12 should be about 4.7V. *Note: No components should be warm.*

5.5.2 Reference Voltage Potentiometers

Purpose: Potentiometers allow adjustment of the voltages at T3, T4, T7, and T8 so that the backup and turn times can be adjusted.

Build and Test: Solder in the potentiometers. Apply voltage to the board again. Adjust each potentiometer and observe that the voltages change at the respective comparator pin. Initially set T4 and T8 at 2V and T3 and T7 at 3V.

5.5.3 Ramp Generator

Purpose: A ramp generator provides timing for the backup and turn behavior. The capacitor is discharged to ground when a sensor switch is grounded. After the switch is ungrounded, the voltage will slowly rise as the capacitor is charged through the 100K resistor connected to the supply voltage. Use a voltmeter to see this ramping voltage.

Build: Solder in the parts for both the ramp generators. C1 and C2 have polarity and therefore, it should not be put backwards. Align the line on the capacitor (the '+' terminal) with the '+' on the silk screen. Also, solder in J2, J3, J4 and J5.

Test: Apply power to the board. Connect the SIG pin of J2 to GND. *Note: If T1 and the output pin DIR at connector*

J3 become 0V disconnect SIG and GND. Then, make sure T1 slowly increases to VCC. Check the DIR pin on J3 again. It should read about 3.3V. Perform the same procedure for the other ramp generator.

5.5.4 Comparators and Pull-up Resistors

Purpose: The Comparators compare the voltages at T1, T4, T5, and T8.

The pull-up resistors allow the comparators to signal a logic true or ”1” to the motor control board. Without the resistor, the comparator can only instruct the motors to go backwards.

Build: Solder in the comparator making sure the chip is oriented correctly. The half circle of of the chip should match the half circle on the board silk screen. Solder in R8 and R9.

5.6 Assemble the Bumpbot

The Bumpbot boards are mounted and wired, and the system is programmed for corresponding movements to the left and right bumpers.

5.6.1 Mounting and Wiring

To implement the above, follow these steps:

1. Mount all of the boards and connect them together. Put the boards anywhere you would like to, but place the sensor board in the front of the TekBot, so that it can bump its environment.
2. Assemble the system as shown in Figure 5.7. To connect power to the boards, and signals between the boards, use pieces of CAT-5 cable available in the kits or at the front of the Lab. (This cable fits nicely into the female headers).

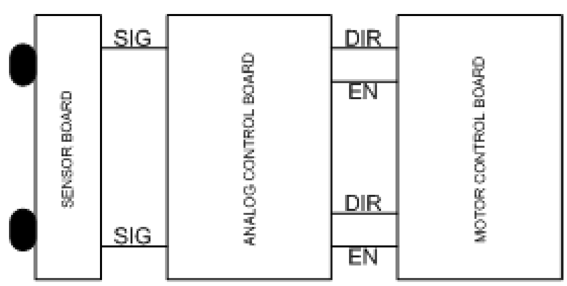

Figure 5.7: The Complete System

3. The ’SIG’ wires connecting the sensor board and the analog control board should connect from the right and left whisker connectors on the sensor board, to the right and left sensor connectors on the analog control board respectively. One wire is a ground and the other is the signal wire. As always, be sure that signal connects to signal, and ground connects to ground.
4. To allow the analog control board to control the motors, the direction (DIR) and enable (EN) signals need to be connected between the analog board and the motor board. Make sure that the left has been connected to left, and right to the right as well.
5. The final step is to connect the motors to the motor controller board. (This should already be done from earlier sections, but if not, do it now.)

5.7 Observing the Ramp Generator

The ramp generator uses a simple RC circuit to time how long each tekbot motor will move in reverse. The comparators compare the voltage from the charging capacitor circuit to a reference voltage controlled by the potentiometers. Using an oscilloscope you will observe the analog control board behavior.

To implement this exercise, follow these steps:

1. You will need to work in groups of two to observe how the ramp generator works.
2. Begin with all four potentiometeres turned all the way to the right.
3. Power the analog control board in the same way you power the motor control board.
4. Strip both ends of two wires and solder them into T4 and T1.
5. Plug in two oscilloscope probes into channel one and two. Be sure to set the ”probe” setting to the proper value of 10X.
6. Connect one probe to T4 and the other to T1.
7. Use the skills and knowledge gained from the previous lab about the oscilloscope to capture a waveform that represents the ramp generator and direction change. Your waveform will look similar to figure 5.8

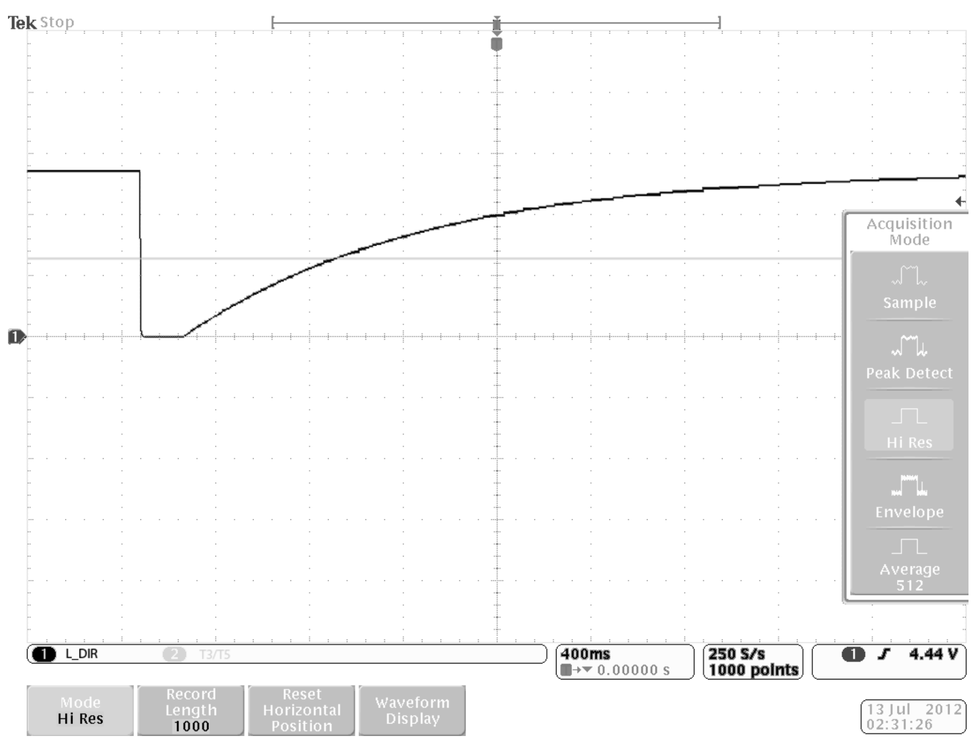

Figure 5.8: Voltage Ramp Example

8. When you have captured a similar image on your oscilloscope have a T.A. sign off on it.

TA Signature: ______________________
(Correct Oscilloscope waveform captured)

5.8 Programming

In order to make the robot work correctly, tune the reference voltages on the analog board. If the right button is pushed, the Bumpbot should back up, turn left, and then continue forward. However, if the left button is pushed, the TekBot should backup, turn right, and then continue forward. See Figure 5.9 for a view of how the finished Bumpbot looks like.

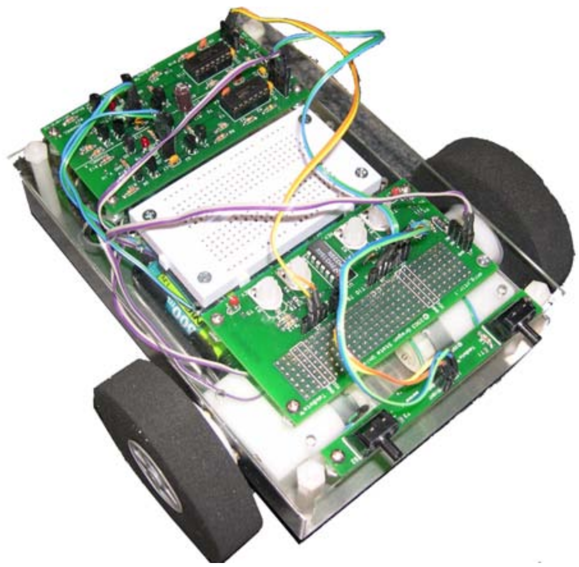

Figure 5.9: Completed Tekbot

5.9 Study Questions

1. This is a troubleshooting question; so, use the block schematic for the analog control board. Here's the scenario: An eager lab student did not want to test his board periodically as he was building it in phases. He attempts to test his board at the end of the entire Lab. The power is plugged in and nothing works. After wasting valuable time by trying to troubleshoot without a schematic, he becomes frustrated. He asks his neighbor or help. The neighbor doesn't want to waste time, so he starts by making a table of test voltages. See table 5.1

Table 5.1: **Test Table**

Test Pad	1	2	3	4	5	6	7	8	9	10	11	12	13
Voltage	0	0	0	0	0	0	0	0	0	0	7.2	0	0

What could be wrong? Dont dismiss anything as too simple of a solution, because many problems in electrical circuits are the simple ones. Describe and justify the steps you would take to find the source of the problem. Suggest at least three possible causes of the problem and how you would check each of those.

2. Throughout the Lab, you have had some experience with troubleshooting. What are some general strategies you would find useful for troubleshooting a circuit and when would each of those strategies be most useful?

3. When the robot is first turned on, the wheels are driven backwards. Why does that happen?

5.9.1 Challenge

1. In this Lab, we have constructed a simple system that uses comparators to compare voltages and makes the TekBot move. Figure 5.10 shows a block diagram for a 'photovore' controller for your TekBot. This circuit will cause your TekBot to always steer using light intensity as a guide. Resistors that change their value in response to light are called photoresistors.

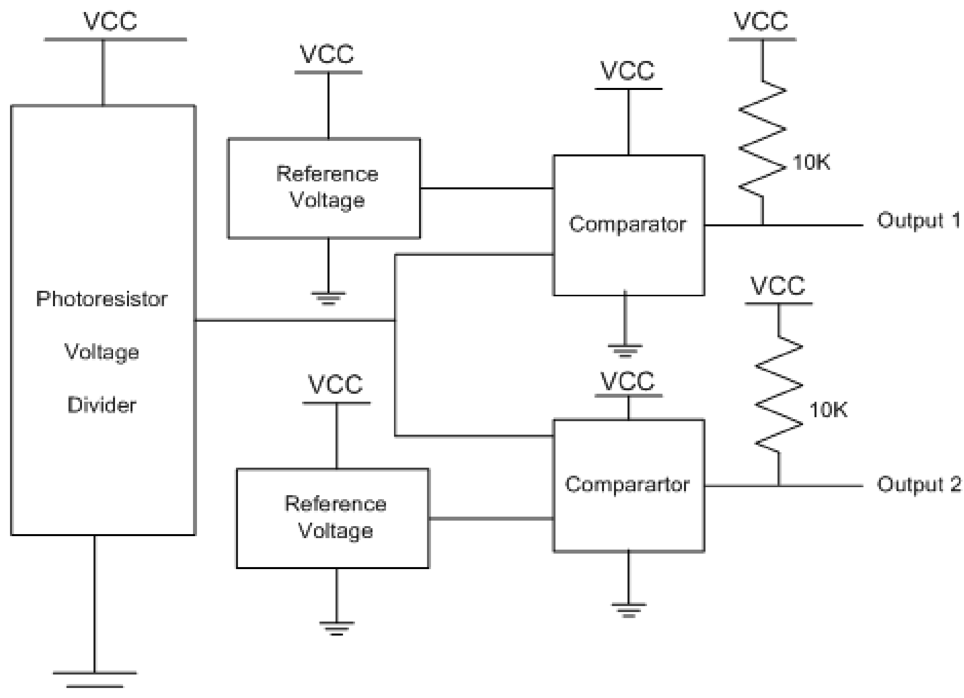

Figure 5.10: Photovore Challenge

To build this circuit, use the comparator datasheet. You will use a LM339 Quad (4) Comparator chip. Part of the challenge is to decide where to put Output 1 and Output 2. Will they go into the *enable* or the *direction* port of the motor controller? What would be the difference in motor behavior, based on where these were plugged?

Write a summary of what you choose to do, and why you choose to do it.

2. The Sensor Board that you have made uses two small buttons to detect objects. These do not work very well if the object is low to the ground, or if you don't run directly into the object. Create your own 'whisker extensions' to expand the area of sensing that your robot has. Figure 5.11 shows two types of whisker extensions, but you may use anything, and may even replace the switches on your TekBot with something different. *Grading is based on your TA's discretion.*

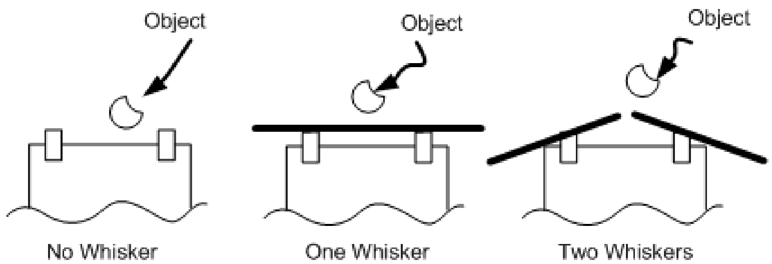

Figure 5.11: Possible Extended Sensors

For this post-lab, please go through the steps of brainstorming, and adding requirements and resources to reduce it down to five possible solutions. *Turn in at least one typed paragraph explaining five possible designs.* For your requirements/resources, you may not spend more than $30.

