Module 2, Add on Lesson – Depth Sensor

Teacher

90 minutes

Purpose of this lesson

- Investigate the relationship between pressure and depth
- Construct a sensor to measure the depth of water
- Graph data and reason about curves and linear relationships
- Calibration of the constructed depth sensor
- Write an NXT program to collect depth measurements

Materials

Copy of the lesson

1 Half of an NXT cable

1 NXT

Electrical tape

1 foot of hook-up wire

3' (or as needed) 1/8" ID (inside diameter) polypropylene tubing

Solder and soldering iron

½ of a Dual Printed Circuit Board (Radio Shack 276-159B)

2 100kΩ resistors

2 2.2kΩ resistors

1 MCP6231 operational amplifier

1 Texas Instruments differential pressure sensor MPX10GP

Cable ties

ruler

Background

The depth of a water body could be determined using several methods, including a device that measures units of length (ruler, calibrated length of rope – sounding line, etc); hydroacoustic assessment (echo sounding – sonar); or pressure.

In this lesson you will use a pressure sensor to measure depth. Pressure increases linearly with depth, so by measuring pressure it is possible to calculate depth. To measure depth, you must build a pressure sensor, figure out a mathematical relationship between pressure and depth, calibrate the sensor, and then write an NXT program which will convert the pressure signals from the pressure sensor into a depth measurement.

What is pressure?

Pressure is a measure of force per unit area. For example, if a force of one pound acts over an area of one square inch, then the pressure is “one pound per square inch” or 1 psi. The standard international unit of pressure is the Pascal or Pa (named after a famous French scientist called Blaise Pascal). One Pascal is equivalent to a force of 1 Newton acting over an area of one square meter, i.e. $1Pa = 1Nm^{-2}$.

Hydrostatic pressure (pressure due to a stationary fluid):

Water is heavy – for example one cubic meter of water weighs one metric ton, or 1000kg. If a diver stands at the bottom of a ten meter deep lake, then he is supporting a ten meter high column of water on the top of his head. The weight of all that water pushes down on the diver’s head. If we divide the weight of that water by the surface area of the top of diver’s head then we will get the *pressure* that the water is exerting on the diver. As the diver goes deeper, then the height of the column of water above his body increases, so that the diver will experience an increase in pressure with increased depth. This is why you can calculate water depth by measuring pressure.

Atmospheric pressure:

The air that we breath and that surrounds us, is also a fluid and also has weight. Air is not nearly as dense as water – once cubic meter of air only weighs about one kilogram (1kg), so it is a bout a thousand times lighter than water. However, as we walk about on the surface of the earth there is a column of air that is many miles high pushing down on our heads, i.e. we all live at the bottom of a sea of air that is many miles deep! All of this air pushes down on our bodies, the same way that water pushes down on the diver, and it causes a considerable pressure. Atmospheric pressure at the earth’s surface (standard atmospheric pressure, or 1atm) is approximately 100,000Pa which is around 10tons per square meter, so all day long your body has a force of several tons pressing on it. This figure of 100,000Pa is also known as “one bar” or 1bar.

Gauge pressure and absolute pressure:

In outer space, pressure is close to zero (perfect vacuum). Pressure on the earth’s surface is about 1bar (due to atmospheric pressure), and as you dive deeper and deeper in water, pressure increases by about 1bar for every additional 10m of water depth.

“Absolute pressure” refers to pressure measured relative to a vacuum (zero). So at 10m depth, *absolute* pressure is around 2bar, at 20m depth 3bar and at 100m depth 11bar.

However, for everyday measurements, we are usually interested in pressure increases relative to the ambient atmospheric pressure. E.g. when you pump up a car tire, you want to know how much more pressurized it is compared to the surrounding air. “Gauge pressure” is zero referenced against ambient air pressure, so it is equal to absolute pressure minus atmospheric pressure. So at the earth’s surface, *gauge* pressure is approximately zero, at 10m depth, *gauge* pressure is around 1bar, at 20m depth 2bar and at 100m depth 10bar.

Water Depth	**Absolute pressure (approx.)**	**Gauge pressure**
Surface	1bar	0bar
10m	2bar	1bar
20m	3bar	2bar
30m	4bar	3bar

<u>Your pressure sensor</u>

The pressure sensor you are about to build will measure *gauge* pressure. To do this, it actually takes two measurements – it measures absolute ambient atmospheric pressure at the surface, and simultaneously measures the absolute underwater pressure at depth. An electronic circuit then subtracts the atmospheric pressure from the underwater pressure reading to give a *gauge* pressure, such that pressure at the surface is defined as zero. Because your sensor takes two measurements and calculates the *difference*, it is known as a *differential* pressure sensor.

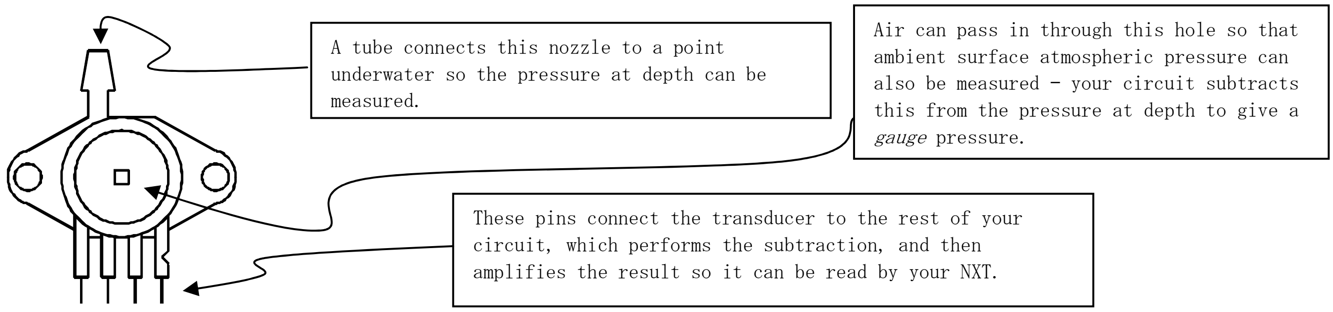
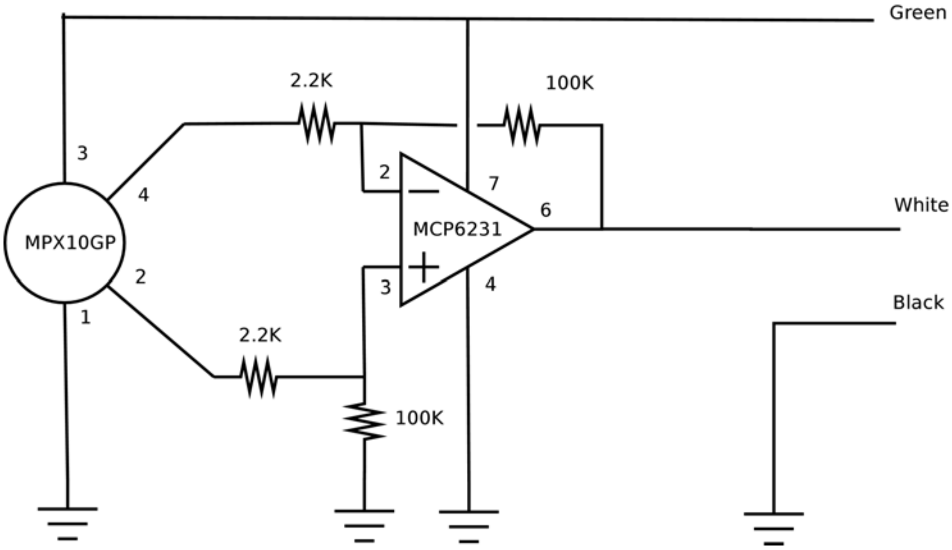


Figure 1. The differential pressure transducer that will form the main component of your pressure sensing circuit.

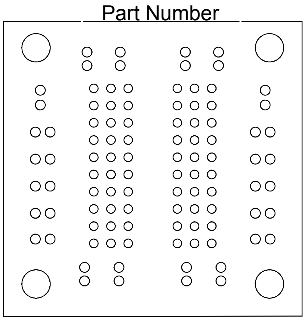
The output from the sensor is extremely small, less than a tenth of a volt. In order to subtract the two small voltages, a differential amplifier is required. A differential amplifier is a pair of voltage dividers coupled with a very high gain amplifier (operational amplifier, or op-amp for short). One microvolt of input results in one volt change in the output.

The maximum amount of difference between the sensor outputs is 80 millivolts. We need to amplify that about 50 times to get a voltage easily measured by the NXT. A 2.2k resistor and 100k resistor give us the gain we need.

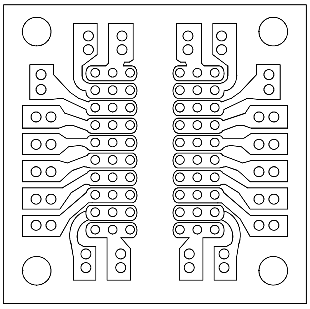
DO NOT WORRY IF YOU DO NOT FULLY UNDERSTAND HOW THIS CIRCUIT WORKS. THE IMPORTANT THING IS TO UNDERSTAND THE BASIC IDEA OF WHAT IT DOES – i.e. it subtracts atmospheric pressure from the pressure underwater to give a gauge pressure, and then this signal is amplified so that it can be read by your NXT. There is not enough time in today's lesson, to explain in detail how operational amplifiers work and how to design circuits with them – but this may be the subject for a future lesson.



Procedure



Top – plastic with holes



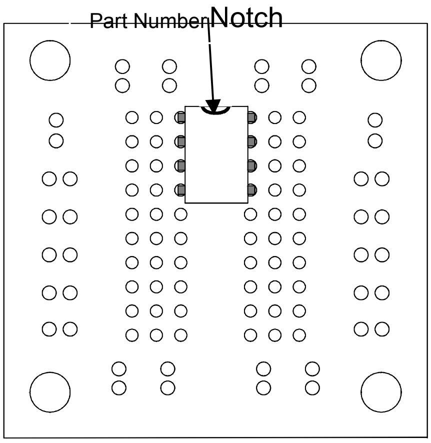
Bottom – copper connections and holes

A printed circuit board is required to solder together the different pieces of the depth sensor. The copper pads have essentially zero resistance, so anything soldered into two holes connected by the pads will behave the same as if they were connected together directly. **Make sure you don't accidently leave two copper segments connected by solder, or your sensor might not work properly.**

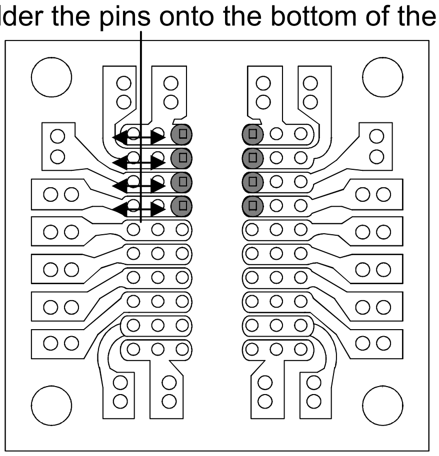
There are four parts to building the sensor: 1) soldering the amplifier chip to the board, 2) soldering the sensor to the board, 3) wiring the resistors, and 4) connecting the NXT cable to the board.

Part 1 - Soldering the MCP6231 operational amplifier (amplifier chip)
The amplifier will strengthen the electrical signal from the pressure transducer so it can be read by the NXT.

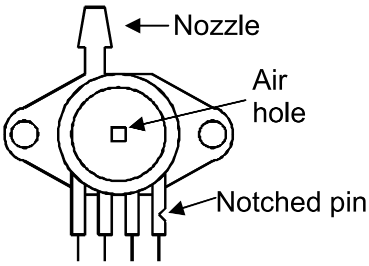
1) Insert the chip on the top of the board with the notch facing up as shown below.
2) Make sure the chip is fully inserted and flush with the board-be careful that it doesn't come away from the board during soldering.
3) First solder two pins at opposite corners in order to get the chip sitting straight and level. Then solder the remaining pins.
4) The chip may become hot during soldering – be careful not to burn your fingers by pressing on the chip during soldering!
5) One way to keep everything in place may be to put the chip on the table, on its back with its legs sticking up, lower the board down over the chip, then press down on the board to hold everything in place while you solder.



Solder the pins onto the bottom of the board

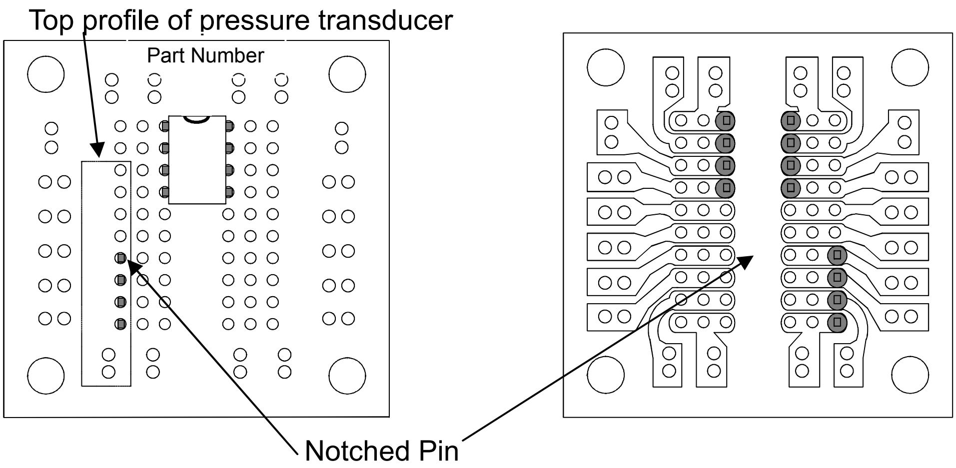


Part 2 - Soldering the pressure transducer to the board



The pressure transducer contains a device called a “strain gauge”. A strain gauge has a resistance which changes with pressure. One side of the gauge is in contact with the outside air (which gets to the gauge through the square hole). The other side is in contact with the air in the nozzle at the top of the device. When powered, there is a linear, but very small, change in the device voltage in response to a pressure difference between the two sides of the strain gauge. The finished sensor will amplify these small voltage changes to be measured by the NXT.

1) Insert the pressure transducer to the board as shown below, and solder the pins on the back of the board. **Make sure the notched pin is placed in the correct hole.**



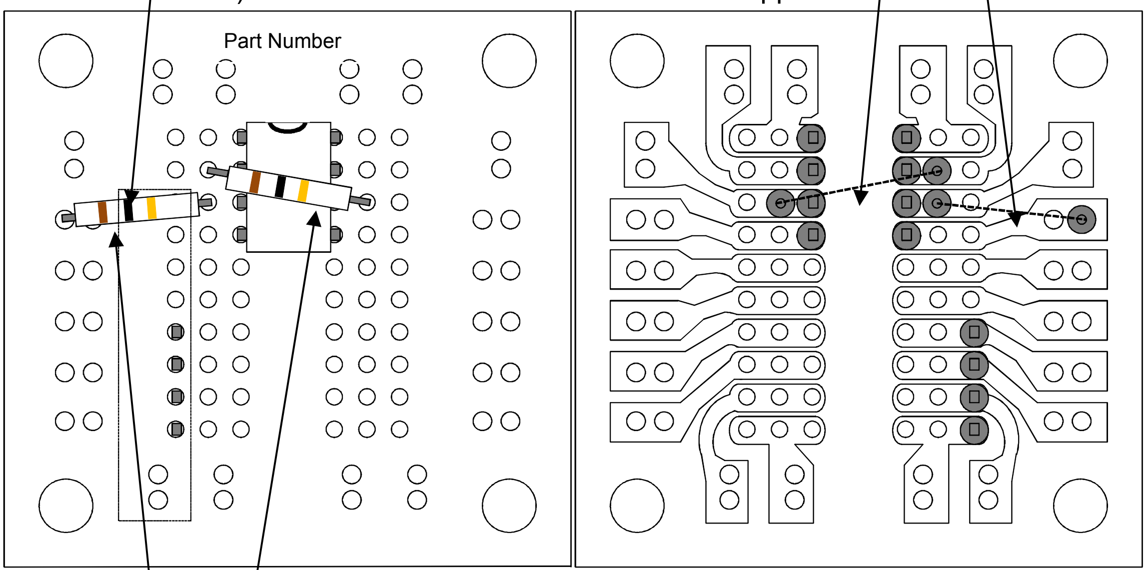
Part 3 - Soldering the resistors to the board

Four resistors are needed to control how much the operational amplifier (Part 1) boosts the signal.

1) Bend the leads of two 100 kΩ resistors (brown, black, and yellow stripes),
2) The first resistor is placed over the operational amplifier.
3) Insert the leads into the correct holes (illustrated below), and pull the leads through the board.
4) The second resistor should be pulled tight to the board (under the pressure transducer).
5) Insert the leads into the correct holes (illustrated below), and pull the leads through the board.
6) Once in position, solder the leads on the bottom of the board.
7) **After soldering the resistors, cut off the long leads to prevent a short circuit.**

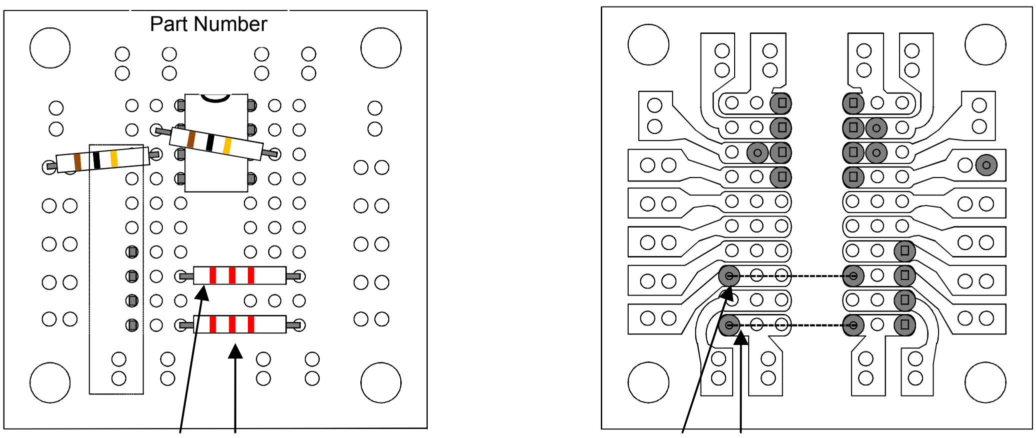
Pull this resistor tight to board (under pressure transducer)

Dashed lines represent the newly placed 100 kΩ resistors on the opposite side of the board



100 kΩ resistors (brown, black, yellow)

8) Insert the two 2.2 kΩ (red, red, red) resistors as illustrated below.
9) Solder and trim the leads.

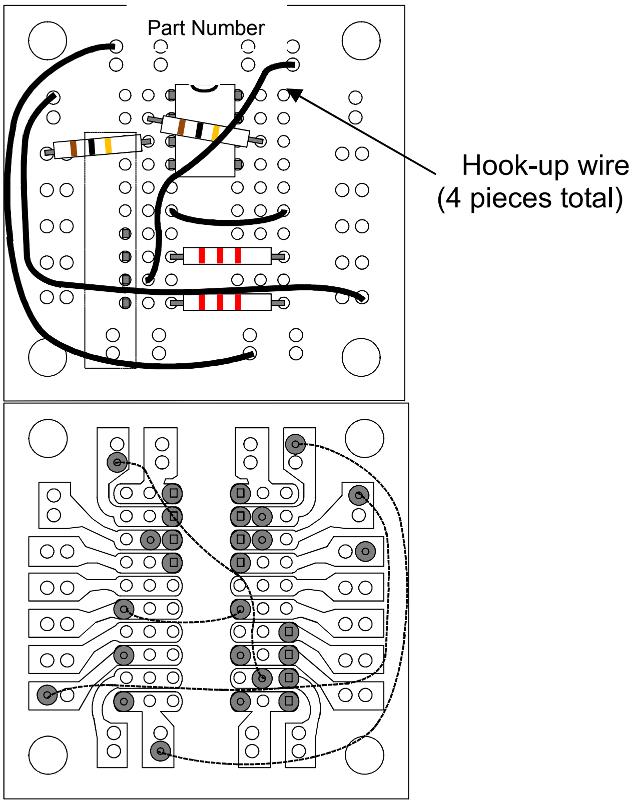


2.2 kΩ resistors

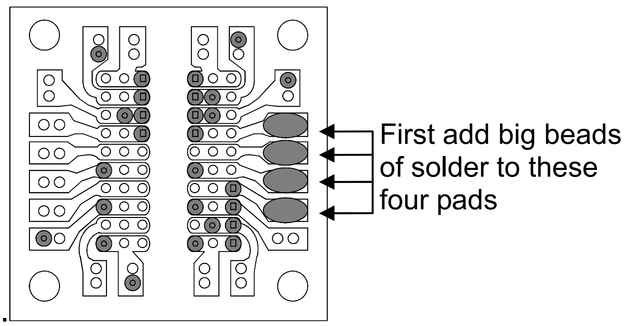
2.2 kΩ resistors in bottom of board

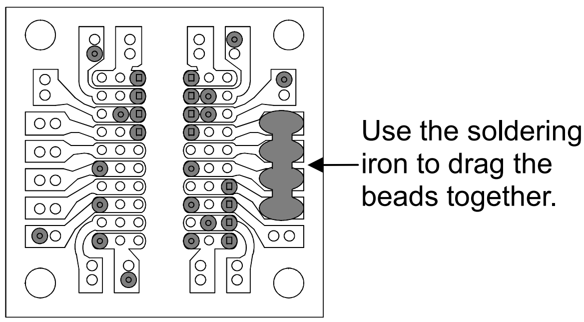
10) Cut 4 pieces of hook-up wire (lengths illustrated below).
11) Strip a little bit of insulation from each end.
12) Twist the wires on each end to ensure the strands stay together.

13) Insert the stripped ends into the holes illustrated below
14) Solder the lengths of hook-up wire in place.



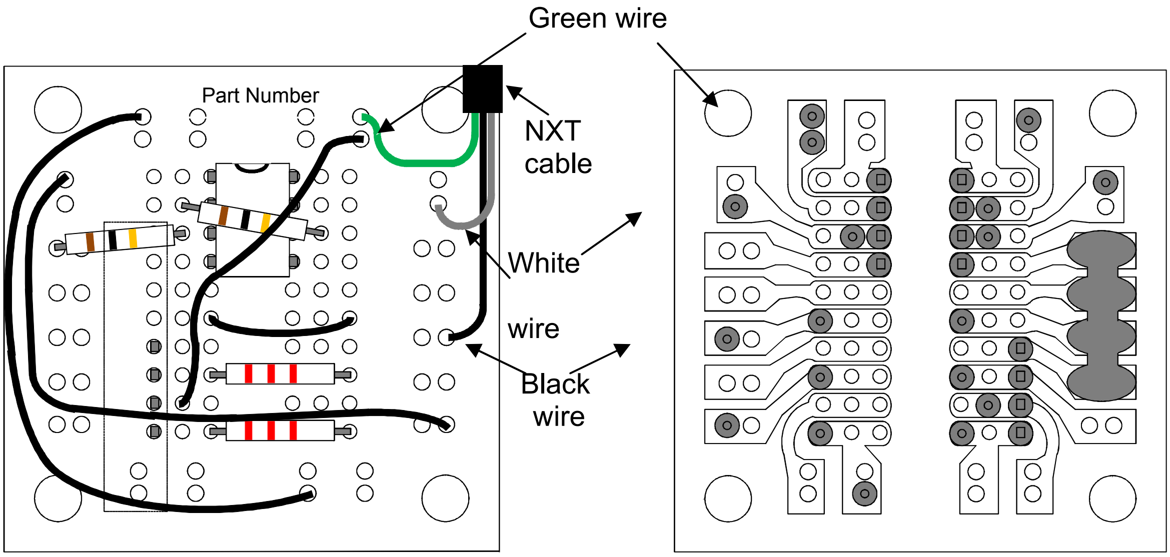
Create the final connections for the circuit. Place a bead of solder on each pad shown below, then use the soldering iron to combine the beads as illustrated below.



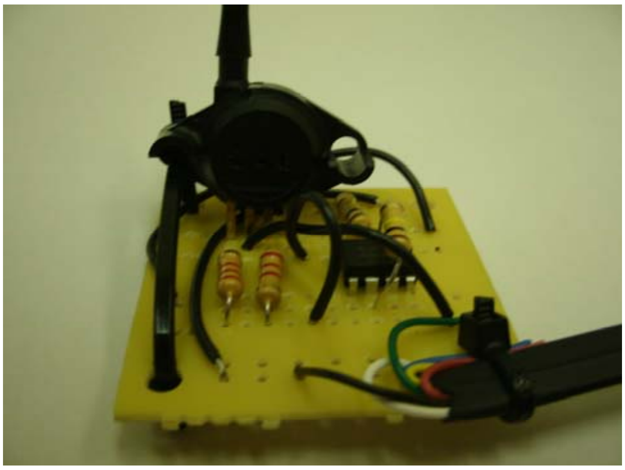


Part 4 - Connecting the NXT cable to the board

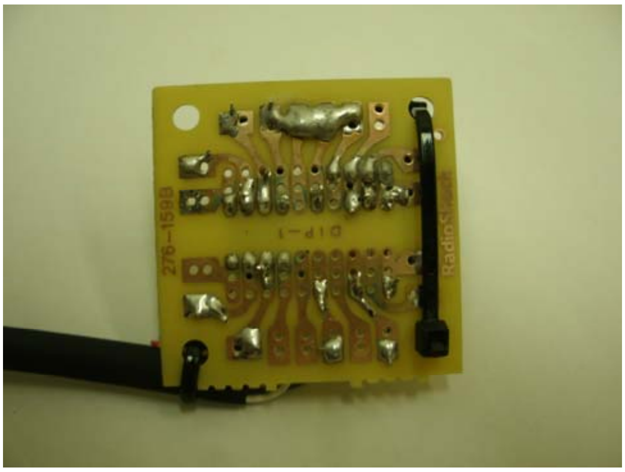
1) Strip the ends of the black, white, and green leads, and solder to the board as shown below.



2) Secure the NXT cable to the board and pressure sensor to the board with cable ties.



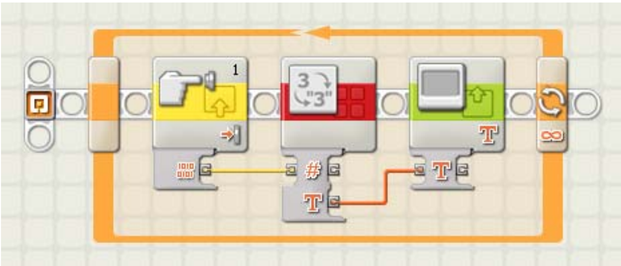
The top of the printed circuit board should look like this when finished.

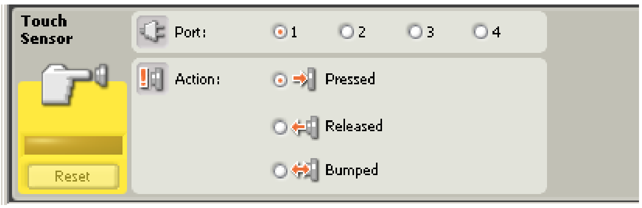


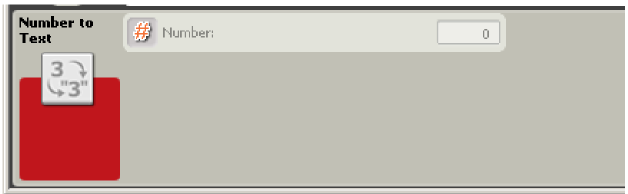
The bottom of the printed circuit board should look like this when finished.

Part 5 – Creating the NXT program

1) Write a program to display the pressure sensor data.

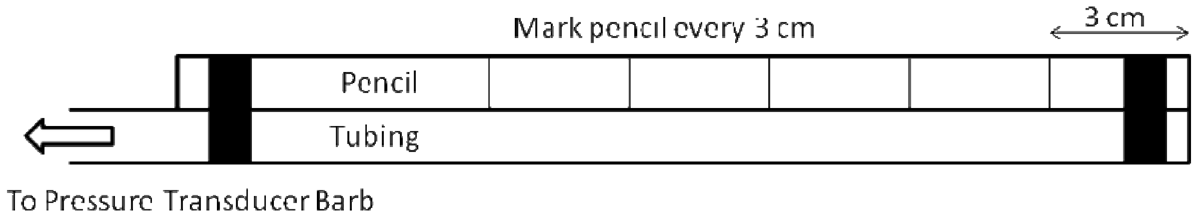






Part 6 – Calibrating the pressure sensor

1) Cut a 3 ft. length of plastic tubing (or whichever anticipated length of tubing required for measuring the depth of the water body where the sensor will be deployed).
2) Tape one end of the tubing to a pencil, the pencil will prevent the tube from curling when placed in water.
3) Starting from the end of the tube, use a ruler to mark the tube with a line every 3 cm.

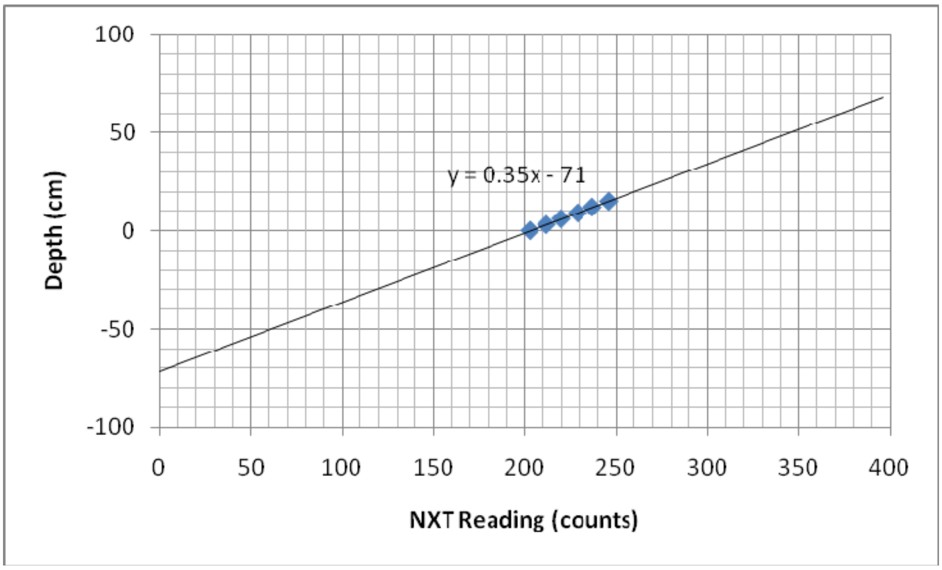


4) Connect the other end of the tube to the pressure sensor by sliding it over the barbed nozzle. Push it down tightly onto the barb – it needs to be an airtight connection.
5) Connect the pressure sensor to the NXT and obtain a reading while the entire sensor is in the air. This reading will serve as the surface level or "0" depth reading.
6) Enter the data in the data table below.
7) Fill a beaker with water, and place the tube (pencil end) until the tube opening is 3 cm in the water.
   IMPORTANT: Always put the tube into the water with the open end facing straight down. This traps the air inside the tubing.
8) Enter the NXT reading on the table below.
9) Put the pencil 6 cm into the water, and take another reading.
10) Continue to take readings at the various depths and complete the table.

NOTE: Make sure water is not trapped in the tubing while taking measurements. **If there is water pouring from the tube or trapped in the tube, the tube is not airtight. If the tube is not airtight, the data is not accurate**.

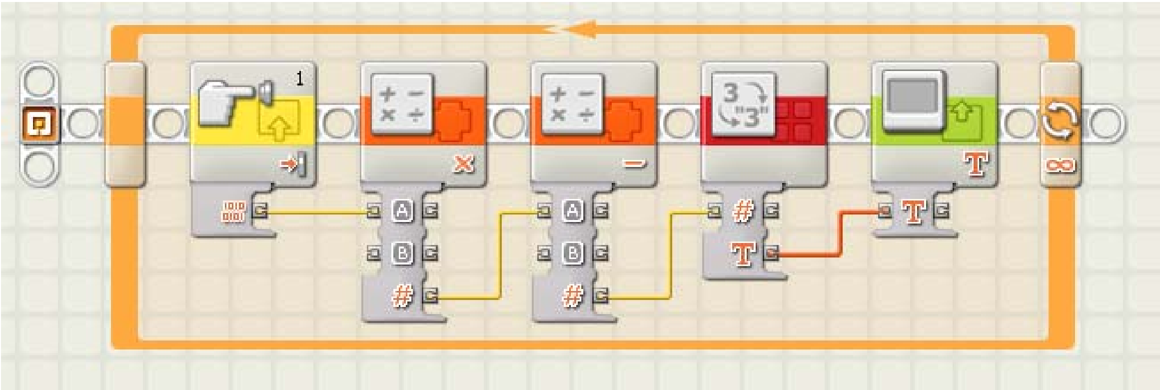
Depth	0	3 cm	6 cm	9 cm	12 cm	15 cm
NXT Reading						

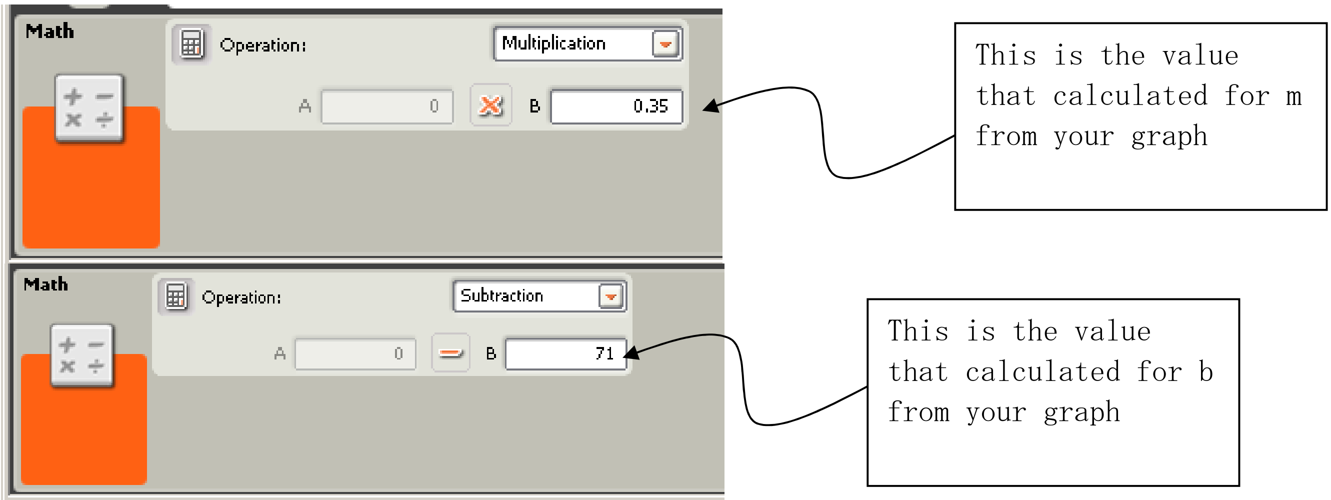
11) Graph the data with depth on the y-axis and the NXT reading on the x-axis.
12) Draw a straight line through the data, and find an equation in the form y = m*x + b.



13) Update the NXT program to convert the NXT raw data reading to a depth reading by adding two math blocks.

14) Use the values for m and b from the graph in the math blocks.





15) After calibration, the sensor should read approximately zero when the sensor is not submerged in the water.

Assessment

1) Do you think the pressure sensor would work equally well for all depths? Explain.

2) Why is it important to obtain a depth measurement in combination with other measurements such as temperature, conductivity (salinity) and turbidity?

3) If you were a company selling this device as a “depth sensor”, how accurate would you claim that its depth measurements were?