ISLAMIC UNIVERSITY OF TECHNOLOGY
(The Organization of Islamic Cooperation)
Gazipur, Dhaka.

PROJECT ON

FOOD QUALITY CONTROL USING AN ECONOMICAL pH METER

SUBMITTED

In partial fulfillment of the requirements for the degree of B.Sc Engineering in Electrical and Electronic Engineering

BY

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DECLARATION

This project is a presentation of our original research work. Wherever contributions of others are involved, every effort is made to indicate this clearly, with due reference to the literature, and acknowledgement of collaborative research and discussions. The work was done under the guidance of **Mr. Golam Sarowar**, at Islamic University of Technology, Gazipur, Dhaka.

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Abstract:

This project is based on designing an economical pH meter, which is capable of controlling food quality.

It would accomplish that through the comparison of the pH values obtained from the food items with the safe pH values which are allowable. If the measured pH values are within that safe range, the foods are fit to be eaten. If not, then the foods are inedible and detrimental to human health if eaten with disregard to their quality.

The aim of the project is also to integrate a wireless data transmission mechanism which will allow the data received at the input end to be sent to the output end, which could be some distance away. This would be highly useful in super-shops and food shops where the cash counter is far from the food display.

Moreover, the intention is to make the provision to detect formalin in food items. Presence of formalin would mean that the pH values of the foods are not within the safe levels allowable. The mechanism should work like an alarm, that is, if the meter detects the presence of formalin, an alarm should be set off, which would caution the customer about the hazardous chemical.

Overview of the Project

- Designing a pH Meter circuit.
- Implement the circuit properly.
- Taking the pH reading of the liquid/solid via the sensor electrode.
- Data from the sensor, which was in microvolts, is converted to volts.
- Use a wireless transmitter to transmit the data to a nearby computer/ tablet.
- Data from the transmitter, which was in volts, is converted to numeric pH values through the use of a micro-controller based program.
- Finally the result is showed in LCD/monitor.

Food Quality Control

- The quality of food is very important to human lives, and thus the devices to maintain that quality have to be up to the mark.
- One of the best and most reliable way is to ensure the pH value of the food is within prescribed limits.

Table 1. Some food pH levels

Note that most foods are below neutral pH (< 7.0).	Lemon juice pH ~2-2.5 Vinegar ~2.5 – 3 Most Fruits ~3-4 Tomatoes ~4-5 Meat and Fish ~6-7 Pure water 7 Soda Crackers ~8

Fig: 1 – pH values of some food items.

Importance of food quality control

- Without the maintenance of the proper quality of the food, it would be unsafe to eat, and would result in detrimental effects to our health.
- Blind belief in the manufactures or suppliers of food items can never be enough nowadays with more and more fraudulent activities taking place every day.
- Consumers, therefore, need to possess an easy-to-use equipment which can allow them to know of the condition of the food they eat.
- The device needs to be cheap, so that almost everyone can afford it.

What is pH?

- pH refers to the concentration of H^+ ions in liquids or aqueous solutions.
- It is a measure of the acidity or alkalinity of the substance in question.
- The higher the pH, the higher is the alkalinity. Conversely, the lower the pH, the higher is the acidity, with a neutral at pH = 7.

The pH Scale

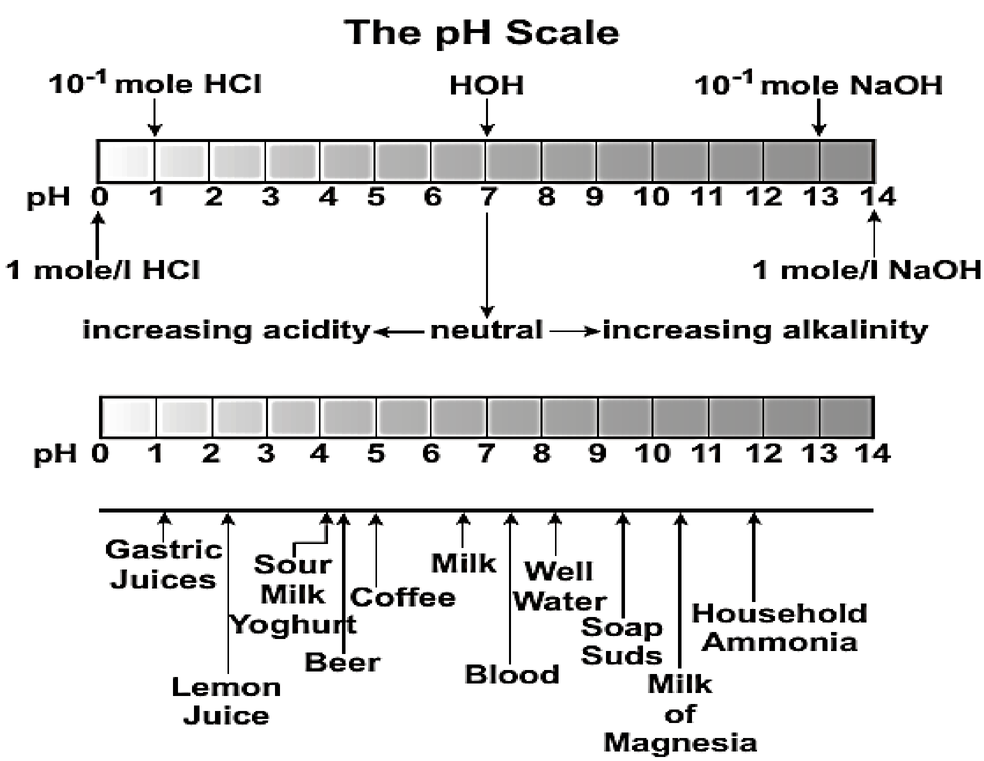


Fig: 2 – The pH Scale.

The Importance of pH in Food Quality and Production

Sanitization of Machinery:

Regulatory bodies such as the departments of health often impose a certain value for the pH of the sanitization solution to be used. For example, the pH should be between 8 and 10 based on the chlorine concentration. Similarly, an iodine solution is meant to have a pH value of 5 or lower.

Milk and Dairy Products:

Milk and Dairy Products: pH of milk is around 6.8 and it is tested for impurities and signs of infection upon collection as well as at point of delivery. In processes such as sterilization, pH is checked since a lower value helps to speed up the process. However, lower pH levels can indicate that the cattle carried leukocyte infections such as marmites.

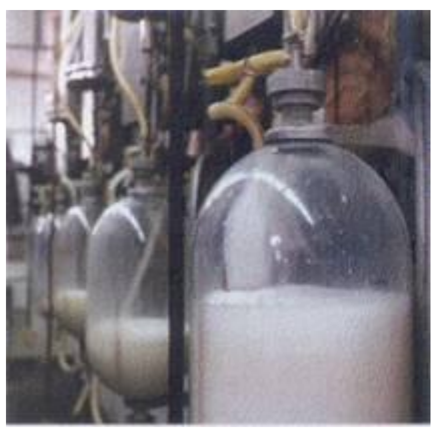


Fig: 3 - pH in milk and dairy products.

Milk used for cheese manufacturing must be of excellent quality and its pH value contributes to whether the cheese will be soft or hard. pH is also checked during cheese preparation, souring of milk and cream maturation. Pathogen multiplication of the fresh and soft variety, is slowed down considerably by ensuring that the pH stays in the 4.1 to 5.3 region.

Controlling the pH value is very important in butter manufacturing processes. For example, cream is cooled after pasteurization at a very strict pH value of 6.70 to 6.85 to generate sweet butter. In order to manufacture sour butter, citric acid extracts are added to acidify the cream to 4.6-5.0 pH. With butter having a high diacetyl content, a starter is added to bring the pH value to around 5. As with other products, a lower pH value enhances the shelf life of the product. With yogurt production, the cooling of cultured milk can start only once acidification has reached a pH value of 4.4 to 4.6. As for fruity yogurts, the pH value of the added fruit must be the same as the yogurt itself to avoid undesirable reaction at the end of the cycle.

The finished product should ideally have a pH value of 4.0 to 4.4 for longer conservation.

Drinks:

Even small changes in the pH value of spring or well waters can indicate a possible fouling of the natural strata. Where municipal water is used, it is often pretreated and its pH monitored. In making fruit juices, the pH of sugar extracts as well as those of juices during purification and refining are checked. pH plays a crucial role in the production of beer. For example the pH value of crushed malt is around 5.8 whereas its ideal value for protein decomposition is around 5.5. To ensure a consistent quality, the pH of brewed beer prior and after bottling is regularly monitored, pH of wine normally ranges from 2.8 to 3.8 with the pH influencing various stages of the process including fermentation and conservation.
With the pH exceeding 3.5, certain bacteria can attack the wine. However, taste of wine also depends largely on its pH value with acidic wines becoming dry.

Meat:

pH of carcasses constitutes an important initial test to determine condition of the animal prior to slaughter, quality of the breeding and any signs of stress during slaughter. The typical pH value, ranging from 5.4 to 7.0, can also provide an indication of whether fresh meat was properly stored as varies in different parts of the animal based on the muscular mass, for example, the loin has a lower pH value. Too high a pH value induces a loss of aroma and a visibly darker meat resulting in a lower market value. In addition to meat, ingredients used in the production of ham and sausages are often refrigerated. By simply checking the pH at the liquefier's intake and drainage points, one can determine if any ammonia has leaked out.

Fig: 4 - pH in meats.

Jam and Jelly Manufacturing:

Jams and jellies have narrow ranges for proper gelling. A pH of 3.3 is best for jelly. At 3.1 it becomes stiff and at 3.5 quite tender. No gelling occurs at all above 3.5. Control is effected by using tartaric or citric acid.

Fruit and Vegetables:

A pH value of 2.5 to 5.5 tends to prolong the shelf life of fresh fruit and inhibit the multiplication of micro-organisms. This is likewise for vegetables with a more neutral pH in the 4.6 to 6.4 range.

Ready-made Food: A pH value of around 4.5 is the simplest way to ensure the stability of the product.

Importance of pH analysis

- pH is a major determining factor for the quality of materials.
- Excesses of either acidity or alkalinity in edible materials could have hazardous effects on the health of humans, animals and plants alike.
- pH imbalance in substances which are tangible can also give rise to problematic situations.

Uses of pH analysis

pH analysis is used in several types of industries:

- Food industries
- Chemical industries
- Water – purification industries
- Textile industries

The analysis is used in the following kinds of food industries:

- Mineral water
- Baby foods
- Fishes
- Cold drinks
- Fruit juices

- All kinds of fruits
- Edible oil (soya bean oil)

How to measure pH?

Quick and dirty pH measurement can be achieved through litmus paper or pH indicators. These are convenient because of their low cost and ease of use, but they can only provide a rough indication of pH, which is insufficient for most applications. The more accurate method involves the use of a measurement system consisting of a pH meter, an electrode that is sensitive to H+ ions, and calibration buffer solutions. The effect that H+ ions have on the electrode can be measured and converted to a pH value by the meter.

Electrodes

Most pH measurement systems feature standard pH electrodes with glass bulbs made from pH-sensitive glass, yet there is a wide variety of configurations to handle specialized applications.

Buffers

All pH meters require calibration standards to ensure that the readings are traceable to a standard. Always choose a pH 7 buffer plus at least one other pH value close to your expected measurement range. Using solutions of known pH value allow you to adjust the system to read accurate measurements. Calibration should be performed before each reading or each set of readings.

Choosing a pH meter

There are four main considerations to keep in mind when selecting a pH meter that would be well suited for use in monitoring production of acidified foods:

Resolution and accuracy of the meter

The cost of pH meters may range from $50 to $1,000 or more. A major factor in determining cost is the accuracy and resolution of the meter. Smaller numbers indicate better resolution and accuracy. The cheapest meters typically feature a resolution of 0.1 pH units. Federal agencies typically require that pH readings be reported to the nearest tenth (0.1) unit. Most units therefore technically offer sufficient resolution to meet government standards. However, it is important to also consider the accuracy range of the meter. Some of the least expensive meters may have an accuracy of plus or minus 0.2 units. In other words, if the meter reads 4.3, the actual pH of the product could be anywhere from 4.1 to 4.5. This might present a problem if the pH of your product approaches the legal limit of 4.6. It is generally advisable to invest in a pH meter/electrode combination that offers resolution and accuracy of 0.1 pH units or better.

Detachable or all in one probe

Meters may come either with detachable, replaceable probes or they may be an all in one unit with an integral probe. Both types may work equally well. The units with detachable probes typically cost a bit more. The all-in-one units are more convenient and may require less maintenance. The important consideration is that all pH probes have a finite lifespan. The useful life of a probe is strongly influenced by the use, or abuse, it receives. But even in the best case, one may expect a probe to have a useful lifespan of about one to three years. Units with a detachable probe allow a user to replace only the probe as needed. All in one type units will need to be completely replaced.

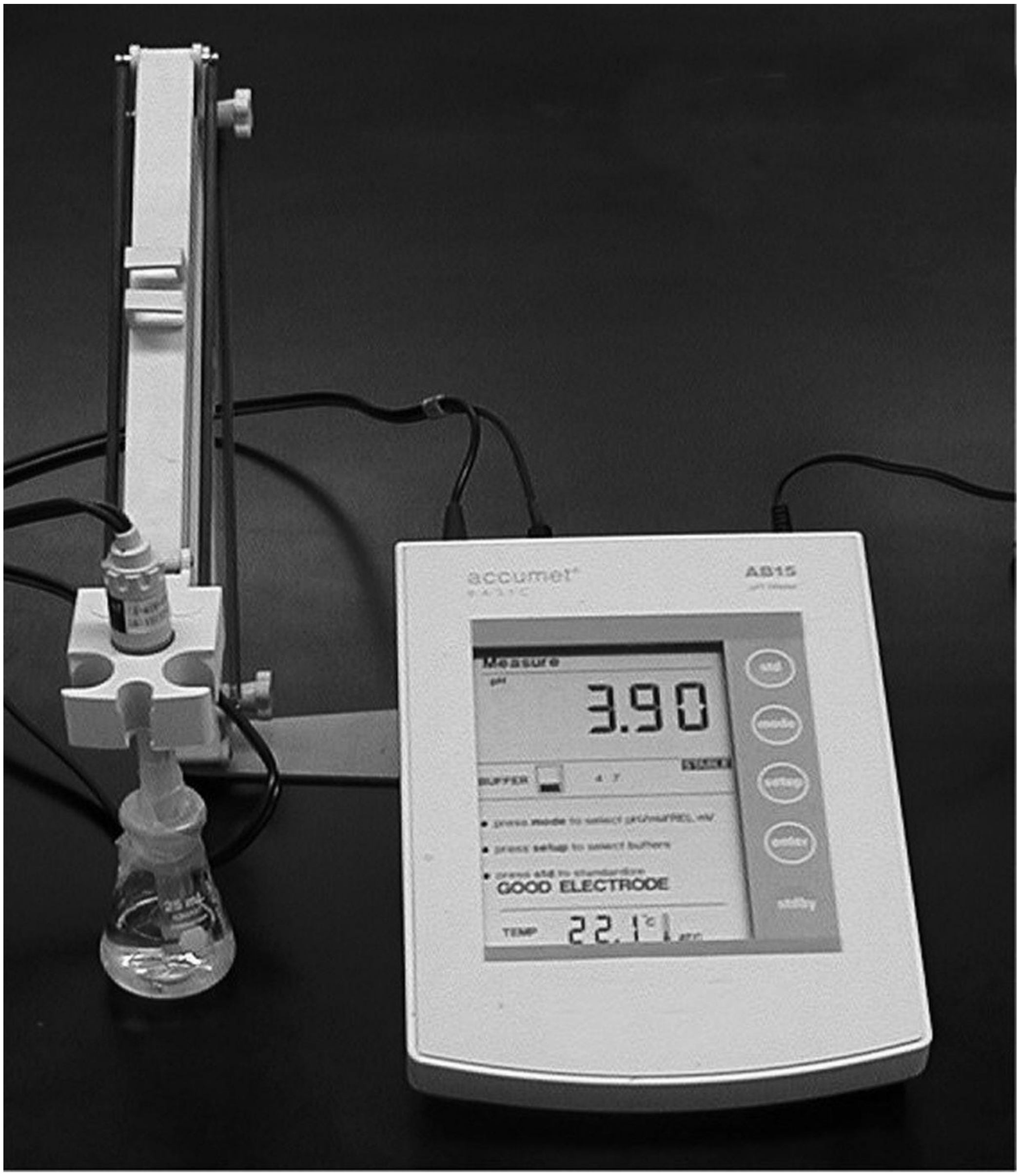


Fig: 5 - Typical pH meter with detachable probe.

Electrode type

Meters with detachable probes typically offer a choice of pH sensing units, called electrodes. Most probes feature a glass bulb type electrode located at the tip of the probe. These may be sealed or refillable. Sealed electrodes require less maintenance and are easier to set up and use. Refillable types may have a longer life since their design allows them to be cleaned and "rejuvenated" when performance begins to suffer. Other electrode specifications, such as reference type and junction type, are typically not important in food testing. It is always important, however, to be sure that the electrode type matches the meter with which it is to be used. Always consult the meter documentation when choosing a new probe. New meters are now available with probes featuring solid state electrodes. These systems offer the advantage of being easily cleanable and requiring very little liquid to sense pH. This makes them especially suitable for oily or semi-solid food testing. Currently, however, these probes are much more expensive than a comparable probe with a glass bulb electrode. They may also be sensitive to static charges and electromagnetic fields such as those generated by magnetic stirring units. Solid-state electrodes may also have a relatively small sensing pore that can easily be obstructed by small particles in the food.

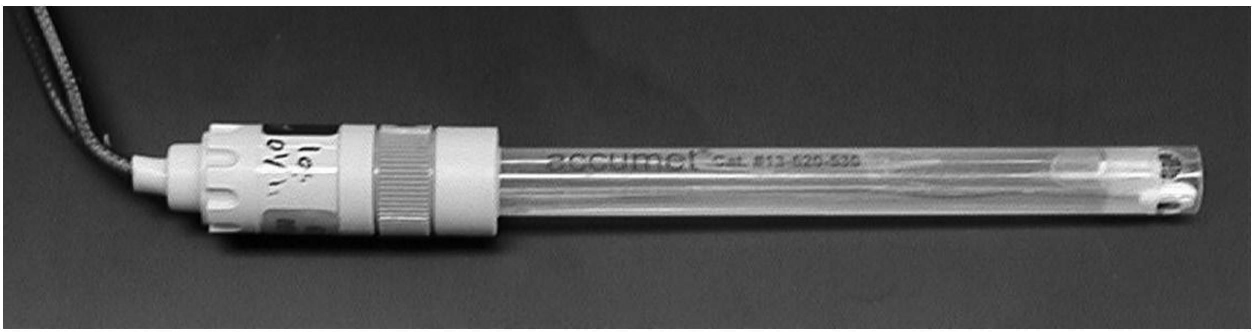


Fig: 6 - Typical pH Meter Probe.

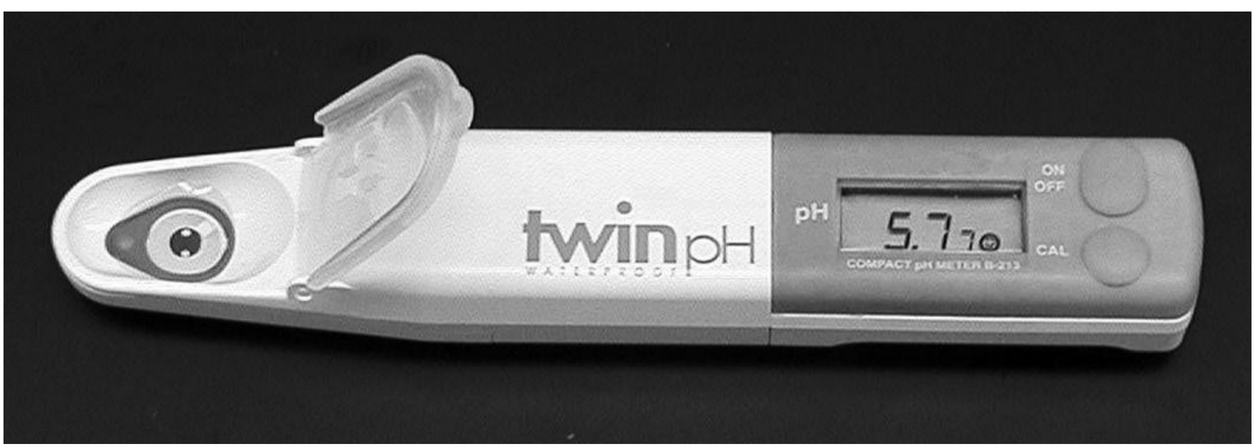


Fig: 7 - Typical all-in-one pH meter.

Auto calibration and temperature compensation

Many pH meters now come with automatic sample temperature compensation and/or automatic calibration buffer sensing. These are conveniences that make it easier to calibrate the meter and to test the pH of samples. Users of meters without these features will need to manually adjust the meter either during calibration, sample measurement or both.

Using a pH meter to test food samples

Calibrating the pH meter

A properly calibrated meter is essential to obtain accurate pH readings. The pH meter MUST be calibrated at least daily, or once per shift, if multiple production shifts are scheduled. It is important to follow the manufacturer's instructions for proper calibrations; exact procedures will vary. A typical calibration procedure will involve the use of standardized buffer solutions, often pH 4 and pH 7 buffers. It is important to use freshly dispensed buffer for calibration. The pH of buffer solutions exposed to air will eventually change due to evaporation and absorption of carbon dioxide from the air.

It is essential to note that calibration will likely involve drying the probe between sample readings. This is usually done by blotting the probe dry with lint-free tissue paper. It is important not to rub the probe with the tissue since this may physically damage the delicate membrane of the probe and/or generate a static charge that can damage the probe or interfere with accurate pH measurements. After calibration, the accuracy of the meter is checked by testing the pH of a standard buffer solution, such as a pH 4 buffer. If the probe is very slow to respond or refuses to calibrate properly, it may need to be cleaned.

Preparing food samples for pH testing

It is important to note that food samples should be at a constant temperature, preferably room temperature, when tested for pH. Recommendations for specific types of food follow.

1. Homogeneous foods:

If a food is homogeneous, that is of uniform consistency, then the pH of any portion may be considered to be representative of the whole. This is typically true of food products that are wholly liquid or contain only very small particles. Examples of this type of food include most barbecue sauces and salad dressings. No special preparation is required for this type of food unless the samples are oily.

2. <u>Liquid and solid food mixtures:</u>

Many food products, such as chunky salsas and pickled vegetables, consist of a mixture of solid particles in a liquid brine or syrup. In these foods, the solid portion may differ in acidity from the covering liquid. Therefore, it is necessary to test both components. It is also important to know the overall pH of the uniformly mixed ingredients. This is termed the "equilibrium pH." Following are the recommended procedures for preparing these foods for testing:

•The liquid and solid components are separated by draining the contents of the container for two minutes on a screen or sieve. Regulations specify a U.S. standard No. 8 sieve (available from scientific supply companies), inclined at a 17 to 20 degree angle. Each portion is saved separately and the weight of both the liquids and the solids are recorded if these will be used in determining the equilibrium pH.

•The pH of the liquid portion is determined. If the liquid is very oily, the point below is followed.

•The drained solids are rinsed with deionized or distilled water to remove any remaining covering liquid. The solids are blended to a uniform paste and the pH measured. If additional liquid is required to blend the samples, up to 20 parts deionized or distilled water may be added per 100 parts food sample.

• To determine the "Equilibrium pH" of the food, either both fractions of both solid and liquid portions are blended in the same ratio as found in the original container, or the entire contents of the container are blended to a uniform paste, and then the pH is tested.

3. <u>Semi-solid foods:</u>

Examples of semi-solid foods include puddings and very thick sauces. These foods should be blended to a uniform paste before testing. If additional liquid is required to blend the samples, up to 20 parts deionized or distilled water may be added per 100 parts food sample. Following blending, the pH should be measured.

4. <u>Oily foods:</u>

Oil and/or grease in a food can coat and seal the membrane of the pH electrode and interfere with proper pH measurement. If possible, any oil layer present in the food should be removed before pH testing. The oil is allowed to rise to the surface, and then removed by skimming or pouring. If the oil cannot be easily separated, freezing and thawing the samples may break an emulsion and allow the oil to separate. Cooling the samples in a refrigerator may solidify the separated oil and facilitate oil removal. The samples should be allowed to return to room temperature before testing the pH.

Our objective

- To create an economical pH meter which can provide an accurate measurement of pH in liquids and aqueous solutions, even in food items.
- To ensure the proper quality of liquids using this pH meter on a small-scale basis, for use in mostly labs and research facilities.

Accessories used

- Project Board (with DC power supply)
- Amplifier (TL072CN)
- Resistors, Capacitors and Wires
- RF Transmitter-Receiver Pair
- BNCPTH connector

- Arduino Uno

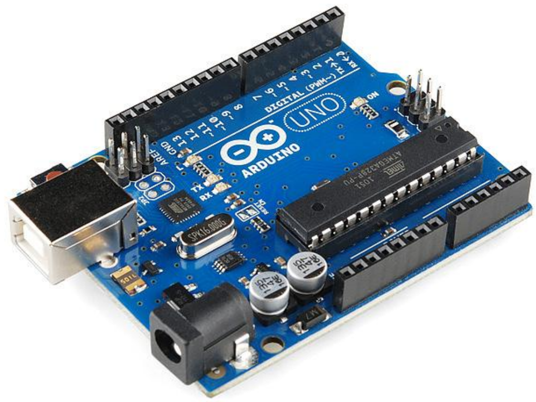


Fig: 8 – Arduino Uno.

- pH Electrode Probe

Fig: 9 - pH Electrode Probe.

pH Electrode Probe working principle:

A pH probe is a very simple single cell battery with a very high resistance, where the voltage produced is proportional to the hydrogen ion concentration around the probe and therefore proportional to the Log of the hydrogen ion concentration as expressed here:

$$pH = -log10(ah)$$

All this really means is when the concentration is greater on either side of the probe, the ion flow will induce a slight voltage between the probes electrodes, this voltage can swing both (+/-) which will indicate either an acid or base.

A pH probe's construction consists of 2 electrodes, one in a solution of KCL and the other in a low concentration in HCL. The center "sensing" electrode (anode) is surrounded by a special glass bulb that allows (Na+) ions to pass, the other electrode (cathode) is sealed off from the "sensing" electrode and is considered a reference.

This is then connected by a porous ceramic plug (or quartz fiber) that forms a salt bridge with the test solution. This bridge is what forms a galvanic cell, and creates the simple single cell battery we can think of in a circuit.

The potential between the electrodes then tells us the concentration of the test solution and which side of the probe the concentration is on.

For each pH step we see a tenfold concentration change, for example a pH of 8 has 1/10th the ion activity as a pH of 7.

Circuit Diagram of the pH meter

We build the circuit diagram by using pspice (capture CIS) software.

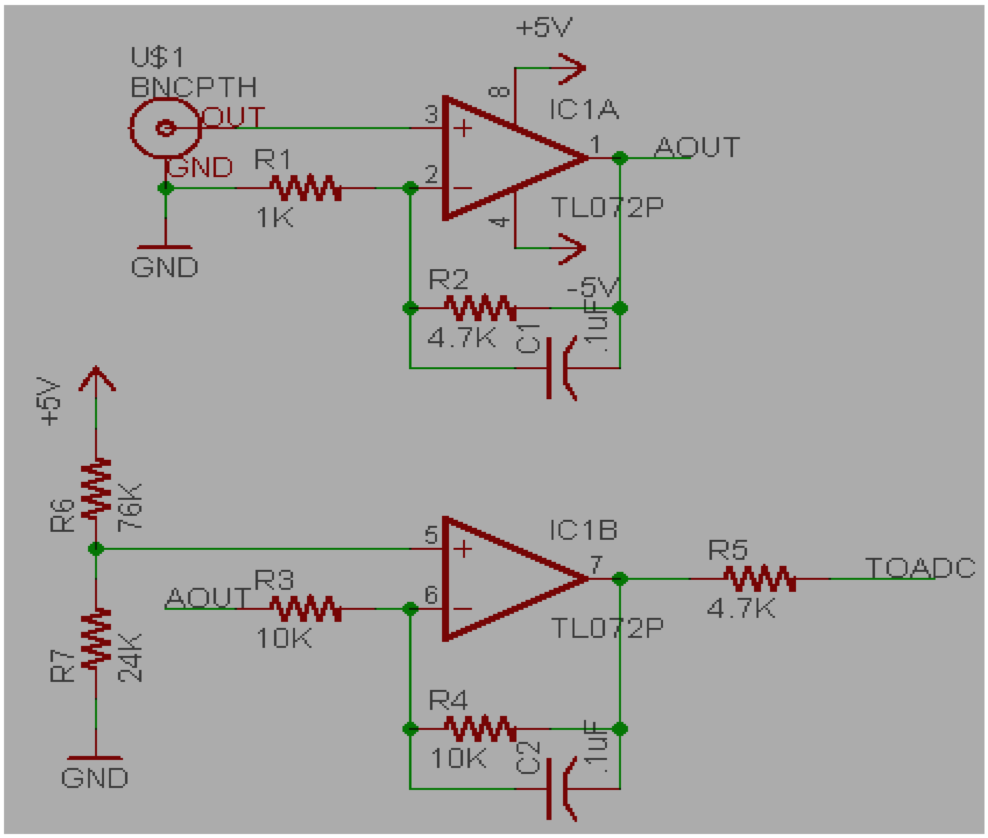


Fig: 10 – Circuit Diagram of the pH meter.

Details of the construction of the pH meter

- After completion of the circuit in Fig: 10, the input to the circuit is drawn from the pH Electrode probe, as shown below:

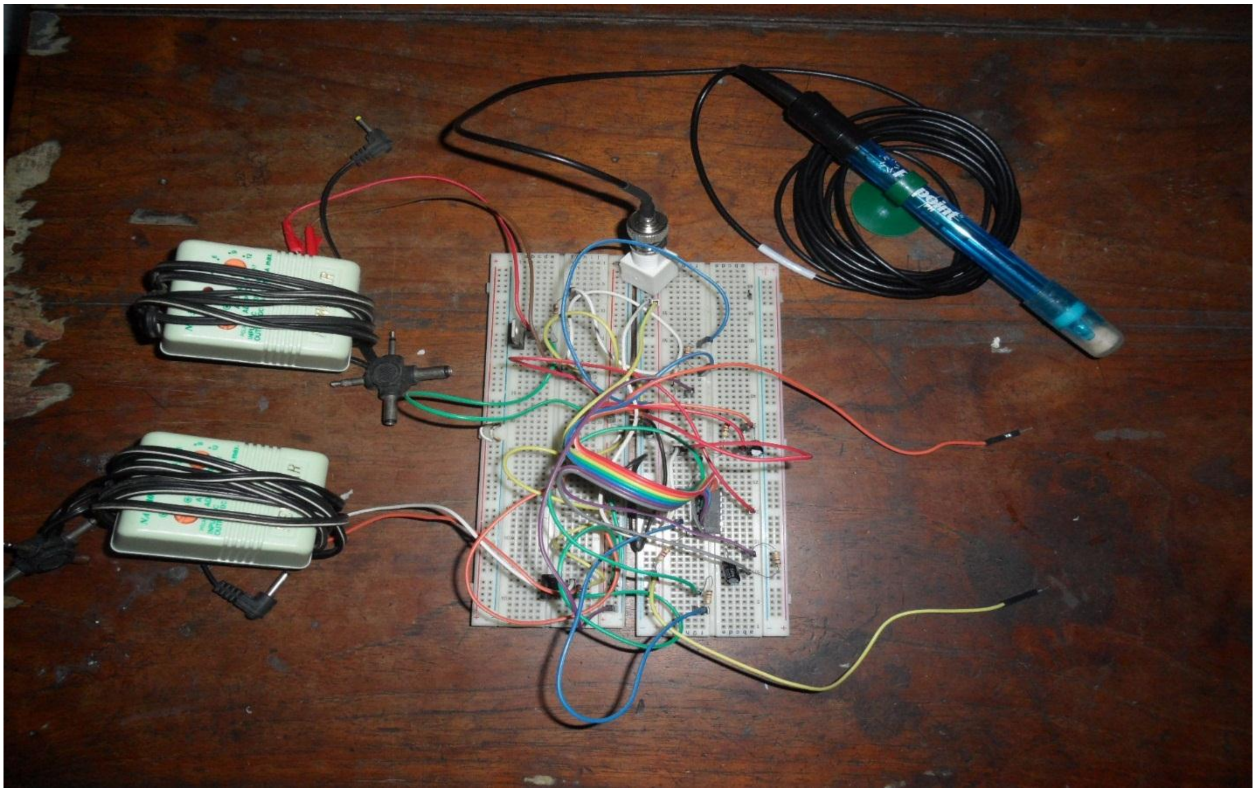


Fig: 11 – Construction of the pH meter.

- The output is transmitted from the transmitting end to the receiving end via the RF Transmitter-Receiver pair.
- The received output is passed through a resistor on its way to the Analog input of the Arduino Uno device.
- Encoded Codes in the Atmel microcontroller calibrate the voltage obtained accordingly to provide the pH value.
- The pH value is then displayed on a connected computer/tablet.

Flowchart for calculations

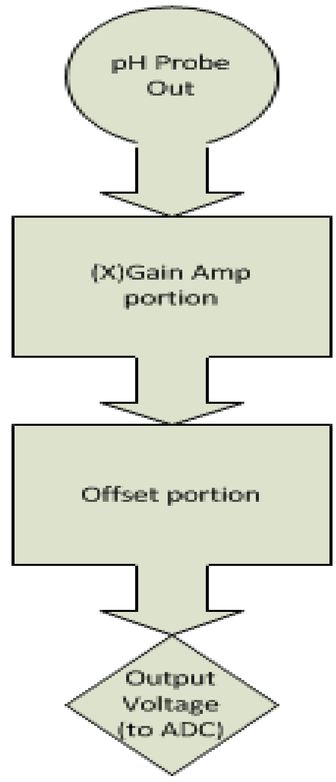
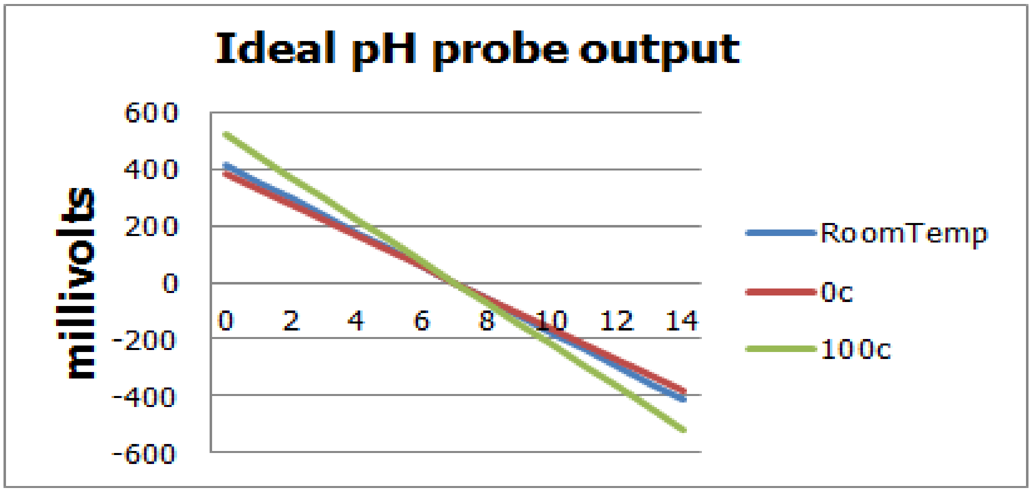


Fig: 12 – Flowchart for Calculations.

Details of Calculations

- Initially we take the input pulse from the probe, which is immersed in the food item.
- That value taken from the probe is then multiplied with the amplifier gain, as the pulse from the probe passes through the amplifier.
- The amplified value is then carried on the offset voltage, to give us an output voltage value.
- The output value that we obtained is in the analog form. However, to display it on a screen/LED display, we need to convert it to it digital form. This is done by the help of an ADC (Analog-to-Digital Converter)

Output of the pH Probe



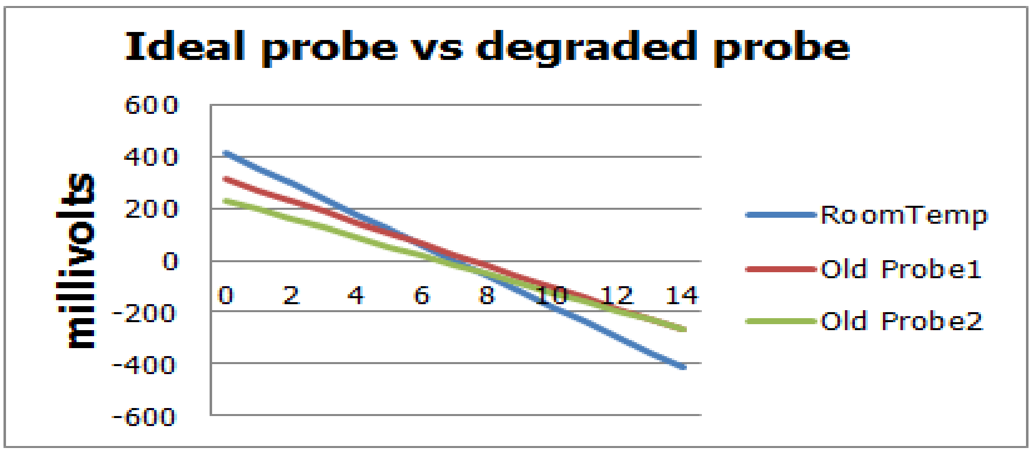


Fig: 13 – Output of the pH probe (ideal & degraded)

As the above graphs show, as probes age they tend to offset a tiny bit in either direction and also weaken their output potential. Luckily both of these can be compensated for either in software, or by adding gain and offset control in the circuit.

- With pH>7, the voltage is in the negative mV range.
- With pH<7, the voltage is in the positive mV range.

Circuit diagram for pH probe output:

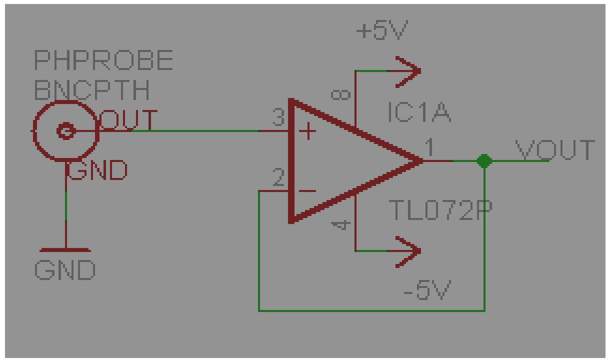


Fig: 14 – Circuit Diagram for the pH probe output.

Actual pH Probe output:

By implementing the above circuit diagram (Fig:14) we got actual pH probe output for both water and pepsi.

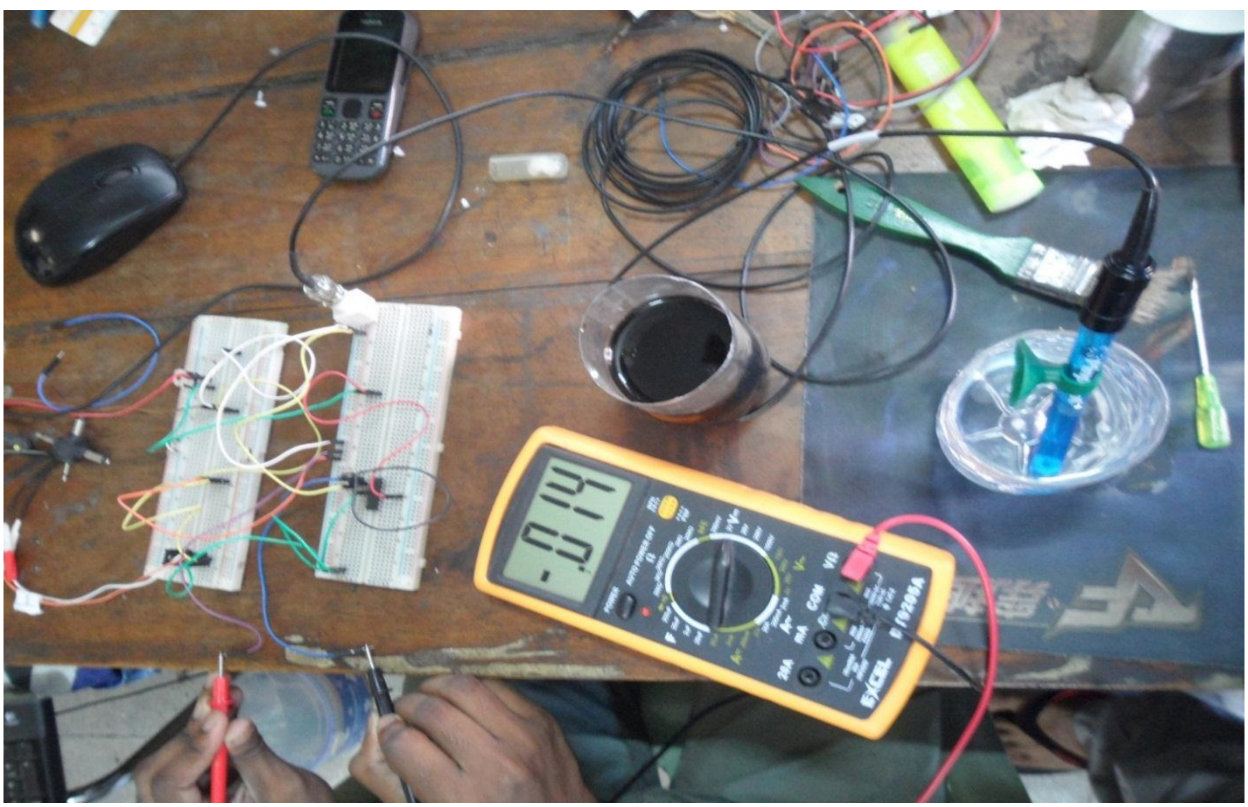


Fig: 15 – Actual pH Probe output (for water).

The input to the pH probe is -0.014mV for water.

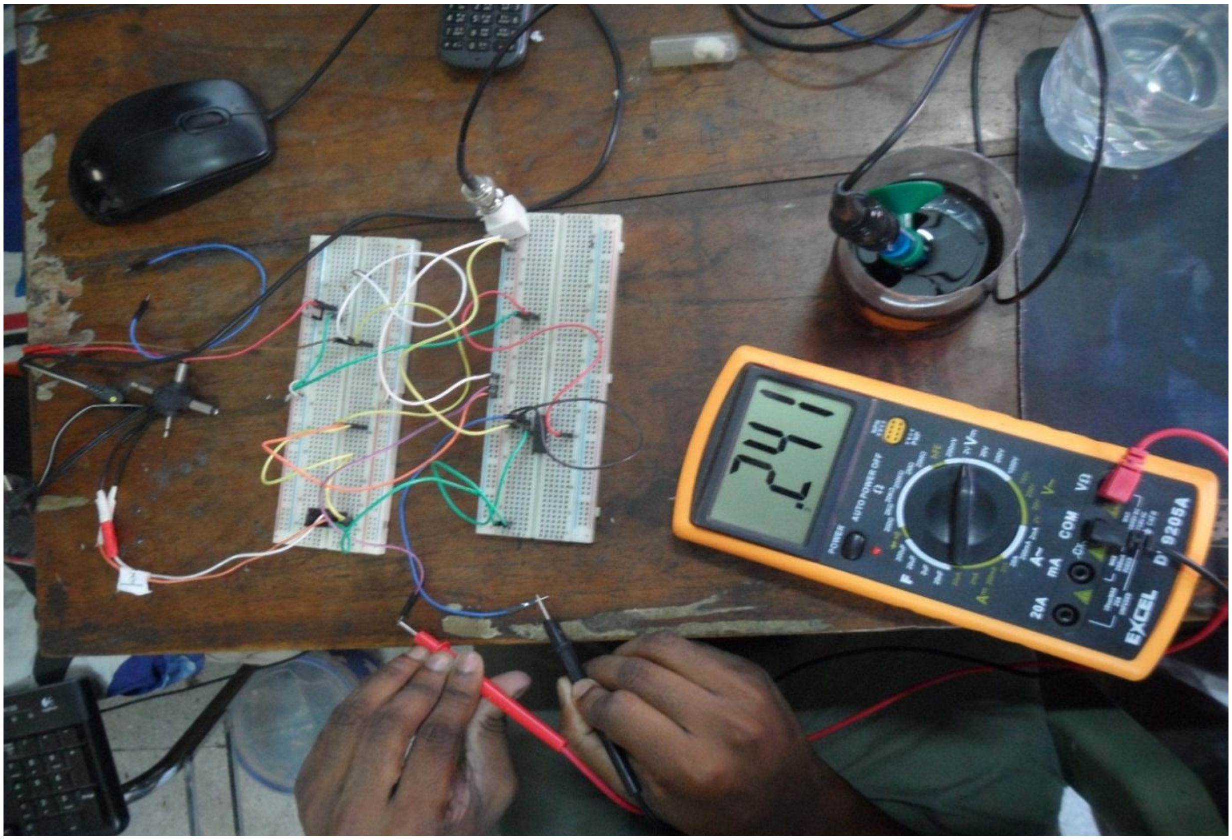


Fig: 16 – Actual pH Probe output (for pepsi).

The input to the pH prove is 0.241mV for Pepsi.

We get a probe output of -0.014v at 7pH (water) and 0.241v at 3pH (pepsi). So, we get -

(7pH-3pH)/4
={0.241-(-0.014)}/4
= 0.255v/4
=63.75mV/pHunit

Which is different from ideal step of 59mV/pHunit. This gives us a useful baseline to compare our circuits while negating most of the error associated with different probes aging rates etc.

So, pH probe output voltage = +/- (7∗0.063) = +/- 0.435 v

Calculation of offset voltage

From the Fig: 10 we get-

X=R2/R1;

Where we use R1=1.18KΩ and R2=4.6KΩ

As X=3.89 and output range for the offset voltage should be 0-5 volt.

Due to simplified non inverting op-amp gain formula –

$$V_{in} = (1+X) * V_{out}$$

Where V_{out} = pH probe output voltage = +/- .435 v

$$V_{in} = (4.89 * .435) \text{ v}$$
$$= 2.13 \text{ v}$$

Again -

$$V_{aout} = V_{in} + V_{offset}$$
$$V_{bout} = - V_{in} + V_{offset}$$

Where V_{aout} offset range of acid side and V_{bout} is the offset range for base side.

In case of acid side:

$$V_{offset} = V_{aout} - V_{in}$$
$$V_{offset} = (5 – 2.13)\ v$$
$$V_{offset} = 2.87\ v$$

In case of base side:

$$V_{offset} = V_{bout} + V_{in}$$
$$V_{offset} = \{0 – (-2.13)\}\ v$$
$$V_{offset} = 2.13\ v$$

V_{offset} should be greater than base voltage and lower than acid voltage.

As 2.87 v (of acid side) > V_{offset} > 2.13 v (of base side)

So, we can take **V_{offset} = <u>2.5 v</u>**

Now-

$$V_{low} = V_{bout} + V_{offset}$$
$$V_{low} = (-2.13 + 2.5)\ v$$
$$V_{low} = 0.37\ v$$

$$V_{high} = V_{aout} + V_{offset}$$
$$V_{high} = (2.13 + 2.5)\ v$$
$$V_{high} = 4.63\ v$$

Finally, Voltage change per pH **= <u>.304 v</u>**

From above calculation and theory we construct a pH table.

Theoretical pH table

pH Scale	Corresponding Voltage value (v)		pH Scale	Corresponding Voltage value (v)
0	0.37		8	2.802
1	0.674		9	3.106
2	0.978		10	3.41
3	1.282		11	3.714
4	1.586		12	4.018
5	1.89		13	4.322
6	2.194		14	4.626
7	2.498			

Fig: 17 – Theoretical pH table.

Experimentally Obtained Results

For Water:

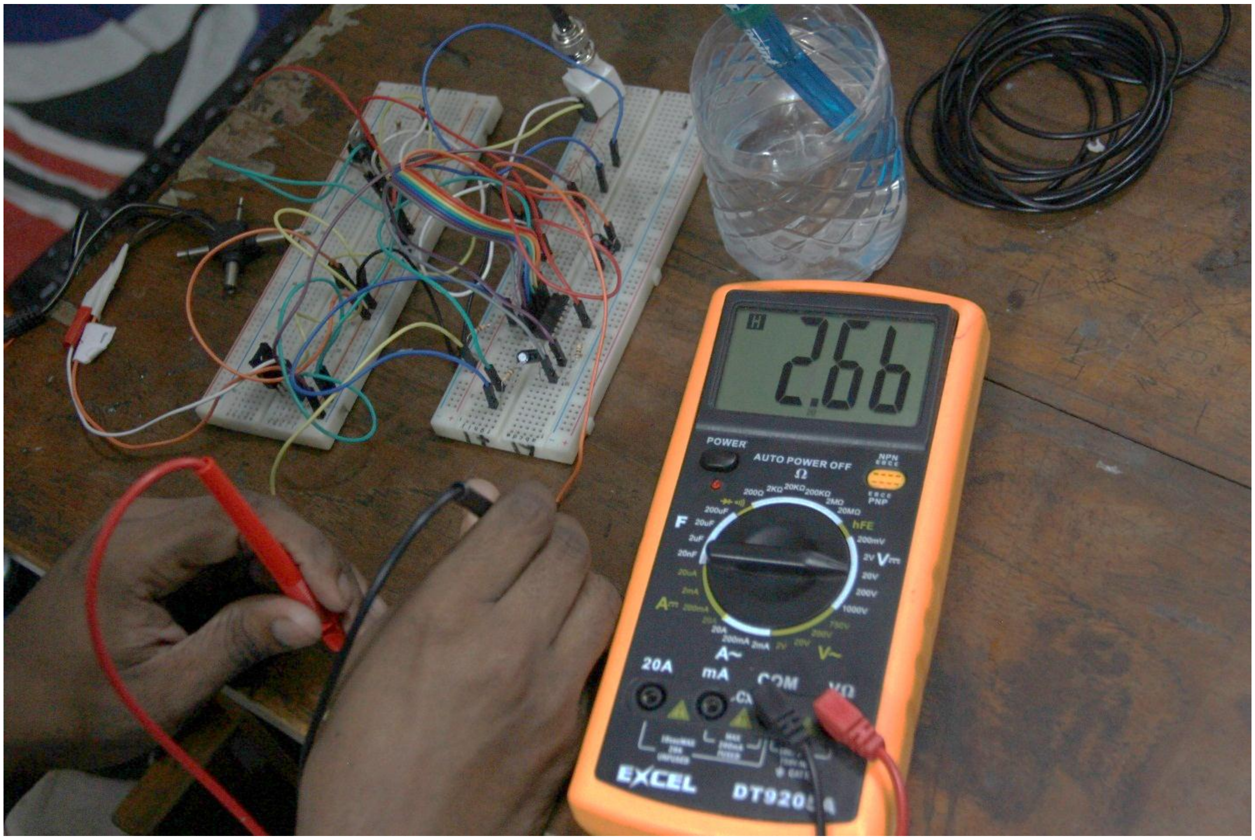
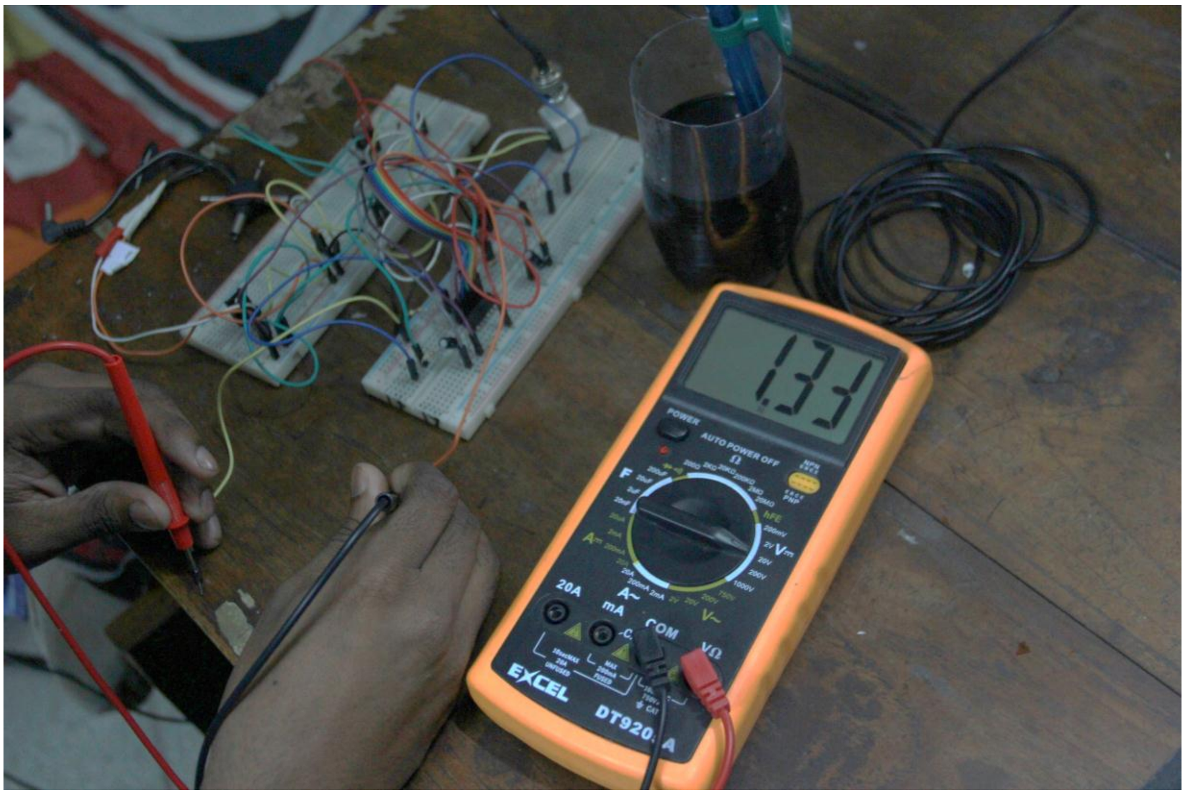


Fig: 18: Experimental output results (for water).

Water has a pH value of 7, which should theoretically, give rise to 2.498V, but experimentally we get a pH value of 2.66.

<u>Experimentally Obtained Results</u>

For Pepsi:



<u>Fig: 19 – Experimental output results (for Pepsi).</u>

Pepsi has a pH value of 3, which should theoretically, give rise to 1.282V, however we get 1.33V experimentally.

Economical Comparison

Fig: 20 – Economical Comparison.

- The pH circuits available in the market costs around $28-30.
- Shipping cost also added, which is different for different areas.
- The pH circuit that we built costs around $8-12 only.

Advantages to analog pH meters

- An analog pH meter has to use a separate voltmeter.
- Analog pH meters have greater losses and lower efficiencies.
- These meters make use of the Nernst Equation, which our pH meter does not require.

- Our pH meter is quite portable.
- Our pH meter is faster in response time.
- Besides being cheaper, it would also ensure a very high degree of correctness.

Correctness is measured in terms of percentage error. Lower is the % error, higher is the correctness.

% Error = **(Difference between the values/Theoretical value) * 100%**

For example, the percentage error of our device, in case of Pepsi:

% Error = ((1.33-1.282)/1.282) * 100%
% Error = **3.74%**

This shows our device has a **high degree of correctness.**

PCB Design of the circuit

PCB is designed by using pad2pad software.

For single layer:

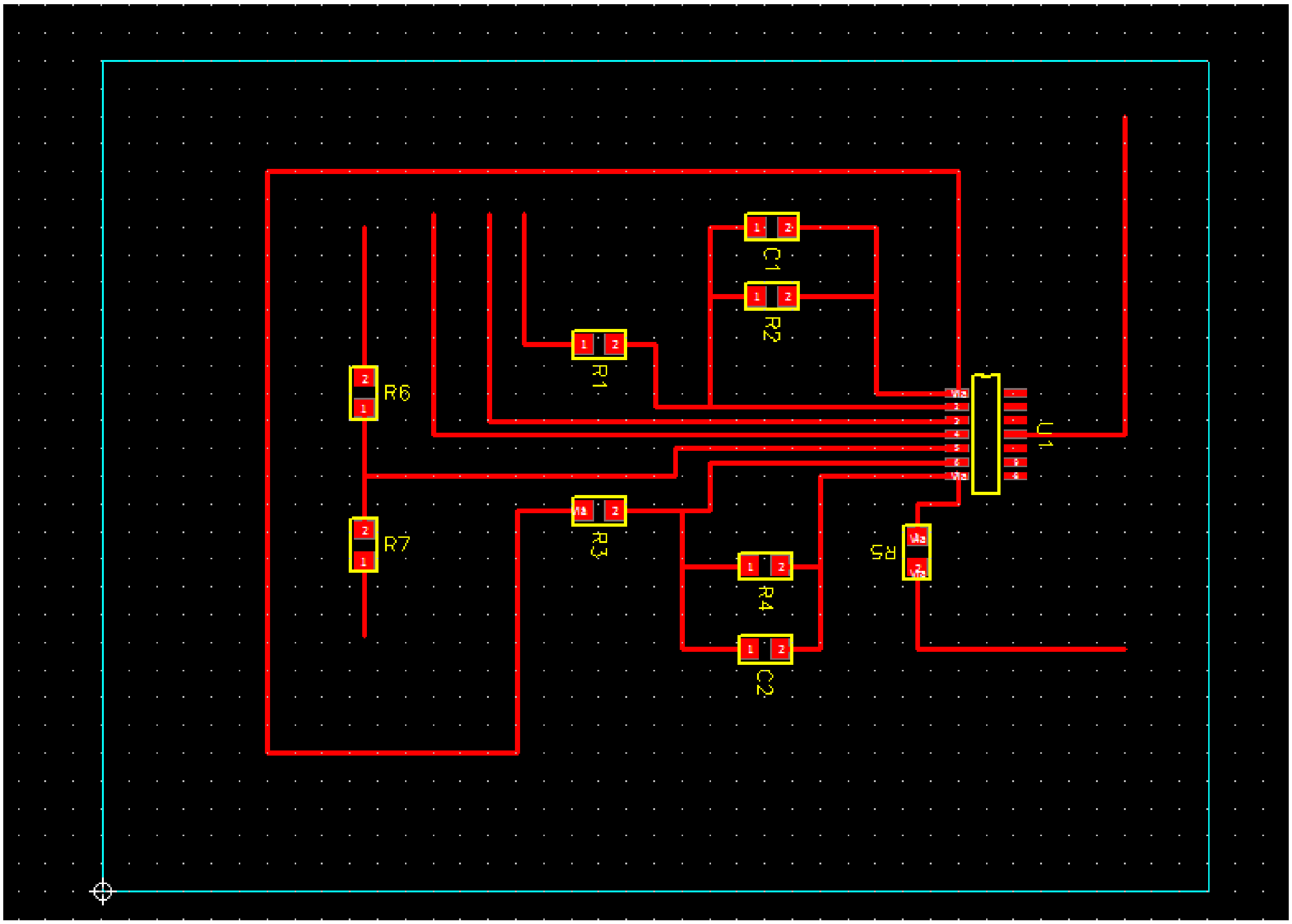


Fig: 21 – PCB design for single layer.

For multiple layer:

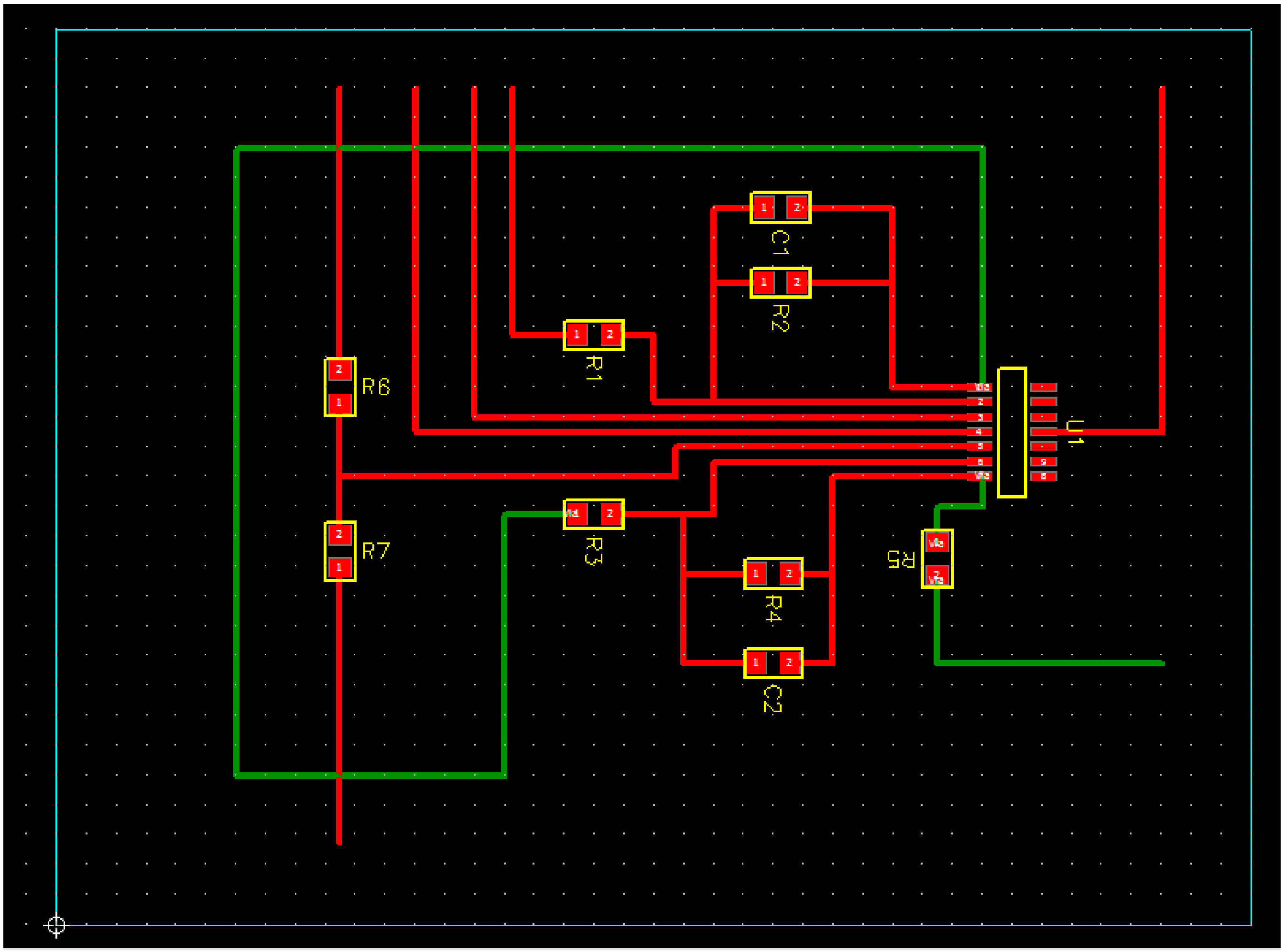


Fig: 22 – PCB design for multi-layer.

CONCLUSION

Reasons to go for our device

- It is quite portable and easy-to-use.
- The price of the device is much lower than the pH devices found in the stores.
- It is able to provide very accurate readings at a lower price.
- With the help of a pH sheet, the experimental and measured pH values can be compared, and a decision can be made about the food.

Hindrance to progress of our work

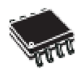
- We experienced problems with a faulty sensor.
- Due to the unavailability of the sensor in Bangladesh, it has to be ordered from abroad every time an error occurs.
- The faulty sensor contributed to even greater errors after the wireless transmission segment was added.
- We contacted the ICDDR,B and were unable to find a circuit design from them for the formalin detection mechanism.
- That particular circuit, by itself, was deemed way too expensive, costing around 150,000 BDT, and so could not be acquired.
- No reasonable designs for the formalin detection mechanism were found anywhere on the Internet.

Plans for the future

- The design which we have now is a prototype.
- Use of a new sensor electrode to correct the errors faced while taking the readings.
- Addition of the Wireless Transmission segment to facilitate easy transmission of the reading in a super-shop, departmental stores, etc.
- Making necessary improvements to get the most precise of readings.
- Making necessary adjustments to test the pH for solid foods, as well as liquids.
- Integration of the formalin detection mechanism, whenever it becomes available and economically feasible.

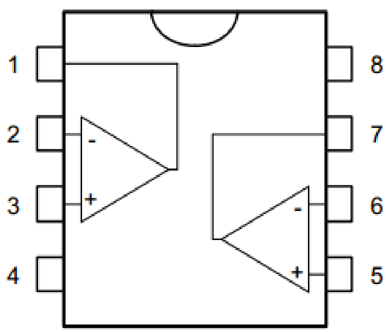
APPENDIX A

TL072CN



D
SO8

Pin connections (top view)



1 - Output 1
2 - Inverting input 1
3 - Non-inverting input 1
4 - V_{CC}^{-}
5 - Non-inverting input 2
6 -Inverting input 2
7 - Output 2
8 - V_{CC}^{+}

Features

- Wide common-mode (up to V_{CC}^{+}) and differential voltage range
- Low input bias and offset current
- Low noise e_n = 15 nV/√Hz (typ)
- Output short-circuit protection
- High input impedance JFET input stage
- Low harmonic distortion: 0.01 % (typical)
- Internal frequency compensation
- Latch-up free operation
- High slew rate: 16 V/µs (typ)

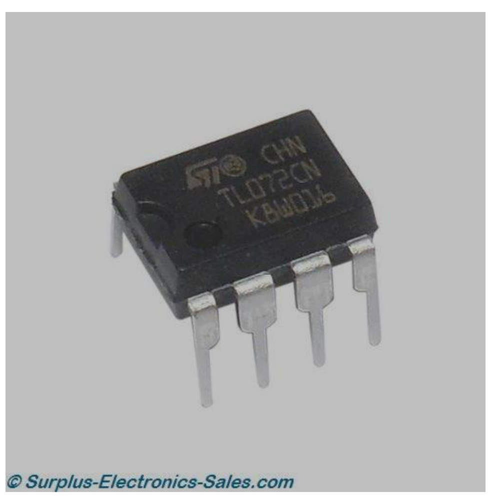
Related products

- See TL071 for single op amp version
- See TL074 for quad op amp version

Description

The TL072, TL072A, and TL072B are high speed JFET input dual operational amplifiers incorporating well-matched, high-voltage JFET and bipolar transistors in a monolithic integrated circuit.

The devices feature high slew rates, low input bias and offset current, and low offset voltage temperature coefficients.



1. All voltage values, except differential voltage, are with respect to the zero reference level (ground) of the supply voltages where the zero reference level is the midpoint between VCC+ and VCC.

2. Differential voltages are at the non-inverting input terminal with respect to the inverting input terminal.

3. The magnitude of the input voltage must never exceed the magnitude of the supply voltage or 15 volts, whichever is less.

4. The output may be shorted to ground or to either supply. Temperature and /or supply voltages must be limited to ensure that the dissipation rating is not exceeded.

ELECTRICAL CHARACTERISTICS

VCC = ±15V, Tamb = 25oC (unless otherwise specified) Symbol Vio Parameter Input Offset Voltage 50) o Tamb 25 C Tmin. Tamb Tmax. DV io Iio Input Offset Voltage Drift Input Offset Current * Tamb = 25oC Tmin. Tamb Tmax. Input Bias Current * o Tamb 25 C Tmin. Tamb Tmax. Large Signal Voltage Gain (RL = ±10V) Tamb = 25oC Tmin. Tamb Tmax. Supply Voltage Rejection Ratio = 50) Tamb = 25oC Tmin. Tamb Tmax. Supply Current, per Amp, no Load Tamb = 25oC Tmin. Tamb Tmax. Input Common Mode Voltage Range Common Mode Rejection Ratio (RS 50) o Tamb 25 C Tmin. Tamb Tmax. Output Short-circuit Current Tamb = 25oC Tmin. Tamb Tmax. Output Voltage Swing Tamb = 25oC Tmin. Tamb Tmax. SR tr KOV GBP Ri THD TL072BC,BI,BM TL072I,M,AC,AI, AM,BC,BI,BM Min. Typ. 3 1 Max. Min. TL072C Typ. 3 Max. mV µV/ pA nA V/mV mA V V/µs µs MHz nV Hz Degrees dB

Slew Rate (Vin = 100pF, Tamb = 25oC, unity gain) Rise Time (Vin 100pF, o Tamb 25 C, unity gain) Overshoot (Vin = 100pF, Tamb = 25oC, unity gain) Gain Bandwidth Product 100kHz, o Tamb 25 C, Vin = 100pF) Input Resistance Total Harmonic Distortion = 100pF, Tamb = 2VPP) Equivalent Input Noise Voltage = 100) Phase Margin Channel Separation (Av = 100)

* The input bias currents are junction leakage currents which approximately double for every 10oC increase in the junction temperature.

APPENDIX B

nRF905

The nRF905 is a radio transceiver IC similar to the well-known nRF24L01, but operates at 433/898/915MHz instead of 2.4GHz, has a much longer range and a few extra IO pins. However the nRF905 data rate is only 50Kbps compared to nRF24L01's 2Mbps.

This library offers quite a bit of flexibility: Optional use of interrupts, 2 of the connections to the module are optional since their states can also be accessed by the ICs status register, and supports basic collision avoidance.

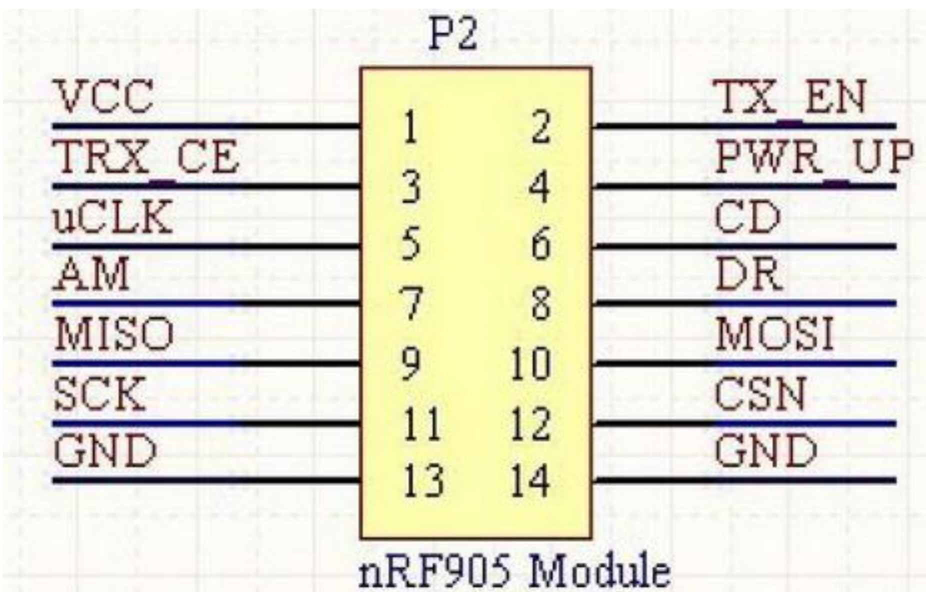
nRF905	ATmega48/88/168/328	Arduino Uno	Description
VCC	3.3V	3.3V	Power (3.3V)
CE	D7 (13)	7	Stand by – High = TX/RX mode, Low = standby
TXE	B1 (15)	9	Transmit or receive mode – High = transmit, Low = receive
PWR	B0 (14)	8	Power up – High = on, Low = off
CD	D2 (4)	2	Carrier detect – High when a signal is detected, for collision avoidance
AM	-	-	Address Match – High when receiving a packet that has the same address as the one set for this device, optional since state is stored in register, not used by this library
DR	D3 (5)	3	Data Ready – High when finished transmitting/High when new data received, optional since state is stored in register, if interrupts are used this pin must be connected
SO	B4 (18)	12	SPI MISO
SI	B3 (17)	11	SPI MOSI
SCK	B5 (19)	13	SPI SCK
CSN	B2 (16)	10	SPI SS
GND	GND	GND	Ground

Some of the module pin names differ from the IC pin names in the datasheet:

Module	IC
CE	TRX_EN
TXE	TX_EN


http://www.aliexpress.com/store/201108
nRF905 V2.0


nRF905


P2
VCC
1
2
TX_EN
TRX_CE
3
4
PWR_UP
uCLK
5
6
CD
AM
7
8
DR
MISO
9
10
MOSI
SCK
11
12
CSN
GND
13
14
GND
nRF905 Module

APPENDIX C

Arduino UNO

An Arduino board consists of an Atmel 8-bit AVR microcontroller with complementary components that facilitate programming and incorporation into other circuits. An important aspect of the Arduino is its standard connectors, which lets users connect the CPU board to a variety of interchangeable add-on modules known as *shields*.

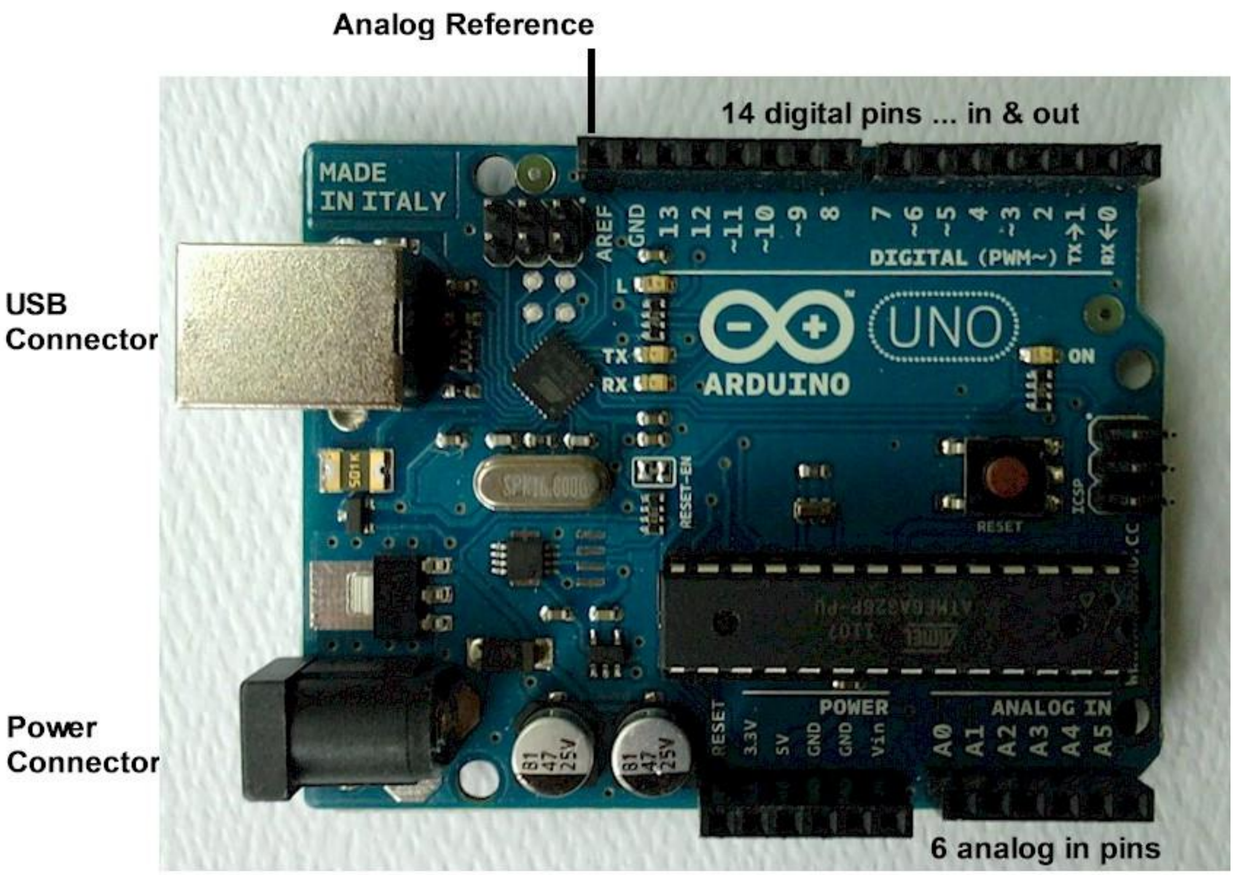
Some shields communicate with the Arduino board directly over various pins, but many shields are individually addressable via an I^2C serial bus—so many shields can be stacked and used in parallel. Official Arduinos have used the megaAVR series of chips, specifically the ATmega8, ATmega168, ATmega328, ATmega1280, and ATmega2560.

A handful of other processors have been used by Arduino compatibles. Most boards include a 5 volt linear regulator and a 16 MHz crystal oscillator (or ceramic resonator in some variants), although some designs such as the Lily Pad run at 8 MHz and dispense with the onboard voltage regulator due to specific form-factor restrictions.

An Arduino's microcontroller is also pre-programmed with a boot loader that simplifies uploading of programs to the on-chip flash memory, compared with other devices that typically need an external programmer. This makes using an Arduino more straightforward by allowing the use of an ordinary computer as the programmer.

At a conceptual level, when using the Arduino software stack, all boards are programmed over an RS-232 serial connection, but the way this is implemented varies by hardware version. Serial Arduino boards contain a level shifter circuit to convert between RS-232-level and TTL-level signals.

Current Arduino boards are programmed via USB, implemented using USB-to-serial adapter chips such as the FTDI FT232. Some variants, such as the Arduino Mini and the unofficial Boarduino, use a detachable USB-to-serial adapter board or cable, Bluetooth or other methods. (When used with traditional microcontroller tools instead of the Arduino IDE, standard AVR ISP programming is used.)



The Arduino board exposes most of the microcontroller's I/O pins for use by other circuits. The Diecimila, Duemilanove, and current Uno provide 14 digital I/O pins, six of which can produce pulse-width modulated signals, and six analog inputs, which can also be used as six digital I/O pins. These pins are on the top of the board, via female 0.10-inch (2.5 mm) headers. Several plug-in application shields are also commercially available. The Arduino Nano, and Arduino-compatible Bare Bones Board and Boarduino boards may provide male header pins on the underside of the board that can plug intosolderless breadboards.

There are many Arduino-compatible and Arduino-derived boards. Some are functionally equivalent to an Arduino and can be used interchangeably. Many enhance the basic Arduino by adding output drivers, often for use in school-level education to simplify the construction of buggies and small robots. Others are electrically equivalent but change the form factor—sometimes retaining compatibility with shields, sometimes not. Some variants use completely different processors, with varying levels of compatibility.

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