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# Design and Development of Microcontroller Based Soil Analyzer

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**Abstract**–Soil management is very important in agriculture and an AVR microcontroller based system to measure and analyze the pH, Conductivity/Salinity and soil VMC with the help sensors is presented in this paper. Soil pH, soil conductivity and soil salinity are the soil properties affecting the soil quality and plant growth. The developed device is designed to measure these soil properties and display the soil quality on LCD as well as on LED panel. Based on the measured data the treatment to the soil and irrigation can be planned. The device is designed using AVR series microcontroller with inbuilt ADC needed for sensor data acquisition and thus reducing the design complexity of the system.

Keywords: VMC, soil conductivity, soil pH, AVR, LCD, irrigation, salinity

## 1. Introduction

The properties or parameters affecting the availability of nutrient to plants in soil, soil life, water stress on plants in absorbing the water from soil, irrigation scheduling, quality of irrigation water to be used for irrigation, irrigation scheduling are:

1. Soil pH.
2. Salinity/Conductivity of soil
3. Moisture content of soil

For effecting use of soil knowledge of soil pH, Conductivity and Volumetric Moisture Content (VMC) is important and plays important role in deciding the treatment for the soil. With the knowledge of these parameters and properly planned treatment tot soil, soil productivity can be increased,

The developed system is developed using 8 – AVR series microcontroller with ISP programming supported and having 10-bit or 8 – bit configurable 8 – channel Analog to Digital Converter (ADC). pH sensor, conducting cell and VMC sensors are used to measure the soil pH, conductivity and soil VMC content. All the sensors are analog sensors and are read by microcontroller through inbuilt ADC. Each sensor output signal is applied to the microcontroller after being processed by the appropriate signal conditioning card. The system is also provided with the 6-LED display for different pH classes of soil and 5-LED display for different conductivity classes. The LED display on the front panel helps in the easy identification of pH class and conductivity class of the soil.

Main Contributions of this paper are as under:

i. The importance of soil pH, soil moisture and soil salinity
ii. The classification of soil in alkaline and acidic soil based on measure soil pH
iii. The classification of soil in various categories of salinity based on measured soil conductivity
iv. The development of the soil analyzer for soil classification based on soil pH, soil moisture content and soil conductivity

## 2. Related Work

[1] discussed that soil pH is important as it regulates the soil properties which effects the storage and supply of nutrient to plants. But the environmental forces such as rain can change the soil pH profile. The paper [] aim to evaluate the global relationship between water and soil water and abrupt change of soil from alkaline to acidic is observed where precipitation exceed the mean annual potential evapotranspiration.

In [2] the classification of nutrients in macronutrients and macronutrients is discussed and presented the macro nutrient analyzer design. The macronutrients analyzer developed measure the NPK in the soil with color sensor and pH of the soil with pH sensor.

[3] has presented that the optimum value for uptake of phosphate, one of the macro plant nutrient, is more consistent at lower pH against the soil phosphate chemistry theory that the optimum value for uptake of phosphate by plant is near neutral value

National Instrument in [4] discusses the basics of pH and measurement. pH measurement involves the determination of hydrogen ion activity in liquid solution. pH is negative log of hydrogen ion activity. pH qualitative measurement is done either by litmus paper or using indicator in solution. For quantitative measurement of pH potentiometer electrode are used.

pH strips, field pH kits i.eRaupach& Tucker method, electronic pH meter and laboratory testing methods for pH measurement are discussed in [5]. Two levels i.e LEVEL 1 and LEVEL 2 of soil H monitoring are also discussed in [5]. LEVEL 1 is used for middle range of pH scale and uses field pH kits. LEVEL 2 monitoring is done using electronic pH meter and is more accurate way of measuring the soil pH

In [6] introduces the technique to measure pH with pH sensor. pH sensor produces electrical potential by measuring the hydrogen ion activity. Operational–Amplifier (op–amp) circuit presented in [6] is used for conditioning the output voltage from pH sensor by connecting inverting terminal to reference voltage and sensor output at non – inverting terminal. The analog circuit presented in [6] addresses both the problems associated with the measurement of pH electrode output with ADC i.e bipolar output and very low level signal.

The pH measurement and data acquisition method in [7]consists of pH sensor, signal conditioning card, Analog to Digital Converter (ADC) and microcontroller. The paper also gives the method for measuringpH sensor’s bipolar output. The system in [7] periodically measures the pH value and stores the values in data logger for future reference.

[9] discussed the information available about the soil from its Electrical Conductivity (EC) measurement. Measurement of soil EC provides the information about the water holding capacity, porosity salinity, and cation exchange capability of soil. Soil EC is determined by the amount of moisture held by soil particles. The measured soil EC gives the information about the soil salinity. EC is proportional to concentration of salts. Higher salt concentration in soil results in high soil EC and higher soil salinity.  [8] discussed the different methods of measuring the soil’s conductivity. Both contact and non contact methods are available for soil EC measurement. Contact type measurement makes the direct contact with the soil for EC measurement while Electromagnetic Induction (EMI) is technique is used in non-contacttype of soil moisture sensors. [9] presented the various factors affecting the soil EC.

In [10] the effect of irrigation water salinity or Total Dissolved Salts (TDS) of water being usedfor irrigation on physical properties of soil is discussed. Excess salt concentration in root region hinders plants from absorbing water from soil and put plants under the water stress.

In [11] discussed the classification of soil in different salinity classes and sources of soluble salts in soil. Soil have salinity problem when there is loss in plant productivity, salt formation on the surface of soil, loss of soil permeability. In [11], soils are categorized soils as saline, slightly saline, moderately saline, very saline and highly saline soils on the basis of its conductivity. Water supply, human diet, detergents, soaps and cleaning agents are the different sources of soluble salts in soil and ads up to the salt concentration of soil.[12] and [13] provides study about the effect of saline irrigation water on soil properties, plant and vegetation growth and management practices.

In [14] the characteristics and performance criteria that need to be considered in selecting a conductivity instrument are discussed. The factors affecting the accuracy of the instrument are temperature compensation, cell constant and accuracy of the system. Format and units of the reported results should be such that they easy to use and any additional information required is also readily available. Environmental factors mainly consist of electrical safety and Ingress Protection (IP) rating. Features assisting the ease of instrument use consist of its ergonomic design and simple, uncomplicated user interface.

The four electrode conductivity sensor presented in [15] has analog front end, multiplexer and voltage to time converter. Excitation voltage to convert the sensor signal into voltage signal is provided by the analog front end and voltage to time converter changes the sensor signal i.e. voltage and the reference signal voltage into period- modulated signal.

In [16] discussed about the care which need to be taken while handling the pH electrode. pH electrode should be carefully handled to avoid damage to the glass membrane. Prior to first measurement, the electrode should be gently shaken down to dislodge any air bubbles which may have settled within the electrode. Before measuring the pH of solution electrode should be calibrated using two buffer solutions. The electrode should be rinsed with a wash bottle of purified water between measurements. Rubbing the electrode with tissue paper should be avoided because this will induce static charges which will result in drift.

Requirement and different components of soil moisture measurement are discussed in[17] and Water Conservation FactSheet [18]. Water is retained in the soil for the use of plants against the gravitational force. By measuring the soil water content irrigation can be properly planned to avoid loss to plants. Soil water available to the plant is termed as Available Water holding Capacity - AWCH of soil which is the soil moisture between the Field Capacity - FC and Permanent Wilting Point - PWP of soil. At FC 100% opf the soil water is available to plant but at PWP plant suffers from water stress. As mentioned in [20] there are various ways of stating the soil moisture content such as moisture content by volume, weight or inches of water per foot. In [17] effective root zone is discussed which is the depth of the root upto which plant absorb the water from soil and moisture control is required.

Various methods and equipment used for soil water management are summarized in [19] and in [20] and are categorized as qualitative and quantitative methods. Gravimetric soil sampling, neutron scatter and di-electric constant are some of the methods used for Quantitative measurement of soil moisture.

In [21] presented that in irrigation scheduling soil, water and plant properties plays vital role. Soil structure greatly affects water and sir movement through the soil which depends on soil permeability. Soil permeability depends upon the size, shape and soil pore continuity. Soil permeability, salinity, texture and texture plays very important role in deciding the schedule of irrigation. It is presented in [21] that highly saline soil needs more frequent irrigation as the available water to plants deceases with increase in soil salinity. Soil moisture tension is the parameter which gives the information about the accessible soil water to the plants, more the soil water tension more strongly the soil will hold the soil moistureand makes ithard for plants to absorb water from soil.In [23] it is presented that the pH level of soil has direct effect on urban tree growth. In the paper performance of 21 sensors for measuring soil pH and moisture is tested with the purpose to identify the best method for soil pH and moisture measurement

## 3. Motivation of the work

Most of the agricultural practices use soil, fertilizers and irrigation water lacking the prior knowledge of their consequence on soil’s physical and chemical properties,life of the soil and on plant growth. This leads to adverse affect on the productivity of soil and the yield quality and quantity of agricultural products. Prior knowledge of soil heath can greatly reduce the losses in agriculture field. With the availability of several electronic sensors due to technical advancements the soil properties can be measure accurately. The developed system measures and analyzes the soil properties with the available electrical sensors. The soil parameterswhich are obtained by using theavailable sensors help in better planning and efficient utilization of soil

 

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resources. With the information obtained from such accurate measurement the farmers can utilize their resources like manures, irrigation water etc efficiently.

## 4. Hardware design of Soil Analyzer

Block diagram of the system is given in Figure 1. To make the hardware development easy and uncomplicated, the whole design procedure is divided into the main modules/ sub-systemseach of the subsystem representing basic element of the complete design. The various modules in which the system is divided are:

- Microcontroller Board
- Power supply unit.
- Sensor Interfacing

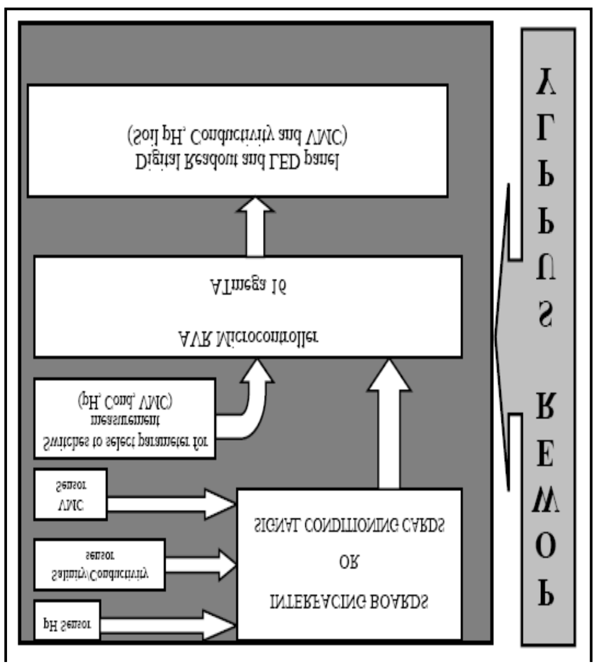


Figure 1 Block diagram

### 4.1. Selection of microcontroller

Microcontroller is a single chip computer and controlled by user written application code. ATmega16 is register based architecture which means that before performing any operation it is necessary to bring the operands in CPU registers. The result is also stored in register. Memoryrelated operations are handled as background operations. The ATmega16 (Figure 2) is low – power 8 – bit microcontroller based on the AVR enhanced RISC architecture. Figure 3 gives the pin configuration of ATmega16

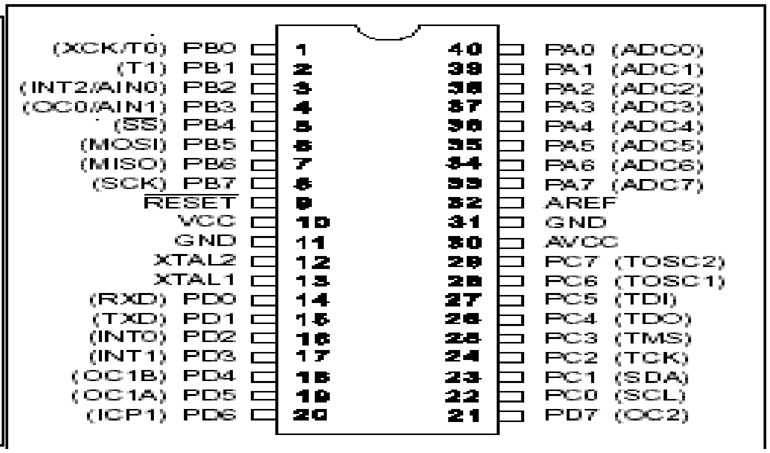


Figure 2 ATmega16 Figure 3 Pin configuration of ATmega16

Microcontroller board consists of 40 pin IC base, 7805 for regulated +5 supply voltage to microcontroller and 4 MHz crystal. Output of voltage regulator IC is connected to pin 10 of ATmega16 and converts the +12V supply voltage from the power supply card to +5V required by the microcontroller. All the input/output ports of microcontroller are extended using male berg strip connector (Figure 4) so that input/output ports of microcontroller can be easily connected to any device using female berg strip connector.

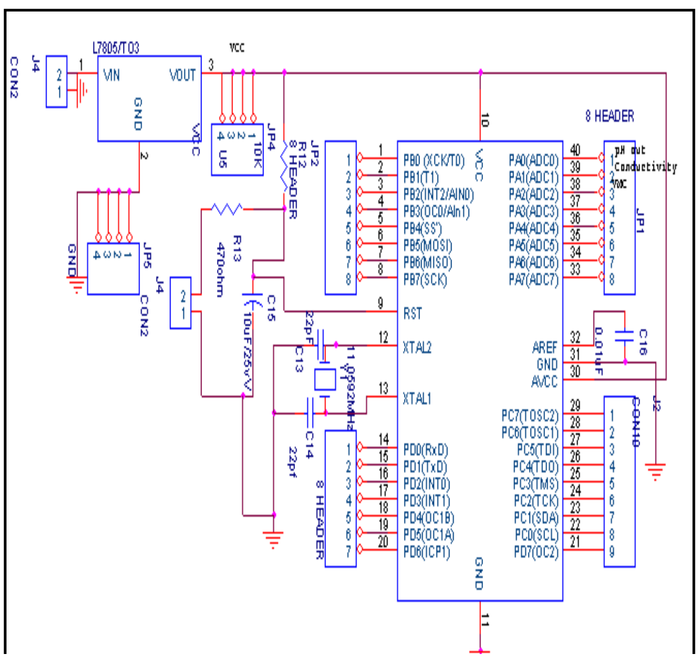

Figure 4 Microcontroller Board Circuit Diagram

### 4.2. Power supply unit

Power supply section of the system provides the required voltage and current to different sections of the system. Power supply is the most important part as proper supply to the electronic component confirms the proper functioning of the electronic components and reduces the risk of

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component damage.Power supply block diagram is provided in figure 5and Figure 6 gives the circuit diagram for the power supply unit.

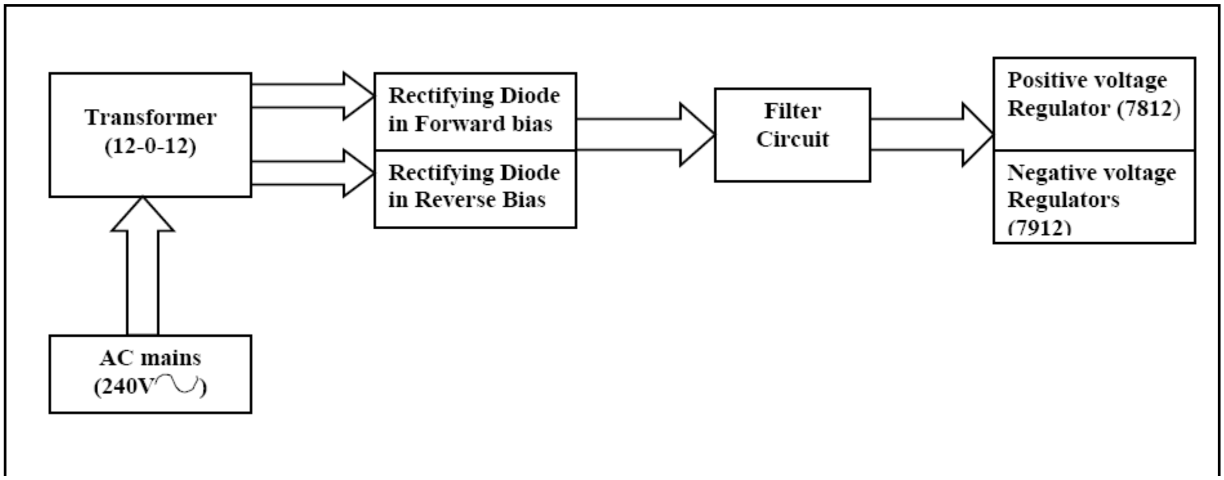


Figure 5Power Supply Block Diagram

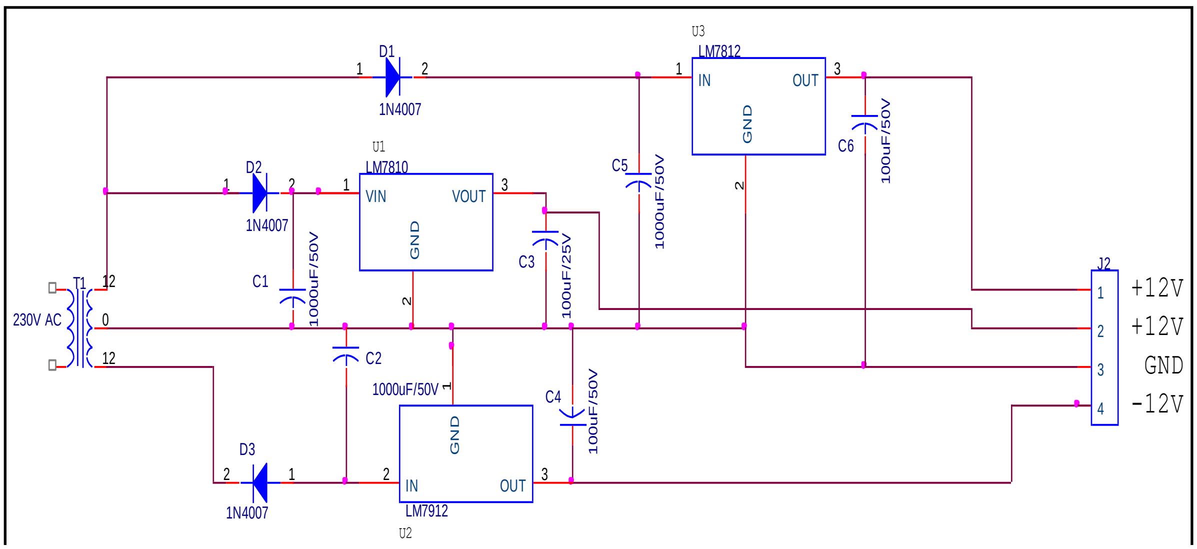


Figure 6 Power supply circuit diagram

## 4.3. Sensor interfacing

The developed soil analyzer consists of soil pH electrode sensor soil conductivity sensor and soil VMC sensor.

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### 5.3.1 pH SENSOR

Pictorial view of pH sensor is given in figure 7 and it main parts are demonstrated in figure 8. glass electrode and reference electrode are the major parts of pH electrode and pH measured as the potential difference between these two electrodes.

Figure 7 pH electrode

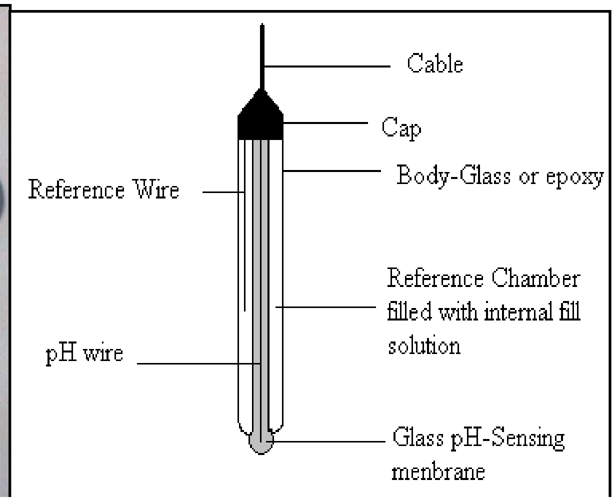


Figure 8 Main parts of pH electrode

The pH electrode being a bipolar sensor thus it has both negative as well as positive output voltage value which is linearly dependent on the pH of the solution under observation. pH sensor output voltage is positive for acids and negative for basic aqueous solutions. For neutral solutions with pH 7.00 the sensor output is 0mV. The sensitivity or the output voltage changing rate of pH sensor to the pH is about 59.16mV/pH. The voltage produced by pH sensor and corresponding pH values are given Figure 9.

**Acids** ← → **Bases** ← →

| **pH** | **0** | **1** | **2** | **3** | **4** | **5** | **6** | **7** | **8** | **9** | **10** | **11** | **12** | **13** | **14** |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **pH electrodevoltage (mV)** | 414.0 | 355.0 | 296.0 | 237.0 | 177.0 | 118.0 | 59.0 | 00.0 | -59.0 | -118.0 | -177.0 | -237.0 | -296.0 | -355.0 | -414.0 |

Figure 9 pH electrode output voltage and pH values

Measuring pH with pH sensor is sensitive to temperature of the aqueous solution under observation and sensitivity of pH electrode increases with the increase in temperature and vice versa. The temperature sensitivity of pH sensor is given by (1) where T is temperature in Kelvin unit.

$$\text{pH electrodesensitivity} = 0.000198 \times T \quad \text{V/pH} \qquad (1)$$

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Temperature from degree Celsius to degree Kelvin unit is converted by (2) where T(K) is temperature in Kelvin and T(C) is temperature in degree Celsius.

$$T(K)=273.13+T(C)\quad(2)$$

Figure 10gives the block diagram for the signal conditioning circuit used with pH sensor. Output of the pH sensor is measured through the impedance matching op–amp circuit. because of the very high source impedance of pH sensor in the range of 10 – 1000 MΩ due to the thin glass bulb at its tip.

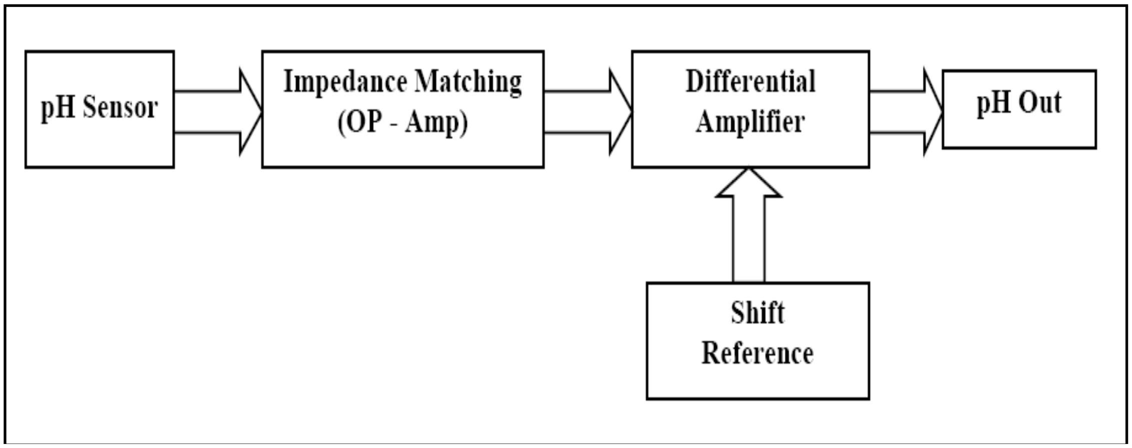


Figure 10 Block Diagram of pH electrode interfacing circuit

The input to the differential amplifier is the signal form sensor through impedance matching circuit and a shift reference voltage to shift the sensor output at the desired level. Shifting of the sensor's output signal is required because ADC can measure only positive signals and pH electrode has bipolar output. Differential amplifier accomplishes the task of converting the negative signal into positive and also provides the required gain.

The analog circuitry is designed keeping in view the two important characteristics of pH sensor i.e very high source impedance of the order of 100 MΩ and bipolar output. TL072 JFET dual op–amp is used for the impedance matching and shifting the reference signal to a level such that the negative output of the sensor becomes positive. Figure 11 shows the circuit diagram for the analog circuit used with pH sensor

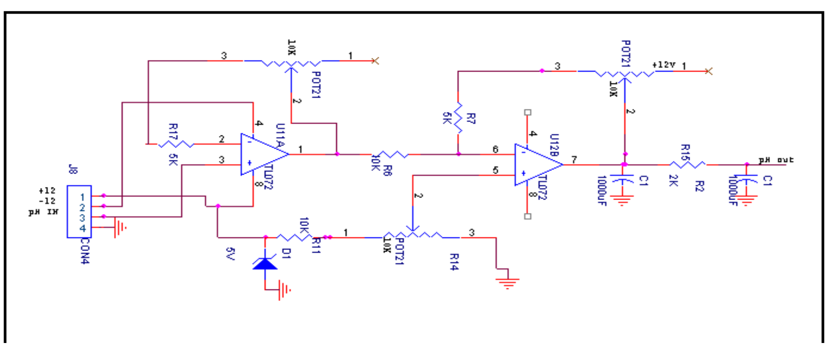

Figure 11 Circuit diagram of pH sensor signal conditioning Card

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### 5.3.2 Conductivity

Conductivity sensor is also called as conductivity cell, shown in figure 12. The conductivity cell is made up of two rectangular electrodes withfixed dimensions placed at a distance of 1 cm. The conductivity cell parameter, cell constant is used for converting conductance as measured by the conductivity cell and is defined in (3)

$$K = d / A \quad (3)$$

K = Cell constant
d = Distance between two electrodes
A = Electrode plate area
Conductivity cell shown in figure 12has cell constant of 01.155. Table 1 shows optimum conductivity ranges for cells of three different cell constants

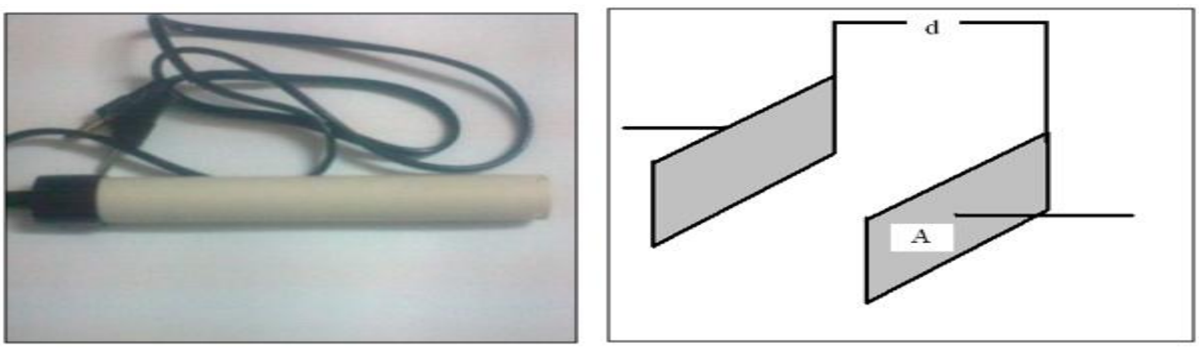


Figure 12 Conductivity Cell (K=1.155)

Table 1 Cell constant and their conductivity measurement range

| **Cell constant** | **Optimum Conductivity Range (µS/cm)** |
|---|---|
| 0.1 | 0.5 to 400 |
| 1.0 | 10 to 2000 |
| 10.0 | 1000 to 200,000 |

To obtained the soil conductance, the measured soil conductivity is multiplied by the cell constant asgiven by (4).

$$C = G \times K \quad (4)$$

C = Conductivity
G = Conductance measured
K = Cell Constant

Conductivity can only be measuredwith alternating electrical current (I),applied to conductivity cell immersed in a solution and measuring the resulting voltage (V) across the cell. Figure 13 shows the construction of simple conductivity meter

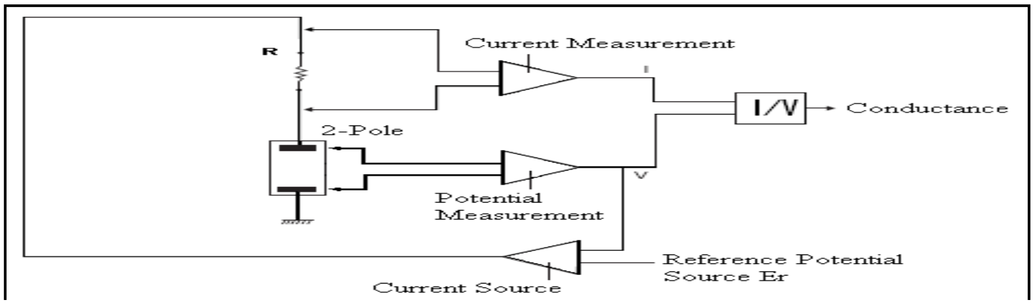


Figure 13 Simplified Conductivity meter

D.C signal cannot be use for the measurement of conductivity because dipping a conductivity cell with D.C. signal applied will pull the ions apart and there will be a constant reading.

### 5.3.3. SOIL VMC SENSOR

[28] The sensors used for the measurement of soil VMC is based on measurement of the dielectric constant of soil. As compared to the dielectric constant of air and soil materials, water has much higher dielectric constant. Therefore, the measurement of soil's dielectric constant is sensitive to soil VMC only.

Figure 14gives the pictorial view of VMC sensor. Figure 15 gives the characteristics of soil VMC sensor. Table2 gives the various parameters associated of VMC sensor.

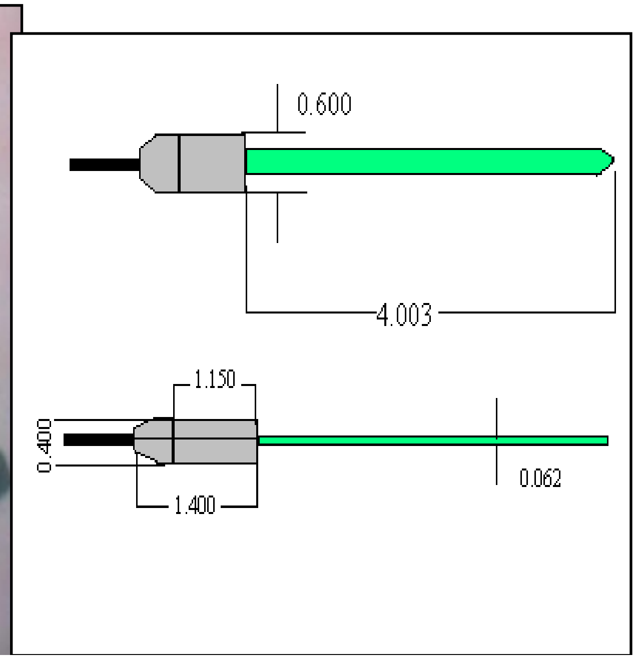


Figure 14 Soil Moisture Sensor Figure 15VMC sensor Physical dimensions

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Table 2 Soil VMC sensor specifications

| **VMC Sensor Parameters** | |
|---|---|
| **Power Consumption** | < 800µA |
| **Supply Voltage** | 3.3V to 20 V DC. |
| **Output** | 0 to 3V proportionaltosoil moisture content |
| **Dimensions** | As per Figure 5.4 |
| **Power on to output stable** | 400 ms |
| **Output Impedance** | 100KΩ |

Sensor has 3–leads and Table 3 give the wiring details of the sensor. In order to measure the VMC of soil, sensor supply leads are connected to dc voltage between 3.2V to 20V. The output D.C voltage produced by the sensor is between 0V–3V dc and has a linear relationship with the VMC of sensor. The relationship between sensor's output and soil's VMC is depicted in figure 16. The calibration equation which converts the output voltage from the sensor into VMC of soil is given by (5).

$$VMC = V \times 21.18644 - 10.3814 \quad (5)$$

VMC = Volumetric Moisture Content
V = Output D.C voltage from sensor

Table 3 Wiring detail of VMC Sensor

| | |
|---|---|
| **Bare** | Ground lead |
| **Red** | Power Lead - 3.3V to 20 V |
| **Black** | Output Lead – 0V to 3V proportional to moisture content |

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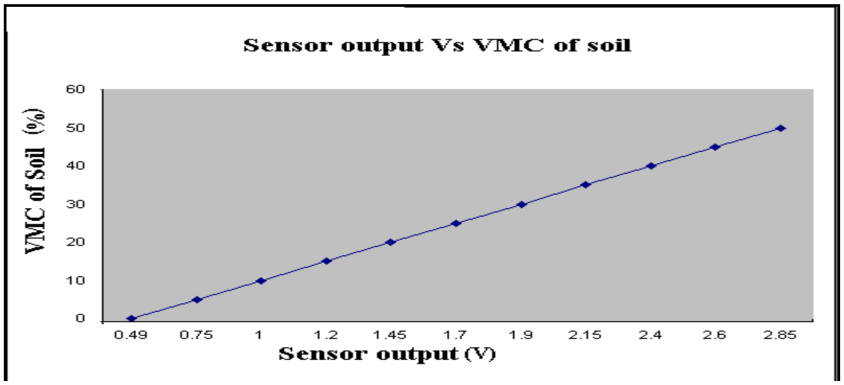


Figure 16 Characteristic of VMC sensor

VMC sensor generates its own signal proportional to soil's volumetric moisture content with the proper supply voltage connected at its input terminal. Therefore, VMC sensor is directly used with microcontroller's ADC without any special circuitry in between ADC and soil VMC sensor.

### 5.3.4. PLACEMENT OF VMC SENSOR

Proper placement of VMC sensor is very is important for irrigation management. VMC sensor is to be place within the root zone of the plants. Usually two sensors are place in the soil at the different depths within the root zone. Figure 17 shows the placement technique of sensors for VMC measurement. The shallow sensor reading is used to decide the time to start irrigation while the reading of the deep sensors gives the idea about the amount of irrigation water to be applied. Schematic of soil analyzer developed is given in figure 18

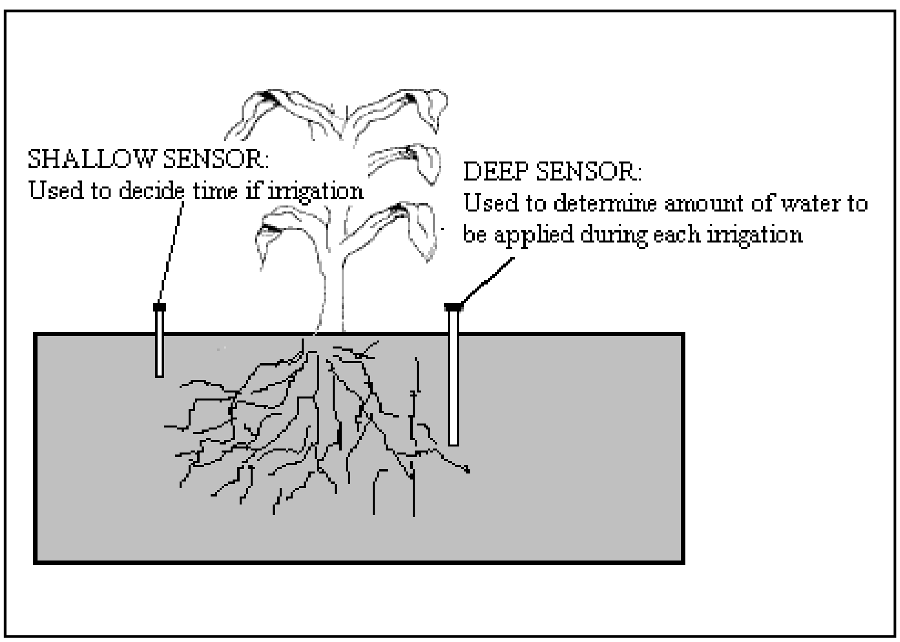


Figure 17 Placement of VMC sensors

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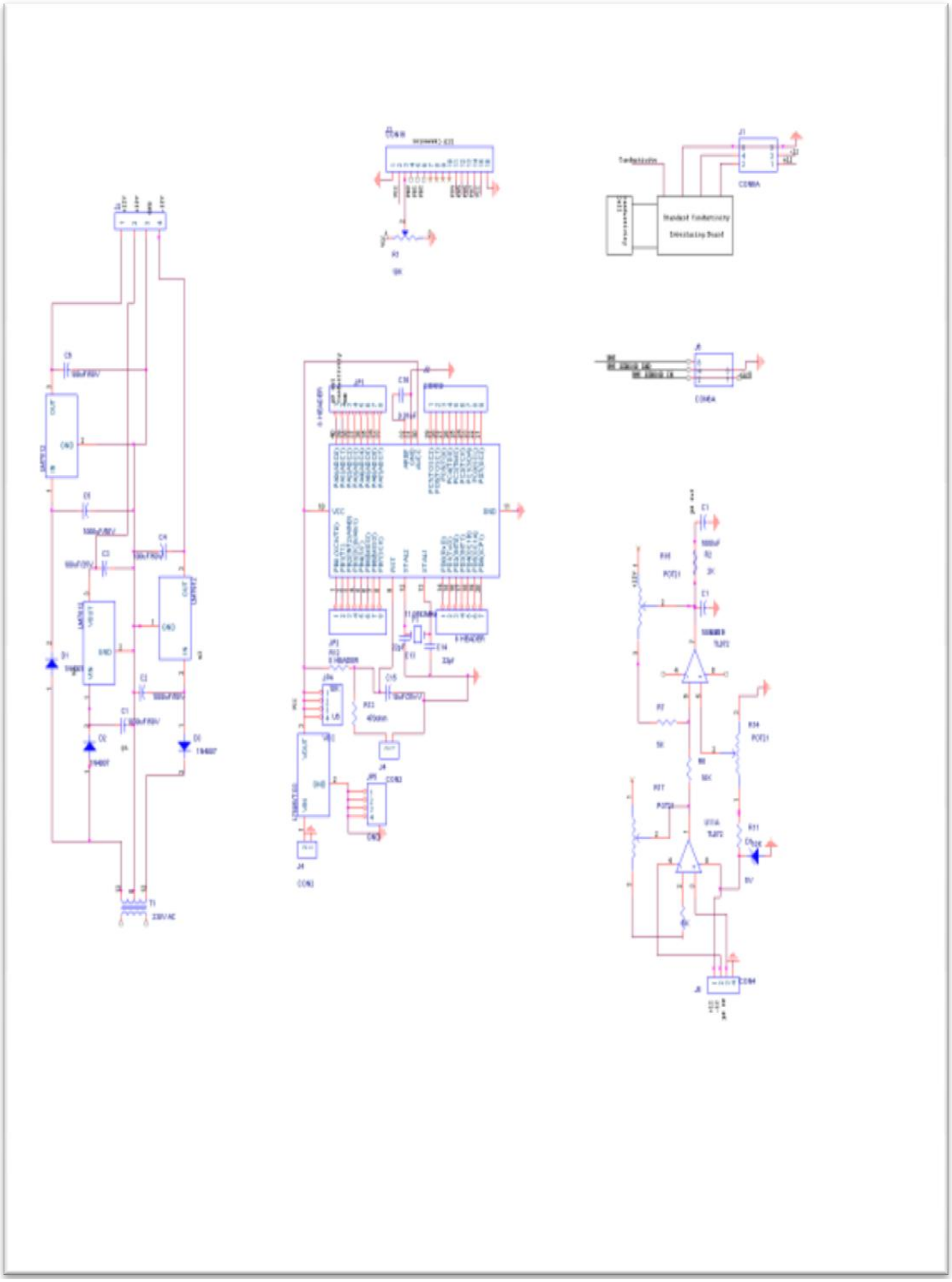

Figure 18 Schematic of soil analyzer

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## 5. PCB Design

The main aim of the Printed Circuit Boards (PCB) are:

1) Designing interconnection for the components
2) Parasitic effect minimization with the realization of these connections.

Figure 19 and figure 20 give the PCB design for power supply and microcontroller board

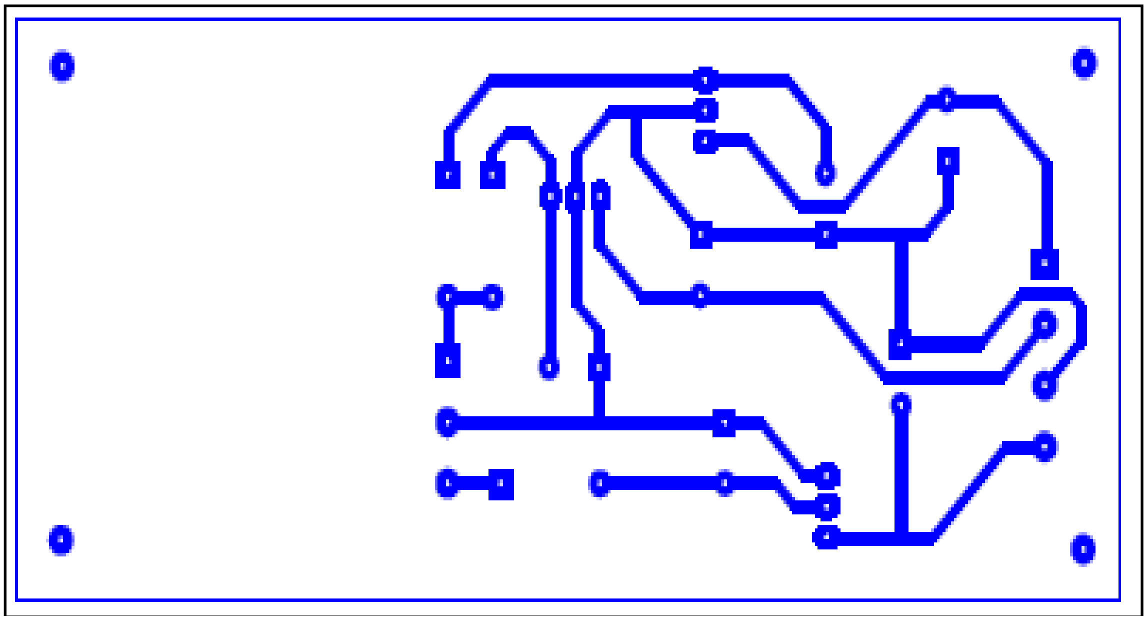

Figure 19 PCB layout of power supply

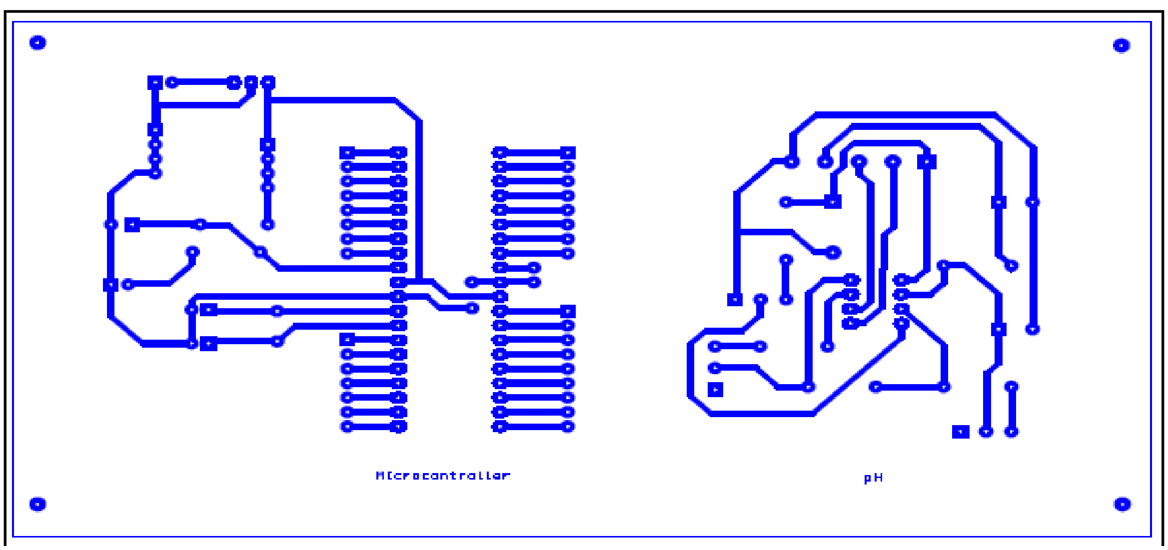


Figure 20 PCB layout of microcontroller board and pH interfacing card

## 6. Soil Analyzer Programming

The flows chart as per figure 32 gives the logic flow chart of soil analyzer

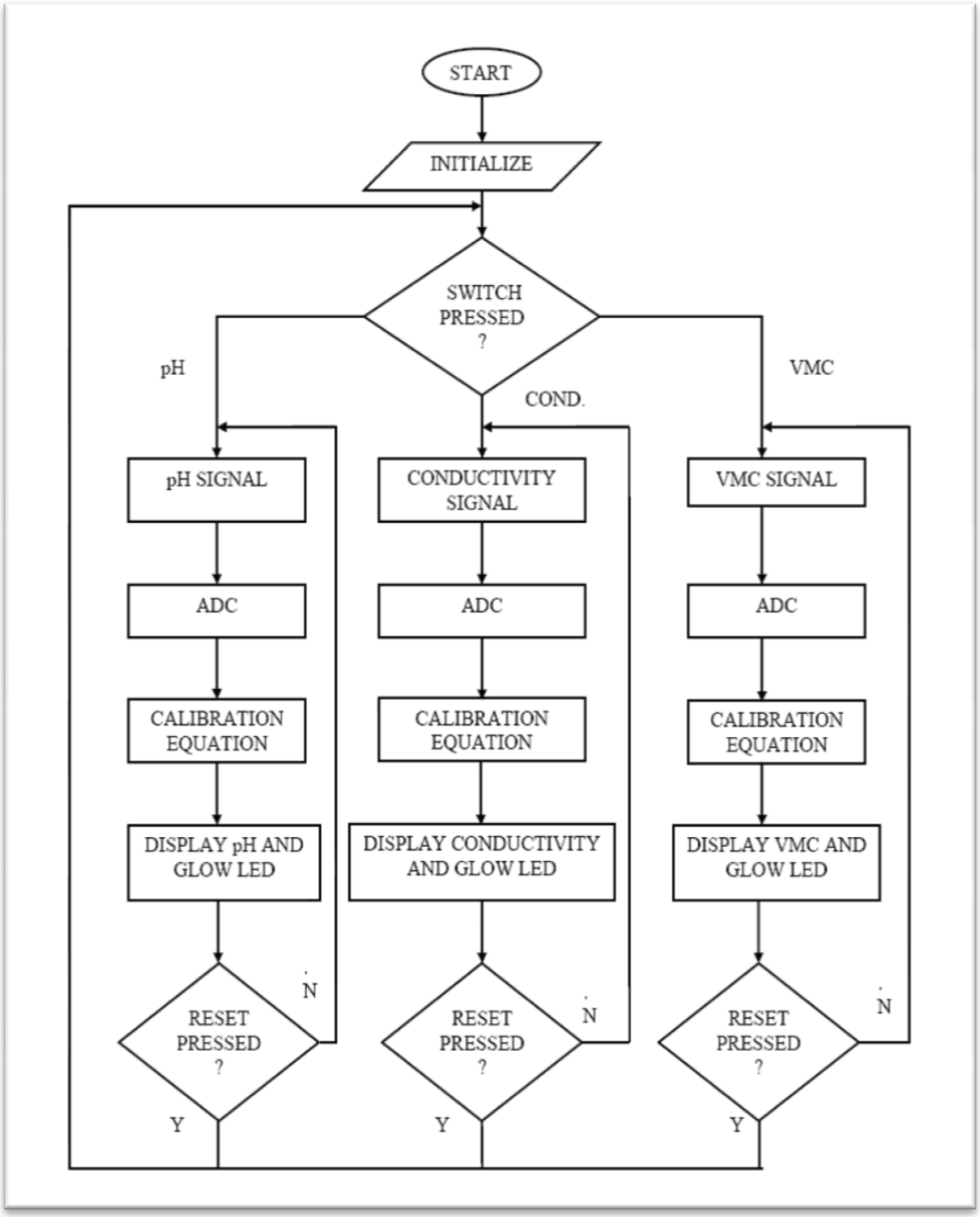


Figure 21 Flow chart

## 7. Results and Discussion

For the purpose of testing of the system ten soil samples are collected at a distance of about 2 meters from an agricultural field. In order to measure soil pH and conductivity, soil extract of each of the sample is prepared. This is the standard method to measure the soil pH and conductivity. The soil extract of each of the sample is prepared by mixing 1–parts of soil in 2–

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parts of water i.e sample in 2:1 parts. The measurement of soil VMC does not require any soil extract preparation. The VMC sensor is directly placed within the effective root zone of the plants for the VMC measurement. Figure 22 below give the pictorial view of developed system

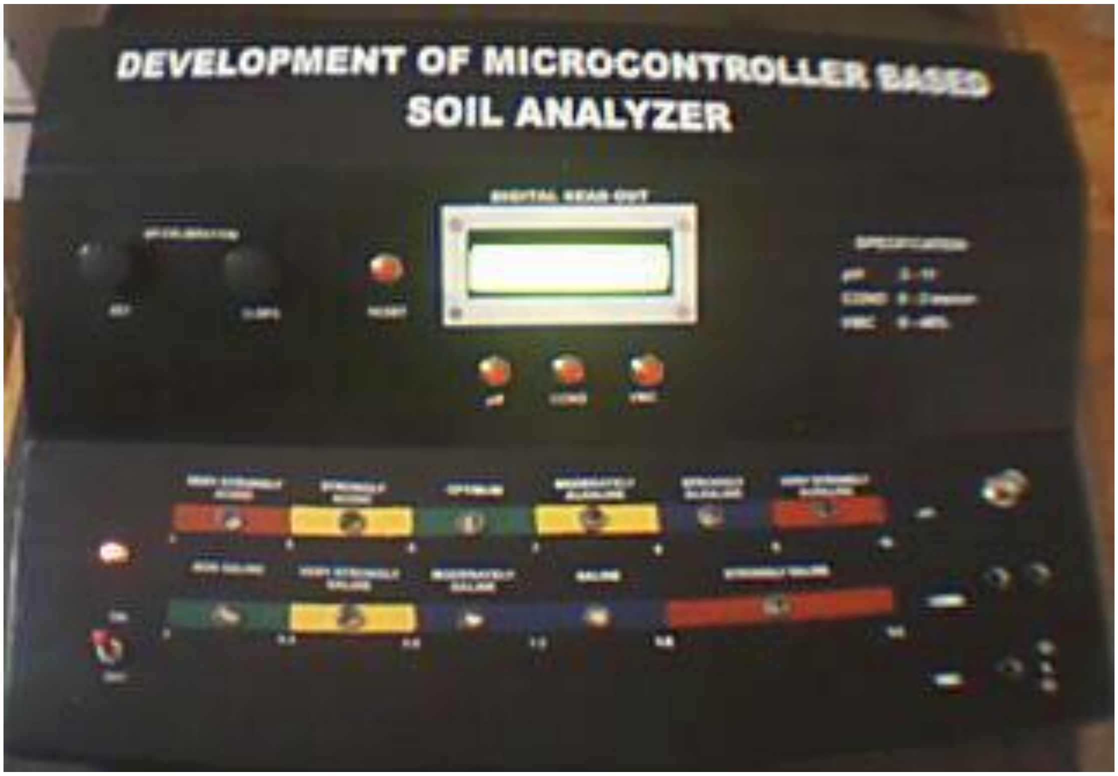


Figure 22 Pictorial view of developed system

### 8.1 MEASUREMENT OF SOIL pH

Before pH sensor can be used for measurement calibration of the sensor is required. pH sensor is calibrated each time the sensor need to be used for pH measurement and is done with the help of standard calibration buffer solution with pH values of 4, 7 and 9.2. mainly pH calibrating buffer with pH 7 and 9.2 are used for the calibration of pH sensor.

### 8.1.1 CALIBRATION OF pH SENSOR

In the system two knobs are provided for calibrating the pH sensor. By pressing the push button on front panel labelled as pH, the pH mode of measurement is selected on the system. For calibrating the pH sensor, it is first placed in buffer solution with pH 7. After placing the sensor in the buffer the display is set to 7 with the help of knob on the front panel of system marked as SET. Thereafter the pH sensor needs to be place in the or calibration or buffer solution with known pH value as 9.2. The readout is then set to 9.2 with the help of second knob marked with SLOPE. Now the system is preparedfor measuring the pH of any unknown aqueous solution.

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### 8.1.2 pH MEASUREMENT OF SOIL SAMPLES

Once the pH sensor is calibrated, the sensor electrode is placed in the soil extract for measurement. The results of measurement for the sample are provided in Table 4.

Figure 23 shows that the pH of soil samples under test lies between 8.0 and 8.6. lies in the strongly alkaline region.

Table 4pH values of tested soil samples

| **Sample Number** | **pH of tested samples** |
|---|---|
| Soil Test Sample 1 | 8.1 |
| Soil Test Sample 2 | 8.5 |
| Soil Test Sample 3 | 8.2 |
| Soil TestSample 4 | 8.3 |
| Soil TestSample 5 | 8.4 |
| Soil TestSample 6 | 8.6 |
| Soil TestSample 7 | 8.3 |
| Soil TestSample 8 | 8.1 |
| Soil TestSample 9 | 8.5 |
| Soil Test  Sample 10 | 8.6 |

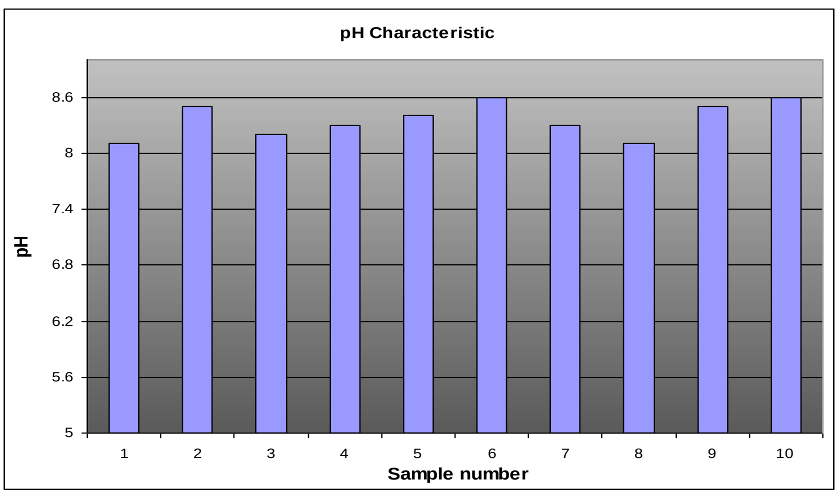


Figure 23 pH characteristic of tested soil samples

### 8.2 MEASUREMENT OF SOIL CONDUCTIVITY

For the measurement of conductivity, conductivity cell is required to be inserted in the soil extract and the value on the digital display is noted down. The test results are given in Table 5.

Figure 24 shows that the conductivityvalues for the tested soil samples which lies between 0.69 mS/cm and 0.76.mS/cm.

Table 5 Conductivity values of tested soil samples

| Sample Number | Conductivity(mS/cm) of tested samples |
|---|---|
| Soil Test Sample 1 | 0.69 |
| Soil Test Sample 2 | 0.73 |
| Soil Test Sample 3 | 0.71 |
| Soil Test Sample 4 | 0.70 |
| Soil Test Sample 5 | 0.68 |
| Soil Test Sample 6 | 0.69 |
| Soil Test Sample 7 | 0.75 |
| Soil Test Sample 8 | 0.71 |
| Soil Test Sample 9 | 0.75 |
| Soil Test Sample 10 | 0.73 |

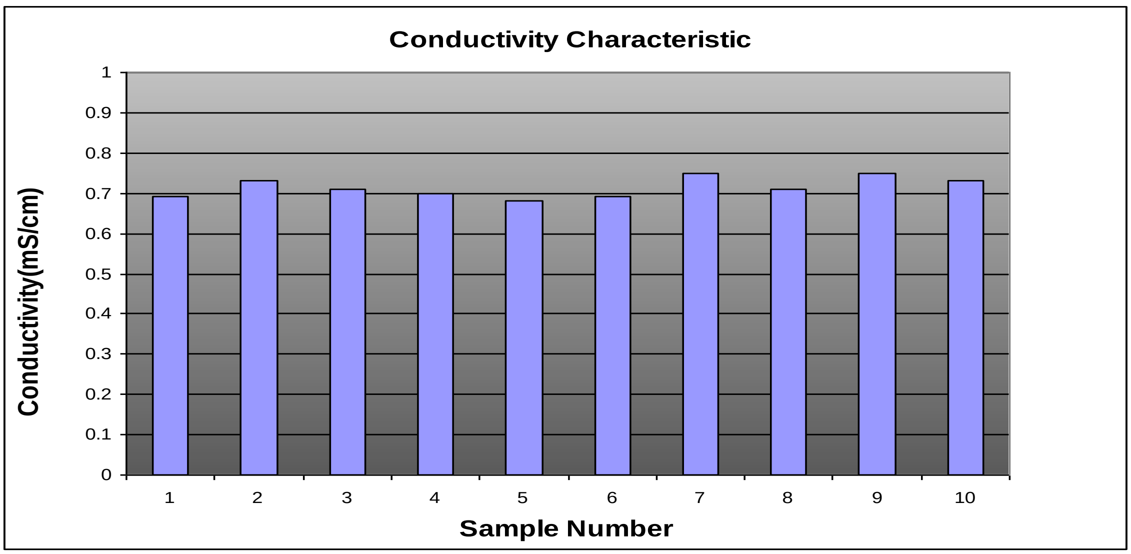


Figure 24 Conductivity characteristic of tested soil samples

### 8.3 MEASUREMENT OF SOIL VMC

The soil VMC sensor is to be placed in the soil in such a way so that it needs to be completely inserted in the soil and soil is properly packed around it. The results of measurement for the soil's VMC are given in Table 6.

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Figure 25 shows that VMC of tested soil samples at the time of testing lies between 16% to 22%.

Table 6 VMC of tested soil samples

| Sample Number | VMC(%) |
|---|---|
| Soil Test Sample 1 | 20.8 |
| Soil Test Sample 2 | 21.8 |
| Soil Test Sample 3 | 19.3 |
| Soil Test Sample 4 | 21.7 |
| Soil Test Sample 5 | 18.9 |
| Soil Test Sample 6 | 21.3 |
| Soil Test Sample 7 | 19.5 |
| Soil Test Sample 8 | 21.6 |
| Soil Test Sample 9 | 19.2 |
| Soil Test Sample 10 | 21.1 |

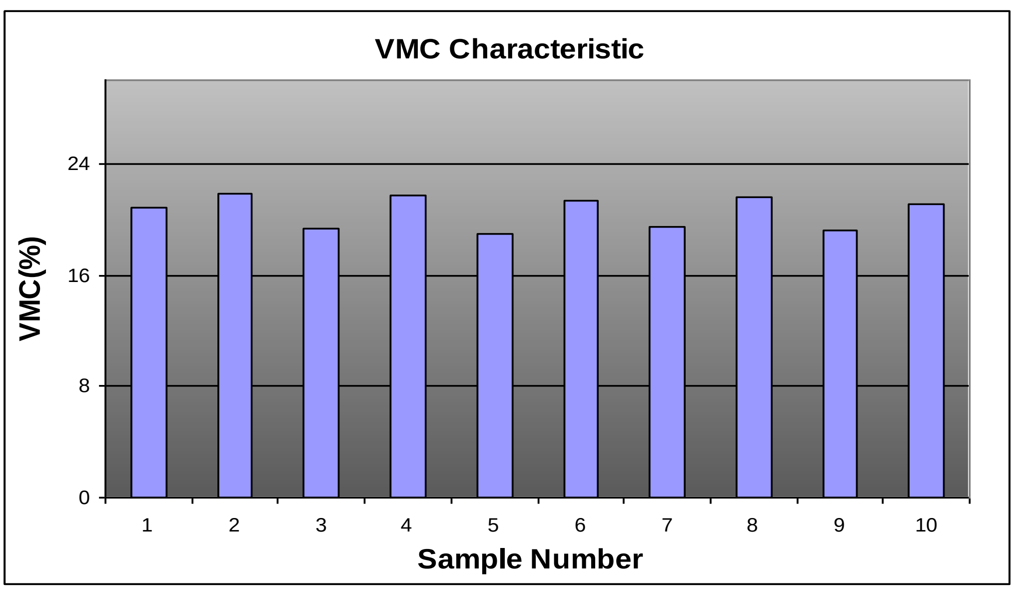


Figure 25 VMC characteristic of tested soil samples

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