Self-Calibrating Soil Moisture Sensor for In-Situ Application

by

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INFORMATION AND COMMUNICATION TECHNOLOGY

with specialization in

VLSI and Embedded Systems

DHIRUBHAI AMBANI INSTITUTE OF INFORMATION AND COMMUNICATION TECHNOLOGY

May,2023

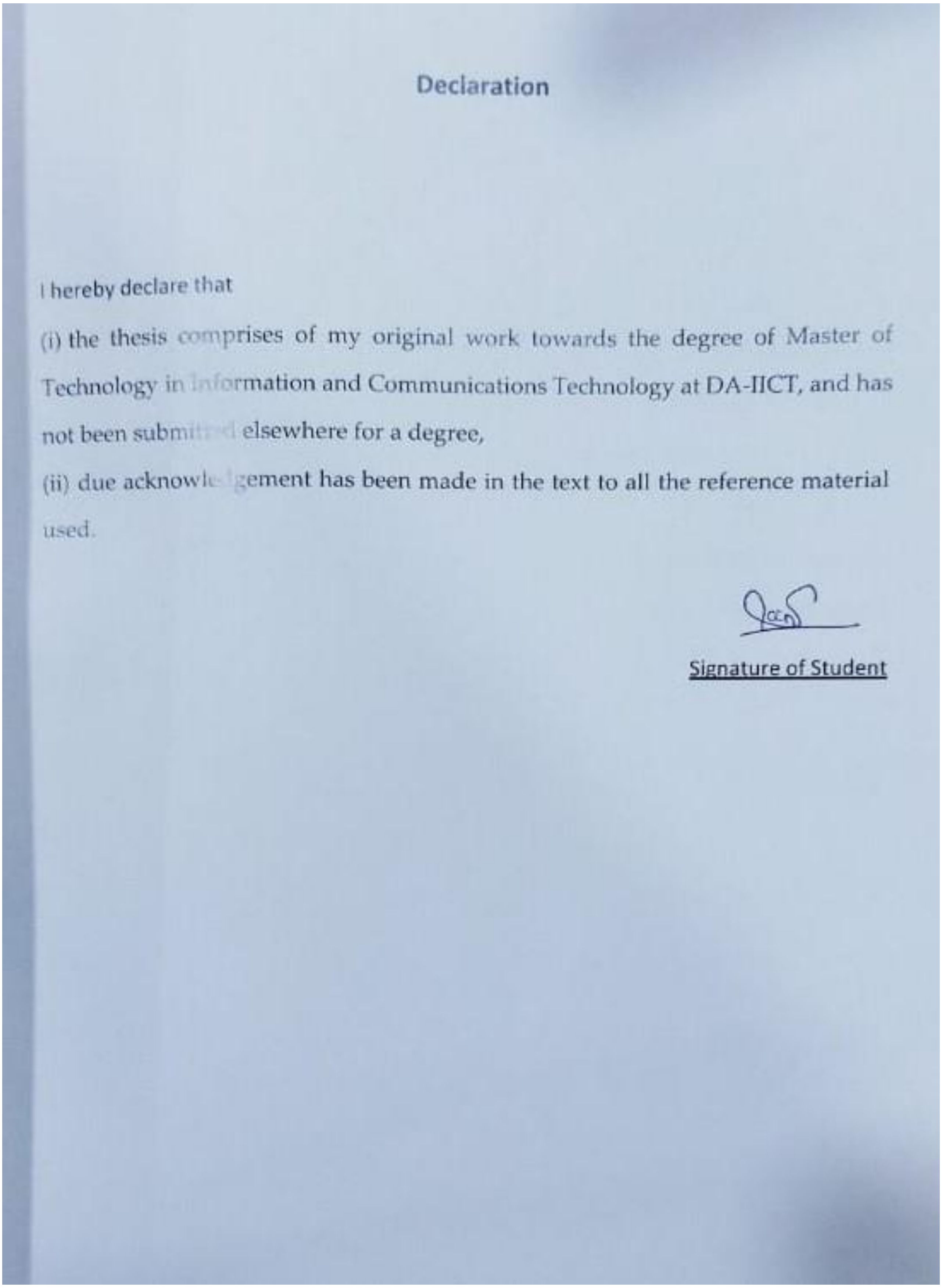
Declaration

I hereby declare that

(i) the thesis comprises of my original work towards the degree of Master of Technology in Information and Communications Technology at DA-IICT, and has not been submitted elsewhere for a degree,

(ii) due acknowledgement has been made in the text to all the reference material used.

Signature of Student



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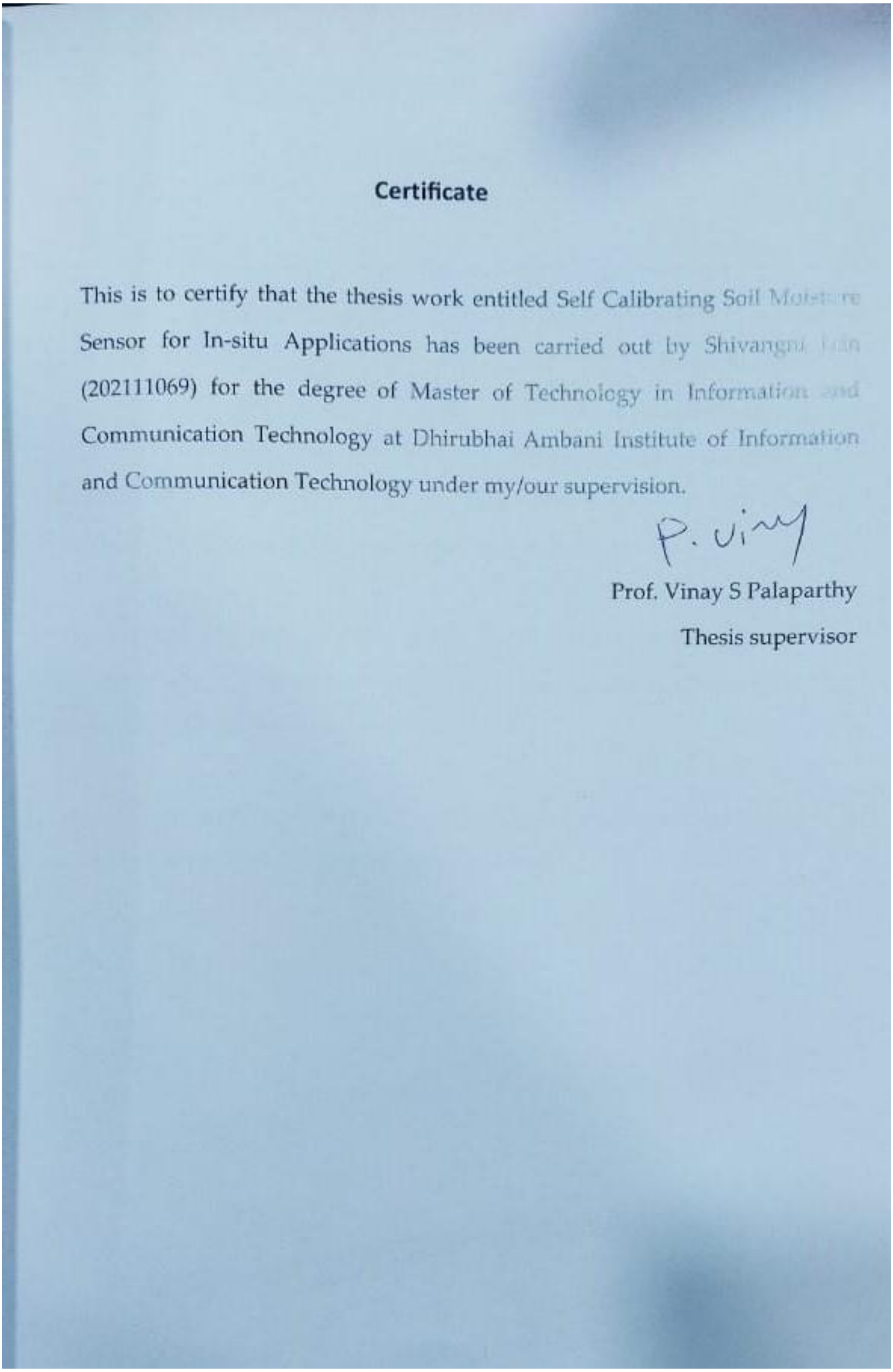
Prof. Vinay S Palaparthy



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P. Viny

Prof. Vinay S Palaparthy
Thesis supervisor

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Abstract

Self-calibration techniques are performed with the following methods like sensor calibration wrt sensor and sensor calibration wrt soil. For self-calibration wrt sensor, we deployed the sensor in different states of soil with different moisture content. We observed that the sensor degrades after being exposed with the soil for long time due to different environmental conditions. Therefore, self-calibration techniques play a vital role when the sensor degrades from its baseline. Both lab and field deployment results show a change in frequency response and capacitive response with respect to gravimetricwater content.

We need that with the help of self-calibration technique when sensor is deployed in any type of soil and for a long period of time will be able to attain its baseline by its own when get diverted from its path.

Keywords:

Gravimetric Water Content
Soil Moisture Sensor
Printed Circuit Board
Self-Calibration
Relaxation Oscillator

List of Principal Symbols and Acronyms

C	Capacitance
E	Electric field
F	Frequency
I	Current
k	Boltzmann's constant
Vc	Capacitive voltage
T	Time Period
Rf	Feedback Resistance
Cx	Sensor capacitance
Vint	Initial Voltage
Vref	Reference Voltage

Other minor symbols are defined at first occurrence; where necessary some symbols are redefined in the text.

PCB	*Printed circuit board*
SMS	*Soil moisture sensor*
GWC	*Gravimetric water content*
C to F	*Capacitor to frequency*
IC	*Integrated circuit*
GND	*Ground*

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Chapter 1

Introduction

1.1 General

1.1.1 Problem Formulation

Hardware systems have become progressively intricate with the use of complex architectures on systems and powerful processors. Hardware systems like this may face failure in any part, which reduces their performance. Failure of hardware can happen anytime during the working of the system when it is performing tasks. Failures like this can arise because of influence from the adjacent environment (e.g., radiation, temperature, etc.) as well as the aging of the hardware. That is why self-calibrating is being proposed as a key with the potential of repairing or calibrating the system even without affecting the system's performance. Hardware components can recover from or attain their original performance without any harm to the system, in self-calibrating, from the inside without requiring any outside involvement of humans.

The process variations have become more difficult as transistor technology has advanced. Circuit performance is affected by process variations that rapidly degrade technology when it is scaled. Analog and mixed-signal circuits are significantly affected due to the minuteness of such hardware designs. The ageing effect of the circuit and other environmental factors will affect the working of the sensor. The study on self-calibrating hardware systems is accomplished by using actuators, sensors, and analog/digital loops of control which measure the system's unpredictability effects and move the system to the best possible performance point via backup components or parameters controlling the system that make up for the variation effects and bring the sensor to attain its original baseline.

1.1.2 Research Objectives

Sensors are need to be calibrated to improves for sensitivity loss, baseline drift, and inter- sensor variability. Usually, calibration is performed by the before and/or after each assessment. Manual calibration not be possible for in situ measurements in agricultural, environmental, where sensors need to be deployed in the field and work autonomously. In these scenarios, self-calibration required which not only saves time and effort but assure the accuracy and precision of measurement.

Self-calibrating can be performed using multiple methods, which are usually dependent on detecting defective components and then repairing them to reintegrate them several of which are usually dependent on detecting defective components and then repairing them to reintegrate back into the hardware system. The main job of self-calibrating hardware is to keep the system working with maximum performance after mending the fault in the system or when the system deviates from its path.

1.2 Novelty of proposed work

We have fabricated the IDE on both sides of PCB that are superbly aligned, this illustrates the novelty of the proposed work. An accessible dielectric (capacitive) based soil moisture sensor on the printed circuit board (PCB) is widely examined. The advantage of the capacitive-based sensor over the resistance-based sensor is that it offers magnificent stability with respect to time and also offers excellent accuracy when compared with the sensing mechanism which is resistive based.

1.3 Organization of the Thesis

The organization of the thesis is as follows: first of all, the background and technique of self-calibrating at a hardware level are explained. Post that, the calibrating mechanism for the power management unit is designed at a block diagram level. Different integrated circuits are chosen and then made compatible with each other with respect to their input and output characteristics. EAGLE software is used to create a schematic of the circuit and then the layout for the same on the printed circuit board. Gerber files are generated and the printed circuit board is fabricated for the self-calibration operation. Results are checked on DSO and with the help of Arduino and cross verified for self-calibration operation.

Chapter 2

Self-Calibration of Soil Moisture Sensor

2.1 Self-calibration technique

Calibration means comparing a device under test (DUT) of an unknown value by taking reference standard of a known value. A calibration is performed to examine the error or confirm the accuracy of the device under test unknown value. Electronic circuitry & devices used in measurement equipment is thread to a certain deviation that impact the stability and accuracy. Offset drift end variations in gain due to temperature changes, aging, and power supply changes cause measurement uncertainties of sometimes unacceptable proportions. The accuracy of a calculation is vastly expanded by using self- calibration circuit and protocol

2.2 Need for self-calibration for SMS

We observe that the sensor output deviates from its base value because of sensor degradation. Factors for sensor degradation are variations in field temperature, aging, and the chemical composition in the soil due to different environmental factors. To overcome this sensor specific self–calibration mechanism has to be implemented in the soil moisturesensor itself

Fig 2.1 Degraded Sensor

2.3 Objective of Self-calibration for soil moisture sensor

An accessible dielectric (capacitive) based soil moisture sensor on the printed circuit board (PCB) is broadly outlined. The superiority of the capacitive based sensor over the resistance-based sensor is that it gives outstanding stability with respect to time and also provides excellent accuracy when differentiated with the resistive based mechanism of sensing. The conventional capacitive based IDEs moisture sensor comprises of solder mask on one side and electrodes on another end of the PCB. If electrode is fabricated on both side of PCB, then sensor sensitivity can be improved. If both the sides of PCB electrode is present it will improves the sensor sensitivity as fringing field on both the side of the PCB enhance the effective zone of influence for the soil moisture measurements. Therefore, in this experiment, we have fabricated the IDE on both sides of PCB that are superbly aligned, this illustrates the novelty of the proposed work when compared with single sided fabrication. Along with the sensitivity, effect of temperature is a concern for capacitive based soil moisture sensors and thus required mechanism of temperature compensation.

We have used the Acrylic Protective Lacquer (APL) coating to mitigate the use of complex temperature compensation algorithms, in this work and on the fabricated SMS and interface electronics. The advantage of APL coating is it makes the system to withstand in temperature drift also protects the electronics from the humidity. Further, to ensure that measured gravimetric water at different depths is accurate, we have prepared the soil sample in the mold with varying soil moisture at different water content and benchmarked with standard gravimetric method taking bothlab and field conditions.

2.4 Methods and material of self-calibration SMS

This section describes the design and development of the soil calibrating moisture sensor (SMS) along with the low-power interface electronics design. Soil sample preparation plays a vital role because preparation of the sample has to follow the same method so we can get the desired accurate results. The schematic and design of eachsensor remain the same but still out of 10 sensors each sensor will have slightly different sensitivities. Characteristics plots of soil moisture sensors are calculated to know the sensor characterization w.r.t temperature, output frequency, hysteresis, and response.

2.3.1 Soil sample preparation

Soil moisture sensors probably will have varying sensitivities, even sensors have same model. For soil sample preparation we collect soil samples from different states then filter out or manually remove any rocks, plant material, or non-organic material from the samples. Dry the soil samples – The most effective way to do this is in an oven by setting temperature to 105 Celsius. Place the dried soil into a mold, the mold should be large enough for the sensing area so soil moisture sensor to be completely deployed without contacting the sides of the container. With a different range of moisture which we decide initially in each sample by adding water and measuring moisture content in IR meter, where the first container is kept dry and the final container is completely slurry. It is important that the soil in each container is equally mixed so that the moisture level is maintained. Measure and record the sensor output in each container.

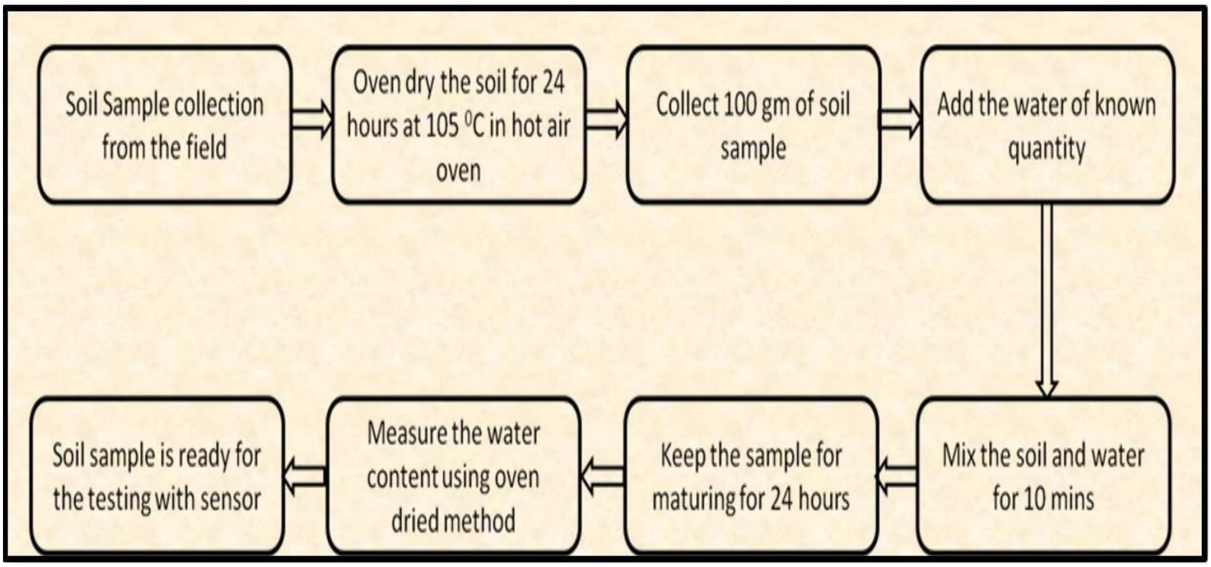

Fig 2.2 Steps of Soil Sample Preparation

CHAPTER 3

INTERNAL ARCHITECTURE

3.1 Implementation of soil moisture self-calibration sensor

In this experiment, Capacitive-based soil moisture sensor has been fabricated. Interface electronics circuit consist of C to F converter, which termed as relaxation oscillator. The correspondence between capacitance and frequency (F) as follows.

$F = 1/ 2.2(R \times Cx)$ (1)

where, F is the sensor's output frequency of the relaxation oscillator, Cx is the sensor capacitance and R is the feedback resistor. The multiplexer and select lines were used to control the sensor's selection in order to neglect sensor-to sensor interference. To get the frequency output of the relaxation oscillator and send the calculated frequency to the cloud using the Wi-Fi module the counter of the microcontroller is used.

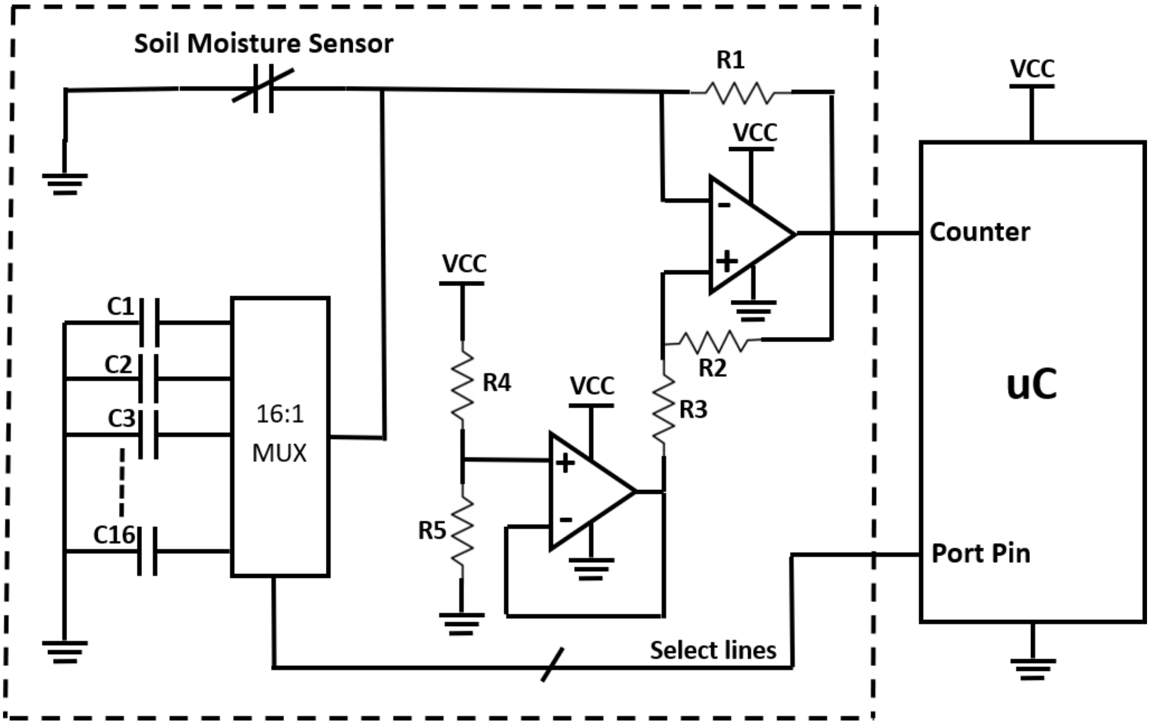

Fig 3.1 Internal Architecture of Self Calibrating Sensor

3.1.1 Multiplexer 16:1

In digital electronics, a **multiplexer,** is a device that selects between multiple analog or digital input signals and passed the selected input to a single output line. The selection is administered by a separate set of digital inputs called as select lines. Which input line should be send to output is decided by a multiplexer of 2^n inputs has n selected lines.

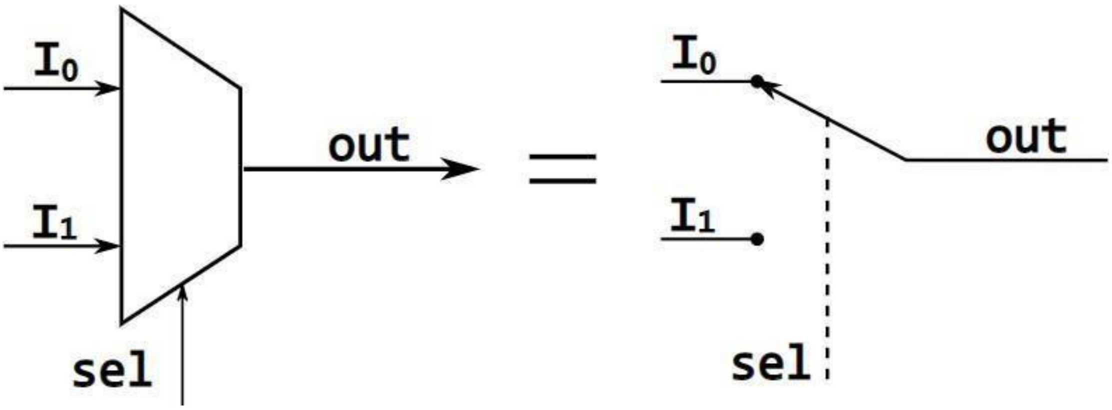

Fig 3.2 Schematic of 2-to-1 multiplexer. It can be equated to controlled switch

3.1.2 Relaxation oscillator

In this section the working of relaxation oscillator shows how change in frequency of relaxation oscillator with change in capacitance. The oscillator circuit has been designed on Tina-TI software, simulated and tested for various values of capacitance. The oscillator circuit is powered with 3.3V excitation. The same oscillator is implemented on a breadboard and tested for various values of capacitance. The output of the oscillator is analyzed on DSO. The oscillator circuits implemented using op-amp LM358.

An op-amp relaxation oscillator is basically a square wave generator. The square wave is generated at a selected frequency by the oscillator circuit. This is achieved by charging and discharging the capacitor, C through the resistor, R.

By the RC time constant of R and C, and the threshold levels set by the resistor network of R1 and R2 the oscillation frequency is determined.

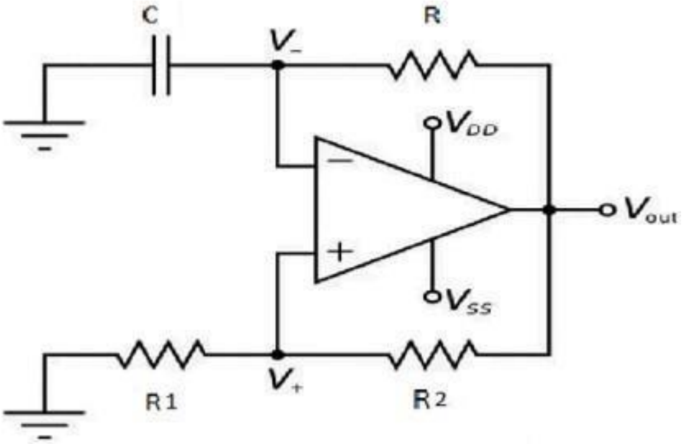

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Fig 3.3 Relaxation Oscillator

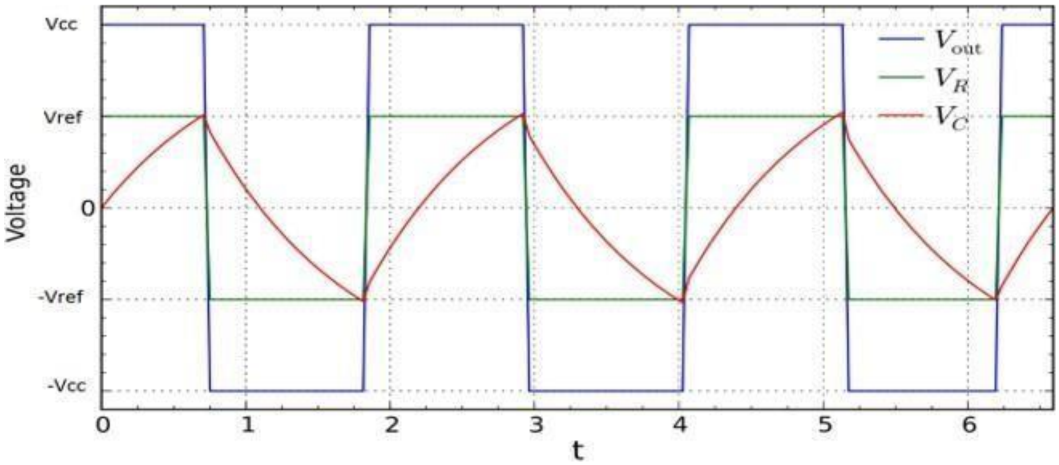

Fig 3.4 Ideal graph of the response of Relaxation oscillator

3.1.2.1 Working of relaxation oscillator

Primarily, if we contemplate the output of the comparator is high, then during this time the capacitor will be charging. From the graph we can observe that with the charging of the capacitor, its terminal voltage will slowly rise.

We can observe from the graph that once the capacitor terminal voltage reaches the threshold voltage, the comparator output will go from high to low and, the capacitor starts discharging to negative threshold voltage when the comparator output goes negative

After the capacitor completely discharges because of the presence of a negative output voltage, it again charges except in the opposite direction. In the graph we cansee, the capacitor voltage also rises in a negative direction. because of the negative output voltage.

The comparator switches output from negative to positive once the capacitor charges to the maximum in a negative direction and the capacitor discharges in the negative path and grow charges in the positive path once the output switches to a positive cycleas shown in the graph.

As shown above, comparator produces a square wave signal at the output when the cycleof capacitor charge and discharge in positive and negative paths triggers the comparator.

3.1.2.2 Derivation of relaxation oscillator

The purpose of a relaxation oscillator is to create a signal of a specific frequency. The oscillator frequency can be calculated by the time period of capacitor charging and discharging which depends upon R and C. The relationship between T = time period and the components of the circuit can be drawn out from the basic charge of the capacitor. Therefore, the capacitor charge as the capacitor voltage can be expressed as:

$$V_c = V(1-e^{-(T/RC)}) \tag{1}$$

With the initial charge in the capacitor, the voltage across the capacitor at a given time can be expressed as:

$$V_{c+} = V-Ve^{-(T/RC)} + V_{init} * e^{-(T/RC)} \tag{2}$$

$$V_{c+} = V + (V_{init} - V) * e^{-(T/RC)} \tag{3}$$

In our case, $V_{init =} - V_{ref}$; $V = V_{cc;;}$ $V_{c+} = V_{ref}$

Therefore, $V_{ref} = V_{cc} + (-V_{ref} - V_{cc}) * e^{-(T/2RC)}$ (4)

$V_{ref} - V_{cc} = (-V_{ref} - V_{cc}) * e^{-(T/2RC)}$

$(V_{ref} + V_{cc}) * e^{-(T/2RC)} = -V_{ref} + V_{cc}$

$e^{-(T/2RC)} = \frac{Vcc - Vref}{Vcc + Vref} \frac{Vcc - Vref}{Vcc + Vref}$

here, $V_{ref =} \frac{R1}{R1+R2} \frac{R1}{R1+R2} * V_{cc}$ and $\beta = \frac{R1}{R1+R2} \frac{R1}{R1+R2}$

$\therefore V_{ref} = \beta * V_{cc}$ (5)

$e^{-(T/2RC)} = \frac{Vcc - Vref}{Vcc + Vref} \frac{Vcc - Vref}{Vcc + Vref} = \frac{1-\beta}{1+\beta} \frac{1-\beta}{1+\beta} \; -\frac{T}{2RC} = ln\,(\frac{1-\beta}{1+\beta}) - \frac{T}{2RC} = ln\,(\frac{1-\beta}{1+\beta})$

(6)

T = - 2 RC $ln\,(\frac{1-\beta}{1+\beta})\ seconds\ ln\,(\frac{1-\beta}{1+\beta})\ seconds$

Time Period T = 2 RC $ln\,(\frac{1+\beta}{1-\beta})\ seconds\ ln\,(\frac{1+\beta}{1-\beta})\ seconds$ (7)

We know, F = 1 /T Hz,

F = 1 / 2 RC $ln\,(\frac{1+\beta}{1-\beta})\ \ ln\,(\frac{1+\beta}{1-\beta})$ Hz, when R1 ≠ R2 (8)

If R1 = R2

Then, β =1/2

T = $2RC \ln{(3)}$

T= $2RC\ (1.099)$ (9)

F= 1 / 2.2RC When R1=R2

(10)

In Our circuit, R1 and R2 are 10 KΩ and 100 KΩ, respectively.

Therefore T = 0.36 RC sec (11)

And

F = 1/0.36 RC (12)

3.2 Internal Design of soil moisture sensor calibration technique

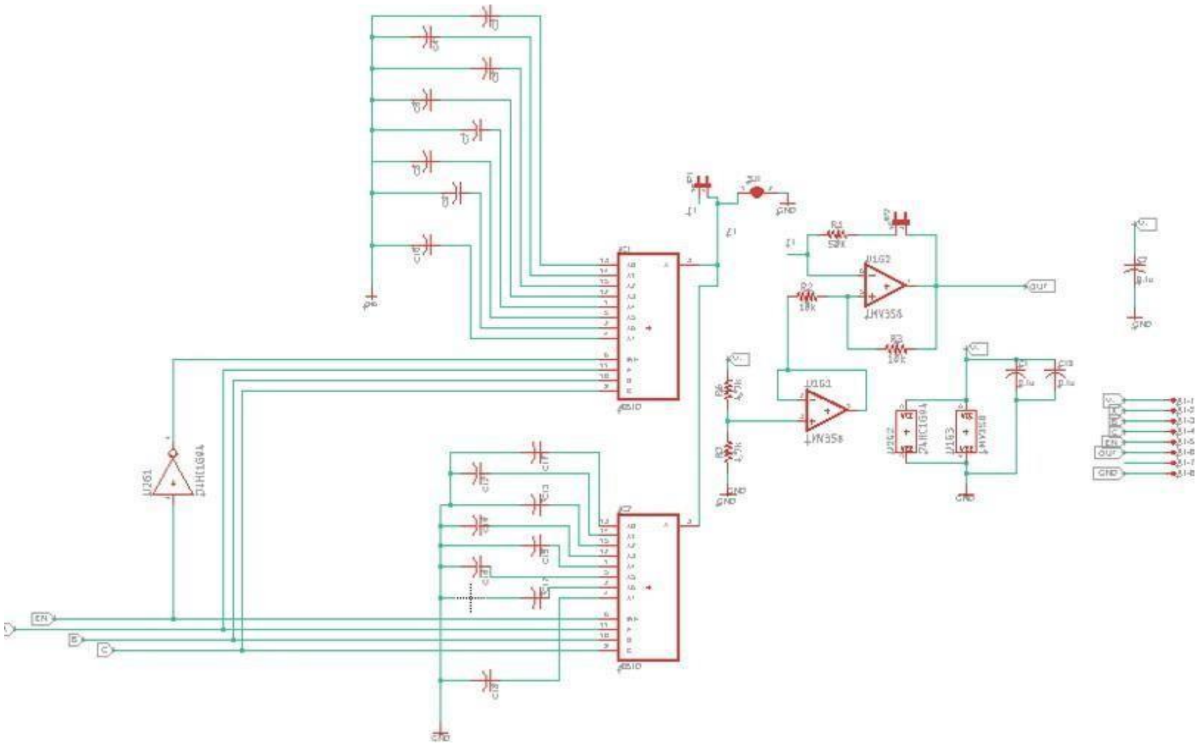

Fig 3.5 Schematic of SMS self-calibration PCB Design in Eagle software

Fig.3.5. shows the schematic of the PCB which is designed on eagle software using various components after which the board file has been created along with the Garber file. The schematic shows the PCB after fabrication consisting of 16:1 mux and relaxation oscillator.16:1 MUX will activate when degradation occurs and the relaxation oscillator will work for both self-calibration techniques and Fig 3.6 shows the layout of designed PCB.

Fig 3.6 Layout of PCB of self-calibrating soil moisture sensor

CHAPTER 4

OBSERVATIONS AND SIMULATION

4.1 Experimental Setup

Fig 4.1 Experimental Setup in Lab

The sensor has been connected with the developed interface electronics, the setup requires the soil contained in the mold, fabricated SMS, developed interface electronics, battery, and Tektronix DSO 1202B (to measure the output frequency of sensor). Perspex mold have been used, which has a width and height of about 15 cm and 15 cm, respectively. We have prepared the soil sample with different water content and then the sensor is deployed in the mold subsequently, a change in the sensor frequency is recorded using Tektronix DSO 1202B. Then, we observed the transfer characteristics of fabricated sensors. In this experiment, we observed the response of frequency changes when the sensor is inserted under the soil. For this motive, we have studied the sensor response (calibration) on different degraded and non-degraded sensors; the depth at which all the sensors are inserted in the soil for different samples remains the same.

Once the finish with our lab testing, we deployed the fabricated SMS along with in-house developed interface electronics and by standard gravimetric method confirmed the measured GWC. For the in-situ soil moisture measurements, it is important to examine the sensor performance under laboratory conditions before the actual field deployments. To attain this motive, first, we have examined the sensor transfer characteristics in which different sensors will have different peel off range.

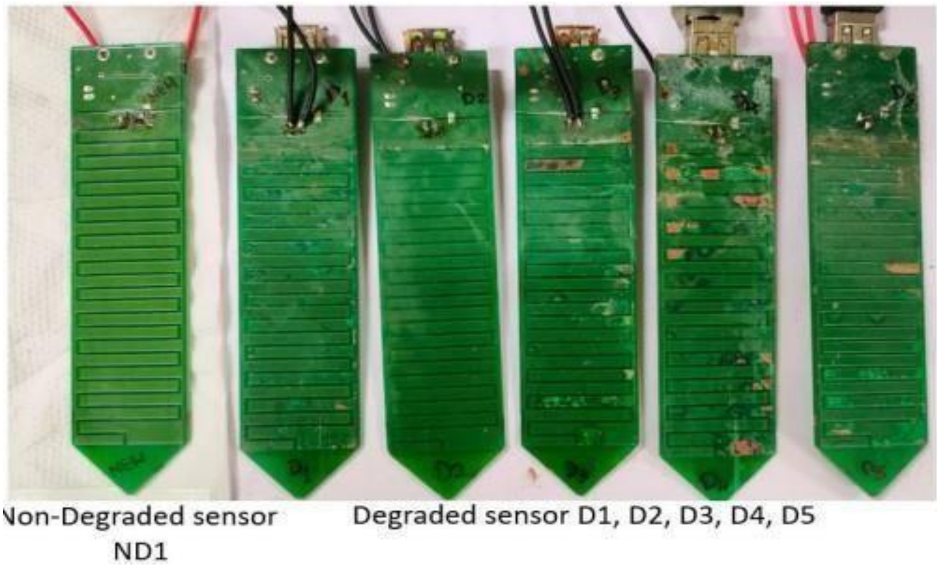

Fig 4.2 Degraded and Non-Degraded Sensor

Considering the fact that there is a need for Sensor-specific calibration needs baseline correction when the sensor deviates from its actual path, to increase sensor life even after it degrades with time.

We carried out the experiment with both non degraded and non-degraded sensor in different medium and observe the following change:

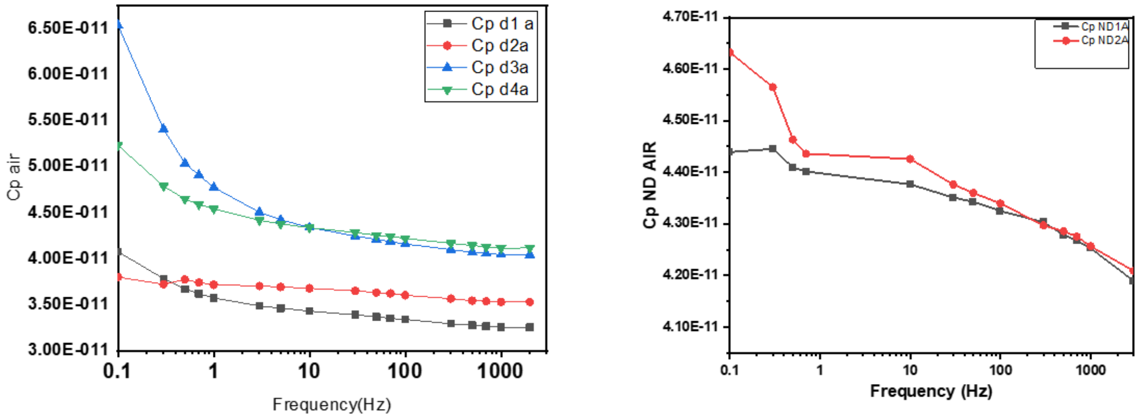

Fig 4.3 Sensor deployed in air as medium

In Figure 4.3 we have performed a comparative analysis of the response of the sensor in the air as medium with respect to frequency for degraded sensor and non-degraded sensor, for this purpose we have used four degraded sensors collected from the field and two newly fabricated sensors. From Figure 4.3, we observed that both the new sensors have the same response and are overlapping with each other on the other hand we can see that the scattered response of the nondegraded sensors. We can see that the sensor output at 1KHz frequency is about 40 pF for the non-degraded sensor and whereas for the degraded sensor, the response is in the range of 35 pF to 45pF which implies that the sensor capacitance has deviated from its actual value.

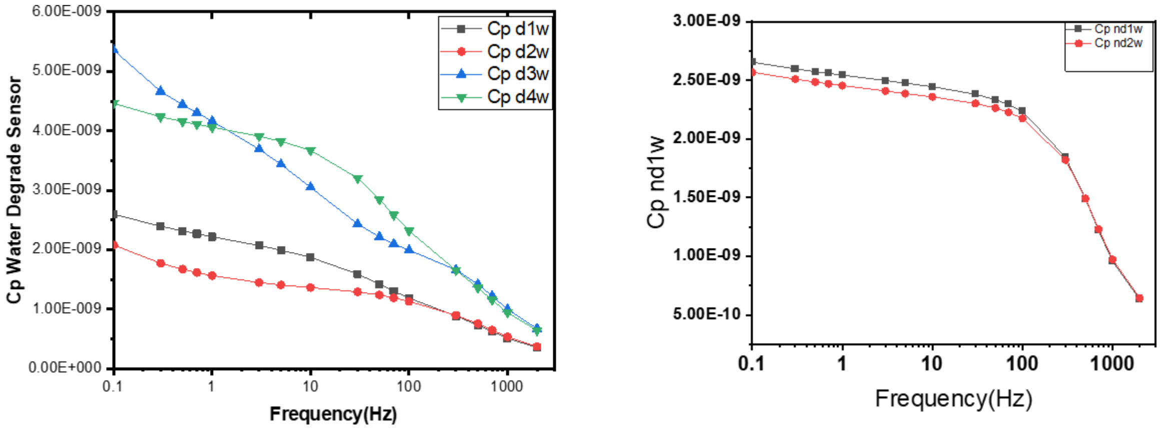

Fig 4.4 Sensor deployed in water as a medium

In Figure 4.4 we have performed a comparative analysis of the response of the sensor in the water as medium with respect to frequency for degraded sensor and non-degraded sensor. From Figure 4.4, we observed that both the new sensors have the same response and are overlapping with each other on the other hand we can see that the scattered response of the nondegraded sensors. We can see that the sensor output at 1KHz frequency is about 2.5nF for the non-degraded sensor and whereas for the degraded sensor, the response is in the range of 1.5nF to 4.3nF which implies that the sensor capacitance has deviated from its actual value.

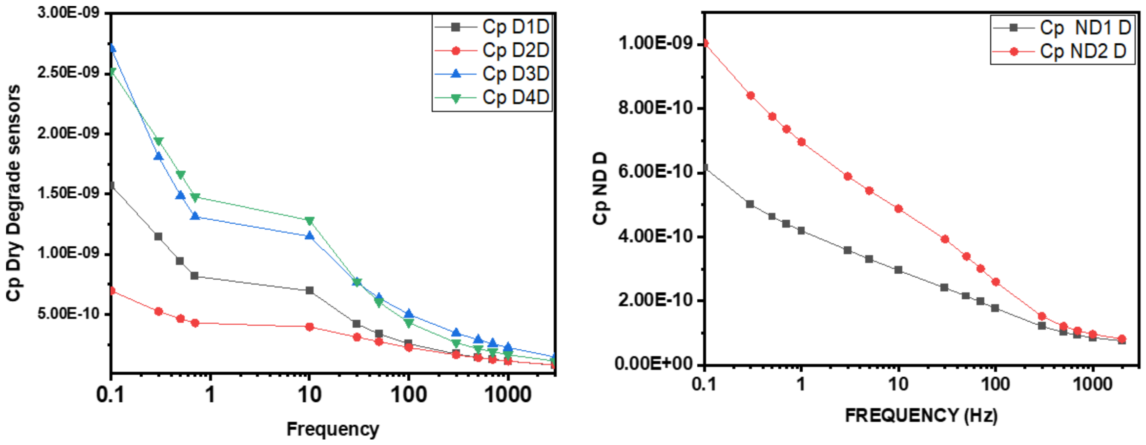

Fig 4.5 Sensor deployed in dry soil as a medium

In Figure 4.5 we have performed a comparative analysis of the response of the sensor in the dry soil as medium with respect to frequency for degraded sensor and non-degraded sensor. From Figure 4.5, we observed that both the new sensors have the same response and are overlapping with each other on the other hand we can see that the scattered response of the nondegraded sensors. We can see that the sensor output at 1KHz frequency is about 600pF for the non-degraded sensor and whereas for the degraded sensor, the response is in the range of 500pF to 1.5nF which implies that the sensor capacitance has deviated from its actual value.

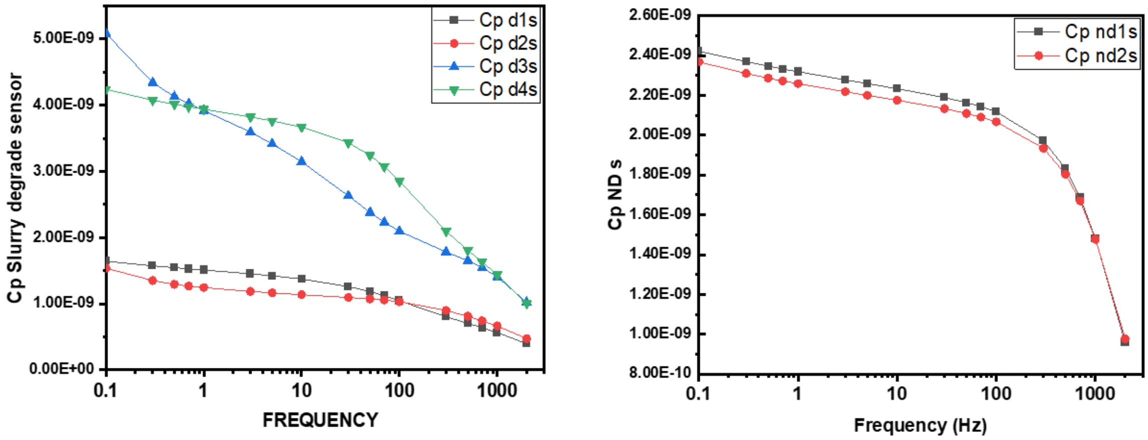

Fig 4.6 Sensor deployed in slurry soil as a medium

In Figure 4.6 we have performed a comparative analysis of the response of the sensor in the slurry soil as medium with respect to frequency for degraded sensor and non-degraded sensor. From Figure 4.6, we observed that both the new sensors have the same response and are overlapping with each other on the other hand we can see that the scattered response of the nondegraded sensors. We can see that the sensor output at 1KHz frequency is about 2.3nF for the non-degraded sensor and whereas for the degraded sensor, the response is in the range of 1.3nF to 4nF which implies that the sensor capacitance has deviated from its actual value.

So, we have examined the response of the sensor for all types of soil moisture content soil from dry soil to slurry soil and we have found that the response of the sensor has deviated from its actual value due to degradation occurring in the field.

MEDIUM	NON-DEGRADE AVERAGE	DEGRADE MINIMUM	DEGRADE MAXIMUM
AIR	44.5Pf	37.5pF	48pF
WATER	2.5nF	1.6nF	4.2nF
DRY	0.8nF	0.5nF	2nF
SLURRY	2.3nF	1.5nF	4nF

Table 1: Comparison of sensors response in various mediums.

Self-calibration of soil moisture sensor wrt sensor is performed when the sensor starts degrading because of Offset, drift end variations in gain due to temperature changes, ageing, and power supply changes cause measurement uncertainties of occasionally intolerable proportions. By making use of a self-calibration circuit and protocol the accuracy of an assessment is vastly increased. To overcome the degradation effect, we use 16:1 mux which comes into role when it observes any degradation. For the new sensor without any peel-off of fabrication, we note down the observation which is known as a baseline when the sensor starts degrading it will show upgradation or degradation from its actual value. So, calibration needs to be performed to bring it back to its base value. This is how we perform our second observation when the degradation effect occurs in the sensor. In the block diagram, the circuitry of the sensor in which the sensing area will have a 16:1 Mux capacitor which helps in calibration by avoiding degradation which is added in the relaxation oscillator which was already present in the soil self-calibrating sensor wrt soil. From DSO tektronics we observe the frequency output and also with the help of an LCR meter observe the capacitor of the sensor. We observe that after a sensor is deployed in a soil for a long time its electrode will remain exposed to soil which leads to resistive effect in capacitive type of sensor which results in sensor degradation.so we cannot get the appropriate results we desire; the data may vary. To overcome this, we designed a PCB in which mux is added if data vary from its baseline this will help to attain back to its baseline. It is tried on different state soil over a period of time the sensor starts degradation over a period of time due to several chemical and environmental factors. The peeling of is because of the resistiveeffect which its electrode catches due to PCB capacitive type.

We observe the effect by taking the non-degrade sensor (new sensor) and sensor with different peels of some highly exposed while some are lightly exposed over different periods of time. Observation of the experiment leads to that highly degraded sensor delta C/C of it changes drastically wrt to GWC whereas lightly degraded sensor Delta C/C is decremented wrt to GWC. So, our challenge is to bring both the increment and decrement results of highly and lightly degraded sensors to attain its baseline.

4.2 Flow of Arduino to carry out soil moisture sensor self-calibration

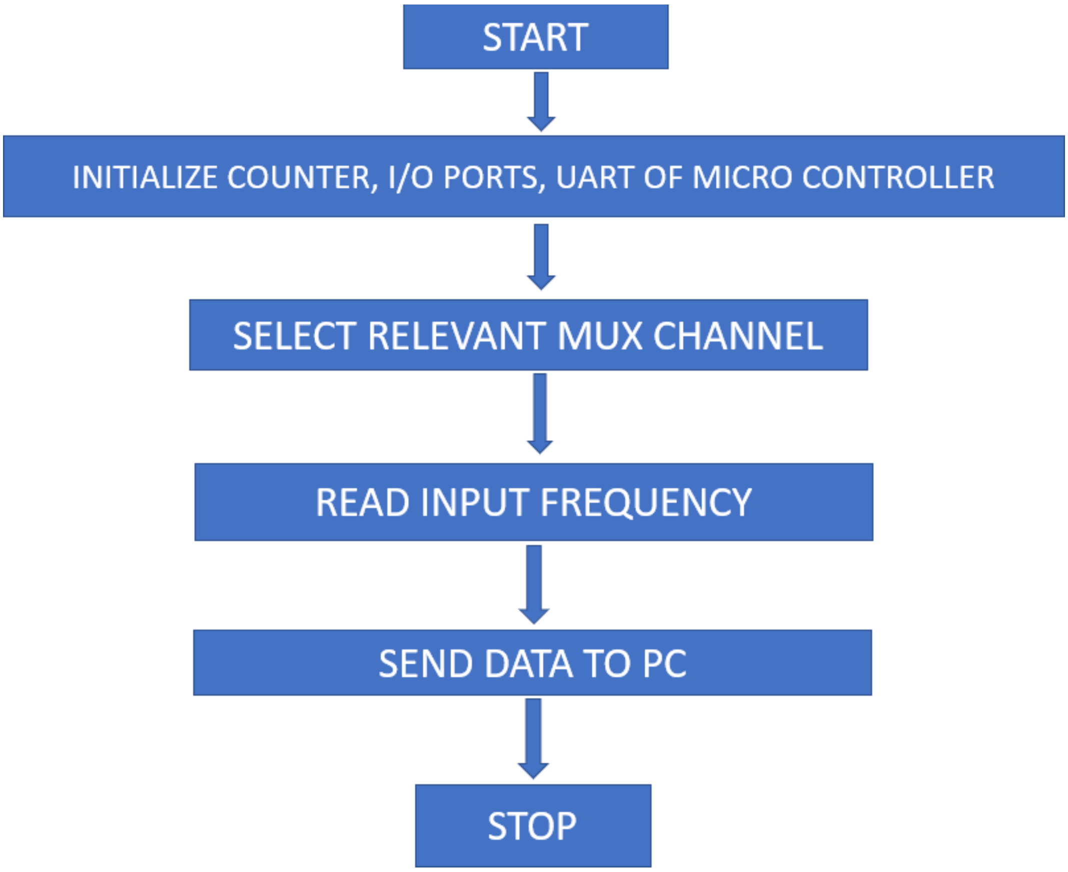

Fig 4.7 Flow of Arduino experiment

Firstly, initialize the counter, i/o ports, and UART of the microcontroller. Then select the relevant mux channel from the 16:1 multiplexer read relevant frequencies set at 250pF, 500pF, 700pF, and 1000pF send output to the PC, and observe the result. Also, compare it with the DSO result.

5 Observation with Hardware and Software Equipment

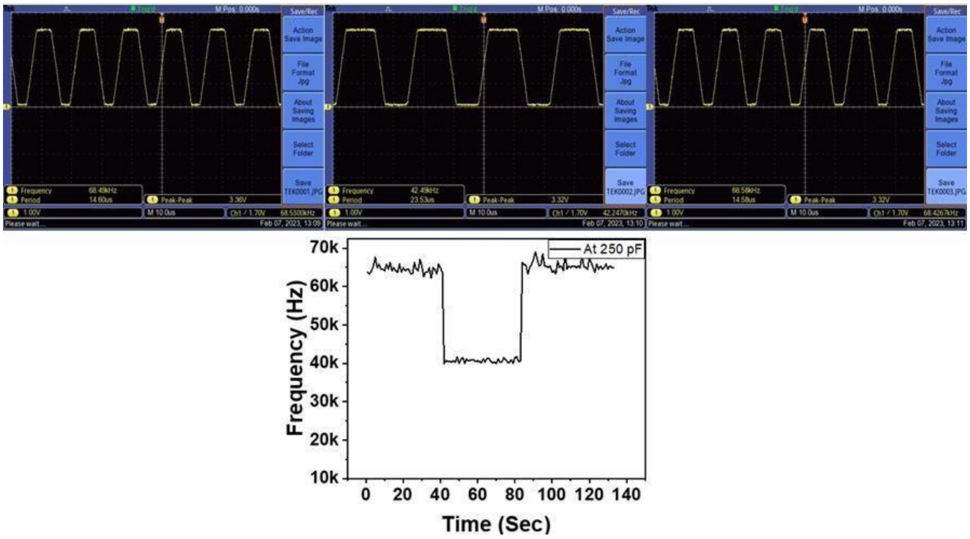

Fig 4.8 Freq v/s Time observation at 250pF

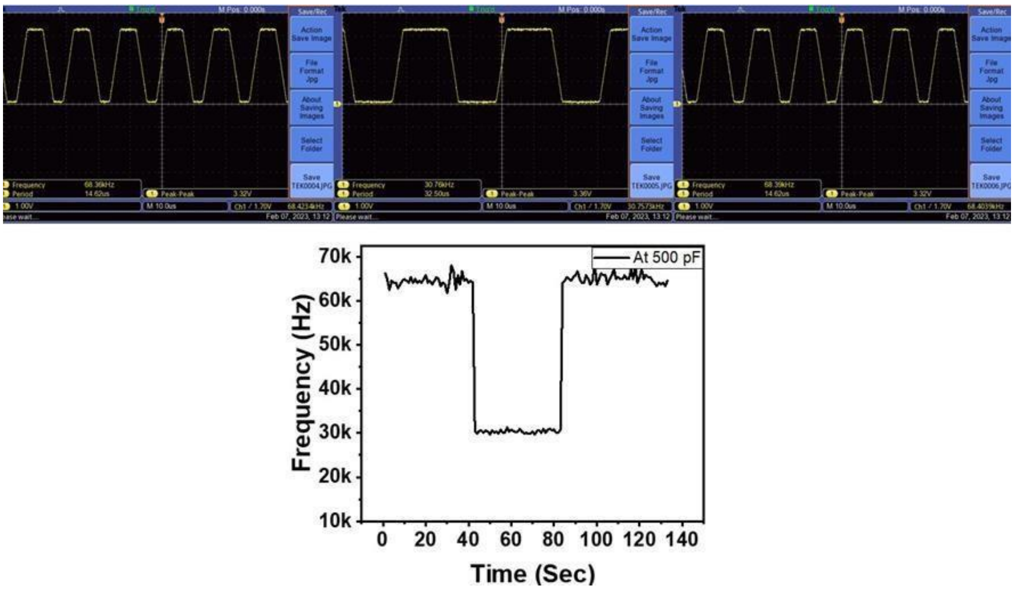

Fig 4.9 Freq v/s Time observation at 500pF

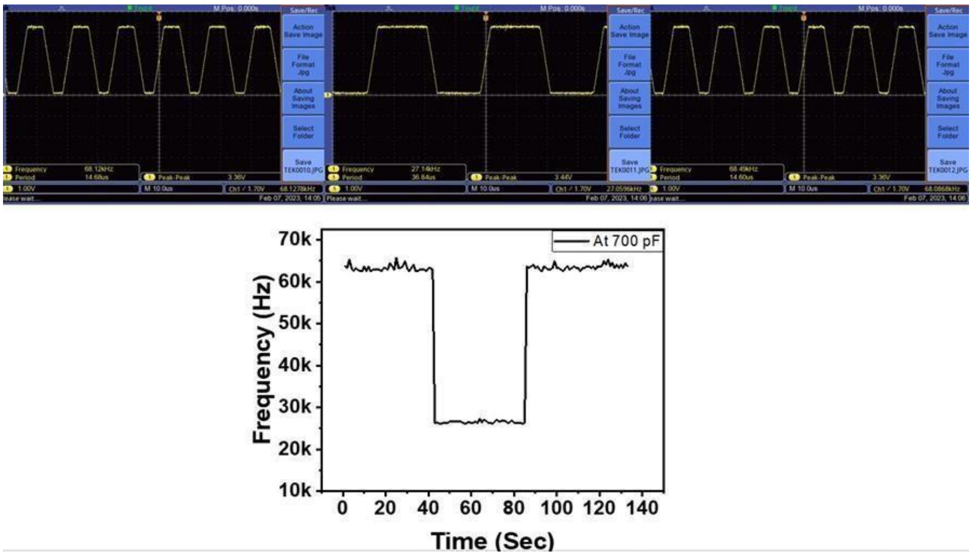

Fig 4.10 Freq v/s Time observation at 700pF

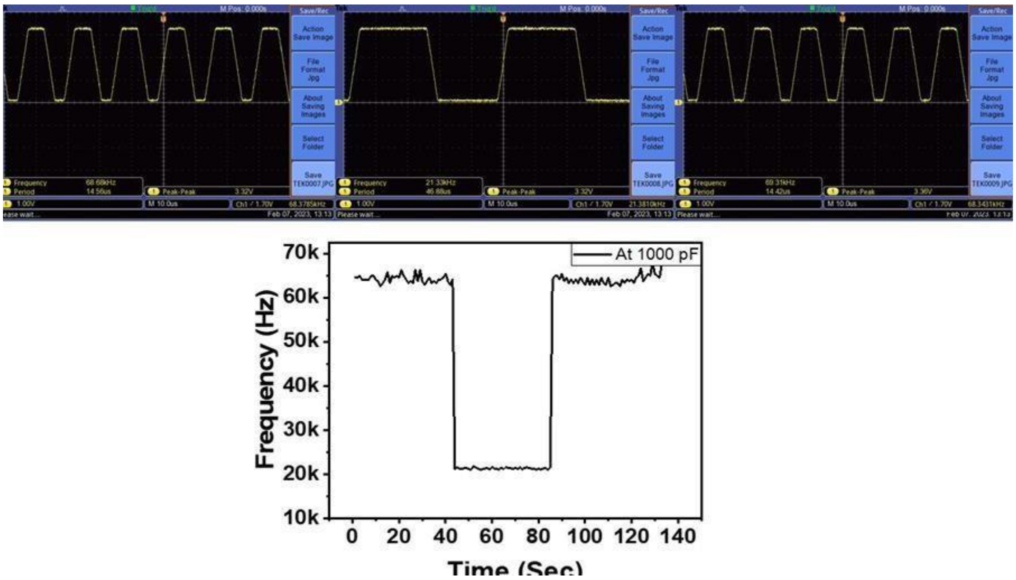

Fig 4.11 Freq v/s Time observation at 1000pF

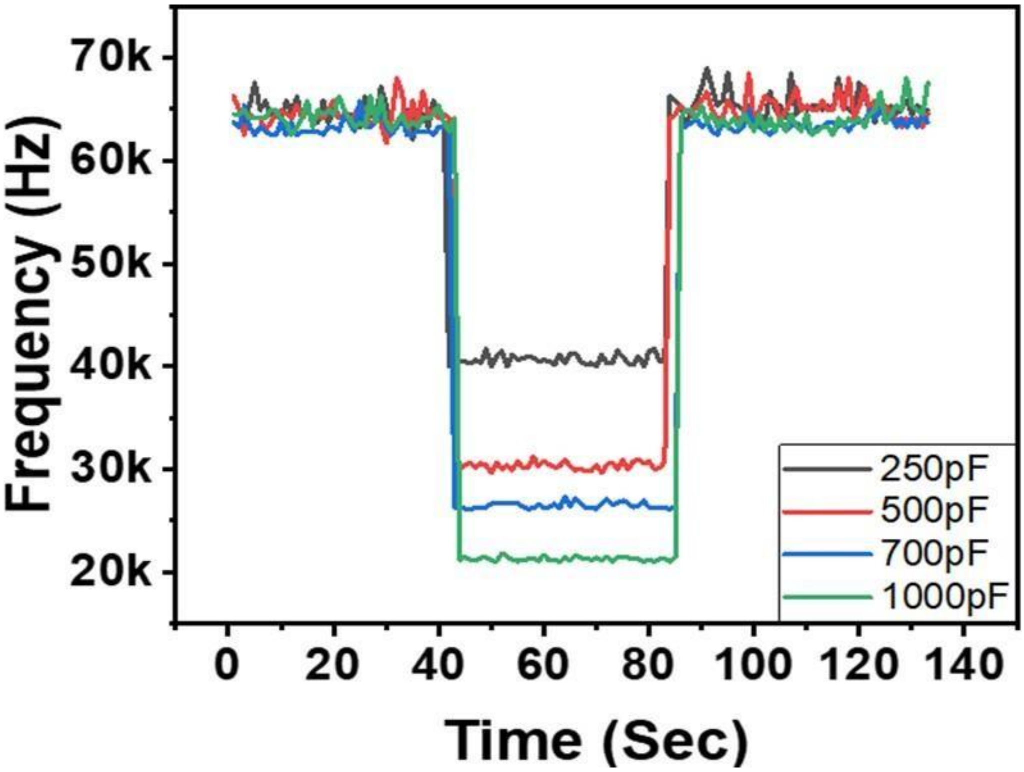

Fig 4.12 Observation merge at different frequency

The fig.4.8 to fig 4.11 depicts the observation carried out in the lab at both hardware and software levels i.e., in DSO and with the help of Arduino but the observation we got is same or both the different methods the sensor frequency degrades from its baseline at a certain time and due to the self-calibration technique, it attains back to its baseline after aperiod of time.

The fig.4.12 is the combined result of the Arduino experiment which tells that we set the frequency at 250pF, 500pF, 700pF, and 1000pF the sensor degrades more as the frequency we set increases at the same level of time.

5.1 Soil specific self- calibration wrt soil

Testing protocols are first, Soil Sample Collection and Preparation with Constant Drive Bulk Density the soil sample is collected from 6 different states of India, and its sample is prepared for each soil with different water content but having the constant drive bulk density wrt dry soil. Secondly, In a Mould deploy the sensor containing Soil Sample. The soil moisture sensor is deployed in a soil sample maintaining the same level as the sensor so measurements will maintain accuracy in all the samples. Tap the sample an equal number of times while inserting the sensor and don’t be harsh while deploying the sensor. Third, Generate the Sensor Response for Various GWCs. After deploying the sensor, we measure the frequency with the help of DSO, a multimeter, and a power supply we got the square wave with help of the frequency we calculated, generate the sensor response for various GWCs, and derive the delta F/F plot from frequency v/s GWC plots. Fourth, examine Delta F/F (Sensor Response). we receive the 6 different delta F/F plot for 6 different sensors. We examine all the plots and the range of sensor response wrt GWC, each sensor has a different delta F/F because each soil is having different physical properties and composition which results in various plots

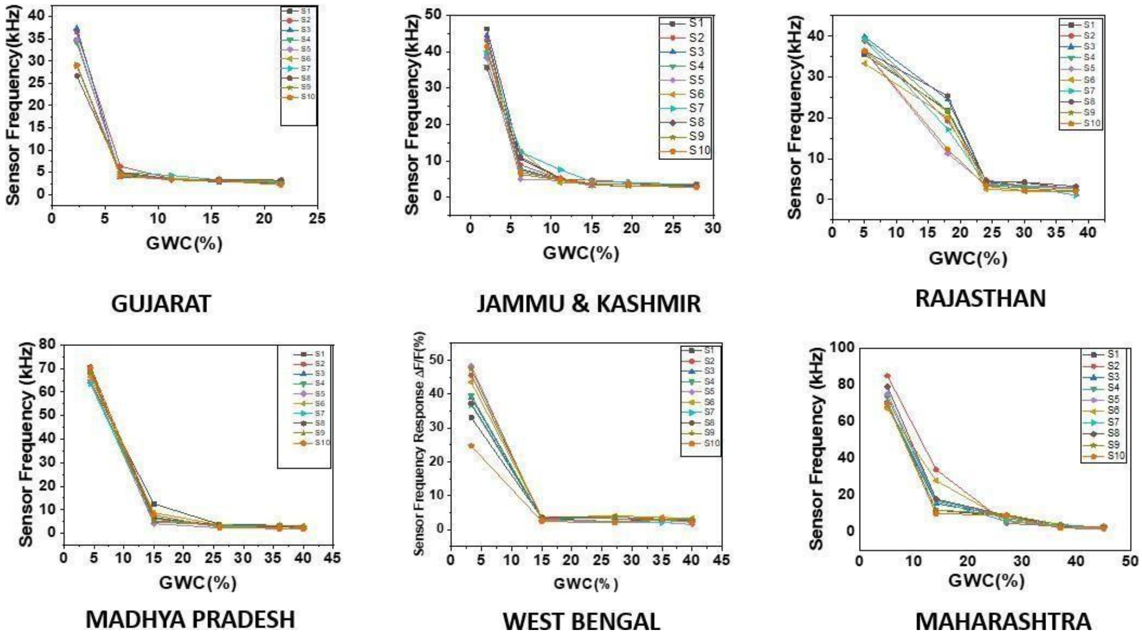

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Fig 4.13 Sensor Frequency (kHz) v/s GWC (%)

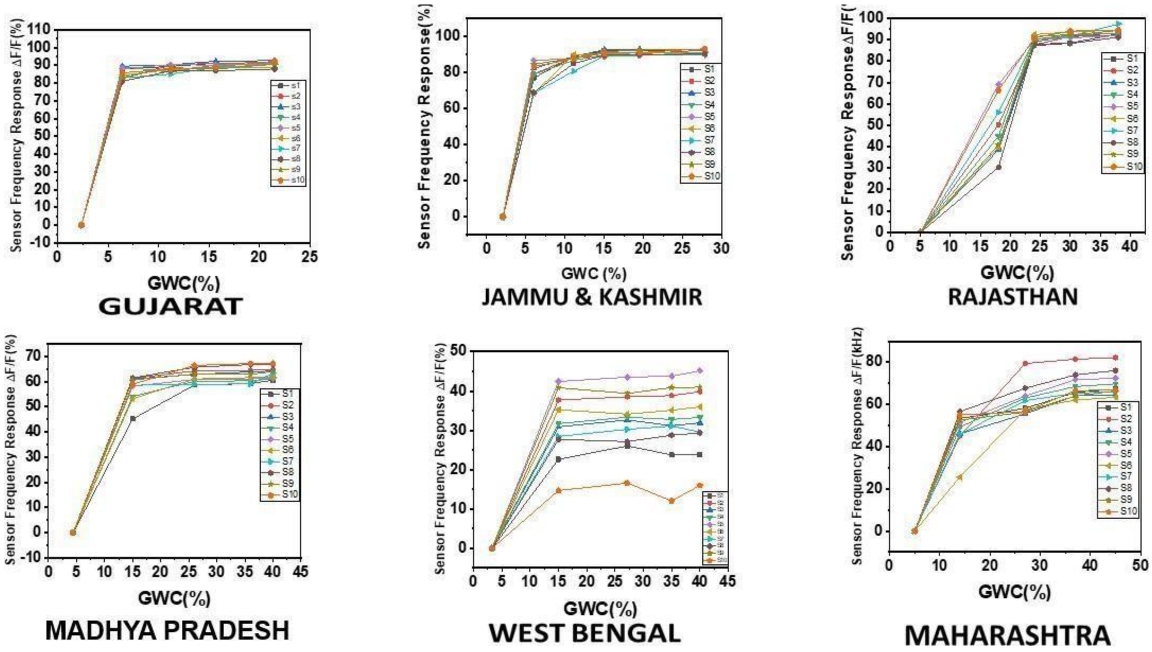

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Fig 4.14 Sensor Frequency Response v/s GWC (%)

As every state has different soil type it become necessary to test sensor behavior for all type of the soil available. For this purpose, we have collected soil from Gujarat, Jammu and Kashmir, Rajasthan, Madhya Pradesh, West Bengal, and Maharashtra. The reason behind to select this state for soil collection is because all these states have different soil type and as reported earlier.

each soil type has different moisture properties. We also taken 10 sensors to carry out these students to minimize the error by taking average of them. The base frequency of these sensors is around 98 KHz.

In Figure 4.13, we have studied the change in frequency of the sensor with respect to soil moisture content for six different states. From the figure, we observed that the pattern of the response is the same for all state soils but the output frequency with respect to soil moisture is different, the reason behind this is that every soil type has different field capacity, chemical, physical, and structural composition. From figure we observed that when soil moisture content increases sensor capacitance decreases monotonically.

By observing the response of the sensor (Sensitivity), from figure 4.14, we can say that the sensor 90% for Gujrat and Jammu & Kashmir soil, 95%b for Rajasthan, 60 to 65% for Madhya Pradesh, 20 to 45% for West Bengal and 60 to 80% for Maharashtra.

Chapter 5

Discussions and Conclusions

For both software and hardware simulation, the results discussed in chapter 4 are used. According to it the selection of the main and the backup path is done. Also, the software and hardware simulation results are the same i.e., The output of the relaxation oscillator (C to F) degrades and attains its baseline at different frequencies in both DSO and Arduino. It is compared with its original baseline. By default, when one 8:1 MUX enables the other 8:1 MUX will disable work according to the self-calibration mechanism. So, self-calibration for in-situ application can be done without any hindrance

Conclusion

In this research, we have developed an adaptive and reconstructible architecture for the signal conditioning and signal processing unit which can impulsively attain its original system structure and restructure system tasks and operations according to the degradation of the sensor detected by the self-calibration mechanism. Such systems will require human interference only in case of no prior existing plan. This research was challenging for us as we need a calibration be automated corrected while considering all undesirable environmental conditions.

We concluded to the point that we tested for different degrading and non-degrading sensor at different soil moisture water content and calculate its capacitance which degrades i.e., the baseline degrades so we tested on both hardware and system methods and concluded to the fact that sensor attain its baseline by adding 16:1 mux and various changes in our PCB circuit design.

We tested in different 6 states soil of India because each soil has its all physical and chemical characteristics Tested each soil with ten different sensor which are replica of each other but still the result a slight variation tested in different soil and also at different moisture content so we concluded the result of each soil of different states and all do have the different dry and slurry soil.

Future Work

Get the plausible plot of all Sensor frequency responses v/s GWC (%). Combining all the plots in one graph with the help of mathematical equations so a single self-calibration plot and sensor can be used for any type of soil irrespective of their soil type and physical or chemical properties. So main target to get single calibrating sensor for any soil or moisture content is so it can work in any situate and act as a calibrating sensor to attain the baseline of degraded sensor in any environmental factor.

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