Self-Healing Instrumentation for Capacitive Based Agriculture Sensors

by

Naisargi D Desai
202011033

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Declaration

I hereby declare that

(i) the thesis comprises of my original work towards the degree of Master of Technology in Information and Communication 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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This is to certify that the thesis work entitled Self-Healing Instrumentation for the Capacitive Based Agriculture Sensors has been carried out by Naisargi D Desai (202011033) for the degree of Master of Technology in Information and Communication Technology at Dhirubhai Ambani Institute of Information and Communication Technology under my/our supervision.

P. Vinay
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Prof. Vinay S Palaparthy
Thesis Supervisor

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Abstract

A digital system having a self-healing mechanism is becoming very promising and it is a kind of system upon which one can rely upon. It can detect failures or faults in the digital system and can fix them through self-healing or repairing. The systems having such kind of mechanism can recompense failures. This paper explains the self-healing mechanism used in the capacitive sensors used for the diagnosis of plant diseases in the agricultural field.

List of Principal Symbols and Acronyms

C	Capacitance
F	Frequency
R	Resistance
V	Voltage

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

CMOS	Complementary Metal Oxide Semiconductor
C to F	Capacitance to Frequency
DMR	Dual Modular Redundancy
GND	Ground
IC	Integrated Circuit
PCB	Printed Circuit Board
SCU	Signal Conditioning Unit
SPU	Signal Processing Unit

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Chapter 1
Introduction

1.1 General

1.1.1 Problem Formulation

The diseases in plants due to weeds or pests present in agriculture fields can damage the crops and their yield. The decrease in crop yield can create a major problem for the farmers as their income and productivity will be affected. The reason for a decrease in crop yield may be due to late recognition of plant disease or due to inefficiency in the field. To lessen such kind of issue, sensor-based technology is used and it is relevant in this field. It plays a very crucial role in diagnosing plant diseases. The novice method based on sensor technology has opened up a new path to improve crop yield and thereby reduce crop losses. To ease crop loss due to plant disease, researchers have proposed plant detection disease models based on external parameters wetness, humidity, and temperature which are worthy parameters for in-situ testing.

During or earlier field studies in-situ measurements, due to either environmental factors or mishandling of the system, the signal conditioning, and processing circuit operation fail quite often. A few of them are listed as follows.

1) The signal conditioning circuit gets defunct and shows wrong data.
2) System battery gets discharged fast because the signal processing unit won’t go into the hibernate mode.

1.1.2 Research Objective

To mitigate the aforementioned issues associated with the field deployments, we propose the self-healing instrumentation circuit. With the motivation of using sensors in the agriculture field to detect diseases and to make it work properly in the field, we have to inculcate the self-healing path in the system. So if there is any fault in the sensors or the system path due to some external interference or if there is some connection error or if there is some defect in the IC or the sensors, the self-healing system can correct the fault itself without halting the process. In this paper, a similar kind of approach is applied in the system which turns out to be a self-healing system for capacitive-based sensors used in the field.

With the use of complicated architectures on systems and powerful processors, hardware systems have become increasingly complex. These kinds of hardware systems are prone to failure in any area, lowering their performance. Hardware failure can occur at any time throughout the system's operation while it is completing duties. As a result, self-healing is being offered as a key that amends the system without impacting its performance. Self-healing hardware components can recover from or mend any damage to the system from within, without the need for human intervention.

The difference between self-repairing and self-healing is that self-repairing is the ability to maintain and reintegrate components into the system, whereas self-healing is the ability to replace damaged or malfunctioning components with functioning components in the same location. There's a link between self-healing and repairing as well. Self-healing is a bottom-up strategy that repairs a defective component, whereas self-repairing is a top-down approach that replaces a defective component. When designing such hardware systems, a hardware engineer can use whichever design method he or she wishes, bottom-up or top-down. Because the meanings of self-healing and self-repairing are so similar, the word self-healing is frequently used to refer to both.

Self-healing can be accomplished in a variety of ways, most of which rely on identifying damaged components and then mending them so that they can be reintegrated back into the hardware system. The primary goal of self-healing hardware is to maintain the system running at peak performance once the problem has been repaired.

With the advancement of transistor technology, process variations have gotten increasingly complex. Process differences have an impact on circuit performance, and as technology is scaled, it degrades quickly. The minuteness of such hardware designs has a considerable impact on analog and mixed-signal circuits. The size of the circuit and the compatibility of different electrical components can have a significant impact on noise characteristics, operating frequency, and other factors. Self-healing hardware systems are studied using actuators, sensors, and analog/digital control loops that detect the system's unpredictability impacts and shift the system to the highest feasible performance point using backup components or parameters that compensate for the variation effects.

Any hardware system's self-healing cycle is depicted in figure 1.1 Self-monitor mode keeps an eye on the system and gives a signal when unbalanced events occur. The following step involves the system changing to a self-diagnosis state where the fault is identified, data is taken out for the erroneous source, and its effect on the hardware system is seen. Upon identification of these, the system will attempt to adjust itself by immediately fixing the faults and switching to the best-expected next state.

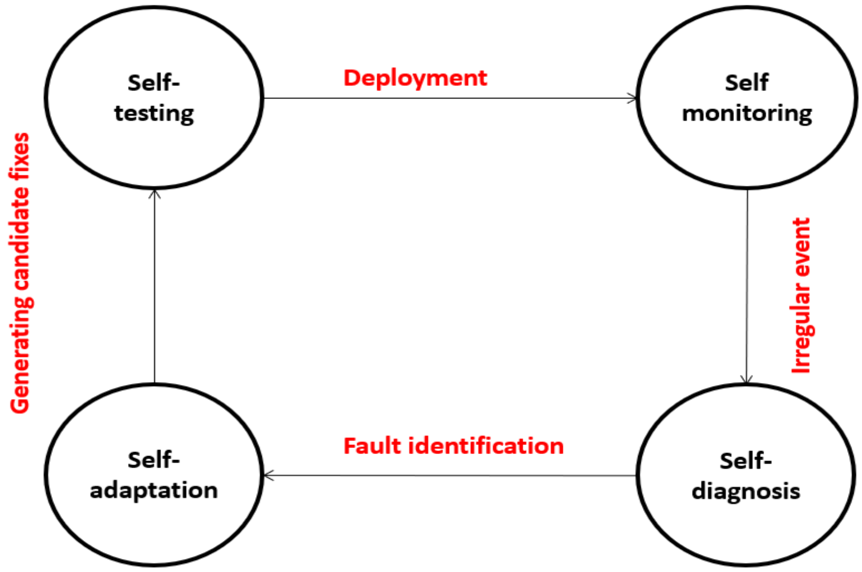

Figure 1.1: Cycle of self-healing of any hardware system [12]

To sustain the system's performance under the given conditions, a hardware system must self-heal. Self-healing can be accomplished in a variety of ways, each with its own set of benefits and drawbacks. Technical system failures can be caused by a variety of factors, including chemical, mechanical, electromagnetic, thermal, electrical, or software failures. Furthermore, the characteristics of failure are either everlasting (that is, they do not change) or transient (that is, they can change).

Self-healing or self-repair methods are based on a variety of ideas, including exposure to radiation, cold, and heat, restoring the system to its original form, reshaping, and self-healing.

The properties of self-healing procedures are governed by the following features:

· The redundancy rate and its percentage.

· The sort of detecting method employed by hardware that is undertaking self-healing.

· The rate at which the system's states are examined, as well as the order in which the system's states are checked, such as arbitrary and periodic checking.

· The method of retentive system performance assistance.

· Fault localization refers to a technique for determining the location of a breakdown.

· The status of the failure recovery strategy, whether offline or online.

1.2 Literature Review

In Ref[13], the aim is to increase the reliability of ANN-based hardware with a newly proposed autonomously reconfigurable neural network architectural framework, which is inspired by the central nervous system's (CNS) self-healing and self-recovery processes to react to unanticipated injuries or disorders. Rather than operating with a statistically overprovisioned redundancy all of the time, the proposed system is capable of dynamically determining an optimal network structure and synaptic connections of individual neurons, as well as incorporating any available spare neurons to maintain the best possible level of operation when errors occur.

In Ref[14], the proposed structure is a multi-cell architecture in which each cell is divided into two layers: functional and control. When its control unit fails, the functional module in the functional layer is utilized to identify a failure in its control unit and automatically pick alternate control units in surrounding cells. The control unit detects a fault in the functional module and uses self-repair algorithms to locate the location of spare cells and move faulty cell data to spare cells.

In Ref[15], the majority of biological creatures have a cellular structure that permits them to acquire fault tolerance and self-healing capacities. By adopting these processes and capacities from nature, scientists have been able to understand related occurrences and connected principles in order to develop complex new digital systems and boost their capacity. Based on these findings, computer-aided modelling, simulation, and experimental research into the fault-tolerance and self-healing abilities of embryonic systems have been conducted, with the goal of developing VLSI hardware structures that can mimic the operation mode of cells or artificial organisms with similar robustness properties as their biological counterparts.

1.3 Novelty of proposed work

The DMR (Dual-Modular Redundancy) technology, which is utilized in the signal conditioning unit, is the most prevalent failure tolerant technique. In this technique, there are two identical occurrences of the same component in the circuit (one is the main and the other is the backup), and the outputs of both are connected to a microcontroller that enables the backup whenever the main fails. DMR provides redundancy if one of the components fails. DMR is particularly beneficial in self-healing hardware systems when identical components are working in parallel. DMR is recommended over other redundancy methods for failure tolerant circuits when the design has reduced area overhead.

1.4 Organisation of the Thesis

The thesis is organized as follows: first, the background and technique of self-healing at the hardware level are described. Following that, the signal conditioning unit's self-healing mechanism is designed at the block diagram level. Different integrated circuits are chosen and then made to work together in terms of input and output properties. The circuit is simulated using TINA TI software to ensure that it works with the chosen components. After the circuit has been confirmed, EAGLE software is used to build a schematic and then a layout for the circuit on the printed circuit board. The signal conditioning unit's Gerber files are created, and a printed circuit board is created. After that, components are soldered to the PCB, and the hardware is verified using the PCB and a source meter.

Chapter 2
Interfacing

The self-healing instrumentation for capacitive-based agriculture sensors consists of signal conditioning and signal processing units. The power supply unit gives the desirable voltage for the system to operate. All the ICs present in this proposed system will get 3.3 V to operate.

In the signal conditioning unit, CMOS switches (ADG1604 and ADG884) and two capacitance to frequency converters (C to F LMV358) are present - one for the main path and the second for a backup path. The backup here means there is one spare component of the same part so if in some case the component in the original path doesn't work, the spare component will turn on. This backup path or a spare part will work as a self-healing path when deployed in the agriculture field.

In the signal processing unit microcontroller and WiFi module are present for IoT communications. All the digital inputs to the proposed system will be provided by the microcontroller (ATMEGA328P) by burning the embedded code into it. Also, the output of the C to F converter will be passed to the WiFi module with the help of a microcontroller. Figure 2.1 shows the interfacing of proposed multiple capacitive-based sensors with IoT features.

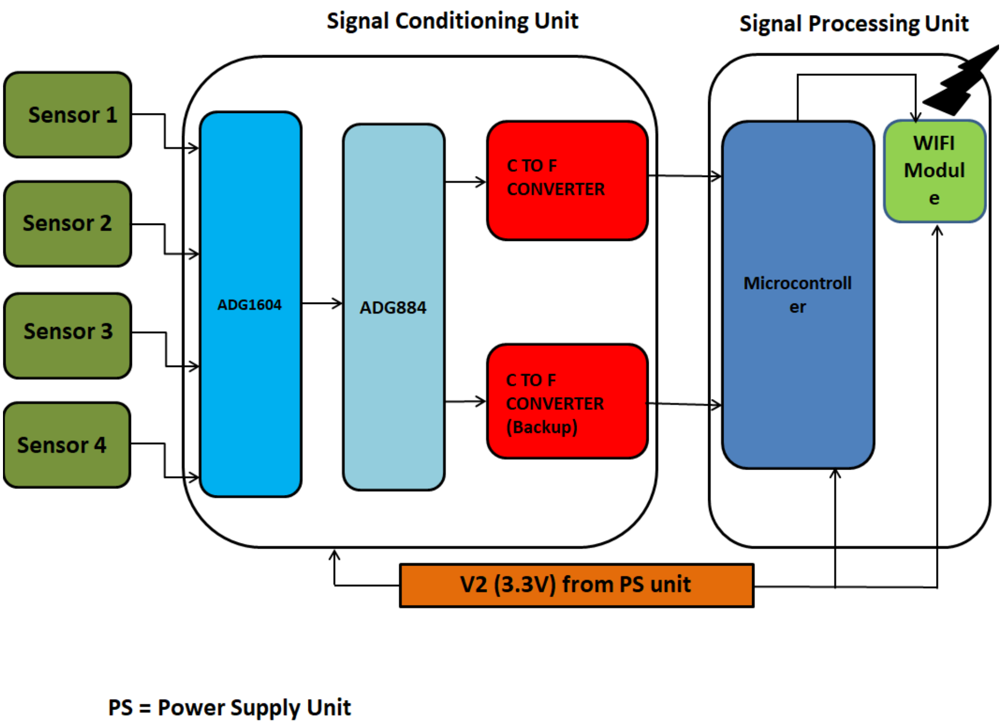

Figure 2.1: Multi-sensor interface electronics with IoT feature

2.1 ICs

The following ICs are taken in the proposed system because of their voltage compatibility to 3.3 V and Rail-to-Rail operation.

1) ADG1604

The above IC is chosen so that one can work with four different sensors together. One can select one sensor out of four and can measure its frequency in the proposed system. The enable signal here is kept high always so that the sensor selection continues without any problem. The selection lines are given the value according to the need and the sensors that need to be measured.

2) ADG884

The ADG884 is a CMOS (analog) switch. This IC is used for the selection of the main and backup paths. The enable signal here is kept high always so that the path selection continues without any problem. Port A and B of the switch can be given the input of the sensor or can be grounded. And the input as a sensor or ground can be selected by giving the appropriate digital value to the input port of the switch.

3) LMV358

The above IC is used for the voltage divider and buffer circuit and as a relaxation oscillator. Voltage divider and buffer will help to provide proper voltage to high impedance circuit and relaxation oscillator will convert the capacitive voltage of sensors into appropriate frequency.

4) ATMEGA328P

The microcontroller IC is used to provide digital inputs to the ADG1604 and ADG884 ICs i.e. 0 or 1. Also, it takes the output of the relaxation oscillator to its counter port and converts it into an appropriate frequency.

5) Wifi Module

The WiFi module takes the output from the microcontroller at its receiver pin and transfers it to the cloud via its transmitter pin.

Chapter 3
Internal Architecture

The detailed internal architecture of the signal conditioning and signal processing unit for the self-healing system is shown in figure 3.1. The internal architecture is designed according to the interfacing of proposed multiple capacitive-based sensors with IoT features explained in chapter 2.

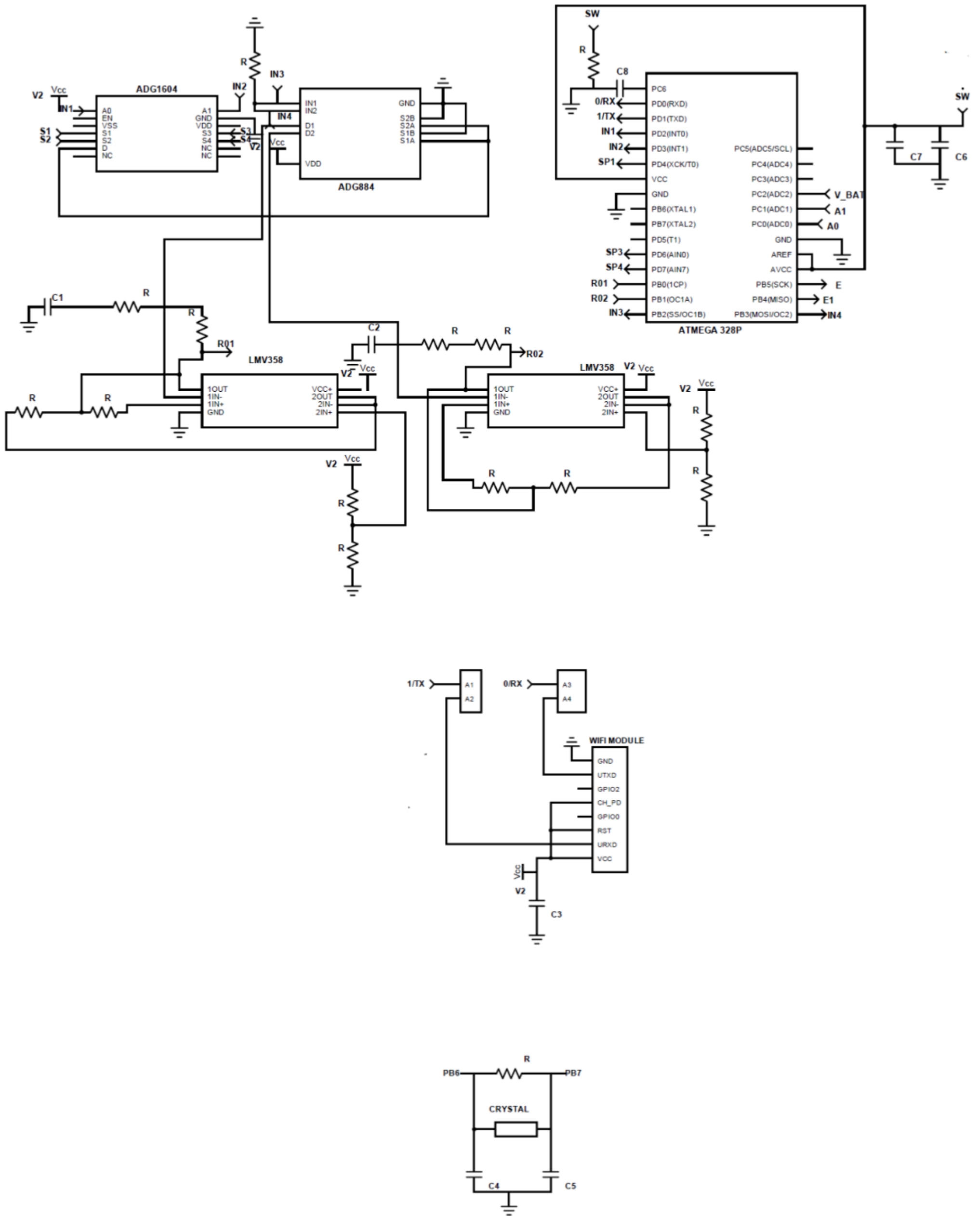

Figure 3.1: Internal Architecture of a proposed self-healing system

3.1 Signal Conditioning Unit

This unit consists of a 4:1 multiplexer (ADG1604), CMOS switch (ADG884), and capacitance to frequency converter (C to F). 4:1 multiplexer is used to select the sensor (capacitance value of one of the sensors) for which we want to see the output. The output of the mux component is given to the CMOS switch which will drive the value to the C to F converter. Here, the CMOS switch will drive both C to F main path and backup path. At a time only one path will be active i.e. main path. The backup path will work only if there is some failure in the main path to drive the device smoothly.

C to F is a relaxation oscillator that is used to measure the capacitance of the sensor which is variable and convert it to the desired frequency by using the following equation

$$F=1/2.2RC \cdots\cdots \text{(eq. 1)}$$

Where F is the measured output frequency of the C to F converter, R is the feedback resistor and C is the capacitance of the sensor.

3.2 Signal Processing Unit

This unit consists of a microcontroller and WiFi module. The output of the C to F converter is given to the counter port of the microcontroller and the analog output of sensors is given to the ADC port of the microcontroller. At a subsequent time, the microcontroller reads the frequency output and analog output and processes it, and then uploads it to the cloud using a WiFi module.

Chapter 4
Simulation

After designing the signal conditioning circuit, the design is verified in software, and also each component is tested individually by soldering it on a PCB board.

4.1 Software Simulation

For the software simulation of the proposed circuit, the testing has been done on Tina-TI. In this software, tested the SCU. First, the testing of the relaxation oscillator which is a C to F converter was done. The circuit for it is shown in figure 4.1 (main and backup path). The oscillator has a buffer and voltage divider circuit present with it. The buffer and voltage divider is used so that an equal and same amount of voltage is distributed in the entire circuit which is a high impedance circuit (among load and resistances).

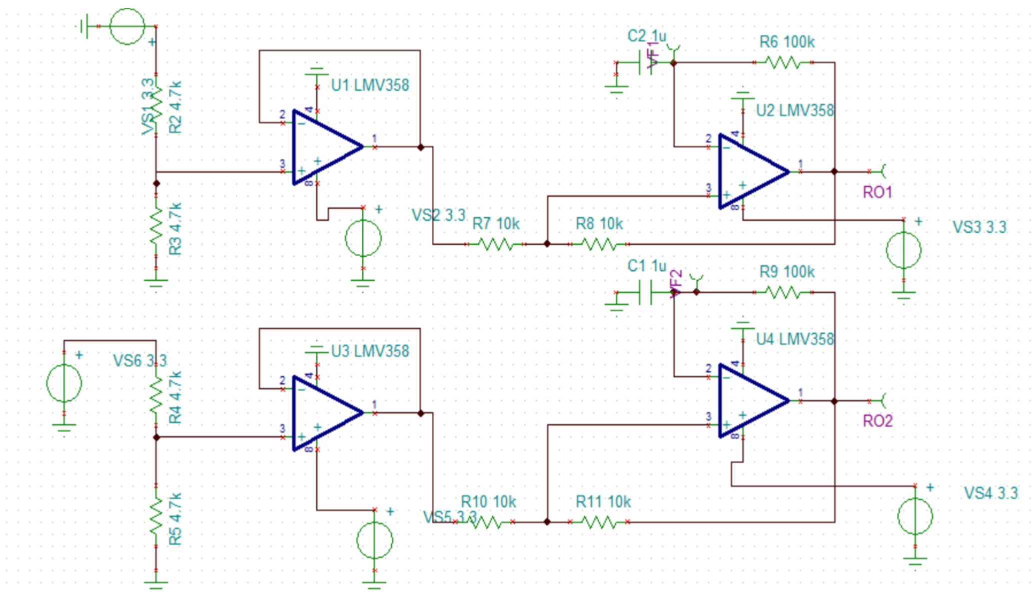

Figure 4.1: Relaxation Oscillator (C to F converter) with a buffer and voltage divider circuit

The expected output is a non-sinusoidal wave and the capacitor will charge and discharge according to the voltage level of the IC (here it is 3.3 v). The output will oscillate according to the capacitor charging and discharging. The output for capacitor valued at 1uF is shown in figure 4.2. At probes, VF1 and VF2 which are kept to observe the capacitor charging and discharging, a triangular waveform is obtained there, and at RO1 and RO2 which are the outputs of the oscillator, a square wave of 3.3 peak to peak voltage is obtained. As the relaxation oscillator circuit design with the buffer and voltage divider circuit works properly as per the expectations one can implement it for the proposed project for different capacitive sensors.

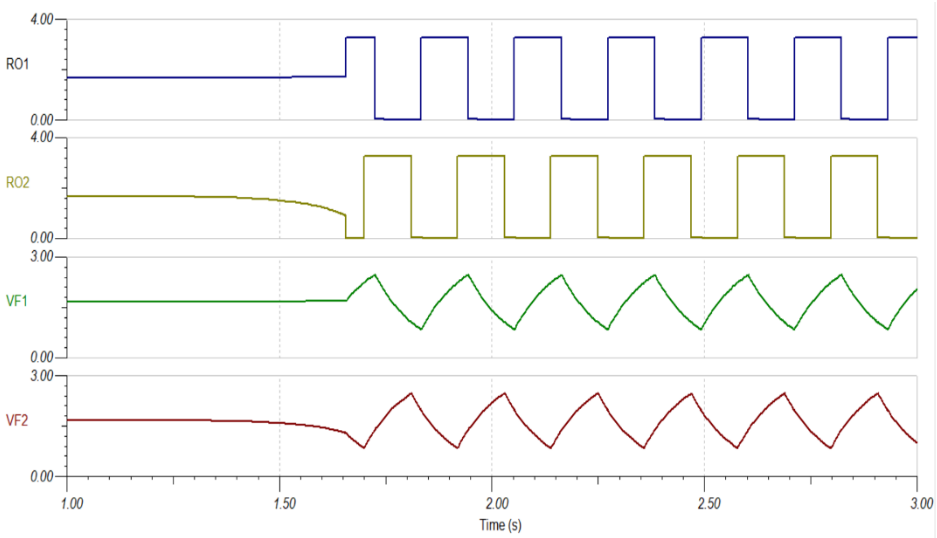

Figure 4.2: Output of Relaxation Oscillator circuit

Now, the simulation of the entire proposed circuit is done in Tina-TI. Figure 4.3 shows the SCU in which the main path is enabled using the ADG884 IC. The input of ADG884 is 1nF capacitance at pins 2 and 10 of IC. The input pins 5 and 7 are grounded. Output pins are 3 and 9 with are connected with the main and backup paths respectively. The enabling of the main path is done by giving IN1 of the IC as 1 and IN2 as 0. So, it will select pin 2 and pin 7 as input. Hence, the output pin 3 will get pin 2 input and output pin 9 will get pin 7 input and so it will enable the main path and backup path will be grounded so it will pass the output accordingly to the C to F converter.

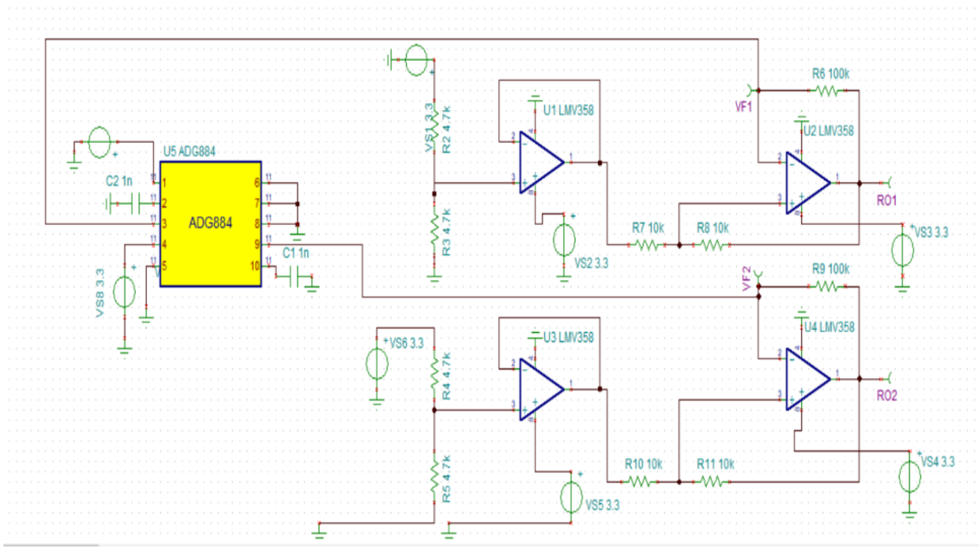

Figure 4.3: SCU - Enabling the main path

At the output of the oscillator, as shown in figure 4.4, at probe VF1, the triangular waveform is obtained which is the charging and discharging of the 1nF capacitor that is present at the input of the analog switch, and at probe RO1 the square wave is obtained which is 3.3V peak to peak as the voltage provided is 3.3 V. And also, as the backup path is grounded the output at RO2 and VF2 is zero.

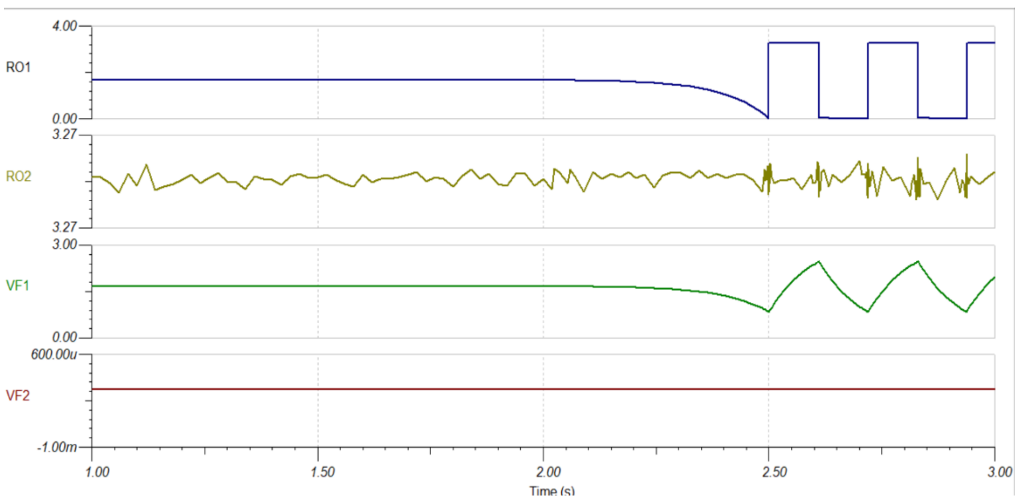

Figure 4.4: Output of the SCU (main path)

Figure 4.5 shows the SCU in which the backup path is enabled using the ADG884 IC. The input of ADG884 is 1nF capacitance at pins 2 and 10 of IC. The input pins 5 and 7 are grounded. Output pins are 3 and 9 with are connected with the main and backup paths respectively. The enabling of the backup path is done by giving IN1 of the IC as 0 and IN2 as 1. So, it will select pin 10 and pin 5 as input. Hence, the output pin 3 will get pin 5 input and output pin 9 will get pin 10 input and so it will enable the backup path and the main path will be grounded so it will pass the output accordingly to the C to F converter.

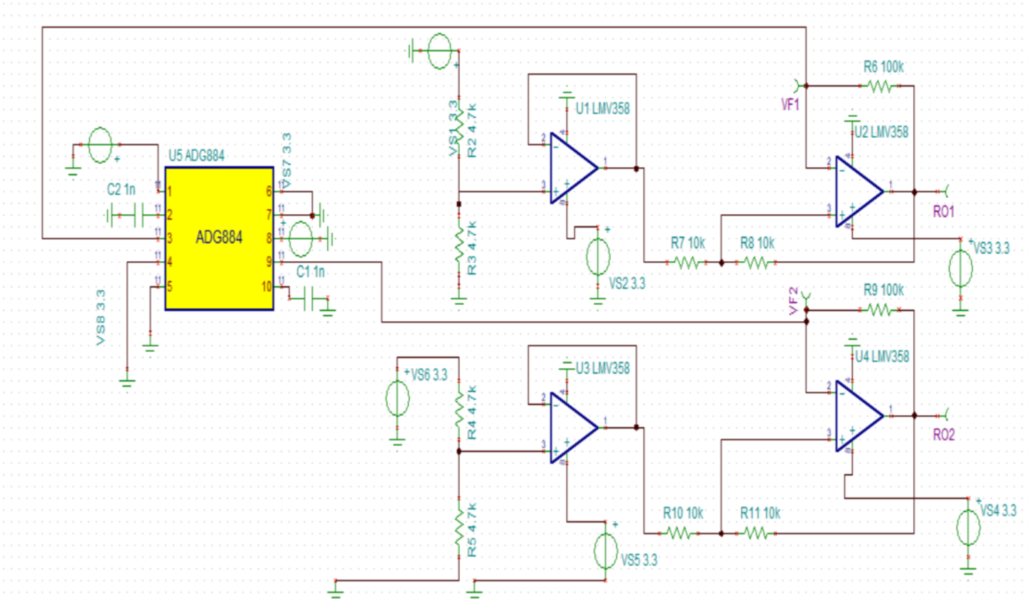

Figure 4.5: SCU - Enabling the backup path

At the output of the oscillator, as shown in figure 4.6, at probe VF2, the triangular waveform is obtained which is the charging and discharging of the 1nF capacitor that is present at the input of the analog switch, and at probe RO2 the square wave is obtained which is 3.3V peak to peak as the voltage provided is 3.3 V. And also, as the main path is grounded the output at RO1 and VF1 is zero.

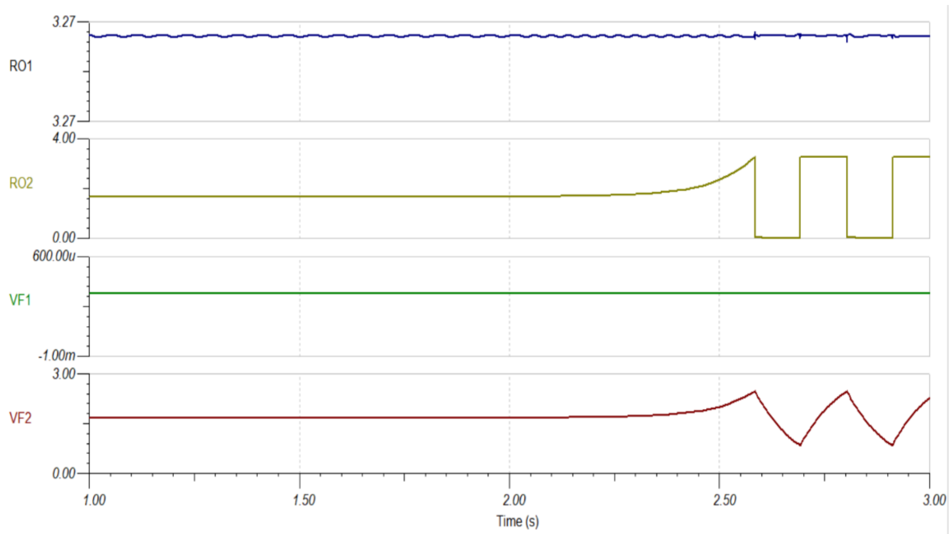

Figure 4.6: Output of the SCU (backup path)

Table 1.1 shows the truth table for the signal conditioning unit which will work on the mechanism of self-healing. Here the working of the system is explained.
Where,
IN1 and IN2 - Port selection input
Port S1B and S2B - GND (0 V)
Port S1A and S2A - 3.3 V
RO1 and RO2 - Output of port

When IN1 and IN2 both are 0 then port B will be selected and the output obtained will be 0 at both RO1 and RO2. When IN1 is 0 and IN2 is 1 then ports B and A are selected respectively and output at RO1 will be 0 V and at RO2 will be 3.3 V. When IN1 is 1 and IN2 is 0 then ports A and B are selected respectively and output at RO1 will be 3.3 V and at RO2 will be 0 V. When both IN1 and IN2 are 1 then output at RO1 and Ro2 will be 3.3 V. This same truth table is applied for the selection of the main and backup paths.

IN1	IN2	PORT SEL(S1)	PORT SEL(S2)	RO1	RO2
0	0	S1B	S2B	GND	GND
0	1	S1B	S2A	GND	3.3V
1	0	S1A	S2B	3.3V	GND
1	1	S1A	S2A	3.3V	3.3V

Table 1.1: Truth table for Signal Conditioning Unit

4.2 Hardware Simulation

The PCB designing of the proposed circuit is done in Eagle software. The hardware verification is done by placing the components on the board.

The placement of the components on PCB for signal conditioning and signal processing is shown in figure 4.7. After soldering all the components on the PCB, every component is checked individually to check its functionality. Also, the continuity is checked to make sure that components are properly connected and have also checked the compliance i.e. current. The highlighted part in red is the self-healing mechanism for SCU and the highlighted part in black is SPU.

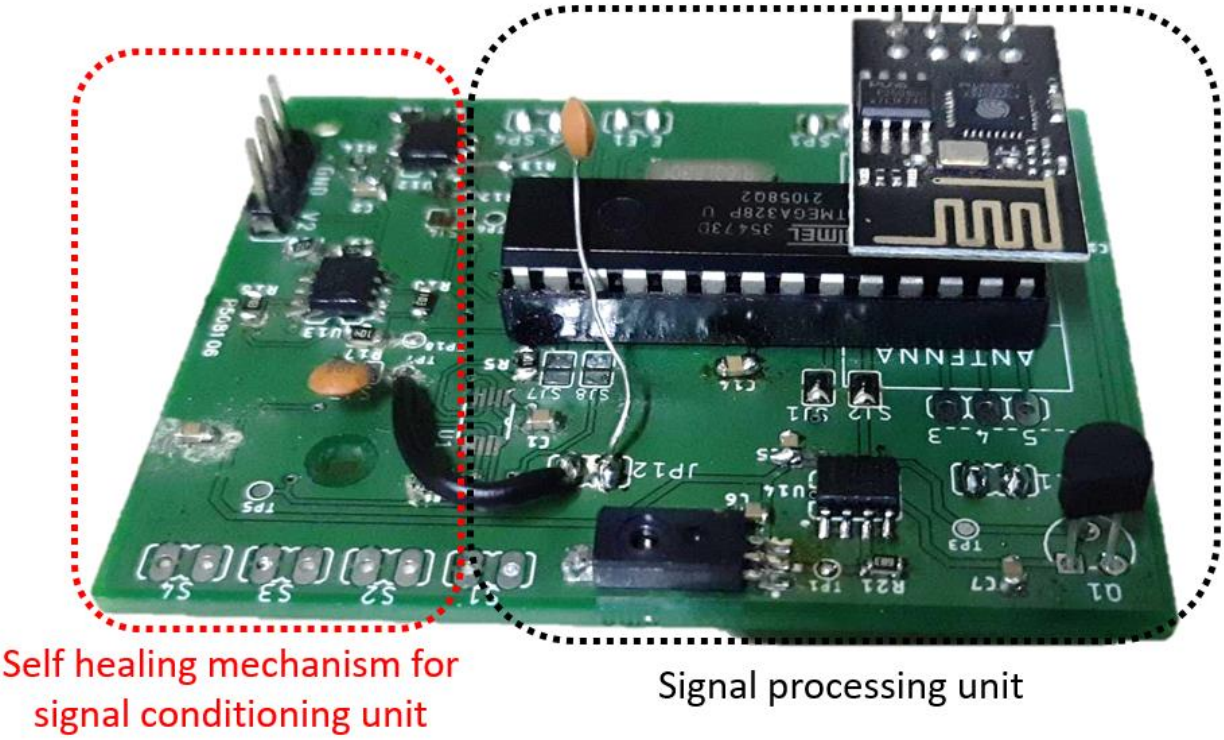

Figure 4.7: Signal conditioning & processing unit soldered PCB

The following component is being tested and verified:
i) C to F converter - The standard capacitance i.e. 1nF is used as its input to check the functionality. According to the theoretical result, its output frequency should be 4.5kHz. So after connecting it with the source meter and oscilloscope we obtained the output which is also approximately 4.5kHz as shown in figure 4.8 for the main path and figure 4.9 for the backup path. So our theoretical and practical values matched. Hence, this part of the circuit was tested and verified successfully. Hence, verification of both the main path and backup path is done.

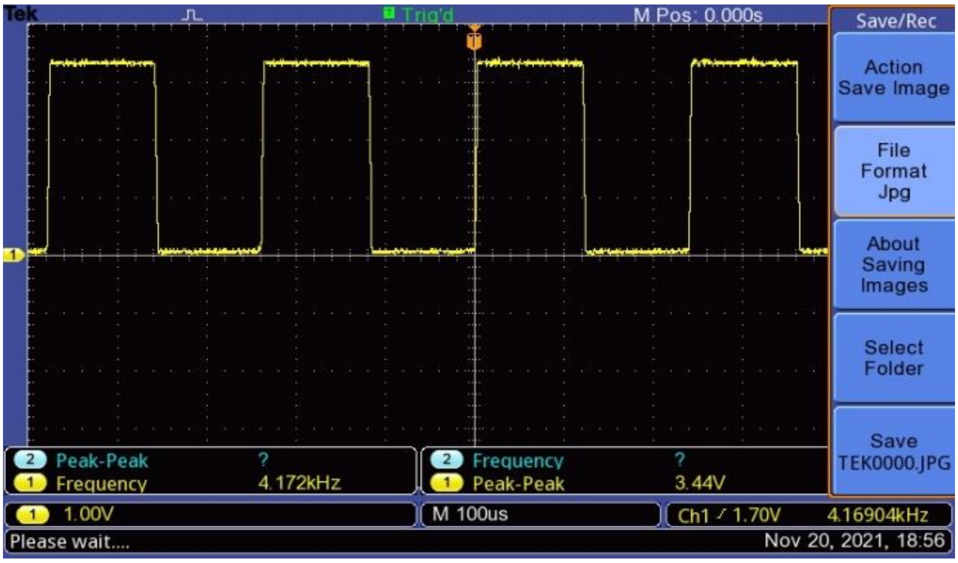

Figure 4.8: Output of C to F converter (main path)

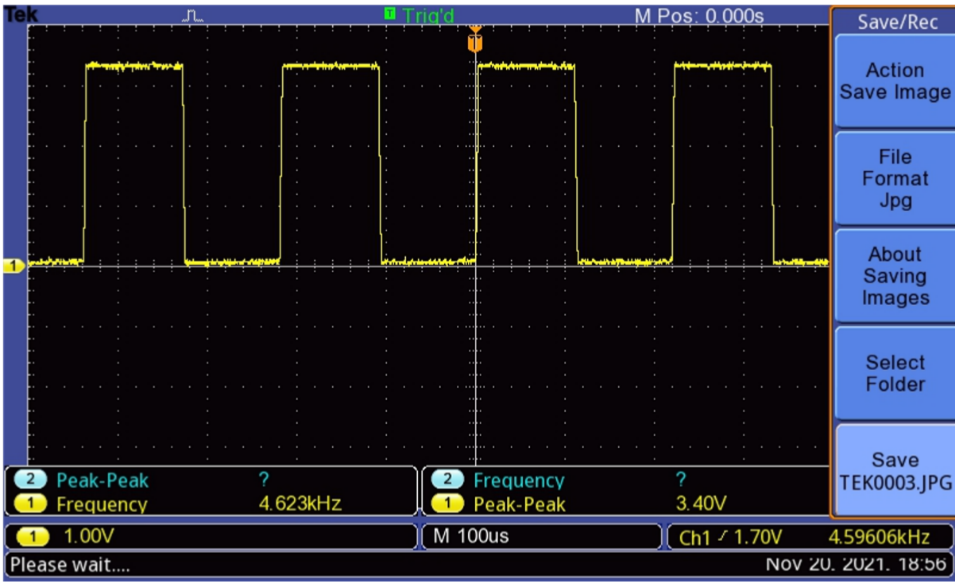

Figure 4.9: Output of C to F converter (backup path)

ii). Temperature sensor – The output of the temperature sensor was around 0.93V after giving it 3.3V as input practically through the source meter at 25° Celsius which was the desired value according to the datasheet.
iii). Humidity sensor – The output of the humidity sensor was 1.7V practically after supplying 3.3V to it through the source meter.
iv). ADG1604 (4:1 mux for sensors selection)
v). ADG884 (Analog Switch for selecting main and backup path)

4.3 Proposed Flow

The proposed flow of the self-healing mechanism for capacitive-based sensors is shown in figure 4.10. It will start by selecting the sensors and then will go to the self-healing part as discussed in the simulation. It will generate the output according to the value of the sensors. If the practical value matches the theoretical value then pass it to the microcontroller counter port where it will count the frequency again and it will be received by the WiFi module and it will transmit the output to the cloud.

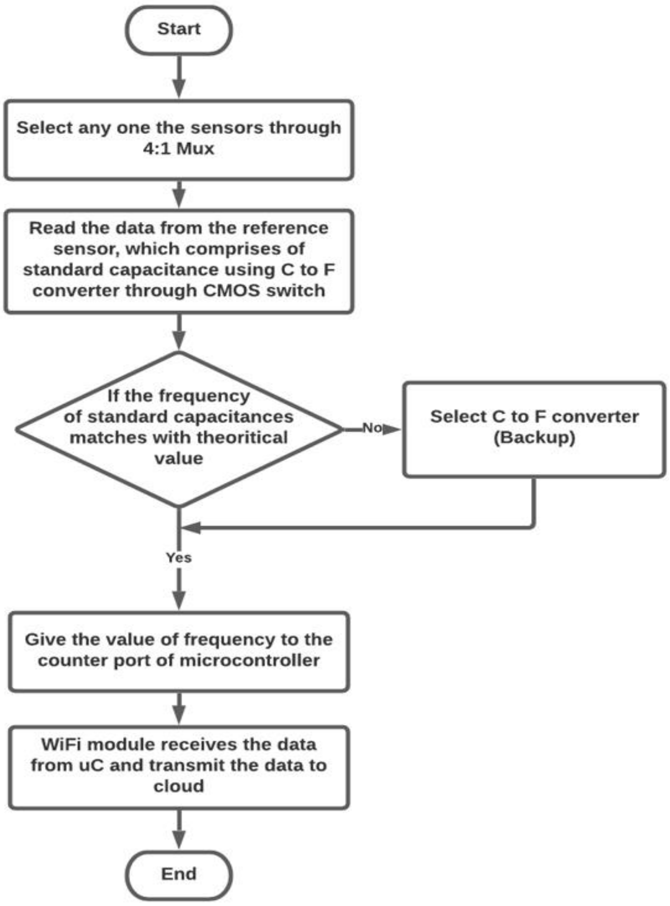

Figure 4.10 Flowchart of a self-healing system

Chapter 5
Discussions and Conclusion

5.1 Discussion of Results

For both software and hardware simulation, the truth table discussed in chapter 4 is 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) is 3.3 V. The main and backup paths will be chosen according to the working of the system. By default, the main path will be selected and if there is some fault or failure in that path then the backup path will work according to the self-healing mechanism. So, plant disease monitoring can be done continuously without any hindrance.

5.2 Conclusion

In this paper, we have developed an adaptive and reconstructable architecture for the signal conditioning and signal processing unit which can automatically adapt its system structure and reorganize system tasks and operations according to the failure detected by the self-healing mechanism. Such systems will require human interference only in case of no prior existing plans.

5.3 Future Work

1). Create artificially intelligent programming (Embedded C code) to detect system flaws and begin system preservation. To describe the estimation of failure using system data, real-time data from the field will be necessary. The system will be monitored throughout time, and any lapses in data collection will be detected. A machine-learning technique will be used to catalog and forecast the system's behavior based on real-time data.
2). Testing and field deployment of the proposed self-healing Signal Conditioning Unit for any IoT-enabled agricultural system.
3). ASIC design can be implemented as the extension for the proposed work.

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