KING FAHD UNIVERSITY OF PETROLEUM & MINERALS

Electrical Engineering Department

EE 411: Senior Design Project

Term # 211
Section #10

Non-Invasive Glucose Monitoring System

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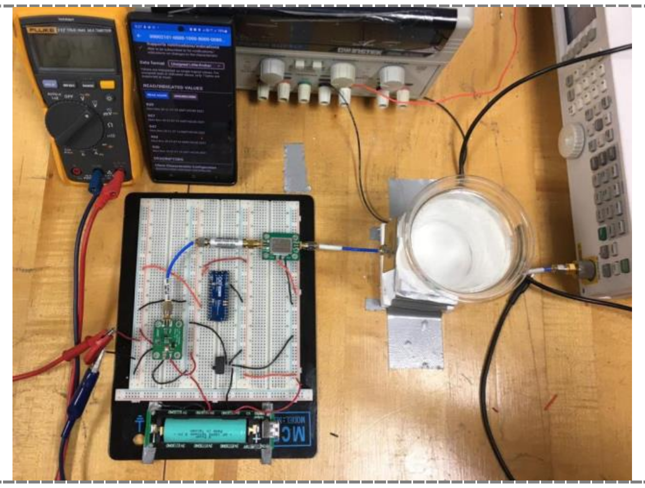

Abstract

This is the final report of our senior design project, which is about designing a non-invasive glucose monitoring system, implement it, and test it experimentally with multiple scenarios to accomplish proper findings of the relationship between the patients’ glucose level and the output voltage from the designed circuit. The designed circuit contains at the input a LNA that amplify the reflected signal, which is weaker than the transmitted signal. The amplified signal, then, get filtered by a BPF to eliminate the surrounding noises. After that, the signal is converted to DC voltage using the RF to transfer it to the microcontroller, which is the BLE Arduino nano, since it accepts DC voltage only. The microcontroller processes the voltage and convert it to glucose level at the patient’s screen.

Acknowledgments

After thanking Allah, we would prefer to acknowledge and thank our university King Fahd University of Petroleum & Minerals for its highly appreciated support throughout our study years. Our great thanks to the university again and the Electrical Engineering Department for the support during our senior design project. Also, we would like to send our special thanks to our project advisor Dr. Yaqub Mahnashi for his remarkable support and his essential advice that guided us to achieve our goal of this senior design project. Our warm appreciation and thanks to Dr. Yaqub Mahnashi again and Dr. Hussein Attia for their patient and support during the whole semester.

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List of Abbreviations

AC	Alternating Current
ADC	Analog to Digital Converter
BPF	Band Pass Filter
CGM	Continuous Glucose Monitoring
DC	Direct Current
IEEE	Institute of Electrical and Electronics Engineers
ISM	Industrial, Scientific, and Medical radio bands
LNA	Low Noise Amplifier
PCB	Printed Circuit Board
RF	Radio Frequency
WHO	World Health Organization
BLE	Bluetooth Low Energy

Chapter 1
Introduction

In this chapter, we will introduce to the main idea about this project. We will also discuss its importance and how it has a high impact on its user's life. In addition, its objectives will be presented.

1.1 Overview

No one can argue nowadays about Diabetes being one of the most common diseases around the world. Diabetes was the direct cause of death to 1.5 million people in 2019 according to WHO [1]. This shows that a diabetes patient has to take serious actions toward his/her health situation by monitoring the glucose level in his/her blood since it is the best criterion that indicates the severity of a patents condition. As a result, patients have to endure inconvenient methods of measuring the blood glucose level that cause pain and stress. Therefore, our project will focus on developing monitoring methods to be more convenient and flexible.

1.2 Needs Statement

According to WHO, blindness, heart attacks, stroke, and lower limb amputation, have one common major cause which is Diabetes [1]. This illustrates the huge impact that Diabetes can do on someone's life. Furthermore, almost half a billion people worldwide have diabetes and most of them lives in low to middle income countries according to WHO [1]. As a result, every Diabetes patient needs to monitor his/her glucose level in the blood in order to maintain the best health care and avoid any dangerous consequences. That is usually done by using an invasive and painful methods that the existing glucose monitor devices provide. As a result, a monitoring system is needed that has a non-invasive and unpainful monitoring process to ensure the most convenient way of blood glucose levels monitoring.

1.3 Project Objectives

The aim of our project is to design a glucose monitoring device that has a convenient, flexible, and efficient method to monitor the glucose level in the blood. The patient will be able to know his/ her glucose level easily without feeling pain or being anxious about using any invasive materials. Moreover, the patient will be observing his/her glucose level more frequently and he/ she will be aware of his/ her condition and its severity. The device will be attached to the patient's body and it will sense the blood glucose level without any physical interaction. The device will process the information that have been sensed and it will interpret it to the patient in a way that is easily observed.

1.4 Project Impact

Unarguably, the impact of this project is huge in various aspects of any diabetes patient's life. First of all, it will facilitate the patient's monitoring experience. The diabetes patient will no longer need to live the frequent painful and stressful process of measuring his/her blood glucose level several times a day. Instead, he/she will just observe his/her blood glucose level that the device will monitor frequently during in its active time unpainfully and noninvasively. Moreover, this easy method of monitoring will allow wider range of patients to monitor their glucose level. Patients who were unable to depend on themselves due to the complexity or the relatively hard way of glucose monitoring that the other devices provide. Second of all, the device's continuous way of monitoring will ensure better health care than the less frequent method that the other monitors require. That is, the patient will be more aware of his/her blood glucose level and how dangerous his/her condition is, which may require fast and efficient way of handling depending on its severity. Third of all, the project will enhance the life of a diabetes patient financially. The existed glucose monitors require consumable parts that are needed to be purchased frequently, such as needles of measuring strippers, which will cost a fortune over a long period of time. In contrast, this project aims to a device that can serve the patient for a long time without any need of purchasing consumable materials or parts which can cost, in some cases,
more than the actual price of their monitor. Lastly, the absence of consumables in our device will lead to less plastic waste which is one of the biggest issues that prevents the enhancement of our environment.

1.5 Project Management

Table 1-1: Team Management

No.	Student Name	Student ID	Main Tasks
1.	Abdullah Alshehri	201665800	- Group Leader. - Analog Part. - Digital Part. - Manage Parts Orders. - Cost analyzing. - Communicating with Other Sections - System Testing.
2.	Ali Alnemer	201627320	- Analog Part. - Power Consumption Unit - PCB Designing. - System Testing.
3.	Majed Albadrani	201684680	- Analog Part. - Digital Part. - System Testing. - Data Gathering/ Analyzation and Presentation. - MATLAB Programming.
4.	Abdulaziz Alamoudi	201645080	- Analog Part. - System Implementation. - System Testing. - Digital Part

Chapter 2
Requirements Specification

This chapter provide an illustration of the limitations of similar existing products and how their functionalities. In addition to the evaluation of the marketing requirements and the constraints will be faced. Also, the standards that will be followed.

2.1 Literature and existing product Survey

One of the most common diseases around the world is diabetes. It is ranked among the top 10 most common diseases of about 422 million people around the globe and it is increasing steadily over the past few decades [1]. The risk of diabetes is getting worse on the low to middle- income people, who is suffering from the expenses of the monitoring devices [1], which increases the need of these devices with lower prices.

The beginning of the monitoring devices can be tracked back to 1970, when Walter Ames developed the first blood glucose test strip and have been developing until the current Continuous Glucose Monitoring devices (CGM) [2]. The most known CGM types are the Freestyle libre, Dexcom G6, and Guardian Connect System. These types are shown in Figure 2.1.

These CGM devices are misunderstood to be non-invasive monitors, but in fact, these are semi-invasive devices, where the sensor is inserted in the patient's body can be seen in Figure 2.1. In addition, the sensor must be replaced over specified period, depending on the module, to avoid infection and to be calibrated.

Figure 2-1: Most used CGM devices [4-6].

The calibration is required to ensure the accuracy of the device three times in the first 12 hours of inserting the sensor, then calibrate once every 12 hours [6]. The calibration methodology can be different from device to the other.

The cost is considered as a problem for low to middle- income people to monitor their glucose level. Table 2.1 below shows the approximated annual cost of each device. As a result, a non-invasive glucose monitoring device is required to remove the sensor replacement cost and to avoid infection happened if not changed. In reality, non-invasive method had not been successfully implemented until now, but there is excessive research on this method by big companies such as Apple in its next series of Apple Watch [7]. Although expensive cost in CGM, there is an intensive demand on the CGM, which reflects the natural demand on the non-invasive device, that will have lower price and higher efficiency.

Table 2-1: Annual cost for each CGM type [4]-[6].

Type	Annual Cost (in Dollars)
Freestyle libre	1702
Dexcom CGM	3588
Medtronic Guardian Connect System	5588

There are several techniques to observe the glucose level using non-invasive method. One of them is by transmitting a signal, optical of Radio Frequency (RF). This signal will penetrate the patient’s skin to the glucose atoms and get reflected by weaker signal in power with a noisy signal. This noise can be filtered using a bandpass filter after being amplified using the Low noise Amplifier (LNA). The output signal will give as a perception of the glucose level [8]. The question then is how we can make a relationship of the reflected signal to the amount of glucose in the blood? Hence, a better understanding of the glucose properties in the blood is required.

The blood properties are dependent on the permittivity of the blood and its conductivity. The permittivity is known as the measurement of the amount of resistance in the medium forming an electric field [8]. The permittivity can be expressed using the following formula:

$$\varepsilon = \varepsilon' - j\varepsilon'' \qquad \textbf{(1)}$$

This formula expresses the permittivity in terms of the frequency dependent complex. The imaginary part refers to the loss, while the real part is referring to the electromagnetic energy amount stored in the material or the medium relative to the electromagnetic energy stored in the vacuum. The imaginary part can be found using the following formula:

$$\varepsilon'' = \sigma / \varepsilon_0 \omega \qquad \textbf{(2)}$$

where σ is the electrical conductivity of the material. These mathematical expressions will be used to find the relationship between the glucose level and the reflected signal. As a result, the glucose level can be determined with a fixed frequency range.

The frequency range is chosen to be in the industrial scientific Medical (ISM) band of medical devices, due to the nature of using the device for medical purposes. This band has a center frequency of about 5.8 GHz. After the signal reflected is processed, the information will be sent to the mobile phone of the patient to show the glucose level using Arduino nano.

2.2 Marketing Requirements

There are five main marketing requirements with many options. Thus, a survey was conducted to determine the user's preference when buying a glucose level monitoring that received 907 responses. The first question asked if the user prefers to buy an expensive glucose level monitoring without needing to buy any additional needs or a glucose level monitoring with a fair price, but it requires many needs, such as needles and test strips. 74.6% preferred to buy an expensive glucose level monitoring without the need to buy any additional accessories, and 18.2% of the participants chose the second option while the remaining 7.2% chose other options.

The second question asks about the user preference usage of the glucose level monitoring where 59.6% prefer to wear a non-invasive device all day and 32.1% preferer to buy an invasive device and carry it while 8.3% chose other options. The third question asks about the user preference to send the glucose level readings to the patient's mobile phone or to a cloud where 62% prefer the data to be sent to the patient's mobile phone and a cloud, and 31.2% prefer it to be sent to the patient mobile phone only while 4.1% prefer the readings to be sent to a cloud only. The fourth question asks about the user's preference in sending an alarm when the glucose level readings are too high or low to the mobile phone, the doctor, or both. 50.9% prefer the alarm to be sent to both the patient's mobile phone and the doctor. While 46.6% prefer to receive the alarm on the patient's mobile phone only, and 1% preferred to send an alarm to the doctor only. The fifth question asks about the number of measurements per day where 72.2% prefer the device that measures the glucose level continuously and 20.8% prefer a measurement every two hours while 5.1% prefer a measurement every 10 minutes and 1.9% prefer a measurement every two minutes. Check appendix B for the survey. According to the study conducted, Table 2-2 shows the marketing requirements for glucose level monitoring.

Table 2-2: Marketing Requirement for a glucose monitoring device.

#	Case study: Marketing requirements for a glucose level monitoring
1	An expensive glucose level monitoring that does not require any additional needs.
2	A non-invasive glucose level monitoring that is to be worn all day.
3	A glaucous level monitoring that sends the readings to the mobile phone and a cloud.
4	A glaucous level monitoring that sends notification to the doctor and the patient's mobile phone when the glucose level is too high or low.
5	A glaucous level monitoring that measures the glucose level continuously.

2.3 Engineering Requirements

Performance:

- The system should have margins between glucose levels of at least 5mV.

Functionality:

- The system should convert the glucose levels to voltage between (0.5-1.5)V

Economic:

- The system should not exceed 2000 SR.
- The maintenance of the system should not exceed the 200 SR annually.

Energy:

- The system should not draw more than 9 mA.
- The system should operate at 5V.
- The system should operate 14 hours.

Environmental:

- The system should be able to operate in the temperature range of 0 – 50 °C.
- The system must be waterproof and operate while submersed in water.

Health and Safety:

- The system will not expose humans to unhealthy levels of electromagnetic radiation and will meet conditions for safe operation identified in ANSI Std. C95.1.
- The final system will be meet UL and CE standards and be tested at an independent laboratory for approval.

Legal:

- An intellectual property search will be conducted to ensure that there is no infringement on prior patents.
- The system will protect the user's identity with 128-bit encryption as required by law.

2.4 Realistic constraints and standards

2.4.1 Realistic constraints

Economic Constraints:

The overall budget of the system should not exceed 2000SAR and it should have an affordable commercial price when it enters the market for any diabetic person that in the range of 400SAR to 1000SAR.

Environmental Constraints:

The device should be environmentally friendly, that is, it should neither affect the environment nor get affected by it.

Social Constraints:

The device should have an acceptable shape and color that suitable for all ages and the Saudi culture. Also, it should not conflict with other cultures and the device should not impede person movement and interactions.

Health & Safety Constraints:

The device should be completely non-invasive and unpainful. Also, the device must be safe in usage that is not overheated or explode for any reason, and it should be unharmful to the human skin.

Manufacturability & Sustainability Constraints:

a. The device Accuracy should be higher than 95%.
b. The device should have a suitable size and weight for portability.
c. The device should have conveniently battery life.
d. The device must endure any simple external damage.

2.4.2 Standards

- The system should follow IEEE 802.15.1 standard.
- Any wireless transmission should follow the ISM band specifications.
- The system should follow the IEC 60601-1 Medical Electrical Equipment standard

2.5 Requirements Specification Assessment

In this subsection we will evaluate the engineering requirements we presented.

Table 2-3: Checklist and self-assessment for the requirements specification

(1 = strongly disagree, 2 =disagree, 3 = neutral, 4 =agree, 5 = strongly agree).

Engineering Requirements	Score
Each engineering requirement is abstract.	5
Each engineering requirement is verifiable.	5
Each engineering requirement is unambiguous and written as a clear statement.	5
Each engineering requirement can be traced to a user need.	4
Each engineering requirement is realistic and has a justification provided.	5
Standards and constraints applicable to the project have been identified and included.	5
Overall score	Sum of all rows

Chapter 3
Design and Development

Write a brief description of this chapter. Briefly explain the subheadings (3.1, 3.2, …etc.).

3.1 Design Concept

The designer contracted from three main parts: the electromagnetic part, the analog part, and the digital pat.

3.1.1 The Electromagnetic Part

The electromagnetic part contracted from three main components a 5.8GHz osculator, narrowband antenna, and coupler. First, the oscillator is going to generate a 5.8GHz signal with a power of 7dBm and send it to a narrow band antenna. Then, the signal will hit the blud and reflect to the antenna where the coupler is going to send the reflected signal to the analog part.

3.1.2 The Analog Part

The analog part is constructed from three main devices the low noise amplifier, the bandpass filter, and the RF detector. When the reflected signal is received it will be very weak in the range of -15dBm to -30dBm so, the signal will pass throw a low noise amplifier with a gain approximately equal to 20dB. Then the signal will pass to the passband filter to eliminate any external noise and unwanted signals. Then the signal will be passed to RF detector where the signal will be scaled to a DC.

3.1.3 The Digital Part

The main goal of the digital part is to translate the received DC analog signal to a readable number using an Arduino. The signal that came from the RF detector will be passed to an analog node in the Arduino, then using an analog to digital converter feature in the Arduino the signal is going to scale to a digital value, then the digital value which represents the blood glucose level will be sent to a Bluetooth module then to a mobile app where the patient can see the result.

3.2 Concept Selection

This project is associated directly with the health of a large scale of people who suffer from diabetes, which means the criteria that should be considered in this project should satisfy the diabetic's needs which will make their life easier. Also, the health of the users of this device should be considered in the criteria selection because the main goal of this device is to reduce the risks associated with glucose measuring. For this project, we choose the following criteria:

1- Accuracy: the device should give accurate results
2- Size: the size of the device should be small enough to carry all day long
3- Battery time: the battery time should be enough for one day
4- Price: the price of the device should be reasonable
5- Comfortability: the device should not be annoying for the user
6- Safe: the device should be safe to use

3.3 Concept Evaluation

Concept evaluation is the process of evaluating consumers' impressions of a prospective product or service based on the level of importance that seeks to compute consistency index, which must be less than 0.1. Each project contains several features that the project needs to have, but some features might be less important than other features. For the continuous non-invasive glucose level monitoring, there is six feature that the project focuses on, which are accuracy, size, battery time, price, comfortability, and safety. These features are called criteria. They are to be put in a diagram called concept fan. As shown in Table 1, the levels of importance can be divided into five levels equal, moderate, strong, very strong, and extremely important. The evaluation depends on the pair-wise comparison, and this process begins with rating the importance concerning each criterion with numbers based on the level of importance. After rating the criteria in Table 2, we must normalize the obtained values by dividing each column by its sum and find each criteria weight, as shown in Table 3.

Table 3-1: Importance level.

Importance				
Equal	Moderate	Strong	Very strong	Extreme
1	3	5	7	9
Values for invers comparison				
1	½	1/5	1/7	1/9

Table 3-2: Pair wise comparison.

Criteria	Accuracy	Size	Battery time	Praise	Comfortability	Safe
Accuracy	1	1/5	1/3	1/5	1/7	1
Size	5	1	3	1/3	1	7
Battery time	3	1/3	1	3	1/7	9
Praise	5	3	1/3	1	1/9	5
Comfortability	7	1	7	9	1	7
Safe	1	1/7	1/9	1/5	1/7	1

Table 3-3: Normalized pair wise comparison.

Criteria	Accuracy	Size	Battery time	Praise	Comfortability	Safe	Criteria weight
Accuracy	0.045	0.035	0.028	0.015	0.056	0.033	0.212
Size	0.23	0.18	0.25	0.024	0.39	0.23	1.304
Battery time	0.14	0.058	0.08	0.22	0.056	0.3	0.854
Praise	0.23	0.53	0.028	0.073	0.044	0.167	1.072
Comfortability	0.32	0.18	0.6	0.66	0.39	0.23	2.38
Safe	0.045	0.025	0.01	0.015	0.056	0.033	0.184

Chapter 4
Final Design

This chapter will discuss the design prior to the implementation stage to do the tests experimentally, First, the design description will be mentioned in general fashion. Second, detailed design illustration will be provided. Then, analysis and results of the digital part and analog part will be illustrated. Finally, the cost of the items used will be discussed.

4.1 Overall Description

The system designed to work at a frequency of 5.8 GHz, in which the frequency will hit the glucose atoms in the blood and get reflected. This can be done by sending high frequency of 5.8 GHz, generated from an oscillator, via the antenna to the desired samples then get reflected. This reflected signal requires a system consists of six main parts: Oscillator, an antenna, LNA, RF detector, Microcontroller, and User Interface. Each of these components will be elaborated more in the subsequent section. Figure 4-1 shows the overall design diagram of the system.

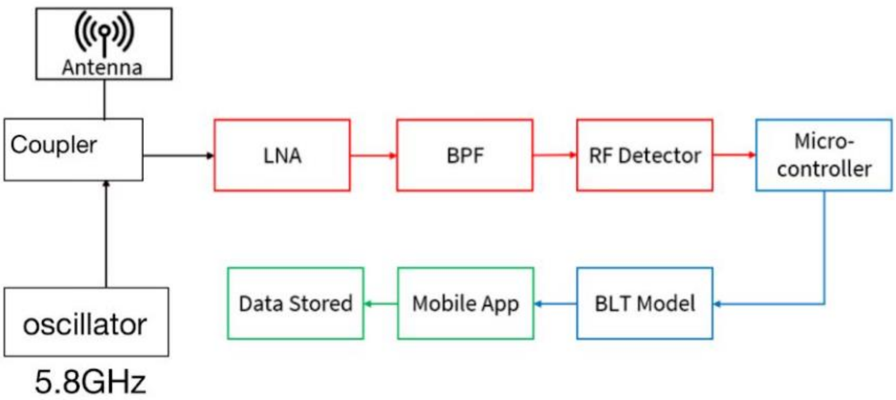


Figure 4-1: Overall Design Diagram of The System.

4.2 Detailed Design Description

The system is operating in dc power supply that consists of a battery with a management power circuit of five volts to protect the circuit from the excessive current that may damage the circuit’s components. In addition, the system operates optimally at a frequency of 5.8 GHz as advised by Dr. Hussain Attia and confirmed by his antenna group previously. It is the best frequency that can be reflected from glucose atoms in the blood. This frequency will be generated from an oscillator and will be transmitted via the antenna to the desired sample and get reflected. These reflected signals are weak and noisy, so LNA is used to amplify the signal. Then, a passive BPF, which has a filter range of (4.9 – 6.2) GHz, is connected to remove the noise. The passive BPF is used rather than the active BPF due to its range can reach high frequency like 5.8 GHz. After that, the filtered signal is transferred to the RF Detector to convert the power in the signal to a DC voltage level to be recognized by the microcontroller. Finally, the microcontroller will interpret the DC voltage and send the interpretation to the user interface to be observed.

This operation took two methodologies to approach. The first was using one antenna and the directional coupler. The second method by eliminating the directional coupler and use two antennas. The two methodologies are to be discussed next.

4.2.1 The First Configuration

In this method, the directional coupler and one antenna to transmit and receive simultaneously was implemented. The test sample was fixed in front of the antenna. The frequency is transmitted through the test sample. The reflection is received by the same antenna and redirected by the directional coupler to the LNA and the rest of the circuit. This will be more illustrated in Chapter 5.

4.2.2 The Second Configuration

In this configuration, the directional coupler was eliminated, and two antennas were used, i.e., transmitter and receiver. The blood samples or the glucose samples are held between the two antennas. The first antenna transmits the given frequency (5.8 GHz) from the oscillator. The second antenna receives the signals penetrated the glucose or the blood samples. The received signal is then transferred to the LNA and the rest of the circuit mentioned earlier. This configuration will be explained later in Chapter 5.

4.3 Analysis and Results

This section will show the components used and the expected results prior to experimental tests that will be showed in the next chapters.

4.3.1 Analysis

4.3.1.1 Analog Part

As discussed, for the analog part, we have six main components: the oscillator, the antenna, the directional coupler, the LNA, a passive BPF, and the RF detector. The oscillator was supposed to be provided by another group, instead, a function generator was used. This function generator is known as (N5183A MXG Analog Signal Generator), which can generate a signal with frequency range of 100 kHz to 40 GHz and power range of -15 dBm to 20 dBm. These limitations were a problem in term of power as the saturation region could not be reached, especially in terms of power as the saturation region expected to be around -40 dBm. Therefore, it was replaced sometimes with the RF Explorer for portable purposes as well as solving this issue. The RF Explorer can generate frequency from 24MHz to 6GHz, which is suitable for our system. However, the minimum power it can generate is -32 dBm, which is higher than -40 dBm. Although the system could not reach the saturation region, the results at that point were close enough from the saturation value to assume the system is operating below it. These generators can be shown in Figure 4.2.

Figure 4-2: The RF Explorer and The Function Generator Used.

The directional coupler used can be seen in Figure 4-3. It is a dual directional coupler that supports 2-8 GHz frequency and input power up to 50 watts. It directs the 5.8Ghz signal that was generated from the oscillator to the antenna, then redirects the reflected signal received to the input of the circuit,i.e, to the LNA.

Figure 4-3: The Directional Coupler Used.

The signal will be transmitted and received by the optimally simulated antenna that we received from Dr. Attia's section which was a dual-band microstrip patch antenna that is shown in Figure 4-4. It was designed to operate at 2.4 GHz and 5.8 GHz resonance frequencies. The proposed antenna is designed on FR-4 dielectric with thickness 1.6 mm and relative permittivity equals 4.3.

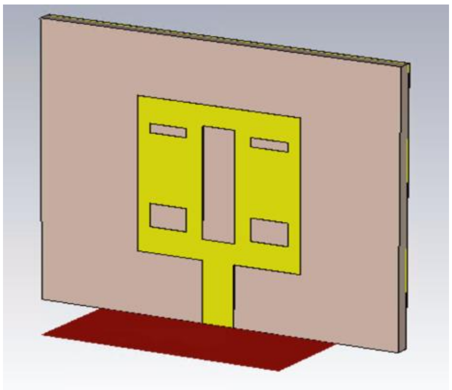


Figure 4-4: The Antenna Used for Transmitting and Receiving the Signal.

Figure 4-5: LNA Chip HMC8412

For amplifying the signal received, we used the LNA chip (HMC8412) that can be seen in Figure 4-5.
This LNA chip can operate at 0.4-10 GHz and with a saturated output power of 20 dBm at 5V and with current drawn equals 60mA.
After the signal is being amplified used to eliminate all signals higher than 6.2 GHz and lower than 4.9 GHz. Finally, the RF detector used is (AD8317) and used to convert the power in the signal to DC voltage level. It operates from 3.3 to 5V and at a frequency of 1 – 10 GHz and a current drawn equals 22mV.
The evaluation boards of the previous parts will be shown in Chapter 5.

4.3.1.2 Digital Part

For the digital part, we have two main aspects: The microcontroller and the user interface. The microcontroller is used to interpret the analog signal that received from the analog circuit, then send the interpretation to the user interface where it can be observed clearly, and the way that the data is sent from the microcontroller to the user interface is via Bluetooth transmitted signal. The microcontroller that we used to fulfill this task is the Arduino Nano 33 BLE shown in Figure 4-6a and the user interface that we decided to use is the user mobile phone, specifically an app application called LightBlue shown in Figure 4-6b.

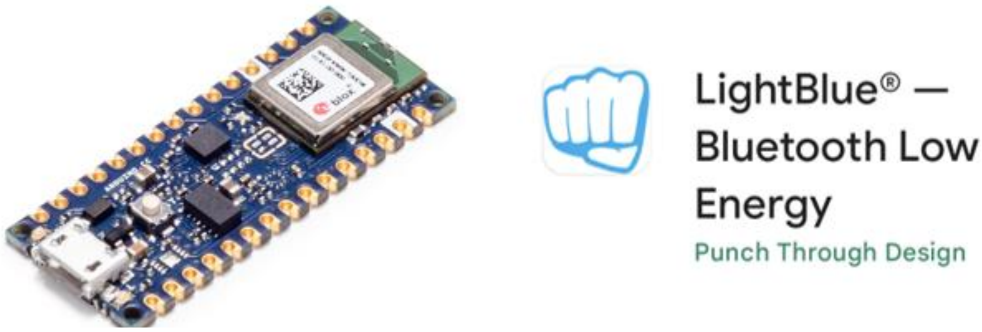


Figure 4-6: a) Arduino Nano 33 BLE, b) LightBlue Mobile App

Arduino Nano 33 BLE:

As we have mentioned, the microcontroller that we used is the Arduino Nano 33 BLE. Arduino Nano 33 BLE is a small microcontroller that has a BLE module built-in to send data within (RF) which is within 1 to 3 GHz. This Arduino is selected over other types of Arduinos due to three main reasons: The low power consumption, the small size, and the built-in Bluetooth module. Arduino Nano 33 BLE operates at 5V from Vin pin and can draw current as low as 15mA and the maximum voltage that a I/O pin can handle is 3.3V. The Arduino will be programed to sense the received analog signal, then through its ADC it will convert it to a digital signal with a maximum resolution of 12 bits, which corresponds to a 4096 (2^{12}) quantization levels. In addition, since the maximum voltage for the input pins is 3.3V, the least sensed voltage will be $\frac{3.3}{4095} = 0.805\ mV$. The Arduino has dimensions of 45mm x 18mm and its built-in Bluetooth module can be detected with mobile phones via RF applications. The Diagram of the Arduino is shown in Figure 4-7.

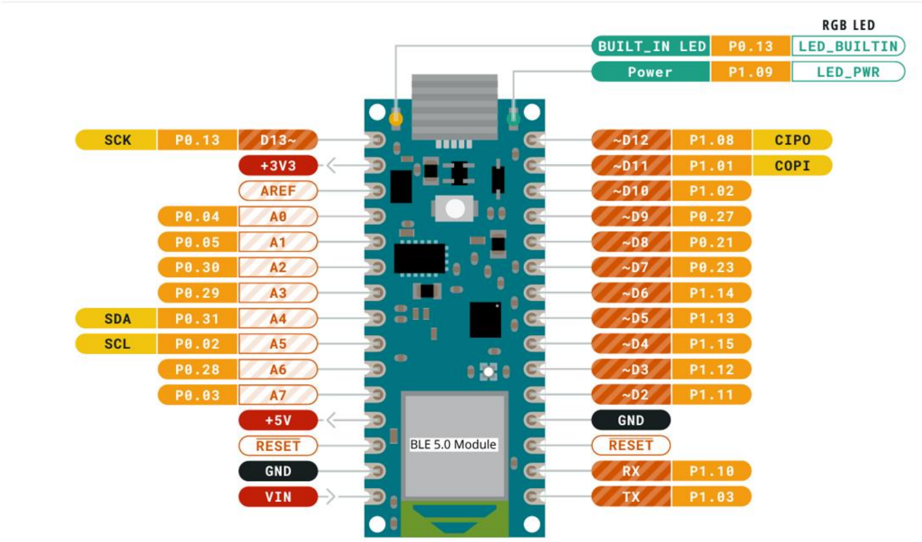


Figure 4-7:The Diagram of The Arduino Nano 33 BLE.

LightBlue App

LightBlue is a mobile phone application that allow the user to detect, browse, and communicate with BLE devices. It is compatible with IOS and Android system. We used this app as the user interface of this project, which means the user will be able to observe his or her blood glucose condition and know the severity of the situation. The app can read the values sent to it in many different formats such as Hex, Binary, and UTF-8 string. Figure4-8 shows the app's interface.

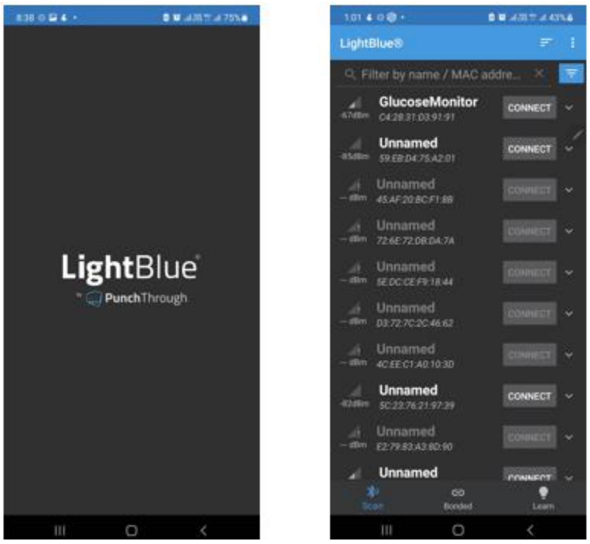


Figure 4-8:The Interface of LightBlue Application.

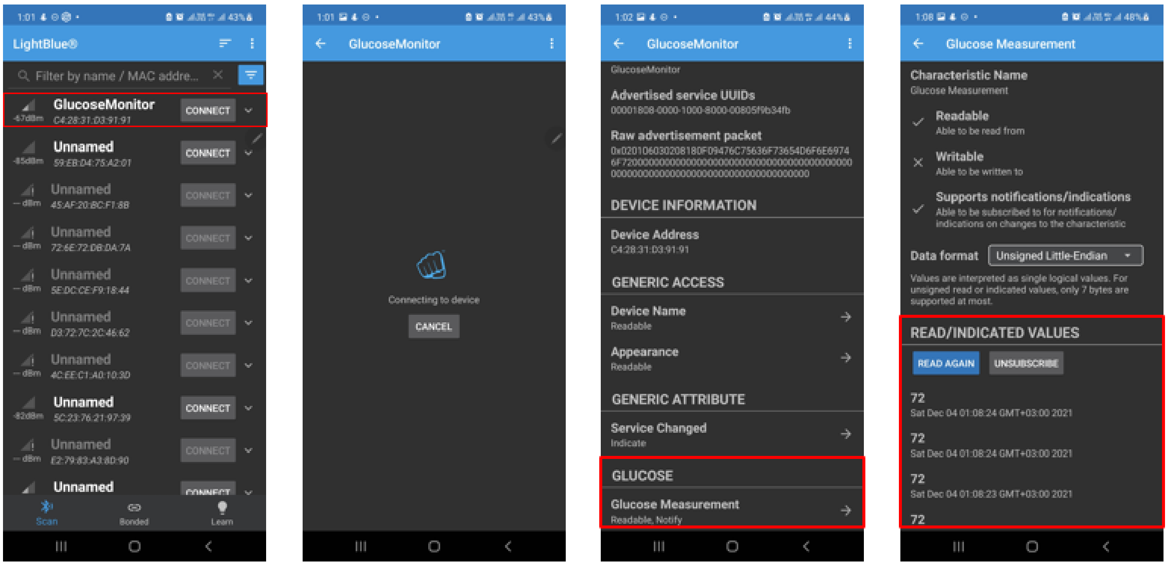
4.3.2 Results

4.3.2.1 Analog part results

The results are experimentally obtained. Thus, the results of the analog part will be discussed in the next chapters.

4.3.2.2 Digital part results

Figure4-9 illustrates the way of detecting and reading a BLE device's signal.



(1) (2) (3) (4)

Figure 4-9:Detecting and Reading a BLE Signal.

4.4 Cost Analysis

Table 4-1:The cost of All the Purchased Items.

Item	Cost (SAR)
BPF & SMA CABLES	608.41
SHIPPING	66
LNA	46.8
PMU	63
Jumpers & SMA Ports	50.72
PCB	597.55
Weighing Scale	60
Total	1492.48

Chapter 5:
Prototype Implementation

In this chapter, the implantation of the system prototypes and are to be discussed and illustrated.

5.1 implementation process

For our design, we made two prototypes, one on the breadboard using evaluation boards and prebuilt components. In the other prototype, we made a very small PCB that connect directly to the Arduino Nano 33 BLE shown in Figure 5.5-4.

Breadboard prototype

First, we implemented the analog design in the breadboard using an evaluation board for each component. The main parts of the analog circuit are LNA, BPF, RF detector, and power circuit. The evaluation boards of each one is shown in Figures 5.5-1 to 5.5-3.

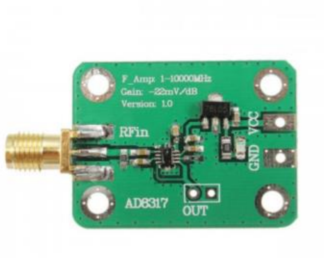


Figure 5.5-2: RF detector

Figure 5.5-1: LNA

Figure 5.5-3: BPF

PCB prototype

based on the system that we implemented using the evaluation boards, we redesigned the PCB which was initially designed at the beginning of the project. The PCB design is constructed of three main stages, (LNA), (BPF), and (RF detector). The printed circuit board (PCB) has been designed using KiCad software and manufactured by (PCBway).

Figure 5.5-4: Arduino nano

5.2 Prototype vs. Planned Design

Breadboard prototype

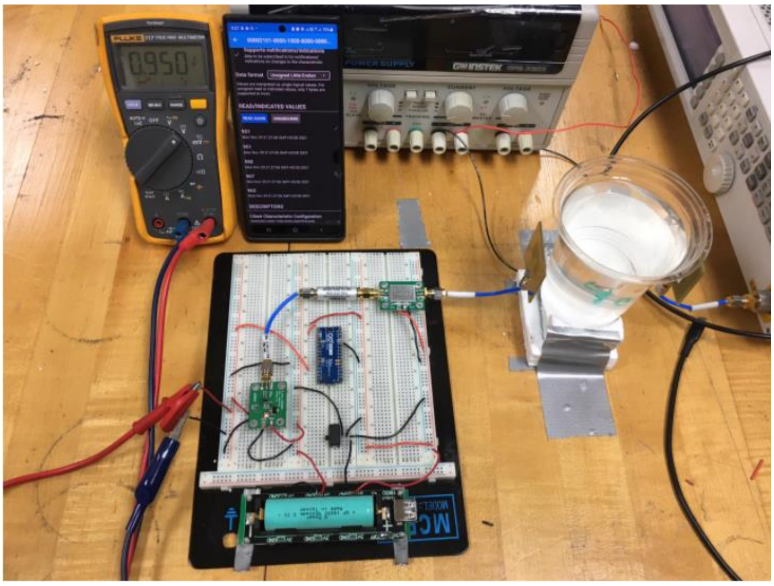


Figure 5.5-5: Breadboard prototype

Figure 5.5-5 shows the complete system implemented in the breadboard. The system started from the frequency generator which will send 0dBm signal with a frequency of 5.7GHz through an antenna. The signal will pass through the sample we are going to measure and recerved on the other side of the sample using another antenna. The received signal will be passed to the LNA with a gain of 20dB. After that, the signal will bass through PBF with a bandwidth between 4.9-6.2 GHz. After that, the signal will go to an RF detector which will rescale the signal to a DC value between 0 and 1.5V. then the DC signal will be detected by the Arduino. The Arduino will convert the analog signal to a digital signal and calculate the corresponding glucose level and send it to the user phone using Bluetooth. The entire system is powered by 5V power supply and consumes 0.45W. We used 5000mAh 3.7V lithium-ion battery with a boost circuit which will increase the output voltage to 5V. this power system can supply the system for 14 hours. Recharging the battery from zero to fall charge with 1W charger takes 8 hours.

PCB prototype

Figure 5.5-6:Top view of PCB Layout

Figure 5.5-7: Bottom view of PCB Layout

After we completed the system in the breadboard using evaluation boards, we integrated the same system into a printed circuit board (PCB). Figure 5.5-6 shows the final PCB circuit which will be connected as a shield to the Arduino nano. The circuit starts with an SMA connecter where the receiver antenna will be connected and end with the RF detector. The circuit has one SMA input, one output pin, and one power supply pin. From figure 5.5-6 we see that we can control the gain of the RF detector using the potentiometer.

Different between plan and implementation

As figure 5.5-9 shows, the first configuration of the system was implemented which is a directional coupler where the signal is going to hit the target and reflect to the same antenna. Figure5.5-8 shows the second configuration which is the use of two antennas opposite to each other, one as a transmitter and the other on as a receiver.

Figure 5.5-9: One Antenna and Coupler Approach

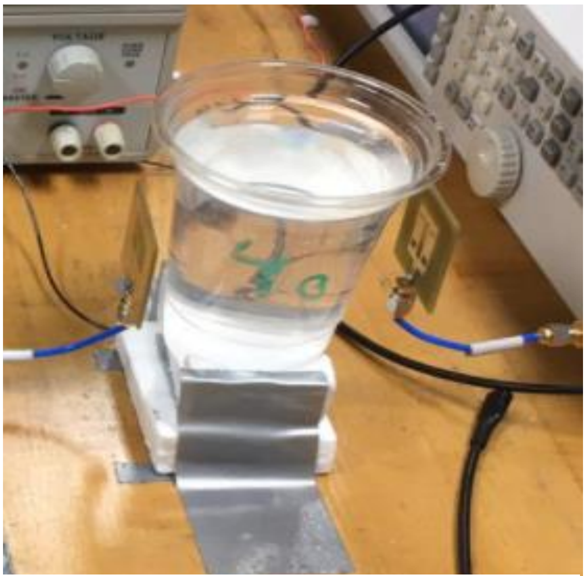


Figure 5.5-8: Two Antennas Approach

Chapter 6
Design Verification

In this chapter, the design verification of the project will be explained in detail. The project is consisting of two main parts which are the analog part and the digital part. All of them will be discussed through two main sections of this chapter which are 6.1 Verification Test Description and 6.2 Detailed Results. Also, the list of items used for the system verification will be illustrated in section 6.3 Specification Verification Check List.

6.1 Verification Test Description

The team criterion of verifying the system is to test each component playing essential role in the system individually and as combination with the other components until the final system combination is reached. Then, the whole system will be tested. This criterion of experimental testing will be helpful in knowing the behavior of each component alone and how each component is contributing to our system.

6.1.1 Analog Part

In our system, we have two main configurations. The first is measuring the reflected signal from the human body through one antenna and a directional coupler. The second is measuring the transmitted signal through the human body using two antennas one transmits the signal and the other one receives it. Furthermore, since we are in the early stages of verifying the product, we wanted to simulate to some extent the actual case of a human body. Therefore, we conducted three different tests with three different samples: Water and Sugar, Blood Plasma, H_2O and Glucose Powder. The scenario of conducting each test was that we measured the RF output voltage that corresponds to the sensed sample five times then we computed the average of these five trials. This scenario of testing is applied to get better result and to minimize error outputs of the whole system including digital part when the patient receives the reading about his/her Glucose level. The details of the implemented tests are listed in Table 6-1 with brief description of each one. Also, the main experimental setups of the implemented tests are shown below. Noticing that when the antenna is a part of the experimental tests Anechoic Chambers are always used to reduce the surrounding's noises. However, they are removed when pictures of the set up are taking.

Table 6-1:Verification Tests of the Analog System.

Number	Test	Description	Test Conditions
1	RF Test 1	The RF is tested alone	*I_s = 20 mA, **V_{DD} = 3.7 V f = 5.8 GHz (RF input signal in Voltage)
2	RF Test 2	The RF is tested alone	I_s = 20 mA, V_{DD} = 5V f = 5.8 GHz (RF input signal in power dBm)
3	LNA Test	The LNA is tested alone using a Network Analyzer	-20dB Attenuator is added for the network analyzer protection.
4	RF with BPF Test	The RF and the BPF are tested together.	RF: I_s = 20mA, V_{DD} = 5V f = 5.8 GHz (Input signal in power dBm)
5	RF, BPF and Arduino Test	The RF and the BPF are tested together. (Output Readings is taken from the Arduino Nano screen monitor)	RF: I_s = 20mA, V_{DD} = 5V f = 5.8 GHz (Input signal in power dBm)
6	System Test 1	Testing the system with Water+Sugar Samples	LNA: I_s = 60mA, V_{DD} = 5 V RF: I_s = 20mA, V_{DD} = 5V

		(Directional Coupler Configuration)	f = 5.7 GHz (Input signal is 0dBm)
7	System Test 2	Testing the system with Human Blood Plasma Samples (Directional Coupler Configuration)	LNA: I_s = 60mA, V_{DD} = 5 V RF: I_s = 20mA, V_{DD} = 5V f = 5.6, 5.7, 5.8, 5.9 GHz (Multi power input signals)
8	System Test 3	Testing the system with Water + Sugar Samples (Two Antennas Configuration)	LNA: I_s = 60mA, V_{DD} = 5 V RF: I_s = 20mA, V_{DD} = 5V f = 5.7 GHz (Input signal is 0dBm) (Distance between the two antennas is 8.5cm)
9	System Test 4	Testing the system with Human Blood Plasma Samples (Two Antennas Configuration)	LNA: I_s = 60mA, V_{DD} = 5 V RF: I_s = 20mA, V_{DD} = 5V f = 5.7 GHz (Input signal is 0dBm) (Distance between the two antennas is 4.5cm)
10	System Test 5	Testing the system with Pure Water (H_2O)+Glucose Powder Samples (Two Antennas Configuration)	LNA: I_s = 60mA, V_{DD} = 5 V RF: I_s = 20mA, V_{DD} = 5V f = 5.7 GHz (Input signal is 0dBm) (Distance between the two antennas is 10cm)

11	Battery of the system Test	Testing the system's battery by connecting it to 0.06 A, 0.3 W load	None
12	System's Power Consumption Test	Measuring the amperes drawn by each component at the operating Voltage 5V	None

*I_S is the supplied current.

** V_{DD} is the supplied Voltage.

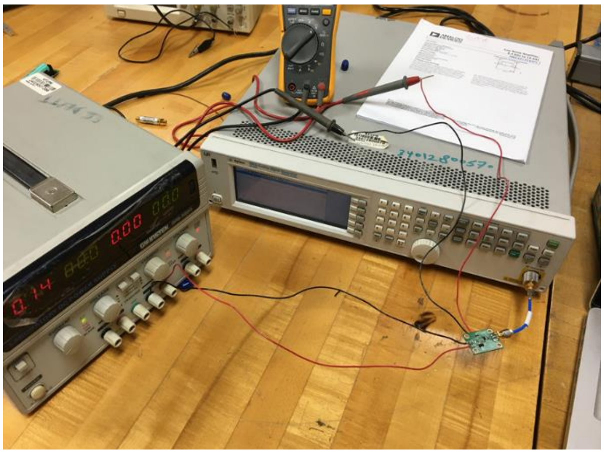


Figure 6-1:RF Test 1&2 Experimental Setup.

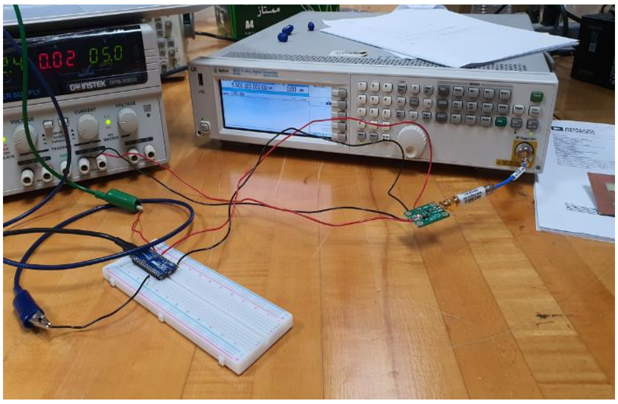


Figure 6-2:RF, BPF and Arduino Test.

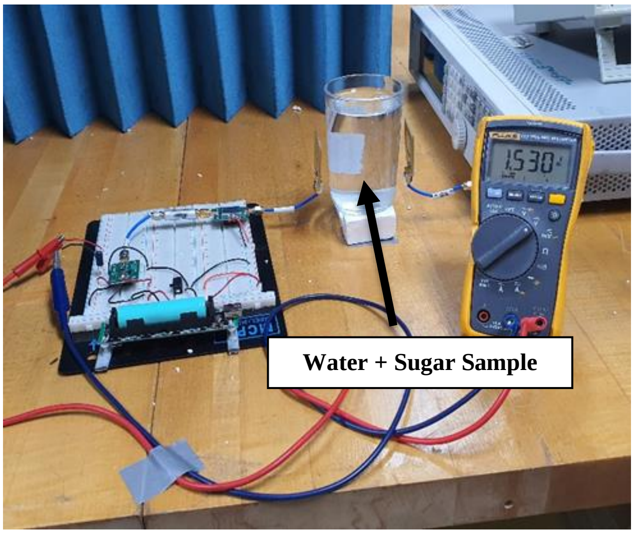


Figure 6-3: System Test 3 Experimental Setup

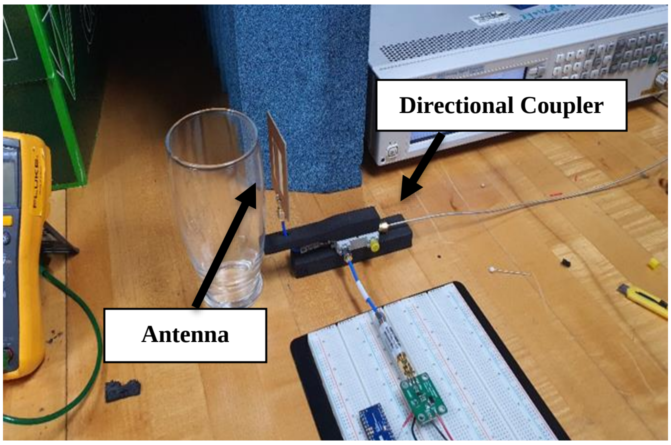


Figure 6-4: System Test 1 Experimental Setup

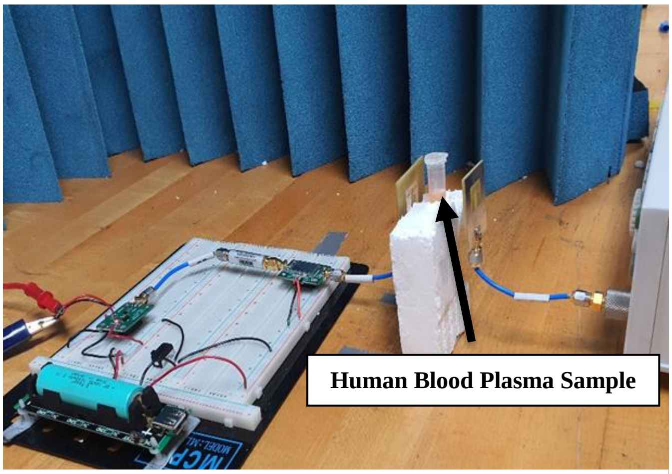


Figure 6-5: System Test 4 Experimental Setup

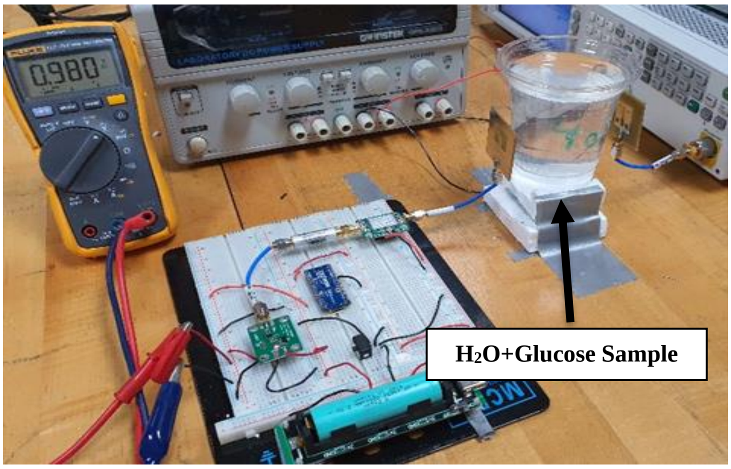


Figure 6-6: System Test 5 Experimental Setup

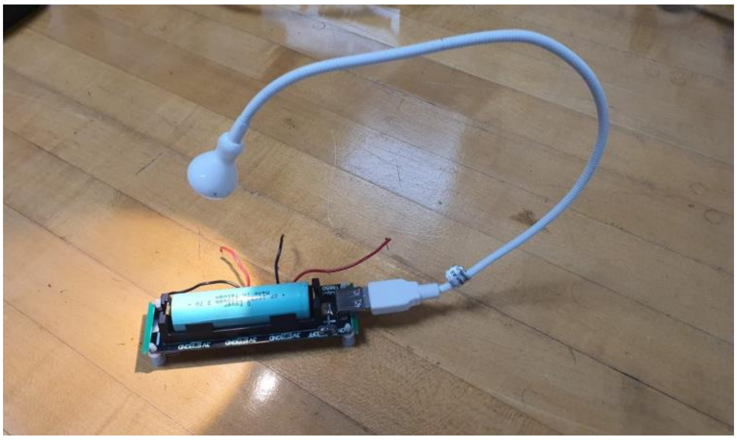


Figure 6-7: Battery of the System Test.

6.1.2 Digital Part

In the digital part we conducted several tests: Reading Accuracy, Transmission Accuracy, Arduino Power Consumption, and Results Interpretation. The verification test of the digital part starts by suppling the Arduino Nano 33 BLE with 5V using the battery, then using pin A0, the output voltage of the RF detector will be sensed, and the received analog signal will be converted to a digital signal. Furthermore, the Arduino will be programed to interpret the signal according to the conclusions of the analog tests results (i.e., the voltage that corresponds to every glucose level). Finally, after interpreting the signal, the Arduino will send this interpretation using the BLE module to the LightBlue application where the user can observe it.

In this project, the glucose concentration in mg/dL was divided to 4 main levels in term severity: Low (0-69), Normal (70-130), High (131-240), and Critical (more than 240) [3]. Therefore, the Arduino is programed to classify the received signal in voltage according to its corresponding level in mg/dL.

6.2 Detailed Results

In this section, the detailed results of the experimental verification tests mentioned in section 6.1 will be illustrated and discussed. For the results analyzing and plotting MATLAB software is used. Also, theoretical equations are developed using MATLAB to give us a good approximation to what happen in between the values that are taken experimentally.

6.2.1 Analog Part

6.2.1.1 System Components Tests

In this subsection, the results of the verification tests implemented on the system components will be illustrated and discussed.

RF Detector

Starting by the RF tests that can be seen in Figure 6-8 and 6-9, both types of inputs (Power dBm and Voltage) that when the input to the RF increases the RF output voltage decreases which means the RF output voltage is inversely proportional the input power (dBm) or Voltage.

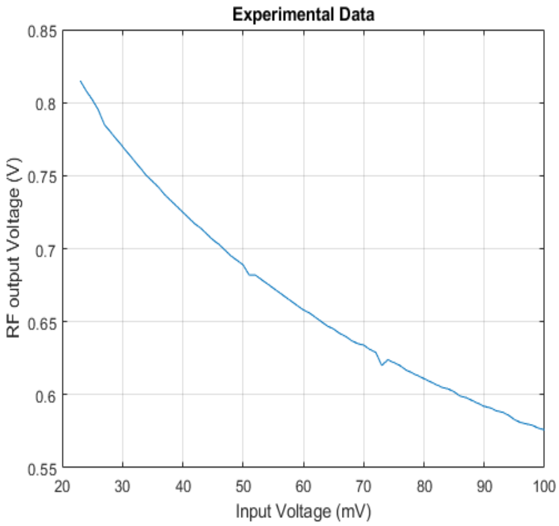


Figure 6-8:RF Test 1 when input in mV

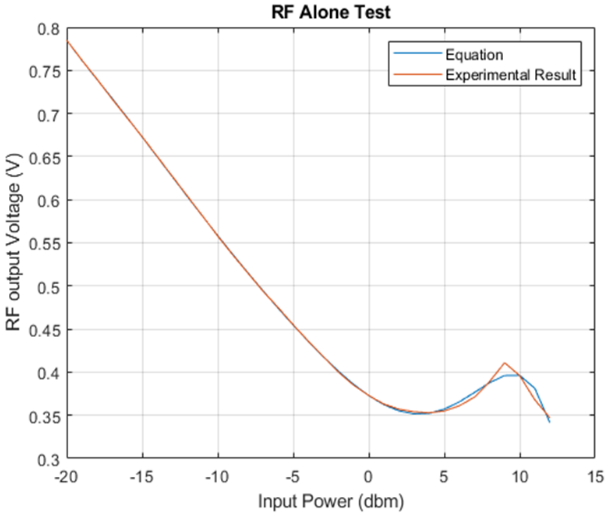


Figure 6-9:RF Test 2 when input in dBm.

Based on the simulation results and theoretical analysis done by the previous group, the voltage decreases as the permittivity increases which means the voltage decreases as the Glucose level increases in human blood. Therefore, because of the characteristics of the RF, the system output voltage will increase as the glucose level increase.

Low Noise Amplifier (LNA)

The LNA characteristics is shown in Figure 6-10 and 6-11 which give us an indication of the exact gain the system is getting from the LNA at our frequencies of interest. We can see that in Figure 6-10 the LNA gain at 5.7 GHz is about 13 dB and in Figure 6-11 the LNA gain at 5.8 GHz is about 14 dB. Noticing that, 20dB is added to the amplitudes in the graph since a -20dB attenuator is used for the Network Analyzer protection.

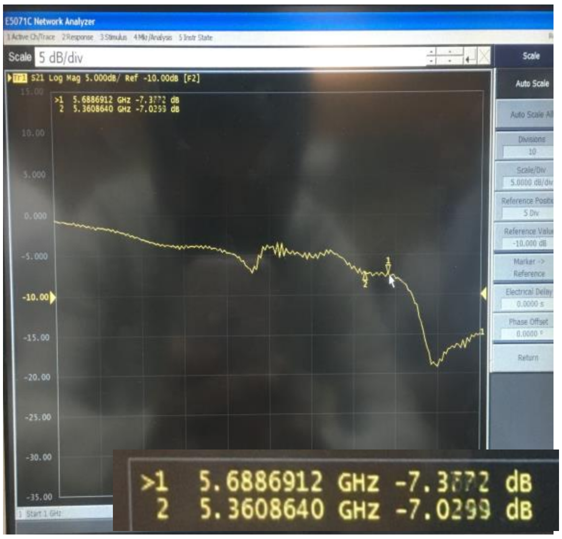


Figure 6-10:LNA Characteristics at 5.7 GHz

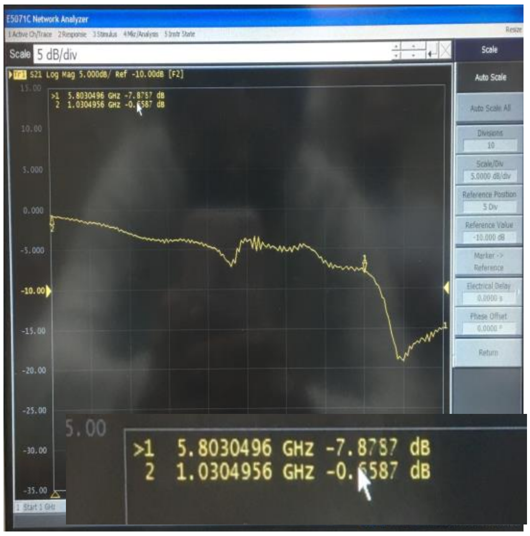


Figure 6-11:: LNA Characteristics at 5.8 GHz

Band Pass Filter

Moreover, the RF with BPF test results are illustrated in Figure 6-12. From this figure, it can be seen that the BPF causing a small drop in the input signal by knowing the characteristics of the RF discussed previously and by seeing the comparison of the plots in Figure 6-13. The drop caused by the BPF is about -2dB as illustrated on its data sheet and is 0.014 V as calculated from the test result. The cutoff frequencies of the BPF are 4.9 GHz and 6.2 GHz and the use of it in our system in essential since it is needed for eliminating the noises caused by surrounding signals and prevent the system interfacing with other communication signals such as Bluetooth signals that at 2.4 GHz.

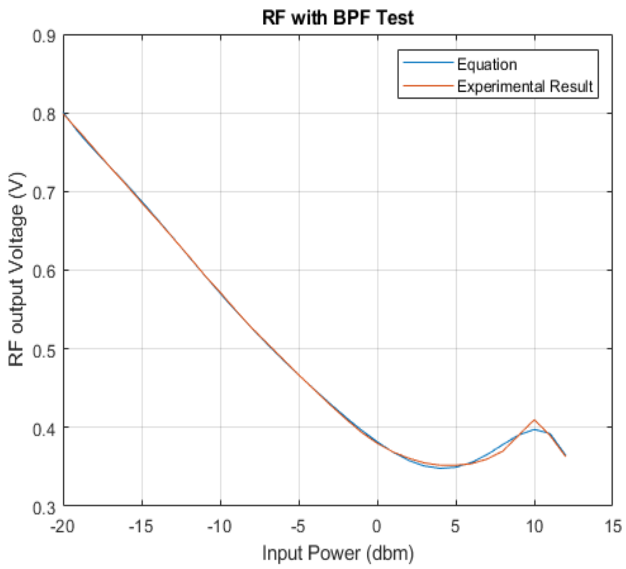


Figure 6-13: RF with BPF Test Results

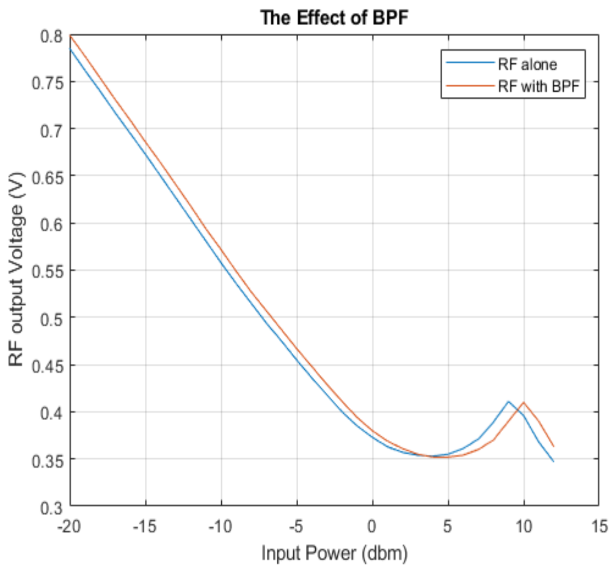


Figure 6-12:The Effect of the BPF.

6.2.1.2 The Whole Analog System Tests

In this subsection, the results of the verification tests implemented on the Analog System will be illustrated and discussed.

Water and Sugar Samples

In this test, we used two different configurations. The First one was the directional coupler configuration, and the second was the two antennas configuration. The transmitted signal from the frequency generator was at 5.7 GHz and with 0 dBm power. Table 6-2 and Figure6-14 Show the test results.

Table 6-2:Water and Sugar Using Directional Coupler

g/dL	Trial 1	Trial 2	Trail 3	Trail 4	Trail 5	Average
0.00	0.5332	0.5341	0.5341	0.5339	0.5338	0.5338
6.49	0.5366	0.5359	0.5373	0.537	0.5377	0.5369
13.64	0.536	0.5352	0.5361	0.5357	0.5362	0.5358
21.10	0.5364	0.5368	0.5367	0.5369	0.5364	0.5366

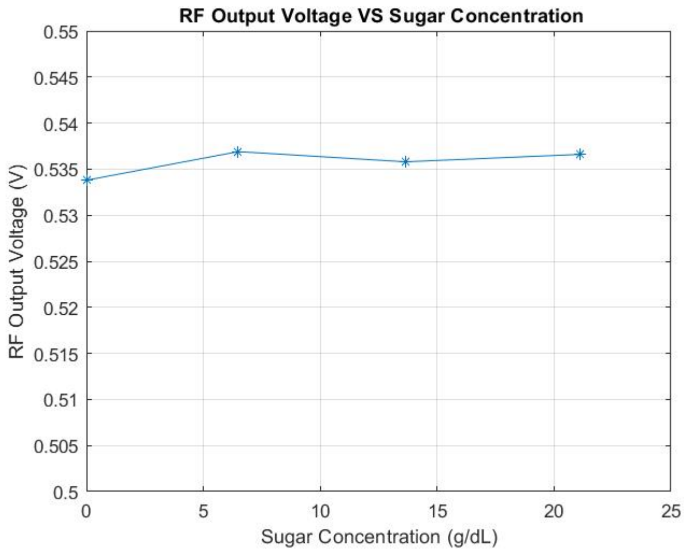


Figure 6-14: Water and Sugar Using Directional Coupler

It can be seen that there is no clear relation that can be interpreted from the figure between the RF output voltages and the sugar concentration in the water.

In System Test 3, samples of drinkable water with different sugar concentrations are tested using the two antennas configuration.

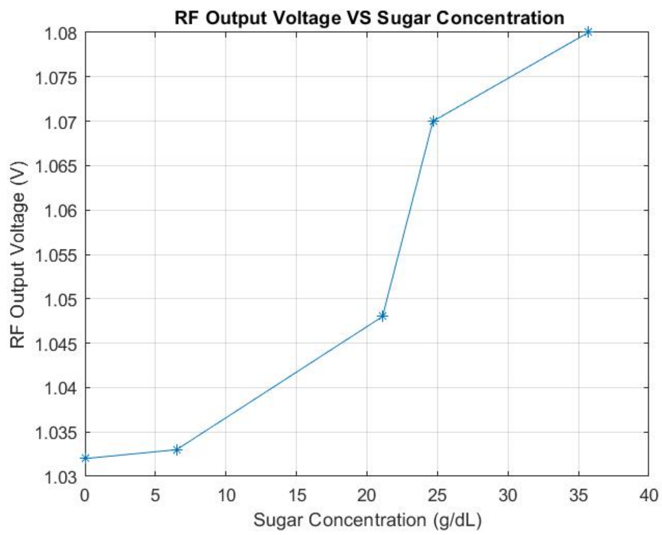


Figure 6-15: Water and Sugar Using Two Antennas.

Table 6-3: System Test 3 Results.

g/dL	Trial 1	Trial 2	Trial 3	Trial 4	Trial 5	Average
0.00	1.032	1.043	1.031	1.025	1.027	1.032
6.49	1.03	1.035	1.036	1.029	1.034	1.033
21.10	1.066	1.041	1.045	1.047	1.043	1.048
24.68	1.078	1.069	1.053	1.065	1.083	1.070
35.71	1.07	1.075	1.085	1.084	1.088	1.080
Nothing	0.721	0.715	0.719	0.716	0.708	0.716
Glass Cup	0.761	0.769	0.759	0.765	0.758	0.762

The test gave promising results that are illustrated in Table 6-3 and Figure6-15. Although the results of the test gave us a relation between the sugar level and the RF output voltage that reflect the theoretical relation obtained between the permittivity and the voltage noticing that more sugar means higher permittivity, the difference between output voltages is small to be detected. In addition to that, sugar cannot be considered as a Glucose only since it contains other chemical compounds and the water used has other minerals that may affect our readings.

Also, as an observation of this test the output voltage is changing with high difference between the sugar levels as it can be seen in Table 6-4 and since our gram scaling is less sensitive, we could not test samples with sugar level that reflect real patient reading like (90 mg/dL, 200 mg/dL …etc).

Blood Plasma Samples

Human blood plasma samples are tested with two configurations also.

In System Test 2, the test was conducted with the directional coupler configuration with different frequencies and power amplitudes. However, the result is not that far from System Test 1 and the antenna could not detect the different between these plasma samples.

The other configuration of two antennas is used to in System Test 4 and the results of this test are illustrated in Table 6-4.

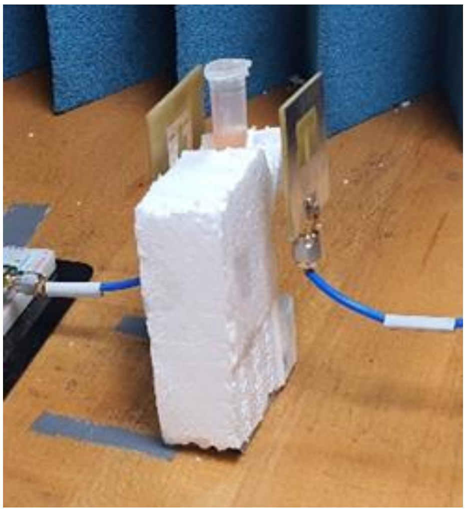


Figure 6-16: Blood Sample Test Configuration

Table 6-4: Blood Plasma Samples Tests Using Two Antennas

Glucose mg/dL	Trail 1 mV	Trail 2 mV	Average mV
0	451	448	449.5
87	428	425	426.5
89	425	424	424.5
92	425	420	422.5
117	423	426	424.5
123	431	430	430.5
138	427	421	424
142	426	426	426
160	432	429	430.5
163	430	426	428
322	432	423	427.5

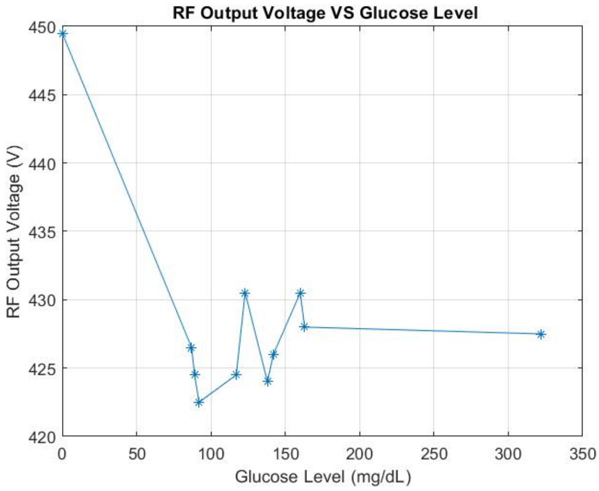


Figure 6-17: Blood Plasma Samples Tests Using Two Antennas

From the table it is obvious that there is no relation can be determined form these results since the RF output voltages are close to each other and give unexpected values that in contrast with the theoretical relation of the voltage and the permittivity. So, as conclusion of using the human plasma samples we decided to use other approaches that may give us a reliable result of the relation between our system output voltage and the Glucose level since these blood plasma sample are very small in size and little in quantity that difficult to be detected by the system.

H_2O and Glucose Powder Samples

Finally, as a conclusion of our tests and since the results are promising, we decided to get samples of Pure water (H_2O) and Glucose Powder to figure out the exact relation of the Glucose level and the system's output voltage.

In System Test 5, the pure water with glucose powder in different concentrations are tested.

Table 6-5 shows the result of this test, and it can be seen that the different Glucose levels give as a detectable difference in the RF output voltage. However, the Glucose level range that reflect the real situation is between 0 mg/dL and 1400 mg/dL and measuring the real Glucose levels experimentally is impossible with the material we had, so we decided figure out an equation using MATLAB to know by how much the RF output voltage is changing in the interested levels of glucose (90 mg/dL, 200 mg/dL …etc). The developed equation with the experimental data is shown in Figure 6.14 and the accuracy of the equation can be seen from the graph especially in our range of interest. Figure 6.15 shows the equation data in the Glucose level range of interest and the equation is illustrated below where V is the RF output voltage in Volt and G is the Glucose level in mg/dL.

$$V = -1.6142 \times 10^{-10} G^2 + 6.6380 \times 10^{-6} G + 0.8804 \qquad (3)$$

$$G = 1.2461 \times 10^{6} V^2 - 2.0731 \times 10^{6} V + 8.5859 \times 10^{5} \qquad (4)$$

In Figure 6.15, the change between the highest voltage that at 500 mg/dL and the lowest one that at 0 mg/dL is 3.28 mV which gives us an indication of what expected in the beginning of this project that the change in output voltage with the glucose levels will be in micro! For a better look to the result the data of the equation is in Appendix D.

Table 6-5: H2O and Glucose Powder Test.

g/dL	mg/dL	Trial 1 mV	Trail 2 mV	Trial 3 mV	Trial 4 mV	Trail 5 mV	Average mV
0	0	0.886	0.883	0.892	0.891	0.88	0.886
1.4	1400	0.893	0.89	0.897	0.904	0.89	0.895
2	2000	0.896	0.894	0.904	0.906	0.891	0.898
5	5000	0.916	0.916	0.914	0.918	0.914	0.916
10	10000	0.925	0.945	0.95	0.94	0.921	0.936

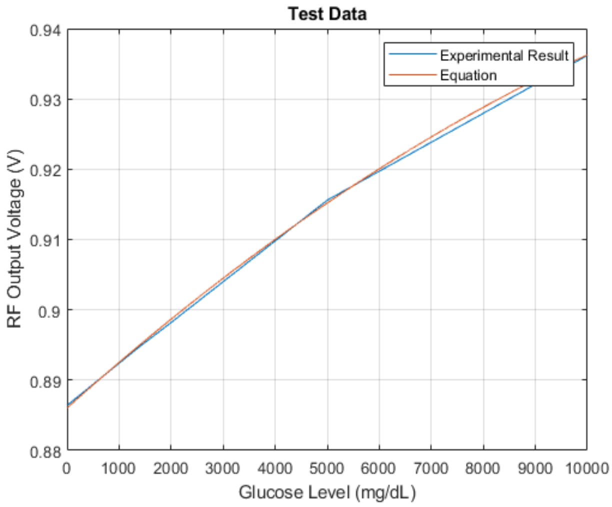


Figure 6-19: RF Output Voltage VS Glucose Level in H2O

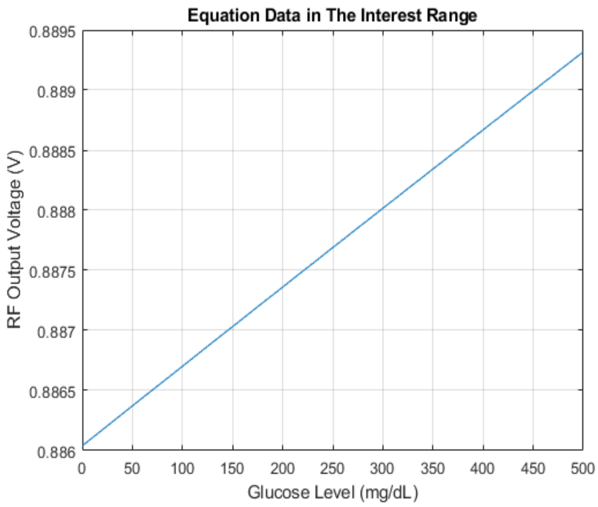


Figure 6-18: Equation Computed from H2O and Glucose Powder Test

Power System Tests

Our system is consuming totally 116.4 mA including the Arduino Nano when it's processing the program as discussed in Table 6-7. The power consumption of the analog system is illustrated below in Table 6-6. These values are measured from the DC Power Supply when the component is under its operated voltage. Therefore, and since we need the system to operate for at least 10 hours we decided to use 5000mAh 3.7V lithium-ion battery with a boost circuit which will increase the output voltage to 5V. After testing this battery with 0.3 W 0.06 A load, the result is that the system battery can supply our system for 11 hours since it is taking 21 hours to discharge when it is connected to the 0.06 A load. Recharging the battery from zero to fall charge with 1W charger takes 8 hours.

Table 6-6:Power Consumption of The Analog System.

System Component	Operating Voltage (V)	Drawn Current (mA)	Power Consumption (mW)
RF	5	20	100
LNA	5	66.4	332
Arduino (Max)	5	30	150
Total Consumption	5	116.4	582

6.2.1.3 The Effect of Changing the Frequency on the System

In this test, we measured the effect of different input frequencies on the system in the without antenna or coupler. We applied frequencies from 5.5 GHz to 6GHz at -20dBm input power using the Analog Signals Generator. Figure 6-20 shows the effect of the change in frequency.

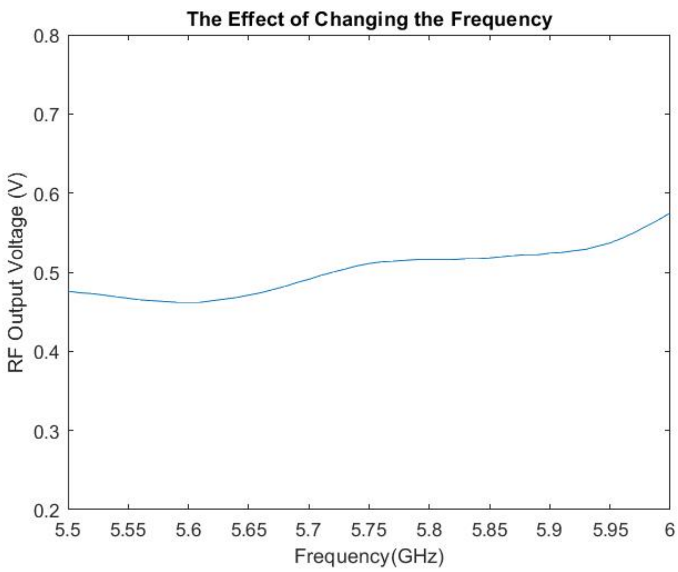


Figure 6-20:shows the Effect of the Change in Frequency.

We can observe that the effect of changing the frequency is not high, but it is still considerable.

6.2.2 Digital Part

In the digital part we conducted several tests: Reading Accuracy, Transmission Accuracy, Arduino Power Consumption, and Results Interpretation.

The Accuracy of the Reading using Arduino

In this test, we tested the Arduino's accuracy of reading by using the DMM (Digital Multimeter) as a reference to our measurements of the RF output voltage. The results of the test we conducted is shown in Figure 6-21.

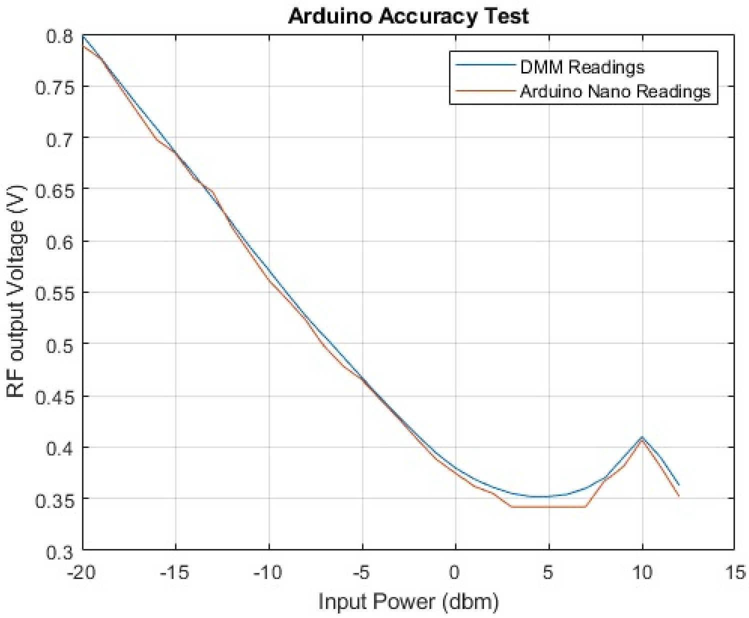
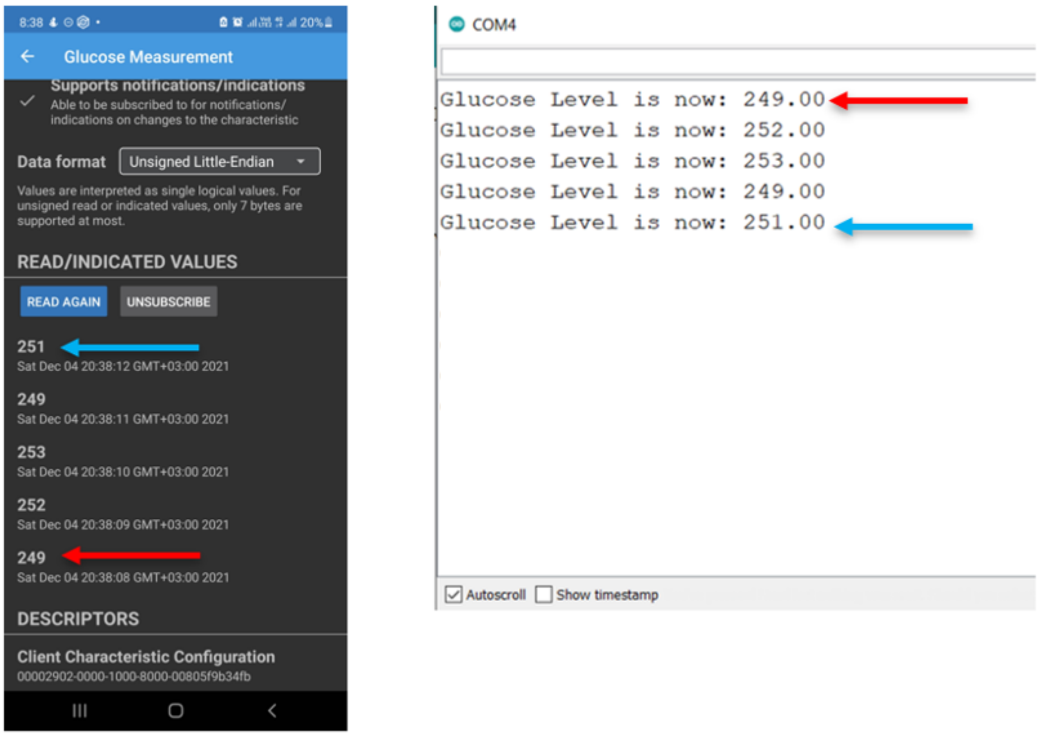


Figure 6-21:The Arduino Readings vs The Reading of the DMM

We observe that the Arduino readings has an error of 1.25% relative to DMM.

The Accuracy of The BLE Transmission

In this test, we tested the Arduino's accuracy of transmitting the data via the BLE module and we compared the values to Arduino measurements of the RF output voltage that are shown on the screen monitor. The results of the test we conducted is shown in Figure 6-22.



(a) (b)

Figure 6-22:The Values of the Transmitted Data(a), and the Values of the Arduino Readings (b).

We observe from the results that if the values were integers the error is 0%, but if the values are decimal the app cannot read the complete values. Which makes the maximum error in this case 0.9%.

One important note: The Arduino's BLE transmission is sensitive to the supplied voltage. If the voltage dropped below 5V the transmitted values will have higher error % that can reach 5.4%.

The Power Consumption of The Arduino

In this test, we measured the Arduino's power consumption at different operation modes at 5V supplied voltage. Table6-7 shows the results.

Table 6-7:The Power Consumption of The Arduino.

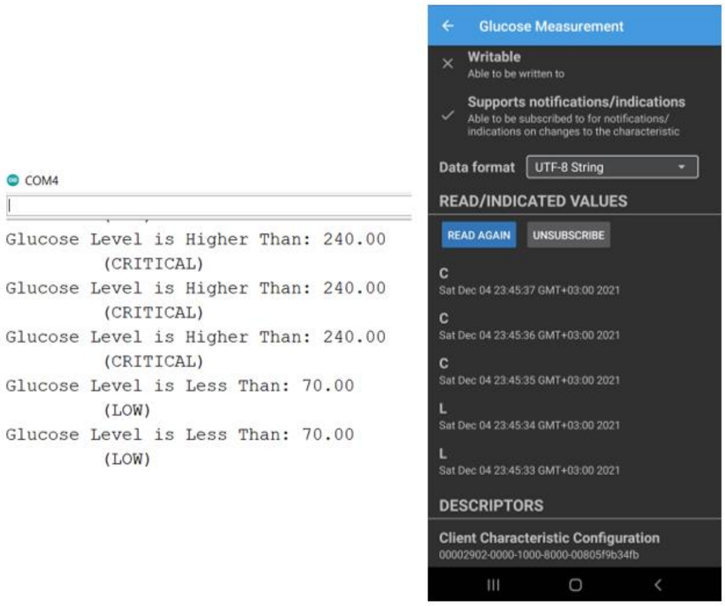
Operation Mode	Current Drawn (mA)	Power Consumed (mW)
Default	20	100
Reading Voltage	20	100
Reading & Transmitting Data	0.30	150

Interpreting The Glucose Test Measurements

According to the test of the glucose concentration that we conducted, we found un equation of the voltage measurements that corresponds to each of glucose levels we mentioned earlier (Low, Normal, High, and Critical). Since the app does not read the values after the decimal point, we decided to send an integer value corresponds to a letter with the format of UTF-8 string value that the app in capable to read.

- (L) for Low
- (N) for Norma
- (H) for High
- (C) for Critical

Figure 6-23 shows the readings and its corresponding letter illustrated by the app.



(a) (b)

Figure 6-23: Arduino Reading (a) and The Data Illustrated in the app (b).

We observed that the different in the voltage for the glucose levels is so small that Arduino Nano will not differentiate between the Low and Normal or Normal and High.

6.3 Specification Verification Check List

The tools that we used to test the system and measure the values are:

- Analog Signal Generator
- DC Power Supply
- The Digital Multimeter
- The Network Analyzer
- Weighing Scale
- Measuring Cup

Chapter 7
Conclusions and Recommendations

In this chapter, conclusion and recommendation will be discussed.

7.1 Conclusions

In this project, we designed a non-invasive glucose monitor that transmits high frequency signal then sense the effect of the glucose permittivity on it, then show the interpreted results to the user. The design is composed of three parts which are electromagnetics, analog, and digital. A 5.8Ghz antenna and oscillator were designed to transmit and receive the signal, then the signal goes through un analog circuit that modifies it to be clear for interpretation at the digital part. The digital part composed of Arduino Nano 33 BLE which the signal is analyzed then transmitted via the BLE module to the user's mobile phone where a special mobile app that detects and reads the BLE signal, then shows it to the user to observe the results that correspond to the glucose level. We managed to get a clear relation between the received signal and the glucose concentration in a distilled water that can be a measuring reference for the user. However, the relation that we found from our experimental results at the analog part's output depends on sensing very small voltage difference that the Arduino is unable to interpret it efficiently. That is, the voltage difference between the Low and the High glucose level was 0.4mV and the Arduino's minimum sensed voltage is 0.8mV, which is double the value. In addition, the 5.7Ghz antenna we used to sense the received signal was very sensitive to any external change in the setup. That made testing different samples less accurate due to any small change in the sample's distance from the antenna or its angle of orientation in front of the antenna. Moreover, the relation mentioned earlier between the glucose level and the sensed voltage was based on the g/dL scale which is 1000 times the desired scale which is mg/dL. This was because the weighing scale we used was unable to weigh less than 1 gram of glucose, and even if that was possible, we could not observe the change in the voltage at that low level of concentration neither on the digital nor the analog parts. However, we belief these issues can be solved, and the design of the system can be greatly enhanced to get un actual direct relation not only at small scale, but even at actual human body samples that reflect the real-life situations.

7.2 Recommendations

There are several recommendations that we highlighted which we belief that they will help enhancing the system's performance:

- Replace Arduino with raspberry pi
  Since the lowest change the Arduino can detect is 0.4mV due to its limited resolution of 12 bits, the raspberry pi has 32 bits in its ADC which means the lowest change the raspberry pi can detect even nanovolts.

- Improve the output signal
  We can add an amplifier with a gain of 10 to the output which will improve the output result and make it easier to detect the changes between different levels.

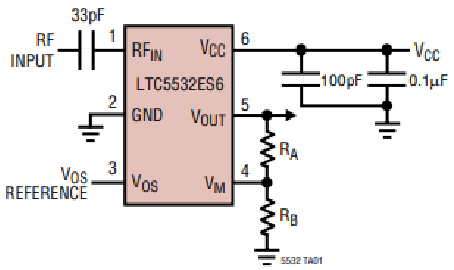
- Fixing the sample during the experiment
  Since the slight change in the antenna or the sample position will result very large change in the reading, even if the change is not noticeable. One of the solutions to this problem is to design a special stand for the experiment, where the antenna and the sample are completely stationary for the duration of the experiment.

Appendix A Gantt Chart

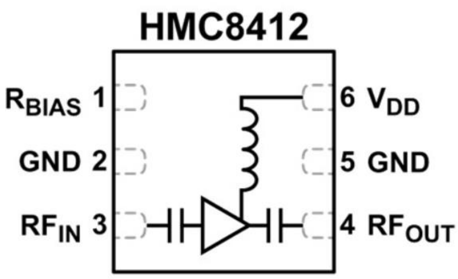
Table A 1: Tasks/Time schedule

Task	Week													
	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Instructor meeting	■	■	■		■	■	■	■	■	■	■	■	■	
Project proposal	■													
Find existing electronic components for the analog circuits		■	■											
Build and verify the BPF		■	■	■										
Build and verify the LNA circuit			■	■										
Build and verify the RF detector circuit				■	■									
Test and approve the analog circuit					■	■	■							
Design power management system							■	■	■					
Prototyping										■	■	■	■	
Early presentation				■										
Midterm progress report								■						
First draft of final report												■	■	
Final report													■	■
Poster and final presentation													■	■

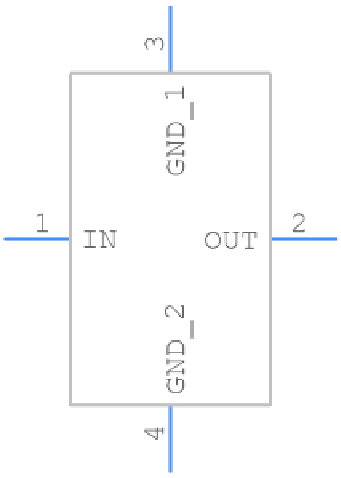
Appendix B
Final Drawing



Appendix B 1:(LTC5532) RF Detector



Appendix B 2:(HMC8412) LNA



Appendix B 3: (DEA255787BT-2044A1) BPF

Appendix C
Specification for Supplied Materials

Include all specification (or properties) of supplied materials and purchased parts.

Appendix D Programing Codes

Arduino Programing Code

BLE_Test §

```
#include <ArduinoBLE.h>
#define BLE_UUID_FILE_NAME "2D2F88C4-F244-5A80-21F1-EE0224E80658"

BLEService GlucoseService("1808");
BLELongCharacteristic GlucoseLevelChar("2a18", BLERead | BLENotify);
BLEStringCharacteristic fileNameCharacteristic( BLE_UUID_FILE_NAME, BLERead | BLEWrite, 20 );



void setup() {
Serial.begin(9600);


pinMode(LED_BUILTIN, OUTPUT);
if (!BLE.begin())
{
Serial.println("starting BLE failed!");
while (1);
}
BLE.setDeviceName( "GlucoseMonitor" );
BLE.setLocalName("GlucoseMonitor");
BLE.setAdvertisedService(GlucoseService);
GlucoseService.addCharacteristic(GlucoseLevelChar);
BLE.addService(GlucoseService);

BLE.advertise();
Serial.println("Bluetooth device active, waiting for connections...");
}

void loop()
{
BLEDevice central = BLE.central();


if (central)
{
Serial.print("Connected to central: ");
Serial.println(central.address());
digitalWrite(LED_BUILTIN, HIGH);

while (central.connected()) {

      analogReadResolution(12);
      int average = 0;
      int RFoutput = 0;
      float Level;
      float VoltageLevel;
      float milliVoltageLevel;
      float GlucoseLevel;
      float GlucoseLevel1;
      float GlucoseLevel2;


       for (int i=0; i < 10; i++) {
            average = average + analogRead(A0);
              }
             average = average/10;
             RFoutput = average;

      int T = map(RFoutput, 0, 4095, 0, 3300);
      float a1 = 1246100;
```

```
    float a2 = 2073100;
    float a3 = 858590;
    milliVoltageLevel = (T*1.0);
    VoltageLevel= milliVoltageLevel/1000;
    GlucoseLevel = a1*pow(VoltageLevel,2)-a2*VoltageLevel+a3;
    //G = 1.2461 x 10^6 V^2 - 2.0731 x 10^6 V + 8.5859 x 10^5

    if ( GlucoseLevel <70)
        {
            Level = 76;

            Serial.print("Glucose Level is Less Than: 70 ");
            Serial.print("\t (LOW) \n");
            GlucoseLevelChar.writeValue(Level);
         }
        else if((  GlucoseLevel >= 70) && ( GlucoseLevel <= 130))
        {

            Level = 78;
            Serial.print("Glucose Level is Between 70 and 130 ");
            Serial.print("\t (NORMAL) \n");
            GlucoseLevelChar.writeValue(Level);
         }
       else if((  GlucoseLevel > 130) && (GlucoseLevel <= 240))
        {


              Level = 72;
              Serial.println(GlucoseLevel);
              Serial.print("Glucose Level is Between 130 and 240");
              Serial.print("\t (HIGH) \n");
               GlucoseLevelChar.writeValue(Level);
           }
          else
          {
               Level = 67;

               Serial.print("Glucose Level is Higher Than: 240");
               Serial.print("\t (CRITICAL) \n");
               GlucoseLevelChar.writeValue(Level);
          }

      delay(1000);

}
}
digitalWrite(LED_BUILTIN, LOW);
Serial.print("Disconnected from central: ");
Serial.println(central.address());
}
```

MATLAB Programing Code

- MATLAB Program of the Glucose Test.

```
clear; clc;
GlucoseLevel = xlsread("Test Glucose Concentration in Pure
Water.xlsx","D41:D45");
Vout = xlsread("Test Glucose Concentration in Pure
Water.xlsx","J41:J45");


plot(GlucoseLevel,Vout)
grid on;
title("Experimental Results")
xlabel("Glucose Level (mg/dL)");
ylabel("RF Output Voltage (V)");
format shortE
G1 = polyfit(GlucoseLevel,Vout,2) % V = -1.6142e-10*G^2 + 6.6380e-06*G
+ 8.8604e-01 Where G is the Glucose Level
x = [0:1:10000];
y1 = polyval(G1,x);


plot(GlucoseLevel,Vout,x,y1);
 grid on;
 title("Test Data")
xlabel("Glucose Level (mg/dL)");
ylabel("RF Output Voltage (V)");
legend("Experimental Result","Equation");
x1 = [0:1:500];
y2 = polyval(G1,x1);
plot(x1,y2);
 grid on;
 title("Equation Data in The Interest Range")
xlabel("Glucose Level (mg/dL)");
ylabel("RF Output Voltage (V)");
y3 = polyval(G1,GlucoseLevel)
perError = abs(((Vout-y3)./Vout))*100 %Relative error between
expermental and equation
```

- MATLAB Program of the Analog System components tests.

```
clear; clc;
Pin = [-20:1:12];


Vout1 = xlsread("System Test(dbm).xlsx","D5:D37");
Vout2 = xlsread("System Test(dbm).xlsx","H5:H37");
Vout3 = xlsread("System Test(dbm).xlsx","K5:K37")./1000;
plot(Pin,Vout1,Pin,Vout2,Pin,Vout3)
grid on;
title("Experimental Data")
xlabel("Input Power (dbm)");
ylabel("RF output Voltage (V)");
legend("RF alone","RF with BPF","RF with BPF(Arduino Nano Readings)");
format shortE
p1 = polyfit(Pin,Vout1,7)
p2 = polyfit(Pin,Vout2,7)
p3 = polyfit(Pin,Vout3,7)
x = [-20:1:12];
y1 = polyval(p1,x);
y2 = polyval(p2,x);
y3 = polyval(p3,x);
plot(x,y1,x,Vout1);
grid on;
title("RF Alone Test")
xlabel("Input Power (dbm)");
ylabel("RF output Voltage (V)");
legend("Equation","Experimental Result");
plot(x,y2,x,Vout2);
grid on;
title("RF with BPF Test")
xlabel("Input Power (dbm)");
ylabel("RF output Voltage (V)");
legend("Equation","Experimental Result");
plot(x,y3,x,Vout3);
grid on;
title("RF with BPF Test (Arduino Nano Readings)")
xlabel("Input Power (dbm)");
ylabel("RF output Voltage (V)");
legend("Equation","Experimental Result");
plot(x,y1,x,y2,x,y3);
grid on;
title("Equations Data")
xlabel("Input Power (dbm)");
ylabel("RF output Voltage (V)");
legend("RF Alone","RF with BPF","RF with BPF (Arduino Nano Readings)");
```

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