



Design and Prototyping of an Early Breast Cancer Detector Using Bio-Impedance Measurement.

By:

BIKORIMANA CHRISTIAN
Reference Number: 217074499

A Dissertation Submitted to the Regional Centre of Excellence in Biomedical Engineering and e-Health (CEBE), University of Rwanda as partial fulfilment of the requirements for the Master's Degree in Biomedical Engineering.

Supervised by

Dr. NSENGIYUMVA PHILIBERT and PROF. YUNJIE TONG

DECLARATION

I, BIKORIMANA CHRISTIAN, declare that this dissertation entitled “Design and Prototyping of a Breast Cancer Early Detector Using Bio-Impedance Measurement.” is my original work based on research and prototype and has not been submitted for any other degree or professional qualification.

Student Name: BIKORIMANA CHRISTIAN

Reference Number: 217074499

Student Signature

Date: 17/04/2024.



Regional Centre of Excellence in Biomedical Engineering and e-Health (CEBE)

CERTIFICATE

This is to certify that the project entitled “Design and Prototyping of a Breast Cancer Early Detector” is a record of original work done by BIKORIMANA CHRISTIAN (Reference number:217074499), a MSc. Degree student in Biomedical Engineering.

This work has been submitted under the guidance of Dr. PHILIBERT NSENGIYUMVA and Prof. YUNJIE TONG.

Main Supervisor:

Dr. PHILIBERT NSENGIYUMVA

17/04/2024

Co-Supervisor:

Prof. YUNJIE TONG.

Biomedical Engineering Master’s Program Coordinator:

Dr. GERARD RUSHINGABIGWI.

ACKNOWLEDGMENTS

Firstly, I would like to express my deepest gratitude to the Almighty God for His abundant blessings and unwavering mercy upon me throughout this journey.

I am profoundly thankful to my esteemed supervisors, Dr. Philibert NGENGIYUMVA and Prof. Yunjie Tong, for their invaluable mentorship, unwavering support, and expert guidance throughout this research. Their wisdom, encouragement, and constructive feedback have been instrumental in shaping the direction and quality of this study.

I extend my appreciation to the dedicated staff of UR/CST and CEBE for providing me with the essential resources, facilities, and administrative support that facilitated the smooth execution of my research. Furthermore, I would like to express my sincere gratitude to my beloved parents, whose unwavering love, encouragement, and sacrifices have been the bedrock of my academic journey.

I am also indebted to my classmates and friends for their support, throughout my studies. Their encouragement during challenging times and shared moments of joy have enriched my academic experience and made this journey all the more meaningful.

I am profoundly grateful to all those who have played a part, big or small, in the completion of this study. Their support, encouragement, and belief in me have been instrumental in reaching this milestone, and I am truly blessed to have such wonderful individuals in my life.

ABSTRACT

Breast cancer remains a significant global health concern, emphasizing the need for effective and cost-effective early detection methods to improve patient outcomes. This research design and prototyping of a breast cancer early detection system by utilizing electrical bio-impedance technology. Electrical bio-impedance involves measuring the resistance and reactance of breast tissue to small electrical currents, providing valuable insights into tissue composition and structure. The proposed system incorporates electrodes placed on the breast surface to deliver low-frequency electrical currents of 20,434 Hz and 0.5 mA to measure the resulting impedance and phase angle. By analyzing the resulting impedance and change in phase angle, characteristic patterns associated with healthy and cancerous breast tissue can be identified. When the difference between right breast impedance and left breast impedance is beyond 4187 Ω , a device warns the user of cancer risk. The breast cancer early detector prototype is designed to be non-invasive, portable, and cost-effective, making it suitable for widespread screening in clinical and community settings. Due to the standardized protocol for testing medical equipment, initial testing was done on a rabbit. Preliminary testing (preclinical testing) demonstrates promising results, indicating that the proposed method can greatly affect the detecting of breast cancer at early stages. Further validation through large-scale clinical trials is necessary to assess the system's sensitivity, specificity, and overall effectiveness in real-world applications. If successful, this technology could significantly enhance current breast cancer screening practices and contribute to improved patient outcomes.

Keywords: breast cancer, impedance, phase angle, Sine wave generator, Voltage-controlled current source, and phase detector.

LIST OF ACRONYMS

AC: Alternating Current.

AD: Analogy Device.

ADC: Analogy to Digital Convertor.

CEBE: Centre of excellence in Biomedical engineering and E-health.

CMRR: Common Mode Rejection Ratio.

CST: College of Science and Technology

CT: Computed Tomography.

DC: Direct Current.

IC: Integrated Circuit.

I2C: Inter-Integrated Circuit.

KHz: Kilohertz.

RF: Radio Frequencies

MRPDD: Magnitude Ratio and Phase Difference Detection Method.

MRI: Magnetic Resonance Imaging.

MHz: Megahertz.

PCB: Printed Circuit Board.

LCD: Liquid Crystal Display.

LED: Light Emitting Diode.

STD: Standard Deviation

UR: University of Rwanda.

VCCS: Voltage Controlled Current Source.

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CHAPTER 1. INTRODUCTION

1.1. General Introduction

The Globocan 2020 data show that, in Rwanda, the breast cancer incidence rate is estimated at 41.0 per 100,000 women with a mortality rate of 19.4 per 100,000. Annually, breast cancer incidence in Rwanda is 16.1% of all new cancer cases. A study completed at Butaro Cancer Center of Excellence in Rwanda revealed that, of the 82% of women diagnosed with breast tumors, 55% of those were diagnosed with breast cancer and 36% were diagnosed with benign tumors. Of the women diagnosed with breast cancer, approximately 20% were stage one or two at diagnosis, 46% had locally progressive disease, and 31% had metastatic breast cancer [1].

To combat the increase in breast cancer cases and its effect, early detection of breast alterations and rapid treatments lead to a better prognosis and lower rates of breast cancer-related mortality. The early detection methods should be decentralized to health posts, health centers, and district hospitals.

Nowadays the existing screening techniques use MRI, mammogram, ultrasound, and CT scans. Some techniques are costly like MRI while others are not user-friendly like CT scans and mammograms, and cannot be easily used for every Rwandan to have check-ups regularly. The proposed solution to this is to develop a cheaper device that can be used to detect breast cancers at health posts, health centers, and district hospitals level. The designed and developed device is the point care device that is cheap compared to the other existing devices and easy to use that will give the warning to the risk of cancer by measuring the difference in bio-impedance of the breast.

The device measures the difference in impedance between the breasts; if the difference is significant, breast cancer risk is indicated, and further testing will be advised. Normally, the breasts (left and right) have the same impedance value or a small difference, which is insignificant [2]. However, when a person is attacked by breast cancer, it typically starts in one breast and spreads to the other over time so that the measurement of the difference in impedance of the breasts can be used to detect the cancer [2].

1.2. Problem Statement

The world incidence and mortality of breast cancer shows that in 2020 there were 2.3 million women diagnosed with breast cancer and 685,000 deaths globally [3]. The World Health Organization addresses the barriers to early diagnosis of breast cancer [4] in their research describing that 67.7% of women in middle-income countries described barriers to cancer diagnosis due to the long distance between their home and qualified hospital for screening the breast cancer and the large cost of the service.

Currently, now, breast cancer screening methods are MRI, CT scans, ultrasound, and mammography. CT- scans are expensive and utilize radiation; MRI is costly and may not be suitable for women with metal implants. Additionally, mammography employs X-rays and can be uncomfortable for women with large breasts, also having a higher rate of false positives for women above forty years [5]. The fact that most facilities for breast cancer screening and diagnosis are located in referral hospitals contributes to the high incidence of breast cancer in middle-income nations by delaying breast cancer diagnosis. There are currently no accessible, low-cost, non-invasive, and easy-to-use early breast cancer techniques for screening.

1.3. Aims and Objectives

1.3.1. General Objective

This project aims to develop a point-of-care device used for screening breast cancer based on measuring electrical bio-impedance.

1.3.2. Specific Objectives

- Design prototyping bio-impedance-based breast cancer detector.
- Prototyping bio-impedance-based breast cancer detector.
- Use the device to measure the electrical bio-impedance of living biological tissue.

1.4. Scope of the Research

This research related to detecting the bi-impedance and phase angle of biological tissue as screening tools, It is advised to use a other advanced techniques to make the diagnosis.

1.5. Significance of the Study

- i. **Early detection:** the main benefit of such a system would be the ability to identify breast cancer at an early stage. The device is low-cost and can detect possible early indicators of breast cancer by using cutting-edge technologies and algorithms. Early diagnosis greatly increases the likelihood of effective therapy and better patient outcomes.
- ii. **Higher survival rates:** Timely medical attention and therapy are made possible by early detection of breast cancer. Patient survival rates may rise because of the cancer being treated before it reaches an advanced stage.
- iii. **Lower death rate:** the death rate linked to breast cancer can be considerably lowered with early identification and prompt care. The approach can assist in identifying those who are at high risk and allow medical professionals to start the proper screening and preventive steps.
- iv. **Low cost and wide availability:** The devices are cost-effective, which makes them available at low-level health centers.

CHAPTER 2: LITERATURE REVIEW

There are several methods for early detection/screening the breast cancer lesions today. Some of these methods include the use of MRI, ultrasound, mammograms, and CT scans. Researchers are now working on a new device for early breast cancer diagnosis that uses impedance techniques and is non-invasive and user-friendly. This section provides an overview of earlier studies and works connected to the application of bio-impedance technology that were conducted by various researchers.

The cell has a membrane enveloping intracellular fluid that can store energy when an electrical current passes through the body. That membrane is considered as a capacitor [6]. On the other hand, the extracellular fluid is made of water and electrolytes and this makes it to be considered as a resistor. So biological tissue is considered to have electrical properties. To measure the electrical properties of tissue different approaches were designed. Morimoto et al. [7] developed a system to detect breast cancer by measuring the change in bio-impedance in the breast, they designed invasive technology made of an outer circuit used for current input and an inner circuit for voltage output. A large reference electrode was placed on the abdomen of the subject.

The purpose was to find if the tumor in the breast is cancer or not based on the output-measured voltage. The applied current was kept as small as $5 \mu\text{A}$ to ensure safety for the heart and the frequency range used was from 0 to 300 kHz. After testing the device, the results showed that extracellular (R_e) resistance and intracellular (R_i) resistance of malignant breast tumors were 'significantly higher than those of benign tumors, and they concluded that impedance measurement might be used for the differential diagnosis of malignant and benign breast tumors. This could be used for breast cancer early detection but it is not non-invasive [7].

Mansouri and al. [2]. Designed a breast cancer detection device using low-frequency bio-impedance. In their study, they modeled the device and tested it in vitro and in vivo [2]. The obtained results indicate that the use of electrical bio-impedance sensors has a great impact on cancer detection. Their device is used to inject the current in each breast to measure the resistances of the extracellular matrix. The performance was tested on a set of reference resistors, and the validation was done in vitro on ($\text{Na}^+ \text{Cl}^-$) solutions and in vivo on a group of forty volunteer women. From their experiments in impedance measurements, they conclude that malignant tumors showed a higher current conductivity, and the mammary impedance measurement shows that malignant breast tumors have lower electrical impedance than normal tissues. When applying a low-frequency current, the cell membrane prevents the current from entering the cell, limiting it to pass only in the extracellular fluid. Since the extracellular resistance of a tumor is less than that of the healthy tissue, then a weak low-frequency current is sufficient to determine the extracellular resistance of the mammary tissues. The device injects the current into the body and the voltage is measured between two points of interest. In their results, the large difference in impedance between the breasts indicates the high risk of breast cancer. It was found that the patients with a difference in impedance greater than 50 ohms had a risk of cancer and this was proven when one of the 40 volunteer women who had a change in impedance of 120 Ohms asked to go to the hospital for further diagnostics and was found with the breast cancer at the second stage. Based on the results the researchers concluded that the difference between measured resistances of the right and left breast is a pertinent parameter to early detection of the presence of a cancer [2].

In their methodology, an FPGA device was used to inject the current in the body by an acquisition card, the NIPXI-7841R, a chassis the NI PXI-1033, a shielded connector blocks the NI SCB-68, and development software. The acquisition module was connected to each breast by two electrodes.

Another related piece of work is by Yuferal et al. [8] who used a probe with four wires. The current was injected within two wires and the voltage as output was measured on the other two wires. The wires considered as electrodes were made in platinum on a needle-shaped silicon substrate.

The external electrodes were employed to inject the current into the tissue sample of unknown impedance and the two inner ones took its response. In their experiment, the current was kept below 5 μA , over a load R -ranging from 100 Ω to 10 $\text{k}\Omega$. The device was tested on passive and active loads on saline solution (Na-Cl). After getting the results, this device was found promising for the diagnosis of different diseases including cancer.

Another important research which is related to the measure of impedance to detect cancer was performed by T. International et al. [9]. The objectives of that study were to study the electrical properties of cancerous tongue tissue and normal tongue tissue, as well as to investigate a new approach for low-cost, noninvasive, and real-time screening of oral cancer. The techniques used can be applied in screening the cancer of the breast.

Four-electrode disposable probe made of silicon was connected to the impedance analyzer for measurement. The test was carried out on 12 healthy subjects and on saline solution of known electrical conductivity and it was found that the device had an accuracy of 98% in measuring resistance. Their study shows that injecting low-level sinusoidal current in the tissue and measuring the voltage drop generated by the tissue impedance can be used to identify tongue cancer.

Another piece of work is by Robert E. Dodde et al. [11] who developed a bio-impedance spectroscopy instrument with compensation techniques for soft tissue characterization. The device uses a maximum output of 60 μA RMS (root mean square) with a frequency ranging between 100 Hz to 100 kHz, the voltage-controlled current source is used to generate the constant current while the frequency is achieved by designing a function generator. A device uses four probes (two for injecting current and two for sensing the voltage).

The sensed voltage is amplified by an instrumentation amplifier and then viewed on an oscilloscope, and the current from the body through the low-current electrode is converted into voltage by the current-to-voltage convertor and then viewed on an oscilloscope. The impedance is calculated by the formula $Z = \frac{c(w)}{R_s}$, where $c(w)$ represents the frequency-dependent CMRR of the output amplifier (dB), and R_s is the parallel combination of the external current sense resistor R , and 25 $\text{k}\Omega$ (reference resistors).

In another related work by H. Mirzaalian et al. [10], a bio-impedance spectroscopy device was developed and tested on a mouse. The result showed the compromise of bioimpedance spectroscopy to be used in different disease screening and diagnosis. Howland circuit current source was used to generate a constant current and the maximum allowable current applied to the body was 100 μA at 1 kHz frequency and 10 mA at higher frequencies. The frequency of the current was ranging between 1 Hz and 10 MHz with an accuracy of 1 Hz. The sensed voltage was sent to the phase detector and voltmeter, the impedance was given by the ratio between the voltage and current. In their study, four Ag/Ag-Cl electrodes were used. The device was tested for measuring bio-impedance for gastrocnemius muscle, skin, liver, and heart tissues. During testing, each measurement was repeated five times at a single frequency, and based on the results the authors confirmed that the device showed significant impedance changes between those tissues.

Abhijit S. Patil developed a bio-impedance spectrometer [11]. The device uses a maximum current of 0.5 mA, and a frequency ranging between 10 KHz to 1 MHz. Voltage-controlled current source which uses an improved Howland current pump circuit to generate the current, The device uses four electrodes for injecting and reading the voltage. The main parameters that are measured are impedance and change in phase angle. The device uses the magnitude ratio and phase difference detection method (MRPDD) to measure the impedance and phase angle. A device using a phase detector based on an AD8302 integrated circuit, this IC receives the voltage across the tissue and reference resistor, based on their amplitude and phase angle, the IC generates an V_{phs} and V_{mag} which are further used in calculating the impedance and phase angle by the microcontroller. A device was tested on a

healthy male person to see the change in impedance because of the reduction of his glucose level; the results show that there was a correlation between bio-impedance and glucose, so the device can be used to check the change in molecules in the body.

Table 2.1: Summary of the previous related works.

SN	Authors	Title	Methods	
1	T. Morimoto[7]	A Study of the Electrical Bio-impedance of Tumors	Maximum Current	5 μ A
			Frequency range	0-200kHz
			Number of Electrodes	3
			Measurement methods	i(t) and v(t) are subjected to Fourier transformation to calculate the impedance.
			Advantage	<ul style="list-style-type: none"> The intracellular & extracellular and cell membranes are displayed. Can be used for diagnostic purposes.
Disadvantage	<ul style="list-style-type: none"> Polarization effect was ignored Invasiveness 			
2	A. Yuferal <i>et al</i> [8]	An integrated circuit for tissue impedance measure	Maximum Current	5 μ A
			Frequency range	100Hz-100KHz
			Number of Electrodes	4
			Measurement methods	demodulator
			Disadvantage	Invasiveness
3	T. International <i>et al</i> [9]	The use of bio-impedance in the detection/screening of tongue cancer.	Maximum Current	Not mentioned
			Optimum frequency	20Hz and 50KHz
			Number of Electrodes	4
			Measurement methods	Not mentioned
			Advantage	Provide immediate results
4	R. E. Dodde, G. H. Kruger, and A. J. Shih[12]	Design of Bio-impedance Spectroscopy Instrument.	Maximum Current	5 μ A
			Frequency range	100 Hz to 100 kHz
			Number of Electrodes	4
			Measurement methods	
5	H. Dastjerdi, R. Soltanzadeh, and H. Rabbani[10]	Designing and implementing bioimpedance spectroscopy device by measuring impedance.	Maximum Current	3.8 mA
			Frequency range	1 Hz to 10 MHz
			Number of Electrodes	4
			Measurement methods	Voltmeter & phase detector
6	A. S. Patil and R. B. Ghongade[11]	Design of bioimpedance spectrometer	Maximum Current	0.5mA
			Frequency range	10 kHz to 1 MHz
			Number of Electrodes	4
			kHz	MRPDD
7	N. N. Khamis, N.	Arduino-Based Biosensor	Maximum Current	Not mentioned

	F. Za’Bah, A. F. Mansor, and A. N. Nordin [13]	Impedance Measurement	Frequency range	20Hz
			Number of Electrodes	4
			Measurement methods	Detect voltage
8	S. Mansouri, Y. Alharbi, J. Nebhen, and A. Alshrouf [2]	Breast cancer detection using low-frequency bioimpedance vice.	Maximum Current	0.9mA
			Frequency	1KHz
			Number of Electrodes	Not mentioned
			Measurement methods	Not mentioned
			Advantage	Non-invasive Diagnostic propose
9	A. Zarafshani, N. Huber, N. Béqo, B. Tunstall, G. Sze, C Chatwin and *Wei Wang[14]	A Flexible Low-Cost, High-Precision, Single Interface Electrical Impedance Tomography System for Breast Cancer Detection Using FPGA	Maximum Current	Not mentioned
			Frequency range	10Hz to 20MHz.
			Number of Electrodes	Not mentioned
			Measurement methods	FPGA returns the amplitude and phase of the measurement.
			Impedance range	100Ω to 50 KΩ
			Advantage	wide bandwidth low noise and high speed
10	wide bandwidth	Design and preliminary evaluation of a portable device for the measurement of bioimpedance spectroscopy	Maximum Current	0.14mA.
			Frequency range	20 kHz to 1 MHz
			Impedance range	9 Ω to 5.7 KΩ
			Number of Electrodes	4
			Measurement methods	MRPDD
11	J. Ugwaha <i>et al</i> [15]	Ex-Vivo Detection of Breast Cancer with a Bio-Impedance Sensor.	Maximum Current	10mV
			Frequency range	1KHz-100KHz
			Optimum frequency	20,434 Hz
			Impedance range	1 KΩ-100 KΩ
			Number of Electrodes	2

Different pieces of work show the approaches/methods used for determining the electrical bio-impedance of the biological tissue, some are invasive and others are non-invasive. Most developed non-invasive methods use the same detection methods and differ in data processing, which makes them complex and more expensive. A simple method of interpreting the signal is needed to make the devices cheap and easy to use. To address the solution to the existing, breast cancer early detector, a device uses magnitude ratio and phase difference detection methods to detect the phase angle and impedance. A designed device uses four electrodes in total, one of them injects current into the body, another one is used as a path to remove current from the body and two remaining electrodes sense the voltage between current electrodes. Breast cancer early detectors use 0.5mA that is generated by the y Howland current pump. Phase detector (AD8302) is used to measure phase angle and impedance therefore the result is processed in the microcontroller then results are displayed on the Liquid crystal display. Based on the materials used to design a breast cancer early detector and compared with the existing technology, the device is cost-effective which makes it available at low-level health centers.

CHAPTER 3. METHODOLOGY

3.1. Research Process

Research methodology describes all techniques used in research to achieve the objectives; it shows the ways and procedures followed from the beginning until the completion of the project. This section shows clearly how research done scientifically, and contains the research method, the research approach, and the designing procedure for designing the breast early detector. The breast cancer detector will be based on measuring the bio-electric properties of tissue to differentiate whether it is normal or abnormal. The process used is illustrated in the flowchart in Figure 3.1.

3.1.1. Flowchart used in designing the breast cancer early detector

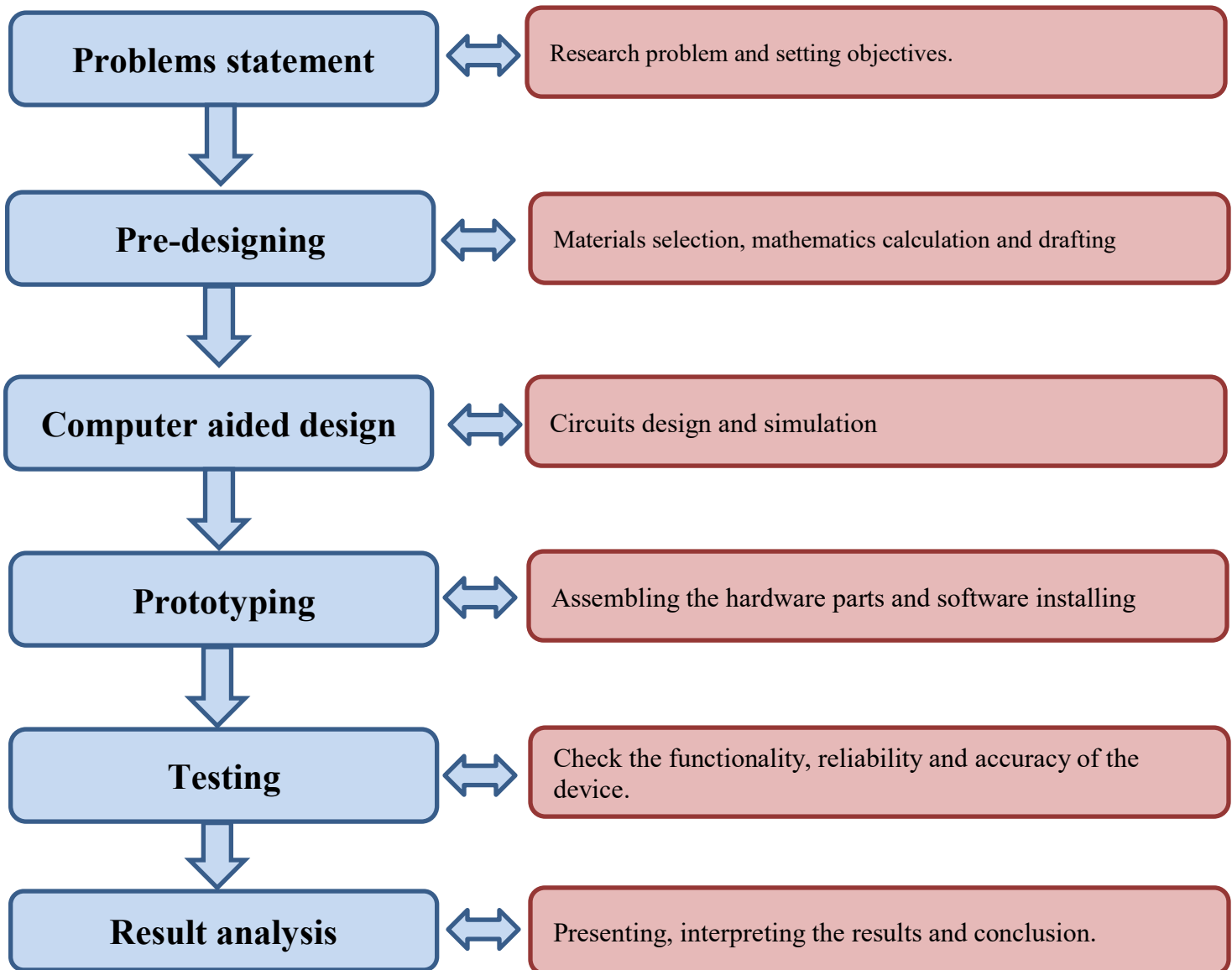


Figure 3.1: Flowchart followed during designing breast cancer detector.

3.2. Research Design Method

3.2.1. Working principles of the breast cancer early detector.

The electrical properties of normal cells and cancer cells are different [16], cancerous transformations affect different cells and change their capacitance which affects the impedance of the overall tissue. It is discussed in a piece of work by Christian Händel et al[17]. Breast cancer has significant effects on the breast tissue structure both the cellular cytoskeleton and cell membrane are highly affected. By examining thermal fluctuations of giant plasma membrane vesicles taken from both plasma membranes of health and breast cancer cells, The study shows that due to the loss of fluid raft forming lipids, which contribute to the rigidity of cell membrane cancer cells have softer membranes than healthy cells [17].

Breast cancer is one the cancers that also change the impedance of the breast, this occurs during breast cancer metastasis preparation. The cell membrane loses its functionality, cancerous cells reduce membrane cholesterol content to increase the membrane fluidity and plasticity [18] this reduces the capacitance of the cell membrane which results in low impedance and a small change in phase angle when current passes through them[19]. Figure 3.2 shows when the current passes through the normal cells and cancer cells. The current passes easily in the cancer cell membrane but it is hard in normal cells.

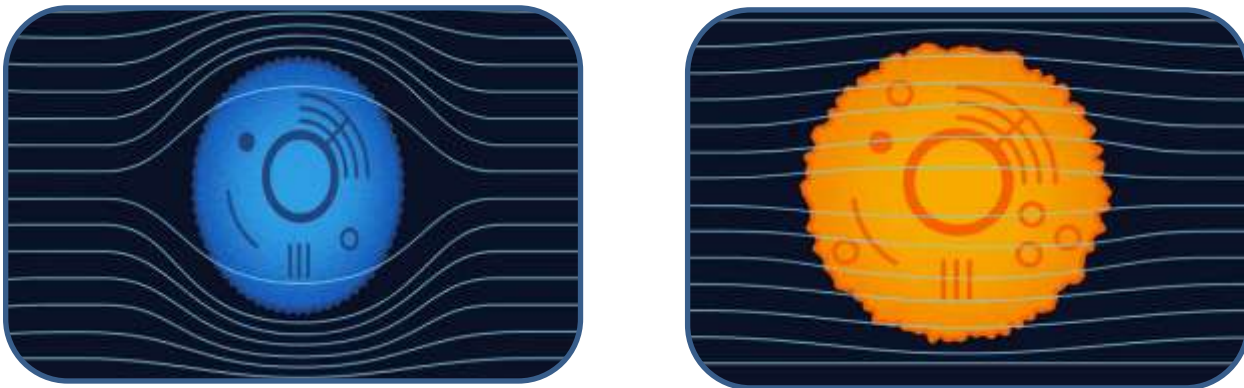


Figure 3.2: Normal cell (left) and Cancer cell (right) under electric current.

The breast cancer detector basing on the theory of changing electrical properties in the breast cancer cells to determine whether the user has a risk of cancer. A low alternating current is injected into each breast and based on the sensed voltage, the phase angle and impedance are calculated then based on the results, the device determines whether the target patient has a risk of cancer. Concerning the work of Mansouri et al. [2] the breast after measuring the impedance of the right and left breast, the minimum difference should be 50 ohms to be free from breast cancer.

To design the breast cancer detector, all parameters are considered, including safety, user-friendliness, fast response, and ease of interpretation. A set of materials used within the five main sub-components to achieve this.

- Sine wave generator
- Voltage-controlled current source
- Sensing system
- Data acquisition system
- Display

Each component implements its function to achieve the required objectives of the early breast cancer detector. it is ensuring the safe current during operation. The voltage-controlled current source is used to regulate it while the frequency convertor regulates the required frequency. The block diagram shown in Figure 3.3 illustrates the path of the current toward the patient and how the data are processed to get meaningful results.

Block diagram of the breast cancer early detector.

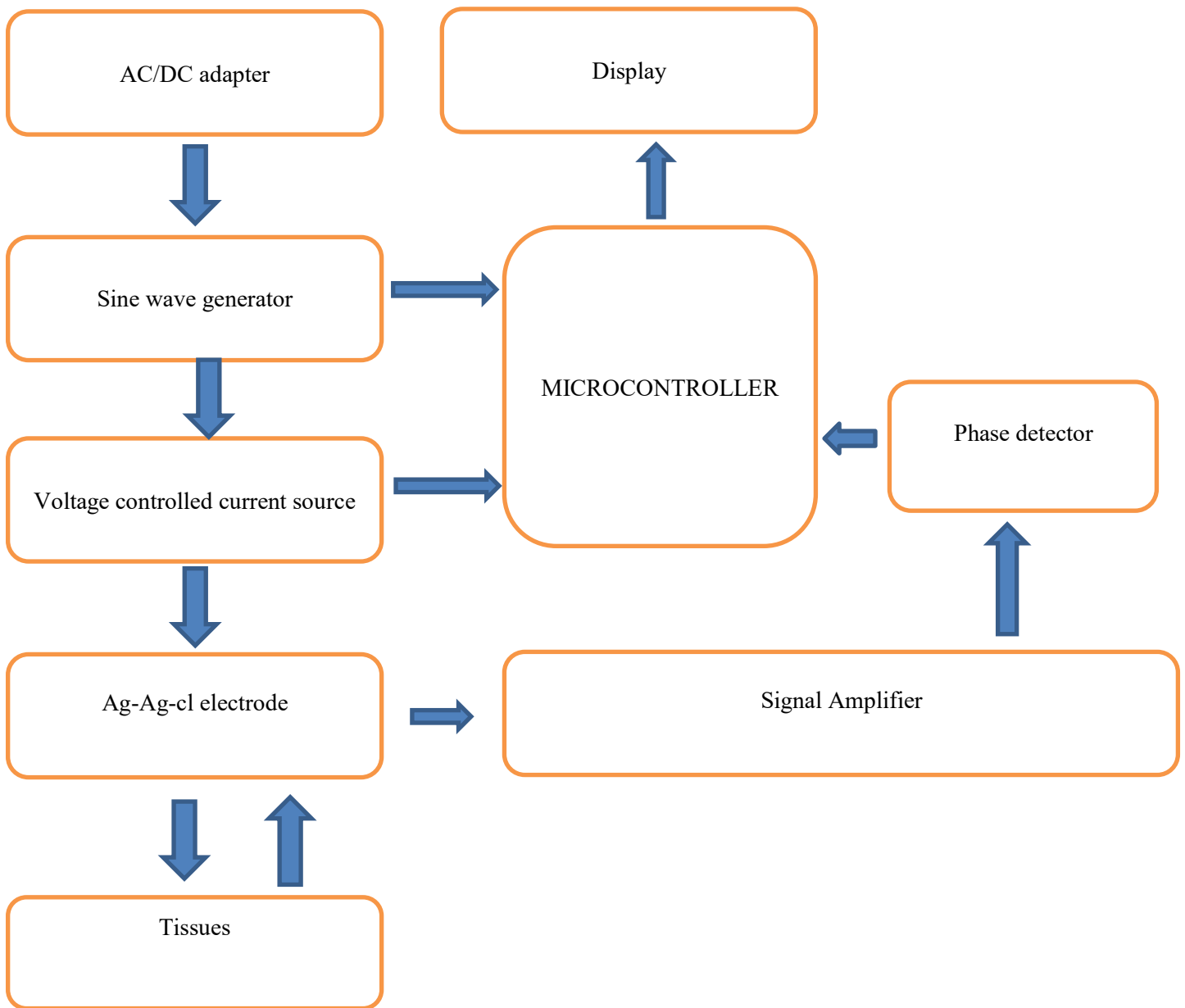


Figure 3.3: Block diagram of the device.

3.2.1. PRE-DESIGNING OF SUBSYSTEM OF THE BREAST CANCER EARLY DETECTOR

This section summarizes the components used to design each sub-system of breast cancer early detection, describes the advantages of using such materials and their technical specifications, and this section describes the mathematical calculations (science theories, electrical and electronics equations) used in designing the breast cancer early detector.

I. MATERIALS/EQUIPMENT SELECTION

1. Sine wave generator

During bio-impedance spectroscopy, the frequency ranging from 10 KHz to 1 MHz is the recommended frequency for β dispersion, the biological pathology is identified at that range of frequencies[11][20]. During bio-impedance measurement, the impedance reduces as the frequency of the current increases[21], however, to ensure a good result in bio-impedance measurement to differentiate normal cells from breast cancer cells the optimum frequency must be used. To achieve the required frequency during designing breast cancer early detector 555 timer was used to generate a square wave then filtered by the Resistor-Capacitor circuit to get a sin wave, Figure 3.4 shows the 555 timer and pins configurations.



Figure 3.4:555-Timer and pin configurations

Technical specifications of 555 timer integrated circuit

Referring to the datasheet of 555 timer IC [22] the important technical specifications are summarized in Table 3.1.

Table 3.1: Technical specifications of 555-TIMER

SN	Parameter	specification	
		Min	max
1	Supply voltage	4.5V	16V
2	Current	10mA	15mA
3	Working temperature	0°C	70°C

The power adapter rated at 12V is used to supply the 555-timer integrated circuit, however, the capacitors and the resistors are connected to the 555-timer to get the required frequency. The values of resistance and capacitance are calculated in the next section.

2. Voltage-controlled current source

The safe current that doesn't have any influence on the human body ranges between 0.1 and 0.9 mA, even if this current flows for a long time[11]. The VCCS is suitable to be used in bio-impedance spectroscopy to generate a constant current that does not change at any load[23][24]. The main components used to design VCCS are the operational amplifier and the resistors used to determine the output current. While designing voltage voltage-controlled current source, an LM 741 op amps integrated circuit is used. LM741 and its pin configuration are illustrated in Figure 3.5.

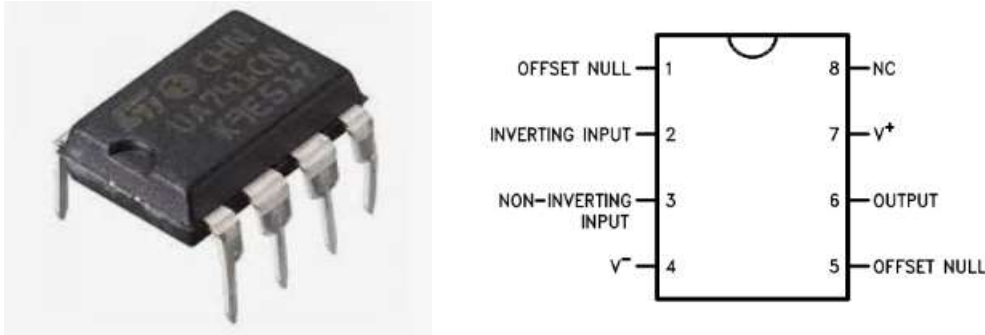


Figure 3.5:LM741 and its pin configurations

Technical specifications of LM741

Concerning the data sheet of the LM741 technical specifications of LM741 are summarized in Table 3.2.

Table 3.2: Technical specifications of LM741.

SN	Parameter	specification	
		Min	max
1	Supply voltage	$\pm 10V$	$\pm 22V$
2	Supply current		2.8mA
3	Working temperature	$-50^{\circ}C$	$125^{\circ}C$

3. Injection and sensing electrodes and wires.

- Disposable ECG Ag/Ag-Cl Electrode

Breast cancer early detectors use disposable ECG Ag/Ag-Cl electrodes, those electrodes show great advantages over the others due to their high stability and low noise [25] and also, they offer rapid setup, user-friendliness, self-application, and wearing comfort[26]. The piece of work by D. Chung and his teams describes Ag/Ag-Cl based electrodes as the best choice of electrode materials to be used in the determination of electrical bio-impedance[27]. Ag/Ag-Cl electrodes are used as they are inexpensive, commercially available, and have low polarization effects[21]. The device also uses the existing wire used in ECG due to its low resistance and insignificant noise. Figure 3.6 shows images of disposable ECG Ag/Ag-Cl electrodes and wires.



Figure 3.6: Disposable Ag/Ag-Cl and wires.

4. Signal detection

Signal detection instruments have the objective of taking the signals from the tissue and transmitting the data to the microprocessor, due to low signal from the body is firstly amplified and then measured by a phase detector.

I. Signal amplifier

Breast cancer early detectors use the operation amplifier of type LM 741 connected to external resistors to magnify the detected weak signal from the body.

II. Phase detector

Phase angle and impedance are the measured parameters by the device to distinguish if the biological tissue is normal or abnormal. There are three basic techniques to measure the impedance of biological systems, bridge method, quadrature demodulation method, and magnitude ratio and phase difference detection method(MRPDD) [11]. Breast cancer early detectors use magnitude ratio and phase difference detection methods due to many advantages over others such as cost-effectiveness, and real-time impedance measurement [28]. However, due to high power consumption, high time, and cost, other methods are inefficient for the bio-impedance spectrometer design [11], while implementing the magnitude ratio and phase difference detection method. The phase detector (AD8302) is used to detect signals from the tissue.

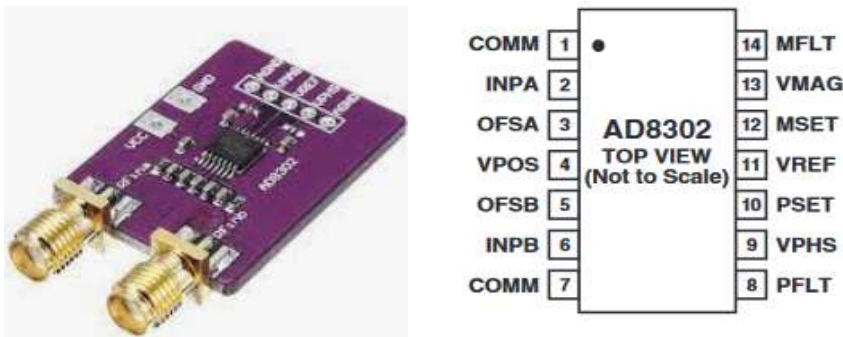


Figure 3.7: Phase detector (AD8302) and pins configurations.

Figure 3.7 shows the integrated circuit of AD8302 and its pins configuration, the IC is connected to the external circuit composed of resistors, capacitors, and an operational amplifier to achieve its functionality.

Table 3.3: Technical specifications of AD8302

SN	Parameter	specification	
		Min	max
1	Supply voltage	2.7V	5V
2	Supply current		2.8mA

3	Working temperature	-40 ⁰ C	85 ⁰ C
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5. Data processing and display

Data are processed in the microcontroller of Arduino Uno due to its cost-effectively, lightweight and data are displayed on a Light crystal display connected to an Inter-Integrated Circuit (I2C), As illustrated in Figure 3.9 shows the Arduino Uno(left), LCD, and I2C(right).








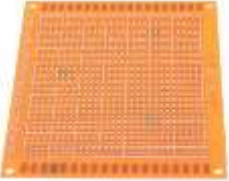



Figure 3.8: Arduino Uno (left) and LCD with I2C (right).

6. Accessories

During the design of breast cancer early detectors, there are other components used as auxiliary parts. The accessories components with their functions summarized in Table 3.4.

Table 3.4: Accessories

SN	Parts	QTY	Image	Functions
1	Push buttons	2		To control the device program
2	Switch buttons	2		To open and close the circuit
3	LED	2		Act as indicators
4	Jumper wires	20		Carry current

5	IC Sockets	4		This holds the IC so that in cases one IC is burn can be removed and replaced without disordering.
6	PCB	1		Providing a platform for connecting and supporting electronic components.
7	12V DC power adopter	1		Supply power to a device
8	Fuses	2		To protect the circuit against overcurrent
9	Capacitors	4		Are used for <ul style="list-style-type: none"> • Removing noise • To regulate the desired frequency and filtration purposes in the sine wave generator. • Used in the negative voltage generator
10	Resistors	10		They are for limiting the current, regulating the desired frequency, filtration purposes, and amplification.
11	Diodes	2		They are used in the circuit of generating negative voltage.

III. DETERMINING OPTIMAL RESISTANCE AND CAPACITANCE VALUES

This section provides theories and the equations used to calculate the required values of resistance and capacitance in each subsystem and shows the mathematical formulas for obtaining impedance and phase angle from the sensed voltage from the biological tissue given by the phase detector.

a) square wave generator

To differentiate cancer breast cells from normal breast cells by using bio-impedance spectroscopy, optimum

frequency is required. In a piece of work by J. Ugwaha *et al* [15] researchers determined the optimum current frequency for separation between normal and abnormal breast tissue. During their experience, by taking the frequencies ranging from 1 KHz to 100 KHz, that current was applied to the normal tissue and breast cancer cells, after the analysis of the results, they concluded that the optimum frequency of 20,434 Hz was able to differentiate between the healthy tissue and both benign and cancerous breast lesion at that frequency. With Concerning the research, the optimum frequency of 20,434 Hz is used during the design of the breast cancer, early detector is chosen to be 20,434 Hz. The circuit diagram of the electrical circuit that gave the output of the square wave is given in Figure 3.10.

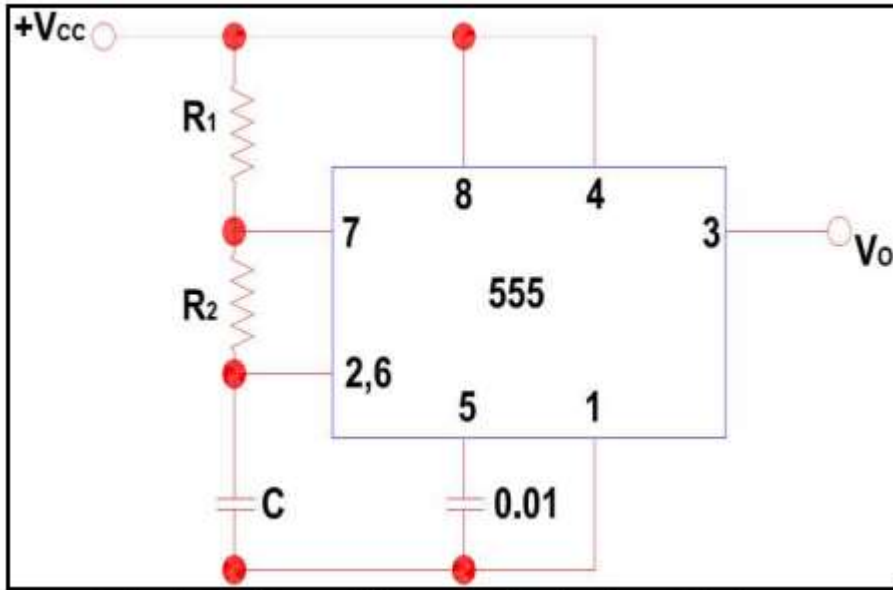


Figure 3.9:555-timer with Astable mode circuit.

The output frequency is given below

$$f \approx \frac{1.44}{(R_1 + 2R_2)C}$$

The output high-level duration *and* low-level duration T_L can be calculated as follows

$$T_H = 0.639(R_A + R_B)C$$

$$T_L = 0.639(R_B)C$$

While the duty cycle D,

$$D = \left(\frac{T_H}{T_L}\right) * 100\% = \left(\frac{0.639(R_A+R_B)C}{0.639(R_B)C+0.639(R_A+R_B)C}\right) * 100\% = \left(\frac{R_A+R_B}{R_A+2R_B}\right) * 100\%$$

- **Calculation of the required capacitor and resistor**

Breast cancer early detector uses a frequency of 20,434Hz and a duty circle of 50%, to achieve the 50% of the duty cycle T_H and T_L must be equal, this implies that the value of R_A to be 0. then the duty cycle and the frequency becomes

$$D = \left(\frac{R_A + R_B}{R_A + 2R_B} \right) = 50\%$$

$$f = \frac{1.44}{(R_1 + 2R_2)C} = \frac{1.44}{RC}$$

For $f = 20,434\text{Hz}$, $RC = 70.47\mu\Omega\text{F}$, the value of the resistor and capacitor is calculated by assigning one value and calculating the other. A capacitor whose capacitance of 1nF , is chosen because of its availability on the market.

$$R_2 = \frac{70.47\mu\Omega\text{F}}{1\text{nF}} = 70.47\text{ k}\Omega$$

- **component of square wave and specifications**

Table 3.5: Components of the frequency converter and their specifications.

SN	Components	Quantity	functions	Specification
1	Timer IC	1	Generate a pulse	IC 555
2	Resistors	1	Regulate the frequency	70.47 kΩ
3	Capacitors	1	Regulate the frequency	1nF
		1	removing the noise	10nF

b) Wave convertor (sine wave generator)

The circuit shown in Figure 3.10 generates a square wave signal while the sinusoidal wave is needed for impedance measurement. In breast cancer early detector, the square wave is converted by a two R-C stage circuit illustrated in Figure 3.11, which acts as a low pass filter.

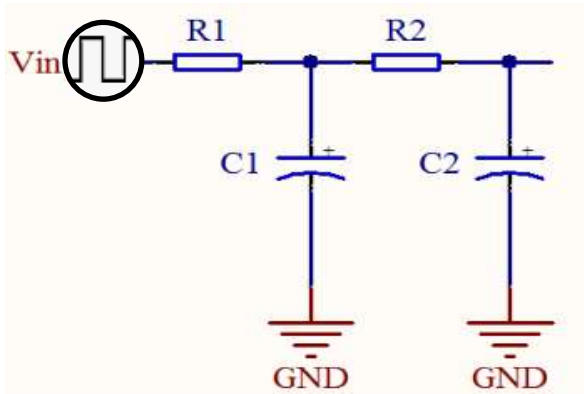


Figure 3.10: A sine wave generator

To achieve the objective, the capacitive reactance must be equal to the resistance.

$$X_C = \frac{1}{2\pi fC} \quad : \text{Capacitive reactance}$$

$$R = X_C = \frac{1}{2\pi fC}$$

$f = \frac{1}{2\pi RC}$, the device operates at $20,434\text{Hz}$, and the values of capacitance are calculated by assigning one value and calculating the other.

$RC = 70.47\mu\Omega\text{F}$. Let take also use $R = 70.47\text{ k}\Omega$, then $C = 1\text{nF}$.

- **Output Voltage**

1. Square wave circuit

Theoretically, a 555 timer can sink 200 mA, which causes voltage drops of about 2 V[29]. Therefore, as it is supplied by 12V, the maximum output voltage of the square wave signal is expected to be 10V, this voltage also drops in the filter.

2. Voltage drops in filters

$V_{out} = V_{in} \frac{X_C}{\sqrt{(X_C^2 + R^2)}}$, where $X_C = R$ therefore the equation becomes

$V_{out} = \frac{1}{\sqrt{2}} V_{in}$: Output voltage for first stage filter

$V_{out} = \frac{1}{2} V_{in}$: Final output voltage

$V_{out} = \frac{1}{2}(12) = 6V$

c) Designing Voltage-Controlled-Current Source(VCCS)

The safe current that doesn't have any influence on the human body ranges between 0.1 and 0.5 mA, even if this current flows for a long time[11]. The VCCS is suitable to be used in bio-impedance spectroscopy to generate a constant current that does not change at any load[23][24]. The VCCS uses the Howland current pump illustrated in Figure 3.12 to achieve it [30].

- Schematic diagram of VCCS

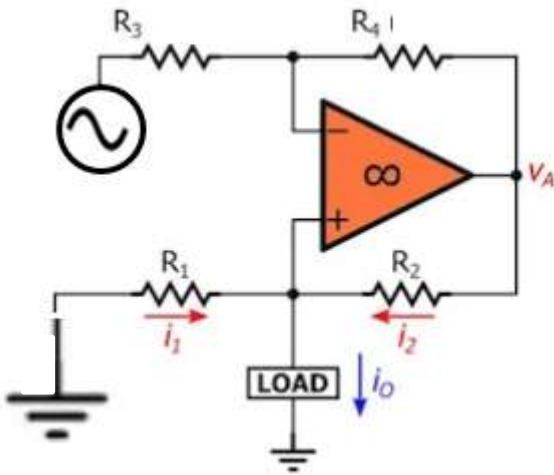


Figure 3.11: Howland current pump.

$$i_o = i_1 + i_2 = \frac{V_I - V_L}{R_1} + \frac{V_A - V_L}{R_2} \quad (i)$$

The op-amp, together with R_3 and R_4 , forms a non-inverting amplifier concerning V_L , thus giving

$$V_A = \left(1 + \frac{R_4}{R_3}\right) V_L \quad (ii)$$

Substituting V_A into Equation 1 and collecting, we put i_o into the insightful form

$$i_o = AV_I - \frac{V_L}{R_0} \quad (iii) \quad A: \text{Conductance gain (I/V), } A = \frac{1}{R_1}$$

R_0 is the output resistance and is given by

$$R_0 = \frac{R_2}{\frac{R_2 R_4}{R_1 R_3}} \quad (\text{iv})$$

To make i_o independent of V_L we must impose $R_0 \rightarrow \infty$, or the balanced bridge condition.

$$\frac{R_1}{R_2} = \frac{R_3}{R_4} \quad (\text{v})$$

By making R_0 the equation (iii) becomes

$$i_o = AV_I \quad (\text{xi})$$

Breast cancer early detector uses a peak current of 0.5 mA, and the VCCS is supplied by 6V, by replacing those values in equation (xi) and calculating the value of R_1 .

$R_1 = 6V / 0.0005 \text{ V} = 12K\Omega$, from equation (v), this implies that $R_1 = R_2 = 12K\Omega$

R_3 and R_4 can have any value, let take $10K\Omega$

To protect the patient from electric shock in case of high current produced in the circuit, an electrical fuse rated at a maximum current of 0.5mA, is added between the current source and the user. The Components used to design a Voltage-Controlled-Current Source are shown in Table 3.6.

Table 3.6: Components used to design Voltage-Controlled-Current Source.

SN	Components	Specifications	Functions
1	Op-amp		
2	Resistors	10K Ω , 12K Ω	Regulate/limit current
3	Fuse	Does not operate above 0.5mA	Prevent electric shock

d) Signal amplifier

Due to low signal from the tissue, it is amplified before being measured. To amplify the signal operational amplifier LM741 with configuration of the external resistors to obtain the gain of five and as shown in Figure 3.13, the signal is amplified in Non-inverting methods. A piece of work by Yang et al [31] shows Gain of at least is needed to magnify the weak signal during bio-impedance spectroscopy, therefore during designing breast cancer early detector gain of 4 is used.

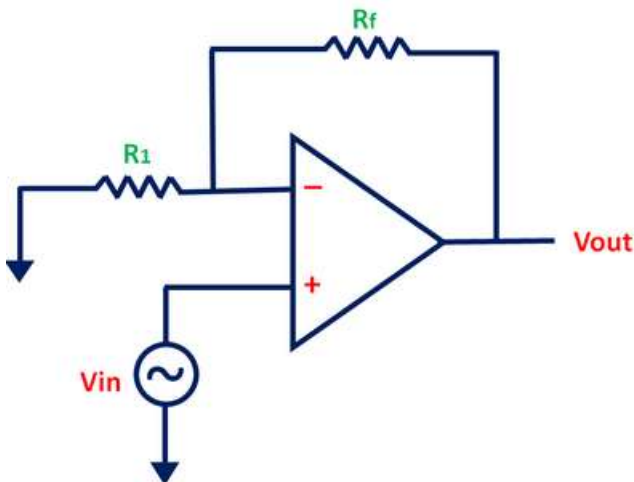


Figure 3.12: Non-inverting signal amplifier

For a non-inverting amplifier gain (G) is given by

$$G = \left(1 + \frac{R_f}{R_1}\right)$$

To achieve a gain of 5, R_1 is fixed to $2.2\text{k}\Omega$ then R_f is $8.9\text{k}\Omega$.

e) Signal detection and measurement

Phase angle and impedance are the measured parameters by the device to distinguish if the biological is normal or abnormal. There are three basic techniques to measure the impedance of biological systems;

- I. Bridge method.
- II. Quadrature demodulation method.
- III. Magnitude ratio and phase difference detection method(MRPDD) [11].

Breast cancer early detectors use magnitude ratio and phase difference detection methods due to their cost effectiveness, and provide real-time impedance measurement [28]. Due to high power consumption, high time, and cost, other methods are inefficient for the bio-impedance spectrometer design [11].

During impedance measurement using magnitude ratio and phase difference detection method, the device uses a gain phase e detector, to determine the phase shift (θ) using and ratio in the magnitude of the voltage across the tissue and reference resistor(θ) [32][11].

The device has 4 wires , first wire is used to inject current into the body while the other takes current out of the body, the other remaining 2 wires are connected to the electrodes which sense the voltage. The detected signals amplified and then pass through a phase detector. Based on the impedance and change angle between the signals phase detector generates V_{phs} and V_{mag} . The software is developed and embedded in the microprocessor which reads the value of the V_{phs} and V_{mag} and calculates the phase angle and impedance then results are displayed on the light crystal display.

• Analog to digital convertor (ADC)

Concerning the data sheet of phase detector AD8302 [33], V_{phs} and V_{mag} both ranging between 30 millivolts to 1.8 Volts. During analog to digital convertor the maximum value of V_{phs} and V_{mag} which is 1.8 Volts correspond to the highest bytes of microprocessor which is 1023(, while the lowest bytes which is 0 corresponding to 0 Volts.

• Magnitude ratio

$$k = \frac{|V_{AZ}|}{|V_{AS}|}$$

• Phase difference

$\theta = \theta_{AZ} - \theta_{AS}$ θ_{AZ} and θ_{AS} are the phase angle of voltage across the tissue and reference resistor

respectively.

The gain-phase detector (GPD) compares V_{AZ} and V_{AS} and outputs two DC voltages proportional to magnitude ratio $|K|$ and phase difference θ of the input voltages [31].

- **Impedance**

The unknown impedance is calculated from the voltage magnitude ratio and the phase difference.

$$\begin{aligned} V_{AZ} &= A_1 V_Z = A_1 I_0 Z_X & A_1 \text{ and } A_2 \text{ are the gains of the amplification amplifier.} \\ V_{AS} &= A_2 V_S = A_2 I_0 R_S \end{aligned}$$

From the above two questions, by taking their ratio, impedance is calculated as

$$z_m = R_S \frac{V_Z}{V_S} = R_S \frac{A_2 V_{AZ}}{A_1 V_{AS}} = R_S \frac{A_2}{A_1} \cdot K \angle \theta.$$

Breast cancer early detectors use a gain phase detector of AD8302 IC, concerning its datasheet [33] and previous works[31][11], the phase angle and magnitude ratio are calculated as follows.

$$\theta = \theta_{AZ} - \theta_{AS} = \pm \left(\frac{900mV - V_{phs}}{100mV/degree} + 90^0 \right)$$

$$K = \frac{V_{AZ}}{V_{AS}} = \frac{V_{AZ}}{V_{AS}} = 10^{\frac{V_{mag} - 900mV}{600mV}} \text{ Where the } V_{phs} \text{ and } V_{mag} \text{ are measured at the output port of the AD8302 IC.}$$

Therefore, the phase angle and the impedance are simply calculated as follows.

- **Electrical tissue impedance**

$$Z = R_S \cdot 10^{\frac{V_{mag} - 900mV}{600mV}}$$

- **Phase angle**

$$\theta = - \left(\frac{900mV - V_{phs}}{10mV/degree} + 90^0 \right)$$

Where

- $v_{mag} = \frac{300mV}{dB^{-1}} \log\left(\frac{|V_{AZ}|}{|V_{AS}|}\right) + 900mV$
- $v_{phs} = \frac{-10mV}{degree} (|\theta_A - \theta_B| - 90) + 900mV$

3.2.2. COMPUTER-AIDED DESIGN

1. SINE WAVE CONERTOR

Figure 3.15 shows the electric circuit of the square wave generator and the two R-C stage filters, an AC voltmeter on the last capacitor to measure the output alternating current while the digital oscilloscope is used to see the signal generated by the square wave generator and filtered signal.

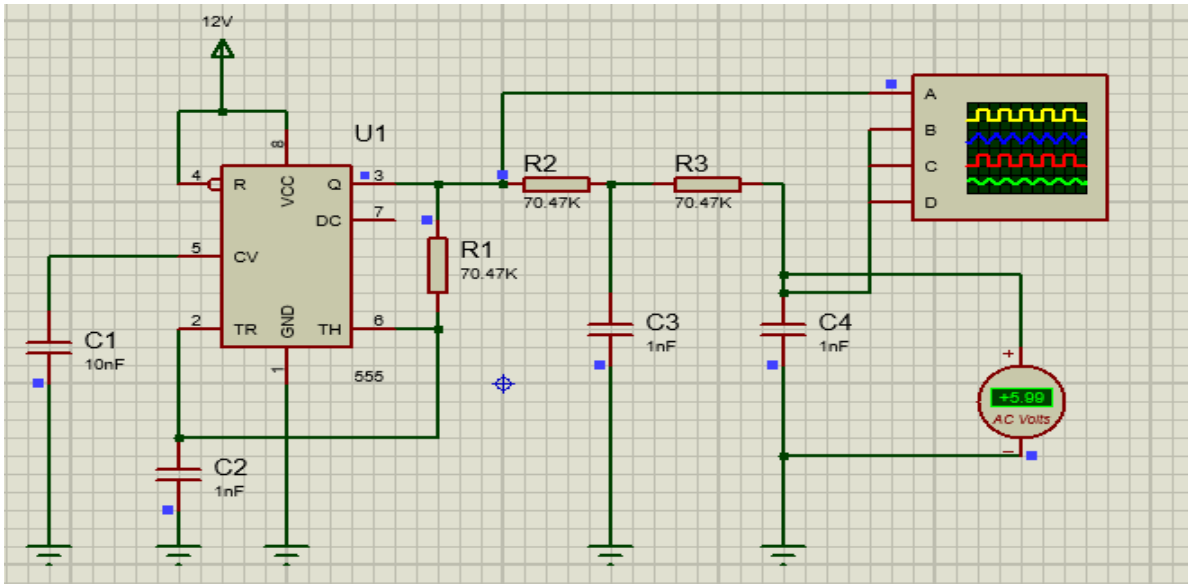


Figure 3.13: Sinewave generator

SIMULATION RESULTS

1. SINEWAVE GENERATOR

Figure 3.16 shows the square wave generator and filtered signal, due to high frequency, which cannot be seen by an aided eye, the division per time and amplitude is increased to make it visible by the digital oscilloscope's knob.

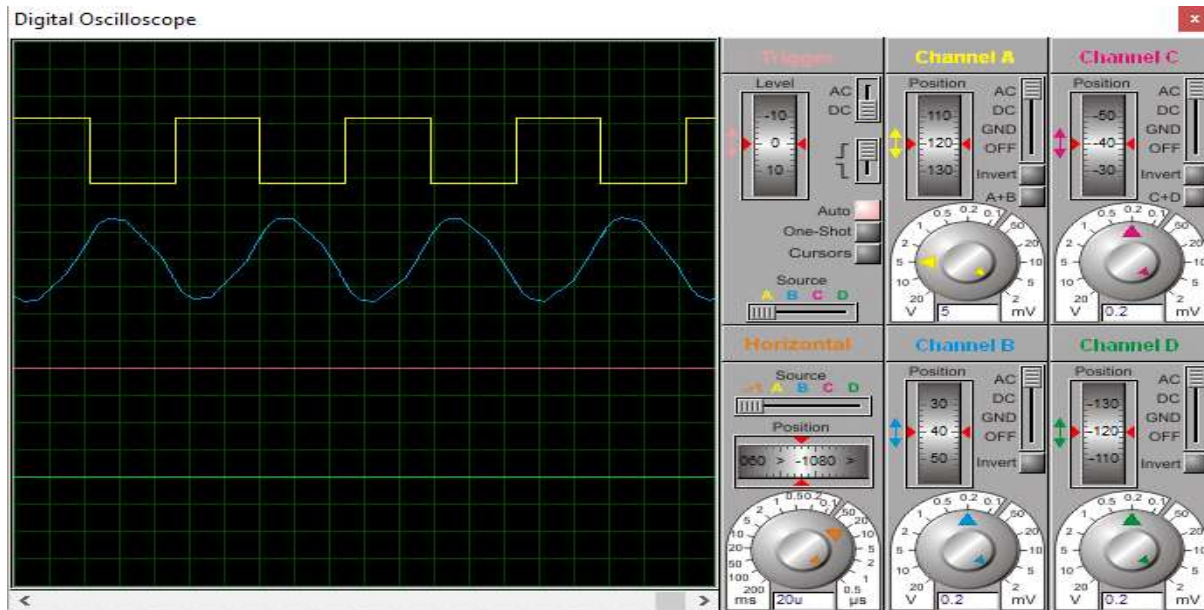


Figure 3.14: Simulation results of sinewave generator.

2. VOLTAGE CONTROLLED CURRENT SOURCE

Voltage-controlled current source aims to generate the constant current at any load, as illustrated in Figure 3.17 (left) the load is $10\text{ K}\Omega$, and the peak alternative current is 0.5 milliamps as the same on the right image load is varied to $5\text{ K}\Omega$ current remains the same.

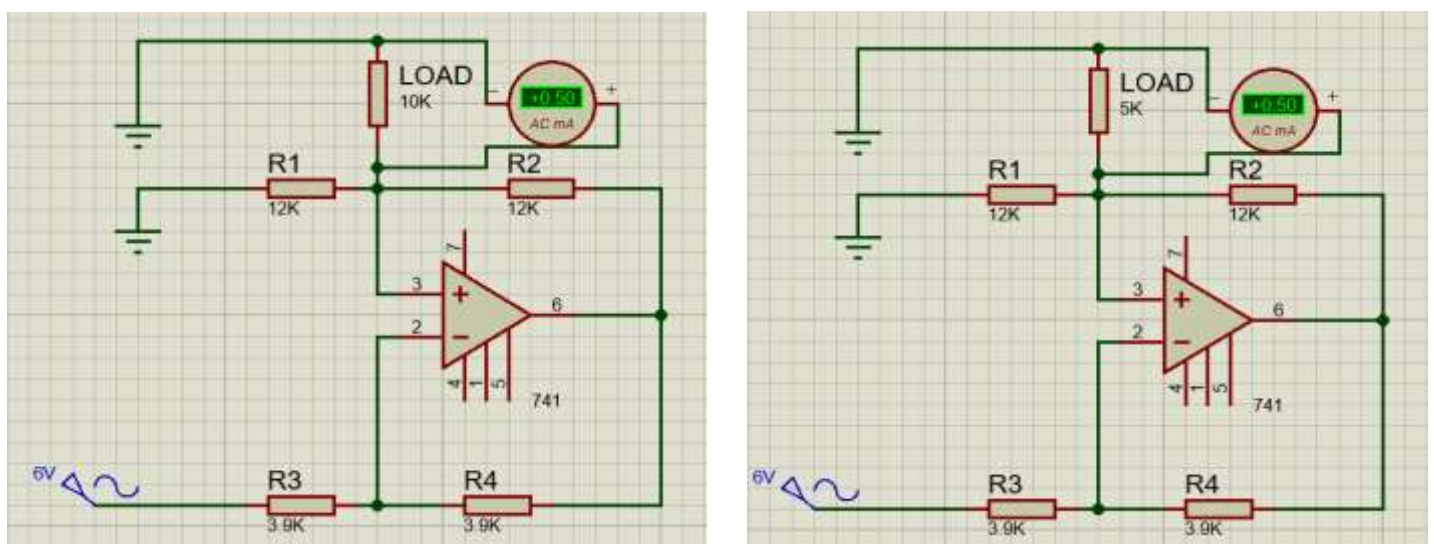


Figure 3.15: Voltage Controlled Current Source.

3. SIGNAL AMPLIFIER

Due to the low signal detected from the body must be amplified before being supplied in the phase detector, the fore signal amplifier circuit is designed to boost the signal, as shown in Figure 3.18, an operational amplifier with external resistors is used to generate a needed signal Gain of five. For example when the input signal is 1V and the output signal of 5.05V.

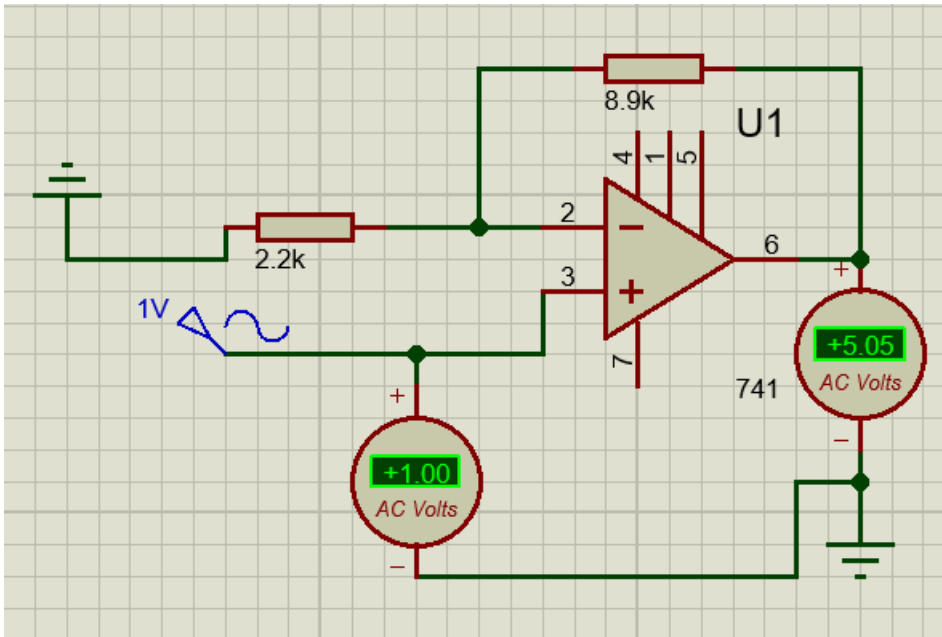


Figure 3.16: Signal amplifier.

4. NEGATIVE VOLTAGE GENERATOR

The operational amplifier requires both positive and negative DC voltage inputs as shown in Figure 3.16. The power adapter only provides a positive voltage to the circuit. To generate the required negative voltage, an additional circuit is created. This circuit, connected to the output of a 555-timer, consists of a diode and capacitor. Figure 3.20 demonstrates a negative voltage generator.

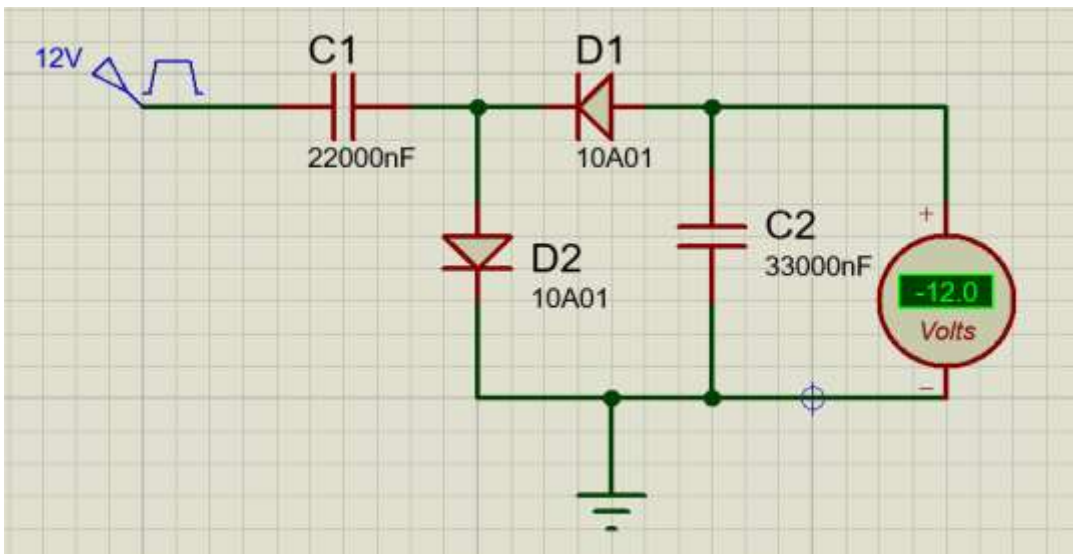


Figure 3.17: Negative voltage generator.

5. OVERALL CIRCUIT OF THE BREAST CANCER EARLY DETECTOR

Figure 3.20 shows the overall electric circuit of the breast cancer early detector in simplified ways, the circuit shows only the main important sub-systems such as

- Sine wave generator
- Voltage-controlled current source
- Sensing electrodes
- Phase detector circuit
- Data processing and display

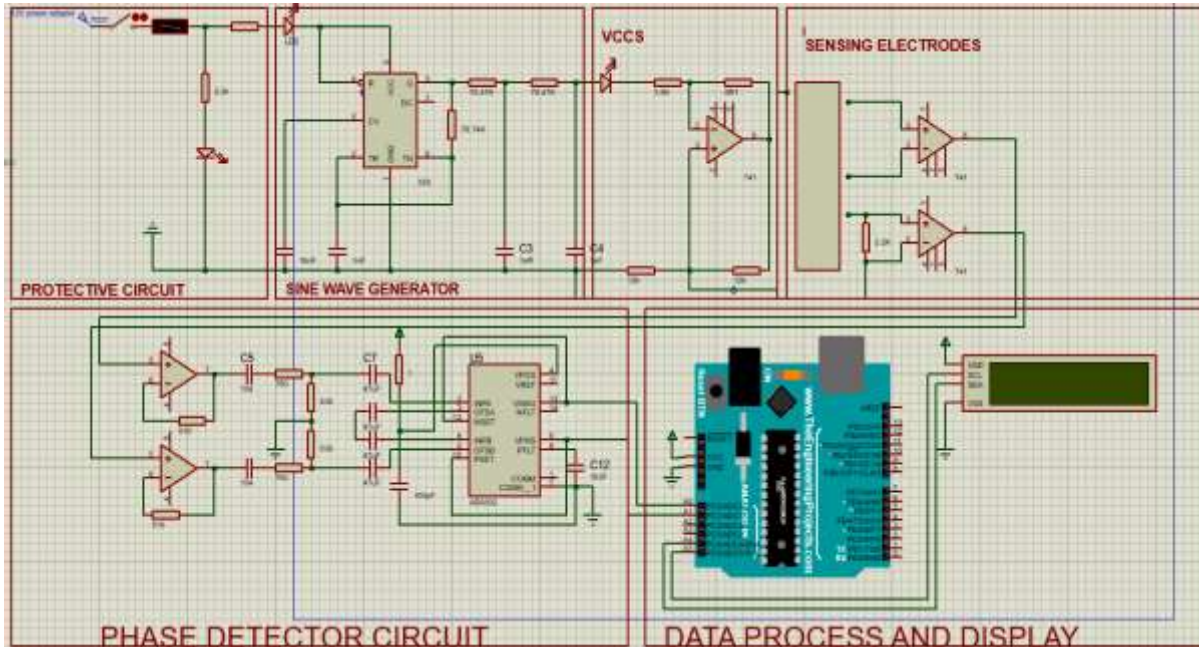


Figure 3.18: The simplified circuit of the breast cancer early detector.

3.2.3. PROTOTYPING

This section describes the assembling procedures to build the prototype of the Breast cancer early detector, prototyping begins with the building of the electronic circuit on the breadboard then is soldered on the Printed circuit board.

1. Temporary circuit

The temporary electronic circuit of the breast cancer early detector is constructed on the breadboard, and a part of the equipment makes a device, other accessories and equipment used during making a temporary circuit are listed in Table 3.7.

Table 3.7: Additional components used to build temporary circuit.

SN	Material	Functions
1	Breadboard	Construction base
2	Jump wires	To connect the path
3	Multimeter	Measuring purposes (resistance, voltage, and continuity)

During the process of building the circuit on the breadboard, the circuit is supplied with a 5V input from the Arduino Uno. As depicted in Figure 3.21 on the left image, the measured voltage at the output of the 555 timers

is 4.41V. This voltage falls within an acceptable range, considering that the output of the 555 timer has a maximum drop of 2V. This observation suggests that the circuit is functioning well. Additionally; a filter circuit (R-C circuit) and a voltage-controlled current source have been constructed on the breadboard. As illustrated in Figure 3.23 on the right image, the complete circuit includes a phase detector. To assess the functionality of the phase detector, it is supplied with 5V. The reference voltage of the phase detector is measured and found to be 1.834V. Upon consulting the datasheet of the AD8302, it is indicated that the reference voltage should range between 1.7V and 1.9V[34]. The measured value of 1.834V falls within this specified range, signifying that the phase detector is in good condition, which ensures that it can provide accurate values for V_{mag} and V_{phase} .

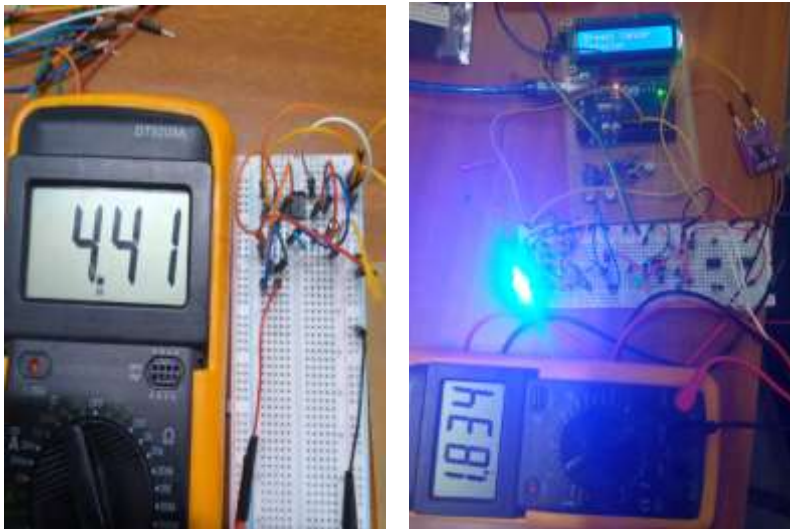


Figure 3.19: Building circuit on a breadboard.

2. Permanent circuit

After designing the circuit on a breadboard, the circuit is then fixed on the circuit board, the materials and accessories used are listed in Table 3.8.

Table 3.8: Additional Components used to build permanent circuit.

SN	Materials	Function
1	Circuit board	Construction base.
2	Soldering iron	To melt the Soldering wire.
3	Soldering wire	Make electrical connections.
4	cutting pliers	To cut wire.
5	Voltage and current meter	Measuring purposes (resistance, voltage, continuity).

All components are assembled about the electric circuit designed in proteus and temporary electrical, the equipment, materials, and the device are shown in Figure 3.22 on the left image. The right image in Figure 3.22 shows the cleaning process by using Isopropyl Alcohol (IPA) and an Anti-static brush to remove flux and remove any remaining residues, which can cause the same pin to be connected accidentally or short circuit.



Figure 3.20: Making a permanent circuit in the workshop.

Figure 3.23 shows the subcomponents of the breast cancer early detector after making a permanent circuit and cleaning.

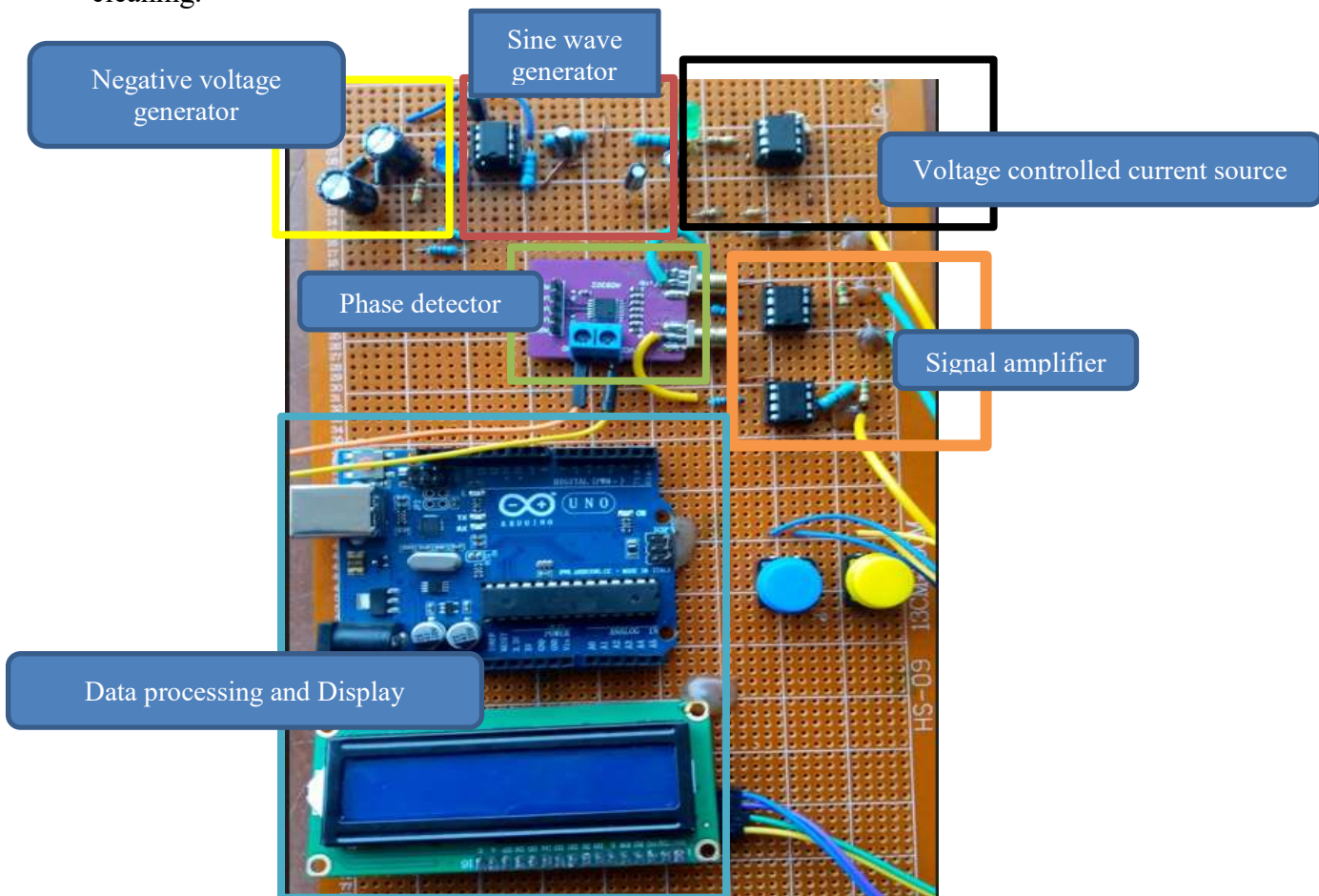


Figure 3.21: Sub-components of device.

Before making the enclosure and adding the additional accessories like switches and pushbuttons and before embedding software in the microprocessor a device (hardware parts) tested with an oscilloscope as illustrated in Figure 3.24.



Figure 3.22: Testing phase detector on an oscilloscope.

Figure 3.24 shows testing the phase angle on an oscilloscope, during testing function generators are used to feed the phase detector. All signals were set to 900 MHz but the phase difference between them was 100° , therefore V_{phase} was measured and compared with the given value given by the manufacturer at that phase difference. As shown in Figure 3.24 digital multi-meter read 0.830V (the negative sign indicates that the probes of the digital multi-meter reversed during measurement). By comparing the obtained result with the results obtained by manufacturers are closer.

Figure 3.25 describes the experimental results obtained by the manufacturer of the phase detector (AD8302), upper curve was due to results obtained at a working temperature of $+85^{\circ}\text{C}$ while the lower curve was -40°C .

3. Enclosure

To protect the circuit, enclosure made in cartons and covered with stickers are used. The model designed in the SOLIDWORKS 2023 software as illustrated in Figure 3.26. The enclosure divided into two parts, the base part and the top part. As shown in Figure 3.26, the left image shows the base part while the right image shows the base part and top cover. The dimensions of the item on the Enclosure expressed in cm and are shown in Appendix 1.

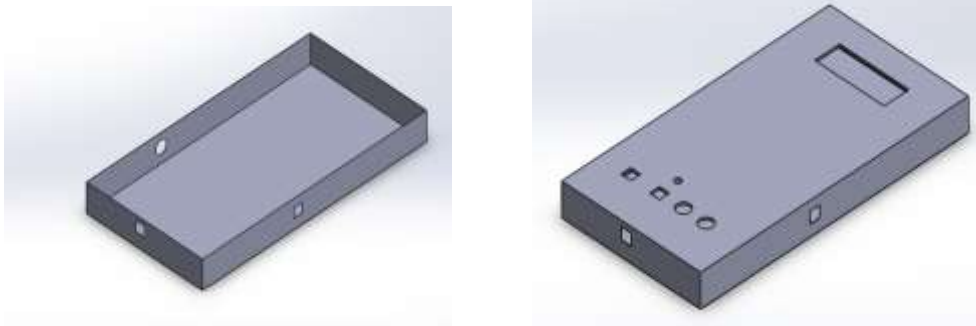


Figure 3.23: Enclosure.

4. Completed Breast cancer early detector.

After designing the breast cancer early detector and its enclosure the electronic circuit is inserted in the enclosure as illustrated on the left image in Figure 3.27, while the right image shows the external components of the device. The technical service manual and user guide manual of the breast cancer early detector are illustrated in Appendix 3 and Appendix 2 respectively.

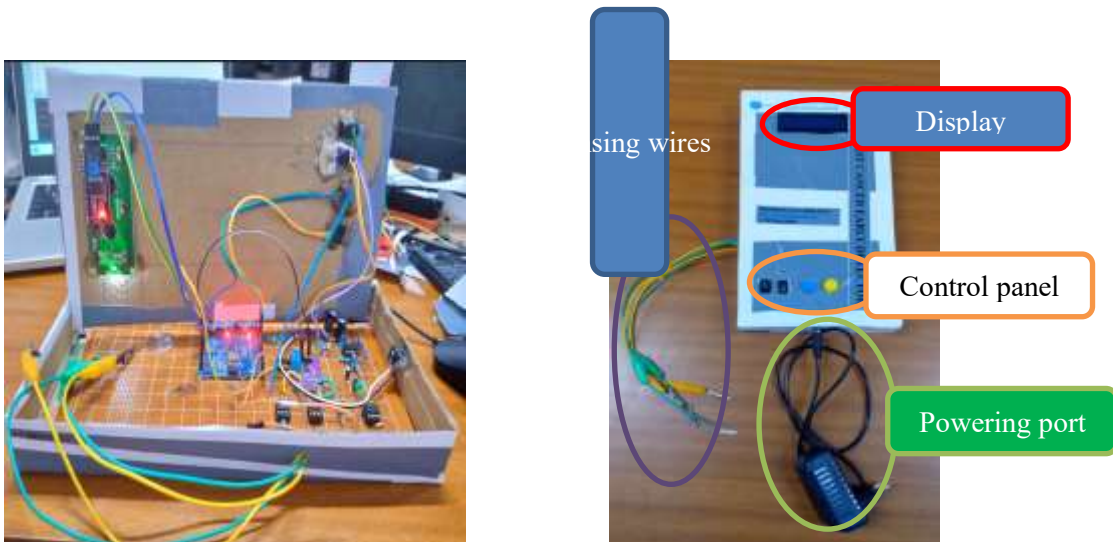


Figure 3.24: Breast Cancer Early Detector.

SOFTWARE DEVELOPMENT

The software designed and embedded in Arduino Uno to control the early breast cancer detector. The device has two power buttons and two push buttons. The first push button used to control the sequences of the program while the second button used to reset the program. On the other hand, the first power button used to turn on the microcontroller and display while the second power button used to turn on the current.

Sequences of activities

1. The user presses the first power button to turn ON the device (microcontroller and display).
2. **“Breast cancer detector”** displayed on the LCD until the first push button is pressed.
3. The user presses the first push button, and the LCD will display **“Put the electrodes on the left breast”** until press the first push button again.
4. User presses the first push-button LCD will display **“turn on the current”**.
5. The user presses the second power button and press the first push button.
6. The microcontroller detects the V_{phase} and V_{mag} then calculates the impedance and change in the phase angle of the left. The result will remain on the screen until the push button pressed again.
7. User presses the first push-button LCD will display **“turn off the current”**.
8. The user presses the first push-button LCD will display **“Put the electrodes on the right breast”** until pressing the first push-button again.
9. The procedure from 2 to 7 will be processed on the right breast
10. The microcontroller will calculate the difference in impedance between two breasts.
11. The user presses the first push button, and it will display whether the user has a risk of cancer or not.

The second push-button used to restart the program. The codes used to develop software for breast cancer early detector depicted in Appendix 4 (due to the device is not tested in real-world application the presented codes are used to measure the impedance and difference in phase phase).

Flowchart of the breast cancer early detector

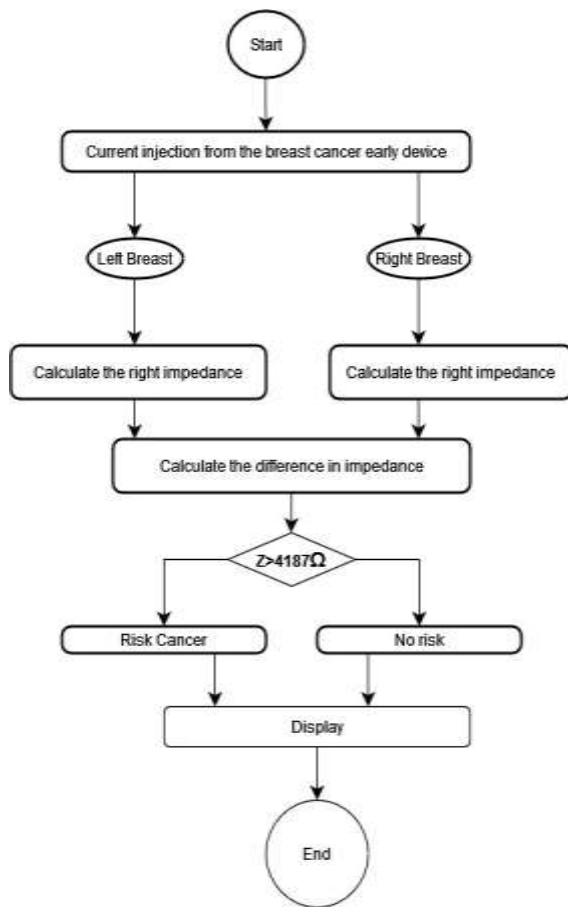


Figure 3.25: Flow chart of the device.

Technical specification of breast cancer early detector

Technical specifications of early breast cancer detectors shown in Table 3.9. These technical specifications provide a framework for designing and developing a breast cancer early detection device that meets the needs of breast cancer screening with the minimum possible current to ensure the safety of the patient.

Table 3.9: Technical specifications of Breast cancer early detector.

SN	Parameter	Specifications
1	Impedance	5.7 Ω to 4.743 k Ω
2	Phase angle	0 ⁰ to -180 ⁰
3	Supply voltage	12V
4	Operating current	0.5 mA
5	Operating frequency	20434 Hz
6	Weight	500g
7	Dimensions	(27*14*2.82)cm

Cost estimation

Table 3.10 summarizes the cost of a breast cancer early detector including equipment and materials, labor, and miscellaneous expenses.

Table 3.10: Cost estimation of breast cancer early detector.

SN	Group	Item	Cost (Rwf)
1	Research and development	Personnel	200000
		Internet fees	20000
2	Equipment and Materials	Phase detector	40000
		555-timer	500
		Operational amplifiers	1500
		Liquid crystal display	8500
		Microcontroller	12000
		Resistors	2000
		Capacitors	2000
		Diodes	1500
		Push buttons/Switches	2000
		Light emitting diodes	500
		Jumper wires	2000
		Sensing wires	4000
		Circuit board	2500
		Power adopter	5000
Others	5000		
3	Other related cost	Soldering Labor Cost	20000
		Miscellaneous income	11000
TOTAL			340,000

CHAPTER 4: TESTING AND RESULT DISCUSSION

4.1.TESTING

Testing medical devices that administer electric currents into the body without proper documentation showing risk assessment from regulatory bodies considered unethical. [35]. The performance of the device is tested on rabbit to check if it can measure the impedance and phase angle, concerning previous works show that there are many bio-impedance experiments carried out on rabbit and researchers concluded that rabbit are also appropriate for testing electrical bio-impedance instruments[36].

During testing, electrodes placed on the left region of the rabbit and its symmetry part (right region). Before placing the electrodes on the rabbit, hairs shaved to make sure that there is a good connection between the electrodes and the rabbit's skin. In the way demonstrated in Figure 4.1, the electrodes placed on hairless parts and the results summarized in Table 4.1. Other related images during testing shown in Appendix 5.



Figure 4.1: Breast cancer early detector under test on rabbit.

4.1.1. RESULT PRESENTATION

The device is tested alive healthy rabbit, the device used to measure the impedance and phase angle of each side of the rabbit, the electrodes placed at same position and fifteen measurements are taken without changing the position of the electrodes. The raw data of the measured impedance and phase angle are recorded the results are summarized in Table 4.1.

Table 4.1: Table of Results.

Measurement index	Right side		Left side	
	Impedance (Ω)	Phase angle(degree)	Impedance(Ω)	Phase angle(degree)
1	902	152	1101	170
2	905	149	1095	173
3	892	151	1096	173
4	910	150	1191	169
5	892	152	1091	169
6	893	150	1004	170
7	917	153	1198	170
8	899	149	1097	174
9	892	149	1099	171
10	906	152	1105	170
11	900	156	1092	168
12	905	148	1100	167
13	901	150	1100	175
14	915	150	1114	173
15	890	147	1103	172

4.2.RESULTS ANALYSIS

To analyze the obtained data, Microsoft Excel and IBM SPSS Statistics data editor used to calculate mean, standard deviation, and t-test and to plot the data distribution of the impedance and phase angle. Those have been conducted to measure device repeatability.

I. Standard deviation

The mean and standard deviation of the taken measurements shown in Table 4.2.
 Table 4.2: Mean and Standard deviation of taken results.

	IMPEDANCE		PHASE ANGLE	
	Mean	STD	MEAN	STD
Right Side	901.27	8.55	170.47	2.26
Left Side	1099.73	6.69	170.93	2.31

II. Data distribution graphs

Data distribution aims to see how the data spreads from the mean, the data distribution of phase angle and Impedance are shown in Figure 4.2.

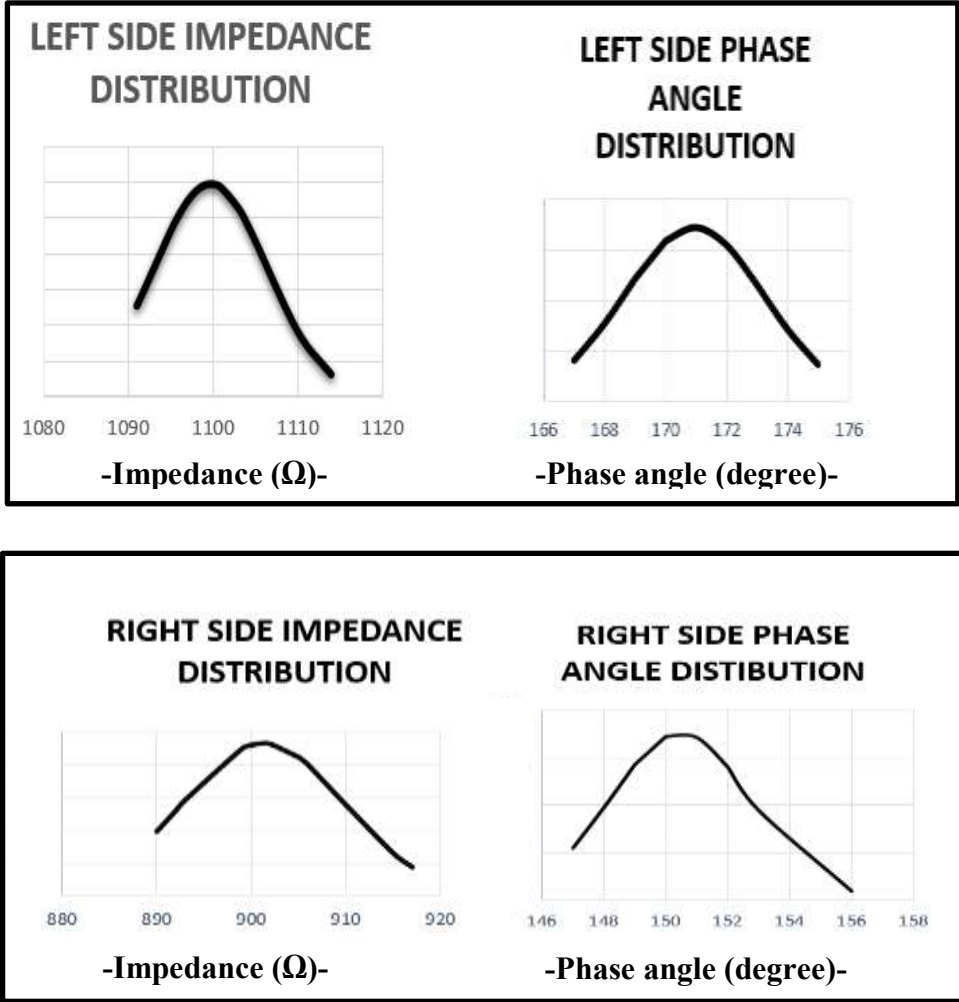


Figure 4.2: Data distributions of impedance and phase angle at both sides.

III. T-TEST

A T-test is conducted to assess whether there is a statistically significant in obtained results, In this research t-test is conducted by using IBM SPSS Statistics data. The P-value and t-value of each set of data calculated by using one sample statistics methods, the results are shown in Figure 4.3.

LEFT SIDE IMPEDENCE						
	t	df	Sig. (2-tailed)	Mean Difference	95% Confidence Interval of the Difference	
					Lower	Upper
LEFT SIDE IMPEDANCE	636.482	14	<.001	1099.73333	1096.0275	1103.4392

LEFT SIDE PHASE ANGLE						
	t	df	Sig. (2-tailed)	Mean Difference	95% Confidence Interval of the Difference	
					Lower	Upper
LEFT SIDE PHASE ANGLE	286.153	14	<.001	170.93333	169.6521	172.2145

RIGHT SIDE IMPEDENCE						
	t	df	Sig. (2-tailed)	Mean Difference	95% Confidence Interval of the Difference	
					Lower	Upper
RIGHT SIDE IMPEDENCE	408.356	14	<.001	901.26667	896.5330	906.0003

RIGHT SIDE PHASE ANGLE						
	t	df	Sig. (2-tailed)	Mean Difference	95% Confidence Interval of the Difference	
					Lower	Upper
RIGHT SIDE PHASE ANGLE	257.448	14	<.001	150.46667	149.2131	151.7202

Figure 4.3: T-test.

4.3.RESULT DISCUSSION

4.3.1. BIOIMPEDANCE

Based on the theoretical value of impedance given by the formula $Z = 150 * 10^{\frac{V_{mag}-900mV}{600mV}}$, where V_{mag} ranges between 30 mV and 1.8V, the predicted range of impedance shown in Figure 4.4.

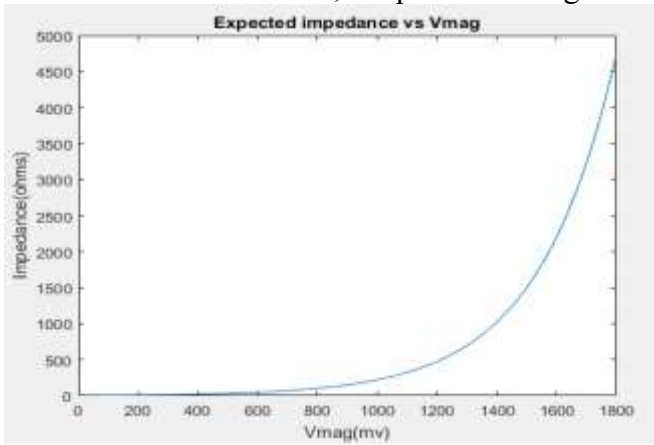


Figure 4.4: Range of expected impedance.

Figure 4.4 shows the minimum value of impedance is 5.3 Ω while the maximum value is 4.743 k Ω , by comparing the measured values of impedances on rabbit listed in Table 4.1, results show that the measured values range in the predicted range. Nevertheless, results show that the impedance of the symmetrical biological tissue of the rabbit is not equal, as indicated in Table 4.2 the left side impedance has average value of 1099.73 Ω and standard deviation of 6.69 Ω while right side impedance has average value of 901.26 and standard deviation of 8.54 Ω . The difference in impedance can be caused by:

- I. Varied tissue compositions within rabbit parts.
- II. Errors during placing the electrodes at the identical site in both regions.
- III. The device's accuracy that requires enhancement.

As depicted in Figure 4.3 the t-test is conducted to see the significant level of the obtained data, among 15 measurement taken on left side and right side when electrodes placed on the same positions, impedance results shows that 4 measurements at left side and 7 measurements at right sides are ranging in 95% confidence interval. Further investigations are necessary to distinguish the precise reason for the variation in impedance. It is essential to confirm whether there are differences in tissue composition between the left and right sides of the rabbit, which could potentially account for the variance in impedance readings. However, if the composition of body tissues is consistent throughout and the electrodes accurately positioned at identical locations, it can be confirmed.

Device does not have a hundred percent accuracy, indicating a need for improvement.

4.2.2. CHANGE IN PHASE ANGLE

Based on the theoretical value of impedance given by the formula $\theta = -\left(\frac{900\text{mV} - V_{phs}}{10\text{mV/degree}} + 90^\circ\right)$, where V_{phase} is ranging between 30 mV to 1.8V, the predicted range of difference in impedance is shown in Figure 4.5.

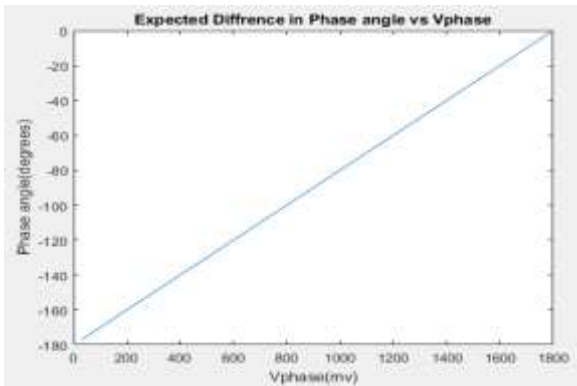


Figure 4.5: Expected range of Difference in phase angle.

As illustrated in Figure 4.5, the phase angle ranges from zero to (-) 180° , and the measured value ranges in that interval. T-test shows among the 15 measurements of phase angle, that six measurements at left side and 4 measurements at right sides are ranging in 95% confidence interval. Therefore in fifteen measurements, left side an average of 170.9° while right side has an average of 150.5° , as same as the impedance, the exactly cause of the unequal in taken measurements should accessed in future studies.

4.2.3. DEVICE REPEATABILITY

Based on the raw data as depicted in Table 4.1 and normal distribution graph in Figure 4.3, there is variation in taken measurements, the normal distribution curve indicate that impedance are more bounds to mean value than phase angle. Due the test is conducted on alive rabbit, the variation of oxygen saturation can cause also the variation of measured impedance and phase angle, but to confirm this the further investigation is needed to access the reason in order to improve device reliability.

4.4. USING DEVICE ON BREAST CANCER SCREENING

The device is being tested on alive rabbit and the results are promising that the device is functioning but the objective is to be used in breast cancer screening. After clinical testing and approving the device by regulatory bodies, breast cancer early detectors can used in screening breast cancer. The device uses the optimum frequency of 20434 Hz to distinguish normal breast cells and cancer cells. When the difference in impedance between the left breast and right breast is greater than 4187Ω , there is a risk of breast cancer; patient should advised for further treatment.

4.5. COST ANALYSIS

The estimated cost of the breast cancer early detector is 340,000 Rwf. Upon comparison with existing breast cancer screening techniques, its cost appears to be effective. The comparison made by consulting the prices of the existing techniques available on Alibaba.com, and their costs are listed in Table 4.3.

Table 4.3: Cost of the existing breast cancer screening technologies.

SN	Methods	Brand name	Cost
1	CT-scan	HEDY	\$55,000
2	Ultrasound	Antonmed	\$1,950
3	Mammography	Ysenmed	\$10,000
4	Magnetic Resonance Imaging	MAYA(1.5T)	\$810,000

The cost of breast cancer early detection is small compared to existing technology. In addition, all existing technologies require contrast, which increases the procedure cost (examination cost). Not only the contrast but also the taken image needs the radiologist for the examination this also increases the cost of the service.

CHAPTER 5: CONCLUSIONS AND RECOMMENDATIONS

CONCLUSIONS

The research project on breast cancer early detection through electrical impedance presents a promising avenue for improving screening capabilities due to its low cost and simplicity of use. Breast cancer, which has a large rate of death in many women, can be reduced by detecting the changes in the electrical properties of breast tissue. The use of electrical impedance as a diagnostic tool offers the potential for non-invasive and early detection, addressing a critical need in breast cancer management. The development of early breast cancer detector systems based on electrical impedance measurements could significantly enhance current breast cancer screening methodologies. This approach not only has the potential to improve the availability of screening tools but also offers the advantage of being non-ionizing and painless, contributing to patient comfort and safety.

This research project on breast cancer early detection using electrical impedance holds promise as an innovative and potentially transformative approach in the field of breast cancer screening and diagnostics. With continued advancements and validation, this technology could make significant contributions to improving early detection rates and ultimately enhancing patient outcomes in the fight against breast cancer.

RECOMMENDATIONS

- **Recommendation to future researchers/future plans**

1. The device is designed based on the optimum frequency to distinguish cancerous cells from normal cells, the decision is taken based on the measured value of impedance compared with the threshold value of impedance, future researchers should determine the threshold value of phase angle so that the decision can be taken by considering both impedance and phase angle.
2. The functionality of the device is optimized for cases where cancer originates in one breast and subsequently spreads to the other breast. However, future researchers should explore alternative approaches for situations where cancer develops simultaneously in both breasts.
3. Future researchers should conduct the research to explore the cause of variability in taken measurements in order to enhance device repeatability and reliability.
4. The device should be tested on breast phantoms to determine the penetration depth of alternating current injected in the body.

- **Recommendation to CEBE management**

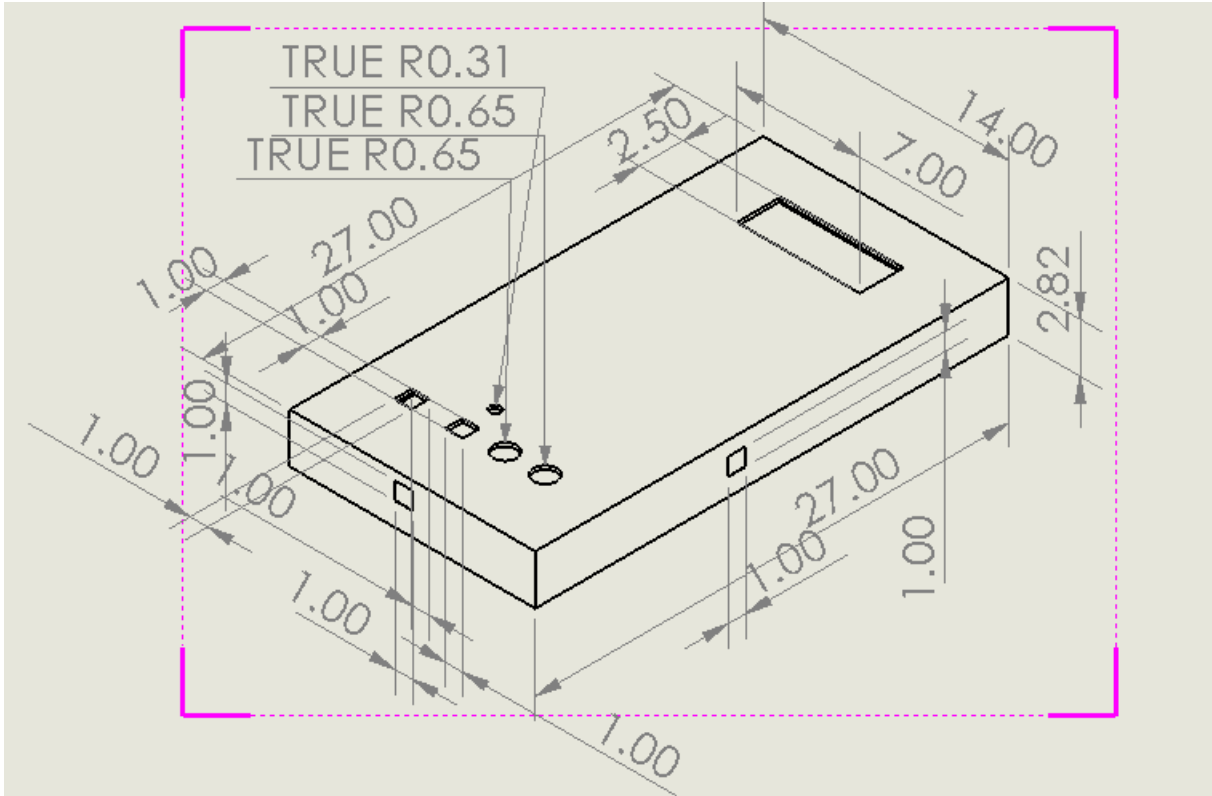
1. The device was tested on a rabbit but designed to measure the electrical properties of humans, it would be better if CEBE provides another platform to continue to work on the project until the project becomes implemented.
2. CEBE should provide the special laboratory with equipped materials and specimens like living animals, which can be used in research.
3. The CEBE management should provide enough funds to conduct the research and research fees should be given before starting.
4. During the research time, monthly allowances are not given; this may compromise the quality of the research outcomes, potentially affecting the overall success of the projects.

REFERENCES

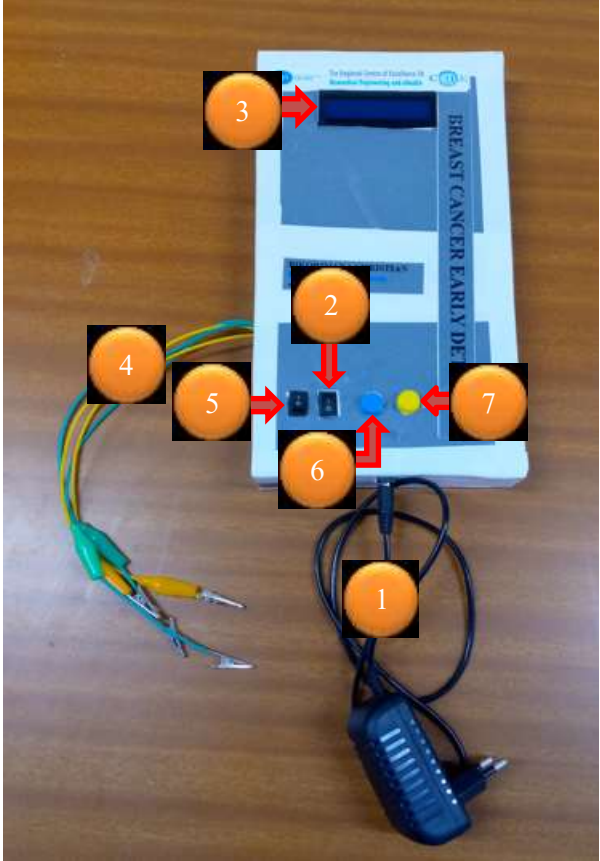
- [1] P. C. Igiraneza, L. A. Omondi, B. Nikuze, M. G. Uwayezu, M. Fitch, and G. Niyonsenga, “Factors influencing breast cancer screening practices among women of reproductive age in South Kayonza District, Rwanda,” *Can. Oncol. Nurs. J.*, vol. 31, no. 3, pp. 251–257, 2021, doi: 10.5737/23688076313251257.
- [2] S. Mansouri, Y. Alharbi, J. Nebhen, and A. Alshrouf, “Breast cancer detection using low frequency bioimpedance device,” vol. 7, no. 05, p. 2476, 2021.
- [3] N. E. Helwig, S. Hong, and E. T. Hsiao-wecksler, “The world incidence and mortality of breast cancer”, doi: DOI:10.13140/RG.2.2.18827.59682.
- [4] N. A. R. B. Rand, L. G. Q. U. Iang, A. N. N. C. Hao, and A. N. M. I. Lbawie, “Delays and Barriers to Cancer Care in Low- and Middle-Income Countries : A Systematic Review,” pp. 1–10, 2019, doi: 10.1634/theoncologist.2019-0057.
- [5] T. E. Kerner, K. D. Paulsen, A. Hartov, S. K. Soho, and S. P. Poplack, “Electrical impedance spectroscopy of the breast: Clinical imaging results in 26 subjects,” *IEEE Trans. Med. Imaging*, vol. 21, no. 6, pp. 638–645, 2002, doi: 10.1109/TMI.2002.800606.
- [6] Y. Zou and Z. Guo, “A review of electrical impedance techniques for breast cancer detection,” *Med. Eng. Phys.*, vol. 25, no. 2, pp. 79–90, 2003, doi: 10.1016/S1350-4533(02)00194-7.
- [7] T. Morimoto, “A Study of the Electrical Bio-impedance of Tumors,” vol. 6, pp. 25–32, 1993.
- [8] A. Yuferal *et al.*, “AN INTEGRATED CIRCUIT FOR TISSUE IMPEDANCE MEASURE,” pp. 88–93, 2002.
- [9] T. International *et al.*, “The use of bioimpedance in the detection / screening of tongue cancer,” *Cancer Epidemiol.*, vol. 34, no. 2, pp. 207–211, 2010, doi: 10.1016/j.canep.2009.12.017.
- [10] H. Dastjerdi, R. Soltanzadeh, and H. Rabbani, “Designing and implementing bioimpedance spectroscopy device by measuring impedance in a mouse tissue,” *J. Med. Signals Sens.*, vol. 3, no. 3, pp. 187–194, 2013, doi: 10.4103/2228-7477.120979.
- [11] A. S. Patil and R. B. Ghongade, “Design of bioimpedance spectrometer,” *2016 Int. Conf. Adv. Comput. Commun. Informatics, ICACCI 2016*, pp. 2724–2728, 2016, doi: 10.1109/ICACCI.2016.7732473.
- [12] R. E. Dodde, G. H. Kruger, and A. J. Shih, “Design of Bioimpedance Spectroscopy Instrument With Compensation Techniques for Soft Tissue Characterization,” *J. Med. Devices, Trans. ASME*, vol. 9, no. 2, pp. 1–8, 2015, doi: 10.1115/1.4029706.
- [13] N. N. Khamis, N. F. Za’Bah, A. F. Mansor, and A. N. Nordin, “Arduino-Based Biosensor Impedance Measurement,” *Proc. - 6th Int. Conf. Comput. Commun. Eng. Innov. Technol. to Serve Humanit. ICCCE 2016*, pp. 191–194, 2016, doi: 10.1109/ICCCE.2016.50.
- [14] A. Zarafshani, N. Huber, N. Béqo, B. Tunstall, G. Sze, and C. Chatwin, “A Flexible Low-Cost , High-Precision , Single Interface Electrical Impedance Tomography System for Breast Cancer Detection Using FPGA,” vol. 224, pp. 1–4, 2010, doi: 10.1088/1742-6596/224/1/012169.
- [15] J. Ugwaha *et al.*, “Ex-Vivo Detection of Breast Cancer with a Bio-Impedance Sensor,” *J. Cancer Treat. Diagnosis*, vol. 5, no. 1, pp. 18–22, 2021, doi: 10.29245/2578-2967/2021/1.1193.
- [16] M. Al Ahmad, Z. Al Natour, F. Mustafa, and T. A. Rizvi, “Electrical Characterization of Normal and Cancer Cells,” *IEEE Access*, vol. 6, pp. 25979–25986, 2018, doi: 10.1109/ACCESS.2018.2830883.
- [17] C. Händel *et al.*, “Cell membrane softening in human breast and cervical cancer cells,” *New J. Phys.*, vol. 17, no. 8, p. 83008, 2015, doi: 10.1088/1367-2630/17/8/083008.
- [18] W. Szlasa, I. Zendran, A. Zalesińska, M. Tarek, and J. Kulbacka, “Lipid composition of the cancer cell membrane,” *J. Bioenerg. Biomembr.*, vol. 52, no. 5, pp. 321–342, 2020, doi: 10.1007/s10863-020-09846-4.
- [19] L. C. Ward and S. Brantlov, “Bioimpedance basics and phase angle fundamentals,” *Rev. Endocr. Metab. Disord.*, vol. 24, no. 3, pp. 381–391, 2023, doi: 10.1007/s11154-022-09780-3.

- [20] D. Naranjo-Hernández, J. Reina-Tosina, and M. Min, “Fundamentals, recent advances, and future challenges in bioimpedance devices for healthcare applications,” *J. Sensors*, vol. 2019, 2019, doi: 10.1155/2019/9210258.
- [21] O. Farag, M. Mohamed, M. Abd El Ghany, and K. Hofmann, “Integrated sensors for early breast cancer diagnostics,” *Proc. - 21st IEEE Int. Symp. Des. Diagnostics Electron. Circuits Syst. DDECS 2018*, pp. 153–157, 2018, doi: 10.1109/DDECS.2018.00034.
- [22] Texas Instrument, “xx555 Precision Timers Datasheet,” 1973.
- [23] B. Ben Atitallah, A. Y. Kallel, D. Bouchaala, N. Derbel, and O. Kanoun, “Comparative Study of Measurement Methods for Embedded Bioimpedance Spectroscopy Systems,” *Sensors*, vol. 22, no. 15, 2022, doi: 10.3390/s22155801.
- [24] K. Ain, R. A. Wibowo, S. Soelistiono, L. Muniroh, and B. Ariwanto, “Design and development of a low-cost arduino-based electrical bioimpedance spectrometer,” *J. Med. Signals Sens.*, vol. 10, no. 2, pp. 125–133, 2020, doi: 10.4103/jmss.JMSS_24_19.
- [25] B. Rostami, S. I. Mirzaei, A. Zamani, A. Simchi, and M. Fardmanesh, “Development of an enhanced porosity AgAgCl reference electrode with improved stability,” *Eng. Res. Express*, vol. 1, no. 1, 2019, doi: 10.1088/2631-8695/ab4544.
- [26] A. Manuscript, “Ac ce d M us pt,” 2020.
- [27] R. Kusche, S. Kaufmann, and M. Ryschka, “Dry electrodes for bioimpedance measurements - Design, characterization and comparison,” *Biomed. Phys. Eng. Express*, vol. 5, no. 1, 2019, doi: 10.1088/2057-1976/aaea59.
- [28] D. Bouchaala, A. Fendri, and O. Kanoun, “A8.3 - Handheld Bioimpedance Spectrometer for the Total Frequency Range of the β -Dispersion,” pp. 175–180, 2020, doi: 10.5162/sensor2013/a8.3.
- [29] H. R. Camenzind, “Redesigning the old 555,” *IEEE Spectr.*, vol. 34, no. 9, pp. 80–85, 1997, doi: 10.1109/6.619384.
- [30] A. Mahnam, H. Yazdani, and M. Mosayebi Samani, “Comprehensive study of Howland circuit with non-ideal components to design high performance current pumps,” *Meas. J. Int. Meas. Confed.*, vol. 82, pp. 94–104, 2016, doi: 10.1016/j.measurement.2015.12.044.
- [31] Y. Yang, J. Wang, G. Yu, F. Niu, and P. He, “Design and preliminary evaluation of a portable device for the measurement of bioimpedance spectroscopy,” *Physiol. Meas.*, vol. 27, no. 12, 2006, doi: 10.1088/0967-3334/27/12/004.
- [32] Y. Yang and J. Wang, “New Tetrapolar Method for Complex Bioimpedance Measurement: Theoretical Analysis and Circuit Realization,” pp. 6605–6607, 2005.
- [33] Analog Devices, “AD8302 Gain Phase detector Datasheet,” *Analog Devices Data Sheets*, pp. 1–23, 2018, [Online]. Available: <https://www.analog.com/media/en/technical-documentation/data-sheets/ad8302.pdf>
- [34] Analog Devices, “AD8302 Gain Phase detector Datasheet,” *Analog Devices Data Sheets*, pp. 1–23, 2018.
- [35] M. Schmettow, R. Schnittker, and J. M. Schraagen, “An extended protocol for usability validation of medical devices: Research design and reference model,” *J. Biomed. Inform.*, vol. 69, pp. 99–114, 2017, doi: 10.1016/j.jbi.2017.03.010.
- [36] A. Saiz, A. I. García-Ruiz, J. Fuentes-Pila, and N. Nicodemus, “Application of bioelectrical impedance analysis to assess rabbit’s body composition from 25 to 77 days of age1,” *J. Anim. Sci.*, vol. 95, no. 6, pp. 2782–2793, 2017, doi: 10.2527/jas.2016.1196.

APPENDIX 1: DIMENSIONS OF BREAST CANCER EARLY DETECTOR DEVICE.



APPENDIX 2: USER MANUEL GUIDE

SN	Procedures	Image
1	Plug the power adopter into the power port	
2	Switch on the main switch (second from left)	
3	Flow the steps indicated on the LCD, Click on the green push button for the next step.	
4	When you asked to put the electrodes, put the yellow wires on extreme electrodes.	
5	When the user asked to turn on the current use the first switch from the left.	
6	Use the green push button to continue until phase angle and impedance displayed.	
7	If the user misses any step, use a yellow push button to start again.	

APPENDIX 3: TECHNICAL SERVICE MANUAL

SN	FAULTS	POSSIBLE CAUSES	SOLUTIONS
1	No power indicator (LED)	No power in the socket	Check if there is electricity in the socket
		Power adopter burn	Check the power adopter
		Led burn	Turn on the main switch, if other components' indicator light is on light then replace the LED.
		Poor connection of wires	If other indicators fail to be on, check the connecting wire with a multi-meter to measure the continuity.
5	There is a power indicator but the LCD does not light	Poor connection of LCD supply	Check the connected wires (power and ground) supply on the microcontroller.
6	LCD light but nothing is displayed	Loose connection on data transfer jumper wires.	Check the jumper wires connected on A4 and A5 on the microcontroller.
7	By pressing the push button, the next step not achieved.	Loose connection	Check the jumper wires connected on D12 and ground on a microcontroller.
8	The program does not restart	Loose connection	Check the jumper wires connected on D13 and ground on a microcontroller.
9	Static measurement	Phase detector failure	Make sure that the phase detector is supplied and measure the reference resistor if is not range between 1.7V and 1.9V replace it.
		Software bugs	Update the software
10	No current on injecting electrodes	555-timer failure	Check the output of the 555 timer on pin 3, if there is no power replace the integrated circuit.
		Operational pump failure	Check the output of the O-amps on pin 6, if no power replace the integrated circuit.
		Op amp failure	Check the functionality of voltage controlled current source.

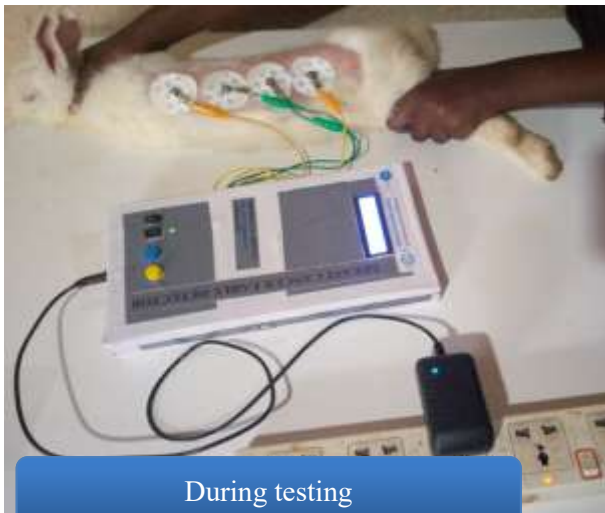
APPENDIX 4: USED CODES

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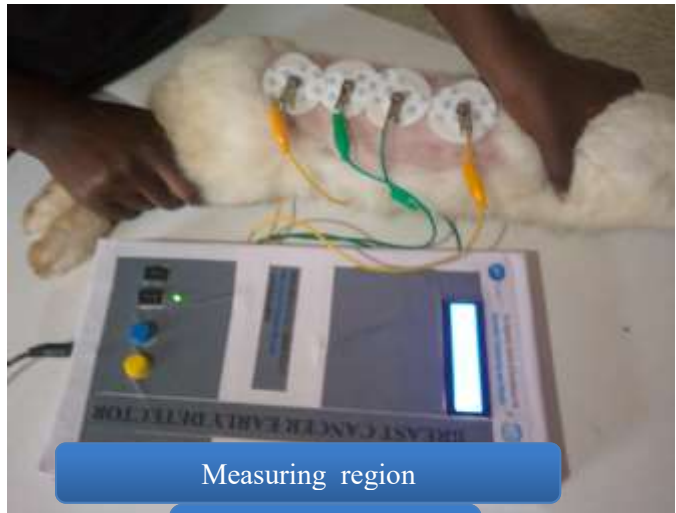
BreastCancerEarlyDetector.h
1 #include <Wire.h>
2 #include <LiquidCrystal_I2C.h>
3 #include <math.h>
4 LiquidCrystal_I2C lcd(0x27, 16, 2); // Address 0x27 for a 16x2 LCD
5 const int buttonPin = 12; // Push button pin
6 const int resetPin = 13; // Push button pin for resetting
7 const int phasePin = A0; // Analog pin for phase angle detection
8 const int magnitudePin = A1; // Analog pin for magnitude detection
9 enum State {
10     DETECTOR,
11     ELECTRODES,
12     TURN_ON_CURRENT,
13     IMPEDANCE,
14     PHASE_ANGLE,
15     THANK_YOU
16 };
17 State currentState = DETECTOR;
18 void setup() {
19     // Initialize the LCD
20     lcd.init();
21     lcd.backlight(); // turn on the backlight
22
23     // Display "Breast Cancer Detector" on the LCD
24     lcd.setCursor(0, 0);
25     lcd.print("Breast Cancer");
26     lcd.setCursor(0, 1);
27     lcd.print("Detector");
28
29     // Set push button pin as input
30     pinMode(buttonPin, INPUT_PULLUP);
31     pinMode(resetPin, INPUT_PULLUP);
32 }
33 void loop() {
34     // Check if reset button is pressed
35     if (digitalRead(resetPin) == LOW) {
36         currentState = DETECTOR;
37         lcd.clear();
38         lcd.setCursor(0, 0);
39         lcd.print("Breast Cancer");
40         lcd.setCursor(0, 1);
41         lcd.print("Detector");
42         delay(200); // Debouncing delay
43     }
44     // Handle state transition
45     switch (currentState) {
46     case DETECTOR:
47         if (digitalRead(buttonPin) == LOW) {
48             currentState = ELECTRODES;
49             lcd.clear();
50             lcd.setCursor(0, 0);
51             lcd.print("Put the electrodes");
52             delay(200); // Debouncing delay
53         }
54         break;
55     case ELECTRODES:
56         if (digitalRead(buttonPin) == LOW) {
57             currentState = TURN_ON_CURRENT;
58             lcd.clear();
59             lcd.setCursor(0, 0);
60             lcd.print("Turn on current");
61             delay(200); // Debouncing delay
62         }
63         break;
64     case TURN_ON_CURRENT:
65         if (digitalRead(buttonPin) == LOW) {
66             currentState = IMPEDANCE;
67             lcd.clear();
68             lcd.setCursor(0, 0);
69             lcd.print("Impedance: ");
70             lcd.print(getImpedance());
71             delay(200); // Debouncing delay
72         }
73         break;
74     case IMPEDANCE:
75         if (digitalRead(buttonPin) == LOW) {
76             currentState = PHASE_ANGLE;
77             lcd.clear();
78             lcd.setCursor(0, 1);
79             lcd.print("Phase angle: ");
80             lcd.print(getPhaseAngle());
81             delay(200); // Debouncing delay
82         }
83         break;
84     case PHASE_ANGLE:
85         if (digitalRead(buttonPin) == LOW) {
86             currentState = THANK_YOU;
87             lcd.clear();
88             lcd.setCursor(0, 0);
89             lcd.print("Thank you");
90             delay(2000); // Display for 2 seconds
91         }
92         break;
93     case THANK_YOU:
94         // Stay in this state until reset button is pressed
95         break;
96     }
97 }
98 float getImpedance() {
99     int analogVmag = analogRead(magnitudePin); // Read the analog value from magnitude pin
100     int Vmag = map(analogVmag, 0, 1023, 0, 1000); // Map to range 0V - 1000V
101     float impedance = 250 * pow(10, (Vmag - 900) / 600.0); // Calculate impedance
102     return impedance;
103 }
104 float getPhaseAngle() {
105     int analogVphase = analogRead(phasePin); // Read the analog value from phase pin
106     int Vphase = map(analogVphase, 0, 1023, 0, 1000); // Map to range 0V - 1000V
107     float phaseAngle = (((900 - Vphase) / 10.0) + 90.0); // Calculate phase angle
108     return phaseAngle;
109 }

```

APPENDIX 5: BREAST CANCER EARLY DETECTOR DURING TESTING



During testing



Measuring region



Rabbit after shave



Electrodes on rabbit.



Results on LCD

APPENDIX 6: ETHICAL CLEARANCE LETTER



UNIVERSITY of
RWANDA

COLLEGE OF MEDICINE AND HEALTH SCIENCES
DIRECTORATE OF RESEARCH & INNOVATION

CMHS INSTITUTIONAL REVIEW BOARD (IRB)

Kigali, 27th/12/2023
Ref: CMHS/IRB/578/2023

BIKORIMANA Christian (Ref. No. 217074499)
MSc. Degree Student in Biomedical Engineering
Centre of Excellence in Biomedical Engineering and E-Health (CEBE), CST, UR

Dear BIKORIMANA Christian

RE: ETHICAL CLEARANCE

Reference is made to your application for ethical clearance for the study entitled "*Design of a Breast Cancer Early Detector*".

Having reviewed your application and been satisfied with your protocol, your study is hereby granted ethical clearance. The ethical clearance is valid for one year starting from the date it is issued and shall be renewed on request. You will be required to submit the progress report and any major changes made in the proposal during the implementation stage. In addition, at the end, the IRB shall need to be given the final report of your study.

We wish you success in this important study.

Assoc. Prof. Stefan Jansen (PhD)
Acting Chairperson Institutional Review Board
College of Medicine and Health Sciences, UR



Cc:

- Principal College of Medicine and Health Sciences, UR
- University Director of Research and Postgraduate studies, UR