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UNIVERSITY OF TECHNOLOGY



# **Monitoring Device for Finding the Fluidity Dynamics of Human Body**

Master's thesis in Electrical Engineering

Aswanth Nagarajan,

Karthik Babu

**DEPARTMENT OF ELECTRICAL ENGINEERING**

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CHALMERS UNIVERSITY OF TECHNOLOGY  
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MASTER'S THESIS 2024

# Monitoring Device for Finding the Fluidity Dynamics of Human Body

Aswanth Nagarajan  
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**CHALMERS**  
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# Monitoring Device for Finding the Fluidity Dynamics of Human Body

Aswanth Nagarajan, Karthik Babu

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Monitoring Device for Finding the Fluidity Dynamics of Human Body  
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## **Abstract:**

Urinary incontinence poses a significant challenge among the elderly, severely impacting their quality of life. Recent clinical studies have underscored the importance of tailored continence care strategies, particularly those based on accurate urine volume measurements within the bladder. Despite this need, the development of a precise and continuous urine volume sensor remains an ongoing challenge in medical research. To address this, we are exploring bioimpedance measurement as a promising method for estimating urine volume. This technique assesses changes in bioimpedance within the bladder, which correlate with varying volumes of urine. The concept revolves around the principle that the bladder's electrical properties change as it fills or empties, allowing for indirect measurement of urine volume without invasive procedures. Advancements in bioelectrical impedance analysis are leading us to develop wearable devices specifically for this purpose. These devices integrate sophisticated hardware setups capable of generating precise sine wave signals, measuring impedance changes, and converting analog signals into digital data for analysis. Ultimately, we aim to integrate bioimpedance-based techniques into clinical practice, advancing non-invasive diagnostics and treatment strategies for urinary disorders. By providing real-time insights into bladder conditions, these innovations will improve patient care and overall quality of life for individuals affected by urinary incontinence and related conditions.

Keywords: Urinary Bladder, Bioimpedance, Carbon electrode, Ag/AgCl electrode, Arduino R4, AD9833 DDS, Proteus design software and Digilent waveform



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Aswanth Nagarajan, Karthik Babu, Gothenburg, August 2024



# Glossary

Below is the list of acronyms that have been used throughout this thesis listed in alphabetical order:

CIC	Clean Intermittent Catheterization
CT	Computed Tomography
AC	Alternating Current
BIA	Bioimpedance Analysis
Ag/AgCl	Silver/Silver Chloride
XI	Inductive Reactance
FEM	Fat-Free Mass
ECW	Extracellular Water
ICW	Intracellular Water
UTIs	Urinary Tract Infections
MCU	Microcontroller Unit
DDS	Direct Digital Synthesizer
ADC	Analog-to-Digital Converter
UART	Universal Asynchronous Receiver-Transmitter
SPI	Serial Peripheral Interface
I2C	Inter Integrated Circuit
DAC	Digital-to-Analog converter
EDA	Electronic Design Automation
SNR	Signal-to-Noise Ratio
HT	Human Trial



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# Chapter 1

## Introduction

It is typical to feel the urge to urinate when your bladder is full. But for some patients suffering from urological or neurological diseases, this sense will vanish, resulting in urine reflux and infections of the urinary tract that may eventually cause renal failure. Consequently, an increasing number of patients are in need of professional nursing care, which raises the workload of the staff and raises the expense of healthcare for the patients. A method for automatically tracking patients' bladder urine capacity and assisting with voiding must be developed. In recent years, significant efforts have been undertaken to address the issue [6]. A common method of emptying the bladder is called clean intermittent catheterization (CIC), which involves periodically putting a catheter into the urethra. However, this procedure is invasive and may cause a urinary tract infection. Another method for addressing this issue is to gauge the bladder's urine volume using ultrasound. After Holmes' 1967 ultrasonography measurement of urinary bladder volume, subsequent studies utilized various imaging techniques, including real-time 3D ultrasound and B-mode ultrasound, to measure bladder volume [3-4]. However, the ultrasonic construction is rather costly and intricate. While certain specialised portable ultrasonography bladder urine volume measuring instruments have been created in these years [5], none of these expensive gadgets can measure the volume of urine in the bladder consistently. Anatomical imaging methods, such as computed tomography (CT), which provides excellent accuracy for assessing bladder volume, are generally associated with high radiation levels, demanding testing environments, usually bulky and need trained individuals for testing and unsuitability for continuous monitoring.

Over the past 30 years, the electrical impedance technique a bio-impedance technology that is still in its infancy has been used more and more in the assessment and tracking of bladder volume [4]. The physiological basis of this technique is based on the theory that variations in the bladder's urine volume may result in comparable variations in electrical impedance, which may be assessed on the exterior of the body. Another name for the bioelectrical impedance technique is medical electrical impedance. It retrieves biological data about the physiological and pathological aspects of human circumstances determined by the electrical properties and variation of biological tissues and organs. Usually, conventional two-electrode method is typically used to measure bladder volume via electrical impedance technique [7]. An alternating current (AC) is induced by applying a constant current and specific frequency electrical signal into the subject's lower abdomen through a pair of electrodes that is attached to the surface, while the induced voltage is simultaneously picked up by other pair of electrodes that is placed on the surface. The corresponding impedance is then computed by Ohm's law [8]. Compared to other traditional measuring methods like CT and ultrasound, it has several advantages. It is non-invasive, more portable, less expensive, and has better long-term monitoring capabilities. It also allows patients for self-monitoring and enhances their mobility. Because of these advantages, electrical impedance is a promising method for noninvasively and in real time monitoring urological disease patients in a clinic.

### 1.1 Motivation

An essential component of urological therapy is urinary bladder volume monitoring, especially when it comes to diagnosing and treating bladder dysfunction. Urinary retention, neurogenic bladder, and overactive bladder syndrome can all be diagnosed with accurate and consistent

assessment of bladder volume changes. While there are a number of ways to estimate the capacity of the bladder, such as pressure-based approaches, catheterization, and ultrasonography, each has drawbacks, such as being intrusive, uncomfortable, or requiring specific equipment [11].

Utilising technology like bioimpedance analysis (BIA), there has been an increase in interest in investigating non-invasive techniques for urine bladder volume monitoring in recent years [14]. By monitoring the electrical characteristics of the bladder wall, BIA provides the possibility of a non-invasive, real-time evaluation of changes in bladder volume. To guarantee accurate and trustworthy results, however, BIA for bladder volume monitoring necessitates careful consideration of electrode location, choice, and signal processing methods [9].

The purpose of this master's thesis is to examine the viability and effectiveness of BIA-based techniques in order to meet the need for more effective non-invasive techniques for urine bladder volume monitoring. The study will specifically compare the performance of Carbon and Ag/AgCl electrodes in clinical situations and assess their suitability for BIA-based bladder volume monitoring. In order to improve patient care and clinical practice in the field of urology, this study aims to advance non-invasive bladder volume monitoring techniques by methodically evaluating the strengths and weaknesses of various electrode types.

## **1.2 Goals**

In this thesis the aim is to determine the exact location for the electrode placement in the human body abdomen and finding the exact frequency, resistor and capacitor values which can be induced to the human body surface by the help of the electrodes. It consists of both software and hardware parts in which software part is to determine the frequency, resistor and capacitor values and hardware part is for designing the prototype which is a non-invasive real time bladder monitoring device.

### **1.2.1 Part of the goals**

The main goal is divided into smaller goals depending on the project needs:

- Review of the literature and previous research which can be useful for our project.
- Studying about Digilent Waveform software which is used for impedance measurement in the human body and also its applications and usages for our experiment.
- Building the circuit for the prototype.
- Finding the component values and testing the results in the human body.
- Studying about the difference between impedance over time graph according to the urinary bladder volume.
- Analysis of the results.

## **1.3 Structure of the Thesis**

This thesis is structured as follows:

Chapter 1 provides the introduction of the work and also represents the goals of this thesis

Chapter 2 provides the theoretical background of our work and talks about the anatomy and function of the urinary bladder.

Chapter 3 discusses the hardware components we utilized and developed for our project.

Chapter 4 provides the results which we have found through our experiments on measuring urinary bladder volume using different types of electrodes and varying frequency settings.

Chapter 5 presents the discussion on how to proceed with the project, explores other potential methods, and outlines the future work of the project.

Chapter 6 summarizes the key findings from our experiments and the progress made in the project to date.

# CHAPTER 2

## Theoretical background

This chapter provides background information on the idea of bioimpedance and how it is used in body measurements for both the examination of the entire body composition and the investigation for certain body parts.

### 2.1 The anatomy and function of the urinary bladder

The urinary bladder is a hollow, muscular organ located in the pelvic cavity, situated behind the pubic symphysis and anterior to the rectum (in males) or anterior to the uterus and vagina (in females) [1-2]. Its primary function is to store urine produced by the kidneys until it is expelled from the body during urination.

#### 2.1.1 Position and Orientation

The position of the bladder affects gynaecological and urological health, and its direction is critical to its function. Its precise anatomical relationships within the pelvic region are outlined in the following parts [1-2].

- The bladder is located inferior to the peritoneum in the anterior region of the pelvic cavity.
- It lies anterior to the rectum and above to the prostate gland in men.
- It is situated anterior to the uterus and vagina and superior to the pubic bone in females.

#### 2.1.2 Shape and Structure

The form of the bladder varies based on the contents inside it, making it a dynamic organ. Its structure is specially made to hold different amounts of urine while still being able to contract efficiently when urinating. The structure of the bladder and the muscles that support it are explained in the following points [3].

- When empty, the bladder usually has a pear-shaped form, as it fills with urine, it becomes more spherical.
- It is made up of the detrusor muscle, a smooth muscle that contracts to expel urine from the bladder during urination.

#### 2.1.3 Internal Anatomy

The bladder wall is made up of several tissue layers, such as the following [3]:

**Mucosa:** The innermost layer that lines the lumen of the bladder, made of transitional epithelium that stretches as the bladder fills.

**Submucosa:** A layer of connective tissue that houses lymphatics, nerves, and blood vessels.

**Muscularis:** The detrusor muscle, a thick layer of smooth muscular tissue, is what contracts the bladder.

Adventitia/Serosa: The outermost layer, whose composition varies according to the body's location of the bladder.

#### 2.1.4 Trigone

Consisting of the internal urethral orifice and the ureter apertures, the trigone is a triangle region situated at the base of the bladder. It functions as a portion of the bladder that holds its size and shape steady throughout filling and emptying and is coated with smooth mucosa [7].

### 2.2 Electrical Impedance

The term “electrical impedance” describes the resistance that a material or component provides to the flow of AC [8]. It is measured in ohms ( $\Omega$ ) and has the symbol “Z” assigned to it. Impedance includes reactance, which is the impact of capacitance or inductance on the alternating current flow, as well as resistance, which is the opposition to the current flow.

Electrical impedance consists of two main components [8]:

Resistance (R): Denotes a material's or circuit's resistance to the passage of electricity. It gets influenced by variables like the length, cross-sectional area, and conductivity of the material. Resistance is the real component of impedance, represented by “R.”

Reactance (X): Indicates how capacitance or inductance affects the alternating current flow. Capacitors provide capacitive reactance ( $X_c$ ), whereas inductors produce inductive reactance ( $X_l$ ). “X” stands for reactance, which is the imaginary part of impedance.

The impedance (Z) in an electrical circuit can be represented as the sum of resistance (R) and reactance (X), where reactance can be either capacitive ( $X_c$ ) or inductive ( $X_l$ ). Mathematically, it is expressed as:

$$Z=R+jX \quad (2.1)$$

Where:

Z = Impedance (ohms)

R = Resistance (ohms)

X = Reactance (ohms)

j = Imaginary unit, representing the phase shift between voltage and current in AC circuits.

### 2.3 Principle of Bioimpedance

The term “bioimpedance” describes biological tissues' resistance to electrical current flow [8]. It is affected by several of factors, including the composition and structure of tissues as well as the volume, conductivity, and distribution of bodily fluids [10]. The electrical characteristics of each tissue in the body differ. Lean muscular tissue, for instance, is low impedance and conductive due to its high water and electrolyte content. On the other hand, fat tissue has a higher impedance and less water [11]. Electrodes positioned on the skin's surface are usually used to conduct a low-level electrical current through the body during bioimpedance study. After measuring the impedance, factors like resistance (R) and capacitive reactance ( $X_c$ ) are examined to determine the approximate composition of the body.

## 2.4 Bioimpedance and Body Composition

The non-invasive urine volume estimation methods for bladder function assessment, understanding the principles of bioimpedance and its correlation with body composition is paramount. Bioimpedance, reflecting the ability of biomaterials to impede electrical current flow, offers valuable insights into the electrical properties of biological tissues, including the bladder. As the bladder fills with urine, changes in its bioimpedance can provide indirect indicators of bladder volume and function.

The concept of fat-free mass (FFM) emerges as particularly relevant in this context, as it constitutes a major contributor to the body's electrical conductivity [14]. By leveraging the relationship between FFM and bioimpedance, researchers can develop non-invasive techniques to estimate bladder volume based on impedance measurements obtained over the bladder region [14]. Additionally, accounting for variations in body composition compartments, such as extracellular water (ECW) and intracellular water (ICW), within FFM enhances the accuracy and specificity of urine volume estimation algorithms.

Advancements in body composition modelling, ranging from the traditional 2-compartment (2-C) model to the comprehensive 5-level model proposed by Wang et al., offer a framework for refining impedance-based bladder assessment techniques [4]. These models enable to dissect the contributions of different tissue compartments to bioimpedance and tailor estimation algorithms to account for individual variations in body composition.

Moreover, incorporating specialized techniques like neutron activation analysis and dual-energy X-ray absorption further enhances the precision and reliability of body composition measurements, facilitating more accurate estimation of bladder volume based on impedance data. By integrating insights from bioimpedance analysis and advanced body composition modelling, non-invasive methods for urine volume estimation hold promise for revolutionizing bladder function assessment and enhancing diagnostic capabilities in clinical settings.

2-components	3-components	4-components	5-components	6-components
Fat mass (FM)	Fat mass (FM)	Fat mass (FM)	Fat mass (FM)	Fat mass (FM)
Fat-free mass* (FFM)	Water	Water	Water	Water
	Fat-free dry mass**	Protein	Protein	Protein
		Mineral	Bone mineral content (BMC)***	Bone mineral content (BMC)***
			Non-osseous mineral content****	Non-osseous mineral content****
			Glycogen	

Figure 2.1: Body composition model [12]

## 2.5 Electrical Model of the Human Bladder

The bladder can be modelled as a combination of resistive and capacitive elements. This model is based on the fact that biological tissues contain both resistive pathways (due to ion-rich

fluids) and capacitive elements (due to cell membranes). One of the commonly referenced models for representing the electrical properties of biological tissues, including the human bladder, is the Fricke model [7]. This model uses a combination of resistors and capacitors to represent the complex impedance characteristics of tissues.

The Fricke model is based on the observation that biological tissues exhibit both resistive and capacitive properties. This model is particularly useful for understanding the impedance behaviour of tissues over a range of frequencies.

Components of Fricke's Circuit Model:

- **Extracellular Resistance ( $R_e$ ):** Represents the resistance of the extracellular fluid.
- **Intracellular Resistance ( $R_i$ ):** Represents the resistance within the cells.
- **Cell Membrane Capacitance ( $C_m$ ):** Represents the capacitive properties of the cell membranes.

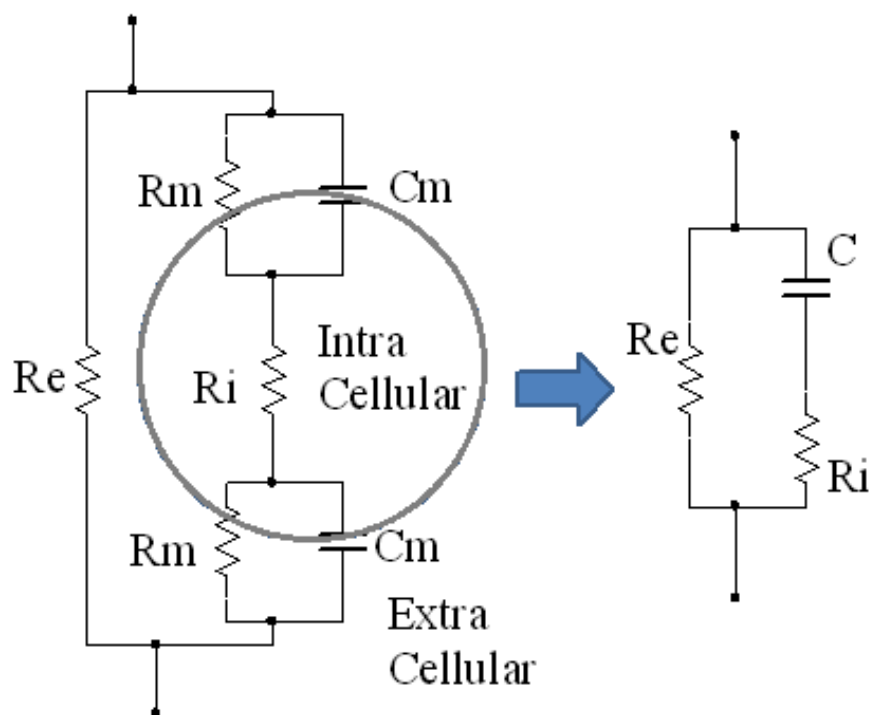


Figure 2.2: Frick's Model [7]

**Extracellular Resistance ( $R_e$ ):** The resistance offered by the fluid outside the cells. This resistance remains relatively constant but can change slightly with different fluid volumes.

**Intracellular Resistance ( $R_i$ ):** The resistance within the cells, which is usually higher than the extracellular resistance due to the relatively lower ion mobility inside cells.

**Cell Membrane Capacitance ( $C_m$ ):** The cell membranes act as capacitors due to their lipid bilayer structure, which can store charge. This capacitance changes slightly with the cell volume and membrane integrity.

When applying this model to the bladder, we consider that the bladder is filled with fluid (urine) and surrounded by muscle tissue. The impedance of the bladder will vary with the volume of urine due to changes in the extracellular and intracellular fluid distribution.

## 2.6 Impedance Measurement of the Urinary Bladder

The total impedance ( $Z$ ) of the bladder tissue can be expressed as a combination of the resistive and capacitive components [3]:

$$Z = \sqrt{(R_e + R_i)^2 + \left(\frac{1}{\omega C_m}\right)^2} \quad (2.2)$$

Where:

- $\omega$  is the angular frequency of the applied AC signal.
- $R_e$  is the extracellular resistance.
- $R_i$  is the intracellular resistance.
- $C_m$  is the cell membrane capacitance.

Impedance measurement serves as an effective method for reflecting bladder volume through the analysis of resistance and capacitance variations. In an empty bladder, the resistance ( $R_e + R_i$ ) is high due to the low volume of urine, resulting in less extracellular fluid and greater resistance to electrical flow. Additionally, the capacitance ( $C_m$ ) may remain relatively unchanged or slightly lower, as the bladder walls are not significantly stretched. Conversely, in a full bladder, resistance decreases as the bladder fills with urine, increasing the extracellular fluid volume and thus reducing overall resistance. Simultaneously, capacitance increases due to the stretching of the bladder wall, which enlarges the surface area and reduces the membrane thickness. By measuring impedance across a range of frequencies, these changes in resistance and capacitance can be analyzed to provide an estimate of bladder volume, facilitating non-invasive monitoring and assessment.

## 2.7 Review of Existing Literature on Urine Volume Estimation Techniques

In reviewing existing literature on urinary volume estimation methods, both invasive and non-invasive techniques have been explored. Invasive methods such as catheterization provide direct measurements but are associated with discomfort and infection risks. Ultrasound bladder scanning offers non-invasive real-time imaging but requires skilled operators and may be affected by operator experience and bowel gas interference. Urodynamic studies, while comprehensive, are invasive and necessitate specialized equipment and expertise. Non-invasive methods like weight-based estimation and fluid intake/output monitoring are simpler but may lack accuracy and depend on patient compliance [12].

## 2.8 Discussion of Traditional Invasive Methods and Their Limitations

Traditional invasive methods, notably catheterization, are associated with several limitations. Beyond patient discomfort and anxiety, there's a significant risk of urinary tract infections (UTIs) and other complications, including urethral trauma and bladder perforation [10]. Moreover, these methods require skilled healthcare personnel and specialized infrastructure, contributing to higher healthcare costs and limited accessibility, particularly in resource-limited settings.

## **2.9 Overview of Impedance-based Methods in Medical Diagnostics**

Non-invasive methods like electrical impedance-based methods emerge as promising alternatives, offering non-invasiveness, real-time monitoring, potential for continuous monitoring, and integration with wearable technology. However, their accuracy may be influenced by factors such as tissue composition and electrode placement, requiring validation against gold standard methods [15].

### **2.10 Studies and Research Related to Impedance-based Bladder Volume Estimation**

Several studies have explored the feasibility and accuracy of impedance-based methods for bladder volume estimation. These studies typically involve validation against gold standard techniques such as catheterization or ultrasound. While promising, impedance-based methods face challenges such as variability in electrode placement, sensitivity to tissue properties, and the need for calibration [15]. Addressing these challenges is crucial for the widespread adoption of impedance-based bladder volume estimation in clinical practice.

# Chapter 3

## Hardware and Software for operation of the system

In this chapter, we will provide a comprehensive discussion of the hardware components and software platforms utilized throughout the project. This includes an in-depth examination of the selection criteria, functionality, and integration of the various technological tools employed in our research. By outlining the specific roles of each component and platform, we aim to illustrate how they collectively contribute to achieving the project's objectives.

### 3.1 Description of the system and Circuit Architecture for Impedance-Based Bladder Volume Estimation

In the hardware setup for impedance-based bladder volume estimation, key components include the Arduino R4 microcontroller unit (MCU), the AD9833 Direct Digital Synthesizer (DDS), electrodes, and an analog-to-digital converter (ADC). The Arduino R4 serves as the central processing unit for controlling signal generation, data acquisition, and communication, offering ample computational capabilities, and integrating various communication interfaces such as UART, SPI, and I2C [16]. The AD9833 DDS chip generates precise sine wave voltage signals required for impedance measurements, with high-resolution frequency synthesis capability and low power consumption [5]. In the circuit architecture, the Arduino R4 controls the AD9833 DDS chip to generate the sine wave voltage signal, which is then applied to the bladder through electrodes. The ADC (analog-to-digital converter) is responsible for converting the analog signal, which represents the measured impedance of the bladder, into a digital format that can be processed and analysed by the MCU (microcontroller unit).

In the described hardware setup, the MCU (Arduino R4), which includes a built-in ADC, controls the ADC to initiate the conversion process and retrieve the digital representation of the analog signal. The ADC samples the analog signal at regular intervals, quantizes it into discrete digital values, and sends these digital samples to the MCU for further processing. The MCU then performs any necessary calculations or analysis on the digital data, such as computing impedance values or estimating bladder volume based on predetermined algorithms. By utilizing the ADC, the MCU can accurately measure the impedance of the bladder in response to the applied sine wave voltage signal, enabling non-invasive bladder volume estimation.

### 3.2 Arduino R4 Microcontroller Unit (MCU)

The Arduino R4 is a versatile microcontroller board based on the ARM Cortex-M4 architecture. Its core components include a powerful 32-bit ARM Cortex-M4 processor running at a clock speed of 120 MHz, providing ample processing power for real-time signal processing tasks [16]. Equipped with 1MB of flash memory and 256KB of SRAM, the Arduino R4 offers sufficient memory for storing program code and data. Additionally, it features a variety of communication interfaces such as UART, SPI, I2C, and USB, enabling seamless interaction with external devices and sensors [16]. The Arduino R4's compact form factor and user-friendly development environment make it an ideal choice for prototyping and developing embedded systems applications.

### 3.3 AD9833 Direct Digital Synthesizer (DDS)

The AD9833 is a low-power, programmable waveform generator designed for precision frequency synthesis applications. Its architecture comprises a phase accumulator, a 10-bit frequency tuning word register, a 28-bit frequency control register, and a digital-to-analog converter (DAC) [5]. The phase accumulator accumulates phase increments based on the frequency tuning word, generating a phase angle that determines the output waveform's frequency. The frequency control register stores the frequency tuning word, allowing precise frequency control with a resolution of 0.0291 Hz per bit and small footprint, the AD9833 is well suited for portable and battery-operated applications requiring accurate waveform generation [5].

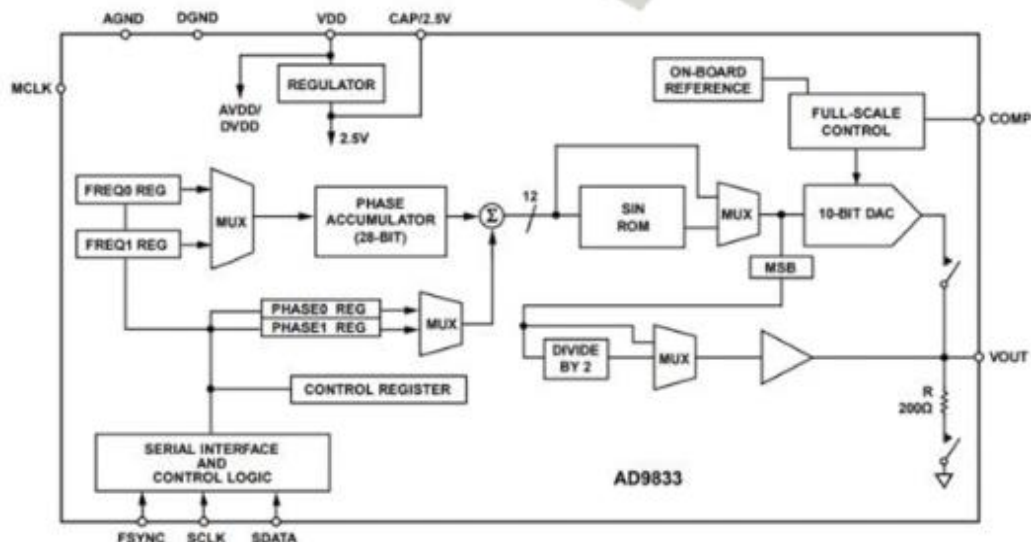


Figure 3.1: AD9833 Block Diagram [5]

### 3.4 Proteus Software Overview

Proteus Design Suite is an electronic design automation (EDA) tool developed by Labcenter Electronics, widely used for the simulation and design of electronic circuits [17]. It combines schematic capture and circuit simulation into a single platform, making it indispensable for

engineers and designers. Proteus allows for the creation and simulation of electronic circuits, including both analog and digital components, before moving to physical prototypes.

**Component Selection:** Proteus offers an extensive library of components, including microcontrollers, passive components, sensors, and more. For our project on impedance-based bladder volume estimation, we would select components such as the Arduino R4, AD9833 DDS, and electrodes.

**Drawing the Circuit:** The software enables users to draw circuit diagrams by placing components on the workspace and connecting them with virtual wires. This involves setting up connections between the Arduino R4, AD9833 DDS, and the electrodes, as well as incorporating any other necessary components like resistors and capacitors.

**Running the Simulation:** Proteus simulates the circuit behavior in real-time, allowing us to visualize the signal generation by the AD9833, its application to the bladder model, and the ADC's role in digitizing the signal for processing by the Arduino R4.

**Analyzing Results:** The software provides tools like oscilloscopes, logic analyzers, and signal generators to analyze simulation results. This helps verify the circuit's functionality and make necessary adjustments.

### 3.5 Application in the Bladder Volume Estimation Project

In our impedance-based bladder volume estimation project, Proteus is invaluable for several reasons [17]:

**Design and Simulation:** Proteus is used to design the circuit incorporating the Arduino R4, AD9833 DDS, electrodes, and other components. The software's simulation capabilities allow us to test the circuit's functionality, ensuring the accuracy of the generated sine wave and impedance measurements.

**Testing Different Configurations:** We can test various circuit configurations virtually, such as different frequencies of the sine wave generated by the AD9833 and different electrode placements.

**Debugging and Optimization:** Proteus helps identify issues in the circuit design, such as incorrect connections or component values, and optimize the circuit for better performance.

By using Proteus, we can conduct the entire design and verification process in a virtual environment, saving time and resources before moving to physical prototypes. This makes Proteus an essential tool in the development of our impedance-based bladder volume estimation system.

# Chapter 4

## Results

In this chapter, we will present and analyze the findings obtained from our various experiments, specifically focusing on the use of different electrodes and the measurements taken at various time intervals. We will discuss the significance of these results in relation to our research objectives and how they contribute to understanding the behavior of the urinary bladder under different conditions. Additionally, this chapter will cover the practical implementation of the designed circuit in real-world scenarios, highlighting its effectiveness in obtaining accurate and reliable measurements. By integrating experimental data with real-world application, we aim to demonstrate the validity and potential impact of our approach.

### 4.1 Type of electrodes

To accurately measure changes in bladder volume over time, electrodes are an essential part of urinary bladder volume monitoring equipment. To track the cycles of bladder filling and emptying in this context, electrodes are usually used in conjunction with pressure sensors or ultrasonic equipment. For our experiment we have used Carbon electrodes and Ag/AgCl electrodes for acting as interfaces between the electrical activity of the bladder and the monitoring apparatus, these electrodes make it possible to quantify bladder pressure and muscle contractions with accuracy.

Carbon electrodes are chosen for urine bladder volume monitoring because of their unique performance features and design. With their dependable signal gathering capabilities, these electrodes guarantee accurate detection of bladder volume changes during the filling and voiding phases [7]. Because of their adhesive qualities, they may be securely attached to the skin's surface and keep steady contact even when moving or changing position. For many types of stimulation devices, carbon electrodes offer a dependable and efficient way to link the device to the body. Additionally, their high porosity, superior conductivity, and huge specific surface area have made them popular in various situations. They are designed with patient comfort in mind, Carbon electrodes reduce discomfort even during extended monitoring sessions.

Another popular option for urine bladder volume monitoring applications is Ag/AgCl electrodes, which have several benefits that make them appropriate for this job [8]. Ag/AgCl electrodes are perfect for recording electrical signals related to bladder contractions during filling and emptying because of their conductivity and stability. They are also non-polarizable electrode and uses a reversible Redox-Reaction to transport charge across its borders. As a result, it is not creating a second layer and has “no” filter characteristics. Long-term performance without signal degradation is ensured by their sturdy structure, which is crucial for collecting precise measurements during prolonged monitoring periods. Furthermore, Ag/AgCl electrodes are simple to include into multi-channel monitoring systems, enabling the simultaneous recording of physiological data and bladder activity in the human body.

To sum up, Carbon and Ag/AgCl electrodes are the better choices for tracking urine output because of their dependability, robustness, and equipment compatibility. By correctly tracking bladder function, these electrodes help researchers and clinicians gain important insights into urine dynamics and support the diagnosis and treatment of bladder illnesses.

## 4.2 Electrode placement

The reliability and accuracy of the measurements are directly impacted by the electrodes' exact placement. Electrode positioning is critical for capturing the electrical impulses coming from the bladder or surrounding muscles when bladder volume is being monitored with BIA.

Proper positioning of the electrodes guarantees ideal skin contact, which promotes electrical signal transfer from the biological tissue to the monitoring apparatus. Placing the device correctly reduces noise and signal interference, which can skew results and cause inaccurate bladder capacity estimation. Additionally, collecting trustworthy longitudinal data and tracking changes in bladder function over time depend on consistent electrode insertion throughout monitoring sessions.

Additionally, during monitoring procedures, the location of electrodes has a direct impact on the comfort and compliance of the patient. By making sure that the electrodes are positioned in anatomically suitable spots and fastened securely but gently, you can reduce patient discomfort and improve their overall experience as well as cooperation during the monitoring procedure.

Position of the electrodes is represented below is the CT scan and model utilised in the simulation study in the accompanying figure. In the below figure If we are using two electrode method in which for our case, we are using positions S1 which is best for measurement and position S2 which can be best for excitation. In which the distance of the electrodes between S1 and S2 should be around 6cms [14], and the electrodes should be placed in parallel to the pelvis for the correct monitoring of the urinary bladder volume.

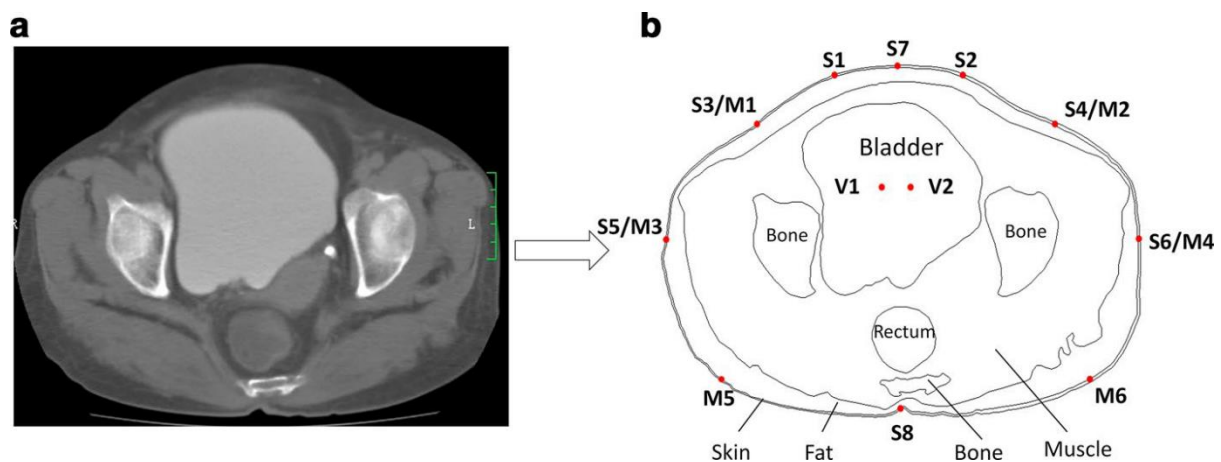


Figure 4.1: a) An individual in good health provided the CT scan image; Figure b) a 2-D model was created using the image and the positions of all the electrodes that were studied (S for excitation electrodes, M for measurement electrodes, and V for measurement electrodes inside the bladder) [7]

## 4.3 Balloon Experiment

Before conducting experiments on human subjects, we conducted preliminary testing using a balloon to simulate varying bladder volumes. The setup was designed to mimic the electrical properties of the urinary bladder under different volume conditions. Initially, the balloon was inflated with air to represent an empty bladder. Subsequently, water was gradually added to the

balloon to simulate a half-filled bladder, followed by further water addition to mimic a fully distended bladder.

Impedance measurements were then taken using the impedance analyzer to assess the electrical properties of the balloon under each simulated bladder volume condition. This preliminary testing allowed us to validate the experimental setup and ensure that the impedance measurements accurately reflected changes in bladder volume.

By conducting these preliminary tests with the balloon model, we were able to fine-tune the experimental procedures and verify the reliability of the impedance measurement technique before proceeding to experiments involving human subjects. This ensured the robustness and accuracy of our experimental approach and provided a basis for interpreting the impedance measurements obtained during human testing.

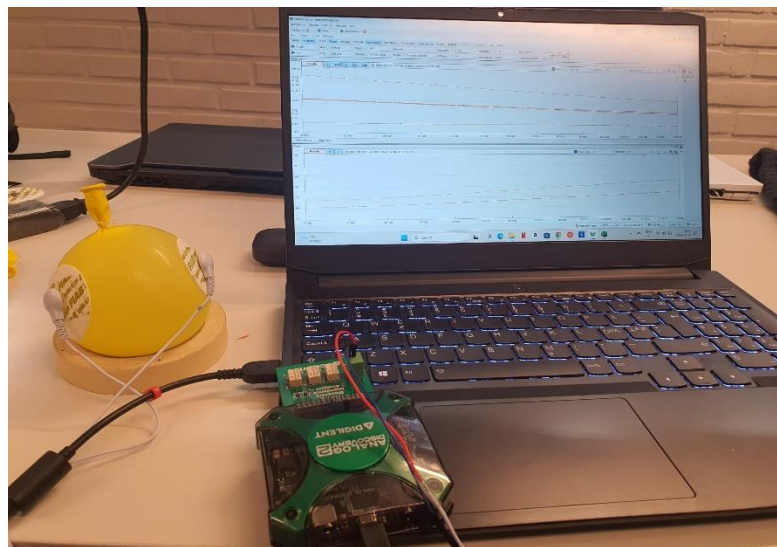


Figure 4.2: Balloon experiment setup for mimicking the urinary bladder volume

The experimental setup depicted in Figure 4.2 illustrates the use of a balloon to simulate bladder volume conditions, with impedance measurements captured using Digilent waveform software. This setup allowed us to mimic the electrical properties of the urinary bladder under different volume conditions, providing valuable insight into the behaviour of our medical device in a controlled environment.

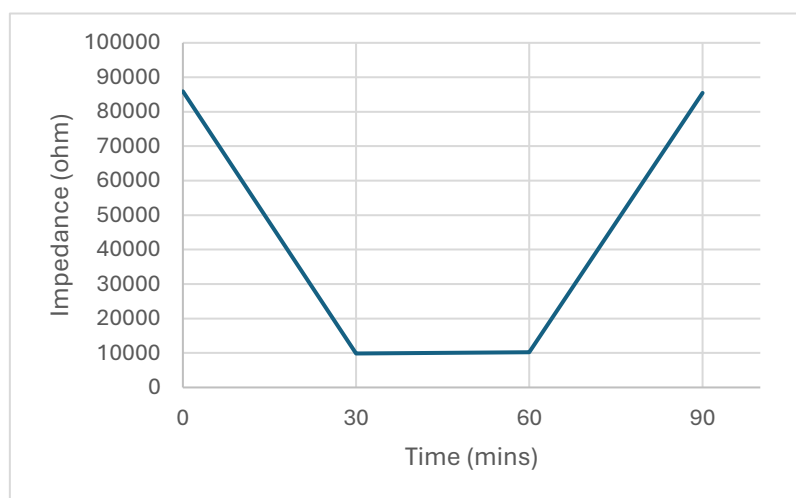


Figure 4.3: Impedance graph for balloon experiment

The impedance graph presented above illustrates the results obtained from our balloon experiment, aligning closely with our expectations. As anticipated, the impedance values were notably higher when the balloon simulated an empty bladder and decreased as the volume of the balloon increased to mimic a full bladder. These findings were in line with our experimental hypotheses and provided encouraging initial validation of our methodology.

To further corroborate these results and ensure their applicability to real-world scenarios, we made the decision to conduct similar experiments using human subjects. This step was crucial in confirming the relevance and reliability of our findings in a clinical context. By involving human participants, we aimed to clarify the consistency of the impedance measurements and validate their correlation with actual bladder volume variations.

#### 4.4 Carbon electrodes measurement

We employed an impedance analyzer to conduct our electrode testing procedures, following the electrode placements detailed in Section 4.2. Initially we are trying by single pair of electrodes, and position is on abdomen below which is shown in Figure 4.4 for ensuring consistent placement across all measurements. This setup is crucial for maintaining standardized conditions and minimizing variability in the recorded data.

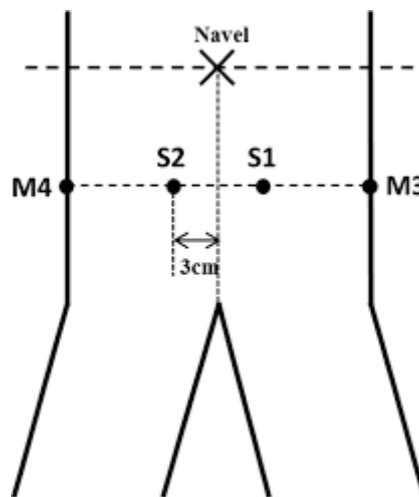


Figure 4.4: Position of the electrodes for measuring the urinary bladder volume [5]

To capture impedance measurements, we utilized the Diligent waveform software and Analog Discovery 2 Impedance analyzer kit, which facilitated real-time data acquisition and analysis. By recording readings at 30-minute intervals, we obtained a comprehensive dataset reflecting changes in impedance over time. This frequency of measurement was chosen to balance the need for capturing dynamic fluctuations in bladder volume while minimizing patient discomfort and inconvenience.

Table 4.1 below presents the impedance measurements obtained for each case, providing insight into the electrical properties of the electrodes under various conditions. These measurements serve as a basis for evaluating electrode performance and assessing their suitability for urinary bladder volume monitoring applications [15].

Time (minutes)	Representation	Impedance
0	Empty urinary bladder	High
30	Half-filled urinary bladder	Little Low
60	Full urinary bladder	Low
90	Empty urinary bladder	Bit High

Table 4.1: Urinary bladder measurements at different time intervals

The experiment aims to investigate the accuracy of Carbon electrodes in determining urinary bladder volume based on the inverse relationship between electrical impedance and bladder volume. Specifically, the experiment seeks to validate whether the impedance values obtained correspond accurately to changes in bladder volume, as expected.

In this experiment, we anticipate that when the urinary bladder is empty, the impedance value will be high due to the limited conductivity of the empty bladder. As the bladder volume increases, the impedance value is expected to decrease progressively, reflecting the increase in fluid content within the bladder. Conversely, when the bladder is emptied, either voluntarily or involuntarily, the impedance value should rise again as the bladder returns to a state of reduced volume. To ensure accuracy, it's crucial to give the body a little time to reestablish mechanical stability after urinating before taking measurements. At the 90-minute mark, when the subject is scheduled to urinate, a 10-minute delay is incorporated before taking the measurement. This gives a more realistic depiction of the bladder's condition by allowing any remaining movement or variations in bladder volume to stabilise. You can reduce the possibility of reading variations brought on by sudden post-voiding variations in bladder volume or bladder wall tension by waiting this short amount of time. This delay allows for mechanical stability to be regained by the body after voiding, ensuring that subsequent impedance measurements reflect the true state of the bladder volume. This experimental design not only evaluates the performance of carbon electrodes in tracking bladder volume changes but also considers factors such as mechanical stability and measurement accuracy. By analyzing impedance trends over the course of the experiment, we aim to assess the reliability and effectiveness of carbon electrodes for urinary bladder volume monitoring.

The results obtained from our experiments, as shown in Figure 4.5, were based on various human trials, denoted as 'HT' in the graph. We took readings across all individuals using varying frequencies, resistances, and current values. We chose frequencies ranging from 50kHz to 120kHz for impedance measurements, as frequencies lower than 50kHz often struggle to penetrate all layers of tissue, including skin, fat, and muscle, resulting in incomplete signal acquisition. Conversely, frequencies higher than 120kHz tend to exhibit a large signal-to-noise ratio (SNR), potentially affecting the accuracy of impedance measurements [12].

In determining the current and resistor values, we referred to existing literature studies, which commonly utilize resistor values of either 1k $\Omega$  or 10k $\Omega$  and current values of either 1mA or 10mA. These values have been established as effective parameters for impedance measurements in similar experiments [7].

We first applied these values in the balloon experiment to establish a baseline for impedance measurements. We then iterated through different combinations of frequency, resistance, and current to identify the most accurate and reliable settings.

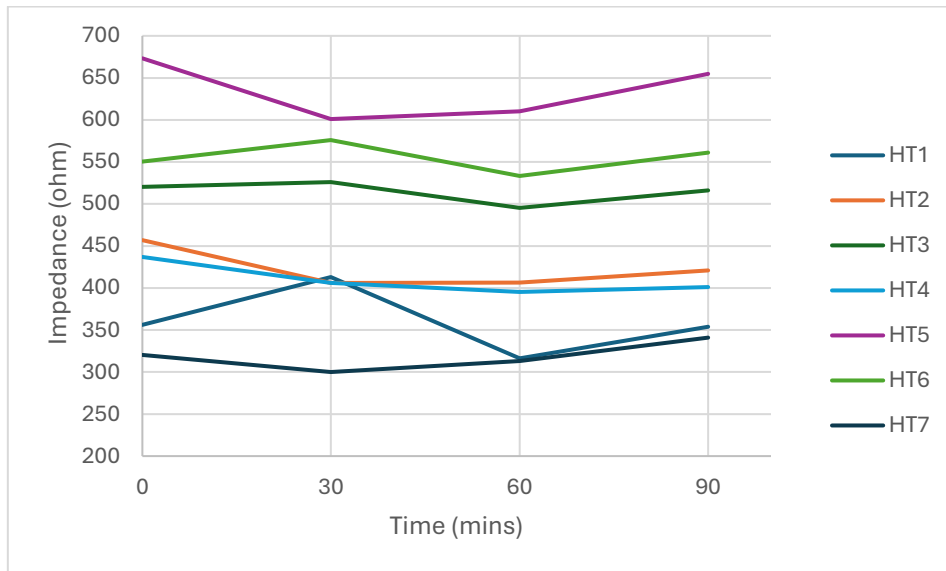
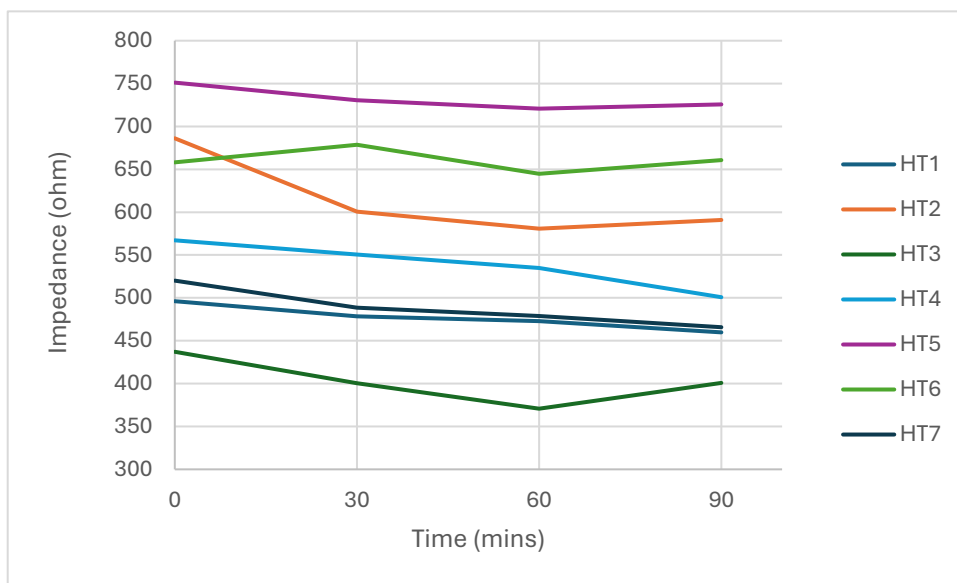
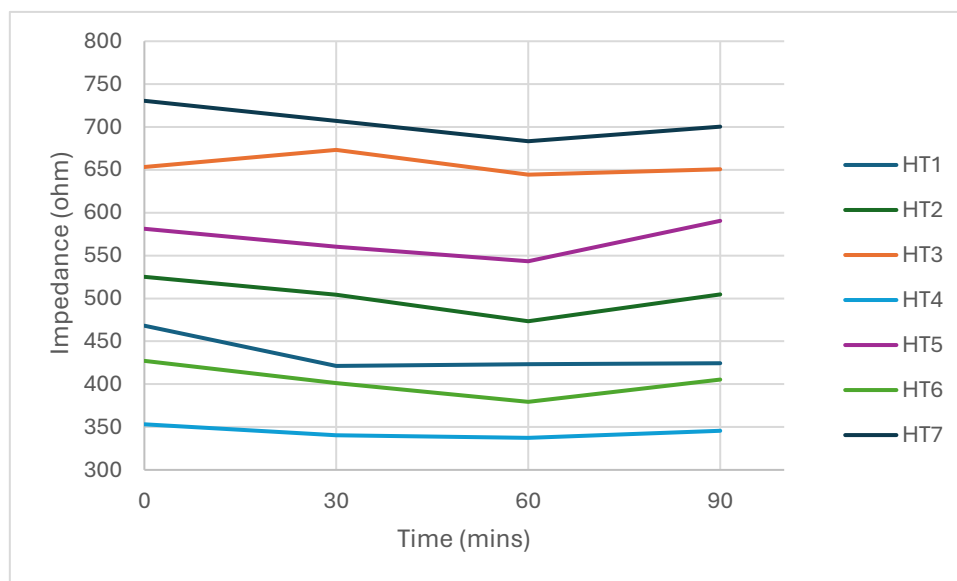


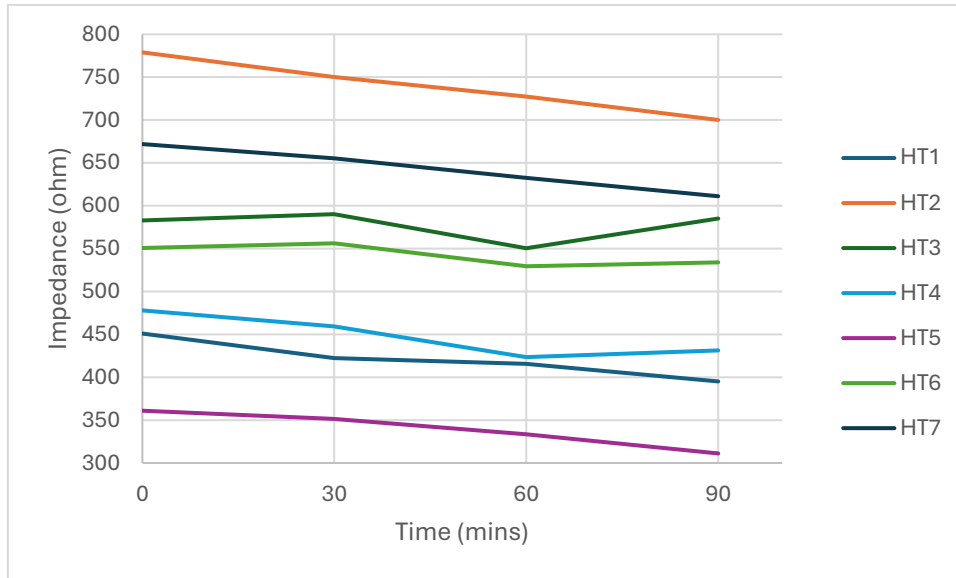
Fig 4.5: a) Impedance graph for 50-120kHz, 1mA, 1kΩ



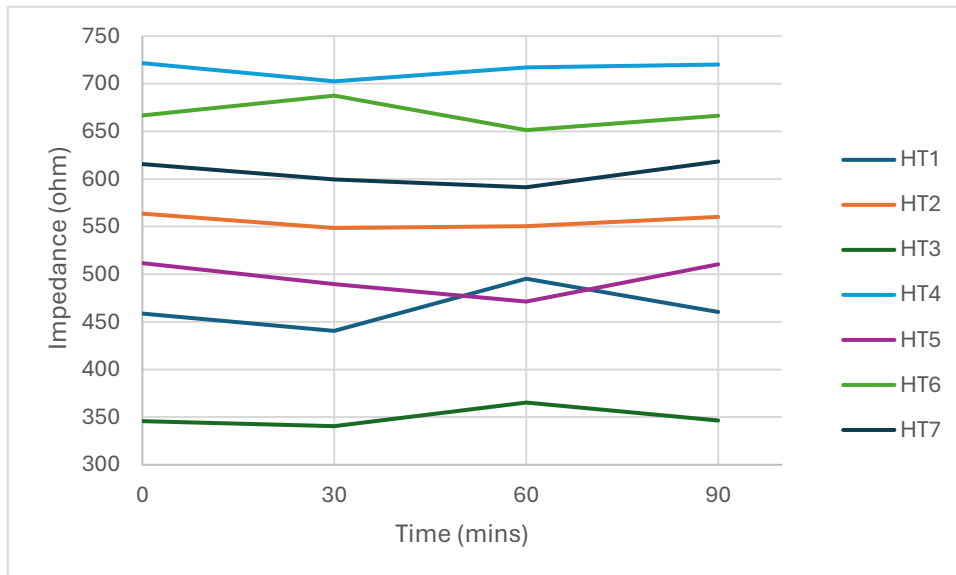
b) Impedance graph for 50-120kHz, 1mA, 10kΩ



c) Impedance graph for 50-120kHz, 10mA, 1kΩ



d) Impedance graph for 50-120kHz, 10mA, 10kΩ



e) Impedance graph for 97kHz, 10mA, 1kΩ

We choose a frequency of 97kHz for impedance measurement due to its ability to exhibit the largest change in impedance values over time. By analyzing the impedance graph, we observed distinct patterns that supported this decision. Specifically, we noted that at the beginning (0<sup>th</sup> minute) and end (90<sup>th</sup> minute) of the experiment, corresponding to an empty bladder, the impedance values remained constant. This consistency suggests that the bladder volume remained unchanged throughout this period.

However, at the 30<sup>th</sup> and 60<sup>th</sup>-minute marks, corresponding to intermediate bladder volumes, we observed noticeable changes in impedance values. These fluctuations indicate variations in bladder volume over time, reflecting the dynamic nature of bladder filling and emptying processes. The observed changes in impedance values provide valuable insights into the temporal dynamics of bladder volume changes and underscore the importance of selecting an appropriate frequency for impedance measurement.

By selecting 97kHz, we optimized our ability to capture these dynamic changes in impedance values, enabling us to monitor bladder volume fluctuations with precision and accuracy. This frequency offers a balance between sensitivity to changes in bladder volume and practical considerations such as signal-to-noise ratio and measurement stability.

## 4.5 Ag/AgCl electrodes measurement

We followed the same experimental protocol outlined in Section 4.4 for the measurement of Ag/AgCl electrodes, mirroring the procedures conducted with carbon electrodes. This involved conducting experiments with bladders in varying states – empty, half-filled, and full – to assess impedance measurements under different bladder volume conditions. The consistency of the electrode placement and measurement methodology ensured comparability between the results obtained with Carbon and Ag/AgCl electrodes.

During the experiments, we systematically varied the frequency, resistor, and capacitor values to explore their impact on impedance measurements. This approach enabled us to investigate the sensitivity of impedance measurements to changes in experimental parameters and evaluate the performance of Ag/AgCl electrodes across a range of conditions.

The results obtained from these experiments provide a comprehensive dataset, encompassing impedance measurements recorded at different frequencies, resistor values, and current settings. By analyzing these results, we gain valuable insights into the electrical behaviour of the bladder and the performance characteristics of Ag/AgCl electrodes for bladder volume monitoring.

The detailed examination of impedance measurements under varying experimental conditions offers critical information for optimizing measurement techniques and improving the accuracy and reliability of bladder volume monitoring methods. These findings contribute to the advancement of non-invasive approaches for assessing bladder function and diagnosing urinary disorders.

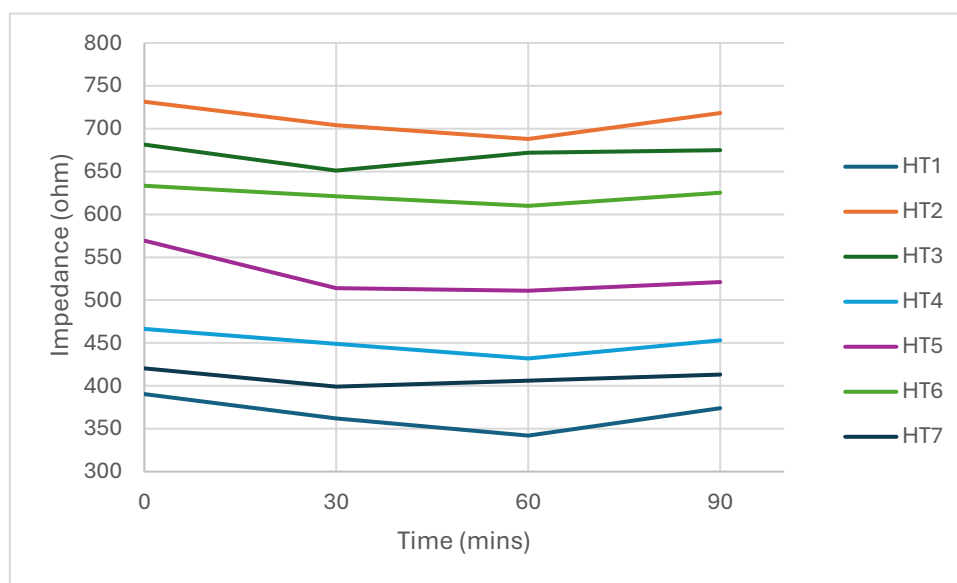
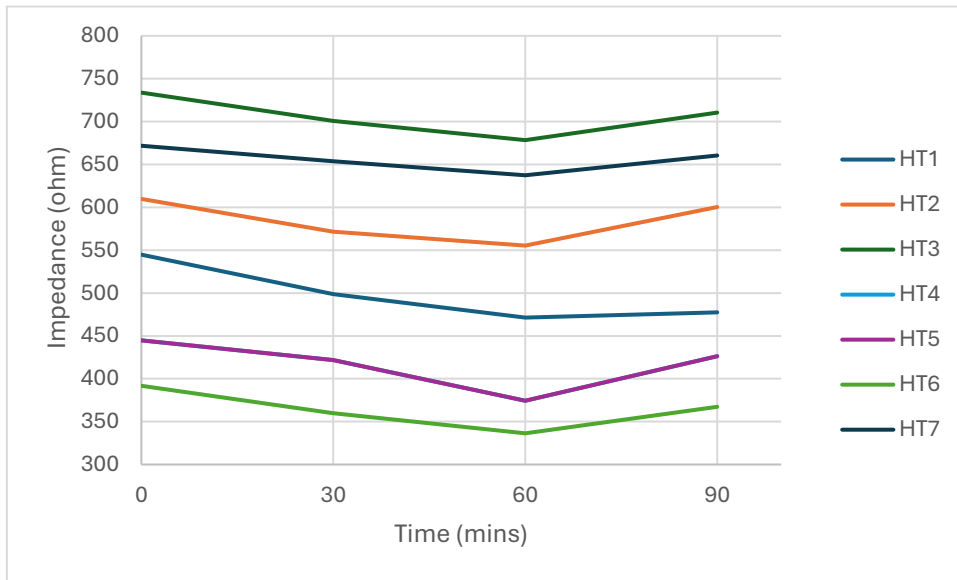
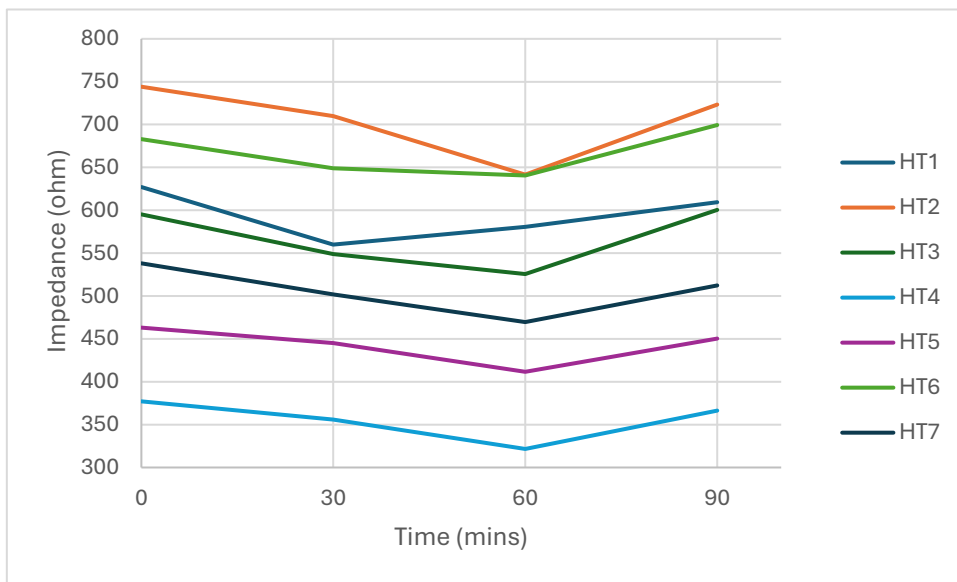


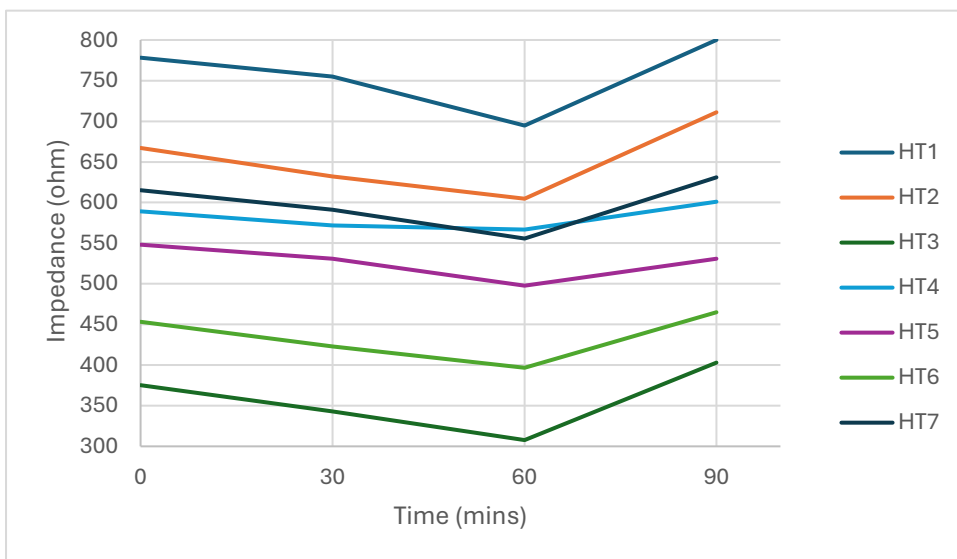
Fig 4.6: a) Impedance graph for 50-120kHz, 1mA, 1kΩ



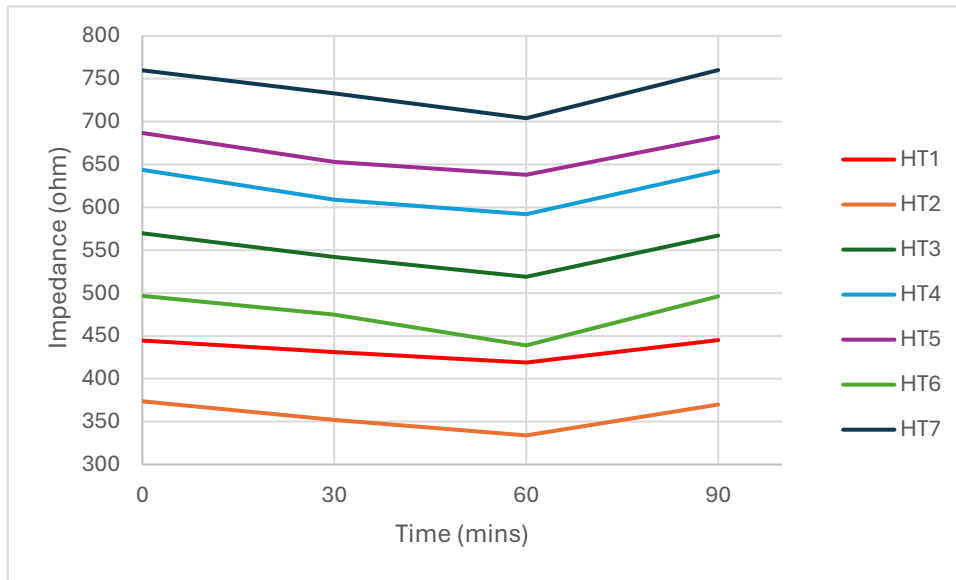
b) Impedance graph for 50-120kHz, 1mA, 10kΩ



c) Impedance graph for 50-120kHz, 10mA, 1kΩ



d) Impedance graph for 50-120kHz, 10mA, 10kΩ



e) Impedance graph for 97kHz,10mA,1kΩ

## 4.6 Difference between Carbon and Ag/AgCl electrodes

The impedance graph obtained with Ag/AgCl electrodes demonstrates consistent and expected patterns compared to Carbon electrodes. Over time, the impedance graph with Ag/AgCl electrodes exhibits minimal fluctuations, indicating stable and reliable measurements. Additionally, the signal-to-noise ratio remains low throughout the experiment, suggesting accurate and precise impedance readings.

Specifically, the impedance values for Ag/AgCl electrodes show a clear distinction between an empty bladder and a full bladder, with high impedance observed during an empty bladder and low impedance during a full bladder. This consistent and predictable response aligns well with our expectations and demonstrates the effectiveness of Ag/AgCl electrodes in capturing changes in bladder volume.

In contrast, the impedance graph with Carbon electrodes may exhibit more variability over time, and the signal noise level could be higher. While both electrode types show similar trends in impedance changes corresponding to bladder volume variations, the performance of Ag/AgCl electrodes appears to be superior in terms of stability and signal quality. Based on these observations, we can tentatively conclude that Ag/AgCl electrodes offer advantages over Carbon electrodes for urinary bladder volume monitoring. However, to confirm these findings and further validate the superiority of Ag/AgCl electrodes, additional experimentation in the actual circuit is warranted.

Moving forward, we plan to integrate Ag/AgCl electrodes into the actual circuit and assess their performance in real-world scenarios. By doing so, we aim to validate our preliminary findings and draw definitive conclusions regarding the effectiveness of Ag/AgCl electrodes for non-invasive bladder volume monitoring.

## 4.7 Circuit Implementation

After determining that a frequency of 97kHz yields optimal results for impedance measurement, we proceeded to generate a sine wave of the required frequency using Arduino. This involved programming the Arduino microcontroller to generate a precise sinusoidal waveform with a frequency of 97kHz.

Once the sine wave was generated, we established connections from the Arduino to the AD9833, a waveform generator module capable of producing high-frequency signals. The connections were made according to the specifications provided by the AD9833 datasheet and the circuit diagram depicted in the figure below.

The Digilent waveform software was then utilized to confirm the successful generation of the 97kHz frequency using Scope mode. This software allowed us to monitor the waveform output and verify that the desired frequency was being generated accurately by the Arduino-AD9833 setup.

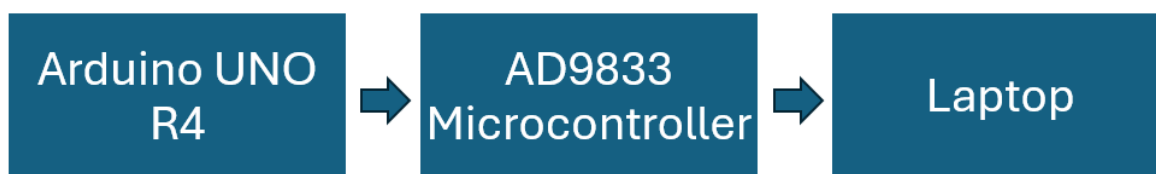


Figure 4.7: Block Diagram of the Circuit implementation in Proteus design software

The figure 4.7 below illustrates the original experimental setup implemented in the real world. Through the integration of Arduino and the AD9833 waveform generator module, we successfully achieved the generation of a precise 97kHz signal which is shown in figure 4.8. This setup served as the foundation for our impedance measurement system, enabling accurate and reliable data acquisition for our research.

The Arduino microcontroller was programmed to generate the sinusoidal waveform with the desired frequency of 97kHz. This frequency was selected based on our earlier findings, which identified it as optimal for impedance measurement in our experiments. The AD9833 waveform generator module, coupled with Arduino, facilitated the generation of this high-frequency signal with precision and stability.

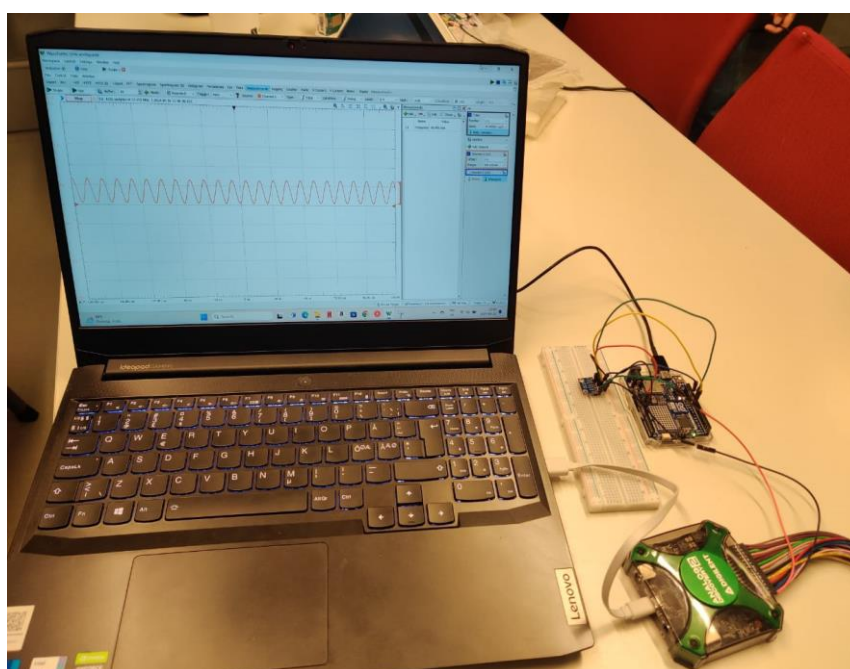


Figure 4.8: Real world setup for generation of 97kHz

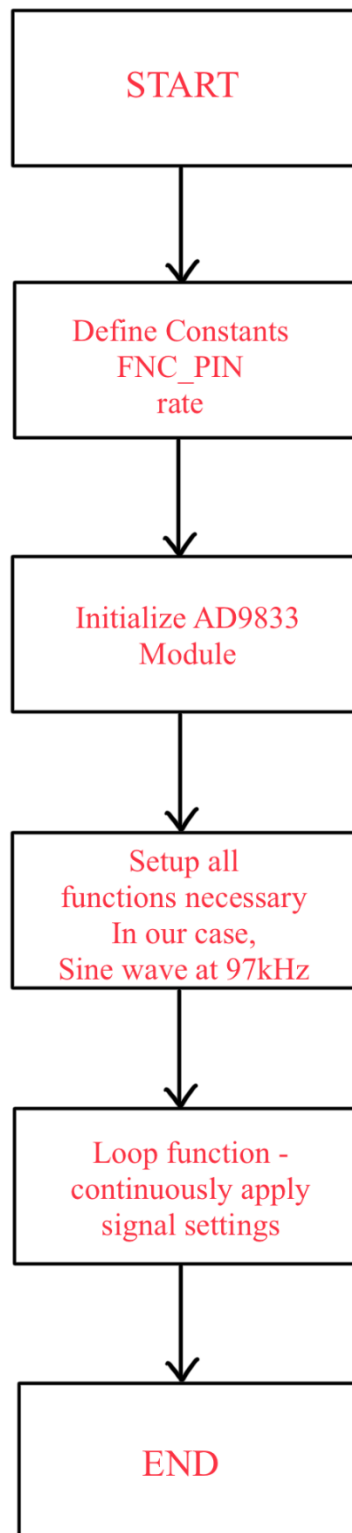


Figure 4.9: Flowchart of the code used in the Arduino program for 97kHz signal generation

The purpose of this flowchart is to generate a sine wave signal at a frequency of 97 kHz using the AD9833 waveform generator module. This setup is crucial for our impedance measurement experiments related to urinary bladder volume monitoring. This flowchart is a component of the experimental setup we used to determine the bladder's impedance. We were able to precisely track variations in bladder volume by producing a 97 kHz sine wave. Our impedance measurement tests depend on having a stable and dependable signal source, which is provided by the Arduino-controlled AD9833 module.

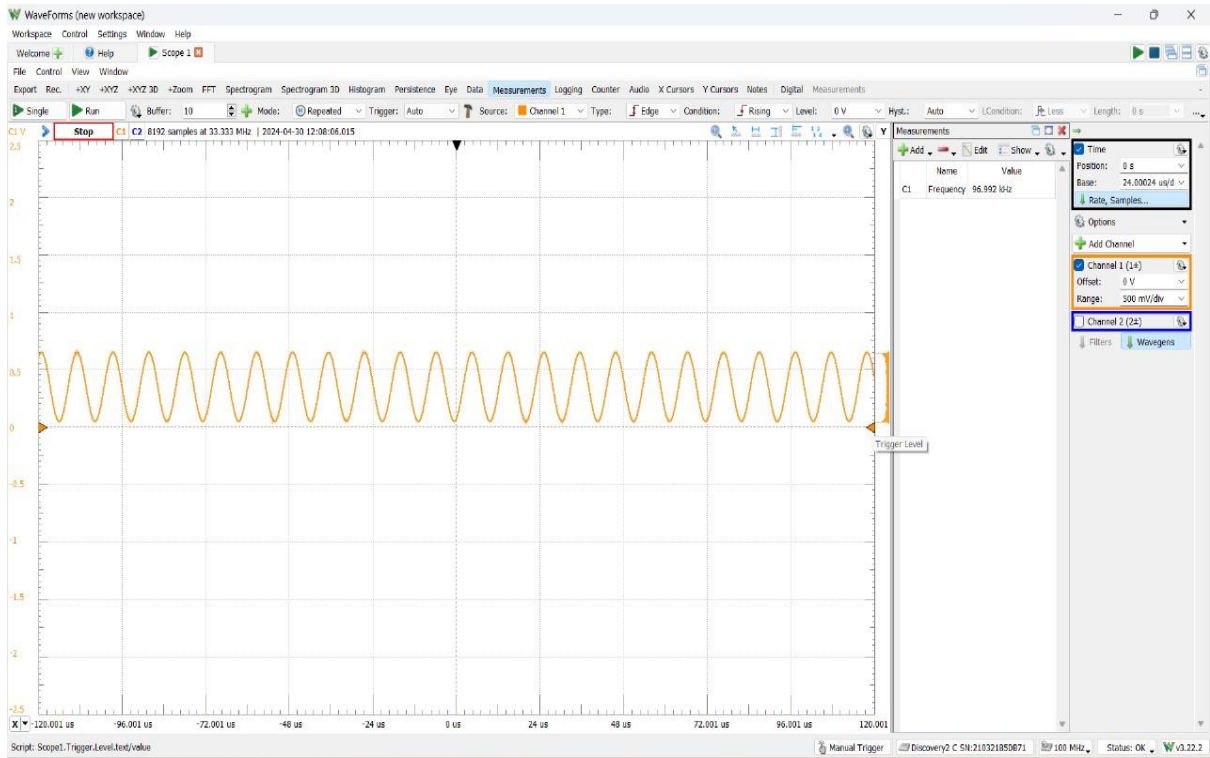


Figure 4.10: Sinusoidal wave signal generation at 97kHz by using the diligent waveform software

The above figure 4.10 illustrates the results obtained using the Digilent waveform software when generating a 97kHz frequency with the Arduino-controlled AD9833 and analyzing it with the impedance analyzer. As shown, the sine wave frequency achieved matches our intended target of 97kHz. This successful generation of the desired frequency is crucial for our impedance measurements of the urinary bladder. The consistency and accuracy of the 97kHz sine wave are essential, as they directly impact the reliability of the bladder volume measurements. The obtained sine wave demonstrated minimal noise and distortion, indicating that the setup is effective for producing the necessary signal for our experiments. Consequently, this setup proved to be reliable for capturing the impedance changes corresponding to different bladder volumes, thereby validating our approach for both the balloon and human subject experiments. This foundational step is critical as we move towards developing a wearable device for continuous bladder monitoring.

# Chapter 5

## Discussions and Future Work

In our initial experiments, we considered the use of four electrodes to enhance the accuracy of our measurements. However, we opted to begin with a simpler setup involving two electrodes. In this configuration, one electrode functions as the measurement electrode, capturing the impedance data, while the other serves as the excitation electrode, providing the necessary electrical stimulation.

To date, our measurements have been conducted exclusively on healthy individuals. This initial phase was crucial for establishing a baseline and validating our experimental setup. The data obtained from these subjects demonstrated expected patterns of impedance changes corresponding to varying bladder volumes.

As we move forward, our research will shift focus to include measurements from patients with urinary bladder problems and neurological disorders. This step is essential for assessing the effectiveness and reliability of our impedance measurement system in clinical scenarios. Patients with these conditions often experience different bladder dynamics compared to healthy individuals, which could significantly impact the impedance readings.

By including these patient groups in our study, we aim to:

**Validate our System:** Confirm that our impedance measurement system accurately reflects bladder volume changes in patients with medical conditions.

**Identify Patterns:** Observe any distinct impedance patterns specific to these conditions, which could inform more precise diagnostic or monitoring tools.

**Improve Clinical Relevance:** Ensure that our research has practical applications in medical diagnostics and patient care, particularly for those with bladder and neurological disorders.

Our next step in this research is to develop an attachable device that can be worn on the body to continuously monitor urinary bladder volume. This device aims to provide real-time alerts to patients when they need to urinate. The primary goal is to enhance patient comfort and autonomy, particularly for individuals with bladder control issues or those unable to sense bladder fullness due to neurological conditions.

To achieve this, we plan to integrate the impedance measurement system with a wireless communication module. The device will send alert messages to a patient's smartphone or a dedicated receiver when a predefined bladder volume threshold is reached. This alert system can significantly improve the quality of life for patients by preventing discomfort and potential complications arising from bladder overfilling.

In a hospital environment, this technology can also be immensely beneficial. For instance, the system can be configured to send alerts to a central monitoring station, allowing nurses and healthcare providers to receive notifications about the bladder status of multiple patients. Each alert can be associated with a specific bed number, enabling the medical staff to promptly assist patients who need to urinate. This feature can enhance patient care by ensuring timely interventions and reducing the risk of bladder-related complications.

Moreover, continuous monitoring and data logging can provide valuable insights into each patient's bladder behaviour over time. This information can be used to tailor individualized care plans, optimize fluid management, and improve overall treatment outcomes. The integration of such a system into hospital workflows can streamline patient management and reduce the burden on healthcare providers.

In summary, the development of a body-attached device for continuous urinary bladder volume monitoring represents a significant advancement in patient care. By providing timely alerts and facilitating better management of bladder health, this technology has the potential to improve patient well-being both in home and clinical settings.

Additionally, advancements in AI and machine learning could be leveraged to analyze the collected data, offering predictive insights and personalized health recommendations. Collaborations with interdisciplinary teams, including engineers, medical professionals, and data scientists, will be essential to refine the technology and ensure its efficacy and safety. Ultimately, the widespread adoption of this device has the potential to revolutionize bladder health management, offering significant benefits to patients and healthcare systems alike.

# Chapter 6

## Conclusion

In conclusion, our experiments demonstrated that Ag/AgCl electrodes are superior to carbon electrodes for measuring urinary bladder volume. The Ag/AgCl electrodes not only provided more accurate and reliable results but were also cost-efficient, making them a practical choice for this application. Through our experiments, we were able to observe significant changes in impedance values at different intervals, which allowed us to accurately track bladder volume changes.

Furthermore, we identified 97kHz as the optimal frequency for impedance measurements of the urinary bladder. This frequency provided the best results when tested with the impedance analyzer, ensuring minimal signal noise and maximum measurement accuracy. This discovery is critical for the development of a reliable and effective urinary bladder monitoring system.

Overall, our research indicates that using Ag/AgCl electrodes and a 97kHz frequency setting is the most effective approach for urinary bladder volume measurement. This finding lays a solid foundation for future work, including the development of wearable devices for continuous bladder monitoring, which can significantly enhance patient care and management both in clinical settings and at home.

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