Republic of Yemen
University of Science and Technology
Faculty of Engineering

# Body composition analyzer using multi-frequency bio-impedance technology

**Submitted by:**

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**Suhaib Mustafa Ismail**

**Final Year Project Submitted to The Department of Biomedical Engineering in Partial Fulfillment of the Requirements for the Award of Bachelor of Science Degree in Biomedical Engineering**

**Supervised by:**
**Dr. Hamdi Ghazi**

**Sana'a**
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أعوذ بالله من الشيطان الرجيم

بسم الله الرحمن الرحيم

(أَنِ اعْمَلْ سَابِغَاتٍ وَقَدِّرْ فِي السَّرْدِ وَاعْمَلُوا صَالِحًا إِنِّي بِمَا تَعْمَلُونَ بَصِيرٌ)

[سبأ:11]

## إهداء

اللهم لك الحمد حتى ترضى ولك الحمد اذا رضيت ولك الحمد في الأولى والاخرة وانت على كل شيء قدير.

الى من أدى الأمانة وبلغ الرسالة ونصح الامة ... الى سيد ولد آدم محمد صل الله عليه وسلم

الى أباءنا وأمهاتنا وإخوننا وأهلينا. فهم سبب في نجاحنا بعد الله

الى أسرتنا الثانية. زملاءنا في التعليم الجامعي

الى أباءنا الكادر التعليمي في جامعة العلوم والتكنولوجيا

واخص منهم الاب والمربي الدكتور حمدي غازي

والاخ الأستاذ المهندس زايد الحاج

وكما نخص لجنة مناقشة المشاريع

الى أوطاننا الغالية. اليمن والوطن العربي والإسلامي

الى كل من يبحث عن المعرفة في ثنايا هذه الأوراق

نهدي لهم هذا البحث

# Declaration

We, Suhaib Al-Qudsi, Maher Al-Zoriqi, Muhammad Al-Ashwal, and Hani Al-Kameem, declare that this graduation project titled “Body composition analyzer using multi-frequency bio-impedance technology” submitted to fulfillment of the requirements for the degree of Bachelor, in Biomedical Engineering, University of Science and Technology, is wholly my own work unless otherwise referenced or acknowledged. This document has not been submitted for qualifications at any other academic institution.

Suhaib Mustafa Ismail
Maher Ahmed Al Zoriqi
Mohammed Yahya Al-Ashwal
Hani Fayez Al-Kumaim

May 2021

# Acknowledgment

First and foremost, all thankfulness to Allah, the Beneficent, the Merciful, the One, on who all depend, and none is like Him. Allah, who helps and guides me to overcome the challenges during my study and my life.

Sincere gratitude and many thanks must be expressed to:

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- Our advisors for their inspirational leadership and advices.
- All our colleagues at the Biomedical Engineering Department for the valuable discussions during all these years.

# Abstract

Due to body composition was directly related to health, so changing body composition can greatly increase your risk, as excess fat is associated with an increased risk of cardiovascular disease and metabolic syndrome, and a higher BMI is associated with the risk of developing type 2 diabetes , High blood pressure due to an increase in obesity in more people As well as fluids and body mass, which can be a crucial assessment tool for your health condition. Also, with the widespread lack of concern for many people in their health, lack of interest in the nutritional balance in our country, and the increase in the prevalence of malnutrition in our country and heart disease related to obesity and fat. We have developed an inexpensive, portable device that uses a multi-frequency bio-impedance analysis to measure fat, fluid, and body mass. It is easy to use and non-invasive to allow early detection of the improper balance in human body composition, which promotes early intervention and prevention of disease and the care of your health.

الملخص

نظرا لارتباط مكونات الجسم مباشرة بالصحة وذلك عند التغير في تكوين الجسم بالاتجاه السلبي يمكن ان يسبب الكثير من الامراض مثل في حالة زيادة الدهون يزداد خطر الاصابة بأمراض القلب والاوعية الدموية والسكري وغيرها وهذا ما تشير اليه كثير من الدراسات وفي حالة تغير نسبة الماء في الجسم وكتلة خلايا الجسم وغيرها من مكونات الجسم الاساسية ولذا تشخيص هذه المكونات مهم لتقييم الحالة الصحية وخصوصا انتشار عدم الاهتمام عند كثير من الناس بصحه البدنية وعدم الاهتمام بالتوازن لمكونات الجسم لذلك زاد انتشار سوء التغذية وامراض القلب والكلى والدهون .لذلك قمنا بتطوير جهاز محمول يستخدم تقنية تحليل المقاومة الحيوية متعددة التردد لقياس كتلة الدهون والكتلة الخالية من الدهون وكمية الماء وكتلة خلايا الجسم وكتلة العضلات يكون سهل الاستخدام وغير جراحي ورخيص الثمن للسماح بالكشف المبكر عن الاختلال في توازن مكونات الجسم مما يعزز التدخل المبكر والوقاية من الامراض و الحفاظ على صحة الجسم .

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# List of Abbreviations

| | |
|---|---|
| WHO | World Health Organization |
| BMI | Body Mass Index |
| DM | Diabetes Mellitus |
| COPD | Chronic Obstructive Pulmonary Disease |
| BCM | Body Cell Mass |
| SMM | Skeletal Muscle Mass |
| FFM | Fat-Free Mass |
| TBW | Total Body Water |
| ICW | Intracellular Water |
| ECW | Extracellular Water |
| SVF | Stromal Vascular Fraction |
| WAT | White Adipose Tissue |
| VAT | Visceral Adipose Tissue |
| BAT | Brown Adipose Tissue |
| TBP | Total Body Potassium |
| BMC | Bone Mass Cell |
| CT | Computed Tomography |
| DXA | Dual X-Ray Absorptiometry |
| MRI | Magnetic Resonance Imaging |
| BIA | Bioelectrical Impedance Analysis |
| AC | Alternating Current |
| DC | Direct Current |
| BIVA | Bioelectrical Impedance Vector Analysis |
| SF-BIA | Single Frequency Bioimpedance Analyze |
| MF-BIA | Multi-Frequency Bioimpedance Analyze |
| BIS | Bioimpedance Spectroscopy |
| TUS | Tissue Under Study |
| ADC | Digital Signal Convert |
| VCCS | Voltage Controlled Current Source |
| DDS | Direct Digital Synthetics |

# Chapter 1

# Introduction

## 1.1 Introduction

The analysis of body composition is a method that provides information on the components of different body tissues and these basic components of cells in tissues such as fat mass, free fat mass, total body water, and muscle mass are important to monitor the health of the body and monitor many common diseases before they occur and also at times of their occurrence such as obesity and poor Nutrition and monitoring the body's immunity in a long time and other diseases because the analysis of body composition is the most representative of the functional state.

## 1.2 Problem statement

High body fat increases the risk of chronic diseases, including heart problems, diabetes, and cancer. In recent World Health Organization (WHO) described obesity as an epidemic hazard worldwide, based on the data analysis of body mass index (BMI). Since then, obesity incidence has increased at an alarming rate and is becoming a major public health concern. Indeed, obesity facilitates the development of metabolic disorders (e.g. diabetes, hypertension), and cardiovascular diseases in addition to chronic diseases (e.g. stroke, osteoarthritis, sleep apnea, cancers, and inflammation-based pathologies) [1].

According to the Global Burden of Disease study 4.7 million people died in 2017 as a result of obesity. To put this into context: this was close to four times the number that died in road accidents and close to five times the number that died from HIV/AIDS in 2017 Global Burden of Disease (Study 2017 (GBD 2017) Results. Seattle, United States: Institute for Health Metrics and Evaluation (IHME), 2018) [2].

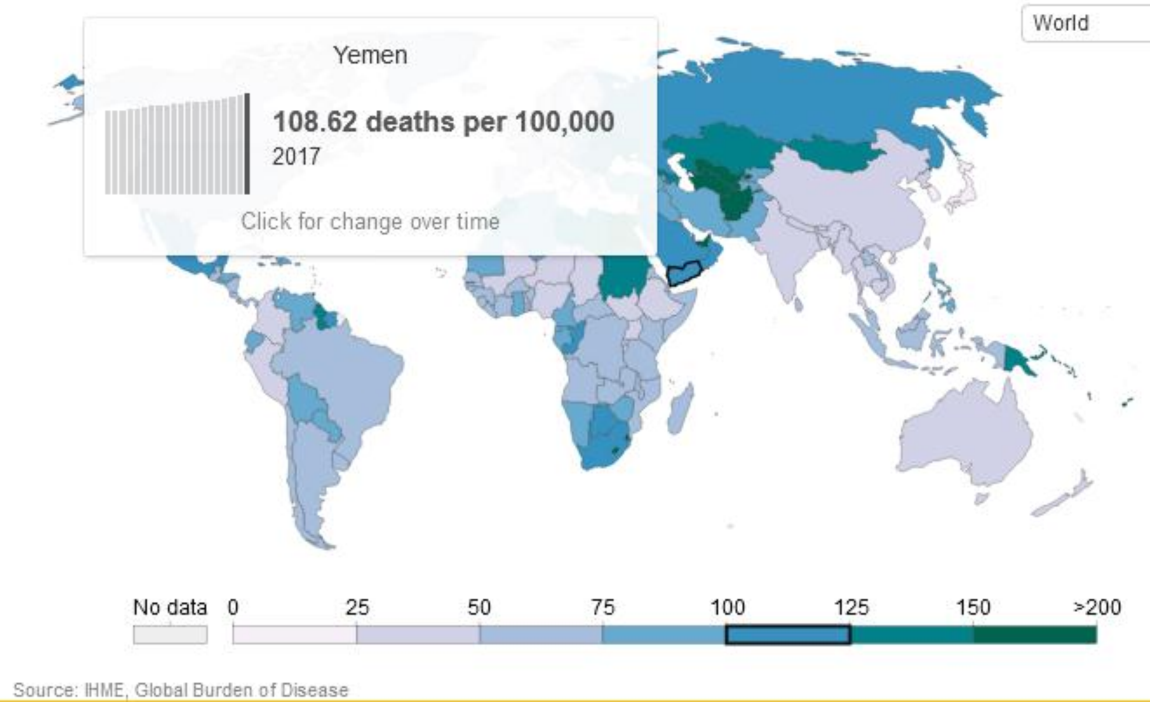



Figure 1.1:explain Death rate from obese in 2017 Premature deaths attributed to obesity per 100,000 individuals . Obesity is defined as having a body-mass index (BMI) equal to or greater than 30.

Also, the prevalence of diabetes mellitus (DM) is rapidly increasing worldwide, with 592 million people expected to have the condition by 2025 ( UNICEF/WHO/World Bank (2018)). As such, the prevention and management of DM have become a crucial public health concern with an emphasis on addressing modifiable risk factors, such as poor diet, sedentary lifestyle, and obesity class 2 [3]. Also, the amount of body water is one of the basic body composition, so in case of decrease of a percent of water in the body, it causes dehydration according to the percentage of deficiency, for example, mild dehydration, which equates to about 1%, can cause symptoms such as thirst, headache, weakness, dizziness, and fatigue, and when a lack of fluids of 4% or more can be observed a decrease Severe performance plus difficulty concentrating, headache, irritability, drowsiness, high body temperature, and breathing rates. Dehydration that causes a loss of 10% or more of human body weight can be fatal [4-6].

Survival studies have consistently shown significantly greater mortality rates in underweight and normal-weight patients with chronic obstructive pulmonary disease (COPD) than in overweight and obese COPD patients. [Global Initiative for Chronic Obstructive Pulmonary Disease (GOLD) stages II-IV southern part of the Netherlands [7, 8].

## 1.3 The main objective:

The main objective of the project is to design a device Body composition analyzer using multi-frequency bio-impedance technology that can be use in clinical diagnosis status. It is inexpensive and portable and high safety.

## 1.4 Partial goals.

- Design circuit a device that Body composition analyzer using multi-frequency bio-impedance technology
- Simulation a device Body composition analyzer using multi-frequency bio-impedance technology by using LabVIEW program.
- Design an Android application to display results with advancing medical advice.
- Implement the hardware circuit.
- Testing the results of the device.
- Comparing the value of the results with the reference standard.

# Chapter 2

# Medical and Engineering background

## 2.1 Introduction

This chapter introduces the main concepts of medical and engineering background to body composition. In addition, the body composition define and parts , techniques for diagnosing body composition ,theories measures are explained. The chapter is organized as follows. Section 2.2 discusses Medical background. section 2.3 explains Engineering background include principle Bioelectrical Impedance Analysis technique and methods measures by its . Finally, section 2.4 explain summary chapter.

## 2.2 Medical background

In this section, include body composition define and parts, the pathologies , techniques for diagnosing , properties electrical tissue . organized as follows. Section 2.2.1 explains body composition . Section 2.2.2 explains electrical properties of biological Tissue . Section 2.2.3 talks about the pathologies . Section 2.2.4 discusses the techniques diagnosis body composition.

### 2.2.1 Body composition

The study of human body composition can be defined as a branch of human biology, which mainly focuses on the in vivo quantification of body components, the quantitative relationships between components, and component alterations related to various influencing factors.

Body composition describes the relative proportions of FM, FFM include many in divide that explain above. The body composition rule area organizes the more than 30 main body components into five distinct levels of increasing complexity: atomic, molecular, cellular , tissue system, and whole body as in the following figure (2-2) [9, 10] .

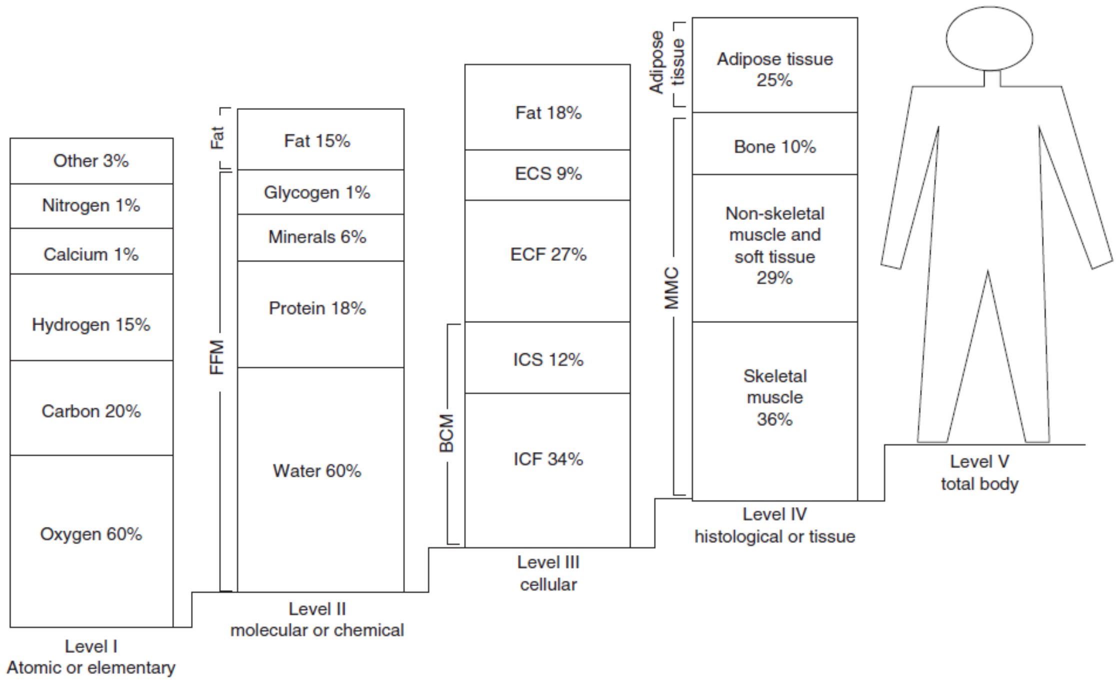



Figure 2.1:multicompartmental or five-level model of body composition.[11].

Body composition assessment is considered a key factor for the evaluation of general health status of humans. Several methods use different assumptions to estimate body composition based on the number of compartments. The two-component or bicompartmental model is the most commonly used to analyze body composition in humans. This model assumes the division of body components into two compartments, total fat mass and fat-free mass, that is, the consideration of the two compartments at the molecular level . According to this model, the chemical characteristics and density of both compartments remain constant, with density for total fat mass being 0.9007g/mL at a temperature of 36°C.11 According to this model, total fat mass is anhydrous, although its degree of hydration in healthy adults is 13%, as will be seen later. Fat-free mass has a density of 1.1000g/mL at a temperature of 36°C12 and a water content of 73%, notably including a potassium concentration of 150mequiv./L[11] .

FFM is composed of bone minerals and body cell mass (BCM) that includes skeletal muscle mass (SMM). BCM contains proteins and TBW that represents 73% of lean mass in normal hydrated subjects. [11, 12] as show figure (2.2) and anatomy model part of body composition show figure (2.3) with body composition of chemical model show figure (2.4).

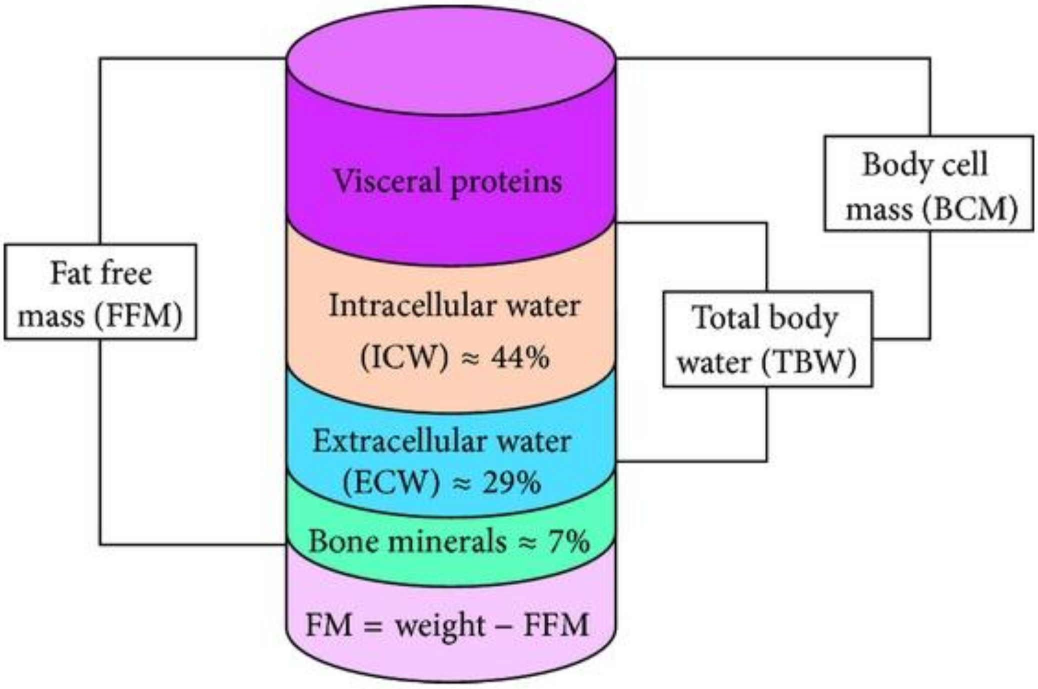



Figure 2.2:Schematic diagram of fat-free mass (FFM), male. [7] total body water (TBW), intracellular water (ICW), extracellular water (ECW) and body cell mass (BCM) [13].

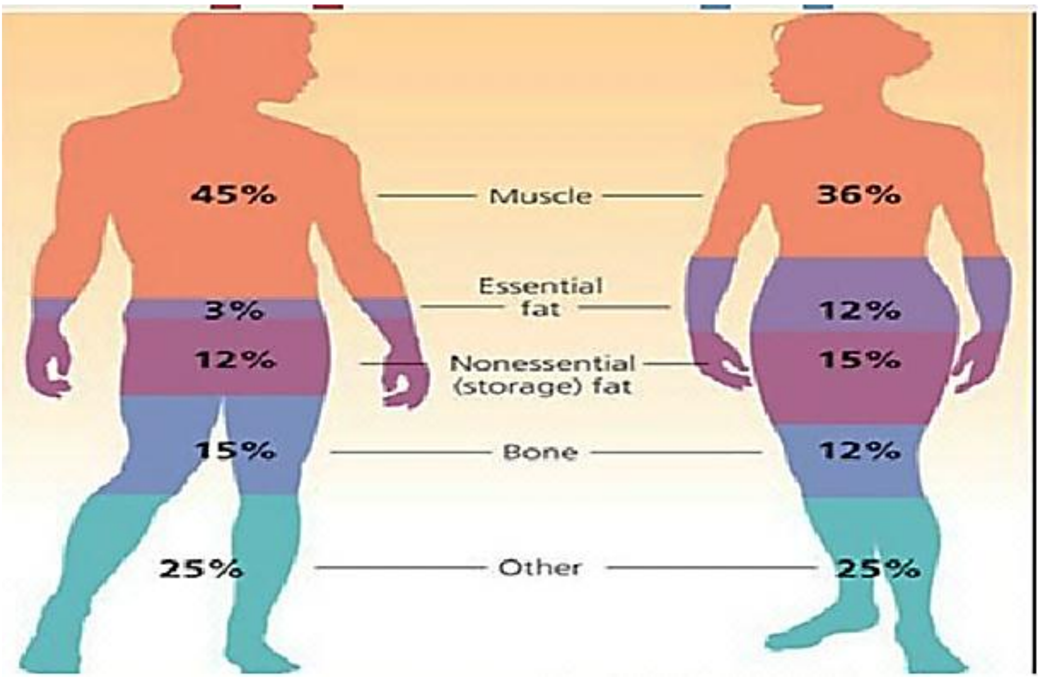



Figure 2.3:The anatomy model part of body composition

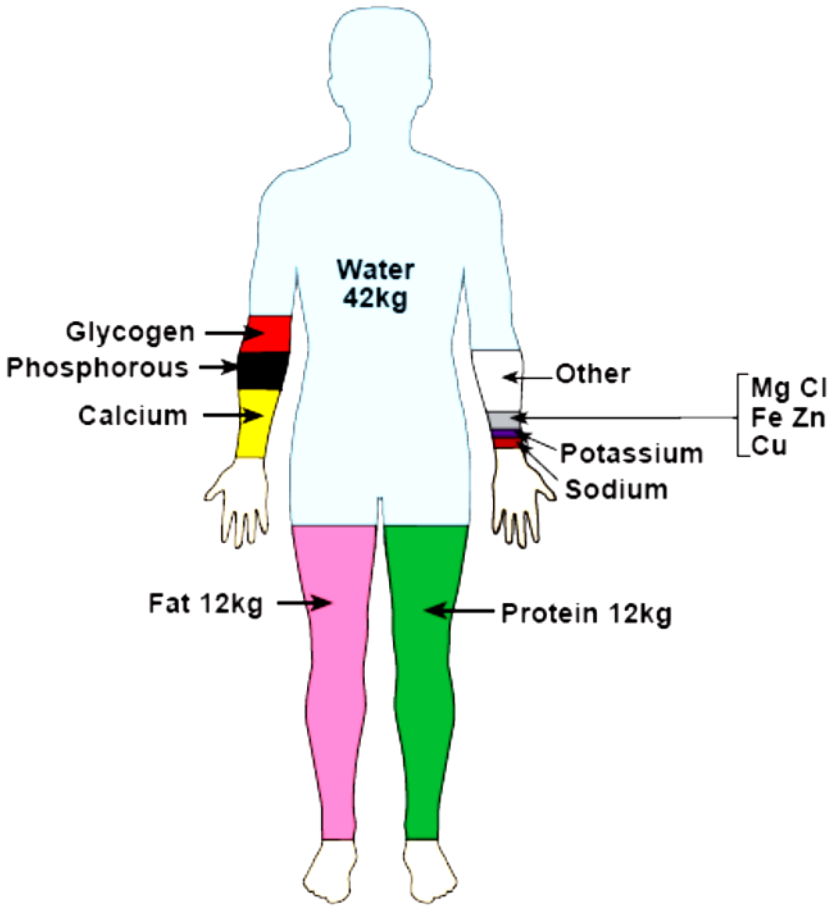



Figure 2.4:Body Composition of chemical model [13].

Discussing body composition should be the cell component then discussing 2-model body composition from fat mass and free fat mass as following :

#### 2.2.1.1 Cell components

Not all parts of the body are made from cells. Cells find in an extracellular form matrix that consists of proteins such as collagen, surrounded by extracellular fluids of the 70 kg (150 lb) weight of an average human body, nearly 25 kg (55 lb) is non-cellular material such as bone and connective tissue. Each cell in the body is surrounded by a cell membrane made of fats [14]. The cells contain intracellular fluid, abbreviated ICF (also called ICW for intracellular water ). The Cells is the microscopic fundamental unit that makes up all living things and have some components important : Cell Membrane is boundary of the cell, sometimes called the plasma membrane is a double layer of fats and proteins that surrounds a cell Cytoplasm: a water-like substance that fills cells and separates the contents of the cell from the external environment. The cytoplasm consists of cytosol and the cellular organelles, except the cell nucleus , as mitochondria, plastides , lumen of endoplasmic reticulum, etc.) .The cytosol is made up of water, salts, organic molecules and many enzymes that catalyze reactions. The cytoplasm holds all of the cellular organelles outside of the nucleus, maintains the shape and consistency of the cell, and serves as a storage place for chemical substances. Cytoskeleton: made of threadlike proteins, helps cells maintain their shape and allows cells and their contents to move between cell [15]. This components cell show figure (2.5)

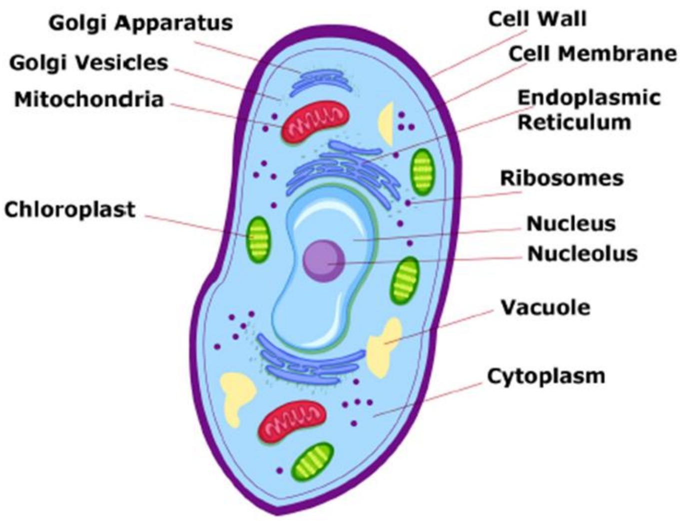



Figure 2.5:anatomy of cell

### 2.2.1.2 Body Fat

Body Fat Percentage is the proportion of fat to the total body weight. Body Fat Mass is the actual weight of fat in human body, essential for maintaining body temperature, cushioning joints and protecting internal organs, so will discussing Lipids structure and Adipose tissue of fat mass.

- Lipids Structure

Structure and properties of two representative lipid. Both stearic acid (a fatty acid) and phosphatidylcholine (a phospholipid) are composed of chemical groups that form polar “heads” and nonpolar “tails.” The polar heads are hydrophilic, or soluble in water, whereas the nonpolar tails are hydrophobic, or insoluble in water. Human fat tissue contains about 87% lipids [16]. structure as show figure (2.6).

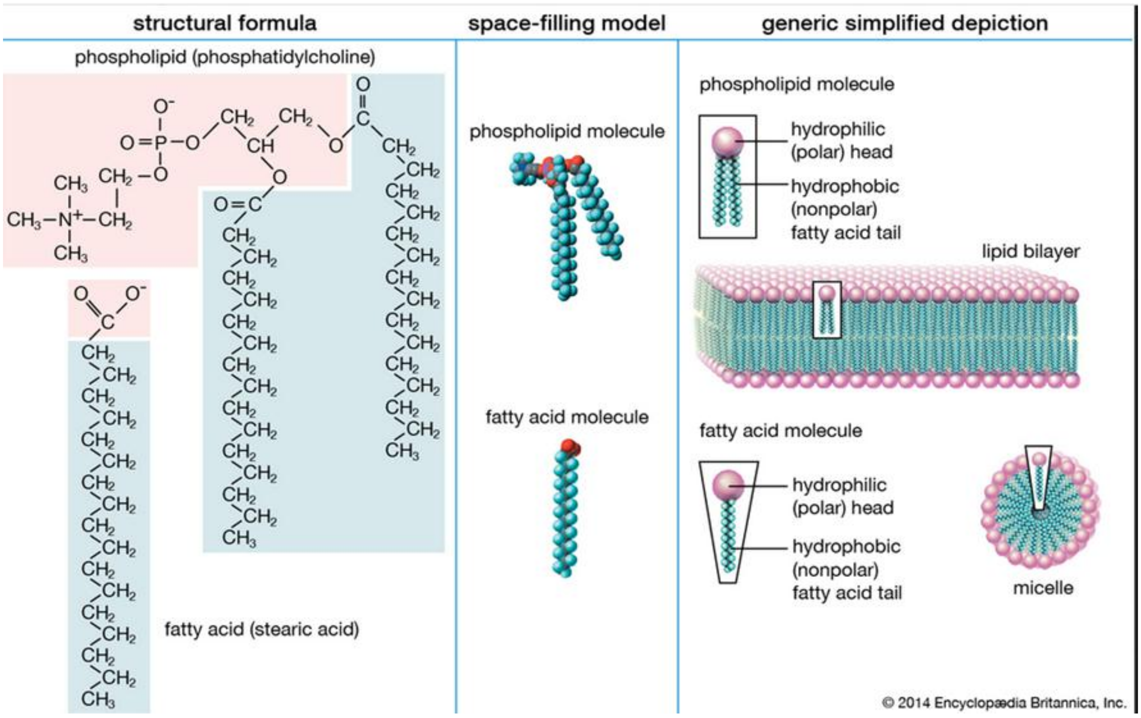



Figure 2.6:lipid structure anatomical and chemical

- Fat Mass or Adipose Tissue

The word "adipose" comes from the Latin origin: adeps, adip- "fat" Adipose tissue, body fat is a loose connective tissue composed mostly of adipocytes , adipose tissue contains the stromal vascular fraction (SVF) of cells including preadipocytes, fibroblasts, vascular endothelial cells and a variety of immune cells such as adipose tissue macrophages . Adipose tissue is derived from preadipocytes Its main role is to store energy in the form of lipids, although it also cushions and insulates the body Far from being hormonally inert. Adipocytes, also known as lipocytes and fat cells, are the cells that primarily compose adipose tissue, specialized in storing energy as fat. Adipocytes are derived from mesenchymal stem cells which give rise to adipocytes through adipogenesis. adipose tissue is located : beneath the skin (subcutaneous fat), around internal organs (visceral fat), in bone marrow (yellow bone marrow), intermuscular (Muscular system) and in the breast (breast tissue). Adipose tissue is found in specific locations, which are referred to as adipose depots and show structure figure (2.7) .

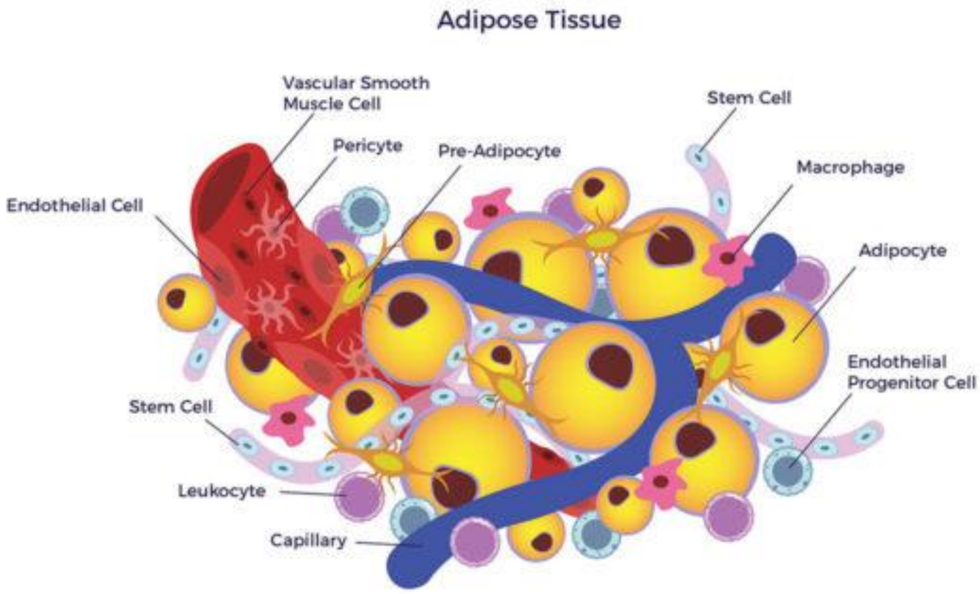



Figure 2.7: anatomy Adipose tissue.

Adipose tissue works As a fuel reserve and helps maintain body heat. Fat cells secrete fatty acids, which can be used by muscles and other tissues as a source of energy. Brown cells use the secretion of fatty acids by the cells' mitochondria to generate heat. Fat cells also synthesize and secrete a complex of fatty acid substances called prostaglandins (for example, prostaglandins), which have various hormone-like actions such as inhibiting the breakdown of fats, and a protein hormone called leptin, which plays a role in regulating metabolism, body weight, and reproductive function and divide the adipose tissue to two types :

### A.1 White Adipose Tissue (WAT)

White fat cells contain a single large lipid droplet surrounded by a layer of cytoplasm, and are known as unilocular. The nucleus is flattened and pushed to the periphery. A typical fat cell is 0.1 mm in diameter with some being twice that size, and others half that size. The fat stored is in a semi-liquid state, and is composed primarily of triglycerides, and cholesteryl ester. White fat cells secrete many proteins acting as adipokines such as resistin, adiponectin, leptin and apelin. An average human adult has 30 billion fat cells with a weight of 30 lbs or 13.5 kg. If excess weight is gained as an adult, fat cells increase in size about fourfold before dividing and increasing the absolute number of fat cells present and explain structure in figure (2.8).

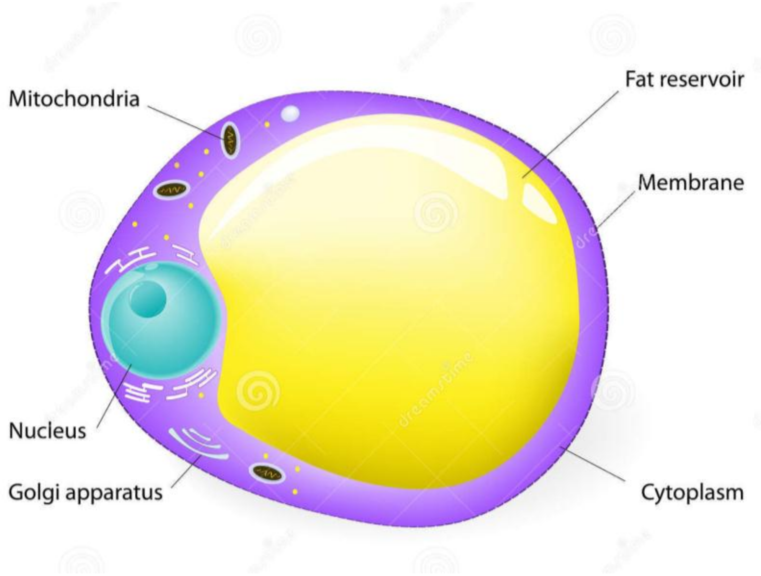



Figure 2.8:White Adipose Tissue (WAT) .

Subcutaneous White Adipose Tissue (WAT) store ~80-90% of total body fat, mainly in the abdominal (around the waist), subscapular (on the upper back), gluteal and femoral (thigh) areas. These subcutaneous adipose tissues have distinct morphological and metabolic profiles and exhibit sex-specific differences in size and function. WAT represents around 15-30% of body weight, and in obese individuals it increases up to 50%. WAT contain a single large droplet, with few mitochondria. Subcutaneous fat is found directly under the skin. Visceral Adipose Tissue (VAT) is found underneath abdominal muscles, around organs, heart, liver and pancreas.

### A.2 Brown Adipose Tissue (BAT)

Brown fat cells are polyhedral (a three-dimensional shape with flat in shape. Unlike white fat cells, these cells have considerable cytoplasm, with several lipid droplets scattered throughout, and are known as multilocular cells. The nucleus is round and, although eccentrically located, it is not in the periphery of the cell. The brown color comes from the large quantity of mitochondria. Brown fat, also known as "baby fat," is used to generate heat. Brown Adipose Tissue (BAT) is located mainly in the supraclavicular/dorsal cervical area and show its in figure (2.9) [17, 18] .

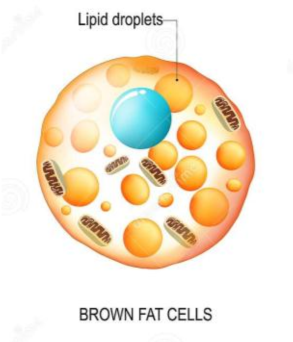



Figure 2.9:Brown Adipose Tissue .

#### 2.2.1.3 Fat-Free Mass (FFM)

Fat-free mass refers to all the body components that also known as lean body mass which includes your bone, body's water, muscle content and organs. In body composition it can also be referred to also as muscle mass because most people who are termed obesity or overweight tend to use that to their advantage when losing weight.

Fat-free body mass includes most of human body's vital tissues and cells:

- Organs: Internal organs such as your heart, brain and liver are examples of fat-free mass.
- Muscle: Cardiac muscle, smooth muscle, and skeletal muscle are examples of fat-free mass. Skeletal muscles contract to produce movement in human body.
- Bone: The bones that protect human body and provide human body's structure are fat-free body mass.
- Connective tissue: Tendons and ligaments that connect human body's bones and muscle are examples of fat-free mass.[19]

It consists of approximately 73% water, 20% protein, 6% mineral, and 1% anther. Overall FFM is one of the very important parameters of body composition evaluation. According to its value, the examiner can conclude if the patient is progressing in his desired treatment and amount of FFM is considered to be directly correlated with health and longevity and it is an important predictor of survival in some critical illnesses and malignancies as such Increasing your fat-free body mass can be helpful for weight management and Improved appearance, Fat-free muscle mass helps to shape a tighter body. When you replace fat mass with fat-free mass, human body looks healthy and lean and protect your organs and build strong bones. Research shows that fat-free mass plays both an active and passive role in the body's energy intake and requirements .

FFM is divided into Total Body Water (TBW) and Body Cell Mass (BCM) and bone mineral (BMC) and different percent in body as explain in figure (2.10) [20] .It organized as follows.

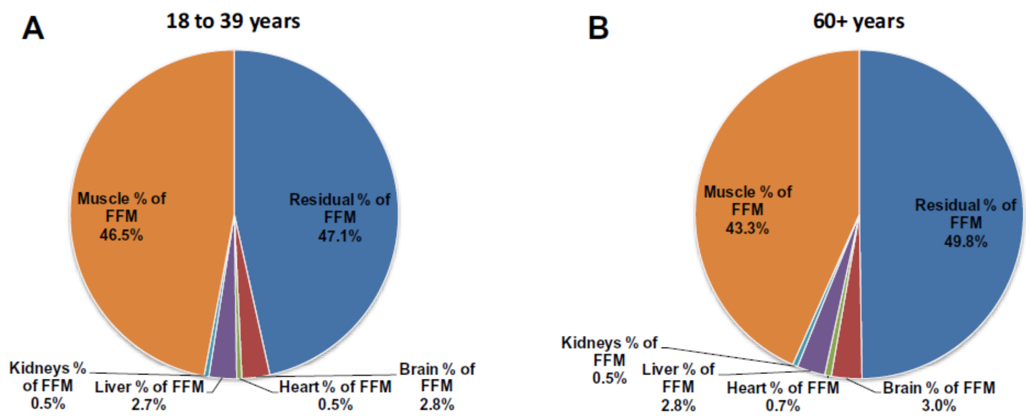



Figure 2.10: Relative amounts of organ masses, residual mass, and muscle mass to fat-free mass (FFM) with different age.[21]

## A. Total Body Water (TBW)

All water content in the human body is called total body water and can be divided into two parts: ICW (water inside cells) and ECW (extracellular water), and it is considered the highest percentage of most body fluids that in divide to Intracellular fluids and The extracellular fluid at following explain figure (2.11).

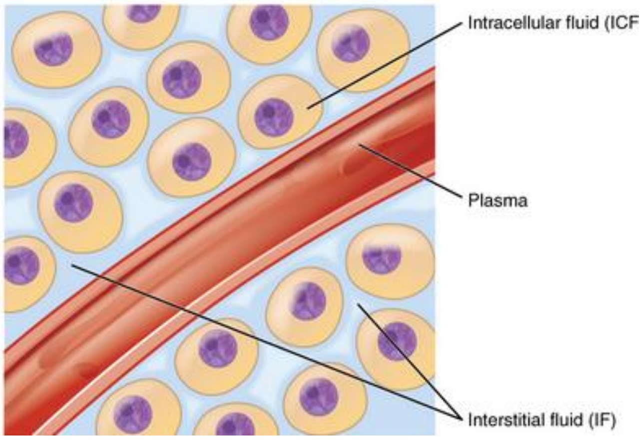
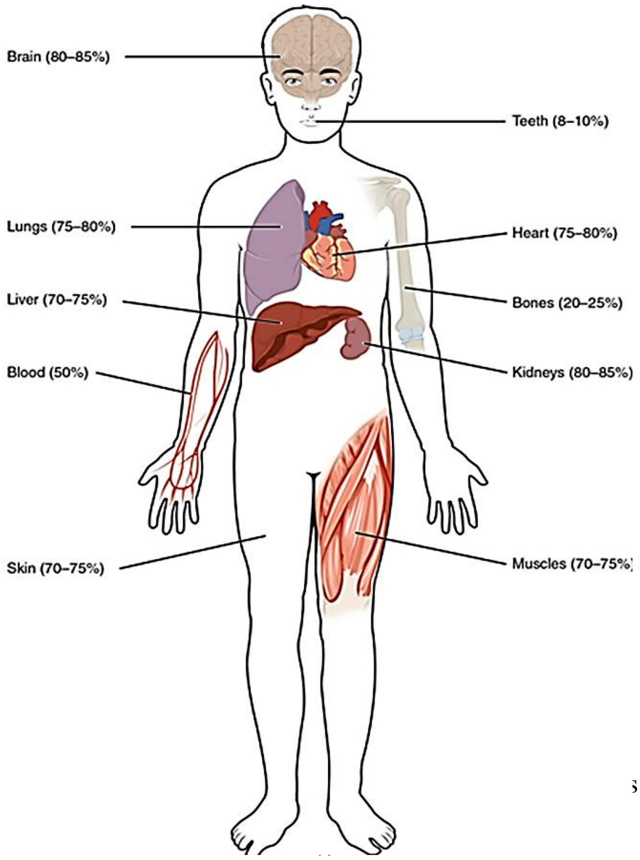



Figure 2.11:Fluid Compartments in the Human Body.

Intracellular fluids consist of the cytoplasm and dissolved ions, small molecules, and large water-soluble molecules (such as proteins). Extracellular fluid (ECF) or extracellular fluid volume (ECFV) usually refers to all of the body fluids found outside of cells. The extracellular fluid can be divided into two main subsections: interstitial fluid and blood plasma. Plasma is composed mostly of water (93% by volume) and contains dissolved proteins (the main proteins are fibrinogen, globulin, and albumin), glucose, clotting factors, and mineral ions (Na +, Ca ++, Mg ++, HCO3- Cl- etc.), hormones. These dissolves are involved in many diverse physiological processes, such as gas exchange, immune system function, and drug distribution throughout the body and constitutes only 2.5% of the ECF In humans. The ECF is normally 15 liters (of which 12 liters are interstitial liquid and 3 liters are plasma). ECF contains extracellular matrices (ECMs) that act as suspension fluids for cells and molecules within the ECF. Total Body water is the water content of the human body and constitute a large percentage of the total body composition. All cells in the human body are mostly made up of the water content in the cytoplasm. Most humans are made of water, and ranges from about 75 percent of the body mass in infants to about 50-60 percent in adult men and women, to 45 percent in old age.

The percentage of body water changes with old, because the proportions of the body given to each organ, muscle, fat, bone, and other tissues change from childhood to adulthood.




Water also provides a liquid environment for extracellular communication and molecular transport throughout the body. Water itself is also a key component in biochemical reactions involved in physiology, such as hydrolysis. Many organ systems depend on the physical properties of water, such as the surface tension of water in the alveoli in the lungs .etc. Water content varies in different body organs and tissues, from as little as 8 percent in the teeth to as much as 85 percent in the brain at show in figure (2.1.1) [22]. The prototypic 70-kg male has ~42 liters of total body water (60% of 70 kg). Of these 42 liters, ~60% (25 liters) is intracellular and ~40% (17 liters) is extracellular. Extracellular fluid is composed of blood plasma, interstitial fluid, and transcellular fluid. Interstitial fluid is present between the cells Approximately 80% of ECF and Plasma present in blood Approximately 20% of ECF . Also includes Lymph cerebrospinal fluid synovial fluid aqueous humor ..atc.

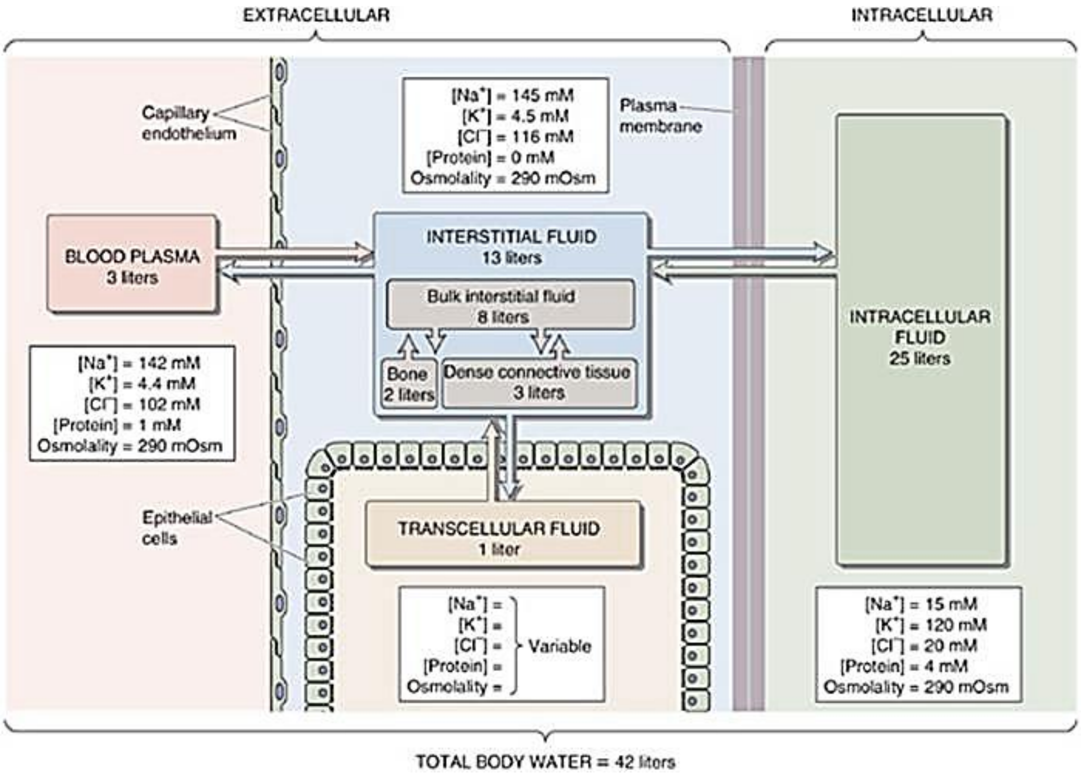



Figure 2.12: illustrated anatomy of the body fluid compartment.

Total body water indicated to dehydration and keeping normal water decreases headaches, muscle aches, and kidney stones and anther disease diagnosis [23] and as such high portion of muscle, water retention (e.g. oedema)and when small portion of muscle, dehydration/ exsiccosis . .

## B. Body Cell Mass (BCM)

According to Moore et al BCM is the "component of the body composition containing the oxygen-exchanging, potassium-rich, glucose-oxidizing, work-performing tissue. The components of BCM are the no adipose cellular fractions of skeletal muscle, viscera, organs, brain, and blood, thus, BCM has a particular importance in the maintenance of the normal physiological function of the body and nutrition case . Body cell mass is consists of all cells that have an effect on metabolism (e.g. muscle, internal organs, nervous system) the most important measurable component at the cellular level , Conceptually, body cell mass consists of two portions: an intracellular fluid component, and an intracellular solid component [24]. There are no methods available for estimating intracellular solids ,but the usual approach in estimating body cell mass is to assume a stable relationship between measurable intracellular fluid and immeasurable intracellular solids . In the normally nourished individual, muscle tissue accounts for approximately 60% of the BCM, organ tissue accounts for 20% of BCM, with the remaining 20% made up of red cells and tissue cells. The BCM also contains the large majority (98-99%) of the body's potassium[25].BCM is a key factor when assessing the nutritional status of a patient as such good training status, intracellular water Retention and malnutrition, cachexia, dehydration .

## C. Total Body Potassium (TBK)

Potassium is a major ion of the body and the most abundant positively charged ion inside of cells. Ninety percent of potassium exists in intracellular fluid, with about 10 percent in extracellular fluid, and only 1 percent in blood plasma[26] .The ratio of intracellular to extracellular potassium is important in determining the cellular membrane potential. Small changes in the extracellular potassium level can have profound effects on the function of the cardiovascular and neuromuscular systems. The normal potassium level is 3.5-5.0 mEq/L, and total body potassium stores are approximately 50 mEq/kg (3500 mEq in a 70-kg person) and TBK, range 1672–4365 mmol[27]. The cell's requirement for potassium for normal metabolism, and the availability of energy derived from glucose.

As about 70 % of body potassium is in the muscle cells, it is obvious that injury or destruction of muscle will liberate much potassium which must be dealt with by the kidney. Also, a large proportion of potassium is in organs with a large cell mass, notably the liver. Total potassium is an index of lean body mass because potassium is only present in the fat-free compartments of the body. It can be measured with K40, a natural isotope present as a small fraction of the total potassium, which emits $\gamma$-rays and can be detected by a sensitive whole-body counter, although other isotopes and other techniques that are not based on total potassium are also available, so in bioimpedance cannot measure but we can calculate by body cell mass that proportion direct with total body potassium BCM(Kg)= 0.00833*TBK .[28]

potassium is required for maintaining sodium levels, and hence fluid balance, about 200 milligrams of potassium are lost from the body every day. Nerve impulse involves not only sodium, but also potassium. A nerve impulse moves along a nerve via the movement of sodium ions into the cell. Potassium also is involved in protein synthesis, energy metabolism, and platelet function, and acts as a buffer in blood, playing a role in acid-base balance [26]. body cell mass (BCM) is indicator on rheumatoid cachexia affects two-thirds of rheumatoid arthritis (RA) patients and is defined as the loss of body cell mass (BCM). BCM is considered to be the most important factor in determining energy expenditure, protein needs, and the metabolic response to stress. [29] .

## D. Bone Mass Cell (BMC)

Bone mass is weight of bone mineral in human body a measure of the amount of minerals (mostly calcium and phosphorous) present in a specific size of bone. Bone mass measurements are used to diagnose osteoporosis (a condition characterized by low bone mass), to see how well osteoporosis treatments are working, and to predict the likelihood of a bone fracturing.

## E. Skeletal Muscle Mass (SMM)

Muscle mass refers to the amount of soft muscle tissue in the body .It is a part of a fat free mass that stands for muscles and is regarded as a significant indicator of overall physical strength. For an average adult male is this value up of 42% of body mass and for an average adult female is this value up to 36% of body mass.

Muscles primarily help with movement, maintaining posture, and supporting bodily functions.

There are three main types of muscle:

- smooth muscle, which is in the internal organs
- cardiac muscle, the muscle of the heart
- skeletal muscle, which exists throughout the body

Skeletal muscle plays a key role in movement. For example, bending the arm upward requires the bicep muscle to contract and the triceps to relax. Exercising the skeletal muscles in various ways can increase the body's mobility, balance, and strength.

Keeping the skeletal muscles healthy is important for daily functioning. This may be particularly important for older adults.

Skeletal muscle tissue is critical for many functions of the body; fundamentally, it is responsible for movement, and loss of muscle mass and quality results in weakness and reduced mobility. However, skeletal muscle is also the largest reserve of protein in the body. During periods of stress, disease, Undernutrition, or starvation, it serves as a source for amino acids that maintain protein synthesis in other vital tissues. Skeletal muscle is also the primary site of glucose disposal, and diminished muscle mass therefore plays a role in impaired glucose metabolism. In addition, skeletal muscle is the major consumer of energy and a contributor to the basal metabolic rate in the body[30].

#### 2.2.1.4 Body Mass Index (BMI)

Body Mass Index (BMI) is a measurement of a person's weight with respect to his or her height. Used to estimate degree of obesity in large populations as Illustrates in figure (2.13 ) . It is more of an indicator than a direct measurement of a person's total body fat. BMI, more often than not, correlates with total body fat. This means that as the BMI score increases, so does a person's total body fat. The WHO defines an adult who has a BMI between 25 and 29.9 as overweight - an adult who has a BMI of 30 or higher is considered obese - a BMI below 18.5 is considered underweight, and between 18.5 to 24.9 a healthy weight [31].

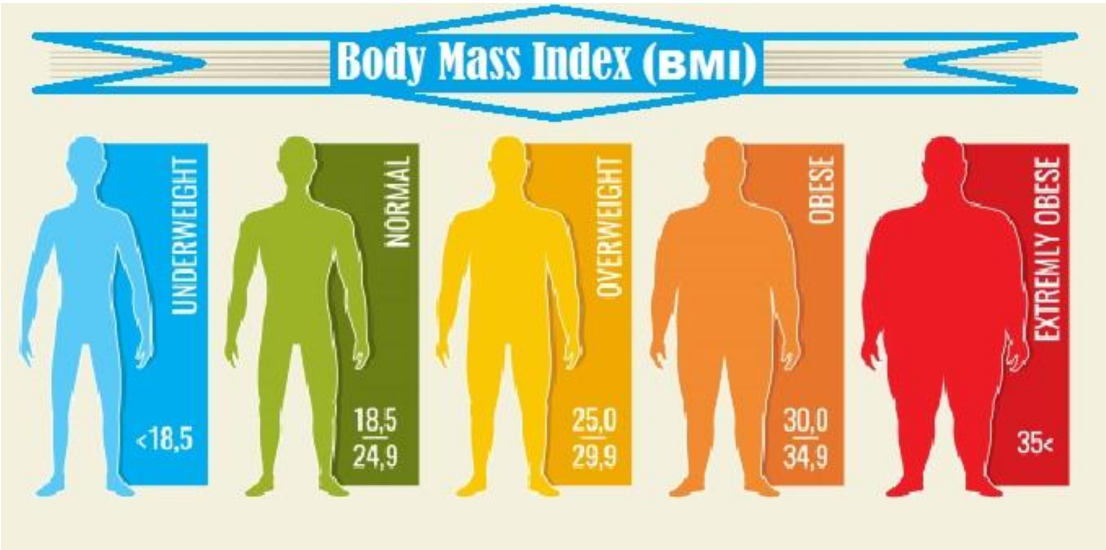



Figure 2.13:Illustrates mass index (BMI) is an asseSMMent to determine the level of obesity.

### 2.2.2 Electrical Properties of Biological Tissue

In order to understand, interpret and study the effects of the current flowing through tissues, there is a need to know the electrical conductive properties of the tissue and to a model that closely interprets and approximates the electrical behavior of the tissues, as detailed below.

### A. Conductance tissue

The electrical conductance of biological tissue is determined by its constituent elements , so the tissue intracellular and extracellular fluids are electrolytes because they contain ions free to migrate and transport the electric charge. Therefore we can consider biological tissue, an ionic conductor electrically The total ionic conductivity of a solution depends on the concentration, activity, charge and mobility of all the free ions in the solution. The most important ions contributing to the ionic current in living tissue are K+, Na+ and Ca2+. The viscosity and temperature of the solution are also important factors influencing in the ionic conductivity[32] .

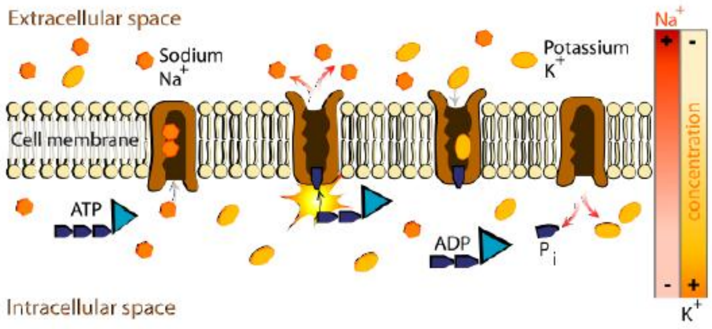



Figure 2.14:This express change ions concentration effect conductive.

The main component of the cells is their cellular membrane, the structure of which is based on a lipid double layer in which proteins are distributed, allowing the formation of channels to exchange ions with the exterior, Figure (2.14) above . Due to its molecular components, the cellular membrane acts as a dielectric interface and can be considered as the two plates of a capacitor .Therefore, when a constant electric field is applied, the electrically charged ions move and accumulate in both sides of the membrane. However, when the field is alternating, an alternating movement of electrons appears at both sides of the cellular wall, producing a relaxation phenomenon. The dielectric relaxation phenomenon in the tissues is the result of the polarization of several dipoles and the movement of the charges that induce a permittivity and conductivity phenomenon . The charge carriers are mainly ions and the main source of dipoles are the water polar molecules in the tissues .The electrical behavior of biological tissues reveals a dependency of the dielectric parameters with the current frequency, due to the different relaxation phenomena that take place when the current flows through the tissue.

## B. Equivalent circuit model for tissue

Model of tissue explain the fluids inside and outside the cell act as electrical conductors and cell membranes act as electrical capacitors and different reactive elements as figure (2.1.2) and have different permittivity and conductivity of body tissues and different electrical values as adipose tissue has a very high resistance (smaller conductance) because it is mainly composed of fat and almost does not contain water. On the other hand, muscle mass or lean mass (excluding bone mass) is mainly composed of water and thus has little resistance (greater conductivity). These key differences (muscle mass has conductivity ten times higher than fat mass) in impedance are used to estimate body composition values (total body water - TBW, extracellular water (ECW), intracellular water (ICW). If current is injected into the extracellular medium, it can do the following things:

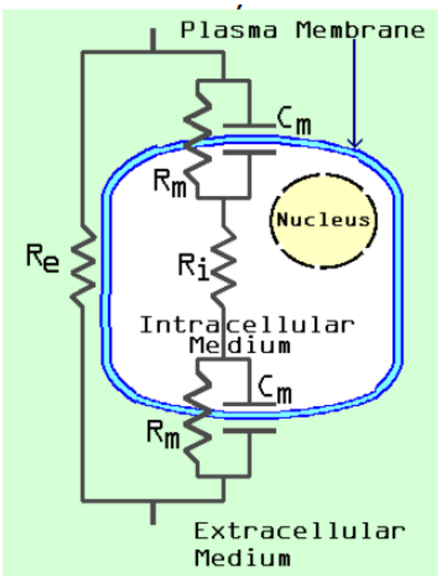


Figure 2.1.2 : Equivalent circuit of a tissue impedance model .

Flow around the cell through the extracellular fluid. (Re) represents the corresponding resistance.

Flow through the cell across the plasma membrane. (Cm) represents the capacitance and Rm the resistance of the plasma membrane. (Rm) is mainly the result of the transmembrane ionic channels and Ri represents the resistance of the intracellular medium [33, 34]. The impedance of a cell follows the following equation (2-1).

$$Z = \frac{R_e(1+jR_iC_m)}{1+jC_m.(R_i+R_e)} \qquad (2\text{-}1)$$

### 2.2.3 Abnormal body composition effects

Abnormal body composition is directly related to health ,so incase change in parameters important body composition from normal rate as body fat and obesity and body water cause many disease that explain at following :

Excessive body fat have many effects that increase the risk of chronic disease, premature death, unhealthy levels of fats in the blood, impaired heart function, heart disease, high blood pressure, cancer, impaired immune function, gallbladder disease, kidney disease, and the problem. the skin [35]. The problems associated with low levels of body fat associated with the reproductive cycle and immune system disorders are less than 10-12% for women and 5% for men. The National Heart, Lung, and Blood Institute suggests that BMI is an indicator of a healthy body [36].

Obesity is a complex disease involving an excessive amount of body fat. Obesity isn't just a cosmetic concern. It is a medical problem that increases your risk of other diseases and health problems such as : heart disease and stroke, high blood pressure, diabetes, some types of cancer, gallbladder disease and gallstones, osteoporosis, gout, breathing problems, such as sleep apnea (when a person stops breathing for short spells during sleep) And asthma. Not everyone who is obese has these problems. The risk is higher if you have a family history of one of these conditions.

Dehydration is less present water in body can lead to fluid loss of more than 4%, and a sharp decrease in performance can be observed, in addition to difficulties with concentration, headache, irritability, drowsiness, increased body temperature and respiratory rates with dehydration, and causing dehydration. Decreased volume of water in the bloodstream, which leads to low blood pressure, and cardiovascular function is affected by increased levels of dehydration, with elevated heart rate and difficulties in maintaining the volume of blood that the heart carries to the tissues. Chronic dehydration can increase the risk of developing infections, especially of the urinary tract. The kidneys and other major organs that receive reduced blood flow may start to fail as well as fail. Reduced blood flow to the brain can cause confusion and impair cognitive function and coordination. changes in body composition even in the early stages of kidney disease and in patients with cardio-renal syndromes, showing lower resistance, abnormal impedance vectors, reduced phase angle, and higher total body water together with a lower body cell mass. Many conditions exist in critical illness (ascites, anasarca, severe peripheral edema, pleural effusions, the massively overhydrated patient .Another diseases in case less muscle mass for normal that Sarcopenia is the age-related decline in muscle mass, and is associated with increased disability and mortality. As muscle is not only responsible for physical strength, stamina and balance, but also metabolically active tissue, Sarcopenia might affect quality of life, the need for supportive services and contribute to the development of metabolic disorders [37] and Decline of muscle mass and increase of body fat is considered a ‘physiological’ feature of aging [38] .

The loss of body cell mass in various diseases, including RA, congestive heart failure, acquired immunodeficiency syndrome (AIDS), starvation, critical illness, and aging has been associated with poor clinical outcomes [29].

in case Insufficient potassium levels in the body (hypokalemia) can be caused by a low dietary intake of potassium or by high sodium intakes, but more commonly it results from medications that increase water excretion, mainly diuretics. The signs and symptoms of hypokalemia are related to the functions of potassium in nerve cells and consequently skeletal and smooth-muscle contraction. The signs and symptoms include muscle weakness and cramps, respiratory distress, and constipation. Severe potassium depletion can cause the heart to have abnormal contractions and can even be fatal. High levels of potassium in the blood, or hyperkalemia, also affects the heart. It is a silent condition as it often displays no signs or symptoms. Extremely high levels of potassium in the blood disrupt the electrical impulses that stimulate the heart and can cause the heart to stop. Hyperkalemia is usually the result of kidney dysfunction [26].

### 2.2.4 Techniques diagnosis body composition

There are many diagnostic techniques used in the medical field and they are organized as follows.

#### 2.2.4.1 Computed tomography (CT)

Computed tomography (CT) generates detailed cross-sectional dimensional radiographic images of body segment  when an X-ray beam (ionizing radiation) passes through tissues of different densities. The CT scan produces pictorial and quantitative information about total tissue area, total fat and muscle area, and thickness and volume of tissues within an organ as figure (2.15) , but have disadvantage  expensive and risk X-ray exposition, It is estimated that 1.5%–2.0% of all cancers in the United States may be attributable to radiation from CT study is Mourtzakis et al [39].

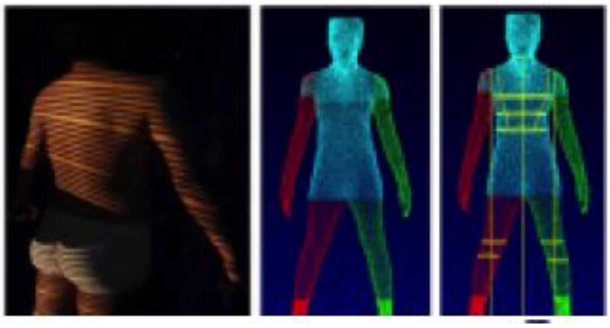


Figure 2.15: Computed tomography  body segment .

#### 2.2.4.2 Dual-energy X-ray absorptiometry

DXA is originally designed for determining bone mineral density and diagnosing osteoporosis and other bone diseases, DXA is also used to assess fat and fat-free soft tissue. To do so, DXA measures the absorption (attenuation) of two X-ray photon energies, typically near 40 and 70 keV, which allows for the distinguishing of bone from soft tissue. After excluding pixels that represent bone tissue, DXA estimates fat from the proportion of fat to lean soft tissue in each pixel of a whole body image based on X-ray attenuation ,although DXA is the gold standard technique for the evaluation of body composition as figure 2.16) ,but used in clinical research , although limited in clinical practice by the radiation exposure, availability and cost [9].

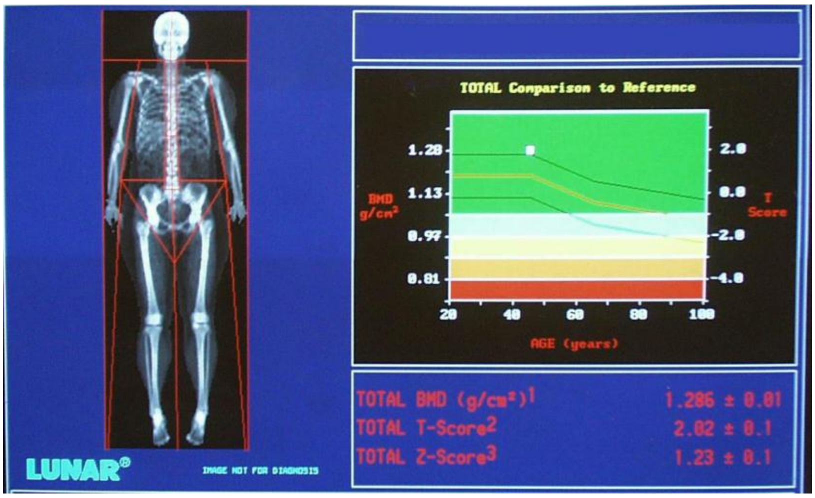



Figure 2.16:Lunar DXA systems diagnosis body composition [9].

### 2.2.4.3 Ultrasound

Another technique, used since decades, to assess BF is ultra-sound. Still now BF-US is not well known as techniques. US, based on echoes reflection, represents a two-dimensional grey-scale image, between white (strong reflections) and black (no echoes), showing borders of the skin-subcutaneous fat, fat-muscle and muscle-bone interfaces. Although the US procedures can be considered relatively simple, the interpretation is more difficult and subjective. US has many advantages such as low cost, capable of measurements, noninvasive, rapid procedure, but also some limitations such as experience-related, absence of standardized procedure and measurement, artifacts. However, different opinions were about US validity. But have disadvantage Experience-related and Absence of standardized procedure ,Not portable , need to use a high voltages is also problematic since it results in a significant power consumption [40]. Show figure (2.17) explain this technique .

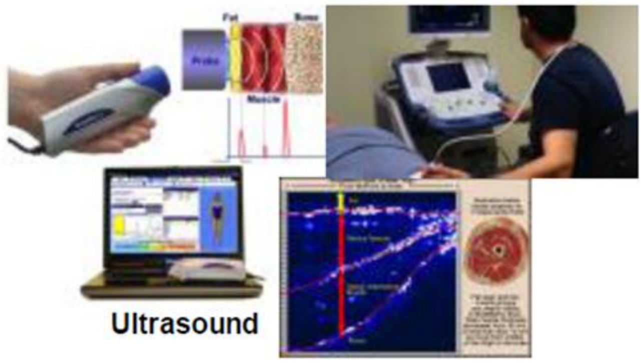



Figure 2.17:explain ultrasound device diagnosis body composition.

#### 2.2.4.4 Magnetic resonance imaging (MRI)

Images of soft tissue in the body can be produced by MRI, which uses the different magnetic properties of the nuclei of elements in the cell, usually hydrogen in water and fat. Diffuse fat infiltration in organs and precise regional measurements of AT (adipose tissue) and LT( lean tissue ) are estimated using ‘quantitative fat water imaging , which is based on Dixon imaging . In this technique, the separation of the signals into water and fat image is made using the magnetic resonance frequencies of protons in fat and water , Dixon method uses repeated acquisitions of the evolving MRI signal to capture images with echo times (TE) when water and fat signals are in phase (signals add) and out of phase (signals subtract) . The contrast between adipose and lean tissue in MRI scans depends on tissue-specific magnetic-resonance properties, such as proton density, longitudinal relaxation time (T1), and transverse relaxation time (T2) and Echo time (TE) describes the time delay of signal acquisition after exciting the fat and water protons with radiofrequency (RF) energy. as also enhanced Dixon methods include improved signal models, increased echo count, optimal TE spacing, asymmetric echo spacing and detailed modeling of differences in the patterns of MR signal decay of the water and fat components that enable more accurate estimates of fat and water within tissues. But have disadvantage Longer image acquisition time and Very expensive and Need of specific software to used detects fat and water in body as figure (2.18) [39, 41].

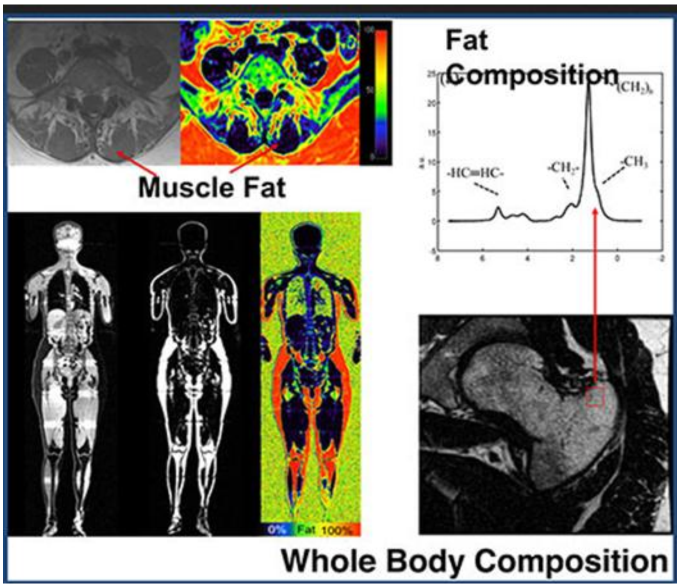



Figure 2.18:Whole body Dixon magnetic resonance imaging

### 2.2.4.5 Bioelectrical Impedance Analysis

Bioimpedance Analysis (BIA) is new technique used for calculation and evaluation of the body composition and monitor of state health to body . BIA is a safe and cost-efficient method that avoids exposure to radiation and is It is based on the difference in resistance when an electrical current is conducted through fat or fat free mass components of the body. It can estimate whole-body fat content based on the determination of total body water content with separation into extracellular and intracellular water (Janssen et al. 1997). also An impedance used specific equation for determining obesity has been developed .Previous and some recent data suggest that BIA may provide useful information not only in different well-established patient groups (dialysis, AIDS, malnutrition), but also in critically ill patients with burns, trauma and sepsis undergoing fluid resuscitation.

## 2.3 Engineering Background

Since there are risks when leaving the human body without health monitoring, many efforts have been made to provide measuring devices that lead to the deterioration of human body composition in many forms, so a number of theories and principles have been devised to measure body composition. In this section, we will deal with the engineering principles and methods used for measurement as organized as follows.

### 2.3.1 Principle of Bioelectrical Impedance Analyze

Impedance (Ω) is a ratio between a current and a voltage that applies in both alternating current (AC) and direct current (DC). From this statement bioimpedance can be described biological resistance is a complex quantity consisting of the resistance value of R (real fraction) describing the tissue values of the current resistance and does not change with the frequency, and the reactive value Xc (imaginary part) presents capacitive properties of the body tissues (the value is affected by the cell membranes - capacitor) and this value changes with frequency , And impedance can also be represented as a vector at equation (2-2), with module | Z | equation (2-3) And phase angle φ equation (2-4) [42]:

$$Z = R + JX_c \quad (2-2)$$

$$|\boldsymbol{Z}| = \sqrt{R^2 + {X_c}^2} \quad (2\text{-}3)$$

$$\theta = tan^{-1}\frac{X_c}{R} \; (2-4)$$

Reactance Xc is the resistance which a condenser exerts to an alternating current. All cell membranes of the body act like mini-condensers due to their protein-lipid layers. The reactance is therefore a measure of the body cell mass. Resistance R is the pure resistance of a conductor to alternating current and is therefore the phase angle can show a relative distribution of fluids. Its value can differ in theory from 0 (no cell membranes) to 90° (cell membranes only). In clinical use the phase angle can be very useful, because it should respond to ECW/ICW ratio that should be a sensitive measurement of malnutrition or illnesses inversely proportional to total body water.

Output is commonly provided in the form of an impedance value (expressed in the unit Ohms, Ω; approximate range between 150Ω - 900Ω) [43].

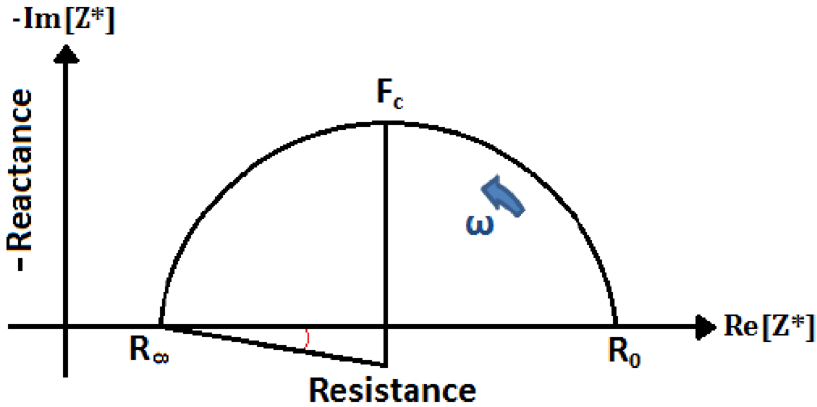
- Cole – principle

The Cole principle is one of the models most used to describe complex impedance measurements in the β dispersion range (kHz-MHz).

In this model, the complex measurements defined by equation (2-5) form a semicircular curve with its center below the real axis. The curve presented in figure (2-19), known as a Cole plot, is a semicircular trace of resistance versus reactance, where frequency increases over the semicircle in a counter-clock wise direction. Bioimpedance is defined as the frequency domain ratio of the voltage to the current. The magnitude of bioimpedance values represents the ratio of the voltage amplitude to the current amplitude. Whereas the phase represents the phase shift by which the current lags the voltage. Using Ohm`s law impedance is expressed as follows:

$$V = I * Z = I * |Z| e^{iarg(z)} \quad (2-5)$$

The magnitude of the impedance |Z| stands for resistance (the drop in voltage amplitude across an impedance) Z for a given current I. The phase factor shows that the current lags the voltage by a phase $=e^{iarg(z)}$.




Cole geometrics measure of impedance depend frequency.

$$Z = R_\infty + \frac{R_0 - R_\infty}{1 + (j\omega\tau)^\alpha} \quad (2-6)$$

where Z is complex impedance [Ω]; R∞ is resistance [Ω] at infinity frequency, j is imaginary unit, ω is angular frequency [1/s], τ is the characteristic relaxation time constant [s]. ∝(Alpha) : Parameter in the mathematical theory, which influences the position of centre of the circle.

In biological tissue there are lots of cells with membranes that have the effect of frequency dependence of bioimpedance. Hence, with at low frequencies, the measurement is only resistive, and corresponds to the extracellular resistance, no current passes through the intracellular path because it cannot cross the cell membrane capacitance. As the applied frequency increases, the phase angle gradually increases as more current is diverted away from the extracellular resistance, and passes through the capacitance of the intracellular route. At high frequencies, the intracellular capacitance becomes negligible, so current enters the parallel resistances of the intracellular and extracellular compartments. The cell membrane reactance is now nil, so the entire impedance again is just resistive and so returns to the X axis. Between these, the current passing through the capacitive path reaches a peak. The frequency at which this occurs is known as center frequency (Fc) and it is a useful measure of the properties of an impedance at equation (2-7) . Inspection of the Cole–Cole plot yields the high and low frequency resistances, as the intercept with the x-axis, and the centre frequency is the point at which the phase angle is greatest.

$$f_c = \frac{1}{2\pi C_m.(R_E + R_I)} \quad (2-7)$$

The electrical/mathematical model used by the Xitron Hydra 4200 current injection in body as figure (2.20)[32, 44, 45].

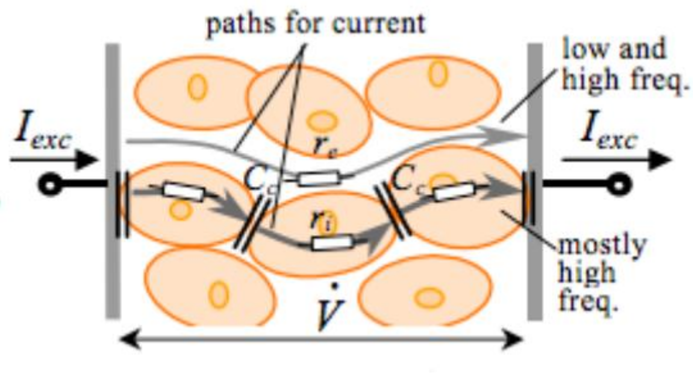



Figure 2.19:current Impedance properties of tissue

The classic BIA method measures the impedance of the whole body on the assumption that the human body can be considered a cylinder for application of this model as figure (2.21) . If A is the cross sectional area, and L is the length, the impedance of the cylinder can be expressed  as figure (2-22) and equation (2.8).

$$V = \frac{\rho L^2}{A} \quad (2-8)$$

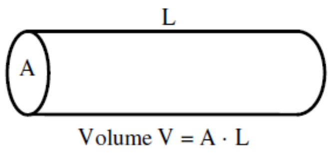



Figure 2.20:The cylindrical volume fluid conducting.

If both sides are multiplied by L, We get the new expression as equation (2-9).

$$V = \frac{\rho L^2}{R} \qquad (2-9)$$

V = volume of the conducting component of the body; R = resistance in ohms; L = conductor length (or height) in cm; and ρ = specific resistivity constant in (ohm·cm ). Bioimpedance Data Can Be Used to Estimate according to this expression, if we know the L and the impedance value, we get the volume. That is to say, if we know the height of the human body (acting as a conductor), and know the impedance value, we can get the volume of body water. Here, the volume of represents examinee's height [39, 46].

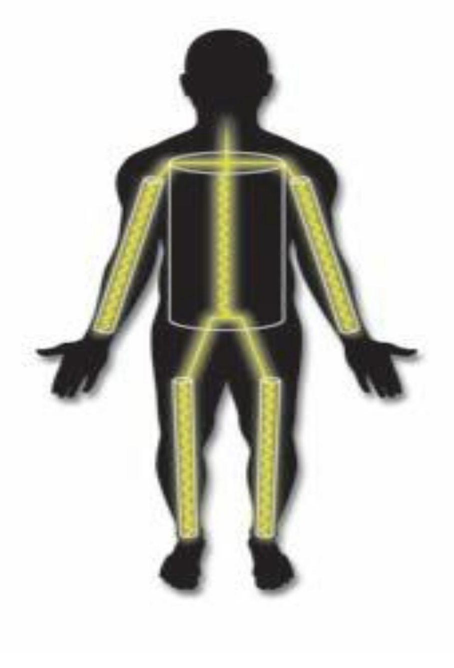


Figure 2.21:The body is a cylinder résistance.

#### 2.3.1.1 Method of Bioelectrical Impedance Analysis

The most common technique for measuring vital resistance is the use of the excitation signal frequency. The simplest tools are based on static frequency measurements (single-frequency bioelectrical impedance analysis, or SF-BIA), and some adopt a multi-frequency system (multi-frequency bioelectrical impedance analysis, or MF-BIA). Of frequencies (bio-impedance spectroscopy, or BIS) at explain following :

#### A. Bioelectrical impedance vector analysis

Bioelectrical Impedance Vector Analysis (BIVA) is a human health asseSMMent technique based on the absolute measurement of bioimpedance. This method uses only impedance vectors and does not take into account models and equations that are used for body composition evaluation. depend on Vectors of reactance and capacitive reactance on the ordinate (or admittance) are plotted in R-Xc plane Figure blow . Individual vectors are compared with reference 50%, 75%, and 95% tolerance ellipses calculated in the healthy population of the same gender and race . Ellipse can vary with age and body size. Major axes interpret hydration status and minor axes stand for tissue mass. A unique application of BIVA is the discrimination of fat and fluid changes in obesity. In comparison with healthy adults with normal BMI, obese individuals have shorter vectors and similar phase angles. Obese adults with edema have significantly shorter vector length than the normal weight and otherwise healthy obese adults, and significantly lower phase angle (2, 60) as figure (2.23). This don't based on equation to estimated value body composition and complex technique , It does not give specific value and accuracy[42] .

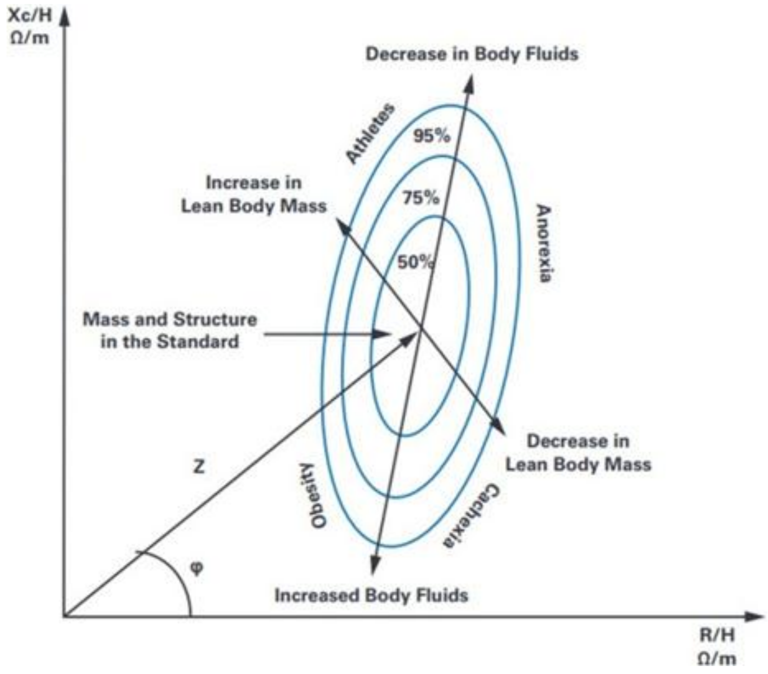



Figure 2.22:Bioelectrical Impedance Vector Analysis vector plot.

## B. Single frequency Bioimpedance Analyze (SF-BIA)

SF-BIA is method of body composition analysis using bioimpedance using a single frequency to measure the tissue impedance, where the body impedance, as well as its resistive and reactive components, is measured at a single frequency, usually 50 kHz, with the measured impedance being due to a mix of contributions of ICW and ECW.

SF-BIA has been widely used to estimate TBW and FFM. Because of the use of a single frequency, however, it is not able to reliably estimate the ECW= ICW ratio. In SF-BIA, the body parameter (usually TBW or FFM) is estimated using empirical linear equations, depending on the characteristics of the subject under test (height, weight, etc)[47].

## C. Multi-Frequency Bioimpedance Analyze ( MF-BIA)

The MF-BIA technique overcomes the limitations of SF-BIA by performing the measurement at low and high frequencies. The low frequency measurement allows for a more accurate estimate of the ECW, whereas at the high frequency, an estimate of the

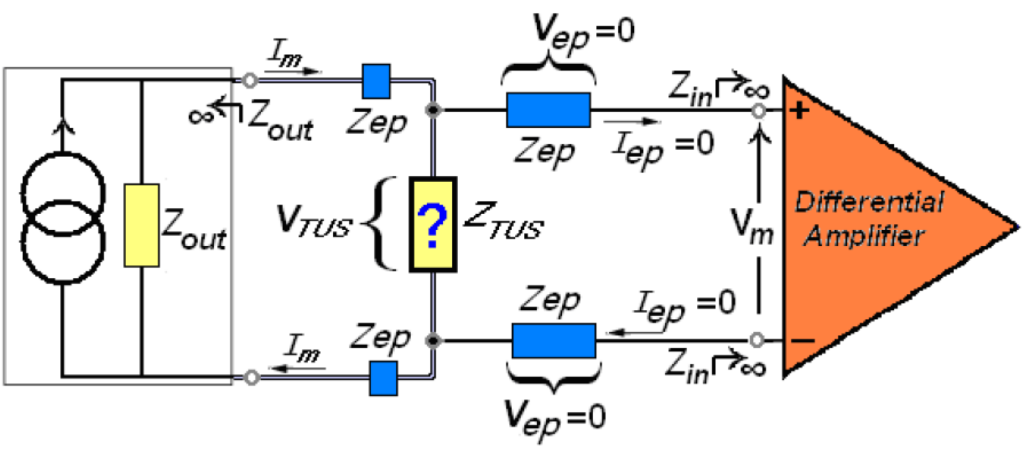
TBW is obtained. The ICW is given by the difference between the two estimates. However, this technique is also not perfect and shows limitations in the estimation of body fluids in the elderly population affected by disease [48].

### D. Bioimpedance Spectroscopy (BIS)

BIS is based on the measurement of impedance at zero frequency, which, is the Resistance Extracellular (RE) due to the extracellular fluids, and at infinite frequency, which is the parallel of RE with Resistance Intracellular (RI ) . At these two frequency extremes, the capacitance due to the cell membrane behaves like an open circuit or a short circuit . Intermediate frequency measurements provide information related to the capacitance value. BIS provides more detailed information than other techniques do, but, in this case, the measurement takes longer time [13].

### 2.3.1.2 Four-Electrode Measurement

The signal injection and the response measurement are performed with two different pairs of electrodes. one of electrodes is used to inject the current into the tissue under study (TUS) and another reference current , while a second pair of electrodes is used to measure the voltage VTUS or two are signal picking . Model four electrode and measure impedance show figure (2.24) .



Standard four-electrode configuration.

$$Z_{m}=\frac{V_m}{I_m} \quad (2-10)$$

$$V_{m}=V_{TUS}+2V_{ep} \quad (2-11)$$

$$Z_{m}=\frac{V_{TUS}+2V_{ep}}{I_m}=Z_{TUS} \quad (2-12)$$

$Z_{ep}$is electrode impedance , $V_{ep}$is the voltage impedance , $V_{TUS}$ is voltage load impedance, $Z_m$ is total impedance measure , $V_m$ voltage output measure , $I_m$ injection current .

The electrodes effect on the total resistance ,but must less error as electrode wet and must by sensitive to current . different type electrode depend on less noise and high quality as recently dry electrode used estimated fat rate high guilty and less effect sweat . Four electrodes are put on the dorsal surfaces of the hands and feet at the distal metacarpals and metatarsals with the skin non-invasive into the tissue and of the distance between electrode pairs is 5 cm. ( by Hoffer and adopted by Nyboer )[13].

### 2.3.2 Our technique in project

This project measured major body components (FM), (FFM) and BCM body cell mass by this can calculate total body potassium (TBK), (TBW) including (ECW) and (ICW), skeletal muscle mass (SMM) is a fraction of the aforementioned BCM and body mass index (BMI). sent data controller for the application via bluetooth technology and the role of the application receives the data from the controller and the user enters the weight, height, gender and age into the application and after obtaining all the data it performs the calculations then the master displays the parameters of the body and also displays the medical advice according to the data of the variables in the body and this project based on electrical impedance principle by used multi-frequency so that it uses four electrodes to transmit a small current at a high frequency and take a body impedance signal in the form of a voltage described previously.

This project must be is not used for diagnosis only, but for monitoring the above-mentioned parameters and determining the state of health and directing the patient to what must be done to maintain his good health, also our project device must be characterized low cost, small size, portable device, and a different number of parameters that are measured by our project device compared to modern technologies that depend on electrical bioimpedance.

## 2.4 Summary

The body composition is evaluation of general health status of patient and important to keep from disease obesity and dehydration and another diseases ,so must diagnosis and monitor of TBW ,FM,BCM are basic parameters can detect states healthy were discussed. This chapter presents the most topics related to the body composition measure , starting a comprehensive description to body composition . Then properties electrical tissue and techniques diagnosis body composition . In addition, principle bioimpedance analyze were briefly discussed. Also, methods used BIA was discussed. This chapter was ended estimate equation parameters basic body composition and and describe our project .

# Chapter 3

# block diagram

## 3.1 Introduction

Recently, the unprecedented advancement technology, studies, and research on the analysis of body organs and sub organs and their importance in the associated related to risk, fat mass, and other components, as well as high rates of obesity, have been the cause of many deaths. Therefore, many technologies and electronics have been developed recently that help to use electrical impedance techniques to measure impedance on the body and this was safe in many research, also it's used in many applications in the medical field, so we will design the device in this project and we start from block diagram that explains components and electronic circuit piece used to implement this project. The chapter is organized as follows. Section 3.1 present a block diagram of our project device. section 3.2 explains electronic components and 3.3 design flow chart software our project. Finally, section 3.4 explains the summary chapter.

# 3.2 block diagram of our project device

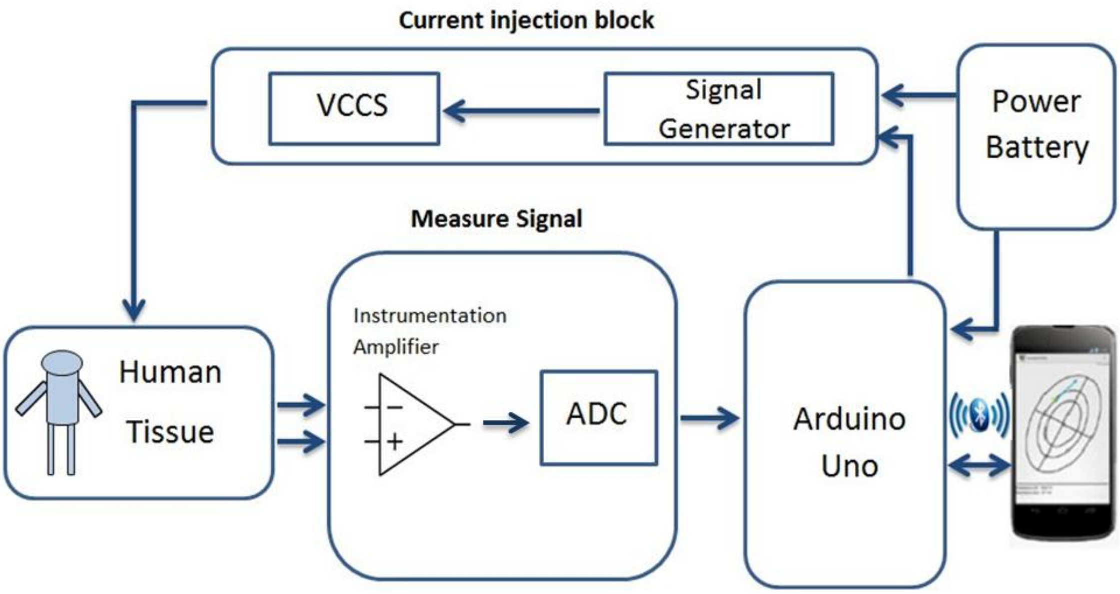



Figure 3.1:Block diagram the our project device.

## 3.2.1 WORKING PRINCIPLE

figure (3.1) shows the block diagram of the body impedance measurement. The process starts by enabling a signal generator using Direct Digital Synthesizer (DDS) which generate sine wave through an external reference clock or an internal oscillator. The sine voltage output excitation pass-through voltage-controlled constant current source (VCCS) converter -a voltage to current- to supply current less than 1mA with frequency limited and constant current for safety body. After that a filter is used to eliminate dc voltage. the current is injected into the body through two electrodes. the voltage of these electrodes are constantly monitored from two other electrodes by an instrument amplifier . Then an analog to digital signal convert (ADC) is utilized to convert analog signal to digital single in order to be processed by a microcontroller. The microcontroller process signal and sent data by Bluetooth to android to calculate body composition and display them . Here after we explain the block diagram components in details as following.

### 3.2.2 Signal generator

The generator produce sine wave to the injection current to the body used AD5933 board generate sine wave by direct digital synthesizer (DDS ) system uses digital data processing to generate a frequency- and phase-tunable output related to a fixed frequency reference, or clock source, across accumulate and The accumulator, a sine lookup table (angle-to-amplitude converter) and a digital-to-analog converter such as explain (3.2).

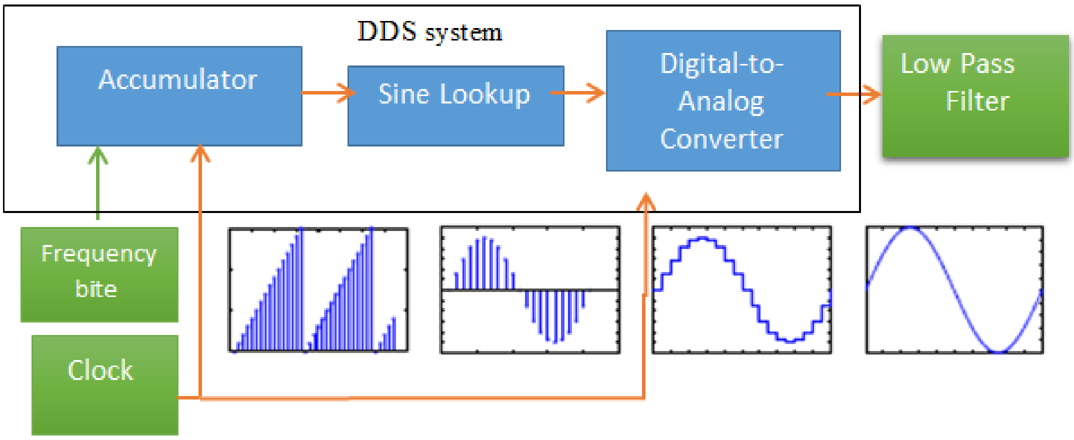



Figure 3.2:Steps generator signal by direct digital synthesizer.

The accumulator increments a number on each clock and works to change in phase with the number of pulse and value output by the accumulator always corresponds to a phase between 0 and 360 degrees. The sine lookup table simply converts the phase angle to a corresponding amplitude by looking up the phase angle in a read-only memory (ROM) and output the amplitude. This creates a discrete sinusoidal signal on the output of the angle-to-amplitude converter. The digital-to-analog converter (DAC) converts the discrete digital sinusoidal signal to a continuous analog sinusoidal voltage or current signal and this signal pass through a low pass filter to remove noise and this signal analog waveform is generated, it is amplified through a programmable gain stage and a programmable voltage output excitation. After the signal generator usually provides a voltage at its output and we need current to injection to the body, so we used Voltage Controlled Current Source (VCCS) [45].

### 3.2.3 Voltage Controlled Current Source (VCCS)

VCCS is a non-inverting amplifier type constant current source is the simplest, accurate, and stable design for maintaining a constant current up to a range of 2MΩ load resistance and it converts the sine wave voltage signal to current constant amplitude and limit this current depends on frequency output as this must be high quality and safety body. The functional purpose of a current source is to generate an electric current signal with a specific magnitude and minimize the common-mode voltage at the load, thereby reducing the errors due to limited CMRR of the voltage measuring differential amplifier and. OPA2134 is the OpAmp of voltage-controlled current source use in a project.

### 3.2.4 Measure signal

- Instrumentation amplifier

The Amplifier Instrument circuit is used to measure the potential leads between electrodes between two points that express body impedance and with response to frequency as can measure impedance at 50kHz. it has input impedances and capacitances high to help measure low body signal voltage.

### 3.2.5 ADC OPERATION

ADC is Convert analog signal to digital signal that digital bits help data process and necessary to control DFT(discrete furrier transformation ) to takes the 16-bit ADC output and converts it to complex impedance with real and imaginary components.

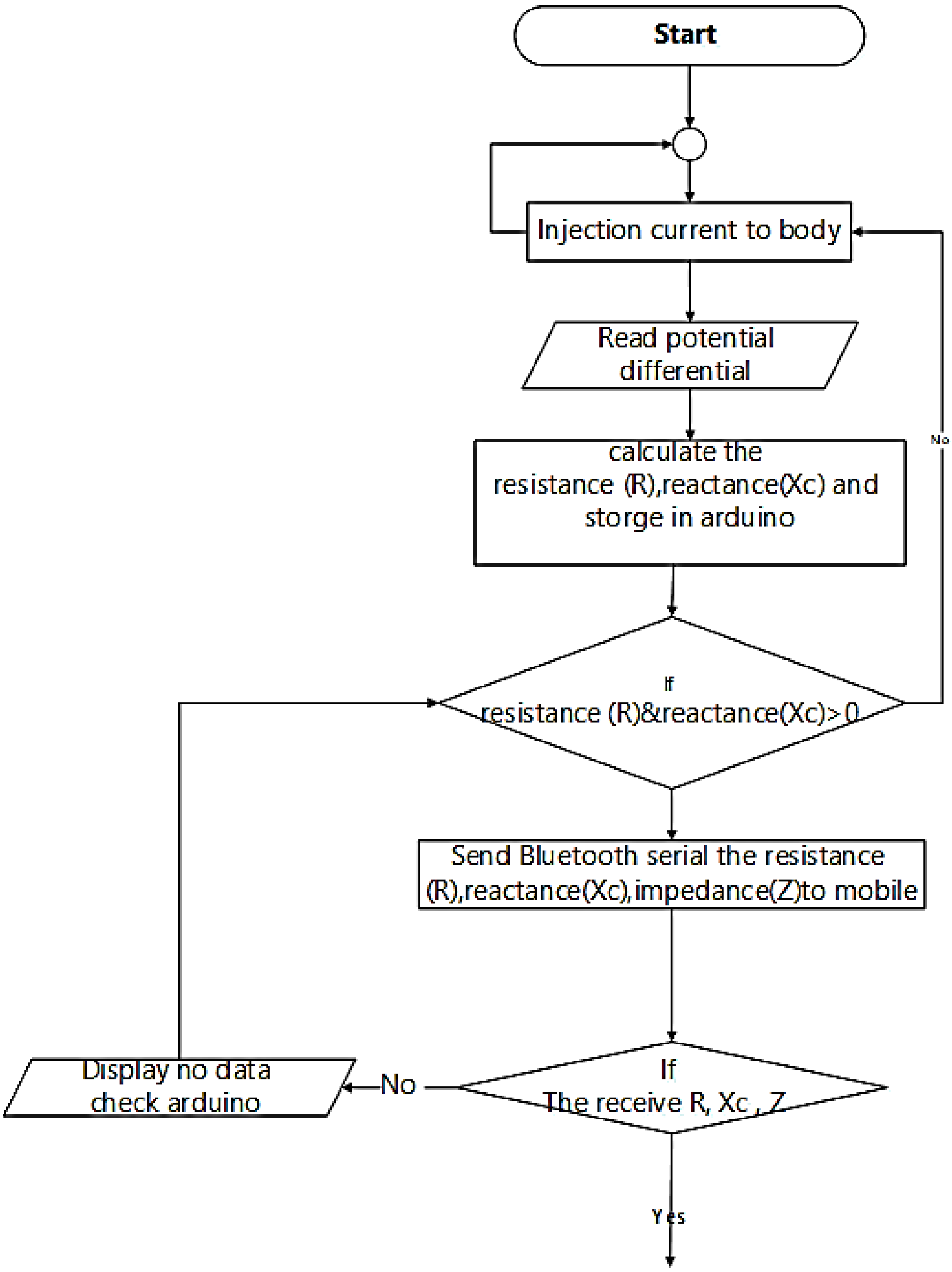
### 3.2.6 Microcontroller

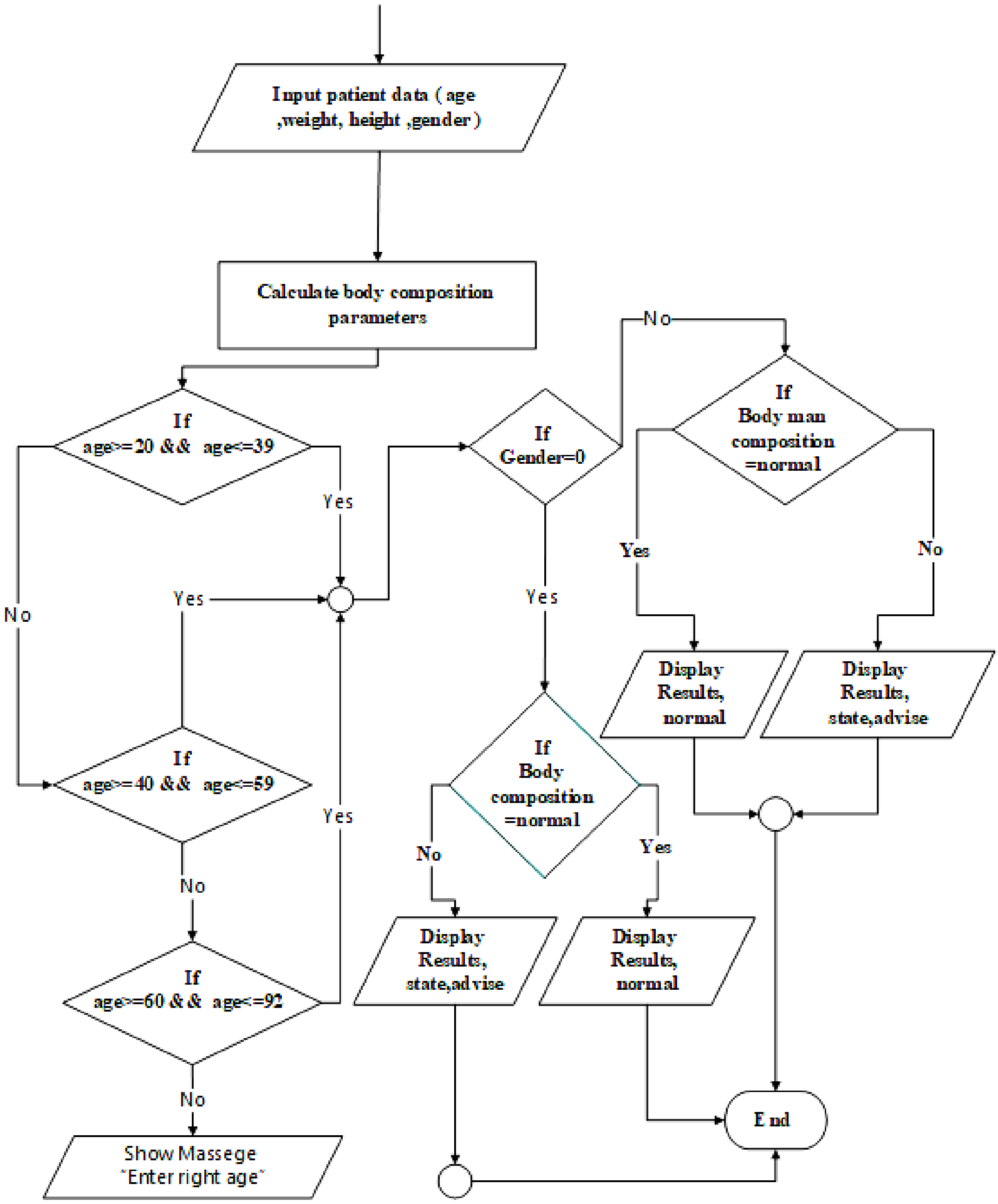
MCU is used to control the whole system. Its data process of code system and control the clock to detect frequency injection current and receive data real and imaginary to bioimpedance measure after analysis and sent theses data by Bluetooth to android application to calculate data body composition used microcontroller in project Arduino.

### 3.2.7 Filter

A high pass filter is used to block low frequency, also helps to remove the DC component from the signal. The filter is intended to attenuate noise at frequencies below the range of the sweep. Low pass filter rejects high-frequency component, it also used remove noise and smooth signal.

## 3.3 Flowchart





Input patient data ( age ,weight, height ,gender )
Calculate body composition parameters
If age>=20 && age<=39
Yes
No
If age>=40 && age<=59
Yes
No
If age>=60 && age<=92
Yes
No
Show Massege "Enter right age"
If Gender=0
Yes
No
If Body composition =normal
No
Yes
Display Results, state,advise
Display Results, normal
If Body man composition =normal
Yes
No
Display Results, normal
Display Results, state,advise
End

# Chapter 4

# Simulation &Implementation

## 4.1 Introduction

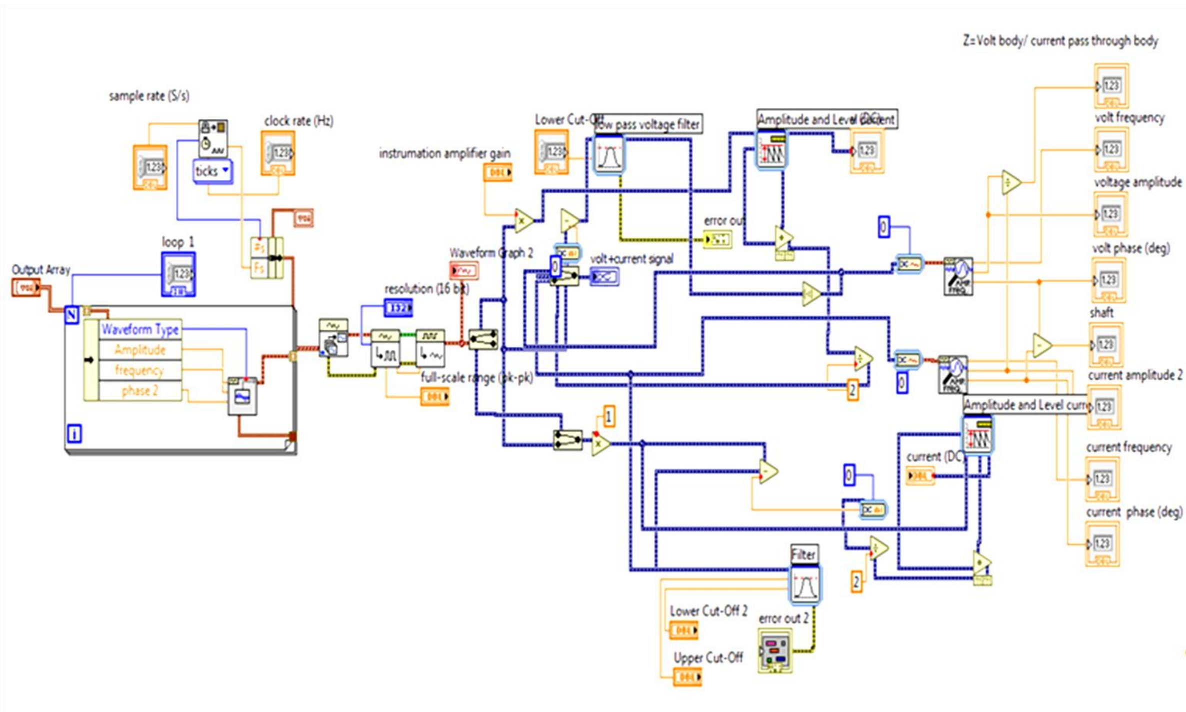
The chapter is organized as follows. Section 4.1.1 present describe simulation of our project . section 4.1.2 explains labview block diagram . section 4.1.3 analysis all part simulation . Finally, section 4.2 explain summary chapter.

## 4.2 describe simulation

We use the labview program to simulation our project by simulation current and voltage to calculate bioimpedance with calculate equation the body composition ( free fat mass ,fat mass , total body water ,skeletal muscle mass, body mass index ,total body potassium ,body cell mass )and include simulation :

- Generator sine wave signal to injection current to body .
- Calculate impedance body and phase through current and voltage detected .
- Calculate all equation body composition and display resulted .
- Diagnosis the states body used loop structures .

This block diagram circuit our project as explain :



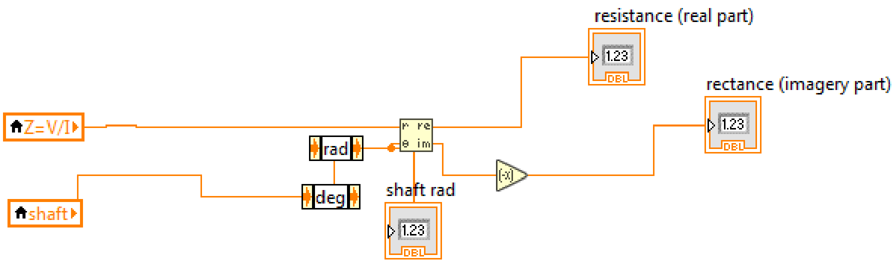
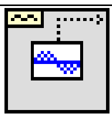



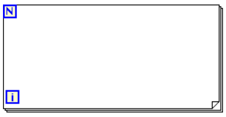
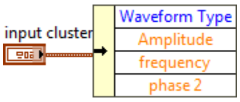
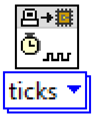
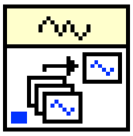
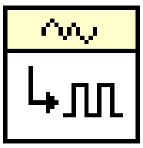
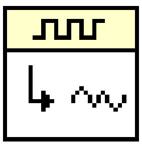
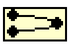

Figure 4.1:labview block circuit our projects.

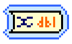
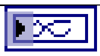
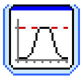
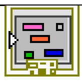
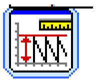
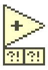
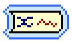
## 4.3 labview block diagram

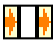
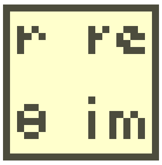
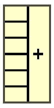
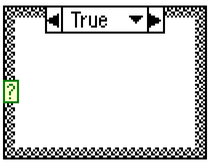
Which terminals used us to simulate block diagram process name and the function in the table .

Table 4.1: terminal name and function used in our project.

| Terminal | | Name | Function |
|---|---|---|---|
| 1 |  | Sine Waveform VI | To generates a waveform a sine wave |

| | | | |
|---|---|---|---|
| 2 |  | For Loop | To provides the current loop iteration count and repeat generate signal |
| 3 |  | Unbundle By Name Function | To returns the cluster elements whose names you specify and binding data |
| 4 |  | Sample Rate To Loop Time VI | To desired sample rate to the appropriate count for the Loop Timer as clock and computes the achievable sample rate . |
| 5 |  | Index Waveform Array VI | Selects one waveform out of an array of analog or digital waveforms by array index or channel name. |
| 6 |  | Analog to Digital VI | Converts analog waveform to a digital waveform to provide less amplitude signal detect . |
| 7 |  | Digital to Analog VI | To convert digital data to analog waveform that injection with current . |
| 8 |  | Merge Signals Function | To Merges two or more supported signals. |

| | | | |
|---|---|---|---|
| 9 |  | Convert from Dynamic Data Express VI | To Converts the dynamic data type to numeric, Boolean, waveform, and array |
| 10 |  | Waveform Graph display | Display output waveform |
| 11 |  | Filter Express VI | Processes signals by low pass or high filters |
| 12 |  | Error output | Detect which icon error |
| 15 |  | Amplitude and Level Measurements Express VI | To voltage or current measurements on a signal |
| 16 |  | Add Function | Add to two waveform values or dynamic data |
| 17 |  | Convert from Dynamic Data Express VI | Converts the dynamic data type to waveform |
| 18 |  | Negate Function | Negates the input value |
| 19 |  | Extract Single Tone Information VI | To finds the single complex with the highest amplitude or a specified frequency range, and detect frequency, amplitude, and phase to this signal measure |

| | | | |
|---|---|---|---|
| 20 |   | Numeric indicator | To indicate the number of interest |
| 21 |   | Numeric control | TO control the amplitude input |
| 22 |   | Local Variable | Use local variables to read or write to one of the controls or indicators on the front panel of a VI |
| 23 |  | Convert Unit Function | Converts a physical number that has a unit to other unit |
| 24 |   | Polar To Re/Im Function | Converts the polar components of a complex number into its rectangular components (real and imagery) . |
| 25 |  | Compound Arithmetic Function | Add one or more number |
| 26 |   | Case Structure | Contains one or more sub diagrams, to case selector determines which case to execute. |

| | | | |
|---|---|---|---|
| 27 |  | Round To Nearest Function | Rounds the input to the nearest integer |
| 28 |  | To Long Integer Function | Converts a number to a 32-bit integer in the range –(2^ 31) to (2^ 31)–1 |
| 29 |  | Status | Display that state find on that write on |

## 4.4 Analysis parts simulation

We divide all stimulate to part and explain with figure their following .

### 4.4.1 Generator sine wave signal block

start sampling time is set (clock ticks per sample) to repeatedly send the same array of numerical values to obtain a periodic signal . it is especially important to indicate with high frequencies and more than signal frequency input needed or must be the sample frequency must be bigger or equal to two times the biggest frequency we need frequency to 100kHz so the sampling rate must be 200kHz . Frequency of the current signal injected into the body is a sinus wave, it must be range 10 to 100KHz and amplitude signal .resolution output frequency convert analog to digital and limit current limit the quantity of current going through the body is limited due to health issues to less 1mA .

The output frequency of indicted compiler is calculated by using equation (4.1).

$$f_{out} = \frac{f_{clk}\Delta\theta}{2^{B_{\theta(n)}}} \quad (4.1)$$

The output signals namely the injected current to the tissue defined by equations (4-2)

$$S_{output}(t) = A_{.}\, sin(\omega_{\circ} n)\ (4.2)$$

$S_{out}$ is sinewave have A amplitude as show figure (4.2).

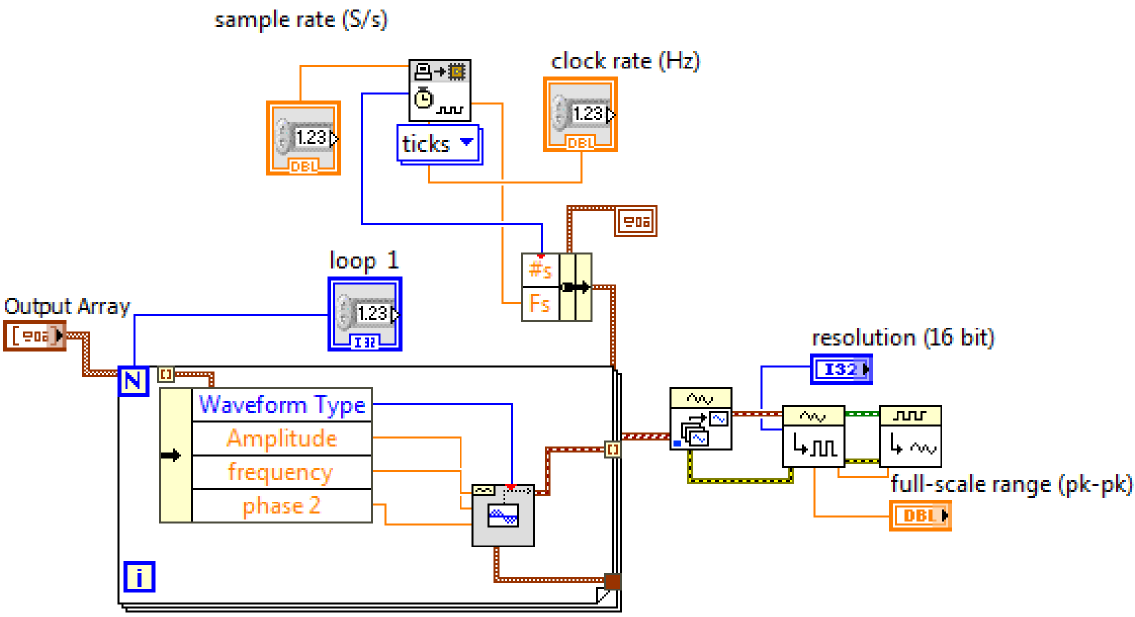



Figure 4.2: Generator sine wave signal block

### 4.4.2 Computation of Complex Voltage and Current

The current when pass through body change voltage with change frequency and change current . we used low pass filter to remove the low output offset and low noise, and to work and be stable at the work-range frequency (100 – 110 kHz) and measure resistance range (100Ω – 2kΩ), and to have a bias current lower than 10nA. The measured tissue voltage is the input signal defined in equation (4.3):

$$V_t(t) = V_{.} \sin(\omega_{\circ} t + \emptyset)\ (4.3)$$

The injected signal $V_0$ is generally low amplitude for the current response remains linear, so the expression of the current response is:

$$i_t(t) = \mathrm{I} \sin(\omega_{\circ} t + \emptyset)\ (4.4)$$

∅ is the delay between the measured voltage and injected current . Each signal is then fed to a digital low pass filter to form a good return signals picked, the one that calculates the parameters for the different measurement such as the frequency, amplitude and phase. To measure the complex impedance we need two essential parameters which are the amplitude and phase of the two signals of voltage and current sampled, the impedance is calculated by equation (4,4 )

$$Z\angle\theta = \frac{V\angle\theta 1}{I\angle\theta 2} \quad (4.4)$$

The calculate real and reactance from impedance and phase as explain equation (4.5,6,7 ) as show figure (4.3).

$$Z = Re * \cos(\emptyset) - j\sin(\emptyset) \quad (4.5)$$

$$Re = |z| * \cos\emptyset \quad (4.6)$$

$$im = |z| \sin\emptyset \quad (4.7)$$

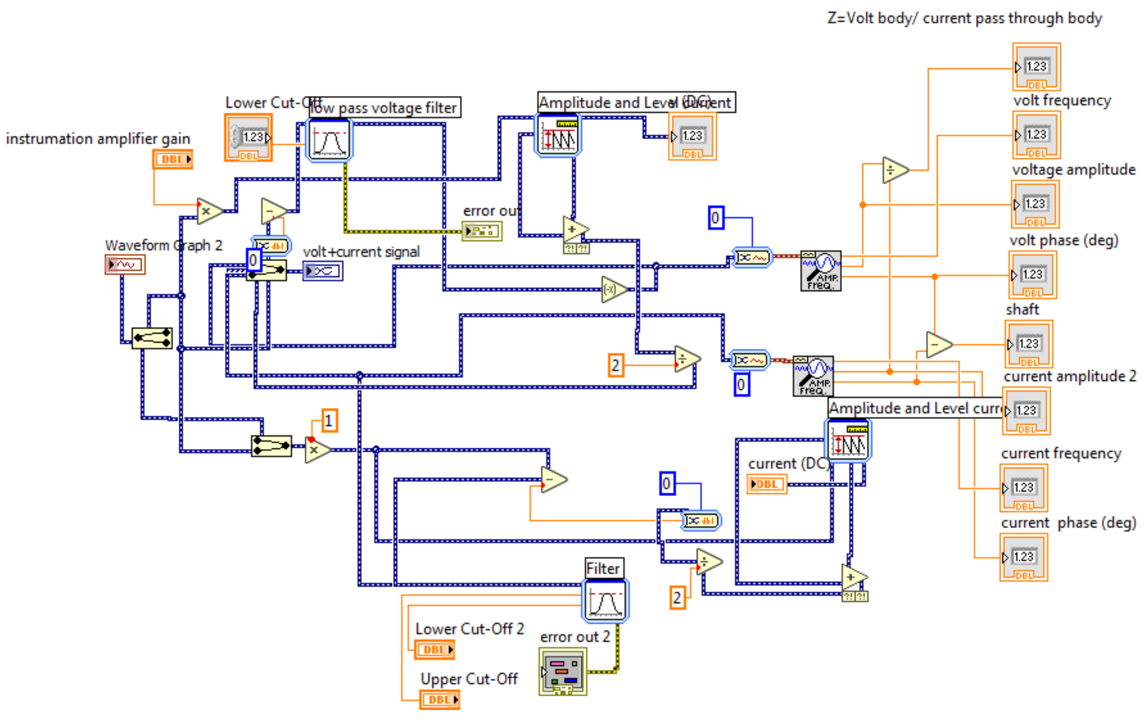



Figure 4.3: block measure voltage and current and calculate impedance.

### 4.4.3 Block calculate all equation body composition and display

- Total Body Water ( TBW)

Calculate total body water after indicate input parameter and calculate impedance by equation TBW ( Total Body Water) = 0.372 * ht2 (height) / R (impedance) + 0.142 * weight - 0.069 * age + 3.05 * gender ; M=0 ,Fem=1 [32, 50] as labview block explained in figure (4.4 ) .

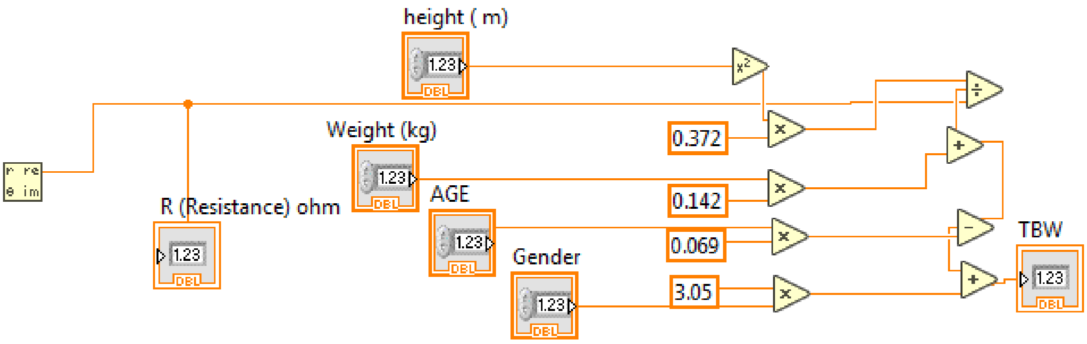



Figure 4.4:Block Calculate total body water

After the measure this value compare with standard data work case structure in labview loop and display states as labview block explained in figure (4.5 ) .

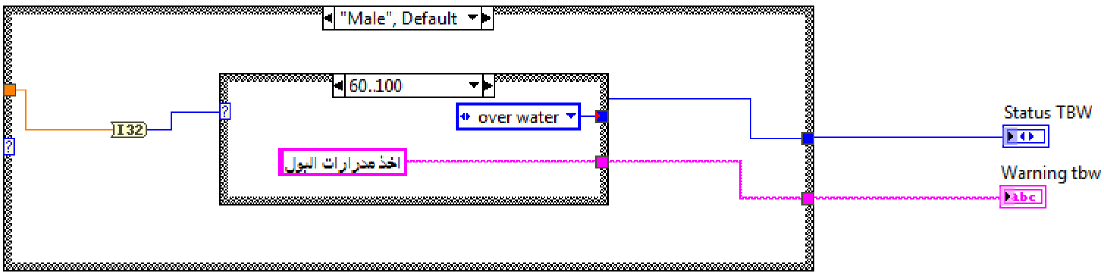



Figure 4.5:Display state water loop.

- Body Fat Percent ( BFP)

Calculate Body Fat Percent depend on Free Fat Mass (FFM) and Fat Mass (FM) after indicate input parameter and calculate impedance by equation :

FFM= -4.104 +0.518ht2/R50 +0.231 * weight + 0.130* Xc +4.229 * gender [50, 51].

FM = (weight - FFM) .

BFP= (FM /Weight) *100 [28], as labview block explained in figure (4.6 ) .

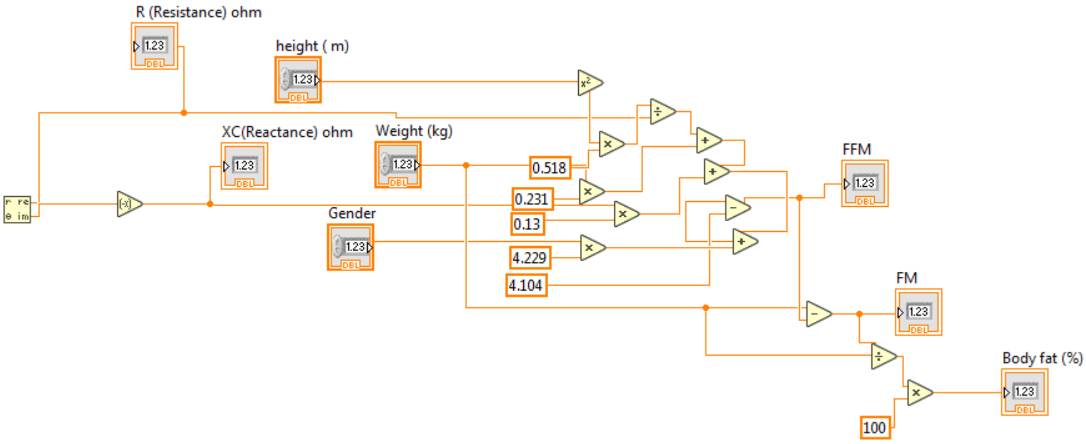



Figure 4.6:Block Calculate body fat percent.

After the measure this value compare with standard data work case structure in labview loop and display states as labview block explained in figure (4.7 )

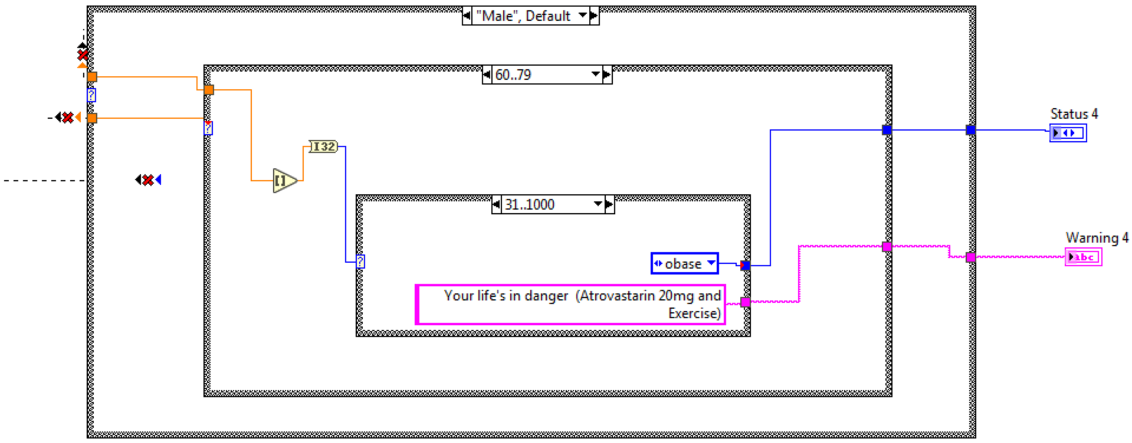



Figure 4.7:Block state display with advice to body fat.

- Body Cell Mass (BCM) and Total Body Potassium (TBK) and Skeletal Muscle Mass (SMM) .

Calculate Body Cell Mass and Total Body Potassium and Skeletal Muscle Mass after indicate input parameter and calculate impedance by equation :

BCM= ((1.898* 〖((Ht )/100)〗 ^2)/(x+(R/X))+(0.051*weight )+(4.180*gender)+15.496 [28] . TBK= BCM / (0.00833 ) (mmol) [52].

SMM= -4.211+((0.267* 〖((Ht )/100)〗 ^2*104)/R)+(0.095*weight )+(1.909*gender)-0.012*age +0.058*X [53] . As explain in figure (4.8) .

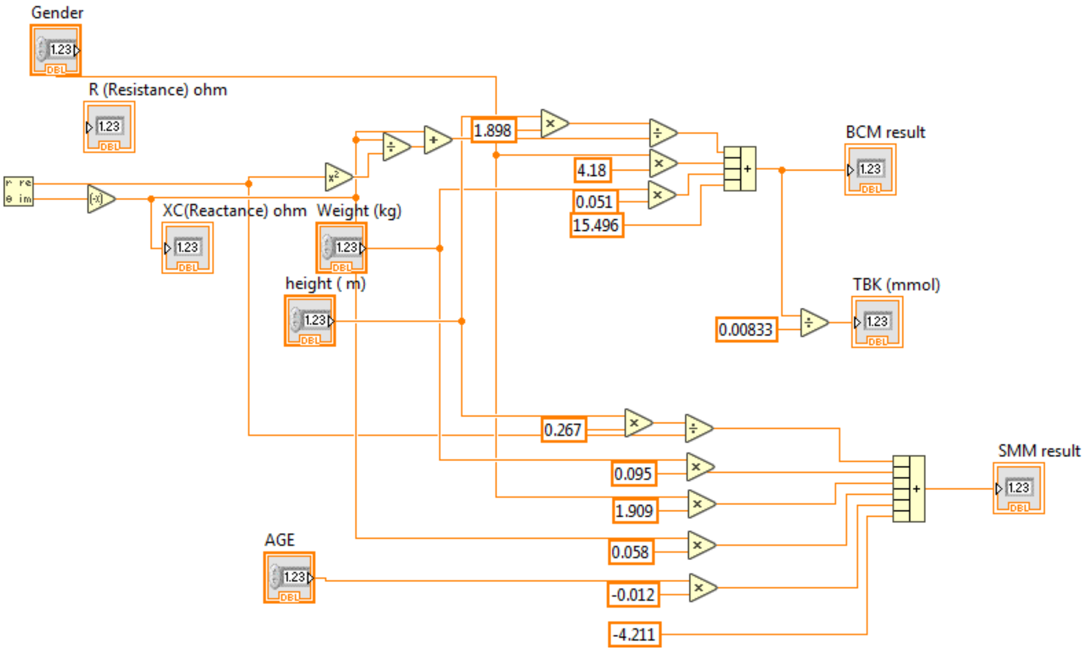



Figure 4.8:Block calculate Body Cell Mass and Total Body Potassium and Skeletal Muscle Mass

- Body Mass Index (BMI)

This parameter depend on the height and weight only and calculate equation that explain block diagram in labview with display states as figure (4.9 ).

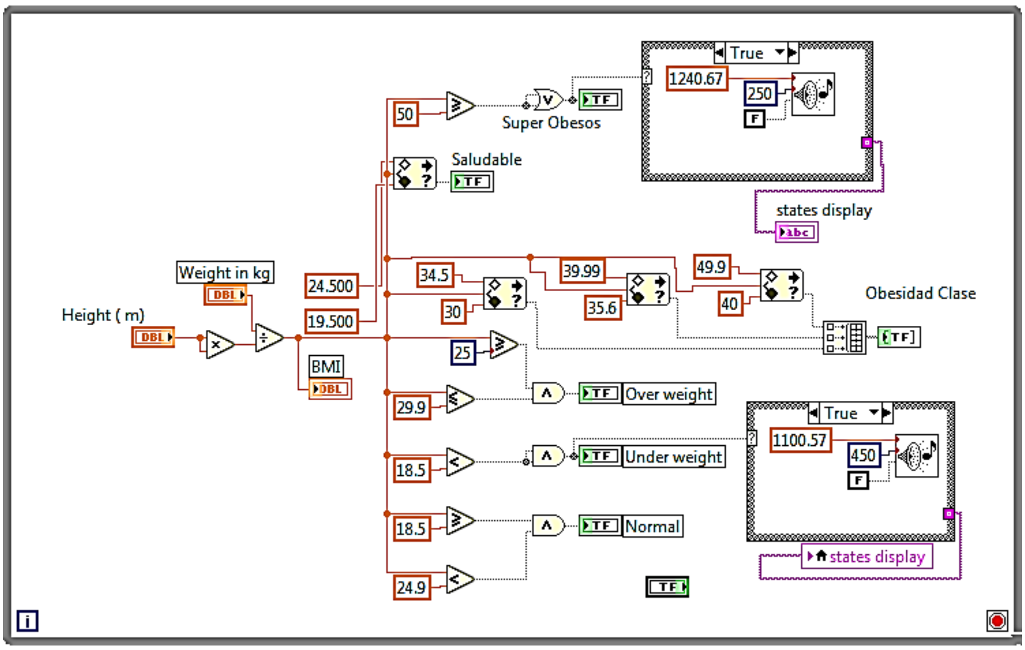



Figure 4.9: Block calculate body mass index with display states

## 4.5 Implementation Of Project

In this part of the project we will review the pieces used in our project with the most important use the pieces with specifications and build circuit in protus.

The hardware is composed of AD5933 board impedance analyzer, Voltage Controlled Current Source (VCCS), Instrument Amplifier, Microcontroller (arduino),bluetooth HC-05 as explain figure ( 4.10).

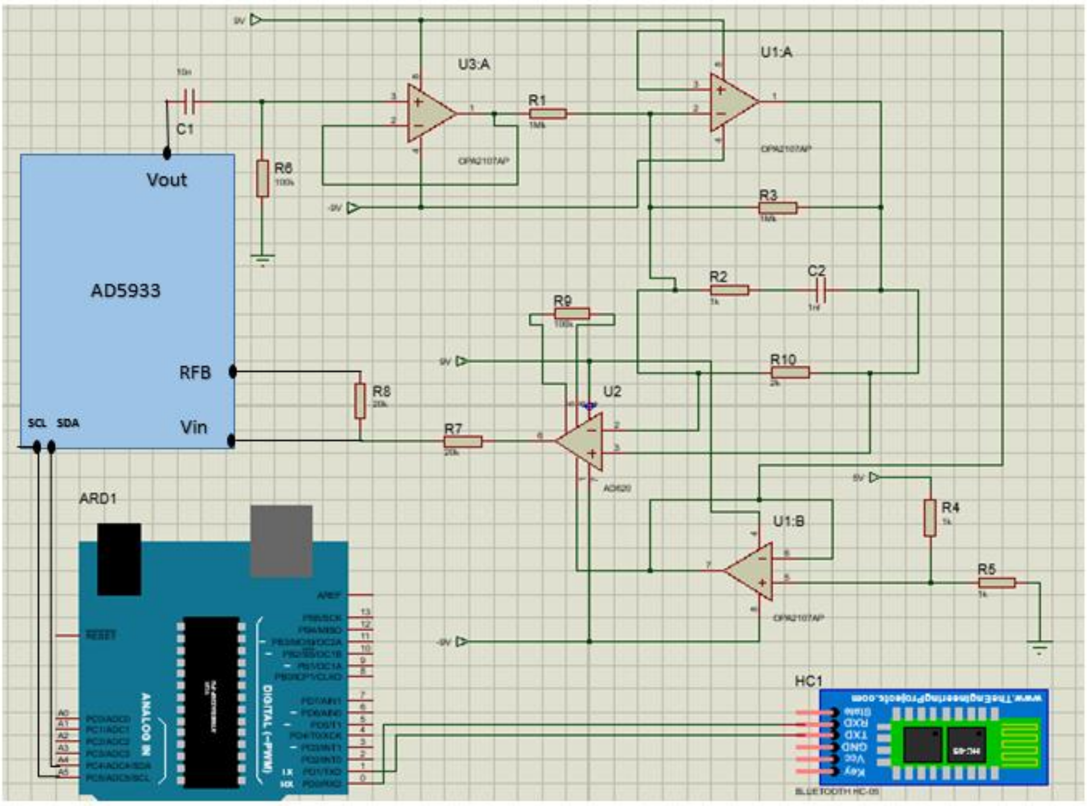



Figure 4.10:Build project circuit in Proteus 8.6

## 4.6 Implementation Of Project

In this part of the project we will review the pieces used in our project with the most important use the pieces with specifications and build circuit in protus.

The hardware is composed of AD5933 board impedance analyzer, Voltage Controlled Current Source (VCCS), Instrument Amplifier, Microcontroller (arduino),bluetooth HC-05 as explain figure ( 4.10).

## A. AD5933 and high pass filter

The AD5933 is a 12-bit precision impedance converter which combines an on board frequency generator with a 1 MSPS Analog-to-Digital Converter (ADC) and a Digital Signal Processor (DSP) engine which performs the impedance estimation. It is can generate a voltage signal with adjustable frequency up to 100 kHz with a resolution of 0.1 Hz the signal generate by clock internal by trimmed 16 MHz crystal the output peak signal reach 1.98 V .Than the a high pass filter using to cancel the DC component of the signal and set it back to VDD/2 from the voltage output of the AD5933 and used high pass filter to remove frequency small that can effect on body , the high pass filter has a cutoff frequency for $R_5$ and $C_1$:

$$f_{c}=\frac{1}{2\pi*(100kohm)*(10nF)}=1.591kHz$$

After filter we used voltage follower ($U_3$-3B ) help don't interface with recurrent resistance $R_1$ that control the current as Vout/ R we need 100uA so the resistance equal to 10kohm with OpAmp ( $U_1$:A ) convert voltage current by After the current sensing resister there is an op-amp in a negative feedback configuration. This is called Load-in-the-Loop setup. The positive input terminal of the op-amp is connected to a VDD/2 voltage. The op-amp will adjust its output in the opposite direction to the excitation signal such that the voltage at the negative terminal will be equal to VDD/2 . This will produce a seesawing potential pushing and pulling the current through the body. The current drawn from the negative terminal of the op-amp is virtually zero. All the current through the current sensing resistor therefore has to flow through the body. This is the mechanism that makes this setup a trans-conductance amplifier (also called a voltage controlled current source, VCCS) and apply a constant-amplitude current to the injecting electrode differential voltage is detected in two additional electrodes by AD620 is instrumentation amplifier able to amplify a voltage difference from a very small current source. We chose resistor values to achieve an overall gain of 3. The voltage-measuring electrodes are inputted into the instrumentation amplifier. OpAmp $U_1$:B connect reference AD620 that implicate the offset voltage necessary for the AD5933 in this stage as well. By setting the reference voltage of the instrumentation amplifier to 2.5 V, we ensure the acceptable range. This offset voltage was achieved by using the 3.3 V source pin from the arduino and a voltage divider with resistor values R5=1kohm R4=3.2kohm in order to achieve 2.5V. The output of the instrumentation amplifier is then fed into the AD5933 input.

feedback Resistor (Rfb) values and the corresponding ranges they are used to measure range impedance The response signal of external impedance by on-chip A/D converter ADC sampling, in order to ensure that the system is linear and avoid signal response signals over the ADC range, at the time of measurement should be an external feedback resistor, feedback resistor selection range is calculated according to the measured impedance is obtained, and then the DFT transform of DAC data by DSP. DFT algorithm returns a real part (R) and a mirage part (I) at each frequency .than arduino read a real part (R) and a mirage part (I) from register AD5933 and calculate impedance and sent by value a real part (R) and a mirage part (I) and impedance by bluetooth serial to smartphone .

## 4.7 standard current safety

The IEC 60601 is a series of technical standards for the patient/wearer safety and effectiveness of medical electrical equipment, published by the International Electrotechnical Commission . This standard specifies the limits of patient leakage currents and patient auxiliary currents under normal conditions and single fault conditions4. These current limits are important parameters in the circuit design.

The maximum DC current allowed to be sourced in the body in normal conditions has to be less than or equal to 10uA and the maximum DC current under single fault condition in the worst scenario is 50uA.

The maximum AC current allowed to be sourced in the body in normal conditions depends on the frequency. If the excitation frequency is less than or equal to 1 kHz, the maximum allowed current is 10uARMS. If the excitation frequency (FE) is greater than 1 kHz, the maximum current is defined by the *Equation 1* [48].

$$I_{Ac}\,\mathrm{max}=\frac{F_E}{1000Hz}\times 10uF \quad (4-8)$$

.

# Chapter 5

# Results and Conclusion

## 5.1 Results

This chapter contains practical results with tests and discussions of these results.

Result software device in labview output display show in this figure (3.5 and 3.6).

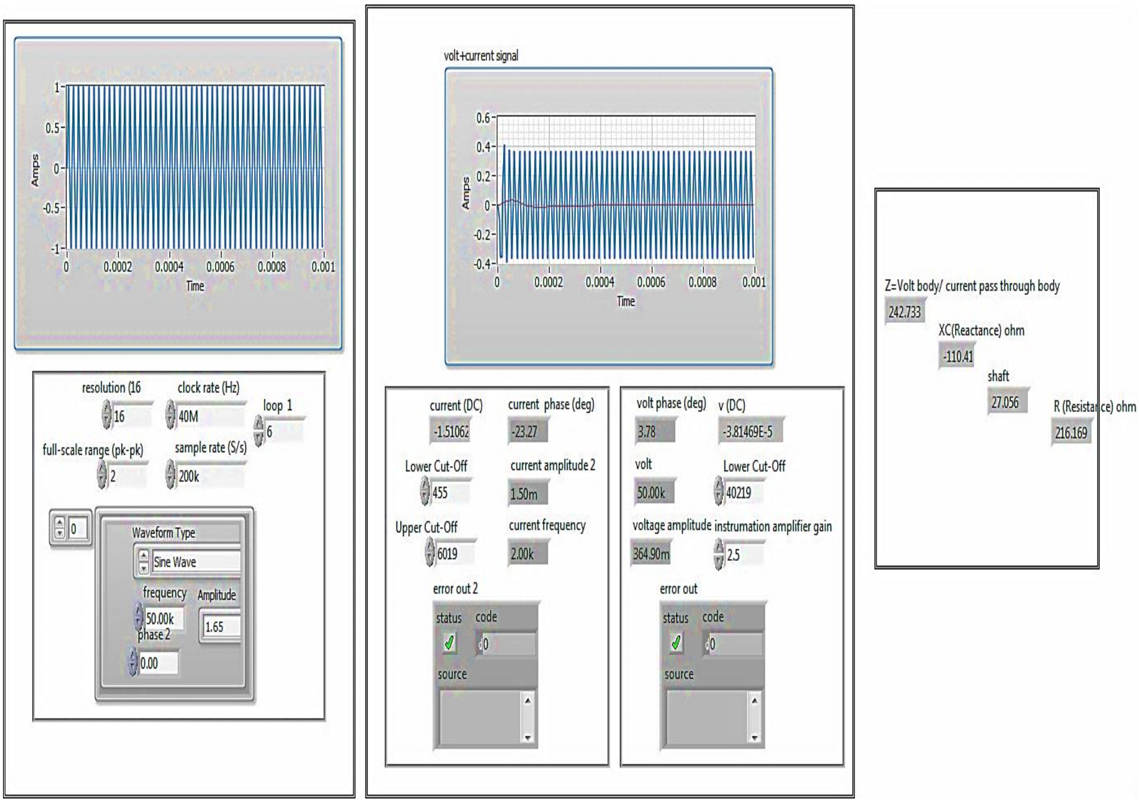



Figure 5.1:Labview front panel screen display.

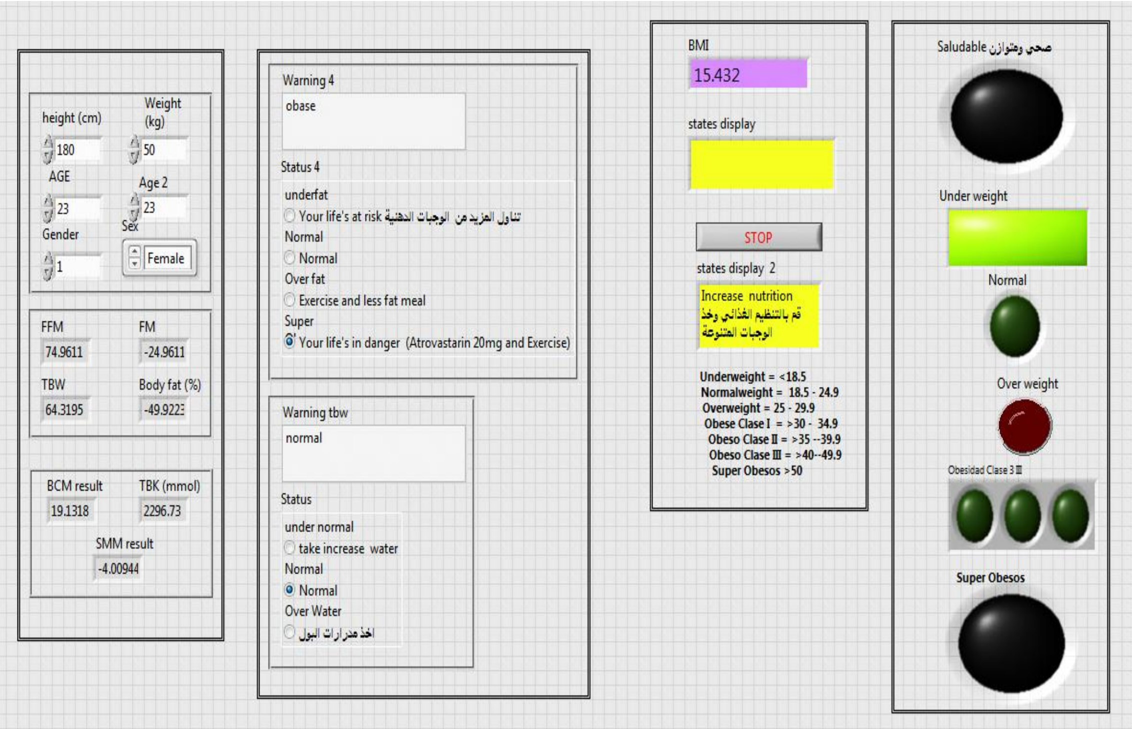



Figure 5.2:Labview front panel screen display.

## 5.2 Hardware the results test

We succuffully in design device the project as show figure ( ) .

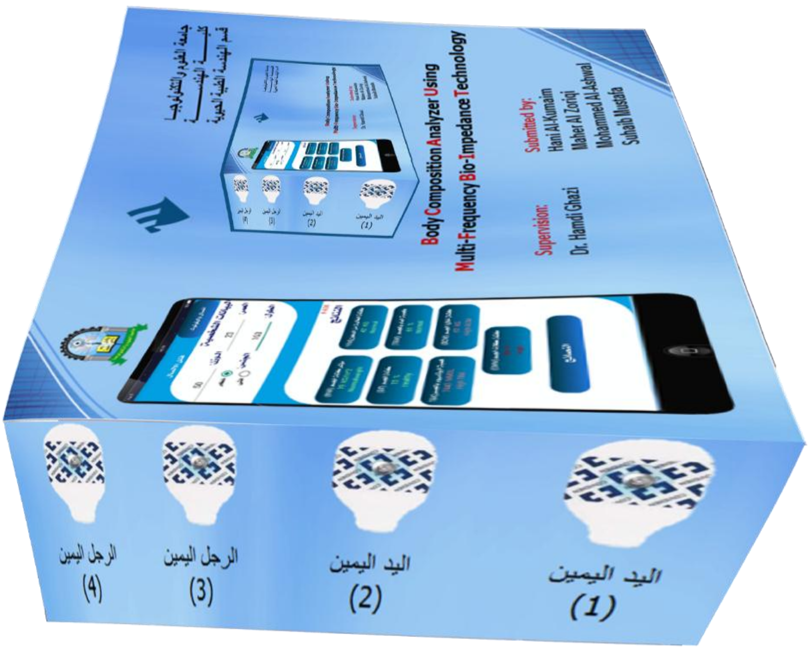



Table 5.1: show the results hardware test

| Analyze data | | | | |
|---|---|---|---|---|
| | $Man_1$ | $Man_2$ | $Man_3$ | Normal Range |
| Age | 24 | 24 | 23 | 18-40 |
| Weight ( Kg) | 55 | 69 | 65 | 40-100 |
| Height (cm) | 174 | 170 | 169 | 120-200 |
| BMI ($Kg/m^2$ ) | 18 | 24 | 22 | 18-22 |
| BF(%) | 14 | 19 | 22 | 8-3 |
| FFM (Kg) | 43 | 42 | 42 | 32-64 |
| TBW (%) | 57 | 53 | 49 | 40-65 |
| BCM (kg) | 22 | 23 | 23 | 17.2–39.0 |
| SMM (kg) | 66 | 62 | 69 | 71%-76% |
| TBK (mmol) | 2641 | 2761 | 2761 | 1,672–4,365 |

Table 5.2:

| Analyze data | | | | |
|---|---|---|---|---|
| | $Man_1$ | $Man_2$ | $Man_3$ | Normal Range |
| Age | 22 | 23 | | 18-40 |
| Weight ( Kg) | 46 | 50 | | 40-100 |
| Height (cm) | 160 | 163 | | 120-200 |
| BMI ($Kg/m^2$ ) | 18 | 19 | | 18-22 |
| BF(%) | 10 | 13 | | 8-3 |
| FFM (Kg) | 39 | 42 | | 32-64 |
| TBW (%) | 63 | 61 | | 40-65 |
| BCM (kg) | 26.52 | 23 | | 17.2–39.0 |
| SMM (%) | 72 | 70 | | 49-73% |
| TBK (mmol) | 3121 | 3734 | | 1,672–4,365 |

Table 5.3: show the results hardware test

| Analysed data | | | | |
|---|---|---|---|---|
| | Man 4 | Man 5 | Man 6 | |
| Age | 52 | 46 | | |
| Weight ( Kg) | 70 | 80 | | |
| Height (cm) | 165 | 172 | | |
| BMI ($Kg/m^2$ ) | 26 | 27 | | 18.5 - 24.9 |
| BF(%) | 26 | 32 | | 11% - 21% |
| FFM (Kg) | 48 | 46 | | 32-64 |
| TBW (%) | 50 | 43 | | 50%-65% |
| BCM (kg) | 23 | 24 | | 17-39 |
| SMM | 39 | 47 | | |
| TBK (mmol) | 2761 | 2881 | | |
| | | | | |

Table 5.4: show the results hardware test

| Analysed data | | | | |
|---|---|---|---|---|
| | Man | | Women | |
| Age | | | | |
| Weight ( Kg) | | | | |
| Height (cm) | | | | |
| BMI ($Kg/m^2$ ) | | | | |
| BF(%) | | | | |
| FFM (Kg) | | | | |

| | | | | |
|---|---|---|---|---|
| TBW (%) | | | | |
| BCM (kg) | | | | |
| SMM (kg) | | | | |
| TBK (mmol) | | | | |
| | | | | |

## 5.3 Conclusion

We have successfully implemented a body composition analyzer using multi-frequency bio-impedance technology and measures fat-free mass, percentage body fat, total body water, skeletal muscle mass, body cell mass, and total body potassium and classify obesity level by body mass index.

Also, we have succeeded in designing an Android application that displays the results with medical advice to assess the health of the human body.

The range bioimpedance (resistance, reactance) measured in the project between 120 – 1000 ohm .

Results in the project were in the range evaluation by World Health Organization and Tanita company, but we unable to compare the project results measured in the project with a device with high accuracy because we could not find a device able to comparing results project.

## 5.4 Future work

We displayed here a few proposals and recommendations for the further advancement of future improvement or expansions of the project.

- adding display screen and memory storage data.
- comparing the results of the device with another device has high accuracy.
- Adding a sensor can be measuring the weight of the person to the device circuit.
- Expanding the database for pre-identifying and diagnosing diseases related to body composition change as chronic obstructive pulmonary disease (such as malnutrition in obese and underweight patients with chronic obstructive pulmonary disease, water retention).

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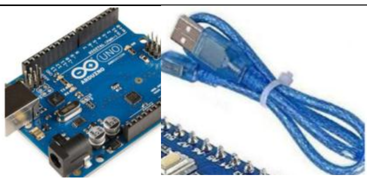
# Appendix

- Electronic piece the project cost.

| NO. | Description | Widget image | Cost ( $) | Quantity |
|---|---|---|---|---|
| 1 | AD5933 |  | 99$ alibaba china store | 1 |
| 2 | Microcontroller (arduino uno) |  | $2 alibaba china store | 1 |
| 3 | AD620 |  | $6 Amazon site USA | 1 |
| 4 | OPA2134 |  | $3 Amazon site USA | 2 |
| 5 | Covidien Electrodes 530 |  | $5 Amazon site USA | 60 |

| | | | | |
|---|---|---|---|---|
| 6 | Bluetooth HC-05 |  | 2$ Amazon site USA ۱ | 2 |
| 7 | Resistors &Capacitors | | 1. | |
| 8 | Battery Power Supply | LITHIUM BATTER 5-9V | 7$ | 2 |
| 9 | telephone | | $25 | 1 |

- Data sheet AD5933 specifications

| Parameter | Y Version[1] Min | Typ | Max | Unit | Test Conditions/Comments |
|---|---|---|---|---|---|
| SYSTEM | | | | | |
| Impedance Range | 0.001 | | 10 | MΩ | |
| Total System Accuracy | | 0.5 | | % | |
| System Impedance Error Drift | | 30 | | ppm/°C | |
| TRANSMIT STAGE | | | | | |
| Output Frequency Range[2] | 1 | | 100 | kHz | |
| Output Frequency Resolution | | 0.1 | | Hz | <0.1 Hz resolution achievable using DDS techniques. |
| MCLK Frequency | | | 16.776 | MHz | Maximum system clock frequency. |
| Internal Oscillator Frequency[3] | | 16.776 | | MHz | Frequency of internal clock. |
| Internal Oscillator Temperature Coefficient | | 30 | | ppm/°C | |

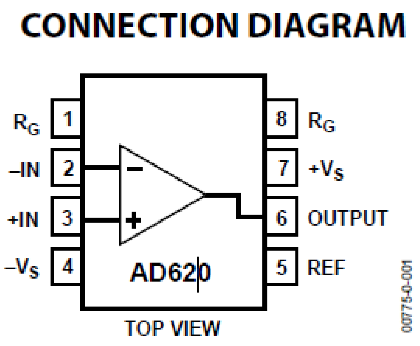
| | | | |
|---|---|---|---|
| TRANSMIT OUTPUT VOLTAGE | | | |
| Range 1 | | | |
| AC Output Excitation Voltage[4] | 1.98 | V p-p | Refer to Figure 4 for output voltage distribution. |
| DC Bias[5] | 1.48 | V | DC bias of the AC excitation signal. See Figure 5. |
| DC Output Impedance | 200 | Ω | $T_A$ = 25°C. |
| Short-Circuit Current to Ground at VOUT | ±5.8 | mA | $T_A$ = 25°C. |
| Range 2 | | | |
| AC Output Excitation Voltage[4] | 0.97 | V p-p | See Figure 6. |
| DC Bias[5] | 0.76 | V | DC bias of output excitation signal. See Figure 7. |
| DC Output Impedance | 2.4 | kΩ | |
| Short-Circuit Current to Ground at VOUT | ±0.25 | mA | |
| Range 3 | | | |
| AC Output Excitation Voltage[4] | 0.383 | V p-p | See Figure 8. |
| DC Bias[5] | 0.31 | V | DC bias of output excitation signal. See Figure 9. |
| DC Output Impedance | 1 | kΩ | |
| Short-Circuit Current to Ground at VOUT | ±0.20 | mA | |
| Range 4 | | | |
| AC Output Excitation Voltage[4] | 0.198 | V p-p | See Figure 10. |
| DC Bias[5] | 0.173 | V | DC bias of output excitation signal. See Figure 11. |
| DC Output Impedance | 600 | Ω | |
| Short-Circuit Current to Ground at VOUT | ±0.15 | mA | |
| Short-Circuit Current to Ground | ±0.15 | mA | |

| | | | |
|---|---|---|---|
| SYSTEM AC CHARACTERISTICS | | | |
| Signal-to-Noise Ratio | 60 | dB | |
| Total Harmonic Distortion | −52 | dB | |
| Spurious-Free Dynamic Range | | | |
| Wide Band (0 MHz to 1 MHz) | −56 | dB | |
| Narrowband (±5 kHz) | −85 | dB | |

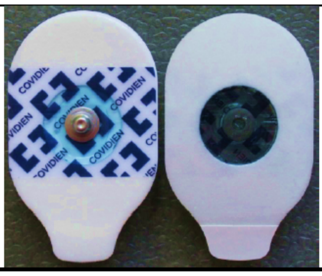
| | | | | | |
|---|---|---|---|---|---|
| RECEIVE STAGE | | | | | |
| Input Leakage Current | | 1 | | nA | To VIN pin. |
| Input Capacitance[6] | | 0.01 | | fF | Pin capacitance between VOUT and GND. |
| Feedback Capacitance $C_{FB}$ | | 3 | | pF | Feedback capacitance around current-to-voltage amplifier; appears in parallel with feedback resistor. |
| ANALOG-TO-DIGITAL CONVERTER[6] | | | | | |
| Resolution | | 12 | | bits | |
| Sampling Rate | | 250 | | kSPS | ADC throughput rate. |
| TEMPERATURE SENSOR | | | | | |
| Accuracy | | ±2.0 | | °C | −40°C to +125°C temperature range. |
| Resolution | | 0.03 | | °C | |
| Temperature Conversion Time | | 800 | | µs | Conversion time of single temperature measurement |
| LOGIC INPUTS | | | | | |
| Input High Voltage ($V_{IH}$) | 0.7 × VDD | | | | |
| Input Low Voltage ($V_{IL}$) | | | 0.3 × VDD | | |
| Input Current[7] | | | 1 | µA | $T_A$ =25°C. |
| Input Capacitance | | | 7 | pF | $T_A$ = 25°C. |
| POWER REQUIREMENTS | | | | | |
| VDD | 2.7 | | 5.5 | V | |
| IDD (Normal Mode ) | | 10 | 15 | mA | VDD = 3.3 V. |
| | | 17 | 25 | mA | VDD = 5.5 V. |
| IDD (Standby Mode) | | 11 | | mA | VDD = 3.3 V; see the Control Register section. |
| | | 16 | | mA | VDD = 5.5 V. |
| IDD (Power-Down Mode) | | 0.7 | 5 | µA | VDD = 3.3 V. |
| | | 1 | 8 | µA | VDD = 5.5 V. |

- Specification AD620

| | |
|---|---|
| Easy to use | |

| | |
|---|---|
| Gain set with one external resistor<br>(Gain range 1 to 10,000)<br>Wide power supply range (±2.3 V to ±18 V)<br>Higher performance than 3 op amp IA designs<br>Available in 8-lead DIP and SOIC packaging<br>Low power, 1.3 mA max supply current<br>Excellent dc performance (B grade)<br>50 $\mu$V max, input offset voltage<br>0.6 $\mu$V/°C max, input offset drift | <br>1.0 nA max, input bias current<br>100 dB min common-mode rejection ratio (G = 10)<br>Low noise<br>9 nV/$\sqrt{}$Hz @ 1 kHz, input voltage noise<br>0.28 $\mu$V p-p noise (0.1 Hz to 10 Hz)<br>Excellent ac specifications<br>120 kHz bandwidth (G = 100)<br>15 $\mu$s settling time to 0.01% |

- Specification Covidien™ H92SG electrode



| 1. Basic Product Information | |
|---|---|
| Shape / size (incl. grip) | *Oval / 57 x 34 mm* |
| Total product surface (incl. grip) | *1522 mm²* |
| Gel area | *254 mm²* |
| Adhesive area | *1050 mm²* |
| Sensor area | *50 mm²* |
| Product thickness (adapter excluded) | *1 mm* |
| Adapter | *Stud* |
| Integrated lead wire (length / colour) | -- |

| 2. Materials Information | |
|---|---|
| Backing material | *Polyethylene foam (PE), white* |
| Adhesive characteristics | *Medical grade pressure sensitive adhesive* |
| Gel characteristics | *Conductive and adhesive hydrogel* |
| Supporting / back label | *Polypropylene film (PP), transparent* |
| Release liner | *PE/Paper/PE, one side siliconized* |
| Sensor | *Polymer Ag/AgCl coated* |
| Adapter / connector | *Stainless steel* |
| Integrated lead wire jacketing | -- |
| Integrated lead wire cord | -- |

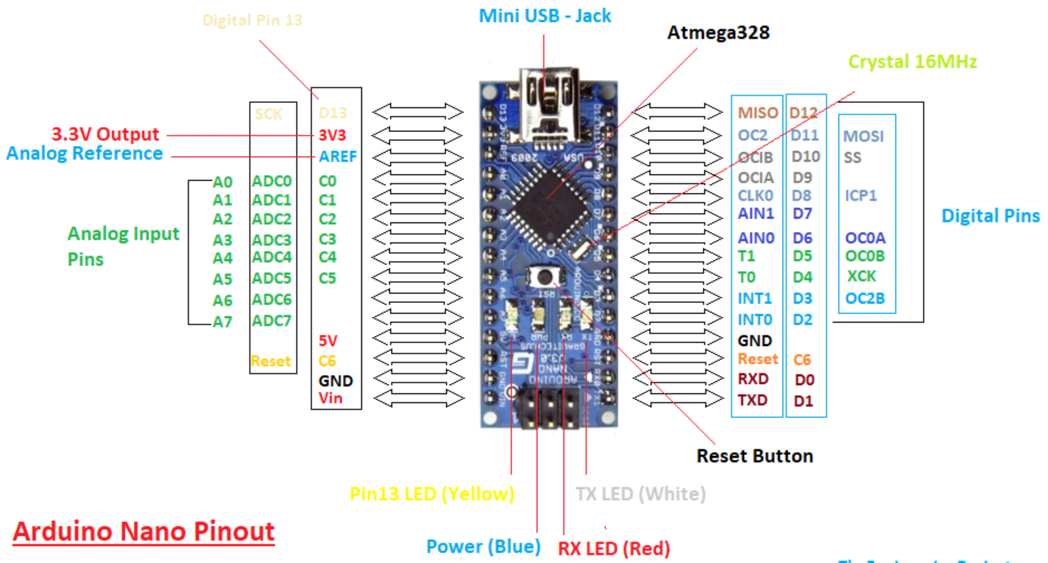
| 3. Electrical Characteristics (ANSI/AAMI EC 12, average measured before packaging) | |
|---|---|
| ACZ I impedance (before defibrillation simulation) | *200 Ohm* |
| DC offset voltage (before defibrillation simulation) | *0.2 mV* |
| SDR (remaining potential after defibrillation simulation) | *11 mV* |
| Slope (potential decline after defibrillation simulation) | *0.2 mV/s* |
| COIIN (combined offset instability and inner noise) | *4 μV* |
| Bias current tolerance (DC offset voltage after DC loading) | *6 mV* |

| 4. Special Features | |
|---|---|
| MRI compatibility (≤ 3T) | *no* |
| X-ray translucence | *no* |
| Peel off resistance, max. (from PE foil, 180 °, 50 mm/min, ASTM D1876) | *5 N* |
| Integrated abrader | *no* |
| Repositionability | *no* |

| 5. Packaging | L x W x H (mm) | Content (electrodes) | Material |
|---|---|---|---|
| Product packaging (pouch) | *220 x 180* | *50* | *Paper / PE / Alu / PE* |
| Department packaging (box) | *194 x 194 x 240* | *500* | *Paper cardboard* |
| Transport packaging (carton) | *600 x 400 x 510* | *6000* | *Paper cardboard* |

| 6. Biocompatibility | |
|---|---|
| Test acc. to DIN ISO 10993 | *passed* |
| LATEX content | *no* |

- Arduino Nano Specification



Arduino Nano Pinout

| | |
|---|---|
| **Microcontroller** | Atmega328p/Atmega 168 |
| **Operating Voltage** | 5V |
| **Input Voltage** | 7 – 12 V |
| **Digital I/O Pins** | 14 |
| **PWM** | 6 out of 14 digital pins |
| **Max. Current Rating** | 40mA |
| **USB** | Mini |
| **Analog Pins** | 8 |
| **Flash Memory** | 16KB or 32KB |
| **SRAM** | 1KB or 2KB |
| **Crystal Oscillator** | 16 MHz |
| **EEPROM** | 512bytes or 1KB |
| **USART** | Yes |

- Specification TL072 Data sheet

| PARAMETER | | TL071BC TL072BC TL074BC | | | TL071I TL072I TL074I | | | UNIT |
|---|---|---|---|---|---|---|---|---|
| | | MIN | TYP | MAX | MIN | TYP | MAX | |
| $V_{IO}$ | Input offset voltage | | 2 | 3 | | 3 | 6 | mV |
| | | | | 5 | | | 8 | |
| $\alpha_{V_{IO}}$ | Temperature coefficient of input offset voltage | | 18 | | | 18 | | µV/°C |
| $I_{IO}$ | Input offset current | | 5 | 100 | | 5 | 100 | pA |
| | | | | 2 | | | 2 | nA |
| $I_{IB}$ | Input bias current§ | | 65 | 200 | | 65 | 200 | pA |
| | | | | 7 | | | 20 | nA |
| $V_{ICR}$ | Common-mode input voltage range | ±11 | −12 to 15 | | ±11 | −12 to 15 | | V |
| $V_{OM}$ | Maximum peak output voltage swing | ±12 | ±13.5 | | ±12 | ±13.5 | | V |
| | | ±12 | | | ±12 | | | |
| | | ±10 | | | ±10 | | | |
| $A_{VD}$ | Large-signal differential voltage amplification | 50 | 200 | | 50 | 200 | | V/mV |
| | | 25 | | | 25 | | | |
| $B_1$ | Unity-gain bandwidth | | 3 | | | 3 | | MHz |
| $r_i$ | Input resistance | | $10^{12}$ | | | $10^{12}$ | | Ω |
| CMRR | Common-mode rejection ratio | 75 | 100 | | 75 | 100 | | dB |
| $k_{SVR}$ | Supply-voltage rejection ratio ($\Delta V_{CC\pm}/\Delta V_{IO}$) | 80 | 100 | | 80 | 100 | | dB |
| $I_{CC}$ | Supply current (each amplifier) | | 1.4 | 2.5 | | 1.4 | 2.5 | mA |
| $V_{O1}/V_{O2}$ | Crosstalk attenuation | | 120 | | | 120 | | dB |

**TL072, TL072A, TL072B**
**D, JG, P, PS, OR PW PACKAGE**
**(TOP VIEW)**