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Senior Design Project Report

Bioelectrical Impedance Analyzer

**In partial fulfillment of the requirements for the
Degree of Bachelor of Science in Electrical Engineering**

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Abstract

Common weight scales cannot assess body composition or determine fat mass and fat-free mass that make up the body weight. This research proposes bio-impedance analysis (BIA) tool capable to body composition assessment. This tool uses t electrodes, two of which are used for 50-100 kHz sine wave current flow to the body and the rest are used to measure the voltage produced by the body for impedance analysis. Parameters such as height, weight, age, and gender are provided individually. These parameters together with impedance measurements are then in the process to produce a body fat percentage. The experimental result shows impressive repeatability for successive measurements. Moreover, result on the hand to hand node scheme reveals average absolute difference of total subjects between two analyzer tools of (fat mass) with maximum absolute discrepancy.

Table of Contents

<i>Abstract</i>	2
1. Introduction	5
1.1 Project Definition	5
1.2 Project Objectives	5
1.3 Project Specifications	5
1.4 Product Architecture and Components	5
1.5 Applications	6
2. Literature Review	7
2.1 Project background	7
2.2 Previous Work	7
2.3 Comparative Study	8
3. System Design	9
3.1 Design Constraints	9
3.1.1 Design Constraints: Sustainability	9
3.1.2 Design Constraints: Economic	9
3.1.3 Design Constraints: Safety	9
3.2 Design Methodology	9
3.3 Product Subsystems and Components	10
3.3.1 Product Subsystem 1: Constant current source	10
3.3.2 Product Subsystem 2: Frequency generator	11
3.3.3 Product Subsystem 3: Obtain voltage across electrodes.	12
3.4 Implementation	12
3.4.1 Estimation of Body composition	14
4. System Testing and Analysis	14
4.1 Subsystem 1: <i>Constant AC current source</i>	14
4.2 Subsystem 2: <i>Frequency generator</i>	15
4.3 Subsystem 3: <i>Obtain voltage across electrodes</i>	16
4.4 Overall Results, Analysis and Discussion	16
5. Project Management	22
5.1 Project Plan	22
5.2 Contribution of Team Members	22
5.3 Project Execution Monitoring	22
5.4 Challenges and Decision Making	23
5.5 Project Bill of Materials and Budget	23
6. Project Analysis	24
6.1 Life-long Learning	24
6.2 Impact of Engineering Solutions	24
6.3 Contemporary Issues Addressed	24
7. Conclusions and Future Recommendations	25

7.1	Conclusions	25
7.2	Future Recommendations	25
7.2.1	AD5933	26
7.2.2	Patient Detection	26
7.2.3	Battery size	26
7.2.4	Mobile Application	26
8.	References	27
	Appendix A: Progress Reports	28
	Appendix B: Bill of Materials	28
	Appendix C: Datasheets	29
	Appendix D: Program Codes	31
	Appendix E: Operation Manual	37

1. Introduction

1.1 Project Definition

To design a bioelectrical impedance analyzer that can measure human body impedance to estimate body fat percentage and mass. The analyzer will have subsystems to send a constant AC current that will flow through the body safely, to measure the voltage across the body and circuit isolation to ensure safety.

1.2 Project Objectives

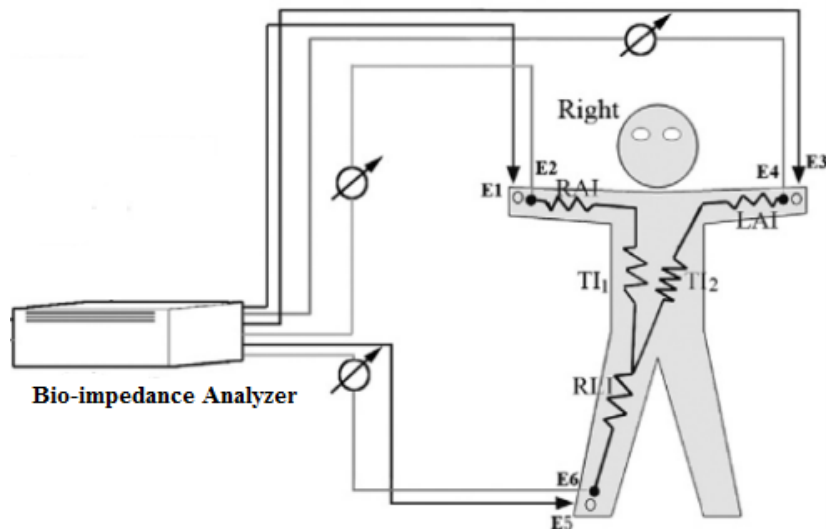
1. Increase public awareness about healthcare and obesity.
2. Encourage adoption of healthy lifestyle.
3. Demonstrate bioelectrical technique to estimate body fat percentage.

1.3 Project Specifications

The project will involve the design and testing of different subsystems. Each subsystem will perform to the following target specifications (to indicate project scope through values and capabilities):

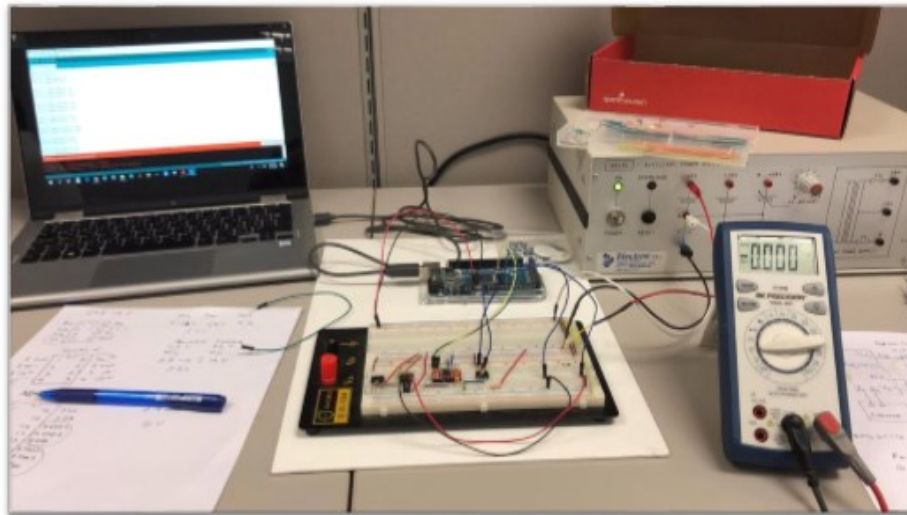
- a. Assumes power supply 220-240V, 60Hz
- b. Operates for current range of $10\mu\text{A}$ to 1mA.
- c. Generates high frequency signal range of 50 kHz to 200 kHz.
- d. Isolates signal circuit.
- e. Measures human body impedance.
- f. Measures body weight.
- g. Measures accurate, reliable and provide highly repeatable results.
- h. Displays data to end-user.

1.4 Product Architecture and Components



Figure#1.4-1: The measurement system of hand-to-foot mode and cross mode

Figure #1.4-1 shows the impedance of the body is calculated by introducing small current into the body and measuring the potential difference between two nodes on the body. Figure 2 shows the simplified concept of the impedance determination. The magnitude of current should be regulated and limited to less than 1 mA to avoid unwanted impact on the health of the user. It is noteworthy that the amount and variety of cells directly determine the resistance along the path taken by the current. Direct current only flow in the fluids between cells, while the alternating current can also flow through the cells, thus the cell characteristics are taken into account with this type of current [6]. Therefore, the alternating current ($f=50/100$ kHz) was applied to be able to calculate the impedance effect in the cells.



Figure#1.4-2: shows a photo of our real system

Figure #1.4-2 shows a photo of our real system after the completion of implementing the resistors, chips, Microprocessor, power supply, and wire connection/soldering.

1.5 Applications

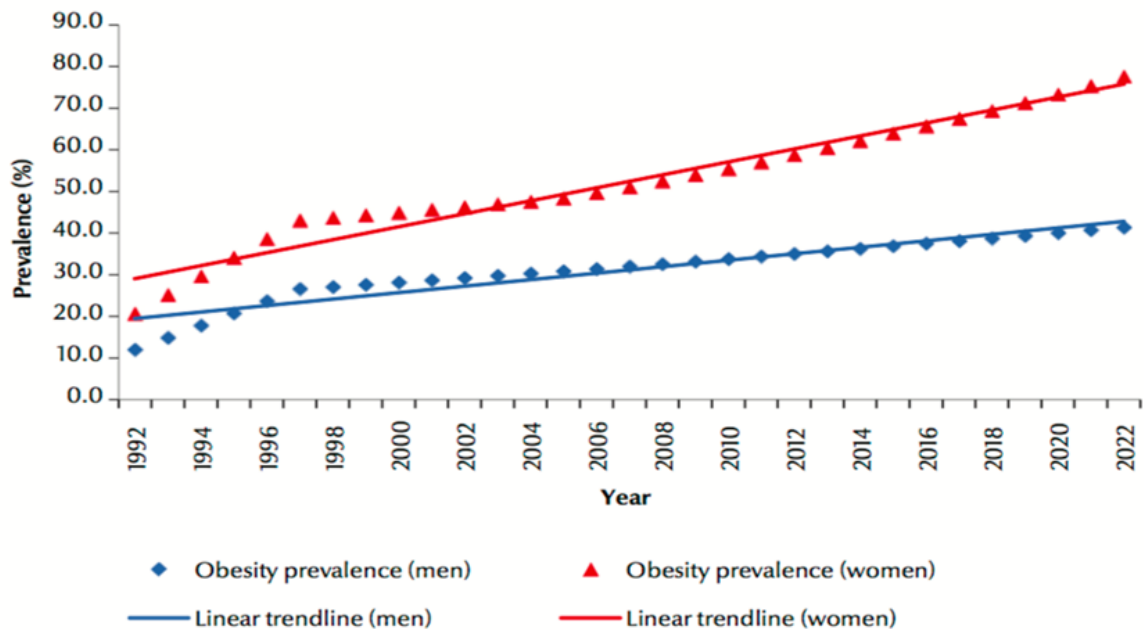
Examples:

- In clinic/hospital to measure and monitor patient's body fat percent.
- In gymnasium/sport center to measure and track athletes' physical progress and performance.
- In education to study human body water content and bioelectrical impedance.
- In school/markets to increase public awareness about healthcare and fat percentage.

2. Literature Review

2.1 Project background

Obesity rate in Saudi Arabia



Figure#2.1-1: shows a trend and projections of obesity among adult men and women in Saudi Arabia, 1992-2002

BIA determines the resistance to flow of the current as it passes through the body, it provides estimates of body water from which body fat is calculated. Its accurate because it takes into account the person height, weight, body type, gender, age, and fitness level. While body mass index (BMI) use formula and manual to do calculation on-comprehensive look of your body composition and its non-accurate because it's only takes into account the height and weight.

2.2 Previous Work

After research conducted, we came across three similar projects of ours took place in three different countries:

- Bioelectrical Body Fat Analyzer designed by Cornell University on 2014. They design and build a device which would measure body fat percentage of one's body. Estimate the water content of the human body. Design input signal isolation circuit.[1]
- MyBIA - Bioelectrical Impedance Analysis for Body fat percentage designed by National Instruments on 2017. Sending a very small current through two points on the body approximately 800 mA at 50 kHz. Wired connection to PC using Labview application as interface for the project.[2]

- Body Composition Analyzer designed by Vanderbilt University, Ameen Farwana, Mikail Siddiki on 2015. They design a device which measure body fat. Design to Send an electrical current to measure a difference in impedance between people with different fat compositions.[3]

2.3 Comparative Study

Table #1: shows a comparison study of our project and the three previous ones.

Projects	1	2	3	Our Project
Electrode systems	Two	Two	Two	Two
Frequency systems	Single	Single	Single	Dual
Frequency range	50 kHz	50 kHz	10 kHz	50/100 kHz
Current Range	10 μ A	800 mA	10 μ A	2 μ A
Rechargeable Battery	No	No	No	Yes
Display	Yes	No	Yes	Yes

3. System Design

3.1 Design Constraints

3.1.1 Design Constraints: Sustainability

Sustainability of our design was considered with respect to future BIA design modifications. Limiting the complexity of our design also facilitates sustainability. Minimizing the assembly required by reducing the number of parts reduces the probability of a discontinued part. The reduction will lead to less of a need for troubleshooting the system. Also, the simpler the design, the easier it will be to find a new chip if one in our design becomes obsolete.

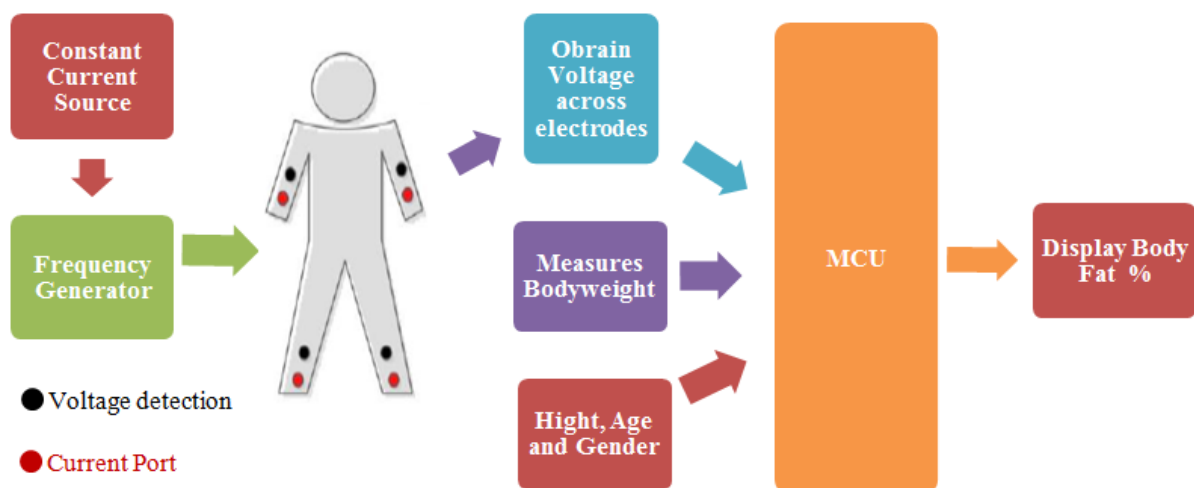
3.1.2 Design Constraints: Economic

The main economic constraint is the cost. The aim of this project is to minimize the complexity of the design in order to reduce the effective cost. These costs mainly consist of out-of-pocket expense and time spent in assembly. The fewer chips in the design, the less likelihood there is to be breakage during the assembly. Also, there would be less time expended troubleshooting a faulty circuit.

3.1.3 Design Constraints: Safety

Health and safety constraints of our design were considered with respect to assembly in the lab environment and testing. There are no additional health and safety risks involved with the Project. We will be using the general lab equipment and Resistance to Simulate Human Body.

3.2 Design Methodology



Figure#3.2-1: Block diagram of proposed bio-impedance analyzer.

Figure #3.2-1 shows the block diagram of our project. The methodology we followed in arranging our subsystems is to have a nearly real arrangement of the physical order of our

project. The project is divided into several parts to make it easy to handle and test. The main part of the project is to build a bioelectrical impedance analyzer that will measure the body fat percentage.

3.3 Product Subsystems and Components

3.3.1 Product Subsystem 1: Constant current source

There are several types of constant source chips that can be used for our project. These are the alternative options we considered for our subsystem:

1. AD5933 chip:



Figure#3.3.1-1: shows AD5933 chip

2. LM317T:



Figure#3.3.1-2: shows LM317T

After searching and discussing we prefer to use the constant current source inside the AD5933 IC. Because we need constant current source of 2 uA and AD5933 can provide that.

3.3.2 Product Subsystem 2: Frequency generator

There are several types of Frequency generator chips that can be used for our project. These are the alternative options we considered for our subsystem:

1. AD5933 chip:



Figure#3.3.2-1: shows AD5933 chip

2. NE555P timer:



Figure#3.3.2-2: shows NE555P timer

After searching and discussing we prefer to use frequency generator inside the AD5933 IC. Because we need the frequency to 50 kHz or higher and AD5933 can provide that.

3.3.3 Product Subsystem 3: Obtain voltage across electrodes.

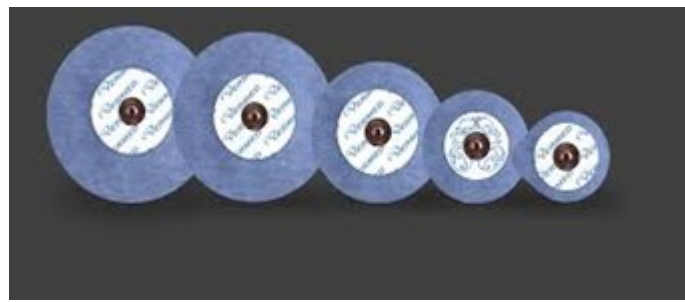
There are several types of electrodes that can be used for our project. These are the alternative options we considered for our subsystem:

1. Covidien Electrodes 530:



Figure#3.3.3-1: shows Covidien Electrodes 530

2. BluFlex Electrodes:



Figure#3.3.3-2: shows BluFlex Electrodes

We have chosen Covidien electrodes 530. Because it is appropriate for the most challenging of monitoring environments. The high quality foam substrate conforms easily to the skin to ensure electrical contact for consistent tracings

3.4 Implementation

From an online research conducted about the BIA and its application, we found similar project with similar application. After, subsystems were identified and studies each as an individual, list the proper specifications based on the conducted research and our studies, we have concluded our target and set our product specifications.

As our specification, we want a constant AC current source of 10 μ A. From our research we found that the AD5933 can provide it. we could not find in our local stores so we had to go online in order to have it. after finding it we had a problem in connecting it to the circuit. we needed a SSOP-16 to DIP Adapter and soldering to connect it. we have managed soldering it perfectly in the circuit, also we got the desirable current source which is 10 μ A.

Upon this, another specification is to have a frequency of 50/100 kHz. we used the same IC which is AD5933 which can also provide the desirable frequency. we had same problem in

connecting it to the circuit as mentioned before and was fixed with a SSOP-16 to DIP Adapter. We generated the desirable frequency which is 50/100 kHz.

After getting the constant current source and the right dual frequencies, we needed to have the current go through the body in order to obtain the voltage impedance across the body. a Covidien electrodes 530 was used to send and to receive the current and the voltage. AD5933 IC is used as a two-electrode impedance measurement system, with a large dynamic range of the measurement load. According to the [datasheet](#), AD5933 is able to measure loads ranging from 1 k Ω to 1 M Ω , although the auxiliary resistor connected to the input feedback resistor (RFB) should be tailored for the specific range.

Moreover, the AD5933 IC contains all the necessary elements to implement a fully integrated impedance spectrometer in this case, a waveform generator, a voltage source output, a current measurement input, a Fourier-based impedance estimator and even a serial communication port. In this case the reference signal represents the applied voltage, while the measurement signal represents the current through the measurement load. The DFT block provides the result as the ratio of reference over measurement, i.e. *volts over amperes*, thus impedance.

In addition, the user needs to enter his weight and age using the keypad whose calculation of body fat is done by MCU, which has executable code. Based the user entries and the electrode voltages derived from the user body, the Fat % is displayed on the character LCD Display.

We were given a shared room with two storage cabinets to put all our components in and have the space to work freely at any time of our convenient. This help us with our team meetings. We brought our own hand tools, and brow the soldering machine from the lab.

Every day we meet after our classes and assemble a certain part of the project with following the agreed and discussed methodology of implementation. Part of the system were verified through the software program. For example, for communicating with Arduino, we used IDE program to configure the appropriate codes. And for other subsystems, we follow the designed circuit and some of the component user manual.

3.4.1 Estimation of Body composition

In BIA method human body is assumed to be a uniform cylinder, so in equation (2.3) we can replace impedance of cylinder (Z) by Impedance of the body (Z_{body}); length of cylinder (L) by height of body (h) and volume of the cylinder (V) by volume of the conducting material in the body i.e. volume of the TBW. Thus by analogy, at high frequency (above 10 kHz) of alternating current, equation (2.3) becomes

$$VolumeOfTBW = \rho \frac{h^2}{Z_{body}} \quad (2.5)$$

The equation (2.5) is the base for the calculation of TBW. This relationship has been used by some investigator to predict conducting volume of total body water. h^2 / Z_{body} is also called as impedance quotient (or impedance index) and many studies have confirmed that the impedance quotient is highly correlated with TBW and therefore, assuming a constant hydration factor (73 %) for the FFM, FM can be estimated as

$$FatFreeMass(FFM) = \frac{TotalBodyWater(TBW)}{0.73} \quad (2.6)$$

$$FatMass(FM) = Weight - FFM \quad (2.7)$$

The equations (2.5) to (2.7) give the body composition. When these equations are applied to the body, many assumptions are made including homogeneity, uniform current distribution and uniform cross sectional area. However, the geometrical relationship in the equation (2.5) is between the value of impedance and the volume of the TBW is not adequately explained in the literature. The uniformity is not a characteristic of the human body or of human populations. The specific resistivity, or ρ , in this volumetric equation (2.5) is an electrical property particular to the conducting medium and independent of its size or shape. For a homogeneous conductor, it is a constant physical property similar to specific gravity. Specific resistivity for the whole body is assumed to be a constant but each tissue has a characteristic specific resistivity.

4. System Testing and Analysis

4.1 Subsystem 1: Constant AC current source

Objectives: To maintain a constant and stable AC current source.

Setup: We used AD5933 IC to give us a constant and stable AC current source. we need to solder the IC on SSOP dip adapter in order to connect the IC in the circuit.

Result: We have successfully completed and did all the needed soldering on the IC. In addition, we managed to have a constant and stable AC current source.

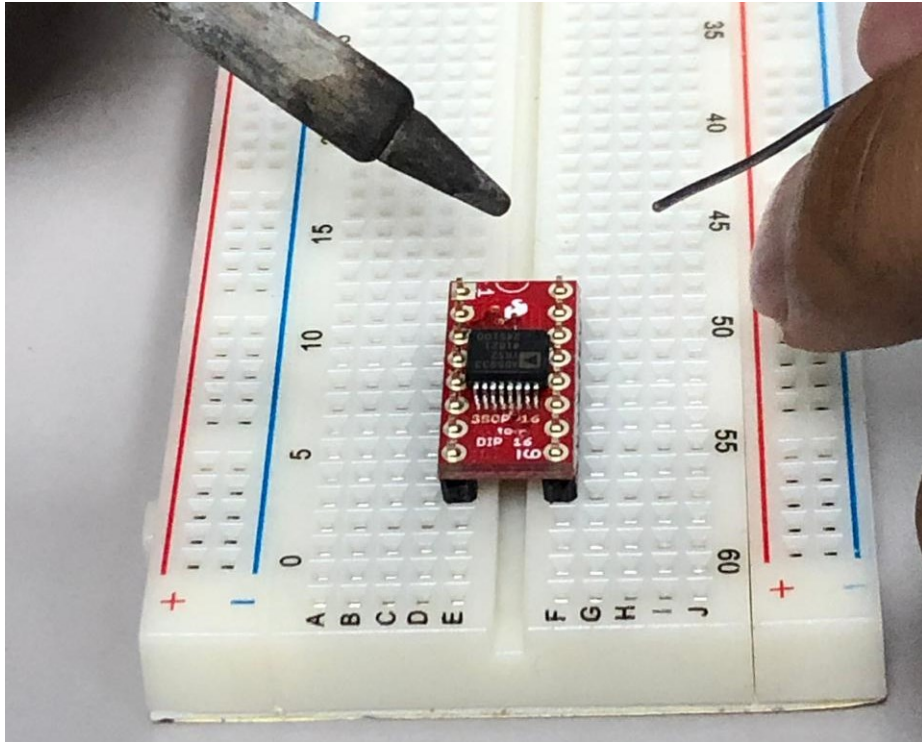


Figure #4.1-1: shows soldering on the IC

4.2 Subsystem 2: *Frequency generator*

Objective: To generate a dual frequencies of 50/100 kHz.

Setup: For the setup we have used AD5933 IC to generate a frequency of 50/100 kHz. we need to solder the IC on SSOP dip adapter in order to connect the IC in the circuit.

Result: We have completed and did all the needed soldering on the IC. In addition, we have managed to generate the dual frequency which is 50/100 kHz.

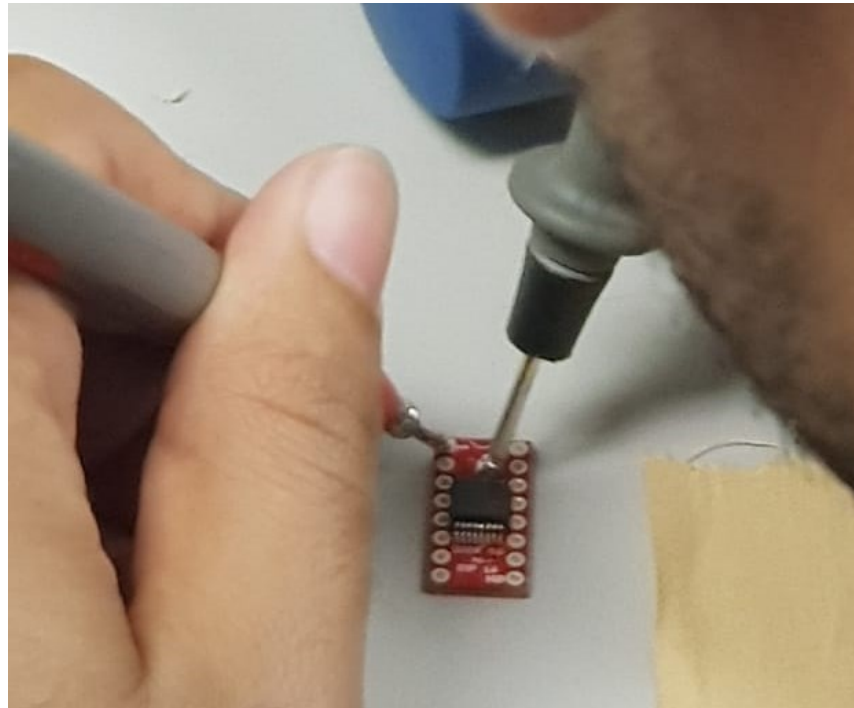


Figure #4.2-1: shows testing after soldering on the IC

4.3 Subsystem 3: *Obtain voltage across electrodes*

Objectives: To obtain voltage across electrodes.

Setup: For the setup we have used convin electrodes 530, from the electrodes we are going to obtain the voltage across the body.

Results: We have received the Covidien electrodes 530. Also, we have managed to obtain the voltage across the body. In this stage, we have used a resistor as load in order to do our testing. Moreover, the result was as expected, we have obtained the voltage across the resistor.

4.4 Overall Results, Analysis and Discussion

4.4.1. Results

The designed bioimpedance analyzer was tested on ten subjects, with equal numbers between man and woman. The subjects were of broad age range between 20-64 years old with various heights and weights as well. Their fat mass percentages were obtained using formula from equation (2), and were compared with the result from similar measurement. Table 1 shows the statistical analysis of repeatability of 10 repeated measurements for each subject. In addition, Table 2 shows the experimental result (P) from the average of repeated measurements for each subject which consists of 10 times of repetition. For the purpose of fair

comparison, the data taken were for hand to hand measurement, i.e. current ports as well as nodes are right and left arms. Although the analyzer is capable to do the impedance analysis for different pair of ports (i.e. hand to foot), the data is focused analysis due to the limited capability of the comparison tool.

Subject No	Fat Mass %			
	Average	Min	Max	Std Dev
1	31.07	31	31	0.08
2	38.19	38.1	38.3	0.1
3	20.16	20.1	20.2	0.05
4	49.43	49.3	49.8	0.16
5	44.52	44.4	44.6	0.09
6	14.35	14.1	14.5	0.12
7	15.74	15.7	25.9	0.07
8	21.27	21.1	21.5	0.13
9	37.24	37.1	37.9	0.25
10	28.08	28	28.2	0.08

Table 1. Statistical analysis of fat mass percentage from repeated measurements

Subject No	h	w	g	a	Fat Mass
	(cm)	(kg)	(M/F)	(Yr)	%
1	157	56	F	23	31.07
2	149	58	F	49	38.18
3	145	40	F	20	20.16
4	147	66	F	64	49.43
5	162	74	F	51	44.52
6	175	556	M	22	14.35
7	165	54	M	23	15.75
8	161	62	M	24	21.27
9	168	80	M	42	37.24
10	158	64	M	31	28.08

Table 2. Result of measurement

The result shows that the analyzer was able to produce output of fat mass percentage for diverse range of input. The fat mass percentage produced by our bio impedance analyzer were in the range of 14.1 (min) to 49.8 (max) on the overall individual measurement, as indicated from Table 1. The statistical analysis also indicates that the repeatability is impressive with the maximum standard deviation of 0.25% (fat mass).

The experiment data shows promising data in comparison with commercial BIA. The small error found, either in the absolute or normalized error, is within acceptable value. Moreover, the usage of relatively cheap components in this system provides good alternative for evaluation of fat mass in the body.

4.4.2. Accuracy

The performance of the EBI measurement system can be observed in figures 5 and 6. Figure 5 contains the measurement error obtained at 10 kHz for measurements of resistive loads with both measurement arrangements, as follows.

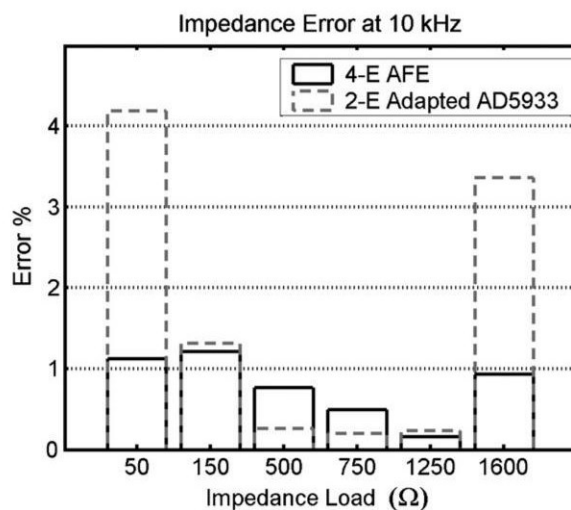


Figure 5. Impedance measurement error for measurements at 10 kHz with both measurement arrangements. Note that the calibration has been done with a resistive load of 1000 .

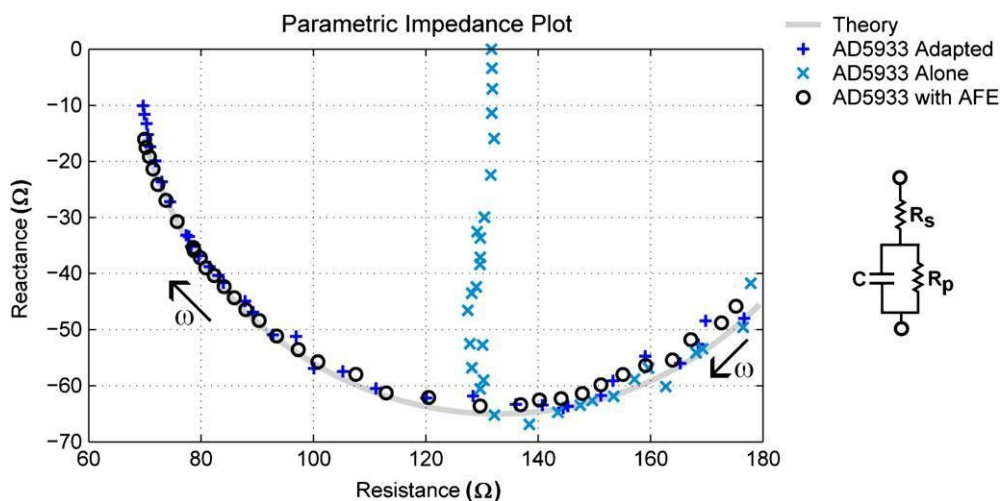


Figure 6. Parametric impedance plot of theoretical and measured values of a series 2R-1C circuit. $R_s = 68$, $R_p = 130$ and $C = 100$ nF. Frequency range: 5–100 kHz. Note that since the TUS used in this measurement is an electrical phantom, there is no electrode polarization impedance present, ZEP.

- (i) Two-electrode setup using the AFE. The bar is plotted with discontinuous trace.
- (ii) Two-electrode setup using the attenuation circuit described in figure 3. The bar is plotted with solid trace.

In general, the measurement error is kept very low for most of the impedance range, especially for values near the calibration value, 1000 . In figure 6, the parametric plot reactance versus resistance contains the impedance values of a 2R-1C series model. For comparison, the measurements obtained with AFE, without

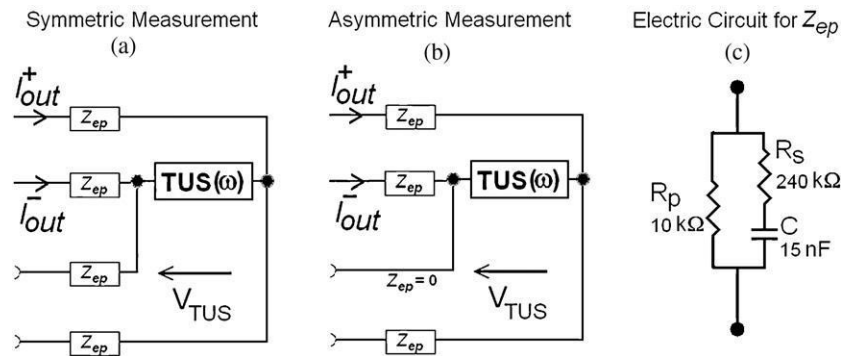


Figure 7. A lead imbalance experiment to test the proper implementation of the two-electrode method.

AFE and with the attenuation circuit are plotted together with the theoretical value. Note that the electrical series circuit is the measurement load as such, and therefore there is no electrode polarization impedance of any kind present in these measurements. It is easy to note, in the impedance plots in figure 6, the remarkable agreement between the theoretical values and the measurement done with the AFE, especially at high frequencies. Note that the frequency range of the measurement is 5–100 kHz, increasing clockwise as indicated in the plots. In figure 6, it is also possible to observe that the measurements performed with AD5933 and the attenuator circuit do not match the theoretical values as well as those with the AFE. Another significant result to remark is the asymptotic behavior of the measurements performed with AD5933 alone. These measurements apparently indicate the lower limit of the impedance measurement range.

4.4.3. Electrode polarization avoidance

The effect of electrodes has been modeled by adding impedances to the measurement leads. The goal pursued with the addition of these impedances is to simulate the effect of the electrode polarization impedance Z_{ep} . The electrode model used for this experiment is depicted in figure 7(c). Impedance measurements have been done with two different setups: symmetric and asymmetric, as depicted in figures 7(a) and (b) respectively, and the results of the corresponding measurements are plotted in the impedance parametric plot in figure 8. The plot contains the value of the measurements, dotted trace and discontinuous trace for the symmetric case and the asymmetric case, respectively, and for comparison the theoretical value of the measurement load is plotted with the continuous trace.

4.5 Discussion

4.5.1. On the application of AD5933 for electrical biomedical impedance

The reported measurements strongly indicate that the AD5933 impedance converter by itself cannot be used for any application EBIS where proper electrical characterization is needed. This result was expected, since AD5933 performs two-electrode measurements only.

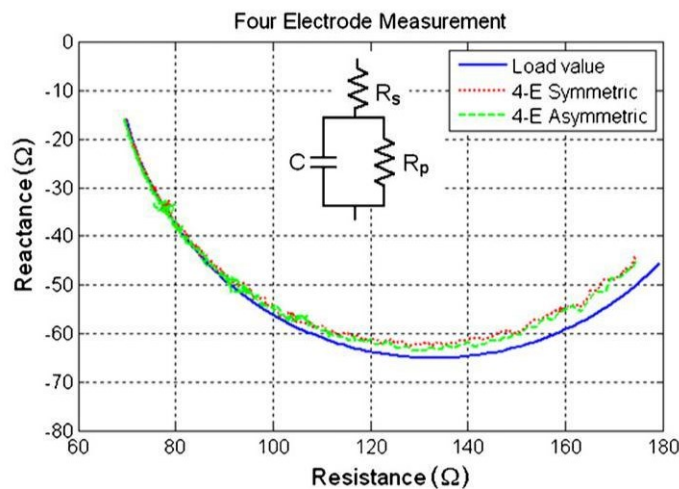


Figure 8. The parametric impedance plot of a series 2R-1C circuit. $R_s = 68$, $R_p = 130$ and $C = 100$ nF, with impedance in leads modeling the effect of electrodes. Frequency range: 5–100 kHz. Note that the value for the capacitor in the theoretical calculations is the nominal value, while the value for the resistors R_s and R_p is the value measured at measured dc.

In addition to this limitation, the excitation signal generated by AD5933 is not dc free and the signal is injected by a voltage source. An important consequence of the voltage excitation is that the current through the load is dependent on the impedance value of the load as well as on the electrode polarization impedance. Since the value of the working load, mostly the electrode polarization impedance, can change with time, the current through the tissue can exceed the limit imposed by IEC-60601.

Another important limitation regarding the voltage source of AD5933 is that its minimum output impedance, R_{out} , is 200 . Such a value is very high for a voltage source, especially when the working load can be very small, as in electrical bioimpedance applications.

Moreover, apparently AD5933 cannot measure loads smaller than 130 approximately. See figure 6. This lower limit is related to the voltage source, R_{out} of 200 and 5.8 mA Vpp of the ac output current. With a maximum current of 5.8 mA and a voltage source providing around 1.9 Vpp, the minimum load is approximately 330 , including 200 of R_{out} . This might not be a limitation in practice, since in a bioimpedance application the presence of the electrodes will increase the value of the working load.

4.5.2. Frequency performance with a whole single dispersion capacitive system.

The measurements obtained with the proposed measurement system and the theoretical values agree significantly well in the whole frequency range. In this frequency range, we should not expect large parasitic effects in RC dummy circuits. Nevertheless, in a wearable application the measurement scenario is much more hostile, and the existence of parasitic capacitances might ruin the measurements. AD5933 has a built-in function for calibration, but at this point it is unknown to what extent such a feature will contribute to minimizing this type of negative effect.

4.5.3. Accuracy performance and load dependence

The reported experimental results indicate that the introduction of an external AFE does not significantly worsen AD5933. As expected, the results suggest that the best performance

is obtained when the measurement load approximates to the calibration load. In a typical application of electrical bio impedance, the target load will have a dynamic range much smaller than the impedance range considered in these tests. Therefore it is most likely that the impedance measurement system will be able to keep, for each specific application, the high accuracy reported in figure 5.

5. Project Management

5.1 Project Plan

- We breakdown the tasks in a list and identify the tasks and activities to meet project requirements through the project management process of initiating, planning, executing, monitoring and control and closing.
- We map tasks and responsibilities to all team members and clarify and understand all tasks and strategies for achieving the project objectives.
- Weekly meeting for the team members to following the activities and moves on from the project.
- Every two weeks write the progress report by one of team members.
- High team performance achieved effective communication, trust of each other and problem solving.

5.2 Contribution of Team Members

Tasks	AL Qahtani	AL Oufi	AL Zahrani	AL Abdullatif	AlGhamdi	Total
Search & Acquiring the components	30	10	20	15	25	100%
Design Subsystems	20	30	15	25	10	100%
Test Subsystem	10	20	25	20	25	100%
Writing reports & presentations	20	15	20	15	20	100%
Configuring the Software	20	25	15	25	15	100%

5.3 Project Execution Monitoring

- Every two weeks we have meeting with our advisors (Dr. Sadiq) to ensuring that assigned to the project are available as planned as well as monitoring the planned versus actual utilization of resources and taking corrective action as necessary.

- We meet in weekly bases two times a week (Mon, Wed) to monitoring and recording results of executing the quality management activities in order to assess performance and ensure the project outputs are complete and correct.
- Every week we test the parts on Wednesday evening and make sure last phase working excellent.

5.4 Challenges and Decision Making

- The AD5933 needs to be programed by assembly language and we have found only few functions written in C++.
- Therefore, we have ordered a full-featured evaluation board for the AD5933 that provides graphic user interface software with frequency sweep capability for board control and data analysis.
- We are planning to work simultaneously on the IC and the board throughout the semester to save time.
- I2C Communication protocol
- We faced a hard time to have communication between AD5933 board and Arduino through I2C serial communication protocol, so data is transferred between devices by two wires
- SDA (Serial Data) and SCL (Serial Clock).
- Research to find writing/reading Register Data to the AD5933

5.5 Project Bill of Materials and Budget

Our estimated budget for the project was 791 SR, and our final cost for this semester for all the materials is 1416 SR. The cost exceeded our expectation, because of adding more components and increase quality of our design. Because of that we have purchase and ship them from the global market due to missing or high cost components inside Saudi Arabia market.

Table 5.5-1: Materials cost.

No.	Description	Quantity	Unit Cost (SR)	Total Cost (SR)
<u>1</u>	<u>Microcontroller</u>	<u>1</u>	<u>300</u>	<u>300</u>
<u>2</u>	<u>MCU Power Supply</u>	<u>1</u>	<u>20</u>	<u>20</u>
<u>3</u>	<u>Evaluation board</u>	<u>1</u>	<u>220</u>	<u>220</u>
<u>4</u>	<u>Display</u>	<u>1</u>	<u>20</u>	<u>20</u>
<u>5</u>	<u>Digital scale</u>	<u>1</u>	<u>200</u>	<u>200</u>
<u>6</u>	<u>Wires</u>	<u>2</u>	<u>12</u>	<u>24</u>
<u>7</u>	<u>Resistors &Capacitors</u>	<u>12</u>	<u>2</u>	<u>24</u>
<u>8</u>	<u>3D design</u>	<u>1</u>	<u>250</u>	<u>250</u>

<u>9</u>	<u>Single Use Electrode</u>	<u>4</u>	<u>50</u>	<u>200</u>
<u>10</u>	<u>Electrode Gel</u>	<u>1</u>	<u>50</u>	<u>50</u>
<u>11</u>	<u>Rechargeable Battery</u>	<u>1</u>	<u>100</u>	<u>100</u>
<u>12</u>	<u>I2C chip</u>	<u>1</u>	<u>20</u>	<u>20</u>
<u>13</u>	<u>Evaluation board</u>	<u>1</u>	<u>20</u>	<u>20</u>
<u>Total</u>				<u>1428</u>

6. Project Analysis

6.1 Life-long Learning

Until this semester, we have learnt and gain new knowledges and skills while we were working on our project. We improve our understanding in this project as following:

- New software tools of MATLAB.
- project management skills,
- time management skills,
- Teamwork skills.

We read and did our research on this project by looking to the similar projects and using internet to get some useful information.

6.2 Impact of Engineering Solutions

Our project will have a great impact on the society while it will save lives. Also, it is an environmental friendly, so there are no any gases that will affect the atmosphere. Our project will help people to monitor their diet in a short time.

6.3 Contemporary Issues Addressed

According the World Health Organization's (WHO) World Health Observatory report, nine Middle Eastern countries have ranked highest in the obesity statistics among adults aged 18 and above.[4] Saudi Arabia are third in rank with 35.4% and its increasing. Rising obesity levels have also led to a growth of a very lucrative cosmetic surgery market in the GCC. Arabian Gulf countries have the highest percentage of bariatric procedures (a variety of procedures used to treat obesity) performed which include sleeve gastrectomy, gastric bypass and the placement of gastric band. Rather than solving the root of problem people tend to bypass them with surgeries.

7. Conclusions and Future Recommendations

7.1 Conclusions

In conclusion, this project was quite different from any other project. We have applied most if not all the skills we learnt and gained during our time in PMU. Research skills, time management, technical skills, technical writing skills, planning and teamwork. As a result, we have accomplished more than half of the overall system.

Starting from the research time, and selecting the components, buying the components, assembling them together. In addition to writing every two weeks progress reports and at the same time looking for more innovative ideas and upcoming some technical difficulties, we are proud to take such a challenging project. All team members are fully aware of all components and their functionality.

Furthermore, each member where involve by somehow in every single step of the project progress with variation of participation. Regarding the component, most of the component weren't bought in Saudi. The major parts were bought from United State. The components were bought from two different stores within the city. Chips were bought from online Amazon.com.

Several meetings with the advisors made a positive impact in accomplishing these results. We got so much help from our advisor regarding the project components and choosing alternatives since we were facing time limitation. They were always helpful with sharing his knowledge and experience in this kind of projects. Also, Dr. Yahya has assigned us a shared room with a private cabinet where we can work freely at our convenient time.

Class lectures are another factor in our success. So many information about the right needed skills to successfully do the project with the proper planning, teamwork, codes & standards, managing the project, and looking for the best and alternatives. Enough time were given by Prof. Yahya for the students to meet their advisors and work on the project which helped us a great deal on accomplishing a lot at this time.

We learned so many skills during this semester. One of the most thing we learned is that nothing impossible as long as it's doable. Design, research, selections, time management and alternative choosing were the most enhanced skills we developed during this semester.

7.2 Future Recommendations

In this section, the team reviews further work that can be done to improve our project.

7.2.1 AD5933

The AD5933 is a capable chip to measure skin impedance but it has its limitations. Because the chip is configured to output a voltage signal (with an DC offset) and receive a current signal, it required the team to design an Analog Front End that is compatible with it. Due to this, extra and somewhat redundant components are needed to convert the VADI to current then to voltage then to current again. Additionally, the AD5933 uses I2C to communicate. This protocol is open drain, which means it is always high (at 5V) until it is transmitting data. This is not the most power efficient communication protocol for a battery operated, low power project. A possible improvement would be to implement the AD5933 functionality in a microcontroller or a FPGA board. This would allow for a different, more power efficient, communication protocol to be used, and it would eliminate the need of both the AD5933 and a microcontroller.

7.2.2 Patient Detection

One more improvement in the design can be automatic detection of a patient. A mechanism can be included in the design which detects whenever the electrodes are attached to the patient. The device can then measure skin impedance once it detects a body and shut off once the measurement is done.

7.2.3 Battery size

The circuit currently uses a 9V battery. Improvement can be made in this regard and a less bulky battery can be used. Further research needs to be done to make sure the battery delivers enough current and the boost regulator is suitable for the application. Ideas include using a appropriate battery and stabilizing the output voltage of the switching regulator.

7.2.4 Mobile Application

Further research can be done in the field of communication. Currently the device uses display to show results. A mobile application which plots and displays the data, maybe in real time, on the mobile screen can be developed to improve the project interface.

8. References

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Appendix A: Progress Reports

Title: Bioelectrical Impedance Analyzer		Advisor: Dr. Sadiq AlHuwaiti		Design II (ASSE 3)		Spring 2019	
Abdulrahman Aloufi 201100677				Project PLAN & Progress			
Ahmed Alabdullatif 201302548				ProgRpt No. 9			
Ahmed Alqahtani 201400392				Plan updated (Date): Apr 4, 2019			
Ahmed Alzahrani 201303935				Instructor: Dr. Chedly B. Yahya			
Abdallah Alghamdi 201400016				Period Highlight: 13			
				Actual (beyond plan)		% Complete (beyond plan)	
				Plan		Actual	
ACTIVITY	PLAN START	PLAN END	Assigned To	ACTUAL START	ACTUAL END	PERCENT COMPLETE	
							Periods (Weeks 1-15)
Write plan	1	1	ALL	2	2	100%	1 2 3 4 5 6 7 8 9 10 11 12 13 14 15
Design subsystem 1 (Determine body fat)	2	1	ALL	2	2	100%	
Test subsystem 1	2	1	ALL	2	2	100%	
Calibrate AD5933	3	2	AG, AA	3	2	100%	
Measure voltage across resistor	3	3	AG, AA	3	4	100%	
Measure voltage across body	4	3	AO, AQ	4	4	100%	
Determine body fat content (Coding)	5	4	AO, AQ	5	4	100%	
Implement user interface (keypad)	6	5	AQ	6	5	100%	
Prepare midterm Presentation	7	3	AA	7	3	100%	
Display data to end-user	8	2	AO	8	2	100%	
Design subsystem 2 (Implement Industrial Design)	9	4	ALL	8	4	100%	
Test subsystem 2	10	2	AZ, AA	10	2	100%	
Implement industrial design	10	1	AQ, AG	11	2	100%	
Prepare final report	12	2	ALL	12	2	100%	
Prepare final presentation	12	2	AZ	12	3	100%	
Prepare Project Demo	13	3	AQ, AG	13	3	100%	
Submit Rpt/PPT/Brochure	14	2	AZ, AA	14	2	100%	
Progress Details:				Issues (delay ...):			
We have received a full-featured evaluation board for AD5933.				AD5933 needs to be programmed by assembly language,			
We have managed to calibrate and measure unknown resistance across AD5933 using the evaluation board.				and we found few functions written in C++			
We are planning to measure the voltage across human body.				thus, we have ordered a full-featured evaluation board for AD5933			
				that provides graphic user interface software with frequency sweep			
				capability for board control and data analysis.			

Appendix B: Bill of Materials

Refer to page 21 ([section 5.5](#))

Appendix C: Datasheets



WiMAX/WiBro RF MxFE MISO Transceiver

AD9355

FEATURES

RF transceiver with integrated ADCs and DACs
IEEE 802.16 WiMAX/WiBro
 Dual receivers, single transmitter
Operating band: 3.3 GHz to 3.8 GHz
3.5 MHz < BW < 10 MHz
Superior receiver sensitivity with NF < 3.5 dB
Manual Rx gain or autonomous AGC mode
Highly linear and spectrally pure transmitter
Tx EVM = -38 dB
Tx noise floor < -134 dBm/Hz at $f_{\text{OFFSET}} > 22$ MHz
Tx power control range of 58 dB, resolution of 0.25 dB
Integrated fractional-N synthesizer
10 Hz LO step size
LO integrated phase noise < 0.5°rms
Automatic frequency correction < 0.012 ppm
Industry-standard JESD-207 digital interface

APPLICATIONS

BWA/WiMAX/WiBro
CPEs
USB dongles/minicards
Pico and femto base stations
Proprietary radio systems

GENERAL DESCRIPTION

The AD9355 is a radio frequency (RF) transceiver with a single transmitter and dual receivers fully integrated into the device. This allows the part to be used for mobile and fixed WiMAX/WiBro wireless network systems. By incorporating an RF MxFE™, the AD9355 offers the combination of an RF front end and a mixed-signal baseband, enabling an easy-to-use JESD-207-compliant digital interface to the baseband application-specific integrated circuit (ASIC) or field-programmable gate array (FPGA). In addition, the AD9355 operates in the 3.3 GHz to 3.8 GHz range, covering most of the licensed and unlicensed bands. Channel bandwidths of 3.5 MHz, 4.375 MHz, 5 MHz, 7 MHz, 8.75 MHz, and 10 MHz are supported.

The direct-conversion receivers have state-of-the-art noise figure (NF) and linearity and, with the exception of baluns, do not require external components. The complete RF subsystem integrates autonomous automatic gain control (AGC) loops and dc offset corrections, thus eliminating the need for high speed interaction with the baseband processor.

The received signal is digitized with a set of four analog-to-digital converters (ADCs) with high dynamic range. Decimation and

FUNCTIONAL BLOCK DIAGRAM

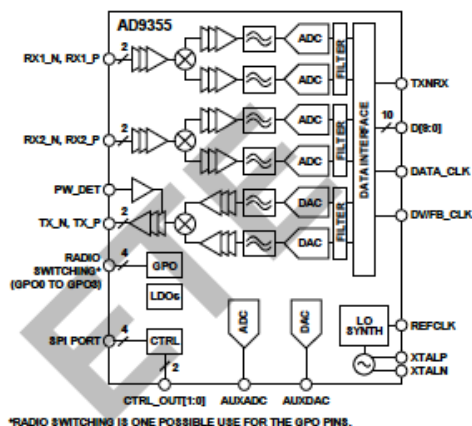


Figure 1.

channel filters produce a 10-bit output signal at the appropriate sample rate determined by the bandwidth mode. The transmit path interpolates 10-bit input data before converting it to the analog domain, and then upconverting it to the carrier frequency.

The highly linear transmit path has excellent spectral purity with sideband noise less than -134 dBm/Hz at 22 MHz offset, and it offers an error vector magnitude (EVM) of -38 dB at 0 dBm output power. The transmit power is detected by an accurate power detector with a range of more than 40 dB and 0.5 dB steps. The output power can be calibrated at the factory by a single measurement.

The reference frequency is produced by an internal digitally controlled crystal oscillator (DCXO) that has a programmable frequency offset correction with a resolution of 0.012 ppm, thus reducing the total bill of materials (BOM) of the device.

An internal auxiliary ADC and an auxiliary digital-to-analog converter (DAC) are available for system monitoring and control. Four general-purpose I/Os are also included and can be register programmed or automatically sequenced by a user-defined state machine. Mode control is via a 3- or 4-wire serial port and four real-time I/O control pins. The AD9355 is powered either from a single 3.3 V supply or, for power savings, from dual supplies and contains on-chip low dropout (LDO) regulators. The AD9355 is packaged in an 8 mm x 8 mm, 56-lead lead frame chip scale package (LFCSP).

Rev. SpA

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Table Appendix C -1: Datasheet AD5933.

Datasheet

I2C 1602 Serial LCD Module



Product features:

The I2C 1602 LCD module is a 2 line by 16 character display interfaced to an I2C daughter board. The I2C interface only requires 2 data connections, +5 VDC and GND to operate

For in depth information on I2C interface and history, visit: <http://www.wikipedia/wiki/i2c>

Specifications:

I2C Address Range	2 lines by 16 character 0x20 to 0x27 (Default=0x27, addressable)
Operating Voltage	5 Vdc
Backlight	White
Contrast	Adjustable by potentiometer on I2c interface
Size	80mm x 36mm x 20 mm
Viewable area	66mm x 16mm

Power:

The device is powered by a single 5Vdc connection.

Table Appendix C -2: Datasheet I2C 1602 Serial LCD Module

Appendix D: Program Codes

```
#include <Wire.h>
#include <LiquidCrystal_I2C.h>
#include <Keypad.h>
#include "AD5933.h"

#define START_FREQ (200000)
#define FREQ_INCR (1000)
#define NUM_INCR (40)
#define REF_RESIST (10000)

double impedanceAvg = 0;
double gain[NUM_INCR + 1];
int phase[NUM_INCR + 1];

float char_to_float(char x) {
    float floatValue = int(x) - 48;
    return floatValue;
}

const byte ROWS = 4;
const byte COLS = 3;

char hexaKeys[ROWS][COLS] = {
    {'1', '2', '3'},
    {'4', '5', '6'},
    {'7', '8', '9'},
    {'*', '0', '#'}
};

byte rowPins[ROWS] = {3, 8, 7, 5}; //connect to the row pinouts of the keypad
byte colPins[COLS] = {4, 2, 6}; //connect to the column pinouts of the keypad

Keypad customKeypad = Keypad(makeKeymap(hexaKeys), rowPins, colPins, ROWS,
COLS);

LiquidCrystal_I2C lcd(0x38, 16, 2);

void frequencySweepRaw() {
    int n = 0;
    impedanceAvg = 0;
    // Create variables to hold the impedance data and track frequency
    int real, imag, i = 0, cfreq = START_FREQ / 1000;

    // Initialize the frequency sweep
    if (!(AD5933::setPowerMode(POWER_STANDBY) && // place in standby
```

```

    AD5933::setControlMode(CTRL_INIT_START_FREQ) && // init start freq
    AD5933::setControlMode(CTRL_START_FREQ_SWEEP)) // begin frequency sweep
{
    Serial.println("Could not initialize frequency sweep...");
}

// Perform the actual sweep
while ((AD5933::readStatusRegister() & STATUS_SWEEP_DONE) !=
STATUS_SWEEP_DONE) {
    // Get the frequency data for this frequency point
    if (!AD5933::getComplexData(&real, &imag)) {
        Serial.println("Could not get raw frequency data...");
    }

    // Print out the frequency data
    Serial.print(cfreq);
    Serial.print(": R=");
    Serial.print(real);
    Serial.print("/I=");
    Serial.print(imag);

    // Compute impedance
    double magnitude = sqrt(pow(real, 2) + pow(imag, 2));
    double impedance = 1 / (magnitude * gain[i]);

    Serial.print(" |Z|=");
    Serial.println(impedance);
    n++;
    impedanceAvg = impedanceAvg * n;
    impedanceAvg = (impedanceAvg + impedance) / (n + 1);
    // Increment the frequency
    i++;
    cfreq += FREQ_INCR / 1000;
    AD5933::setControlMode(CTRL_INCREMENT_FREQ);
}

Serial.println("Frequency sweep complete!");

// Set AD5933 power mode to standby when finished
if (!AD5933::setPowerMode(POWER_STANDBY))
    Serial.println("Could not set to standby...");
}

void setup() {
    lcd.backlight();
}

```

```

lcd.init();
// Begin I2C
Wire.begin();

// Begin serial at 9600 baud for output
Serial.begin(9600);
Serial.println("AD5933 Test Started!");

// Perform initial configuration. Fail if any one of these fail.
if (!(AD5933::reset() &&
      AD5933::setInternalClock(true) &&
      AD5933::setStartFrequency(START_FREQ) &&
      AD5933::setIncrementFrequency(FREQ_INCR) &&
      AD5933::setNumberIncrements(NUM_INCR) &&
      AD5933::setPGAGain(PGA_GAIN_X1)))
{
  Serial.println("FAILED in initialization!");
  while (true) ;
}

// Perform calibration sweep
if (AD5933::calibrate(gain, phase, REF_RESIST, NUM_INCR + 1))
  Serial.println("Calibrated!");
else
  Serial.println("Calibration failed...");
}

void loop() {
  char customKey = 0;
  float FFM = 0;
  float height = 0;
  float weight = 0;
  float age = 0;
  float gender = 0;
  float FM = 0;

  lcd.clear();
  lcd.setCursor(0, 0);
  lcd.print("Please enter");
  lcd.setCursor(0, 1);
  lcd.print("Required Data");
  delay(2000);
  lcd.clear();
  lcd.setCursor(0, 0);
  lcd.print("enter values in");
  lcd.setCursor(0, 1);
  lcd.print("3 digit fomrat");
  delay(2000);
  lcd.clear();
}

```

```

lcd.print("to reset values");
lcd.setCursor(0, 1);
lcd.print("Press the *");
delay(2000);

```

ResetAge:

```

age = 0;
lcd.clear();
lcd.setCursor(0, 0);
lcd.print("Enter Age");
lcd.setCursor(0, 1);
lcd.print("XXX");
for (int i = 0; i < 3; i++) {
  customKey = 0;
  while (customKey == 0) {
    customKey = customKeypad.getKey();
    if (customKey == '*') {
      goto ResetAge;
    }
    else if (customKey != 0) {
      lcd.setCursor(i, 1);
      lcd.print(customKey);
      age = age + char_to_float(customKey) * pow(10.0, 2 - i);
    }
  }
}
Serial.println(age);
delay(1500);

```

ResetWeight:

```

weight = 0;
lcd.clear();
lcd.setCursor(0, 0);
lcd.print("Enter Weight");
lcd.setCursor(0, 1);
lcd.print("XXX");
for (int i = 0; i < 3; i++) {
  customKey = 0;
  while (customKey == 0) {
    customKey = customKeypad.getKey();
    if (customKey == '*') {
      goto ResetWeight;
    }
    else if (customKey != 0) {
      lcd.setCursor(i, 1);
      lcd.print(customKey);
      weight = weight + char_to_float(customKey) * pow(10.0, 2 - i);
    }
  }
}
}

```

```
Serial.println(weight);
delay(1500);
```

ResetHeight:

```
height = 0;
```

```
lcd.clear();
lcd.setCursor(0, 0);
lcd.print("Enter Height");
lcd.setCursor(0, 1);
lcd.print("XXX");
for (int i = 0; i < 3; i++) {
  customKey = 0;
  while (customKey == 0) {
    customKey = customKeypad.getKey();
    if (customKey == '*') {
      goto ResetHeight;
    }
    else if (customKey != 0) {
      lcd.setCursor(i, 1);
      lcd.print(customKey);
      height = height + char_to_float(customKey) * pow(10.0, 2 - i);
    }
  }
}
Serial.println(height);
delay(1500);
```

ResetGender:

```
gender = 0;
```

```
lcd.clear();
lcd.setCursor(0, 0);
lcd.print("1-Male 2-Female");
lcd.setCursor(0, 1);
lcd.print("XXX");
for (int i = 0; i < 3; i++) {
  customKey = 0;
  while (customKey == 0) {
    customKey = customKeypad.getKey();
    if (customKey == '*') {
      goto ResetGender;
    }
    else if (customKey != 0) {
      lcd.setCursor(i, 1);
      lcd.print(customKey);
      gender = gender + char_to_float(customKey) * pow(10.0, 2 - i);
      if (gender > 1.5) {
        gender = 0;
      }
    }
  }
}
```

```

    }
  }
}
Serial.println(gender);
delay(1500);

lcd.clear();
lcd.setCursor(0, 0);
lcd.print("Measuring impedance");
lcd.setCursor(0, 1);
lcd.print("Processing...");

//I2C stuff
#####

frequencySweepRaw();

#####

lcd.clear();
lcd.setCursor(0, 0);
lcd.print("Measurment complete");
lcd.setCursor(0, 1);
lcd.print("Calculating Fat %");

FFM = 0.36 * (sq(height) / impedanceAvg) + 0.162 * height + 0.289 * weight - 0.134 * age
+ 4.83 * gender;
FM = (weight - FFM);
delay(1000);

customKey = 0;
while (customKey == 0) {
  lcd.clear();
  lcd.setCursor(0, 0);
  lcd.print("Fat Percentage");
  lcd.setCursor(0, 1);
  lcd.print(FM);
  lcd.print("%");
  delay(5000);
  lcd.clear();
  lcd.setCursor(0, 0);
  lcd.print("Hold any key");
  lcd.setCursor(0, 1);
  lcd.print("now to restart");
  delay(2000);
  customKey = customKeypad.getKey();
}
}

```

Appendix E: Operation Manual

How To use BIA device to Measure body Fat%

- 1- Switch ON
- 2- Press and Hold any Key to Start the Device
- 3- Display will Show ("Enter Age"), Enter your age with 3 digit number XXX example your age 24, so Type 024.
- 4- Display will Show ("Enter Weight") Enter your Weight with 3 digit number XXX example your Weight 56 Kg, so Type 056.
- 5- Display will Show ("Enter Height");Enter your Height in CM with 3 digit number XXX example your Height 169 CM Kg, so Type 169.
- 6- Display will Show ("1-Male 2-Female"); Enter 001 for Male, or Enter 002 for Female.
- 7- Finally, the Display will Show ("Measuring impedance Processing..."), wait for seconds and the display will show as ("Measurment complete"), the your result will appear as Fat Percentage %