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Measurement System for Bio-impedance Signal Analysis using Impedance Analyzer

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***Abstract*— Bio-Electrical Impedance shows the electrical properties of body which gives the provision to develop non-invasive system for bio-impedance measurement. Single lead sample failed to give proper information. Therefore this paper designs multi-lead system for getting more accurate results. The main aim of the proposed system is to observe volume which changes at the different location of body with respect to time using multi-electrodes. The present paper utilizes bio-impedance of body to analyze changes in real time. Impedance analyzer is used to develop the prototype. Multifrequency concept is applied for better accuracy. This prototype is tested on electrical models in order to reduce electrical interaction and frequency interference between the leads. The obtained result shows that the system reduces the error and gives better result for real life implementation. It is concluded that the present multilead system performs better with low power consumption with better accuracy.**

Keywords- AD5933 impedance Analyzer, LPC1768 cortex, Bio-impedance and Electrodes.

I. INTRODUCTION

Bio-impedance measurement technique has been widely employed in many biomedical applications (such as bio-sensing), to detect various physiological parameters, tissue characterization measurements, various skin diseases etc. Bio-impedance is nothing but the electrical properties of the living organisms which can be obtained by supplying the excitation current and obtaining the voltage response from the body. Impedance analyzer or network analyzer is a device which helps to get bio-impedance value of body. It performs the process i.e injecting the current and taking the voltage as output. Internal calibration gives impedance values. The obtained bio-impedance signal is utilized for various purposes. For the analysis of the bio-impedance signal, following techniques are used.

A. Frequency Domain Analysis

Frequency domain analysis is one of the techniques to analyze the bio-impedance of the body in which changes in impedance values occurs due to increasing frequency. The frequency component provides detail information of organic composition. It is mainly used for estimating composition such as fat mass, fat free mass, total body water etc.

B. Time Domain Analysis

Variation in the bio-impedance values over time give details of physiological parameters and biological signals. Biological tissue exhibits electrical nature due to free ions present in the body fluid [1]. Intracellular fluid surrounded by cell membrane, are suspended on extracellular fluid.

Electrical impedance of thorax had been taken for the study of cardiac function. Band electrodes were used around the thorax to measure cardiac stroke volume and cardiac output measurement in [2] over the frequency of 100 kHz 4mA rms. Long-term monitoring of tidal breathing was assessed with the help of impedance pnemography [3]. Plethysmography technique is utilized for respiration monitoring [4] which uses five electrodes. As multi-frequency approach is useful and important for the tissue characteristics, frequency in the particular range (1 kHz to 100 MHz) was applied to identify the bio-impedance of tissue and Electrical Impedance Tomography (EIT) as mentioned in [6], [7]. Suitability of IP proved that it can be utilized for continuous pulmonary flow and volume signal of respiratory system measurement. Although there were many artifacts generated during processing due to which necessary information gets hide. To remove this noise, wavelet transform is explained in [4] which help in feature extraction of ECG signal.

A device is presented in [8] used for physiological signal recording. Mainly it is a design for measuring impedance for respiration monitoring, ECG signal monitoring and to note user activities. The device is attached to the body with the electrodes which takes response from the body. The related work is also based on the principle of FDM where current injecting electrodes is provided with different frequencies and measures the different voltage response from body, because the electrical properties of tissues gets change with frequency.

Among all this survey, there is a lack of information about the error caused by the application of electrodes. There are several errors which need to be explained that comes in picture due to multi-frequency approach such as frequency interference between the leads and electrical interaction between the leads. Here in this paper, the system is designed to measure the impedance and to reduce the above mentioned error. This system is applied on real application to observe the blood volume changes at various positions of the body and to perform the time-domain analysis.

The paper is arranged as follows: Section II gives implementation of paper, Section III gives Methodology with A) hardware part and explanation of respective Blocks and B) software part, Section IV gives Performance testing with their Result and V is conclusion.

II. IMPLEMENTATION OF PAPER

In this paper, the multi-lead system is designed for the measurement of the bio-impedance, error reduction and blood volume extraction. The hardware part provides the impedance value and software part shows graph and results.

III. METHODOLOGY AND MATERIAL

A) Hardware Development

This section describes the design of bio-impedance measuring system. The block diagram of system is shown in figure 1. The hardware includes three components AD5933 impedance analyzer, 4052 multiplexer and microcontroller LPC1768. The digital data from AD5933 is through mux which is processed to the microcontroller to display the values on software.

Impedance converter AD5933 generates excitation signal, which is applied to tissue under study (TUS) through leads. Strip leads and ECG electrodes are used for different purposes. The response signal from TUS is measured using different leads with their sensing terminals and processed internally in impedance analyzer AD5933 which gives impedance values. These values are obtained at each sweep of frequency and transferred to LPC1768 cortex Micro-controller through I2C interface. LPC1768 cortex is ultra-low power MCU which takes only 3.3V and it is useful to give the digital values of impedance and then the data is transferred to PC through USB interface.

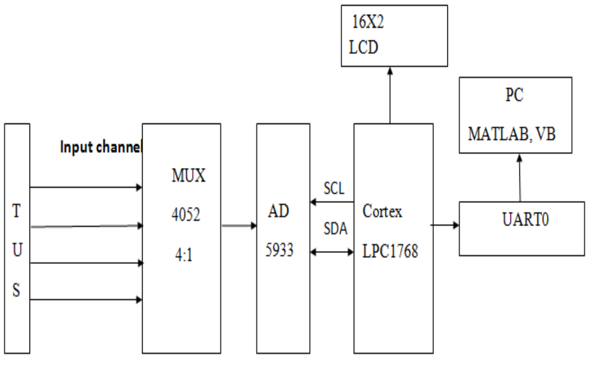

Figure1: System Block Diagram.

i). AD5933 impedance converter

The AD5933 is a high precision impedance analyzer system. It has 12bit analog-to-digital converter (ADC) and on-board frequency generator which allow external impedance to be excited at known frequency.

Applications of AD5933:

- Bioelectrical impedance analysis
- Impedance spectroscopy
- Complex impedance measurement

a) Processing of AD5933 impedance converter: Input to the AD5933 impedance convertor is voltage response from the body.

The response signal from the impedance is sampled by the on-board ADC and it is processed to perform discrete Fourier transform (DFT) by an on-board DSP engine. The DFT algorithm returns a real (R) and imaginary (I) data-word at each output frequency as shown in figure 2.

It includes a serial interface protocol I2C port such as communication interface which allows the adjusting of several operation parameters as well as the transmission with an external Host of the impedance data results.

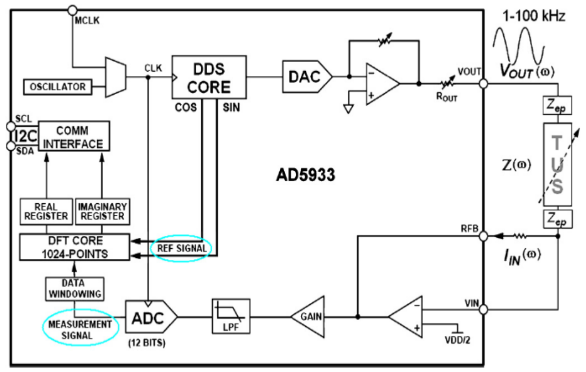

Figure 2: Functional block diagram of AD5933

ii). LPC1768 Cortex MCU: The microcontroller used here is LPC1768 processor [9]. LPC1768 ARM Cortex-M3 is based on microcontrollers and it has a high level of integration and low power consumption. Various points are - it operates at CPU frequencies of up-to 100 MHz, includes up to 512 Kb flash memory, Ethernet MAC for network connection, 64 Kb of data memory, SPI interface, USB Device/Host/OTG interface, 4 UARTs, 6-output general purpose PWM, 3 I2C-bus interfaces, 2-input plus 2-output I2S-bus interface, 8-channel 12-bit ADC, 70 general purpose I/O pins, 10-bit DAC, 2 SSP controllers, 8-channel general purpose DMA controller, Quadrature Encoder interface, up to four general purpose timers, motor control PWM and ultra-low power Real Time Clock (RTC) with separate battery supply.

iii). MUX 4052:

The 4052Mux is a dual 4-channel analog multiplexer with a common channel select line. Each multiplexer has four independent inputs/outputs Y0 to Y3 and a common input/output Z. The select input S1, S2 and active LOW enable are common. Multiplexer consists of four bidirectional analog switches; each one is connected to their respective sides of connection but only common input/output is connected to Z. With E LOW, one of the four switches is selected (low-impedance ON-state) by S1 and S2. Mux 4052 output is connected to AD5933 which takes response from it and processed to MCU through select line.

B). Impedance Estimation

For impedance estimation, AD5933 implements the Discrete Fourier Transform on DSP over the sampled current signal and the reference injecting signal. The DSP core calculates 1024 points DFT transform for each frequency point in the frequency sweep obtaining the real and imaginary components.

The impedance can be estimated directly by applying the Ohm's law in the frequency domain:

$$\frac{1}{Z(w)} = \frac{V_{out}(w) - V_{in}(w)}{I_{load}(w)} \quad \text{............ (1)}$$

Where $Z(w)$ is the impedance at the measured frequency, $Vout$ and Vin are respectively the output and input voltages of the sensing stage and $Iload$ is the current that flows through the impedance that we want to measure.

As a result, the DFT along with the Fourier Coefficients provides the relationship between the voltage signal controlling the excitation and the current signal through the load. From those coefficients, the magnitude and the phase can be calculated from each frequency.

$$Magnitude = \sqrt{R^2 + I^2} \quad \text{............ (2)}$$

$$Phase = Tan^{-1}(I/R) \quad \text{........ (3)}$$

c). SOFTWARE DEVELOPMENT

The response impedance signal is displayed on Visual Basic. It displays the parameters: impedance, Real and Imaginary values, phase and magnitude of selected leads at different frequencies as shown in figure 3.

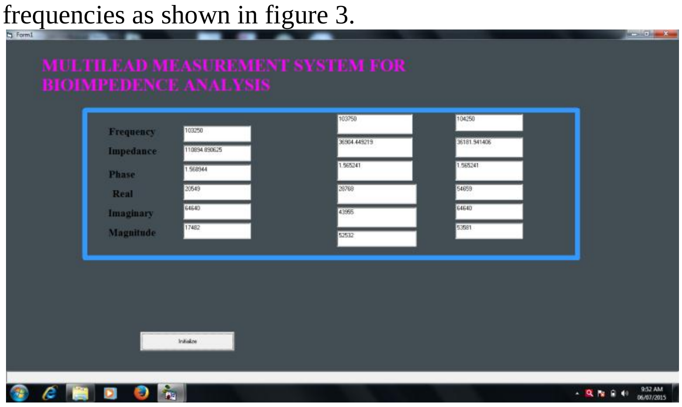

Figure 3: Output displayed on VB

IV. Performance Testing

In order to evaluate the performance of the Impedance measurement system based on AD5933, certain measurements have been taken. Experimental measurements on electrical equivalent models have been taken with the AD5933+ 3 stripe leads and ECG electrodes. The obtained impedance spectral data have been used to estimate the values of the equivalent circuit under measurement and the estimated values have been mutually compared.

TEST 1: Here three leads are simultaneously connected to the load RL=500Ω for different combinations of frequency. Mean and variance is calculated. Connection of the lead terminal is shown in figure 4.

RESULT 1: The variance of 0.0000060943 is calculated by AD5933. These results shows that the application of multifrequency for this system gives better accuracy.

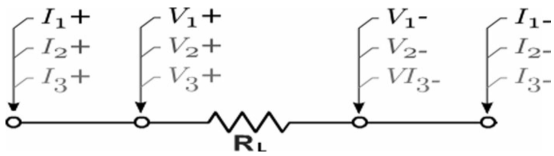

Figure 4: Circuit diagram used for test 1 and test 2 at various excitation frequency.

TEST 2: This test is done to quantify the error due to addition of leads. Load RL of figure 7 is configured for ten different resistors 100 Ω to 1000 Ω. Error is calculated to remove resistor tolerance.

$$E_{test:n}(Rl) = \frac{R_{test:n}(Rl) - R_{test:1}(Rl)}{R_{test:1}(Rl)} \times 100 \quad \text{.......... (4)}$$

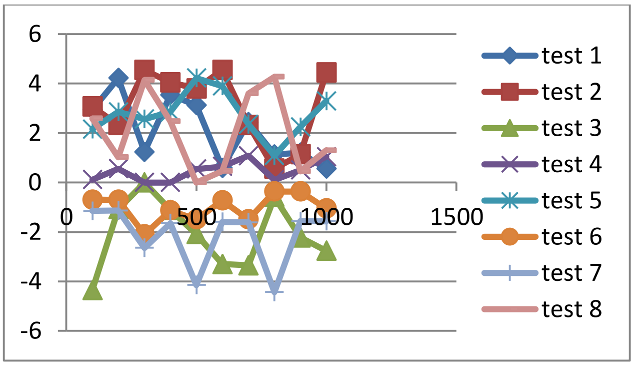

Figure 5: Electrical Interference results due to addition of lead. Reference line is used to calculate the error, where test 4 and test 6 shows minimum error.

RESULT 2: The error does not exceed ±4.5%. The abscissa shows the value for load RL. Each line of graph shows the result for load combination. RL=400Ω and 600Ω are near to the reference line which indicates less error.

TEST 3**:** This test is performed on bio-impedance electrical model which consists of R1, R2 and C. This test is conducted to check the system performance for biological model. The relative error among the components is obtained for different configuration.

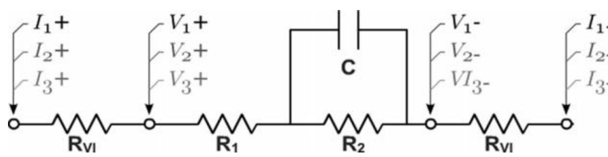

Figure 6: Biological organic tissue model for bio-impedance test.

Table 1 Result for Biological organic tissue model test.

Configuration No.	R1 (Ω)	R2 (Ω)	C (nF)	Relative error		
				Lead 1	Lead 2	Lead 3
1	309	182	220	0.24%	0.98%	1.25%
2	475	442	100	0.28%	0.42%	0.70%
3	301	953	68	-1.14%	1.03%	0.69%
4	133	243	22	0.35%	1.35%	1.50%
5	475	442	10	-0.30%	0.02%	1.46%
6	120	952	10	-1.20%	1.32%	-0.9%
7	82	27	68	0.03%	-1.3%	-0.8%
8	180	243	10	-0.21%	0.73%	1.07%

Table 1 shows the result for Biological organic tissue model test.

RESULT 3: The error does not exceed ±1.5%.

V. CONCLUSION

Design and implementation of bio-impedance measurement system using AD5933 impedance analyzer has been presented in the paper. Above mentioned tests were performed on system and it gives better accuracy for electrical interference between the leads. Result of test 1, test 3 provides system accuracy of 0.0000060943 for electrical equivalent circuit and ±1.5% error for biological model.

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