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Integrated Circuit Applications in Body Composition Analysis

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Abstract—

The nature of measurement technique of bio-impedance has proved to be of non-invasive nature hence is a important reason for adopting this technique in medical research. BIA is a vital and useful method for measuring the total composition of the body. Analysis of Bio-impedance plays a vital role in the assessment of health and nutritional value of the body. Using different integrated circuits different techniques for measurement of body composition is presented in this paper.

Keywords—Bio-impedance, Bio-impedance analysis, Non-invasive measurements, A.C rectification, I/Q demodulation.

I. INTRODUCTION

Bio-impedance, in recent years, is gaining popularity in the field of bio-medical research applications, contents of body fat, freshness of food and many more. According to the research human body has a number of electrical features and one of the important features among them is impedance. The property of opposing the flow of AC current is known as impedance. Thus the method of measuring impedance is the same as that of conventional impedance measuring, which consists of supplying a small amount of alternating current signal and measuring the voltage differences and then calculating the impedance using amplitude and phase changes between the original signal and the recorded one [1]. BIA is also used to detect improper balance in body composition; it also allows detection of earlier prevention and intervention. BIA can be used for measurement of content of body mass and fluid that can be a critical assessment for body health [2].

II. BIO-IMPEDANCE ANALYSIS PRINCIPLE

Bio-impedance is the response of a living organism to externally applied electric current [3]. Bio-impedance is a measure of the opposition to the flow of that electric current through the tissues, the opposite of the electrical conductivity. The bio-impedance measurement of human body has proved very useful as a non-invasive method for measuring body composition and blood flow [4].

III. TECHNIQUES OF BODY COMPOSITION ANALYSIS

Body composition is obtained by measuring the impedance at several points on the body and thus matching the result in a table consisting of both the impedance measured and the body composition. This table is being created by different manufacturer and is usually based on sex, weight, age group and other parameters.

The body impedance that we want to measure i.e. Z (f) is a function of the excitation frequency and is represented by polar or Cartesian notations

$$Z(f) = |Z(f)| \cdot e^{j\theta(f)}$$
$$Z(f) = R(f) + jX((f) \quad (1)$$

Where,

$$|Z| = \sqrt{R^2 + X^2}$$

$$\theta = arctg\left(\frac{X}{R}\right)$$

The AFE4300 is an IC developed by Texas Instruments and provides two options for body impedance measurement namely I/Q demodulation and ac rectification. Both, I/Q demodulation and ac rectification work on the principle of injecting a sinusoidal current into the body and measuring the voltage drop across the body. The circuit that injects the current into the body is the same for both the techniques. The difference lies in how the voltage measured across the impedance is processed to obtain the final result.

A. AC Rectification

The upper portion of Figure 1 represents the current-injection circuit. A digital pattern is being generated by direct digital synthesizer with a frequency obtained by dividing a 1-MHz clock with a 10-bit counter.

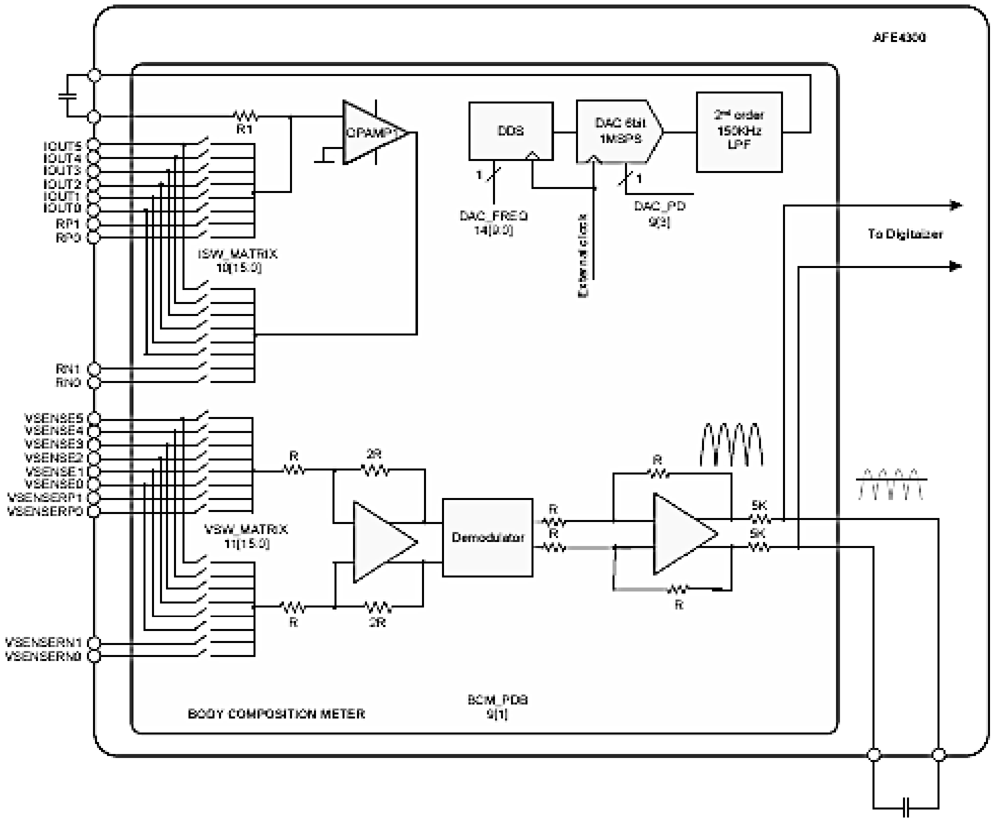

Figure 1 AC Rectification [5].

The digital pattern given by Direct Digital Synthesizer drives a 6-bit, DAC. The output of Digital to Analog Converter is filtered by a 150-kHz filter and the images are removed by the second order filter, which is followed by the capacitor that blocks the dc current and avoid injection of dc current into the body. The filters output is used to drive a resistor that set the amplitude of the current that is being injected in the body, as shown in Equation (2)

$$I(t) = \frac{VDAC}{R1} = A\sin(t) \quad (2)$$

The resistor R1 and the DAC amplitude are set so that the current injected is 375 µAmp when all the elements are nominal. With an error of 20%, the source is 450 µAmp, this is still below the 500 µAmp limit. Current will flow into the body through an output analog multiplexer which allows the selection of up to six different contacts on the body. The current that is injected will cross the body impedance while the second multiplexer will select the return path on the body that will complete the loop to the output of the amplifier. As the current is inserted in the body of the person, second multiplexer connects the differential amplifier across the same body impedance in order to measure the voltage drop created by the current being injected is shown in Equation (3)

$$V(t) = A|Z|.\sin(\omega_0 t + \theta) \quad (3)$$

The output of the amplifier is routed to a pair of switches that will implement the demodulation at the same frequency as that of the excitation current source in order to drive the control of the switches. This circuit performs a full-wave rectification operation of the differential amplifier output and the dc level at its output is recovered by a low-pass filter and finally routes it to the same 16-bit digitizer.

$$DC = 2/T \int_{T/2} A|Z|\sin(\omega_0 t + \theta)dt.\, 2A|Z|/\pi \quad (4)$$

From the Equation (4) the dc output is directly proportional to the magnitude of the impedance. Thus, using four external impedances proportionality factor can be obtained through calibration. With single frequency, only the magnitude of the impedance can be obtained thus by using two different frequencies we could obtain both the real and the imaginary parts [4].

B. I/Q DEMODULATION

The AFE4300 includes a circuit that obtains both the real and the imaginary portions with a single frequency measurement, as shown in Figure 2. The current injecting principle is same as that of RMS detector. Thus, the V(t) signal is taken by I/Q demodulator and two dc values are given. These two values are used to extract the impedance module and phase with a single frequency measurement. The I/Q demodulator technique helps to reduce power consumption also it gives the excellent performance. The local oscillator signals for the mixers are generated from the same clock driving the

DDS/DAC and are of the same phase and frequency as the sinusoidal i(t). The LO signals directly control the switches on the in-phase (I) path, and after a delay of 90° it controls the switches on the quadrature (Q) path.

Thus, due to switching it results in multiplying the v(t) signal by a square signal swinging from –1 to 1. Breaking down the LO signal into Fourier terms as given in Equation (5)

$$LO_I(t) = \frac{4}{3}\left(\sin(\omega_0 t) + \frac{1}{3}\mathrm{Sin}(3\omega_0 t) + \frac{1}{5}\mathrm{Sin}(5\omega_0 t) + \cdots\right)$$

(5)

Therefore, the output voltage of the mixer is as shown in Equation (6)

$$I(t) = A|Z|\frac{4}{3}\left(\sin(\omega_0 t + \theta)\sin(\omega_0 t) + \frac{1}{3}\mathrm{Sin}(3\omega_0 t + \theta)\sin(3\omega_0 t) + \frac{1}{5}\mathrm{Sin}(5\omega_0 t + \theta)\sin(5\omega_0 t) + \cdots\right)$$

(6)

Where, I (t) is in-phase output.

Applying fundamental trigonometry gives

$$\sin a \cdot \sin b = -\frac{1}{2}\cos(a+b) + \frac{1}{2}\cos(a-b)$$

(7)

Each product of sinusoids can be broken down into two sinusoids. The first term is shown in Equation (8)

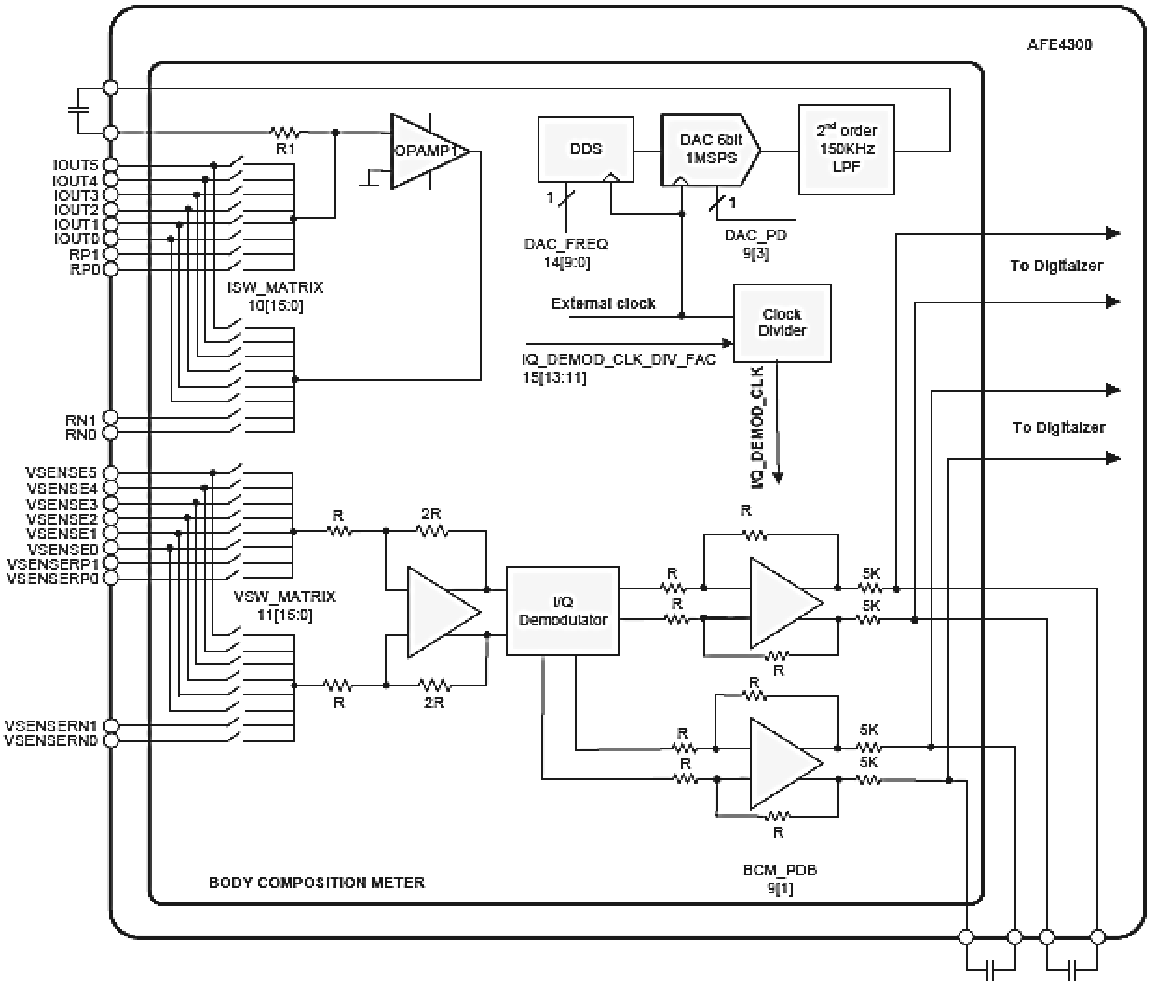

Figure 2 I/Q demodulation [5].

$$\sin(\omega_0 t + \theta)\sin(\omega_0 t) = \frac{1}{2}\cos(\omega_0 t + \theta - \omega_0 t) - \frac{1}{2}\cos(\omega_0 t + \omega_0 t + \theta) = \frac{1}{2}\cos(\theta) - \frac{1}{2}\cos(2\omega_0 t + \theta)$$

(8)

Equation (9) shows the second product

$$\sin(\omega_0 t + \theta)\sin(3\omega_0 t) = \frac{1}{2}\cos(\omega_0 t + \theta - 3\omega_0 t) - \frac{1}{2}\cos(3\omega_0 t + \omega_0 t + \theta) = \frac{1}{2}\cos(-2\omega_0 t + \theta) - \frac{1}{2}\cos(4\omega_0 t + \theta)$$

(9)

And so on. Performing the same analysis on the Q side, the voltage of the mixer is shown in Equation (10)

$$Q(t) = A|Z|\frac{4}{\pi}(\sin(\omega_0 t + \theta).\cos(\omega_0 t + \theta - 3\omega_0 t) + \frac{1}{5}\sin(\omega_0 t + \theta)\cos(5\omega_0 t) + \cdots)$$

(10)

Again, applying fundamental trigonometry gives Equation (11)

$$\sin a \cos b = \frac{1}{2}\sin(a+b) + \frac{1}{2}\sin(a-b)$$

(11)

Each of the products can be broken up into sums. Starting with first product is as shown in Equation (12)

$$\sin(\omega_0 t + \theta)\cos(\omega_0 t) = \frac{1}{2}\sin(2\omega_0 t + \theta) + \frac{1}{2}$$

(12)

And so on. Note that on I(t) as well as on Q(t), all the terms beyond the cut-off frequency of the low-pass filter at the output of the mixers (setup by the two 1-kΩ resistors and an external capacitor) are removed, leaving only the dc terms, giving Equation(13) for I_{DC} and Equation(14) for Q_{DC}

$$I_{DC} = \frac{2A|Z|}{\pi}\cos\theta = K|Z|\cos\theta$$

(13)

$$Q_{DC} = \frac{2A|Z|}{\pi}\sin\theta = K|Z|\sin\theta$$

(14)

In reality, the LO amplitude is not known and thus it affects the value of K in I_{DC} and Q_{DC} equations. Solving Equations (13) and (14) gives Equation (15).

$$\theta = \arctan\frac{Q_{DC}}{I_{DC}}$$

(15)

$$Z = \frac{1}{K}\cdot\sqrt{I_{DC}^{\ 2} + Q_{DC}^{\ 2}}$$

(16)

The AFE4300 also provides four extra terminals on the driving side, two to drive and two for the return path for current and four extra term [5].

C. USING AD5933

The AD5933 is used for measuring unknown impedance values by obtaining the real and imaginary values of unknown impedance. The magnitude of the real and imaginary data contents is given by the Equation (17).

$$magnitude = \sqrt{R^2 + I^2}$$

(17)

The value of the actual impedance under test at the known frequency is equal to the magnitude value [6]. To determine the actual impedance the magnitude must be multiply with Gain Factor GF. The GF is measured using known external impedance connected between Vout and Vin as close as possible to the pins [7].

$$Gain\ Factor = \frac{\frac{1}{impedance}}{magnitude}$$

(18)

The Gain Factor is calculated that calibrates the parasitic impedance between Vout and Vin at a given frequency. By measuring the unknown impedance at a frequency that is known, the measured impedance at that frequency is calculated using the Equation (19).

$$impedance = \frac{1}{gain\,factor \times magnitude}$$

(19)

IV. CONCLUSIONS

In this paper, we have discussed the different techniques used for obtaining the body composition using different integrated circuits. In AC Rectification method using single frequency only the magnitude of the impedance can be obtained and by using two different frequencies can obtain both the real and the imaginary parts. Using I/Q demodulation with a single frequency measurement we can obtains both the real and the imaginary portions. I/Q demodulation is being widely used for the accurate results.

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