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Impedance Measurement System for Bio-Impedance Spectroscopy Using Under Sampling

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Abstract: In embedded systems, Impedance spectroscopy is used to measure the impedance of the system as a function of frequency. The standard U-I method for designing impedance analyzer includes use of Gain-Phase Detector (GPD), Peak Detector, Discrete Fourier Transform (DFT). This project aims at designing of a microcontroller based impedance measurement system using DFT and Under Sampling to enhance the frequency range in portable bio-impedance measurement systems. The impedance analyzer implements a digital concept with appropriate signal conditioning for voltage and current measurement, early signal digitization and subsequent digital signal processing in order to calculate the components of impedance. The designed impedance analyzer measures the impedance magnitude and phase at frequencies up to 10 MHz at low frequencies, the module utilizes the conventional direct conversion method, whereas at high frequencies the under sampling technique is used. The results from the impedance analyzer for commonly used tissue model (Device Under Test) are validated by comparing it with the theoretical results from matlab. The results show a good performance to frequencies up to 3 MHz Above 3 MHz systematic deviations are becoming visible. The system was observed for impedance magnitude and phase out of 10 measurements and shows standard deviation of 0.2 Ω (0.2%) for impedance magnitude and a standard deviation of 0.5° for impedance phase.

Keywords: Embedded systems, Gain-Phase Detector (GPD), Peak Detector, Discrete Fourier Transform (DFT).

1. Introduction

Impedance analyzer is a device used for impedance spectroscopy [1]. Impedance spectroscopy measures electrical impedance which is the measure of opposition that a material presents when placed under an alternating electrical field. It is a complex vector quantity which gives information about magnitude and phase. It also measures multiple electrical properties of materials as a function of frequency using a sinusoidal varying voltage. It has wide range of applications in different fields such as electrochemistry, material science, biology and medicine, semiconductor industry and sensors. It can be used to:

- Determine corrosion rates of materials
- Probe linearity of electrical/electrochemical reactions
- Characterize electrical activity across interfaces to determine carrier concentration

- Determine diffusion rate of counter ions in conducting polymer/carbon nano-tube composites

There is a sharp increase of demand in life care and medical monitoring [2], so impedance spectroscopy has also gained a lot of popularity in the field of medicine and bio analysis such as cardiograph (strokes), detection of proteins, DNA hybridization, common allergens, sciatic nerve injury monitoring, cell characterization, diagnosis of dehydration [3], prostate biopsies, assessing body composition (body fat in relation to body mass), renal ischemia monitoring etc [4]. There is also sharp increase in wearable devices with RF interface which uses impedance spectroscopy for monitoring health (heart rate monitoring, blood pressure monitoring etc. refer to Figure 1).

Figure 1: Wearable devices

2. Methodology to measure impedance

An impedance analyzer is a computational device that measures the opposition to current in alternating current (AC) systems at a given frequency, i.e. it is used to measure impedance. It is a part of larger measurement/signal processing chain summarized in Figure 2.

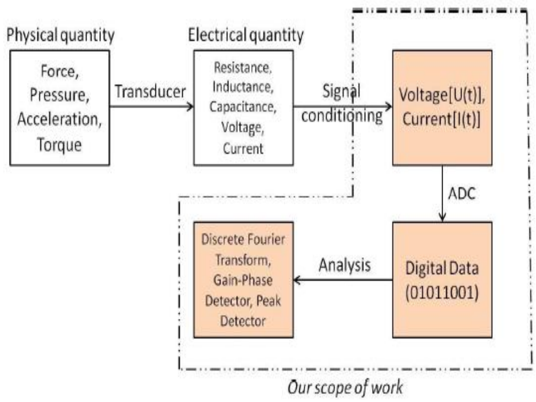

Figure 2: Standard Measurement chain

3. Implementation

The proposed impedance analyzer is designed on ARM cortex M-4 microcontroller by ST Microelectronics (STM32F407VGxx) using 12-bit successive approximation type inbuilt ADC. The test signal is generated from AD9850 module and passed through the DUT (Equivalent circuit to biological tissue). After this, signal is amplified using differential op-amp 'ADA4940' from Analog devices. These signals are fed to two different channels for voltage and current in ADC. The data from ADC peripheral is transferred to the memory location using DMA and is then processed. After data is processed, DFT is implemented which determines the spectral information of the signal. The device uses DFT technique on certain number of samples to obtain the amplitude and phase for both voltage and current channel. This information can be used to calculate the impedance and phase difference of the device under test. We first use a regular DFT with fulfilling nyquist criteria for sampling the measuring frequencies in the range of 50-250 kHz with a sample rate of 500 kSamples/sec. Later DFT is used together with under sampling for analyzing frequencies above 500 kHz with the same sample rate.

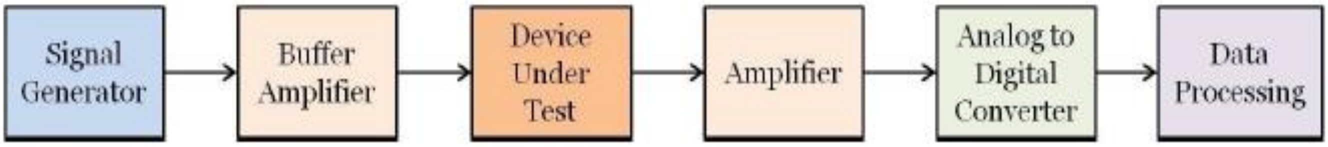

Figure 3: Impendence analyzer structure

The structural details are summarized in figure 3 which show a signal generator followed by buffer amplifier, device under test block, amplifier, A-D converter and data processing unit

4. Experimental Tests/Findings

For designing the impedance analyzer, we first validate the design by measuring the magnitude of voltage for sinusoidal signal at different frequencies and compare it with the theoretical results from matlab. We used single channel ADC for measuring the magnitude of voltage using DFT. The test signal of different frequency is generated by an Agilent signal generator with a maximum frequency of 15 MHz The test signal is the sine wave with 1.5 V amplitude and an offset of 1.5 V at different testing frequencies. We can see the comparisons of time domain data for sinusoidal signal of 1.1 MHz in Figure 4. When DFT is applied to the time signal, results can be seen in frequency domain. The level of the sample points is drifting due to a mismatch in the time base of the signal generator and the microcontroller. In Figure 30, amplitude at 1.1 MHz can be observed and matches the theoretical amplitude from the matlab. Likewise, results for different frequencies are observed and graphs are plotted in time and frequency domain for the same. The module is tested further for the different frequencies of 5.6 MHz, 10.1 MHz and 14.2 MHz The results for the mentioned frequencies can be seen from Figure 30 to Figure 4. The systematic errors due to the difference in time base of microcontroller and signal generator increases with the frequency.

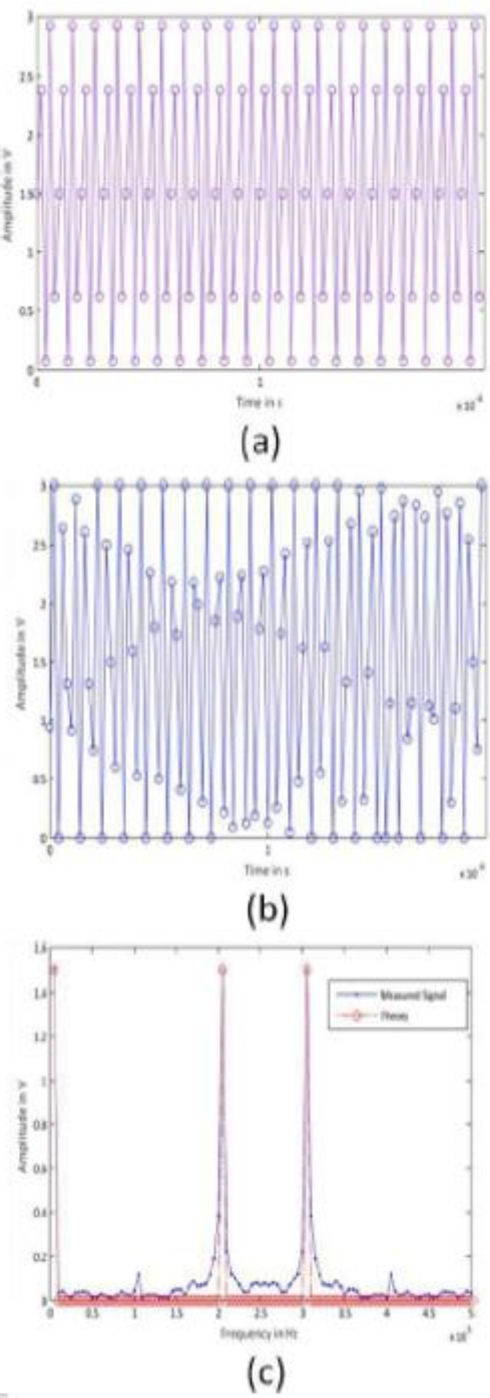

Figure 4: 10.1 MHz (a) Theoretical time series (b) Practical time series (c) Theoretical and practical amplitude

Author Contributions: All authors contributed equally.

Conflicts of Interest: The authors declare no conflict of interest.

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