# MICROCONTROLLER CONTROLLED, MULTIFREQUENCY ELECTRICAL IMPEDANCE TOMOGRAPH

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*Abstract*- **In this study, development of a microcontroller controlled multifrequency electrical impedance tomography system is aimed. In this system, current injection and voltage measurements are both performed by the surface electrodes, which are microcontroller controlled. Data acquisition system process the measured signal using continuous time quadrature demodulator. After that, it converts analog information to digital and transfers it to the PC.**

*Keywords* – **electrical impedance tomograph, multifrequency**

## I. INTRODUCTION

Electrical Impedance Tomography (EIT) is a technique that produces images of impedance distribution in a slice through a volume conductor body, by means of electrical measurements made on the surface of the conductor. Electrical measurements are then used to reconstruct images of impedance distribution. Since different tissues have different impedances, it is possible to characterize tissues in impedance images and to monitor physiological events [1].

In conventional *static* and *differential* imaging methods, current is applied at a single frequency. Impedance of biological tissues are not purely resistive but they also exhibit a reactance component, due to the cell membranes. Therefore, single-frequency EIT cannot produce *static* images of tissue properties [2]. This has led to the construction of images in which tissues can be discriminated by their frequency behavior. For this purpose EIT systems capable of making impedance measurements at various frequencies are needed. These methods are classified as *multifrequency impedance tomography* methods. Depending on the applied frequencies, the impedance change can be very large.

## II. DESIGN

The principle of the data acquisition system is based on a conventional four-electrode impedance measurement system, represented in Fig. 1. Multiple (typically 16 to 32) electrodes are placed around the object to be imaged. A sinusoidal current with frequency range 10kHz to 100kHz is applied between a pair of electrodes, which are called current electrodes. The current can be switched between different electrode pairs by means of analog multiplexers. Potential values are measured at the remaining electrodes. Selection of measurement electrodes is made by using analog demultiplexers. The system is designed to operate under the control of a microcontroller. The microcontroller can be programmed at the beginning of each imaging session via a PC. The PC transfers the current injection and measurement
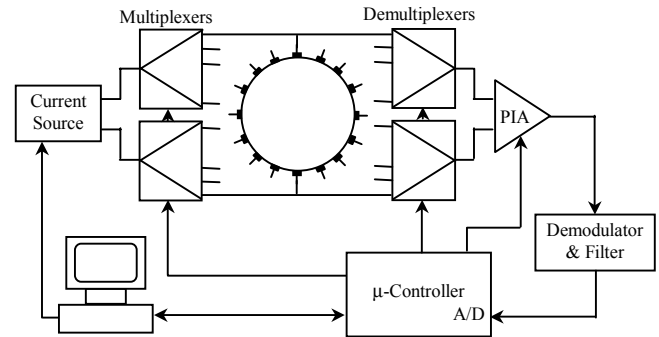


Fig. 1. Electrical Impedance Tomograph Overview

protocol to the microcontroller. The samples of the current pattern, which define the frequency of the applied current, are also sent by the PC. Microcontroller selects the current and the measurement electrodes and applies the current according to the user defined protocol. Different blocks of the design are described below:

### A. Current source:

The current source composed of a microcontroller (Microchip 16C774), D/A converter (National DAC0808) and a low pass filter (LPF). The current source is used to generate a sinusoidal signal where the frequency can be selected between 10kHz to 100kHz. The block diagram of the current source is shown in Fig. 2.

Microcontroller is connected directly to the ISA bus of the computer via its parallel slave port. Computer calculates the sample points to be applied, according to user defined waveform. Microcontroller receives the waveform samples from the PC and writes to its RAM. 128 bytes of microcontroller RAM is used for this purpose. The time difference between the samples is also variable and can be defined by the user. The maximum frequency of the current waveform is 100kHz and the minimum number of sample points per period is 16 in order to obtain a sinusoidal signal with low distortion. The minimum time difference between two samples, $\Delta t$, can be expressed as

$$\Delta t = \frac{1}{N \cdot f_{MAX}} \qquad (1)$$

where $N$ denotes the minimum number of samples per period and $f_{MAX}$ denotes the maximum waveform frequency. For the worst case $\Delta t$ is calculated to be 625ns. Therefore, the maximum allowable settling time for the D/A converters is 625ns. In the proposed design, National DAC 0808, which has 8-bit digital input, 150ns settling time, and ±0.19%
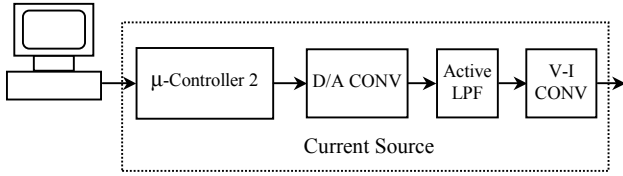
Fig. 2. Current source

relative maximum error is used. Settling time of the selected D/A converter satisfies the requirements.

Although the output of the D/A converter is current, it can not directly be applied to the object since it contains high harmonic components. It should be converted into a voltage waveform for not only filtering purposes but also for the generation of a reference voltage signal. The active LPF contains a current-to-voltage converter at the input stage. In the second stage of the LPF filter, a 2nd order Butterworth low pass filter is used to suppress harmonics generated due to D/A conversion. At this stage, universal filter, Burr-Brown UA42AP, is used. Butterworth filter is selected because its performance is better compared to Chebyshev and Bessel type filters. It has the flattest possible response in the pass-band; its pulse response is better than Chebyshev type and the rate of attenuation is better than Bessel type filters [3].

At the output of the LPF, the desired waveform is obtained in voltage form. It should be converted into a sinsoidal current waveform using a voltage-to-current (V/I) converter. The V/I converter, depicted in Fig. 3, is used. The main limitation on the selection of the Op-Amps, used in the V/I converter, is the amount of the phase introduced. Ideally, the phase difference between the input voltage and the output current should be either 0 or 180 or a known constant which can be compansated. In this design, ultra low noise precision operational amplifier, Burr-Brown OP37G, is used. The maximum phase difference between the input and output of the V/I converter is observed at the maximum frequency, 100kHz. The frequency response of this circuit is simulated using Electronics Workbench$^{TM}$. The phase and the gain of the V/I converter is found to be 179.67° and 0.9999 respectively at 100kHz.
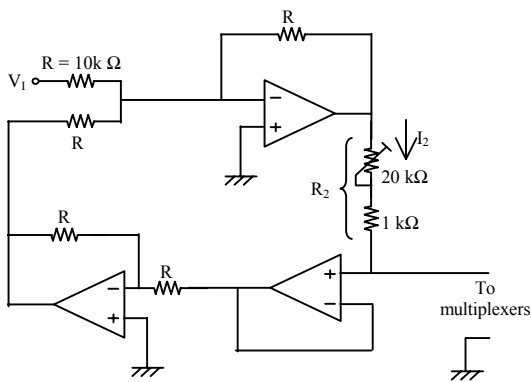
## B. Multiplexers and Demultiplexers:

The output of the current source should be directed to the current injection electrodes as defined by the measurement protocol. For this purpose, analog mutiplexers can be used. The impedance of the multiplexers must be very small compared to measured impedance, not to effect the measurement. Switching time of the multiplexers must be small in order to collect the data as fast as possible. Since the analog multiplexers are connected to the isolated power supply, current consumption of the multiplexers must be small. For analog multiplexer, 16-channel high performance analog multiplexer, Analog Devices ADG 406, is used. It has low resistance, typical 50Ω with 4Ω mismatch and 200ns switching time. In the same manner, for the demultiplexing operation Analog Devices ADG 406 is used. Configuration of multiplexers, demultiplexers and units between micro-controller and electrodes are given in Fig. 4.

Patient should be isolated from the system for safety requirements. Digital outputs of the microcontroller which controls the analog multiplexers are isolated using a digital coupler. Digital coupler should have a small propagation delay time for fast data collection. Moreover, there should be no glitches at the output. Burr-Brown ISO508, uni-directional isolated coupler is selected in this design. It has 8-bit data input and 8-bit output, with propagation delay time 1μs. Uni-directional isolated coupler is very fast and compact compared to the standard opto-coupler design. The switching time is sufficient since the time between two successive measurements is 300μs. For Burr-Brown ISO508, outputs change simultaneously so there is no glitch at the output. This avoids false selections of electrodes at transition times. The maximum current supplied from isolated 5V power-supply is 10mA for each chip.
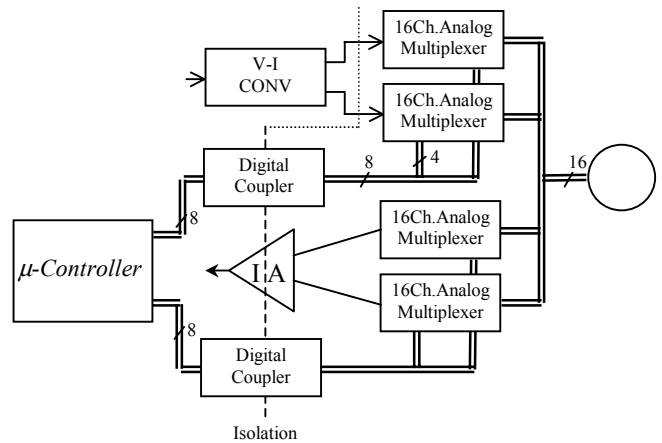


Fig. 3. Voltage to current converter circuit



Fig. 4. Multiplexer and demultiplexer part

## C. Phase-Sensitive Voltage Measurement:

Applying a sinusoidal current with frequency $f_0$ the measured voltage is also sinusoidal with the same frequency but the phase and magnitude of the measured signal is modified by the volume conduction properties. Using this fact imaginary and real part of the signal can be found.

Following the analog demultiplexers, low distortion isolation amplifier, Analog Devices AD215, which is shown in Fig. 5, is used. For increasing the dynamic range of the system, AD215 is followed by a digitally controlled gain instrumentation amplifier. To recover the imaginary and real part of the signal, continuous quadrature demodulator is used.

For analog multiplier, wide bandwidth precision analog multiplier, Burr-Brown MPY634, is used. It has ±0.5% max four-quadrant accuracy, and input voltage range is $10V_{peak}$ for each channel. The output is equation is given in (2)

$$V_{out} = A(V_1 \cdot V_2) \qquad (2)$$

For the low pass filtering after the multiplication universal active filter, Burr-Brown UFA42, is used in butterworth configuration. The order of filter is 3 for more suppression, and the cut-off frequency of the filter is 2kHz. The suppression of the filter at 200kHz is −80dB, which is sufficient. After the low pass filtering the signal is converted to a digital signal by using 12 bit A/D converter within the microcontroller. This information is send through to computer using the parallel slave port of the microcontroller.
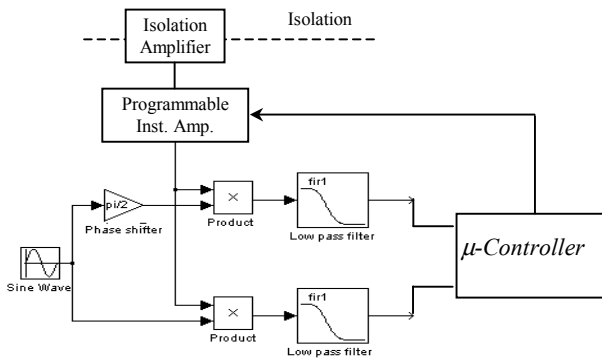


Fig. 5. Voltage measurement circuit.

## III. CONCLUSION

In this study, a microcontroller controlled programmable multifrequency electrical impedance data acquisition system is designed. In this system, the measurement protocol is defined by the user and downloaded to the microcontroller via a PC. In addition, the range of frequencies to be used are also programmable. Measured signal is demodulated by continuous-time quadrature demodulator to measure both in phase and quadrature components of the measured voltages. After demodulation, signal is fed to A/D converter. The resulting digital signal is transferred to the PC by the microcontroller for further processing and image reconstruction. With this method it is possible to collect fully computer controlled data.

## REFERENCES

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