Test Bench to Validate Audio CODEC Kit as EIT Complex Voltage Measurement Circuit

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Abstract— **A simple bench test instrument was developed to measure the real part of the impedance of a patient simulated by a phantom (variable R 350-600 ohm in parallel with C=47nF). The instrument is part of an EIT design which includes a EVM-L137 evaluation kit to enhance previous designs. The DSP included in the kit generates the waveform to control current sources. We use this original signal as a time reference to measure voltage phase, thus minimizing unknown delays. Once data are corrected by a linear fit to remove systematic errors in measurement, the values obtained deviate on average 0.9% from the expected. This instrument will allow to further compare design options in EIT circuit development.**

Keywords— **Electrical Impedance Tomography, Audio Codec, Digital Signal Processor, Howland Current Source, Test Bench**

I. Introduction

Stemming from clinical practice, IMPETOM is an instrument to solve the problem of obtaining simple and reliable graphical information on liquid occupancy of the thorax of intensive care patients[1][2]. Following the seminal papers of the Sheffield School[3] the first prototypes of IMPETOM included a 16 electrodes chest strap, a multiplexed 30KHz current source and 16 voltage meters. The resulting matrix was processed based on “back projection” algorithms to show impedance moduli color coded areas. Different architecture were devised and put in operation [4] including three rows of electrodes to better control current dispersion[5]. In 2014 a new processing alternative, based on better finite elements mesh shapes, was associated with enhanced hardware solutions, taken from “off the shelf” circuit elements rather than in house development [6].

DSP technology and audio CODEC circuitry were adopted for IMPETOM when an EVM-L137 evaluation board was used [7]. The first results of such tomographic reconstruction were calibration measurements, published in 2015 [8], the layout of which is shown in Figure 1.

While at least one commercial option is available on the market [9], we are faced here with the problem of developing a bench test to compare strategies and design options. Our goal is a tool to measure complex voltage resulting from different body impedance simulators.

II. System Description

We build a simple phantom with a parallel RC circuit, where R is variable from 350 ohms to 600 ohms and fixed C= 47 nF. This circuit is fed by a modified Howland current source [10], controlled by one of the CODEC output signals. This signal is proportional to a DSP originated 16 KHz sinus wave. In parallel to feeding the current source, the 16 KHz wave is measured by the oscilloscope, allowing to have a phase reference for the current measurements.

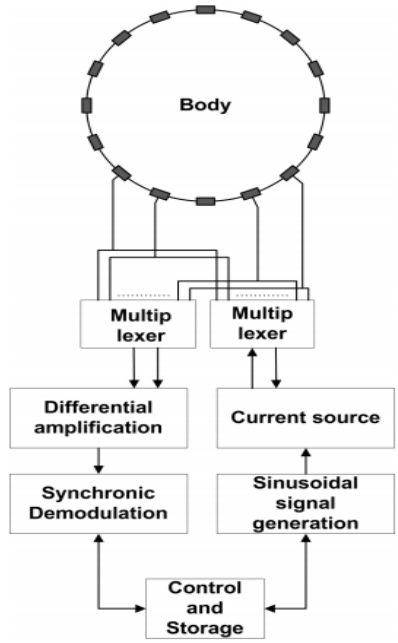

Fig. 1: EIT system block structure. Current source and resulting 16 voltage measurements are both referenced to the same DSP generated 16 KHz sinusoidal signal. Taken from Santos et al. [8].

The CODEC was configured to work with a 48 kHz sampling frequency in slave mode, the data transfer protocol was “I2S to DSP” and 16 bits word length. No offset is added to the data. The PGA gain of each channel was set to 0db. Communication between DSP and CODEC is through McASP serial port communication settings synchronized with 2 slots TDM format.

In parallel, an oscilloscope is connected to the output of the phantom circuit and to the input of the current source, where the voltage is in phase with the current

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injected into the phantom. This allows to compare measurements made by the system under test implemented with a reliable instrument such as a laboratory oscilloscope.

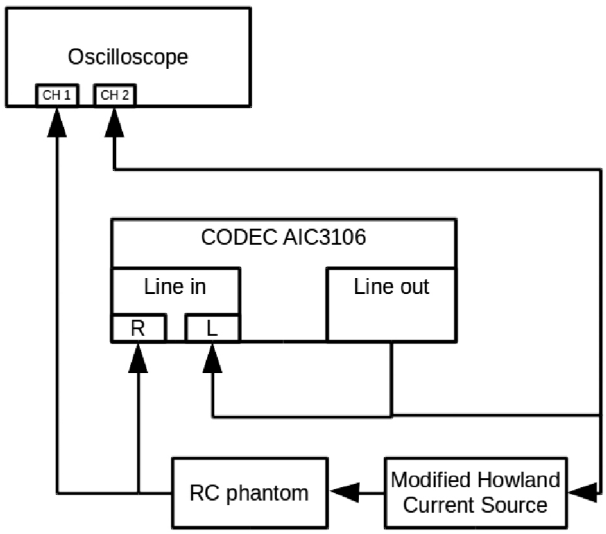

Fig. 2: Connection diagram of the test bench. The modified Howland current source feeds a phantom (parallel RC: C= 47nF and a variable resistor). The oscilloscope allows to compare the original CODEC voltage signal to the phantom-shaped voltage.

The software we developed uses the phase of the reference voltage signal to compare it to the phase of the resulting phantom voltage. The output voltage signal of the phantom circuit allows to calculate the real part of the phantom impedance. We do not use the original DSP generated signal which is fed to the CODEC to control the current source, because it would introduce a lag from the time the DSP sends the signal to the time the CODEC effectively outputs the signal at its output channel. To cancel this delay we chose to use a second CODEC input channel to measure the signal of its own output port. In this way we reduce the time overhead derived from causes other than the wanted phase change between the input and output signals caused by the RC phantom.

Once sampled signals and data are sent from the CODEC to the DSP, the software routine behaves according to the diagram in Figure 3.

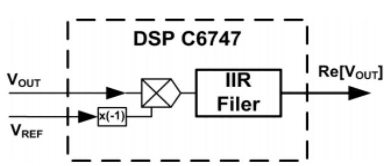

Fig. 3: DSP Implemented Synchronous Demodulator. Real part of V_{OUT} is output.

III. Results

We have tested our circuit with several values of R and a fixed C value, all reported in Table 1.

Table. 1: Real part of the phantom impedance.

R PHANTOM (Ω)	Impedance R//C real part @ 16KHz (Ω)	Oscil. measurement (Ω)	IMPETOM measurement (Ω)	IMPETOM adjusted R//C (Ω)	Relative Error
350	93.7	107.6	108.3	92.6	1.23%
400	87.5	111.3	104.5	88.2	0.82%
450	81.5	101.3	98.8	81.8	0.38%
500	76.0	94.7	94.6	77.1	1.43%
550	70.9	85.5	88.7	70.4	0.74%
600	66.4	78.9	84.7	66.0	0.66%
				Average Error	0.876%

Note: The first column shows the R value of the parallel RC circuit.

IV. Discussion

Our previous IMPETOM designs, along with other projects, include current control by a single analog signal multiplexed into 16 current sources. When a decision was made to use digital circuits and audio kits to cut costs and ease reliable duplication of IMPETOM instruments, real part impedance measurement errors were high. Debugging gave as a result an unexpected phase lag between signals. A theoretical internal digital signal as a vector in CODEC memory was initially used as a reference to measure real world hardware signal phases. This gave rise to uncontrolled errors. By using the same CODEC generated D/A signal as a reference for measurement as well as to create the signal to submit to the “patient simulator” or phantom, reliable values were expected. This was actually the case and the present paper describes therefor the error found with the suggested circuit. An error of approximately 1% was measured, which insures a reliable enough test bench.

We found that the implemented system manages to make consistent and comparable measurements. Once the data are corrected by a linear fit to remove systematic errors in measurement, the values obtained deviate 1% on average from the expected. This shows that our system inherits the precision of a laboratory instrument. Without our system, the impedance real part would only be estimated with an error due to lack of common time reference. This special measurement is necessary because modern designs include software signal generation, as opposed to traditional layouts with a central analog oscillator to command all current sources.

V. Conclusions

We obtained a test bench that allows us to evaluate the circuit configurations for EIT design as well as for future modifications and enhancements. The ability to test the behaviour of hardware and software components on a simple phantom is a great advantage for design purposes and decision making. Several improvements can be made to the system, such as reducing the test impedance vulnerability to noise derived from the lack of electrical shielding. Additionally the inclusion of measuring bridges to improve system sensitivity should be considered. We also plan to explore the use of 32-bit digital encoding to reduce quantization errors.

VI. Acknowledgment

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VII. Conflict of Interest

The authors declare they have no conflict of interest.

VIII. References

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