Audio Codec and Digital Signal Processor for an Electrical Impedance Tomography System

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Abstract— **Electrical Impedance Tomography (EIT) can estimate thorax fluid/air content and distribution. Its use in critically ill patients is promising and may prove clinically useful. Currents are injected and voltages measured in the thorax boundary. The measurements are used to reconstruct tomographic images. An EIT system was implemented based on evaluation board OMAP-L137 (Spectrum Digital) and Howland current source. The board main components are the OMAP-L137 processor with DSP C6747 and AIC 3106 audio codec (Texas Instrument). Fewer than 5% difference in voltages against the oscilloscope was measured in the range between 42mV and 1.5V. The entire system showed 8.53% difference when measuring the real part of impedance.**

Keywords— **Electrical Impedance Tomography, Audio Codec, Digital Signal Processor, Synchronous Demodulation, Howland Current Source**

I. INTRODUCTION

Estimation of alveolar fluid content and distribution is essential in the management of conditions such as cardiogenic pulmonary oedema, pleural effusions, pneumonia and acute respiratory distress syndrome (ARDS). Electrical impedance of tissues can be estimated by measuring voltages on the skin while applying high frequency currents ($>$ 10 kHz) whose amplitudes ($<$ 5 mA) are below perception thresholds. Processing electrical impedance matrices yields tomographic images. This method, known as Electrical Impedance Tomography (EIT), is a low-cost, non-invasive, continuous-measurement method used to obtain low resolution images of the distribution of pleuro-pulmonary fluids and air. Figure 1 shows an EIT system typical architecture.

Since the pioneering work of Barber and Brown in 1984 [1], the last three decades have seen a considerable growth of EIT applications in research centers, with few commercial offers, notably Swisstom Pioneer system (Swisstom AG, Landquart, Switzerland)and PulmoVista 500 (Drägerwerk AG, Germany [2]). Since 1995 the Núcleo de Ingeniería Biomédica (nib) has developed circuits [3], reconstruction softwares [4] and complete prototypes [5, 6] under the name of IMPETOM (**impe**dance **tom**ography) with test results in phantoms and healthy volunteers.

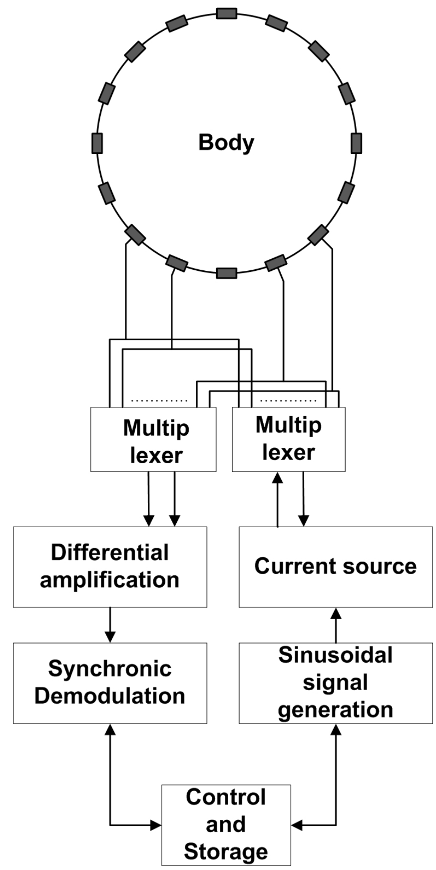

Fig. 1: EIT system basic block structure with a differential current source. There are 16 electrodes affixed onto the skin of the patient's body

The systems developed in recent years by research groups largely share some methods, such as direct digital synthesizer (DDS) to generate the sinusoidal signal or a configuration of simple or modified Howland as current source. In the measurement stage, the instrumentation amplifier is followed by an analog to digital converter of at least 16 bit resolution, then, in the digital domain the filtering, synchronous demodulation and other data processing is performed. For control and data processing the DSP is the most popular option for its speed and calculation capacity. In addition, the fewer mul-

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tiplexers are used, the better the performance of the system. This setting seems to give the best compromise between performance and cost. An extended review on those methods can be found in [7]

This paper assesses the use of the Evaluation Module OMAP L137 from Spectrum Digital as core part of an EIT system. Particularly the audio codec AIC 3106 as signal generator and voltage measurements, and DSP C6747 from Texas Instruments for data processing.

II. SYSTEM DESCRIPTION

The EVM OMAP-L137 is an independent platform that allows developing and studying several applications for the OMAP-L137 integer circuit. It has incorporated a multi-core system on-chip (SoC) that permits to work simultaneously the two processors nested within: The floating point Digital Signal Processor (DSP) C6747 VLIW with 32bits, running at 300 Mhz and the RISC processor ARM926EJ-S also running at 300 Mhz (both from Texas Instrument). Besides, the EVM has a series of microcontrollers, peripherals, inputs and outputs for diverse purposes. We use the audio codec AIC3106 wich has two separate input channels with a resolution of 24 bits and 48 kHz sampling rate, the multichannel serial port McASP, the stereo inputs and outputs Line IN and Line OUT, and 32Megabytes of SDRAM. Figure 2 shows the EVM block diagram.

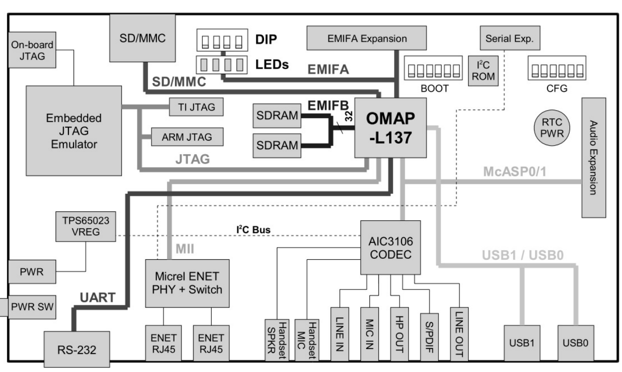

Fig. 2: Block Diagram OMAP-L137 EVM, taken from the module's Technical Reference Manual [8]

A. System Implementation

The system implemented is shown in figure 3. A 16 kHz digital sine wave is generated using a table within the DSP and sent to the Audio Codec through the serial channel McASP. The internal Digital to Analog Converter (DAC) in

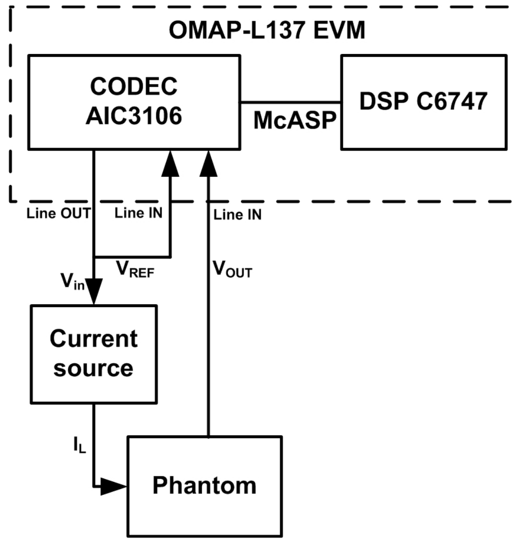

Fig. 3: Schematic block diagram for the OMAP L137 EVM based EIT System.

the AIC3106 transmits the converted signal through the Line OUT port. The voltage signal V_{in} feeds a Howland current source (figure 4). The source's output impedance depends on

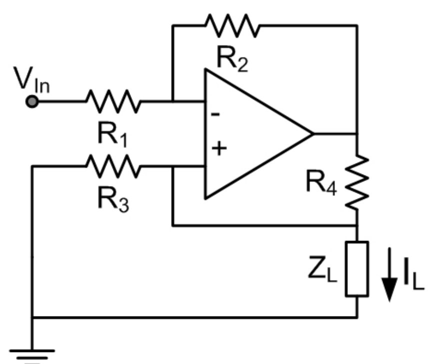

Fig. 4: Howland current source with operational OPA227.

the matching of the resistors and the operational's nonlinearities. In an ideal situation:

$$\frac{R_1}{R_2} = \frac{R_3}{R_4}, \tag{1}$$

and the output current, load independent, is given by the equation:

$$I_L = -\frac{V_{in}}{R_3}. \tag{2}$$

Input signals to the audio codec V_{REF} and V_{OUT} are amplified by an Programmable Gain Amplifier (PGA). Then signals pass through an antialiasing filter. Resultant signals are converted to digital samples at a sample rate of 48 kHz by means of an ADC that utilize sigma-delta technique. These samples are sent from AIC3106 to DSP C6747 through McASP channel.

A synchronous demodulator is implemented in the DSP in order to obtain the real part of the voltage V_{OUT} (figure 2). After digitizing, both input signals are multiplied sample to sample and inverted (because the current source has an inverter configuration). The real part of V_{OUT} is proportional to the DC component of the resulting signal. An Infinite Impulse Response (IIR) filter is used to filter the signal and the result corresponds to the DC component.

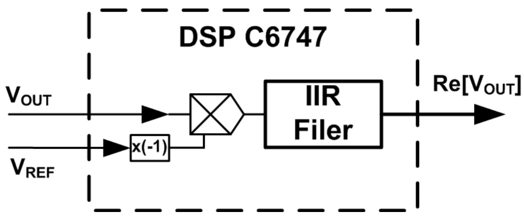

Fig. 5: synchronous demodulator implemented in the DSP to obtain V_{OUT} real component.

III. Results

First we wanted to test the audio codec behavior as the ADC input channel. We used a Tektronix CFG253 signal generator directly connected to one of the Line in channels in the EVM. The sinusoidals input signals were simultaneously measured with oscilloscope Tektronix TDS210. The results show a linear response from the codec (figure 6), with differences under 5% between measured values in the range from 42 mV and 1.5 V.

Then the system in figure 3 was implemented with the Howland current source described before. A RC parallel circuit worked as our load impedance. An 100 nF capacitor was in parallel with a variable resistor. An algorithm to obtain the real part of the impedance was realized in the DSP given the linearity between Vref and the current generated. Figure 7 compares the DSP's estimated real part from the data measured with the codec with theoretical values and values obtained from the data measured with the oscilloscope. The EVM responds correctly to changes in the load impedance.

The mean difference between values estimated at the EVM with those based on the oscilloscope measurements was 8.53%. Every measurement was repeated 5 times to assess repeatability, with a result of 0.34% of mean deviation.

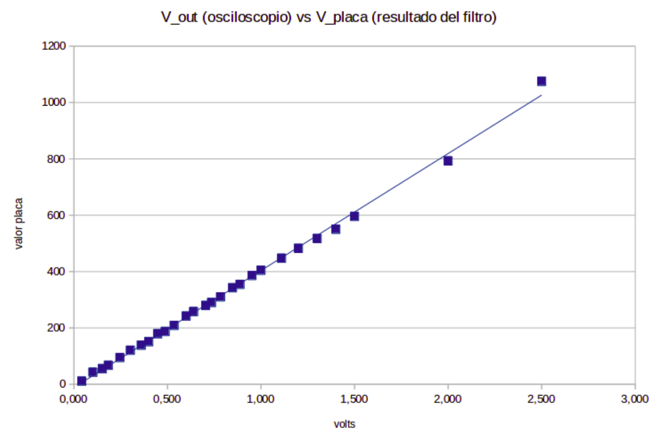

Fig. 6: Audio codec's Line In channel response to sinusoidal signals directly connected. Raw values displayed in the y-axis show the linearity between input and output. A simple gain adjustment is necessary to couple the signals.

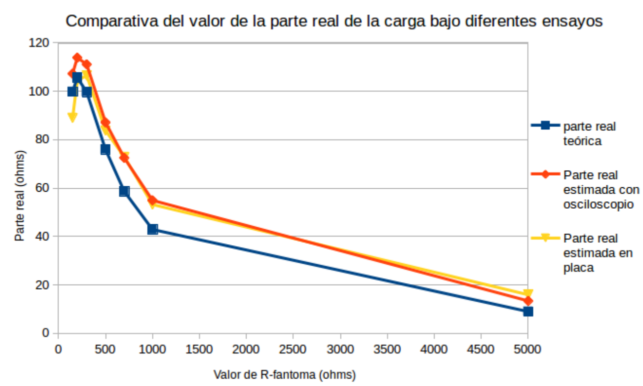

Fig. 7: Comparison of real part estimated in EVM, Oscilloscope and theoretical for a RC parallel circuit with 100 nF capacitor and variable resistor.

IV. Conclusion

The EVM OMAP-L137 with audio codec AIC3106 has proven apt to be an EIT system core. The system's measurement block shows a linear response for a broad range of voltages. The system as a whole, with a current source, showed bigger differences with respect to the estimation with the oscilloscope. Improving the current source is essential. Since EIT is a method of differences, the current should be such to provoke that the minimum voltage difference that we would like to distinguish (corresponding to the minimum changes in resistivity within the body) be greater than 42mV.

Conflict of Interest

The authors declare that they have no conflict of interest.

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