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## CALIBRATION OF A LOW COST ELECTRICAL IMPEDANCE TOMOGRAPHY SYSTEM WITH A RING OF RESISTORS AND A KCL SOLUTION

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**Abstract.** *Electrical impedance tomography (EIT) is widely employed to determine the flow pattern of multiphase flow. This method presents a technical advantage over others imaging techniques, as it is a non-intrusive and radiation-free technique. The method consists of setting electrodes in the boundary of a vessel, obtaining information about the voltages produced by the injected current. The information produced by the acquisition system is used to solve an inverse problem. This combination allows estimating the distribution of conductivity within the domain. In this work, a calibration through a ring of resistors and KCl solution vessel, which is a standard in regards to conductivity measurements, are performed in order to diminish the influence of the systematic error. The random error and the signal-to-noise ratio are also evaluated for this system.*

**Keywords:** *Electrical Impedance Tomography, Acquisition System, Calibration*

### 1. INTRODUCTION

The electrical impedance tomography (EIT) is a technique that, through the injection of electrical current inside a vessel, it is possible to obtain a conductivity distribution of the domain. Due to the differences in the conductivity of the media, it forms an image of the phases inside a tube, for example, so a computed image of the flow pattern is displayed by this technique. The application of the electrodes is non-intrusive and low-cost, which makes this technique extremely attractive. Also, the application is non-radiative and has a high temporal resolution. Those techniques are employed in biomedical applications (Bodenstein et al., 2009) and industrial applications (Sharifi and Young, 2013).

The data acquisition injects a constant current and measures the boundary voltage through 8, 16 or 32 electrodes. After the acquisition, these measurements are used in order to estimate the conductivity field by an inverse problem technique (Graham, 2007).

Several works investigate the causes of error in EIT acquisition system. Boone et al. (1996) defines the equivalent circuit of a real acquisition system and states the major errors contained in the design, such as the common-mode signal influence in the in-amp, effect of noise and stray capacitances. Jennings and Schneider (2001) improves the front-end circuit design, investigates the influence of errors in the design, and proposes an architecture for a multifrequency acquisition system. McEwan et al. (2007) details the errors contained in a multifrequency EIT system, such as the parasitic capacitances, and other types of systematics errors.

In this work, the accuracy and precision of the acquisition system developed are investigated along with the Signal-to-Noise ratio. A calibration procedure is performed in order to minimize the systematic error. The frequency operating point is determined by this investigation.

## 2. ACQUISITION SYSTEM

The designed system consists of the following main modules in Figure 1:

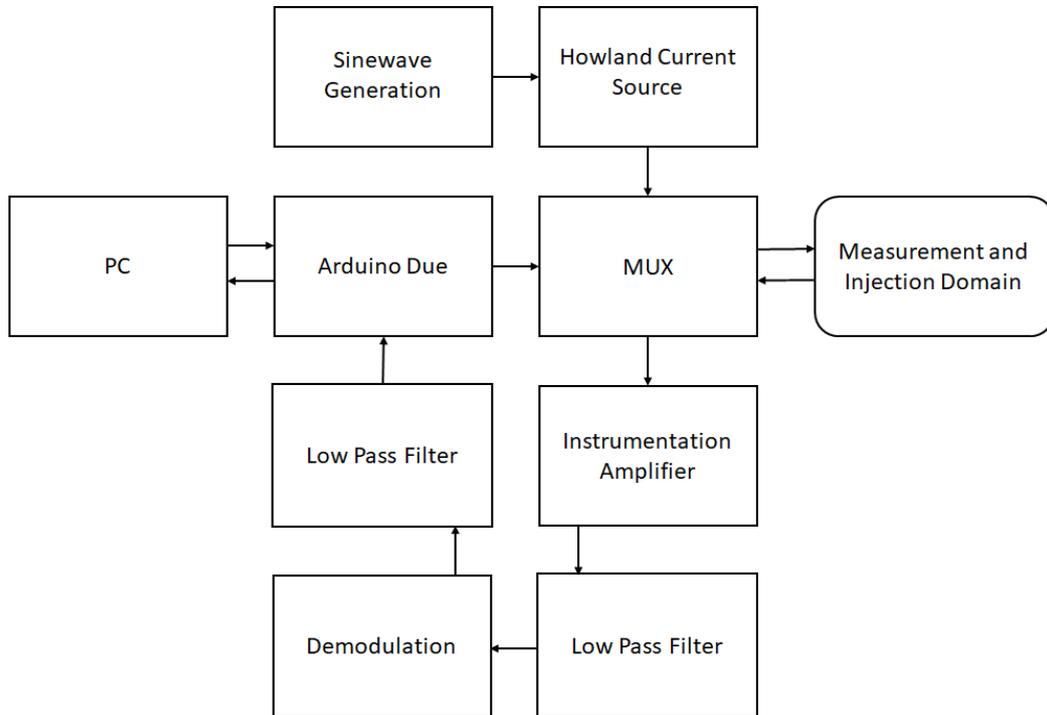


Figure 1: Designed EIT acquisition system.

First, a 1 V RMS sinewave is injected into the domain by the first multiplexer, ADG506, while the second multiplexers sinks the current to ground. The following two multiplexers measures the voltage, which is taken to the instrumentation amplifier, INA128, with a gain of 7.25. The differential signal passes through a third order Butterworth low pass filter, with a cutoff frequency of 80 kHz and bandstop frequency of 200 kHz. To demodulate the signal, a RMS-to-dc converter module, AD536, is used to convert the sinewave into a dc signal. The ADC of Arduino Due converts the dc signal into a digital value. The sensors consists of 16 stainless steel electrodes radially set in a circumferential domain of 15 cm.

## 3. INJECTION PROTOCOL

The injection pattern of the acquisition system is the adjacent method which consists in inject a current through neighboring electrodes, or adjacent, and the consequent measurement of the voltage though the neighboring electrodes which are not operating current in a differentially form. The cycle repeats until all electrodes injects current into the medium. Figure 2 presents information about the method.

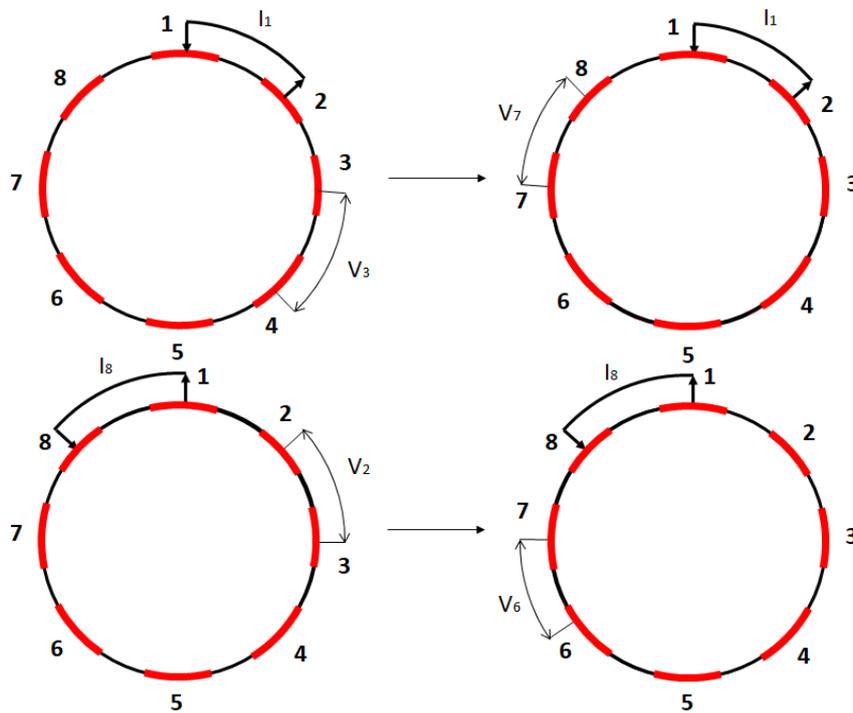


Figure 2: Schematic explaining the adjacent pattern.

The method presents  $L(L - 3)$  measurements, where  $L$  is the number of electrodes, where half of this are independents measurements (Dickin and Wang, 1996).

#### 4. FORWARD PROBLEM

Let be a domain  $\Omega$  with a conductivity  $\sigma$  with a potential  $u$  on the electrodes which are applied a current. The equation that represents the phenomena is described as (Holder, 2004):

$$\nabla \cdot (\sigma \nabla u) = 0, x \in \Omega \quad (1)$$

In order to express completely the model, boundary conditions must be set. In this work, the Complete Electrode Model is used, which involves the consideration of a contact impedance in the electrodes. Thus,

$$u + z_l \sigma \frac{\partial u}{\partial n} = U_l, x \in e_l, l = 1, 2, \dots, L \quad (2)$$

$$\int \sigma \frac{\partial u}{\partial n} dS = I_l, x \in e_l, l = 1, 2, \dots, L \quad (3)$$

$$\sigma \frac{\partial u}{\partial n} = 0, x \in \partial\Omega \setminus \cup_{l=1}^L e_l \quad (4)$$

where  $u$  is the potential distribution,  $n$  is the normal of the boundary  $\partial\Omega$ ,  $z_l$  is the contact impedance,  $dS$  is the infinitesimal area and  $L$  is the number of electrodes.

Additionally to those conditions, in order to ensure existence the and the uniqueness of the solution, it is necessary to add to the model the law of conservation of charge

$$\sum_{l=1}^L I_l = 0 \quad (5)$$

And to set a reference point

$$\sum_{l=1}^L U_l = 0 \quad (6)$$

## 5. MATERIAL AND METHODS

In order to calibrate the measurements of the EIT acquisition system, two references are used to compare the values. To calculate a calibration factor for each frequency, the following is used

$$f = \frac{V_{ref_i}}{V_{meas_i}} \quad (7)$$

To evaluate the repeatability and the total error, the RMS error is calculated as follows (Wang, 2005):

$$RMS = 100\% \times \sqrt{\frac{1}{208} \sum_{i=1}^{208} \left( \frac{V_{meas_i} - V_{ref_i}}{V_{ref_i}} \right)^2} \quad (8)$$

It is important for the system to present low noise disturbance, as the noise corruption interfere in the reconstruction. The SNR is the parameter which indicates the level of noise in the system. It is calculated by

$$SNR = 20 \cdot \log \frac{|E(V_{meas_i})|}{Std(V_{meas_i})} \quad (9)$$

where  $|E(V_i)|$  is the mean of the voltage measurements read by the analog-to-digital converter,  $Std(V_i)$  is the standard deviation. The total number of measurements frame is 500.

Two methods are used to evaluate the system. It is used a ring of resistors and a KCl reference solution. Details are explained in the following section.

## 6. RESULTS

### 6.1 Ring of resistors

A ring of 16 100  $\Omega$  1% tolerance resistors is used in order to calibrate the voltage measured by the system. The signal was measured for 13 different frequencies. Results are shown in Figure 3.

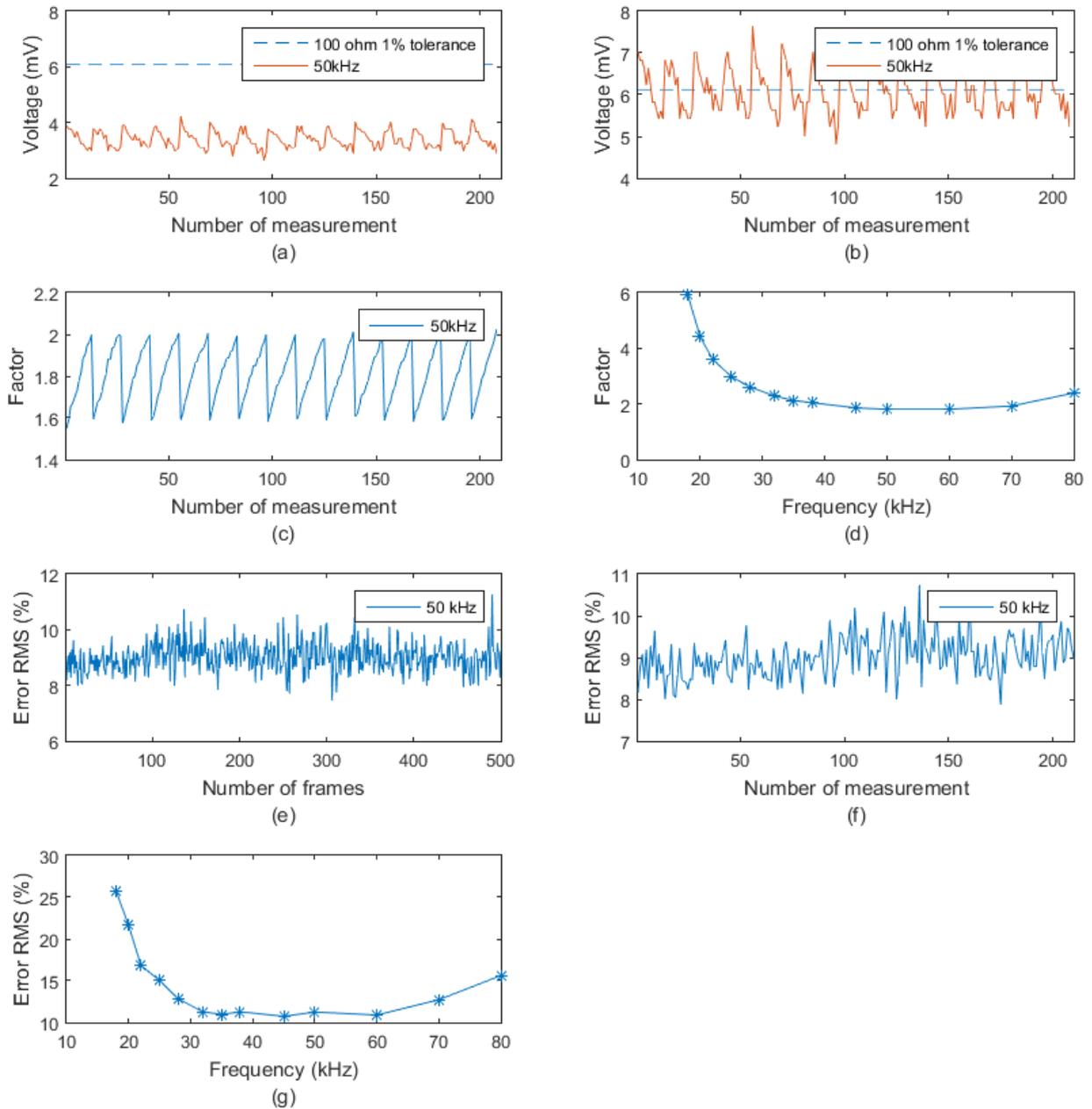


Figure 3. Calibration procedure utilizing a ring of 16 100 Ω 1% tolerance resistors.

According to a LTSpice simulation, considering a 1 mA injected current, the differential voltage value for this circuit in each measurement corresponds to 6.1016 mV. As it is shown in Figure 2(a), the measurement is displaced from the true value by a factor calculated by Equation 1. The system is calibrated in Figure 2(b) by multiplying by the factor, which can be seen for each measurement in Figure 2(c) and the mean value for each frequency in Figure 2(d). The error is shown in Figure 2(e) by each frame, which indicates that the error is not superior to 11% and the fluctuations in each measurement is shown in Figure 2(f). The system also presented results with consistency. The max error is shown for each frequency, in Figure 2(g), which indicates that the error is minimal close to 50 kHz.

## 6.2 KCl reference solution

A solution of 0.01 M of KCl is prepared in order to evaluate the results in a vessel. Results are shown in Figure 4.

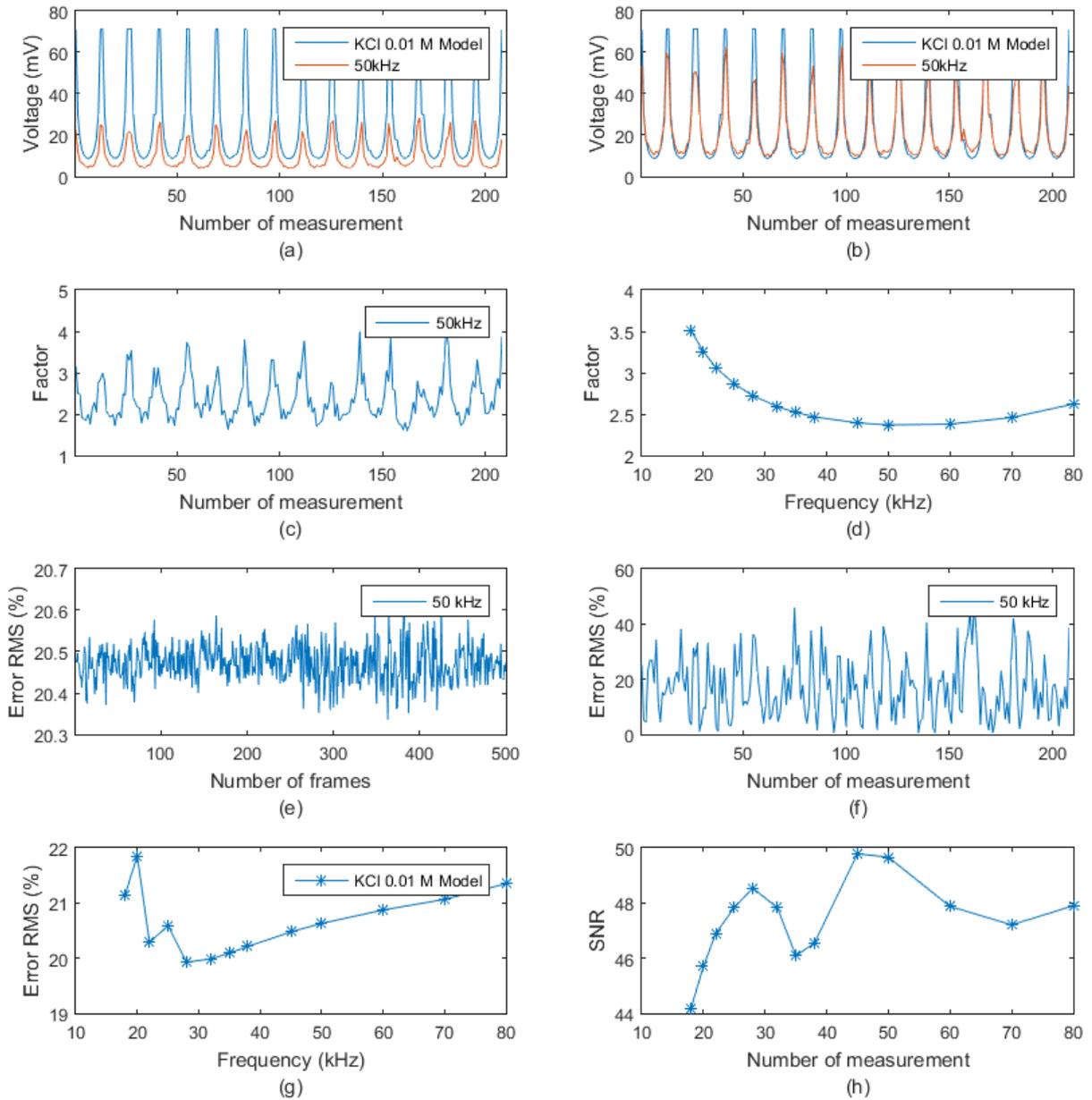


Figure 4. Calibration procedure utilizing a vessel with 0.01 M KCl solution.

The KCl solution is used as a standard of electrical conductivity with a value of 0.140823 S/m (Wu et al., 2013). The forward problem of EIDORS is utilized with the same value for the conductivity to produce a reference signal, same method employed by Wilkinson, (2005). As it is shown, the signal is calibrated from Figure 3(a) to Figure 3(b) and the factor is shown in Figure 3(c) and Figure 3(d). The error is more consistent, showing result lower than 20.7% in Figure 4(e). The error varies little when considered the frequency, between 20% and 22%. The SNR of the equipment is maximized near 50 kHz, with values approaching 50 dB. The error of the system is accounted by positioning the electrodes.

## 7. CONCLUSION

In this work, a calibration method procedure is performed in order to eliminate the systematic error of an Electrical Impedance Tomography acquisition system. The SNR is also evaluated within a frequency range. The error was minimal in 50 kHz both for the ring of resistors and the KCl solution, with a corresponding value lesser than 11% and 21% respectively. The SNR considering the ring of resistor is between 48-50 dB. Some investigations are needed in order to determine the causes of the error to decrease its levels to an acceptable value.

## 8. ACKNOWLEDGEMENTS

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