Switch Matrix Logic Implementation of Electrical Impedance Tomography Measurement System

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Abstract

Electrical Impedance Tomography (EIT) is non-invasive technique that has the potential to be used in clinical environments for lung ventilation monitoring, cardiac and brain imaging applications. EIT has many advantages in terms of simplicity, cost and the absence of ionising radiations compared to the traditional imaging techniques such as magnetic resonance imaging (MRI) and X-rays. EIT systems usually consist of a ring of equally spaced electrodes placed around the part of the body of interest. A sinusoidal current source with a typical frequency of 50 kHz is used to inject current between an adjacent pair of electrodes. Then the imposed voltages on the remaining electrodes are measured sequentially. After that the current source is routed to the next pair and the cycle is repeated until one frame of data is collected. For eight electrodes 8x5 measurements per frame are collected. Mathematical algorithms are used to construct an image of the impedance distribution inside the closed volume. In order to apply the current source and measure the imposed voltages on the electrodes a switch matrix is needed. In this work, a circuit implementation of the switch matrix for eight electrodes is presented. The system consists of logic blocks used to generate eight logic signals (CL1-CL8) needed to route the differential current source to the appropriate electrode pair. For example, when the logic signals CL1 and CL2 are both high, the differential current is routed to electrode pair 1 and 2. During this time other blocks are used to generate 8 logic signals (VL1-VL8) required to measure the imposed voltages on the remaining electrodes in the following sequence, V3-V4, V4-V5, V5-V6, V6-V7 and V7-V8. The logic blocks used in the implementation consists of mono-stable elements in addition to standard logic gates. Simulation results indicate that the implementation of the designed circuit is feasible in both hardware and software form.

Keywords: Electrical Impedance Tomography, Switch Matrix Logic, Simulated Measurement Systems.

1. Introduction

Tomography (EIT) is an imaging technique that estimates the complex conductivities of the interior of an object from measurements made on its surface. In the medical field EIT has the potential for use in various applications such as breast, brain and lung imaging (Bayford 2006). In particular, EIT has the ability to become a clinical tool for studying regional lung ventilation in particular for neonate applications, which can only be viably assessed through EIT due to the difficulty of applying traditional techniques such as X-ray and MRI. Although EIT suffers from poor resolution compared to traditional imaging techniques; it has advantages compared to these in terms of simplicity, cost, non-invasive, and the absence of ionizing radiation (Brown et al 1989). EIT data are collected via an array of electrodes (multiple electrodes) (Rahal et al 2009) attached on the surface of the subject where the induced voltages are measured (Bayford 2006). Fig.1 shows a typical EIT application where a small alternating current (AC) (< 1mA) at 50 kHz is commonly injected through one electrode pair and voltages differences are recorded from the remaining electrodes (Hong et al 2009). Then, the current is injected using the next pair of electrodes until all the available electrodes have been switched. The speed of the switching determines the frame rate, with real time imaging requiring frame rates from a few Hz up to 30Hz. Recent studies have shown that injecting multiple frequencies at the same time will produce better tissue characterization. In addition, injecting multiple frequencies simultaneously reduces the measurement time. One of the important blocks in an EIT system is the switch matrix that allows the current to be routed to an electrode pair and the voltage to be measured from the remaining electrodes. In this work a switch matrix implementation is described using mono-stable element as the basic building block. After this introductory part, section 2 describes the methods used in the circuit implementation. Simulated results are presented in section 3 while conclusions are suitably drawn in section 4.

2. Components and Overall System

Figure 2 shows the overall system of a typical analogue EIT system that is capable of driving 8 electrodes and it consists of the following main components:

2.1 Waveform Generator

This part is responsible for the generation of repeating or non-repeating electronic signals. Usually, a single sine wave or composite signal is generated for multi-frequency EIT systems. The main technology used in these devices is Direct Digital Synthesis (DDS).

2.2 Single to Differential Converter

This component converts the single output from the DDS to a differential signal to drive the input to the Modified Howland Current Source

2.3 Modified Howland Current Source.

This is one of the important parts of the system where high output impedance and stable sensitivity are required. Current amplitudes are limited to less than 1mA for electrical safety (Hong et al 2009).

2.4 Current and Voltage Switches Controller

The controller activates the switches that are used to route the differential output of the current source to the appropriate electrode pair and to measure the voltages from the remaining pairs sequentially to complete one frame of data. The work described in this paper is related to this part.

2.5 Differential Amplifier

The measured voltages from the electrodes are too small therefore they require amplification, typical gain is between 100-1000 depending on the amplitude of the current and the application.

2.6 Modulator/Filter

The purpose of this component is to modulate the amplified recorded voltages with a signal with a frequency equal to the frequency of the signal injected at the inputs of the current source. A sharp filter is used to remove the high frequency components and the output of the filter is proportional to the impedance measured by the electrodes.

A. Current Source Switch Control: Frame rate of 4 Hz was chosen for this design giving current injection time for a pair of electrodes equal to about 33 ms. Figure 3 shows the waveforms needed to inject the output of the current source onto the 8 electrodes sequentially.

A 555 timer in a mono-stable mode is used as the key block to generate the required waveform for the control of the current source switches. The mono-stable design is shown in figure 4. The pulse width is determined by the following formula:

$$pulse\_width = 1.1 \times R \times C \tag{1}$$

where R is equal to 30kΩ and C is 1μF giving 33ms. Capacitor C2 is charged through R5 and R6 until the voltage on the capacitor reaches certain threshold where the capacitor is quickly discharged via pin 7 of the 555 timer. Eight waveform generators are required in order to switch the current source onto the eight electrodes. Each CLi generator is triggered by the previous stage on the falling edge.

B. Voltage Measurement Switch Control: The control of the switches for the voltage measurements from the electrodes requires synchronization with the control of the current source switches. For example when electrode 1 and 2 are used for current injection voltages on the electrodes should be read from the following pairs: 3-4, 4-5, 5-6, 6-7 and 7-8. Then, the current source is switched to pair 2-2 and the voltage measurements are taken from the remaining electrodes. The process is repeated until one frame of data (8 x 5 = 40) is collected.

There are certain restrictions on the control (VL1-VL8) of switches for voltage measurements. These restrictions can be classified as follows:

- If a pair of electrodes is used for current injection then no voltage measurements can be collected from these electrodes as the impedances of the electrodes affect the measurements.
- If the electrode were the voltage is measured is adjacent to an electrode where current is injected, the duration for the voltage measurement should be half compared to a measuring electrode not adjacent to an electrode where current is injected.
- The trigger to measure voltage from electrode n is derived from the falling edge of the control signal on the electrode n-2 if the concerned electrode is not adjacent to current injecting electrodes.
- If the electrode used for voltage measurements is adjacent to current injecting electrodes then the trigger for this electrode is derived from the rising edge of current source control signals (CLi).

Figure 5 shows the waveform generator for the voltage measurements. It consists of two mono-stable elements such as the top mono-stable element has a pulse width twice (6.6 ms) that of the bottom mono-stable element (3.3ms). A multiplexer is employed to select which mono-stable is used based on whether the voltage measuring electrode is adjacent to current injecting electrodes. The waveform generator is controlled by a logic circuit shown in figure 6. The CBF output determines whether the voltage measurement control signal VLi is required to run at 6.6ms or 3.3ms based on information from CLi-1, CLi-2 and CLi+1. For example if CL1 and CL2 go both high then CBF is set to 1 and the bottom mono-stable of figure 5 is used to set VL3. The same condition applies if the measuring electrode is the last in the sequence. In addition, VLx (at electrode x) signal should be zero if the control signal CLx is high. A NAND gate is employed at the output which normally stays at logic high. If the all the conditions are met the output of the NAND gate goes low triggering the waveform generator for voltage measurement with CBF at logic 0 or 1 depending on the position of the measuring electrode with respect to the two injecting electrodes.

3. Simulated Results

The overall system was simulated using MicoSim software. Figure 7 shows the 8 waveforms CL1 to CL8 generated from the control of current source switches. Each CLi is generated on the falling edge of the CLi-2. The CLi waveform lasts for about 33ms.

The voltage measurements control signal VL1 to VL8 are shown in figure 8 when current are injected at electrodes 2 and 3. When CL2 and CL3 are both high VL4 is set to half pulse width as it is associated with electrode 4 which is adjacent to the injecting electrodes 2 and 3. Similarly, VL1 is set to half pulse width as it is the last in the sequence. Each VLi is generated and triggered by the falling edge of VLi-2 when the measuring electrode is not adjacent to the current injecting electrodes. When the measuring electrode is adjacent to the injecting electrodes VLi is triggered by the rising edge of CLi-1.

4. Conclusions

In this paper a design for the implementation of a switch matrix controller is presented. The design is suitable for 8 electrodes for neonatal applications. The frame is set to 4Hz allowing 33ms for current injection and 6.6 ms for voltage measurement per electrode pair. Each waveform generator for current source injection is based on a mono-stable element that is triggered by the previous stage. For the voltage measurement control a logic circuit is used in order to choose the pulse width depending on the position of the measuring electrode. Future work will concentrate on the hardware implementation of the design and its comparisons with field programmable gate array

(FPGA) implementation.

References

[1] Barber D C 2000 Electrical impedance tomography The Biomedical Engineering Handbook 2nd edn ed J D Bronzino (Boca Raton, FL: CRC Press) pp 1151–64.

[2] Bayford R 2006 Bioimpedance tomography (electrical impedance tomography) Annu. Rev. Biomed. Eng. 8 63–91.

[3] Brown B, Barber D and Seagar A 1989 Applied potential tomography: possible clinical application Clin. Phys. Physiol. Meas. 6 109–21.

[4] Grimnes S and Martinsen Ø 2000 Bioimpedance & Bioelectricity Basics (New York: Academic).

[5] Hong H., Rahal M., Demosthenous A., and H Bayford R., 2009 Comparison of a new integrated current source with the modified Howland circuit for EIT applications. Physiol. Meas. 30, 999–1007.

[6] Rahal M., Moy Khor J., Demosthenous A., Tizzard A. and Bayford R., 2009. A comparison study of electrodes for neonate electrical impedance tomography. Physiol. Meas., 30, 11-14, S73–S84.

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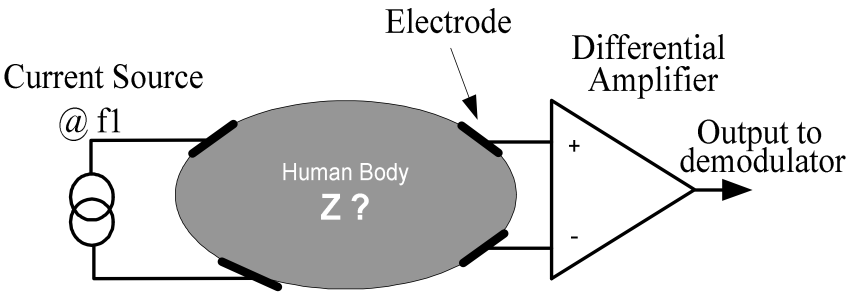

Figure 1. Simple EIT injection/recording system

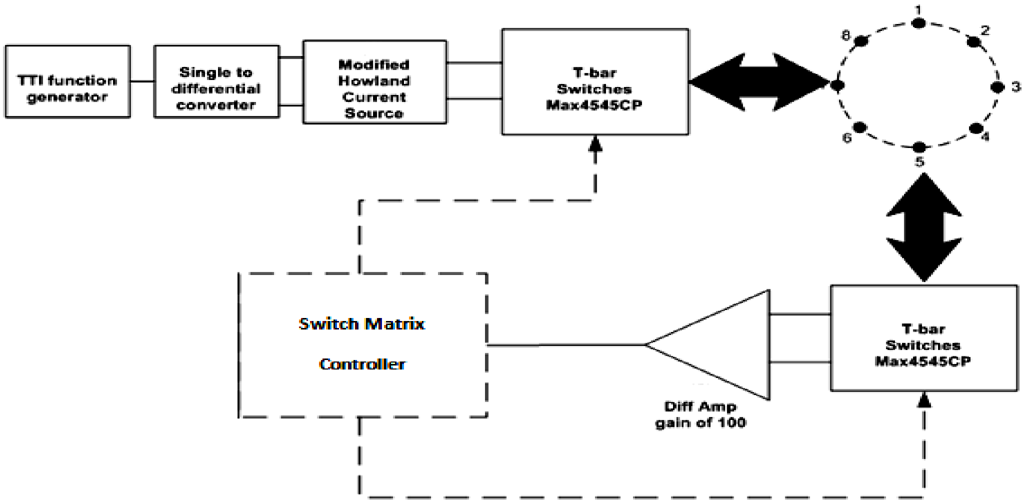

Figure 2. Simple Analogue EIT System

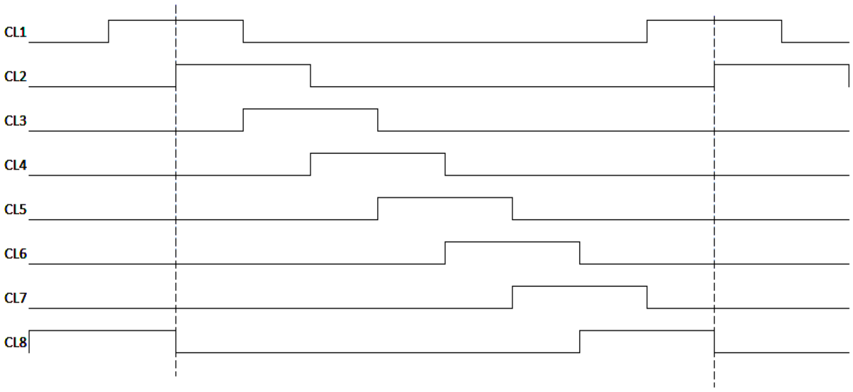

Figure 3. Control of current source switches

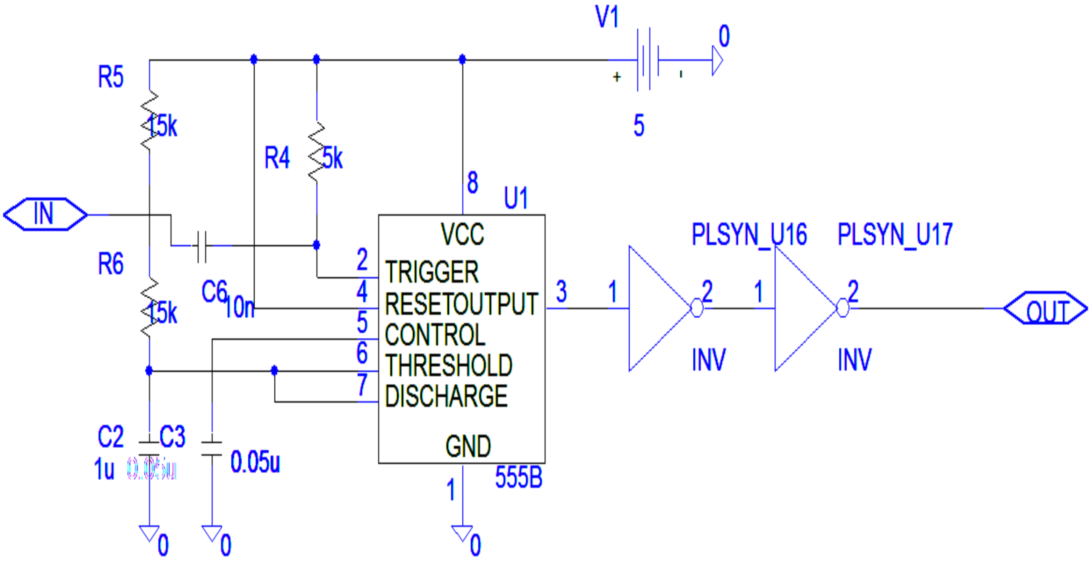

Figure 4. Waveform generator for control of current source

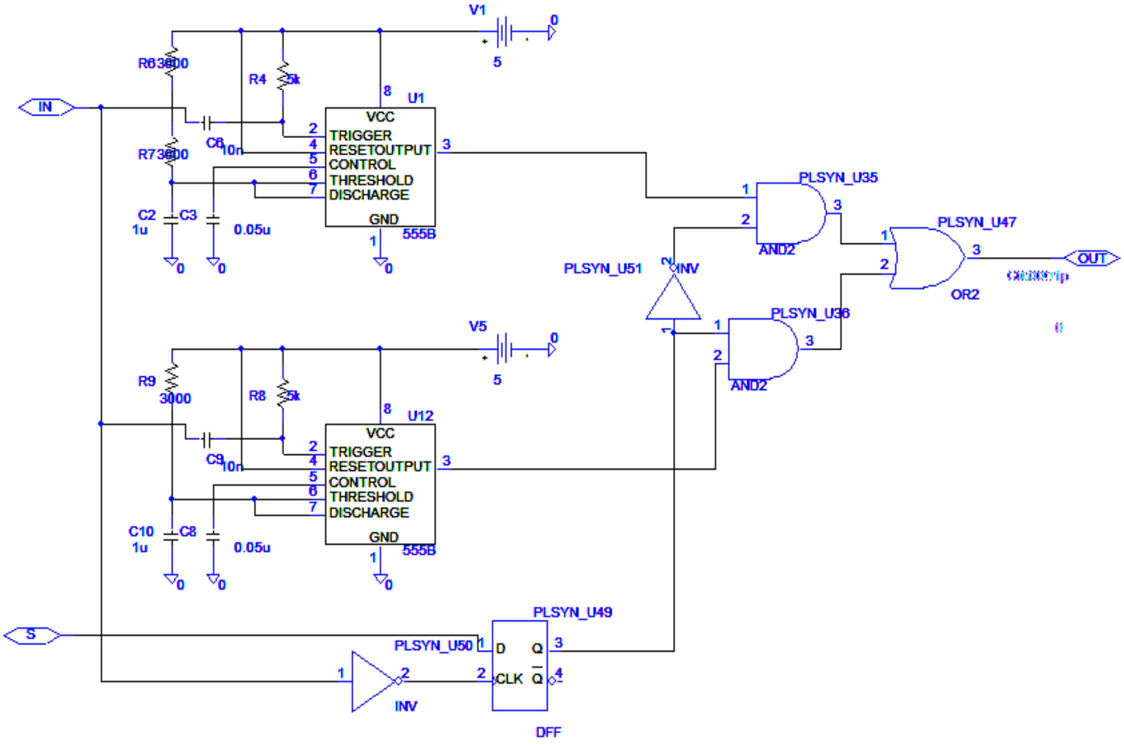

Figure 5. Waveform generator for voltage measurements control.

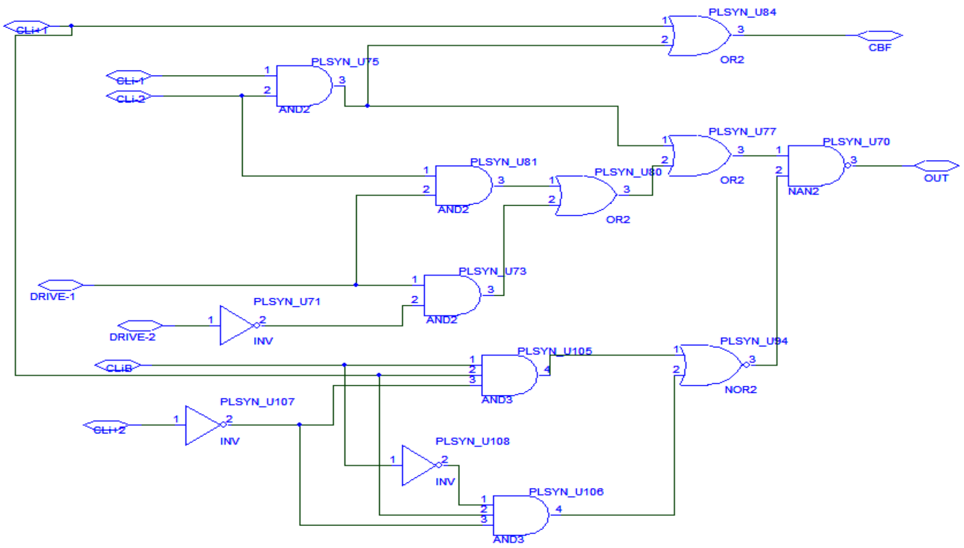

Figure 6. Logic circuit employed to control the waveform generator for voltage measurements

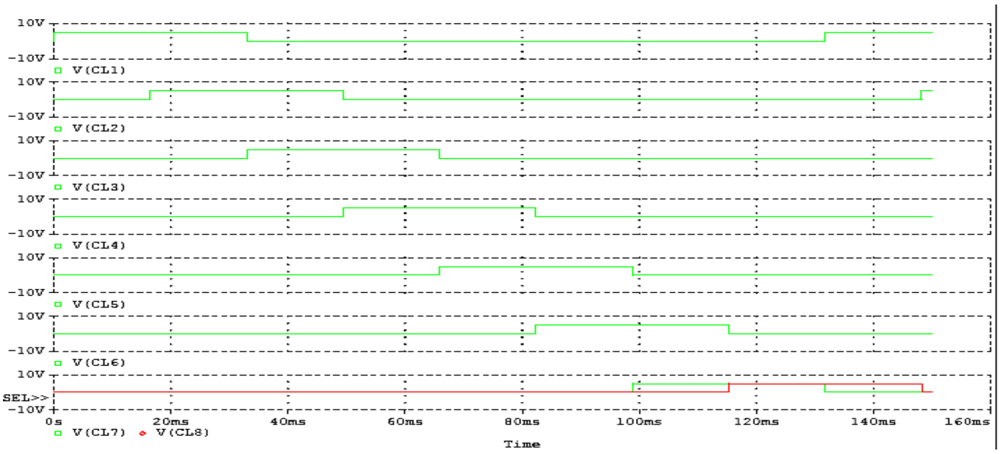

Figure 7. Simulated CL_1 to CL_8

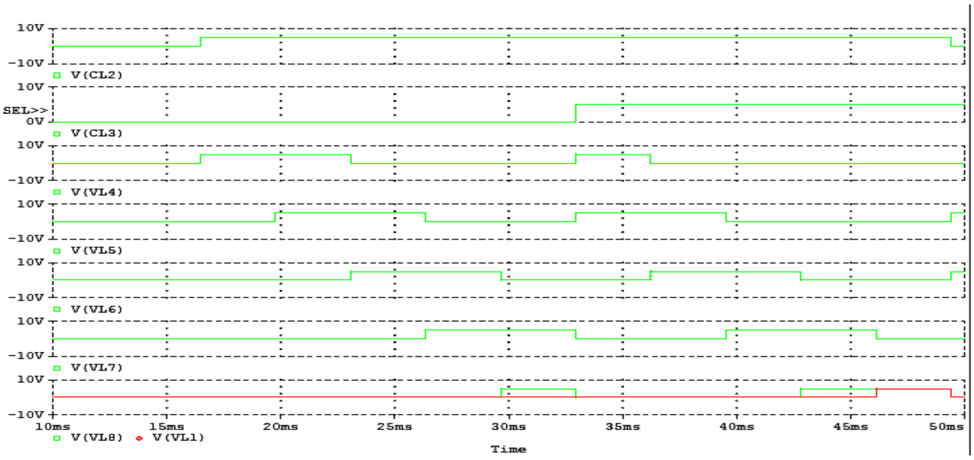

Figure 8. Simulated VL_1 - VL_8 when CL_2 and CL_3 are high