

Impedance Simulator for Testing of Instruments for Bioimpedance Sensing

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Abstract: Bioimpedance sensing is a noninvasive technique for measuring parameters related to tissue structure or physiological events. Generally, the impedance is sensed by injecting a high frequency low intensity current through a pair of electrodes placed across the selected region of the body and monitoring the voltage developed across the same or another pair of electrodes. The base value of the impedance and its variation can be used, with the help of an appropriate model, for obtaining diagnostic information. For testing and calibration of instruments developed for bioimpedance sensing, we have developed an impedance simulator by using a microcontroller and analog switches. It can be used for measuring sensitivity and frequency response for bioimpedance signals, and for studying the effect of various electrode configurations and common mode interference caused by bioelectric sources and external pickups.

Indexing terms: Bioimpedance sensing, testing and calibration, impedance simulator.

1. INTRODUCTION

Bioimpedance sensing is a noninvasive technique based on measurement of changes in the impedance across the selected region of the body. The technique involves injecting alternating current of a value much below the excitation threshold for biological tissue, in kHz-MHz range, through the selected body region. In this frequency range, the impedances are nearly resistive. The voltage developed gets amplitude modulated due to variation in the bioimpedance and it is demodulated to sense the bioimpedance signal. The time varying component of the signal is generally less than 1–2 % of the base value [1]-[5]. Bioimpedance signal reflects electrical characteristic of tissue structure and properties, or parameters related to physiological events.

The changes in the impedance may be due to a change in the fluid content in the region, or due to a physiological event across the selected region. Analysis of bioimpedance signals, with the help of an appropriate model of the region, can provide valuable diagnostic information. Variation in arterial and venous blood supplies, with cardiac

cycle, in a body part can be studied using impedance plethysmography [3]. Impedance cardiography can be used for monitoring stroke volume [2]-[4]. Impedance glottography or electroglottography is used for monitoring the closure phase dynamics in the vibration of vocal cords in the larynx, by sensing variation in impedance across two disc electrodes placed on either side of the larynx [5]-[8].

Most of the *in vivo* bioimpedance sensing applications use surface spot or band electrodes. In 2-electrode configuration, voltage is monitored across the electrodes used for passing the current. In this method, the skin-electrode contact impedance may swamp the variation in bioimpedance. Also, the current density being generally higher near the electrodes than elsewhere in the tissue, the measured impedance is dependent more on the tissues near the electrodes than elsewhere in the body. A 4-electrode configuration can be used for reducing the effect of skin-electrode contact impedance and for facilitating a uniform current distribution [1]-[3]. Generally, the outer pair of electrodes is used

to inject the current and the resulting voltage drop is picked up across the inner pair of electrodes. In some situations, 3-electrode configuration may be used, with one electrode being common to current and voltage electrode pair. In some other situations, one pair of electrodes is used as current as well as voltage electrode pair, with one or two more electrodes serving as guard electrodes to reduce flow of stray currents [9].

Output of the bioimpedance sensing circuit typically consists of a signal component related to the physiological phenomenon of interest, dc offset because of the base impedance, and artifacts caused by impedance variations due to motion or other physiological phenomena. Sensed signals may also be contaminated by noise due to internal bioelectric sources, power line harmonics, and radio interference. Operation of the instrument developed should not be affected by the variation in the base value of the bioimpedance and skin-electrode contact impedance. It should have appropriate sensitivity and frequency response (magnitude as well as phase) for bioimpedance variation. The sensing should not be affected by bioelectric sources, artifacts, and external pickups.

An impedance simulator can be used for comprehensive testing and calibration of the instrument for the various features important for sensing of a specific bioimpedance signal. Bioimpedance sensing instruments often have an internal calibrator, in which a specific value of resistance and/or a switching resistance gets internally connected across the electrode terminals. Jindal *et al.* [10] have reported another approach involving amplitude modulation of the excitation source to simulate the amplitude variation in the voltage across the electrodes because of bioimpedance variation. Both these methods can be used only for testing/calibration of detector sensitivity. As they are instrument specific, they cannot be used for testing different instruments developed for a specific application.

After examining requirements of comprehensive testing and calibration of various instruments for sensing of bioimpedance signals, we have developed an impedance simulator which can be used for measuring sensitivity and frequency response, testing the effect of variation in the value of base impedance, common mode interference, and different electrode configurations.

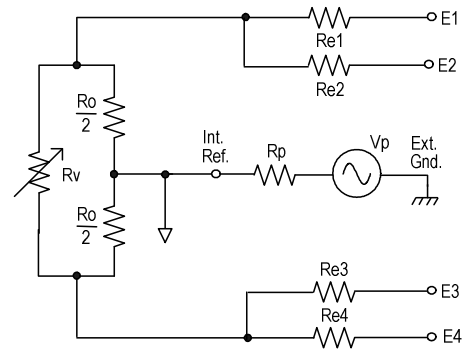


Fig. 1. Electrical model for bioimpedance sensing.

2. IMPEDANCE MODEL

An electrical model for bioimpedance sensing is shown in Fig. 1. The tissue impedance is modeled by constant resistance R_o in parallel with variable resistance R_v varying due to the physiological phenomenon of interest or other internal artifacts. Terminals E1-E4 represent the electrodes, with resistances R_{e1} , R_{e2} , R_{e3} , and R_{e4} representing skin-electrode contact resistances. In 2-electrode arrangement, E1 and E4 can be used for current injection as well as for voltage monitoring. Common mode interference due to bioelectric sources inside the body or pickup of external interference are represented by V_p in series with R_p connected between the internal reference point in the body and the ground of the instrument for bioimpedance sensing.

3. CIRCUIT DESCRIPTION

Instrument for bioimpedance sensing consists of hardware for detection of impedance variation, and hardware and software for signal acquisition and processing. The bioimpedance simulator should provide a range of base resistances and variable resistances for testing the response of the impedance variation detector circuit.

For testing the specific blocks of bioimpedance signal processing, the resistance variation can be in the form of a sinusoidal wave, a triangular wave, or it can simulate the actual bioimpedance signal waveform. However, the main application of simulator is testing of the hardware of the impedance variation detector. For measuring frequency response of the detector, we can use sinusoidal variation. But this requires time

consuming swept frequency measurement. Many bioimpedance sensing instruments have a block for obtaining the derivative of the impedance. Use of a triangular variation in the bioimpedance facilitates the testing and calibration of this block. However, the current trend is to have this block implemented as part of the signal processing after digitization of the signal. Variation in the form of a square wave, with the frequency selectable over a wide range, can be conveniently used for studying the transient response as well as the frequency response [11]. This variation is easily realizable with the help of analog switches.

Selection of base resistance values and square wave variation in resistance values has been realized by using parallel combination of resistances in series with analog switches in U1-U3 (CD4066), as shown in Fig. 2. In order to have a compact circuit realization, flexible operation, and reduced wiring (which could result in pick-up), all the control signals for analog switches are generated by port pins of microcontroller U4 (AT89C52). The entire circuit is operated with a single 5V supply.

As the on-resistance of a single analog switch in CD4066 with +5 V supply is approximately

270 Ω, the analog switches need to be paralleled together for reducing the on-resistance, and more importantly for reducing the variation in on-resistance. Four analog switches in U1, paralleled to form S1, are controlled by port pin P2.7 of the microcontroller. Similarly the analog switches in U2, forming S2, are controlled by port pin P2.6. Switches S3 and S4 are realized by paralleling two analog switches in U3 and they are controlled by port pins P2.4 and P2.5 respectively. For a set of given resistors in the circuit, these switches can be controlled to select one of sixteen resistance values, which can be used for varying the base resistance and variation step. Square wave of a selected frequency at one of the controlling port pins can generate square wave variation in resistance.

The resistance value in the model of Fig. 1 can be related to resistor values in the circuit of Fig. 2 as follows

$$R_{e1} = R_1, R_{e2} = R_2, R_{e3} = R_3, R_{e4} = R_4.$$

$$R_0 \parallel R_v = (R_5 + R_6) \parallel (R_7 + R_8 + R_{s1}) \parallel (R_9 + R_{10} + R_{s2})$$

$$\parallel (R_{11} + R_{12} + R_{s3}) \parallel (R_{13} + R_{14} + R_{s4}),$$

where R_{s1} , R_{s2} , R_{s3} , and R_{s4} are the on/off resistances of switches S1, S2, S3, and S4 respectively.

The simulator circuit is powered by a single 5 V

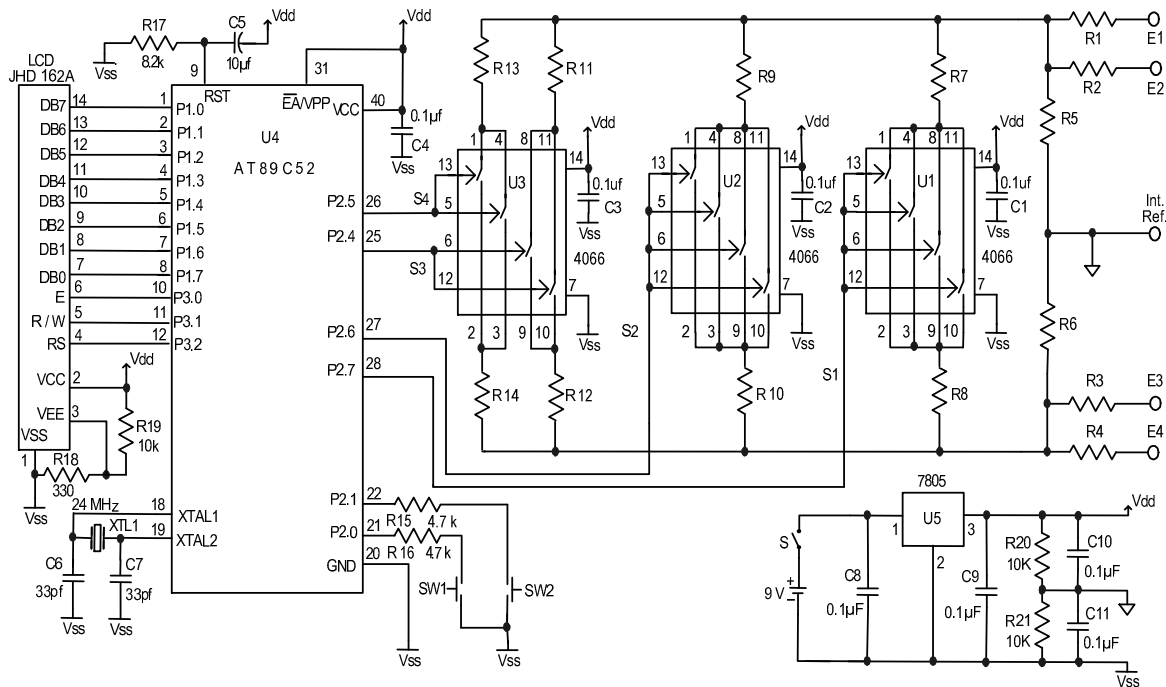


Fig. 2. Circuit diagram of the impedance simulator

regulator U5. As the impedance sensing is carried out with a bipolar current source, an internal reference point of the circuit has been generated at the mid potential of the power supply. Resistances in series with each switch have been symmetrically placed on both sides of the switch in order to obtain proper switching operation for a maximum possible bipolar voltage swing. Common mode bioelectric sources and external pickups can be simulated by connecting a source in series with a resistance between the internal reference point and the ground of the measuring instrument.

The values of the base resistance, peak-to-peak variation step, and frequency of square wave can be selected using two push button switches SW1 and SW2 along with a 16-character \times 2-line LCD. The program on the microcontroller takes care of interfacing the two input keys and LCD display with a menu based parameter selection. It also generates the control voltages for switches S1 and S2 for selecting the value of base resistance and square waves for controlling switches S3 and S4 for variation in the resistance.

4. TEST RESULTS

By using different set of resistors, the bio-impedance simulator circuit of Fig. 2 was used for simulating thoracic impedance for impedance cardiography with 4-electrode configuration and laryngeal impedance for electroglottography with 2-electrode configuration. Various features of different instruments for both of these applications were tested.

As an example, we present the results for electroglottography, for monitoring the variation in the contact area between vibrating vocal cords in the larynx. The basal impedance of neck is normally in the range of 100-500 Ω , and change in the impedance due to vocal folds variation is less than 1%. For simulating the laryngeal resistance, values of resistances R_1 to R_{14} in the circuit of Fig. 2 were selected as the following

$$R_1 = R_2 = R_3 = R_4 = 68 \Omega, R_5 = R_6 = 120 \Omega,$$

$$R_7 = R_8 = 22 \Omega, R_9 = R_{10} = 82 \Omega,$$

$$R_{11} = R_{12} = 2.7 \text{ k}\Omega, R_{13} = R_{14} = 100 \text{ k}\Omega.$$

With these resistor values in the circuit and on-state values of $R_{s1} = R_{s2} \approx 68 \Omega$ and $R_{s3} = R_{s4} \approx 135 \Omega$, the base value could be set as 193.3 Ω , 212.1 Ω , 253.8 Ω , or 376.0 Ω , and the simulated glottal resistance could be varied from 0 to 2.7 %.

These values cover the normal variation of the laryngeal resistance, but individual values have no specific physiological significance.

The microcontroller was programmed so that the frequency of square wave could be varied over the values of 0.5 Hz, 1 Hz, 5 Hz, 10 Hz, 50 Hz, and 100 – 500 Hz in steps of 50 Hz. The functioning and features of the impedance simulator was validated by connecting it to an electroglottograph instrument model type EG-90 (F-J Electronics, Denmark). The output waveform obtained from the electroglottograph instrument by connecting it to the laryngeal impedance simulator is shown in Fig. 3.

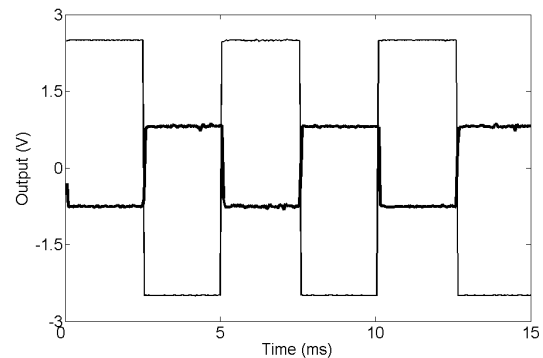


Fig. 3. Test waveform with electroglottograph, for square wave frequency of 200 Hz, with $R = 212.1 \Omega$, $\Delta R = 1.06 \Omega$ (lighter trace: control signal from port pin P2.5 of U4, darker trace: output from electroglottograph). Electrodes were connected across E1 and E4, leaving E2 and E3 open.

5. CONCLUSION

A microcontroller based impedance simulator is developed for testing and calibration of instruments for sensing of bioimpedance signals. It can be particularly useful for comparing different instruments developed for a specific application.

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