

A microcontroller based thorax simulator for testing and calibration of impedance cardiographs

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1. Introduction

A thorax simulator is developed for testing and calibration of the instruments used for impedance cardiography. Variations in the resistances and the bioelectric voltage sources in the thorax model are realized using digital potentiometers and a microcontroller. It provides a small (0.1 – 1.2 %) periodic resistance variation over the selected base resistance (20 – 200 Ω) for testing of the impedance detector and the voltage signals for testing of the ECG amplifier.

Impedance cardiography can be used for estimating the stroke volume and cardiac output by sensing the variation in thoracic impedance during the cardiac cycle [1]. The variation in the bioimpedance across a body segment is generally monitored by passing a low level high frequency current (<5 mA, 20 kHz – 1 MHz) through a pair of surface electrodes (spot or band electrodes). The resulting voltage, sensed using the same or another pair of electrodes, gets amplitude modulated due to the impedance variation. This voltage is demodulated to get the impedance signal. The sensed impedance consists of basal impedance, a time-varying component related to the physiological phenomenon of interest, and various physiological and non-physiological artifacts. For satisfactory operation of the instrument [2], the impedance detector should have appropriate sensitivity and the frequency response. The measurement of the variation in the impedance should not be affected by variation in the basal impedance, the skin-electrode contact impedances, the artifacts, and the external interferences. Here we present a thorax simulator for measuring various performance parameters of an impedance cardiograph: the range of basal resistance, sensitivity, and frequency response of the impedance detector, difference mode gain and CMRR of the ECG amplifier, and rejection of the common mode interference from external sources.

2. Thorax model and the simulator circuit

For the purpose of impedance cardiography, the thorax can be modeled by a network as shown in Fig.1 [3]. It represents the basal resistance, variation in the resistance related to the cardiac cycle, ECG voltage, electrode-tissue contact resistances, and externally introduced common mode interference. It has two voltage sources without a common node. For realizing it as a circuit without using transformers, the model is modified with two sources connected to a common reference. It is realized as the circuit in Fig. 2.

The variation in the thoracic resistance due to cardiovascular activity is a small percentage (< 2 %) of the basal resistance (20 – 200 Ω). The resistance variation is realized using the digital potentiometer IC5 (MCP 4105), with its resistance variable in 256 steps over 0 – 5 k Ω . The base resistance values can be selected through jumpers by connecting R14 and R15. The resistance can be varied in accordance with the selected waveshape by providing appropriate sequence of digital control words to the digital potentiometer. The voltage, representing internal bioelectric sources, with the selected waveform is generated by digital potentiometer IC2, with its peak-to-peak

amplitude controlled by the digital potentiometer IC3. A polarity controlled unity gain amplifier is used to control the phase relationship between the voltages E_{x1} and E_{x2} . For testing the rejection of external common mode interference by the impedance detector, the common mode interference can be externally applied to E_p .

The controller and the power supply circuit is shown in Fig. 3. The microcontroller IC1 (AT 89S52) is used as the controller of the hardware. The three digital potentiometers are controlled via SPI bus. The various wave shapes like sinusoidal, square, and a typical ECG have been realized using different lookup tables in the microcontroller's memory. The synchronization test outputs are provided on the microcontroller's port pins P3.6 and P3.7 for testing synchronization of the outputs of the ECG amplifier and the impedance detector. The LCD display LCD1 and the two soft keys SW1 and SW2 provide the user interface. The circuit is powered by a single 9 V supply, with two fixed voltage regulators (IC6, IC7) for the digital and the analog parts of the circuit. The various parameters for simulation, type of waveshape (square, sine), the ECG mode (common, differential), frequency (1 – 250 Hz), the amplitude of ECG voltages (0 – 100 mV), and variation in the resistance (0.1 – 1.2 %) are selected using LCD and the two soft keys. The simulator can be used for simultaneous testing of the impedance detector and ECG part of the impedance cardiograph, and also for estimating the effect of external common mode interference on the measurements.

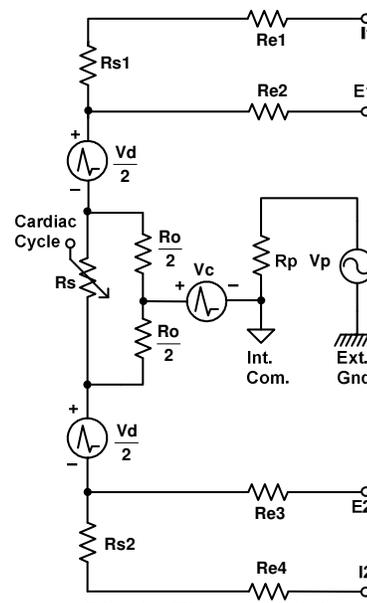


Fig. 1 Thorax model.

3. Results and conclusion

In the common mode, the voltage can be varied in the range of 50 – 100 mV (p-p), with less than 200 μ V (p-p) of differential voltage. In the difference mode, the voltage can be varied in the range of 0-50 mV, with less than 0.9 mV (p-p) common mode voltage. The base resistances for different jumper settings are found to be 23.77 Ω , 28.24 Ω , 84.98 Ω , and 196.07 Ω . The resistance can be varied in the range of 0.1 – 1.2 % of the selected base resistance.

In summary, a thorax simulator has been developed for testing and calibration of the instruments for impedance cardiography. The features includes settable values of heart beat rate, basal resistance, % variation in resistance, the ECG voltage sources, and the various wave shapes (square, sinusoidal, and typical ECG) for simulating the bioimpedance signal and the ECG.

References

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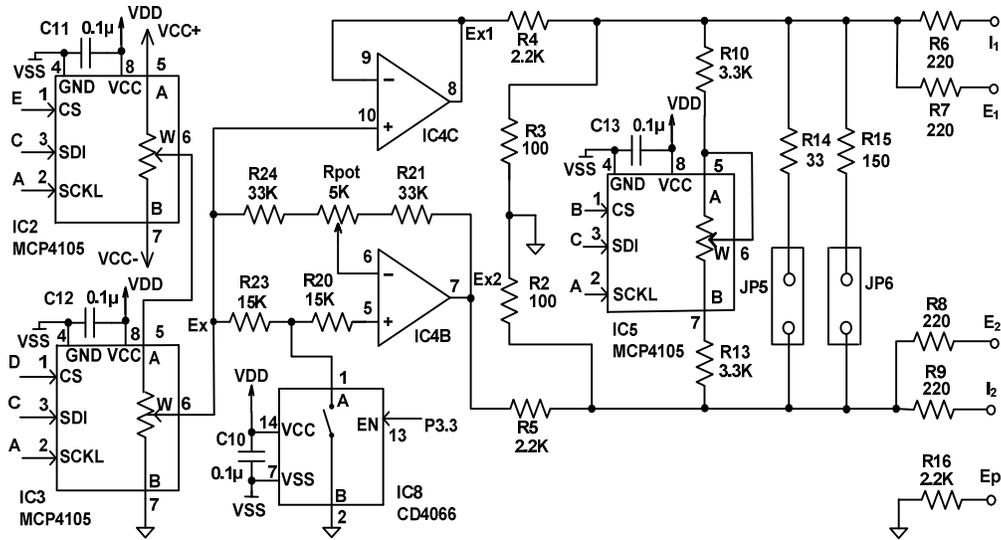


Fig. 2 Thorax simulator circuit.

Model Relations

$$R_{s1} + R_{e1} = R_6, \quad R_{e2} = R_7, \quad R_{e3} = R_8, \quad R_{s2} + R_{e4} = R_9$$

$$R_s \parallel R_o = (R_2 + R_3) \parallel (R_{10} + R_{WB} + R_{13}) \parallel R_{14} \parallel R_{15} \parallel (R_4 + R_5)$$

$$V_c + V_d / 2 = \left(R'_3 / (R'_3 + R_4) \right) E_{x1} \quad V_c - V_d / 2 = \left(R'_2 / (R'_2 + R_5) \right) E_{x2}$$

where $R'_3 = R_3 \parallel \left((R_2 \parallel R_5) + \left((R_{10} + R_{WB} + R_{13}) \parallel R_{14} \parallel R_{15} \right) \right)$

$$R'_2 = R_2 \parallel \left((R_3 \parallel R_4) + \left((R_{10} + R_{WB} + R_{13}) \parallel R_{14} \parallel R_{15} \right) \right)$$

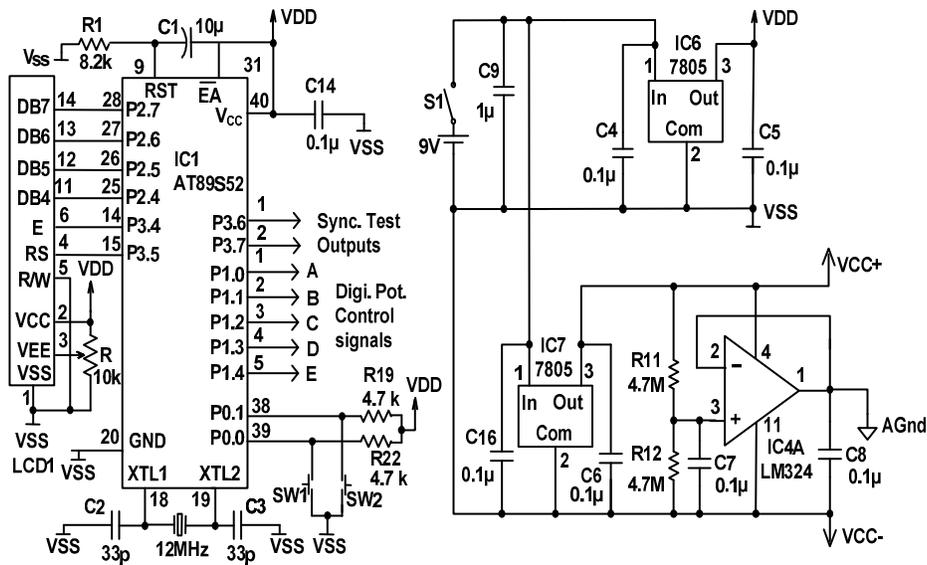


Fig. 3 The controller and power supply circuit.