Proc. National Symposium on Instrumentation (NSI-28), Pantnagar, India, Nov 3 to 5, 2003.

Thoracic Simulator for Impedance Cardiography

Manigandan N S[1], Vinod K Pandey[1] and Prem C Pandey[2]

[1]BME Group, IIT Bombay, Powai Mumbai-400 076, India
manigandanns@iitb.ac.in, vinod@ee.iitb.ac.in

[2]EE Dept., IIT Bombay, Powai Mumbai-400 076, India
pcpandey@ee.iitb.ac.in

***Abstract*– Impedance cardiography is a non-invasive technique for measuring cardiac output and for diagnosing cardiac disorders. During systol, blood is pumped into the thoracic region which changes its basal impedance. High frequency (20–100 kHz) current (3–10 mA) is injected into the thoracic region through a pair of electrodes and the impedance change is sensed, by measuring the voltage across another pair of electrodes. The impedance variation thus measured is known as impedance cardiogram (ICG) and can be used for estimating stroke volume by using appropriate models of blood flow and can also be used for diagnostic information. As part of instrumentation development, a thoracic impedance simulator has been developed for comprehensive testing and calibration of the impedance cardiograph instrument to ensure proper signal pickup and detection of impedance variation. Features of this simulator include the variation of base impedance of the thorax by less than 1 percent as a square wave, electrode–tissue contact impedances for 4 – electrode configuration, 24 – 300 beats/min heart beat rate, 0 – 60 mV common mode ECG, 0 – 20 mV differential ECG, and option for feeding external pickup.**

1. INTRODUCTION

Impedance cardiography is a non-invasive technique for measuring the cardiac output and diagnosing cardiac disorders [1], [4], [6]. This is essentially a development to replace the existing invasive techniques to measure the cardiac output such as the Fick's dye dilution method, thermo dilution method, which are widely used in clinical practice [3], [7]. In impedance cardiograph technique, high frequency (20 – 100 kHz), low intensity (1-5 mA) current is injected through a pair of electrodes [1], [2], [4]. Resulting voltage waveform gets amplitude modulated because of variation in the thoracic impedance. The sensed voltage waveform is demodulated to get the impedance variation and this can be used with the help of appropriate model, for estimating the cardiac stroke volume and for obtaining diagnostic information [5], [8].

As part of instrumentation development for the impedance cardiography, a thoracic impedance simulator has been developed and presented here. This simulator is used for comprehensive testing and calibration of the impedance cardiograph instrument to ensure proper signal pickup and detection of impedance variation. It has the facility for varying the beat rate, magnitude of common and differential mode ECG signals and a fixed percentage variation in the thoracic impedance as a square wave. Option for feeding external pickups is also incorporated. The simulator can be operated either through battery or external power supply.

2. THORACIC MODEL ANALYSIS

A typical impedance cardiograph system uses four-electrode configuration [2], [5], [8]. In the physical arrangement of the outer pair, one electrode is placed around abdomen and the other around upper part of the neck. For the inner electrode pair, one electrode is placed around he thorax at the level of joint between xiphoid and sternum, called the xiphisternal joint, and the other around the lower part of the neck [3]. The impedance change sensed by this electrode configuration is sensed by the impedance cardiograph. To calibrate the impedance cardiograph instrument thoracic simulator was developed and tested.

2.1 Thoracic Impedance Simulator Model

The thoracic impedance simulator model is shown in Fig 1. The variation of the impedance can be measured through the output E_1 and E_2. In this model, R_e's constitute the tissue-electrode contact resistances for four-electrode model, R_o and R_s parallel column model resistances and R_{s1} & R_{s2} fixed resistances in current path. Option for feeding external pickup is denoted by E_p and the pickup resistance by R_p. The voltage sources E_d and E_c illustrate the common mode and differential mode ECG signals respectively. The high frequency current is fed through the inputs I_1 and I_2. The cardiac pulses are simulated by the opening and closure of the switch. The base impedance is R_o when the switch is open and the impedance when the switch is closed is (R_s || R_o) which constitutes the decrease in impedance.

2.2 Model Relations with the Schematic

The thorax model of Fig 1 has several sources without a common node. In order to have an easily realizable circuit, the model can be modified to a schematic shown in Fig 2. Relations of the schematic with the model are given below.

$$R_1 = R_{s1} + R_{e1} \tag{1}$$

$$R_2 = R_{e2} \tag{2}$$

$$R_4 = R_{e4} + R_{s2} \tag{3}$$

$$R_3 = R_{e3} \tag{4}$$

$$R_{y1}' = R_{y1} \parallel \left(R_z + \left(R_{y2} \parallel R_{x2}\right)\right) \tag{5}$$

$$R_{y2}' = R_{y2} \parallel \left(R_z + \left(R_{y1} \parallel R_{x1}\right)\right) \tag{6}$$

$$V_1 = E_{x1}\left[\frac{R_{y1}'}{R_{x1} + R_{y1}'}\right] = E_c + \frac{E_d}{2} \tag{7}$$

$$V_2 = E_{x2}\left[\frac{R_{y2}'}{R_{x2} + R_{y2}'}\right] = E_c - \frac{E_d}{2} \tag{8}$$

$$R_a = R_b = \frac{R_s}{2} \tag{9}$$

$$R_z = R_o \tag{10}$$

3. EXPERIMENTAL RESULTS

The circuit development for the schematic of Fig 2 is shown in Fig 3. The switch is realized using a quad analog switches in IC 4066. The heart beat and common/ differentiation mode ECG generation is done using an astable multivibrator and inverter. The beat rate is variable from 0.4 – 5 Hz (24 – 300 beats/min). The four analog switches in IC CD4066 are paralleled together for a reduced "on" resistance. Switching in ICG mode results in approximately 1% variation in the base impedance.

$$R_{eq(on)} = R_z \parallel (R_a + R_b) \parallel (R_{y1} + R_{y2}) \tag{11}$$

$$R_{eq(off)} = R_z \parallel (R_{y1} + R_{y2}) \tag{12}$$

CD4066 analog switch have typical on-resistance of 120 Ω (for $V_{DD} - V_{SS} \approx 10$ V). The base impedance when the switch was "off" is 19.8 Ω and the impedance when the switch was "on" is 19.6 Ω. So a change in impedance of 0.2 Ω was simulated using this impedance simulator. For sample test results, the frequency of the heartbeat generator was selected to be 461.6 mHz. The differential voltage present in this signal was found to be 875.0 μV(p-p). When the differential mode was selected the common mode voltage was found to be 2.144 mV(p-p). When the simulator is put in ICG mode, the changing impedance of 0.2 Ω was obtained from the simulator after demodulation and DC cancellation using the ICG instrument earlier developed by SPI Lab, EE Dept, IIT Bombay [9].

4. CONCLUSION

In order to ensure proper operation of impedance cardiograph, a thoracic simulator is required for calibration. To serve that purpose thoracic impedance simulator is developed for testing and calibration of ICG and ECG extraction circuits in impedance cardiograph.

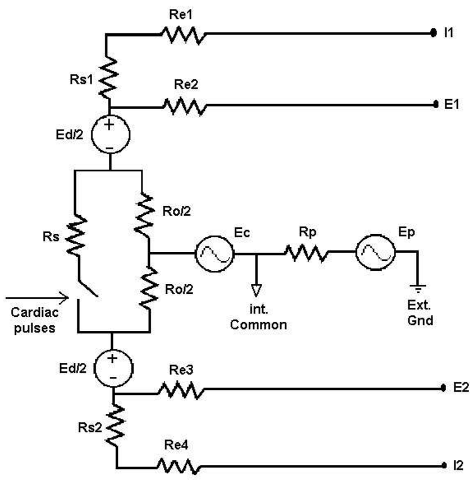

Fig 1 Thorax impedance model

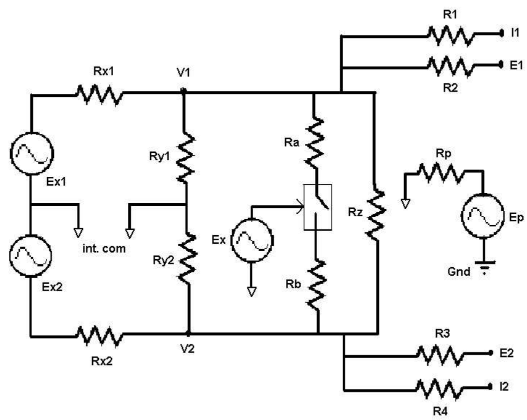

Fig 2 Schematic of thorax impedance simulator

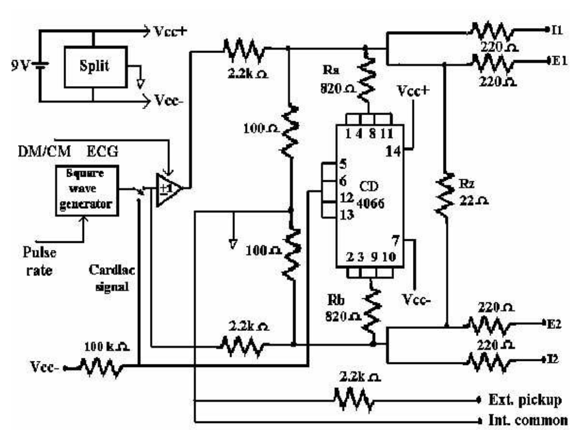

Fig 3 Circuit diagram of thoracic simulator

REFERENCES

[1] L. E. Baker, ‘Priciple of the impedance cardiography technique’, *IEEE Eng. Med. Biol. Mag.*, 11-15 (1989).

[2] S. M. Joshi, and P. C. Pandey, ‘A cardiac output monitoring using impedance plethysmography’, in *Proc. Int. Conf. Rec. Adv. Biomed. Eng.*, 157-160 (1994).

[3] J. Nyboer, ‘Electrical Impedance Plethysmography’, Third Edition, Charles C. Thomas, Springfield (1970).

[4] R. P. Patterson, ‘Fundamental of impedance cardiography’, *IEEE Eng, Med. Biol. Mag.*, 35-38 (1989).

[5] M. Qu., Y. Zang, J. G. Webster, and W. J. Tompkins, ‘Motion artifacts from spot andband electrodes during impedance cardiography’, *IEEE Trans. Biomed. Eng.*, **33**, 1029-1036 (1986).

[6] B. C. Taylor, W. D. Timmons, and A. S. Hines, ‘A modeling solution to the origin of the electrical impedance cardiogram’, in *Proc. 1st Annu. Int. Conf. BMES/EMBS IEEE Eng. Med. Biol. Soc.*, 233 (1999).

[7] J. G. Webster, ‘*Medical* Instrumentation-Application and Design’, Third Edition, John Wiley, New Delhi (1998).

[8] Y. Zang, M. Qu., J. G. Webster, W. J. Tompkins, B. A. Ward, and D. R. Bassett, ‘Cardiac output monitoring by impedance cardiography during treadmill exercise’, *IEEE Trans. Biomed. Eng.*, **33**, 1029-1041 (1986).

[9] B. P. Kuriakose, ‘An impedance cardiograph’, M.Tech dissertation, BME Dept., IIT Bombay, 2000.