

Indigenous Design of Electronic Circuit for Electrocardiograph

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Abstract: This paper provides electronic implementation of electrocardiograph (ECG) circuit by using instrumentation amplifier (IA) as bio-potential amplifier in such a manner which reduces noise, common voltage, DC offset value and RF interference from the existing circuit. Noise and common voltage can be removed from ECG using driven right leg circuit or by using isolator circuit. DC offset can be removed by using integrator as feedback. In the differential amplifier part of IA, we can add single resistance, T-network or inverter circuit with integrator to improve impulse response. By using filters, we can reduce RF interference. In this paper, we have used instrumentation amplifier as a bio-potential amplifier.

Keywords: ECG, Bio-potential amplifier, Driven right leg circuit, DC offset, Common mode rejection Ratio, Filter.

I. INTRODUCTION

An electrocardiogram (ECG or EKG) is the measurement and graphical representation of electrical signals associated with the human heart. Applications of an ECG range from monitoring heart rate, heartbeat, heart rhythm to the diagnosis of specific heart conditions. The basics of ECG measurement are the same for all applications, but there can be variation in the methods and representation of the circuit.

All ECGs pick up heart signals through electrodes connected externally to specific locations on the body i.e. arms and legs. Then the body generates the heart signals which are of few mill volts amplitudes. The specific locations of the electrodes allow the heart's electrical activity to be viewed from different angles, each of which is displayed as a channel on the ECG printout. The channels are commonly referred to as "leads" and the number of leads varies from 1 to 12 depending on the application [1]. 12-lead ECG are recorded using right arm (RA), left arm (LA), left leg (LL), right leg (RL), and chest (C) electrodes. Standard lead system can be divided into two planes i.e. frontal and transverse plane. They comprise a combination of electrodes taking measurements from different regions and can be further divided into bipolar limb leads, unipolar leads and the chest leads. Bipolar limb leads derive signals from electrodes on the limbs, and are designated as leads I (RA to LA), II (RA to LL), and III (LA to LL). Unipolar leads are designated as aVR, aVL, and aVF, and can be designed by connecting RA, LA and LL respectively to non-inverting terminal and remaining two electrodes to inverting terminal of IA. The remaining six leads, V1, V2, ... V6, are chest leads [2]. In this paper we are using lead I ECG system.

The basic design of a bio-potential amplifier consists of an instrumentation amplifier. The amplifier should possess several characteristics, including high amplification, high input impedance [3], high common mode rejection ratio (CMRR) and the ability to reject electrical interference, all of which are needed for the measurement of these bio-potentials [4]. Our aim in this paper is to reduce the electronic circuit of ECG as simple as possible.

II. RELATED WORK

In this section we will discuss the existing functional blocks of ECG as shown in fig. 1.

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- a. **Protection circuit:** This circuit includes protection devices so that the high voltages that may appear across the input to the electrocardiograph under certain conditions do not damage it.
- b. **Lead selector:** Each electrode connected to the patient is attached to the lead selector of the electrocardiograph. The function of this block is to determine which electrodes are necessary for a particular lead and to connect them to the remainder of the circuit. It selects one or more leads to be recorded.

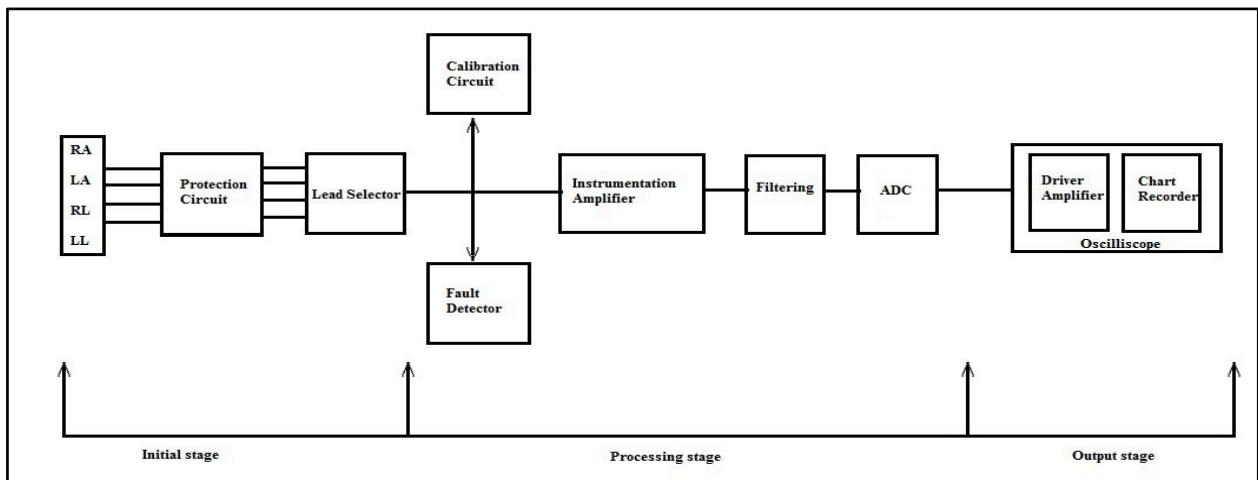


Fig.1 Block diagram of ECG

- c. **Instrumentation amplifier:** It is sometimes desired to amplify the difference of two signals. The difference amplifier may not meet circuit design criteria due to its low input resistance. Here, two non-inverting amplifiers may be combined with a difference amplifier in order to create an instrumentation amplifier as shown in fig.2 and its output voltage is given as (eq. 1).

$$V_{out} = \left(1 + \frac{2R_2}{R_1}\right) \left(\frac{R_4}{R_3}\right) (V_2 - V_1) \tag{1}$$

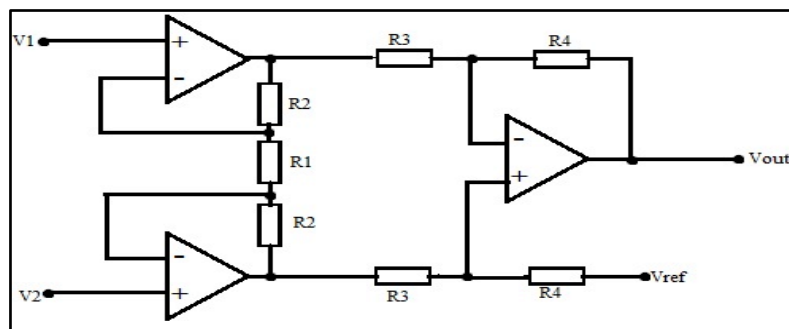


Fig.2 Instrumentation amplifier

- d. **Filters:** Filters are used to remove unwanted noise. Especially in ECG work, the signal levels are very small (around 1mV), so it is necessary to use filtering to remove a wide range of noise. This noise may come from an unstable dc offset from electrode/body interface, muscle noise, mains hum (50/60Hz), electrical noise from equipment in the environment and from within the ECG equipment itself, such as from internal dc/dc converters.

On the basis of block discussed in fig. 1, internal circuit diagram is shown in fig. 3 which is already discussed in several papers[5] [6]. But this circuit diagram has problems associated with it. They are mentioned below:

1. No need of inverter at RA.
2. Presence of noise and common mode values.
3. DC offset and suppression.
4. Separate filters at the end are making circuit complex.

All these problems are explained and resolved further in this paper.

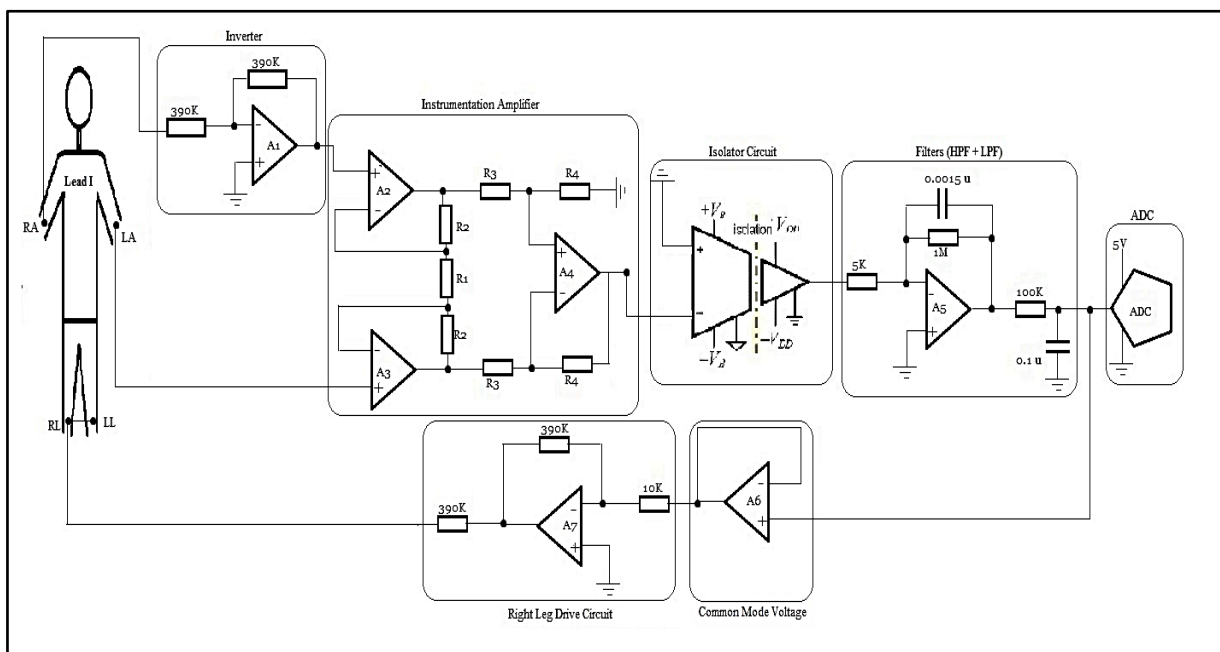


Fig. 3 Existing Circuit diagram of an ECG

III. MATERIALS AND METHODS

3.1 Removal of inverter: As for lead I, RA (right arm) is at negative terminal and LA (left arm) is at positive terminal so, instead of using inverter after RA we put this point at the negative terminal of instrumentation amplifier.

3.2 Removal of noise and common mode values: Followings are the methods to remove noise and common mode values from ECG waveform to increase CMRR.

- a) *Driven right leg system (Feedback loop to reduce noise):* This circuit provides a reference point on the patient that normally is at ground potential [7]. This connection is made to an electrode on the patient's right leg as shown in Fig.4. Right leg driver circuit is used in a feedback configuration to reduce 60 Hz noise and drive noise on patient to a lower level. V_{CM} (common mode voltage) is given by eq. 2.

$$V_{cm} = \frac{R_{RL} i_D}{1 + \frac{2R_F}{R_a}} \quad (2)$$

Where R_{RL} = Right leg resistance
 R_F = Feedback resistance
 i_D = Displacement current flows from power lines to the patient
 R_a = Averaging resistance.

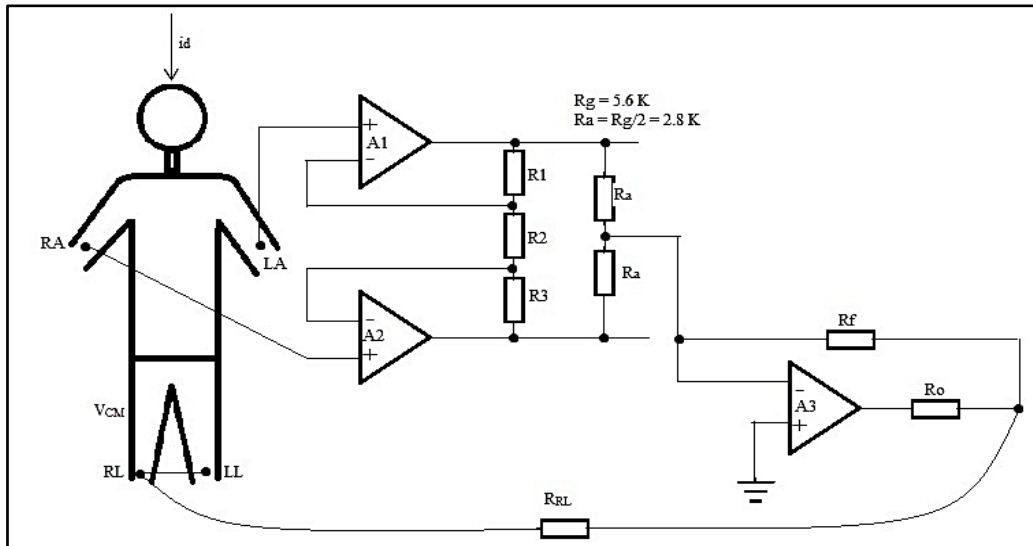


Fig. 4: Driven right leg circuit

- b) *Isolation amplifier*: It is used to isolate patient from high voltages and currents to prevent electric shock where there is specifically a barrier between passage of current from the power line to the patient. It can be done by two ways i.e. electrical isolation and optical isolation. Electrical isolation can be done by inserting a transformer in the signal path (Fig. 5(a)). It limits the possibility of the passage of any leakage current from the instrument in use to the patient. Optical isolation can be done by introducing an optical coupler (Fig. 5(b)). The electric signal from the amplifier is first converted to light by a light-emitting diode (LED). This optical signal is modulated in proportion to the electric signal, and transmitted to the detector. [8]

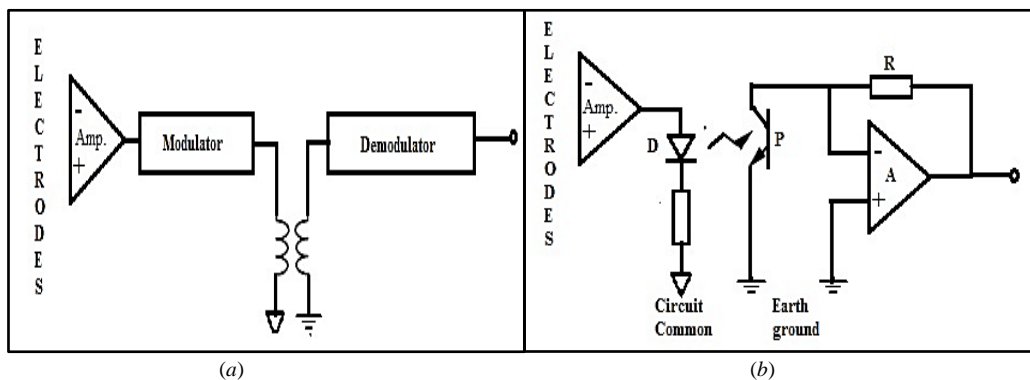


Fig. 5 Isolation amplifiers (a) Electronic isolator (b) Optical Isolator [8]

This method is bit costly so we prefer to use driven right leg circuit for removal of noise and common mode values.

3.3 Removal of DC offset and DC suppression: DC-offset and DC-suppression are key parameters in bioelectric amplifiers. Bioelectric amplifiers require a high gain level, a low density of equivalent input noise, a high common mode rejection ratio (CMRR) [9] and a high-impedance input. Most of these features can be achieved by using an instrumentation amplifier (IA) as a front stage. But some DC voltage levels appear at the output of the IA. These levels are produced by several factors such as impedance imbalance from the input electrodes, electrode contact potentials and input bias currents. These DC levels must be removed; otherwise, they would produce output saturation phenomena

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when amplified in the subsequent stages. Several techniques have been developed to remove the DC levels. These are explained below:

- a) As shown in Fig.6, the stage is a high-pass filter with gain, cascaded after the instrumentation amplifier [10]. This circuit consists of feedback integrator which acts as low pass filter and used to eliminate DC level. Hence when feedback is applied, the DC component is eliminated at output voltage and whole stage thus behaves as a HPF with gain G. As input voltage is given on inverting terminal so this behaves like an inverter circuit which will amplify the input. Eq. 3 shows transfer function for the circuit shown in fig. 6.

$$H(\omega) = \frac{V_o}{V_i} = \frac{-G}{1 + \frac{G}{sR_3C}} \quad (3)$$

Where $G = R_2 / R_1$

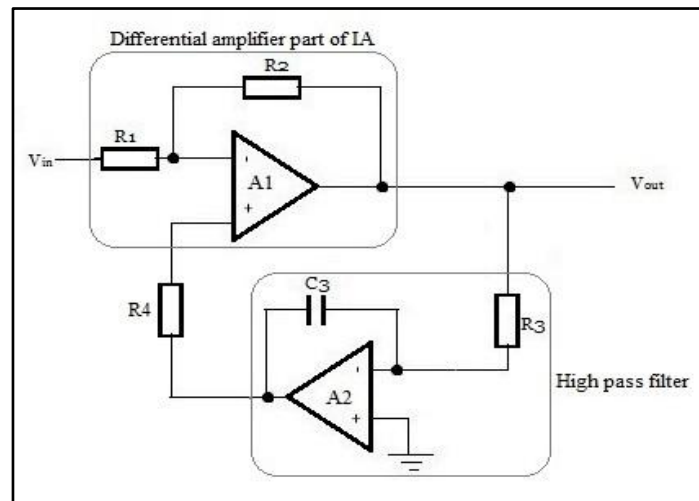


Fig. 6 High-pass filter with gain.

- b) Our objective is to improve impulse response with HPF selection. Output DC offset must be low and independent from the selected cut-off frequency. Fig. 7 has a T-resistor network in the feedback (R3, R4, R5). The new transfer function is obtained in Eq. (4). This transfer function has a magnifying factor (written in brackets) when compared to Eq. (3).

$$H(\omega) = \frac{v_o}{v_i} = \frac{-G}{G+1} \frac{1}{1 + \frac{G}{sR_3C \left(\frac{R_4}{R_5} + \frac{R_4}{R_3} + 1 \right)}} \quad (4)$$

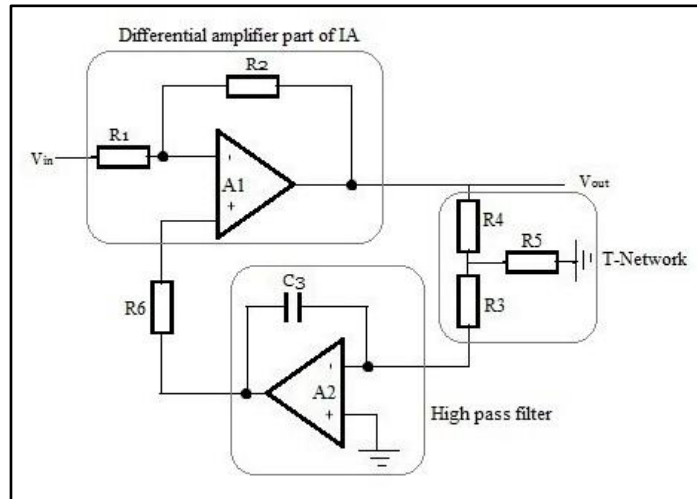


Fig.7 High-pass filter with gain using a T-resistor network in the feedback

- c) In this configuration feedback includes an op-amp inverting stage previous to the integrator as shown in Fig.8 which further improves the response and suppress the DC level.

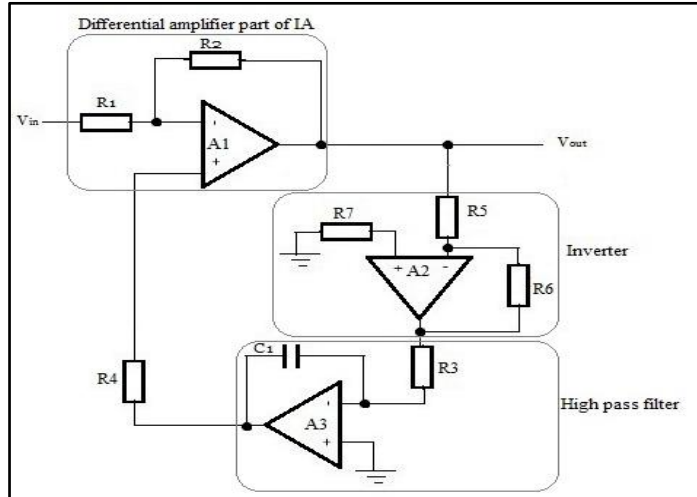


Fig. 8 High-pass filter with gain using an inverter op-amp stage in the feedback.

Both designs add resistors or an op-amp stage in the feedback-loop to create the magnifying factor, if compared with Fig.6. But we are using HPF with gain using an inverter op-amp stage in the feedback in our final diagram because the HPF cut-off frequency is the simpler in Equation (5), and as in the previous design, it can be adjusted by selecting R3.

$$H(\omega) = \frac{v_o}{v_i} = \frac{-G}{1 + \frac{R_6 R_2}{s C R_4 R_3 R_5}} \quad (5)$$

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3.4 Filters: Sometimes there is RF interference in circuit so to reduce it we need to add LPF [11]. Filtering should be included in the front end of the instrumentation amplifier. As shown in Fig.9, low pass filter is adjusted with instrumentation amplifier. Now with this there is no need of filtering after IA.

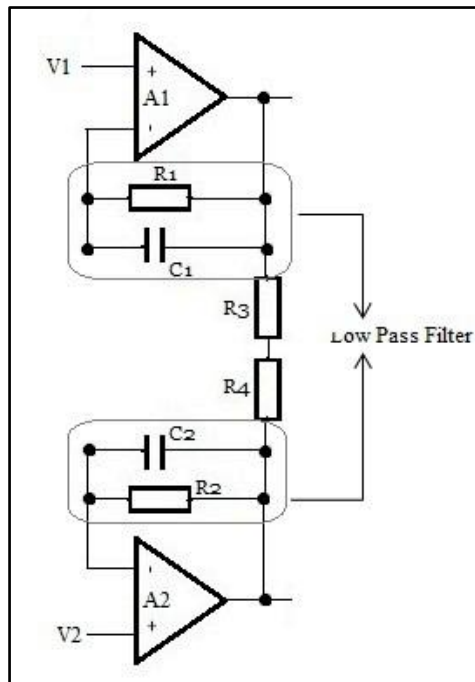


Fig. 9 Low pass filter with IA

IV. PROPOSED CIRCUIT DIAGRAM OF AN ECG

Fig. 10 shows the proposed circuit diagram of ECG system. This circuit diagram comprises of instrumentation amplifier with pre-amplifier circuit and right leg drive circuit to reduce noise and common mode value from circuit, high-pass filter with gain using an inverter op-amp stage in the feedback to block DC offset value. The final circuit diagram is small and compact in comparison with the existing circuit.

V. CONCLUSION

This paper proposes the electronic implementation of ECG circuit by using instrumentation amplifier as bio-potential amplifier. This paper also explains the several techniques to reduce noise and to increase CMRR by using driven right leg circuit. With the help of high pass filter with gain G , we can reduce DC offset. RF interference can be reduced by filtering. At the end we have combined all the parts and made the existing circuit compact in size. In future we will check all the electrical parameters with the help of this circuit.

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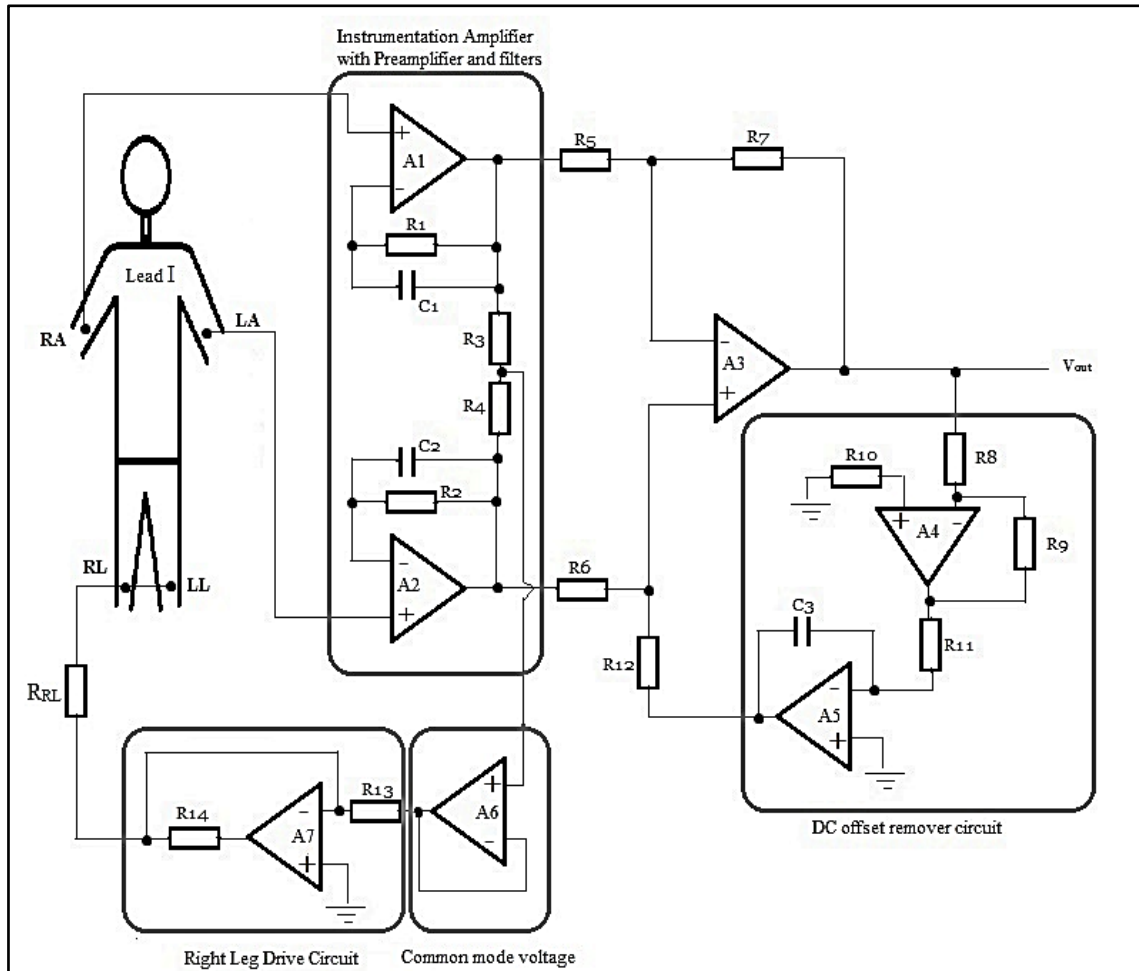


Fig. 10 Proposed circuit diagram of an ECG

REFERENCES

- [1] Thakor N.V., "Electrocardiographic monitors," in Encyclopedia of Medical Devices and Instrumentation, Webster J. G., Ed., New York: Wiley, pp. 1002-1017, 1988.
- [2] Carr, J.J., Brown, J.M., "Introduction to Biomedical Equipment Technology", Pearson Education, Inc.: edition 7th; Chapter 8.
- [3] Franco S., "Design with Operational Amplifiers", New York: McGraw-Hill, 1988.
- [4] Neuman, M.R., "Biopotential electrodes" in Medical Instrumentation: Application and Design, Webster J. G., Ed., 3rd ed., New York: Wiley, 1988.
- [5] Nathan M K., "Electrocardiography Circuit Design", ECE 480 - DESIGN TEAM 3, 4, May 2013.
- [6] Dr. Neil Townsend, Medical Electronics, Michaelmas Terms 2001, notes 2, page 9-19.
- [7] Bruce B. Winter, John G. Webster, "Driven Right Leg Circuit Design", IEEE transaction on Biomedical Engineering, Vol. BME 30, No. 1, page 62-66, Jan 1983.
- [8] Thakor N.V., "Bipotentials and Electrophysiology Measurement." Copyright 2000 CRC Press LLC.
- [9] Webster J. G., "Medical Instrumentation", 3rd ed, New York: John Wiley & Sons, 1998, ISBN 0-471-15368-0.
- [10] Carrera A, Rosa R.D. and Alonso A., "Programmable Gain Amplifiers with DC Suppression and Low Output Offset for Bioelectric Sensors", Sensors 2013, 13, 13123-13142; doi: 10.3390/s131013123, 27, September 2013.
- [11] Yelderma, M., Widrow, B., Cioffi, J., Hesler, E., and Leddy, J.E. "ECG enhancement by adaptive cancellation of electrosurgical interference. IEEE Transactions on Biomedical Engineering", Vol. BME-30, No. 7, July 1983.