ECG Measurement System

Home Assignment 1

Qixun Qu
Chalmers University of Technology
Department of Signals and Systems
qixun@student.chalmers.se

1 Introduction of ECG System

ECG, short of electrocardiography, is a kind of biological signal which indicates status of heart. Doctors are able to diagnosis several heart diseases by analyzing patients' ECG. Nowadays, many excellent devices that measure ECG signals have been manufactured. Thanks to all scientists and engineers for their hard work to make the world better.

In this home assignment, a simple ECG measurement system is designed. The requirements and the diagram of all stages are shown in this section. The second section displays the circuit of every stage and all component values as well as calculations.

1.1 Requirements of ECG Amplifier

There are many factors that influence the performance of ECG amplifier. Here, five of them are being considered in circuit to insure the design meet all requirements.

Electrodes Electrodes are classified into two types, non-polarizable and polarizable. The non-polarizable one can pass current without any energy. Silver Chloride(AgCl) is usually used for making non-polarizable electrodes. While, by contrast, polarizable electrodes are unable to pass current unless supplying energy. Direct voltage is not allowed to through it neither. The closest material to make polarizable electrodes is Platinum Chloride, which is harder to be produced than AgCl. Thus, non-polarizable electrodes are used in this design to collect signals from different part of body. The ECG signal is collected on body surface, so that the metal-plate electrodes is a better choice.

Input protection A transient will input and damage the ECG amplifier while a high voltage is add to the human body[1]. The input protection circuit can reduce the effect of transient to a low range. Actually, the protection is necessary in specific situation, such as surgery. Although the protection circuit is included in this design, it may not interfere in most cases.

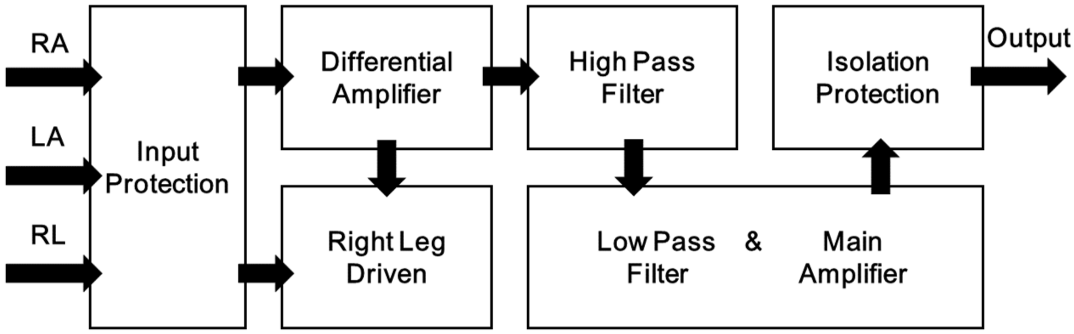

Figure 1.1: *Diagram of ECG Amplifier*

Amplification The ECG signals are collected from different positions of body with a very small amplitude, which is about 0.5mV to 4mV. ECG amplifier should amplify the signal so that it can be shown in display equipment. The operational amplifier has a limit voltage between -13V to +13V. Thus, it is appropriate to set the gain at 1000.

The amplification process consists of two steps. First, a preamplifier, differential amplifier with low amplification at about 10, is used to amplify the different mode signals of input signals. Then, a main amplifier provides a gain around 100 to make amplification up to 1000.

Cut-off frequencies The Range of ECG signals is from 0.01Hz to 250Hz. A typical diagnostic filter range is 0.05 Hz to 150Hz, which ECG signals possess a majority of energy and information[2]. In the circuit, a high pass filter and a low pass filter is designed to remove unwanted signals outside the scope of 0.05Hz to 150Hz.

Isolation protection The output signals generated by ECG amplifier is connected to display device, such as oscilloscope. Usually, a high voltage is supplied to the display device. To protect the ECG system from being damaged by the high voltage, an isolation circuit needs to be included in the design.

1.2 Diagram of ECG Amplifier

The flow chart of the ECG amplifier design is shown as Figure 1.1. Seven parts are contained to measure the ECG signals.

Input stage has a protection circuit to void the damage of transient. Differential amplifier and right leg driven circuit amplifies different mode signals and restrain common mode signals. High pass filter and low pass filter removes the noise signals in a certain range. Main amplifier has a higher gain than preamplifier, amplifying the gain up to around 1000. The final stage has an isolation circuit to protect ECG amplifier from the high voltage. The circuit scheme of every stage, as well as components values, are given in next section.

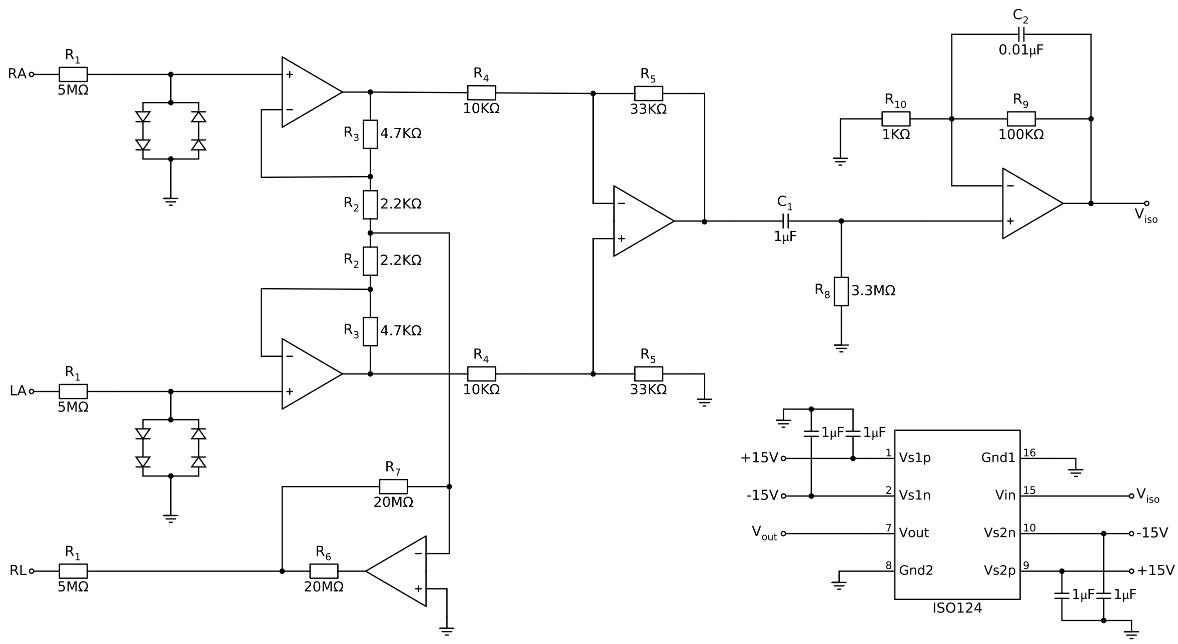

Figure 2.1: *Complete Circuit of ECG Amplifier*

2 Design of ECG Amplifier Circuit

The complete circuit of ECG amplifier is shown as Figure 2.1. Maybe the characters in this circuit are too small to be read. In this section, all separate circuit parts are displayed, and value of each component is also calculated later.

2.1 Signals Input Stage

The input stage in this design needs three electrodes. One electrode is connected to the right leg, the other two electrodes are fixed on two different positions on chest or upper limb. Non-polarizable electrodes are preferred to be applied. Two resistors R_1 limit the input current.

Then, antiparallel silicon diodes pair is connected to ground. One silicon diode has a breakdown voltage at about 600mv. The diodes are in antiparallel because the input signal is alternating. As the input voltage is excessive, diodes in one branch get forward bias, the other branch obtains reverse bias. Thus, the input voltage of ECG amplifier is limited to the forward bias drop of diodes in one branch. Since the ECG signals amplitude is too small, it's better to enhance the forward bias drop by putting two or three diodes in series connection in each branch[1]. Consequently, the input stage can prevent high voltage flowing into the amplifier while transient occurs. The input circuitry is shown in Figure 2.2.

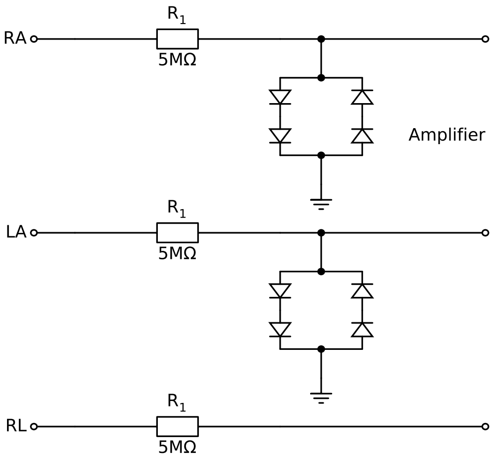

Figure 2.2: *Input Protection Circuit*

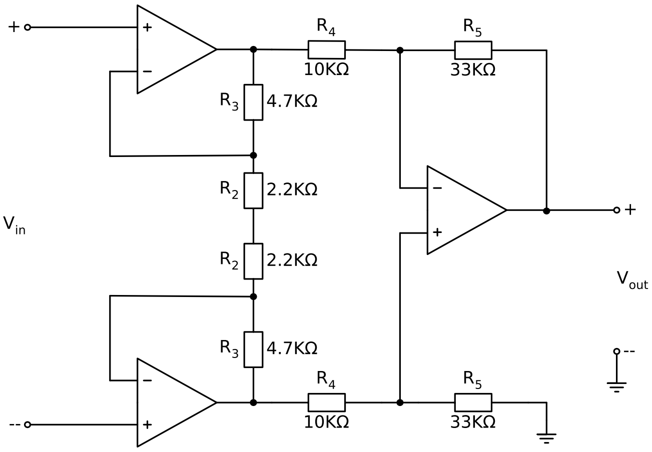

Figure 2.3: *Differential Amplifier*

2.2 Differential Amplifier

The differential amplifier is able to amplify the different mode signals. It has high input impedance and high common mode rejection ratio (CMRR). In this stage, the differential amplifier gives a gain of about 10. The amplification is not very high, because it is better not to amplify the unwanted noise, contained in original inputs, very much. The circuit and components values are displayed in Figure 2.3. The calculation of amplification is shown as follows.

$$A_{da} = \frac{V_{out}}{V_{in}} = \frac{2R_2 + 2R_3}{2R_2} \cdot \frac{R_5}{R_4} = 10.35 \tag{2.1}$$

2.3 Right Leg Driven Circuit

A right leg driven circuitry, on the one hand, reduces the value of common mode signals. On the other hand, it can protected human body from being damaged by high voltage[1]. The right leg driven circuit is shown in Figure 2.4. V_{cm} is the input common mode signal. At point V_1, according to Kirchhoff Current Law, the equation 2.2 can be got. There is an equation 2.3 at point V_0. Thus, V_{cm} can be calculated as the equation 2.4.

$$\frac{2 \cdot V_{cm}}{R_2} + \frac{V_0}{R_7} = 0 \tag{2.2}$$

$$V_{cm} - R_1 \cdot i_d = V_0 \tag{2.3}$$

$$V_{cm} = \frac{R_1 \cdot i_d}{1 + \frac{2 \cdot R_7}{R_2}} = 363 \cdot i_d \tag{2.4}$$

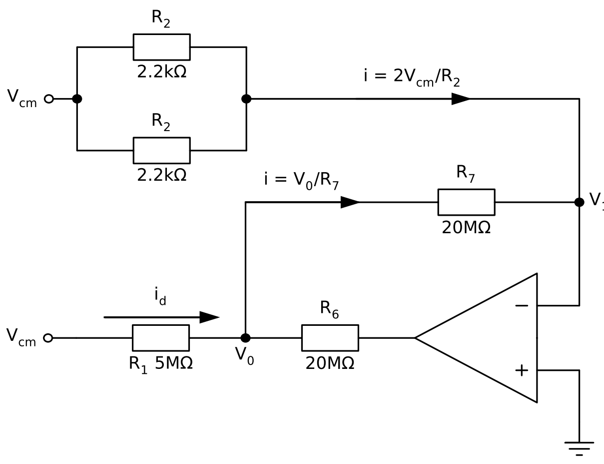

Figure 2.4: *Right Leg Driven Circuit*

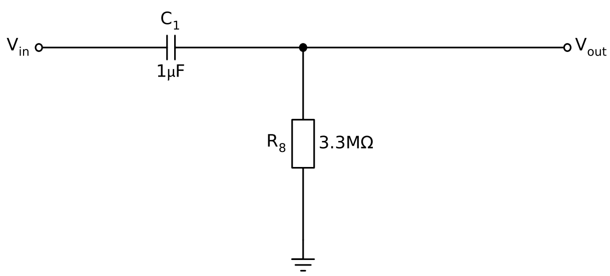

Figure 2.5: *High Pass Filter*

On account of i_d, the displacement current caused by power line radiation, has a rather low value, so the amplitude of V_{cm} is decreased greatly.

2.4 High Pass Filter

The high pass filter can pass the signals with the frequency that is higher than cut-off frequency. The circuit of the filter is shown in Figure 2.5. The calculation of cut-off frequency is as follows.

$$F_{lower} = \frac{1}{2\pi C_1 R_8} = 0.048Hz \tag{2.5}$$

2.5 Low Pass Filter & Main Amplifier

As shown in Figure 2.6, this stage consists of low pass filter and main amplifier. The signal with a lower frequency can through the low pass filter. The calculation of cut-off frequency is shown below.

$$F_{upper} = \frac{1}{2\pi C_2 R_9} = 159Hz \tag{2.6}$$

A non-inverting amplifier is the main amplifier to provide a big gain. Accordance with requirements, the amplification of this stage is 100 at least. The calculation of gain is displayed below.

$$A_{ma} = \frac{V_{out}}{V_{in}} = \frac{R_9 + R_{10}}{R_{10}} = 101 \tag{2.7}$$

So, the whole gain of ECG amplifier is:

$$A = A_{da} \cdot A_{ma} = 1045 \tag{2.8}$$

2.6 Isolation Stage

In this stage, an isolation amplifier named ISO124 is applied, shown in Figure 2.7. According to its technical manual, ISO124 transfers signal by its differential capacitive barrier without signal loss[3]. Its normal supply voltages are ±15V. No other components are needed to connected to it. After this stage, the output of ECG amplifier is obtained.

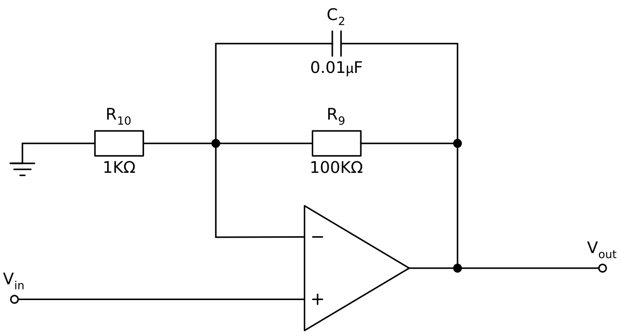

Figure 2.6: *Low Pass Filter & Main Amplifier*

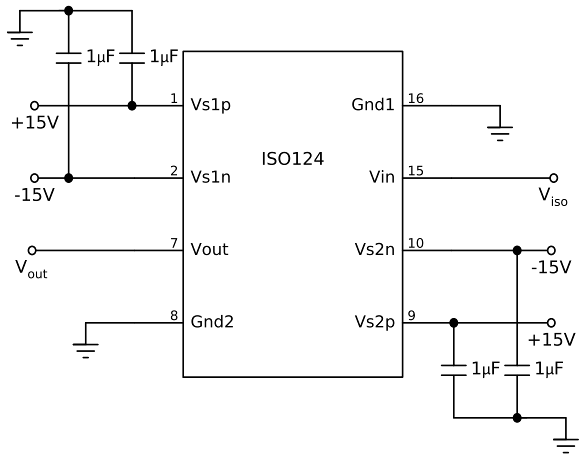

Figure 2.7: *Isolation Amplifier*

3 Conclusion

In this assignment, a simple ECG measurement system is designed. Its amplification is around 1000, output signal's frequency is between 0.05Hz and 150 Hz. It has input protection to protect amplifier circuit, as well as an isolation stage to protect human body. But, I have no idea about whether it works well in real situation.

References

[1] John G. Webster, *Medical Instrumentation: Application and Design 4th Edition*, 2009, ISBN: 9780471676003.

[2] http://www.medteq.info/med/ECGFilters

[3] http://www.ti.com/lit/ds/symlink/iso124.pdf

These papers and websites also give me lots of help to construct circuit and select elements.

[4] A.C. Metting van Rijn, A. Peper and C.A. Grimbergen, *High-quality recording of bioelectric events. Part 1 Interference reduction, theory and practice.*, Med. & Biol. Eng. & Comput, 1990, 28:389397.

[5] A.C. Metting van Rijn, A. Peper and C.A. Grimbergen, *The isolation mode rejection ratio in bioelectric amplifiers.*, IEEE Trans Biomed Eng., 1991, 38(11):1154-1157.

[6] http://archives.sensorsmag.com/articles/0199/iso0199/index.htm

External Files

I use Python with package SchemDraw to plot all circuits shown in this report. You can download package ScheDraw and learn how to use it on the website:
https://pypi.python.org/pypi/SchemDrawSchemDraw.

I use LaTex to create this document. The template of this report is downloaded from http://www.howtotex.com/, a blog that provides many kinds of LaTex templates and using skills.

In case you are interested, all source files of this assignment, including code for plotting circuits and LaTex file, can be downloaded on
http://quqixun.com/wp-content/uploads/2016/09/qixun-handin1.zip.