

A Double- electrodes Amplifier use for Portable ECG Equipment

Jiayu Zhu

Fan Gongxiu Honors College, Beijing University of Technology, Beijing, 100083, China

* Corresponding Author Email: zhujiayu@emails.bjut.edu.cn

Abstract. Wearable electrocardiogram (ECG) sensors is a simple test that can be used to check people's heart's rhythm and electrical activity. With individuals' increasing attention to their own health, developing a timely and portable bio-sensing recorder has become an urgent task. This paper presents the working principle of a common ECG signal recorder. A double-electrode voltage amplifier that can be used for portable ECG sensors has been set out to design. The amplifier is mainly composed of a differential amplifier circuit, which can lower power supply and power consumption. CoolSpice environment was utilized to simulate the circuit and analyze the result. The simulation presented that the common-mode gain is under 30dB up to 5KHz and the differential-mode gain is larger than 40 dB up to 5KHz. And the total current consumption has been under 20uA. The result demonstrated that the amplifier can perform well. The noise from human body has been eliminated by the amplifier. The amplifier has the ability to extract and amplify clean ECG signals and its structure has the characteristics of low cost and portability. It may be used in portable wearable ECG sensor technology.

Keywords: Double-electrodes Amplifier, ECG reader, CoolSpice environment, Sensor technology.

1. Introduction

With the development of social economy and the change of national lifestyle, the problem of residents' unhealthy lifestyle has become increasingly prominent. Especially the aging of population and the acceleration of urbanization process. The prevalence and incidence of cardiovascular diseases are continuously increasing. Cardiovascular disease is influenced by multiple risk factors. Adjustment of lifestyle and inhibition of risk factors can effectively delay or avoid the occurrence of cardiovascular events. Promotion of a healthy lifestyle and comprehensive management of the combined risk factors are key to improving the ability to prevent cardiovascular diseases[1]. In medical treatment and individuals' daily health detection needs, ECG has become an important indicator of people's health standards.

This paper presents and explains the working principle and operation processes of each part for ECG monitoring manufactured and the designing of a double-electrode ECG voltage amplifier. We use a differential amplifier circuit and use the gates of two transistors as input to get signals from the human body. The ECG signal is input as a differential mode signal and the noise generated in the human body is input as a common mode signal. The ultimate purpose of differential amplifier circuit is to amplify the differential mode signal and suppress the common mode signal. Compared with single-ended amplifier circuit, differential amplifier circuit has stronger anti-interference ability and can effectively suppress zero drift and common-mode signal[2].

Section II introduces the reading procedure and principle of electrocardiogram signal. Section III shows the basic structure and the circuit principle of this design. It also performs the results of reading analog ECG signals. In section IV, the double-electrode amplifier are compared with three-electrode amplifier based on its characteristics and performance. And put forward the existing shortcomings and the possibility of improvement.

2. Introduction of the ECG Signals' Reading Process

2.1. Input of ECG Signal

The input part of the ECG measurement device is responsible for feeding the human signal to the amplifier and reducing interference. Human signals are read through the epidermal electronic system which contacts to human body. The core integrated circuit of an epidermal electronic system consists of a microcontroller (MCU), RF memory (RFIC), analog signal conditioning (dual op amp) and charge regulator[3]. The most common method to read signals is placing small metal electrodes on the skin. And the micro-volt sized electrical activity from the sino-atrial node and heart muscle contractions that cause the heart pumping action can be sensed as electrical signals[4]. The input signal will be mixed with noise. In order to filter out the unwanted high frequency signals and screen out the human signals within the specified range, the input part is equipped with a low pass filter with a fixed cut-off frequency. Common RC high-pass filter circuits are show in Figure 1. The low-pass cutoff frequency can be calculated by the following formula :

$$f = \frac{1}{2\pi RC} \quad (1)$$

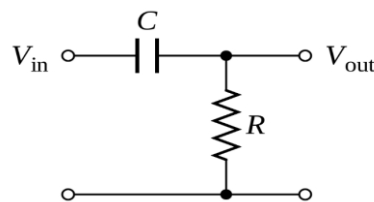


Figure 1. An example of RC high-pass filter circuits

2.2. The Amplification Process of the Signal

The amplifier part is the core of the process of reading the ECG signal. The human signal will be transmitted to the input ports of the amplifier after being sensed and processed by the input circuit. The amplifier consists of front-end amplifier circuit, voltage amplifier circuit and power amplifier circuit. The origin ECG signal changes very slowly. When the signals reach the pre-amplifier, they will be amplified high enough to drive the voltage amplifier circuit. And various interference will also be suppressed by the pre-amplifier. Then the signal can be sent to the voltage amplifier circuit. The ECG signal from the pre-amplifier is about 20mV and is too low to be transmitted to the post amplifier. After processed by the voltage amplifier which has high common-mode gain and difference-mode gain, the voltage of the ECG signal can be enhanced[5]. As the recorder requires a signal with sufficient current and power, after passing through the voltage amplifier circuit, the signal is sent to the power amplifier circuit to obtain sufficient current and power. Symmetrical complementary emitter output single end push-pull circuit the circuit works by the two output tube alternating work by turns.

2.3. Recording and Presentation of Electrocardiogram Signals

After the ECG signal is amplified, it will be conveyed into the ECG recorder. The ECG recorder is consist of a dial plate and tracer. The signal which has been amplified can drive the recorder's roller to rotate, which means the ECG signal is converted into mechanical motion. At the same time, a tracer fixed to the roller moves with the rotation angle. Then the recording paper can be presented with the image which is depicted by the tracer. And the image is going to be an ECG curve over the time.

While the tracer is moving, the electric paper moving circuit controls the movement of the recording paper[6]. The paper needs to move at a constant speed so that tracer's graph can be linear in time. This part is consisted of gearing, pilot circuit and paper moving machine. The speed at which the paper moves can be achieved by switching gears. The most frequently used speed can be 25mm/s and 50mm/s.

3. Design of The Double-electrodes Voltage Amplifier

3.1. Design of the basic structure of the amplifier

The portable ECG detection device should have simple structure and low cost. Different from the traditional electrocardiogram measuring equipment with three electrodes, the design in this paper adopts a double-electrode structure which is more convenient. By combining the reference electrode and the ground electrode, the ground electrode can pick up background noise just like the signal electrodes. The following explanation and design will be based on the two-electrode structure.

3.2. Simulation of the reading the signal process

In order to better show the working effect of the voltage amplifier, we set a human signal model with output ports at both ends to replace the signal provided by the input circuit(Figure 2). The human signal model is connected to the ground. Vmeter1 and Vmeter2 are the ports to check the human body signals.

The checking result are shown in Figure 3. According to the bottom two images, the signals directly acquired by the two input ports of the amplifier is irregular. This is because the ECG signal will be affected by the interferential noise of other signals in the human body. Since the ECG signal is very weak, other noise will become obvious influence on the measured results. The image on the top is the result of Vmeter1 - Vmeter2. We got an ECG signal with the noise removed. Sometimes the reference electrode and the ground electrode can be combined when the ground electrode is quite near to the signal electrodes. The ground electrode can pick up background noise just like the signal electrodes[7]. The different inputs of the amplifier can exclude the common background noise from the signal, hence, improving the signal-to-noise ratio (SNR).

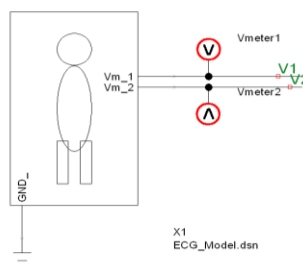


Figure 2. Detection circuit with human signal model as direct input

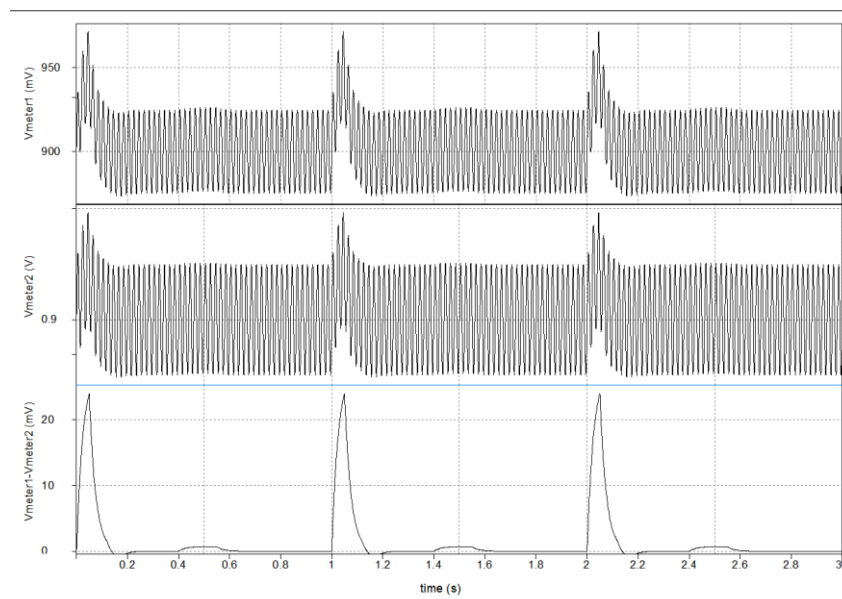


Figure 3. Transient run result of Vmeter1, Vmeter2, Vmeter1-Vmeter2

The results of Vmeter1 and Vmeter2 are both with noise. The noise had been offset during Vmeter1-Vmeter2 since the noise of Vmeter1 and Vmeter2 are the same. Vmeter1-Vmeter2 is the correct ECG signal.

3.3. Realization of differential amplifier circuit

The ideal effect we want to obtain should be shown as the bottom diagram of Figure 3. In order to extract the ECG signals efficiently and concisely in a portable detection device, we use differential amplifier circuit to achieve the effect of noise elimination. The differential amplifier is an electronic amplifier that amplifies the difference between two input voltages with a fixed gain. Figure 4 shows a differential amplifier circuit with simple structure. The ECG signals from the human body are input by the gates of N3 and N4. And the 50 Hz noise from the electrical power lines is a common-mode noise which is emitted by the human body. The differential circuit have two equal outputs. To compare with single-ended operational amplifiers, it can suppressing the output of the common-mode signal[8].

Figure 5 shows the simulation result of the circuit in Figure 4. The common-mode noise at Vmeter1 and Vmeter2 cancels each other out by the differential amplifier with a single-ended output.

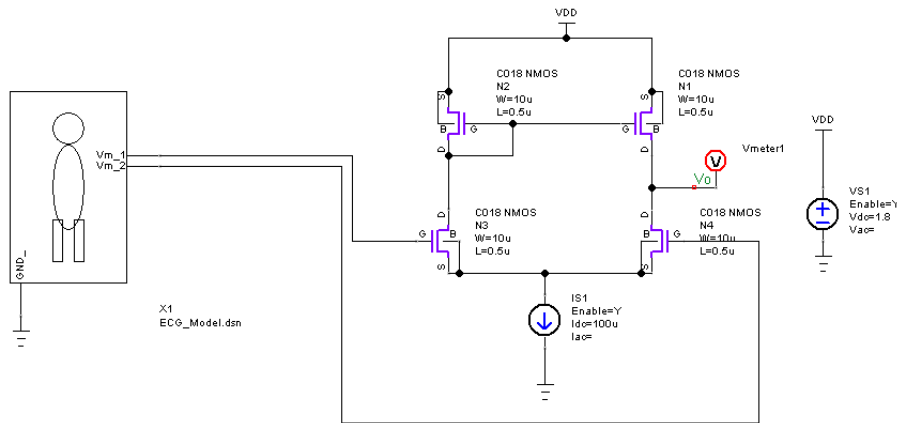


Figure 4. Circuit diagram of using differential amplifier circuit with the basic structure to detect the human body signals

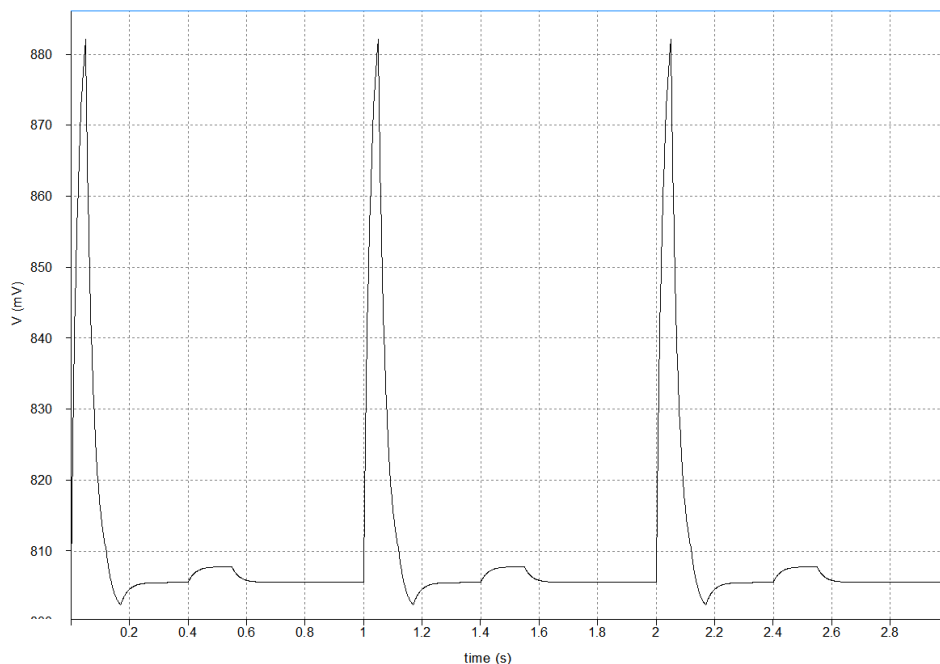


Figure 5. Simulation result of using differential amplifier circuit in Figure

The direct results obtained with differential amplifiers are the same as those obtained with Vmeter1-Vmeter2.

3.4. Design of voltage amplifier for ECG equipment with two stage structure

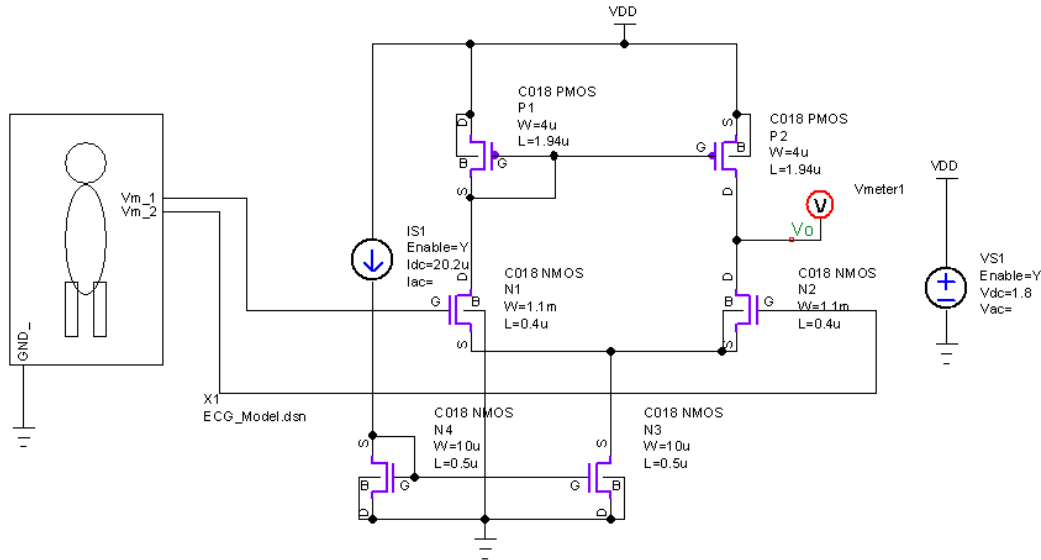


Figure 6. design of voltage amplifier for ECG equipment with two stage structure

During the operation of the circuit, each MOS transistor in the operational amplifier should be in its saturation region[9], which means the parameter of the transistors should meet the following condition:

$$V_{ds} > V_{gs} - V_{TH} \quad (2)$$

When the NMOS or PMOS device is in the saturation region, the operating point analysis function in circuit simulation is used to obtain the g_m , r_o and other parameter values of the NMOS or PMOS device in the saturation region, and then according to the expressions of g_m and r_o :

$$g_m = K \frac{W}{L} (V_{GS} - V_{TH}) = \sqrt{\left(2K \frac{W}{L}\right) I_D} = \sqrt{2\beta I_D} \quad (3)$$

$$\frac{1}{r_o} = g_{ds} = \lambda I_D \quad (4)$$

Then the estimation V_{THN} and V_{THP} can be obtained. Parameters were estimated using V_{THO} in BSIM model.

In the design of this paper (Figure 6), N3 and N4 are current mirrors which can control the output current. Provide a bias current of $20.2\mu A$ and adjust the aspect ratio of N3 and N4 to make the device work in the saturation region. Reduce the channel length modulation effect and improve the output

impedance. $I_{out} = \frac{\left(\frac{W}{L}\right)_{N3}}{\left(\frac{W}{L}\right)_{N4}} I_{bias}$. The total current consumption of this circuit should not exceed $20\mu A$.

P1 and P2 take the form of mirror current source as the active load of differential input tube to improve the voltage gain. The static operation point is reduced to about 0.9V by adjusting the value of $\frac{W}{L}$ of P1 and P2. Since the ECG signal needs a sufficiently high voltage value to be transmitted to the back-end amplifier, N1 and N2 are used to construct input-stage differential amplifiers. We adjust the $\frac{W}{L}$ of N1 and N2 to make the amplifier have sufficient common mode gain and differential mode gain. In this design, the common mode gain is under 30dB up to 5KHz and the differential gain is larger than 40 dB up to 5KHz.

By calculating the distribution voltage and I_d required by PMOS and NMOS transistors, the approximate value of $\frac{W}{L}$ can be estimated by using the relationship between I_d and $\frac{W}{L}$. Finally, by constantly adjusting the value of W and L of each transistor we get the parameters of each transistor as follows:

Table 1. The parameters of each transistor in this design

	W (Width)	L (Length)	W/L
P1	4u	1.94u	2.06
P2	4u	1.94u	2.06
N1	1.1m	0.4u	2500
N2	1.1m	0.4u	2500
N3	10u	0.5u	20
N4	10u	0.5u	20

3.5. Simulation results of the voltage amplifier for ECG equipment with two stage structure

Then check the common- mode gain and the differential- mode gain by using the alternating current running. By supplying the voltage source as 1.8v and the input voltage of N3 and N4 as 0.9v, when setting the input alternating current voltages as both 1V, the common- mode gain is under 30dB up to 5KHz as shown in Figure7 . When setting the input alternating current voltages as 0.5v and - 0.5v, the testing differential- mode gain is larger than 40 dB up to 5KHz in Figure8. And Figure9 shows the total current consumption has been under 20μA.

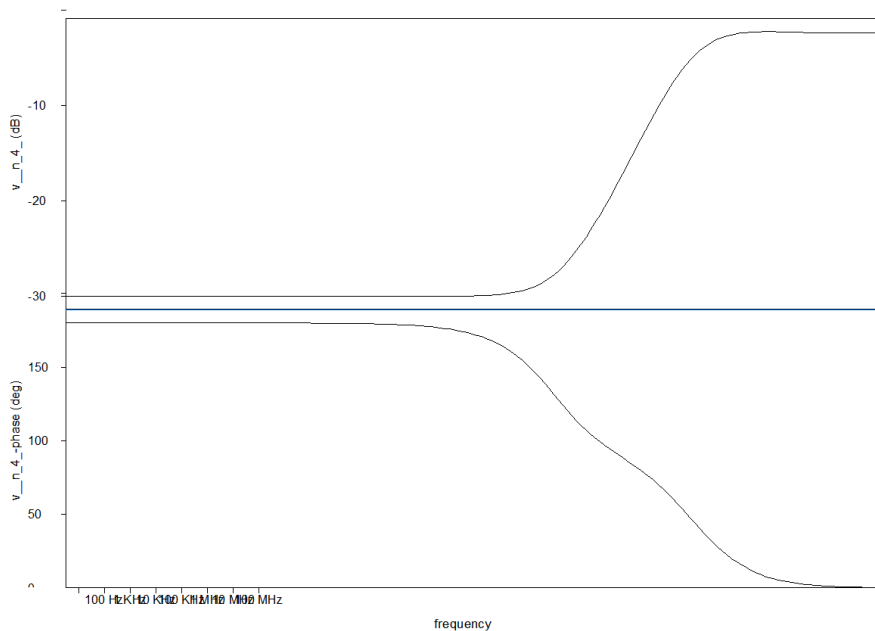


Figure 7. Bode plot and Phase margin plot of common mode

The top line represents the trend plot of common mode gain during AC simulation. The common mode gain increases with increasing frequency. The bottom line represents the phase margin plot, which decreases with increasing frequency.

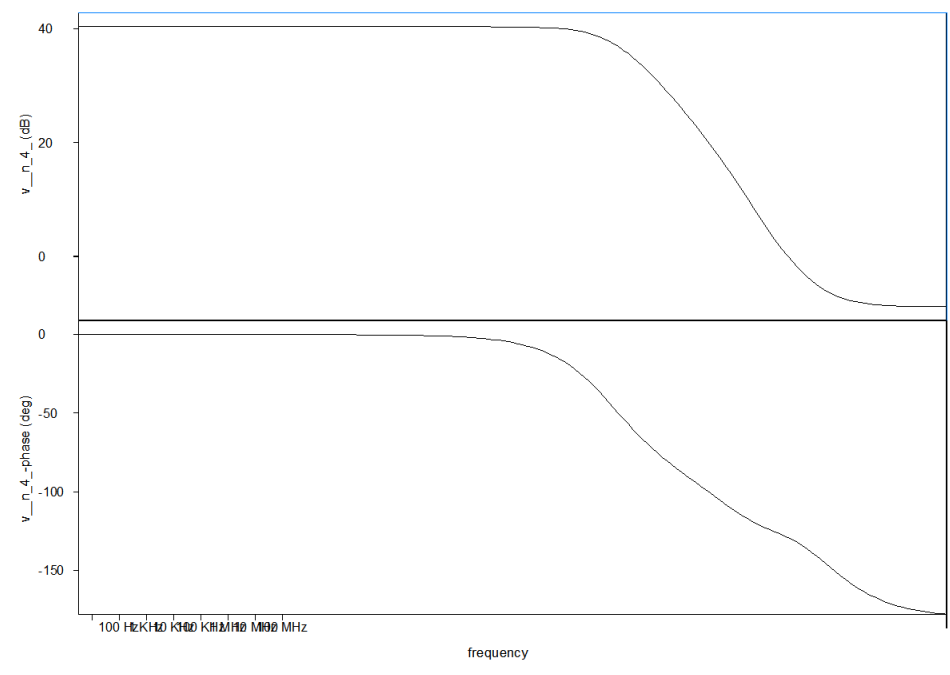


Figure 8. Bode plot and Phase margin plot of differential mode

The top line represents the trend plot of the time difference mode gain in AC simulation. The difference mode gain decreases with increasing frequency. The bottom line represents the phase margin plot, which decreases with increasing frequency.

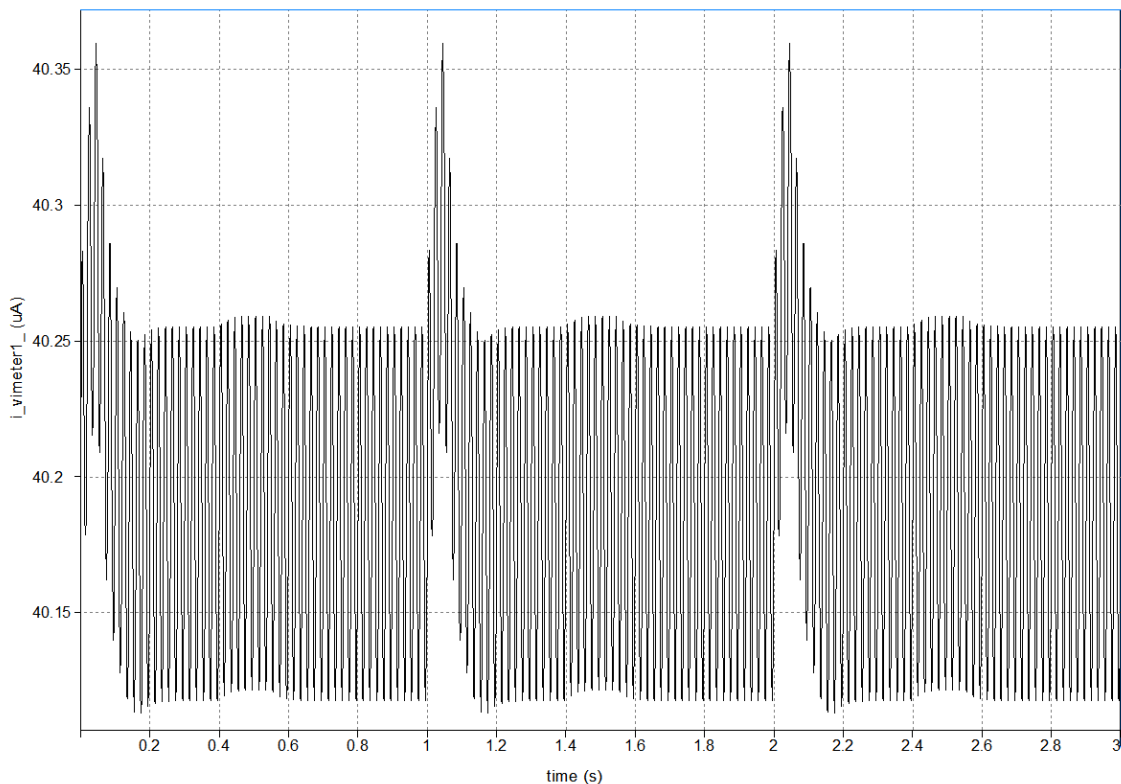


Figure 9. design of voltage amplifier for ECG equipment with two stage structure

Setting the supply voltage to 1.8V and connect the gate inputs of N3 and N4 to the human signal model. By using transient running, we got the signal voltage simulation results shown as Figure10. The static operation point is at 0.9V. Using the relation formula to calculate the voltage gain:

$$G_u = 20lg \frac{V_{OUT}}{V_{IN}} = 20lgAv \tag{5}$$

And the 50 Hz noise which plays the role of common-mode signal has been fully removed by the voltage amplifier.

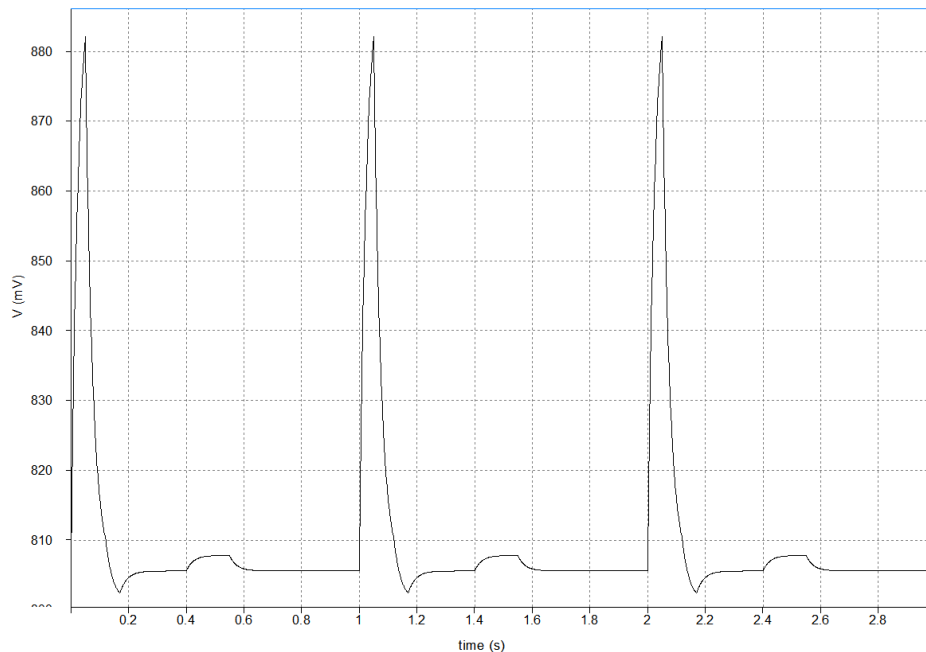


Figure 10. Simulation result of using the circuit in Figure to detect the ECG signal

4. Challenges and prospect

4.1. Challenges

For the consideration of convenience and cost performance, the design in this paper uses a double-electrode voltage amplifier. Compared with the three-electrode voltage amplifier, the ECG signal detected by this design is not accurate enough. It means that this design can not be used for precise medical treatment[10]. Under the condition of only use two electrodes, how to improve the measurement accuracy is the challenge we now face. We will do our best to study this issue.

The selection of transistor parameters in an amplifier is a complex matter. The reason lies in the diversity of system design requirements and the multiplicity of circuit configurations. In this design, in order to achieve the ideal gain and reduce the current consumption, the size of some transistors is too large. This is also a challenge for this design.

The design of this paper is a voltage amplifier. During operation, voltage amplifiers require high input impedance in order to match the sensor and do not have sufficient anti-interference capability. The bandwidth and sensitivity are limited by the capacity of the sensor line[11]. In contrast, the output voltage of the charge amplifier is proportional to the amount of input charge, and the SNR is high. This is also a challenge for this design[12].

4.2. Prospects

Portable wearable heart rate measuring devices are available to a wide range of people. Therefore, it requires lower cost to produce. Trends in the manufacturing process and design of integrated circuits will continue to provide users with lower price points, smaller packages, and improved performance. Although the two-electrode voltage amplifier cannot measure the signal accurately, it has greater portability and lower cost. During the process of measuring heart rate that don't require an exact electrocardiogram, the design in this article can completely meet the need.

For applications that require power from AA or nickel-metal hydride batteries, size and power consumption are of primary concern. When precision, low voltage operation and low power consumption are fully required, the 1 μ A supply current only needs to be powered by A single battery

for the precision amplifier to work[13]. The power supply current designed in this paper is 20uA. Later, the structure and parameters of this design can be adjusted to make the power supply current smaller. To reduce power consumption. In order to save power consumption, the amplifier product can also adopt intelligent shutdown circuit.

5. Conclusion

In this article, the working principle of ECG reader and differential amplifier circuit model are introduced. Aiming at the problem that the human body produces noise at about 50Hz that interferes with reading the ecg signal, a differential amplifier with two electrodes is established to eliminate interference signals. After adjusting the size parameters of NMOS and PMOS transistors, while reading the ecg signal, the 50Hz noise from the human body was successfully eliminated. Ecg shape and heart rate information can be successfully obtained. The amplifying circuit achieves the ideal common-mode gain and differential mode gain while keeping the total current consumption under 20uA.

In addition, according to the characteristics of the design structure, the reasons for the application of the amplifier in portable ECG signal measuring instrument are presented. The portability and low cost of this design are analyzed. Based on the comparison of the characteristics of two - pole amplifier and three - pole amplifier, the content that can be improved in this design is proposed. The proposed model can serve as a useful tool for portable electrocardiogram meter, such as software and hardware ECG signal processing systems.

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