Design of ECG Signals Filter Circuit Based on OTA Filtering

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Abstract. The ECG signal reflects the physiological characteristics of the heart to a certain extent and is an extremely important clinical reference for the diagnosis, treatment, and prevention of cardiovascular diseases. However, the ECG signal is affected by various noises during the acquisition process, especially the 50Hz noise from power lines which makes the diagnosis and analysis of ECG difficult. In this paper, a transconductance amplifier with strong practical applications is proposed and designed to filter out interference from ECG signals in power lines, based on the characteristics of ECG signals and the ability of differential signals to effectively resist external common-mode noise. This amplifier is able to effectively filter out 50Hz interference from power lines and features a high common-mode rejection ratio and low power consumption, in addition to using relatively few components and low production costs.

Keywords: Electrocardiograph (ECG) signals, operational transconductance amplifier (OTA), 50Hz power line interference

1. Introduction

The operational transconductance amplifier (OTA) is a transconductance type device. With the aid of the device's trans-conductivity gm, the output current is controlled by the input voltage. It is a voltage-controlled voltage source as opposed to ordinary operational amplifiers, which are voltage-controlled current sources (VCVS). OTA is frequently employed as a filtering tool since it outperforms traditional operational amplifiers in terms of gain and noise.

In recent years, the prevention and treatment of cardiovascular disease have received increasing attention in healthcare. The ECG signal reflects some extent the physiological characteristics of the heart and is of great clinical importance for the diagnosis, treatment, and prevention of cardiovascular disease. However, the ECG signal is affected by various noises during the acquisition process, and these noises make the diagnosis and analysis of ECG difficult and may lead to incorrect judgments in serious cases. This paper introduces the sources and characteristics of ECG signals and their interfering signals. Based on the characteristics of ECG signals, we propose and design a transduction amplifier with strong practical application to filter out the interference brought by power lines on ECG signals, using the characteristics of differential signals with strong anti-interference ability and effective resistance to common mode noise from outside. The simulation results before and after the addition of the amplifier to the human model were compared and analyzed to demonstrate that the designed transduction amplifier with high gain and low noise has a filtering effect and can eliminate power lines on the ECG signal to obtain a good ECG. In addition to this, the amplifier designed in this study tries to achieve the basic filtering requirements while minimising power consumption and

2. Background and basic principles of ECG

2.1. ECG waveform analysis

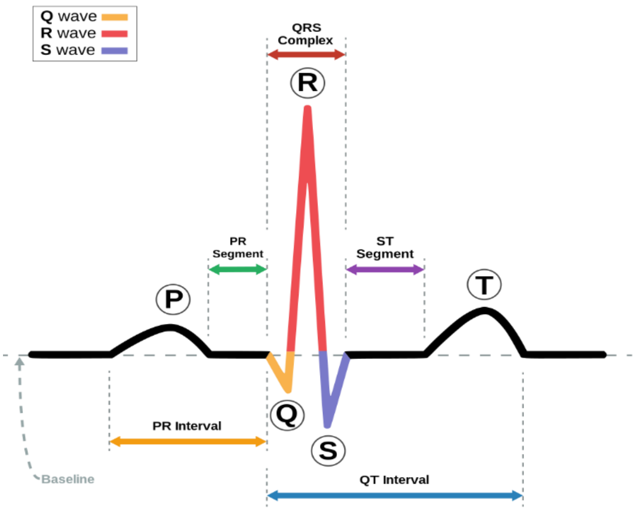

Figure 1. ECG waveform

Figure 1. shows atypical cardiac waveform cycle, which is used to give a brief overview of the individual ECG waveforms.

P wave: The electrical excitation mechanisms in the left and right atria are reflected in the P wave. Right atrium production dominates the first half, whereas left atrium production dominates the second. A healthy person's P wave has a maximum amplitude of 2.5mv and a breadth of no more than 0.11s.

P-R segment: After the P wave appears, the heart's excitation travels along the atrial muscle to the conduction system that passes through the atria and ventricles and down to the ventricles. The potential effect of the excitation through this segment of the conduction tissue is extremely weak, consequently, there is a window of time following the P wave but prior to the ventricular excitation during which no potential effect is produced, and this is called the P-R segment.

P-R interval: P-R interval on an ECG refers to the time between the beginning of the P wave and the beginning of the QRS wave group. An average PR interval lasts 0.1–0.2 seconds.

QRS wave groups: When the right and left ventricles to depolarize, QRS wave groups show variations in electrical activity. A descending Q wave, an upward R wave, and a downward S wave make up the three waveforms that make up a typical QRS wave group. The QRS time frame, which is the width of the complete QRS wave group, denotes the duration of the full ventricular myocardial excitation process, which in a healthy individual does not last longer than 0.1 seconds at most.

The S-T segment: The S-T segment is defined as the time between the end of the QRS wave group and the start of the T wave. A healthy person's S-T segment is near to the baseline and typically does not exceed 0.1 seconds.

T wave: T wave represents the effect of the potential generated during recovery from ventricular excitation. Normally the T wave is 0.1-0.25s in duration and should be oriented in the same direction as the main QRS wave group.

Q-T interval: The Q-T interval, which varies depending on age and gender, is the amount of time between the beginning of the QRS wave and the end of the T wave on the ECG.

2.2. Characteristics of the ECG signal

The ECG signal is weak, only at the millivolt level, and is easily affected by the environment. It has the same five characteristics as other biomedical signals: weakness, low frequency, high impedance, instability, and susceptibility to noise interference.

Weakness: ECG signal is a very weak bioelectric signal collected at a specific point on the surface of the human body, its normal amplitude is usually between 10uV-5mV, and in most cases, its amplitude is around 1mV.

Low frequency: The clinical diagnostic frequency range of ECG signals is usually 0.05-100Hz.

High impedance: the impedance of the human body is large, so the impedance of the ECG signal is usually several hundred to several hundred thousand ohms

Randomness and instability: ECG signals are subject to changes in the human environment and differences between individuals.

Vulnerable to noise interference: ECG signals are easily disturbed by the external environment during the acquisition process, making the new signal often mixed with noise interference signals.

2.3. The main sources of noise in ECG signals

The ECG signal is always affected by interfering signals when detecting the activity of the heart due to interference from the external environment, thus causing non-physiological changes in the ECG signal and making the ECG diagnosis more difficult. The four main types of ECG signal disturbances are baseline drift, I.F. disturbances, inotropic disturbances, and motion artefacts, and power line disturbances.

2.3.1 Baseline drift

Baseline drift during signal capture is mostly brought on by subject breathing, body movement, inadequate electrode contact, and skin electrode impedance. The electrolyte, electrode, skin, and body movement qualities all affect the drift's magnitude and duration. The baseline drift signal had low and gradual frequency shifts and an amplitude in the 0.15-2Hz range. ECG recordings under stress settings demonstrate an increase in the frequency of baseline drift due to an increase in breathing rate.

2.3.2 Industrial frequency disturbances

The ECG signal is usually disturbed by industrial frequency circuit interference or magnetic fields, which is mainly manifested in the ECG as a sine wave or a superposition of sine waves, usually with low amplitude. The frequency of the ECG varies from country to country; in China and the UK, the frequency of the ECG is mainly 50Hz, while in the USA and Korea, the frequency of the ECG is 60Hz.

2.3.3 Electromyographic interference and motion artefacts

Myoelectric disturbances and motion artefacts are caused by a range of physiological activities such as exercise or stress and are manifested on the ECG as irregular, rapidly changing waveforms. Severe EMG interference and motion artifacts can cause the ECG signal to be completely overwritten by noise, making the ECG more difficult to diagnose.

2.3.4 Power line interference.

Power line interference is a narrow band noise with an amplitude of up to 50% of the peak-to-peak amplitude of the ECG. It is centered at 50/60Hz and has a bandwidth of less than 1Hz. Severe structural noise can lead to distortion of ECG morphological properties such as the amplitude, duration, and form of the low amplitude local waves of the ECG signal because the low-frequency noise component of the power line mixes with the frequency content of the ECG signal. P-wave distortions in particular may result in an inaccurate atrial arrhythmias diagnosis.

3. Experiment of OTA filtering

3.1. Circuit design of OTA

The characteristic of ECG signal is that the signal is very weak, which needs to be amplified by more than 1000 times before it can be detected. It has been observed that the ECG signal will be submerged in the interference signal mainly at 50Hz. Only an amplifier with a very high common-mode rejection ratio can be used to detect the ECG signal. As a result, the features of the ECG signal served as the foundation for this paper's design, by using the characteristics of differential signal strong anti-interference ability and can effectively resist common mode noise from the outside world to design a good performance Operational Transconductance Amplifier (OTA) to meet the requirements of ECG signal detection, get a clearer and more accurate ECG Signal.

The experiments were performed on cool spice to simulate the removal of the 50Hz interference of ECG. First of all, a model to simulate the human heart activity was necessary to be created to provide the human model needed for the experiment to simulate the process of directly measuring the human ECG signal before adding the transduction amplifier (Figure.2), Vm_1 and Vm_2 two interfaces to simulate the two electrodes placed on the human body, respectively, in these two places to place the voltmeter Vmeter1 and Vmeter2 and transient analysis of the model. Second step is to design an OTA amplifier, which consists of a current mirror and a common source and common gate amplifier with a differential input stage, and connect the Vm_1 and Vm_2 interfaces of the simulated electrodes in the model to the two inputs of the differential amplifier. The two interfaces of Vm_1 and Vm_2 of the analog electrodes in the model are connected to the two inputs of the differential amplifier, and the two voltmeters Vmeter1 and Vmeter2 are removed.

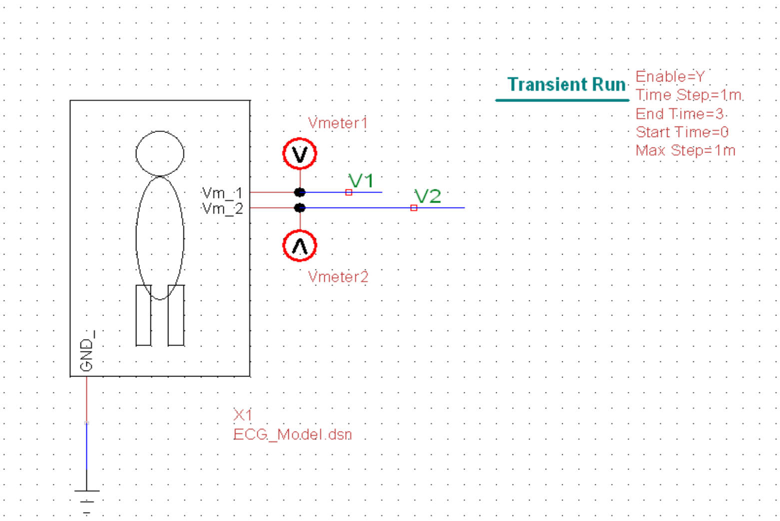

Figure 2. Human model

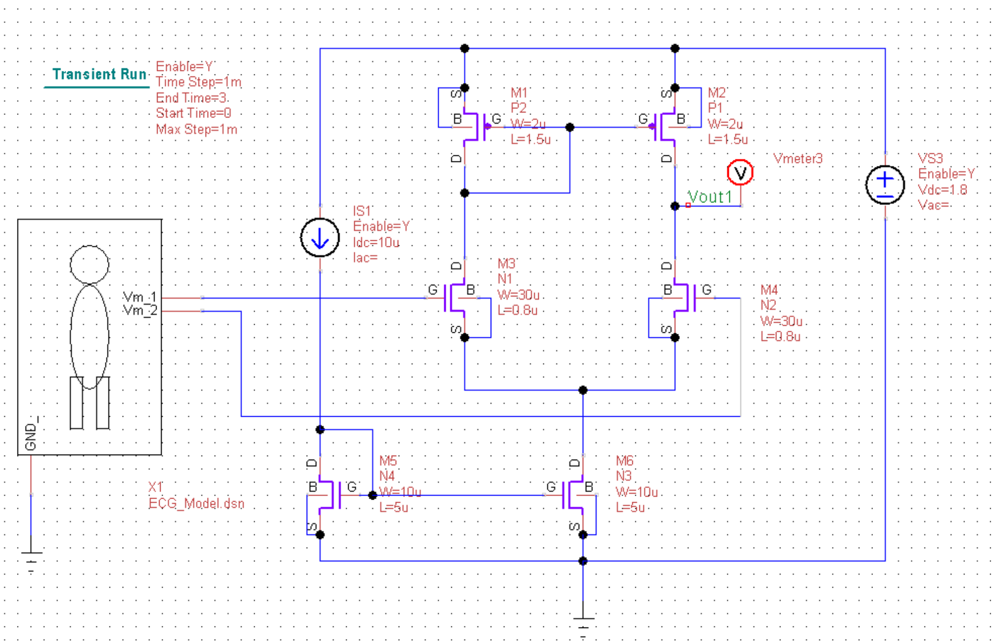

Figure 3. OTA amplifier

Differential mode voltage refers to the voltage difference between positive input and negative input, which is the effective component of the input signal, and the larger the amplification, the better, and the common mode voltage refers to the same phase voltage added to the two inputs, most of which are electromagnetic interference signals and need to be eliminated as much as possible. In the design of this paper, the differential mode gain is set to be greater than 40db in the 0-50kHz range, and the common mode gain is less than -30db. To detect the ECG signal. In order to maintain the low power consumption of the ECG system, the voltage source is 1.8 V and the total current consumption of the amplifier is less than 20 μA. The current mirror provides a stable bias current to the whole circuit. In order to control the overall current consumption not exceed 20μA, the current source on the right side of the figure (Figure.3) is set to 10μA, which provides the tail current to the differential amplifier. Based on the above conditions, the circuit is built and run in cool spice, and the transistor size is adjusted according to the results, and the results are as shown in Table.1.

Table. 1. Transistor size values

Transistor	M1	M2	M3	M4	M5	M6
Width	2d	2d	30μ	30μ	10μ	10μ
Length	1.5μ	1.5μ	0.8μ	0.8μ	58	58

3.2. Experiment simulation results and discussion

Figure 4 shows the ECG signal obtained by running the human model only, the orange and green curves show the change in V1 and V2 respectively, which is the graph of the voltage change measured by the two electrodes placed on the body. Using the calculator in cool spice simulates the differential amplifier to calculate V1-V2 to obtain a graph of the voltage change of the ECG signal without noise processing, the amplitude is around 20mV.

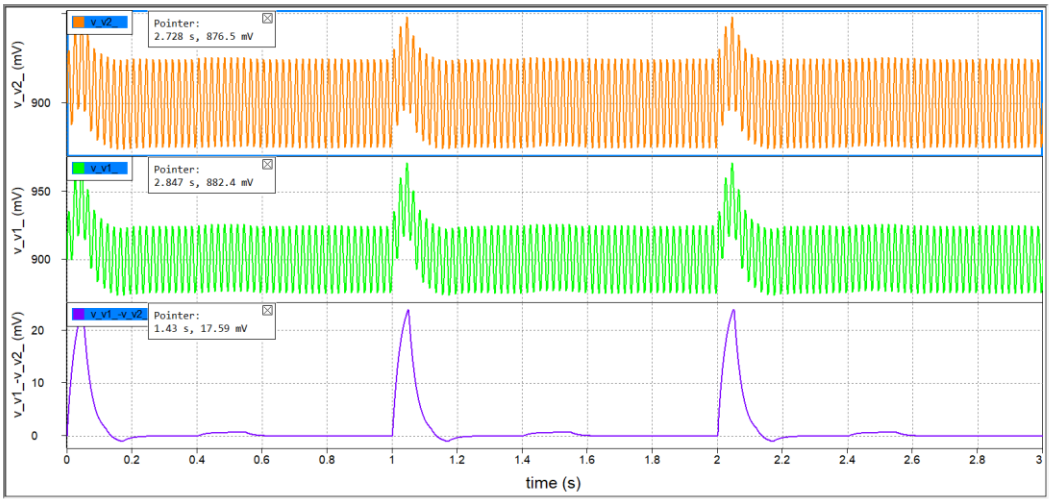

Figure 4. Human model ECG signal

Figures 5, 6, and 7 show the common mode gain, differential mode gain, and current consumption of the OTA respectively, all of which meet the conditions of the amplifier design. Figure 5 shows that the differential mode gain of the OTA is about 40db in the 0-50 kHz range, Figure 6 shows that the common mode gain of the OTA is about -40db in the same range, and Figure 7 shows that the total current consumption is about 13.3 μA. The performance of the designed OTA is depicted in the accompanying figure. As shown in Figure. 8, the addition of the OTA to the ECG signal can effectively amplify the ECG signal to the order of V, with an amplitude of approximately 1.7V, and almost eliminates the 50Hz interference signal.

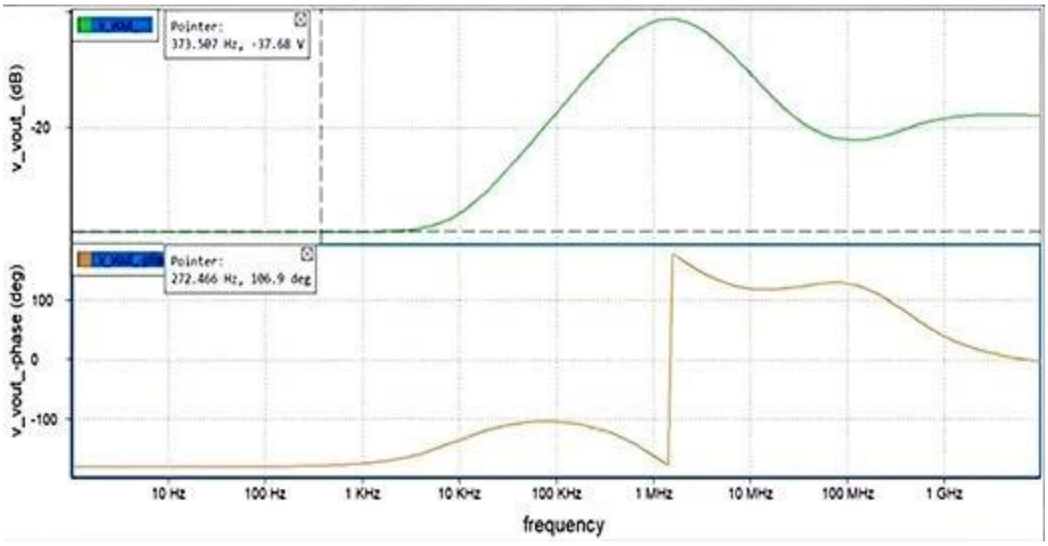

Figure 5. Common mode gain

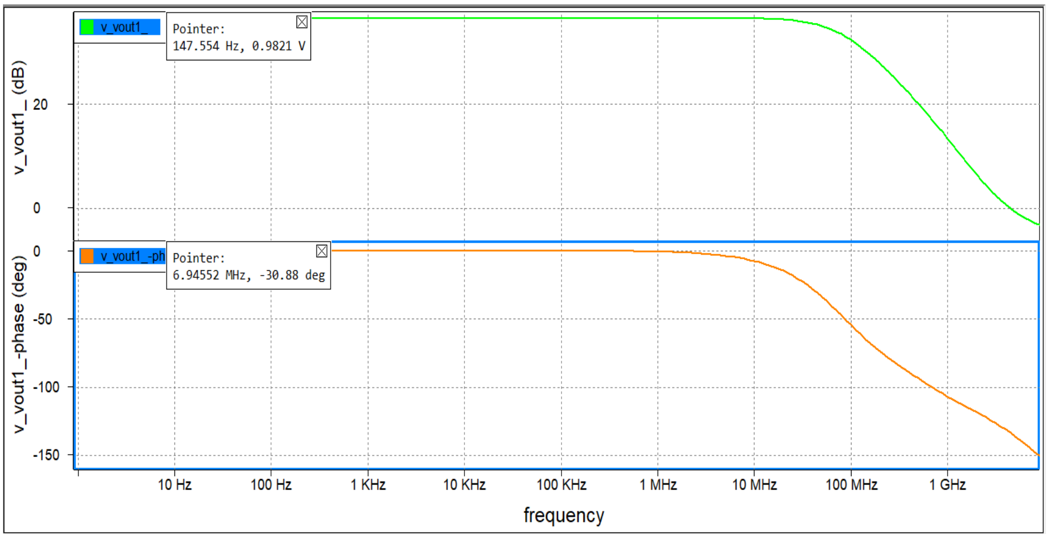

Figure 6. Differential mode gain

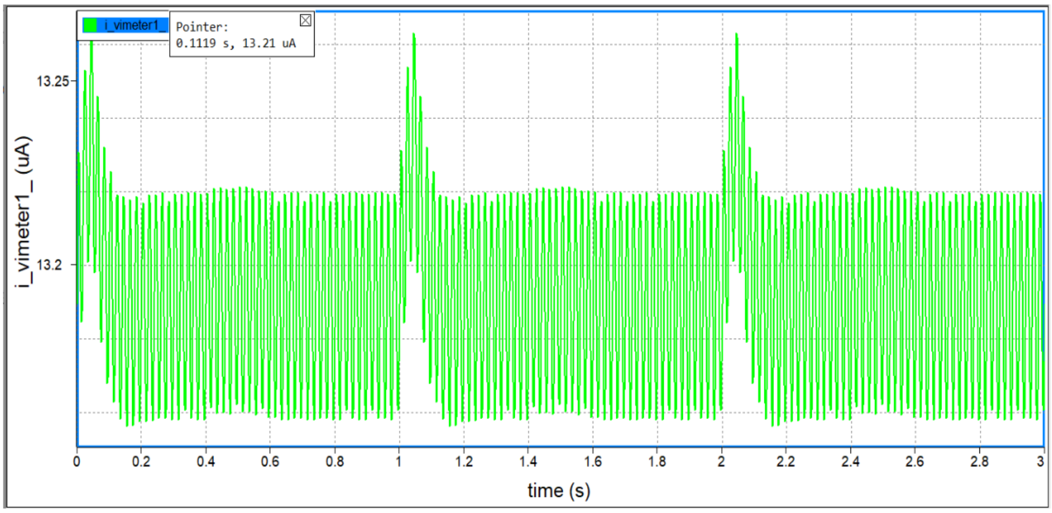

Figure 7. Current consumption<20μA

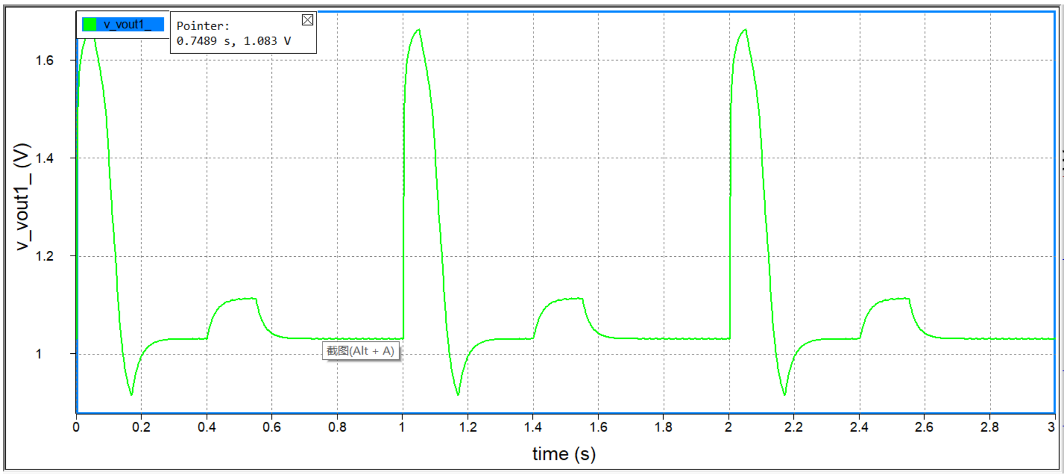

Figure 8. ECG signal without 50 Hz noise

4. Compare to other design and development

The current ECG amplifier in the majority of the design will contain five parts respectively, a preamplifier circuit, a common mode signal suppression circuit, high-frequency signal filtering circuit, a 50Hz trap circuit and the main amplifier circuit five parts, preamplifier circuit can amplify the weak ECG signal, common mode signal suppression circuit can eliminate the common mode voltage to improve the common mode rejection ratio so that the signal output quality The preamplifier circuit amplifies the weak ECG signal, the common-mode signal suppression circuit eliminates the common-mode voltage and improves the common-mode suppression ratio, which improves the signal output quality, and the high-frequency signal filtering circuit is connected afterward to protect the signal within 100Hz and filter out all the high-frequency signals outside 100Hz. This makes the ECG easier to observe. This complete amplification system is more detailed than the design of this paper, and each function of the amplifier is designed separately to achieve a better filtering effect while ensuring the amplified signal. However, the larger and more detailed design also brings problems such as high cost due to more circuit components, difficulty in mass production, and high-power consumption leading to relatively weak endurance of the ECG instrument, while the amplifier designed in this experiment can achieve the basic filtering requirements while minimizing power consumption and production cost.

With the continuous phalanx of science, ECG has gradually become an important role in the medical field that cannot be ignored. After entering the 21st century, ECG gradually adopts digital signal processors as the core of processing, with powerful computing power and processing ability to process ECG signals, eliminating a large number of analogue hardware circuits; and with the depth of low-power technology, future ECG instruments may greatly extend the working time, and most likely It is possible to integrate other physiological parameters monitoring in the dynamic ECG monitoring system to achieve a multi-use situation. The future direction of development is likely to be closer to telemedicine, i.e., remote monitoring of patient conditions, so that ECG devices can integrate amplifiers, filters, analogue-to-digital converters, and wireless communication modules on a single chip, and the collected ECG data will be sent in real time to a storage center connected to the network, which can be used by medical experts for diagnosis.

5. Conclusion

This study is based on the properties of ECG signals, using the characteristics of differential signals with high immunity to interference and effective resistance to common mode noise from outside, to propose and design a good performance operational transconductance amplifier (OTA) suitable for eliminating 50Hz power line interference from ECG signals, comparing the simulation results before and after adding the amplifier to the human model, thus illustrating that the designed OTA amplifier can substantially amplify the weak ECG signal from the original 20mV to about 1.7V with a guaranteed low current consumption of about 13.3uA, and can almost filter out the 50Hz signal from the power line, resulting in a clearer and more accurate ECG to meet the requirements of ECG signal detection and to obtain a clearer and more accurate ECG signal.

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