Simulation Analysis of ECG Denoising Based on Common Mode Feedback Technology

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Abstract. In the global health field, cardiovascular disease has become a major public health problem, early and accurate diagnosis is critical to saving lives, and electrocardiogram (ECG) as a widely used non-invasive diagnostic tool, its signal quality directly affects the diagnostic accuracy. However, the actual ECG signal acquisition is often affected by the internal noise of the organism, the thermal noise of the equipment and the electromagnetic interference of the environment, which leads to the deterioration of signal quality. Therefore, this study focuses on effective methods to suppress the noise of human ECG signals, especially a noise reduction solution based on common mode feedback technology is proposed. In this paper, the importance of ECG signal and the problem of its susceptibility to noise are discussed, which highlights the urgency of using circuit noise reduction technology. Then, the principle of common-mode feedback technology is analyzed deeply, and its superiority in eliminating common-mode noise and enhancing signal-to-noise ratio is revealed. By establishing a simulation model, the differential noise reduction circuit based on load current mirror is simulated by Coolspice software, and the effect of ECG signal noise reduction under simulated noise environment is simulated. The simulation results show that the noise component in ECG signal can be significantly reduced and the signal quality can be effectively improved by using the load current mirror to provide a more accurate and reliable basis for the subsequent ECG data analysis.

Keywords: Common mode feedback technology; eliminating; ECG; common mode noise.

1. Introduction

Worldwide, cardiovascular disease has become one of the leading causes of death threatening human health, and early detection and accurate diagnosis are essential to reduce mortality [1, 2]. Electrocardiogram (ECG) is a non-invasive and widely used diagnostic tool for cardiovascular diseases, and its signal quality directly affects the accuracy of disease identification and evaluation [3]. However, in the actual ECG signal acquisition process, the original ECG signal is often seriously polluted due to the endogenous noise of organisms, thermal noise of electronic equipment and environmental electromagnetic interference, which reduces the reliability of diagnosis.

In this paper, a noise reduction method based on common mode feedback technology is proposed to solve the problem of noise interference in human ECG signal. Firstly, the importance of ECG signal and the influence of noise on signal detection and analysis are emphasized, and the necessity of using circuit noise reduction technology is clarified. Secondly, the technical principle of common-mode feedback and its advantages in suppressing common-mode noise and improving SNR are introduced in detail. By building a simulation model, Coolspice software is used to simulate and analyze the proposed differential amplifier circuit to simulate its noise reduction effect on ECG signal under simulated noise environment. The experimental results show that the differential amplifier circuit can effectively filter out the noise in the ECG signal and improve the signal quality. This study provides theoretical support and technical reference for the realization of high precision and low noise ECG signal acquisition.

2. ECG Signal

2.1. Characteristic

The human electrocardiogram (ECG or EKG) signal is an important bioelectrical signal that measures the electrophysiological activity of the heart, and its characteristics can be summarized as follows: The human electrocardiogram (ECG) signal is a weak and important bioelectrical signal, its amplitude is usually between 0.05 and 5 millivolts, reflecting significant low-frequency characteristics, the frequency range is roughly 0.05 to 100 Hz (weak), which includes the key waveforms representing the electrophysiological activity of various parts of the heart [4]. Such as P wave, QRS complex wave and T wave (low frequency). The generation and expression of the signal are affected by a variety of physiological factors, showing obvious instability and non-stationary randomness, that is, the signal will change with the individual physiological state, emotional changes, breathing rhythm and other factors in real time, without constancy. (Instability and non-stationary randomness) In addition, through the simultaneous recording of multiple leads, the full picture of the electrical activity of the heart can be revealed from different angles, for example, the standard 12-lead ECG can reflect the electrophysiological differences in different areas of the heart. It is worth noting that the waveform structure of the ECG signal is rich in characteristics, each waveform corresponds to the different stages of the heart, at the same time, with the increase of age, the characteristics of the ECG will also undergo corresponding physiological changes, thus reflecting the aging process of the heart structure and function. Overall, the unique nature of electrocardiogram signals makes it a powerful tool for evaluating cardiac function and diagnosing cardiovascular disease, and plays a key role in clinical medicine, health management, and bio signal processing. The waveform of human ECG signal is shown in figure 1 [5].

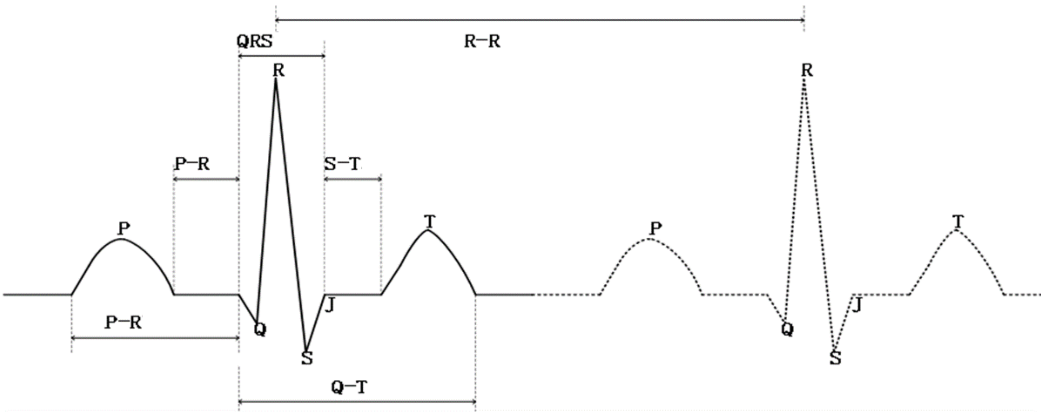

Fig. 1 Waveform of human ECG signal [5]

2.2. Noise generation

The main cause of generating power frequency noise in human electrocardiogram (ECG) signals comes from the 50Hz or 60Hz AC power supply in the power system [6]. This noise is introduced by several mechanisms:

Electrode impedance interference: When recording an ECG, the contact impedance between the surface electrode and the skin may not be ideal, especially if the skin surface is oily, sweaty, dry, or dirty, and the electrode impedance can increase significantly. The high-impedance connection is easy to sense changes in the electromagnetic field of the surrounding environment, especially the power frequency electromagnetic field with low frequency and high intensity.

Ground circuit interference: If the ECG device itself is not well grounded or a poor ground circuit is formed between the patient and the instrument, it will also lead to power frequency interference coupled into the measurement circuit.

Cable induction: When the lead wire used to connect the electrode and the ECG machine is surrounded by an AC magnetic field, it can be used as an antenna to sense a 50/60Hz AC voltage, and then introduce these power frequency signals into the ECG signal.

Power leakage current: If the ECG machine or other medical equipment internal power supply is not properly designed, there may be power leakage current, this part of the current may also contain power frequency components, thereby contaminating the original ECG signal.

3. Basic principles of common mode feedback technology

Common-mode feedback is a negative feedback mechanism widely used in analog circuit design, which is mainly used to suppress and control the common-mode voltage at the output of amplifier or differential amplifier. A common-mode signal is a signal that is added to two inputs at the same time and has the same amplitude and phase. It is not the type of signal that we usually want to amplify, but often comes from noise, power fluctuations or other unexpected sources of interference.

Common-mode feedback is a key strategy in analog circuit design, especially in differential amplifiers and high-precision signal processing systems. The following is mainly to explain its principle

3.1. Principle of common mode signal and common mode feedback

In electronic circuits, especially in the design of differential amplifiers and data acquisition systems, a common-mode signal refers to the average voltage between two inputs or outputs to ground. The existence of common mode signal will bring noise interference, distortion and other problems, which will seriously affect the circuit performance. To counteract this effect, designers often introduce common-mode feedback mechanisms into the system.

Common-mode feedback is a technique that maintains a constant or expected value by detecting and controlling common-mode signals in a circuit. It works by building a closed-loop control system. The system senses changes in the common-mode voltage at the output and generates an opposing regulatory signal that drives the internal bias network or power level element to pull the common-mode voltage back to the preset ideal state. This negative feedback ensures that the circuit can maintain stable common-mode performance under various operating conditions. The basic difference pair is shown in figure 2 [7].

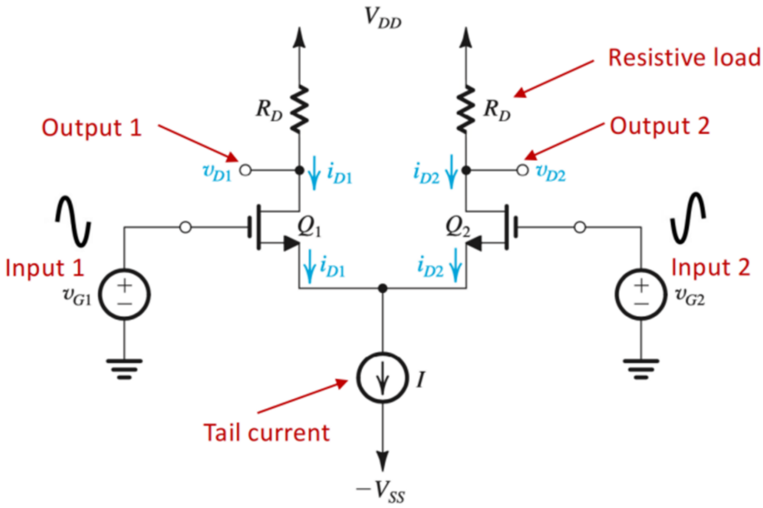

Fig. 2 Basic difference pair [7]

The common mode feedback basic circuit is shown in figure 3.

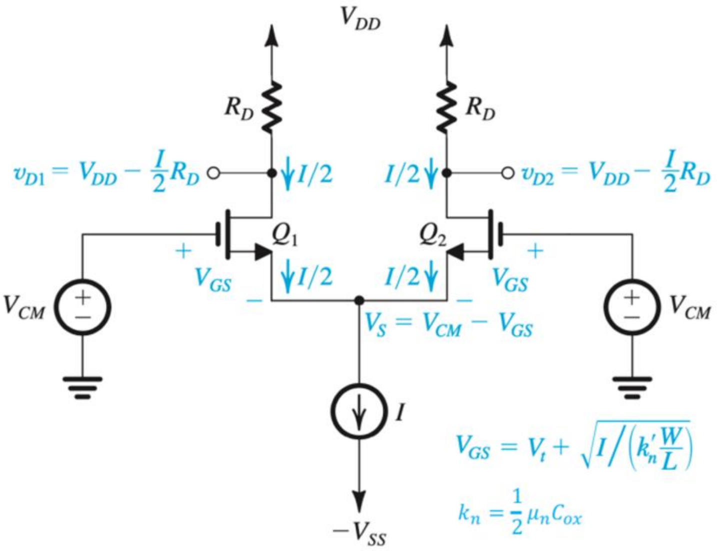

Fig. 3 Common mode feedback basic circuit [7]

3.2. The basic structure and operation process of common mode feedback circuit

A common-mode feedback circuit usually consists of several key components: a common-mode detector (or sensor), an error amplifier, and an actuator.

Common mode detector: Located at the output, by sampling the output signal and processing it in a specific way (such as using a resistance divider or a trans-resistance amplifier, etc.), the common mode component is extracted and converted into a quantifiable electrical signal [8].

Error amplifier: Receives the signal from the common-mode detector and compares it to a reference or set reference voltage. If the actual common-mode voltage deviates from the ideal value, the error amplifier generates an error signal proportional to the deviation.

Actuator: After receiving the control signal output by the error amplifier, it performs the corresponding action to adjust the internal parameters of the circuit (such as bias current, supply voltage, etc.) in order to return the common mode voltage to the expected value. The actuator can be a current source that directly changes the operating point of the transistor, or it can indirectly adjust the common-mode response of the circuit through some form of voltage control.

3.3. The key role of common mode feedback on noise suppression and accuracy improvement

In electronic systems, especially analog signal processing circuits, noise is one of the important factors affecting systemic energy. The noise can be derived from the power supply, the environmental electromagnetic interference, the internal noise of the device, and it is often coupled to the signal path in the form of common mode. The common mode feedback technique has a significant effect on the suppression of these noise and the accuracy of the high system.

3.3.1 Noise suppression

Power noise suppression: the power noise is usually represented as a common mode, which is directly added to the output of the difference amplifier. By introducing the common mode feedback mechanism, it can monitor and adjust the common mode voltage of the output, effectively offset the influence of the power fluctuation, and thus increase the power supply suppression ratio (psrr) [9].

Ambient electromagnetic interference suppression: external electromagnetic interference often leads to changes in common mode voltage. Good common mode feedback can respond quickly to this change and suppress it in the acceptable range to reduce the sensitivity of external noise sources.

Internal noise control: the thermal noise of the device itself and the flashing noise can also affect the common mode signal. The dynamic adjustment of the circuit parameters can reduce the effect of these internal noise on the output signal quality.

3.3.2 Precision hoisting

Linear improvement: effective common mode feedback helps to maintain the input level of the difference amplifier or data converter in the online area, thereby improving the linearity of the system and the total harmonic distortion performance.

The noise ratio is improved: because the common mode feedback can stabilize the common mode voltage, reduce the degree of noise and the mixing of the useful signal, and make the system signal-noise ratio significantly improved [10]. Higher signal-to-noise ratio means clearer, accurate data transmission or signal detection capabilities.

Measurement precision optimization: in high precision measurement applications, such as medical equipment, tester instrument, etc., common mode feedback can ensure that the system is not disturbed by the noise of the common mode, and the results of the higher precision are achieved.

In conclusion, the common mode feedback is one of the core technologies of modern simulation and hybrid signal circuit design, and the performance and long-term stability of the system in the noise environment are greatly improved by the fine regulation circuit, which provides a solid guaranteed basis for high-speed signal processing. The difference amplifier of simple single is designed to complex high-speed data transmission system, the application of common mode feedback is everywhere, and its design concept and technology approach as the progress of science and technology evolve and improve.

4. Analysis of modeling and simulation results

4.1. Parameter setting and modeling

Modeling: First, the 50Hz noise generated by the wire is known to be common mode noise, so consider building a MOS differential pair circuit; In the second step, in the acquisition, filtering and amplification of the ECG signal, two circuits are used to measure the parameters of the ECG signal. Circuit A uses the operational transconductance amplifier (OTA), connects the ECG signal with the operational transconductance amplifier, collects the ECG signal to obtain the waveform diagram and measures the gain effect of the design circuit. Circuit B is used to test the filtering effect of the design circuit. The current mirror is used to replace the ideal current source, adjust the transverse and longitudinal ratio of NMOS tube and PMOS tube, and build the MOS differential pair circuit of the load current mirror. Then, the ECG signals at the input voltages V1 and V2 of the connected circuit B are changed to ideal voltage sources VS2 and VS4, and the common-mode gain and differential mode gain are measured by adjusting the voltage parameters of ideal voltage sources VS2 and VS4, respectively.

Parameter setting: The drain voltage (VDD) of the MOS transistor is uniformly set to 1.8V ground in the illustrated circuit. In circuit A, the w of PMOS tube and NMOS tube is set to 10u, L is set to 0.5u, and the ideal current source IS1 is set to 150u ground. In circuit B, the w of the PMOS tube is set to 10u, L is set to 1u, w of the NMOS tube is set to 40u, L is set to 1u, and the ideal current source connected to the current mirror is set to 150u. In the simulation measurement of common mode gain and differential mode gain, the voltage of the ground ideal voltage source VS3 is set to 0.9V. In the measurement of common mode gain, the voltages of VS2 and VS4 are set to 1V and -1V; In the measurement of differential mode gain, the voltages of VS2 and VS4 are set to 0.5V and -0.5V.

4.2. Analysis of simulation results

1.Inference: The application of common mode feedback technology can eliminate the interference of 50Hz common mode interference noise in the common circuit wire to the ECG human signal.

2.data analysis: According to the simulation results, the gain of the design circuit A for the ECG signal is about 777. The figure 4 is the waveform of ECG signal after noise reduction.

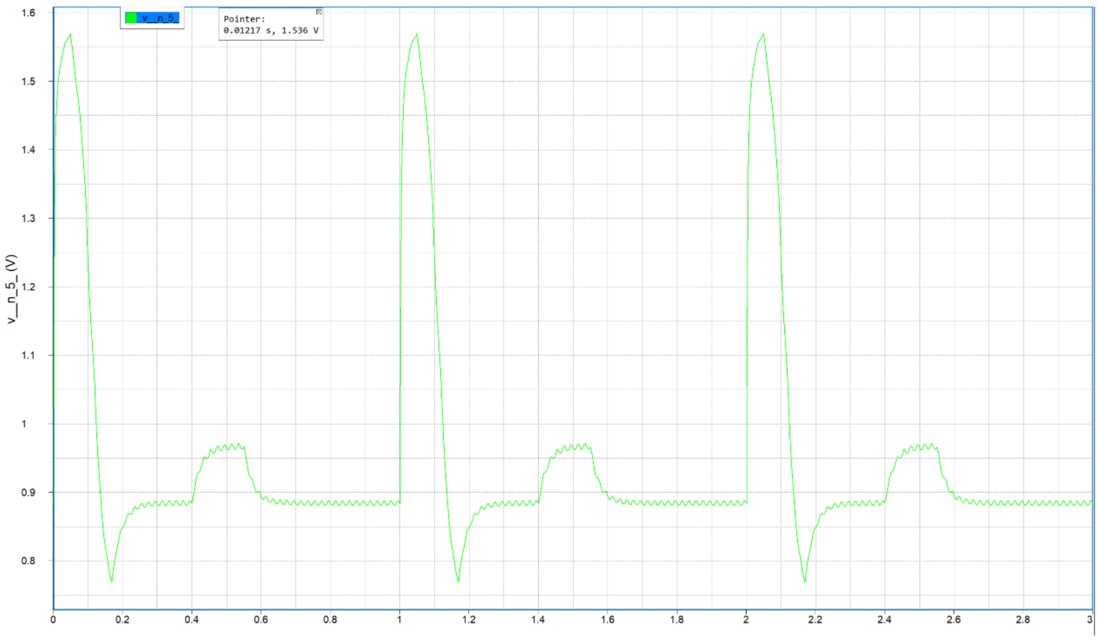

Fig. 4 Waveform of ECG signal after noise reduction (Photo/Picture credit: Original)

The design circuit is still less than -30db for a common mode gain in the band of 5kHz which is shown in figure 5.

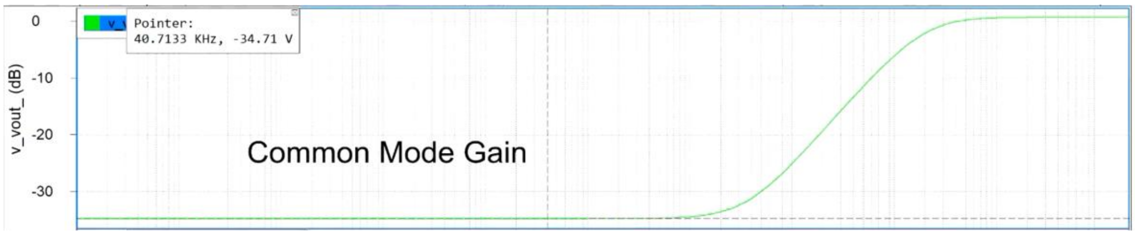

Fig. 5 Common mode gain (Photo/Picture credit: Original)

The design circuit is still greater than 40db for the differential mode gain in the band of 5kHz which is shown in figure 6.

Fig. 6 Differential mode gain (Photo/Picture credit: Original)

5. Conclusion

In this paper, the characteristics of ECG signals and the generation of related noise in human ECG are introduced. Secondly, the principle of common mode feedback technique used for noise reduction and ECG signal processing is introduced, and the basic circuit of common mode feedback technique principle and related calculation formula are shown. Finally, according to the written idea of modeling simulation analysis, in the process of simulation experiment, the differential pair noise reduction circuit of the load current mirror is constructed to reduce the noise of the ECG signal, and the ideal voltage source is connected to verify its common mode gain and differential mode gain effect. The simulation results show that the differential pair of load current mirror has a remarkable effect on the noise reduction of ECG signals.

In practice, the use of load current mirror differential circuit to denoise ECG signals faces many challenges. The primary challenge is that although this circuit structure is good for suppressing common-mode noise, it is susceptible to power supply fluctuations, temperature drift and other factors, and requires careful design to ensure noise suppression performance. At the same time, the need for high gain amplification and signal bandwidth must be balanced in order to fully preserve the high-frequency details of the ECG signal. Especially in low-power portable devices, how to reduce energy consumption while ensuring high performance is a key task. In addition, there is a need to focus on biocompatibility and miniaturization design, so that the circuit is suitable for direct contact with the human body and easy to carry.

Looking forward to the future, with the development of new semiconductor technology and materials, it is expected to improve the anti-interference of the circuit, expand the bandwidth and reduce the power consumption, and deepen the application of load current mirror differential to the noise reduction of the ECG signal. Under the trend of integration, a variety of functions (such as preprocessing, filtering, and amplification) may be integrated into a single chip to achieve an efficient and integrated ECG signal acquisition system. At the same time, combined with the hardware and algorithm collaborative design, the initial noise reduction in the hardware stage, combined with subsequent digital signal processing technology, improve the detection accuracy and energy saving effect. Finally, with the help of Internet of Things technology, this type of circuit is expected to promote the development of miniature wireless ECG monitoring equipment, achieve real-time remote ECG signal monitoring, and bring innovative breakthroughs for cardiovascular disease prevention and treatment.

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