A Balanced OTA ECG Amplifier and Its Development Directions

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Abstract. Electrocardiograph (ECG) is a technology that uses an electrocardiograph to record the electrical activity change pattern generated by each cardiac cycle of the heart from the body surface. It is a simple test that can be used to check heart's rhythm and electrical activity of human. The amplifying and filtering of the ECG signal is the most important part of ECG signal procedures and this paper shows a balanced OTA that can fully remove the 50hz noise from the power line. Due to cost performance for the real situation in the hospital and industrial cost, the balanced OTA filter in this paper is simple and cannot guarantee a long stable use when it is implemented on an ECG machine with other models. This paper will show two different ways to increase gain and power efficiency which are using fully differential OTA and using higher bandwidth.

Keywords: Ecg, Ota, Denosing, Development

1. Introduction

The Electrocardiograph (ECG) is widely used in many fields, it is a test that record the heart rate. ECG signal is of vital importance in medical use, especially in first aid. Also, it can be used in the smartwatch or other motion detection equipment used to capture heart rate to avoid heart attack and record workout performance. Usually, the ECG signal has a 50hz noise from the power line which make it hard to record the characteristic waveforms. The balanced operational transconductance amplifier (OTA) can be an ECG signal amplifier to filter the 50hz noise [1]. This paper shows the basic and normal ECG signal process procedures and a way of differential recording using a balanced OTA filter to denoise. The circuit and simulation are based on the Cool Spice using 0.18um CMOS which has a differential mode gain of 40v up to 5Khz and a common mode gain of -107v up to 5Khz and 18uA current consumption. The balanced OTA has many advantages it improves the power rejection ratio and the signal-to-noise ratio and overcomes the high-frequency distortion of an unbalanced structure. But it increases the power consumption at the same time. In that case, this paper shows some existing problems and two improvement directions that are using fully differential OTA and higher bandwidth. This circuit design has a profound studying significance and can be used in practical situations. It is a basic and economical way to denoise and process the ECG signal and has a promising design and improvement future with the development of CMOS technology.

2. ECG signal process

2.1. Introduction and application of ECG signal

The electrocardiogram (ECG), a basic test that can be used to monitor your heart's rhythm and electrical activity, employs an electrocardiograph to record the electrical activity change pattern generated by each cardiac cycle of the heart from the body surface. It is measured by applying electrodes to the skin and recording the electrical signal sent by the heart [1]. ECG is one of the most regularly utilized diagnostics in clinical evaluations. It has numerous applications, including Capture the electrical activity of heart; Assists in the diagnosis of arrhythmia, myocardial ischemia, myocardial infarction, and site; determining cardiac enlargement and hypertrophy; assessing the effect of medications or electrolytes on the heart; evaluating the artificial heart's pacing condition.

ECG is a weak physiological signal. Generally, the amplitude range of ECG is 10 UV ~ 5 mV. ECG signals belong to low-frequency signals, and most of the spectral energy is distributed between 0.05 and 40Hz [2]. The original ECG signal has a low signal-to-noise ratio, and it is influenced by

some interference during signal acquisition, including power frequency interference, baseline drift, and EMG interference. Power frequency interference is a kind of interference generated by the electrified system. It will act on the loop circuit between the lead and the human body in the form of electromagnetic wave radiation, so that sine waves and waveforms similar to sine waves appear on the pure ECG signal. The main frequency of the interference is 50Hz. The ECG form including industrial frequency interference is shown in Figure 1.

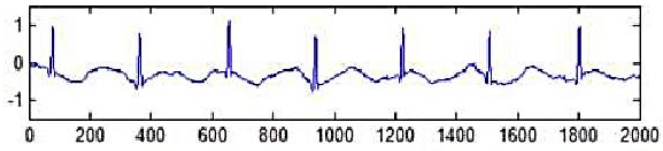


Figure 1. ECG with power frequency interference

This paper mainly emphasizes the elimination of industrial interference. This 50 Hz noise is a common-mode noise, hence can be removed by differential recording using an operational transconductance amplifier (OTA) as shown in Figure 2.

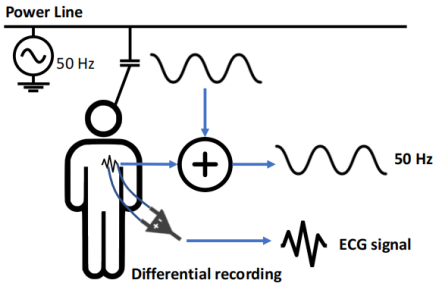


Figure 2. Use the differential recording to remove 50hz noise

2.2. ECG signal process procedures

2.2.1 ECG signal denoising

Because the ECG signal is collected through the human body surface, the collected signal inevitably has a lot of noise interference such as EMG interference, power frequency interference, and so on. Effective noise removal can pave the way for feature band extraction of ECG signals.

2.2.2 Extraction of the characteristic waveforms of ECG signals

Whether the characteristic bands as shown in Figure 3 (P wave, QRS wave, etc.) of ECG signal can be accurately extracted is very important for the next step of computer recognition. The researchers propose relevant algorithms based on the morphological characteristics of the bands that need to be detected.

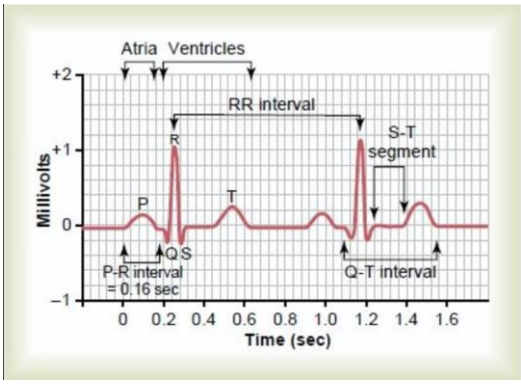


Figure 3. ECG signal characteristic bands

Full-wave detection is often usedby combining the wavelet transform and the rough set, for the multi-scale decomposition of ECG signals using quadratic spline wavelets as a basis function to

remove baseline drift, QRS, R, Q, S, P, and T. And based on the rough-set theory to get 5 approximate subtraction sets, classified identification of normal sinus signal, premature atrial beats, and premature ventricular beats. The identification rate is 96% and above [3]; the location of the R point was first determined by the differential algorithm, then use the maximum value to compare the Q and S positions. The maximum value in the search area was then obtained by region search to extract the P and T waves. This method extracted the QRS waveform from the MIT-BIH database with an accuracy of 99.3% and processed the actual collected ECG data with more than 92% accuracy. This method has the advantages of being simple, fast, high accuracy and small error, simple calculation and easy to implement, and is suitable as a real-time feature extraction method for ECG signals [4].

2.2.3 ECG signal compression, transmission, and recovery

There are a large number of ECG data in the hospital database, especially the dynamic electrocardiogram. Because it collects the ECG waveform of the patient for 24 hours or even longer, the storage of ECG data puts forward higher requirements for the equipment. In this regard, researchers have proposed effective solutions for the compression, transmission, and recovery of ECG data. These algorithms are roughly concentrated on machine learning algorithms. Among them, the block sparse Bayesian learning uses the random binary matrix to observe the ECG signal at the sensor node end. After transmission, the ECG algorithm is reconstructed by the transform matrix and the block sparse Bayesian learning in the sparse mode of discrete cosine transform. The ECG signals of the MIT-BIH heart rate anomaly database and the noise pressure test database are used for simulation experiments. The results show that the method improves the compression rate and helps to reduce transmission power consumption [5].

2.2.4 Classification of ECG signals, human identification

Accurately extracting ECG signals and distinguishing the different ECG signals corresponding to the human health and disease types is the basis of ECG automatic analysis. And in recent years, researchers have found that different people's ECG signals in the form of appearance seem to be roughly the same, but in fact, there are differences, so some people have conducted research in this area and found that different people's ECG signals can be used as a fingerprint between different individuals.

3. Circuit design

The circuit design and simulation of this paper are based on the Cool Spice simulator.

3.1. Balanced OTA circuit design

A standard balanced OTA model is shown in Figure 4. The Complementary Metal Oxide semiconductors used in this circuit are C018 NMOS 0.18um and C018 PMOS 0.18um with a supply voltage of 3.6v.

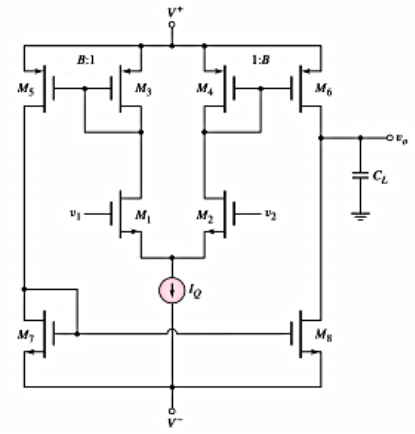


Figure 4. Standard balanced OTA model

The gain formula of this balanced OTA is:

$$A_d=Bg_{m1,2}(r_{o6}||r_{o8}) \quad (1)$$

Where Ad means the gain, gm is the transconductance of the MOS and r_{o6} and r_{o8} are the output impedance of the MOS and B is the width ratio of the two NMOS. And the relationship between gain and frequency is shown in Figure 5:

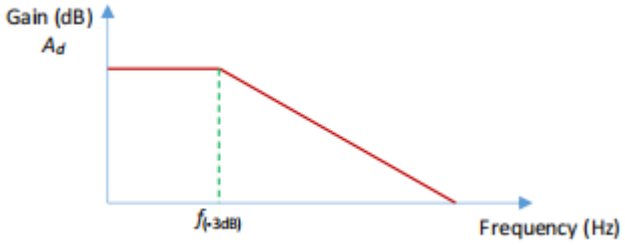


Figure 5. Relationship between gain and frequency

Where f(-3dB) is:

$$f_{(-3\,dB)}=\frac{1}{2\pi(r_{o6}||r_{o8})C_L} \quad (2)$$

Where C_L is the Load capacitance. When the frequency is less than the cutoff frequency, the gain does not change; when the frequency is greater than the cutoff frequency, the gain begins to decrease linearly.

This is an ECG amplifier using a balanced OTA as shown in Figure 6. The Complementary Metal Oxide semiconductors used in this circuit are C018 NMOS 0.18um and C018 PMOS 0.18um with a supply voltage of 3.6v. And the value of the capacitor is 10pF.

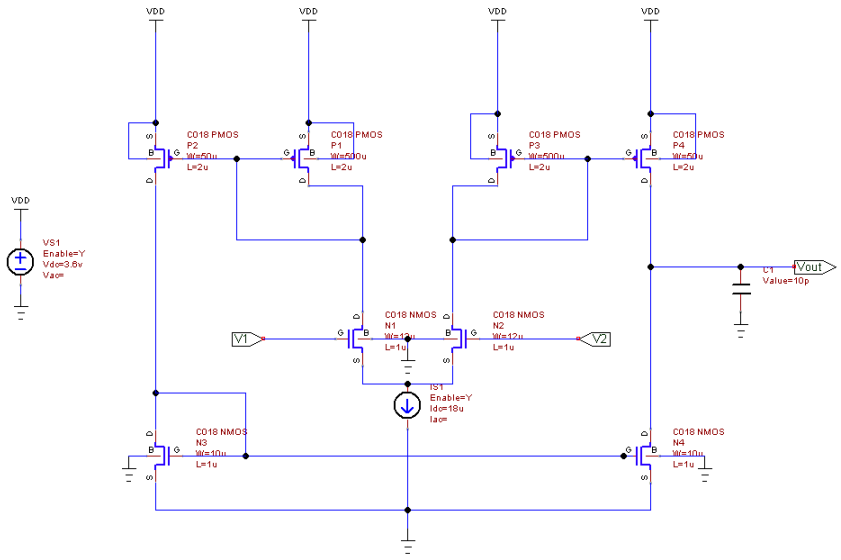


Figure 6. ECG amplifier circuit design

This is a balanced OTA filter, compared with simple OTA, it improves the power rejection ratio and the signal-to-noise ratio, and overcomes the high-frequency distortion of an unbalanced structure. But it increases the power consumption at the same time.

3.2. Simulation results

The simulation of this paper is based on the Cool Spice. These simulation results below are the results of the circuit in figure 7.

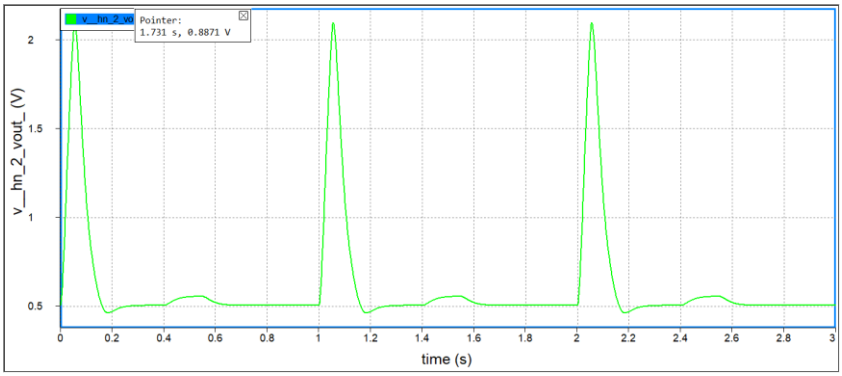


Figure 7. ECG signal after filtering

As shown in Figure 7 the 50hz noise from the power line is fully removed, and all the characteristic waveforms of ECG signals are clearly shown. The amplitude of the ECG signal is about 2v from 0.4v to 2.4v.

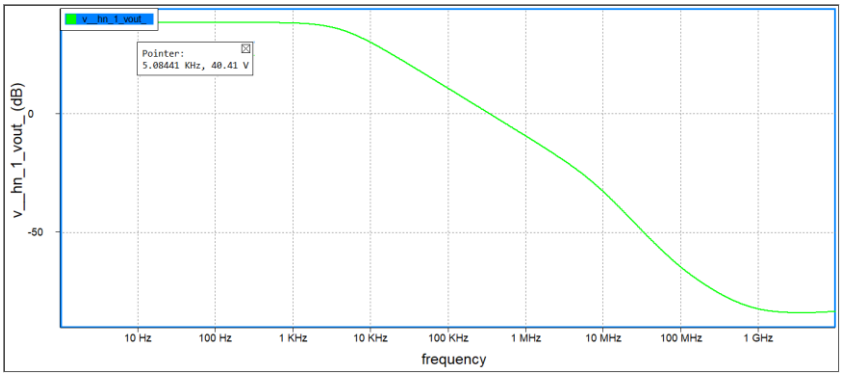


Figure 8. Differential mode gain

As shown in Figure 8, the differential mode gain of the circuit is around 40v up to 5Khz and decreases after 5Khz.

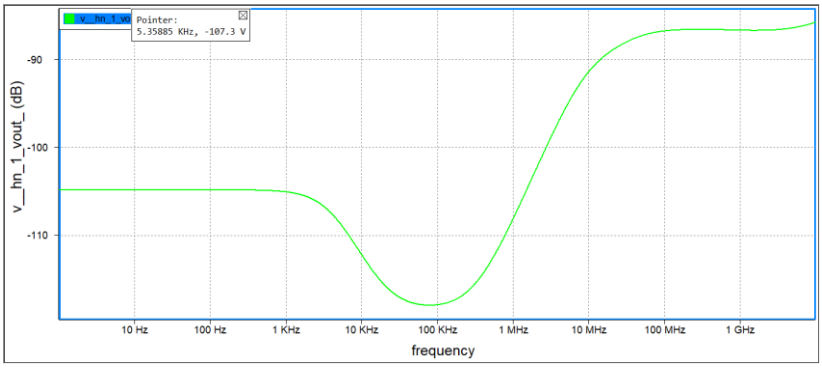


Figure 9. Common mode gain

As shown in Figure 9, the common mode gain of the circuit is around -107v up to 5Khz and decreases after 5Khz then increase to become stable after 100Khz.

3.3. Advantages of balanced OTA

Pipelined analog-to-digital converter (ADC) is widely used in communication systems with high data throughput because of its structural characteristics, which makes a good compromise between high sampling rate and high resolution. The sample and hold amplifier is an important unit of ADC. It needs to complete the signal establishment in a very short time, and the establishment error is less than the minimum resolution of the subsequent quantization circuit [6]. Therefore, the gain and bandwidth of a balanced operational transconductance amplifier are required. Compared with the single-ended low-noise amplifier, the balanced low-noise amplifier has better port matching, can

obtain a better standing wave ratio, and the dynamic range, reliability, and stability of the amplifier are also improved, thus reducing the noise figure [7].

The advantages of the balanced amplifier can be summarized as follows:

(1) Considering the non-ideal characteristics of the actual microstrip line, no amplifier matching network can realize the absolute matching of impedance, and the reflection of the signal will inevitably occur due to the discontinuity of impedance. However, due to the existence of a branch line coupler, the signal will have a phase difference of 90 degrees when it is transmitted to the mismatched interface. After reflection, the phase difference of 90 degrees will be superposed again, So that mutual cancellation of signals due to inversion occurs at the input and output ports. Therefore, the return loss of the terminal source and the load end is smaller than that of the traditional class AB power amplifier, which improves the standing wave condition of the input-output matching network and improves the stability.

(2) The individual amplifier stage can work in the state of gain flattening or noise figure optimization and is independent of input-output matching.

(3) Even if a single-ended amplifier section is damaged, the circuit can still work normally, but its power gain will be reduced by 6dB.

(4) The working bandwidth can reach more than one octave, which is mainly determined by the bandwidth of the branch line coupler. Although the balanced power amplifier is composed of two single-ended amplifiers, which will consume more DC energy, it can not be ignored that it can provide higher output power and wider bandwidth. Another point is that the circuit board size of a balanced amplifier is generally large because of the existence of input and output branch-line couplers.

4. Existing challenges and improvement directions

4.1. Existing challenges

Due to cost performance for the real situation in the hospital and industrial cost, the balanced OTA filter in this paper is simple and cannot guarantee a long stable use when it is implemented on an ECG machine with other models. In spite of that this model is surely an economical and practical model to study and use and there is much improvement space that can make it more industrial-friendly and reliable.

4.2. Improvement directions

There are two different ways to increase gain and power efficiency which are two elements to improve the current circuit.

4.2.1. Fully differential OTA

The traditional OTA adopts the sleeve-type cascade structure, with two-stage voltage gain and only one main pole. The output voltage swing and gain are mutually restricted. The gain improvement technology is a common method to solve this problem. However, the new pole introduced by the auxiliary amplifier will affect the setup time and require additional power consumption [8]. The folded structure can alleviate the problem of limited output voltage swing to a certain extent, but the power consumption is greatly increased and the bandwidth is limited in reference [9], a sleeve type full differential Ota is designed to solve the above problems. Using only a pair of auxiliary amplifiers to supply the gate voltage of the common gate NMOS transistor, the gain bandwidth product of 526mhz and the DC gain of 119dB are obtained under the condition of consuming 2.3ma current and driving 2pF load capacitance, and the output voltage swing can still reach 1.8vpp. It provides ideas for increasing revenue and power.

4.2.2. Higher bandwidth

As a bridge between an analog signal and a digital signal, an analog-to-digital converter is more and more important. As the core module of the analog-to-digital converter, the performance of the

operational amplifier will directly affect the quality of the residual signal generated by the pipeline at all levels of ADC, thus affecting the accuracy of ADC. Gain enhancement technology has been widely used in the design of high gain operational amplifiers because of its excellent characteristics. Because of the above problems, document [10] provides the idea of increasing revenue and bandwidth, that is, to realize the high gain and high bandwidth operational amplifiers, the structure should be optimized, the gain improvement technology should be reasonably applied, the circuit should be simplified, and the power consumption should be reduced as much as possible, to design high-quality operational amplifiers.

5. Conclusion

The amplifying and filtering of the ECG signal is the most important part of ECG signal procedures and this balanced OTA can fully remove the 50hz noise from the power line with 40v gain up to 5Khz in differential mode and -107v gain up to 5Khz in common mode and 18uA current consumption. Though it has advantages in improving the power rejection ratio and the signal-to-noise ratio and overcoming the high-frequency distortion of an unbalanced structure, it has a lot of work to do to improve it and make it more industrial-friendly and reliable to face the existing challenges. This circuit can perform well in practical situations and has a profound studying significance and promising economic future with the development of the CMOS technology.

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