Experiments of An active electrode amplifier using SIP with DC rejection for bio-potential recording

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ABSTRACT
We present a bioelectric amplifier with SIP for active electrode in this paper .The mid-band gain of the amplifier is 39.95dB.The bandwidth extends from a low frequency cutoff of 7.9mHz to a high frequency cutoff of 2.1kHz.The working voltage is 1.8V and the power consumption of per channel is 6.7uW.The chip has been fabricated with 0.18um 1P6M CMOS process and then using System-In-Package (SIP) to guarantee the performance of the amplifier.

Keywords
Active electrode, SIP ,DC rejection

1. INTRODUCTION
Electroencephalograms (EEG) [1],electrocardiograms (ECG) [2]， electromyograms (EMG) and electrooculograms (EOG) which record physiological information are indispensable and vital tools for both medical and research use. However, these signals are small at the level of millvolt even microvolt.It's critical to acquire signal with amplified and filter out the noise before processing these information. Since the human skin resistance is high at about 10-100k Ω /cm2, the potential derived from electrode is affected by the electrode-tisssue contact impedance[3].To solve the problem, traditional wet electrode has been used.In the process of using wet electrode to record the signals from the human body, the skin cleaner and the conductive paste are used to reduce the resistance and keep good conductivity, respectively.But this solution presents several problems.Firstly,the conductive paste makes it more strict to place the electrode .Once an interelectrode distance is too short,the paste would cause a short circuit between adjacent electrodes.Secondly,the preparation time is so long and the paste gradually dries out with time goes on, which breaks the integrities of the signals .Moreover, the chemical paste might damage the skin and make the patients uncomfortable. These features make the traditional wet electrode not suitable for long-time monitoring. And traditional electrode is susceptible to outside influences. More seriously, the leads wire creat artifact during the recording .

To overcome these drawbacks, we adopt an active electrode [4]-[9]. Amplifier is directly integrated on the electrode to creat a minimal signal path between the electrode and amplifier. High input impedance and low output impedance are the characteristics of the active electrode. The input impedance is high enough compared with the skin impedance,thus avoiding the use of skin preparations and the conductive paste. The low output impedance can reduce the amount of the environmental noise induced by the lead wire .

The paper presents an active electrode minimizing the problems listed above. To reduce the large RC time constant, pseudo and de-blocking technologies [10] are adopted .The active electrode presents the characteristics of high input impedance ,low output impedance. Moreover ,the performance of the active electrode chip is guaranteed by inserting the active electrode chip into SIP . In the SIP technology ,active components and passive components are embedded in a package substrate.SIP is normally used as a tool to implement the miniaturization of the device. SIP can be a solution to meet the requirements of the physical size for wearable devices.

The paper is organized as follows. In section II, the schematic structures are presented. In section III, the simulation and experimental results of active electrode chip and the chip using SIP technology are shown. In section IV, conclusions are drawn.

2. DISIGN

2.1 The architecture of active electrode
In order to suppress DC-offset voltage from the skin, many previous works adopts AC-coupled circuit [11]. However, the input impedance is too small to meet the demand of high impedance for the active electrode. In this paper ,a high input impedance amplifier is implemented .The overall schematic is illustrated in Figure 1.The input electrophysiological signal is connected directly to the gate of the MOS transistor. In the schematic ,a chopper structure is bestowed as the main filter ,and another amplifier is availed in a feedback circuit. In bioelectric recording a high pass filter capability should be present. DC suppression is accomplished with the active DC-rejection by feedback.The transfer function of the amplifier can been approximately calculated in equation (1),

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$$H(s) = A_d \frac{S R_0 C_0}{(1 + S R_0 C_0)(1 + S \frac{A_d \tau_1}{A_1})(1 + S \frac{\tau_2}{A_2})} \qquad (1)$$

Where Ad=(1+R2/R1)(1+R4/R3),R0 is the equivalent impedance of the pseudo resistance M1,M2;A1,A2 represent open-loop voltage gains of op-amps AMP1 and AMP2,τ1,τ2 are time constant of the two amplifiers ,respectively.

The overall amplifier is designed as a band-pass filter from 7.9 mHz to 2.1 kHz.The low frequency cutoff is controlled by the product of R_0 and C_0. Low frequency cutoff means large R_0 or C_0. In this paper ,we adopt pseudo resistance to replace the ordinary resistance to acquire a large enough resistance with a small area. Thus ,a small chip area can be achieved with a small capacitance.

However,ultra-low high-pass frequency cutoff means high time constant. Though the problem of the area is resolved by using the pseudo resistance. It will take a long time for the circuit to stabilize. The slow response is a serious problem when a large disturbance occurs in the signal like movement artifacts and others. To handle the problem, a de-blocking technology is introduced in Figure 1.In the circuit , a nMOS acts as a switch in parallel with pseudo resistors. Two comparators control the gate voltage of the nMOS,making the time constant temporarily smaller during overload. Therefore the circuit will be DC stable in a short time .

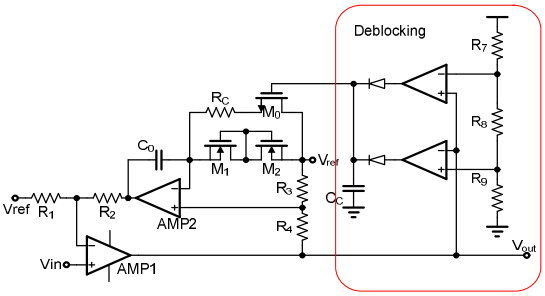

Figure 1.The overall schematic

2.2 The chopper amplifier

The paper presents the main amplifier in the Figure 2.It is controlled by a bidirectional non-overlapping clock which is illustrated in Figure 3.

In order to reduce noise introduced from the outside interferences, a low output showed be guaranteed.However a single amplifier with a low output impedance can't achieved the goal of the relatively large gain of 40dB.Thus,we adopt two-stage amplifier in the chopper amplifier.C_c and R_c are Miller compensation capacitance and resistance for stability. The bio-potential signal we process is within the frequency of 1kHz.Therefore the GBW of the chopper amplifier has to be larger than 100kHz with a 40dB closed loop gain of the amplifier. Concerning the low-pass frequency of 2.1kHz, circuit flicker noise preserves attention.In order to reduce it,gate areas has been increased.

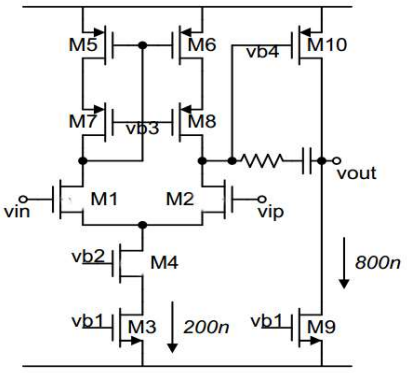

Figure 2. The schematic of the main amplifier

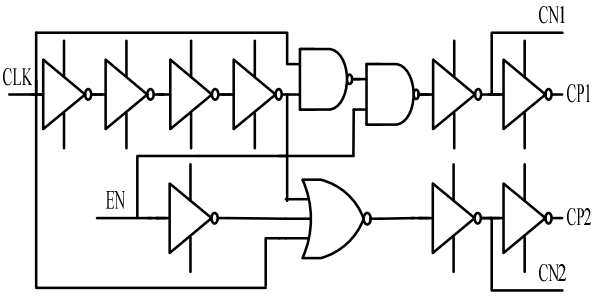

Figure 3. The structure of the bidirectional non-overlapping clock

2.3 The auxiliary circuits

In order to improve the functions of the amplifier ,some auxiliary circuits are included in SIP [12]. For the reason of the polarization voltage(about±300mv) between different two places on the body,we place a level-shifting circuit at the chip input to raise the voltage of the bio-potential signal up to 900 mV .The bandwidth of the amplifier covers majority of the biological signals in human body,a filter placed at the chip output in SIP to acquire a specific signal.

3 SIMULATION RESULTS

The frequency response is illustrated in Figure 4.The mid-band gain is 39.95dB and the high-pass cutoff frequency and the low-pass cutoff frequency are 7.9mHz and 2.1kHz respectively.

The simulated CMRR and PSRR is shown in Figure 5.The CMRR and PSRR were measured 159dB and 106dB at 1hertz respectively, which proves that the circuit can achieve good performance. The transient response is simulated in Figure 6 with a mixture of AC and DC of the input signal, it takes 10ms to be DC stable.

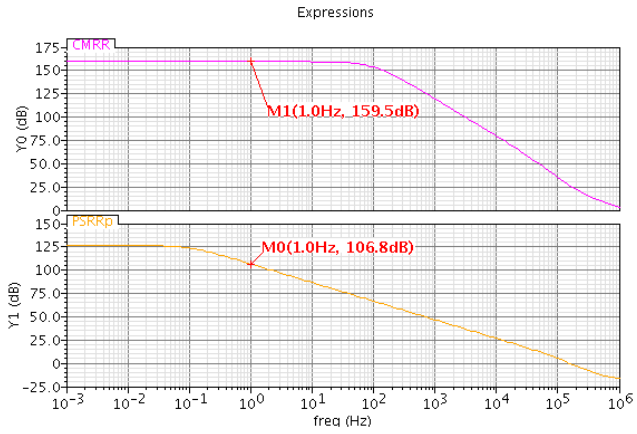

Figure 5. CMRR and PSRR of the main amplifier

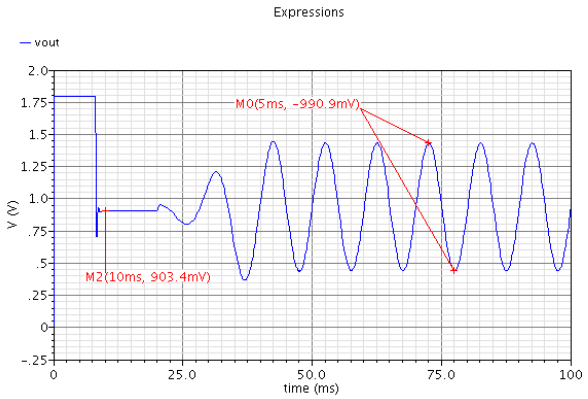

Figure 6.Transient response

4 EXPERIMENT RESULTS

The testing PCB(Printed Circuit Board) including the SIP is illustrated in Figure 7.The primary goal of SIP is miniaturization.A combination of more than one die in a single package drove the SIP technology to high volumn.Based on this ,the size of the testing PCB board could reach even smaller dimension.

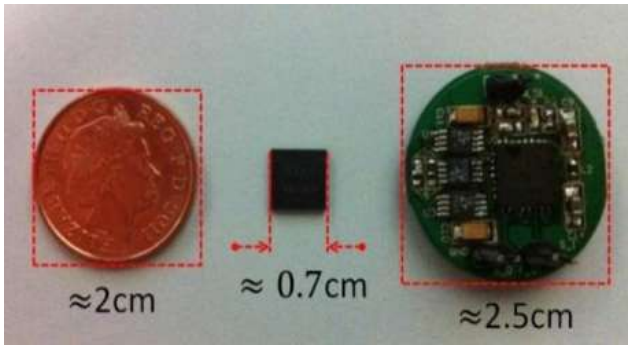

Figure 7.the testing PCB and chip compared with one penny

In order to demonstrate the function of chip ,we use the Agilent E36020A as the power supply a LDO(Low Dropout Regulator) circuit convert the supply voltage to a relatively stable value of 1.8V.We take advantage of a IBUSS(p-type) analog meter to generate an ECG signal and use the signal as the input of the amplifier .The Tektronix AFG3102 was used to show the output result of the chip .The diagram of the output result of the chip and the chip using SIP are illustrated in the Figure 8 and Figure 9 respectively.

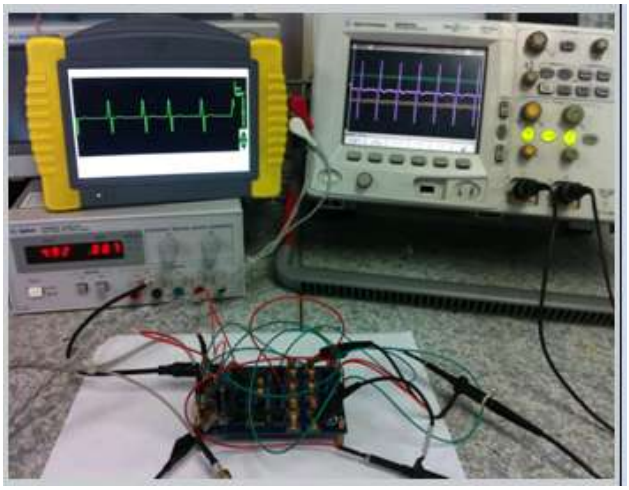

Figure 8 .the output result of the chip with the ECG

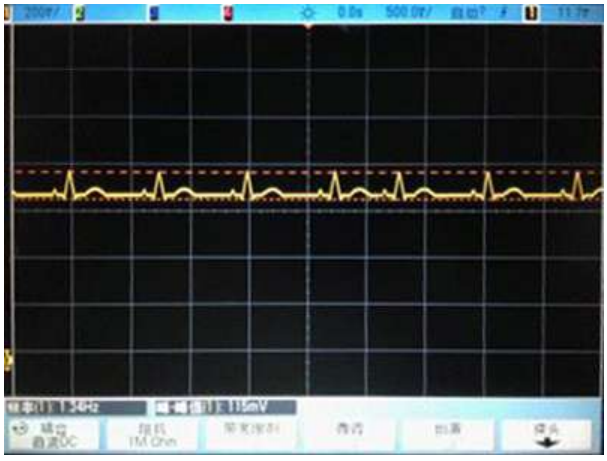

Figure 9.the output result of the chip using SIP

Amplification and filtering functions of the chip is fully showed in the experiment.And this chip is proved to work in good condition after 48 hours in the lab.The Figure 8 and Figure 9 clearly show the ECG signals with no significant noise effects,especially 50Hz noise .

5. CONCLUSION

In this work,an active electrode amplifier using SIP with DC rejection for bio-potential recording has been presented. Pseudo resistance and the de-blocking circuit were introduced to decrease the chip area and response time respectively in this paper. The chip is successfully fabricated in a SMIC 0.18um process. It achieves low power of 6.7uW, low cut-off frequency of 7.9mHz,high cut-off frequency of 2.1kHz and high input impedance. Based on the large enough bandwidth, SIP technology

can be used to acquire different kinds of biological signals for different purpose. And the advantage of the SIP can be considered to apply the active electrode bio-potential chip to the wearable devices in the next work.

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