A Double Ended Active Electrode Using SiP with DC and 50 Hz Rejection

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Abstract— Active electrode is considered an extremely effective structure for capturing human bio-potential signals when compared with the traditional Ag/AgCl electrodes. This work presents a new configuration for a double ended active electrode included in a System-in-Package (SiP) solution. The chip overcomes the traditional problems of relatively large area and slow time response, and it demonstrates the characteristics of low power consumption, DC and 50 Hz rejection. It has a 2.1 kHz bandwidth with a 40 dB gain, and it reaches the extremely low cut-off frequency of 7.9 MHz. The working voltage is 1.8 V, and the power consumption of per channel is 6.7 μW. This chip has been fabricated with 0.18 μm 1P6M CMOS Process and then inserted in a SiP.

1. INTRODUCTION

In order to measure and record biological potential or current, there should be an "interface" between the body and the measuring instruments; this converts body current into circuits current. Electrode attributes to the interfaces, which not only works as simple contact point, but it also plays a significant part in the process of detection of a signal. The performance of the electrodes affects the inspection results of various biological signals such as EEG, EKG, EMG and ECG, to some extent [1]. As the resistance of the body surface is extremely high, conductive paste is applied on traditional electrodes. However, this solution presents several problems. For example, the chemical paste might damage the skin and induce uncomfortable feelings to patients. The preparation time is normally long and this structure cannot be utilized for a long-term test. Moreover, the bio-potential signal is extremely small and the leads are very susceptible to outside influences [2–4].

To solve these problems, new dry alternatives have been studied; among these, active electrode can be considered one of the most successful designs [4]. With this technology, amplifiers are directly integrated on the electrodes for ECG measurements. With active electrodes, conductive paste is not required and the preparation time will be drastically reduced. The most significant advantage of active electrode is that, compared to standard electrodes, it presents a more enhanced ability of anti-interference of physiological signals. The main objective of active electrode is to amplify small ECG signals and eliminate DC off-set voltages at different testing points. In as much as the low cut-off frequency of ECG is around 0.05 Hz, it is complicated to resolve the large reaction time and chip area aroused by ultra-low cutoff frequency [4, 5].

In this letter, a new active electrode design, which minimizes the problems listed above, is implemented. Additionally, pseudo resistances and de-blocking [6] technologies are applied in the circuit to reduce the large RC time constant. The active electrode chip shows the attributes of high input resistance, low output resistance and low-power consumptions. Moreover, the active electrode performance is guaranteed by inserting the active electrode system in a SiP; this is a quite new technology considered an attractive alternative to System-on-Circuit (SoC). In a SiP system, active and passive components are included on a single package substrate; on the contrary, in the SoC system, they are completely integrated in a silicon die [7–9].

The letter is organized as follows. In Section 2, the schematic structures are presented. In Section 3, the simulation and experimental results of active electrode are shown. Then conclusions are drawn in Section 4.

2. DESIGN

In order to get the inhibition of DC-off voltages coming from the skin, previous works have taken use of AC-coupled circuit [10]. The input resistance of traditional circuits is smaller than the one presented in this letter. In this letter, a chopper structure is bestowed as the main filter, and another amplifier is availed in a negative feedback circuit. The main amplifier is a differential circuit whose input is fed with the bio-potential signal at two testing points. It is illustrated in Figure 1 that bio-potential signal is pushed into a high resistance grid electrode whose resistance is extremely high. As the frequency bandwidth spectrum of ECG signal ranges from 0.05 Hz up to

350 Hz, it will be complicated to trade-off between the chip area and the time response based on the high-pass frequency. The amplifier structure is designed as a band-pass filter from 7.9 MHz to 2.1 kHz, and traditional resistance is replaced by pseudo resistor, shown as M_1 and M_2.

The transfer function of the double ended amplifier has been approximately calculated and shown in Equation (1), where A_d is magnification as 100, R is the equivalent value of pseudo resistor; τ_1 and τ_2 are time constants for the two amplifiers, respectively. In order to minimize the response time, a de-block technology [6] has been applied. In this design, one MOS transistor is employed as a switch for pseudo resistors and the gate voltage of this transistor is controlled by two comparators:

$$H(s) = A_d \frac{sR_0C_0}{(1+sR_0C_0)\left(1+s\frac{A_d\tau_1}{A_1}\right)\left(1+s\frac{\tau_2}{A_2}\right)} \tag{1}$$

The chopper structure: Figure 2 displays the schematic structure of chopper amplifier which is controlled by a bidirectional non-overlapping clock. The structure of this clock is illustrated in Figure 3.

It is necessary to have low output resistance because of the impendence feedback in the circuit; guaranteeing a low output resistance the noise introduced from outside interferences can be reduced.

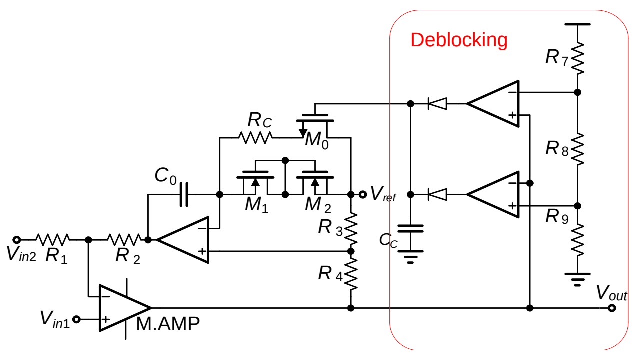

Figure 1: Schematic of the double ended amplifier

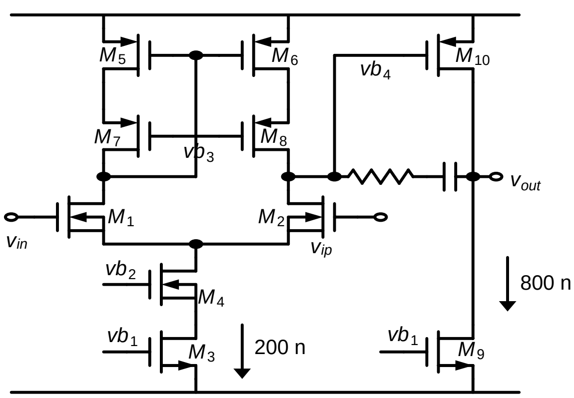

Figure 2: Schematic of the main amplifier.

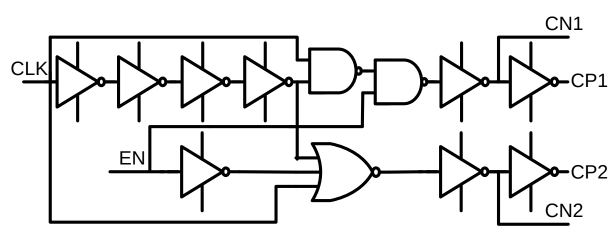

Figure 3: Logical diagram of the bidirectional non-overlapping clock.

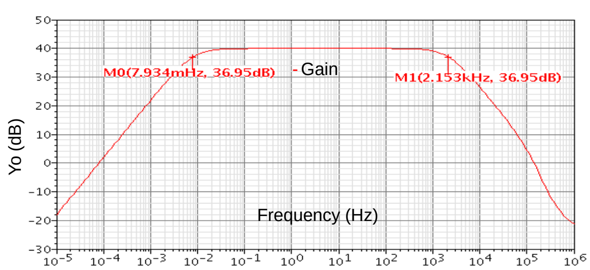

Figure 4: Closed loop gain of the main amplifier.

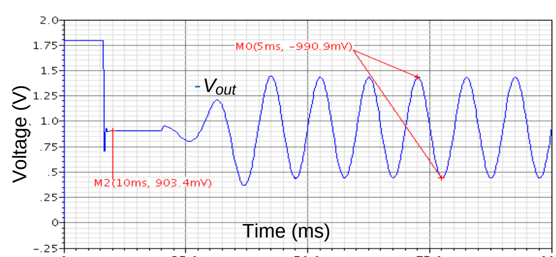

Figure 5: Transient response.

A single stage amplifier cannot achieve sufficient common mode rejection ratio and power supply rejection ratio. Thus a relatively large gain of 40 dB is anticipated in our circuit, so the two-stage structure is designed, and the bandwidth of chopper amplifier is supposed to be larger than 100 kHz. In virtue of the low-pass frequency of 2.1 kHz, it is only necessary to focus on the circuit flicker noise; for reducing it, gate areas have been increased, however, this choice made the parasitic capacitances increase leading to lower input resistance. In order to counter this effect, the substrate and source of each input component are connected together [11].

Auxiliary circuits have been included in SiP; this package improves the functions of the double ended amplifier. Working voltage of the amplifier goes from 0 V to 1.8 V; for this reason, a level-shifting circuit has been placed at the chip input to raise the voltages of bio-potential signal up to 900 mV. The bandwidth of the amplifier covers the majority of biological signals in human body, consequently, a filter is placed in the SiP to obtain a specific bandwidth for different types of signals. Since one of the advantages of SIP technology is to provide a quick and low-cost solution, the separation of amplifier and band-pass filter designs in SiP will enable the whole SiP system to be more flexible for different applications [12].

3. SIMULATION RESULTS

The frequency response is illustrated in Figure 4, this demonstrates that the low cut-off frequency is about 7.9 MHz. And, the transient response is simulated in Figure 5; the input signal is a mixture of AC and DC, and it only takes 10 µs to be DC stable.

4. EXPERIMENTAL RESULTS

The testing PCB board including the SiP is shown in Figure 6. In order to demonstrate the good functioning of the chip, the amplifier input has been fed with an ECG signal simulation generated by an IBUSS (p-type) analog meter. The TEKtronix AFG3102 has been employed as oscilloscope during the test and the Agilent E36020A has been used as the power supply. The minimum possible power supply value is 1.5 V; this is based on the feedback circuit. In addition, a LDO circuit converts the supply voltage to a relatively stable value of 1.8 V.

Figure 6 illustrates the SiP, the testing PCB and their dimensions. Even ifthe dimensions of this SiP have been determined, taking in account the necessity of soldering by hand, the package sizes obtained employing this technology can reach smaller values than those obtained with traditional packaging technologies. Based on this, the size of the testing PCB board could reach even smaller dimension. The ECG signal, created by the analog meter and detected by the active electrode is shown in Figure 7, the yellow line is the output of ECG signal. And this chip can work in good condition after 48 hours testing in this lab.

The experimental results demonstrate the amplification and filtering functions of this chip; Figure 7 shows the good quality of ECG signal and no significant noise effects (especially the 50 Hz noise). Moreover, the active electrode has also shown the characteristics of continuity and stability over a long time.

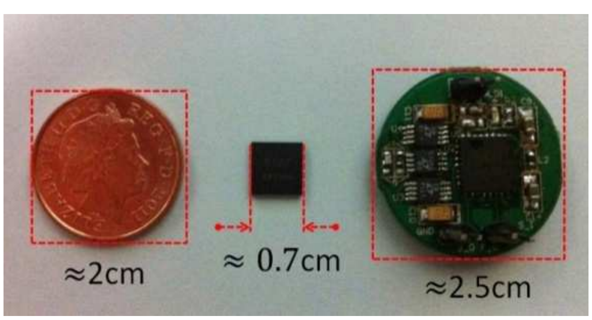

Figure 6: The chip and PCB are compared with one penny.

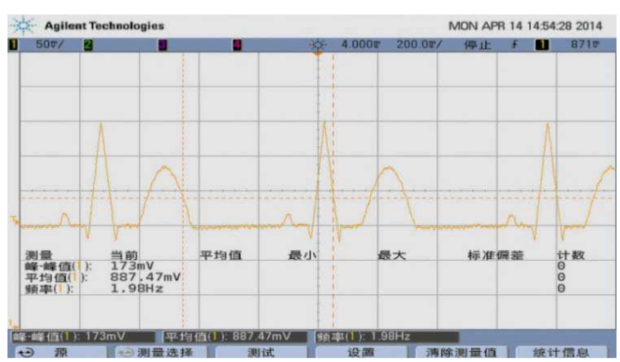

Figure 7: Timing waveform of the ECG.

5. CONCLUSIONS

In this letter, the structure of a double ended active electrode which had DC and 50 Hz rejection was presented. In this structure, pseudo resistances and de-blocking technology were firstly combined to decrease the chip area and response time. This chip was successfully fabricated using SMIC 0.18 μm process. It achieved the characteristics of low power consumption of 6.7 μW, extremely low cut-off frequency of 7.9 MHz and high input impedance. Since the bandwidth was large enough, and the encapsulation technology of SiP was applied, they would ensure the chip was multipurpose for different kinds of biological signals.

ACKNOWLEDGMENT

This study was financed partially by the 'One-hundred Talent' and the 'Low-cost Healthcare' Programs of the Chinese Academy of Sciences, the project of science and technology of Guangdong Province (2010A030500014).

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