

An ECG Front-End Subsystem for Portable Physiological Monitoring Applications

Hsiu-Cheng Lee, Ching-Sung Lee, Yu-Ming Hsiao, Miin-Shyue Shiau, Kuang-Hung Chen, Heng-Shou Hsu, and Don-Gey Liu

Department of Electronic Engineering, Feng Chia University

Taichung, Taiwan, ROC.

hclee@entrepot.com.tw, cslee@fcu.edu.tw, ryoownt@gmail.com, msshiau@fcu.edu.tw, kuanhung@fcu.edu.tw, hshsu@fcu.edu.tw, dgliu@fcu.edu.tw

Abstract— This study proposes an integrated analog measuring interface IC chip module used for portable personal healthcare electrocardiograph (ECG) system by considering factors of chip size, weight, portability, and fabrication simplicity. An instrumentation amplifier with an active DC suppression feedback, a “driven right leg (DRL)” circuit, and an on-chip active low-pass filter (LPF) are included. The chip design with an intended operation frequency range of 0.5-40 Hz was realized by using TSMC 0.35- μ m 2P4M mixed-mode process technology. Experimental results show that the present cost-effective and compact design can fulfill the minimum requirements of the front-end planning structure of a fully functional complex cardiac rhythm and ECG morphology of heart diseases. The circuit specifications also meet the standards provided by the Association for the Advancement of Medical Instrumentation (AAMI) [1].

Keywords- Portable, ECG, DRL

I. INTRODUCTION

As the ageing of the society in Taiwan due to a longer life expectancy, an increasing cost for medical care leads to much efforts to develop low cost, smart and personal health-caring devices supporting for those diseased peoples. Among the personal healthcare circumstances, the monitoring of heart activity is of special interest. The monitoring devices can record and transmit the physiological information of patient to the physician for physiology management and supervision. This study is focused on the chip design and realization of a micro ECG technology. Along with the use of instrumentation amplifier and filter circuits, the DRL and AC couple circuits are also included in the proposed design.

II. CIRCUIT DESCRIPTION

A. AC couple circuit

The electrocardiogram (ECG) is the largest biopotential in the body, generated by electrical polarization and depolarization of the heart muscle. Normally, the ECG is measured on the body surface by using conductive electrodes. The main role of AC Couple circuit is to make this small measured AC signal can be effectively coupled into the following signal processing circuits, that is the amplifier/ filters, and blocking the electrode DC offset voltage. Thus, protecting the smaller signal of the electrodes from the saturation phenomenon of the amplifier is very important. Otherwise, it will result in miss-measured or

even more fail-function due to out of work [2]. In order to precisely determine the cutoff-frequency of this high-pass behavior of the electrodes, a parallel resistance R_2 much smaller than the input impedance of the amplifier is connected to ground in parallel

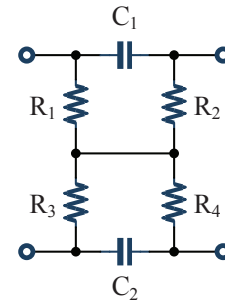


Figure 1. AC Couple Circuit

Figure 1 shows the AC coupled circuit we used[3]. If $R_2C_1 = R_3C_2 = \tau$, then the transfer function can be written as

$$GDD(S) = \frac{S\tau}{1 + S\tau} \quad (1)$$

and the corner-frequency is

$$f_c = \frac{1}{2\pi R_2 C_1} \quad (2)$$

B. Differential Instrument Amplifier with Active DC Suppression High Pass Filter

A fully-differential instrumentation amplifier (IA) with finite gain (<10), high input impedance and high CMRR is designed amplify the small biopotential and to suppress the common-mode DC level. The output of IA is followed with an active DC suppression filter to form an integral accumulation mode, so that the whole system has high-pass filter function. As long as any additional DC component existed in the output of the IA, it will be effectively filtered out by the integrator immediately.

$$V_{O1} = \left(1 + \frac{RF}{RG}\right)V_{in1} - \left(\frac{RF}{RG}\right)V_{in2} + V_{cm}$$

$$V_{O2} = \left(1 + \frac{RF}{RG}\right)V_{in2} - \left(\frac{RF}{RG}\right)V_{in1} + V_{cm}$$

If $R_4/R_3 = R_2/R_1$ then

$$V_O = \frac{R_2}{R_1}(V_{O2} - V_{O1}) \quad (3)$$

The overall transfer function of this DC-suppressing IA :

$$T(s) = \frac{R2}{R1} \left(1 + \frac{2Rf}{RG} \right) \left(\frac{SC_1R_5}{1 + SC_1R_5} \right) \quad (4)$$

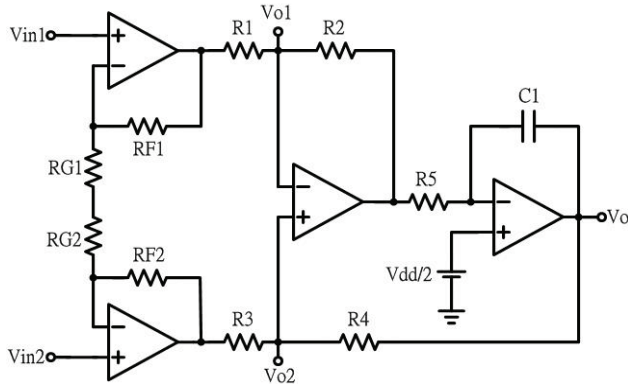


Figure 2. Instrument Amplifier with Active DC Suppression High-Pass Filter

C. Drive Right Leg (DRL)

Due to mismatching or position difference of electrodes, there always have DC difference practically between two biopotential from both electrodes which can not cancellation by the IA, then a third electrode is required to inversely feedback the common-mode output to the right leg of patient body to cancel the common mode noise in the body. The DRL circuit used as shown in Figure3 greatly reduces the common mode noise with fully capacitive system [3]

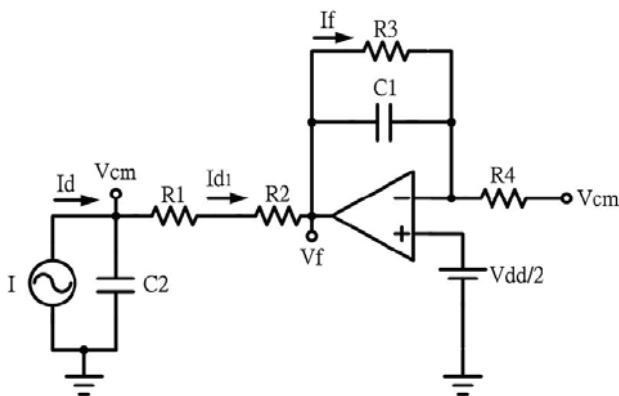


Figure 3. Driven-Right-Leg Circuit

Let $R_3=Z_3$, $s \cdot C_1=Z_4$, $R_4=Z_5$, $R_1+R_2=Z_1$, and

$$Z_f = Z_3 // Z_4 = \frac{Z_3 Z_4}{Z_3 + Z_4} = \frac{R_3 \frac{1}{SC_1}}{R_3 + \frac{1}{SC_1}} = \frac{R_3}{1 + SR_3 C_1}$$

we get the relationship between feedback common mode signal V_{cm} and the resistance ratio as

$$V_{cm} = \frac{R_1 i_{d1}}{1 + \frac{R3}{R4}} \quad (5)$$

It shows that the attenuation of V_{CM} is proportional to the ratio of R_3 and R_4 .

D. Low-pass Filter

Following the IA, a filtered-amplifier unit offering the additional noise-filtering and biopotential amplification is needed. According to the characteristics of ECG signal, the frequency range is about 0.05 Hz ~ 100 Hz. For our study in order to focus on the standard ECG monitoring the frequency range of 0.5 Hz ~ 40 Hz is designed. A simply Sallen-key low-pass filter, shown in Figure 4, using only single op amp. is functionality enough for usage. The transfer function of it is

$$\frac{V_O}{V_i} = \frac{1}{s^2 \cdot (R_1 R_2 C_1 C_2) + s(R_1 C_1 + R_1 C_2 + R_2 C_2) + 1}$$

This second-order LPF has the standard equation form as :

$$H_{LP} = \frac{K}{-(\frac{f}{f_c})^2 + \frac{jf}{Qf_c} + 1} \quad (6)$$

where f_c is the corner frequency K =gain factor Q =quality factor. That is $\text{Gain} = |V_o/V_i| = K = 1$

$$f_c = \frac{1}{2\pi\sqrt{R_1 R_2 C_1 C_2}} \quad (7)$$

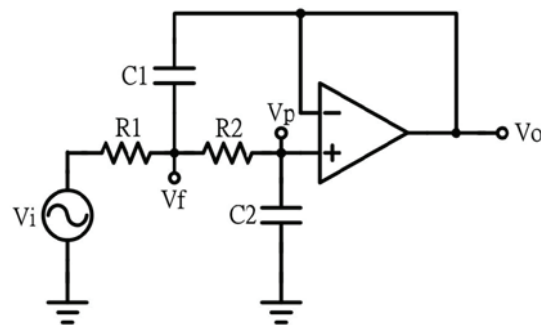


Figure 4. Sallen-Key Low-pass Filter

E. Some design criteria of Overall system

Diagnostic ECG bandwidth of about 0.05 ~ 100Hz design;
The wider used the more informations offer to doctors for

diagnosis in the clinical. reference; but relatively susceptible to interference from supply noise. In our study , the monitor is designed to use about 0.5 ~ 40Hz, system gain is 57.7dB. This biopotential is amplified significantly for monitoring convience and the common mode signal and noises are attenuated significantly.

III. SIMULATION RESULT

An single powered op amp. is designed using the following data, and its open-loop gain is about 65dB.

$$I_{d1} = I_{d2} = 30 \text{ uA} ; (W / L)_1 = (W / L)_2 = (1.5 / 80) \text{ u}$$

$$g_{m1} = g_{m2} = 374.9379 \text{ u/v}$$

$$A_{V1} = g_{m2} (r_{o2} // r_{o4})$$

$$A_{V2} = g_{m7} (r_{o6} // r_{o7})$$

$$A_V = A_{V1} \times A_{V2} = 1795 \text{ V/V} = 65 \text{ dB}$$

Figure 5 shows the simulation results of its Bode plot, and the corresponding SNR of it is selected listing in Table 1.

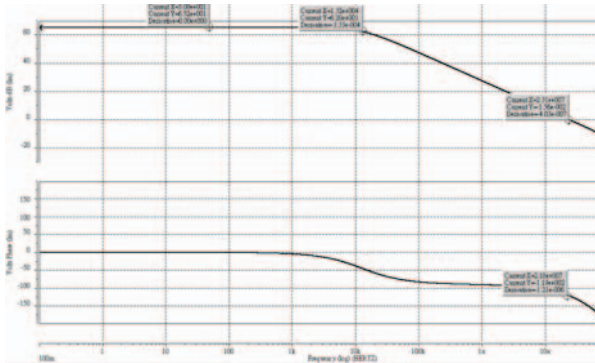


Figure5. Op-Amp Gain and Phase

Table I : SNR of each frequency

Frequency	Total Output Noise Voltage (V / rt Hz)	SNR
1	9.0510 m	42.66 dB
10	3.1153 m	51.92 dB
50	1.4898 m	58.33 dB
100	1.0884 m	61.06 dB
1 K	384.8407 μ	70.09 dB
10 K	110.2015 μ	80.95 dB
100K	6.8679 μ	105.04 dB
1 M	818.8140 n	123.53 dB

It shows that when the noise above 100 Hz, SNR has more than 60 dB. Figure 6 shows the THD of this op. amp..

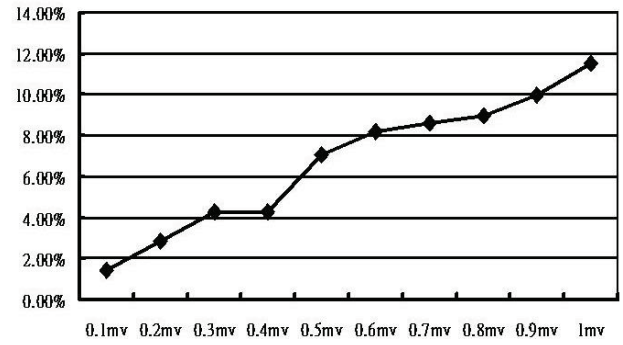


Figure6. Output Total Harmonic Distortion

A. Instrument Amplifier

The IA designed with $R_F = 4 \text{ k}\Omega$, $R_G = 1 \text{ k}\Omega$, $R_1 = 1 \text{ k}\Omega$, $R_2 = 3.5 \text{ k}\Omega$, $R_3 = 1 \text{ k}\Omega$, and $R_4 = 1 \text{ k}\Omega$. The gain has been calculated by hand as 24.86 dB, and the simulation results is 23.24 dB, 1 dB less. This value(about 23 ~ 24 dB) is suitable for the IA preamplifier application.

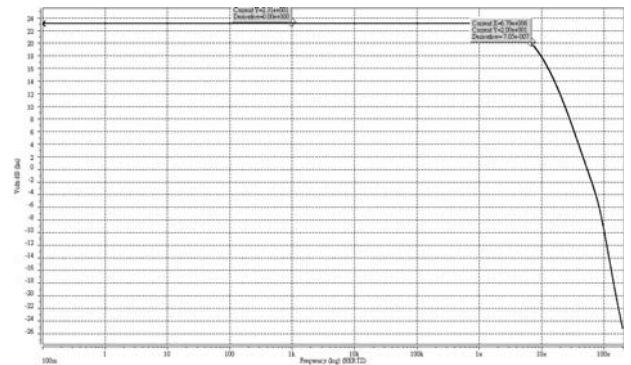


Figure7. Instrument Amplifier Gain

B. Sallen-Key Low-Pass Filter

Let $R_1 = R_2 = 8.2 \text{ k}\Omega$, $C_1 = C_3 = 220 \text{ nF}$, $C_2 = C_4 = 470 \text{ nF}$ Sallen-key low-pass filter is designed for 40 Hz.

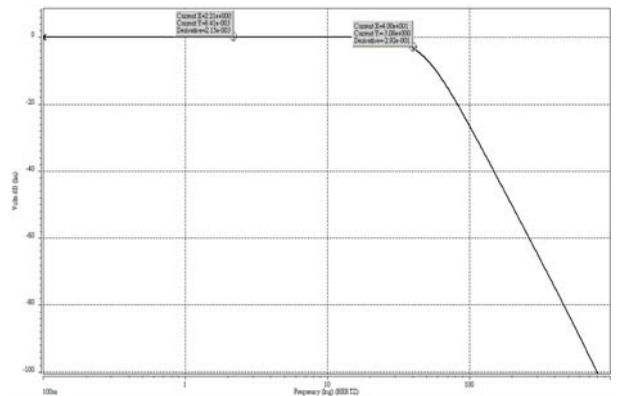


Figure 8. Simulation for Sallen-Key Low-Pass Filter

C. Review of Overall System

The simulated performance of the overall system with maximum gain is 57.7 dB, $f_{L-3\text{ dB}} = 0.5\text{ Hz}$, $f_{H-3\text{ dB}} = 40\text{ Hz}$ is shown in Figure 9,

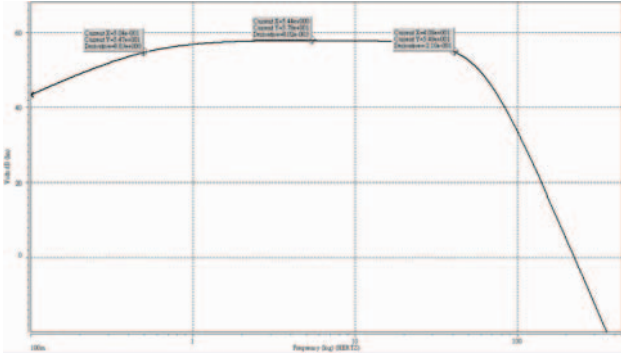


Figure 9. Simulation for Overall System

The Pre-Layout Simulation and Post-Layout Simulation results are also shown in Table 2

Table II : ECG System Pre-Sim and Post-Sim Simulation

parameter	spec	Pre-sim	Post-sim
Power supply	3.3 V	3.3 V	3.3 V
Band width	0.5 ~ 40 Hz	0.5 ~ 40 Hz	0.5~40 Hz
power dissipation	< 9.5 mW	6.36 mW	6.3662 mW
Gain	>40 db	57.7 db	58 db
Chip size (mm ²)	< 1.5 × 1.5	----	1.05 × 0.77

The corner frequencies variations of this ECG system simulated for process TT, FF, FS, SS, SF are shown in Table 3. It is relatively stable for the standard ECG specifications noted previously..

Table III: Corner Simulation

ECG corner	FF	TT	SS
gain	5.77E+01	5.76E+01	5.72E+01
Power dissipation	14.12mw	6.36mw	2.13mw
Frequency-3dB	5.17E-01	5.15E-01	5.09E-01
Bandwidth(Hz)	0.51~41.5	0.51~40.7	0.51~40.1

Table IV: Corner Simulation

ECG corner	FS	SF
gain	5.73E+01	5.77E+01
Power dissipation	2.44mw	12.46mw
Frequency-3dB	5.10E-01	5.16E-01
Bandwidth(Hz)	0.51~41.1	0.51~40.4

IV. MEASUREMENT

The chip implemented using TSMC 0.35μm technology is shown in Figure 10, and the practical ECG monitoring process

was examined with ECG signal extracted from Angilent scope shows the real 6 peaks-and-valleys ECG form. In additions, we also testing our system with external notch-filter, the results, as shown in Figure 11, is obviously better for a notch-filtering ECG system to reject the power-line coupled noises.

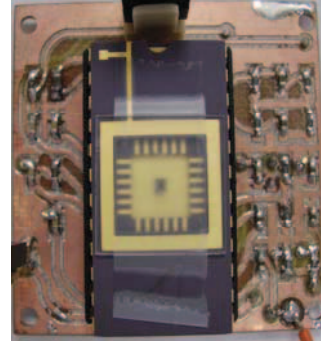


Figure 10 ECG Test Board



Figure 11. (a) The 60Hz Notch Filter ECG Signal Processing (b) Without 60Hz Notch Filter ECG Signal Processing.

V. CONCLUSIONS

An integrated micro-ECG front-end interface module is designed in this paper. An overall gain about 42-bB obtained with the frequency response over 0.5Hz to 40 Hz. Both sSimulation and measurement results show that it is practical to be used in the applications for personal health caring, and the notch filter process is very important for the rejection of the power line noises.

REFERENCES

- [1] Standards EC13:2002, ANSI/AAMI, 2002.
- [2]..Spinelli E.M , Pallas-Areny, R , and Mayosky M.A , “AC-Coupled Front-End for Biopotential Measurement,” *IEEE Trans. Biomedical Engineering* , Vol.50 , pp.391-395, March 2003.
- [3] M. Steffen, A. Aleksandrowies and S. Leonhardt, “Mobile Nonconductact Monitoring of Heart and Lung Activity,” *IEEE Trans. Biomedical Circuits and Systems*, Vol.1, No.4, pp.250-257, Dec. 2007.