SSY091 Biomedical Instrumentation

Laboratory Report
Electrocardiogram Amplifier

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1. Introduction

The purpose of this experiment session is to complete an electrocardiogram(ECG) amplifier, including three steps which are simulating design, welding circuit and measuring data. In this report, the simulation results, derived from *Multisim*, are introduced in Section 2. Section 3 shows all measurement data and calculations to describe the circuit's performance. Several real ECG are displayed in Section 4.

2. Simulation in Multisim

2.1 Circuit Design

The ECG amplifier, shown in Figure 2.1, consists of several stages which are input and differential amplifier, high pass filter and low pass filter. (There is an isolation amplifier after the last filter that is not shown in the figure.) The requirements of each stage are displayed in Table 2.1. The gain of differential amplifier is about 10. High pass filter, with a gain of around 100, provides a low cut off frequency 0.05Hz. In the final stage, low pass filter with the high cut off frequency of 150Hz complete the amplification of ECG signal. Three measurement points named *out1*, *out2* and *out3* go after each stage, as shown in Figure 2.1, to obtain the data while in simulating process.

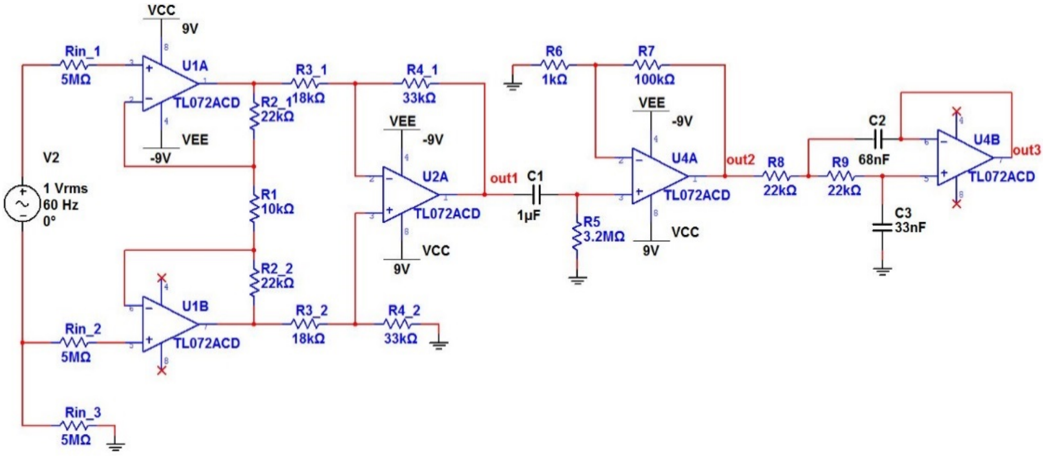


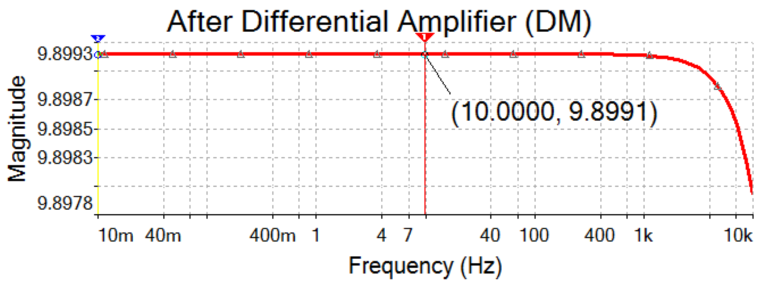
Figure 2.1 Design of ECG Amplifier Circuit

Stage	Requirement	Component	Value
Input and Differential Amplifier a = 10	$\frac{(R_1+2R_2)\cdot R_4}{R_1\cdot R_3}=10$	R_{in}	5MΩ
		R_1	10kΩ
		R_2	22kΩ
		R_3	18kΩ
		R_4	33kΩ
High Pass Filter f = 0.05Hz a = 100	$\frac{1}{2\pi C_1 R_5}=0.05Hz$	C_1	1µF
		R_5	3.3MΩ
	$\frac{R_6+R_7}{R_6}=100$	R_6	1kΩ
		R_7	100kΩ
Low Pass Filter f = 150Hz	$\frac{1}{2\pi\sqrt{C_2C_3R_8R_9}}=150Hz$	C_2	68nF
		C_3	33nF
		R_8	22kΩ
		R_9	22kΩ

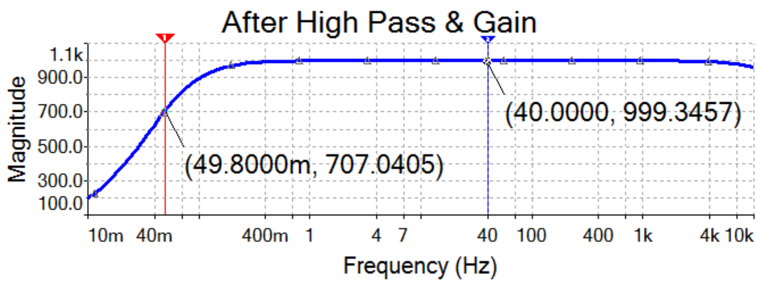
Table 2.1 Components' Values of the ECG Amplifier Circuit

2.2 Simulation Results

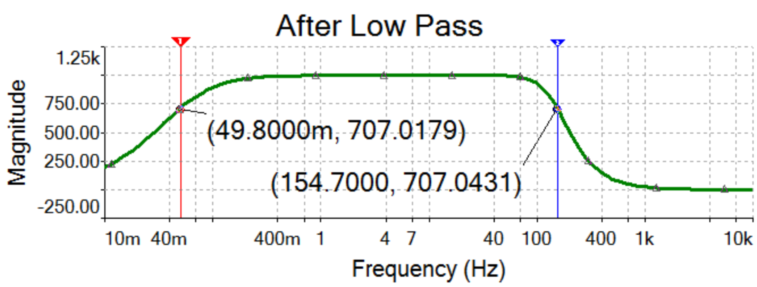
The circuit is established in *Multisim* as Figure 1.1. Then, simulating the circuit by applying AC Analysis with differential mode signals, which derivates the result as shown in Figure 2.2. In subplot (a), it is clear that the differential amplifier provides an amplification about 9.9. After the high pass filter, a low cut off frequency around 0.05Hz can be recognized as well as a gain of 1000 shown in subplot (b). Thus, the gain of the high pass filter is about 100. After the low pass filter as shown in subplot (c), obviously, a pass band from 0.05Hz to 155Hz is obtained. Therefore, all stages satisfy the requirements of circuit design.



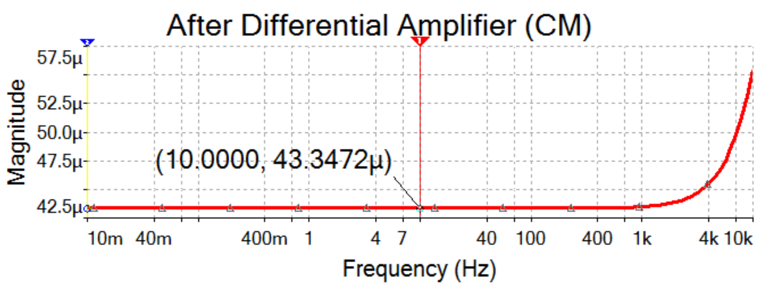
(a) Simulation Result after Differential Amplifier (Differential Mode Signals)



(b) Simulation Result after High Pass Filter



(c) Simulation Result after Low Pass Filter



(d) Simulation Result after Differential Amplifier (Common Mode Signals)

Figure 2.2 Simulation Result after Each Stage

While the common mode signals are input to the differential amplifier, the simulation result is shown as subplot (d) of Figure 2.2. Then, the common mode rejection ratio(CMRR) can be calculated as Equation 2.1 and 2.2. It can be seen that, in simulation process, the ideal CMRR of the instrumentation amplifier is 127dB in the range of pass band.

$$\text{CMRR} = \left|\frac{A_{DM}}{A_{CM}}\right| = \frac{9.8991}{43.3472 \times 10^{-6}} \approx 2283677 \tag{2.1}$$

$$CMRR_{dB} = 20log_{10}CMRR = 20log_{10}2283677 \ \approx 127dB \tag{2.2}$$

3. Measurement Task

3.1 Differential Gain

After inputting the different mode signals into the circuit, the measured gain of each stage is shown in Table 3.1. In the part of instrumentation amplifier, the expected gain is about 10, the measured gain is 10.53. The high pass filter, with expected amplification is 100, gives a measured gain of 97.82. The final part, low pass filter, should not amplify the input signal, while its real gain is 1.02. Therefore, the measured values of real gain satisfy the expected requirements of the ECG amplifier.

Stage	Expected Gain	Measured Gain
Instrumentation amplifier	10	10.53
High-pass filter	100	97.82
Low-pass filter	1	1.02

Table 3.1 Expected Gain and Measured Gain in Each Stage

3.2 DC Gain

We are so sorry that we forgot to measure the DC gain. But we guess the DC gain would be around 10 which is the gain of the differential amplifier. The output is unaffected by the DC offset, because the high pass filter that applied in this design has a low cut off frequency of 0.05Hz. Thus, the DC part of input signal can be removed.

3.3 Frequency Characteristics

The amplifications of different mode signals, A_{DM}, in different frequencies are shown in Table 3.2. It is clear that while the signal's frequency locates in the pass band which is from 0.05Hz to 150Hz, the gain is high to amplify the signal's amplitude. However, the amplifications of signals with frequencies of 200Hz and 500Hz are much lower than others because of the low pass filter. The Figure 3.1 gives a graphically describe.

Frequency (Hz)	Input (mV)	Output (V)	A_{DM}
0.5	5	4.563	912.6
1	5	5.113	1022.6
10	5	5.145	1029
50	5	5.185	1037
100	5	4.658	931.6
200	5	2.784	556.7
500	5	0.492	98.4

Table 3.2 Frequency Characteristics of ECG Amplifier

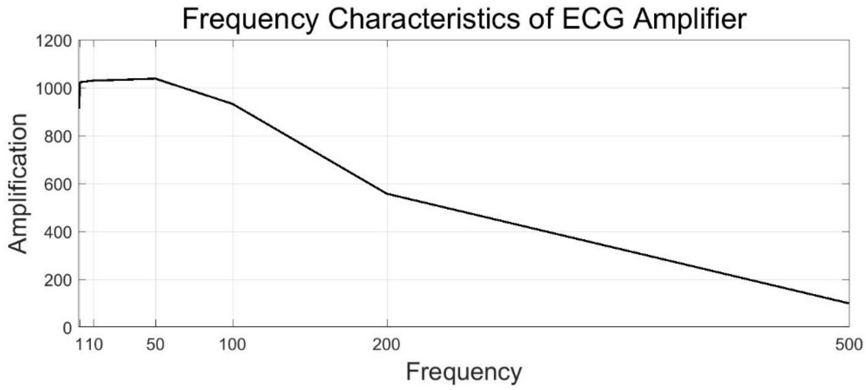


Figure 3.1 Plot of Frequency Characteristics

3.4 Common Mode Gain

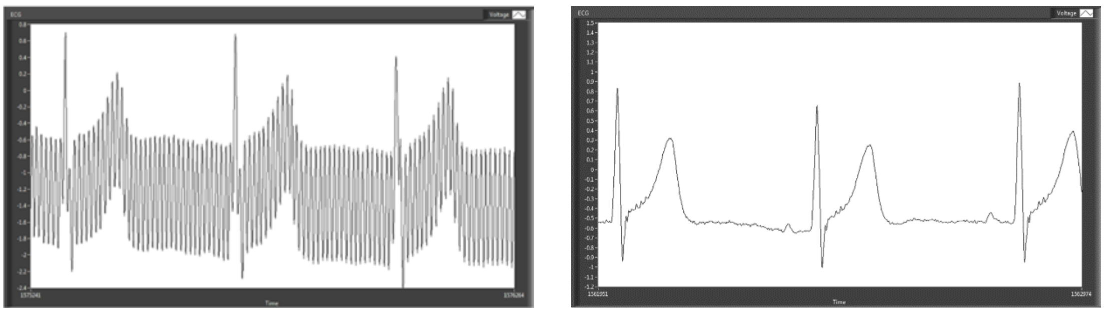
As shown in Table 3.3, the gains A_{CM} of common mode signals are obtained, and CMRRs of signals with different frequencies are listed as well. It is can be seen that the gain of common mode signal is much smaller than different mode signal's, since the differential amplifier rejects the common mode signal. Also, the CMRR, with the increasing of frequency, goes down by degrees. But, the values of measured CMRR is not as good as the ideal one calculated in Equation 2.2.

Frequency (Hz)	Input (V)	Output (V)	A_{CM}	CMRR	CMRR(dB)
0.5	5	0.283	0.0566	16187	84
1	5	0.335	0.067	15263	84
10	5	0.784	0.1568	6563	76
50	5	2.712	0.5424	1912	66
100	5	5.02	1.004	928	59
200	5	4.555	0.911	611	56
500	5	0.8895	0.1779	553	55

Table 3.3 Common Mode Gain and Common Mode Rejection Ratio

4. ECG Measuring

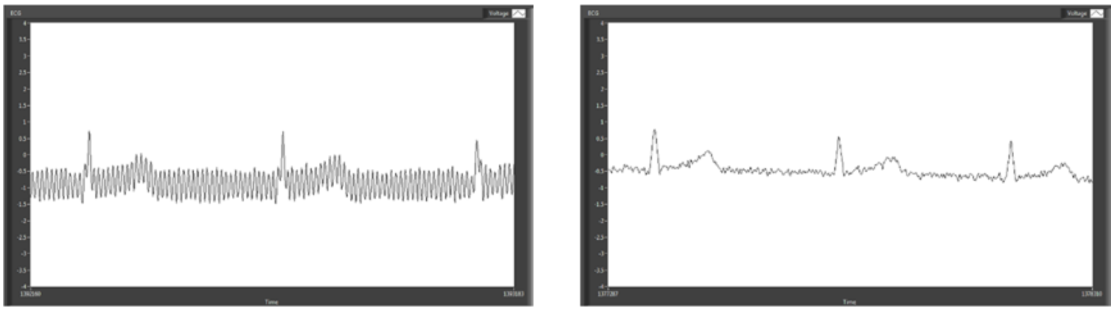
Measurement tasks have been finished shown as above, whose performance meets the requirement. Then, the isolation amplifier is welded to the circuit to provide protection. Three surface electrodes are also connected to the input part of circuit, two of them input ECG signal into the differential amplifier, the other one attaches to the ground. The output of ECG amplifier is converted to digital signals, and finally, displayed in LabVIEW program. The ECG shown in Figure 4.1 is measured from chest.



(a) Original Data　　　　(b) Filtered Data

Figure 4.1 ECG Measured form Chest

The ECG shown in Figure 4.2 is measured from arms. Compared with the ECG in figure 4.1, it is can be seen that ECG measured from chest has less noise after being filtered than ECG measured from arms. What's more, the S wave and T wave in Figure 4.1 are more obvious than in Figure 4.2, indicating that chest ECG contains more details.



(a) Original Data (b) Filtered Data

Figure 4.2 ECG Measured from Arms

Acknowledgement

We thank to each other for our good cooperation, including a clear division of labor, discussing and overcoming problems, and finally we obtained a desirable experiment result. We are also very grateful to Sabine and Cristina for your patience and professional tutorial. This is a really unforgettable experience.