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Circuit Design for Front-End Electrocardiograph

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Abstract

This paper studies the characteristics of ECG signal. In order to complete ECG signal acquisition, the electrocardiograph front-end circuit includes instrumentation amplifier circuit, high-pass filter circuit, 50 Hz notch circuits, four-pass amplification circuit and low-pass filter circuit. To drive subsequent circuit accurately recorded ECG signal, through the Multisim simulation verifies the feasibility of the circuit, which are verified availability through the experimental test.

***Keywords**: ECG signal acquisition, amplify, filter, Multisim simulation*

1. Introduction

Congratulations! Your paper has been accepted for journal publication. Please follow the steps outlined below when submitting your final draft to the SERSC Press. These guidelines include complete descriptions of the fonts, spacing, and related information for producing your proceedings manuscripts. Please follow them and if you have any questions, direct them to the production editor in charge of your journal at the SERSC, sersc@sersc.org. ECG signal as a surface characteristics, the working state of the heart by the accuracy of the ECG signal acquisition and analysis, can be related to pathological changes of clinical diagnosis and treatment have an important reference. Visible, accurately for ECG signal acquisition, is for the doctor to improve effective diagnostic methods cannot be ignored and significant research subject. At present, the state of severe cardiovascular diseases, and people to the requirement of the cardiovascular system healthy, we must attach importance to the imaging quality of electrocardiograph, determinants for the imaging quality of electrocardiograph signal acquisition circuit is undoubtedly one of the focuses of current research.

After entering the 21st century, along with people is higher and higher demand for health, dynamic ECG monitoring system is starting to get people's attention and recognition, the combination of emerging technologies and ECG acquisition and analysis system, make the ECG signal acquisition and analysis can satisfy the precision, in time, distance, convenient wait for a request.

ECG signal is a kind of typical electrical signals. It has the following electrical characteristics.

(1) Weak. ECG signal is very weak electrical signals, and its amplitude is only from 0.05mV to 5 mV.

(2) Low frequency willfulness. ECG signal with low frequency, the energy is concentrated in the 0.25-30 Hz frequency range.

(3) High impedance. The impedance of the human body is bigger, so the impedance of the ECG signal can reach several Ω or KΩ.

(4) Randomness and instability. Stochastic and instability of the ECG signal is mainly with the change of the human environment and the differences between different individuals.

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Electrocardiograph is the main purpose of the front-end circuit will be collected from the electrodes to the ECG signal, through filtering interference noise reduction technology, through to drive subsequent circuit of signal amplification. Because of the ECG signal amplitude and frequency is low, and vulnerable to all kinds of noise in the process of acquisition of submerged. So in order to accurately collected ECG signal, first of all, from the lead wire of the ECG signal is preamplifier. It is through the high-pass filter to remove dc signal and low frequency interference, through the trap circuit to remove 50Hz frequency interference. Finally after a four-pass amplification circuit and low-pass filter circuit for further processing in 0.05 100Hz frequency, amplitude in v level of ECG signals.

ECG signal is very weak, the frequency is very low, so in the process of acquisition are highly susceptible to noise interference, which submerged in noise. Common interference mainly has the following kinds:

(1) 50 Hz power frequency interference is one of the biggest influence on ECG detecting interference noise, is derived from the power supply of 50 Hz for chip.

(2) Power frequency interference and ECG signal can be equivalent to amplitude P-P value equal or greater 50 Hz sinusoidal signal and its harmonics.

(3) Electrode contact transient interference, noise is derived from the bad contact between the electrode and the skin. Electrode contact noise can be equivalent to the exponential form step signal attenuation to the baseline value.

(4) Myoelectricity interference is the high frequency interference, is derived from the muscle tremor of the body. Myoelectricity interference signal to a maximum of 5 mv, the amplitude of energy concentration is in the range of 30-300Hz.

(5) Baseline drift is low frequency interference, from respiratory movement or the impedance of the electrode and the skin contact. Baseline drift interference can be equivalent to a frequency is equal to the breathing frequency sinusoidal component,

Signal processing in electric equipment instrument can include a resistor thermal noise, triode shot noise, *etc.*

To obtain accurate ECG signal, it has to adopt appropriate methods to suppress interference. For 50 Hz frequency interference, usually adopt the center frequency of 50 Hz Notch filter. For high frequency electrical noise, usually using low-pass filter or blocking capacitor filter. Electrodes for low frequency interference, it usually uses the high-pass filter for filtering. Because of the instrument noise, it usually used in the system of low noise devices.

2. Design for Front-End Electrocardiograph

2.1. Design of Instrumentation Amplifier

Electrode is to complete the ion current to wire electronic current transformation of key components, so the stand or fall of electrode directly determines the stand or fall of ECG signals were collected. In practice, usually using a strong adhesive force, good air permeability, absorb sweat, good conductivity, and the advantages of small skin irritation of high quality electrode. Instrumentation amplifier circuit is a key link in the process of ECG signal acquisition, relationship to the whole front end circuit to signal quality. The instrumentation amplifier is the core of the ECG amplifier circuit. This paper chooses the AD620 as instrumentation amplifier, which is a low price, low power consumption, high precision instrumentation amplifier. The magnification can be set with an external resistor in the range from1 to 1000.

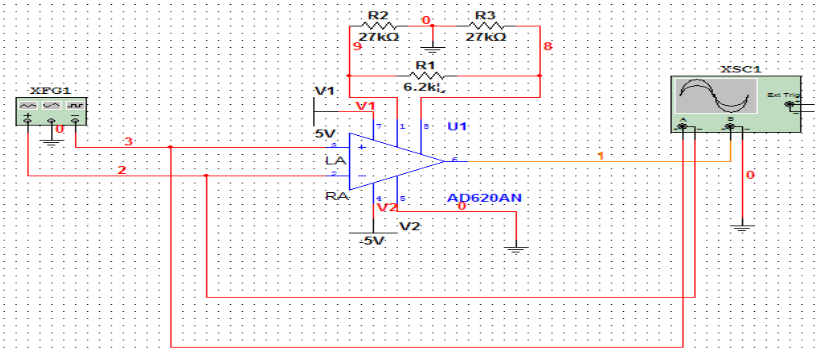

Figure 1. Instrumentation Amplifier

When designing the circuit, the differential input is adopted. At the same time for ECG signals is a mixture of amplitude is larger than ECG signal amplitude many dc signal, if the instrumentation amplifier gain is too large, on the one hand will affect the stability of the dc circuit, on the other hand can make the instrumentation amplifier working in the area or saturated zone, unfavorable to ECG signal processing. So design the first level of magnification for nine times.

Because only adjusting an external resistor, AD620 magnification can be achieved. Based on AD620 magnification formula is $Av = \frac{49.4K\Omega}{R_1} + 1$.

That is R=6.2KΩ.

2.2. Design of High-Pass Filter circuit

Because in the process of ECG test, polarization of electrode voltage is not stable, instrumentation amplifier drift happens disorder, people realized that the factors such as sports, instrumentation amplifier output of ECG signals in addition to be mixed with larger outside the power frequency interference, and strong dc and low frequency interference, which is brought by ECG signal baseline drift, at the same time give serious impact the subsequent signal processing circuit, then the quality of the ECG signal processing. This paper designed a TL084 as the core of the second-order high-pass filter to the output of the instrumentation amplifier DC and low-frequency interference for processing.

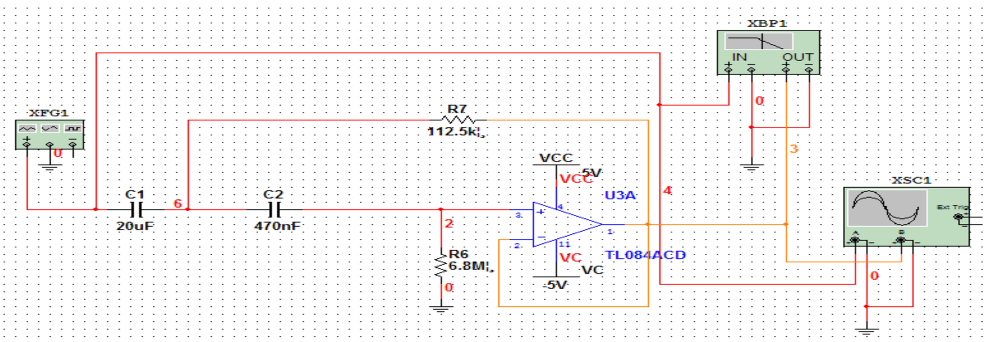

Figure 2. High-Pass Filter Circuit

In the design of high-pass filter circuit, 50 Hz notch, four-pass amplification circuit and low-pass filter circuit to also use TL084 operational amplifier. According to the design of Figure 2, you can see that the second-order high-pass filter circuit is a second-order voltage-controlled voltage source filter. It is the transfer function.

$$G(s)=\frac{U_o(s)}{U_i(s)}=\frac{A_O}{s^2+\xi w_n s+w_n{}^2}$$

The angular frequency is $w_n{}^2=\dfrac{1}{R_1R_2C_1C_2}$.

The pass-band gain is $A_o=1+\dfrac{R_f}{R}$.

Damping coefficient is $\xi=\sqrt{\dfrac{R_2C_2}{R_1C_1}}+\sqrt{\dfrac{R_1C_2}{R_2C_1}}-(A_o-1)\sqrt{\dfrac{R_1C_1}{R_2C_2}}$.

The Cutoff frequency is $f=\dfrac{1}{2\pi\sqrt{R_1R_2C_1C_2}}$.

It needs $f=50mHz$, and then the parameters are $C_1=20uF, C_2=470nF, R_1=112.5K\Omega, R_2=6.8M\Omega$.

2.3. 50 Hz Notch Circuit Design

Mains frequency 50 hz caused by common-mode interference is the main interference in the ECG signal acquisition process, although in the instrumentation amplifier circuit has carried on the processing of common-mode interference, but there is still a part of the power frequency interference in the form of differential mode signal into the circuit, the signal within the frequency range of frequency in ECG signals, for the sake of ECG signal acquisition quality, for these signals must be special filter, so need to design a trap.

Trap is band-stop filter. Band-stop filter can be regarded as a low pass filter and a high-pass filter in parallel, its role is to prevent a certain frequency band signals. This paper USES a TL084 as the core of the second-order band-stop filter to process the work frequency interference. The specific circuit is shown in Figure 3.

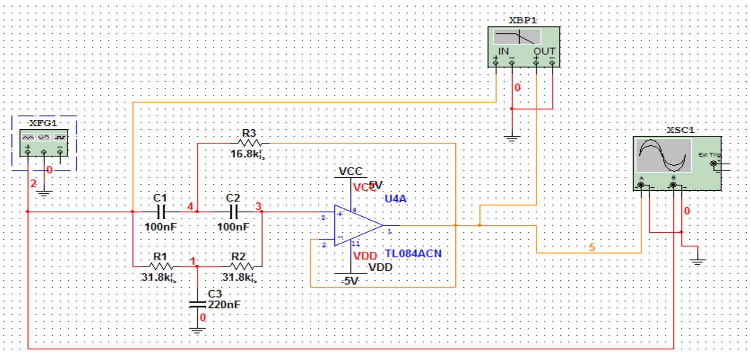

Figure 3. 50 Hz Notch Circuit Design

As can be seen from the Figure 3, trap circuit is actually a high-pass filter in parallel with a low pass filter, so the key to the circuit is the center frequency to trap circuit around 50 Hz, according to the formula:

$$f=\frac{1}{2\pi RC}$$

Selecting R=31.8KΩ,C=100nf. When determining the values of R1, R2, C1 and C2, can according to qualcomm, the cut-off frequency formula of low pass, make the cutoff frequency is 50 Hz or so. So selecting R3=16.8 KΩ, C3=220nF.

2.4. Main Amplifier Circuit

Through the front circuit processing of ECG signal amplitude in the mV level, but the follow-up circuit of A/D converter to the requirement of signal amplitude in V grade, so in 50 Hz notch after the circuit designed A four-pass amplification circuit for ECG signal amplification. The main amplifier has a magnification of 100 times, and instrumentation amplifier 10 x magnification, can ensure that after the main amplifier signal amplitude in the V level. This paper designed the four-pass amplification TL084 as the core of the circuit to implement the magnification of 100 times. The specific circuit is shown in Figure 7.

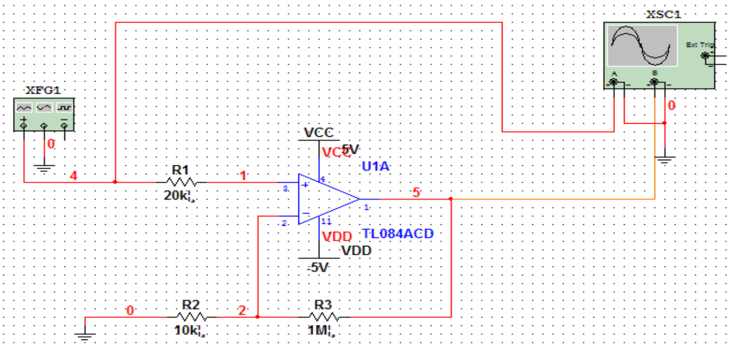

Figure 4. Main Amplifier

As can be seen from the Figure 4, with TL084 four-pass amplification circuit design, is with the method of partial pressure amplifier, according to the formula: $Av = \frac{(R_2 + R_3)}{R_2} \approx \frac{R_3}{R_2}$,

So selecting is in the following. R2=10KΩ, R3=1MΩ.

2.5. Low-Pass Filter

After dealing with the front of the circuit, in ECG signal is mixed with larger electrical high frequency interference, its energy is concentrated within the range of 30-300 Hz, after amplification and amplitude reached around 5V, there are big interference to ECG signal processing. In order to filter out high frequency noise, this paper designed a Tl084 as the core of the second order low-pass filter. The specific circuit is shown in Figure 5.

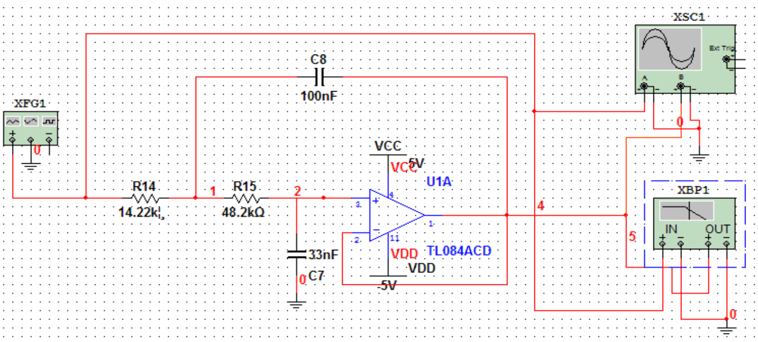

Figure 5. Low-Pass Filter Circuit

According to the design of Figure 5, you can see that the second-order low-pass filter circuit is a second-order voltage-controlled voltage source low high-pass filter. Its transfer function is in the following.

$$G(s)=\frac{U_o(s)}{U_i(s)}=\frac{A_o}{(\frac{s}{w_n})^2+\frac{1}{Q}\cdot\frac{s}{w}+1}=\frac{A_o w_n{}^2}{s^2+\frac{w_n}{Q}s+w_n{}^2}$$

The angular frequency is $w_n{}^2=\frac{1}{R_1R_2C_1C_2}$. The pass-band gain is $A_o=1+\frac{R_f}{R}$.

Equivalent quality function is $Q=\frac{\sqrt{R_1R_2C_1C_2}}{C_2(R_1+R_2)+R_1C_1(1-A_0)}$.

The Cutoff frequency is $f=\frac{1}{2\pi\sqrt{R_1R_2C_1C_2}}$.

It needs $f=100Hz$ .Then the parameters are $C_1=100nF, C_2=33nF, R_1=14.22K\Omega, R_2=48.2K\Omega$

2.6. System Circuit Design

Connect each module circuit is composed of the system circuit, the input signal generator was used to simulate the differential mode signal, the signal source was used to simulate common-mode interference. The specific circuit is shown in Figure6.

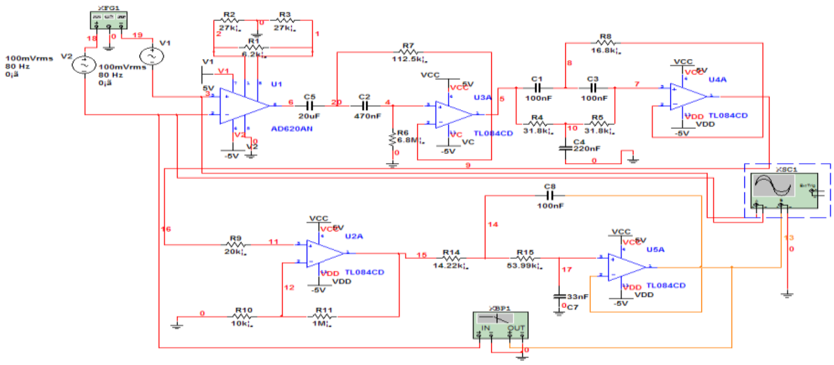

Figure 6. System Circuit

3. System Circuit Simulation

With circuit simulation software Multisim circuit simulation to the system, the input signal the signal generator output 80 Hz, 2 mV sinusoidal signal analog differential mode signal, using 80 Hz, 100 mV communication signal source simulation common-mode interference, using oscilloscope and potter Figure drawing device of signal measurement results as shown in Figure 7 and 8, respectively. Red lines in Figure 7 - the input signal, the yellow line, the output signal.

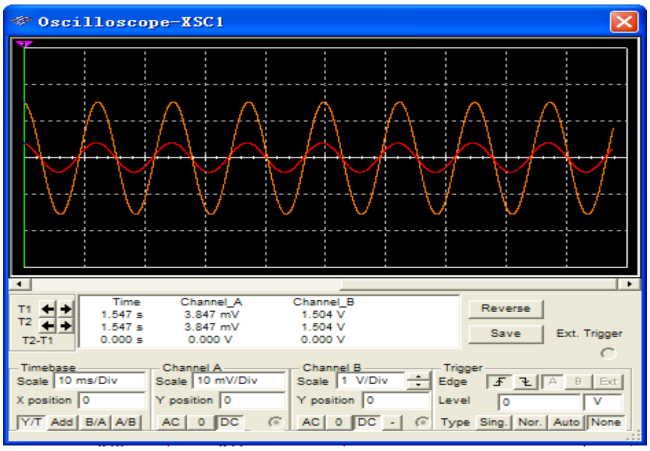

Figure 7. (a) System Circuit Simulation

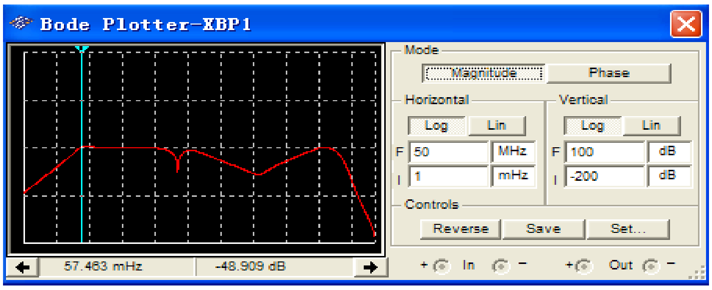

Figure 7. (b) Amplitude-Frequency Characteristics

According to the Figure 7 (a) it can be seen that the input signal amplitude is 3.847 mV, output signal amplitude is 1.504 V, about 500 times magnification, although with 1000 times of the design of index is far off, but the basic reached the millivolt level of ECG signal amplification to V level requirements, to meet the follow-up circuit to the requirement of amplitude in analog-to-digital conversion.

According to the Figure 7 (b) it can be seen that the lower limit of system frequency in the 57.463 mHz, the cut-off frequency in the 50.997 Hz, maximum frequency in the 98.368 Hz. And ECG signal frequency range is 50 mHz - 100 Hz, 50 Hz power frequency interference, so through the system, ECG signal collecting, obtained the better frequency range basic requirements of power frequency interference to obtain the very good filtering.

4. System Alignment Test

Input signal for 40 mV sinusoidal signals, frequency of 20 Hz respectively, 10 Hz, 5 Hz, because of the ECG signal energy is concentrated in the 0.25-30 Hz frequency range, so the ECG signal processing quality is mainly reflected in the spectrum.

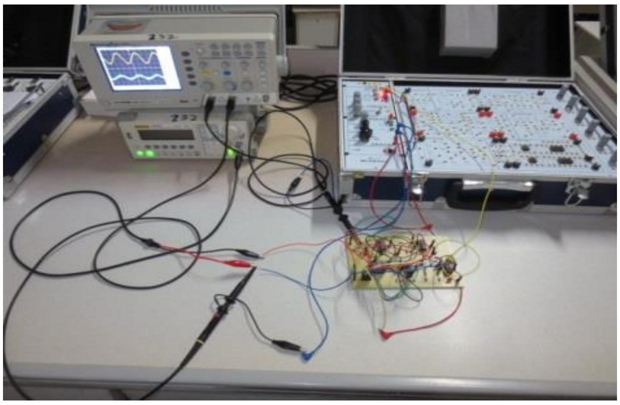

Figure 8. System Alignment

The input signal is the 20 Hz.

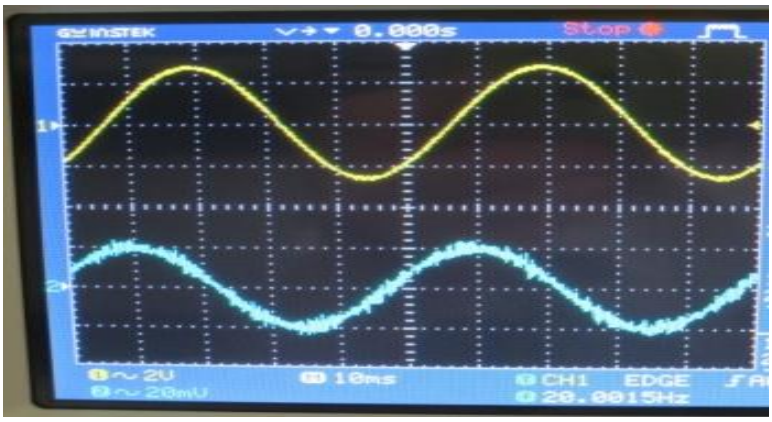

Figure 9. Test System Circuit Diagram (a)

(The channel 1 waveform for the output signal, 2 waveform of the input signal)

It can be seen from the result of the oscilloscope, the input signal amplitude in 38.4 mV, output signal amplitude is 5.28 V, so the magnification

$$Av = \frac{5.28V}{38.4mV} = 137.5$$

Basic no change in frequency, so the design of ECG signal can be amplified circuit to level the volt, and at 0.25-30 Hz frequency range do better filtering acquisition, so as to drive the follow-up circuit for further processing of signals. The input signal is the 10 Hz.

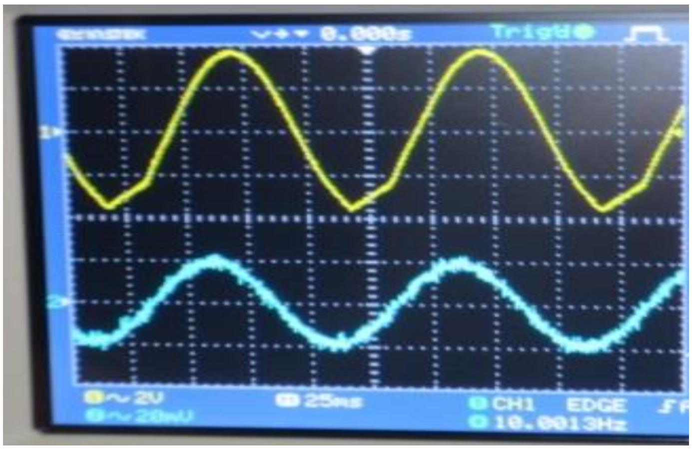

Figure 9. Test System Circuit Diagram (b)

(The channel 1 waveform for the output signal, 2 waveform of the input signal)

Output signal was 199.7 times of amplification, the frequency of the input and output signal, the output waveform distortion, this is mainly because the oscilloscope to the signal frequency is too small cannot be shown.

5. Conclusion

It studies the characteristics of ECG signal. In order to complete ECG signal acquisition, the electrocardiograph front-end circuit includes instrumentation amplifier circuit, high-pass filter circuit, 50 Hz notch circuits, four-pass amplification circuit and low-pass filter circuit. To drive subsequent circuit accurately recorded ECG signal, through the Multisim simulation verifies the feasibility of the circuit, which are verified availability through the experimental test.

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