Using Simulation to Design and Implement a EEG Pre-amplifier Circuit

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Abstract: - Electroencephalography (EEG) is the recording of the brain's activity over a short period of time. EEG measures voltage fluctuations from currents within the brain's neurons. Neuroscientists use EEG to diagnose brain pathology. Educational and cognitive physiology researchers use EEG to help understand the brain's physiological state. The range of amplitude of EEG signals is very small, between 1~100 uV. Only sensitive experimental equipment can record neural impulses for data analysis. Multi-channel EEG instrumentation can be prohibitively expensive for research purposes. So, the purpose of this study is to design and implement a cost-effective pre-amplifier circuit that still allows successful brainwave pattern analysis. This project comprises two phases. First we designed a pre-amplifier circuit by means of electronic circuit simulation. Secondly, we ran the pre-amplifier and verified the accuracy of neural signals taken from 14 people without known pre-existing pathological conditions. We concluded that the system we designed is workable.

Key-Words: - brainwave, EEG, pre-amplifier, simulation, electronic circuit

1 Introduction

EEG is a summation of varying impulses generated by cortical neurons. Neurologists consider EEG to be the most harmless medical technology for diagnosis and observation of brain illness. But, the range of amplitude of EEG signals is very small, and multi-channel EEG instrumentation can be prohibitively expensive for research purposes. So, the purpose of this study is to design and implement a cost-effective pre-amplifier circuit that still allows successful brainwave pattern analysis.

2 Related Literatures and Methods

2.1 Brainwaves

The brainwave signal was discovered in 1924 by Hans Berger, and he called electroencephalogram [1]. The brain's top layer contains a concentration of 100 billion or more brain cells. Electroencephalography (EEG) measures the brain's neurons' electrical current. The amplitude of the signals generated by brain cells lies in the range 1~100 uV [2] and the same signals have frequencies between 0.5-100 Hz

EEG represents the tracings of summated cortical electrical activity, with signals collected by applying EEG electrodes placed on the scalp in accordance with the International 10-20 system of electrode placement.

The combination of electrical activity in the brain might simply be referred to as a brainwave. There are four known brainwave types: δ band activity between 0.2 to 3 Hz; θ band activity between 3 to 8 Hz; α band activity between 8 to 12 Hz, and β band activity between 12 to 38 Hz [3].

2.1 Designing a Pre-amplifier Circuit

The amplitudes of neural signals are very small, lying in the range 1-100 μV. A pre-amplifier circuit will sufficiently amplify differential neural signals.

Op-amps (chip - LM324) are typical components of pre-amplifier circuits. A diagram of a pre-amplifier circuit is presented as figure 1. The features of a pre-amplifier are high input impedance, low input bias current, low input offset current and wide bandwidth (about 1.3 MHz) [4]. The equation of amplifier gain is Av= (1+R2/R1).

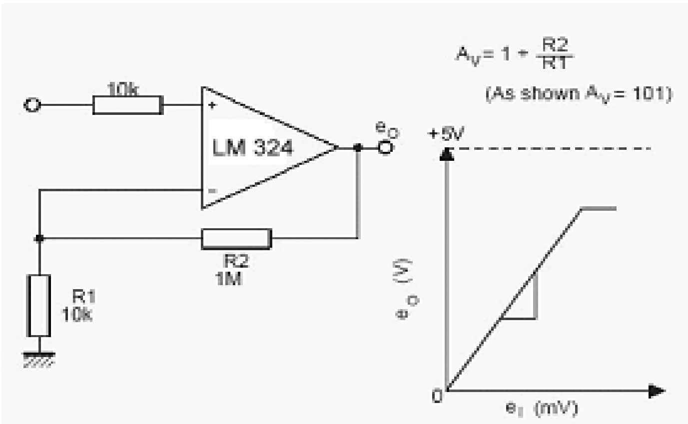


Figure 1 Diagram of pre-amplifier

Here we simulated a two-stage op-amp pre-amplifier circuit. The first-stage amplifier gain was 2, to stabilize the brainwave signals. The second-stage amplifier gain was 201, to increase the voltage of the brainwave signals. The total gain, therefore, of the pre-amplifier circuit was $2 \times 201 = 402$. The diagram of the electronic circuit simulation is presented as figure 2.

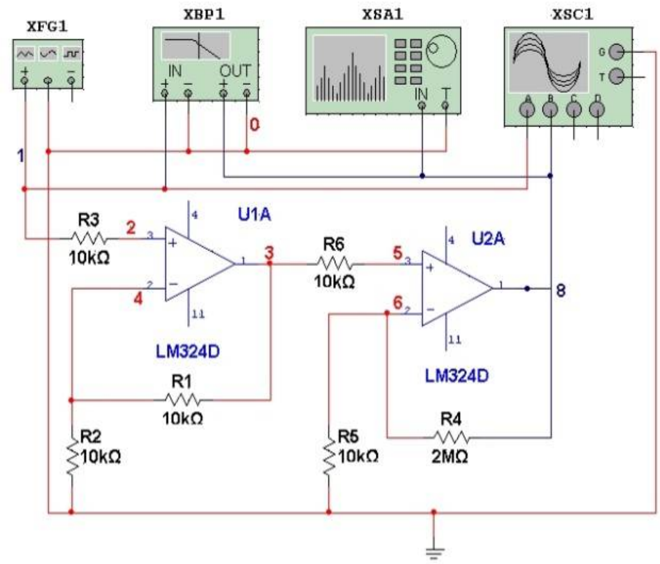


Figure 2 Electronic circuit simulation

2.1.1 Analysis of Electronic Circuit Settings

We first had to verify that our electronic circuit could gain the voltage of brainwave signals. We simulated a 10 Hz sin wave with amplitude of 50 μV. Analysis of the electronic circuit settings focused on three phases, namely:

- **Gain of simulated electronic circuit**

According to electrical theory, the gain of the electronic circuit should be 402.

- **Bandwidth of electronic circuit**

Op-amps are relatively less reliable at higher frequencies because of their limited open-loop bandwidth.

- **Waveform and frequency of signal gained**

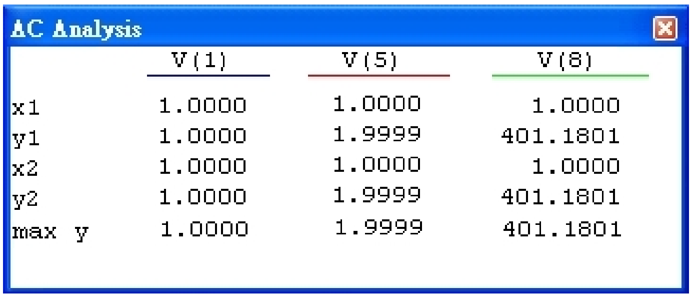
Were the waveform and frequency of the gained signal altered?

2.2.2 Results of Electronic Circuit Analysis

Our analysis of the electronic circuit settings, the signal gain of the pre-amplifier circuit and the bandwidth and frequency of the gained signal were as follows:

- **Results of pre-amplifier gain**

The first-stage amplifier gain was 1.999, the second-stage amplifier gain 200.6 and the total pre-amplifier gain was 401.1801, as shown in the data from figure 3.



AC Analysis

	V(1)	V(5)	V(8)
x1	1.0000	1.0000	1.0000
y1	1.0000	1.9999	401.1801
x2	1.0000	1.0000	1.0000
y2	1.0000	1.9999	401.1801
max y	1.0000	1.9999	401.1801

Figure 3 Diagram of AC analysis

- **Results of electronic circuit bandwidth**

The frequency at which the output power gain drops to 50% of the maximum sampling frequency is the cutoff frequency.

The cutoff frequency of chip-LM324 is 4.94 kHz, within the accepted range of brainwave frequency between 0 to 38 Hz. Hence, the bandwidth of our electronic circuit did not affect the signal acquisition. The data of the cutoff frequency are shown in figure 4.

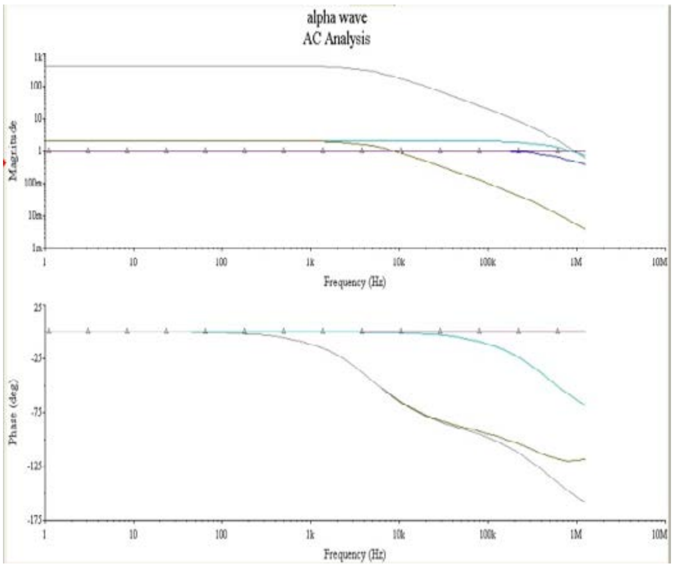


Figure 4 Diagram of electronic circuit bandwidth

- **Results of waveform and frequency of gained signal**

The simulated signal is a 10 Hz sin wave with amplitude of 50 μV, and the gained signal is still a 10 Hz sin wave. Figure 5 shows the waveform and frequency of the gained signal.

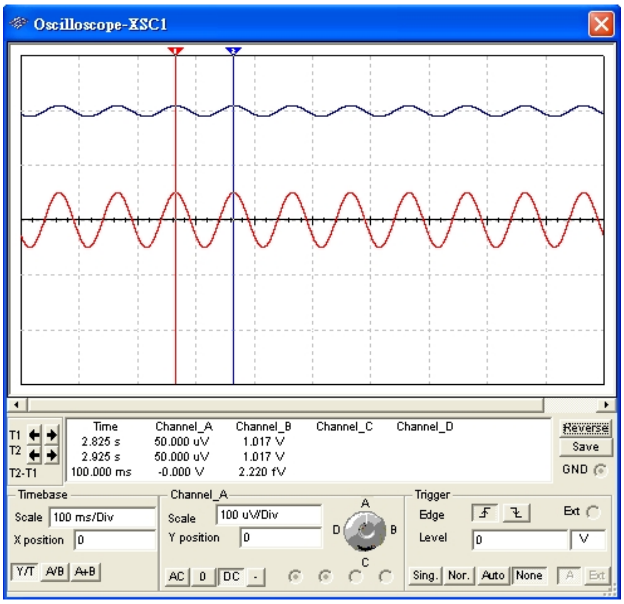


Figure 5 Diagram of waveform and frequency of gained signal

Our electronic circuit analysis showed a pre-amplifier gain of 401.1801, close to the theoretical value of 402; an electronic circuit bandwidth of 4.94 kHz which does not affect the signal acquisition; and that the waveform and frequency of the gained signal were not changed.

2.3. Implementing a Neural Recording and Measurement System

After we analyzed our electronic circuit simulation, we implemented our real circuit, incorporating both the pre-amplifier circuit and our system for recording and measuring brainwaves. Below we describe in more detail our pre-amplifier circuit and our brainwave measurement system.

2.3.1. Pre-amplifier circuit

Our pre-amplifier circuit was implemented based on our electronic circuit simulation. We show a diagram of the pre-amplifier circuit in figure 6.

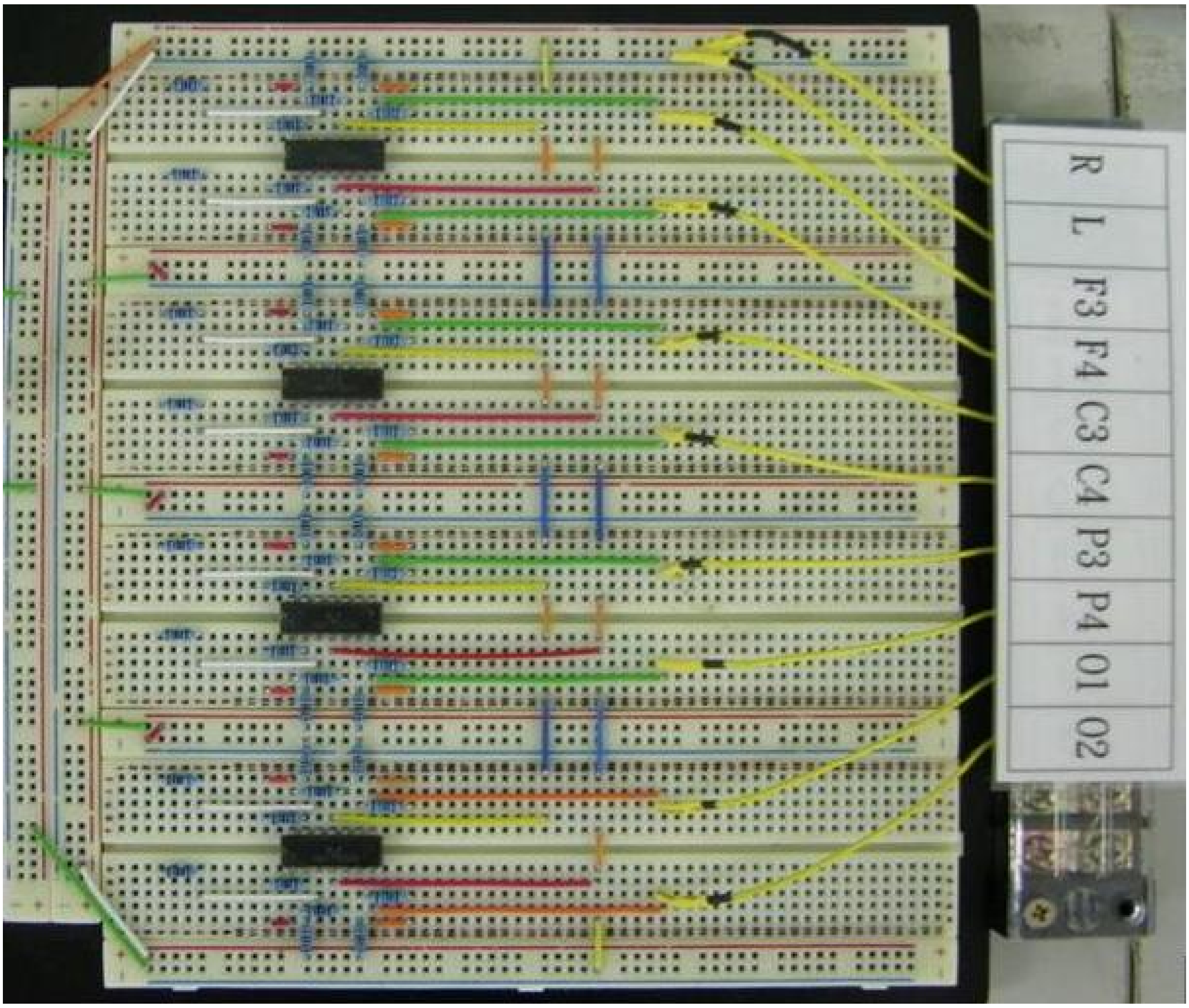


Figure 6 Diagram of pre-amplifier circuit

2.3.2 Data Recording System

We constructed our brainwave data recording system using Labview, a suitable programming environment for controlling electronic testing equipment, with the following hardware and software: personal computer with a data acquisition card (PCI-6221, National Instruments) running on Microsoft XP sp3 operating system.

The PCI-6221 card has a fast (up to 250 kHz sampling rate) 16-bit analog to digital converter (ADC). The sampling rate of each channel was 250Hz. EEG data were amplified with the band-stop (notch) filter and cutoff frequency set at 60Hz to minimize 60Hz noise. A diagram of the data recording system is shown in figure 7. The brainwave data recording system utilized the following features:

- **Multi-channel setting**

Labview with eight analog input channels .

- **Sampling rate setting**

We set up a sampling rate at 250 Hz for each channel and a Samples to Read (STR) rate of 250 per second. The data recording system captured data from each channel per second.

- **60Hz noise reduction**

We connected Labview with a band-stop (notch) filter with cutoff frequency at 60Hz and butterworth order set at 3 to reduce 60Hz background noise.

- **Signal frequency range settings**

We connected Labview with a band-pass filter, butterworth order of 3, and set a frequency range of 8-13 Hz to record alpha brainwave signals.

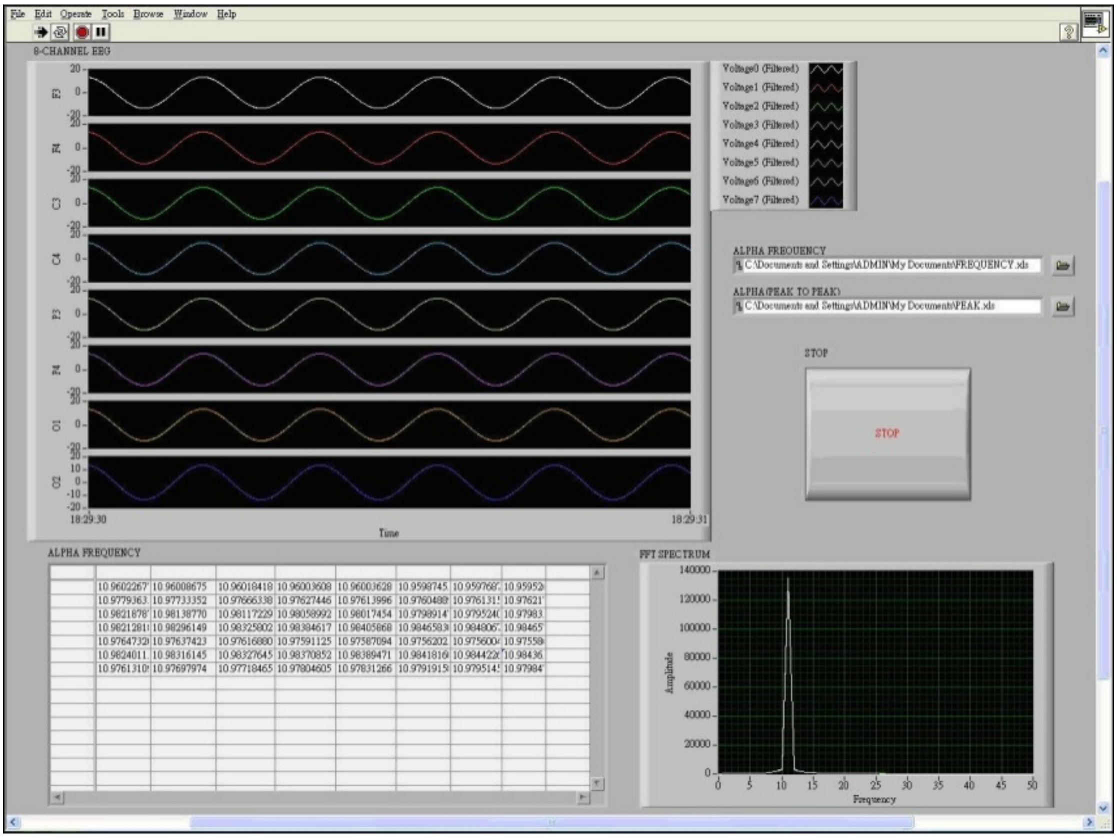


Figure 7 Diagram of data recording system

3 Validating the Pre-Amplifier and Measurement System

After implementing the electronic circuit, we carried out our EEG experiments.

3.1 Test subjects

Brainwave signals were recorded from fourteen adults (7 males and 7 females) who were students of academic institutes in Kaohsiung. All subjects were healthy without epilepsy or brain illness. The subjects were asked to sit in chairs and remain quiet. Electrodes were fixed to their scalps at points F3, F4, C3, C4, P3, P4, O1 and O2 according to the International 10-20 system. All electrodes were referenced to the ipsilateral ear electrode.

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3.2 Experiment results

The data of the experiment results are shown in Table 3.1 and 3.2. Table 3.1 represents the amplitude of the alpha brainwaves, while Table 3.2 represents the average frequency of the alpha brainwaves. The results are close to the theoretical values.

Table 3.1 Amplitude of alpha brainwaves

ITEM / Position	experiment results		
	Samples	Average	Standard deviation
F3	10	76.2	14.3
F4	12	73.2	14.7
C3	11	78.0	19.8
C4	6	78.2	18.8
P3	12	81.8	16.7
P4	11	80.7	18.8
O1	11	103.8	30.8
O2	12	106.8	40.5

Table 3.2 Average frequency of alpha brainwaves

ITEM / Position	experiment results		
	Samples	Average	Standard deviation
F3	10	10.1	0.2
F4	12	10.1	0.2
C3	11	10.3	0.2
C4	6	10.3	0.3
P3	12	10.4	0.3
P4	11	10.4	0.3
O1	11	10.5	0.4
O2	12	10.5	0.4

4 Discussions

The purpose of this study was to design a pre-amplifier circuit using simulation software, to implement a neural recording and measurement system, and to validate that the system is workable. From this study we can confirm that using simulation software will help researchers to develop brainwave or biological signals measurement systems.

5 Conclusions

We have verified the workability of our self-designed brainwave measurement system. Our work could lead to further research into biological signals measurement systems. Our study applies simulation software for designing a pre-amplifier circuit, but we have not explored the possibility of a mobile measurement system. Other researchers with an interest in developing brainwave measurement systems could look into the development of such a mobile system.

References:

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