Design of Transistor Amplification Circuit for SEMG Signal Processing

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ABSTRACT

Nowadays, science and technology have penetrated the medical field and played an indispensable role. The main purpose of this paper is to research Surface Electromyography (SEMG) signal processing systems. During the research, the article firstly presented a flowchart of SEMG signal processing. And then, the emphasis was placed on the studying of signal amplification operation in the process. In order to demonstrate how this process achieves amplification, the article designs a simple amplification circuit in the second part. At the same time, its working principle was analyzed from the perspective of the basic component transistor. Finally, the article concludes that the SEMG signal processing system is a progressive process. Every step of it is very important. On the other hand, amplification operation is essential, and the amplifier circuit constructed by the NPN Bipolar Junction Transistor can achieve signal amplification. Different amplification factors can be achieved by adjusting the internal variable resistance of the circuit. This paper not only introduces readers to the processing process of SEMG signals, but also tells them how to design an amplifier for SEMG signal amplification. The author wants to tell readers that combining the theoretical knowledge with practical application is very meaningful.

CCS CONCEPTS

• **Hardware** → Communication hardware, interfaces and storage; Signal processing systems; Digital signal processing; Communication hardware, interfaces and storage; Sensors and actuators; • **Applied computing** → Life and medical sciences; Health informatics.

KEYWORDS

SEMG signal processing, Flowchart, Amplifier, NPN Bipolar Junction Transistor

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1 INTRODUCTION

With the progress of the times. The science and technology are more closely related to the level of medicine. Doctors and medical researchers prefer to use some technology to solve problems. Compared to some traditional medical treatment methods, science and technology not only improve the efficiency of treatment, but also improve the accuracy of treatment. They have continuously made breakthroughs in research of medicine, and the speed is getting faster and faster. Wearing intelligent devices can monitor Health data [1]. Some artificial intelligence can predict Protein structure [2]. These technologies have truly benefited human health. So, it is meaningful to study some technology involved in medicine.

In certain medical fields. Some advanced signal acquisition and processing methods start to appear and have had a huge impact on it. The theme of this article is to study the processing process of Surface electromyographic signal which is generated when muscle contract. It can reflect the activities of muscle, thus reflecting the health status of the body. The purpose of this process is to transform muscle conditions that we cannot observe into visual information. Of course, it is not an easy task. It often requires complex processes such as signal acquisition, amplification, filtering, and computer analysis. The most important part of this is the amplification. To better showcase this process. The article also designed a simple amplifier. Before that, article will also show the core component of the amplifier, transistor, and then analyzed its working principle and construct a simple amplifier based on its working principle. Finally, MATLAB simulation was used to demonstrate how to achieve amplification.

The significance of this article is that it presents a specific medical testing process and visually demonstrates how technology affects medicine. Readers can also understand the working principle of amplifiers from a theoretical perspective, which can also be a meaningful knowledge extension.

2 SEMG SIGNAL PROCESSING FLOW

2.1 Definition of SEMG Signal

EMG is an Abbreviation of Electromyography, and EMG signal is an electrical signal which can record muscle activity. It measures and records the changes in electrical potential generated during muscle contraction and relaxation [3]. EMG signals can be used to analyze and assess muscle function, motor control, motor disease and rehabilitation [4].

Action potentials are electrical signals generated inside nerve cells. These signals are used for information transmission and conduction in the nervous system. Normally, the resting potential of the neuron is maintained by a difference in the concentration

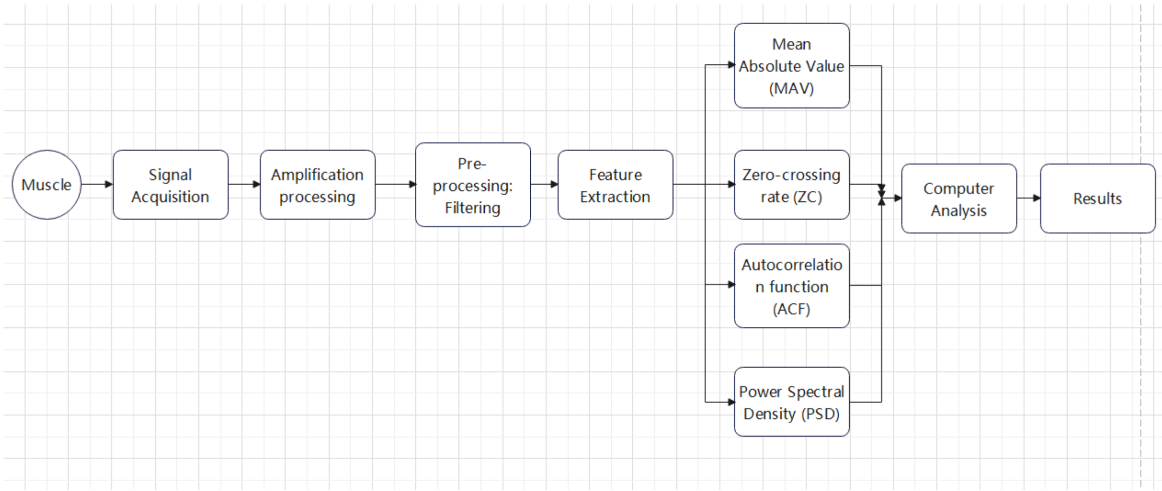

Figure 1: SEMG signal processing flowchart

of ions inside and outside the cell membrane. When a neuron is stimulated sufficiently, for example by chemical or electrical signals from other neurons, ion channels in the cell membrane open rapidly, causing a change in the balance of ions inside and outside the cell. This change causes a transient reversal of the charge distribution inside and outside the cell, resulting in action potential [5].

Action potentials from several muscle fibers' motor units are superimposed in time and space to create an EMG signal. Surface electromyographic signal (SEMG) is the combined effect of superficial muscle EMG and electrical activity on the nerve trunk on the skin surface, which can reflect neuromuscular activity. Compared with EMG, SEMG has the advantages of non-invasive and simple operation in measurement. Therefore, SEMG signals have gradually started to replace EMG signals for comprehensive clinical nondestructive diagnosis [6].

Human SEMG, however, is weak, easily distorted, and challenging to measure. The primary difficulty for SEMG applications now is how to efficiently collect SEMG and how to process the received data. The amplifier is a key component in SEMG signal processing. It is mainly used to amplify the weak electrical signals generated by the muscles to a level suitable for recording and analysis. In this way, doctors, researchers, or rehabilitation professionals can better understand and evaluate muscle activity and use it for diagnostic, research, or rehabilitation treatment purposes.

2.2 Signal Processing Flow-Block Diagram

For SEMG signal processing, there is a general flow as shown in the Figure 1. Firstly, stick the electrode at the corresponding muscle position and connect the sensor. After starting the collection, the sensor transmits the SEMG signal to the receiver. Then amplify and filter the signal, thus, the received information will become clearer. Finally, the processed signal is transmitted to the computer, and subsequent processing will be carried out on the computer.

After the above process, muscle conditions which are difficult to detect by human will be presented in intuitive data or visual waveform. This will bring generational significance to medical research.

2.2.1 Signal Feature Acquisition. The first step is signal acquisition, the SEMG signal is captured from the target muscle through surface electrodes. The appropriate surface electrodes should be selected to acquire the SEMG signal from the muscle surface. Make sure the electrodes are in good contact with the muscle and placed at the appropriate location on the target muscle. The electrodes are attached to the surface of the target muscle while ensuring that the electrodes can make good contact with the skin.

2.2.2 Signal Amplification. In general, muscle action will produce a potential difference of -90mV to 30mV, and since the human body is a poor conductor of electricity and can be regarded as a 1MΩ resistance, only a peak of about 1mV can be obtained from the patch electrodes on the body surface [7]. Therefore, the signal needs to be amplified after it is collected.

2.2.3 Filtering. Filtering is the operation of filtering out specific frequency bands from a signal, and it is an important measure to suppress and prevent interference. SEMG is often mixed with very low frequency (Almost equivalent to DC) and high frequency interference signals, while the effective SEMG signal spectrum is distributed between 10-500Hz [8]. Therefore, the signal detected from the patch electrode needs to be filtered.

2.2.4 Feature Extraction. After the Signal feature acquisition and amplification operations, useful features need to be extracted from the processed SEMG signal to describe muscle activity patterns and parameters. The main parameters include MAV, ZC, ACF, and PSD. MAV is Main Absolute Value, and the average of the absolute values of the calculated signals is used to describe the amplitude of muscle activity. ZC is Zero-Crossing, calculating the number of times of the signal passes the zero point can describe the frequency of muscle activity. ACF is Auto Correlation Function, which is used to describe the time-domain characteristics of the muscle activity. PSD means Power Spectral Density of the signal, which is used to describe the spectral characteristics of the muscle activity.

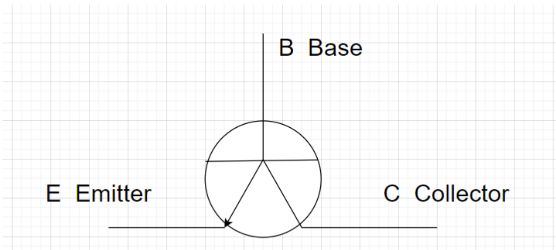

Figure 2: Structure model of NPN Bipolar Junction Transistor

3 TRANSISTOR-BASED EMITTER AMPLIFIER DESIGN

3.1 Definition of Bipolar Junction Transistors (BJT)

Transistors are one of the most important circuit components in modern electronics. They refer to all single components based on semiconductor materials. Their applications span from the amplifiers in analog electronics to logic circuits in digital electronics and to load switching in power electronics [9]. Bipolar Junction Transistors is a semiconductor device that controls electric current. As a type of transistor, it has a current amplification effect [10]. On the semiconductor substrate of a Bipolar Junction Transistor (BJT), there are two PN junctions close to each other. And the entire semiconductor will be divided into three parts by two PN junctions, the middle part is the base area, the two sides of the part is the emission area and collector area [11]. BJT can be divided into PNP and NPN according to the arrangement. In the subsequent design of the amplifier circuit, NPN type Bipolar Junction Transistors are mainly used [12].

3.2 Working Principle and Working Area of NPN Type BJT

NPN is a Bipolar Junction Transistor consisting of two N-type semiconductors sandwiched between a P-type semiconductor. N refers to negative, P refers to positive. As mentioned above. The two PN junctions of the BJT divide itself into three electrodes [13]. They are the base (B), collector (C) and emitter (E). As shown in Figure 2 below.

BJT as a control element, its main role is to control the amount of current. When the base voltage UB has a small change, the base current IB will also have a small change. Due to the influence of the base current IB, the collector current IC will have a change at the same time. But the change in collector current is much larger than the change in base current, which is the amplification function of the transistor. In this case, theoretically there would be a linear relationship between IC and IB: $I_C = \beta I_B$. This relationship plays a major role in the general amplifier circuit. As shown in Figure 3 below.

In order to verify this linear relationship, MATLAB can be used as a great calculation and simulation software. The simulated linear relationship is shown in the following Figure 4.

It is important to keep in mind that a proper bias circuit needs to be added to the real amplifier circuit, because of the non-linearity

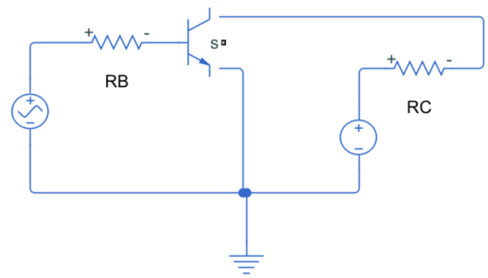

Figure 3: Basic circuit diagram of NPN Bipolar Junction Transistor amplifier

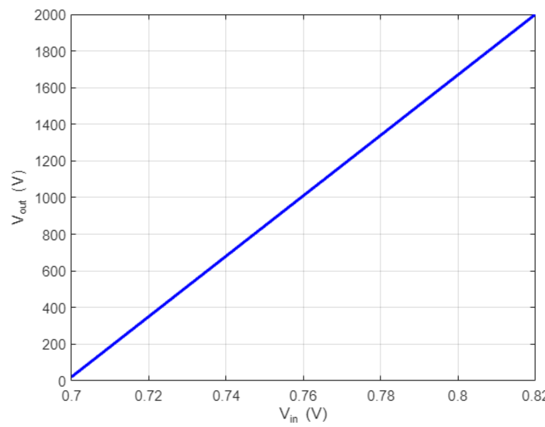

Figure 4: Diagram of the relationship between input signal and output signal under ideal conditions

of the Bipolar Junction Transistor BE junction. Once the input voltage is sufficient, the base current will be generated, typically 0.7 V. However, the base current can be regarded as zero if the voltage between the base and the emitter is below 0.7 V. The signal that needs to be amplified always much lower than 0.7 V. Such a weak signal won't be enough to alter the base current in the absence of bias. Thus, the RB is required.

RC of the circuit in Figure 3 is a fixed value, then the maximum current should be U/RC. So the collector current cannot be increased indefinitely. When the increase in the base current cannot continue to influence the collector current, the transistor enters a saturation state. If the base current is 0 as mentioned above, transistor will be the cutoff state. The operating state of the BJT in all cases should be as shown in Figure 5 below.

3.3 Design Emitter Amplifier Circuit

The next step is to build the circuit. The expected result is to design a common emitter amplifier that amplifies the voltage signal to 10 times at a load of 100000Ω, and the circuit current should be kept below 10mA for safety. The E6 resistors were selected for designing the amplifier circuit in order that the appropriate

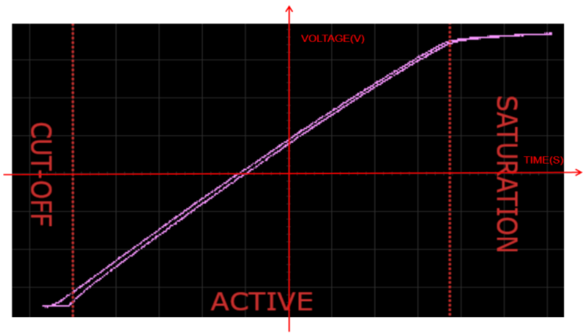

Figure 5: Three operating state distribution diagrams of amplifiers

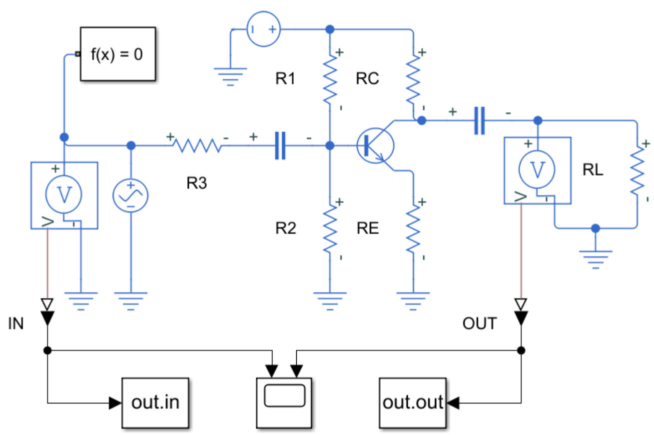

Figure 6: Designed amplifier circuit diagram

resistor series could be selected according to the accuracy of the circuit design. They usually provide an adequate range of choices in general applications and are relatively common and easily available. The components used in the design of the circuit are E6 series resistors, two Ceramic capacitor, a NPN transistor, 2 Voltmeters, An AC power supply, a DC power supply, and an oscilloscope.

The peak value of the AC voltage source is set to 0.1V and the frequency is 1000Hz. The DC voltage source is set to 12V. R3 and RL are fixed resistances, they are 50 ohms and 10,000 ohms respectively. RC is also a fixed resistance with 3300 ohms. The remaining resistors are used to control the amplification effect by changing the resistance value to control the voltage on the base and collector. An oscilloscope is used to display the results. The specific design diagram is shown in Figure 6.

The process of designing the circuit requires some optimization to achieve the best results. Before trying, some theoretical methods can be adopted to simply the process. Some simple optimizations are shown below.

$$A = 10 \approx -\frac{(R_C R_L)}{\frac{2V_T R_C}{V_{CC}} + R_E} \tag{1}$$

"A" refers to the amplification factor of the amplifier, "VCC" is DC voltage source in the circuit. "VT" is the thermal voltage, and it is usually equal to 0.025A. "R3" and "RL" can be considered as resistors that protect the circuit (allowing the circuit to operate normally and meet its operating conditions). "R1", "R2", "RC", "RE" are some variable resistors, and changing their resistance values can achieve different amplification effects. In this situation RE=234.37Ω can be calculated.

$$\frac{V_{CC}}{2R_C} \approx \frac{R_2 V_{CC} - R_1 U_{BE}}{R_E (R_1 + R_2)} \tag{2}$$

$$R_1 \approx V_{CC} \frac{2R_C - R_E}{2R_C U_{BE} + R_E V_{CC}} R_2 \tag{3}$$

$$I_{max} \cong V_{CC} \frac{R_C + R_E + R_1 + R_2}{(R_C + R_E)(R_1 + R_2)} \tag{4}$$

The current in the circuit cannot exceed a specific value, as exceeding it may cause some danger. Assuming this value is 10mA (I max=10mA). The above calculation gives result R1=1655.764Ω, R2=161.104Ω. Then MTALAB will show the simulation results as shown in the Figure 7 below.

The obtained amplification is approximately 5 times, it requires further adjustment. So the resistance values should be rounded to the nearest E6 series value and simulate again which is shown in Figure 8.

When RE=150Ω, R1=2200Ω, R2=220Ω. The obtained amplification will be 10 times. This shows that the designed circuit above is feasible, and the amplification factor of the amplifier can be controlled by changing the resistance values of R1, R2, and RE. Thus, different amplification effects can be achieved.

4 CONCLUSION

The above article explains the definition of SEMG signal and its significance in medical research. Then demonstrates the basic process of SEMG signal processing. The article emphasizes the amplification operation in the process. An amplifier is required, and the article proposes a design concept for a simple amplifier. For SEMG signals, it is a class of EMG signals. Compared to needle electrode EMG, SEMG has the advantages of non-invasive and simple operation in measurement. So SEMG is mostly used to detect the muscle condition of the human body in modern medicine. For the SEMG signal processing, the flowchart in the previous text has been well demonstrated. It is a progressive flowchart, which means that every step is important. Moreover, the SEMG of the human body is very weak. So, the amplification operation is necessary. For the design process of amplifiers, it is important to consider the principle of transistors when designing them to meet the positive state. Then the circuit diagram designed in the above article achieved amplification effect. This indicates that the method proposed in the flowchart is feasible.

This type of SEMG signal processing is currently considered very advanced. But there are also many shortcomings. The biggest drawback is that electrodes need to be attached to specific muscles when extracting raw signals. Moreover, the current signal processing technology is not yet very mature. Most hospitals still use needle electrodes to detect EMG signals. This is undoubtedly very inconvenient. So, the author hopes to solve this problem in the future. By using more advanced methods such as infrared detection

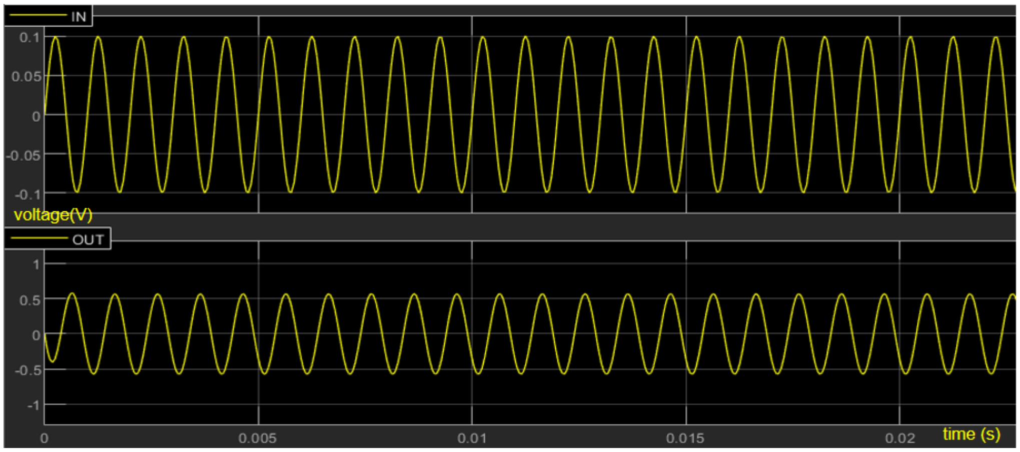

Figure 7: Amplifier rendering simulated with MTALAB

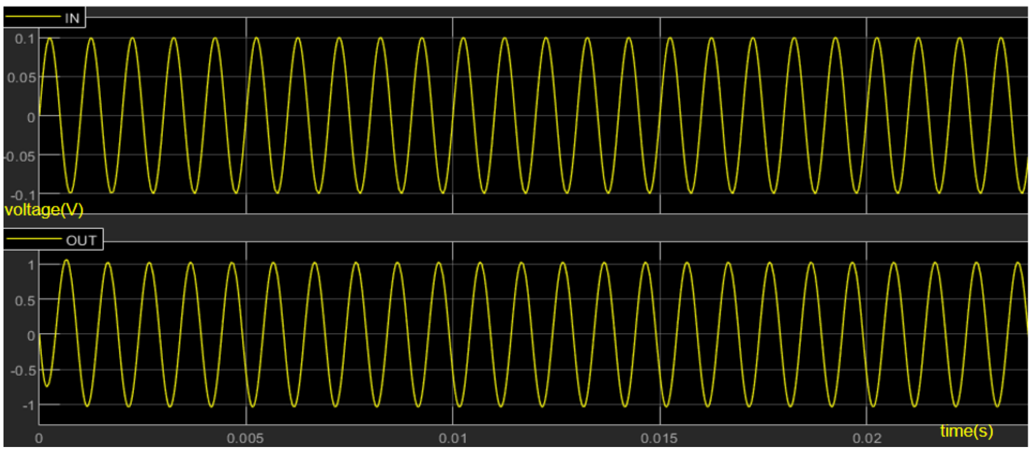

Figure 8: Optimized Amplifier rendering

technology. Information can be extracted by simply scanning the corresponding positions.

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