Design and Implementation of a Low-Frequency Band-Pass Circuit for EMG Signal Detection

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I. Introduction

The human body is a complicated system with numerous functions and activities that are not yet completely understood. Biomedical signals, such as the electrocardiogram (ECG), electromyogram (EMG), and electroencephalogram (EEG), can provide insight into the functioning of the human body. Electrical signals, in particular, are characterized by their frequency, amplitude, and phase, making them easy to study and an effective tool for understanding the body and its activities. EMG is a technique used to measure and record the electrical activity of muscles, which occurs when muscles contract or relax and is caused by the flow of ions across the muscle fiber membrane. The EMG signal is influenced by both physical movement and neurological activity, and is used in a variety of fields, including clinical rehabilitation, sports science, ergonomics, and biofeedback. [2]

Both invasive and non-invasive techniques can be used to acquire EMG signals by inserting probes into the tissue or placing surface electrodes on the skin over the muscle, respectively. Surface EMG is utilised frequently in clinical settings due to its portability, ease of use, and relatively low cost. We intend to design a data acquisition circuit with as few components as possible in order to reduce its size.

The EMG signals have a frequency range of 0.01 Hz to 10 kHz, with a practical frequency range of 20Hz to 200Hz. Multiple factors, including the interaction of the electrode with the skin, radiation from the power source at 50Hz (or 60Hz), blood flow velocity, etc., cause these low frequency signals to get distorted. Consequently, filtering out undesired signal is a key challenge.[1]

In this paper, we present the design and implementation of a low-frequency band-pass circuit for EMG signal detection. We describe the method of circuit design and the optimization of circuit parameters to obtain the desired frequency range while minimizing the number of components. The findings of our experimental testing of the circuit, including its performance characteristics, are also presented. Finally, we analyze the potential applications and limits of the circuit.

II. Circuit design and implementation

The EMG signals recorded from the electrodes/sensors contain a lot of noise. These can arise from various sources like electrode contacts, ambient surroundings, power supply, and cross talk. A lot of frequency distortion is induced into the EMG signal which needs to be removed. The objective of the circuit is to convert the raw EMG signal from electrodes to a refined signal which can be used for further processing. The proposed circuit comprises a pre-amplifier stage, a bandpass filter, and a post-amplification stage.

A. Preamplifier

The preamplifier is implemented to amplify the signal strength so that filtering can be possible. The

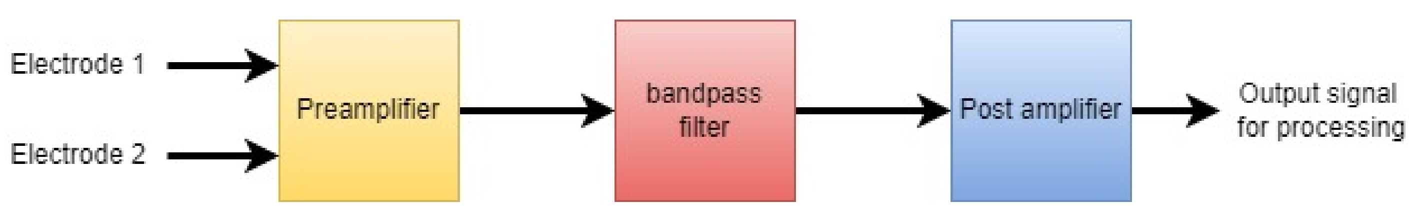

Fig. 1. Block Diagram Representation of the EMG Detection Circuit

primary function of a preamplifier is to extract the signal from the detector without significantly degrading the intrinsic signal-to-noise ratio. Therefore, the preamplifier is located as close as possible to the detector, and the input circuits are designed to match the characteristics of the detector. The preamplifier used is an instrumentation amplifier (AD620).

B. Bandpass filters

The bandpass filter is required to filter out all the low-frequency noise and to remove the undesired high-frequency components from the signal. The filter is designed by combining a low pass and a high pass filter. The lower cutoff frequency is kept at 20Hz and the higher cutoff frequency is 200Hz. The circuit is being designed from the second-order Sallen key filters.

To reduce the number of components and the complexity of the circuit, the first-order passive bandpass circuit was also designed. RC low pass and high pass filters were stacked together to form the bandpass filter with 20Hz as the low cutoff frequency and 200Hz as the high cutoff frequency.

C. Post amplifier

In order to obtain a final signal that can be processed and analyzed further by control and storage elements, some post-amplification is necessary. With sufficient gain, the signal can be made usable beyond the processing circuit. In the circuits, the post-amplification is done with an OP1177 amplifier which provides a gain of 78dB.

D. Notch Filter

A notch filter was implemented to cut off the noise at 60Hz induced by the power supply. Keeping in mind the complexity and number of components, it was also designed using both active and passive components. A comparison was made to find out the most suitable configuration as per the needs and requirements. The results for the same are presented in Table 1, where we compare the essential metrics; the lower cutoff frequency f_L, the upper cutoff frequency f_H and bandwidth. The bandstop range is also measured for the circuits utilizing a notch bandstop filter.

However, the notch filter showed poor roll-off and consumed a lot of useful bandwidth. Hence, it was deemed unsuitable for the final circuit.

III. Simulation and Results

The circuits were designed and simulated on LT-Spice. Small signal AC analysis was performed to find out the frequency response of the circuits. The input chosen was 5.5mV, comparable to the actual EMG signals.

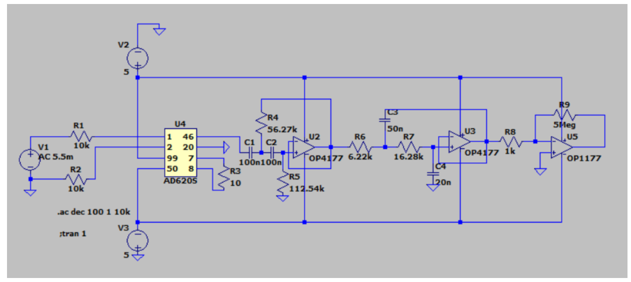

Fig. 2. Sallen Key Active Bandpass Filter Circuit Schematic

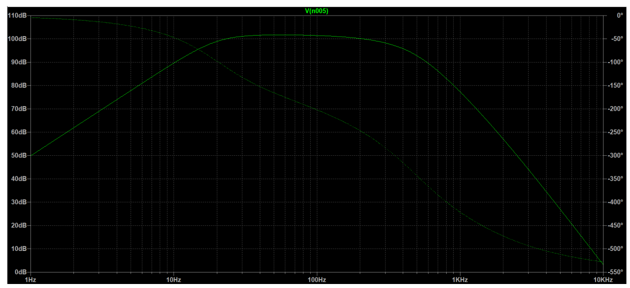

Fig. 3. Sallen Key Active Bandpass Filter Circuit Schematic

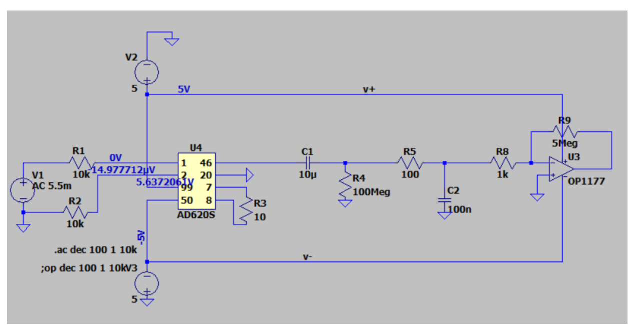

Fig. 4. Passive Bandpass Filter Circuit Schematic

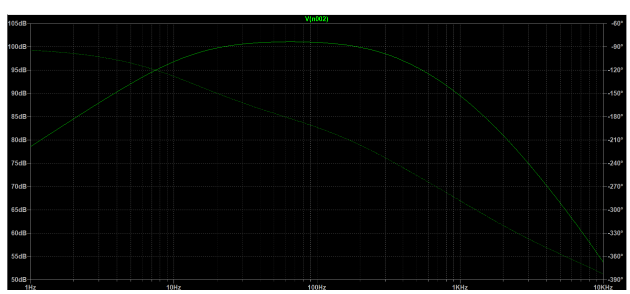

Fig. 5. Sallen Key Active Bandpass Filter Circuit Schematic

Circuit	f_L (Hz)	f_H (Hz)	Bandwidth (Hz)	Notch Bandstop
Active BPF, no notch	13	328	315	-
Passive BPF, no notch	18	305	287	-
Active BPF, Active notch	18	305	287	37.7 - 97.7Hz
Active BPF, Passive notch	18	305	287	34.3 - 117Hz
Passive BPF, active notch	13	328	315	34.4 - 100.8 Hz
Passive BPF, Passive notch	13	328	315	25.7 - 105 Hz

TABLE I
COMPARISON OF DIFFERENT FILTER DESIGNS

For the active bandpass circuit, the lower cutoff frequency is 13 Hz and the higher cutoff frequency is 328 Hz. The overall gain is 146dB. For the passive bandpass circuit, the lower cutoff frequency is 18 Hz and the higher cutoff frequency is 305 Hz. The overall gain is 146dB. The results for various configurations are present in table 1.

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