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Design Considerations for a Robust EMG Amplifier

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Abstract: ***As the field of medicine and healthcare technology is flourishing with each passing day, it has become more important for an electronics system designer to understand the nuances of this field. The technologies like EMG, ECG and EEG are being used extensively in the new designs of healthcare equipments. This paper has been focused mainly on the signal amplification stage for EMG signals. The muscle activity of a human body produces electrical signals called as electromyogram (EMG). These signals have to be processed and amplified for the accurate analysis of the muscle activities. The amplification of EMG signals is of utmost importance in the fields such as prosthetics, rehabilitation, movement analysis etc. This paper gives review of all the packages and techniques that can be used while designing the EMG front-end amplifier. The paper lists and compares several IC packages used for various stages of amplification. Choosing the right components while designing, which is considered one of the most time consuming tasks, becomes much easier with the comparisons and explanations given in this paper. This paper provides researchers a good understanding of EMG signal amplification and its stages in detail. This knowledge will help them develop more powerful, flexible, and efficient applications.***

Keywords: EMG signals, bio-amplifier, signal amplification, biomedical, Instrumentation Amplifier, Operational Amplifier

1. Introduction

EMG testing has a variety of clinical and biomedical applications. So far, research and extensive efforts have been made in the area, developing better algorithms, upgrading existing methodologies, improving detection techniques to reduce noise, and to acquire accurate EMG signals. Few hardware implementations have been done for prosthetic hand control, grasp recognition, and human-machine interaction. It is quite important to carry out an accurate processing of these signals to achieve optimum results. EMG signal is a bio-potential signal and thus a brief knowledge of the bio-signals is essential to understand the concept properly.

2. Bio Signals

A bio signal is a signal generated by living beings which can be continually measured and monitored. The term bio signal is often used to refer to bioelectrical signals, but it may refer to both electrical and non-electrical signals in a human body. The usual understanding is to refer only to time-varying signals.

Electrical bio signals, or bioelectrical time signals, usually refer to the change in electric current produced by the sum of an electrical potential difference across a specialized tissue, organ or cell system like the nervous system. Thus, among the best-known bioelectrical signals are: EEG (Electroencephalogram), ECG/EKG (Electrocardiogram), EMG (Electromyography), MMG (Mechanomyogram) etc.

2.1 Electromyography

An electromyography (EMG) is a measurement of the electrical activity in muscles generated due to the flexion and contraction of muscles. An EMG is the summation of action potentials from the muscle fibers under the electrodes placed on the skin. As more muscles fire, greater is the amount of action potentials recorded and greater the EMG reading.

The EMG is generated when a motor neuron action potential from the spinal cord arrives at a motor end plate. Its arrival causes a release of ACh (Acetylcholine) at the synaptic cleft. This electrical activity can thus be measured and detected at the skin surface using non-invasive surface mounted EMG electrodes.

Pertaining to its efficiency in measuring and detecting the muscle activity, EMG has a widespread use in Orthopedics, Surgery, Functional Neurology, Gait & Posture Analysis, Biomechanics, Movement Analysis, Athletes Strength Training, and Prosthetics

3. Factors affecting EMG Signals

Basically the factor affecting the EMG signal quality can be categorized in three types:

- **Extrinsic factors**: Noise introduced by the environment of the amplifier can be considered as extrinsic factors such as signal distortion due to equipment, electrode placement and positioning, background electromagnetic radiation.
- **Intrinsic factors**: The noise introduced by the human body can be considered under Intrinsic factors such as, motion artefacts, random nature of motor firing unit, aberrant signal from the central nervous system, blood flow in the muscles, the amount of non-muscle tissue under the electrode, crosstalk from other active muscle fibres, and the duration of the intracellular action potential.
- **Determinant Factors**: These are the factors that arrive primarily due to the activity of Central nervous system. These factors include both motor unit recruitment and motor unit firing frequency. As the signal from the central nervous system is not continuous, the op-mp must be capable to recognize and amplify the erratic signals coming at its input terminal. Many a times this results in borrowing signal from the neighboring muscle producing inaccurate results.

4. EMG Amplifiers

Amplifier Requirement:
- Low internal noise
- Input impedance greater than 10 MΩ
- Flat bandwidth with sharp high and low frequency cut-offs
- High common mode rejection ratio
- Static electricity shock protection circuitry to limit the current through the electrode to safe level
- Adjustable Gain
- Output impedance should be low to drive an external load with minimal distortion

EMG-amplifiers act as differential amplifiers and their main purpose is the ability to reject or eliminate noise signals. The differential amplification detects the difference in potential between the electrodes and cancels out external interferences. EMG amplifiers typically consist of the following stages:
1. Pre-amplifier/ Differential amplifier/ Instrumentation amplifier stage
2. Band Pass Filtering (LPF and HPF) stage
3. Rectification stage
4. Smoothing stage

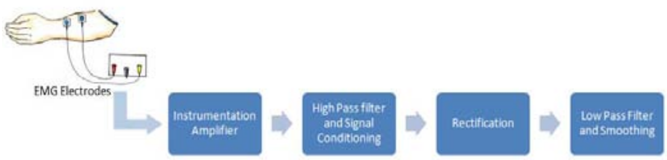

Figure 1: Block Diagram of EMG amplifier

4.1 Instrumentation Amplifier stage

Instrumentation amplifiers serve as an important signal conditioning block at the front end for the amplification of bio signals. The instrumentation amplifier is a typical precision closed loop gain block having a pair of differential input terminals and a single ended output working with respect to a common reference terminal.

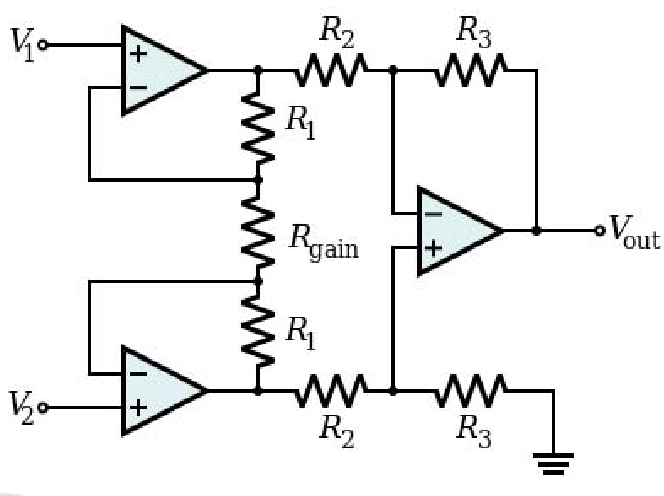

Figure 2: Typical 3 op-amp instrumentation amplifier

Instrumentation amplifiers do not require external feedback resistors as they have laser-trimmed resistors fabricated on the IC itself. The instrumentation amplifier makes use of a single external resistor for setting the gain of the circuit as and when required. Most biomedical sensors such as blood pressure sensors, ultrasound transducers, polarized and non-polarized electrodes, and radiation thermometry transducers have very high impedance and generate signals of very low magnitude. As the characteristics of bio potential electrodes can cause distortion of the signal, an instrumentation amplifier offers the required high input impedance to cancel out noise and signal distortion.

A comparison of few instrumentation amplifiers used for EMG signal amplification is presented below:

Table 1: IC package comparison for Instrumentation Amplifier Stage

Sr No.	Integrated Circuit Package	Gain	Input Impedance	CMRR	Power supply required	Operating Voltage
1	INA106	10	10kΩ	86dB	±18V	±15V
2	INA128	100	10^{10}Ω	120dB	±18V	±15V
3	INA122	5 to 10k	10^{10}Ω	96dB	±18V	
4	INA333	1 to 1000	100Ω	100dB	±5V	
5	INA141	100	10^{10}Ω	117dB	±18V	±15V
6	INA114AP	1 to 10k	10^{10}Ω	115dB	±18V	±15V
7	AD620	1 to 10k	10^{10}Ω	130dB	±18V	
8	AD623	1 to 1000	2GΩ	110dB	±5V	
9	AD8223	5 to 1000	2GΩ	96dB	±12V	±10V
10	AMP04	1 to 1000	4GΩ	85dB	±15V	

4.2 Band Pass Filtering Stage:

- **Active Filters:**

Active Filters contain active components such as operational amplifiers, transistors or FET's within their circuit design. They draw the power required for functioning from an external power source and use it to boost or amplify the output signal. An active filter generally uses an operational amplifier (op-amp) within its design. These are typically active high pass and active low pass filter with substantial amount of gain.

- **High Pass Filter**:

A high-pass filter is an filter designed using an operational amplifier that passes signals with a frequency higher than a certain cutoff frequency and attenuates signals with frequencies lower than the cutoff frequency. The amount of attenuation for each frequency depends on the filter design. The simplest form of an active high pass filter using op-amp can be achieved by connecting a standard inverting or non-inverting operational amplifier to the basic RC high pass passive filter circuit. The cut off frequency is set around 10 kHz at the high pass filter stage

- **Low Pass Filter:**

A filter that passes signals with a frequency lower than a certain cut-off frequency and attenuates signals with frequencies higher than the cut-off frequency, is called active low pass filter. The exact frequency response of the filter depends on the filter design. The simplest form of a low pass active filter is to connect an inverting or non-inverting amplifier. The cut off frequency is set around 5Hz at the low pass filter.

4.3 Rectification Stage

Rectification is the translation of the raw EMG signal to a single polarity frequency. The purpose of rectifying a signal is to ensure the raw signal does not average zero, due to the raw EMG signal having positive and negative components. It facilitates the signals and process and calculates the mean, integration and the Fast Fourier Transform (FFT). The rectifier will take the negative portion of EMG pre-processed signal and turn it positive so the entire signal falls within the positive voltage region.

4.4 Smoothing Stage

Rectification stage is combined with a low pass filter to give a smooth and even signal at the output. 2 algorithms are used for smoothing the EMG signals "Moving Average" and "Root mean Square" Algorithm. The steep amplitude spikes of amplified EMG signals are cut away and the signal receives a "linear envelope".

For all the stages except the instrumentation amplifier stage, an op-amp can be used. The table below indicates all the Op-amp packages that can be efficiently used along with an instrumentation amplifier for accurate gain results:

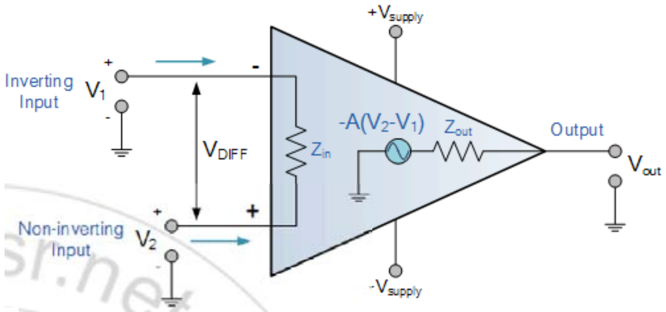

Figure 3: Typical Operational Amplifier

Table 2: IC package comparison of different Operational Amplifiers

Sr. No	Op-Amp IC package	Band-width	Open Loop Gain	Input Impedance	Common Mode Rejection	Operating Voltage
1	OPA2604	20MHz	100dB	$10^{12}\Omega$	100dB	±15V
2	TLO72P	3MHz	86dB	$10^{12}\Omega$	100dB	±15V
3	TLO84	3MHz		$10^{12}\Omega$	86dB	±15V
4	OPA2241	35kHz.	100dB	$10^{7}\Omega$	100dB	±15V
5	LF353	4MHz	100dB	$10^{12}\Omega$	100dB	±18V
6	TLO82CP	3MHz	120dB	$10^{12}\Omega$	86dB	±18V
7	OPA2650	36MHz	51dB	15kΩ	90dB	±5V

5. Bio potential front end amplifier packages:

5.1 ADS129X (Texas Instruments Series):

Texas Instruments Inc. introduced the ADS1298 a fully integrated eight channel analog front-end device for bio-electrical signal acquisition. Every channel has 24 bit resolution and an individual gain setting, ranging from 1to12.The highest resolution is only provided up to a sampling frequency of 8kS/s per channel, it decreases to 17bit at 16kS/s and 32kS/s. The chip requires a single supply voltage, ranging from 2.8V to 5.25V.

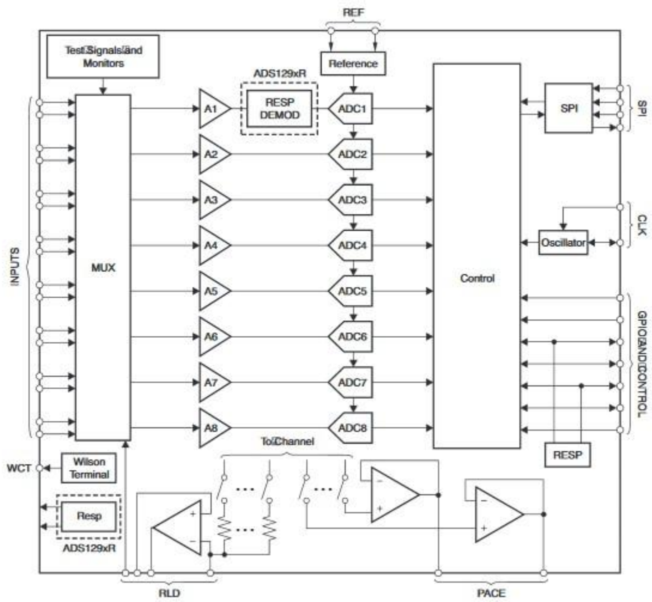

Figure 4: ADS129X bio-potential front end amplifier module

Features:

- Eight Low-Noise PGAs and Eight High-Resolution ADCs

- Programmable Gain:1, 2, 3, 4, 6, 8, or 12
- Unipolar or Bipolar Supplies:
  – AVDD = 2.7 V to 5.25V
  – DVDD= 1.65V to 3.6 V
- DC input impedance: 10MHz, 500MHz or 1000MHz (according to the lead-off settings)
- Bandwidth: 32 to 237 KHz (according to the gain settings)
- Signal to Noise ratio (SNR): 112dB

Even though the TI ADS129X series is mainly marketed for ECG and EEG use, EMG signals can be recorded since the frequency range is adjustable. Thus, this package enables the development of scalable medical instrumentation systems at significantly reduced size, power, and overall cost.

6. Conclusion

In this paper, the various IC packages have been explained and compared. The requirements are specified for a good EMG amplifier which involves high input impedance, high common mode rejection ratio, high and adjustable gain, sharp and steep cut-off frequencies for low and high pass filter etc. If the IC packages discussed are used in the circuit along with good combination of external components such as resistor, capacitors etc, the EMG front end amplifier will give accurate results with very high efficiency.

Among the instrumentation amplifiers discussed, INA128, AD620 and INA141 are found to give the most optimum results. Operational amplifiers used in conjunction with these instrumentation amplifiers need to have high noise cancellation and can be used in the form of band pass filter, rectifier and for the smoothing purpose. Of the operational amplifiers listed, OPA2604, TLO72P and LF353 have to capability to fulfil all the requirements of the amplifier giving a strong and clean output signal.

In addition to the individual amplifier IC's which can be used in combination to achieve good amplification of EMG signals, a bio-potential amplifier is also discussed which eliminates the need of any external circuitry. This amplifier is a low cost substitute for all the stages of amplification and amplifies the signal taking a Raw EMG signal as input and giving fully amplified signal with little to no noise element in the output

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- LF353
- TLO82CP
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