Electromyograph (EMG)

Purpose

An electromyograph (EMG) is an instrument used to study neuromuscular condition and function, extent of nerve lesion, reflex responses, etc. It is specifically used for recording the electrical activity of the muscles to determine whether the muscle is contracting or not; or for displaying the action potentials spontaneously or those induced by voluntary contractions for detecting the nature and location of motor unit lesions; or for recording the electrical activity evoked in a muscle by the stimulation of its nerve. EMG measurements are important for the myoelectric control of prosthetic devices (artificial limbs). Electromyography is the technique that deals with the detection, analysis, and use of the electrical signal that emanates from the muscles. The resultant record obtained via the electromyograph is known as electromyogram.

EMG Signal

The EMG signal is the electrical manifestation of the neuromuscular activation associated with a contracting muscle. The activity is similar to that observed in the cardiac muscle, but in the skeletal muscle, repolarization takes place much more rapidly, the action potential lasting only a few milliseconds. Since most EMG measurements are made to obtain an indication of the amount of activity of a given muscle, or a group of muscles, rather than of an individual muscle fiber, the EMG pattern is usually a summation of the individual action potentials from the fibers constituting the muscle or muscles being studied. The signal is affected by the anatomical and physiological properties of muscles and the control scheme of the nervous system.

In voluntary contraction of the skeletal muscle, the muscle potentials range from 50 μV to 5 mV and the duration from 2 to 15 ms. The signal lies in the frequency range 0-500 Hz and most dominant in between 50 and 150 Hz. The values vary with the anatomic position of the muscle and the size and location of the electrode. In a relaxed muscle, there are normally no action potentials. **Figure 1** shows a typical EMG signal characterized by positive and negative peaks. The amplitudes and frequency content of this signal provides information about the contraction or resting state of the muscle under study.

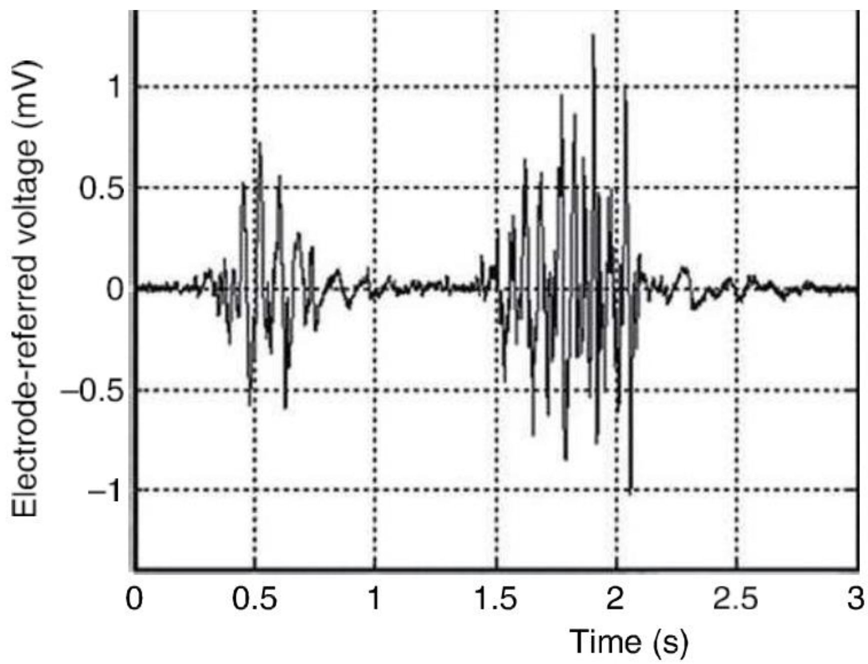

Figure 1: Typical EMG signal characterized by positive and negative peaks.

Electrodes

The electrical activity of the underlying muscle mass can be observed by means of sur- face electrodes on the skin. The surface electrodes may be disposable, adhesive types or the ones that can be used repeatedly. A ground electrode is necessary for providing a common reference for measurement. However, it is usually preferred to record the action potentials from individual motor units for better diagnostic information using needle electrodes, which are inserted directly into the muscle. The needle electrodes may be monopolar having a Teflon-coated stainless-steel wire, which is bare at the tip or bipolar containing two insulated wires within a metal cannula.

System Description

The block diagram in **Figure 2** shows the various subsystems in an EMG machine. The myoelectric signals are amplified by using a preamplifier followed by a differential amplifier together having an effective passband of 10-1000 Hz. The signals are sampled at 10kHz with 16 bit analog-to-digital converter (ADC), rectified, and smoothed with a running time window average with a window length of 240 ms that is updated every

80 ms. The processed signals are normalized by the amplitudes of the maximum voluntary contractions and are displayed on a computer monitor. The waveforms can be stored to facilitate playback and study of the EMG waveforms at a later convenient time. The waveform can also be printed as a hard copy for records. The output is also applied to an audio-amplifier connected to a speaker. A trained EMG interpreter can diagnose various muscular disorders by listening to the sounds produced when the muscle potentials are fed to the speaker.

The amplitude of the EMG signals depends upon the type and placement of electrodes used and the degree of muscular exertions. The needle electrode in contact with a single muscle fiber will pick up spike-type voltages, whereas a surface electrode picks up many overlapping spikes and therefore produces an average voltage effect. A typical EMG signal ranges from 0.1 to 0.5mV. They may contain frequency components extending up to 10kHz. Such high frequency signals cannot be recorded on the conventional pen recorders and therefore are usually displayed on the PC monitor screen.

Preamplifier The preamplifiers used for EMG are generally of differential type with a good bandwidth. The input impedance of the amplifier must be greater than 2 x 50 M2. Present-day differential amplifiers easily provide input impedances of the order of 102 in parallel with 5 pF. The signal from the EMG detecting surfaces is captured by appropriate electrodes with respect to a reference electrode that acts as a ground for the signal. It should be placed far from the EMG detecting surfaces, on an electrically neutral tissue.

The leads to the input of the preamplifier should be as short as possible and should not be susceptible to movement. This can be achieved by building the first stage of the preamplifiers very near the subject using very small electrode leads. This minimizes the undesirable effects of stray capacitance between connecting cables and the earth. Also, any movement of the cable from the output of the electrode will not generate significant noise signals in the cable, which feeds into the subsequent amplifier. The property of a differential amplification to reject signals common to both inputs is determined by common mode rejection ratio (CMRR). A CMRR of 90 dB is adequate for elimination of common signals for instrumentation amplifiers, but today's technology provides us with a CMRR of 120dB. A calibrating square wave signal of 100 μV (peak to peak) at a frequency of 100 Hz is usually available. The main amplifier has controls for gain adjustment from 5μV/div to 10 mV/div for selecting the sensitivity most appropriate to the incoming signal from the patient. To ensure patient safety, the subject should be electrically isolated from any electrical connection to the power line or ground. This isolation is achieved either using optical isolators or through the use of isolation transformers.

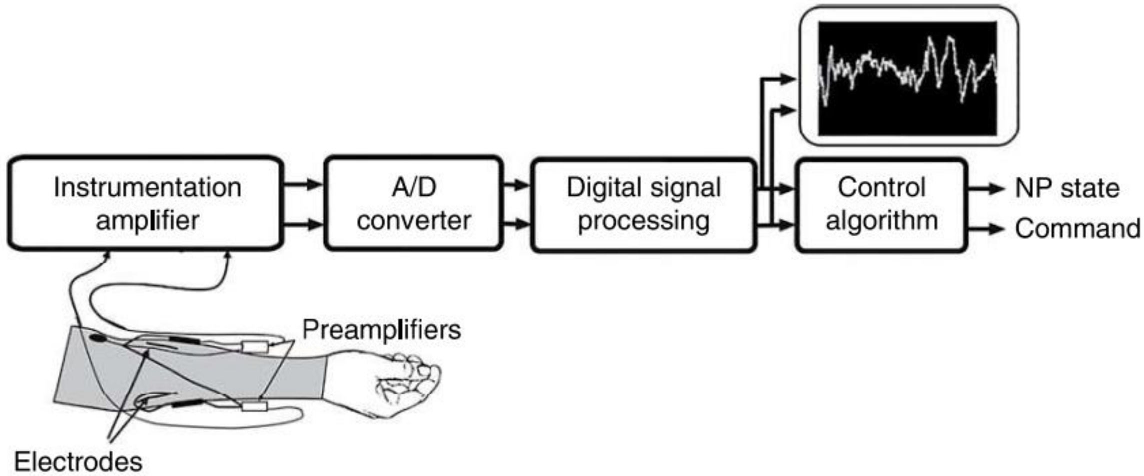

Figure 2: Block diagram of an EMG machine.

Digitization After proper amplification of the signal, a suitable band of EMG signal frequency is obtained. The signal is further amplified in a non-inverting amplifier to a suitable level. The amplified analog signal is then digitized with an ADC. Once the signal is digitized, it is given to a microcontroller followed by its display and printer. The quality of an EMG signal is largely dependent on the resolution, accuracy, and sampling rate of the ADC used. Present-day ADCs used in EMG equipment range in 10-24 bit systems. The sampling rate used in any EMG system must at least follow Nyquist's theorem, whereby the minimum sampling rate must be twice that of the signal frequency in question. In all present-day EMG applications, the upper limit on the frequency of interest is around 500 Hz, and so the sampling frequency may be kept at 1000 samples/s.

Most EMG machines are PC based ard are available in both console and laptop models. They provide full colour waveform display, automatic cursors for marking and making measurements, and a keyboard for access to convenient and important test controls. The system usually incorporates facilities for recording of the EMG and evoked potentials. The stimulators are software controlled. For report generation in the hard copy form, popular laser printers can be used. A typical EMG machine is shown in **Figure 3.**

Recent developments in electronic technologies have enabled EMG equipment to include a range of new features and networking capabilities. The RS-232 serial data transfer protocol previously used in the PC-based systems is now replaced by the Universal Serial Bus 2.0, which provides faster data exchange rates and even a means of capacity of data recordings on digital storage media has become a common feature. Wireless technologies such as Wi-Fi and Bluetooth have also been incorporated into today's EMG equipment to provide the user with extended mobility from the PC on PC-based systems. Acquired EMG signals can now be picked up on the body and sent wirelessly to a PC where it is recorded, processed, and analyzed.

Figure 3: Typical an EMG machine

Common Artefacts in EMG:

While recording EMG, many types of artefacts may be present, if proper care is not taken. Power line interference (50-60Hz) is caused by the electrical devices present around the EMG equipment. Typically, this interference is removed by using a software implemented notch filter. The instability of electrode skin interface and movement of the electrode cable result in movement artefacts, which are caused whenever a patient moves and the electrodes are disturbed or the cables are pulled. To minimize these artefacts, the electrodes must be placed in firm contact with the skin and electrode cables must be fastened firmly. The electrical signals generated by muscles other than the one under investigation results in muscle crosstalk. This type of interference can be minimized through the appropriate placement of the electrodes. The recommended inter-electrode distance is about 2cm.

Stimulators The modern EMG machines include another important feature in the form of a built-in stimulator. The stimulator aids in nerve conduction or nerve velocity measurements. Stimulus amplitude, duration, repetition, and delay are all adjustable, and facilities are provided for external triggering. The output is either of the constant voltage type or of the constant current type. The constant voltage type stimulator provides square wave pulses with amplitudes in the range of 0-500 V, a pulse duration of 0.1-3ms, and frequency between 0 and 100 Hz. Output of the constant current generator can be adjusted from 0 to 100 mA

Electroneurography The recording and study of action potential propagation along peripheral nerves is known as electroneurography. The technique is primarily used in nerve conduction study and is considered as a reliable diagnostic test of peripheral nerve function. It is used routinely for localization of the site of a nerve lesion and the diagnosis of conditions such as diabetic neuropathy, which affects primarily nerve fibers. Electroneurography recordings can be done using EMG machines.

Specifications

Amplifier channels: 2 or 4

Sensitivity: Adjustable from 1 μV/div to 10 mV/div in steps

High cut filters: Selectable from 30 to 10kHz

Low cut filters: Selectable at 0.04 Hz, 2kHz

Notch filter: 50 or 60 Hz

Common mode rejection: >100dB

Input impedance: >1000MQ (common mode)

Noise: <6µV peak to peak

Number of averages per channel: 1-10000

Stimulators: Repetition rates at 0.1-90 pulses/s

Applications

Clinically, electromyography is being used as diagnostic tool for neurological disorders, such as neuromuscular diseases and low back pain, and disorders of motor control. EMG is routinely employed as an evaluation tool in applied research, physiotherapy, rehabilitation, sports medicine and training, and biofeedback and ergonomics research.

The contraction of the skeletal muscle results in the generation of action potentials in the individual muscle fibers, a record of which is known as electromyogram. The activity is similar to that observed in the cardiac muscle, but in the skeletal muscle, repolarization takes place much more rapidly, the action potential lasting only a few milliseconds. Since most EMG measurements are made to obtain an indication of the amount of activity of a given muscle, or a group of muscles, rather than of an individual muscle fiber, the EMG pattern is usually a summation of the individual action potentials from the fibers constituting the muscle or muscles being studied.

The electrical activity of the underlying muscle mass can be observed by means of surface electrodes on the skin. However, it is usually preferred to record the action potentials from individual motor units for better diagnostic information using needle electrodes. In voluntary contraction of the skeletal muscle, the muscle potentials range from 50 µV to 5 mV and the duration from 2 to 15 ms. The values vary with the anatomic position of the muscle and the size and location of the electrode. In a relaxed muscle, there are normally no action potentials. **Figure 4** shows the unprocessed EMG signal characterized by positive and negative peaks. The amplitudes and frequency content of this signal provides information about the contraction or resting state of the muscle under study.

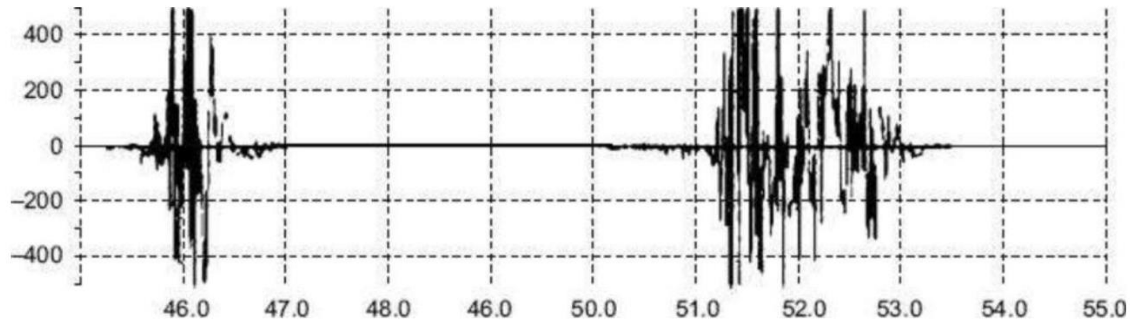

Figure 4: The unprocessed EMG signal characterized by positive and negative peaks.

In summary, the skeletal muscle is the force-generating component of a human body. It is a system of many tiny contractile fibers placed in parallel. These fibers are organized in-groups called motor units. Each unit has a single motor neuron to convey motor impulses from the central nervous system. The contraction of muscle fiber involves depolarization and repolarization of cell membrane resulting into electrical potentials called myoelectric signals. Therefore, an Electromyogram or EMG is the representation of electrical signals generated by the neuro- muscular activation of a contracting muscle. The signal represents the current generated by the ionic flow across the membrane of the muscle fibers, which propagates through the intervening tissues to reach the detection surface of an electrode located in the environment. It is a complicated signal, which is affected by the anatomical and physiological properties of the muscle and control scheme of the nervous system, as well as the characteristics of the instrumentation used to detect it. The motor unit action potential (MUAP) of a single motor unit is shown in **Figure 5**.

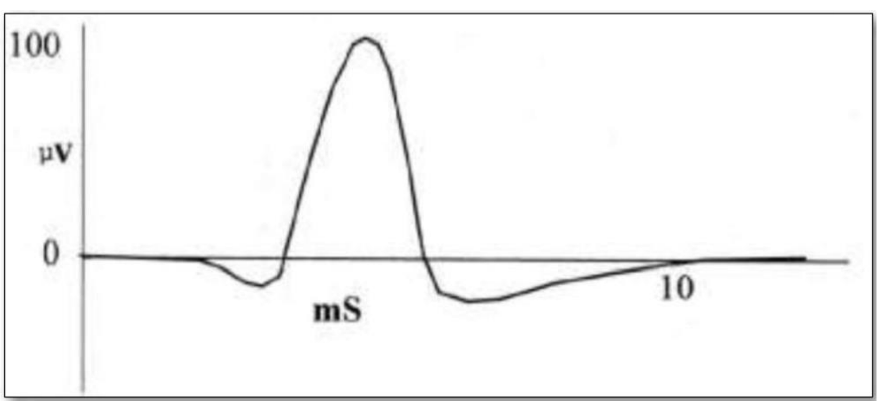

Figure 5 : The motor unit action potential (MUAP) of a single motor unit.

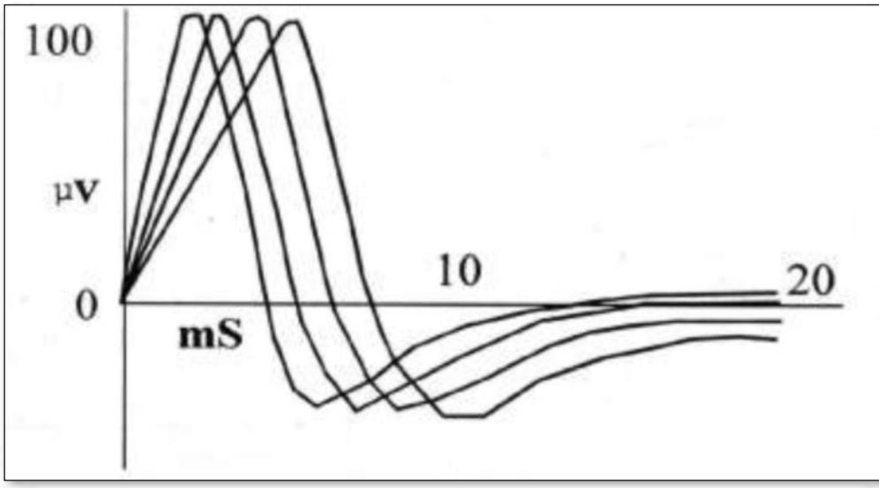

Figure 6: The summation of many trains of single motor.

The motor units of a muscle are activated repeatedly to sustain contraction, resulting into sequence of MUAPs, known as motor unit action potential train (MUAPT). It is shown in **Figure 6**. The summation of many trains of single motor unit potential is called gross myoelectric signal (GMS).

The electrical potentials generated by the muscle range from 5 microvolt to 5 mill volts and their duration range between 2 milliseconds to 15 milliseconds. EMG is a fastest signal inside our body. It is a signal, which has highest frequencies compared to the other electrical signals. The frequency of EMG signals approximately falls between 10 to 3000 Hz. In a relaxed muscle, there are normally no action potentials. The amplitude of EMG signal depends on type of electrode used and degree of muscular contraction. The needle electrode inserted into the muscle fiber generates spike type voltage, whereas a surface electrode picks up many overlapping spikes and therefore produces an average effect. As stated the action potential of a given muscle (or nerve fiber) has a fixed magnitude, regardless of the intensity of the stimulus that generates the response. Thus, in a muscle, the intensity with which the muscle acts do not increase the net height of the action potential pulse but does increase the rate with which each muscle fiber fires and the number of fibers that are activated at any given time. The amplitude of the measured EMG waveform is the instantaneous sum of all the action potentials generated at any given time. Because these action potentials occur in both positive and negative polarities at a given pair of electrodes, they sometimes add and sometimes cancel. Thus, the EMG waveform appears very much like a random-noise waveform, with the energy of the signal a function of the amount of muscle activity and electrode placement. Typica1 EMG waveforms are shown in **Figure 7.**

Recording Techniques:
There are two basic methods for recording of EMG signals.
1. EMG with voluntary muscular action, and
2. EMG with electrical stimulation.
To obtain a good and noiseless EMG, it is essential to clean the recording site thoroughly. The disc or needle electrodes used must be clean and fixed on the recording site with conductive electrode jelly. The patient should be asked to relax completely to avoid activity from other muscles, which may otherwise, interfere or mix with the signals to be recorded from the selected site

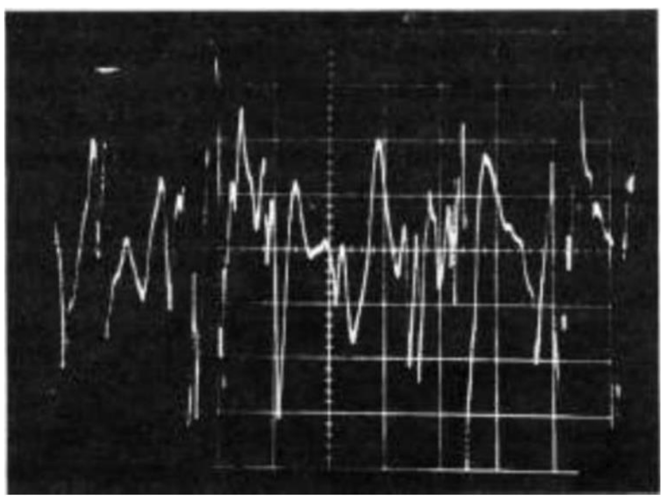

Figure 7: Typica1 EMG waveforms

EMG with Voluntary Action:

In this recording method the action potential generated during voluntary contraction is picked up by needle electrode inserted into the muscle or by surface electrode placed over the muscle. The EMG produced during voluntary contraction may spread over a period of 100 milliseconds or more and can have number of spikes or a train of spikes. This is because the propagation delay from the spinal cord to the muscle concerned is different for all nerve fibers. Hence, impulses to the all-motor units do not reach at the same time. In mild contraction of a muscle, it is possible to identify an action potential of even single motor unit. During a forceful voluntary contraction, as many motor units are involved, the EMG obtained is a result of the action potential produced by all these motor units together. EMG generated during voluntary contraction is shown in **Figure 8.**

The quantity of electrical activity produced by voluntary muscle contraction depends on the strength of the contraction. Since it is difficult to estimate the quantity from an observation of the EMG waveform on the screen of the oscilloscope, the absolute integral of the EMG is used as a measure of this quantity. Being EMG information is in audible range; it is often presented in audio quantity. Being EMG information is in audible range; it is often presented in audio form. A trained listener can judge the condition of the muscle by listening to the volume and characteristic tones produced during muscular contractions.

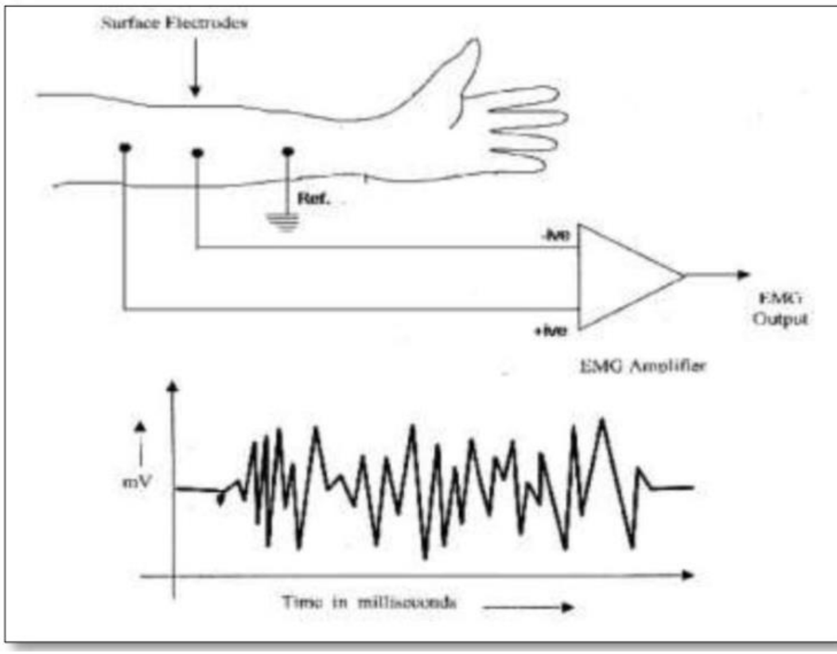

Figure 8: EMG generated during voluntary contraction.

EMG with Electrical Stimulation:

As discussed above, an EMG produced during voluntary contraction has several action potentials. You know that an electrical impulse can be used to stimulate a nerve or muscle i.e. when an electrical current of certain quantity allowed to flow through the nerve or muscle cell, the cell gets depolarized. This phenomenon has been used in stimulation electromyography to activate all the fibers of a muscle at a time and to obtain synchronized action potential. Here, all neurons with thresholds above the set stimulation intensity are simultaneously stimulated by the electrical impulse. This therefore produces substantial activity for brief periods, which are less than 10 milliseconds. This is an unnatural occurrence referred as myographic response or muscle action potential. The electrical pulse used to initiate this response has pulse duration equals to either 0.1 milliseconds or 0.3 milliseconds and voltage above 100 volts. The typical EMG produced by electrical stimulation is shown in **Figure 9**.

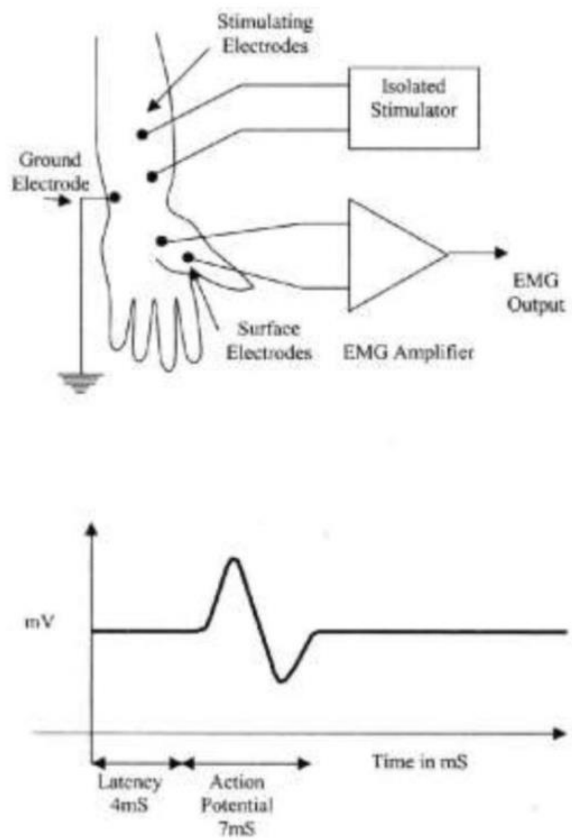

Figure 9: The typical EMG produced by electrical stimulation.

Electromyograph graphic (EMG) Measurements:

The first attempt to obtain biopotential tracings in cases involving peripheral nerve paralysis, by R.P Proebster in 1928, has been credited with initiating clinical electromyography EMG). EMG has been a valuable clinical tool for muscular disorders since 1960. Muscles fall into three general classifications: skeletal, cardiac, and smooth. The EMG is the bioelectronics measurement of limbs, thorax, heart, intestines, and involuntary muscles. The EMG potentials from a muscle or group of muscles produce a noise like waveform that varies in amplitude with the amount of muscular activity. Peak amplitudes vary from 50mV to about 1mV, depending on the location of the measuring electrodes with respect to the muscle and the activity of the muscle. A frequency response from about 10 Hz to well over 3000 Hz is required for faithful reproduction. A simplified diagram of an electromyographic device is shown in **Figure 10** Semiconductor amplifiers are used to magnify the small voltage input picked up by the electrodes to a level adequate for the operation for a readout device, such as the oscilloscope or loudspeaker. Surface, needle, and fine-wire electrodes are all used for different types of EMG measurement. Surface electrodes are generally used where gross indications are suitable, but where localized measurement of specific muscles is required, needle or wire electrodes that penetrate the skin and contact the muscle to be measured are needed. As in neuronal firing measurements, both unipolar and bipolar measurements of EMG are used. Most Electromyograph includes an audio amplifier and loudspeaker in addition to the display to permit the operator to hear the "crackling" sounds of the EMG. This audio presentation is especially helpful in the placement of needle or wire electrodes into a muscle. A trained operator is able to tell from the sound not only that his electrodes are making good contact with a muscle but also which of several adjacent muscles he has contacted.

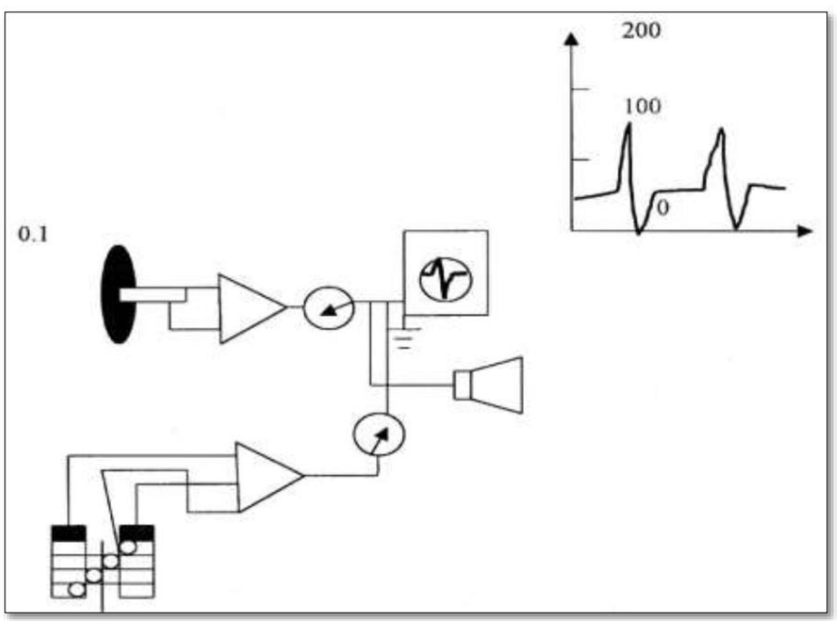

Figure 10: A simplified diagram of an electromyographic device