Biomedical Instrumentation: Diagnosis and Therapy

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ABSTRACT

This paper covers the measurement of biopotentials for diagnosis: the electrical voltages that can be measured from electrodes placed on the skin or within the body. Biopotentials include: the electrocardiogram (ECG), electroencephalogram (EEG), electrocortogram (ECoG), electromyogram (EMG), electroneurogram (ENG), electrogastrogram (EGG), action potential (AP), electroretinogram (ERG), electro-oculogram (EOG). This paper also covers skin conductance, pulse oximeters, urology, wearable systems and important therapeutic devices such as: the artificial cardiac pacemaker, defibrillator, cochlear implant, hemodialysis, lithotripsy, ventilator, anesthesia machine, heart-lung machine, infant incubator, infusion pumps, electrosurgery, tissue ablation, and medical imaging. It concludes by covering electrical safety. It provides future subjects for research such as a blood glucose sensor and a permanently implanted intracranial pressure sensor.

Keywords: Biomedical Instrumentation, Biopotentials, Diagnosis, Therapy

INTRODUCTION

Medical instrumentation is a subdivision of biomedical engineering. It emphasizes the measurement of all the variables in the body for the use of diagnosis and all the devices that perform therapy. Because the bulk of these measurements and therapies involves electronics and computers, the ideal background is in electrical and computer engineering.

HISTORICAL BACKGROUND AND LITERATURE OVERVIEW

Among the earliest electrical experiments were those by Luigi Galvani. In 1771, he discovered that the muscles of dead frogs’ legs twitched when struck by a spark. Willemin Einthoven invented the first practical electrocardiogram (ECG or EKG) in 1903. Einthoven placed the hands and feet of subjects in buckets of saline and used the string galvanometer to record the electrocardiogram (ECG) without electronics. The string galvanometer used a thin filament of conductive wire passing through strong electromagnets. When current passed through the wire, it would move the wire and its shadow from a light, which darkened moving photographic paper, which recorded the ECG.

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In 1926 William Bovie developed the electrosurgical unit, which permitted surgery on vascular organs such as the brain, liver, and spleen. The development of the transistor and the computer enabled a flowering of the many advanced diagnostic and therapeutic devices we find in hospitals today.


**ELECTROCARDIOGRAPHIC AMPLIFIER**

The high fat, low roughage diet of the western world promotes development of plaque, which deposits inside arteries and eventually plugs them. This can cause a heart attack, stroke, or kidney failure. When a subject experiences chest pain, the first measurement is to take an electrocardiogram (ECG) to determine damage to the heart. Electrodes are applied to the chest. The best electrodes are formed of silver/silver chloride (Ag/AgCl) because the AgCl salt coating the Ag electrodes is very stable, with the voltage changing little in response to movement or electric current flow. Placing a conductive gel between the electrode and the skin promotes good electrical contact. The gel may also be an adhesive or may be surrounded by an adhesive to mechanically stabilize the electrode on the skin. The electrodes are placed above and below the heart to continuously monitor the maximum voltage of about 1 mV. Different waves occur: atrial contraction causes the P wave, ventricular contraction causes the QRS waves, ventricular relaxation causes the T wave. Ten electrodes may be placed surrounding the heart to yield a one-time 12-lead diagnostic ECG. This yields views of the cardiac excitation from different angles. The ECG yields information on rhythm, such as bradycardia (slow rhythm), tachycardia (fast rhythm), total heart block (no excitation from the atria to the ventricles), atrial fibrillation (chaotic atrium), and ventricular fibrillation (chaotic ventricles). S–T depression also yields information on cardiac damage.

Figure 1 shows an ECG amplifier which has a high gain to boost the 1 mV ECG to about 1 V. The LT1920 instrumentation amplifier has high input impedance. The high input impedance is required to prevent attenuated loading because the skin may have a resistance of about 1 MΩ. The amplifier also has high common mode rejection ratio (CMRR = \( G_d/G_c \)) where \( G_d \) is the differential gain and \( G_c \) is the common mode gain. High CMRR minimizes the power line interference from appearing on the ECG. The amplifier gain is \( G_1 = (49.4 \, \text{kΩ}/R_g) + 1 = (49.4 \, \text{kΩ}/3 \, \text{kΩ}) + 1 = 17.5 \). The Association for the Advancement of Medical Instrumentation (AAMI) specification requires that the amplifier operate with differential 0.3 V dc, so the gain must be kept low (Neuman, 2010a, p. 252).

The AAMI specification also requires a frequency bandwidth from 0.05 to 150 Hz, so the following amplifier has an input capacitor that blocks dc but passes frequencies higher than 0.05 Hz. The feedback capacitor attenuates frequencies higher than 150 Hz. The TL032 amplifier gain is \( G_2 = -R_f/R_i = 100/1.8 = 55.6 \) where \( R_f \) is the feedback resistor and \( R_i \) is the input resistor.

Example 1. Calculate the ECG amplifier corner frequencies using the equation \( \omega \tau = 2\pi f \) \( RC = 1 \). Calculate the ECG amplifier gain.
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