Lab 8

Biomedical Technologies, EMG & ECG

Introduction

In this lab you will investigate the electrical signals from your muscles and nerves.

- You will build a high gain amplifier and take electromyography (EMG) measurements from your arm muscle.
- You will use the same amplifier to take electrocardiography (ECG) measurements from your heart.

Before do this, we should learn about:

- Electrical signals in nerves and muscles.
- How to measure weak electrical signals in the body.
- Some other types of biomedical diagnostic technologies.

Some Biomedical Diagnostic Technologies

Biomedical Technologies

EMG and ECG that you will study today are only two of the many diagnostic techniques that electrical and computer engineers research and develop.

- Some of the others are shown on the following slides.

Electroencephalography (EEG) is the monitoring of electrical activity in the brain.

- EEG signals have been used to control prosthetic limbs and interface with computers.

Picture from Wikipedia

X-Ray Technologies

The first x-ray picture of a human body part was taken in 1895, by the German physicist Wilhelm Röntgen (1845 - 1923).

- In 1901, he received the first ever Nobel Prize in Physics for his X-ray work.
- Images are formed because different tissues in the body absorb different amounts of x-ray photons.

Picture from Wikipedia

X-ray picture of Röntgen's wife's hand.

X-Ray Computed Tomography

X-ray computed axial tomography (CAT or CT scan) is an imaging technique where multiple x-ray images are used to create high resolution 2-D and 3-D images.

- X-ray images are taken from all sides of an object.
- Tomography and computer imaging techniques are used to form 2-D slice and 3-D images.

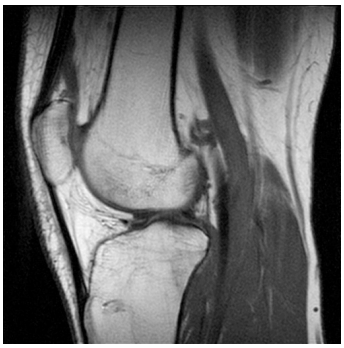
2-D slice image of a skull.

Picture from Wikipedia

3-D reconstruction from multiple 2-D slice images.

Magnetic Resonance Imaging (MRI)

MRI image of a knee.



Picture from Wikipedia

MRI uses strong magnetic fields and radio waves to image objects.

- It provides much greater image contrast for soft tissues compared to x-rays.

IMRIS is a Winnipeg company that is a world leader in MRI technologies.

An IMRIS operating room MRI surgical imaging system.

Ultrasound & OCT Imaging

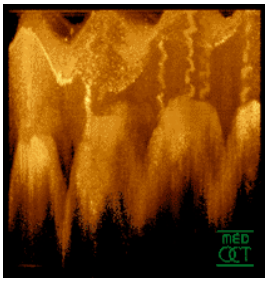
Sonoscape A8 ultrasound system

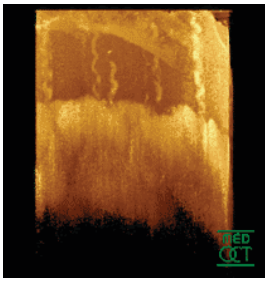
Ultrasound imaging (ultrasonography) uses sound waves to image inside objects.

- Focused sound waves are reflected back from locations in the body where there is a change in density.

Optical Coherence Tomography (OCT) uses light waves to image inside objects.

- Light penetrating the body is reflected back from different tissues layers in the body.



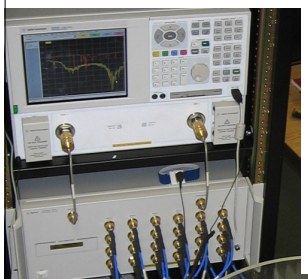


Sweat ducts can be seen in this OCT image of a finger tip.

Pictures from Wikipedia

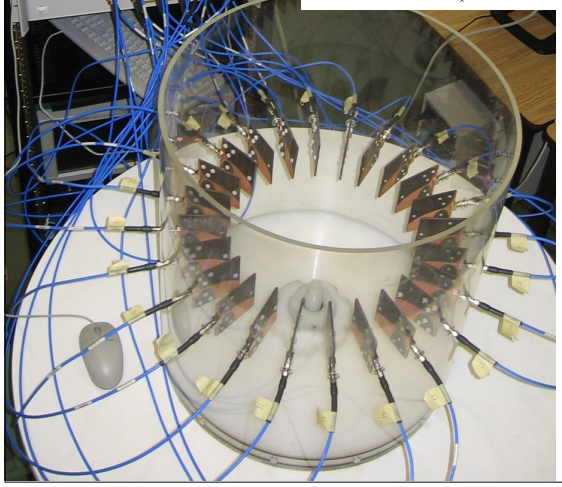
Microwave Tomography

Microwave tomography uses high frequency radio waves to scan inside an object.



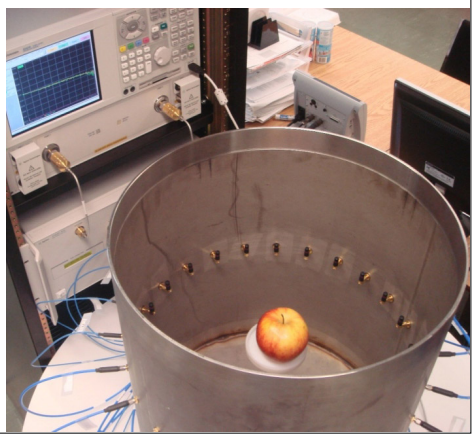
Reconstructed cross-section image of a human forearm.

Arm bones



ECE microwave tomography research

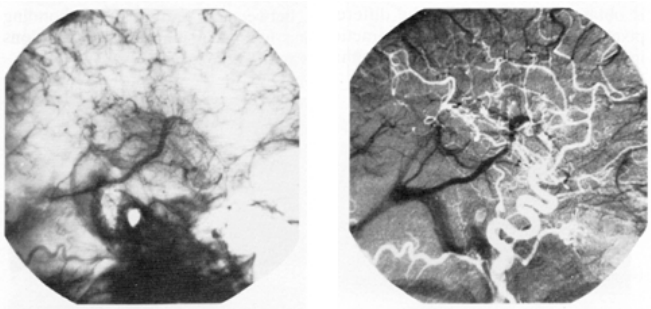
Imaging the interior of an apple.



Imaging Technologies

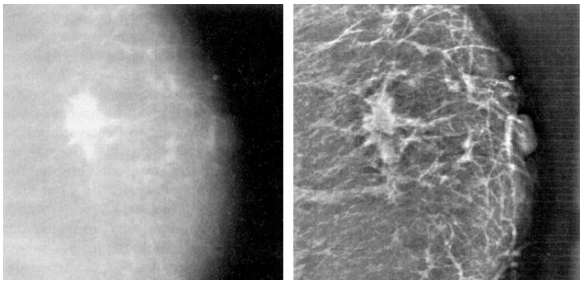
Imaging technologies are developed for improving medical diagnosis, as well as for "augmented reality" real time imaging during advanced surgery.

Image of blood vessels before (left) and after (right) image enhancement.



Picture from Digital Image Processing (Gonzalez and Woods) Addison Wesley

Mammogram image before (left) and after (right) noise removal and contrast enhancement, making the star shaped lesion is much more visible.



Picture from IEEE Spectrum

The Human Body as an Electrical System

EMG and ECG are electrical measurement techniques. We need to know how the human body works in order to understand how to build EMG and ECG systems.

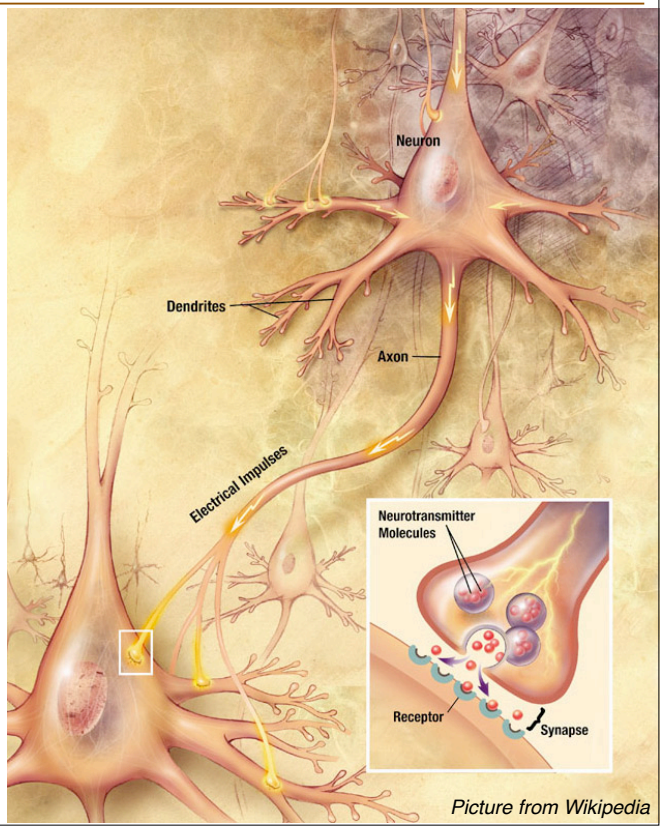
The Nervous System

Neuron cells are the building blocks of the nervous system.

- Neurons process and transmit information by electrical signalling.

Together, your neurons form a massive electrical network.

- Each neuron may be connected to 1000's of other neurons.
- The human brain has an estimated 100 billion neurons and 100 trillion synapses.

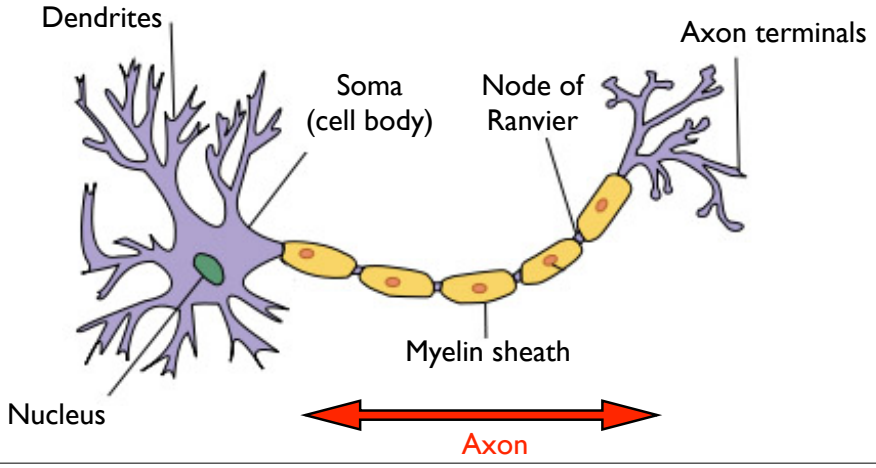


Picture from Wikipedia

The Neuron

There are many types of neurons, but the basic neuron looks like this.

- Dendrites receive synaptic signals from other neurons.
- Axons are the "electrical cabling" of the neuron, and can be very long. Sensory neurons running from the spine to the toes are over 1.5 m long.
- Myelin coats the axon in many neurons, except at periodic breaks called nodes of Ranvier.

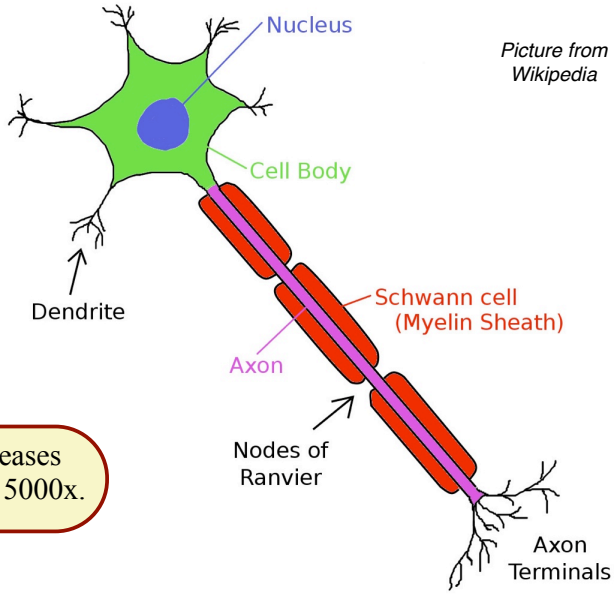


Picture from Wikipedia

Myelin

Myelin is a dielectric material, and so the myelin sheath surrounding the axon acts as an electrical insulator.

- It enables electrical signals to pass without significant decay.
  - Better energy efficiency.
- The myelin also reduces the electrical capacitance of the axon.
  - Signals can travel faster.



Picture from Wikipedia

Myelin decreases capacitance by 50x, and increases electrical resistance across the cell membrane by 5000x.

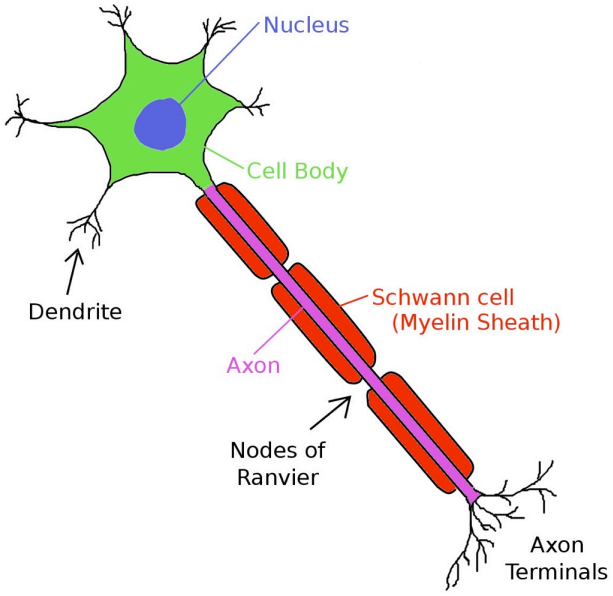
In the disease Multiple Sclerosis (MS), the immune system attacks the myelin, resulting in inefficient nerve function.

Nodes of Ranvier

Even with the myelin sheath, the electrical signal slowly decays over distance.

At the nodes of Ranvier new electrical impulses are generated.

- The nodes of Ranvier act as regularly spaced signal boosters !!



Periodic signal repeaters are also used in long distance telecommunication networks.

Neuron Electrical Signals

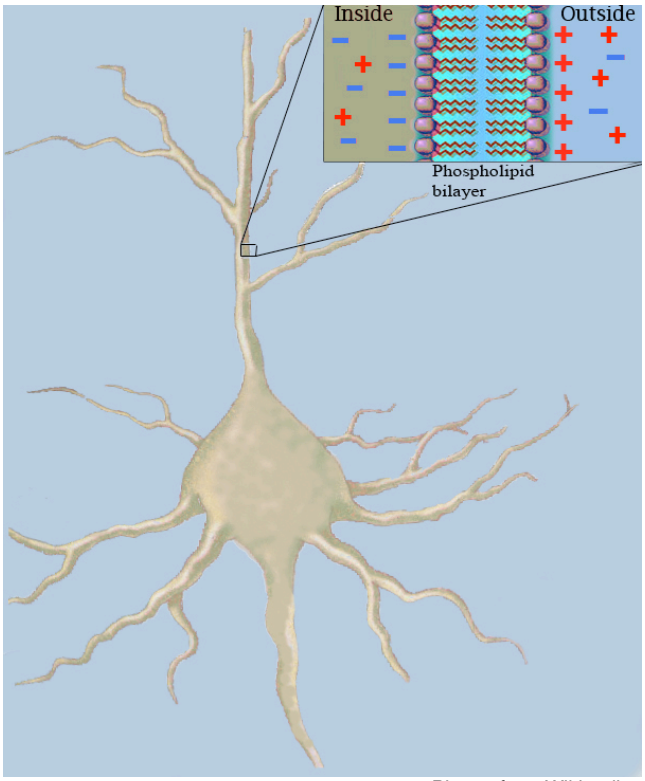
Neuron electrical signals are produced chemically.

- Ionic solutions exist inside and outside the cell membrane.
- Electrical impulses are generated by mixing these ionic solutions.

The ionic solutions inside and outside the cell membrane possess different concentrations of ions.

- Therefore, a charge difference exists across the cell membrane.
- When at rest, membrane potential is:

$$V_m \cong -70\ mV$$



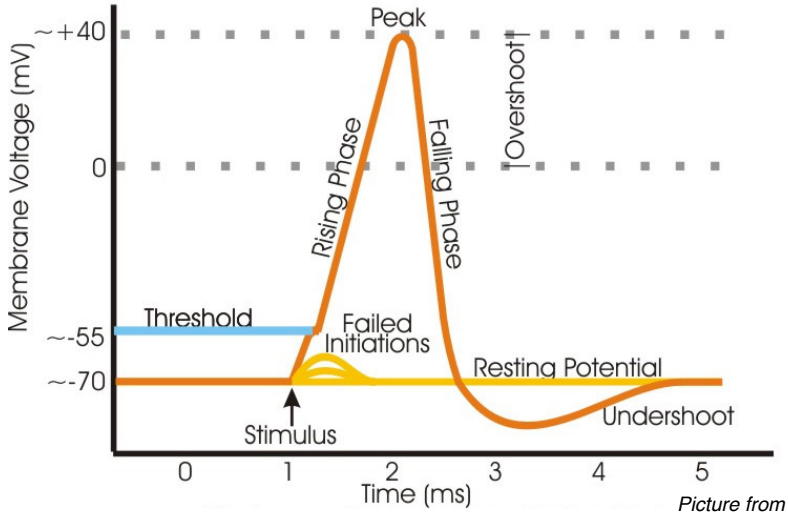
Picture from Wikipedia

Action Potential Generation

Stimulus on the neuron causes ion exchange across the cell membrane, increasing V_m.

- If stimulus is sufficient (increasing V_m above a threshold), rapid ion exchange occurs, raising V_m to a positive voltage (~ 40 mV).
- The generated electrical pulse then travels down the nerve.

This pulse is called an "action potential".



Picture from Wikipedia

Muscle Contraction

When nerve impulses arrive at muscles, muscle motor units are activated.

- A muscle motor unit consists of a motoneuron, who's axon connects to many individual muscle fibres.

Control of muscle force is achieved not by the strength of nerve impulses, but from the frequency of impulses to muscle motor units and/or the number of motor units excited.

- However, the EMG signal that you are measuring on your skin includes muscle fibres which may not be excited. Thus, the voltage you measure is an ***average*** over many nerves fibres, and so you will see both more impulses per second and a stronger signal when your muscle produces more force.

Incredible Hulk
Universal Studios

Electromyography

Electricity in the Body

In 1666, the Italian physician Francesco Redi (1626 - 1698) discovered the muscle in the electric eel which generates electricity.

He also demonstrated that maggots do not form naturally from rotting flesh, thus disproving "spontaneous generation" of life. This was a major step in biology.

Picture from Wikipedia

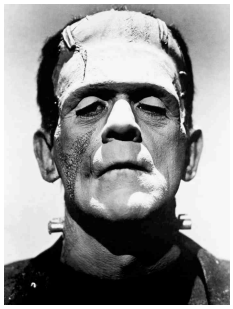
Electricity generating cells in electric eels produce 0.15 V each.

- 5,000 - 6,000 cells stacked together can generate approximately 500 V and 1 A.

Electricity & Muscle Contraction

In 1786, Luigi Galvani discovered that the muscles in a frog's leg can be stimulated by electricity.

His work influenced the author Mary Shelly, who wrote Frankenstein.



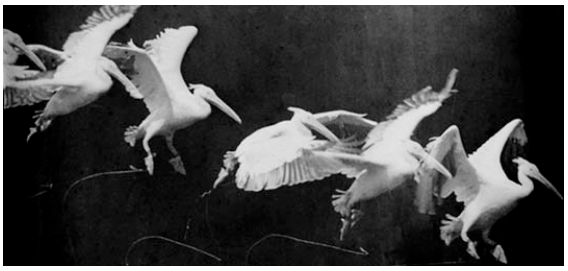
Emil du Bois-Reymond (1818 - 1896) was a German physician and physiologist.

- In 1848, he detected electrical activity in the voluntary muscle contraction of a man.

Electromyography

In 1890, the French scientist Étienne-Jules Marley (1830 - 1904) recorded the first electrical signals from muscles, and introduced the term electromyography.

- He also studied motion through photography, and made the first cinematography films.



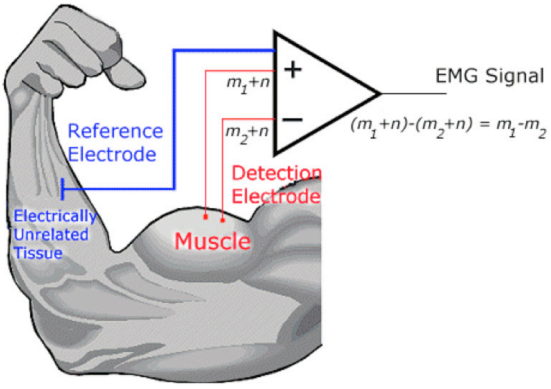
He famously demonstrated that cats always land on their feet.

- His studies with a chicken and a dog found that they don't. ☹

Electromyography (EMG)

EMG is the monitoring of electrical signals in muscles.

- By using signal processing techniques to analyze EMG signals, you can detect medical abnormalities, muscle fatigue, or study the workings of muscles.
- EMG signals can be used to control prosthetic devices.



Muscles at rest normally are electrically inactive. Electrical signals appear when a muscle is used.

- As the strength of contraction is increased, more action potentials are produced, and so the EMG signal measured from outside the body will be larger.

EMG Measurements

Problem 1: The electrical signal measured on the surface of the skin over the muscle is very weak.

- Measured EMG potentials range from microvolts - millivolts. A high gain amplifier is needed to measure the signals.
- The amplifier you will use today will have a gain of close to 1000x.
- Such high amplification requires a high precision "instrumentation amplifier" with very small offset error signal.

Problem 2: Other muscles and nerves in the body are also producing electrical signals.

- The EMG measurement is the summation of all electrical signals in the muscle, as well as interfering electrical signals from adjacent muscles and nerves.
- We need to filter these interfering signals.
- Noise interference is a common problem in measuring any small electrical signal.

Eliminating Measurement Noise

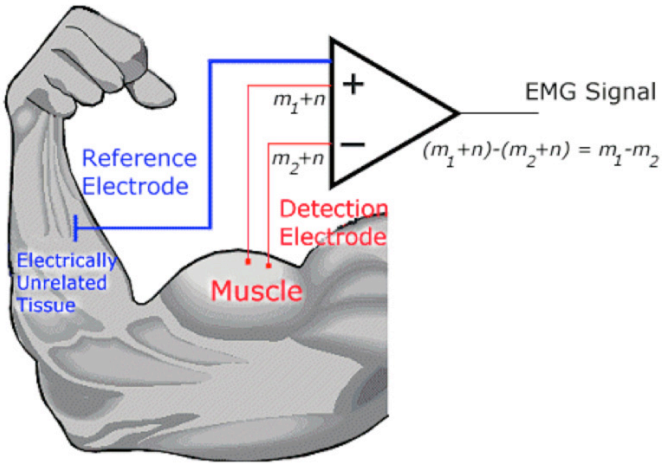
The EMG measurement is made by placing two electrodes 1 - 2 cm apart over the muscle, in the direction that the muscle fibres run.

- With the electrodes close together, the interfering electrical noise will be nearly common to these two electrodes.

Electrode 1 signal = m_1 + *noise* Electrode 2 signal = m_2 + *noise*

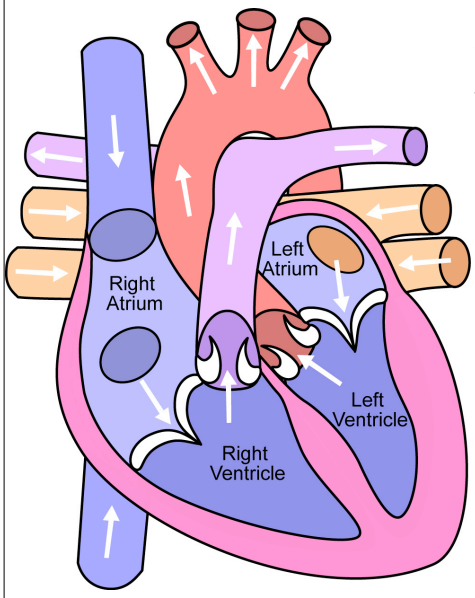
How to eliminate the common noise:

- Place a third electrode on a different muscle to provide a reference voltage to the amplifier.



Electrocardiography

The Heart



Picture from Wikipedia

The heart pumps ~ 20 litres of blood per minute, through nearly 100,000 miles of blood vessels in an adult human body.

- The heart contains 4 chambers.
- Your heart beat is a rhythmic contraction of these chambers.
- The atria contract first, followed by the ventricles.

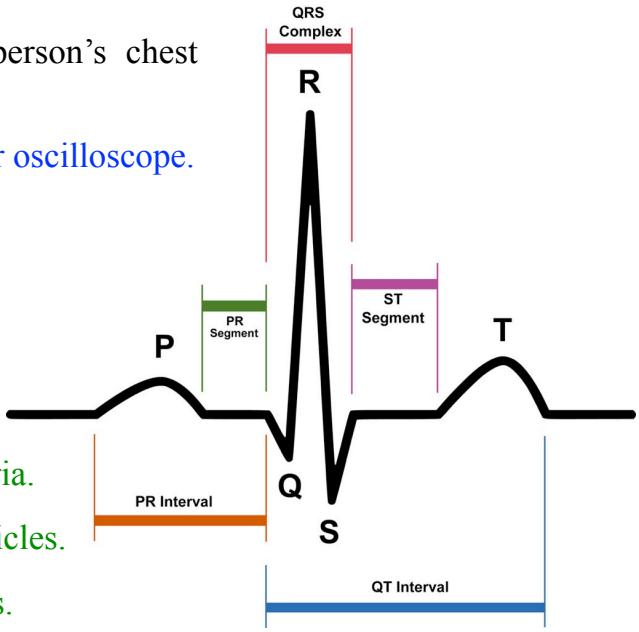
In order to enable the rhythmic contraction of the 4 chambers, electrical signals travel first through the atria, and then to the ventricles.

- Therefore, the voltage measured across the heart changes with time.
- This time varying "voltage vector" forms the ECG measurement.

ECG Waveform

An ECG recording measured across a person's chest looks like this figure.

- You should see this waveform on your oscilloscope.

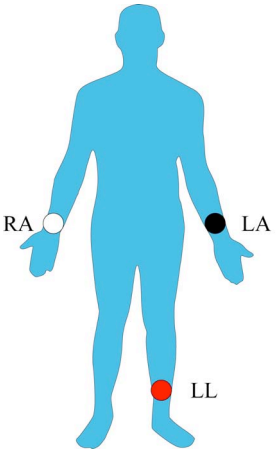


The different voltage peaks represent:

- P signal is the depolarization of the atria.
- QRS is the depolarization of the ventricles.
- T is the repolarization of the ventricles.

The peak values and various time intervals can be used to diagnose the health of the heart.

ECG Measurements



ECG measurements can be taken with 3 electrodes placed as follows.

- Left wrist, right wrist, and the left ankle (as reference).

Two suggested alternative arrangements for better signal acquisition:

- You can also use your lower left abdomen as the reference, instead of the left ankle.
- You can put the RA and LA electrodes on the chest, on either side of the heart.

Defibrillators & Pacemakers

Heart Defibrillator

Ventricular fibrillation is a condition where the heart chambers do not contract in a coordinated fashion, and so the heart fails to pump blood.

- A defibrillator uses DC electrical discharge to depolarize the entire heart, stopping the arrhythmia, and hopefully enabling the heart to re-start normal heart rhythm.

Philips

Heart Pacemaker

Medical pacemakers use electrical impulses to regulate the beating of the heart.

- Modern pacemakers can be externally programmed to provide optimum control for individual patients.
- Rate responsive pacemakers can detect changes in a person's physical activity and automatically adjust heart rate in accordance with physical activity.
- Some pacemakers also function as defibrillators.

World's first pacemaker

A modern pacemaker

Pictures from Wikipedia

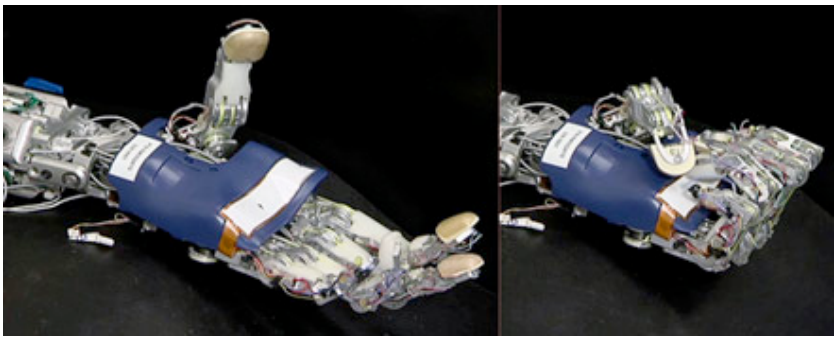
Electrically Interfacing with the Human Body

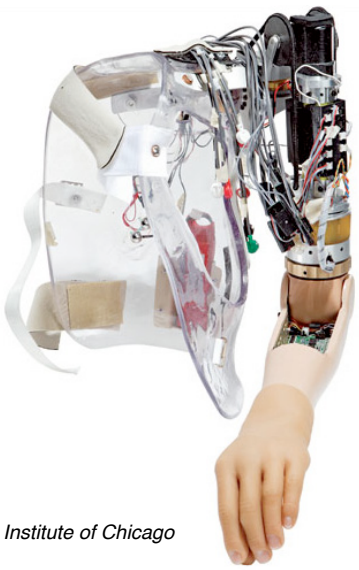
Interfacing with the Human Body

Since the body is an electrical system, we can interface with it.

- Many advanced medical devices are now being implemented.

This advanced prosthetic arm has electronics that relay sensor data back to the body, enabling the wearer to gauge pressure and control grip strength.





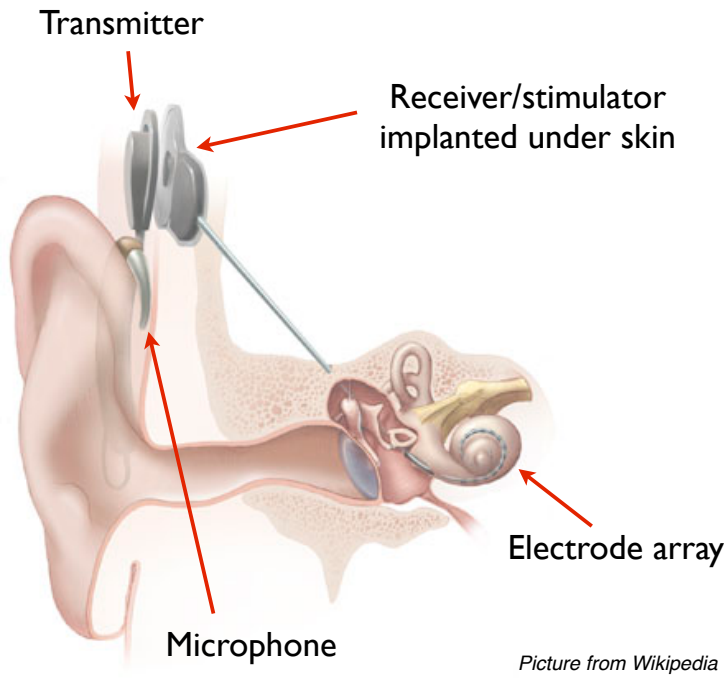
Johns Hopkins University Applied Physics Laboratory, and the Rehabilitation Institute of Chicago

Cochlear Implant

Unlike hearing aids which amplify sounds, a cochlear implant directly stimulates auditory nerves inside the cochlea.

Sounds captured by the microphone are transmitted to the implanted receiver.

Electrodes implanted in the cochlea stimulate auditory nerves.

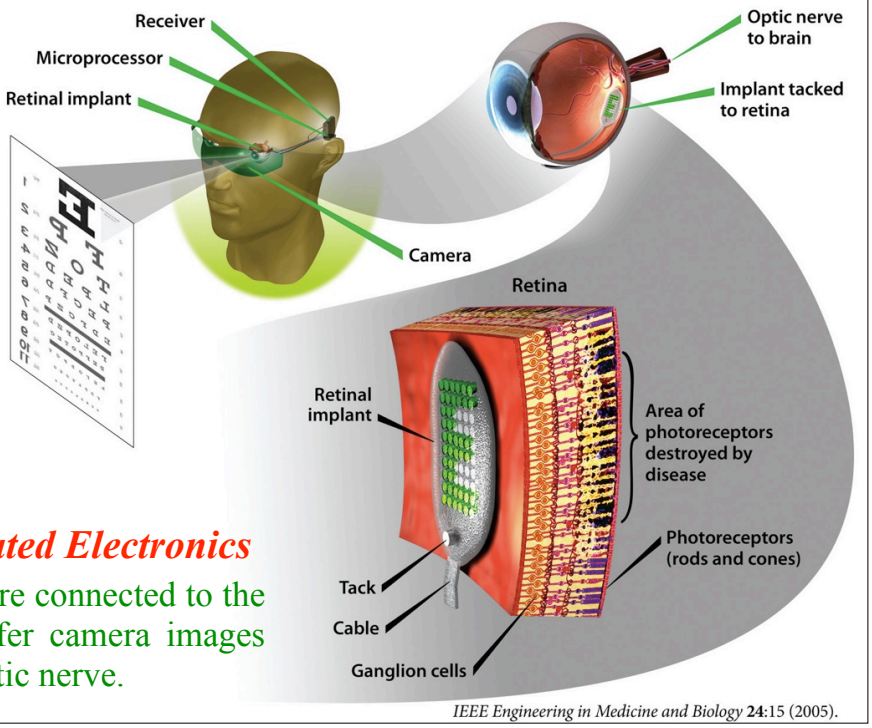


Picture from Wikipedia

Retina Interface

A camera (on the glasses) transmits images to a computer chip implanted in the eye.

Retina implant patient visiting Disneyland



IEEE Engineering in Medicine and Biology **24**:15 (2005).

Nano-Fabricated Electronics

Tiny electrodes are connected to the retina, and transfer camera images directly to the optic nerve.

Measuring Weak Electrical Signals

Measuring Weak Signals

EMG, and especially ECG, electrical signals are very weak. Below are some helpful tips that may assist you in today's lab.

- Use short wires, instead of long wires. Shorter wires will pick up less electrical noise from the environment.
- Limit the number of electrical connections in your circuit. When possible, you should have a direct path between elements you want to connect together.
- Use batteries to supply DC voltage, instead of the power supplies on the project board. The project board will couple electrical noise from the building wiring into your circuit.

ECG measurement issues.

- A high quality ECG system will use electrical noise filters to help obtain a clean ECG signal. However, the amplifier circuit you will build today is very simple. If you have difficulties, you can share data with another group.
- In upper years in electrical and computer engineering, you will learn how to construct noise filters and use signal processing techniques to remove noise.