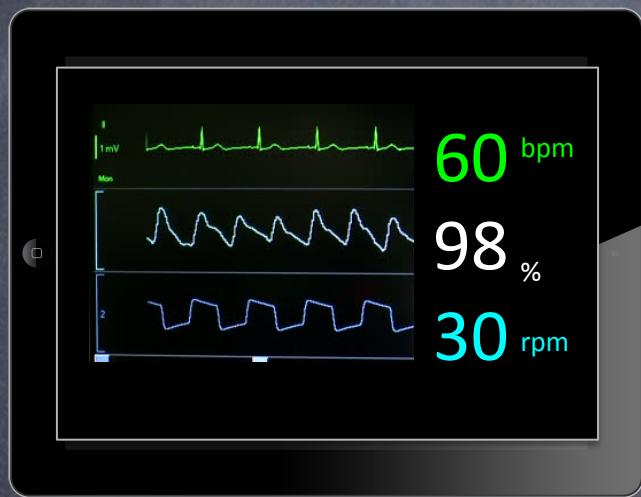

EE93 – Medical Mobile Devices and Apps



Lecture: Instrumentation

Introduction

- The Heart
- Electrocardiography
- 12-Lead ECG
- 3-Lead ECG
- Instrumentation Amplifier
- Digital Signal Processing

The Heart

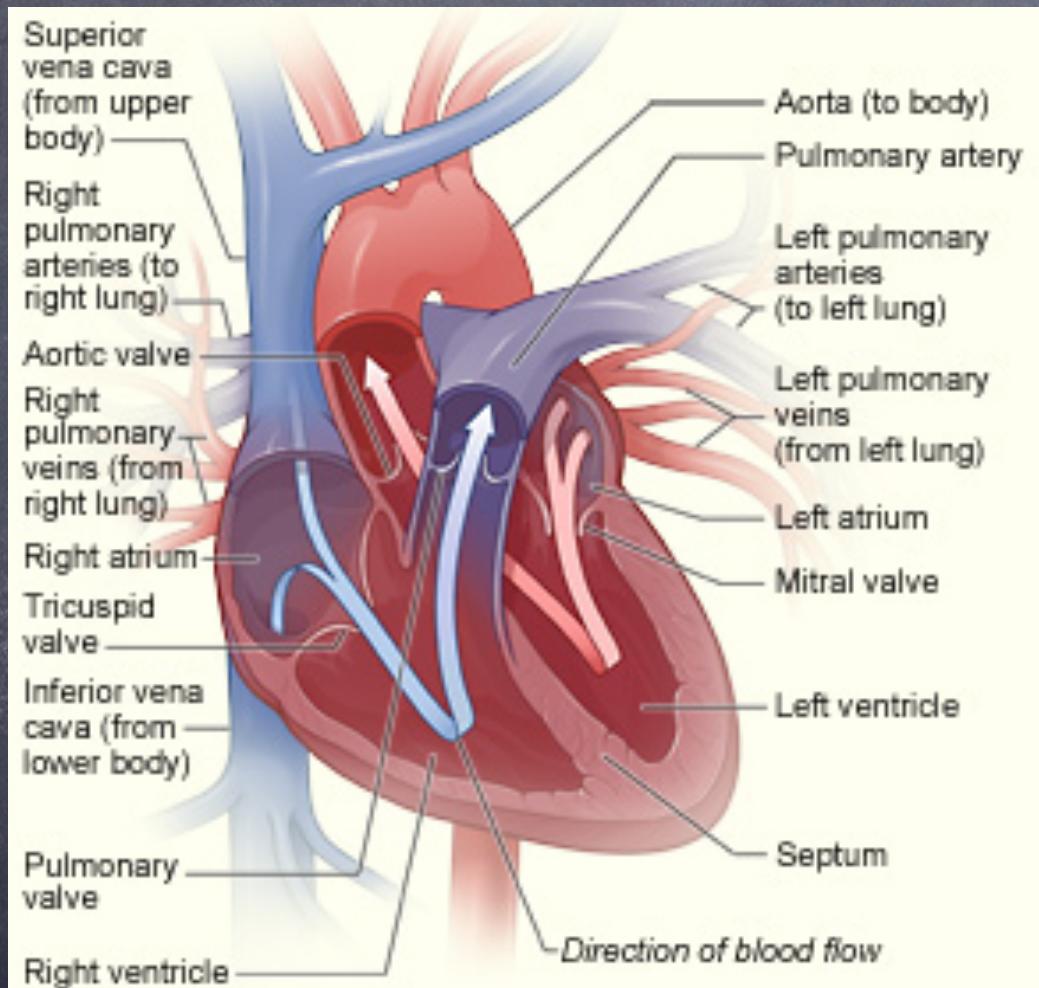
- Hollow muscular organ that pumps blood throughout the body by repeated, rhythmic contractions
- Cardiac from the Greek καρδιά, kardia, for "heart".



The Heart

- Located in the pericardium – a double-walled protective sac, center of human chest inside rib cage
- Three layers:
 - Epicardium – outer layer connective & protective tissue
 - Myocardium – the striated muscle of the heart, performs contraction
 - Endocardium – responsible for contraction
- Four chambers:
 - Two upper chambers: left atrium and right atrium (atria)
 - Two lower chambers: right and the left ventricle
 - Septum – dividing wall of muscle, separating right side from left side
 - Ventricular septum thicker than atria septum.

The Heart



Source: www.nhlbi.nih.gov

- Blue arrow → direction of oxygen-poor blood flow from rest of body to heart to lungs.
- Red arrow → direction of oxygen-rich blood flows from lungs to heart and to rest of body

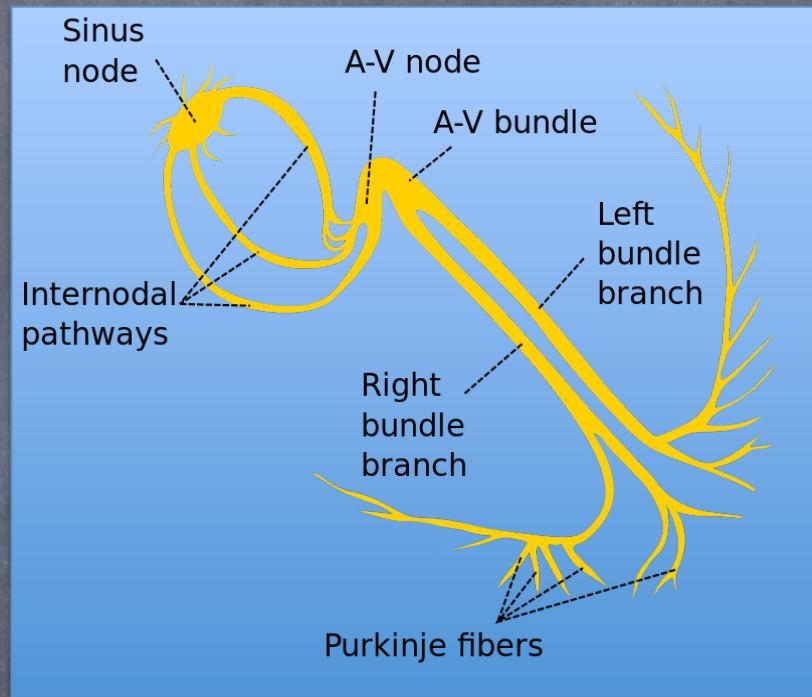
How the Heart Functions

- Right atrium collects de-oxygenated blood from the body
- Right atrium contracts pumping blood through tricuspid valve
- Tricuspid valve to right ventricle to the lungs
- Lung function – exchanged carbon dioxide for oxygen
- Oxygenated blood returns from lungs
- Left atrium collects oxygenated blood from the lung
- Left atrium pumps blood to left ventricle via bicuspid valve (mitral valve)
- Mitral valve pumps it out to the body (via the aorta)
- Blood returns to right atrium repeating the process

Note: ventricles are thicker, bigger than atria as they pump the blood into the circulatory system throughout the body

Electric Overview of the Heart

- Electrical conduction
 - Electrical potential begins at sinus node (right atrium)
 - Propagates across atria
 - Purkinje fibers conduct charge across ventricles and transmit signal to myocardium



Source: wiki

Electrocardiography (ECG)

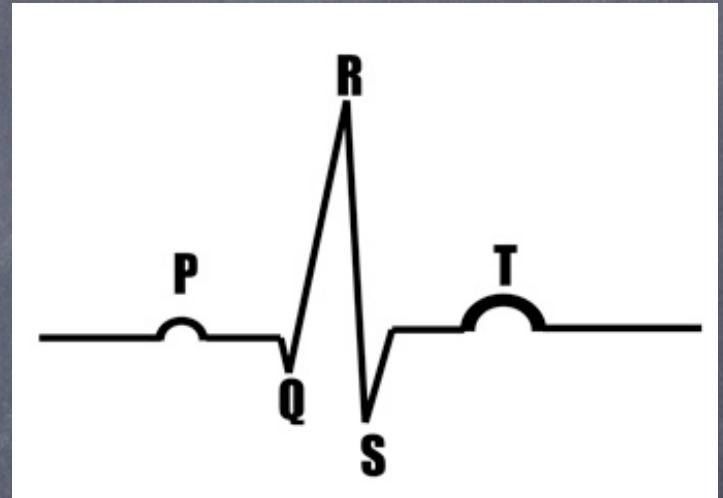
- Records the electrical activity and conduction system of the heart over time
- Measures electrical impulses of the polarization and depolarization of cardiac tissue capturing an electrical signal
- Calculates and translates electrical signal into a waveform

Why ECG? The Medical Approach

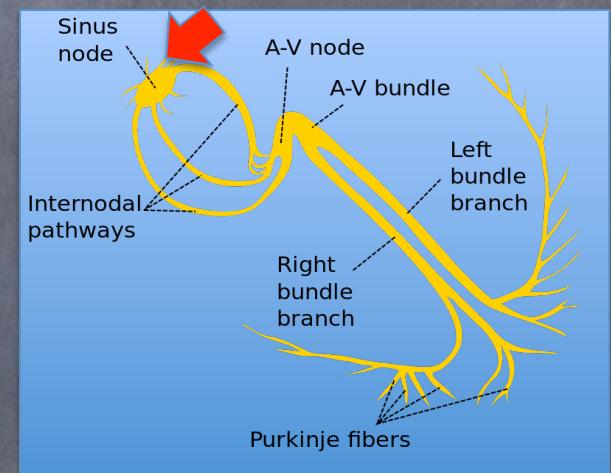
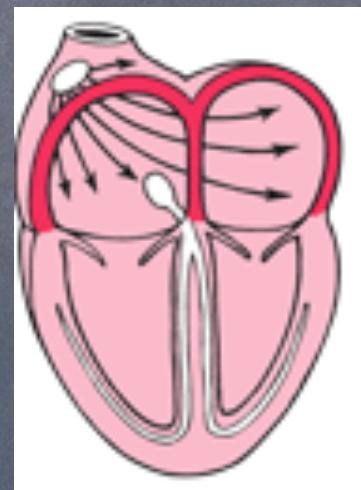
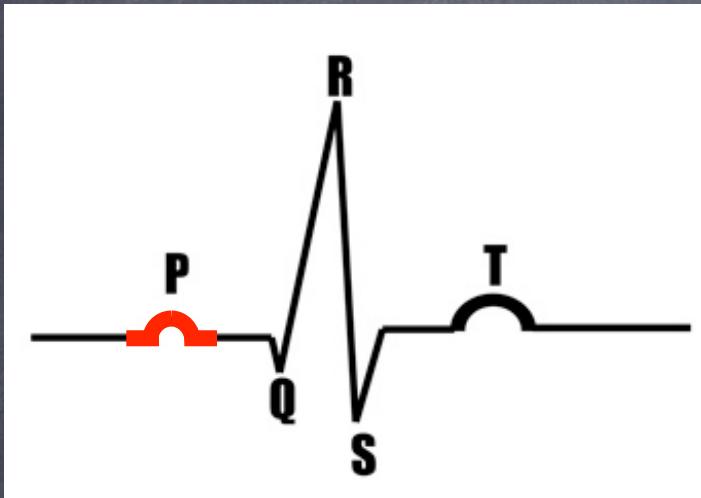
- General population screening for coronary heart disease
- Myocardial infarction (heart attack)
- Pulmonary embolism (blockage of the main artery of the lung)
- Other disease history contributions
 - Hypertension
 - Arterial
 - Diabetes
 - Stroke

ECG – PQRST Wave

- ECG has five deflections
- Name is arbitrary
- QRS wave (complex) occurs in rapids succession
- Q is any downward deflection after the P wave
- R wave is upward deflection
- S is downward
- T wave follows S
- And sometimes a upward U wave (very small and not often seen; repolarization)

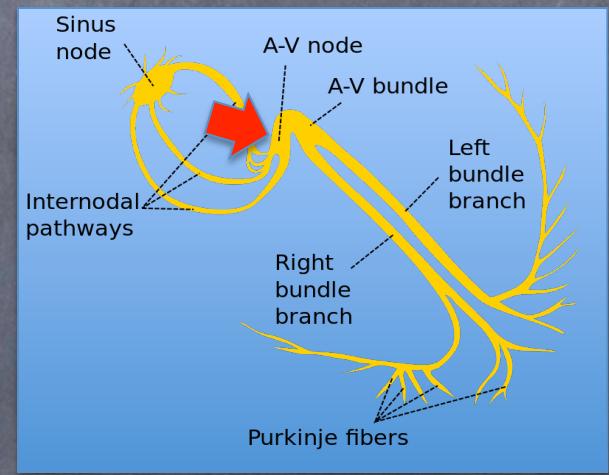
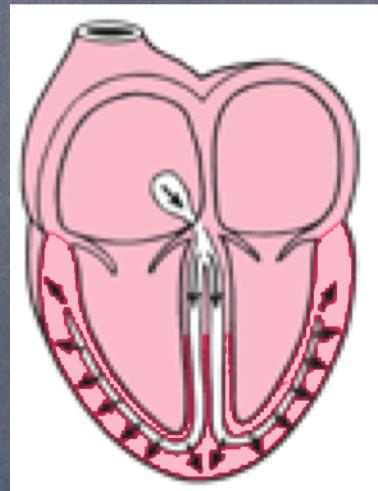
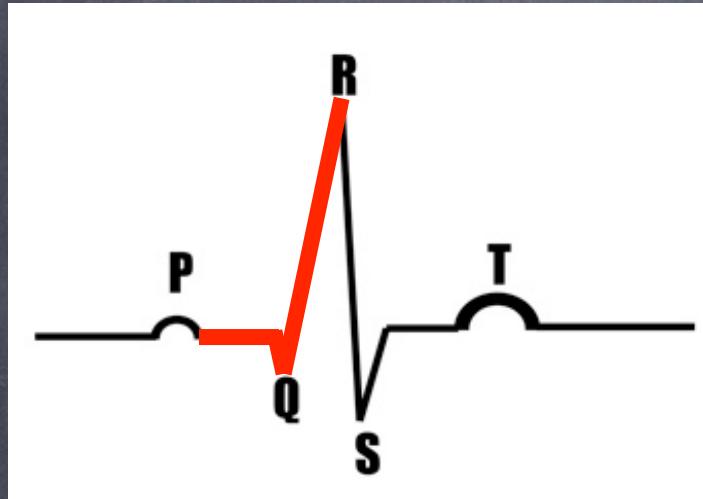


PQRST Wave



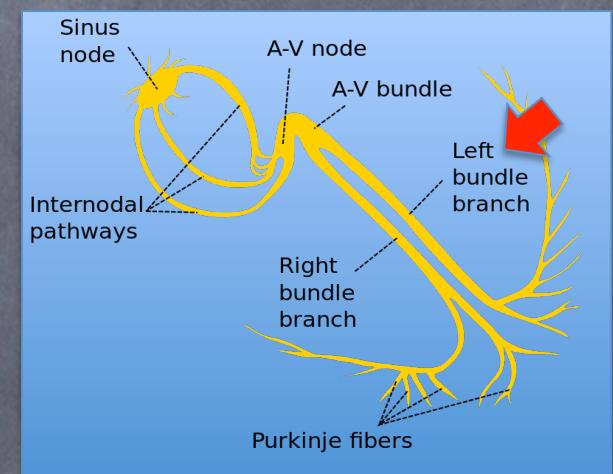
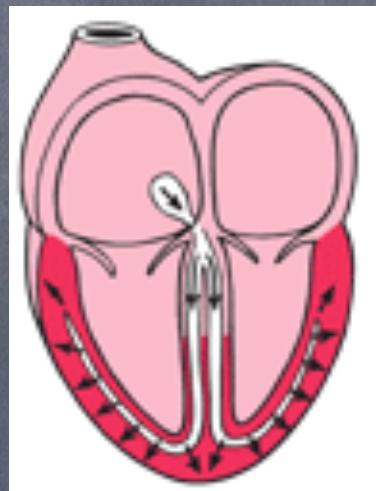
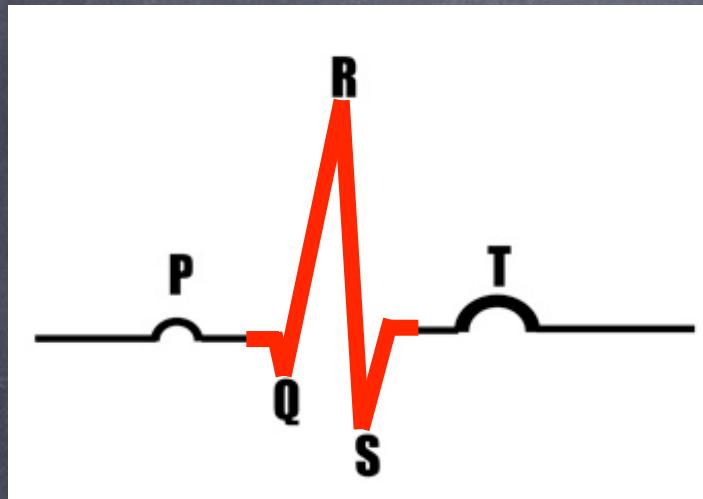
- Electrical impulse generated by is spontaneously generated by the sinoatrial node, nature's pacemaker
- Impulse propagates via right atrium to Bachmann's bundle (fibers on outside of left atrium)
- Myocardium contracts
- Seen on the ECG as the P wave

PR Interval



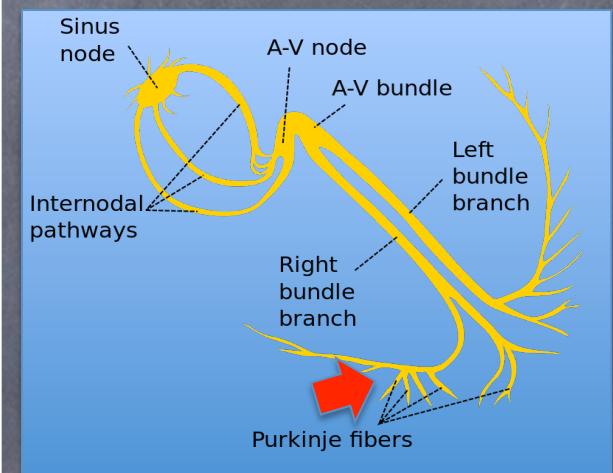
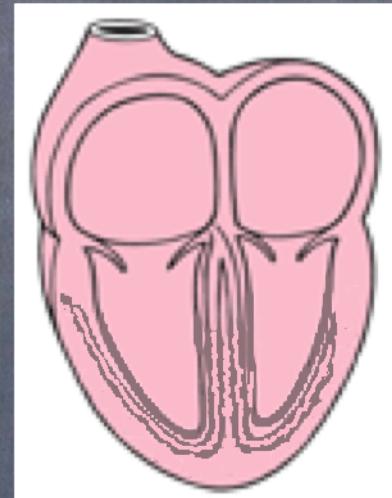
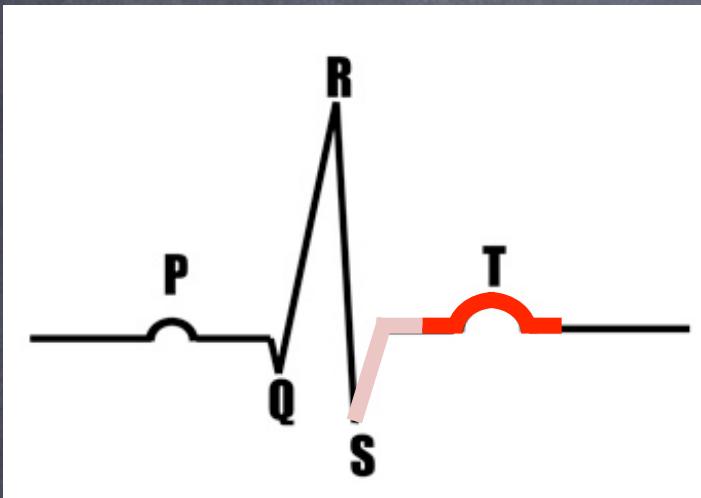
- PR Interval displays atrioventricular node's critical delay in conduct of the impulse
- Delay prevents atria and ventricles from contracting at the same time (blood flow would cease to flow)
- PR Interval is made up of AV node delay and atrial repolarization

PQRST Wave



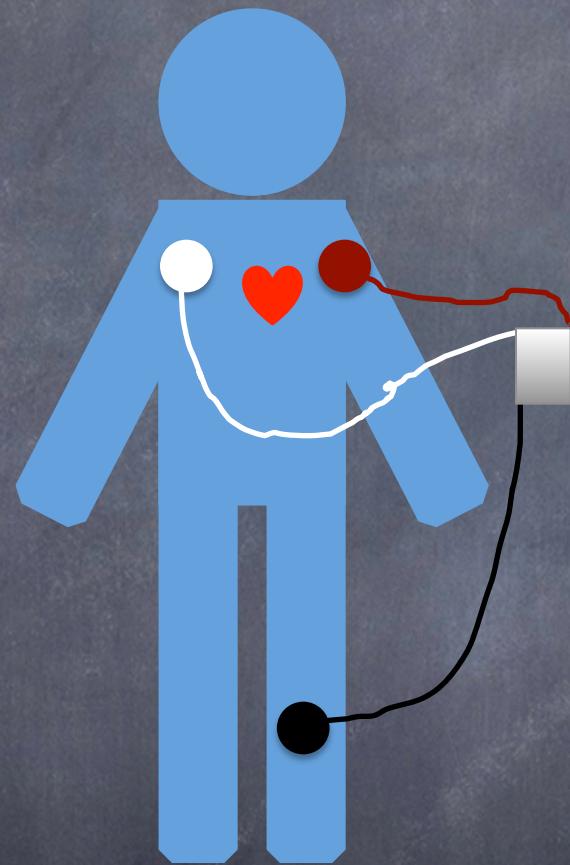
- Spread of electrical impulse across the ventricular myocardium
- Purkinje fibers:
 - Located in inner ventricular walls
 - Creates synchronized contractions of ventricles
 - Critical for maintenance of a consistent heart rhythm
- QRS complex – very rapid occurrence
- Begins (normal) with a downward deflection
 - Q: a larger upwards deflection
 - R: high peak
 - S: a downwards wave
- Action represents a complex ventricular depolarization and contraction.

ST Interval & PQRST Wave



- Ventricular repolarization
- Recovery and resting state
- T wave – moderate upward wave indicating
- Includes ST Interval, T Wave, & U Wave

Measuring ECG



Source for ECG slides: *Computing the Electrical Activity in the Heart: I (Monographs in Computational Science and Engineering)* by Joakim Sundnes, Glenn Terje Lines, Xing Cai and Bjørn Frederik Nielsen (2007)

Measuring The Heart

- Use the Electrocardiogram (ECG)
- ECG:
 - Generates a waveform representing the electrical activity of the heart
 - Waveform patterns provide signs, symptoms, and damage of heart muscle
- ECG cannot:
 - Determine blood flow rate or pumping blood pressure
 - Masked conditions, e.g., cardiac arrest

ECG History

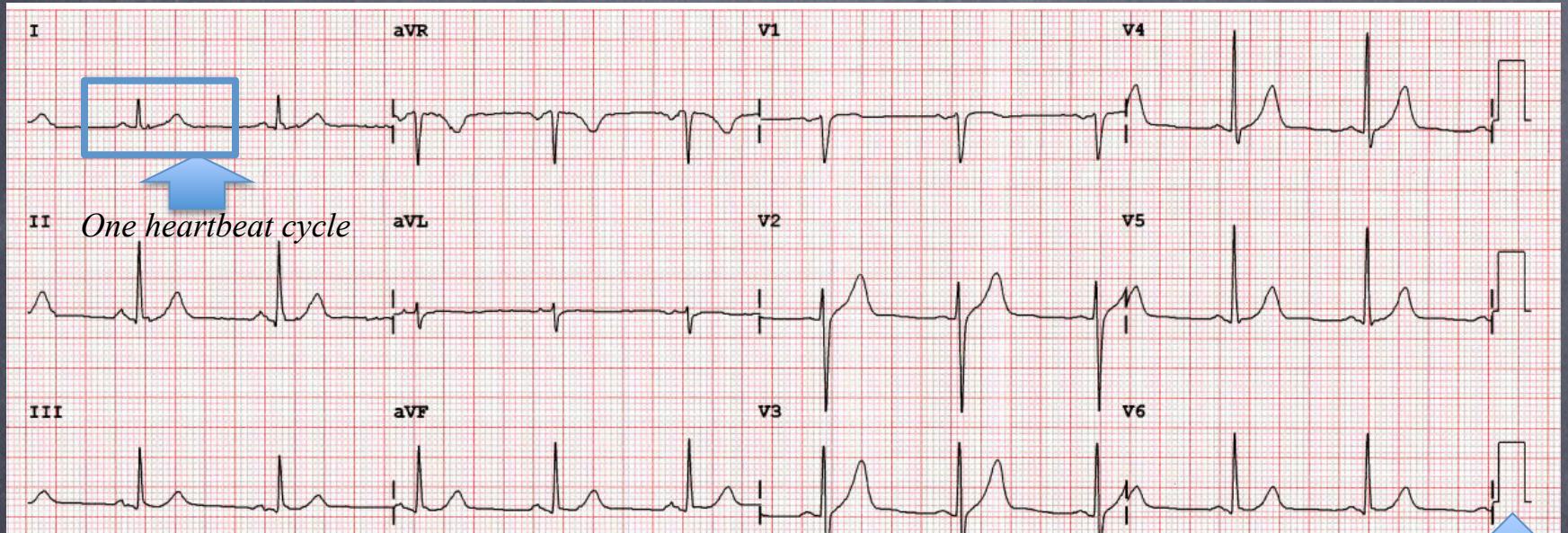
- *Augustus Désiré Waller, St Mary's Hospital, Edinburgh, shows cardiograph to students of the medical school, during lecture in 1888*
- *Wilhelm Einthoven, The Netherlands, demonstrates string galvanometer – with the limb leads labeled I, II, and III and the waveform labeled P, QRS, and T; receives Nobel prize in 1924 for discovering mechanism of the electrocardiogram*
- *Einthoven actually credits Waller with this discovery in 1895 paper; "Über die Form des menschlichen Elektrokardiogramms"*
- *Dutch spelling with a “K” often has ECG referred to as EKG*
- *Frank Wilson showed ECG unipolar potentials could be defined using a central terminal as reference by connecting 5 kΩ resistor from each terminal of the limb leads to the central terminal*

ECG: How & Why

- Amplifies depolarization and repolarization of the heart muscles through changes in the skin
- Heart cells at rest have negative polarity
 - Outside +, inside -, - 90 mV potential difference
- Movement toward neutral (0 volts) is called depolarization
 - Stimulated by Ca^+ and Na^+ flow into heart cells
 - Cell outside -, inside +
 - Current spreads along cells in a particular direction
- Repolarization: outside returns to +, inside -, returns to rest

ECG Waveform on Strip Chart

12-lead – showing in 4 columns by 3 rows



5 mm by 5 mm
reference square
0,200 s duration by
0.5 mV amplitude

1 mm by 1 mm
reference square
0,040 s duration by
0.1 mV amplitude

1 mV, 10 mm high reference pulse
Length: 0.200 s

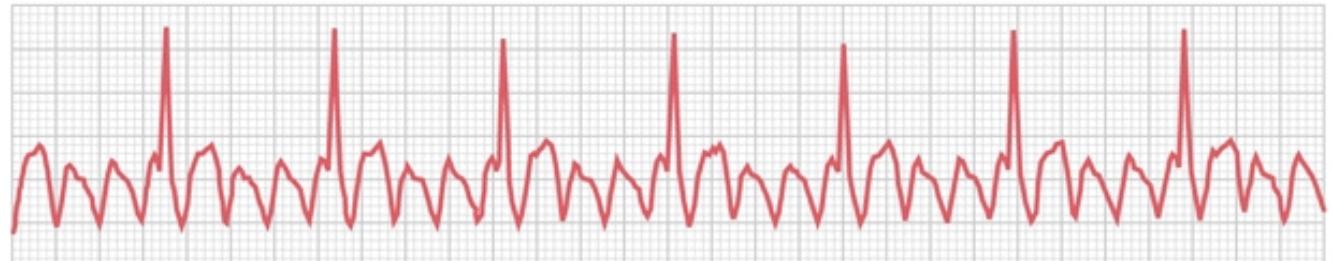
Measuring ECG

- ECG showing lack of sinus heart rhythm

ECG: Artrial Fibrillation (loss of T wave)



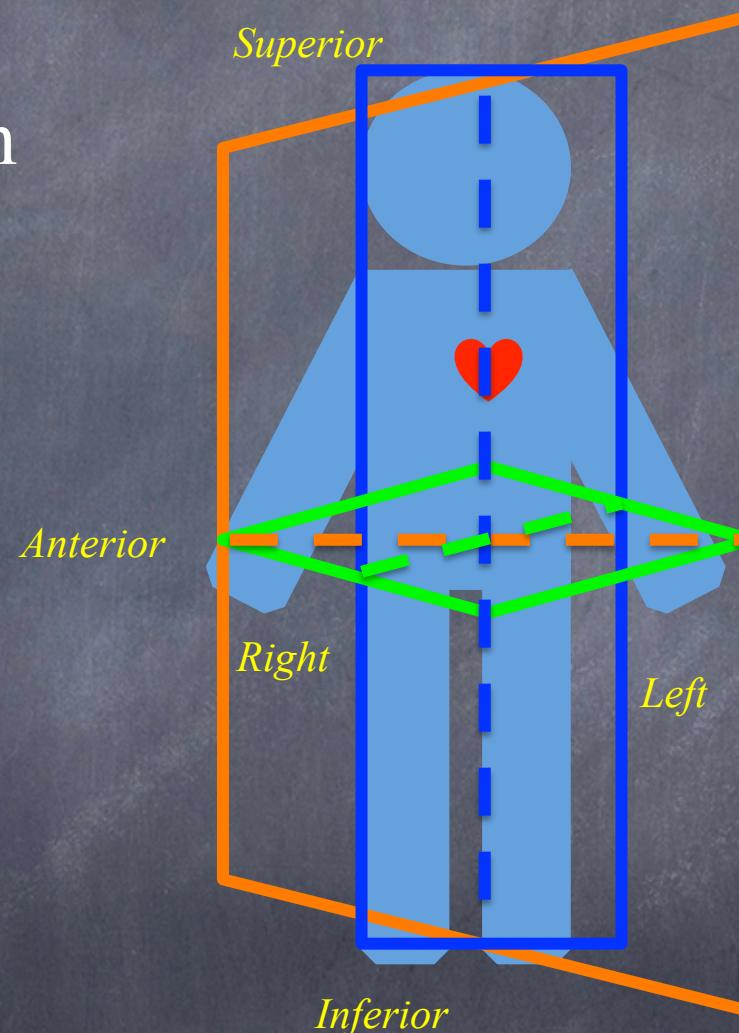
ECG: Artrial Flutter (sawtooth)



Source: <http://www.ncbi.nlm.nih.gov/books/NBK2214/>

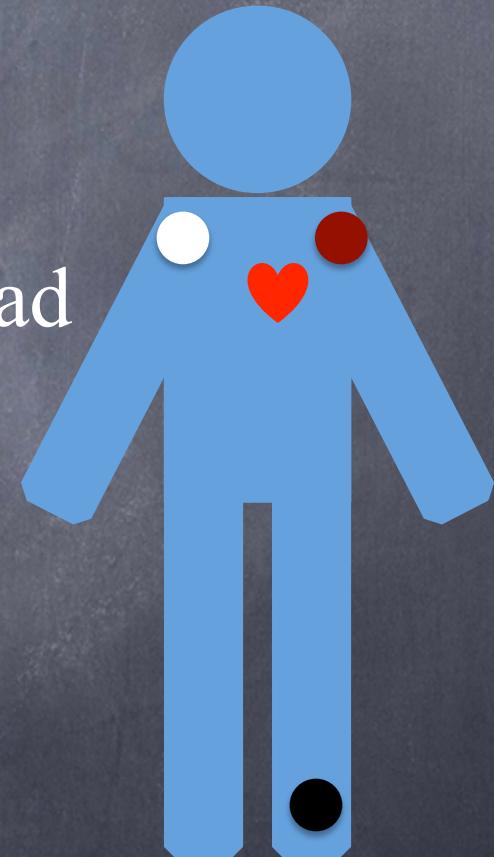
Lead Orientation (12-lead)

- ECG provides spatial information of electrical activity of heart
- Three orthogonal directions (approximate)
 - Right $\leftarrow \rightarrow$ Left
 - Superior $\leftarrow \rightarrow$ Inferior
 - Anterior $\leftarrow \rightarrow$ Posterior



Lead Placement (12-lead)

- Electrodes positioned on body in pairs
 - LA+RA (left arm + right arm)
 - LA+LL (left arm + left leg)
 - RA+LL(right arm + left leg)
- Output from each pair is called a lead
- Leads
 - Bipolar (frontal plane)
 - Augmented (frontal plane)
 - Unipolar (horizontal plane)

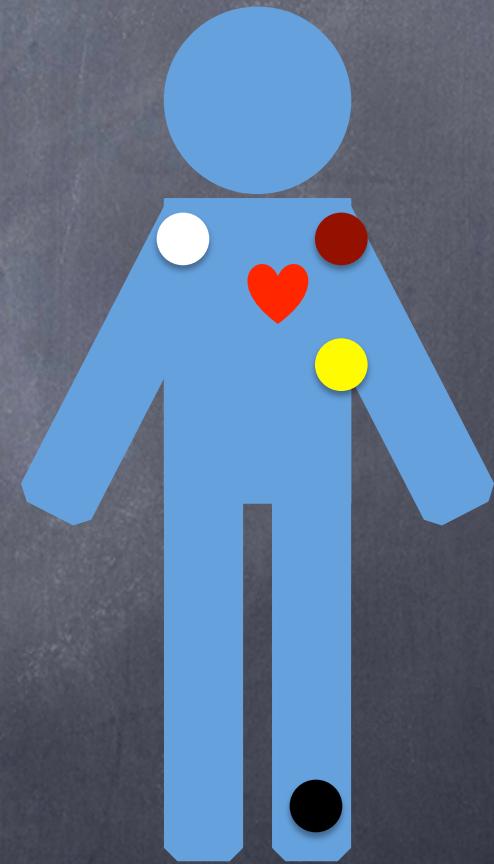


Lead Names

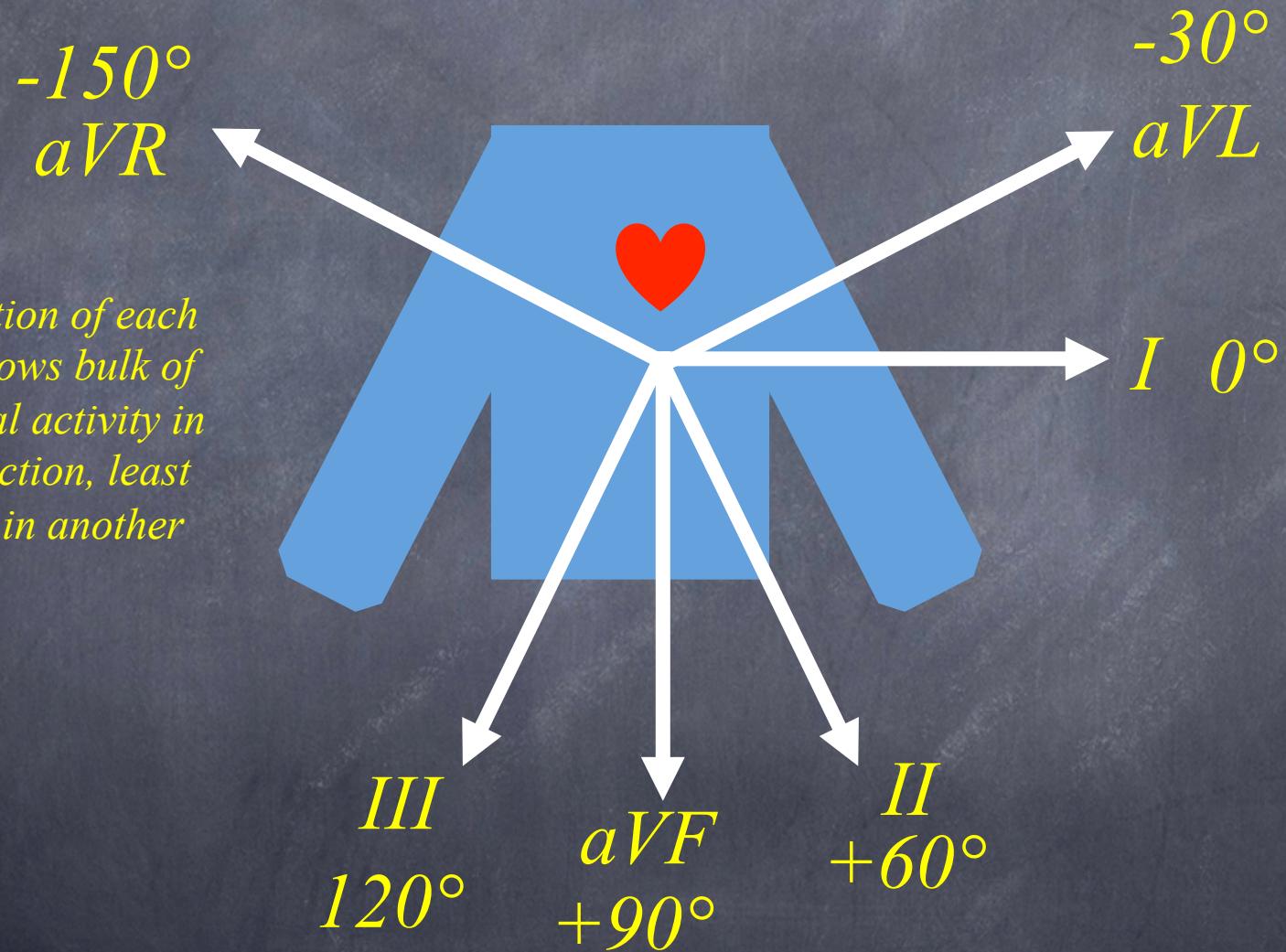
- Bipolar
 - Lead I (RA- to LA+), right, left
 - Lead II (RA- to LL+), superior, inferior
 - Lead III (LA- to LL+), superior, inferior
- Augmented
 - Lead aVR (RA+ to LA&LL-), right
 - Lead aVL (LA+ to RA&LL+), left
 - Lead aVF (LL+ to RA&LA-), inferior
- Unipolar (or precordial)
 - Leads V1, V2, V3, posterior, anterior
 - Leads V4, V5, V6, right, left



Vn

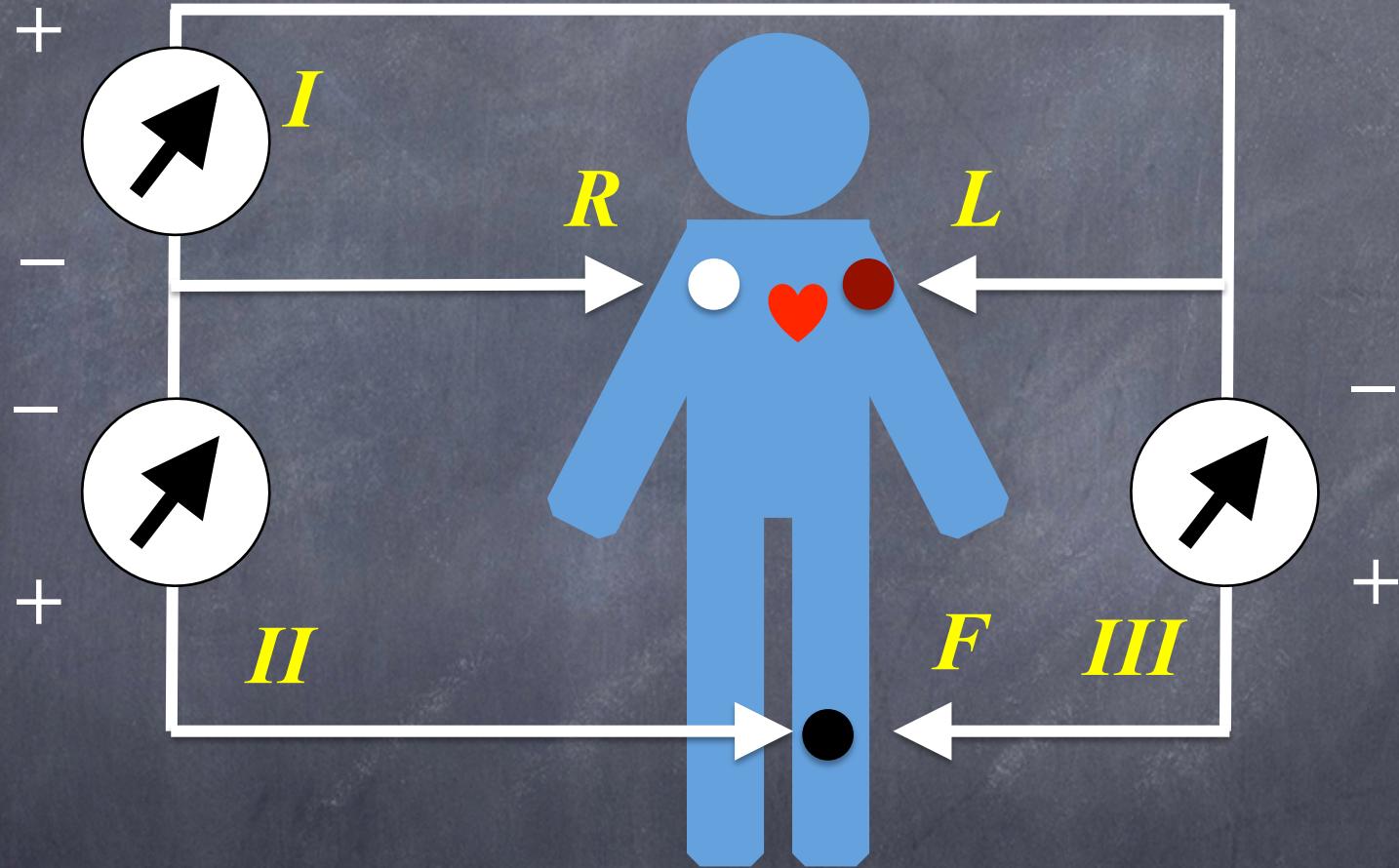


Hexaxial Reference System



The Einthoven Leads I, II, III

RA



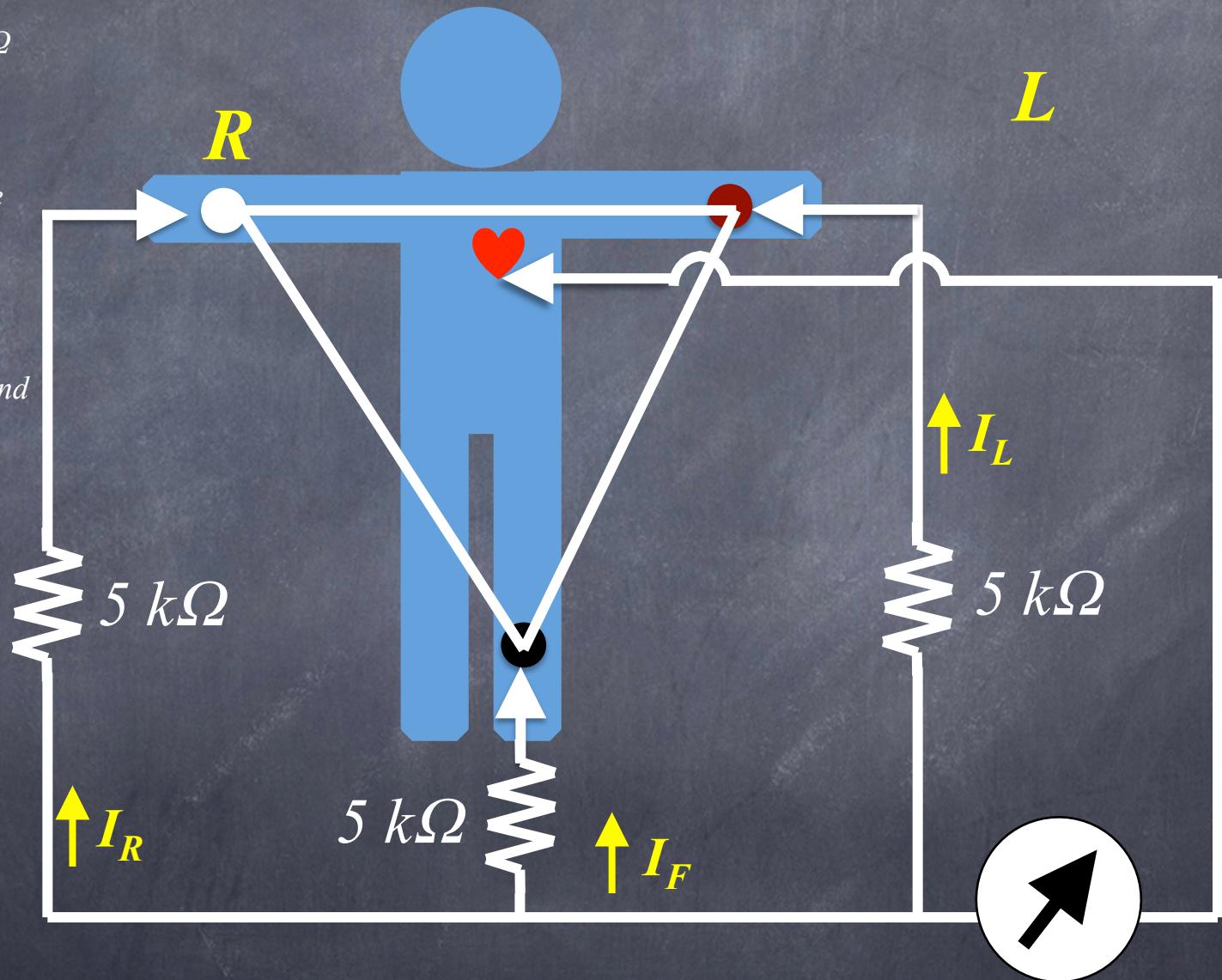
$$I = \phi_{LA} - \phi_{RA}$$

$$II = \phi_{LL} - \phi_{RA}$$

$$III = \phi_{LL} - \phi_{LA}$$

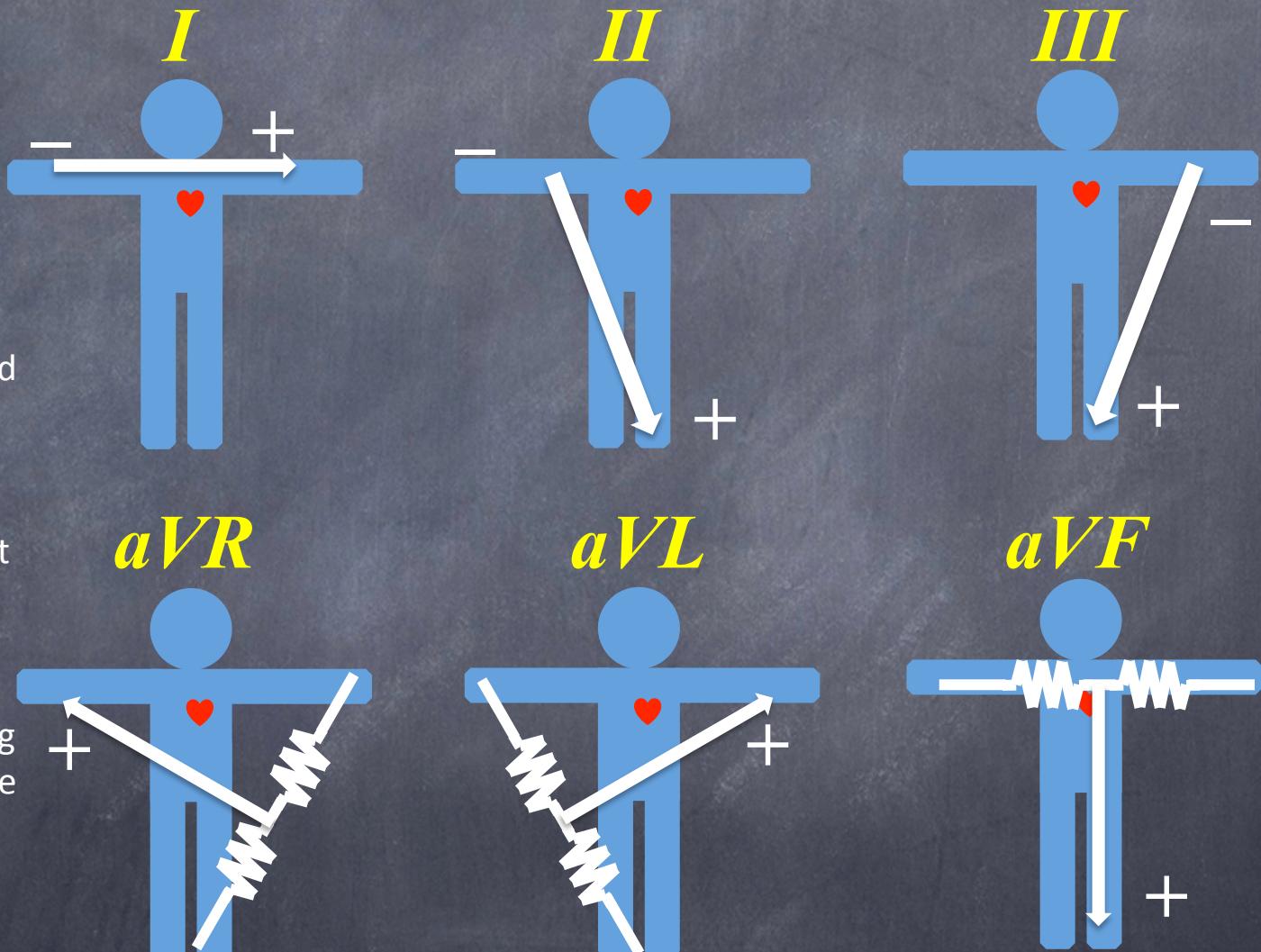
Wilson Central Terminal

Wilson suggested $5\text{ k}\Omega$ resistances; while widely used today, high-input impedance bio amplifiers provide significantly higher impedances which increases CMRR and attenuates artifacts caused by electrode and skin impedance



Einthoven Leads & Triangle

- Twelve electrodes
- Leads placed between two limb (arm or leg) electrodes
- Einthoven: designated limb leads as standard lead I, II and III
- Created triangle to show relationship of electrodes where heart at center is electrically null
- Einthoven's triangle is used when determining the electrical axis of the heart (heart angle)



Mathematical Relationship of Leads

- 12-lead
 - I, II, & III are bipolar
 - aVR, aVL, aVF, and V₁, V₂, V₃, V₄, V₅, V₆ are unipolar

Limb Leads

$$I = LA - RA$$

$$II = LL - RA$$

$$III = LL - LA$$

Augmented Limb Leads

$$aVR = -\frac{I + II}{2}$$

$$aVL = I - \frac{II}{2}$$

$$aVF = II - \frac{I}{2}$$

Einthoven's Law

$$I + (-II) = III$$

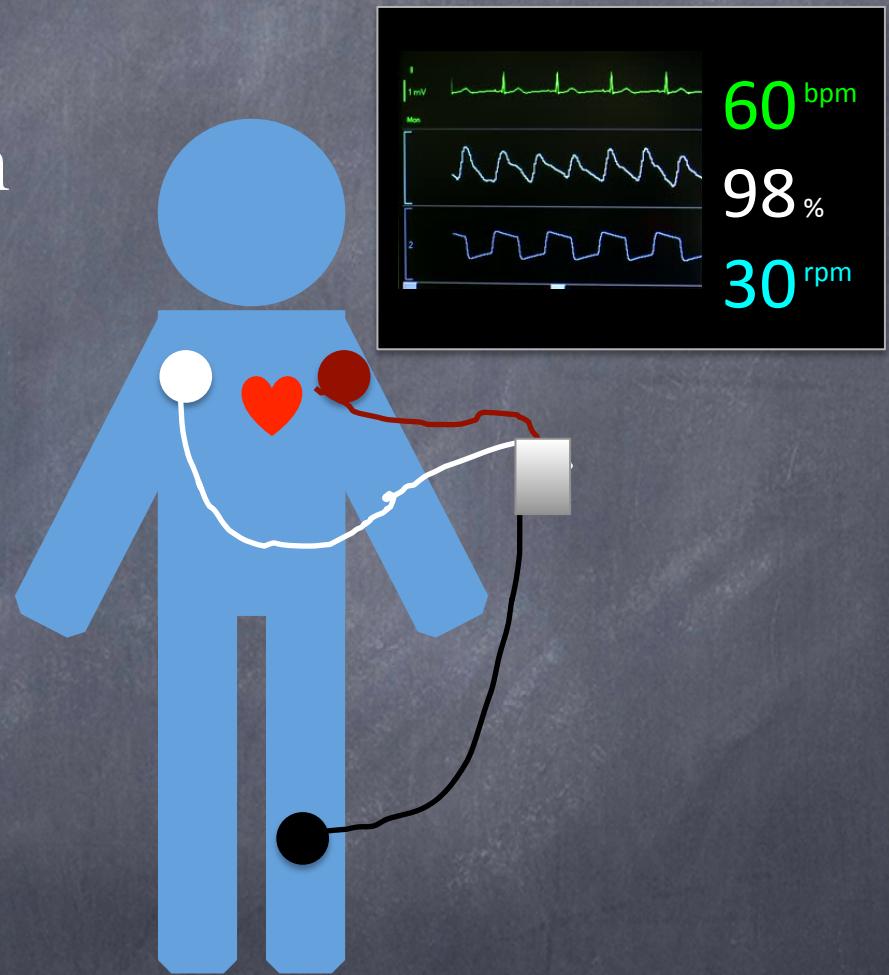
ECG Artifacts

- Pacing spikes
 - Due to implanted artificial pacemaker – impacts QRS complex
- Reversed or misplaced leads
 - Causes upside down waveforms
- AC interference
 - Due to 60 Hz (in USA) or 50 Hz (in EUR) noise coupled from power source
- Muscle tremor
 - Skeletal tremors from muscle contracture
- Wandering baseline
 - Patient moving, dirty leads, loose electrodes, DC power source ripple
- Heart block
 - Impulse does not travel from SA node to atrium



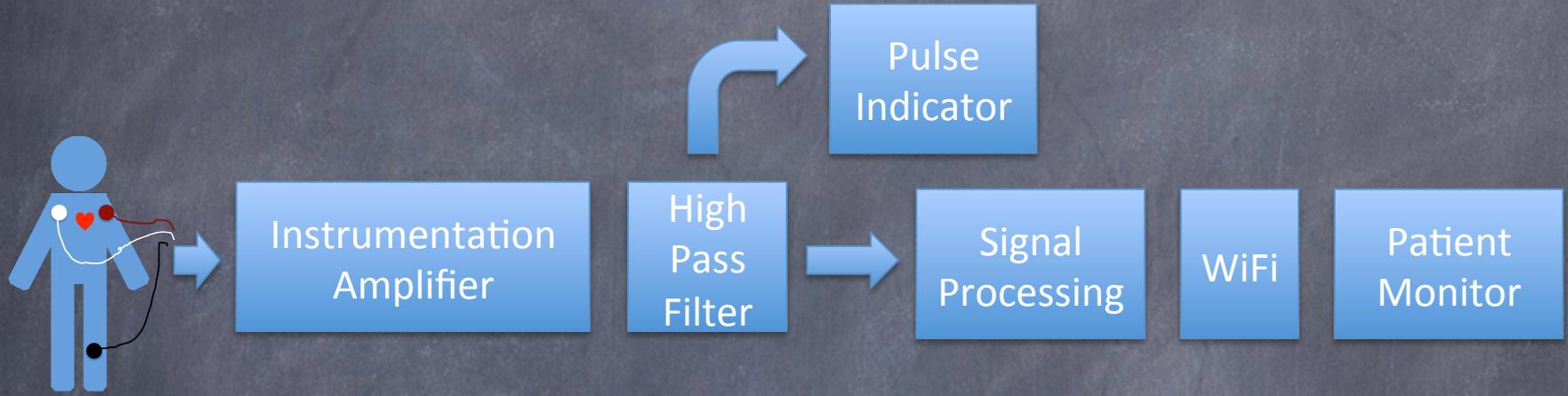
Measuring ECG (3-Lead)

- 3-lead ECG uses right arm (or chest), left arm (or chest) and left foot
- Able to obtain PQRST wave
- Unable to obtain other leads and heart angle



Source for ECG slides: Computing the Electrical Activity in the Heart: 1 (Monographs in Computational Science and Engineering) by Joakim Sundnes, Glenn Terje Lines, Xing Cai and Bjørn Frederik Nielsen (2007)

Designing & Building ECG (3-Lead)



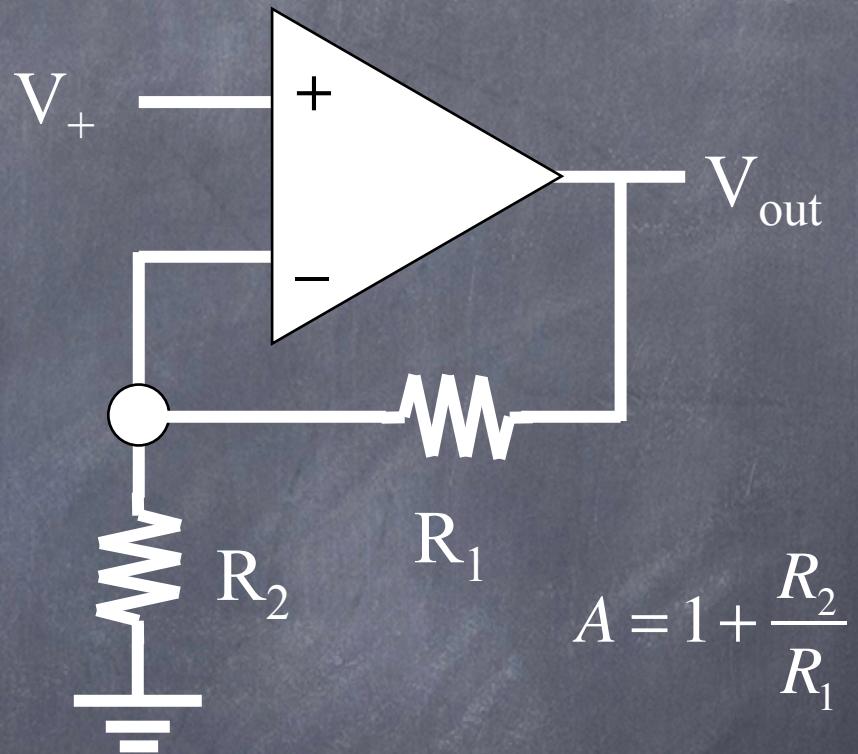
- Uses one-channel
- Collects Einthoven I
- Sufficiently easy, sufficiently difficult

Bio Amplifier

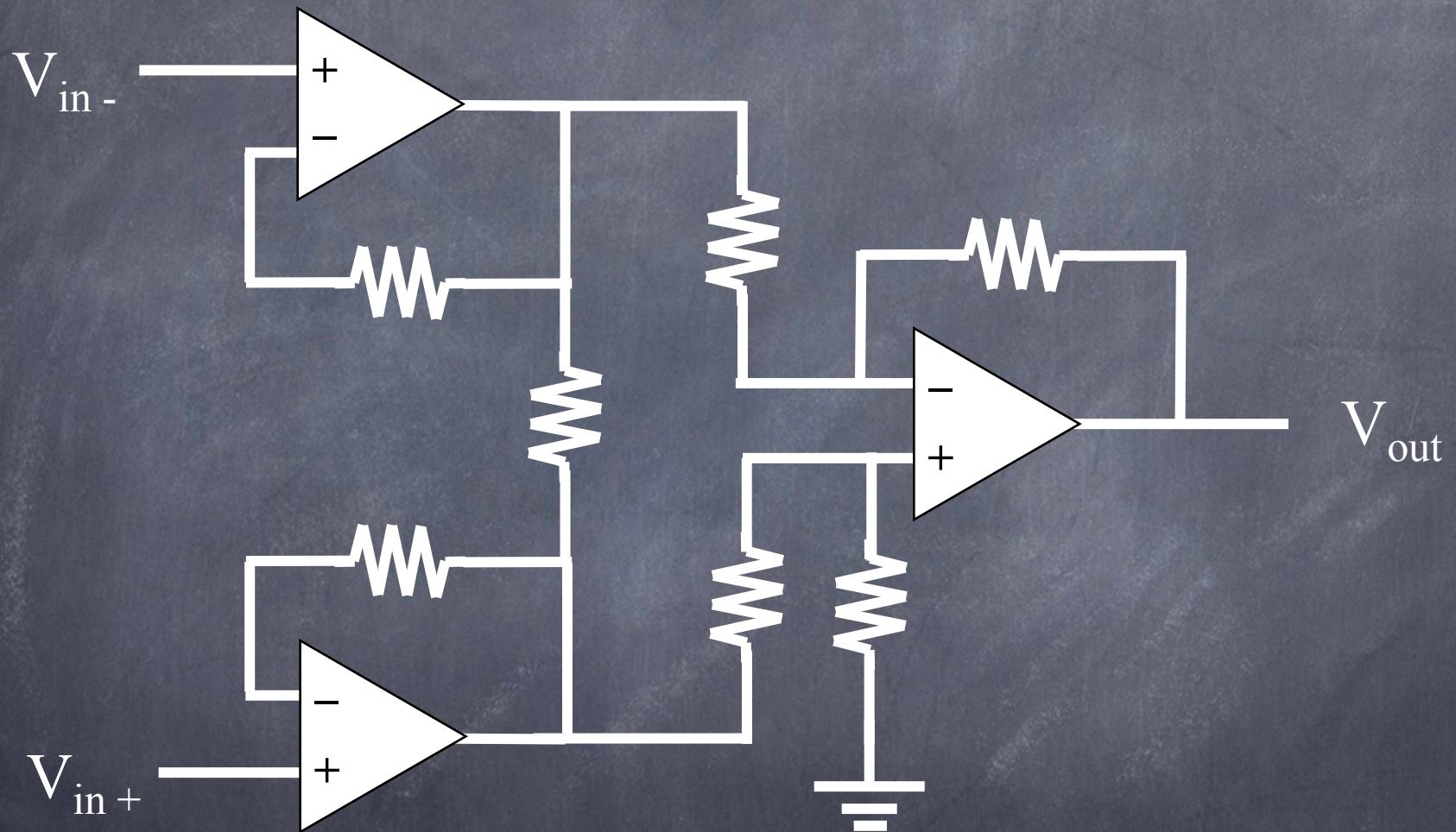
- Used to measure biological electrical signals from human beings (and animals)
- ECG signals:
 - Electrical range: $0.3 \text{ mV} < V_{QRS} < 2 \text{ mV}$ for
 - Frequency range: 10 Hz to $F_{\text{samp}} = 1\text{kHz}$
- Bio amplifier spec (typical): [1]
 - Internal noise: $< 2 \text{ mV}$
 - Input Impedance 10 MV
 - Operational bandwidth: 0.16 to 250 Hz
 - Bandwidth cutoffs $>18 \text{ dB/octave}$
 - 60 Hz Notch filter
 - CMRR > 100
 - CM input range: $\pm 200 \text{ MV}$)
 - Shock protection: $>2000 \text{ V}$

Bio Amplifier

- Use non-inverting op amp configuration
- Typical amplification gain: $100 < A < 500$
- $100 \text{ k}\Omega / 1\text{k } \Omega$

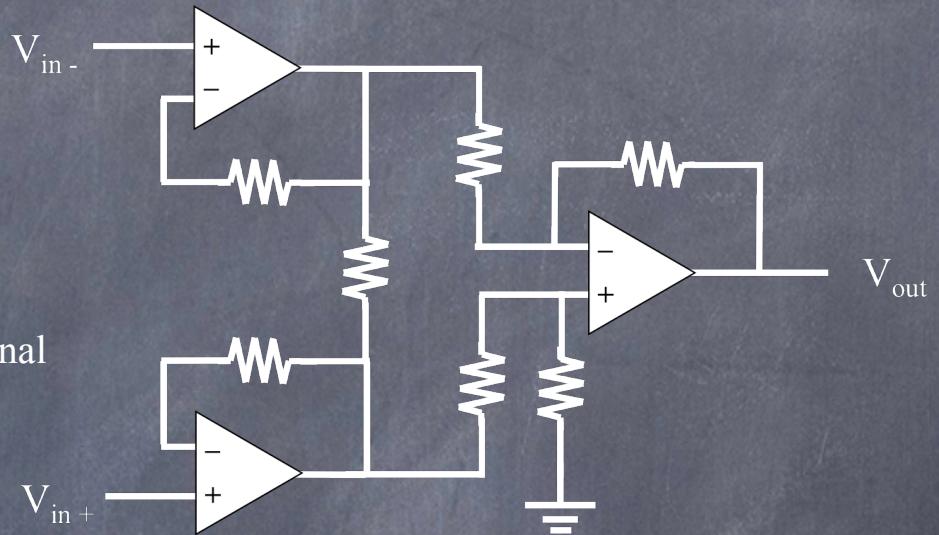


Instrumentation Amplifier

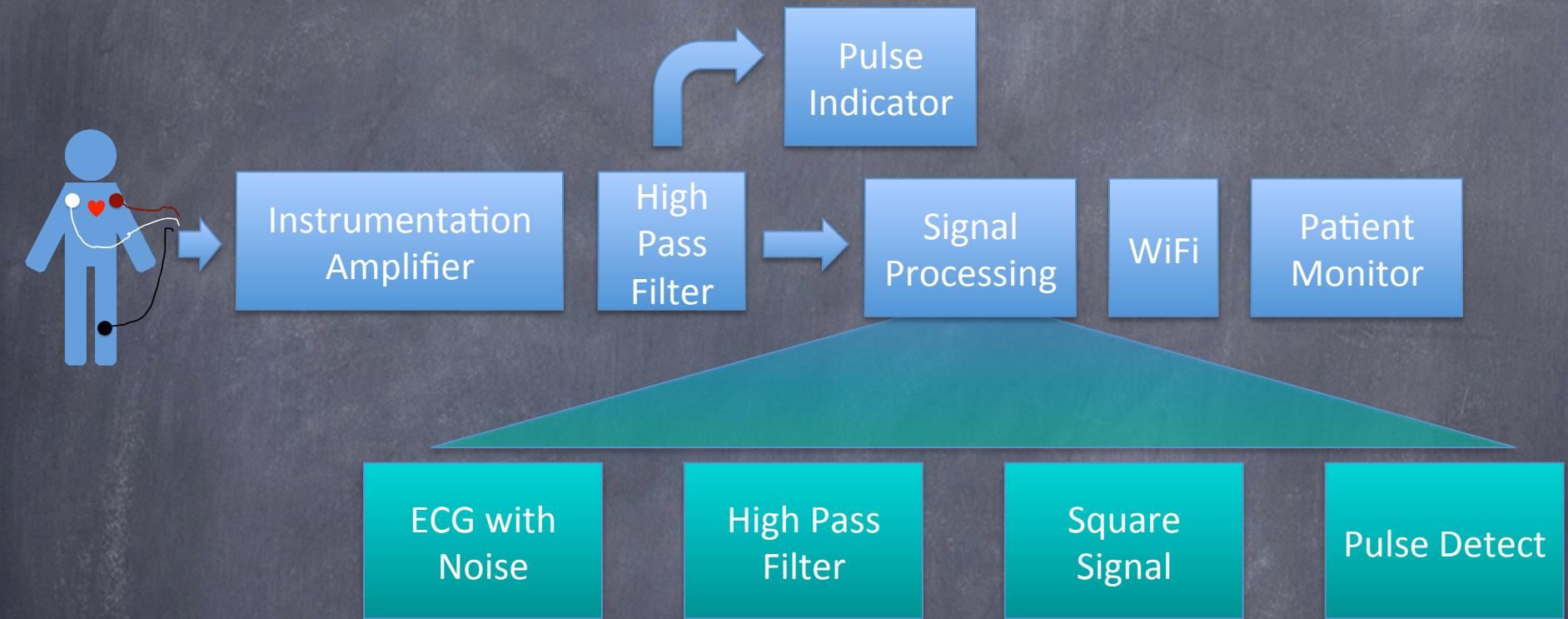


Instrumentation Amplifier

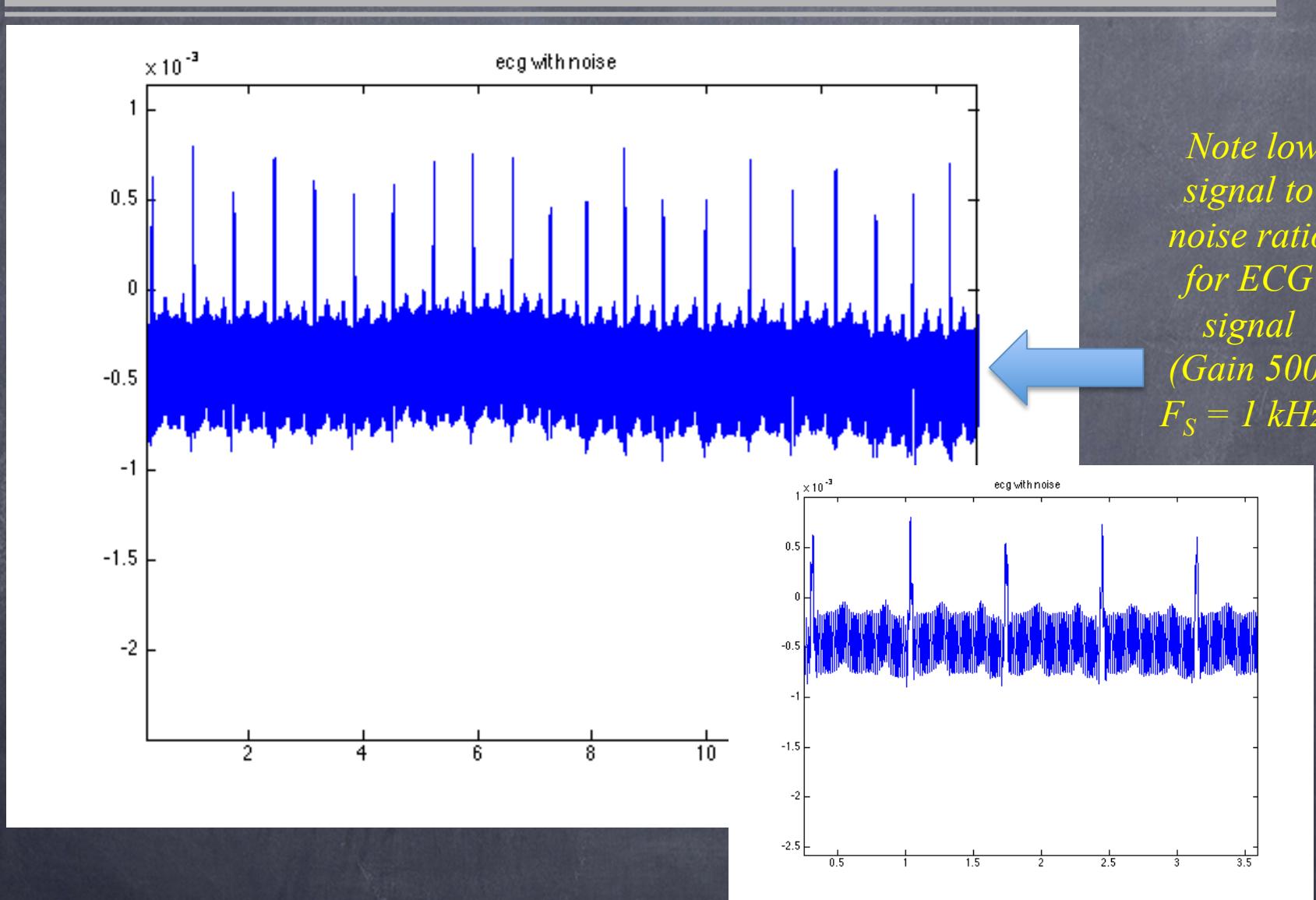
- Two different stages
 - Gain stage
 - Differential stage
- Purpose of each stage
 - Gain stage
 - Provides gain to entire signal
 - Does not remove common mode signal
 - Differential stage
 - Does not apply gain
 - Remove common mode signal
- Advantages
 - Amplifies signal, then in second stage remove noise and non-ideal or non-linear modalities to signal that has been gained
 - Symmetric front end provides great common mode rejection, common mode rejection vs frequency, and nice noise performance
- Disadvantage
 - Ability to have gain near voltage rails is limited



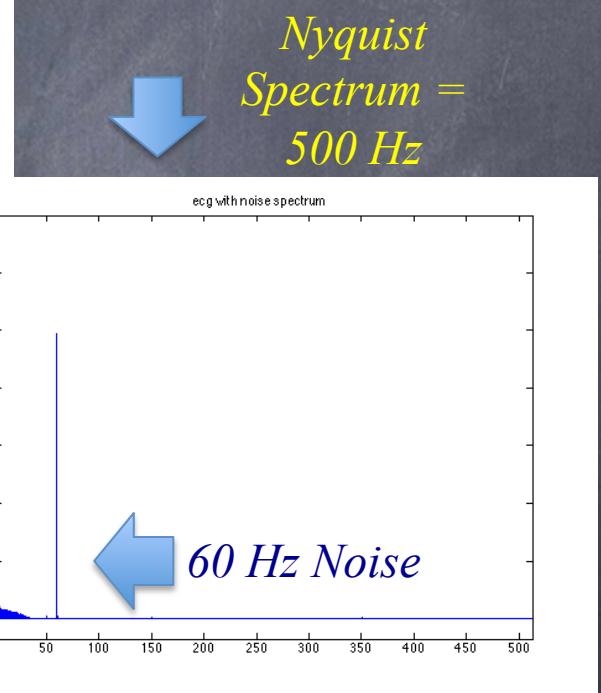
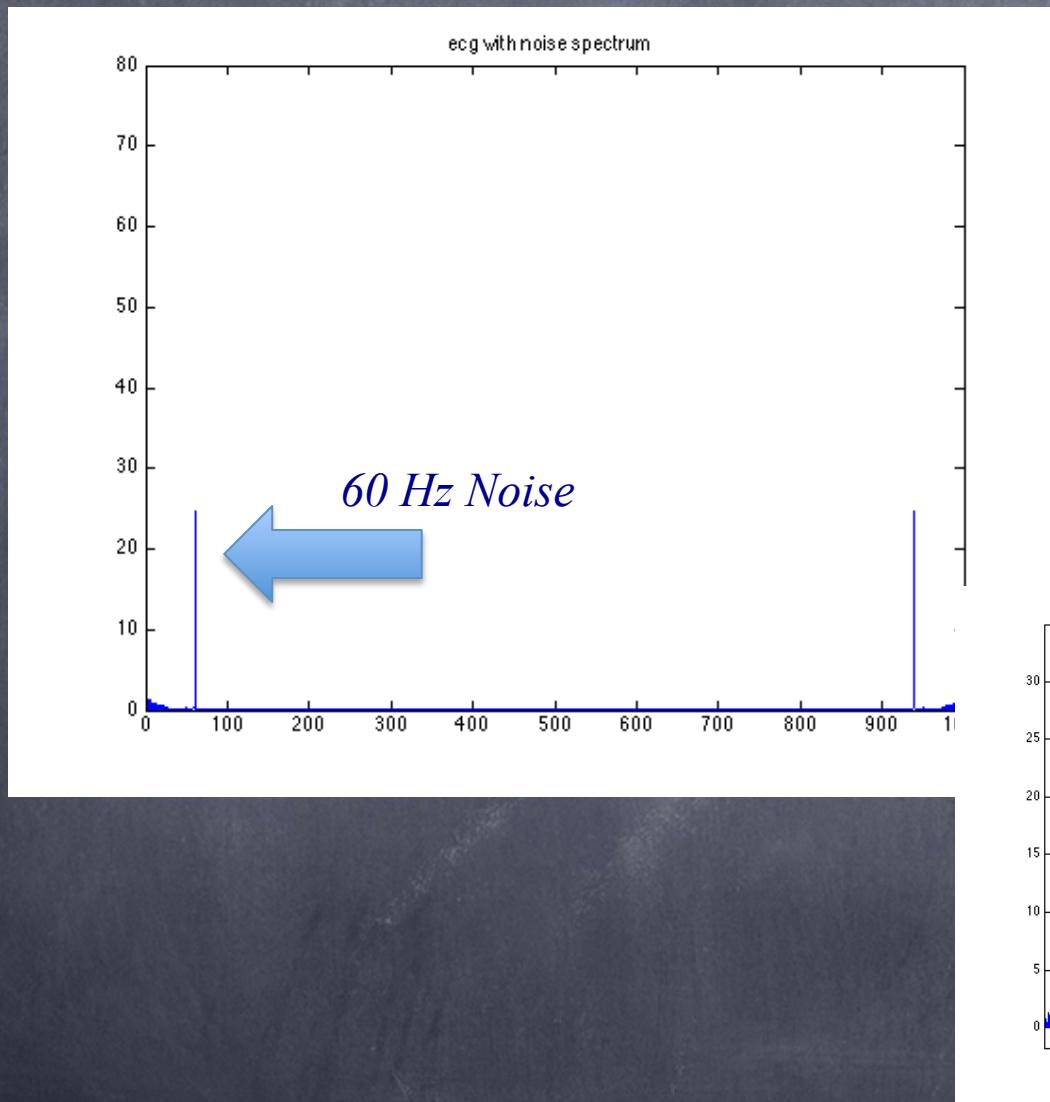
Signal Processing



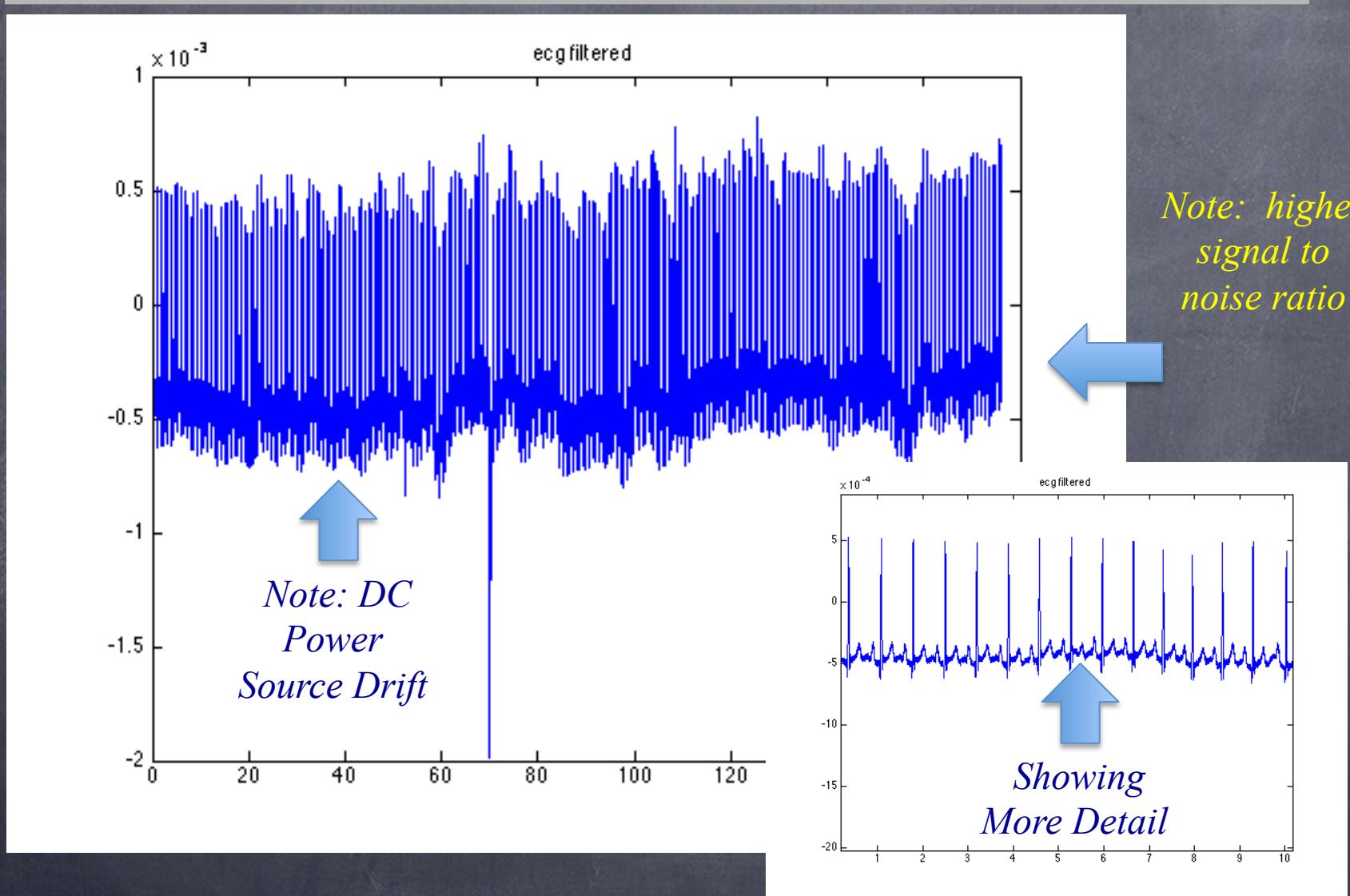
ECG with Noise



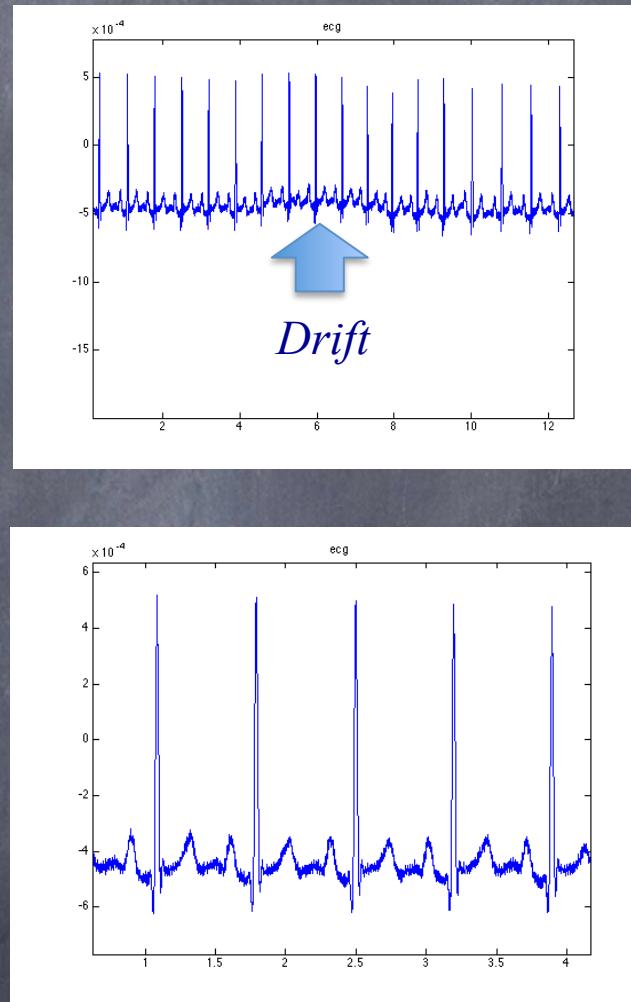
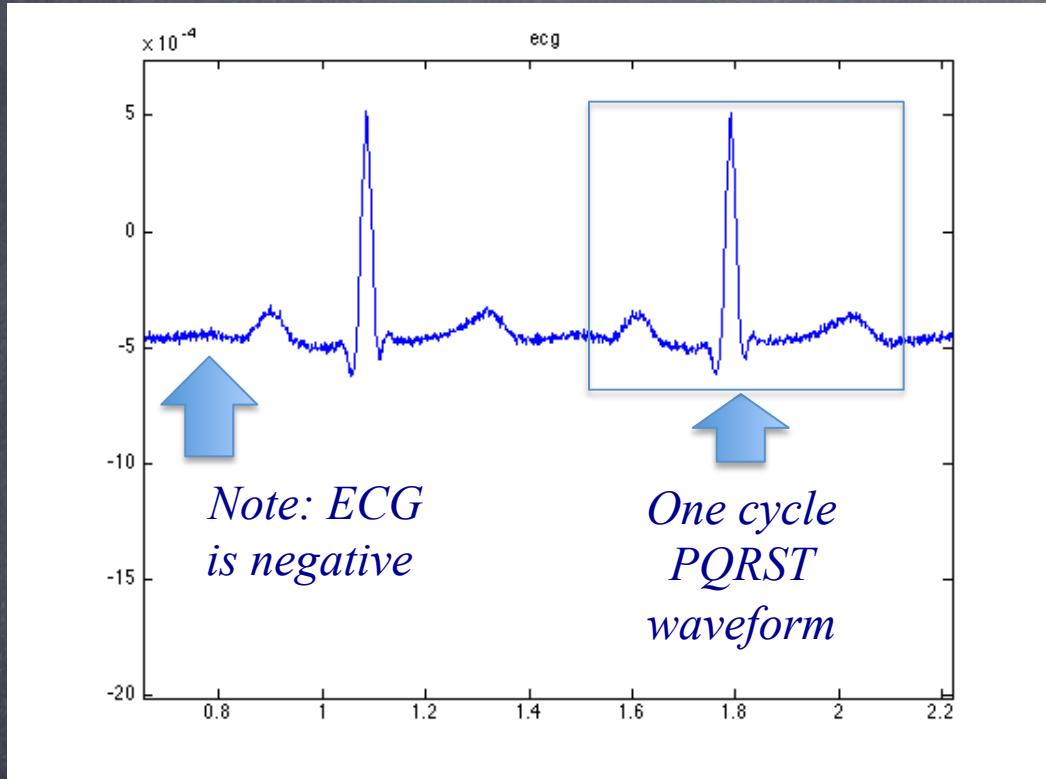
ECG with Noise Spectrum



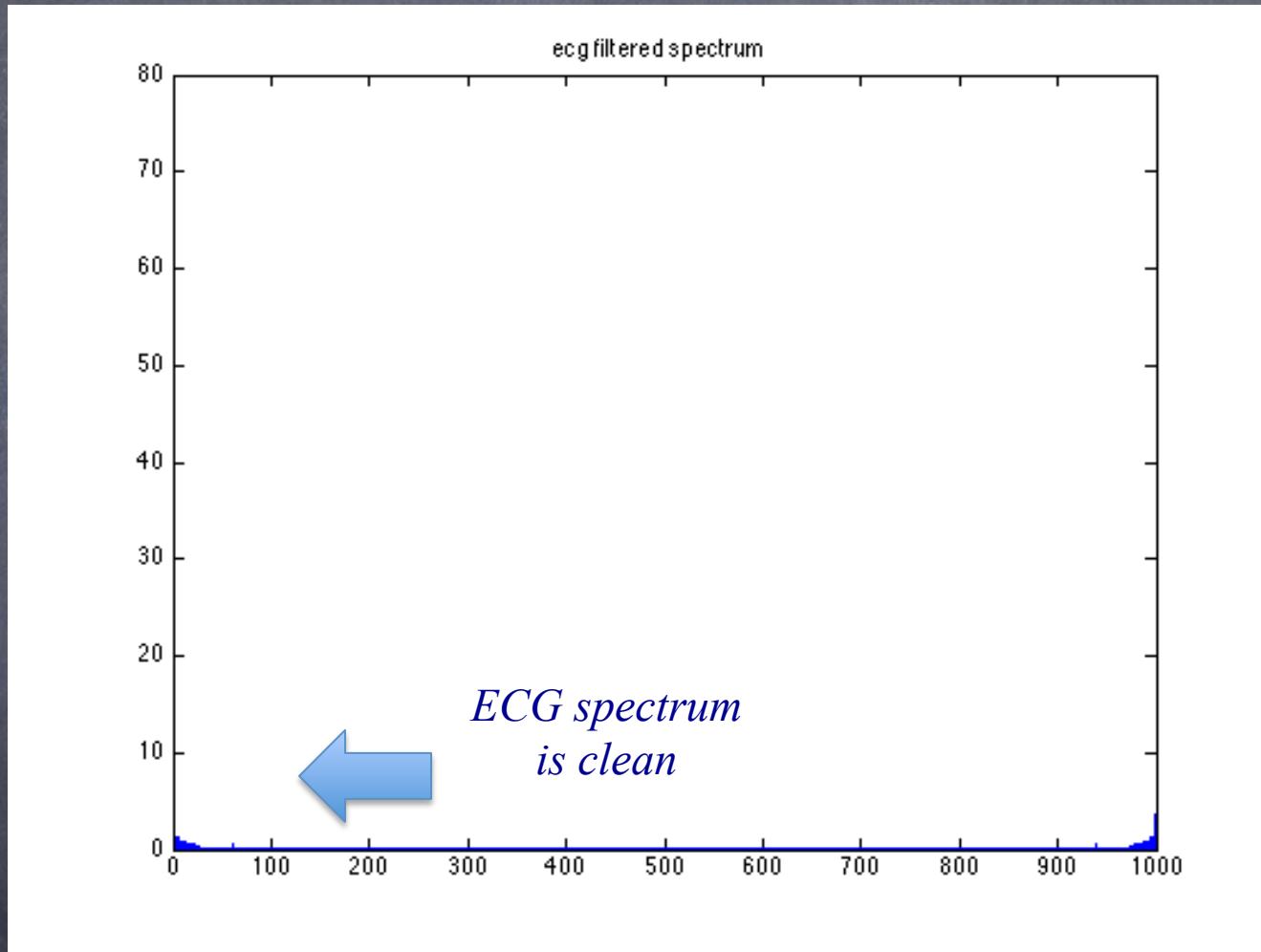
ECG after High Pass Filter



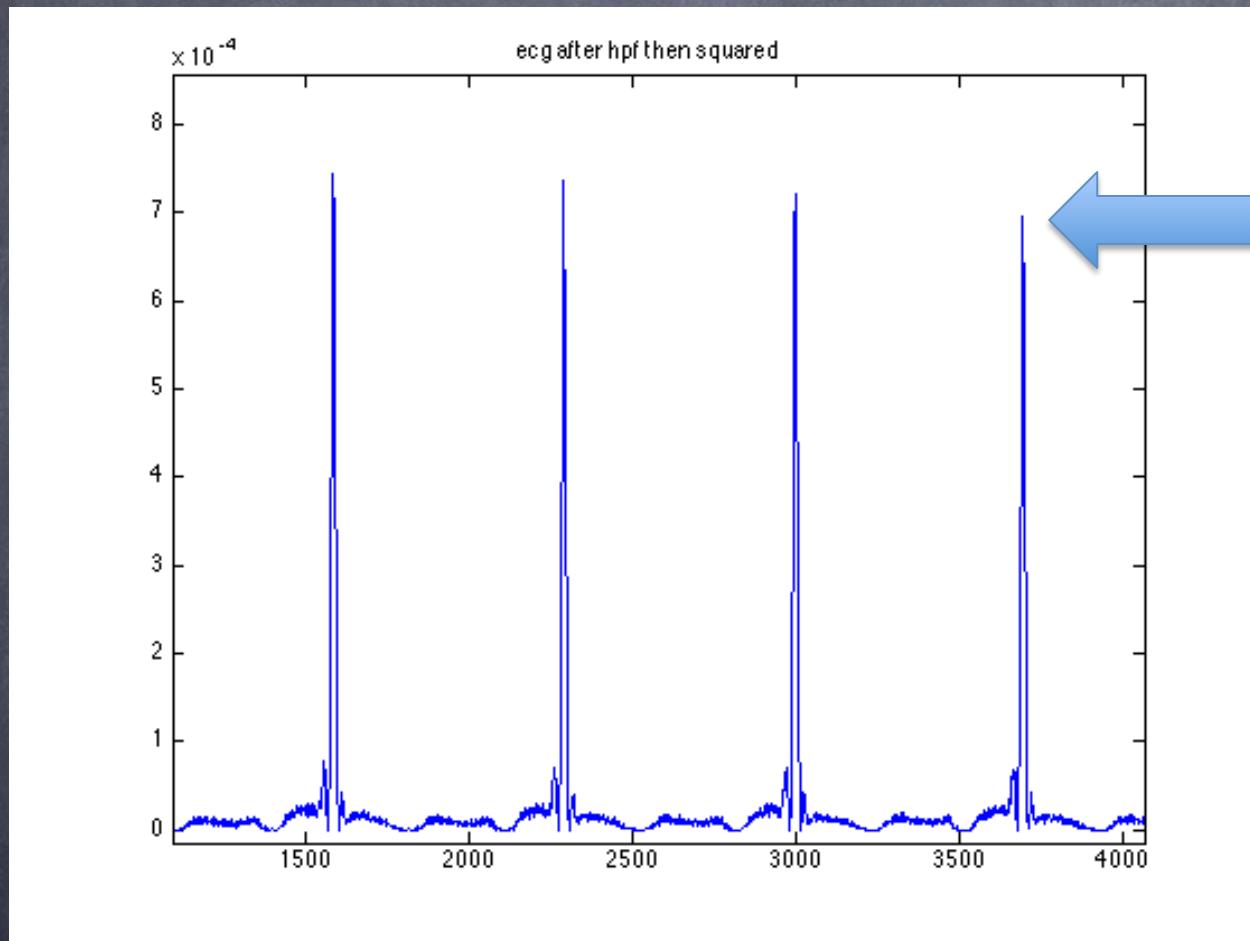
ECG after High Pass Filter -- Tight



ECG after High Pass Filter Spectrum



ECG after HPF Squared



*Able to count peaks
Threshold = 0.0005 mV*

- Note:*
- *Very high signal to noise ratio*
 - *No DC drift*
 - *Positive*

ECG Pulse

