ELECTROCARDIOGRAPHY (ECG)

EE 471 – F2016

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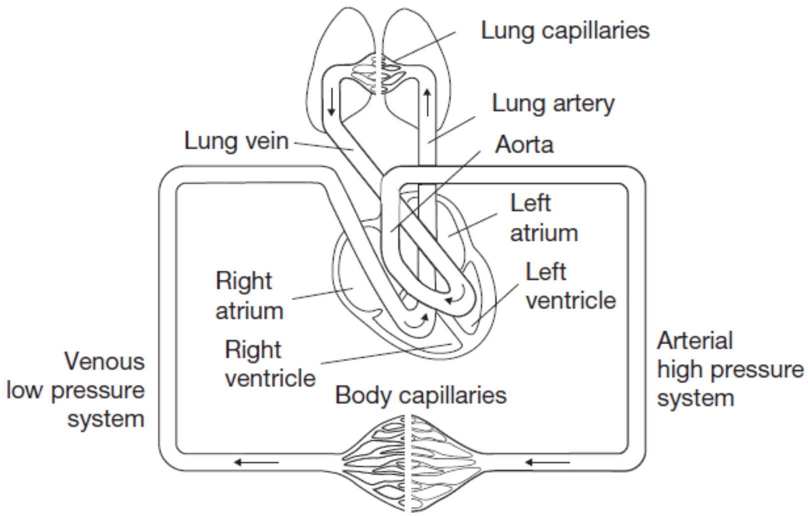
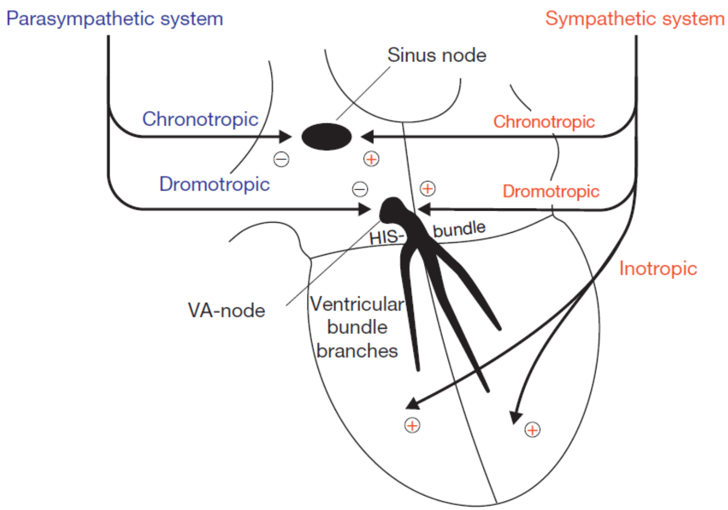
Cardiac Autorhythm

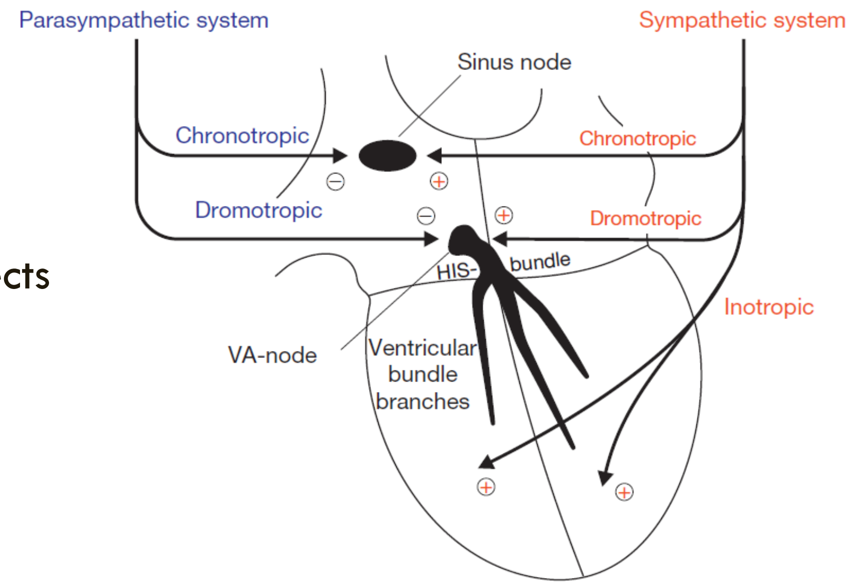
- The heart is a synchronized double pump
  - Right part pumps blood with low O_2 and high CO_2 to lungs
  - Left part pumps blood with high O_2 and low CO_2 to body organs
- Rhythmic contractions of myocardium are triggered by electrical impulses generated within heart and conducted via special conductive system embedded in myocardium
  - Thus, heart cells are characterized by rhythmic autonomy or autorhythm





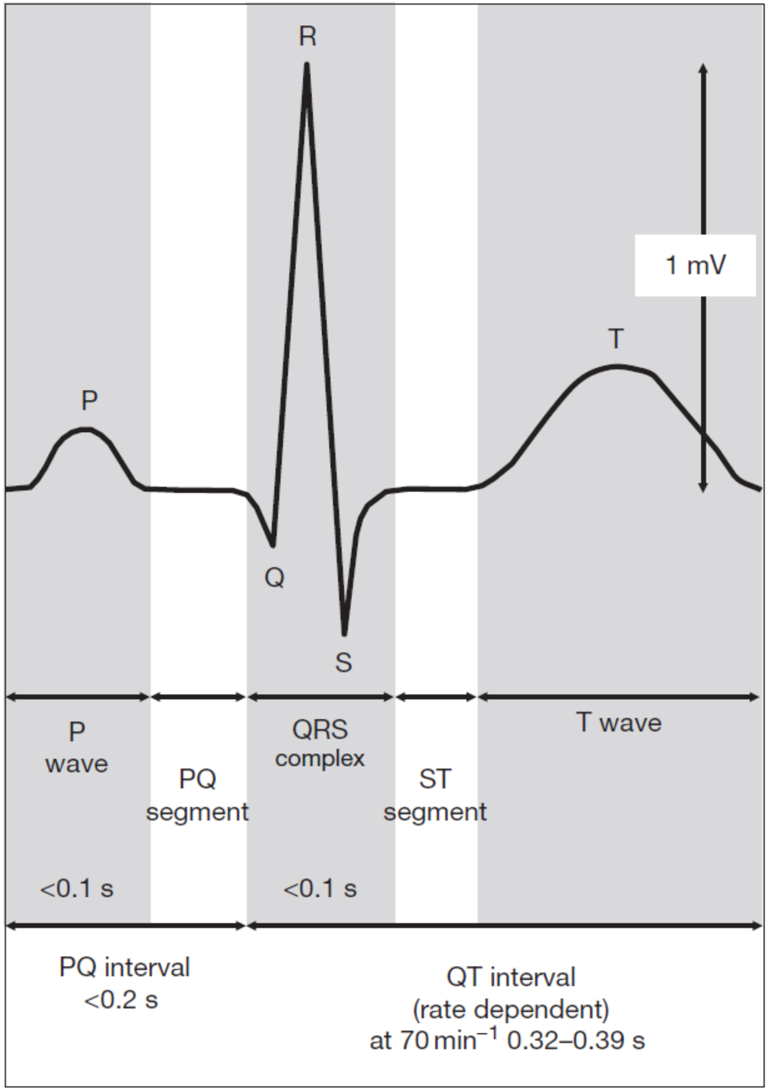
Control by Autonomous Nervous System

- Autonomous nervous system can be separated into two antagonistic parts: sympathetic and parasympathetic
  - SA-node, AV-node, and atrial myocardium: controlled by both
  - Ventricular myocardium: essentially controlled by sympathetic only
- Sympathetic activation causes:
  - Positive chronotropic effect at SA-node: increase in heart rate
  - Positive dromotropic effect at AV-node: shorten conductive delay
  - Positive inotropic effect: increase in contractility in both atrial and ventricular myocardia
- Parasympathetic activation causes opposite effects
  - Only atrial myocardium is affected by negative inotropic effect



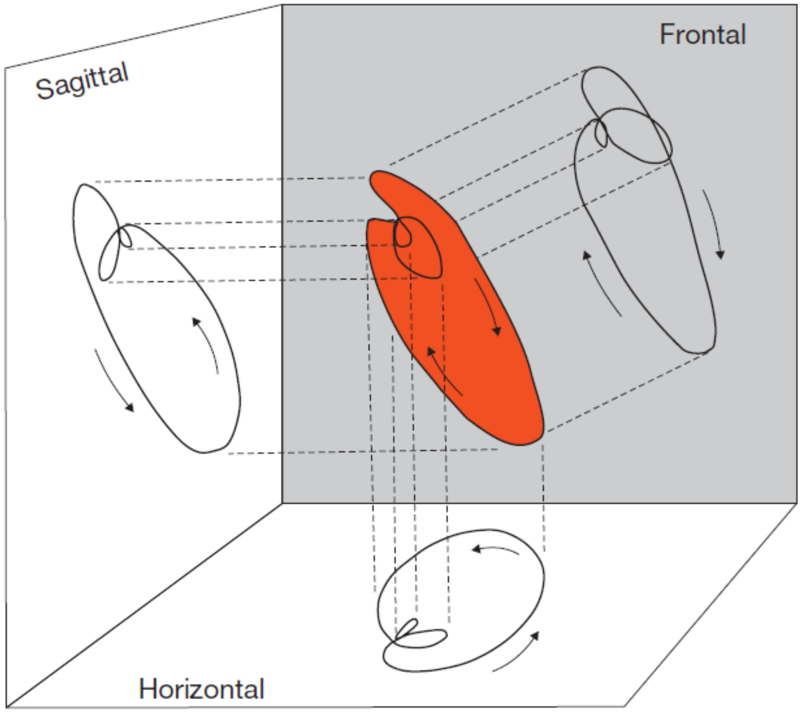
Diagnostic Signals: Electrocardiogram (ECG)

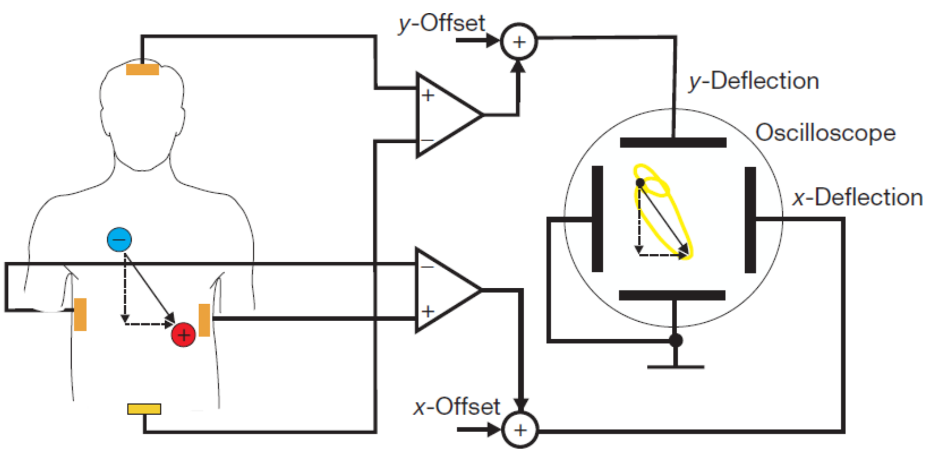
- Excitatory and conductive processes within heart may be analyzed from electrically recorded signals
  - Recorded traces of fluctuations in body surface potentials are called ECG
- Each section in ECG waveform corresponds to particular event
  - P-wave: atrial excitation
  - PQ-segment: conduction of excitation to ventricles
  - QRS-complex: spreading of excitation within ventricles up to complete excitation
  - ST-segment and T-wave: repolarization of ventricles



Diagnostic Signals: Vectorcardiogram (VCG)

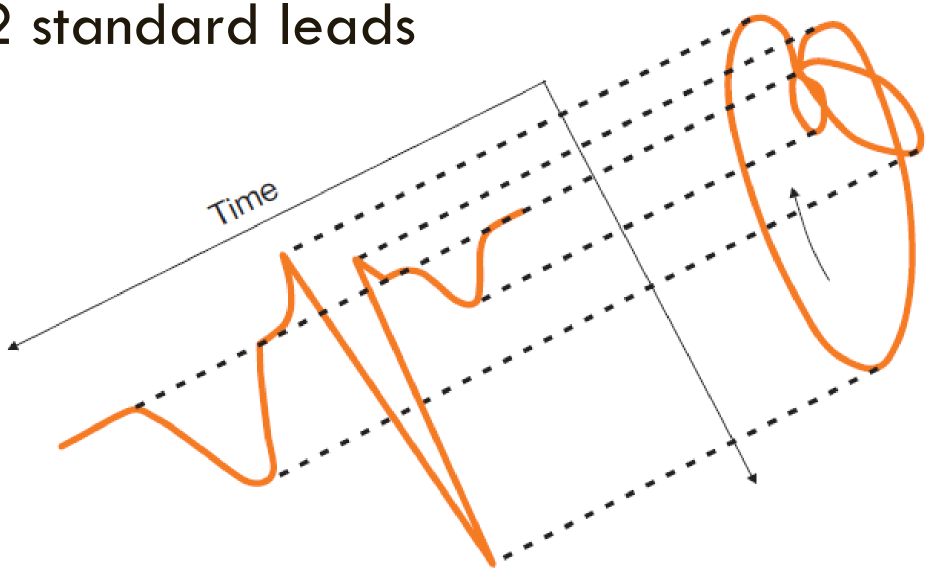
- As excitations spread via fibers in 3D, net magnitude and angle of all electrical excitations in the heart muscle changes
  - Generates 3D vector trajectory called VCG
- To record 2D projection of vector loop on given plane, two electrode pairs with their lead direction perpendicular to one another are used





ECG from VCG: ECG Leads

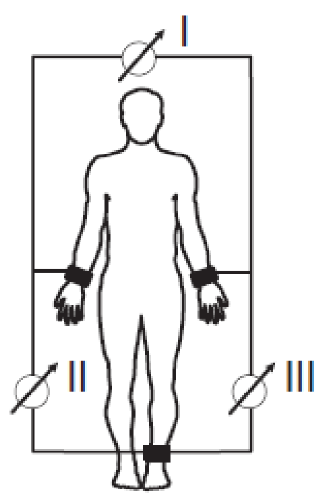
- 3D VCG can be projected on one axis (lead direction) and represented as a function of time and get ECG
  - ECG is 1D projection of VCG onto lead direction as a function of time
  - First loop of VCG (atrial excitation): P-wave in ECG
  - Second large loop of VCG (ventricular excitation): QRS-complex in ECG
  - Third loop (depolarization) in VCG: T-wave in ECG
- Clinical cardiographs use 12 standard leads
  - Three Einthoven leads
  - Three Goldberger leads
  - Six Wilson leads



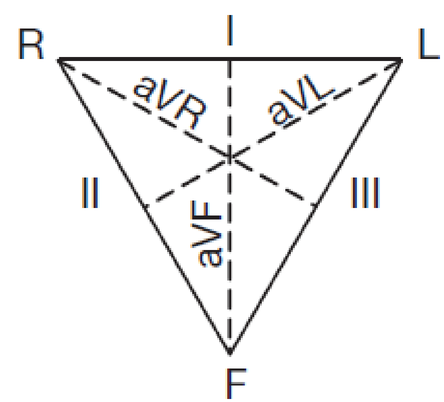
Einthoven Leads (Bipolar Limb Leads)

- Positioning two electrodes at transition from thorax to arms (or on wrists) and third one near umbilicus (or on left ankle) yields three recording directions forming triangle in frontal plane of body
  - Form Einthoven Triangle leads I, II, and III
  - Additional lead, usually right leg, for grounding purposes

Einthoven leads

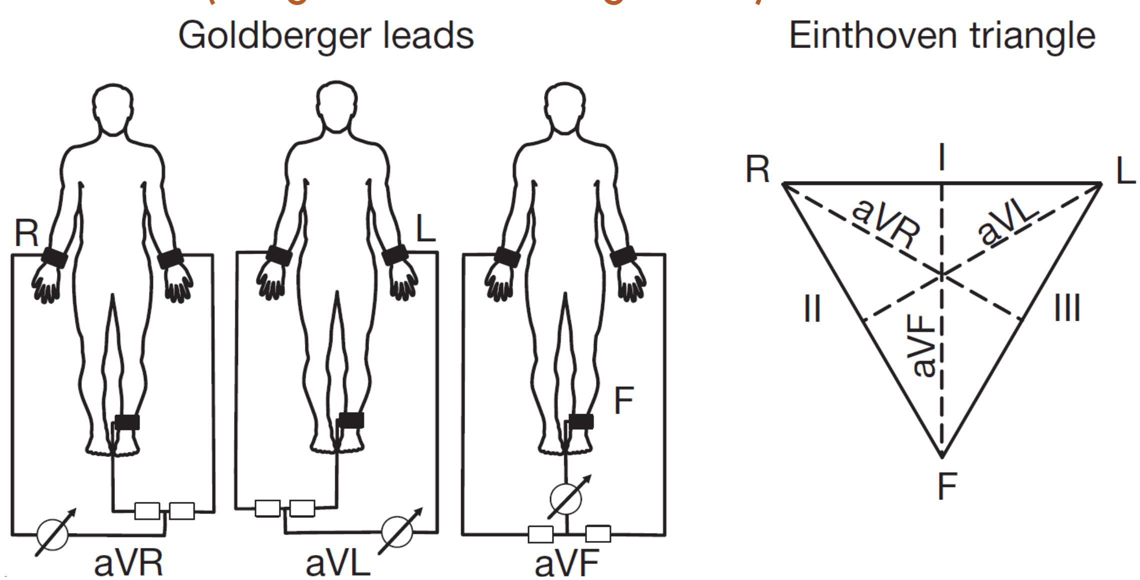


Einthoven triangle



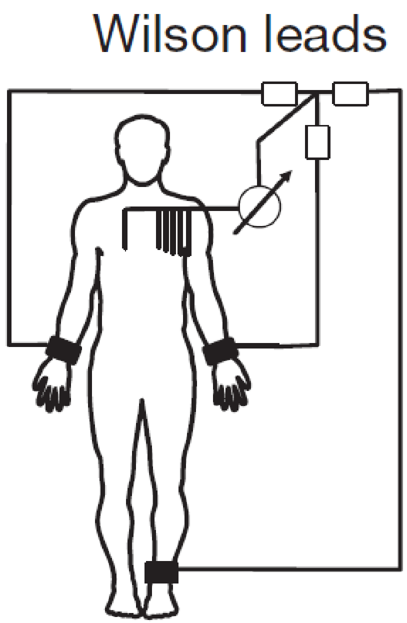
Goldberger Leads (Unipolar Limb Leads)

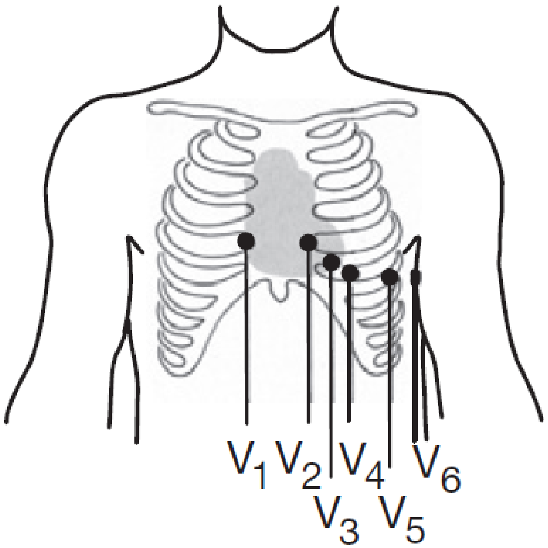
- To ensure easier and more accurate detection of certain pathophysiological conditions, three further limb leads, also in the frontal plane, are often used: Goldberger leads
  - Obtained by connecting pairs of Einthoven leads via two equal resistors and recording between third Einthoven lead and mid-point of resistors
  - New leads: aVR (augmented voltage right), aVL (augmented voltage left), and aVF ('augmented' voltage foot)



Wilson Leads (Unipolar Chest Leads)

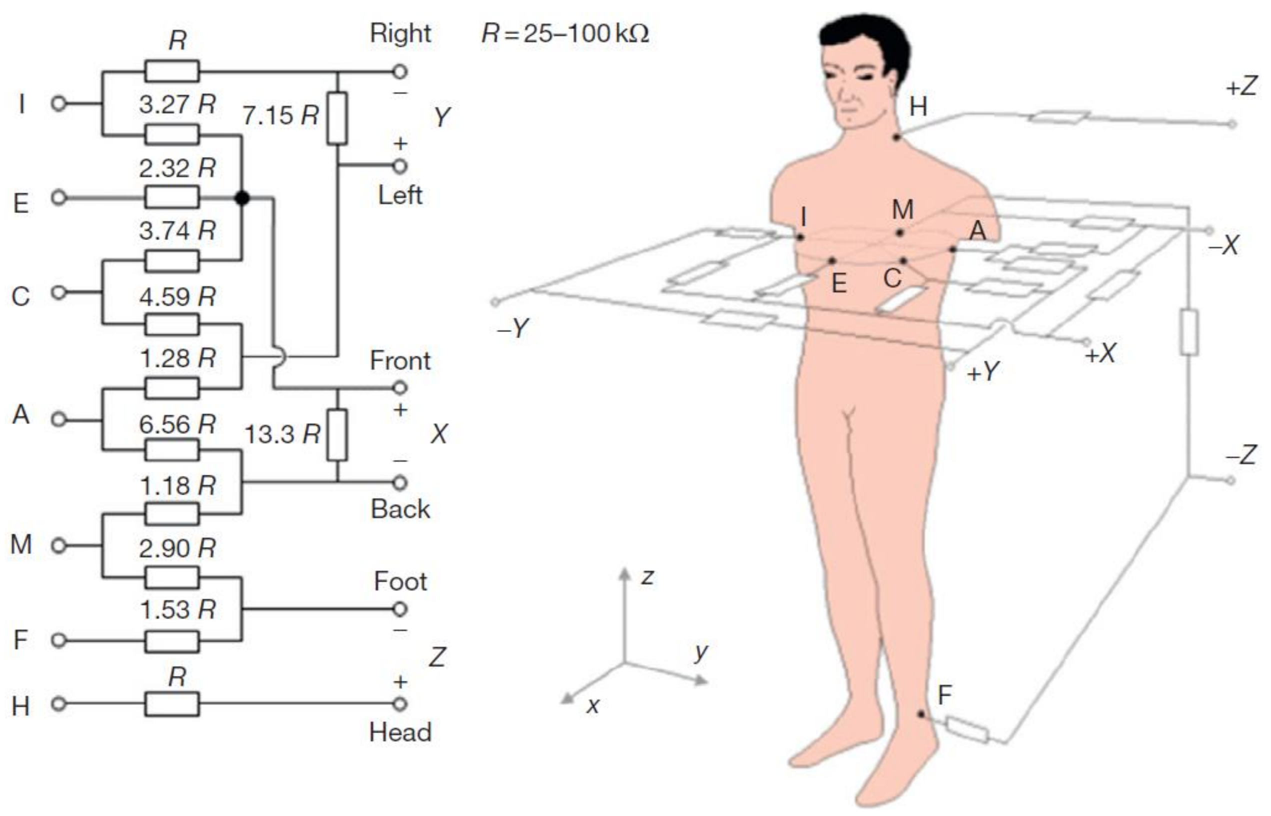
- Six further leads termed V1–V6 are used
  - Potentials of six definite precordial points on chest surface measured against central reference point, achieved by connecting the three Einthoven electrodes via three identical resistors
  - Recordings from Wilson leads are in horizontal plane and supplement information from other six frontal leads



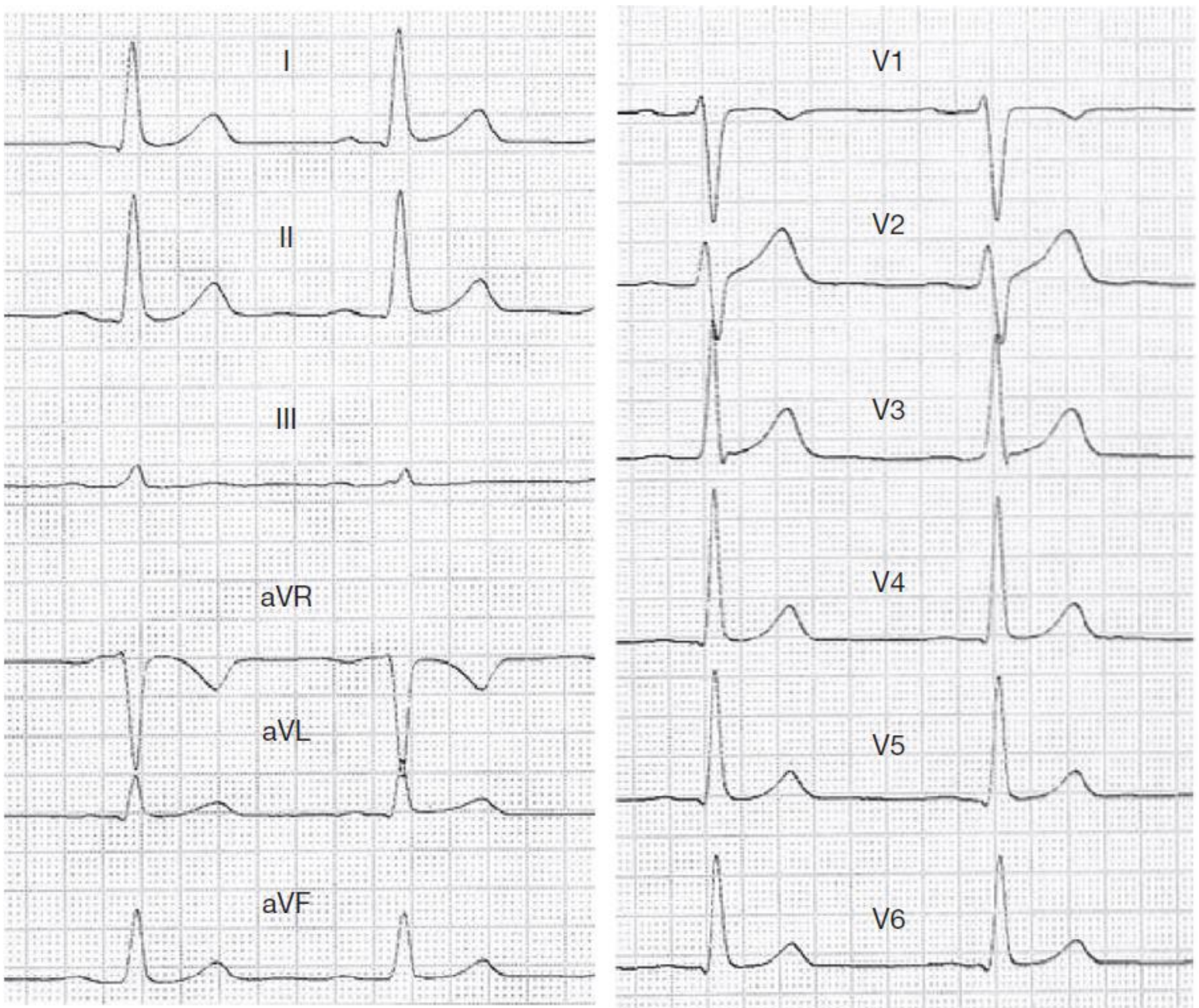


Orthogonal Frank Leads

- Three new orthogonal ECG leads Vx, Vy, and Vz using seven recording positions and suitable resistor network
  - Now used as basis of more accurate VCG recordings



Normal ECG from 12 Standard Leads



ECG Lead Definitions and Color Code

System	Code1) Patient electrode connection identifier	Color code	Code 2) Patient electrode connection Identifier	Color code	Position on body surface
	R	Red	RA	White	Right arm
	L	Yellow	LA	Black	Left arm
	F	Green	LL	Red	Left leg
	C	White	V	Brown	Single movable chest electrodes
	C1	White/red	V1	Brown/red	4th intercostal (IC) space at right border of sternum
Conven-tional	C2	White/yellow	V2	Brown/yellow	4th intercostal (IC) space at right border of sternum
	C3	White/green	V3	Brown/green	Midway between C2 and C4
	C4	White/brown	V4	Brown/blue	5th IC space on left midclavicular line
	C5	White/black	V5	Brown/orange	Left anterior axillary line at the horizontal level of C4
	C6	White/violet	V6	Brown/violet	Left midaxillary line at the horizontal level of C4
	N	Black	RL	Green	Right leg
	I	Light blue/red	I	Orange/red	At the right midaxillary line3)
	E	Light blue/yellow	E	Orange/yellow	At the front midline3)
Frank vector	C	Light blue/green	C	Orange/green	Between front midline and left midaxillary line at an angle of 45 degrees3)
	A	Light blue/brown	A	Orange/brown	At the left midaxillar line3)
	M	Light blue/black	M	Orange/black	At the back midline
	H	Light blue/violet	H	Orange/violet	On the back of the neck or on the forehead
	F	Green	F	Red	On the left leg

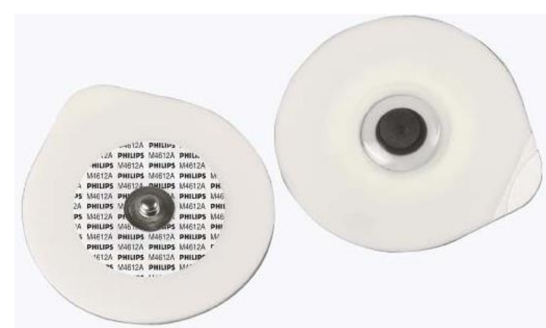
[1]Color code 1 is that commonly used in Europe and recommended by the International Electrotechnical commission.

[2]Color code 2 is that commonly used in the U.S.A. and recommended by the American Heart Association

ECG Leads in Practice

ECG Electrodes

- General requirements
  - Low electrical interface impedance
  - High mechanical resistance
  - Low interface (‘reversible’ or ‘half-cell’) potential
  - Low distortion of signal
  - Low polarization
- Different shapes
  - Metal-plate electrodes (reusable)
  - Suction electrodes (reusable)
  - Floating/hydrogel electrodes (disposable)



Electrode Operation

- Electrode-electrolyte interface: double layer
  - Local change in ion concentration near metal surface
  - Charge neutrality is not maintained: half-cell potential at no current
- Polarizable electrodes pass current between electrode and electrolyte by changing the charge distribution near electrode
  - Serious limitations when movement is present and with low frequency biosignals
- Non-polarizable electrodes allow current to pass freely across interface without changing charge distribution near electrode
  - Preferred in most biomedical applications (e.g., Ag-AgCl electrodes)

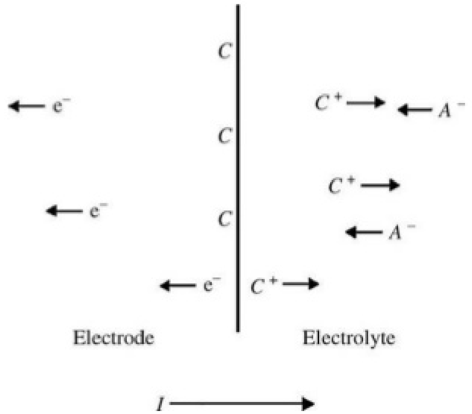
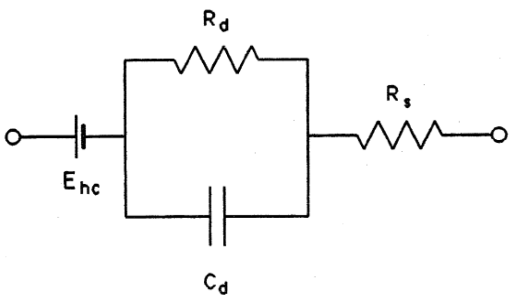


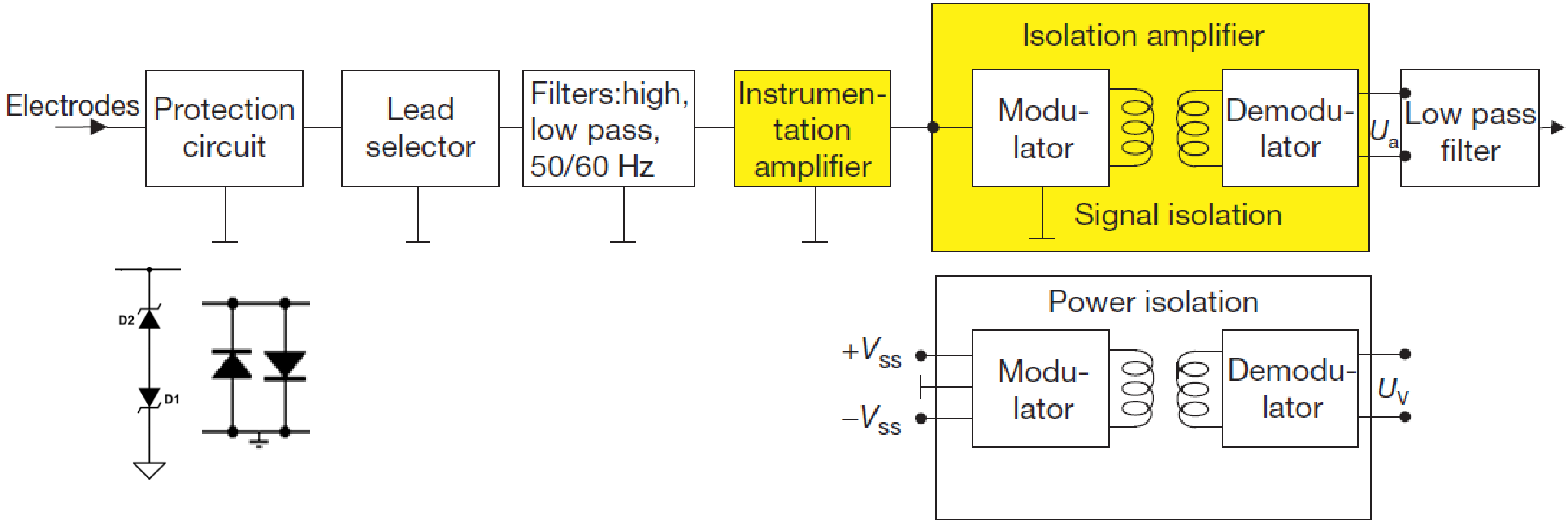
TABLE 48.2 Half-cell Potentials for Materials and Reactions Encountered in Biopotential Measurement

Metal and Reaction	Half-cell Potential, V
$Al \rightarrow Al^{3+} + 3e^-$	–1.706
$Ni \rightarrow Ni^{2+} + 2e^-$	–0.230
$H_2 \rightarrow 2H^+ + 2e^-$	0.000 (by definition)
$Ag + Cl^- \rightarrow AgCl + e^-$	+0.223
$Ag \rightarrow Ag^+ + e^-$	+0.799
$Au \rightarrow Au^+ + e^-$	+1.680

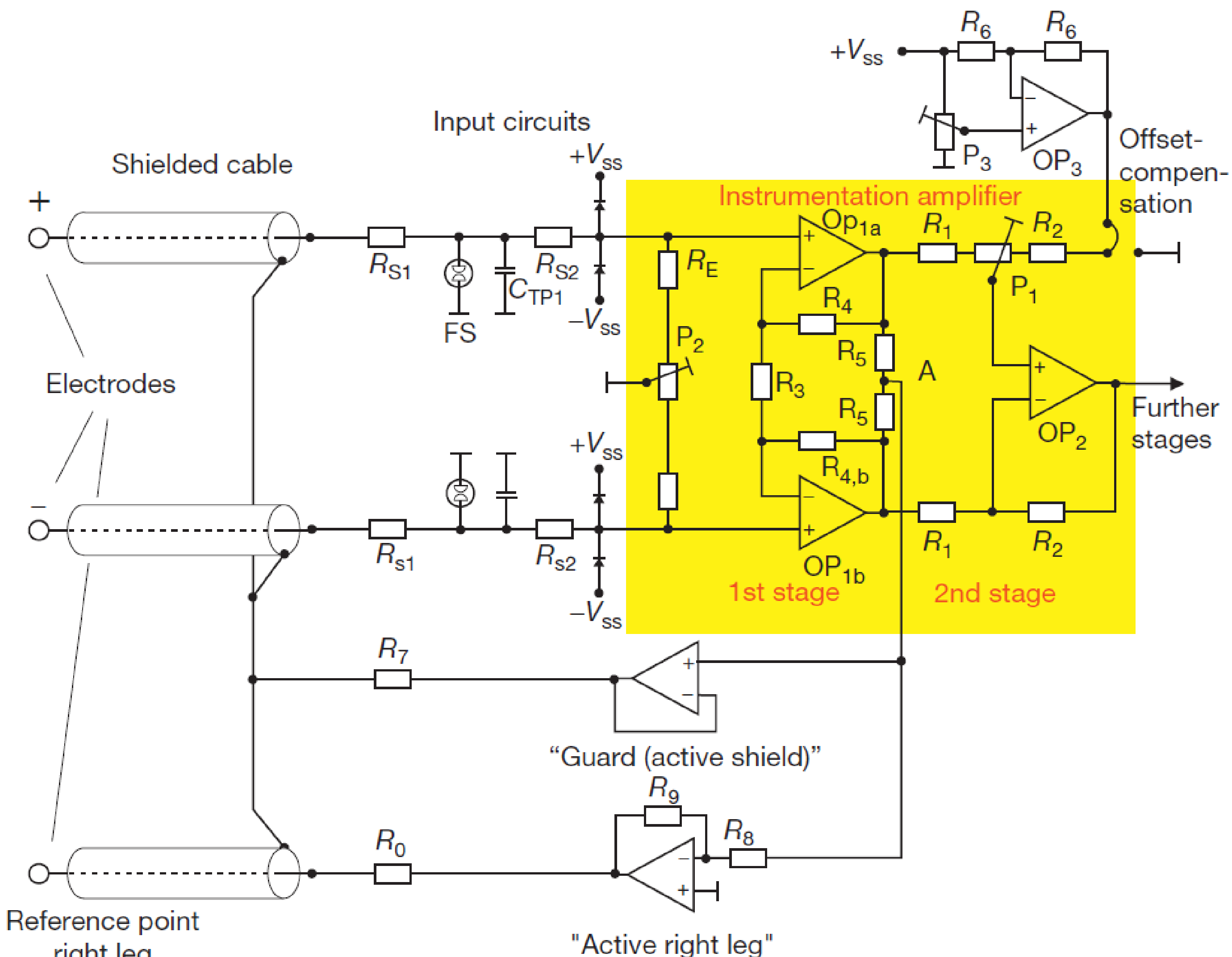


ECG Acquisition Chain

- Use isolation to break ohmic continuity between AC and patient
  - Not needed for battery powered devices
- Instrumentation amplifier usually precedes filters
- Lead selector is analog multiplexer



Example ECG Analog Front End

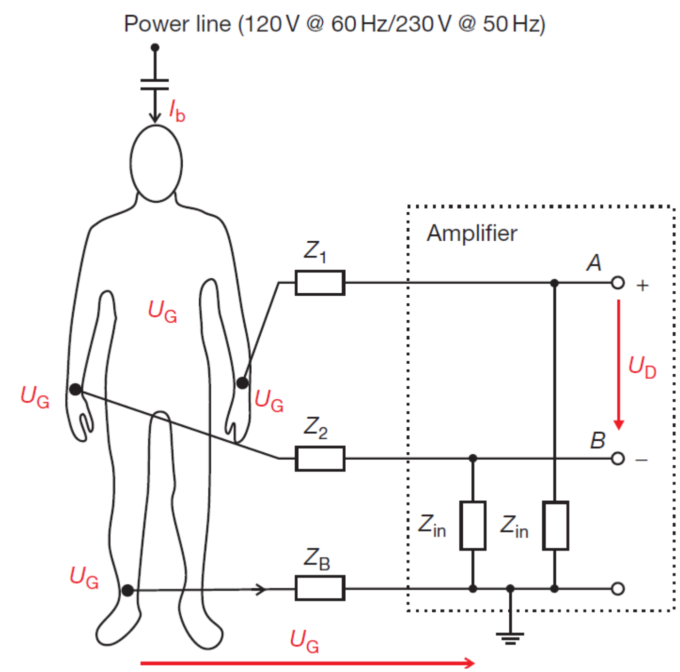


Analysis of ECG Analog Front End

- R_{s1} and R_{s2} are protection resistors
- FS are voltage-limiting devices which limit input to amplifier
- Diodes limit power supply to operating voltage
- R_{s1} and C_{TP} constitute low pass filter eliminating higher noise frequencies induced via the cables
- R_E provides pathway for bias currents of amplifiers
- Common-mode rejection of the circuit is adjusted by P_2
- Active shield: Common-mode voltage at point A is connected to shield of cables to reduce effective cable capacitance and may reduce sensitivity of cables to motion artifacts
- Active right leg: voltage at point A is also used to influence common-mode voltage itself where amplifier inverts and amplifies it before it is fed back via right leg to body compensating origin of common-mode voltage (e.g., coupling from power line) and also avoids direct connection of patient to ground, which is forbidden for safety

Disturbances to ECG: Electric Fields

- Electric field coupling from nearby power lines to body is frequent cause of unwanted common-mode voltage
  - Common-mode voltages UG >100 mV possible with 220–240 V power lines – underlines necessity of common-mode rejection in amplifiers
  - Unbalance of electrode contact impedances and existence of common-mode voltage generate differential 50/60 Hz disturbance inputs UD to biopotential amplifier
- Minimize by:
  - High amplifier input resistances
  - Care with selection and application of electrodes
    - Cleaning of skin and use of electrode gel to avoid significant contact impedance mismatch

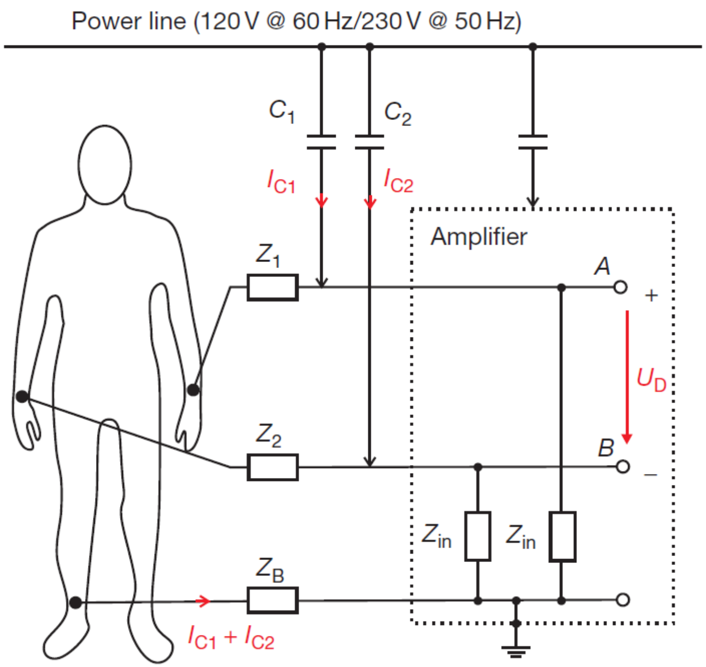


Disturbances to ECG: Motion Artifacts

- Artifacts are largely due to deformation of skin under electrode
- Minimize by:
  - Use of nonpolarizable Ag–AgCl electrodes with low stable contact potentials
  - Use of electrode gel to minimize skin impedance and stabilize skin potential
  - Use of amplifiers with input current <10 pA
  - Use of lightweight connections, leads, and wires causing only minimal pull on electrode, thus minimizing deformation of skin site and motion artifacts
  - Use of wet gel electrodes with offset connectors
  - Avoiding patient movement
    - If necessary, for short-term diagnostic applications, resting patient can stop breathing for few seconds during measurement

Disturbances to ECG: Electromagnetic Fields

- Alternating magnetic fields from power lines and from high frequency sources (e.g., communication or therapeutic devices) induce parasitic currents
  - In combination with imbalanced impedances result in unwanted differential inputs to biopotential amplifier
- Minimize by:
  - Wires tightly twisted to avoid aerial effect due to large area inductive loops
  - Increasing distance from disturbing source
  - Shielding magnetic fields
  - Optimally choosing position of patient
  - Optimally choosing orientation of leads

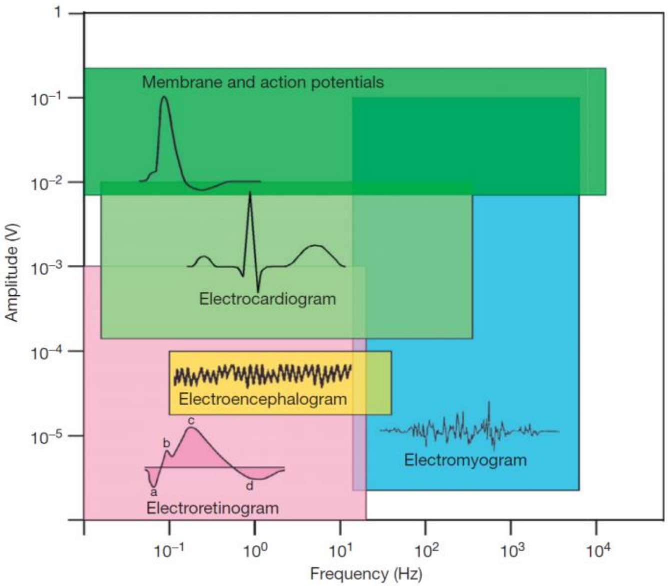


Disturbances to ECG: Resistor Noise

- All resistors between biosignal source and instrumentation amplifier contribute to noise
  - Amplitude of noise is proportional to square of product of bandwidth and resistor value
- Amplifier itself may constitute additional noise component
  - Depends heavily on applied amplifier technology
- Minimize by:
  - Larger surface of electrode and use of conductive electrode gel reduce resistances at skin and electrode interface
  - Use of low noise amplifiers

Disturbances to ECG: Other Biosignals

- Electrical signals underlying muscle activity (EMG) can disturb ECG as muscles are generally located near ECG recording electrodes
  - If possible, patient should not move and should be relaxed during ECG
  - If patient movement is required or unavoidable, great care should be taken to choose electrode positions that are minimally influenced by muscle movement
- Elimination of EMG-components may be achieved by adequate filtering
  - ECG and EMG bandwidths overlap: such filtering can remove important ECG features



Reading Assignment

- Read Chapter 5.02 of *Physics of Physiological Measurements*