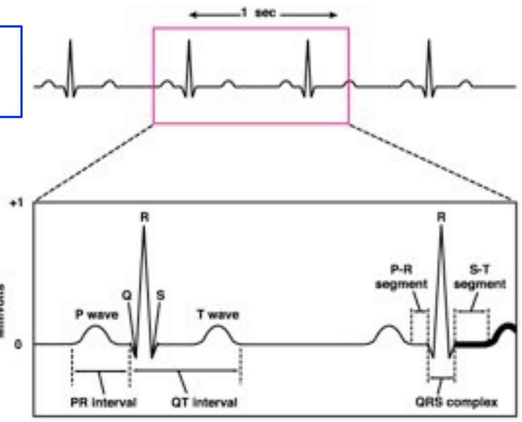
Electrocardiography and Electroencephalography

Components of the Electrocardiogram (ECG)

- Source(s)
  - Potential differences within the heart
  - Spatially distributed and time varying
- Volume conductor
  - Inhomogeneous and anisotropic
  - Unique to each individual
  - Boundary effects
- ECG measurement
  - Lead systems
  - Bipolar versus unipolar measurements
  - Mapping procedures
- Analysis
  - Signal analysis
  - Spatial analysis
  - Dipole analysis
  - Simulation and modeling approaches

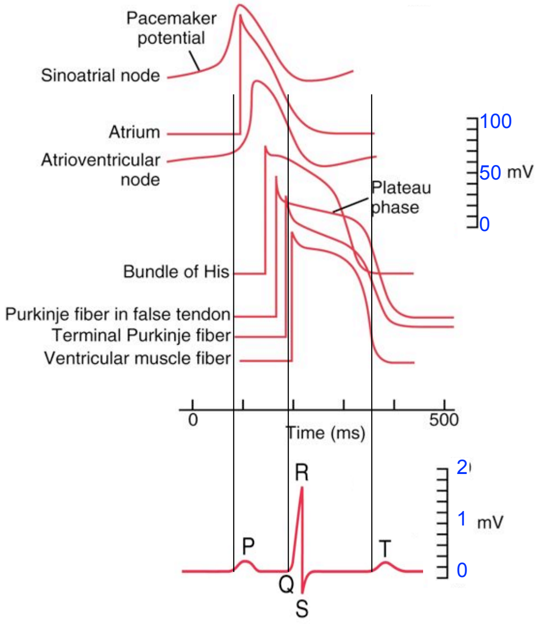
ECG History and Basics

- Represents electrical activity (not contraction)
- Marey, 1867, first electrical measurement from the heart.
- Waller, 1887, first human ECG published.
- Einthoven, 1895, names waves, 1912 invents triangle, 1924, wins Nobel Prize.
- Goldberger, 1924, adds precordial leads

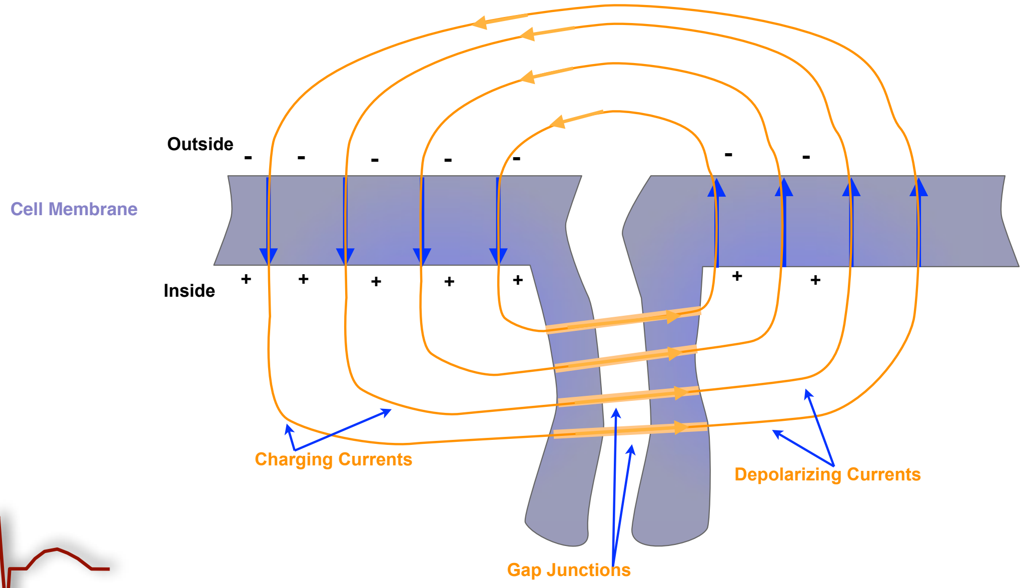


Electrophysiology Overview

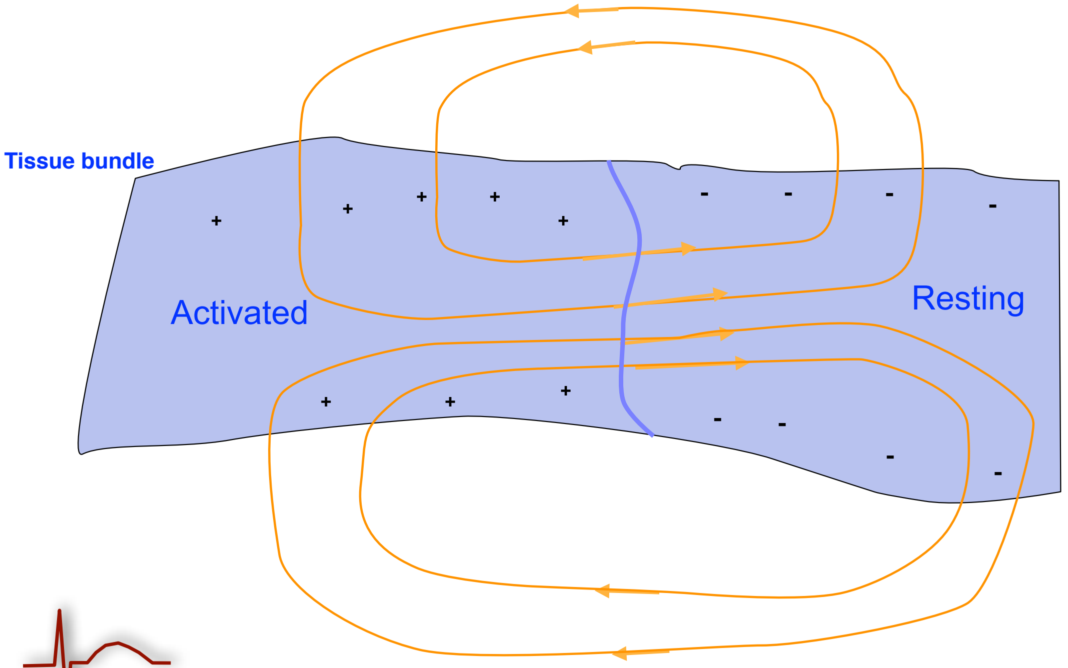
- Pacemaker cells
  - SA Node
  - AV Node
  - Purkinje Fibers
  - Overdrive suppression
- Conduction system
  - Varied propagation
- Ventricular myocytes
  - Electrical coupling
  - Anisotropy
- The Electrocardiogram (ECG)



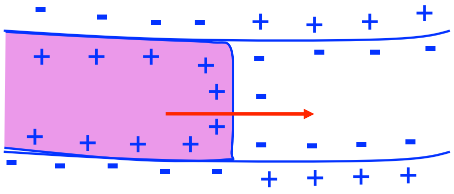
ECG Source Basics

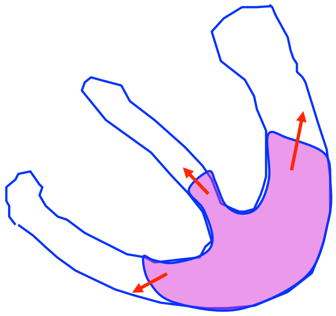


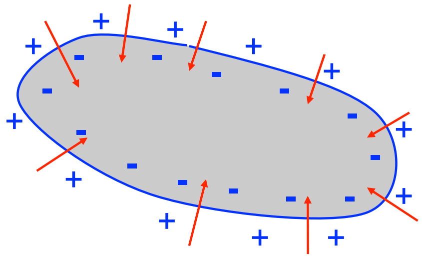
ECG Source Basics



Dipole(s) Source







Equivalent Sources

- Match cell/tissue structure to current sources
- Multiple models possible depending on formulation and assumptions
- Typical assumptions:
  - uniform characteristics of tissue
  - simple geometries
- Primary (versus secondary) sources

Cardiac Sources

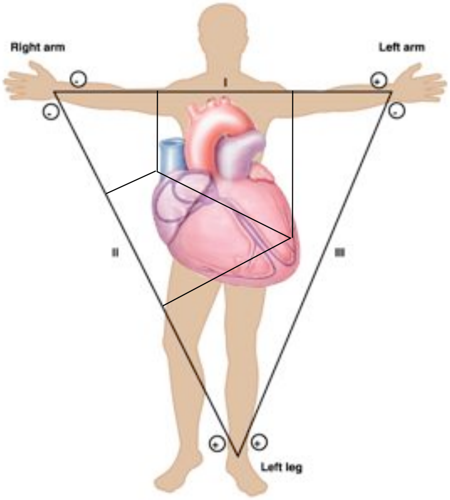
- Formulation in terms of cells impossible
- Dipole(s), multipoles: simple but incomplete
- Volume dipole density: hard to describe
- Surface dipole density: good compromise in some problems
- All require some model of time dependence (propagation)

Heart Dipole Approaches

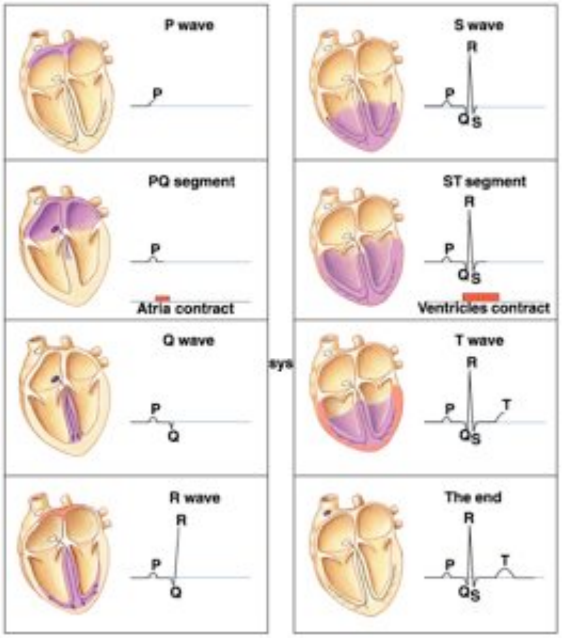
- Treat the heart as single dipole
- Fixed in space but free to rotate and change amplitude
- Einthoven triangle
- Vector ECG (Vectorcardiogram)
- Lead fields: generalization of heart dipole

Heart Dipole and the ECG

- Represent the heart as a single moving dipole
- ECG measures projection of the dipole vector
- Why a dipole?
- Is this a good model?
- How can we tell?

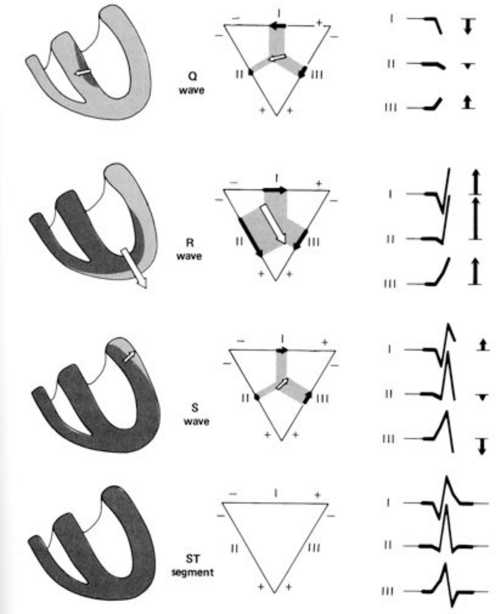


Cardiac Activation Sequence and ECG



Cardiac Activation Sequence as a Moving Dipole

- Oriented from active to inactive tissue
- Changes location and magnitude
- Gross simplification that is clinical important

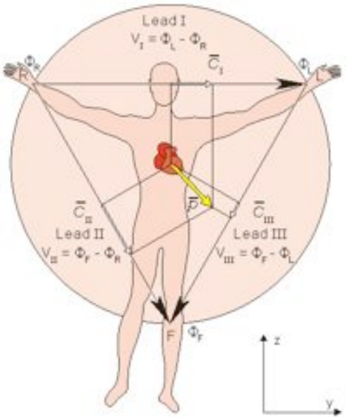


Electrocardiographic Lead Systems

- Einthoven Limb Leads (1895--1912): heart vector, Einthoven triangle, string galvanometer
- Goldberger, 1924: adds augmented and precordial leads, the standard ECG
- Wilson Central Terminal (1944): the "indifferent" reference
- Frank Lead System (1956): based on three-dimensional Dipole
- Body Surface Potential Mapping (Taccardi, 1963)

Einthoven ECG

- Bipolar limb leads
- Einthoven Triangle
- Based on heart vector



$$V_I = \Phi_{LA} - \Phi_{RA}$$
$$V_{II} = \Phi_{LL} - \Phi_{RA}$$
$$V_{III} = \Phi_{LL} - \Phi_{LA}$$

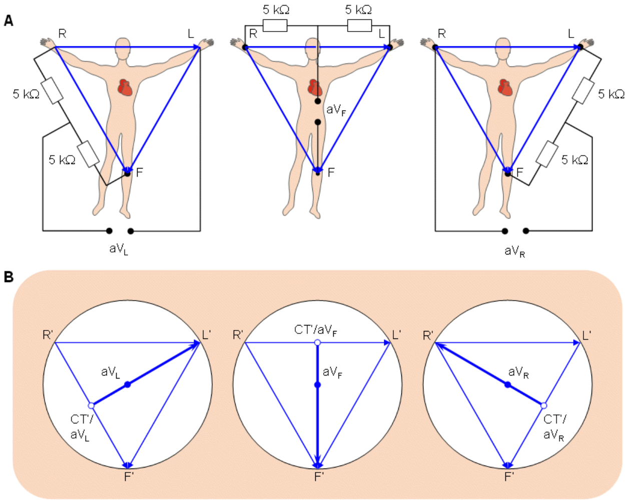
(Note typo in text)

Applying Kirchoff's Laws to these definitions yields:

$$V_I + V_{III} = V_{II}$$

Augmented Leads

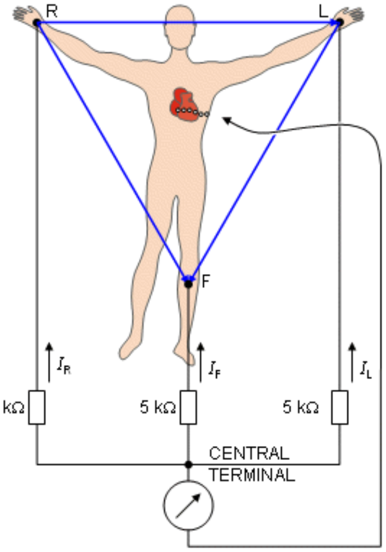
- Provide projections in additional directions
- Redundant to limb leads, i.e., no new information.



$$\begin{aligned} aVL &= V_I - \frac{1}{2}V_{II} \\ aVF &= V_{II} - \frac{1}{2}V_I \\ aVR &= -\frac{1}{2}(V_I + V_{II}) \end{aligned}$$

Wilson Central Terminal

- Goldberger (1924) and Wilson (1944)
- “Invariant” reference
- “Unipolar” leads
- Standard in clinical applications
- Driven right leg circuit



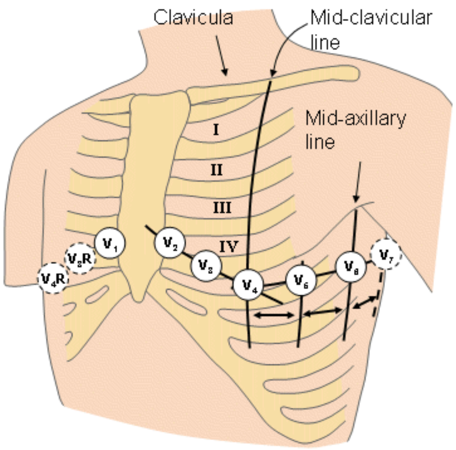
$$I_R + I_F + I_L = 0$$

$$\frac{\Phi_{CT} - \Phi_{RA}}{5000} + \frac{\Phi_{CT} - \Phi_{LA}}{5000} + \frac{\Phi_{CT} - \Phi_{LL}}{5000} = 0$$

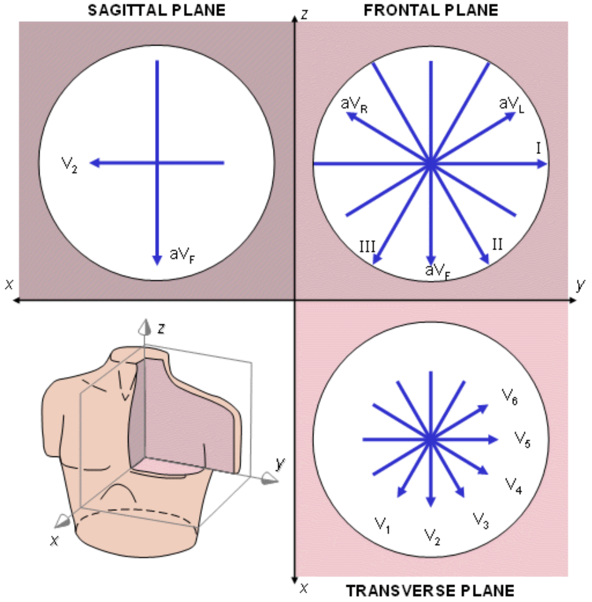
$$\Phi_{CT} = \frac{\Phi_{RA} + \Phi_{LA} + \Phi_{LL}}{3}$$

Precordial Leads

- Modern clinical standard (V1-V6)
- Note enhanced precordials on right side of chest and V7

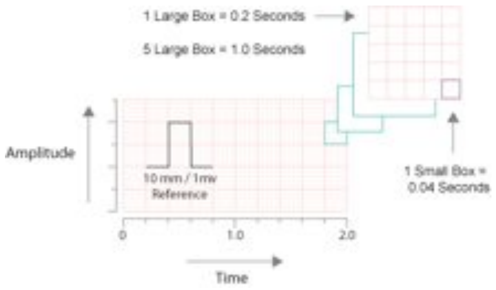


Projection Summary

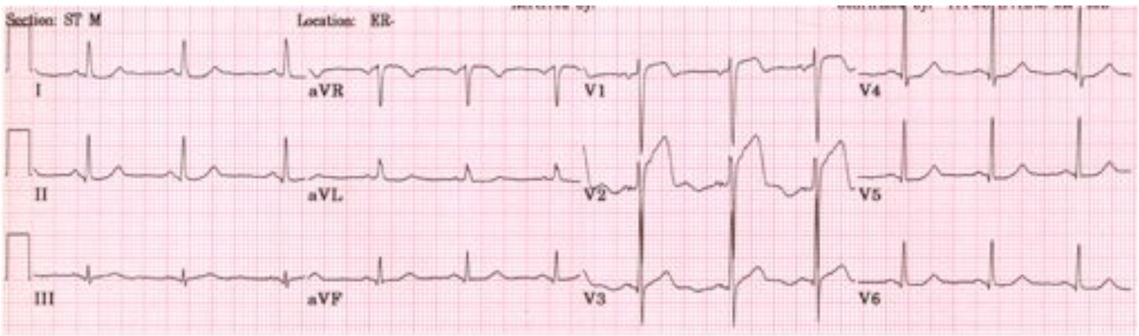


Standard (12-lead) ECG

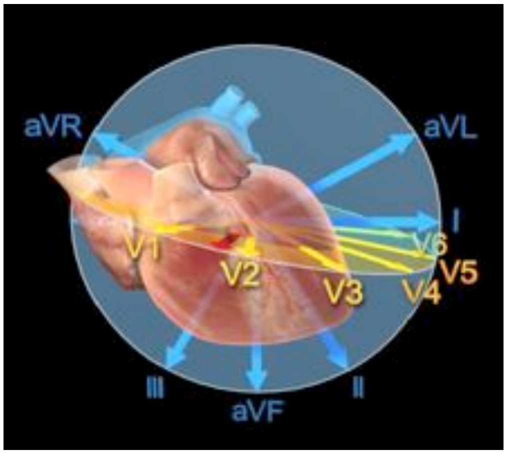
1mm = 100 µV

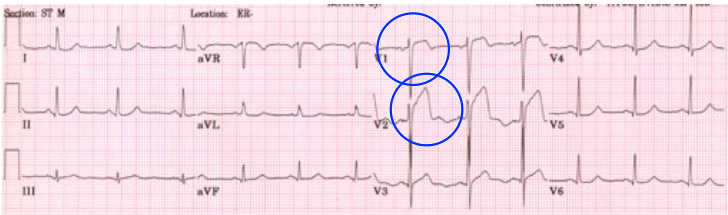


50 mm = 1 s 1 mm = 40 ms

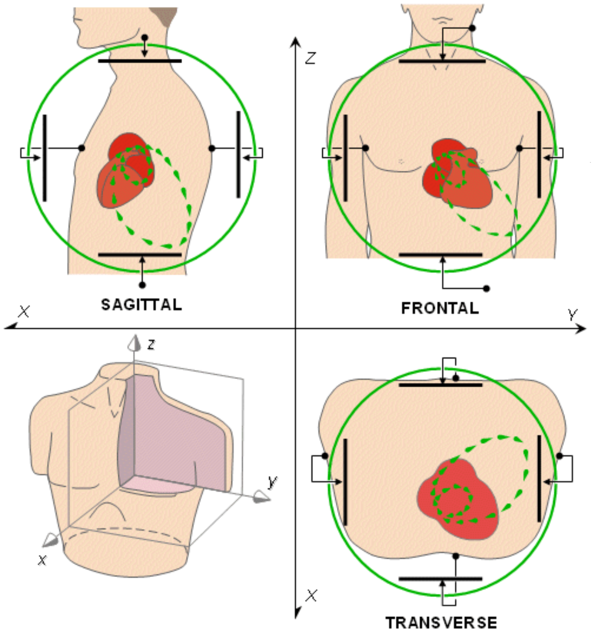


Sample ECG

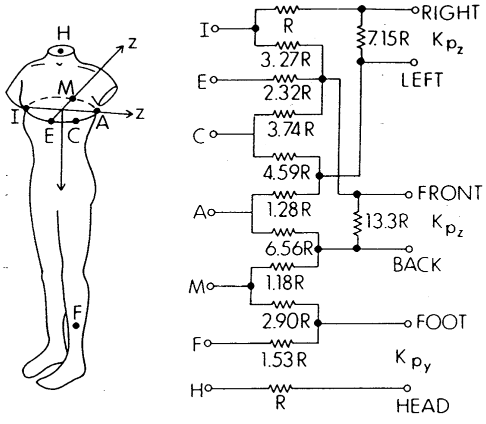




Vectorcardiographic Lead Systems



Frank Lead System



Lead Vector

Burger and van Milaan (1940’s)

Recall that for a dipole:

$$\Phi(r) = -\frac{p_s \Omega}{4\pi\sigma}$$

Now generalize this idea to

$$V_{AB} = \Phi_A - \Phi_B = L_x p_x + L_y p_y + L_z p_z$$

$$V_{AB} = \vec{L} \cdot \vec{p}$$

L = lead vector, depends on lead location, dipole location, and torso geometry and conductivity.

B & vM used phantom model of torso with dipole source to estimate L.

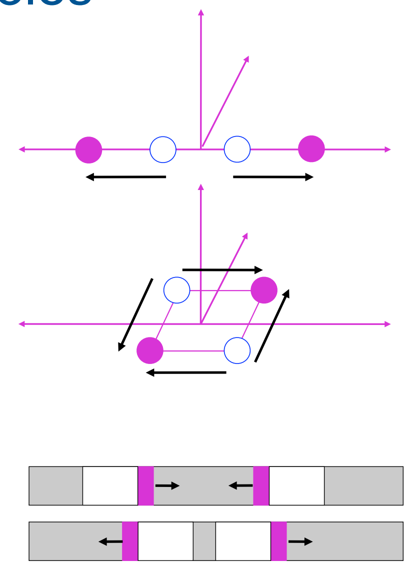
http://www.bem.fi/book/

Lead Field Based Leads

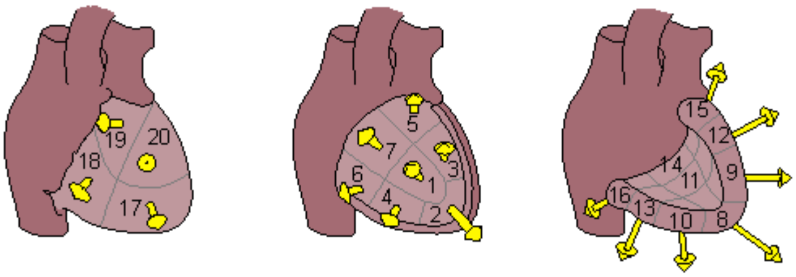
- McFee and Johnston, 1950’s
  - Tried to define leads such that E and I were constant over the heart volume. This way, dipole movement would not change L
  - Developed lead system on this basis from torso phantom measurements
  - Performance was improved for homogenous torso but the same for realistic torso.

Multipoles

- Higher order expansion of solution to Poisson's equation
- Monopole, dipole, quadropole, octopole…
- Example: two wavefronts in cardiac tissue



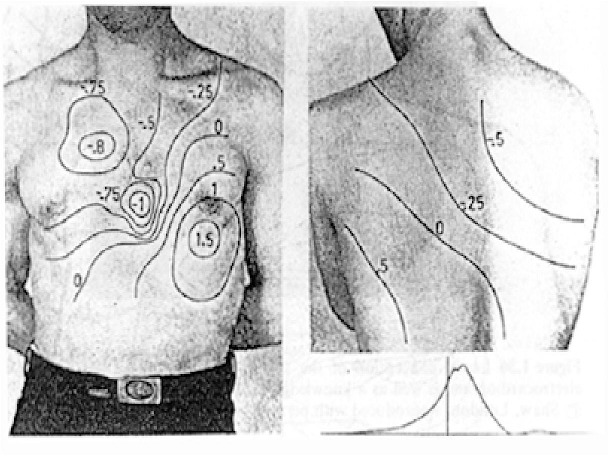
Multipole Based Models



RIGHT VENTRICLE SEPTUM LEFT VENTRICLE

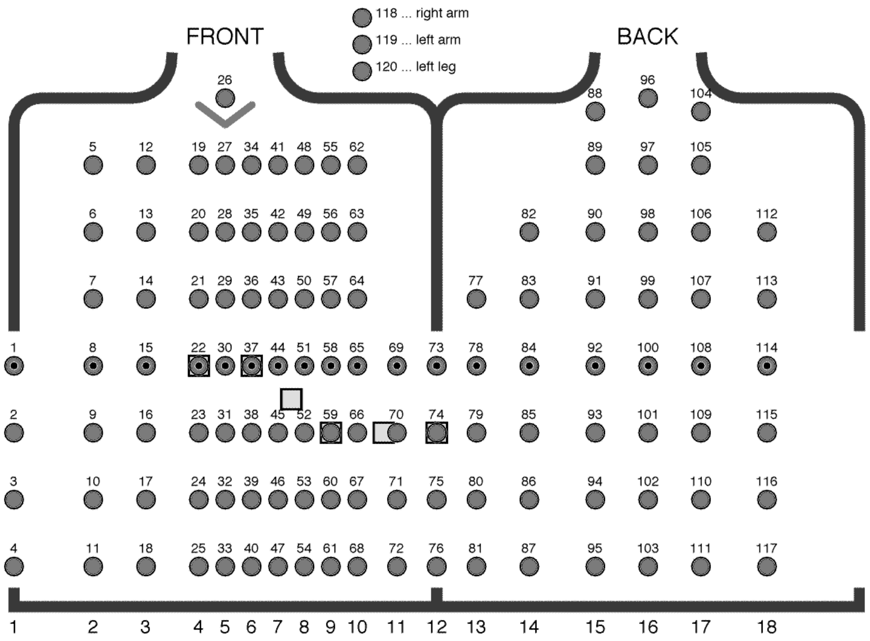
Body Surface Potential Mapping

- Measurements over entire torso
- Showed that resulting pattern was not (always) dipolar
- More complex source model than dipole required



Taccardi et al, Circ., 1963

Body Surface Potential Mapping



118 ... right arm
119 ... left arm
120 ... left leg

BSPM Hisory

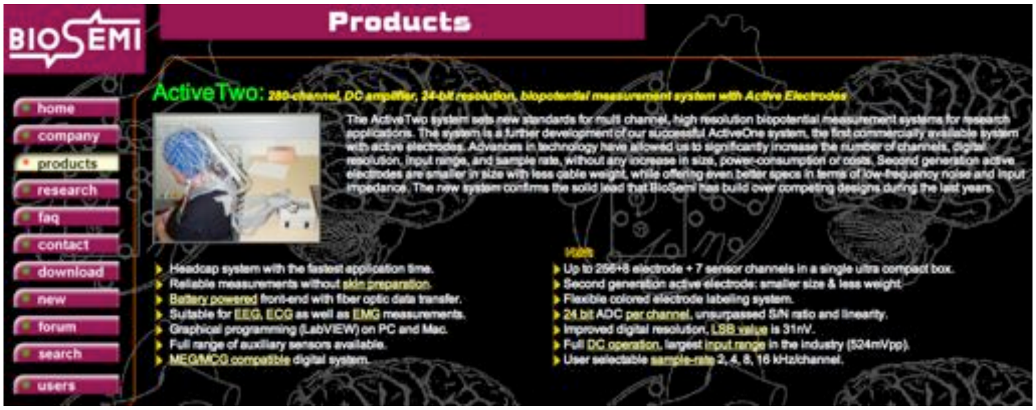
Small version:

http://www.sci.utah.edu/gallery2/v/cibc/taccardi_sm.html

Large version:

http://www.sci.utah.edu/gallery2/v/cibc/taccardi_lg.html

State of the Art



Products

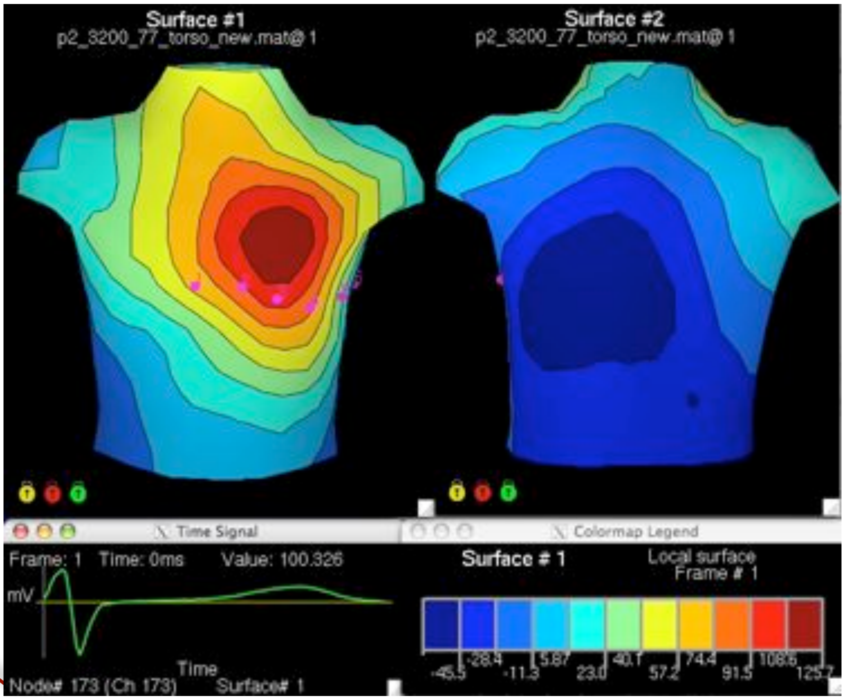
ActiveTwo: *280-channel, DC amplifier, 24-bit resolution, biopotential measurement system with Active Electrodes*

The ActiveTwo system sets new standards for multi channel, high resolution biopotential measurement systems for research applications. The system is a further development of our successful ActiveOne system, the first commercially available system with active electrodes. Advances in technology have allowed us to significantly increase the number of channels, digital resolution, input range, and sample rate, without any increase in size, power-consumption or costs. Second generation active electrodes are smaller in size with less cable weight, while offering even better specs in terms of low-frequency noise and input impedance. The new system confirms the solid lead that BioSemi has build over competing designs during the last years.

- Headcap system with the fastest application time.
- Reliable measurements without skin preparation.
- Battery powered front-end with fiber optic data transfer.
- Suitable for EEG, ECG as well as EMG measurements.
- Graphical programming (LabVIEW) on PC and Mac.
- Full range of auxiliary sensors available.
- MEG/MCG compatible digital system.

- Up to 256+8 electrode + 7 sensor channels in a single ultra compact box.
- Second generation active electrode: smaller size & less weight.
- Flexible colored electrode labeling system.
- 24 bit ADC per channel, unsurpassed S/N ratio and linearity.
- Improved digital resolution, LSB value is 31nV.
- Full DC operation, largest input range in the industry (524mVpp).
- User selectable sample-rate 2, 4, 8, 16 kHz/channel.

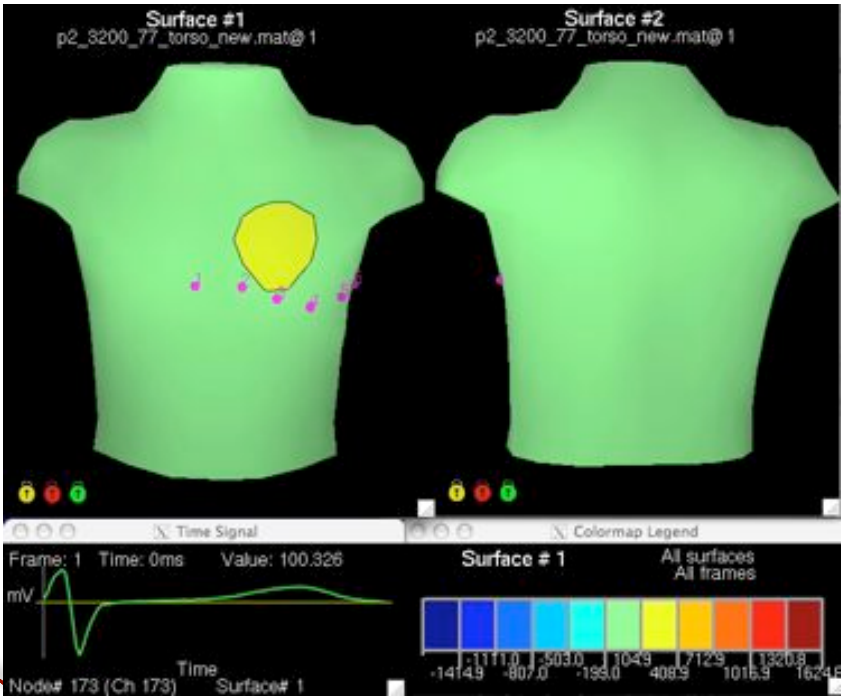
Sample Map Display



Frame: 1 Time: 0ms Value: 100.326

Node# 173 (Ch 173) Surface# 1

Sample Map Display

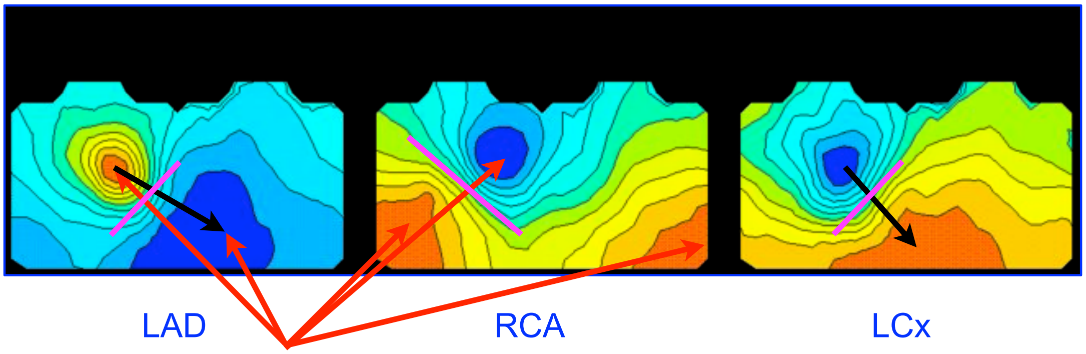


Frame: 1 Time: 0ms Value: 100.326

Node# 173 (Ch 173) Surface# 1

Feature/Pattern Analysis

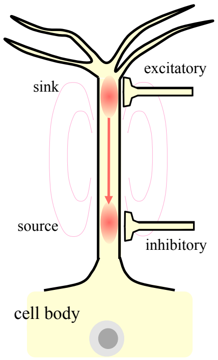
PTCA Mapping

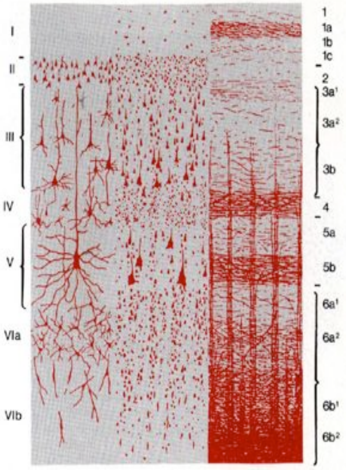


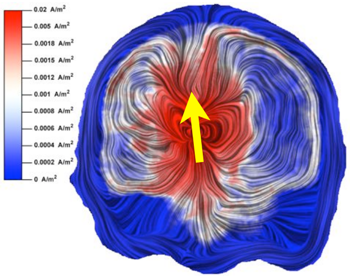
- Use spatial features to identify underlying conditions
  - maxima, minima, zero lines, etc.
  - very condition dependent

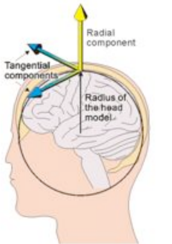
Basics of the EEG

- Sources
  - Cortical layer 5 pyramidal cells
    - currents of -0.78 to 2.97 pAm
  - Burst of 10,000-50,000 synchronously active pyramidal cells required for detection
    - Equivalent to 1 mm^2 of activated cells
  - Modeled as a current dipole
- EEG Measurements
  - Return current (like ECG)
  - Strongly affected by head conductivities
  - Sensitive to radially and tangentially oriented sources



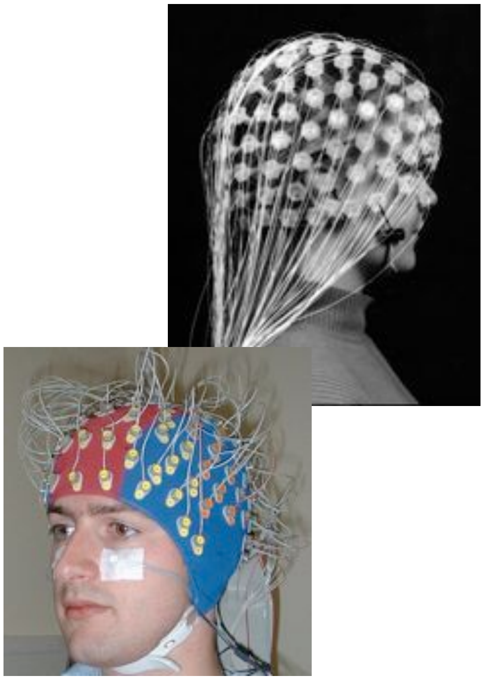






EEG Recording

- Scalp and cortex recording
- Unipolar and bipolar modes
- Filtering/averaging critical



Nunez, http://www.scholarpedia.org/article/Electroencephalogram

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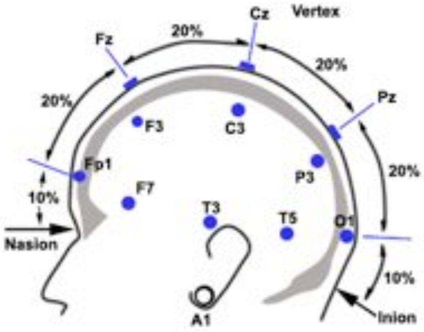
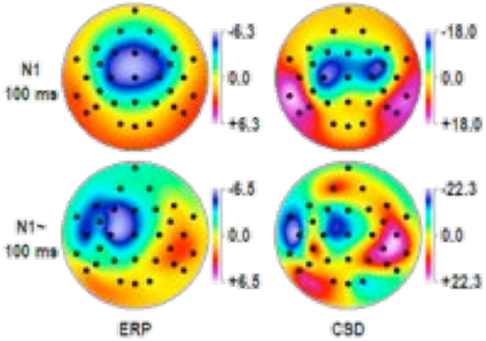
EEG Montages

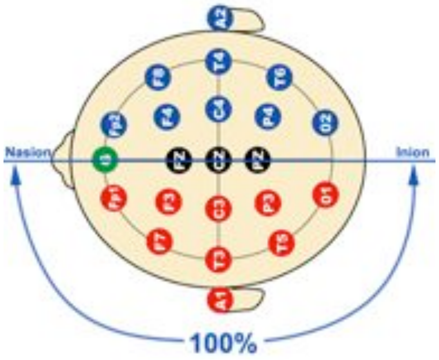
- Many systems (montages), 10-20 is standard
- Reference electrode variable
- Electrode placement critical



Correct Placement

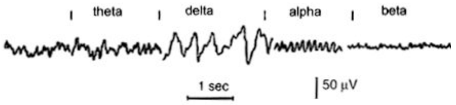
Incorrect Placement

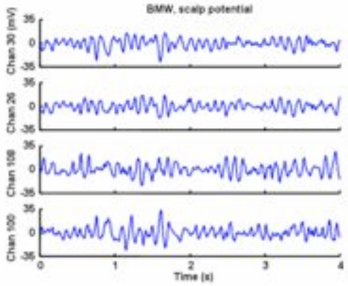


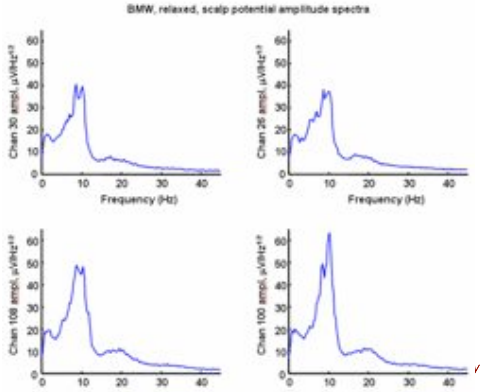


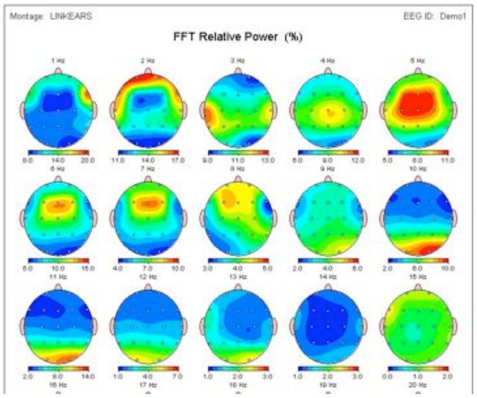
EEG Analysis

- Frequency based
  - Delta: < 3.5 Hz
  - Theta: 3.5-7.5 Hz
  - Alpha: 7.5-13 Hz
  - Beta: > 13 Hz
  - Rhythmic, arrhythmic, disrhythmic
- Voltage
- Morphology



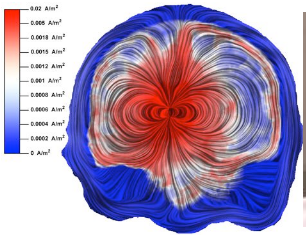


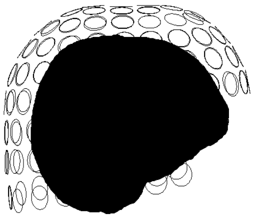




MEG Measurement

- Measures magnetic field mostly induced from primary current and some from return current
- Not so affect by tissue conductivity
- Poor sensitivity to radially oriented sources
- Good sensitivity to tangentially oriented sources





Tangential vs. Radial Sources

http://www.mrc-cbu.cam.ac.uk/research/eeg/eeg_intro.html