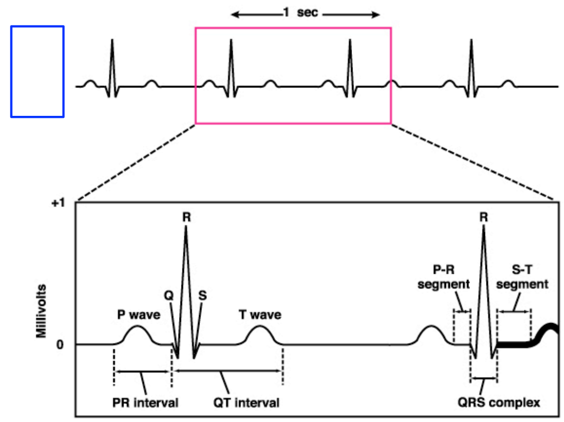
Electrocardiography and Electroencephalography

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

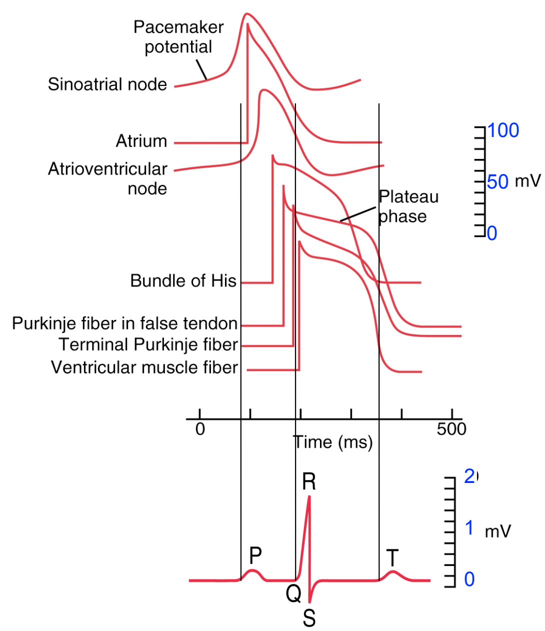
ECG History and Basics

- 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

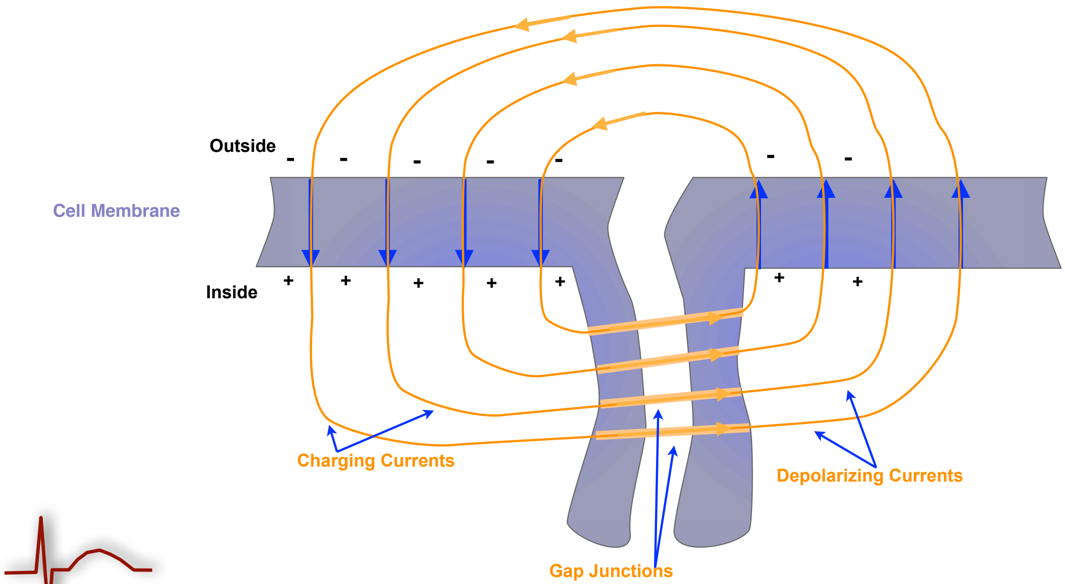


Electrophysiology Overview

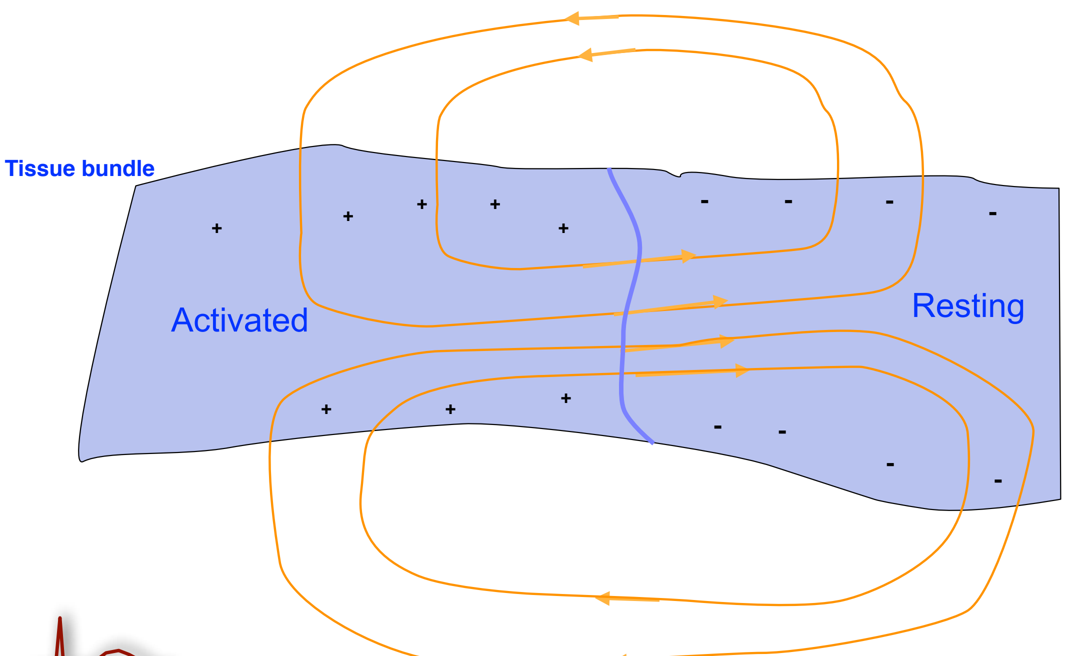
- Pacemaker cells
  - SA Node
  - AV Node
  - Purkinje Fibers
  - Overdrive suppression
- Conduction system
  - Varied propagation
- Ventricular myocytes
  - Electrical coupling
  - Anisotropy
- The Electrocardiogram (ECG)



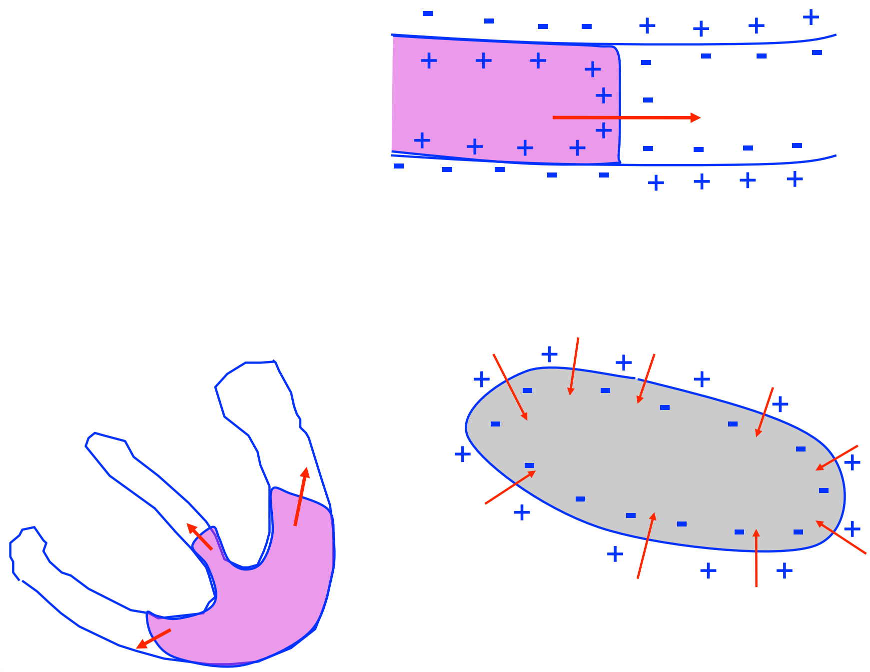
ECG Source Basics



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

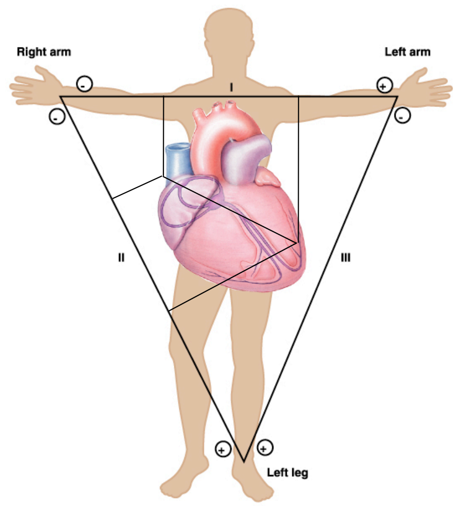
- Formulation in terms of cells impossible
- Dipole(s), multipoles: simple but incomplete
- Volume dipole density: hard to describe
- Surface dipole density: good compromise in some problems
- All require some model of time dependence (propagation)

Heart Dipole Approaches

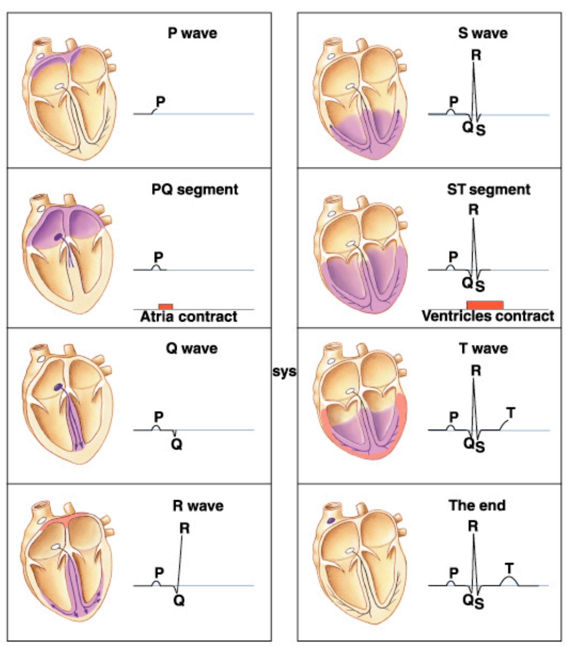
- Treat the heart as single dipole
- Fixed in space but free to rotate and change amplitude
- Einthoven triangle
- Vector ECG (Vectorcardiogram)
- Lead fields: generalization of heart dipole

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?

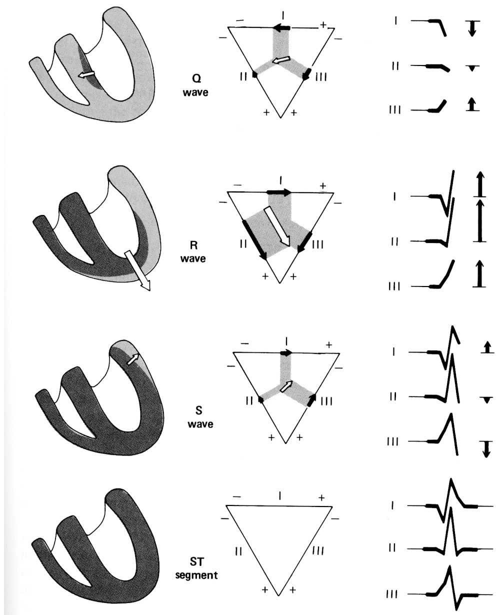


Cardiac Activation Sequence and ECG



Cardiac Activation Sequence as a Moving Dipole

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

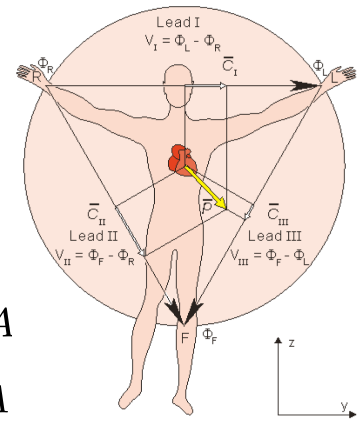


Electrocardiographic Lead Systems

- 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



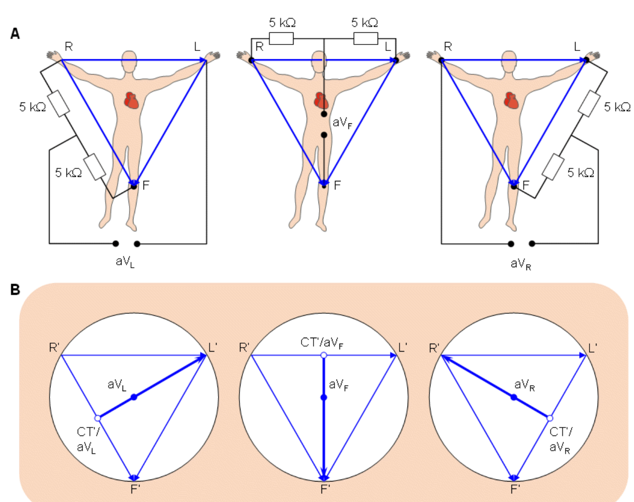
$$V_I = \Phi_{LA} - \Phi_{RA}$$
$$V_{II} = \Phi_{LL} - \Phi_{RA}$$
$$V_{III} = \Phi_{LL} - \Phi_{LA}$$ (Note typo in text)

Applying Kirchoff's Laws to these definitions yields:

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

Augmented Leads

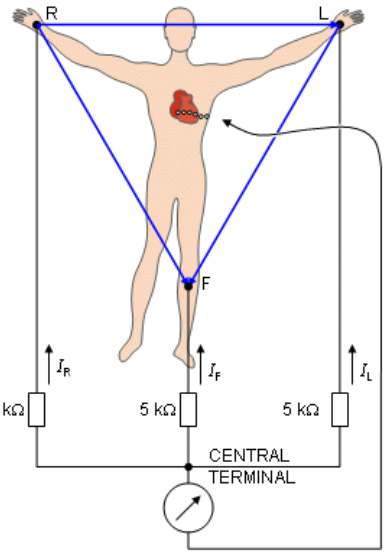
- Provide projections in additional directions
- Redundant to limb leads, i.e., no new information.



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

Wilson Central Terminal

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



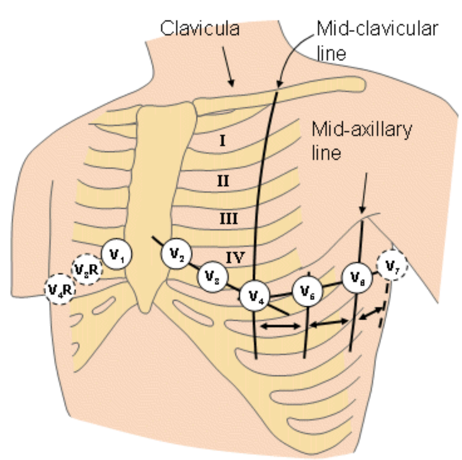
$$I_R + I_F + I_L = 0$$

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

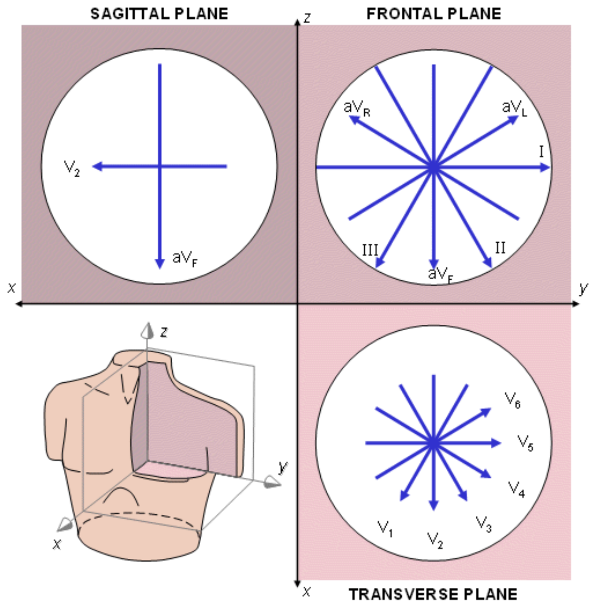
$$\Phi_{CT} = \frac{\Phi_{RA} + \Phi_{LA} + \Phi_{LL}}{3}$$

Precordial Leads

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

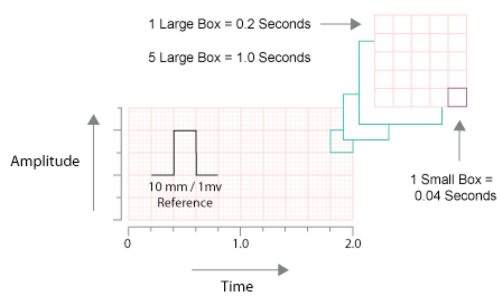


Projection Summary

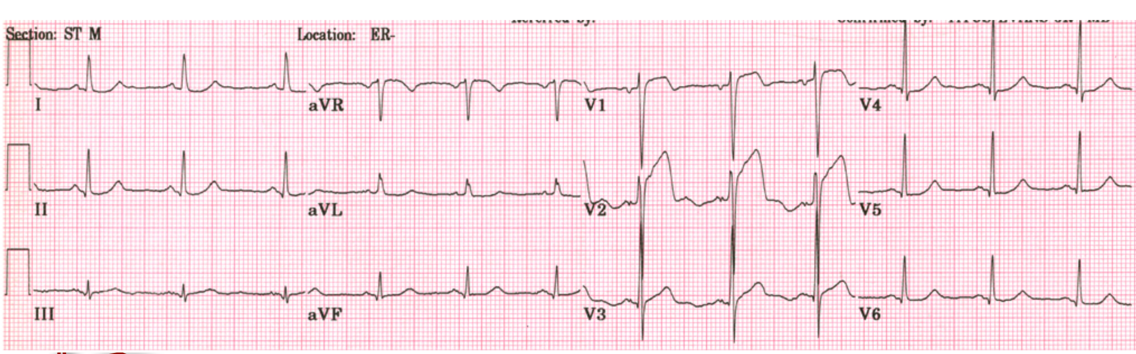


Standard (12-lead) ECG

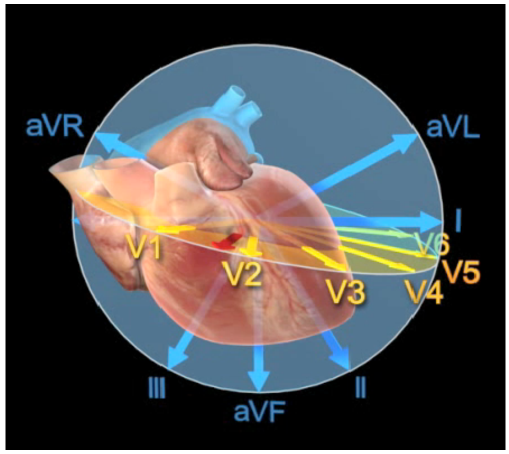
1mm = 100 µV

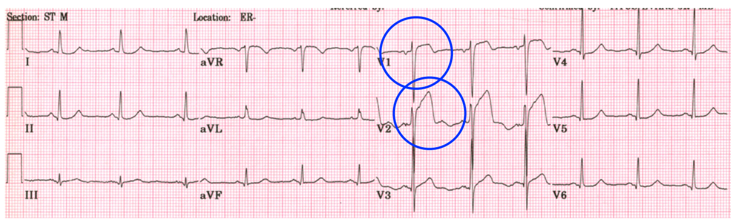


50 mm = 1 s   1 mm = 40 ms

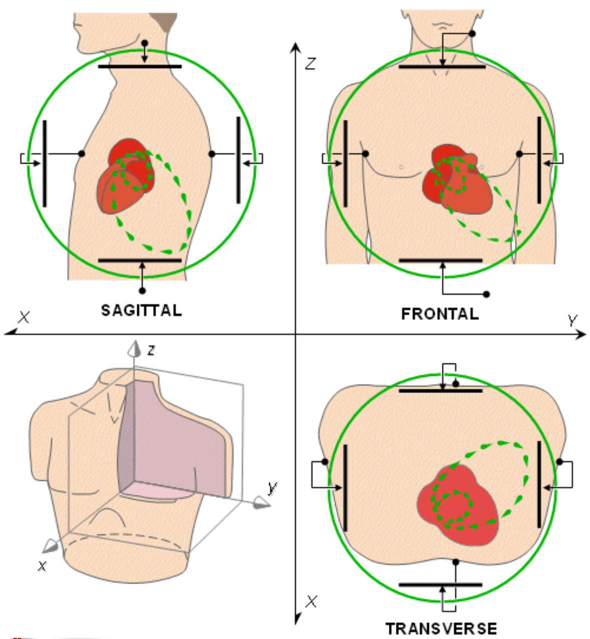


Sample ECG

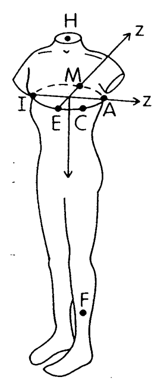


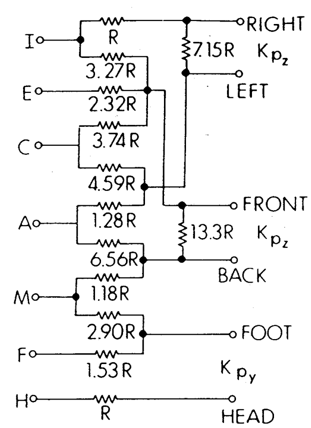


Vectorcardiographic Lead Systems



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.

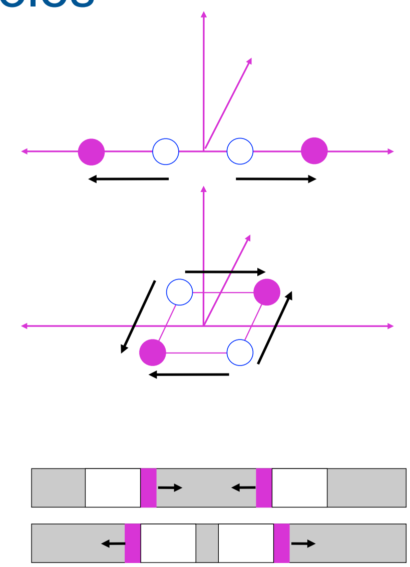
http://www.bem.fi/book/

Lead Field Based Leads

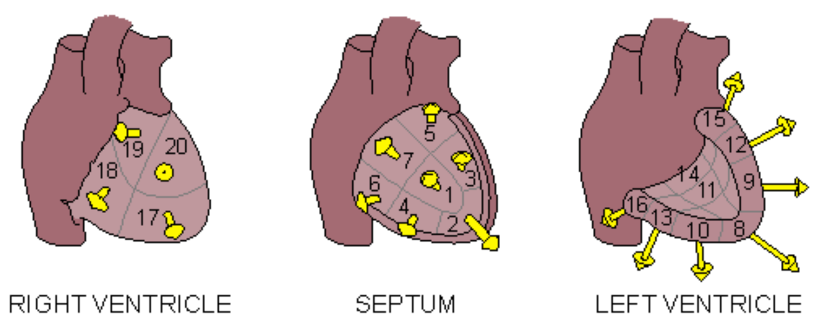
- McFee and Johnston, 1950's
  - Tried to define leads such that E and I were constant over the heart volume. This way, dipole movement would not change L
  - Developed lead system on this basis from torso phantom measurements
  - Performance was improved for homogenous torso but the same for realistic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

Multipoles

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

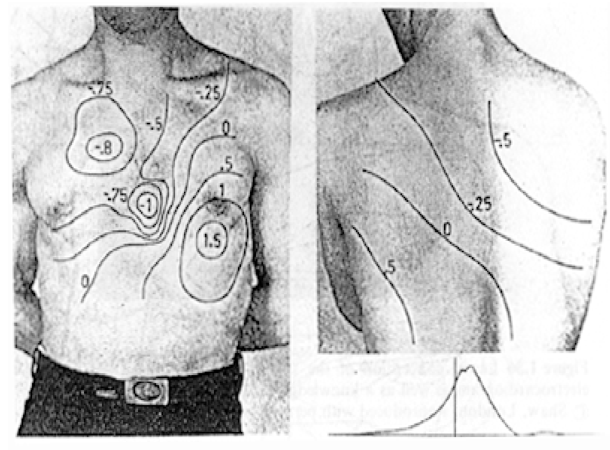


Multipole Based Models



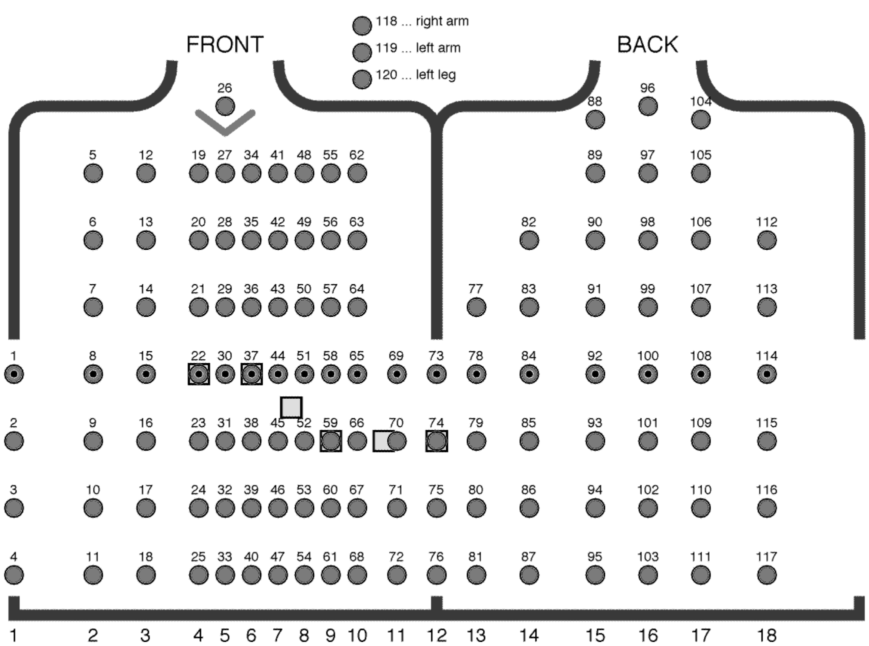
Body Surface Potential Mapping

- 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



BSPM Hisory

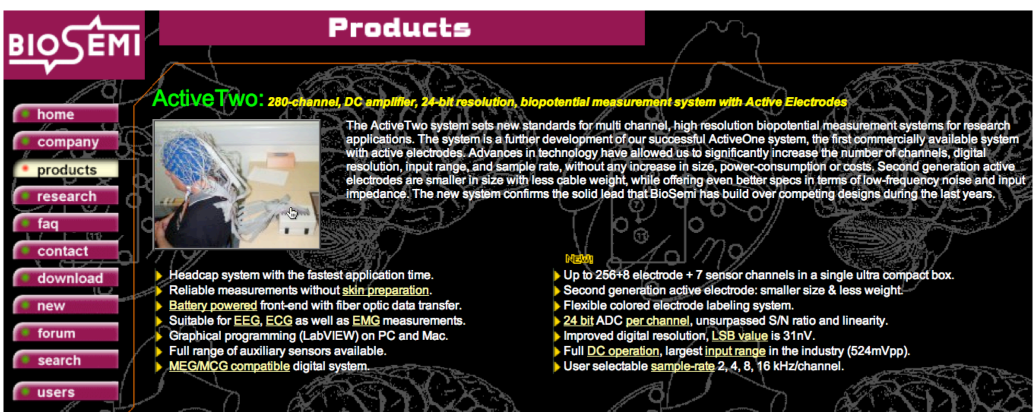
Small version:

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

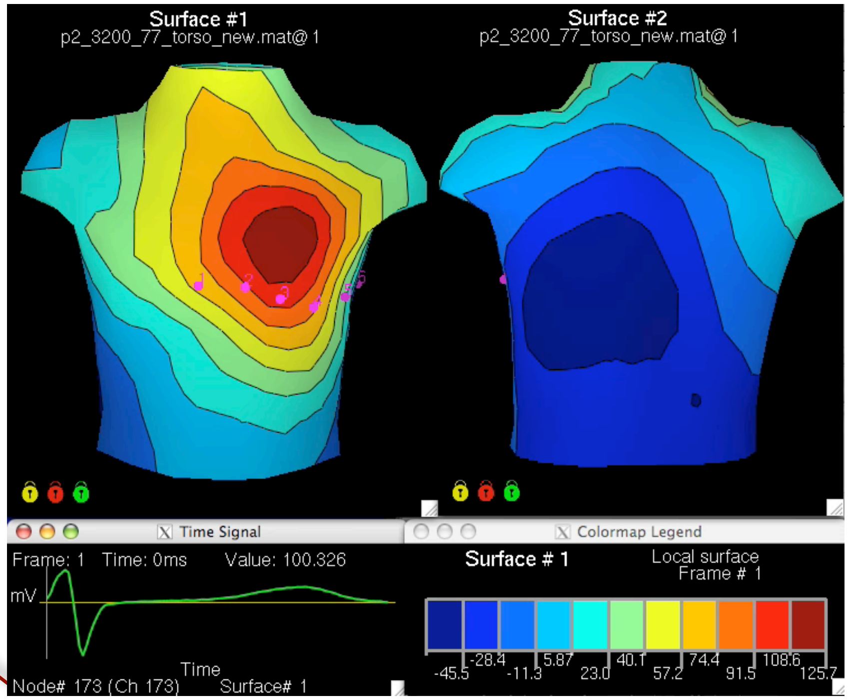
Large version:

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

State of the Art



Sample Map Display



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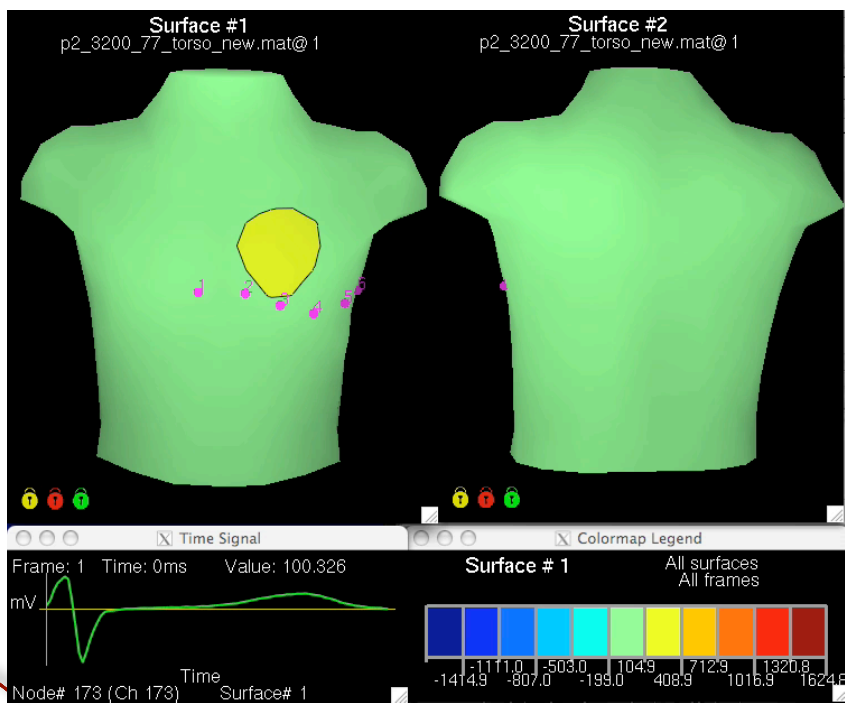
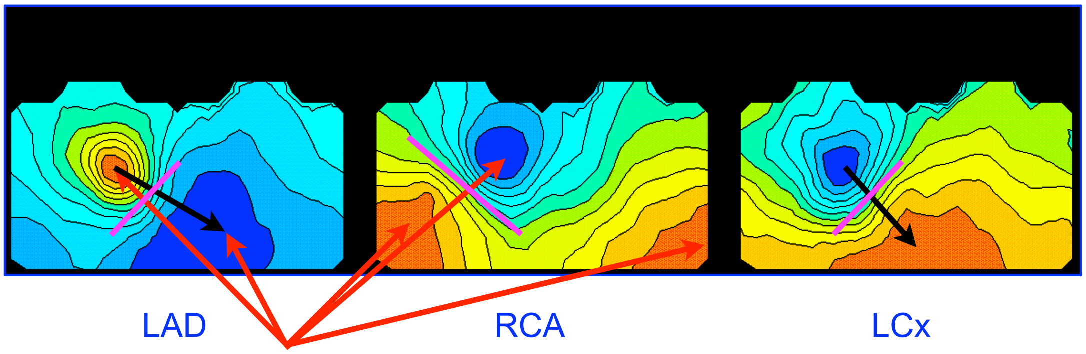


Feature/Pattern Analysis

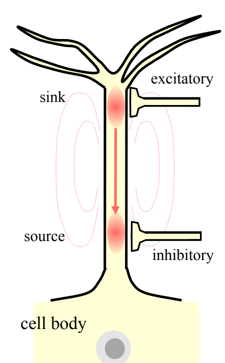
PTCA Mapping

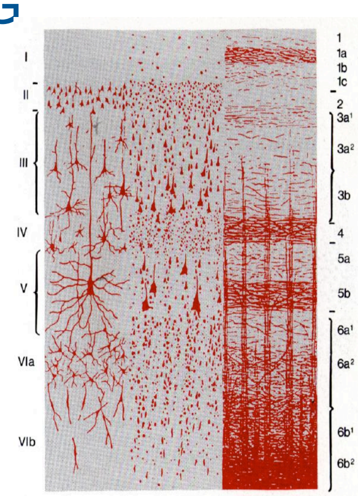


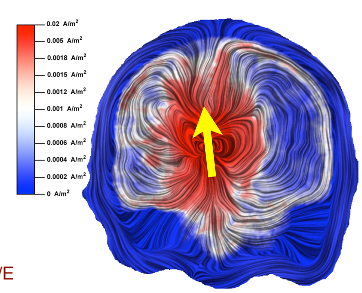
- Use spatial features to identify underlying conditions
  - maxima, minima, zero lines, etc.
  - very condition dependent

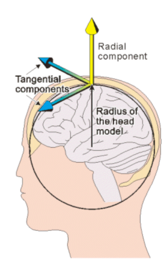
Basics of the EEG

- 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



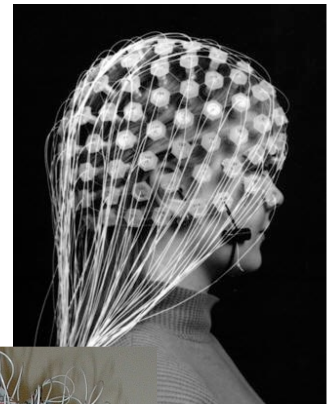


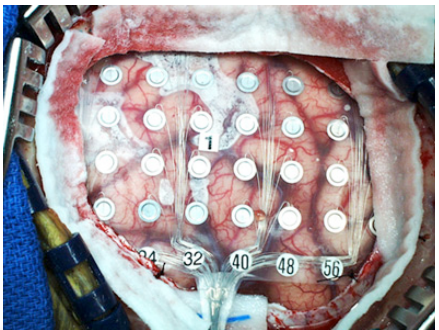


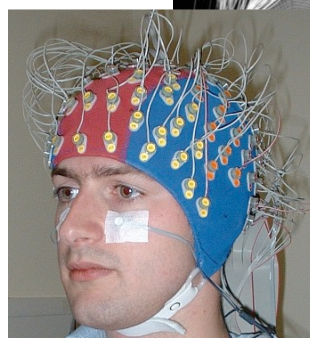


EEG Recording

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



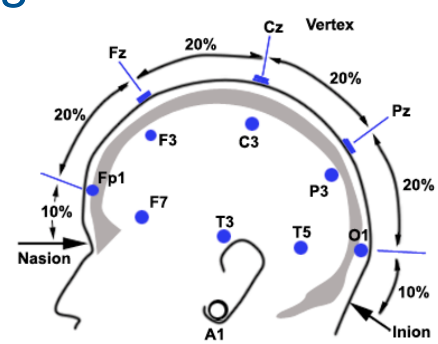


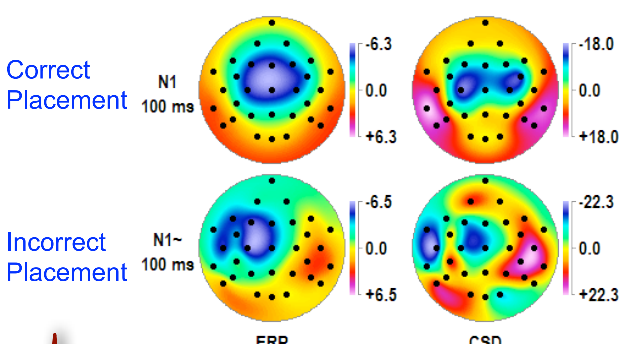


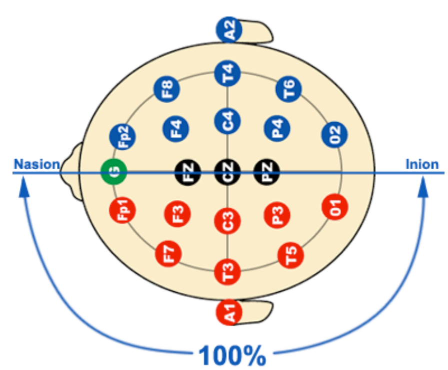
Nunez, http://www.scholarpedia.org/article/Electroencephalogram

EEG Montages

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

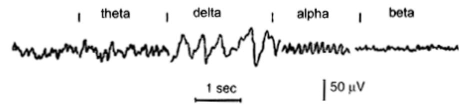


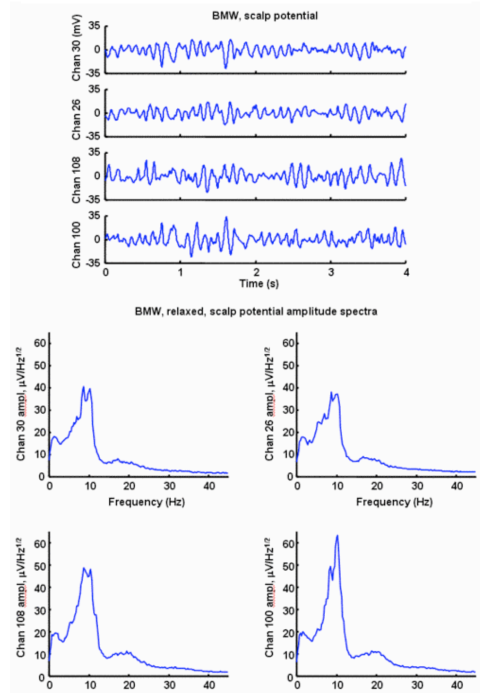


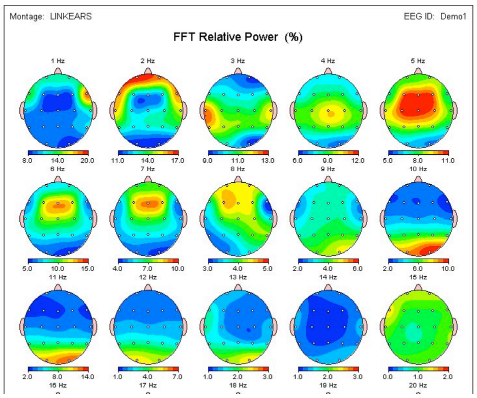


EEG Analysis

- 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

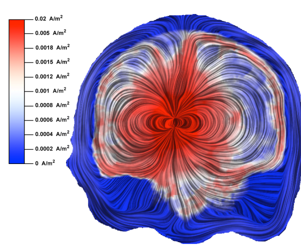


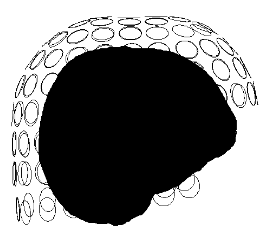




MEG Measurement

- 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