FUNDAMENTALS of EEG TECHNOLOGY

All you need to know about electricity and electronics as they relate to EEG

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LEARNING OBJECTIVES

• Basic and applied physics as they relate to EEG
• Practical issues related to the acquisition of EEG
• Basic features of digital EEG
Disclosures: Conflict of Interest

- Ives EEG Solutions, Inc
- Patent: Ambulatory EEG: DigiTrace/SleepMed
- Patent: fMRI/EEG: NeuroScan/Compumedics
- Stellate, Ad-Tech, MVAP, Grass
- Jordan Neuroscience
Source of the EEG

• Neurons
  – post synaptic junction of the pyramidal cell

• Cerebral cortex
  – 2mm thick by 1.6 m² (16,000 cm² or 17.2 sq ft)

• Spike in the EEG
  – at least 6 cm² of synchronous cortex (0.04%)

• Problem
  – human cortex is a super origami figure surrounded by bone and skin
Spike in a Cortex-Stack

1.6m² area of cortex, 6cm² of epileptic spike activity, 24 surface EEG electrodes
References

- http:www.ccs.fau.edu/~bressler/EDU/NSP/Modules/IV.pdf
Pyramidal Neurons

- Perpendicular to cortex
- Elongated neurons
- Parallel with apical dendrites
Electromagnetic Field

- EEG measures electrical potential
- MEG measures magnetic activity
- EEG and MEG are 90 degrees
- EEG “sees” gyri activity
- MEG “sees” sulcus activity
Solid Angle EEG Potential

- Gloor 1975
- \( P = \text{proportional to } \Omega \)
- Where \( \Omega = \Omega_+ - \Omega_- \)
  - \( P \) is EEG potential
  - \( \Omega \) solid angle
How to Record EEG

- Transducer: electrode
- Amplifier: increase signal amplitude
- Display: was paper now CPU screen
- Storage: was paper now digital media
- # of channels: 2, 4, 8, 16, 24, 32, 64, 128, 256
- Montage: sequenced bipolar, now referential
- Surface invasive


EEG Electrodes

• **SURFACE**
  – Cup or disc electrode: metal or plastic
  – Subdermal needle electrode
  – Subdermal wire electrode

• **Experimental**
  – “dry” or capacitive
  – nano electrodes

• **INVASIVE**
  – Depth electrode
  – Strip electrode
  – Grid electrode
EEG Electrodes: Ideal

- **Low Resistance**
  - large surface area
  - rough surface

- **Low DC Offset**
  - Silver-Silver/Chloride (Ag-Ag/Cl)
  - Similar material, do not mix electrode types
  - Pure silver, no contaminants

- **Imaging Compatible**
  - convenient; particularly, in the ICU during cEEG

- **Ideal is pure silver with a Ag-Ag/Cl coat**
  - Ok for scalp and subdermal
  - not OK for invasive neuronal contact, best with SS, Au, Pt
EEG Electrodes

FIG. 10.1. Charge layer at electrode—electrolyte interface. Modified from Geddes (13).

FIG. 10.2. Series equivalent circuit of a single electrode in contact with an electrolyte. Redrawn from Geddes (14).

TABLE 10.1. Typical half-cell potential values

<table>
<thead>
<tr>
<th>Electrode material</th>
<th>Electrode potential (V)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lead (Pb)</td>
<td>-0.13</td>
</tr>
<tr>
<td>Tin (Sn)</td>
<td>+0.14</td>
</tr>
<tr>
<td>Silver chloride (AgCl)</td>
<td>+0.22</td>
</tr>
<tr>
<td>Copper (Cu)</td>
<td>+0.52</td>
</tr>
<tr>
<td>Silver (Ag)</td>
<td>+0.80</td>
</tr>
<tr>
<td>Platinum (Pt)</td>
<td>+0.86</td>
</tr>
<tr>
<td>Gold (Au)</td>
<td>+1.90</td>
</tr>
</tbody>
</table>

FIG. 10.3. Equivalent circuit of electrode pair with input to an EEG amplifier. G = Cerebral generator; Rg = internal resistance of generator; Rt = tissue resistance; Rs = scalp resistance; E1 = electrode potential; Z1 = capacitive and resistive properties of electrodes; R1 and R2 = input resistance (impedance) of amplifier. Redrawn from Geddes (14).
Some Basic: Resistor

- Resistor, R, ohm, Ω
- Voltage drops across a resistor
- Resistance: DC current
- Impedance: AC current
Some Basic: Capacitor

- Capacitance, C, farad, F
- Voltage stored in a capacitor
- Used to in a filter to tune frequency
- Used in combination with R to create HFF, LFF, BPF (notch)
**Preamp vs Amp**

- Amplifier is usually designed in stages
- Preamp, front-end, high impedance, buffer, usually low gain, LFF, decoupling
- Amp, high gain, HFF
- Using modern operational amplifiers, all functionality can be achieved with a single stage
Input Impedance: Mismatch

• If the electrode impedance (Re) is too high or the amplifier input impedance (Ri) is too low = mismatch

• Because of Ohms Law: \( V = I \times R \), if the \( Re = Ri \), then the voltage measured is 1/2 of the actual.

• If \( Re \) is 1/10th of \( Ri \) then the voltage measured is 90% of actual

• Thus best to make \( Ri >> Re \)

• Usually \( Ri \) is >1M\( \Omega \), \( Re < 20k \Omega \)
Ground and Leakage Current

- Best to ground the patient at one point
- If not possible, make sure that leakage current is low (<3 µA)
- Leakage current is generated by long AC cable and power supply
- Best to have current limiting in all patient leads (std in modern EEG)
Impedance Simplified

Ohm’s Law: \( V = IR \)

R: Resistance (DC) or Impedance (Hz)
EEG Characteristics

- Amplitude: ranges from a few micro-volts to several milli-volts, normal activity around 100 micro-volts
- Frequency: DC to 100 Hz, normal activity 0.5 Hz to 25 Hz (Hz = cycles per sec)
- Note: depth electrodes can “see” higher frequencies (600 Hz) near Sz focus
EEG Machine (analog): paper/ink

From: Tyner et al.
Digital: not much analog left

- Input box
- Amplifier
- A/D converter
- everything else is software
  - montage
  - gain
  - high frequency filter (HFF)
  - low frequency filter (LFF)
  - notch filter (BPF)
EEG Machine (digital): CPU based
Digital Front-End

- Low-frequency filter (LFF), decoupling
- High-frequency filter (HFF), anti-aliasing
- Wide-band, open filter
- All selective filtering performed by software
- Referential based amplifiers
- remontaging performed by software
- Sample/hold, A/D converter
Sensitivity & Gain

- Sensitivity is microvolts (µ) of input to produce 1mm of “pen” deflection (CPU screen), 1µV/mm, 10µV/mm, 100 µV/mm

- Gain is the amplification factor of the preamp. A gain of 1,000 means that an EEG signal of 10µV becomes 10mV
Analog Front-End Filter

- F = 1/2πRC, where RC is the time constant (TC)
- Resistor and Capacitor define 3db down point
- Wide-band recording
- Low frequency is usually 0.5Hz
- High frequency is usually 100Hz
- Digital sample rate > 200Samples/Sec/Chan
Filter Characteristics

- Filters attenuate they do not eliminate
- Filters will attenuate high frequencies, but may reveal low frequency components within
- Filters attenuate spikes, but will not eliminate them, just changes the degree of “sharpness”
- Filters should be used selectively not generally
- Filters will not generate frequencies, unless there is aliasing
- Aliasing is the fold back of frequencies
High Frequency Filtering

*Figure 8.20: Frequency response characteristics of HF filters 70 Hz, 35 Hz, and 15 Hz compared with unfiltered channel (DC). S = 10 µV/mm; LF (channel 3) = 0.1 Hz.*

- Function generator constant voltage out, sine wave output
- All S = 10 µV/mm
- Input frequency (Hz): 5, 10, 15, 20, 25, 35, 40, 50, 55, 60, 70, 100
HFF Example

FIG. 8.19. Effects of HF filters on high voltage, fast activity. LF = 1 Hz; S = 7 μV/mm.
Effects of HFF and LFF on DC Pulse

FIG. 4.29. Interactive effects of LF and HF filters on step function. (Note decreased amplitude as HF cut-off is lowered and LF cut-off is increased.) Paper speed = 15 mm/sec; 5 = 10 μV/mm; Input = 100 μV.
HFF and LFF

Low Frequency Filter (LFF)
DC Decoupling

\[ LF = \frac{1}{2\pi R_1 C_1} \]
\[ TC = R_1 C_1 \]

3db down point
db is logarithmic measure
3db down is a reduction of about 30%

High Frequency Filter (HFF)
Anti-aliasing

\[ HF = \frac{1}{2\pi R_3 C_3} \]
\[ TC = R_3 C_3 \]
Diff/Ref EEG Amplifier

Differential Amplifier

Referential Amplifier

G = R3/R1
HF = 1/(2πR3C3)
LF = 1/(2πR1C1)
Real Differential EEG Amplifier

Referential Amplifier

C1 0.33μF
R1 1MΩ
LFF

F3  E

R2 1MΩ
C2 0.33μF

+ve

Operational Amplifier
(almost any)
Low noise
Low power
small

G=R3/R1
G=100M/1M
G=100

LFF=1/2πR1C1
LFF=1/2π1MΩx0.33μF
LFF=0.5Hz

HFF=1/2πR3C3
HFF=1/2π100MΩx160pF
HFF=100Hz

TC=R1C1 or .33sec
TC=R3C3 or 160x10^{-12} sec or 160psec

Where: μ (micro) is 10^{-6}; p (pico) is 10^{-12}
A/D Converter

- At least 2x (best 5x) any frequency of interest
- >200S/S/Chan, surface
- >700S/S/Chan, invasive
- bit resolution: amplitude
- 8bit  256 levels  1µV to 256µV range
- 12bit  4,096 levels  1µV to 4mV
- 16bit  65,536 levels  1µV to 0.65V
EEG Clinical Applications

- Clinical
- Prolonged (or Day LTM)
- LTM in the EMU
  - LTM with invasive electrodes
- Ambulatory LTM
- cEEG in the NICU
- EEG in the ED
cEEG in the NeuroICU

• Same as LTM in the EMU
• BUT
  – the NICU is not under the control of EEG
  – EEG conflicts with imaging
  – lots of external artifact
  – EEG not the priority
  – on/off of electrodes for imaging
Skin Prep, Electrode Glue, Gels
Surface Electrodes

- Skin is a good insulator and must be prepared to allow some conduction
- Electrodes need to be fixed to the head with a paste or glue such as collodion
- Conductive gel needs to “wet” the scalp and electrode
- Electrode impedance is always deteriorating
Skin Prep, Electrode Glue, Gels

Invasive Scalp Electrodes

- None of the above needed for subdermal needle SNE or subdermal wire electrodes SWE
- SNL: not a chronic electrode
  - rigid needle, needle stick problems
- SWE: is a chronic electrode
  - flexible electrode
- Electrode impedance is steady
Head-Mounted 32-Channel Preamp/Multiplexer

MRI Compatible Electrode Module (1of4)

Quarter for Scale

Head-Waist Signal Cable

Waist-Worn Power Pack

Patient Cable (up to 100ft)
Subdermal Wire Electrode (SWE): 0.25x3mm Ag-Ag/Cl tip
SWE: 3-Stages of Insertion
Conductive Plastic Electrodes
Harness System
Electrodes Ready for Imaging