FUNDAMENTALS of EEG TECHNOLOGY

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

Mr. John R. Ives, B.Sc.

University of Western Ontario

London, Ontario, Canada

jives@uwo.ca

LEARNING OBJECTIVES

- Basic and applied physics as they relate to EEG
- Practical issues related to the acquisition of EEG
- Basic features of digital EEG

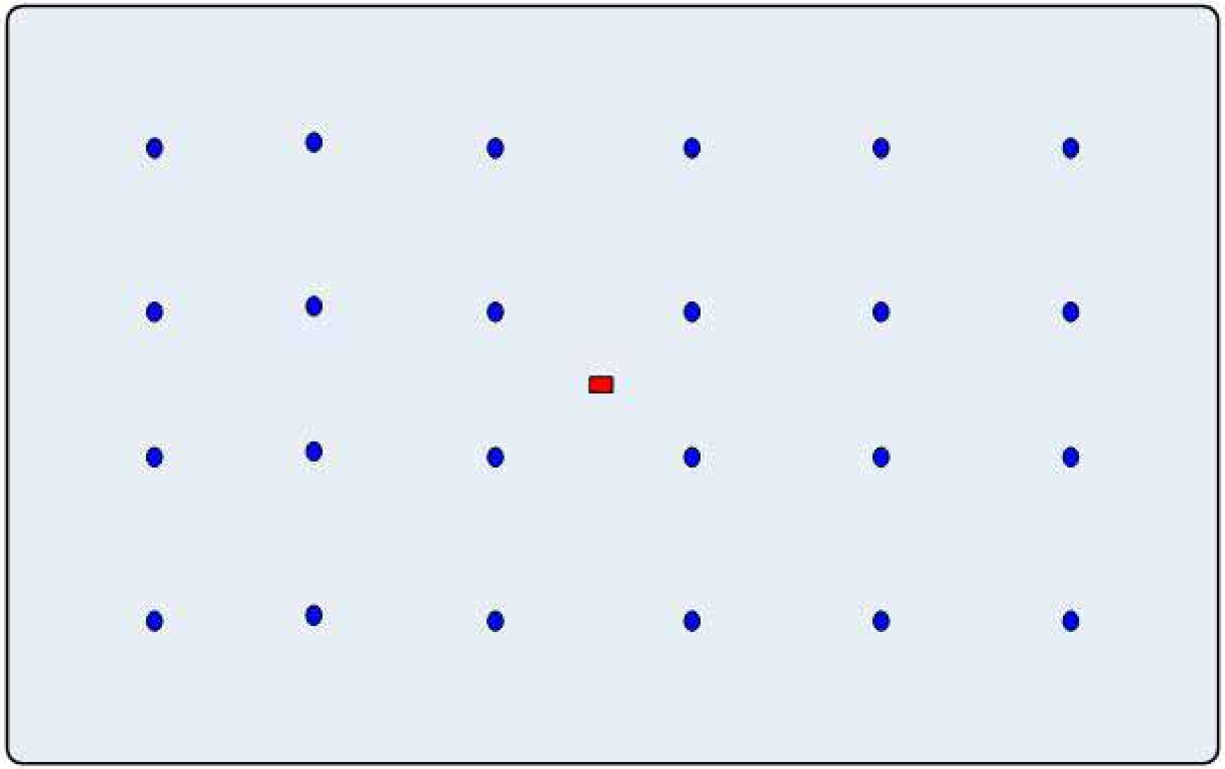
Disclosures: Conflict of Interest

- 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 m^2 (16,000 cm^2 or 17.2 sq ft)
- Spike in the EEG
  - at least 6 cm^2 of synchronous cortex (0.04%)
- Problem
  - human cortex is a super origami figure surrounded by bone and skin

Spike in a Cortex-Stack



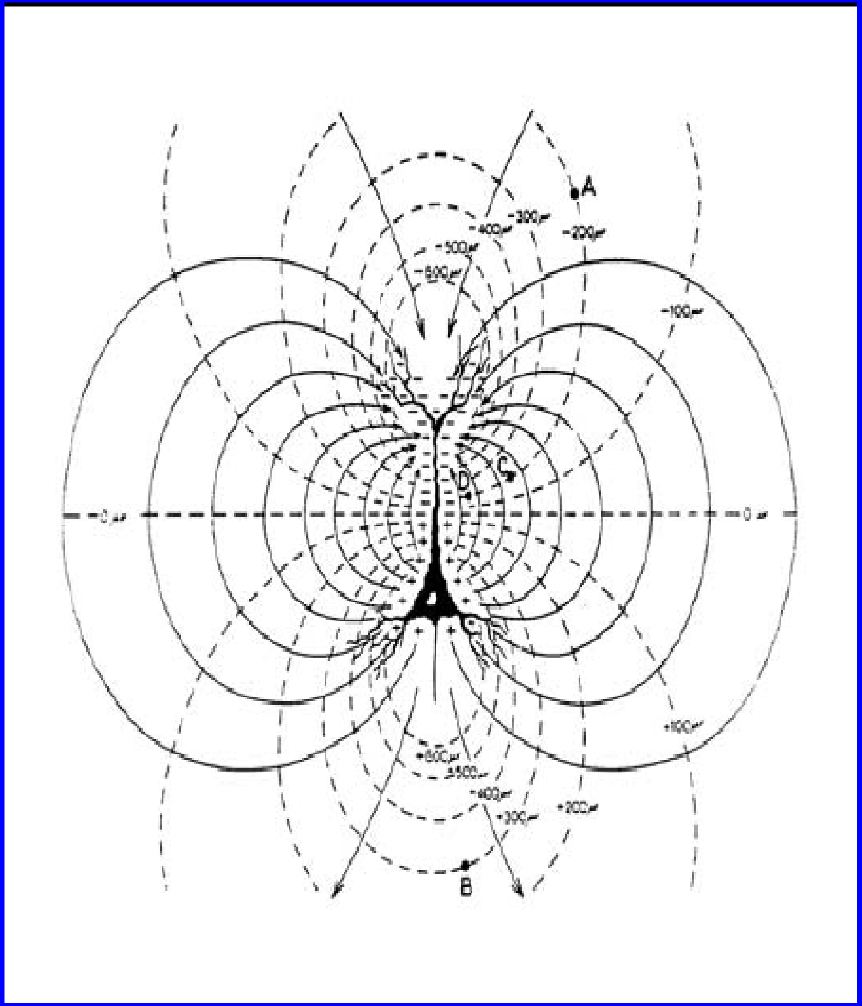
$1.6m^2$ area of cortex, $6cm^2$ of epileptic spike activity ■, 24 surface EEG electrodes ●

References

- Elul, R. The Genesis of the EEG. *International Review of Neurobiology*, 15:227-272 (1972).
- Speckmann, E-J. and Elger, C.E. Neurophysiological Basis of the EEG and of DC Potentials. In: E. Niedermeyer and F. Lopes daSilva, eds. Electroencephalography: Basic Principles, Clinical Applications and Related Fields. Urban and Schwarzenberg, Baltimore-Munich, pp. 1-13 (1982).
- Lopes daSilva, F. and Van Rotterdam, A. Biophysical Aspects of EEG and MEG Generation. In: E. Niedermeyer and F. Lopes daSilva, eds. Electroencephalography: Basic Principles, Clinical Applications and Related Fields. Urban and Schwarzenberg, Baltimore-Munich, pp. 15-26 (1982).
- Gloor, P. Neuronal Generators and the Problem of Localization in Electroencephalography: Application of Volume Conductor Theory to Electroencephalography. *Journal of Clinical Neurophysiology*, 2(4):327-354 (1985).
- Plonsey, R. Volume-conductor Fields. Chapter 5 in Bioelectric Phenomena. McGraw Hill, New York, pp. 202-275 (1969).
- Tyner, F., Knott, J., and Mayer, W. Fundamentals of EEG Technology. Lippincott Williams & Wilkins, 1983
- Ebersole, J. Defining epileptogenic foci: past, present, future. J. of Clin. Neurophysio., 14(6), 470-483, 1997.
- 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 measure electrical potential
- MEG measures magnetic activity
- EEG and MEG 90 degrees
- EEG “sees” gyri activity
- MEG “sees” sulcus activity

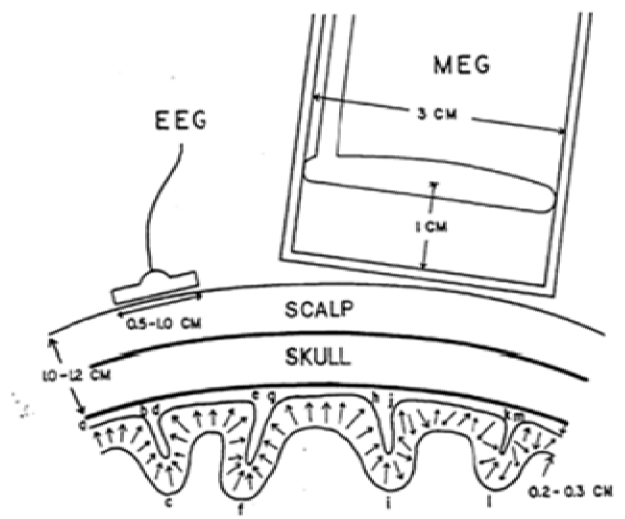


Figure 1-4. Extracranial recording of electroencephalographic (EEG) and magnetoencephalographic (MEG) data. EEG is most sensitive to correlated dipole layer in gyri (ab, de, gh), less sensitive to correlated dipole layer in sulcus (hi), and insensitive to opposing dipole layer in sulci (bcd, efg) and random dipole layer (ijklm). MEG is most sensitive to correlated dipole layer in sulcus (hi) and much less sensitive to all other sources shown because of opposing dipoles, randomly oriented dipoles, or radial dipoles. (The external magnetic field due to a radial dipole in a medium of spherically symmetric conductive layers is zero.) MEG is measured with a superconducting quantum interference device, typically consisting of several coils used to cancel spatially constant magnetic fields. Only the coil closest to the head is shown here. (Reproduced with permission from Nunez, 1990b.)

Solid Angle EEG Potential

- Gloor 1975
- P= proportional to Ω
- Where $\Omega = \Omega_{+} - \Omega_{-}$
  - P is EEG potential
  - Ω solid angle

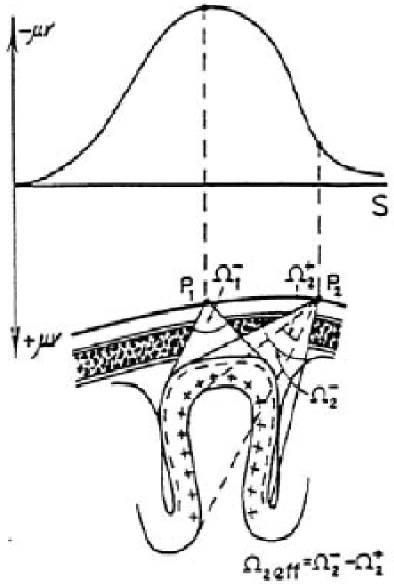


FIG. 7. Potential distribution along line S on the scalp created by the synchronous activation of a curved portion of cortex that occupies the crown of a gyrus and its two sides forming the proximal walls of the two adjacent sulci. At P1, the potential depends only on the solid angle Ω_1^-, since at this point an electrode "sees" only a portion of the negative side of the dipole layer. At P2, an electrode "sees" the negative side of the portion of the dipole layer occupying the crown of the gyrus and the wall of the proximal sulcus under the angle Ω_2^-; however, it also "sees" under the smaller angle Ω_2^+ the positive side of the portion of the dipole layer located in the wall of the distal sulcus. The potential at P2 is therefore smaller than would be expected if only Ω_2^- were the angle determining the size of the potential at P2 and is proportional to the effective solid angle Ω_{eff}, which equals the difference between Ω_2^- and Ω_2^+, the polarity being negative, since $\Omega_2^- > \Omega_2^+$. As is the case for a flat area of cortex oriented in parallel to the scalp the potential profile is bell-shaped. (Taken in part from Gloor, 1975.)

Convoluted Generators

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
  surface invasive
- Montage: sequenced bipolar, now referential

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

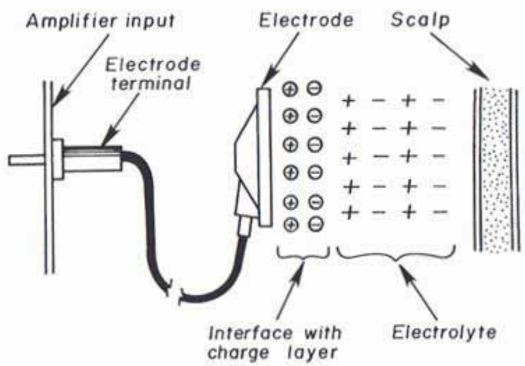


FIG. 10.1. Charge layer at electrode–electrolyte interface. Modified from Geddes (13).

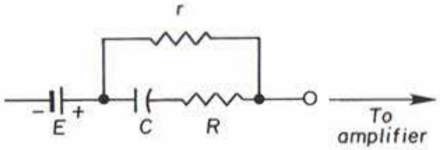


FIG. 10.2. Series equivalent circuit of a single electrode in contact with an electrolyte. Redrawn from Geddes (14).

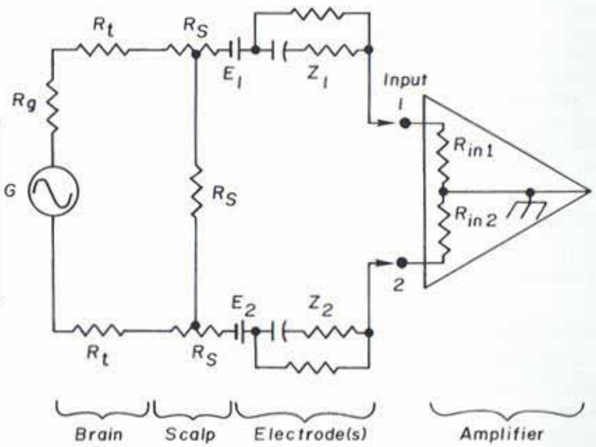


FIG. 10.3. Equivalent circuit of electrode pair with input to an EEG amplifier. G = Cerebral generator; Rg = internal resistance of generator; Rt = tissue resistance; Rs = scalp resistance; $E_{1,2}$ = electrode potential; $Z_{1,2}$ = capacitive and resistive properties of electrodes; $R_{in,1}$ and $R_{in,2}$ = input resistance (impedance) of amplifier. Redrawn from Geddes (14).

TABLE 10.1. *Typical half-cell potential values*

Electrode material	Electrode potential (V)
Lead (Pb)	−0.13
Tin (Sn)	+0.14
Silver chloride (AgCl)	+0.22
Copper (Cu)	+0.52
Silver (Ag)	+0.80
Platinum (Pt)	+0.86
Gold (Au)	+1.50

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

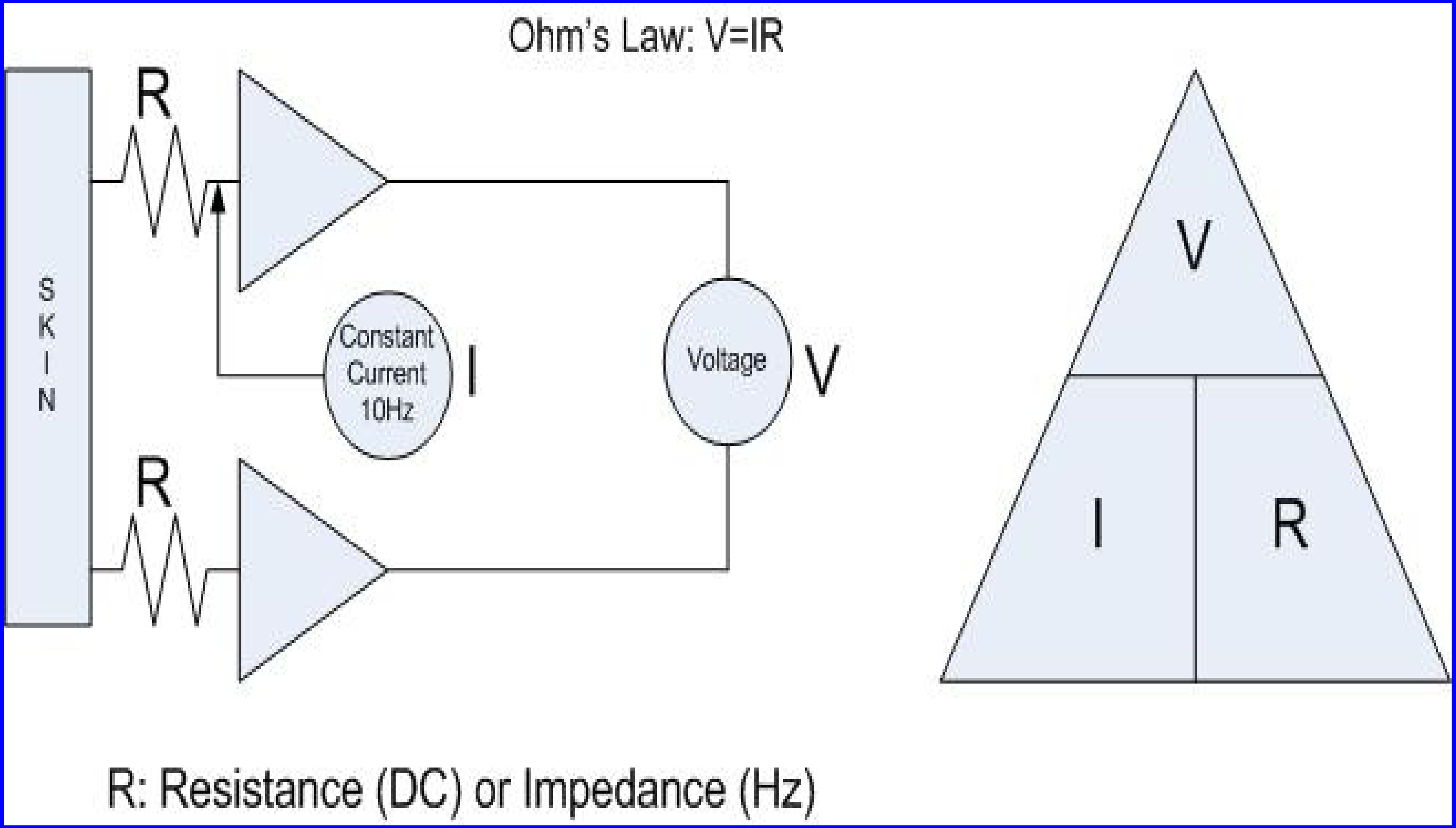
Input Impedance: Mismatch

- If the electrode impedance (Re) is too high or the amplifier input impedance (Ri) is too low= mismatch
- Because of Ohms Law: V=IxR, 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 >1MΩ, Re<20k Ω

Ground and Leakage Current

- Best to ground the patient at one point
- If not possible, make sure that leakage current is low (<3μA)
- 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



EEG Characteristics

- Amplitude: ranges from a few micro-volts to several milli-volts, normal activity around 100micro-volts
- Frequency: DC to 100Hz, normal activity 0.5Hz to 25Hz (Hz=cycles per sec)

- Note: depth electrodes can “see” higher frequencies (600Hz) near Sz focus

EEG Machine (analog): paper/ink

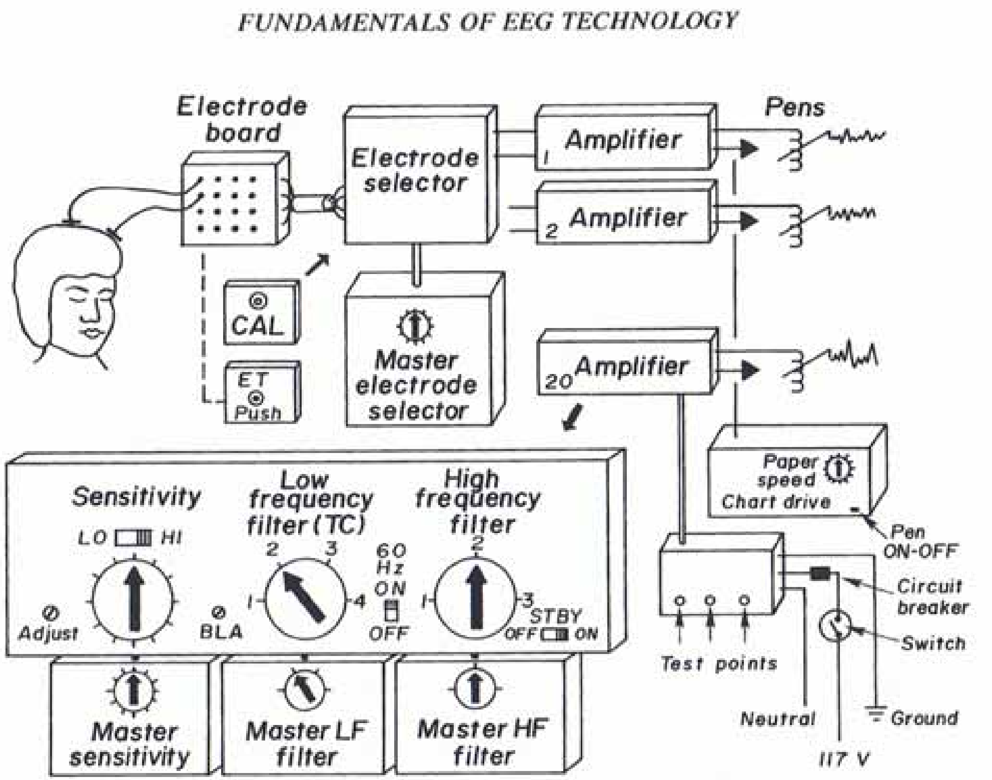


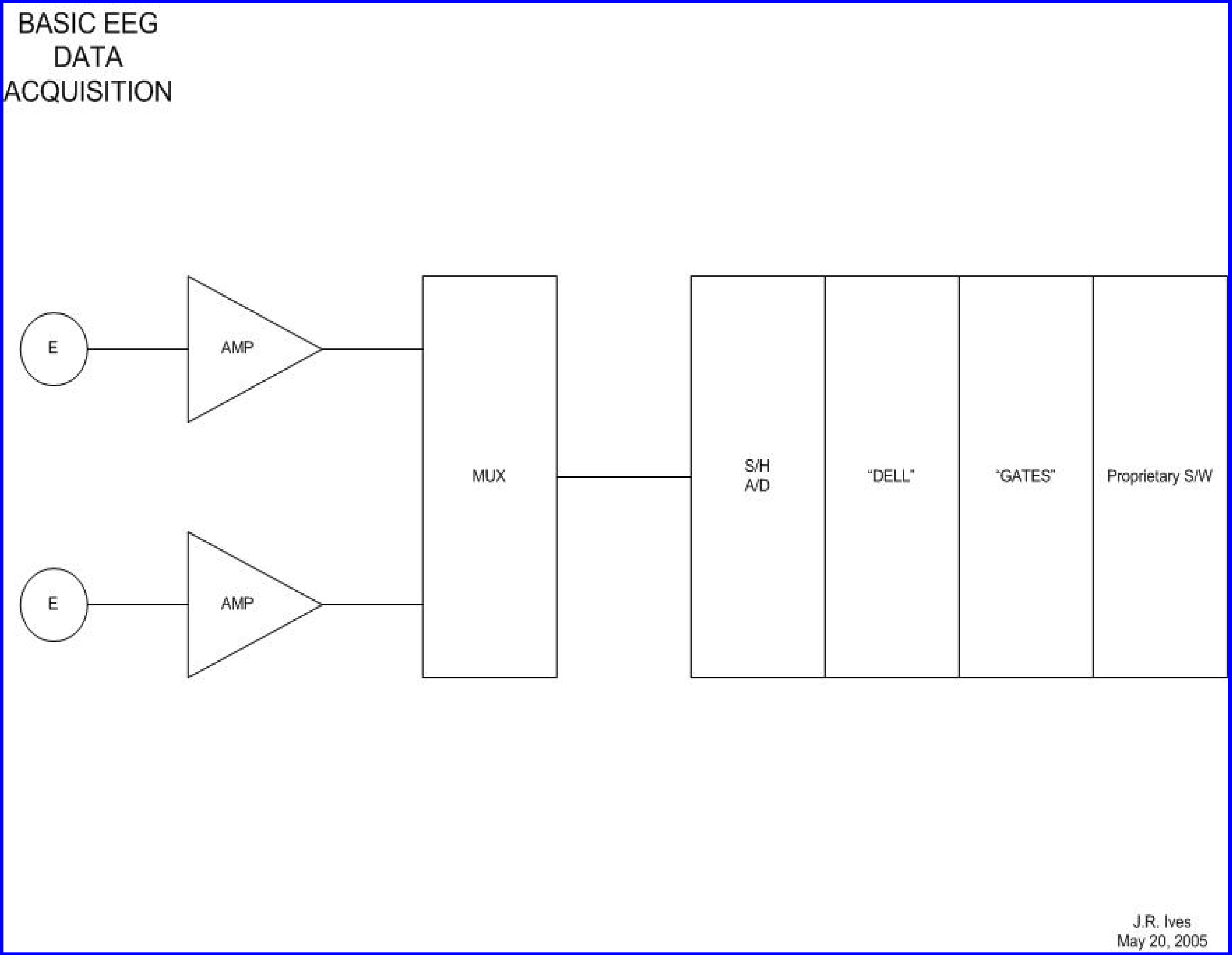
FIG. 2.14. Common components of a typical electroencephalograph.

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

- $F=1/2\pi RC$, 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

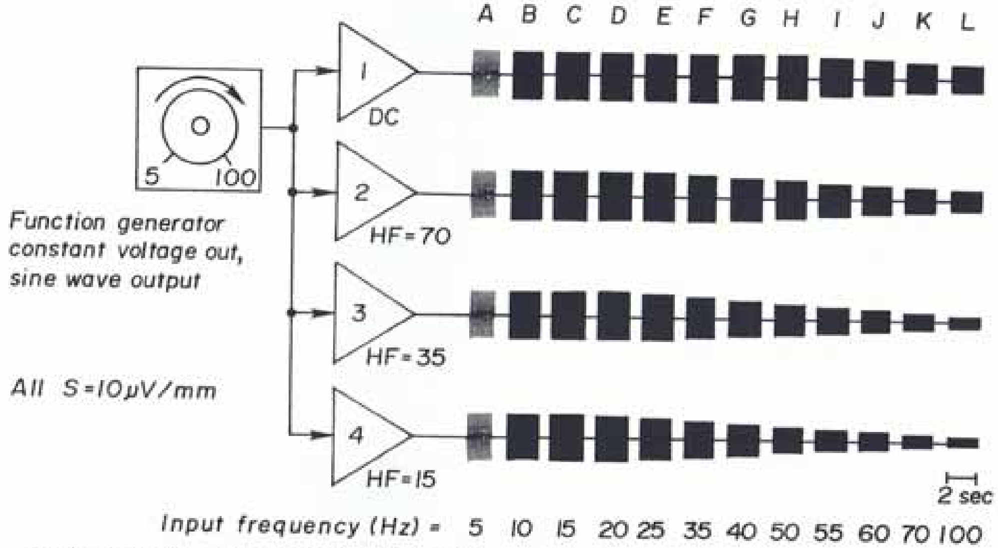


FIG. 8.20. Frequency response characteristics of HF filters 70 Hz, 35 Hz, and 15 Hz compared with unfiltered channel (DC). S = 10 μV/mm; LF (channels 2–4) = 0.1 Hz.

HFF Example

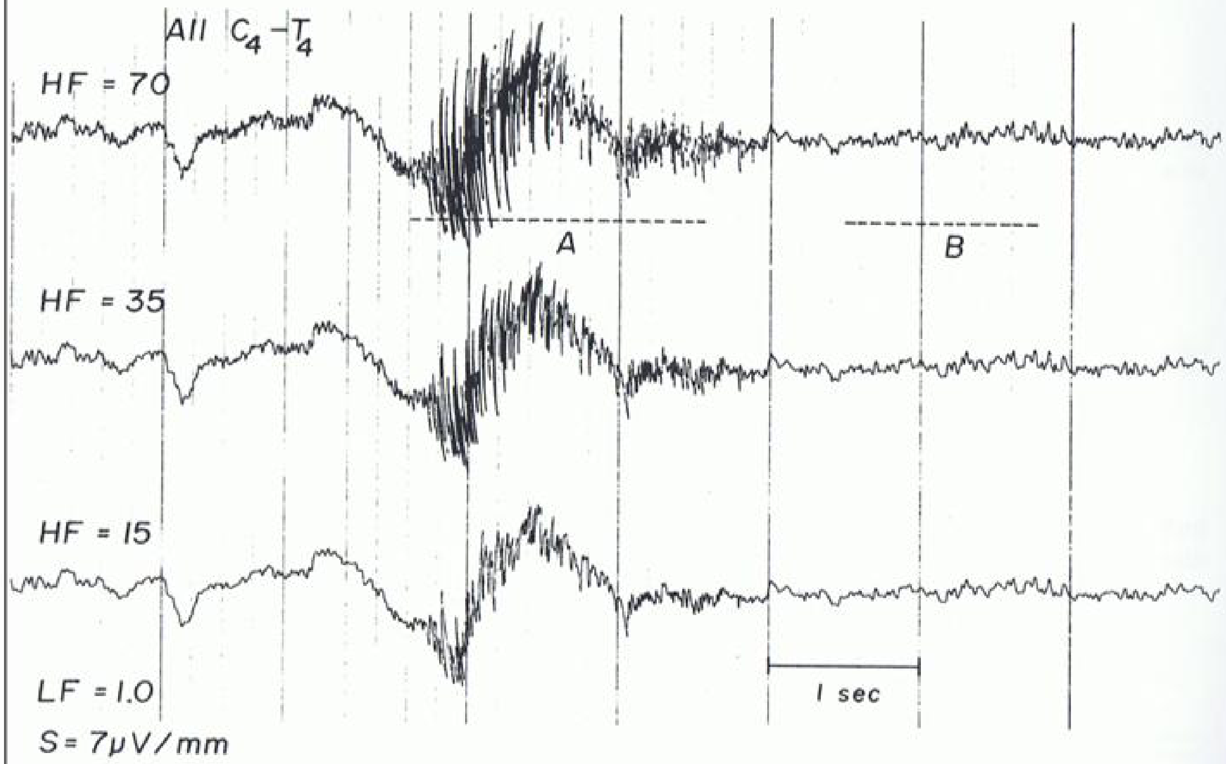


FIG. 8.19. Effects of HF filters on high voltage, fast activity. LF = 1 Hz; S = 7 μV/mm.

Effects of HFF and LFF on DC Pulse

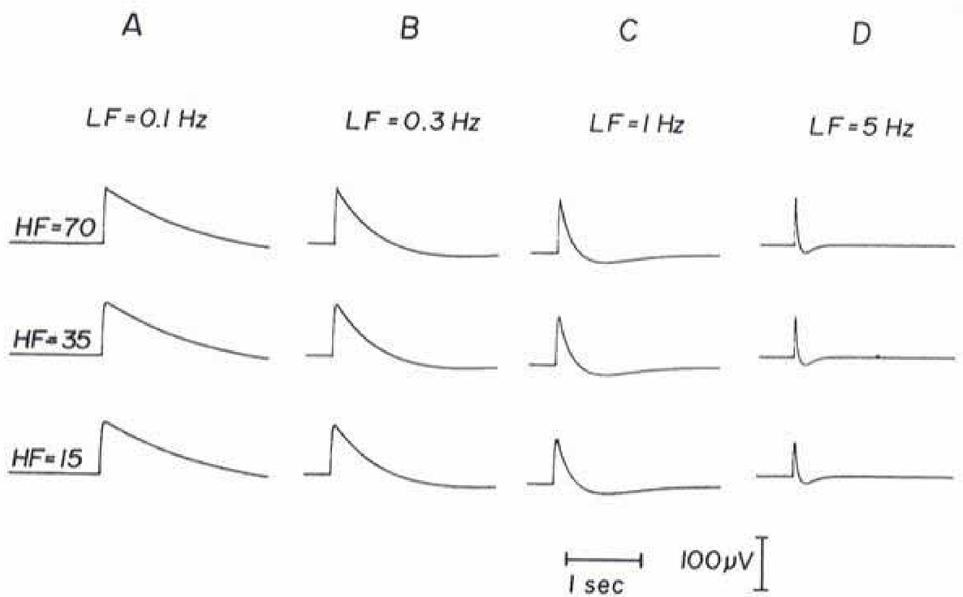
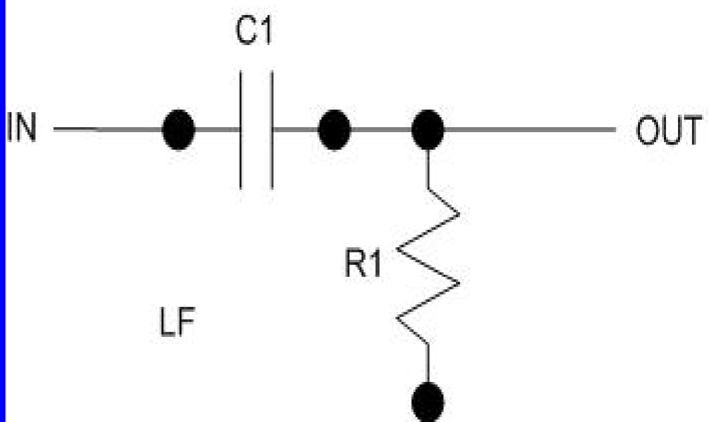


FIG. 8.29. Interactive effects of LF and HF filters on step function. (Note decreased amplitude as HF cut-off is lowered and LF cut-off is increased.) Paper speed = 15 mm/sec. S = 10 μV/mm. Input = 100 μV.

HFF and LFF

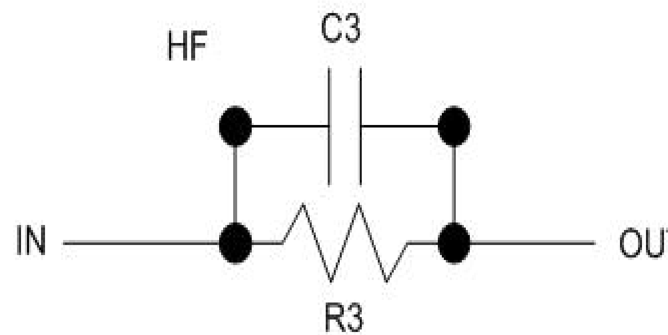
Low Frequency Filter (LFF)
DC Decoupling



LF=1/2πR1C1
TC=R1C1

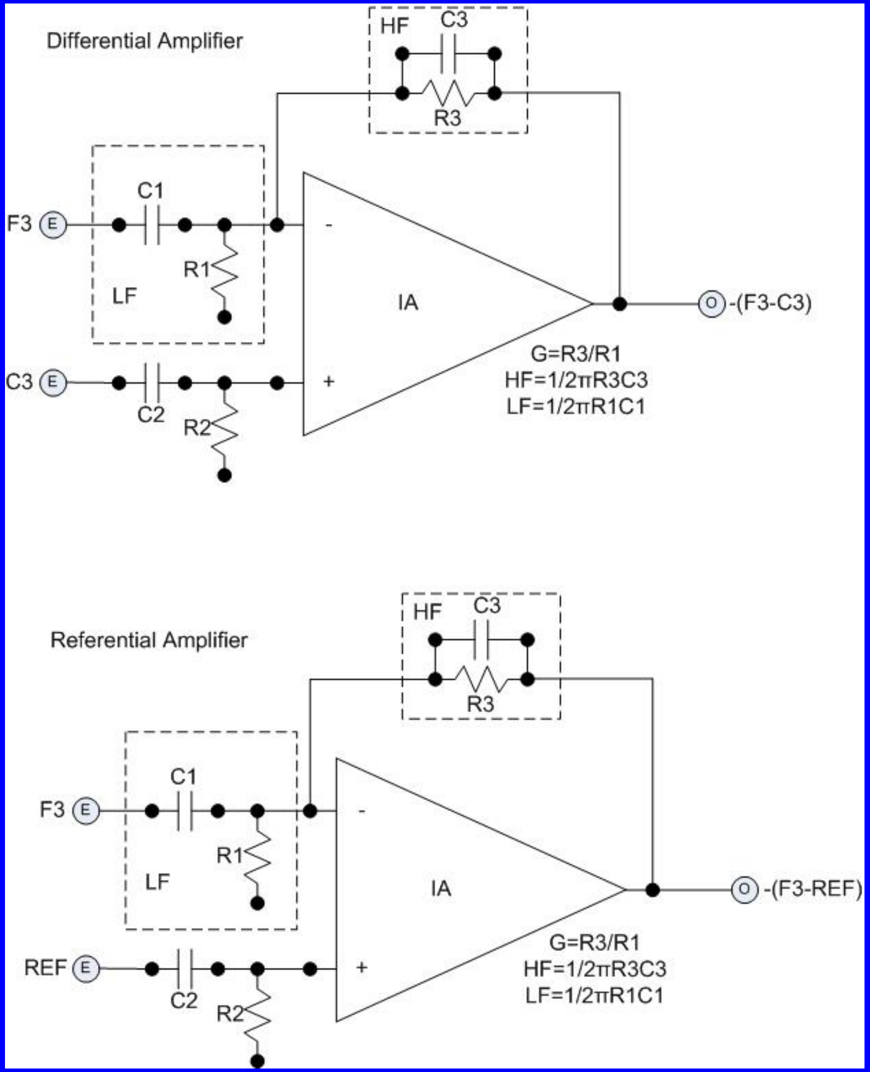
3db down point
db is logarithmic measure
3db down is a reduction of about 30%

High Frequency Filter (HFF)
Anti-aliasing

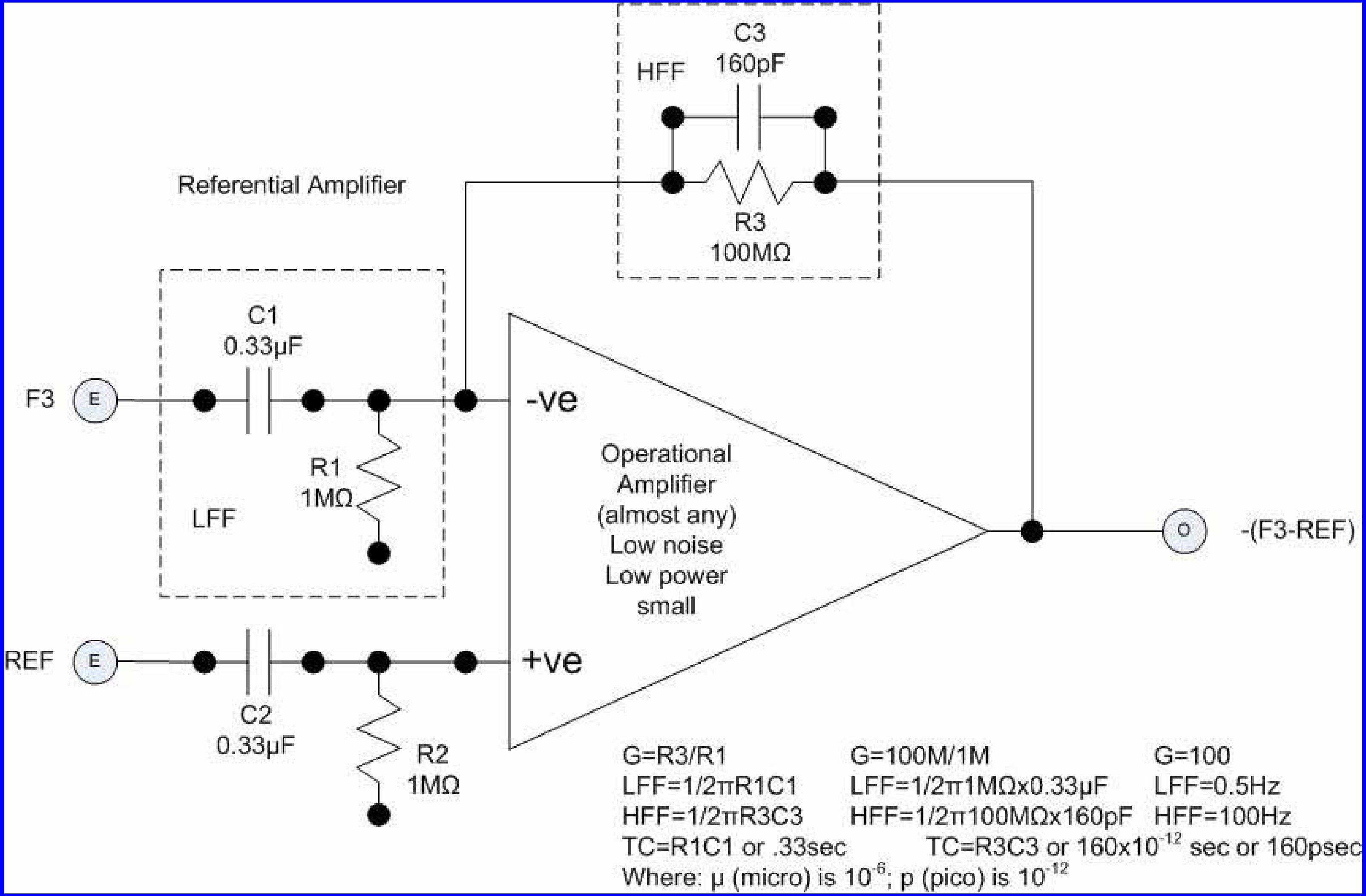


HF=1/2πR3C3
TC=R3C3

Diff/Ref EEG Amplifier



Real Differential EEG Amplifier



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

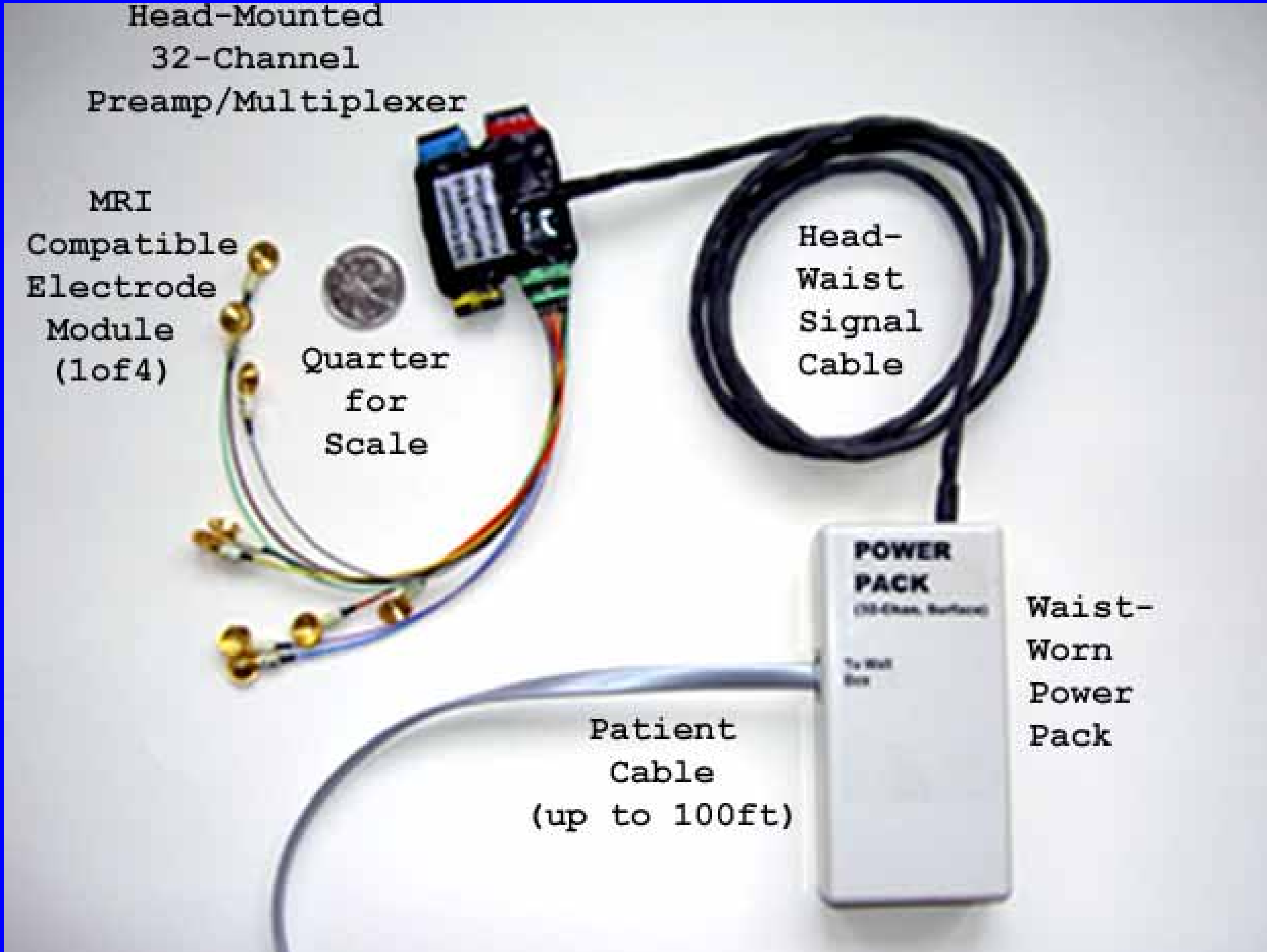
- Same as LTM in the EMU
- BUT
  - the NICU is <u>not</u> under the control of EEG
  - EEG conflicts with imaging
  - <u>lots</u> of external artifact
  - EEG <u>not</u> the priority
  - on/off of electrodes for imaging

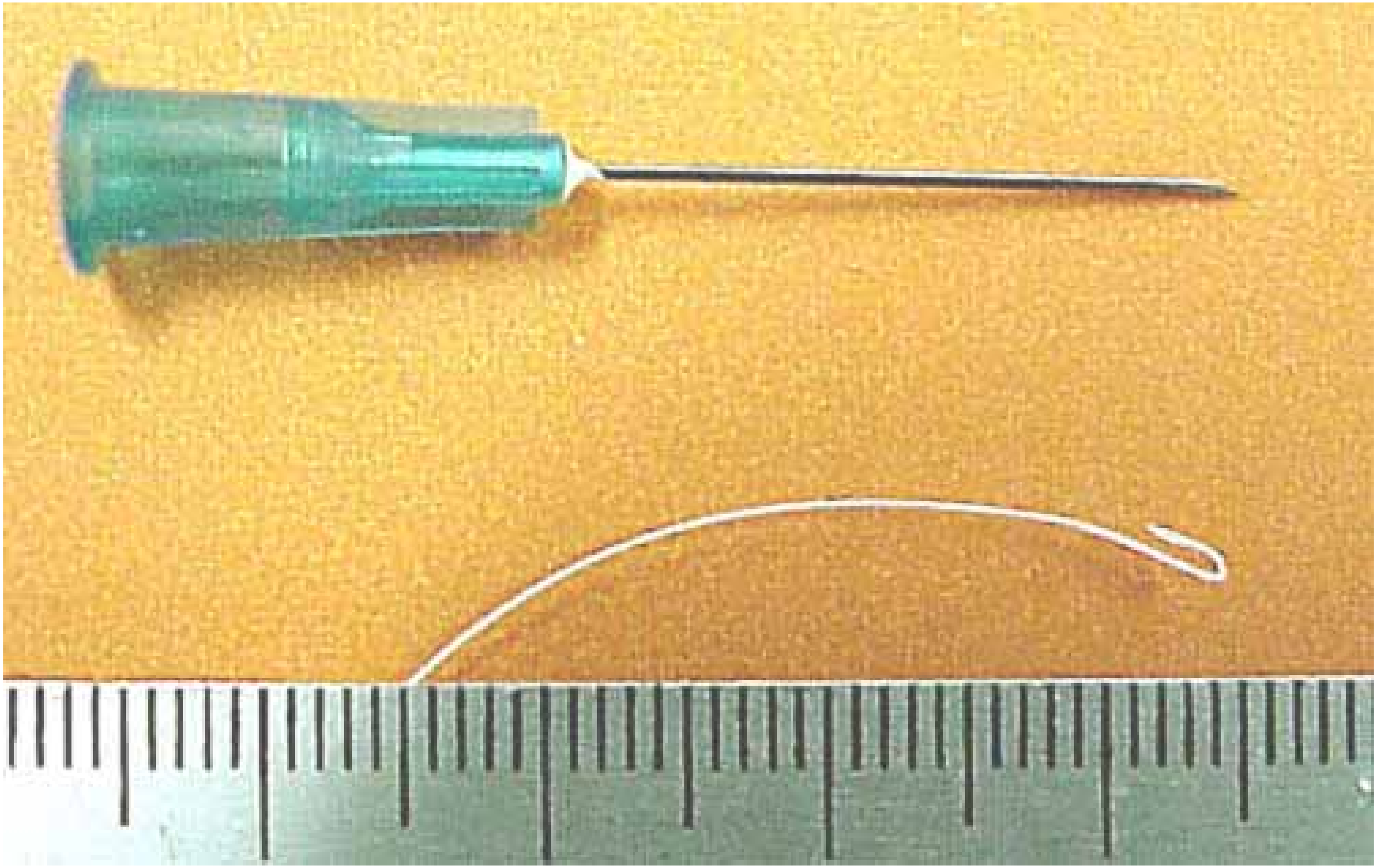
Skin Prep, Electrode Glue, Gels Surface Electrodes

- 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

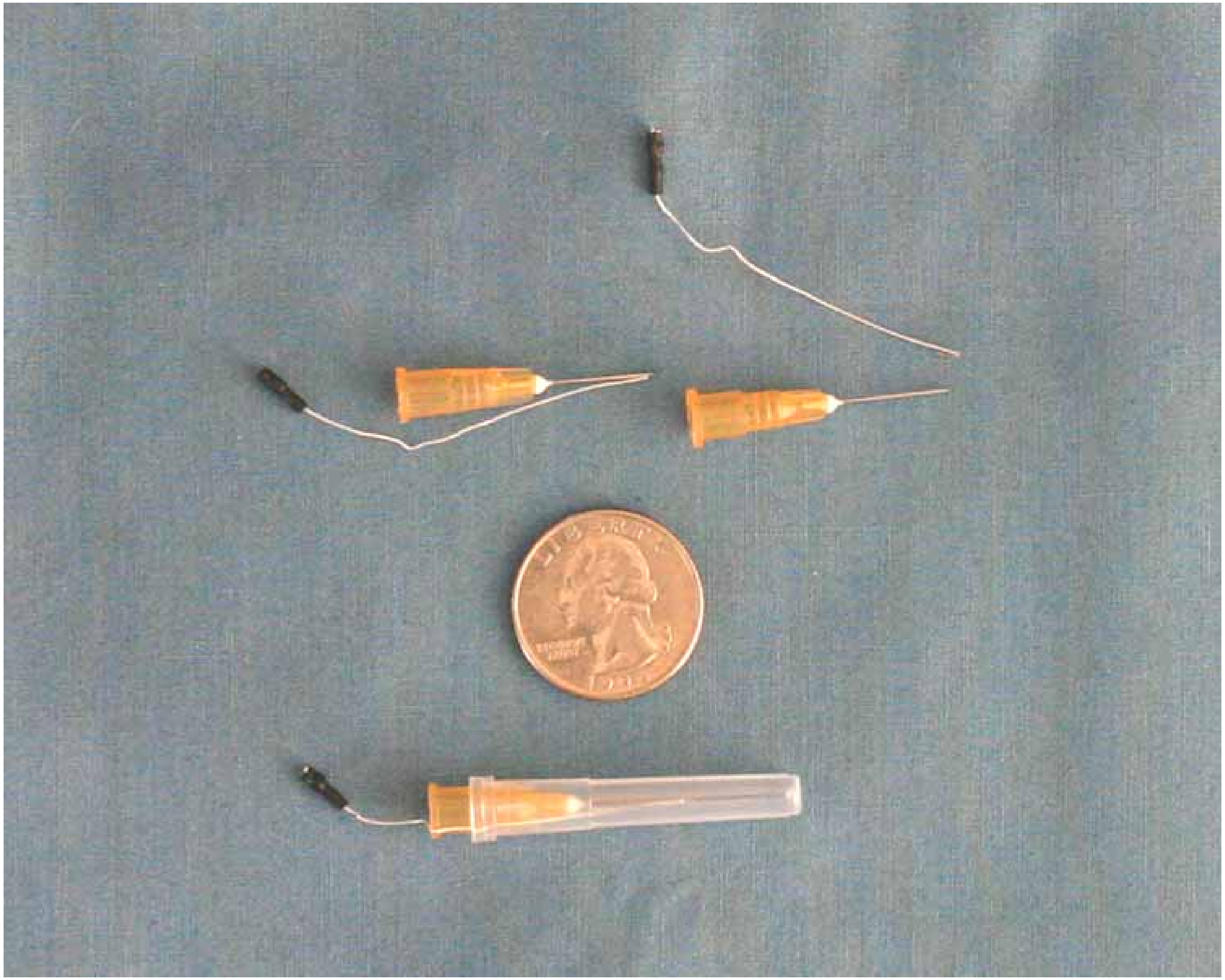
- None of the above needed for subdermal needle SNE or subdermal wire electrodes SWE
- SNL: not a chronic electrode
  - rigid needle, needle stick problems
- SWE: is a chronic electrode
  - flexible electrode
- Electrode impedance is steady


Head-Mounted
32-Channel
Preamp/Multiplexer
MRI
Compatible
Electrode
Module
(1of4)
Quarter
for
Scale
Head-
Waist
Signal
Cable
POWER
PACK
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