Frequency, Voltage, and Morphology of Signals

Robertson Chapter 4

Introduction

Polysomnogram (PSG) means:

Poly = Many	Somno = Sleep	Gram = Writing or Recording

Term polysomnography 1st used in 1974 by Holland and colleagues

Analog PSGs have been replaced by digital PSGs

But need to understand analog to understand digital

Frequency and Duration

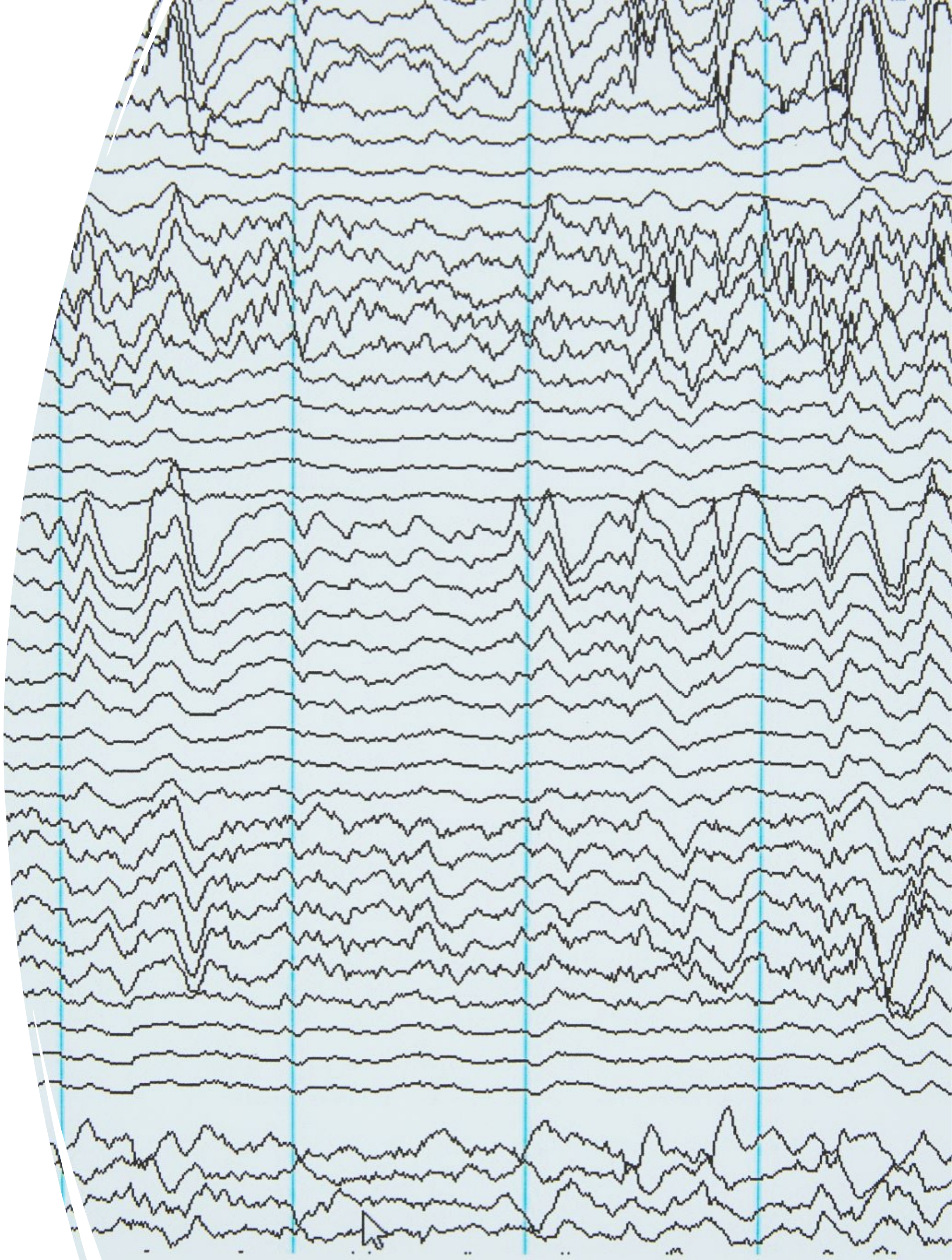
- Frequency = Number of events observed to occur within a particular period
- Duration = How long a particular event lasts
  - Measured in milliseconds, seconds, minutes, and hours
  - Measured from trough to trough along the x-axis (horizontally)

Frequency and Duration

- Average duration of one cycle of a spindle burst is 0.07 seconds
  - If frequency = 14 Hz, then take 1 ÷ 14 = 0.07 seconds
- Average frequency of a cycle with a 4 second duration is 0.25 Hz
  - If waveform duration = 4 seconds, then take 1 ÷ 4 = 0.25 Hz
- The accuracy of these calculations depend on the rhythmicity of the waves

Amplitude

- Vertical height of a waveform
  - Distance between most positive and most negative part of a wave
  - Index of voltage responsible for producing the deflection
- Negative signal = Upward deflection
- Positive signal = Downward deflection
- Electrical brain biopotentials are measured in microvolts (uV)

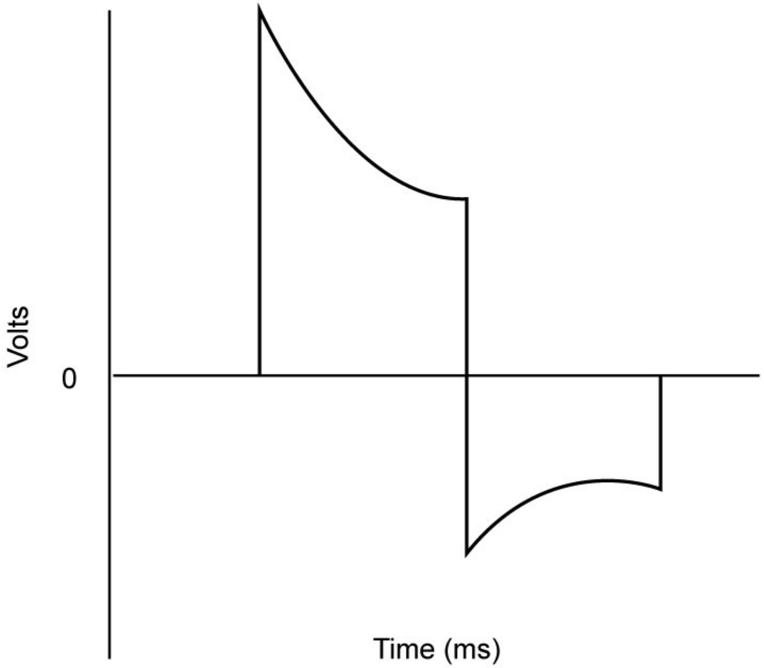


Morphology

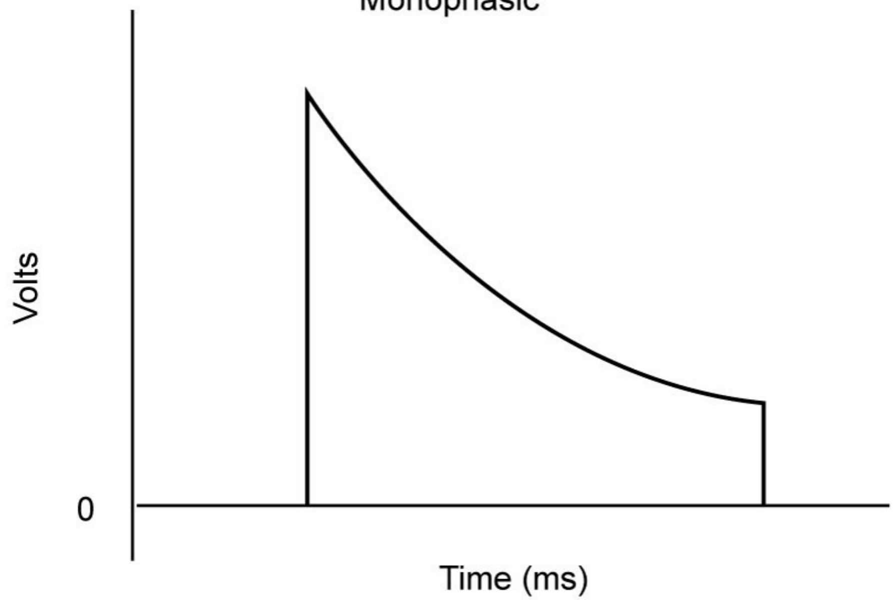
- Shape and number of phases that make up a waveform
- Waveform may be:
  - Sinusoidal (s-shaped)
    - Example: Sinusoidal spindle (12-14 Hz)
  - Irregular
  - Monophasic (one phase)
    - Example: Delta wave
  - Biphasic (two phases)
  - Triphasic (three phases)
  - Polyphasic (many phases)
    - Example: Low amplitude, mixed frequency EEG

Morphology

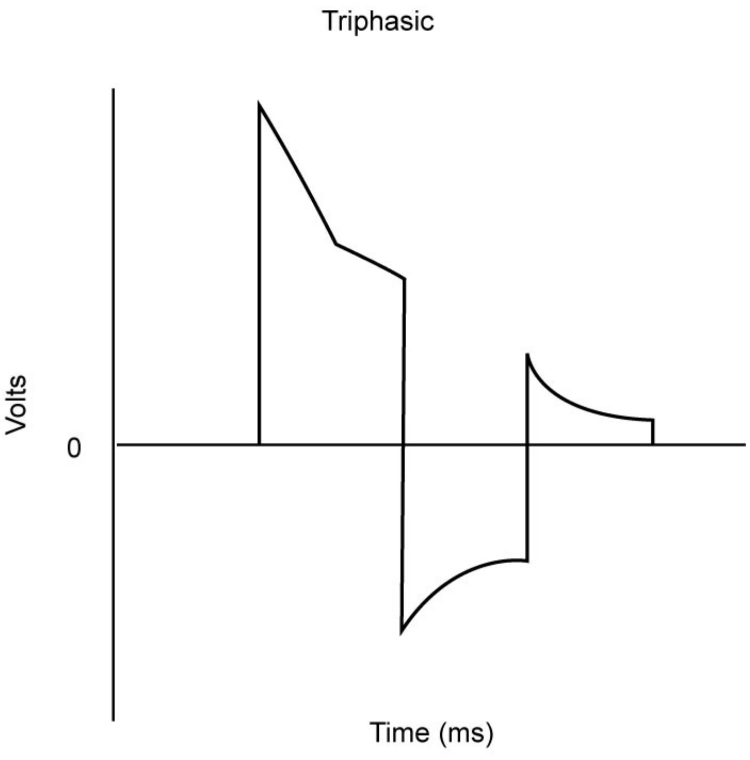
Biophasic

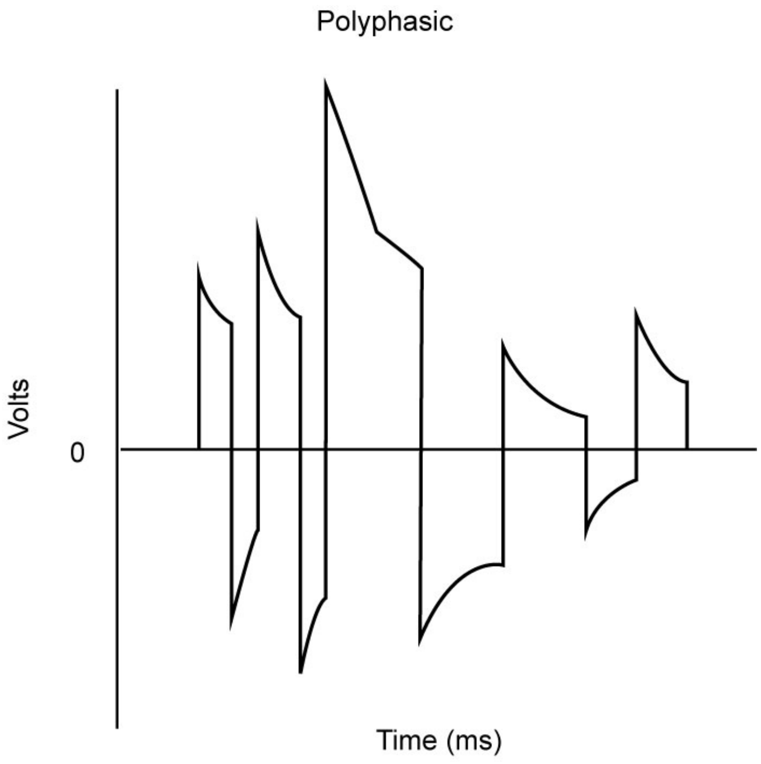


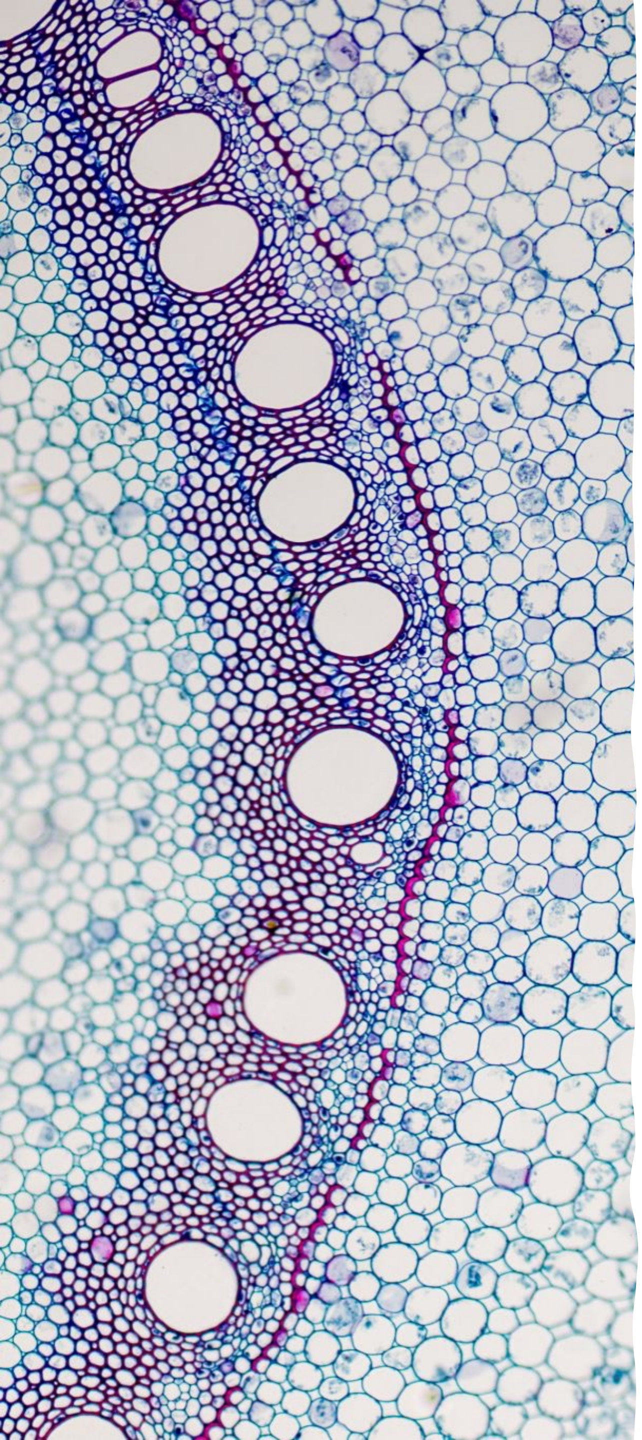
Monophasic



Morphology







Bioelectrical Signals

- Biopotentials = Electrical signals produced from living tissues
- Resting potential = Point when the amount of potassium leaving a cell is very close to the amount of potassium entering a cell
  - Depolarized when membrane is less negative than resting membrane potential
  - Hyperpolarized when membrane more negative than resting membrane potential

Bioelectrical Signals

- Graded potential = When a stimulus such as heat causes part of the membrane to change potential
  - Play important role in nerve activity
- Action potential = Occur when a stimulus leads to a rapid change in cell membrane potential
  - Cell membrane becomes hundreds of times more permeable to sodium ions (positive ions)

Polarity

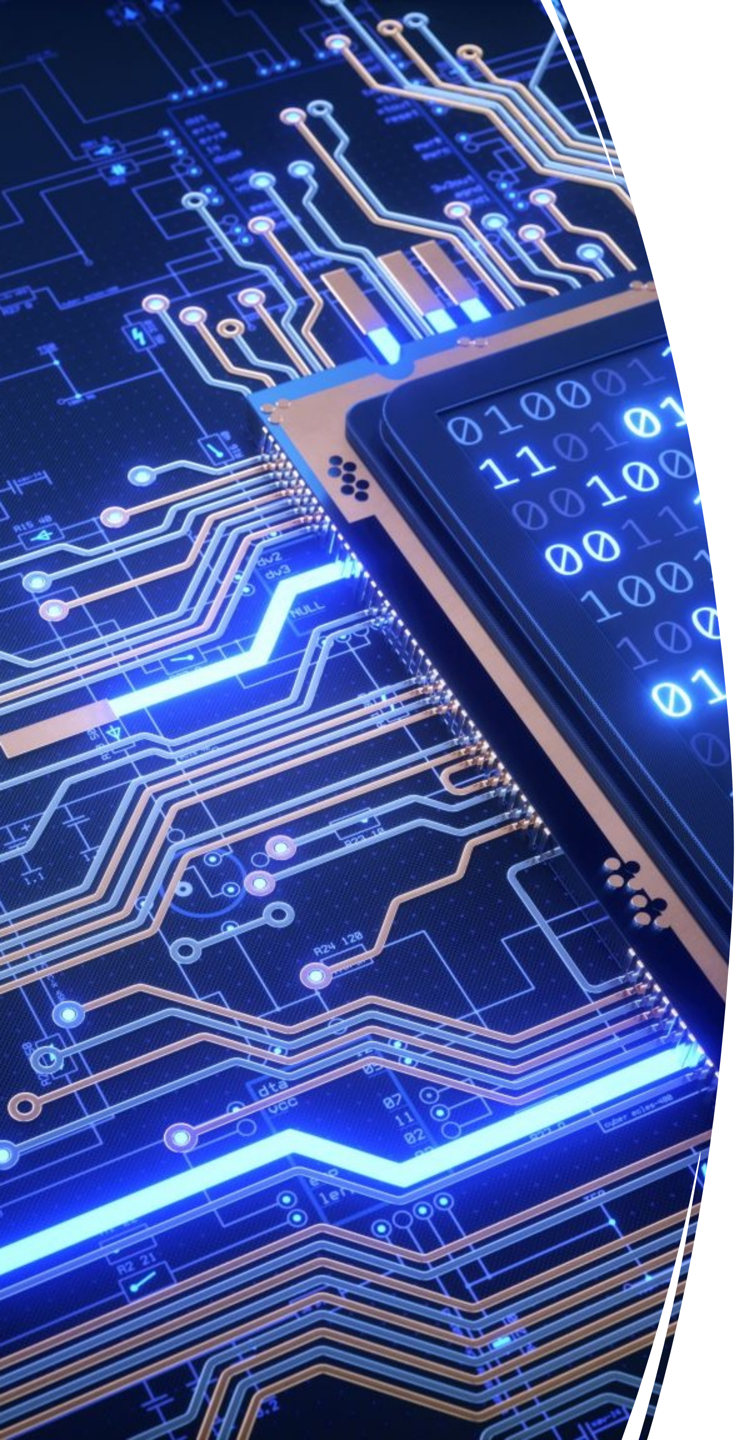
- Having oppositely charged poles (dipoles), one positive and one negative
  - Determines which direction a current flows
- Capacitance = Ability of body, or capacitor, to store a charge
- Inductance occurs as result of electromagnetic properties of AC electricity

Electrodes and Electrode Boards

- Electrode = Small device, typically constructed from highly conductive metal, which provides an interface between skin and amplifier through a small insulated wire (electrode lead or electrode wire)
- Must be careful with the handling of wires
- Conductive paste/gel reduces resistance between skin and electrode
  - Enhances electrode's ability to detect uV changes at skin surface
- Electrodes attached to patient and plugged into electrode board (head box) at bedside

Monitoring Devices

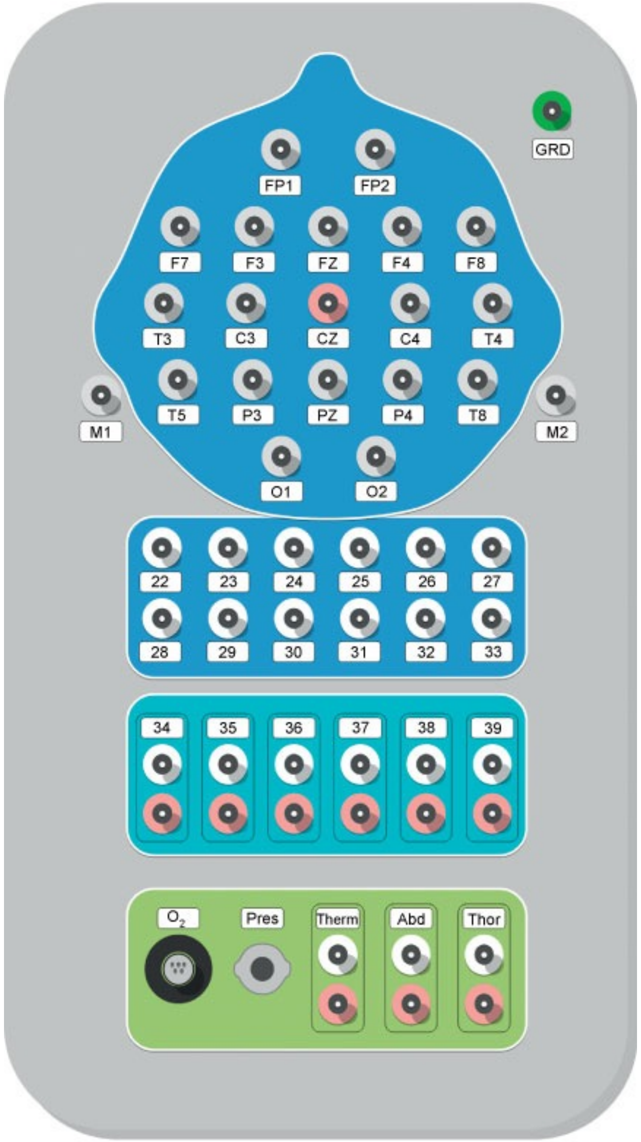
- Snap or Clip Electrodes
  - Used for EMGs and EKGs
  - Sticky patch placed on skin with conductive gel in middle
  - Electrodes snap to patch
- Cup Electrodes
  - Ideal for EEGs
  - Plated with highly conductive metal, usually gold



Data Acquisition Systems

- International nomenclature = System of organizing electrodes and associated equipment using anatomic locations
- Numerical nomenclature = System of numbers used to identify electrodes and associated equipment
- System reference electrode is typically Cz although Pz may be used
  - Backup reference is usually Fz or Pz

Data Acquisition Systems



Electrode Impedance

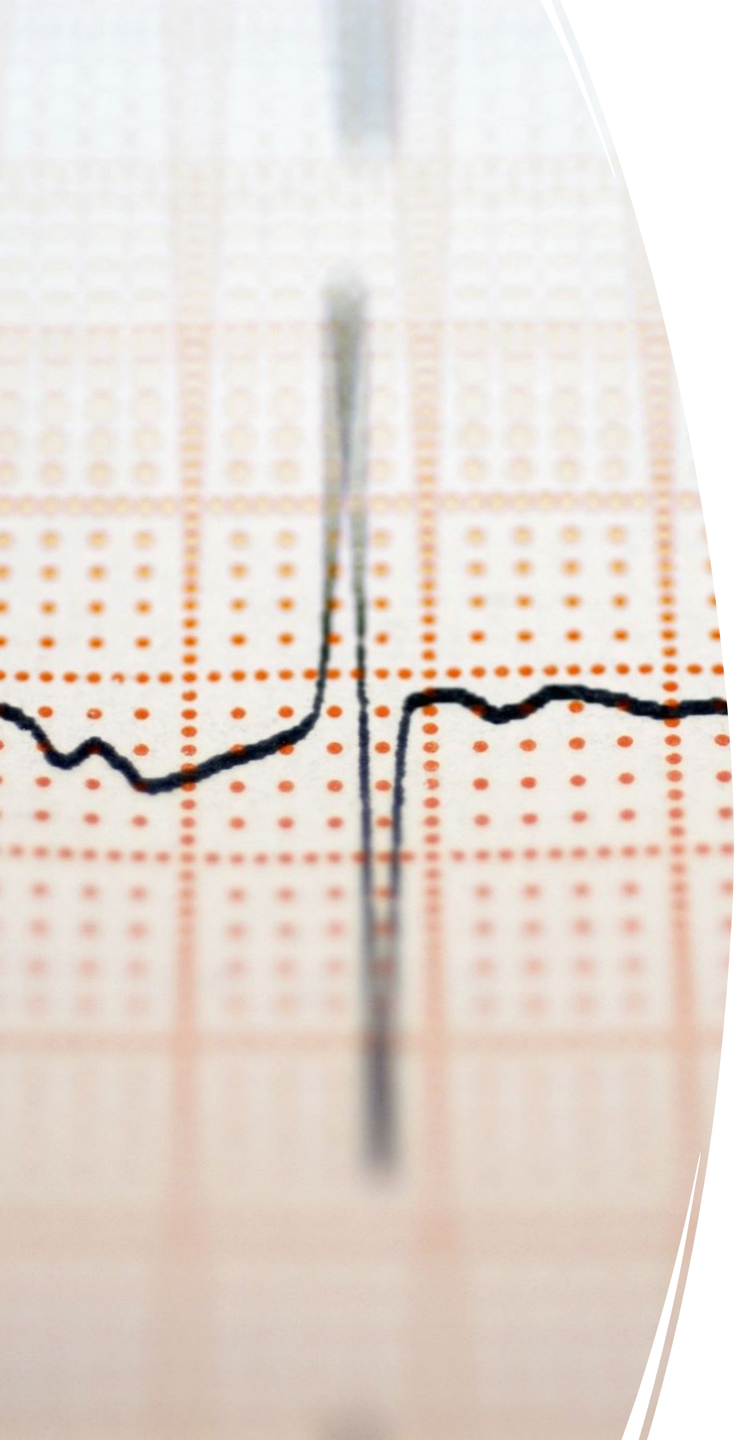
- Impedance meter measures resistance between electrode and scalp
- Impedance is combined measure of skin resistance, electrode resistance, electrode wire resistance, and resistance within input board
- Common Mode Rejection = Ability of a differential amplifier to minimize signals common at both inputs
  - Minimizes artifacts

Signal Pathways

- Electrical signal from patient's body
- Signal travels from skin to electrode
- Signal transmits from electrode through lead wire to head box
- Signal passes from head box to differential amplifier through shielded cable
- Differential amplifier subtracts reference signal and ground signal from original signal using Common Mode Rejection

Signal Pathways

- CMRR gives clean, accurate signal
  - Most EEG amplifiers have CMRR set to 5,000 to 10,000
- New signal sent to PSG for viewing via CAT-5
- Filters can be applied to ease viewing but should be used conservatively
- Maximum electrical leakage allowed is 100 uA



Recording Polarity

- 2 dedicated rows of inputs (grids): G1 and G2
- G2 subtracted from G1 to get the potential difference between 2 input signals
- To reverse polarity, reverse inputs or change it on the PSG software
  - Usually only have to do this for channels like EKG or respiratory

Amplifiers

- Differential amplifier retains difference between two input signals while subtracting components simultaneously common to both inputs
- Common amplifier controls include:
  - Gain/sensitivity – Adjusts amplitude/height of signal
  - Low-frequency filter (LFF) - Removes undesired slow frequencies
  - High-frequency filter (HFF) - Removes undesired fast frequencies

DC Amplifier

DC = When current is constant and flows in only one direction

- Either on or off
- DC devices: Pulse oximeter, capnograph

DC amplifier lacks LFF

- Does have HFF though
- No fall time constant exists

AC Amplifier

Polarity of AC electricity alternates at a constant frequency of 60 Hz in the US and 50 Hz in many other countries

AC amplifier has both LFF and HFF

AC channels include EEG, EOG, EMG, and EKG/ECG

Differential Amplifiers

- Amplifier that multiplies difference between 2 inputs by a common factor called differential gain
  - Records differences in voltages of 2 inputs to help eliminate unwanted signals
- G1 (Gate 1) = Exploring electrode
- G2 (Gate 2) = Reference electrode
- G1 – G2 = Output signal

Differential Amplifiers

If G1 = 10 uV and G2 = 5 uV, output would = 5 uV

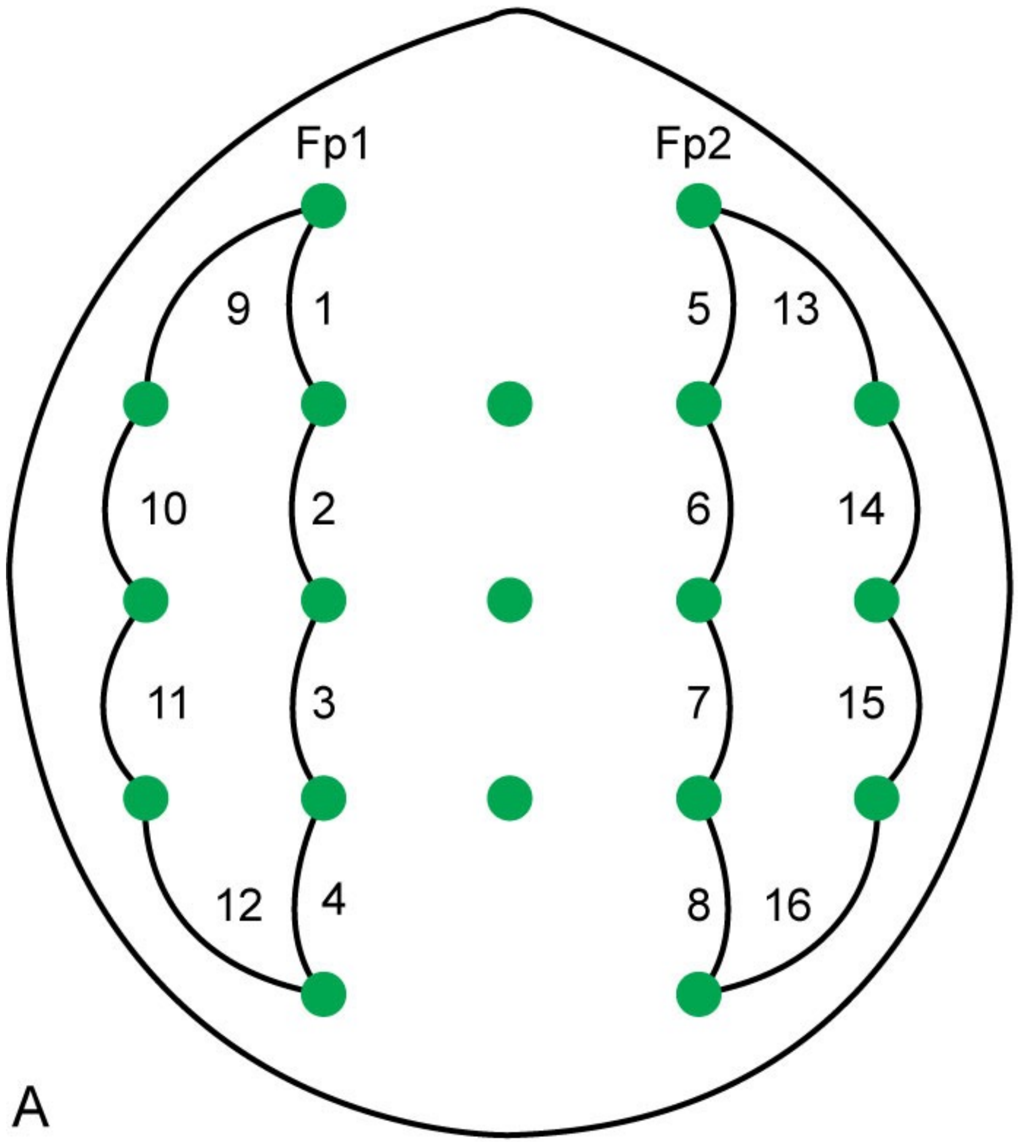
If O1 (G1) = 25 uV and M2 (G2) = 40 uV, output would = -15 uV

Frequency Response Curve = ability to eliminate unwanted signals through use of filters

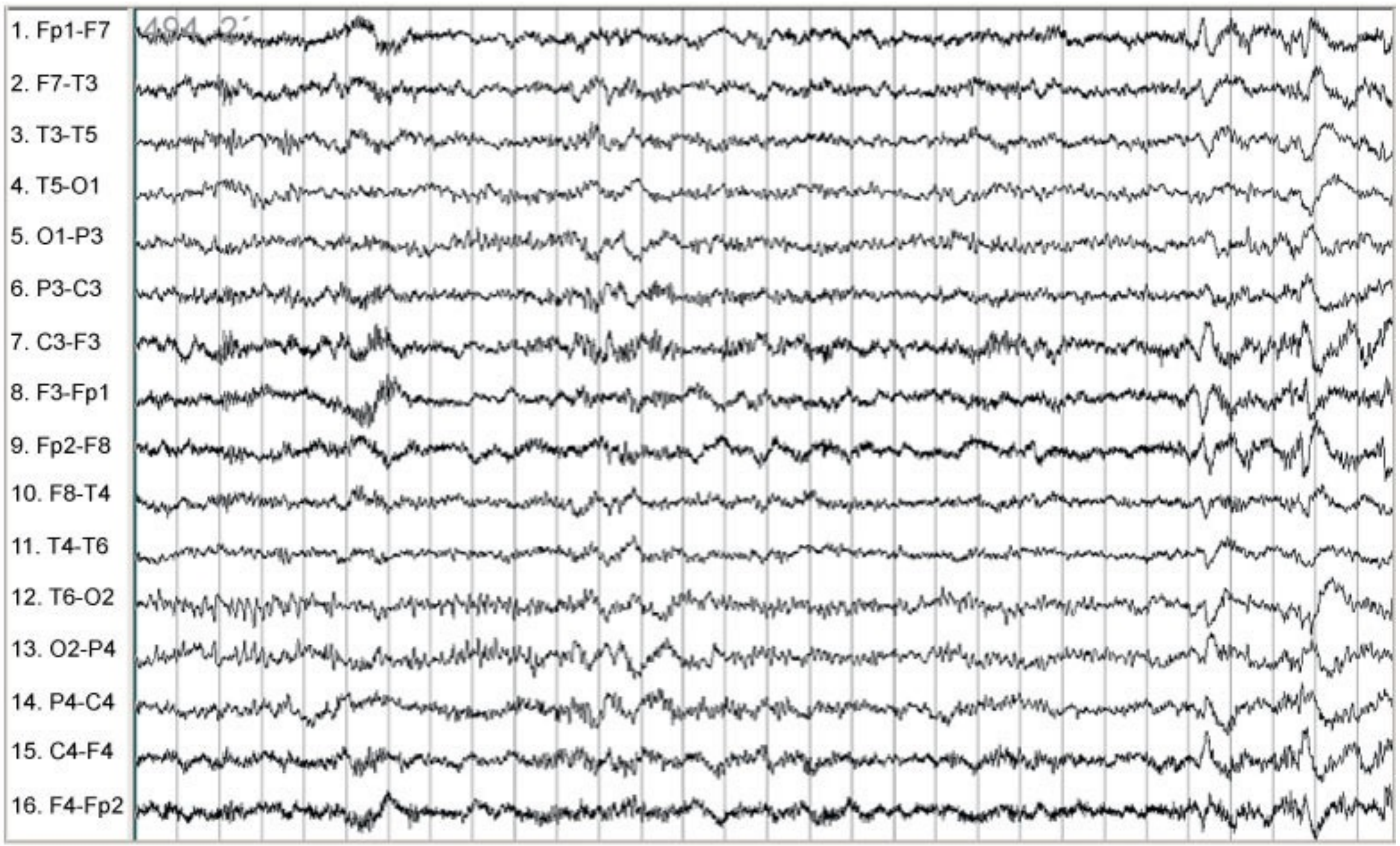
Montages

- Listing of derivations or recording channels
- Bipolar montage is made up of bipolar derivations that allow recording of data from electrically active recording sites on each channel
  - Used mainly in seizure/full EEG studies
- Referential montage
  - Utilizes referential derivations (M1, M2)
  - Most PSGs utilize this montage

Montages

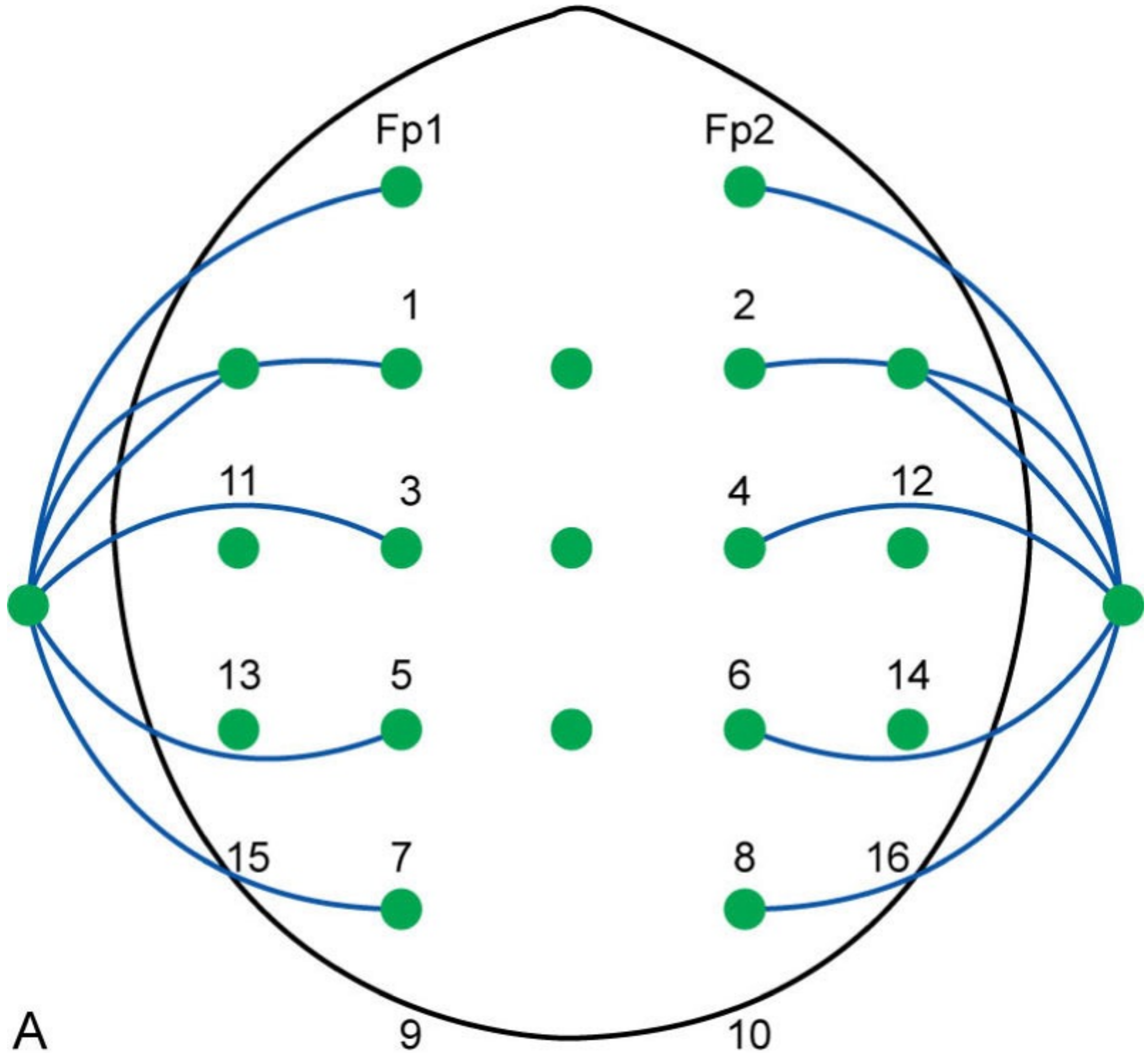


Montages

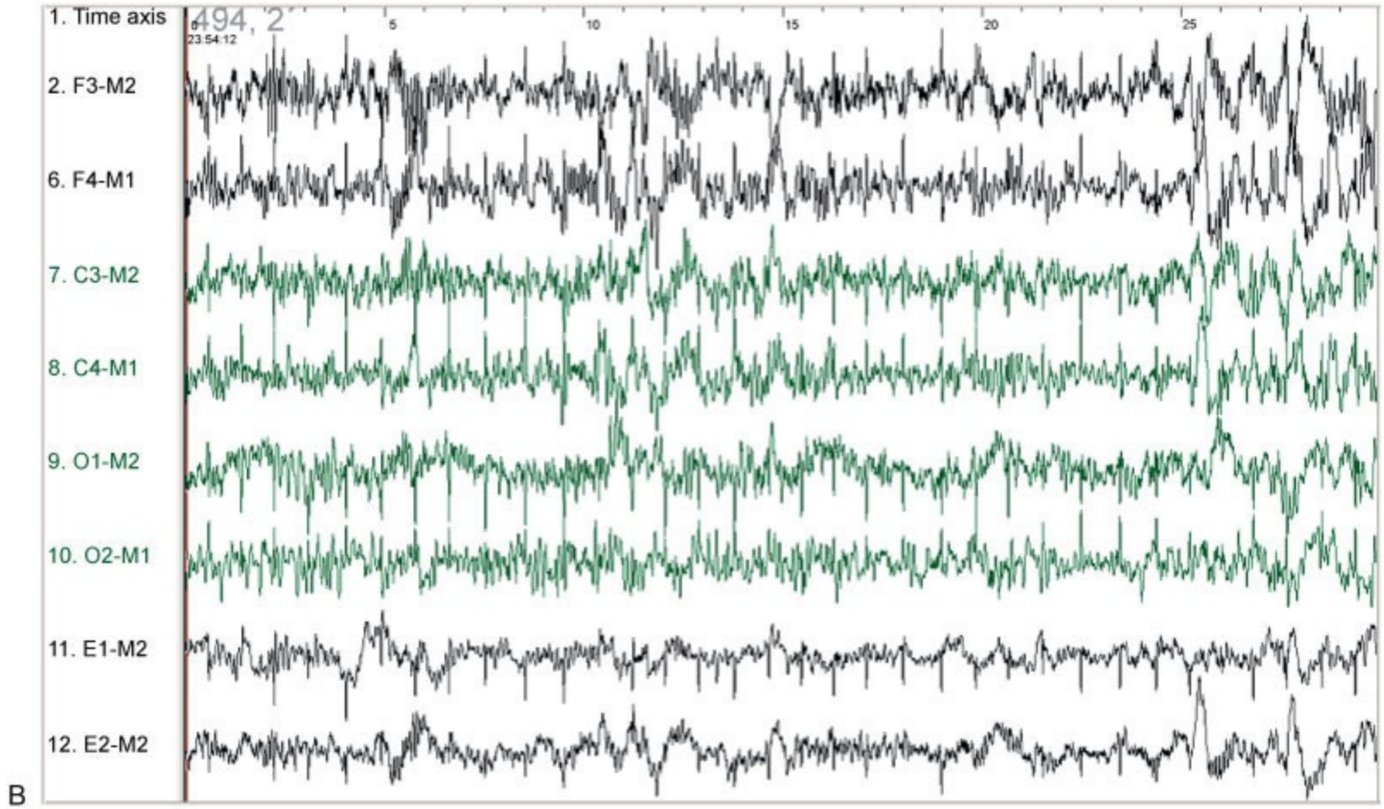

1. Fp1-F7
2. F7-T3
3. T3-T5
4. T5-O1
5. O1-P3
6. P3-C3
7. C3-F3
8. F3-Fp1
9. Fp2-F8
10. F8-T4
11. T4-T6
12. T6-O2
13. O2-P4
14. P4-C4
15. C4-F4
16. F4-Fp2

B

Montages

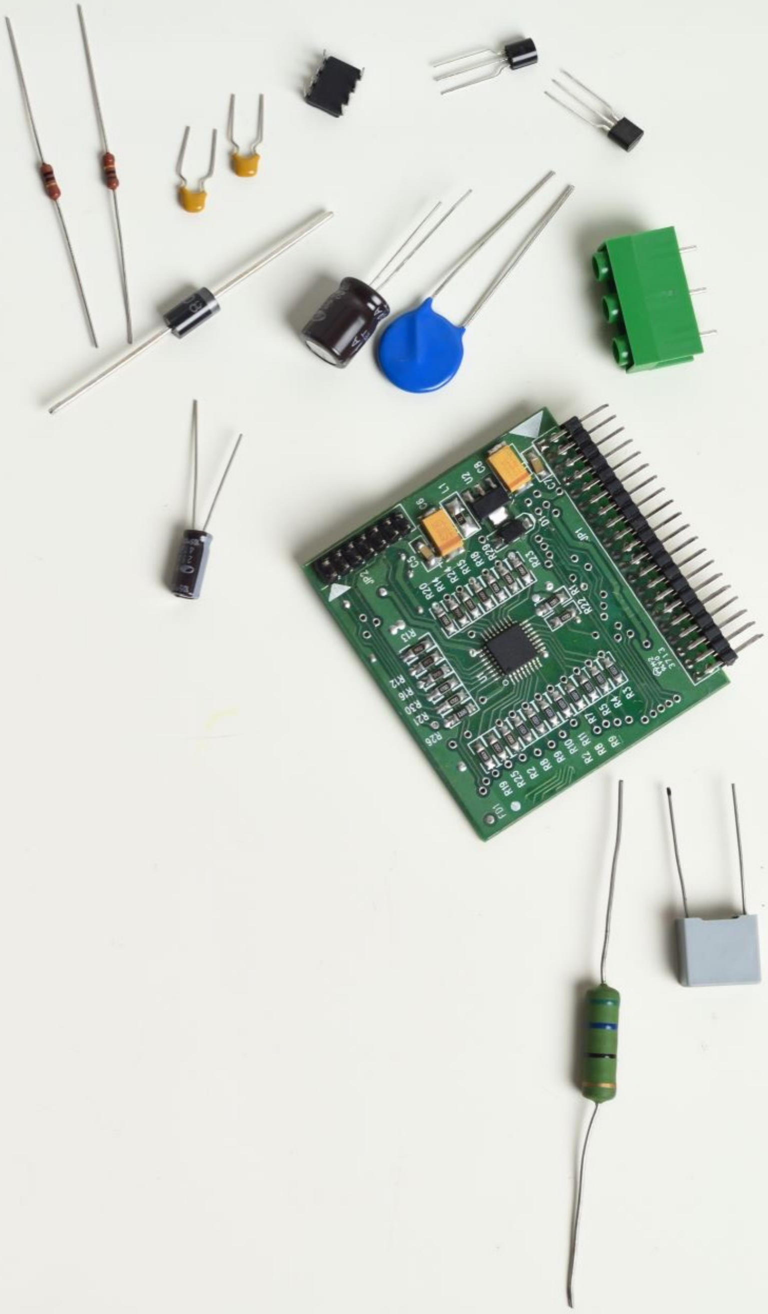


Montages


1. Time axis
494, 2
23:54:12
5
10
15
20
25
2. F3-M2
6. F4-M1
7. C3-M2
8. C4-M1
9. O1-M2
10. O2-M1
11. E1-M2
12. E2-M2
B

Data Recording

- Drawback to using a system reference electrode is what happens if the signal goes bad for that electrode
- Even though you can make adjustments during the viewing of a study, this is not a substitute for a clear study
    - Digital recordings are limited by GIGO (garbage-in-garbage-out)
    - Need to clean up artifacts
        - Filters only useful if underlying signal is intact

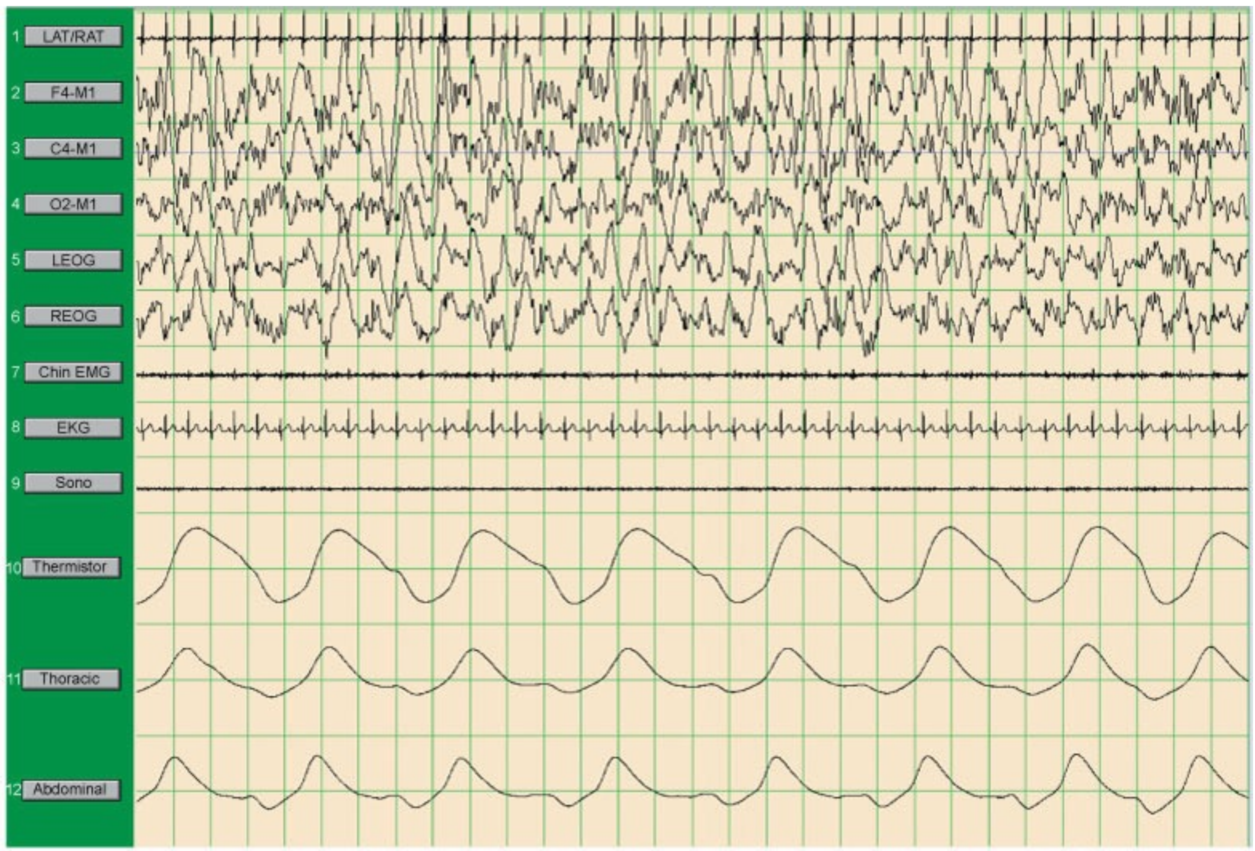


The Recorder

- Old systems used paper chart recorders
  - Paper speed was very well controlled
    - Analog paper speed = 10 mm/second
- Data can be viewed in 1 second, 10 seconds, 30 seconds, 1 minute, 2 minutes, 5 minutes, 1 hour, or the entire study
  - Changing the time base = Compressing or stretching data for viewing
- Digital systems more efficient but autoscoring not as accurate on difficult studies as human scoring

The Recorder

The Recorder



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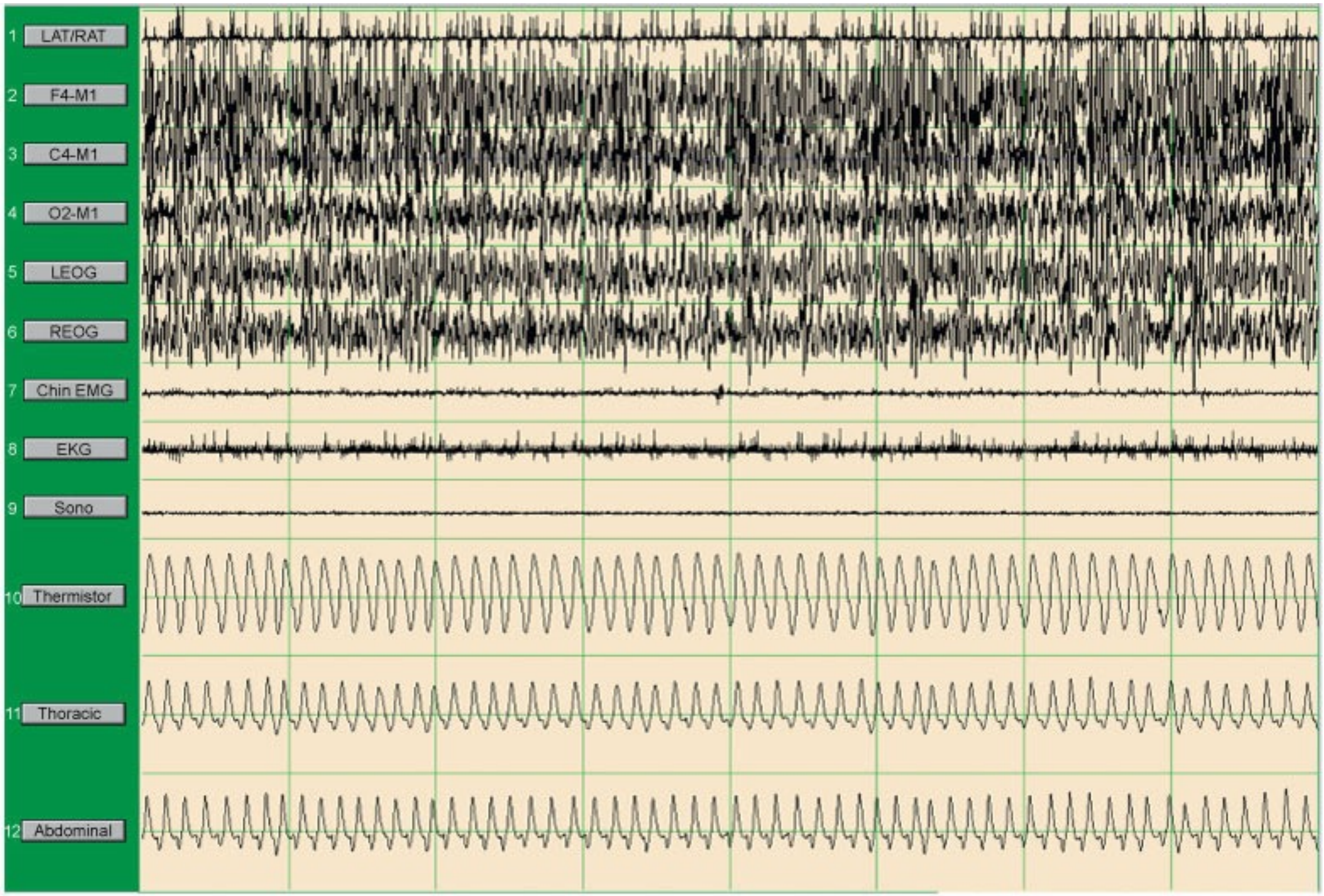
The Recorder



C

Referential Recording

- Not the same as referential montages
  - Referential montage = Way of displaying data
  - Referential recording = Method of acquiring data using digital recorder
- Data can be displayed in bipolar derivations, referential derivations, bipolar montages, or referential montages
- Data from each exploring and reference electrode is saved independent of other recording electrodes

Referential Recording

- Have a common or system reference electrode (Fz, Cz) in addition to each exploring and reference electrode
- Differential amplifiers perform first step in signal processing

Recommended Recording Parameters							
Physiologic parameter	Signal	Reference	High freq filter	Low freq filter	Sensitivity	Recommended storage rate	Acceptable storage rate
EEG	C_4	M_1	35 Hz	0.3 Hz	5 µV/mm	500 Hz	200 Hz
EEG	C_3	M_2	35 Hz	0.3 Hz	5 µV/mm	500 Hz	200 Hz
EEG	O_2	M_1	35 Hz	0.3 Hz	5 µV/mm	500 Hz	200 Hz
EEG	O_1	M_2	35 Hz	0.3 Hz	5 µV/mm	500 Hz	200 Hz
EEG	F_4	M_1	35 Hz	0.3 Hz	5 µV/mm	500 Hz	200 Hz
EEG	F_3	M_2	35 Hz	0.3 Hz	5 µV/mm	500 Hz	200 Hz
EOG	ROC (E_2)	M_1	35 Hz	0.3 Hz	5 µV/mm	500 Hz	200 Hz
EOG	LOC (E1)	M_2	35 Hz	0.3 Hz	5 µV/mm	500 Hz	200 Hz
ECG	Modified lead 2	Bi-polar	70Hz	0.3 Hz	Gain	500 Hz	200 Hz
EMG	Anterior tibialis	Bi-polar	100 Hz	10 Hz	Gain	500 Hz	200 Hz
EMG	Sub-mental chin	Bi-polar	100 Hz	10 Hz	Gain	500 Hz	200 Hz
EMG	Intercostal	Bi-polar	100 Hz	10 Hz	Gain	100 Hz	25 Hz
Airflow	Thermal sensor	Bi-polar	15 Hz	0.1 Hz	Gain	100 Hz	25 Hz
Airflow	Nasal pressure	DC	100 Hz	—	Gain	100 Hz	25 Hz
Snoring	Microphone or sensor	DC	100 Hz	10 Hz	Gain	500 Hz	200 Hz
Effort	Esophageal pressure	DC	100 Hz	25 Hz	Gain	100 Hz	25 Hz
Effort	Thoricic RIP	Bi-polar	15 Hz	0.1 Hz	Gain	100 Hz	25 Hz
Effort	Abdominal RIP	Bi-polar	15 Hz	0.1 Hz	Gain	100 Hz	25 Hz
Position	Position sensor	Bi-polar	See mfg spec	—	Gain	1 Hz	1 Hz
Oximetry	SpO2	DC	15	—	Gain	25 Hz	10 Hz

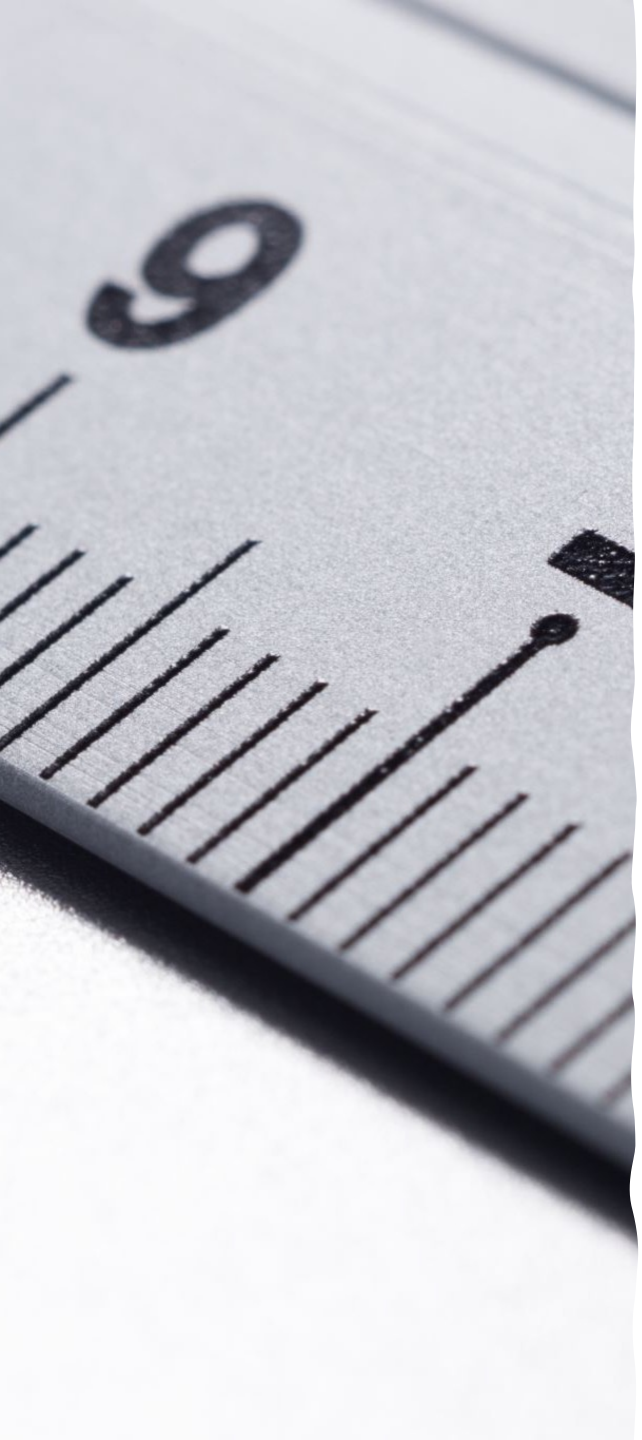
Data from Berry R, Brooks R, Gamaldo C, Harding S, Marcus C, Vaughn B: The AASM Manual for the Scoring of Sleep and Associated Events, *V2.0, Darien, Ill, 2012, American Academy of Sleep Medicine.*

Annotation and Documentation

- Note study conditions, patient actions, and anything relevant to testing
  - Real-time annotation
- Annotations are part of medical record
  - Helpful in reviewing record as they point out specific events

Signal Sampling

- Sampling rate = Fixed rate
  - Determined by taking the highest frequency of the data and doubling it
- Aliases = Distortions of lower frequency signals
  - Not part of original signal
  - Aliasing is less likely the more sampling is increased above minimum rate
    - But increasing sampling rate takes up more recorder storage space



Sensitivity and Gain

- Sensitivity increases or decreases amplitude of recorded data
  - Ratio of input voltage to output deflection
    - Sensitivity = Voltage ÷ Pen deflection
    - Example: If Voltage = 75 uV and sensitivity = 10 uV/cm, pen deflection will = 7.5 cm or 75 mm
    - Ratio typically 5 uV : 1 mm
      - 5 uV of input required to generate 1 mm deflection
- Gain = Ratio of output deflection to input voltage

Common Mode Rejection

- Common mode signal = When artifact is superimposed on both inputs of a recording channel
- Common mode rejection eliminates like components of an artifact signal to both inputs
  - Most effective when the electrodes of both inputs share low and fairly equal impedances

Common Mode Rejection

- Common mode rejection ratio (CMRR) = Differential gain ÷ common mode gain
  - The higher the CMRR, the more efficient the amplifier and less common mode signal reaches the output
    - Minimizes artifact
  - Not having a patient ground can reduce the effectiveness of common mode rejection
    - Ground electrode creates universal reference for all scalp potentials

Amplifier Filters

Frequency can be determined by counting # of waveforms recorded during 1 second

Adjusted using filters

Low frequency filter (LFF)

Also known as high-pass filter

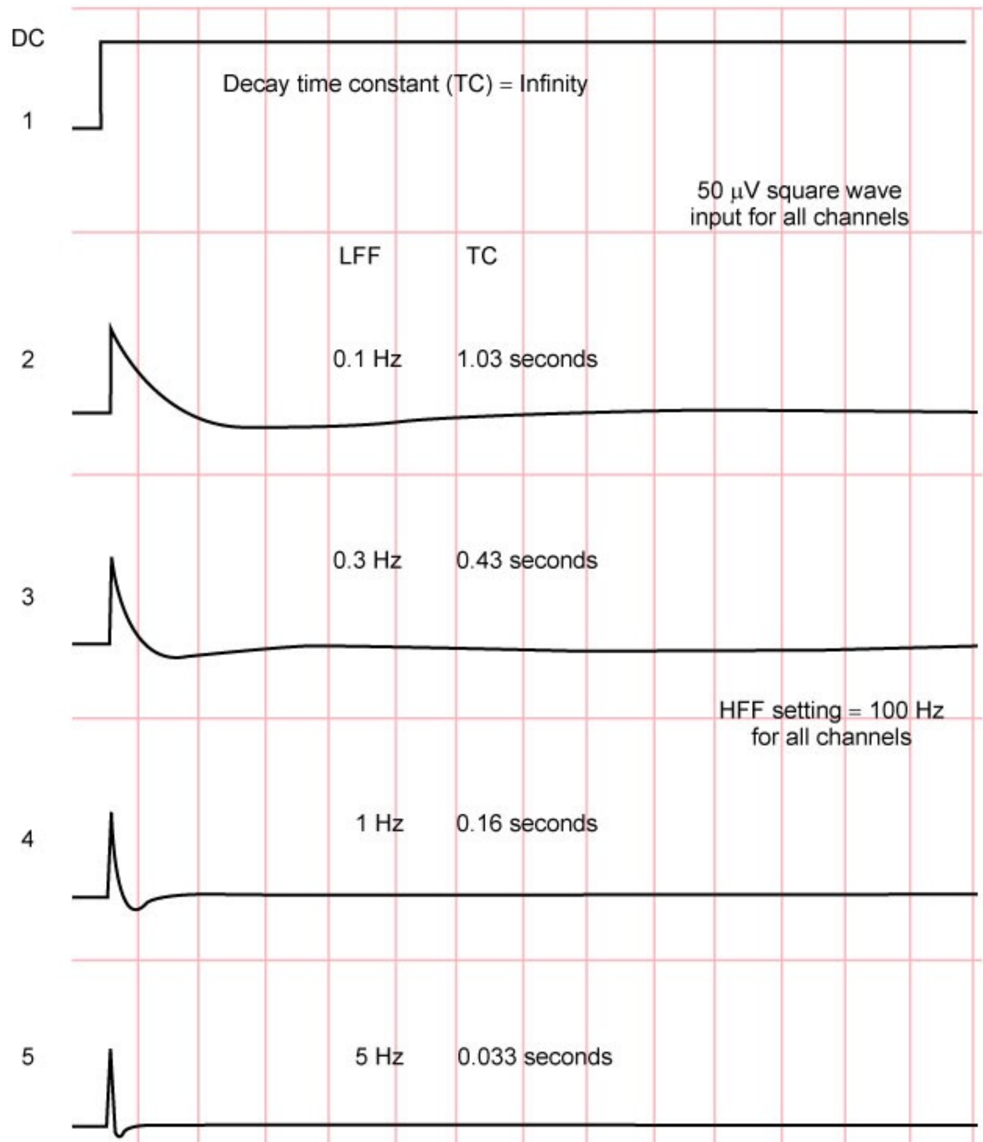
Attenuates signals below the filter setting and preserves those above it

- Remove slow waves
- Helpful with sweat artifact and respiratory artifact

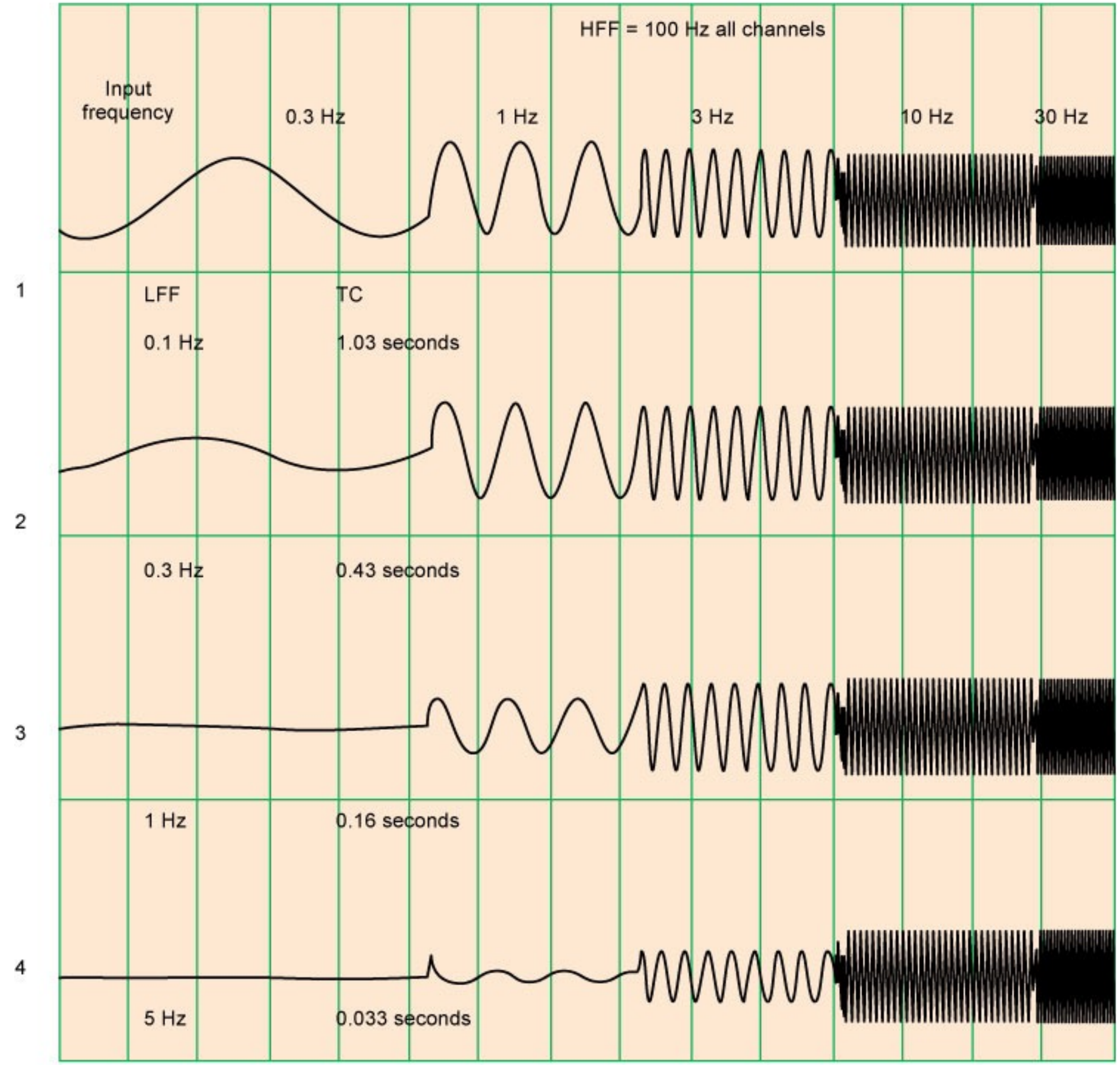
Amplifier Filters

- Decay Time Constant (TC)
  - Also known as fall TC
  - Time it takes, in seconds, for a square wave to fall to 37% of its original amplitude
  - LFF and decay TC used for same purpose
  - The shorter the TC, the more slow frequencies will be attenuated
    - Can affect how much N3 sleep can be scored
  - A higher LFF corresponds to a shorter TC

The Effect of Various LFF Settings on a DC Square Wave



The Effect of LFF Settings on a Sine Wave Signal



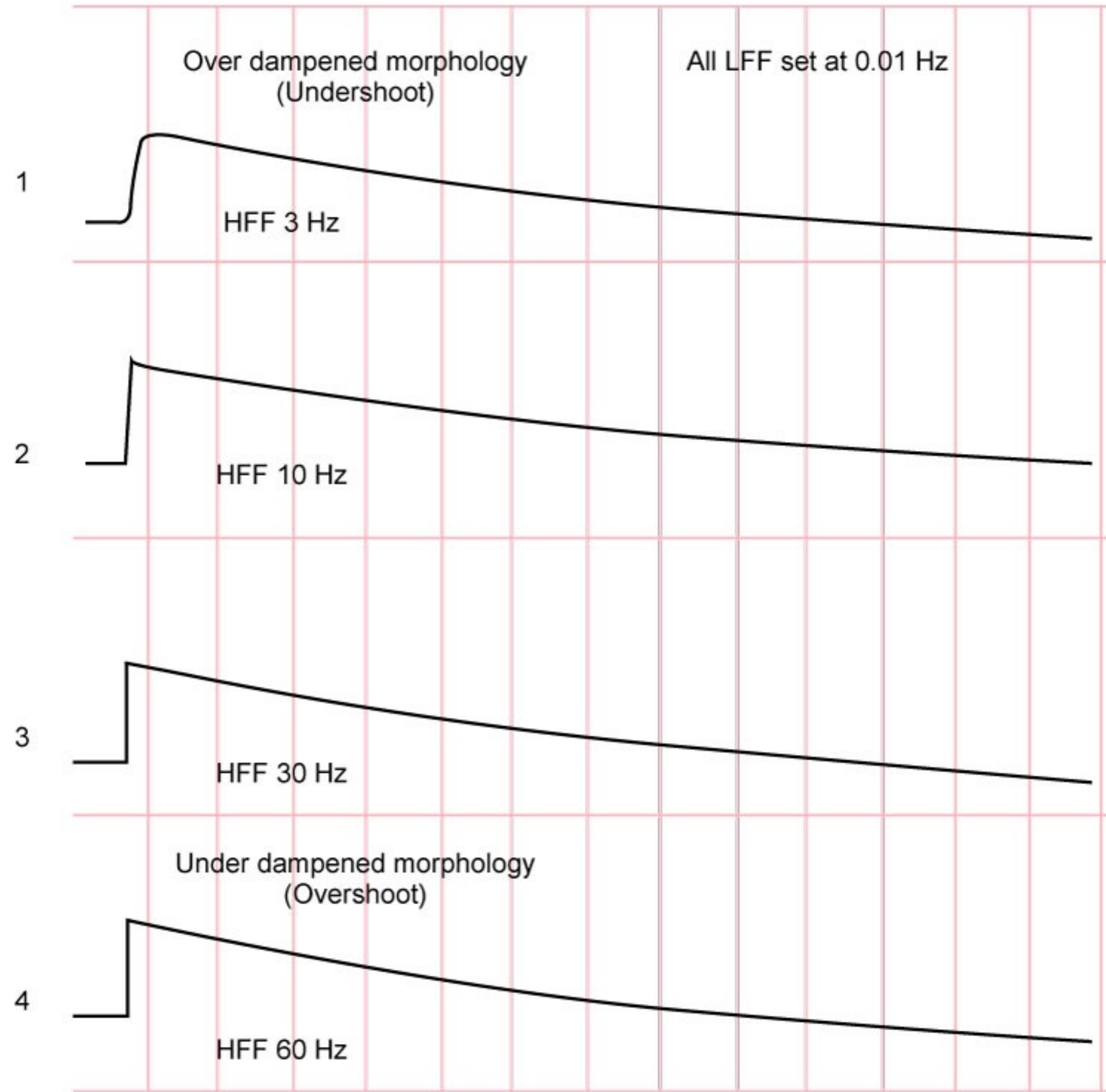
Amplifier Filters

- High frequency filter (HFF)
  - Also known as a low-pass filter
  - Attenuates signals with a frequency approaching, meeting, and surpassing the cut-off frequency
    - Eliminates fast frequencies
  - AASM recommendation is 35 Hz for EEG
    - But this may attenuate things like seizure spikes
  - Not good to reduce HFF in response to artifact
    - Better to reapply electrodes
    - Changing filters should not be first line of resolution

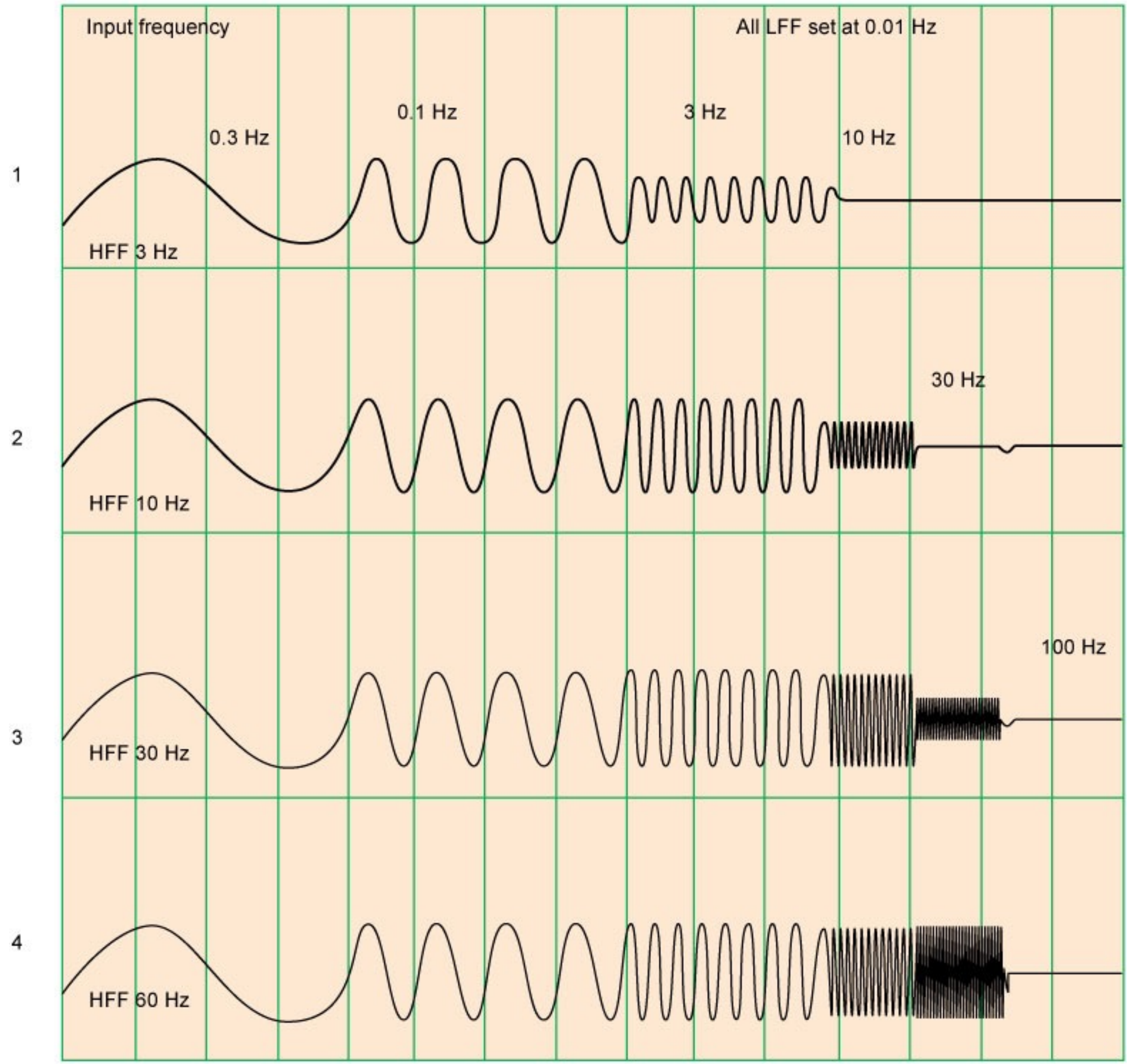
Amplifier Filters

- High frequency filter (HFF)
  - Imposes a rise TC on the recording
    - Rise TC = Time it takes for the signal to attain 63% of its peak amplitude
  - Higher HFF allows fast signals to pass and results in more peaked output
  - Lower HFF attenuates fast signals and results in a more dampened or rounded output

The Effect of HFF Settings on a Square Wave



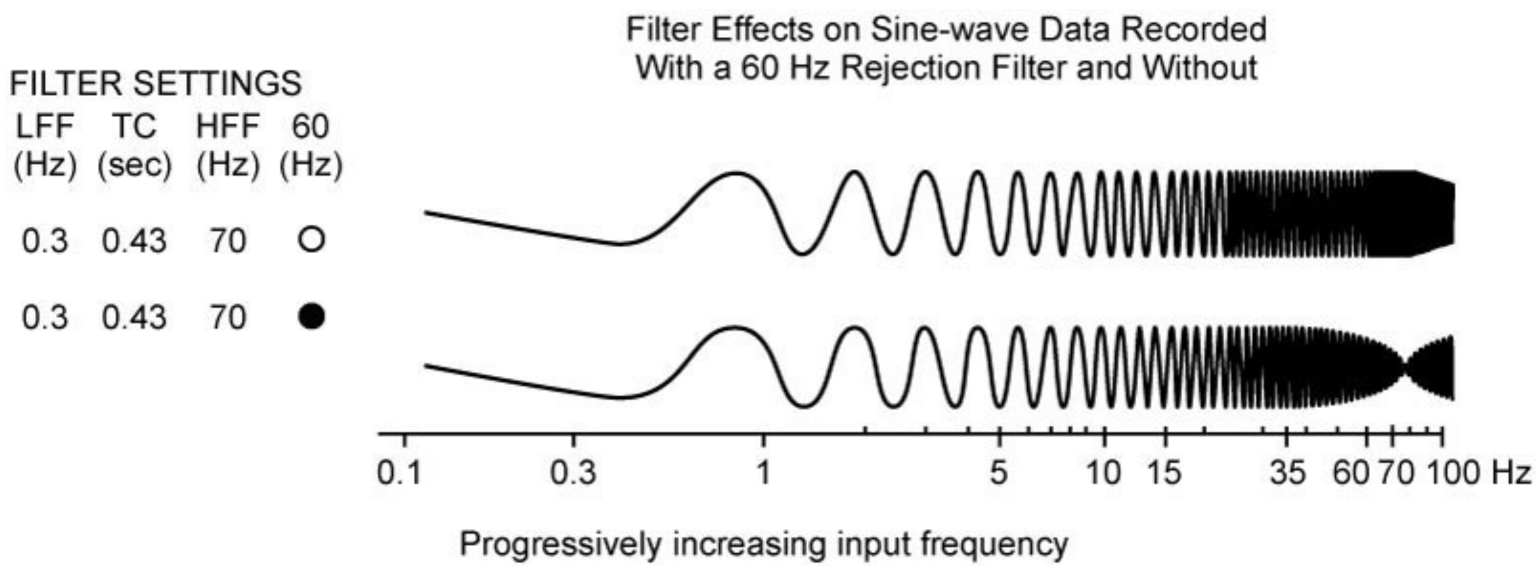
HFF Attenuation of Fast Input Frequencies



Amplifier Filters

- 60-Hz Filter
  - Also known as a notch filter
  - Attenuates frequencies of 58-62 Hz
  - Should only be employed when necessary
    - Tech needs to be proficient at troubleshooting rather than just applying a filter to distort the data

Amplifier Filters



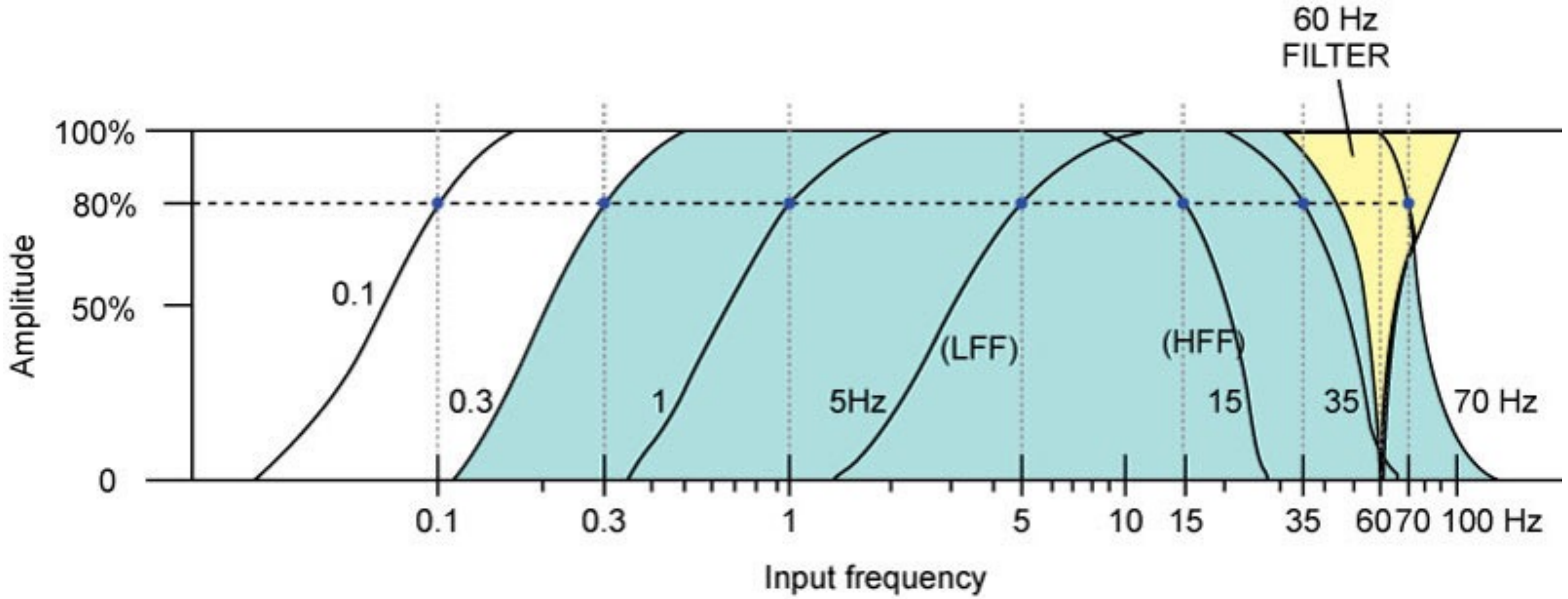
Amplifier Filters

- Digital filtering
  - Allows you to change filters during scoring
  - 3 types of digital filters:
    - Finite impulse response (FIR)
      - Most PSG systems use this
    - Infinite impulse response
    - Fast Fourier transform

Amplifier Filters

- Frequency Response
  - Cutoff frequency = Frequency at which the output declines to 80% of original amplitude (3 dB point)
  - Frequency response curve provides an estimation of signal attenuation for a variety of amplifier settings when the frequency of the input signal is known or can be measured
  - As input frequency decreases, at some frequency above LFF its amplitude will begin being attenuated for output less than 100% but greater than 80% of the original

Amplifier Filters



Filters

- AASM Recommendations
  - EEG/EOG filters:
    - LFF = 0.3 Hz
    - HFF = 35 Hz
  - EMG filters:
    - LFF = 10 Hz
    - HFF = 100 Hz

Additional Testing Equipment Parameters

- Transduced signals
  - Includes respiratory effort, pressure
  - Records mechanical functions
  - Transducer = Device that converts one form of energy into another
    - For PSG, converts mechanical signal into electrical signal
    - Thermal sensors detect temperature changes, resulting in a difference in voltage traveling through conductors to PSG
    - Nasal pressure is derived from pressure changes on the opening of the cannula
      - Cannula is attached to pressure transducer that turns those pressure changes into an electrical signal

Additional Testing Equipment Parameters

- Transduced signals
    - Esophageal manometry detects intrathoracic pressure exerted on the esophagus through a cannula placed in esophagus
        - Pressure transducer converts pressure to signal
    - RIP belts and piezoelectric belts transduce movement or pressure into an electrical signal
- Ancillary equipment
    - Include oximeters, capnographs, and PAP devices

Additional Testing Equipment Parameters

- The PSG
  - Sleep studies are broken down into 30-second epochs which are assigned a sleep stage
    - Also must identify, quantify, and tabulate EEG arousals, SDB events, and EMG changes
      - Data organized into report for sleep medicine physician
  - Required paper speed is 10 mm/sec

Additional Testing Equipment Parameters

- Viewing the study
  - Screen resolution for scoring raw data must be a minimum of 1600 x 1200 pixels
  - Video must be synched with PSG
  - Vertical spacing between channels = 15 mm
  - Digital systems must provide montage-changing controls without relying on a common reference electrode
  - 60 Hz filter and impedance meter for each channel are mandatory
  - Must be able to manually score data

Additional Testing Equipment Parameters

- Data storage
  - Paper studies would take up a 17 lb box for an 8 hour study
  - Sleep studies are medical-legal records
    - Should be archived according to state, federal, and accrediting body regulations

Recorded Data

EEG

Biopotentials from the brain as recorded at scalp’s surface

EOG

Retina at back of eye is negative with respect to cornea at front of eye

As eyes move, the potential difference between EOG electrodes is based on placement in relation to retina and cornea

If cornea is closer to electrode, a positive (downward) deflection recorded

If retina is closer to electrode, a negative (upward) deflection recorded

Recorded Data

Chin EMG

Muscle tone in the submentalis decreases as patient falls asleep

- At lowest during REM sleep

Limb EMG

Recorded from anterior tibialis muscles on legs

Electrodes placed 2-3 cm apart longitudinally

Used to detect PLMs