EEG Anaesthesia Monitor

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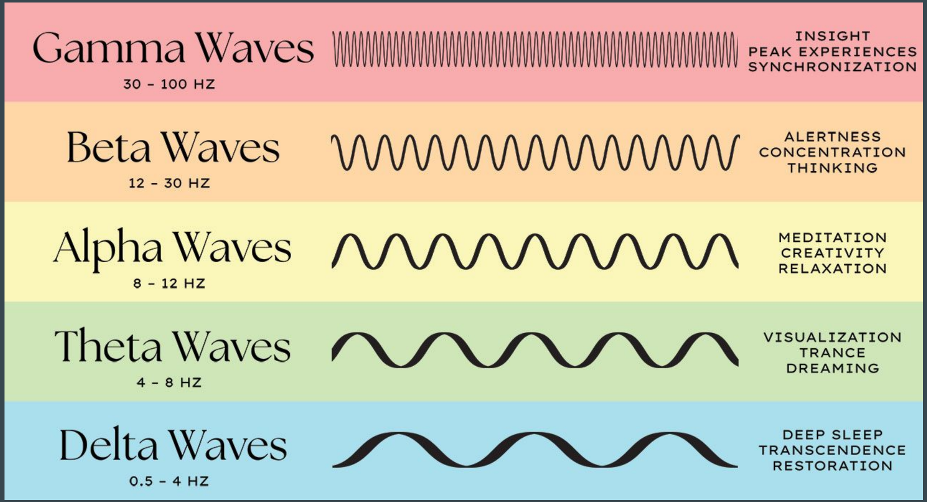
Motivations & Goals

- Improve non-invasive anaesthetic monitoring for surgical procedures
- Improve post-operative outcomes by reducing risk of infection
- Decrease long term cost of anaesthetic delivery by reducing single-use needle usage

GOAL: Create EEG monitor to process electrical activity in the brain and analyze level of sedation in clinical anaesthetic practices with the goal of providing better surgical patient care and minimize risks associated with over or under sedation

Background

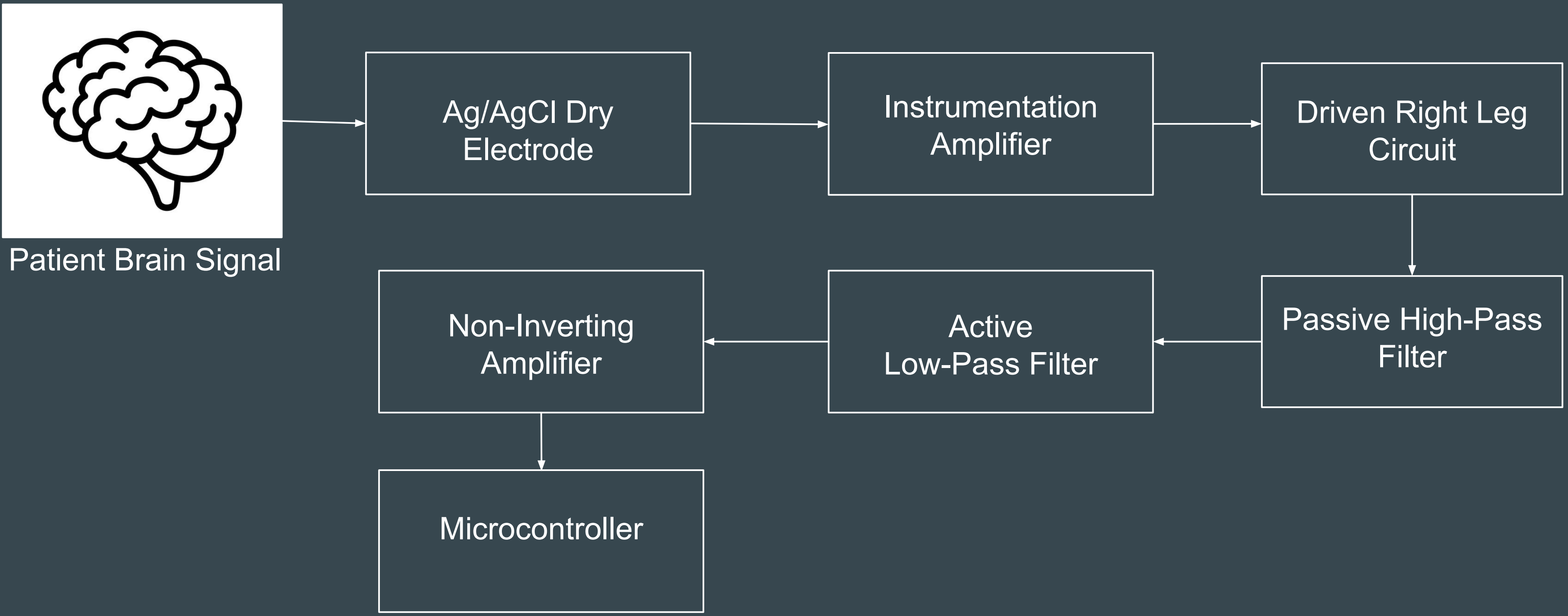
- Anaesthetic agents are used to prevent pain during procedures and surgeries by slowing ion channel actions
- Electroencephalography (EEG) is a device that detects the electrical activity of the brain and any abnormalities that may be present
- EEG Signal Waves:



Background

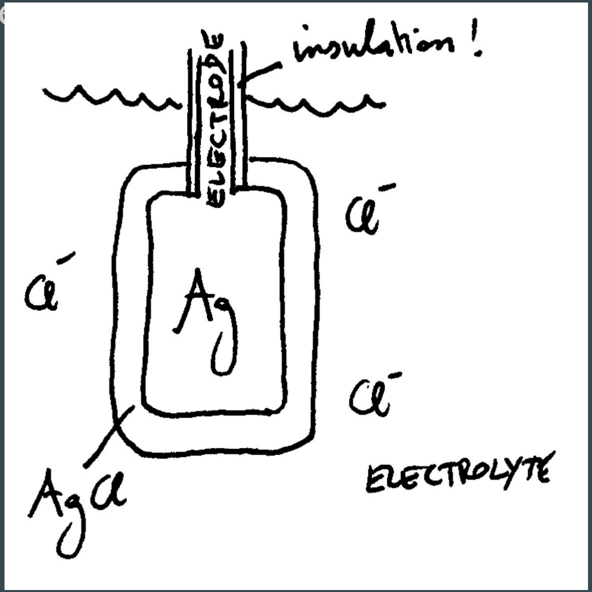
- EEG can be used to assess the level of sedation on the patient provided by the anaesthetic
- EEG Frequency bands change when anaesthetised
  - Delta waves (0.5Hz to 4Hz): voltage **increases** under anesthesia
  - Theta waves (4Hz to 8Hz): voltage **decreases** under anaesthesia
  - Alpha waves (8Hz to 12Hz): voltage **decreases** under anaesthesia
  - Beta waves (12Hz to 30Hz): voltage **decreases** under anaesthesia
- As the anaesthetic agent wears off the delta waves decrease in magnitude while the other increase in magnitude
  - This can be used to create a device that regulates anesthesia levels in a patient

Block Diagram



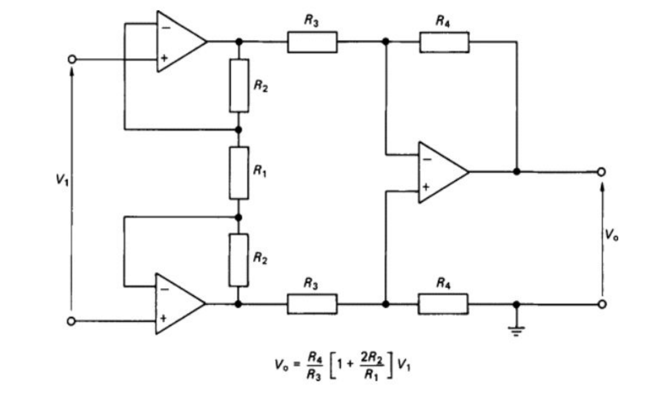
Circuit Components - Dry Electrode

- **Ag/AgCl electrodes** measure voltage (electrical potential) on the scalp (10-100 uV for EEG)
    - Useful for long term monitoring
    - Works even with slight movement
    - Has low impedance



Circuit Components - Instrumental Amplifier (AD624)

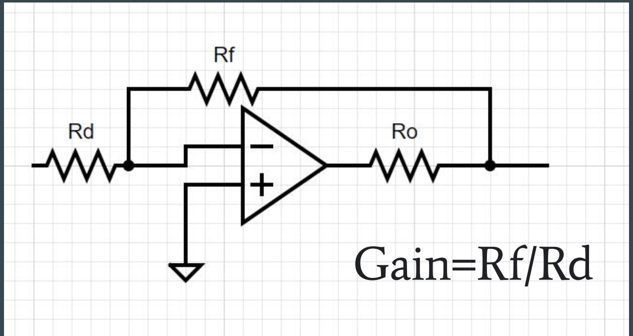
- Amplified with an **instrumental amplifier** with a gain of ~1000 (for microcontroller)
  - Chosen over a regular non-inverting op-amp due to:
    - higher input impedance
    - differential amplification
    - better CMRR, adjustable gain
    - low drift/stability



R1 = 10 kΩ
R2 = 500 kΩ
R3 = 10 kΩ
R4 = 100 kΩ
G = R4/R3 * (1 + 2R2/R1) = 1010

Circuit Components - DRL

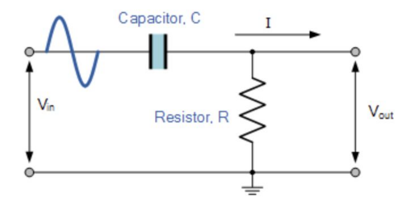
- Connected to **driven right leg circuit** with a gain of 160
  - Provides a feedback loop for noise, effectively reducing system noise and interference
  - Improves patient safety.



Rf = 800 kΩ
Rd = 5 kΩ
Ro = 5 kΩ
Gain = Rf/Rd = 160

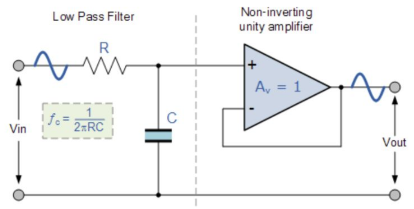
Circuit Components - Cascading Filters

- Passive High-Pass Filter
  - attenuate signals below the minimum frequency
- Active Low Pass Filters
  - attenuates signals above the maximum frequency and amplifies the output signal
- Cascading them effectively creates a band pass filter that can be used to isolate each wave



Passive High Pass Filter

A High Pass Filter is the exact opposite to the low pass filter circuit as the two components have been interchanged with the filters output signal now being taken from across the resistor



Active Low Pass Filter

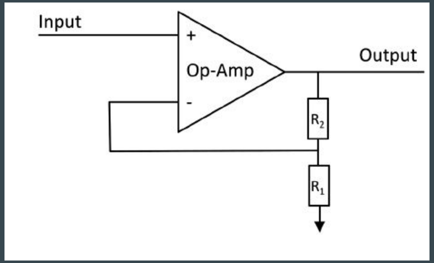
By combining a basic RC Low Pass Filter circuit with an operational amplifier we can create an Active Low Pass Filter circuit complete with amplification

Active High Pass Frequency= 1/2πRC @each frequency within EEG signal , 4 Hz (R13=400 kΩ, C2=100 nF), 8 Hz (R16=200kΩ, C4=100nF), 12 Hz (R25=130 kΩ, C6=100 nF), 30 Hz (R28=500 kΩ, C8=10 nF)

Passive Cutoff Frequency= 1/2πRC @each frequency within EEG signal , 0 Hz (R12=100kΩ, C1=1μF) , 12 Hz (R27=125 kΩ, C7=100nF), 30 Hz (R18=50 kΩ, C5=100nF), and 50 Hz (R18=32.5 kΩ, C3=100nF)

Circuit Components - Non Inverting Op Amp

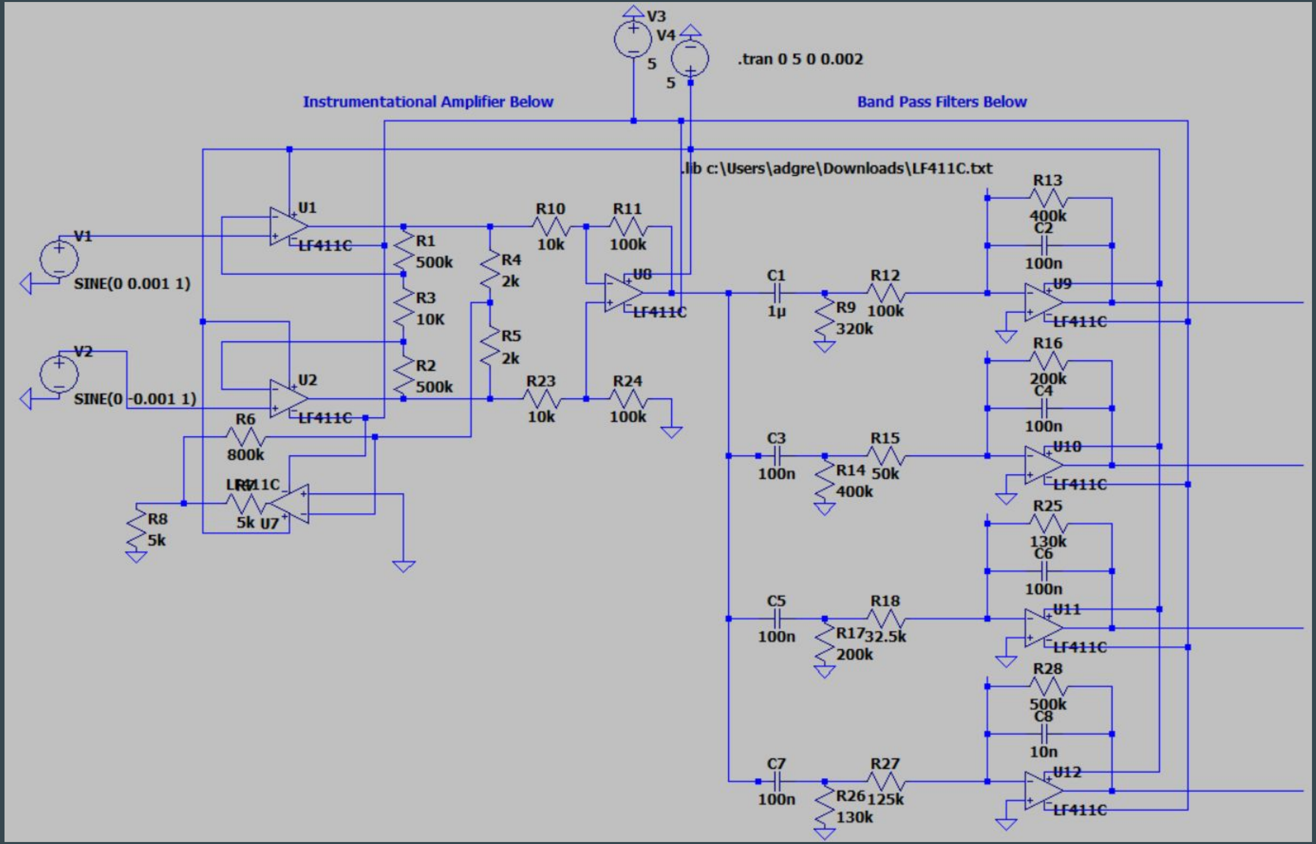
- Each filtered signal is amplified with **non-inverting op-amp** with gain of ~50 for total gain of ~10,000 for output to ADC (in microcontroller)
  - an overall gain of ~10,000 converts signals in the 10-100 uV range to 1 V which is more suitable for analog-to-digital conversion



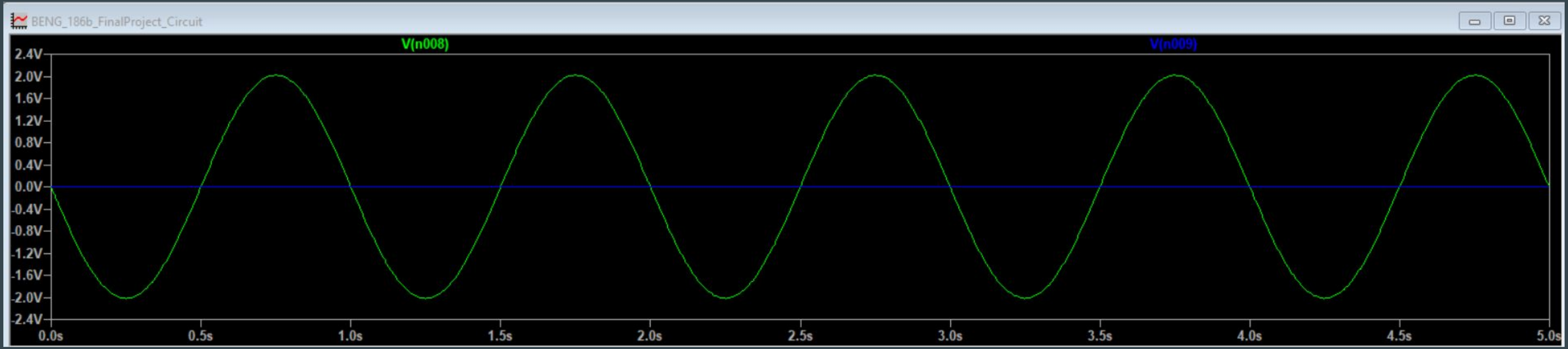
R1 = 10 kΩ
R2 = 1MΩ=1000 kΩ
G = 1 + R2/R1 = 101

- Goes to **microcontroller** for digital output to computer for further analysis

Circuit Schematic

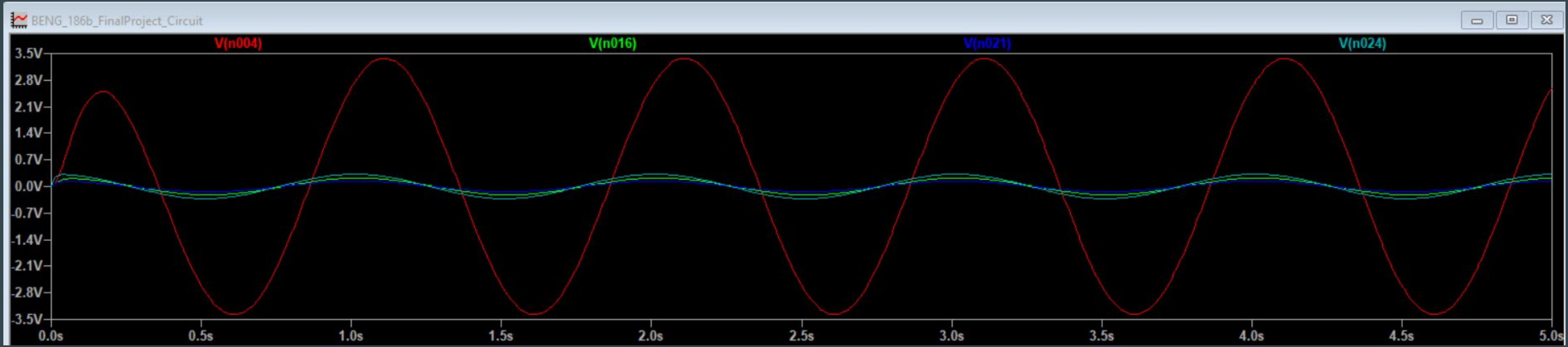


Instrumentation Amplifier Simulation



Blue - Input sine wave: Vpp = 0.002V @ 1Hz
Green - Output sine wave: Vpp = 4V @ 1Hz

Filter Simulation



Input wave → Vpp = 4V, sine wave @ 1Hz
Delta filter (red) → Vpp = 3V, sine wave @ 1Hz
Theta filter (green) → Vpp = 200mV, sine wave @ 1Hz
Alpha filter (blue) → Vpp = 140mV, sine wave @ 1Hz
Beta filter (turquoise) → Vpp = 320mV, sine wave @ 1Hz

Results & Improvements

Results

- Display of changes in each wave of interest: delta, theta, alpha, and beta waves without noise

Improvements

- High order butterworth bandpass filters could be used instead of cascading filters for more drastic attenuation at cutoff frequencies

Advantages & Limitations

Advantages:

- Easy and cheap to implement
- Noninvasive monitoring
- Gets rid of noise to focus analysis only one specific brain waves of interest— delta, theta, beta, and alpha waves
- Allows more personalized patient care

Limitations:

- EEG readings can be inaccurate in infants and the elderly
- Different anesthetic agents produced different brain states
- Anesthesiologists may need training to learn to interpret unprocessed EEG data
- EEG as a standard anesthetic monitor has been difficult to implement

Significance

More accurate assessment of the depth of anesthesia to avoid oversedation or inadequate levels of sedation to minimize risks associated with excessive sedation including hemodynamic instability, respiratory depression, and prolonged recovery times, or conversely intraoperative awareness and stress response

The use of EEG in clinical practice is important as it has many widespread applications beyond just anesthesia monitoring:

1. Comatose patient monitoring
2. Epilepsy
3. Sleep cycle research
4. Detection of neural diseases

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