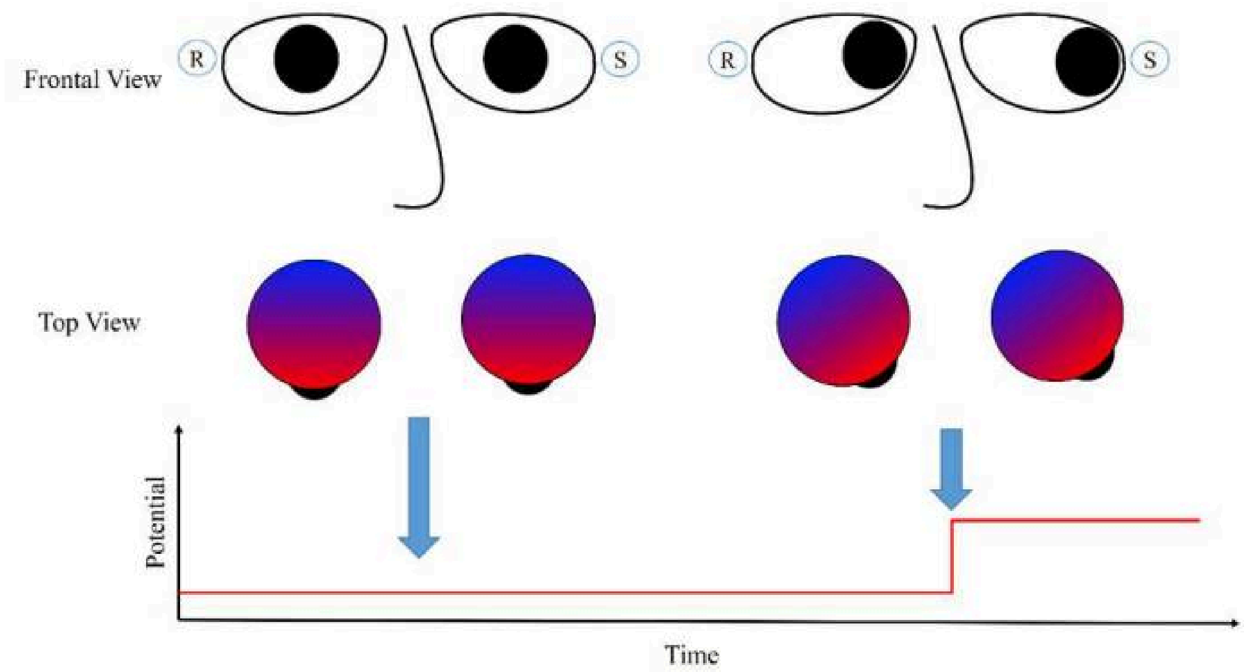
P02 : EOG-integrated eyeglasses

Types of Biomedical Signals:

1. **Electrocardiogram (ECG/EKG):** Records the electrical activity of the heart.
2. **Electroencephalogram (EEG):** Measures the electrical activity of the brain.
3. **Electromyogram (EMG):** Detects the electrical activity produced by skeletal muscles.
4. **Electrooculography (EOG):** Measures the electrical potential between different parts of the eye.
5. **Galvanic Skin Response (GSR):** Records changes in the electrical conductivity of the skin.

The primary objective of EOG is to measure the voltage changes resulting from the rotation of the eye, which can be used to determine the direction and amplitude of eye movements.

- ➔ In general, the amplitude of the EOG signal is between 0.05 mV-3.5 mV per degree of eyeball movement in the range of 0.1 to 15 Hz.
- ➔ Therefore, in order to successfully measure, filter out and record these small signals we need to amplify them correctly.
- ➔ The primary advantage of using EOG for human–computer interaction (HCI) is its ability to estimate eye movements with low-cost devices and a precision of up to 1.5°.
- ➔ An EOG signal varies with eye movements due to the standing potential between the retina and cornea. The potential increases when the cornea approaches an electrode and decreases when it moves away.
- ➔ When the eyes are directed straight and the gaze is fixed, the electric potential remains constant. When the eyes move left towards a sensor, the potential increases sharply as the cornea approaches the sensor. This phenomenon also occurs when the eyes are closed or in blind individuals.



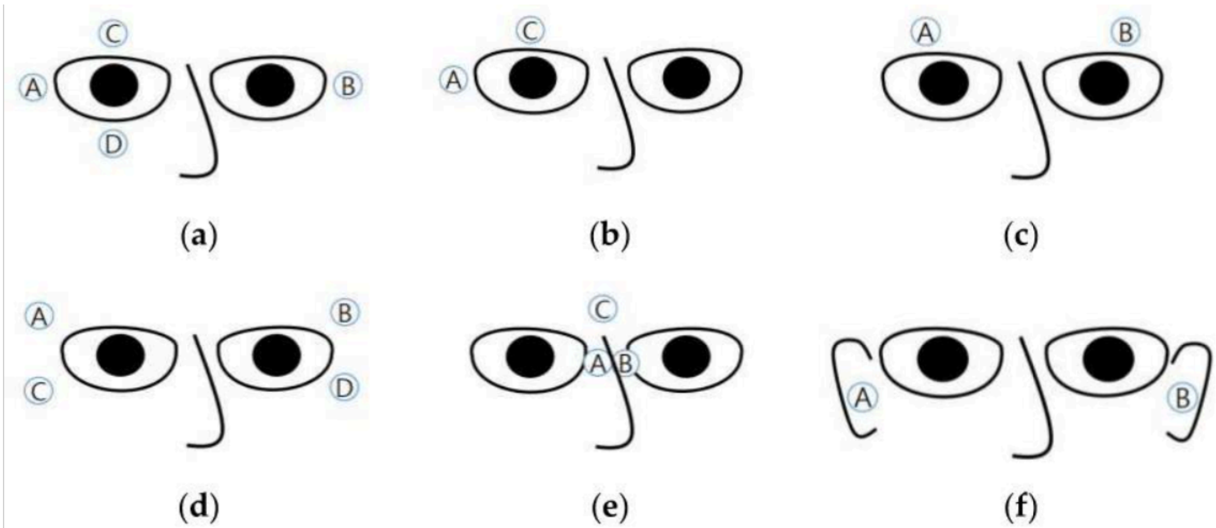
S denotes the location at which a sensor is placed to record the EOG signal, and R is the location of a reference electrode.

An Electrooculogram (EOG) often captures activities beyond eye movements, known as artifacts. Eyelid-related artifacts are strong and frequent during eye closure and opening, resulting in a significant increase in potential above the eyes. This increase combines the retinal and corneal potentials, as the eyelid conducts the cornea's positive charges to the frontopolar region of the brain.

Although these artifacts originate from the same source as eye-movement signals, they are not closely related to eye movements since the eyes move only slightly (less than 5°) during blinks due to a mechanism that suppresses saccadic movements.

Electromyograms (EMGs) represent another type of artifact in EOGs, observed when facial or body muscles move during measurement. EMGs arise from activities such as jaw clenching, raising eyebrows, smiling, or walking. The shapes of these artifacts vary with movement type, electrode position, and sampling rates. Generally, EMGs manifest as high-frequency noise and plateau-like waveforms, exceeding the potential range of eye-movement-related signals.

EOG measurement typically involves placing sensors at the left and right sides of the eyes for horizontal EOG, and above and below an eye for vertical EOG.



Six different electrode positions (from a to f) to measure EOGs in the literature. The letters A, B, C, and D in circles denote the electrode locations.

Some studies used only two electrodes plus a reference electrode: one above an eye and the other to the right of the right eye (or left of the left eye) (Figure b). Although this placement yielded less stable signals , it enabled recognition of eye movements in eight directions with over 80% accuracy. (need to research about why and how this was achieved)

Electrode Placements and Signal Processing for EOG Measurements:

Typical Electrode Placements:

1. Figure a: The horizontal EOG is obtained by subtracting the signal at B from A (or vice versa), and the vertical EOG by subtracting the signal at D from C (or vice versa). The reference electrode is commonly placed on the forehead, between the eyes, or on the mastoids.
2. Figure b utilizes a similar measurement technique as Figure a, just that measurements are done w.r.t to the reference electrode placed as mentioned above.
3. Figure c: Headband Embedding - Electrodes embedded in a headband and ignoring vertical eye movements. (as in figure c)
4. Figure d: Above and Below Eyes - Electrodes placed above and below the right eye and left eye. Achieved 87.1% accuracy in classifying 24 levels of horizontal eye movements (-75° to 75°).
5. Figure e: Nose-Pads and Eyeglass Bridge - This method uses three electrodes: two on nose-pads (A and B) and one on the eyeglass bridge (C). (Commercialized by a Japanese company)
    a. Horizontal EOG: A - B
    b. Vertical EOG: (A+B)/2 - C.

6. Figure f: In-Ear Electrodes - Using in-ear electrodes for recording horizontal EOGs . Slightly lower accuracy compared to conventional EOGs (82.60% vs. 90.11%), with potential improvements through advanced signal processing.

Electrode placements in Figures b, c, e, and f are designed for mobile devices.

EOG Signal Characteristics:
1. Typical EOG amplitude is about 500 µV , proportional to eye movement magnitude.
2. Challenges include DC drifts (Drift in electronic circuits refers to a variation in the output offset voltage, often induced by temperature changes) and other noises, increasing with recording time.

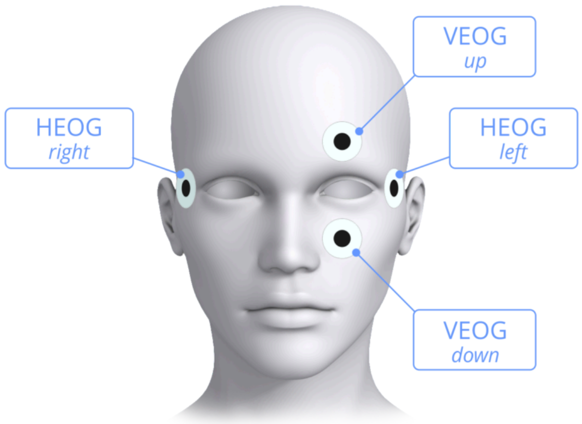
➔ EOG Recording Systems: EOG signals are microvolt-level, requiring amplification for recording.

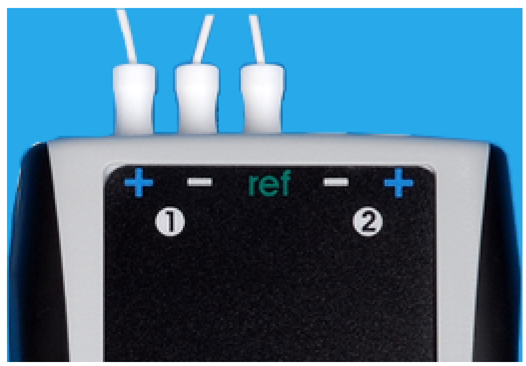
➔ Measurement Systems

EOG-Specific Systems: Cost ₹ 27,084 - 144,448 (e.g., BlueGain, NI-USB-6008, JinsMeme).

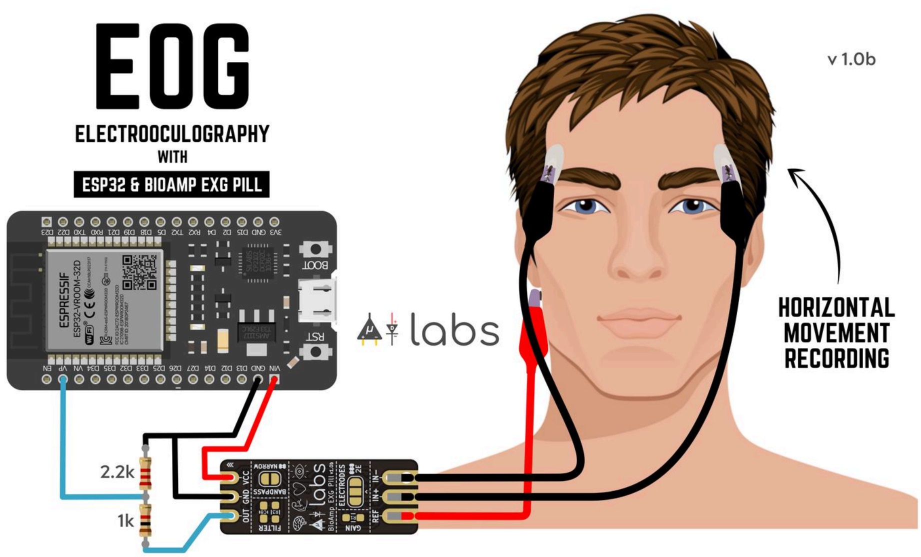
1. **JinsMeme** integrates EOG amplifiers in eyeglasses :

2. **BlueGain** (Cambridge Research systems):





3. **BioAMP EXG PILL** - BioAmp EXG Pill is a small (2.54 X 1.00 cm) and elegant Analog Front End (AFE) board for BioPotential signal acquisition.



Researchers have developed stationary and portable EOG systems, some embedded in wheelchair or goggles.

Electrode Types and Performance:

Wet vs. Dry Electrodes

Wet electrodes are popular due to higher signal-to-noise ratios (SNRs).	Glasses with dry electrodes have demonstrated impressive performance comparable to that of wet electrodes.

1. It can be expected that the noises caused by body movements or sweat degrade the quality of the signal more when dry electrodes are used compared to that in the case of wet electrodes, because the contact between the electrodes and skin could worsen in mobile environments.
2. Although Various researchers have achieved accuracies up to 87-90% in classifying various eye movements using dry electrodes.

Signal Processing:

Different types of eye movements:
1. saccades (fast eye movement)
2. fixation (fixing gaze onto a subject)
3. miniature eye movements (drift, tremor, and microsaccades during fixation)
4. smooth pursuit (when tracking a slowly moving target)
5. vergence (inward and outward eye movements)

Noise Removal:

1. Median filters are nonlinear filters that replace each entry in the signal with the median of neighboring entries. They effectively remove artifacts and noise from EOG signals without distorting eye movement parameters. Median filtering has been proposed as an effective tool for denoising EOG signals, especially for removing high-frequency noise. Median filters maintain signal edge steepness better than low-pass filters. A low-pass filter does not preserve steepness of saccadic eye movements. Using median filters various eye gestures could be obtained with high accuracy (about 90%).

However, a recent study employed the median filter together with a 20-Hz low-pass filter which provided better results. Further, it was claimed that a cut-off frequency of 20 Hz is sufficient to include intentional eye-movements and remove high-frequency noises.

1. EMG and tremor are high frequency signals so they are filtered put using median or low pass filters (typical cutoff frequency - 10 to 60 Hz)
2. Drift Removal: Conventionally removed using high-pass filters with cut-off frequencies from 0.05 to 0.1 Hz . Alternative methods include polynomial regression and wavelet transformation . Wavelet transformation preserves fixation signals while removing gradual drift.

Wavelet Transform (WT):

1. The wavelet transform decomposes a signal into different frequency components. Unlike the Fourier transform, which uses fixed sinusoidal basis functions, the wavelet transform uses wavelets that are localized in both time and frequency.
2. The Discrete Wavelet Transform (DWT) is commonly used for signal processing. It breaks down the signal into different scales (or levels) by applying a series of high-pass and low-pass filters.
3. The DWT provides a multiresolution analysis, allowing us to analyze different frequency components of the signal.

Filtering with Wavelets:
Once we have decomposed the signal using the DWT, we can filter it in the wavelet space.
The steps for filtering signals using wavelets are as follows:

1. Decompose the Signal: Apply the DWT to the original signal, resulting in a set of wavelet coefficients at different scales.
2. Filter in Wavelet Space: Apply a thresholding technique to the wavelet coefficients. This helps remove noise or unwanted components while preserving important features.
3. Inverse Transform: Invert the filtered wavelet coefficients using the inverse DWT to reconstruct the filtered signal.

Blink Artifact Removal: Blink artifacts are typically removed, and the signal is interpolated before and after the blink.

Crosstalk Removal: Crosstalk between horizontal and vertical channels is addressed by measuring and removing the crosstalk component from the test signals .

The resting current flows progressively from the retina side to the cornea side, such that an electrical field comes into play with a negative pole at the retina and a positive pole at the cornea.

This paper also provides that the amplitude of the pulse increased with the increment of rolling angle and the width of the positive (negative) pulse is proportional to the duration of eyeball rolling process

According to this paper, EOG has 10-100 µV, light adaptation is kept. In this paper, it has also been tried to predict EEG data according to eye movements. In this paper [4] implemented an EOG based Human Computer Interface model. This paper also provides that the amplitude of the pulse increases with the increment of rolling angle and the width of the positive (negative) pulse is proportional to the duration of eyeball rolling process. The gain of the preamp used for the model is 10 and that of the main amplifier is 800. For eliminating the base-line higher frequency, a band-pass filter of 1-100 Hz has been used. In this paper [5] author discusses the instrumentation for EOG acquisition and signal processing. An AD521 instrumentation amplifier has been used in this model that provides the proper amplification of (25) and bandwidth, high input impedance, high CMRR, low noise, and stability against voltage fluctuations and temperature. Then a non-inverting amplifier of 510 amplification is used.

Importance of High CMRR in EOG Preamplifiers

1. Bioelectrical Signal Sensitivity:
   a. EOG signals, which are generated by eye movements, are typically very small in amplitude, often in the range of microvolts (µV).
   b. These small signals are susceptible to various sources of electrical noise and interference.

2. Common-Mode Noise Rejection:
   a. Common-mode noise can arise from multiple sources, such as power line interference (Power line interference originates from the electrical power supply network. It can be introduced into the measurement system through various pathways, including power cables, nearby electronic devices, and even the human body acting as an antenna.)(50/60 Hz hum), electromagnetic interference from nearby electronic devices, and movement artifacts.
   b. Since EOG electrodes pick up signals from the surface of the skin, they are particularly prone to picking up these common-mode noises.

3. Enhanced Signal Quality:
    a. A high CMRR ensures that the EOG preamplifier effectively rejects the common-mode noise, thereby isolating and amplifying only the differential EOG signal.
    b. This results in a cleaner, more accurate representation of the eye movement signals, which is crucial for reliable measurement and analysis.
4. Improved Signal-to-Noise Ratio (SNR):
    a. By minimizing the amplification of unwanted noise and interference, a high CMRR improves the overall signal-to-noise ratio.
    b. A better SNR is essential for precise interpretation of eye movements, especially in clinical and research settings.

5. Minimized Artifacts and Distortions:
    a. Low CMRR can lead to the amplification of artifacts and distortions in the recorded EOG signal.
    b. High CMRR helps maintain the integrity of the signal by preventing these artifacts from overwhelming the actual bioelectrical signals.

It consists of EOG signal acquisition, EOG filter and amplifier, ARM microcontroller and Zigbee wireless module. In this scheme, an embedded microcontroller is adopted to perform a wireless control of a toy car.

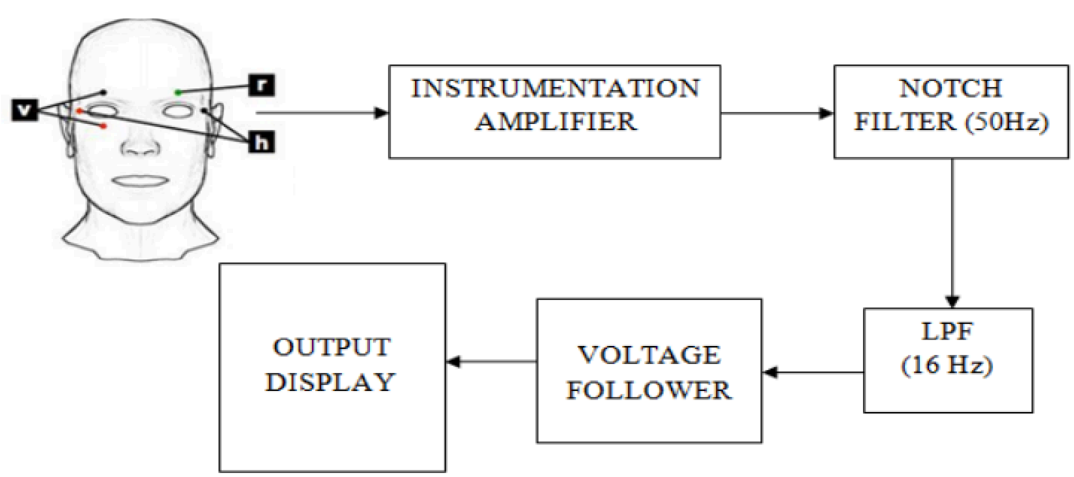


Fig.1 block diagram

A. Instrumentation amplifier

This INA118 is a low power, amplifier that offers high gain. It provides a high CMRR of about 110 dB at G=1000. The block diagram of the instrumentation amplifier is as shown in Fig.3.

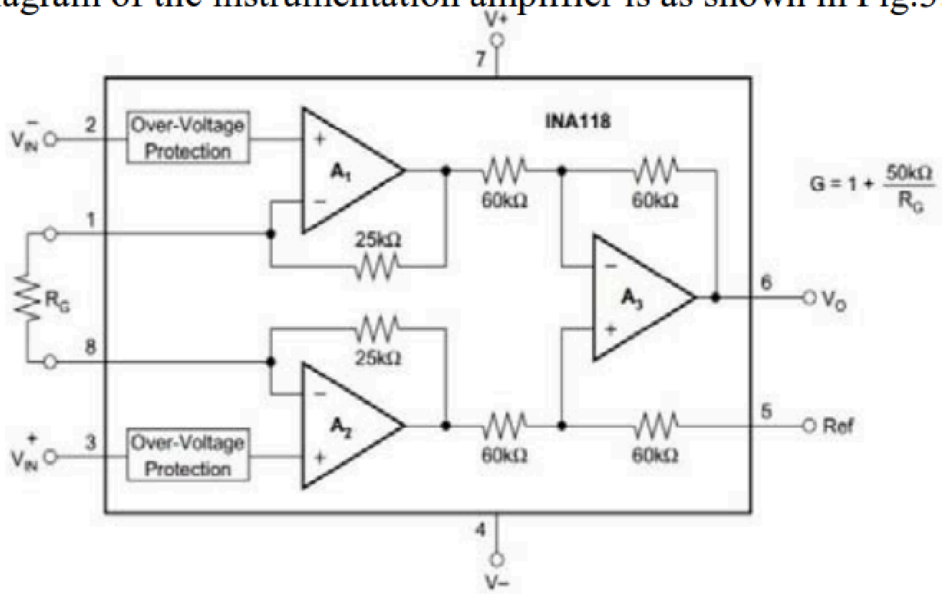


Fig.3 Instrumentation amplifier

C. Notch filter

Filters are that electronic circuits which are used to remove unwanted frequency components that is noise from the signal, to enhance the wanted signal. In this we requires a filter of high gain and twin T notch filter is used that can tune up to 100dB. Here, the required frequency for filtering is 50Hz for that the resistance and capacitance values are chosen appropriately. The notch filter is shown in Fig.4.

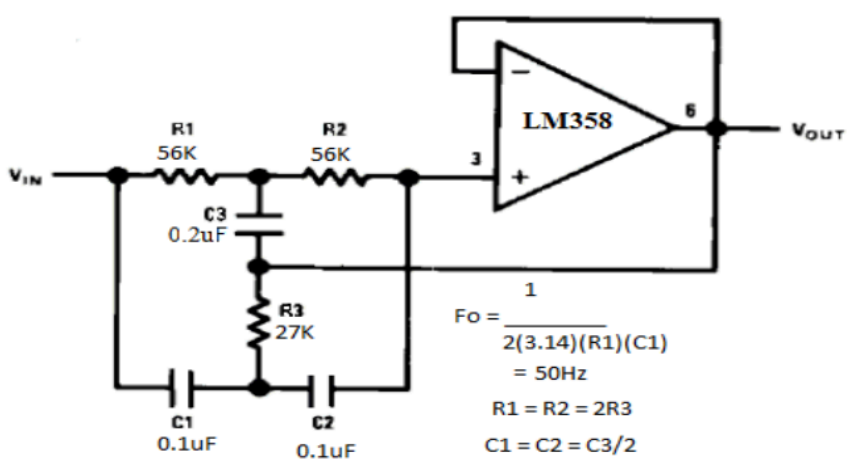


Fig.4 Notch filter

C. Low pass filter: The noises and other artifacts come under high frequencies and they have to be removed. For that, a low pass filter with the frequency range 0-16Hz is implemented and the corresponding resistor, capacitors are chosen accordingly.

D. Voltage follower: A voltage follower (buffer) is the one that provides the transformation of electrical impedance from one circuit to another. And this is designed to have an amplifier gain of 1. Buffers are used in impedance matching for maximizing energy transfer between circuits.

E. DC bias removal: The resting potential between the eyes varies depending upon several parameters such as nature of the skin, conductivity, lighting of the type of electrodes used and electrodes placement. After the process of amplification, the resting potential is then amplified, but it is not desired in the EOG signal. A differentiator circuit is used to remove the DC drifts for providing better high frequency responses.

Brief overview of EOG Signal processing:

Electrooculography (EOG) signal acquisition involves capturing, preprocessing, and processing bioelectrical signals generated by eye movements. This process typically includes several steps to ensure the signal's quality and interpretability. Here's a detailed list and explanation of the filters and processing steps involved in obtaining a clean, amplified EOG signal from raw data:

Filters Used in EOG Signal Acquisition

1. **Low-Pass Filter**:
    a. **Purpose**: Removes high-frequency noise.
    b. **Frequency Range**: Typically set below 30 Hz, as EOG signals are primarily low-frequency.
    c. **Application**: Filters out high-frequency components such as electromyographic (EMG) noise.
2. **High-Pass Filter**:
    a. **Purpose**: Removes low-frequency drift and baseline wander.(the baseline signal of any biomedical signal keeps fluctuating a little)
    b. **Frequency Range**: Typically set around 0.1-1 Hz.
    c. **Application**: Eliminates very low-frequency components, such as baseline wander caused by slow changes in electrode impedance(the measure of how much an electrode resists the flow of electrical current) or movement artifacts.

3. **Band-Pass Filter**:
    a. **Purpose**: Combines the effects of low-pass and high-pass filters to allow only the desired frequency band.
    b. **Frequency Range**: Typically between 0.1 Hz and 30 Hz.
    c. **Application**: Isolates the frequency range where the majority of EOG signal energy resides.
4. **Notch Filter**:
    a. **Purpose**: Removes specific frequency interference, particularly power line noise.
    b. **Frequency Range**: Typically set at 50 Hz or 60 Hz, depending on the local power grid frequency.
    c. **Application**: Suppresses power line interference, which is a common source of noise in bioelectrical measurements.

Preprocessing Steps

1. **Signal Amplification**:
    a. **Purpose**: Amplifies the small EOG signals to a more usable level.
    b. **Components**: Utilizes instrumentation amplifiers like INA118 or AD8251, which provide high gain and high CMRR.
    c. **Application**: Enhances the amplitude of the EOG signal while minimizing noise and interference.
2. **Analog Filtering**:
    a. **Purpose**: Initial filtering of the raw signal to reduce noise and interference before digitization.
    b. **Components**: Includes low-pass, high-pass, and notch filters.
    c. **Application**: Prepares the signal for digitization by removing unwanted frequency components.
3. **Analog-to-Digital Conversion (ADC)**:
    a. **Purpose**: Converts the amplified and filtered analog signal into a digital format for further processing.
    b. **Resolution**: High-resolution ADCs (e.g., 12-bit or 16-bit) are preferred for capturing detailed EOG signals.
    c. **Sampling Rate**: Typically set between 100 Hz and 1000 Hz to accurately capture the dynamics of eye movements.

Processing Steps

4. **Digital Filtering**:
    a. **Purpose**: Further refines the signal quality using digital filters.
    b. **Components**: Digital implementations of low-pass, high-pass, band-pass, and notch filters.
    c. **Application**: Provides additional noise reduction and signal conditioning after digitization.
5. **Artifact Removal**:
    a. **Purpose**: Identifies and removes or corrects artifacts caused by blinking, muscle movements, or other external factors.
    b. **Methods**: Techniques include independent component analysis (ICA), wavelet transforms, and adaptive filtering.
    c. **Application**: Ensures that artifacts do not distort the EOG signal interpretation.
6. **Baseline Correction**:
    a. **Purpose**: Removes any residual baseline drift to stabilize the signal.
    b. **Methods**: Polynomial fitting, moving average filters, or high-pass filtering.
    c. **Application**: Ensures a consistent baseline for accurate signal analysis.
7. **Segmentation**:
    a. **Purpose**: Divides the continuous EOG signal into meaningful segments based on specific events or time windows.
    b. **Methods**: Event detection algorithms based on signal thresholds or derivative analysis.
    c. **Application**: Facilitates detailed analysis of specific eye movements or periods.
8. **Feature Extraction**:
    a. **Purpose**: Extracts relevant features from the EOG signal for analysis or classification.
    b. **Methods**: Time-domain features (e.g., peak amplitude, duration), frequency-domain features (e.g., power spectral density), and wavelet features.
    c. **Application**: Provides the necessary parameters for interpreting eye movements or for use in further applications like machine learning.
9. **Signal Averaging**:
    a. **Purpose**: Enhances signal quality by averaging multiple instances of the EOG signal.
    b. **Methods**: Synchronized averaging based on repeated stimuli or voluntary eye movements.
    c. **Application**: Reduces random noise and improves the signal-to-noise ratio.

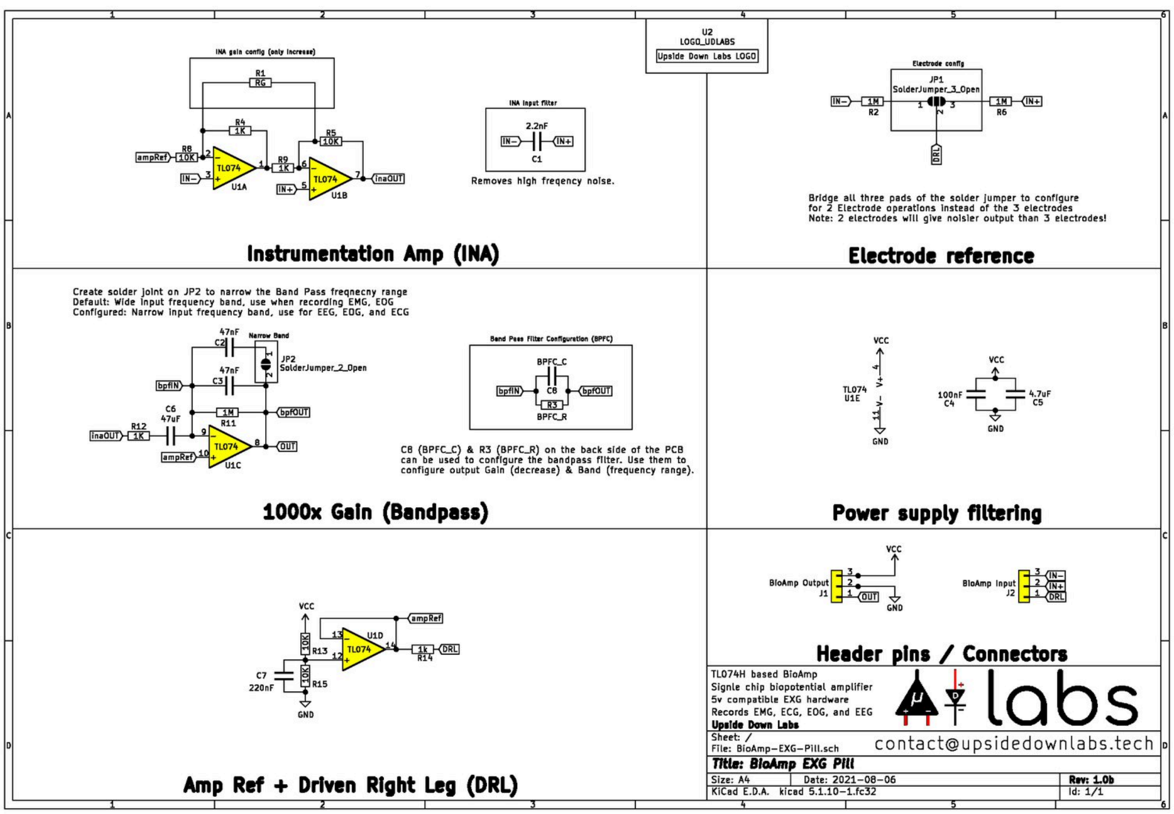
Final EOG Signal

- The final EOG signal is a clean, amplified, and processed representation of the eye movement activity, free from significant noise and artifacts. This signal is now suitable for further analysis, interpretation, or use in applications such as eye-tracking systems, clinical diagnostics, or human-computer interfaces.

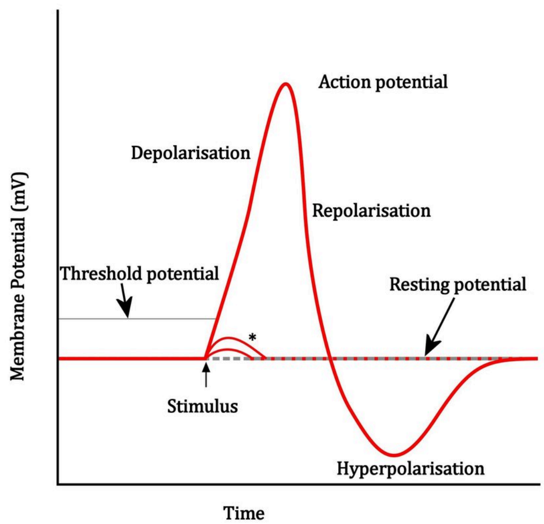
Summary

In summary, the process of obtaining a clean EOG signal from raw data involves a series of steps including signal amplification, analog and digital filtering, artifact removal, baseline correction, segmentation, feature extraction, and signal averaging. Each step is crucial in ensuring that the final EOG signal is accurate and reliable for the intended application.

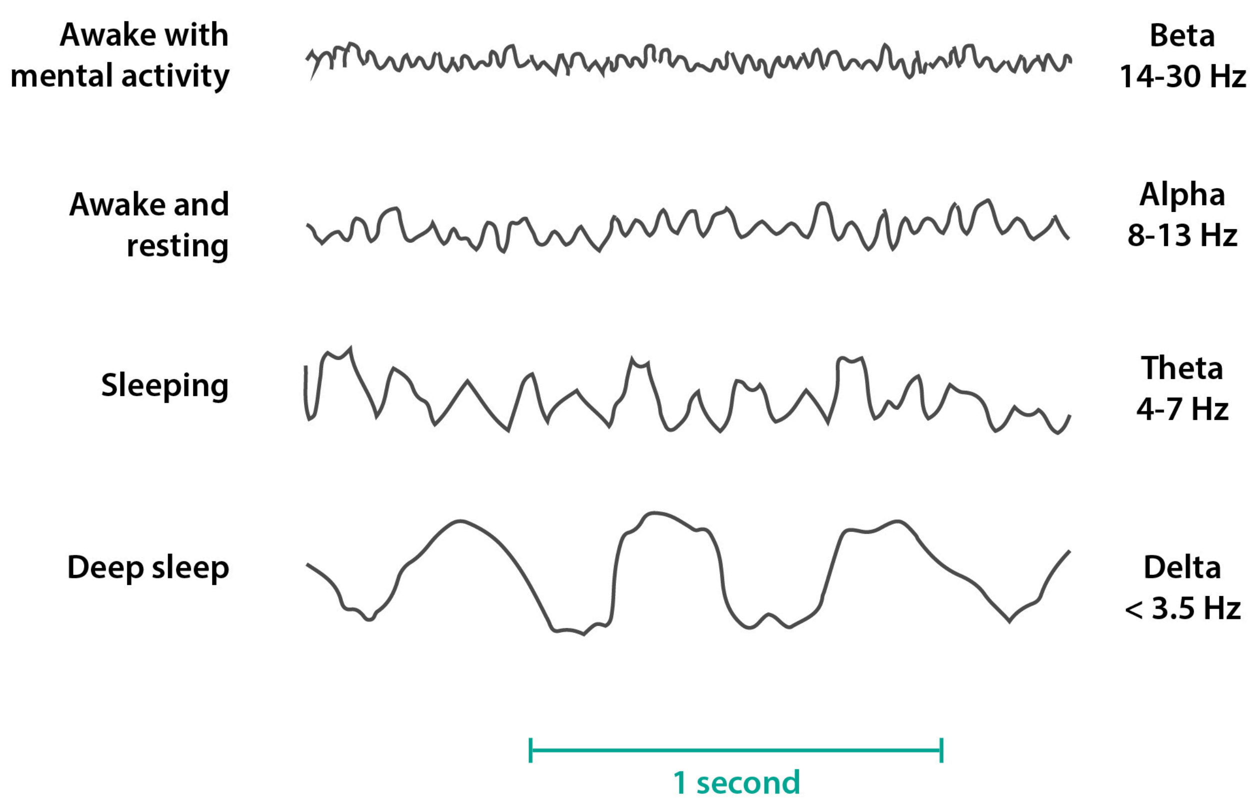
EXG PILL CIRCUIT



GRAPHS OF BIOMEDICAL SIGNALS

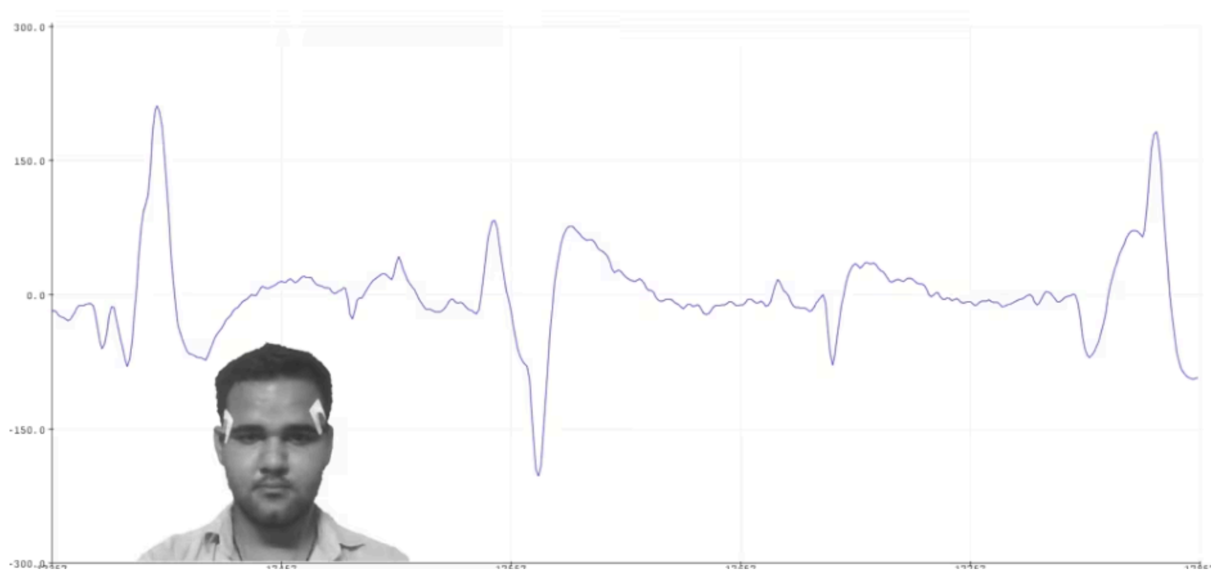


Action Potential of a neuron



WAVE	VOLTAGE	FREQUENCY
α(alpha)	50 mV	8-13 Hz
β(beta)	< 50 mV	14-30 Hz
Θ(theta)	50 mV	4-7 Hz
Δ(delta)	100 to 200 mV	< 3.5 Hz

Eye blink(VEM)



Left right(HEM)