

Biosignal Acquisition and Signal Conditioning

1. Overview

Biological signals are tiny, low-frequency and buried in noise, so they cannot be used directly. They pass through an **acquisition chain** that converts, boosts, cleans and digitises them before display or analysis.

Body → Electrodes → Amplification (in-amp) → Signal conditioning → Digitisation (ADC) → Processor / display

2. Stages of the Acquisition Process

2.1 Electrodes

- Convert ionic currents from the body into electrical currents.
- Ag/AgCl electrodes are standard because of their low polarisation.

2.2 Amplification

- The acquired signal is often in the millivolt or microvolt range.
- An Instrumentation Amplifier (in-amp) with a high Common Mode Rejection Ratio (CMRR) amplifies the wanted signal while ignoring common noise (e.g. mains pickup appearing equally on both inputs).
- $CMRR = A_d / A_c$ (differential gain ÷ common-mode gain), usually expressed in dB. Higher is better.

2.3 Signal Conditioning

- Prepares the signal for digital conversion.
- Includes buffering, scaling and initial analogue filtering (anti-aliasing low-pass filter before the ADC).

2.4 Digitisation (ADC)

- Translates continuous analogue waves into discrete digital data points.
- Must follow the Nyquist theorem: sampling rate $> 2 \times$ the highest signal frequency.
- Sampling too slowly causes aliasing – high frequencies appear falsely as low frequencies and cannot be removed afterwards.

3. Choosing the Sampling Rate

Biosignal	Highest frequency of interest	Minimum sampling rate ($> 2 \times f_{\max}$)
ECG	150 Hz	> 300 Hz
EEG	100 Hz (gamma band)	> 200 Hz

Biosignal	Highest frequency of interest	Minimum sampling rate ($> 2 \times f_{\text{max}}$)
EMG	500 Hz	> 1000 Hz
EOG	30 Hz	> 60 Hz

In practice the sampling rate is chosen with a safety margin above the Nyquist minimum.

4. Signal Bandwidths for Conditioning

Biosignal	Signal frequency range	Typical recording pass-band
ECG	0.05 – 150 Hz	0.05 – 100 Hz
EEG	0.5 – 100 Hz	0.5 – 50 Hz
EMG	10 – 500 Hz	10 – 500 Hz
EOG	0 – 30 Hz	0 – 30 Hz

Noise Sources and Artifact Removal

1. Introduction

An artifact is any unwanted signal in a recording that does not come from the activity being measured. Because biosignals are only microvolts to millivolts, artifacts can easily be as large as the signal itself. They are grouped as physiological (internal) and non-physiological (external).

2. Sources of Noise and Artifacts

2.1 Physiological artifacts (internal)

- **Muscle activity (EMG):** high-frequency muscular contractions that often interfere with EEG and ECG recordings.
- **Ocular artifacts:** eye blinks and eye movements create strong electrical potentials, mainly disrupting EEG readings.
- **Cardiac artifacts:** the heart's strong electrical field (QRS complex) can show up as unwanted noise in EEG and EMG signals.
- **Motion artifacts and baseline wander:** movement of electrodes or cables, or respiration, causes low-frequency baseline shifts.

2.2 Non-physiological artifacts (external)

- **Power-line interference:** spikes at **50 or 60 Hz** caused by nearby electrical equipment and AC mains.

- **Instrumentation and thermal noise:** random electronic fluctuations inside the recording equipment, e.g. **Johnson noise**.

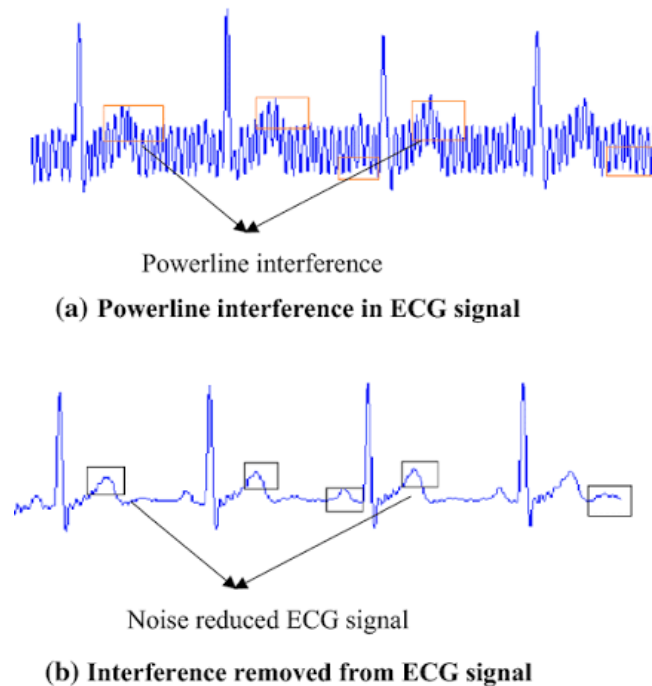


Figure 2: (a) ECG with power-line interference; (b) interference removed from the ECG signal

3. Summary of Artifacts

Artifact	Origin	Frequency nature	Mostly affects
Muscle (EMG)	Muscle contraction	High frequency	EEG, ECG
Ocular	Blinks and eye movement	Low frequency, large	EEG
Cardiac (QRS)	Heart electrical field	Periodic, mid-range	EEG, EMG
Motion / baseline wander	Electrode, cable movement; respiration	Low frequency	ECG, EEG
Power-line	AC mains and equipment	50 / 60 Hz	All biosignals
Thermal / instrumentation	Electronic components	Wideband random	All biosignals

4. Artifact Removal and Filtering Techniques

4.1 Band-pass filtering

Keeps only the frequency band that contains the signal and rejects everything outside it.

Signal	Typical pass-band
ECG	0.05 – 100 Hz

Signal	Typical pass-band
EEG	0.5 – 50 Hz
EMG	10 – 500 Hz

4.2 Other filters

Filter	Purpose	Example
Low-pass	Eliminate high-frequency noise	Remove EMG activity from an ECG recording
High-pass	Remove low-frequency baseline wander and slow drifts	Drift caused by breathing or electrode movement
Notch (band-stop)	Isolate and strictly remove a single narrow frequency	50 Hz or 60 Hz power-line interference
Adaptive filter	Remove artifacts that overlap in frequency with the signal	Subtract ECG from EMG using the Least Mean Square (LMS) algorithm

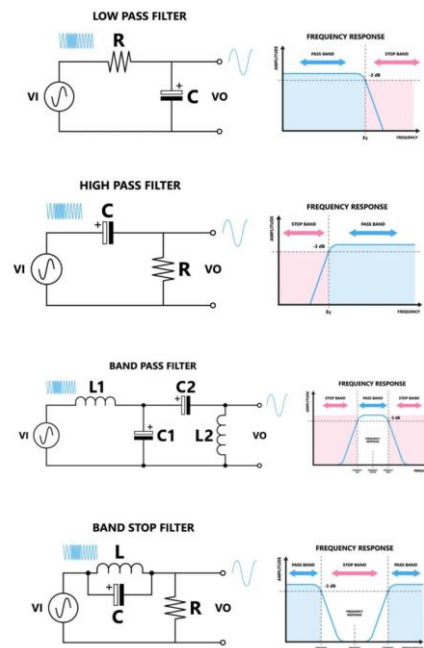


Figure 3: Low-pass, high-pass, band-pass and band-stop filter circuits with their frequency responses

Why adaptive filtering?

A fixed filter cannot separate noise that overlaps the signal band (for example ECG contamination of EMG, both in the same frequency range).

An adaptive filter uses a reference noise input and the LMS algorithm to keep adjusting its weights until the estimated noise can be subtracted from the recorded signal.

5. Practical Ways to Reduce Noise at the Source

- Good skin preparation and electrolyte jelly for low contact impedance.
- Secure electrodes and cables to reduce motion artifacts.
- Use an instrumentation amplifier with high CMRR to reject common-mode mains pickup.
- Use shielded leads and proper grounding.