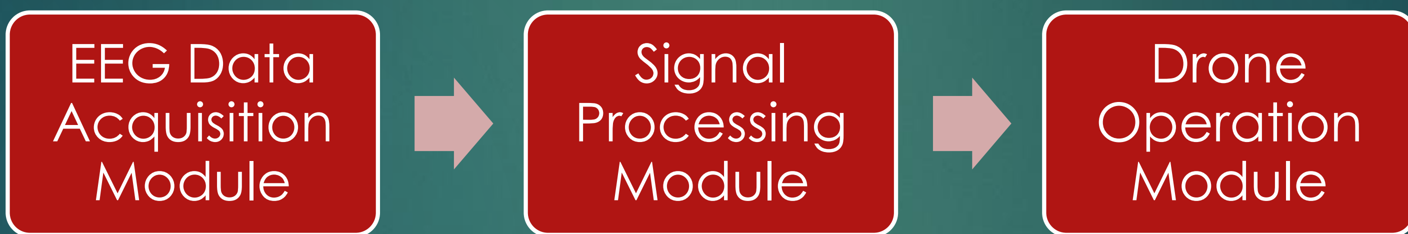
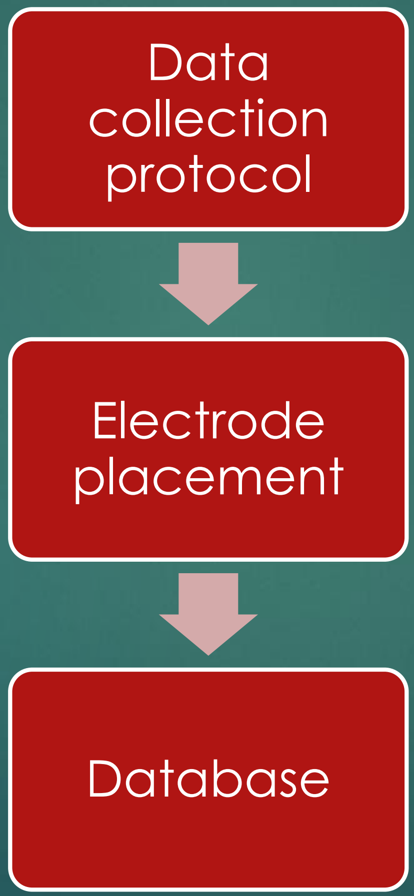
Brain-computer Interface

PREPARED BY DR. BONG SIAO ZHENG

Flow-chart of a Real-time Mind-controlled Drone



EEG Data Acquisition



Signal Processing

Drone operation

Programme the drone using Arduino IDE

↓

Interface with computer

↓

Send command for drone movement through Bluetooth

Encephalogram (EEG)

Introduction to EEG

- Electroencephalogram (EEG) is a representation (writing on paper or display on computer monitor) of the electrical activity of the brain.

Introduction to EEG

- The EEG record obtained is used primarily for diagnosis, including the following:
  i. Help detect and localize brain lesions (assymetry / irregularity in EEG tracings).
  ii. Aid in studying epilepsy (recurrent, transient attacks of disturbed brain function with irregular sensory and motor activity such as convulsions).
  iii. Assist in diagnosing mental disorders.
  iv. Assist in studying sleep patterns.
  v. Allow observations and analysis of brain responses to sensory stimuli.

The EEG Signal

- The EEG is composed of electrical rhythms and transient discharges which are distinguished by:
  1. Location
  2. Frequency
  3. Amplitude
  4. Form
  5. Periodicity
  6. Functional properties
- Synchronization appears in the EEG, and the resulting slow activity is evident.

The EEG Signal

EEG Electrodes

- EEG electrodes transform ionic currents from cerebral tissue into electrical currents used in EEG preamplifiers.
- The electrical characteristics are determined primarily by the type of metal used.
- Silver-silver chloride (Ag/AgCl) is commonly found in electrode discs.

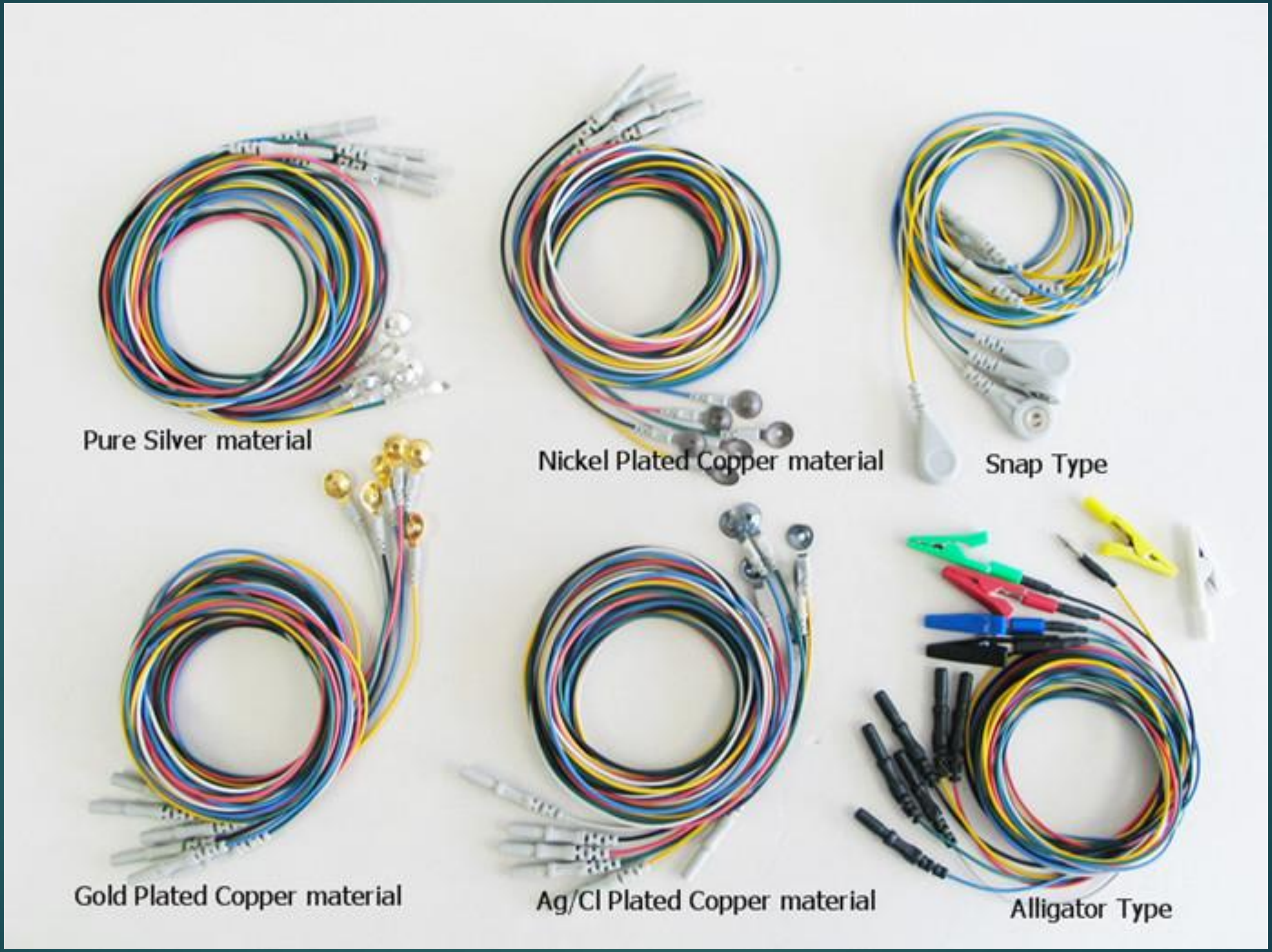
Types of EEG electrodes

1. Reusable disks.
   - can be placed close to the scalp, even in a region with hair, small. conducting gel. held in place by a washable elastic head band. Disks made of tin, silver, and gold are available. cleaned with soap and water or Cidex. The cost of each disk and lead is dependent on the type of metal used as a conductor, the gauge of wire used as a lead, and the type of insulation on the wire lead. Since these electrodes and leads can be used for years, their expense is low.
2. EEG Caps with disks.
   - Different styles of caps are available with different numbers and types of electrodes. Some caps are available for use with replaceable disks and leads. Gel is injected. Since the disks on a region of the scalp covered with hair cannot be placed as close to the scalp as individual disc electrodes, a greater amount of conducting gel needs to be injected under each. more time is required to clean the cap and its electrodes, as well as the hair of the subject. Depending on the style and longevity of the cap and the electrodes, their expense can be moderate to high.

Types of EEG electrodes

3. Adhesive Gel Electrodes.
   - These are the same disposable silver/silver chloride electrodes used to record ECGs and EMGs, and they can be used with the same snap leads used for recording those signals. These electrodes are an inexpensive solution for recording from regions of the scalp without hair. They cannot be placed close to the scalp in regions with hair, since the adhesive pad around the electrode would attach to hair and not the scalp. When purchased in bulk, their expense is very low.
4. Subdermal Needles.
   - These are sterilized, single-use needles that are placed under the skin. Needles are available with permanently attached wire leads, where the whole assembly is discarded, or sockets that are attached to lead wires with matching plugs. Since they are a sterile single-use item, the expense of needle electrodes is moderate to high. Also, human subjects and, in some situations, regulatory committees need to approve the use of these electrodes before they are used.

Types of electrodes



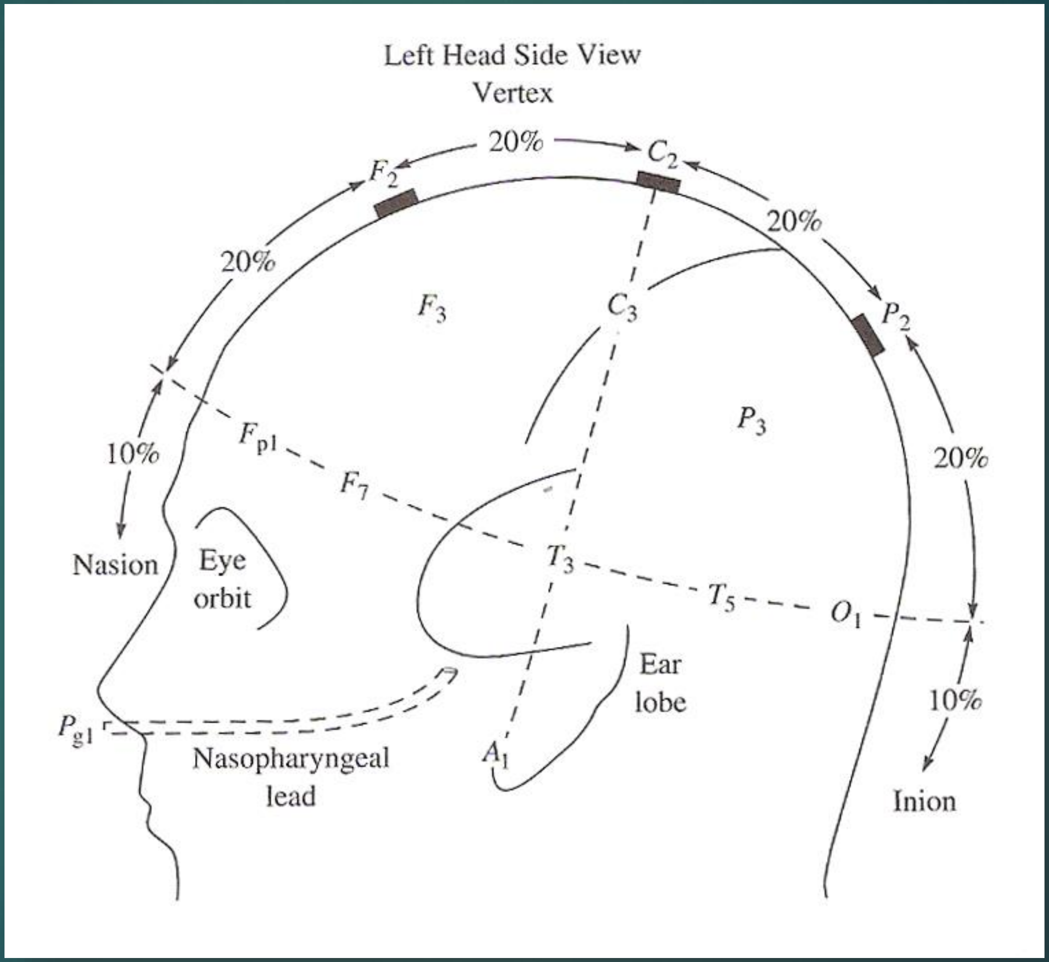
10-20 System

- The amplitude, phase and frequency of EEG signals depend on electrode placement.
- This placement is based on the frontal, parietal, temporal and occipital cranial areas.
- One of the most popular schemes is the 10-20 electrode placement system established by the International Federation of EEG Societies.

10-20 System

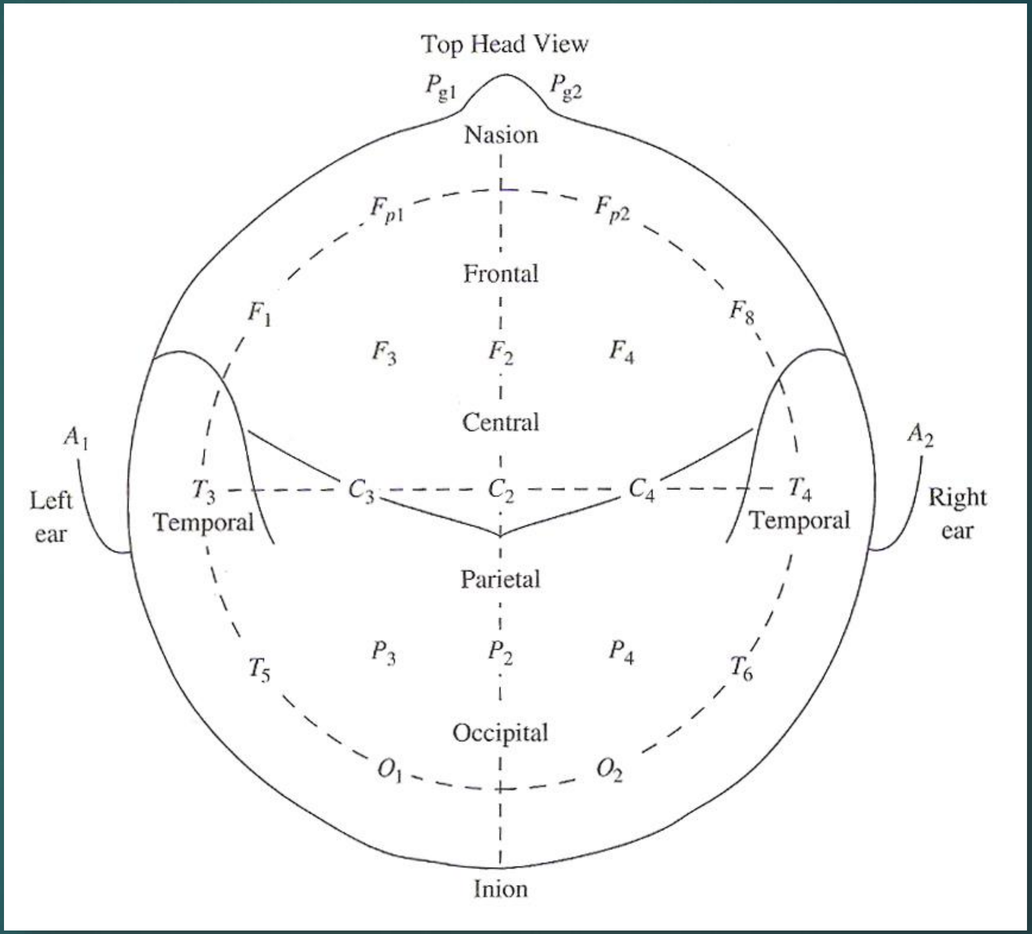
- In this setup, the head is mapped by four standard points:
  1. The nasion (nose)
  2. The inion (external occipital proturberence)
  3. Left preauricular point
  4. Right preauricular point
- Nineteen electrodes, plus one for grounding the subject is used.

10-20 System



Left Head Side View
Vertex
20%
C_2
F_2
20%
20%
F_3
C_3
P_2
P_3
10%
F_{p1}
F_7
20%
Nasion
Eye
orbit
T_3
T_5
O_1
Ear
lobe
10%
P_{g1}
Nasopharyngeal
lead
A_1
Inion

10-20 System



Top Head View
P_{g1}
P_{g2}
Nasion
F_{p1}
F_{p2}
Frontal
F_1
F_8
F_3
F_2
F_4
Central
A_1
A_2
Left
ear
T_3
Temporal
C_3
C_2
C_4
T_4
Temporal
Right
ear
Parietal
T_5
P_3
P_2
P_4
T_6
Occipital
O_1
O_2
Inion

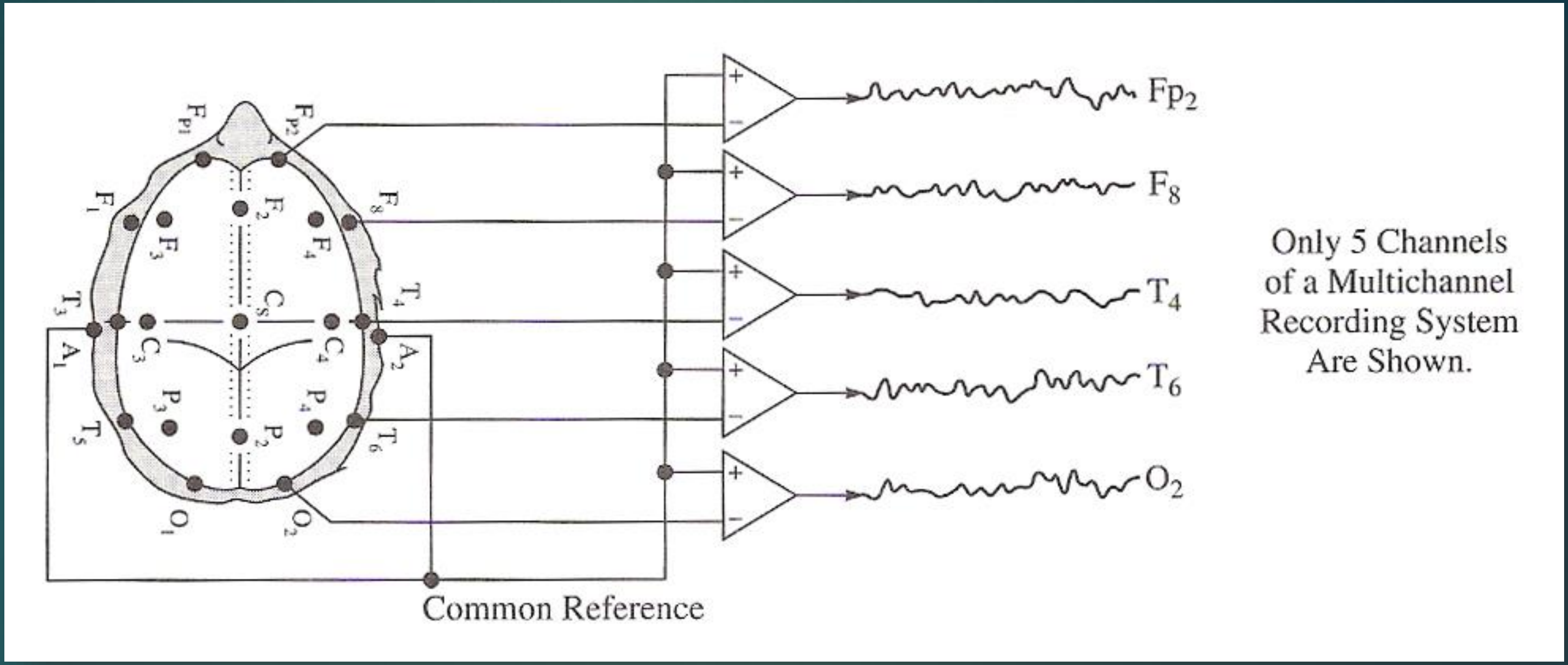
10-20 System

- Electrode arrangements may be either unipolar or bipolar.
- A unipolar arrangement:

  Composed of a number of scalp leads connected to a common indifference point such as an earlobe. Hence one electrode is common to all channels.
- A bipolar arrangement:

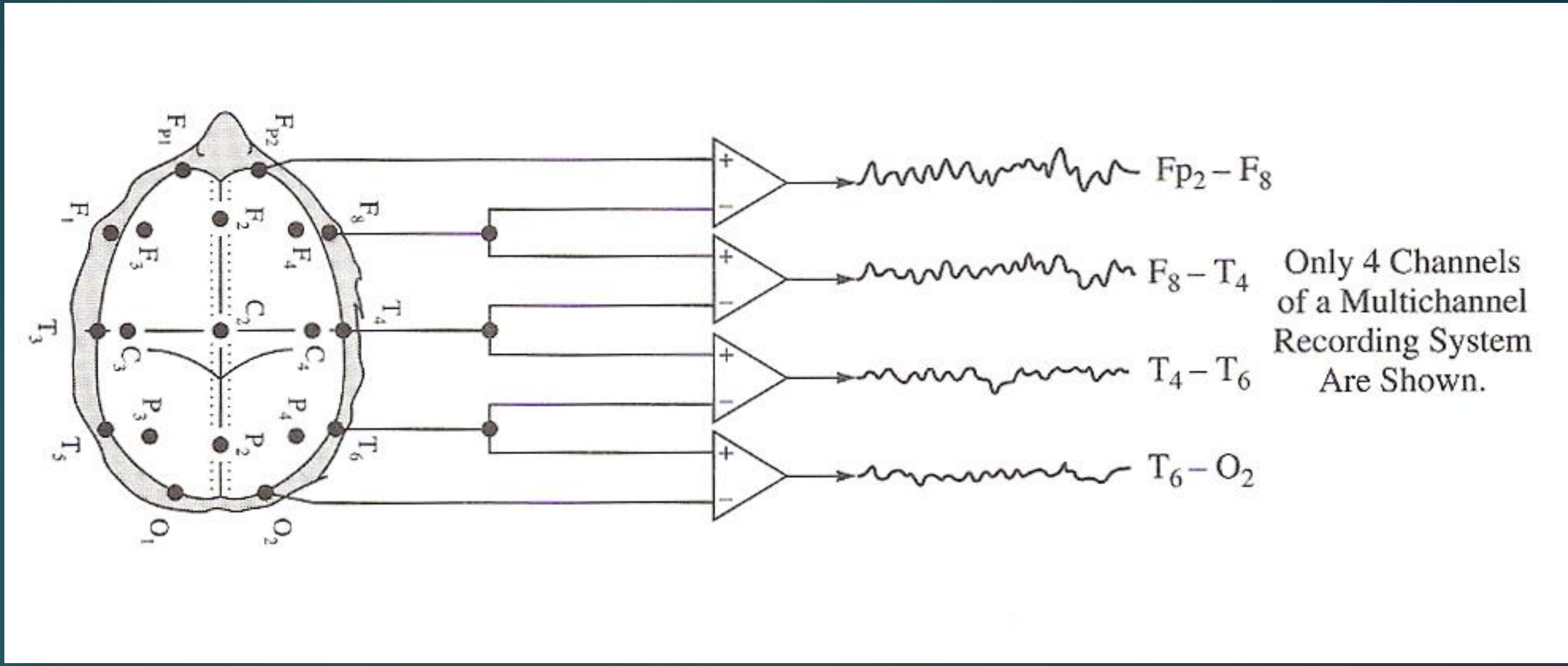
  Achieved by the interconnection of scalp electrodes.

10-20 System



Unipolar Arrangement

10-20 System



Bipolar Arrangement

EEG Frequency Bands

- EEG frequency bands are normally classified into five categories:
  1. Delta (δ): 0.5-4Hz
  2. Theta (θ): 4-8Hz
  3. Alpha (α): 8-13Hz
  4. Beta (β): 13-30Hz
  5. Gamma (γ): 30Hz and higher
- The meaning of these frequencies is not completely known.

EEG Frequency Bands

- Alpha activity
  1. Less than $10\mu V_{pp}$ and are reasonably stable.
  2. These signal arises from the posterior brain in a waking person with eyes closed.
  3. Opening and focusing attention greatly reduces alpha waves.
- Beta activity
  1. Less than $20\mu V_{pp}$ over the entire brain but is predominant over the central region at rest.
  2. High states of wakefulness and desynchronized alpha patterns produce beta waves.

EEG Frequency Bands

- Gamma activity
  1. Less than $2\mu V_{pp}$ and consists of low-amplitude, high frequency waves.
  2. Result from attention or sensory stimulation.
- Theta and Delta activity
  1. Less than $100\mu V_{pp}$ and are the strongest over the central region.
  2. Indications of sleep.
- The usable bandwidth is not much beyond 50Hz.

Further Reading…

1. The Introductory Guide to EEG(Electroencephalography), Emotiv, https://www.emotiv.com/eeg-guide
2. Webster, J.G. (1997). *Medical Instrumentation: Application and Design*. 3rd Ed., Wiley.

MEDICAL SIGNAL PROCESSING

WHAT IS SIGNAL & SIGNAL PROCESSING?

- **Signal** is a flow of information (or anything which carries information).
  - It either dependent on **single variable** (ex: time – speech signal – temporal domain) or **two variables** (ex: position – image – (x,y) – spatial), or **more variables** (ex: film – time and spatial domain)
  - If it depends on single variable – **one dimensional signal** (ex: speech, pressure, distance, position, temperature, annual rainfall at one place
  - If it depends on two variables – **two dimensional signal** (ex: image)
  - If it depends on more variables – **multi dimensional signal** (ex: our physical world – how many variables?)

General representation of signal,

$$y= f(t)$$

Where t is a independent variable which specifies the domain of the signal.

- ✓ $y=sin(\omega \boldsymbol{t})$ is a function of a variable in the **time domain** and is thus a time signal;
- ✓ $X(\omega)=1/(-m\omega^2+\boldsymbol{i}c\omega+k)$ is a **frequency domain signal**;
- ✓ An image $I(\boldsymbol{x,y})$ is in the spatial domain

WHAT IS SIGNAL & SIGNAL PROCESSING?

- **System** is a one which transforms the input into desired output.
  - (OR) **a physical device that performs an operation on a signal**
  - Example: Amplifier, Noise canceller, etc
- **Signal processing** – method or processing of signal to extract some useful information.
  - **Mathematical representation** of signal and the **algorithmic operation** carried out on it to **extract the information** present in it.
- **Digital Signal Processing** – if the processing is done by a digital computer or digital processor to extract some useful information from the signal.
- **Medical Signal Processing** – if we process the **biomedical signals** to extract some useful **information about human physiological activity** using **digital computer or digital processor**.

DSP - APPLICATIONS

- **Sound applications**
  - Compression, enhancement, special effects, synthesis, recognition, echo cancellation,…
  - Cell Phones, MP3 Players, Movies, Dictation, Text-to-speech,…
- **Communication**
  - Modulation, coding, detection, equalization, echo cancellation,…
  - Cell Phones, dial-up modem, DSL modem, Satellite Receiver,…
- **Automotive**
  - ABS, GPS, Active Noise Cancellation, Cruise Control, Parking,…
- **Medical**
  - Magnetic Resonance, Tomography, Electrocardiogram,…
- **Military**
  - Radar, Sonar, Space photographs, remote sensing,…
- **Image and Video Applications**
  - DVD, JPEG, Movie special effects, video conferencing,…
- **Mechanical**
  - Motor control, process control, oil and mineral prospecting,…

SIGNAL PROCESSING

- Humans are the **most advanced signal processors**
  - speech and pattern recognition, speech synthesis,…
- We encounter **many types of signals** in various applications
  - Electrical signals: voltage, current, magnetic and electric fields,…
  - Mechanical signals: velocity, force, displacement,…
  - Acoustic signals: sound, vibration,…
  - Other signals: pressure, temperature,…
- Most **real-world signals are analog**
  - They are continuous in time and amplitude
  - Convert to voltage or currents using sensors and transducers
- Analog circuits **process these signals** using
  - Resistors, Capacitors, Inductors, Amplifiers,…
- Analog signal processing **examples**
  - **Audio processing** in FM radios
  - **Video processing** in traditional TV sets

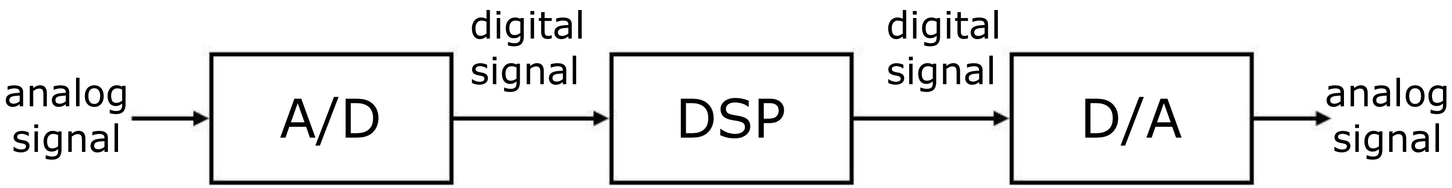
LIMITATIONS OF ANALOG PROCESSING

- Accuracy **limitations** due to
  - Component tolerances
  - Undesired nonlinearities
- Limited **repeatability** due to
  - Tolerances
  - Changes in environmental conditions
    - Temperature
    - Vibration
- Sensitivity to electrical noise
- Limited dynamic range for voltage and currents
- Inflexibility to changes
- Difficulty of implementing certain operations
  - Nonlinear operations
  - Time-varying operations
- Difficulty of storing information

Dynamic Range: the ratio of a specified maximum level of a parameter, such as power, voltage, current or frequency, to the minimum detectable value of that parameter.

DIGITAL SIGNAL PROCESSING

- Represent signals by a sequence of numbers
  - Sampling or analog-to-digital conversions
- Perform processing on these numbers with a digital processor
  - Digital signal processing
- Reconstruct analog signal from processed numbers
  - Reconstruction or digital-to-analog conversion



- **Conversions:**
  - Analog input – analog output
    - Digital recording of music
  - Analog input – digital output
    - Touch tone phone dialing
  - Digital input – analog output
    - Text to speech
  - Digital input – digital output
    - Compression of a file on computer

PROS AND CONS OF DSP

- **Pros**
  - Digital information can be encrypted for security
  - Repeatable
  - Sensitivity to electrical noise is minimal
  - Digital storage is cheap
  - Accuracy can be controlled by choosing word length
  - Price/performance and reduced time-to-market
  - Flexibility can be achieved with software implementations
  - Non-linear and time-varying operations are easier to implement
  - Dynamic range can be controlled using floating point numbers
- **Cons**
  - Sampling causes loss of information
  - A/D and D/A requires mixed-signal hardware
  - Limited speed of processors
  - Quantization and round-off errors

HANDLING OF SIGNALS IN DSP

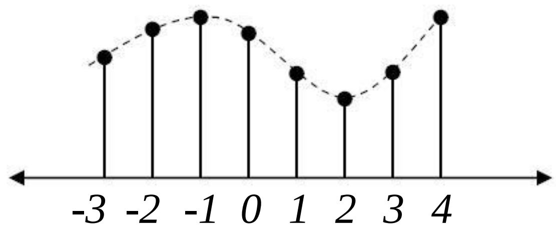
- Most introductions to signals and systems deal strictly with deterministic signals.
- Each value of these signals are fixed and can be determined by a mathematical expression, rule, or table.
- Because of this, future values of any deterministic signal can be calculated from past values.
- For this reason, these signals are relatively easy to analyze as they do not change, and we can make accurate assumptions about their past and future behavior.

RANDOM SIGNALS

- Random Signals
  - Unlike deterministic signals, **stochastic signals** or random signals, are not so nice.
  - Random signals cannot be characterized by a simple, well-defined mathematical equation.
  - Their future value cannot be predicted. Rather, we must use probability and statistics to analyze their behavior.
  - Also, because of their randomness, average values from a collection of signals are usually studied rather than analyzing one individual signal.

SAMPLING

- Sampling is a process of converting continuous to discrete-time conversion.



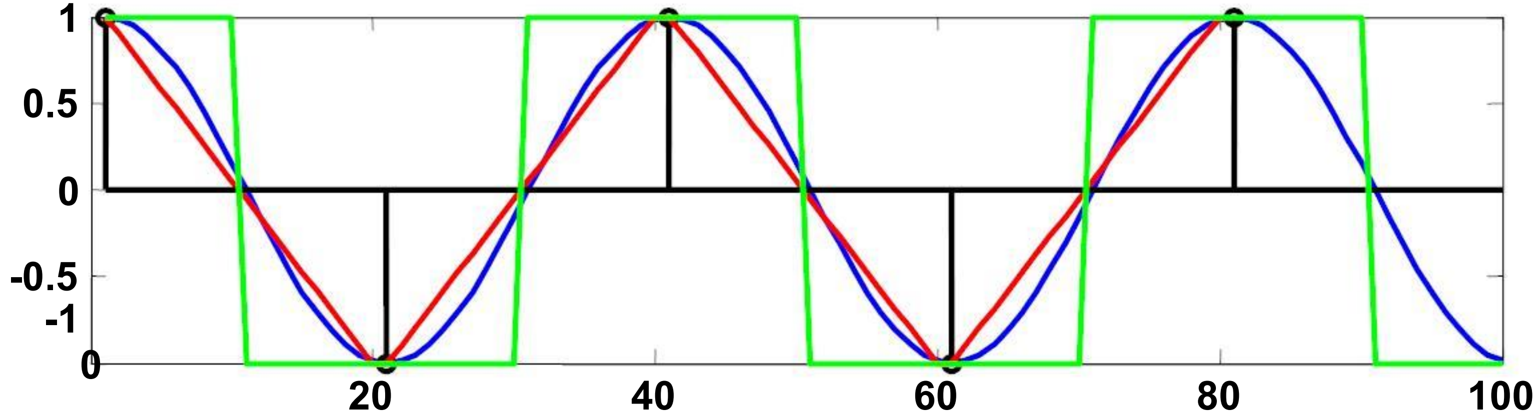
- Types of sampling: Periodic and Non-periodic
  - Periodic : Samples are placed at constant distance
  - Non-periodic: Samples are not placed at constant distance
- Most common type of sampling is periodic

$$x[n] = x_c(nT), \quad -\infty < n < \infty$$

  - T is the sampling period in second
  - fs = 1/T is the sampling frequency in Hz
  - Sampling frequency can also be expressed as radian per second $\Omega_s = 2\pi f_s$ rad/sec
  - Use [.] for discrete – time and (.) for continuous time signals
- In practice, Analog to Digital Convertor (ADC) is used to perform sampling in digital signal processing.

SAMPLING

- Sampling is, in general, is not reversible process.
- Given a sampled signal one could fit infinite continuous signals through samples.

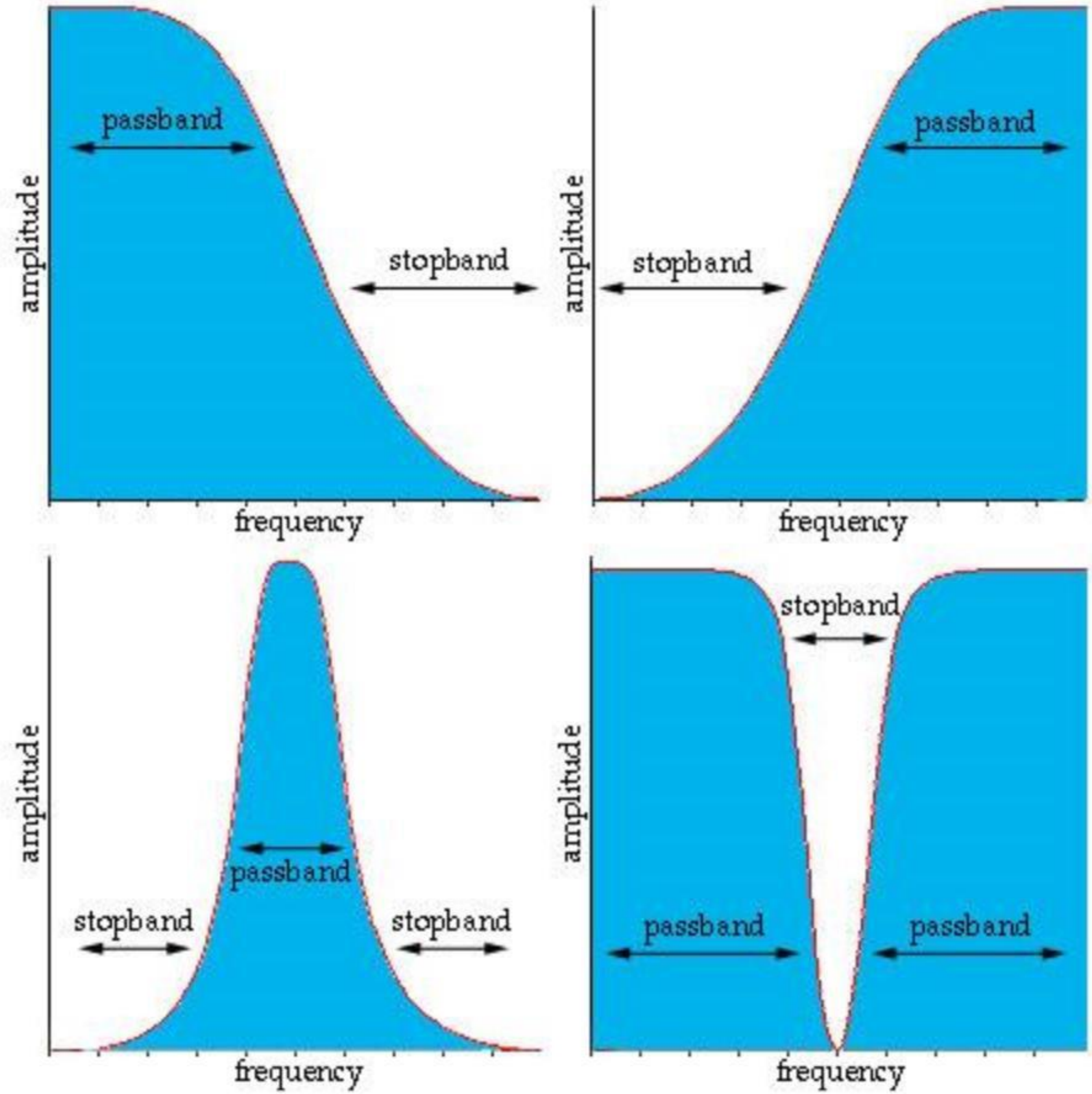


- **Limitations:**
  - If we loose any information during sampling, that cannot be recovered it at any time
  - Choice of proper sampling method is more important and higher sampling rate gives us more valuable information about the continuous – time signal information in discrete – time domain.
- **Constraint:**
  - **It should satisfy Nyquist Sampling criteria fs ≥ 2fm (**where fs: sampling frequency and fm is the maximum frequency of interest in original signal)

FILTERING

- It is one of the most widely used complex signal processing operations.
- The system implementing this operation is called a filter.
- **A filter passes certain frequency components without any distortion and blocks other frequency components**.
- The range of frequencies that is allowed to pass through the filter is called the passband and the range of frequencies that is blocked by the filter is called the stopband.
- In most cases the filtering operation for analog signals is linear
- The filtering operation of a linear analog filter is described by the convolution integral

TYPES OF FILTERS



FILTERING

- **Lowpass Filters**
  - A lowpass filter passes all low-frequency components below a certain specified frequency f_c called cutoff frequency and blocks all high-frequency components above f_c.
- **Highpass Filters**
  - A high pass filter passes all high-frequency components a certain cutoff frequency f_c and blocks all low-frequency components below.
- **Bandpass Filters**
  - A bandpass filter passes all frequency components between 2 cutoff frequencies f_{c1} and f_{c2} where $f_{c1} < f_{c2}$ and blocks all frequency components below $f_{c\,1}$ and above f_{c2}.
- **Bandstop Filters**
  - A bandstop filter blocks all frequency components between 2 cutoff frequencies $f_{c\,1}$ and f_{c2} where $f_{c1} < f_{c2}$ and passes all frequency below f_{c1} and above f_{c2}.

OTHER TYPES OF FILTERS

- **Notch Filter**
  - A filter that blocks a single frequency component is called a notch filer.
  - Example: A notch filter to remove the power frequency noise.
- **Multiband Filter**
  - A multiband filter has more than one passband and more than one stopband.
- **Comb Filter**
  - A comb filter blocks frequencies that are integral multiplies of a low frequency

FILTERING

- In many applications the desired signal occupies a low-frequency band from dc to some frequency f_L Hz and gets corrupted by a high-frequency noise with frequency components above f_H Hz with $f_H > f_L$.
- In such cases the desired signal can be recovered from the noise-corrupted signal by passing the latter through a lowpass filter with a cutoff frequency f_c where $f_L < f_c < f_H$.
- A common source of noise is power lines radiating electric and magnetic fields. The noise generated by power lines appears as a 50 Hz sinusoidal signal corrupting the desired signal and can be removed by passing the corrupted signal through a notch filter with a notch frequency of 50 Hz.

Data Collection Protocol

THINGS TO AVOID DURING PROTOCOL DESIGN

Type of Noises in EEG

- External, environmental sources of noise
  - AC power lines, lighting and a large array of electronic equipment (from computers, displays and TVs to wirelles routers, notebooks and mobile phones).
- Physiological noise
  - Common examples of such noise are cardiac signal (electrocardiogram, ECG), movement artifacts caused by muscle contraction (electromyogram, EMG) and ocular signal caused by eyeball movement (electrooculogram, EOG). Of these, ECG signal is not preventable, but also has the lowest effect on the recorded EEG signal. Noise caused by EMG and EOG signals can often be avoided.

Reduce external noise

- The most basic steps in dealing with environmental noise are removing any unnecessary sources of electro-magnetic (EM) noise from the recording room and its immediate vicinity, and, where possible, replacing equipment using alternate current with equipment using direct current (such as direct current lighting).
- A more advanced and costly measure is to insulate the recording room from EM noise by use of a Faraday cage. While very effective in eliminating most of environmental EM noise, EM insulation requires either advance planning or costly rebuilding work.

Reduce physiological noise

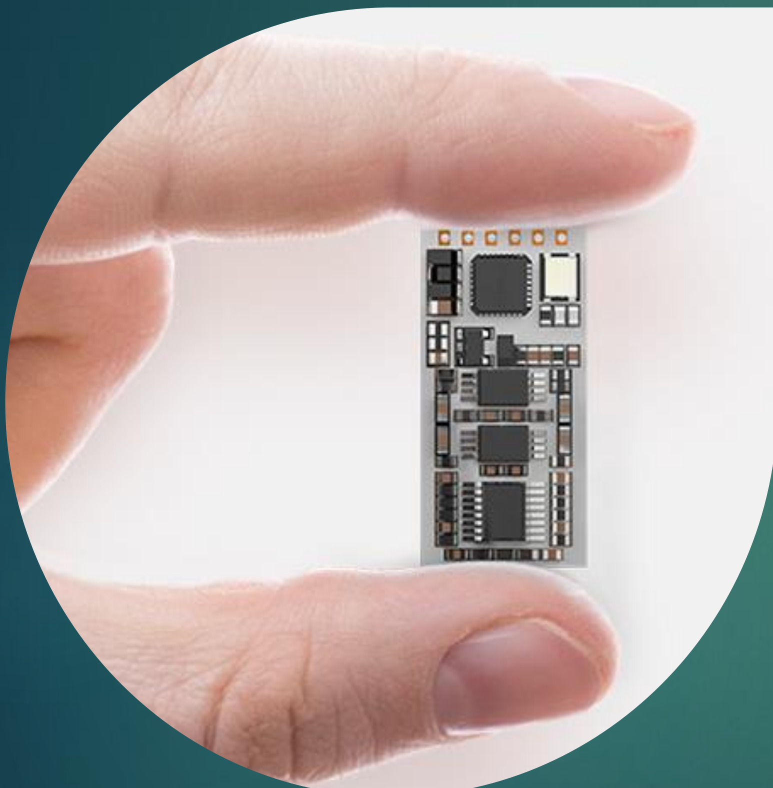
- EMG noise can be avoided or reduced by asking the participant to find a comfortable position and relax before the start of a recording session, and by avoiding tasks that require verbal responses or large movements.
- EOG signals are generated by eye saccades or pursuit movements as well as blinks. Saccade and pursuit movement signals can be avoided by designing tasks that do not require eye movements but rather encourage participants to hold gaze in the same location throughout the critical periods of the task. Blinks are more difficult to avoid; one possibility is to ask participants not to blink during critical periods of the task and then provide cues for periods when they can blink freely.

Creating EEG Device using Mindata

EEG Sensor Pads

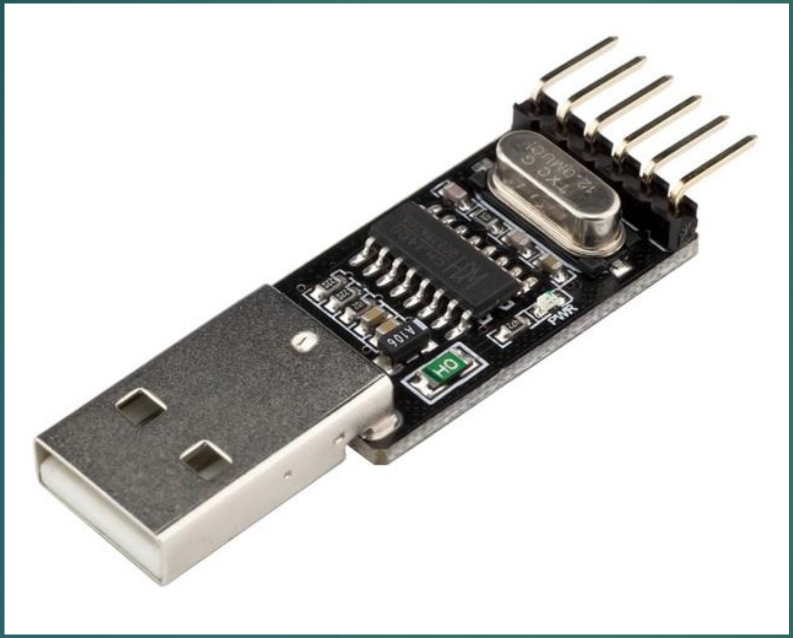
Snap-on Lead Wires

Mindata Chip

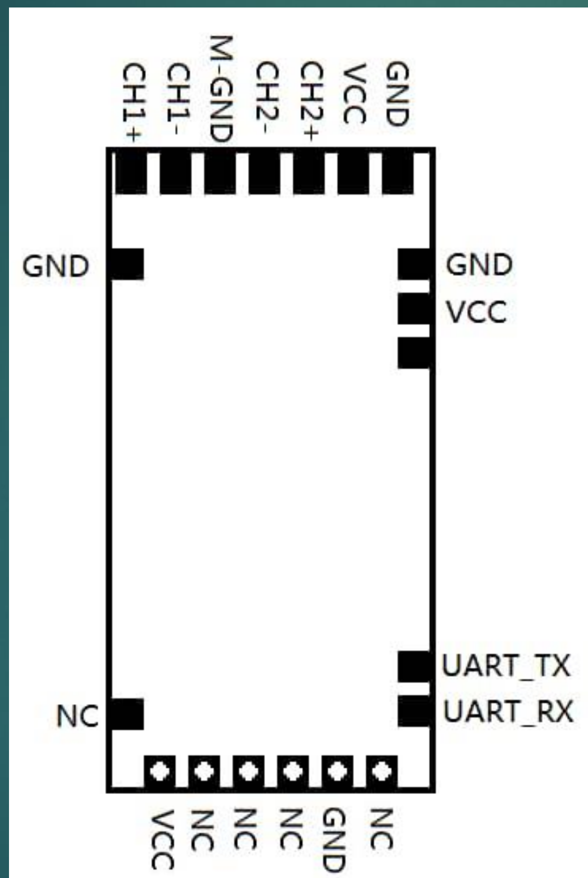


Mindata	
Component Size	28mm X 13mm X 2.3mm
EEG Channel	2 channe
Collection Rate	256Hz
Brain wave Frequency Range	0.16Hz - 100 Hz
Baud rate Output	115200
Data Bits	8
Transmission Speed	921,600bps
Power Consumption	13mA @ 3.3v
Electrostatic Discharge	4kV Contact
Output Interface Standard	UART (Serial)

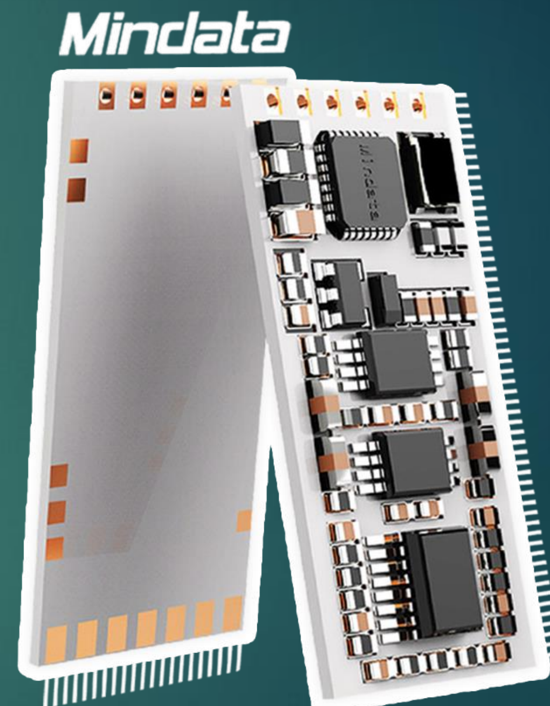
USB To TTL UART, CH340



Datasheet



CH1+
CH1-
M-GND
CH2-
CH2+
VCC
GND
GND
GND
VCC
UART_TX
NC
UART_RX
VCC
NC
NC
NC
GND
NC



Mindata

Thank you