

# Foundations of Psychophysiology

Part 3: Foundations of psychophysiological measurement

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NEUROADAPTIVE  
HUMAN-COMPUTER  
INTERACTION



Brandenburg  
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# Psychophysiology

## Measuring (electro)physiological parameters

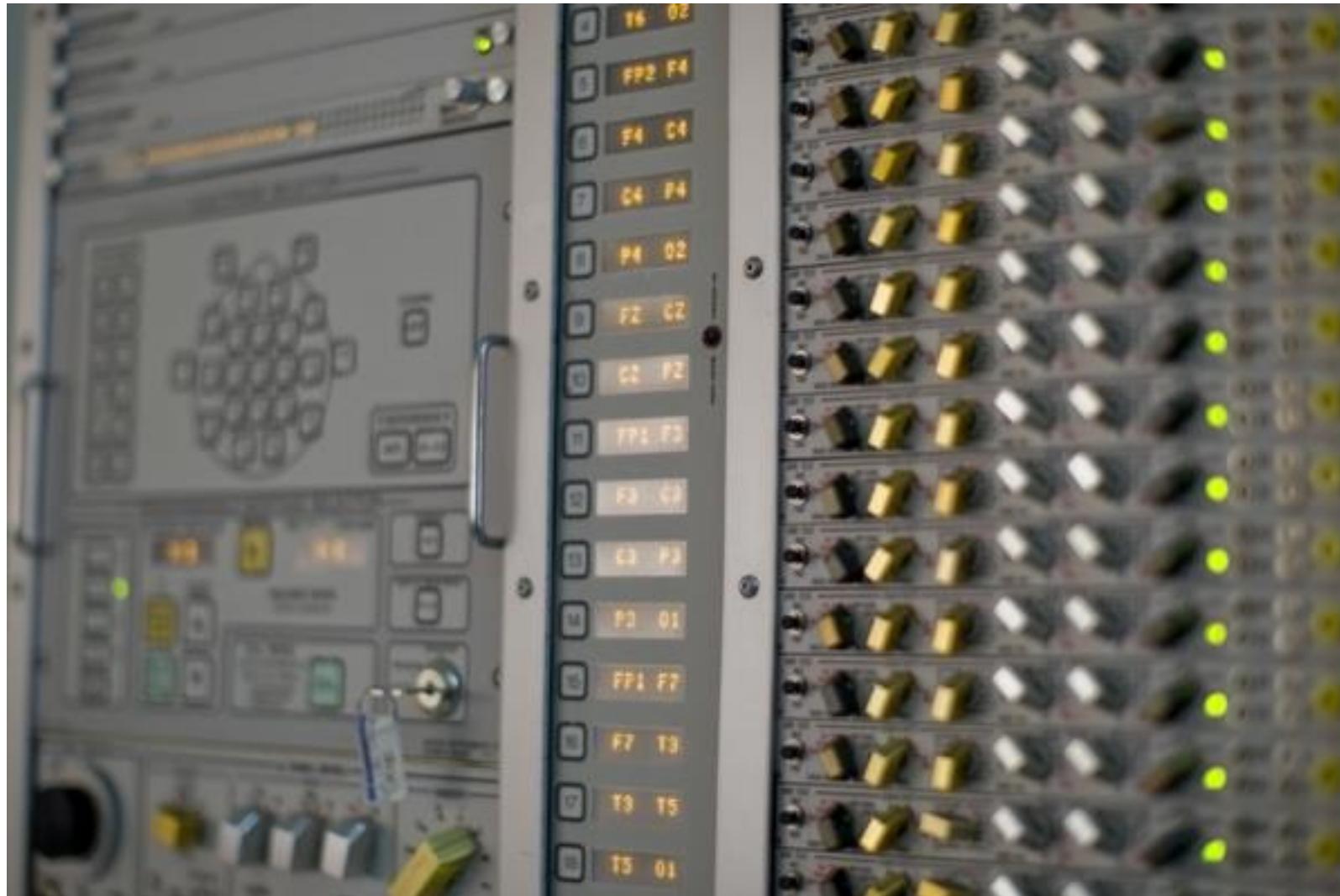
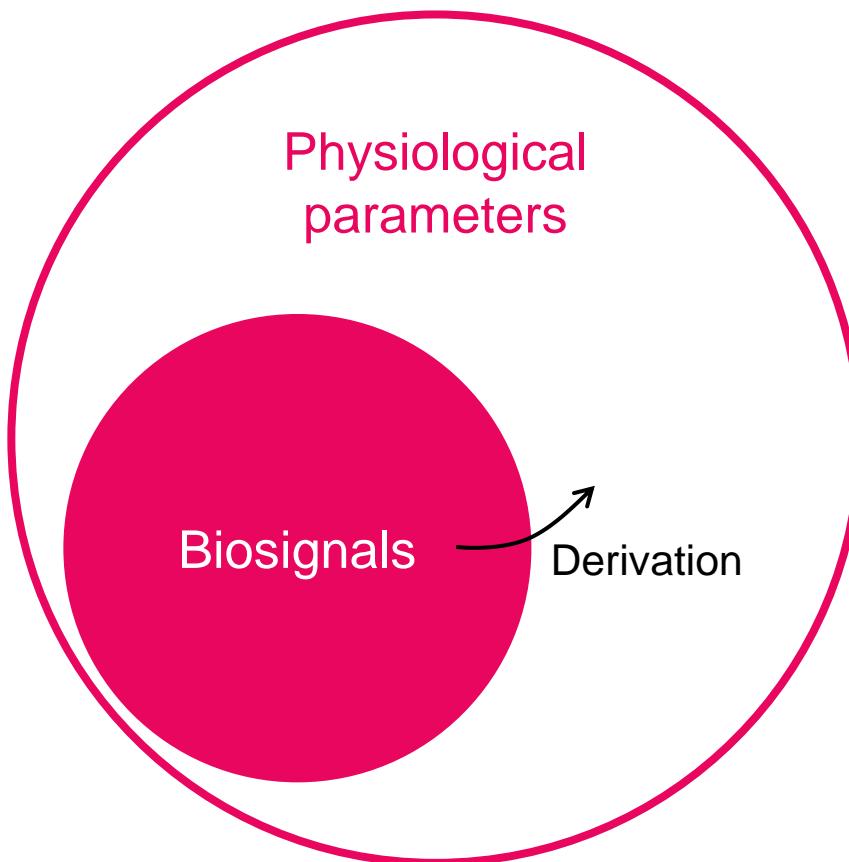


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# Psychophysiology: Measurement

## Biosignals

Directly measurable, time-varying parameters that reflect physiological activity in living beings are referred to as biosignals.



# Psychophysiological measurement

## Contents

Electricity

Electrodes

Digital signals

Psychophysiological measurement

## **Electricity**

# Psychophysiology: Measurement

## Electricity

- Current

The flow of charged particles through a conductor, measured in ampere (A).

- Voltage

The potential for current to flow from one place to another, measured in volt (V).

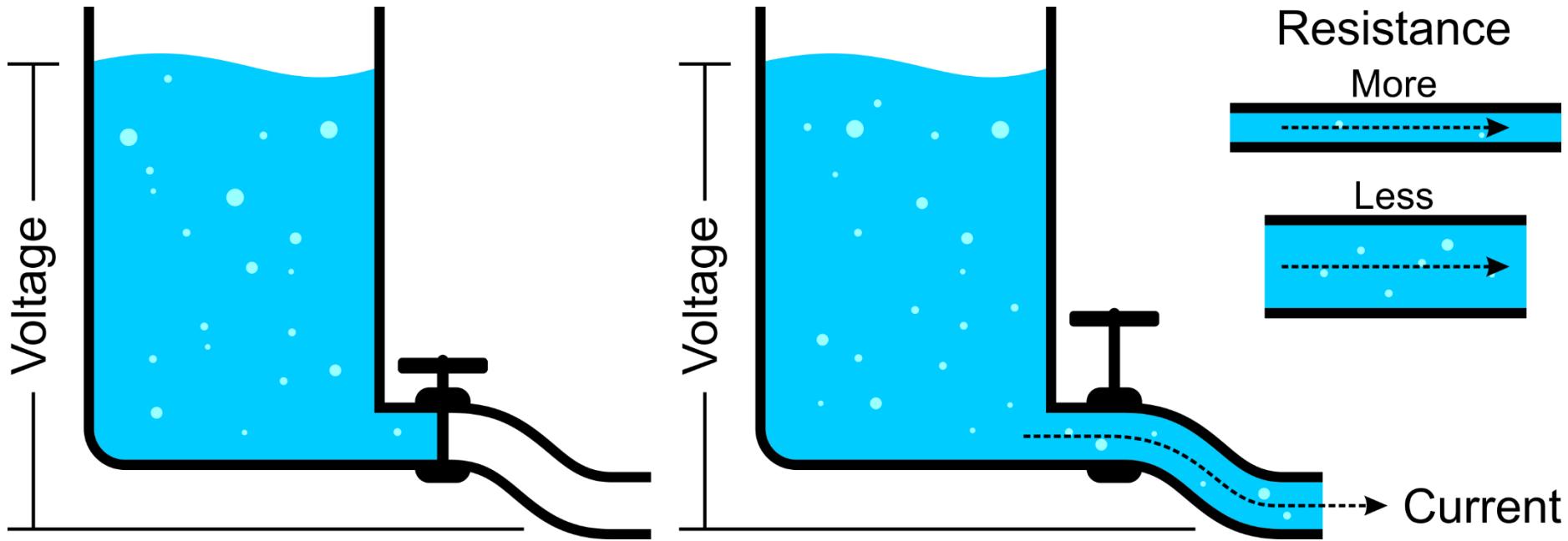
- Resistance

A substance's ability to resist the flow of current, measured in ohm ( $\Omega$ ).

Impedance is resistance for alternating currents.

# Psychophysiology: Measurement: Electricity

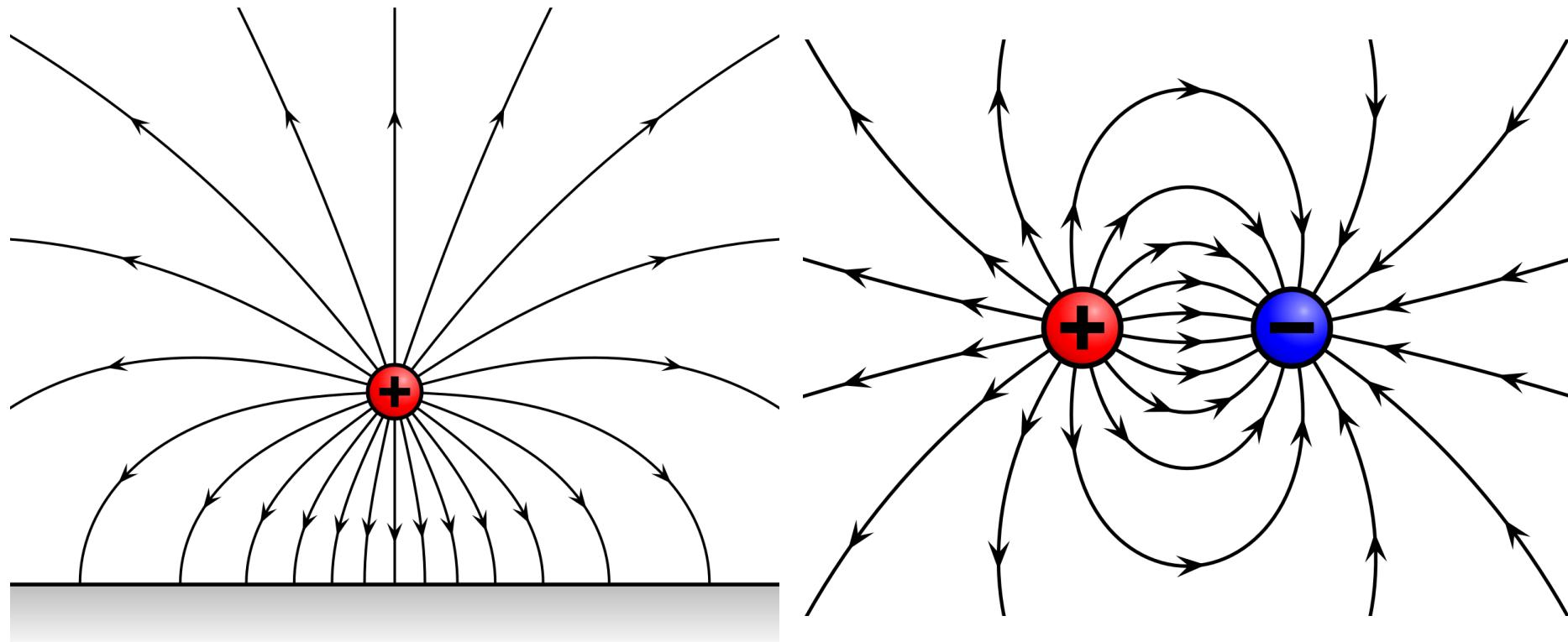
## Electricity: Water analogy



$$\text{Ohm's law: } R = \frac{V}{I}$$

# Psychophysiology: Measurement: Electricity

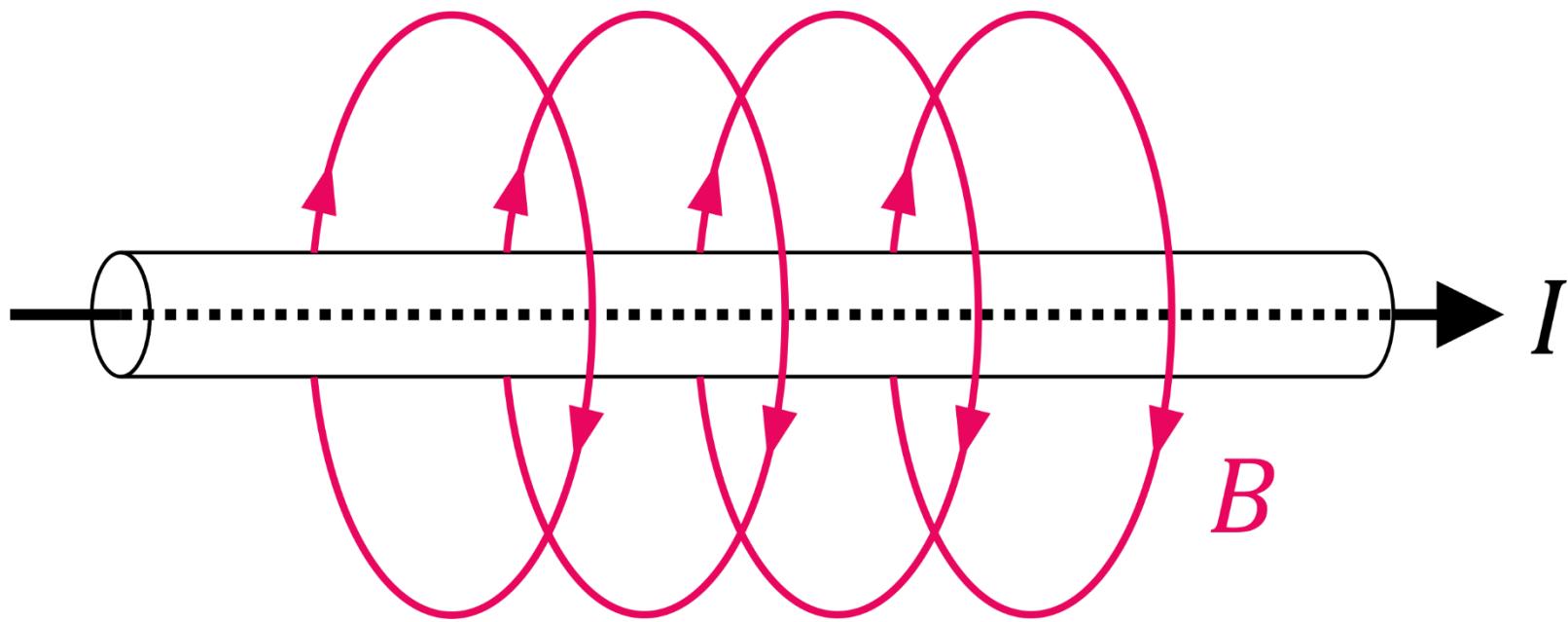
## Electric fields



# Psychophysiology: Measurement: Electricity

## Electromagnetism

A current produces a magnetic field.



A magnetic fields induces a current.

# Psychophysiological measurement

## Electrodes

# Psychophysiology: Measurement

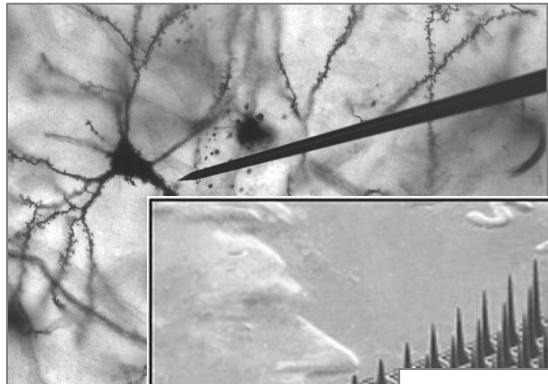
## Electrodes

Biosignals that are of an electric nature can be measured using electrodes.

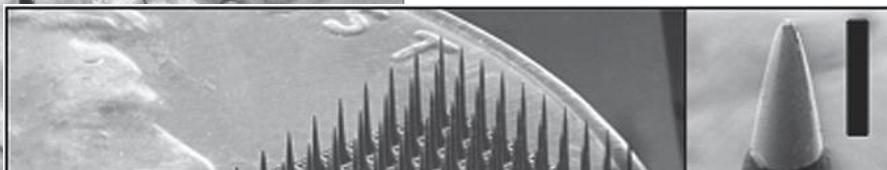
An electrode is an element of an electronic circuit that connects it to a nonmetallic part – such as the human body.

# Psychophysiology: Measurement: Electrodes

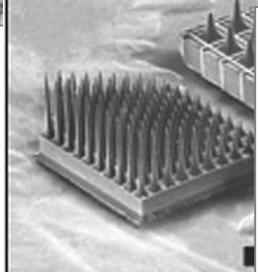
## Types of electrodes



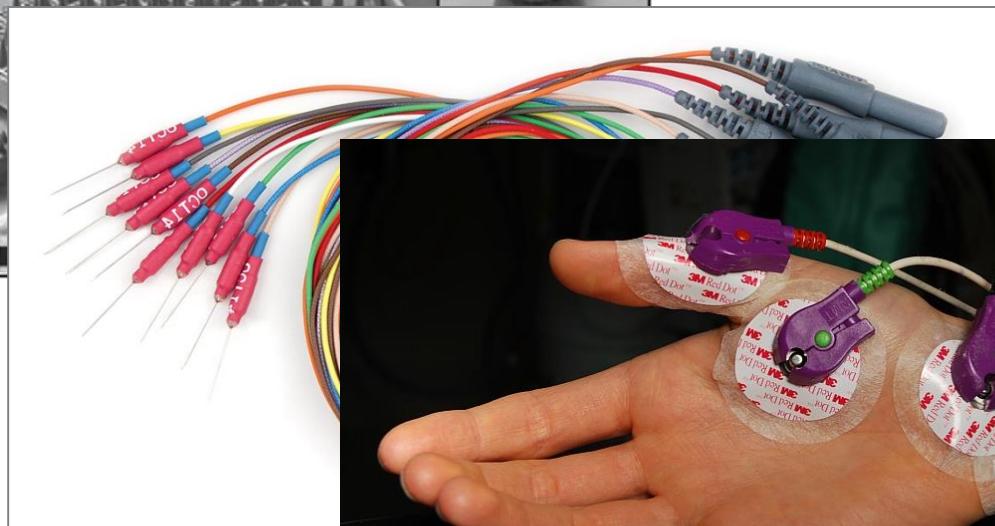
Microelectrodes



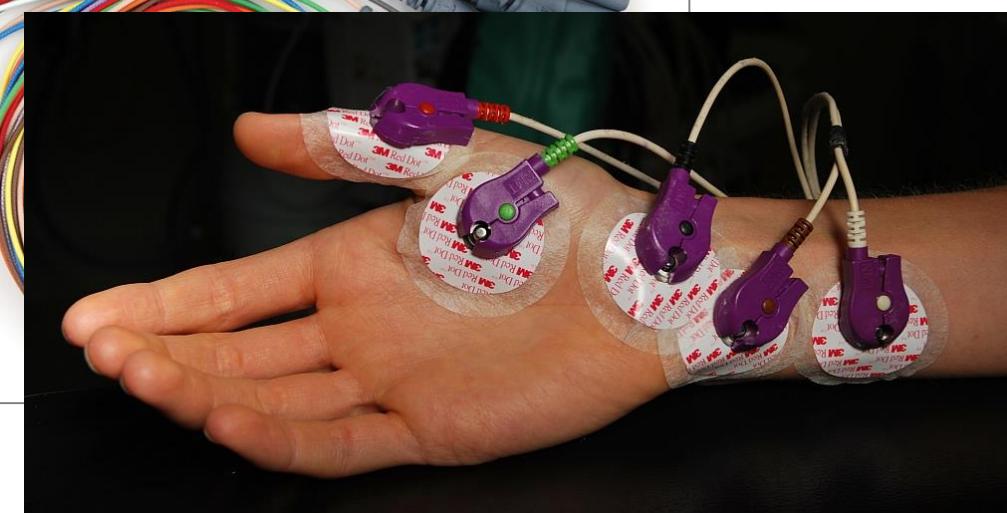
Microelectrode arrays



Subdermal electrodes



Surface electrodes



Microelectrode: original photo "pyramidal hippocampal neuron 40x" by MethoxyRoxy is licensed under [CC BY-SA 2.5](#) / Added electrode  
Microelectrode array: Wark, H. A. C., Sharma, R., Mathews, K. S., Fernandez, E., Yoo, J., Christensen, B., ... Tathireddy, P. (2013). A new high-density (25 electrodes/mm<sup>2</sup>) penetrating microelectrode array for recording and stimulating sub-millimeter neuroanatomical structures. *Journal of Neural Engineering*, 10(4), 045003. doi: 10.1088/1741-2560/10/4/045003. Licensed under CC BY-NC-SA 3.0.

Subdermal electrodes: © Natus Medical Incorporated. Surface electrode photo by Paul Anthony Stewart is licensed under [CC BY-SA 4.0](#)

# Psychophysiology: Measurement: Electrodes

## Choice of electrode

The goal is to have the highest possible signal-to-noise ratio.

An ideal electrode does not change the properties of the tissue it is connected to, nor does it interfere with the signal it measures.

The ideal electrode does not exist.

Choose the electrode material and placement based on the biosignal you intend to measure.

# Psychophysiology: Measurement: Electrodes

## Electrode placement

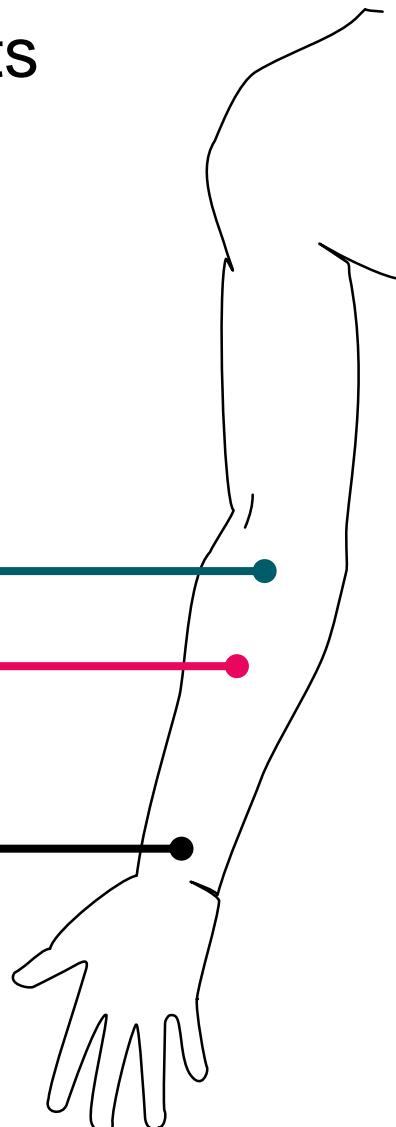
Most physiological measurements reflect potential differences.

What is needed to record one channel of such *biopotentials*?

Reference electrode

Recording electrode

Ground electrode



# Psychophysiology: Measurement: Electrodes

## Bipolar and unipolar recording techniques

Placement specifics will be discussed for the different psychophysiological modalities. In general, there is:

- Bipolar measurement:

Each recorded channel reflects the difference between two (different) electrodes.

- Unipolar or reference measurement:

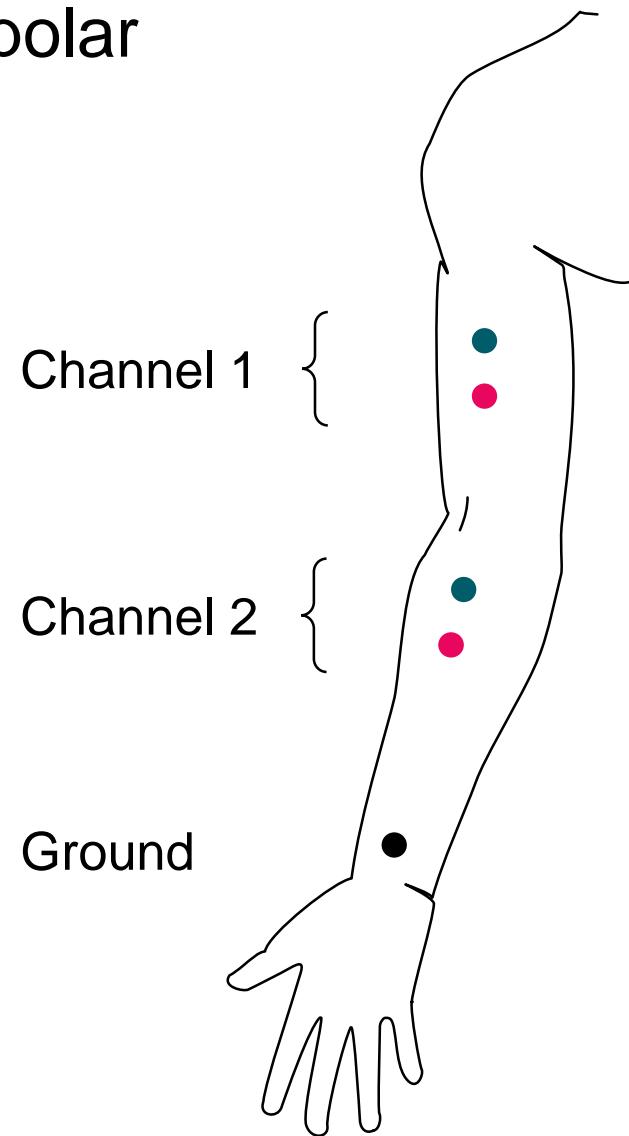
All recorded channels share the same reference electrode.

(Either way, all electrodes do usually share the same ground electrode.)

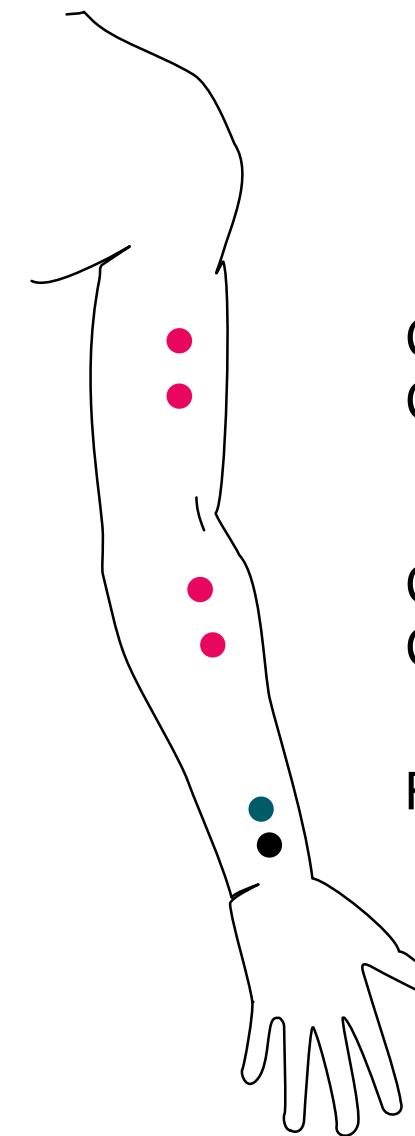
# Psychophysiology: Measurement: Electrodes

## Bipolar and unipolar recording techniques

Bipolar



Unipolar



# Psychophysiology: Measurement: Electrodes: Unipolar

## The reference electrode in unipolar recordings

Recording or “active” electrodes are placed near “electrically active” regions to measure voltage relative to an “electrically neutral” reference electrode.

However, there is no “electrically neutral” reference location on the human body.

Use a reference location that has a good connection.

Use a reference location that is common practice for the experiment you’re conducting.

(NB: The term “active electrode” often also refers to electrodes that have their own pre-amplifier built-in)

# Psychophysiological measurement

## Digital signals

# Psychophysiology: Measurement

## Digitizing the measurement

Physiological activity represents a continuous, often very small, analog signal.

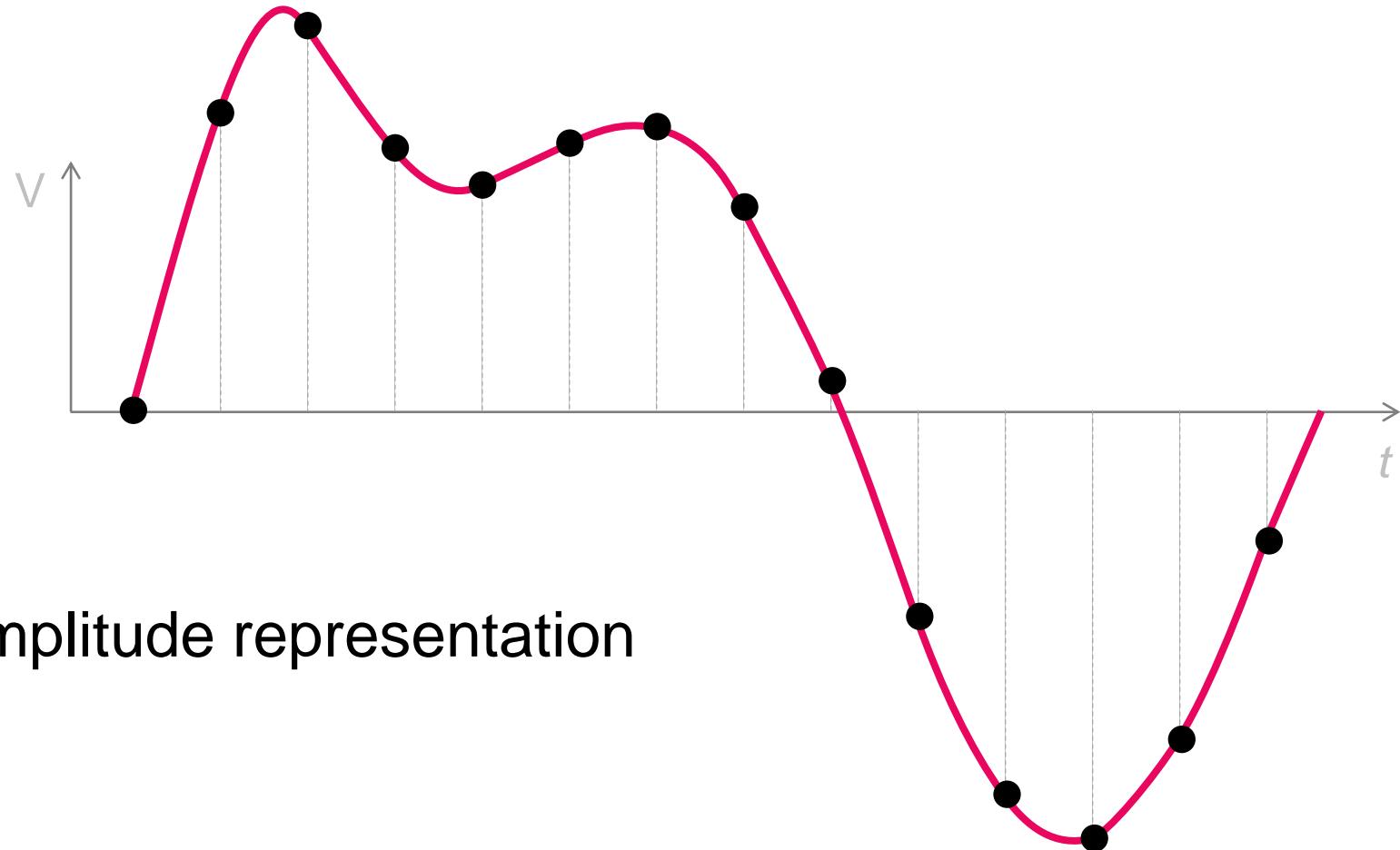
To record biosignals, they need to be amplified and digitized, turning them into discrete-time signals.

Different signals may require different degrees of amplification, and different sampling rates.



# Psychophysiology: Measurement: Signal

## Temporal signal properties

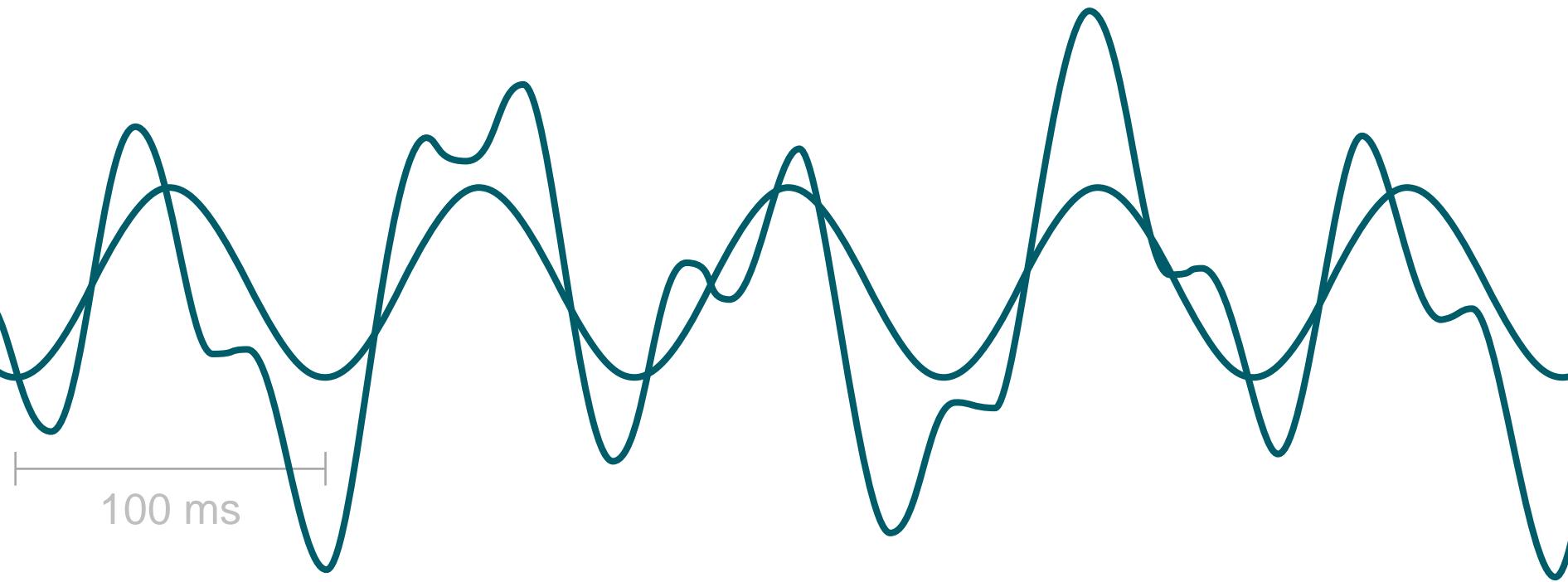


Time-amplitude representation

# Psychophysiology: Measurement: Signal

## Spectral signal properties

Time-varying signals can be very complex.

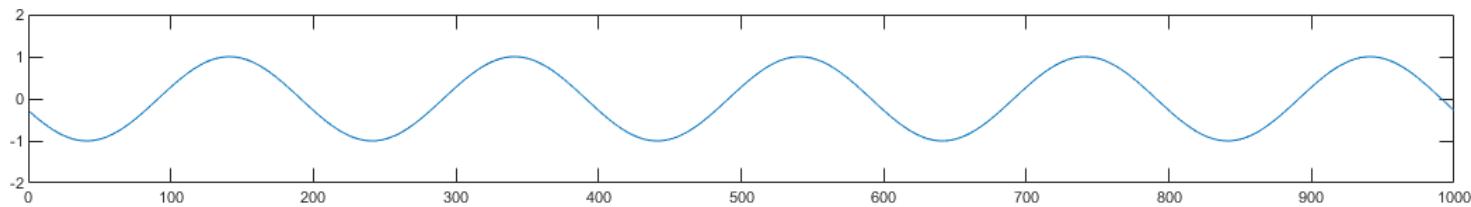


It is sometimes easier to look at them as frequencies.

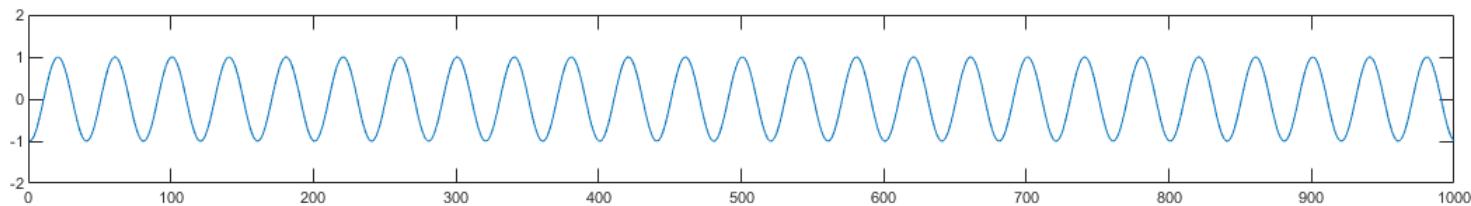
# Psychophysiology: Measurement: Signal: Spectral properties

## Mixing frequencies

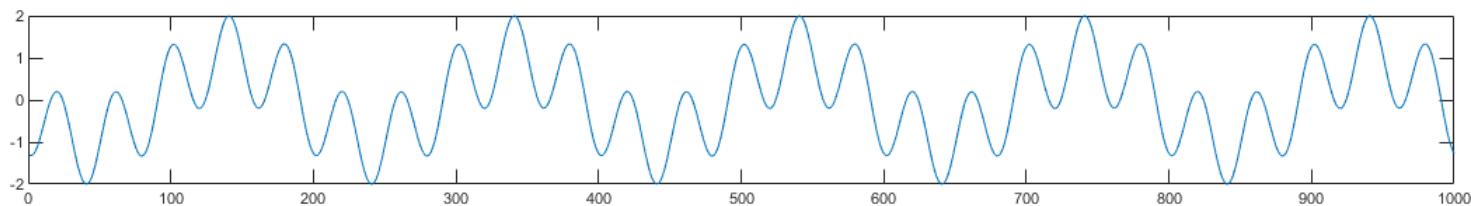
5 Hz



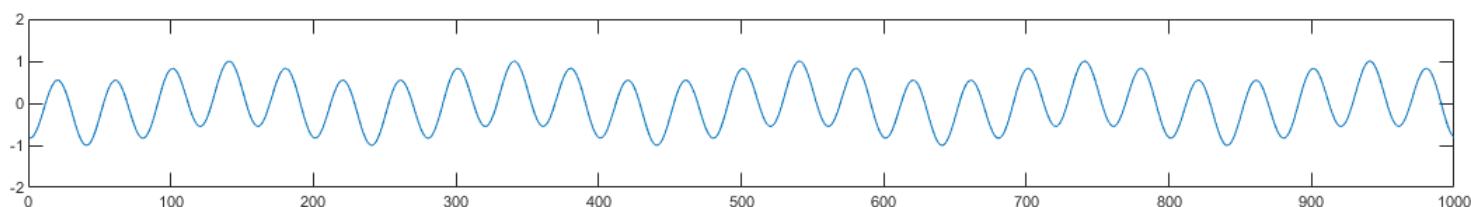
25 Hz



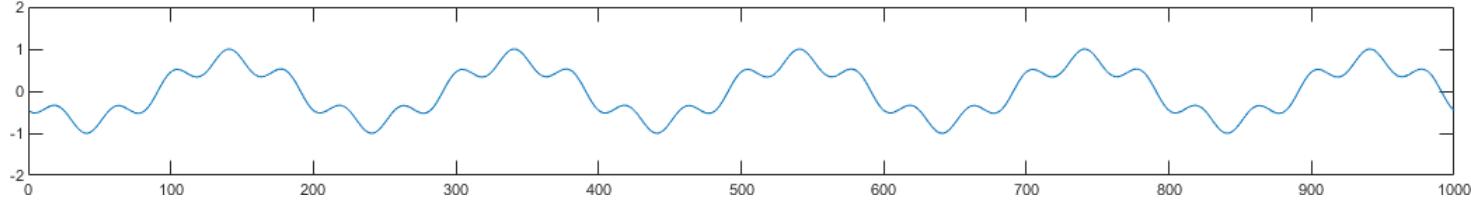
5 + 25



$\frac{1}{4}(5) + \frac{3}{4}(25)$

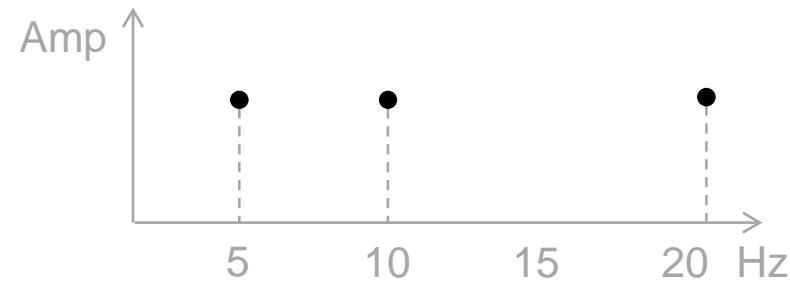
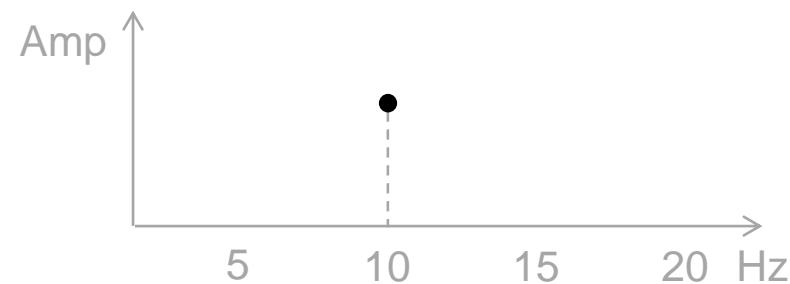
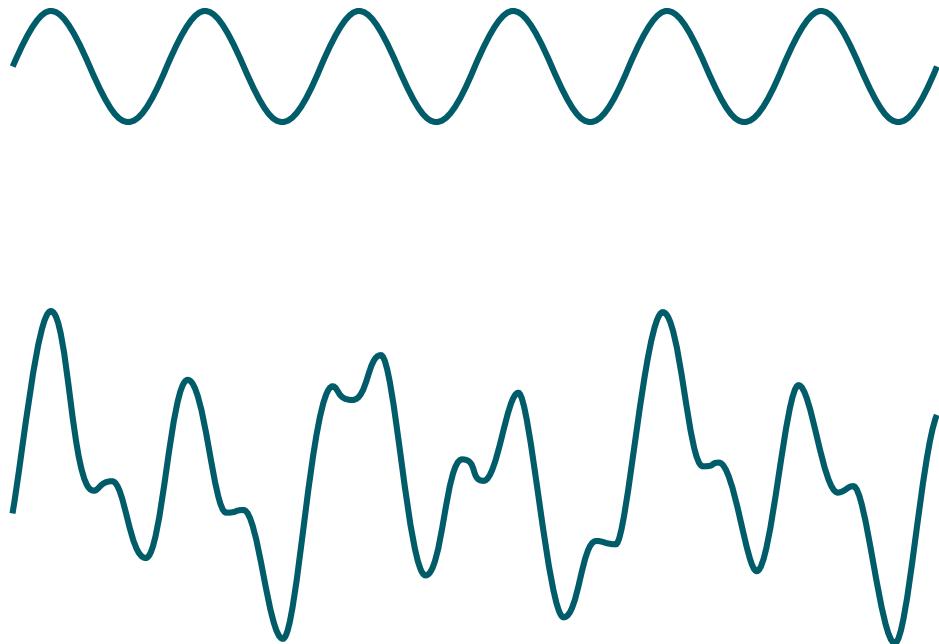


$\frac{3}{4}(5) + \frac{1}{4}(25)$



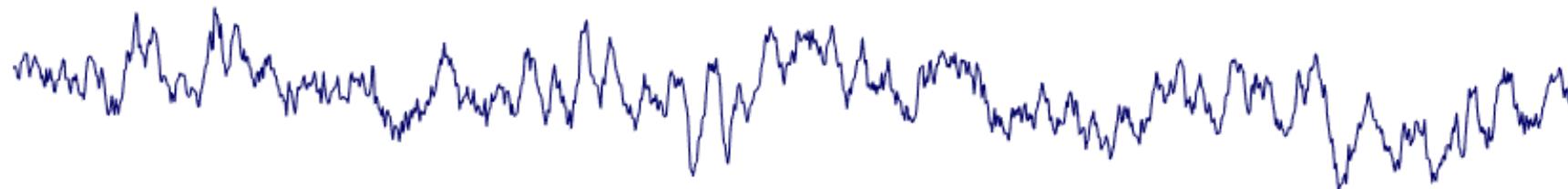
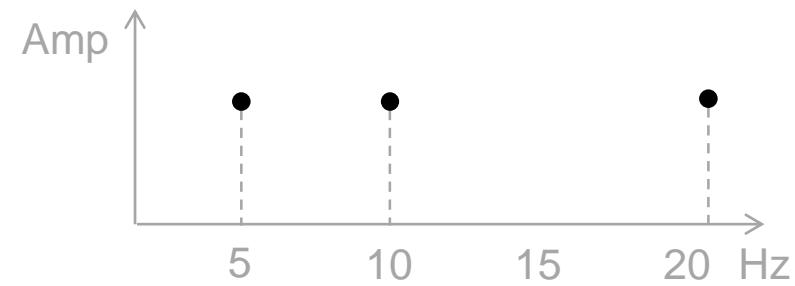
## Spectral analysis

Frequency-amplitude representation



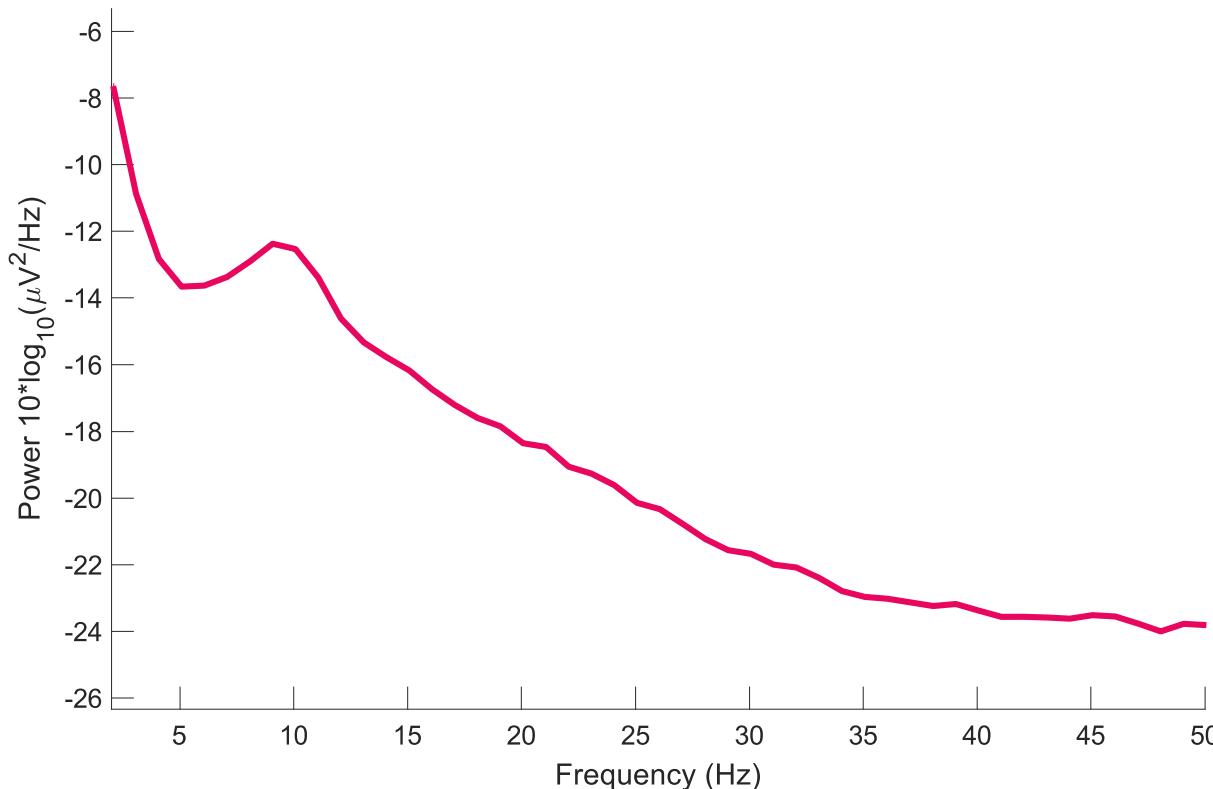
## Spectral analysis

Real data is more complex!



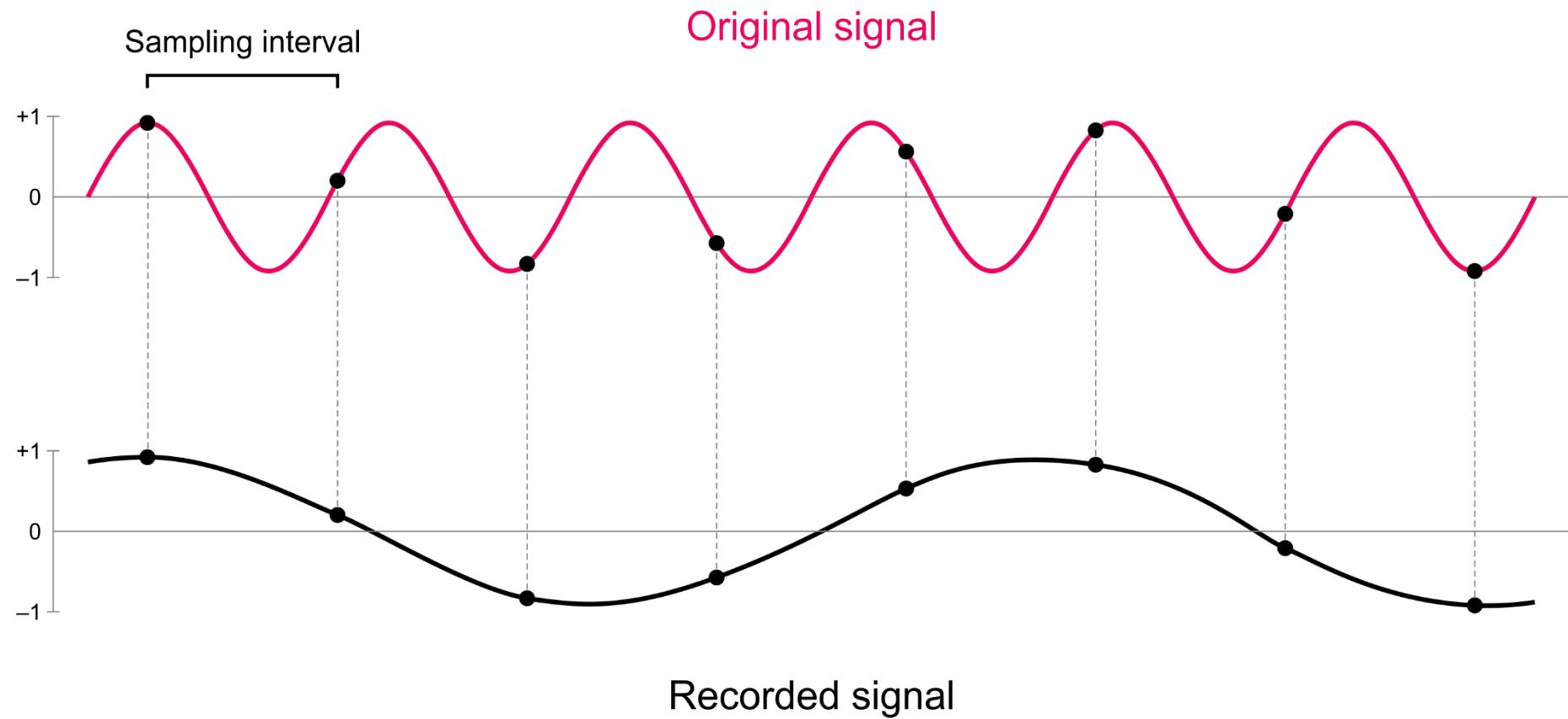
## Frequency spectrum

One way to analyse data is to look at its power spectrum, representing the power (amplitude) in all the different frequencies contributing to the recorded signal.



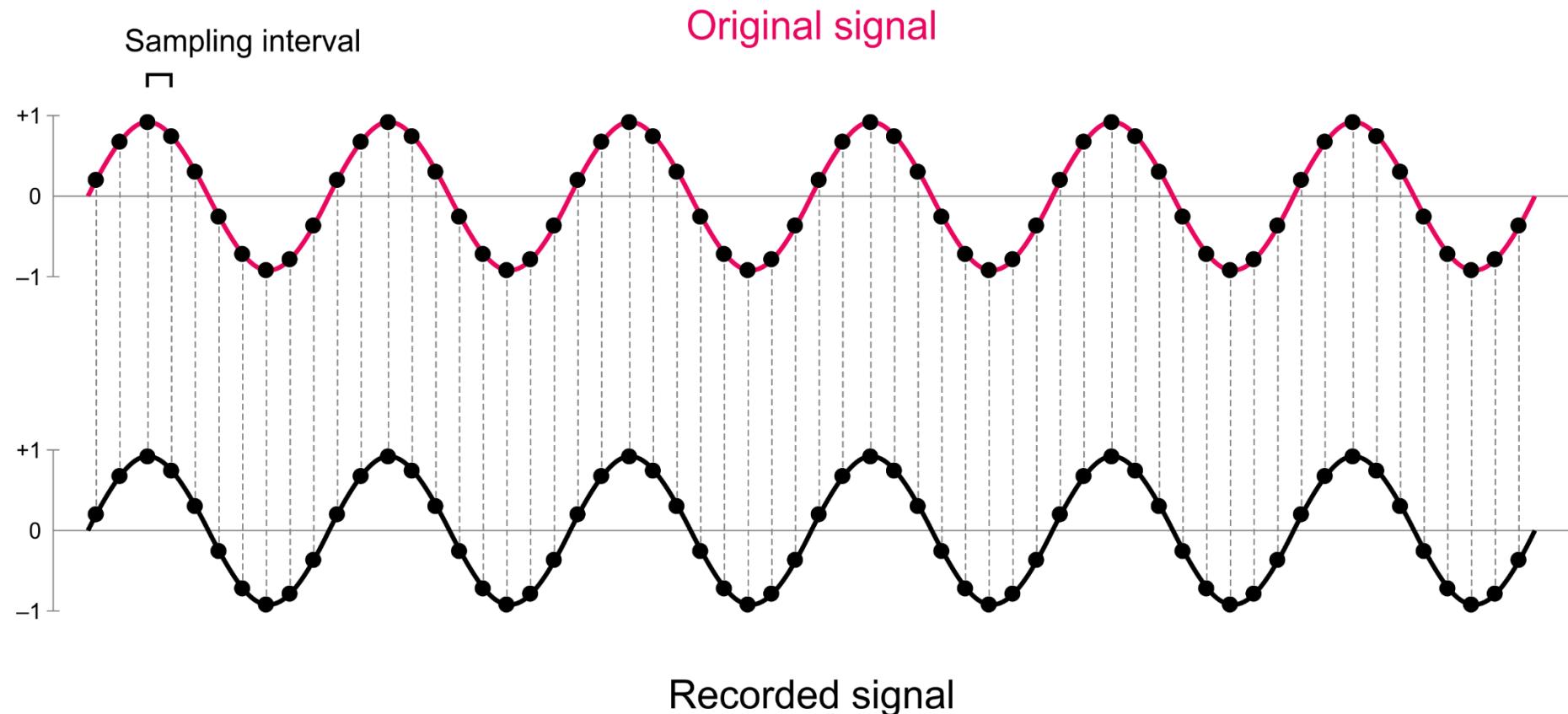
# Psychophysiology: Measurement: Signal

## Aliasing



# Psychophysiology: Measurement: Signal

## Nyquist frequency

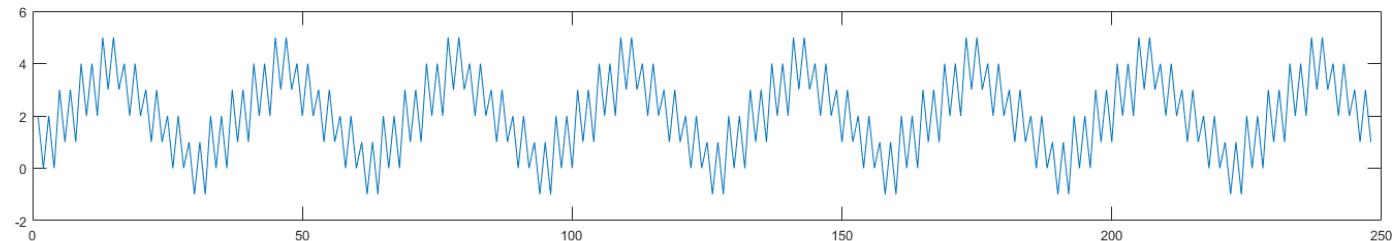


The Nyquist frequency is one half of the sampling rate. Frequencies higher than this are affected by aliasing. A 10 Hz signal must be sampled at 20 Hz or more.

# Psychophysiology: Measurement: Signal

## Separating frequencies

Recorded signal

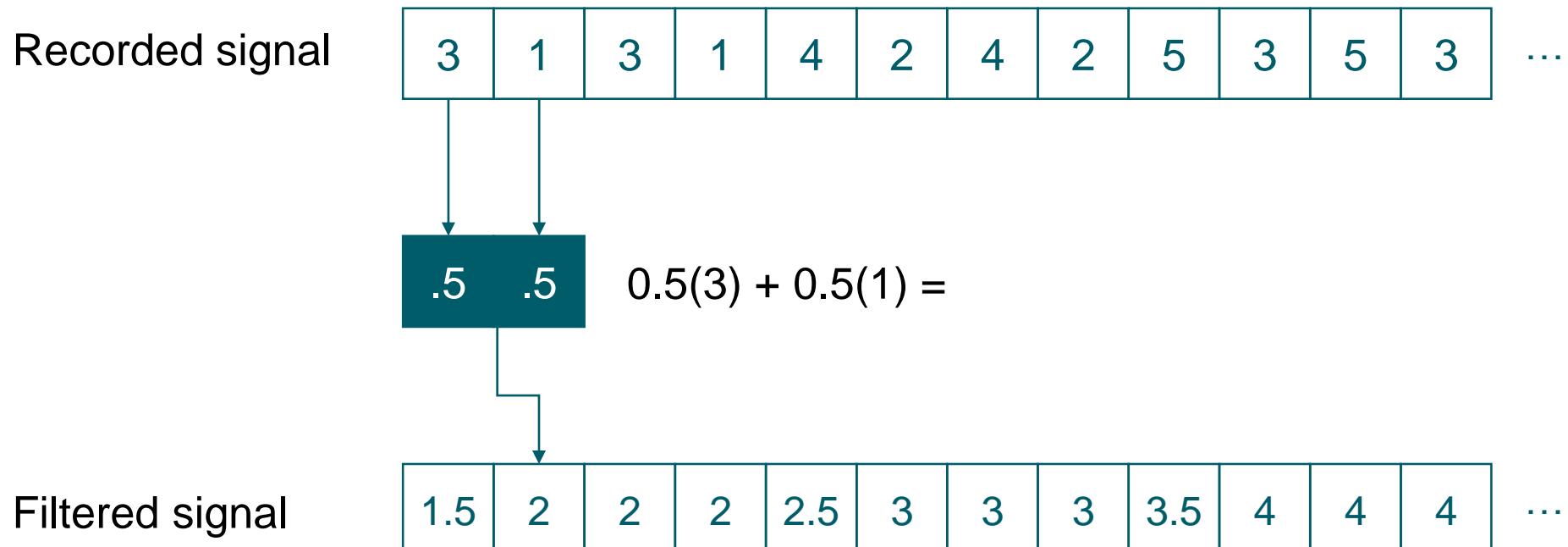


As an example, this recorded signal appears to be a mixture of one lower-frequency and one higher-frequency component.

How can we separate them?

# Psychophysiology: Measurement: Signal: Filter

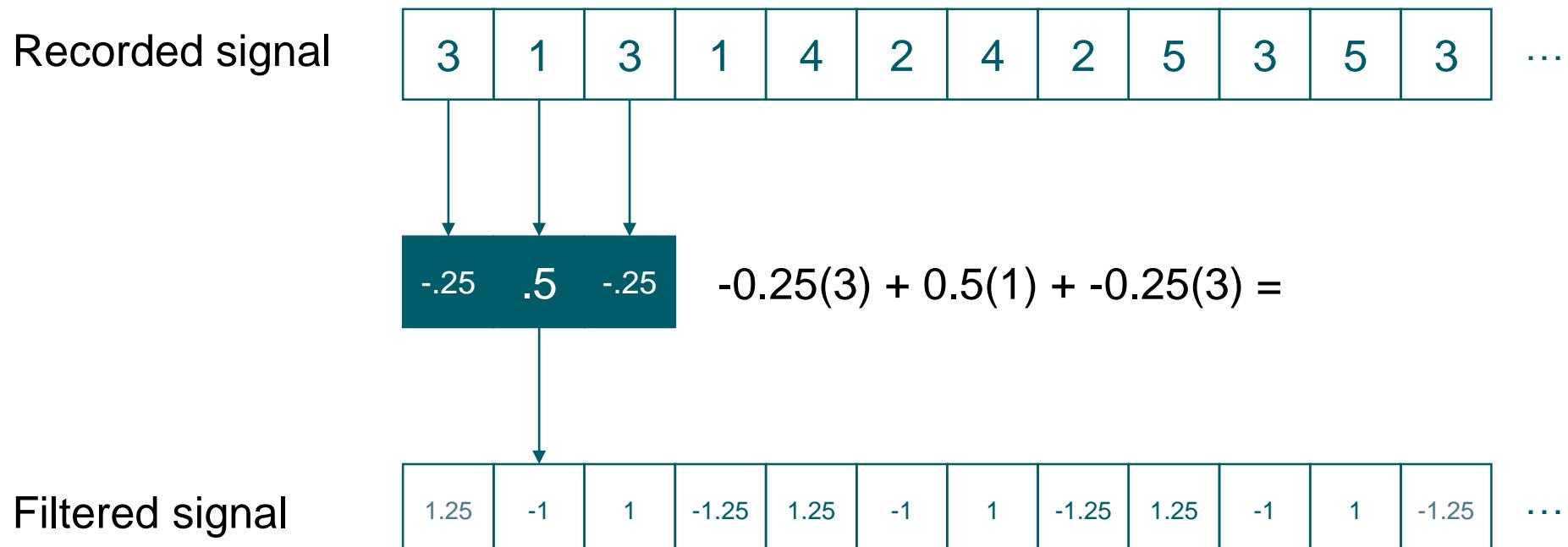
## Digital filters: Low-pass example



Only the lower-frequency component remains!

# Psychophysiology: Measurement: Signal: Filter

## Digital filters: High-pass example



Only the higher-frequency component remains!

# Psychophysiology: Measurement: Signal: Filter

## Digital filters

Recorded signal

3	1	3	1	4	2	4	2	5	3	5	3	...
---	---	---	---	---	---	---	---	---	---	---	---	-----

Low-pass filtered

1.5	2	2	2	2.5	3	3	3	3.5	4	4	4	...
-----	---	---	---	-----	---	---	---	-----	---	---	---	-----

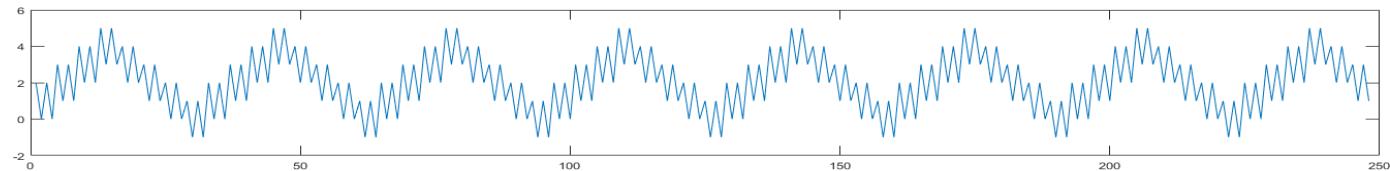
High-pass filtered

1.25	-1	1	-1.25	1.25	-1	1	-1.25	1.25	-1	1	-1.25	...
------	----	---	-------	------	----	---	-------	------	----	---	-------	-----

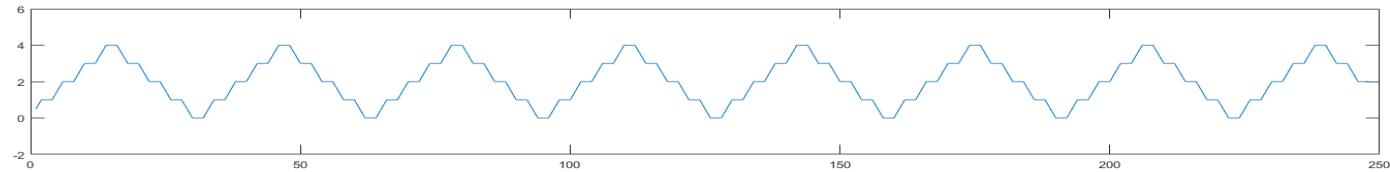
# Psychophysiology: Measurement: Signal: Filter

## Digital filters

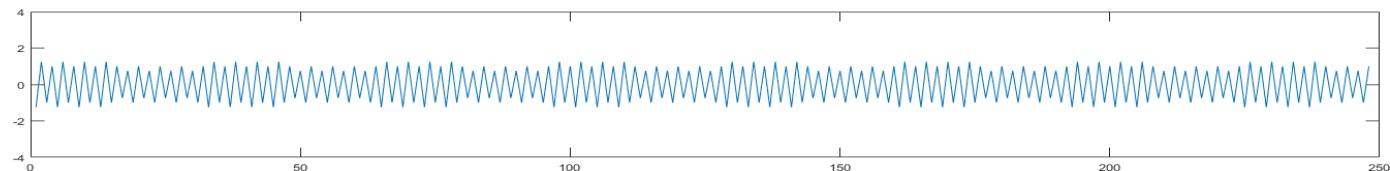
Recorded signal



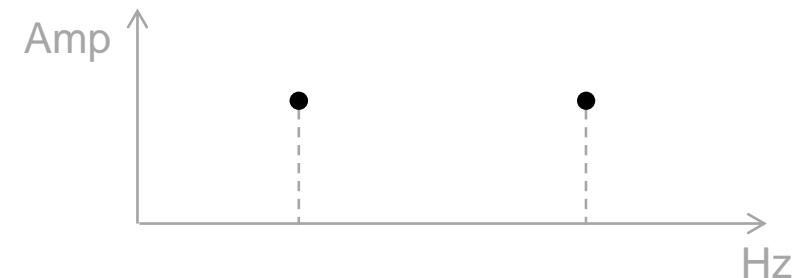
Low-pass filtered



High-pass filtered



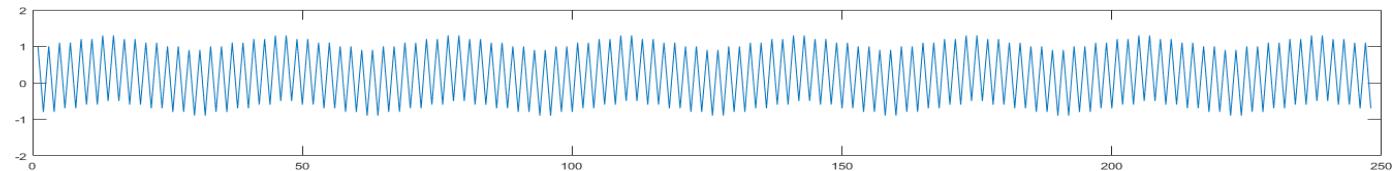
Filters allow components of different frequencies to be isolated (filtered) from a signal.



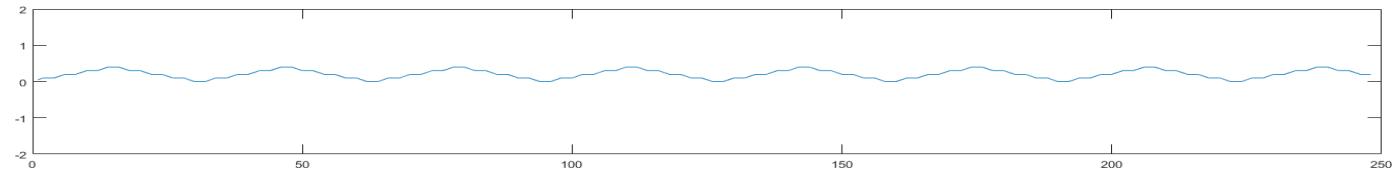
# Psychophysiology: Measurement: Signal: Filter

## Digital filters

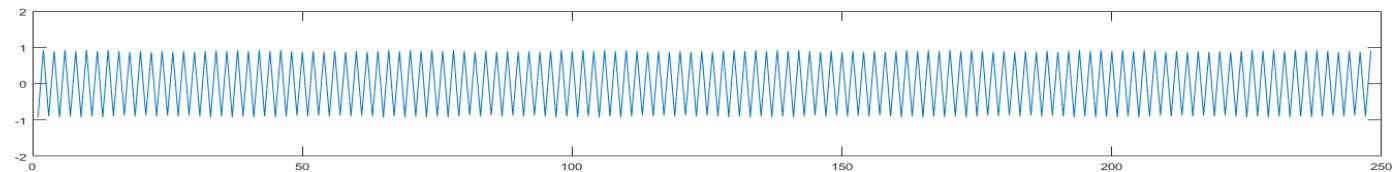
Recorded signal  
with more high-  
frequency power



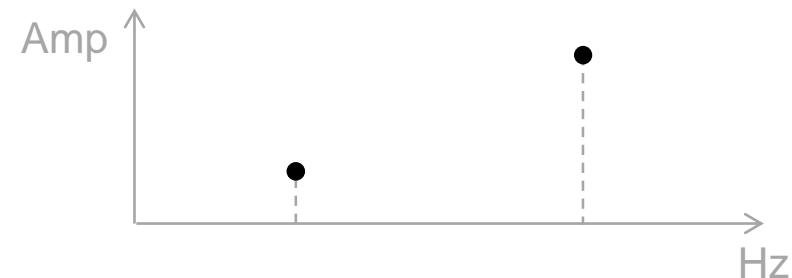
Low-pass filtered



High-pass filtered



Filters and other transformations  
allow us to investigate the  
power of specific frequencies.



# Psychophysiology: Measurement: Signal: Filter

## Filter design

Proper filter design is a field of study in its own right.

Different types of filter are used to filter out different parts of the signal.



**Low-pass and high-pass** filters attenuate all frequencies above or below a certain threshold.



**Band-pass and band-stop** filters attenuate all frequencies within or outside of a given range.

**Notch** filters attenuate a single frequency.

# Psychophysiology: Measurement: Signal

## Digitizing the signal

The sampling rate and some filters will need to be configured when recording. This cannot be undone!

Further filtering can be done later, depending on the analysis.

It is also possible to create bipolar channels from unipolar recordings, or to change the reference electrode.



# Psychophysiology: Measurement

## Every modality is different

- Cardiac and hemodynamic measures
- Electromyographic measures
- Electrodermal activity
- Electroencephalographic measures
- Oculomotor and pupillometric measures
- Respiration
- Salivary activity
- Gastrointestinal activity
- ...

# Psychophysiology

## Measurement

Biosignals are directly measurable, time-varying parameters that reflect physiological activity. Further physiological parameters can be derived from them.

Biosignals of an electric nature are measured using various kinds of electrodes placed at various locations.

Time-varying signals can also be described using spectral features. Filters can be used to isolate or attenuate different frequencies.

# Psychophysiology

## Part 3: Foundations of psychophysiological measurement



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