The AsTeRICS Academy

for cross-cultural education in Assistive Technology

AsTeRICS academy

MA23 Wirtschaft, Arbeit Statistik

Stadt Wien

FH University of Applied Sciences TECHNIKUM WIEN

Module 4b: Bioelectric Signals

Origin and Measurement

AsTeRICS academy

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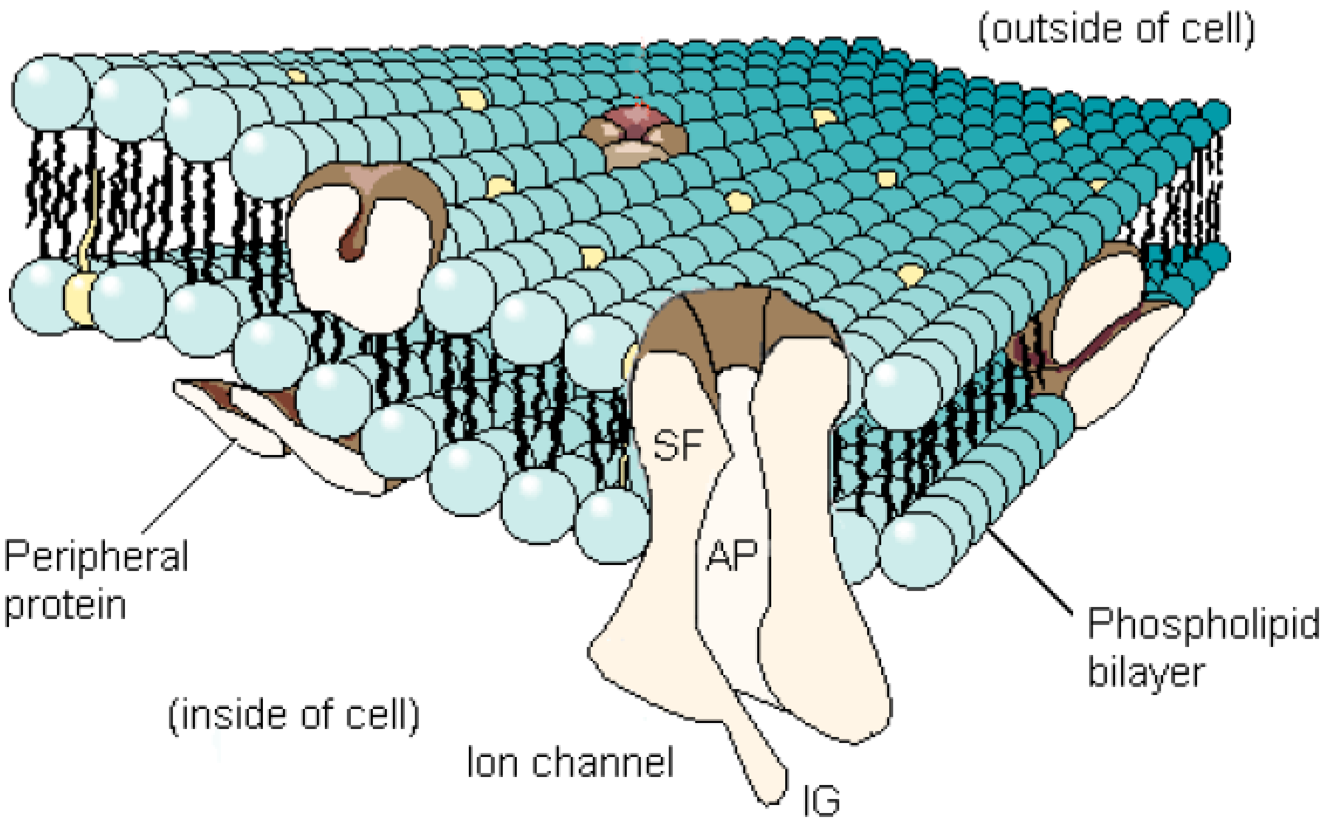
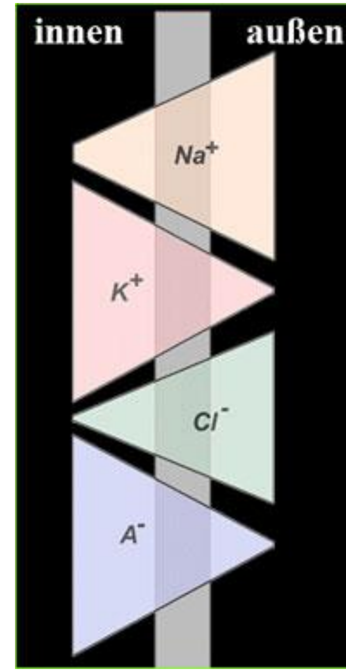
Origin of Bioelectric Signals

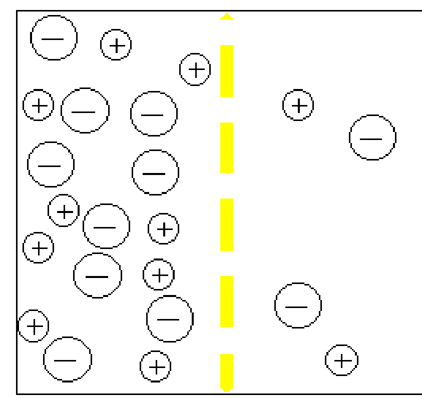


Cell membrane, channel proteines

Origin of Bioelectric Signals

Iones	Intracel.	extracel.
potassum K^+	400	20
Sodium Na^+	50	440
Chlorid Cl^-	108	560
organic Aniones	460	0





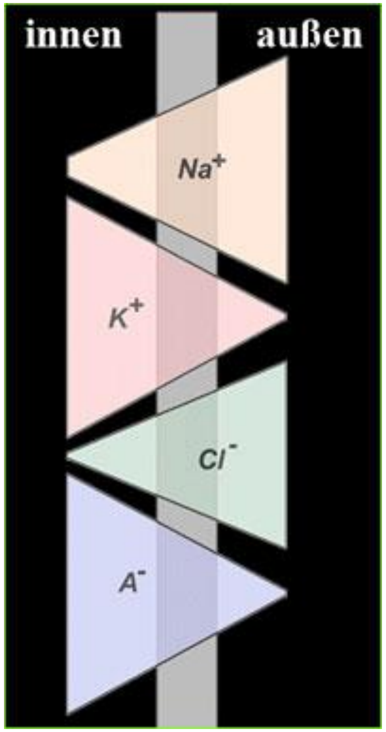
Electrical and chemical gradients
at the semi-permeable cell membrane

Origin of Bioelectric Signals

Nernst – equation (chemical potential):

$$\Delta G = \mathrm{R} \cdot T \cdot \ln \frac{c(A_i)}{c(A_a)}$$

R … Gas-Constant = 8,3143 J / (mol·K)
T … Temperature (Kelvin)

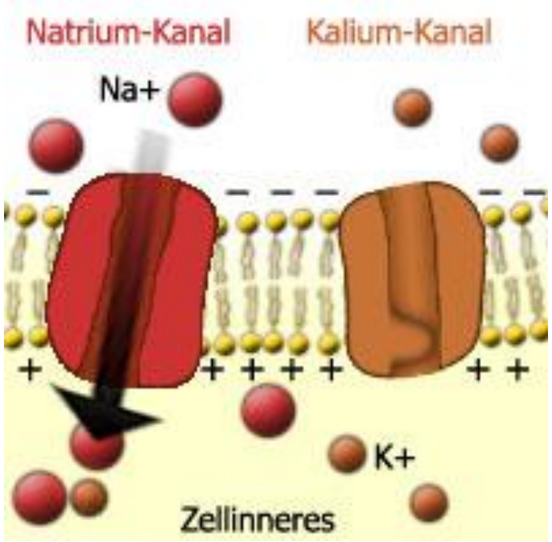


Goldman – equation (for different ions):

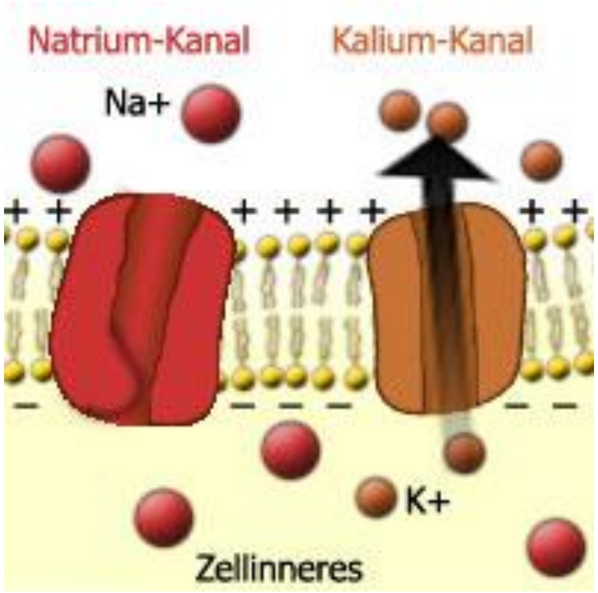
$$\Delta\Psi = \frac{\mathrm{R}T}{\mathrm{F}} \cdot \ln \frac{\Sigma[P_{ka} \cdot c_{ka-a}] + \Sigma[P_{an} \cdot c_{an-a}]}{\Sigma[P_{ka} \cdot c_{ka-i}] + \Sigma[P_{an} \cdot c_{an-i}]}$$

As a result, we get a membrane resting potential of about -70mV

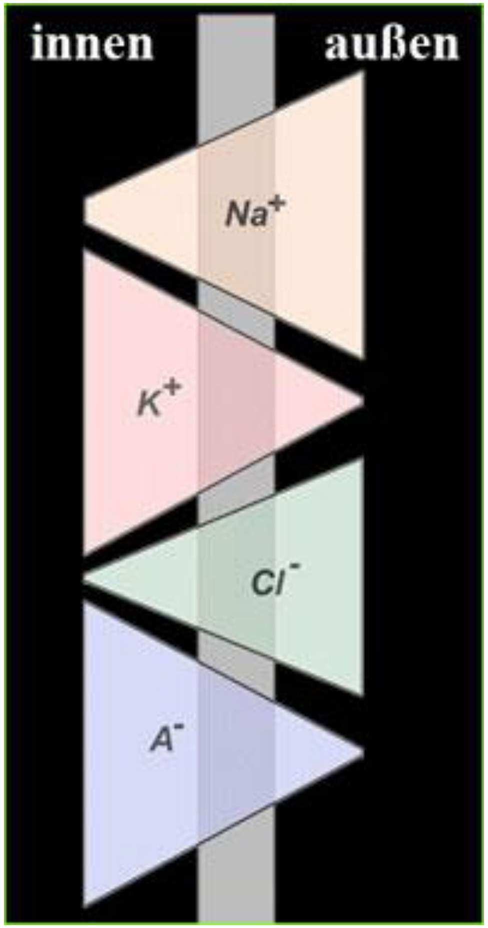
Origin of Bioelectric Signals



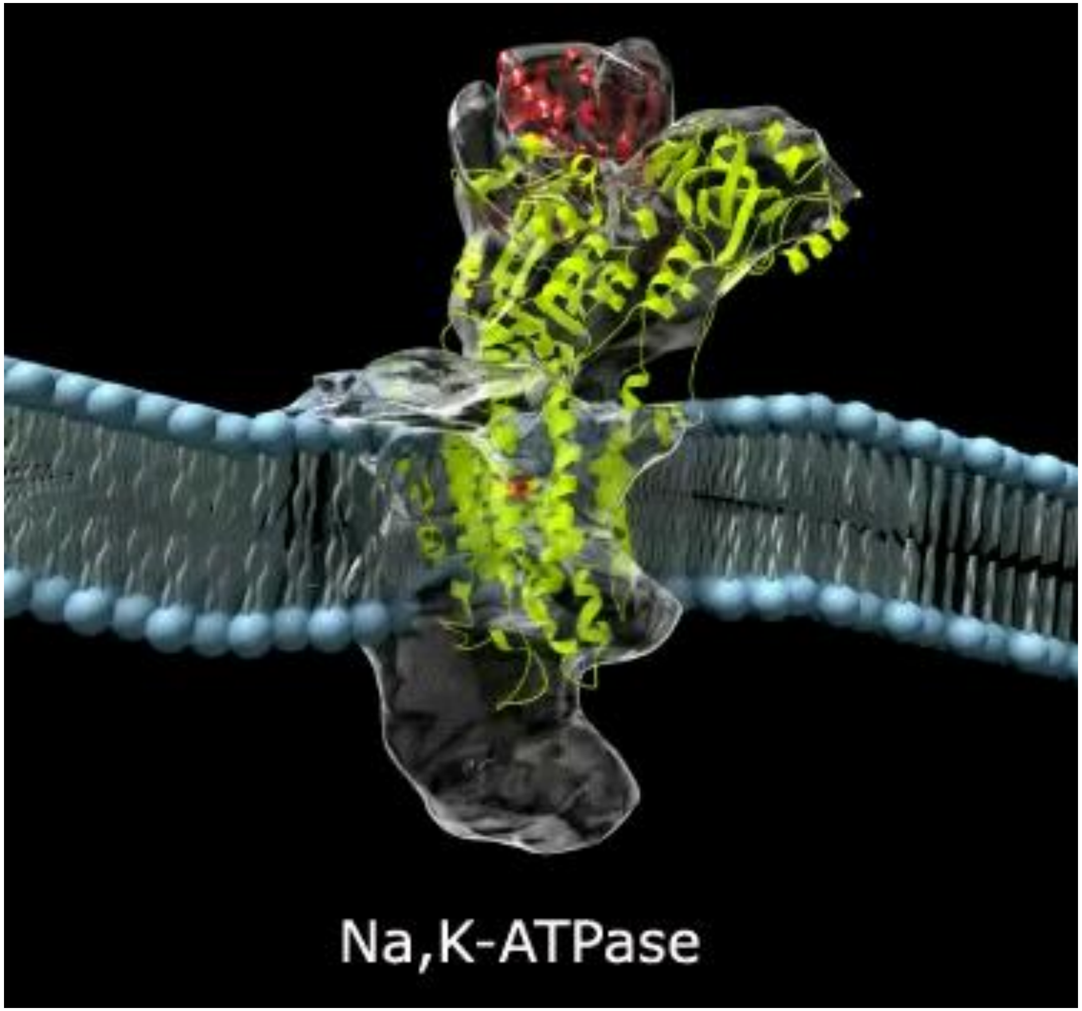
Depolarization
Sodium Cations rush in

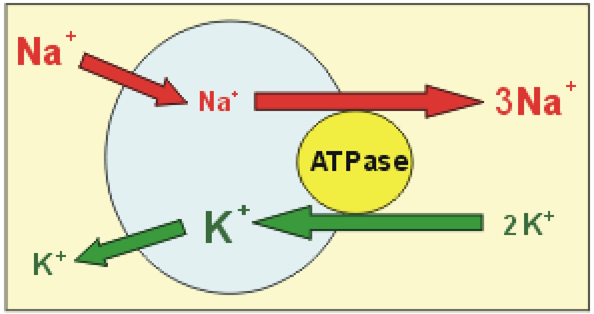


Hyperpolarization
Potassom Cations rush out



Origin of Bioelectric Signals



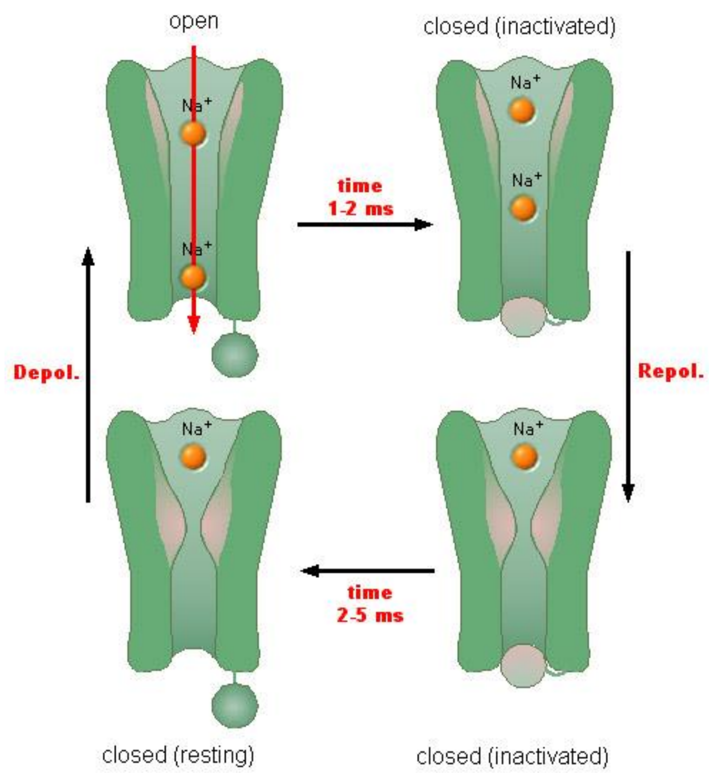


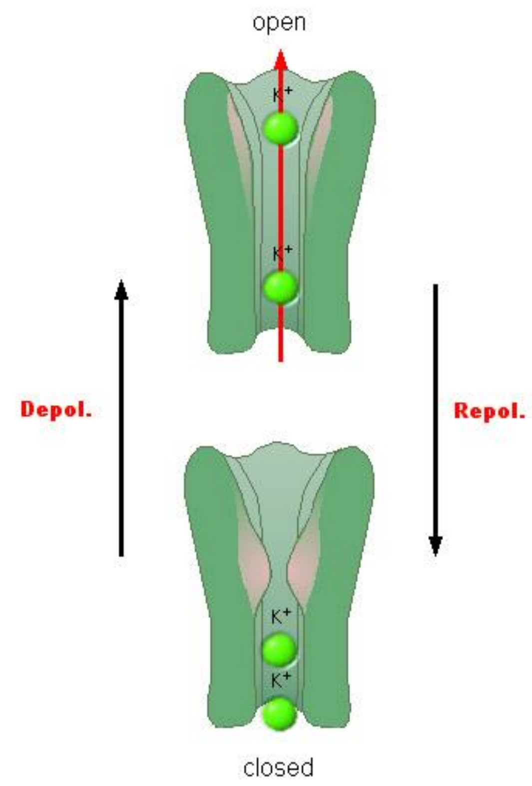
Maintaining the
Resting potential

Sodium/potassum
Ion pump

Origin of Bioelectric Signals

Voltage- and Time dependent activation of Ion Channels: the physiological basis for action potentials

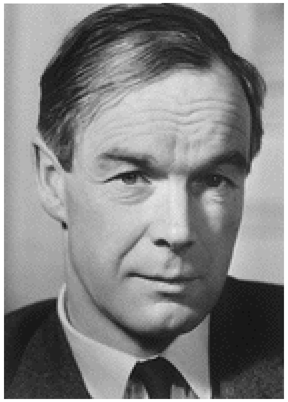


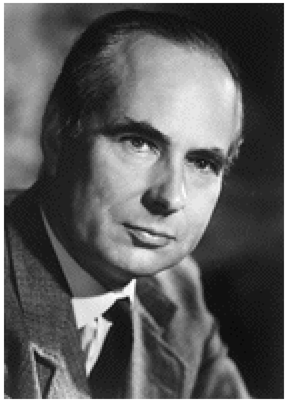


Sodium-Channel

Potassum- Channel

Origin of Bioelectric Signals


Alan Hodgkin

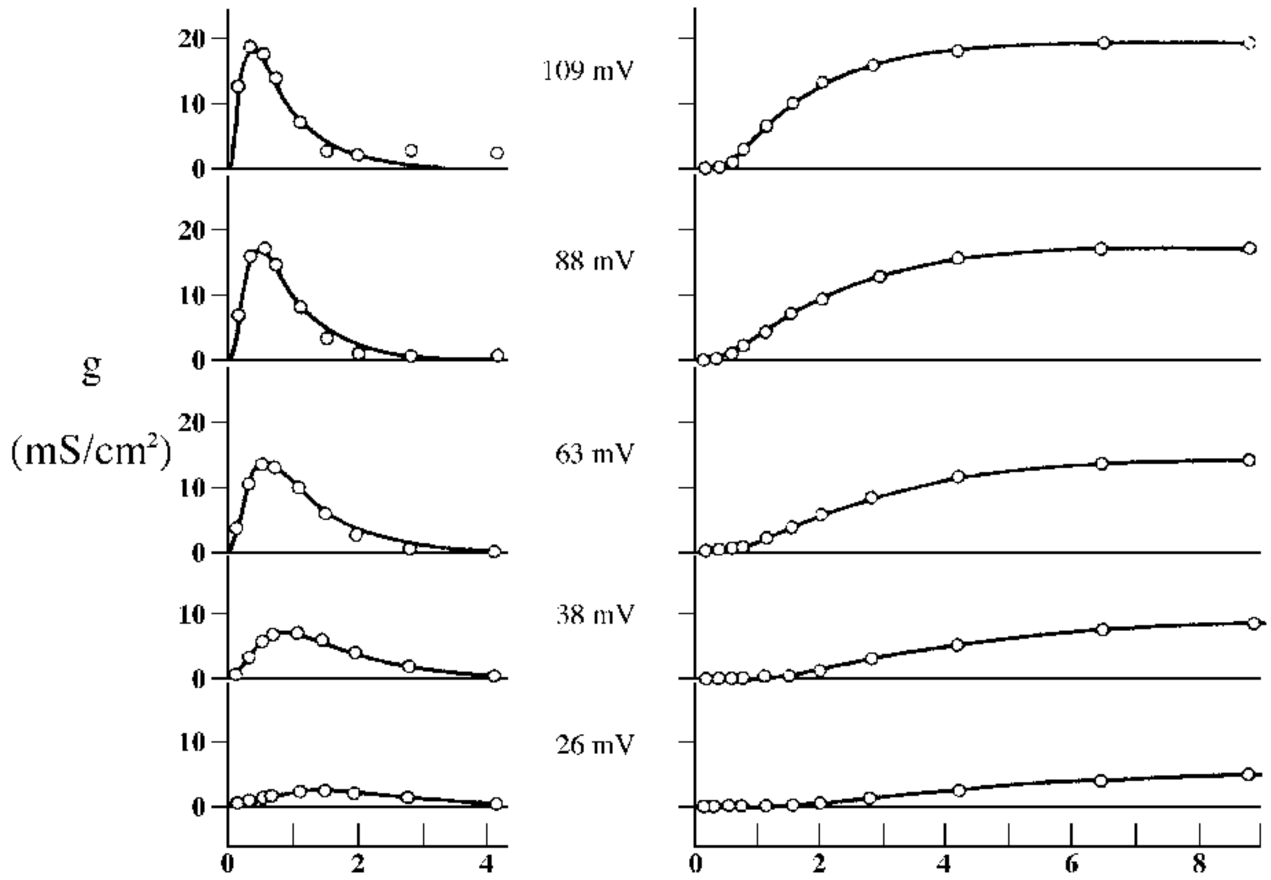

Andrew Huxley

Hodgkin - Huxley Model (1952)

- Researched the Giant Squid-Axon
- Used the Voltage-Clamp technique
  -> Isolation of channel currents of
  Na und K
- Developed a model for the function
  of the channel proteines

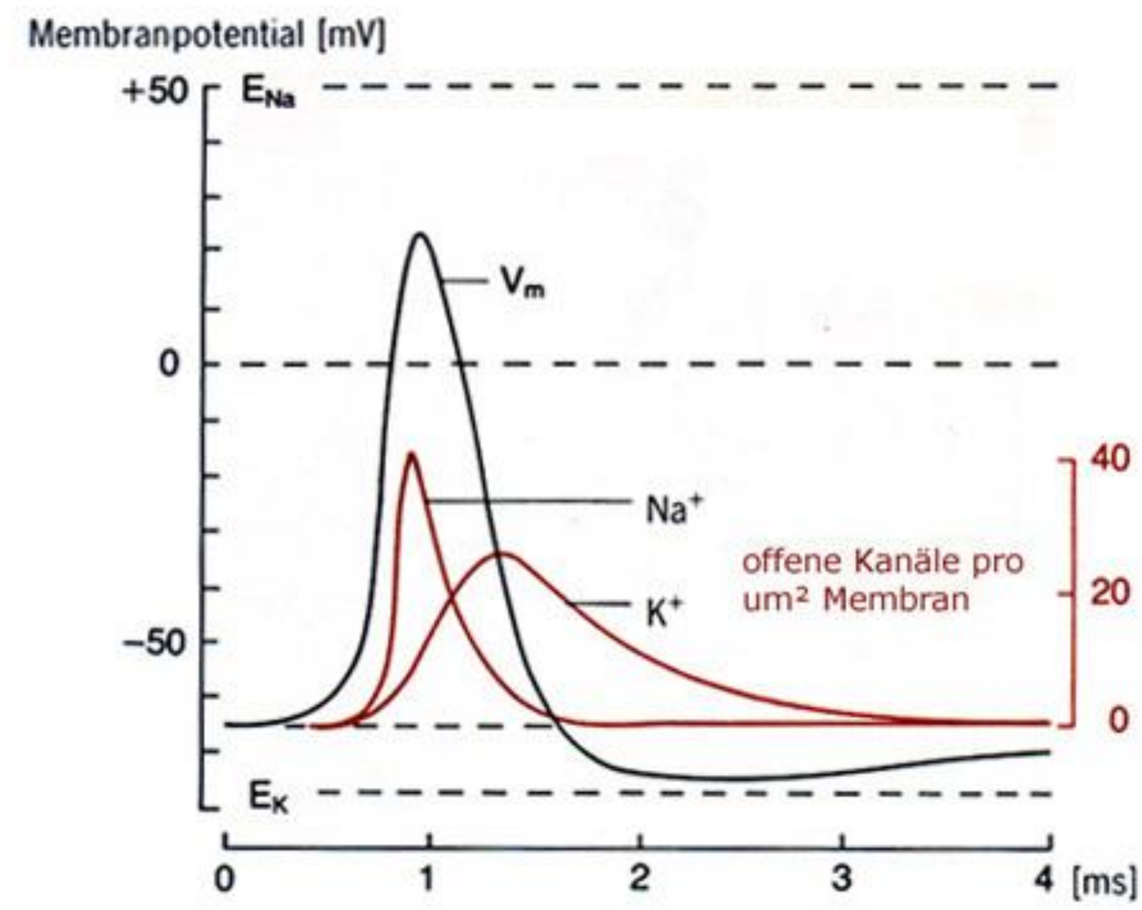
$$C_m \frac{dV}{dt} = \overline{G}_{Na} m^3 h (E_{Na} - V) + \overline{G}_K n^4 (E_K - V) + G_m (V_{rest} - V) + I_{inj}(t)$$

Origin of Bioelectric Signals



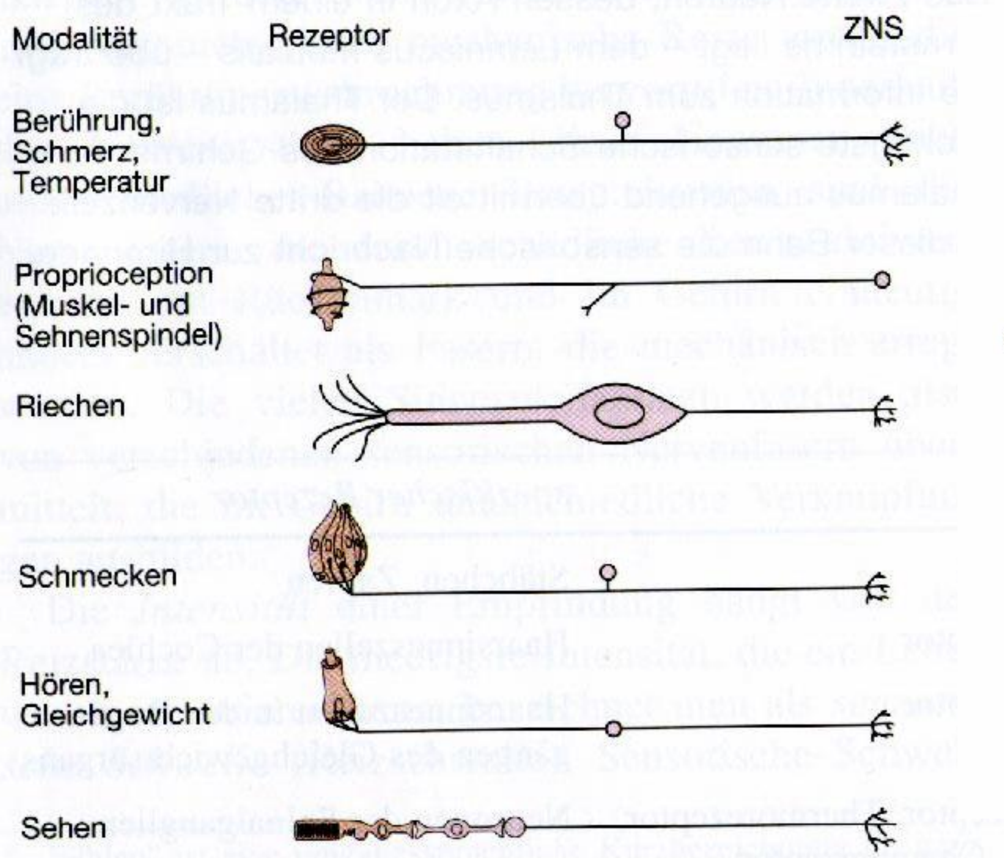
Sodium and Potassum conductance
Calculated by the Hodkin Huxley Model (curve), measured (dots)

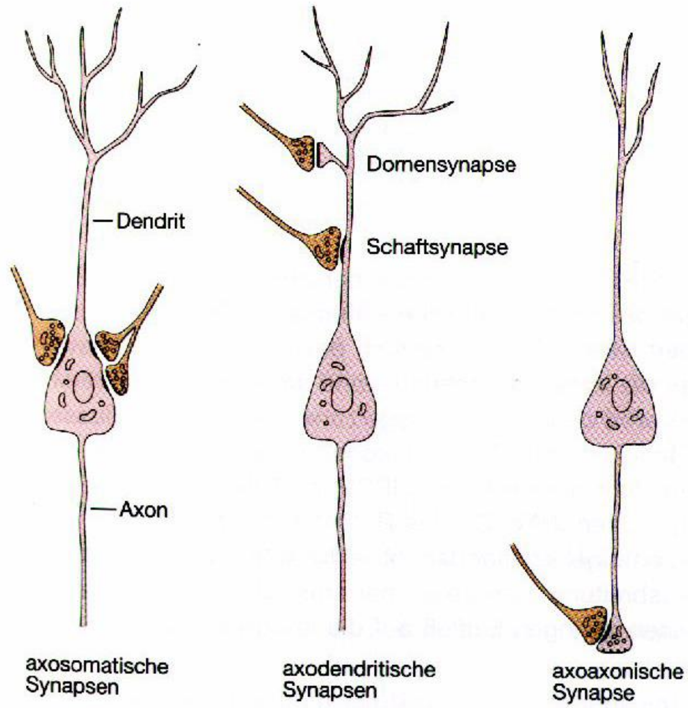
Origin of Bioelectric Signals



Action potential: the result of Na and K Ion movement through the membrane

Origin of Bioelectric Signals

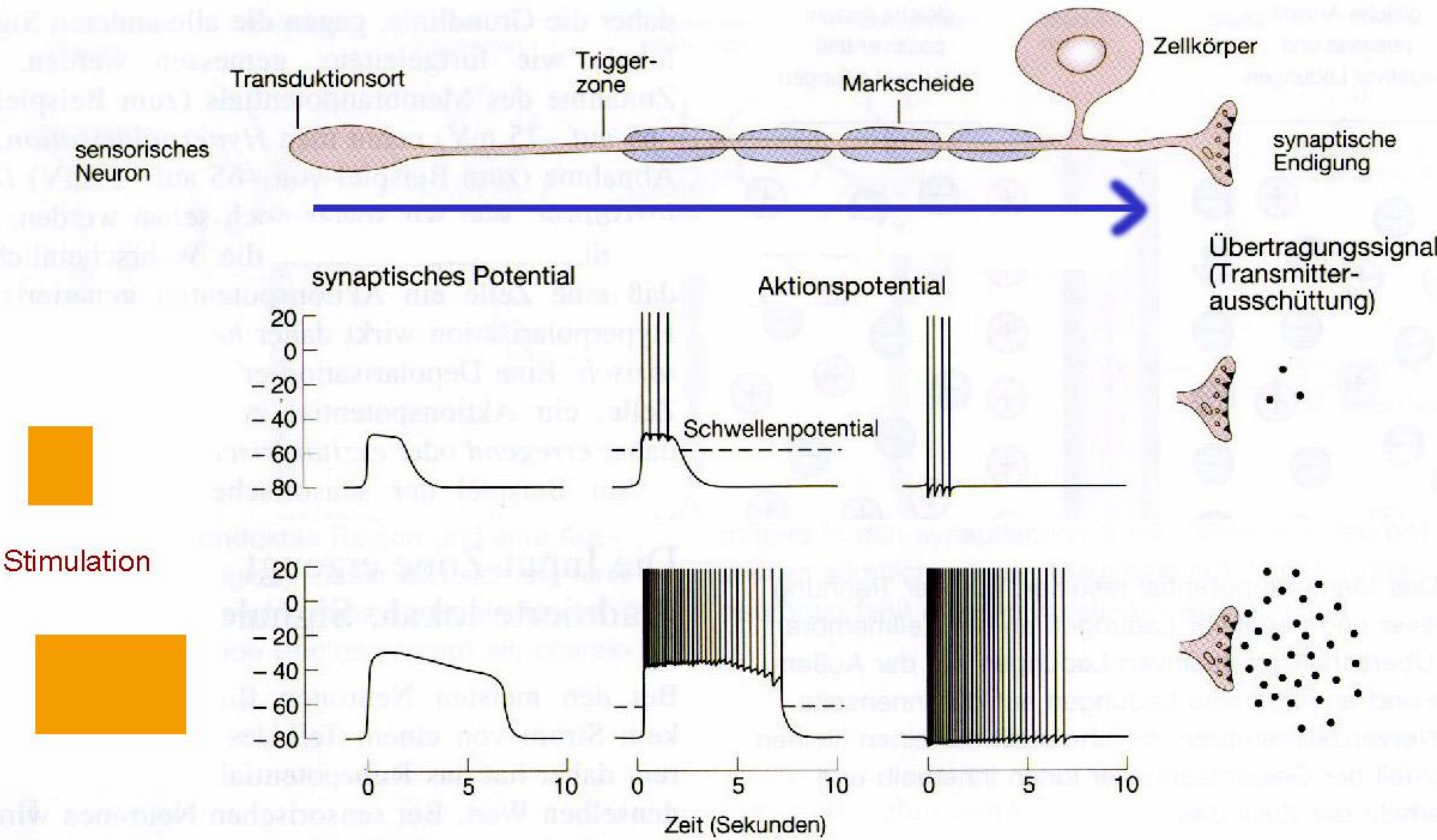




Types of nerve cells, Synaptic coupling

Origin of Bioelectric Signals

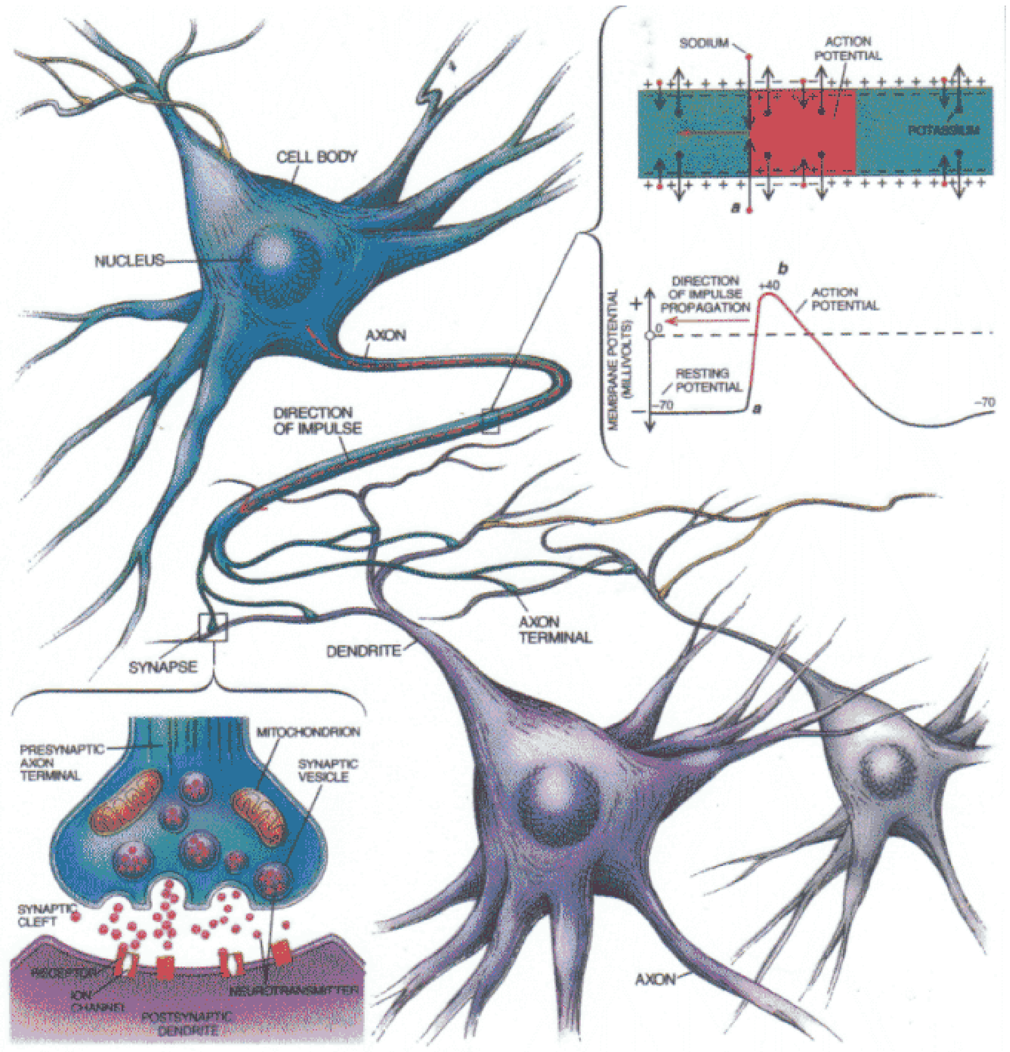
Action Potentials



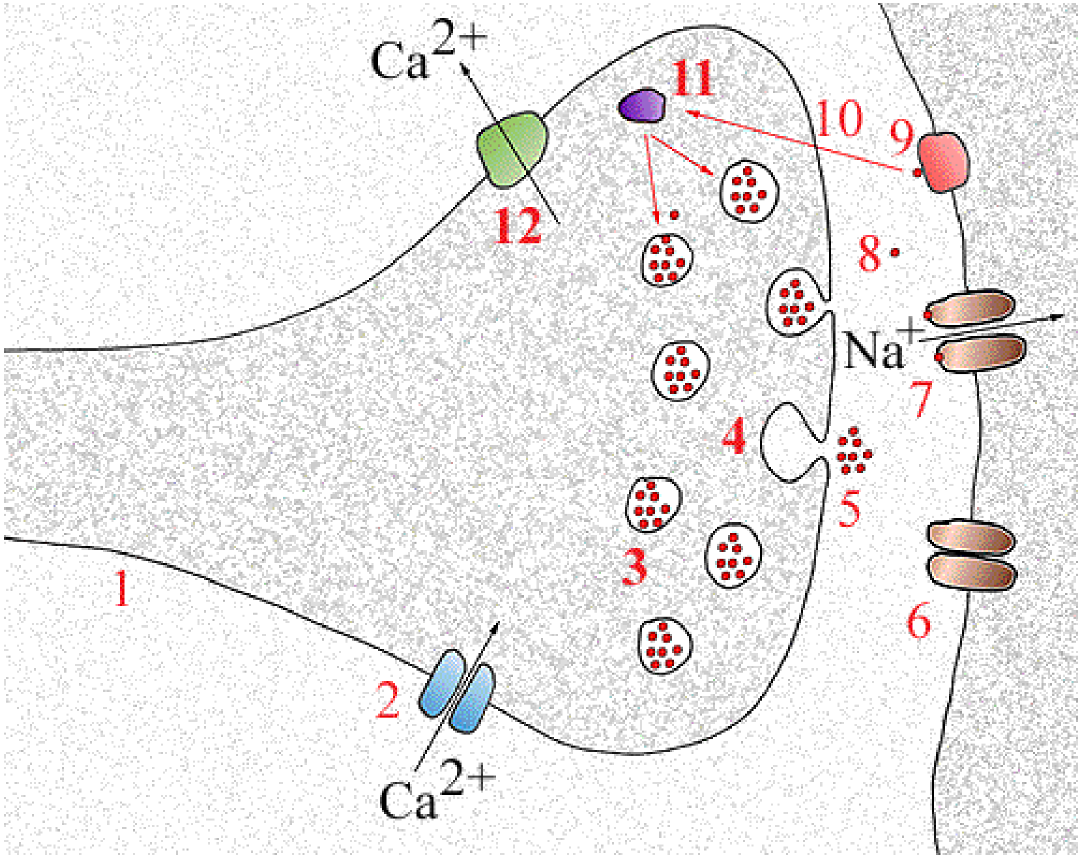
Origin of Bioelectric Signals

Axo-dendritic transmission of action potentials,

Synaptic transduction

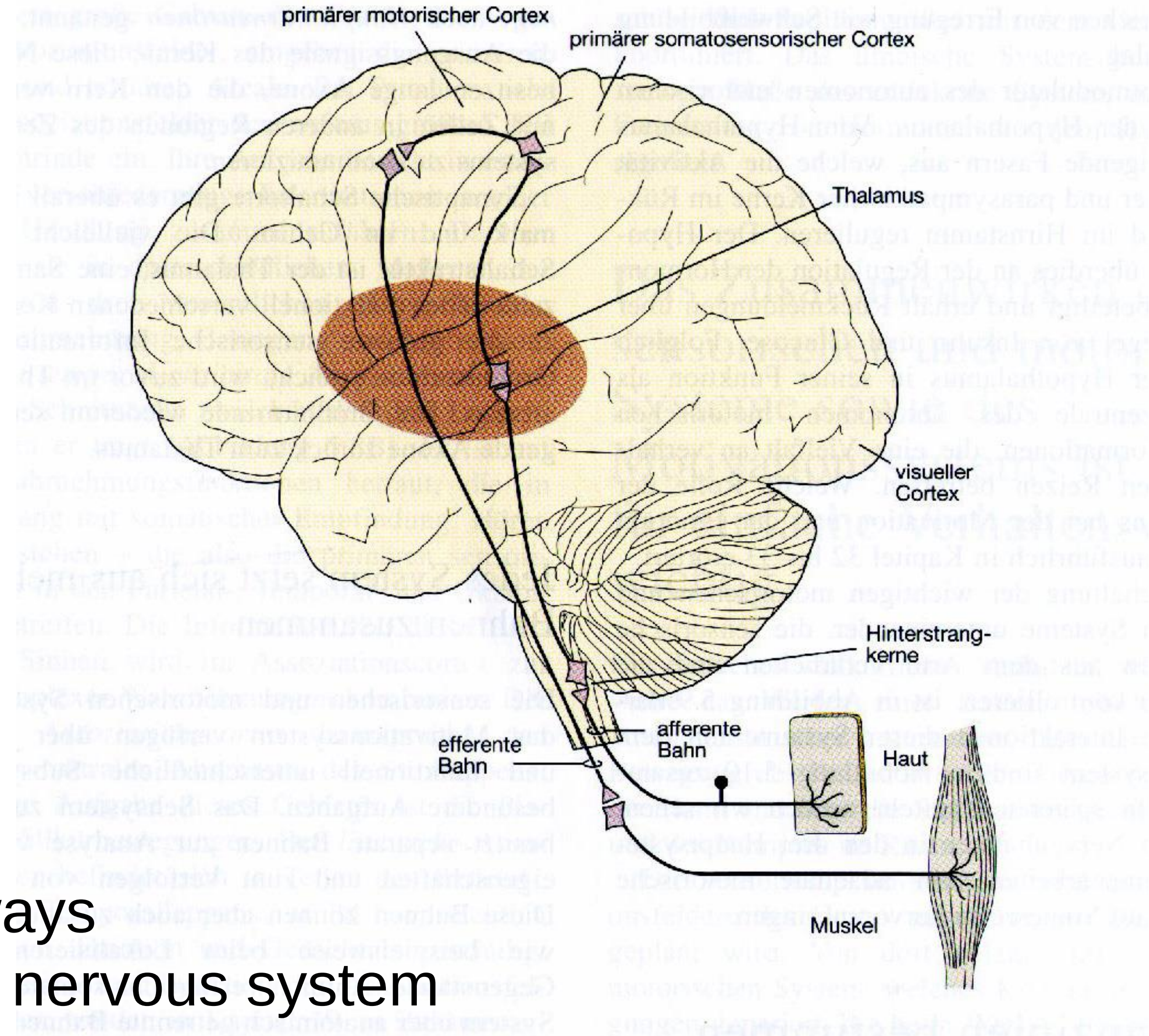


Origin of Bioelectric Signals



Synaptic coupling, release and uptake of neurotransmitters

Origin of Bioelectric Signals

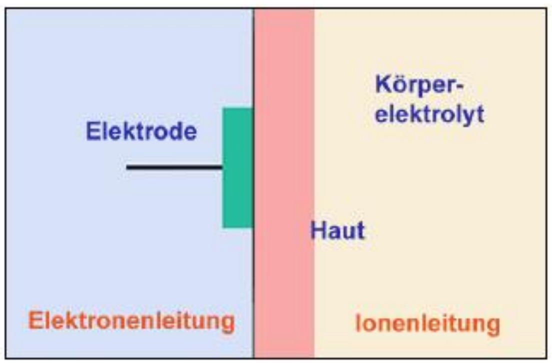


Signal Pathways
in the central nervous system

Measuring Bioelectric Signals

At the skin surface, we can measure the summed electric potentials resulting from multiple action potentials and post-synaptic potentials of the underlying nerve or muscle cells.

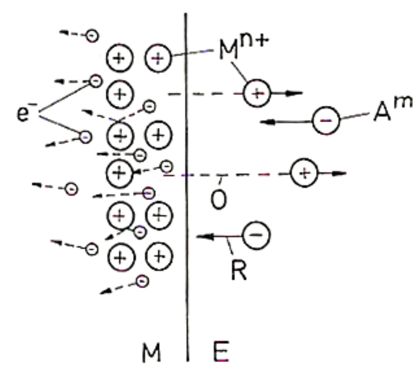
Electrode – Skin Interface:



Using electrodes, ionic current in the biologic tissue is transferred into electron current in a metallic conductor

$$M \underset{\text{Reduktion}}{\overset{\text{Oxidation}}{\rightleftarrows}} M^{n+} + ne$$

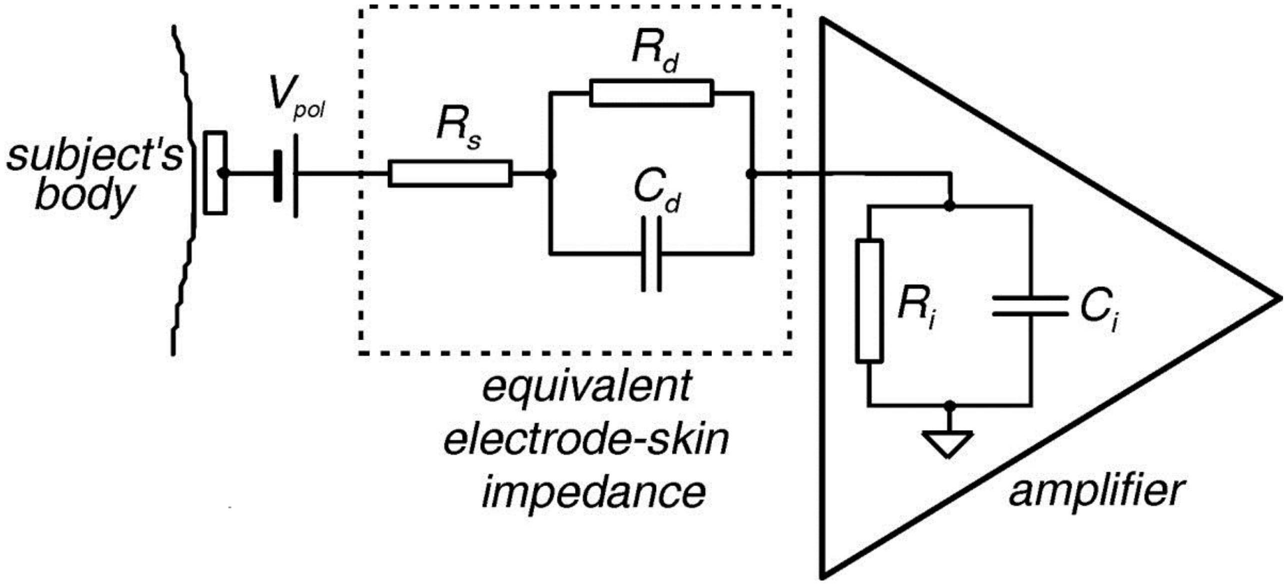
$$A^{m-} \underset{\text{Reduktion}}{\overset{\text{Oxidation}}{\rightleftarrows}} A + me$$

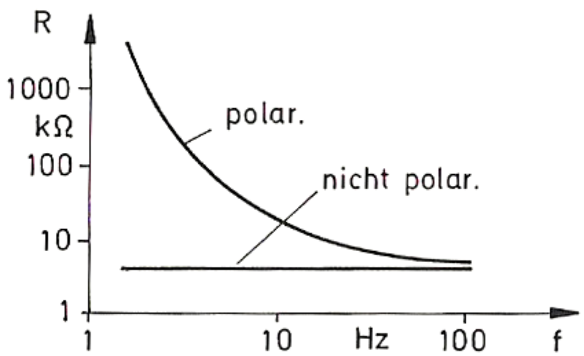


M+ : metallic Cathions
A- : organic Anions

Measuring Bioelectric Signals

Electrode – Skin Interface:

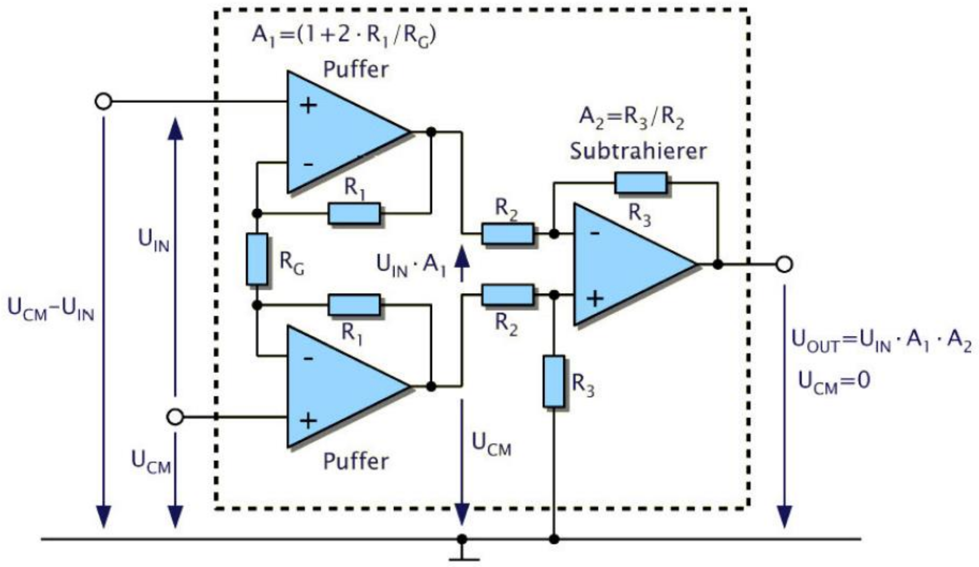




- Electrode-polarization can reach several hundert millivolts
- Non-polarizable electrodes: chlorided silver Ag/AgCl

Measuring Bioelectric Signals

Instrumentation Amplifier

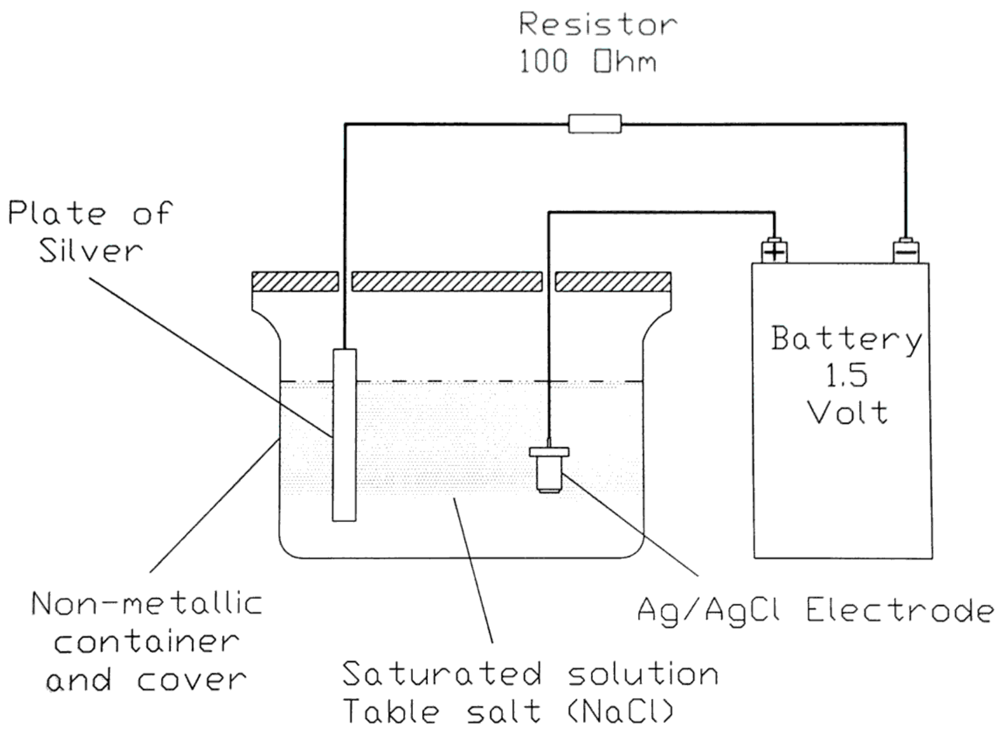


- **high input impedance ~ 1GOhm**
- **low output impedance**
- **high common mode rejection CMRR ~ 110 dB**
- **adjustable gain (Rg)**

Capacitive coupling of Common Mode voltages into cables ~ 100 mV !

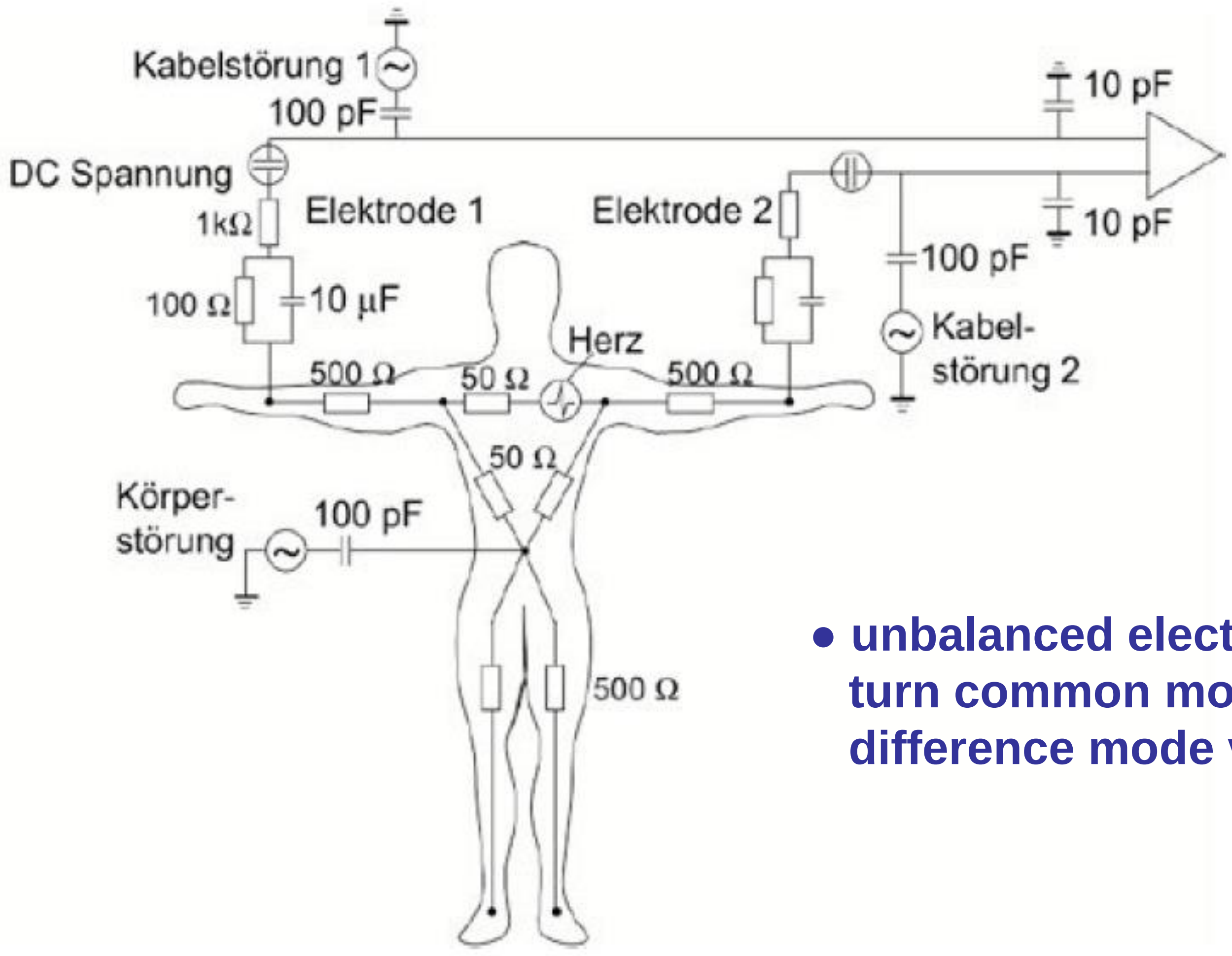
-> Instrumentation Amplifier measures voltage difference

Chloriding a silver electrode:



- **Apply current for approximately 1 minute.**
- **The chloriding electrode darkens, while the other bubbles**

Capacitive coupling, body model:



- **unbalanced electrode impedances turn common mode voltage into difference mode voltage**

Impedance monitoring:

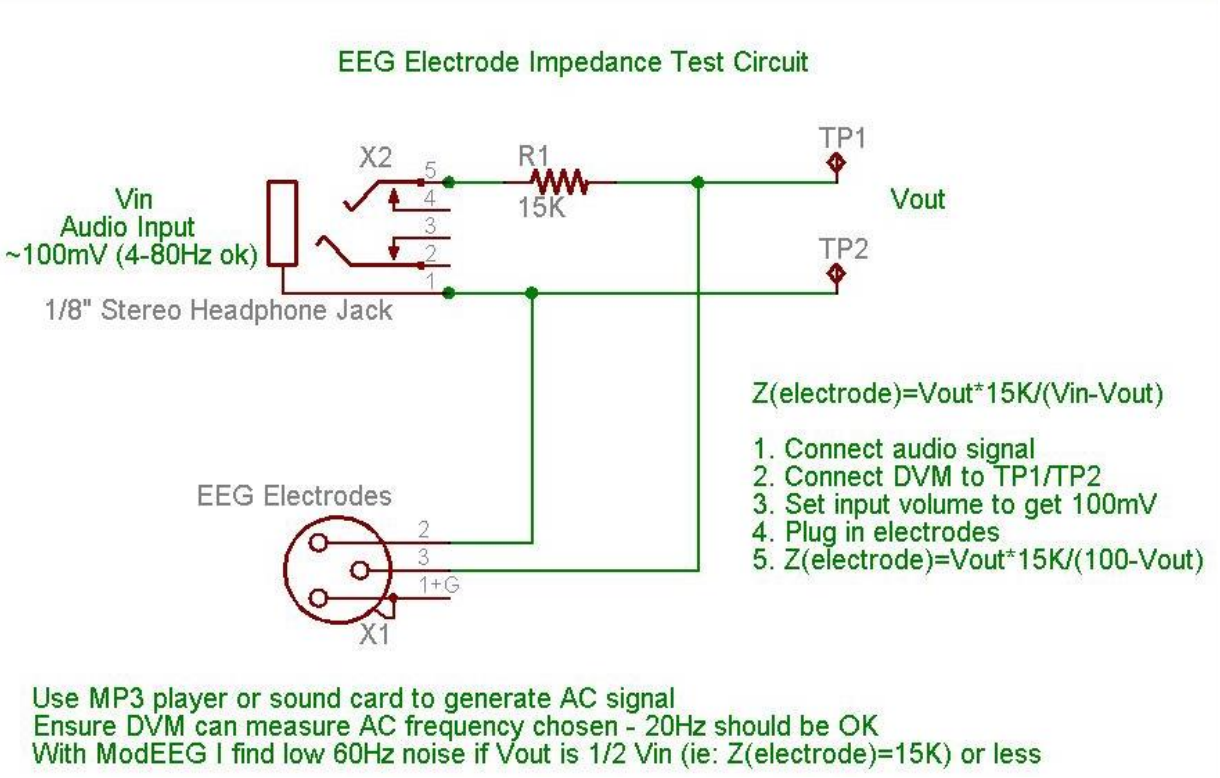
http://www.brainmaster.com/productinfo
/accessoryequip/checktrode3.jpg

http://www.general-devices.com/pcheck1.jpg

Low cost impedance checker:

- MP3 player or Laptop SoundCard as AC source
- Voltage divider effect: mesaure AC with multimeter at TP1/2
- Vout > ½ Vin

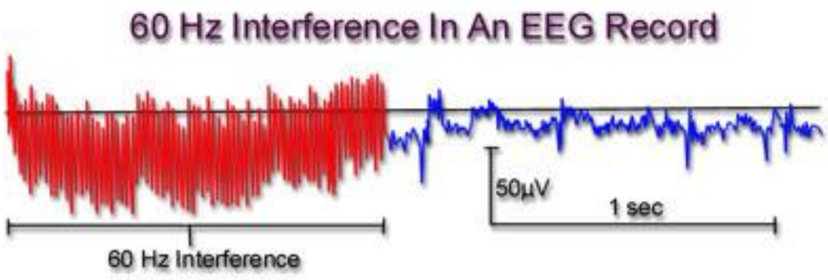
Use a battery powered Mp3 player or laptop for Safety reasons !



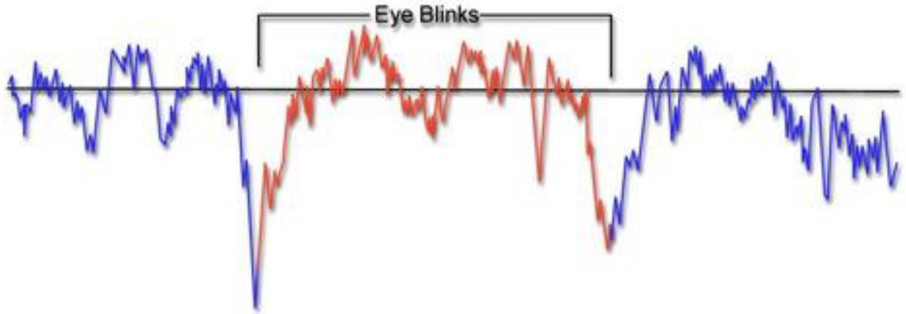
by Ian McCulloch, http://flickr.com/photos/ianmc333/458904528

Sources of Interference / Noise:

Capacitive coupling of noise / line-hum
(common mode voltages)



Artefacts due to other (stronger) biosignals or movement



High or unbalanced electrode impedances, Electrode - Polarization

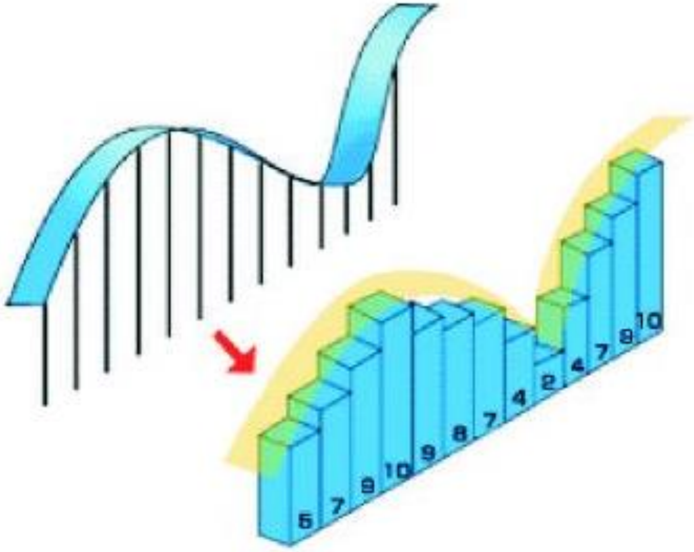
Strategies to handle noise

- increase distance to electrical devices and cables
- use shielding (Faraday - Cage)
- decrease Electrode impedance (contact gel, skin cleaning)
- avoid ground loops
- use a 50/60Hz *notch filter*
- cable shielding and driven shields (*guarding*).
- use a driven right leg circuit / closed loop system
  to increase common mode rejection

$$CMRR = A_D \left(\frac{U_{CM}}{U_A} \right)$$

Ad … Differential gain
Ucm … Common mode voltage at the inputs
Ua … voltage at the output

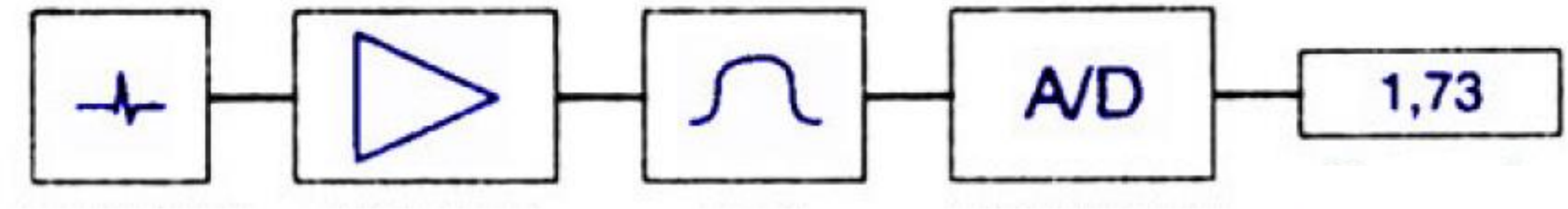
Analog-Digital Conversion



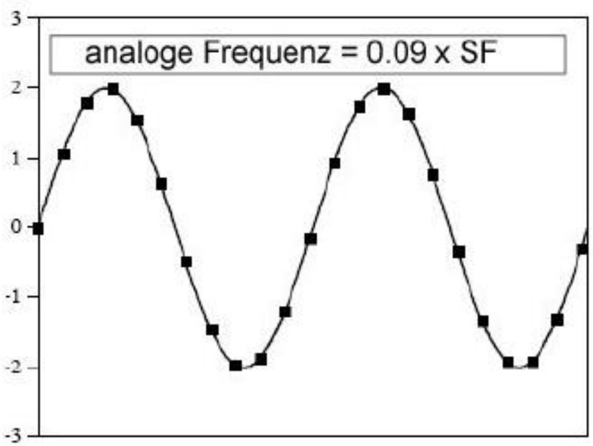
http://www.reedag.ch

Measurement Chain, Aliasing

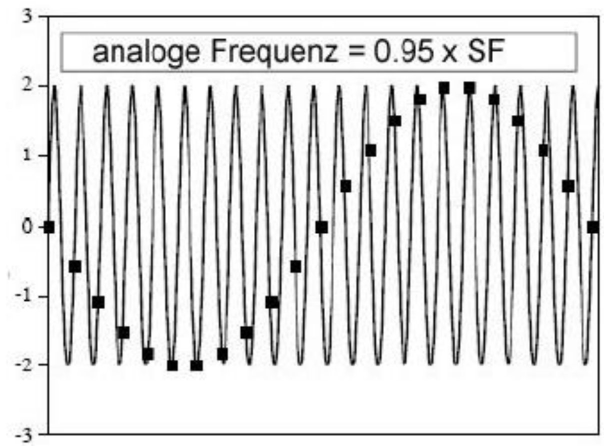
$f_{sample} > 2 \times f_{signal}$!



Source **Amplification** **Filtering** **A/D-Conversion** **Digital Value**



correct f_{sample}

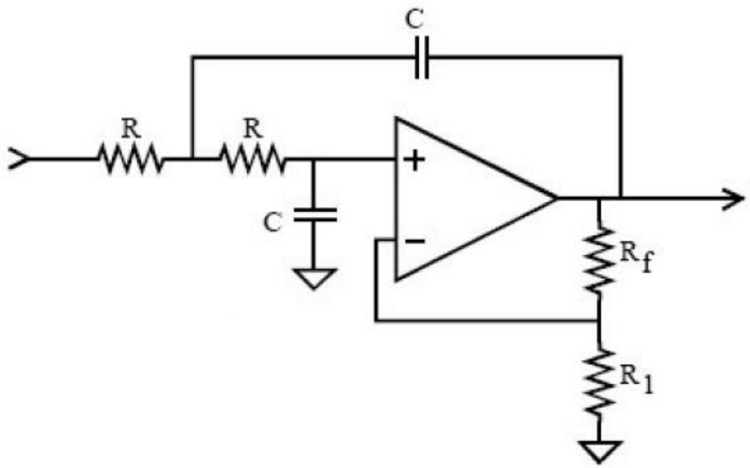


insufficient f_{sample}

Nyquist Frequency, Anti-Aliasing Filter

fsignal < fNyquist   (fNyquist = ½ fsample)
  -> band-limit the Input Signal using a Low Pass Filter

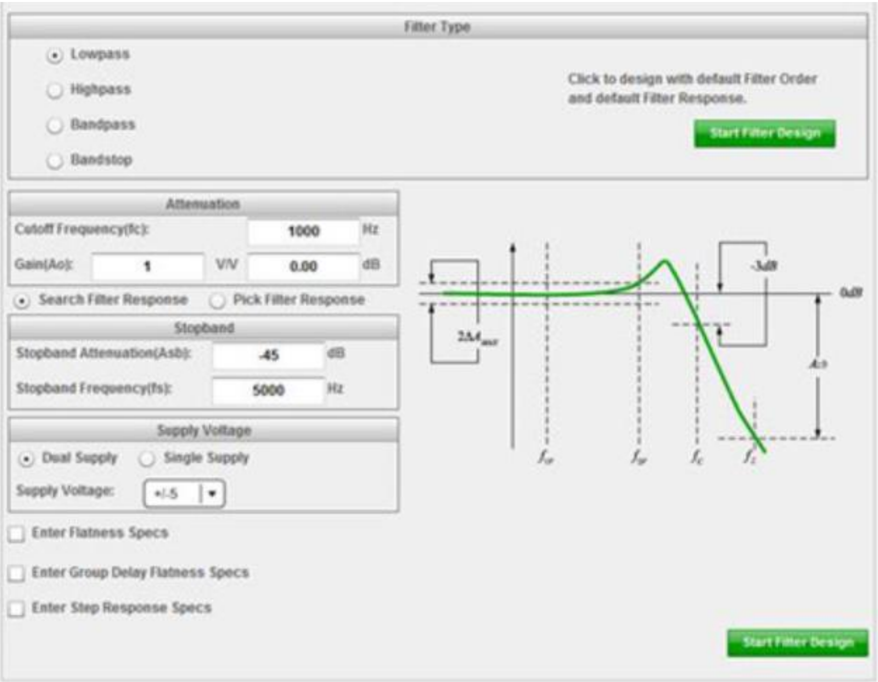
Sallen Key (lowpass configuration):
  cutoff fc = 1 / (2π*R*C)
  gain G = 1+Rf/R1

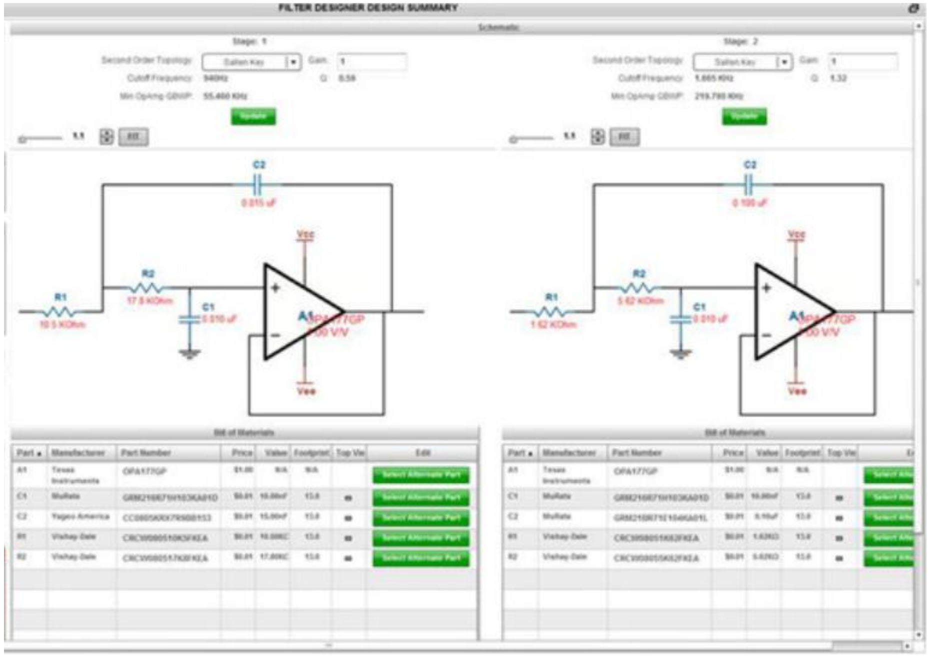


OpAmp slew-rate has to
  match frequency range

active Low Pass Filter (Sallen Key Circuit)

Active Filter designer software (TI)





http://www.ti.com/lsds/ti/analog/webench/webench-filters.page

Commercial EEG Amplifiers

g.tec USBamp

Channels:	16
Resolution:	24 bit
1 LSB:	30 nV
CMMR:	98 dB
Noise:	< 0,3 uVpp
Filtering:	Highpass generic Lowpass generic
Sampling Rate:	38,4 kHz
Interface:	serial (USB)
Power Supply:	mains adapter
Med. certified:	yes
Price:	$ 10.100
Company:	*http://www.gtec.at*

Commercial EEG Amplifiers

Neuroscan Synamp2 EEG Verstärker

Channels:	64
Resolution:	24 bit
1 LSB:	3 nV
CMMR:	108 dB
Noise:	< 0,4 uVpp
Filtering:	Highpass DC/0,5Hz
	Lowpass 3.500 Hz
Sampling Rate:	20,4 kHz
Interface:	serial (USB)
Power Supply:	mains adapter
Med. certified:	yes
Price:	$ 32.000 (48.000 inc. Software)
Company:	*http://www.neuro.at*

OpenEEG project: HW and SW

http://openeeg.sf.net

- Online since 1999
- Project aims:

  development of a lost cost, high quality EEG amplifier
  development of Open Source firmware / PC-software
  sharing of knowledge the area of EEG / biosignal - instrumentation and application

- Major Hardware Designs :

  ModularEEG (6 Chn, non-SMD, Kit)
  MonolithEEG (2 Chn, SMD, USB)
  SoundcardEEG (FM/AM - Modulation

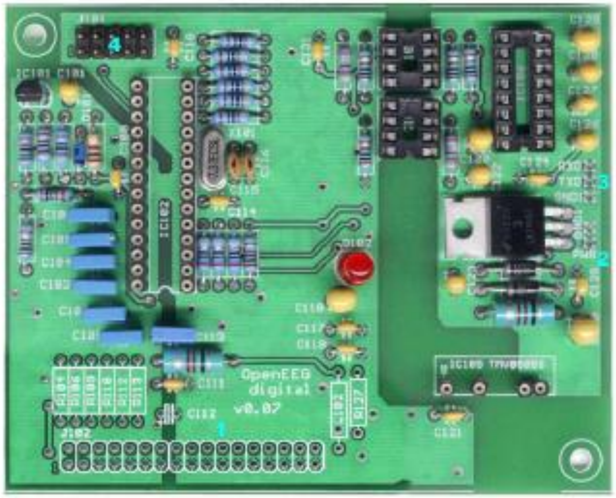
OpenEEG project

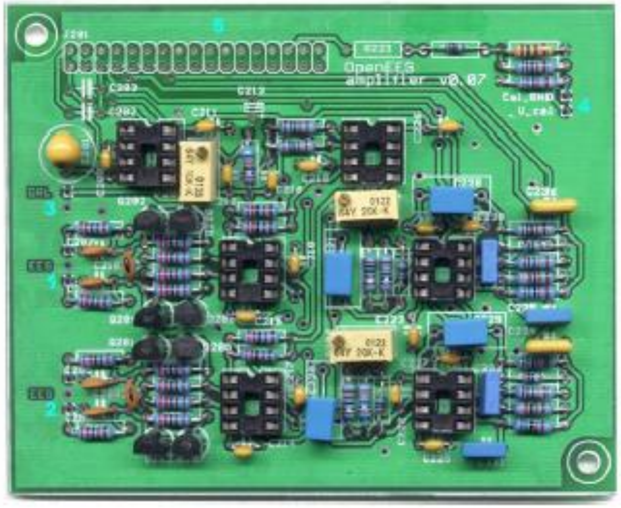
- Available Software:

different firmware implementations
PC host software in JAVA, C++
Client/Server architecture for biosignal sharing
Software for filter design and application
Experimental BCI-software

ModularEEG, digital + analogue boards.

OpenEEG project

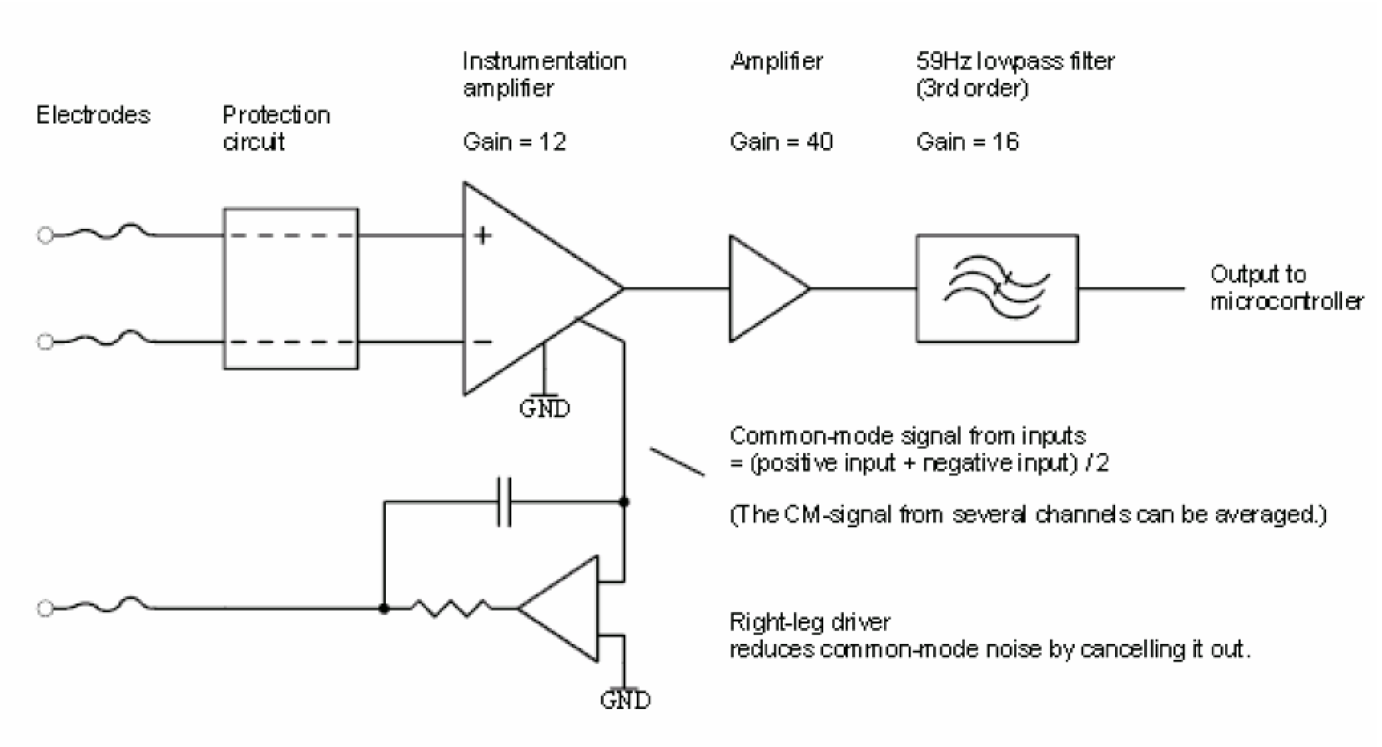




- ModularEEG - design by Joerg Hansmann
- one digital board, up to three analog boards, 2 to 6 channels
- AVR-Atmega8 Microcontroller, ADC-Resolution: 10bit / 0.5 uV
- Samplingrate: up to 1kHz
- DRL (driven right leg) – circuit, CMRR < -94dB
- Isolation: 2.500V (1 minute), 480V (continuous)
- no medical certification (use at own risk)

OpenEEG project

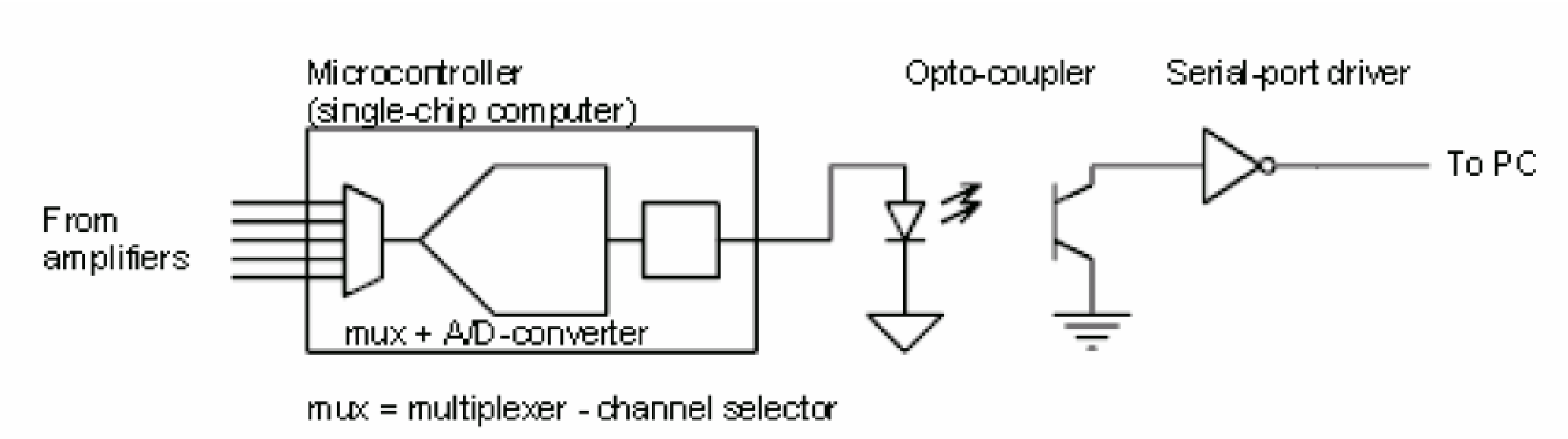
ModularEEG analog board block diagram (1 channel)



- User current limiter / ESD protection
- Signal conditioning: amplification + HP / LP filtering
- DRL: closed control loop to cancel CM

OpenEEG project

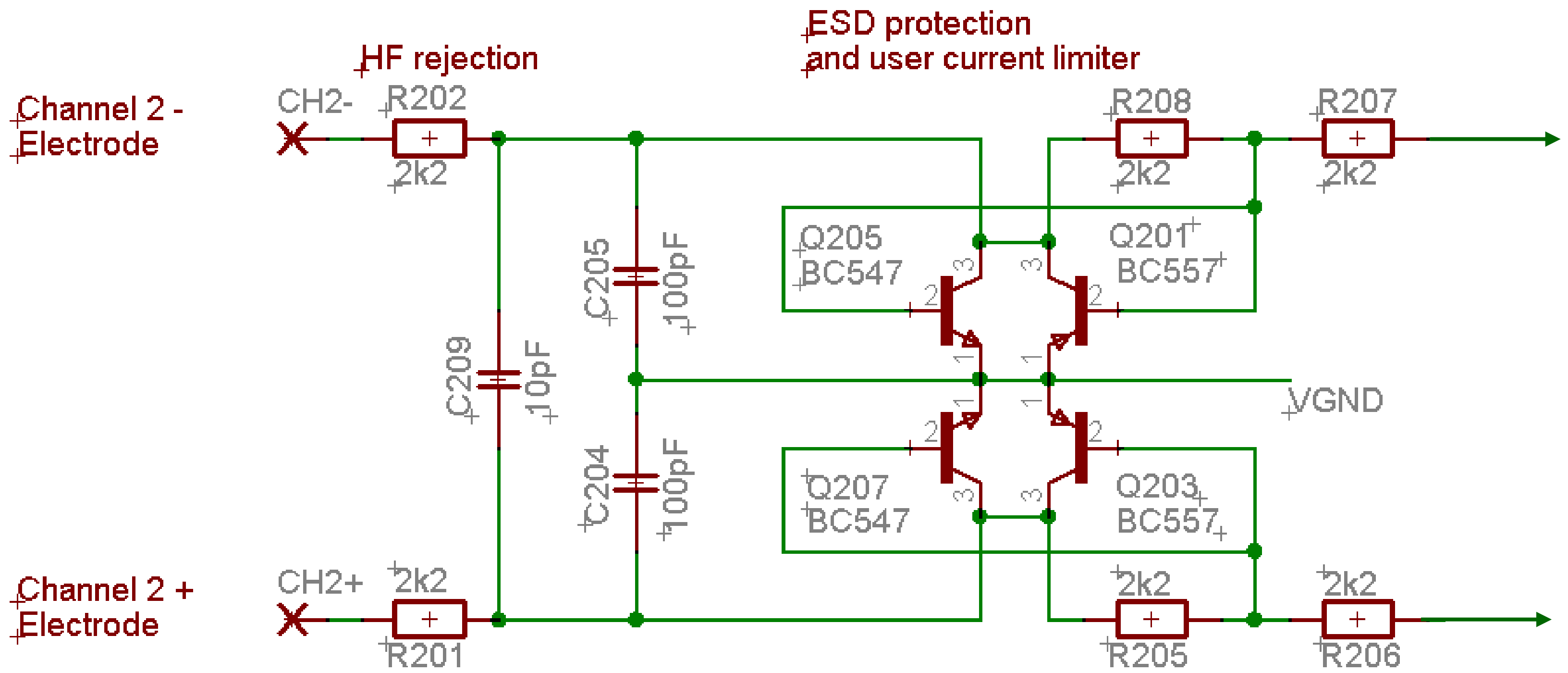
ModularEEG digital board block diagram



- Power supply regulation, DC/DC-conversion, LP-filter
- uC: Sampling and data protocol management
- Isolated data transfer: optocouplers

OpenEEG project

ModularEEG analog stages schematics – protection circuit

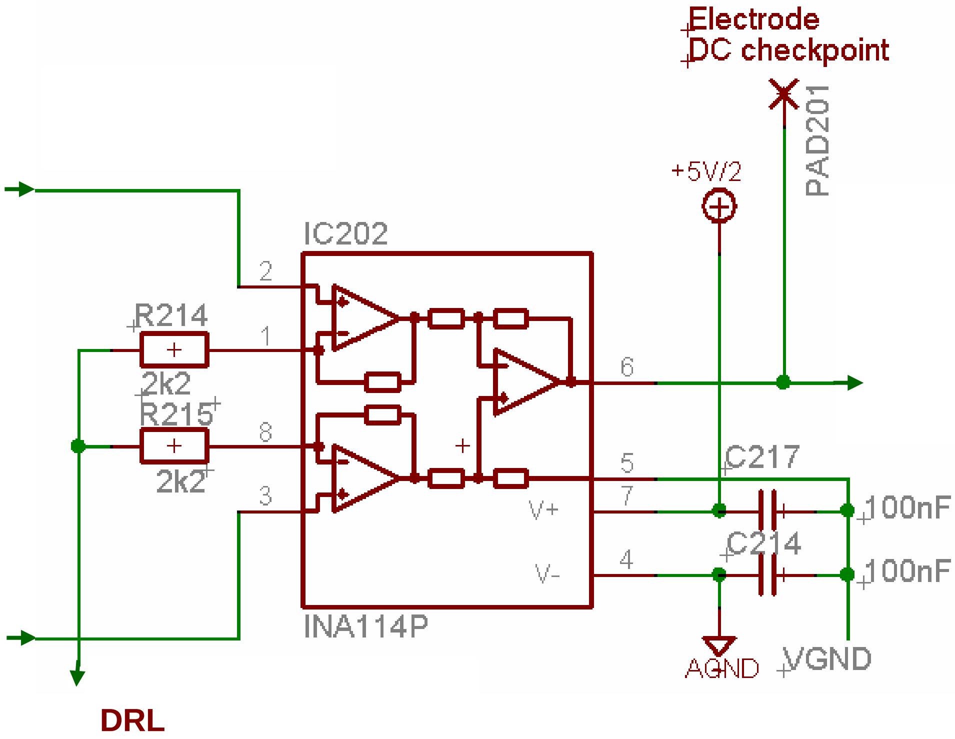


- C204, 205,209 suppress RF-signals
- Q201, 203, 205, 207 + R201, 202, 205-208 limit current
  transistors are used as clamping diodes -> V < 0,7 Volts

OpenEEG project

ModularEEG analog stages schematics - first gain stage

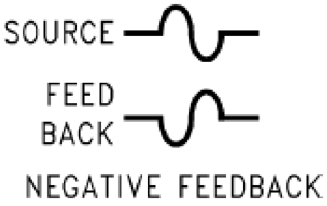
- **INA114 Instrumentation Amp.**
- **suitable supply range: +/-2,25V**
- **low drift and offset voltage**
- **low noise for given source impedances: 0.4uVpp (.1-10Hz)**
- **Gain 1 to 10000**
  1 + (50kOhm / (R214+R215))
  set to 12.2
- **Comon mode voltage measured between R214 and R215 and passed to DRL circuit**

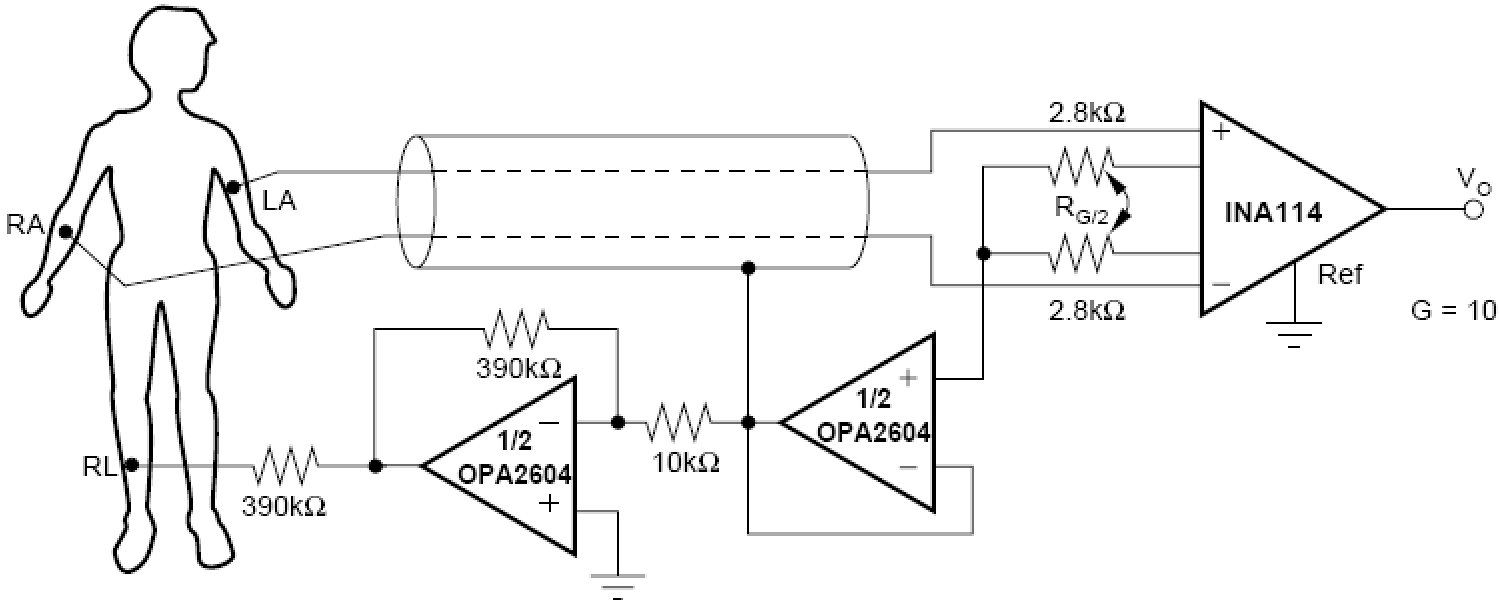


OpenEEG project

DRL: Driven Right Leg circuit

- negative Feedback loop
- output to the body
- improves CMRR by cancelling out CM

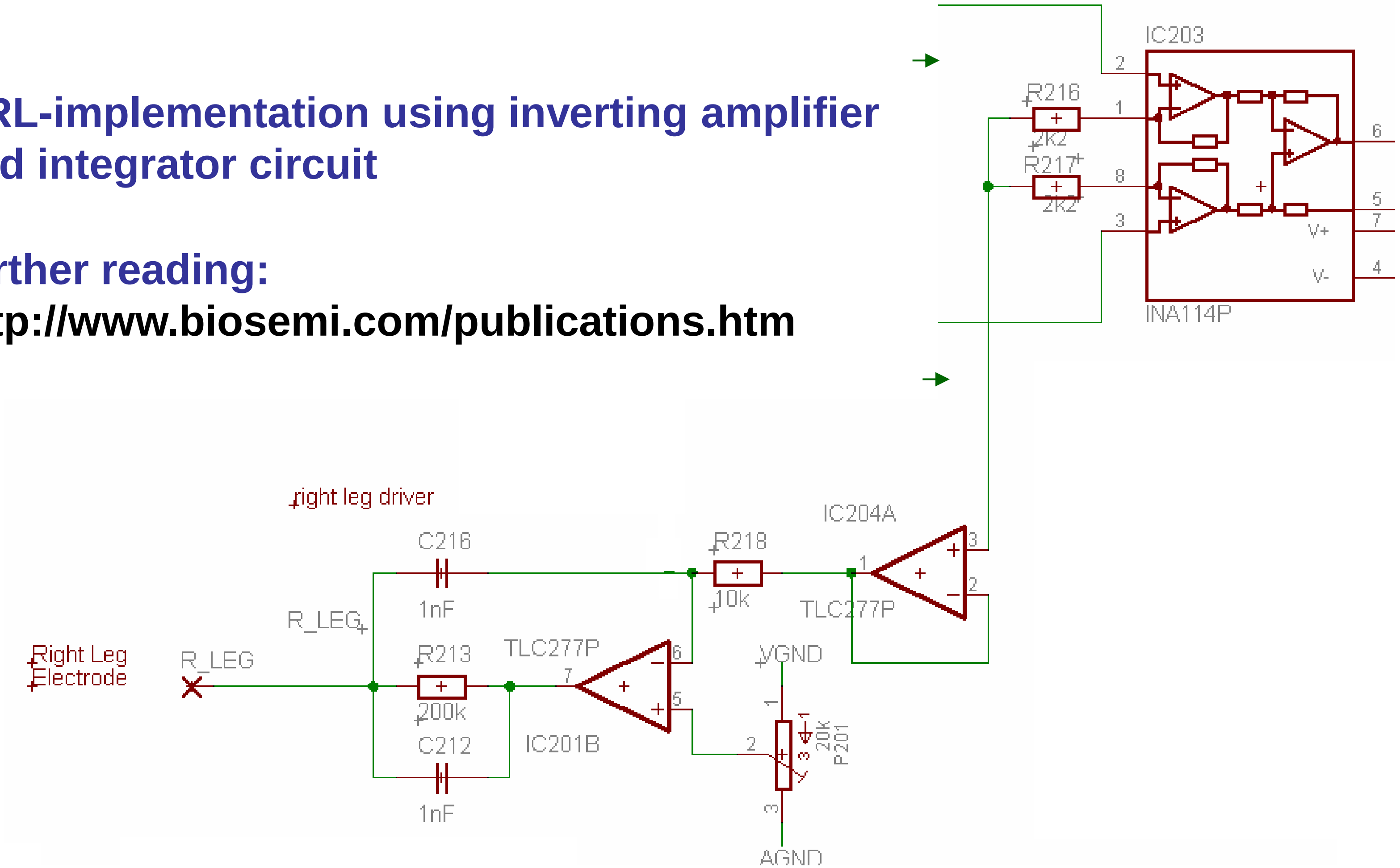




OpenEEG project

ModularEEG analog stages schematics - DRL circuit

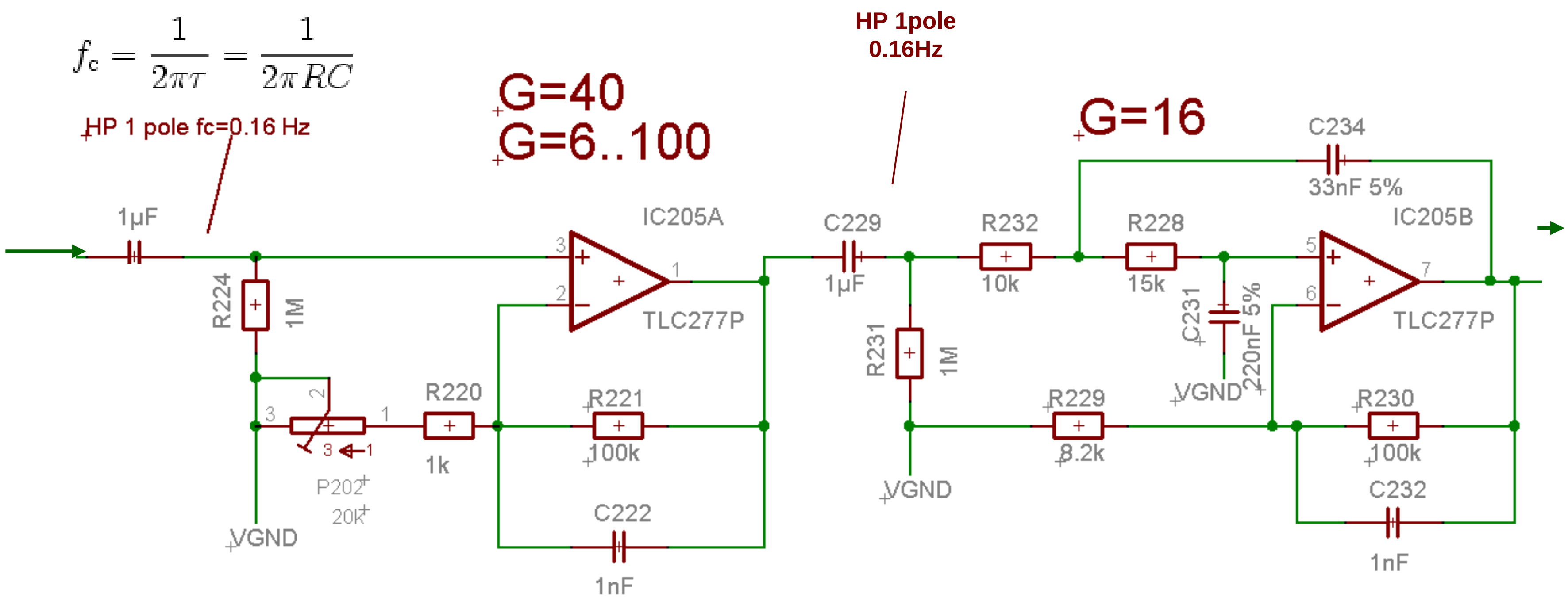
- **DRL-implementation using inverting amplifier and integrator circuit**
- **further reading:**
  http://www.biosemi.com/publications.htm



OpenEEG project

ModularEEG analog stages schematics - filter / gain stages

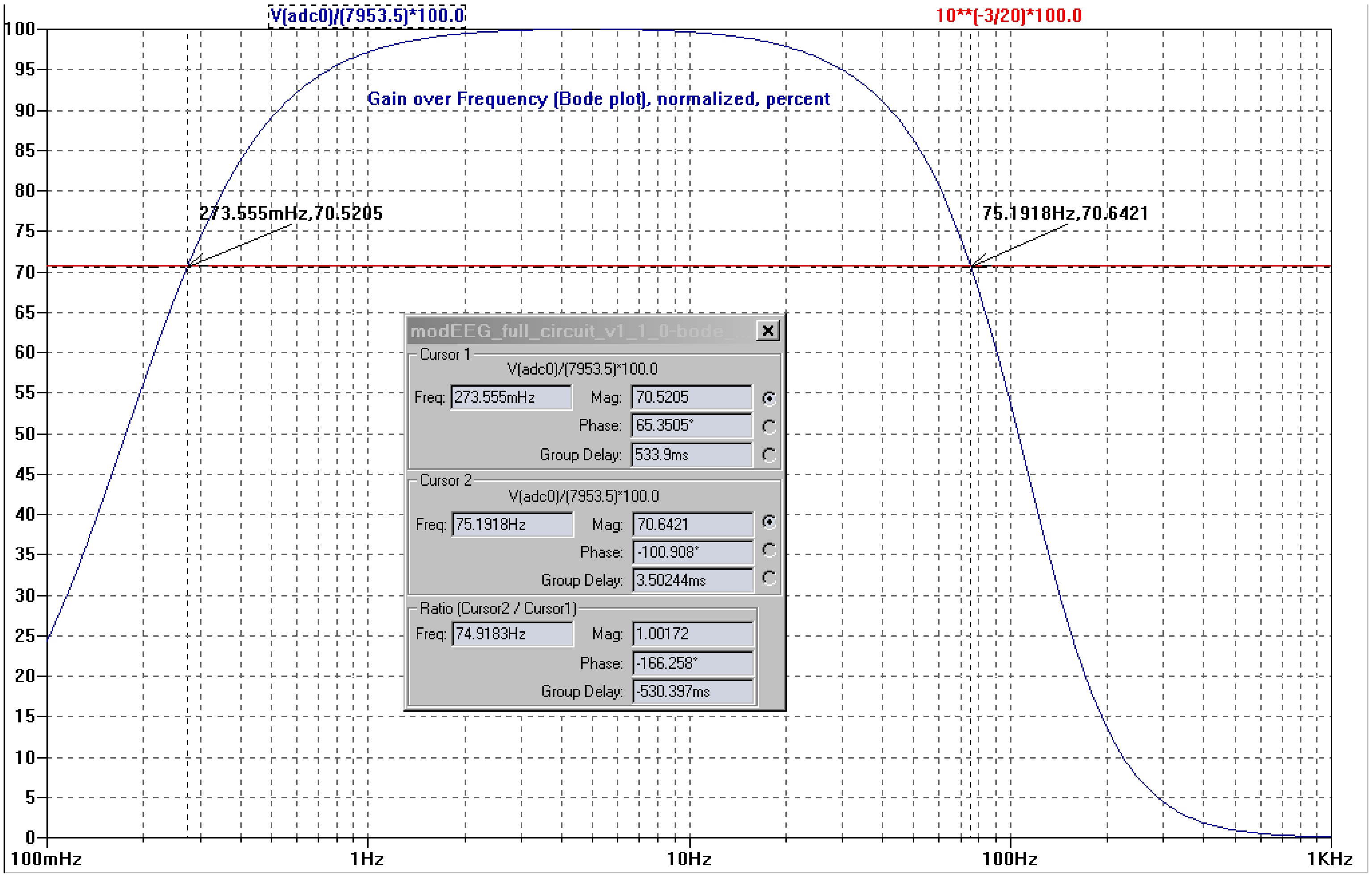
$$f_c = \frac{1}{2\pi\tau} = \frac{1}{2\pi RC}$$



- first high-pass 0.16 Hz
- Non-inverting amplifier G = (Ra+Rb) / Ra (Ra=1k + P202 Rb=100k)
- second high-pass 0.16 Hz
- active 2nd order low-pass 59Hz, gain=16
- 3rd pole located at digital board, near ADC input pin

OpenEEG project

ModularEEG Bode Plot: LTSpice Simulation (linear scale)



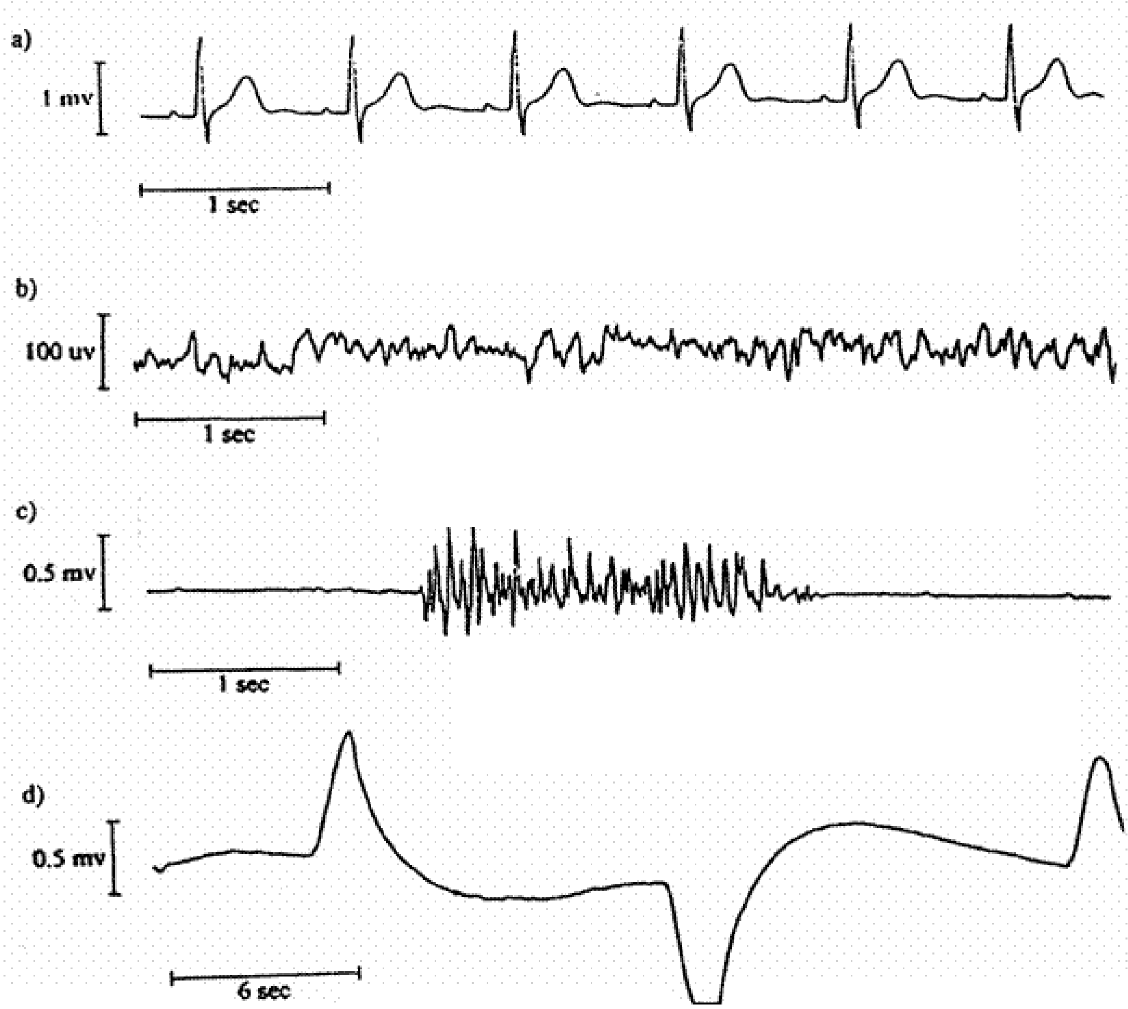
Types of Bioelectric Signals

ECG
Electro-Cardiogram
Heart activity

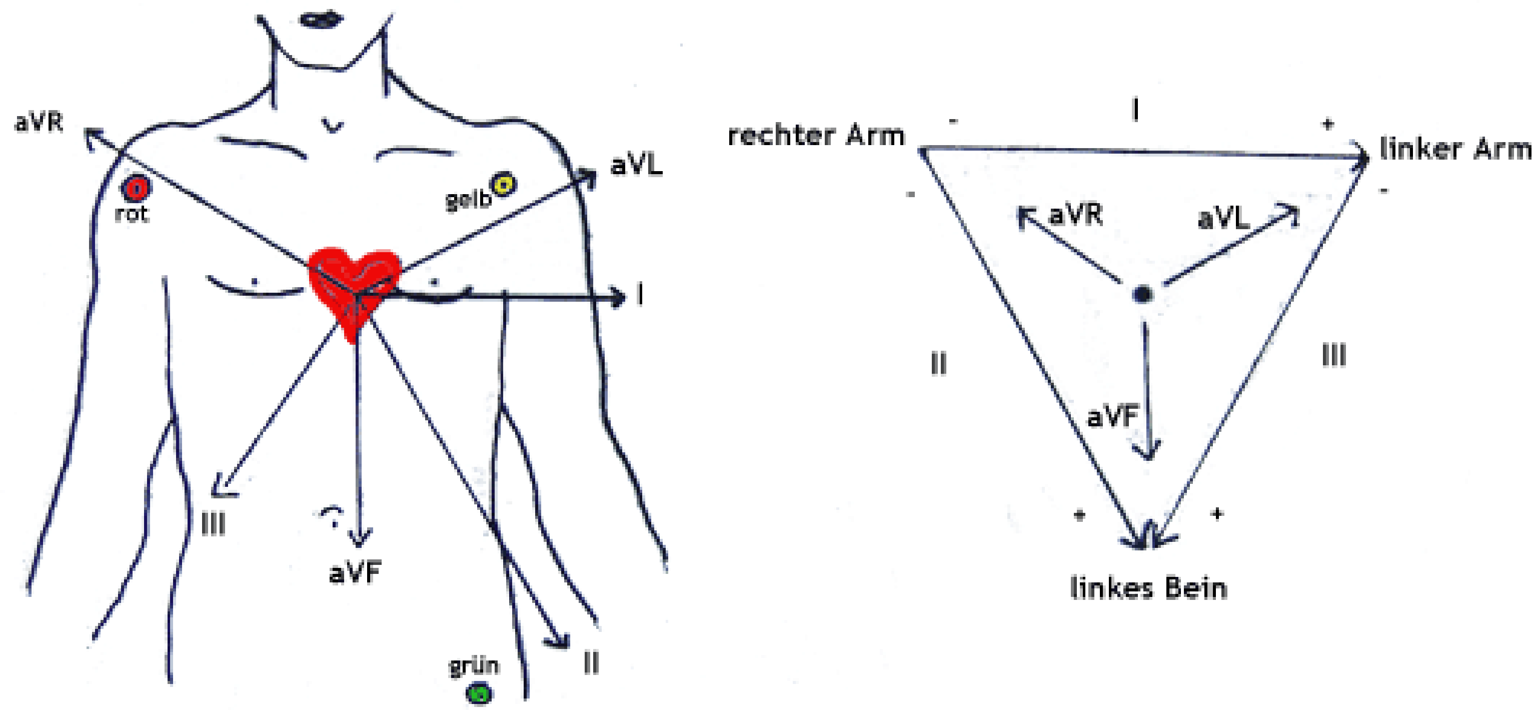
EEG
Electro-Encephalogram

EMG
Electro-Myogram
Muscle movement

EOG
Electro-Oculogram
Eye movement

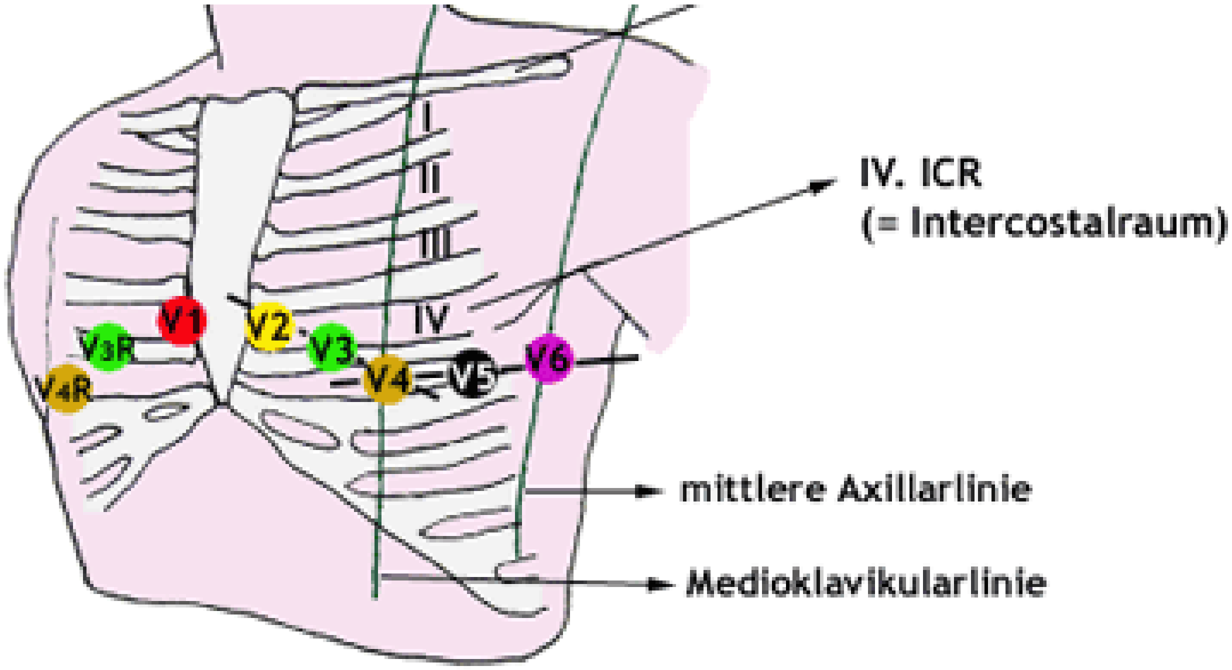


Electrocardiogram



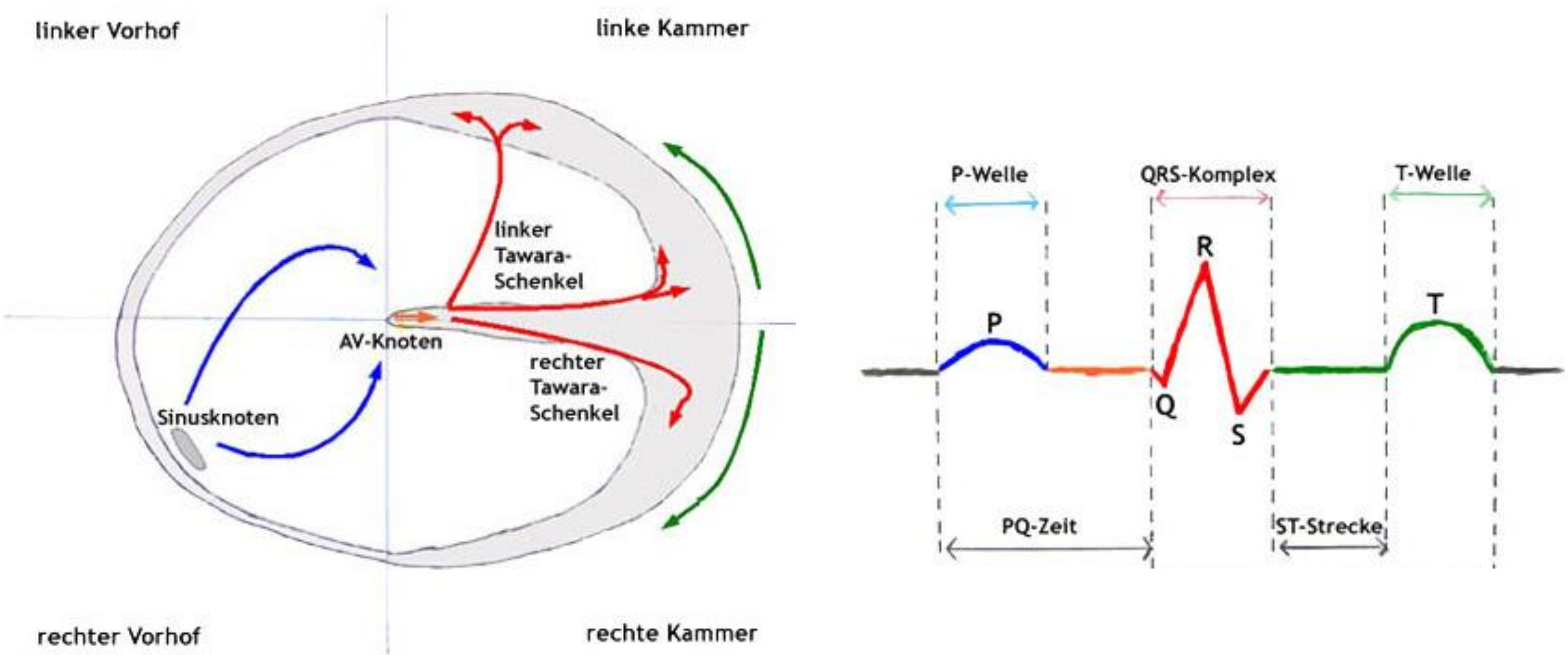
ECG measurement: Goldberger (left) and Einthoven (right)

Electrocardiogram



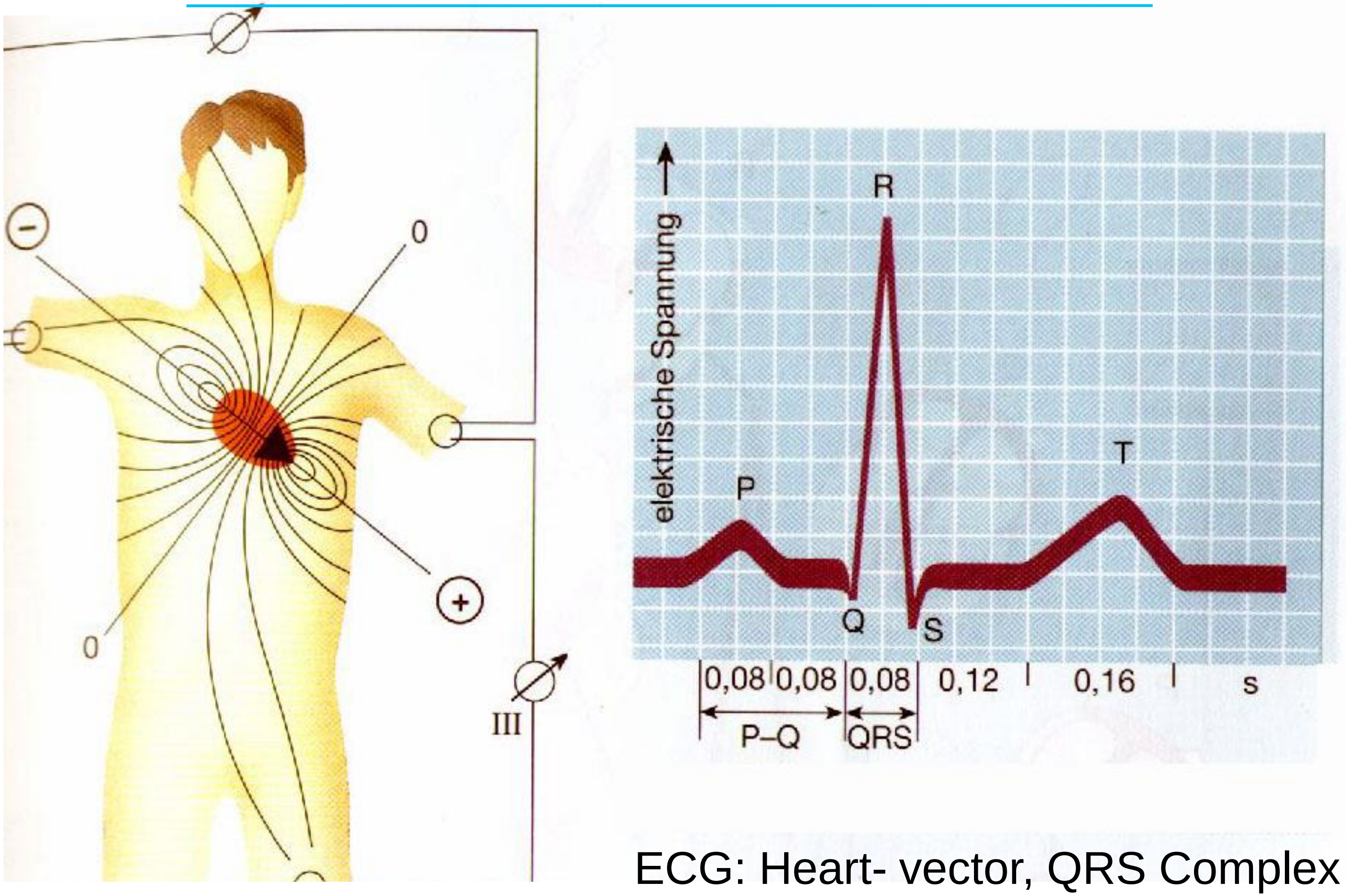
ECG measurement: Wilson

Electrocardiogram



Origination of the QRS - Signal

Types of Bioelectric Signals

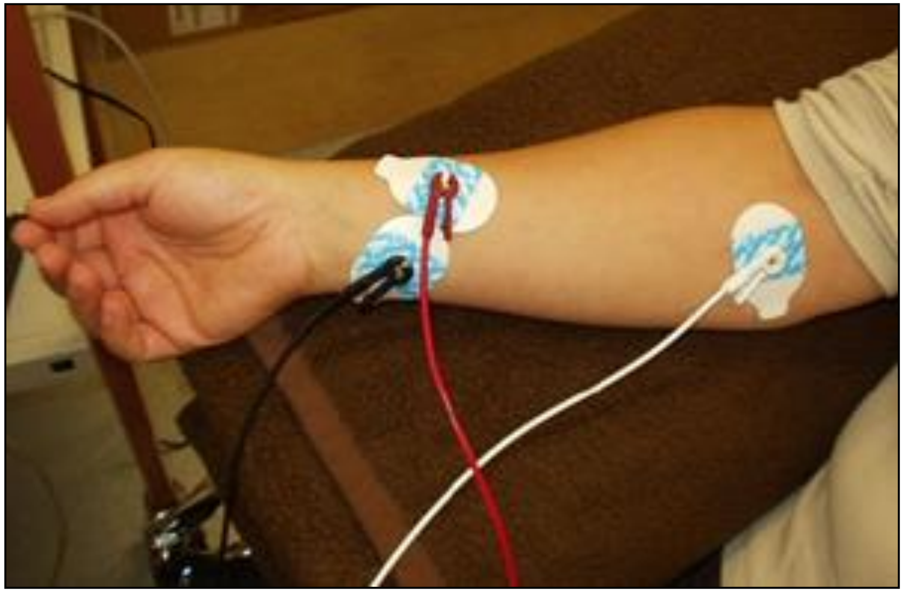


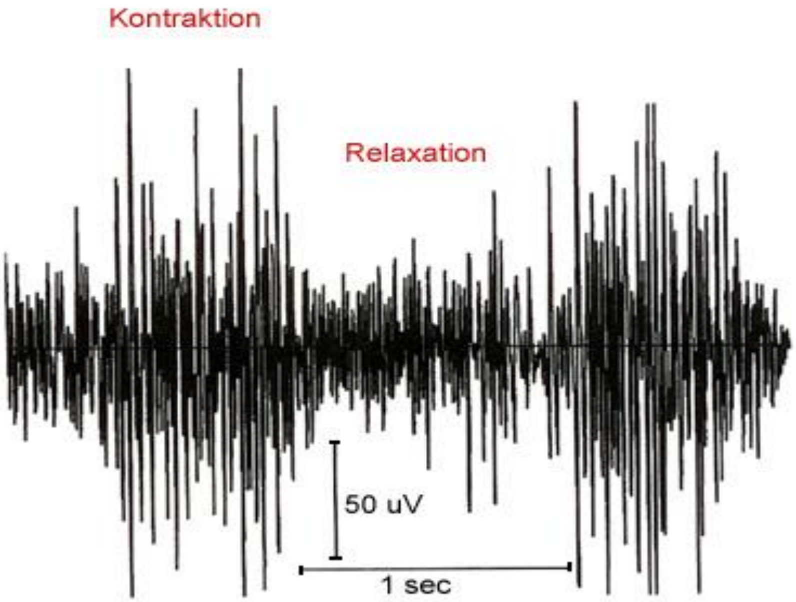
ECG: Heart- vector, QRS Complex

ECG - applications

- Diagnostics
- Functional analysis
- Implants (pace maker)
- Biofeedback (Heartrate variability, HRV)
- Peak Performacne Training, Monitoring

Electromyogram

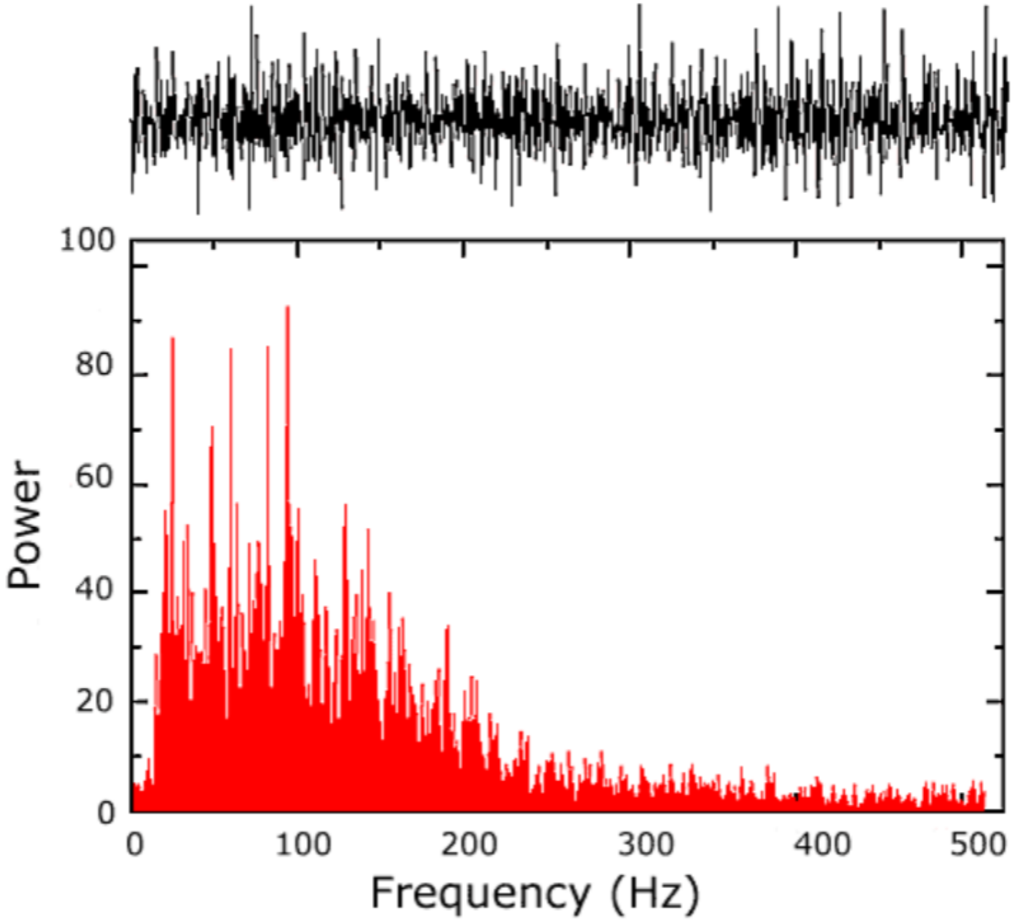




EMG surface (glue-) electrodes

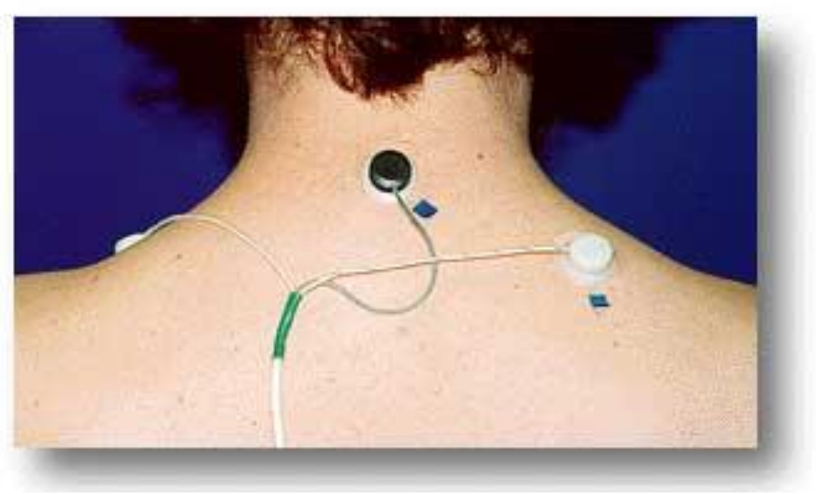
EMG - signal (up to 3mV, 1kHz)

Electromyogram



Frequency spectrum of the EMG signal detected from the Tibialis Anterior muscle during a constant force isometric contraction at 50% of voluntary maximum

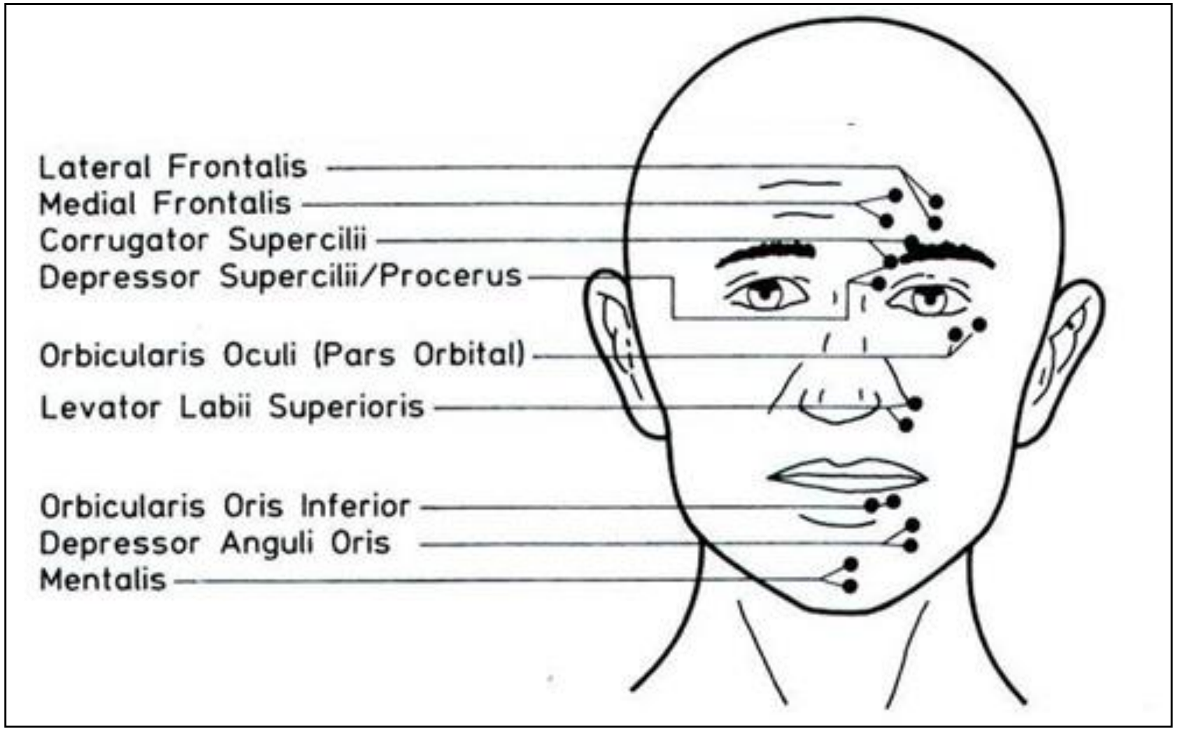
Electromyogram



EMG electrodes (passive)

EMG electrodes (active)

Electromyogram



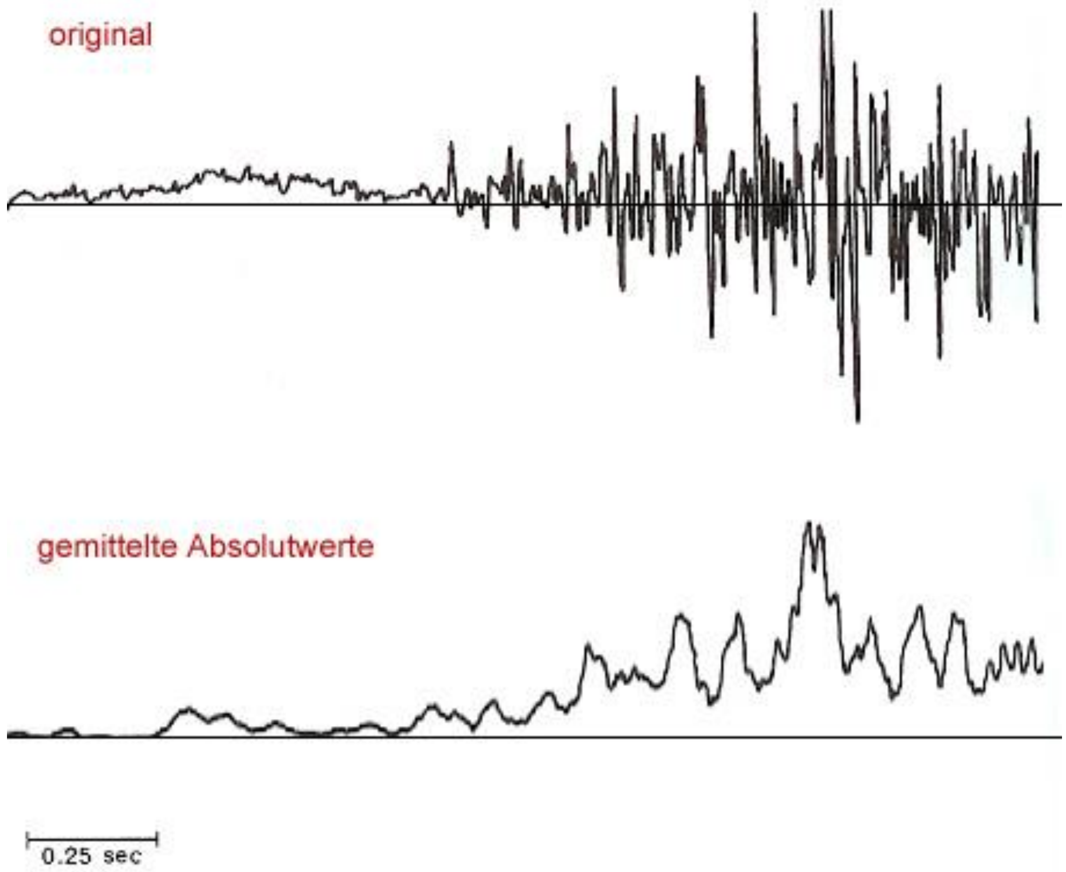
Recording locations for facial EMG

Electromyogram

Needle electrodes

adhesive electrode

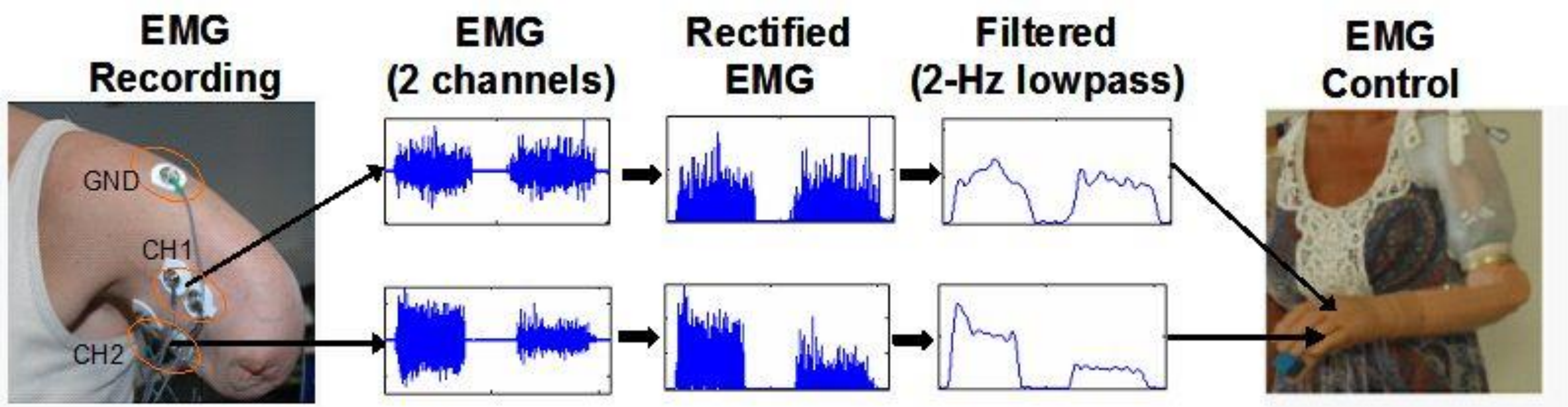
Electromyogram



EMG activity: averaging absolute vaues

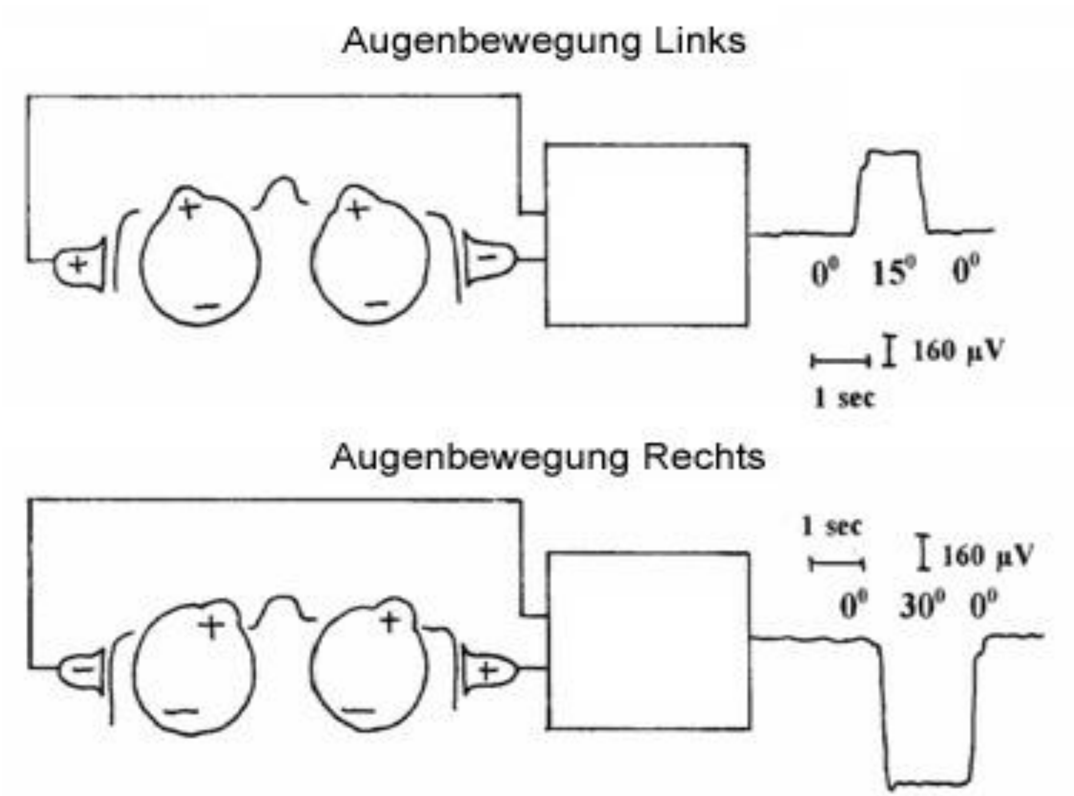
EMG – applications in assistive technology

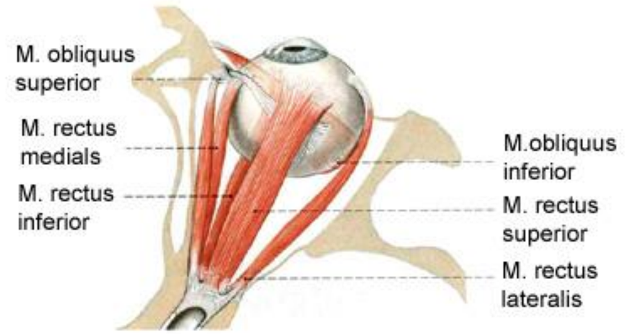
- active Prosthesis, Orthesis
- Alternative Human-Computer Interfaces



Guanglin Li: Electromyography Pattern-Recognition-Based Control of Powered Multifunctional Upper-Limb Prostheses

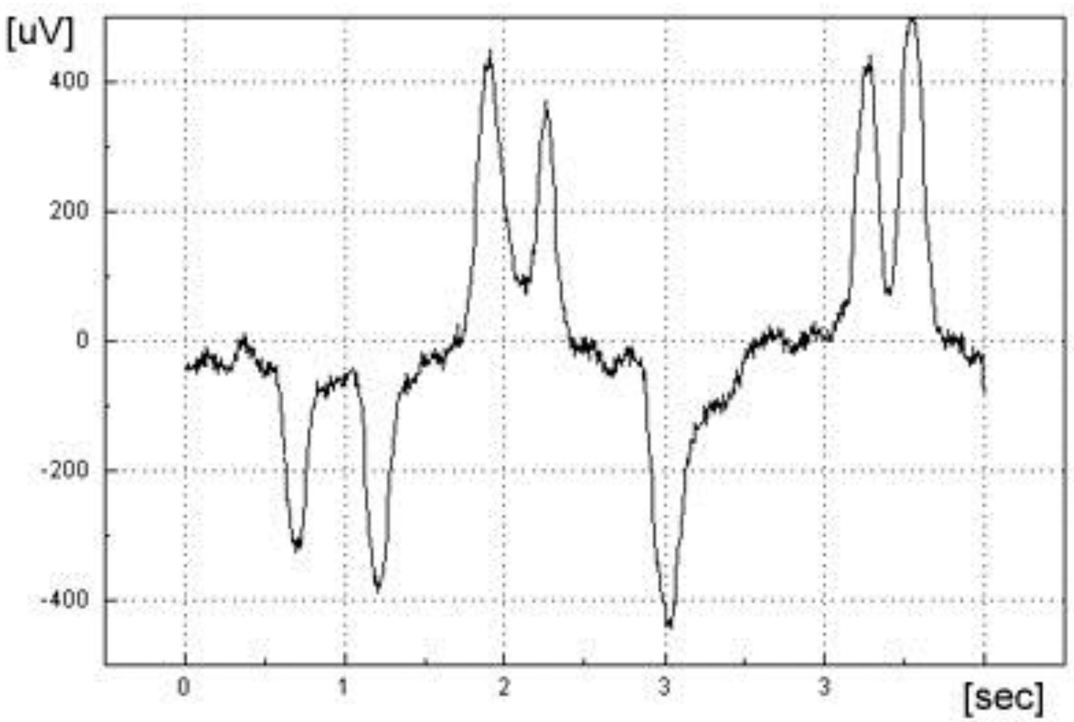
Electro-oculogram





Electrooculogram (EOG), Eye Dipole

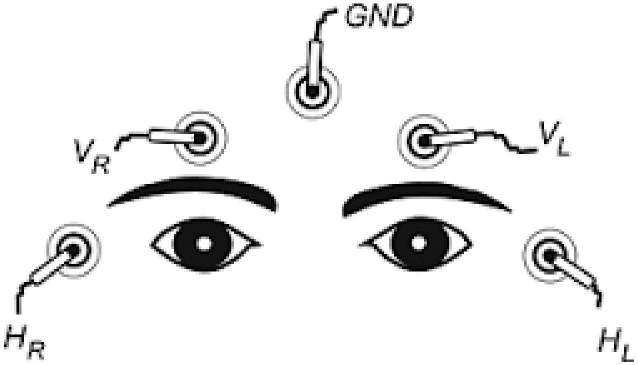
Electro-oculogram



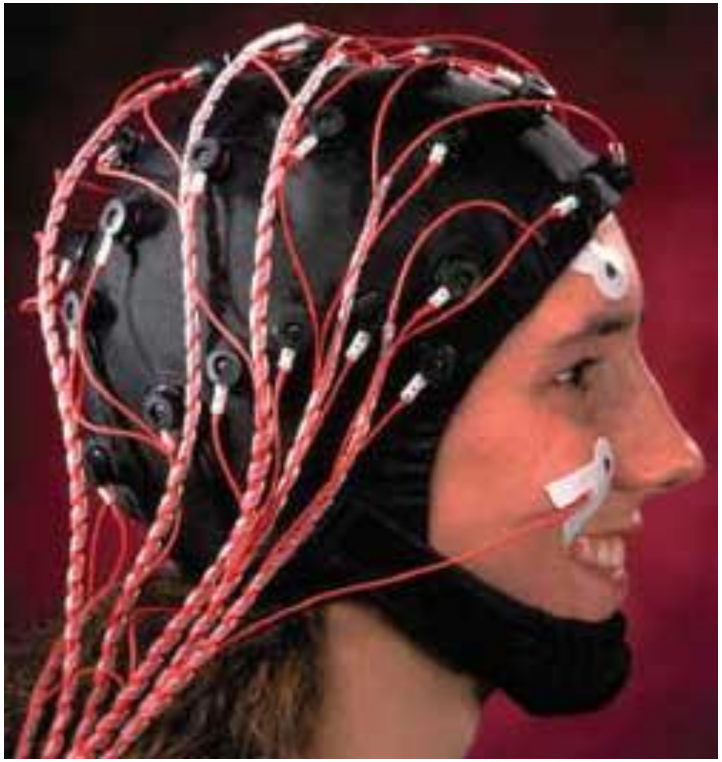
Saccadic eye movements to the left and right

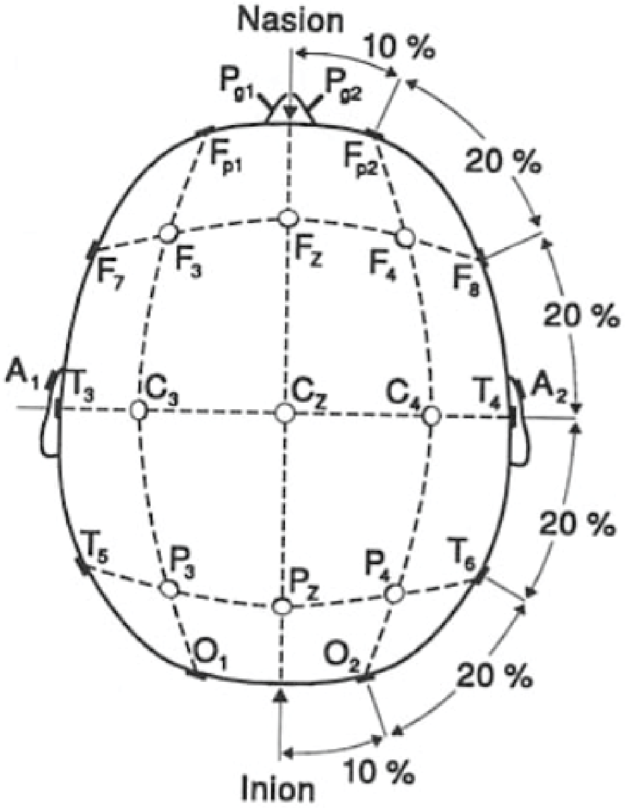
EOG - applications in assistive technology

- Functional analysis
- Human Computer Interfaces



Electroencephalogram

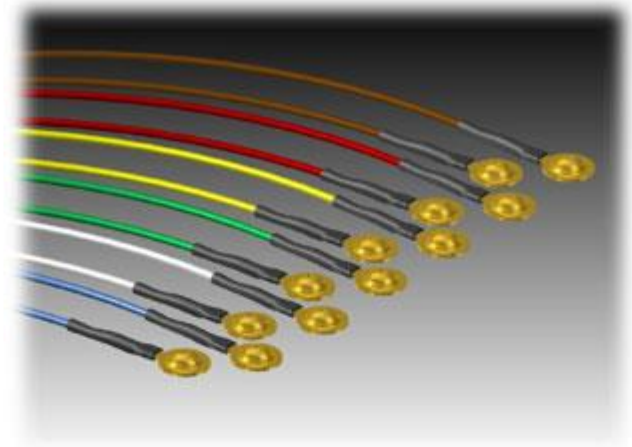




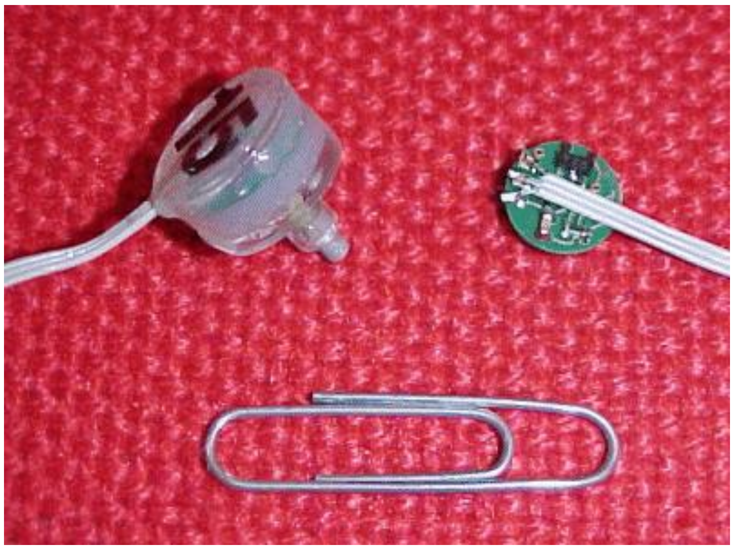
EEG Electrode – cap

locations of the 10/20 system

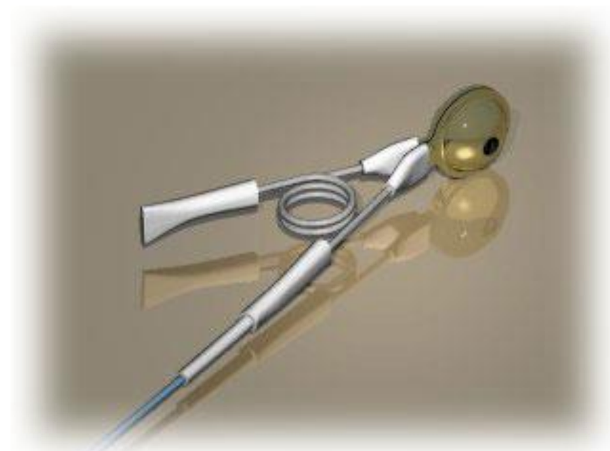
Electroencephalogram



Singe disk gold plated electrodes

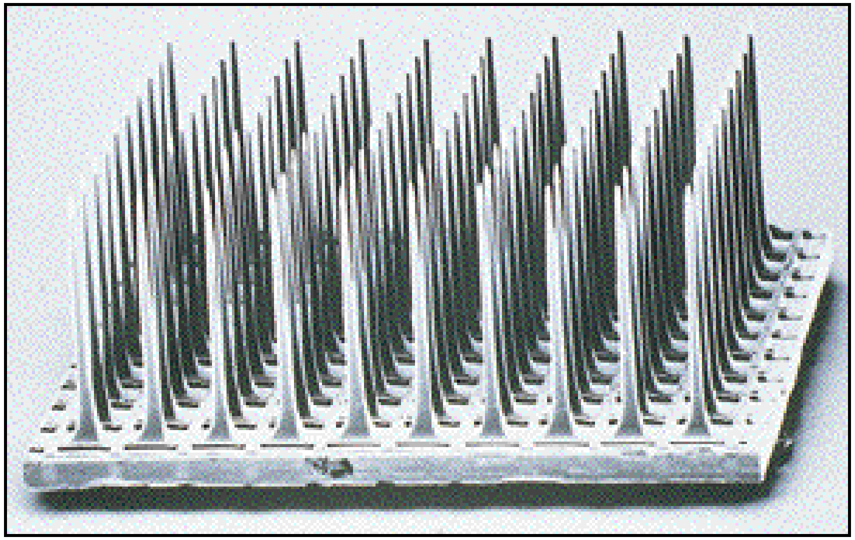


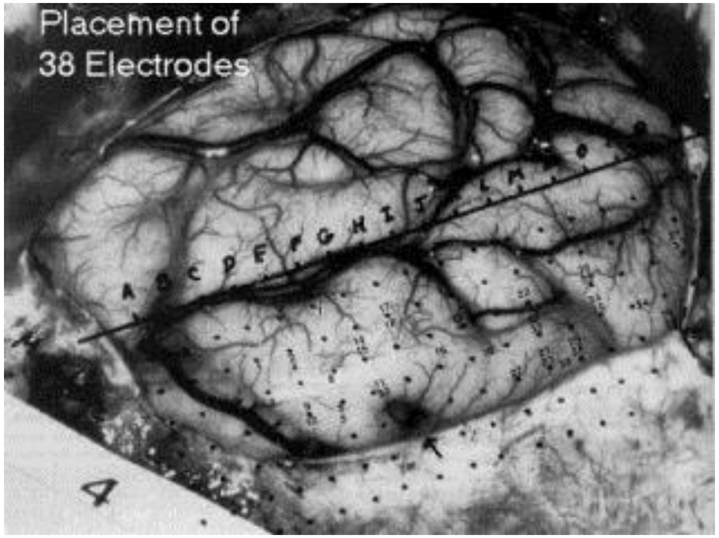
Active EEG- electrode



Ear clip electrode

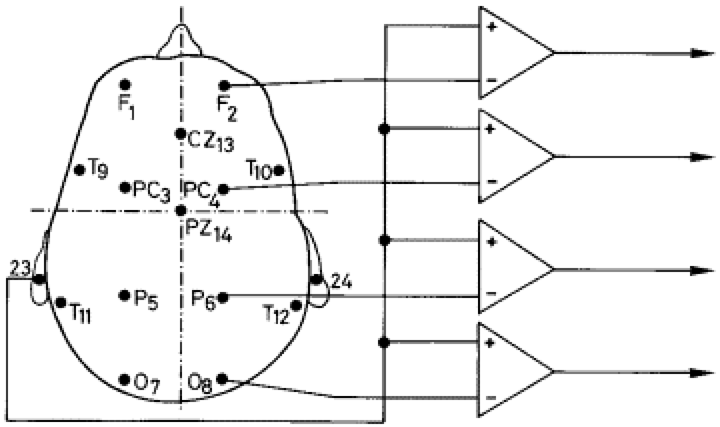
Electroencephalogram



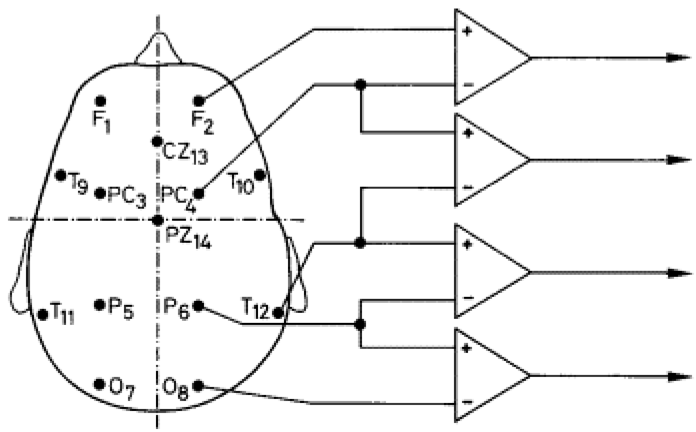


Intracortical / chronical electrodes

Electroencephalogram

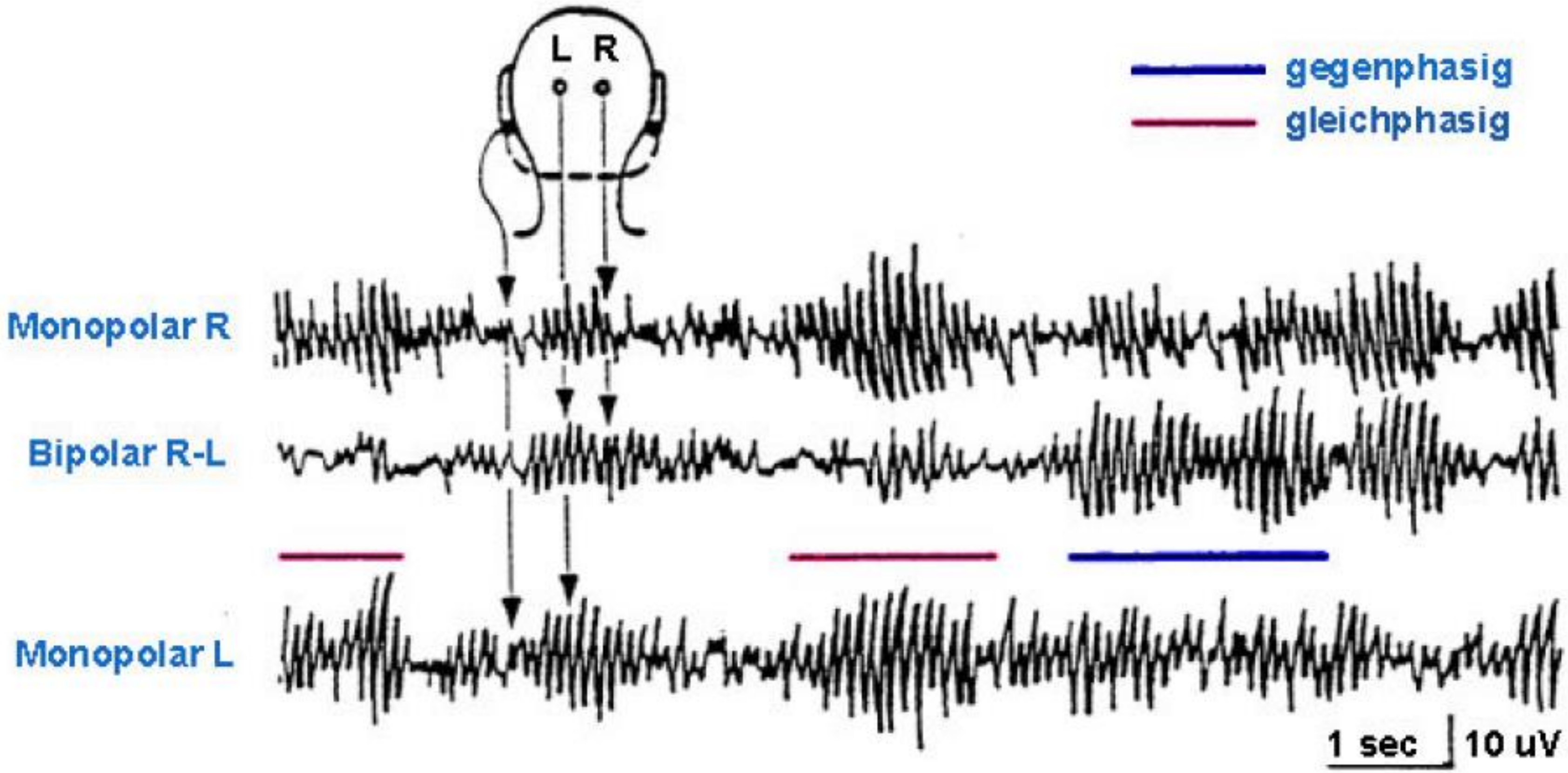


Unipolar measurement
(indifferential right ear
electrode)

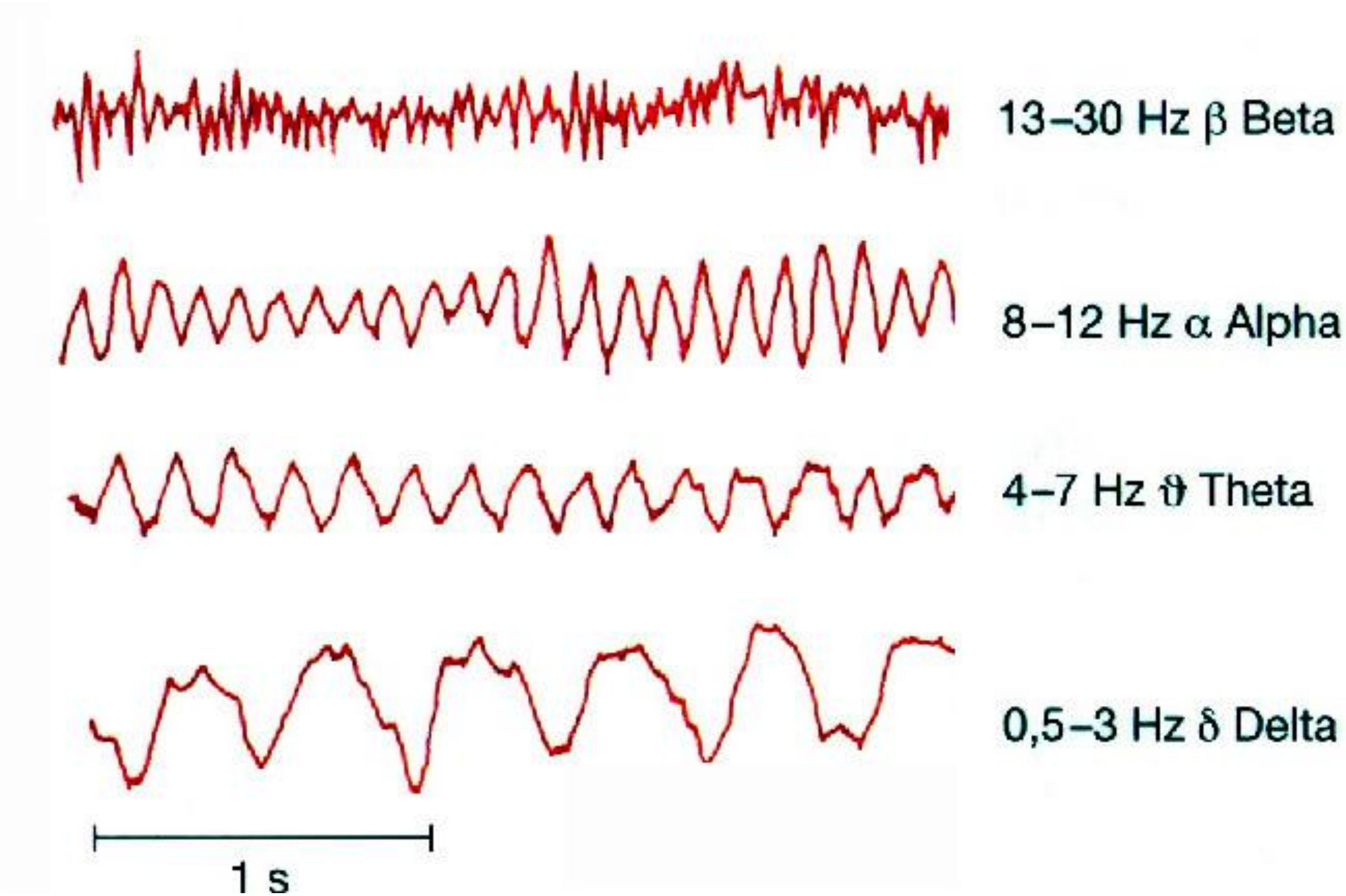


Bipolar measurement

Electroencephalogram

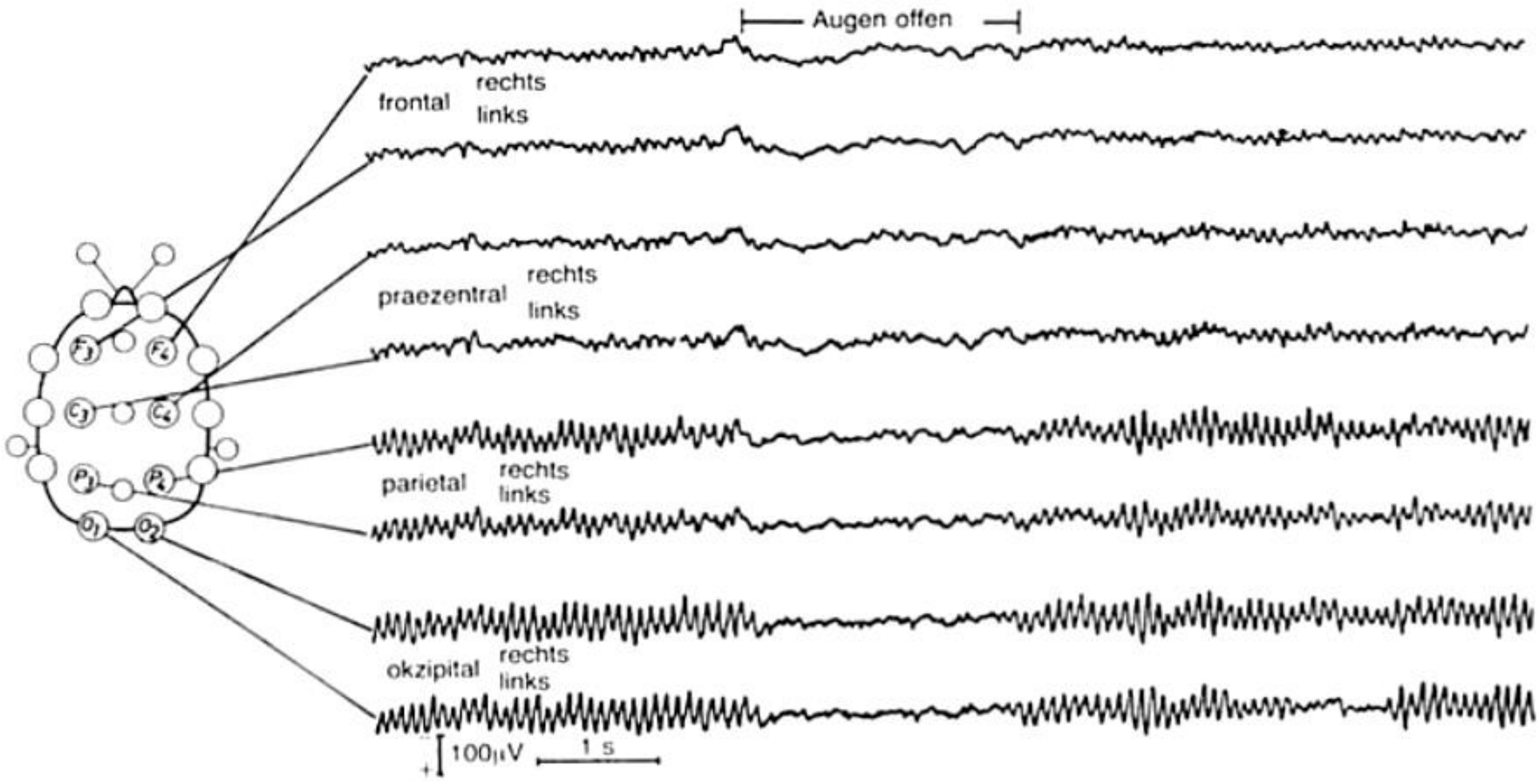


Electroencephalogram



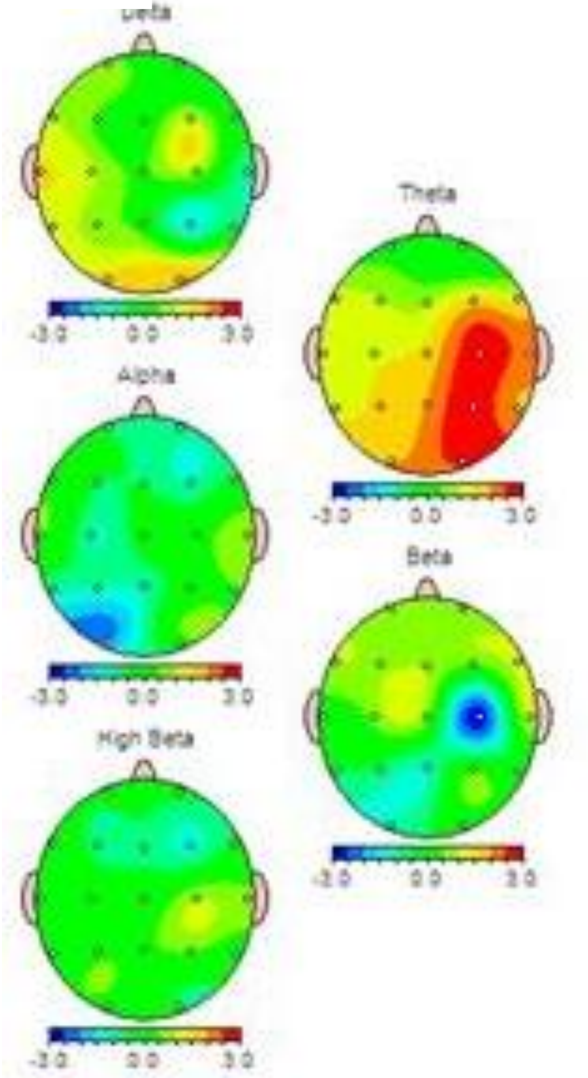
EEG, dominant frequencies, < 300 uV

Electroencephalogram



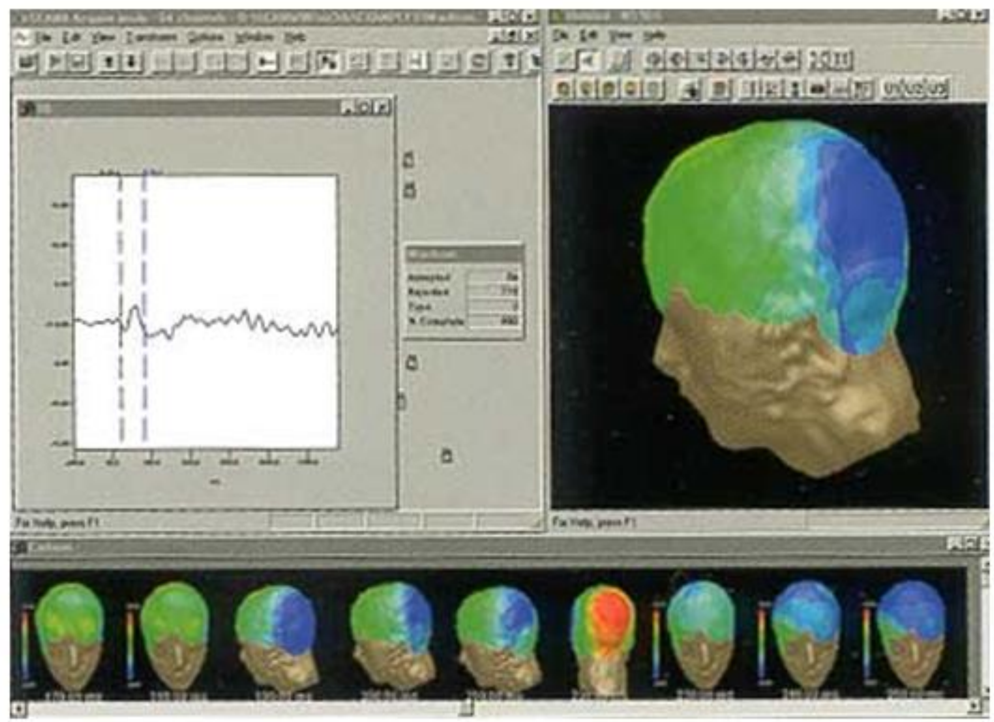
EEG, Alpha bursts when eyes closed,
alpha desynchronisation when eyes opened

Electroencephalogram



Quantitative EEG (QEEG)

many EEG channels (up to 256)
source / dipole localisation

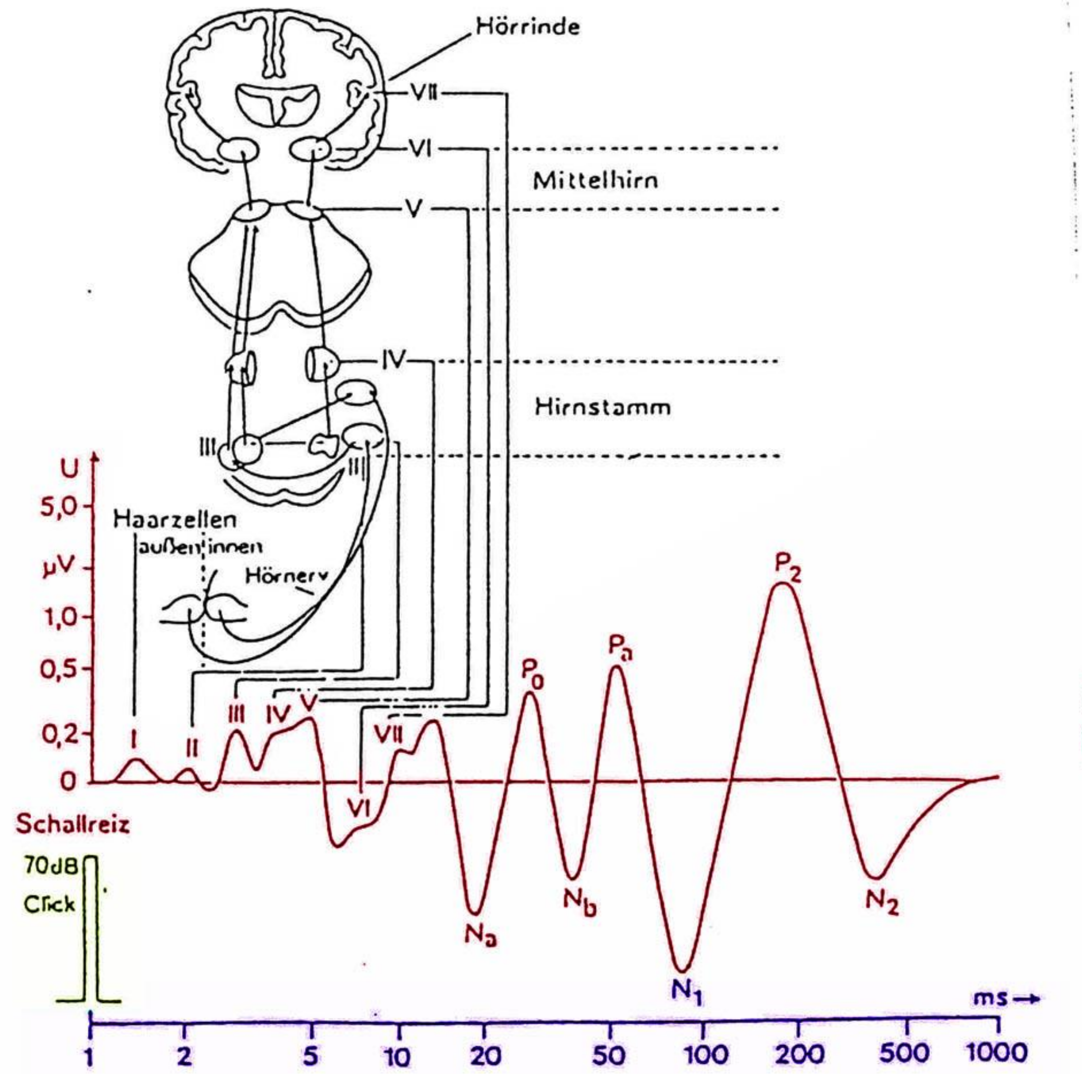


Electroencephalogram

Auditory Evoked Potentials (AEP)

Trial averaging

Also:
VEP
SSEP



EEG – applications in assisitve technolgy:

Brain-Computer Interfaces (BCI)

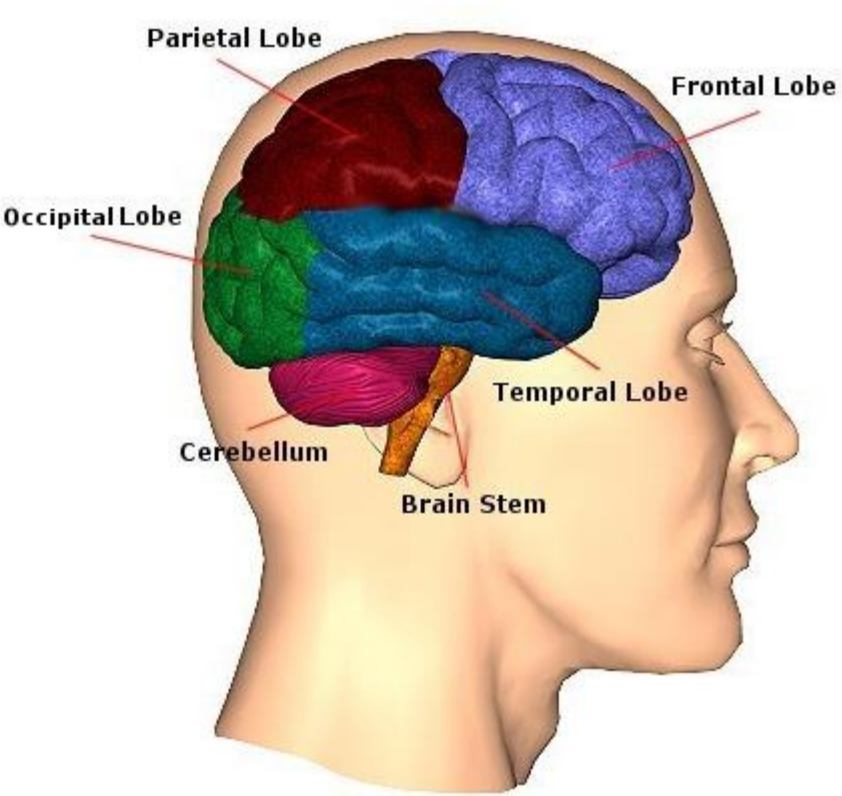
- SSVEP (steady state visual evoked potentials)
- P300 (event related potentials)
- SCP (slow cortical potentials)
- µ-rhythm (movement imagination)

Bioelectric signals: comparison

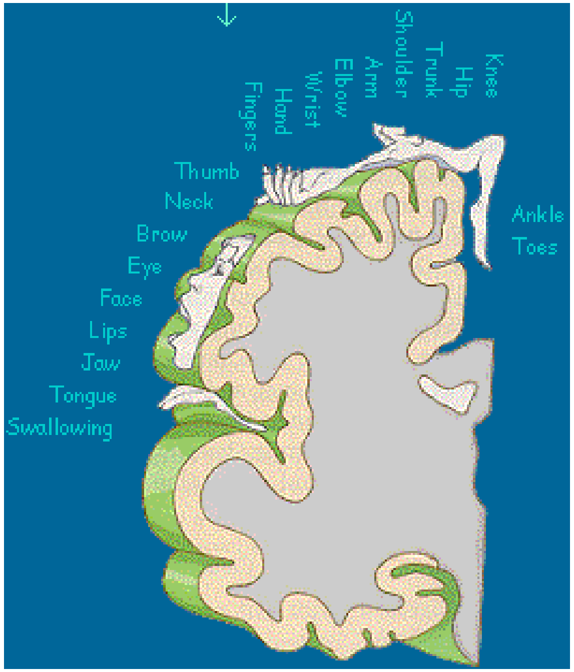
	Frequency	Amplitude (mV)
ECG	0,2 – 300	0,1 - 2
EEG	DC – 100	0,005 - 0,2
EEG (cortical)	10 – 100	0,015 - 0,3
EMG	10 – 1000	0,1 - 1
EMG (needle)	10 – 10000	0,05 - 5
EOG	0 – 30	0,1 - 2
Intracell.	0 – 10000	50 .. 130

Brain Computer Interfaces

Brain / Cortex Topography:

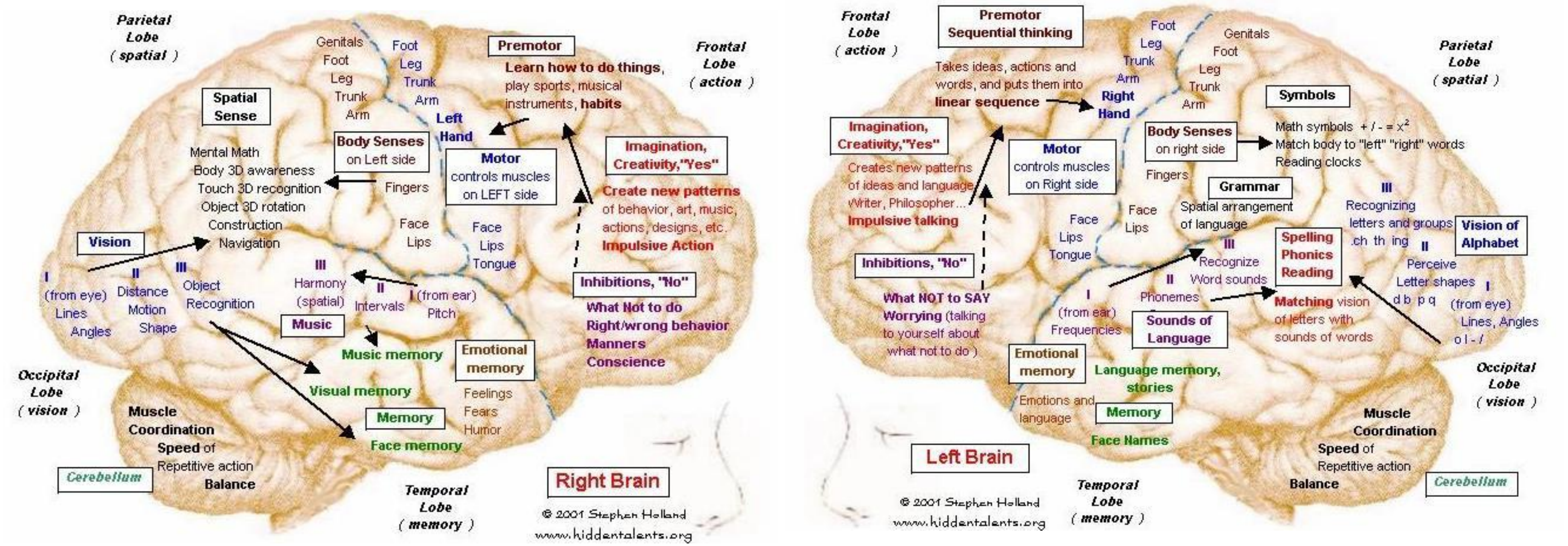


http://www.neuroskills.com/brain.shtml



Sensomototic humunculus:
(top) frontal lobe, gyrus precentralis

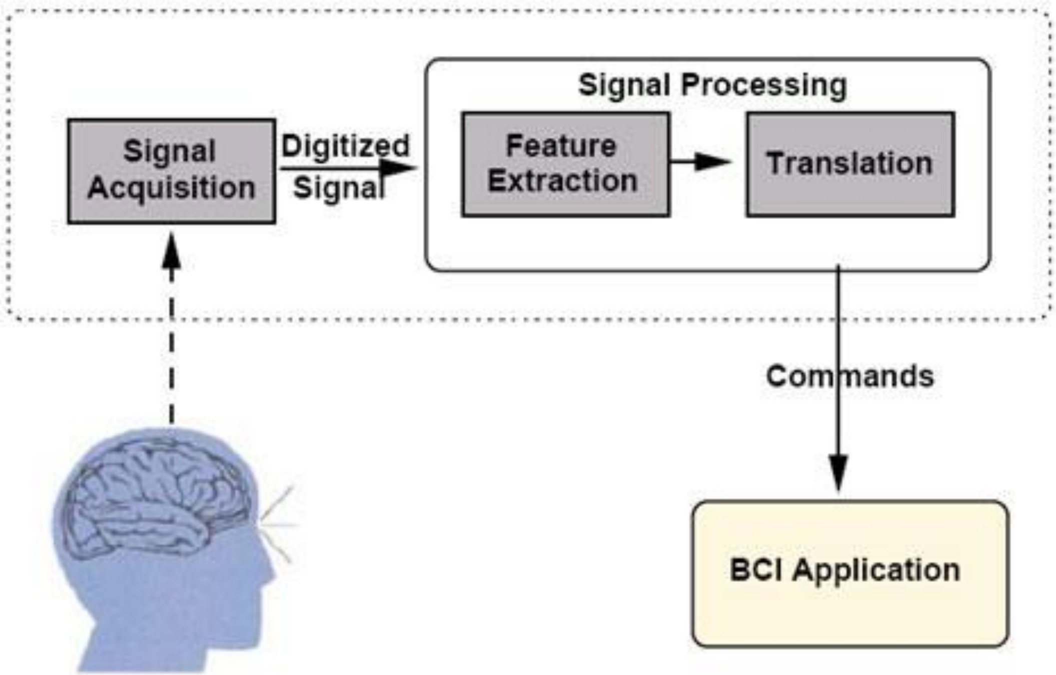
Brain / Cortex Topography:



Right and left brain map   http://members.shaw.ca/hidden-talents/brain

Brain Computer Interfaces

Principles of operation:



The control information is extracted from the real time EEG-recording

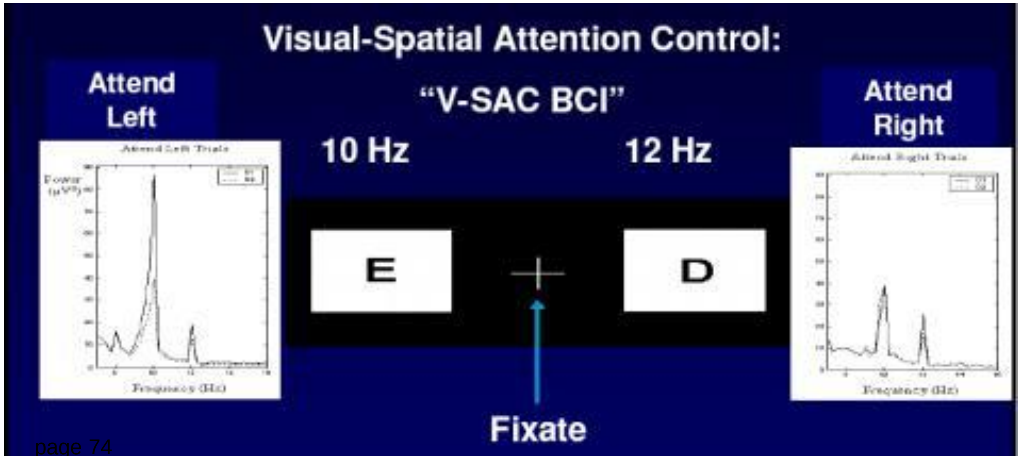
Brain Computer Interfaces

- allow patients to control a computer by concious changes of brain activity
- provide a means of communication to completeley paralysed patients: amyotrophic lateral sclerosis (ALS), cerebral palsy, locked in
- can be used to control a cursor, select symbols, control external devices like orthesis / prothesis (depending on type of BCI)
- have a very low data rate, typical a few bit per second or less
- first results in the 1970ies (Vidal, visual evoked potentials, VEP-BCI)

Brain Computer Interfaces

SSVEP

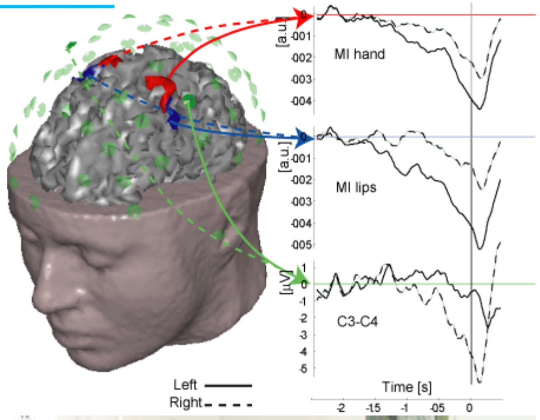
- **Steady State Visual Evoked Potentials derived from the visual (occipital) cortex**
- **focussing attention to visual stimuli of different frequency shows up in the EEG freqeuncy bands**
- **relibable and high transfer rate, but some prerequisites (eyes)**



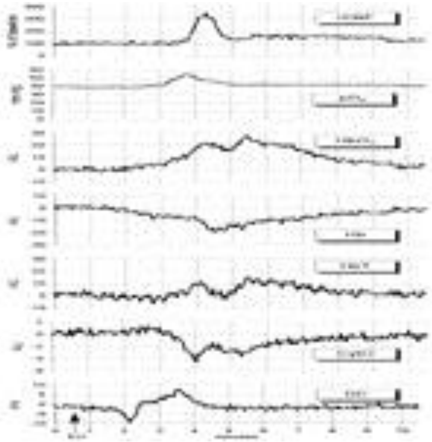
http://www.iua.upf.es/activitats/semirec/semi-Reilly/

Brain Computer Interfaces

SCP BCIs



- **detection of slow cortical potentials (SCPs)**
- **needs DC EEG Amplifiers (no highpass filter)**
- **first successful device end 1990‘s:**
  Niels Birbaumers Thought translation device
  intensive training with necessary to gain
  control over the SCP waves



<u>SCPs:</u>

DC-shifts, slow negativation of cortical areas

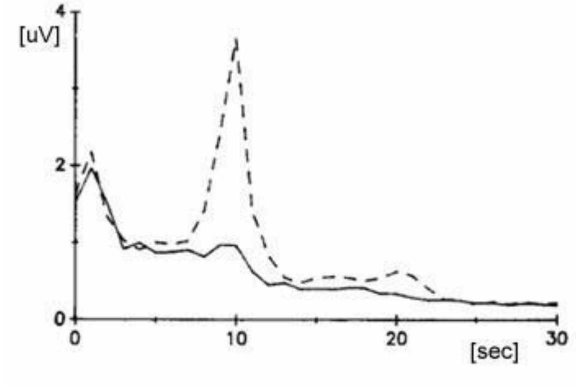
Preparation of movement and cognitive tasks,

Several hundert milliseconds before the task

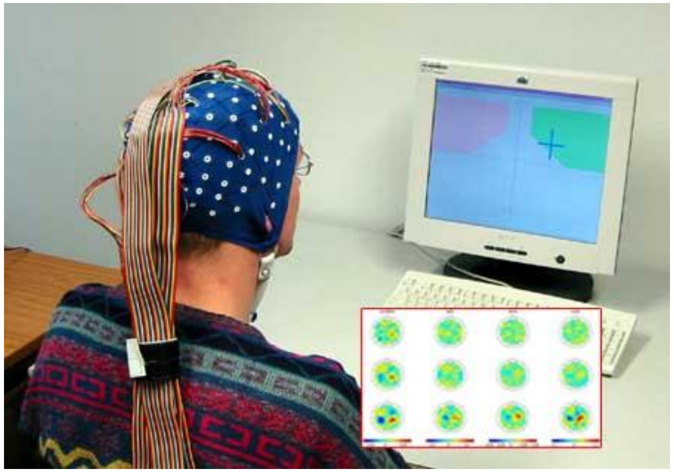
Patinet using TTD to write a letter
http://www.heise.de/ct/06/18/088/bild1.jpg

μ-rhythm BCIs

- **μ–rhythm is the idle-rhythm of the motor cortex**
- **frequencies around 10 and 18 Hz, location : gyrus praecentralis individual differences -> multichannel EEG (QEEG) for offline analysis**
- **ERD / ERS – event related desynchronisation / synchronisation movements <u>or imagination of movements</u> inhibit the μ–rhythm**



ERD/ERS at around 10, 22 Hz

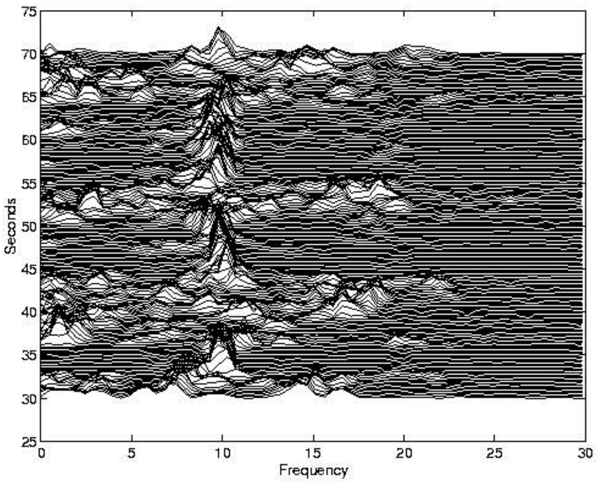


Berlin-BCI, http://www.fraunhofer.de/

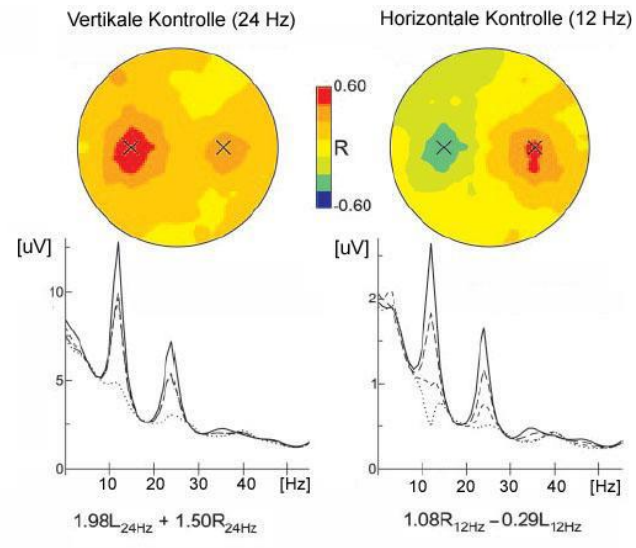
Brain Computer Interfaces

µ-rhythm BCIs

- **two dimensional cursor control using different frequency bands for vertical horizontal movements (Wadsworth BCI)**
- **control of an orthesis, adaptive algorithm (Graz BCI)**



CSA of Mu-rhythms, http://www.robots.ox.ac.uk/



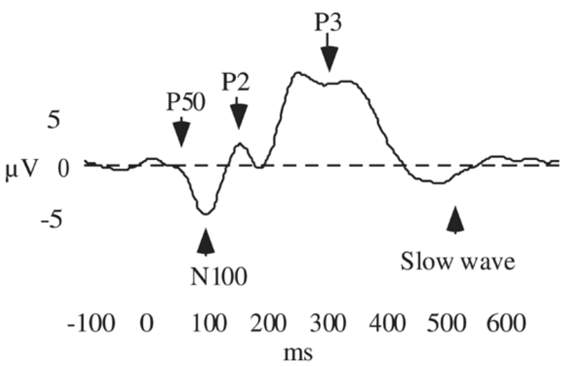
Wadsworth BCI, 2 dimensional control

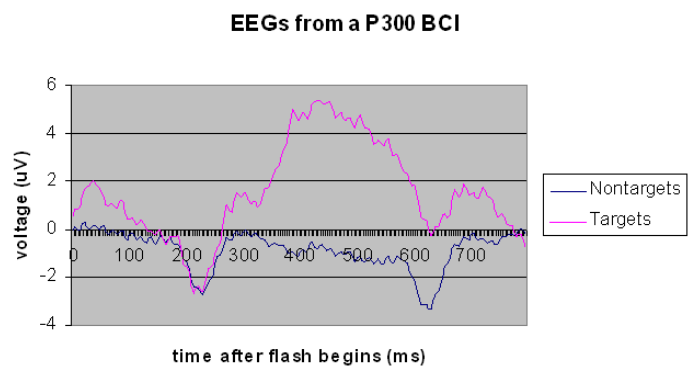
Graz BCI, orthesis

Brain Computer Interfaces

P300 BCIs

- **P300 wave – posivite component in the event related potential, 300ms after a stimulus**
- **natural response to events considered as important**
- **selection of a symbol: count the flashes, algorithm averages trails and finds a P300**



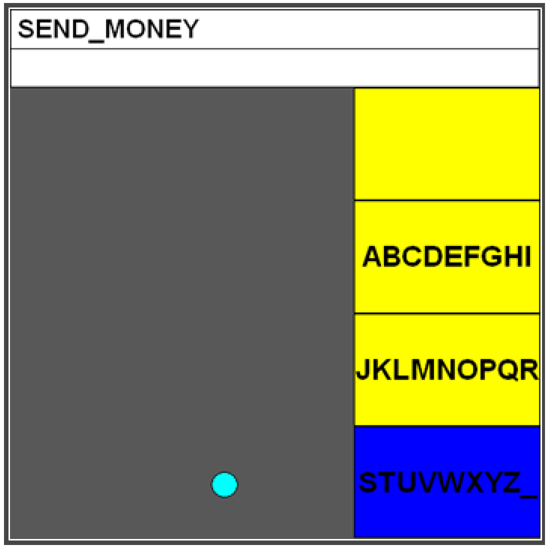


P300 runtime user interface

Brain Computer Interfaces

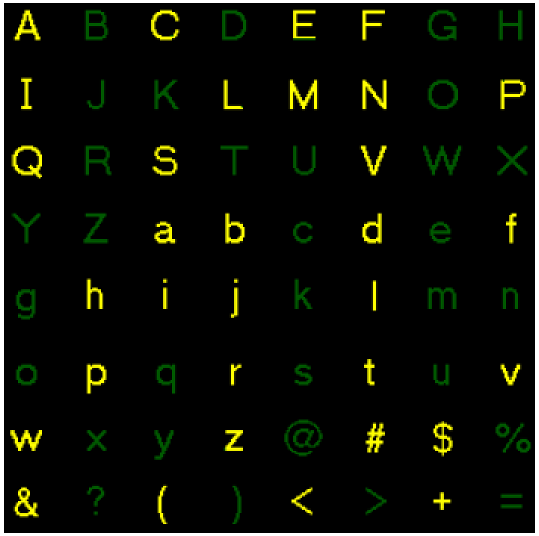
µ - BCIs

Require training
Work in realtime
2d-control possible
Continous control
movement imagination
affected by movement



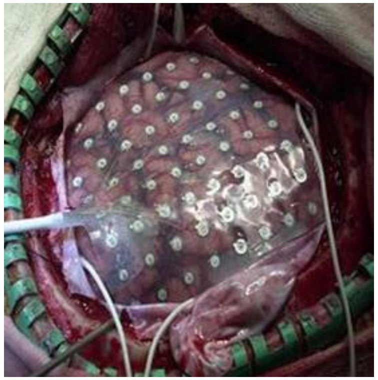
P300 BCIs

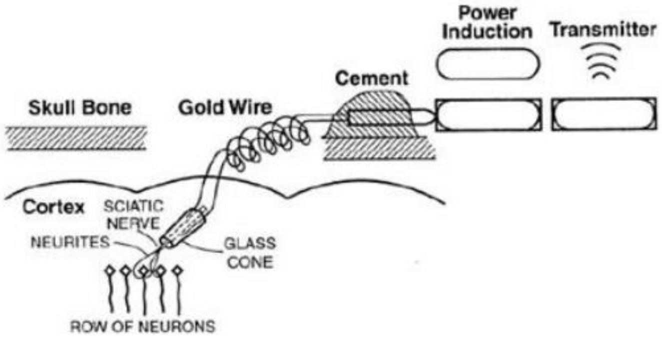
do not require training
require averaging
1D control only
discrete control
concentration / decision
affected by distraction



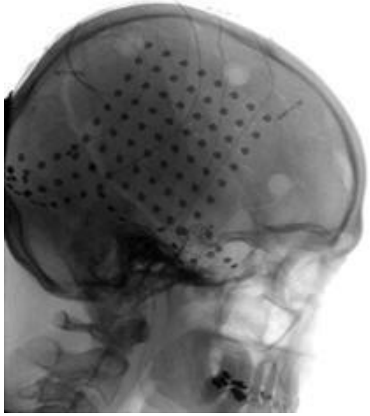
direct brain interfaces

- **Electrocorticogram: implanted electrode array**
- **better signal quality , increased SNR radio transmission of signals**
- **problems: decreasing signal quality, risk of infection, invasive technique**





Components of a DBI system,
P.R. Kennedy, R.A. Bakey, M.M. Moore,
1987, IEEE Trans Rehabil Eng. 8 (2):198-202

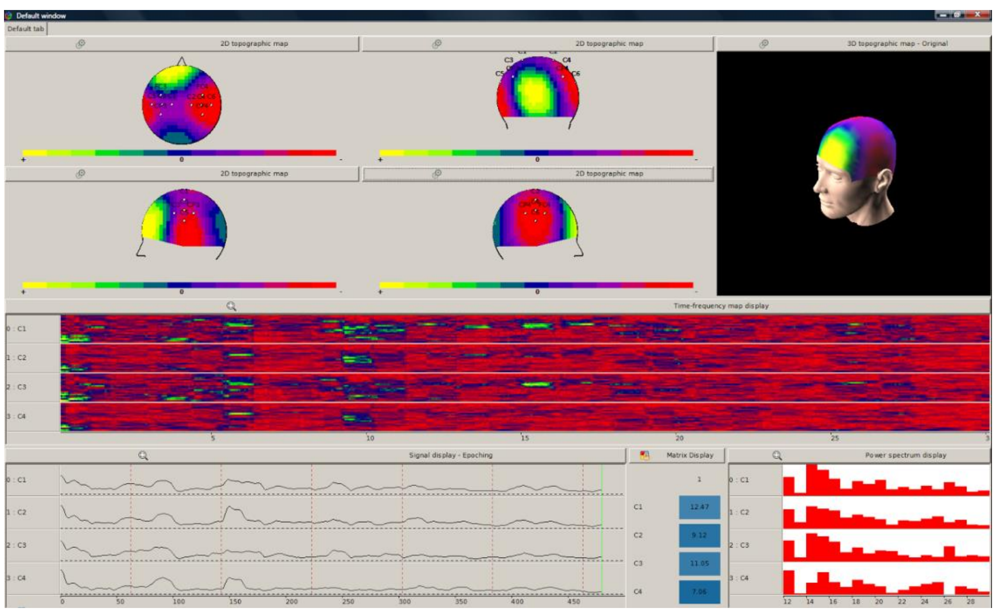


ECoG electrode grid photo by
Gerwin Schalk (Wadsworth Center, Albany, USA),
Kai Miller, Jeff Ojemann (University of Washington)

Brain Computer Interfaces

OpenVibe (http://openvibe.inria.fr/)

- Open source BCI framework with statistical classifiers, epoching, spatial and temporal filters, VR-bridge, …
- Demo designs for SSEP, P300 and motor imagination BCIs
- Open EEG and OpenBCI amplifiers supported



Other BCI resources

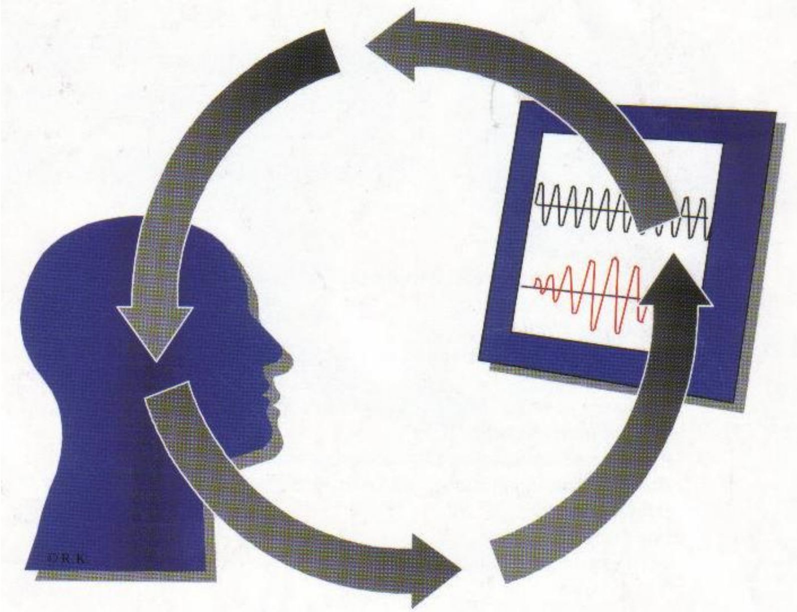
- BCI 2000 (http://www.schalklab.org/research/bci2000)
- BNCI Horizon 2020: http://bnci-horizon-2020.eu/project/related-projects
  comprehensive database of EEG signals / BCI trials
- EEGLab, EEG Signal toolbox for Matlab
- Articles & scientific papers:
  http://journal.frontiersin.org/journal/neuroscience/section/neuroprosthetics#archive

Biofeedback

- **Transformation of physiological processes into visual, acoustic and / or sensual information**

Biofeedbacktherapy:

- **Concious regulation of vital processes by learning how to change the feedback values**



Biofeedback

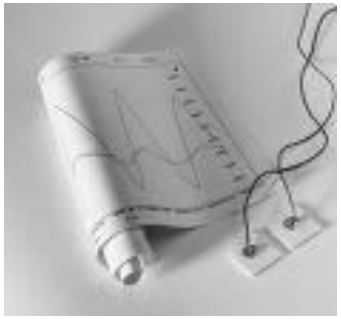
Key-elements for a successful Biofeedback treatment:

Expierienced therapist, who has knowledge about:

- correct measurement of vital parameters
- desired and problematic levels of vital parameters
- psycho-physical processes and interrelations

- Intregration into a holistic Therapy
- Intregration of achievements into everyday life

Biofeedback



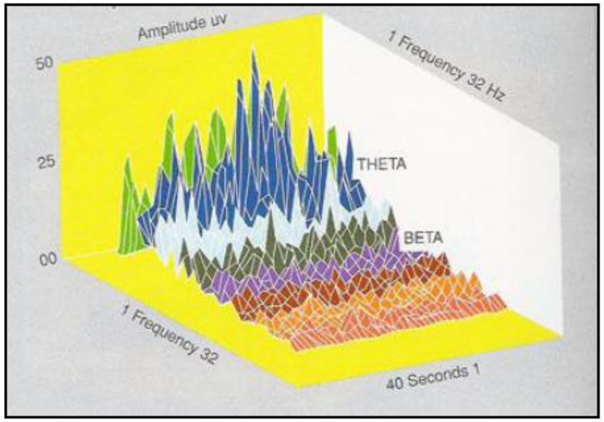
Vital parameters that can be modified by Biofeedback-Training:

Muscle activity	EMG
Heart rate	ECG
Breathing patterns	breathing belt
Blood pressure	Plethysmography
Vessel constriction and dilation	
Peripheral blood flow	
Perspiratory gland activity (sweat)	GSR / EDA
Skin- and body temperature	Peripheral Body Temp.
Brainwave activity	EEG

Neurofeedback

● re-establish physiological distribution
of brainwave frequencies in ADHD-patients
(Attention deficit hyperactivity disorder) :

- increased Theta, decreased Beta
- strong asymmetric distributions
- strong frontal alpha waves



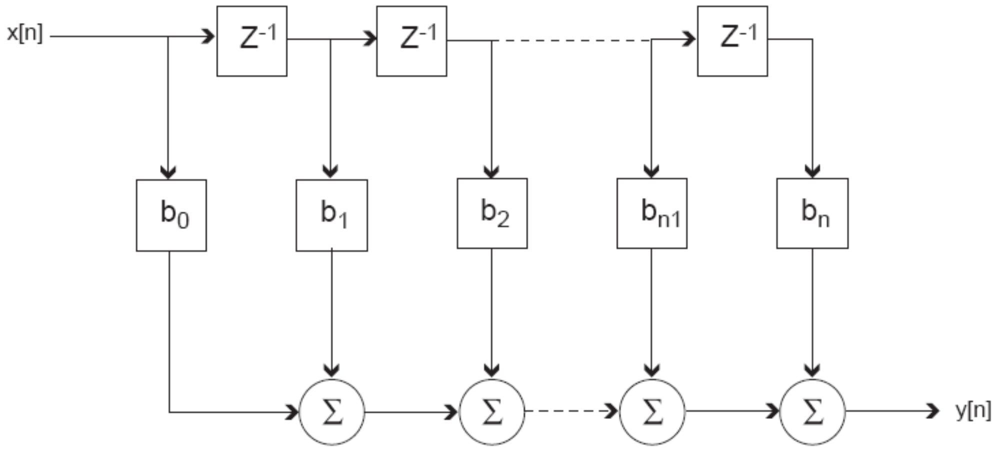
● treatment of sleep disorders, stroke, depression, tourette syndrome

● training of positivation of slow cortical potentials can lower epileptic seizures

● relaxation, meditation and peak performance training
(Alpha / Theta – feedback)

Digital Filters – FIR filters

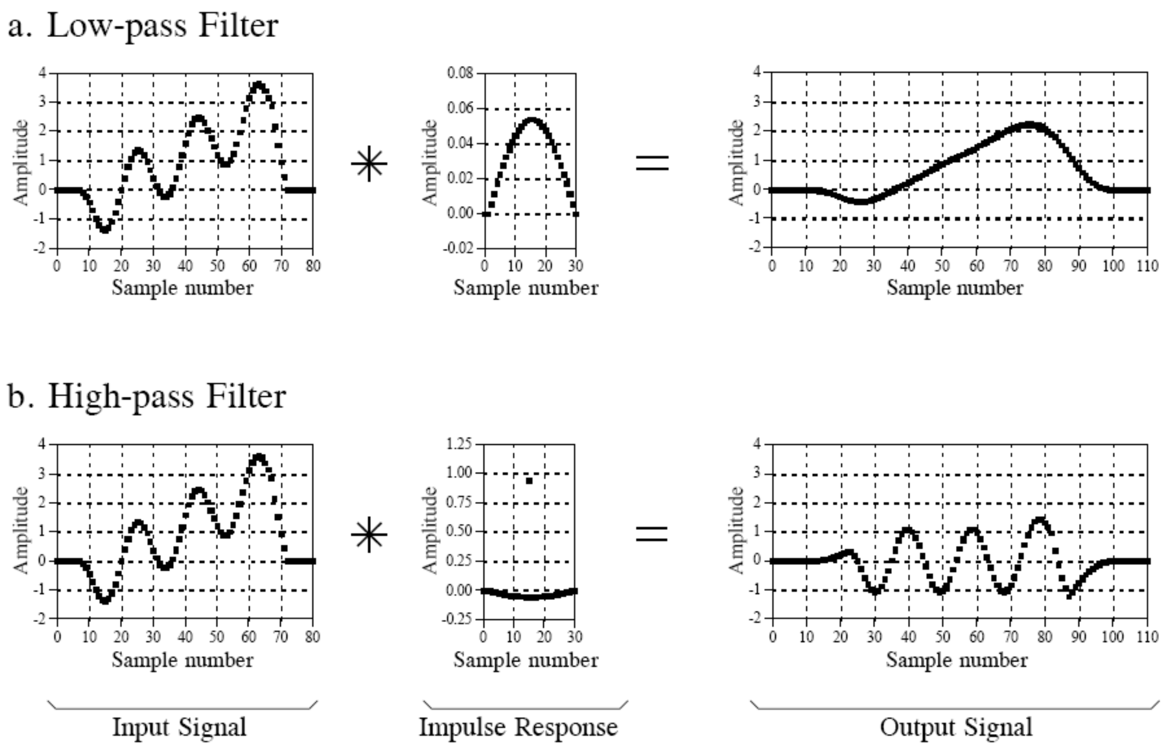
$$y[n] = \sum_{k=0}^{N} b_k \cdot x[n-k]$$



- finite impulse response, no recursion
- described by multiplication coefficients
- less sufficient (need higher order)

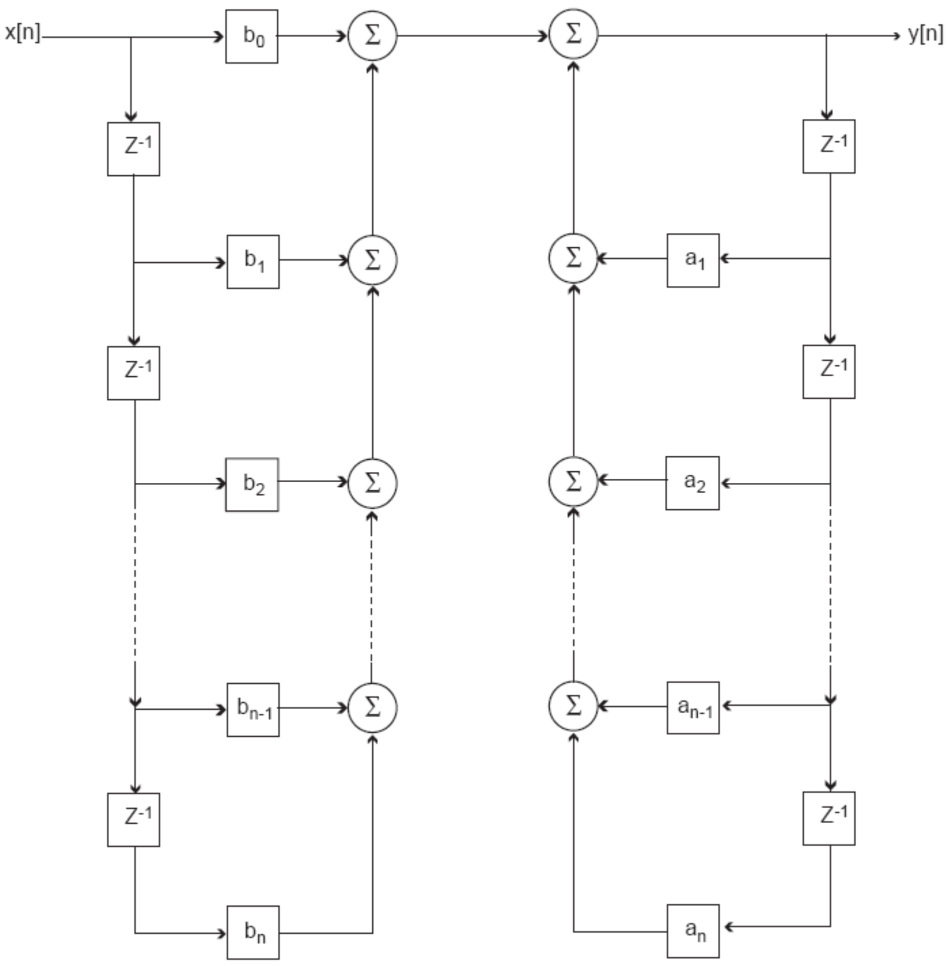
FIR Filters

Example High and Lowpass Filter-Kernels:



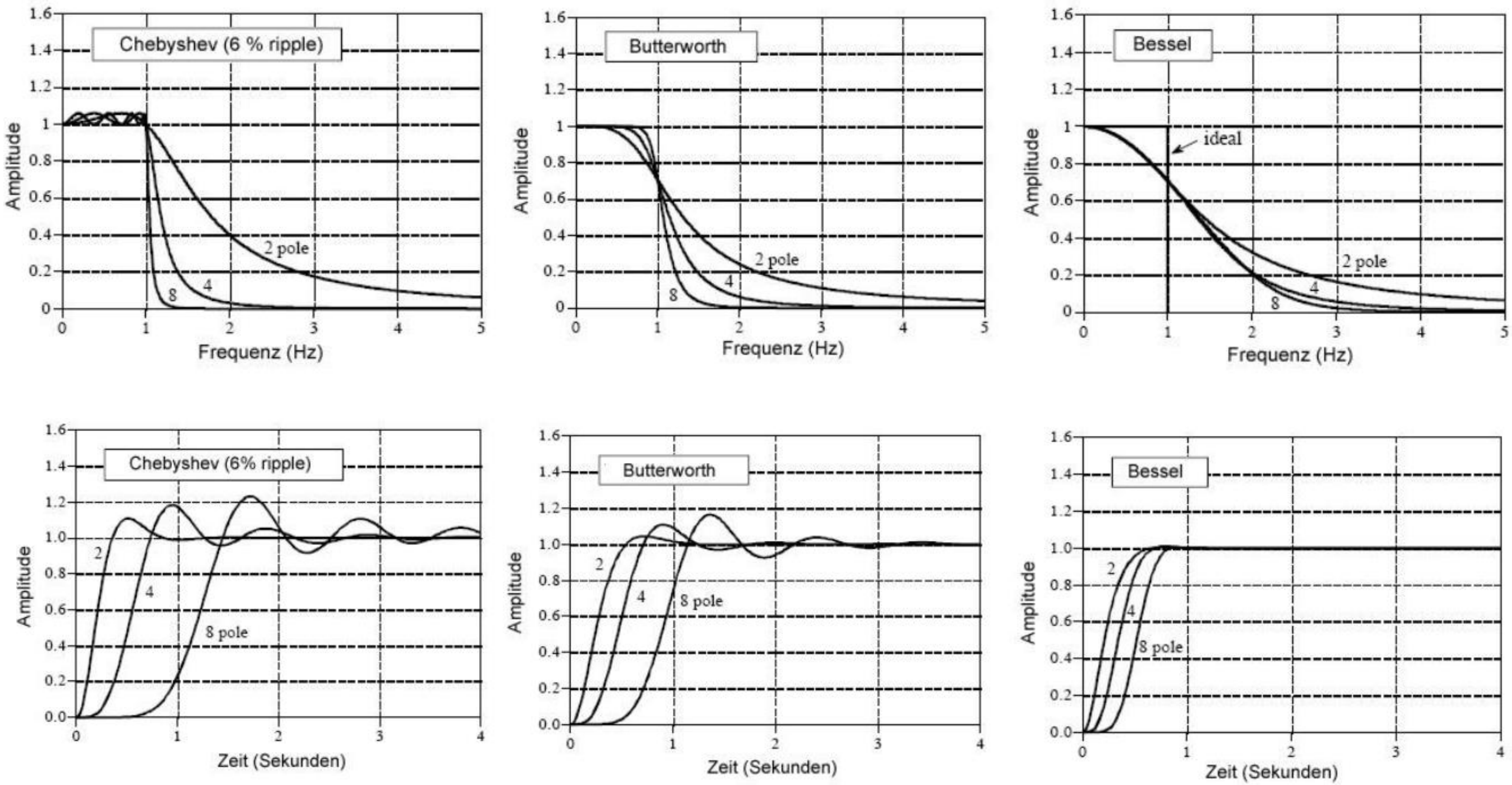
Digital Filters – IIR filters

$$y[n]=\sum_{k=0}^{N} b_k \cdot x[n-k]+\sum_{m=1}^{M} -a_m \cdot y[n-m]$$



- infinite impulse response, truncated at a certain precision
- use previously calculated values from the output (recursion)
- described by recursion coefficients
- more efficient, but can be unstable

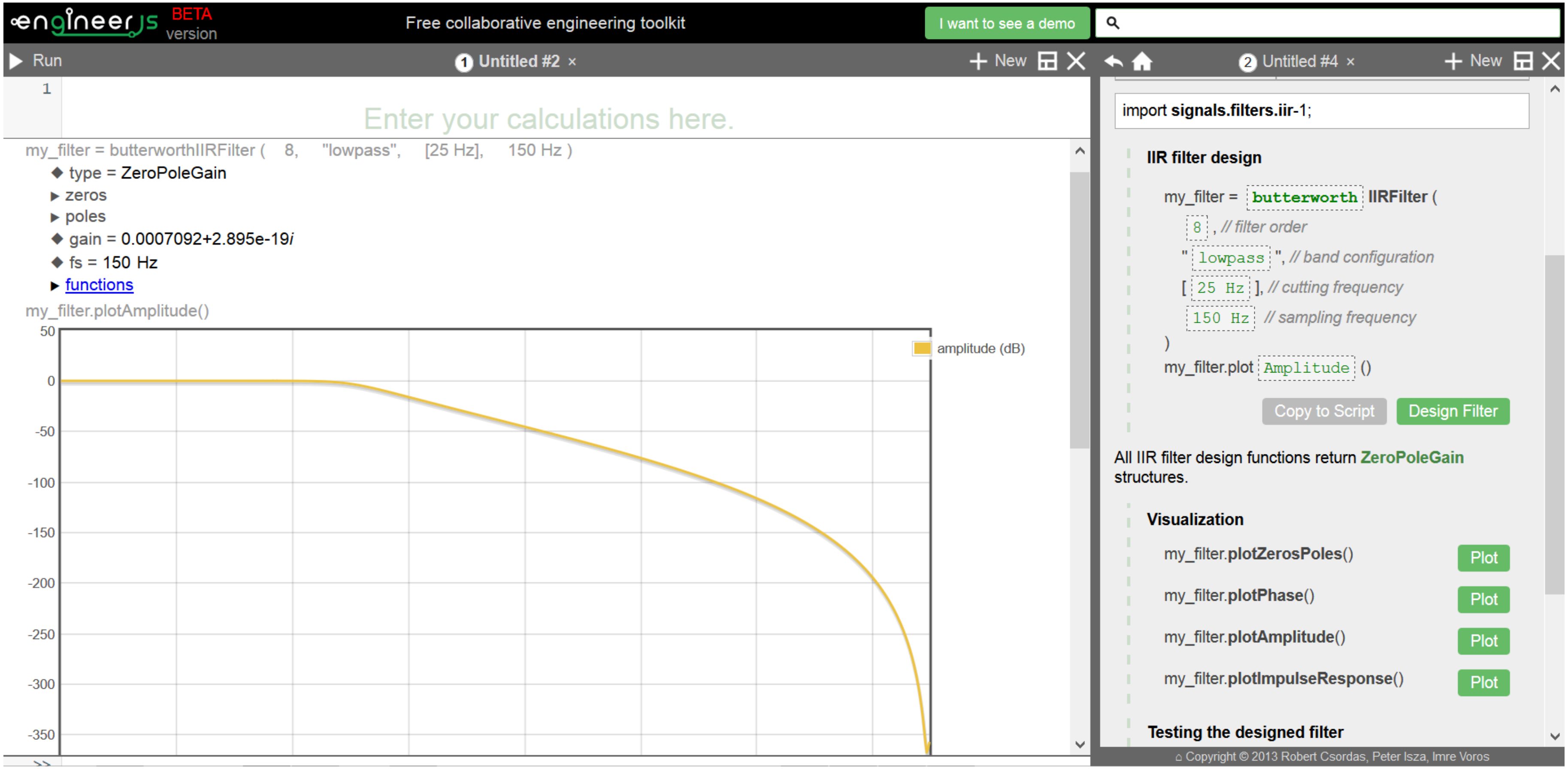
typical IIR filters



Chebyshev, Butterworth and Bessel characteristics

Tools and Libraries

EngineerJS: Online JavaScript IIR filter design Tool

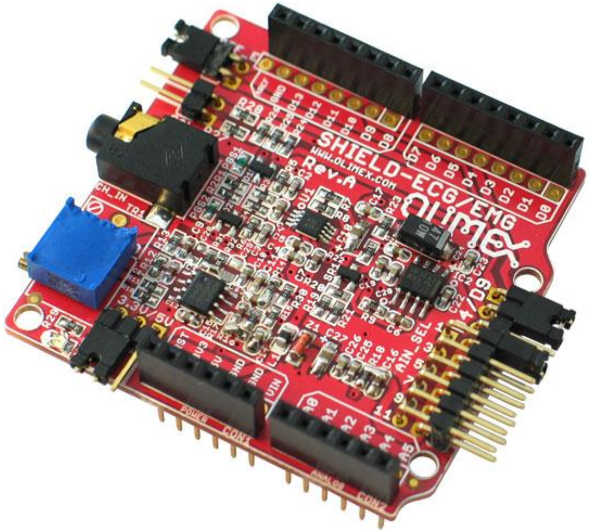


http://engineerjs.com/?sidebar=docs/iir.html

Time for a Break !!

Using the Arduino UNO + EMG shield

For our practical measurement tasks
we will use the Arduino UNO microcontroller !

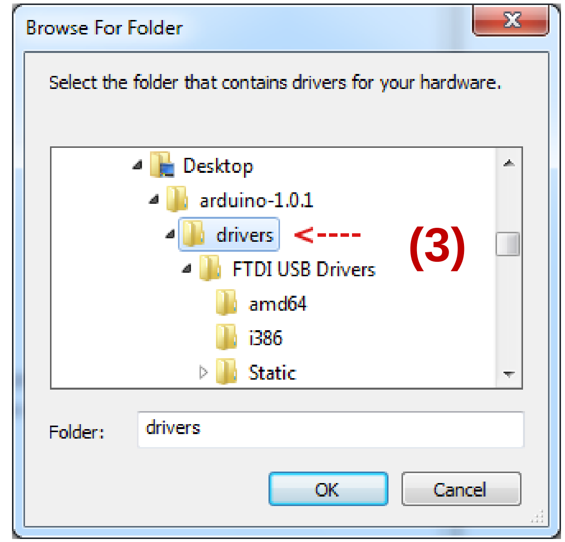


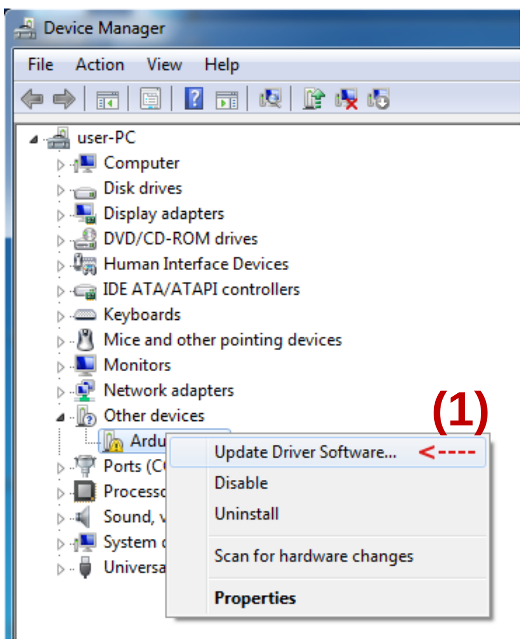
carefully attach the ECG/EMG -„shield“
to the Arduino for measuring bioelectric signals !

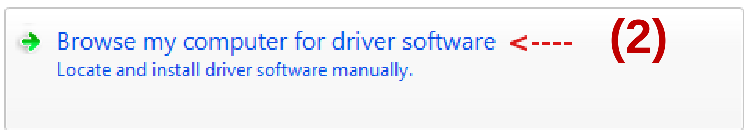
Installing driver for Arduino UNO

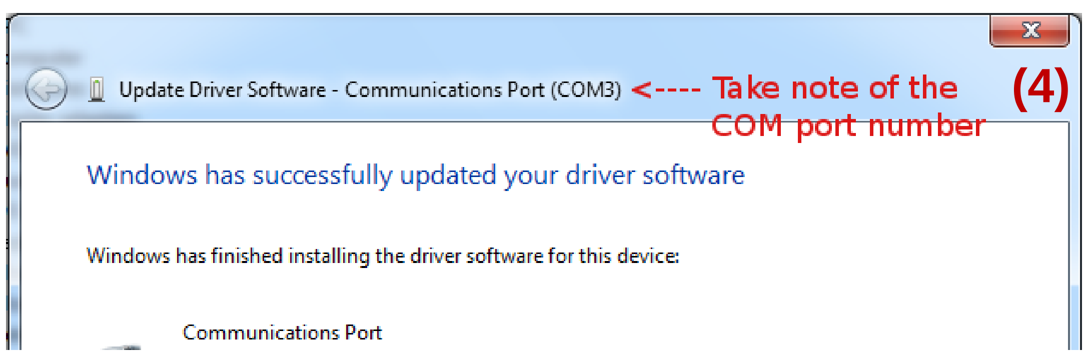
Plug in the Arduino UNO.
Windows should install the COM Port driver.

If that fails, select the Arduino „drivers“ folder in the device manger‘s „update driver software“ dialog:

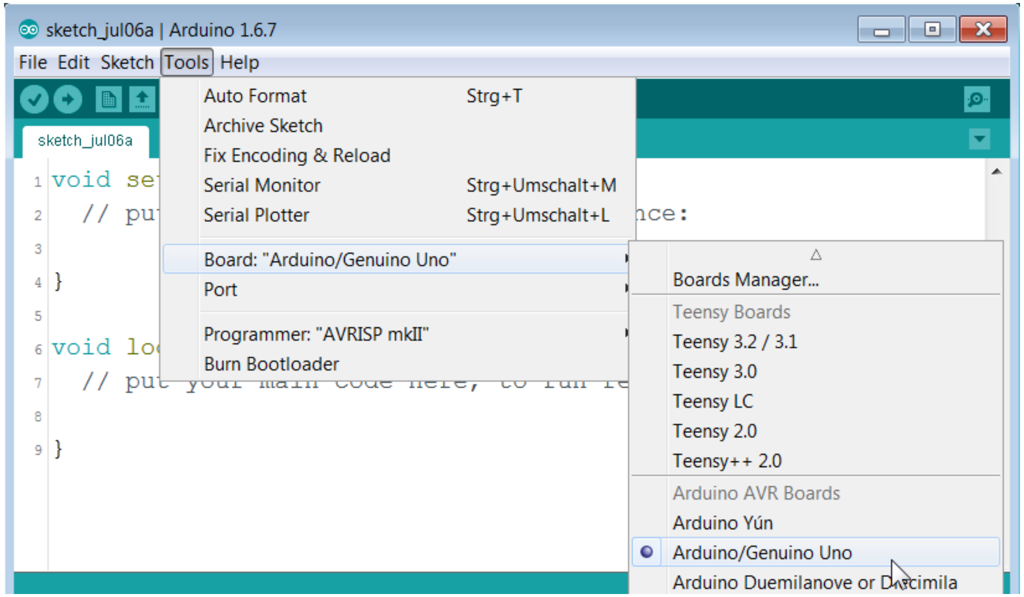




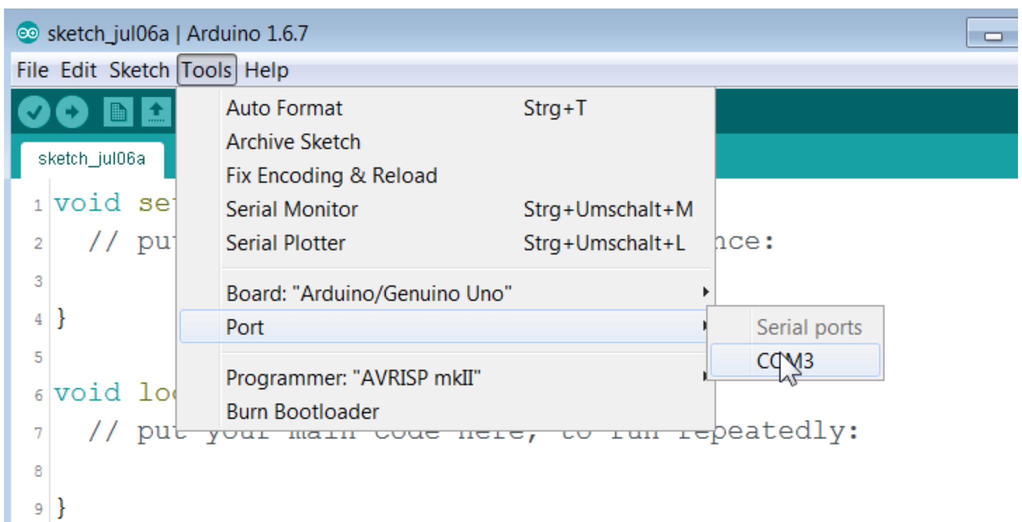




Configure the Arduino IDE



(Re-) start the Arduino Software and select board type „Arduino/Genuino Uno“



and select the new COM Port !

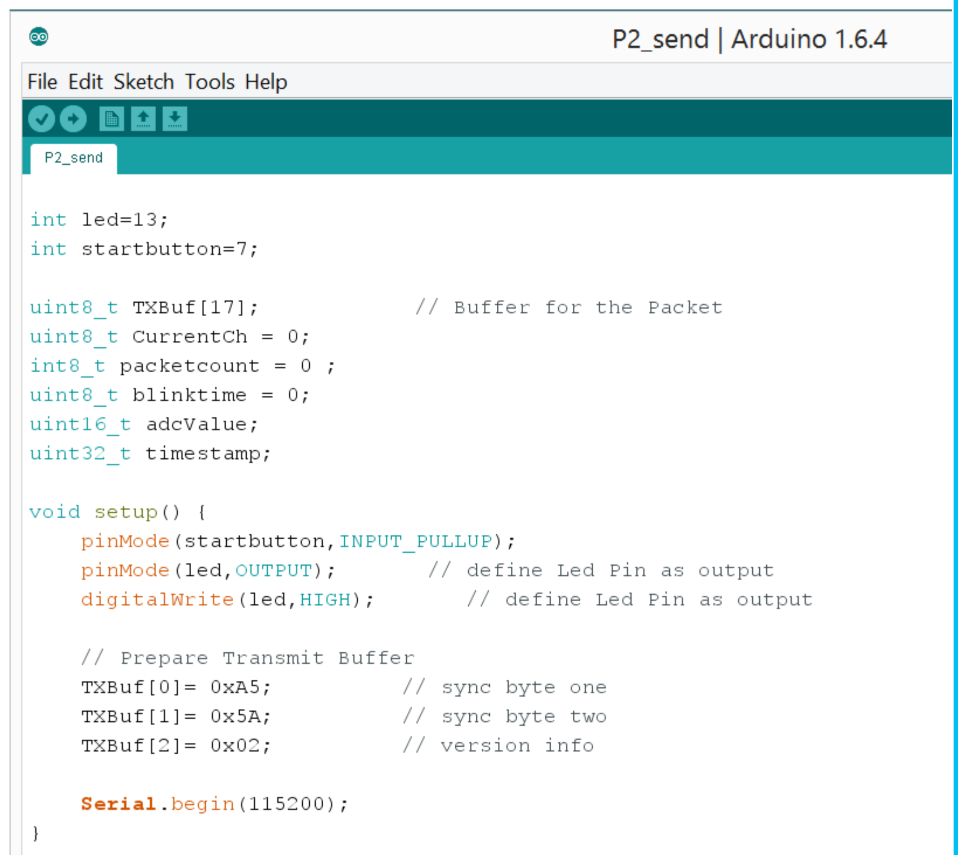
Upload the P2 firmware

- Open and upload the P2 firmware in the Arduino IDE (/SummerSchool/Module4…/ArduinoExamples/P2_send)

This firmware:

- measures all 6 ADC channels 256 times per second
- transmits the data in a P2-compatible packet to the PC where suitable applications (eg. BrainBay or AsTeRICS) can receive the data and perform further processing

Note: a cable connected to GND and pin 7 (D7) pauses the transmission




```
int led=13;
int startbutton=7;

uint8_t TXBuf[17];           // Buffer for the Packet
uint8_t CurrentCh = 0;
int8_t packetcount = 0 ;
uint8_t blinktime = 0;
uint16_t adcValue;
uint32_t timestamp;

void setup() {
    pinMode(startbutton,INPUT_PULLUP);
    pinMode(led,OUTPUT);       // define Led Pin as output
    digitalWrite(led,HIGH);       // define Led Pin as output

    // Prepare Transmit Buffer
    TXBuf[0]= 0xA5;          // sync byte one
    TXBuf[1]= 0x5A;          // sync byte two
    TXBuf[2]= 0x02;          // version info

    Serial.begin(115200);
}
```

OpenEEG project

The OpenEEG P2 Packet Format

- Compatible to several PC-applications, eg.:
  - Brainbay
  - AsTeRICS
  - OpenVibe
- Easy to generate with microcontroller firmware

Byte 1: Sync Value 0xa5
Byte 2: Sync Value 0x5a
Byte 3: Version
Byte 4: Frame Number
Byte 5: Channel 1 High Byte
Byte 6: Channel 1 Low Byte
Byte 7: Channel 2 High Byte
Byte 8: Channel 2 Low Byte
Byte 9: Channel 3 High Byte
Byte 10: Channel 3 Low Byte
Byte 11: Channel 4 High Byte
Byte 12: Channel 4 Low Byte
Byte 13: Channel 5 High Byte
Byte 14: Channel 5 Low Byte
Byte 15: Channel 6 High Byte
Byte 16: Channel 6 Low Byte
Byte 17: Button States (b1-b4)

OpenEEG project

Demo OpenEEG P2 Packet Parser (PC-side)

```
void parse_byte_P2(unsigned char actbyte)
{
    switch (PACKET.readstate)
            {
              case 0: if (actbyte==165) PACKET.readstate++;   break;
              case 1: if (actbyte==90)  PACKET.readstate++;  else PACKET.readstate=0;  break;
              case 2: PACKET.readstate++;   break;
              case 3: PACKET.number = actbyte;
                      PACKET.extract_pos=0;PACKET.readstate++; break;
              case 4: if (PACKET.extract_pos < 12)
              {
                   if ((PACKET.extract_pos & 1) == 0)
                       PACKET.buffer[PACKET.extract_pos>>1]=actbyte*256;
                      else PACKET.buffer[PACKET.extract_pos>>1]+=actbyte;
                           PACKET.extract_pos++;
              }
              else
              {
                    PACKET.switches= actbyte;
                    PACKET.readstate=0;
                    process_packets();
              }  break;

              default: PACKET.readstate=0;
            }
}
```

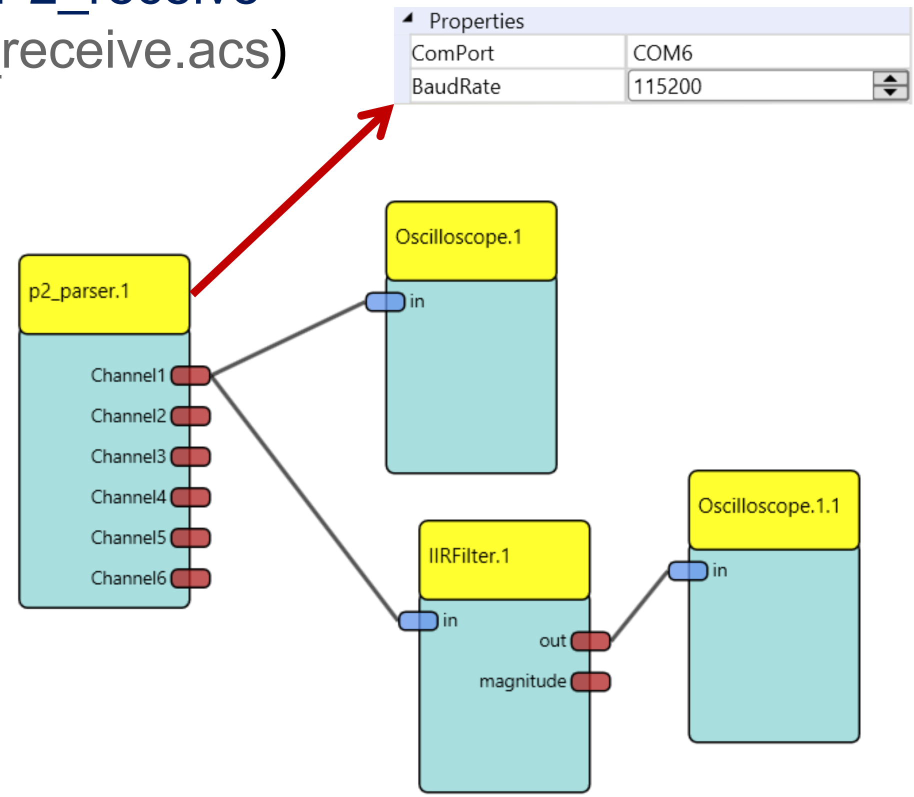
Using AsTeRICS for signal processing

Start ARE and ACS
(for this you need the AsTeRICS framework installed: /Software/AsTeRICS)

In the ACS, load the example model „P2_receive“
(SummerSchool/Module4…/ACS/P2_receive.acs)

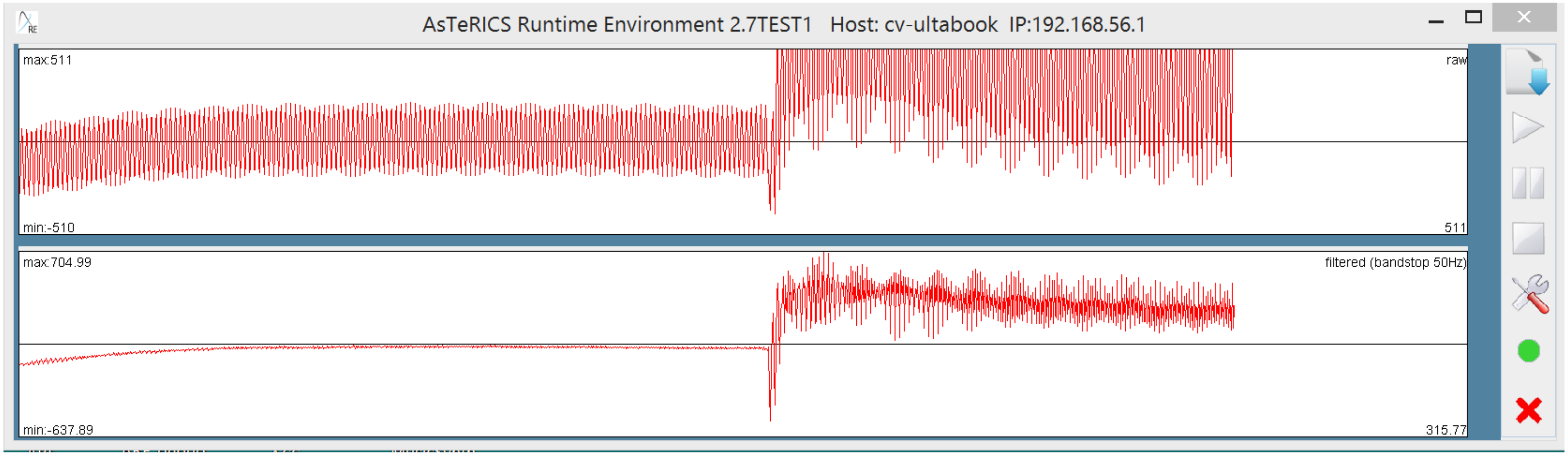
In the p2_parser plugin properties, select the correct COM port number for your Arduino UNO

Press „Connect to the ARE“, then „Upload“, and „Start“



Raw signal view from P2 packets

- This example is a simple signal display
- the top window shows the raw signal
- the bottom window shows a 50Hz notch filtered version



Results could look similar …. Lots of noise when electrodes not attached or unbalances electrode impedances

Attaching Electrodes: User Safety !!

WARNING:

EKG DEVICE DISCLAIMER

IEC601 is a standard that specifies tests and requirements that medical devices must pass before they can be used on humans. However, none of the devices built from these designs have been tested according to these guidelines because of the costs involved. Therefore, a device based on any of these designs may not be used for medical purposes as no medical claims are made.

NOTE THAT CONNECTING A DEVICE VIA ELECTRODES TO HUMANS OR ANIMALS IS POTENTIALLY HAZARDOUS AND MAY RESULT IN ELECTRIC SHOCK AND/OR SEIZURE.

Avoid any current path to the mains (230V) supply !

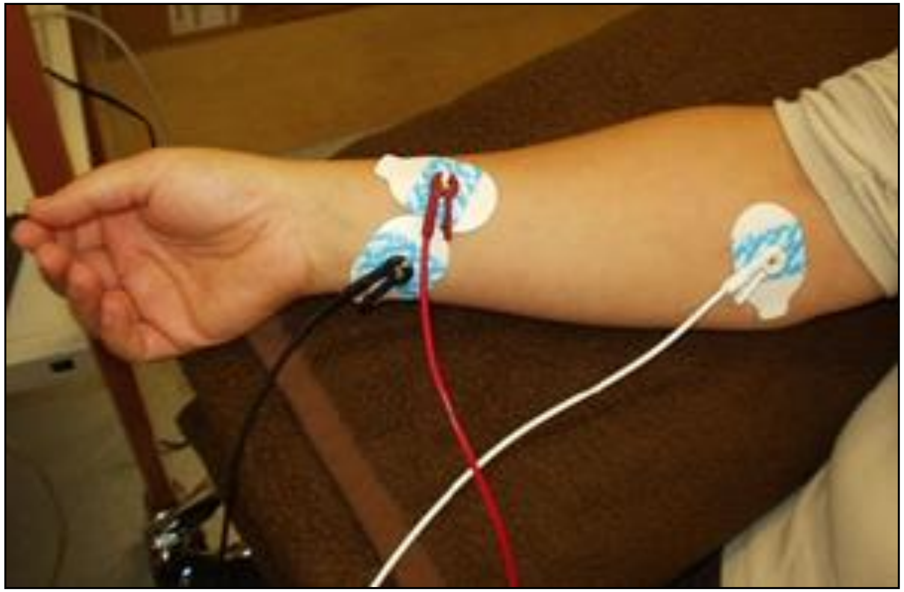
Use a Laptop with battery-supply
when the Arduino + ECG/EMG shield is attached !

Using the Arduino UNO + EMG shield

Attach the electrodes

and plug the electrode cables
into the ECG/EMG shield

Measuring EMG



- Connect the electrodes
  as shown in the picture here:

- The muscle you want to measure should be located between the red and the white electrode connection (channel0, + and -)

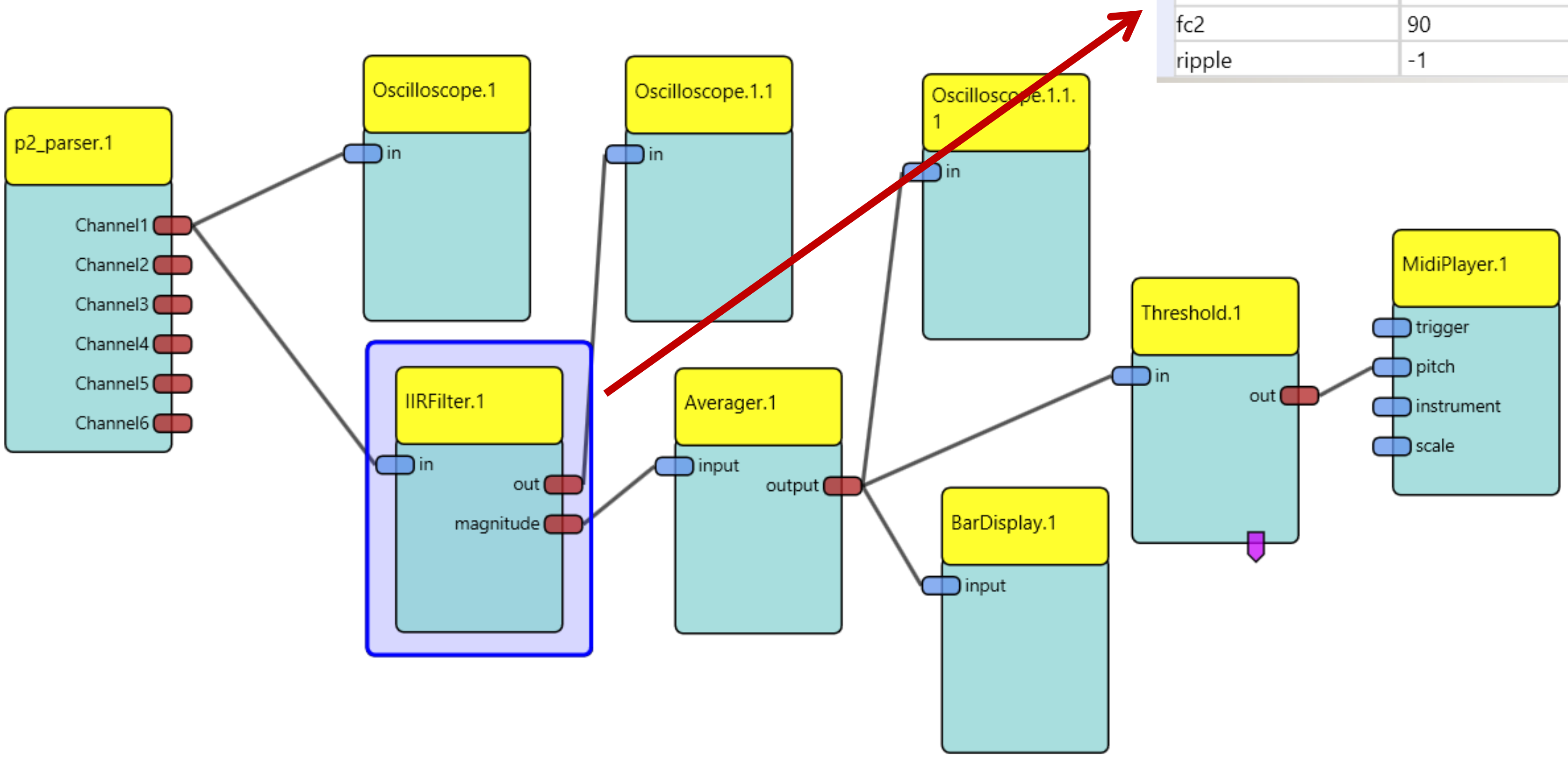
- The black lead connects the DRL circuit
  (reduces noise, can be connected anywhere to the body)

- Clean the skin before applying the electrodes (use alcohol etc.)

Measuring EMG

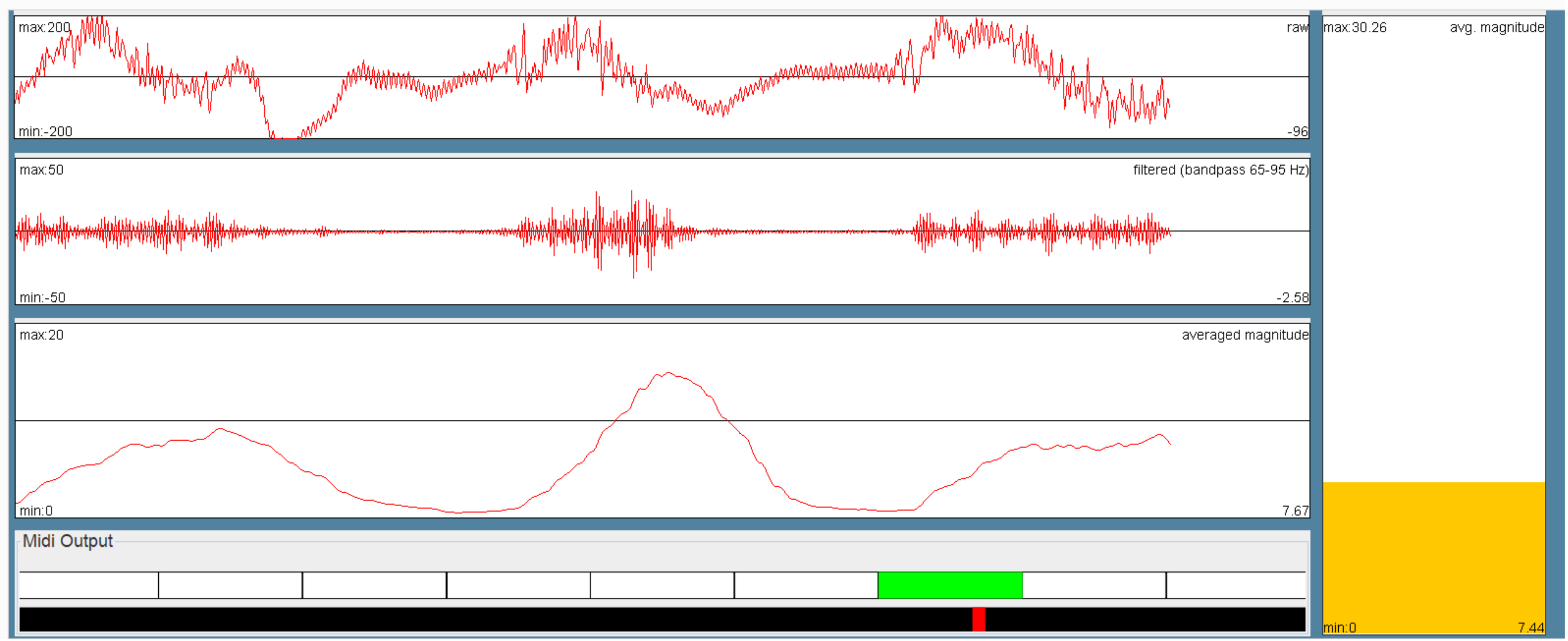
- ACS-model for filtering muscle activity from a raw EMG signal for control purposes (/SummerSchool/Module4…/P2_EMG.acs)

Properties	
passType	bandpass
characteristicType	butterworth
order	8
samplingFrequency	256
fc1	65
fc2	90
ripple	-1



Measuring EMG

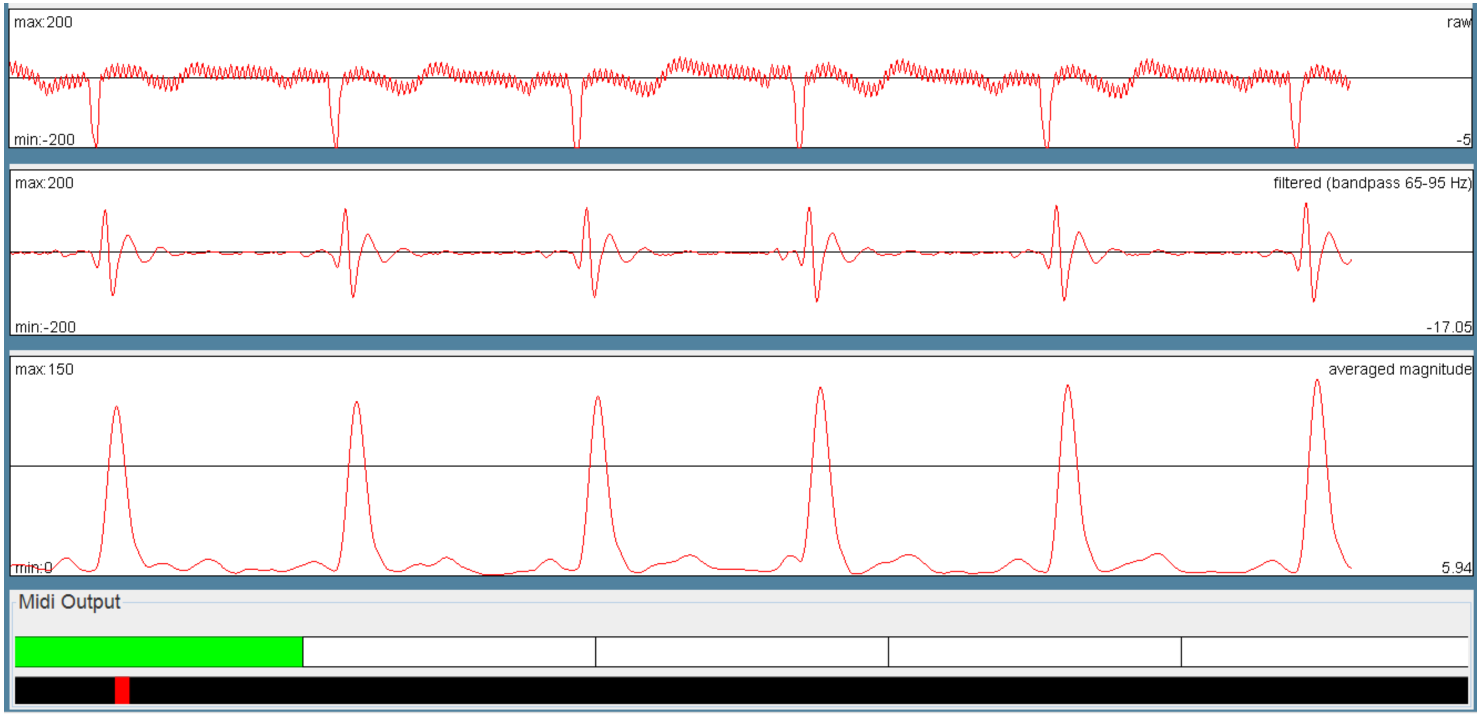
- EMG signal and IIR-passband filtered signal, averaged magnitude used as midi tone feedback:



Measuring ECG

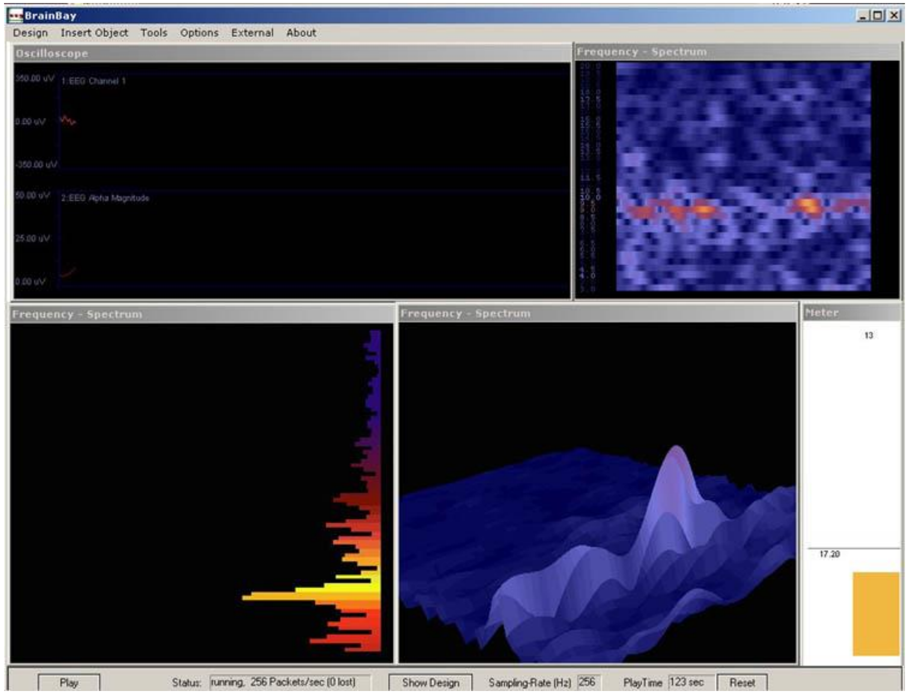
- Connect the electrodes across the heart – for example white lead to left hand and red lead to right shoulder

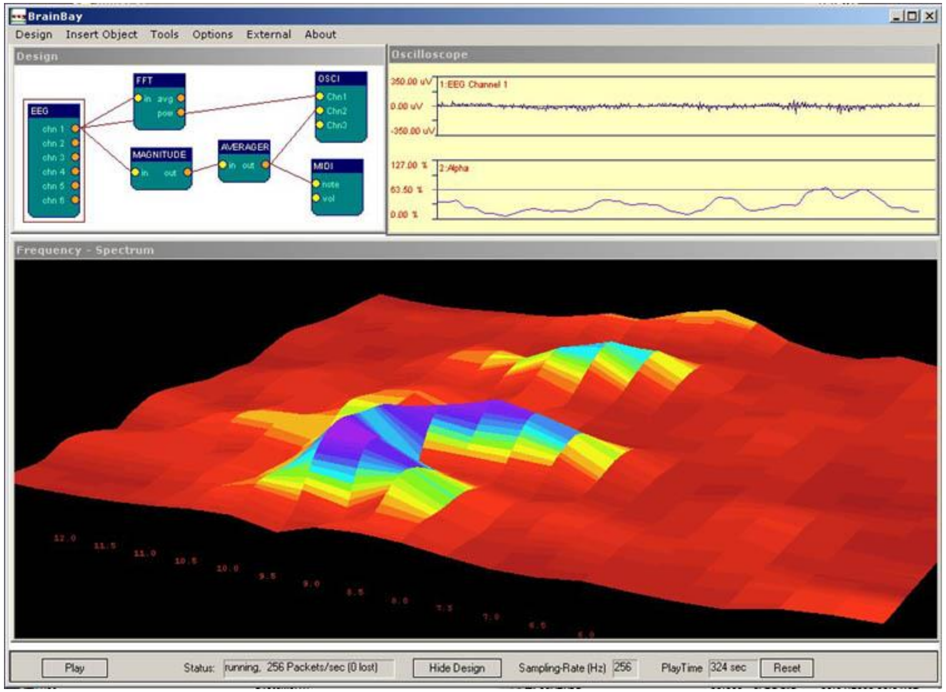
- load ACS Model (/SummerSchool/Module4…/P2_EMG.acs) modified filter parameters and midi tones (play with the settings!)



EEG-Feedback: BrainBay

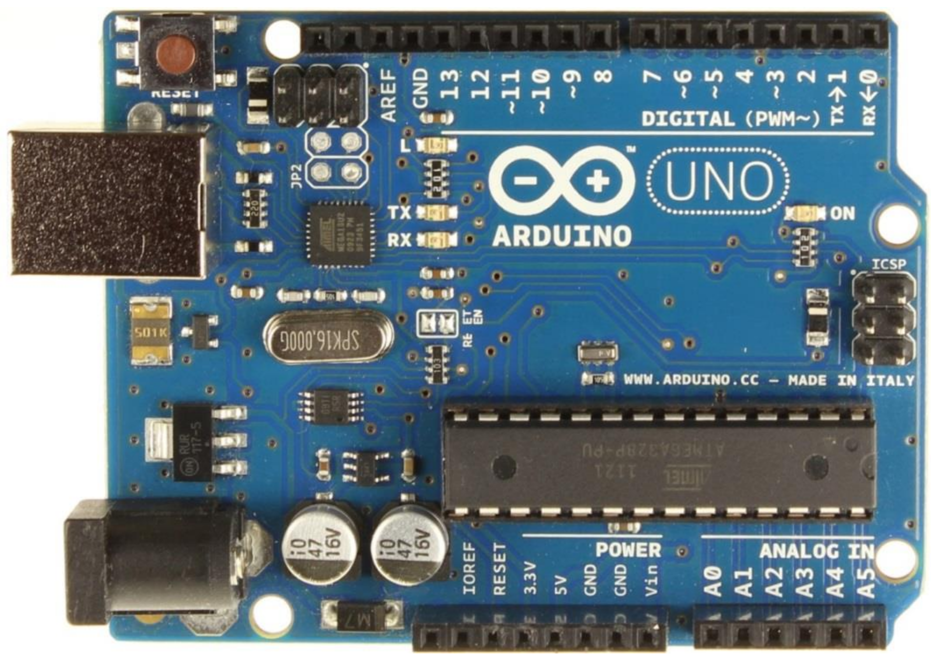
- Windows software for Biosignal Processing and Biofeedback
- Several EEG amplifiers supported
- More processing elements (FFT, 3D-display, spectrogram, ..)
- Biofeedback support: Movie Player





http://brainbay.lo-res.org

Using the Arduino AsTeRICS plugin

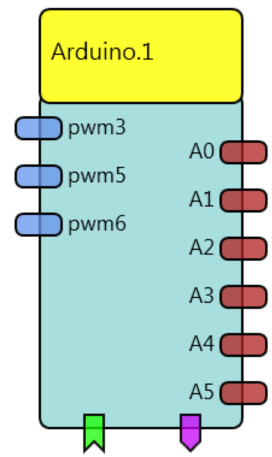


- For using digital and analog input / output in AsTeRICS, the ACS provides a dedicated plugin for the Arduino UNO
- It allows reading button states reading analog voltage, setting digital outputs and servo positions directly from an AsTeRICS model

For using this plugin, a special firmware must be installed on the Arduino

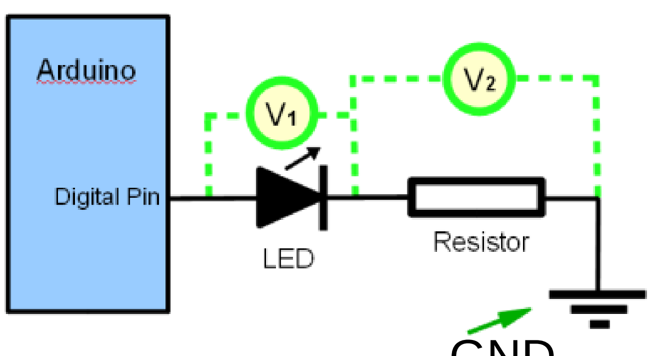
For firmware installation, see asterics subfolder

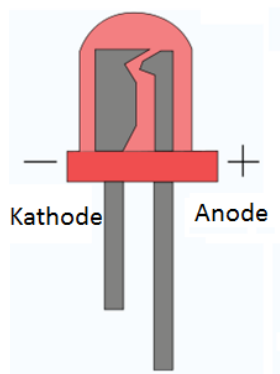
CIMs\Arduino\readme.txt

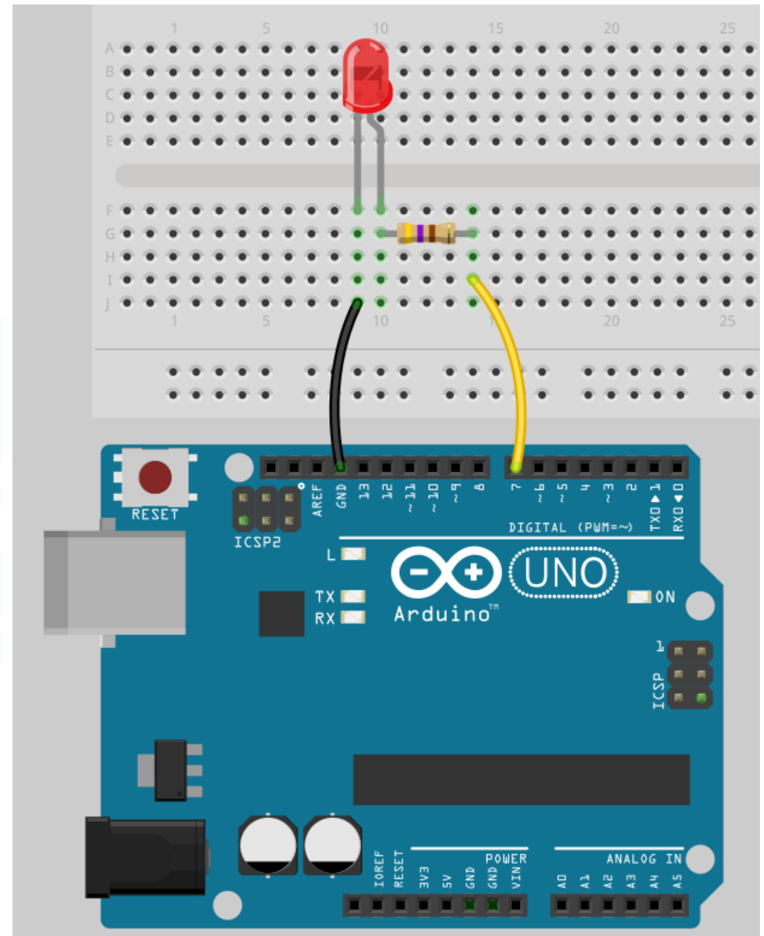


Example 1: Control LED via Arduino Plugin

- Connect the **Anode** of the Led to Pin7 (positive lead, usually the long leg)
- Connect the **Kathode** of the Led to a 470 Ohm resistor
- Connect the resistor's other end to GND (0 Volt)

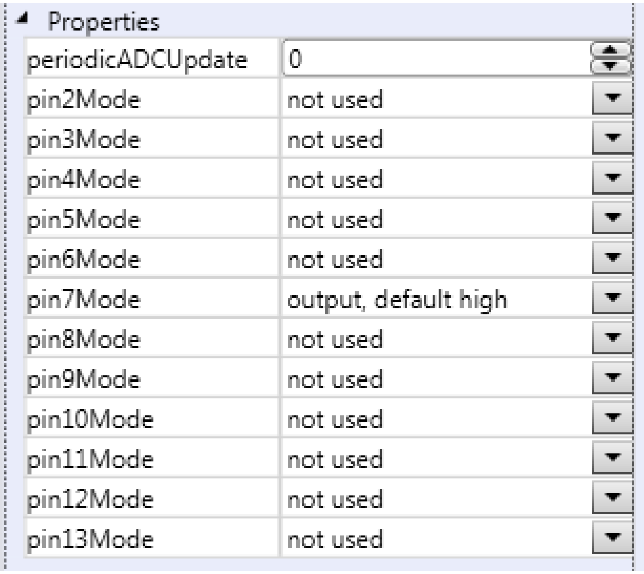


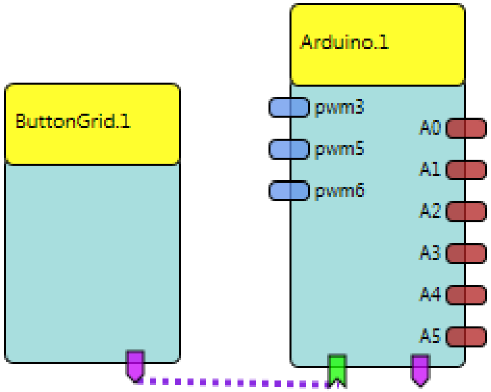


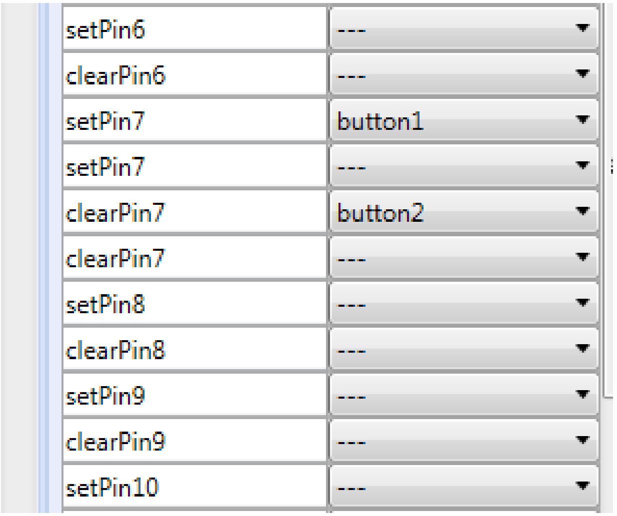


Example 1: Control LED via Arduino Plugin

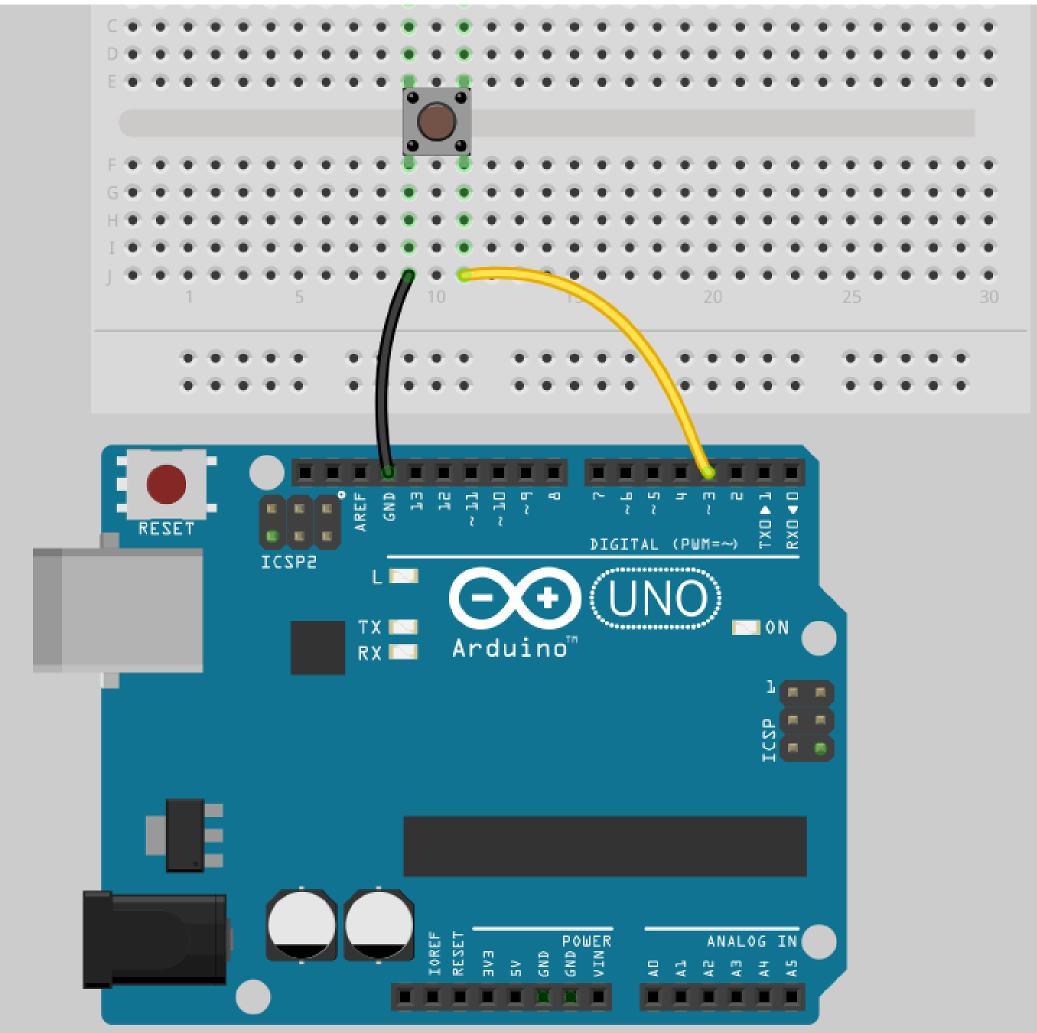
- In the Arduino processor plugin's properties:
  - Define pin7Mode „output, default high“ or „output, default low“
  - Use Events Listeners to set output high or low (turn on/off)



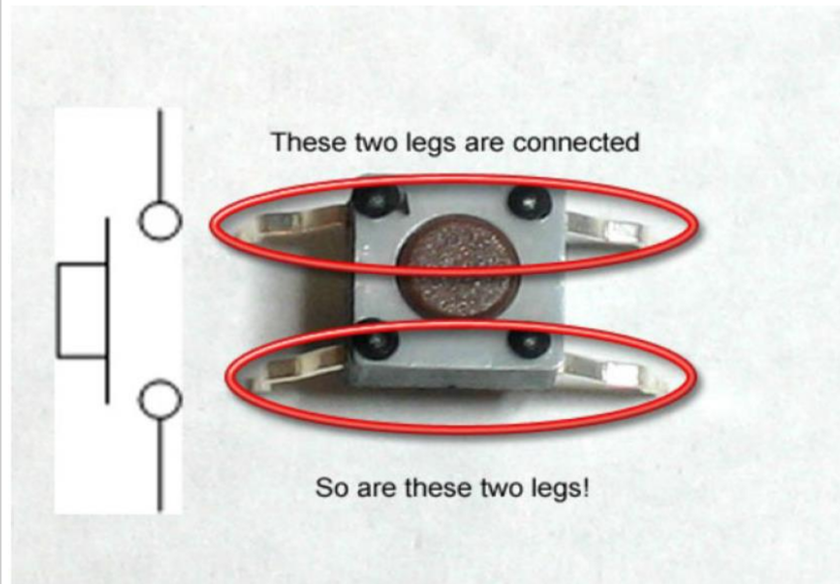




Example 2: Read button via Arduino Plugin

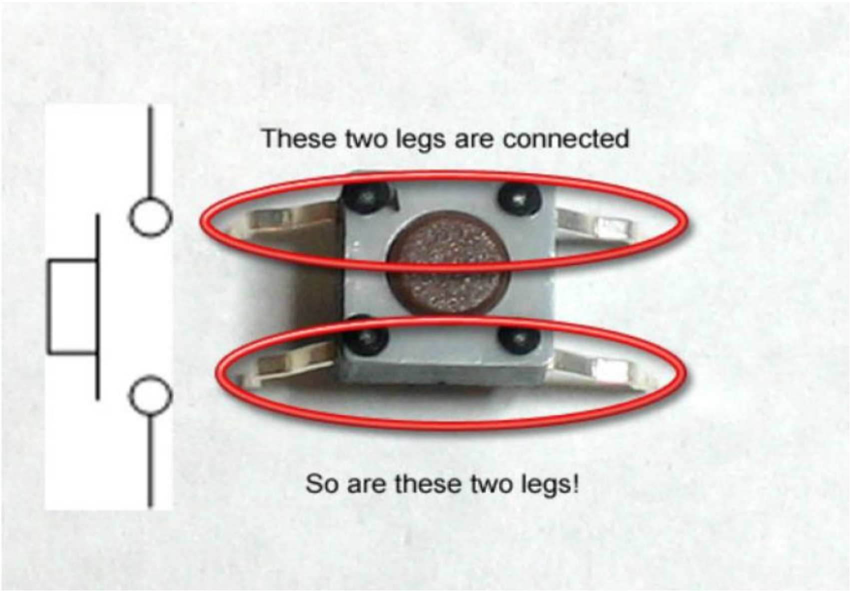


- Connect one side of switch to GND and the other side to Pin 3

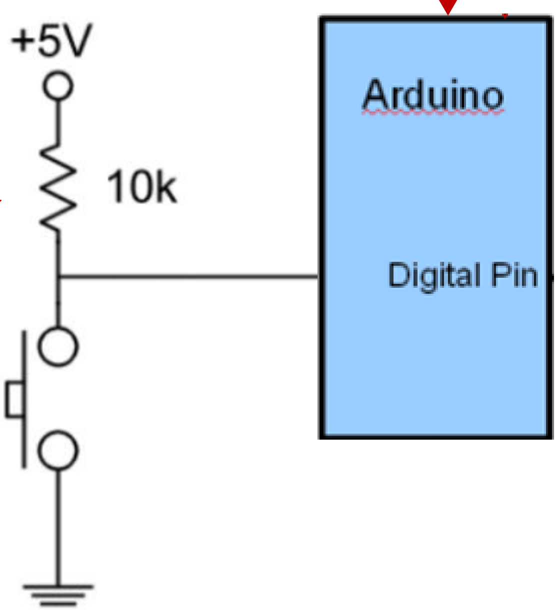


- When switch is pressed: all 4 leads connected !

Example 2: Read button via Arduino Plugin



Microcontroller can measure voltage (high or low) at a digital <u>input</u> Pin

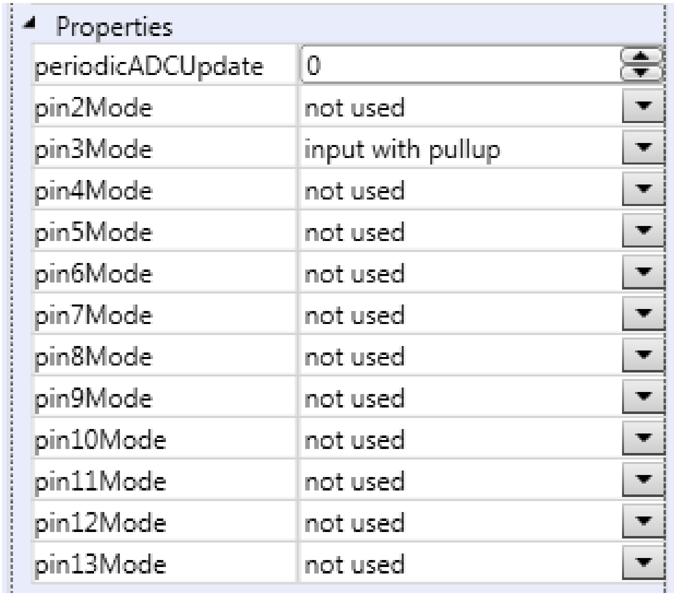


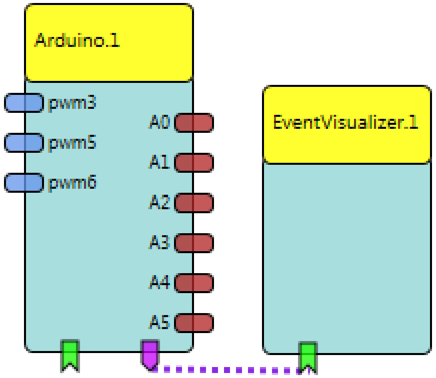
Resistor pulls Pin-voltage to 5V (high) if the switch is not pressed

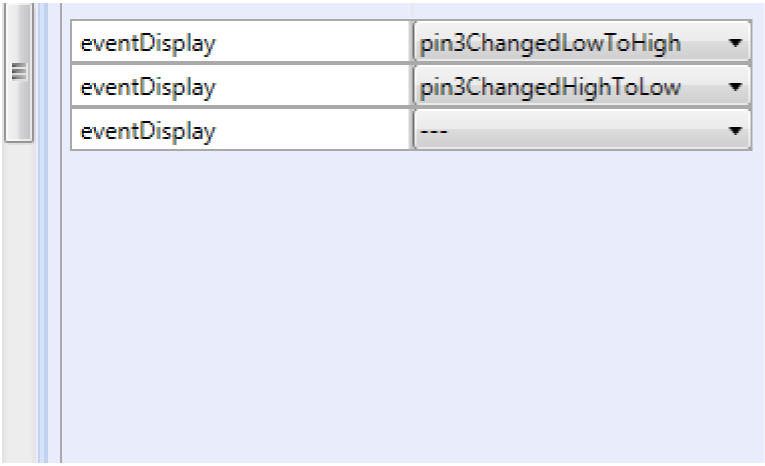
Button connects Pin to 0V (low) if pressed

Example 2: Read button via Arduino Plugin

- In the Arduino processor plugin:
  - Select pin3Mode: “input with pullup”
  - Event is triggered when PushButton is pressed (high -> low)
  - Event is triggered when PushButton is relesed (low -> high)

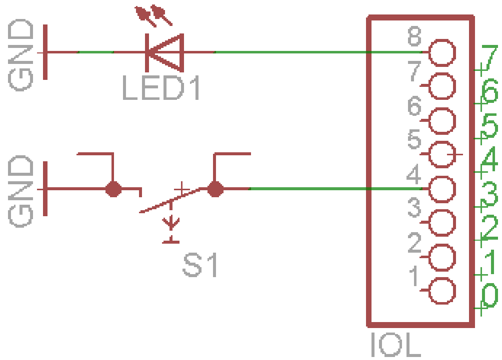


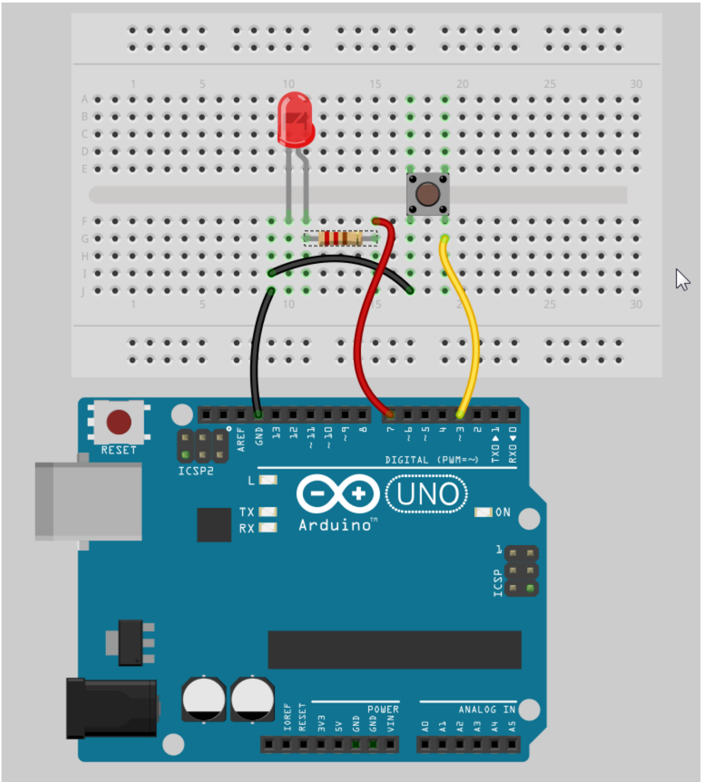




Example 3: Switch a led via button

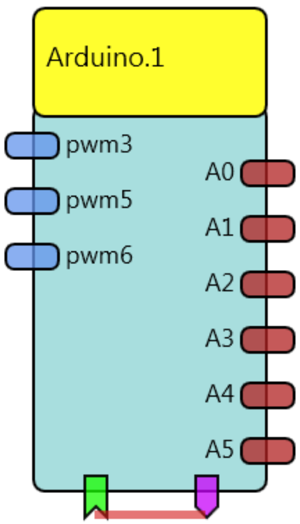
- Switch is connected to Pin3 (internal PullUp)
- LED is connected to Pin7
- Switch Open → LED on
- Switch Closed → LED off

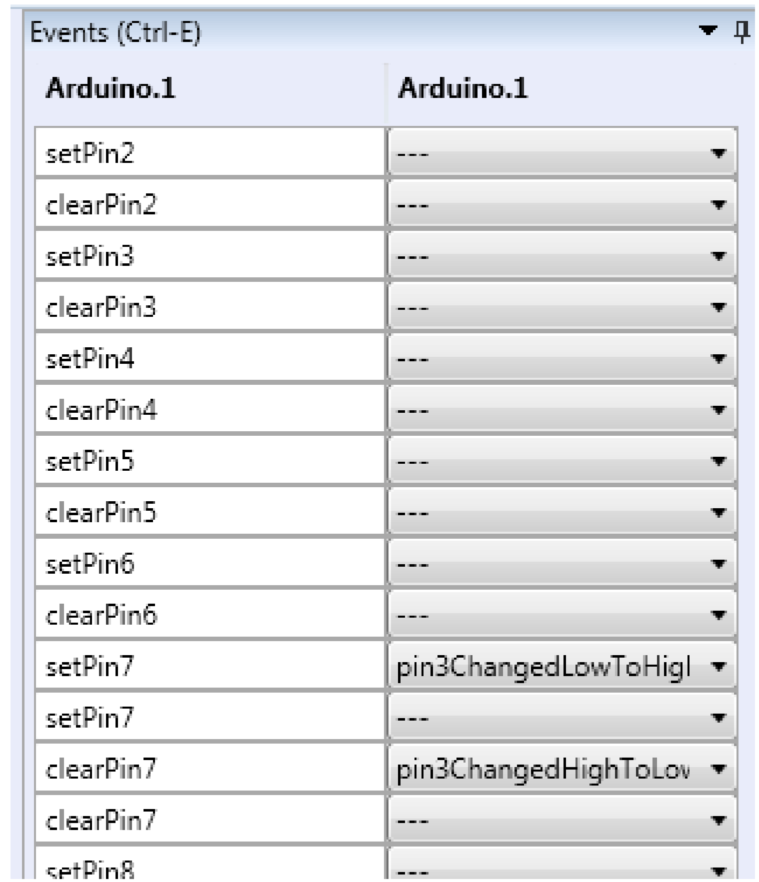




Properties	
periodicADCUpdate	0
pin2Mode	not used
pin3Mode	input with pullup
pin4Mode	not used
pin5Mode	not used
pin6Mode	not used
pin7Mode	output, default high
pin8Mode	not used
pin9Mode	not used
pin10Mode	not used
pin11Mode	not used
pin12Mode	not used
pin13Mode	not used

Example 3: Switch a led via button

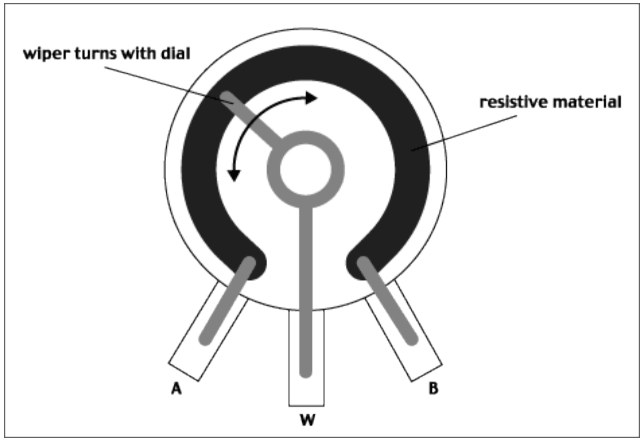


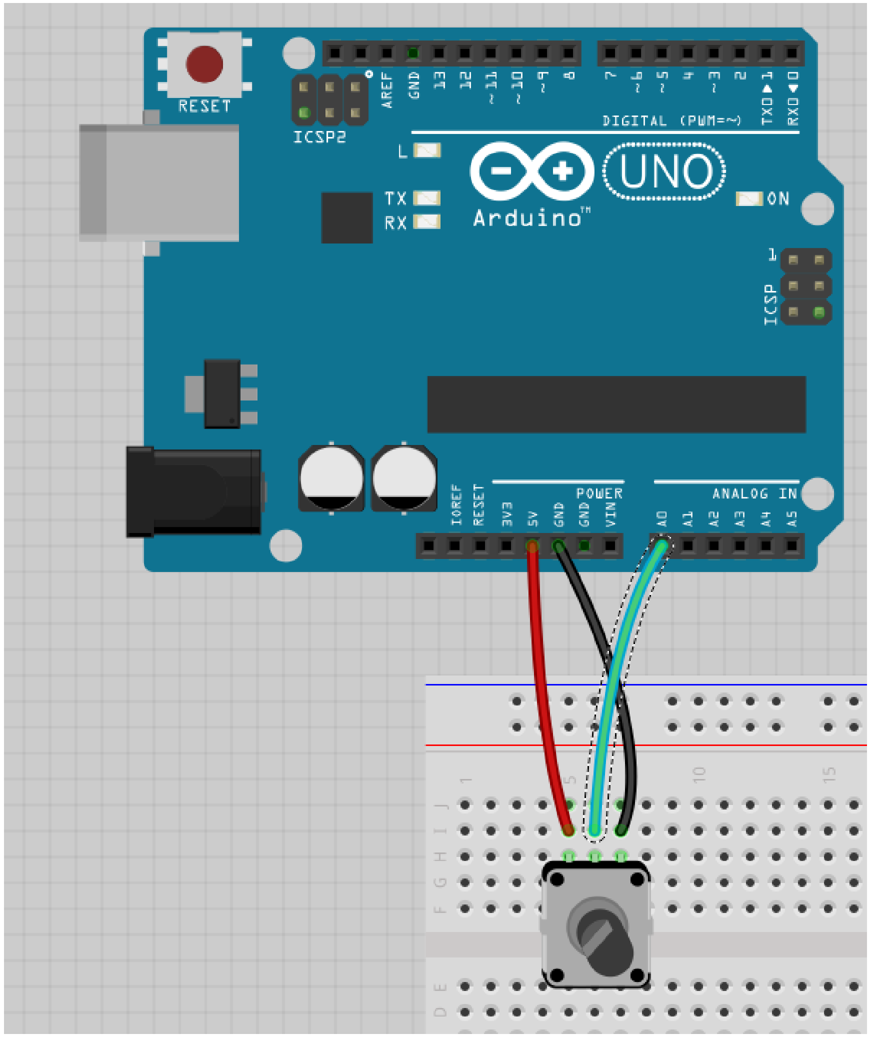


Example 3: Read analogue values

- Connect a Potentiomenter
  - Right lead goes to 5 V
  - Middle lead goes to A0
  - Left leads goes to GND

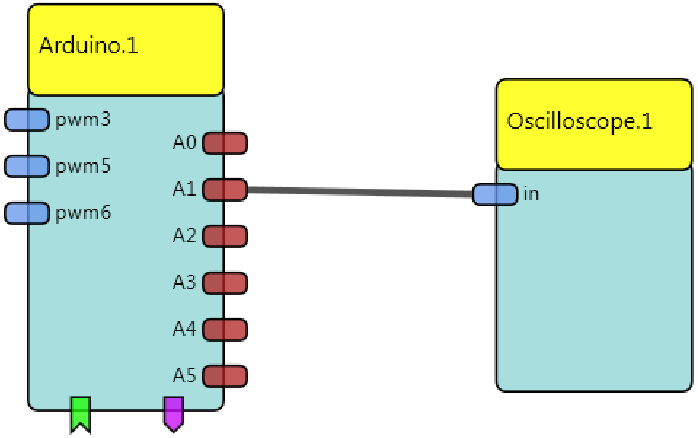
- Voltage at A0 will vary from 0V to 5V when turning





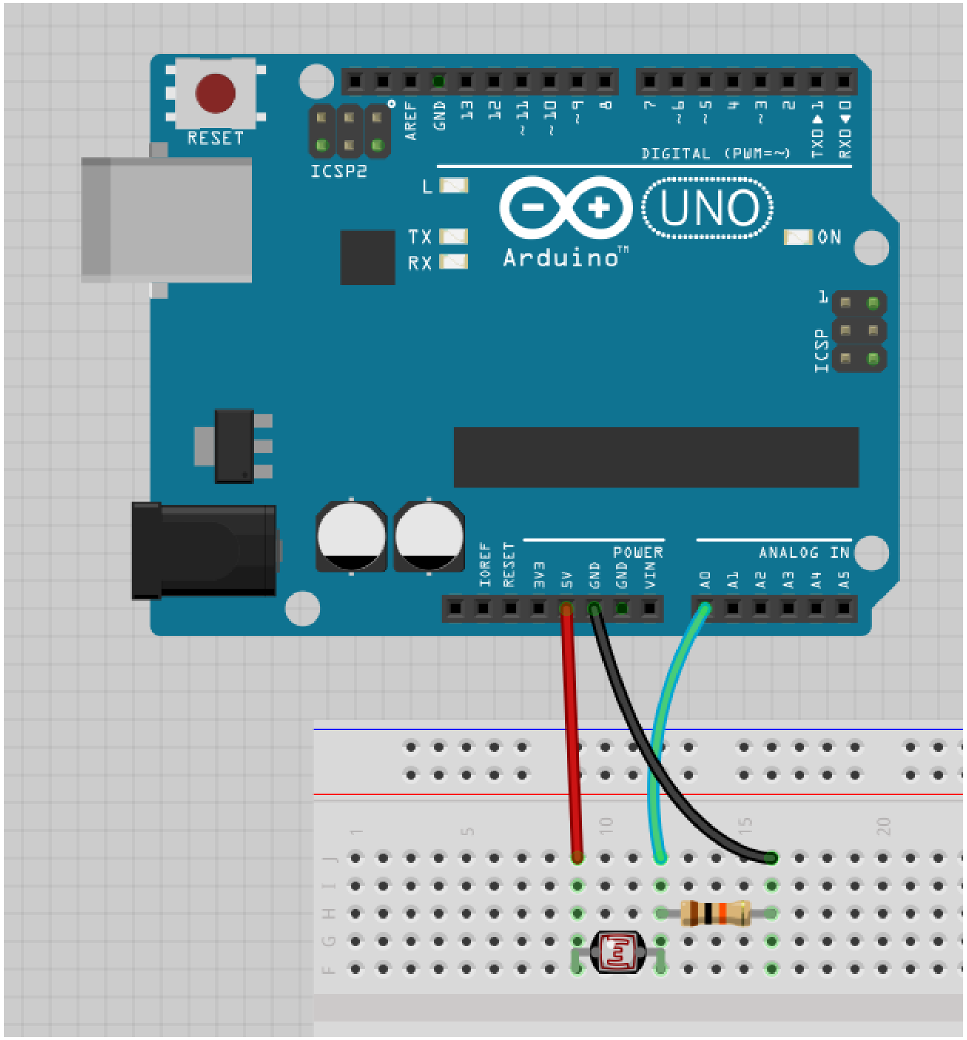
Example 3: Read analogue values

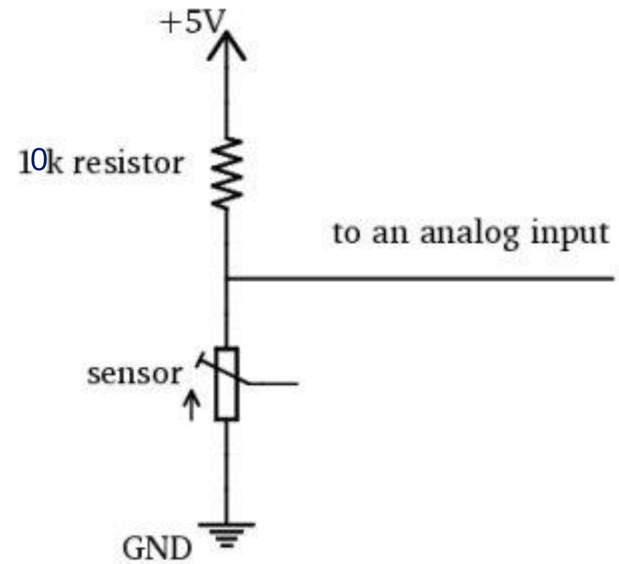
- Arduino Analog-Digital Converter
  - 10 bit → 1024 Values
  - Zero Volt = Value 0
  - 5 Volt = value 1023
- Important: Set periodicADCUpdate to a positive Time (in miiliseconds) otherwise the ADC is off !!!



Properties	
periodicADCUpdate	10
pin2Mode	not used
pin3Mode	not used
pin4Mode	not used
pin5Mode	not used
pin6Mode	not used
pin7Mode	not used
pin8Mode	not used
pin9Mode	not used
pin10Mode	not used
pin11Mode	not used
pin12Mode	not used
pin13Mode	not used

Example 3: Read analogue values



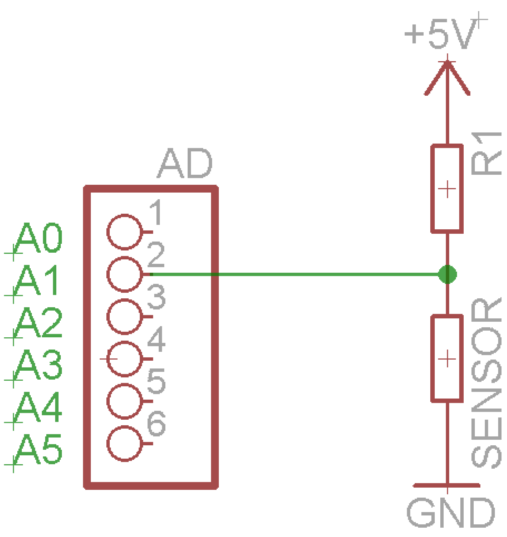


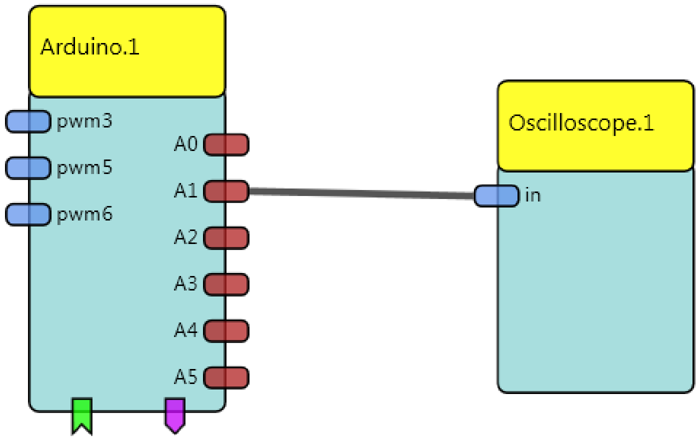
A voltage divider with a resistive sensor
(e.g. LDR – Light dependent resistor)
could also be a force sensor, temperature sensor etc.

<u>Try:</u> to print the brightness value in the ARE Window !

Example 3: Read analogue values

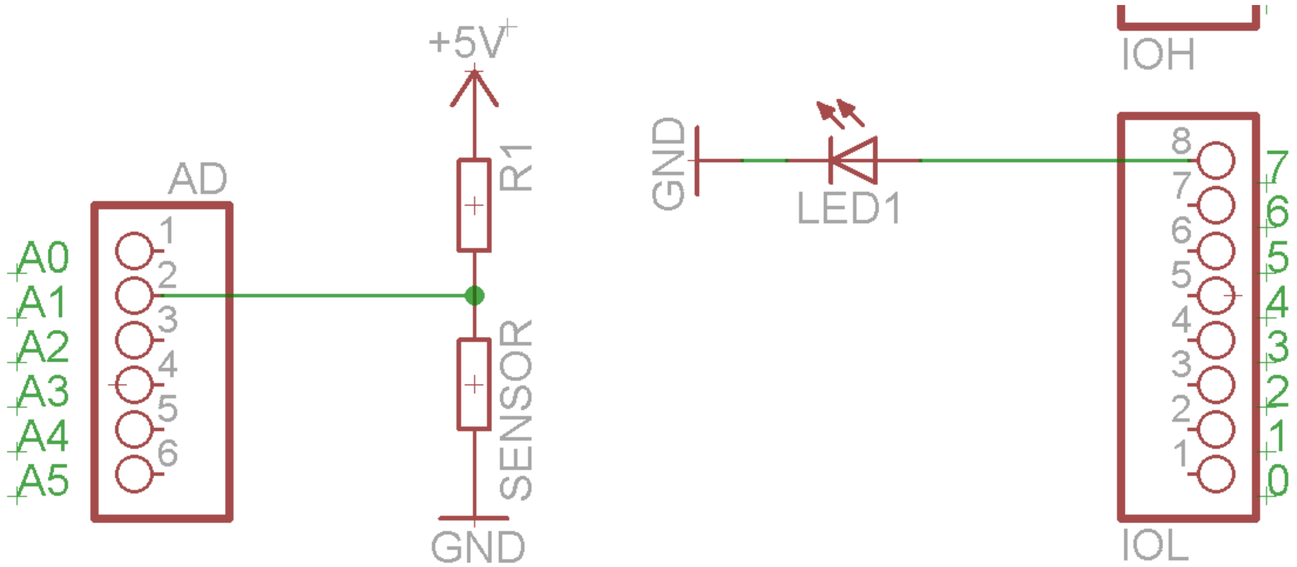
- Read a resistive sensor:
  - build a voltage divider!
  - R1 depends on the Sensor





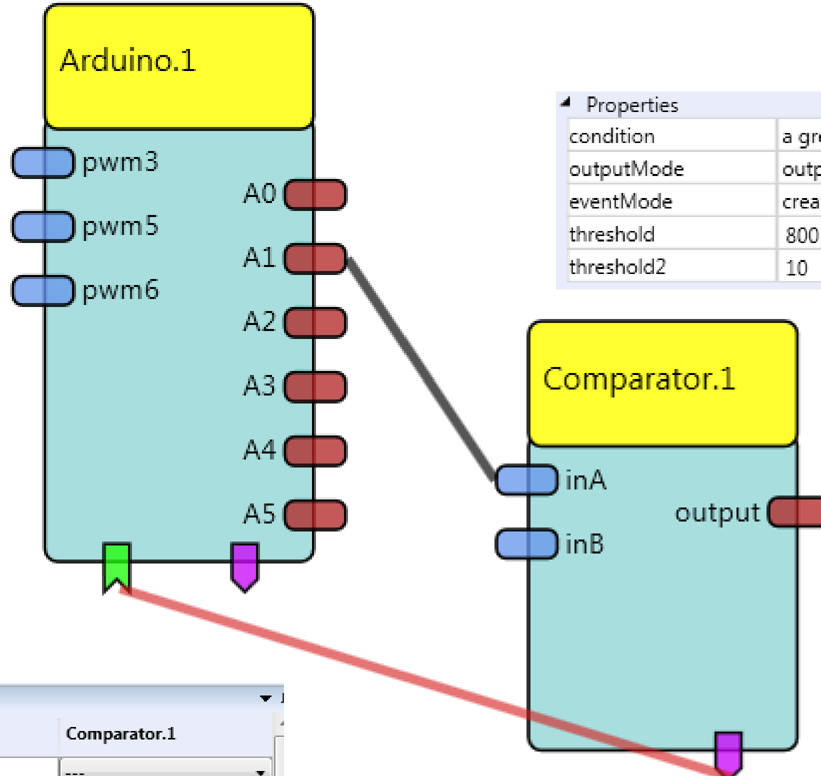
Example 4: Control Led via sensor

- Try: Switch LED on
  if Sensor value reaches threshold



Example 4: Control Led via sensor

Component Descriptio	Arduino Microcontroller CIM
Properties	
periodicADCUpdate	50
pin2Mode	not used
pin3Mode	not used
pin4Mode	not used
pin5Mode	not used
pin6Mode	not used
pin7Mode	output, default low
pin8Mode	not used
pin9Mode	not used
pin10Mode	not used
pin11Mode	not used
pin12Mode	not used
pin13Mode	not used



Properties	
condition	a greater threshold
outputMode	output a if condition met
eventMode	create event only if conditic
threshold	800
threshold2	10

Events (Ctrl-E)

Arduino.1	Comparator.1
setPin2	---
clearPin2	---
setPin7	conditionTrue
setPin7	---
clearPin7	conditionFalse
clearPin7	---

Applying EMG/ECG feedback

- You can now process raw bioelectric signals using simple filters and thresholds
- This can be used to create various biofeedback scenarios or alternative/accessible computer interfaces

Project outlook …

You can apply the EMG/ECG setup for:

heart rate feedback, muscle control for mouse clicks / navigation, on-screen keyboard scanning, environmental- or game control etc.

We have also an OpenEEG 6 Channel device available which could be used together with OpenVibe for BCI experiments