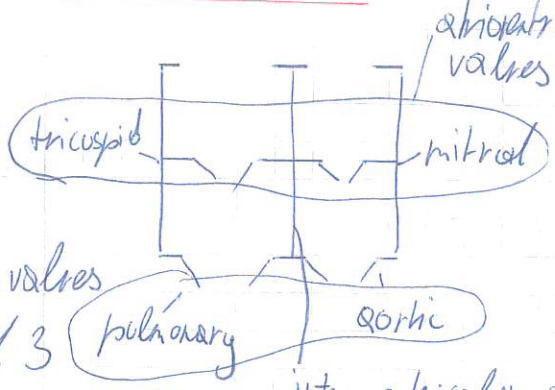
heart structure



2 individual muscles
- atria
- ventricular

valves close smooth (like leaflets) - low bpc.
pathological sound - high bpc. (stiffer valves)

right side:
de-oxygenated blood from body - right atrium - tricuspid valve - right ventricle - pulmonary valve - pulmonary artery to lung

left side:
oxygenated blood from lungs - left atrium - mitral valve - left ventricle - aortic valve - aorta into body

blood pressure lung +20 mm Hg (~3% of sys bp)
bp left ventricle +100 mm Hg (~15% of sys bp)

valves
- passive tissue - no muscles
- open: pressure difference
- close: by pressure difference and zero flow
- AV valves: multicusped valves
- semilunar valves: valves with 3 cusps

activation of the heart - pacemakers

- sinoatrial node (primary - 70bpm)
- atrioventricular node (secondary - 50bpm)
- bundle of His incl. purkinje fibers (tertiary - 30bpm)

- atria / ventricles are ele. isolated
- pacemaker potential, sort of competition
- AV node slows signal down (ele. signal faster than blood flow)

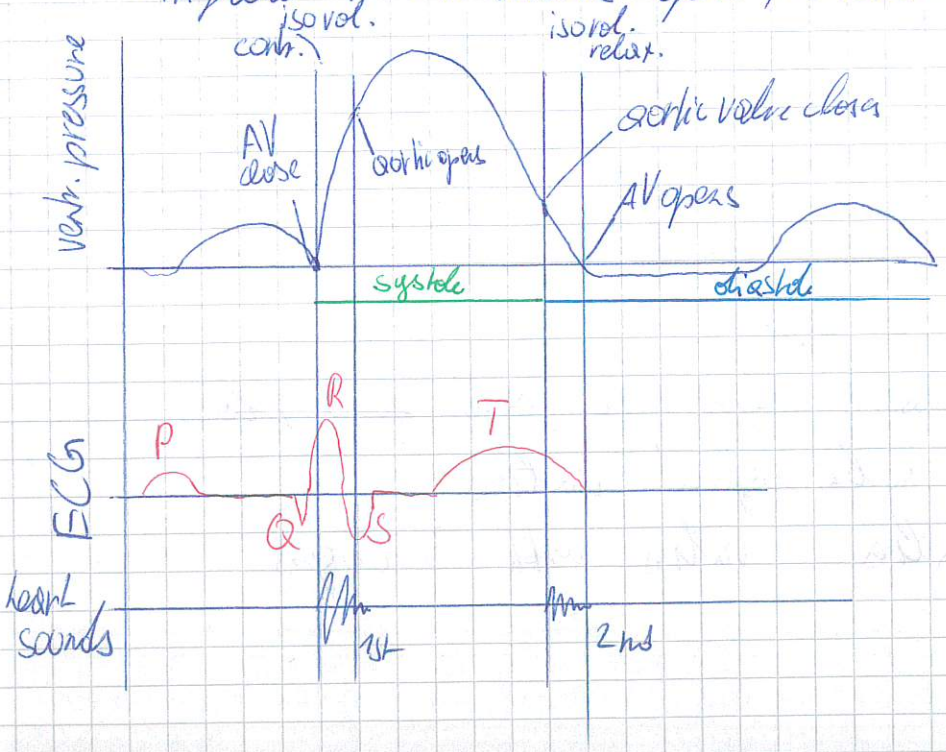
cardiac cycle

systole

- contraction: closed valves - inc. pressure in ventricle
- ejection: pressure high - aortic valve opens (also pulmonary)

diastole

- relaxation: pressure drops until smaller than in atria
- inflow: AV valves open, blood inflow



lung

structure:

- trachea
- right + left lung lobes
- alveoli ($\varnothing \approx 1\,mm$), enormous surface for gas exchange ($\approx 100\,m^2$)
- pleura (prevents collapse of lungs)
- diaphragm (muscles)

$p \cdot V = n R \cdot T$ ideal gas law

$\frac{pV}{T} = const$ $\quad V \uparrow - p \downarrow$

lung function

- oxygen delivery to cells and excretion CO_2 from cells
- pass. diff. CO_2 and O_2

inspiration – active process

- contr. diaphragm + intercostals muscles
- rib cage expands

expiration

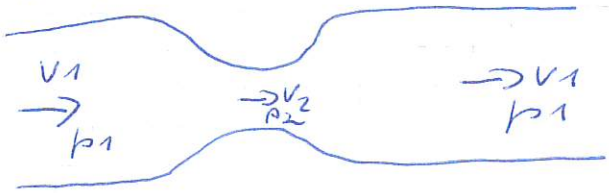
- relaxation diaphragm + intercostals muscles
- rib cage contracts

pharynx

- nasal cavity
- oral cavity
- junction nasal/oral cavity
- soft/hard palate
- uvula
- tongue

respiration disease - obstructive sleep apnea

- cessation of breathing for at least 10s
- physical block to airflow
  - reduce muscle tone
  - high body mass index
  - narrowing upper airways
- usually accompanied by snoring (oscillation uvula and/or soft palate)



$p_1 > p_2$

$v_1 < v_2$

cardiorespiratory system

- systemic circulation
  - oxygenated blood to the body (upper and lower) and deoxygenated blood back to heart
  - oxygenated blood: l. vent. → aorta → arteries → arterioles → capillaries
  - deoxygenated blood: venules → veins → vena cava → right atrium

place bp. sensor near vital organs (brain, heart) carotis region

- pulmonary circulation
  - deoxygenated blood to lungs, oxygenated to heart
  - deoxygenated blood: right ventricle → pulmonary artery → lung
  - oxygenated blood: lung → pulmonary vein → left atrium

5 l blood in body $Q = 5\ l/min$

$Q = SV \cdot f_c = 70ml \cdot 70bpm$

1 droplet of blood - 1 min to pass whole body

systemic / pulmonary circulation in series

- 80% blood in low pressure system
  - acts as blood storage / accumulator
- 20% in high pressure system

Electrical biosignals

$U = Z \cdot I$

medium impedance

resistivity ρ (local char.)
Resistance R (global)

$R = \frac{\rho \cdot l}{A}$

} const. ele. field

in alternating ele. field

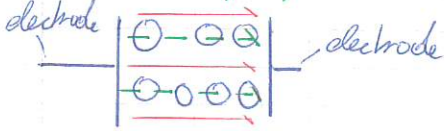
- typ. dependence of effective conductivity γ (local char.)

$\vec{J} = \gamma \cdot \vec{E}$

$\vec{J}$ current density, $\vec{E}$ ele. field

- typ. dependence of permittivity

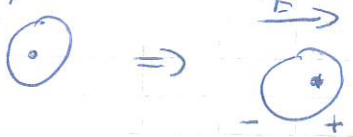
typ. typ. (Z_L, wide cross area A_L)



low typ. (Z_T, narrow cross area A_T)

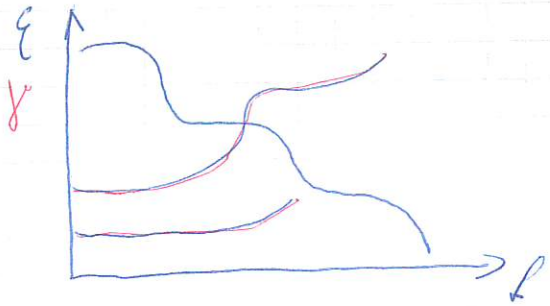
dispersion mechanism

- displacement polarization ($f < 100\,000$ GHz)

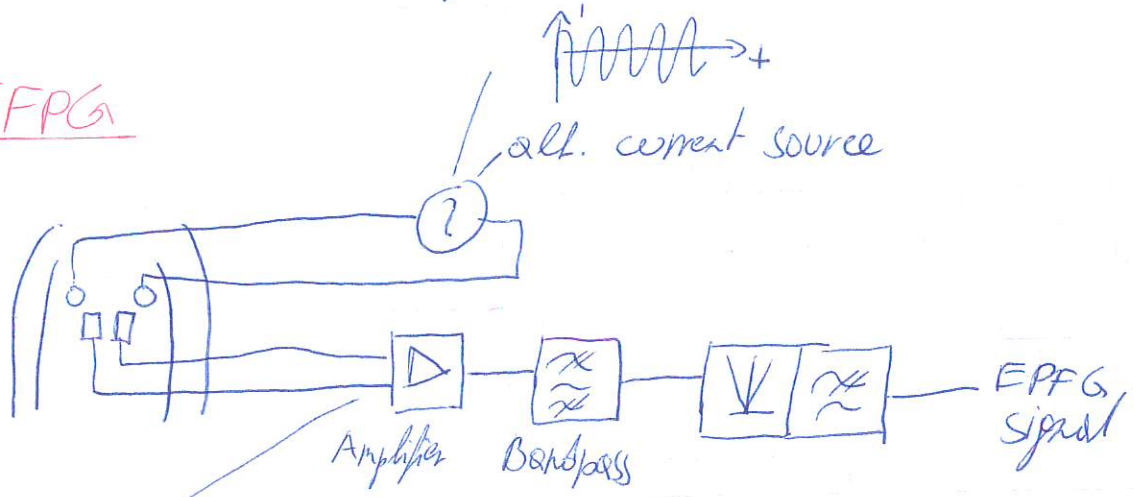


- γ dispersion, orientation pol. ($f < 30$ GHz)
  elliptical water mol.

- β dispersion, cell mem. pol. ($f < 100$ kHz)
  cross area, cell mem. bypassed
  ε... permittivity



EFPG



- const. component U_0 (> 90%) - initial state of medium impedance
- alternating component (< 10%)
  - respiratory / cardiac activity
  - displacement of organs
  - displacement liquids
  - blood vol. / velocity changes

physiological correlations

inhalation / expiration

conductivity ↑ - less equipotential lines

inhalation: more isolating vol. (air), less conductivity
exhalation: less isolating vol., higher conductivity
heart is conductive tissue (blood)

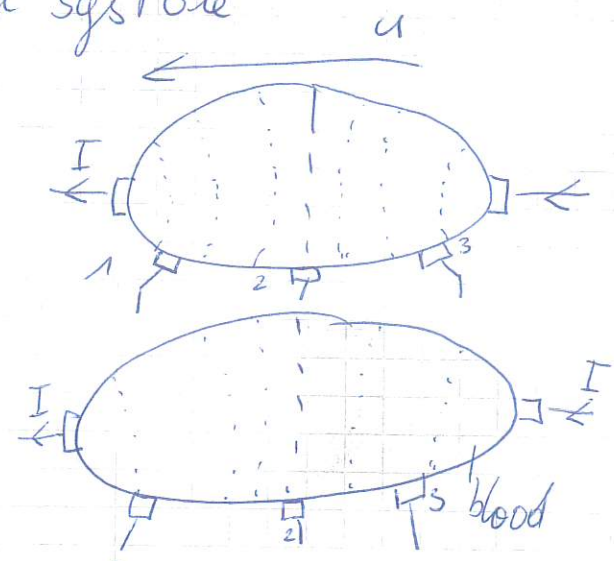
Systole vs. diastole

late systole: blood is ejected from heart to arteries
- more blood in arteries - less in heart
conductivity ↓

late diastole: heart filled with blood, blood has good conductance → ρ↑, u↓

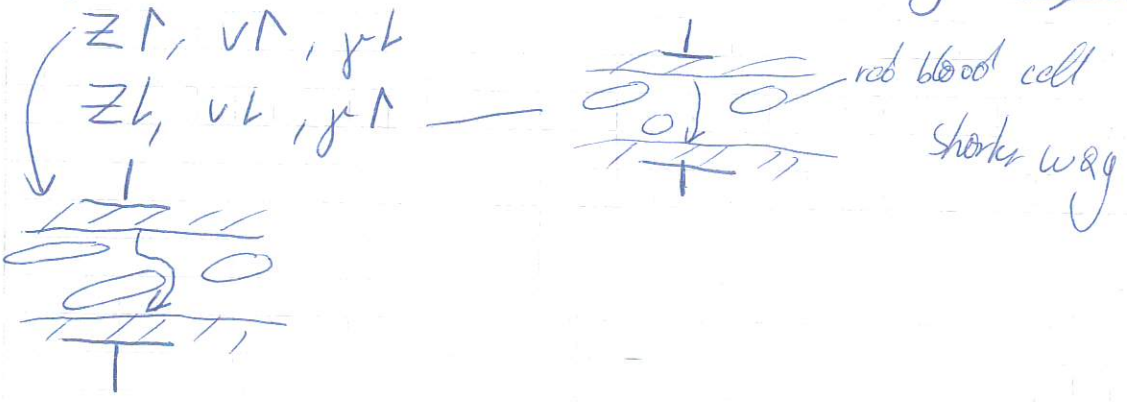
ρ change only local around heart

late systole



$u = \frac{1}{G}$

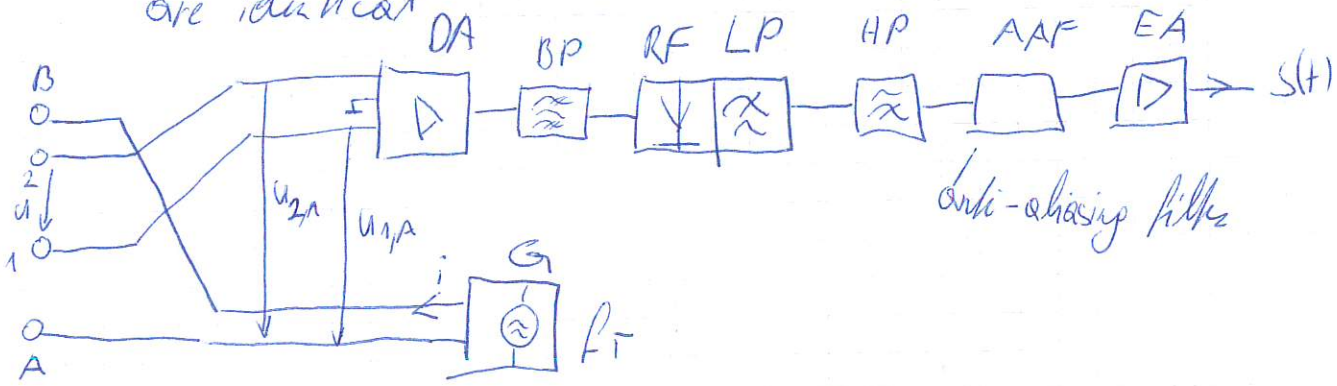
response impedance to flow velocity changes



if $\vec{v}$ rises, blood cells allign more in flow direction → more complicated way

recording system

- frequency f
  - 20–100 kHz, flat course of ε and γ
  - > 20 kHz to avoid stimulation of nerve system (allowed current I↑ with f↑)
  - < 100 kHz due to dispersion
    if f↑↑ then εγ of tissue, lung and blood are identical

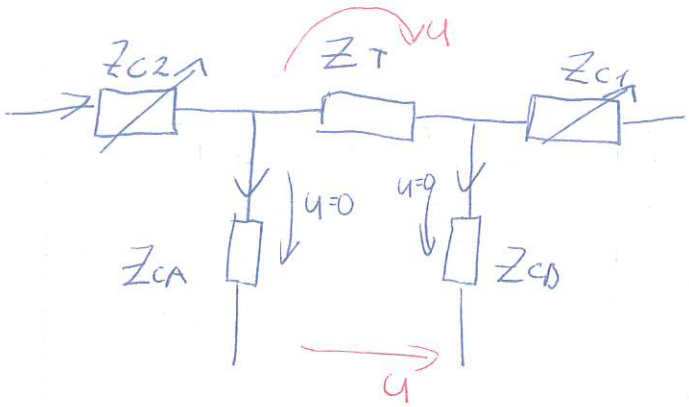


- current amplitude I
  - ≈ 1 mA
  - probability of neural stimulation inc. with inc. I and dec. f
  - thermal effects inc. with inc. I
  - signal to noise ratio of alt. component (information carrier) inc. with inc. I

2 electrode vs. 4 electrode technique

2 electrodes:
- contact + electrode impedance (even if I is const.)
- movement artefacts

4 electrodes: (better)
- no influence of contact impedances
- no influence skin impedance

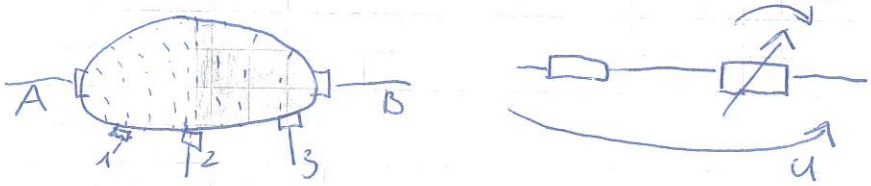


Voltage vs. current application

voltage application:

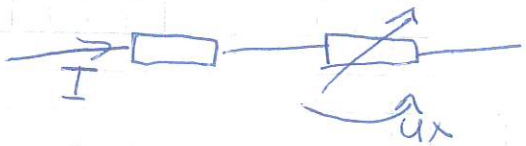
local "no blood" (change in impedance) yields misleading changes in voltage drop U_x

$\Delta U_{32} \neq 0$



current application:

local "no blood" yields non misleading no-changes in voltage drop U_{21}, higher sensitivity

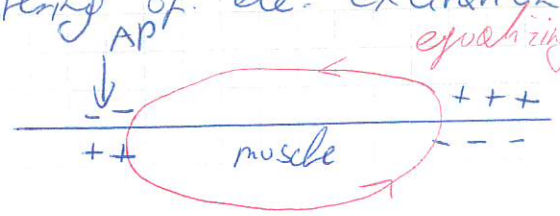


what can you use it for?

- cardiac / respiratory activity (signal seperation necessary)
- apneas (= cessation of breathing)

ECG

= registering of ele. excitation of heart muscles



current dipole

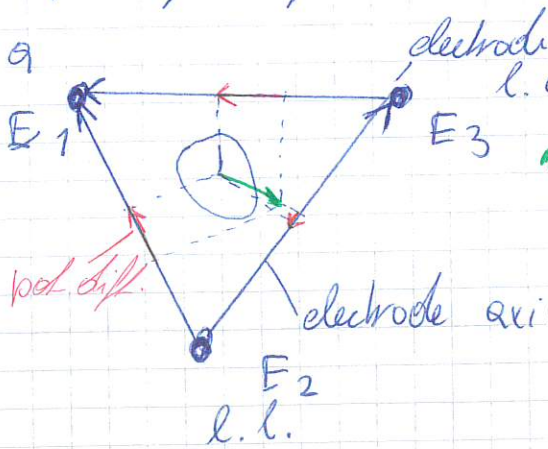
propagation direction

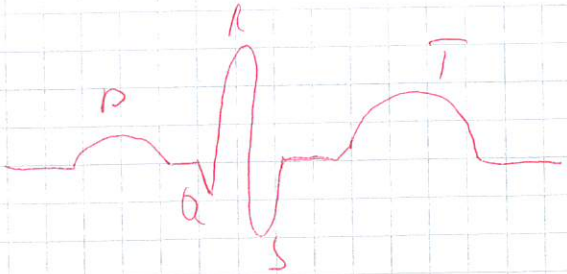
- measure pot. diff. on body surface

$\vec{j} = \gamma \cdot \vec{E} = -\gamma \, \text{grad} \, \varphi$

if there is material or tissue with high γ↑ (good conductor), there are less potential lines (ideal conductor has 1 α outside)

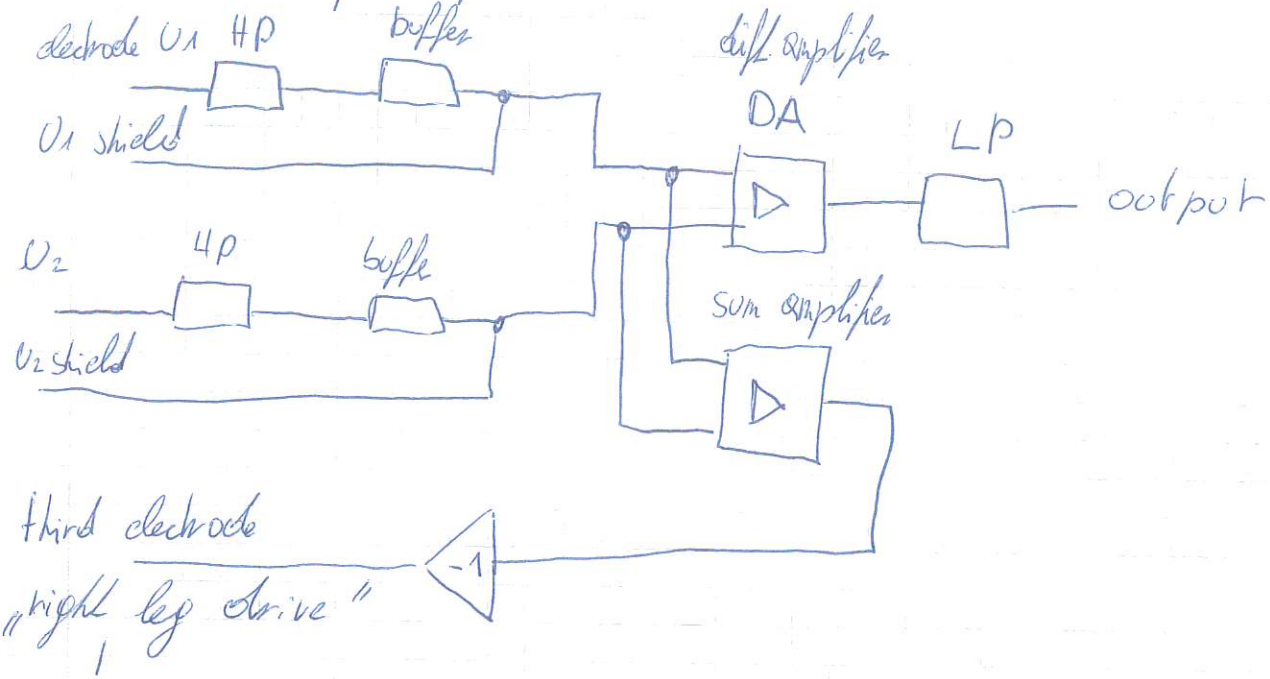
- projection of tot. dipole on the electrode axis (inverse projection)
- min. diff. 90° to dipole vector
- max. diff. parallel to dipole vector





- time and space dynamic
  - p wave: excitation of atria
  - PQ: atria fully excited → no pot. diff.
  - QRS complex: propagation of excitation in ventricles
  - ST interval: ventricles fully excited → no pot. diff.
  - T: repolarization of ventricles

hardware principle:



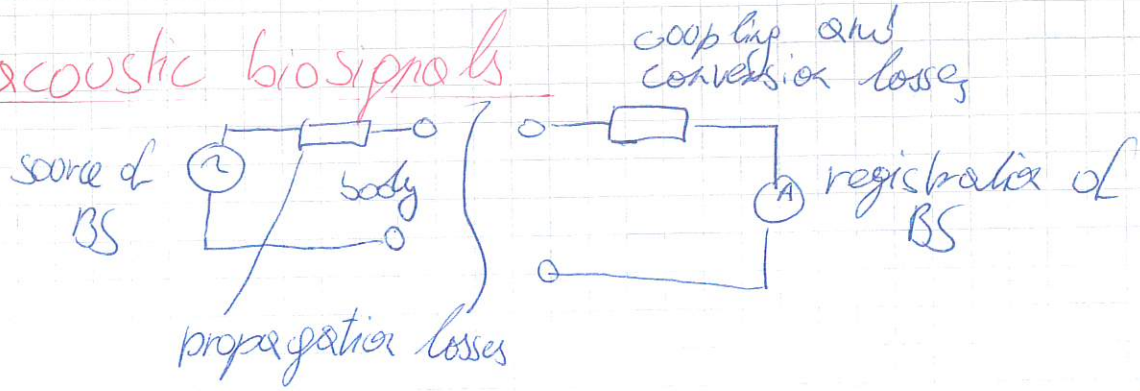
used to reduce noise + improve signal quality
works as active grounding system
cancels out common-mode noise by driving a small, inverted version of the noise back into body (ex. 50Hz)

clinical use for:
- propagation of excitation and back formation
- heart position, heart rate

NOT for:
- pumping capacity
- mech. contraction of heart

frontal plane: Einthoven derivation
horizontal plane: Wilson derivation

acoustic biosignals



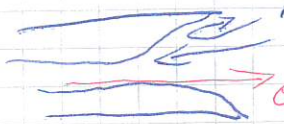
heart sounds

- 1st sound
  - close mitral and tricuspid value (=lesion of valves, deceleration of blood)
  - loudest, low fqc, longest (140ms)
- 2nd sound
  - close more rigid aortic and pulmonary valves (also vibrations of atria and ventricles)
  - lower intensity, snapping quality, shorter (110ms)
- fqc. range up to 100Hz

lung sounds

classification based on

- location of auscultation region
  - vesicular sounds (at peripheral lung fields, air turbulences, arise mainly during inspiration, distributed)



  - bronchial sounds (over large airways, e.g. on the neck, turbulent airflow, induce vibration of airway walls, central source)

- Sound type
  - continuous sounds (normal and pathological (narrowing and constriction of airways)
  - discontinuous sounds (pathological only) (explosive reopening of small airways, e.g. of excessive fluid)
- properties
  - normal 100-500 Hz
  - abnormal up to 1000 Hz

sound amplitude $S \sim F^n$ / stronger airflow - higher ampl.
F... airflow velocity index $n = 2$ / periphery - lower airflow - lower amplitude

<u>snoring sounds</u>

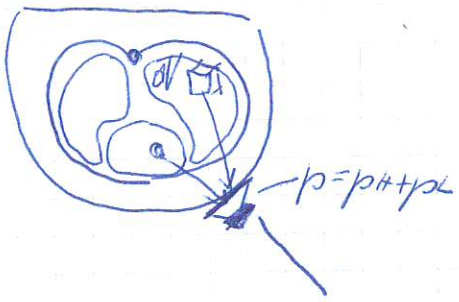
classification based on
- location of origination region
  - nasal snoring (uvula oscillation)
  - oral snoring (soft palate oscillation)
- type of generation
  - normal snoring (flow limitation, narrowing of airways during inspiration, reduced tone of muscles due to stress, tiredness, alcohol)
  - obstructive snoring (narrowing and temporal occlusion of airways due high compliance of airway walls and masses obstructing airways)

- distinct signal waveform
  - simple waveform snoring (sinosodial, oscillation without closure)
  - complex waveform snoring (train structures, temporal colliding of airways)

- properties
  - normal 100 - 800 Hz
  - obstructive up to 2000 Hz

sound propagation

- medium damping factor $e^{-\alpha r}$



heart sounds - point source

$p_H = k \cdot \frac{P_0}{r} e^{-\alpha r}$

p... sound pressure

k... konstant

α... absorption coefficient

P_0... power

lung sounds - distributed sound source

$p_L = k \int_V \frac{s(r)}{r} e^{-\alpha r} dV$ s... sound power density

propagation and attenuation in short

- highly inhomogenous propagation medium
- frequency dependent sound pathway
- frq. dependent attenuation $\alpha \approx f^2$ (α... inner friction)

  high frqc. get more attenuated, can't really enter tissue for sound propagation

Coupling

- chestpiece as acoustic amplifier
- microphone as acoustic-electric converter

- Reflection $R = \frac{Z_A - Z_T}{Z_A + Z_T}$ T... tissue A... air

$Z = \rho \cdot v$ ... sound radiation impedance

$Z_A : Z_T = \frac{1}{10}$ $R = \frac{9}{11}$

middle layer with $Z = 5$ $R = \frac{2}{9}$ → less reflection

- Refraction (bending of waves entering the air)

$v_A < v_T$, $\lambda_A < \lambda_T$, $Z_A < Z_T$

$\frac{v_A}{v_T} = \frac{\sin \beta_A}{\sin \beta_T}$ β... refracted angle

refracted wave is bent towards the normal of skin
→ flattened wave front

bell: has eigenfrq. of membrane
resonance frq. of bell

↓

specific amplification

$\lambda = \frac{v}{f}$

low frq → higher wavelength

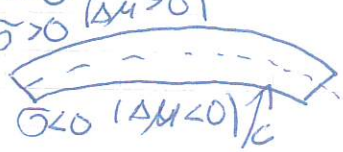
↙

low frq.: little memb. tension, large memb., large bell

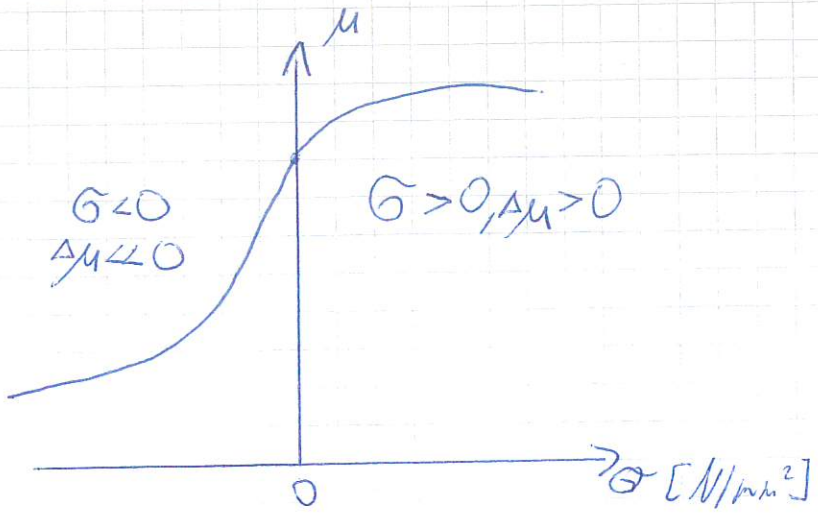
high frq: high memb. tension, little memb., small bell

Skin curvature sensor

- single ML (magnetostrictive layer)
- neutral bending plane $\sigma = 0$ inside of ML
- total $\Delta\mu \neq 0$

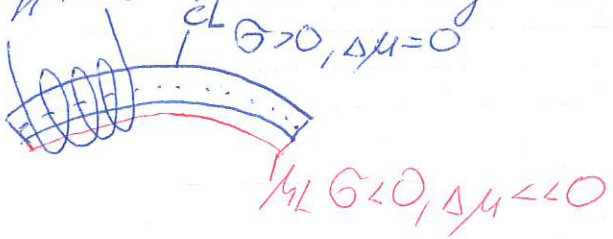


μ... permeability
σ... mech. stress
c... curvature



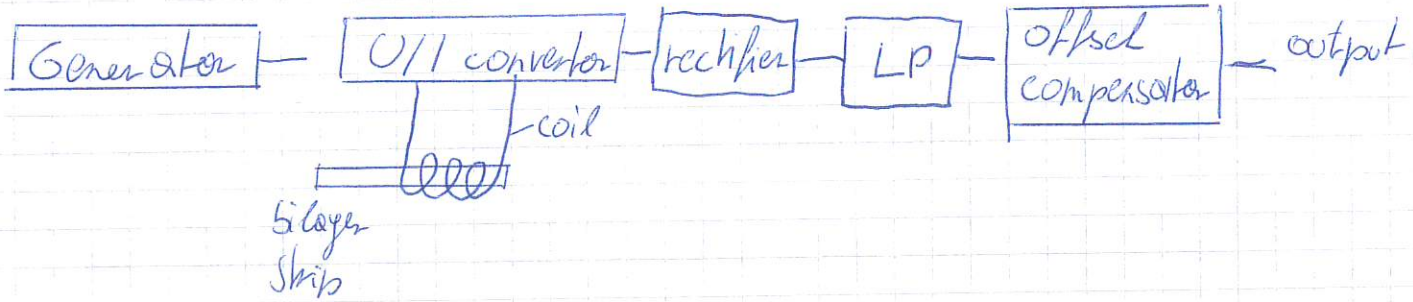
- bilayer structure

ML affixed to a nonmagnetic counter layer CL



- bilayer as sensor element
- coil for the establishment of an ele. sensor signal
- extremly flat (0,1 × 3 × 50mm)

$U = Z \cdot I = \omega \cdot L \cdot I \qquad L \propto \mu \propto \frac{1}{c}$



ideal bilayer $\Delta\mu \approx \frac{1}{c}$ (strongly)

glued bilayer $\Delta\mu \approx \frac{1}{c}$ (less strongly)

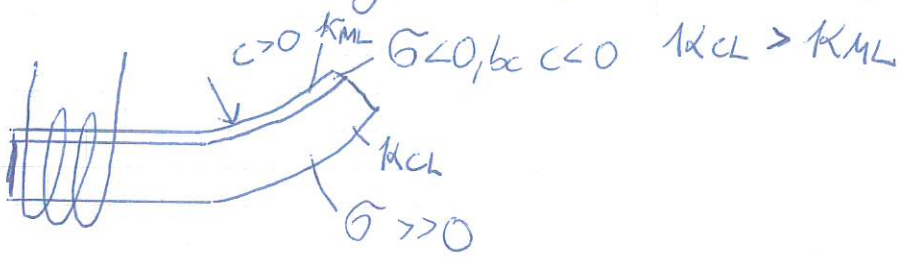
bending sensitivity

ML not as good

bilayer better, Al good, non-magnetic steel better

thermal sensitivity

- non-zero sensitivity bc of $\alpha_{ML} \neq \alpha_{CL}$

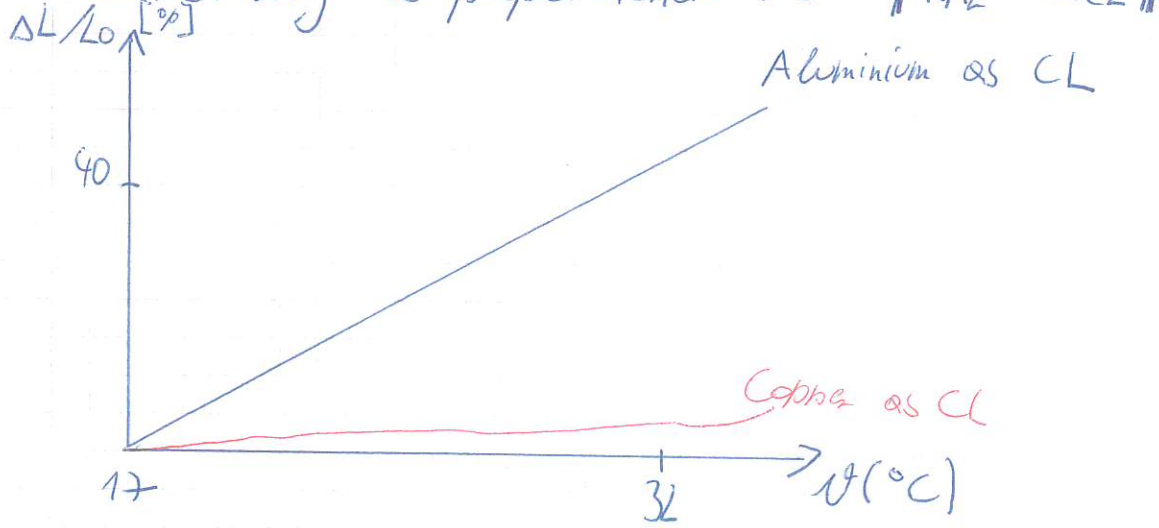


in total $\sigma > 0$ $\Delta\mu > 0$

α... thermal expansion coefficient

c... curvature

- sensitivity is proportional to $|\alpha_{ML} - \alpha_{CL}|$



one can monitor cardiac activity, blood vessels (arteries) expand during systole

also respiratory activity - ribcage

also blood pressure on neck

also eye movement, pelvis movements, muscles