Biomedical Instrumentation/

Biomedizinische Technik

2015, [354.042] Professors: Kaniusas, Wanzenböck, Bertagnolli, Mayr,...

Basic Principles

1) SAFETY. What is the let-go current, how is it defined? Draw a simple diagram to underline your definition.

The "Let Go" threshold is the current level where we lose control of our muscles and the electricity causes muscles to contract until the current is removed. (Slides: Defined as external current which starts to control the nerves and muscles)

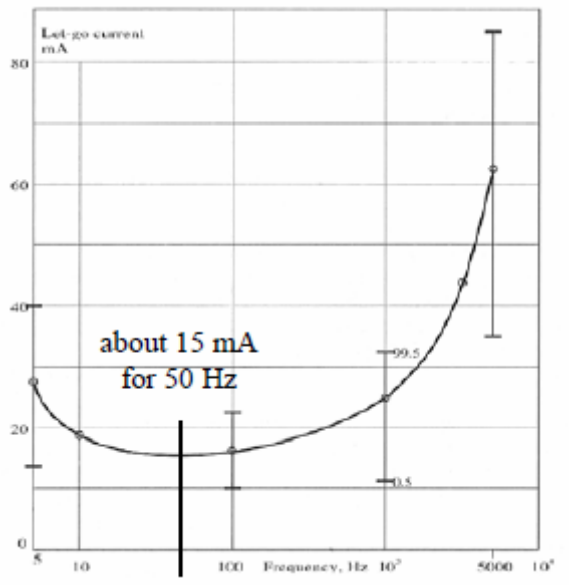


Figure 1.Let go current.

2) SAFETY. Why direct current (DC) should be avoided during electrical stimulation and how this is guaranteed in the construction of an electrical stimulator?

The attached electrode together with the skin has a capacitive behavior which doesn't allow the DC current flow to cross it. That is why for the electrical stimulation electrodes one should not use the DC current. The electrical stimulator can be constructed by the means of transformer isolation or capacitive coupling which do not let DC current to flow through.

3) SAFETY. Describe the possibilities for **isolation** of the patient from an applied biomedical device for **safety reasons**, add drawings.

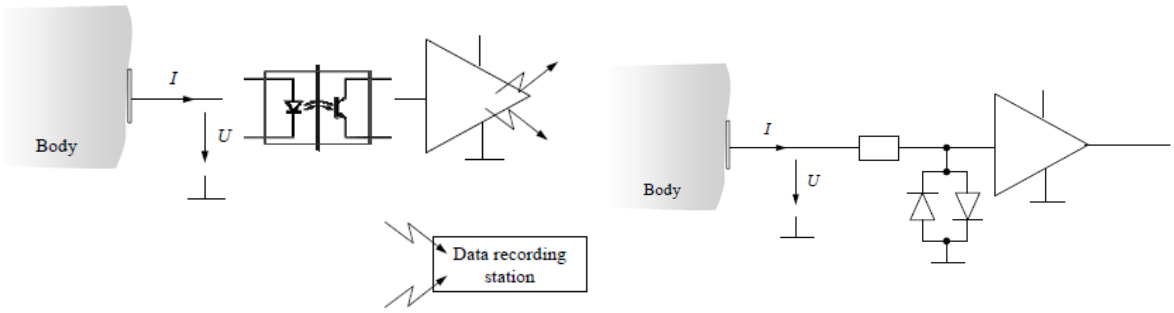


Figure 2. Left: Transformer isolation. Right: Isolation via current limiting resistor and voltage limiting diodes[1].

For the patient isolation we want to avoid high currents, and to avoid voltage (ether V=0 or V<<1)... The current is reduced through the resistor, and the voltage is limited by the application of the diodes. The isolation can also be achieved through application of light-transmission which is optical isolation, applied for the near distances. For far distances- wireless isolation.

- Photo-optic isolation (modulated LED and photo detector)
- Transformer isolation (coupled coils, only AC path)
- Capacitive coupling (only AC path)

Hardware: - Chassis grounded: if isolation fails then the current flows safely to ground (= fault-current circuit breaker opens).

4) X--Passive Shielding, how is it done, disadvantages? Describe active shielding.

While the cassis is usually grounded, cables have to be shielded in order to reduce the noise that electrical field would capacitive couple to the signal. The antenna effect can be reduced significantly by twisting the cables, but still such fields could influence the signal.

Therefore shields of conductive or magnetic material are used to create barriers between the isolated electric device and the "outside world" as shown in Figure 3. Since the shield acts also as resistor and capacitor in parallel, the measured voltage is reduced by the effect of this **resistive voltage divider**. The capacitive behavior on the contrary, charges and discharges with a shield specific time constant.

In active shielding an additional operational amplifier is used that influences the behavior of the shield as shown in Figure 3.

Shielding and grounding reduce the frequency noise of the AC-signal to a great extent. Nevertheless further measures have to be considered such as:

- Twisting the leads of the electrodes to annihilate there antenna effect.
- Notch filters that filter a small band around 50/60 Hz.
- Low-pass filters for high frequency noise & high-pass filters for low-frequency noise.
- … (many more)

[1] Diodes in opposite pairs needed, since we have AC voltage and therefore –V & +V!

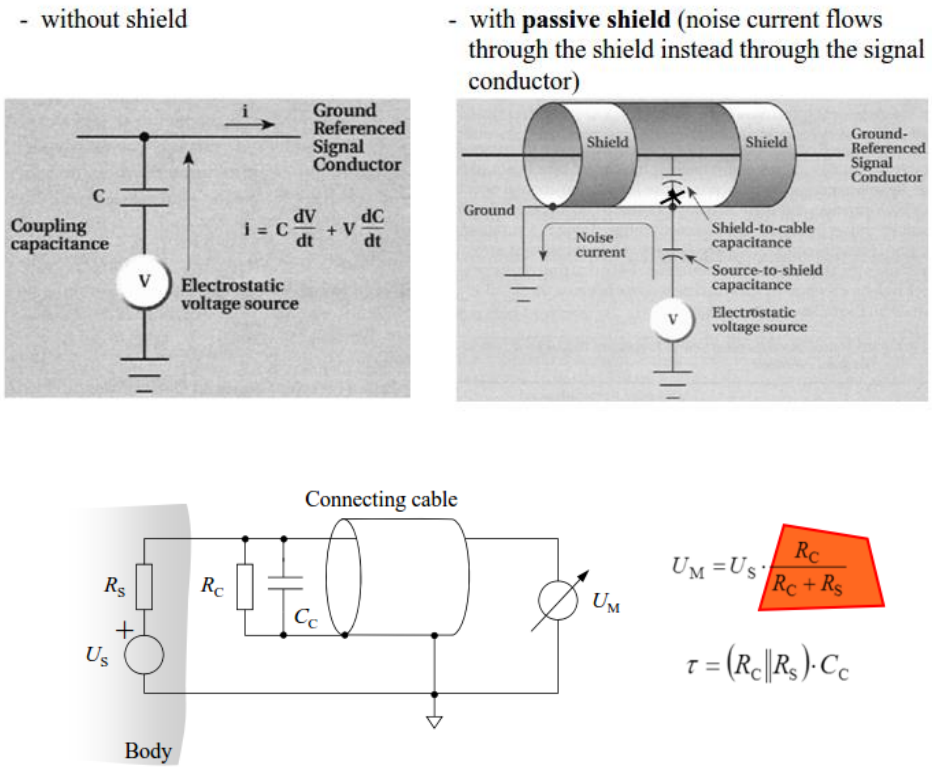


Figure 3. TOP: Passive shielding of the cables. R_C & C_C should model the shunt resistive and shunt capacitive behavior of the shield. BOTTOM: Active shielding. (Bioinstrumentation, Kaniusas: Basics)

5) C--SIGNAL ACQUISITION. DEMODULATION: What is phase sensitive demodulation and how does it work? Add Drawings.

Modulation: Altering one signal by the use of another signal. Original signal is called “baseband”, the signal modulated by the baseband is called “carrier”. **Demodulation** is the process of recovering the original signal.

6) ELECTRODES: Describe the perfectly polarizable and non-polarizable electrodes.

a) Polarizable electrode:

Polarization done through the current, and overpotential is induced.

ONLY DISPLACEMENT CURRENTS, this kind of electrode together with the electrolyte acts as capacitor. Lets only AC current go through.

Example: Pt-electrodes (Noble metals). These electrodes are used for stimulation.

b) Non-plarizable electrodes:

There is no overpotential, current passes freely across the electrode-electrolyte interface, behaves as a resistance. Used for recording.

Example : Ag /AgCl electrode

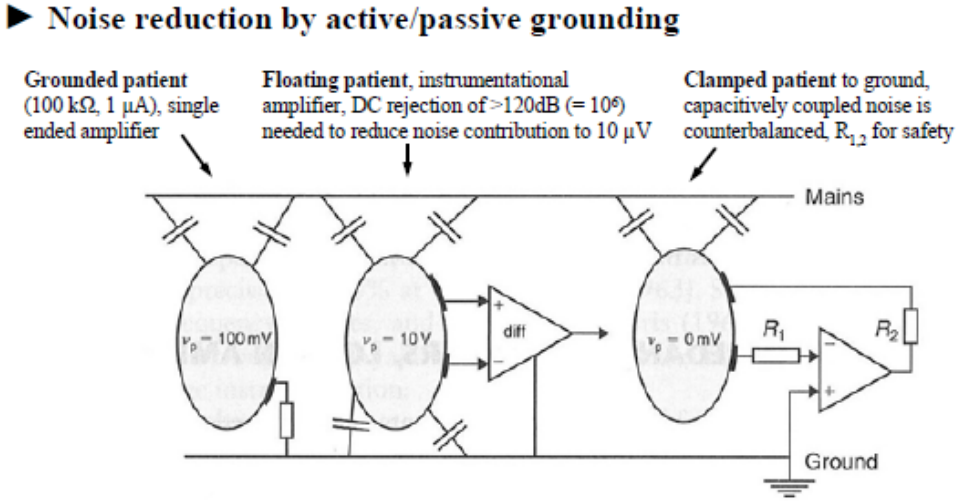
7) NOISE: How is the noise coupled into a biomedical device? How to avoid/prevent it? Add a drawing and possible (simple) countermeasures?

- Capacitative coupling - for AC currents, since if there were DC current, the capacitor would stop all the noise
- Inductive coupling (should be avoided)- …
- To reduce the noise - grounding through the ohmic resistor.

a. Different noise types, spectral characteristics?

- The noise (white ß=0, pink ß=1, brown ß=2, black ß>2) states how fast this noise decreases over frequency.
- The power spectral density is determined by the slope 1/f ß
- The whiter the noise the more difficult is the distortion.

b. Noise coupling. How to avoid/ prevent it? How does it occur?



c. Inductive noise coupling, how and how to get rid of it?

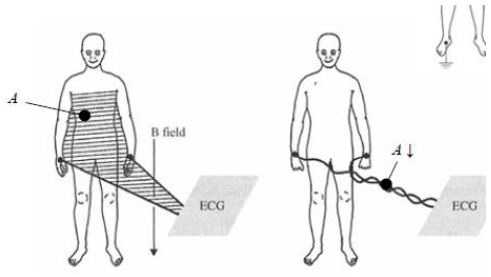


Figure 4. Where do I belong too?

The smaller the area, the lower the induced voltage → twist the wires to reduce the induction.

Diagnostic devices

8) GENERAL. Should the Body Output Impedance be low or high? And what about the sensor input impedance? Explain why. Ratio: body (b) impedance/ sensor (s) impedance?

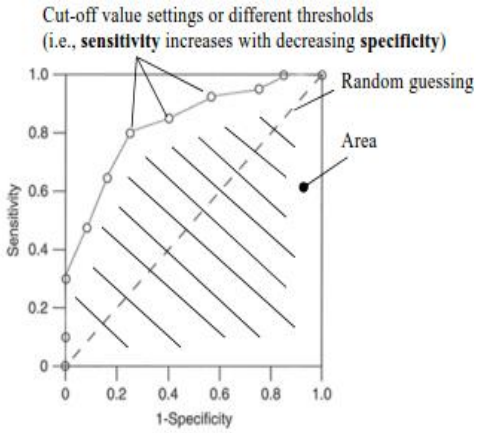
The body output impedance is finite but hard to define (considered unknown), that is why we want the **input impedance of the sensor to be very** high in so that we could neglect the body output impedance.

Furthermore current always takes the way of the least resistance. Having a large body output impedance, minimizes the risk of electrical accidents!

$$\mathrm{I} = \frac{U}{(Zs,in + Zb.out)} \ldots \; Zb,out << Zs,in \ldots \; \mathrm{I} = \frac{U}{Zs,in}$$

9) How is specificity/sensitivity defined? *Also known as:* What is a receiver operating characteristic (ROC)? Add drawing.

Hints: "Operational characteristic of receiver?" - The answer is sensitivity, specificity and the diagram provided in the script



ROC is used to analyze and optimize the receiver. A diagonal characteristic would indicate random behavior. The further away from the diagonal, the better. The high slope @ the beginning indicates that many true positives will be analyzed in this region. Further to the right, the

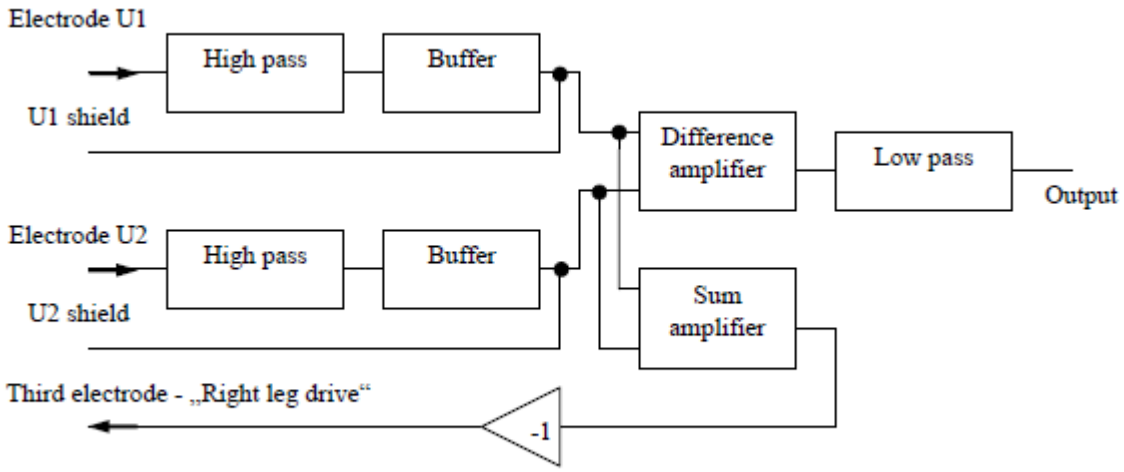
number of false positives increases, which lead to a decrease in the slope of the ROC curve.

Sensitivity=TP/(TP+TN) & Specifity= TN/(TP+TN)

Specifity is the capability to discriminate ill patients (TP) from healthy patients (TN in our case).

Figure 5. Receiving operating characteristic. (Bioinstrumentation, Kaniusas: Diagnostics)

10) ECG: Draw a block diagram or an electrical circuit of an ECG amplifier with right leg drive. What is the third electrode used for?



Buffer (operational amplifier) for each electrode use to eliminate the need for impedance matching. Diff. amplifier used to amplify only the difference between U1 and U2. This is the first interference elimination step. Nevertheless **capacitive coupling induces noise** via current flows across the body towards the ground. This interference is recorded in the right leg, inverted (-1) and then added (this means subtracted) from the U1/U2 difference.[2]

Leg-driven ECG raises the overall ECG amplifiers **common-mode rejection ratio (CMRR)** via a common-mode negative feedback (CMNF), making the ECG differential amplifier less sensitive to common-mode hum (50 Hz from main supply) and interference. [3]

11) Draw the correlations between the pulse wave signal (optical plethysmography sensor) at the finger and the ECG. Mark cardiac period & respiratory period.

Plethysmography means the noninvasive measuring of **volume changes** in parts of the body or even the whole body. In the course of the change of volume, also the impedance changes.

[2] Lab 3, tutorial text.
[3] Northrop, 2002: Noninvasive Instrumentation and Measurement in Medical Diagnosis.

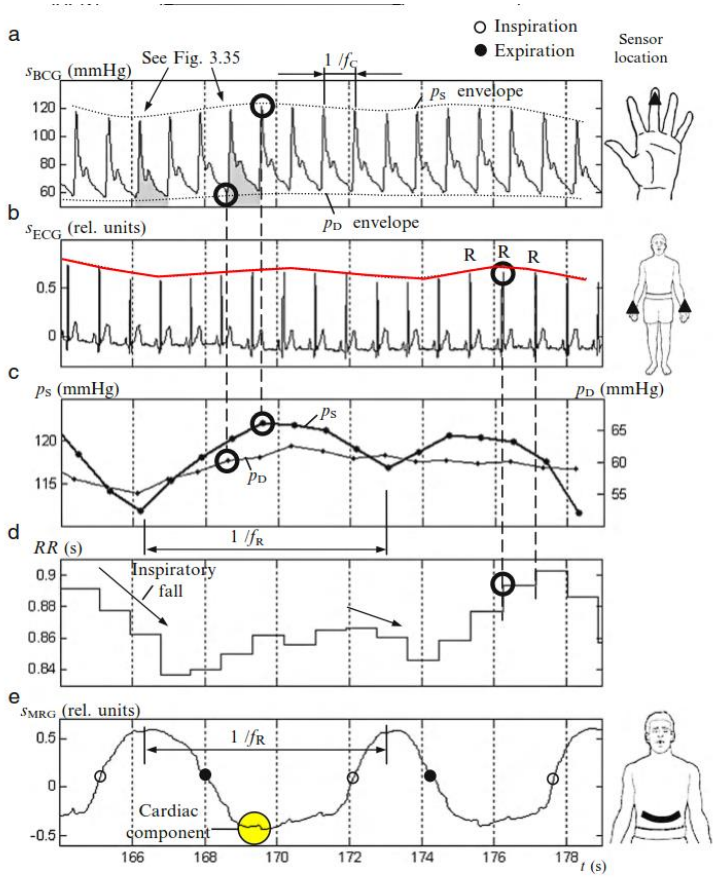


Fig. 3.30 Influence of respiration on cardiac and respiratory signals exemplified by synchronous (**a**) mechanic biosignal barocardiogram s_{BCG} (from a finger on the left hand), (**b**) electric biosignal electrocardiogram s_{ECG} (lead I Einthoven) with indicated R peaks, (**c**) systolic blood pressure p_S and diastolic pressure p_D derived from s_{BCG} (relevant pressure points indicated by *circles in bold*), (**d**) interbeat intervals $RR\,(=1/f_C$ with f_C as instantaneous heart rate) derived from s_{ECG} (relevant time instants indicated by *circles in bold*), and (**e**) mechanic biosignal mechanorespirogram s_{MRG} (from abdominal circumference changes). The respiratory modulations of biosignals with respiratory rate f_R are shown. The pulses from s_{BCG} with a *grey background* are analyzed in Fig. 3.35

Figure 6.ECG vs. respiration. Biosignals I, Kaniusas, 2012, p. 243. Red line: respiratory influence.

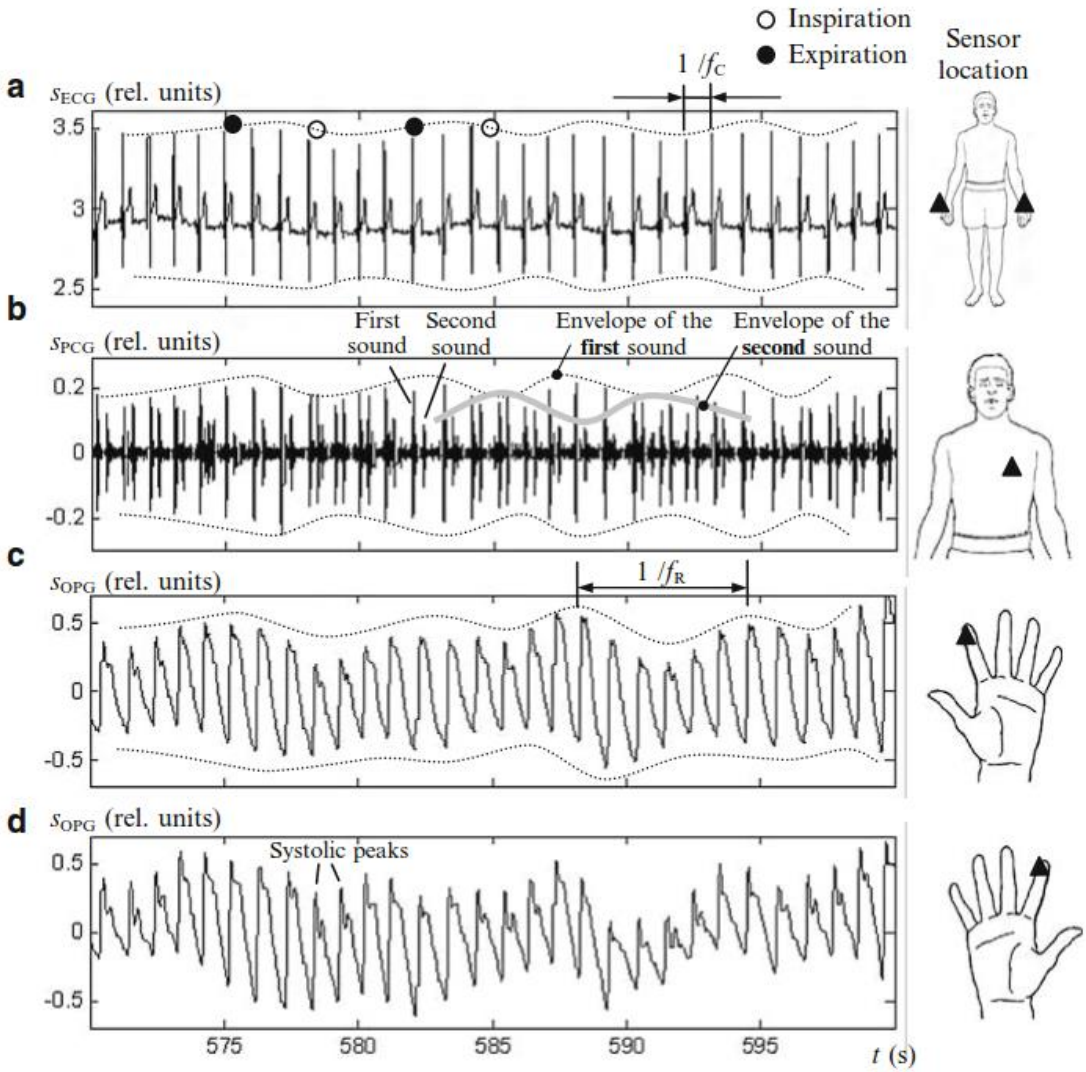


Fig. 3.31 Influence of respiration on cardiac signals exemplified by synchronous (**a**) electric biosignal electrocardiogram s_{ECG} (lead I Einthoven), (**b**) acoustic biosignal phonocardiogram s_{PCG} (from the heart region on the chest), (**c**) optic biosignal optoplethysmogram s_{OPG} (from a finger on the left hand), and (**d**) another optoplethysmogram s_{OPG} (from a finger on the right hand) with indicated heart rate f_C and amplitude modulation of cardiac deflections with respiratory rate f_R

Figure 7. ECG vs respiration vs. OPG. Biosignals I, Kaniusas: p. 245.(c)… marked respiratory period. (d)… marked cardiac period.

12) ENG/FES: How can the neural conduction velocity be measured? Add drawings.

There are two type of nerve fibers. **Sensory nerves and motor nerves**. The velocity of motor nerves can be measured by stimulating the nerves at two spatial distinct points, leading to the generation of an electric response in the muscle. The so generated voltage can be measured temporary. The known distance and time difference between the input signals yield the information about the velocity of the nerve fiber. This velocity measurements can further be **used to check if there is a cardiac conduction disorder (eg. AV-block ← arrythmia)**.

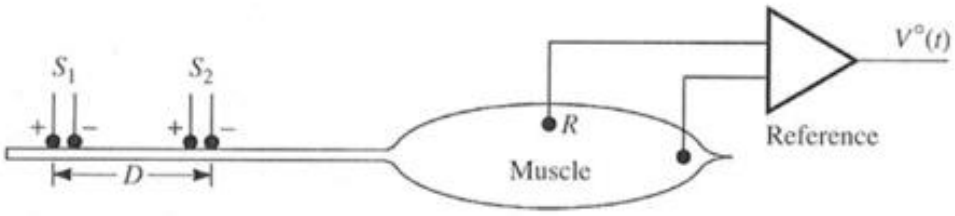


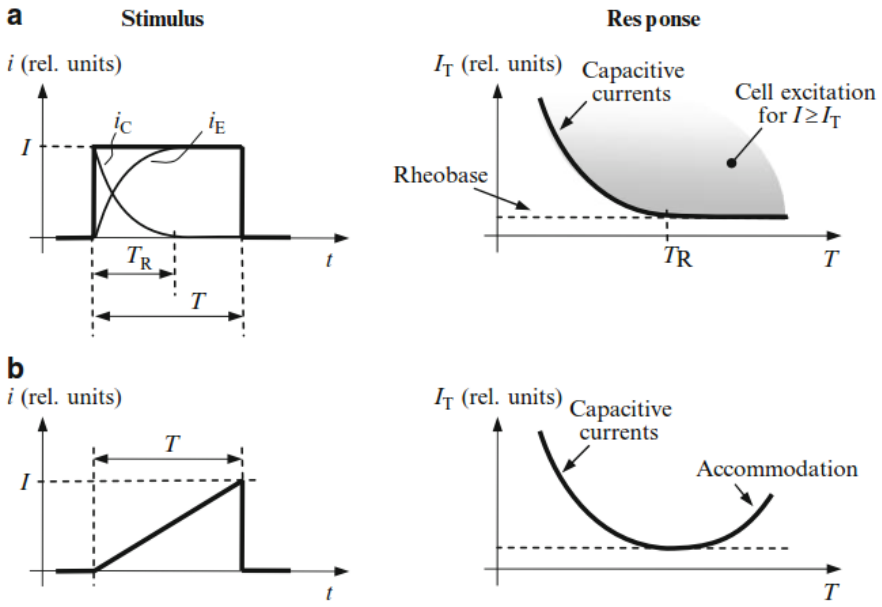
Figure 8.Motor nerve stimulation. (Bioinstrumentation lecture slides, part: Diagnostics)

For sensory nerves…

13) What waveforms are being used in neuromuscular stimulation, which parameters can be set and what influence do they have on the stimulation?

To create AI´s we need a stimulus above a certain threshold. There are two kinds of stimuli: hyperpolarizing stimuli (=inhibitory) and depolarizing stimuli (=excitatory). Since a constant stimulus would have the least impact on the excitable cell, we need dynamic stimuli.

The excitation threshold depends on the strength (current, "I") and the duration of the stimulus (time, "T"), which means the **waveform of the stimulus** (see **Error! Reference source not found.**) **is the cause for the observed threshold value.**



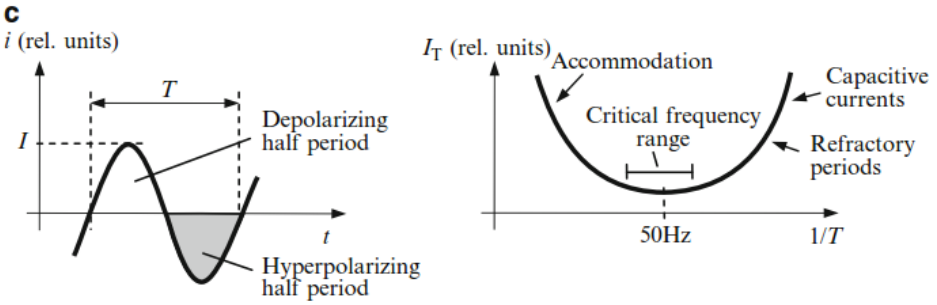


Fig. 2.16 Various waveforms of the current stimuli i (left subfigure) injected into an excitable cell according to Fig. 2.13a. The corresponding cell response is shown (*right subfigure*), quantified as the threshold current amplitude I_T which is now sufficient to excite the membrane; i.e., the current amplitude $I \geq I_T$ leads to triggering of an action membrane potential. (**a**) Rectangular current stimulus with the impulse duration T. Arising current components in the membrane are indicated within the rectangular shape of i, such as the electric ionic current i_E and the capacitive current i_C; in accordance with the equivalent circuit model from Fig. 2.13a, (**b**) Sawtooth current stimulus with the ascending slope I/T. (**c**) Sinusoidal current stimulus with the oscillating period T

Figure 9. Most common depolarizing stimuli. (Biosignals I, Kaniusas, p. 72)

- Rectangular pulse.

  Threshold reached either by short pulse of high current or long pulse of low current. As can be seen in Figure 10, the current I is composed of ionic and capacitive elements.

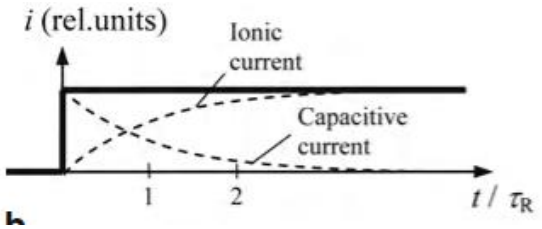


Figure 10. Membrane currents. (Biosignals I, Kaniusas, p. 44)

- Saw tooth pulse.

  The slope reaches a minimum at certain levels of 1/T. IF the time for the impulse is further increase, the cell can counteract the stimulus (=accommodation). Usually an AI is generated by fast depolarizing of the membrane potential due to the opening of Na^+ channels. When the depolarization is occurring quite slow (large T), then some Na-channels have time to inactivate. This makes it more difficult to generate AIs. That´s what we call accommodation of the cell. It is similar to the absolute refractory period, where the Na channels are inactivated and it is not possible to generate a new AI, no matter how intense the stimulus would be. Only when there are some Na channels available again (relative refractory period), it is possible to stimulate the cell again.[4]

- Sinusoidal oscillation.

  Low frequencies fall in the range of accommodation as described above. When the frequency is risen above the point of minimum let-go current, it is possible that the depolarizing half period of the stimulus falls into the refractory period of the AI, where

[4] Biomedical Engineering Principles, Arthur B. Ritter, 2011, p. 133

it is somewhere more difficult to generate new AI and therefore having a slightly higher threshold. As seen in Figure 10, the capacitive currents are the major source of bridging the membrane if the frequency is in the kHz- range:

$$i_C = C \cdot \frac{d(U_C \cdot \sin(2\pi\ f \cdot t))}{dt} = C \cdot 2\pi\ f \cdot U_C \cdot \cos(2\pi\ f \cdot t) = I_C \cdot \cos(2\pi\ f \cdot t).$$

It can be observed from the above equation that the oscillating amplitude I_C of i_C *increases with rising* f if U_C is given.

Equation 1. Capacitor driven with sinusoidal voltage. Biosignals I, Kaniusas, p.46

14) ENG. What is stimulated first during functional electric stimulation with increasing stimulation voltage: synapse or muscle?

Concept of FES: Apply electrical current to excitable tissue via implanted or superficial electrodes. This should activate the intact motor neurons. One motor neuron is then bound to several muscle cells and activates them. As can be seen in Figure 11, **the nerve gets activated first, then the muscle follows**. It can be concluded that in cases where the muscle is already denervated, a much stronger current impulse is needed to activate all muscle cells, since the amplification effect of the motor nerves is missing. This higher current stimulus may cause injury to the cells close to the electrode.

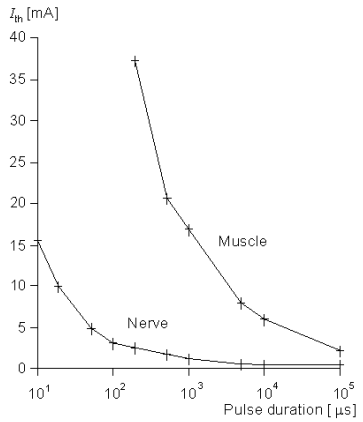


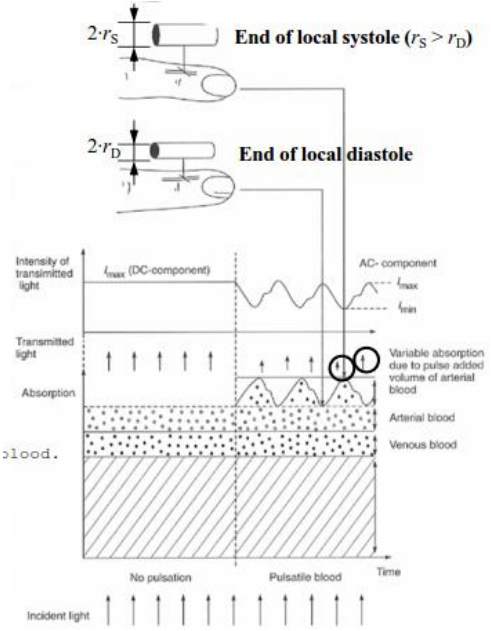
Figure 11. Strength-duration curve for motor-nerve stimulation and direct stimulation of the muscle. (Mortimer, 1981)

15) BLOOD PRESSURE: How can blood pressure be measured?

Either invasive or non-invasive. Invasive measures using a catheter and a pressure transducer.

Non-invasive by Korotkoff sounds or Tonometry (sensor placed over radialis artery).

16) OXIOMETRY. Optical plethysmography: principle, drawing of pulsatile absorption, mark systolic/diastolic parts.



Therapeutic devices

17) HEARING: Describe the difference between hearing aid and cochlear implant. Add block diagrams.

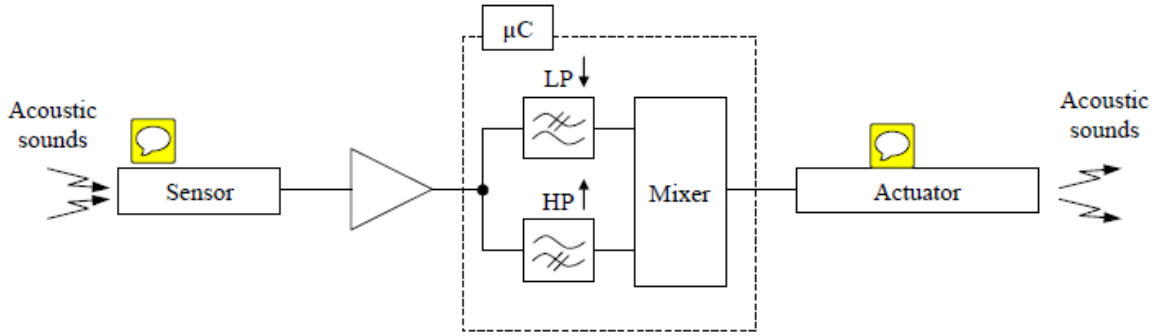
a) Hearing aids amplify sound, a **cochlear implant** transforms sounds into electrical energy that stimulates your auditory nerve. Hearing aids are for patients diagnosed with:

- Impairment of hearing/ Impairment of **sound conduction**

  - Air conduction (external ear → middle ear → inner ear)
  - Bone conduction (cranial bones/soft tissues → inner ear; bone conduction dominates at higher sound frequencies)

- Impairment of **loudness** (e.g., due to an increased mechanical impedance between outer ear and inner ear)

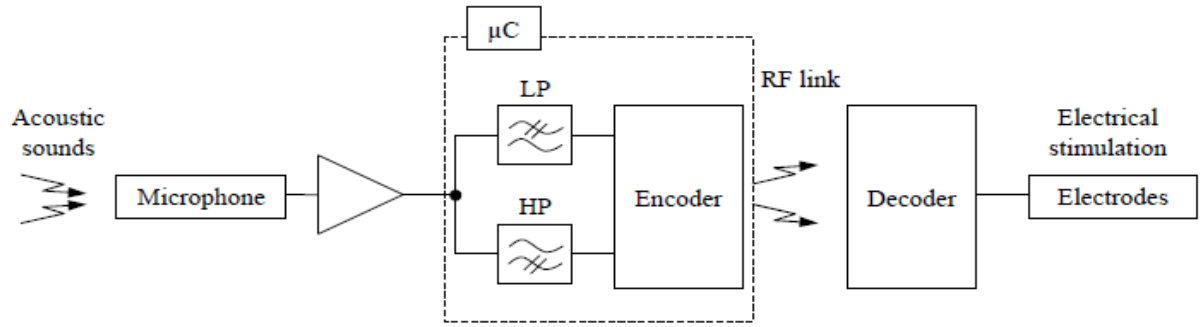
- Impairment of **discrimination** ability (e.g., loss of sensory cells)



Sensor that collects the audio signal, the signal is amplified and it goes further to a micro controller where it splits to the low freq. and high freq. signal...normally the high freq. signal is amplified and low freq. signal is attenuated (since hearing problems nearly always involve the disability to hear higher frequencies). These two are again mixed together and sent away to an actuator which again makes the acoustic signal which can be heard by the patient.

b) cochlear implant:

Normally used by patients with severe to profound hearing loss.



Sounds receiver → Processing (feature extraction in frequency bands) →Wireless transmission to implant (usually inductive)→ Electrical (pulsatile) excitation of electrodes (single-channel and multiple-channel)

- Mapping "frequency-to-place", i.e., high-frequency sounds do not "pass" far along the membrane, but low frequency sounds pass farther in.

18) HEATING/ DIATHERMY: Describe the principles of diathermy in therapeutic devices and the types of the diathermy approaches.

The physical diathermy is a kind of a thermal therapy which is based on:

- **DIPOLE polarization** - An applied E field on the body yields the water molecule (that is a dipole) to reorient according to the E field. This movement of the diploes causes friction which causes micro heating.
- **CONDUCTANCE currents** when the ion within the tissue moves according to the applied E field, this movement causes friction, resulting current (ion flow) yields local heating.

- Methods: short wave, micro wave, ultrasonic approach

a) Short wave:

Short wave diathermy machines use **two condenser plates that are placed on either side of the body** part to be treated. **Another mode of application is by induction coils** that are pliable and can be molded to fit the part of the body under treatment. As the high-frequency (these do not stimulate the nerves!) waves travel through the body tissues between the condensers or the coils, they are converted into heat. The degree of heat and **depth of penetration depend in part on the absorptive and resistance properties of the tissues that the waves encounter.** Fat (adipose tissue) resists current flow. Since the produced heat is proportional to the resistance of the underlying structure, **conductive plates effectively head superficial fat tissue (=adipose tissue),** while inducting coils are used for the underlying muscular tissue.

● Vibration of ions (due to oscillating electric field), dipole rotation in the tissue, molecular distortion, and conductance currents
● Do not stimulate nerves (f ↑), near field ($r < \lambda$)
● Energy of several 100W
● Patient as a part of the electrical circuit

b) micro wave:

Microwave diathermy uses microwaves, radio waves which are higher in frequency and shorter in wavelength than the short waves above. Microwaves, which are also used in radar, have a frequency above 300 MHz and a wavelength less than one meter. Most, if not all, of the therapeutic effects of microwave therapy are related to the conversion of energy into heat and its distribution throughout the body tissues. This mode of diathermy is considered to be the easiest to use, but the microwaves have a relatively poor depth of penetration.

● Vibration of water molecules, dipole rotation
● Typical frequency 2.45 GHz (λ = 11cm in the air), do not stimulate nerves, near/far field
● No direct contact with the patient
● Energy of several 100W
● **Tissues of lower water content (e.g., fat) are penetrated to a greater depth with little absorption**, whereas the reverse is true for high water content (e.g., muscle); induction law limits penetration depth.
● **Heat development mainly in muscle** (high absorption)

c) ultrasonic approach:

● Typical frequency 1 MHz, intensity 3 W/cm 2 , acoustic waves
● Mechanic micro-massage and heating effect to increase all three: tissue relaxation, local blood flow, and scar tissue breakdown
● Continuous mode (e.g., 1 MHz amplitude modulated with 100 Hz) and pulsed mode (e.g., 1MHz is produced only for half of the cycle)

● Absorption increases with frequency (e.g., 1MHz yields 50% reduction at 5cm while 3MHz yields 50% at 1.5cm)
● **Heat development mainly on the bone (strong reflections of waves)**

d) Surgical:

Surgical diathermy involve the use of **high frequency** A.C. electrical current in surgery as either a cutting modality, or else to cauterize small blood vessels to stop bleeding. This technique induces localized tissue burning and damage, the zone of which is controlled by the frequency and power of the device.

- Cutting and coagulation

● High local current density at active electrode → excessive local heating → cells torn apart/evaporated/burned away; large indifferent/reference electrode to keep current density low
● 1-3MHz, 200-500V, visible arc from 1 kV/mm with a cross-section of < 1mm, do not stimulate nerves (f ↑), no electrolytic effects (f ↑)
● Mono-polar technique and bipolar technique (bipolar: tips of two electrodes in the cutting instrument). Cutting without application of force with an instantaneous sealing of capillaries
● Waveforms, e.g., RF amplitude modulated with 100Hz
● higher voltage yields disadvantageous tissue carbonization

19) Show ways of doing deep tissue heating and superficial heating on patients.

a. How do you heat fat tissue (graphic)?

Physiological diathermy - condenser method (relatively low frequencies: few MHz) is applied for deep tissue heating - there is not direct contact with the patient (Fat is heated more than muscle (normal E in fat higher than in muscle because boundary condition applies $E_m \cdot \varepsilon_m = E_f \cdot \varepsilon$) Induced method (relatively high frequencies 13 or 27 MHz, $\lambda \approx 11m$ in the air): (Muscle is heated more than fat (induction law induces E, local currents increase with increasing local γ, and $J = \gamma \cdot E$)

20) VENTILATION. Volume, Pressure and associated risks.

In the cause of ventilation the following lung harms can occur:

- Barotrauma: Ventilation pressure too high→ Pneumothorax.
- Volutrauma: Too high air volume → Hyperextension of the lung. → Development of edema. Those compartments are therefore not used for the gas exchange anymore.
- Low-Tital-Volume-Injury: Alveoli collapse because there is not enough pressure to keep them open (use PEEP!). If the collapsed alveoli will be opened again, then the shear stress might lead to fatigue of those structures.
- Biotrauma: Less surfactant due to ventilation. But surfactant is needed in the tiny alveolus to reduce the surface tension. Without surfactant the compliance of the lung would be reduced and the surface tension of the water would lead to a fast collapse of the alveoli[5].

21) What is a lithotripter?

A non-invasive treatment of kidney stones, using an acoustic pulse. Application of acoustic shock-waves generated by:

● High voltage spark and plasma explosion
● electromagnetic coil (+ metal membrane)
● spherically mounted piezo elements (multiple self-focusing spherical waves)

- Elliptic reflector with two foci, water for acoustical coupling

[5] Alveoli: Small compartments in the lung where the gas exchange takes place. Therefore → quite important for survival.

22) Describe synchronous/asynchronous single chamber / dual chamber pacemakers?

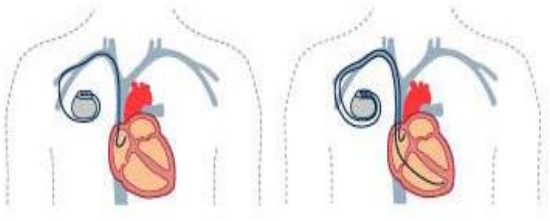


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Figure 12.Pacemakers. Left: single chamber. Right: double chamber.

A pacemaker is a small device that's placed in the chest or abdomen to help control abnormal heart rhythms. Since there are two distinct muscle groups (one for the atrium, one for the ventricles), you can have single-chamber or dual-chamber pacemakers as described below.

a) Atrium or ventricle (= single-chamber pacemaker)

Single-chamber systems have a single lead connected into one of the chambers of the heart. This is most commonly the right ventricle and occasionally the right atrium. Cases where this is chosen include **atrial fibrillation** or **sinus node dysfunction**

b) Atrium and ventricle (= dual-chamber pacemaker)

Dual-chamber pacemakers are connected to the heart by two thin leads, with one in the atrium and one in the ventricle (see figure). This allows them to monitor both the atrium and the ventricle—and to pace them as required. This **allows a more physiological response** where pacing can occur in either the atrium or the ventricle.

Asynchronous pacemaker an implanted pacemaker that delivers **stimuli at a fixed rate**, independent of any atrial or ventricular activity; this type is now **rarely used** except to initiate or terminate some tachycardias.

Synchronous pacemaker an implanted pacemaker that synchronizes the physiological events in the atrium with those of the ventricle; it stimulates the ventricle when triggered by the P wave from the atrium. Synchronous pacemaker **enhance the spontaneous heart activity**, if own heart rate is below a certain **threshold**, it will adapt the stimulation frequency to the activity of the sinus node, body activity.

(SLIDES E/30)

Microelectronics

23) Which connections does an ideal **operational amplifier** have? Add a schematic drawing of the operational amplifier and a simple circuit of your choice. Input-output characteristics?

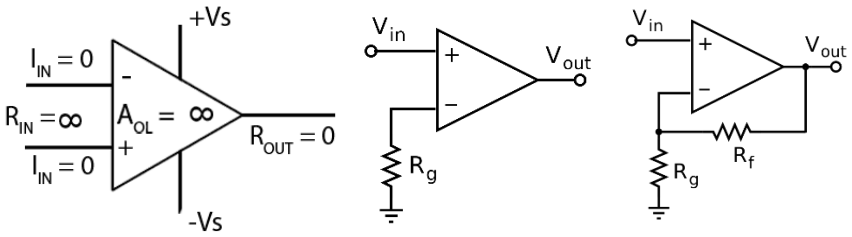


Figure 13.Op-amps. From left to right: ideal op-amp., op-amp. without feedback, op-amp. with (negative) feedback.

An operational amplifier has at the input side a non-inverting input (V+) & an inverting input (V-). At the output side it has the amplified voltage V_{out}. There are also two power supply connections, indicated in Figure 13 as +Vs & -Vs.

The ideal op-amplifier has the following characteristics:

- infinite gain, $G=V_{OUT}/V_{IN}$
- infinite input impedance, R_{IN} <-> zero output impedance R_{OUT}
- Infinite voltage range available @ the output.
- infinite CMRR
- infinite Power supply rejection ratio
- …→ *This means that no current get lost at the input and the output tries to make the voltage difference between the inputs zero.*

It shows a linear relationship in its working range.

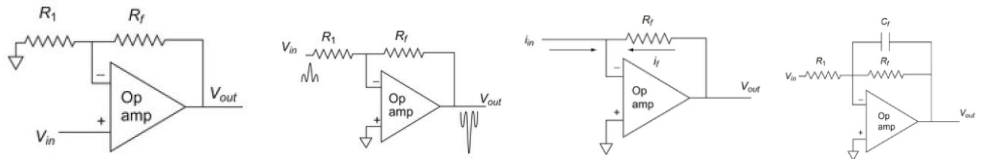


Figure 14.Operational amp circuits. Left to right: non-inverting, inverting, transconductance amplifier (current → voltage), low-pass filter by using an inverting amplifier.

The tc. op. amplifier is used to convert the current from the photodetector (photodiode,…) into a voltage. Further possibilities are the instrumentation amplifier, a differential amplifier circuit and many more (see Horowitz and Hill, 1989, The Art of electronics for more examples).

24) FILTER: How to filter a a) 100Hz b)50Hz Signal ?

Hint: *You have a signal that contains both a 50Hz and a 100 Hz component. You are supposed to build an electrical device that:*

a) Eliminates the 50Hz component and leaves the 100Hz component intact.
b) Eliminates the 100Hz component and leaves the 50Hz component intact.

SOLUTION:

a) High pass filter with cutoff-frequency of 50 Hz.

Transfer function (high pass): $H(j\omega) = \frac{\widetilde{Z_R}}{\widetilde{Z_R}+\widetilde{Z_C}} = \frac{j\omega RC}{j\omega RC+1}$

b) Low-pass filter with cutoff frequency of 100 Hz.

Transfer function (lowpass): $H(j\omega) = \frac{\widetilde{Z_C}}{\widetilde{Z_R}+\widetilde{Z_C}} = \frac{1}{j\omega RC+1}$

Draw the appropriate electrical circuits and the appropriate transfer functions (see (25)).

25) FILTER: How are low pass filter and high pass filter defined? Please consider the corresponding transfer functions and realizations (simple circuits→ drawing noise).

A **high-pass filter** is an electronic filter that passes signals with a frequency higher than a certain cutoff frequency and attenuates signals with frequencies lower than the cutoff frequency. A **low-pass filter** is a filter that passes signals with a frequency lower than a certain cutoff frequency and attenuates signals with frequencies higher than the cutoff frequency.

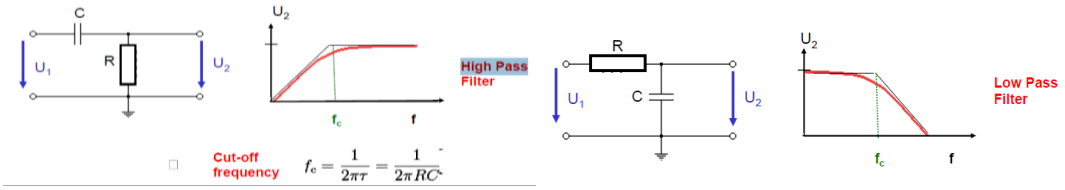


Figure 15. Right: Low-pass filter: electrical circuit and transfer function. Left: High-pass filter: electrical circuit and t.function.

26) CIRCUITS: Voltage divider circuit.

A voltage divider (also known as a potential divider) is a passive[6] linear circuit that produces an output voltage (Vout) that is a fraction of its input voltage (Vin). Voltage division is the result of distributing the input voltage among the components of the divider. A simple example of a voltage divider is two resistors connected in series, with the input voltage applied across the resistor pair and the output voltage emerging from the connection between them. The two resistor voltage divider is used often to supply a voltage different from that of an available battery or power supply. In application the output voltage depends upon the resistance of the load it drives.

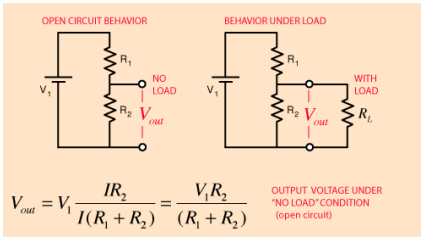


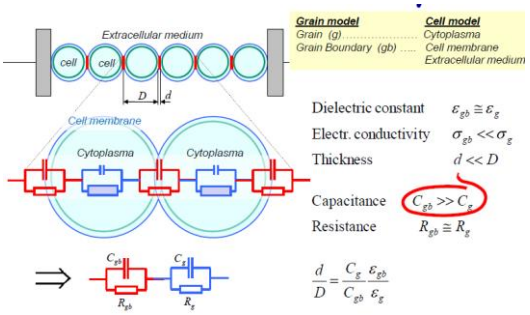
Figure 16. Voltage divider circuit.

[6] See question (28)

27) Draw the brick layer model of a cells and intercellular space and point out R_s and C_s and their sizes in regard to each other.

The resistance of the membrane is almost the same as the one of the cytoplasm, but the capacitance of the membrane is much higher due to the very low thickness (about 8nm)

The resistance of the membrane is almost the same as the one of the cytoplasm, but the capacitance of the grain boundary (membrane) is much higher as the one from the grain (nucleus).



The brick layer model (BLM) as first derived to describe the electrical properties for polycrystalline electroceramics, can be used to discriminate resistive grain boundary (membrane) from conducting grain core (nucleus) behavior. It successfully allows to describe the dual- arc behavior that is seen in impedance measures.

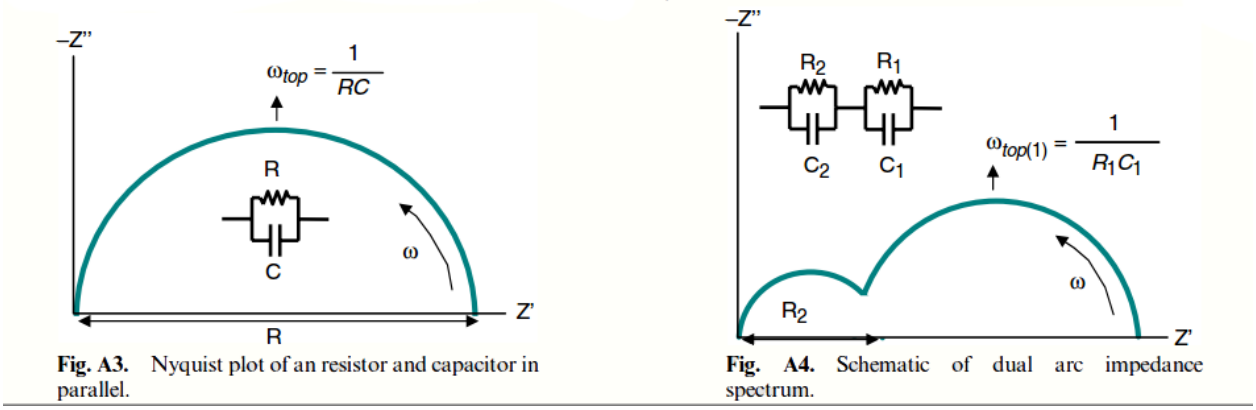


Fig. A3. Nyquist plot of an resistor and capacitor in parallel.

Fig. A4. Schematic of dual arc impedance spectrum.

Figure 17.Nyquist plot of the BLM. (Kidner, 2008, p.1734).On top of the arc the value of ω rises to $\omega_{top}=1/\tau=1/(RC)$. Therefore the time constant, τ, can directly be measured by applying voltage to the sample.

Typically during impedance measurements a small oscillating voltage is applied to the specimen:

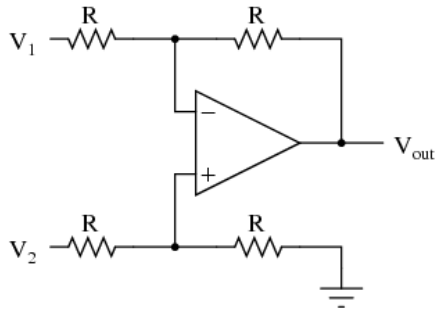
$V(t) = V_m * \sin(\omega t + \varphi_V)$. The time- dependent current response: $I(t) = I_m * \sin(\omega t + \varphi_I)$ will then be measured. Keeping in mind that the phase difference $\theta = \varphi_V - \varphi_I$ is 0° for pure resistors, -90° for pure capacitors and +90° for pure inductors, the time-dependent impedance $Z(\omega) = {V(t)}/{I(t)} = Re(Z) + j * Im(Z) = |Z| * \cos\theta + j * |Z| * \sin\theta$ will be influenced by the underlying microelectronic models.

28) What is a passive and active electronic device? Give some examples.

Electrical elements can be grouped in two categories, depending on their ability to supply energy to the circuit. **Resistors, capacitors, inductors and diodes are passive elements**. While resistors dissipate

energy to heat, capacitors can only give back what they stored before. Other elements like **transistors and operational amplifiers are therefore called active electronic devices**.

29) Add a schematic drawing of a non-inverting electrometer amplifier for gain equal to 1. What is the advantage of this circuit?



op-amp circuit maintaining both voltage inputs, yet with a controlled gain set by external resistors. If all the resistor values are equal, this amplifier will have a differential voltage gain of 1. The analysis of this circuit is essentially the same as that of an inverting amplifier, except that the noninverting input (+) of the op-amp is at a voltage equal to a fraction of V2, rather than being connected directly to ground. As would stand to reason, V2 functions as the noninverting input and V1 functions as the inverting input of the final amplifier circuit. Therefore:

If we wanted to provide a differential gain of anything other than 1, we would have to adjust the resistances in both upper and lower voltage dividers, necessitating multiple resistor changes and balancing between the two dividers for symmetrical operation.

30) INTERFACE: Metal-electrolyte surface (equivalent circuit). Discuss the influence of the interface boundary of metal/ electrolyte in case of physiological measurements.

When a metal is placed inside a solution containing ions, the ions move towards the contrary charged electrode. This will give rise to the inner “Helmholtz” layer, which is also called electrical double layer. Further away this attraction now decreases as most negative charges in Figure 18 will be balanced with the positively charged ions that have already attached to the surface. Only a diffuse, second layer remains.

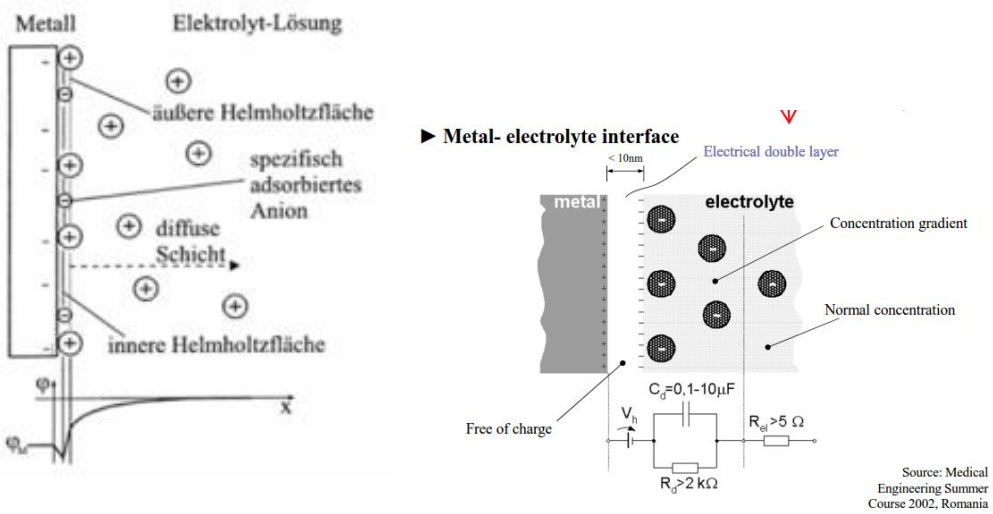


Figure 18. Right: Creation of Helmholtz double layer. (Bioinstrumentation, Kaniusas, lecture content)

Impedance tells you which type of tissue[7] you are looking at, the size of the cell, defects in the membrane, cell necrosis …

31) What problems are there when measuring tissue impedance with a metallic electrode? How can such influences be avoided? Application field of impedance measurement in medicine and biology? (blood, tissue, etc…)

(again see biosignals, reference electrode, or 2nd lab)

How would you define the impedance of two skin electrodes? Of course with a third electrode, called reference. This reference electrode has a negligible contribution on the impedance of the overall system and can therefore be used to determine the impedance of the other two electrodes.

[7] As used in **bioimpedance measures**: Different water content in muscle, blood, bone and fat. Fat has little electrical conductivity, while the high water content in muscle, blood vessels and bone is a good electrical conductor.

Slides and lab: study goals and questions.

Basics (2)

Diagnostics (2)

Therapeutics (2)

Microelectronics (2)

32) What are AC- Signals / DC- Signals?

33) What is a conduction band / a band gap?

The energy range in a solid where no electron states can exist is called band gap or energy gap. The band gap is a major factor if one want to determine the conductivity of a material. Based on the size of the band gap materials can be placed in three categories:

- Insulators: large band gap
- Semiconductors: if doped with impurities the conductivity can be enhanced largely.
- Metals: either very small band gap or overlapping valence and conduction band.

34) What is p-doping / n-doping in a semiconductor?[8]

Take for example silicon. It has 4 outer electrons in an 8 electron shell. When silicon forms a lattice and bonds with other silicon atoms they fill this shell. So now all electrons are bound to the nuclei and there is no free charge.

Fortunately above zero degree atoms begin to vibrate. This thermal energy will “shake” an electron out of its bound and creates a pair of a hole and a free electron. This process is called “generation”. Without an external electric field that would act via Lorentz forces on this electron it can move freely in the solid, therefore it is called “carrier”. But how will a hole move?

If a nearby electron falls into the hole, it leaves another hole. Therefore we can say a hole moves. If again a free electron and a hole meet- they annihilate each other. This process is called “recombination”.

Nevertheless, without doping, those processes would not occur frequent enough to make a good semiconductor. We are still left with a resistor that has a decreasing resistance with increasing temperature. For doping we need atoms that have fewer (boron, 3) or more (phosphorus, 5) electrons in their outer shell. If we bound P to silicon, we speak about n-type silicon, because it brings an extra electron into the system and therefore adds **n**egative charge. Unlike a hole, the positive charge is bound to the P-atom and can´t move. This creates the desired unbalance between holes and electrons.

[8] This section was created by R.R. Harrisons genuine file called: “Introduction to MOSFET Operation”.

B, on the other hand donates holes to the system. Therefore such a mix would be called p-typed silicon.

If we attach a p-type silicon to an n-type silicon we get a diode. But more about this later in question (40).

35) What is a resistor? How does he influence the signal?

36) What is a capacitor?

37) What is an inductor?

38) What is "microelectronics"? How are microelectronic chips fabricated?

39) What is an insulating transformer?

40) What is a diode? (physical setup)

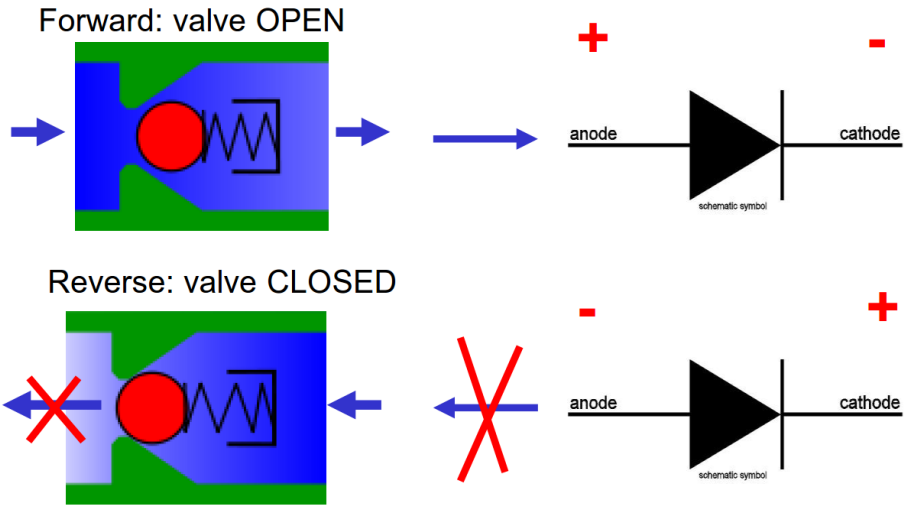


Figure 19.Diode as one- way valve. (Bioinstrumentation I, Kaniusas: Microelectronics)

As already mentioned in the section about doping, a diode is a one- way valve that´s made by sticking together a p-type semiconductor and an n-type semiconductor. Initially there is no drift, but with time a depletion region will arise, which will create an electric field. This field let the developing current "drift" in the opposite direction to the diffusion process. When there is no outside voltage, both forces, diffusion and drift will balance each other.

Diodes are nowadays used in biomedical devices as LEDs in lasers to generate bioacoustics signals.

41) Operation principles of a diode? (forward / reverse biased)

When operating a diode, we have an outside voltage. Depending on what sign the external voltage (bias) has, we speak about forward (+ to -) or reverse (- to +) bias. While forward bias diminish the depletion region (→ diode becomes conductive), this region increases in reverse bias and also produces a tiny drift (commonly called leakage current).

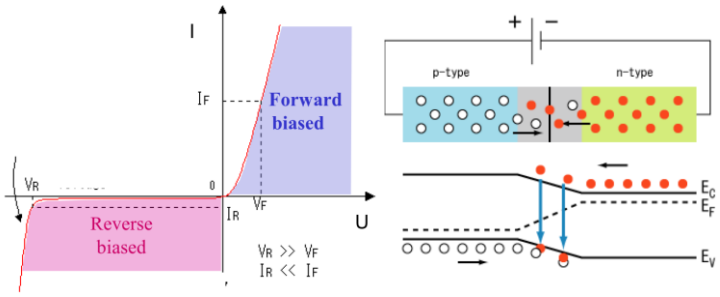


Figure 20. Diode: Operational principles. (Bioinstrumentation I, Kaniusas: Microelectronics))

42) Optical diodes: Photovoltaic cell & light emitting diodes.

Leakage current is directly proportional to light intensity. This is used in photodiodes or photovoltaic cells. Absorbed photons generate electron-hole pairs that have sufficient energy to leave the depletion region. The can then be "sucked away". LEDs use the reverse principle. The annulation of pairs in forward biased circuits lead to the emittance of light. Typically only one color of light will be emitted.

By using different layer thicknesses and different semiconductor crystals, the manufacturer can adjust the frequency of the emitted light→ different colors.

43) What is a bridge rectifier using diodes?

Used to convert AC (generator) into DC (power line).

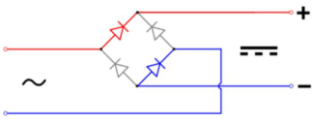


Figure 21.Bridge Rectifier Circuit.

44) What is a transistor?

A solid piece of **semiconductor** material with at least (!) 3 terminals for connection to external circuits. It can be used as on/off- switch or as amplifier. A bipolar transistor consists of 3 semiconductor regions and can therefore be considered as 2 diodes (one forward and one reverse biased) that share an anode region. A MOSFET on the other hand has at least 4 terminals, including the body region.

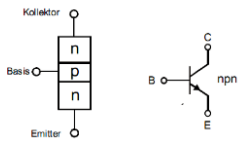


Figure 22. Bipolar transistor.

45) Operational principles of BPT/MOSFET?

46) The 3 main differences between BPT & MOSFET?

- BPT: exponential transfer ratio, while it's quadratic in MOSFETS.

- Direction of current is vertical in BPTs (emitter→collector), but lateral in MOSFETS (gain→body).
- There is no current flow along the MOSFET when it is in the OFF- switched state, while there would be current flow in the BPT. This makes the MOSFET ideal for neural measurements, as current induces heat and neuron are sensitive to long heat treatments.
- **BJTs use small current** to manipulate large current, while **MOSFET uses small voltage** to manipulate large current.

47) Use of field effective devices as sensors (nerve, DNA)?

There are chemFETs, Ion-sensitive FETs, neuronFETs and many more. DNA is sensed by chemFETs that have proteins or oligonucleotides attached to the gate region. A change in conformation will give rise to a difference in current. This can then further be measured with the FET.

48) What is a differential amplifier? What does he do with the two input signals?

A differential amplifier is the combination of an inverting and a non-inverting amplifier.

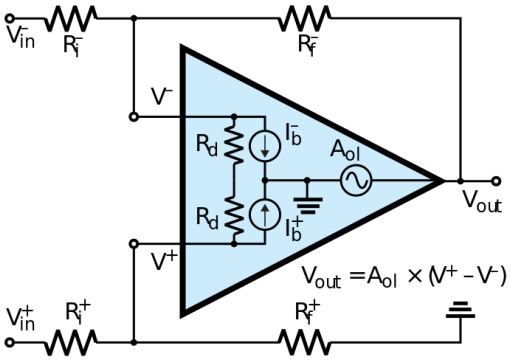


Figure 23. Differential amplifier with transfer function (V_{OUT} vs V_{IN}) as proportional to the gain A_{OI}.

To derive the transfer function, the principle of superposition can be used. **Setting the lower voltage input to zero, one would end up with an inverting operational amp**. Setting the upper input to zero, we end up with a non-inverting amp. Since the lower input is grounded, we need to apply the **voltage divider rule** to get the real input voltage at the lower input. By superposition we end up with:

$$V_{OUT} = \frac{R_f}{R_i} * \left(V_{in,low} - V_{in,up}\right)$$

R_f is needed as negative feedback to adjust (limit) the gain which should be infinite if we would have an ideal operational amplifier.

49) What is an A/D converter and how does it operates?

50) How information is stored (DRAM, Flash Memory)?

51) How is a logical circuit build up?

LAB-QUESTIONS

Blood pressure.

52) Does you systolic and/ or diastolic arterial pressure changes as you heart rate increases? How does this change affect your pulse pressure? How would you expect sys./dia./pulse –pressure to change in normal healthy individuals as their heart rate increases?

Systolic pressure changes, diastolic pressure stays the same, since diastolic is the pressure between the strokes when the heart is at rest. If ventricles can´t expand sufficiently anymore (old people), the diastolic changes as well. If you suddenly quit the exercise, your diastolic blood pressure might drop rapidly. Without enough oxygen reaching the heart therefore, this can be dangerous. Therefore- use a cool-down period! If diastolic pressure heavily increases during exercise you might have hypertension. Should also be checked.

53) Give 3 sources of error in the indirect method of determining systematic arterial blood pressure.

- Using the wrong sized cuff. Oversized gives too small readings, too small cuffs would over proportionally increase the reading.
- The cuff is not at the heart level. Therefore you have gravity effects.
- The subject has exercised shortly before measuring. This will influence the systolic pressure!
- Stress or anxiety (influence of sympathetic system!) might influence the measurement.
- Use of alcohol/caffeine shortly before measurement.

54) Use an equation that relates flow, pressure, resistance to define the mean arterial pressure.

mean flow=<q>=stroke volume(V_S) * heart frequency (f_C). <p>=<q>*Resistance.

55) Define the first and second sounds of Korotkoff. Which is used to approximate systolic pressure? Which is used for diastolic pressure?

- 1st sound: pressure release leads to turbulence. Indicates systolic pressure.
- Can´t hear the sound anymore? Then you got laminar flow. Indicates diastolic pressure.

56) Why is mean arterial pressure (MAP) not equal to the arithmetic mean of sys. & dia. pressure?

Cause ventricles spend more time in diastole then systole. Therefore use: MAP=1/2*(sys+2*dia)

57) Define pulse pressure.

Pulse pressure is the difference between systolic and diastolic pressure. As systole changes during exercise, so will also the pulse pressure! Cause exercise enhances the stroke volume.

58) What could be the reason that the blood pressure in the left arm is different to the one in the right arm?

Maybe atherosclerosis in old people, muscle compression of on artery in young people or a peripheral disease? Therefore check both arms to see if they differ significantly. This could indicate on of the three factors described before.

59) What other artery could be used beside the brachii for indirect blood pressure monitoring?

If for any reason ever (prosthesis, burns, adipose, etc) one can´t use the brachi for measurement of blood pressure, then another must hold. Using the carotis (neck), would choke the patient, the femoralis is hard to cut off, as the muscles around it are too large and there are hardly cuffs that are big enough. Better use the ankle. In most cases it has almost the same size as the brachi so you can use standard cuffs. Also there is hardly any adipose tissue around the ankle, which makes it ideal to measure. Again, to avoid gravity artefacts- place the patients foot on the table so that is on the same level as the heart.

Pulmonary:

60) Why the predicted vital capacity of a patient does varies with height? Which factors besides height might influence the vital capacity?

Because of the larger body surface area. Therefore also the body mass index might be a good indicator for vital capacity. But also age and sex can change the vital capacity. (decreases with age).

61) How would this volume measurement change after heavy exercise?

Muscles need oxygen to work. During workout you acquire an oxygen dept. This has to be paid off by an enhancement in vital capacity. The lungs will expand further to allow a higher oxygen inflow.

62) What is the difference between volume measurements and capacities?

63) Define: Tidal volume? Inspiratory Reserve Volume? Exp. Reserve Volume? Respiratory Volume? Pulmonary Capacity?

64) Name the pulmonary capacities.

Heart:

65) More questions to be added.

Brain, Eye, FES:

66) And even more here!

67) How can you see in ECG that a person is in a deep sleep phase?

By the delta-waves. They only occur during sleep.

68) What do you mean by brain death?

Complete and irreversible loss of brain function. States that are difficult to distinguish from brain death are: sedative coma, hypoglycemia, chronic vegetative states, alcohol intoxication …

69) What is the 10-20 system?

It´s a position system for the electrodes.

70) Why is it theoretically impossible to read one's mind with an EEG?

Cause you got a sum potential over all the areas. During the summation process, the information about the creation of the signal will be lost.

71) How to use a Brain-Computer- Interface in the future?

Might be used for people with "Lock-In Syndrome" to communicate with the "outside world". Or many other possible uses.

72) h

73) h