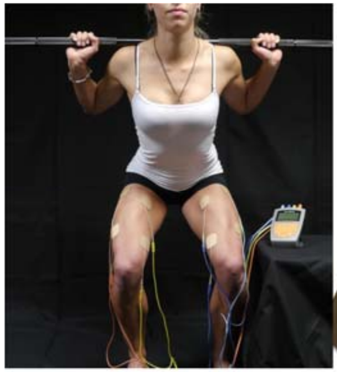


Medical applications of electricity

"I told you nylon carpets were a mistake."

KAD 2016.02.18

signal processing. (dB, Fourier, filters, amplifier, frequency response, feedback)
– it was a separate lecture

bioelectric phenomena (membrane-, resting-, action-potential)
– it will be a separate lecture

medical applications of electricity

resistor–capacitor (RC) circuit, charging, discharging, timeconstant
ideal square pulses and real square pulses (effect of filters)
Strength-Duration Curve, rheobase, chronaxie
sine wave oscillators and diathermy for treatment of muscles and joints
high frequency surgery
Extracorporeal Schockwave Lithotripsy

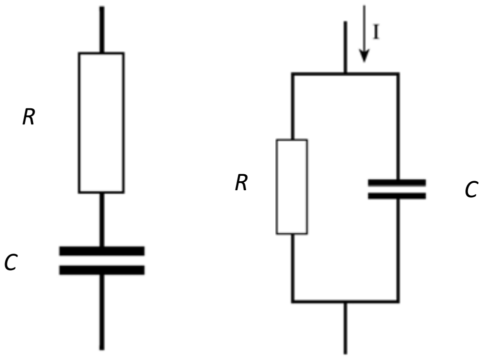
related practices:
in the 1st semester: measuring devices, skin impedance
in the 2nd semester: Coulter counter, amplifier, ECG, puls generators, audiometry, sensor, flow of fluids

Resistor and capacitor in DC circuits

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

$$C = \frac{Q}{U} \qquad C = \varepsilon \frac{A}{l}$$

$$E = \frac{1}{2} C U^2$$

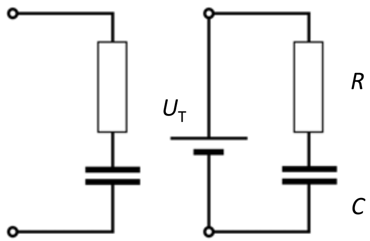


serial RC circuit

parallel RC circuit

electrical behavior of our skin,
skin impedance practice

Charging in a series RC-circuit

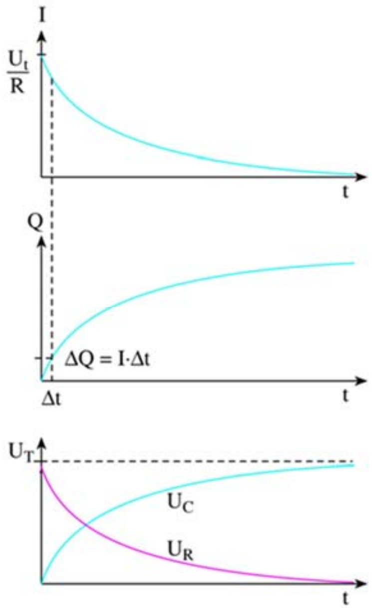


C in series with R and its charging

$$U_R = RI = U_T e^{-\frac{t}{RC}}$$

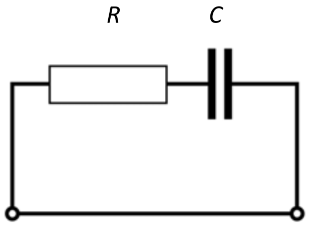
$$U_C = U_T - U_R = U_T\left(1 - e^{-\frac{t}{RC}}\right)$$

textbook, Fig. VII. 6.



textbook, Fig. VII. 7.

Discharging in a series RC-circuit



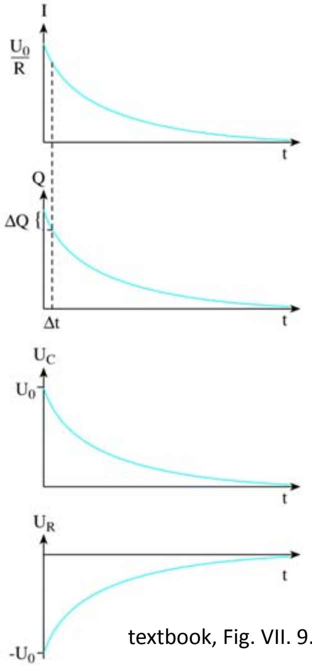
C in series with R and its discharging

$$U_R = RI = U_0 e^{-\frac{t}{RC}}$$

$$U_C = -U_0 e^{-\frac{t}{RC}}$$

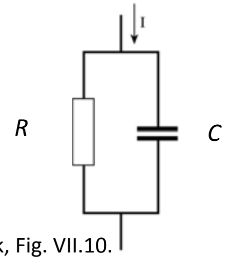
$\tau = RC$ **time constant** (cf. radioactive/fluor. lifetime

textbook, Fig. VII. 8.



textbook, Fig. VII. 9.

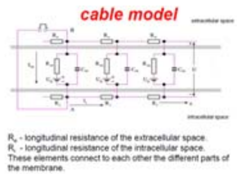
Charging in a parallel RC-circuit



textbook, Fig. VII.10.

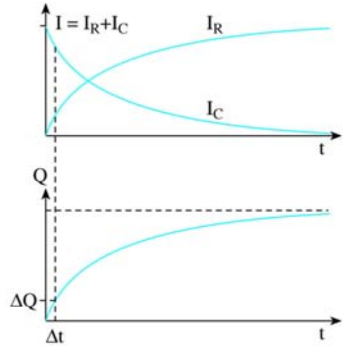
$$U_C = U_R = RI(1 - e^{-\frac{t}{RC}})$$

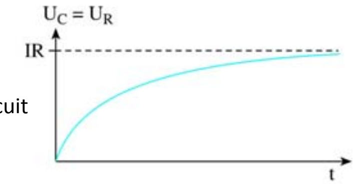
Discharging in a parallel RC-circuit ≡ discharging in a series RC-circuit



cell membrane as an RC-circuit (cf. lecture of „Bioelectric phenomena ”)

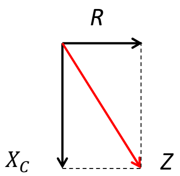
problems: 60, 61



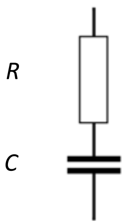


textbook, Fig. VII.11.

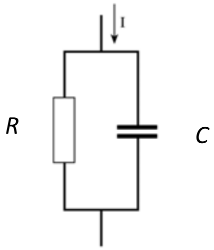
Resistor and capacitor in AC circuits



Pytagorean theorem



in series RC circuit

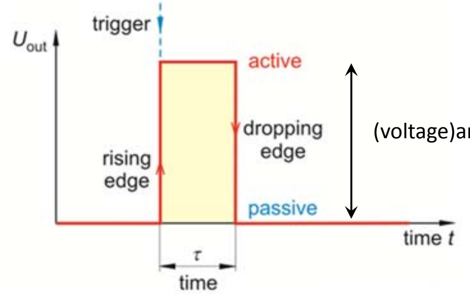


parallel RC circuit

the quantity to be summed	resistance	conductance = 1/resistance
	$R, \quad X_C = \frac{1}{2\pi f C}$	$\frac{1}{R}, \quad \frac{1}{X_C}$
	$Z = \sqrt{R^2 + {X_C}^2}$	$\frac{1}{Z} = \sqrt{\frac{1}{R^2} + \frac{1}{{X_C}^2}}$

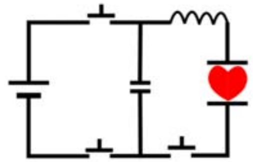
Characteristics of electrical square pulses

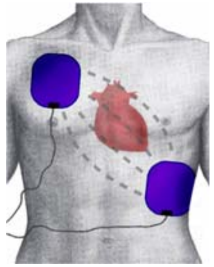
1 square puls (simplest puls)



(voltage)amplitude

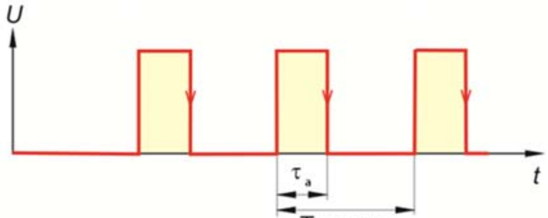
e.g. puls of defibrillator





problem: 67

periodic
square pulses



time period: $T = \tau_a + \tau_p$

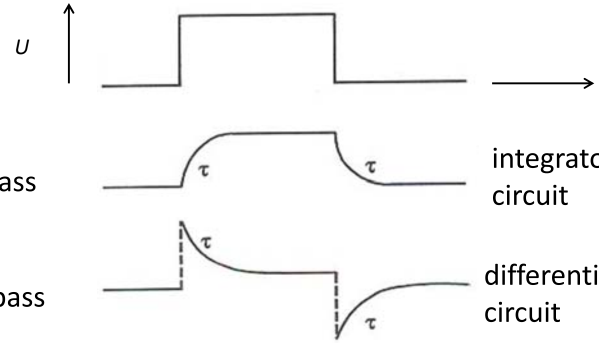
duty cycle: $\frac{\tau_a}{\tau_a + \tau_p} \cdot 100\%$

e.g. pacemaker

astable pulse generator
(cf. pulse generators
practice)

problem: 68

Deformation of square pulses in RC circuit elements



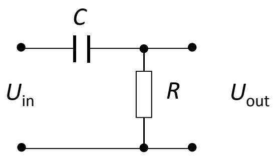
effect of low-pass filter — integrator circuit

effect of high-pass filter — differentiator circuit

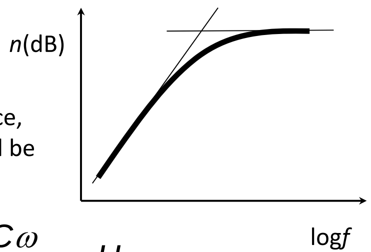
τ: time constant

High-pass/low-cut **filter**

$R_C = \frac{1}{C\omega}$ at high frequencies the capacitor is a shortcut



because of the phase difference, the sum should be calculated as vectors



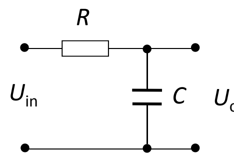
$$U_{out} = \frac{R}{\sqrt{\frac{1}{C^2\omega^2} + R^2}} U_{in} = \frac{RC\omega}{\sqrt{1 + R^2C^2\omega^2}} U_{in}$$

at very low frequencies: if $\omega << \omega_0$ $(\omega \approx 0)$, $U_{out} = 0$

at low frequencies: if $\omega << \omega_0$, $U_{out} = RC\omega\, U_{in}$ ↔ 6 dB/octave

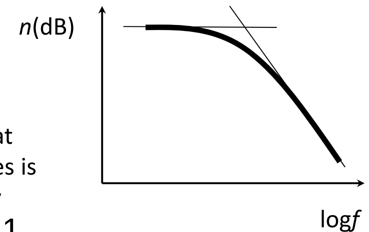
at high frequencies : if $\omega \approx \infty$, $U_{out} = U_{in}$

Low-pass/high-cut **filter**



$R_C = \frac{1}{C\omega}$

the capacitor at low frequencies is a discontinuity

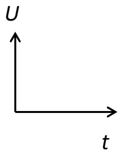


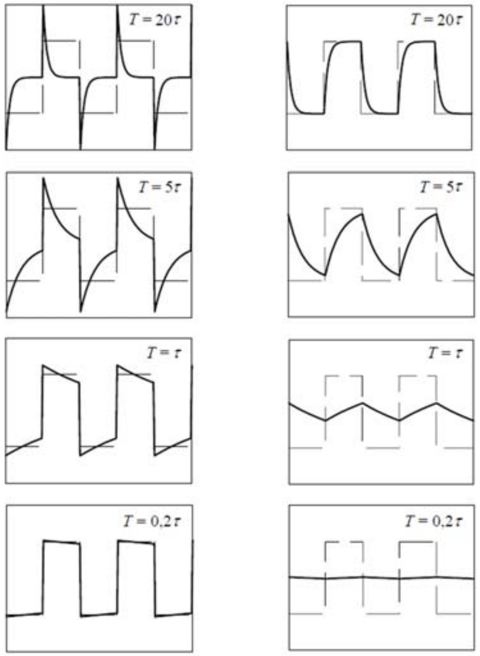
$$U_{out} = \frac{\frac{1}{C\omega}}{\sqrt{R^2 + \frac{1}{C^2\omega^2}}} U_{in} = \frac{1}{\sqrt{R^2C^2\omega^2 + 1}} U_{in}$$

at low frequencies: if $\omega << \omega_0$ $(\omega \approx 0)$, $U_{out} = U_{in}$

at high frequencies: if $\omega >> \omega_0$, $U_{out} = \frac{1}{RC\omega} U_{in}$ ↔ -6 dB/octave

at very high frequencies : if $\omega >> \omega_0$ $(\omega \approx \infty)$, $U_{out} = 0$





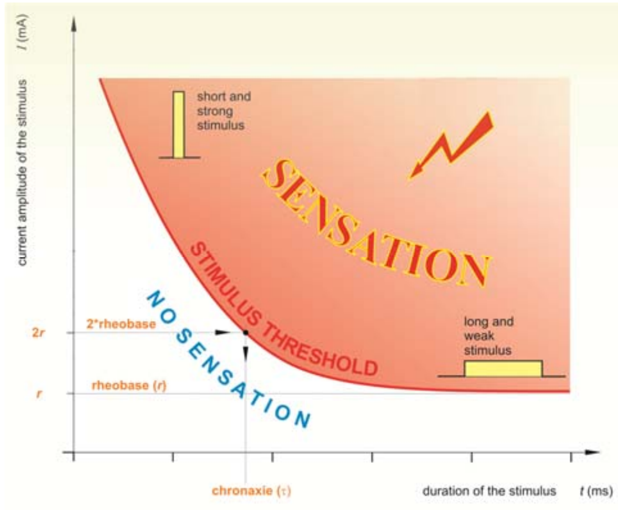
differentiator circuit

smallest deformation: $\tau >>$ pulse duration

smallest deformation: $\tau <<$ pulse duration

integrator circuit

Strength-duration curve



rheobase:
the minimal current amplitude of infinite duration to cause sensation

chronaxie:
the minimum time required for an electric current double the strength of the rheobase to cause sensation

$$I = \frac{q}{t} + r$$

skin impedance practice
scales: lin-lin

Problem. How many moles transport of univalent ions corresponds to the threshold charge, if the rehobase is 4 mA and the chronaxie is 0,4 ms?

$r = 4\ \mathrm{mA}$

$t_c = 0{,}4\ \mathrm{ms}$

$$I = \frac{q}{t} + r$$

$$2r = \frac{q}{t_c} + r$$

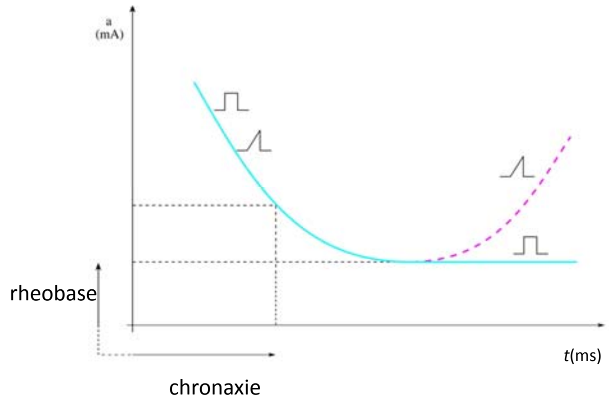
$$r = \frac{q}{t_c}$$

$$q = t_c r = 0{,}4\mathrm{ms}\ 4\mathrm{mA} = 1{,}6\mu\mathrm{C}$$

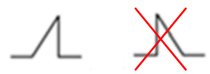
1 mole 96500 C
x mole 1,6 μC

$$x = \frac{1{,}6\mu\mathrm{C}}{96500\mathrm{C}}\mathrm{mole} = 1{,}66\mathrm{x}10^{-11}\mathrm{mole}$$

Strength-duration curve for sawtooth pulses



sawtooth pulse



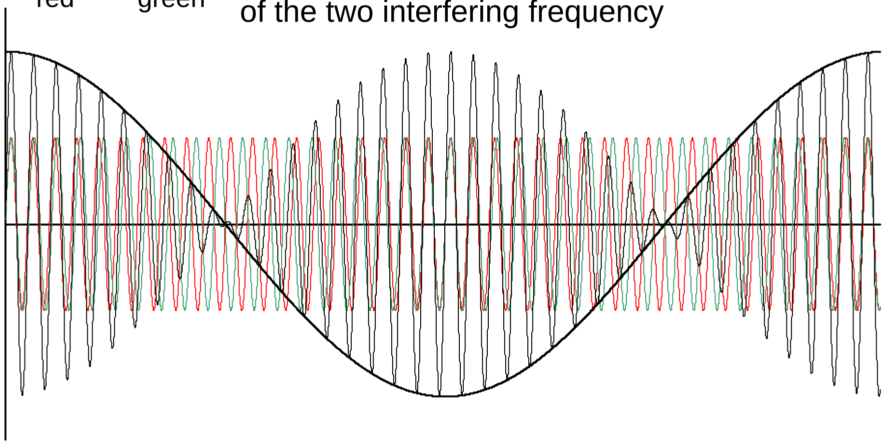
in the case of sufficiently long pulse duration (~100 ms) the cell is capable of **accommodation** (ion currents are triggered which act against the stimulation)

in pathological conditions, the muscle loses its adaptability: **selective electrical stimulus therapy**
in the range of sufficiently long pulse duration sawtooth pulses can be below the threshold for healthy muscles but above-threshold for the damaged muscles

textbook, Fig. IX.22,
scales: lin-lin

Beating phenomenon

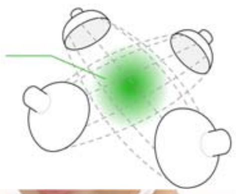
$f_{red} \geq f_{green}$ the beating frequency equals to the difference of the two interfering frequency

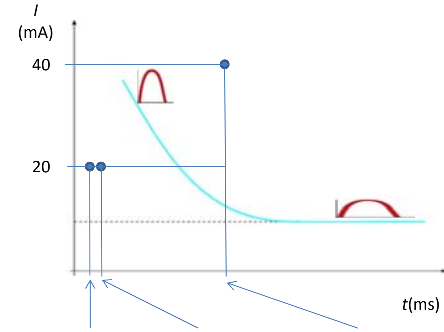


reminder: $\sin\alpha + \sin\beta = 2\sin\frac{\alpha+\beta}{2}\cos\frac{\alpha-\beta}{2}$

Interferential current therapy

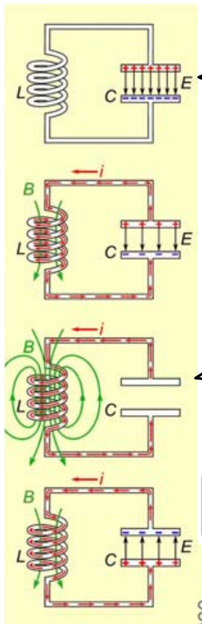
there is an interference on the overlapping range:
the difference signal is above-threshold
anywhere else: the stimulus is below-threshold





$\frac{1}{f}$	$\frac{1}{4100\text{Hz}}$	$\frac{1}{4000\text{Hz}}$	$\frac{1}{100\text{Hz}}$
T	0,24 ms	0,25 ms	10 ms
t	0,12 ms	0,125 ms	5 ms

LC circuits. Oscillating circuits



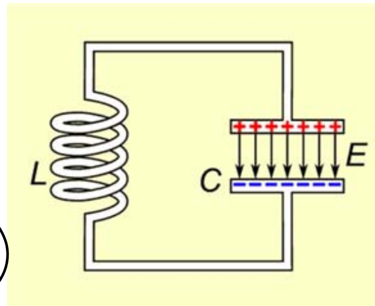
total energy in the electric field

$W = \frac{1}{2}CU_{\max}^2$

$W = \frac{1}{2}CU^2 + \frac{1}{2}LI^2$

total energy in the magnetic field

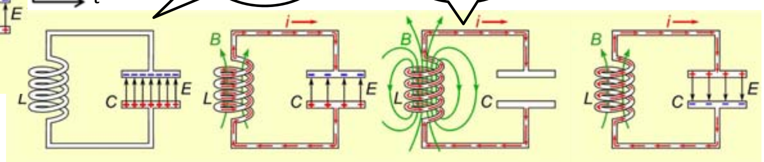
$W = \frac{1}{2}LI_{\max}^2$



the energy (W) oscillates between the electric (E) and magnetic (B) fields

total energy in the electric field

total energy in the magnetic field

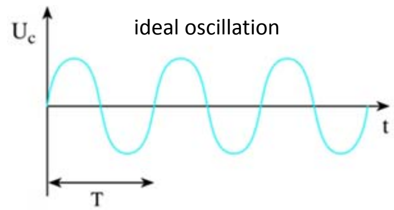


cf. textbook, Fig. VII. 14.

Ideal and real oscillating circuits

undamped free oscillation

ideal oscillation



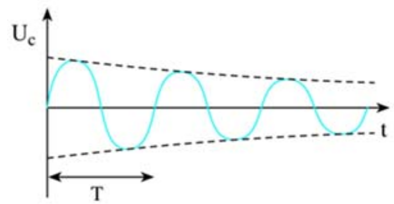
eigenfrequency (resonance), the capacitive and the inductive impedances have the same value

$X_C = X_L$

$\frac{1}{C2\pi f} = L2\pi f$

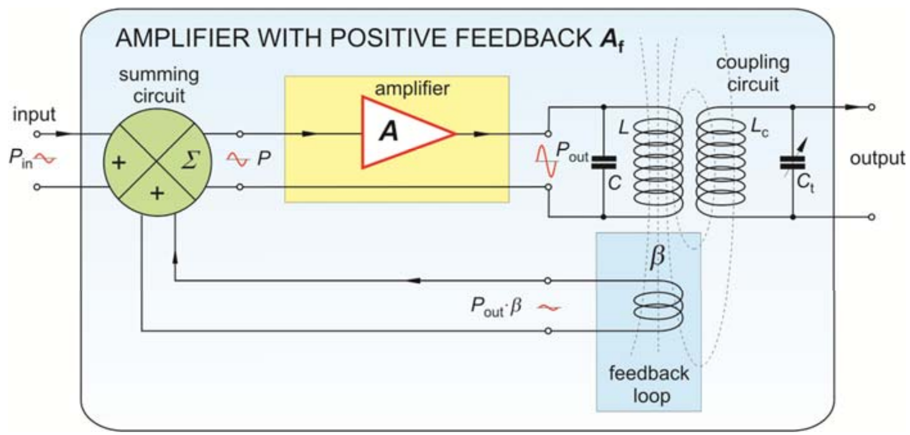
$f = \frac{1}{2\pi\sqrt{LC}}$

real oscillation



textbook, Fig. VII.15

Amplifier with positive feedback



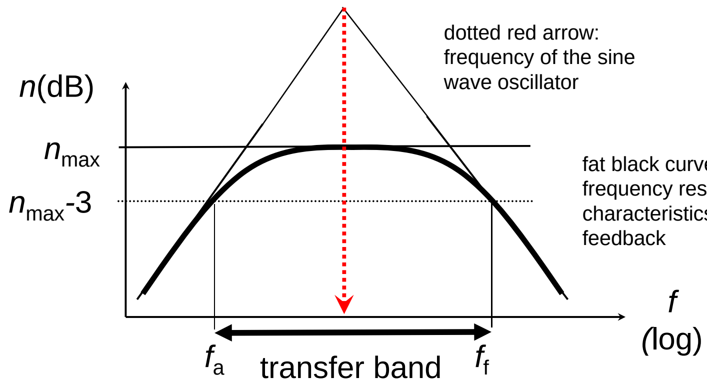
Sine wave oscillator

amplifier with positive feedback

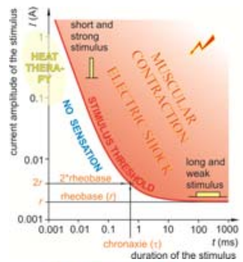
$$A_{P,\,\text{feedback}} = \frac{A_P}{1-\beta A_P}$$

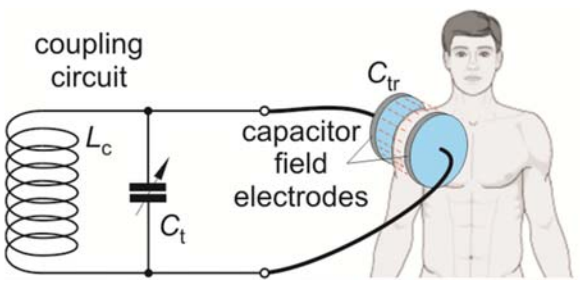
βA_P=1, amplification = „infinity“ ➡ sine wave oscillator

no input signal, output signal: sine voltage



Heat therapy generators. Capacitor field method





Laboratory manual, Meas. 18. Sine wave oscillator, Fig. 5.(a)

cf. textbook, Fig. 9.28

resonance criterion:

$$LC = L_c \cdot (C_t + C_{tr})$$

outcoupling of energy through the electric field

Warming up of a muscle

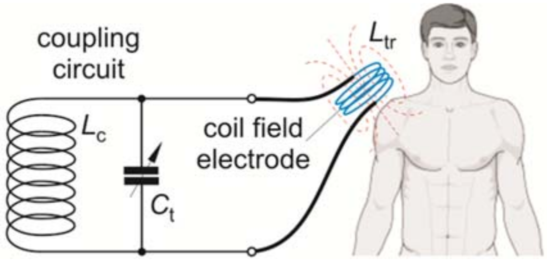
$$Q = \frac{U^2}{R} \cdot t = \frac{U^2}{\rho \frac{l}{A}} \cdot t = \sigma \frac{U^2}{l^2} \cdot l \cdot A \cdot t = \sigma \cdot E^2 \cdot V \cdot t\,,$$

where:

Q	is the produced heat,
$\sigma = 1/\rho$	is the electric conductivity of the tissue,
$E = U/l$	is the electric field strength in the treated tissue,
$V = l \cdot A$	is the treated volume of the tissue, and
t	is the duration (time) of the treatment

problem: 66

Heat therapy generators. Coil field method



... Fig. 5.(b)

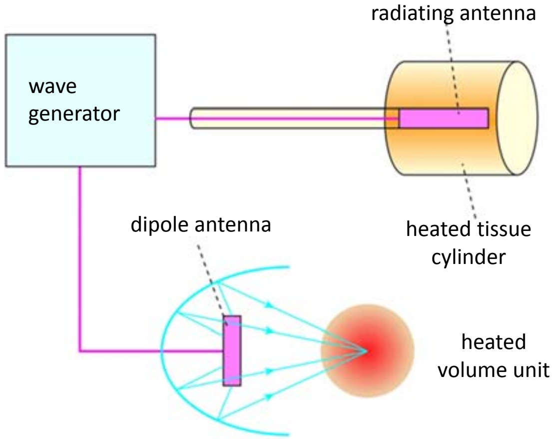
cf.. textbook, Fig. IX.29

resonance criterion:

$$LC = (L_c \otimes L_{tr}) \cdot C_t$$

outcoupling of energy through the magnetic field

Heat therapy generators. Radiation field method

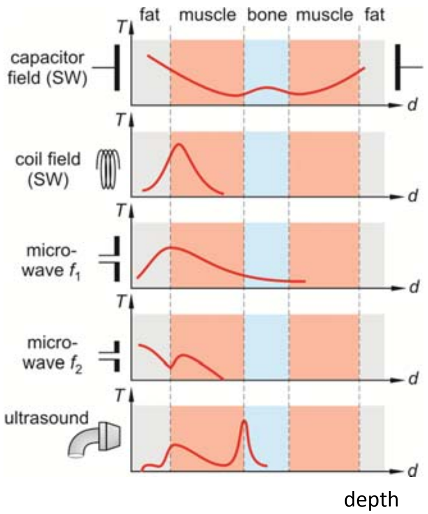


textbook, Fig. IX.33

cf. microwave oven

outcoupling of energy through the radiation field

Temperature distribution with different methods



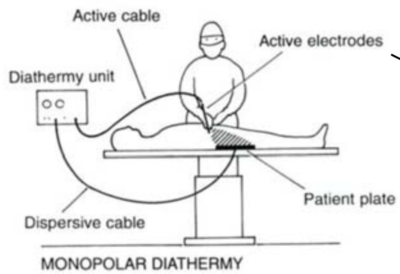
heating of fat;
long range effects

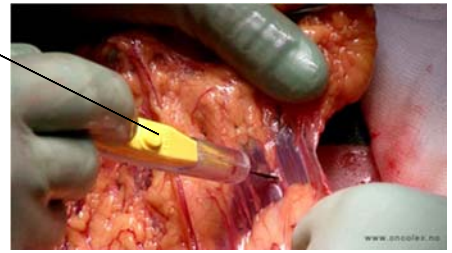
heating of muscle

radiation field (smaller *f*)

radiation field (larger *f*)

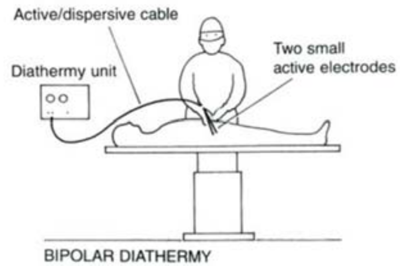
Monopolar and bipolar diathermy. Highfrequency surgery

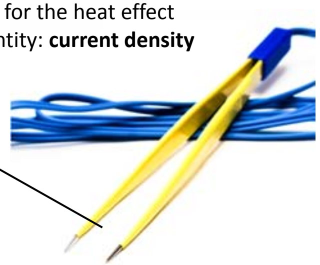




$A_{passive} \gg A_{active}$

below-threshold currents; for the heat effect the characteristic quantity: **current density**



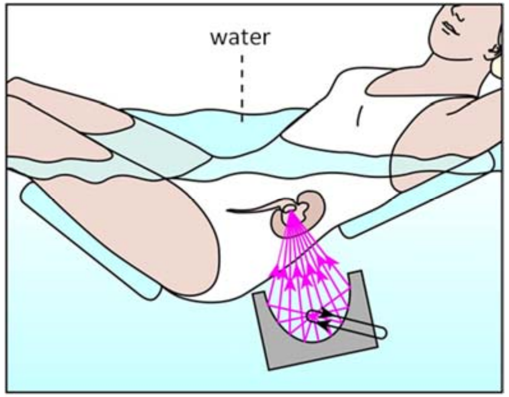


ESWL (Extracorporeal Schockwave Lithotripsy)

breaking up kidney stones and biliary calculi

focused high-intensity acoustic wave generated by electric discharge of a high voltage (20 kV) condenser (ellipse, 2 focal points)

simultaneous follow-up with X-ray and/or US



textbook IX.1. comment