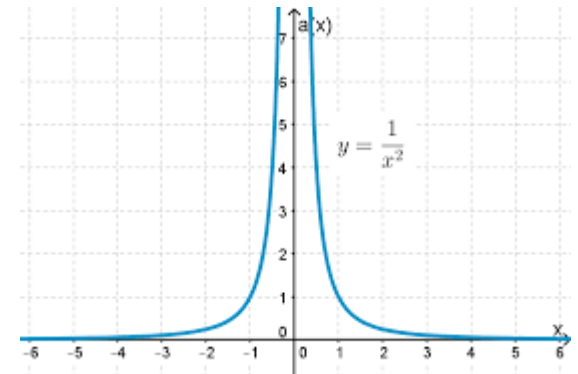
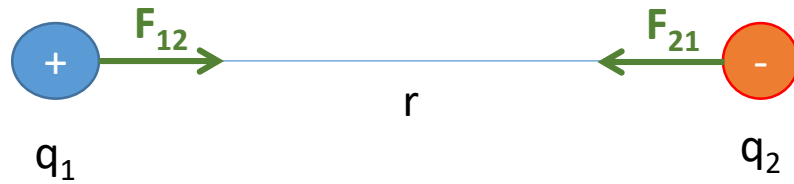


electro - cardiography





magnitude:  $F_{12}=F_{21}$   $F = k \frac{q_1 q_2}{r^2}$

just like gravity, we have  
**1/squared relationship**

there exists a minimal, elementary charge:  $e = 1,6 \cdot 10^{-19} \text{C}$

charge only appears bound to material

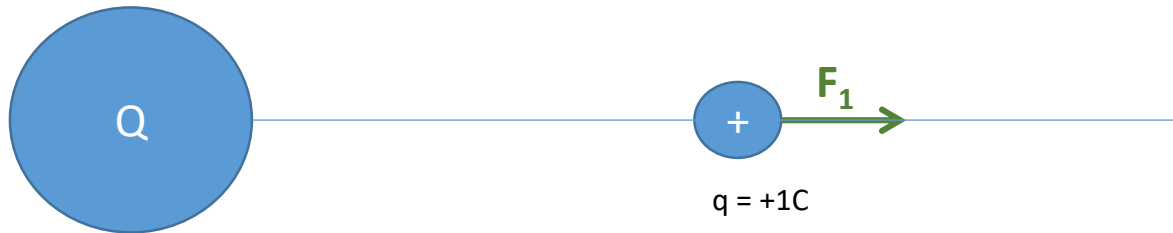
$$k_e = \frac{1}{4\pi\epsilon_0} = \frac{c_0^2 \mu_0}{4\pi} = c_0^2 \times 10^{-7} \text{ H} \cdot \text{m}^{-1}$$

$$= 8.987\,551\,787\,368\,176\,4 \times 10^9 \text{ N} \cdot \text{m}^2 \cdot \text{C}^{-2}$$

what “conveys” the force?

electric **FIELD**

the **electric field strength** is the force acting on a +1C probe.  
**E**

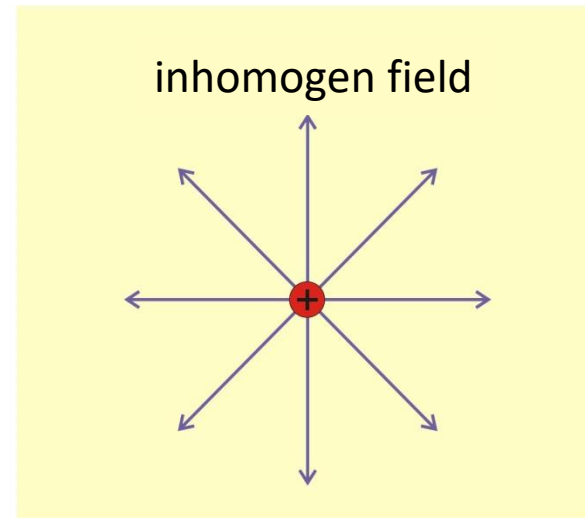
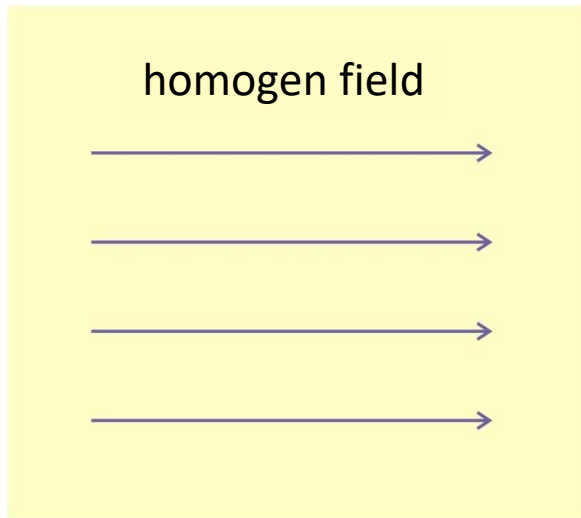


$$F = q \cdot E$$

and  $E = k \cdot Q / r^2$

unit:  $[F] / [q] = \text{N/C}$

**FIELD LINES** are always parallel to the direction of the coulomb's force.



magnitude of the force is proportional to the field-line DENSITY (Flux)

## work in electric field:

$W = \vec{F} \cdot \vec{s}$ , but is a scalar product

but  $F = q \cdot E$

so

$$W = q \cdot E \cdot s$$

**ELECTRIC POTENTIAL:**  $W = q \cdot \Delta\phi$

( just like in gravity field:  $E_{\text{pot}} = mgh$ )

so  $\phi = E \cdot s$ , we need a 0 point.

**Legyen  $\phi = 0$  at infinitely far away**

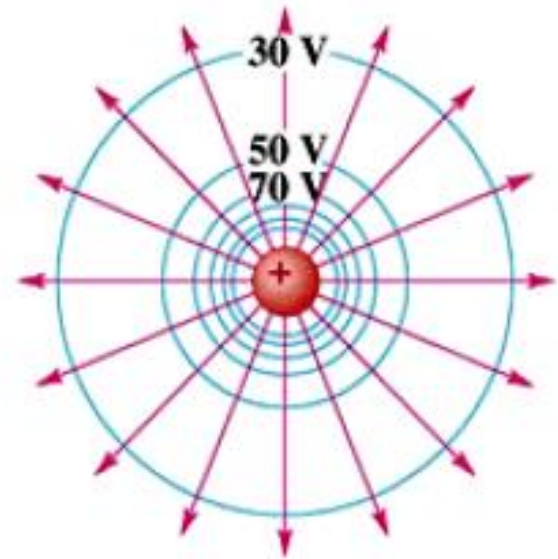
on a closed loop the work is zero, the E is a conservative field.

**$U = \Delta\phi$ , ELECTRIC VOLTAGE, unit:  $[W]/[q] = J/C = \text{Volt } [V]$ .**

thus  **$W = q \cdot U$**

Field lines

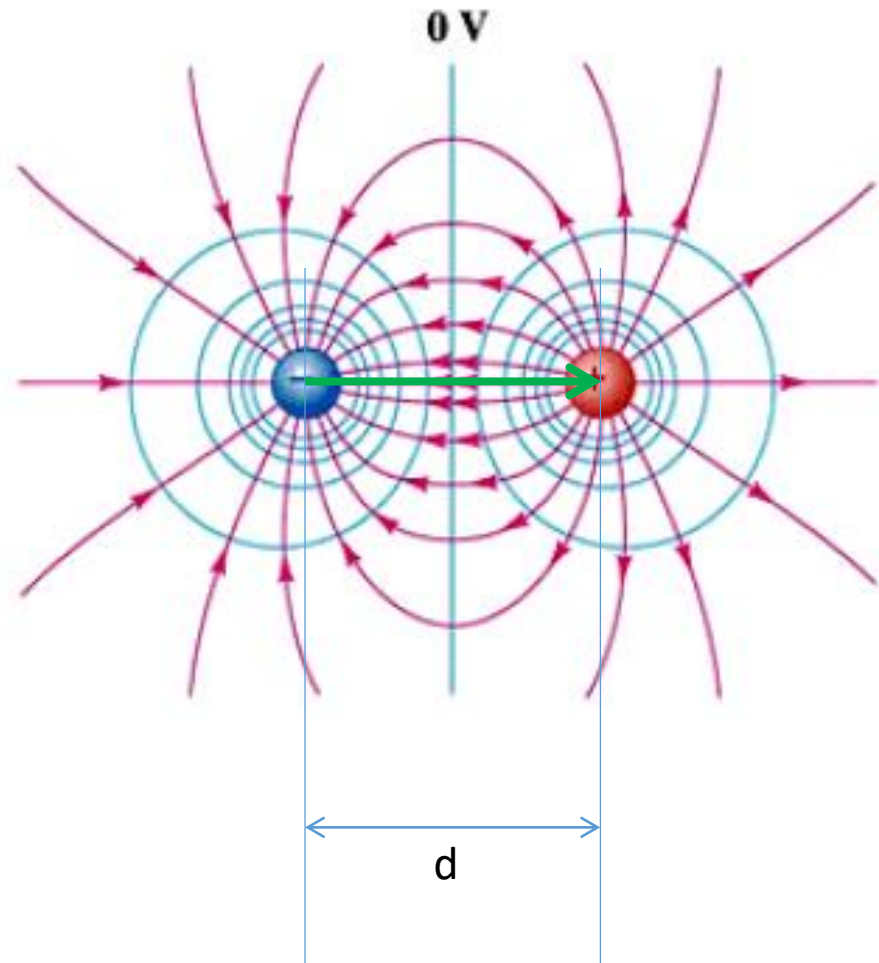
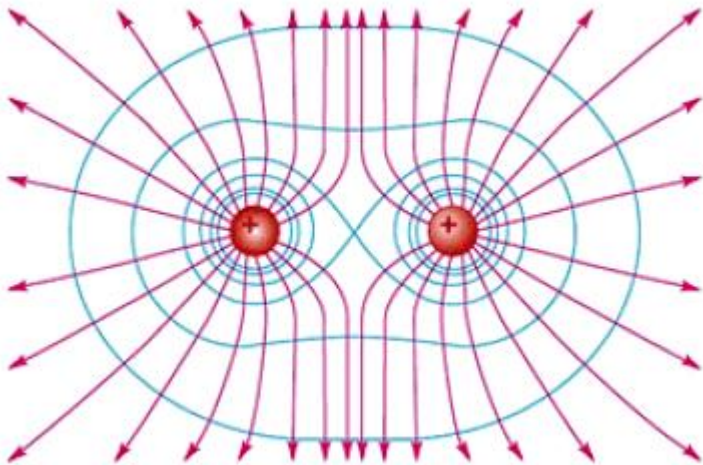
equipotential lines



MONOPOLE: 1 charge

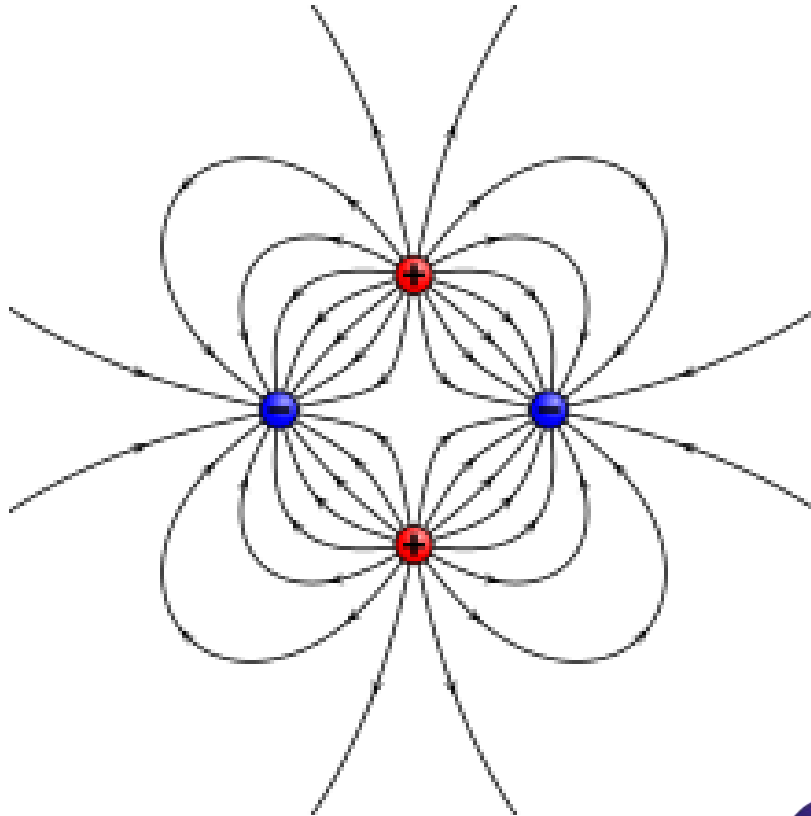
## DIPOLE

dipole vectorm:  $\mathbf{p} = q \cdot \mathbf{d}$   
(**vector**)

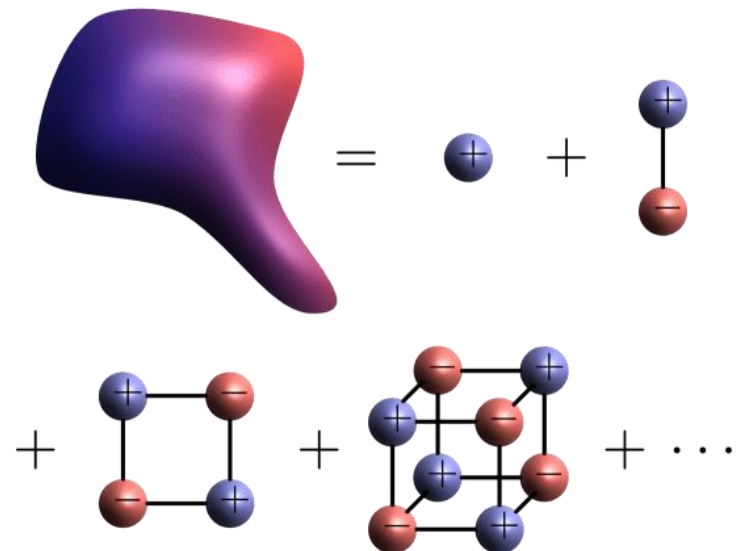


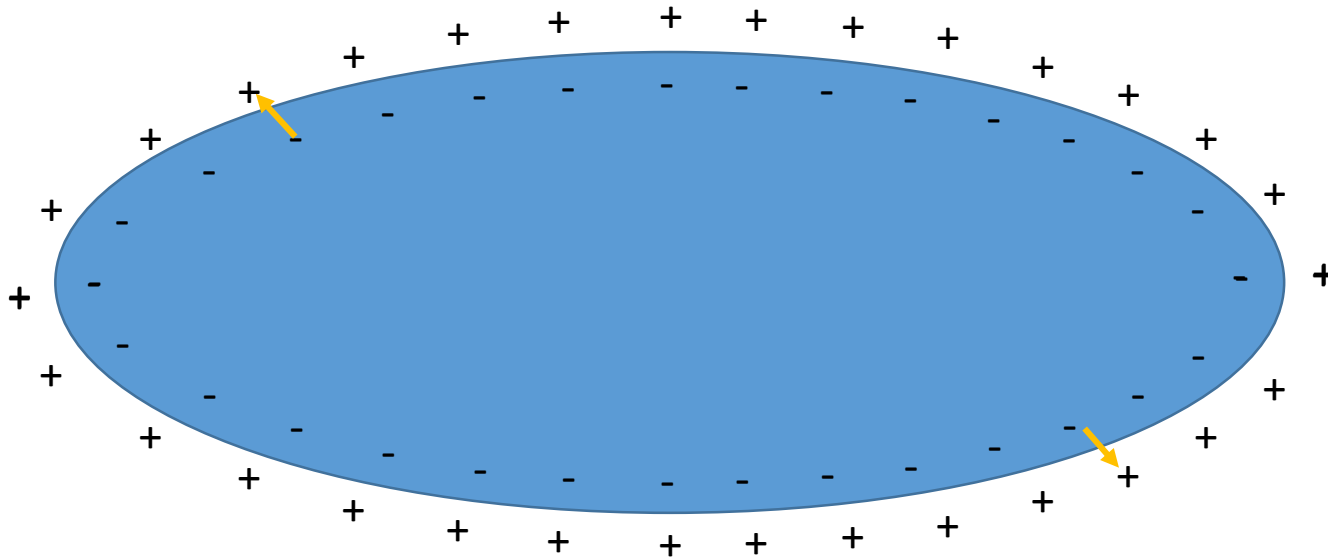


Quadrupole...

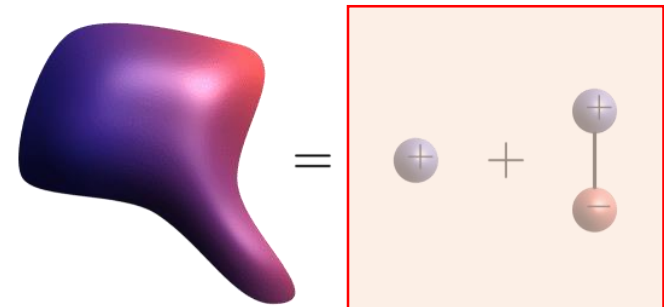


Multipole series expansion

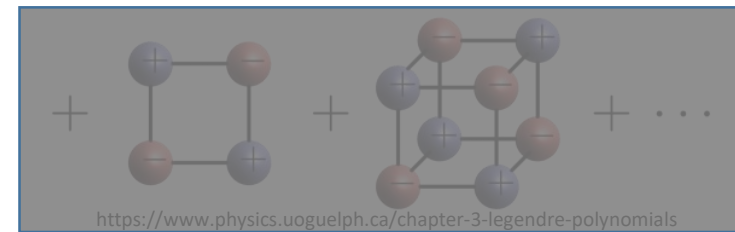


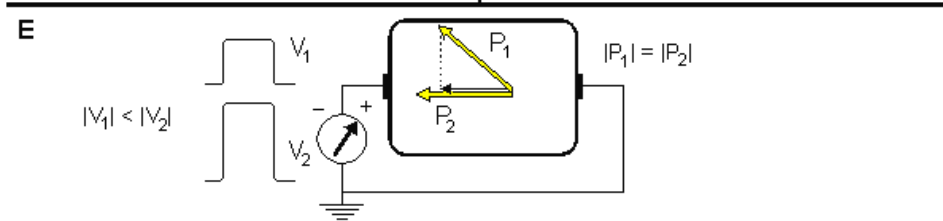
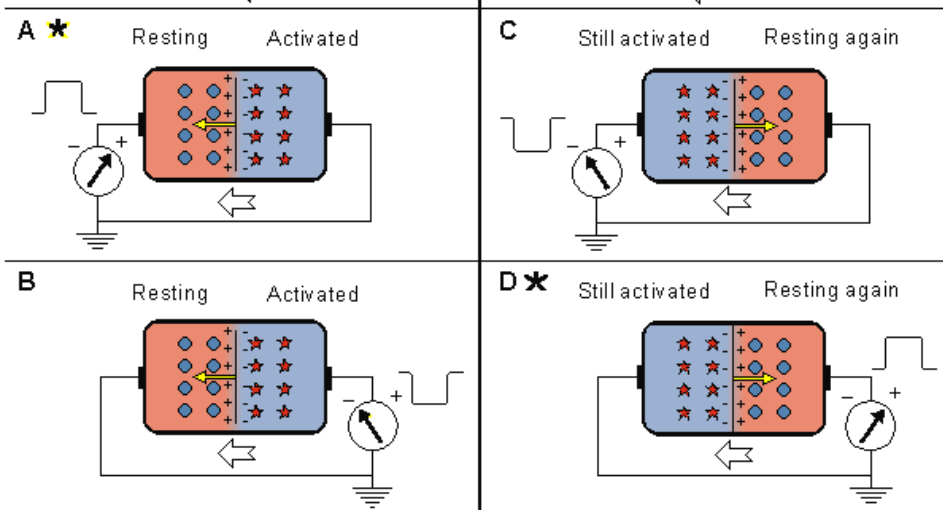
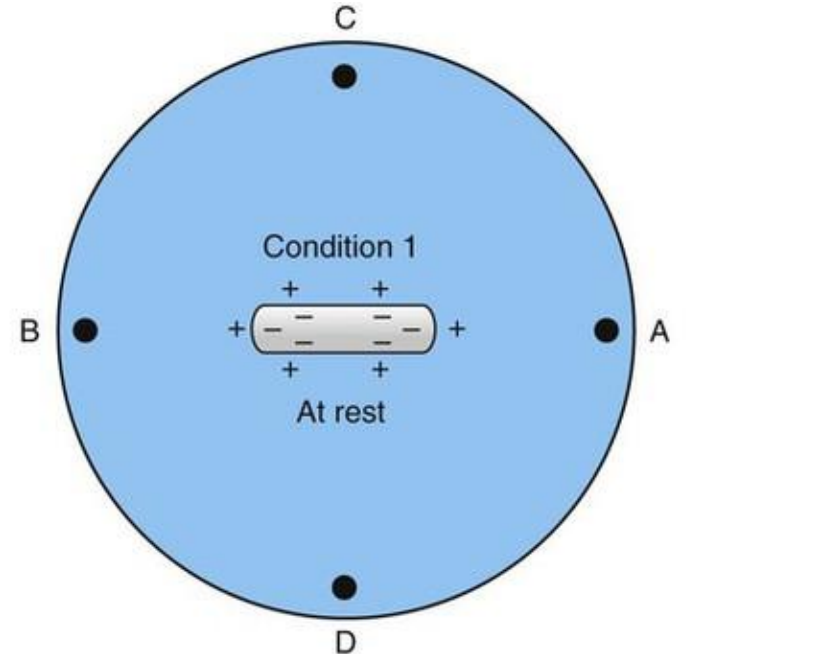
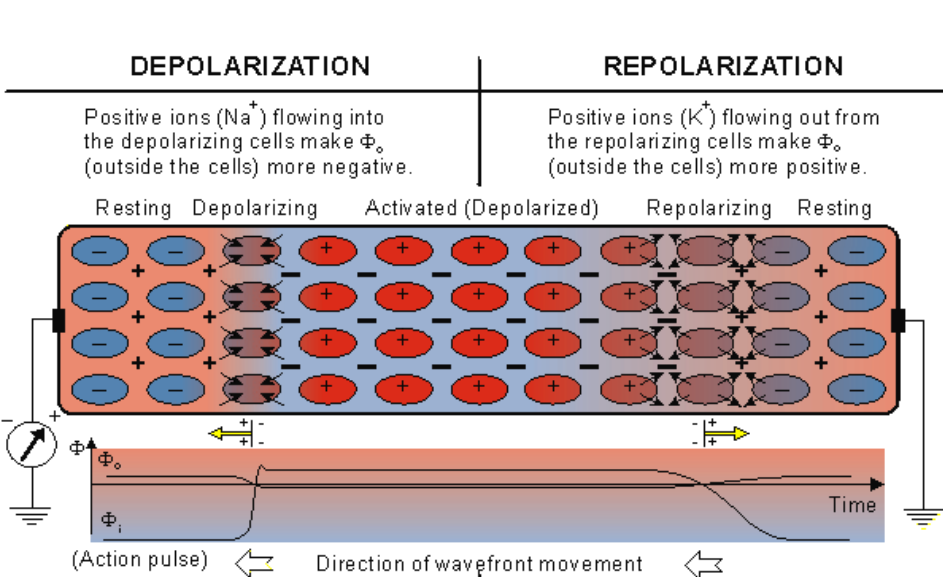


resting state or fully depolarized cells have 0 dipole.

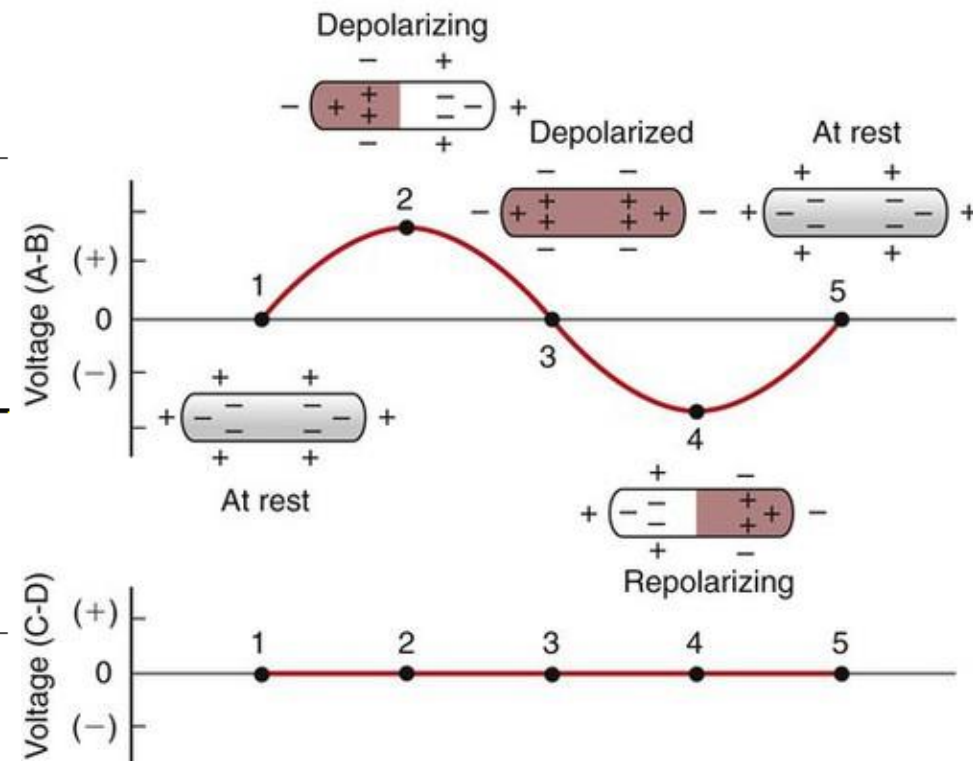


the monopole term is 0

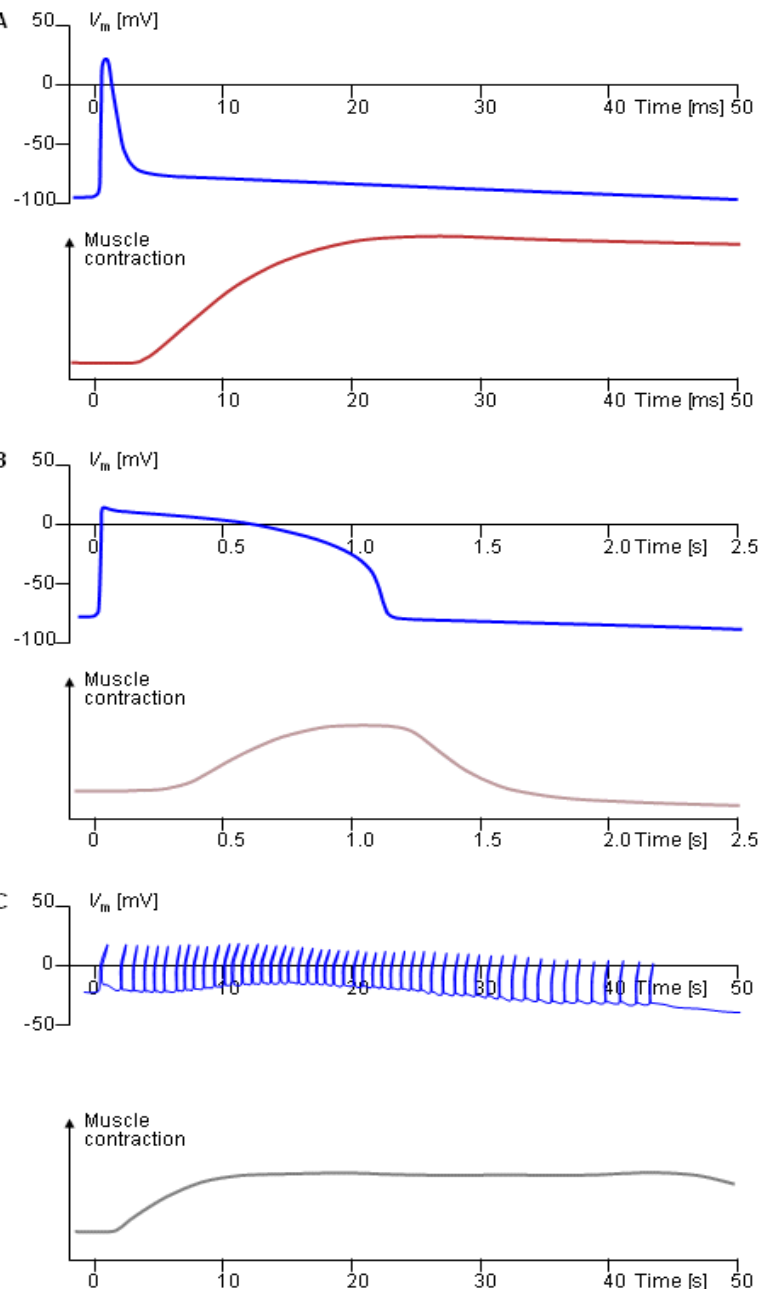




- ★ = Activated (depolarized) cell
- = Resting (repolarized) cell
- ← = Direction of depolarization or repolarization wavefront
- ↔ = Polarity of the double layer and its resultant dipole



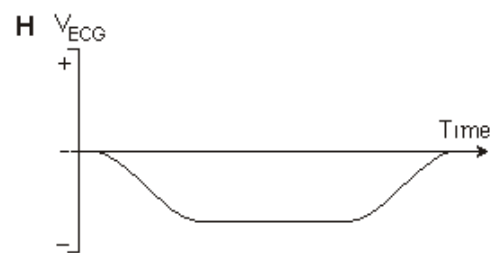
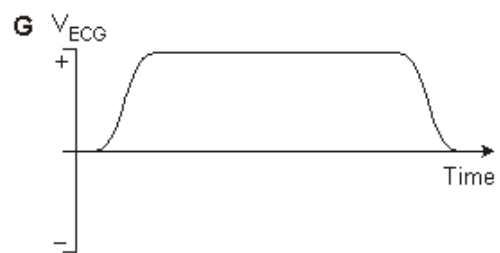
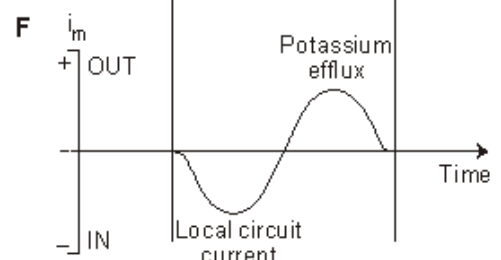
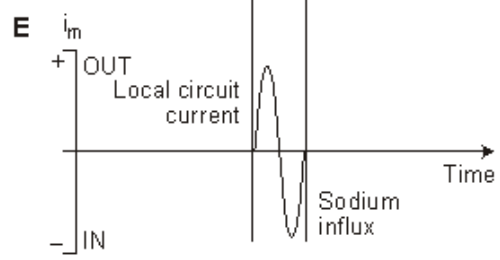
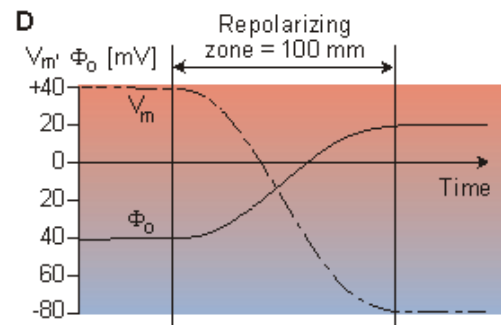
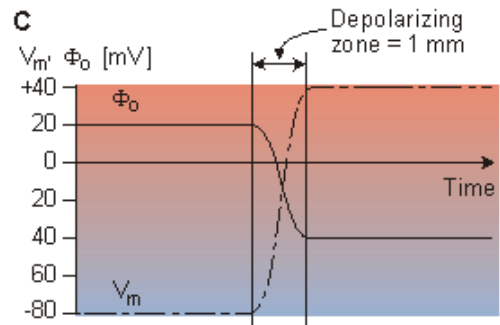
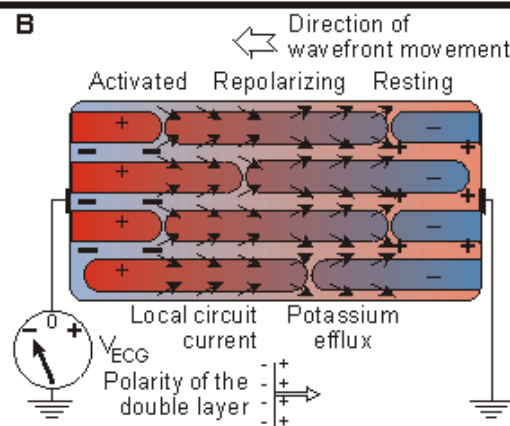
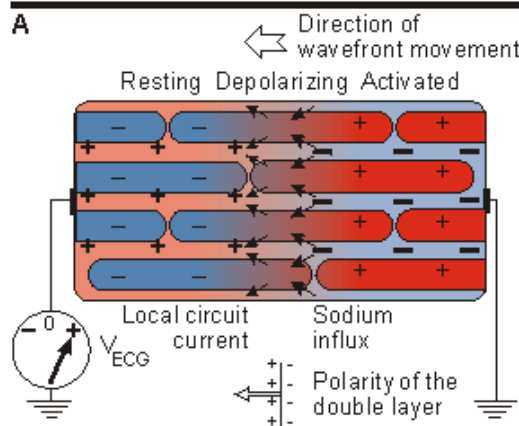
contraction and electric activity in muscle cells are strictly coupled.



biphasic extracellular signal

DEPOLARIZATION

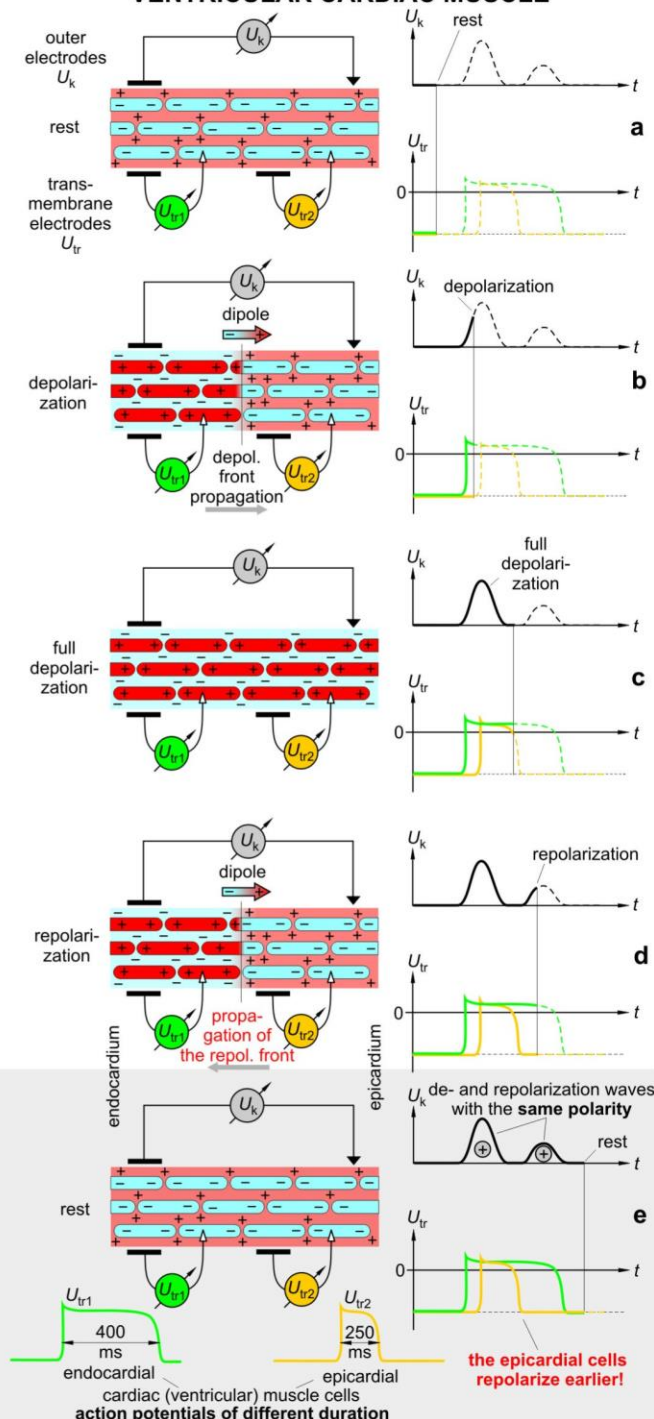
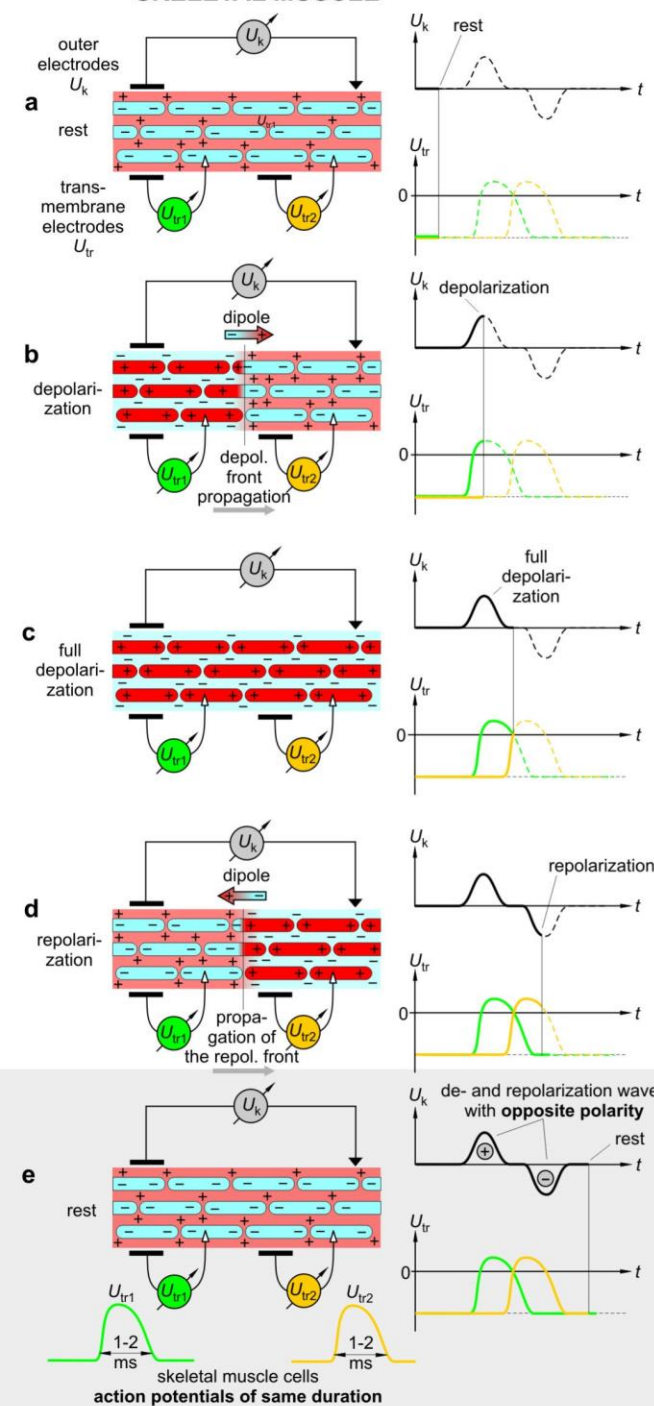
REPOLARIZATION



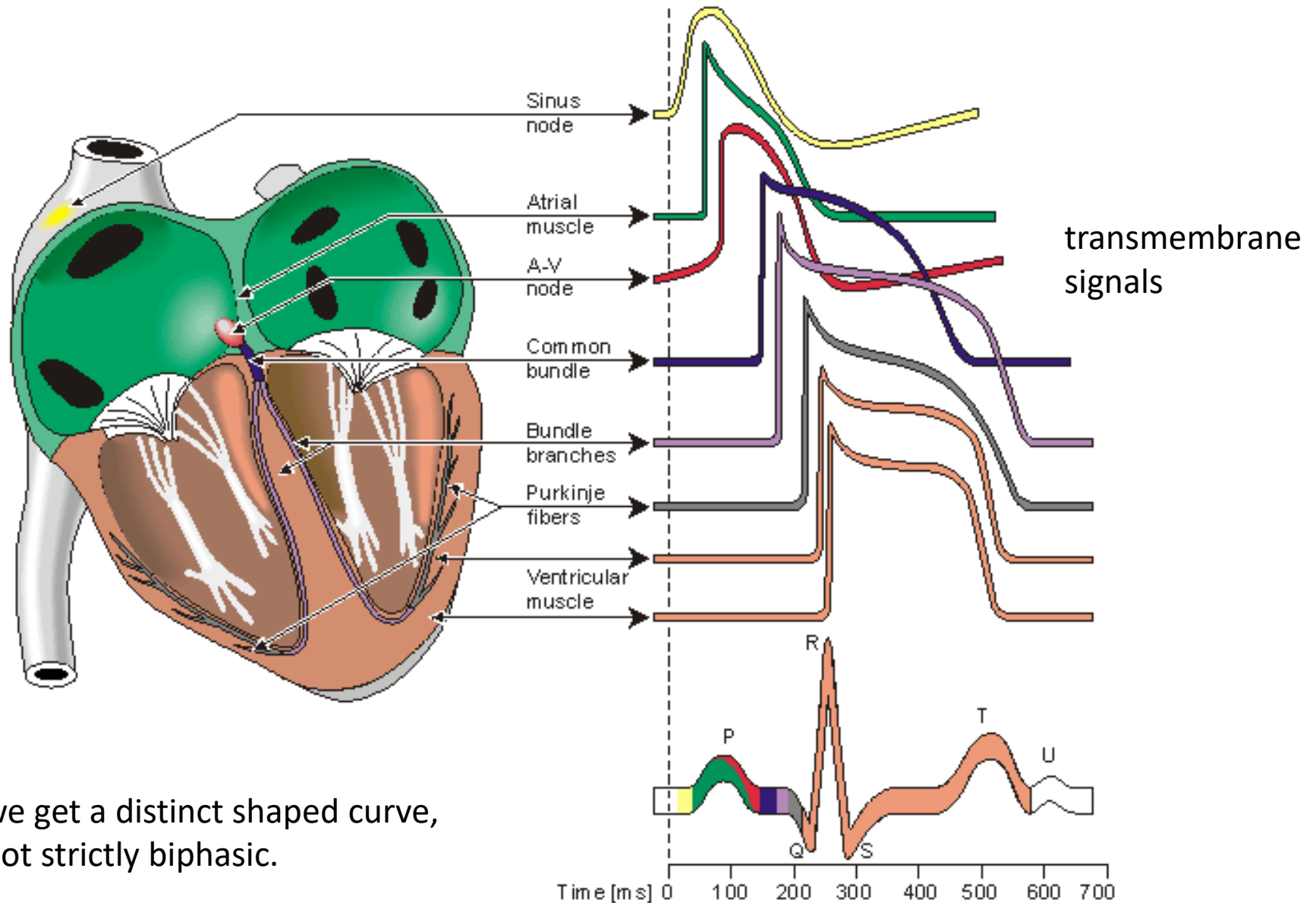
# **SKELETAL MUSCLE**

# **VENTRICULAR CARDIAC MUSCLE**

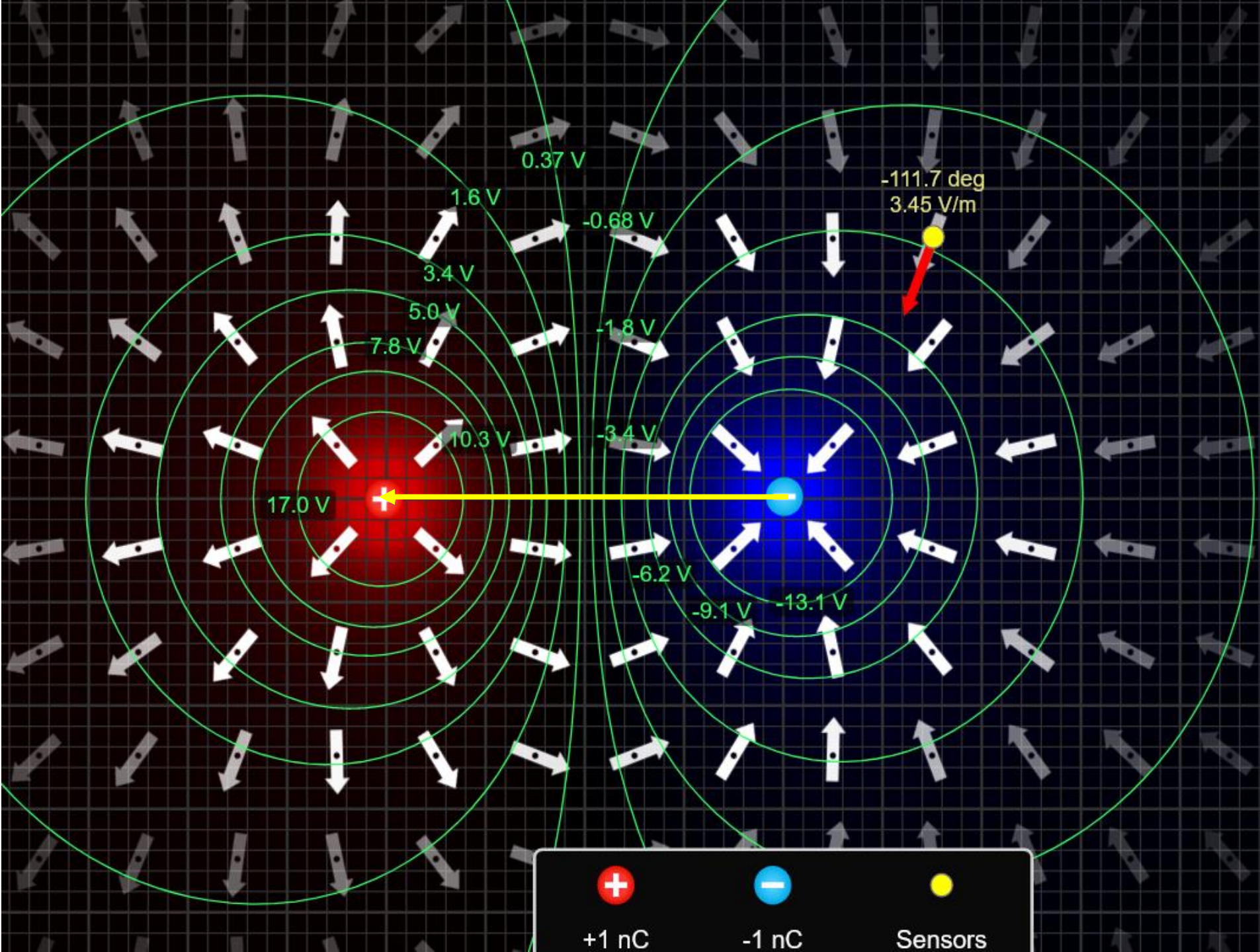
if different type of cells are distributed in space, then we can get a non-biphasic signal.



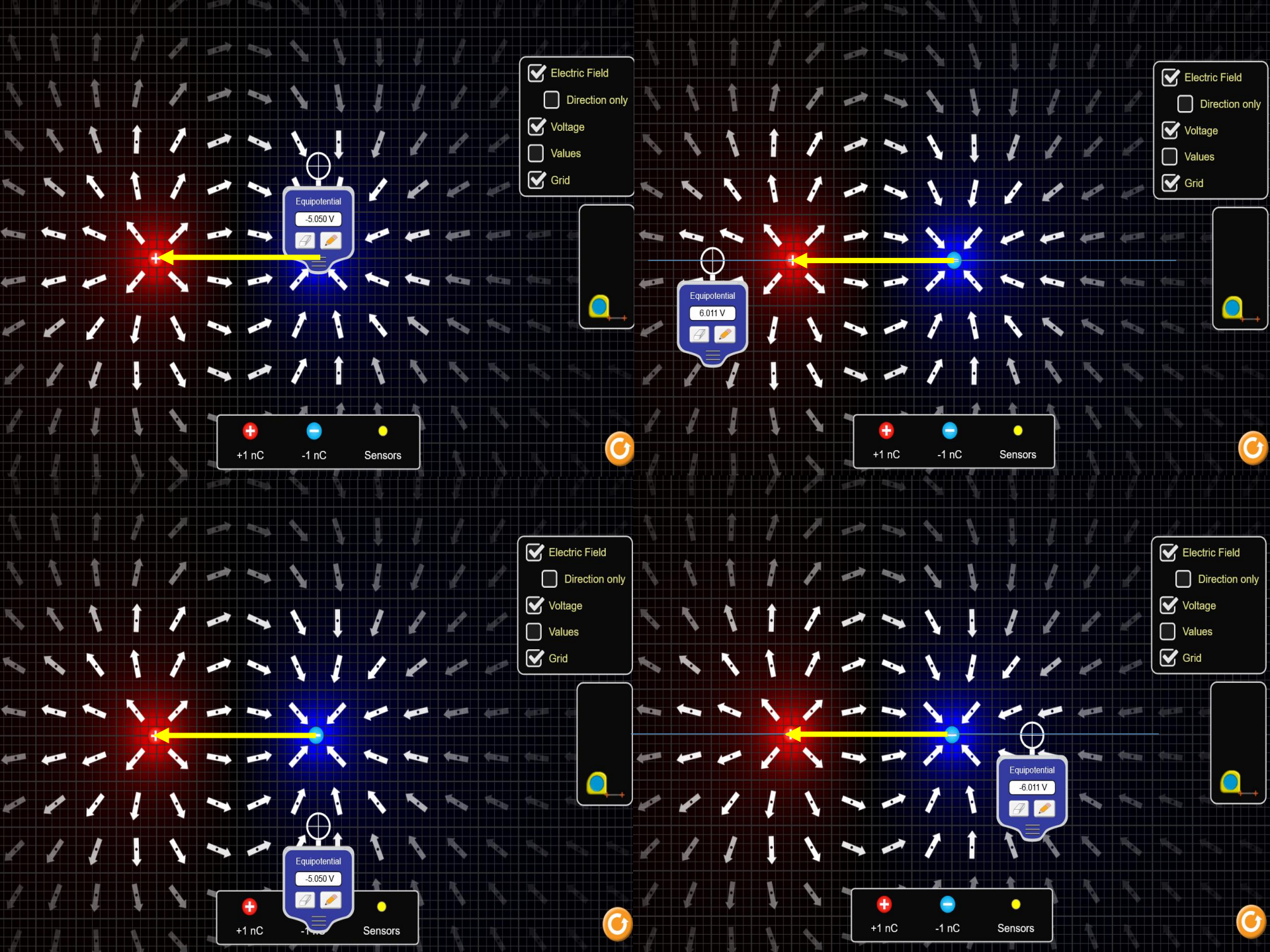
in the heart very different cell types are located at various structures





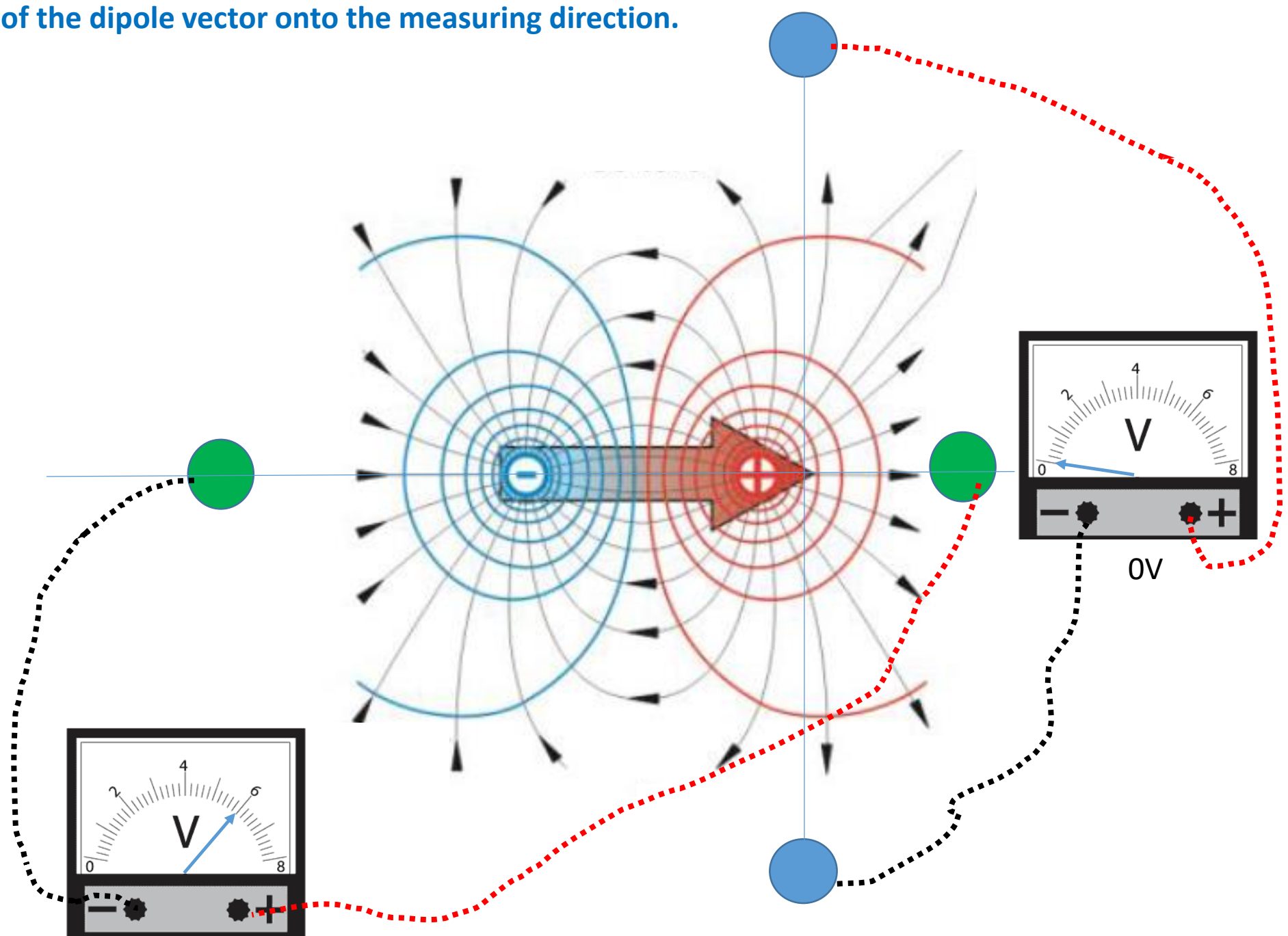




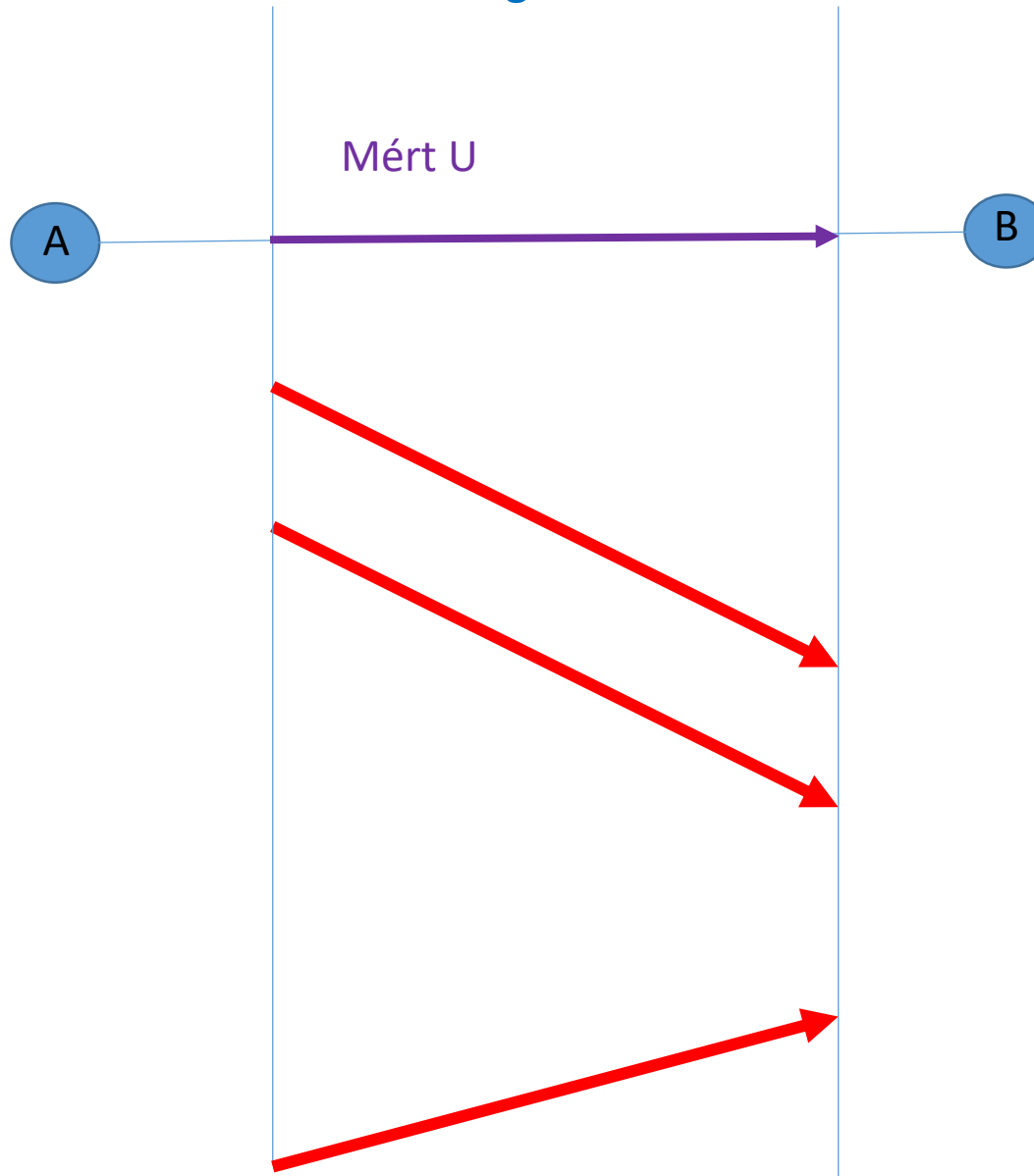


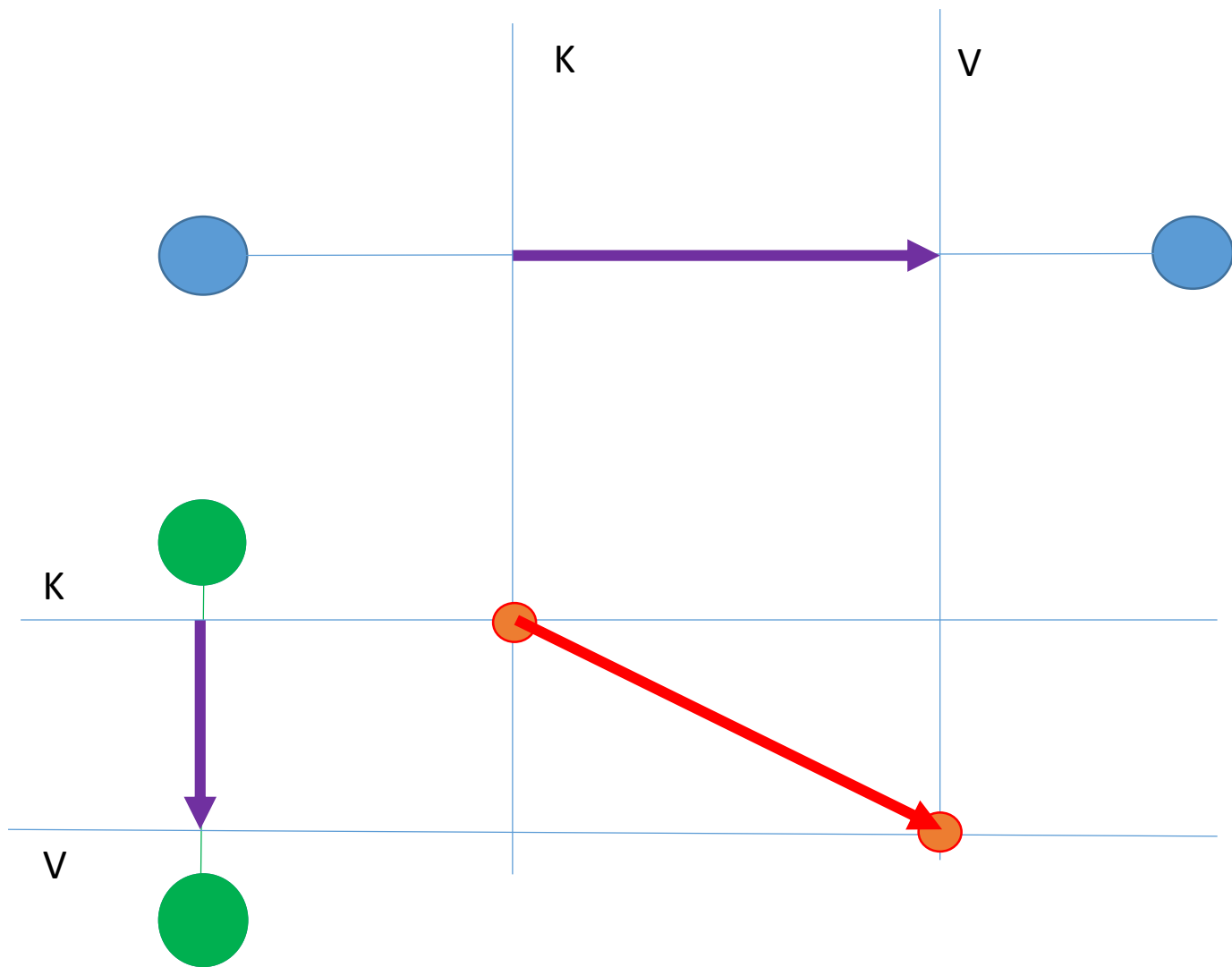


The measured voltage is proportional to the **projection** of the dipole vector onto the measuring direction.

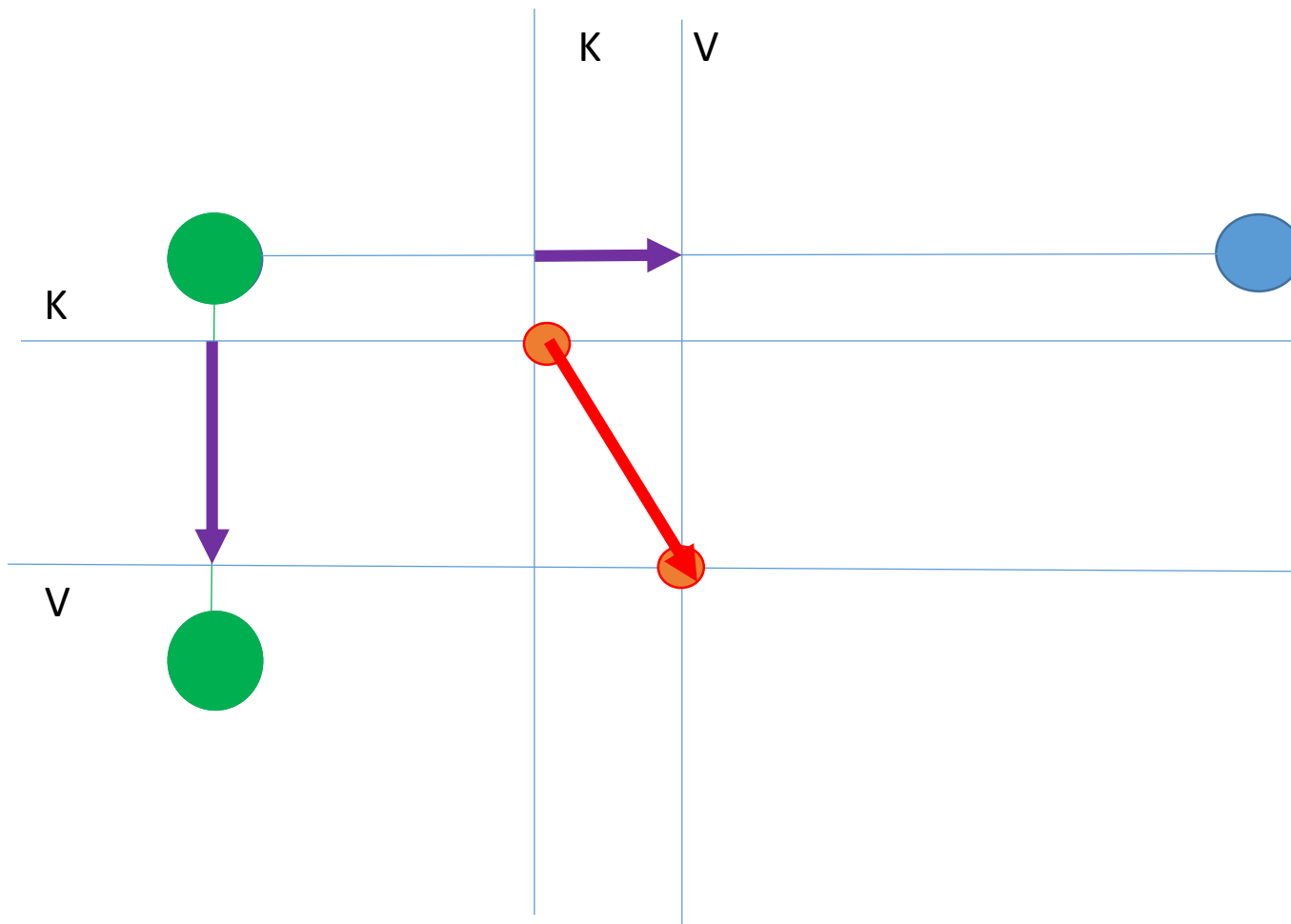


The measured voltage is proportional to the **projection** of the dipole vector onto the measuring direction.



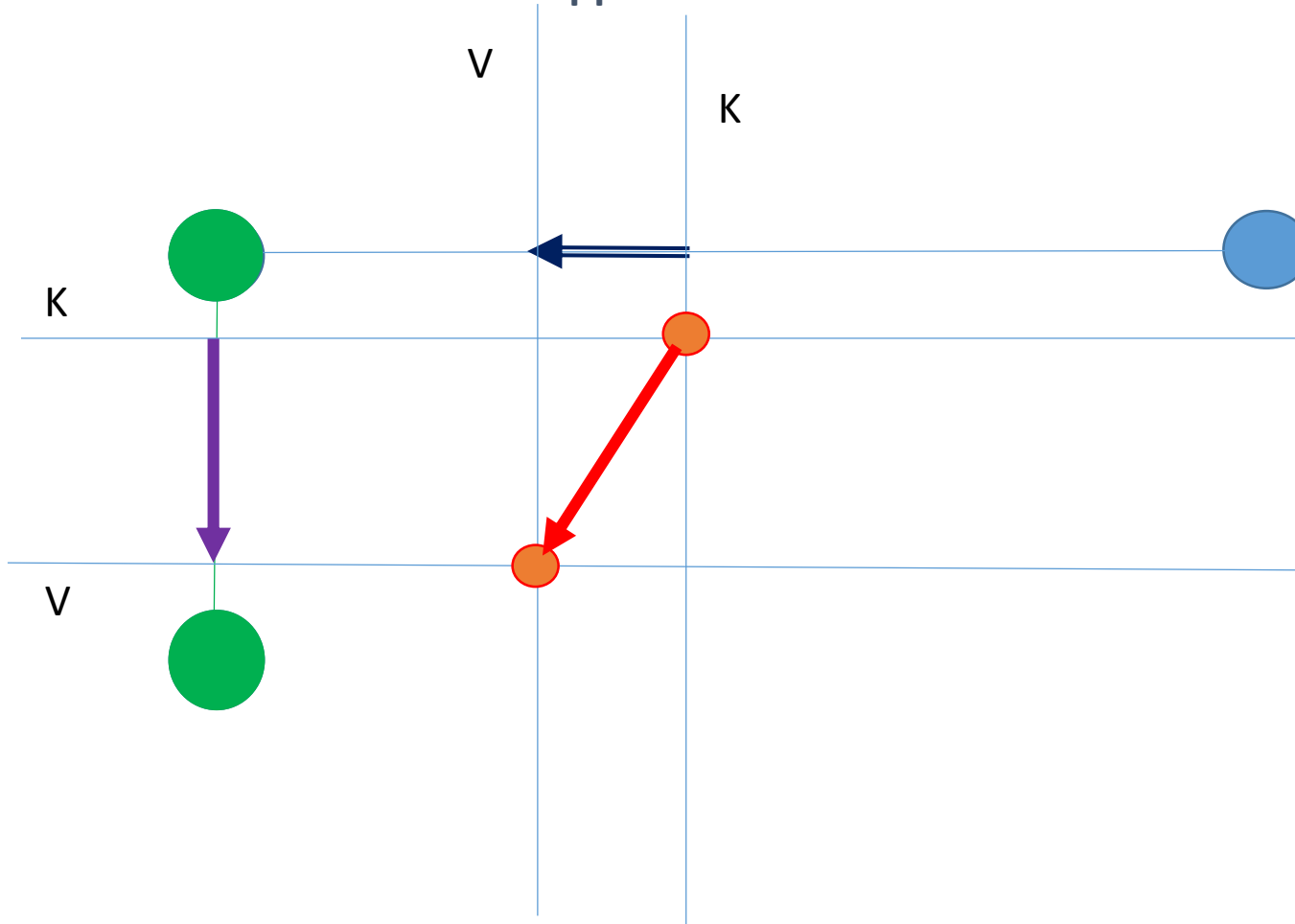


the original dipole can be reconstructed

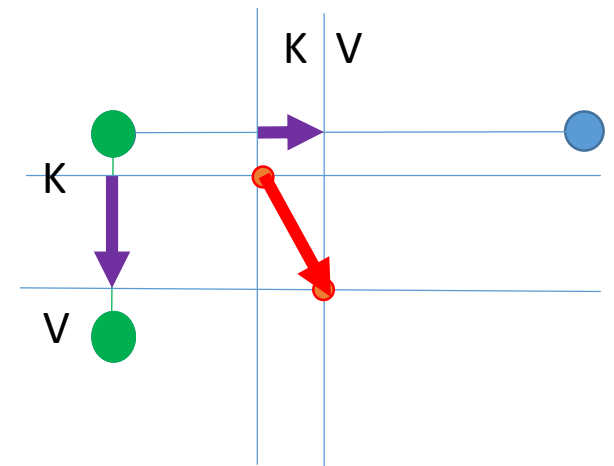


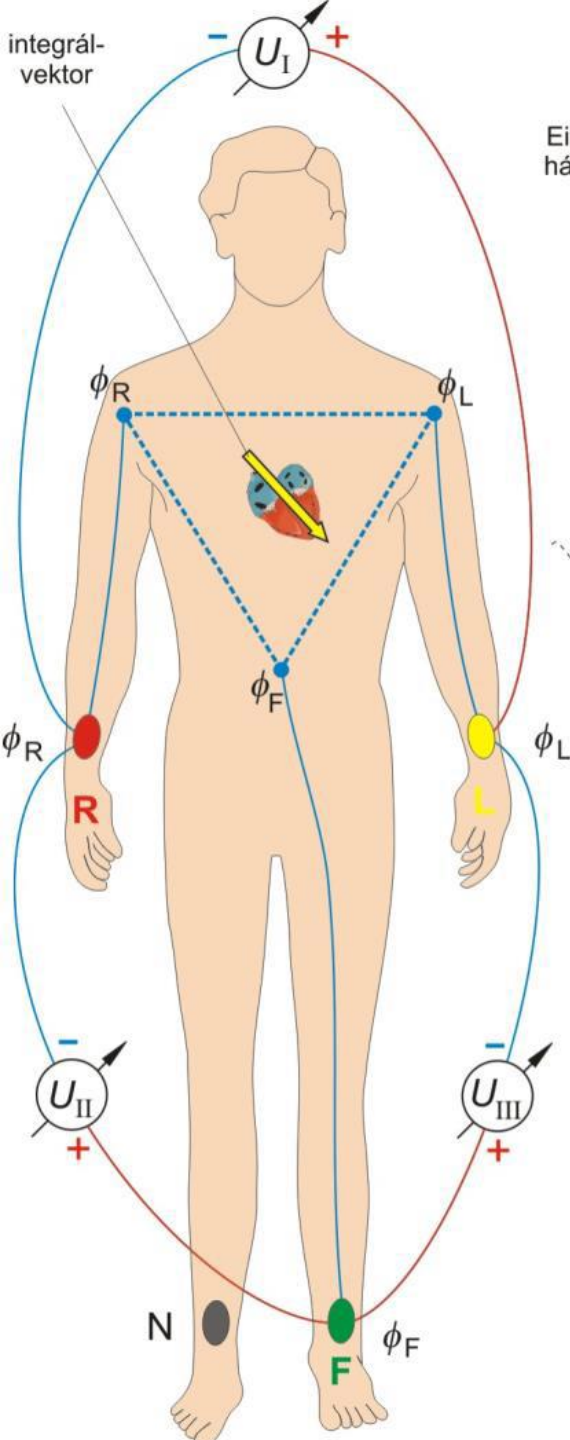
uncontrolled leads: risk of wrong data!

swapped electrodes here

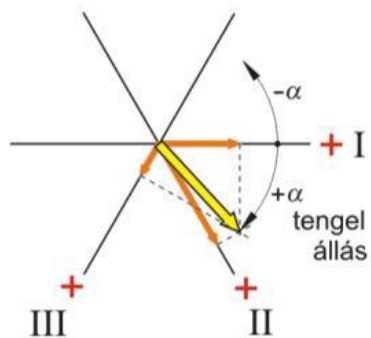
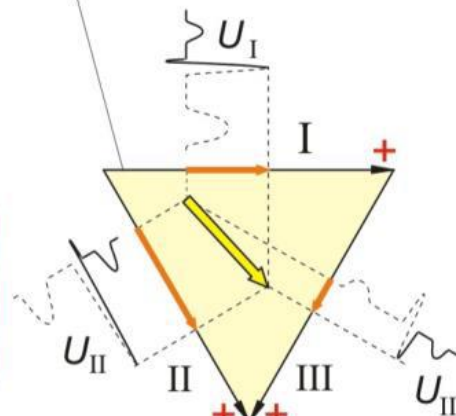


uncontrolled leads: risk of wrong data!





Einthoven-háromszög

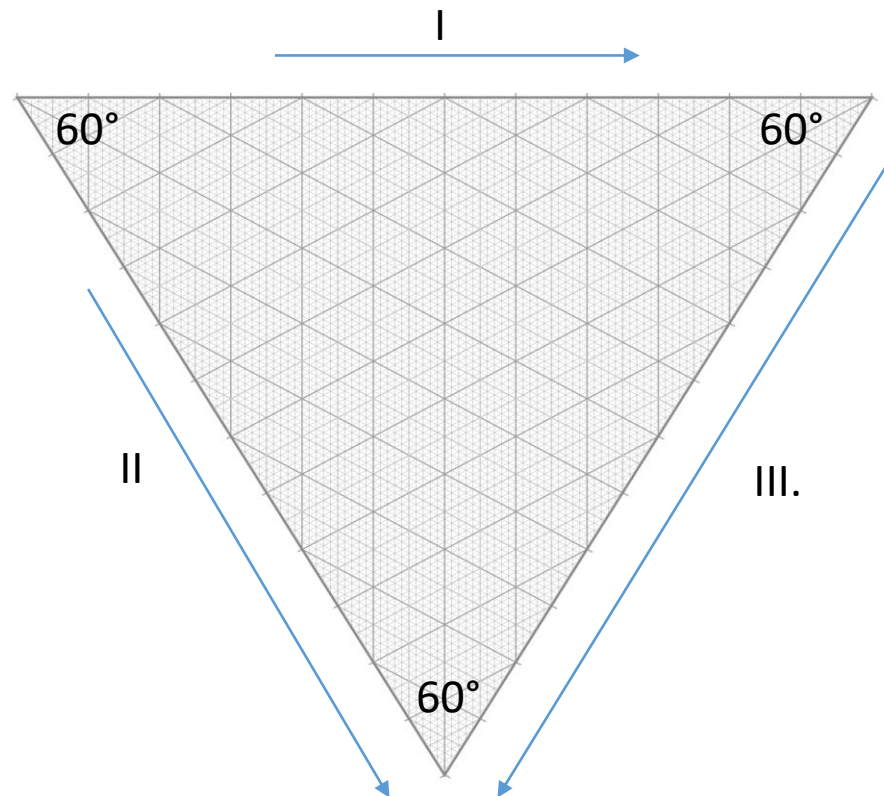


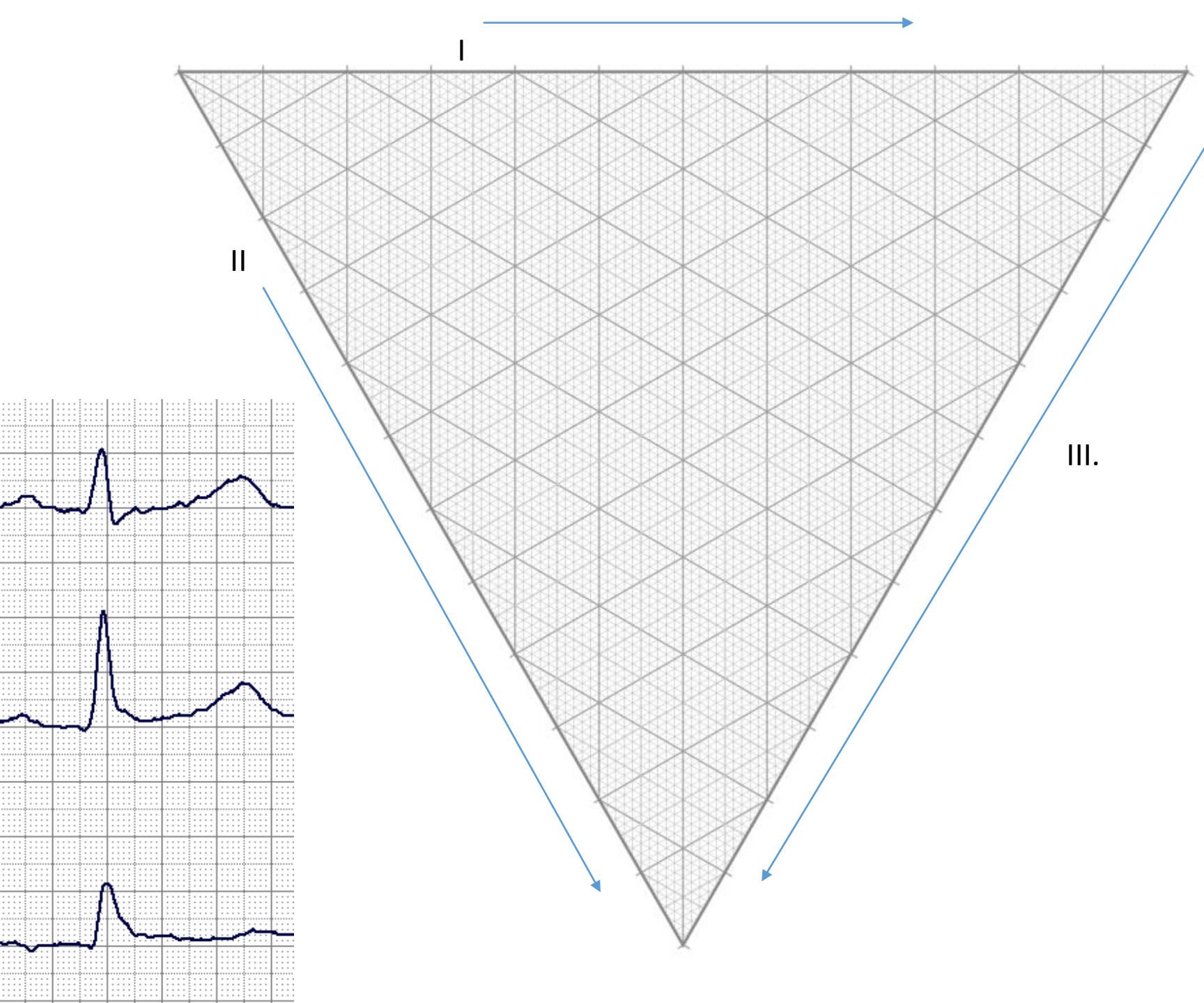
$$U_I = \phi_L - \phi_R$$

$$U_{II} = \phi_F - \phi_R$$

$$U_{III} = \phi_F - \phi_L$$

Einthoven : controlled leads,  
the three projections are NOT independent.

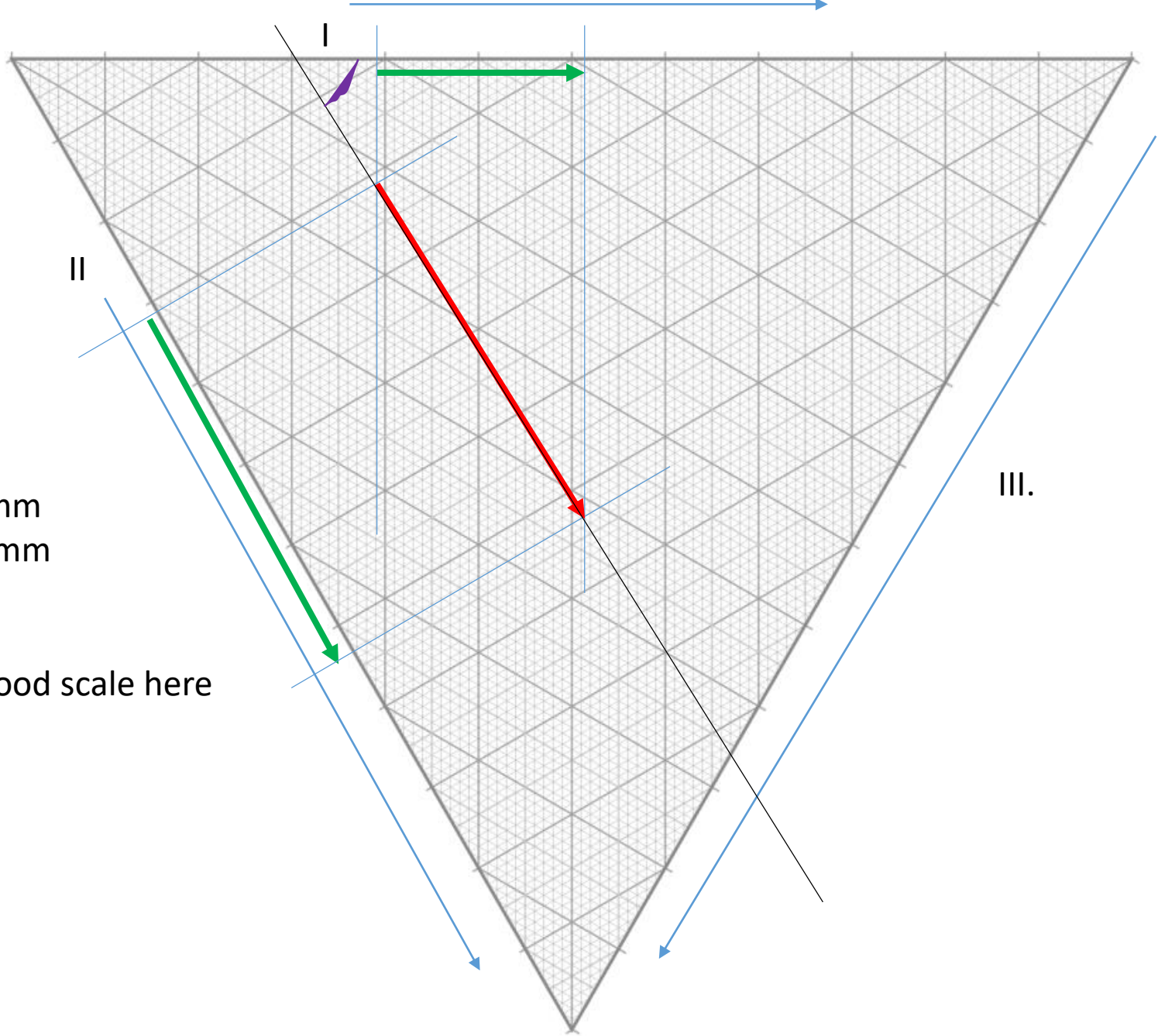






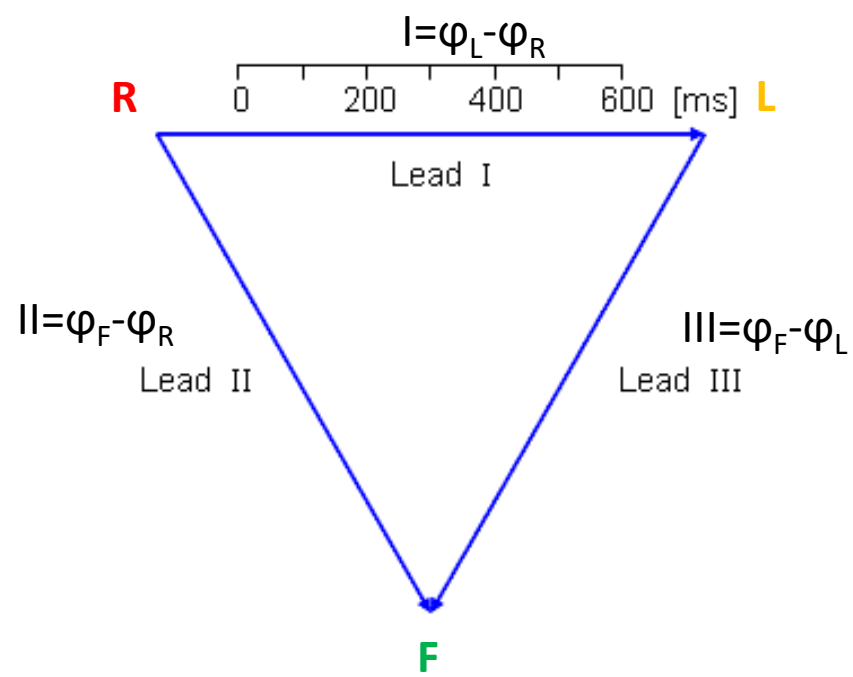
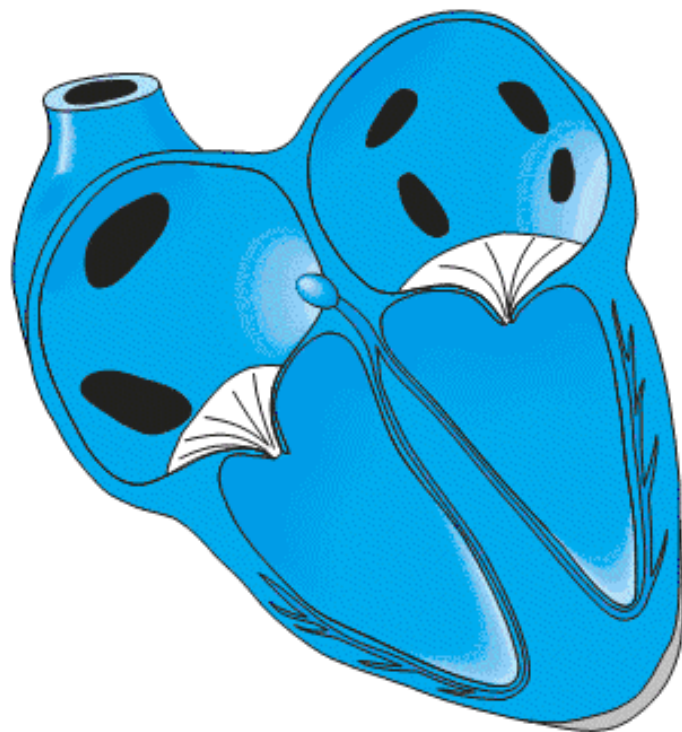
U\_I: 11mm  
U\_II: 21mm

2x is a good scale here

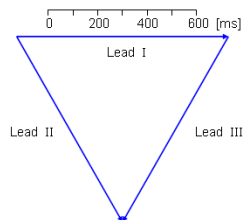
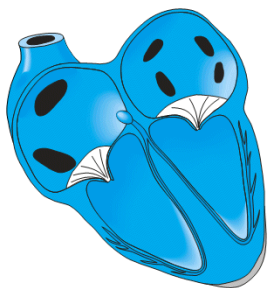




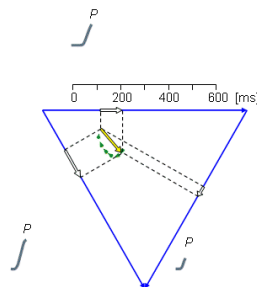
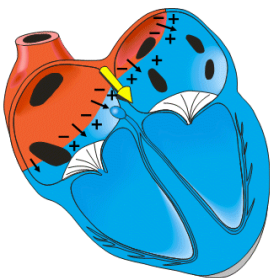
SINUS NODE  
0 ms



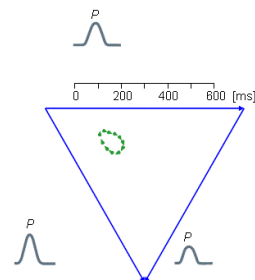
SINUS NODE  
0 ms



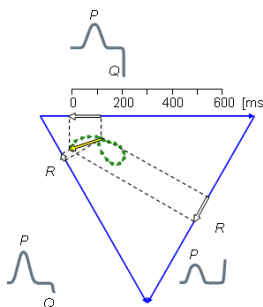
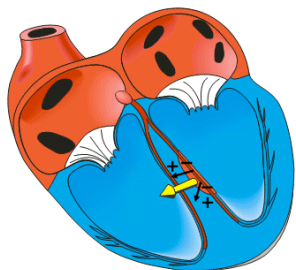
ATRIAL DEPOLARIZATION  
80 ms



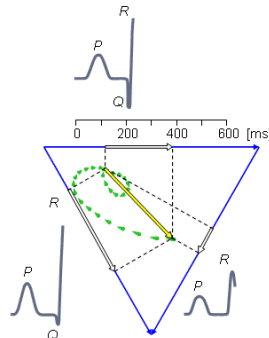
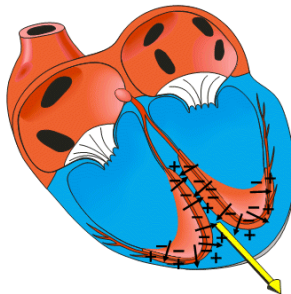
DELAY AT A-V NODE  
200 ms



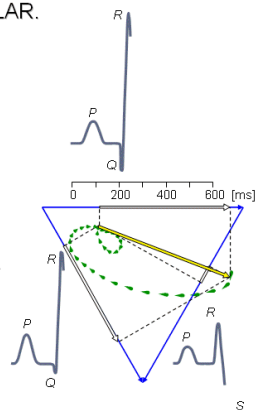
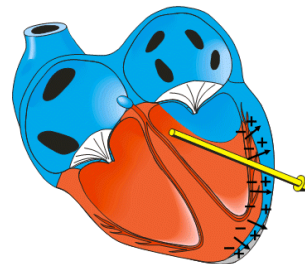
SEPTAL DEPOLARIZATION  
220 ms



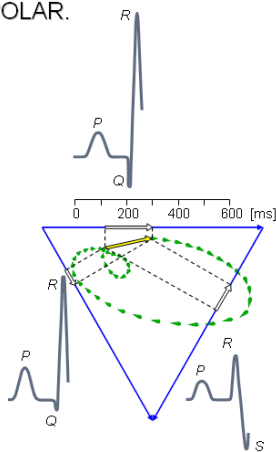
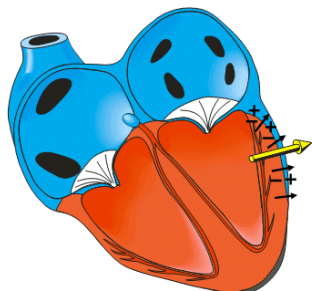
APICAL DEPOLARIZATION  
230 ms



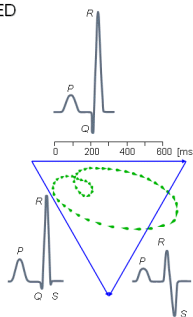
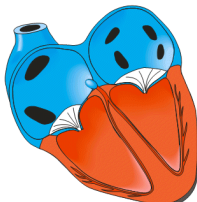
LEFT VENTRICULAR DEPOLAR.  
240 ms



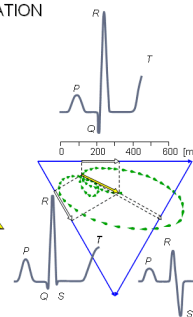
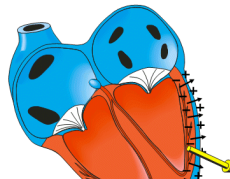
LATE LEFT VENTRICULAR DEPOLAR.  
250 ms



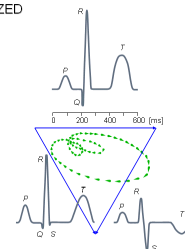
VENTRICLES DEPOLARIZED  
350 ms

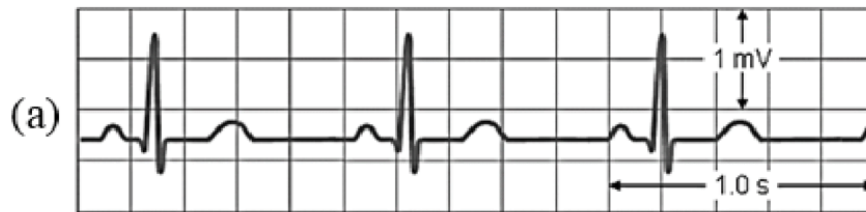


VENTRICULAR REPOLARIZATION  
450 ms



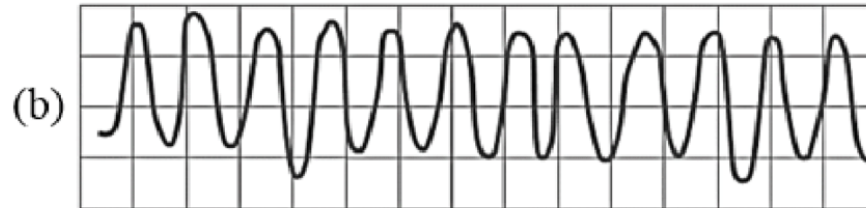
VENTRICLES REPOLARIZED  
600 ms



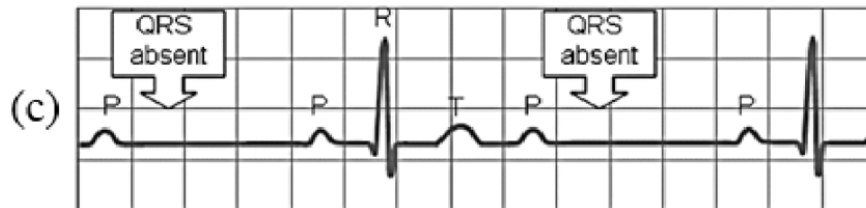


**(a) Normal Sinus Rhythm**

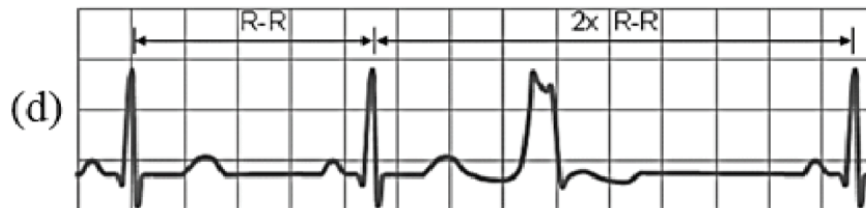
csaknem minden funkcionális  
zavar EKG jel változással jár!  
-> diagnózis



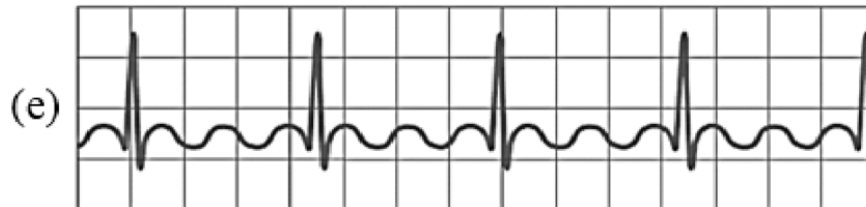
**(b) Ventricular Fibrillation**



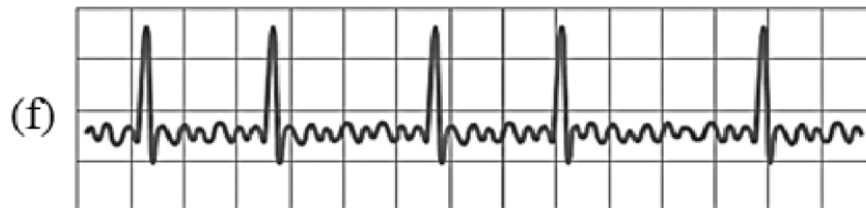
**(c) Atrioventricular Block**



**(d) Premature Ventricular Contraction**

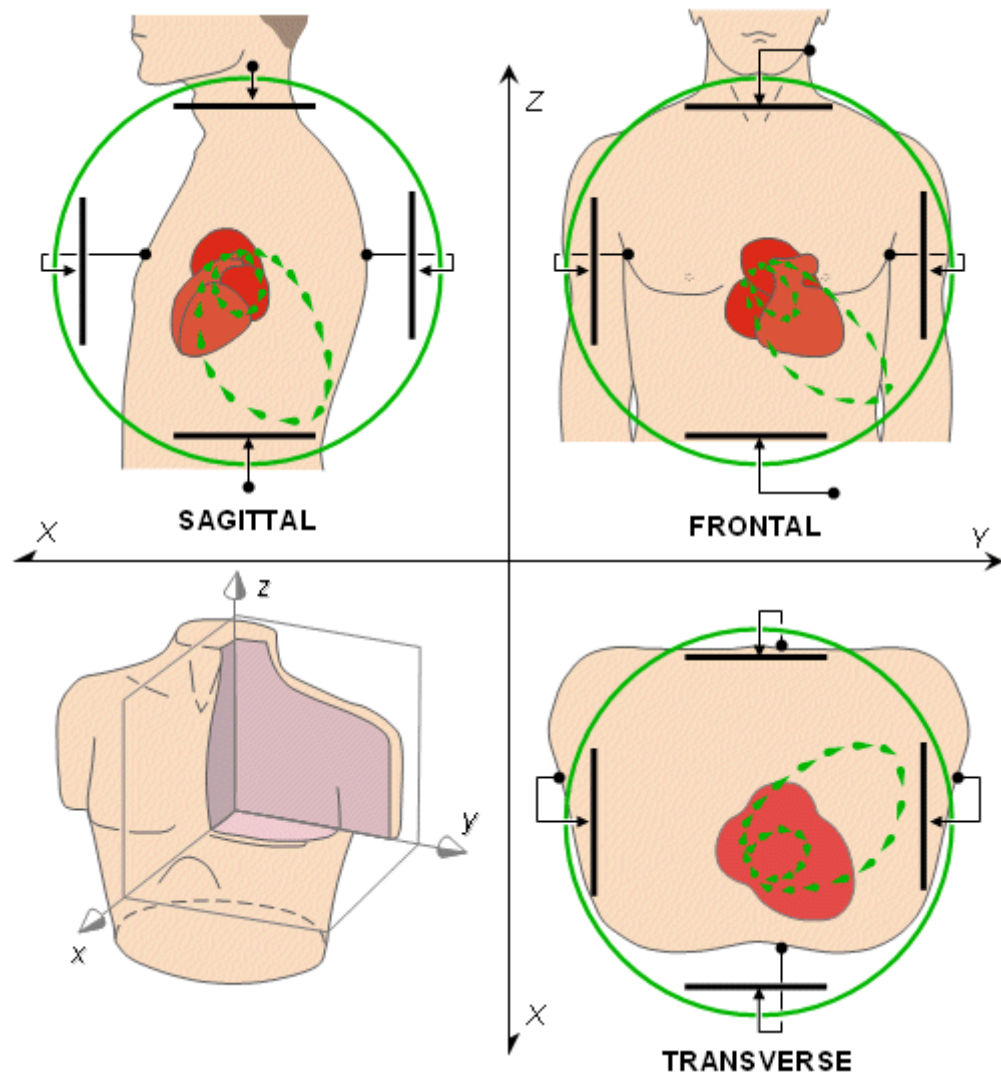


**(e) Atrial Flutter**

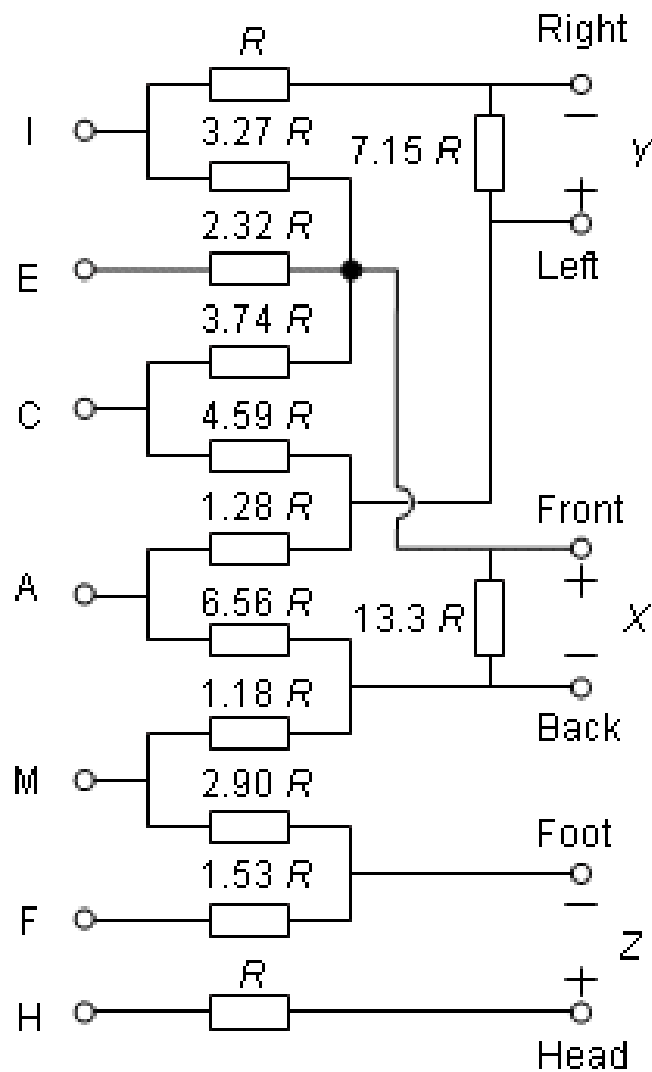


**(f) Atrial Fibrillation.**

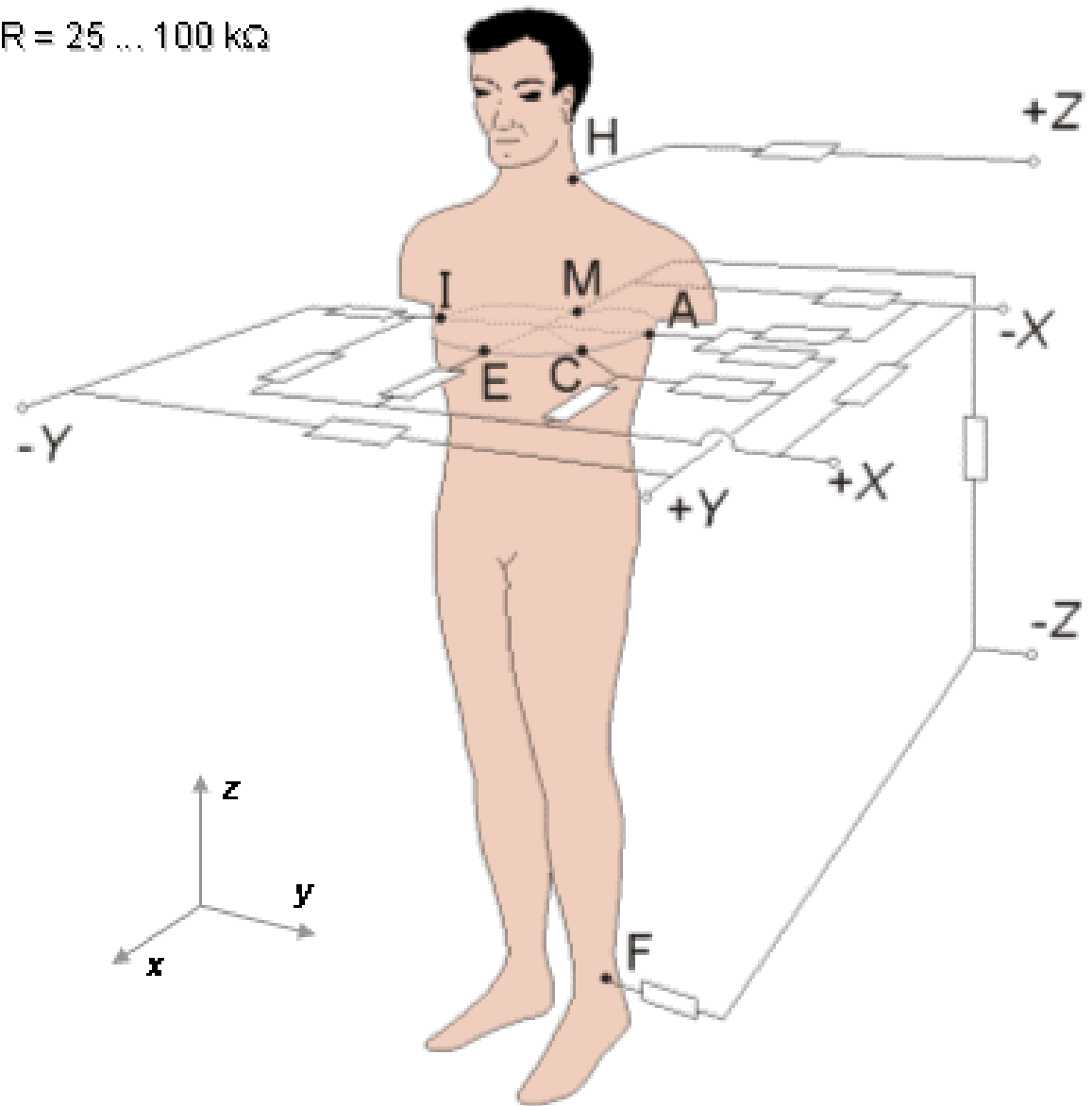
## Vectorcardiography (vcg)

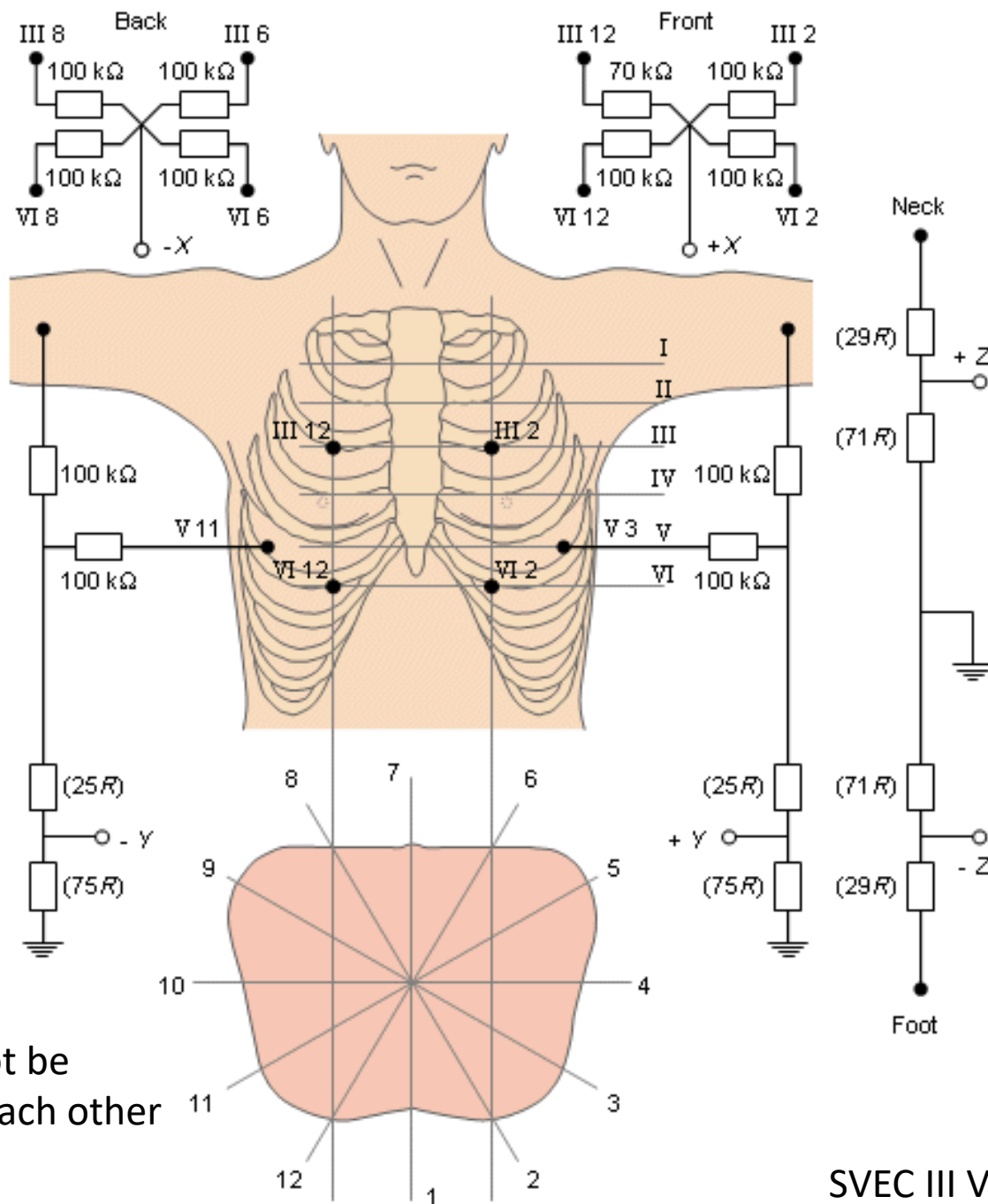


# Frank Lead Matrix



$R = 25 \dots 100 \text{ k}\Omega$

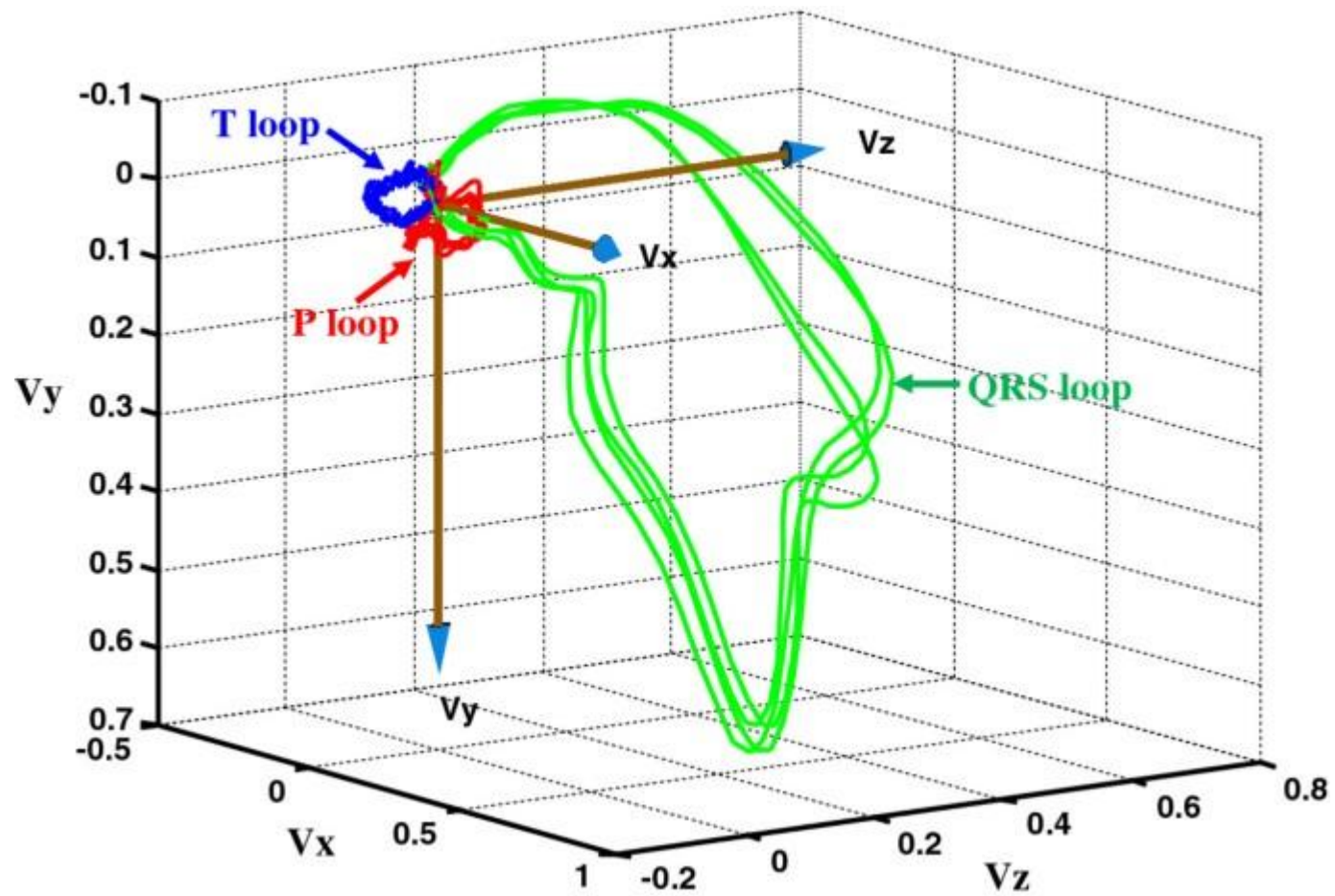




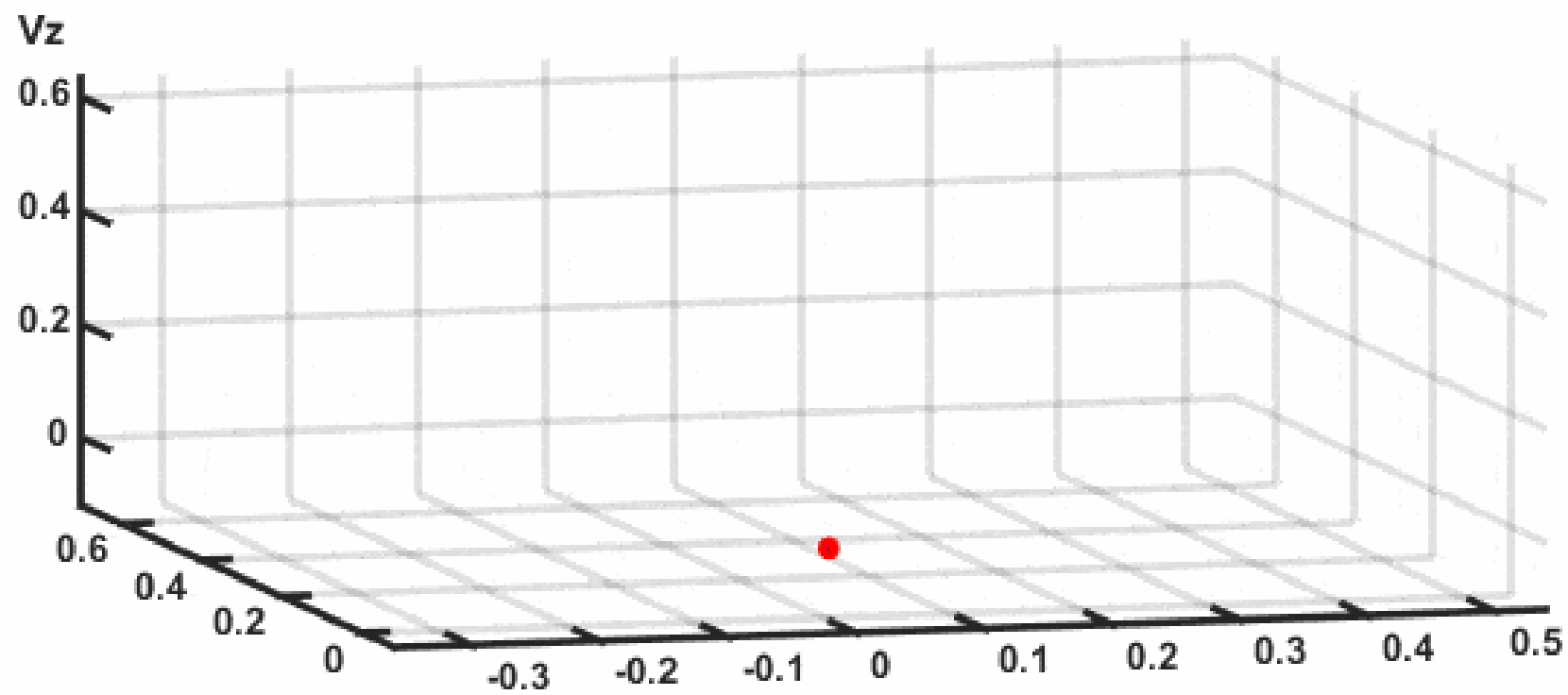
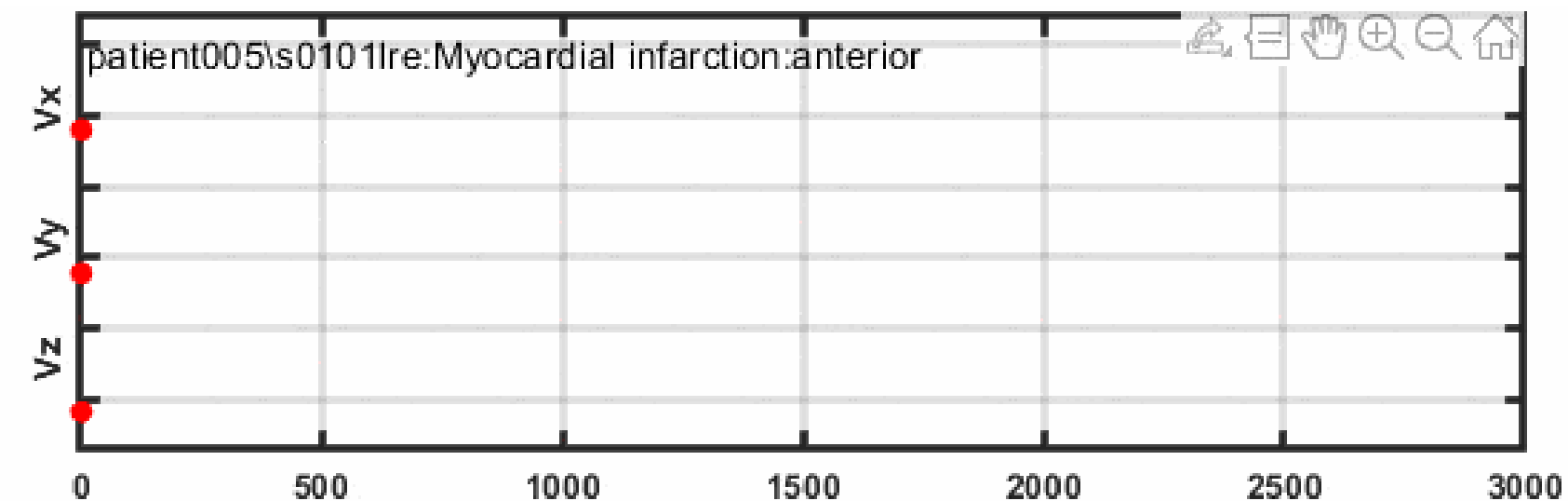
the systems can not be transformed into each other unambiguously

SVEC III VCG lead system.



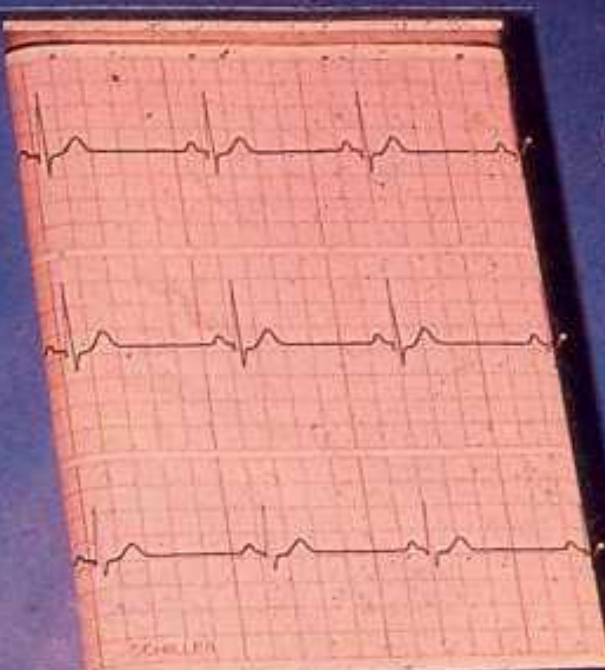


3D representation





SCHILLER  
Switzerland

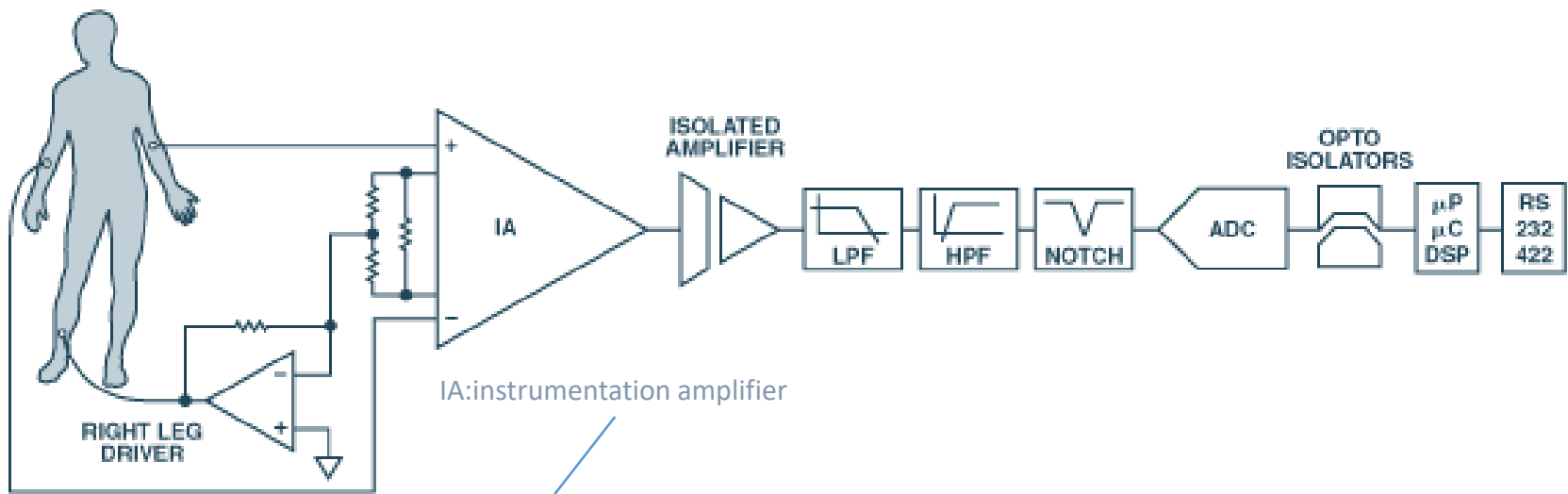


CAL	I II III	aVR aVL aVF
V1 V2 V3	V4 V5 V6	V7 V8 V9
V10	0.25 cm/mV	0.5 cm/mV
1 mV	1.0 cm/mV	2.0 cm/mV

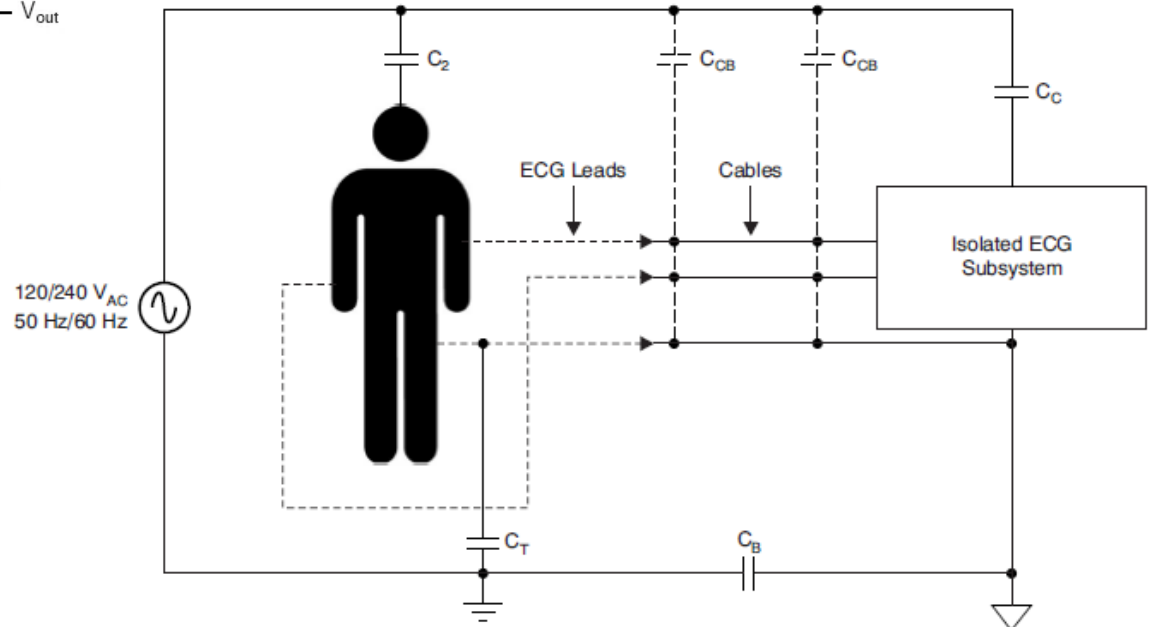
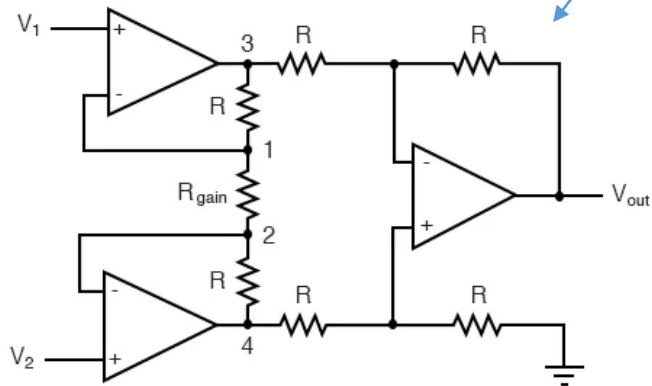
POWER OFF ON BATTERY

MAN START AUTO START STOP RESET

HEART RATE 79

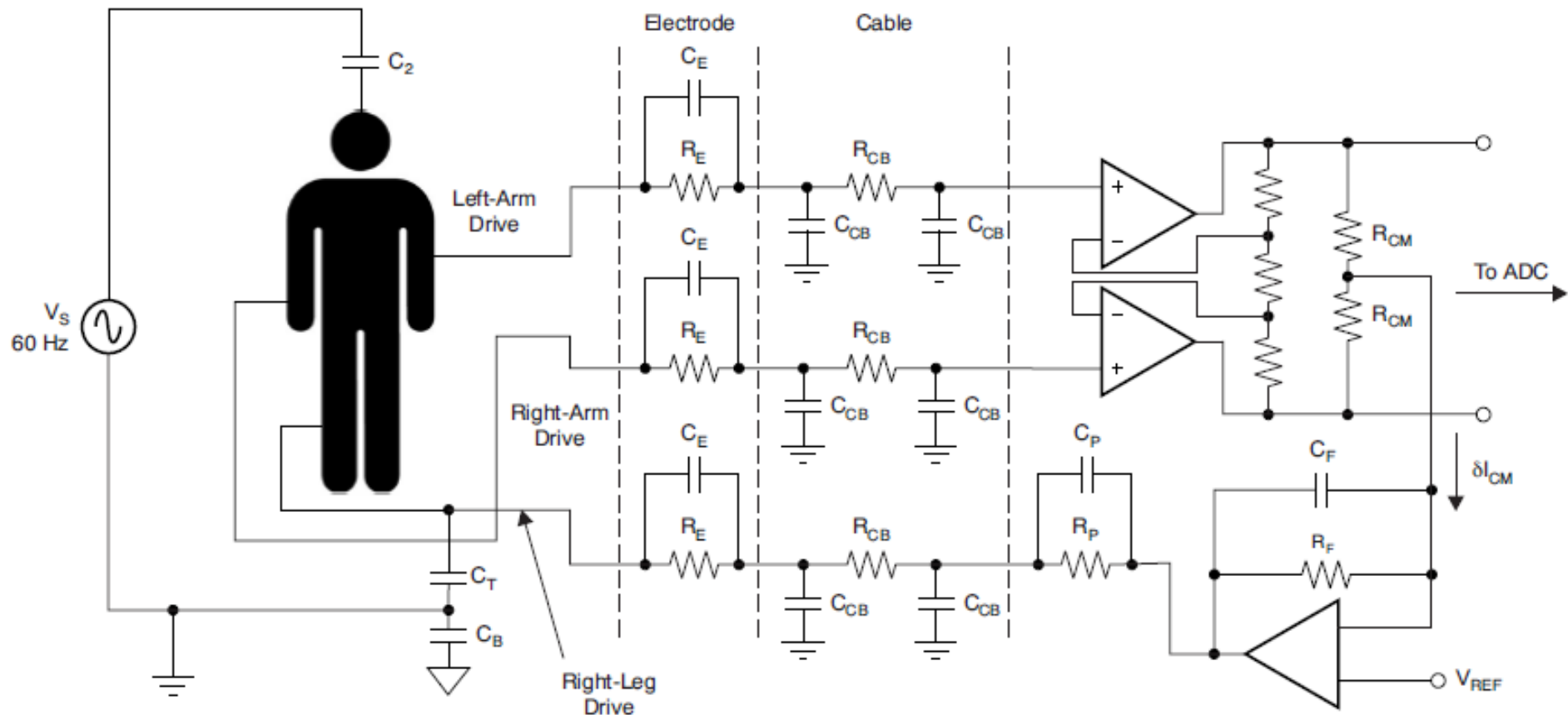


capacitive noise sources  
 50/60 Hz civilian power network  
 $16 \frac{2}{3}$  Hz vacy 25 Hz railway traction networks



the **F** (right leg) is not just a reference input, but the CMR is feed back to it, hence **common mode rejection** improves. (-96dB with RLD feedback from -60dB)

CMR

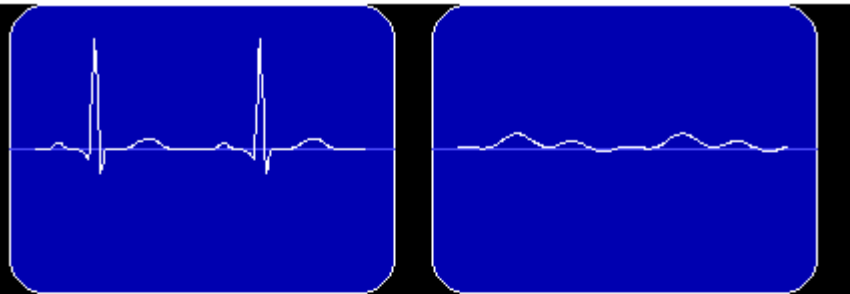


one channel of the ECG amplifier system

$$Signal(t) \longleftrightarrow \sum_i A_i \cdot \sin(\omega_i t) + B_i \cos(\omega_i t)$$

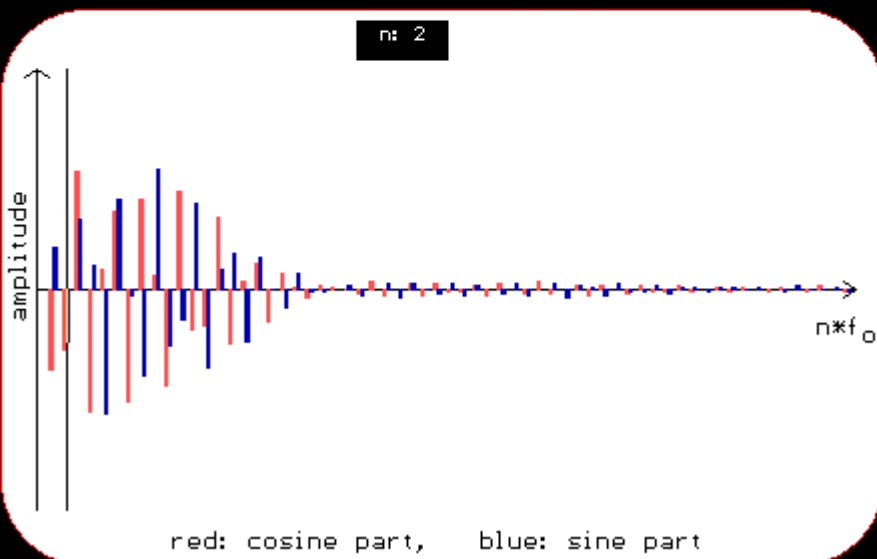
first few components

DOSBox 0.74-3, Cpu speed: 3000 cycles, Frameskip 0, Program: FOURIERA



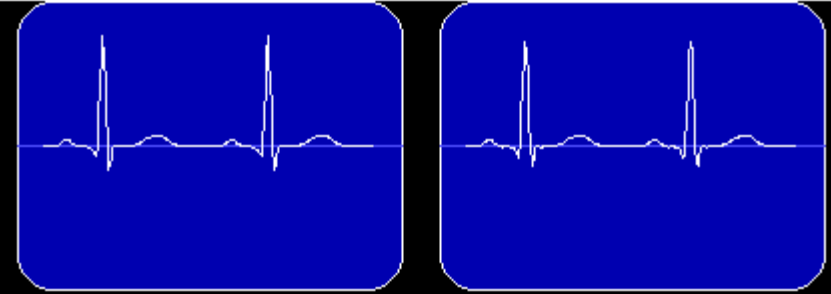
original signal

modified signal



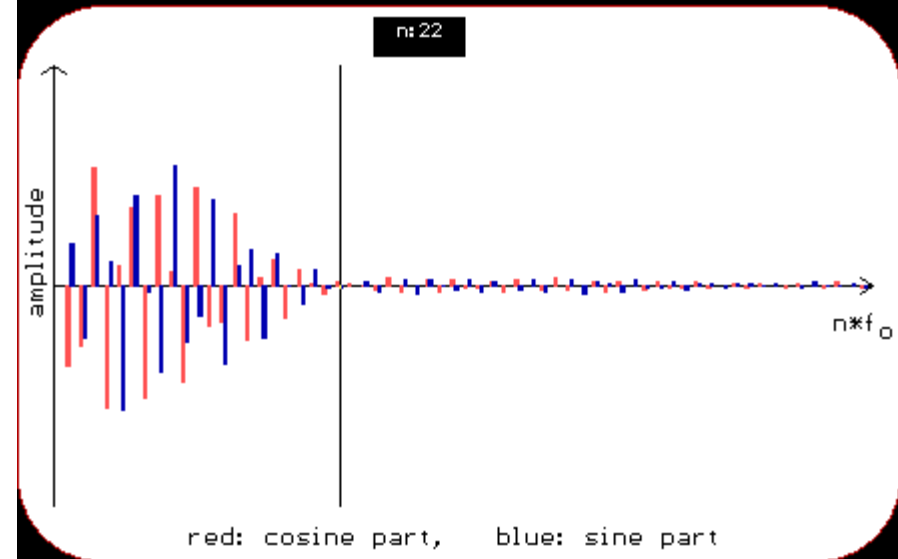
the full band

DOSBox 0.74-3, Cpu speed: 3000 cycles, Frameskip 0, Program: FOURIERA



original signal

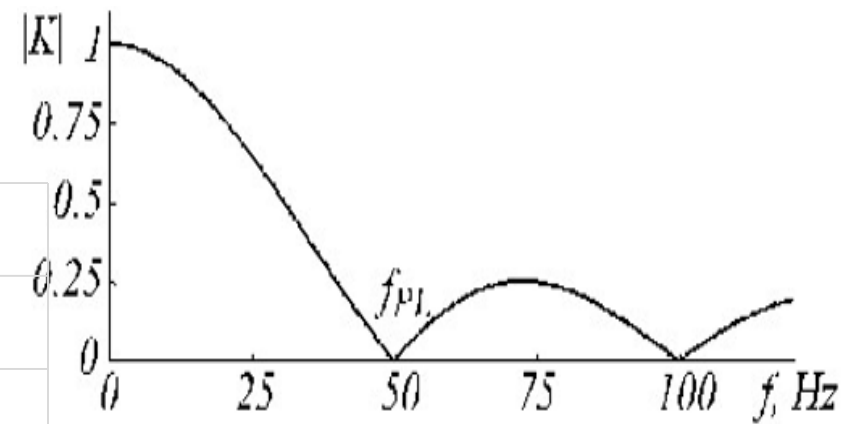
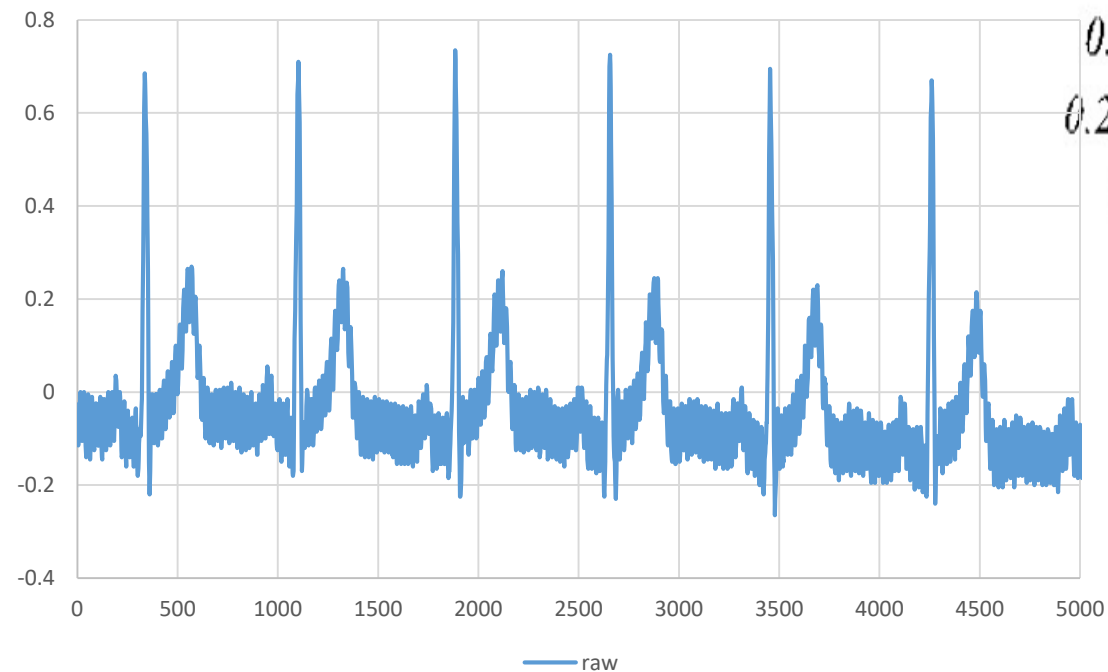
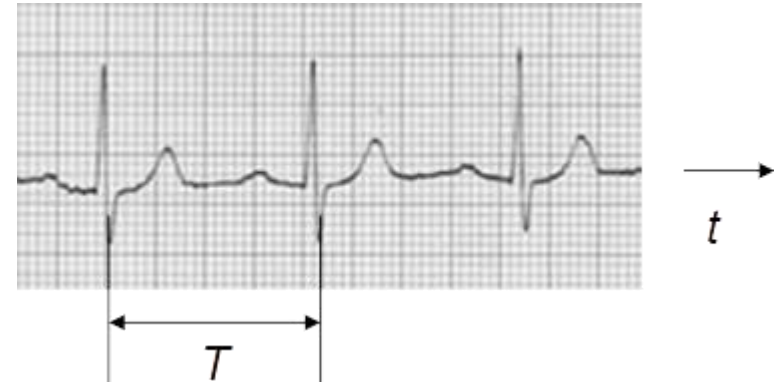
modified signal

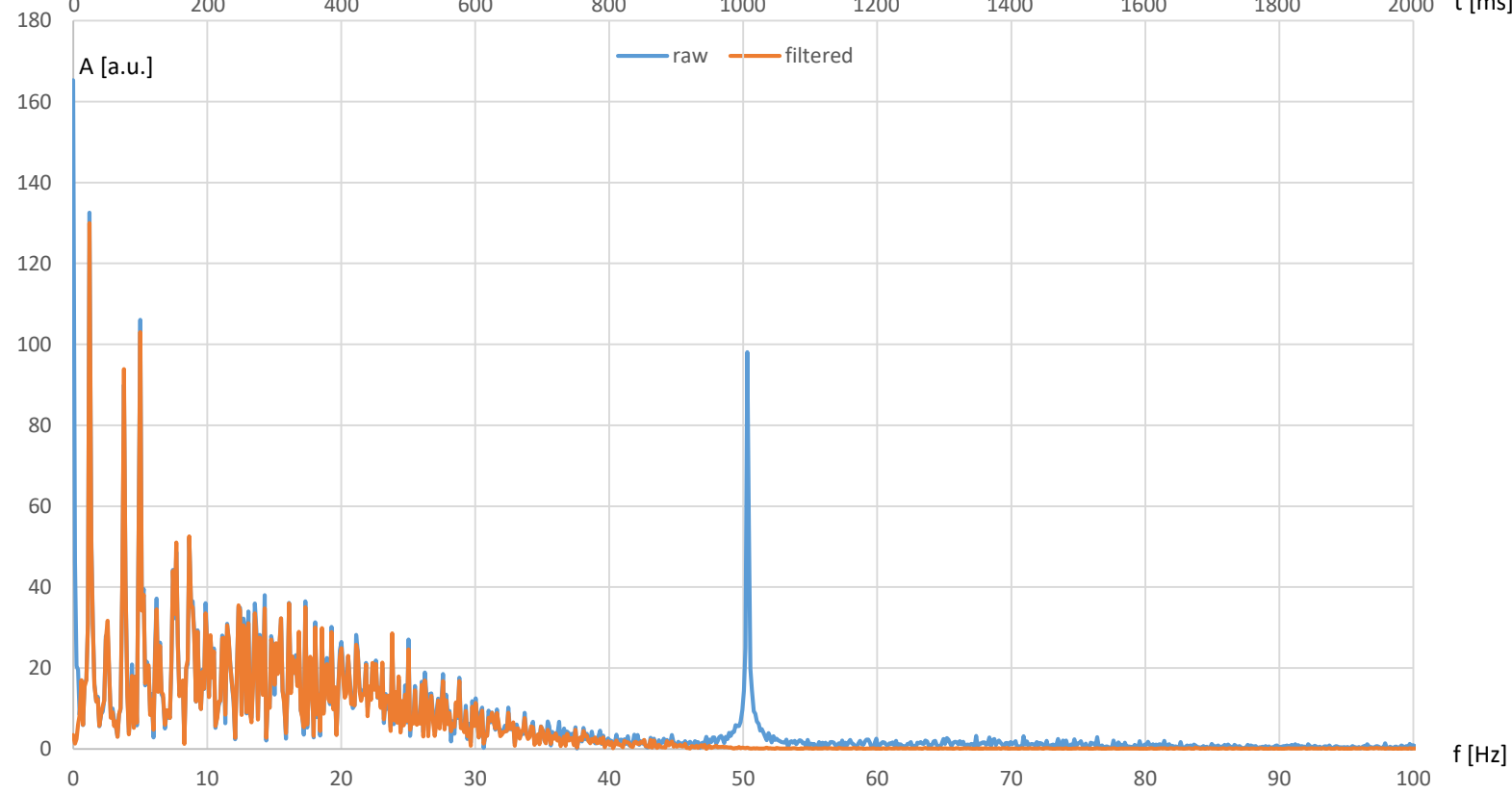
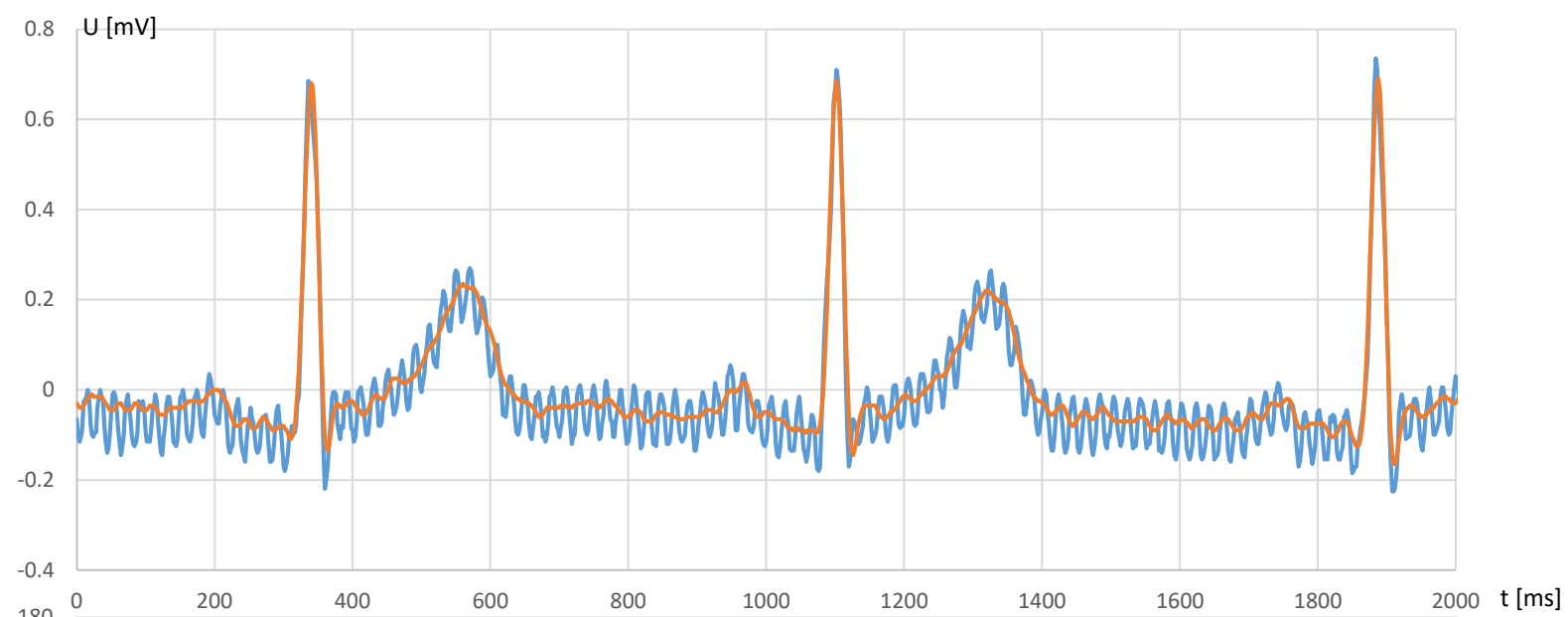


$$\text{Signal}(t) \longleftrightarrow \sum_i A_i \cdot \sin(\omega_i t) + B_i \cos(\omega_i t)$$

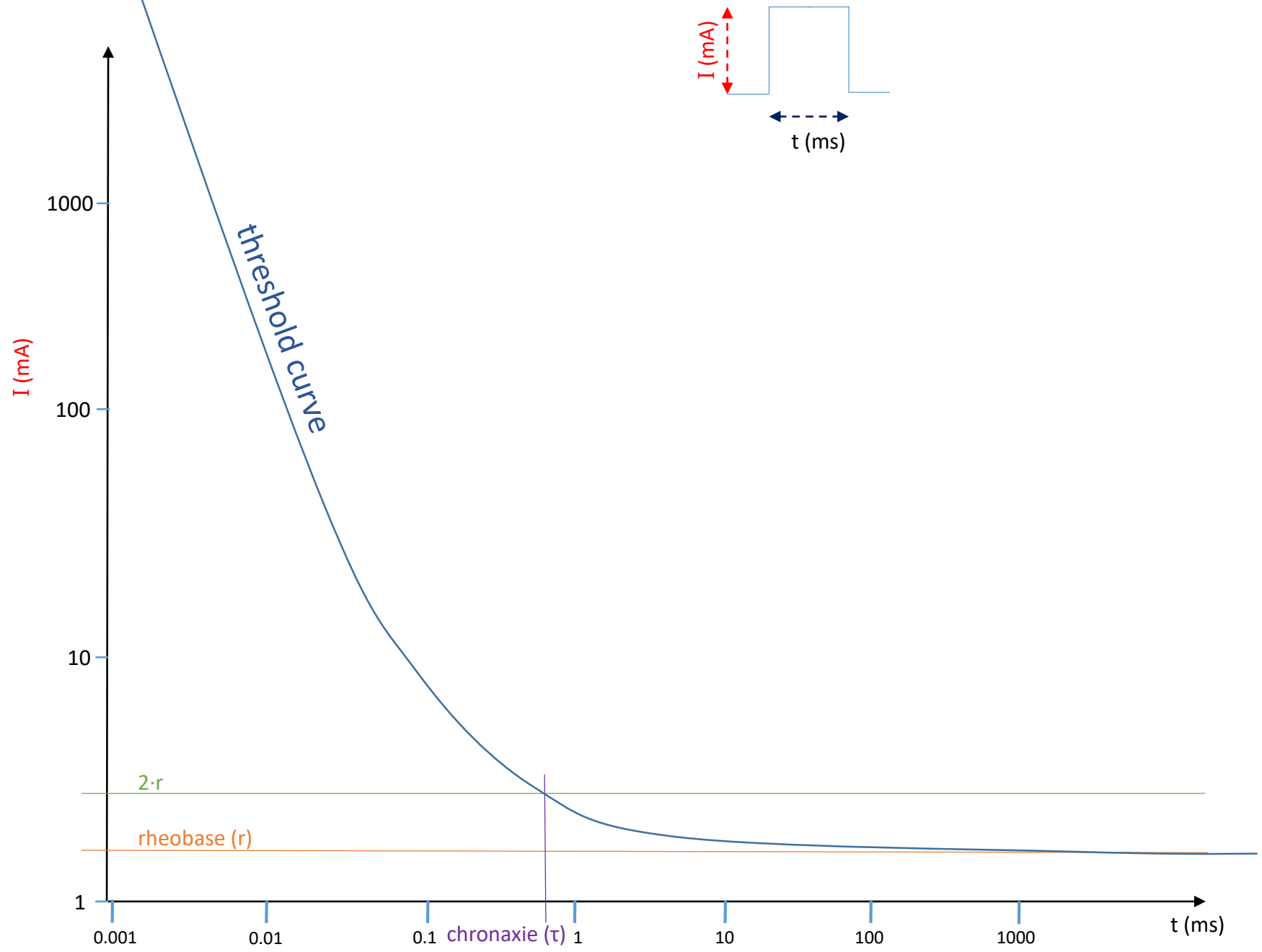
$$\omega_i = 2\pi i / T$$

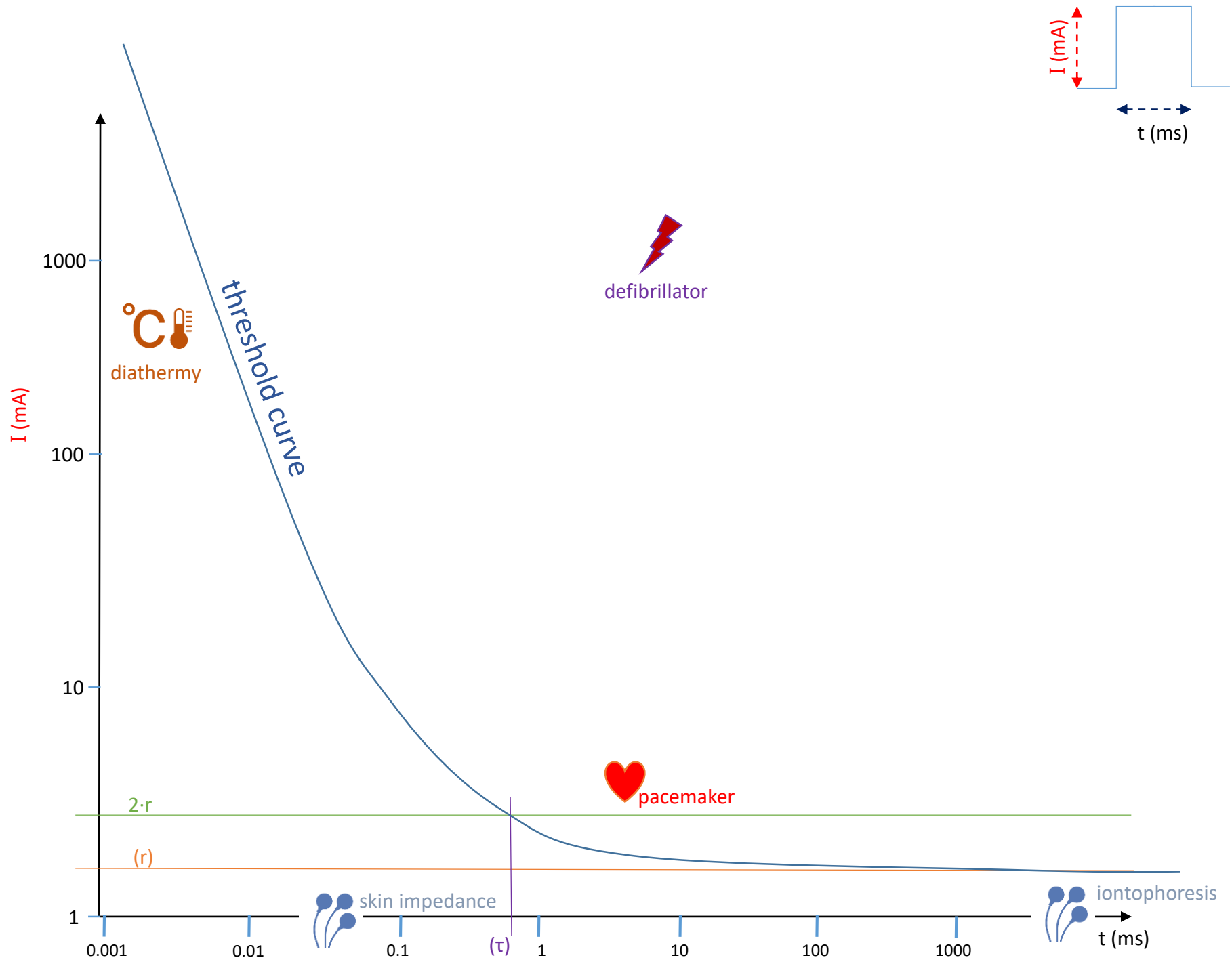
$$F(\omega) = \frac{1}{\sqrt{(2\pi)}} \cdot \int_{-\infty}^{+\infty} f(t) e^{i\omega t} dt$$





# pulsed excitation

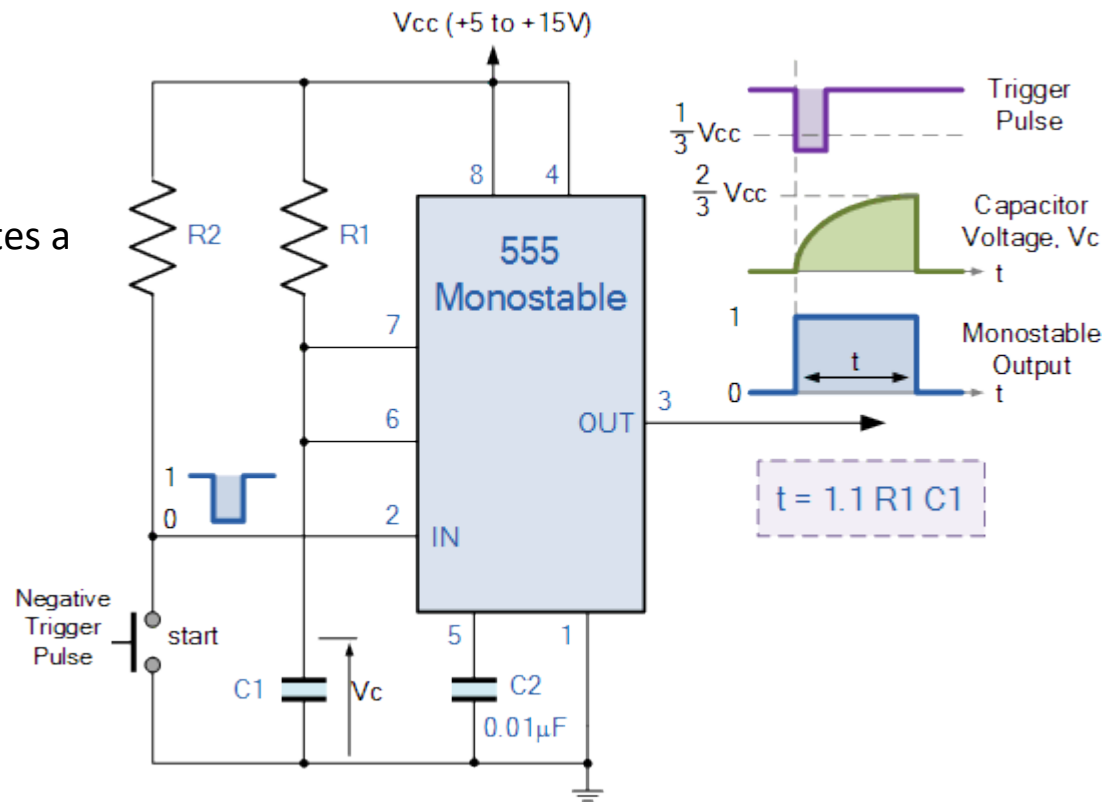
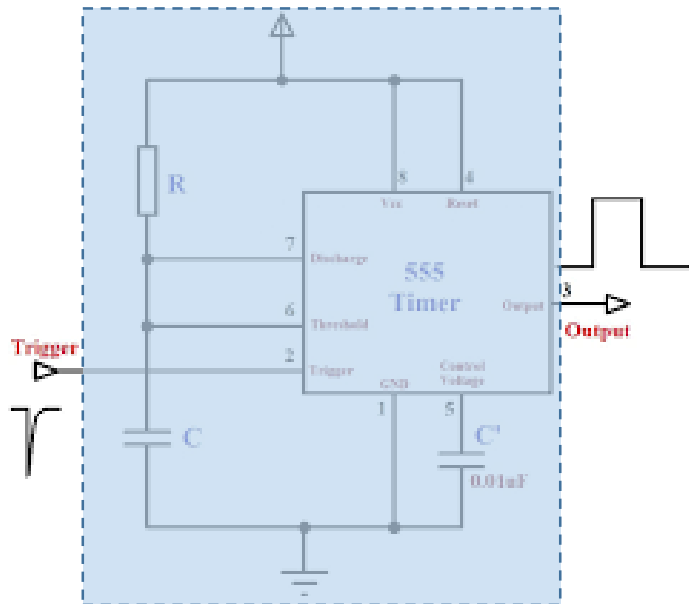






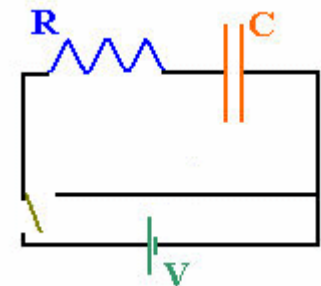
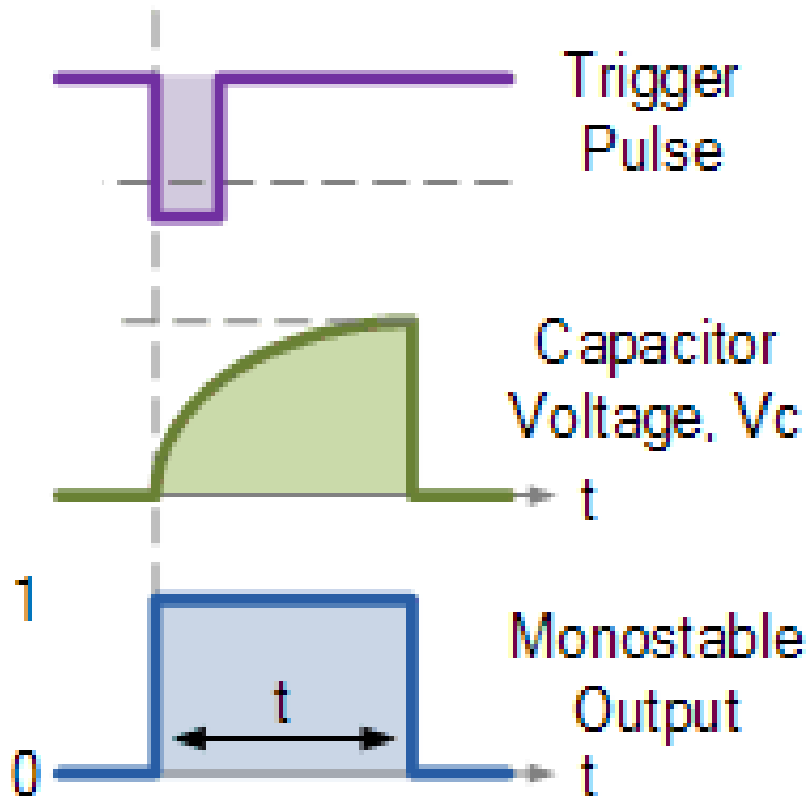
## Pulse generators

Trigger is an INPUT signal which generates a controlled voltage-duration pulse at the output of the monostable circuit.

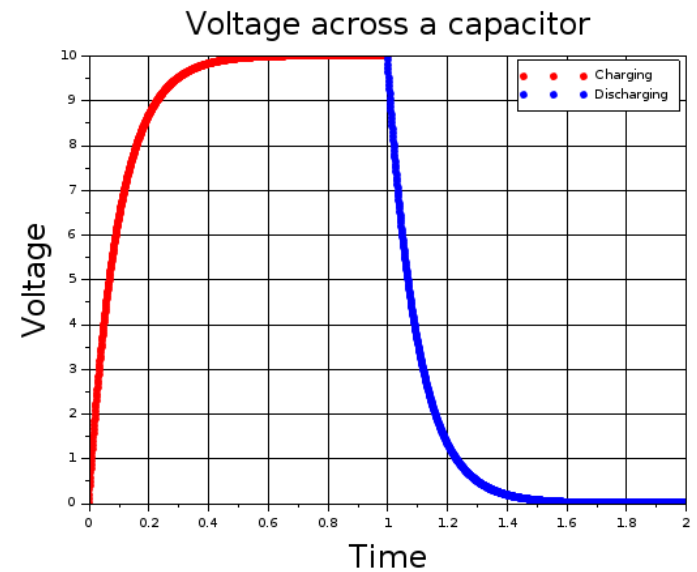


The **monostable** has ONE stable state, which is the inactive one. The active output state is transient, and will be automatically switched off by the device without further external intervention.

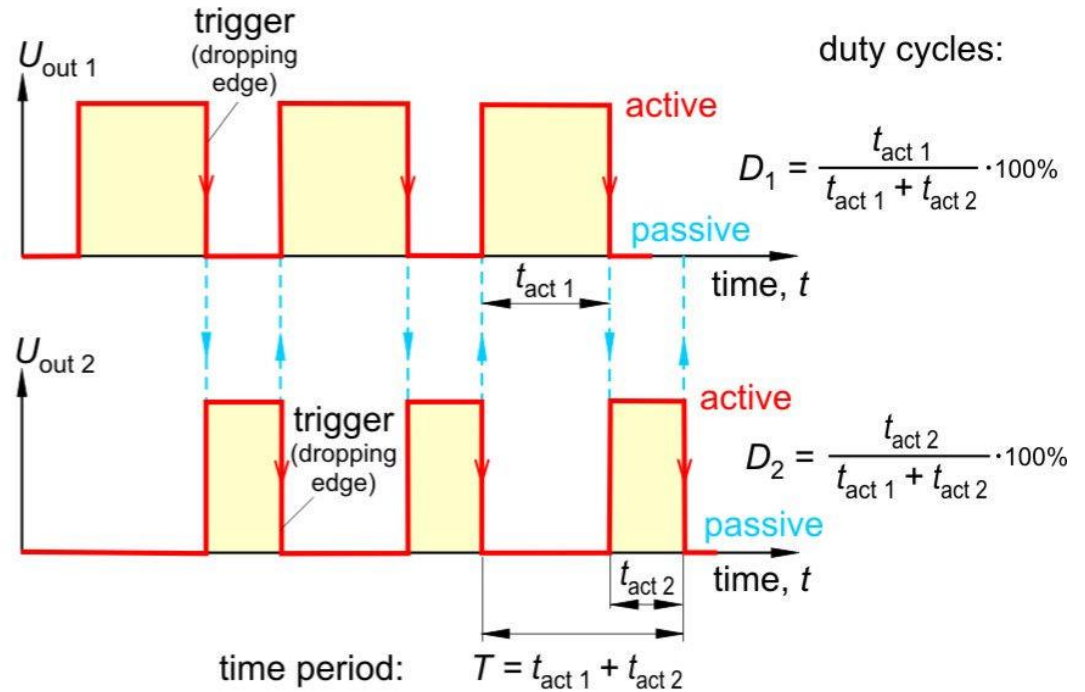
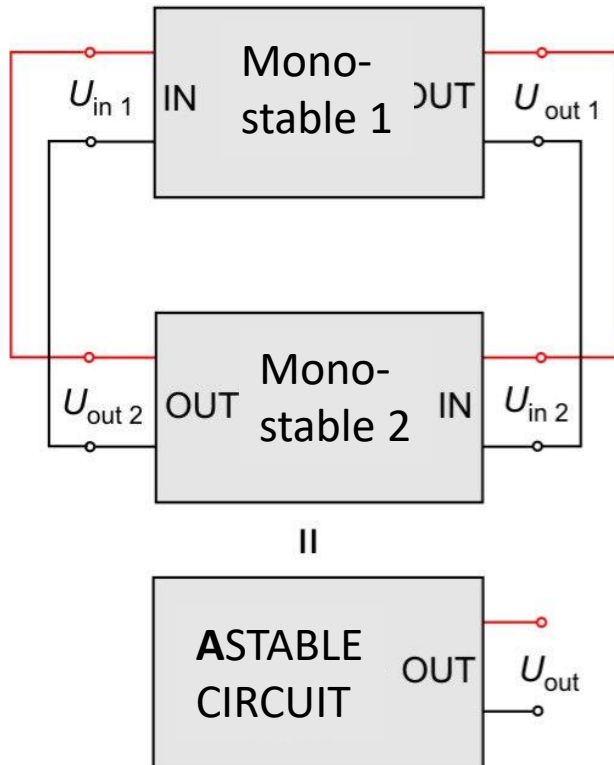
The easiest/robust way to measure time is to charge or discharge a capacitor.

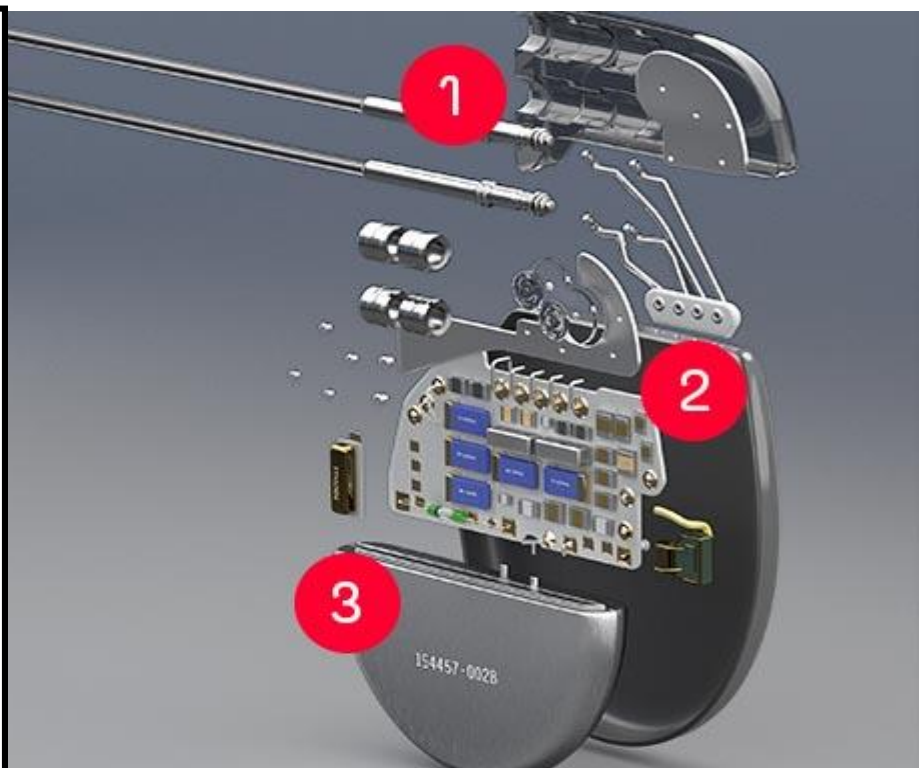
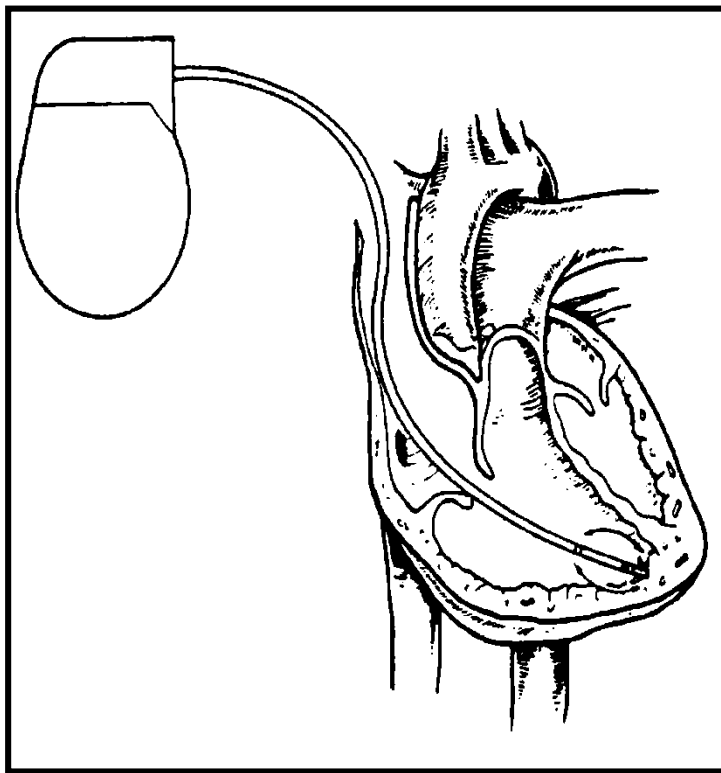


RC circuit  
charging or  
discharging



**Astable circuit:** generates a pulse train without external intervention, has no stable, persistent state.





Pacemaker



# Pacemaker

I.	II.	III.	IV.	V.
Chamber(s) Paced	Chamber(s) Sensed	Response to Sensing	Rate Modulation	Multisite Pacing
0 = None	0 = None	0 = None	0 = None	0 = None
A = Atrium	A = Atrium	I = Inhibited	R = Rate Modulation	A = Atrium
V = Ventricle	V = Ventricle	T = Triggered		V = Ventricle
D = Dual (A+V)	D = Dual (A+V)	D = Dual (I+T)		D = Dual (A+V)



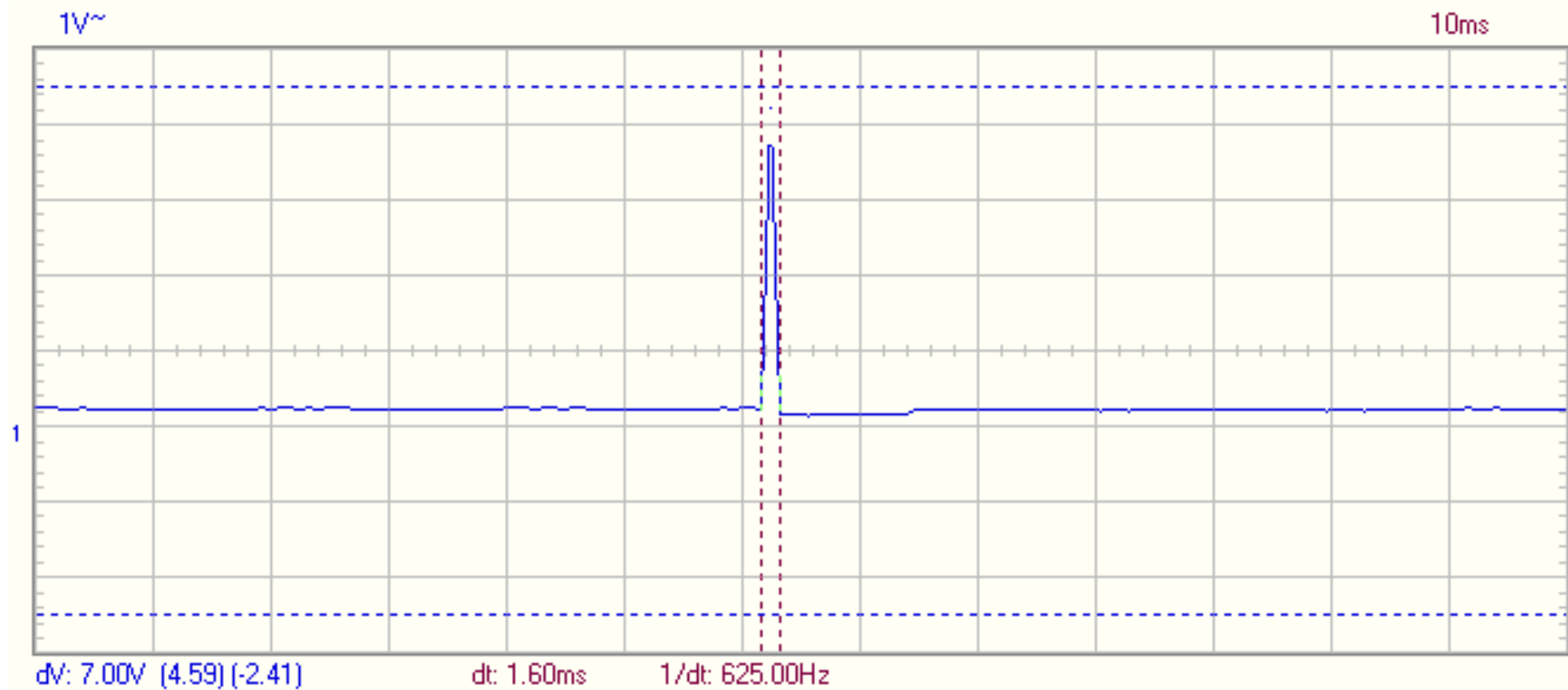
Here we have: VVIR/AAIR



The time period is approx. 1s without regulation



Typical pulse duration is 1-2 ms



## Calculation of pulse energy

Known voltage and tissue resistance, known pulse duration time

$$E = \frac{U^2}{R} \tau$$

$$Q = \frac{U}{R} \tau$$

$$P = U \cdot I, I = U/R$$

$$P = U^2/R$$

$$R = P \cdot t$$

$$t = \tau = R \cdot C$$

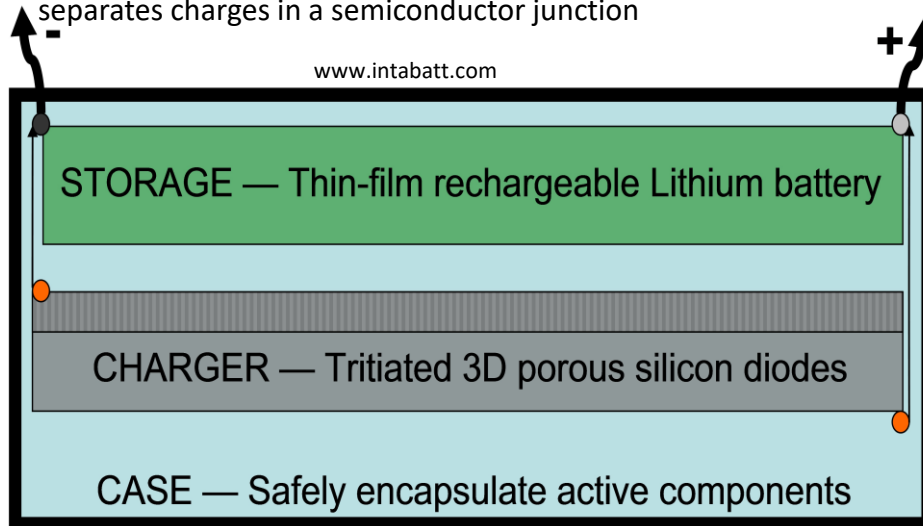
$$Q = I \cdot t$$

**A LONG lasting battery is needed.**

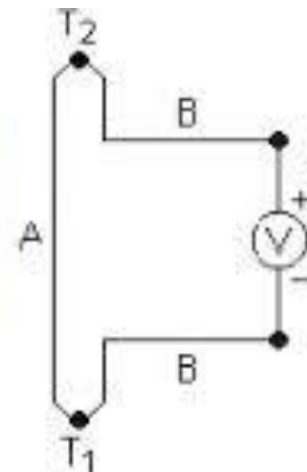
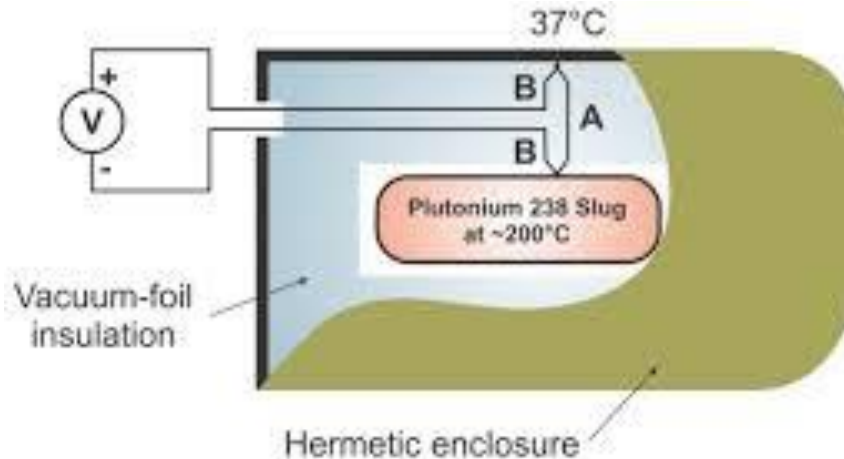
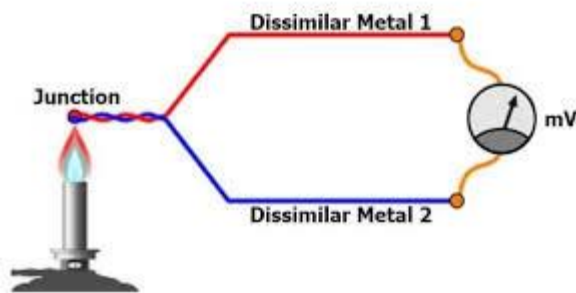
**A battery change = exchange of the whole device = operation!**

## $\beta$ -radiation powered cell.

Betavoltaic cell: similar to photovoltaics, the ionization separates charges in a semiconductor junction



## RTG : radioaktive thermoelectric generator



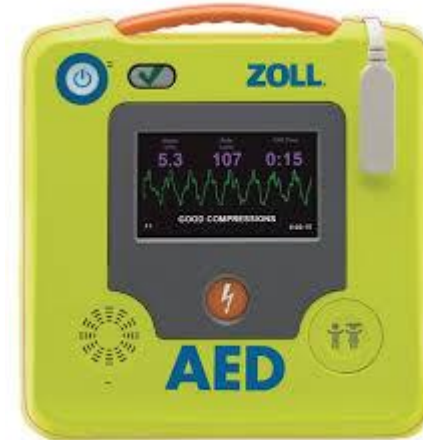
## Defibrillator

(monostable)

fibrillation

defibrillation

back to normal



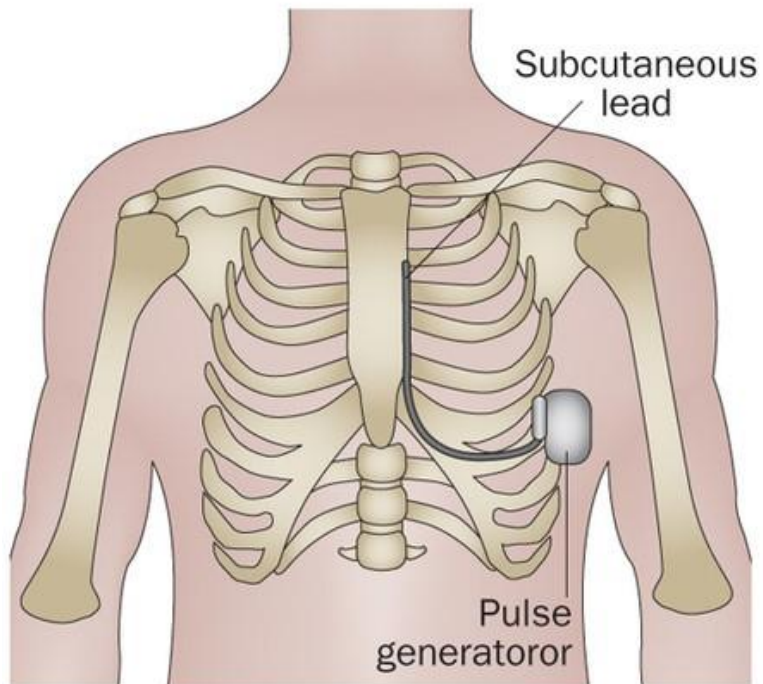
AED: Automated External Defibrillator

## Cardioverter

ICD: Implantable Cardioverter Defibrillator



S-ICD



Transvenous ICD

