Quiz

Electrodes N and RL are

- ☐ averaged for Wilson CT potential
- ☐ negative and right-lead electrodes
- ☐ white and purple electrodes
- ☐ two names for the same electrode

Atrial fibrillation may cause

- ☐ brain stroke
- ☐ heart attack
- ☐ heart failure
- ☐ ischemia

The stratum corneum is

- ☐ a good electrical conductor
- ☐ about 1 mm thick
- ☐ made of keratin
- ☐ made of living cells and fat

Cells transmit signals with an

- ☐ electron current
- ☐ ion current
- ☐ action potential wave
- ☐ electromagnetic wave

Quiz

The 12-lead ECG system is a set of

- ☐ independent signals
- ☐ standardized signals
- ☐ 12-electrode potentials
- ☐ signals displayed for 12 s

A current electrode is

- ☐ not for potential measurement
- ☐ for current measurement
- ☐ ideally a polarized electrode
- ☐ for defibrillation

Systole is the period defined by high

- ☐ right ventricle pressure
- ☐ left ventricle pressure
- ☐ right atrium pressure
- ☐ left atrium pressure

$Ag/Ag^{+}Cl^{-}$ electrodes

- ☐ are made of three materials
- ☐ are non-polarized electrodes
- ☐ do not have half-cell potential
- ☐ are best for dry electrodes

EE-511 Sensors in medical instrumentation

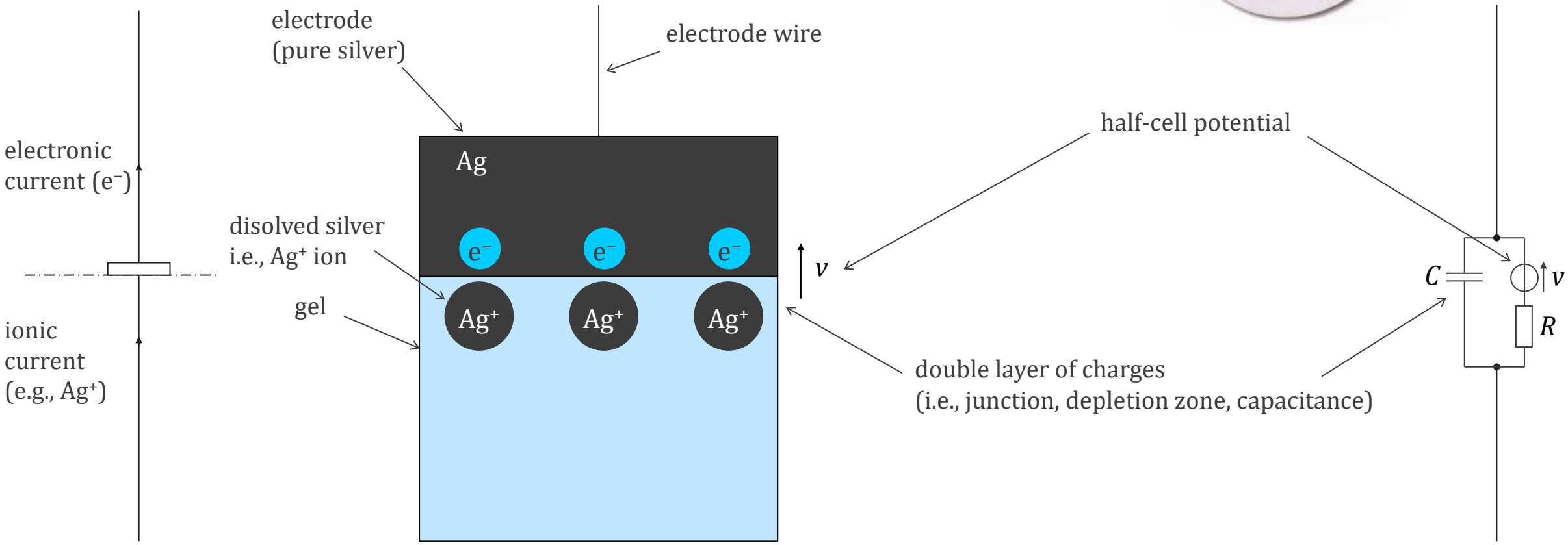
Section 4.4 – Electrodes

Objectives

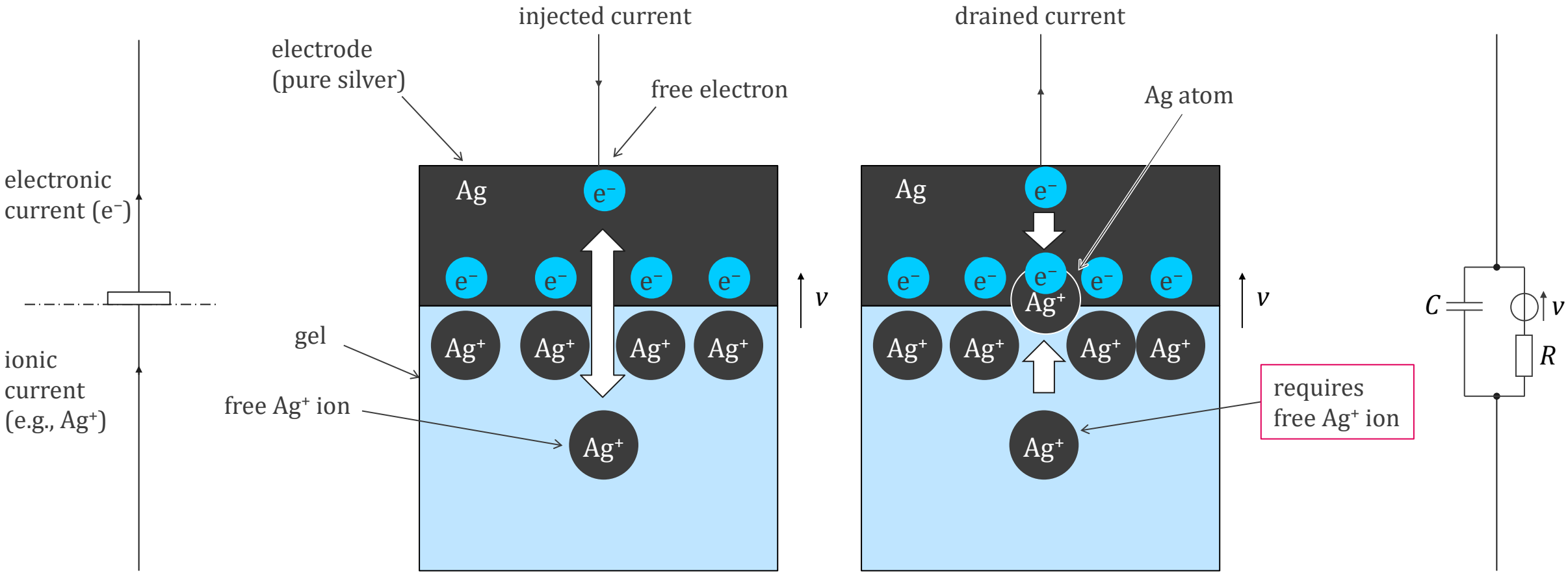
understand:

- contact, electrode
- electrode model, electrode potential, polarized, non-polarized electrode
- motion artefacts
- galvanic, capacitive electrode, noise
- stratum corneum, dry electrode
- potential electrode, current electrode

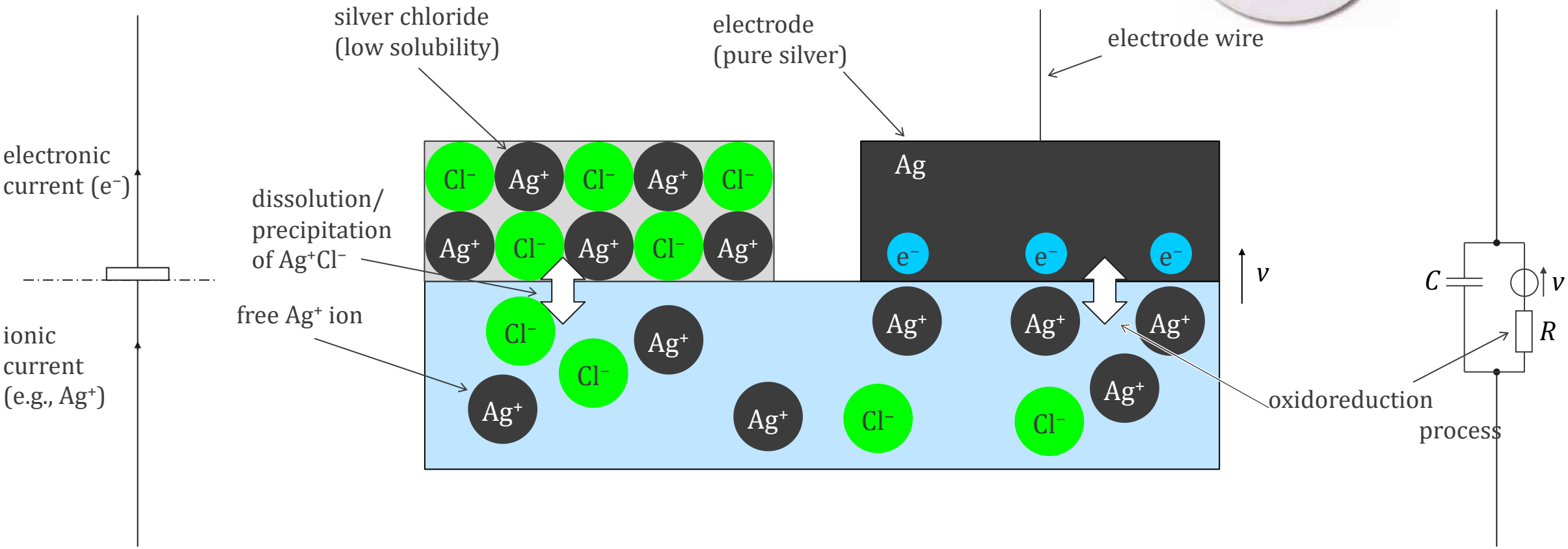
4.4.1 Half-cell potential



4.4.2 Electron-ion transducer and electrode model



4.4.3 Ag/Ag^+Cl^- electrode

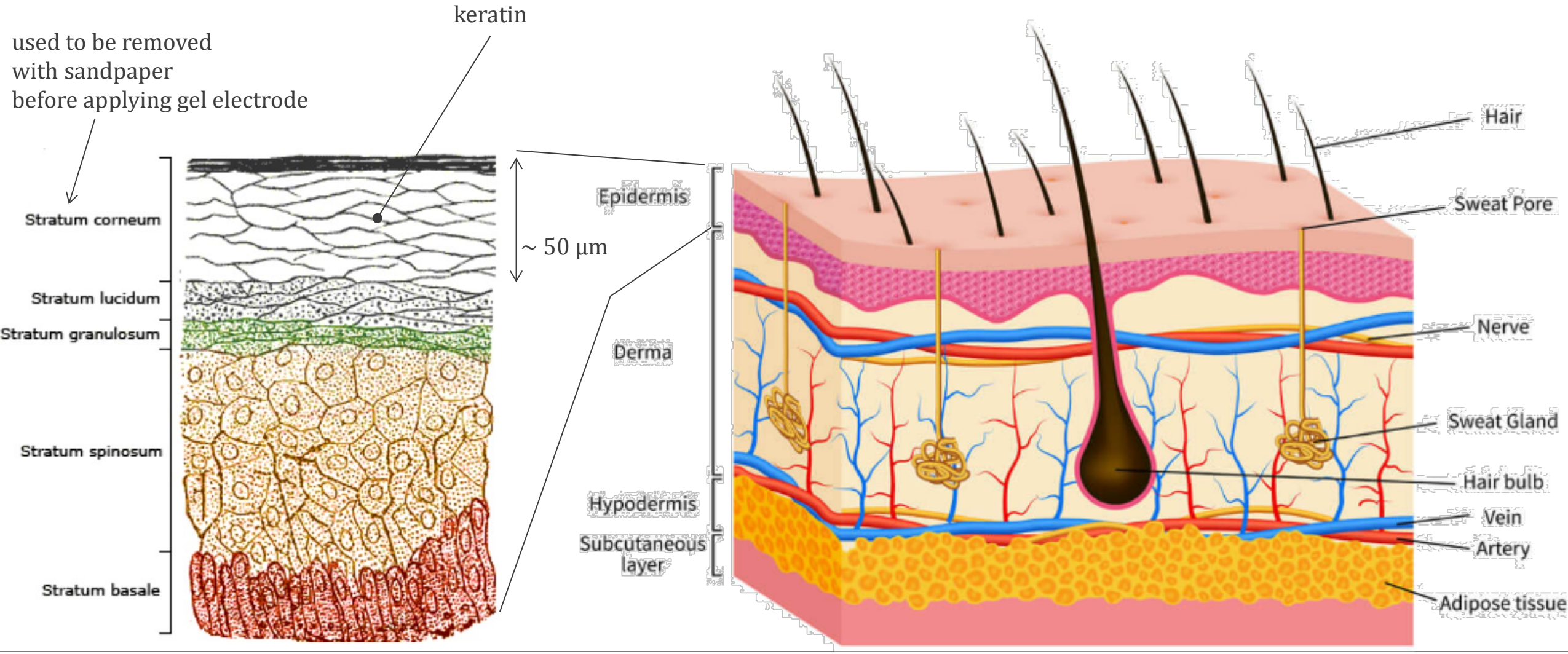


Definition:

polarized electrode: $R \to \infty$ (e.g., Pt)

non-polarized electrode: $R \to 0$ (e.g., Ag/Ag^+Cl^-)

4.4.4Skin

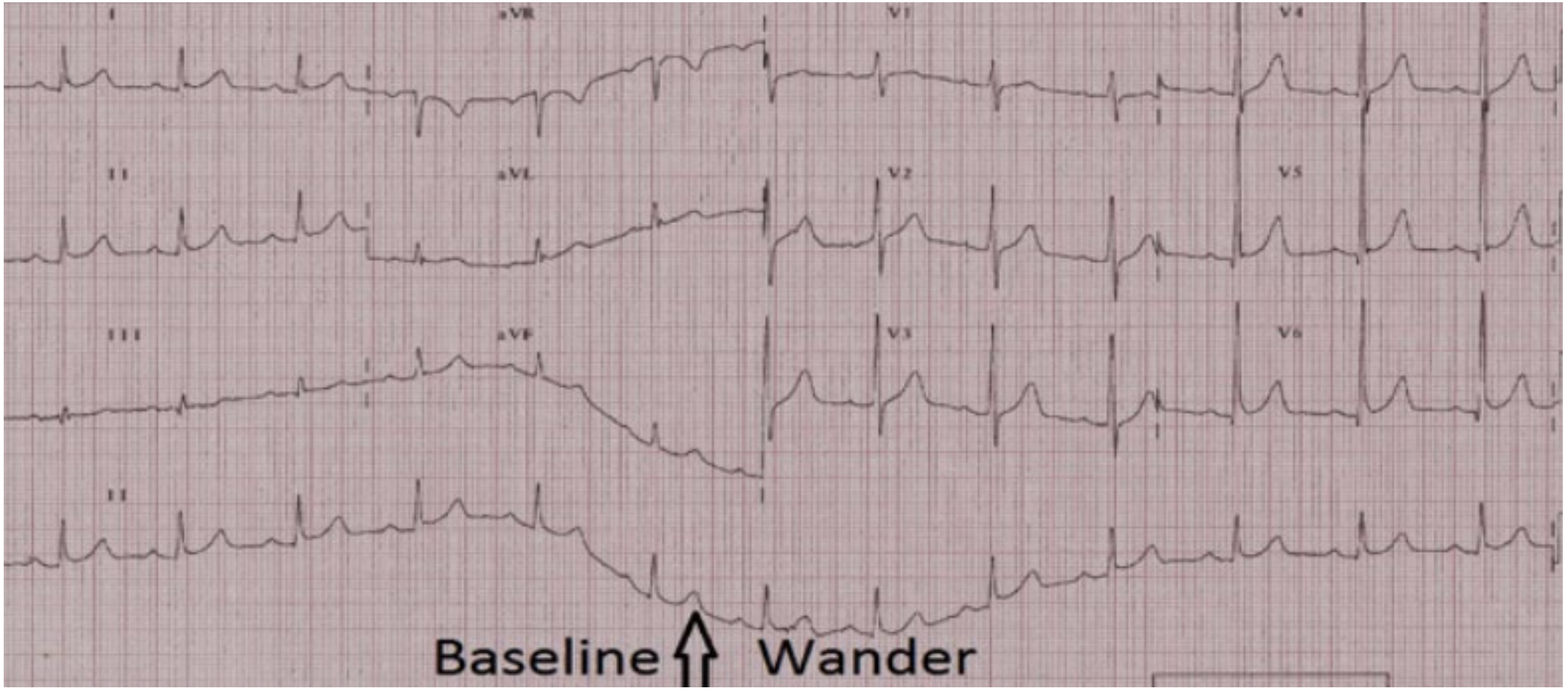

keratin
used to be removed
with sandpaper
before applying gel electrode
Stratum corneum
Stratum lucidum
Stratum granulosum
Stratum spinosum
Stratum basale
~ 50 µm
Epidermis
Derma
Hypodermis
Subcutaneous layer
Hair
Sweat Pore
Nerve
Sweat Gland
Hair bulb
Vein
Artery
Adipose tissue

4.4.5Dry electrodes

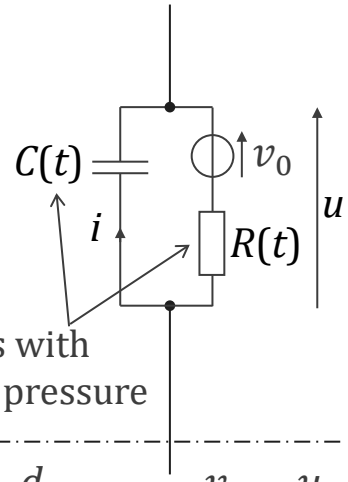
Dry electrodes versus gel electrodes

- Dry electrodes
  - have a lower effective contact area
  - have a higher impedance (at least an order of magnitude)
  - which is also more variable with changes of pressure (gel/water makes a cushion)

4.4.7Motion artefact

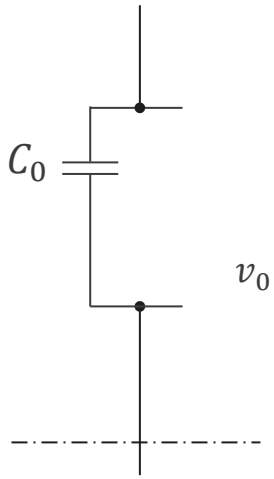


4.4.7Motion artefact (continued)



changes with contact pressure

$$\frac{d}{dt}\underbrace{(uC)}_{q} = \frac{v_0 - u}{\underbrace{R}_{i}}$$

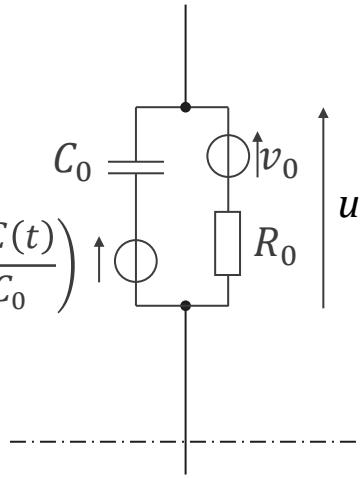


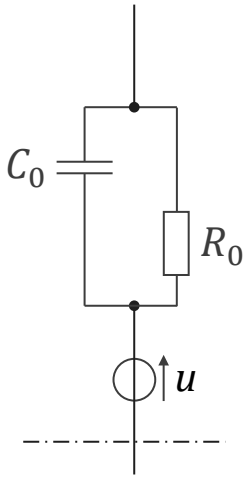
charges are conserved:

$$q = v_0 C_0 = vC$$

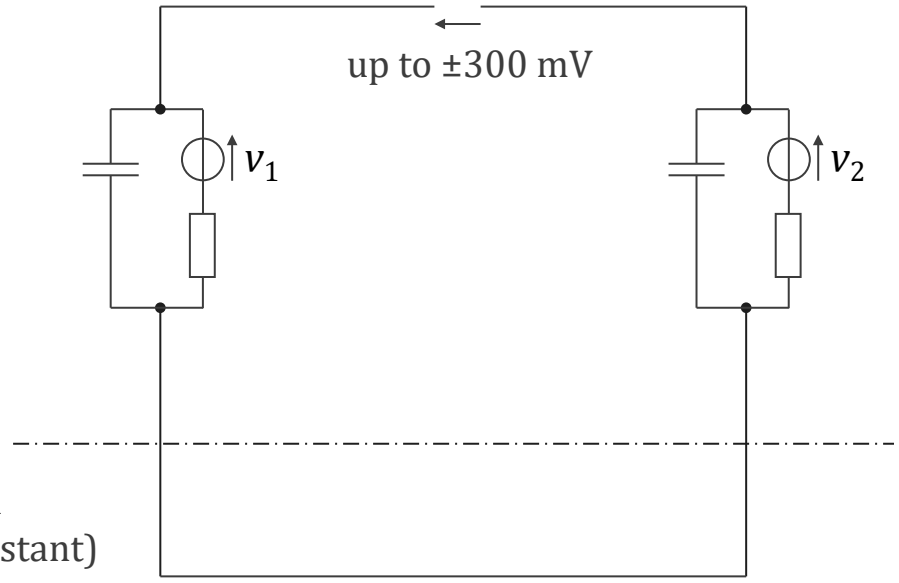
$$\Rightarrow v = \frac{v_0 C_0}{C} \simeq v_0\left(1 - \frac{\Delta C}{C_0}\right)$$

Taylor expansion



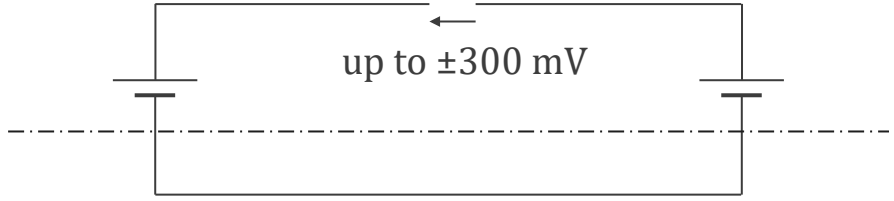


simplified model
(assuming C and R constant)

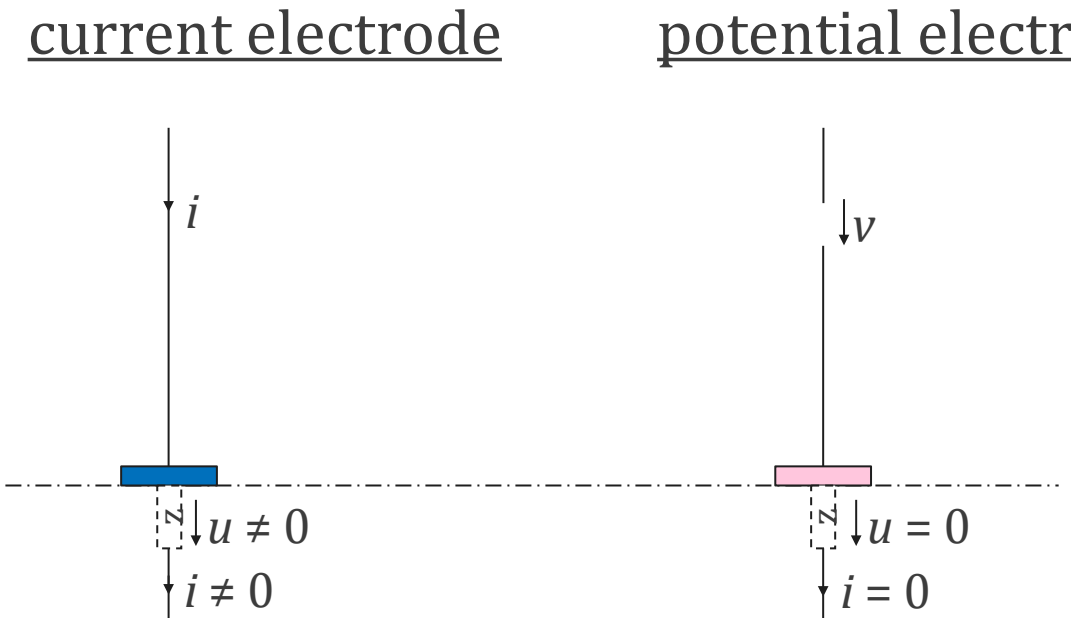


$$\boxed{u = v_0\left(1 - \frac{R_0 s}{1 + R_0 C_0 s}\Delta C(t)\right)}$$

small $R_0|C_0$ is good
$(\sim 1/A|A)$



4.4.6Potential and current electrodes

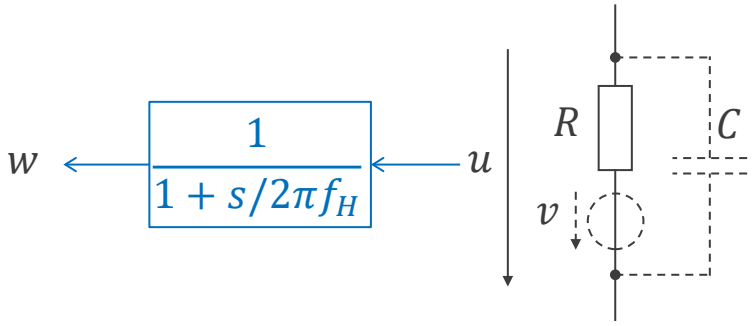


note: an electrode can be of a given type for a channel (e.g., frequency band or time slot) and of another type for another channel

4.4.8Galvanic and capacitive electrodes

galvanic electrodes

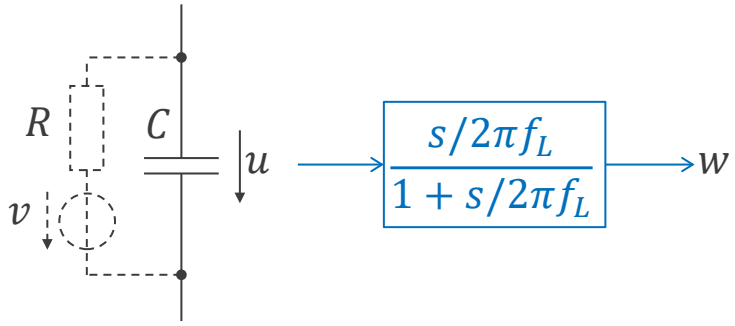
- too much thermal noise when $R > 1$ MΩ



$$\sigma_w^2 = 2\pi f_H k_B T R$$

capacitive electrodes

- too much thermal noise when $R < 300$ TΩ



$$\sigma_w^2 = \frac{k_B T}{C(1 + 2\pi f_L RC)}$$

(see section 2.1.7)

EE-511 Sensors in medical instrumentation

Section 4.5 – Metrology of biopotentials

4.5.1 Devices for biopotential measurement

4.5.2 Magnetic interferences

4.5.3 Electric interferences

4.5.4 Common mode

~~4.5.5 BASIC SAFETY and ESSENTIAL REQUIREMENTS for ECG~~

~~4.5.6 BASIC SAFETY and ESSENTIAL REQUIREMENTS for EEG~~

~~4.5.7 Other requirements~~

4.5.8 Examples of complete circuits

~~4.5.9 Two-electrode devices~~

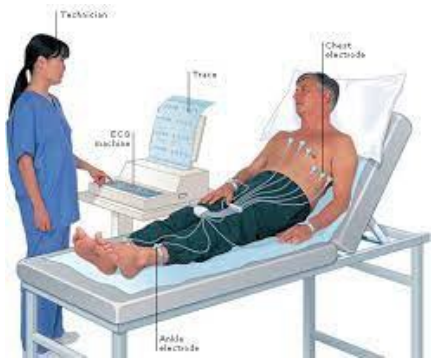
Objectives

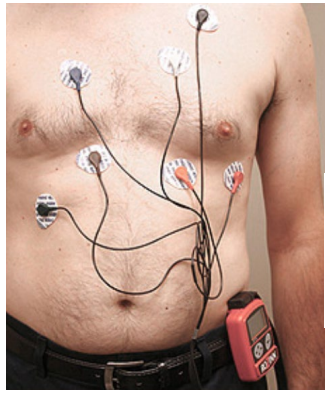
understand:

- EM interference, shielding
- neutral electrode
- gain mismatch, common mode
- defibrillation, ESD protection

4.5.1Devices for biopotential measurement

- Electrocardiographs (60601-2-25)
- Electrocardiographic monitoring equipment (60601-2-27)
- Ambulatory electrocardiographic systems (60601-2-47)—Holter
- Heartrate monitors (sports, fitness)



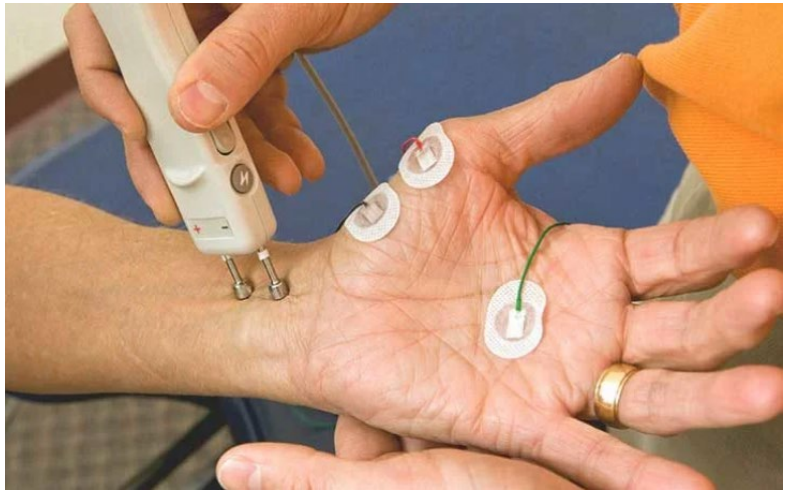


4.5.1Devices for biopotential measurement (continued)

- Electroencephalographs (60601-2-26)

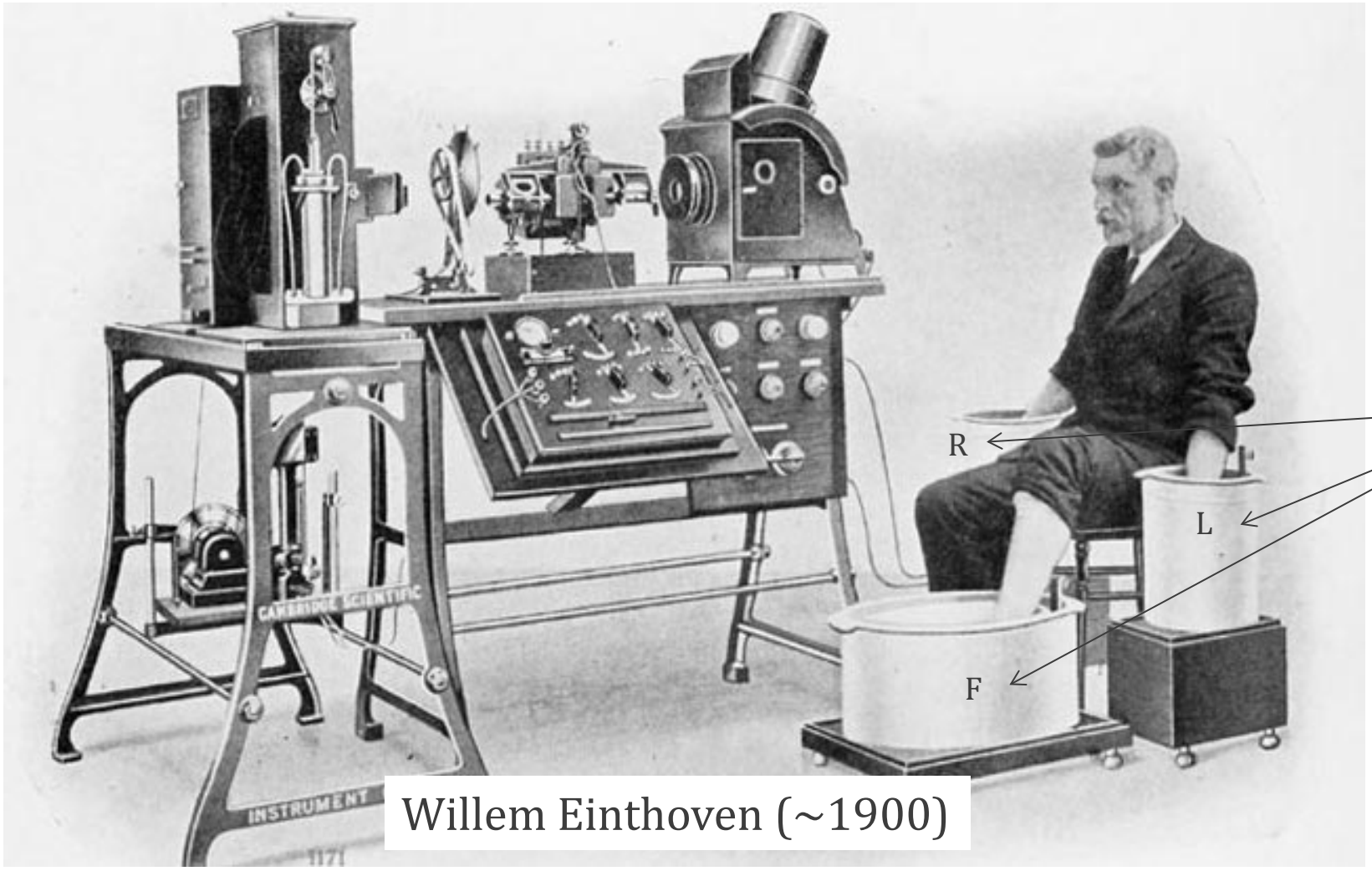
- Electromyographs and evoked response equipment

- ECGi (electrocardiographic imaging)



4.5.1Devices for biopotential measurement (continued)

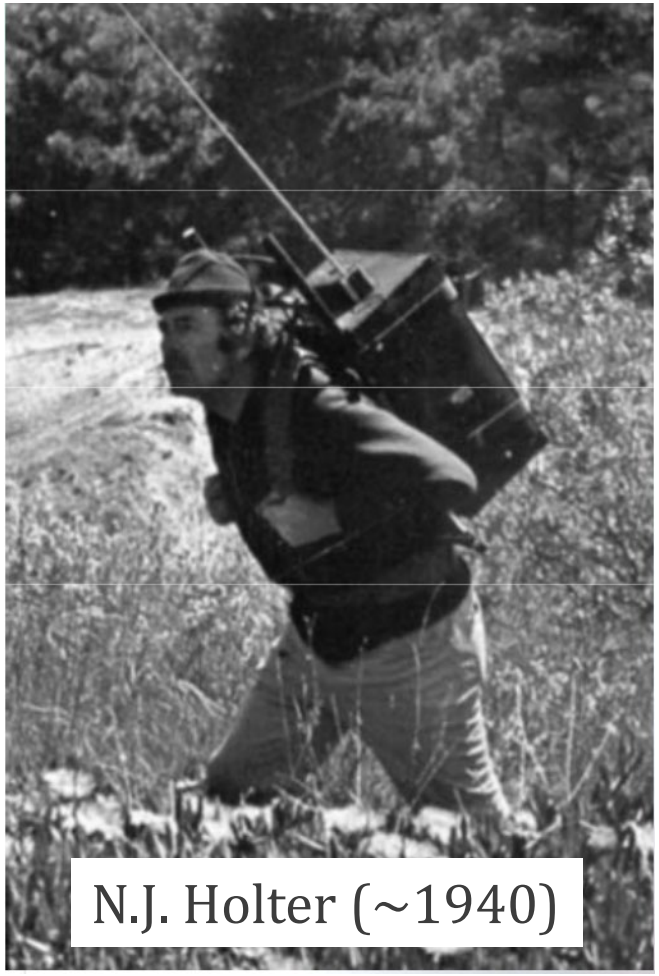
Precursors



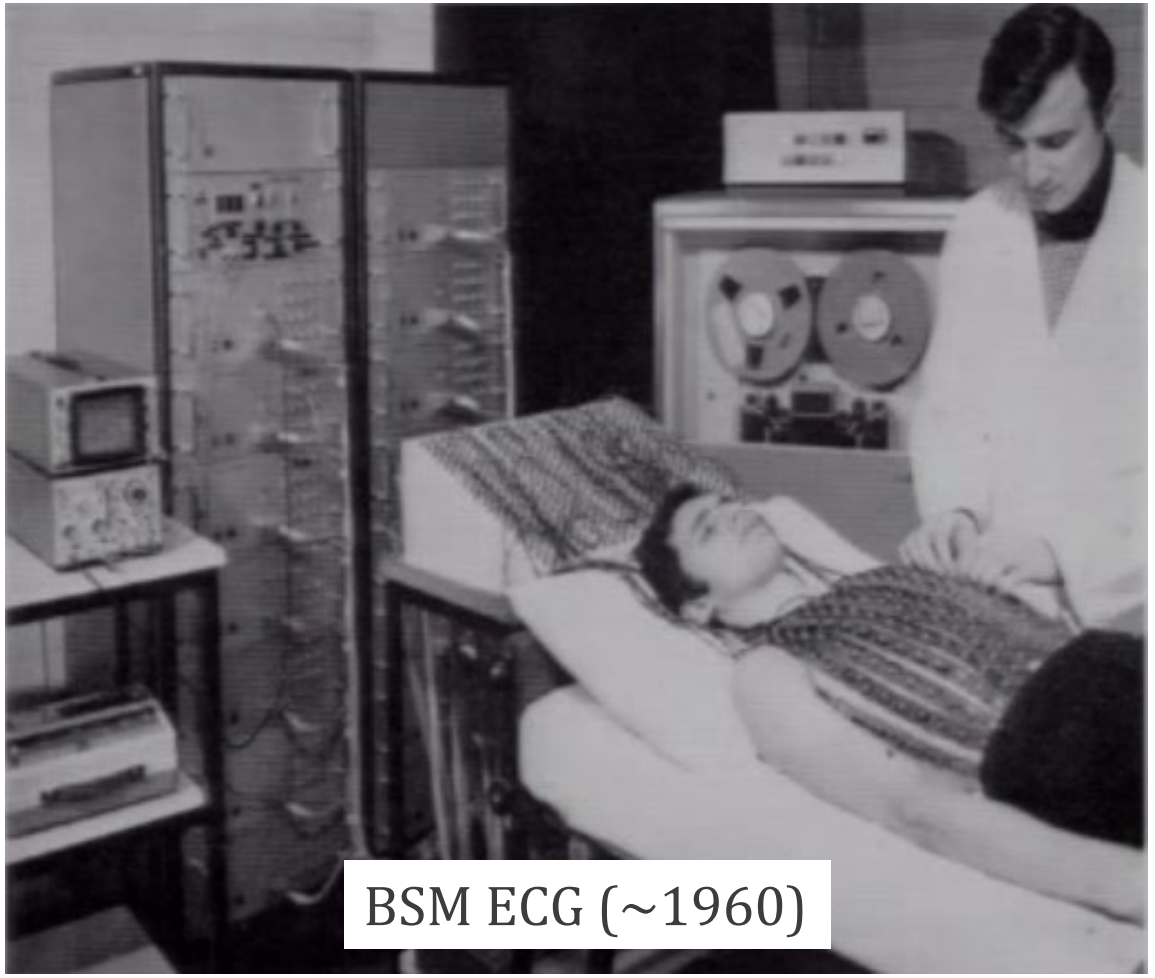
Willem Einthoven (~1900)

4.5.1Devices for biopotential measurement (continued)

Precursors



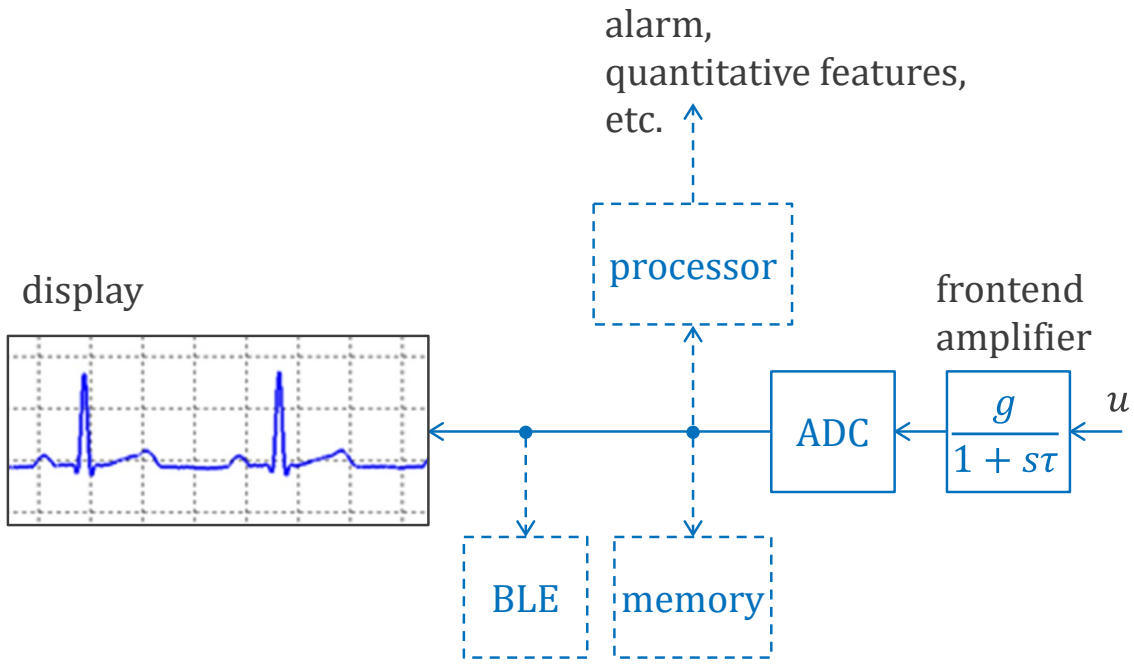
N.J. Holter (~1940)

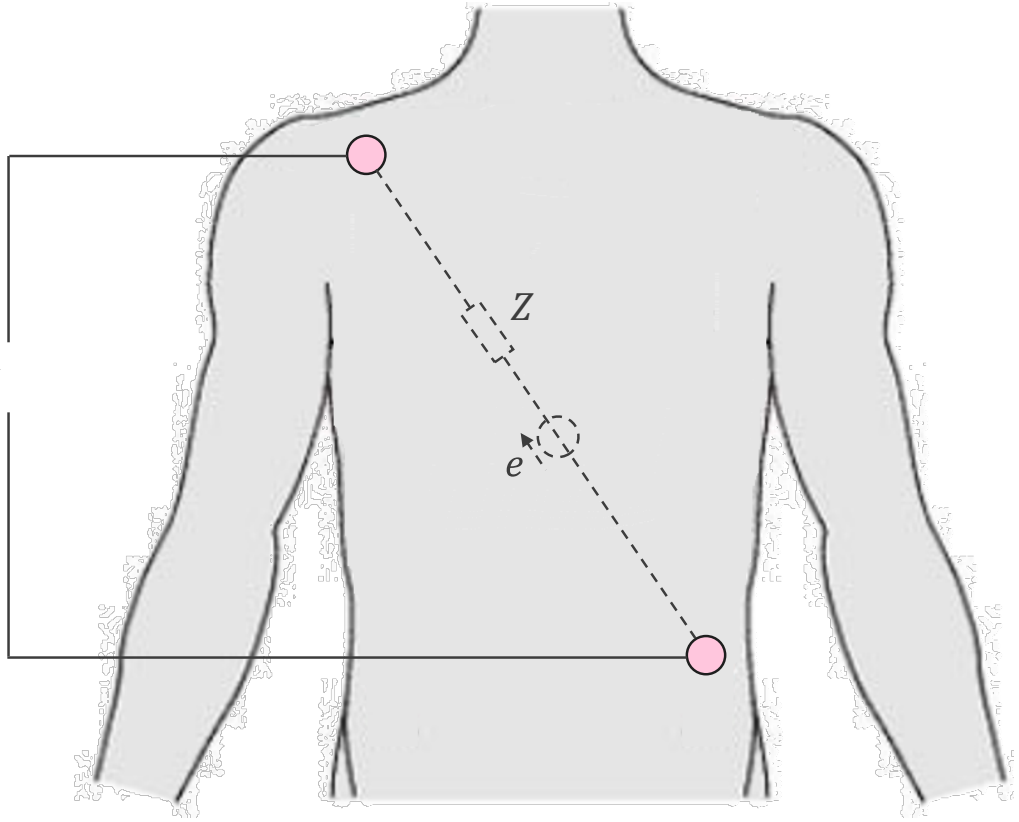


BSM ECG (~1960)

4.5.1Devices for biopotential measurement (continued)

Basic principle



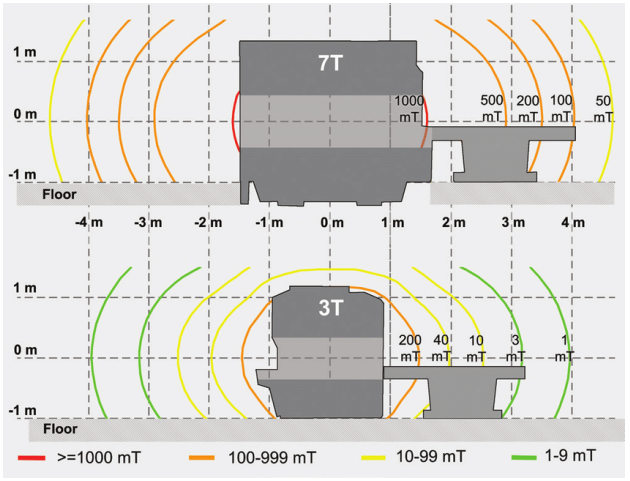


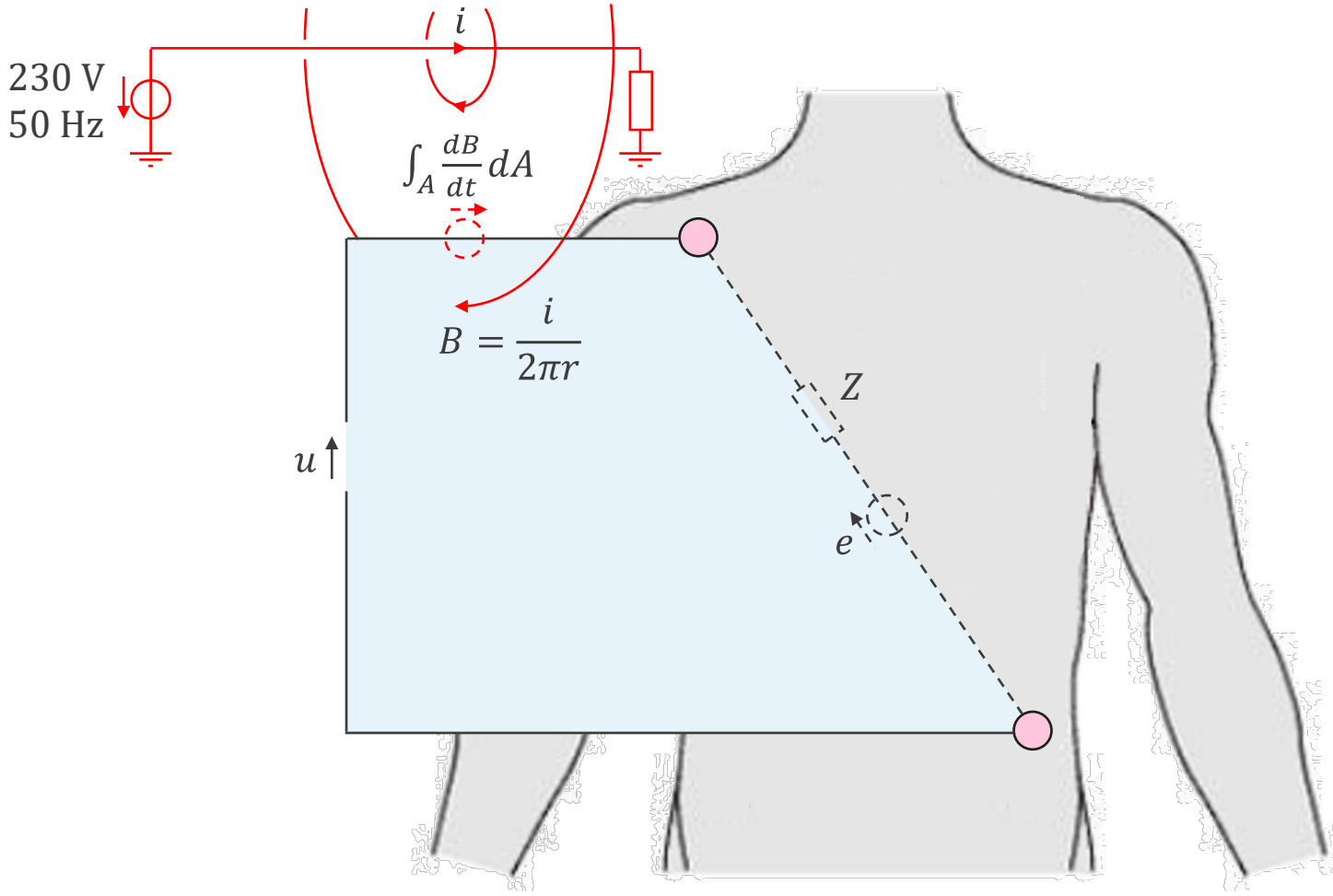
4.5.2Magnetic interferences

from

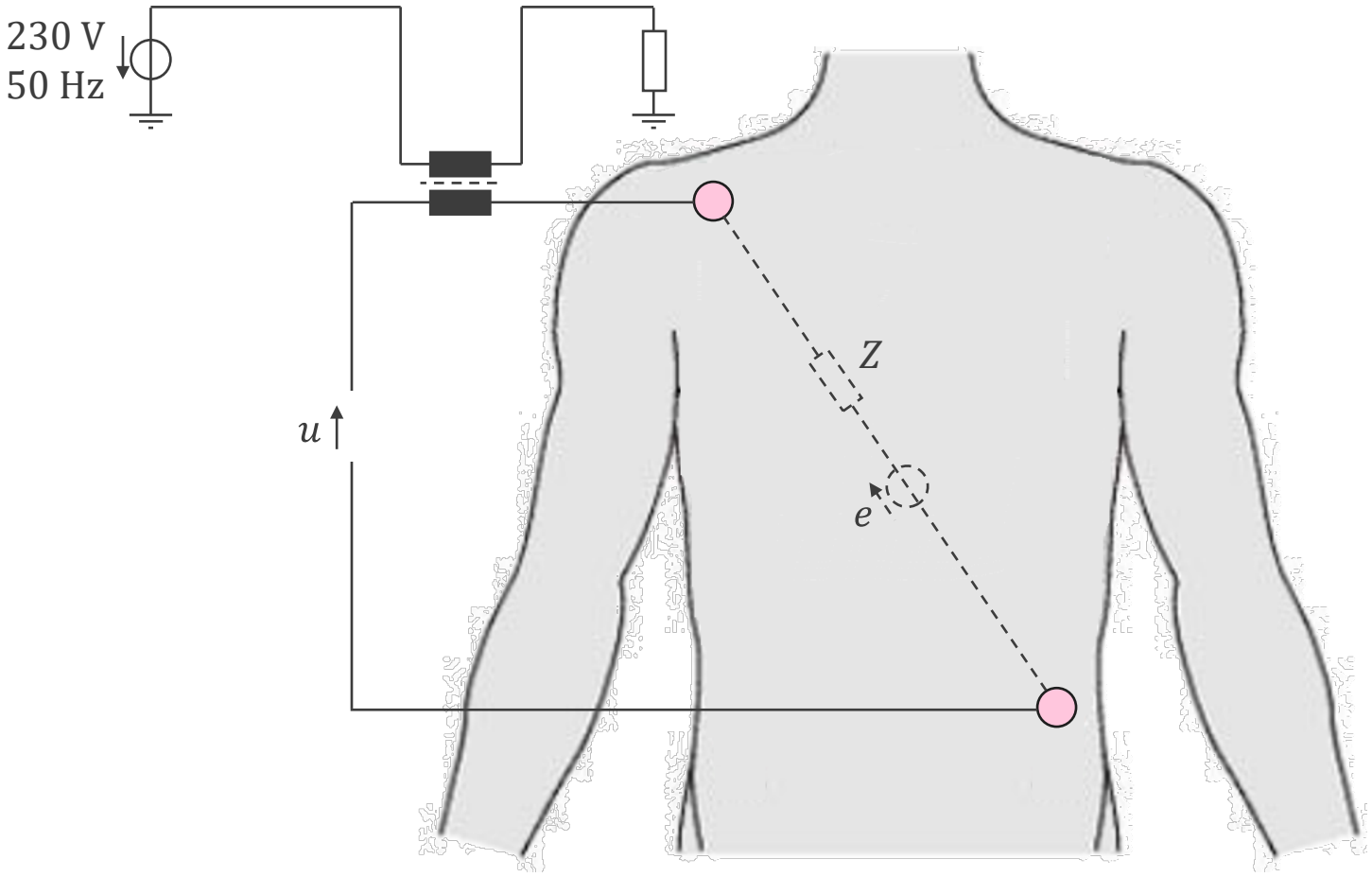
- current of mains (50 Hz, 60 Hz, 16⅔ Hz)
- motion in Earth magnetic field (50 µT)
- or near/in MRI (mT to T)

MRI and its environment



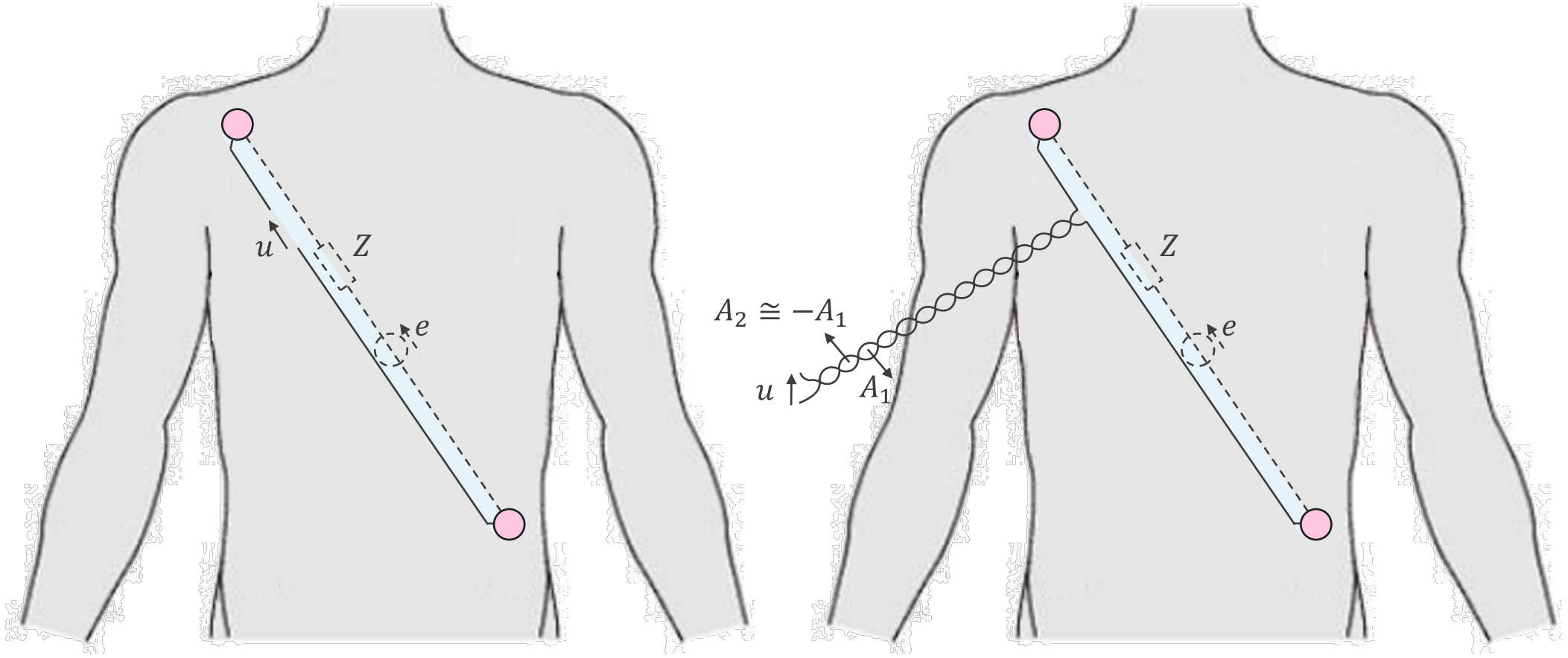


4.5.2Magnetic interferences (continued)

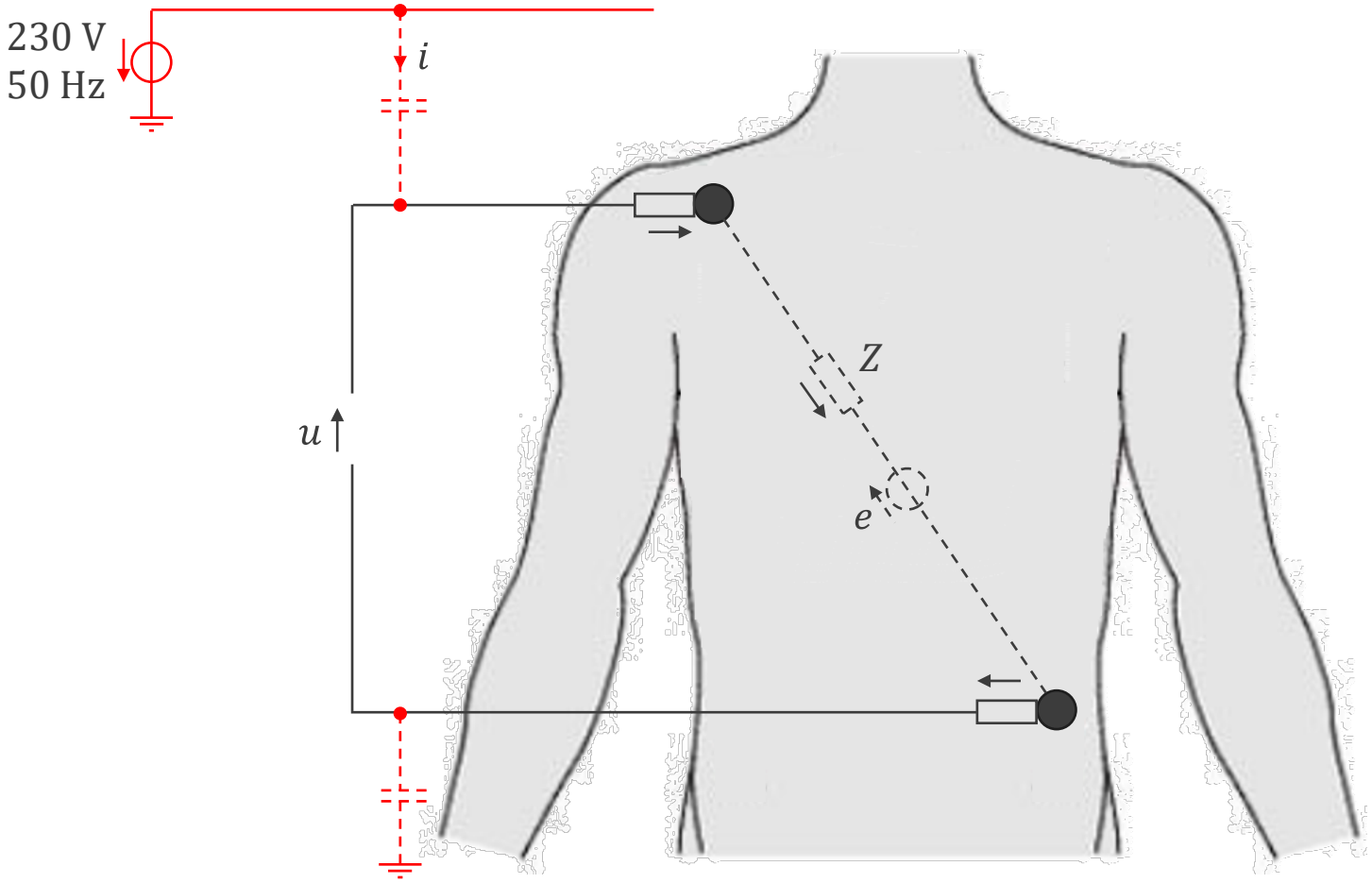


4.5.2Magnetic interferences (continued)

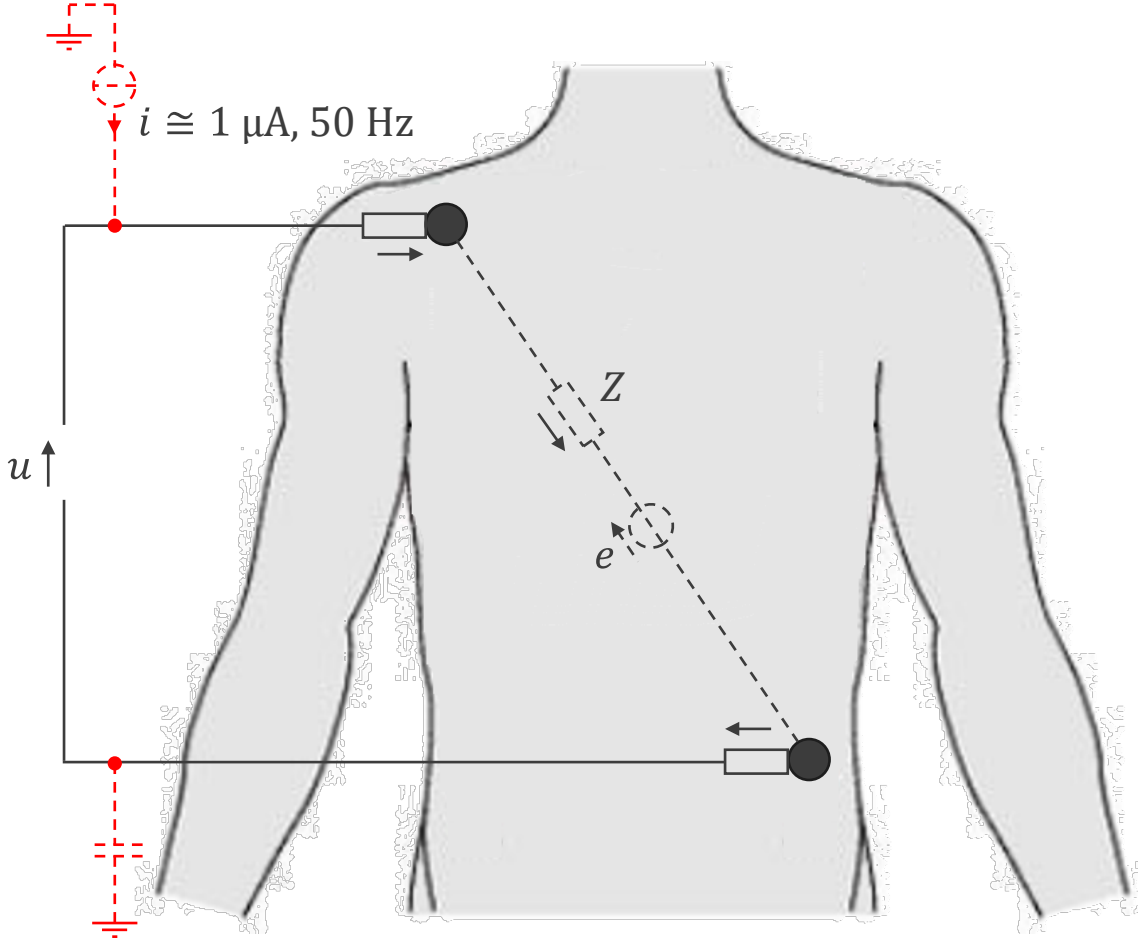
measures to minimize magnetic interferences



4.5.3 Electric interferences



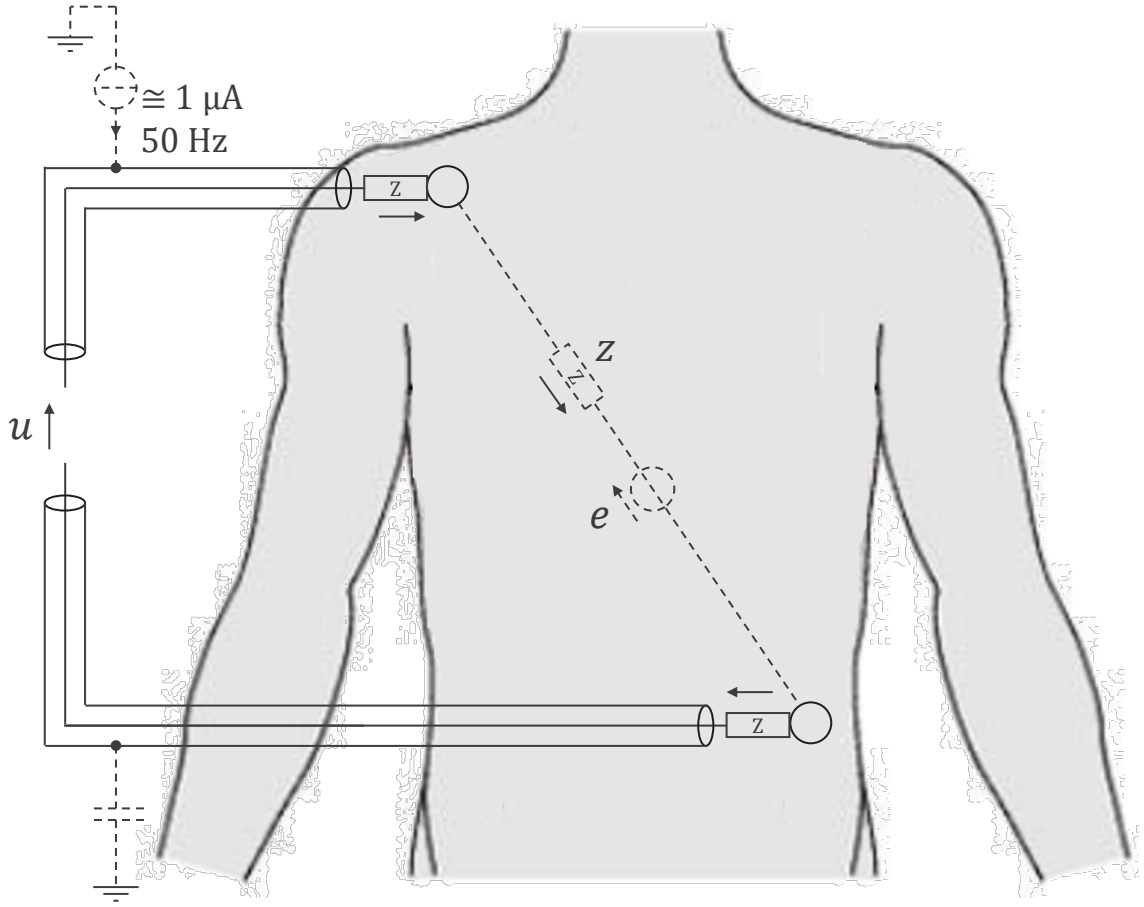
4.5.3 Electric interferences (continued)



4.5.3 Electric interferences (continued)

measures to minimize electric interferences

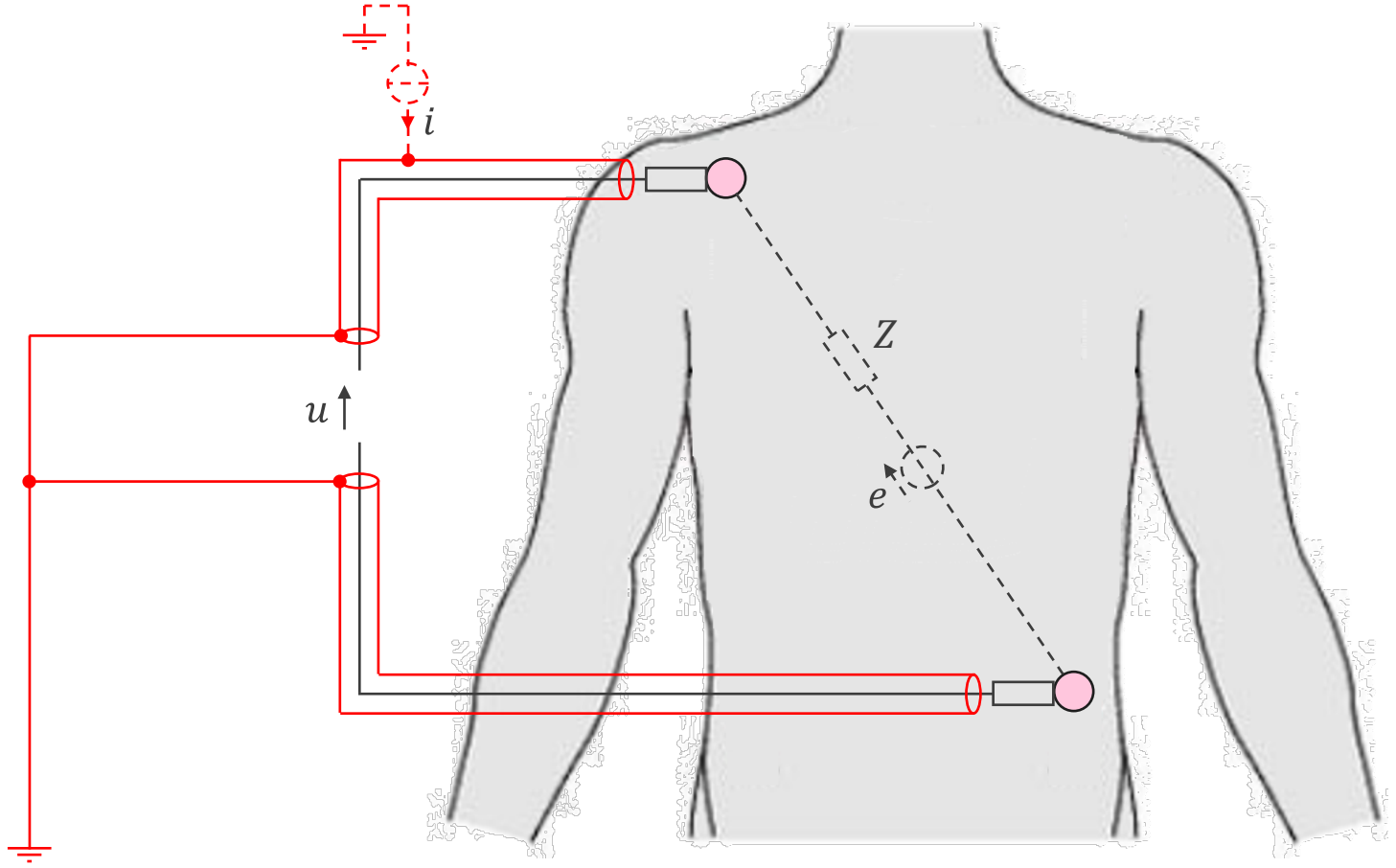
- shielding
- issue: ineffective because no path for current to return to earth



4.5.3 Electric interferences (continued)

measures to minimize electric interferences

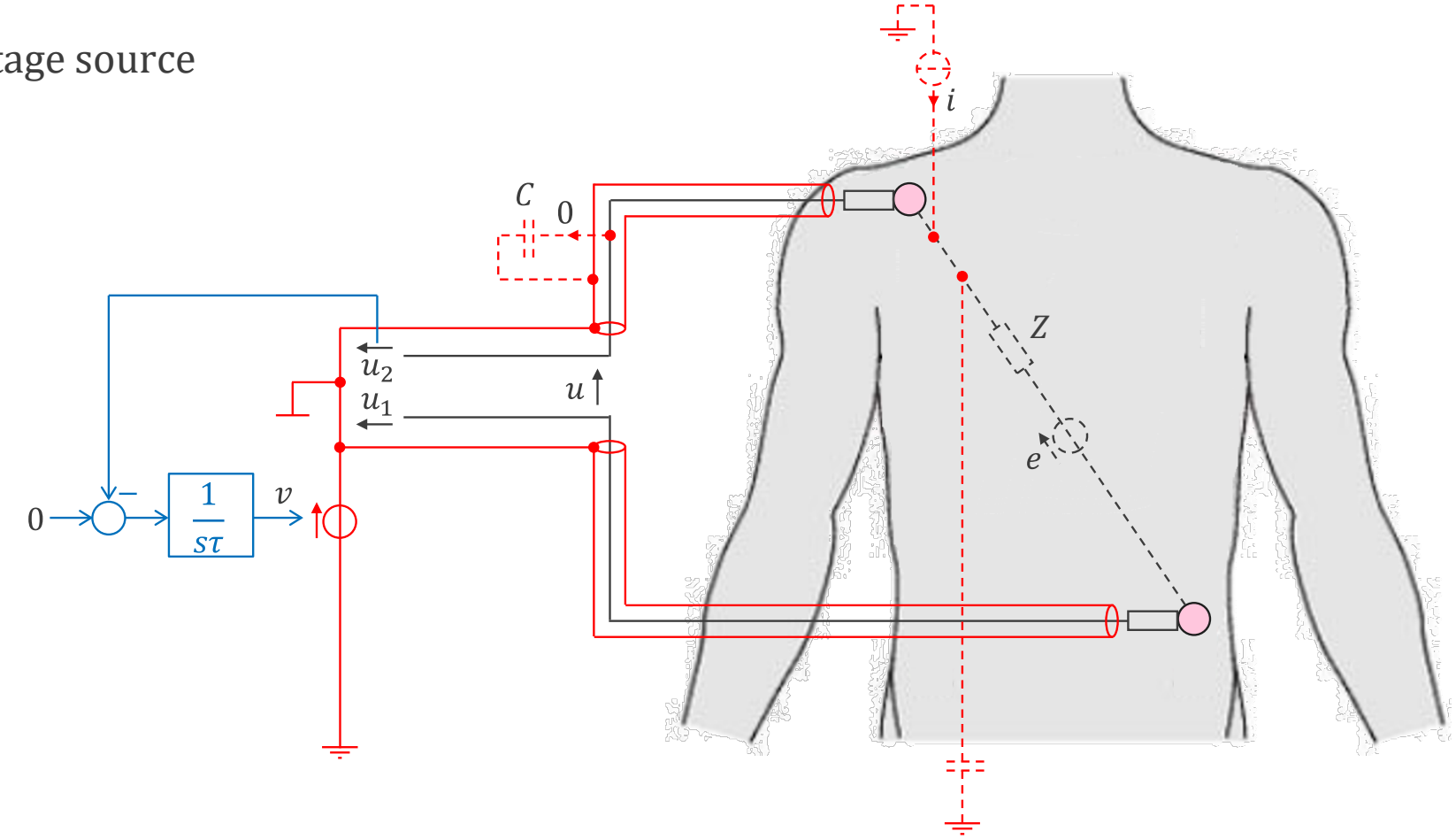
- shield connected to earth
- issue: high voltage between shield and body



4.5.3 Electric interferences (continued)

measures to minimize electric interferences

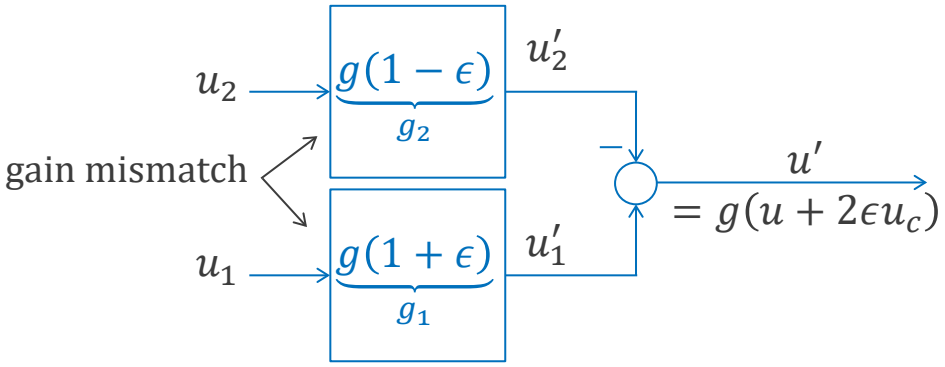
- shield/ground driven by voltage source connected to earth
- issue: high voltage range of voltage source

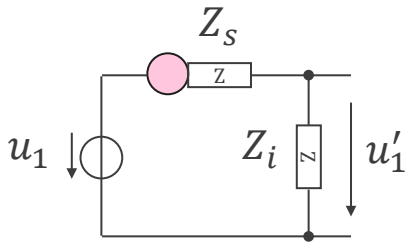


4.5.3Common mode

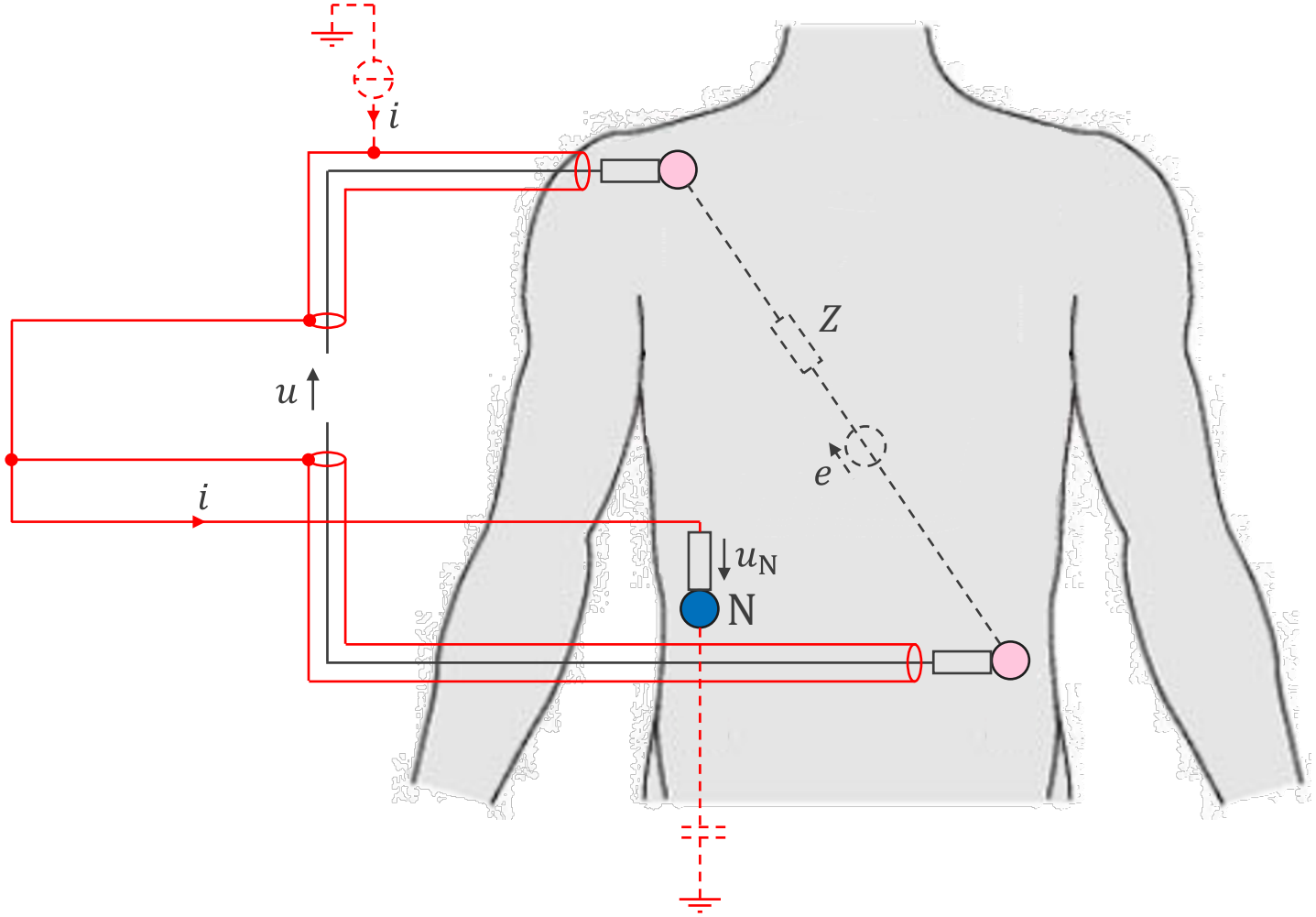
also called: RL or GND

- shield/ground to neutral electrode
- issue: gain mismatch, ampli. saturation



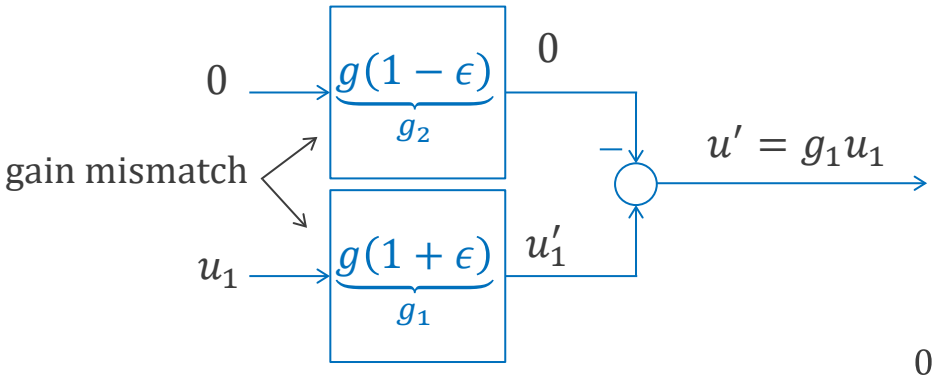


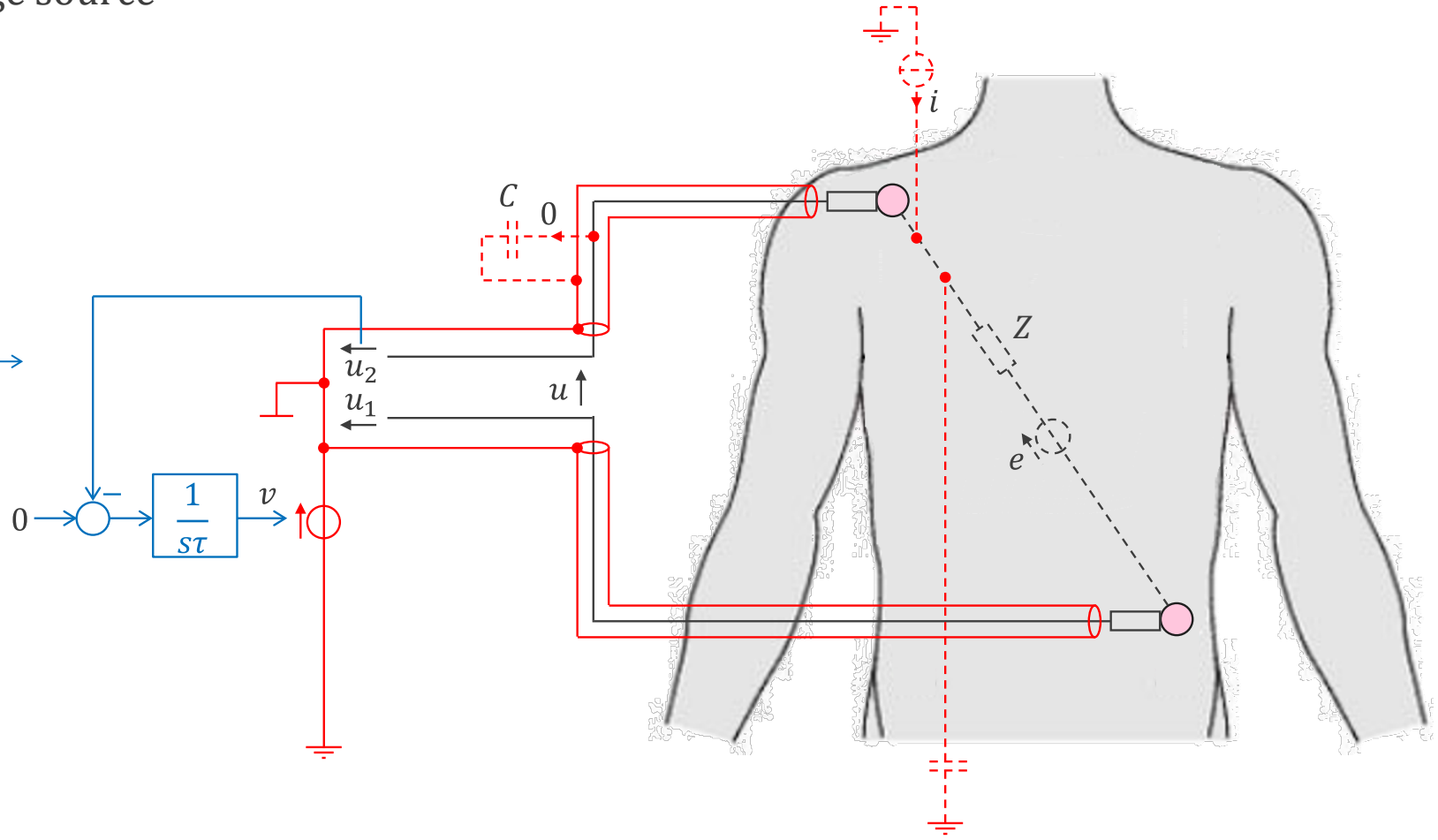
$$g_1 = \frac{Z_i}{Z_s + Z_i}$$



4.5.3Common mode (continued)

- shield/ground driven by voltage source connected to neutral electrode

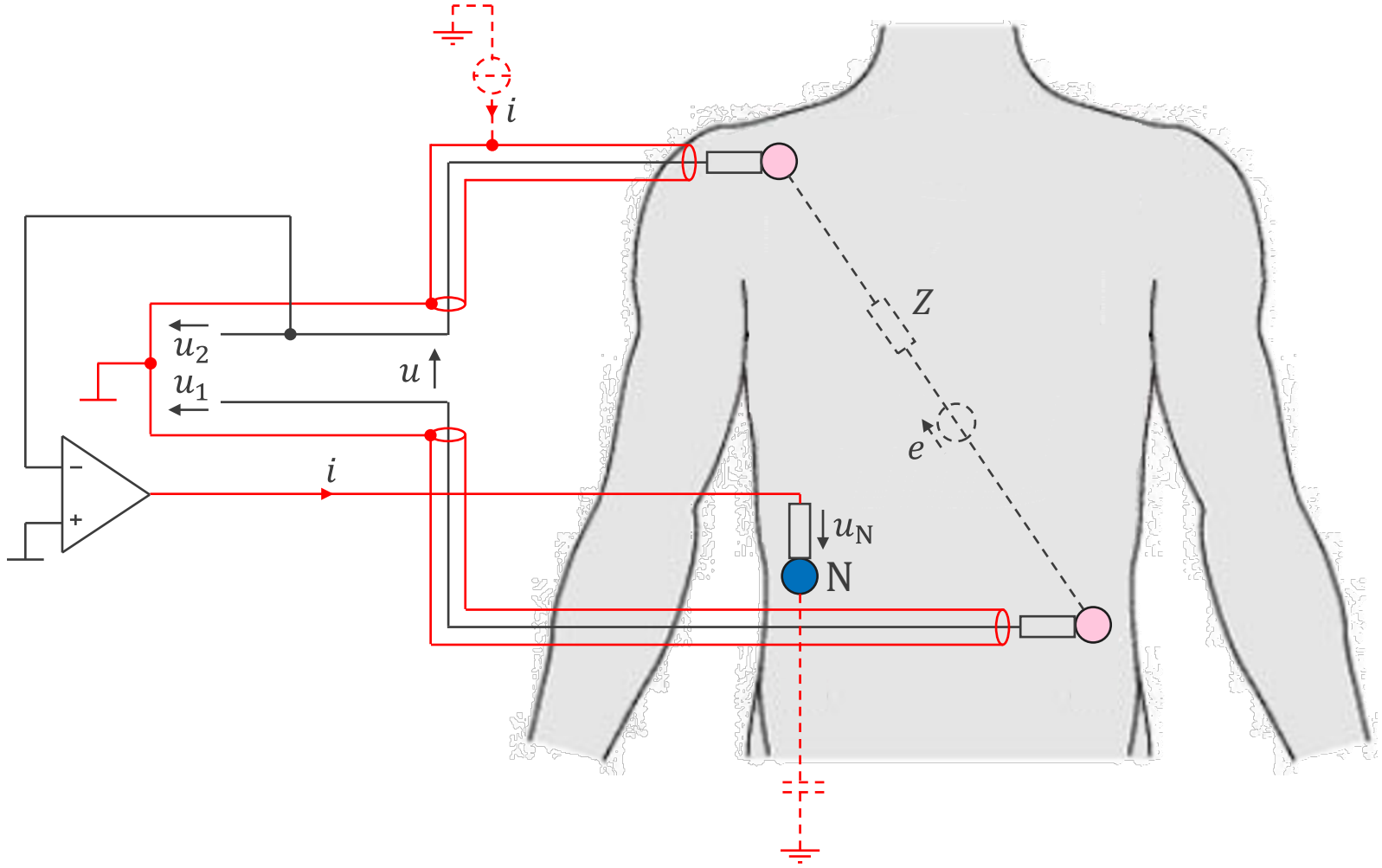




- $u_2 = u_2' = 0$
- $u' = g_1 u = g_1 u_1$

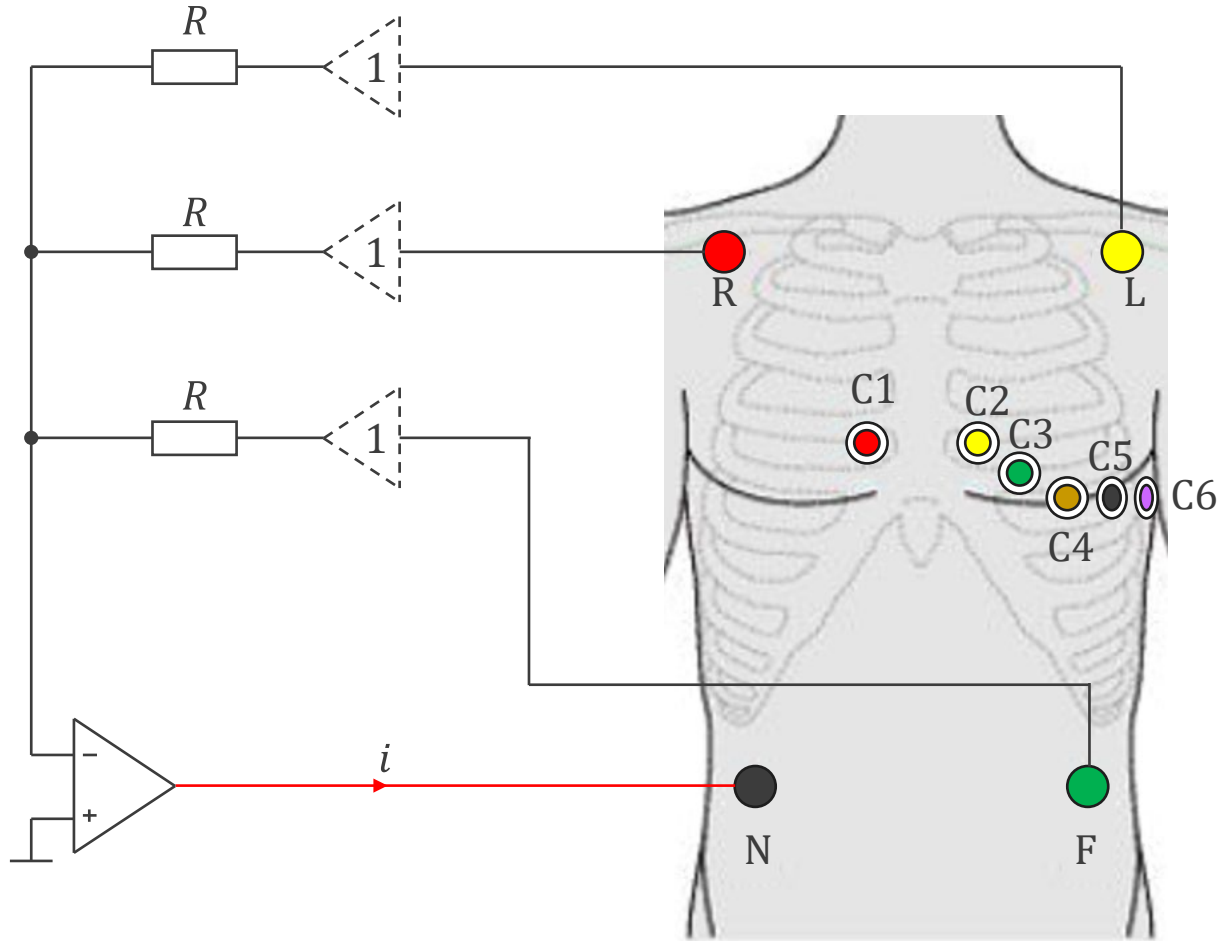
4.5.3Common mode (continued)

controller implementation

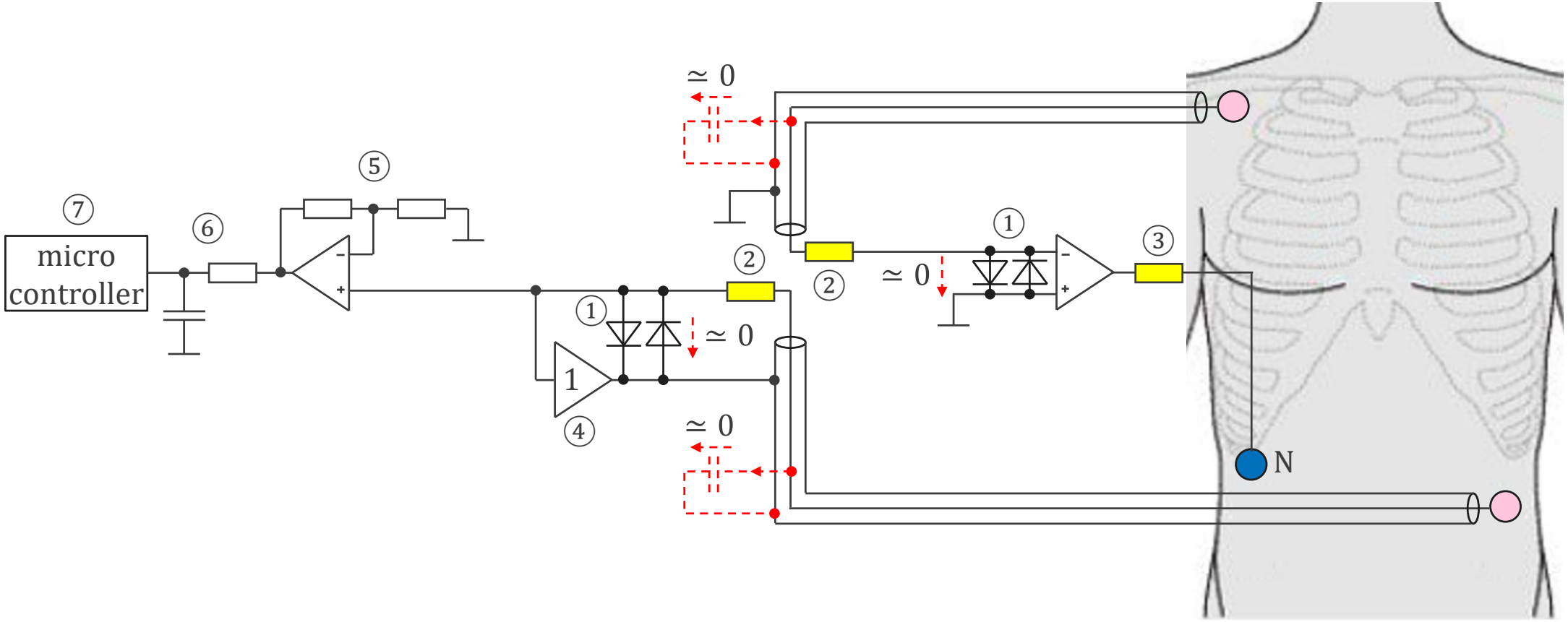


4.5.3Common mode (continued)

example: 12-lead ECG

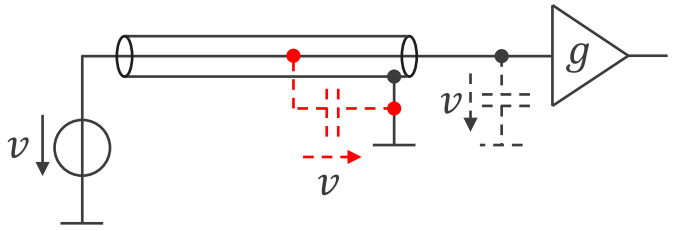


4.5.8Examples of complete circuits

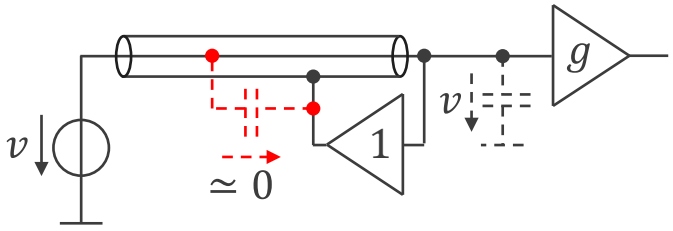


4.5.8Examples of complete circuits (continued)

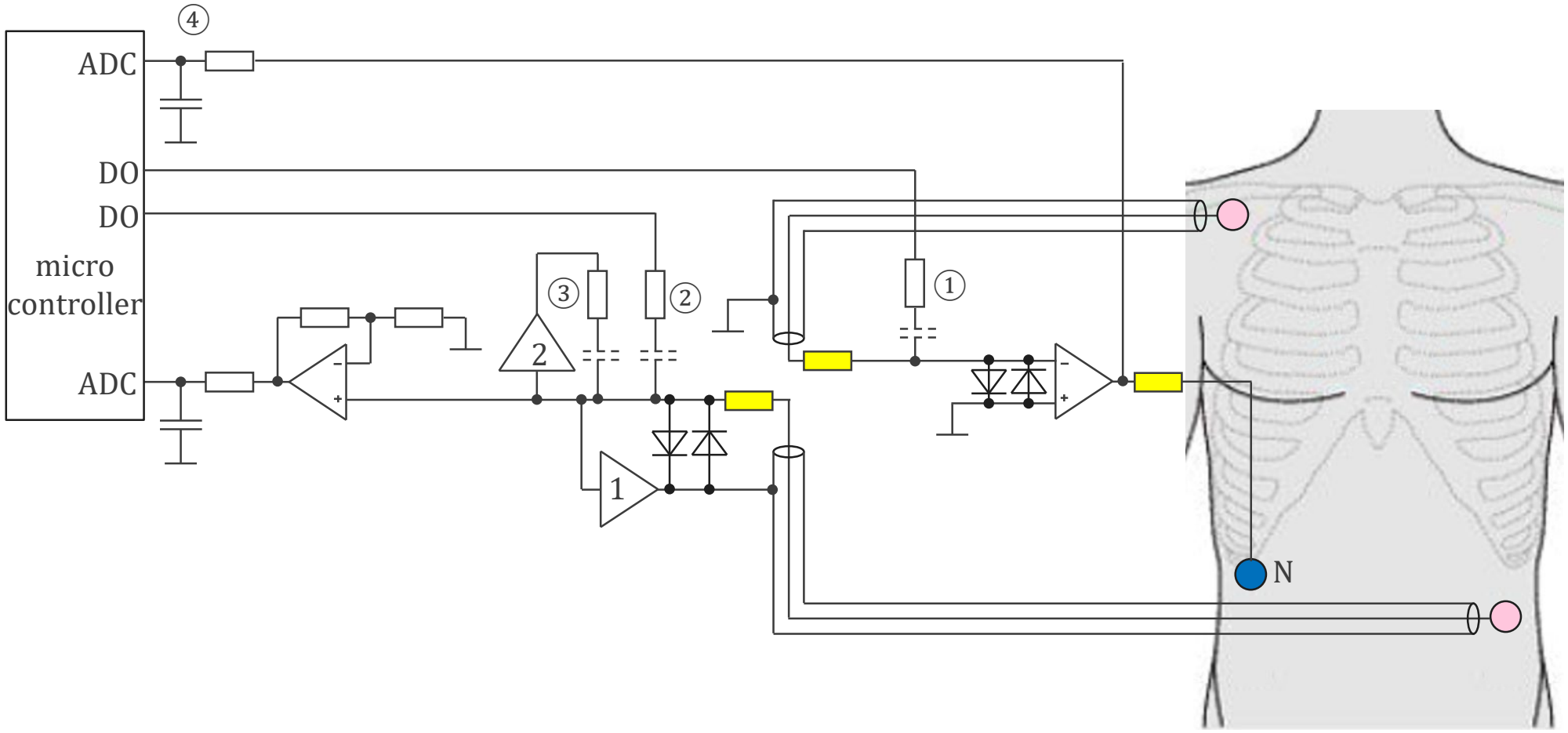
grounded shield



driven shield



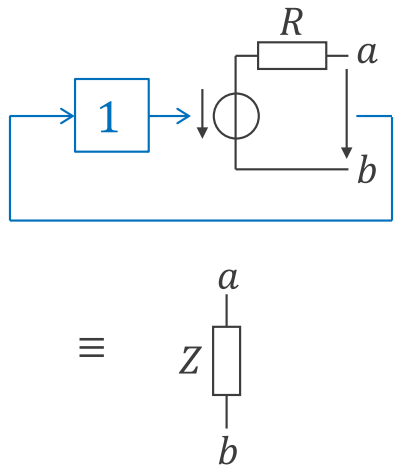
4.5.8Examples of complete circuits (continued)



Quiz

We have

- ☐ $Z = 0$
- ☐ $Z = -R$
- ☐ $Z = \infty$
- ☐ $Z = 2R$



We have

- ☐ $Z = 0$
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- ☐ $Z = \infty$
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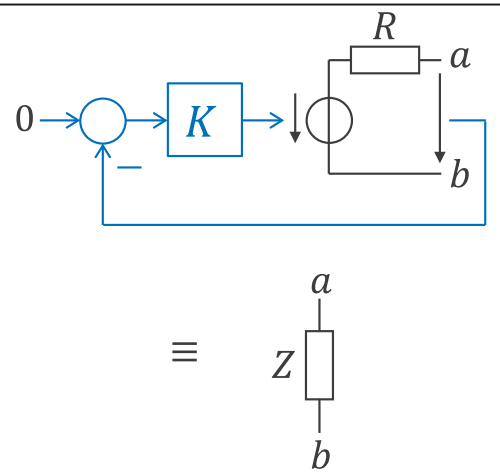


A Holter is a

- ☐ bedside ECG monitor
- ☐ ambulatory ECG recorder
- ☐ rest ECG diagnostic device
- ☐ stress-test diagnostic device

Quiz

For safety analysis, a 12-lead ECG

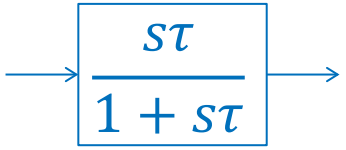
- ☐ has 9 PATIENT CONNECTIONS
- ☐ has 10 PATIENT CONNECTIONS
- ☐ has 11 PATIENT CONNECTIONS
- ☐ has 12 PATIENT CONNECTIONS

An ideal operational amplifier has

- ☐ a constant unity gain
- ☐ two inputs and two outputs
- ☐ a zero-phase transfer function
- ☐ an integrator as transfer function

This transfer function is a

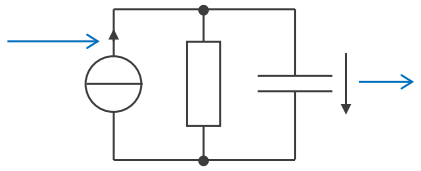
- ☐ high-pass filter
- ☐ low-pass filter
- ☐ integrator
- ☐ derivator



Quiz

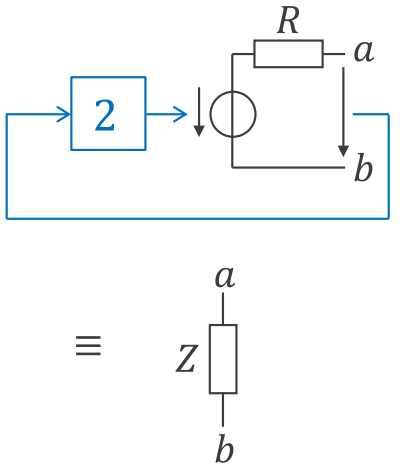
This circuit implements a

- ☐ high-pass filter
- ☐ low-pass filter
- ☐ integrator
- ☐ derivator



We have

- ☐ $Z = 0$
- ☐ $Z = -R$
- ☐ $Z = \infty$
- ☐ $Z = 2R$



We have

- ☐ $v = -u$
- ☐ $v = u$
- ☐ $v = 2u$
- ☐ $v = Ru$