ESE 3400: Medical Devices Lab

Lec 4: September 14, 2022

Physical Sensors

Lecture Outline

- Vital signs
- Physical Sensor Types
  - Surface electrodes
  - Pressure sensors
  - Thermistors
  - Photodiodes
- Biosensors
- Lab 2 discussion (if time)

Monitoring Vital Signs

- Body Temperature
  - Thermistors
- Heart Rate and Heart Rate Variability
  - Surface electrodes
- Respiration Rate
  - Photodiodes
- Blood Pressure
  - Pressure sensors
- Height/Weight
  - Scale and ruler

Physical Sensors

- Surface electrodes
- Pressure sensors
- Thermistors
- Photodiodes

Surface Electrodes

- Monitor biopotential voltages
  - Reflects the electrical stimulation that precedes muscle contraction
  - EEG – electroencephalogram reflects brain activity
  - EMG – muscle activity
  - ECG – electrocardiogram specific to heart muscles

Surface Electrodes

- Monitor biopotential voltages

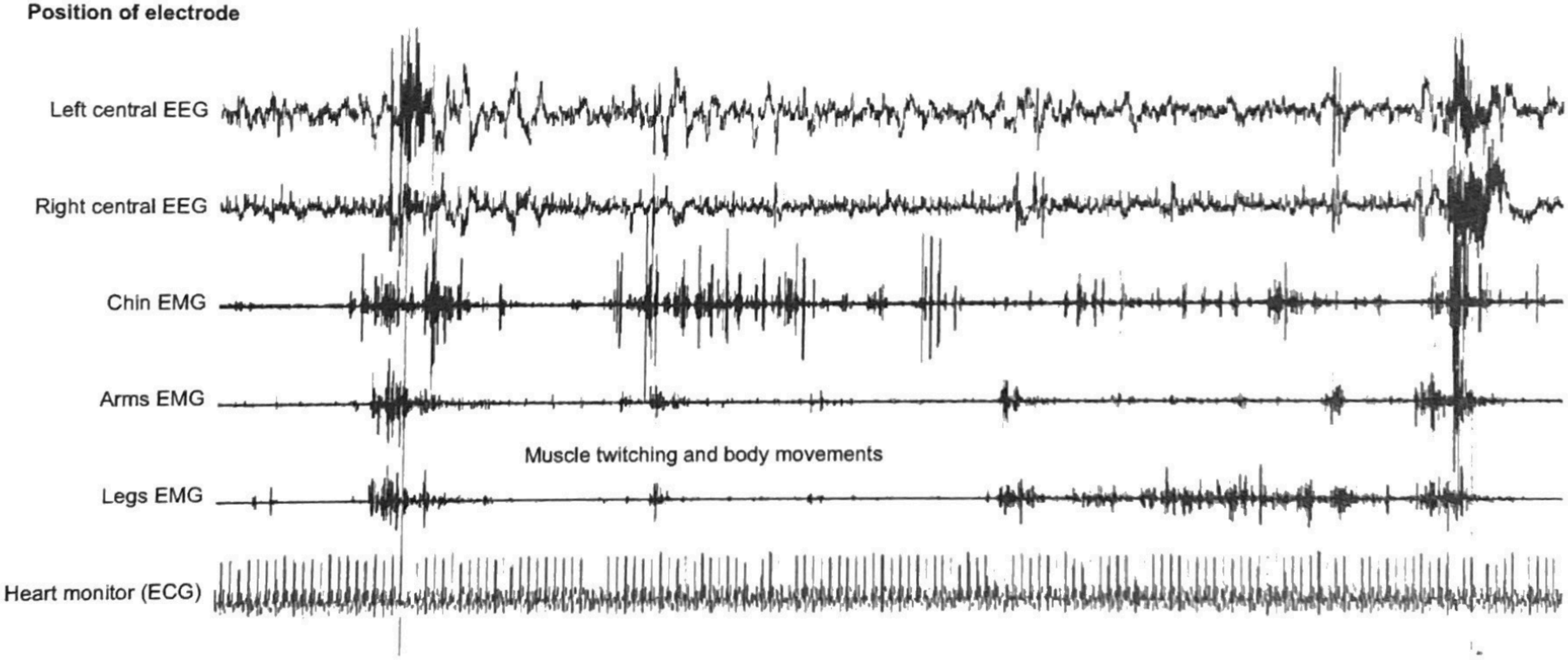


FIGURE 1.7

Examples of biopotentials in a patient with a sleep disorder.

Surface Electrodes

- Converts ionic current to electric current

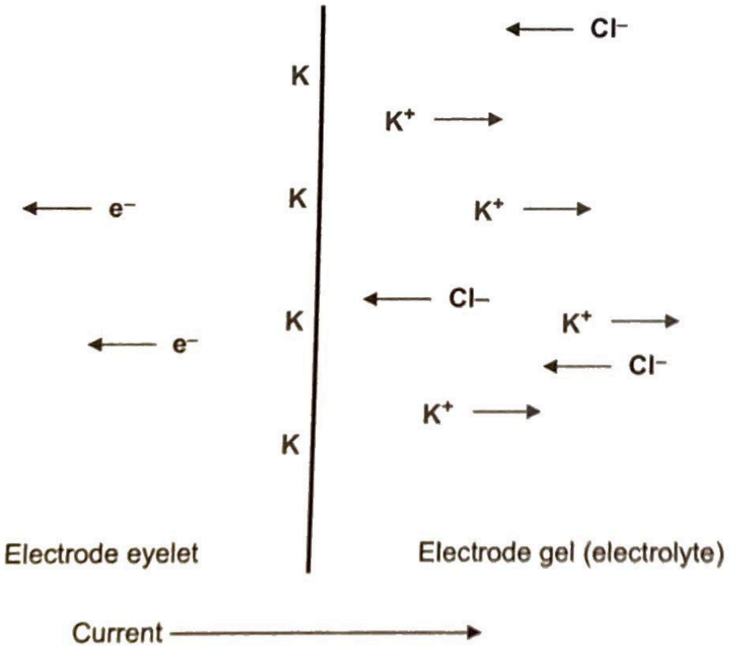


FIGURE 1.8

Electrode–electrolyte interface for KCl.

Surface Electrodes

- Modern electrodes
  - Cloth, vinyl or foam basepad
  - Polystyrene label
  - Nickel-plated brass stud
  - Carbon eyelet coated with Ag/AgCl
  - Wet or solid gel

Pressure Sensors

- Measures mechanical action changes as pressure
  - P in units of millimeters of mercury (mm Hg)
  - 760 mm Hg = 101,325 Pascals = 1 atm

- In lungs pressure is a measure of kinetic energy of the gas molecules

$$P = NRT$$

  - N = number of moles per unit volume, R = gas constant, T = absolute temperature

- For a liquid, such as blood at rest,

$$P = \frac{dF}{dA}$$

Pressure Sensors

- A pressure sensor contains three components
  - Diaphragm or plate of known area, A
  - Detector that responds to applied force
  - Interface circuit that ouptuts voltage

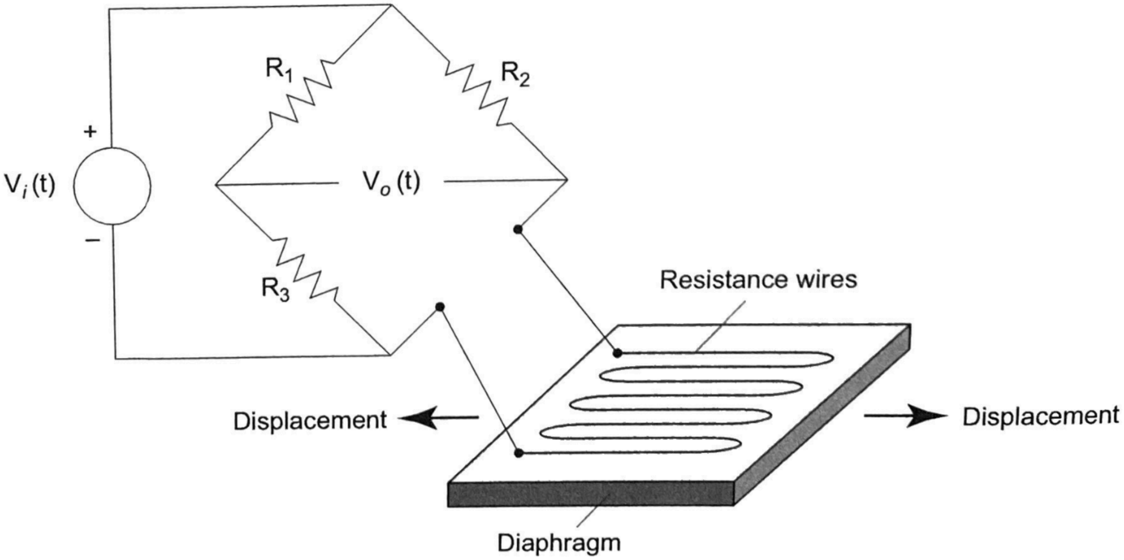


FIGURE 1.11

Pressure sensor components: a diaphragm, strain gauge, and Wheatstone bridge.

Pressure Sensors

- Intraarterial blood pressure (IAP) sensor

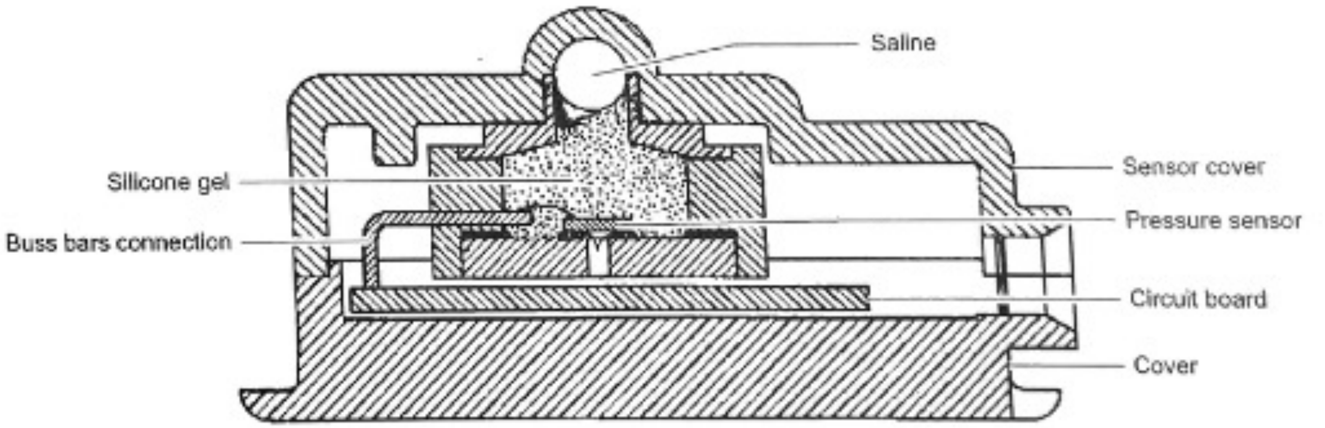


FIGURE 1.13

Deseret Medical pressure sensor cross section.

From Hanlon et al. (1987).

Thermistors

- Measures temperature

- Negative thermal coefficient (NTC) bead thermometer
  - Decreasing resistance with increasing temperature

Thermistors

- Bead thermometer
  - Best for measuring body temperature because it is stable (resistance does not change with age) and has fast response time

- Based on empirical data

$$R_T(T) = \exp\left(A_o + \frac{A_1}{T} + \frac{A_2}{T^2} + \frac{A_3}{T^3}\right)$$

- T = temperature, A_i are specified by the manufacturer

Thermistors

- Typical resistance curve

$$R_T(T) \approx \mathrm{R_c} \exp\left(\beta_m \left(\frac{1}{T} - \frac{1}{T_c}\right)\right)$$

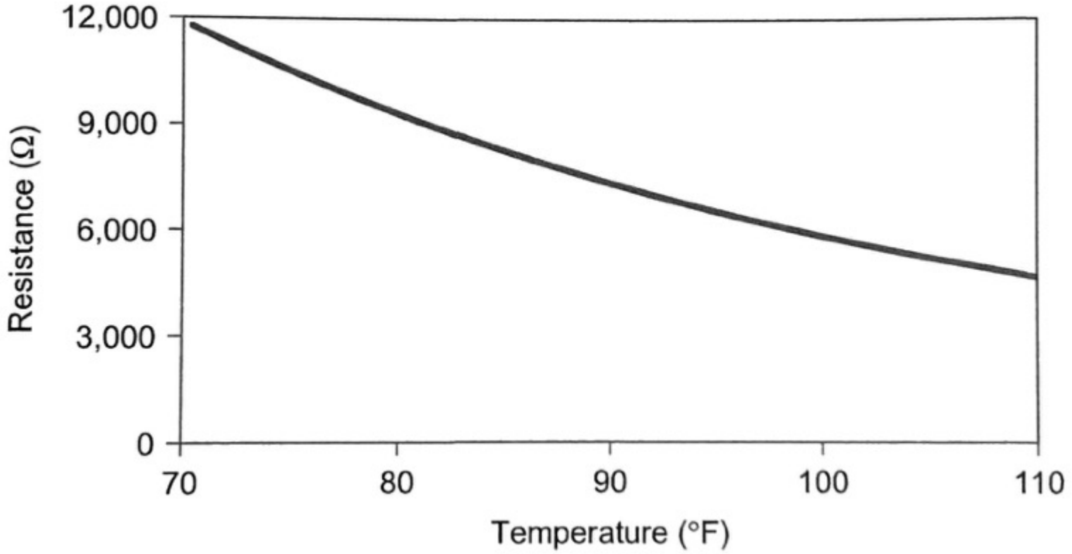


FIGURE 1.15

Resistance as a function of temperature.

- Interface circuitry is used so that output voltage is proportional to temperature

Photodiodes

- Measures changes in light interacting with the body
  - Typically light source is LED
    - Eg. Pulse oximetry uses red and infrared LEDs
  - LEDs emit range of wavelengths
    - Speed of light is the product of wavelength and optical frequency, $c = \lambda v$
    - Energy of a photon, $\mathrm{E} = hv$

Photodiodes

- Measures changes in light interacting with the body
  - Photon with energy, hv strikes reverse biased photodiode surface

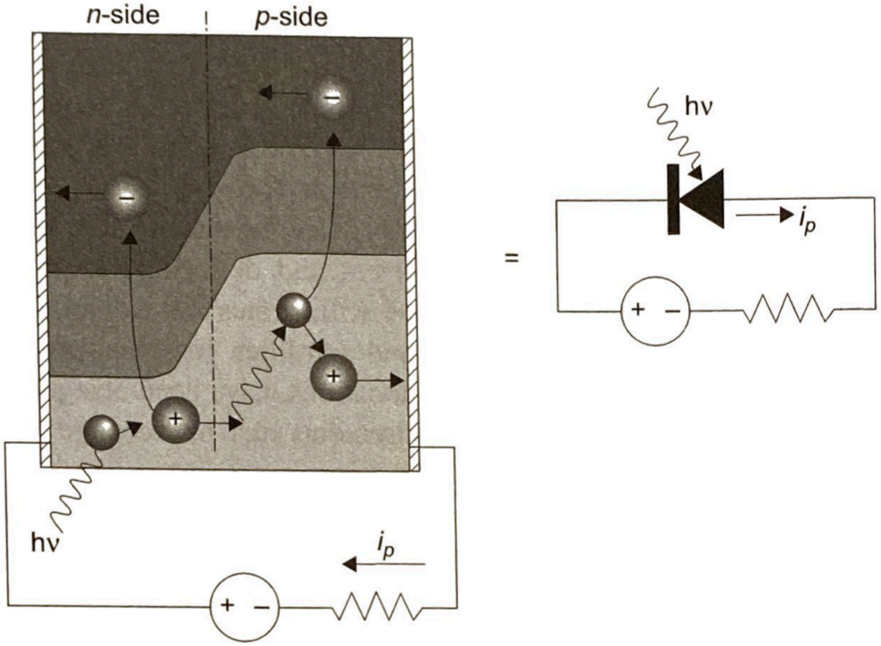


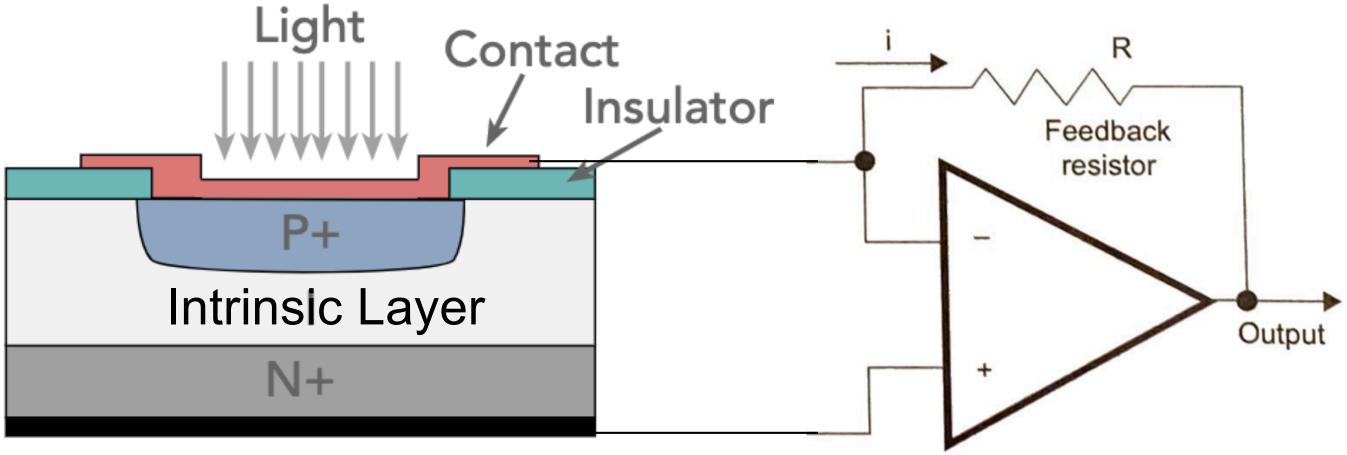
FIGURE 1.16

Photodiode structure and equivalent circuit.

Reproduced by permission from Fraden (2004).

Photodiodes

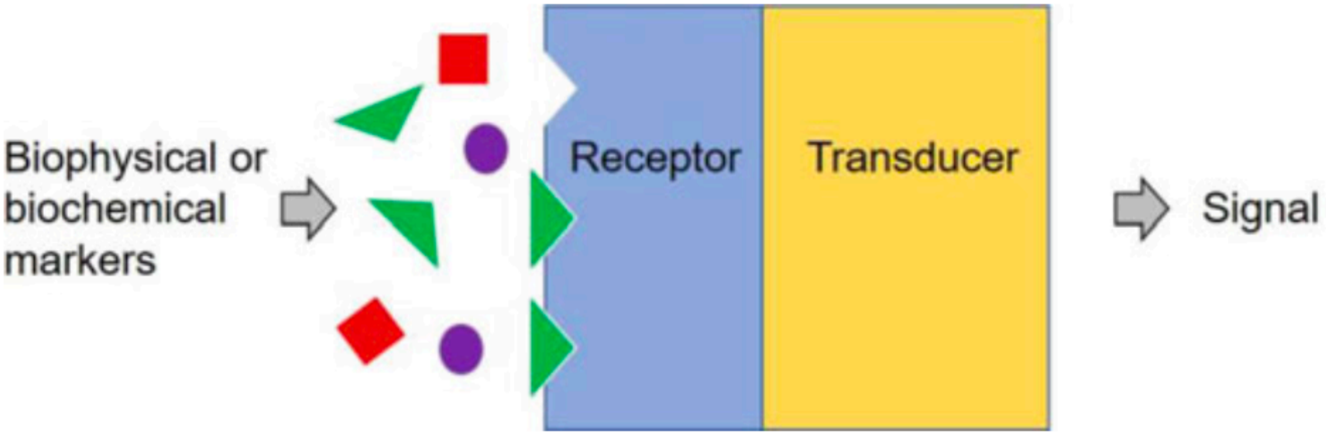
- Measures changes in light interacting with the body
  - Photon with energy, hv strikes reverse biased photodiode surface



PIN photodiode structure

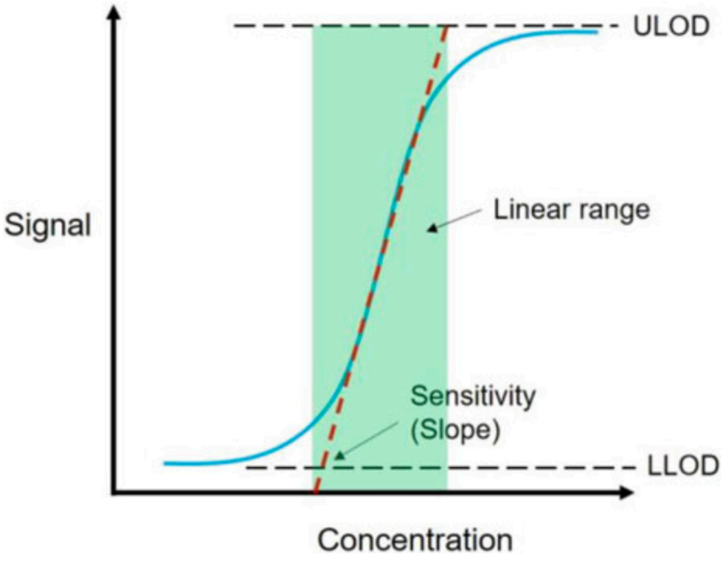
Biosenser

- The basic units of a biosensor are receptor and transducer. The receptor comes in close contact with the analyte and the chemical/physical interactions between the two are translated into a measurable signal by the transducer (Fig. 2.1).



Characteristics of Biosensors

- Limit of Detection (LOD)
  - minimum amount or concentration of the analyte that can be detected
- Detection Range
  - reflection of how much change caused by the external stimuli can be measured



Characteristics of Biosensors

- Sensitivity
  - ratio between the output signal and the input measured property
- Selectivity
  - indicates the sensor's ability to differentiate one analyte from another

Characteristics of Biosensors

- Reproducability
  - ability of the sensor to generate identical results when it is measuring the same level of external stimuli
- Stability
  - ability to maintain the same level of output signal under various environmental disturbances
- Biocompatibility
  - level of compatibility of the material/device with living tissue
    - Toxicity of materials, ractivity with living tissue, mechanical compatibility, biodegradability

Biosensors

- Rely on chemical reactions or receptor–ligand binding to detect the presence of target analytes.
  - biochemical markers are cells including protein, cytokines, DNA, RNA, ions, metabolites, dissolved gases, and circulating tumor cells.
  - They are found in body fluids which are either enclosed inside body such as blood and interstitial fluid or secreted by body such as sweat and urine.

Biosensors

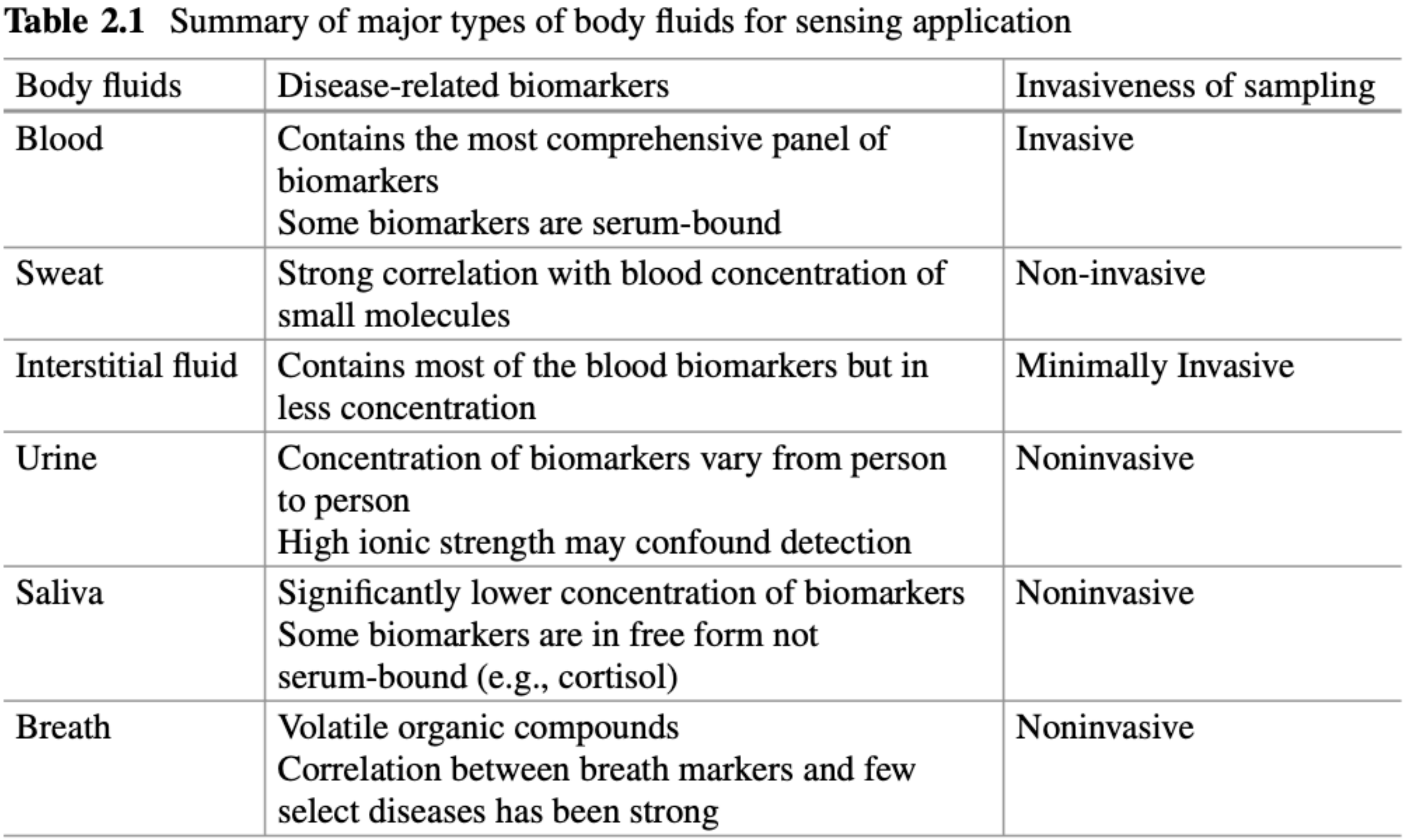
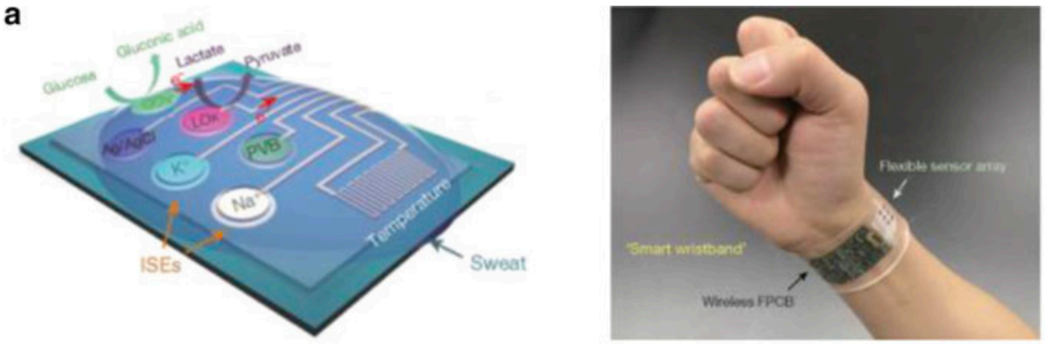


Table 2.1 Summary of major types of body fluids for sensing application

Body fluids	Disease-related biomarkers	Invasiveness of sampling
Blood	Contains the most comprehensive panel of biomarkers Some biomarkers are serum-bound	Invasive
Sweat	Strong correlation with blood concentration of small molecules	Non-invasive
Interstitial fluid	Contains most of the blood biomarkers but in less concentration	Minimally Invasive
Urine	Concentration of biomarkers vary from person to person High ionic strength may confound detection	Noninvasive
Saliva	Significantly lower concentration of biomarkers Some biomarkers are in free form not serum-bound (e.g., cortisol)	Noninvasive
Breath	Volatile organic compounds Correlation between breath markers and few select diseases has been strong	Noninvasive

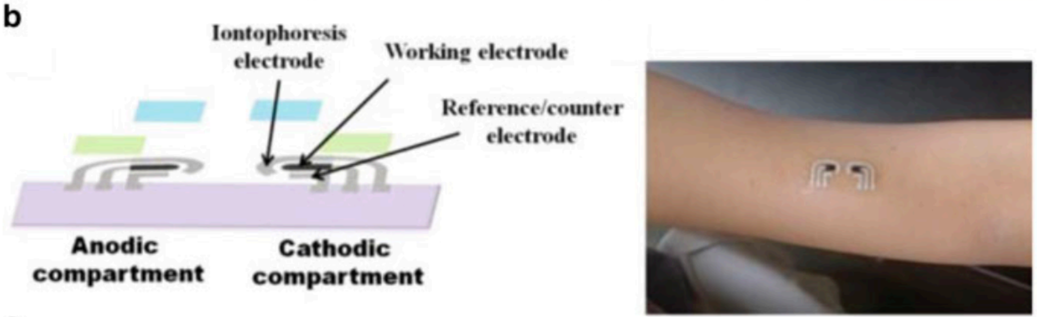
Biosensors

a



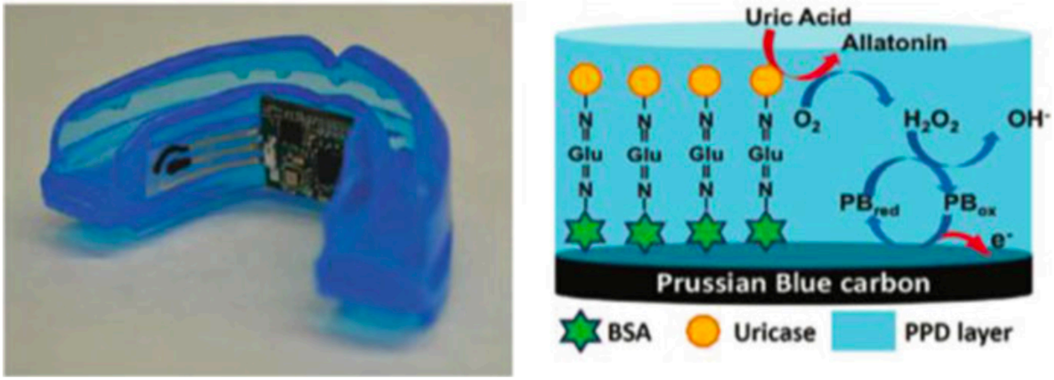
a) W. Gao, S. Emaminejad, H.Y.Y. Nyein, S. Challa, K. Chen, A. Peck, et al., Fully integrated wearable sensor arrays for multiplexed in situ perspiration analysis. Nature **529**, 509–514 (2016)

b



b) Tattoo-based platform for noninvasive glucose sensing

c



c) J. Kim, S. Imani, W.R. de Araujo, J. Warchall, G. Valdes-Ramirez, T.R. Paixao, et al., Wearable salivary uric acid mouthguard biosensor with integrated wireless electronics. Biosens. Bioelectron. **74**, 1061–1068 (2015)

Big Ideas

- Six* main vital signs for health monitoring
- Four physical sensor types
  - Electrodes
  - Pressure sensors
  - Thermistors
  - Photodiodes
- Biosensors
  - Use fluids for sensing biomarkers

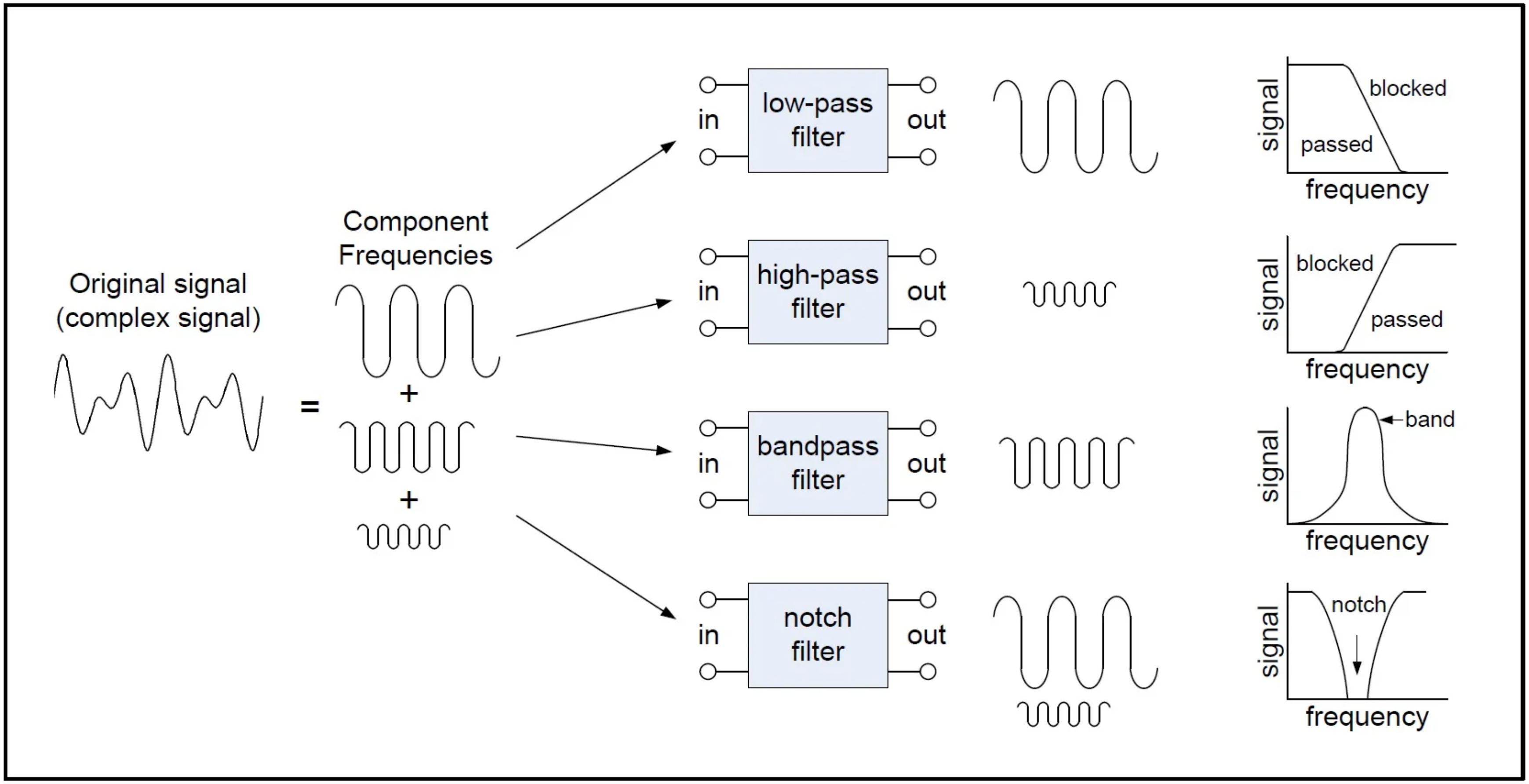
Admin

- Finish Lab 2 and submit deliverables in Canvas by next lab day at midnight

ESE 3400 Lab 2

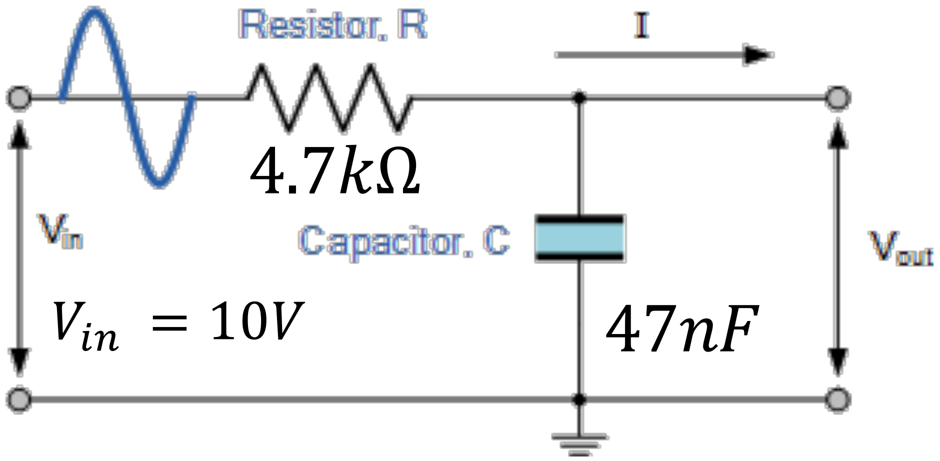
Filters

Four Basic Filters



allaboutcircuits.com

What is the frequency response of this circuit?

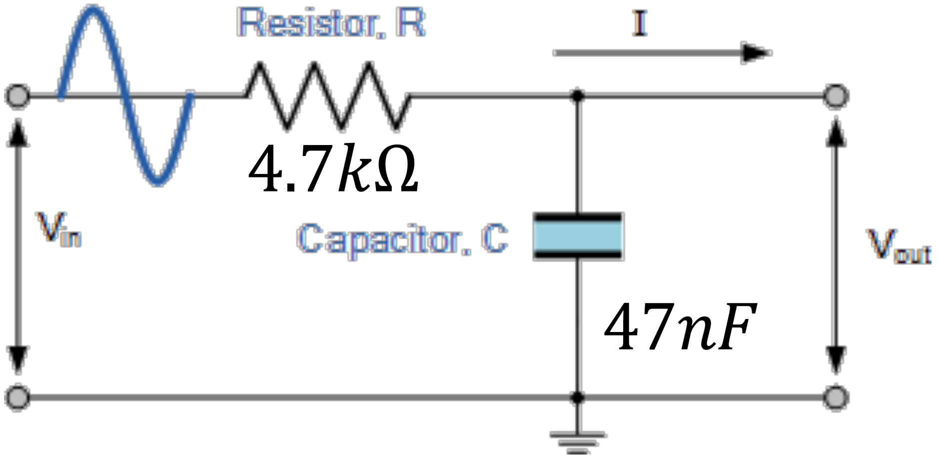


$$X_C = \frac{1}{2\pi f C}$$

$$|Z| = \sqrt{R^2 + \ {X_C}^2}$$

$$V_{out} \ = \ V_{in} \times \frac{X_C}{\sqrt{R^2 + \ {X_C}^2}} = V_{in} \ \frac{X_C}{|Z|}$$

What is the frequency response of this circuit?



$$X_C = \frac{1}{2\pi f C}$$

$$|Z| = \sqrt{R^2 + X_C{}^2}$$

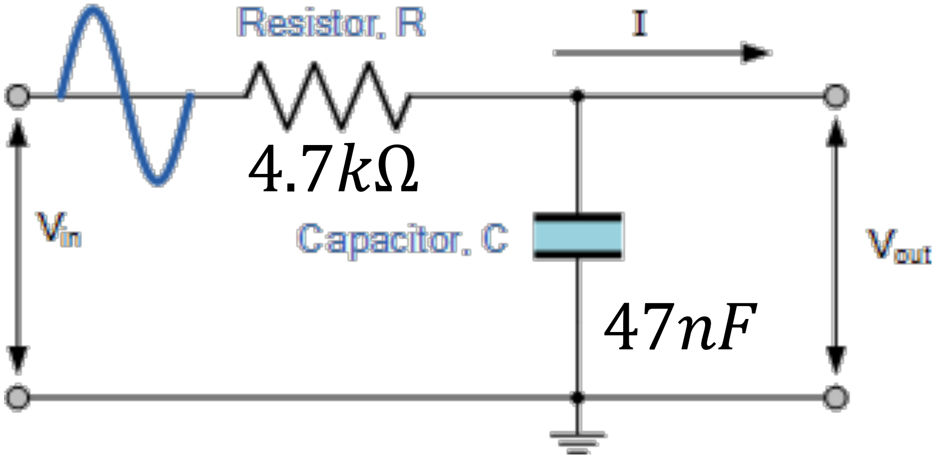
$$V_{out} = V_{in} \times \frac{X_C}{\sqrt{R^2 + X_C{}^2}} = V_{in}\,\frac{X_C}{|Z|}$$

$V_{in} = 10V\ at\ 100Hz$

$$V_{out} = 10\times \frac{33{,}863}{\sqrt{(4700)^2 + (33{,}863)^2}}$$

$$= 9.9V$$

What is the frequency response of this circuit?



$V_{in} = 10V \text{ at } 10kHz$

$$X_C = \frac{1}{2\pi f C}$$

$$|Z| = \sqrt{R^2 + {X_C}^2}$$

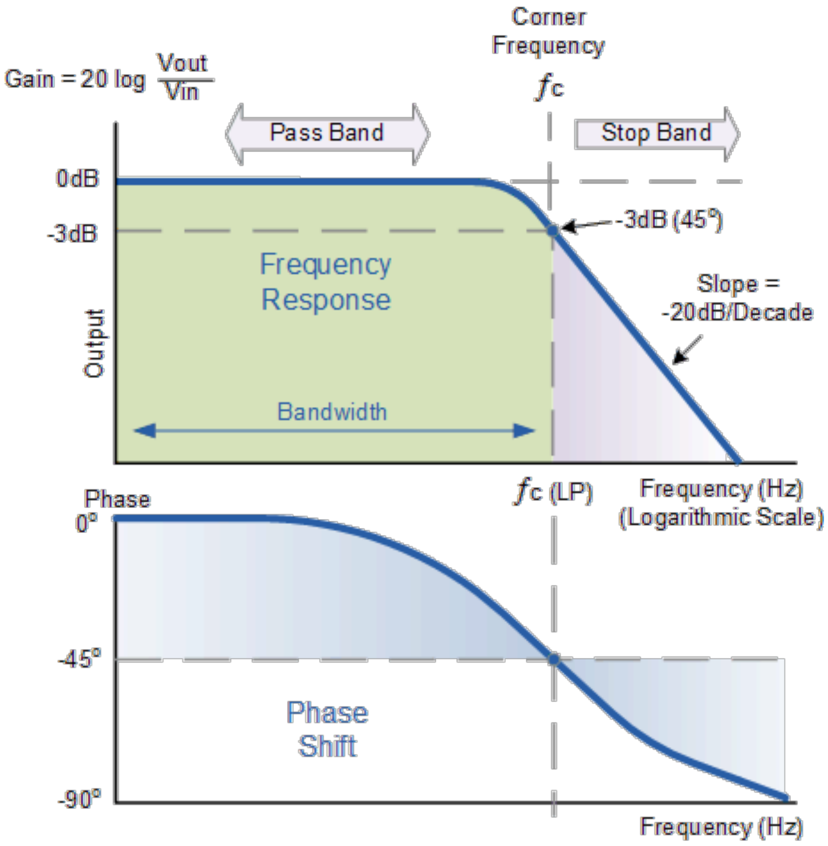
$$V_{out} = V_{in} \times \frac{X_C}{\sqrt{R^2 + {X_C}^2}} = V_{in} \frac{X_C}{|Z|}$$

$$V_{out} = 10\times \frac{338.6}{\sqrt{(4700)^2 + (338.6)^2}}$$

$$= .72V$$

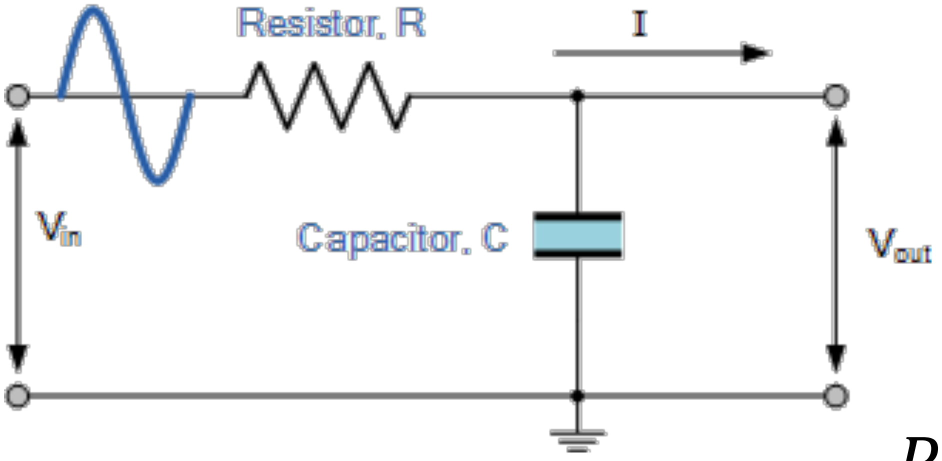
Frequency response of a low pass filter

- ❑ Gain
- ❑ Bandwidth
- ❑ Pass band vs stop band
- ❑ Corner frequency
- ❑ 3dB point
- ❑ Roll off



https://www.electronics-tutorials.ws/filter/filter_2.html

Back to the previous example



$$f_c = \frac{1}{2\pi RC} = \frac{1}{2\pi \times 4.7k\Omega \times 47nF}$$

$$f_c = 720Hz$$

$$Phase\ shift\ \varphi = -\tan^{-1}(2\pi fRC)$$

$$\varphi = -45°\ at\ 720Hz$$

At f_c, $20\log\left({}^{V_{in}}/_{V_{out}}\right) = 70.7\%$ of the input