SENSORS

EE 306 – SS2016

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Measured Signals

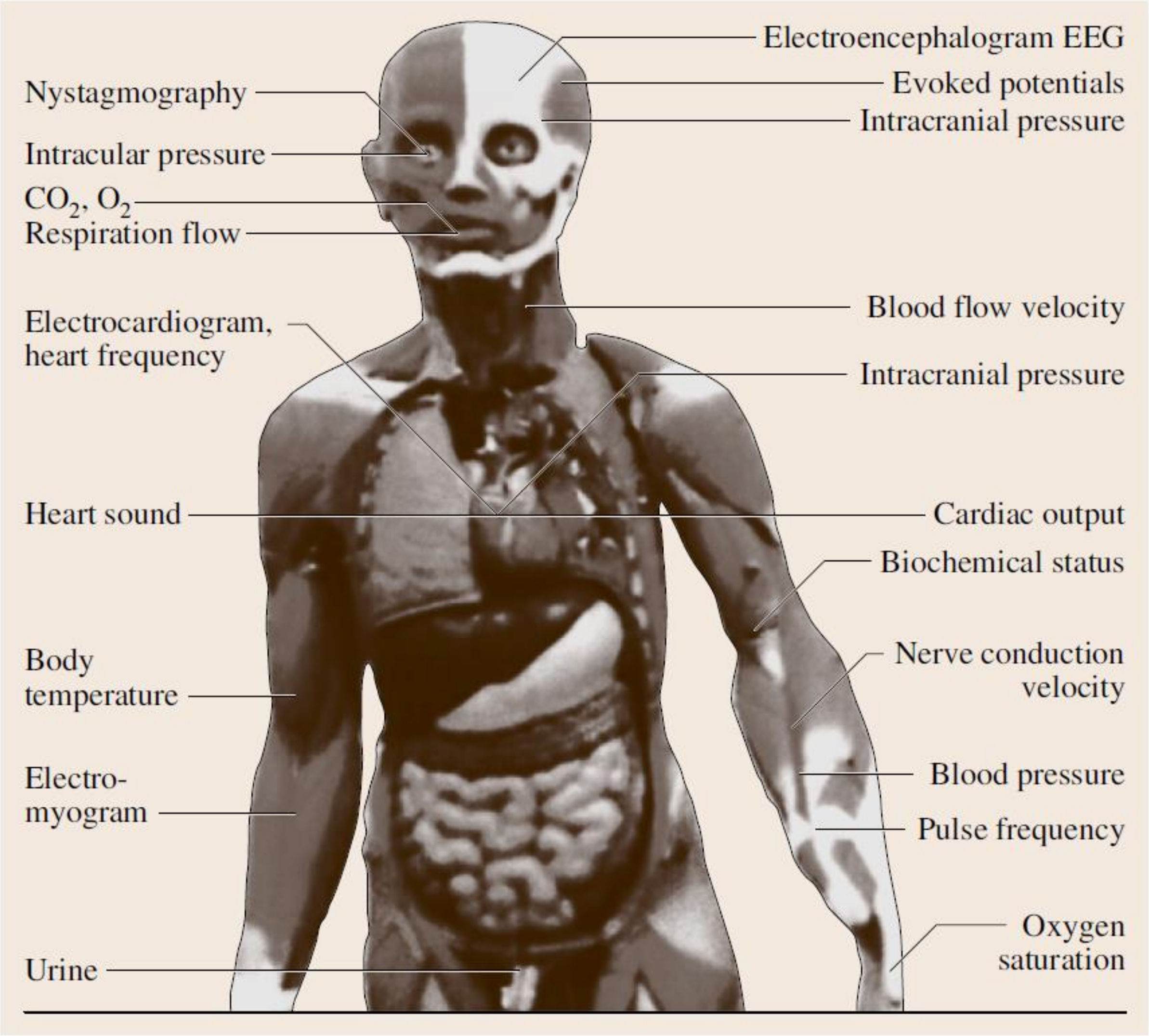
- Signals can be defined as phenomena to describe functional states and their variations in a system
  - Actual measurand that should be metrologically determined
- Provide information about state as well as process dynamics
- To analyze them, generation locus and thus spatial and temporal correlation is significant

- Special Case: Biosignals are acquired from living organisms, organs and organ parts down to single cells

Signal Types

- Electric and magnetic signals (electric potentials, ion currents)
- Acoustic signals (sound intensity, speech)
- Chemical signals (substance compositions, concentrations)
- Mechanical signals (size, shape, displacement, acceleration, flow)
- Optical signals (color, luminescence)
- Thermal signals (temperature)

Biosignal Examples

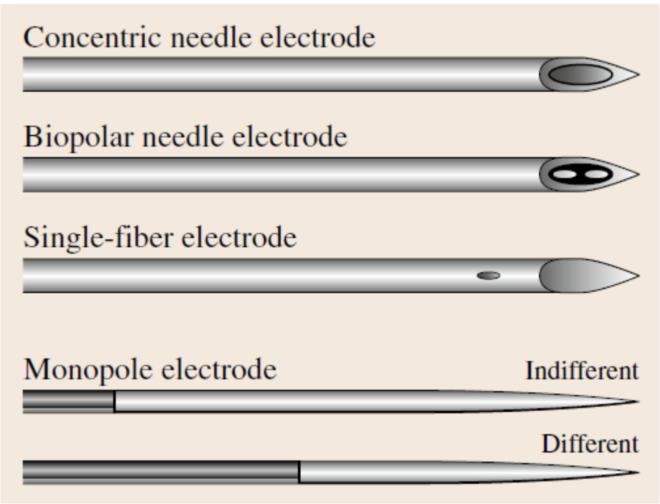


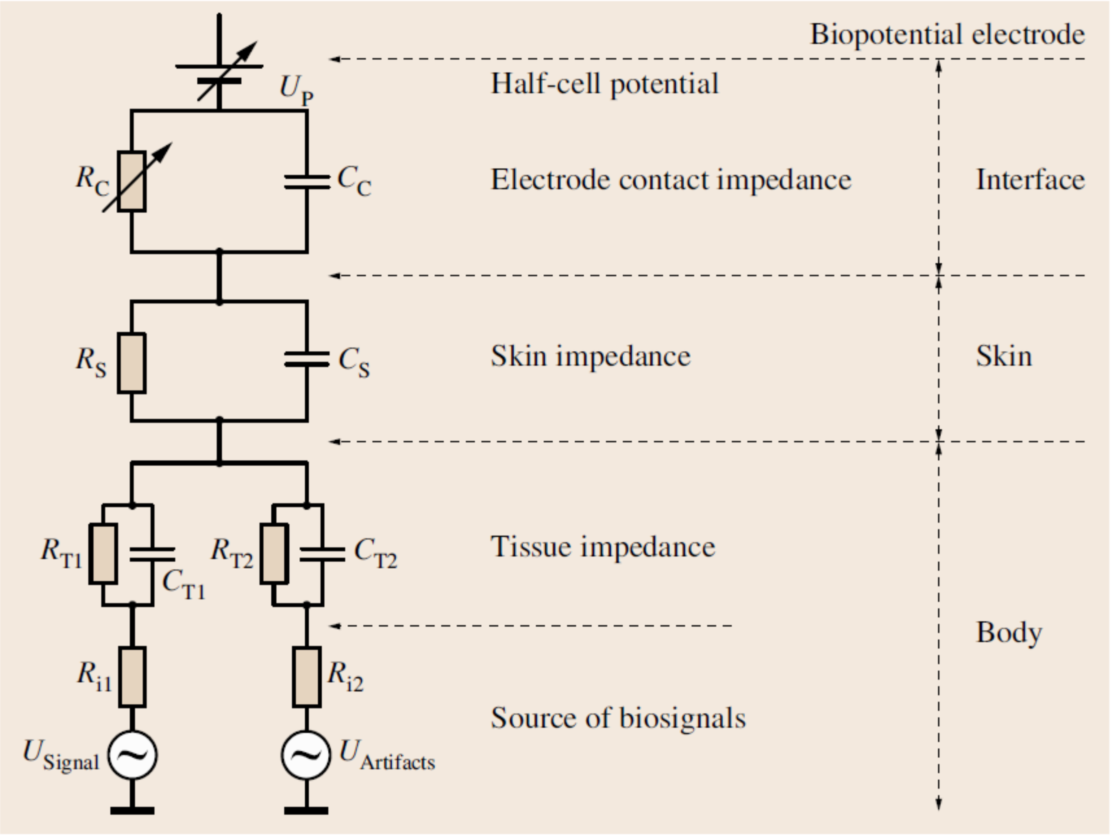
Sensing Effects

- Two basic elements in the operation of sensors
- Sensing effect
  - Physical or chemical interaction between environment and sensing material altering the material properties
- Transduction mechanism
  - Conversion of this material property change into useful electrical signal

Electric and Magnetic Transducers

- Transduce electric signal (ion current) into electric signal (electron current)
- Two groups: microelectrodes (metal microelectrodes) and macroelectrodes (surface electrodes)





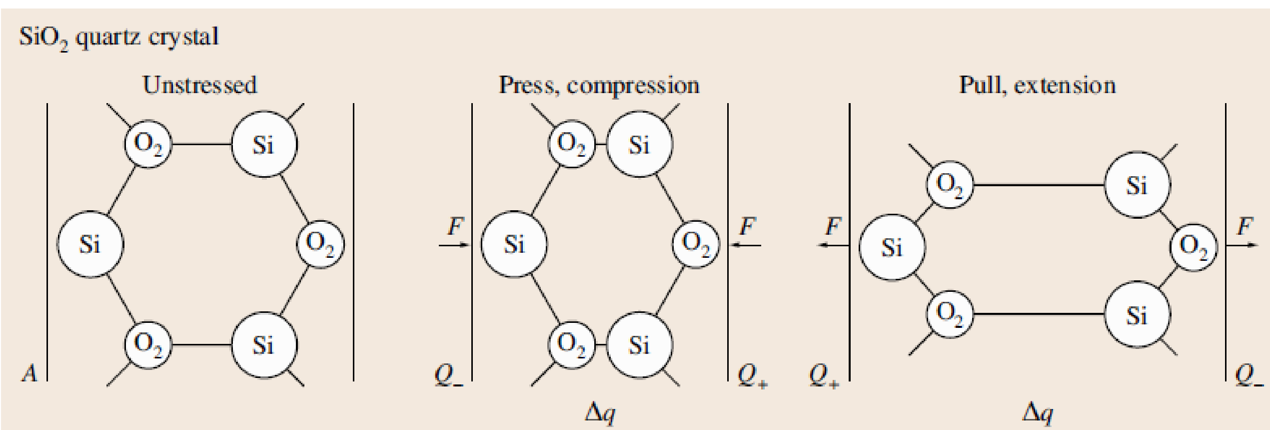
Mechanoelectric Transducers

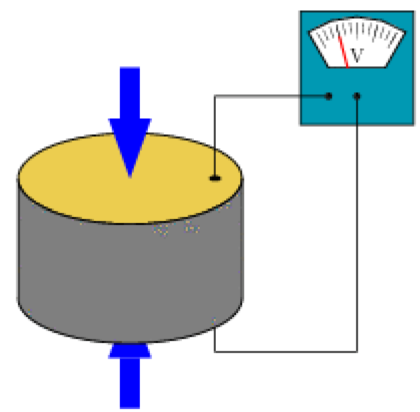
- Measure length changes, strains, pressure changes in tissue, body fluids and organs as well as for the measurement of sounds, microvibrations and blood flow
- Strain Gauge: $R=\rho L/A$ allows detecting changes in L
- Piezoresistive elements as strain gauge in a Wheatstone bridge
  - Changes in resistivity can be observed that are up to 100 times larger than the geometric effect yielding a more sensitive strain gauge
- Capacitive transducer: force applied to capacitor yielding a change in the distance between its two plates changes C

$$C_X = \varepsilon_0 \varepsilon_\gamma \frac{A}{x}$$

Piezoelectric Effect

- Production of electricity by pressure
  - Practically measured as generated voltage between two electrodes
- Piezoelectricity occurs only in insulating materials and is manifested by the appearance of charges on the surfaces of a piece of material that is being mechanically deformed

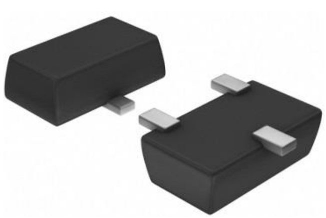


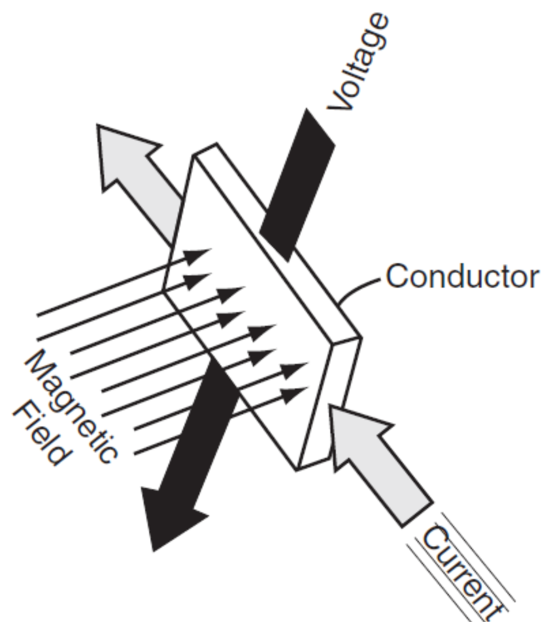


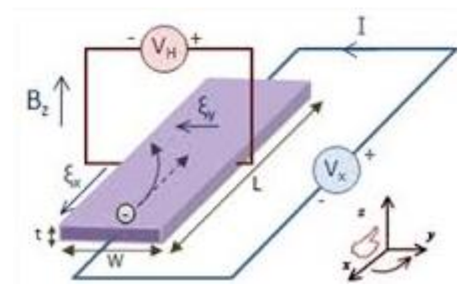
$$\Delta q = k \Delta F$$

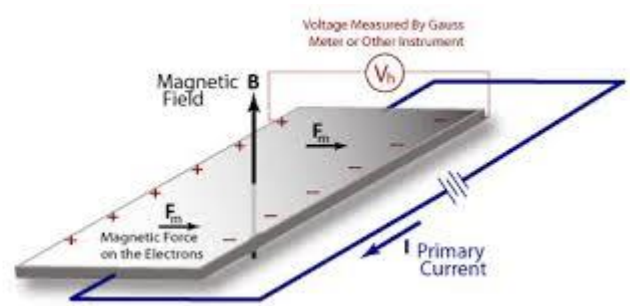
Hall Effect

- Electric current flows through material in pretty much a straight line
- When magnetic field is present, Lorentz force makes them deviate from their straight path
- With more electrons on one side of the material, there would be a difference in Hall potential (or Hall voltage) between two sides
  - Voltage proportional to electric current and strength of magnetic field







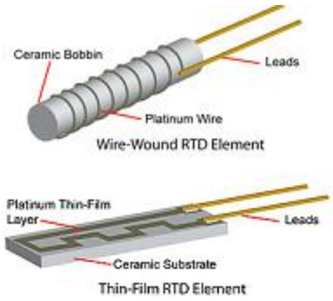


Thermoresistive Effect

- Temperature variations change electrical resistivity of conductor and semiconductor materials
- Examples: *Resistance temperature detector (RTD), Thermistor*

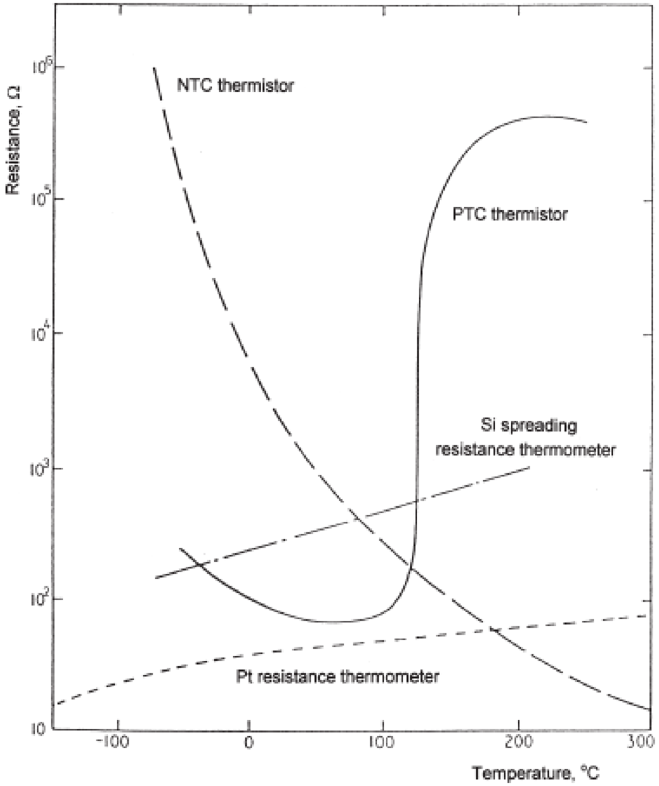
  - *Linear (RTD)*

$$\rho(T) = \rho_o(1 + \alpha \Delta T)$$



  - *Nonlinear (NTC Thermistor)*

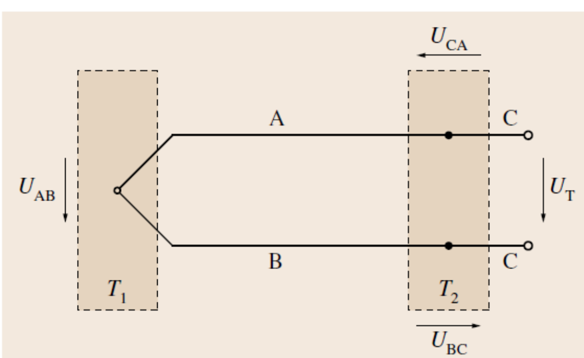
$$\rho(T) = \rho_o \exp(B/T)$$

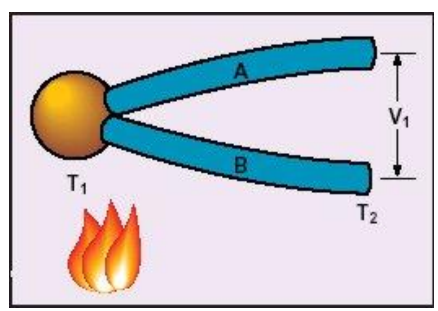


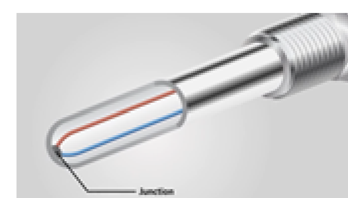
Thermoelectric Effect

- Generation of electric voltage proportional to temperature difference
- Thermoelement (thermocouple) is a junction of two conducting (metal or semiconductor) materials, A and B, electrically connected at a “hot” point of temperature, T1, while the nonconnected ends of both legs are kept at another temperature T2 (“cold” point)
  - Seebeck EMF

$$U_{\mathrm{T}} = \alpha_{\mathrm{T}} \cdot (T_2 - T_1)$$

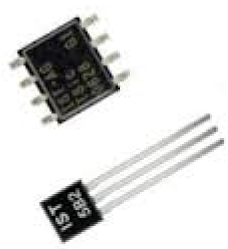






Semiconductor Temperature Dependence

- Semiconductor diodes have temperature-sensitive voltage vs. current characteristics
  - When two identical transistors are operated at a constant ratio of collector current densities, the difference in base-emitter voltages is directly proportional to the absolute temperature
- Use of IC temperature sensors is limited to applications where the temperature is within –55° to 150°C range
  - Advantages: small, accurate, and inexpensive
- Output in analog form (voltage or current proportional to temperature) or digital (communicate digital temperature value)

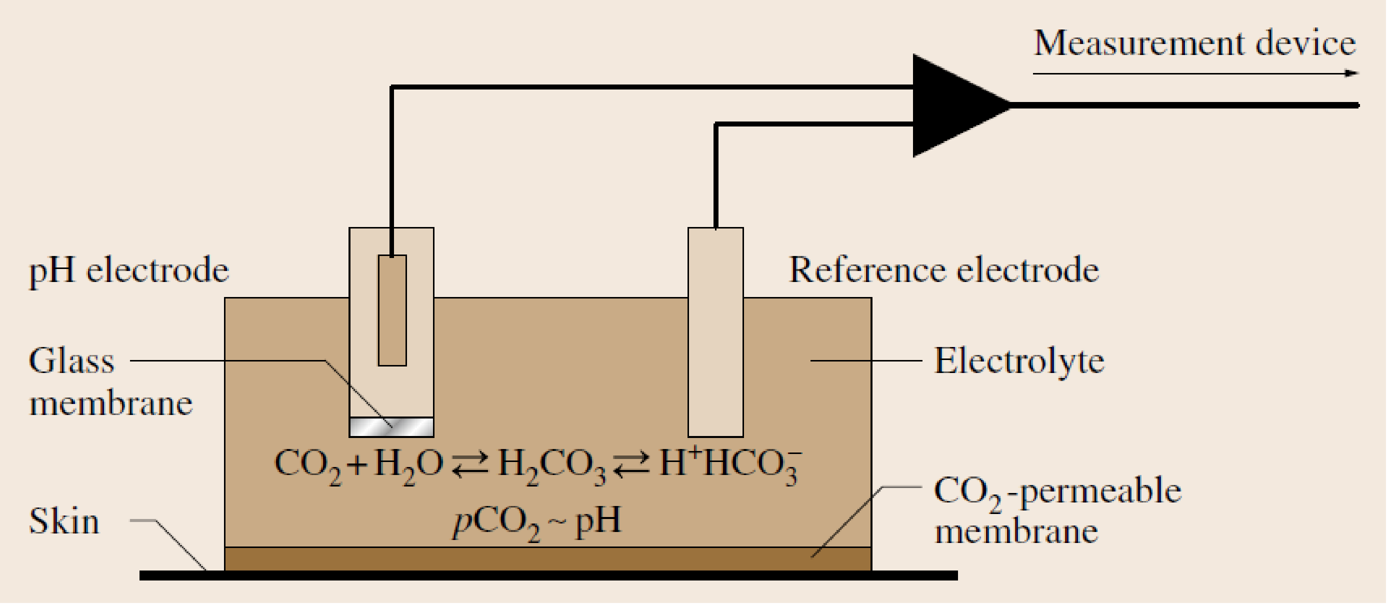


Comparison of Temperature Sensors

Characteristic	Platinum RTD	Thermistor	Thermocouple	Temperature IC
Active Material	Platinum Wire	Metal Oxide Ceramic	Two Dissimilar Metals	Silicon Transistors
Changing Parameter	Resistance	Resistance	Voltage	Voltage or Current
Temperature Range	-200°C to 500°C	-40°C to 260°C	-270°C to 1750°C	-55°C to 150°C
Sensitivity	2 mv/°C	40 mV/°C	0.05 mV/°C	~1 mv/°C or ~1 uA/°C
Accuracy	-45 to 100°C: ±0.5°C; 100 to 500°C: ±1.5°C; 500 to 1200°C: ±3°C	-45 to 100°C: ±0.5°C; degrades rapidly over 100°C	0 to 275°C: ±1.5 °C to ±4°C; 275 to 1260°C: ±0.5 to ±0.75%	±2 °C
Linearity	Excellent	Logarithmic, Poor	Moderate	Excellent
Response Time	2-5 s	1-2 s	2-5 s	
Stability	Excellent	Moderate	Poor	Excellent
Base Value	100 Ω to 2 kΩ	1 kΩ to 1 MΩ	< 10 mV	Various
Noise Susceptibility	Low	Low	High	High
Drift	+/- 0.01% for 5 years	+/- 0.2 to 0.5°F per year	1 to 2°F per year	0.1°C per month
Special Requirements	Lead Compensation	Linearization	Reference Junction	None
Device Cost	$60 - $215	$10 - $350	$20 - $235	$5 - $50
Relative System Cost	Moderate	Low to Moderate	Moderate	Low

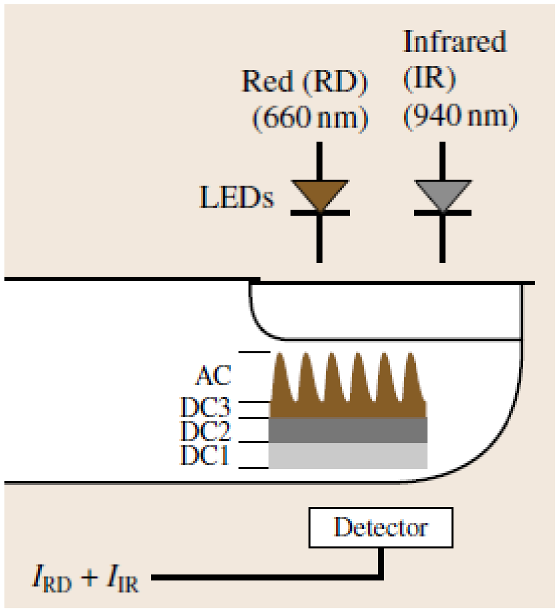
Chemoelectric Transducers

- Used for the measurement of individual chemical components in the blood, in body tissues, in the exhaled air or on the skin
  - Potentiometric sensors, based on the measurement of cell potential
  - Amperometric sensors, based on cell current
  - Conductometric sensors, based on admittance



Photoelectric Effect

- Depending on the incident light intensity, current flowing through the sensor changes
  - Examples: photoresistors, photodiodes, and phototransistors



Further Reading and Assignments

- Chapter 46 of *Springer Handbook of Medical Technology (2011)*.
- Chapter 4 of *Sensors in Biomedical Applications* (2000).
- Chapter 2 of Sensors, An Introductory Course (2013).