Melissa's Thesis :

Dienstag, 16. März 2021 10:45

Summary : More in depth the light-matter interaction and absorbtion coefficients...

Main subject : Cardiovascular deseases and effect on automobile accidents

- Mean age : 56 yo
- monitoring the heart rate is possible to track the trends and patterns of each person
- ontact electrode on the steering wheel and one capacitive coupling electrode on the driver's seat to realize an R-R interval measurement and focused on the drowsiness detection
- BP: force that the blood produces by pushing against the artery walls
- made with each heartbeat as blood is pumped from the heart into the blood vessels; this force is called systolic blood pressure (SBP)
- When the heart goes into the relaxation phase, the arteries stay at a lower resting tone to maintain some pressure in the artery; this force created in the arteries when the heart is relaxed is called diastolic blood pressure (DBP)

Causes of high blood pressure :
verweight - Having lots of salt in the diet - Not getting much physical activity - Family history of high blood pressure - High-stress level - Not getting enough sleep - Excessive alcohol use - Kidney disease. [20]

Blood pressure classification in adults

Blood pressure classification	SBP (mm Hg)	DBP (mm Hg)
Optimal	<120	<80
Normal	120–129	80–84
High normal	130–139	85–89
Grade 1 hypertension (mild)	140–159	90–99
Grade 2 hypertension (moderate)	160–179	100–109
Grade 3 hypertension (severe)	≥180	≥110
Isolated systolic hypertension	≥140	<90

PPG

- a technology that allows measuring the changes in blood volume (blood pressure)
- easy to set up, non-invasive, has a low cost and is simple.

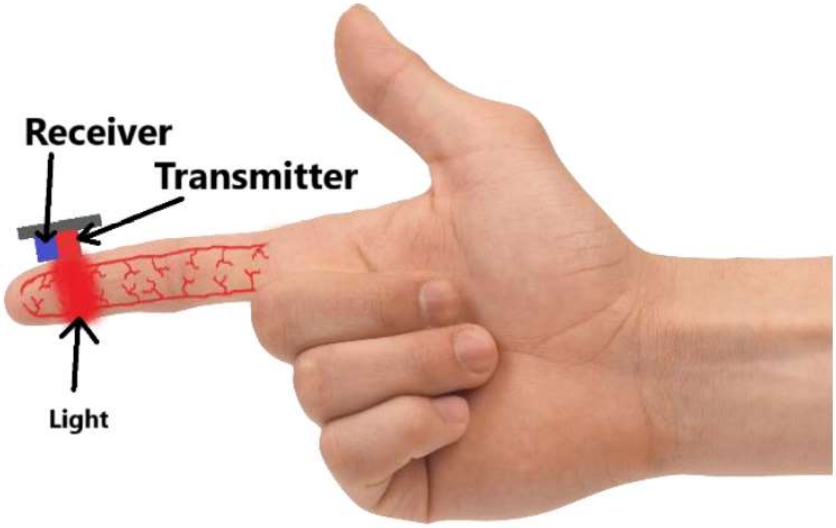


Figure 4: Photoplethysmography's principle

- The light emitted is absorbed by blood rather than the tissues or bones, so this amount of light absorbed is determined by the receiver that is a photodetector. Therefore, a reduction in the amount of blood can be detected as an increase in the detected light
- The interaction between light and the tissues and bones is complicated and may involve scattering, absorption, and reflection. According to Anderson and Parrisch, the regular reflectance of incident radiation on the skin is between 4% and 7% over the entire light spectrum from 250-3000nm for light and dark skin color. A 93% to 96% of the incident radiation that does not return by regular reflectance may be absorbed or scattered

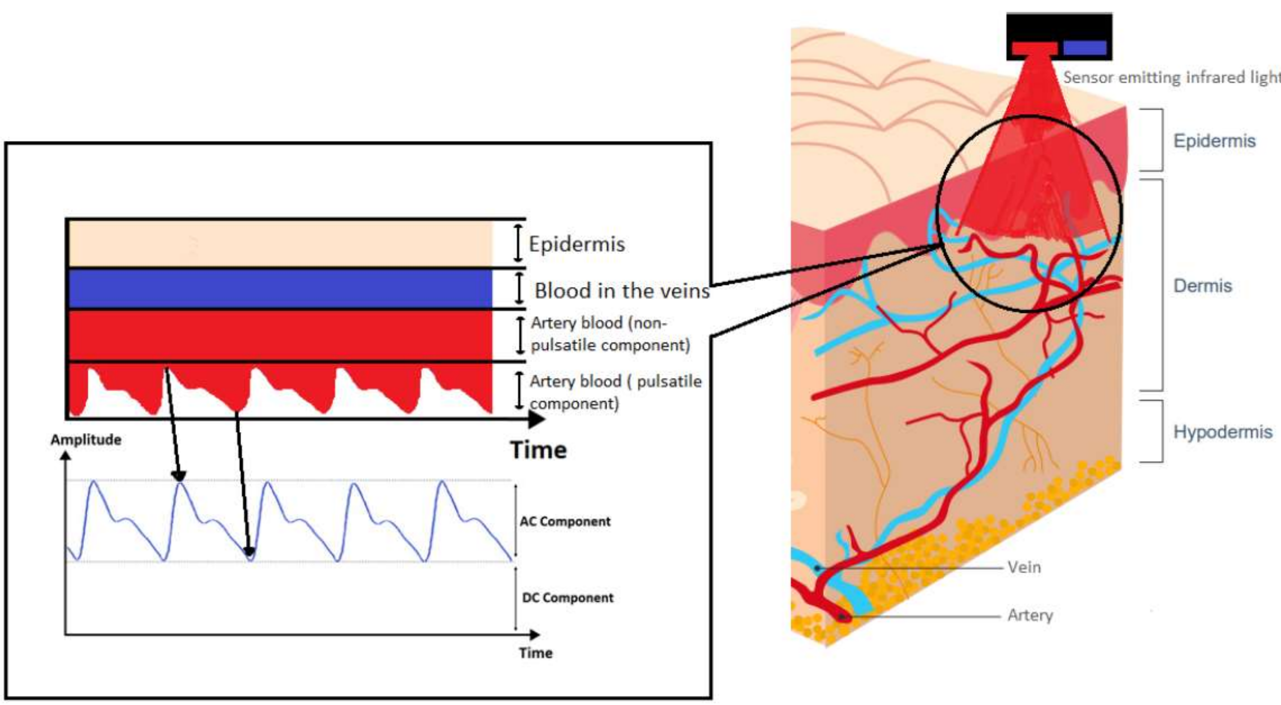


Figure 5: Working principle of PPG on the skin [27].

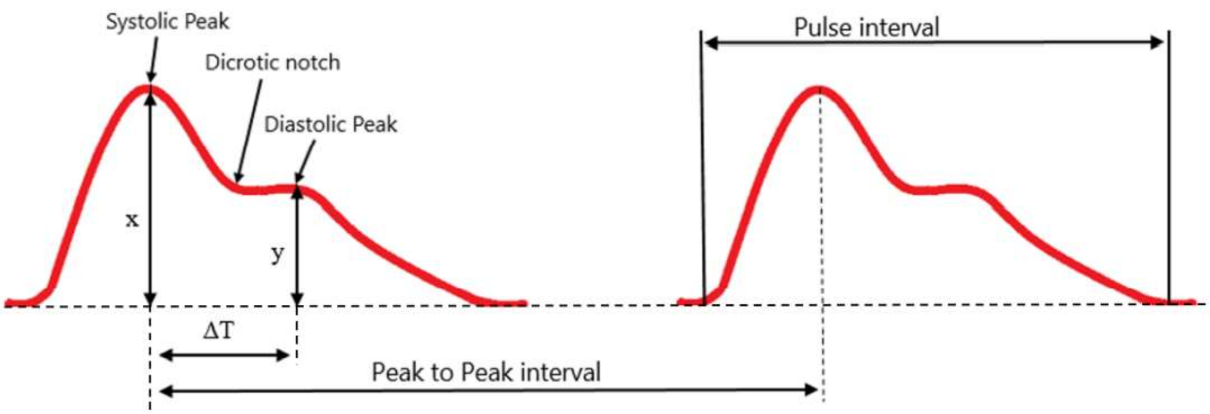
- <u>DC component :</u> depends on the **structure of the epidermis** and tissues and the **average blood volume** in arteries and veins

- <u>AC component</u> : shows the blood volume **change during a certain time** in the arteries and veins
- <u>Melanin</u> plays a significant role in **determining the transmission of optical radiation through the epidermi**s; it **affects the transmittance of normal human epidermis**. Melanin is not a filter of the skin; on the contrary, it <u>absorbs light</u>. The shorter light wavelengths there are, the stronger the light absorbed is. They also observed that near the infrared zone, further away the 1100nm, the absorption by melanin is almost imperceptible; it means that for longer wavelengths than 1100nm, the light quickly passes through. [26]
  Therefore, infrared light has been used in PPG sensors and devices
- green light LEDs have significantly more absorptivity for oxyhemoglobin2 and deoxyhemoglobin3 => better signal on noise ratio. But limits the depth of the light bc the body absorbs it +.darker skin absorbs more green light, which means that the signal can not get through, this can also be a problem when measuring the heart rate of tattooed skin.

	IR	**Green**
+	Independant of melanin rate -> more incluse More penetration	Better signal on noise ratio
-		Less penetration

=> Infrared

PPG Signal

- 

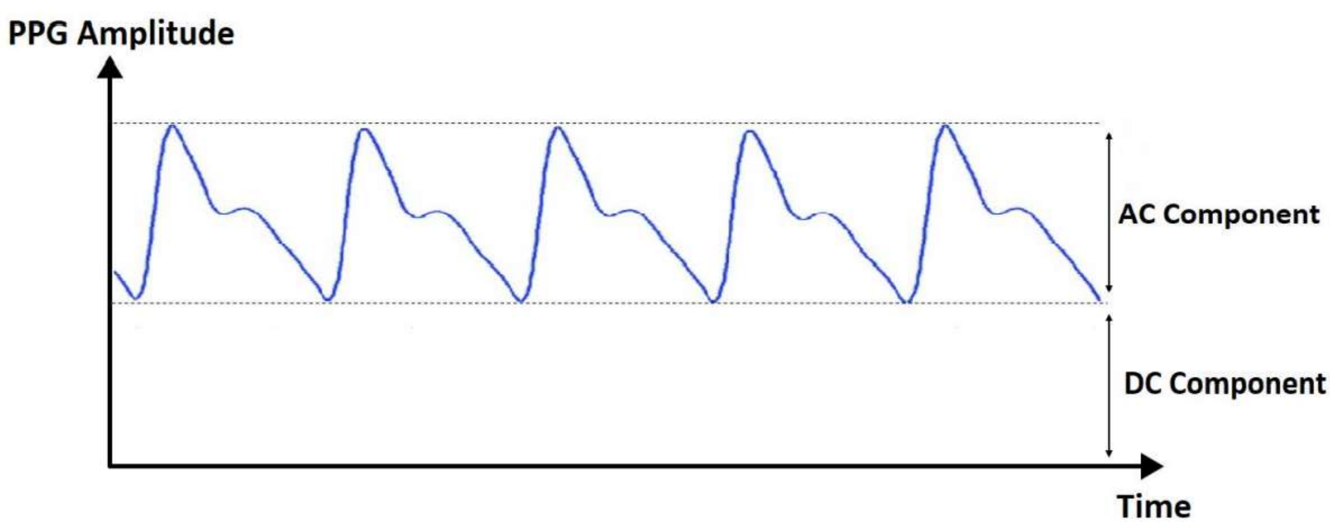
- Same "motif" everywhere
- 

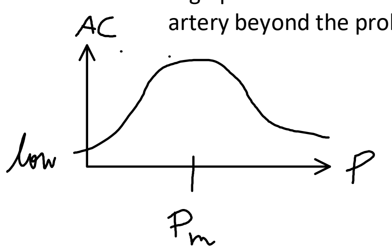
Figure 8: Representation of a PPG composition

- A PPG waveform consists of a direct (DC) and an alternating current (AC) component.

- The DC component : detected transmitted (or reflected) optical signal from the tissue. The DC component changes slowly with a person's breath
- the AC component: shows the **blood volume changes that occur between the systolic and diastolic phase**s. The cardiac frequency is represented by the AC component, depends on the heart rate, and is placed above the DC component, as shown in Figure 8. It is essential to consider that the venous pulsations can cause small changes or even error in PPG detection

Factors affecting the PPG signal:
- Measurement site of the probe : affects quality of the signal + robustness against motion.
- Distance of the PPG imaging : some devices are limited to short distance / subject to change in ambiant light. low signal scattering and reduced tissue irradiance at long distances.

one issue while attempting to monitor the Heart rate (HR) from a long distance, the light source must be close, at around 20cm distant from the object to measure.
- Contact force probe-measurement:
    - Low pressure : inadequate contact, and therefore, a **low AC** signal amplitude is shown
    - High pressure :can cause a **low AC** signal amplitude and distorted waveforms caused by the occluded artery beyond the probe



does not exist accepted standards for optimal contact pressure for clinical or fundamental PPG measurements.

Forehead region : 8 to 12 kPa (60-90 mmHg) have revealed the largest PPG amplitude for a reflectance-type sensor

Factors affecting the HR :
- Age -
- Fitness and activity levels -
- Being a smoker -
- Having cardiovascular diseases, high cholesterol or diabetes -
- Air temperature -
- Body position (standing up or lying) -
- Emotions -
- Body size -
- Medications [34]

How to determine the HR from the PPG signal
1. Measure the period between two systolic peaks :T

$$\mathrm{HR}_{\mathrm{inst}} = \frac{60}{t}$$

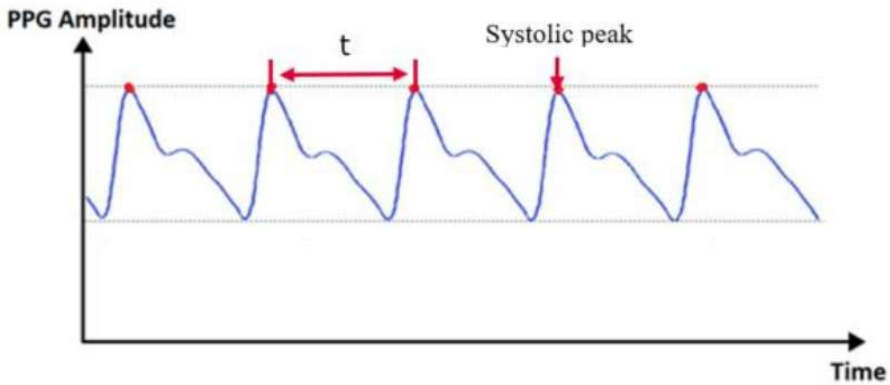


Figure 9: PPG waveform and time t

Tachychardia : HR >100 beats/min
Bradychardia : HR<60beats/min

Table 7: Summary of the window functions. [43, 56]

Window	Pros	Cons	Use case
Rectangular	- Small smear.	- Big leak effect.	- Periodic signals whose period is known. - Finite signals. - Relative flat spectrums.
Hanning	- Leak effect is at least 19 dB damped.	- The spectral resolution is worse than the one from the rectangular window.	- Signals with different or unknown frequencies.
Hamming	- Faster roll-off than the Blackman window.	- Worse stopband attenuation than the Blackman window.	- Smoothing the autocovariance function in the time domain.
Blackman	- Close to an optimal window.	- Slightly worse than the Kaiser window.	- Looking to have minimal leakage possible.
Kaiser	- The bigger the β the smaller the leak effect.	- The bigger the β the bigger the smear.	- Signal present oscillations of unknown frequency.

Digital filters are an important class of linear time invariant systems. They are used for two general purposes: 1- Separate signals that have been combined 2- Restore distorted signals

Some classic filters are:
1- Lowpass: This filter lets go through all the signals with a lower frequency than a selected cutoff frequency and attenuates the signals with higher frequencies than this cutoff frequency.
2- High-pass: This filter lets pass all the signals with a bigger frequency than a selected cutoff frequency and attenuates the signals with lower frequencies than this cutoff frequency
3- Bandpass: There are two cutoff frequencies selected for this filter. The lower and upper cutoff frequency, all signals outside that range will be attenuated, and the ones inside it will pass.
4- Bandstop: This filter makes the opposite of the Bandpass filter. It attenuates all signals inside a selected range and passes all the others outside this range.
5- Allpass: This filter passes all frequencies and has a constant frequency response, but displaces signals in time depending on the frequency. [57]

There exist three ways to characterize a filter:
1- Impulse response
2- Frequency response
3- Step response

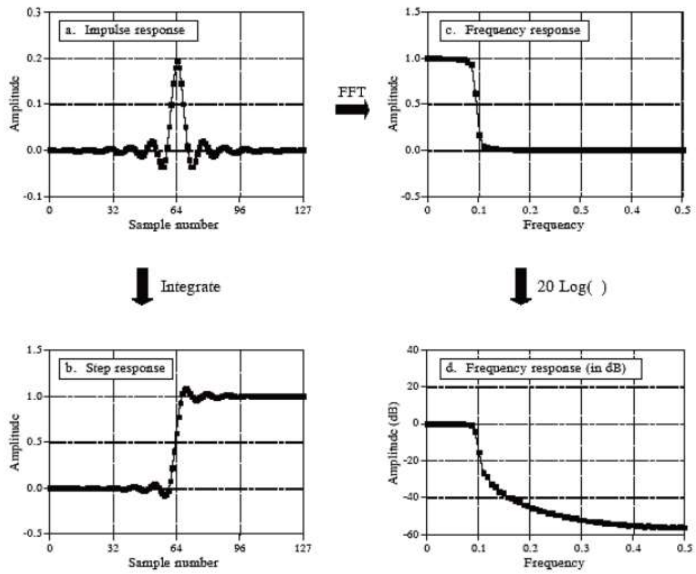


Figure 21: Filter parameters. [56]

That is the reason why recursive filters are also called infinite impulse response (IIR) filters. The transfer function of this IIR filter is defined by the equation (32), where the coefficients a and b are chosen during the filter design and only the biggest value of N, and M corresponds to the filter's order:

$$H(z) = \frac{Y(z)}{X(z)} = \frac{b_0 + b_1 z^{-1} + \dots + b_N z^{-N}}{1 + a_1 z^{-1} + \dots + a_M z^{-M}}$$

Signal to Noise ratio

$$\mathrm{SNR} = 10 \log \frac{P_{\mathrm{signal}}}{P_{\mathrm{noise}}} = 20 \log \frac{V_{\mathrm{RMS\,signal}}}{V_{\mathrm{RMS\,noise}}}$$

$$\mathrm{SNR} = 10 \log \left\{ \frac{\sum_{i=1}^{N} (x_i)^2}{\sum_{i=1}^{N} (x_i - y_i)^2} \right\}$$

Signal processing steps

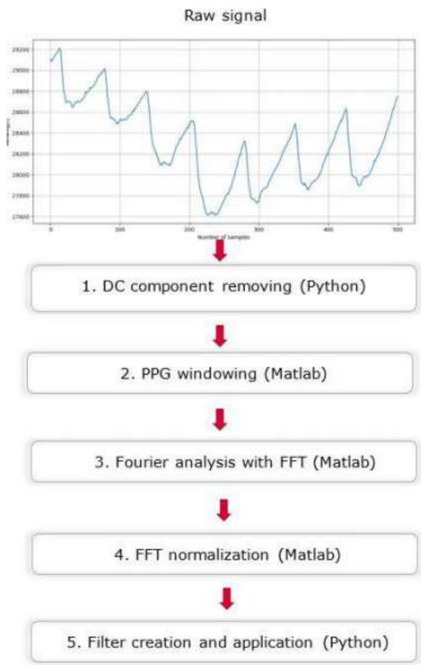


Figure 22: Signal-processing flowchart.

Applying an IIR filter could also be an option, but it was decided to use the FIR filter because it has been working with a finite time that is continuously updating its amplitude values. This process is made with Matlab's help because it had been tried with python, but the signal windowing is not working correctly. For this, the Matlab tool "sptool" is used to make the complete design process. First, the FFT is applied and normalized to find the frequencies that have to be attenuated. Later the filters with the different windows are created with the help of the sptool. The filter order is chosen to be small to not filter that much the signal, because it also means a loss of signal's information, and after analyzing the impulse response, the best one was applied to each window. Then the filters are applied to the original signal.

PALS2 Sensor

The PALS-2 ASIC is a proximity and ambient light sensor with some integrated photodiodes and several LEDs. The proximity and ambient light channels are measured with 16-bit resolution; this allows an excellent performance behind a glass or plastic cover without using cross-talk reduction measures. The device is controlled via a standard I2C interface. An interrupt output pin with programmable results thresholds (high and low for both Proximity (PROX) and Ambient light sensor (ALS) results) can be used to wake a microcontroller on a particular event. For the thesis, the proximity function was used. The main features of the PALS-2 and as regards the functionalities of proximity and Heart rate monitoring (HRM) can be summarized as follows:

- 300nA power-down current;
- 1.8V to 2.7V supply;
- I^2C interface, 1.7V to 3.6V bus level;
- Three integrated LEDs with 200mA driving capability;
- HRM functionality with dark skin types;
- Up to 250 readouts/second, ambient light suppression in PROX/HRM mode up to 100klux;
- 16-bit resolution digital output;
- Sensitivity up to 300mm distance;
- Pulse Oximetry function supported.

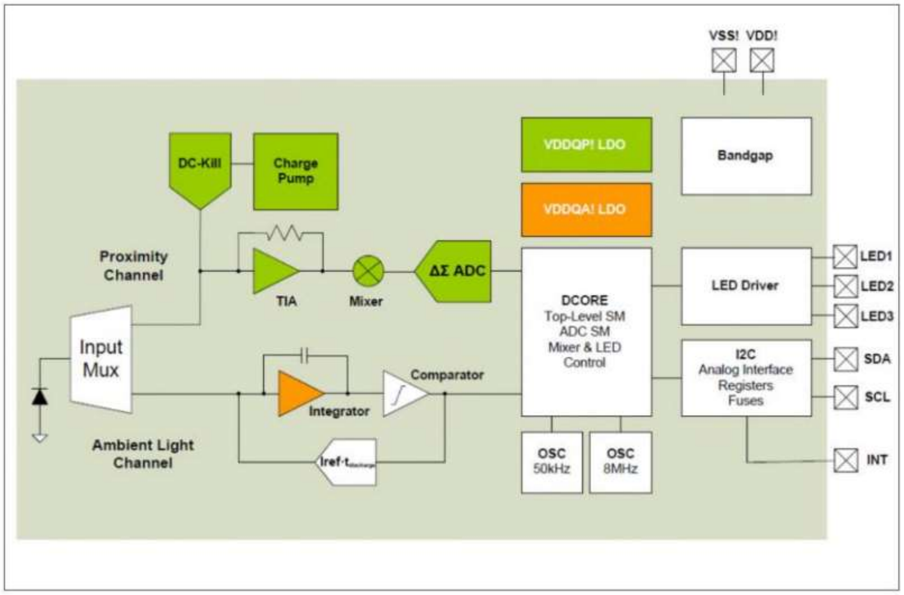


Figure 23: PALS-2 block diagram [31].

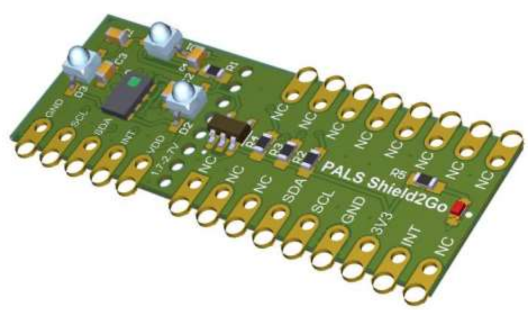


Figure 24: PALS shield2Go 3D design by Infineon technologies.

The pressure sensor signal is conditioned with an instrumentation amplifier before data conversion by an analog-to-digital converter (ADC). The systolic pressure, diastolic pressure, and pulse rate are then calculated in the digital domain using an algorithm appropriate for the type of monitor and sensor used. The resulting systolic, diastolic, and pulse-rate measurements are displayed on a liquid-crystal display (LCD), time-stamped, and if the person wants, stored

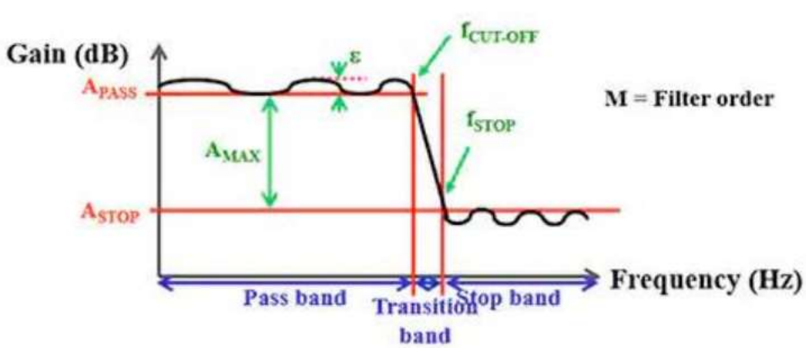


Figure 34: Frequency response of a low pass filter. [69]

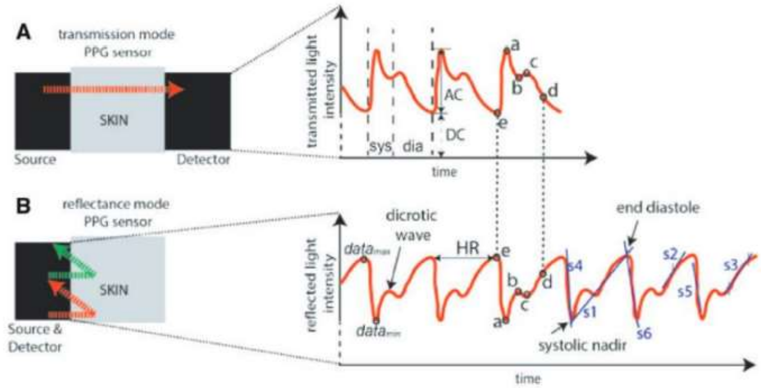


Figure 39: Difference of the transmission (a) and reflectance (b) mode PPG sensors. [71]