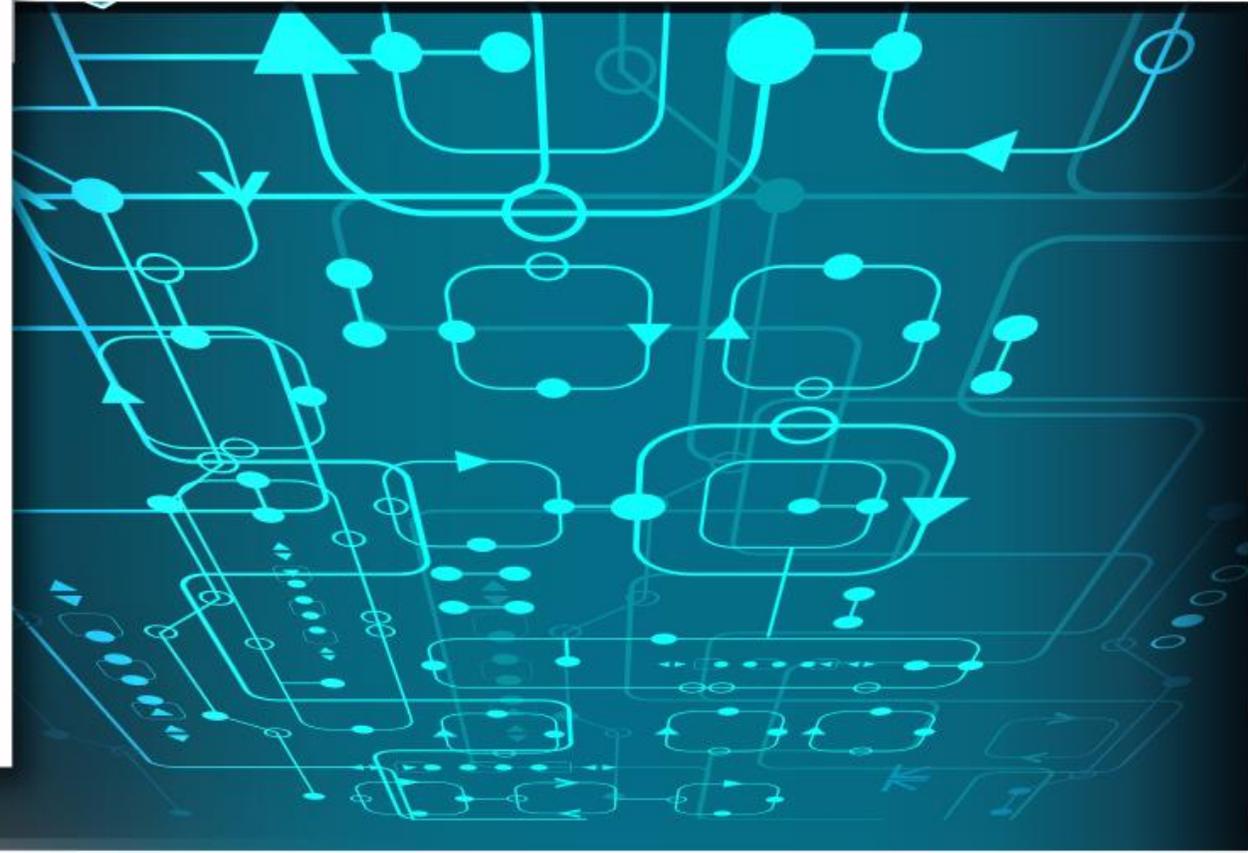


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Fundamentals of Pulse Oximetry

Digital Systems for
Industry

Alessandro Borghese

Outline

- Definition of Pulse Oximetry
- Principle of operation of non invasive measurement
- Types of Pulse Oximeter
- Heart rate measurement
- MAX30102: reflectance pulse oximeter

What is Pulse Oximetry?

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The measurement of oxygenation of arterial blood (SaO₂)

SaO₂ = **oxygen saturation** of arterial blood

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The measurement will be

- **Non-invasive**
- **Indirect**

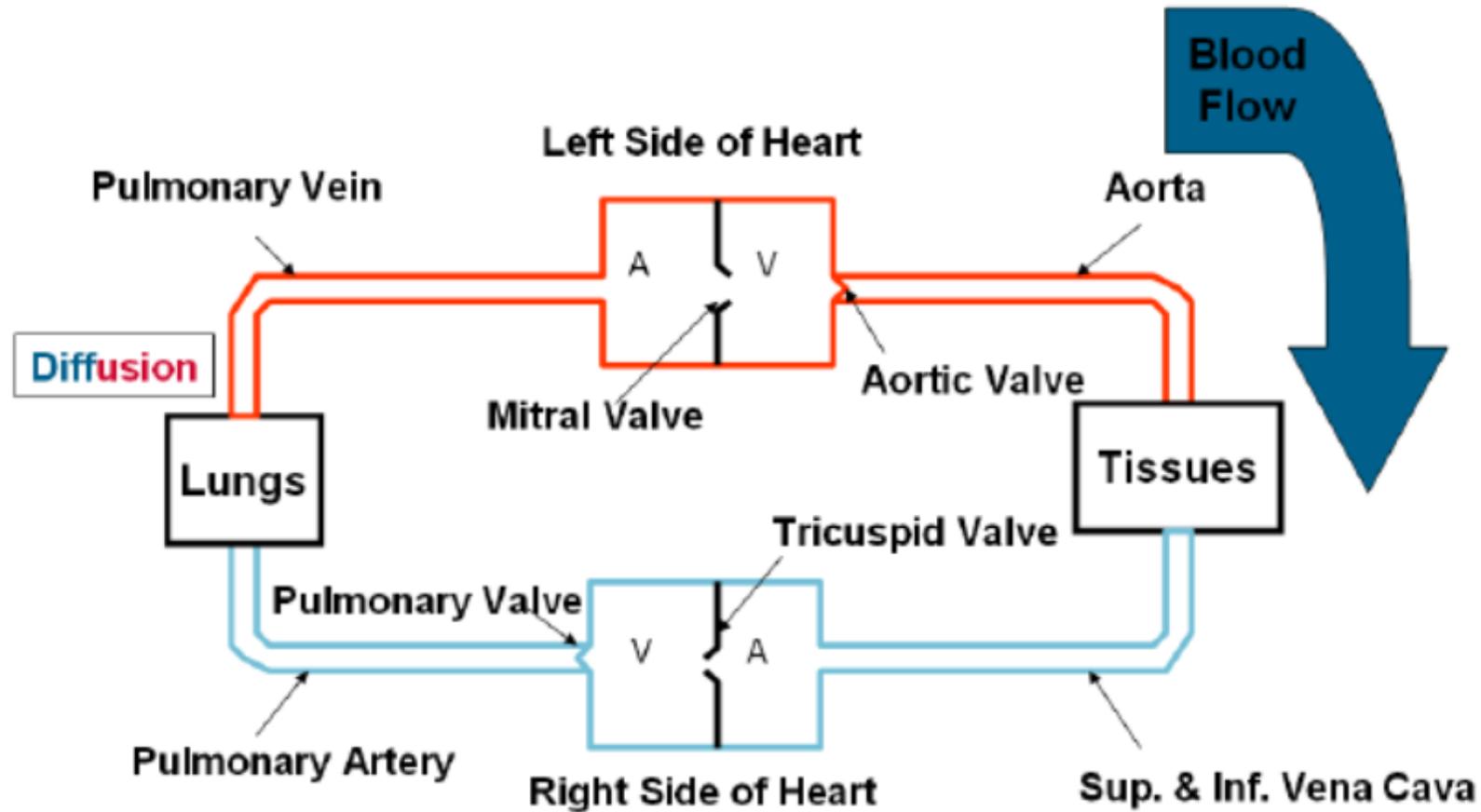
History



Only option to measure the oxygenation level **was to draw a blood sample**

- Invasive
- Time consuming

Blood circulating diagram



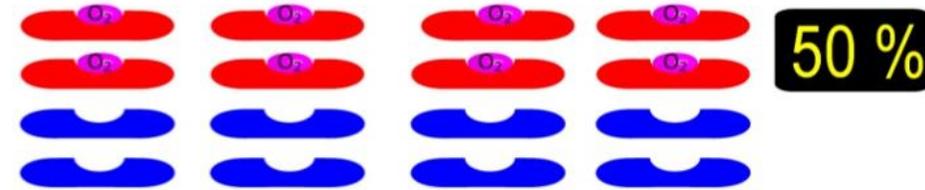
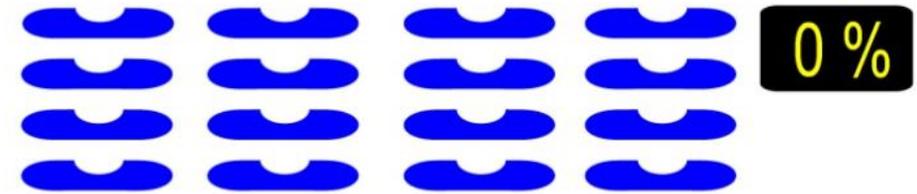
Hemoglobin

Transfer of oxygen from the lungs to the tissue cells is carried out **mainly by hemoglobin** (protein) molecules in the red blood cells

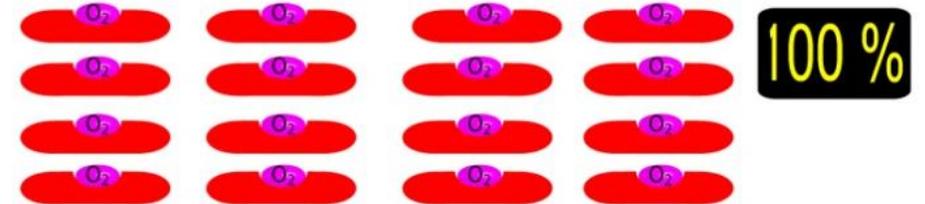
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Non-oxygenated hemoglobin: Hb



oxygenated hemoglobin HbO₂



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The measurement of oxygenation of arterial blood (SaO₂)

SaO₂ = **oxygen saturation** of arterial blood

- **Oxygen saturation** percentage of **oxygenated hemoglobin** (hemoglobin containing oxygen) compared to the total amount of hemoglobin in the blood (oxygenated and non-oxygenated hemoglobin)

$$\text{Oxygen saturation} = \text{SaO}_2 = \frac{\text{HbO}_2}{(\text{HbO}_2 + \text{Hb})}$$

How to non-invasively measure SaO₂?

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- Optical technique
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- Optical technique
- **HbO₂** and **Hb** differently absorb red and near-infrared (IR) light
- These two wavelengths well penetrate tissues (whereas blue, green, yellow, and far-IR light are significantly absorbed by nonvascular tissues and water)
- **HbO₂** absorbs greater amounts of IR light and lower amounts of red
- Consistent with experience e well oxygenated blood (high **HbO₂**) appears bright red to the eye because it scatters more red light than **Hb** does. On the other hand, **Hb** absorb more red light and appears less red.

Different absorption of Red and IR light

Lambert-Beer law

Describes how a light wave
attenuates when propagating into
a solution

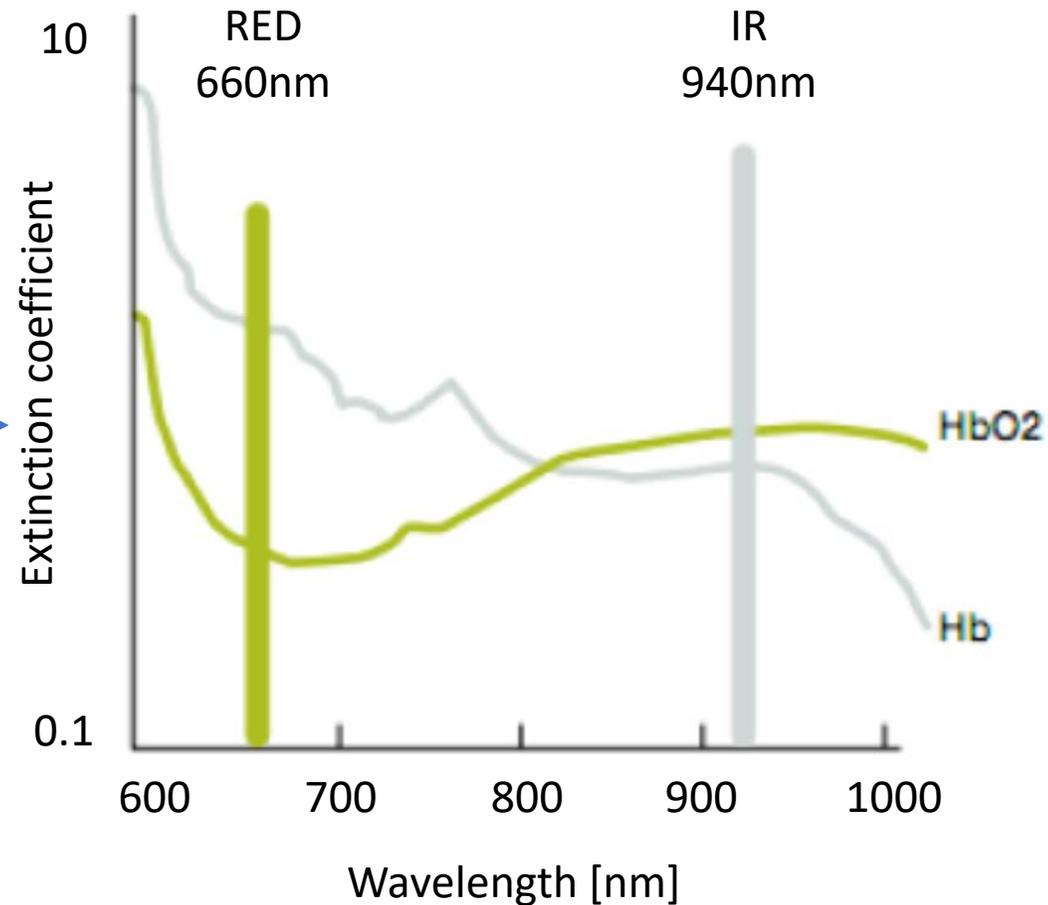
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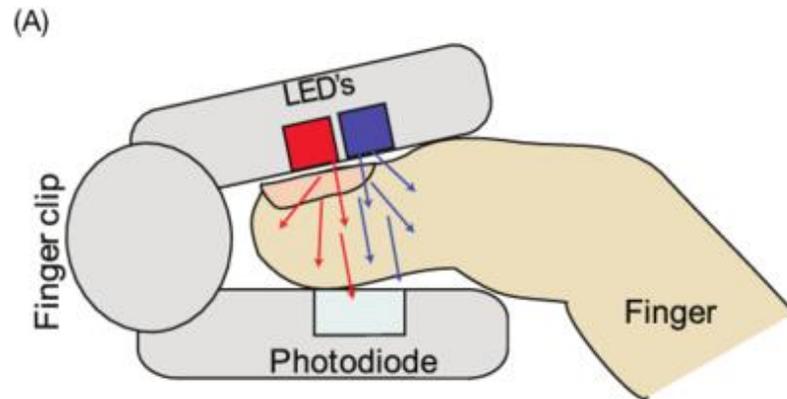
$$I = I_0 e^{-\underbrace{\varepsilon(\lambda)}_{\text{Extinction coefficient}} cd}$$

c =substance concentration
 d =length of the light path



Types of Pulse Oximeter

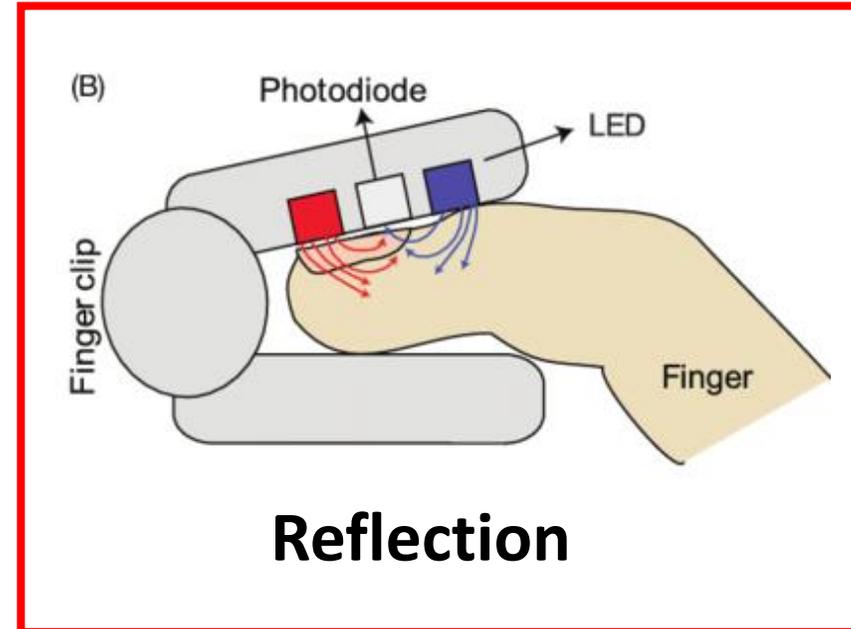
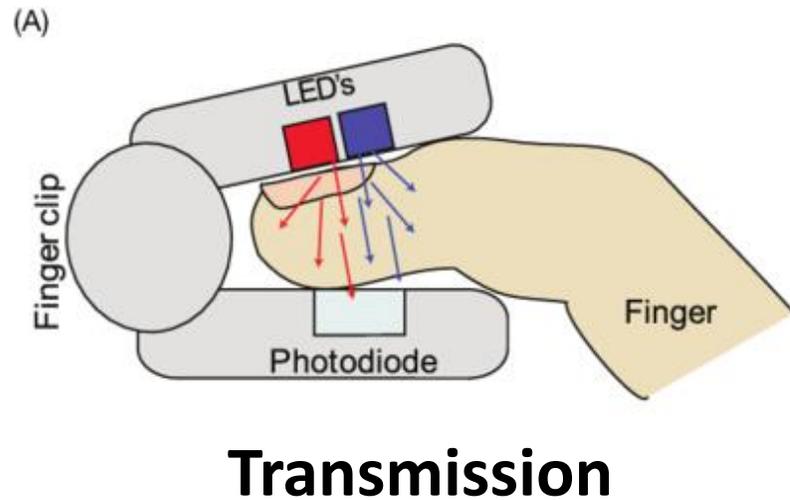
- Pulse oximeters emit **two wavelengths** of light, **red at 660 nm** and **near-IR at 940 nm** from a pair of small **LEDs** (light-emitting diodes).
- A **PD (photodiode)** detects the amount of transmitted or reflected light (depending on its location)



Transmission

Types of Pulse Oximeter

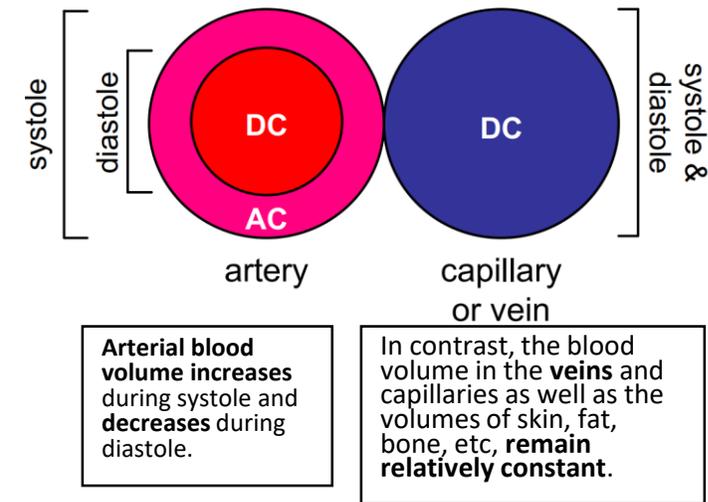
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Most adopted in wearable and portable applications

Principle of operation (1/2)

The amount of red and IR light absorbed **fluctuates** with the cardiac cycle



$$I = I_0 e^{-\varepsilon(\lambda)cd}$$

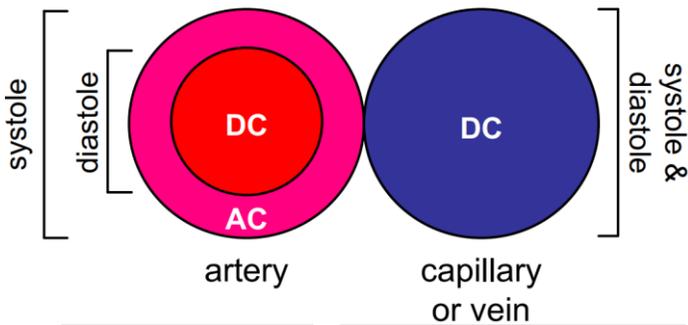
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The amount of red and IR light absorbed **fluctuates** with the cardiac cycle



Arterial blood volume increases during systole and decreases during diastole.

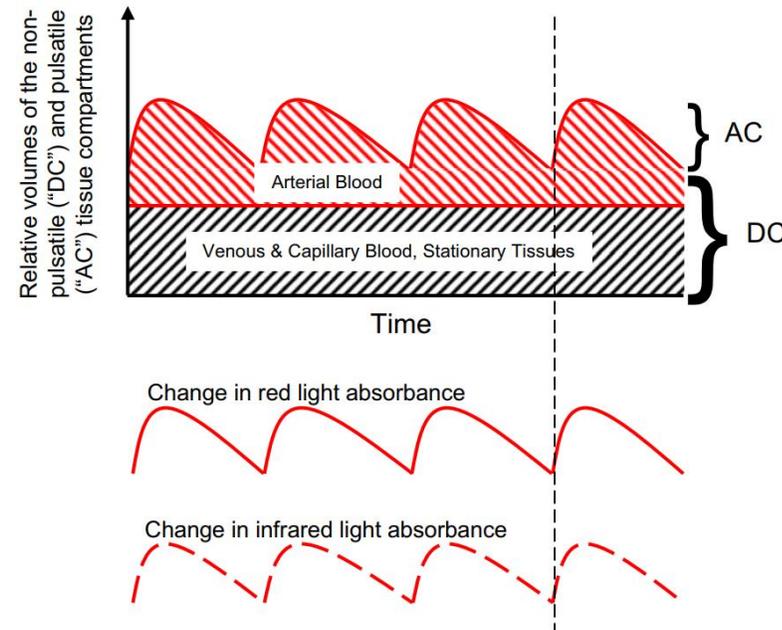
In contrast, the blood volume in the veins and capillaries as well as the volumes of skin, fat, bone, etc, remain relatively constant.

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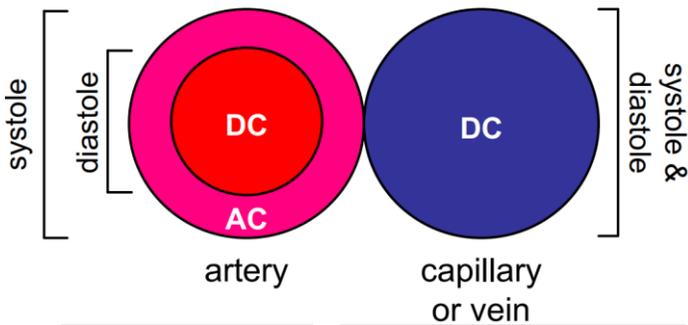
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A portion strikes the probe's photodetector and, accordingly, creates signals with a relatively stable and non-pulsatile "direct current" (DC) component and a pulsatile "alternating signal" (AC) component

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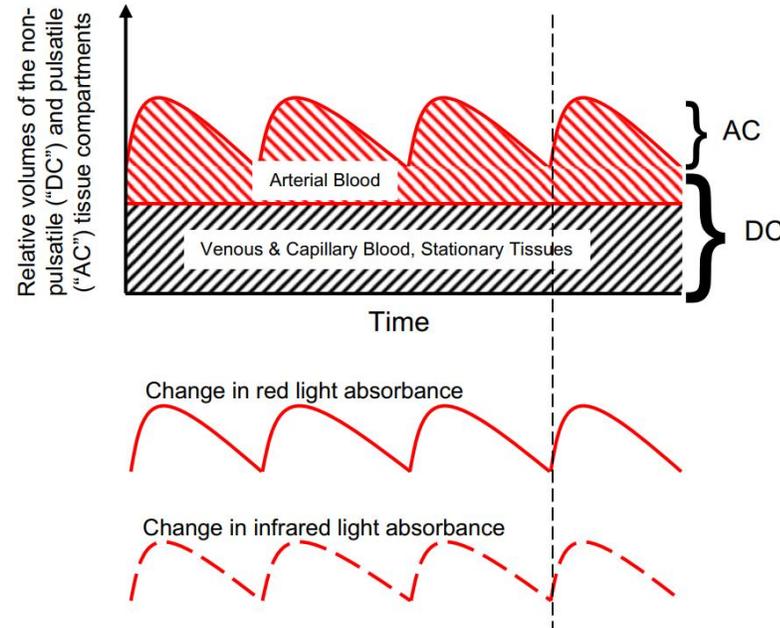
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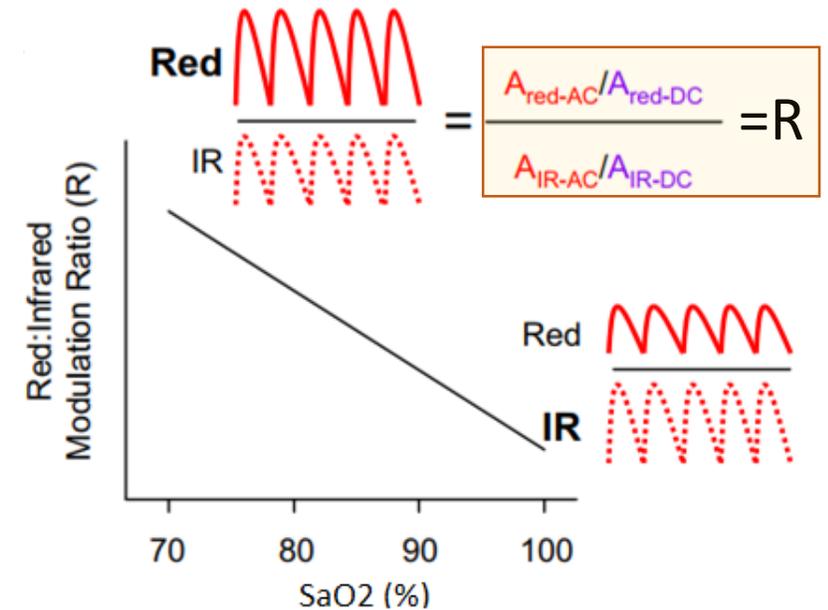
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R is a double-ratio of the pulsatile and non-pulsatile components of red light absorption to IR light absorption

Principle of operation (2/2)

- A **microcontroller calculates** this ratio (**R**) over a series of pulses.
- A **calibration curve** (generated empirically) is then utilized to **relate R to SaO₂**.

How to measure only arterial saturation?

Separate veins and arteries contributions

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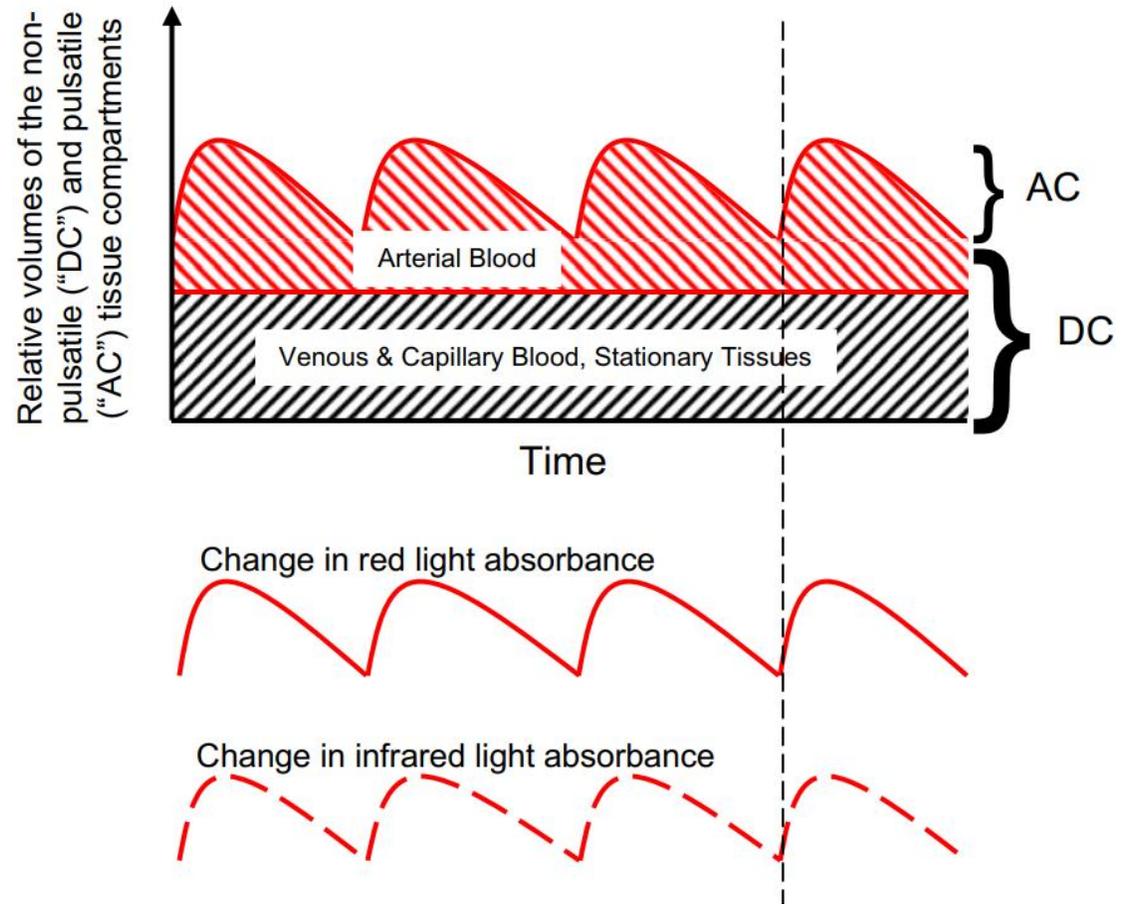
$$A_t = A_v + A_a = \varepsilon_v c_v d_v + \varepsilon_a c_a d_a$$

$$\frac{dA_t}{dt} = \frac{d(\varepsilon_v c_v d_v)}{dt} + \frac{d(\varepsilon_a c_a d_a)}{dt}$$

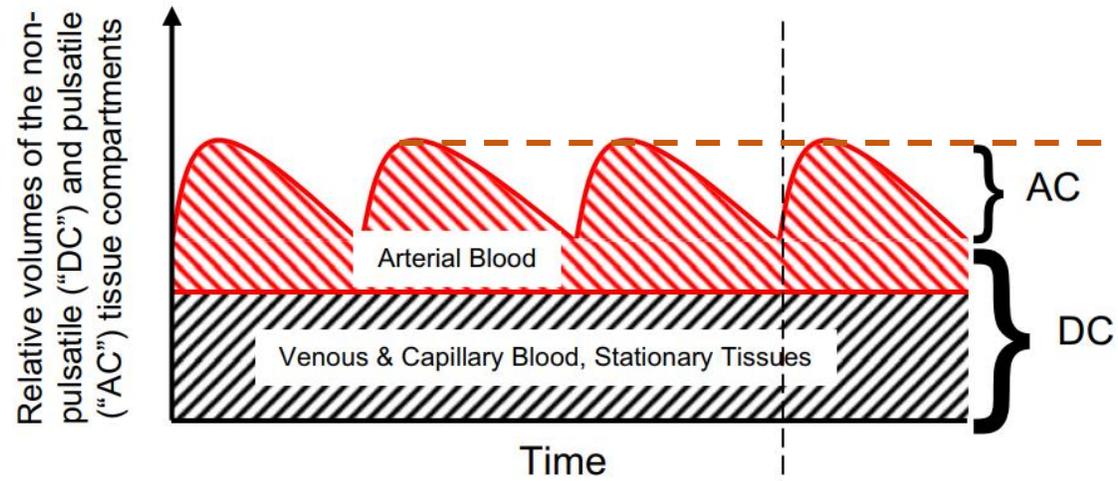
$$\frac{dA_t}{dt} = \frac{\varepsilon_v c_v d(d_v)}{dt} + \frac{\varepsilon_a c_a d(d_a)}{dt} \approx \frac{\varepsilon_a c_a d(d_a)}{dt}$$

$\frac{d(d_v)}{dt} \approx 0$

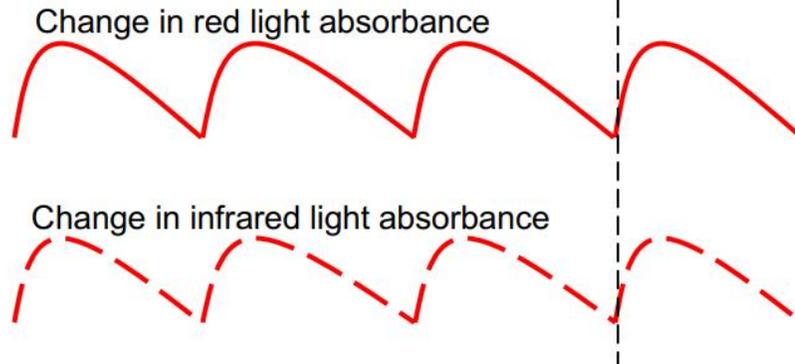
Heart rate



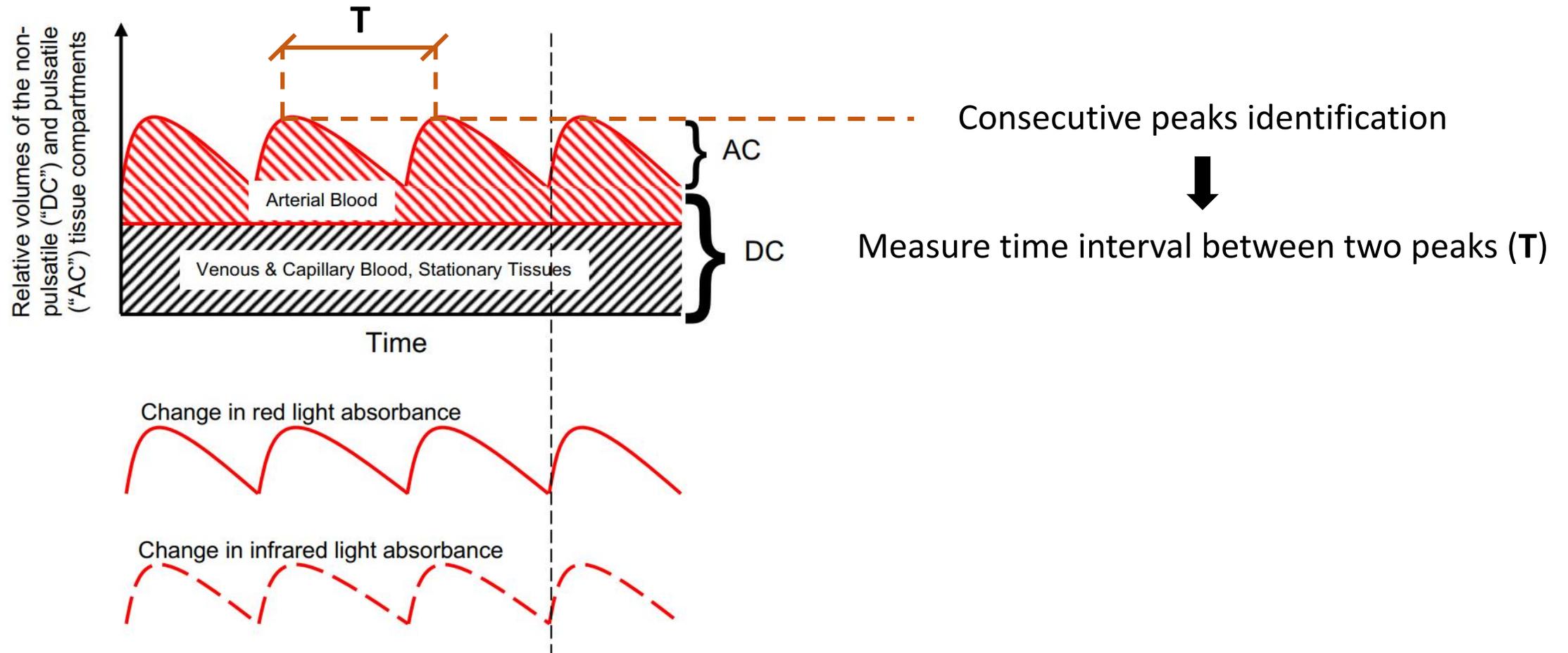
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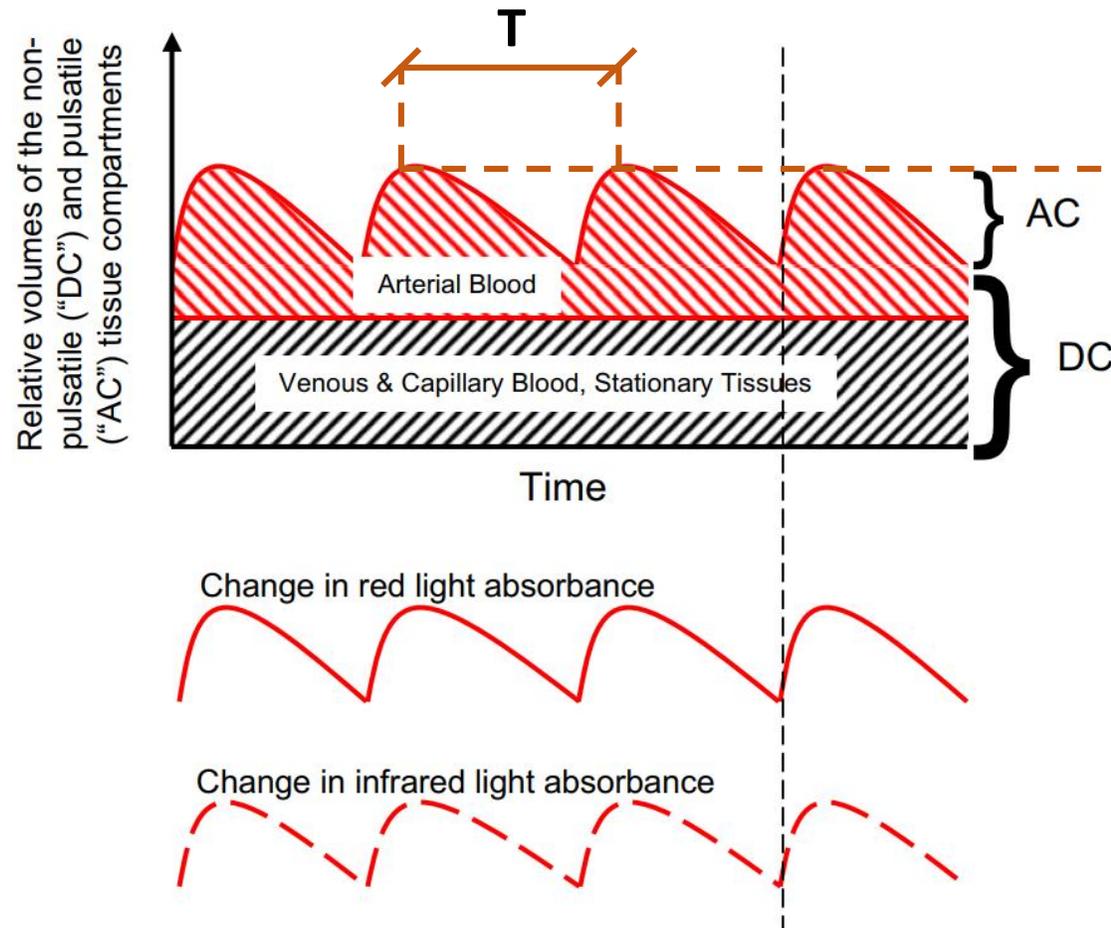
Consecutive peaks identification



Heart rate



Heart rate



Consecutive peaks identification

↓

Measure time interval between two peaks (**T**)

↓

Evaluate the heart rate (**HR**) as:

$$HR = \frac{60}{T}$$

MAX30102: reflectance pulse oximeter



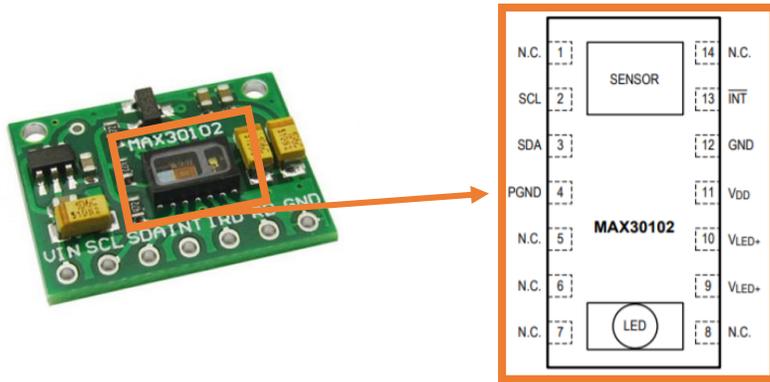
Benefits and Features

- Tiny 5.6mm x 3.3mm x 1.55mm 14-Pin Optical Module
 - Integrated Cover Glass for Optimal, Robust Performance
- Ultra-Low Power Operation for Mobile Devices
 - Programmable Sample Rate and LED Current for Power Savings
 - Low-Power Heart-Rate Monitor (< 1mW)
- Robust Motion Artifact Resilience
- -40°C to +85°C Operating Temperature Range

Applications

- Wearable Devices
- Fitness Assistant Devices
- Smartphones
- Tablets

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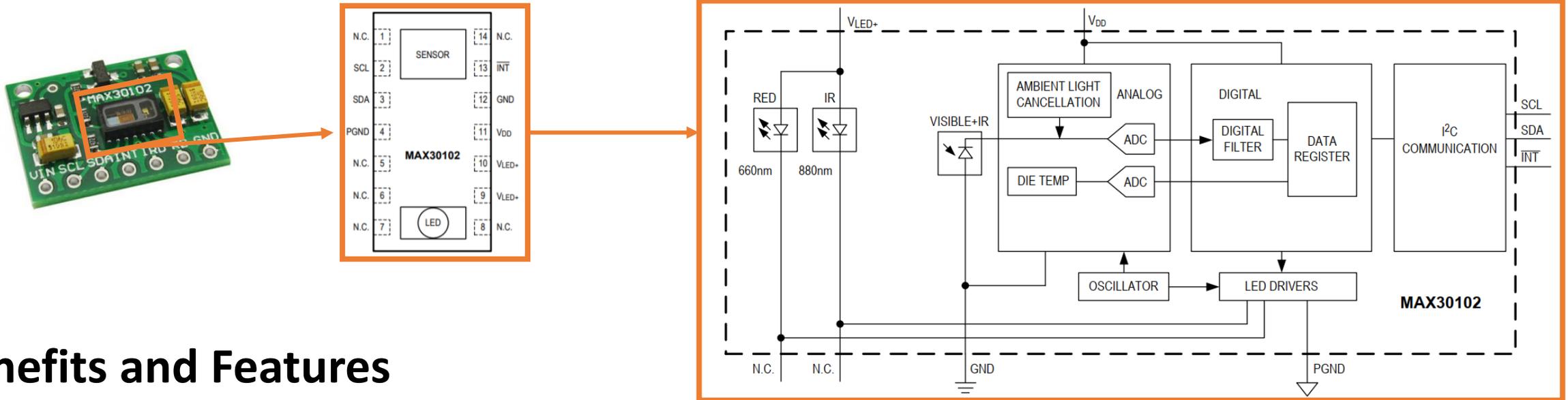
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