Photo PlethysmoGraphy (PPG) Sensor System
Part I: hardware

DBB170 Sensors for Physiology

Geert Langereis and Loe Feijs

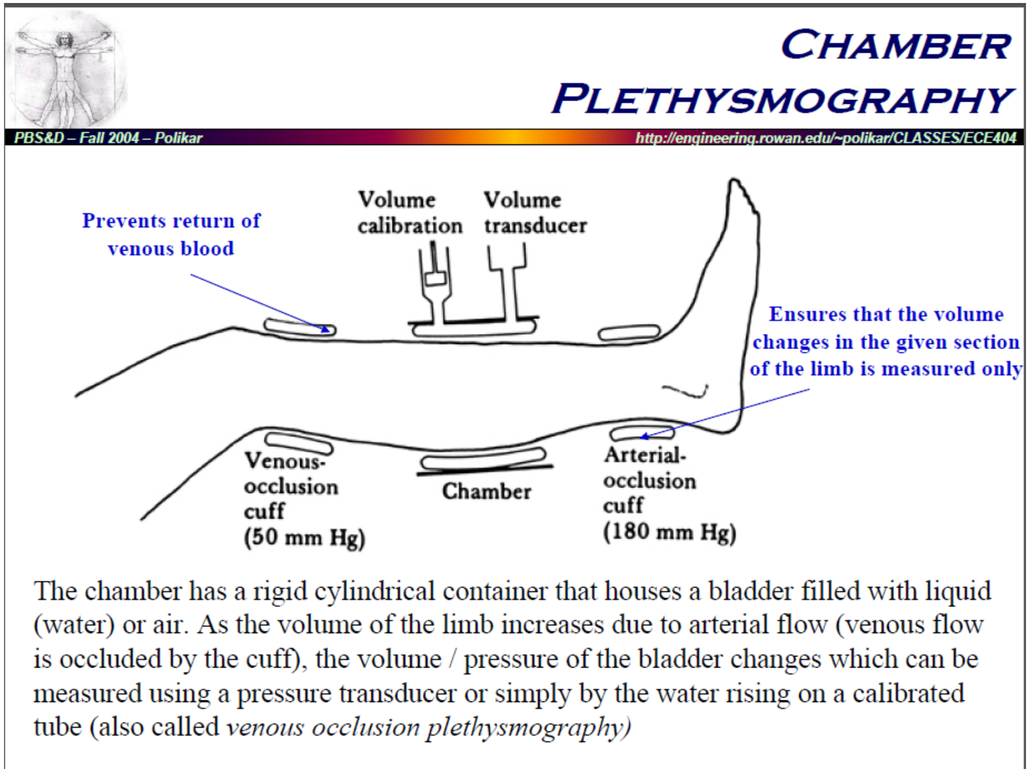
2012 - 2017

Plethysmography

- ECG measures the electrical activity of the heart
- Plethysmographs measure changes in volume
- πλήθυειν to be full, to become full
- γράφειν to write

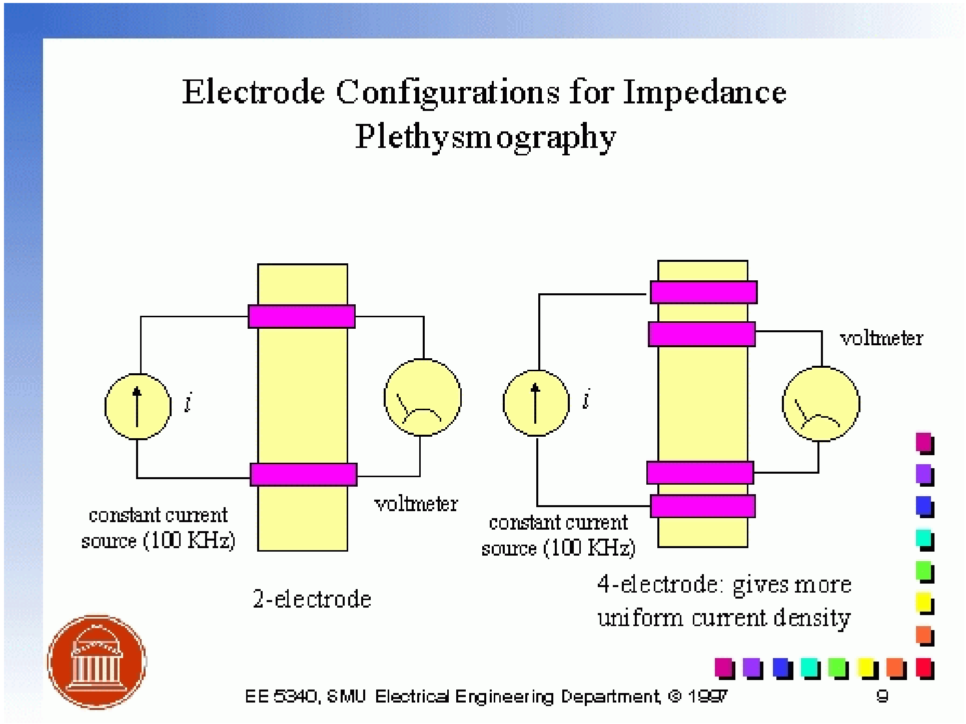
- Options for plethysmography are:
  - Impedance plethysmography
  - Photo plethysmography (PPG)
  - Blood pressure in the finger by a **plethysmomanometer**

John G. Webster (editor), Medical instrumentation, application and design, second edition, Houghton Mifflin Company, 1992

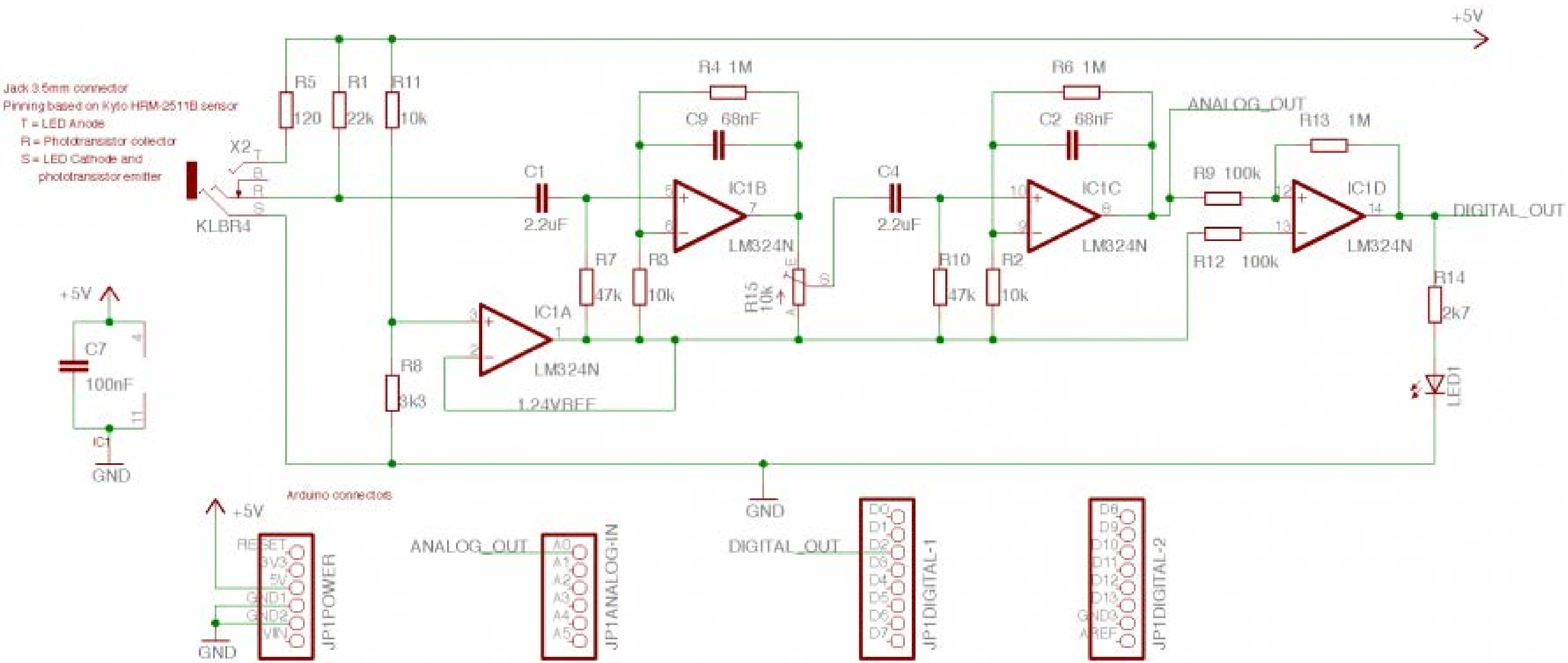


Source: File:Body plethysmography male subject.jpg, Finchbook01 at English Wikipedia, Creative Commons Attribution-Share Alike 3.0 Unported

Source: Polikar R., Tahamont, R. Principles of Biomedical Systems & Devices, Rowan University (lecture notes), users.rowan.edu/~polikar/CLASSES/ECE404/Lecture13.pdf



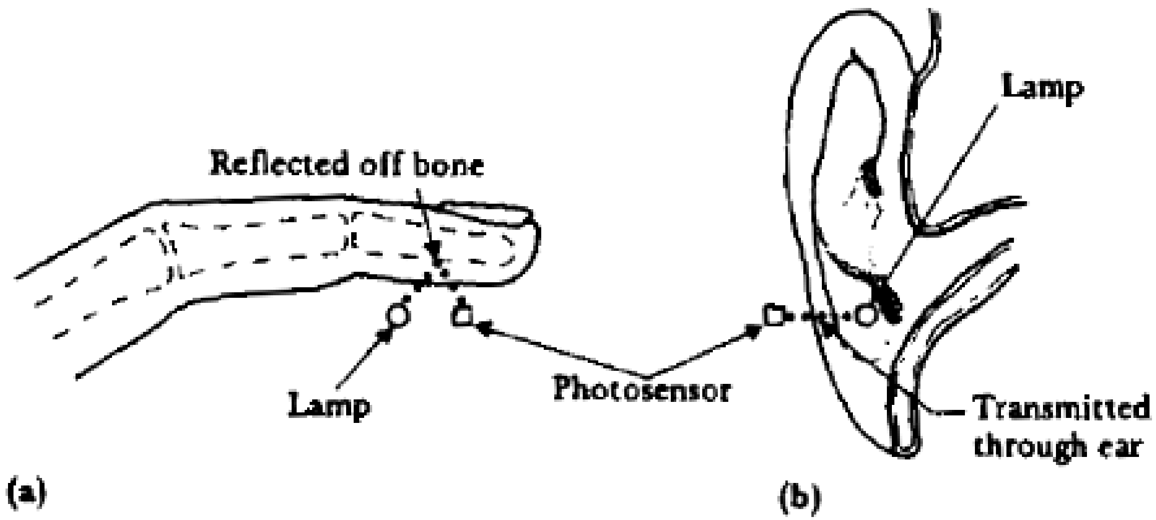
Davila, C.E., Introduction to biomedical engineering EE5340 (1997), https://lyle.smu.edu/~cd/EE5340/lect27/sld009.htm



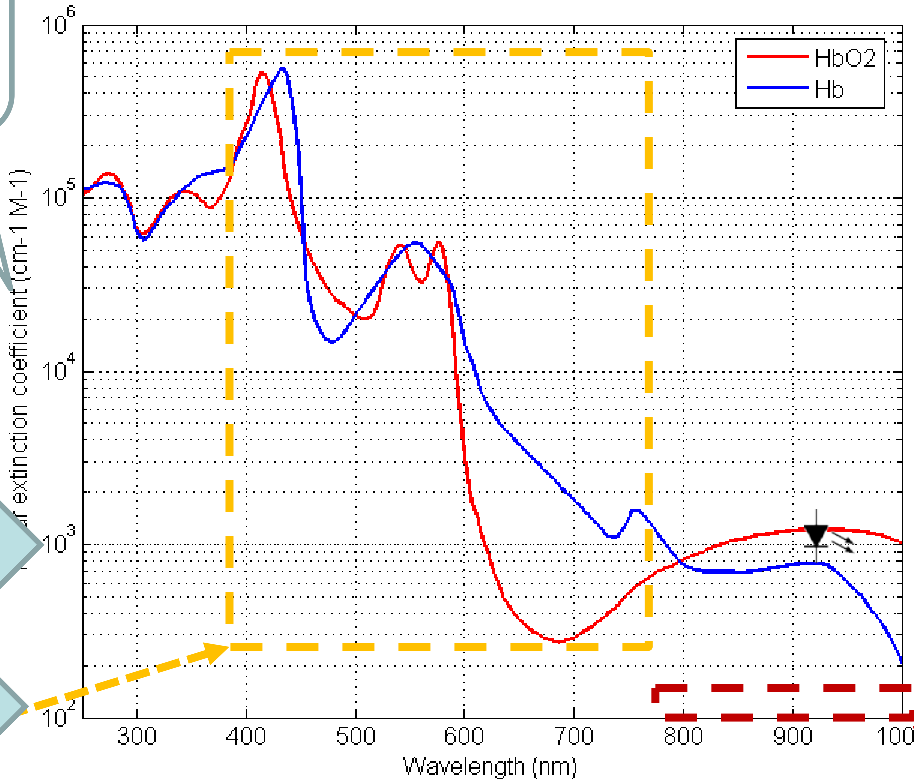
+5V
Jack 3.5mm connector
Pinning based on Kyto HRM-2511B sensor
T = LED Anode
R = Phototransistor collector
S = LED Cathode and
phototransistor emitter
X2
KLBR4
R5
120
R1
22k
R11
10k
R4 1M
C9 68nF
C1
2.2uF
IC1B
LM324N
R7
47k
R3
10k
R15
10k
C4
2.2uF
R6 1M
C2 68nF
IC1C
LM324N
R10
47k
R2
10k
ANALOG_OUT
R13 1M
R9 100k
R12 100k
IC1D
LM324N
DIGITAL_OUT
R14
2k7
LED1
IC1A
LM324N
R8
3k3
1.24VREF
C7
100nF
IC1
GND
Arduino connectors
RESET
3V3
5V
GND1
GND2
VIN
JP1POWER
A0
A1
A2
A3
A4
A5
JP1ANALOG-IN
D0
D1
D2
D3
D4
D5
D6
D7
JP1DIGITAL-1
D8
D9
D10
D11
D12
D13
GND3
AREF
JP1DIGITAL-2

Photoplethysmography (PPG)

Plethysmographs measure changes in volume



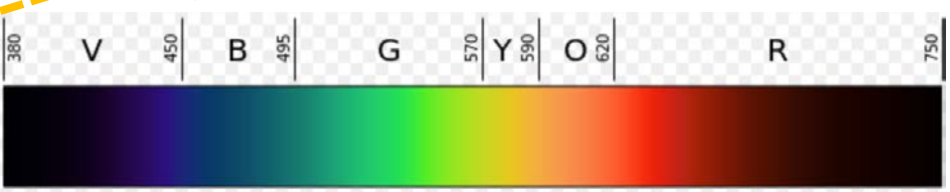
John G. Webster (editor), Medical instrumentation, application and design, second edition, Houghton Mifflin Company, 1992 how strongly the material attenuates light



Source: wikimedia, The_molar_extinction_coefficient_of_HbO2_and_Hb.png

99.9% absorbed

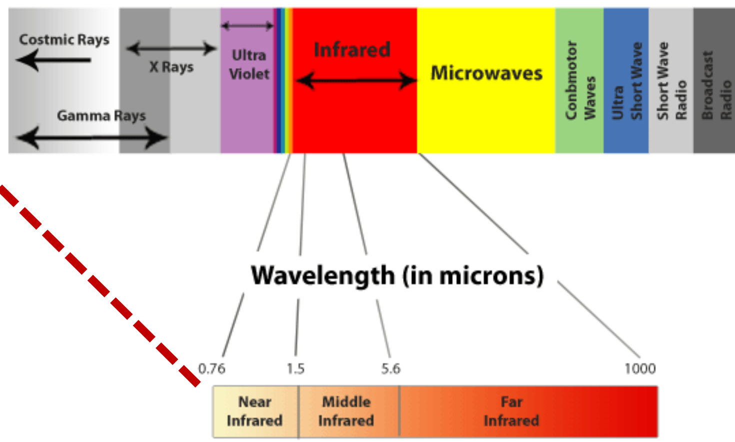
99% absorbed



Source: wikimedia File:Linear visible spectrum.svg

Langereis: Normally, a wavelength in the near-infrared is used because there we have the strongest modulation of the signal due to light absorption in the haemoglobin in the blood[5]

5) Note that heamoglobin and oxyheamoglobin pass equally at 805nm and have maximal difference at 660nm. This difference is used in optical oxygen saturation sensors



Source: http://www.health-mate.co.uk/thebestchoice/the-science/

Photoplethysmography (PPG)

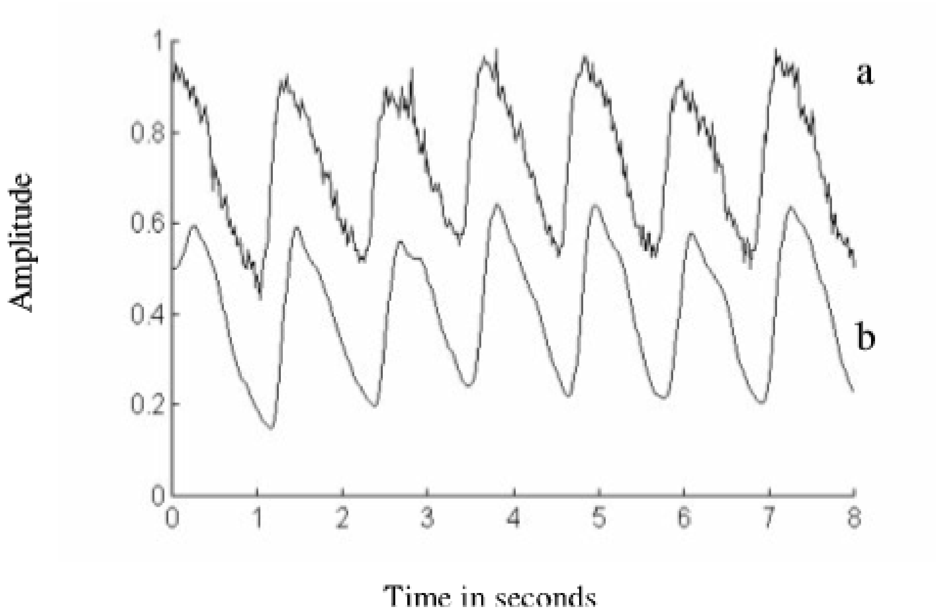


Fig 1a. Raw PPG Signal. Fig 1b. Filtered PPG signal.

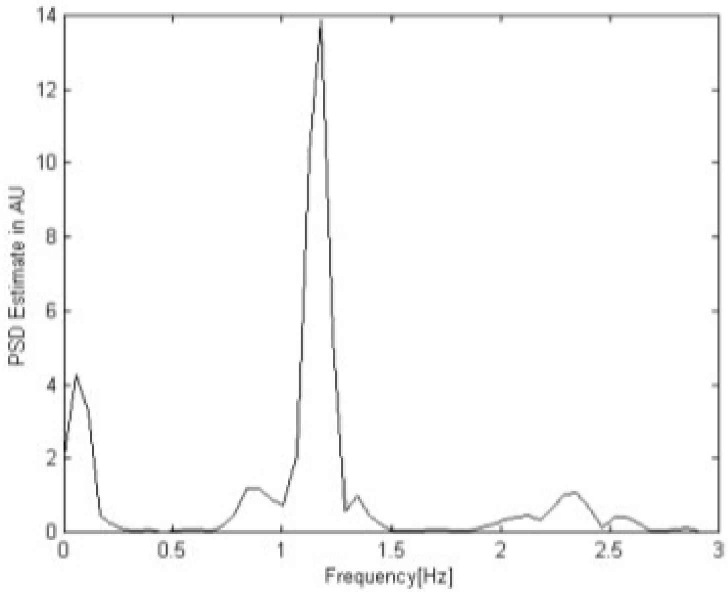
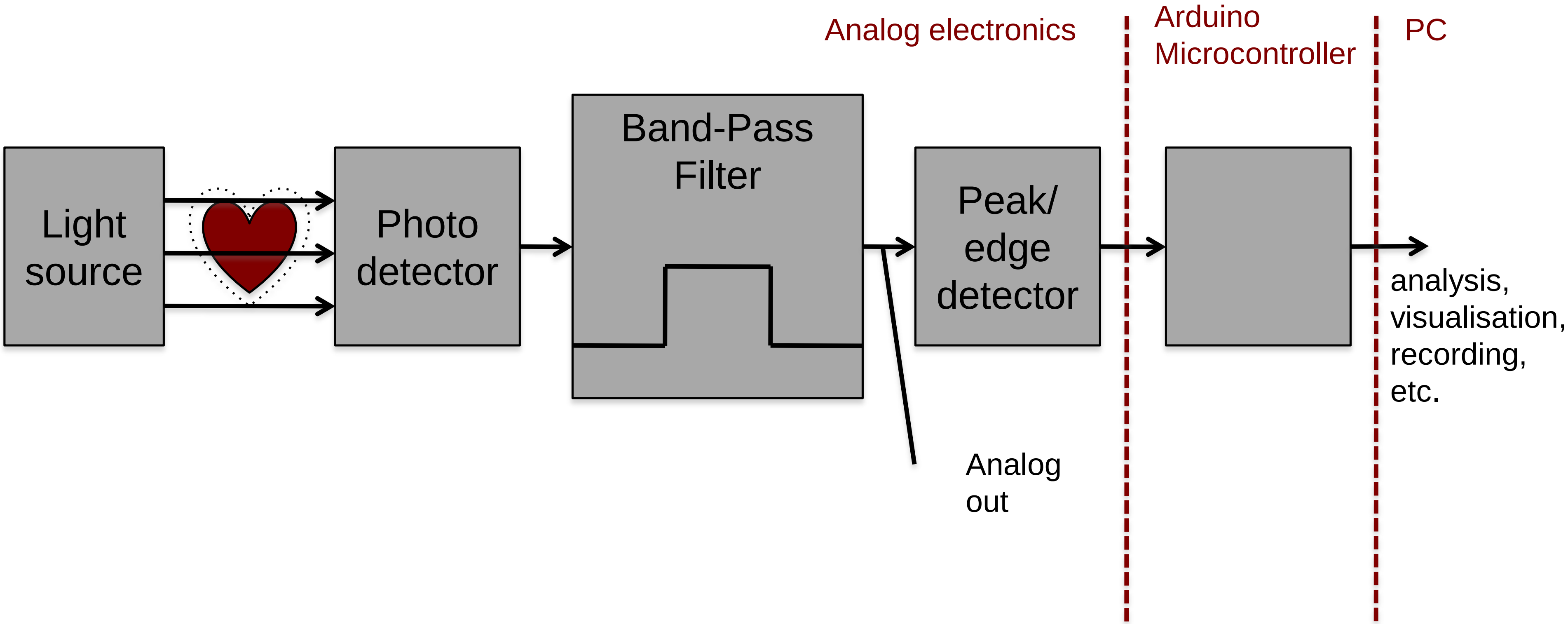


Fig 3 PSD Spectra for normal subject

V.S. Murthy, Sripad Ramamoorthy, Narayanan Srinivasan, Sriram Rajagopal, M. Mukunda Rao, Analysis of photoplethysmographic signals of cardiovascular patients, In: 23rd Annual International Conference of the IEEE Engineering in Medicine and Biology Society, October 25-28, 2001, held in Istanbul

Photoplethysmography (PPG)

Block scheme:

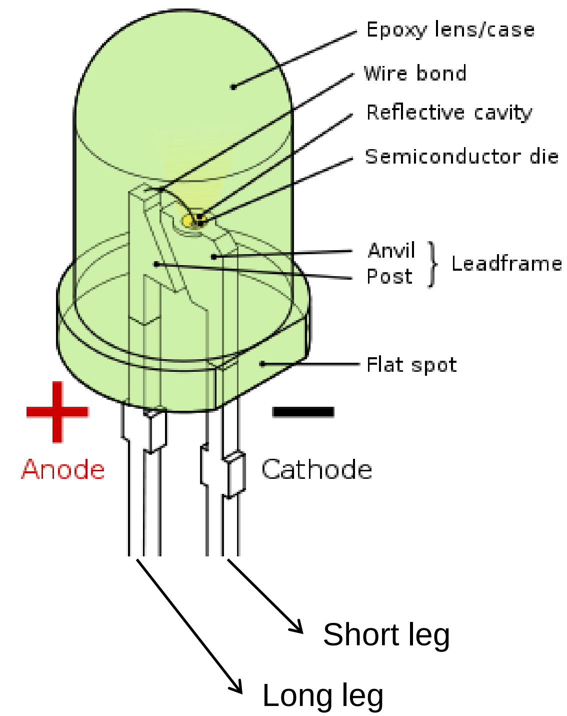


Design choices

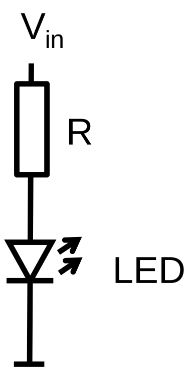
- Use ear clip
- Filter signal electronically
- Detect edges electronically (comparator)
- Let Arduino calculate the pulse periods
- Send periods over USB bus to computer

LEDs

- Current for our IR LED = 65mA max
- Voltage drop over LED 1.2V



$$R = \frac{V_{in} - V_{LED}}{I_{LED}} = \frac{5V - 1.2V}{32mA} \approx 120\Omega$$



Current limiter

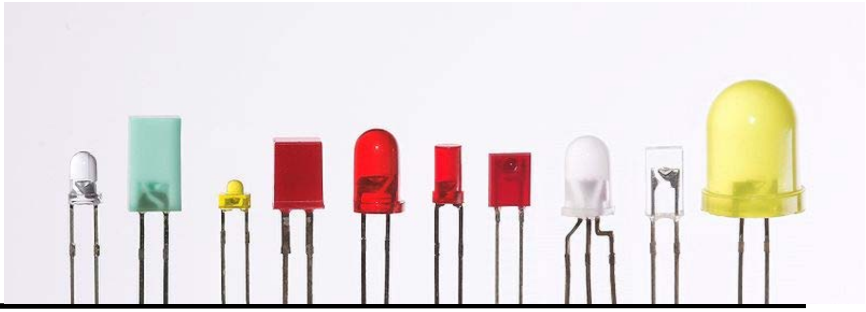
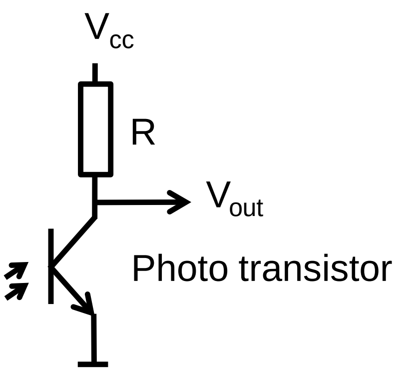
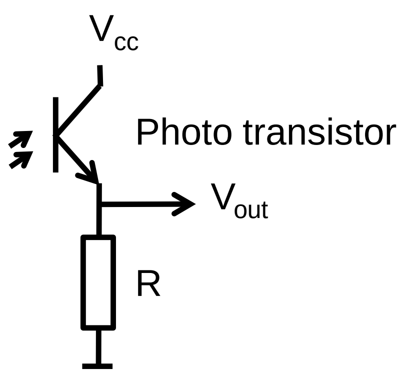


Photo transistors

- In common emitter mode, light at the base causes the output to decrease from high to low voltage
- In common collector mode, light at the base causes the output to increase from low to high voltage
- Typical value for R using the infrared sensor “Lucky Light LL-AR180PTC-1A” is 22kΩ.



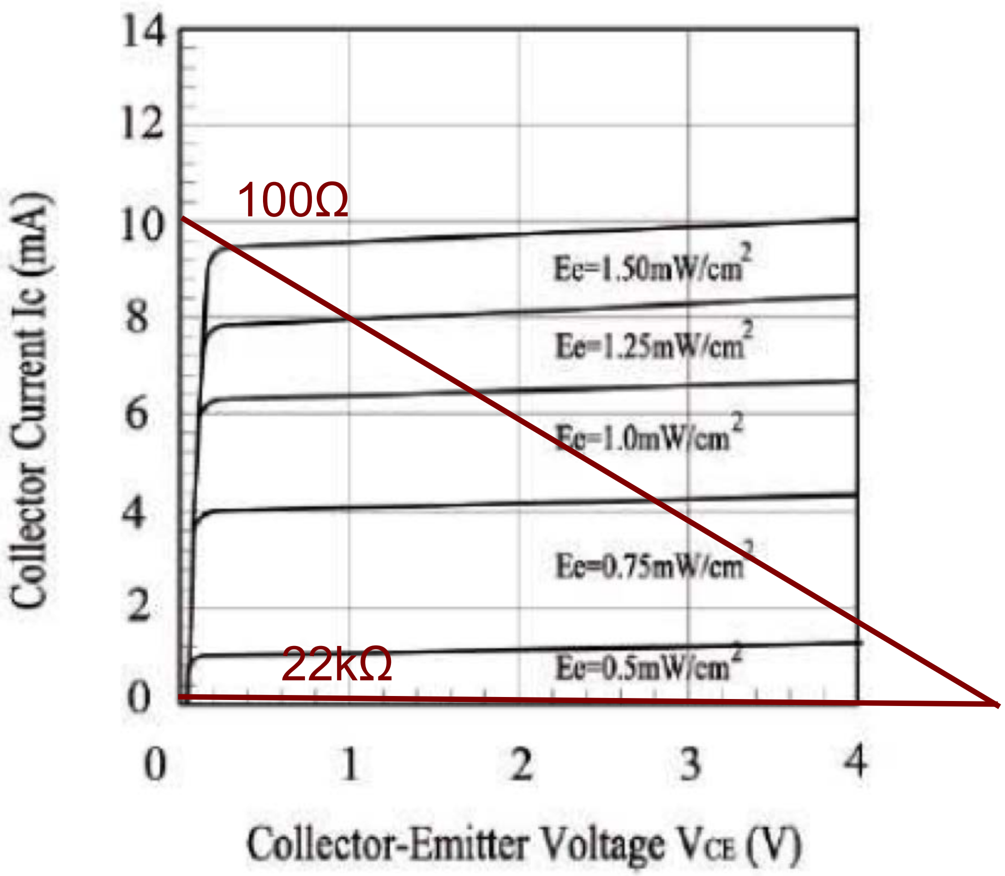
Biasing circuit
common emitter

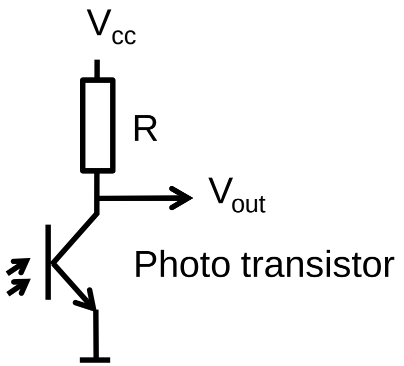


Biasing circuit
common collector

Photo transistors

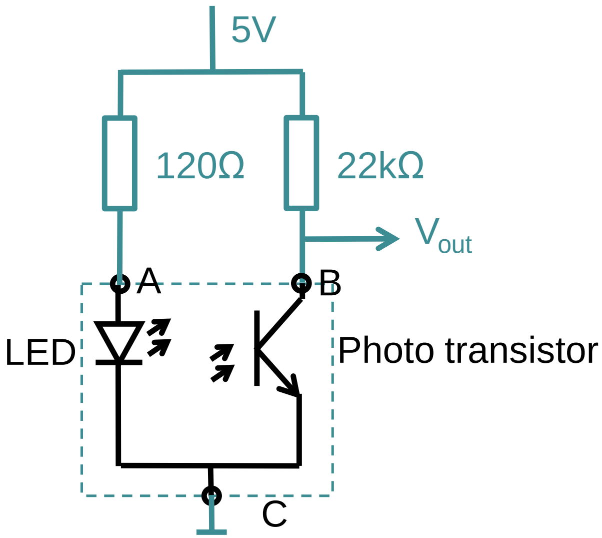
Sensor “Lucky Light LL-AR180PTC-1A”



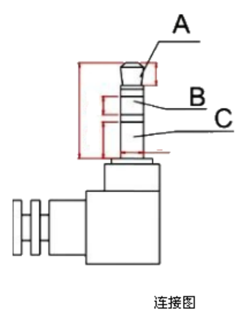


Optical earclip

- Some products, like the ear clip of Kyto Electronics, include both an infrared LED and a photo-transistor to detect blood pulses between the clip-ends

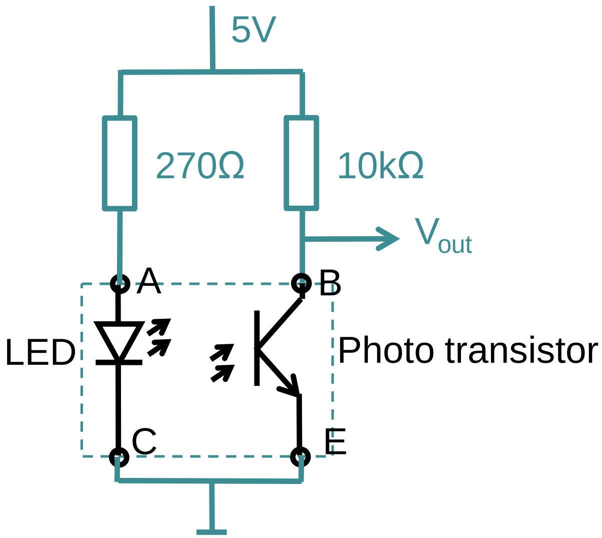


Kyto HRM-2511B

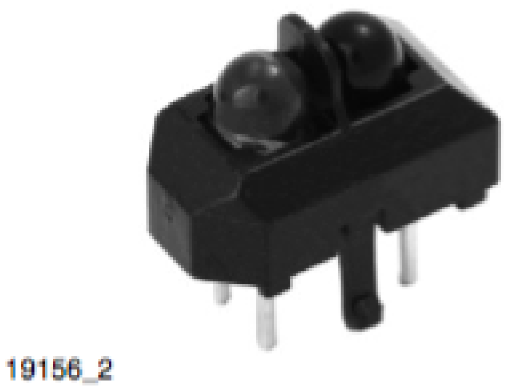


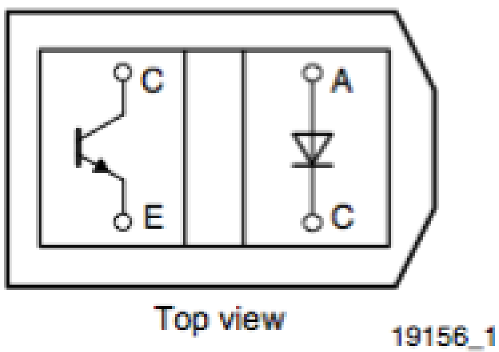
Reflective Sensor

- Vishay TCRT5000

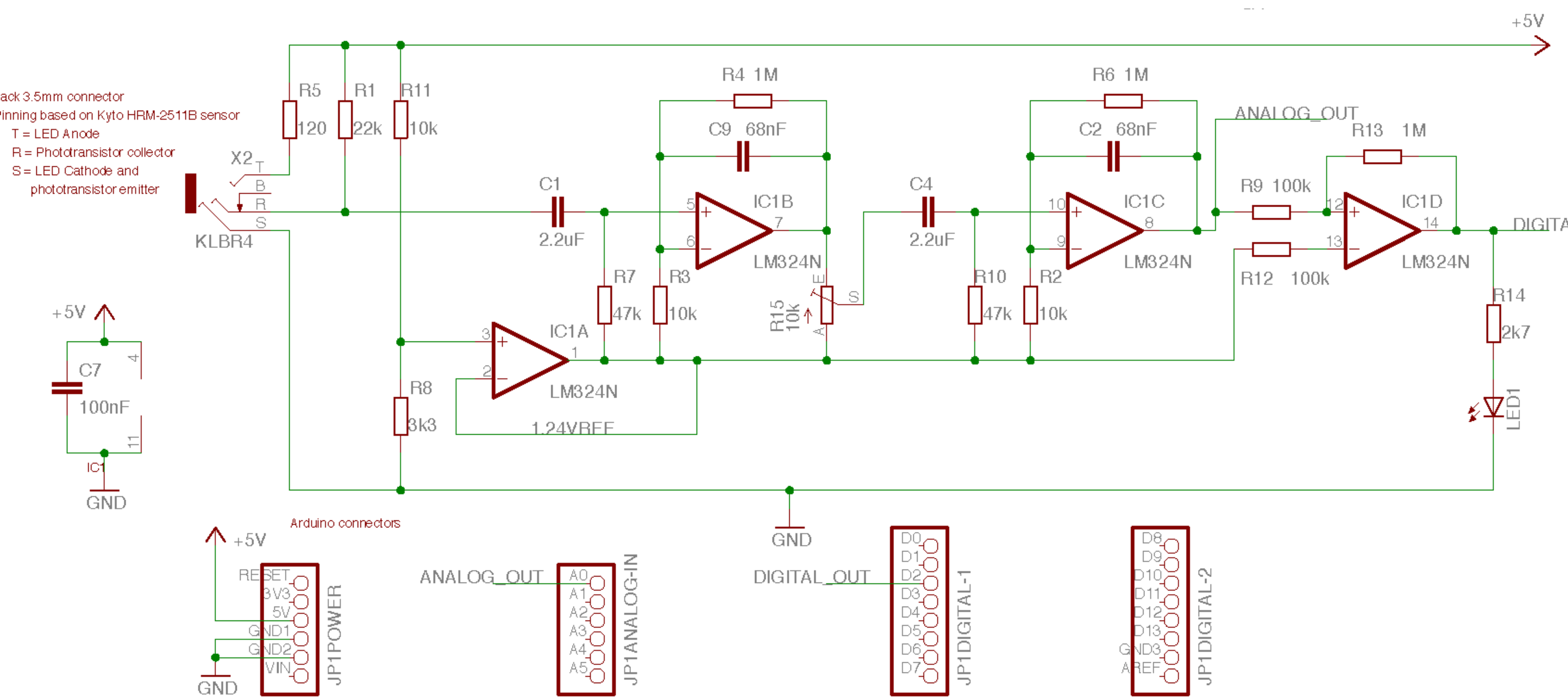


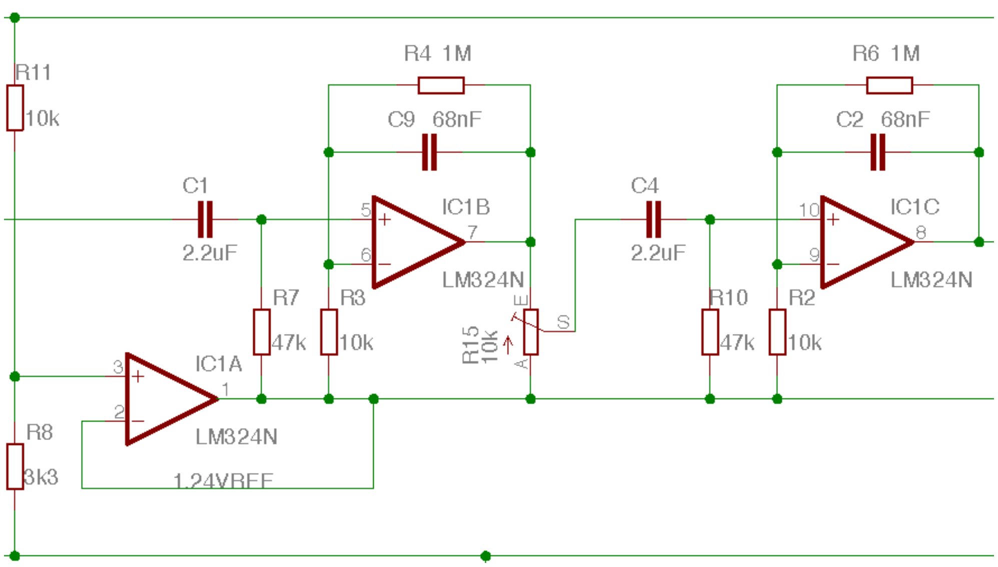
TCRT5000



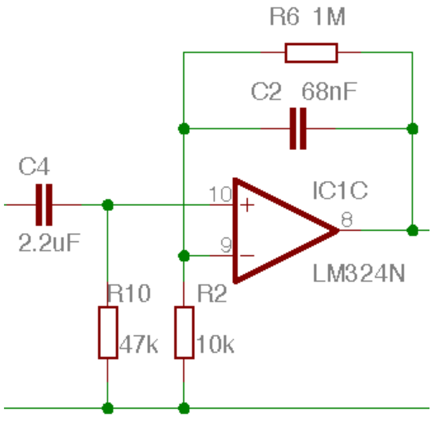


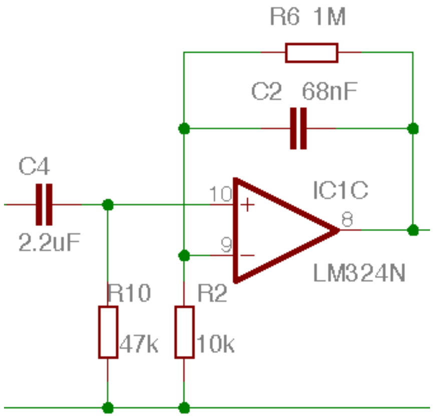
Electronic circuit



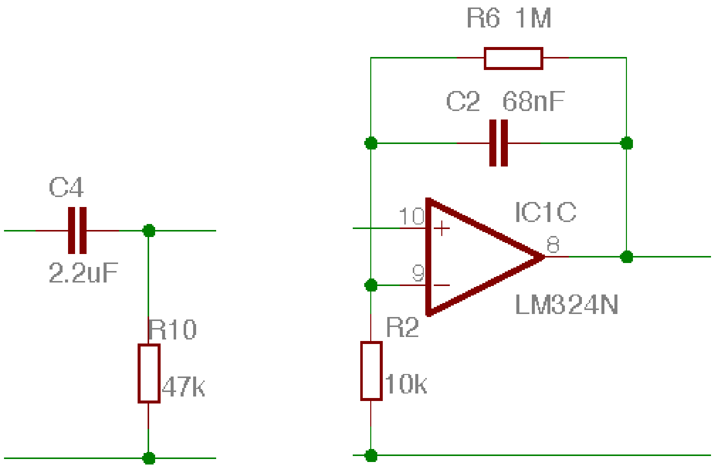


= two times basic filter:

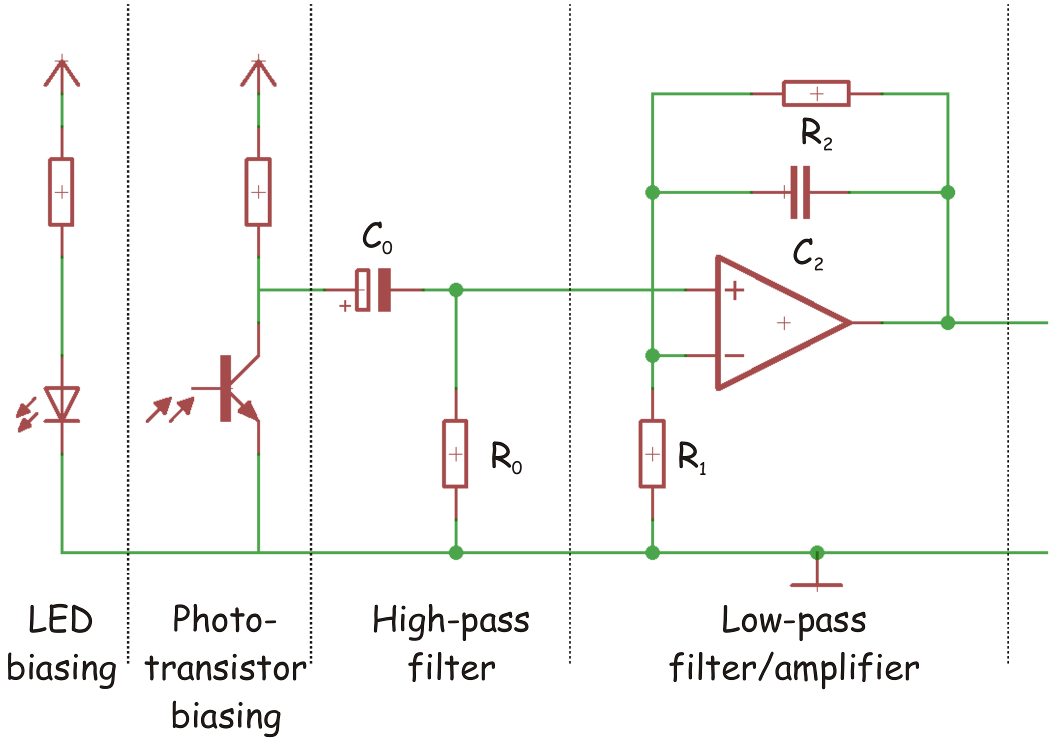




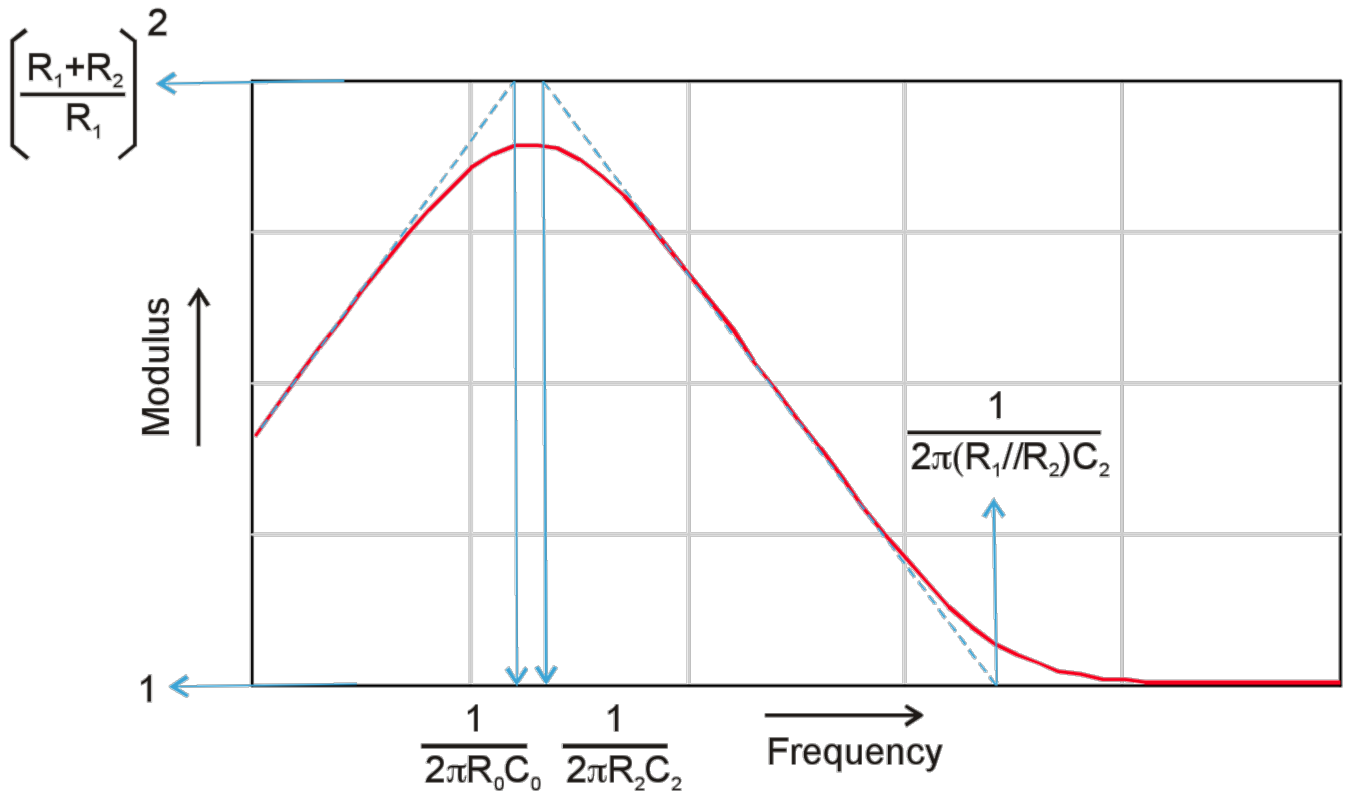
basic filter:
= high-pass
(passive) +
low-pass
(active)



Electronic circuit



Electronic circuit

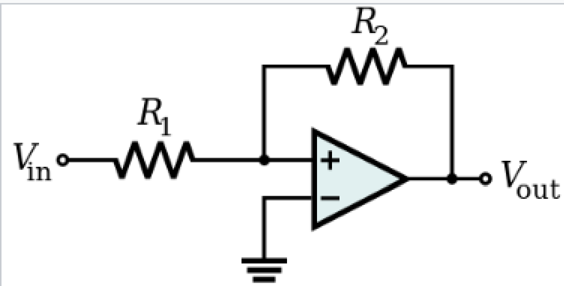


$1/(2\pi R_0 C_0) = 1.54$ Hz
$1/(2\pi R_2 C_2) = 2.34$ Hz

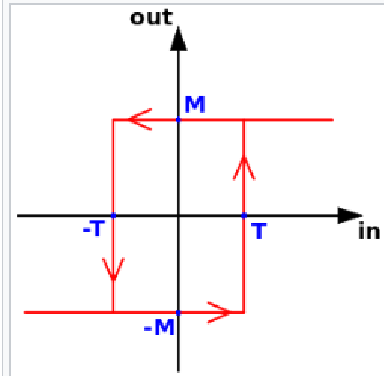
The high-pass filter is a simple first-order RC circuit with a lower frequency bound of $(2\pi R_0 C_0)^{-1}$. The low-pass filter is implemented as an active filter to facilitate amplification as well. The low-pass filter has a cut-off at $(2\pi R_2 C_2)^{-1}$ and amplifies $(R_1 + R_2)/R_1$ times. The high-pass filter frequency and the low –pass filter frequency have to be chosen such that we end-up with a band-pass filter to amplify the $2Hz$ frequency, because that is the steepness of the PPG pulse signal. To make the bandpass-filter more effective, the high-pass and low-pass filters are implemented twice resulting in a transfer function given by

$$H(j\omega) = \left[\frac{R_1 + R_2}{R_1} \frac{1 + j\omega \frac{R_1 R_2}{R_1 + R_2} C_2}{1 + j\omega R_2 C_2} \frac{j\omega R_0 C_0}{1 + j\omega R_0 C_0} \right]^2$$

Source: http://www.fontyssensorwiki.nl/doku.php?id=methods:ppg:ppg_main https://en.wikipedia.org/wiki/Schmitt_trigger



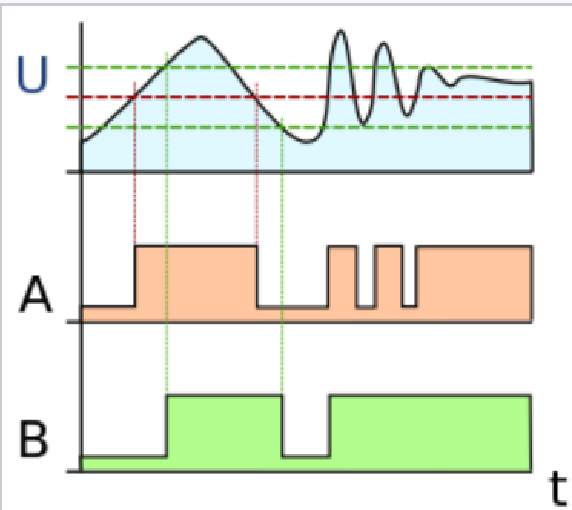
Schmitt trigger implemented by a non-inverting comparator



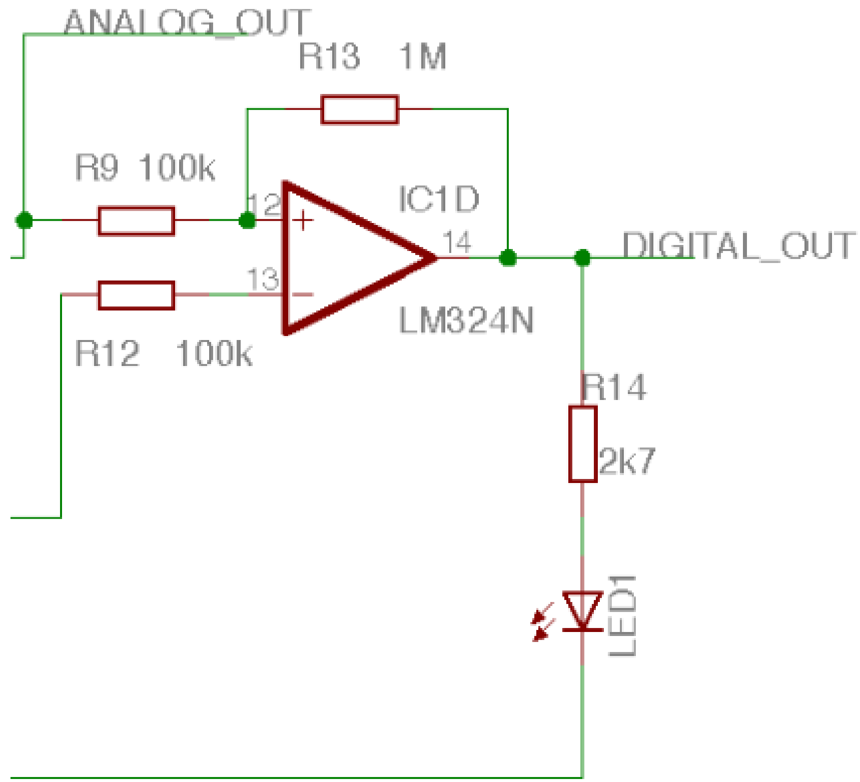
Typical transfer function of a non-inverting Schmidt trigger like the circuit above.

The value of the threshold T is given by $\frac{R_1}{R_2}V_s$ and the maximum value of the output M is the power supply rail.

Source: https://en.wikipedia.org/wiki/Schmitt_trigger

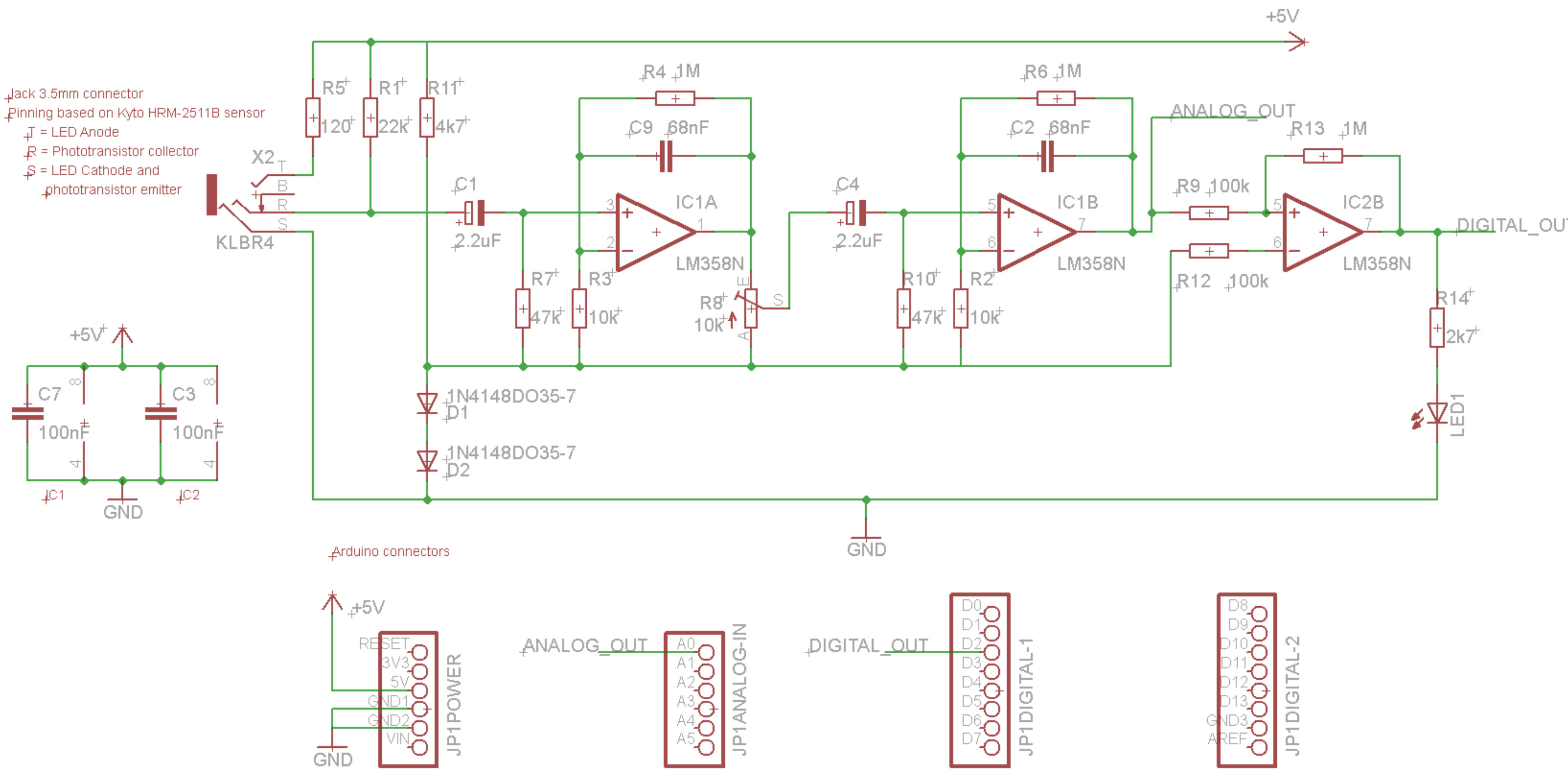


A noisy signal (U) fed into a comparator (A) and a Schmitt trigger (B). The green dotted lines are the circuit's switching thresholds. The Schmitt trigger tends to remove noise from the signal.

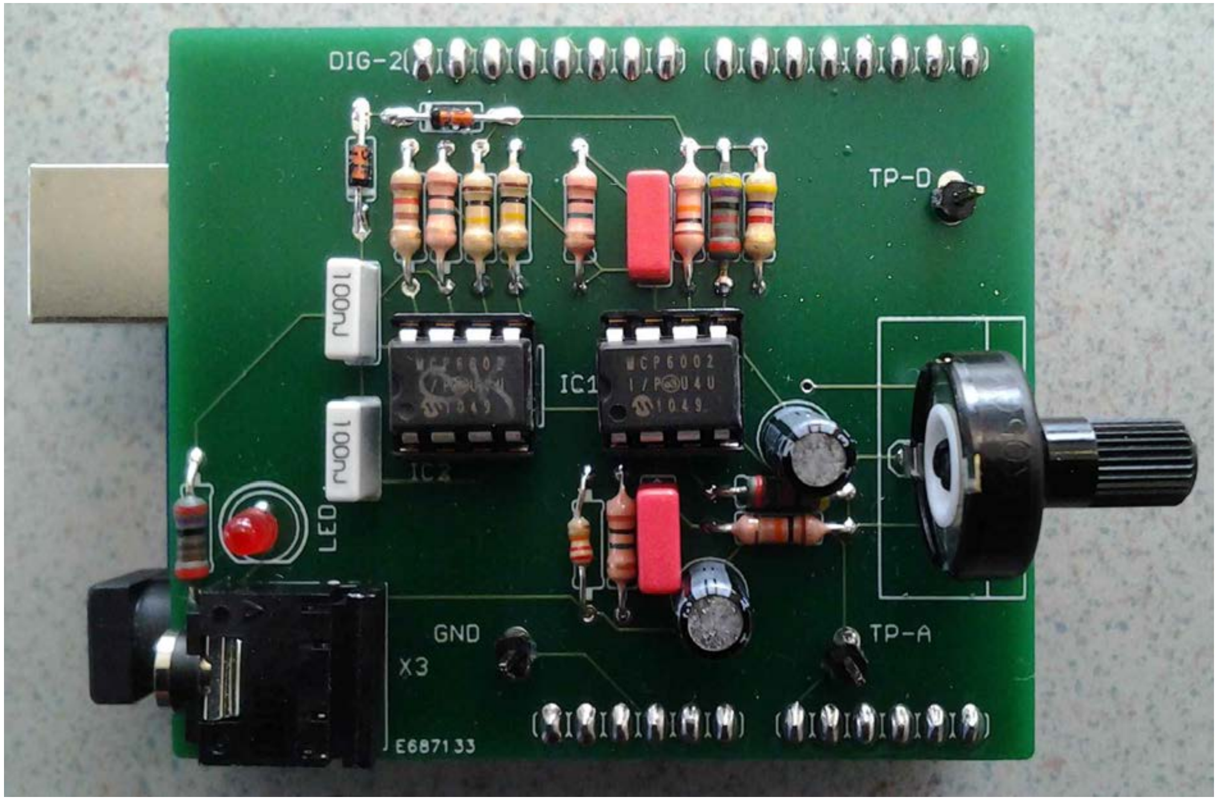


Source: Langereis, G. PhotoPlethysmoGraphy (PPG), http://www.fontyssensorwiki.nl/doku.php?id=methods:ppg:ppg_main

Electronic circuit

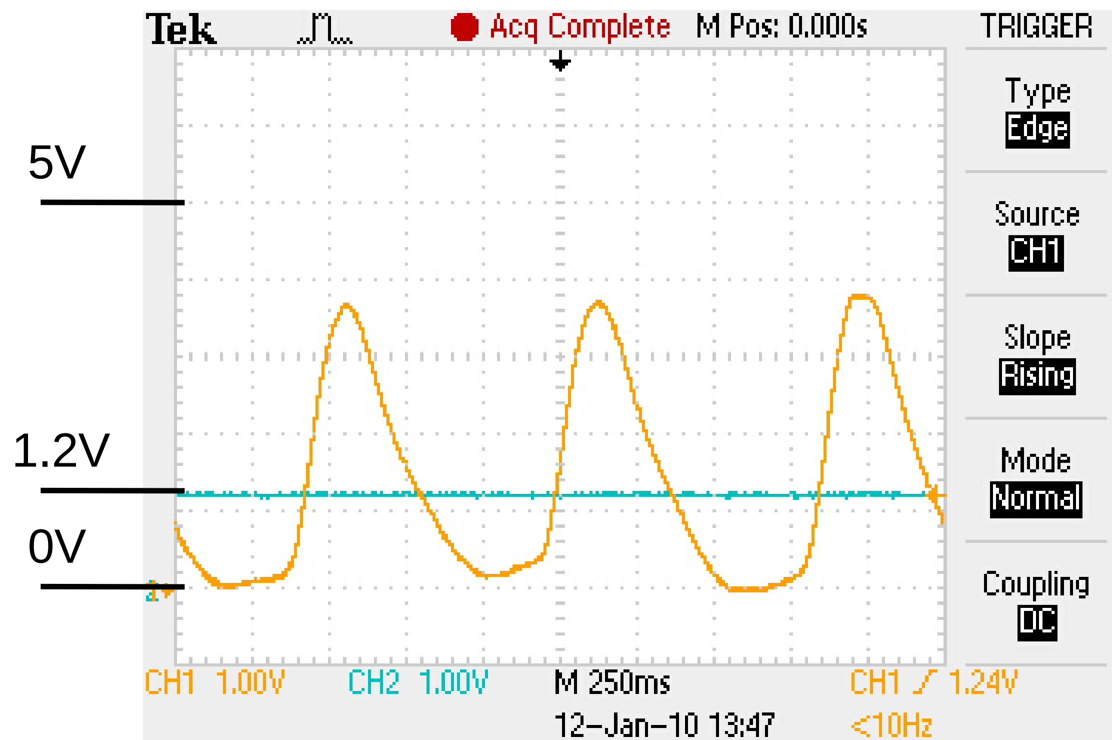


Electronics

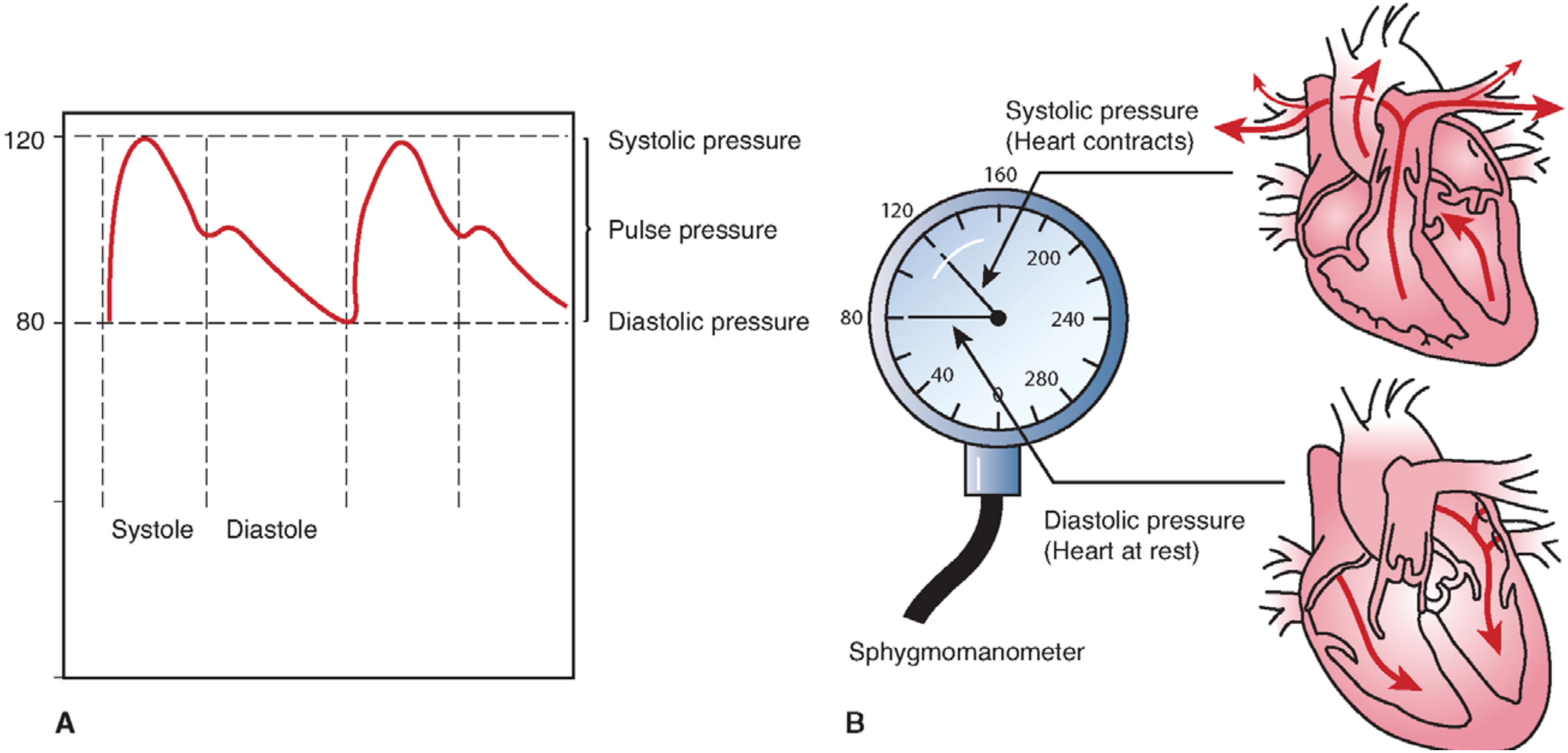


The PPG signal (ear)

After filtering



More about the PPG signal



Source: Vital Signs (Client Care) (Nursing) Part 4, http://what-when-how.com/nursing/vital-signs-client-care-nursing-part-4/

Understanding the wave form

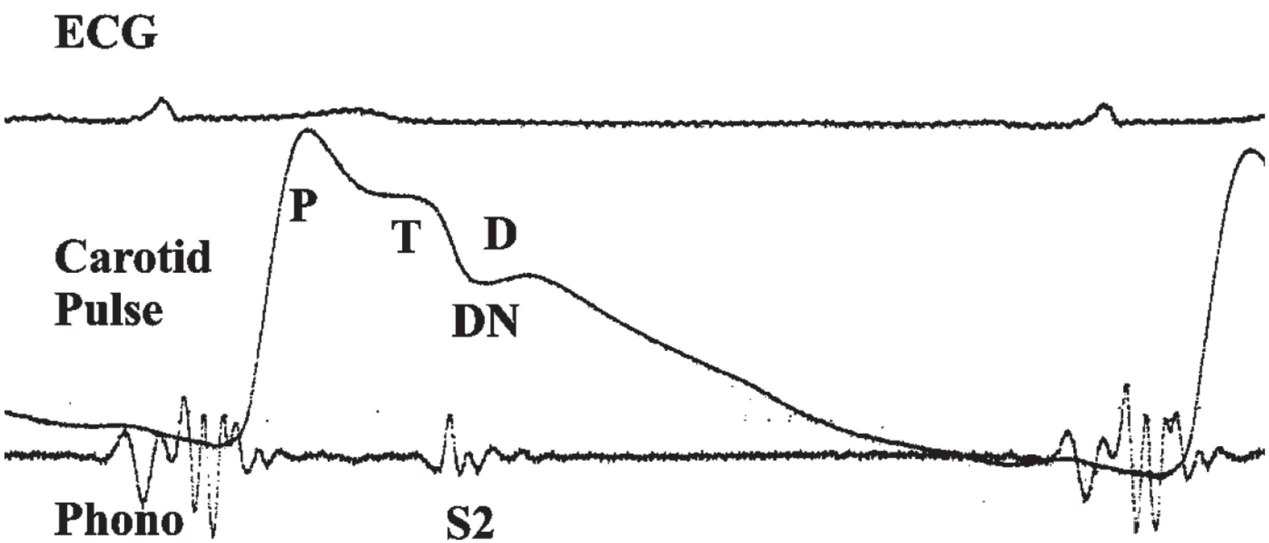


Fig. 2. Simultaneous recordings of ECG, carotid pulse tracing, and phonocardiogram. The carotid pulse shows the percussion wave (P), the tidal wave (T), and the dicrotic wave (D), which follows the dicrotic notch (DN).

N. Ranganathan, V. Siaviyan, F. Saksena.
The art and science of cardiac physical examination
with heart sounds and pulse wave forms.
Springer Verlag 2007.

- Ranganathan et al.: Experimental studies have clearly shown that pressure pulse wave generated artificially by a pump connected to a system of fluid-filled closed tubes or branching tubes with changing calibre gets reflected. The reflective sites appear to be branching points . This implies that the incident pressure pulse (not flow) produced by the contracting left ventricle gets reflected back. It is reflection of the pressure pulse that gives the pulse wave its characteristic contour.

N. Ranganathan, V. Siaviyan, F. Saksena. The art and science of cardiac physical examination with heart sounds and pulse wave forms. Springer Verlag 2007.

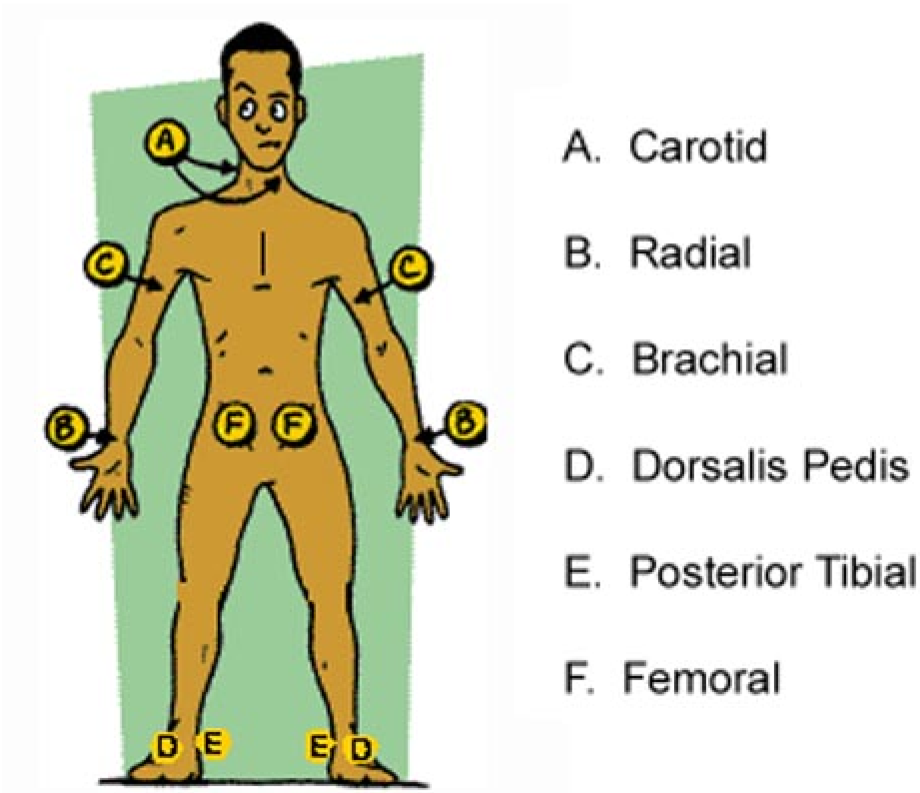
Wikimedia commons: Gentle_waves_come_in_at_a_sandy_beach.JPG

- Ranganathan et al.: The pressure pulse generated by the contraction of the left ventricle is transmitted to the most peripheral artery almost immediately, and yet the blood that leaves the left ventricle takes several cardiac cycles to reach the same distance.

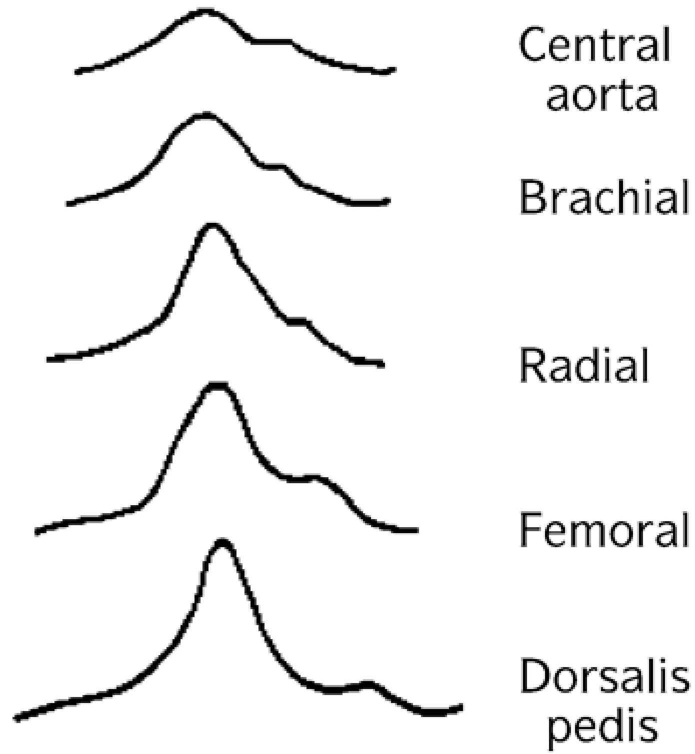
N. Ranganathan, V. Siaviyan, F. Saksena.
The art and science of cardiac physical examination
with heart sounds and pulse wave forms.
Springer Verlag 2007.

Steven volp modelbouw, www.stevenvolp.nl/

When further away from the heart, the pulse form is different (usually sharper and with more delay between first and second peak).



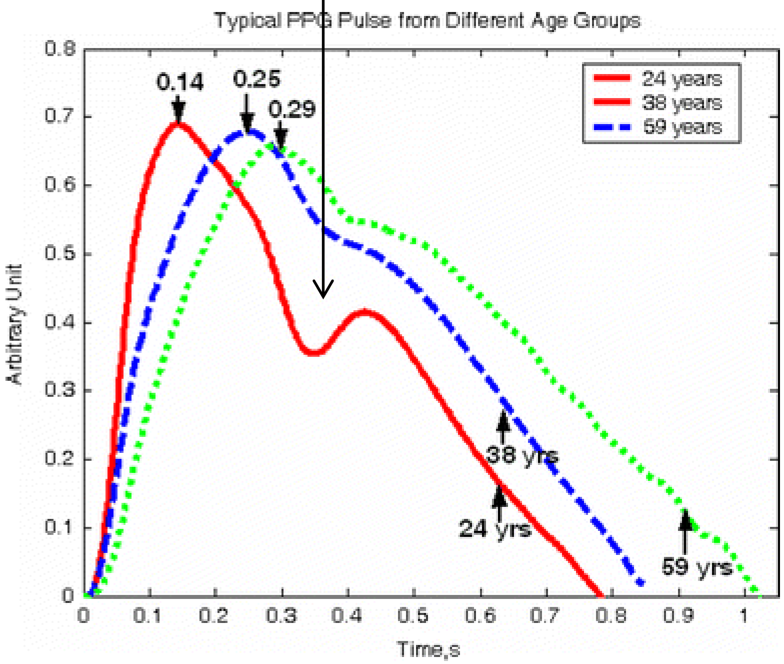
http://www.austincc.edu/adnlev1/rnsgskills2online/physical_assessment_b/



Gorny DA. Arterial blood pressure measurement technique. AACN Clin Issues. 1993;4:66–80.

PPG pulse form changes with age

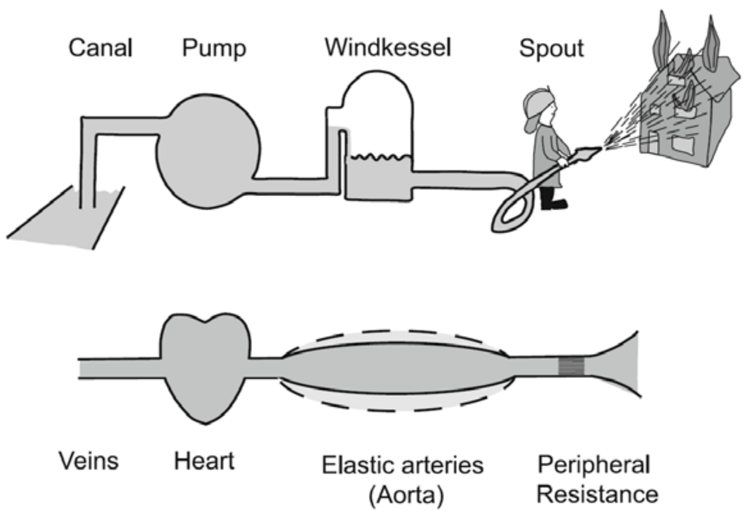
dicrotic notch at closure
of the aortic valve



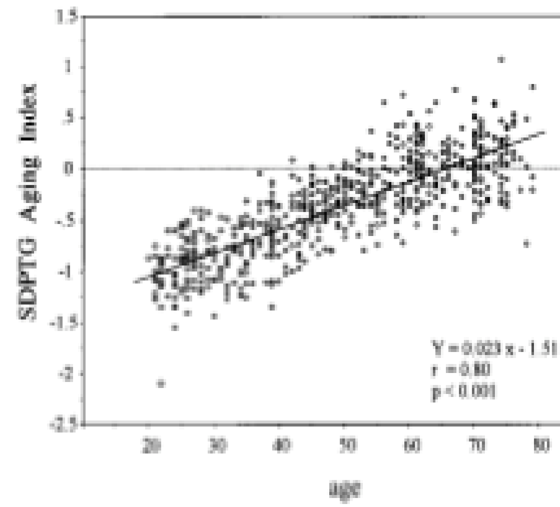
Zahedi, Chellappan, Mohd Ali and Singh, Analysis of the Effect of Ageing on Rising Edge Characteristics of the Photoplethysmogram using a Modified Windkessel Model Cardiovascular Engineering, Springer Verlag 2007

[From Greek dikrotos, *double-beating* : di–, *two*; see **di-**[1] + krotos, *rattling noise*.]

Because… but..!



The arterial Windkessel Nico Westerhof, Jan-Willem Lankhaar, Berend E. Westerhof, Med Biol Eng Comput (2009) 47:131–141



Takazawa, at al. Assessment of Vasoactive Agents and Vascular Aging by the Second Derivative of Photoplethysmogram Waveform, Hypertension, 1998, vol. 32, issue 2, pp. 365-370, American Heart Association, Inc.

PPG sensors

kyto ear lobe pulse sensor HRM-2511B

US $2-6 / Piece (FOB Price)
500 Pieces (Min. Order)
100000 Piece/Pieces per Month (Supply Ability)

Tags: Pulse Sensor | Ear Pulse Sensor | Ear Lobe Pulse Sensor

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kyto ear lobe pulse sensor HRM-2511B

US $2-6 / Piece (FOB Price)
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Tags: Pulse Sensor | Ear Pulse Sensor | Ear Lobe Pulse Sensor

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ear lobe pulse sensor HRM-2511B

US $2.58-3 / Piece (FOB Price)
100 Pieces (Min. Order)
10000 Piece/Pieces per Week (Supply Ability)

Tags: Pulse Detection Sensor | Heart Pulse Sensor | Ear Clip Pulse Sensor

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