USC University of Southern California

ECE 105: Introduction to Electrical Engineering

Lecture 12

Bio 2

Yasser Khan

Rehan Kapadia

Pulse oximetry

ECG

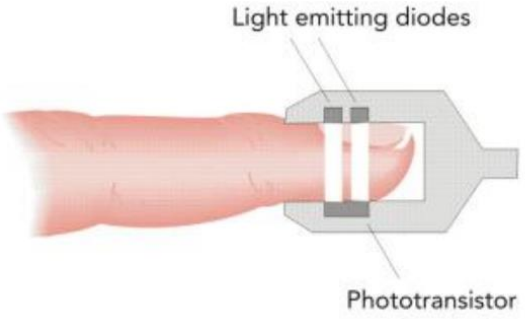
Pulse Ox

Respiration

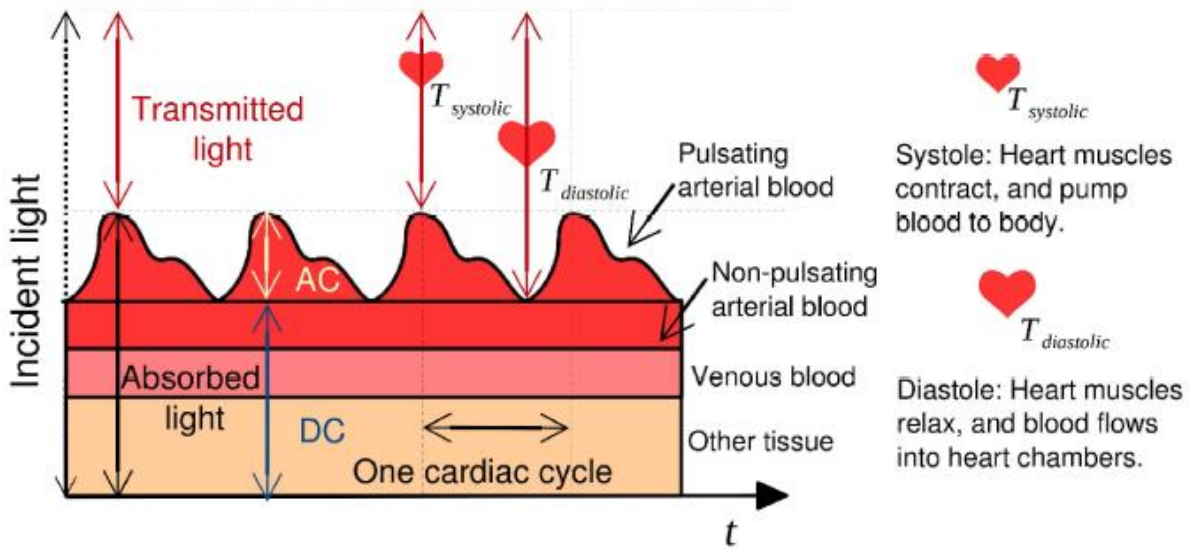
Blood Pressure

Temperature

- Pulse oximetry measures blood oxygenation. Using spectrophotometry of absorptivity of blood at two distinct wavelengths, blood oxygen saturation is quantified.
- Can detect hypoxemia, ie. lower than normal blood oxygenation.

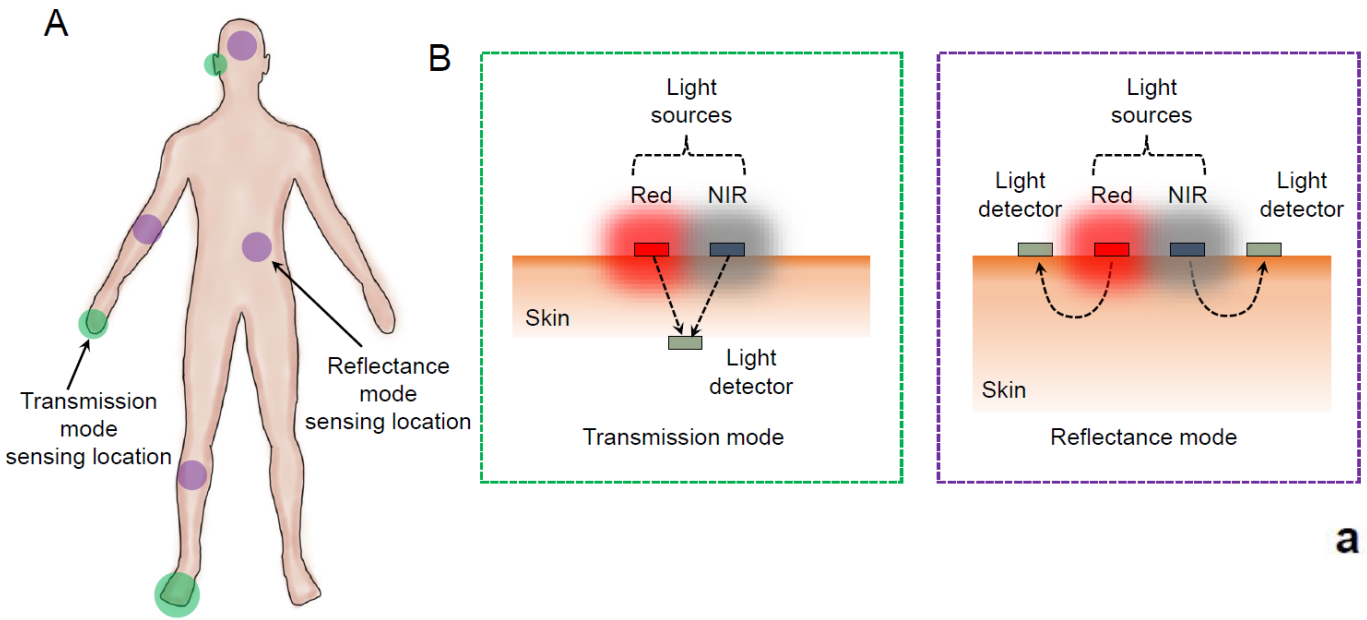


$$SO_2 = \frac{C_{HbO_2}}{C_{HbO_2} + C_{Hb}}$$



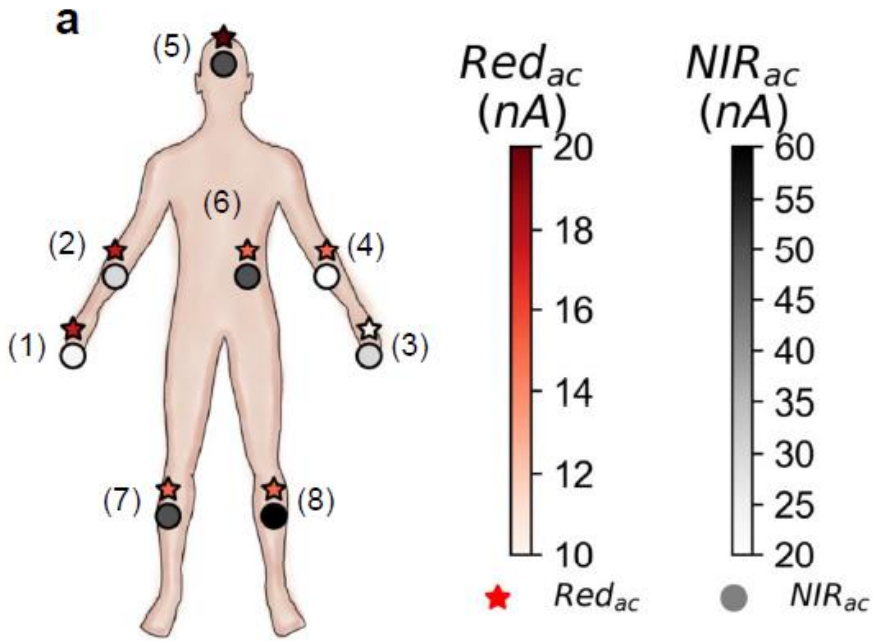
- SO_2 The saturation of oxygen in blood,
- C_{HbO_2} Concentration of oxygenated hemoglobin (HbO_2),
- C_{Hb} Concentration of deoxygenated hemoglobin (Hb).

Transmission vs. reflectance oximetry

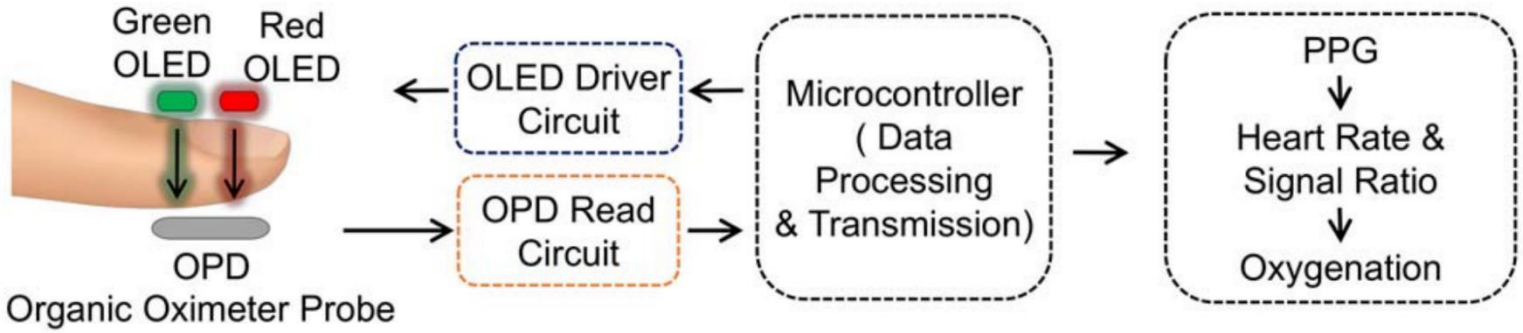


- Transmission-mode pulse oximetry is limited only to tissues that can be transilluminated, such as the earlobes and the fingers.
- If reflected light is used as the signal, the sensor can be used beyond the conventional sensing locations.

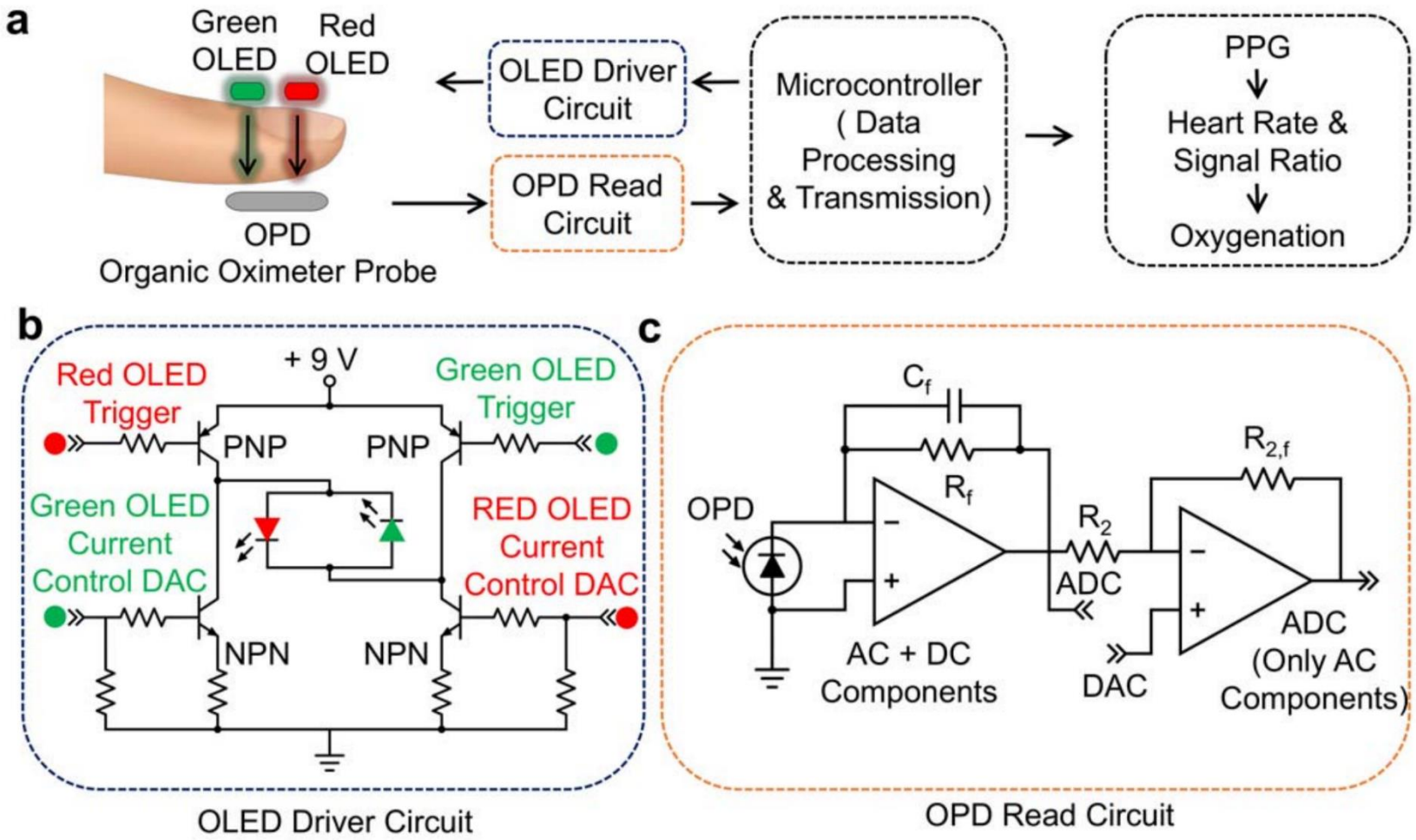
- AC signal is the highest at the forehead for both Red and NIR channels.
- Arms provide mid-range AC amplitude, while signal strength is low in the legs and chest area.
- Forehead is the best location for reflectance pulse oximetry.



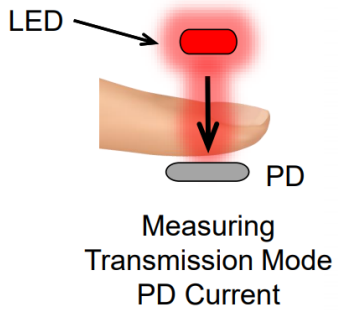
Oximeter readout circuit

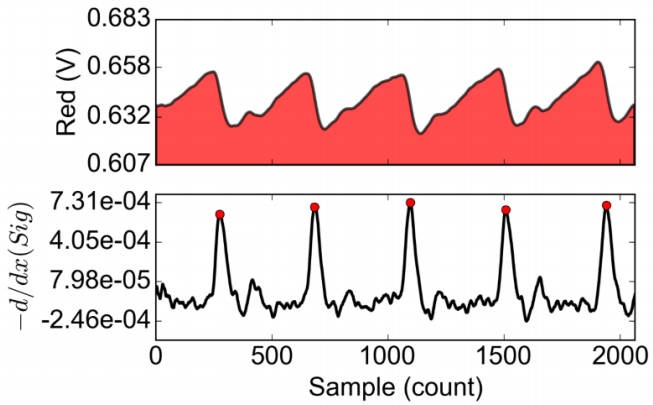


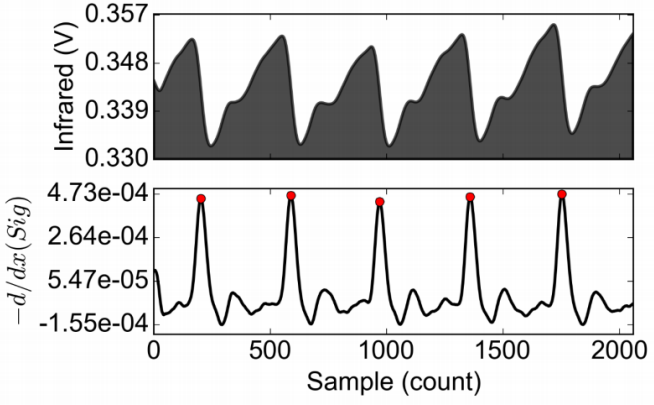
Oximeter readout circuit



Calculating oxygen saturation

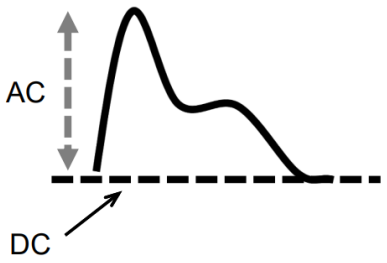


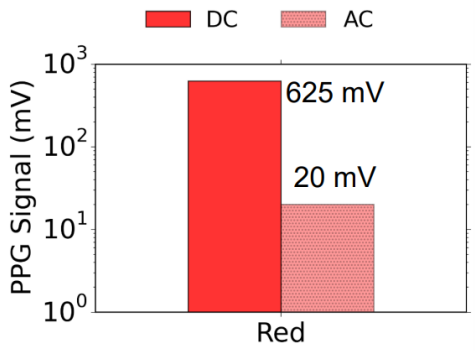


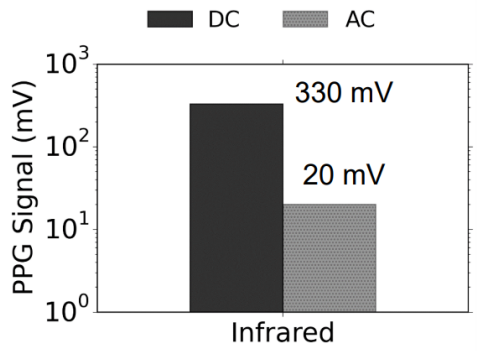


$$R = \frac{AC_{rd}/DC_{rd}}{AC_{ir}/DC_{ir}}$$

$$R = \frac{20mV/625mV}{20mV/330mV} = .528$$







Pulse oximeter basics

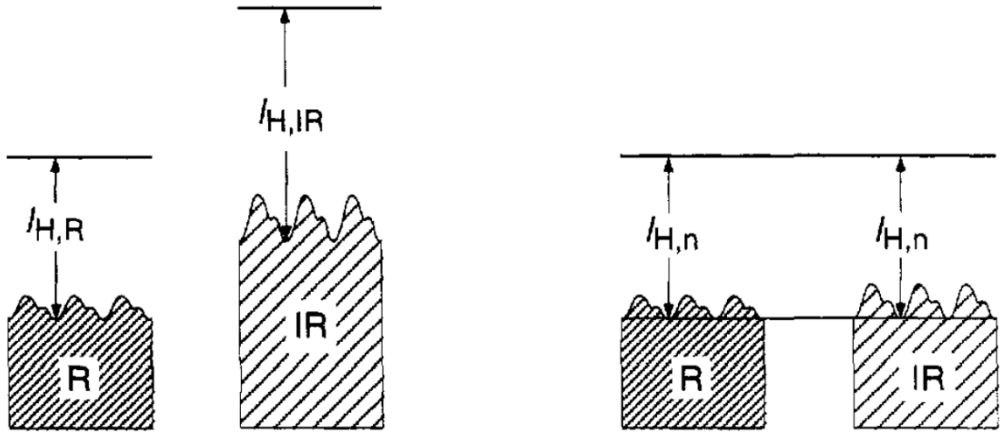


Figure 4.6 The normalization of the signals. The transmitted light from the red LED (R) and from the infrared LED (IR) is divided by its individual DC component. Thus, both normalized light intensities have the same magnitude during diastole. The normalized signals determine the basis for the calculation of the arterial oxygen saturation.

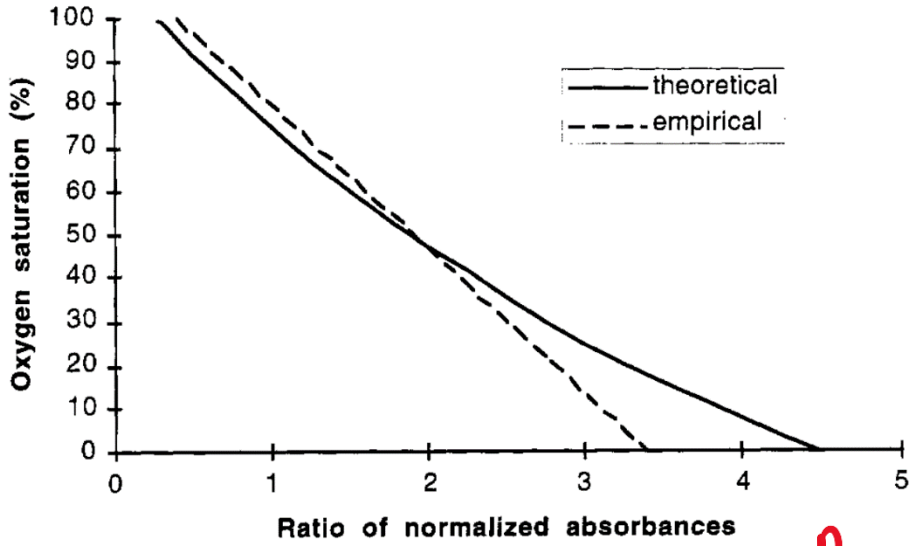


Figure 4.7 Calibration curves for pulse oximeters: the solid line is the theoretical curve by Beer's law and the dashed line is the empirical curve. The difference between these curves is due mainly to light scattering effects. This empirical calibration curve is derived by a second order polynomial.

Oximeter prototype

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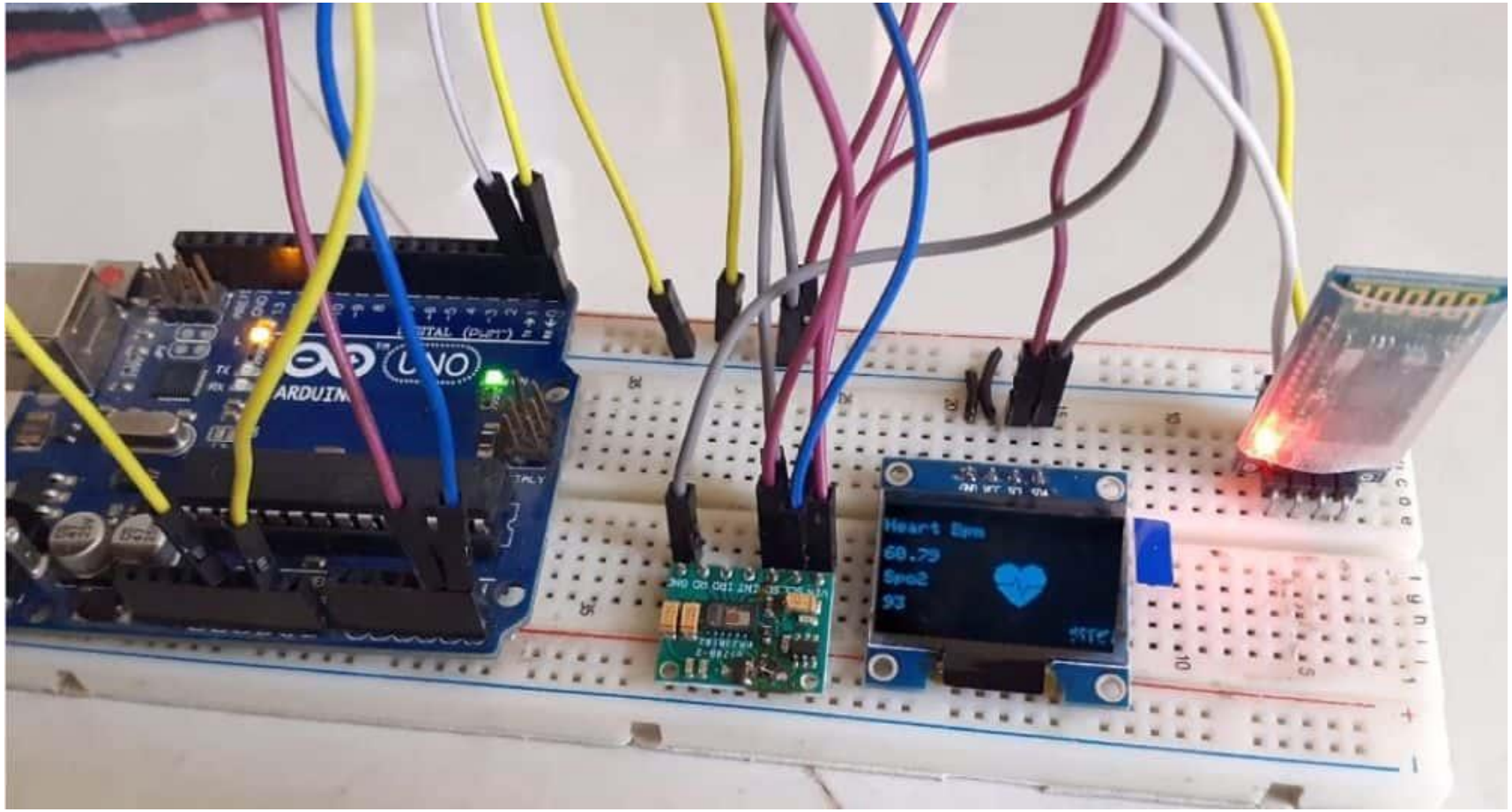

AFE – MAX30102

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Click here for production status of specific part numbers.

MAX30102

High-Sensitivity Pulse Oximeter and Heart-Rate Sensor for Wearable Health

General Description

The MAX30102 is an integrated pulse oximetry and heart-rate monitor module. It includes internal LEDs, photodetectors, optical elements, and low-noise electronics with ambient light rejection. The MAX30102 provides a complete system solution to ease the design-in process for mobile and wearable devices.

The MAX30102 operates on a single 1.8V power supply and a separate 3.3V power supply for the internal LEDs. Communication is through a standard I^2C-compatible interface. The module can be shut down through software with zero standby current, allowing the power rails to remain powered at all times.

Applications

- Wearable Devices
- Fitness Assistant Devices
- Smartphones
- Tablets

Benefits and Features

- Heart-Rate Monitor and Pulse Oximeter Sensor in LED Reflective Solution
- 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)
  - Ultra-Low Shutdown Current (0.7µA, typ)
- Fast Data Output Capability
  - High Sample Rates
- Robust Motion Artifact Resilience
  - High SNR
- -40°C to +85°C Operating Temperature Range

Ordering Information appears at end of data sheet.

System design

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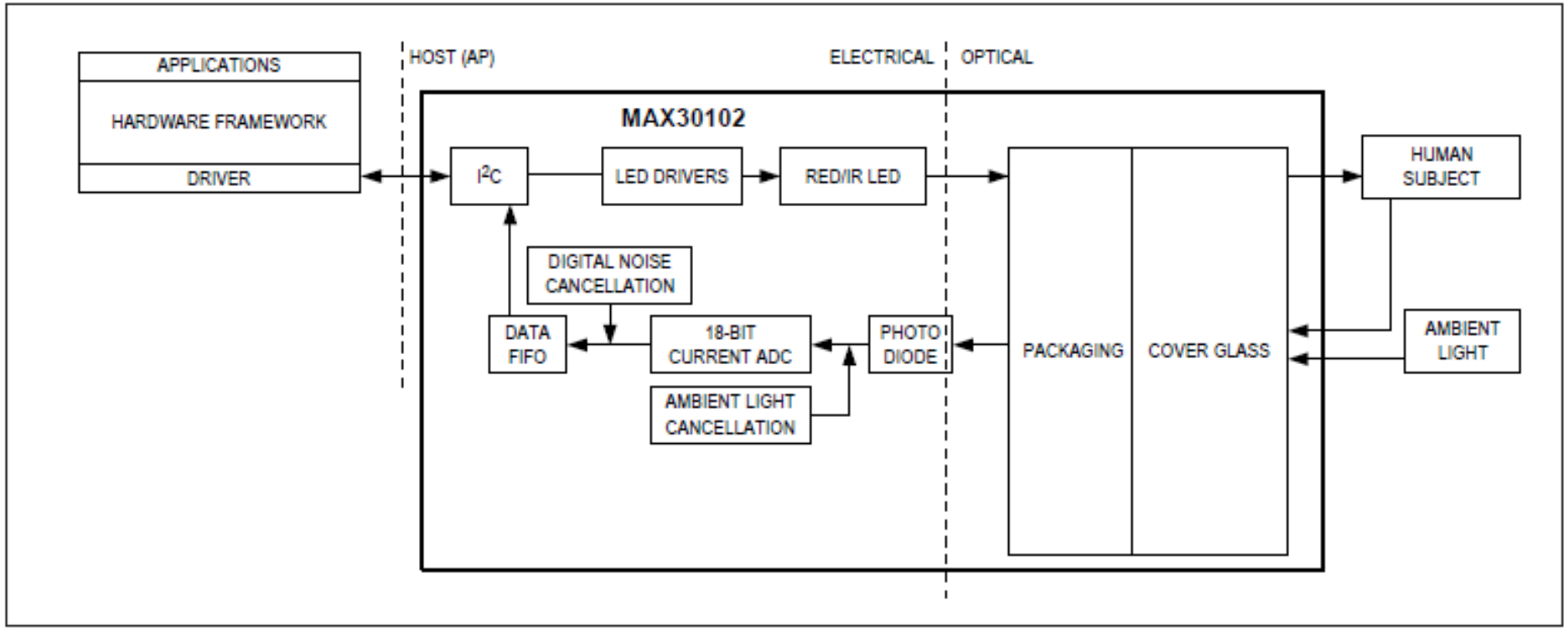
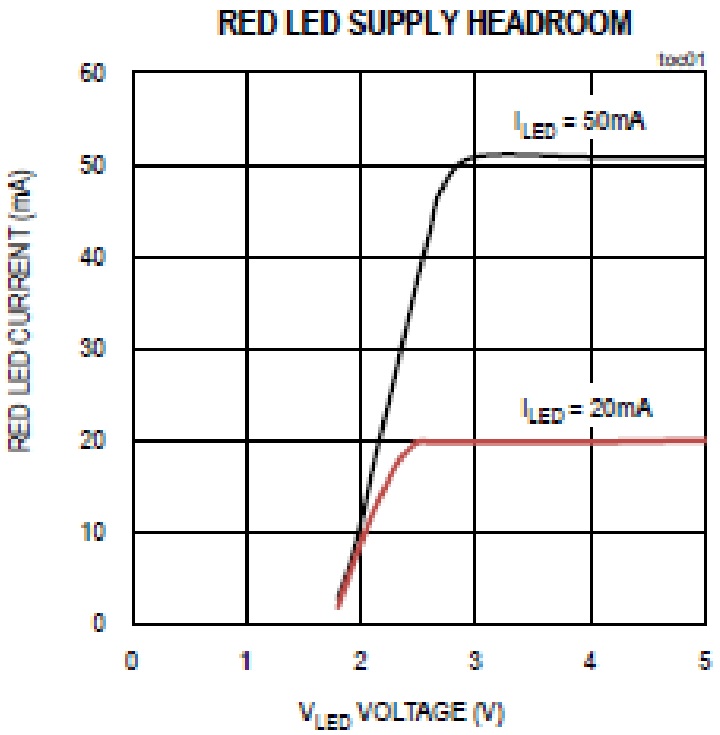
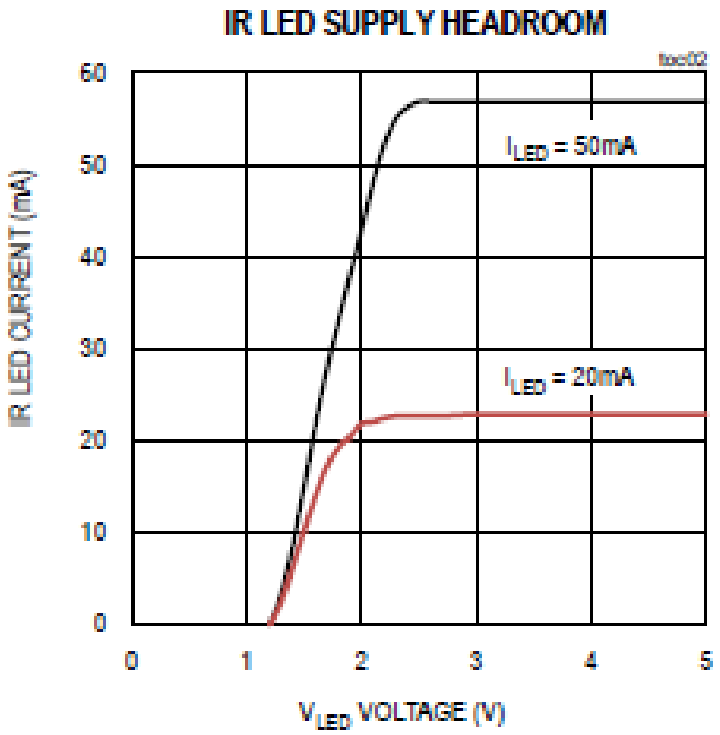
System Diagram

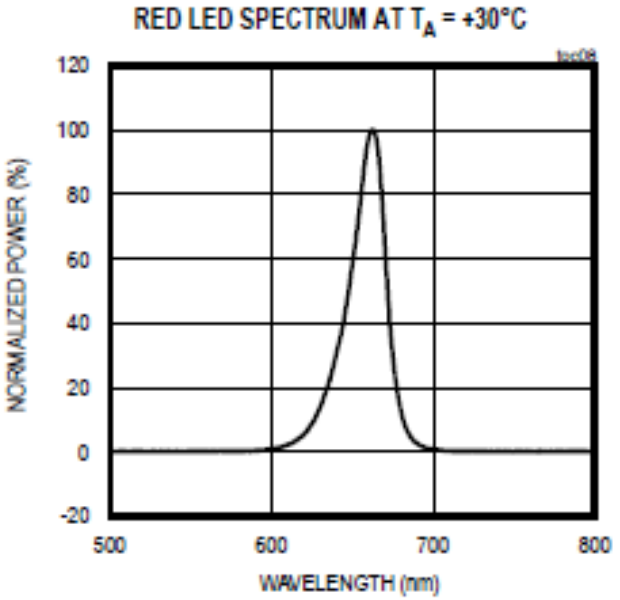


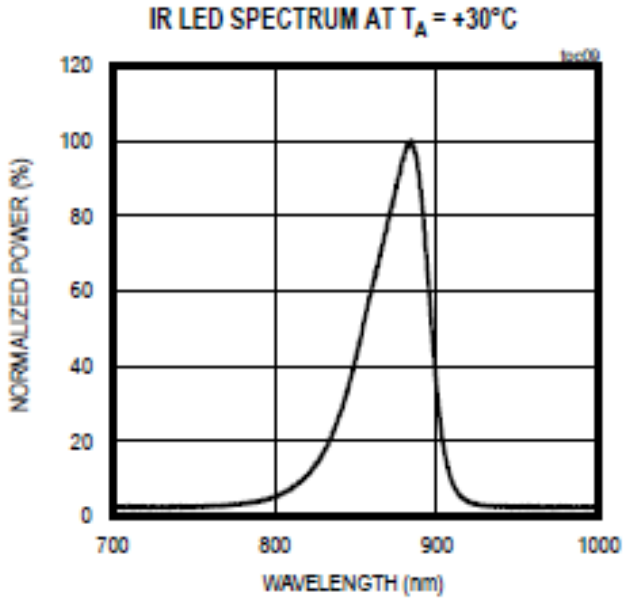
LEDs

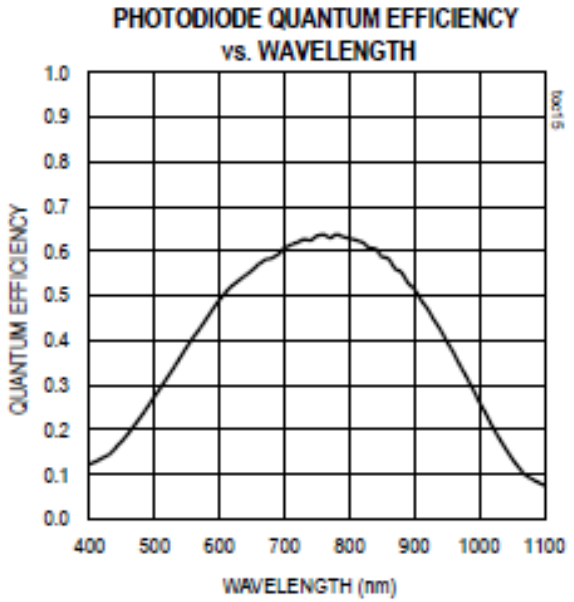

RED LED SUPPLY HEADROOM
toc01
RED LED CURRENT (mA)
60
50
40
30
20
10
0
0
1
2
3
4
5
I_{LED} = 50mA
I_{LED} = 20mA
V_{LED} VOLTAGE (V)


IR LED SUPPLY HEADROOM
toc02
IR LED CURRENT (mA)
60
50
40
30
20
10
0
0
1
2
3
4
5
I_{LED} = 50mA
I_{LED} = 20mA
V_{LED} VOLTAGE (V)

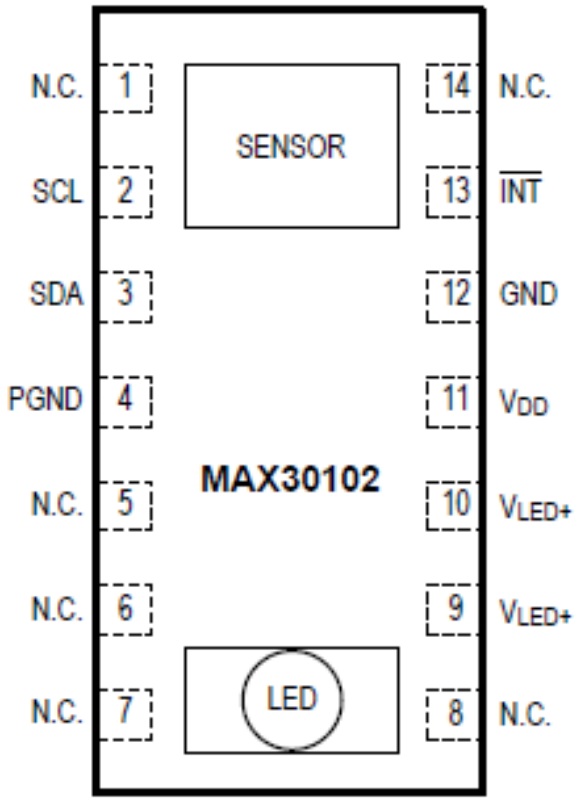
LED – PD spectrum







Connection


N.C. 1
SCL 2
SDA 3
PGND 4
N.C. 5
N.C. 6
N.C. 7
14 N.C.
13 INT
12 GND
11 VDD
10 VLED+
9 VLED+
8 N.C.
SENSOR
MAX30102
LED


VIN
GND
SCL
SDA
INT

Connection

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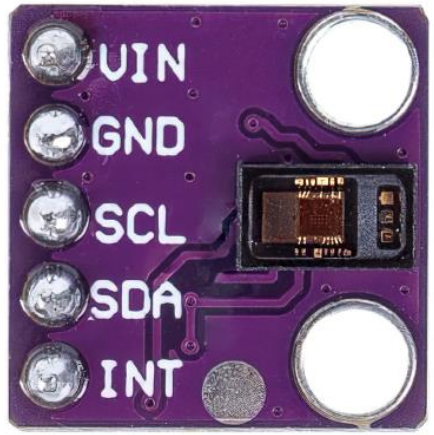
Pin Description

PIN	NAME	FUNCTION
1, 5, 6, 7, 8, 14	N.C.	No Connection. Connect to PCB pad for mechanical stability.
2	SCL	I²C Clock Input
3	SDA	I²C Data, Bidirectional (Open-Drain)
4	PGND	Power Ground of the LED Driver Blocks
9	V_{LED+}	LED Power Supply (anode connection). Use a bypass capacitor to PGND for best performance.
10	V_{LED+}	
11	V_{DD}	Analog Power Supply Input. Use a bypass capacitor to GND for best performance.
12	GND	Analog Ground
13	$\overline{INT}$	Active-Low Interrupt (Open-Drain). Connect to an external voltage with a pullup resistor.



How does the AFE work

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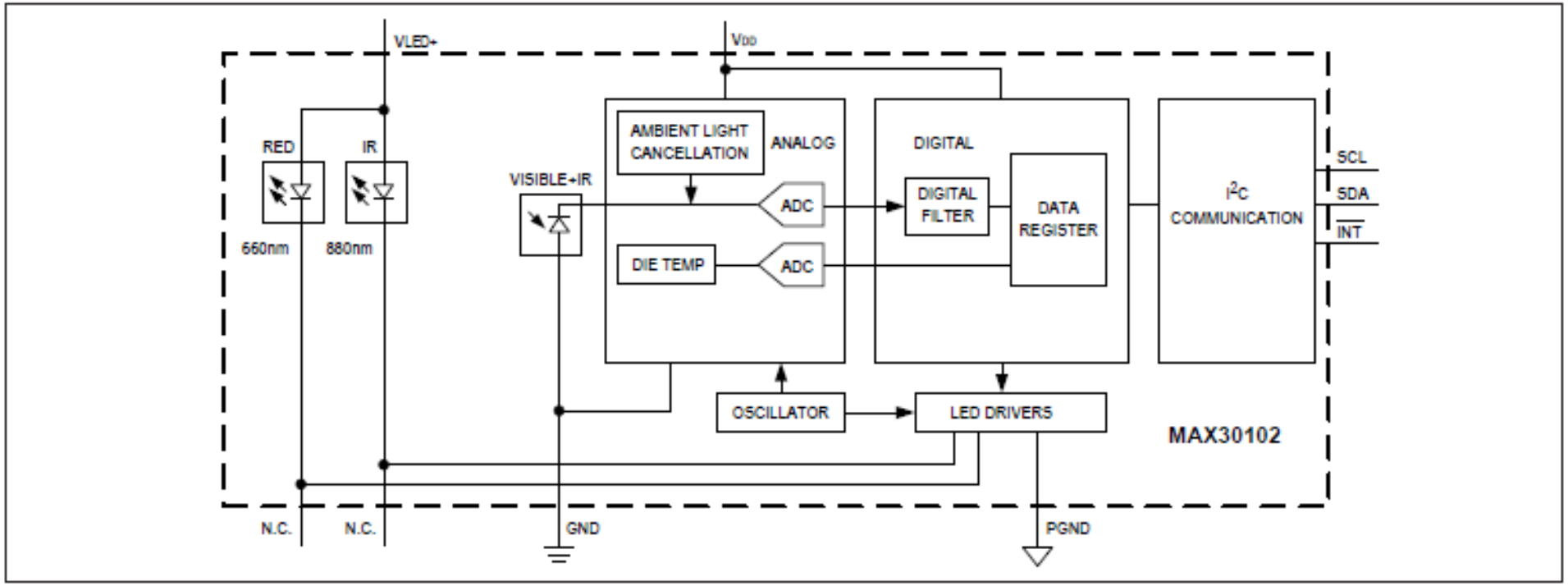
Functional Diagram



Data capture

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Timing in SpO_2 Mode

The internal FIFO stores up to 32 samples, so that the system processor does not need to read the data after every sample. The temperature does not need to be sampled very often–once a second or every few seconds should be sufficient.

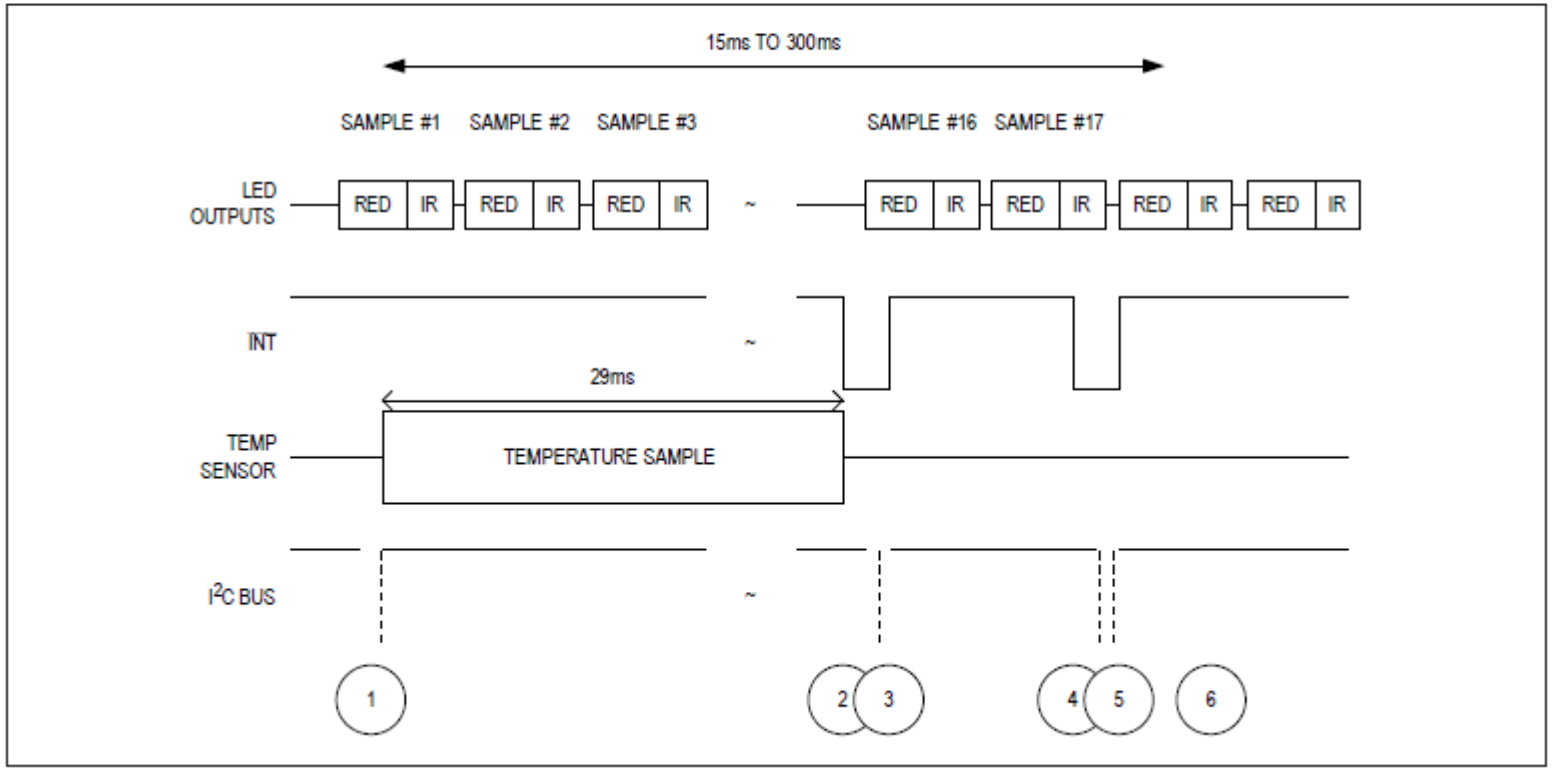


Figure 4. Timing for Data Acquisition and Communication When in SpO_2 Mode

Data capture

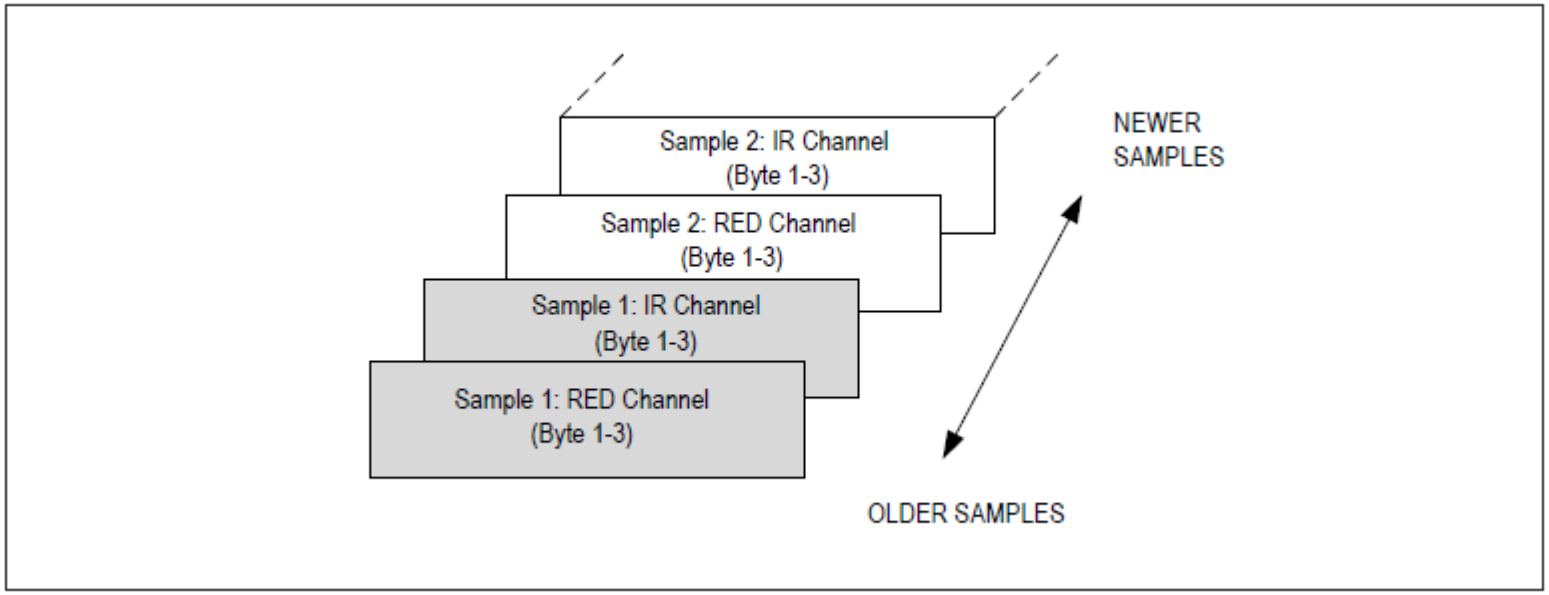


Figure 2. Graphical Representation of the FIFO Data Register. It shows IR and Red in SpO_2 Mode.

Bits 4:2: SpO_2 Sample Rate Control

These bits define the effective sampling rate with one sample consisting of one IR pulse/conversion and one Red pulse/conversion.

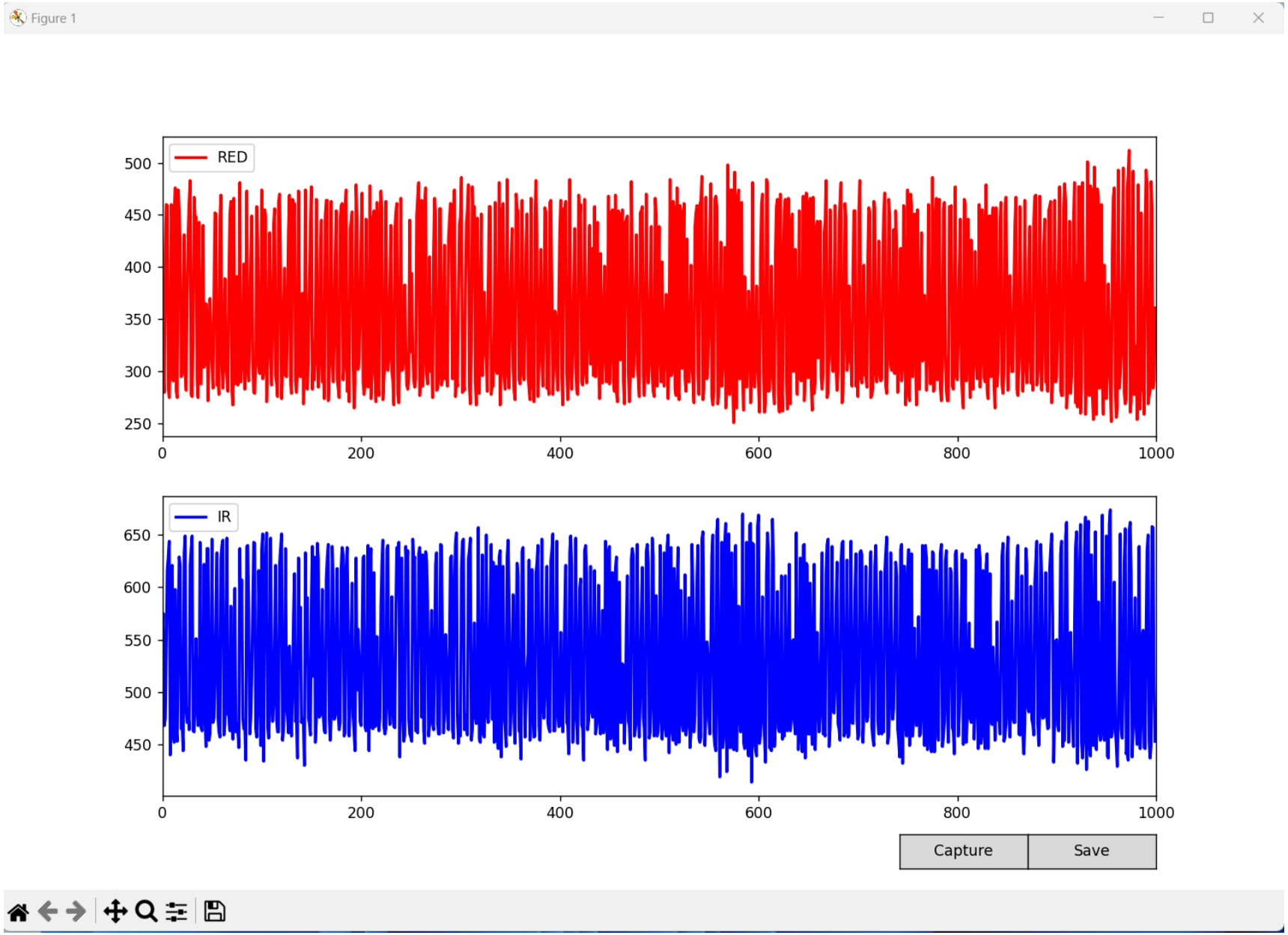
The sample rate and pulse width are related in that the sample rate sets an upper bound on the pulse width time. If the user selects a sample rate that is too high for the selected LED_PW setting, the highest possible sample rate is programmed instead into the register.

Table 6. SpO_2 Sample Rate Control

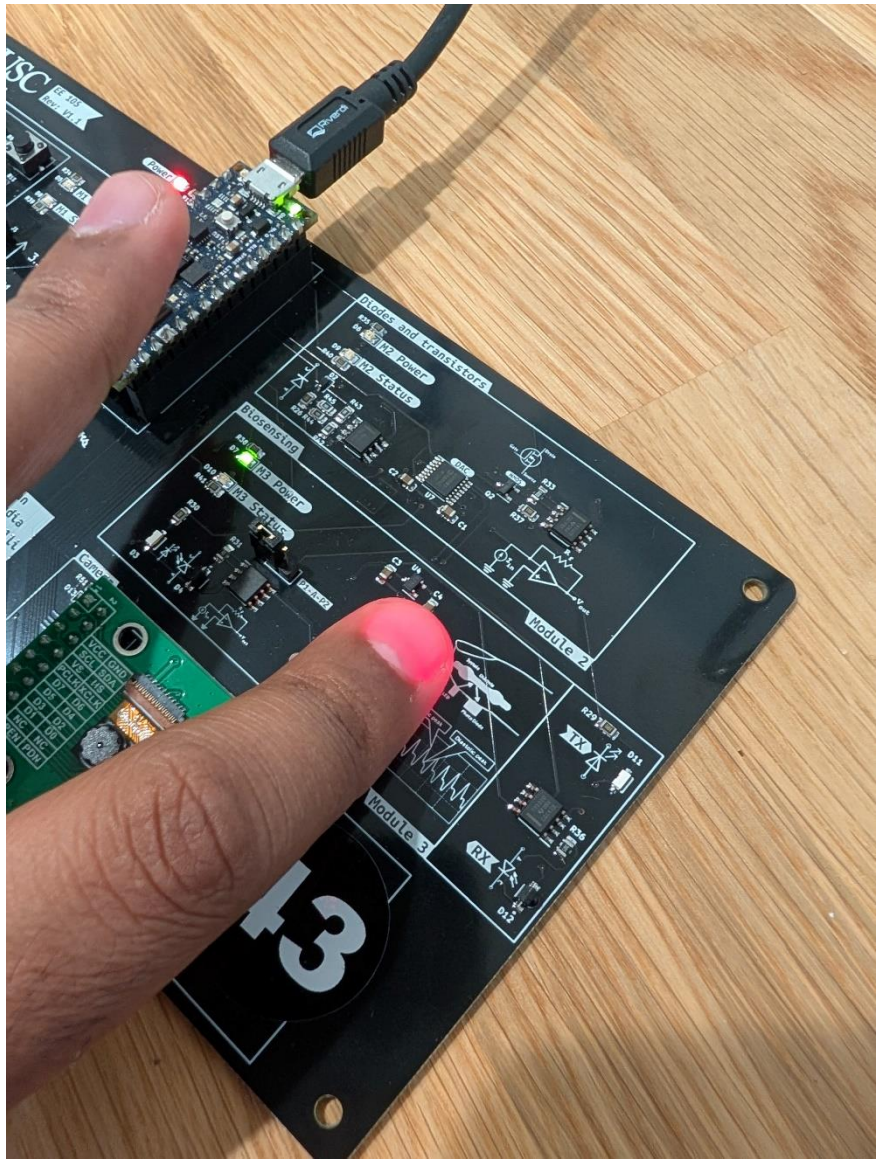
SPO2_SR[2:0]	SAMPLES PER SECOND
000	50
001	100
010	200
011	400
100	800
101	1000
110	1600
111	3200

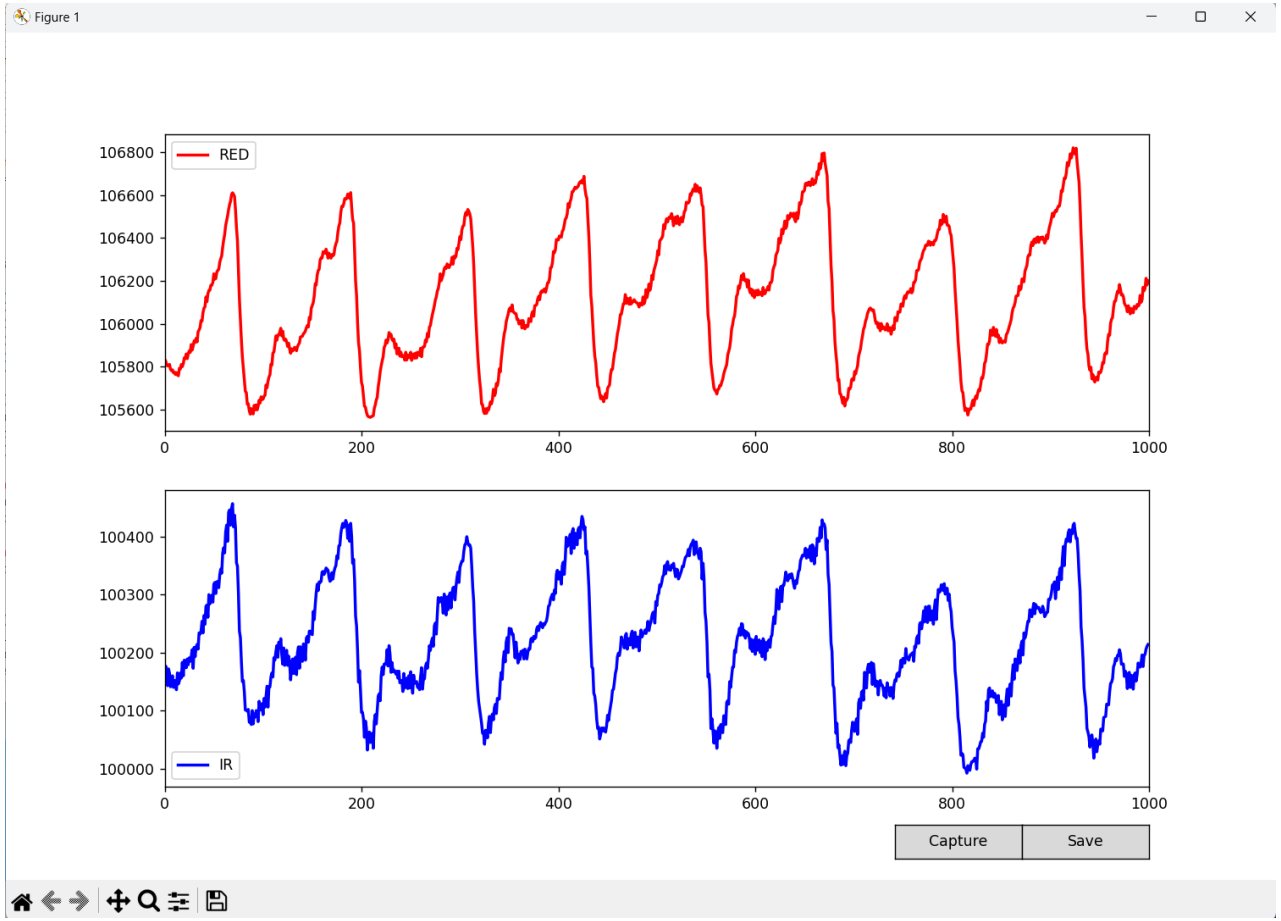
See Table 11 and Table 12 for Pulse Width vs. Sample Rate information.

Press capture



Keep your finger gently on the sensor





Time domain to frequency domain

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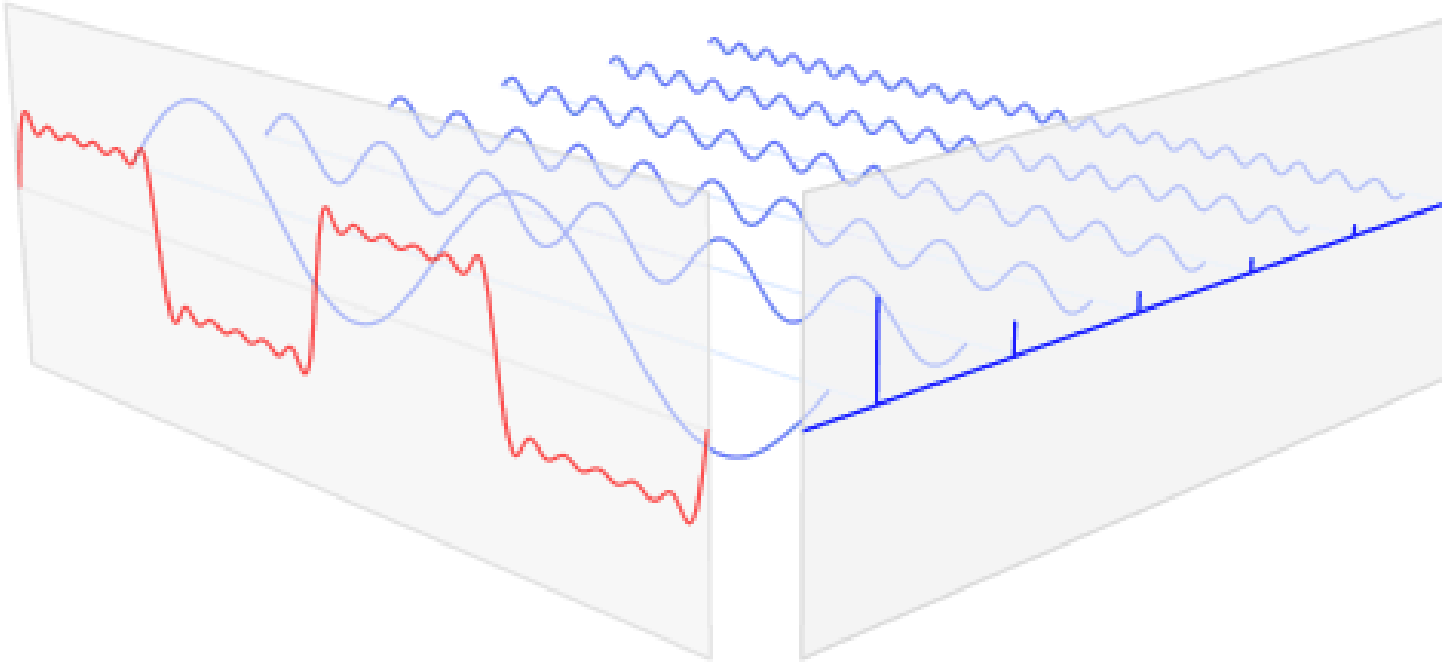
- The Fourier transform is an analysis process, decomposing a complex-valued function into its constituent frequencies and their amplitudes.



Time domain to frequency domain

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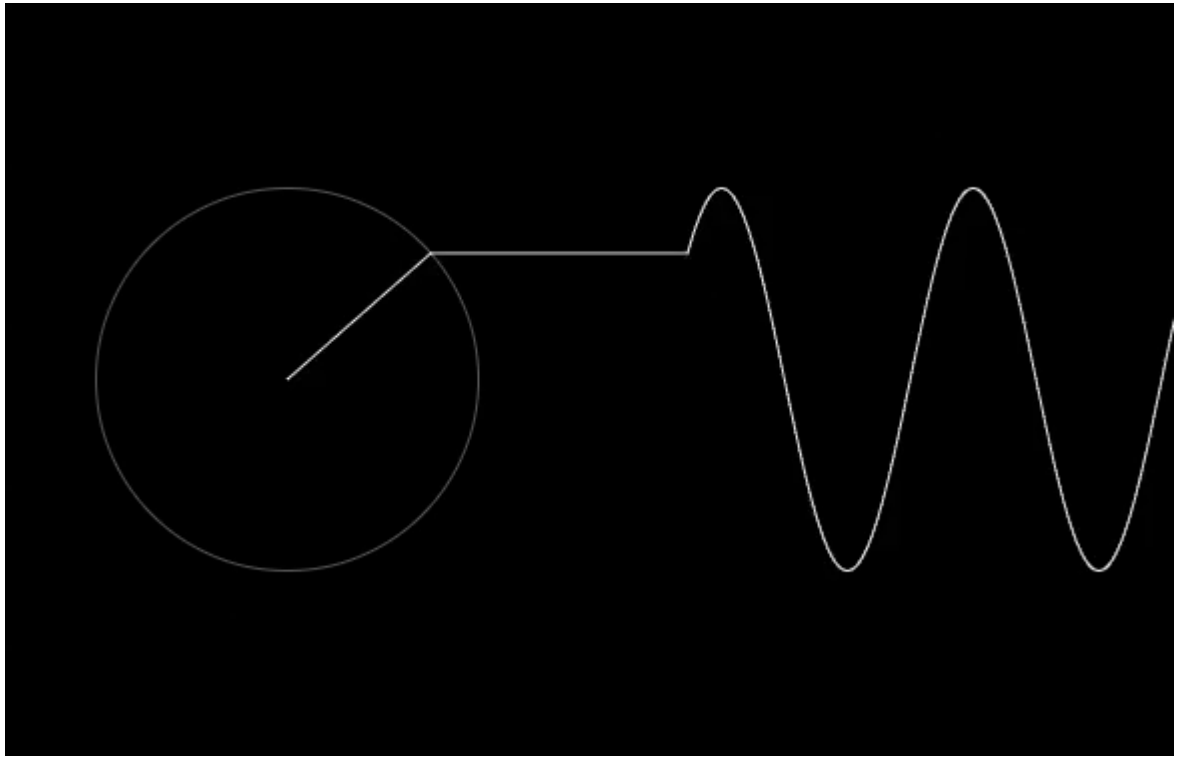
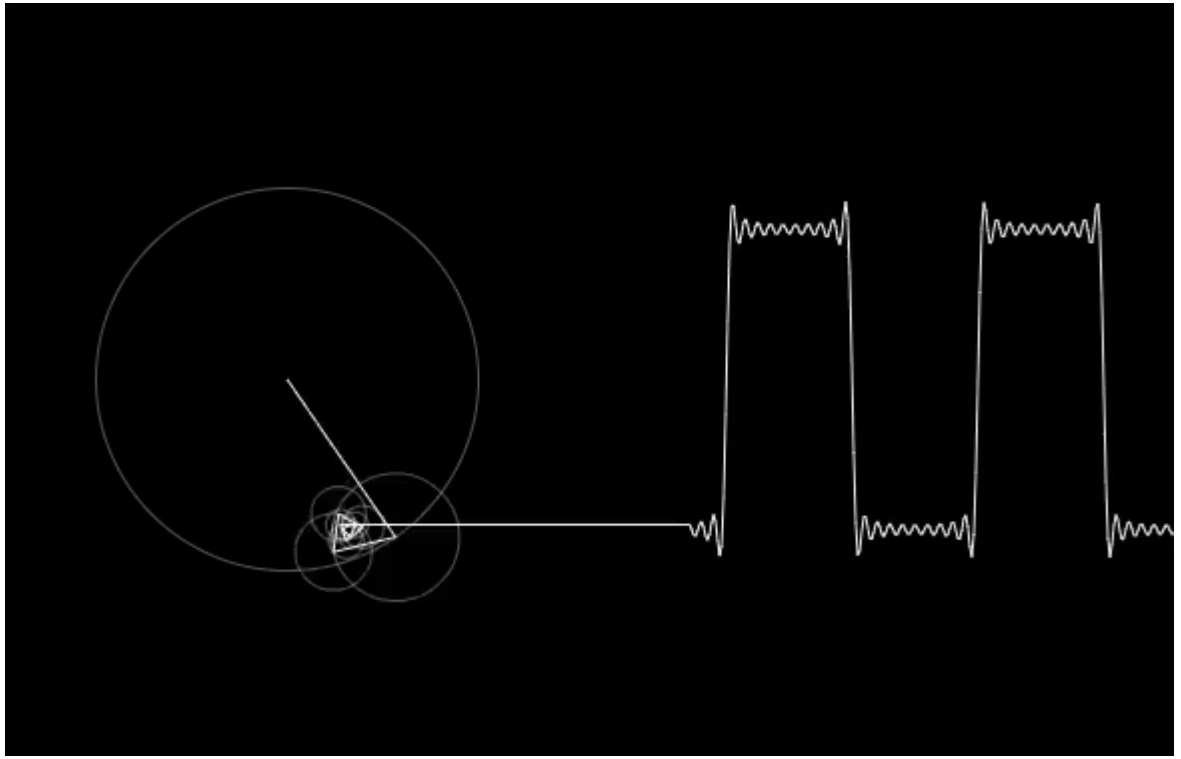
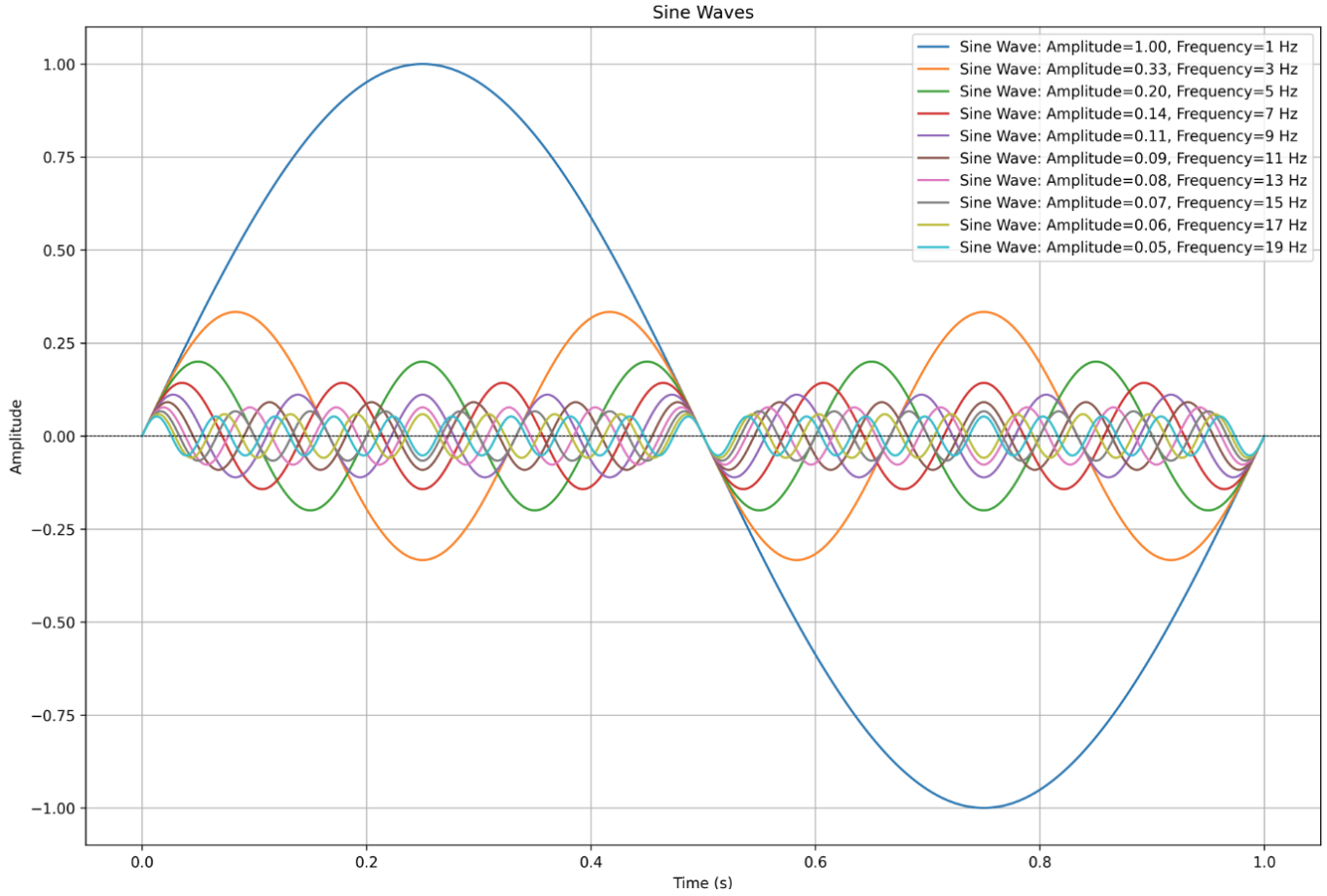
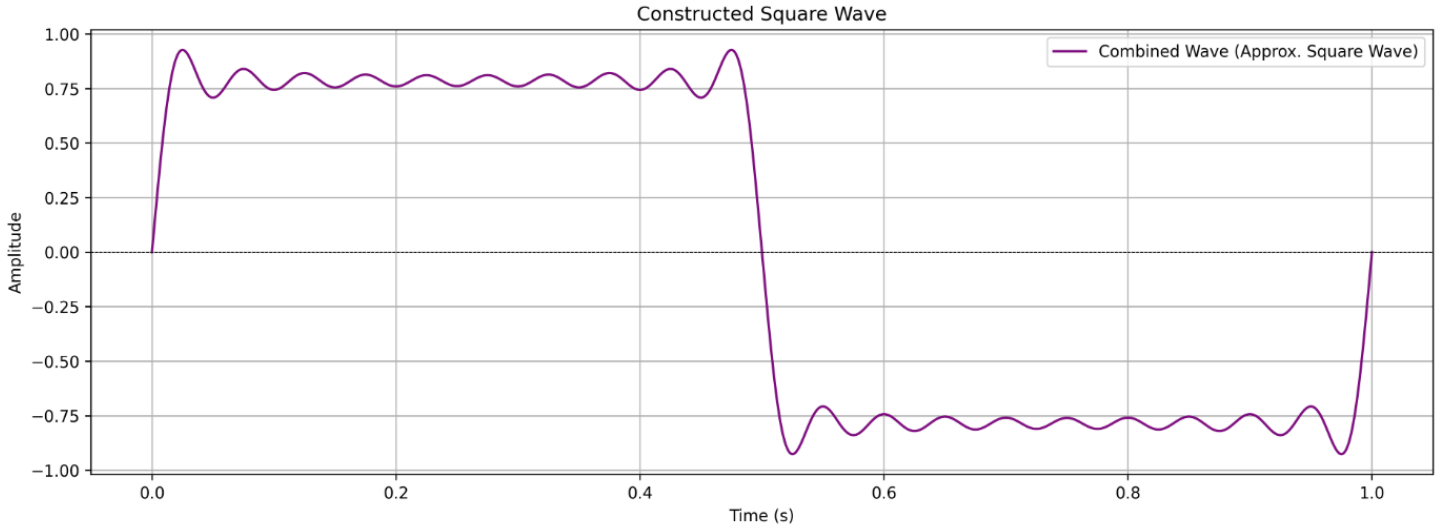


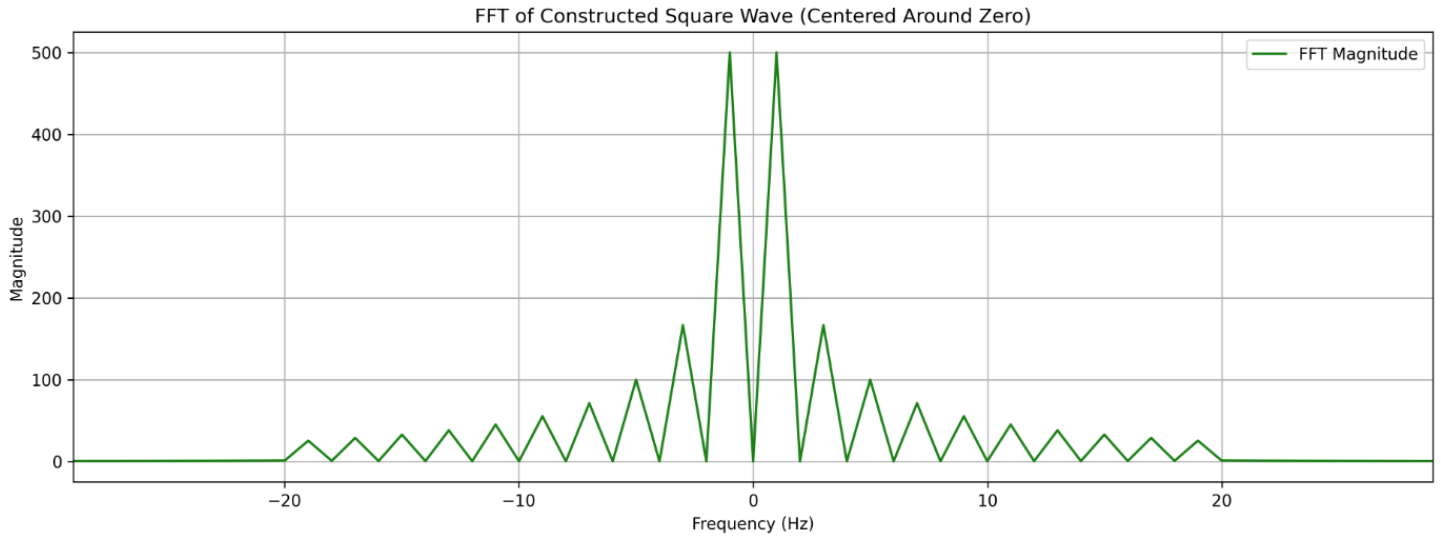


Time domain to frequency domain

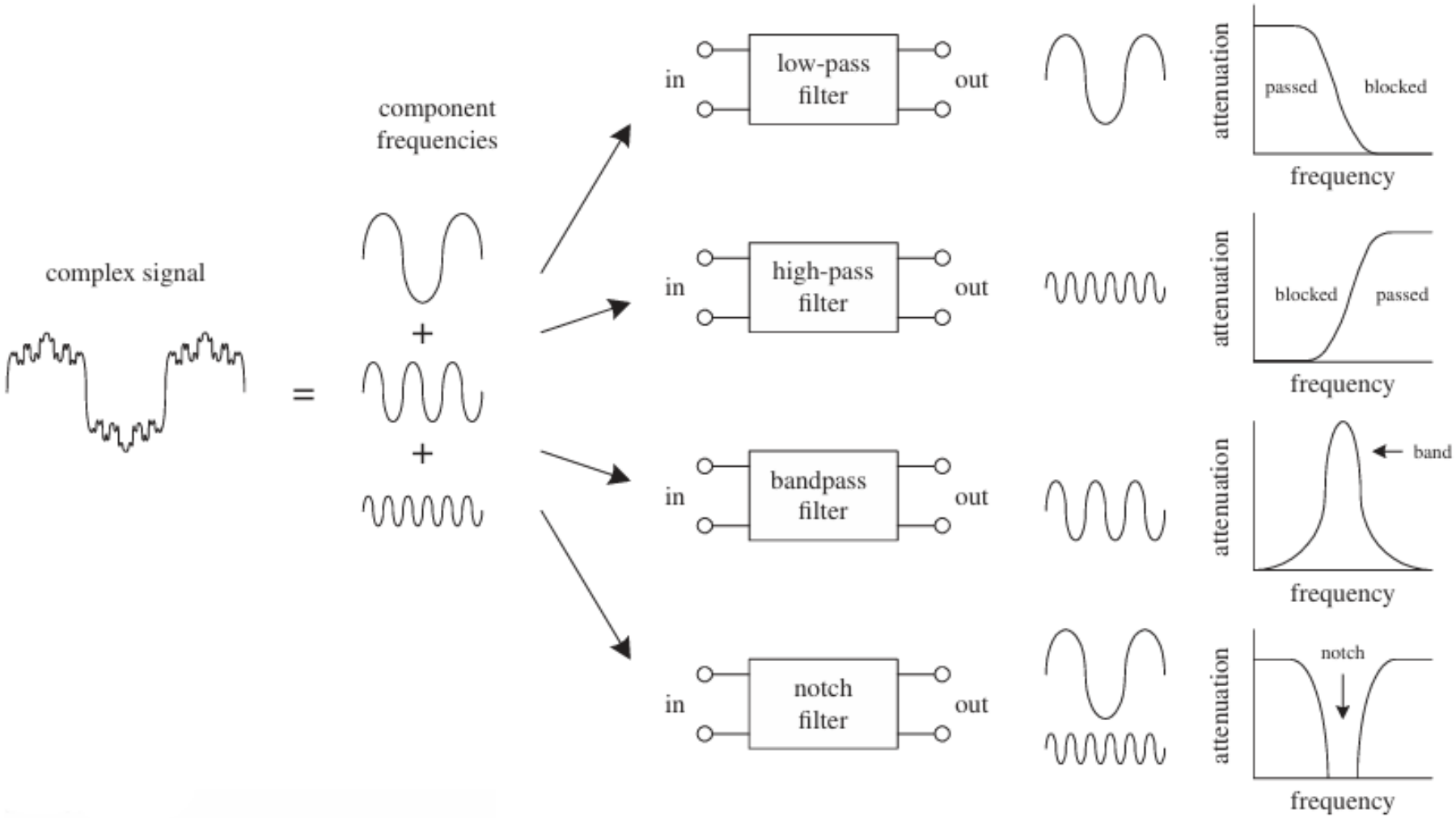


What makes a square wave

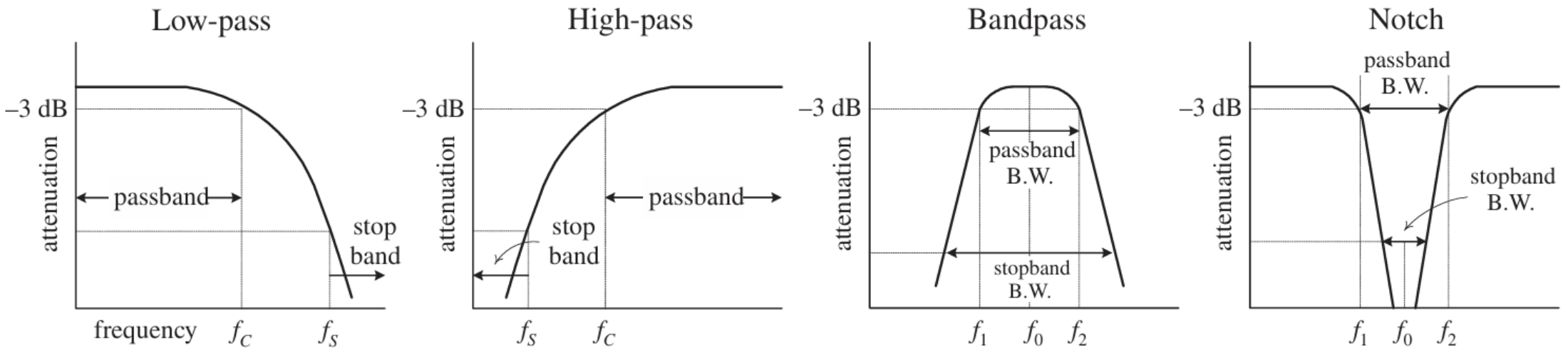




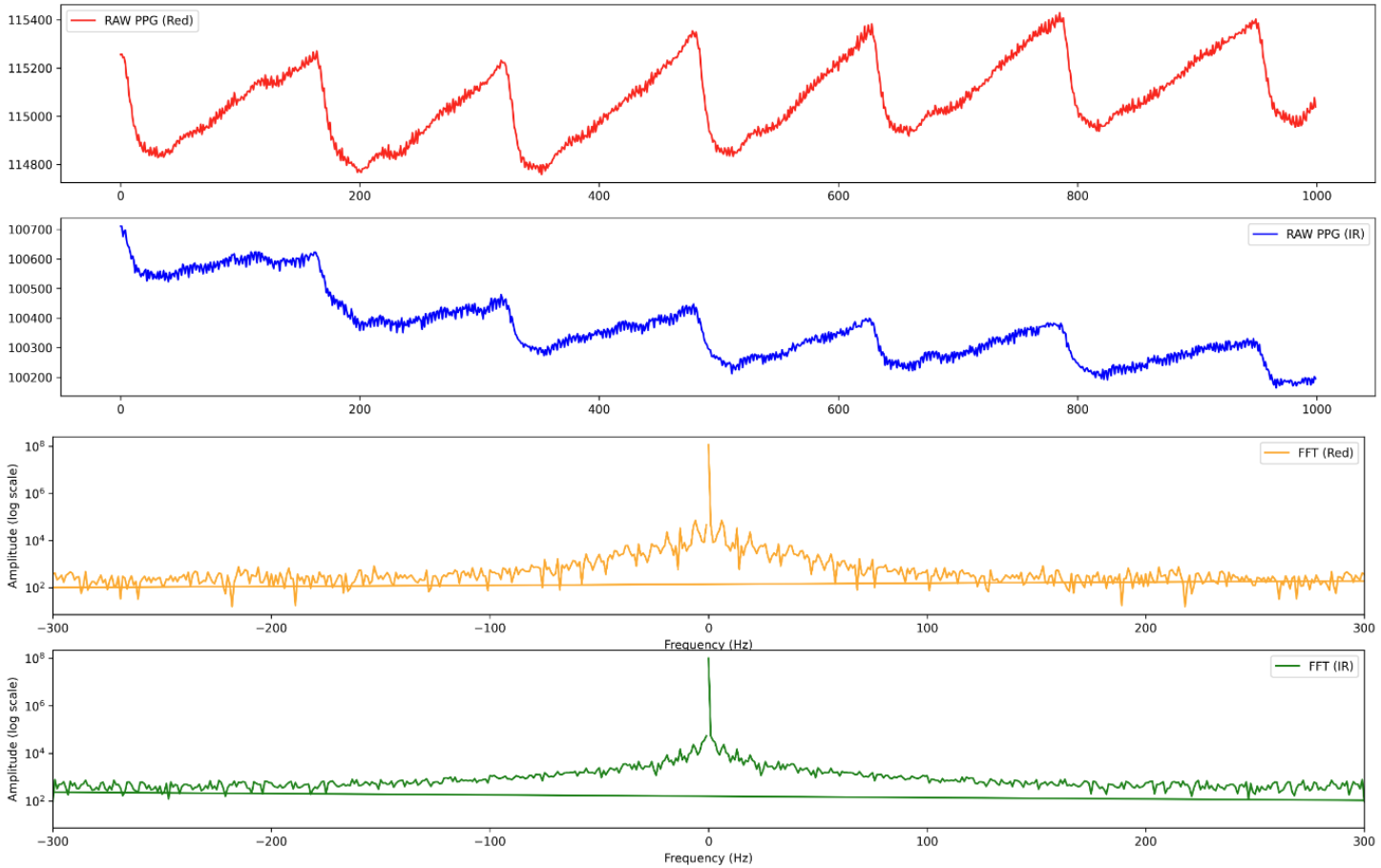
Filters


complex signal
=
component frequencies
+
+
in
low-pass filter
out
high-pass filter
bandpass filter
notch filter
attenuation
passed
blocked
frequency
band
notch

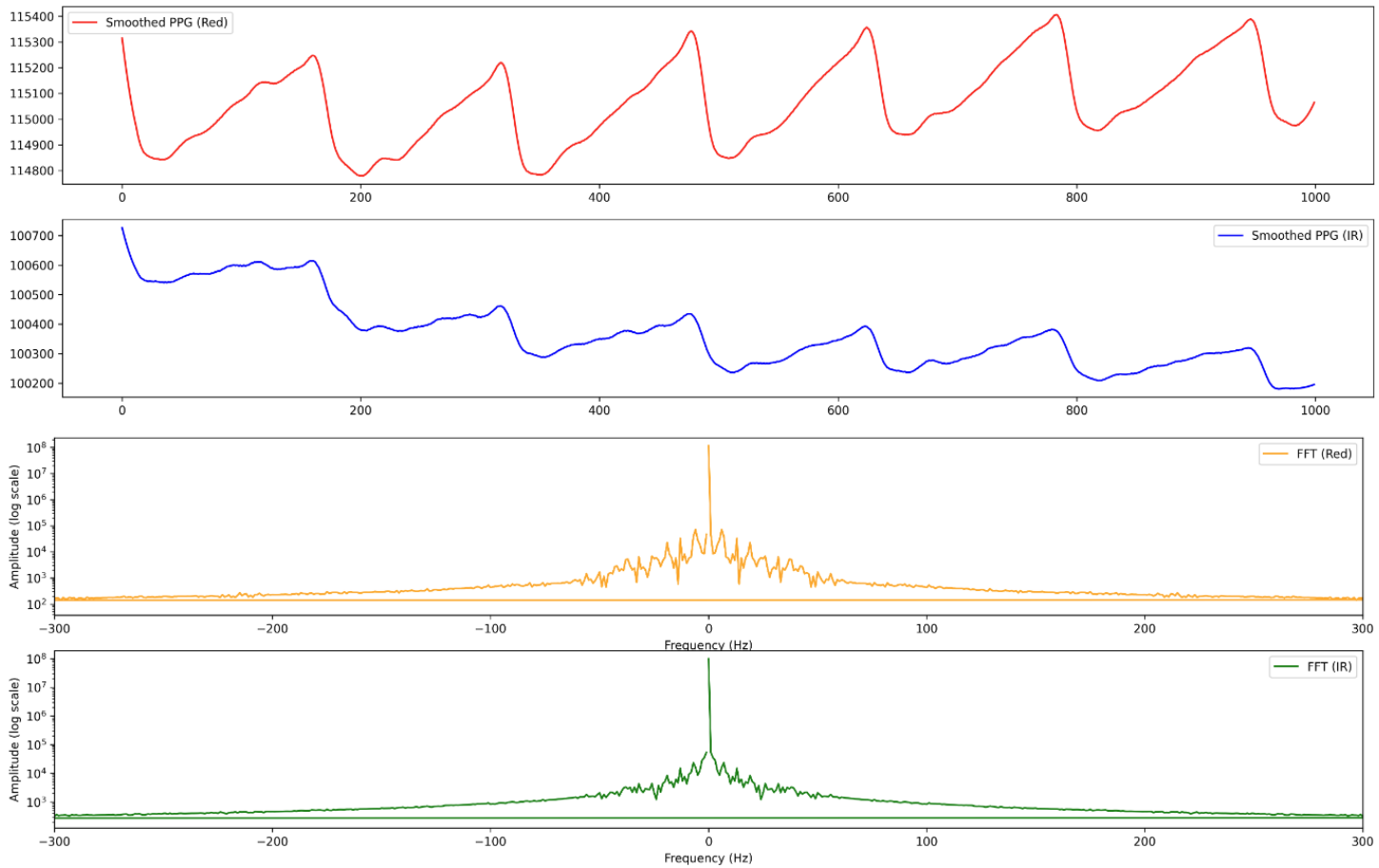
Filters


Low-pass
–3 dB
attenuation
passband
stop
band
frequency
f_C
f_S
High-pass
–3 dB
attenuation
stop
band
passband
f_S
f_C
Bandpass
–3 dB
attenuation
passband
B.W.
stopband
B.W.
f_1
f_0
f_2
Notch
–3 dB
attenuation
passband
B.W.
stopband
B.W.
f_1
f_0
f_2

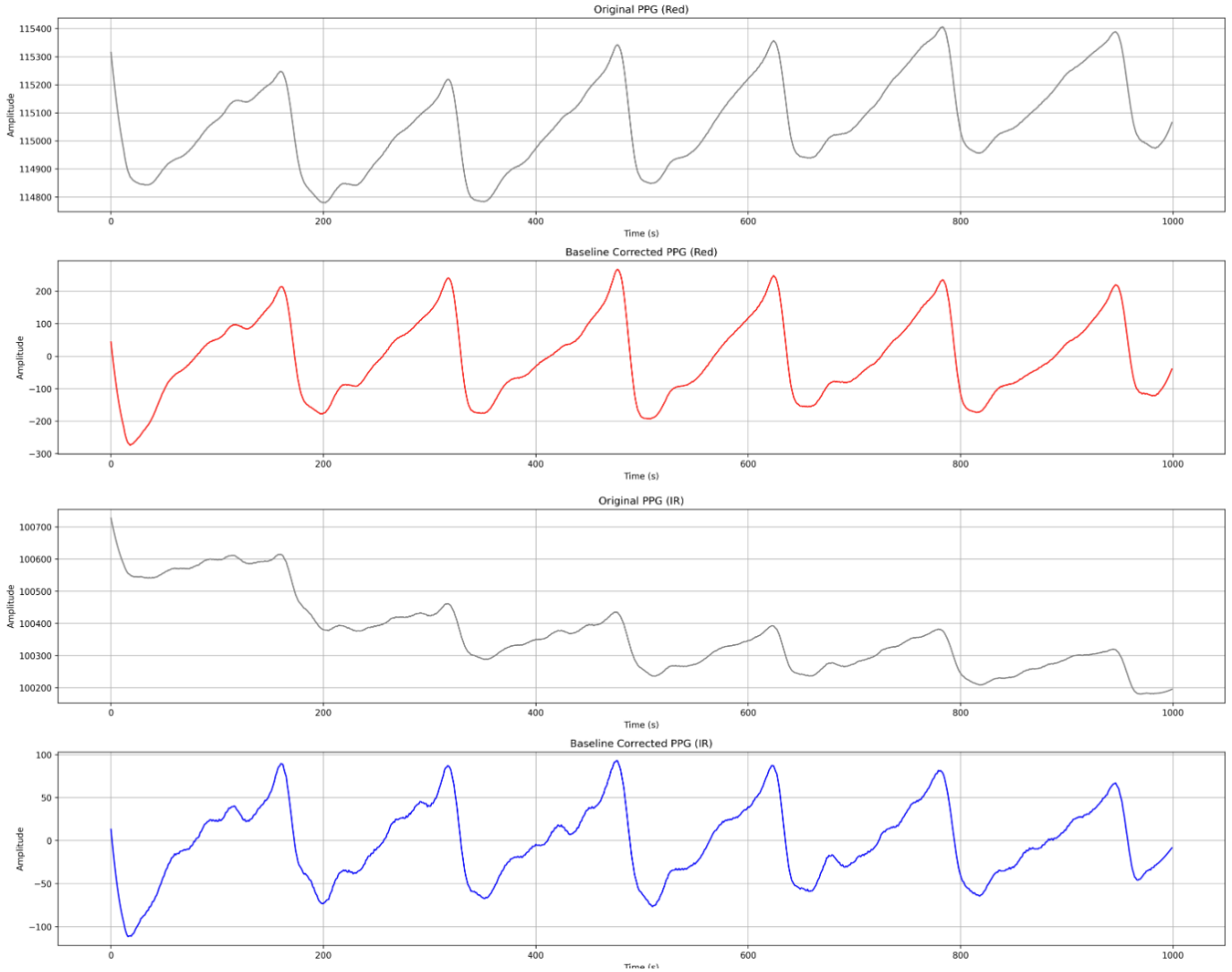
Going back to the PPG data collected



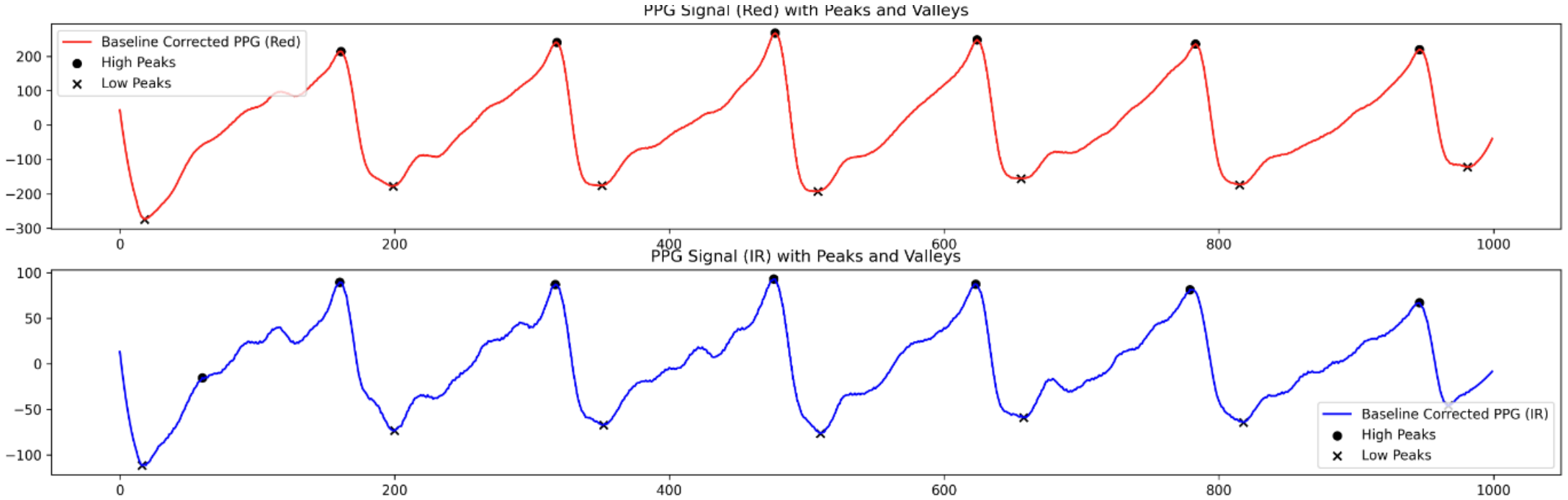
Smoothing


Smoothed PPG (Red)
115400
115300
115200
115100
115000
114900
114800
0
200
400
600
800
1000
Smoothed PPG (IR)
100700
100600
100500
100400
100300
100200
FFT (Red)
Amplitude (log scale)
Frequency (Hz)
−300
−200
−100
100
200
300
FFT (IR)

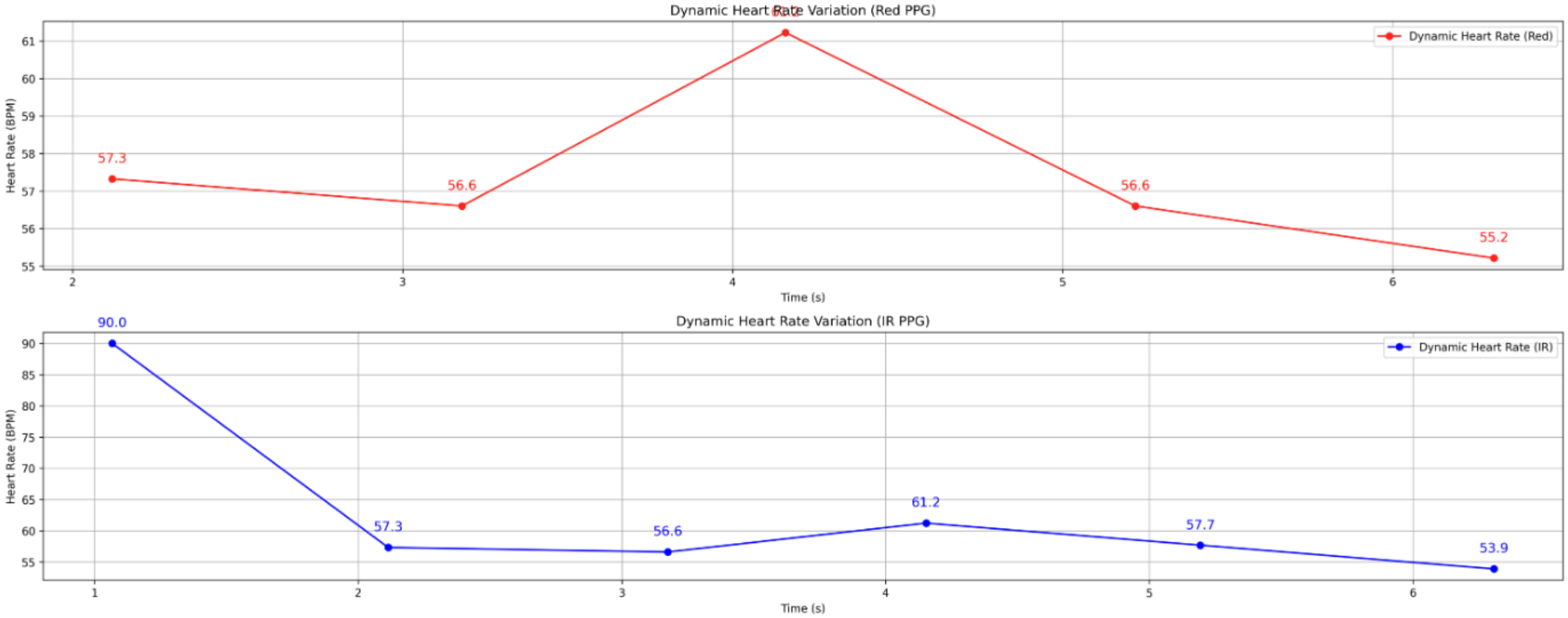
Drift correction



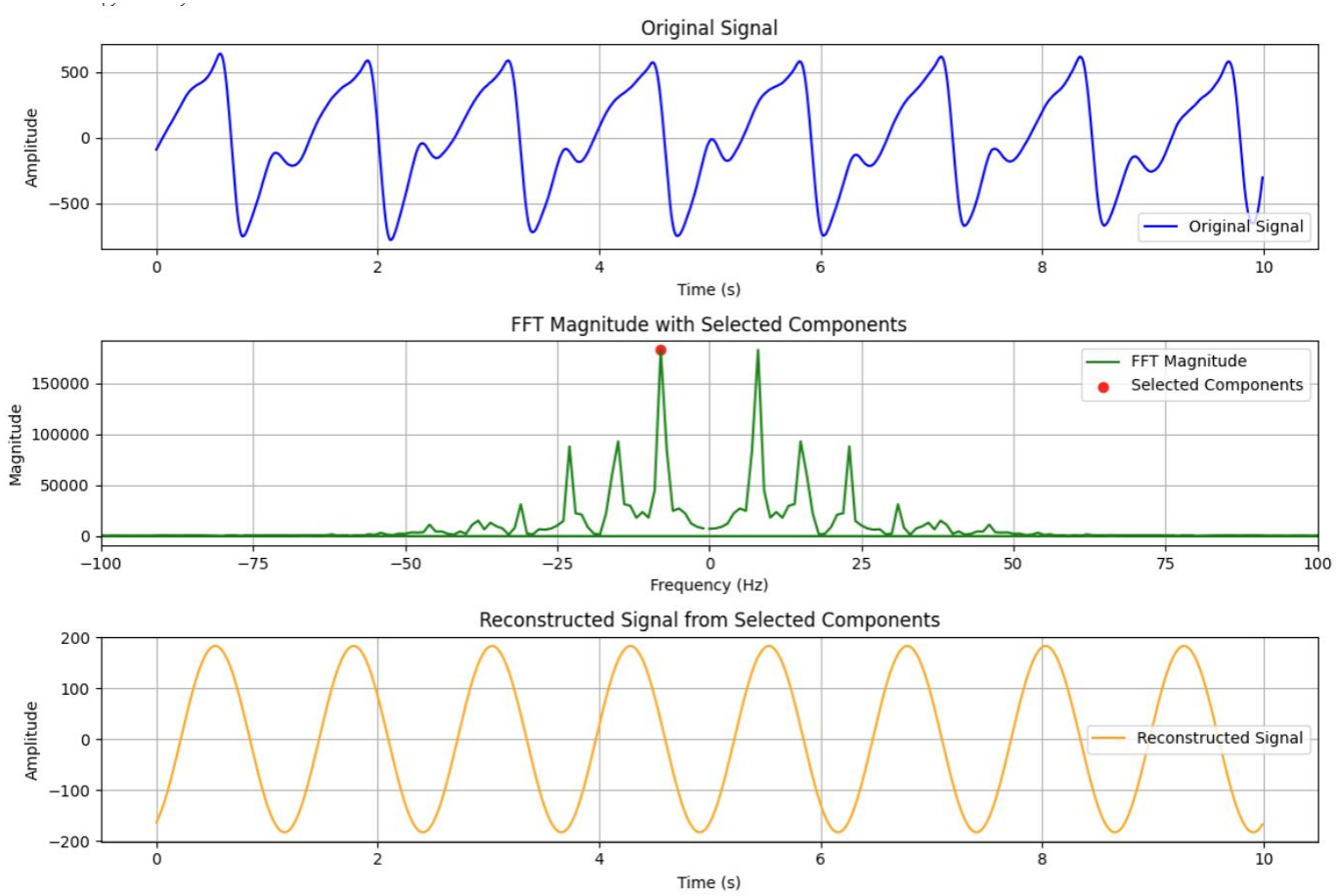
Peak detection



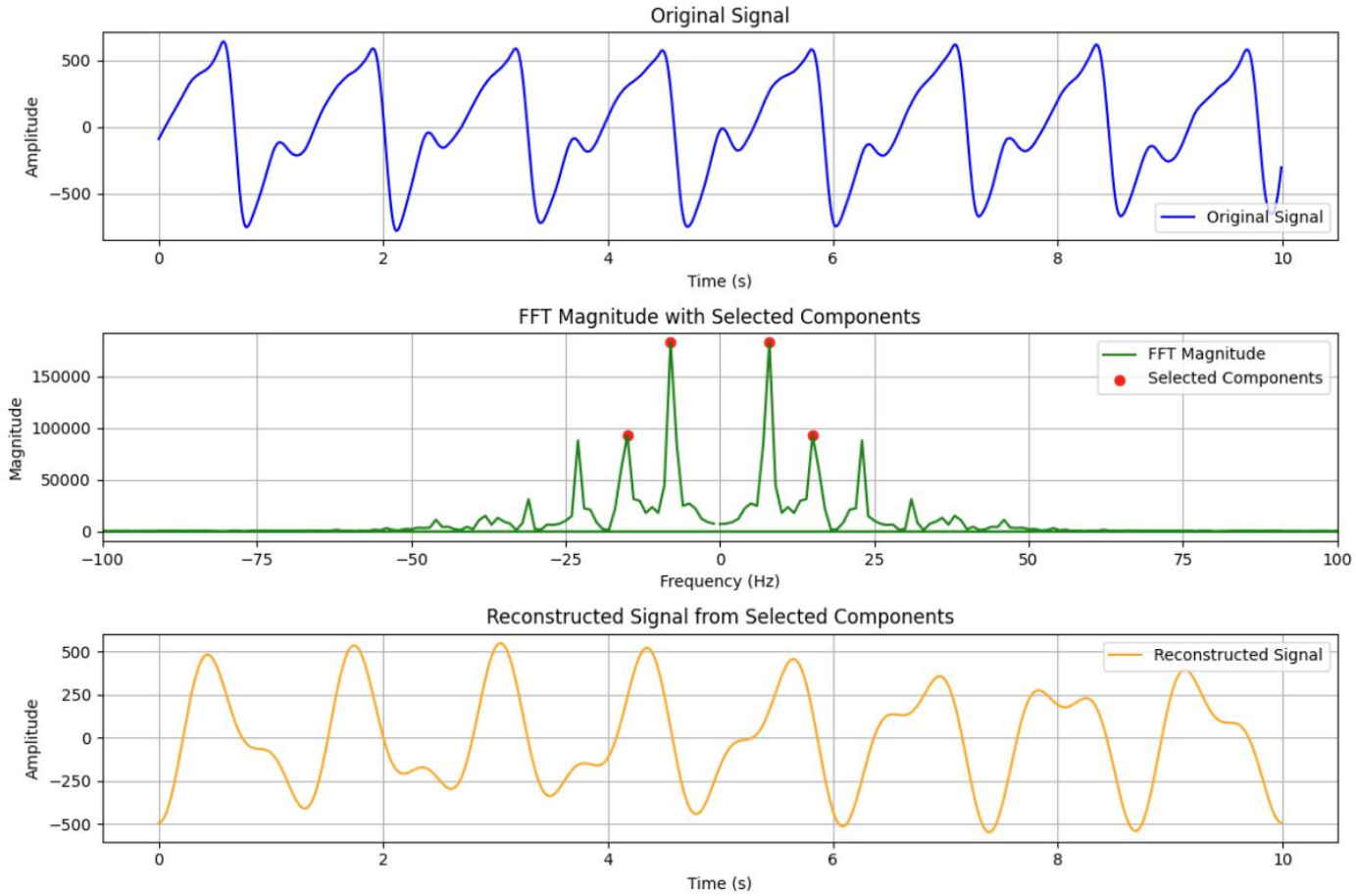
Heart rate


Dynamic Heart Rate Variation (Red PPG)
Dynamic Heart Rate (Red)
Heart Rate (BPM)
Time (s)
57.3
56.6
56.6
55.2
Dynamic Heart Rate Variation (IR PPG)
Dynamic Heart Rate (IR)
Heart Rate (BPM)
Time (s)
90.0
57.3
56.6
61.2
57.7
53.9

Using single component to find heart rate



4 components in the PPG signal – signal loss



Taking all the components provides the original signal