Applications and Analysis of Commercial Millimeter-wave Radar Sensors in a Student Project at Metropolia UAS

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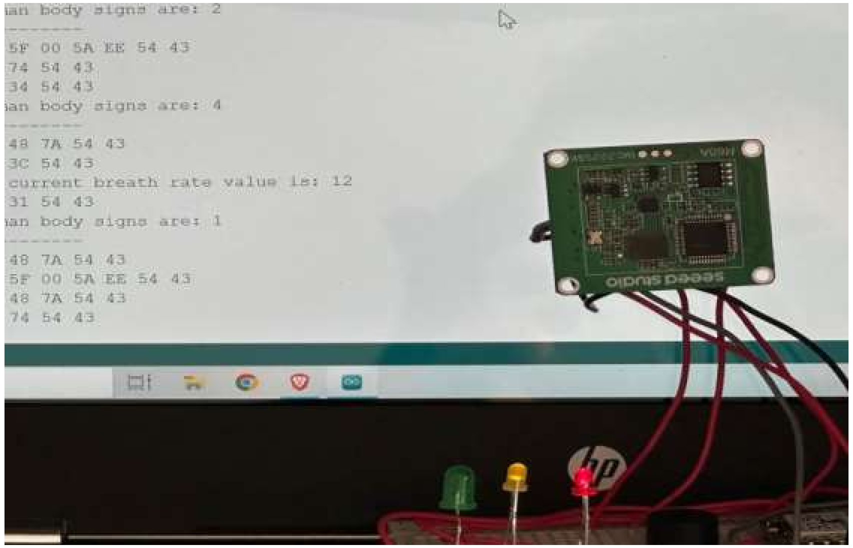
The Sensors Course Implementation

- 15 ECTS – 4 sensor projects – 8 weeks
- Strain gauges – temp sensors – light sensors – mm-Wave radar sensors
- 24 students in 8 subgroups of 3 in 2024
- 6th semester Bachelor studens in DP of Electronics
- Tuition in English

The mm-Wave Radar Sensor Project



- Commercial low-cost FMCW radars at 24 and 61 GHz
- 4 week project to test the radar sensors and create an application
- Tools or Toys?

Learning Objectives / Topics / Activities

- Prior knowledge: radio and uWave engineering, Arduino C, fundamentals of analog and digital electronics, …
- This applied to mm-waves, radar technology, microstrip antennas, antenna arrays, …
- To see whether the radars are able to keep their promises
- Two exams, multiple HW, project tasks to test a 24 GHz and a 61 GHz radar and create an application using either of those.

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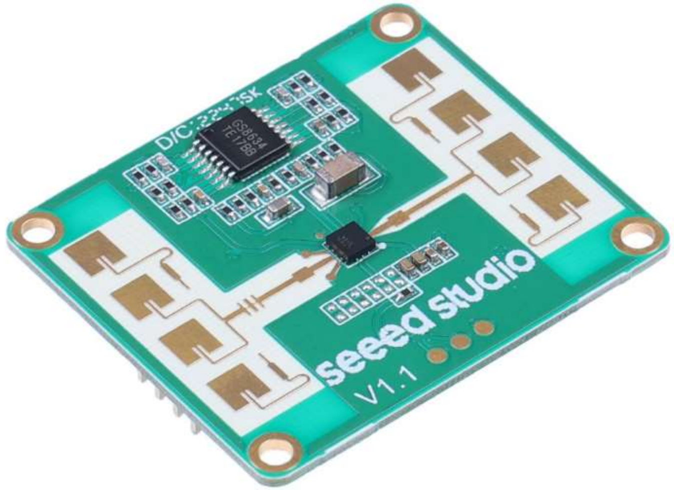
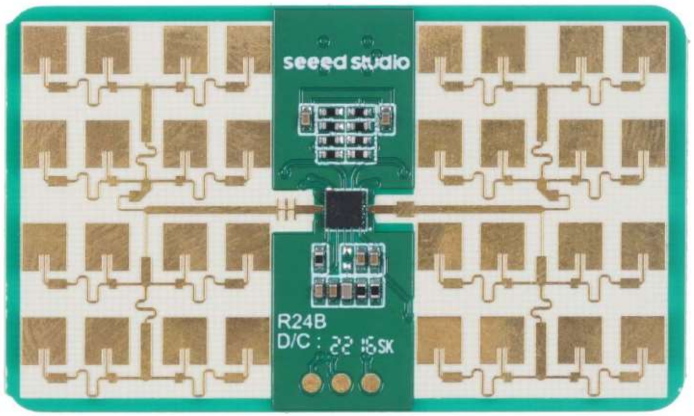
24 GHz radars to detect human presence





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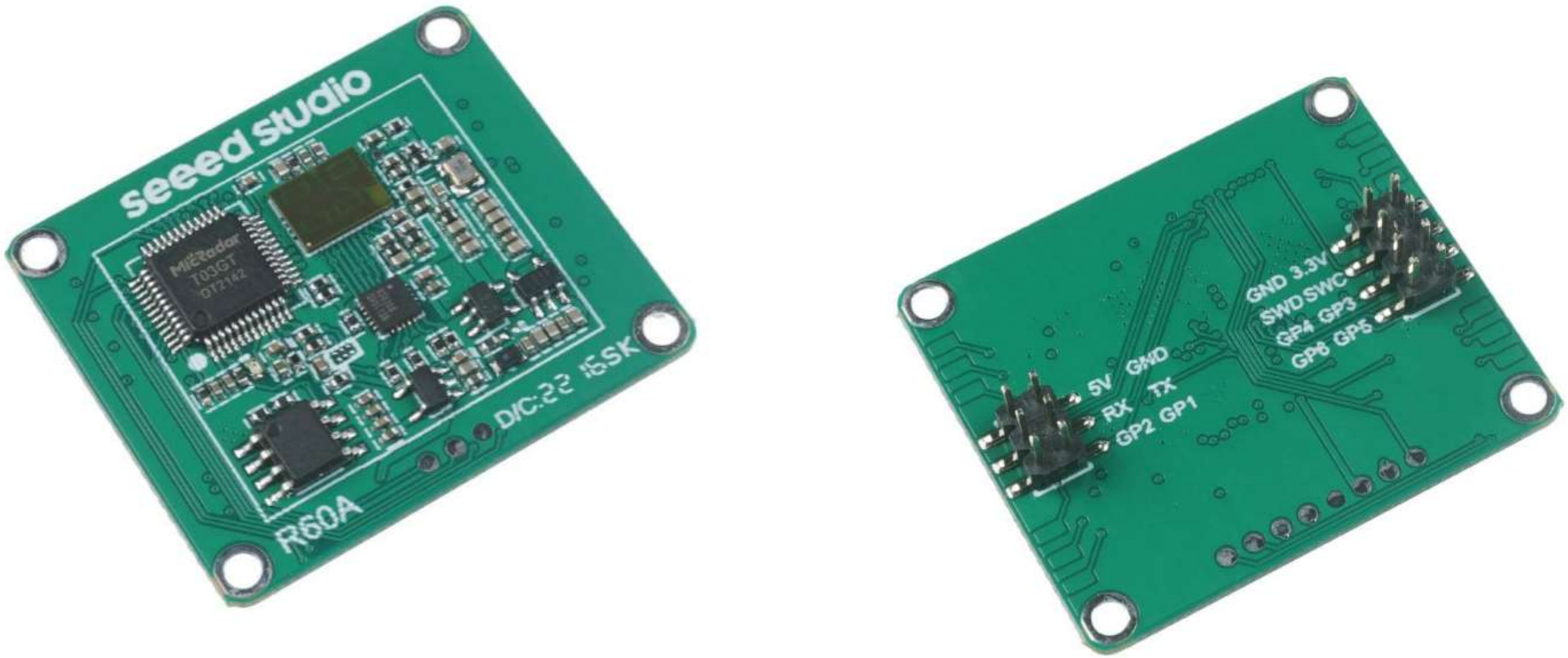
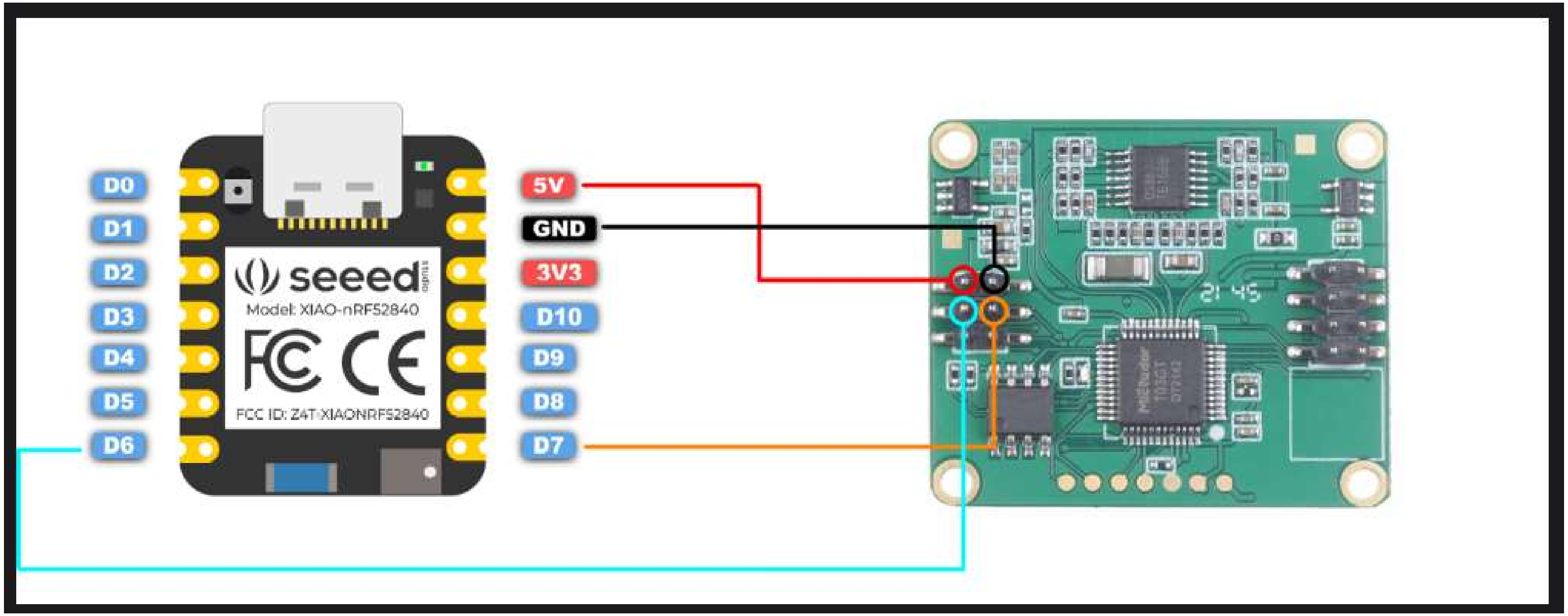
60 GHz radars to measure breath and heart rate



Radar Comparison

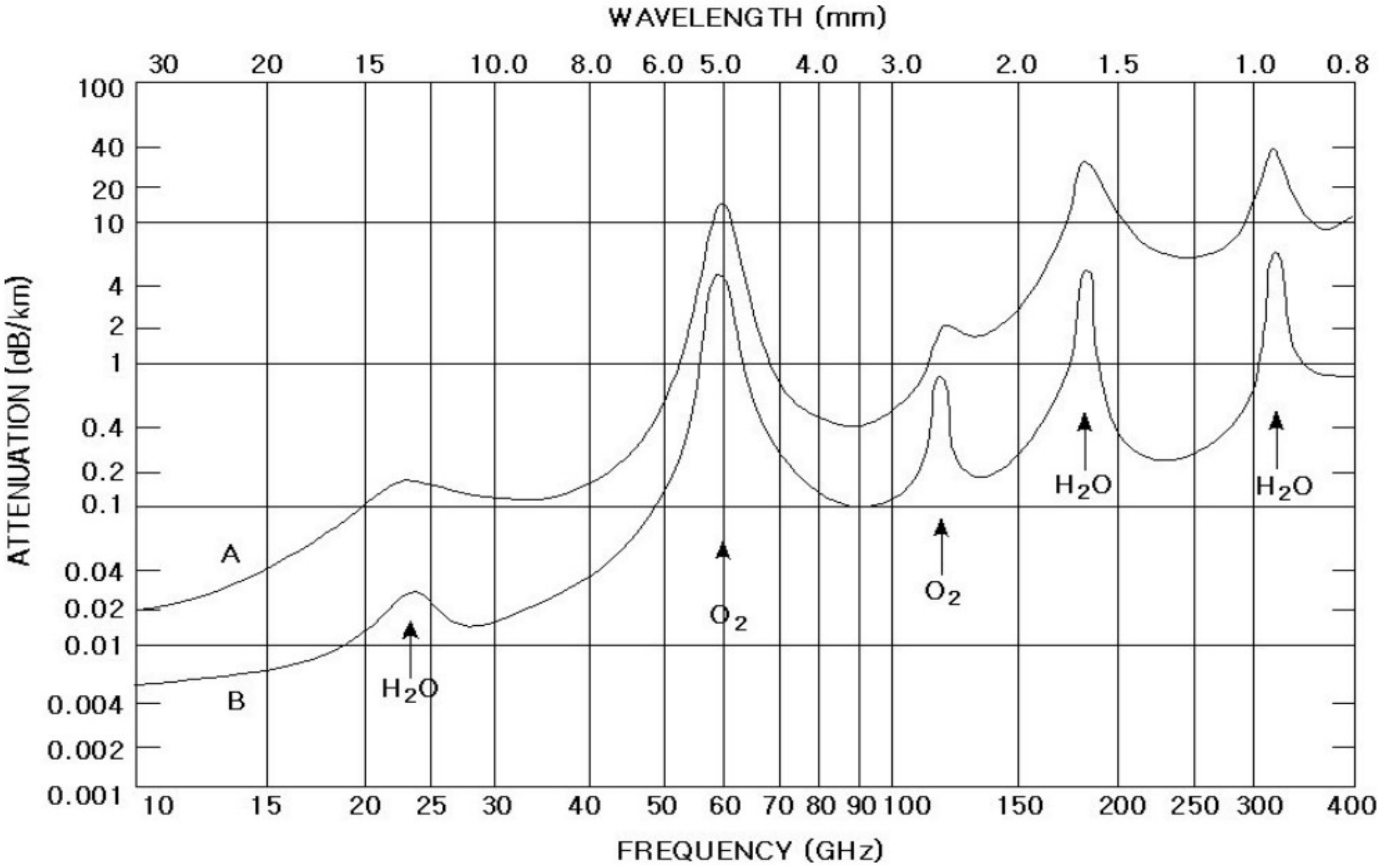
MR24HPC1	MR60BHA1	MR24BSD1
human presence and absence <=3m	Human presence (2.5m) measured 2.42m	human presence
motion perception <= 5m	motion perception	the motion
static perception <=4m	respiratory and heart rate(maximum 1.5m)	respiratory <=1.5m
	Sleep status combined with long-term sleep posture and body movement collection (2.5m)	Sleep quality monitoring by detecting body moving and stationary along with human breathing rate <=2.75m, Relection time <=60s
Antenna beam width: 90° horizontal / 60° vertical sector beam	Radar beam: 80° horizontally and 80° tilted.	Antenna beamwidth: Horizontal 40°/vertical 40° sector beam

The Seeed Studio 24 GHz Radar

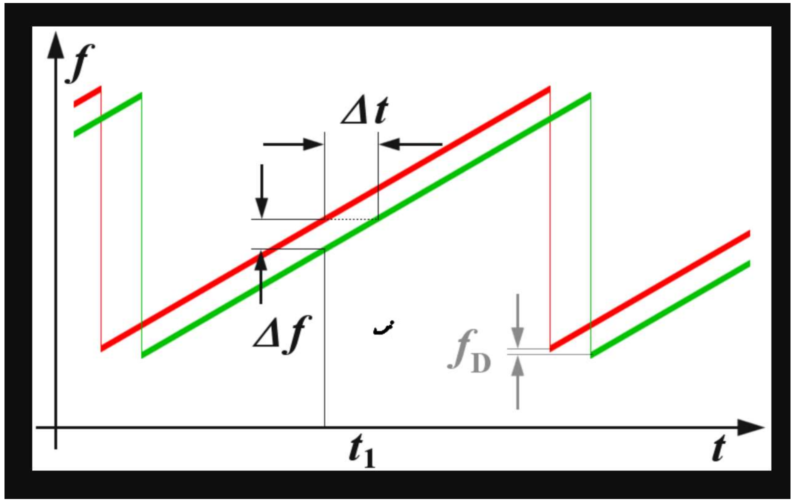


mm-WAVES

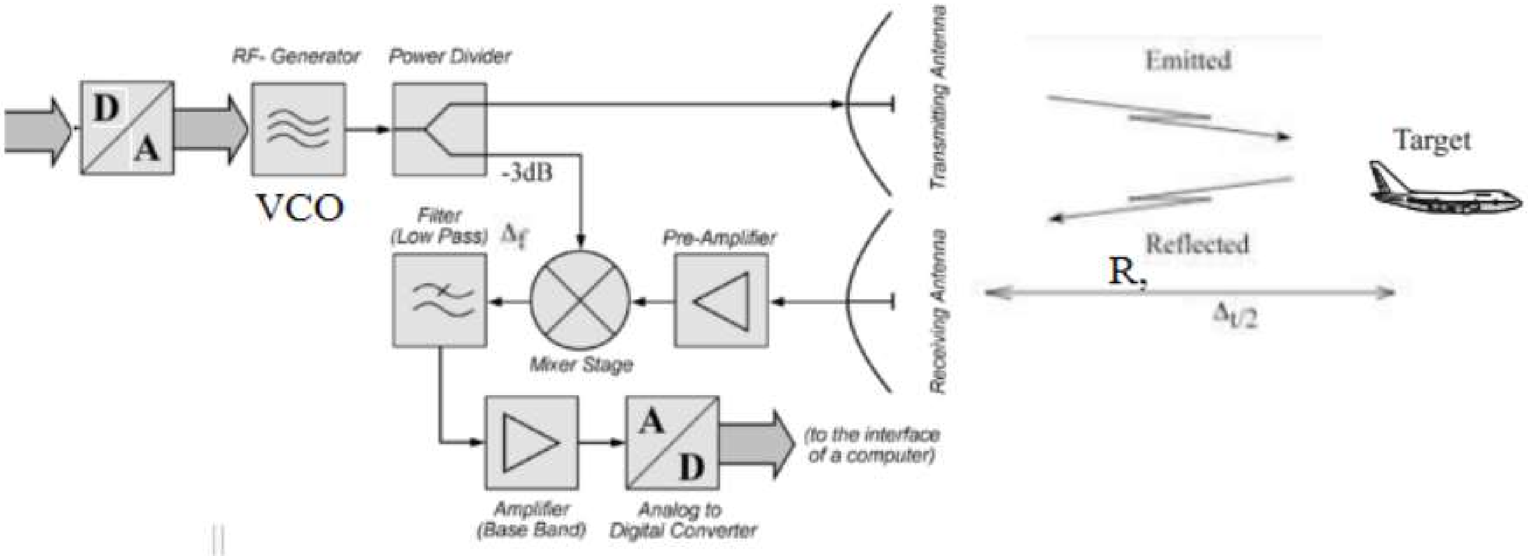
ISM Band Frequency Limits	
6.765 MHz	6.795 MHz
13.553 MHz	13.567 MHz
26.957 MHz	27.283 MHz
40.66 MHz	40.7 MHz
433.05 MHz	434.79 MHz
902 MHz	928 MHz
2.4 GHz	2.5 GHz
5.725 GHz	5.875 GHz
24 GHz	24.25 GHz
61 GHz	61.5 GHz
122 GHz	123 GHz
244 GHz	246 GHz



FMCW RADAR

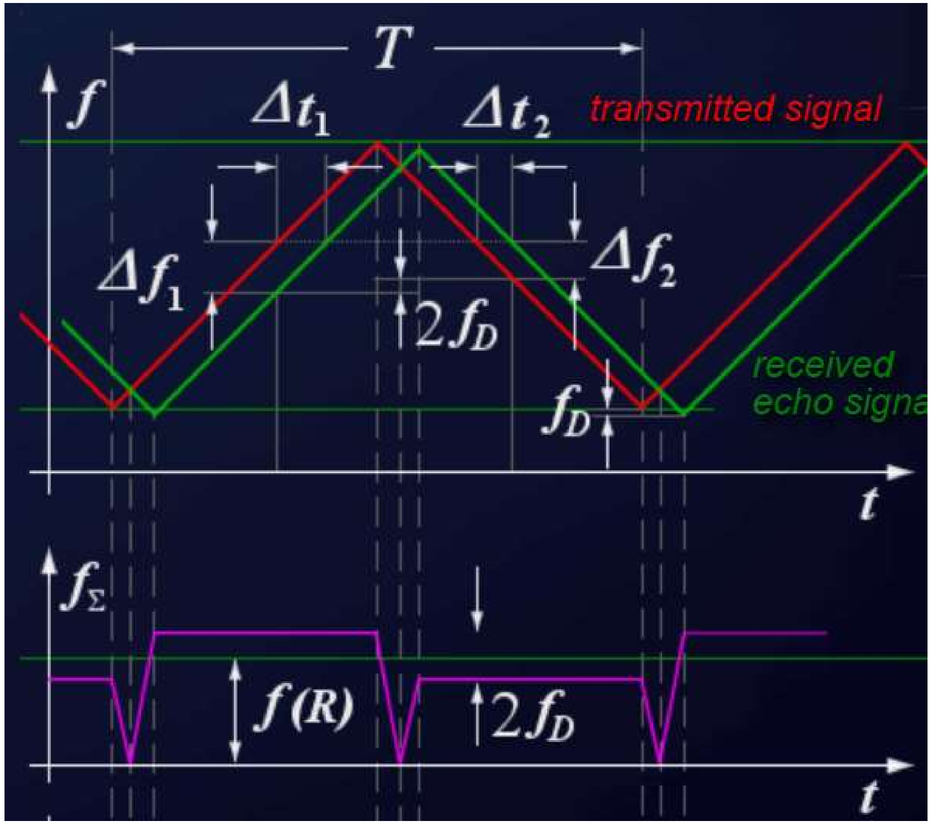


f
Δt
Δf
f_D
t_1
t



RF- Generator
Power Divider
D
A
VCO
-3dB
Transmitting Antenna
Emitted
Target
Filter
(Low Pass)
Pre-Amplifier
Mixer Stage
Receiving Antenna
Reflected
R,
A
D
(to the interface
of a computer)
Amplifier
(Base Band)
Analog to
Digital Converter

FMCW RADAR

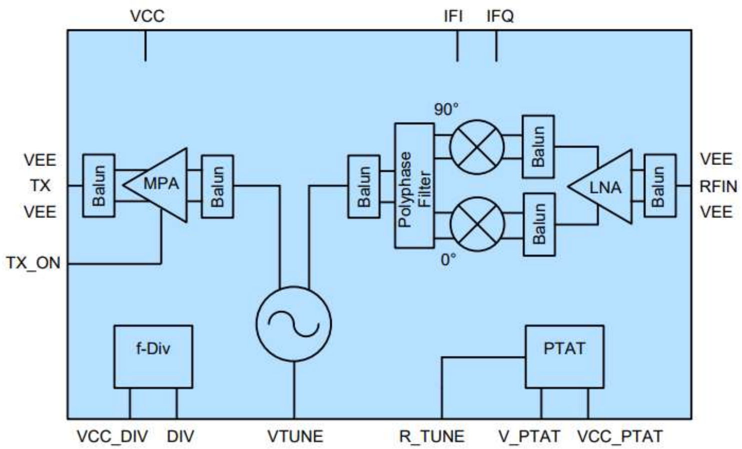


$$f(R) = \frac{\Delta(f_1) + \Delta(f_2)}{2}$$

$$f(D) = \frac{|\Delta(f_1) - \Delta(f_2)|}{2}$$

https://www.radartutorial.eu/02.basics/Frequency%20Modulated%20Continuous%20Wave%20Radar.en.html

The Radio (Infineon BGT24LTR11)



Parameter	Symbol	Value			Unit
		Min.	Typ.	Max.	
RX frequency range	f_{RX}	24.0		24.25	GHz
RX input impedance	Z_{RXIN}		50		Ω
Voltage conversion gain	G_C	15.5	20	26.5	dB
SSB noise figure	NF_{SSB}		10	18	dB
Input compression point	IP_{1dB}	-28			dBm
Quadrat. phase imbalance	ε_P	0		24	deg
Quadrat. amplitude imbalance	ε_A	-1		1	dB
IF output impedance	Z_{IF}			1	kΩ

Parameter	Symbol	Value			Unit
		Min.	Typ.	Max.	
VCO frequency range	f_{VCO}	24.050		24.250	GHz
VCO phase noise	P_N			-55 -80	dBc/ Hz
VCO AM noise	P_{AM}			-135	dBc/ Hz
Tuning voltage to cover VCO frequency range	$VTUNE$	0.7		2.5	V
VCO tuning sensitivity within VCO frequency range			720	2000	MHz/V
Second Harmonic Suppression		25			dBc
Non-harmonic suppression		62			dBc
Non-harmonic suppression		45			dBc
TX output power	P_{TX}	2	6	10	dBm
TX load impedance	Z_{TXOUT}		50		Ω

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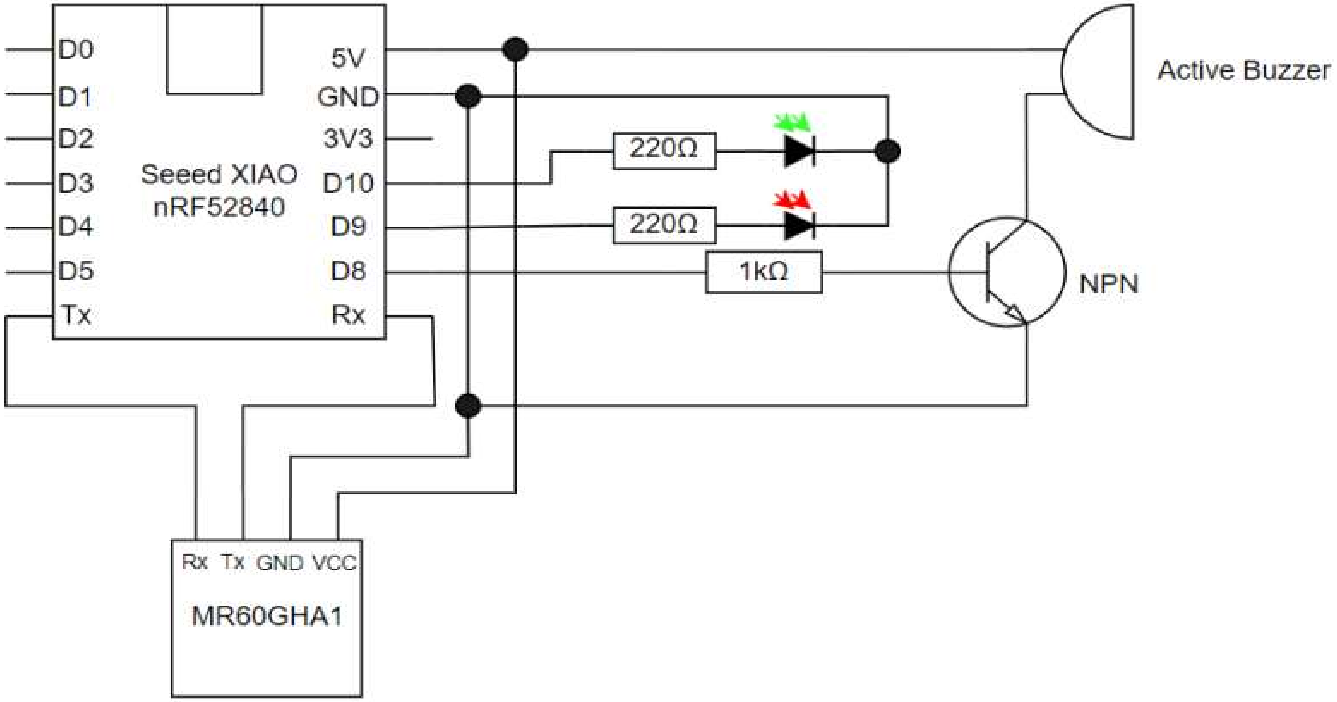
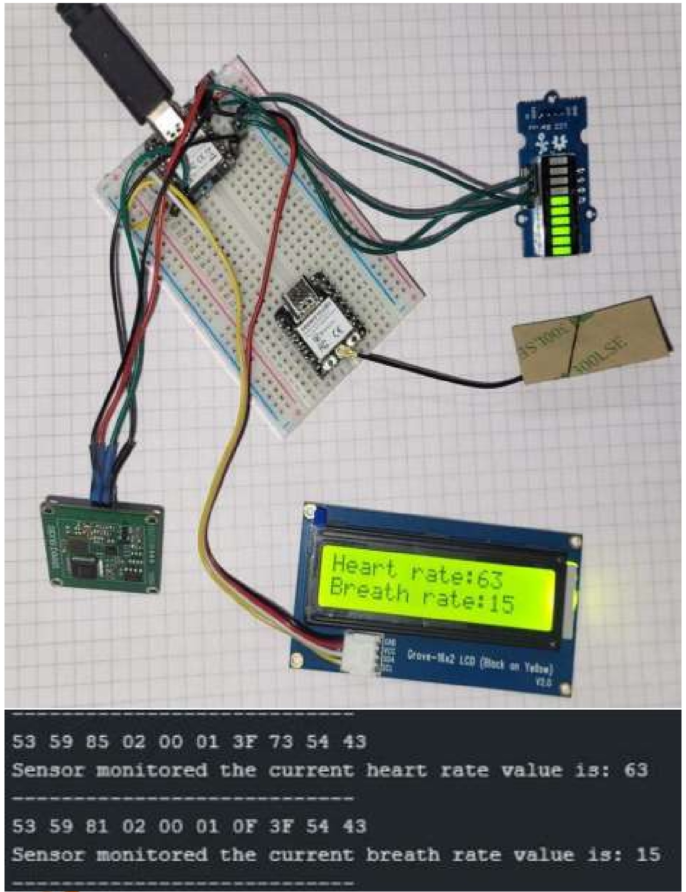
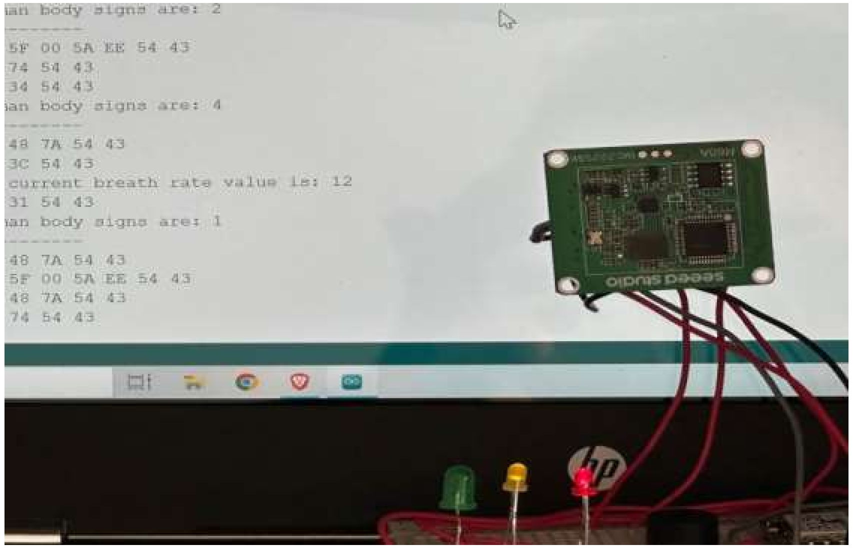
The Student Applications



Some Applications tested by the Students





Some examples of course exercises

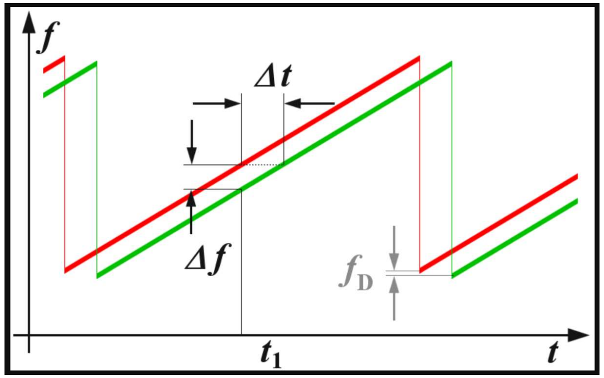
- Design a rectangular microstrip antenna for a frequency of 5.8 GHz. The substrate is 1.55 mm thick FR4. Match the antenna to 50 Ω using a quarter wavelength transformer. As a result give a picture of the whole thing with its physical dimensions.

- Estimate the radiation pattern of the 24 GHz mmWave Sleep Breathing Monitoring Module (the one having the 16-element antenna arrays as both antennas). The distance between the antenna elements is 5 mm horizontally and 6 mm vertically. Give the radiation patterns in both planes (E-plane and H-plane) as well as the 3dB beamwidth in both planes and estimate the directivity of the antenna. Estimate as well the antenna gain if the internal antenna losses are 2.8 dB.

Some examples of course exercises

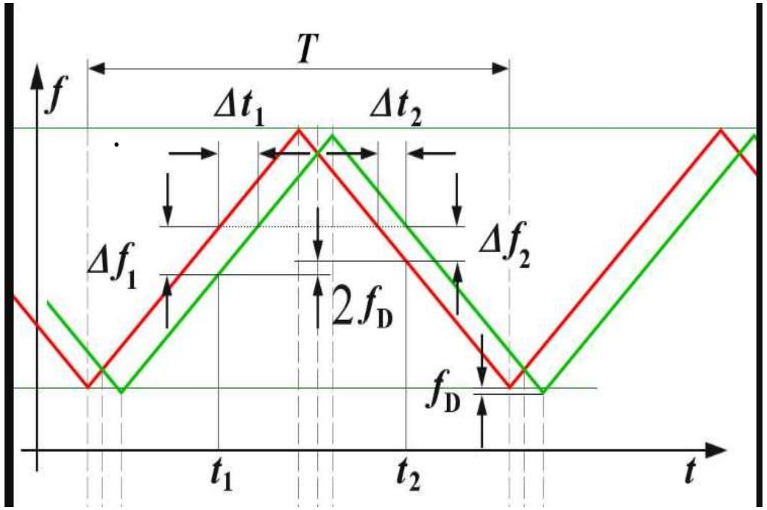
- The frequency of a FMCW radar is 24 GHz and the modulation waveform is sawtooth as shown in the picture below. You measure the distance of the target as 2m. The bandwidth of the sweep is 200 MHz.

  a) How much in that case is Δt?
  b) And Δf (assuming that the chirp time is 1ms and the target is not moving)?
  c) What’s the error in the distance measurement due to the doppler effect if the target is moving away from the radar with a velocity of 2 m/s?



Some examples of course exercises

- The waveform of the radar of the problem above is now triangular (as in the picture below). The chirp time and the BW remain the same. You measure Δf1 as 4.500 MHz and Δf2 as 4.520 MHz. Calculate the distance of the target and its axial speed (and tell whether the target is moving towards you or away from you).



Some examples of course exercises

Analyze a 2.3 GHz radio link from a base station to a 5G mobile phone in the distance of 500 m from the base station. Calculate the received power if the base station antenna gain is 20 dB and the receiving antenna has a gain of 3 dB. The transmitted power is 24 dBm. Calculate as well the power density where the mobile phone is located.

Continue the analysis of the same radio link if the frequency of 60 GHz is used. The 5G mobile phone is still in the same distance and its antenna gain is still 3 dB. You need to receive the same power level as before, and therefore you have to increase either the antenna gain or the transmitted power, or both. How much the EIRP (transmitted power multiplied by the transmitter gain) has to be increased. The received power stays the same, but what happens to the power density by the receiver? Any comments?

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Conclusions and future actions

- 4 weeks two short
- The radar specs mostly as promised
- The level of radar documentation too poor

- Two successful implementations (2023 and 2024) => probably something else in 2025

- The recurring question from students: **Aren't these frequencies harmful?**

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THANK YOU!

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