FACULTY OF BIOMEDICAL ENGINEERING CTU IN PRAGUE

Instructions for laboratory exercises
Localization of person and remote vital sign detection (acquisition of breathing and pulse signal) based on UWB radar

Course name: Medical microwave sensing
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1. Exercise / experiment annotation:

The detection of a person position and its remote vital sign detection is one of the important applications where microwaves can help. The UWB radar is ideal system which can remotely register person position and vital signs which exploits the permanent variation of the body geometry. This application can be used for the searching people under critical conditions as well as health care monitoring (earthquake, snow avalanche, ambient assisted living, assistance for special forces and firefighters). The basic principle is based on the detection of changes in the reflected signals in time caused by the person movements. The antenna is emitting the electromagnetic wave which is propagating to the person's body from which the electromagnetic wave is partially reflected.

2. Objectives of exercise / experiment:

The main goal of this exercise is to familiarize students with the basic principle of the UWB radar, microwave measurements and signal processing with the emphasis on the detection of the vital signs and person localization.

3. Description of used devices:

1. Workstation
2. Sim4life light
3. MATLAB
4. Radar device or VNA analyzer
5. UWB antennas, coaxial cables

4. Introduction:

Microwave radar technology is one of the very fast developing part of microwaves. The first radar systems were used and developed in 1930s. The major practical implementation of the radar was for the military purposes (air-defense in WW II, non-metallic mine detection). Nowadays, microwave radars started to play one of the main roles in real-time monitoring i.e. in the automotive safety systems (obstacles detection, autonomous driving), in the precise person localization (i.e. under avalanches), ambient assisted living or vital sign detection (infants monitoring). In last decade the radar technology founds its way into medicine.

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5. Principle of detection of person position:

The basic principle is based on the detection of changes in the reflected signals in time caused by the person movements. As you can see in the figure 1, the antenna (2) is emitting the electromagnetic wave which is propagating to the person's body from which the electromagnetic wave is partially reflected.
The basic radar system is composed of transmitter, coaxial cables, antennas and receiver. The transmitter is generating the required electromagnetic signal of the required power. The signal is delivered through coaxial cables to the transmitting antenna. The transmitting antenna is emitting the ultrawideband signal to the free space. The directionality of the radiating pattern depends on the type of antenna. The electromagnetic (EM) wave is propagating through free space. When the EM wave impact on the obstacle (i.e. human person) two basic phenomena occur:

1) Part of EM wave is partially reflected from the interface air/skin back to the antennas.
2) The rest of the EM wave penetrates to the human body, where is continuing to spread.

The backscattered signal impacts on the receiving antennas and is recorded by the radar receiver. When the backscattered signal is recorded, the main task is to determine where the EM wave was reflected. In the recorded radar signal thousands of different reflections from the surrounding areas are included. This echo signals are out of our interest and it is necessary to subtract them from the signal. These unwanted echoes are called background or clutter. The signal background could be subtracted from the signal. When the background is subtracted from the signal, only the component of our interest will remain in the signal. In the figure 2 there you can see the example of the background subtraction from the signal. In the upper figure there is the received signal with two visible peaks. When we subtract the background signal (see figure below), only the reflection from the person, which we would like localized is visible.

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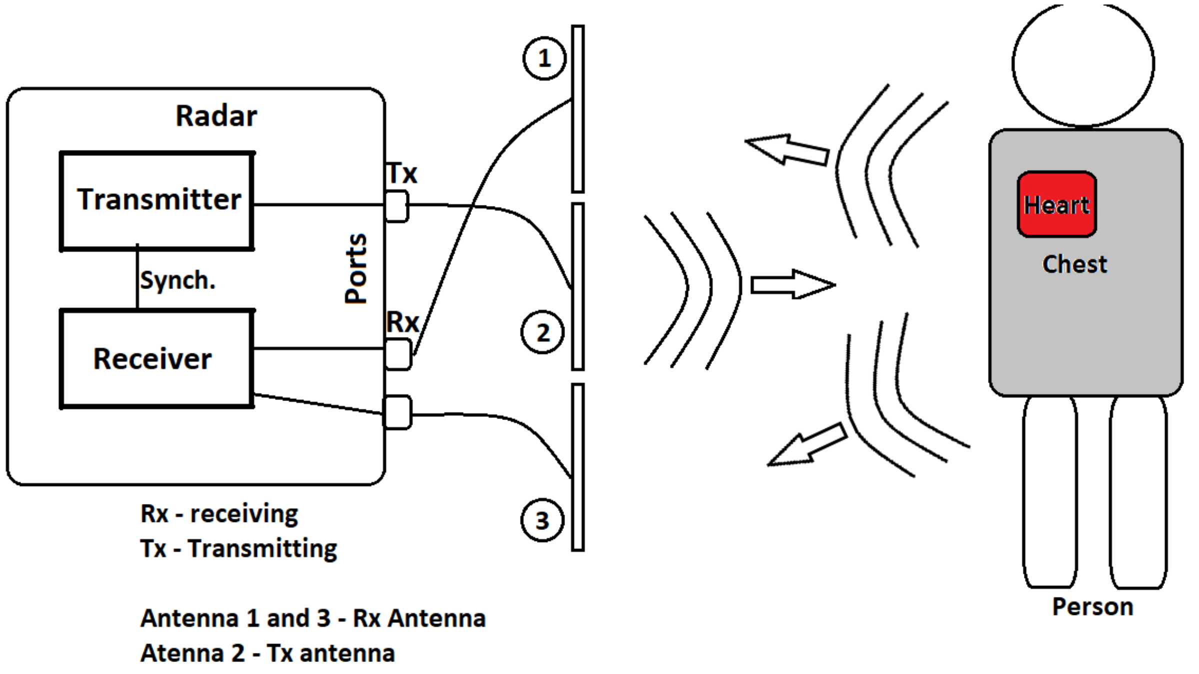

Figure 1. Measurement setup for the person localization and remote vital sign monitoring.

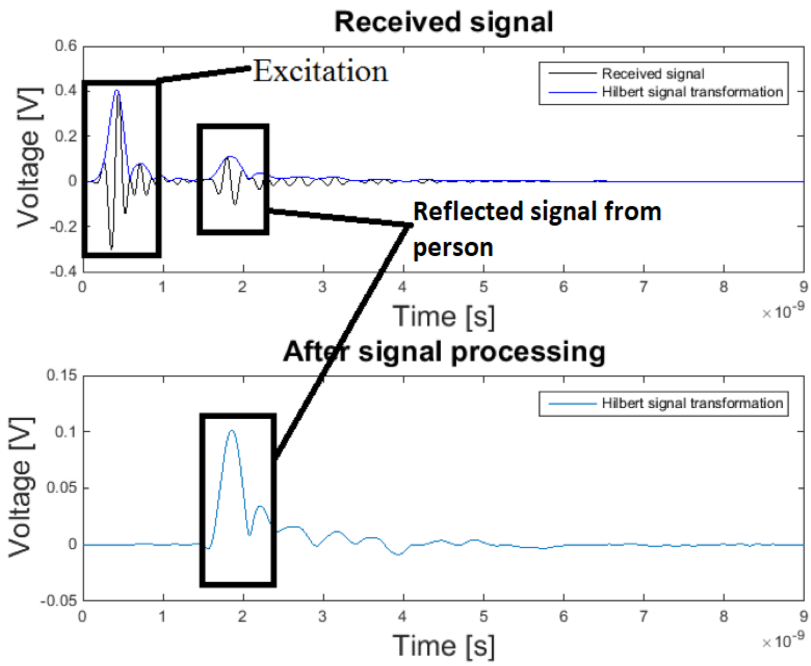

Figure 2. Analysis of the received signal and background subtraction.

Exercise:
The exercise is intended to practice basic knowledge about radars and linking them to other areas of interest.

Task 1: Estimate the frequency of breathing and heart rate via numerical simulator Sim4life light.

Remote vital sign monitoring of infant via UWB radar in Sim4life light:

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1. Use computer, where the numerical simulator of EM field Sim4life light is installed. Open the Sim4life light numerical model with the name: Radar_model.smash. The used frequency of the radar signal is in the range 1-6 GHz.

2. The numerical model consists of three ultra-wideband (UWB) antennas (see model of antenna – figure 3) and the simplified human body model composed of skin, chest, heart and head. The simulation has to be divided in several steps to simulate the movements. The simulation setup is presented in the figure 4. The distance between antennas and person is 60 cm.

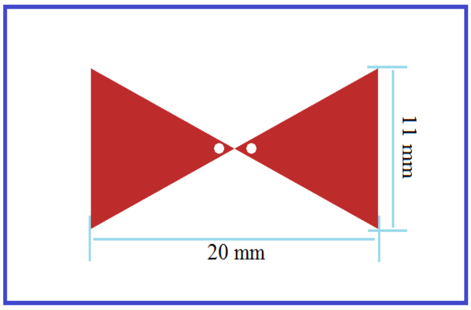
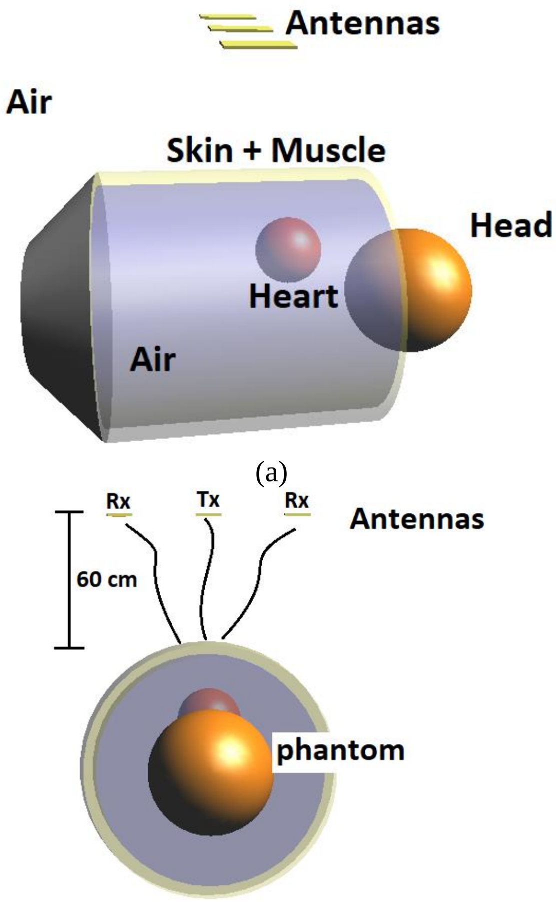


Figure 3. Antenna for biomedical imaging via UWB radar method.



(b)

Figure 4. Simulation setup (a) and (b).

3. Setting up the model: In the tab "*Model*" there are all parts of the model. For this exercise please do not change them.

4. Click on the tab” Simulation” (see figure 5). There are three preset simulation states: inhale, half inhale and exhale. The respiratory frequency is 1 Hz. Each of this simulation also consists variable heart rate of 2 Hz. Click on materials and set (or check) the correct dielectric material parameters. The dielectric parametres (relative permittivity and conductivity) could be downloaded from IT’IS database available here: https://itis.swiss/virtual-population/tissue-properties/database/tissue-frequency-chart/. The dielectric parameters are frequency dependent. For our purposes, use the values for the mean frequency of the UWB pulse (3.5 GHz). The UWB pulse, which will be emitted from the Tx antenna has frequency band 1-6 GHz. Please see the pulse in the figure XX. Each simulation consists one position of chest and heart.

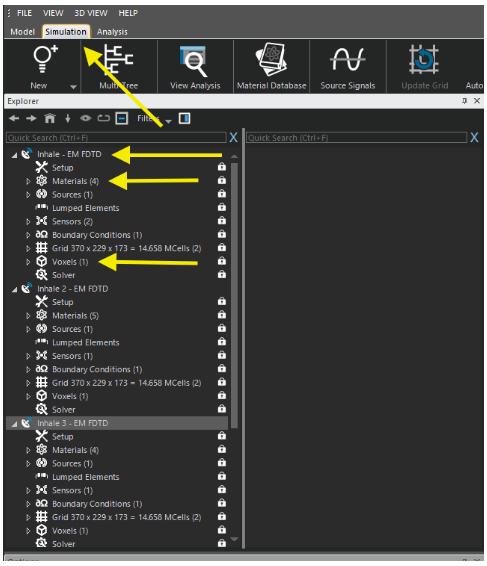


Figure 5. Simulation settings.

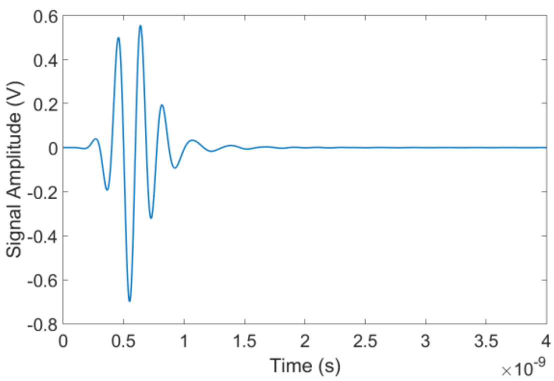


Figure 6. Excitation pulse in the frequency band 1-6 GHz.

5. Do this for all predefined simulations. Then click on “*Run*” (green arrow) simulation and select “*Batch run*”. All simulations will be voxel - Use please the predefined voxels.

6. Once all simulations are complete, click on tab “*Analysis*” and follow the workflow in the following figures 1 - 4. After the Voltage/time dependence is obtained, save this waveform to the *.csv file. Repeat it for all simulations.

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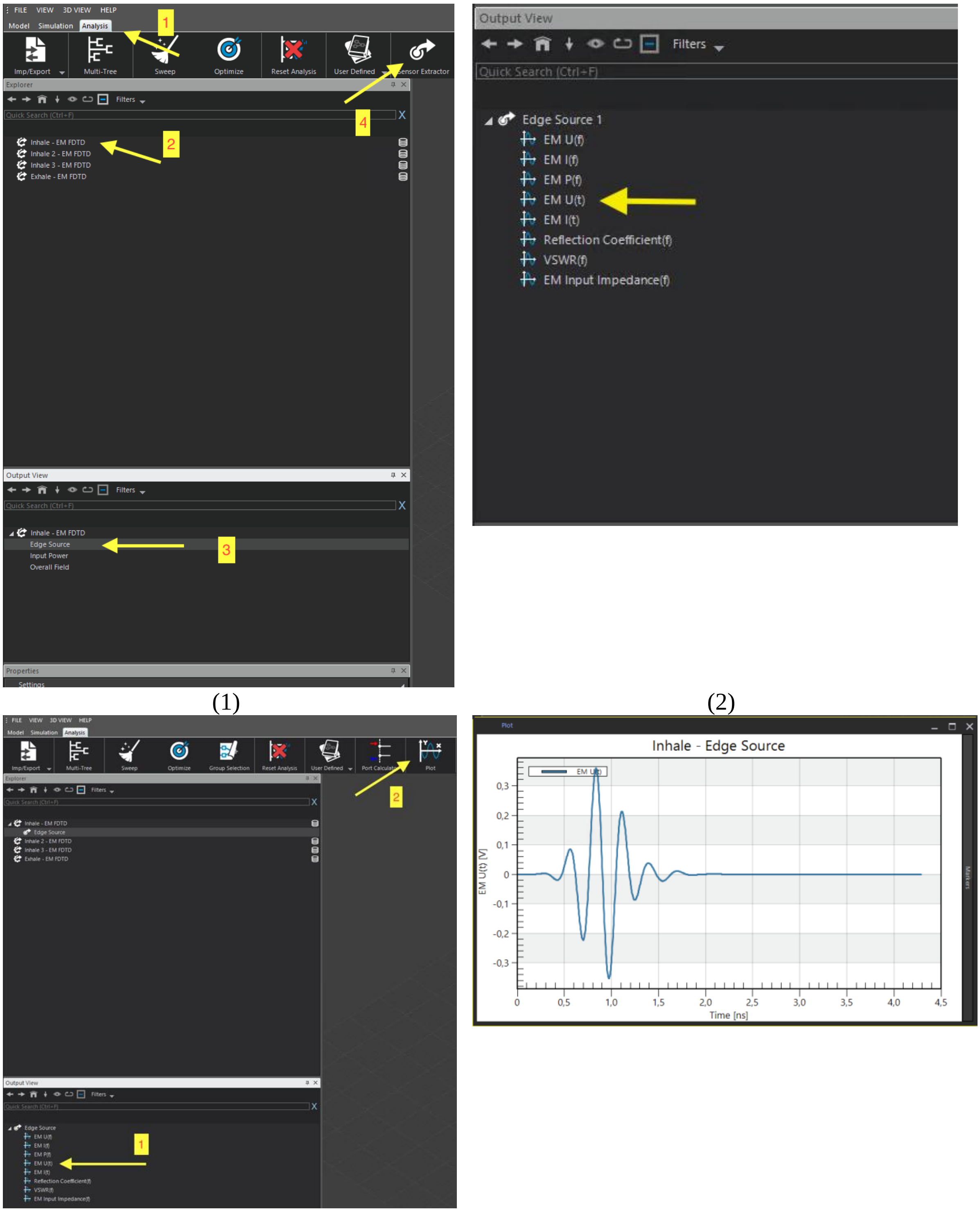

(1) (2)

(3) (4)

Figure 7. Simulation workflow.

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Signal processing in MATLAB – evaluation algorithm:

1. Load all simulated signals you exported from Sim4life light to the MATLAB. The first column is time and second column are the values of the recorded voltage by the radar device. Exhale signal will be considered as a background signal $y_0(t)$.

2. Plot all raw signals together in one graph to see the differences between signals.

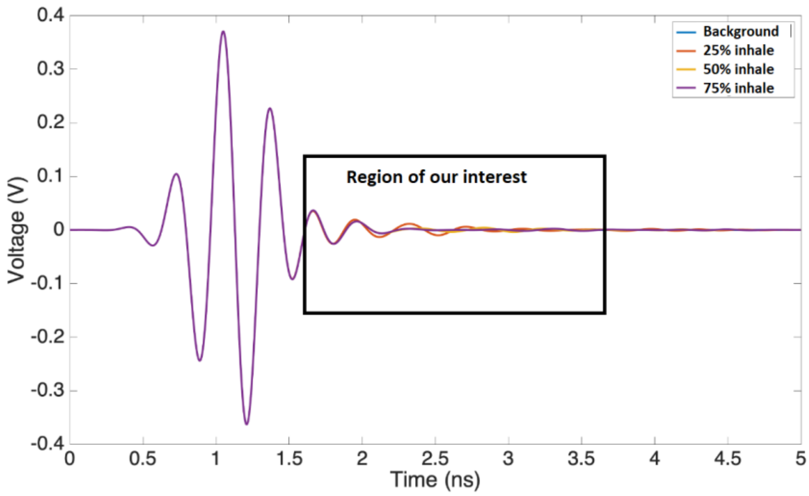

Figure 8. Raw simulated signals.

3. Subtract the background (voltage) signal from other signal according to the following equation:

$$y_d(t, \tau) = y_S\ (t, \tau) - y_0(t) \qquad (1)$$

where *t* is the propagation time, τ is the observation time, $y_d\ (t, \tau)$ is the differential signal of the infant, $y_s\ (t, \tau)$ is the signal at a certain point in reflection and $y_0\ (t)$ is the signal representing the clutter.

4. Apply the Hilbert transformation on the signal to obtain the signal envelope (hint: use the inbuild MATLAB function "*hilbert*" see more: https://www.mathworks.com/help/signal/ref/hilbert.html). Normalize all signals to the maximum voltage value in each signal. After this signal process, we can see specific reflections from the infant. We can find in the signal obvious reflections from chest (reflection 1) and from heart (reflection 2) - see the figure below.
In the reality, the chest and heart are continuously moving in the physiology ranges.

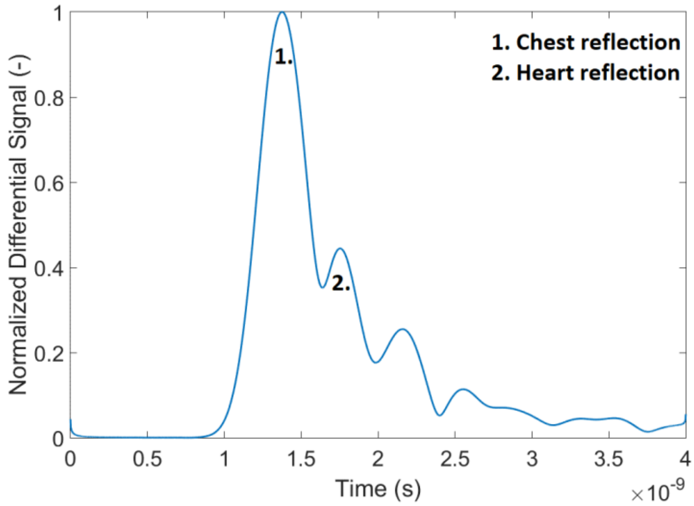

Figure 9. Signal after Hilbert transformation.

5. Plot all signals after background subtraction and after Hilbert transformation. Each simulated and exported signal is corresponding to the different position of the chest and heart (volume changing). In the following figure each curve is representing the one state of the chest position and heart volume. Blue curve is corresponding to the case of expiration and cardiac diastole. All other curves are representing the gradual tint with the frequency 1 Hz and heart movement with the cycle frequency of 2 Hz.

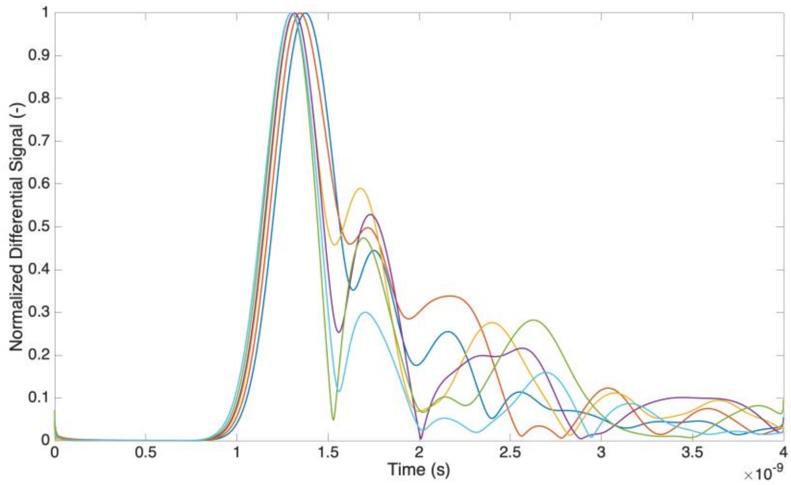

Figure 10. All signals after Hilbert transformation.

6. Recalculate the x-axis => propagation time to distance. Use the following simplified equations:

$$wave\ velocity = \frac{c}{\sqrt{\varepsilon_r}} \qquad (2)$$

$$distance = \frac{wave\ velocity \cdot time}{2} \qquad (3)$$

where ε_r is relative permittivity.

7. Register movements of peak 1 (chest reflection) and peak 2 (heart reflection) – hint: use inbuild function "*findpeaks*" see more: https://www.mathworks.com/help/signal/ref/findpeaks.html.

8. Plot the positions of peak 1 and peak 2 depending on observation time. In Sim4life light 5 simulations were performed. The total observation time was 1 second – this means that the time between simulation is 1/5 seconds = 0.2 second. The required resulting graph:

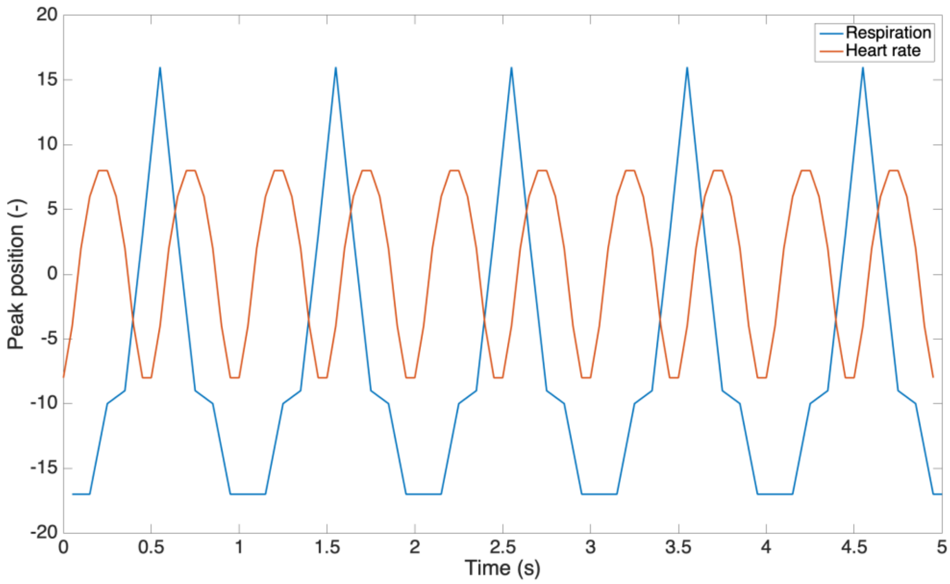

Figure 11. Peak position during time – respiration and heart rate.

Real measurement by UWB radar:

1. Prepare the measurement setup according the following figure:

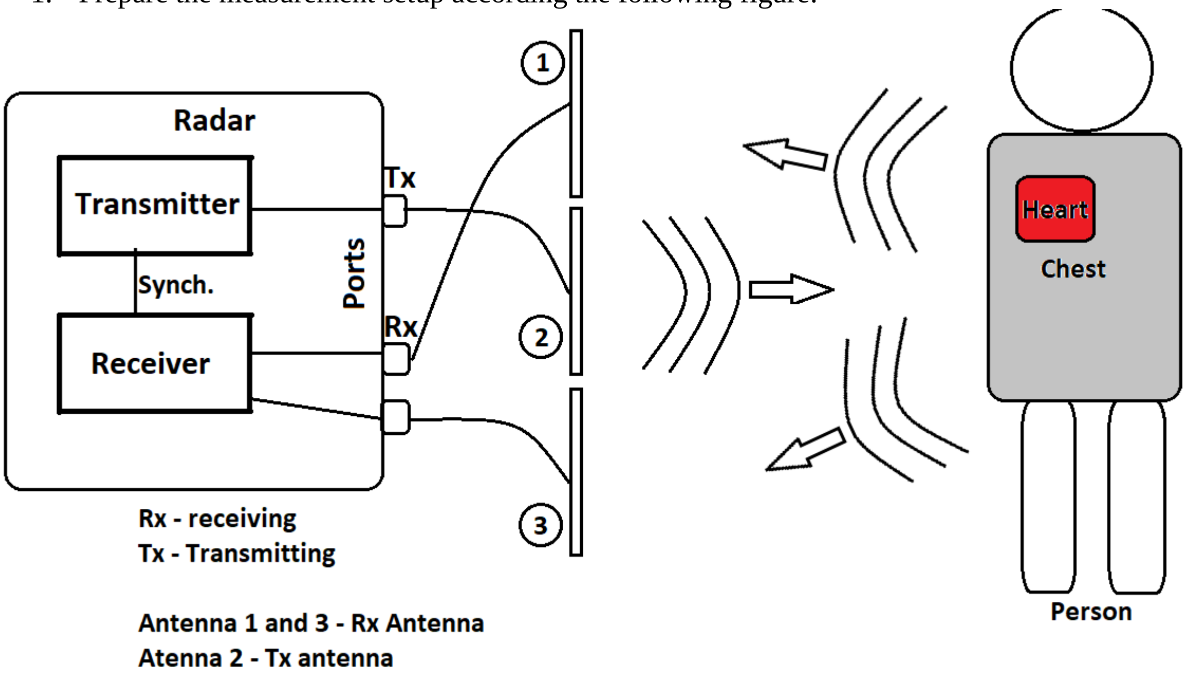

Figure 12. Measurement setup for the person localization and remote vital sign monitoring.

The observed person should be at least 1 meter from the antennas. Connect all antennas to the UWB radar via coaxial cables.

2. Run the reading algorithm. Initially the algorithm performs 30 signal scans to get the mean value of the background. During this time (approx. 10 seconds), it is necessary that the detected person holds his breath.

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3. Perform the second measurement, while the tested person is normally breathing.

4. Download the measured signals and perform the signal processing procedure, which you implemented in MATLAB during the first and second part of the exercise.

5. Evaluate the resulted signals and estimate the position and frequency of breathing and heart beating.

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