



UWB Radar Applications in Life Detection of Hidden Human

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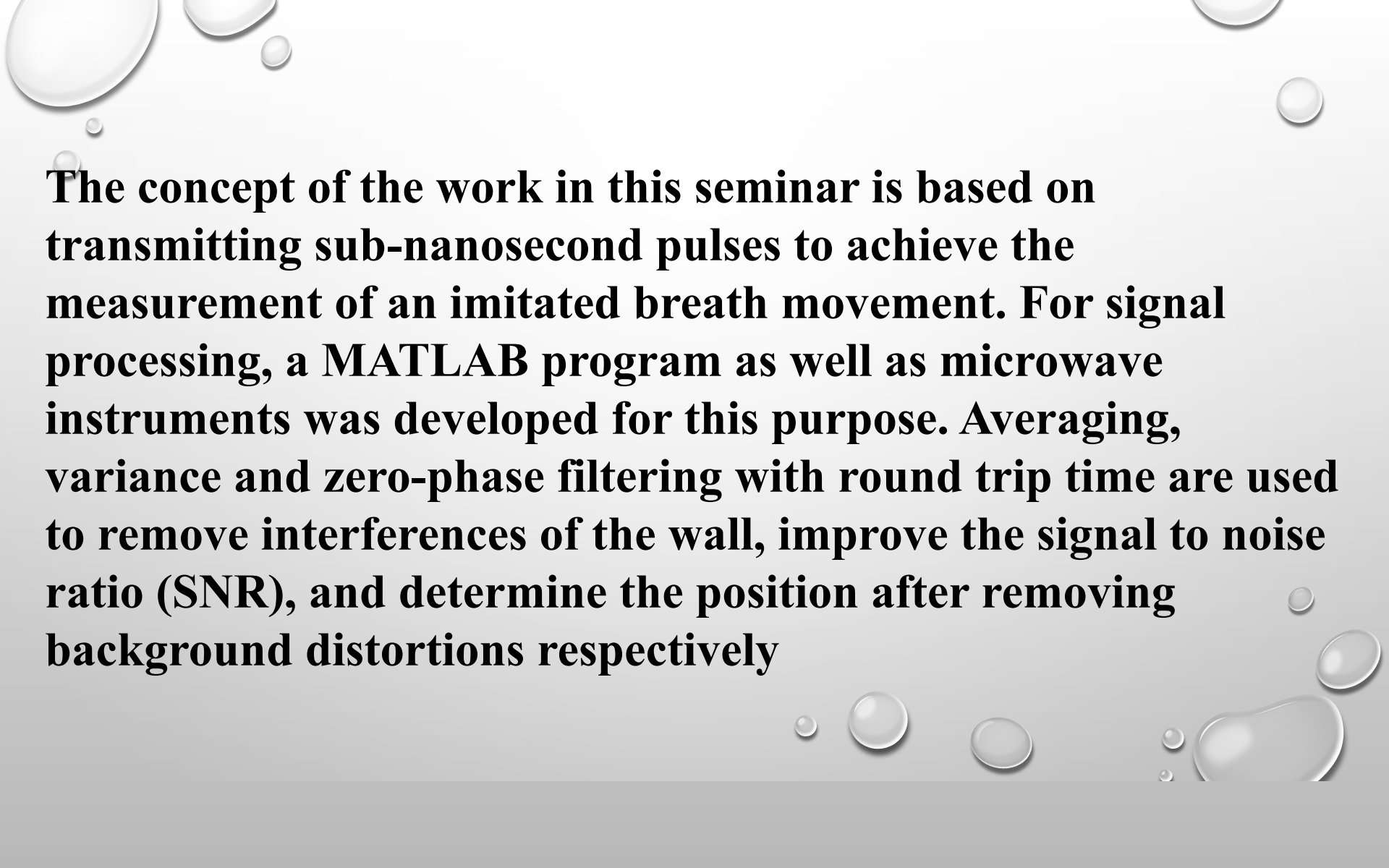
Introduction

A review is given of present state of the art, and likely to be developed or futuristic, biomedical applications of Ultra Wide Band (UWB) radar. UWB radar is something like a mix of conventional radar (Radio Detection And Ranging) technology and spread spectrum radio (SSR) technology, both directly coming from military applications.



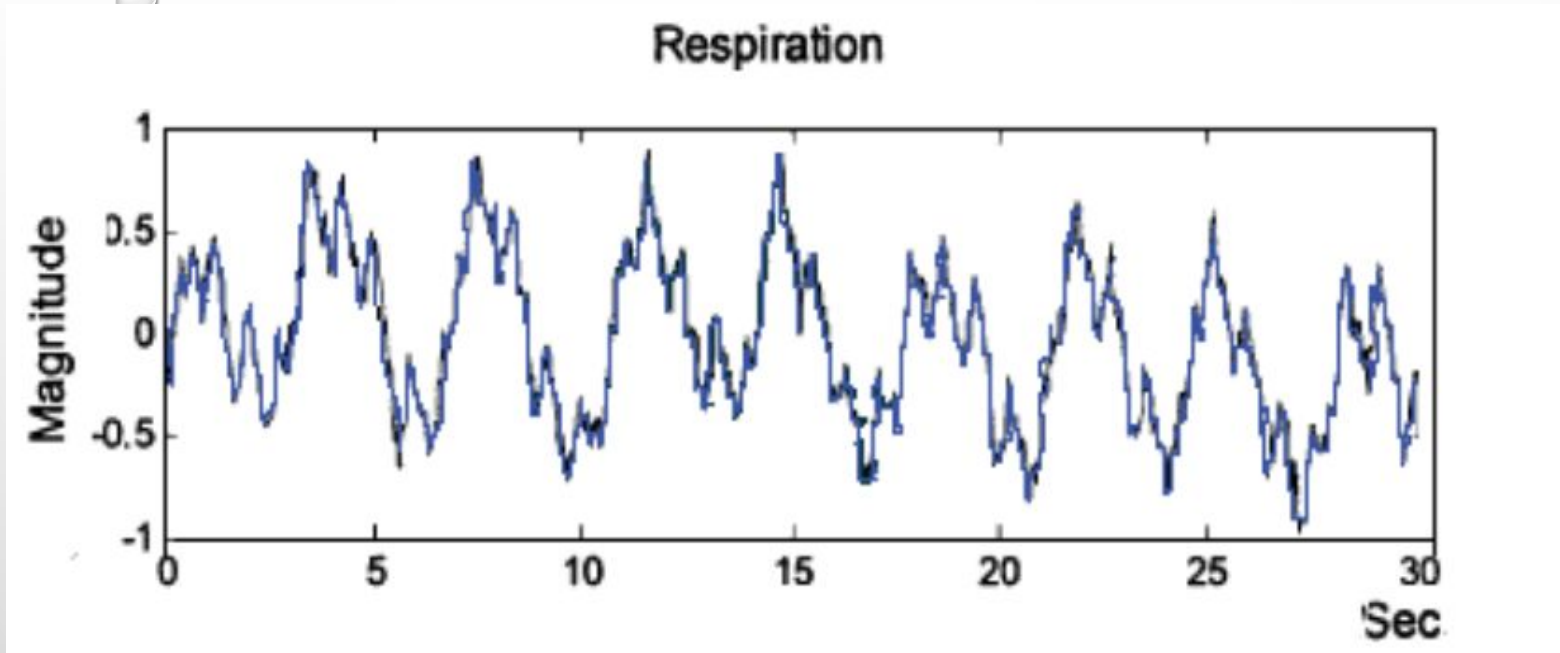
- **What renders UWB radar very much interesting is the possibility to probe the motion of the internal organs of the human body with a remote non-contact approach which is unique at present time. The very low cost, the high miniaturization capability and the environmental friendliness due to the very low electromagnetic energy emission are other aspects of specific interest of the technique.**
- **UWB radar technology, which is quite unknown at present time to the general public, and physicians as well, is about to strongly impact in everyday life and in the medical field as well, making it possible to design a novel kind of noninvasive measurement and monitoring devices.**

- **The overall conceptual working mode of a UWB radar system resembles that of ultrasonic echo transducers used in many applications, from *autofocus* cameras to proximity and range detectors. The main and fundamental difference being that, on the contrary to ultrasounds, electromagnetic pulses propagate through walls, ground, ice, mud, concrete and the human body as well.**
- **Although many researchers around have been working on UWB technology for many years, a great concern on UWB radar arose in 1993 when it is reported that a Lawrence Livermore National Laboratory's (LLNL) engineer, Thomas McEwan, discovered a possibly new and original implementation of an UWB radar.**
- **While working on a new high speed low cost sampler for pulse laser research, McEwan developed a system which was called MIR: Micropower Impulse Radar. The patents on MIR technology describe a wonderful spectrum of applications coming from the low cost MIR technology: from plastic bodied mine detection, to remote vital signs monitoring, to the '3-D radar camera'. Of course the ultimate application being the futuristic 'X-ray specs' (until now just a science fiction device).**

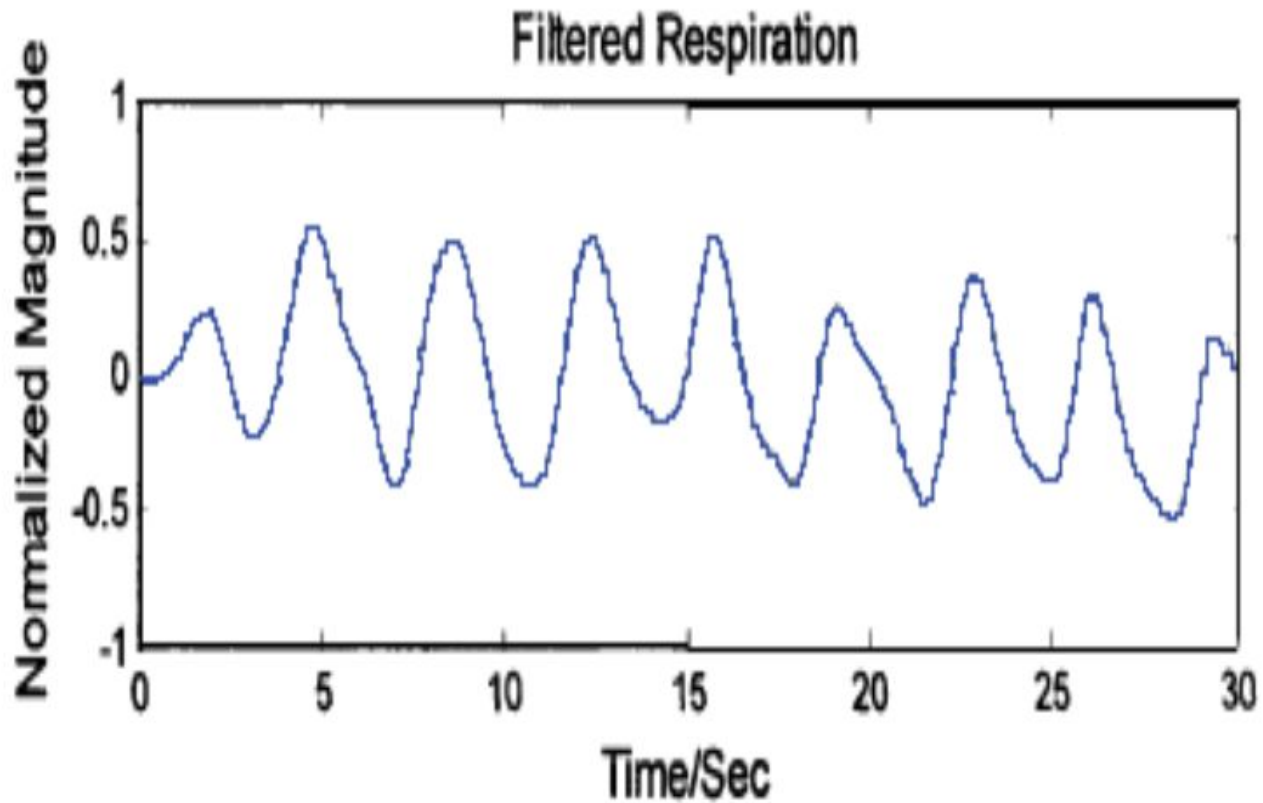


The concept of the work in this seminar is based on transmitting sub-nanosecond pulses to achieve the measurement of an imitated breath movement. For signal processing, a MATLAB program as well as microwave instruments was developed for this purpose. Averaging, variance and zero-phase filtering with round trip time are used to remove interferences of the wall, improve the signal to noise ratio (SNR), and determine the position after removing background distortions respectively

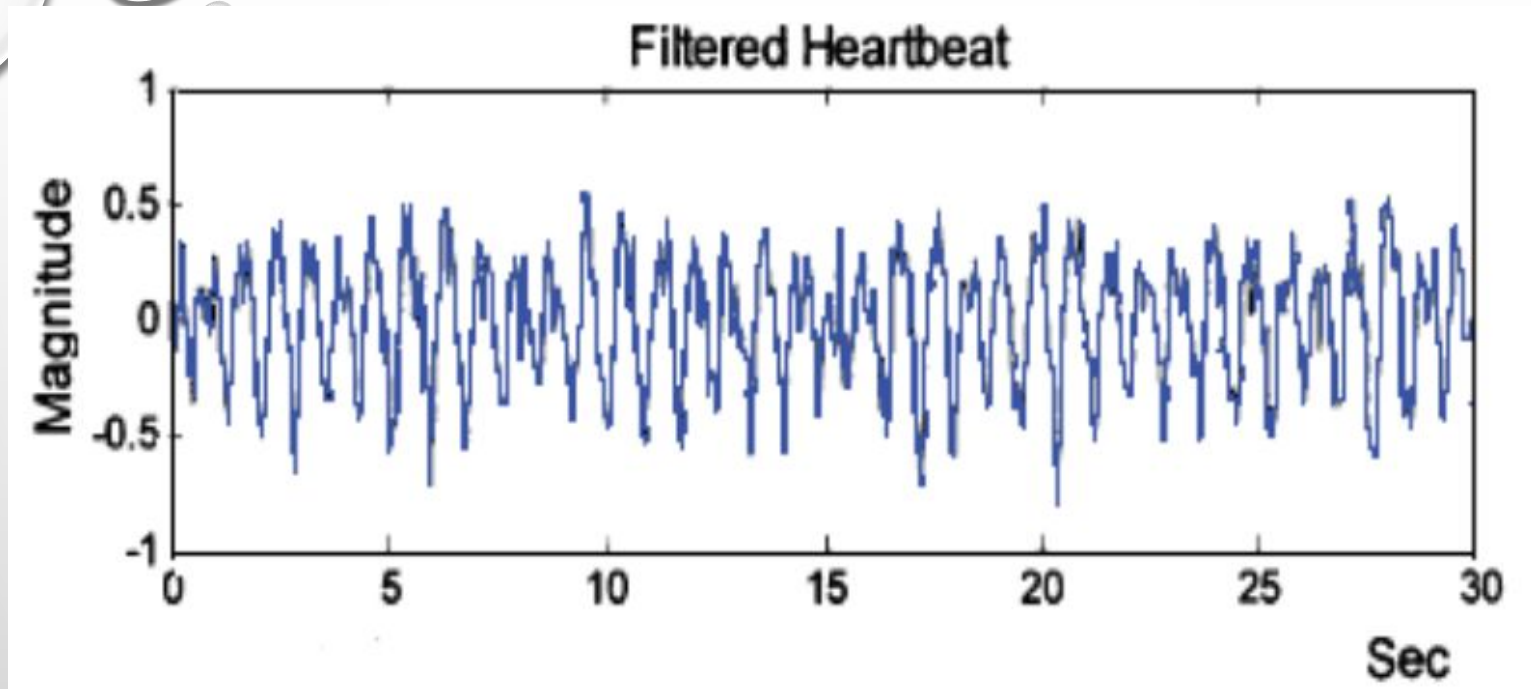
- ❑ **The breath frequency is determined from received reflected signal. The method can help us to detect the existence of human beings effectively and to identify parameters like respiration and body position signals automatically.**
- ❑ **The frequency of human breathing is below 0.5Hz in general, heartbeat about 60-100 times per minute that means the frequency is 1.0Hz to 1.6Hz. So digital filter can be used to isolate the two signals.**
- ❑ **The ultra-wideband (UWB) is a radio technology which can be used at very low energy levels for short-range high-bandwidth communications by using a large portion of the radio spectrum.**



The waveform of the respiration

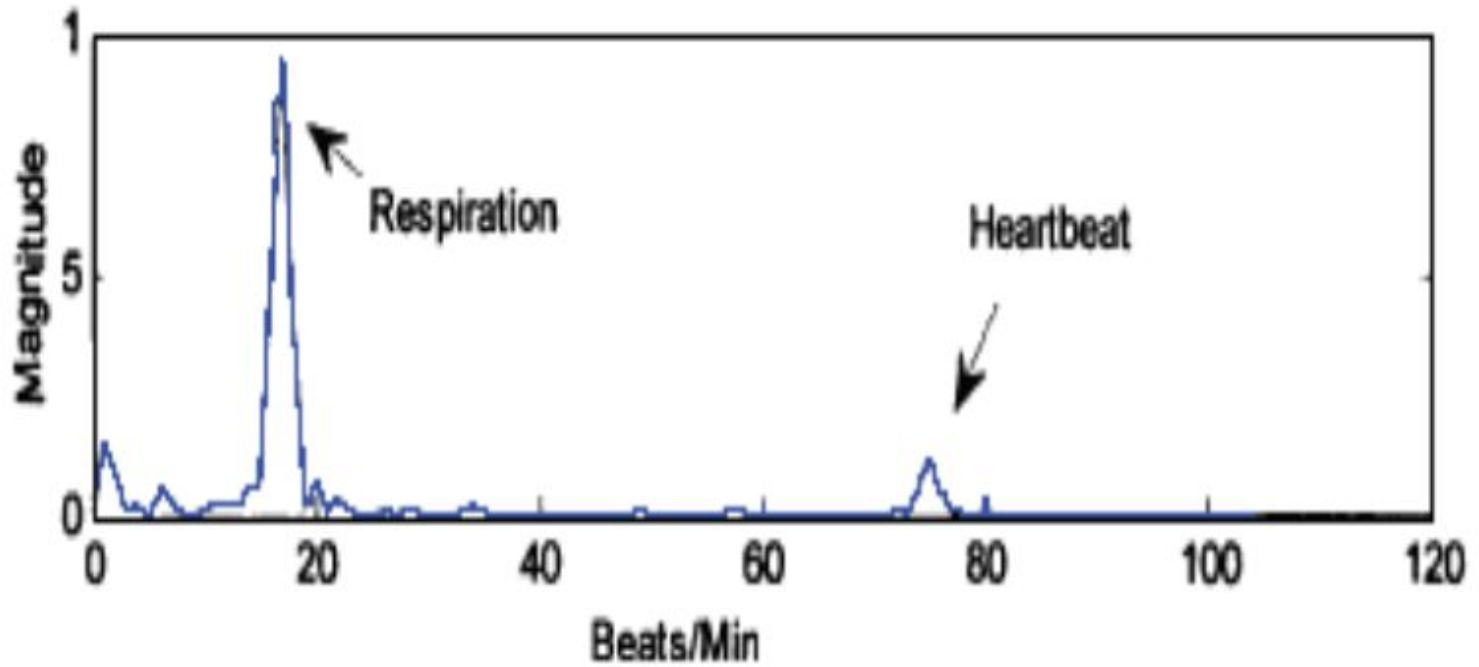


The waveform of the filtered respiration



The waveform of the filtered heartbeat

Respiration and Heartbeat, frequency domain



The waveform of the heartbeat and respiration in frequency domain

- ❑ In various situations, the life-detection system for vital parameter detection is a highly useful and important application. It can be used to search for living objects in collapsed buildings after an earthquake or trapped in buildings on fire, or avalanche victims.**
- ❑ It can also be used to monitor patients in clinics or at home where it can provide remote measurements of the parameters of a patient's vital activity without having contact with them.**
- ❑ In addition, it can be used by law-enforcement services to search for criminals hiding behind various covers. Consequently, there is a growing demand for remote monitoring appliances of human life detector systems**

□ Recently, the attention to radar based life detection systems has increased. The UWB radar is widely used to detect life parameters because of its simple structure and high sensitivity. It can detect life parameters of humans non-invasively, even behind a barrier such as brick walls, debris, and clothes.

□ The radar transmits electromagnetic waves to the human body and receives echo waves modulated by the body surface movements caused by its physiological activities. Life parameters such as distance (or direction), position, and breath frequency can be extracted according to the echo waves.

Four raised practical problems for radar seeing through the wall A

- The first problem is the calculation of the distance or position of a person. A reason for this is not only the effect of the wall with different permittivity and thickness but also the wave transmission angle toward the wall. These effects can cause errors in the distance calculation.**

Another reason is that the origin of moving signals due to chest

movement is not fixed. Therefore the result of the distance calculation is changed over the time.

- ❑ The second problem is that the conventional signal processing is not fast, robust and accurate enough for an application in practical situations, especially in rescue operations.**
- ❑ The third problem is that most of the articles also do not describe whether their systems are automatic or not. In practical situations, an automatic system is necessary.**
- ❑ The fourth problem is that the surface of a human chest is not smooth and the chest movement in front of a human is more intensive than at the back. The breath frequency due to chest movement is easy to get in front of a human.**

2. Wall measurements using UWB pulses

Electromagnetic Theory

**Differential form of
Maxwell's
equations**

$$\nabla \times \vec{E} = -\frac{\partial \vec{B}}{\partial t},$$

$$\nabla \times \vec{H} = \vec{J} + \frac{\partial \vec{D}}{\partial t},$$

$$\nabla \cdot \vec{D} = \rho_v,$$

$$\nabla \cdot \vec{B} = 0.$$

**Integral form of
Maxwell's**

$$\oint_c \vec{E} \cdot d\vec{l} = - \oint_s \frac{\partial \vec{B}}{\partial t} \cdot d\vec{S},$$

$$\oint_c \vec{H} \cdot d\vec{l} = (\vec{J} + \frac{\partial \vec{D}}{\partial t}) \cdot d\vec{S},$$

$$\oint_s \vec{D} \cdot d\vec{S} = \oint_v \rho_v dv,$$

$$\oint_s \vec{B} \cdot d\vec{S} = 0.$$

\vec{D} is the electric flux density in *Coulombs/m²*

\vec{B} is the magnetic flux density in *Wb/m²*

\vec{E} is the electric field intensity in *V/m*

\vec{H} is magnetic field intensity in *A/m*

ρ_v is the electric charge density in *Coulombs/m³*

\vec{J} is the current density in *A/m²*

$$\vec{B} = \mu_0 \vec{H},$$

$$\vec{D} = \epsilon_0 \vec{E},$$

$$\vec{J} = 0.$$

$$\vec{B} = \mu \vec{H},$$

$$\vec{D} = \epsilon \vec{E},$$

$$\vec{J} = \sigma \vec{E}.$$

Where $\epsilon = \epsilon_r \epsilon_0$, $\mu = \mu_r \mu_0$, ϵ_r is the permittivity of material, μ_r is the permeability of material. σ is the specific electric conductivity in a unit of (A/Vm). In general ϵ_r , μ_r and σ are functions of the location and direction in the medium as well as the power level applied to the medium.

Target model

- ❑ A model for the target properties and the expected target movement has to be defined for this UWB radar application.
- ❑ The human lung of an adult human is located behind the chest and has a volume of approximately 4 to 6 liters. The tidal chest volume is normally between 500 ml and 800 ml.
- ❑ The breath rate is about 16 to 18 cycles per minute. The chest movement caused by breathing activity is around 1 to 2 cm.

- ❑ **This movement is relatively small, a high resolution radar like a UWB radar has to be used to achieve breath detection.**
- ❑ **The radiated electromagnetic pulse coming from the transmitting antenna of the UWB radar will be reflected partly at every dielectric boundary.**
- ❑ **The main reflection will happen at the air/chest interface. The propagation impedance in free space η_0 is defined to**

$$\eta_0 = \sqrt{\frac{\mu_0}{\epsilon_0}}$$

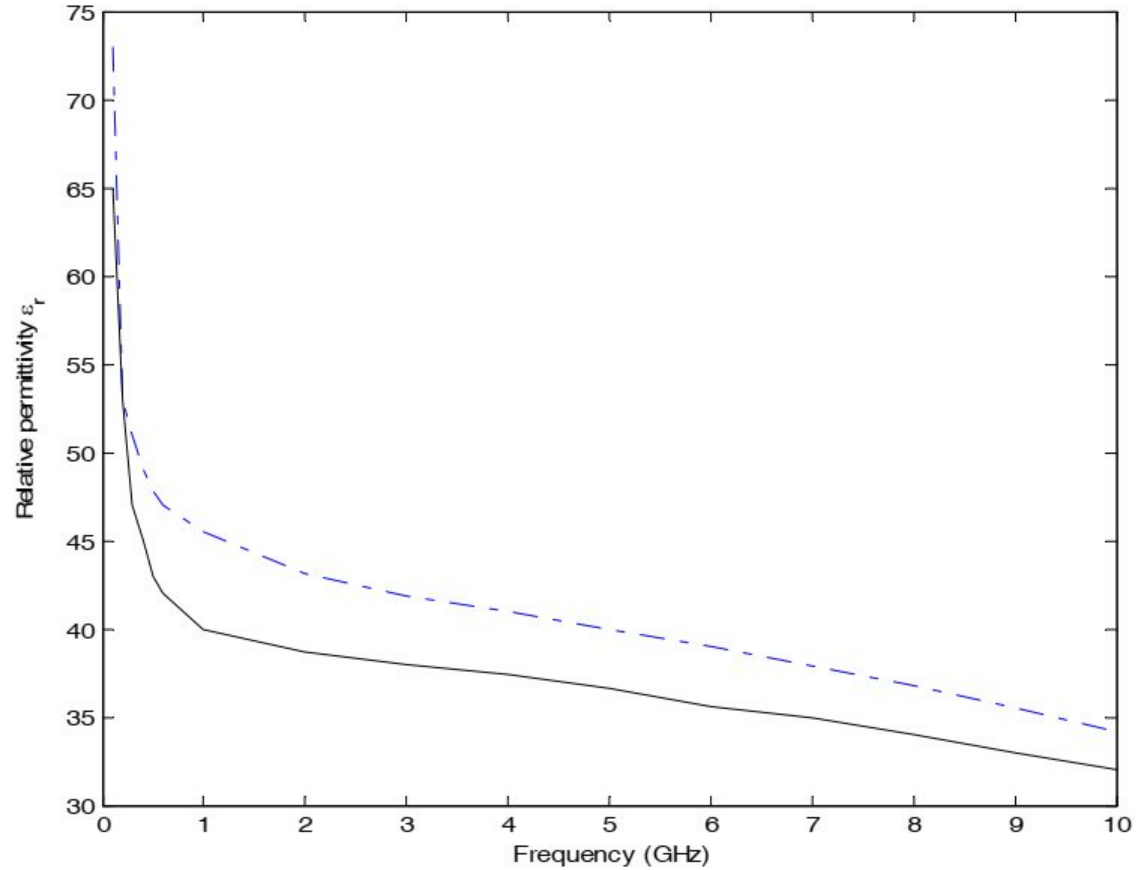


Figure 2.1: Relative permittivity of dry skin (solid) and wet skin (dashed and dot) for the frequency range of 100 MHz to 10 GHz.

The value 376.3Ω of η_0 can be calculated from equation. By taking the relative permittivity into account, the propagation impedance η in a material can be determined by

$$\eta = \sqrt{\frac{\mu_0}{\epsilon_0 \epsilon_r}}$$

Due to dielectric relaxation of polar molecules (water), the relative permittivity of dry skin and wet skin is dependent for the frequency range of 100 MHz to 10 GHz [19] as shown in Figure 2.1.

For example dry skin has a relative permittivity 40 at a frequency of 1.4 GHz. This leads to a propagation impedance of

$$\eta_{skin} = \sqrt{\frac{\mu_0}{\epsilon_0 \epsilon_r}} = 59.57 \Omega.$$

The reflection coefficient Γ is defined as

$$\Gamma = \frac{\eta_{skin} - \eta_0}{\eta_{skin} + \eta_0}.$$

Therefore the reflection at the air/skin interface can be calculated at 72%. This means it is possible to receive a reflected signal from the air/chest interface.

Breathing activity causes a chest movement of about 1 to 2 cm. If it is possible to detect the distance of the air/skin interface exactly with an appropriate repetition frequency, the according breathing rate could be determined.

2.3 The penetrated wall

- ❖ **It is necessary to determine the permittivity of the walls for doing measurements.**
- ❖ **Practically, walls are not simple dielectric layers with easily measurable permittivity.**
- ❖ **Generally, walls contain a certain number of layers with different permittivity, for example, a gas-concrete wall with gypsum board and rock wool heat-insulation.**

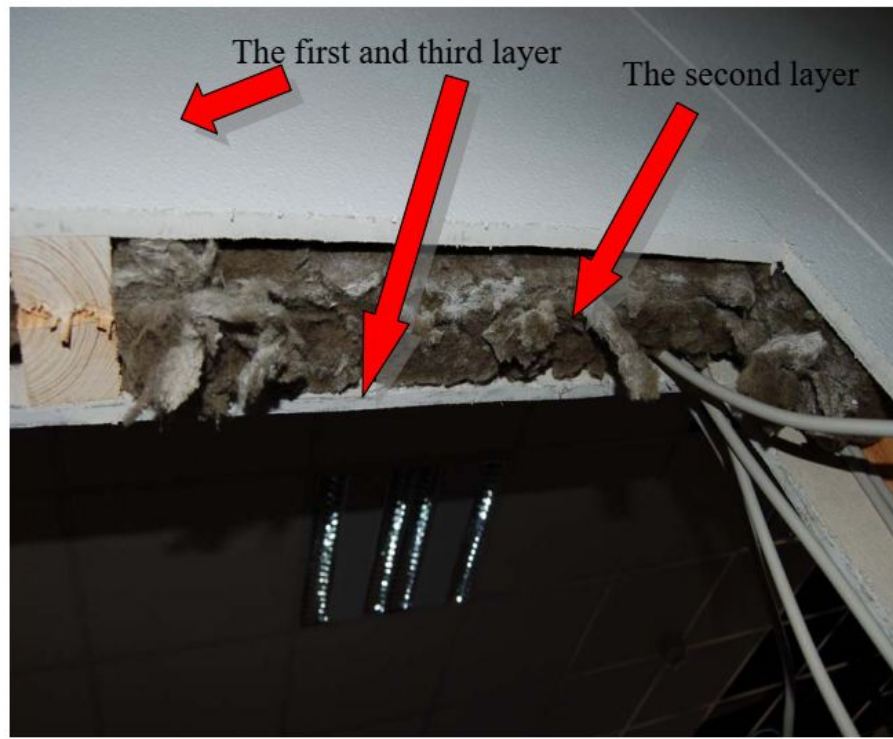


Figure 2.2: *Real structure of the wall for the measurements made in this work.*

Figure 2.2 shows the lightweight structure of the wall including three layers of materials for the measurements made in this work. Both the first and third layer are gypsum boards with 1.5 cm thickness. The second layer between the two boards is filled with rock wool with a thickness of 9 cm. The whole thickness of 9 cm.

- ❑ The whole thickness of the wall is 12 cm.**
- ❑ The permittivity of rock wool and gypsum are approximately 2 and 3.7 respectively.**
- ❑ It should be mentioned that a real wall has often pieces of metal are much thinner than the wall, hence the distortions of the metals are relatively low.**
- ❑ In addition, the system used in this research is a UWB system and this distortion does not have a big effect on the accuracy of the measurement.**

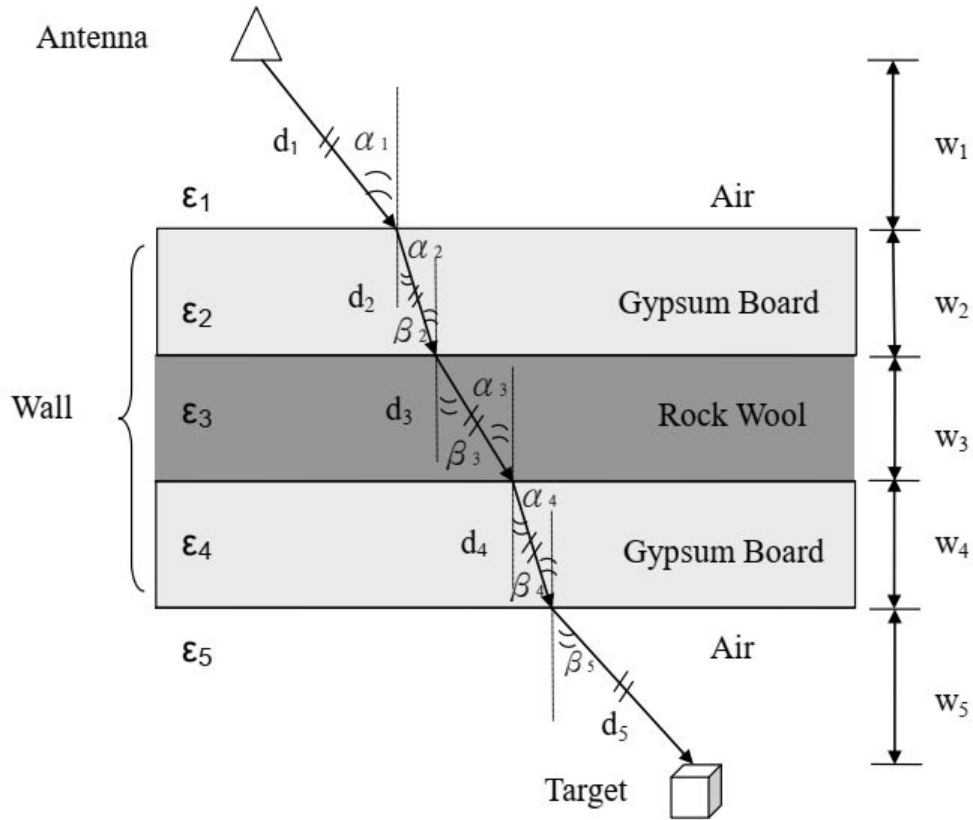


Figure 2.3: True flight distance model through the wall.

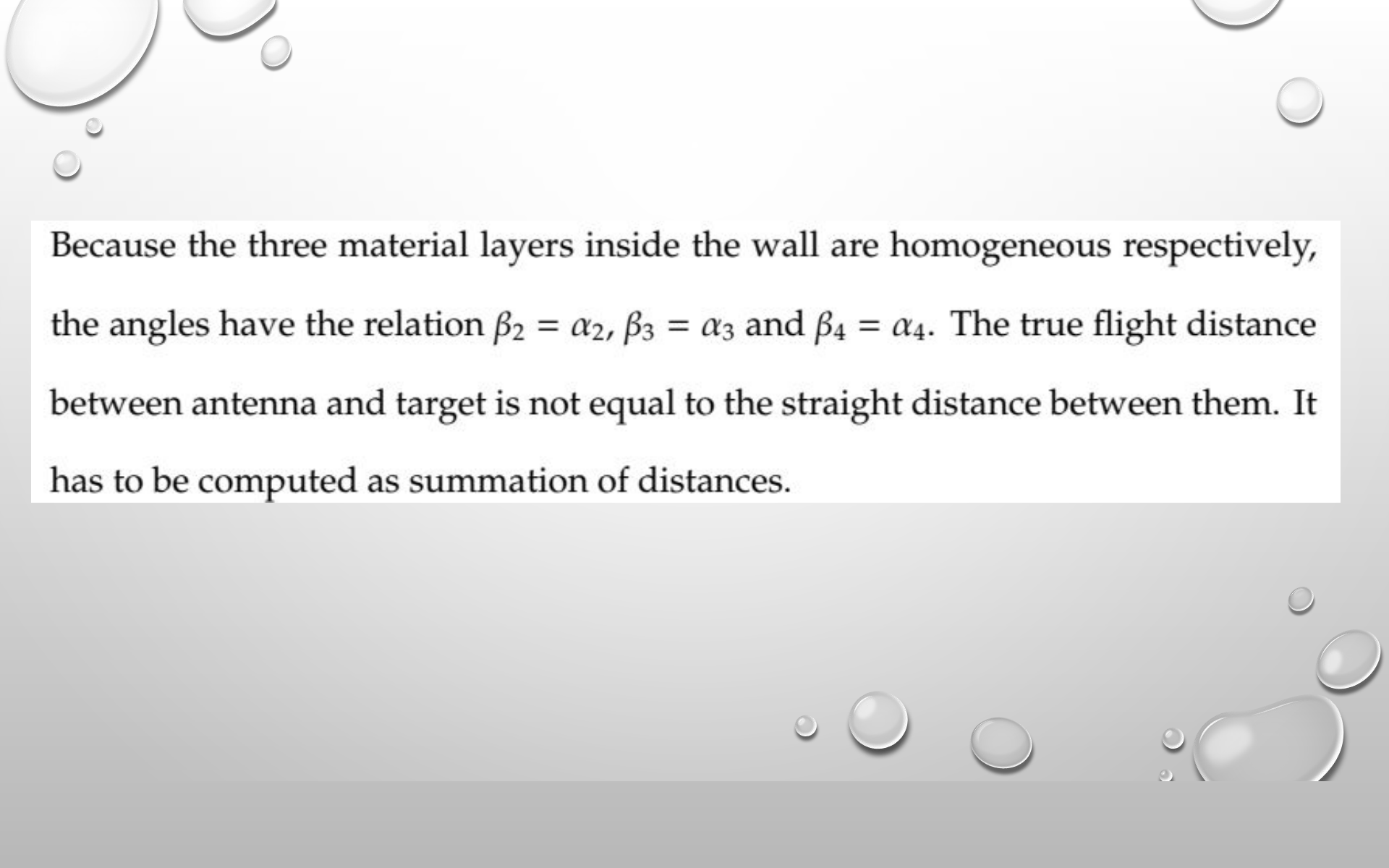
- **To estimate the correct distance or position of the objects behind the wall, the exact time of arrival (TOA) between the antenna and the object has to be known.**
- **The research in this seminar is focused on computation of the true TOA between antenna and target, with a wall between them. The losses in the wall are not considered. For the calculation of this time, the model shown in Figure 2.3 is used .**

The wall with 3 layers is almost homogeneous with constant permittivity and constant thickness.

The values of relative permittivity of the wall are $\epsilon_2 = \epsilon_4 = 3.7$

and $\epsilon_3 = 2.0$. The thicknesses are $w_2 = w_4 = 1.5$ cm and $w_3 = 9.0$ cm. The relative permittivity ϵ_1 and ϵ_5 of the air in front of the wall and behind are the same and equal to 1. The wave velocity in the air is equal to the velocity of light c . The velocity in different permittivity layers is given as

$$v_n = \frac{c}{\sqrt{\epsilon_n}}$$



Because the three material layers inside the wall are homogeneous respectively, the angles have the relation $\beta_2 = \alpha_2$, $\beta_3 = \alpha_3$ and $\beta_4 = \alpha_4$. The true flight distance between antenna and target is not equal to the straight distance between them. It has to be computed as summation of distances.

$$d_{tot} = \sum_{i=1}^n d_n.$$

The travelling time in each layer is the ratio of distance to speed

$$t_n = \frac{d_n}{v_n}.$$

Now, the true TOA can be computed as the summation of 5 times

$$\begin{aligned} TOA &= \sum_{i=1}^n t_n \\ &= \sum_{i=1}^n \frac{d_n}{v_n}. \end{aligned}$$

Figure 2.4 shows the geometry for a plane wave obliquely incident at the interface between two dielectric layers. Snell's law expresses that the ratio of the sines of the angles of incident and refracted wave equals to the ratio of velocities in the

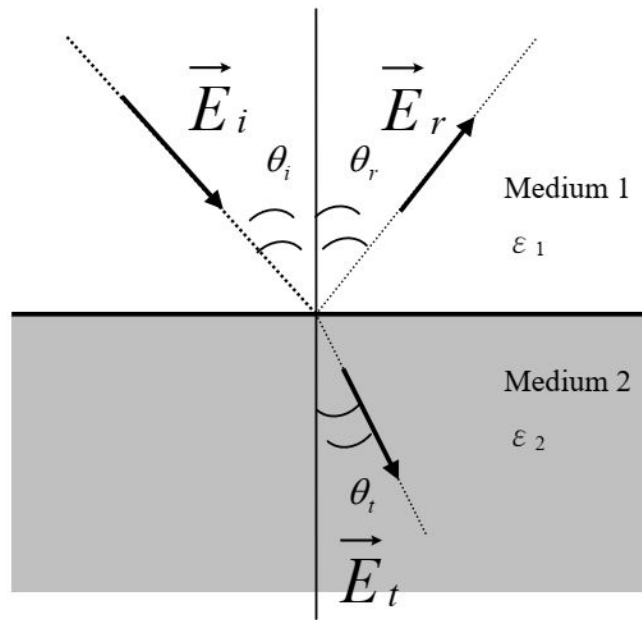


Figure 2.4: Geometry for a plane wave obliquely incident at the interface between two

dielectric regions.

two media [22]. θ_i is the angle of incidence. θ_t is the angle of refract
equation can be defined as

$$\frac{\sin \theta_i}{\sin \theta_t} = \frac{v_1}{v_2}.$$

θ_t can be written as

$$\theta_t = \arcsin\left(\frac{v_2}{v_1} \sin \theta_i\right).$$

In a medium with many layers θ_{tn} replaces θ_t and can be written as

$$\theta_{tn} = \arcsin\left(\frac{v_n}{v_1} \sin \theta_i\right).$$

• In our case v_1 is equal to c , the time of arrival would be:

$$\begin{aligned} TOA &= \sum_{i=1}^n \left[\frac{w_n}{c} (\sqrt{\epsilon_n}) \right] \left[1 - \left(\frac{v_n}{v_1} \sin \theta_i \right)^2 \right]^{-\frac{1}{2}} \\ &= \sum_{i=1}^n \left(\frac{w_n}{c} \right) \left(\frac{\epsilon_n}{\sqrt{\epsilon_n - \sin^2 \theta_i}} \right). \end{aligned}$$

2.4 UWB pulse

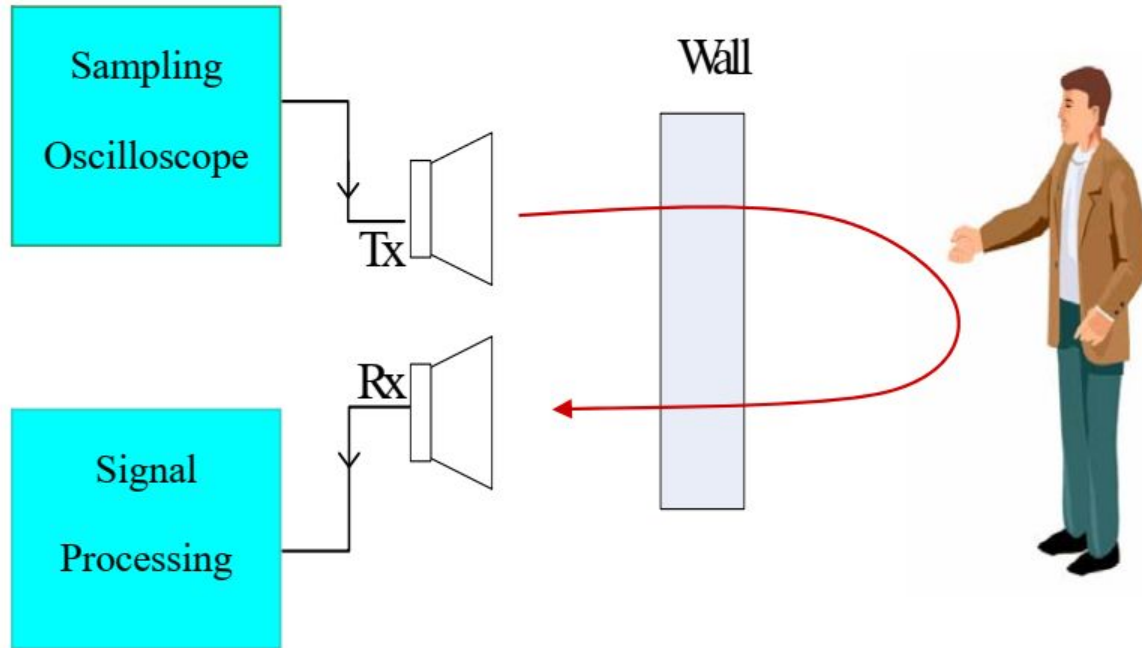


Figure 2.5: *The basic physical principle of a microwave life-detection system.*

A UWB radar transmits short impulses with pulse duration ranging from subnanoseconds to a few nanoseconds.

Due to the high resolution of UWB signals, the expansion of a chest cavity will cause noticeable variations to estimate the position and respiration rates.

For all life-detection radar systems, it is difficult to extract weak life signals from strong echo waves of the background. In a practical application there are four major problems:

The first is the complexity of the algorithm.

The second is how fast the result can be determined.

The third is how robust the prediction of the life parameters is.

The last is how accurate the results are.

For the purposes of getting distance, position or frequency, a UWB system with a MATLAB program has been developed to process the measured

2.5 Mathematical approach

2.5.1 Mean

2.5.2 Digital finite impulse response (FIR) filters

2.5.3 Variance

2.5.4 Fast Fourier transform(FFT)

3. One-dimensional design

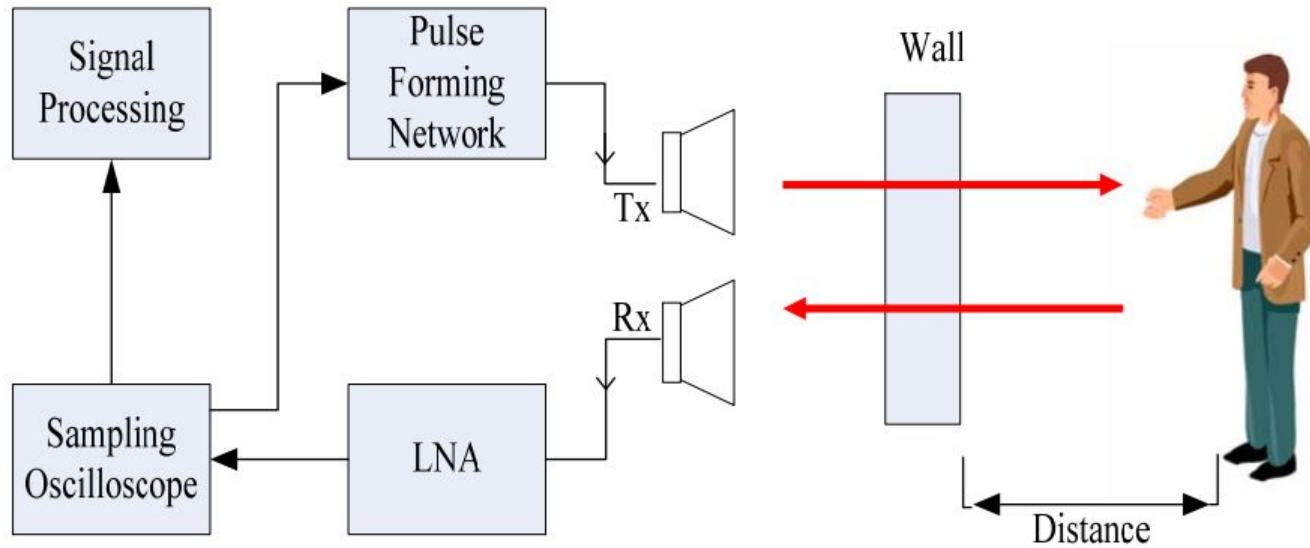


Figure 3.1: Set-up breath movement detection measurement system.

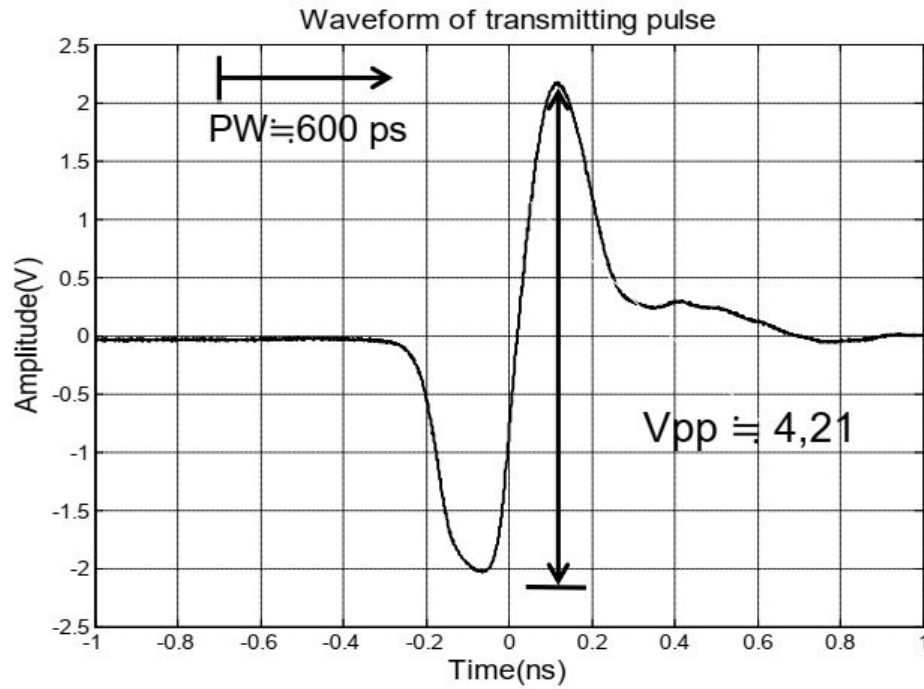


Figure 3.3: Measurement signal consisting of Gaussian monocycles, fed directly into broadband antenna.



The transmitting pulse touches the chest of a person whose breathing rate is 12- 15 times/minute (0.2-0.25 times per second).

The radiated pulse is reflected and received by another double-ridged horn antenna.

The measurement set-up for breath detection is behind a wall of light construction having a thickness of 12 cm and the distance between the antennas and the wall is 53 cm.



The received signal is amplified by an amplifier which achieves a maximum gain of 26 dB from DC to 12.5 GHz. It is a broadband linear amplifier (Model 5865 from the company *Picosecond*).

The sampling of the received signal is performed by the *Tektronix TDS-8000* sampling oscilloscope ($t_s = 12.5$ ps) too, which is triggered by the internal pulse generator. The time length of each record profile $\delta\tau$ is 50 ns. This implies that each waveform comprises $N = \delta t/t_s = 4000$ sample points.

3.2 Signal processing

Determination of position

With the presented UWB radar set-up,
several breath movement
measurements
of a person at 14 different distances

Position	Distance (cm) Behind The Wall
1	55
2	85
3	115
4	145
5	175
6	205
7	235
8	265
9	295
10	325
11	355
12	385
13	415
14	445

The original reflected pulse plotted by the *MATLAB* program is shown in Figure 3.4. It can be seen that the crosstalk is much higher than the reflection of the person. The reflection at the expected position is not observed clearly. An algorithm of signal processing was developed to process the measured data.

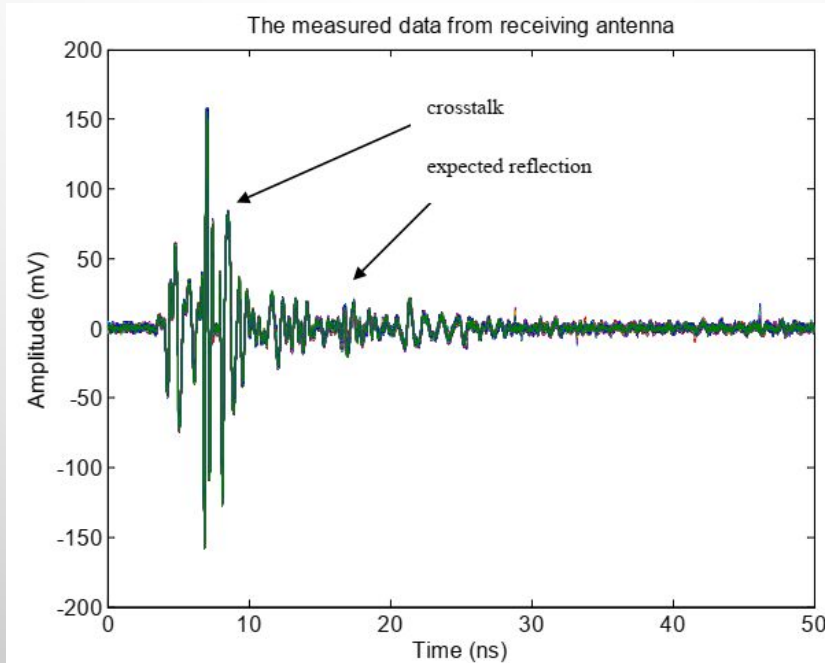


Figure 3.4: *Measured data from receiving antenna.*

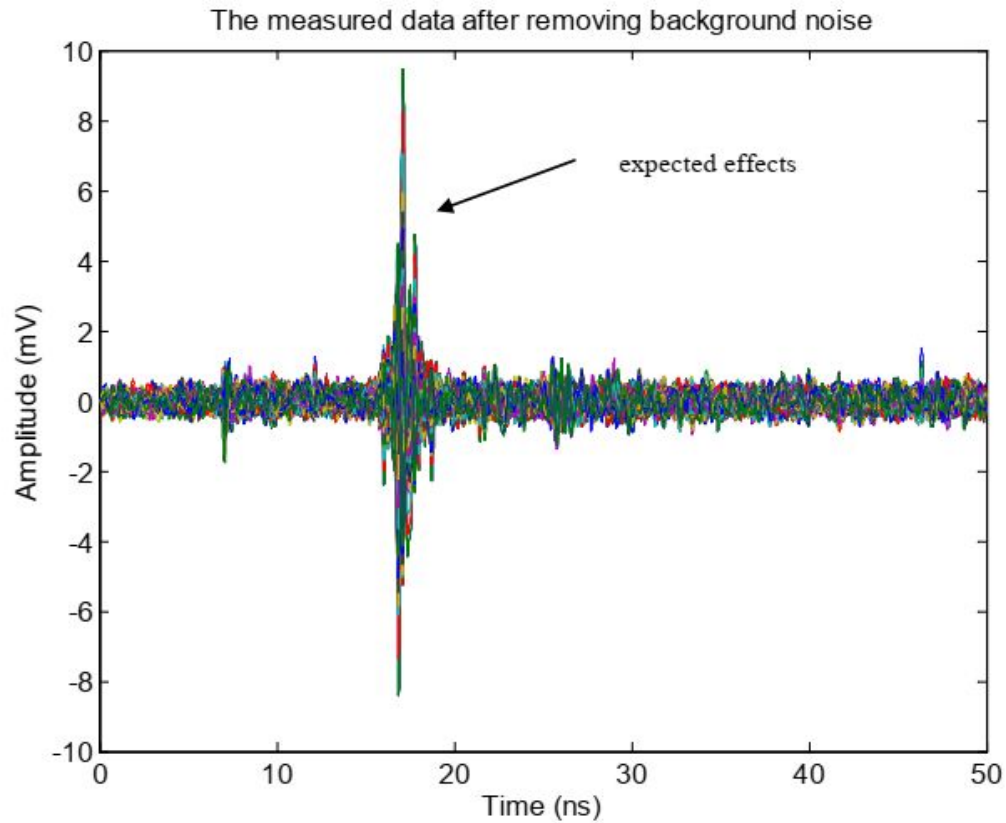


Figure 3.5: Measured data after removing the background noise.

After the method of mean-subtraction, a finite impulse response filter is used to remove the background noise. The filter is a linear-phase FIR digital filter with an order l .

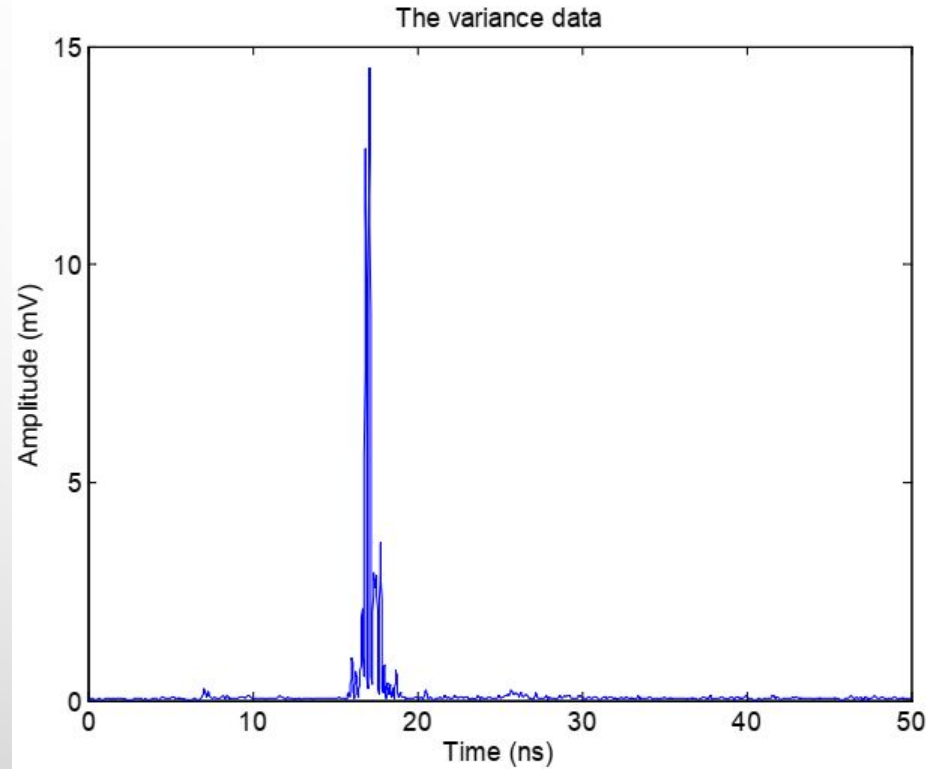


Figure 3.6: *Variance data.*

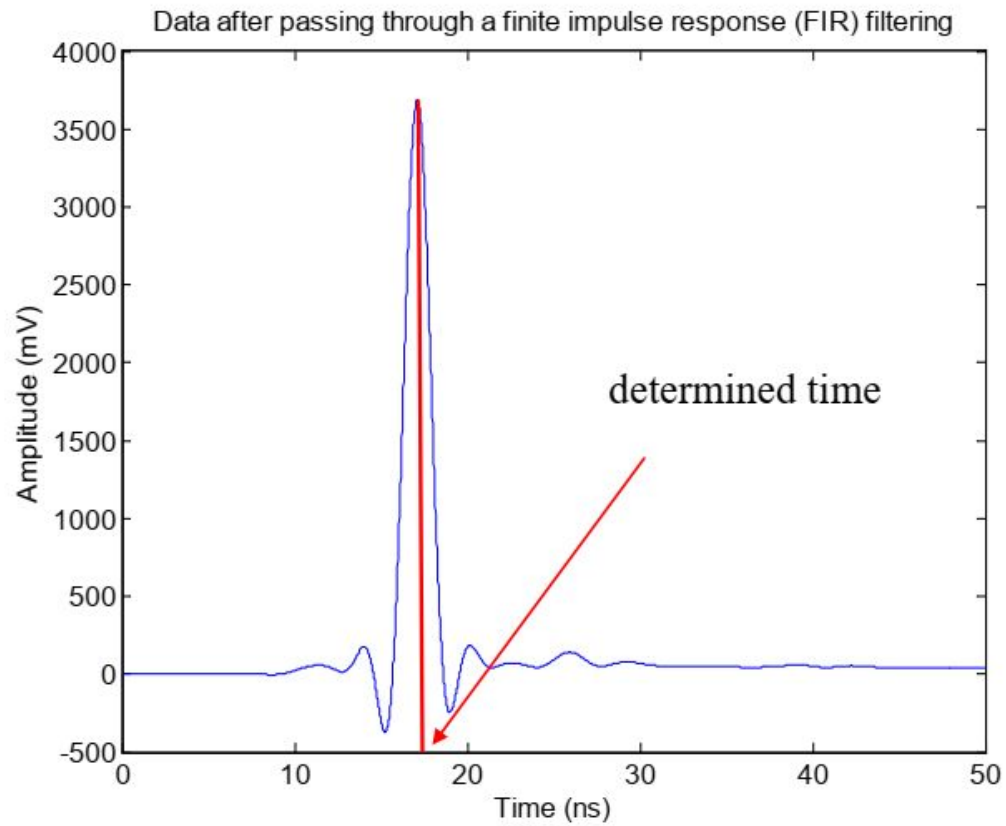


Figure 3.7: *Data after passing through a finite impulse response (FIR) filtering.*

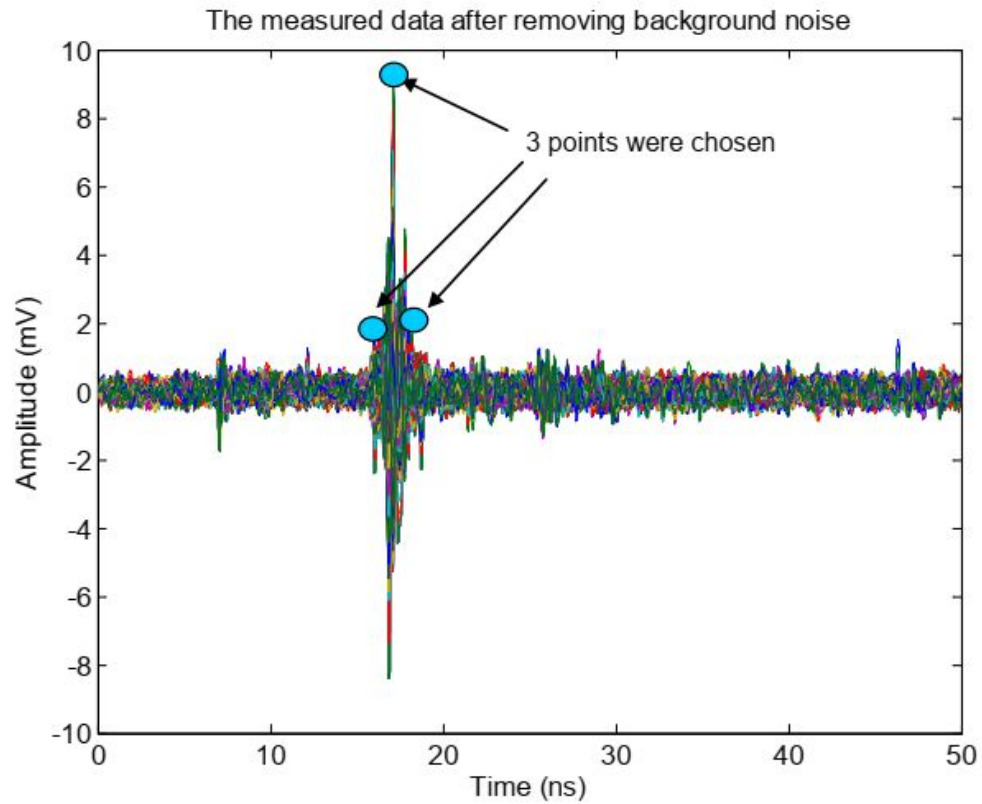


Figure 3.8: *Three points are chosen.*

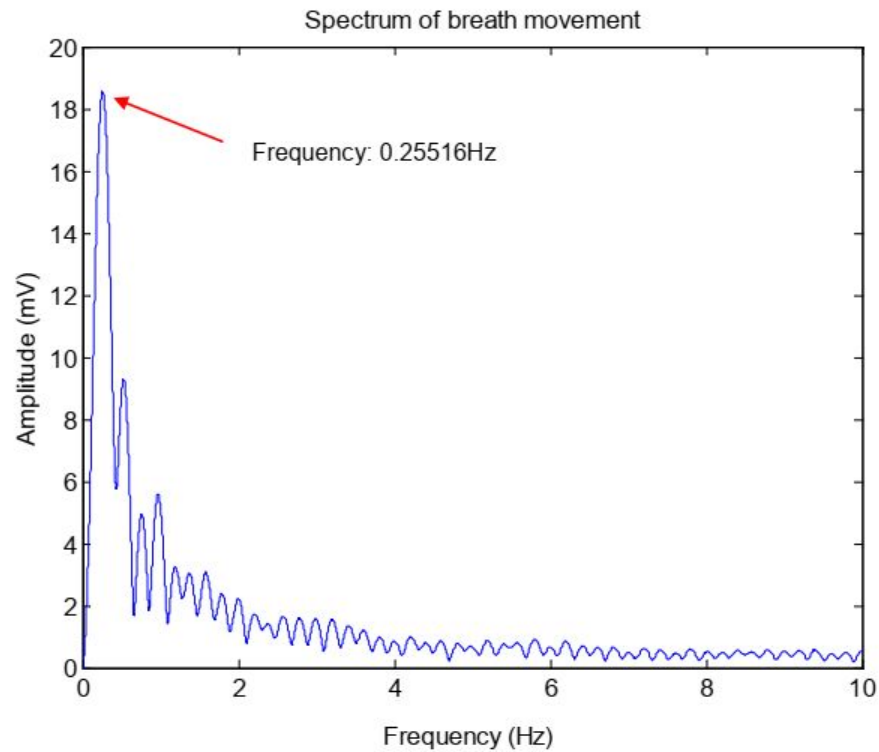


Figure 3.10: *Breath frequency determined by using the mean of the fast Fourier transforms from the magnitude changes of three points.*

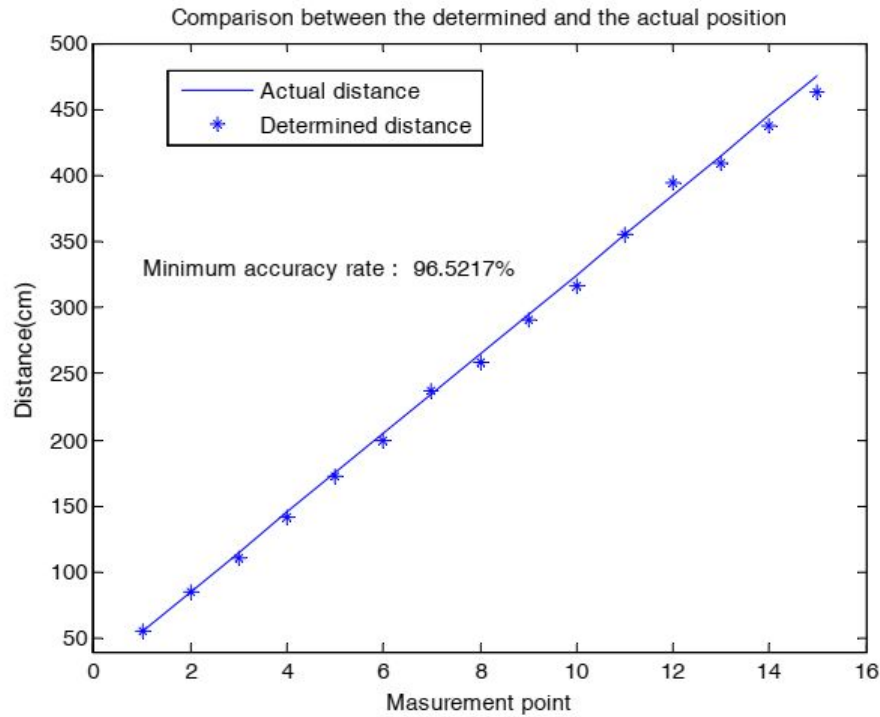


Figure 3.11: Comparison of determined (*) and actual (solid) distance with 15 distances behind the wall from 0.55 m to 4.75 m.

Two-dimensional measurement

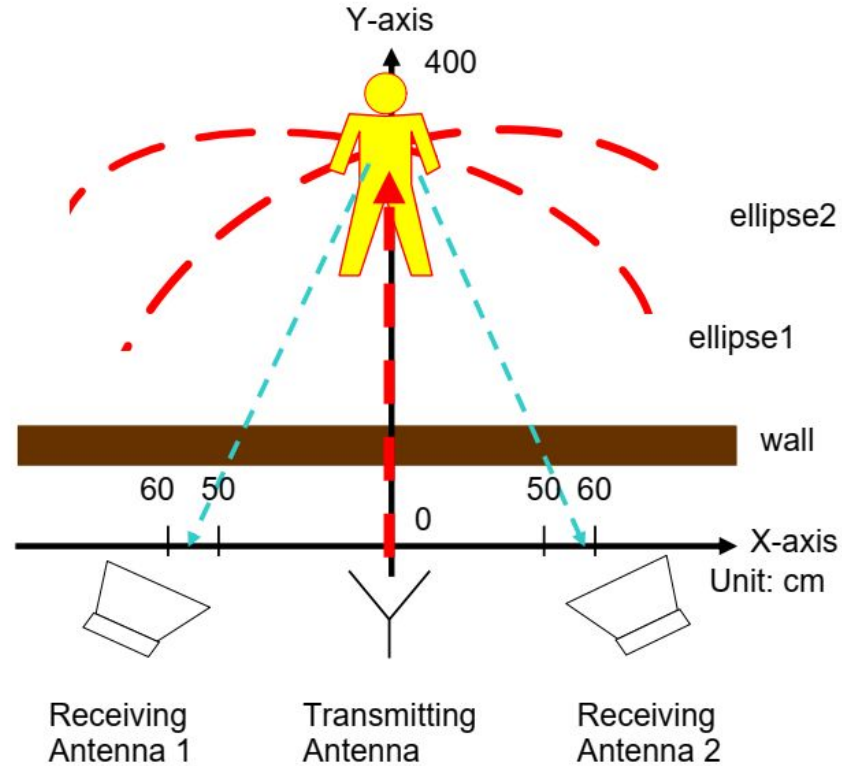


Figure 4.1: Geometrical setup for two-dimensional measurement.

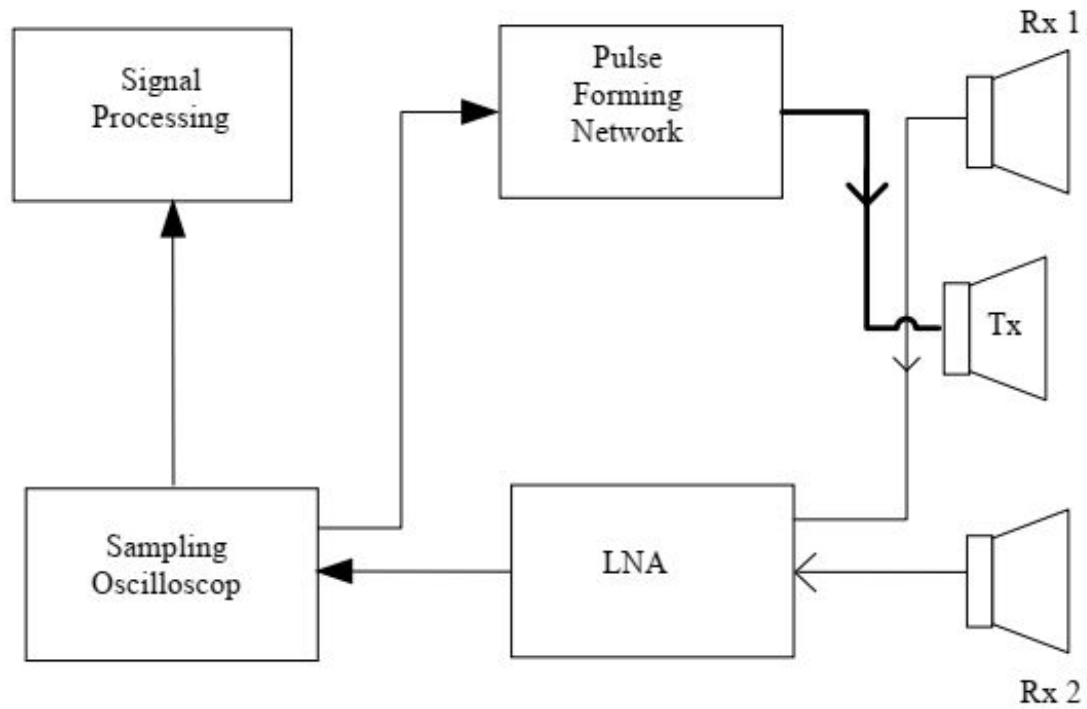


Figure 4.3: *Block diagram of measurement setup.*

RTT :Round-Trip Time

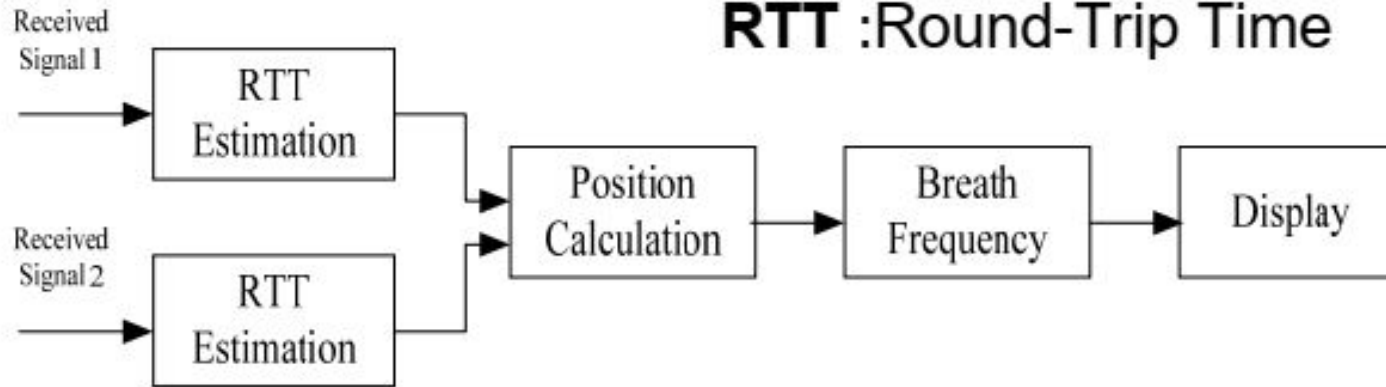


Figure 4.4: *Block diagram of signal processing.*

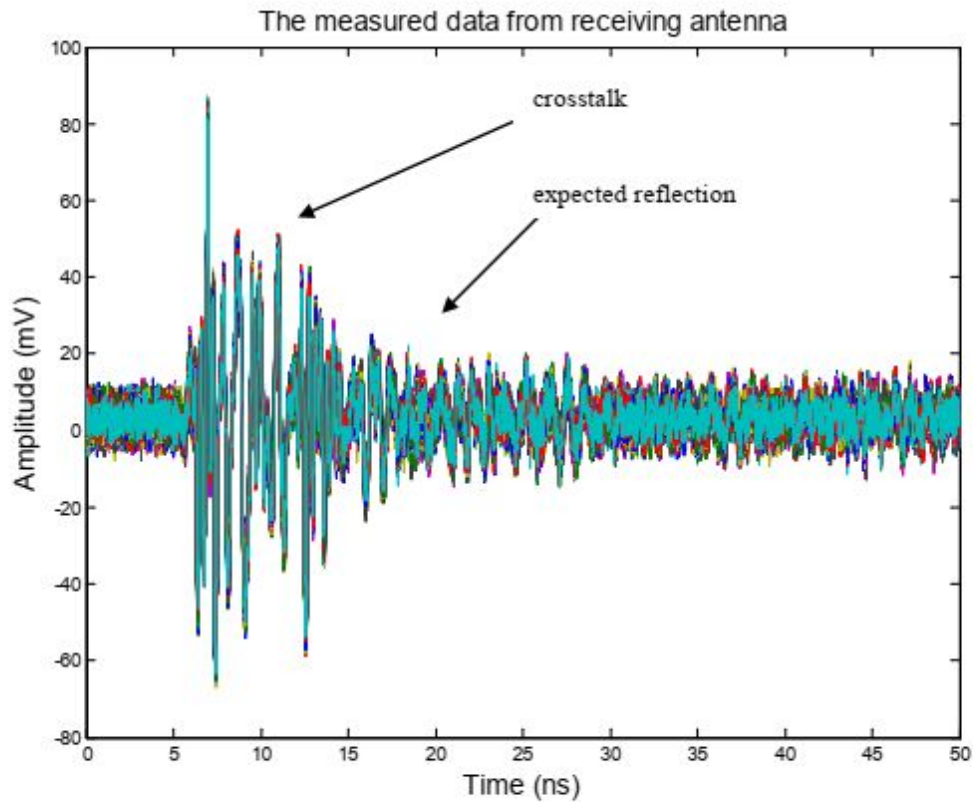


Figure 4.5: *Measured data from receiving antenna.*

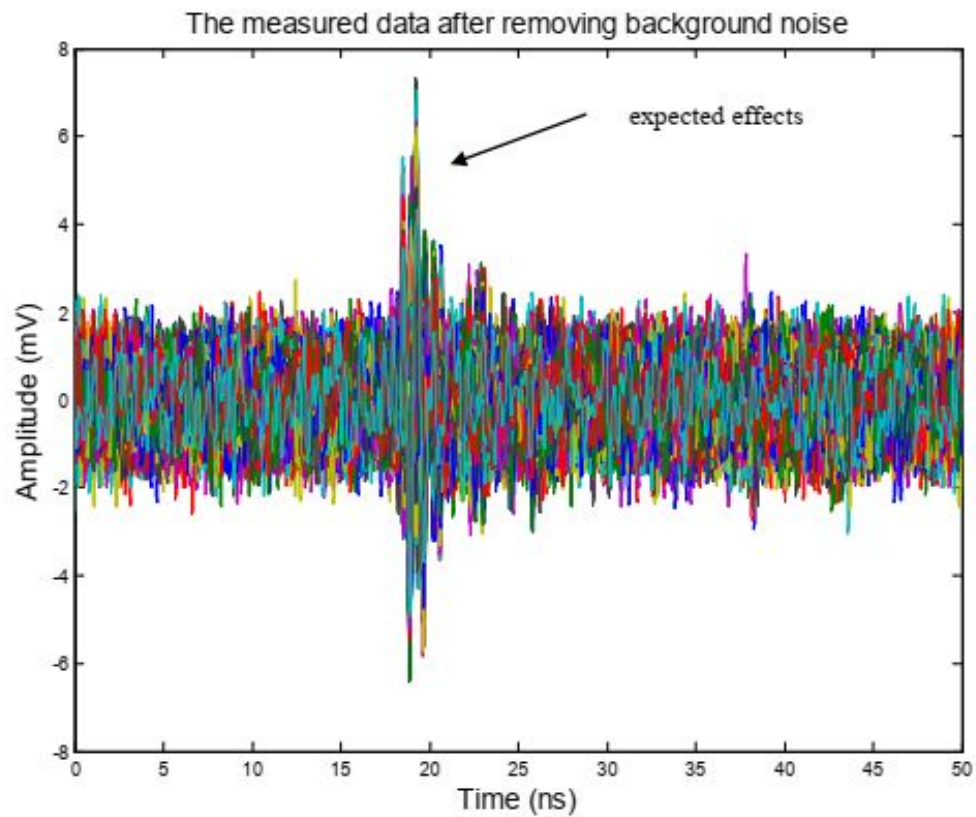


Figure 4.6: *Measured data after removing background noise.*

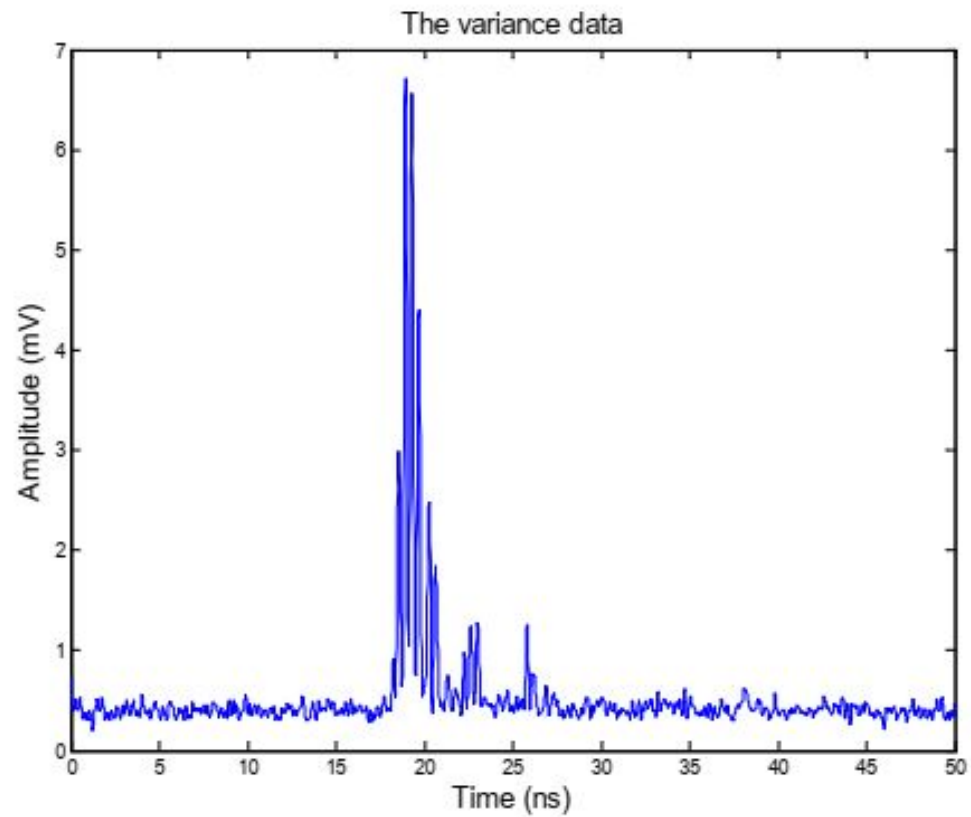


Figure 4.7: Variance data of the signal.

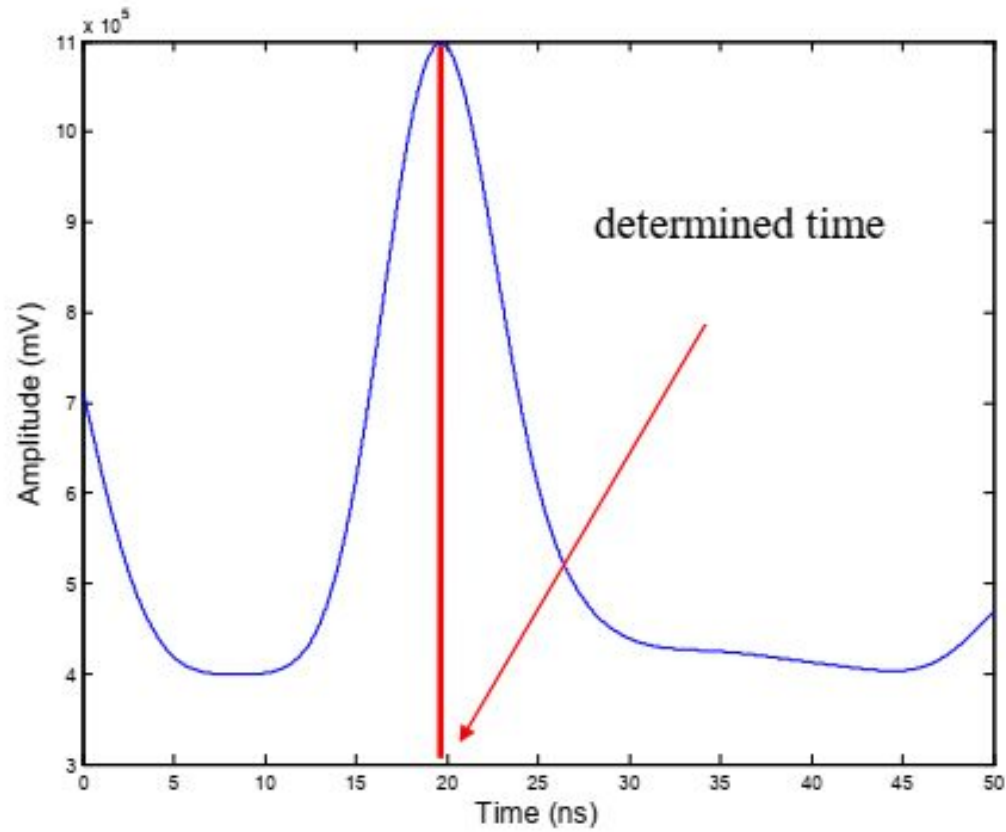


Figure 4.8: *Data after passing a zero-phase with FIR filtering.*

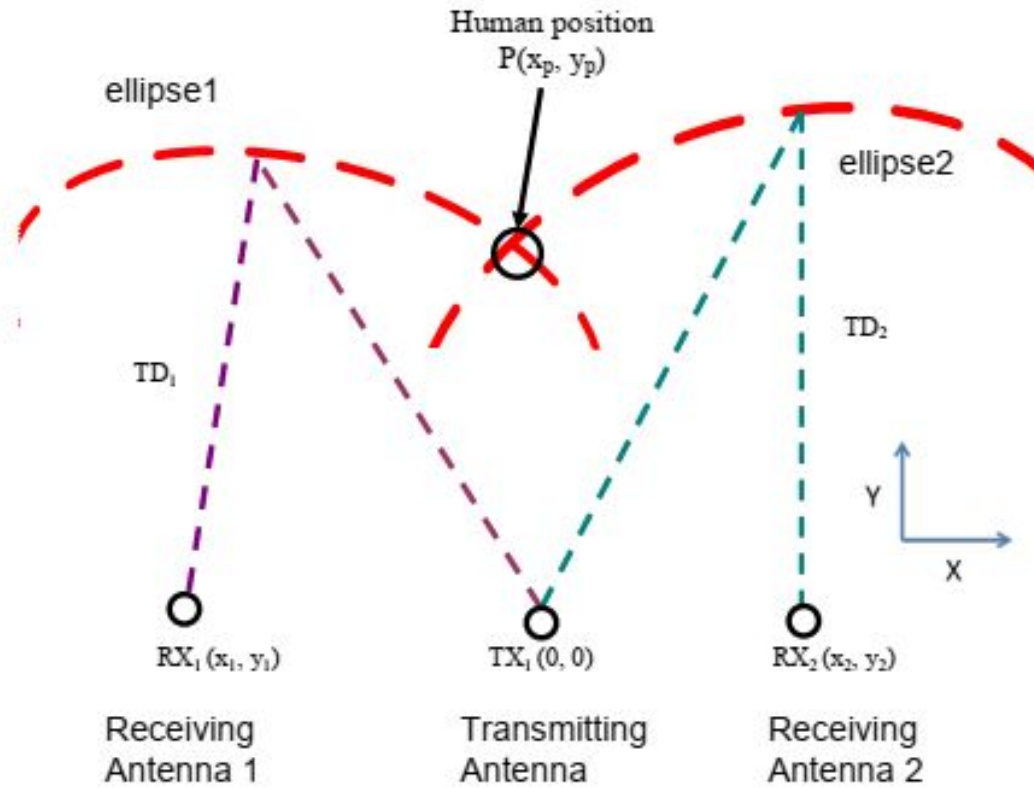


Figure 4.9: *The human position.*

Conclusions

- ❖ An ultra wideband radar system for breath and position detection of hidden humans has been presented in this research. By using a UWB radar it is possible to penetrate materials and detect the distance, position and chest movement of hidden persons.
- ❖ The UWB radar setup which is in one-dimensional measurement consists of a sub-nanosecond pulse generator, two wideband antennas and two low noise amplifiers.

CONCLUSIONS

- ✓ The applied research on biomedical applications of UWB radar will be targeted to the identification of the possible new devices made possible by the technology, to the design and development of those devices and to the clinical testing of the systems obtained.
- ✓ Applications can be divided into two main sectors according to the frequency range used in the UWB device. For the conventional UWB radar microwave region, the devices could be listed for:

CONCLUSIONS (cont.)

- ✓ cardiac biomechanics assessment
- ✓ chest movements assessment
- ✓ OSA (obstructive sleep apnoea) monitors
- ✓ soft-tissue biomechanics research
- ✓ heart imaging ('Holter type' echocardiography)
- ✓ chest imaging

along with systems for:

- cardiac monitoring
- respiratory monitoring
- SIDS (sudden infant death syndrome) monitors

The image features a light gray background with a subtle gradient. In the top-left and bottom-right corners, there are clusters of realistic water droplets of various sizes, rendered with soft shadows and highlights to give them a three-dimensional appearance. The word "Thanks...." is centered in the middle of the page in a large, bold, black sans-serif font.

Thanks....