UWB Pulse Propagation into a Layered Model of the Human Body

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***Abstract*— The biomedical applications of Ultra-Wide Band (UWB) radar system promise a very important means to remotely monitor physiological signal. Researchers have shown great interest in proposing analytical techniques to accurately predict the propagation of UWB pulse in tissues layers. This paper focuses the study of the propagation of a UWB pulse into a human body to characterize the absorption and reflection of UWB signal due to different layers. Several time behaviors for the reflected pulse were used and compared with the transmitted pulse to the feasibility of movement and heartbeat activity monitoring. Results from the simulation showed that if the UWB transmit antenna is placed far from the human body, the reflection from the interface between the air and the fat can be used to detect the movements of the activity. Therefore, we proposed designing an analytic model of tissue layers, considering some parameters. Furthermore, the frequency dependency of the different layers, tissues dielectric properties and the continuous motion of intra thoracic tissue layers were incorporated. The present work illustrates an application of UWB system for contactless detection and analysis of the human vital signal. This paper focuses on the design of a propagation UWB pulse into a layered model of the human body using the tool of modeling Agilent Advanced Design System.**

***Index Terms*— Antenna; Detection; Heart; Layers; Radar; Target; Ultra-Wide Band; Vital.**

I. INTRODUCTION

Radar is a detection system, which uses electromagnetic wave to determine parameters, such as the target distance or the moving speed. The principle operation of radar consists of transmitting a wave signal by an emitter: This signal is reflected by a target and it reaches a receiver. Depending on the signal processing at the receiver chain, the distance or the speed of the moving target is determined. Medical radar, which is intended to monitor human vital signal without contact, has been the subject of investigation by several researches.

Ultra-Wide Band (UWB) radar for remote sensing of vital signs, such as breathing and heart activity, is based on the detection of UWB time pulses reflected by the human body. The amplitude and different variations of the pulse are used to estimate the thorax and heart movement, which then derive the cardiopulmonary activity [1] [2].

Figure 1 illustrates the principle of the UWB radar system to monitor heart rate and respiratory rate. The transmitter produces UWB short duration pulses. This signal is transmitted to a heart body by UWB transmit antenna and reflected for the demodulation in the receiver. UWB radar remote sensing constitutes of UWB pulse generator, UWB receiver, moving target and two UWB antennas. Thereafter, an UWB pulse is generated, it is sent from the transmitter to the UWB transmit antenna and it is radiated toward the target. Once a pulse is reflected by the target, the pulse is detected by a UWB receiver antenna and processed to evaluate the distance between the antenna and the target [3].

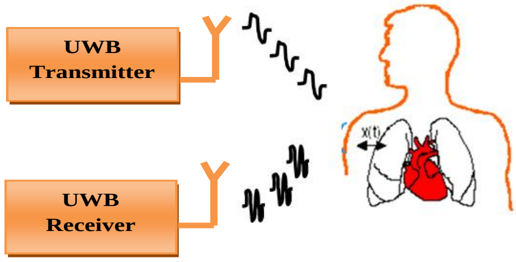


Figure 1: Principle of UWB radar system

In this paper, we begin by presenting the general architecture of Ultra-Wide Band radar. After that, we studied the propagation of UWB impulses in human tissues. Attention will be given on the tissue layers responsible for the signal reflection and the definition of the temporal behavior of the incident pulse used to monitor cardio-respiratory activity. Then, a model to study the propagation of pulses in a tissue layers is designed using the ADS tool. Finally, various simulations of this design were conducted followed by conclusions.

II. HUMAN BODY MODEL

Different research that considers the absorption and reflection of a pulse on the flat surface of the multilayer model has been conducted. The reflection coefficient at air-heart-air interface and the pulse propagation in different layers can be studied using microstrip transmission lines. We can design each tissue layers with a transmission line characterized by the same dielectric properties of layers tissue [4] [5].

Each transmission line is characterized by a constant propagation and characteristic impedance that depends on the frequency as well as the dielectric properties of the corresponding tissues. Human body consists of multiple layers of tissues that have different dielectric properties [6].

Figure 2 shows the proposed thorax model layers for studying the UWB radar. A planar model of the thorax constituted by five layers from the fat up to the heart (fat, muscle, cartilage, lung, heart) has been considered to study the propagation of UWB impulses in human tissues [7][8]. Under these conditions, a transmission line model can be developed taking into account the characteristic behavior of the tissues (thickness, relative permittivity, attenuation and impedance).

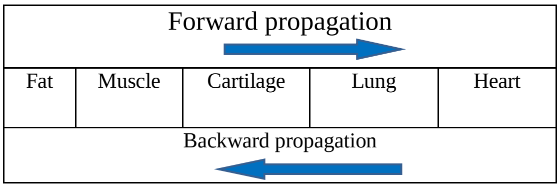


Figure 2 : The layered structure of the thorax model

Table 1 shows the parameters of a plane wave impinging orthogonally on the multilayer model as a function of the frequency [9] [10].

Table 1
Parameters Human Layers for 4 GHz

	Thickness [cm]	Relative permittivity	Attenuation [dB/m]	Impedance [Ω]
Fat	0.96	5	5	160.64
Muscle	1.35	50.5	10	53.28
Cartilage	1.10	35	12	63.68
Lung	0.578	20	5	84.24
Heart	0.9	55	12	50.8

Many researchers have studied the interaction of the UWB pulse with the layers of thorax [5] [9]. However, the aim of this research is to compute the attenuation of an electromagnetic wave that will suffer when traversing the human body. A pulse wave sent toward the heart crosses all layers and the interfaces as indicated in Table 1. At each interface, a reflection occurs due to the impedance mismatch between the two adjacent tissues. In a very simple case, researches focus on computing the attenuation and delay coming from the interface fat-heart-fat more precisely, without taking into consideration a reflection coming from each inner interface [11].

The purpose of collecting this data was to investigate for a more accurate model which considers thickness, impedance, linear attenuation and relative permittivity of five superimposed living tissues to be found by the UWB pulse while travelling through the human thorax from the fat up to the heart. Based on these works and the results in Table 1, we present the shape of the attenuation and time delay for 4 GHz frequency in the human body, as shown in Figure 3 and 4.

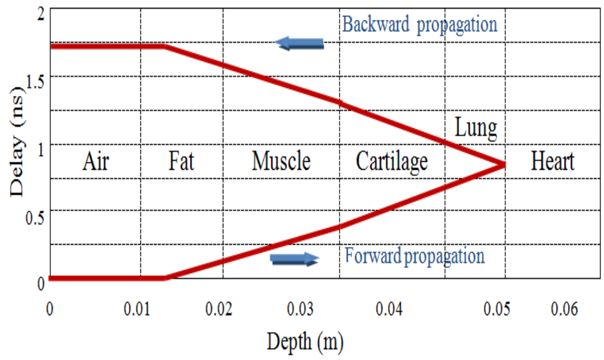


Figure 3: Return delay echo of human tissues

It is found that the echo from the skin to the heart at frequency 4 GHz shows attenuation of 72 dB and a time delay about 1.7 ns.

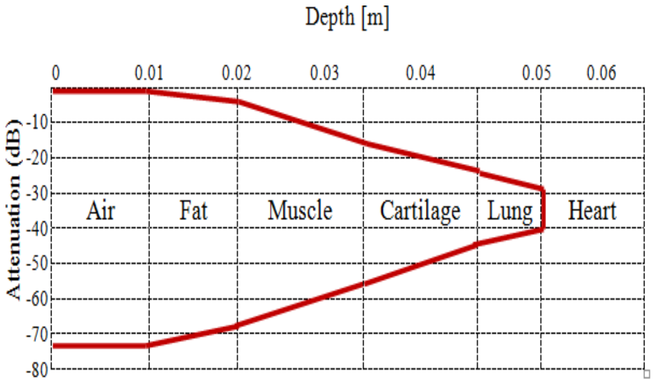


Figure 4: Attenuation pulse from the fat to the heart at 4 GHz

III. MONITORING OF VITAL SIGNALS WITH A UWB RADAR SYSTEM

Many studies have shown that UWB radar system can be used for vital monitoring. However, the UWB radar includes the main components such as transmitter, antenna, receiver and the field propagation.

The UWB generator is used to generate a nanosecond pulse with a central frequency of 4 GHz. It is connected to the UWB transmitter antenna with the frequency ranges from 3.1 to 5.1 GHz. The radiated pulse is reflected by the person and detected by the receiving antenna.

To evaluate the feasibility of monitoring the breathing and heart rate activity with UWB radar, it is essential to determine the amplitude of the input pulse propagation on the human layers [12].

According to Federal Communication Commission (FCC), Ultra-Wide Band radar should comply with the compatibility of FCC emission mask that is used to assess the maximum amplitude allowed for the UWB pulse. The FCC regulation also fixed the maximum average equivalent radiated isotropic Power Spectral Density (PSD) of –41.3 dBm /MHz [13] [14].

The propagation time from a radar system to the moving target can be determined by measuring the distance between the transmitted and the received signal. We can calculate the propagation time delay (ΔT) between the obstacle and the radar system via the round trip distance. The distance (D = 1 m) presents the space of propagation pulse between a transmitting-receiving antenna and a target. This distance produces a time delay of the reflected pulse equals to 7 ns (see equation 1):

$$\Delta T = \frac{2D}{C} \qquad (1)$$

Where: C = Speed of light (C = 3 10^8 m/s)

The time of flight (T_F), corresponding a time between radiated pulses from antenna to moving target, is equal to the time return from a target to receiver antenna return (T_R). The equation below proves that the times T_F and T_R are equal to 3.5 ns:

$$T_F = T_R = \frac{\Delta T}{2} \qquad (2)$$

Friis free space path loss (A) is used to calculate the attenuation in UWB propagation channel with the following expression:

$$A = 20\log\frac{4\pi D}{\lambda} - Ge - Gr \tag{3}$$

Where: Ge = Transmit antenna gain
Gr = Receive antenna gain
λ = Wave length (λ = C/f)

The pulse attenuation (free space path loss) measuring between the transmitter antenna to the target (A_F) is equal to the attenuation of the reflected pulse from the target to the receiver antenna (A_R). These attenuations pulses (A_F and A_R) are equal to 18.11 dB calculated using the following equation:

$$A_F = A_R = \frac{A}{2} \tag{4}$$

Figure 5 shows the proposed architecture model for studying pulse propagation in layers of thorax human, designed using the software modeling ADS. TLINP microstrip component simulates a layer tissue structure of the human thorax model. A Mode of propagating pulse in microstrip transmission line is specified in user frequency by its attenuation, impedance of layers, thickness, conductivity and relative permittivity.
Simulations were performed by considering the absorption and reflection of a plane wave, with a UWB frequency spectrum on the surface of the planar multilayer model. The time behavior of the UWB pulse propagation into the different human tissues can be estimated by using the transmission line model, which assigns to each tissue layer a transmission line of the same length. Each transmission line was then characterized by its propagation constant and characteristic impedance both dependent on the frequency and on the dielectric properties of the corresponding tissue [15].
In the literature, there are different pulse shapes for UWB transmitter such as gaussian pulse and its derivatives, triangular, rectangular, and cosine envelope. The new pulses are generated by multiplying the triangular pulse envelope to a sinusoidal wave to generate the nanosecond pulse [16]. The pulse shape is characterized by some parameters, such as pulse repetition period about 10 ns, pulse duration is 1 ns and bandwidth of 2 GHz from 3.1 GHz to 5.1 GHz.

The shape of the UWB generated pulse is shown in Figure 6. It can be seen that the amplitude is 70 mV and the duration of the pulse is approximately 1 ns. In this simulation, frequency range of the UWB excitation signal varies from 3 to 5 GHz. This UWB generated pulse (Figure 6) is applied at the input of transmitting antenna.
The spectral shape allocates under the FCC mask for applications in the entire UWB frequency range. From this figure, it is clear that the received pulse perfectly complies with FCC mask with high spectral efficiency [14]. We note the maximum PSD is less to -41.3 dBm/MHz (-41.87 dBm/MHz) that complies with the FCC mask and the bandwidth is 2 GHz at -10 dB.

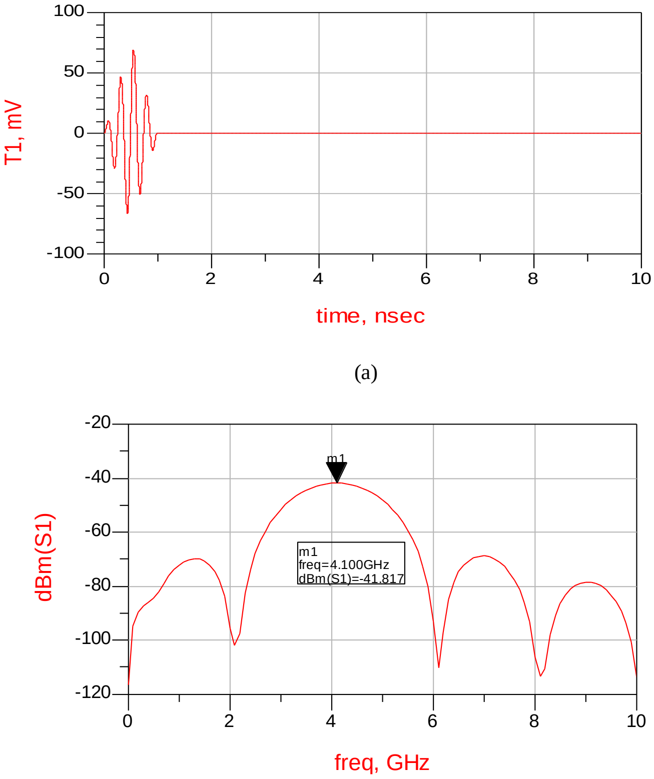


Figure 6: Excitation signal: (a) time domain and (b) frequency domain

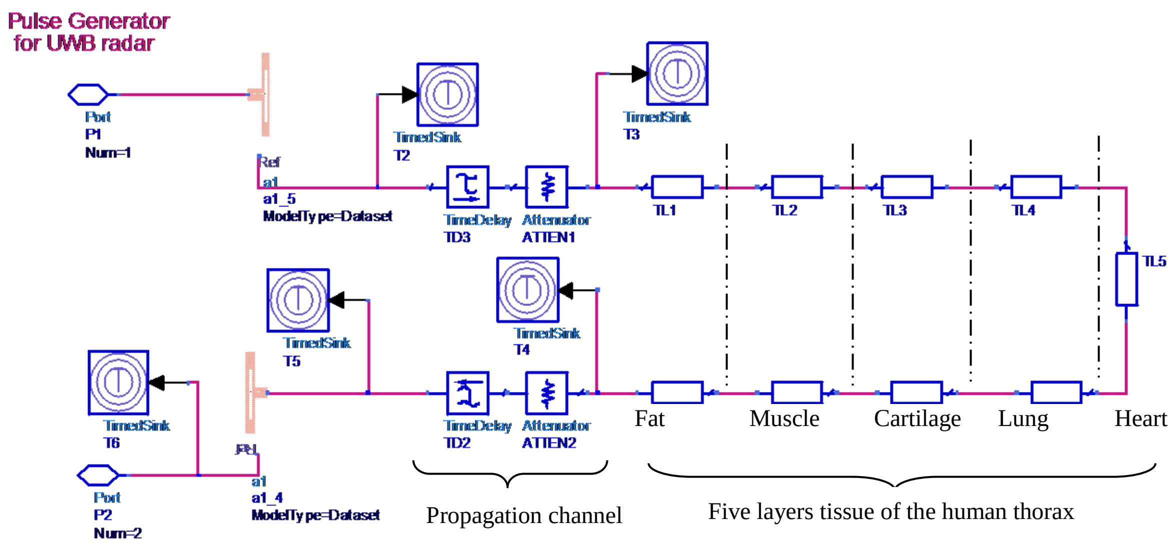
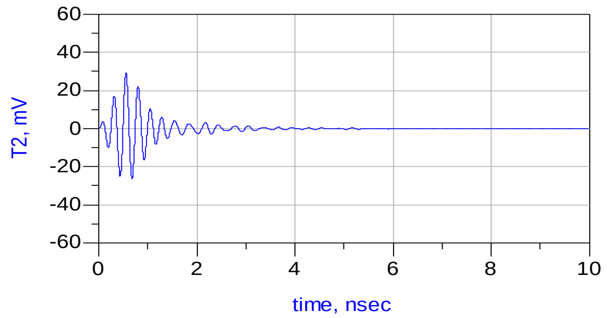


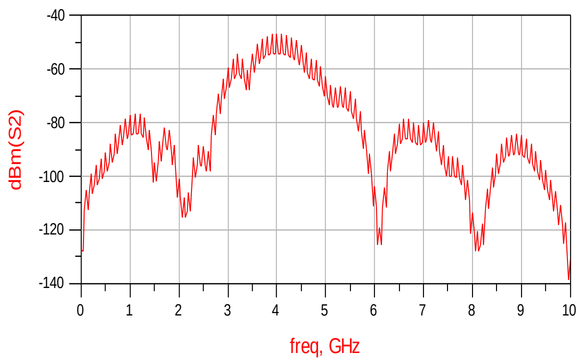
Figure 5: Simplified model of human composed of five layers

The rectangular microstrip patch antenna is the essential element in UWB radar; it can capture or radiate short pulse. The microstrip antenna is designed using electromagnetism ADS Momentum [17] with various specifications such as a resonant frequency equals to 4.1 GHz, frequency range [3.1-5.1] GHz, Glass Epoxy substrate dielectric (FR4) with 4.4 dielectric constant, 1.6 mm height and loss tangent equals to 0.02.

The proposed antenna is assumed to be excited by the UWB signal to examine the time domain response of the proposed antenna. UWB signal with a bandwidth of [3.1-5.1] GHz, shown in Figure 7 is applied at the input of transmitting antenna.



(a)



(b)

Figure 7: Radiation pulse of rectangular microstrip patch antenna: (a) time domain, (b) frequency domain

Figure 7 (a) shows the radiated UWB pulse for rectangular patch antenna in time domain, which is characterized by maximum amplitude of 30 mV.

Figure 7(b**)** presents the PSD of the pulse radiated by the patch antenna in frequency domain. We note the maximum PSD is less to - 41.3 dBm/MHz.

The simulation result of the UWB pulses propagation channel system in the distance covered between the transmitting antenna and the target is shown in Figure 8 with an attenuation of path loss of 18.11 dB (Equation 4) and a time-of-flight T_F = 3.5 ns (Equation 2).

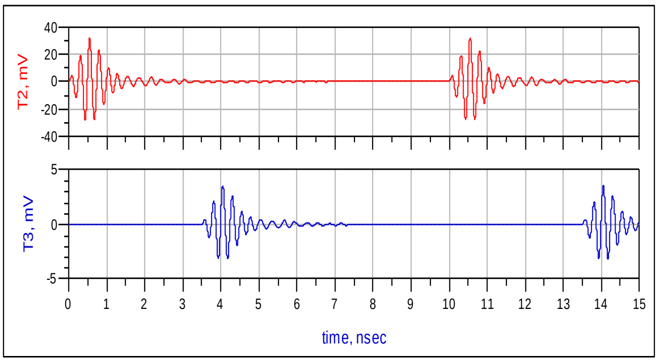


Figure 8: Temporal simulation of the UWB pulses propagation channel (antenna-target)

Figure 9 shows the reflected UWB pulse by the thorax multilayer model (see in Figure 5) as a function of the time and the attenuation given by a plane wave multilayer model. It can be noted that the attenuation of the signal is −71.39 dB at 4 GHz and the return echo delay is 1.6 ns (Figure 9). Our results for the UWB pulse propagation into the layered model human tissues are similar to the results given by the works of various researchers [9], where a signal attenuation of −72 dB and the delay of the return echo of 1.7 ns have been evaluated at 4 GHz for a body model.

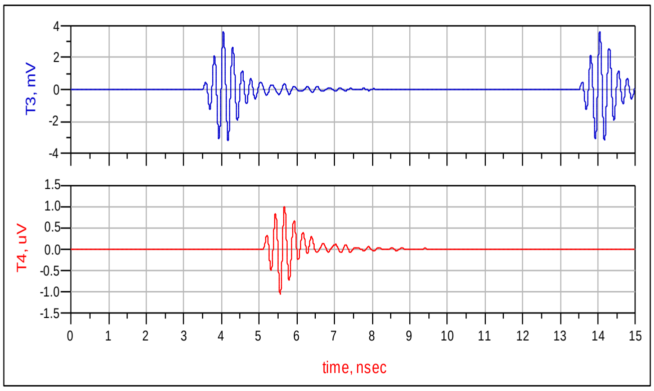


Figure 9: Simulation of UWB reflected pulse by the multilayer model

The simulation of the UWB propagation channel system between target and the receiving antenna as shown in Figure 10 presented the attenuation of 18.11 dB (equation 4) and a time-of-flight T_R= 3.5 ns. This value is consistent with the parameter set previously.

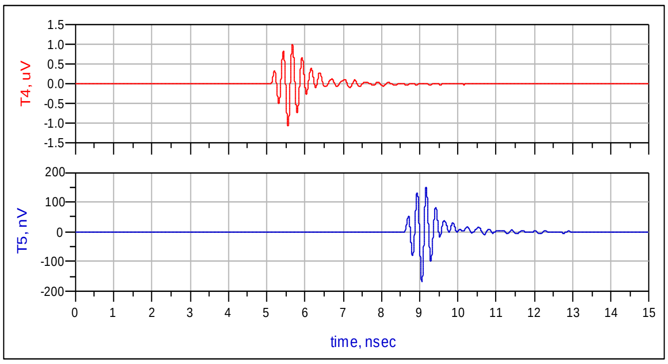


Figure 10: Temporal simulation of the UWB propagation channel (target-antenna)

Figure 11 shows the results when a distance between the UWB radar and the body model equal to 1 m were considered. This figure shows the UWB pulse generator (T1), pulse radiated by transmitting antenna to the multilayer body model (T2) and pulse detected by receiving antenna (T6).

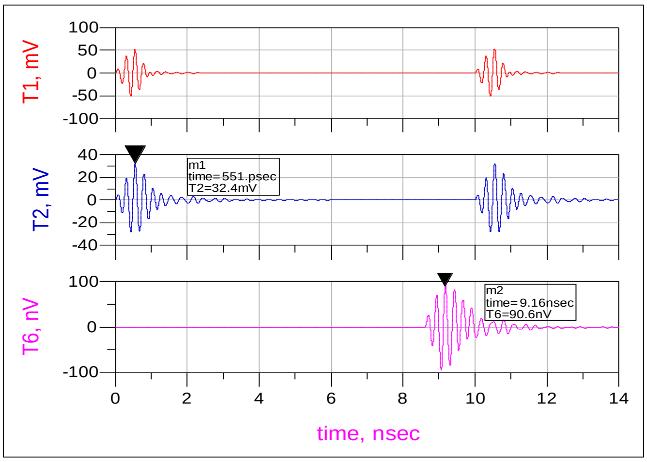


Figure 11: Temporal simulation of the pulse generated, radiated by transmit antenna and pulse detected by the receiver antenna

The UWB radar system consists of sending an UWB pulse and analyzing the echo reflected by the human thorax tissue. Considering the distance between the UWB transmitter and the human model equals to 1 m, the reflected pulse from the heart is detected by UWB antenna after a delay time 8.6 ns from the onset of the incident UWB pulse.

IV. HEARTBEAT DETECTION

In the UWB radar vital monitoring system, the transmitter generates a short pulse. These nanosecond pulses excite the antenna and are radiated into space. Then, the pulses are reflected by the moving target to the receiver antenna. According to the radar theory, a target with a varying position will reflect the signal proportionally to the moving varying [3].

The Doppler Effect describes any pulse transmitted or reflected from a moving object. The Doppler frequency can be described mathematically: In the case of a reflection from a moving object, this Doppler frequency (d) is defined by following equation:

$$\Delta f = \frac{2\,f\,v(t)}{C} = \frac{2\,v(t)}{\lambda} \qquad (5)$$

Where:

f : Transmit frequency

$v(t)$: Range velocity

λ : Wave length

C: Speed of light

Equation (5) proves that the Doppler frequency for a target moving at the speed 0.03 m/s [18] is equal to 6.3 Hz.

Based on the Doppler theory, a target with periodic movement reflects the transmitted signal modulated by the time-varying position of the target. When the target is the thorax, the reflected signal contains information about the chest displacement due to heartbeat and respiration. However, the reflected signal depends on the thorax displacement due to heartbeat. At rest, the displacement of the thorax activity is expected to be in the order of 3 cm [19]. This displacement produces a time delay of the order 0.2 ns.

The incident signal is divided equally by a power splitter. One of the outputs of the power divider passes through a phase-shifter (phase shift produced by the electromagnetic propagation between the antenna and the target) with 90° phase shift, while the other one goes unchanged (0 degree):

- ∅ = 0°: the target is moving perpendicular to the microwave beam
- ∅ = 90°: the target is moving parallel to the microwave beam

SRC1 and SRC2: They are the two sinusoidal sources, which simulate the periodical body movement due to heartbeat activity (Figure 12). We consider that the amplitude of the heartbeat signal is 0.08 V and the frequency (Doppler frequency) is equal to 6.3 Hz in usual cases.

This model receives an incident signal and generates the corresponding reflected signal from a generally moving target. As a result, the outputs of the phase-shifters are multiplied with the moving signal terms (sinusoidal source SRC1 and SRC2). The outputs of the multipliers are added using a power combiner.

For the target model, there are mainly two factors to be considered: The attenuation of the received signal compared to the transmitted waveform, due to propagation loss and reflection from the target, and the time difference between transmission and reflection of pulse due to the two-way travel time of moving target.

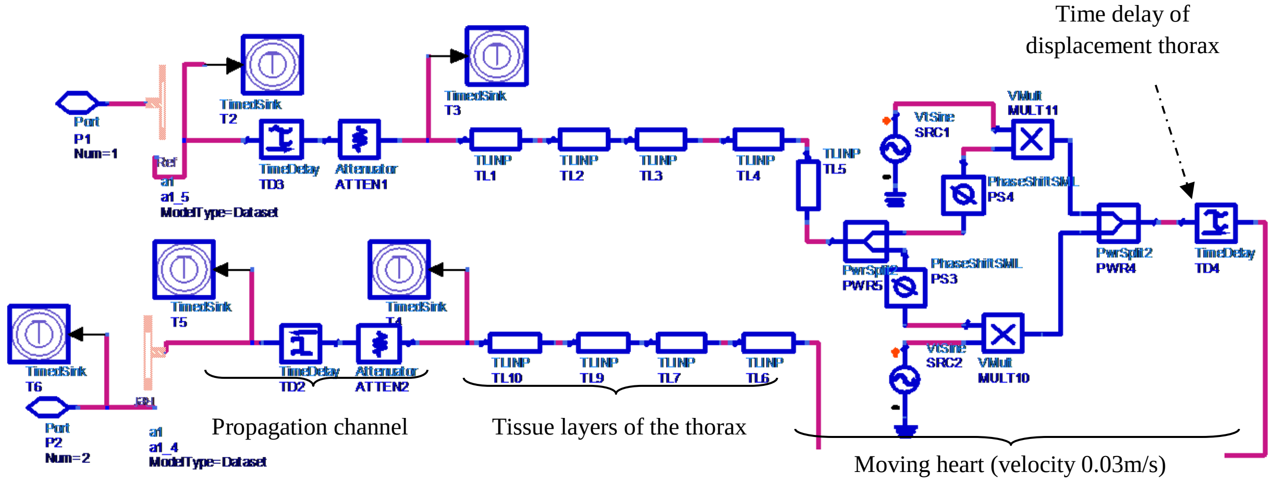


Figure 12: Schematic of the vital signal monitoring UWB radar system in ADS

Assuming that the signal travels thorax at the speed of light, the transit delay related to the target range (R) is 0.2 ns (displacement on the order of 3 cm), with the following expression.

$$Transit\ delay = \frac{2*R}{C} \tag{6}$$

Figure 12 shows the schematic of the radar used in our simulation. We consider that the radar transmits a UWB pulse at the operating frequency 4 GHz.

The displacement of the thorax due to heart activity is expected to be of the order of 3 cm, which produces a time delay of the order of 0.2 ns. The receiver antenna detects sudden changes of displacement thorax. Indeed, this displacement has been designed as a time delay blocks.

Figure 13 shows a comparison between two conditions: stationary target and moving target. We observed that the amplitude and pulse shape change during movements that explain our radar is able to detect the state of a human body person: living or dead during an accident, earthquake...

The simulation of a 3 case of chest that varies its movement from 0 to 0.2 ns is represented in Figure 13, where:

- 0 ns delay: thorax of the initial state.
- 0.1 ns delay: thorax displacement of 1.5 cm.
- 0.2 ns delay: thorax displacement of 3 cm (Maximum displacement of thorax).

The UWB Radar system is used to determine the detection of moving target. The radiated pulse is reflected from the thorax and detected by the receiver antenna.

The simulation result of a monitoring UWB radar system for displacement thoracic is shown in Figure 14. To simulate the motion of any target, The UWB pulse propagates from the antenna to the target and generates an echo, returning to the receiving antenna. The simulation results show that the signal reflected from the moving thorax (displacement 0 to 0.2 ns) is able to detect the cardiorespiratory activity when the radar is placed at a distance from the human body.

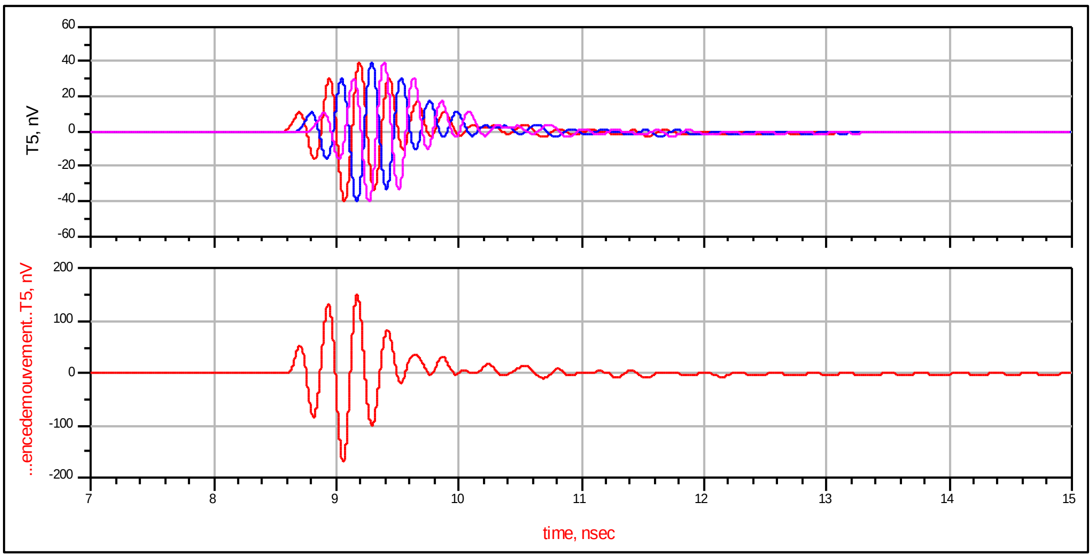


Figure 13: Comparison between moving and fixed Target

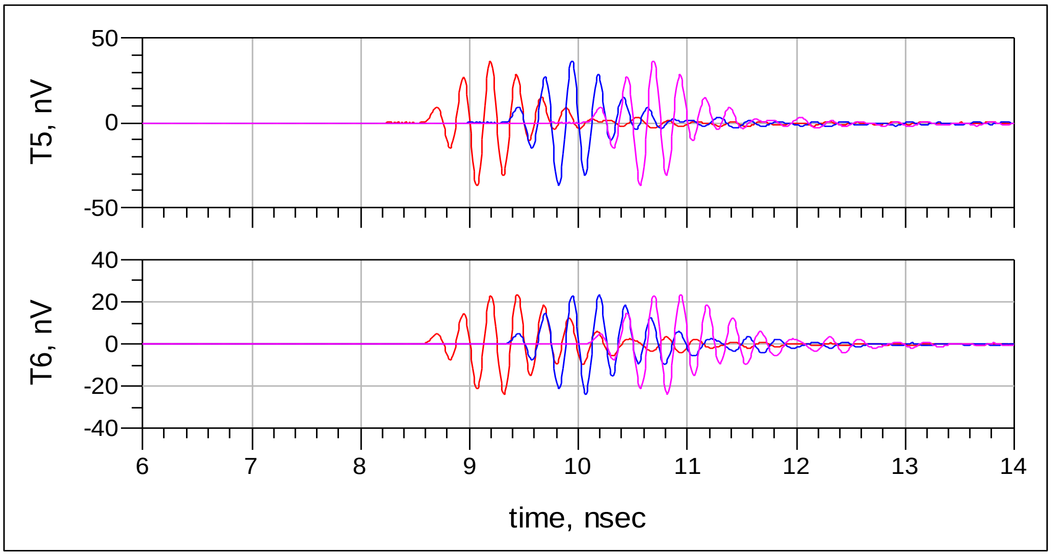


Figure 14: Temporal simulation of detected pulse by the receiver antenna

V. CONCLUSION

This paper proposed a model of the layers of human tissue to analyze an UWB radar system, taking into account the pulse transmitter, the transceiver antenna and a layered of the thorax, has been presented.

The interaction of UWB signals with the human body has been studied considering an incident UWB pulse on a layered model of the thorax. In the model, the frequency dependence of the dielectric properties of the tissues has been included.

The layers of human tissue simulation results constitute a step forward in the state of the art of vital signs monitoring when the radar is placed at a distance from the human body. The results show that the UWB pulse reflected from the skin-heart interface can be used to detect the cardio respiratory activity when the radar is placed at a distance from the human.

REFERENCES

[1] Stefano Pisa, Paolo Bernardi, Marta Cavagnaro, Erika Pittella, Emanuele Piuzzi, "Monitoring of cardio-pulmonary activity with UWB radar: a circuital model,"*19th International Zurich Symposium on Electromagnetic Compatibility*, 2008, Asia.

[2] Erika Pittella, Paolo Bernardi, Marta Cavagnaro, Stefano Pisa, Emanuele Piuzzi, "Design of UWB antennas to monitor cardiac activity," *Applied Computational Electromagnetics Society Journal* 04/2011.

[3] Marta Cavagnaro, Erika Pittella, Stefano Pisa, "Anatomical models of breathing subjects for absorption and scattering analysis," *Conference, EMC* Europe 2013.

[4] Moez Ketata, Mohamed Dhieb, Ghazi Ben Hmida, Hamadi Ghariani, Mongi Lahiani, "UWB pulse propagation in human tissue: Comparison between Gaussian and square waves shape," 1*6th International Conference on Sciences and Techniques of Automatic Control and Computer Engineering (STA)*, 07 July 2016.

[5] Faheem Khan and Sung Ho Cho, "A Detailed Algorithm for Vital Sign Monitoring of a Stationary/Non-Stationary Human through IR-UWB Radar," *Sensors (Basel)*, 4 February 2017.

[6] M. Cavagnaro, E. Pittella, S. Pisa, "UWB pulse propagation into human tissues,"*Physics in Medicine and Biology*, 22 November 2013.

[7] Kedar Nath Sahu, Challa Dhanunjaya Naidu, M. Satyam, and K. Jaya Sankar , "Study of RF Signal Attenuation of Human Heart," *Journal of Engineering*, 2015.

[8] Erika Pittella, Anna Bottiglieri, Stefano Pisa, and Marta Cavagnaro, "Cardiorespiratory Frequency Monitoring Using the Principal Component Analysis Technique on UWB Radar Signal ," *Hindawi International Journal of Antennas and Propagation*, *2017*.

[9] Moez Ketata, Mohamed Dhieb, Mondher Chaoui, Mongi Lahiani and Hamadi Ghariani, "Electric field attenuation of an Ultra-Wide Band wave (UWB) during propagation in the human body," *International journal of Sciences and Techniques of Automatic control & computer engineering (IJ-STA)*, 2010.

[10] Kedar Nath Sahu, Dr. Challa Dhanunjay Naidu & Dr. K Jaya Sankar, "Frequency Dependent Planar Electromagnetic Modeling of Human Body and Theoretical Study on Attenuation for Power Budget Estimation of UWB Radar," *Global Journal of Researches in Engineering: F Electrical and Electronics Engineering*, 2014.

[11] Graziano Varotto and Enrico M. Staderini, "On the UWB medical radars working principles," *International Journal of Ultra-Wide Band Communications and Systems*, October 2011.

[12] Florian Thiel, Olaf Kosch and Frank Seifert, "Ultra-Wide Band sensors for improved magnetic resonance imaging, cardiovascular monitoring and tumour diagnostics," *Sensors*, 2010.

[13] Paolo Bernardi, Renato Cicchetti, Stefano Pisa, Erika Pittella, Emanuele Piuzzi, and Orlandino Testa, "Design, realization, and test of a UWB radar sensor for breath activity monitoring", *IEEE Sensors Journal* , October 2013.

[14] Taoufik Elmissaoui, Nabila Soudani, Ridha Bouallegue, "Optimization of the UWB radar system in medical imaging," *Journal of Signal and Information Processing,* Auguest 2011.

[15] S. Pisa, P. Bernardi, M. Cavagnaro, E. Pittella and E. Piuzzi, "A circuit model of an Ultra-Wideband impulse radar system for breath-activity monitoring, " *International Journal of Numerical Modeling: Electronic Networks, Devices and Fields*, 2012.

[16] Houda Werfelli, Mondher Chaoui, Mongi Lahiani and Hamadi Ghariani, "UWB Excitation Pulse for Rectangular Patch Antenna," International *Journal of Sciences and Techniques of Automatic control & computer engineering (IJ-STA)*, July 2016.

[17] H. Werfelli, M. Chaoui, M. Lahiani and H. Ghariani, "Design of 3.1-5.1 GHz Pulse Generator for UWB Communications,"*16th International Conference on Science and Techniques of Automatic Control & Computer Engineering (STA)*, December 2015.

[18] Antonio Lazar, David Girbau and Ramon Villarino, " Techniques for Clutter Suppression in the Presence of Body Movements during the Detection of Respiratory Activity through UWB Radars, "*Sensors* , 2014.

[19] Shankar Siva, Daniel Pham, Suki Gill, Mathias Bressel , Kim Dang, Thomas Devereux , Tomas Kron and Farshad Foroudi," An analysis of respiratory induced kidney motion on four-dimensional computed tomography and its implications for stereotactic kidney radiotherapy," *Radiation Oncology* , 2013.