ABSTRACT

Simulation of Dynamic On-body Wave Propagations: Comparison with Measured Values

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Wireless body area network (WBAN) technology shows potential for improving human quality of life by facilitating remote, long-term health monitoring. Designing small, wearable, and power efficient on-body WBAN sensors requires an understanding of electromagnetic (EM) wave propagation behavior on and around the moving human body. This thesis describes research using a phantom body model in CST software to simulate EM wave propagation between antennas mounted on moving humans. The model is directed by body motion data collected from motion capture experiments. The experiments and simulations cover a range of conditions common in daily life, including various motion activities, body sizes, and antenna placements. The simulations are tested by comparison with on-body EM signal data collected simultaneously with the motion capture data. The simulation results captured the key features of the EM propagation characteristics, thus the simulation framework shows promise for guiding the design of highly-efficient antennas needed for WBAN technology.

Simulation of Dynamic On-body Wave Propagations: Comparison with Measured Values

by

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DEDICATION

To my family, who have supported me throughout all my life’s endeavors.

CHAPTER ONE

Introduction

1.1 Applications of Wireless Body Area Networks (WBAN)

Imagine if a loved one suffered from a sudden medical emergency. Wouldn't you like to know that they would receive timely and appropriate medical care? In 2003, 16.2 million patients arrived at medical emergency departments via ambulance in the United States, which was about 31 ambulances arriving per minute (Burt 2006). The vast amount of ambulance arrivals shows how often medical emergencies can occur and why it is important that there are ways to ensure that any medical emergency is quickly detected in order to prevent the worsening of a medical incident. WBAN is a technology that can greatly improve human quality of life by enabling long-term health monitoring by which health anomalies can be detected and responded to in a timely manner.

1.1.1 Wireless Body Area Networks

WBAN systems can be implemented in many ways. For health monitoring, they are often implemented as a variety of sensors that a patient wears throughout the day, such as a heart rate monitor, a blood pressure sensor, or a motion sensor. Ideally, these sensors will be small and power efficient in order to prevent physical nuisances to the wearer and excessive time spent charging the devices. The sensors worn by the user will continuously transmit their collected health data, such as blood pressure or heart rate, wirelessly to a control unit that is also worn by the user. The control unit can be implemented in a WBAN system in many ways, such as a discrete unit that collects and transmits the collected health data or via a cell phone application compatible with the on-body sensors. Regardless of the control unit's implementation in the WBAN system, its role is the collection of the health data being transmitted by the on-body sensors and then transmission of the data over the internet to a medical facility where the data can be continuously monitored for any anomalies. If any sudden, abnormal changes in the health data are detected, such as a sudden increase in heart rate or motion patterns indicating a fall, then the medical facility will know to send medical aid.

1.1.2 WBAN Design Factors

An optimal WBAN system will use small, unobtrusive on-body sensors that are very long lasting. These two design factors are very important due to the need for patient compliance in wearing the on-body sensors and maximizing the up-time of the WBAN system in order to allow for constant health monitoring to ensure health anomalies are detected. The less the sensors affect the user's daily life, such as by causing discomfort when worn, feeling the weight of the sensor, or negatively impacting the user's aesthetic confidence, the more likely the WBAN system will be worn as prescribed in order to maximize health monitoring time, which prevents any medical emergencies from slipping through undetected if the user chose not to wear their sensors for any reason.

The same logic of wanting to maximize the time that the on-body sensors are worn can be applied to the need for long lasting sensors, specifically in terms of battery life. Antenna design for the on-body sensors must be optimized so little power is expended during the data transmission from the sensor to the control unit. By increasing power efficiency, the duration of time before the on-body sensors need to be recharged for use will also increase. Reducing the amount of the times the on-body sensors need to be recharged will reduce the chance that the user will forget to charge their sensors and be left without their WBAN system to help monitor their health. Additionally, increased power efficiency would allow for smaller battery sizes to achieve similar up-time, which assists with accommodating the design factor of reducing sensor size. It is clear that increased power efficiency is a solution to reducing size and increasing battery life of on-body sensors. The key to increasing power efficiency for the purpose of designing usable and practical WBAN sensors is understanding on-body wave propagation.

1.1.3 Challenges with WBAN Design – On-body Wave Propagation

In order to optimize on-body sensor antenna design and WBAN design, one must first understand electromagnetic (EM) wave propagation along and around the human body. Studying on-body wave propagation is essential in order to predict how EM waves will behave on the human body, which can greatly impact antenna performance. In the case of the WBAN system described in this paper, the transmitting antenna represent the on-body sensors and the receiving antenna represent the control unit. There are several ways that the EM signal between transmitting and receiving antenna can be affected by the human body. The three main factors are line of sight, wave scattering (echo), and the creeping wave, which can be seeing in Figure 1.1. It is very important to study the effect the human body has on these three wave transmission mechanisms when the body is static and when the body is in motion to understand how antenna performance will be affected in various scenarios.

Since the human body is a dynamic object that is generally in motion, the positioning of the various parts of the body, such as the arms and legs, will be in different positions and can change position fairly quickly. Changes in body position can affect the line of sight between antennas, wave scattering, as well as the optimal creeping wave path. It is possible that even slight changes in body position can significantly impact the optimal EM wave path, which is why studying on-body wave propagation in order to understand the patterns and paths that the on-body EM waves use to propagate on the human body is important.

In this study, there is significant focus on studying the creeping wave along the human body in order to predict how the creeping wave behaves during dynamic human motion. Gaining insight into the behavior of on-body wave propagation will allow for optimized antenna design for on-body sensors used in WBAN systems. Optimizing antenna design will enable reduced sensor size and increased power efficiency, which will allow for practical WBAN systems to be implemented to help improve human quality of life, specifically in the field of long term health monitoring.

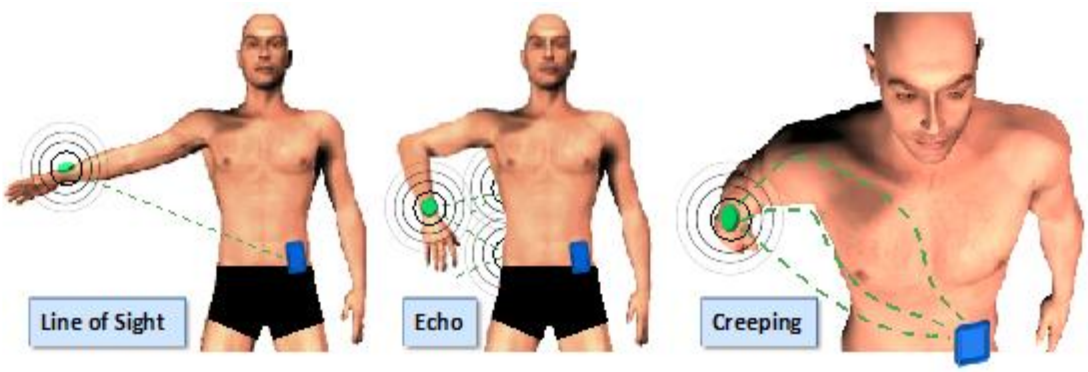

Figure 1.1. Factors Affecting On-body Wave Propagation: line of sight, wave scattering (echo), and the creeping wave

1.1.4 Simulation of On-body Wave propagation

Many previous studies, which will be discussed in further detail in Chapter Two, have sought to understand on-body wave propagation through experimental methods. These techniques generally involved either a human volunteer or a phantom body model wearing a transmitting and receiving antenna to collect point-to-point transmission loss data between the two antennas. However, these experimental methods have several limitations.

One critical limitation is that these experimental data collection techniques can only give insight on point-to-point transmission loss between the transmitting and receiving antenna. This data, while valuable, would not give a complete picture of the pathways EM waves travel on the human body. The point-to-point data would only show how the signal strength between the antennas behaves at the points where the antennas are placed, and not which pathways around the body they travel. Additionally, due to the need for physical antenna to be worn to collect transmission data, certain positions on the body may impede motion, which makes transmission data collection for certain human motions difficult based on what antenna placements are desired.

Another limitation of experimental methods of studying on-body wave propagation is time. Since collecting data can be time consuming, it can be difficult for data to be collected for all experimental configurations, such as varied antenna frequencies, antenna positions, antenna types, or human motion activities. Performing extensive experimental trials with many motions and antenna configurations would be a way to alleviate some of the point-to-point limitations of experimental methods, but this would still be very time consuming.

Simulation methods can be very valuable to help overcome some of the limitations of purely experimental methods for studying on-body wave propagation. Using a simulation model of the human body, it is possible to simulate the transmission pathways around the human body in order to determine which paths are optimal. This would provide more than just a point-to-point analysis of the signal pathway between transmitting and receiving antennas. In addition, due to the use of a simulation model, the time constraint limitation, especially if using human volunteers, will not be an issue. This would allow for the simulation of whatever motions, antenna frequencies, antenna positions, and antenna types as needed to study on-body wave propagation.

The human body simulation must have its accuracy verified in order to trust the results of the simulation model. Verification of the simulation model can be done by using experimental data collection techniques to collect transmission data between a transmitting and receiving antenna at various frequencies and positions on the human body. This point-to-point transmission data can then be used to compare to the simulation results of signal strength using antenna parameters and a size scaled human body model to match the experimental techniques. If the signal strength matches for the experimental data and simulation results, then the simulation model is verified. Verification of the simulation model allows for the in-depth study of on-body wave propagation due to the simulation's ability to simulation transmission data beyond the point-to-point data that experimental techniques yield.

1.1.5 Use of Experimental and Simulation Methods to Optimize WBAN Systems

Using an experimentally verified simulation model allows on-body wave propagation to be thoroughly studied. Comparison of measured and simulated signal strength (S_{21}) can be performed for verification purposes. Finding which pathways around the human body are optimal during certain scenarios and body motions will provide great insight into on-body antenna design. Optimal on-body antenna design enables the design of small and power efficient on-body sensors. This allows for practical and easy to use WBAN systems to be used, which can significantly improve human quality of life. The goal of this study is to combine experimental and simulation methods for studying on-body wave propagation in order to optimize WBAN design.

1.2 Thesis Overview

This thesis is organized as follows. Chapter Two will discuss the background of study, referencing previous works from other research groups. Chapter Three will discuss our study's materials and methods, both experimental and simulation. Chapter Three will also go in-depth about the simulation model and the model parameters. Chapter Four will show the simulation results compared to experimentally measured data. Chapter Five will be a discussion of results and factors affecting that could affect the results. Chapter Six will be a conclusion and proposal of future work based on our study's findings.

The contribution of our study will be the creation of a simulation framework that can be used to simulate on-body wave propagation, which has valuable applications in studying entire EM pathways around the human body beyond just point-to-point analysis. This model will be verified using experimentally measured on-body wave propagation data, specifically S_{21}, the signal strength between the transmitting and receiving antenna. The model will be controlled using motion capture that is synchronized with the experimental data to ensure a proper comparison between the simulation model and measured data can be made. The simulation model accuracy being verified using as direct comparison to a moving human body as possible allows for future work to be done using the model for simulating entire EM wave pathways.

CHAPTER TWO

Background

The study of on-body wave propagation generally has three main focuses, experimental measurement, theory, and simulation. The focus of this study is simulation of on-body wave propagation using experimental measurement as a verification tool. Many previous studies have used experimental measurement and simulation in order to gain insight on on-body wave propagation, which will be described in this chapter.

2.1 Experimental Study of On-body Wave Propagation

Using experimental measurement to study on-body wave propagation has yielded valuable knowledge about on-body wave propagation. Many experimental parameters have been studied, such as antenna placements and antenna type/frequency. Several previous measurement-based studies and their findings will be discussed.

Zedong et al. (2011) performed a study using human volunteers wearing transmitting and receiving antenna in various positions on the human body. Antenna positions used were placing transmitting and receiving antenna on the human forearms or calves (Zedong 2011). Additionally, several scenarios, both dynamic and motionless, were performed while wearing these antenna (Zedong 2011). This study is significant because of its study of multiple on-body channels.

Taparugssanagorn et al. (2010) performed experimental measurement of signal data for various human motions and body position relevant to hospital care. This study used static motions, such as standing still or lying down, and dynamic motions, such as walking and eating while lying down (Taparugssanagorn 2010). A VNA and antennas were used to collect channel data, with an antenna placed on the chest and left wrist (Taparugssanagorn 2011). However, even during dynamic motions, the data was measured in a pseudo-dynamic method by having pauses during each motion to allow for processing of the 3.1-10 GHz frequencies to be measured (Taparugssanagorn 2010). This study is significant because of its use of relevant motion activities from a hospital environment to measure signal loss on the human body.

Yamamoto et al. (2013) created a physical phantom model of the human body to study on-body wave propagation. The phantom model was constructed out of 3-5 mm thickness polypropylene shaped to be similar in size of structure of a human body (Yamamoto 2013). Key features include the distinct construction of shoulder pieces on the phantom model and the ability for the arms to swing like a human arm swing during walking (Yamamoto 2013). Half-wavelength dipole antennas were used to measure path loss during motion of the phantom model (Yamamoto 2013). The phantom model was used to study the effect of arm swinging on the signal performance of on-body devices (Yamamoto 2013). This study is significant because of its use of a physical phantom model to allow for easy to replicate experimental data.

2.2 Simulation Study of On-Body Wave Propagation

Simulation methods can provide similar insights into on-body wave propagation as experimental techniques, but also have the potential to allow for simulation of entire EM pathways. Measuring the signal loss along an entire pathway on a physical human body would be cumbersome and extremely time consuming, which is not ideal, especially since a human volunteer would be need to devote large amounts of time to data collection. Many previous studies have used simulation methods to study on-body wave propagation in lieu of measuring signal loss experimentally. Additionally, some studies used experimental data to validate their simulation models.

In a series of studies by Gallo et al. (2008, 2011), on-body wave propagation on a dynamic human body was studied using human phantom models to simulate signal data. In the first study, it was determined that even slight movements of the human body would significantly affect signal loss (Gallo 2008). Gallo et al. (2011) utilized Poser models for their simulation methods at 2.45 GHz. Additionally, measured S_{21} was collected by performing simple motions, such as walking, while wearing antennas and using a VNA and the simulation and measured data were compared by having the human volunteer imitate the motion and rhythm of the simulation model (Gallo 2011). This study is significant because of its use of measurement for simulation validation.

A study by Iswandi et al. (2011) compared simulation results of two models of vastly different model complexity. One model was a simplified model consisting of simple geometric cylinders while the other model was a Poser model, which is a very detailed rendering of the human form (Iswandi 2011). This study was significant because comparing human phantom models of varying complexities is important in order to optimize simulation efficiency, since computing power and time is often the limiting factor for how accurate or fast a simulation can be.

Uusitupa et al. (2013) used animation software and voxelizing code to create a human phantom model for simulation. This model was a more complex model, more similar to Poser models than the simplified models used in our or Iswandi et al.'s study. It can be seen that using the more complex model resulted in higher simulation times, since each frame of simulation took two hours with an eight core computer (Uusitupa 2013), while in Chapter Three, our methods of reducing simulation time will be discussed. This study performed simulation of the EM field on the human body for three motions, which were walking, weakly walking, and running (Uusitupa 2013). Uusitupa et al. (2013) were able to understand polarization and reception on the human body using their simulation method. This study is significant because of its use of relevant motion activities and use of complex modeling to create a phantom model.

Swaisaenyakorn et al. (2014) sought to study the effect of human motion on on-body wave propagation. Similar to Gallo et al. (2011), this study utilizes simulation methods and experimental validation (2014). Using motion capture and 3D body scans, Swaisaenyakorn et al. (2014) were able to create avatars for use in simulation that closely resembled the likeness of the human volunteers performing the experimental trials. Using walking motions, the avatars were used to simulate S_{21} for various right wrist to left chest and right wrist to right hip antenna configurations and used outside data from similar motions and antenna placements to validate the avatar models (Swaisaenyakorn 2014). This study is significant because it uses motion capture methods to create simulation models.

Paraskevopoulos et al. (2013) performed a study that simulated signal loss during various motions in order to gain insight on the waist to foot channel. The study used two types of printed antennas (inverted-F and microstrip patch) and simulated walking and running motions (Paraskevopoulos et al. 2013). The study used software tools to create realistic phantom models rather than simplified models (Paraskevopoulos et al. 2013).

This study was significant because of its use of multiple antenna types and comparison of signal loss for the various antennas for relevant human motions.

Fujie et al. (2013) utilized the Microsoft Kinect to create a voxel model for simulation of propagation channels on the human body. The voxel model was a simplified human body model consisting of rectangular prisms and cylinders (Fujie 2013). This study was significant because it used motion capture techniques to create a simplified human body model.

Liu et al. (2011) utilized measurement and simulation to study on-body wave propagation. The experimental set-up sought to study the wave propagation using measurable geometry of the body during motions (Liu 2011). The channel distribution on the body was explained using the human body's geometry (Liu 2011). A cylindrical scatterer represented the human body, which was used to simulate on-body channel data and was able to achieve good agreement with the measured results (Liu 2011). The study was significant due to its study of the human geometry and its potential effects on channel performance.

2.2.1 Static On-body Wave Propagation

The study of static on-body wave propagation is a necessary step that comes before understanding dynamic on-body wave propagation. A previous study by Xue et al (2015), revealed many insights about static on-body wave propagation and how the creeping wave on the human body can be modeled for simulation through a combination of simulation and experimental techniques. Xue et al. (2015) collected experimental data of the signal loss between a transmitting and receiving antenna on the human torso. The transmitting antenna was placed on the chest, while the receiving antenna was placed at various positions wrapping around the torso at the same height as the transmitting antenna. This set-up allowed for the study of the on-body creeping wave around a segment of the human body moving the receiving antenna around the torso would capture the EM wave signal at various points along the creeping path along the body. Xue et al. (2015) also used simulation methods in FEKO to simulate the human torso as a finite-height, simple geometric cylinder that was sized to match the human volunteer's torso from the experimental trials. Xue et al. (2015) found that using the cylinder for simulation of the torso with transmitting and receiving antennas placed to match the experimental setup was able to agree with the experimental measurements as well as theory for static on-body wave propagation. This showed that using cylinders to model segments of the human body is an accurate and able to model the creeping wave around segments of the human body, which is part of the basis of our study using cylindrical segments to construct the human body phantom model used in our study.

2.3 Summary of Previous Works

There have been many previous studies that studied on-body wave propagation. Most studies have used singular methods of study, either experimental measurement or simulation, while some studies have combined these methods. The goal of most studies was to understand optimal channel performance on the human body, often for applications in WBAN. Both experimental and simulation based studies focused on either measuring or simulating channel performance on the human body. Our study seeks to improve upon previous works by using more motion activities and antenna configurations to gain a broader database of channel data and motion data that can be used to extensively verify simulation results and models. Our study builds upon these previous works by combining experimental and simulation methods towards the goal of using measured results to verify our simulation model, which can allow for in-depth study of entire EM pathways.

CHAPTER THREE

Materials and Methods

This study combined experimental and simulation methods in order to study on-body wave propagation. The experimental methods were used in order to measure signal strength, specifically S_{21}, during human motion. The simulation methods were used in order to develop a simulation framework that can be used to simulate on-body wave propagation. For the purposes of this study, the simulation framework produced simulation results in the form of S_{21}, which could then be compared to the measured values collected from the experimental methods. The comparison of measured values and simulation will be discussed further in Chapters Four and Five.

3.1 Experimental Methods

Experimental data collection was performed in order to create a data base of transmission and motion data. The transmission data and motion data needed to be time synchronized in order for proper comparison with simulation results, which will be discussed later in this chapter.

The two key components of the experimental set up were the motion capture system and the vector network analyzer (VNA). The Phasespace Improv eight camera motion capture system was used to collect motion data while the VNA, a 2-port Agilent N5230C PNA-L Network Analyzer, was used to collect transmission data (signal strength or S_{21}) between transmitting and receiving antennas.

3.1.1 Experimental Materials

In the Baylor IRB approved experimental procedure, motion and transmission data was collected using human volunteers in order to study on-body wave propagation. The human volunteers wore a tight fitting body suit and cap that was lined with 38 active motion capture markers according the Phasespace's recommended marker set up for a human skeleton. General information about the human volunteers, such as gender, height, and weight, can be found in Table A.1. The volunteers also wore a set of transmitting and receiving antennas, which were quarter-length monopoles mounted on metal ground plates. The ground plates had folded edges in order to allow the antenna to be mounted on Velcro attachment points on the body suit. The antennas were mounted on a 4 cm x 4 cm flat area on the ground plate that was also 1.5 cm above the human body surface. These antennas were connected to the VNA with 3-meter long Workhorse Plus 524 cables.

Figure 3.1. Motion capture set-up, Vector Network Analyzer (VNA), and Bridge Monopole Antenna

3.1.2 Experimental Test Configurations

The key variations between each experimental test configuration that the human volunteers performed were motion activity and antenna configuration. Various motion activities were performed in order to simulate common daily activities, and to determine if on-body transmission loss would be affected by different motions. The different antenna configurations changed the positions of the transmitting and receiving antenna on the human body in order to simulate common WBAN sensor configurations.

The six motion activities that each volunteer performed were a left arm swing motion, a both arm swing motion, a boxing motion, a rowing motion, sitting and rising from a chair, and hopping. These motions were chosen because several are common motions that are performed by people daily, such as swinging of the arms while walking, and other motions are commonly used in fall detection studies, such as the chair activity (Bian 2015).

The three antenna configurations used were placing the transmitting antenna on the chest and receiving antenna on the back (chest/back), placing the transmitting antenna on the chest and receiving antenna on the left wrist (chest/left wrist), and placing the transmitting antenna on the right wrist and receiving antenna on the left wrist (both wrists). These antenna configurations were chosen in order to study the effect on on-body transmission loss between different points on the human body. Having antenna cases where the antennas don't move, such the chest/back configuration, and where antenna do move, such as the chest/left wrist and both wrists configurations, also allowed for further insight on how the creeping wave can be affected by motion.

3.1.3 Experimental Data Collection Procedure

The first step of the experimental data collection procedure was to calibrate the motion capture system and VNA. The eight camera motion capture system was placed in a circular pattern of approximately 12 ft in diameter with each camera spaced evenly along the circumference of the circle. The cameras were calibrated using the Phasespace calibration software and calibration wand. The VNA was calibrated at the desired frequency of 433MHz using SmartCal calibration software. The motion capture system and the VNA had their data collection start time synchronized by connecting them using a switch. The motion capture system was set to capture at 120 fps and the VNA had its sweep set to collect 120 data points per second. A common trigger initiated recording in both systems so the data was synchronized

Seven human volunteers participated in the experimental data collection procedure. Each data collection session with the volunteers used the following format. The volunteer put on the body suit and cap with the motion capture markers. Once the suit was on, the markers were moved accordingly to match up with the correct landmarks on the body, such as the hip or elbow joint bones, due to the different size of each volunteer.

The volunteer performed skeleton training in the motion capture system that was guided by the researchers in order to ensure the correct motions were performed and were captured by the camera system. The skeleton training consisted of motions that moved the wrists, elbows, knees, hips, and ankles in flexion, extension, abduction, adduction, and circumduction to allow for each key joint to be recognized by the Phasespace motion capture software.

After having each motion (left arm swing, both arm swing, boxing, rowing, chair sitting/rising, hopping) demonstrated, the volunteer performed each motion for 40 s to collect 40 s of S_{21} transmission data. This was done for each antenna configuration (chest/back, chest/left wrist, both wrists), meaning that each of the six motions were performed three times, once for each antenna configuration at 433MHz. The researchers moved the antennas to switch to the next configuration to ensure correct positioning and avoid motion capture marker occlusion that can be caused by the antenna ground plates.

3.2 Simulation Methods

Simulation of on-body wave propagation was performed using CST Studio Suite. Motion capture techniques combined with MATLAB code and a Visual Basic for Applications (VBA) macro for CST were used to create a human body simulation model in CST. The key factors allowing the CST simulation model to produce accurate comparison with experimental data were a scaled simulation model, accurate replication of experimental motions, and utilizing the simulation of discrete frames of time in CST.

3.2.1 Simulation Materials

Simulations were performed using CST Microwave Studio Suite 2014 and 2015. The computer specifications were an Intel Xeon CPU E5-2687W v3, 64GB RAM, and an Nvidia Quadro K6000 graphics card. Data processing for use in simulation was performed using Phasespace Recap2 motion capture software and MATLAB 2014 and 2015. VBA macro capability in CST was utilized for simulation model creation and simulation automation, which will be further discussed in this chapter.

3.2.2 CST Human Body Simulation Model

Due to the nature of this study, transmission and motion data was recorded for several human volunteers to create a database of experimental data for a variety of body types and both male and female subjects. However, as mentioned previously, there are limits to the knowledge that can be gained by solely relying on experimental methods. A simulation model can allow for the study of on-body wave propagation beyond point-to-point comparison of a transmitting and receiving antenna. In order to reliably use simulation methods to gain further insight into on-body wave propagation than current experimental methods, it is necessary to be able to compare simulation results to the experimentally collected data.

The first step towards allowing for reasonable comparison between simulation results and experimental data is creating a simulation model that can accurately represent the body of the human subject used to collect experimental transmission and motion data. This study used a human body phantom model consisting of ten simple geometric cylinders. Each cylinder represented a key part of the human body, such as the head, torso, upper arms, forearms, thighs, and calves. The size of each cylinder was scaled in diameter and length based on measurements taken from each human volunteer used to collect experimental data. For example, if a simulation using subject 1's motion data was performed, then the cylinders would be scaled to match subject 1's physical size based on the measurements of subject 1's body segments recorded during the experimental data collection procedure. This would allow for the simulation results of the model representing subject 1 to be compared to the experimental data collected by subject 1. In addition, due to the scaling of each key body component, such as the upper arms and forearms, the simulation model was a volunteer-specific model unique to each human volunteer's body.

The solid cylinders that were used to create the human body model were assigned homogenous muscle tissue properties. The key properties are a permittivity of 56.8 F/m and conductivity of 0.8 S/m. Homogeneous muscle tissue property was used to represent the EM properties of the human body due to previous studies that have the effectiveness of using muscle tissue property when simulating EM propagation on human body tissue (Hoeckel 2015, Xue 2015). The resulting 10 cylinder model can be seen in Figure 3.2, which depicts the 10 cylinder model performing frames of motion from the both arm swing motion, rowing motion, and boxing motion. Figure 3.3 shows the simulation model with an antenna and probe placed to match the experimental antenna configurations.

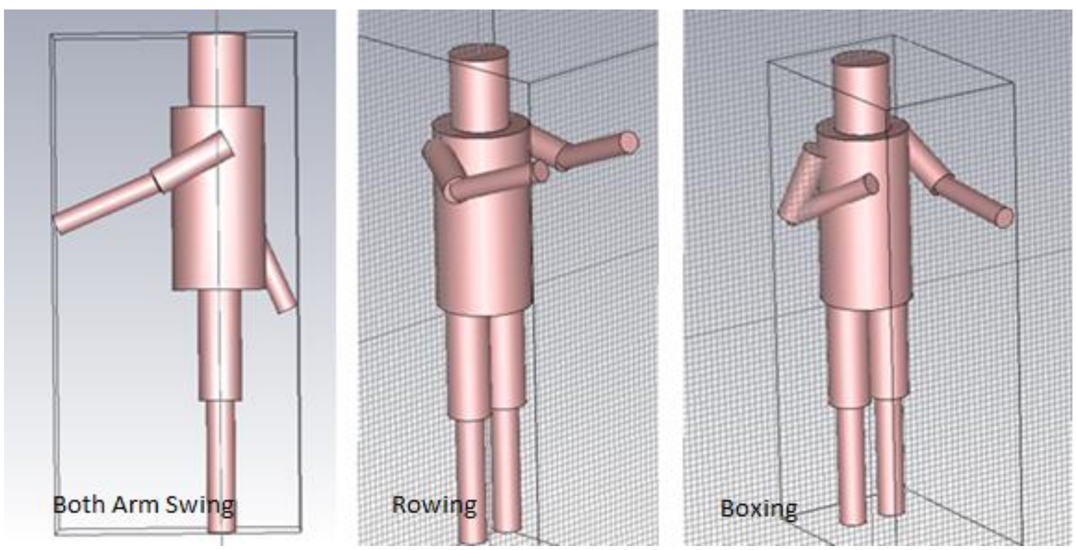

Figure 3.2. The 10 Cylinder Human Body Phantom Model Used for CST Simulation Performing Both Arm Swing, Rowing, and Boxing Motions

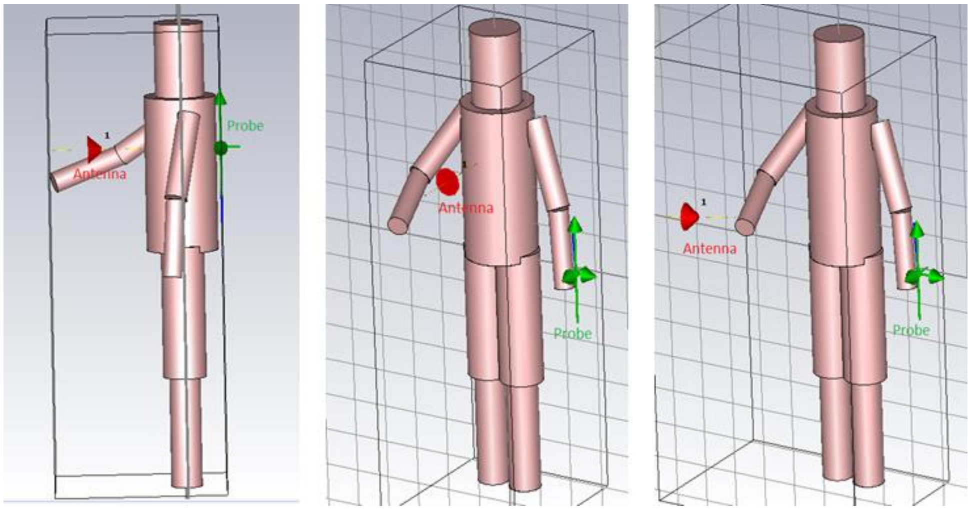

Figure 3.3. Comparison of Antenna/Probe Configurations (Chest/Back, Chest/Left Wrist, both Wrists) on the Ten Cylinder Phantom Model

3.2.3 Visual Basic for Applications (VBA) Macro in CST

A VBA macro, Construct Human, which can be found in Appendix B, was written to allow for the creation of the human body simulation model in CST. The macro allows for the user to define the sizes of each cylinder of the model. The use of a macro that takes custom inputs allows the human body model to be rapidly generated rather than manually generating a ten cylinder model each time a simulation is run, which significantly saves user time. The macro is also critical for automating the simulation of many frames of time in succession to simulate entire motions, as described later in this chapter. In addition, the macro can be modified to study the effects on simulation accuracy and efficiency caused by changing simulation model parameters, which will also be discussed later in this chapter.

3.2.4 Using Motion Capture to Replicate Motion in the CST Simulation Model

Due to the desire to simulate entire ranges of motion, it is necessary to allow the CST human body simulation model to perform motions that can be defined by the user.

In addition, as stated before, the model must be similar enough to allow for reasonable comparison between the simulated results and the experimental data. Thus, the motion that the simulation model performs must match the motion performed by the corresponding human volunteer.

The experimentally collected motion capture data provides a method for the simulation model to replicate the motions of the human volunteers. Using the motion capture system previously described, the motion from each experimental activity is recorded in .c3d format. The .c3d file can be read using PhaseSpace Recap2 motion capture software. Recap2 allows the motion capture markers from each frame of motion to be viewed.

In order to convert the motion capture marker data into a form that can be used to manipulate the segments of the CST human body model, a skeleton was created from the marker data using Recap2. Using the skeleton training file, Recap2 can identify each of the joints the body, such as the elbow or shoulder. Once the joints have been identified and are determined to be accurately placed after user review, then Recap2 can generate a skeleton model of the human body from the marker data in the .c3d file. Alternatively, a motion capture frame of the human volunteer in a neutral position, such as a T-position, can be used to directly generate a skeleton without skeleton training; however, this method may not always yield a skeleton with appropriately placed joints based on marker positions.

Once a Recap2 skeleton was created for the .c3d file, the data in the file was exported as a .bvh file. The .bvh file format is very convenient for the purpose of manipulating the movement of the CST simulation model because the .bvh file format stores the motion data in easily accessible joint angle format in Euler ZXY form. For each discrete frame of time the .bvh file provided the Z, X, then Y rotation in Euler form for each joint defined in Recap2. The joint angle form can be input to the previously mentioned VBA macro to automatically move the segments of the CST simulation model for as many motion frames as desired. Comparison of a frame of Recap2 skeleton model and the CST phantom model can be seen in Figure 3.4.

Fixed XYZ angle form is ideal for implementation in CST using the VBA macro. Thus, the joint angles from the .bvh file, which are in Euler ZXY form are converted to Fixed XYZ form using a custom MATLAB function, bvhEulerZXYtoFixedXYZ, which can be found in Appendix C. Due to the time constraints of simulation, not every experimentally captured frame of motion was used. The data collected was taken with the motion capture cameras recording at 120fps. The desired simulation sampling speed we used was 15fps. 15fps was chosen because preliminary testing of the simulation model results compared to experimentally measured data showed that 15fps provided enough resolution to capture the fluctuations and characteristics of the signal data; however, in some cases where signal response rapidly changed, 20fps was used in order to increase simulation resolution. In order to quickly convert the .bvh file data from 120fps to 15fps, a written MATLAB function, convertTO_Xfps, which can be found in Appendix D, was used. This function can reduce any original sampling rate to the desired rate, not just 120fps to 15fps, by reading through the data file and only keeping data at the appropriate time intervals (based on comparison of the desired fps and the original fps) to achieve the desired fps. For example, if the original file was recorded at 100 fps, and 10 fps was desired, convertTO_Xfps would read through the original file and keep only every tenth row of data to produce 10 fps. Due to the .bvh data conversion taking place in MATLAB, the data is stored in a matrix in MATLAB. A written MATLAB function, matrixTObvh, which can be found in Appendix E, takes the stored matrix of desired motion capture frames in Fixed XYZ from and converts the matrix into a text file. The text file can be read by the VBA macro to provide the motion data to CST human body model, fulfilling the role of the .bvh file.

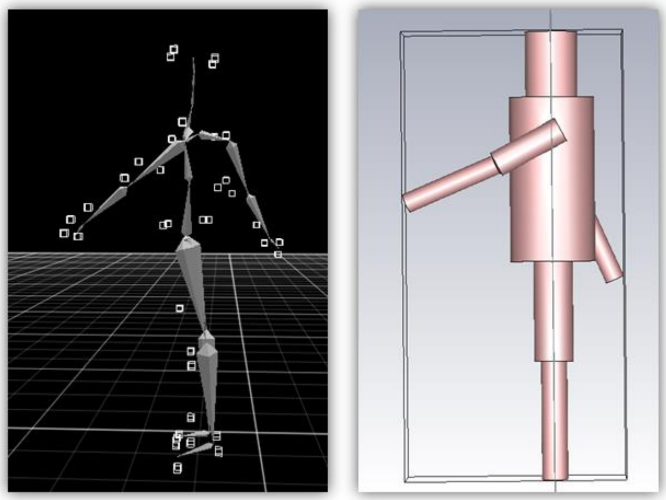

Figure 3.4. Comparison of Recap2 Motion Capture Skeleton and CST Human Body Model

3.2.5 Using Discrete Frames of Time to Simulate Whole Motions in CST

CST is able to simulate EM propagation only at discrete instances (frames) of time. CST was used to simulate a motion activity by simulating each motion frame in turn, and repeating sequentially frame-by-frame over the duration of the activity. Once each frame of time was simulated by CST, the human body model was moved into the next position in time, and the simulation was performed by CST for that frame of time. This was repeated until several seconds of motion had been simulated using the CST human body model.

The previously mentioned VBA macro was used in order to automate the process of simulating periods of time instead of discrete instances of time. The macro takes advantage of the format of the .bvh files. The .bvh files are formatted where the rows represent a frame of time, while the columns hold the joint angle data. The macro can easily take this data and put it in a matrix. After each frame of time is simulated, the macro deletes the human body model. After the model for the previous frame of time is deleted, the model for the next frame of time is created. This model is set to the correct joint angles for the current motion frame based on the matrix containing the time ordered joint angle data. Using the method described, the macro is able to continuously move the human body model into the correct position for the next sequential frame of time and perform the simulation of transmission loss for the activity in CST. Figure 3.5, from Hoeckel et al. (2015), shows how the physical motions performed by the human volunteer are represented frame-by-frame in CST.

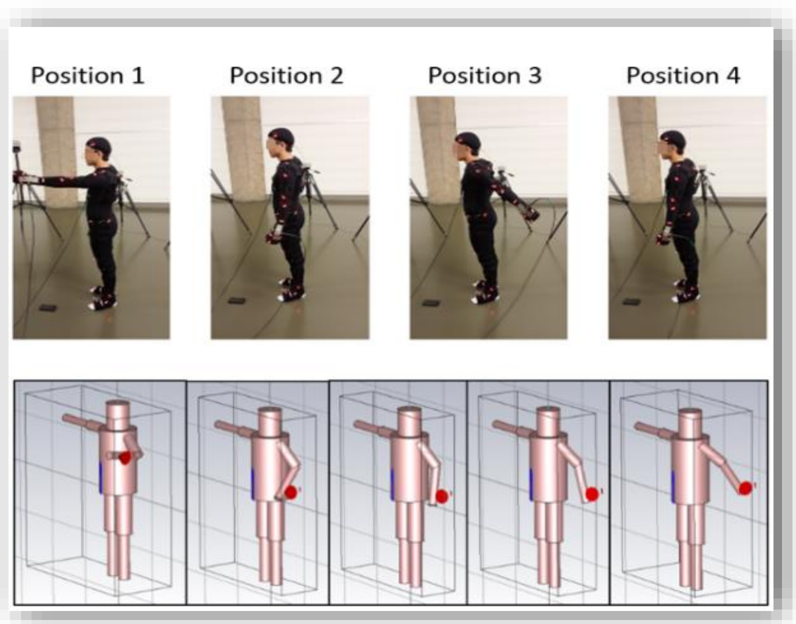

Figure 3.5. Simulation of Entire Motions Frame-by-Frame in CST

3.2.6 Simulation Results Extraction

The CST simulations were set to output a text file with transmission loss results for a set range of frequencies. For the case of this study, the range was 400-450 MHz. The transmission loss result for 433MHz was extracted from this file and used as the corresponding S_{21} (signal strength between antennas) for the frame of time that the human body model represented. The experimental frames of time corresponding to the S_{21} data points can be calculated by using the start time of the .bvh file, the frame number, and the simulation rate, 15 fps for this study. For example, since not every simulation starts from time 0 of the .bvh file, a simulation could start at 3 s in terms of the experimental data. Then, if the frame in question was the 20^{th} frame simulated, and the simulation rate was 15 Hz, then the frame in question would correspond to 4.3333 s in the experimental data.

3.3 CST Simulation Model Complexity and Parameters

While the model used to produce the majority of the simulation results was the previously described ten cylinder model, there are many parameters that were tested in order to strike a balance between simulation efficiency and simulation accuracy. Many parameters tested sought to enhance the realism of the model by smoothing out edges or adding additional segments to the body. Mesh density was another parameter that required optimization in order to reduce simulation time while retaining accurate results.

3.3.1 Mesh Density

The choice of simulation mesh density can have a significant impact on simulation results and efficiency. If the mesh is not refined or too refined for the model's needs, then results will be inaccurate. On the other hand, refining the mesh density will also significantly increase simulation time. Increasing simulation time decreases simulation efficiency because the time to simulate a motion frame will increase without producing any more accurate results. However, the decrease in simulation efficiency is necessary because accurate simulation results are the higher priority.

An experiment was performed in order to determine the optimal simulation mesh density. The optimal simulation mesh density is the least refined mesh possible that will still provide accurate and consistent results. In the experiment, a single frame of motion was simulated at varied mesh densities, starting from 10 line/wavelength and going up to 30 lines/wavelength. The model was scaled to the same size for each mesh density. The simulation time for the single frame of motion at each mesh density was recorded.

The simulation transmission loss for each frame was plotted against the corresponding mesh densities. The optimal mesh density was considered to be the lowest mesh density when the S_{21} values began to plateau, meaning a consistent result was obtained. This mesh density was considered optimal due to the convergence in S_{21} values signifying the stabilization of simulation results when the mesh density parameter is changed. The stabilization of simulation results implies the results should no longer be significantly affected by any further refinement of mesh, which then implies the results should be accurate and consistent for the model at the stable mesh densities. Choosing the lowest mesh density maximizes simulation efficiency since lower mesh densities reduce simulation times, which could range from less than 30 min/frame for less than 15 lines/wavelength up to over 3 hr/frame for greater than 25 lines/wavelength. Based on the experimental results, which can be seen in Figure 3.6, the mesh density of 20 lines/wavelength was optimal for the ten cylinder human body model. The optimal mesh density of 20 lines/wavelength is used for the rest of the simulation studies in order to maximize simulation efficiency without sacrificing simulation accuracy and consistency. 20 lines/wavelength was also optimal because of its general simulation time of 20 to 40 min/frame, which was a useable simulation time compared to higher mesh densities.

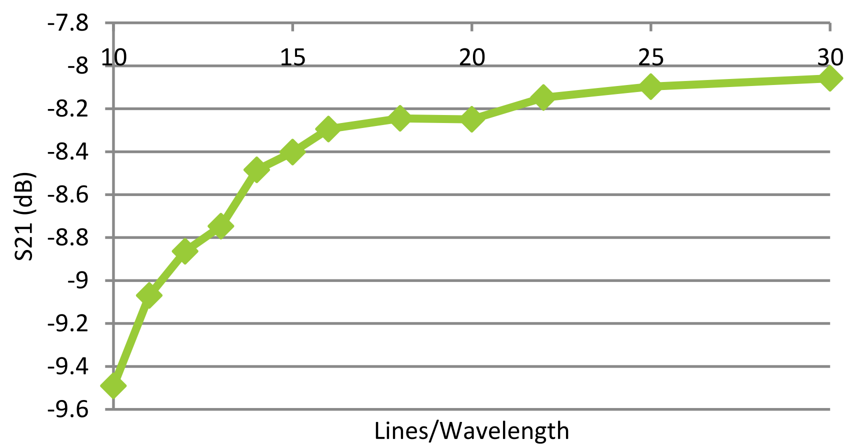

Figure 3.6. Mesh Density Convergence Test at 433MHz with 10 Cylinder Human Body Phantom Model

3.3.2 Human Body Model Complexity

The complexity of the human body model used for CST simulation was another important parameter that required optimization in terms of simulation results accuracy and simulation efficiency. Using a model consisting of ten simple geometric cylinders that are scaled to match the human volunteers' dimensions, while close to the physical shape of the volunteers, is not a completely accurate replication of the volunteers' likeness. The slight differences between the cylinder-based model and the actual shape of the volunteers has the potential to impact the ability of the simulated S_{21} to match the experimentally collected data. However, if model complexity is significantly increased to the point where the model almost perfectly replicates the human likeness rather than the general shape of the human body, then simulation time will drastically increase.

The two key model complexity parameters were studied; smoothing of cylinder edges and number of cylindrical parts used in the model. These parameters were studied because for this study of on-body wave propagation, the goal was not to create a model that perfectly matches a human body, such as in Poser. The goal of this study was to determine the effectiveness of the simple geometric cylinder model and to examine what potential changes to the model would increase accuracy while not significantly increasing simulation time.

The first parameter tested was smoothing of cylinder edges. This parameter was studied because the original ten cylinder model had gaps at each of the joints of the model. There was the potential that these gaps could significantly impact the on-body wave propagation in ways that the physical human body would not, such as changing the optimal creeping wave path through a gap or by changing the effects of wave scattering.

The method used to smooth the cylinder edges was placing scaled spheres in between the joints of the human body model. These spheres were mainly placed on the upper body that is where the focus of the simulated activities was. The model that was used to compare with the original ten cylinder model had spheres placed at both shoulder and elbow joints. The VBA macro was modified to create the smoothing spheres and place them at the appropriate joint spaces during each frame of motion. A comparison between the original model and the sphere-smoothed model can be seen in Figure 3.7.

An identical segment of motion was simulated using both the original model and the model with spheres. These results were both compared to the experimental data, which can be seen in Figure 3.8. Based on these results, it could be determined that the use of spheres to smooth the model edges did not significantly impact simulation accuracy. Additionally, simulation time was not significantly increased; however, due to the negligible change in simulation results, spheres were not used for the main simulation model used in this study.

The second model complexity parameter that was tested was model segments. The study of model segments took many forms, which included adding segments in an attempt to improve the model's likeness to the physical human motion and removing segments in order to increase simulation efficiency.

The main segments that were in consideration for being added to the original ten cylinder model were chest and shoulder segments, which would also have been implemented as size scaled, simple geometric cylinders. The goal of adding additional segments to the upper body was to capture more of the torso and shoulder motion that occurs during upper body based motions, such as rowing and boxing. Adding additional chest and shoulder segments is possible due to the .bvh file containing motion data for more body segments than are used in the ten cylinder model. The inclusion of chest and shoulder motion data in the .bvh file allows for the experimental motion to be replicated in the simulation model. If there was no further motion data available, adding additional segments and adding them to the motion of the model could not guarantee that the motion of the simulation model would match the experimental motions.

The VBA macro was modified to create four additional cylinders, one for each chest and shoulder segment. In addition, the macro was modified to account for the motion of these additional segments. The modification included proper rotation of the new chest and shoulder segments, as well as changing the attachment points. For example, the previous attachment point at the shoulder joint was connecting the upper arm cylinder to the torso cylinder, with the extra segments the attachment would be connecting the chest cylinder to the shoulder cylinder. The difference between models can be seen in Figure 3.9.

An identical subset of motion was simulated using the original ten cylinder model and the expanded model with additional chest and shoulder segments. The S_{21} simulation results for both models were compared to corresponding experimental data points. Based on the comparison of results, which can be seen in Figure 3.10, there is not a significant difference between the two models' simulation results and both show appropriate agreement with the experimental data. This result showed that both models were comparable in simulation accuracy and consistency. However, the expanded model takes up to 50% longer to simulate a single frame of time compared to the ten cylinder model, showing a noticeable decrease in simulation efficiency. Based on the result of comparable simulation accuracy and superior simulation efficiency, it was determined that the ten cylinder model was better suited for use in future simulations instead of the expanded model.

Removing segments was another facet of the parameter of model segments that was tested. In this case, the legs were removed from the model in order to reduce simulation time. It was found that removing the legs could reduce simulation time by around 33%, where frames could take less than 20 minutes to simulate compared to around 30 minutes with the original 10 cylinder model. The legless model variant compared to the original model can be seen in Figure 3.11. This was compared for motions that do not have antenna passing the legs, such as the boxing motion because the legs would be unlikely to have any wave scattering or creeping wave effect in these cases. However, in a motion such as both arm swing, where the arms pass the legs often if the antenna is on a wrist position, removing the legs could adversely affect simulation accuracy. A comparison of simulation results between the legless variant and the original model can be seen in Figure 3.12. Based on these results, it can be seen that for an upper body based motion, such as boxing, the legs on the model do not have much impact on simulation accuracy, while being able to save on simulation time.

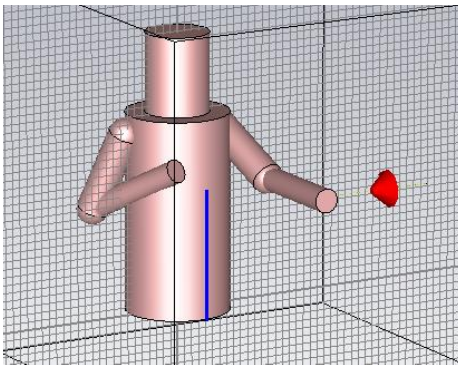

Figure 3.7. Legless Human Body Phantom Model Variant with Edge Smoothing Spheres

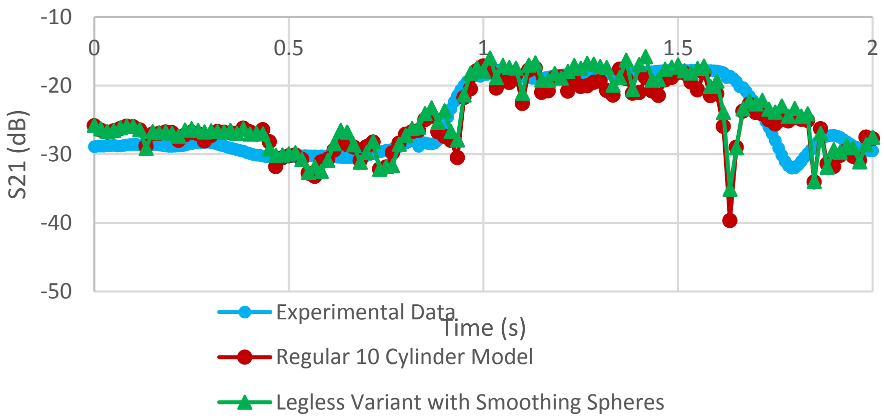

Figure 3.8. Comparison of Simulated and Measured S_{21} for Regular 10 Cylinder Model and Legless Variant with Smoothing Spheres for Boxing with Antenna on Chest/Left Wrist

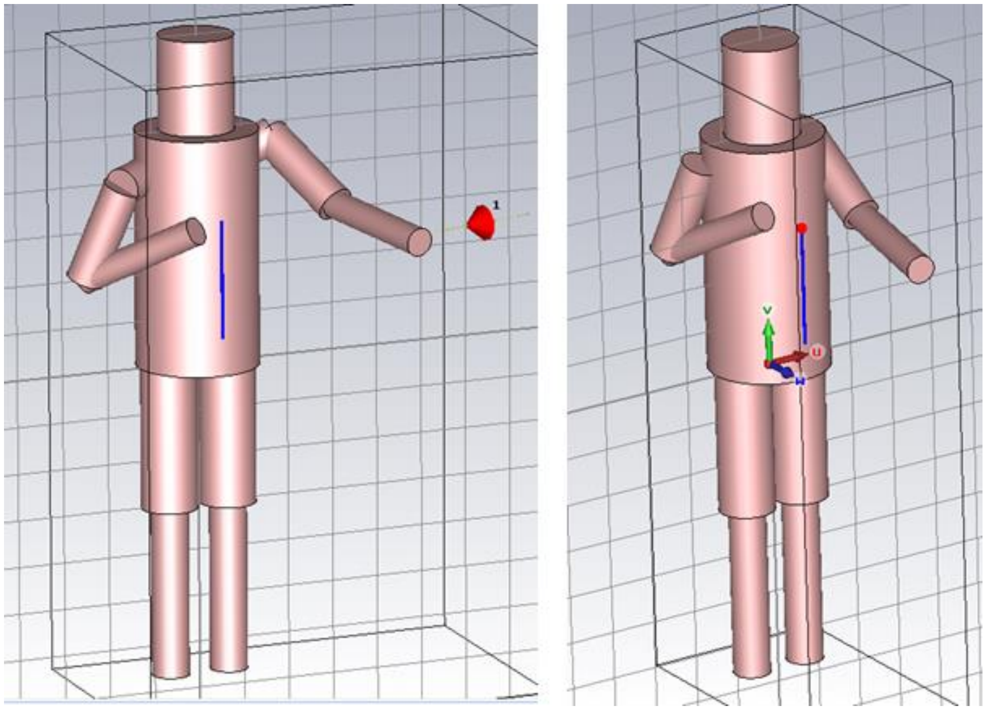

Figure 3.9. Comparison of 14 and 10 Cylinder Human Body Phantom Models

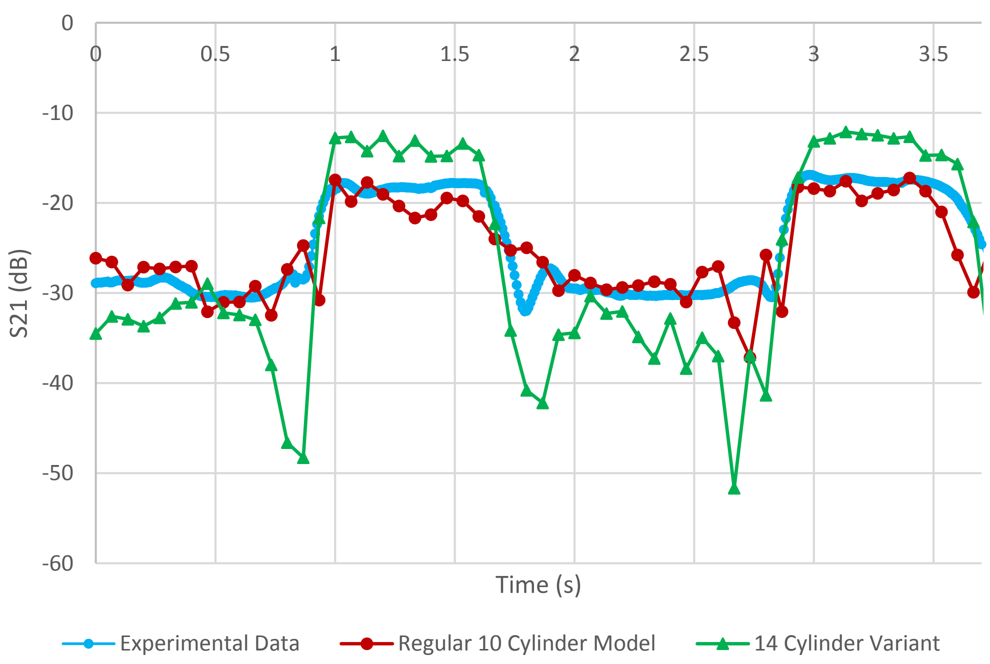

Figure 3.10. Comparison of Simulated and Measured S_{21} for 14 Cylinder Model Variant and Regular 10 Cylinder Model for Boxing with Antenna on Chest/Left Wrist

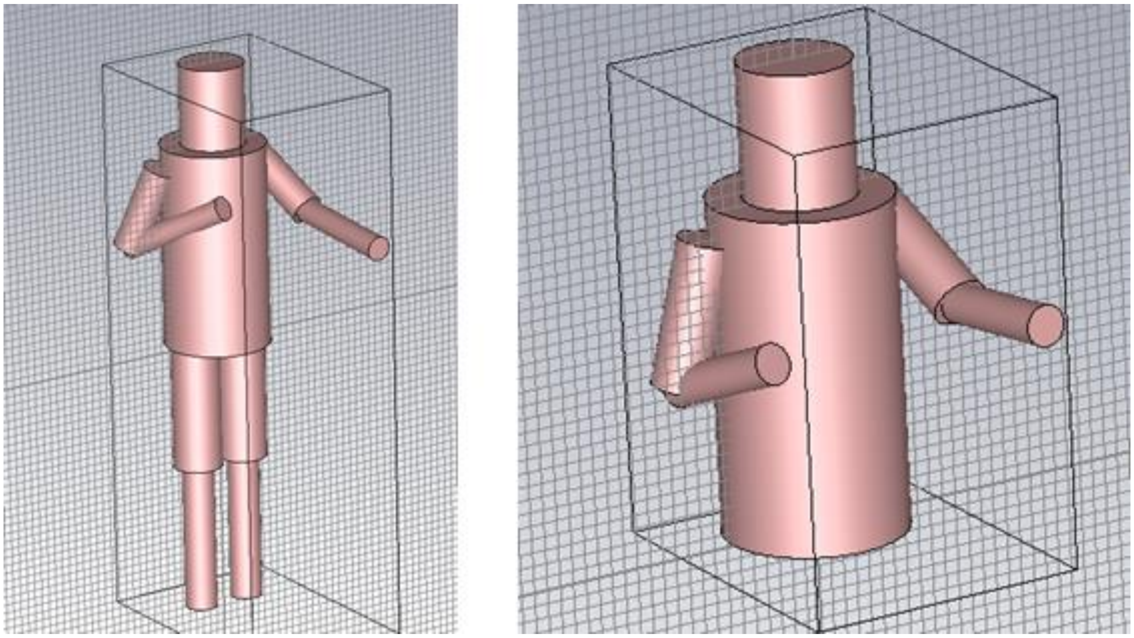

Figure 3.11. Comparison of Regular 10 Cylinder Model and Legless Variant

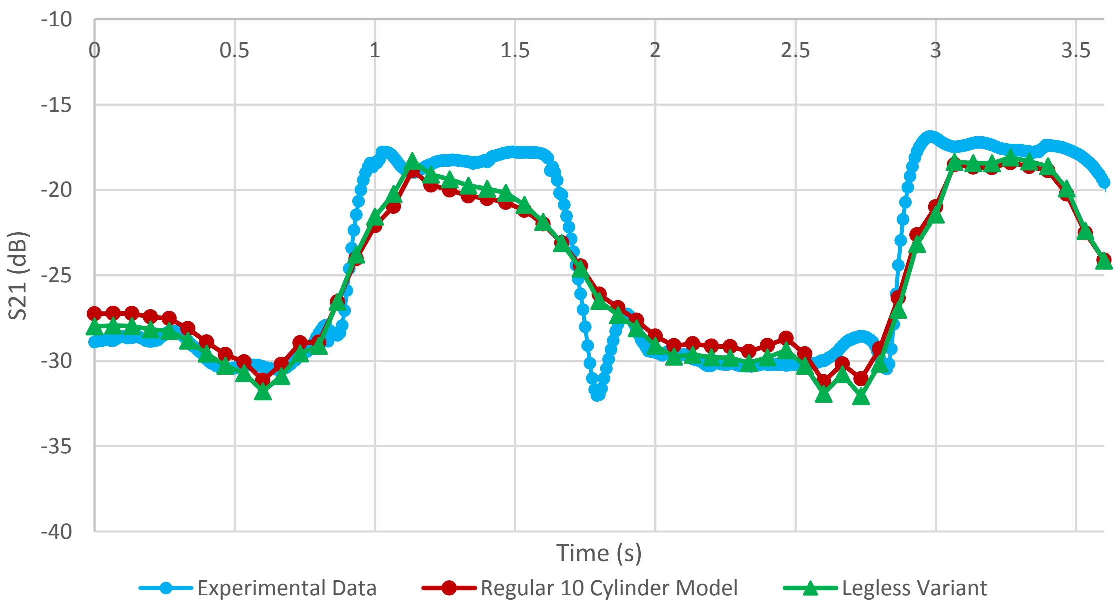

Figure 3.12. Comparison of Simulated and Measured S_{21} for Regular 10 Cylinder Model and Legless Variant for Boxing with Antenna on Chest/Left Wrist

CHAPTER FOUR

Results

4.1 Comparison of Simulated S_{21} to Experimental Data

In order to verify the accuracy of the previously described CST simulation model of the human body, a comparison between simulated results and experimental data was necessary. More specifically, a comparison of point-to-point on-body wave propagation was performed using data from a single transmitting antenna to a single receiving antenna. The simulation model had an antenna and probe placed on the model in positions corresponding to the experimental placement of the transmitting and receiving antennas.

The comparison of simulated S_{21} and experimentally collected S_{21} can be seen in Figures 4.1-4.18. S_{21} is the signal strength between the transmitting and receiving antennas. Each of these figures compare the simulated and measured S_{21} for a single motion activity and antenna configuration for a single human volunteer. For example, Figure 1 shows the comparison of results for subject 1, performing the both arm swing motion while using the chest/back antenna configuration. The results are organized by antenna configuration. An additional note is the simulated results are vertically shifted in order to be compared to the measured data. The vertical shift is applied in order to normalize the simulated results with the measured data. All of the simulated data points receive the same magnitude of vertical shift, which means the simulated signal loss patterns and trends will not be changed. The results presented represent a subset of comparison of simulation and experimental data using three human volunteers, two male and one female, two unique motions (both arm swing, boxing), and all three antenna configurations. Additional results comparing simulation and experimental data for other subjects and motions can be found in Appendix F, Figures F.1-F.9.

4.1.1 Antenna Configuration: Chest/Back

Figures 4.1-4.6 show the comparison of simulated and measured S_{21} for the antenna on chest/back antenna configuration for the both arm swing and boxing motions for subjects 1, 2, and 5. Figures 4.1-4.3 show results for both arm swing. Figures 4.4-4.6 show results for the boxing swing motion.

As shown in Figures 4.1-4.6, the agreement between simulation and measured data is very good, and in some cases, such as Figure 4.1, it is a near perfect match for the both arm swing motion. While there is good agreement for most cases, there are still discrepancies between simulation and measurement, which will be discussed later in this chapter.

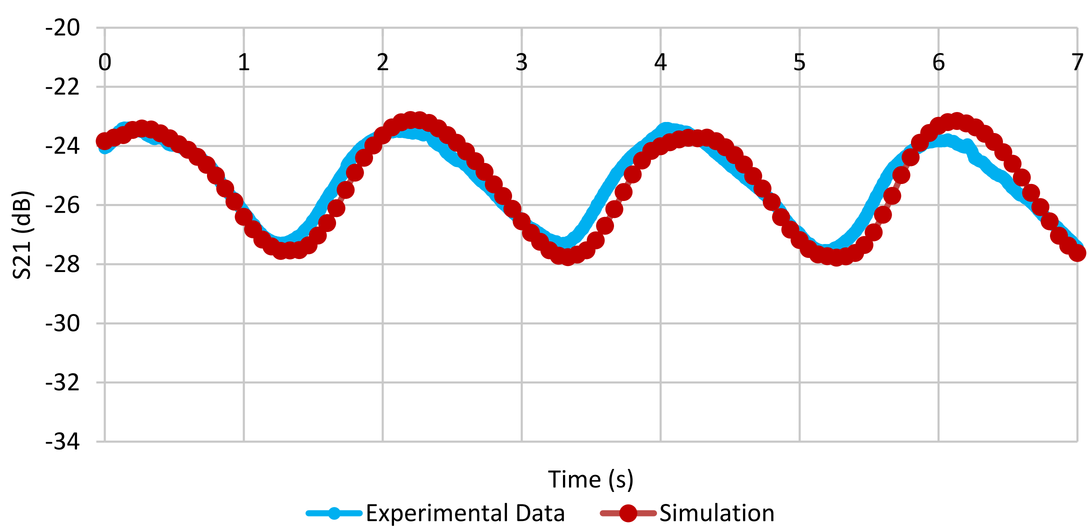

Figure 4.1. Subject 1 Both Arm Swing, Antenna on Chest/Back at 433MHz, Simulation vs. Measurement

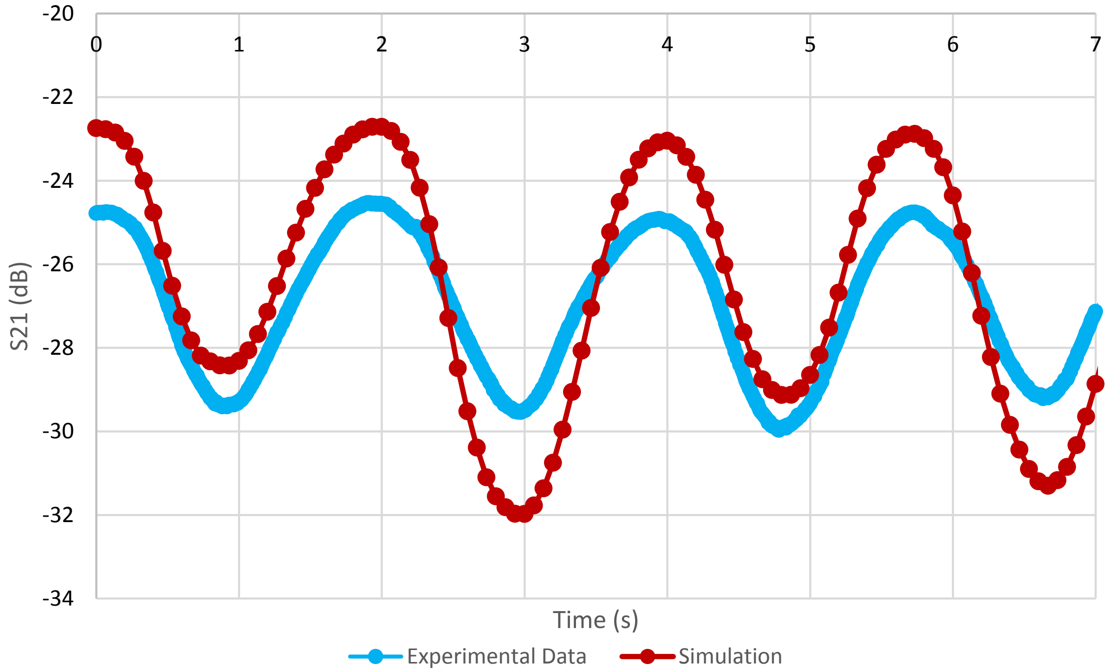

Figure 4.2. Subject 2 Both Arm Swing, Antenna on Chest/Back at 433MHz, Simulation vs. Measurement

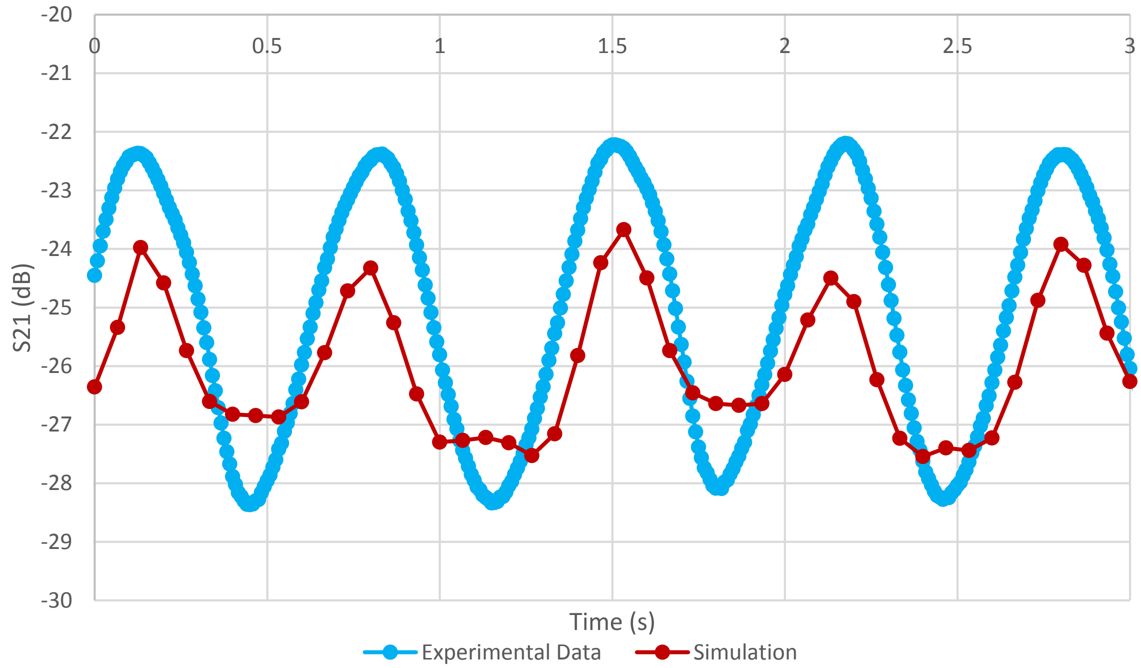

Figure 4.3. Subject 5 Both Arm Swing, Antenna on Chest/Back at 433MHz, Simulation vs. Measurement

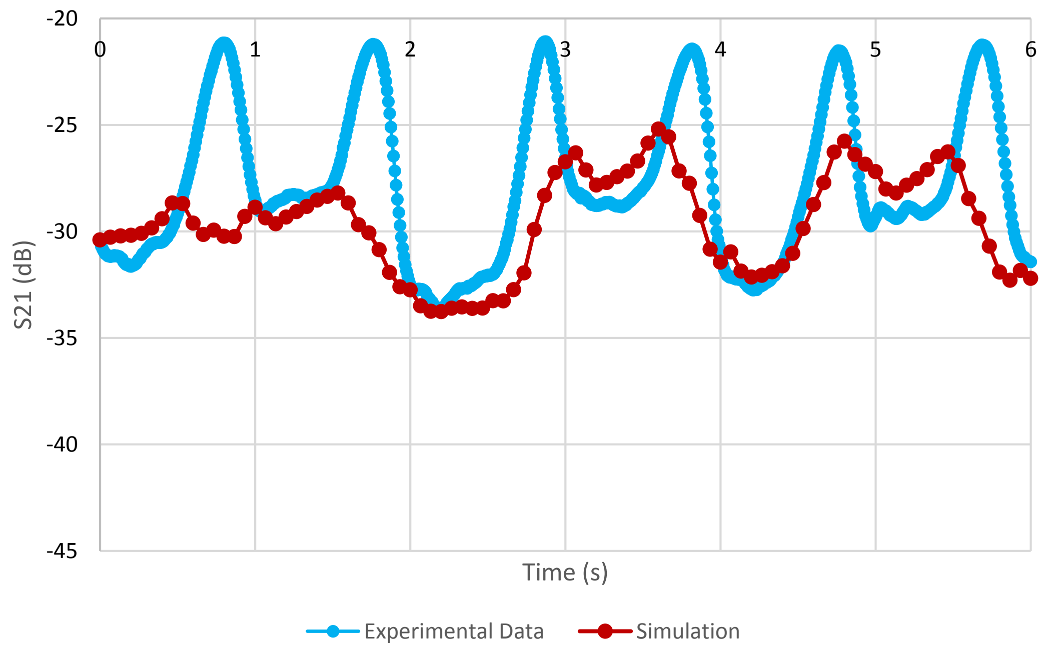

Figure 4.4. Subject 1 Boxing, Antenna on Chest/Back at 433MHz, Simulation vs. Measurement

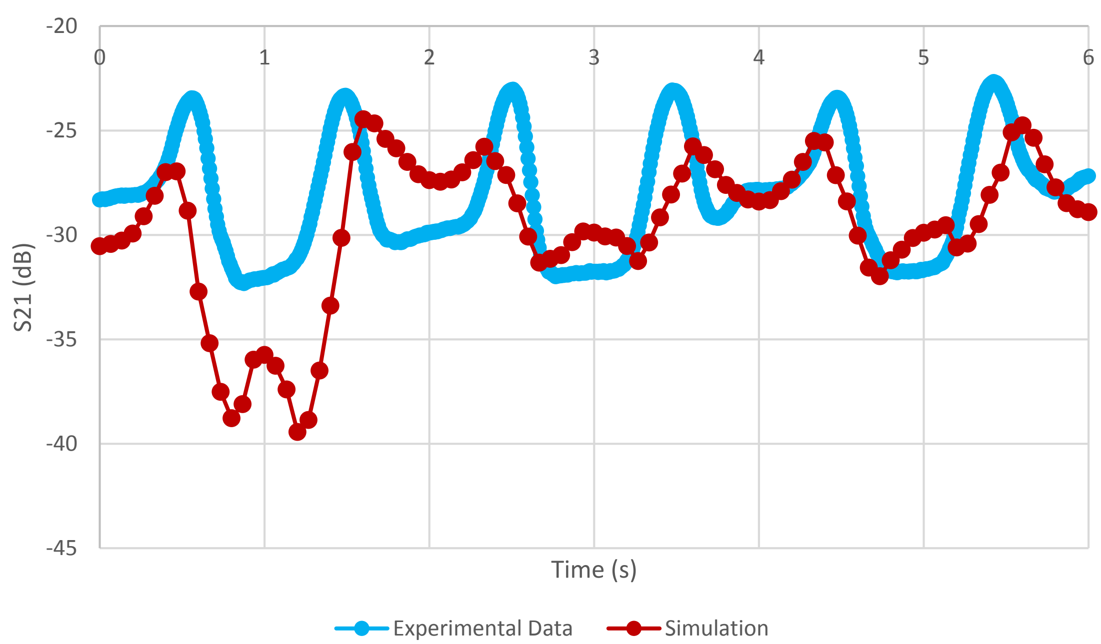

Figure 4.5. Subject 2 Boxing, Antenna on Chest/Back at 433MHz, Simulation vs. Measurement

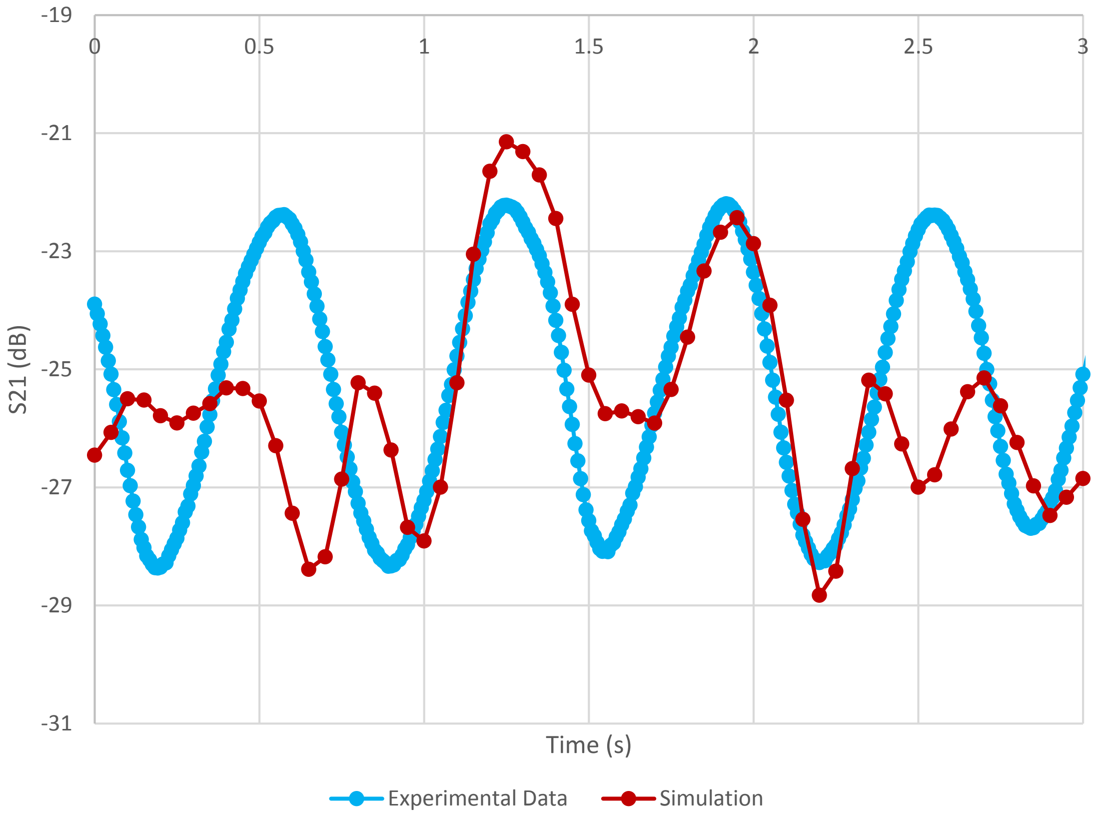

Figure 4.6. Subject 5 Boxing, Antenna on Chest/Back at 433MHz, Simulation vs. Measurement

4.1.2 Antenna Configuration: Chest/Left Wrist

Figures 4.7-4.12 show the comparison of simulated and measured S_{21} for the antenna on chest/left wrist antenna configuration for the both arm swing and boxing motions for subjects 1, 2, and 5. Figures 4.7-4.9 show results for both arm swing. Figures 4.10-4.12 show results for the boxing swing motion.

Compared to the results of the chest/back antenna configuration, the results do not show as good agreement for the most part; however, the agreement between simulation and experimental data is still acceptable.

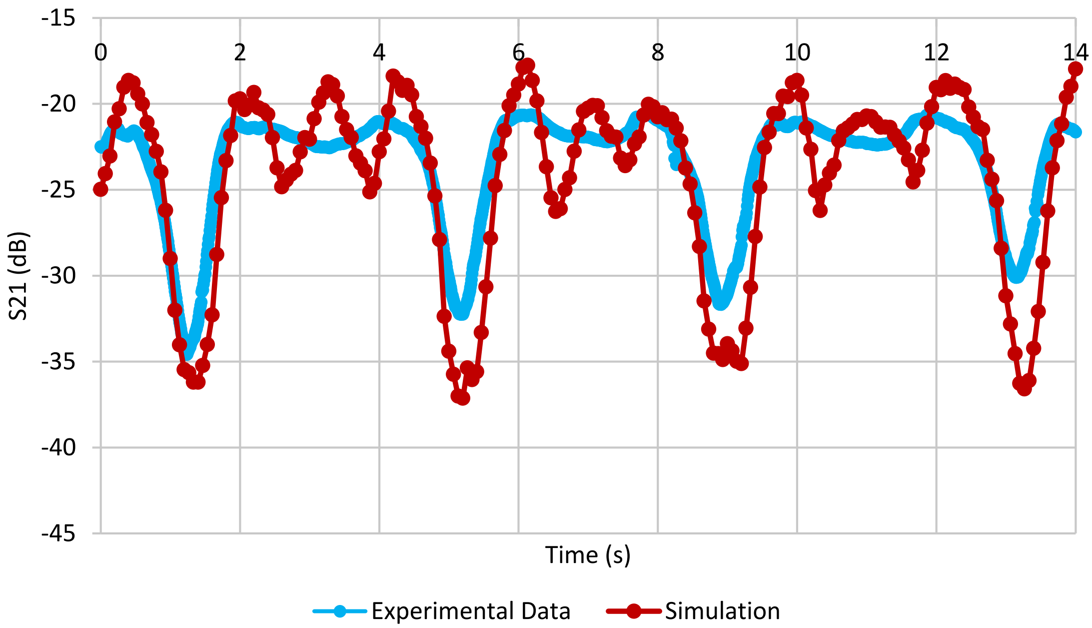

Figure 4.7. Subject 1 Both Arm Swing, Antenna on Chest/Left Wrist at 433MHz, Simulation vs. Measurement

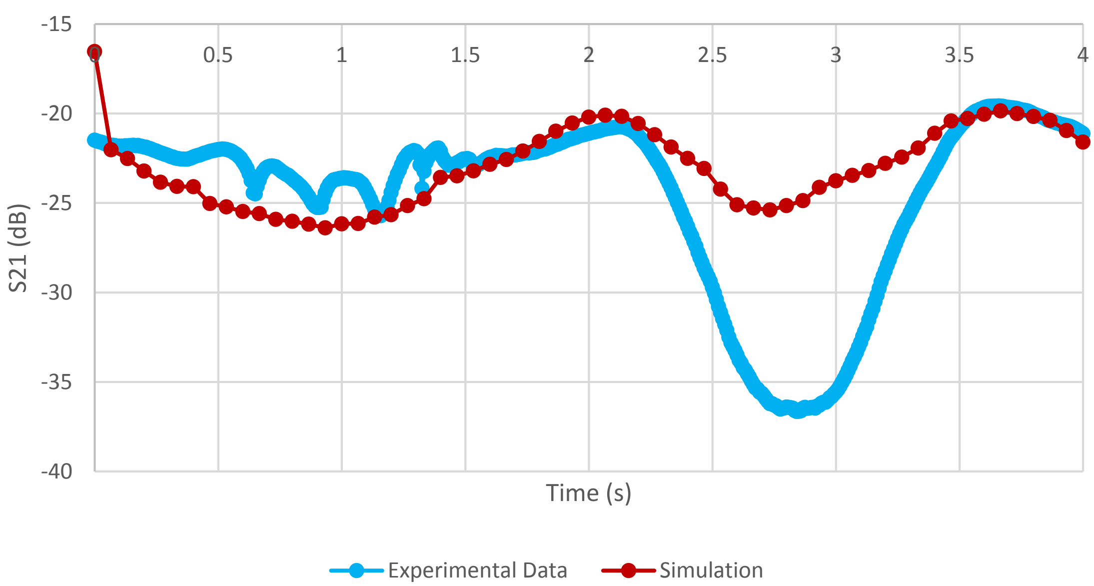

Figure 4.8. Subject 2 Both Arm Swing, Antenna on Chest/Left Wrist at 433MHz, Simulation vs. Measurement

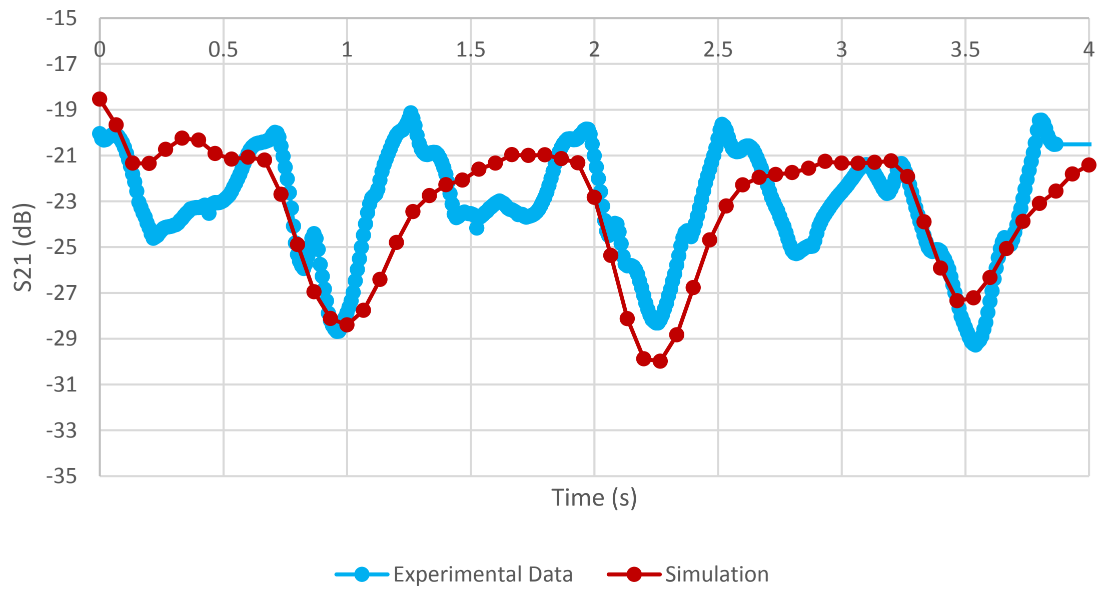

Figure 4.9. Subject 5 Both Arm Swing, Antenna on Chest/Left Wrist at 433MHz, Simulation vs. Measurement

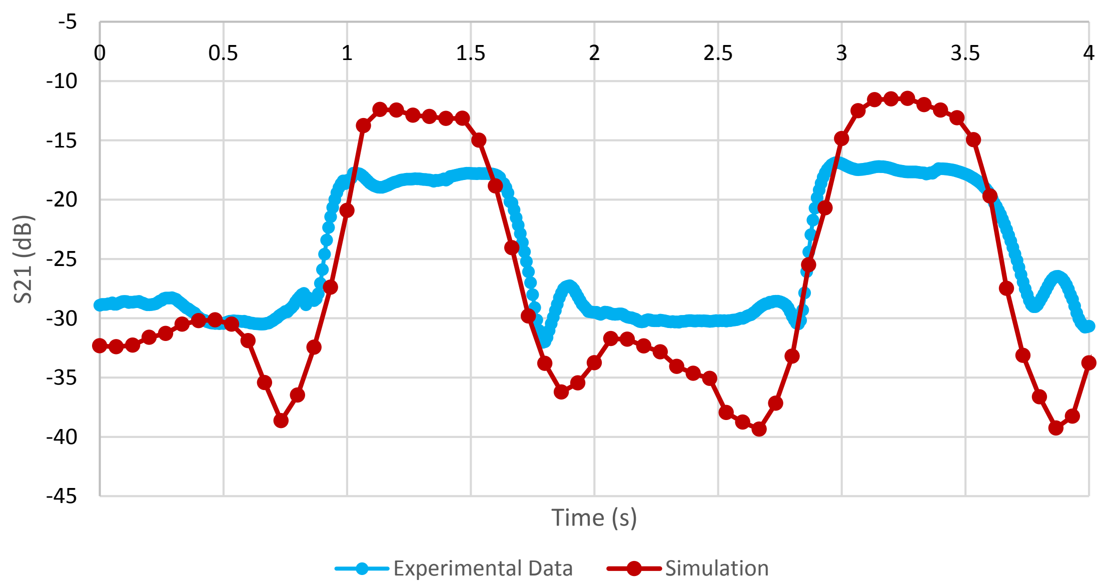

Figure 4.10. Subject 1 Boxing, Antenna on Chest/Left Wrist at 433MHz, Simulation vs. Measurement

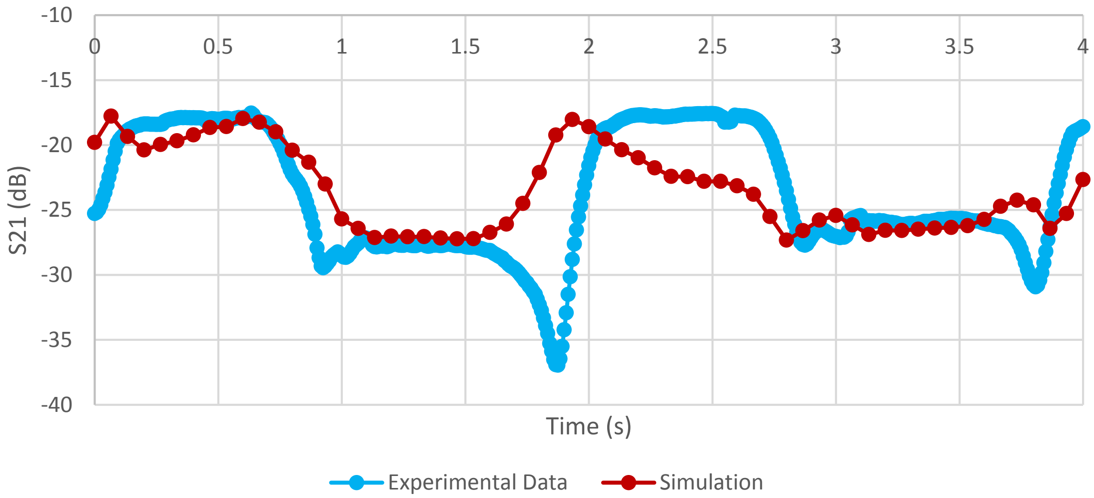

Figure 4.11. Subject 2 Boxing, Antenna on Chest/Left Wrist at 433MHz, Simulation vs. Measurement

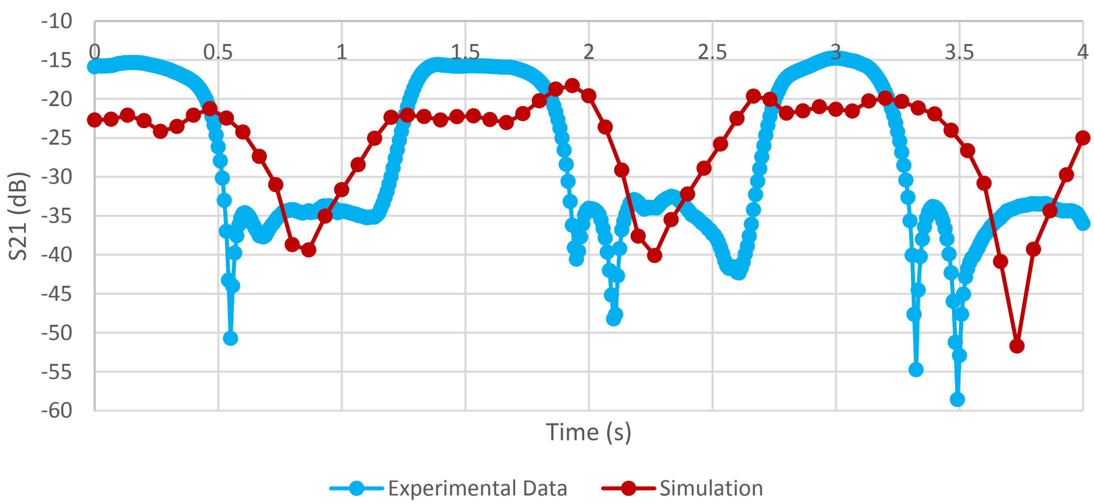

Figure 4.12. Subject 5 Boxing, Antenna on Chest/Left Wrist at 433MHz, Simulation vs. Measurement

4.1.3 Antenna Configuration: Both Wrists

Figures 4.13-4.18 show the comparison of simulated and measured S_{21} for the antenna on both wrists antenna configuration for the both arm swing and boxing motions for subjects 1, 2, and 5. Figures 4.13-4.15 show results for both arm swing. Figures 4.16-4.18 show results for the boxing swing motion.

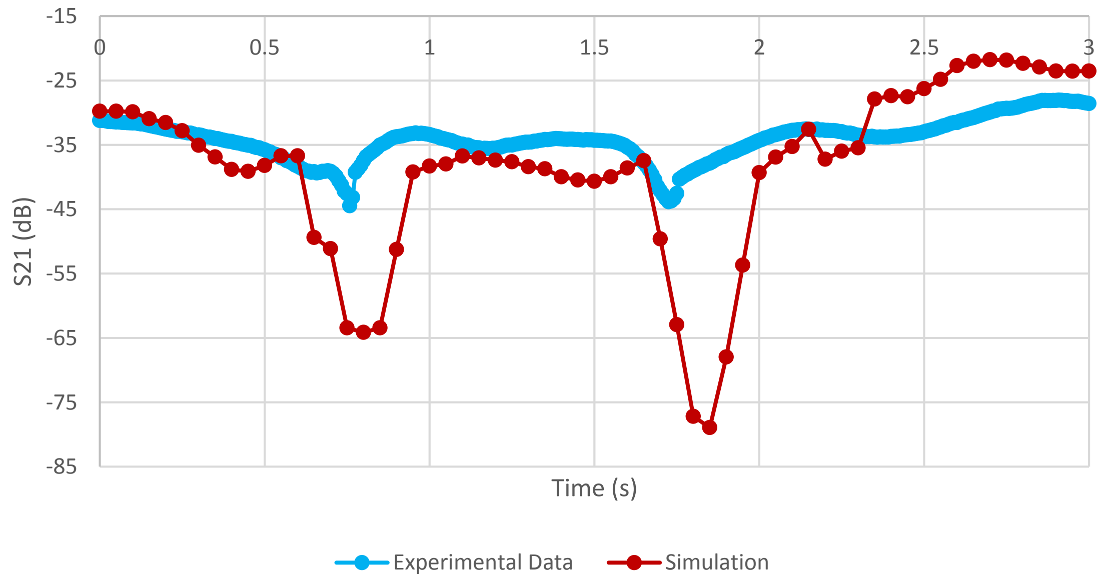

Figure 4.13. Subject 1 Both Arm Swing, Antenna on Both Wrists at 433MHz, Simulation vs. Measurement

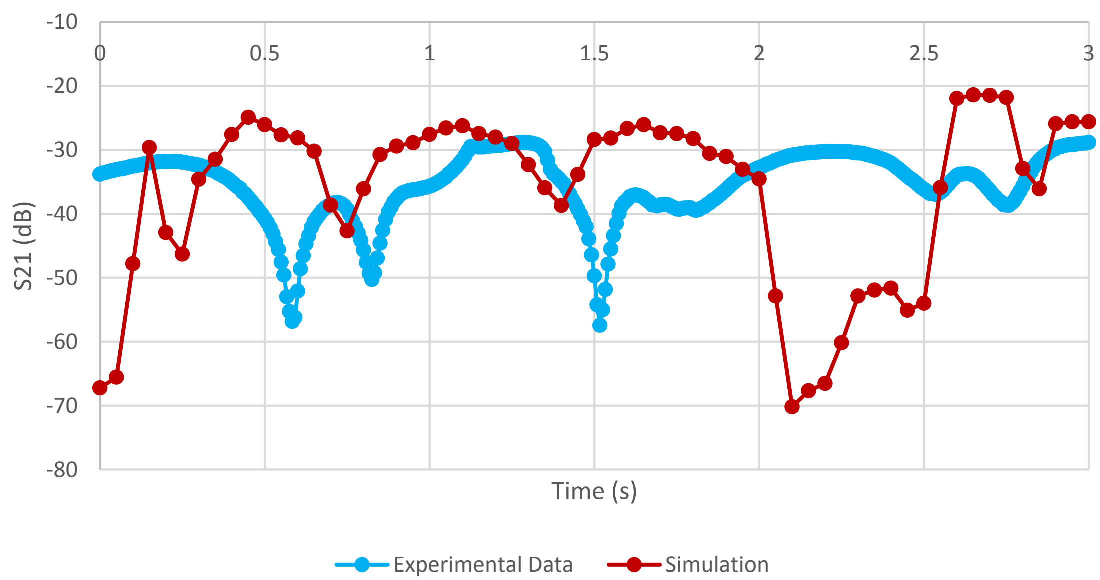

Figure 4.14. Subject 2 Both Arm Swing, Antenna on Both Wrists at 433MHz, Simulation vs. Measurement

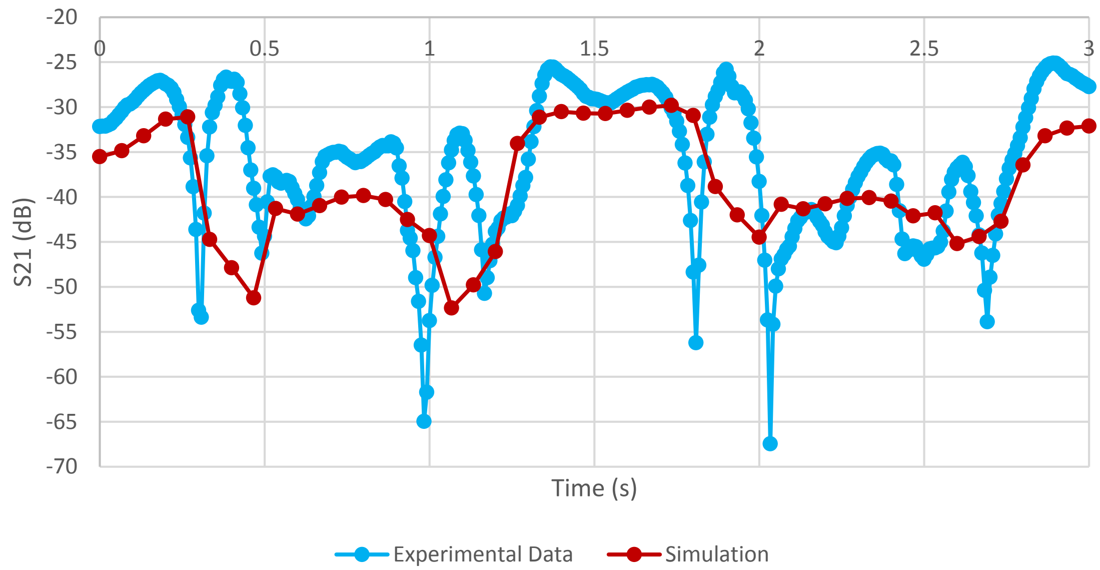

Figure 4.15. Subject 5 Both Arm Swing, Antenna on Both Wrists at 433MHz, Simulation vs. Measurement

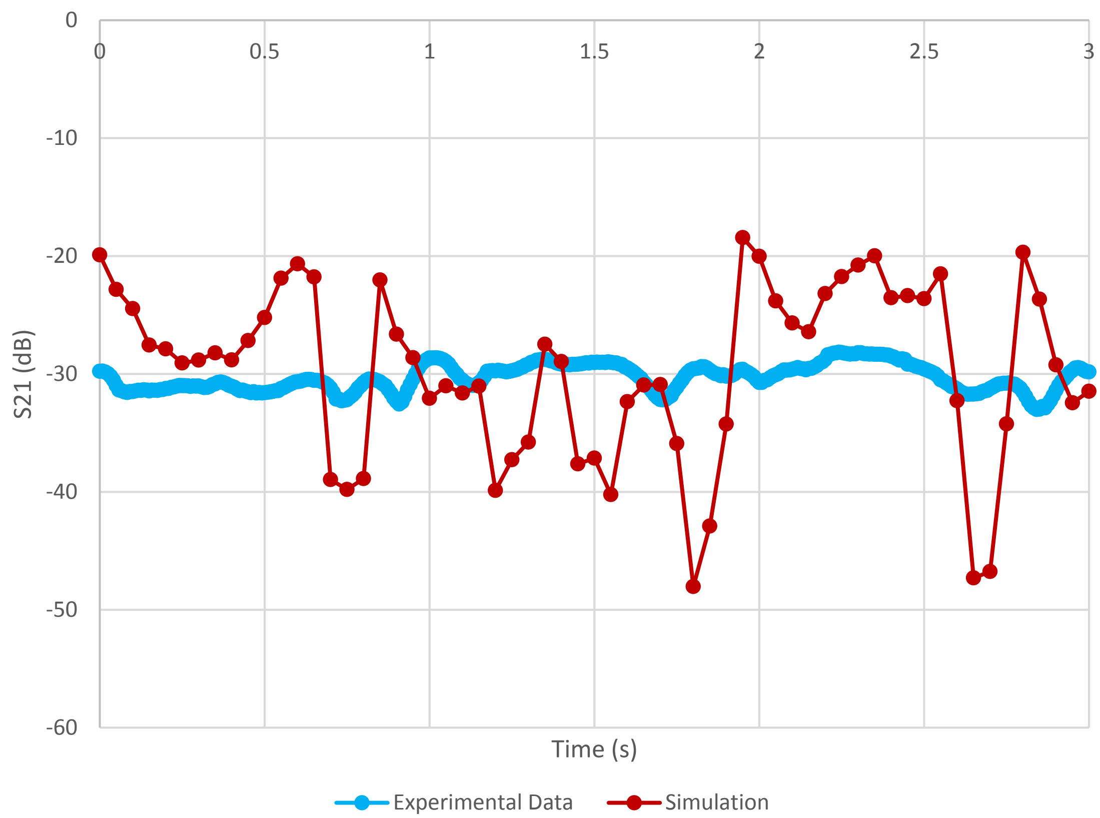

Figure 4.16. Subject 1 Boxing, Antenna on Both Wrists at 433MHz, Simulation vs. Measurement

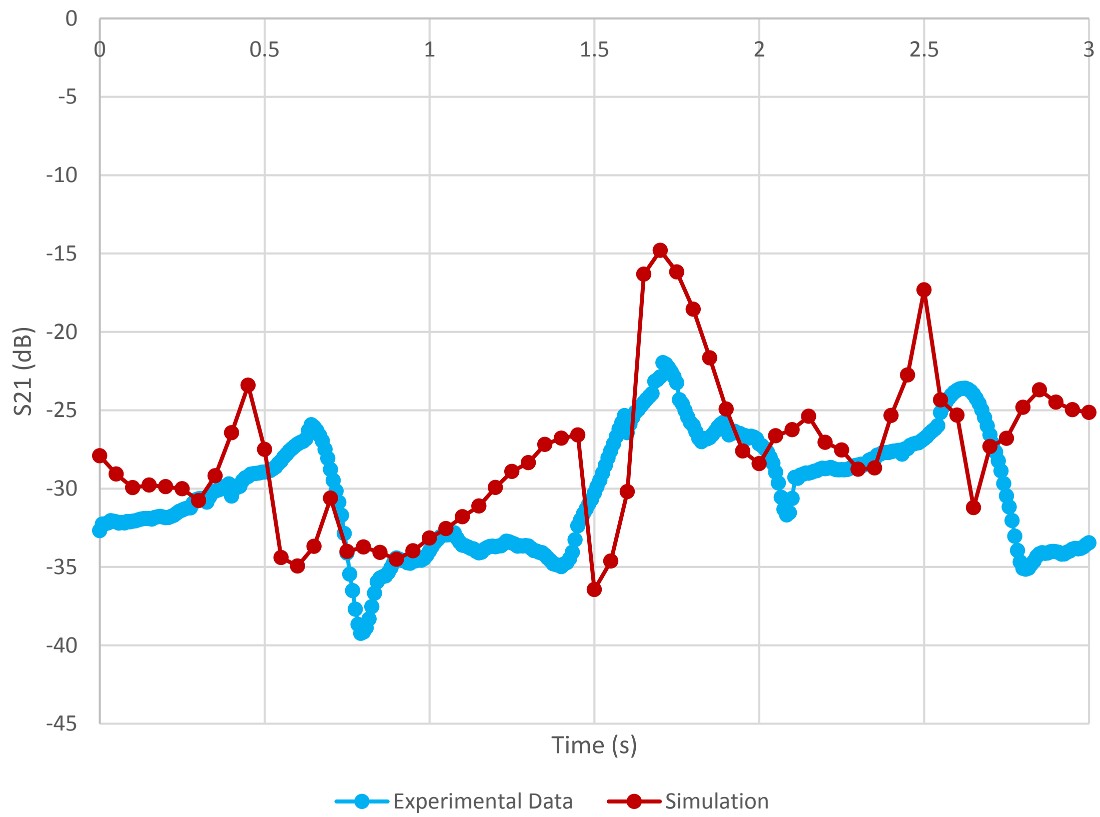

Figure 4.17. Subject 2 Boxing, Antenna on Both Wrists at 433MHz, Simulation vs. Measurement

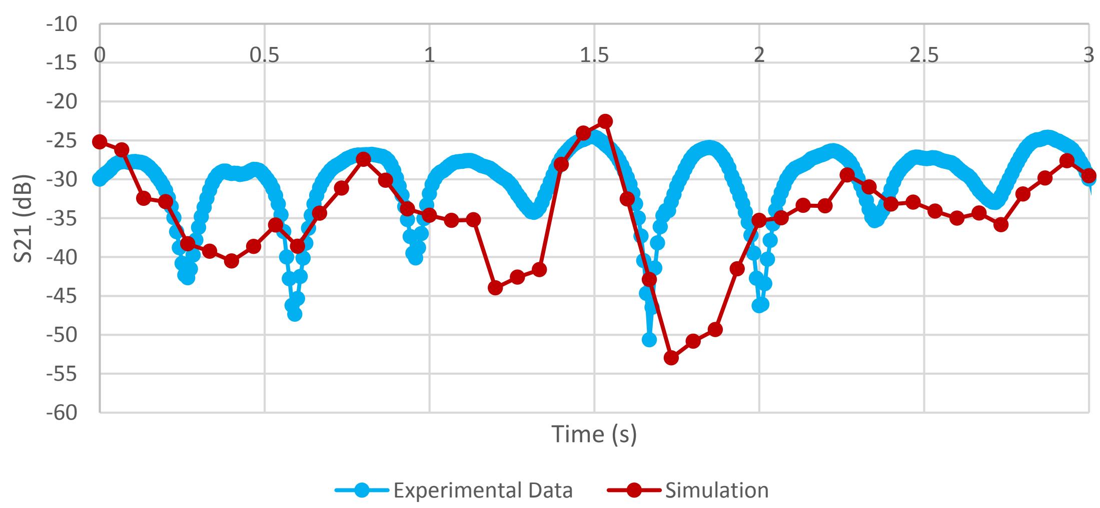

Figure 4.18. Subject 5 Boxing, Antenna on Both Wrists at 433MHz, Simulation vs. Measurement

CHAPTER FIVE

Discussion

This research work focused on the development of a simulation framework to predict on-body EM wave propagation characteristics for common human motion activities and on comparison of the predictions with corresponding experimental measurements. In this chapter the results will be discussed in terms of how well the simulations matched the experimental data, what are possible explanations for some of the minor discrepancies, and how this work advances the body of knowledge.

5.1 Observations on the Comparison between Simulated and Measured S_{21}

Based on Figures 4.1-4.18, a subset of simulation results compared to measured data has been created that includes three human volunteers, both male and female, two motion activities that are significantly different from each other (both arm swing and boxing), and all three antenna configurations (chest/back, chest/left wrist, both wrists). Using this subset of data, many observations can be made about simulation accuracy compared to the experimentally measured data based on agreement between results. When agreement between simulation and measurement is discussed, the main factors that are considered are matches in amplitude, such as whether the magnitude of peaks and dips in signal strength match, and in pattern, such as if peaks and dips in signal strength occur at the same time period.

5.1.1 Antenna on Chest and Back

Figures 4.1-4.6 show that for the antenna on chest/back configuration, there is generally very good agreement between simulated S_{21} and the measured data. In the case of Figure 4.1 for the both arm swing motion of subject 1, there is a near perfect match between the simulation and experimental data. Based on the acceptable agreement for multiple motions and human volunteers, the simulation model's accuracy using the chest/back antenna configuration is generally close to the measured data.

5.1.2 Antenna on Chest and Left Wrist

Figures 4.7-4.12 show generally good agreement between simulated results and experimentally measured data for the antenna on chest/left wrist configuration; however, it is clear that the agreement is not as close as the chest/back configuration. Figure 4.7 is a good example of how the simulated results of chest/left wrist show more noise patterns than the chest/back counterpart, which can be seen in Figure 4.1, both showing the case of both arm swing for subject 1. Based on the good agreement between simulation and measured data, the simulation model results should also have reliable accuracy for the antenna on chest/left wrist configuration.

5.1.3 Antenna on Both Wrists

Figures 4.13-4.18 show how there can be generally good agreement in pattern between simulation and measured data, but the noise patterns in the simulation are much more apparent. Figure 4.15 is a good example of how the pattern and amplitudes show good agreement for a significant portion of the motion activity, but there are spikes in noise patterns in the simulation that make the agreement less clear when compared to the chest/back and chest/left wrist configurations. This shows that the simulation model can still provide results that show general agreement for the both wrist configuration, but with slightly less clarity than the other two configurations.

5.1.4 General Trends on Ten Cylinder Model Accuracy

Based on the results from Chapter Four, there is general confidence in the accuracy of the simulation model presented in this study due to general agreement in S_{21} trends and changes in magnitude between simulated results and experimentally measured data.

The ten cylinder model shows that it is able capture the trends and fluctuations of the signal data better than it is able to capture exact changes in magnitude. This is most clearly demonstrated when comparing Figures 4.1-4.3, where it is clear that all three figures show the simulated results closely following the fluctuations in S_{21} for the both arm swing with antenna on chest/back, but Figures 4.2 and 4.3 show that the changes in magnitude are similar, but not perfectly matched with the measured data. This trend of the model capturing signal fluctuation trends better than changes in magnitude can specifically be seen again in Figures 4.10-4.12. This subset of results shows the boxing with antenna on chest/left wrist simulated results compared with measured data. Again, it is clear that the fluctuation pattern of S_{21} is followed by the model, but the changes in magnitude are not as closely matched. The simulation model's ability to capture the general fluctuation patterns of the measured S_{21} values is very promising for future applications of using this study's simulation framework for more in-depth study of on-body wave propagation. This is because having a model that can show what points in time during human motion will result in weaker signal strength will be very beneficial for antenna design optimization. When clear dips in the signal strength are apparent in simulation of certain motions at certain positions on the body, then it will be possible for the antenna to be designed to eliminate any clear weaknesses in the signal strength along and around the human body in those scenarios. While having a perfect match between simulated and measured S_{21} would be ideal, it is not completely necessary for this study's application of studying on-body wave propagation patterns, because as stated above, knowing when clear dips in S_{21} will occur is sufficient for improved antenna design. However, it is still an important future goal to continue to optimize and improve the simulation framework used in this study to achieve better agreement between simulated and measured S_{21} in order to provide more effective simulation for antenna design and increase confidence in simulation accuracy.

The use of multiple human volunteers for different physical sizes, and thus different sized simulation models, as well as multiple motions shows that the model's accuracy is robust, meaning the model's size and range of motion can be changed while still providing results that are similar to the measured data. The use of multiple antenna configurations shows that the model is able to shows good agreement in signal strength between multiple points on the human body Additionally, the points on the body showed variety in their properties, such as being static during motion (chest/back) and actively moving (chest/left wrist and both wrists), as well as having antenna in positions of varying distance from each other. However, it must be noted that antenna configurations with moving antenna (chest/left wrist and both wrists) generally do not produce as close of a match with measured data as the chest/back antenna configuration. This suggests that the model could produce simulated S_{21} with similar trends as measured data when simulating signal data between other points on the body as well; however, this would require additional study, such as more experimental trials to collect measured data to compare with simulation of alternative motions and antenna configurations This is a key point because future work that the model can be used for is the simulation of entire EM pathways, and being able to show good agreement using multiple antenna configurations along the human body suggests the model can be used for such future work. Before this step can be taken, the simulation model requires additional testing and agreement between simulated results and measured data for the motion and S_{21} data currently collected must be further improved. The next section of this chapter will discuss the discrepancy between simulated results and experimentally measured data that is present despite the generally good agreement.

5.2 Discrepancy between Simulation and Measurement

Based on the previously shown results, it can be seen that the ten cylinder model used for CST simulation of on-body wave propagation shows appropriate agreement between simulation results and experimental data for multiple human volunteers (male and female), multiple motions, and multiple antenna configurations. The main points of discussion will be simulation accuracy and simulation efficiency.

While the results have given confidence that the simulation model can produce results with general agreement with measured data, the match is not perfect. There are several possible reasons for the discrepancy between the simulation and experimental results which will be discussed. The possible explanations that are most likely to cause the discrepancy in results are environment, model complexity, difference in antenna, and antenna rotation. Another point to be noted is that synchronization between motion data and VNA data collection may not be perfect, which resulted in some simulation results (Figures 4.6, 4.8, F.6, F.8) requiring a slight horizontal shift of around 0.5s. Additionally, the results shown in Chapter Four include a median filter of size 3 and 5 to smooth the simulated results to account for the gradual change in S_{21} that should occur with the gradual motion of the human body. A comparison of data with and without the median filter of size 5 can be found in Appendix F, Figures F.10-F.11. Figures F.10-F.11 shows that the filter does smooth the simulated results, but does not have a large impact on the general trends of the results.

There is a considerable difference between the simulation environment and the environment in which experimental data was collected. The simulation environment is a vacuum. This means the human body model is CST has its transmission loss simulated in a vacuum environment where only the body model is present. On the other hand, the experimental environment had many other factors that are present, unlike in a vacuum setting. The experimental data was collected in either a large, open hallway or in a large open room. Both of these environmental settings have walls, floors, and ceilings that could potentially impact on-body wave propagation. While the walls and floors may not have much impact on on-body line-of-sight between antennas or the creeping pathway, it is possible that wave scattering would be affected. In a vacuum, there would not be the opportunity for EM waves from the transmitting antenna to be reflected by the walls and floor towards the receiving antenna. This difference in simulation and experimental data collection environment is a potential cause for the discrepancy between simulation and experimental results.

Model complexity is another potential cause for the discrepancy between simulation and experimental results. While the human body model does use the human volunteers' dimensions to create a scaled model that matches the general shape of the volunteer, the model does not perfectly match all the details of the human body. The difference between the simulation model and the volunteer's actual body could impact how the creeping wave travels along and around the human body. For example, the use of simple geometric cylinders to represent segments of the human body smooths out the general features of the human body while capturing the general shape and size of desired segment. However, it is possible that losing some of the finer details on the body, such as muscle tone or natural curves of the body may change the optimal creeping wave pathway. As mentioned in Chapter Three, some time was dedicated to studying the optimal model complexity for simulation accuracy, consistency, and efficiency. Using more segments to better replicate the experimental motion and using spheres to smooth the sharp edges at joints and cylinder ends was shown to not have significantly changed the simulate S_{21} results compared to the original ten cylinder model. However, this study of model complexity did not contain a comparison of a model that can almost perfectly match a human body, such as a scaled Poser model. Despite knowing that the ten cylinder model has the same accuracy and consistency as slightly more complex models, such as the model with additional chest and shoulder segments or the sphere-smoothed model, it is still unknown whether using a model that more closely resembles the human body would improve results agreement further. The lack of comparison with more complex model shows that model complexity is still a potential cause for discrepancy between simulated and experimental results.

The difference between the antenna used in simulation and the antenna used during experimental data collection is another potential cause for the discrepancy between simulation and experimental results. The simulation used a dipole antenna for the transmitting antenna and a probe to represent the receiving antenna. On the other hand, the experimental set-up used a bridge monopole antenna, which was described in Chapter Three. While the use of the dipole antenna with double the experimental antenna length should be a good approximation of the experimental bridge monopole, there can still be some difference in results. This difference in results could potentially have manifest itself in the general trend of simulated results showing more of a noise pattern than the measured data.

Another possible cause of the discrepancy between the simulation and experimental results is antenna rotation. In the experimental set-up described in Chapter Three, motion capture markers were not placed on the antennas using the collected transmission data. While these antenna were fixed on the human body and could not make any major changes in position, it is possible that the antennas underwent minor rotations during human motion. These small rotations could be caused by gravitational pull during certain motions, such as during arm swings or boxing when the antenna is parallel to the floor. Additionally, human soft tissue movement that occurs when the body moves can cause the fixation point of the antenna to move slightly, which would also cause slight antenna rotation. Even though the human volunteers were wearing a tight-fitting body suit that the antennas were mounted on, the slight rotations caused by soft tissue movement are still present and are not captured by the motion capture techniques used. Placing additional motion capture markers to capture antenna rotation could be used to improve motion data collection techniques in the future. Not having information about the antenna rotation that occurs during the experimental trials means the simulation model cannot account for these rotation in the human body model. Due to the inability to account for the antenna rotations, the CST model has the antennas placed perpendicular to the mounted surface, which is the way the antennas are experimentally mounted without accounting for additional antenna rotation. For example, during more fast paced motions, such as boxing, the sudden and more forceful changes in motion of the arms and chest are more likely to cause large soft tissue movement, which would cause the antennas to rotate out of their usual positioning perpendicular to the human body surface. Even more specifically, in the moving antenna cases, the sudden motions of the arms and hands is more likely to cause sudden movement of the antenna on the wrist positions. This is a very possible explanation for why the results comparing S_{21} for boxing generally were not as close in agreement as the smoother both arm swing motion. This can be seen in Figures 4.4-4.6 that show S_{21} for boxing with the chest/back antenna configuration, compared to Figures 4.1-4.3 that show S_{21} for both arm swing with the chest/back antenna configuration. Figures 4.1-4.3 show simulated results with very good match in pattern and similar changes in magnitude. On the other hand, Figures 4.4-4.6 show some similarity in both trend and magnitude, but there are more points of discrepancy. This trend of the both arm swing motions results showing better agreement than boxing results can be seen for the chest/left wrist and both wrists antenna configurations as well in Figures 4.7-4.18. It is possible that accounting for antenna rotations during motion activities in the CST simulation would improve the agreement between simulation and experimental results, which is a potential topic for future work. Antenna rotation is a potential cause for the discrepancy between simulation and experimental results because of the lack of experimental rotation data that can be input to test the effect of antenna rotation in simulation results.

5.3 Comparison with Previous Works

There have been many previous works related to studying on-body wave propagation, most of which can be separated between experimental and simulation based studies, with some combination studies. These studies all have key features that contributed significantly to the study of on-body wave propagation, and this study sought to improve upon previous works in order to achieve the goal of implementing a simulation model that can be used for simulation of entire EM pathways that has been verified using measured data.

One key feature in several studies was the use of relevant human motions, such as in Taparugssanagorn et al (2010), Uusitupa et al. (2013), and Paraskevopoulos et al. (2013). These studies sought to perform experimental data collection or simulation using motions relevant to hospital settings or human daily life. When compared to Taparugssanagorn et al. (2010), our study also seeks to use relevant human motions to measure on-body wave propagation. Additionally, our study built upon this previous work by measuring signal loss in a fully dynamic manner at different frequencies, using additional antenna placements, and using measurement data as a means for validating simulation methods. Our study differs from Uusitupa et al. (2013) because while our study utilized simulation methods to gain insight on on-body wave propagation as well, it also used experimental data for model validation as well as a simplified model to improve simulation efficiency and simulate longer periods of time. In comparison with

Paraskevopoulos et al. (2013), our study has a similar goal of using simulation methods to gain insight into on-body channels, which is why our study will build upon this previous work by using multiple antenna configurations, motion capture to capture live human motion patterns, and verifying the model with measured data.

Another key feature of previous works was the ability to produce replicable data, which was key for Zedong et al. and Yamamoto et al. (2013) due to their study of multiple channels and use of a physical phantom model, respectively. Our study differs from Zedong et al. (2011) by using different antenna configurations, more motions, and also using the experimentally collected to data as a means to verify a simulation model. In comparison with Yamamoto et al. (2013), our study includes experimental data collection that can be used to analyze how motion affects signal performance; however, the focus of our study is to use the experimental data to verify a simulation model that will also allow for study of on-body signal performance. Our study used alternative methods of collecting experimental data, mainly through use of human volunteers to perform various motion activities rather than the construction of a physical phantom model.

Using motion capture to generate simulation models was a feature of several studies, such as Swaisaenyakorn et al. (2014) and Fujie et al. (2013). Our study proposed a different type of motion capture powered phantom model while collecting our own measurement data to allow for more direct validation of the simulation model rather than Swaisaenyakorn et al.'s (2014) method of using a complex model and outside motion data to compare with their measured data. Similar to Fujie et al. (2013), our study also used motion capture and simplified human body models, but will go further by also using experimental verification and additional motion activities.

Understanding model complexity and how the human body affects on-body wave propagation was another important factor of previous studies, such as Iswandi et al. (2011) and Liu et al. (2013). Our study will build upon the previous work of Iswandi et al. (2011) by further studying model complexity to improve simulation efficiency and by using experimental validation. Similar to Liu et al. (2013), our study will also study how the body geometry affects channel performance by using multiple motions and antenna configurations and using this data to verify is a simulation can agree with the collected data. Our study will differ by putting more focus on the study of our phantom model's performance compared to measured data rather than focusing directly on the effects of body geometry on channel performance.

Using experimental data to validate simulation methods was another key feature that was seen in Swaisaenyakorn et al (2014) Gallo et al. (2011). As mentioned before, our study will differ from Swaisaenyakorn et al (2014) by using simultaneously collected motion data (for use in the simulation model) and signal data for comparison of simulation model results and measured signal data. Similar to Gallo et al. (2011), our study also seeks to compare simulation to measured data; however, our study will have improved synchronization of simulation results and measured S_{21} through the simultaneous use of motion capture and a VNA. Additionally, our study will include more motion activities and alternative antenna positions.

It can be seen that the previous studies discussed in Chapter Two and this chapter made many significant advances in the study of on-body wave propagation. This section of Chapter Five has shown how this study has differentiated itself from previous works and sought to improve on previous methods of studying on-body wave propagation through combination simulation and experimental methods to create a validated simulation model based on human motion data.

CHAPTER SIX

Conclusion

This study's goal was to develop a framework for simulating on-body EM propagation and validating the simulations by comparison with experimental data. The methods used sought to verify the simulation model through many means, including multiple motion activities, various sized human volunteers and their corresponding phantom models. The simulation framework has shown that it is able to match the major features of EM transmission signal strength observed in the experimental data. The simulation model has been optimized for accuracy and efficiency through tests of model complexity and other simulation parameters such as mesh density.

The comparison of the simulation results with point-to-point experimental data from transmitting and receiving antennas gives reasonable confidence that the model can predict the major features and characteristics of on-body signal strength. Analysis of this comparison shows that the simulation model does well at matching S_{21} fluctuation trends while being less effective at matching exact changes in magnitude. Being able to use the simulation model to capture the fluctuations of S_{21} is most important for understanding when the signal strength is weak during human motion. The reasonable confidence of model accuracy gained from comparison of simulated and measured S_{21} for multiple motions, model sizes, and antenna configurations opens up the opportunity for the simulation model to be expanded upon by placing multiple probes on the phantom model in order to simulate transmit transmission data all around the body. This could reveal valuable insights about the creeping wave and what pathways are optimal for EM waves to travel through on a dynamic human body. However, future work on the simulation framework presented in this study should be performed in order to improve agreement between simulated results and measured data.

The more that is understood about on-body wave propagation will allow for optimized on-body antenna design for many valuable real world applications, specifically for WBAN systems. The WBAN systems would benefit a lot from having small, power efficient sensors that can be used for long periods of time. The findings of this study are a first step in the direction of optimizing WBAN systems because the simulation model has the potential to provide insight into on-body wave propagation that will facilitate the design of power efficient on-body antennas.

APPENDICES

APPENDIX A

Human Volunteer Data

Table A.1. Human Volunteer Gender, Age, Height, and Weight

Volunteer Subject #	Gender	Age (years)	Height (in)	Weight (lb)
1	Male	23	66	135
2	Female	25	64	110
3	Male	22	68.5	140
4	Female	24	66	125
5	Male	26	66.5	135
6	Female	21	59.5	140
7	Male	22	67.4	135

APPENDIX B

Visual Basic for Applications (VBA) Macro – Construct Human

```
' Construct Human
'Defining variables that are used in many sub routines
Dim Frame As Integer
Dim LastFrame As Integer
Dim AngleArray() As Double
Dim ProbeNum As String
Dim SelectAlong As Integer
Dim SelectAround As Integer
Dim SelectFront As Integer
Dim SelectBack As Integer
Dim SelectChest As Integer
Dim SelectLWrist As Integer
Dim SelectRWrist As Integer
Dim SelectLAnkle As Integer
Dim SelectRAnkle As Integer
Dim SelectTorso As Integer
Dim SelectHead As Integer
Dim SelectLForearm As Integer
Dim SelectLShldr As Integer
Dim SelectRForearm As Integer
Dim SelectRShldr As Integer
Dim SelectLCalf As Integer
Dim SelectLThigh As Integer
Dim SelectRCalf As Integer
Dim SelectRThigh As Integer
Dim ProbeOffset As String
Dim SegDiameter As Double
Dim SegLength As Double
Dim Segment As String
Dim ProbeLength As Double
Dim ProbeDiameter As Double
Dim Anglediff As Double
Const Pi = 4*Atn(1)
Dim AntOffset As String
Dim AntRotation As String
Dim Antenna2 As Integer
Dim AntennaNum As Integer
Dim DataLocation As String
Dim NumFrames As Integer
Dim Frequency As Double

Sub Main ()
' Open the user interface
	GUI()
' Constructing the components of the human model out of cylinders
	DefineMatl()
For Frame = 0 To NumFrames-1
' Loading a bvh file and repositioning the model based on joint rotations
	LastFrame = Frame-1
	If Frame > 0 Then
		DeleteCyl()
	End If
	ConstructCyl()
	OpenBVH24()
'Placing Antenna And creating probes
	ProbePlace()
	'ProbePlace24_v13_3_3() 'use this for chest/back
'Merge Cylinders to reduce Simulation time
	MergePieces()
'Run Simulation and store results
	Results()

Next

End Sub
' The user interface to gather component properties such as arm length etc
Private Sub GUI()

	Begin Dialog UserDialog 620,238 ' %GRID:10,7,1,1
		GroupBox 10,7,390,224,"Component Dimensions",.GroupBox1
		Text 110,35,80,14,"Length (in)",.Text1
		OKButton 460,203,100,21,.Run
		Text 30,196,60,14,"Shoulder",.Text2
		Text 260,35,90,14,"Diameter (in)",.Text3
		Text 30,56,60,14,"Torso",.Text4
		Text 30,84,60,21,"Head",.Text5
		Text 30,112,60,21,"Calf",.Text6
		Text 30,140,60,21,"Thigh",.Text7
		Text 30,168,60,14,"Forearm",.Text8
		TextBox 100,56,110,21,.LengthTorso
		TextBox 260,56,120,21,.DiameterTorso
		TextBox 100,84,110,21,.LengthHead
		TextBox 260,84,120,21,.DiameterHead
		TextBox 100,112,110,21,.LengthCalf
		TextBox 260,112,120,21,.DiameterCalf
		TextBox 100,140,110,21,.LengthThigh
		TextBox 260,140,120,21,.DiameterThigh
		TextBox 100,168,110,21,.LengthForearm
		TextBox 260,168,120,21,.DiameterForearm
		TextBox 100,196,110,21,.LengthShldr
		TextBox 260,196,120,21,.DiameterShldr
		Text 430,35,160,14,"Number of Frames",.Text9
		TextBox 430,49,150,21,.FrameNum
		Text 430,84,150,14,"Frequency (MHz)",.Text10
		TextBox 430,98,150,21,.Freq
	End Dialog
	Dim dlg As UserDialog
	Dialog dlg
	' Defining the user input values and storing them as parameters
```

```
			StoreParameter("Torso_Length",
dlg.LengthTorso)
			StoreParameter("Torso_Diameter",
dlg.DiameterTorso)
			StoreParameter("Head_Length",
dlg.LengthHead)
			StoreParameter("Head_Diameter",
dlg.DiameterHead)
			StoreParameter("Calf_Length",
dlg.LengthCalf)
			StoreParameter("Calf_Diameter",
dlg.DiameterCalf)
			StoreParameter("Thigh_Length",
dlg.LengthThigh)
			StoreParameter("Thigh_Diameter",
dlg.DiameterThigh)
			StoreParameter("Forearm_Length",
dlg.LengthForearm)
			StoreParameter("Forearm_Diameter",
dlg.DiameterForearm)
			StoreParameter("Shoulder_Length",
dlg.LengthShldr)
			StoreParameter("Shoulder_Diameter",
dlg.DiameterShldr)
		'NumFrames is used to control the number of
iterations, AngleArray must be redimensioned with the
correct number of columns
			NumFrames = cInt(dlg.FrameNum)
			ReDim AngleArray(NumFrames-1,74)
As Double
		'The Frequency will be used to dimension the
antenna
			Frequency = cDbl(dlg.Freq)

End Sub
Sub ConstructCyl()

			With Units
		  .Geometry "in"
		  .Frequency "MHz"
		  .Time "ns"
		  .TemperatureUnit "Kelvin"
		  .Voltage "V"
		  .Current "A"
		  .Resistance "Ohm"
		  .Conductance "Siemens"
		  .Capacitance "PikoF"
		  .Inductance "NanoH"
		End With


' Constructing the components of the human model out of
cylinders
' Rotating the drawing plane to construct vertical cylinders
		'@ activate local coordinates
		WCS.ActivateWCS "local"
		'@ rotate wcs
		WCS.AlignWCSWithGlobalCoordinates
		WCS.RotateWCS "u", "-90"
Component.New "Torso"
'@ define cylinder: Torso:solid1
With Cylinder
    .Reset
    .Name "solid1"
    .Component "Torso"
    .Material "Bio Tissue/Skin"
    .OuterRadius ".5*Torso_Diameter"
    .InnerRadius "0"
    .Axis "x"
    .Xrange "0", "Torso_Length"
    .Zcenter "0"
    .Ycenter "-0"
    .Segments "0"
    .Create
End With

Component.New "Head"
'@ define cylinder: Head:solid1
With Cylinder
    .Reset
    .Name "solid1"
    .Component "Head"
    .Material "Bio Tissue/Skin"
    .OuterRadius ".5*Head_Diameter"
    .InnerRadius "0"
    .Axis "x"
    .Xrange "0", "Head_Length"
    .Zcenter "0"
    .Ycenter "-0"
    .Segments "0"
    .Create
End With

Component.New "L_Calf"
'@ define cylinder: L_Calf:solid1
With Cylinder
    .Reset
    .Name "solid1"
    .Component "L_Calf"
    .Material "Bio Tissue/Skin"
    .OuterRadius ".5*Calf_Diameter"
    .InnerRadius "0"
    .Axis "x"
    .Xrange "0", "-Calf_Length"
    .Zcenter "0"
    .Ycenter "-0"
    .Segments "0"
    .Create
End With

Component.New "R_Calf"
'@ define cylinder: R_Calf:solid1
With Cylinder
    .Reset
    .Name "solid1"
    .Component "R_Calf"
    .Material "Bio Tissue/Skin"
    .OuterRadius ".5*Calf_Diameter"
    .InnerRadius "0"
    .Axis "x"
    .Xrange "0", "-Calf_Length"
    .Zcenter "0"
    .Ycenter "-0"
    .Segments "0"
    .Create
End With

Component.New "L_Thigh"
'@ define cylinder: L_Thigh:solid1
With Cylinder
    .Reset
    .Name "solid1"
    .Component "L_Thigh"
    .Material "Bio Tissue/Skin"
    .OuterRadius ".5*Thigh_Diameter"
    .InnerRadius "0"
    .Axis "x"
    .Xrange "0", "-Thigh_Length"
    .Zcenter "0"
    .Ycenter "-0"
```

```
    .Segments "0"
    .Create
End With

Component.New "R_Thigh"
'@ define cylinder: R_Thigh:solid1
With Cylinder
    .Reset
    .Name "solid1"
    .Component "R_Thigh"
    .Material "Bio Tissue/Skin"
    .OuterRadius ".5*Thigh_Diameter"
    .InnerRadius "0"
    .Axis "x"
    .Xrange "0", "-Thigh_Length"
    .Zcenter "0"
    .Ycenter "-0"
    .Segments "0"
    .Create
End With

Component.New "L_Forearm"
'@ define cylinder: L_Forearm:solid1
With Cylinder
    .Reset
    .Name "solid1"
    .Component "L_Forearm"
    .Material "Bio Tissue/Skin"
    .OuterRadius ".5*Forearm_Diameter"
    .InnerRadius "0"
    .Axis "x"
    .Xrange "0", "Forearm_Length"
    .Zcenter "0"
    .Ycenter "-0"
    .Segments "0"
    .Create
End With

Component.New "R_Forearm"
'@ define cylinder: R_Forearm:solid1
With Cylinder
    .Reset
    .Name "solid1"
    .Component "R_Forearm"
    .Material "Bio Tissue/Skin"
    .OuterRadius ".5*Forearm_Diameter"
    .InnerRadius "0"
    .Axis "x"
    .Xrange "0", "Forearm_Length"
    .Zcenter "0"
    .Ycenter "-0"
    .Segments "0"
    .Create
End With

Component.New "L_Shoulder"
'@ define cylinder: L_Shoulder:solid1
With Cylinder
    .Reset
    .Name "solid1"
    .Component "L_Shoulder"
    .Material "Bio Tissue/Skin"
    .OuterRadius ".5*Shoulder_Diameter"
    .InnerRadius "0"
    .Axis "x"
    .Xrange "0", "Shoulder_Length"
    .Zcenter "0"
    .Ycenter "-0"
    .Segments "0"
    .Create
End With

Component.New "R_Shoulder"
'@ define cylinder: R_Shoulder:solid1
With Cylinder
    .Reset
    .Name "solid1"
    .Component "R_Shoulder"
    .Material "Bio Tissue/Skin"
    .OuterRadius ".5*Shoulder_Diameter"
    .InnerRadius "0"
    .Axis "x"
    .Xrange "0", "Shoulder_Length"
    .Zcenter "0"
    .Ycenter "-0"
    .Segments "0"
    .Create
End With

'@ align wcs with global coordinates
WCS.AlignWCSWithGlobalCoordinates
'@ activate global coordinates
WCS.ActivateWCS "global"

End Sub

Sub DefineMatl()

'@ define material: Copper (annealed)
With Material
    .Reset
    .Name "Copper (annealed)"
    .Folder ""
.FrqType "static"
.Type "Normal"
.SetMaterialUnit "Hz", "mm"
.Epsilon "1"
.Mue "1.0"
.Kappa "5.8e+007"
.TanD "0.0"
.TanDFreq "0.0"
.TanDGiven "False"
.TanDModel "ConstTanD"
.KappaM "0"
.TanDM "0.0"
.TanDMFreq "0.0"
.TanDMGiven "False"
.TanDMModel "ConstTanD"
.DispModelEps "None"
.DispModelMue "None"
.DispersiveFittingSchemeEps "1st Order"
.DispersiveFittingSchemeMue "1st Order"
.UseGeneralDispersionEps "False"
.UseGeneralDispersionMue "False"
.FrqType "all"
.Type "Lossy metal"
.SetMaterialUnit "GHz", "mm"
.Mue "1.0"
.Kappa "5.8e+007"
.Rho "8930.0"
.ThermalType "Normal"
.ThermalConductivity "401.0"
.HeatCapacity "0.39"
.MetabolicRate "0"
.BloodFlow "0"
.VoxelConvection "0"
.MechanicsType "Isotropic"
.YoungsModulus "120"
.PoissonsRatio "0.33"
.ThermalExpansionRate "17"
```

```
.Colour "1", "1", "0"
.Wireframe "False"
.Reflection "False"
.Allowoutline "True"
.Transparentoutline "False"
.Transparency "0"
.Create
End With

'@ define material: Skin
With Material
    .Reset
    .Name "Skin"
    .Folder "Bio Tissue"
.FrqType "all"
.Type "Normal"
.SetMaterialUnit "GHz", "mm"
.Epsilon "1"
.Mue "1"
.Sigma "0.0"
.TanD "0.0"
.TanDFreq "0.0"
.TanDGiven "False"
.TanDModel "ConstSigma"
.ConstTanDModelOrderEps "1"
.ReferenceCoordSystem "Global"
.CoordSystemType "Cartesian"
.SigmaM "0"
.TanDM "0.0"
.TanDMFreq "0.0"
.TanDMGiven "False"
.TanDMModel "ConstSigma"
.ConstTanDModelOrderMue "1"
.DispModelEps "None"
.DispModelMue "None"
.DispersiveFittingSchemeEps "Nth Order"
.MaximalOrderNthModelFitEps "4"
.ErrorLimitNthModelFitEps "0.01"
.DispersiveFittingSchemeMue "1st Order"
.AddDispersionFittingValueEps "0.1", "72.9292535628039",
"88.2632660909989", "1.0"
.AddDispersionFittingValueEps "0.2", "55.7158312396806",
"52.3170905464558", "1.0"
.AddDispersionFittingValueEps "0.3", "49.8211358473071",
"38.4200231803573", "1.0"
.AddDispersionFittingValueEps "0.4", "46.7865013629648",
"30.9116039943208", "1.0"
.AddDispersionFittingValueEps "0.422222222222222",
"46.2985892900637", "29.6840852715643", "1.0"
.AddDispersionFittingValueEps "0.5", "44.9149575916886",
"26.1793723038478", "1.0"
.AddDispersionFittingValueEps "0.6", "43.6347300752935",
"22.918505517248", "1.0"
.AddDispersionFittingValueEps "0.7", "42.6976586657568",
"20.537164445657", "1.0"
.AddDispersionFittingValueEps "0.744444444444444",
"42.3560481598765", "19.6745123154283", "1.0"
.AddDispersionFittingValueEps "0.8", "41.9780517230144",
"18.7261004758795", "1.0"
.AddDispersionFittingValueEps "0.9", "41.4051932848551",
"17.30719259806", "1.0"
.AddDispersionFittingValueEps "1.06666666666667",
"40.6670269832481", "15.5323066449888", "1.0"
.AddDispersionFittingValueEps "1.38888888888889",
"39.6880059457526", "13.3529660007423", "1.0"
.AddDispersionFittingValueEps "1.71111111111111",
"39.0226484698438", "12.0815280728444", "1.0"
.AddDispersionFittingValueEps "2.03333333333333",
"38.5211569335458", "11.3077400973221", "1.0"
.AddDispersionFittingValueEps "2.35555555555556",
"38.1139219216606", "10.8369905187628", "1.0"
.AddDispersionFittingValueEps "2.67777777777778",
"37.7640861873856", "10.5643561070191", "1.0"
.AddDispersionFittingValueEps "3", "37.4503009263213",
"10.4279238404566", "1.0"
.UseGeneralDispersionEps "True"
.UseGeneralDispersionMue "False"
.NLAnisotropy "False"
.NLAStackingFactor "1"
.NLADirectionX "1"
.NLADirectionY "0"
.NLADirectionZ "0"
.Rho "1100"
.ThermalType "Normal"
.ThermalConductivity "0.293"
.HeatCapacity "3.5"
.MetabolicRate "1620"
.BloodFlow "9100"
.VoxelConvection "0"
.MechanicsType "Unused"
.Colour "1", "0.752941", "0.752941"
.Wireframe "False"
.Reflection "False"
.Allowoutline "True"
.Transparentoutline "False"
.Transparency "0"
.Create
End With
End Sub
Sub ProbePlace()
' Antenna and Probes
If Frame=0 Then
        'The Dialog box asks how many probes the user
wants and where they want them placed
        'It also asks if an antenna should be placed, where
it should be placed, and if another antenna should be added
        Begin Dialog UserDialog 540,294 '
%GRID:10,7,1,1
                GroupBox 10,28,160,231,"Select body
part",.GroupBox1
                GroupBox 200,28,150,154,"Select
Orientation",.GroupBox2
                CheckBox
210,49,130,14,"Along",.Along
                CheckBox
210,112,130,21,"Around",.Around
                Text 210,133,130,21,"Offset from
joint:",.Text2
                TextBox 210,154,110,21,.Offset
                GroupBox 380,28,150,203,"Antenna
Placement",.GroupBox3
                CheckBox
220,70,100,14,"Front",.Front
                CheckBox
220,91,100,14,"Back",.Back
                OKButton 430,266,100,21
                CancelButton 320,266,100,21
                TextBox 140,0,110,21,.ProbeNum
                Text 10,0,130,21,"How Many
Probes?",.Text3
                CheckBox
20,42,130,14,"Torso",.Torso
                CheckBox 20,63,130,14,"Head",.Head
                CheckBox 20,84,130,14,"Left
Forearm",.LForearm
                CheckBox 20,105,130,14,"Left
Shoulder",.LShldr
                CheckBox 20,126,130,14,"Right
Forearm",.RForearm
```

```
			CheckBox 20,147,130,14,"Right
Shoulder",.RShldr
			CheckBox 20,168,130,14,"Left
Calf",.LCalf
			CheckBox 20,189,130,14,"Left
Thigh",.LThigh
			CheckBox 20,210,130,14,"Right
Calf",.RCalf
			CheckBox 20,231,130,14,"Right
Thigh",.RThigh
			CheckBox
390,42,130,14,"Chest",.Chest
			CheckBox 390,63,130,14,"Left
Wrist",.LWrist
			CheckBox 390,84,130,14,"Right
Wrist",.RWrist
			CheckBox 390,105,130,14,"Left
Ankle",.LAnkle
			CheckBox 390,126,130,14,"Right
Ankle",.RAnkle
			CheckBox 380,7,130,14,"Create
Antenna?",.Antenna
			TextBox
390,161,130,21,.AntennaOffset
			TextBox
390,203,130,21,.AntennaRotate
			Text 390,147,120,14,"Offset from
joint:",.Text1
			Text 390,189,120,14,"Antenna
Rotation",.Text4
			CheckBox 340,245,180,14,"Add
another antenna?",.Antenna2
		End Dialog
		Dim dlg As UserDialog
		Dialog dlg
		SelectAlong = dlg.Along
		SelectAround = dlg.Around
		SelectFront = dlg.Front
		SelectBack = dlg.Back
		SelectChest = dlg.Chest
		SelectLWrist = dlg.LWrist
		SelectRWrist = dlg.RWrist
		SelectLAnkle = dlg.LAnkle
		SelectRAnkle = dlg.RAnkle
		SelectTorso = dlg.Torso
		SelectHead = dlg.Head
		SelectLForearm = dlg.LForearm
		SelectLShldr = dlg.LShldr
		SelectRForearm = dlg.RForearm
		SelectRShldr = dlg.RShldr
		SelectLCalf = dlg.LCalf
		SelectLThigh= dlg.LThigh
		SelectRCalf = dlg.RCalf
		SelectRThigh = dlg.LThigh
		ProbeNum = dlg.ProbeNum
		ProbeOffset = dlg.Offset
		AntOffset = dlg.AntennaOffset
		AntRotation = dlg.AntennaRotate
		Antenna2 = dlg.Antenna2
		AntennaNum = 1
'x y and z will be the coordinates of the probe
Dim x As Double
Dim y As Double
Dim z As Double
End If
If CInt(ProbeNum) > 0 Then
		'When a selection is made, the variables
ProbeLength and ProbeDiameter are set to the cooresponding
components length and diameter
		'The coordinate system is then aligned with that
component
		If SelectTorso=1 Then
			ProbeLength = CDbl(Torso_Length)
			ProbeDiameter =
CDbl(Torso_Diameter)
			'@ pick face
			Pick.PickFaceFromId "Torso:solid1",
"1"
			'@ align wcs with face
			WCS.AlignWCSWithSelected "Face"
		ElseIf SelectLForearm=1 Then
			ProbeLength =
CDbl(Forearm_Length)
			ProbeDiameter =
CDbl(Forearm_Diameter)
			'@ pick face
			Pick.PickFaceFromId
"L_Forearm:solid1", "3"
			'@ align wcs with face
			WCS.AlignWCSWithSelected "Face"
			WCS.MoveWCS "local", "0.0", "0.0",
"-2"
			'@ rotate wcs
			WCS.RotateWCS "w", "270.0"
		ElseIf SelectRForearm=1 Then
			ProbeLength =
CDbl(Forearm_Length)
			ProbeDiameter =
CDbl(Forearm_Diameter)
			'@ pick face
			Pick.PickFaceFromId
"R_Forearm:solid1", "3"
			'@ align wcs with face
			WCS.AlignWCSWithSelected "Face"
			WCS.MoveWCS "local", "0.0", "0.0",
"-2"
			'@ rotate wcs
			WCS.RotateWCS "w", "90.0"
		ElseIf SelectLShldr=1 Then
			ProbeLength =
CDbl(Shoulder_Length)
			ProbeDiameter =
CDbl(Shoulder_Diameter)
			'@ pick face
			Pick.PickFaceFromId
"L_Shoulder:solid1", "1"
			'@ align wcs with face
			WCS.AlignWCSWithSelected "Face"
			'@ rotate wcs
			WCS.RotateWCS "w", "270.0"
		ElseIf SelectRShldr=1 Then
			ProbeLength =
CDbl(Shoulder_Length)
			ProbeDiameter =
CDbl(Shoulder_Diameter)
			'@ pick face
			Pick.PickFaceFromId
"R_Shoulder:solid1", "1"
			'@ align wcs with face
			WCS.AlignWCSWithSelected "Face"
			'@ rotate wcs
			WCS.RotateWCS "w", "90.0"
		ElseIf SelectLCalf=1 Then
			ProbeLength = CDbl(Calf_Length)
			ProbeDiameter =
CDbl(Calf_Diameter)
			'@ pick face
			Pick.PickFaceFromId "L_Calf:solid1",
"3"
```

```
'@ align wcs with face
WCS.AlignWCSWithSelected "Face"
'@ rotate wcs
WCS.RotateWCS "w", "180.0"
ElseIf SelectRCalf=1 Then
ProbeLength = CDbl(Calf_Length)
ProbeDiameter =
CDbl(Calf_Diameter)
'@ pick face
Pick.PickFaceFromId "R_Calf:solid1",
"3"
'@ align wcs with face
WCS.AlignWCSWithSelected "Face"
'@ rotate wcs
WCS.RotateWCS "w", "180.0"
ElseIf SelectLThigh=1 Then
ProbeLength = CDbl(Thigh_Length)
ProbeDiameter =
CDbl(Thigh_Diameter)
'@ pick face
Pick.PickFaceFromId
"L_Thigh:solid1", "3"
'@ align wcs with face
WCS.AlignWCSWithSelected "Face"
'@ rotate wcs
WCS.RotateWCS "w", "180.0"
ElseIf SelectRThigh=1 Then
ProbeLength = CDbl(Thigh_Length)
ProbeDiameter =
CDbl(Thigh_Diameter)
'@ pick face
Pick.PickFaceFromId
"R_Thigh:solid1", "3"
'@ align wcs with face
WCS.AlignWCSWithSelected "Face"
'@ rotate wcs
WCS.RotateWCS "w", "180.0"
End If
'The option buttons and user input are checked.
Then, the probes are placed according to a polygon that is
constructed
'The polygon must be used rather than straight
placement because probe placement can only be in reference
to the global coordinate system
If SelectAlong = 1 Then
If SelectFront = 1 Then
If CDbl(ProbeNum) = 1
Then
WCS.MoveWCS "local",
"0.00", CStr(.5*CDbl(ProbeDiameter)+0.590551), "0.00"
'@ rotate wcs
WCS.RotateWCS "u", "-
90.0"
With Polygon
.Reset
.Name "polygon1"
.Curve "curve1"
.Point "0",
CStr(CDbl(ProbeLength)*.66)
.Point "0","0"
.Create
End With
Else
WCS.MoveWCS "local",
"0.00", CStr(.5*CDbl(ProbeDiameter)+0.590551), "0.00"
'@ rotate wcs
WCS.RotateWCS "u", "-
90.0"
With Polygon
.Reset
.Name "polygon1"
.Curve "curve1"
For iv = 1 To
CInt(ProbeNum)
.Point "0", CStr((iv-
1)*CDbl(ProbeLength)/(CInt(ProbeNum)-1))
Next
.Create
End With
End If
ElseIf SelectBack = 1 Then

If CDbl(ProbeNum) = 1
Then
WCS.MoveWCS "local",
"0.00", CStr(-.5*CDbl(ProbeDiameter)+0.590551), "0.00"
'@ rotate wcs
WCS.RotateWCS "u", "-
90.0"
With Polygon
.Reset
.Name "polygon1"
.Curve "curve1"
.Point "0",
CStr(CDbl(ProbeLength)/2)
.Point "0","0"
.Create
End With

With Polygon
.Reset
.Name "polygon1"
.Curve "curve1"
For iv = 1 To
CInt(ProbeNum)
.Point "0", CStr((iv-
1)*CDbl(ProbeLength)/(CInt(ProbeNum)-1))
Next
.Create
End With
End If
End If
ElseIf SelectAround = 1 Then
'@ define probes
WCS.MoveWCS "local",
"0.00", "0.00", CStr(-CDbl(ProbeOffset))
'@ rotate wcs
WCS.RotateWCS "w",
"90.0"
With Polygon
.Reset
.Name "polygon1"
.Curve "curve1"
For iv = 1 To
CInt(ProbeNum)

Anglediff = 2*Pi/CInt(ProbeNum)
.Point
CStr((.5*CDbl(ProbeDiameter)+1)*Cos((iv-1)*Anglediff)),
CStr((.5*CDbl(ProbeDiameter)+1)*Sin((iv-1)*Anglediff))
Next
.Create
End With
End If
'After a polygon is created, this for loop gets the
global coordinate location of every point on the polygon and
places a probe
For iii=1 To CInt(ProbeNum)
'@ clear picks
'       Pick.ClearAllPicks
```

```
'               Pick.PickCurveEndpointFromId
"curve1:polygon1", CStr(iii)
'               Pick.GetPickpointCoordinates(1,x,y,z)

'FOR RIGHT WRIST PLACEMENT change to 2

        Pick.ClearAllPicks
                Pick.PickCurveEndpointFromId
"curve1:polygon1","2"
                Pick.GetPickpointCoordinates(1,x,y,z)

                With Probe
                  .Reset
                  .Name "E-field " & CStr(iii)
                  .Field "Efield"
                  .Orientation "All"
                  .Xpos CStr(x)
                  .Ypos CStr(y)
                  .Zpos CStr(z)
                  .Create
                End With
                Next
'@ align wcs with global coordinates
WCS.AlignWCSWithGlobalCoordinates
End If
'Next, the antenna variables are set to the user specified
values
'The SegDiameter is the diameter of the selected body part
'The SegLength is user input in the "antenna offset" text box
'The local coordinate system also has to be repositioned at the
root joint of the selected component
        If SelectChest = 1 Then
                SegDiameter = CDbl(Torso_Diameter)
                SegLength = CDbl(AntOffset)
                '@ pick face
                Pick.PickExtraCirclepointFromId
"Torso:solid1", "2", "3", "2"

                '@ align wcs with face
                WCS.AlignWCSWithSelected "Point"
                WCS.MoveWCS "local", "0.0", "-
Torso_Length*.33", "-Torso_Length*.25"
                '@ rotate wcs
                WCS.RotateWCS "u",
CStr(CDbl(AntRotation) + 90.0) 'try editing this to rotate
probe?
        ElseIf SelectLWrist = 1 Then
                SegDiameter =
CDbl(Forearm_Diameter)
                SegLength = CDbl(AntOffset)
                '@ pick face
                Pick.PickFaceFromId
"L_Forearm:solid1", "3"
                '@ align wcs with face
                WCS.AlignWCSWithSelected "Face"
                WCS.MoveWCS "local", "0.0", "0.0",
"-2"
                '@ rotate wcs
                WCS.RotateWCS "w", CStr(360.0 +
CDbl(AntRotation))
        ElseIf SelectRWrist = 1 Then
                SegDiameter =
CDbl(Forearm_Diameter)
                SegLength = CDbl(AntOffset)
                '@ pick face
                Pick.PickFaceFromId
"R_Forearm:solid1", "3"
                WCS.MoveWCS "local", "0.0", "0.0",
"-2"
                '@ align wcs with face
                WCS.AlignWCSWithSelected "Face"
                WCS.MoveWCS "local", "0.0", "0.0",
"-2"
                '@ rotate wcs
                WCS.RotateWCS "w", CStr(90 -
CDbl(AntRotation))
        ElseIf SelectLAnkle = 1 Then
                SegDiameter = CDbl(Calf_Diameter)
                SegLength = CDbl(AntOffset)
                '@ pick face
                Pick.PickFaceFromId "L_Calf:solid1",
"3"
                '@ align wcs with face
                WCS.AlignWCSWithSelected "Face"
                '@ rotate wcs
                WCS.RotateWCS "w", CStr(180.0 +
CDbl(AntRotation))
        ElseIf SelectRAnkle = 1 Then
                SegDiameter = CDbl(Calf_Diameter)
                SegLength = CDbl(AntOffset)
                '@ pick face
                Pick.PickFaceFromId "R_Calf:solid1",
"3"
                '@ align wcs with face
                WCS.AlignWCSWithSelected "Face"
                '@ rotate wcs
                WCS.RotateWCS "w", CStr(180.0 +
CDbl(AntRotation))
        End If
        Antenna()

End Sub
Sub Antenna()
'These variables are specified according to standard antenna
theory there is a CST demo if you are curious
        Dim f As Double
        Dim L As Double
        Dim Wv As Double
        Dim R As Double
        Dim g As Double
        f = Frequency*1000000
        Wv = 299792458/f
        L = .475*Wv*39.3701
        R = .001 * Wv*39.3701
        g = L/200
        Component.New "Antenna"
        With Cylinder
   .Reset
   .Name "cylinder1"
   .Component "Antenna"
   .Material "Copper (annealed)"
   .OuterRadius CStr(R)
   .InnerRadius "0.0"
   .Axis "y"
   .Yrange CStr(.5*SegDiameter + 0.590551),
CStr(.5*SegDiameter + 0.590551 + L/2)
   .Xcenter "0"
   .Zcenter CStr(-SegLength)
   .Segments "0"
   .Create
        End With
        '@ pick face
        Pick.PickFaceFromId "Antenna:cylinder1", "3"
        '@ align wcs with face
        WCS.AlignWCSWithSelected "Face"
        Pick.PickFaceFromId "Antenna:gap", "1"
        '@ define cylinder: component1:cylinder2
        With Cylinder
           .Reset
           .Name "cylinder2"
```

```
            .Component "Antenna"
            .Material "Copper (annealed)"
            .OuterRadius Cstr(R)
            .InnerRadius "0.0"
            .Axis "z"
            .Zrange Cstr(g), CStr(L/2+g)
            .Xcenter "0"
            .Ycenter "0"
            .Segments "0"
            .Create
        End With
        '@ align wcs with global coordinates
        WCS.AlignWCSWithGlobalCoordinates
        '@ activate global coordinates
        WCS.ActivateWCS "global"
        Pick.ClearAllPicks
        '@ pick point
        Pick.PickCirclecenterFromId
"Antenna:cylinder2", "1"
        '@ pick point
        Pick.PickCirclecenterFromId
"Antenna:cylinder1", "2"
        '@ define discrete face port: 1
        With DiscretePort
            .Reset
            .PortNumber "1"
            .Type "Voltage"
            .Label ""
            .Impedance "50.0"
            .VoltagePortImpedance "0.0"
            .Voltage "1.0"
            .Current "1.0"
            .SetP1 "True", "31.483195723568",
"14.304179557519", "-3.9471072624022"
            .SetP2 "True", "31.444355843531",
"14.260422748171", "-3.9748179939157"
            .InvertDirection "False"
            .LocalCoordinates "False"
            .Monitor "True"
            .Radius "0.0"
            .Wire ""
            .Position "end1"
            .Create
        End With
        AntennaNum = AntennaNum+1
End Sub

Sub Results()
        '@ define units
        With Units
            .Geometry "in"
            .Frequency "MHz"
            .Time "ns"
            .TemperatureUnit "Kelvin"
            .Voltage "V"
            .Current "A"
            .Resistance "Ohm"
            .Conductance "Siemens"
            .Capacitance "PikoF"
            .Inductance "NanoH"
        End With
'The frequency range might need to be changed
        '@ define frequency range
        Solver.FrequencyRange "400", "450"
        '@ define time domain solver parameters
        'Mesh.SetCreator "High Frequency"
        With Solver
            .Method "Hexahedral"
            .CalculationType "TD-S"
            .StimulationPort "All"
            .StimulationMode "All"
            .SteadyStateLimit "-30.0"
            .MeshAdaption "False"
            .AutoNormImpedance "True"
            .NormingImpedance "73"
            .CalculateModesOnly "False"
            .SParaSymmetry "False"
            .StoreTDResultsInCache  "False"
            .FullDeembedding "False"
            .SuperimposePLWExcitation "False"
            .UseSensitivityAnalysis "False"
        End With
        '@ define time domain solver acceleration
        With Solver
            .UseParallelization "True"
            .MaximumNumberOfThreads "48"
            .UseDistributedComputing "False"
            .MaxNumberOfDistributedComputingPorts
"2"
            .DistributeMatrixCalculation "True"
            .MPIParallelization "False"
            .HardwareAcceleration "True"
            .MaximumNumberOfGPUs "1"
        End With
        UseDistributedComputingForParameters "False"
        MaxNumberOfDistributedComputingParameters
"2"
        UseDistributedComputingMemorySetting "False"
        MinDistributedComputingMemoryLimit "0"
        '@ define time domain solver parameters
        'Mesh.SetCreator "High Frequency"
        With Solver
            .Method "Hexahedral"
            .CalculationType "TD-S"
            .StimulationPort "All"
            .StimulationMode "All"
            .SteadyStateLimit "-30.0"
            .MeshAdaption "False"
            .AutoNormImpedance "True"
            .NormingImpedance "73"
            .CalculateModesOnly "False"
            .SParaSymmetry "False"
            .StoreTDResultsInCache  "False"
            .FullDeembedding "False"
            .SuperimposePLWExcitation "False"
            .UseSensitivityAnalysis "False"
        End With
        With MeshSettings
            .SetMeshType "Hex"
            .Set "Version", 0%
        End With
'The mesh settings might need to be changed. Increase
"LinesPerWavelength" to refine the mesh
        With Mesh
            .UseRatioLimit "True"
            .RatioLimit "100"
            .LinesPerWavelength "20"
            .MinimumStepNumber "2"
            .Automesh "True"
            .MeshType "PBA"
            '.SetCreator "High Frequency"
        End With

        If Frame = 0 Then
        Begin Dialog UserDialog 400,84 '
%GRID:10,7,1,1
                TextBox 30,28,340,21,.DataLocation
                OKButton 270,56,130,21
                Text 20,7,280,21,"Enter a file
location",.Text1
```

```
		End Dialog
		Dim dlg As UserDialog
		Dialog dlg
		DataLocation = dlg.DataLocation
		End If
		'Run simulation
		Solver.start
		'Store results in text file on desktop
			SelectTreeItem("1D Results\Probes\E-
Field\E-field " & 1 & "(Z) [1]")
			Plot1D.PlotView "Phase"
			With ASCIIExport
				.Reset
				.FileName(DataLocation &
Frame & "_Phase.txt")
				.Execute
			End With
			SelectTreeItem("1D Results\Probes\E-
Field\E-field " & 1 & "(Z) [1]")
			Plot1D.PlotView "magnitudedb"
			With ASCIIExport
				.Reset
				.FileName(DataLocation &
Frame & "_db.txt")
				.Execute
			End With
End Sub

Sub OpenBVH24()

		If Frame = 0 Then 'We don't want the user to have
to specify the file every iteration
			'Dialog asking user to specify file
location
			Begin Dialog UserDialog 300,154 '
%GRID:10,7,1,1
				Text 20,77,150,14,"or enter
bvh file location:",.Text1
				TextBox
20,98,220,21,.Location
				OKButton 100,126,110,21
				Text 20,28,90,21,"Use T
pose?",.Text2
				CheckBox
120,28,20,14,"CheckBox1",.CheckBox1
			End Dialog
			Dim dlg As UserDialog
			Dialog dlg
			If dlg.CheckBox1 = 0 Then
		'Opening the file and inputing lines as a 1D array
			Open dlg.Location For Input As #1
		   ReDim sTxt(0)
		   Do While Not EOF(1)
		      Input #1, sTxt(UBound(sTxt))
		      ReDim Preserve sTxt(UBound(sTxt) + 1)
		   Loop
		   Close #1
		'Creating an array by splitting lines into their parts
			For i = 0 To NumFrames-1
				For j = 0 To 74 '74 for full
body, 11 for one arm

		AngleArray(i,j)=Split(sTxt(i))(j)
				Next
			Next
			End If
		End If
		' Checking if checkbox is checked
		If dlg.CheckBox1 = 1 Then
		'Position in the T Position
				TPosition()
		Else

		ForwardMotion()

		'The coordinate system should be realigned with
the global coordinates for the sake of h
		'@ align wcs with global coordinates
		WCS.AlignWCSWithGlobalCoordinates
		'@ activate global coordinates
		WCS.ActivateWCS "global"
		End If

End Sub
Sub L_ShoulderForward()

		WCS.ActivateWCS "global"
		WCS.ActivateWCS "local"
			'@ activate local coordinates
			'WCS.ActivateWCS "local"
			'@ align wcs with point
			Pick.PickCirclecenterFromId
"L_Shoulder:solid1", "1"
			WCS.AlignWCSWithSelectedPoint
		'	WCS.RotateWCS "u", "180"
		'	WCS.RotateWCS "w", "180"
'		WCS.RotateWCS "v", "90.0"

		'shoulder---------------------------------

			With Transform
			   .Reset
			   .Name "L_Shoulder"
			   .Origin "Free"
			   .Center "0", "0", "0"
			   .Angle
Cstr(AngleArray(Frame,27)),"0", "0"
			   .MultipleObjects "False"
			   .GroupObjects "False"
			   .Repetitions "1"
			   .MultipleSelection "False"
			   .Transform "Shape", "Rotate"
			End With

			With Transform
			   .Reset
			   .Name "L_Shoulder"
			   .Origin "Free"
			   .Center "0", "0", "0"
			   .Angle
"0",Cstr(AngleArray(Frame,28)), "0"
			   .MultipleObjects "False"
			   .GroupObjects "False"
			   .Repetitions "1"
			   .MultipleSelection "False"
			   .Transform "Shape", "Rotate"
			End With

			With Transform
			   .Reset
			   .Name "L_Shoulder"
			   .Origin "Free"
			   .Center "0", "0", "0"
			   .Angle "0",
"0",Cstr(AngleArray(Frame,29))
			   .MultipleObjects "False"
			   .GroupObjects "False"
			   .Repetitions "1"
			   .MultipleSelection "False"
			   .Transform "Shape", "Rotate"
```

```
                                End With


                                'rotates 90 degrees to compensate for
subject having faced the x axis
                                With Transform
                                    .Reset
                                    .Name "L_Shoulder"
                                    .Origin "Free"
                                    .Center "0", "0", "0"
                                    .Angle  "0","0", "0"
                                    .MultipleObjects "False"
                                    .GroupObjects "False"
                                    .Repetitions "1"
                                    .MultipleSelection "False"
                                    .Transform "Shape", "Rotate"
                                End With

                                'translate to proper position

With Transform
    .Reset
    .Name "L_Shoulder:solid1"
    .Vector "0.5075*Torso_Diameter", "0.9*Torso_Length",
"-0.125*Torso_Diameter"
    .UsePickedPoints "False"
    .InvertPickedPoints "False"
    .MultipleObjects "False"
    .GroupObjects "False"
    .Repetitions "1"
    .MultipleSelection "False"
    .Transform "Shape", "Translate"
End With

End Sub
Sub L_UpperForward()

WCS.ActivateWCS "global"
                WCS.ActivateWCS "local"
                                '@ activate local coordinates
                                'WCS.ActivateWCS "local"
                                '@ align wcs with point
                                Pick.PickCirclecenterFromId
"L_Upper:solid1", "1"
                                WCS.AlignWCSWithSelectedPoint
                '               WCS.RotateWCS "u", "180"
                '               WCS.RotateWCS "w", "180"
'WCS.RotateWCS "v", "90.0"

                'upper---------------------------------

                                With Transform
                                    .Reset
                                    .Name "L_Upper"
                                    .Origin "Free"
                                    .Center "0", "0", "0"
                                    .Angle
Cstr(AngleArray(Frame,27)),"0", "0"
                                    .MultipleObjects "False"
                                    .GroupObjects "False"
                                    .Repetitions "1"
                                    .MultipleSelection "False"
                                    .Transform "Shape", "Rotate"
                                End With

                                With Transform
                                    .Reset
                                    .Name "L_Upper"
                                    .Origin "Free"
                                    .Center "0", "0", "0"
                                    .Angle
"0",Cstr(AngleArray(Frame,28)), "0"
                                    .MultipleObjects "False"
                                    .GroupObjects "False"
                                    .Repetitions "1"
                                    .MultipleSelection "False"
                                    .Transform "Shape", "Rotate"
                                End With

                                With Transform
                                    .Reset
                                    .Name "L_Upper"
                                    .Origin "Free"
                                    .Center "0", "0", "0"
                                    .Angle "0", "0",
Cstr(AngleArray(Frame,29))
                                    .MultipleObjects "False"
                                    .GroupObjects "False"
                                    .Repetitions "1"
                                    .MultipleSelection "False"
                                    .Transform "Shape", "Rotate"
                                End With

                                'translate to proper position
Pick.PickCenterpointFromId "L_Shoulder:solid1", "3"
Pick.PickCenterpointFromId "L_Upper:solid1", "1"
With Transform
    .Reset
    .Name "L_Upper:solid1"
    .Vector "-22.3", "-4.6", "15"
    .UsePickedPoints "True"
    .InvertPickedPoints "True"
    .MultipleObjects "False"
    .GroupObjects "False"
    .Repetitions "1"
    .MultipleSelection "False"
    .Transform "Shape", "Translate"
End With

Pick.PickCenterpointFromId "L_Upper:solid1", "3"
WCS.AlignWCSWithSelected "Point"
'left foot/calf
With Sphere
    .Reset
    .Name "solid1"
    .Component "sphere11"
    .Material "Bio Tissue/Skin"
    .Axis "z"
    .CenterRadius ".5*LUpper_Diameter"
    .TopRadius "0"
    .BottomRadius "0"
    .Center "0", "0", "0"
    .Segments "0"
    .Create
End With

End Sub
Sub L_ForearmForward()

WCS.ActivateWCS "global"
                WCS.ActivateWCS "local"
                                '@ activate local coordinates
                                'WCS.ActivateWCS "local"
                                '@ align wcs with point
                                Pick.PickCirclecenterFromId
"L_Forearm:solid1", "1"
                                WCS.AlignWCSWithSelectedPoint
                '               WCS.RotateWCS "u", "180"
                '               WCS.RotateWCS "w", "180"
'               WCS.RotateWCS "v", "90.0"
```

```
                    'forearm following upper motion-------
--------------

                    With Transform
                       .Reset
                       .Name "L_Forearm"
                       .Origin "Free"
                       .Center "0", "0", "0"
                       .Angle
Cstr(AngleArray(Frame,30)),"0", "0"
                       .MultipleObjects "False"
                       .GroupObjects "False"
                       .Repetitions "1"
                       .MultipleSelection "False"
                       .Transform "Shape", "Rotate"
                    End With

                    With Transform
                       .Reset
                       .Name "L_Forearm"
                       .Origin "Free"
                       .Center "0", "0", "0"
                       .Angle
"0",Cstr(AngleArray(Frame,31)), "0"
                       .MultipleObjects "False"
                       .GroupObjects "False"
                       .Repetitions "1"
                       .MultipleSelection "False"
                       .Transform "Shape", "Rotate"
                    End With

                    With Transform
                       .Reset
                       .Name "L_Forearm"
                       .Origin "Free"
                       .Center "0", "0", "0"
                       .Angle "0", "0",
Cstr(AngleArray(Frame,32))
                       .MultipleObjects "False"
                       .GroupObjects "False"
                       .Repetitions "1"
                       .MultipleSelection "False"
                       .Transform "Shape", "Rotate"
                    End With

                    'rotates 90 degrees to compensate for
subject having faced the x axis
                    With Transform
                       .Reset
                       .Name "L_Forearm"
                       .Origin "Free"
                       .Center "0", "0", "0"
                       .Angle  "0","0", "0"
                       .MultipleObjects "False"
                       .GroupObjects "False"
                       .Repetitions "1"
                       .MultipleSelection "False"
                       .Transform "Shape", "Rotate"
                    End With

                    'translate to proper position
Pick.PickCenterpointFromId "L_Shoulder:solid1", "3"
Pick.PickCenterpointFromId "L_Forearm:solid1", "1"
With Transform
   .Reset
   .Name "L_Forearm:solid1"
   .Vector "-22.3", "-4.6", "15"
   .UsePickedPoints "True"
   .InvertPickedPoints "True"
   .MultipleObjects "False"
   .GroupObjects "False"
   .Repetitions "1"
   .MultipleSelection "False"
   .Transform "Shape", "Translate"
End With

End Sub
Sub L_HandForward()

WCS.ActivateWCS "global"
          WCS.ActivateWCS "local"
                    '@ activate local coordinates
                    'WCS.ActivateWCS "local"
                    '@ align wcs with point
                    Pick.PickCirclecenterFromId
"L_Hand:solid1", "1"
                    WCS.AlignWCSWithSelectedPoint
         '          WCS.RotateWCS "u", "180"
         '          WCS.RotateWCS "w", "180"
'         WCS.RotateWCS "v", "90.0"

                    'forearm following upper motion-------
--------------

                    With Transform
                       .Reset
                       .Name "L_Hand"
                       .Origin "Free"
                       .Center "0", "0", "0"
                       .Angle
Cstr(AngleArray(Frame,33)),"0", "0"
                       .MultipleObjects "False"
                       .GroupObjects "False"
                       .Repetitions "1"
                       .MultipleSelection "False"
                       .Transform "Shape", "Rotate"
                    End With

                    With Transform
                       .Reset
                       .Name "L_Hand"
                       .Origin "Free"
                       .Center "0", "0", "0"
                       .Angle
"0",Cstr(AngleArray(Frame,34)), "0"
                       .MultipleObjects "False"
                       .GroupObjects "False"
                       .Repetitions "1"
                       .MultipleSelection "False"
                       .Transform "Shape", "Rotate"
                    End With

                    With Transform
                       .Reset
                       .Name "L_Hand"
                       .Origin "Free"
                       .Center "0", "0", "0"
                       .Angle "0", "0",
Cstr(AngleArray(Frame,35))
                       .MultipleObjects "False"
                       .GroupObjects "False"
                       .Repetitions "1"
                       .MultipleSelection "False"
                       .Transform "Shape", "Rotate"
                    End With

                    'translate to proper position
Pick.PickCenterpointFromId "L_Forearm:solid1", "3"
Pick.PickCenterpointFromId "L_Hand:solid1", "1"
```

```
With Transform
    .Reset
    .Name "L_Hand:solid1"
    .Vector "-22.3", "-4.6", "15"
    .UsePickedPoints "True"
    .InvertPickedPoints "True"
    .MultipleObjects "False"
    .GroupObjects "False"
    .Repetitions "1"
    .MultipleSelection "False"
    .Transform "Shape", "Translate"
End With

End Sub

Sub ForwardMotion()

TorsoForward()
WCS.ActivateWCS "global"
HeadForward()
WCS.ActivateWCS "global"
L_ShoulderForward()
WCS.ActivateWCS "global"
L_ForearmForward()
WCS.ActivateWCS "global"
R_ShoulderForward()
WCS.ActivateWCS "global"
R_ForearmForward()
WCS.ActivateWCS "global"
L_ThighForward()
WCS.ActivateWCS "global"
L_CalfForward()
WCS.ActivateWCS "global"
R_ThighForward()
WCS.ActivateWCS "global"
R_CalfForward()
WCS.ActivateWCS "global"

End Sub
Sub R_UpperForward()

WCS.ActivateWCS "global"
        WCS.ActivateWCS "local"
                '@ activate local coordinates
                'WCS.ActivateWCS "local"
                '@ align wcs with point
                Pick.PickCirclecenterFromId
"R_Upper:solid1", "1"
                WCS.AlignWCSWithSelectedPoint
        '       WCS.RotateWCS "u", "180"
        '       WCS.RotateWCS "w", "180"

        'upper---------------------------------

                With Transform
                    .Reset
                    .Name "R_Upper"
                    .Origin "Free"
                    .Center "0", "0", "0"
                    .Angle
Cstr(AngleArray(Frame,42)),"0", "0"
                    .MultipleObjects "False"
                    .GroupObjects "False"
                    .Repetitions "1"
                    .MultipleSelection "False"
                    .Transform "Shape", "Rotate"
                End With

                With Transform
                    .Reset
                    .Name "R_Upper"
                    .Origin "Free"
                    .Center "0", "0", "0"
                    .Angle
"0",Cstr(AngleArray(Frame,43)), "0"
                    .MultipleObjects "False"
                    .GroupObjects "False"
                    .Repetitions "1"
                    .MultipleSelection "False"
                    .Transform "Shape", "Rotate"
                End With

                With Transform
                    .Reset
                    .Name "R_Upper"
                    .Origin "Free"
                    .Center "0", "0", "0"
                    .Angle "0",
"0",Cstr(AngleArray(Frame,44))
                    .MultipleObjects "False"
                    .GroupObjects "False"
                    .Repetitions "1"
                    .MultipleSelection "False"
                    .Transform "Shape", "Rotate"
                End With

                'translate to proper position
Pick.PickCenterpointFromId "R_Shoulder:solid1", "3"
Pick.PickCenterpointFromId "R_Upper:solid1", "1"
With Transform
    .Reset
    .Name "R_Upper:solid1"
    .Vector "-22.3", "-4.6", "15"
    .UsePickedPoints "True"
    .InvertPickedPoints "True"
    .MultipleObjects "False"
    .GroupObjects "False"
    .Repetitions "1"
    .MultipleSelection "False"
    .Transform "Shape", "Translate"
End With

Pick.PickCenterpointFromId "R_Upper:solid1", "3"
WCS.AlignWCSWithSelected "Point"
'right upper/fore
With Sphere
    .Reset
    .Name "solid1"
    .Component "sphere8"
    .Material "Bio Tissue/Skin"
    .Axis "z"
    .CenterRadius ".5*RUpper_Diameter"
    .TopRadius "0"
    .BottomRadius "0"
    .Center "0", "0", "0"
    .Segments "0"
    .Create
End With

End Sub
Sub R_ShoulderForward()

        WCS.ActivateWCS "global"
        WCS.ActivateWCS "local"
                '@ activate local coordinates
                'WCS.ActivateWCS "local"
                '@ align wcs with point
                Pick.PickCirclecenterFromId
"R_Shoulder:solid1", "1"
                WCS.AlignWCSWithSelectedPoint
```

```
'		WCS.RotateWCS "u", "180"
'		WCS.RotateWCS "w", "180"

	'shoulder---------------------------------

		With Transform
		    .Reset
		    .Name "R_Shoulder"
		    .Origin "Free"
		    .Center "0", "0", "0"
		    .Angle
Cstr(AngleArray(Frame,42)),"0", "0"
		    .MultipleObjects "False"
		    .GroupObjects "False"
		    .Repetitions "1"
		    .MultipleSelection "False"
		    .Transform "Shape", "Rotate"
		End With

		With Transform
		    .Reset
		    .Name "R_Shoulder"
		    .Origin "Free"
		    .Center "0", "0", "0"
		    .Angle
"0",Cstr(AngleArray(Frame,43)), "0"
		    .MultipleObjects "False"
		    .GroupObjects "False"
		    .Repetitions "1"
		    .MultipleSelection "False"
		    .Transform "Shape", "Rotate"
		End With

		With Transform
		    .Reset
		    .Name "R_Shoulder"
		    .Origin "Free"
		    .Center "0", "0", "0"
		    .Angle "0",
"0",Cstr(AngleArray(Frame,44))
		    .MultipleObjects "False"
		    .GroupObjects "False"
		    .Repetitions "1"
		    .MultipleSelection "False"
		    .Transform "Shape", "Rotate"
		End With

						'rotates 90
degrees to compensate for subject having faced the x axis
		With Transform
		    .Reset
		    .Name "R_Shoulder"
		    .Origin "Free"
		    .Center "0", "0", "0"
		    .Angle  "0","0", "0"
		    .MultipleObjects "False"
		    .GroupObjects "False"
		    .Repetitions "1"
		    .MultipleSelection "False"
		    .Transform "Shape", "Rotate"
		End With

		'translate to proper position
With Transform
    .Reset
    .Name "R_Shoulder:solid1"
    .Vector "-0.5025*Torso_Diameter", "0.9*Torso_Length",
"-0.125*Torso_Diameter"
    .UsePickedPoints "False"
    .InvertPickedPoints "False"
    .MultipleObjects "False"
    .GroupObjects "False"
    .Repetitions "1"
    .MultipleSelection "False"
    .Transform "Shape", "Translate"
End With

End Sub
Sub R_ForearmForward()

WCS.ActivateWCS "global"
	WCS.ActivateWCS "local"
			'@ activate local coordinates
			'WCS.ActivateWCS "local"
			'@ align wcs with point
			Pick.PickCirclecenterFromId
"R_Forearm:solid1", "1"
			WCS.AlignWCSWithSelectedPoint
	'		WCS.RotateWCS "u", "180"
	'		WCS.RotateWCS "w", "180"

			'forearm following upper motion-------
--------------

			With Transform
			    .Reset
			    .Name "R_Forearm"
			    .Origin "Free"
			    .Center "0", "0", "0"
			    .Angle
Cstr(AngleArray(Frame,45)),"0", "0"
			    .MultipleObjects "False"
			    .GroupObjects "False"
			    .Repetitions "1"
			    .MultipleSelection "False"
			    .Transform "Shape", "Rotate"
			End With

			With Transform
			    .Reset
			    .Name "R_Forearm"
			    .Origin "Free"
			    .Center "0", "0", "0"
			    .Angle
"0",Cstr(AngleArray(Frame,46)), "0"
			    .MultipleObjects "False"
			    .GroupObjects "False"
			    .Repetitions "1"
			    .MultipleSelection "False"
			    .Transform "Shape", "Rotate"
			End With

			With Transform
			    .Reset
			    .Name "R_Forearm"
			    .Origin "Free"
			    .Center "0", "0", "0"
			    .Angle "0",
"0",Cstr(AngleArray(Frame,47))
			    .MultipleObjects "False"
			    .GroupObjects "False"
			    .Repetitions "1"
			    .MultipleSelection "False"
			    .Transform "Shape", "Rotate"
			End With


							'rotates 90
degrees to compensate for subject having faced the x axis
			With Transform
```

```
                              .Reset
                              .Name "R_Forearm"
                              .Origin "Free"
                              .Center "0", "0", "0"
                              .Angle  "0","0", "0"
                              .MultipleObjects "False"
                              .GroupObjects "False"
                              .Repetitions "1"
                              .MultipleSelection "False"
                              .Transform "Shape", "Rotate"
                         End With

                         'translate to proper position
Pick.PickCenterpointFromId "R_Shoulder:solid1", "3"
Pick.PickCenterpointFromId "R_Forearm:solid1", "1"
With Transform
    .Reset
    .Name "R_Forearm:solid1"
    .Vector "-22.3", "-4.6", "15"
    .UsePickedPoints "True"
    .InvertPickedPoints "True"
    .MultipleObjects "False"
    .GroupObjects "False"
    .Repetitions "1"
    .MultipleSelection "False"
    .Transform "Shape", "Translate"
End With

End Sub

Sub R_HandForward()

WCS.ActivateWCS "global"
            WCS.ActivateWCS "local"
                         '@ activate local coordinates
                         'WCS.ActivateWCS "local"
                         '@ align wcs with point
                         Pick.PickCirclecenterFromId
"R_Hand:solid1", "1"
                         WCS.AlignWCSWithSelectedPoint
            '            WCS.RotateWCS "u", "180"
            '            WCS.RotateWCS "w", "180"

                         'forearm following upper motion-------
--------------

                         With Transform
                              .Reset
                              .Name "R_Hand"
                              .Origin "Free"
                              .Center "0", "0", "0"
                              .Angle
Cstr(AngleArray(Frame,48)),"0", "0"
                              .MultipleObjects "False"
                              .GroupObjects "False"
                              .Repetitions "1"
                              .MultipleSelection "False"
                              .Transform "Shape", "Rotate"
                         End With

                         With Transform
                              .Reset
                              .Name "R_Hand"
                              .Origin "Free"
                              .Center "0", "0", "0"
                              .Angle
"0",Cstr(AngleArray(Frame,49)), "0"
                              .MultipleObjects "False"
                              .GroupObjects "False"
                              .Repetitions "1"
                              .MultipleSelection "False"
                              .Transform "Shape", "Rotate"
                         End With

                         With Transform
                              .Reset
                              .Name "R_Hand"
                              .Origin "Free"
                              .Center "0", "0", "0"
                              .Angle "0",
"0",Cstr(AngleArray(Frame,50))
                              .MultipleObjects "False"
                              .GroupObjects "False"
                              .Repetitions "1"
                              .MultipleSelection "False"
                              .Transform "Shape", "Rotate"
                         End With

                         'translate to proper position
Pick.PickCenterpointFromId "R_Forearm:solid1", "3"
Pick.PickCenterpointFromId "R_Hand:solid1", "1"
With Transform
    .Reset
    .Name "R_Hand:solid1"
    .Vector "-22.3", "-4.6", "15"
    .UsePickedPoints "True"
    .InvertPickedPoints "True"
    .MultipleObjects "False"
    .GroupObjects "False"
    .Repetitions "1"
    .MultipleSelection "False"
    .Transform "Shape", "Translate"
End With

End Sub

Sub L_ThighForward()

WCS.ActivateWCS "global"
            WCS.ActivateWCS "local"
                         '@ activate local coordinates
                         'WCS.ActivateWCS "local"
                         '@ align wcs with point
                         Pick.PickCirclecenterFromId
"L_Thigh:solid1", "1"
                         WCS.AlignWCSWithSelectedPoint
            '            WCS.RotateWCS "u", "180"
            '            WCS.RotateWCS "w", "180"

'           WCS.RotateWCS "v", "90.0"

                         'thigh motion---------------------

                         With Transform
                              .Reset
                              .Name "L_Thigh"
                              .Origin "Free"
                              .Center "0", "0", "0"
                              .Angle "0","0", "0"
                              .MultipleObjects "False"
                              .GroupObjects "False"
                              .Repetitions "1"
                              .MultipleSelection "False"
                              .Transform "Shape", "Rotate"
                         End With

                         With Transform
                              .Reset
                              .Name "L_Thigh"
                              .Origin "Free"
```

```
            .Center "0", "0", "0"
            .Angle  "0","0", "0"
            .MultipleObjects "False"
            .GroupObjects "False"
            .Repetitions "1"
            .MultipleSelection "False"
            .Transform "Shape", "Rotate"
        End With

        With Transform
            .Reset
            .Name "L_Thigh"
            .Origin "Free"
            .Center "0", "0", "0"
            .Angle "0",  "0","-90"
            .MultipleObjects "False"
            .GroupObjects "False"
            .Repetitions "1"
            .MultipleSelection "False"
            .Transform "Shape", "Rotate"
        End With

        'translate to proper position

With Transform
    .Reset
    .Name "L_Thigh:solid1"
    .Vector "Thigh_Length+.25*Torso_Diameter",
"0.05*Thigh_Length", "0"
    .UsePickedPoints "False"
    .InvertPickedPoints "False"
    .MultipleObjects "False"
    .GroupObjects "False"
    .Repetitions "1"
    .MultipleSelection "False"
    .Transform "Shape", "Translate"
End With

End Sub
Sub L_CalfForward()

WCS.ActivateWCS "global"
    WCS.ActivateWCS "local"
        '@ activate local coordinates
        'WCS.ActivateWCS "local"
        '@ align wcs with point
        Pick.PickCirclecenterFromId
"L_Calf:solid1", "1"
        WCS.AlignWCSWithSelectedPoint
    '   WCS.RotateWCS "u", "180"
    '   WCS.RotateWCS "w", "180"

'   WCS.RotateWCS "v", "90.0"
        'calf motion---------------------

        With Transform
            .Reset
            .Name "L_Calf"
            .Origin "Free"
            .Center "0", "0", "0"
            .Angle "0","0", "0"
            .MultipleObjects "False"
            .GroupObjects "False"
            .Repetitions "1"
            .MultipleSelection "False"
            .Transform "Shape", "Rotate"
        End With

        With Transform
            .Reset
            .Name "L_Calf"
            .Origin "Free"
            .Center "0", "0", "0"
            .Angle "0","0", "0"
            .MultipleObjects "False"
            .GroupObjects "False"
            .Repetitions "1"
            .MultipleSelection "False"
            .Transform "Shape", "Rotate"
        End With

        With Transform
            .Reset
            .Name "L_Calf"
            .Origin "Free"
            .Center "0", "0", "0"
            .Angle "0", "0","-90"
            .MultipleObjects "False"
            .GroupObjects "False"
            .Repetitions "1"
            .MultipleSelection "False"
            .Transform "Shape", "Rotate"
        End With

        'translate to proper position
Pick.PickCenterpointFromId "L_Thigh:solid1", "3"
Pick.PickCenterpointFromId "L_Calf:solid1", "1"
With Transform
    .Reset
    .Name "L_Calf:solid1"
    .Vector "-22.3", "-4.6", "15"
    .UsePickedPoints "True"
    .InvertPickedPoints "True"
    .MultipleObjects "False"
    .GroupObjects "False"
    .Repetitions "1"
    .MultipleSelection "False"
    .Transform "Shape", "Translate"
End With

End Sub
Sub L_FootForward()

WCS.ActivateWCS "global"
    WCS.ActivateWCS "local"
        '@ activate local coordinates
        'WCS.ActivateWCS "local"
        '@ align wcs with point
        Pick.PickCirclecenterFromId
"L_Foot:solid1", "1"
        WCS.AlignWCSWithSelectedPoint
    '   WCS.RotateWCS "u", "180"
    '   WCS.RotateWCS "w", "180"

'   WCS.RotateWCS "v", "90.0"
        'calf motion---------------------

        With Transform
            .Reset
            .Name "L_Foot"
            .Origin "Free"
            .Center "0", "0", "0"
            .Angle
Cstr(AngleArray(Frame,60)),"0", "0"
            .MultipleObjects "False"
            .GroupObjects "False"
            .Repetitions "1"
            .MultipleSelection "False"
            .Transform "Shape", "Rotate"
        End With
```

```
                    With Transform
                        .Reset
                        .Name "L_Foot"
                        .Origin "Free"
                        .Center "0", "0", "0"
                        .Angle
"0",Cstr(AngleArray(Frame,61)), "0"
                        .MultipleObjects "False"
                        .GroupObjects "False"
                        .Repetitions "1"
                        .MultipleSelection "False"
                        .Transform "Shape", "Rotate"
                    End With

                    With Transform
                        .Reset
                        .Name "L_Foot"
                        .Origin "Free"
                        .Center "0", "0", "0"
                        .Angle "0",
"0",Cstr(AngleArray(Frame,62))
                        .MultipleObjects "False"
                        .GroupObjects "False"
                        .Repetitions "1"
                        .MultipleSelection "False"
                        .Transform "Shape", "Rotate"
                    End With

                    'translate to proper position
Pick.PickCenterpointFromId "L_Calf:solid1", "3"
Pick.PickCenterpointFromId "L_Foot:solid1", "1"
With Transform
    .Reset
    .Name "L_Foot:solid1"
    .Vector "-22.3", "-4.6", "15"
    .UsePickedPoints "True"
    .InvertPickedPoints "True"
    .MultipleObjects "False"
    .GroupObjects "False"
    .Repetitions "1"
    .MultipleSelection "False"
    .Transform "Shape", "Translate"
End With

End Sub

Sub R_CalfForward()

WCS.ActivateWCS "global"
          WCS.ActivateWCS "local"
                    '@ activate local coordinates
                    'WCS.ActivateWCS "local"
                    '@ align wcs with point
                    Pick.PickCirclecenterFromId
"R_Calf:solid1", "1"
                    WCS.AlignWCSWithSelectedPoint
          '         WCS.RotateWCS "u", "180"
          '         WCS.RotateWCS "w", "180"
'         WCS.RotateWCS "v", "90.0"

                    'calf motion--------------------

                    With Transform
                        .Reset
                        .Name "R_Calf"
                        .Origin "Free"
                        .Center "0", "0", "0"
                        .Angle "0","0", "0"
                        .MultipleObjects "False"
                        .GroupObjects "False"
                        .Repetitions "1"
                        .MultipleSelection "False"
                        .Transform "Shape", "Rotate"
                    End With

                    With Transform
                        .Reset
                        .Name "R_Calf"
                        .Origin "Free"
                        .Center "0", "0", "0"
                        .Angle  "0","0", "0"
                        .MultipleObjects "False"
                        .GroupObjects "False"
                        .Repetitions "1"
                        .MultipleSelection "False"
                        .Transform "Shape", "Rotate"
                    End With

                    With Transform
                        .Reset
                        .Name "R_Calf"
                        .Origin "Free"
                        .Center "0", "0", "0"
                        .Angle "0",  "0","-90"
                        .MultipleObjects "False"
                        .GroupObjects "False"
                        .Repetitions "1"
                        .MultipleSelection "False"
                        .Transform "Shape", "Rotate"
                    End With

                    'translate to proper position
Pick.PickCenterpointFromId "R_Thigh:solid1", "3"
Pick.PickCenterpointFromId "R_Calf:solid1", "1"
With Transform
    .Reset
    .Name "R_Calf:solid1"
    .Vector "-22.3", "-4.6", "15"
    .UsePickedPoints "True"
    .InvertPickedPoints "True"
    .MultipleObjects "False"
    .GroupObjects "False"
    .Repetitions "1"
    .MultipleSelection "False"
    .Transform "Shape", "Translate"
End With

End Sub
Sub R_FootForward()

WCS.ActivateWCS "global"
          WCS.ActivateWCS "local"
                    '@ activate local coordinates
                    'WCS.ActivateWCS "local"
                    '@ align wcs with point
                    Pick.PickCirclecenterFromId
"R_Foot:solid1", "1"
                    WCS.AlignWCSWithSelectedPoint
          '         WCS.RotateWCS "u", "180"
          '         WCS.RotateWCS "w", "180"
'         WCS.RotateWCS "v", "90.0"

                    'calf motion--------------------

                    With Transform
                        .Reset
                        .Name "R_Foot"
                        .Origin "Free"
                        .Center "0", "0", "0"
```

```
                .Angle
Cstr(AngleArray(Frame,72)),"0", "0"
                .MultipleObjects "False"
                .GroupObjects "False"
                .Repetitions "1"
                .MultipleSelection "False"
                .Transform "Shape", "Rotate"
            End With

            With Transform
                .Reset
                .Name "R_Foot"
                .Origin "Free"
                .Center "0", "0", "0"
                .Angle
"0",Cstr(AngleArray(Frame,73)), "0"
                .MultipleObjects "False"
                .GroupObjects "False"
                .Repetitions "1"
                .MultipleSelection "False"
                .Transform "Shape", "Rotate"
            End With

            With Transform
                .Reset
                .Name "R_Foot"
                .Origin "Free"
                .Center "0", "0", "0"
                .Angle "0",
"0",Cstr(AngleArray(Frame,74))
                .MultipleObjects "False"
                .GroupObjects "False"
                .Repetitions "1"
                .MultipleSelection "False"
                .Transform "Shape", "Rotate"
            End With

            'translate to proper position
Pick.PickCenterpointFromId "R_Calf:solid1", "3"
Pick.PickCenterpointFromId "R_Foot:solid1", "1"
With Transform
    .Reset
    .Name "R_Foot:solid1"
    .Vector "-22.3", "-4.6", "15"
    .UsePickedPoints "True"
    .InvertPickedPoints "True"
    .MultipleObjects "False"
    .GroupObjects "False"
    .Repetitions "1"
    .MultipleSelection "False"
    .Transform "Shape", "Translate"
End With

End Sub

Sub R_ThighForward()

WCS.ActivateWCS "global"
        WCS.ActivateWCS "local"
            '@ activate local coordinates
            'WCS.ActivateWCS "local"
            '@ align wcs with point
            Pick.PickCirclecenterFromId
"R_Thigh:solid1", "1"
            WCS.AlignWCSWithSelectedPoint
        '   WCS.RotateWCS "u", "180"
        '   WCS.RotateWCS "w", "180"
'       WCS.RotateWCS "v", "90.0"

            'thigh motion---------------------

            With Transform
                .Reset
                .Name "R_Thigh"
                .Origin "Free"
                .Center "0", "0", "0"
                .Angle  "0","0", "0"
                .MultipleObjects "False"
                .GroupObjects "False"
                .Repetitions "1"
                .MultipleSelection "False"
                .Transform "Shape", "Rotate"
            End With

            With Transform
                .Reset
                .Name "R_Thigh"
                .Origin "Free"
                .Center "0", "0", "0"
                .Angle  "0","0", "0"
                .MultipleObjects "False"
                .GroupObjects "False"
                .Repetitions "1"
                .MultipleSelection "False"
                .Transform "Shape", "Rotate"
            End With

            With Transform
                .Reset
                .Name "R_Thigh"
                .Origin "Free"
                .Center "0", "0", "0"
                .Angle "0", "0", "-90"
                .MultipleObjects "False"
                .GroupObjects "False"
                .Repetitions "1"
                .MultipleSelection "False"
                .Transform "Shape", "Rotate"
            End With


                                'translate to
proper position

With Transform
    .Reset
    .Name "R_Thigh:solid1"
    .Vector "Thigh_Length-0.25*Torso_Diameter",
"0.05*Thigh_Length", "0"
    .UsePickedPoints "False"
    .InvertPickedPoints "False"
    .MultipleObjects "False"
    .GroupObjects "False"
    .Repetitions "1"
    .MultipleSelection "False"
    .Transform "Shape", "Translate"
End With

End Sub

Sub DeleteCyl()
        Component.Delete "Head"
        Component.Delete "L_Calf"

        Component.Delete "L_Forearm"

        Component.Delete "L_Shoulder"
        Component.Delete "L_Thigh"

        Component.Delete "R_Calf"
```

```
            Component.Delete "R_Forearm"

            Component.Delete "R_Shoulder"
            Component.Delete "R_Thigh"

            Component.Delete "Torso"

            Probe.Delete "E-field 1"
            Curve.DeleteCurve "curve1"
            'Curve.DeleteCurve "curve2" 'curve2 appears for
chest/back
            Port.Delete "1"
            Component.Delete "Antenna"

End Sub

Sub HeadForward()

            WCS.ActivateWCS "global"
            WCS.ActivateWCS "local"
                        '@ activate local coordinates
                        'WCS.ActivateWCS "local"
                        '@ align wcs with point
                        Pick.PickCirclecenterFromId
"Head:solid1", "1"
                        WCS.AlignWCSWithSelectedPoint
            '           WCS.RotateWCS "v", "90.0"


                        '------------move headcover--------------
---------
                                                With Transform
                           .Reset
                           .Name "Head"
                           .Origin "Free"
                           .Center "0", "0", "0"
                           .Angle "0","0", "0"
                           .MultipleObjects "False"
                           .GroupObjects "False"
                           .Repetitions "1"
                           .MultipleSelection "False"
                           .Transform "Shape", "Rotate"
                        End With

                        With Transform
                           .Reset
                           .Name "Head"
                           .Origin "Free"
                           .Center "0", "0", "0"
                           .Angle "0","0", "0"
                           .MultipleObjects "False"
                           .GroupObjects "False"
                           .Repetitions "1"
                           .MultipleSelection "False"
                           .Transform "Shape", "Rotate"
                        End With

                        With Transform
                           .Reset
                           .Name "Head"
                           .Origin "Free"
                           .Center "0", "0", "0"
                           .Angle "0",  "0","90"
                           .MultipleObjects "False"
                           .GroupObjects "False"
                           .Repetitions "1"
                           .MultipleSelection "False"
                           .Transform "Shape", "Rotate"
                        End With
                        'translate to proper position
Pick.PickCenterpointFromId "Torso:solid1", "3"
Pick.PickCenterpointFromId "Head:solid1", "1"
With Transform
   .Reset
   .Name "Head:solid1"
   .Vector "-22.3", "-4.6", "15"
   .UsePickedPoints "True"
   .InvertPickedPoints "True"
   .MultipleObjects "False"
   .GroupObjects "False"
   .Repetitions "1"
   .MultipleSelection "False"
   .Transform "Shape", "Translate"
End With

End Sub

Sub TorsoForward()

WCS.ActivateWCS "global"
            WCS.ActivateWCS "local"
                        '@ activate local coordinates
                        'WCS.ActivateWCS "local"
                        '@ align wcs with point
                        Pick.PickCirclecenterFromId
"Torso:solid1", "1"
                        WCS.AlignWCSWithSelectedPoint
            '           WCS.RotateWCS "v", "90.0"

                        With Transform
                           .Reset
                           .Name "Torso"
                           .Origin "Free"
                           .Center "0", "0", "0"
                           .Angle "0","0", "0"
                           .MultipleObjects "False"
                           .GroupObjects "False"
                           .Repetitions "1"
                           .MultipleSelection "False"
                           .Transform "Shape", "Rotate"
                        End With

                        With Transform
                           .Reset
                           .Name "Torso"
                           .Origin "Free"
                           .Center "0", "0", "0"
                           .Angle "0","0", "0"
                           .MultipleObjects "False"
                           .GroupObjects "False"
                           .Repetitions "1"
                           .MultipleSelection "False"
                           .Transform "Shape", "Rotate"
                        End With

                        With Transform
                           .Reset
                           .Name "Torso"
                           .Origin "Free"
                           .Center "0", "0", "0"
                           .Angle "0","0","90"
                           .MultipleObjects "False"
                           .GroupObjects "False"
                           .Repetitions "1"
                           .MultipleSelection "False"
                           .Transform "Shape", "Rotate"
                        End With
```

```
End Sub
Sub MergePieces()

' , , , , , ,

' , , , , , ,
With Solid
    .Version 9
    .Add "L_Calf:solid1", "L_Thigh:solid1"
    .Version 1
End With
With Solid
    .Version 9
    .Add "L_Calf:solid1", "Torso:solid1"
    .Version 1
End With
With Solid
    .Version 9
    .Add "L_Calf:solid1", "R_Thigh:solid1"
    .Version 1
End With
With Solid
    .Version 9
    .Add "L_Calf:solid1", "R_Calf:solid1"
    .Version 1
End With
With Solid
    .Version 9
    .Add "L_Calf:solid1", "L_Shoulder:solid1"
    .Version 1
End With
With Solid
    .Version 9
    .Add "L_Calf:solid1", "L_Forearm:solid1"
    .Version 1
End With
With Solid
    .Version 9
    .Add "L_Calf:solid1", "R_Shoulder:solid1"
    .Version 1
End With
With Solid
    .Version 9
    .Add "L_Calf:solid1", "R_Forearm:solid1"
    .Version 1
End With
With Solid
    .Version 9
    .Add "L_Calf:solid1", "Head:solid1"
    .Version 1
End With

End Sub
Sub ProbePlace24_v13_3_3()

' Antenna and Probes
If Frame=0 Then
        'The Dialog box asks how many probes the user
wants and where they want them placed
        'It also asks if an antenna should be placed, where
it should be placed, and if another antenna should be added
        Begin Dialog UserDialog 540,294 '
%GRID:10,7,1,1
                GroupBox 10,28,160,231,"Select body
part",.GroupBox1
                GroupBox 200,28,150,154,"Select
Orientation",.GroupBox2
                CheckBox
210,49,130,14,"Along",.Along
                CheckBox
210,112,130,21,"Around",.Around
                Text 210,133,130,21,"Offset from
joint:",.Text2
                TextBox 210,154,110,21,.Offset
                GroupBox 380,28,150,203,"Antenna
Placement",.GroupBox3
                CheckBox
220,70,100,14,"Front",.Front
                CheckBox
220,91,100,14,"Back",.Back
                OKButton 430,266,100,21
                CancelButton 320,266,100,21
                TextBox 140,0,110,21,.ProbeNum
                Text 10,0,130,21,"How Many
Probes?",.Text3
                CheckBox
20,42,130,14,"Torso",.Torso
                CheckBox 20,63,130,14,"Head",.Head
                CheckBox 20,84,130,14,"Left
Forearm",.LForearm
                CheckBox 20,105,130,14,"Left
Shoulder",.LShldr
                CheckBox 20,126,130,14,"Right
Forearm",.RForearm
                CheckBox 20,147,130,14,"Right
Shoulder",.RShldr
                CheckBox 20,168,130,14,"Left
Calf",.LCalf
                CheckBox 20,189,130,14,"Left
Thigh",.LThigh
                CheckBox 20,210,130,14,"Right
Calf",.RCalf
                CheckBox 20,231,130,14,"Right
Thigh",.RThigh
                CheckBox
390,42,130,14,"Chest",.Chest
                CheckBox 390,63,130,14,"Left
Wrist",.LWrist
                CheckBox 390,84,130,14,"Right
Wrist",.RWrist
                CheckBox 390,105,130,14,"Left
Ankle",.LAnkle
                CheckBox 390,126,130,14,"Right
Ankle",.RAnkle
                CheckBox 380,7,130,14,"Create
Antenna?",.Antenna
                TextBox
390,161,130,21,.AntennaOffset
                TextBox
390,203,130,21,.AntennaRotate
                Text 390,147,120,14,"Offset from
joint:",.Text1
                Text 390,189,120,14,"Antenna
Rotation",.Text4
                CheckBox 340,245,180,14,"Add
another antenna?",.Antenna2
        End Dialog
        Dim dlg As UserDialog
        Dialog dlg
        SelectAlong = dlg.Along
        SelectAround = dlg.Around
        SelectFront = dlg.Front
        SelectBack = dlg.Back
        SelectChest = dlg.Chest
        SelectLWrist = dlg.LWrist
        SelectRWrist = dlg.RWrist
        SelectLAnkle = dlg.LAnkle
        SelectRAnkle = dlg.RAnkle
        SelectTorso = dlg.Torso
```

```
SelectHead = dlg.Head
SelectLForearm = dlg.LForearm
SelectLShldr = dlg.LShldr
SelectRForearm = dlg.RForearm
SelectRShldr = dlg.RShldr
SelectLCalf = dlg.LCalf
SelectLThigh= dlg.LThigh
SelectRCalf = dlg.RCalf
SelectRThigh = dlg.LThigh
ProbeNum = dlg.ProbeNum
ProbeOffset = dlg.Offset
AntOffset = dlg.AntennaOffset
AntRotation = dlg.AntennaRotate
Antenna2 = dlg.Antenna2
AntennaNum = 1
'x y and z will be the coordinates of the probe
Dim x As Double
Dim y As Double
Dim z As Double
End If

If CInt(ProbeNum) > 0 Then
'When a selection is made, the variables
ProbeLength and ProbeDiameter are set to the cooresponding
components length and diameter
'The coordinate system is then aligned with that
component
If SelectTorso=1 Then
ProbeLength =
CDbl(0.3333*Torso_Length)
ProbeDiameter =
CDbl(Torso_Diameter)
'@ pick face
Pick.PickFaceFromId "Torso:solid1",
"1"
'@ align wcs with face
WCS.AlignWCSWithSelected "Face"
ElseIf SelectLForearm=1 Then
ProbeLength =
CDbl(Forearm_Length)
ProbeDiameter =
CDbl(Forearm_Diameter)
'@ pick face
Pick.PickFaceFromId
"L_Forearm:solid1", "1"
'@ align wcs with face
WCS.AlignWCSWithSelected "Face"
'@ rotate wcs
WCS.RotateWCS "w", "270.0"
ElseIf SelectRForearm=1 Then
ProbeLength =
CDbl(Forearm_Length)
ProbeDiameter =
CDbl(Forearm_Diameter)
'@ pick face
Pick.PickFaceFromId
"R_Forearm:solid1", "1"
'@ align wcs with face
WCS.AlignWCSWithSelected "Face"
'@ rotate wcs
WCS.RotateWCS "w", "90.0"
ElseIf SelectLShldr=1 Then
ProbeLength =
CDbl(Shoulder_Length)
ProbeDiameter =
CDbl(Shoulder_Diameter)
'@ pick face
Pick.PickFaceFromId
"L_Shoulder:solid1", "1"
'@ align wcs with face
WCS.AlignWCSWithSelected "Face"
'@ rotate wcs
WCS.RotateWCS "w", "270.0"
ElseIf SelectRShldr=1 Then
ProbeLength =
CDbl(Shoulder_Length)
ProbeDiameter =
CDbl(Shoulder_Diameter)
'@ pick face
Pick.PickFaceFromId
"R_Shoulder:solid1", "1"
'@ align wcs with face
WCS.AlignWCSWithSelected "Face"
'@ rotate wcs
WCS.RotateWCS "w", "90.0"
ElseIf SelectLCalf=1 Then
ProbeLength = CDbl(Calf_Length)
ProbeDiameter =
CDbl(Calf_Diameter)
'@ pick face
Pick.PickFaceFromId "L_Calf:solid1",
"3"
'@ align wcs with face
WCS.AlignWCSWithSelected "Face"
'@ rotate wcs
WCS.RotateWCS "w", "180.0"
ElseIf SelectRCalf=1 Then
ProbeLength = CDbl(Calf_Length)
ProbeDiameter =
CDbl(Calf_Diameter)
'@ pick face
Pick.PickFaceFromId "R_Calf:solid1",
"3"
'@ align wcs with face
WCS.AlignWCSWithSelected "Face"
'@ rotate wcs
WCS.RotateWCS "w", "180.0"
ElseIf SelectLThigh=1 Then
ProbeLength = CDbl(Thigh_Length)
ProbeDiameter =
CDbl(Thigh_Diameter)
'@ pick face
Pick.PickFaceFromId
"L_Thigh:solid1", "3"
'@ align wcs with face
WCS.AlignWCSWithSelected "Face"
'@ rotate wcs
WCS.RotateWCS "w", "180.0"
ElseIf SelectRThigh=1 Then
ProbeLength = CDbl(Thigh_Length)
ProbeDiameter =
CDbl(Thigh_Diameter)
'@ pick face
Pick.PickFaceFromId
"R_Thigh:solid1", "3"
'@ align wcs with face
WCS.AlignWCSWithSelected "Face"
'@ rotate wcs
WCS.RotateWCS "w", "180.0"
End If
'The option buttons and user input are checked.
Then, the probes are placed according to a polygon that is
constructed
'The polygon must be used rather than straight
placement because probe placement can only be in reference
to the global coordinate system
If SelectAlong = 1 Then
If SelectFront = 1 Then
If CDbl(ProbeNum) = 1
Then
```

```
WCS.MoveWCS "local",
"0.00", CStr(.5*CDbl(ProbeDiameter)+0.590551), "0.00"
'@ rotate wcs
WCS.RotateWCS "u", "-
90.0"
        With Polygon
    .Reset
    .Name "polygon1"
    .Curve "curve1"
    .Point "0",
CStr(CDbl(ProbeLength)/2)
    .Point
"0",".66666*Torso_Length"
    .Create
End With
Else
WCS.MoveWCS "local",
"0.00", CStr(.5*CDbl(ProbeDiameter)+0.590551), "0.00"
'@ rotate wcs
WCS.RotateWCS "u", "-
90.0"
With Polygon
    .Reset
    .Name "polygon1"
    .Curve "curve1"
    For iv = 1 To
CInt(ProbeNum)
    .Point "0", CStr((iv-
1)*CDbl(ProbeLength)/(CInt(ProbeNum)-1))
    Next
    .Create
End With
End If
    ElseIf SelectBack = 1 Then
If CDbl(ProbeNum) = 1
Then
'@ define probes
WCS.MoveWCS "local",
"0.00", CStr(-(.5*CDbl(ProbeDiameter)+0.590551)), "0.00"
'@ rotate wcs
WCS.RotateWCS "u", "-
90.0"
With Polygon
    .Reset
    .Name "polygon1"
    .Curve "curve1"
    .Point "0",
CStr(CDbl(ProbeLength)/2)
    .Point
"0",".66*Torso_Length"
    .Create
End With

Else
WCS.RotateWCS "u", "-
90.0"
With Polygon
    .Reset
    .Name "polygon1"
    .Curve "curve1"
    For iv = 1 To
CInt(ProbeNum)
        .Point "0",
CStr((iv-1)*CDbl(ProbeLength)/(CInt(ProbeNum)-1))
    '.Point "0", CStr((iv-
1)*CDbl(ProbeLength)/(CInt(ProbeNum)-1))
    Next
    .Create
End With
End If
End If
    ElseIf SelectAround = 1 Then
        '@ define probes
        WCS.MoveWCS "local",
"0.00", "0.00", CStr(-CDbl(ProbeOffset))
        '@ rotate wcs
        WCS.RotateWCS "w",
"90.0"
        With Polygon
            .Reset
            .Name "polygon1"
            .Curve "curve1"
            For iv = 1 To
CInt(ProbeNum)

    Anglediff = 2*Pi/CInt(ProbeNum)
                .Point
CStr((.5*CDbl(ProbeDiameter)+1)*Cos((iv-1)*Anglediff)),
CStr((.5*CDbl(ProbeDiameter)+1)*Sin((iv-1)*Anglediff))
            Next
            .Create
        End With
    End If
    'After a polygon is created, this for loop gets the
global coordinate location of every point on the polygon and
places a probe
    For iii=1 To CInt(ProbeNum)
        '@ clear picks
        Pick.ClearAllPicks
        Pick.PickCurveEndpointFromId
"curve1:polygon1","2"
        Pick.GetPickpointCoordinates(1,x,y,z)

        With Probe
            .Reset
            .Name "E-field " & CStr(iii)
            .Field "Efield"
            .Orientation "All"
            .Xpos CStr(x)
            .Ypos CStr(y)
            .Zpos CStr(z)
            .Create
        End With
        Next
'@ align wcs with global coordinates
WCS.AlignWCSWithGlobalCoordinates
End If
'Next, the antenna variables are set to the user specified
values
'The SegDiameter is the diameter of the selected body part
'The SegLength is user input in the "antenna offset" text box
'The local coordinate system also has to be repositioned at the
root joint of the selected component
    If SelectChest = 1 Then
        SegDiameter = CDbl(Torso_Diameter)
        SegLength = CDbl(AntOffset)
        '@ pick face
        Pick.PickFaceFromId "Torso:solid1",
"1"
        '@ align wcs with face
        WCS.AlignWCSWithSelected "Face"
        '@ rotate wcs
        WCS.RotateWCS "w",
CStr(AntRotation) 'try editing this to rotate probe?

            'WCS.MoveWCS "local",
"0.00", CStr(.5*CDbl(ProbeDiameter)+0.590551), "0.00"
            '@ rotate wcs
            WCS.RotateWCS "u", "-
90.0"
```

```
                    With Polygon
                .Reset
                .Name "polygon1"
                .Curve "curve2"
                .Point "0",
CStr(CDbl(ProbeLength)/2)
                .Point
"0",".66*Torso_Length"
                .Create
            End With

    Pick.PickCurveEndpointFromId
"curve2:polygon1", "2"

    WCS.AlignWCSWithSelected "Point"
        WCS.RotateWCS "u", "90.0"

    ElseIf SelectLWrist = 1 Then
        SegDiameter =
CDbl(LFore_Diameter)
        SegLength = CDbl(AntOffset)
        '@ pick face
        Pick.PickFaceFromId
"L_Forearm:solid1", "3"
        '@ align wcs with face
        WCS.AlignWCSWithSelected "Face"
        '@ rotate wcs
        WCS.RotateWCS "w", CStr(270.0 +
CDbl(AntRotation))
    ElseIf SelectRWrist = 1 Then
        SegDiameter =
CDbl(RFore_Diameter)
        SegLength = CDbl(AntOffset)
        '@ pick face
        Pick.PickFaceFromId
"R_Forearm:solid1", "3"
        '@ align wcs with face
        WCS.AlignWCSWithSelected "Face"
        '@ rotate wcs
        WCS.RotateWCS "w", CStr(90.0 -
CDbl(AntRotation))
    ElseIf SelectLAnkle = 1 Then
        SegDiameter = CDbl(LCalf_Diameter)
        SegLength = CDbl(AntOffset)
        '@ pick face
        Pick.PickFaceFromId "L_Calf:solid1",
"3"
        '@ align wcs with face
        WCS.AlignWCSWithSelected "Face"
        '@ rotate wcs
        WCS.RotateWCS "w", CStr(180.0 +
CDbl(AntRotation))
    ElseIf SelectRAnkle = 1 Then
        SegDiameter = CDbl(RCalf_Diameter)
        SegLength = CDbl(AntOffset)
        '@ pick face
        Pick.PickFaceFromId "R_Calf:solid1",
"3"
        '@ align wcs with face
        WCS.AlignWCSWithSelected "Face"
        '@ rotate wcs
        WCS.RotateWCS "w", CStr(180.0 +
CDbl(AntRotation))
    End If
    Antenna()

End Sub

Sub TPosition()
```

```
'Rotate Arm Components for T-pose

'----------------left chest and upper shoulder ----------------------
------------------------------------
With Transform
   .Reset
   .Name "L__Upper_Shoulder"
   .Origin "Free"
   .Center "0", "0", "0"
   .Angle "0", "0", "-90"
   .MultipleObjects "False"
   .GroupObjects "False"
   .Repetitions "1"
   .MultipleSelection "False"
   .Transform "Shape", "Rotate"
End With

With Transform
   .Reset
   .Name "L_Chest"
   .Origin "Free"
   .Center "0", "0", "0"
   .Angle "0", "0", "-45"
   .MultipleObjects "False"
   .GroupObjects "False"
   .Repetitions "1"
   .MultipleSelection "False"
   .Transform "Shape", "Rotate"
End With
'------------------------------------------------------------------------
----------------------------------


'@ transform: rotate L_Shoulder
With Transform
   .Reset
   .Name "L_Shoulder"
   .Origin "Free"
   .Center "0", "0", "0"
   .Angle "0", "0", "-90"
   .MultipleObjects "False"
   .GroupObjects "False"
   .Repetitions "1"
   .MultipleSelection "False"
   .Transform "Shape", "Rotate"
End With

'@ transform: rotate L_Forearm
With Transform
   .Reset
   .Name "L_Forearm"
   .Origin "Free"
   .Center "0", "0", "0"
   .Angle "0", "0", "-90"
   .MultipleObjects "False"
   .GroupObjects "False"
   .Repetitions "1"
   .MultipleSelection "False"
   .Transform "Shape", "Rotate"
End With

'@ transform: rotate R_Shoulder
With Transform
   .Reset
   .Name "R_Shoulder"
   .Origin "Free"
   .Center "0", "0", "0"
   .Angle "0", "0", "90"
   .MultipleObjects "False"
   .GroupObjects "False"
```

```
    .Repetitions "1"
    .MultipleSelection "False"
    .Transform "Shape", "Rotate"
End With

'@ transform: rotate R_Forearm
With Transform
    .Reset
    .Name "R_Forearm"
    .Origin "Free"
    .Center "0", "0", "0"
    .Angle "0", "0", "90"
    .MultipleObjects "False"
    .GroupObjects "False"
    .Repetitions "1"
    .MultipleSelection "False"
    .Transform "Shape", "Rotate"
End With

'Position Head at Top of Torso
        '@ pick circle center point
        Pick.PickCirclecenterFromId "Head:solid1", "1"
        '@ pick circle center point
        Pick.PickCirclecenterFromId "Torso:solid1", "2"
        '@ transform: translate Head
        With Transform
            .Reset
            .Name "Head"
            .Vector "0", "0", "0"
            .UsePickedPoints "True"
            .InvertPickedPoints "False"
            .MultipleObjects "False"
            .GroupObjects "False"
            .Repetitions "1"
            .MultipleSelection "False"
            .Transform "Shape", "Translate"
        End With
        '@ clear picks
        Pick.ClearAllPicks
'Position Left Shoulder -------------------------------------- plus
chest and upper shoulder
        With Transform
            .Reset
            .Name "L_Shoulder"
            .Vector ".4*Torso_Diameter", "Torso_Length-
.5*Shoulder_Diameter", "0"
            .UsePickedPoints "False"
            .InvertPickedPoints "False"
            .MultipleObjects "False"
            .GroupObjects "False"
            .Repetitions "1"
            .MultipleSelection "False"
            .Transform "Shape", "Translate"
        End With

'Position Left Upper Shoulder
        '@ pick circle center point
        Pick.PickCirclecenterFromId
"L_Shoulder:solid1", "1"
        '@ pick circle center point
        Pick.PickCirclecenterFromId
"L_Upper_Shoulder:solid1", "3"
        '@ transform: translate L_Forearm
        With Transform
            .Reset
            .Name "L_Upper_Shoulder"
            .Vector "0", "0", "0"
            .UsePickedPoints "True"
            .InvertPickedPoints "False"
            .MultipleObjects "False"
            .GroupObjects "False"
            .Repetitions "1"
            .MultipleSelection "False"
            .Transform "Shape", "Translate"
        End With
        '@ clear picks
        Pick.ClearAllPicks

        'Position Left Chest
        '@ pick circle center point
        Pick.PickCirclecenterFromId
"L_Upper_Shoulder:solid1", "1"
        '@ pick circle center point
        Pick.PickCirclecenterFromId "L_Chest:solid1",
"3"
        '@ transform: translate L_Forearm
        With Transform
            .Reset
            .Name "L_Chest"
            .Vector "0", "0", "0"
            .UsePickedPoints "True"
            .InvertPickedPoints "False"
            .MultipleObjects "False"
            .GroupObjects "False"
            .Repetitions "1"
            .MultipleSelection "False"
            .Transform "Shape", "Translate"
        End With
        '@ clear picks
        Pick.ClearAllPicks


'-----------------------------------------------------------------------
------------------------------

'Position Right Shoulder
        With Transform
            .Reset
            .Name "R_Shoulder"
            .Vector "-.4*Torso_Diameter",
"Torso_Length-.5*Shoulder_Diameter", "0"
            .UsePickedPoints "False"
            .InvertPickedPoints "False"
            .MultipleObjects "False"
            .GroupObjects "False"
            .Repetitions "1"
            .MultipleSelection "False"
            .Transform "Shape", "Translate"
        End With
'Position Left Forearm
        '@ pick circle center point
        Pick.PickCirclecenterFromId "L_Forearm:solid1",
"1"
        '@ pick circle center point
        Pick.PickCirclecenterFromId
"L_Shoulder:solid1", "2"
        '@ transform: translate L_Forearm
        With Transform
            .Reset
            .Name "L_Forearm"
            .Vector "0", "0", "0"
            .UsePickedPoints "True"
            .InvertPickedPoints "False"
            .MultipleObjects "False"
            .GroupObjects "False"
            .Repetitions "1"
            .MultipleSelection "False"
            .Transform "Shape", "Translate"
        End With
        '@ clear picks
```

```
        Pick.ClearAllPicks
'Position Right Forearm
        '@ pick circle center point
        Pick.PickCirclecenterFromId
"R_Forearm:solid1", "1"
        '@ pick circle center point
        Pick.PickCirclecenterFromId
"R_Shoulder:solid1", "2"
        '@ transform: translate R_Forearm
        With Transform
          .Reset
          .Name "R_Forearm"
          .Vector "0", "0", "0"
          .UsePickedPoints "True"
          .InvertPickedPoints "False"
          .MultipleObjects "False"
          .GroupObjects "False"
          .Repetitions "1"
          .MultipleSelection "False"
          .Transform "Shape", "Translate"
        End With
        '@ clear picks
        Pick.ClearAllPicks
'Position Left Thigh
        With Transform
          .Reset
          .Name "L_Thigh"
          .Vector ".25*Torso_Diameter", "0", "0"
          .UsePickedPoints "False"
          .InvertPickedPoints "False"
          .MultipleObjects "False"
          .GroupObjects "False"
          .Repetitions "1"
          .MultipleSelection "False"
          .Transform "Shape", "Translate"
        End With
'Position Right Thigh
        With Transform
          .Reset
          .Name "R_Thigh"
          .Vector "-.25*Torso_Diameter", "0", "0"
          .UsePickedPoints "False"
          .InvertPickedPoints "False"
          .MultipleObjects "False"
          .GroupObjects "False"
          .Repetitions "1"
          .MultipleSelection "False"
          .Transform "Shape", "Translate"
        End With
'Position Left Calf
        '@ pick circle center point
        Pick.PickCirclecenterFromId "L_Calf:solid1", "2"
        '@ pick circle center point
        Pick.PickCirclecenterFromId "L_Thigh:solid1",
"1"
        '@ transform: translate L_Calf
        With Transform
          .Reset
          .Name "L_Calf"
          .Vector "3", "-10", "0"
          .UsePickedPoints "True"
          .InvertPickedPoints "False"
          .MultipleObjects "False"
          .GroupObjects "False"
          .Repetitions "1"
          .MultipleSelection "False"
          .Transform "Shape", "Translate"
        End With
        '@ clear picks
        Pick.ClearAllPicks
'Position Right Calf
        '@ pick circle center point
        Pick.PickCirclecenterFromId "R_Calf:solid1", "2"
        '@ pick circle center point
        Pick.PickCirclecenterFromId "R_Thigh:solid1",
"1"
        '@ transform: translate R_Calf
        With Transform
          .Reset
          .Name "R_Calf"
          .Vector "-3", "-10", "0"
          .UsePickedPoints "True"
          .InvertPickedPoints "False"
          .MultipleObjects "False"
          .GroupObjects "False"
          .Repetitions "1"
          .MultipleSelection "False"
          .Transform "Shape", "Translate"
        End With
        '@ clear picks
        Pick.ClearAllPicks
End Sub
```

APPENDIX C

MATLAB Code – bvhEulerZXYtoFixedXYZ

```
function Z = bvhEulerZXYtoFixedXYZ ( A,N )
%George Lee - WBAN Research Group - Baylor University
%this version is able to convert multiple frames of a bvh file
%Inputs:
%   A = matrix containing full body bvh Euler angles
%   N = number of frames in the bvh
%Outputs:
%   Z = matrix containing full body bvh angles converted to fixed
angles
tic
h = waitbar(0,'Storing Euler Angles...');
allEuler = [];

%this looping fills allEuler, a matrix containing all roation matrices
for
%the joints of the body described in the Recap2 bvh file
for n=1:1:N %cycles through each frame for each joint

    for i=1:3:73 %cycles through the joints
%   a = Euler z rot
%   b = Euler x rot
%   c = Euler y rot
    a = A(n,i);
    b = A(n,i+1);
    c = A(n,i+2);


    %set values of rotation matrix using Euler angles
    EulerR = [-sind(a)*sind(b)*sind(c)+cosd(a)*cosd(c) -sind(a)*cosd(b)
...
        sind(a)*sind(b)*cosd(c)+cosd(a)*sind(c); ...
            cosd(a)*sind(b)*sind(c)+sind(a)*cosd(c) ...
            cosd(a)*cosd(b) -cosd(a)*sind(b)*cosd(c)+sind(a)*sind(c);
...
            -cosd(b)*sind(c) sind(b) cosd(b)*cosd(c)];

    %save Euler rotation matrix into larger matrix that holds all
rotation
    %matrices in where every three rows is a new matrix

    allEuler = [allEuler;EulerR];


    end
    waitbar(n/N)
end
close(h);
```

```
%allEuler %uncomment if want to check for correct contents

%extract euler rotation matrices from allEuler for use in
multiplication
c = 1;
q = 1;
Z = zeros(N,75);

r = waitbar(0,'Converting to Fixed Angles ...');
for i=1:75:N*75

    E_spine1 = [allEuler(3+i,1) allEuler(3+i,2) allEuler(3+i,3);
                allEuler(4+i,1) allEuler(4+i,2) allEuler(4+i,3);
                allEuler(5+i,1) allEuler(5+i,2) allEuler(5+i,3)];

    E_spine2 = [allEuler(6+i,1) allEuler(6+i,2) allEuler(6+i,3);
                allEuler(7+i,1) allEuler(7+i,2) allEuler(7+i,3);
                allEuler(8+i,1) allEuler(8+i,2) allEuler(8+i,3)];

    E_spine3 = [allEuler(9+i,1) allEuler(9+i,2) allEuler(9+i,3);
                allEuler(10+i,1) allEuler(10+i,2) allEuler(10+i,3);
                allEuler(11+i,1) allEuler(11+i,2) allEuler(11+i,3)];

    E_head = [allEuler(12+i,1) allEuler(12+i,2) allEuler(12+i,3);
                allEuler(13+i,1) allEuler(13+i,2) allEuler(13+i,3);
                allEuler(14+i,1) allEuler(14+i,2) allEuler(14+i,3)];

    E_head2 = [allEuler(15+i,1) allEuler(15+i,2) allEuler(15+i,3);
                allEuler(16+i,1) allEuler(16+i,2) allEuler(16+i,3);
                allEuler(17+i,1) allEuler(17+i,2) allEuler(17+i,3)];

    E_headend = [allEuler(18+i,1) allEuler(18+i,2) allEuler(18+i,3);
                allEuler(19+i,1) allEuler(19+i,2) allEuler(19+i,3);
                allEuler(20+i,1) allEuler(20+i,2) allEuler(20+i,3)];

    E_LChest = [allEuler(21+i,1) allEuler(21+i,2) allEuler(21+i,3);
                allEuler(22+i,1) allEuler(22+i,2) allEuler(22+i,3);
                allEuler(23+i,1) allEuler(23+i,2) allEuler(23+i,3)];

    E_LShoulder = [allEuler(24+i,1) allEuler(24+i,2) allEuler(24+i,3);
                allEuler(25+i,1) allEuler(25+i,2) allEuler(25+i,3);
                allEuler(26+i,1) allEuler(26+i,2) allEuler(26+i,3)];

    E_LUpper = [allEuler(27+i,1) allEuler(27+i,2) allEuler(27+i,3);
                allEuler(28+i,1) allEuler(28+i,2) allEuler(28+i,3);
                allEuler(29+i,1) allEuler(29+i,2) allEuler(29+i,3)];

    E_LFore = [allEuler(30+i,1) allEuler(30+i,2) allEuler(30+i,3);
                allEuler(31+i,1) allEuler(31+i,2) allEuler(31+i,3);
                allEuler(32+i,1) allEuler(32+i,2) allEuler(32+i,3)];

    E_LHand = [allEuler(33+i,1) allEuler(33+i,2) allEuler(33+i,3);
                allEuler(34+i,1) allEuler(34+i,2) allEuler(34+i,3);
                allEuler(35+i,1) allEuler(35+i,2) allEuler(35+i,3)];
```

```
E_RChest = [allEuler(36+i,1) allEuler(36+i,2) allEuler(36+i,3);
            allEuler(37+i,1) allEuler(37+i,2) allEuler(37+i,3);
            allEuler(38+i,1) allEuler(38+i,2) allEuler(38+i,3)];

E_RShoulder = [allEuler(39+i,1) allEuler(39+i,2) allEuler(39+i,3);
            allEuler(40+i,1) allEuler(40+i,2) allEuler(40+i,3);
            allEuler(41+i,1) allEuler(41+i,2) allEuler(41+i,3)];

E_RUpper = [allEuler(42+i,1) allEuler(42+i,2) allEuler(42+i,3);
            allEuler(43+i,1) allEuler(43+i,2) allEuler(43+i,3);
            allEuler(44+i,1) allEuler(44+i,2) allEuler(44+i,3)];

E_RFore = [allEuler(45+i,1) allEuler(45+i,2) allEuler(45+i,3);
            allEuler(46+i,1) allEuler(46+i,2) allEuler(46+i,3);
            allEuler(47+i,1) allEuler(47+i,2) allEuler(47+i,3)];

E_RHand = [allEuler(48+i,1) allEuler(48+i,2) allEuler(48+i,3);
            allEuler(49+i,1) allEuler(49+i,2) allEuler(49+i,3);
            allEuler(50+i,1) allEuler(50+i,2) allEuler(50+i,3)];

E_LPelvis = [allEuler(51+i,1) allEuler(51+i,2) allEuler(51+i,3);
            allEuler(52+i,1) allEuler(52+i,2) allEuler(52+i,3);
            allEuler(53+i,1) allEuler(53+i,2) allEuler(53+i,3)];

E_LThigh = [allEuler(54+i,1) allEuler(54+i,2) allEuler(54+i,3);
            allEuler(55+i,1) allEuler(55+i,2) allEuler(55+i,3);
            allEuler(56+i,1) allEuler(56+i,2) allEuler(56+i,3)];


E_LCalf = [allEuler(57+i,1) allEuler(57+i,2) allEuler(57+i,3);
            allEuler(58+i,1) allEuler(58+i,2) allEuler(58+i,3);
            allEuler(59+i,1) allEuler(59+i,2) allEuler(59+i,3)];

E_LFoot = [allEuler(60+i,1) allEuler(60+i,2) allEuler(60+i,3);
            allEuler(61+i,1) allEuler(61+i,2) allEuler(61+i,3);
            allEuler(62+i,1) allEuler(62+i,2) allEuler(62+i,3)];

E_RPelvis = [allEuler(63+i,1) allEuler(63+i,2) allEuler(63+i,3);
            allEuler(64+i,1) allEuler(64+i,2) allEuler(64+i,3);
            allEuler(65+i,1) allEuler(65+i,2) allEuler(65+i,3)];

E_RThigh = [allEuler(66+i,1) allEuler(66+i,2) allEuler(66+i,3);
            allEuler(67+i,1) allEuler(67+i,2) allEuler(67+i,3);
            allEuler(68+i,1) allEuler(68+i,2) allEuler(68+i,3)];

E_RCalf = [allEuler(69+i,1) allEuler(69+i,2) allEuler(69+i,3);
            allEuler(70+i,1) allEuler(70+i,2) allEuler(70+i,3);
            allEuler(71+i,1) allEuler(71+i,2) allEuler(71+i,3)];

E_RFoot = [allEuler(72+i,1) allEuler(72+i,2) allEuler(72+i,3);
            allEuler(73+i,1) allEuler(73+i,2) allEuler(73+i,3);
            allEuler(74+i,1) allEuler(74+i,2) allEuler(74+i,3)];
```

```
%multiply matrices based on hierarchy-------------------------

    %end result: spine 1


EF_spine1 = E_spine1;
EF_spine1 = EF_spine1*pi/180;

Z(c,5) = atan2(-
EF_spine1(3,q),sqrt(EF_spine1(1,q)^2+EF_spine1(2,q)^2)); %y---------
fixed
Z(c,6) =
atan2(EF_spine1(2,q)/cosd(Z(c,5)),EF_spine1(1,q)/cosd(Z(c,5))); %z-----
---fixed
Z(c,4) =
atan2(EF_spine1(3,q+1)/cosd(Z(c,5)),EF_spine1(3,q+2)/cosd(Z(c,5))); %x-
--------fixed

%end result: spine2

EF_spine2 = E_spine1*E_spine2;
EF_spine2 = EF_spine2*pi/180;

Z(c,8) = atan2(-
EF_spine2(3,q),sqrt(EF_spine2(1,q)^2+EF_spine2(2,q)^2)); %y---------
fixed
Z(c,9) =
atan2(EF_spine2(2,q)/cosd(Z(c,8)),EF_spine2(1,q)/cosd(Z(c,8))); %z-----
---fixed
Z(c,7) =
atan2(EF_spine2(3,q+1)/cosd(Z(c,8)),EF_spine2(3,q+2)/cosd(Z(c,8))); %x-
--------fixed

%end result: spine3

EF_spine3 = E_spine1*E_spine2*E_spine3;
EF_spine3 = EF_spine3*pi/180;

Z(c,11) = atan2(-
EF_spine3(3,q),sqrt(EF_spine3(1,q)^2+EF_spine3(2,q)^2)); %y---------
fixed
Z(c,12) =
atan2(EF_spine3(2,q)/cosd(Z(c,11)),EF_spine3(1,q)/cosd(Z(c,11))); %z---
-----fixed
Z(c,10) =
atan2(EF_spine3(3,q+1)/cosd(Z(c,11)),EF_spine3(3,q+2)/cosd(Z(c,11)));
%x---------fixed

%end result: head

EF_head = E_spine1*E_spine2*E_spine3*E_head;
EF_head = EF_head*pi/180;
```

```
Z(c,14) = atan2(-EF_head(3,q),sqrt(EF_head(1,q)^2+EF_head(2,q)^2)); %y-
--------fixed
Z(c,15) = atan2(EF_head(2,q)/cosd(Z(c,14)),EF_head(1,q)/cosd(Z(c,14)));
%z--------fixed
Z(c,13) =
atan2(EF_head(3,q+1)/cosd(Z(c,14)),EF_head(3,q+2)/cosd(Z(c,14))); %x---
------fixed

%end result: head2

EF_head2 = E_spine1*E_spine2*E_spine3*E_head*E_head2;
EF_head2 = EF_head2*pi/180;

Z(c,17) = atan2(-EF_head2(3,q),sqrt(EF_head2(1,q)^2+EF_head2(2,q)^2));
%y---------fixed
Z(c,18) =
atan2(EF_head2(2,q)/cosd(Z(c,17)),EF_head2(1,q)/cosd(Z(c,17))); %z-----
---fixed
Z(c,16) =
atan2(EF_head2(3,q+1)/cosd(Z(c,17)),EF_head2(3,q+2)/cosd(Z(c,17))); %x-
--------fixed

%end result: headend

EF_headend = E_spine1*E_spine2*E_spine3*E_head*E_head2*E_headend;
EF_headend = EF_headend*pi/180;

Z(c,20) = atan2(-
EF_headend(3,q),sqrt(EF_headend(1,q)^2+EF_headend(2,q)^2)); %y---------
fixed
Z(c,21) =
atan2(EF_headend(2,q)/cosd(Z(c,20)),EF_headend(1,q)/cosd(Z(c,20))); %z-
-------fixed
Z(c,19) =
atan2(EF_headend(3,q+1)/cosd(Z(c,20)),EF_headend(3,q+2)/cosd(Z(c,20)));
%x---------fixed

%end result: LChest

EF_LChest = E_spine1*E_LChest;
EF_LChest = EF_LChest*pi/180;

Z(c,23) = atan2(-
EF_LChest(3,q),sqrt(EF_LChest(1,q)^2+EF_LChest(2,q)^2)); %y---------
fixed
Z(c,24) =
atan2(EF_LChest(2,q)/cosd(Z(c,23)),EF_LChest(1,q)/cosd(Z(c,23))); %z---
-----fixed
Z(c,22) =
atan2(EF_LChest(3,q+1)/cosd(Z(c,23)),EF_LChest(3,q+2)/cosd(Z(c,23)));
%x---------fixed

%end result: LShoulder
```

```
EF_LShoulder = E_spine1*E_LChest*E_LShoulder;
EF_LShoulder = EF_LShoulder*pi/180;

Z(c,26) = atan2(-
EF_LShoulder(3,q),sqrt(EF_LShoulder(1,q)^2+EF_LShoulder(2,q)^2)); %y---
------fixed
Z(c,27) =
atan2(EF_LShoulder(2,q)/cosd(Z(c,26)),EF_LShoulder(1,q)/cosd(Z(c,26)));
%z--------fixed
Z(c,25) =
atan2(EF_LShoulder(3,q+1)/cosd(Z(c,26)),EF_LShoulder(3,q+2)/cosd(Z(c,26
))); %x---------fixed

%end result: LUpper

EF_LUpper = E_spine1*E_LChest*E_LShoulder*E_LUpper;
EF_LUpper = EF_LUpper*pi/180;

Z(c,29) = atan2(-
EF_LUpper(3,q),sqrt(EF_LUpper(1,q)^2+EF_LUpper(2,q)^2)); %y---------
fixed
Z(c,30) =
atan2(EF_LUpper(2,q)/cosd(Z(c,29)),EF_LUpper(1,q)/cosd(Z(c,29))); %z---
-----fixed
Z(c,28) =
atan2(EF_LUpper(3,q+1)/cosd(Z(c,29)),EF_LUpper(3,q+2)/cosd(Z(c,29)));
%x---------fixed

%end result: LFore

EF_LFore = E_spine1*E_LChest*E_LShoulder*E_LUpper*E_LFore;
EF_LFore = EF_LFore*pi/180;

Z(c,32) = atan2(-EF_LFore(3,q),sqrt(EF_LFore(1,q)^2+EF_LFore(2,q)^2));
%y---------fixed
Z(c,33) =
atan2(EF_LFore(2,q)/cosd(Z(c,32)),EF_LFore(1,q)/cosd(Z(c,32))); %z-----
---fixed
Z(c,31) =
atan2(EF_LFore(3,q+1)/cosd(Z(c,32)),EF_LFore(3,q+2)/cosd(Z(c,32))); %x-
--------fixed

%end result: LHand

EF_LHand = E_spine1*E_LChest*E_LShoulder*E_LUpper*E_LFore*E_LHand;
EF_LHand = EF_LHand*pi/180;

Z(c,35) = atan2(-EF_LHand(3,q),sqrt(EF_LHand(1,q)^2+EF_LHand(2,q)^2));
%y---------fixed
Z(c,36) =
atan2(EF_LHand(2,q)/cosd(Z(c,35)),EF_LHand(1,q)/cosd(Z(c,35))); %z-----
---fixed
```

```
Z(c,34) =
atan2(EF_LHand(3,q+1)/cosd(Z(c,35)),EF_LHand(3,q+2)/cosd(Z(c,35))); %x-
--------fixed

%end result: RChest

EF_RChest = E_spine1*E_RChest;
EF_RChest = EF_RChest*pi/180;

Z(c,38) = atan2(-
EF_RChest(3,q),sqrt(EF_RChest(1,q)^2+EF_RChest(2,q)^2)); %y---------
fixed
Z(c,39) =
atan2(EF_RChest(2,q)/cosd(Z(c,38)),EF_RChest(1,q)/cosd(Z(c,38))); %z---
-----fixed
Z(c,37) =
atan2(EF_RChest(3,q+1)/cosd(Z(c,38)),EF_RChest(3,q+2)/cosd(Z(c,38)));
%x---------fixed

%end result: RShoulder

EF_RShoulder = E_spine1*E_RChest*E_RShoulder;
EF_RShoulder = EF_RShoulder*pi/180;

Z(c,41) = atan2(-
EF_RShoulder(3,q),sqrt(EF_RShoulder(1,q)^2+EF_RShoulder(2,q)^2)); %y---
------fixed
Z(c,42) =
atan2(EF_RShoulder(2,q)/cosd(Z(c,41)),EF_RShoulder(1,q)/cosd(Z(c,41)));
%z--------fixed
Z(c,40) =
atan2(EF_RShoulder(3,q+1)/cosd(Z(c,41)),EF_RShoulder(3,q+2)/cosd(Z(c,41
))); %x---------fixed

%end result: RUpper

EF_RUpper = E_spine1*E_RChest*E_RShoulder*E_RUpper;
EF_RUpper = EF_RUpper*pi/180;

Z(c,44) = atan2(-
EF_RUpper(3,q),sqrt(EF_RUpper(1,q)^2+EF_RUpper(2,q)^2)); %y---------
fixed
Z(c,45) =
atan2(EF_RUpper(2,q)/cosd(Z(c,44)),EF_RUpper(1,q)/cosd(Z(c,44))); %z---
-----fixed
Z(c,43) =
atan2(EF_RUpper(3,q+1)/cosd(Z(c,44)),EF_RUpper(3,q+2)/cosd(Z(c,44)));
%x---------fixed

%end result: RFore

EF_RFore = E_spine1*E_RChest*E_RShoulder*E_RUpper*E_RFore;
EF_RFore = EF_RFore*pi/180;
```

```
Z(c,47) = atan2(-EF_RFore(3,q),sqrt(EF_RFore(1,q)^2+EF_RFore(2,q)^2));
%y---------fixed
Z(c,48) =
atan2(EF_RFore(2,q)/cosd(Z(c,47)),EF_RFore(1,q)/cosd(Z(c,47))); %z-----
---fixed
Z(c,46) =
atan2(EF_RFore(3,q+1)/cosd(Z(c,47)),EF_RFore(3,q+2)/cosd(Z(c,47))); %x-
--------fixed

%end result: RHand

EF_RHand = E_spine1*E_RChest*E_RShoulder*E_RUpper*E_RFore*E_RHand;
EF_RHand = EF_RHand*pi/180;

Z(c,50) = atan2(-EF_RHand(3,q),sqrt(EF_RHand(1,q)^2+EF_RHand(2,q)^2));
%y---------fixed
Z(c,51) =
atan2(EF_RHand(2,q)/cosd(Z(c,50)),EF_RHand(1,q)/cosd(Z(c,50))); %z-----
---fixed
Z(c,49) =
atan2(EF_RHand(3,q+1)/cosd(Z(c,50)),EF_RHand(3,q+2)/cosd(Z(c,50))); %x-
--------fixed

%end result: LPelvis

EF_LPelvis = E_spine1*E_LPelvis;
EF_LPelvis = EF_LPelvis*pi/180;

Z(c,53) = atan2(-
EF_LPelvis(3,q),sqrt(EF_LPelvis(1,q)^2+EF_LPelvis(2,q)^2)); %y---------
fixed
Z(c,54) =
atan2(EF_LPelvis(2,q)/cosd(Z(c,53)),EF_LPelvis(1,q)/cosd(Z(c,53))); %z-
-------fixed
Z(c,52) =
atan2(EF_LPelvis(3,q+1)/cosd(Z(c,53)),EF_LPelvis(3,q+2)/cosd(Z(c,53)));
%x---------fixed

%end result: LThigh

EF_LThigh = E_spine1*E_LPelvis*E_LThigh;
EF_LThigh = EF_LThigh*pi/180;

Z(c,56) = atan2(-
EF_LThigh(3,q),sqrt(EF_LThigh(1,q)^2+EF_LThigh(2,q)^2)); %y---------
fixed
Z(c,57) =
atan2(EF_LThigh(2,q)/cosd(Z(c,56)),EF_LThigh(1,q)/cosd(Z(c,56))); %z---
-----fixed
Z(c,55) =
atan2(EF_LThigh(3,q+1)/cosd(Z(c,56)),EF_LThigh(3,q+2)/cosd(Z(c,56)));
%x---------fixed

%end result: LCalf
```

```
EF_LCalf = E_spine1*E_LPelvis*E_LThigh*E_LCalf;
EF_LCalf = EF_LCalf*pi/180;

Z(c,59) = atan2(-EF_LCalf(3,q),sqrt(EF_LCalf(1,q)^2+EF_LCalf(2,q)^2));
%y---------fixed
Z(c,60) =
atan2(EF_LCalf(2,q)/cosd(Z(c,59)),EF_LCalf(1,q)/cosd(Z(c,59))); %z-----
---fixed
Z(c,58) =
atan2(EF_LCalf(3,q+1)/cosd(Z(c,59)),EF_LCalf(3,q+2)/cosd(Z(c,59))); %x-
--------fixed

%end result: LFoot

EF_LFoot = E_spine1*E_LPelvis*E_LThigh*E_LCalf*E_LFoot;
EF_LFoot = EF_LFoot*pi/180;

Z(c,62) = atan2(-EF_LFoot(3,q),sqrt(EF_LFoot(1,q)^2+EF_LFoot(2,q)^2));
%y---------fixed
Z(c,63) =
atan2(EF_LFoot(2,q)/cosd(Z(c,62)),EF_LFoot(1,q)/cosd(Z(c,62))); %z-----
---fixed
Z(c,61) =
atan2(EF_LFoot(3,q+1)/cosd(Z(c,62)),EF_LFoot(3,q+2)/cosd(Z(c,62))); %x-
--------fixed

%end result: RPelvis

EF_RPelvis = E_spine1*E_RPelvis;
EF_RPelvis = EF_RPelvis*pi/180;

Z(c,65) = atan2(-
EF_RPelvis(3,q),sqrt(EF_RPelvis(1,q)^2+EF_RPelvis(2,q)^2)); %y---------
fixed
Z(c,66) =
atan2(EF_RPelvis(2,q)/cosd(Z(c,65)),EF_RPelvis(1,q)/cosd(Z(c,65))); %z-
-------fixed
Z(c,64) =
atan2(EF_RPelvis(3,q+1)/cosd(Z(c,65)),EF_RPelvis(3,q+2)/cosd(Z(c,65)));
%x---------fixed

%end result: RThigh

EF_RThigh = E_spine1*E_RPelvis*E_RThigh;
EF_RThigh = EF_RThigh*pi/180;

Z(c,68) = atan2(-
EF_RThigh(3,q),sqrt(EF_RThigh(1,q)^2+EF_RThigh(2,q)^2)); %y---------
fixed
Z(c,69) =
atan2(EF_RThigh(2,q)/cosd(Z(c,68)),EF_RThigh(1,q)/cosd(Z(c,68))); %z---
-----fixed
Z(c,67) =
atan2(EF_RThigh(3,q+1)/cosd(Z(c,68)),EF_RThigh(3,q+2)/cosd(Z(c,68)));
%x---------fixed
```

```
%end result: RCalf

EF_RCalf = E_spine1*E_RPelvis*E_RThigh*E_RCalf;
EF_RCalf = EF_RCalf*pi/180;

Z(c,71) = atan2(-EF_RCalf(3,q),sqrt(EF_RCalf(1,q)^2+EF_RCalf(2,q)^2));
%y---------fixed
Z(c,72) =
atan2(EF_RCalf(2,q)/cosd(Z(c,71)),EF_RCalf(1,q)/cosd(Z(c,71))); %z-----
---fixed
Z(c,70) =
atan2(EF_RCalf(3,q+1)/cosd(Z(c,71)),EF_RCalf(3,q+2)/cosd(Z(c,71))); %x-
--------fixed


%end result: RFoot

EF_RFoot = E_spine1*E_RPelvis*E_RThigh*E_RCalf*E_RFoot;
EF_RFoot = EF_RFoot*pi/180;

Z(c,74) = atan2(-EF_RFoot(3,q),sqrt(EF_RFoot(1,q)^2+EF_RFoot(2,q)^2));
%y---------fixed
Z(c,75) =
atan2(EF_RFoot(2,q)/cosd(Z(c,74)),EF_RFoot(1,q)/cosd(Z(c,74))); %z-----
---fixed
Z(c,73) =
atan2(EF_RFoot(3,q+1)/cosd(Z(c,74)),EF_RFoot(3,q+2)/cosd(Z(c,74))); %x-
--------fixed

        c = c+1;

waitbar(i/(N*75))

end

Z = Z*180/pi;

close(r);

toc


end
```

APPENDIX D

MATLAB Code – convertTO_Xfps

```
function [ Z ] = convertTO_Xfps(A,n,X,Y)
%George Lee - WBAN Research Group - Baylor University
%takes mocap data that is  y fps and cuts out data to get data in x fps
%in order reduce frames used in simulation
%Input:
%   A = 75 column array, where columns are the 75 columns of a bvh
%   n = number of rows in A (ie the number of frames in the bvh)
%   X = desired fps
%   Y = input fps
%Output:
%   Z = the 75 column array in X fps
count0 = round(Y/X); %counts to determine which data is taken
init = round(Y/X);

count1 = 1; %counts to add values to Z
count2 = 1; %counts position in A

for z = 0:1:n
    test = count0-init;
    if test == 0
        Z(count1,1)=A(count2,1);
        Z(count1,2)=A(count2,2);
        Z(count1,3)=A(count2,3);
        Z(count1,4)=A(count2,4);
        Z(count1,5)=A(count2,5);
        Z(count1,6)=A(count2,6);
        Z(count1,7)=A(count2,7);
        Z(count1,8)=A(count2,8);
        Z(count1,9)=A(count2,9);
        Z(count1,10)=A(count2,10);
        Z(count1,11)=A(count2,11);
        Z(count1,12)=A(count2,12);
        Z(count1,13)=A(count2,13);
        Z(count1,14)=A(count2,14);
        Z(count1,15)=A(count2,15);
        Z(count1,16)=A(count2,16);
        Z(count1,17)=A(count2,17);
        Z(count1,18)=A(count2,18);
        Z(count1,19)=A(count2,19);
        Z(count1,20)=A(count2,20);
        Z(count1,21)=A(count2,21);
        Z(count1,22)=A(count2,22);
        Z(count1,23)=A(count2,23);
        Z(count1,24)=A(count2,24);
        Z(count1,25)=A(count2,25);
        Z(count1,26)=A(count2,26);
        Z(count1,27)=A(count2,27);
```

```
        Z(count1,28)=A(count2,28);
        Z(count1,29)=A(count2,29);
        Z(count1,30)=A(count2,30);
        Z(count1,31)=A(count2,31);
        Z(count1,32)=A(count2,32);
        Z(count1,33)=A(count2,33);
        Z(count1,34)=A(count2,34);
        Z(count1,35)=A(count2,35);
        Z(count1,36)=A(count2,36);
        Z(count1,37)=A(count2,37);
        Z(count1,38)=A(count2,38);
        Z(count1,39)=A(count2,39);
        Z(count1,40)=A(count2,40);
        Z(count1,41)=A(count2,41);
        Z(count1,42)=A(count2,42);
        Z(count1,43)=A(count2,43);
        Z(count1,44)=A(count2,44);
        Z(count1,45)=A(count2,45);
        Z(count1,46)=A(count2,46);
        Z(count1,47)=A(count2,47);
        Z(count1,48)=A(count2,48);
        Z(count1,49)=A(count2,49);
        Z(count1,50)=A(count2,50);
        Z(count1,51)=A(count2,51);
        Z(count1,52)=A(count2,52);
        Z(count1,53)=A(count2,53);
        Z(count1,54)=A(count2,54);
        Z(count1,55)=A(count2,55);
        Z(count1,56)=A(count2,56);
        Z(count1,57)=A(count2,57);
        Z(count1,58)=A(count2,58);
        Z(count1,59)=A(count2,59);
        Z(count1,60)=A(count2,60);
        Z(count1,61)=A(count2,61);
        Z(count1,62)=A(count2,62);
        Z(count1,63)=A(count2,63);
        Z(count1,64)=A(count2,64);
        Z(count1,65)=A(count2,65);
        Z(count1,66)=A(count2,66);
        Z(count1,67)=A(count2,67);
        Z(count1,68)=A(count2,68);
        Z(count1,69)=A(count2,69);
        Z(count1,70)=A(count2,70);
        Z(count1,71)=A(count2,71);
        Z(count1,72)=A(count2,72);
        Z(count1,73)=A(count2,73);
        Z(count1,74)=A(count2,74);
        Z(count1,75)=A(count2,75);
        count0 = 0;
        count1 = count1+1;
    end
    count0 = count0+1;
    count2 = count2 +1;
end
end
```

APPENDIX E

MATLAB Code – matrixTObvh

```
function matrixTObvh ( x ,N,name )
%   x = matrix with full body bvh values (i.e. 75 columns, n rows)
%   name = the name you want to give your bvh file (must be a string)
%   N = number of frames
NAME = strcat(name,'.txt');
f = fopen( NAME, 'wt' );
for n = 1:N
  a1 = x(n,1); a2 = x(n,2); a3 = x(n,3); a4 = x(n,4); a5 = x(n,5);
  a6 = x(n,6); a7 = x(n,7); a8 = x(n,8); a9 = x(n,9); a10 = x(n,10);
  a11 = x(n,11); a12 = x(n,12); a13 = x(n,13); a14 = x(n,14); a15 =
x(n,15);
  a16 = x(n,16); a17 = x(n,17); a18 = x(n,18); a19 = x(n,19); a20 =
x(n,20);
  a21 = x(n,21); a22 = x(n,22); a23 = x(n,23); a24 = x(n,24); a25 =
x(n,25);
  a26 = x(n,26); a27 = x(n,27); a28 = x(n,28); a29 = x(n,29); a30 =
x(n,30);
  a31 = x(n,31); a32 = x(n,32); a33 = x(n,33); a34 = x(n,34); a35 =
x(n,35);
  a36 = x(n,36); a37 = x(n,37); a38 = x(n,38); a39 = x(n,39); a40 =
x(n,40);
  a41 = x(n,41); a42 = x(n,42); a43 = x(n,43); a44 = x(n,44); a45 =
x(n,45);
  a46 = x(n,46); a47 = x(n,47); a48 = x(n,48); a49 = x(n,49); a50 =
x(n,50);
  a51 = x(n,51); a52 = x(n,52); a53 = x(n,53); a54 = x(n,54); a55 =
x(n,55);
  a56 = x(n,56); a57 = x(n,57); a58 = x(n,58); a59 = x(n,59); a60 =
x(n,60);
  a61 = x(n,61); a62 = x(n,62); a63 = x(n,63); a64 = x(n,64); a65 =
x(n,65);
  a66 = x(n,66); a67 = x(n,67); a68 = x(n,68); a69 = x(n,69); a70 =
x(n,70);
  a71 = x(n,71); a72 = x(n,72); a73 = x(n,73); a74 = x(n,74); a75 =
x(n,75);
  fprintf( f, '%f %f %f %f %f %f %f %f %f %f %f %f %f %f %f %f %f %f %f
%f %f %f %f %f %f %f %f %f %f %f %f %f %f %f %f %f %f %f %f %f %f %f %f
%f %f %f %f %f %f %f %f %f %f %f %f %f %f %f %f %f %f %f %f %f %f %f %f
%f %f %f %f %f %f %f %f\n' ...
      , a1, a2, a3, a4, a5, a6, a7, a8, a9, a10, a11, a12, a13, a14,
a15, a16, a17, a18, a19, a20, a21, a22, a23, a24, a25, a26, a27, a28,
a29, a30, a31, a32, a33, a34, a35, a36, a37, a38, a39 ,a40 , a41, a42,
a43, a44, a45, a46, a47, a48, a49, a50, a51, a52, a53, a54, a55, a56,
a57, a58, a59, a60, a61, a62, a63, a64, a65, a66, a67, a68, a69, a70,
a71, a72, a73, a74, a75);
end
fclose(f);
```

APPENDIX F

Additional Simulated vs. Measured S_{21} Comparison

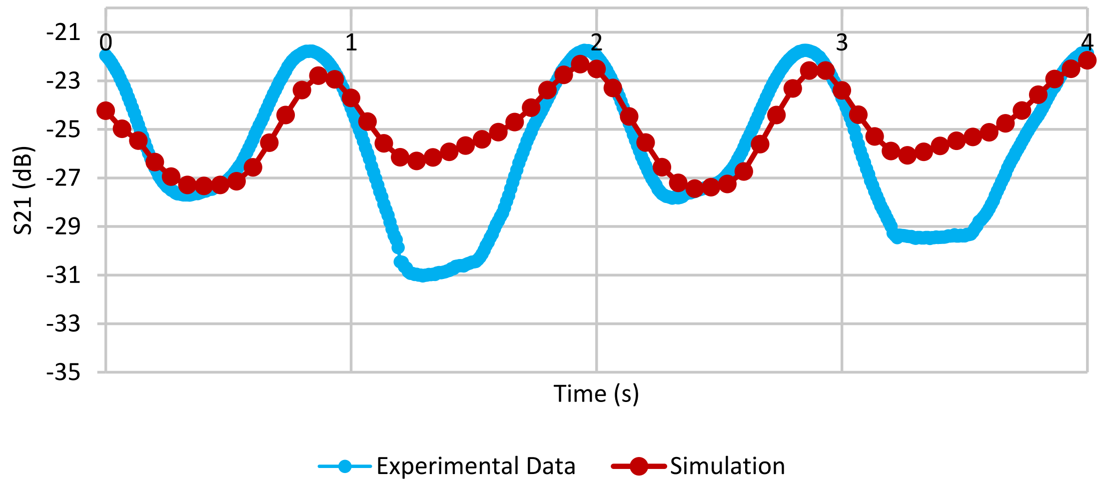

Figure F.1. Subject 1 Rowing, Antenna on Chest/Back at 433MHz, Simulation vs. Measurement

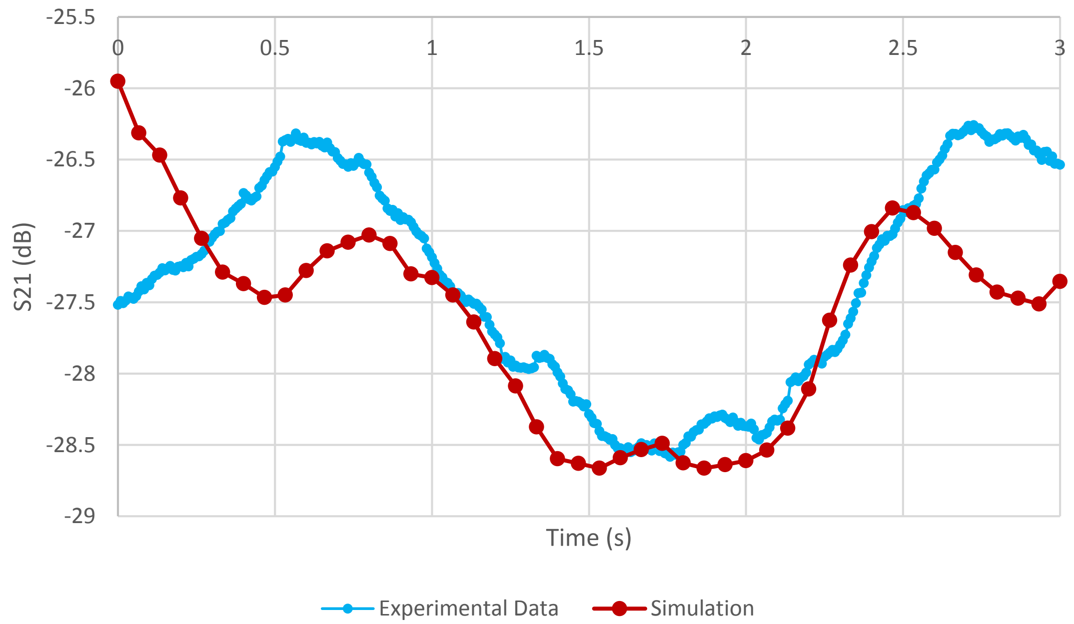

Figure F.2. Subject 1 Left Arm Swing, Antenna on Chest/Back at 433MHz, Simulation vs. Measurement

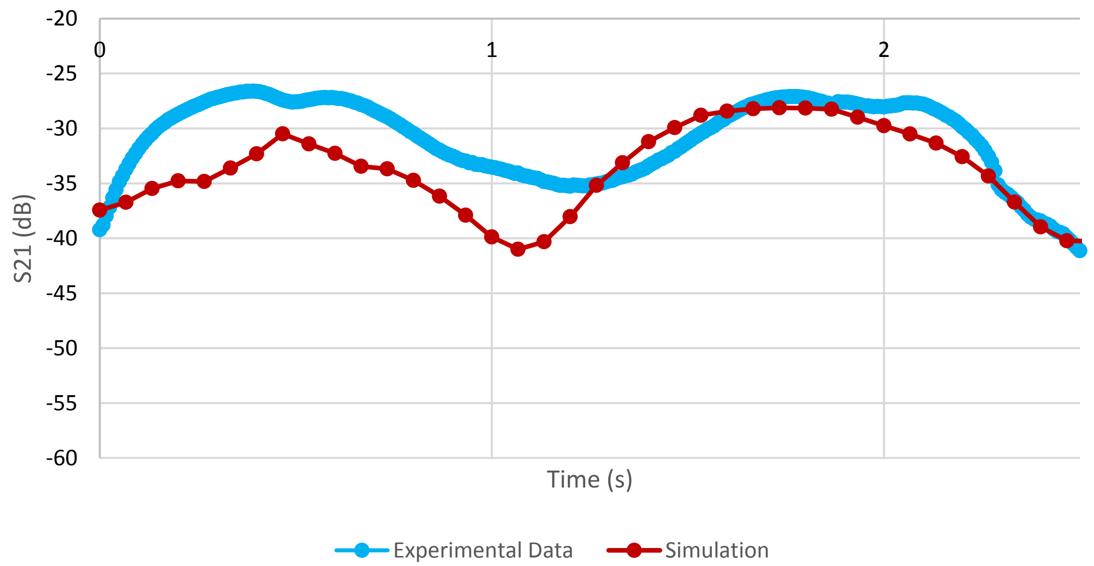

Figure F.3. Subject 1 Left Arm Swing, Antenna on Both Wrists at 433MHz, Simulation vs. Measurement

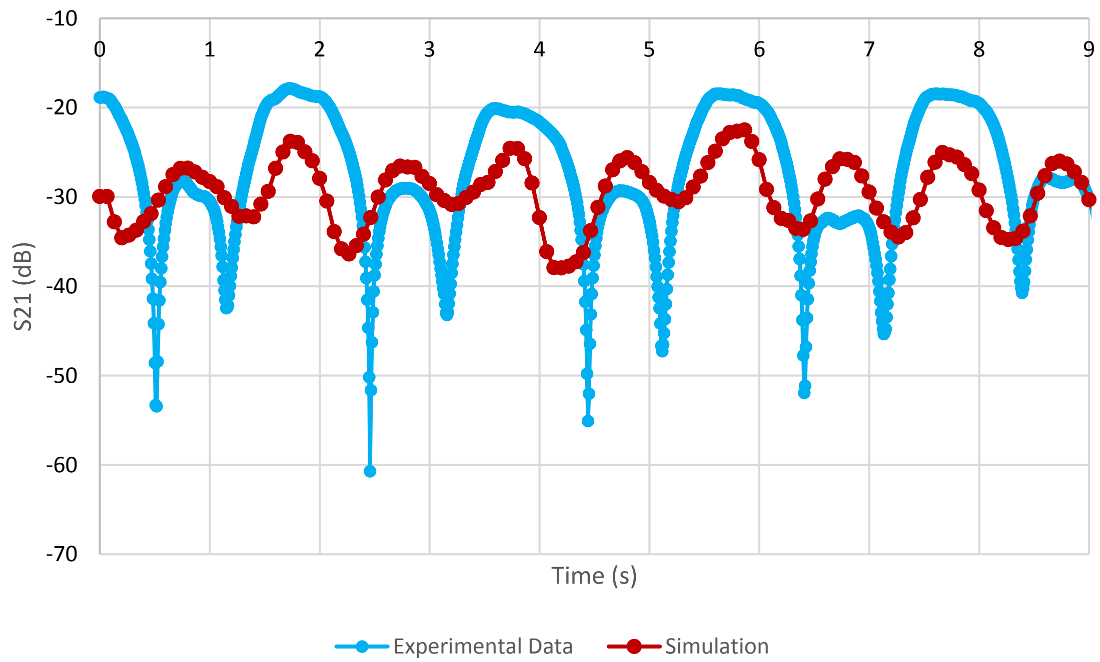

Figure F.4. Subject 1 Rowing, Antenna on Both Wrists at 433MHz, Simulation vs. Measurement

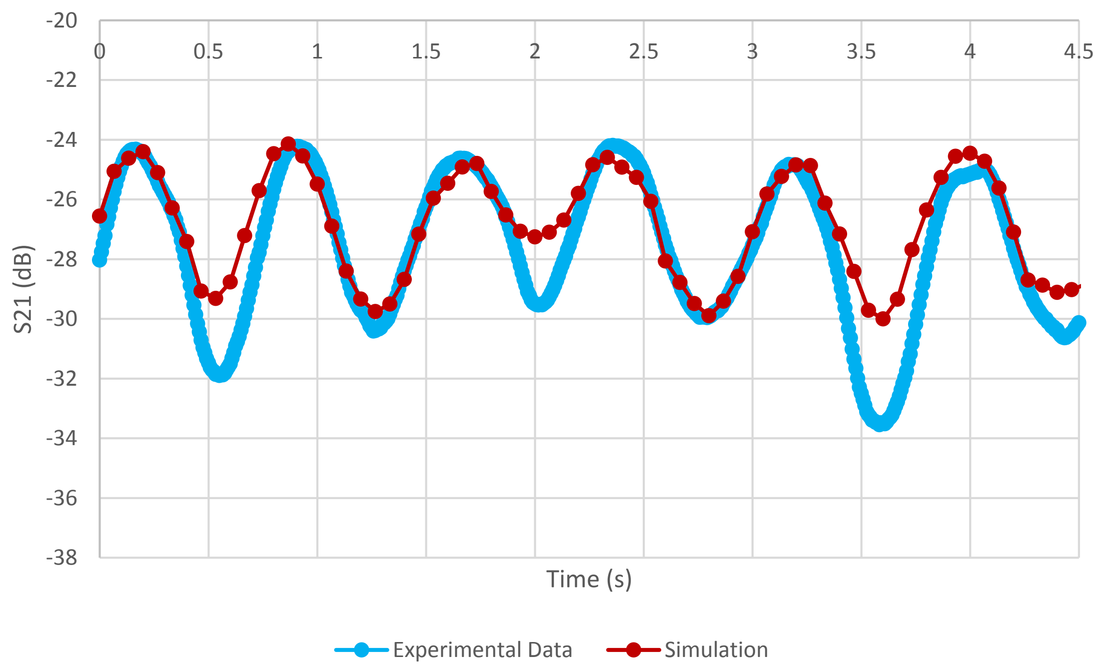

Figure F.5. Subject 4 Both Arm Swing, Antenna on Chest/Back at 433MHz, Simulation vs. Measurement

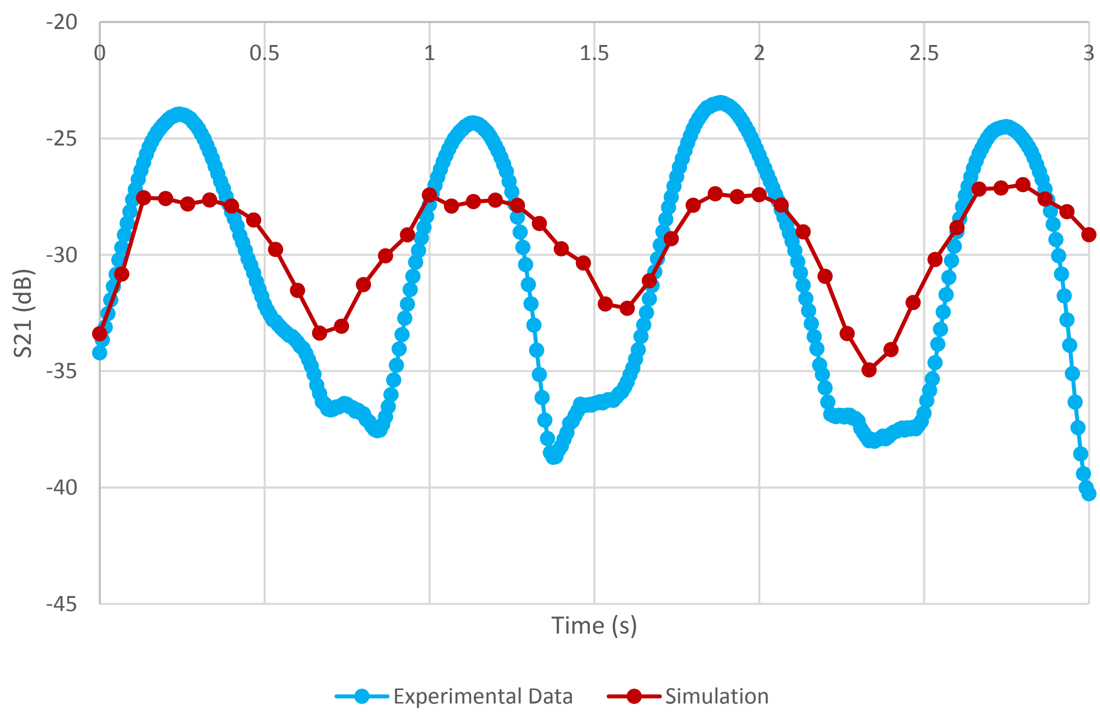

Figure F.6. Subject 4 Boxing, Antenna on Chest/Back at 433MHz, Simulation vs. Measurement

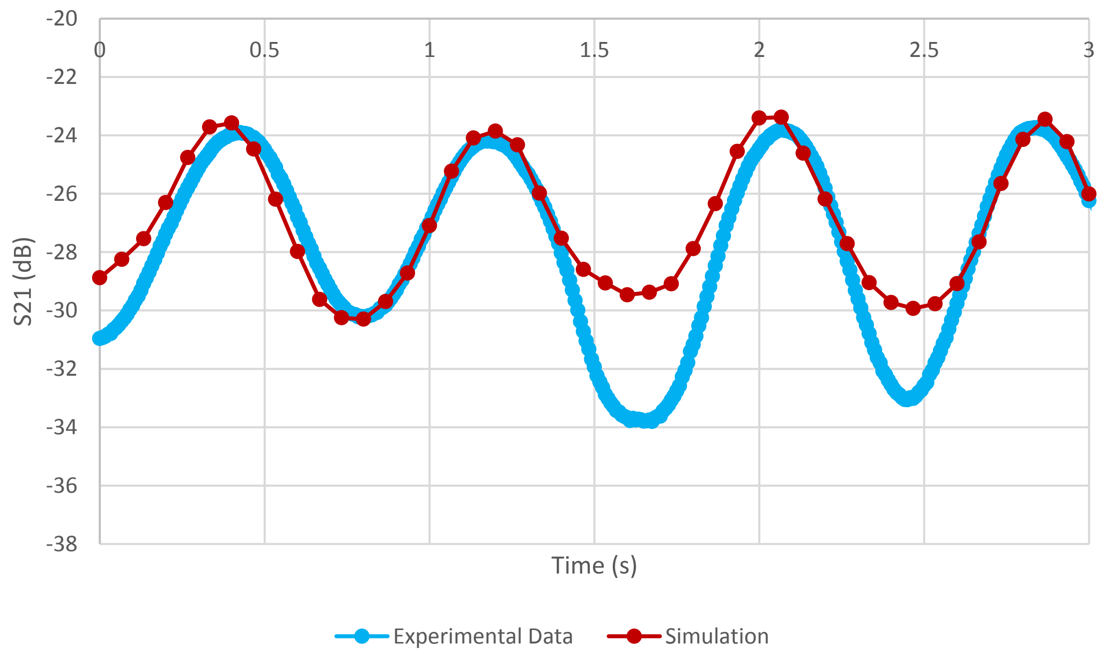

Figure F.7. Subject 7 Both Arm Swing, Antenna on Chest/Back at 433MHz, Simulation vs. Measurement

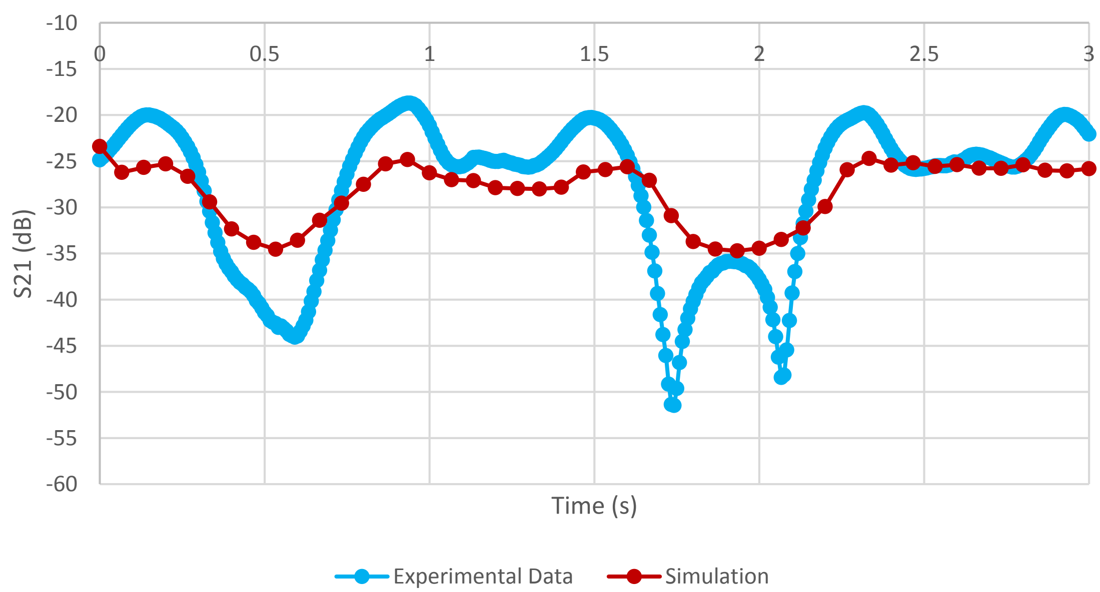

Figure F.8. Subject 7 Both Arm Swing, Antenna on Chest/Left Wrist at 433MHz, Simulation vs. Measurement

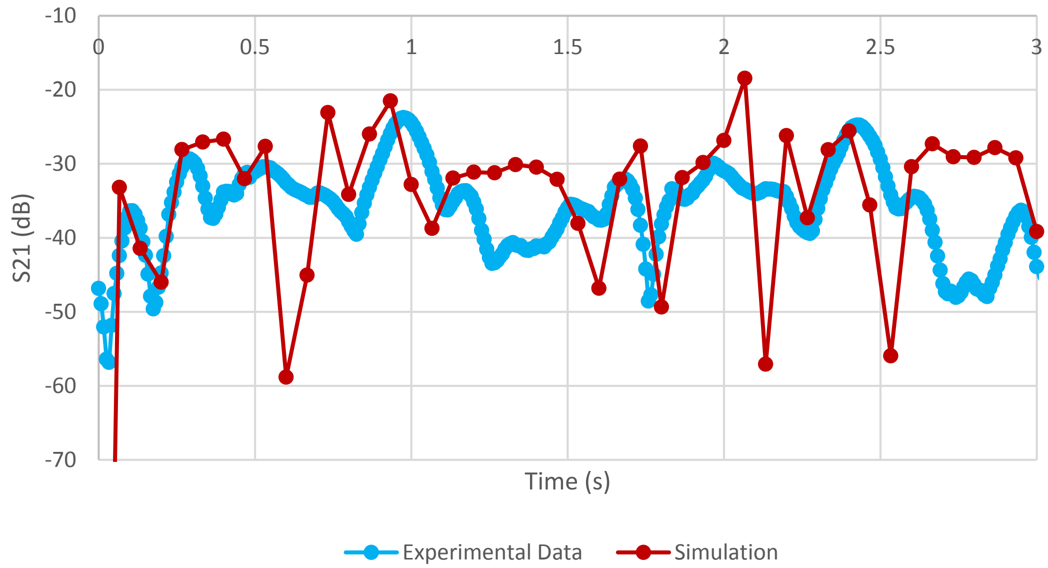

Figure F.9. Subject 7 Both Arm Swing, Antenna on Both Wrists at 433MHz, Simulation vs. Measurement

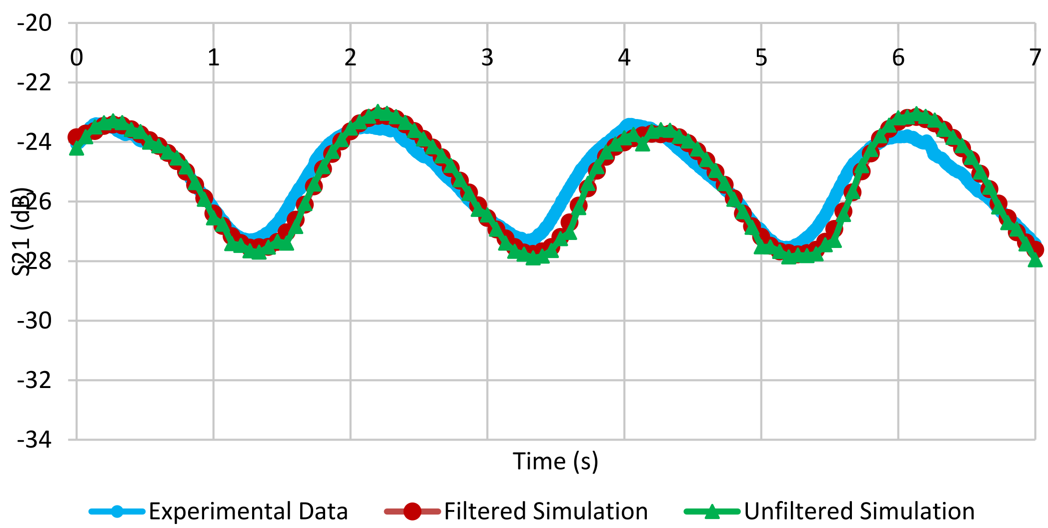

Figure F.10. Comparison of Filtered and Unfiltered Simulation Results for Subject 1, Both Arm Swing with Antenna on Chest/Back at 433MHz

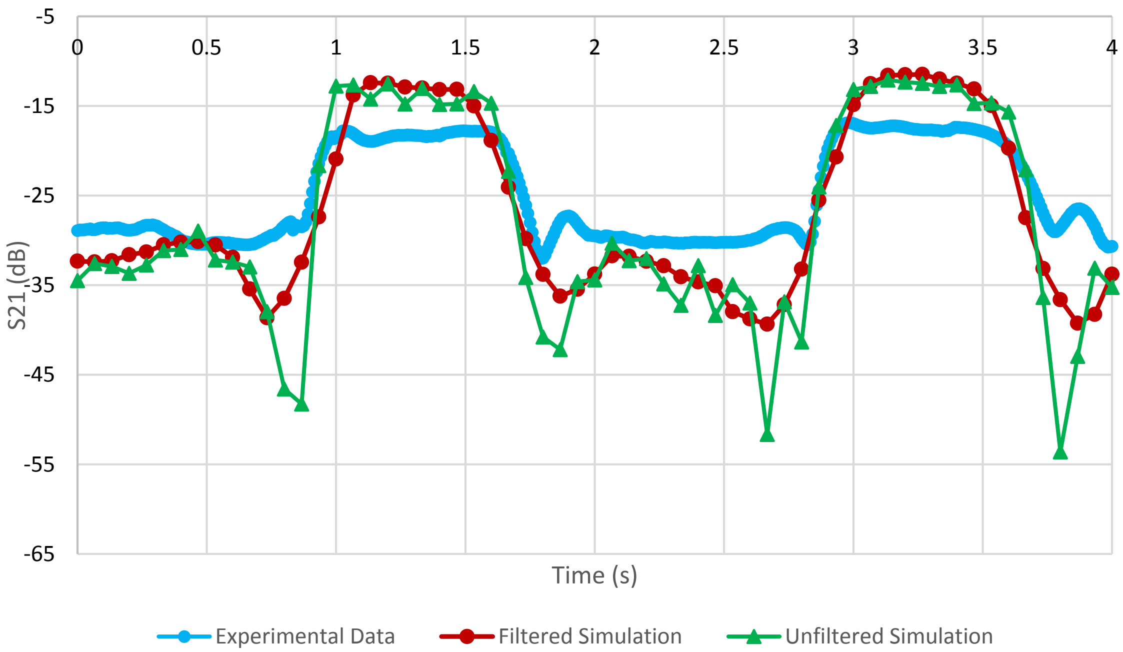

Figure F.11. Comparison of Filtered and Unfiltered Simulation Results for Subject 1, Boxing with Antenna on Chest/Left Wrist at 433MHz

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