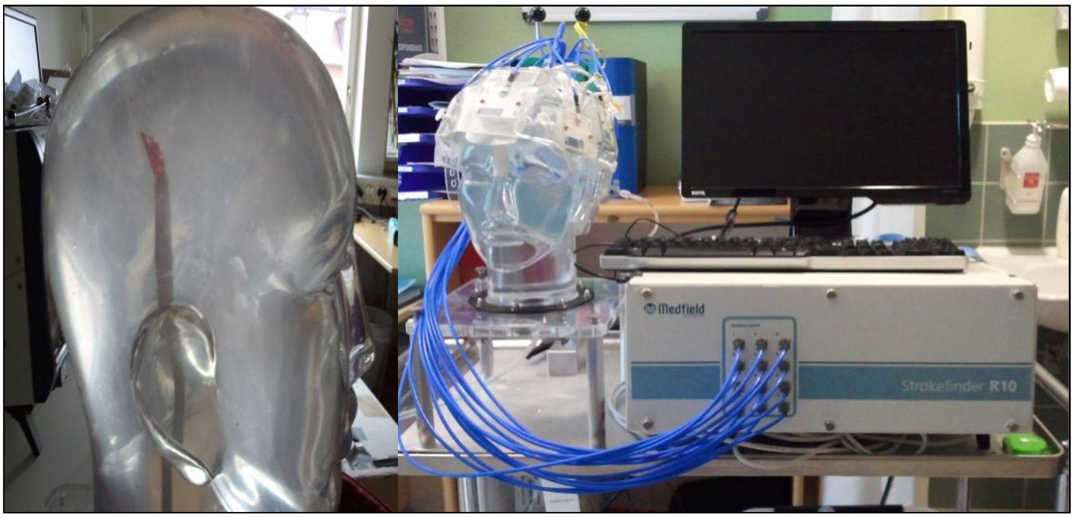

Microwave Measurements on Brain Phantom for Brain stroke Diagnosis

Master of Science Thesis in Biomedical Engineering

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Master of Science Thesis

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Abstract

Electromagnetic waves at microwave frequencies are capable of deeply penetrating into the body and then scattering inside the tissues. With this property of microwave signals, Microwave tomography was developed in order to image tissues in the body with the aid of their dielectric properties as each tissue poses its own dielectric properties. Medfield Diagnostics AB developed a strokefinder R10 device based on this principle of Microwave Tomography.

Aim of the work is to do conduct experiments of phantom model with StrokefinderR10 device for the purpose of Brain Stroke Diagnosis. This work involves development of Human Brain phantom model which possess the dielectric properties of a human brain. Various experimental works and analysis were carried out on healthy volunteers and on the phantom model with different setups in order to perform experimental studies for the device.

Keywords: Microwave Tomography, Human brain, Phantom model, Dielectric properties

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Göteborg, Sweden

SARATHY KRISHNAN

List of Abbreviations

ICH	Intra-cerebral Haemorrhage
IS	Ischemic Stroke
CT	Computer Tomography
MRI	Magnetic Resonance Imaging
PET	Positron Emission Tomography
VNA	Vector Network Analyzer
EEG	Electroencephalographs
GHz	Gigahertz
HOSVD	Higher Order Singular Value Decomposition
Rx	Receiver
Tx	Transmitter

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Chapter 1

Introduction

Electromagnetic waves at microwave frequencies can able to penetrate deep inside human tissue and scatters inside the body[1]. The reflected signals can be measured and used to detect the changes. This property leads to the development of microwave technology for diagnosis purpose. Microwave signals are non-invasive and non-ionizing radiation which does not cause any radiation effects to the patients under investigation. By considering these factors, Microwave tomography is used in the application of brain stroke diagnosis. A detailed note on background and an overview of microwave tomography are given in this chapter.

1.1 **Background**

Brain stroke happens when there is an interruption in the blood flow to parts of the brain. The symptom of the stroke is recognized mainly depending on injured area of the brain and therefore the symptoms include sensory problem, language problem, motor problem and other changes according to the injury[2]. Strokes are usually results from the inadequate blood supply to the brain either by clotting or bleeding that occurs inside the brain.

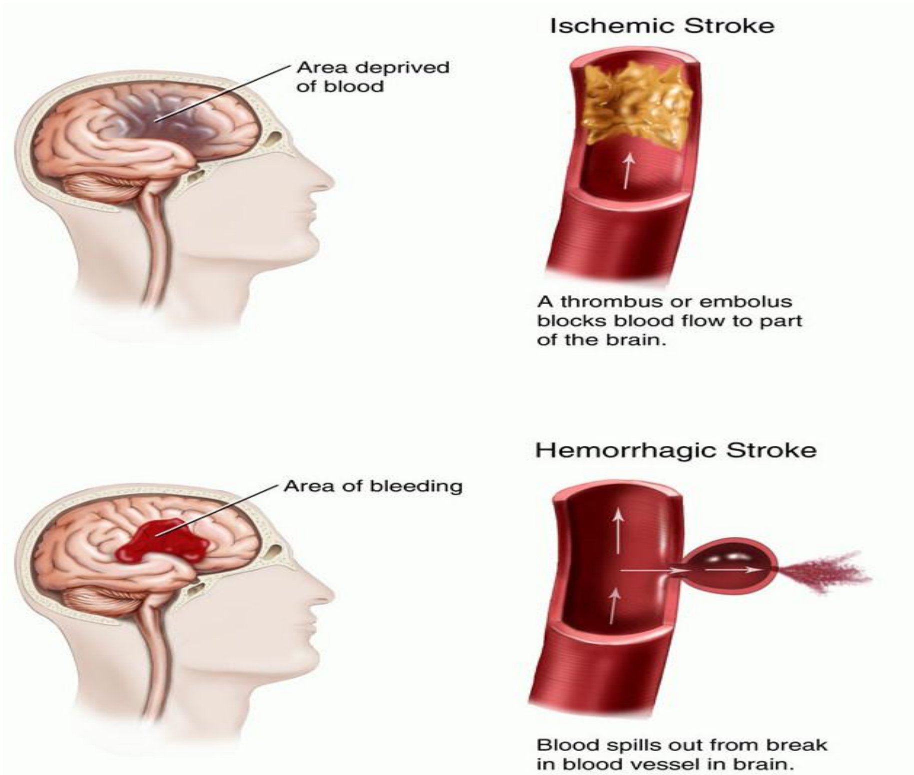


Figure 1.1 V.S. of Human head showing brain having Ischemic stroke and Hemorrhagic stroke [3]

There are two types of stroke such as **Ischemic Stroke** (IS) and **Intra Cerebral Haemorrhagic Stroke** (ICH). During an IS, there is a shortage of blood supply to the brain due to the blockage of blood vessels by blood clot or thrombus. The most common type of IS is **Thrombotic Stroke**, in this type, the thrombus is formed inside the blood vessel walls and narrows down the flow. Whereas in the other type, the clot formed in the blood vessel get loosened from the walls and floats through the blood flow as embolus until it get struck with narrow vessels, resulting in a block of blood flow and this type is known as **Embolic Stroke**[2].**Atherosclerosis** also causes this kind of stroke by narrowing down the blood vessels. In common, Ischemic Stroke results in tissue death by lacking of nutrients and oxygen supply.

In contrast ICH occurs when blood vessels burst inside the brain and therefore blood directly flows onto the brain tissues. This will cause irritation and swelling up of the tissues and resulting in tissue death. In addition to the damage caused by direct blood contact, the other factors also kills brain tissue during ICH stroke such as lack of nutrient, oxygen supply to brain tissues and build-up of pressure inside the brain; resulting because of the breakage in blood flow. The excess pressure is due to the released blood pushing up against the cells and in addition to this, body pumps extra body fluid to the affected area, thereby increasing the pressure even more. In general aspects, ICH stroke has caused more functional disability to the affected person than the IS, but it's much less common compared to Ischemic Stroke.

Some Facts about Strokes

- Ischemic strokes are common, contributing 84% of the brain strokes and 16% are ICH[2].
- Considering the above provided stats 20% of the ischemic strokes are fatal, whereas the risk of fatal is high in ICH which is about 50%[2].
- The general contrast between two strokes: ICH stroke occurs when people are active, where Ischemic occurs usually during night times or in the morning within 1 hour from wakeup time[2]

1.2 Current Diagnostic Methods

With the significant difference between types of stroke, it's a necessary to perform diagnosis before the treatment was given. Currently, when symptoms are found, the current imaging modalities such as computerized tomography (CT), Magnetic Resonance Imaging (MRI) and Positron Emission Tomography (PET) are performed to determine the current state of the brain and each technique offers useful information on various tissue properties related to ischemic, infarction.

On the contrary, none of this results in a rapid and cost effective treatment and also it does not fit into the emergency department as 'bedside' device. Usually within the onset of symptoms for the stroke, the treatment should be provided within 3 hrs[4]or else it would lead to high risk of death to the patient because clinical imaging methods such as CT, MRI,PET takes longer time to perform diagnosis and the results are not conclusive. To overcome this issue, Microwave tomography has ability to do perform rapid, cost effective diagnosis in a safe environment as a bedside device.

1.3 Microwave tomography

Microwave tomography is a growing imaging modality in biomedical field with great potential for imaging pathological and functional conditions of soft tissues.

Microwave tomography differs on a basic level from the other imaging tools. In case of CT, X rays are passed through the investigated matter and in ultrasound imaging, the reflections of sound waves are used to diagnose but in microwave tomography the principle are based on the dielectric properties of the investigated matter. In the microwave spectrum, biological tissues are differentiated and imaged by their dielectric properties[5]. Every tissue has its own dielectric properties and therefore different dielectric properties of body tissues causes' different amplitude and phase values when microwave signals propagated into the body[6]. In addition to this, microwave tomography is a safe device for imaging which has no radiating effects on the patients under investigation. Time also an important factor to consider microwave imaging than the current modalities. Approximately a measurement can be done in few minutes; therefore it ultimately helps the physician to treat their patients after the onset of stroke. Microwave tomography is currently developing modality and it can be widely used for applications like breast cancer detection, brain stroke diagnosis etc., generally it can be used wherever high contrast of dielectric properties are noticed[7].

1.4 Strokefinder R10

Medfield Diagnostics AB, a medical device company in Sahlgrenska science park, Goteborg, Sweden. It developed an instrument called **Strokefinder R10.** A microwave tomography device capable of differentiate between ICH and IS by preceding over CT and MRI scanning.

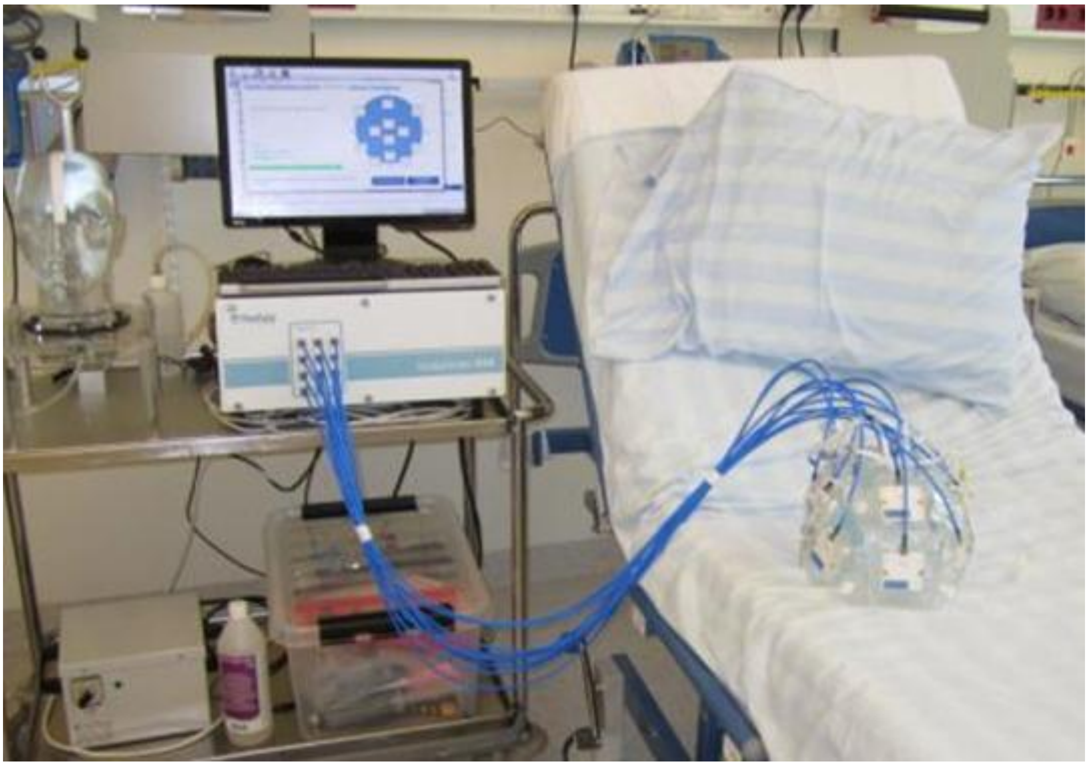


Figure 1.2 Medfield's Strokefinder R10 device

Advantages of Medfield's Strokefinder R10

- Capable of a rapid and cost effective diagnosis.
- As a portable device, it can be used in emergency rooms as bedside
- Can be used in ambulance for screening patients to detect *stroke type, location and size of bleeding* within the brain.

1.5 Thesis Objective

The experimental studies should be performed on any device to minimize error and to produce high quality service to the users. For this purpose, Phantom measurements are carried out on strokefinder R10 device to know how it reacts whenever stroke happens in the brain. As already mentioned, blood can change the dielectric properties of the brain when bleeding happens inside brain[6] and the device can able to detect the changes during such circumstances.

For experiments, preparing the tissue equivalent liquids play an important role in analyzing the expected effects when tissues exposed to microwave spectrum. Experimental studies can be carried out on this liquid with different environmental setup to minimize the errors.

The prime focus of this thesis work is to design a phantom model with dielectric properties to comply with the human brain tissue's dielectric properties. Experimental studies are carried out using strokefinder R10 device by stimulating various setups and analysis of these results are produced in this work.

Chapter 2

Phantom preparation

The phantom preparation is the main task of this thesis. Most of the experiments were carried out on a Phantom model. In this section, the clear description for why phantom model was built on the basis of dielectric properties of Human grey matter and Human blood for bleeding mixture are given.

2.1 Dielectric properties

Electromagnetic energy when interacts with biological tissues, it affects the tissue at molecular and cellular level[8]. In this study, phantom was characterized by its dielectric parameters such as permittivity and conductivity. The permittivity is the polarization on charged particles due to applied field whereas conductivity is the electrical losses in the material due to applied field[8]. Biological tissues have distinct permittivity and conductivity values. These parameters play a major role to distinguish between each tissue types. Both permittivity and conductivity are frequency dependence. Permittivity decreases with increase in frequency where conductivity increases with increase in frequency.

2.2 Human brain

Human brain is normally composed of white matter and grey matter tissue. Cerebrospinal fluid runs in between the layers of human brain to avoid any friction. White matter is present in the superficial region which is composed of myelinated axons where grey matter is present in the deep groves and plays a major component in the central nervous system with neuronal cell bodies, neutrophil, glial cells and capillaries. Grey brownish colour for the grey matter is due to the presence of capillary blood vessels and neuronal cell bodies whereas in white matter, the myelin gives white colour.

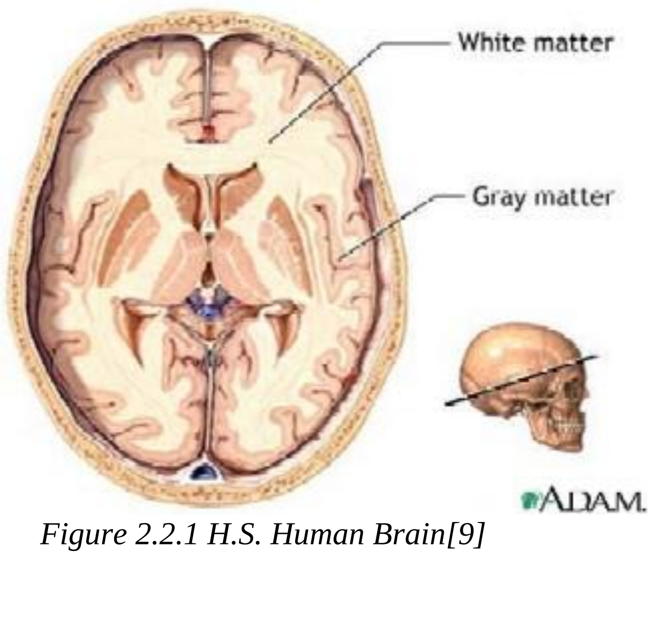


Figure 2.2.1 H.S. Human Brain[9]

The total volume of human brain is about 1.5 liters for men and 1.32 liters for female approximately [10]. In that volume, grey matter occupies 54%, the rest of the human brain is occupied by white matter and cerebrospinal fluid with 28% and 18% respectively [10].

Making a liquid mixture equivalent to a whole human brain is difficult task because it has composed of tissues like grey matter, white matter and cerebrospinal fluid. Each tissue has different values of dielectric properties. According to the dielectric properties measurements done by Gabriel et al [8], the permittivity and conductivity values for human brain components are listed out in the following table 2.1

At 1 GHz	**Permittivity**	**Conductivity**
Grey Matter	52	0.9
White matter	38	0.6
CSF	68	2

Table 2.2.1 Permittivity and Conductivity values for Human Brain at 1 GHz [8]

Due to this change in properties, it's difficult to make a liquid mixture equivalent to all the tissues. For that purpose, dielectric properties of **grey matter** equivalent liquid mixture is considered to design a phantom.

2.3 Normal healthy Phantom Setup

The Normal healthy phantom model is built with the liquid mixture equivalent to the dielectric properties of human brain Grey matter of a healthy person as shown in the figure 2.3.1. The dielectric properties of biological tissues - studies were conducted by Gabriel et al., [11] in 1996, which serves as a main database for dielectric properties values of biological tissues in the range of 10 Hz to 20 Ghz. Bao et al,. in 1997, performed dielectric measurements and analysis of brain tissues in microwave frequencies [12]. In 2003, schmid et al conducted a study on dielectric properties of human brain tissue in less than 10h from the post-mortem at the microwave frequency of 800 to 2450 MHz [13].Peyman et al in 2007 measured the dielectric properties of porcine cerebrospinal tissues at microwave frequencies; in vivo and in vitro[14]. Again in 2007, Peyman et al,. Performed study on cole –cole parameters for the dielectric properties of porcine tissues [15].

Figure 2.3.1Phantom model

By considering the dielectric properties of grey matter from these studies, phantom is modelled with the liquid equivalent to dielectric properties of grey matter. Grey matter is picked because it constitutes the major part of human brain among the others. The phantom is made up of sugar, salt, water and also agar for solidification process. The mixture for normal healthy Brain setup has shown in below table 2.3.1

Content	Amount (in %)
Water	60%
Sugar	36%
Salt	0.1%
Agar	3.9%

Table 2.3.1 Mixture for Normal Healthy Phantom Setup

Agilent 85070E Dielectric Probe Kit with an Agilent network analyzer is used to measure the dielectric properties of mixture. The permittivity and conductivity values of the mixture are given in figure 2.3.2 and figure 2.3.3 respectively.

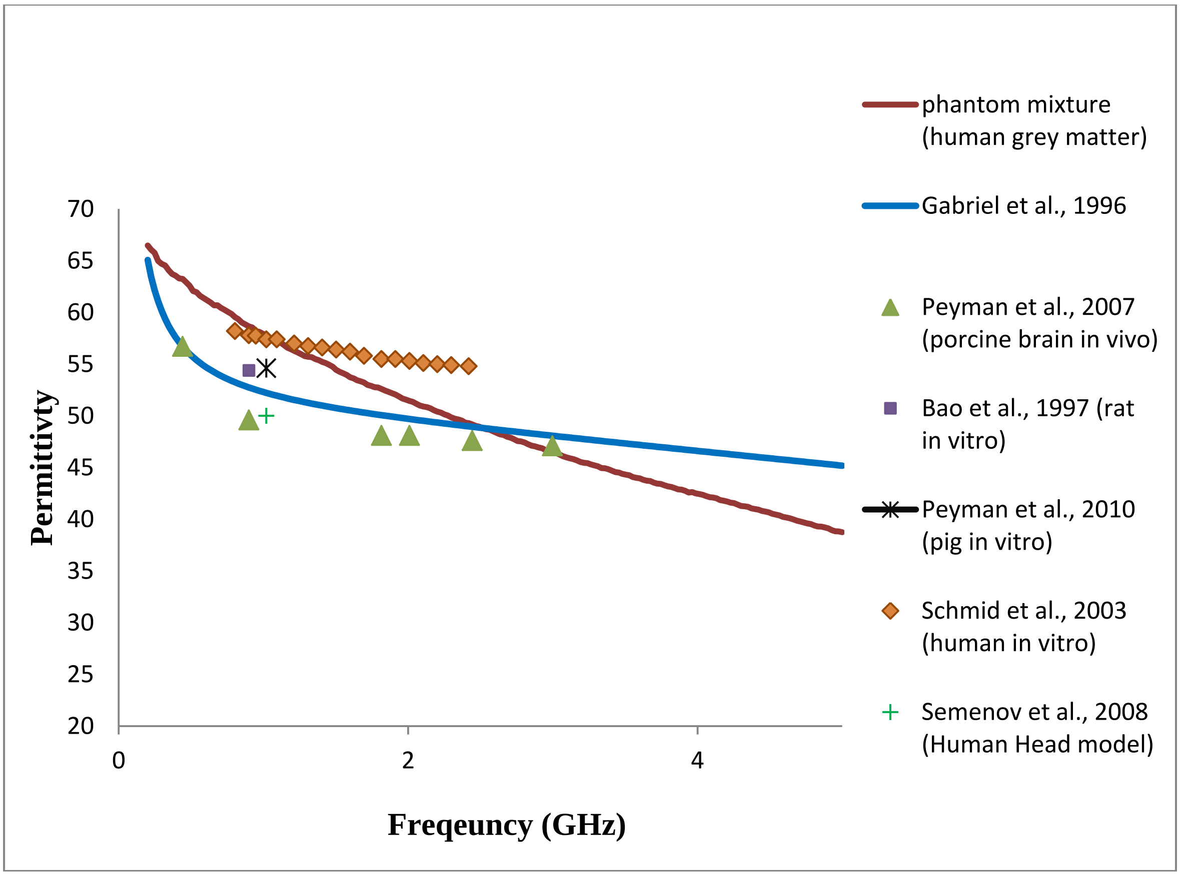


Figure 2.3.2 Permittivity values for Phantom mixture (grey matter) in comparison with other works [5, 8, 12-15]

From the inferred permittivity values, the phantom mixture values are closer to the Gabriel et al., values [8] at frequency range from 2 GHz to 2.5 GHz whereas it's closer to the dielectric values of human brain measured less than 10 hrs. from post-mortem – a study conducted by Schmid et al [13]   at 1 GHz to 1.5 GHz.

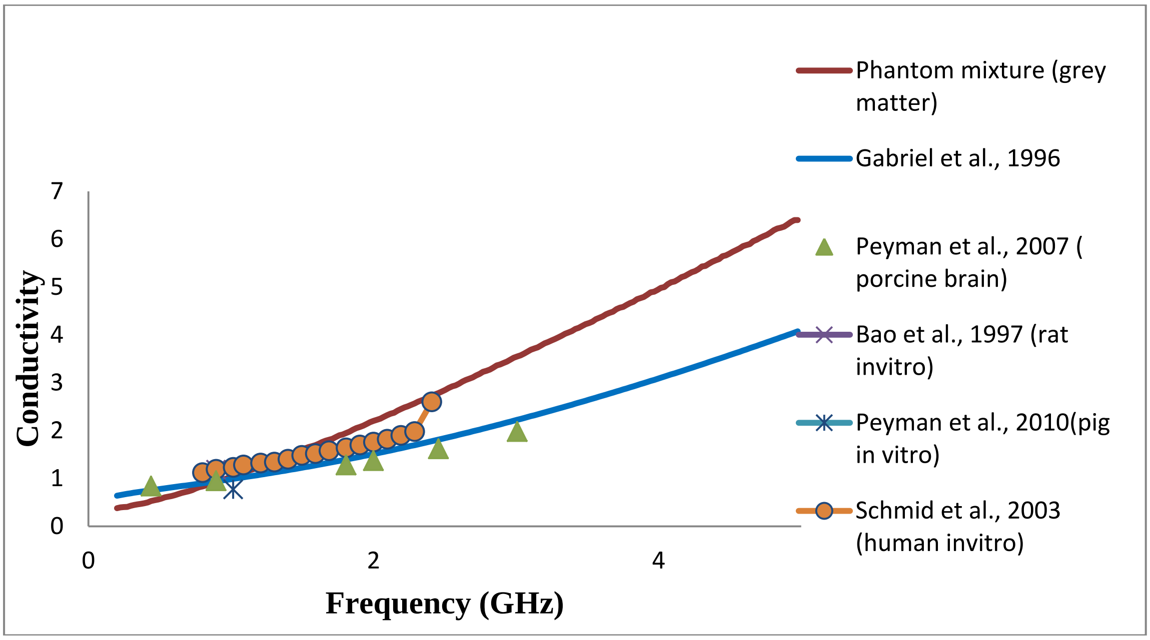
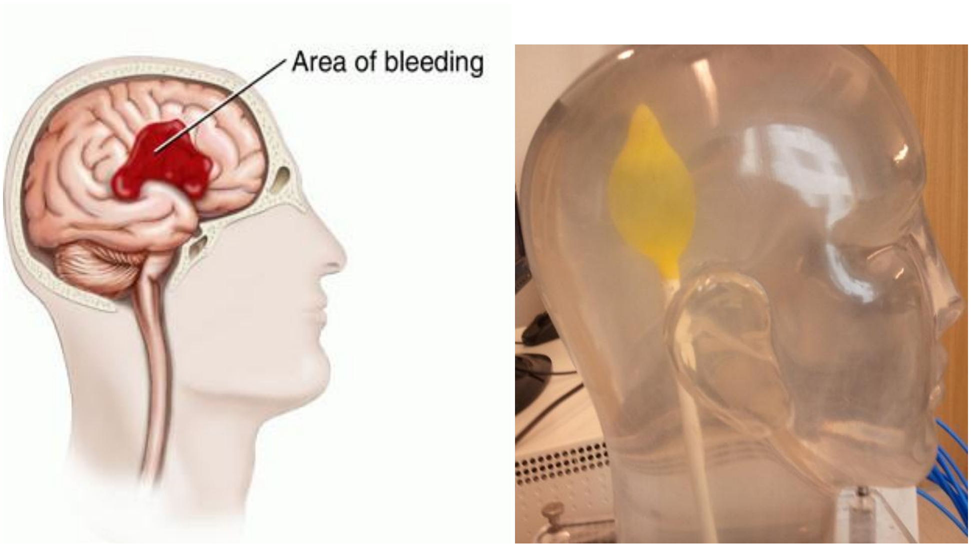


Figure 2.3.3 Conductivity values for Brain Phantom mixture in comparison with other works [5,8,12-15]

2.4 Bleeding Brain Phantom Setup

Bleeding brain is the haemorrhage affected brain. When blood vessels damaged or ruptured inside the brain, the blood flows outside the brain and causes damage to the brain function and leads to death, if it's not treated within 3 hours from the onset of stroke. As mentioned in the chapter 1, it's important to diagnose the stroke type before proceeding for the treatment. In order to do the experiments with the same setup as brain, normal healthy brain phantom model was constructed and to stimulate the bleeding, a balloon was inserted inside the model. The balloon contains the liquid mixture equivalent to dielectric properties of blood. The set up can be seen from the figure 2.4.1(b) below



(a) (b)

Figure 2.4.1(a) Human Bleeding brain (b) bleeding brain phantom setup

As mentioned before, bleeding brain is built with normal healthy brain phantom setup which is discussed earlier in this chapter. The plastic head model should be filled with Normal healthy brain phantom mixture and the balloon fixed pipe is inserted into the plastic head whereas the inserted balloon contains the liquid mixture equivalent to blood dielectric properties.

Measurements on dielectric properties of blood are carried out before. Gabriel et al., in 1996 performed measurements on biological tissues in the frequency range of microwave spectrum [8]. Alison et al., measured dielectric properties of blood at microwave frequencies in 1993 [16]. Jaspard et al in 2003 measured the dielectric properties of blood and produced their results in their paper [17]. By considering all these studies made on dielectric properties of blood, bleeding mixture is made with water, sugar, salt in appropriate proportion to match the dielectric properties of blood. The mixture can be seen in the table 2.4.1

Content	Amount (in %)
Water	68%
Sugar	26%
Salt	0.2%
Agar	5.8%

Table 2.4.1 bleeding mixture components

The microwave tomography device can detect the changes when there is a high contrast of dielectric properties between the tissues under investigation. In order to obtain the setup , the dielectric properties of normal healthy phantom mixture and the bleeding mixture is measured with the help of dielectric probe kit and compared their permittivity and conductivity values in the figure 2.4.2 and figure 2.4.3 respectively.

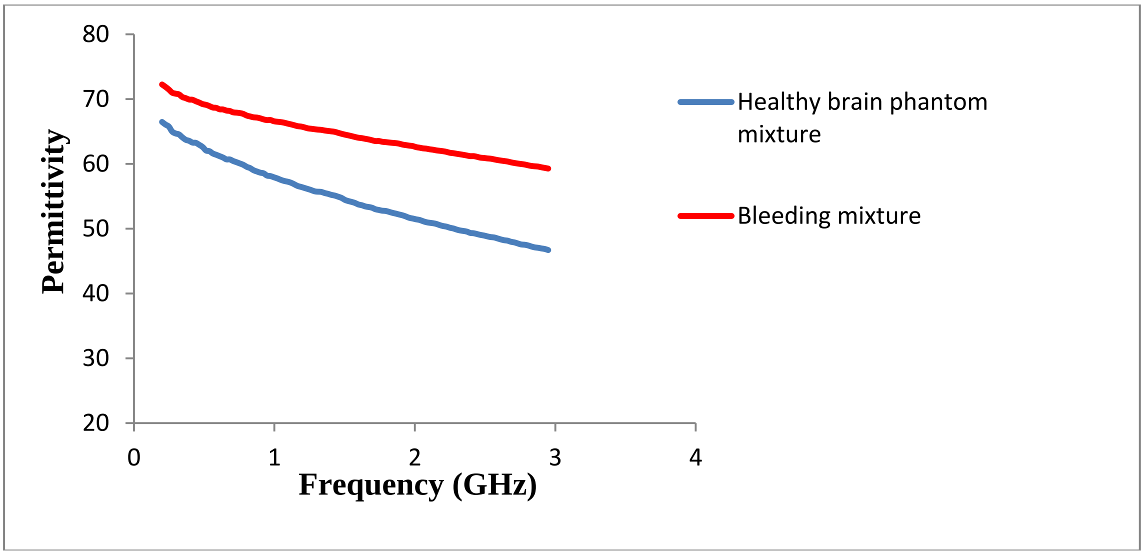


Figure 2.4.2 Permittivity values of bleeding brain phantom setup

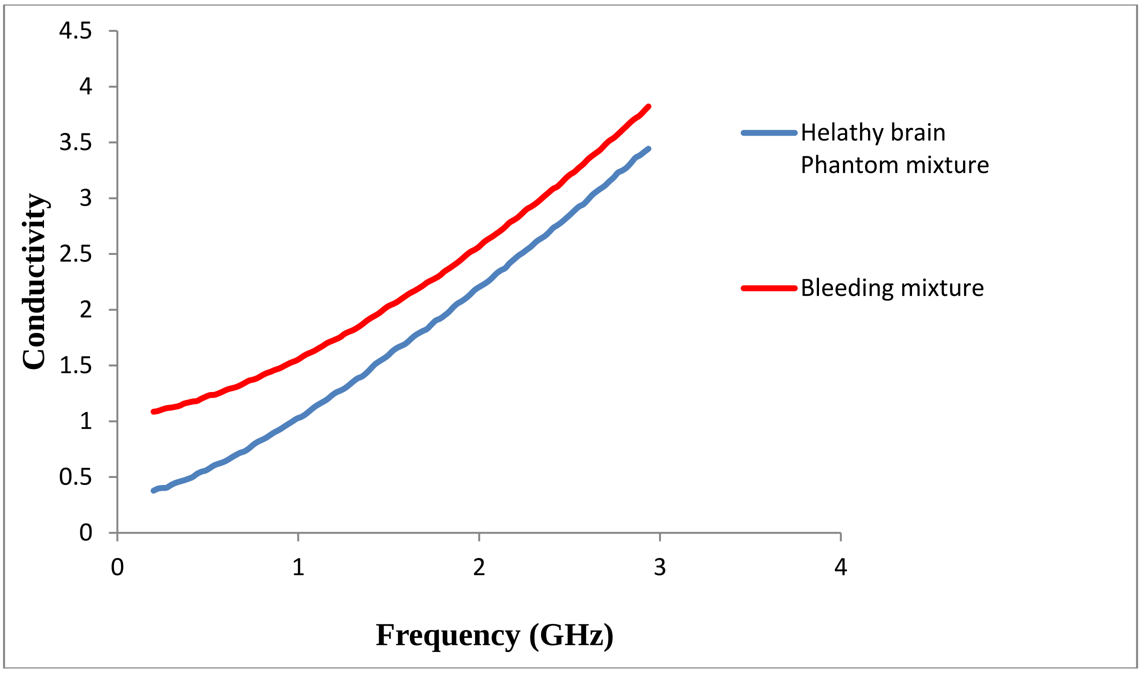


Figure 2.4.2 Conductivity values of bleeding brain phantom setup

From the permittivity and conductivity values of bleeding brain phantom, the significant contrast can be seen between the mixtures, which are a positive result for conducting experiments on this phantom model.

Chapter 3

Measurement Device Setup

The measurement device consists of several hardware components starting from antenna array helmet, cables, vector network analyzer (VNA) and a PC.

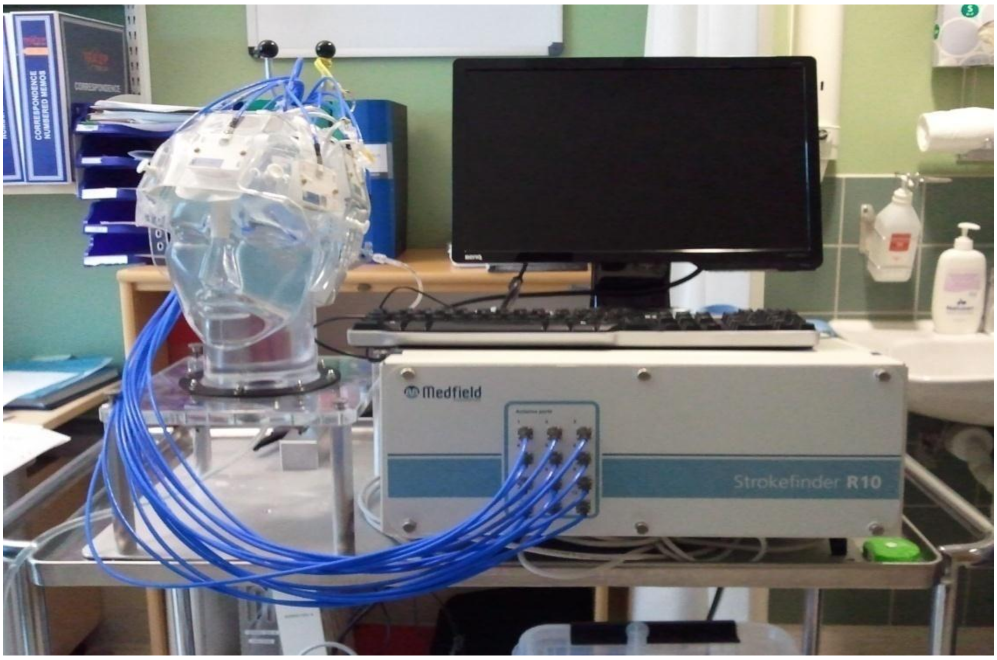


Figure 3.1 Measurement device with reference head

3.1 Helmet

The helmet is used to place over the subject to obtain the measurements. It is made up of semi flexible plastic with antenna placed according to the international 10-20 system of EEG signal measurement.12 antennas are used in this system and each antenna placed inside the helmet with water bags. Water bag helps the helmet to keep attached to head of the subject.

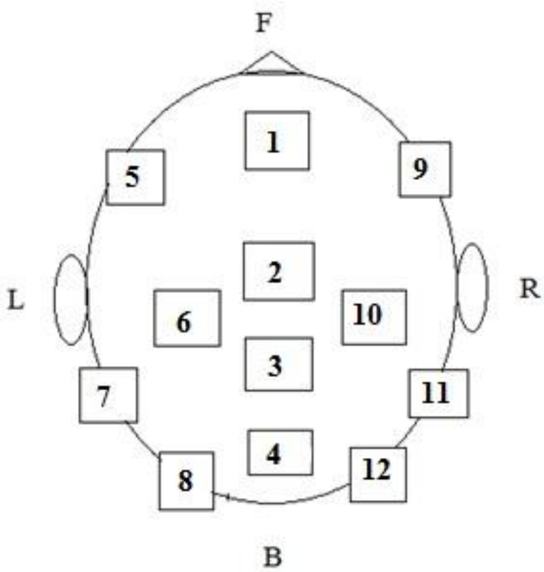


Figure 3.1.1 Top view of antenna position in the helmet with its schematic numbers

In the figure 3.1.1, placement of the antenna in the helmet is explained and each antenna assigned to a specific number in order to get a sequential order for measurement and analysis purpose. The letter F,B,L,R in the figure 3.1.1 indicates the front, back, left, right of the helmet respectively.

3.2 Antenna

Antennas play an important role in sending and receiving the signals. In this device, triangular patch antennas are used. Patch antenna consists of a metallic patch radiator on an electrically thin grounded dielectric subspace[19]. This antenna works in the range of 0.1 GHz to 3 GHz with circularly polarized single feed type antenna. The significance of using this antennas because they are light weight, small size and low cost [6].

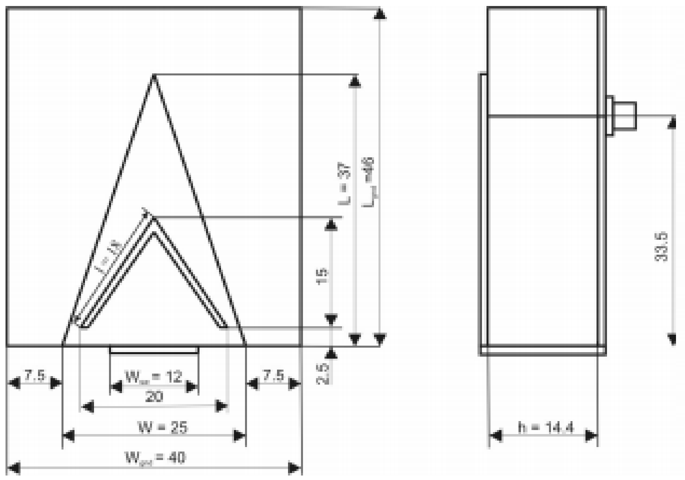


Figure 3.2.1 Geometrical view of the patch antenna with cross section and top side views respectively [6]

The geometrical details of the antenna are given in the figure 3.2.1. In the cross sectional view of the figure 3.2.1, the shape with isoceles triangle with length L=37mm is observed in the patch antenna, with width W=25 mm. This isoceles triangle patch is printed in dielectric substrate with relative permittivity of $\acute{\varepsilon}_r$= 2.34. the substrate and the ground plane are rectangular plates with the length and width of 46mm and 40mm respectively [6]. The antenna is excited by a probe feed through the center line of the patch antenna with the distance of d_f= 3.5mm [6].

3.3 Vector Network Analyzer

A vector network analyzer plays an important role in this measurement device. Normally network analyzer measures the S parameters such as reflection and transmission co efficient of the signals. With this VNA measures the amplitude and phase value of the signals at certain frequencies including microwave frequencies. It also analyzes the incident signal which passes through the analyzer, whether it is transmitted through the subject or the reflected signal from the input. It measures the transmission co efficient as S_{12}, S_{13}, S_{14}…S_{n-1} and reflection coefficients as S_{11},S_{22},S_{33},...S_{nn} where n denote the antenna numbers here. The calibration should be done on the network analyzer to reduce noise and to obtain the ideal results.

Antennas are connected to VNA through cables. 12 antennas are used in this system and each antenna serves as both transmitter and receiver. When one antenna serves as a transmitter then rest of the antennas serves as receiver. The antennas are connected to VNA where it performs the measurement of transmission and reflection coefficients.

Each antenna sends out a microwave signal in the frequency range of 0.1 to 3 GHz to the subject. When all antennas have received signals from the 1st antenna, then the 2nd antenna serves as a transmitter until the rest of the antennas received the signal. This will goes on till all the antennas have served as a transmitter and receiver, which yields 12x12 measurement data sets.

3.4 Water Bags

In order to obtain better result by assuring direct contact between the subject's head and antennas, water bags are placed in between the head and antennas. The amount of water in the water bags could be checked and refilled using the pipe connected with syringe. It's important for the antenna's to be in contact with the head, but the difference that prevails with the size of each subject's head causes the obstacle. To eliminate the problem faced with size, the amount of water in the water bags are adjusted according to the size of the subject, thereby providing a firm contact between the antenna's and subjects' head.

3.5 Data Acquisition Setup

Most of the measurement is carried out in Sahlgrenska Hospital and in the laboratory of Medfield Diagnostics AB. During the setup, the Device is set to be on and everything around the device should be checked before taking the measurement to avoid external noises. Before obtaining measurements from the subject, test measurements should be performed with the Reference head model filled with water to ensure that antennas are having resonance peak of closer to -20 dB.

Figure 3.5.1 Data Acquisition Setup showing Healthy volunteer under investigation

After testing the antenna, the reference measurement is taken on the subject. Before starting the measurement, the operator notes down the subject's personal details like name, age, head size and hair length for reference. After this procedure, subject would be asked to lie on the bed for performing measurements. The helmet is mounted on subject’s head to precede the measurements. The patient is requested to stay still during the course of measurement, which is 5min approximately.

Usually the number of measurement taken for a subject varies. For most of the patients and healthy volunteers, the measurement is conducted three times, it is done so to make sure that each measurement values acknowledges the other set of obtained values and there is no difference with them because of any external factors. In case of drastic differences between the values of the measurements performed, to correct the errors, the helmet is adjusted, checked for environmental disturbances like mobile phone, movement of cables, etc. After the measurement was performed, the helmet is removed from the subject and placed on the reference head model.

The external disturbances such as talking in mobile phone during the measurement, shaking the device, applying pressure on the helmet should be normally avoided.

Chapter 4

Methods for Data Analysis

The measured microwave signals from VNA are in complex forms, with real and imaginary parts. In order to analyze this empirical data, the Higher Order Single Value Decomposition method is considered. The HOSVD classifier and the feature extraction algorithm was developed by Hamed et al [20], the method is used in this study as Classification algorithm for analysis purpose.

Reasons to use HOSVD

As mentioned above, the data from the VNA results were in complex forms, with real and imaginary parts. It's difficult to analyze the data using other methods. By using multi linear algebra, the task can be performed with ease. So, HOSVD was preferred to extract powerful features from the microwave scattering data and used in investigating the obtained results.

The transmission and reflection coefficients were obtained from two antennas at each time slot. The incident signal from the antenna strikes the head surface causing part of the incident signals to be reflected back by the body surface and the rest transmitted through the head. The reflected signal has no influence on the measurements, whereas the rest of the signal carries valuable information. The scattered signals were collected by the other antennas and the transmission coefficient was obtained.

For analysis, only the transmission coefficients were considered because of the scarcity in information and high amplitude values of reflection coefficient. 12 antennas were used in this system and the measurements were repeated for each one of them. The microwave scattered data comprises transmitting ,receiving antenna values and their frequency range, arranged into 3D tensor form [20].

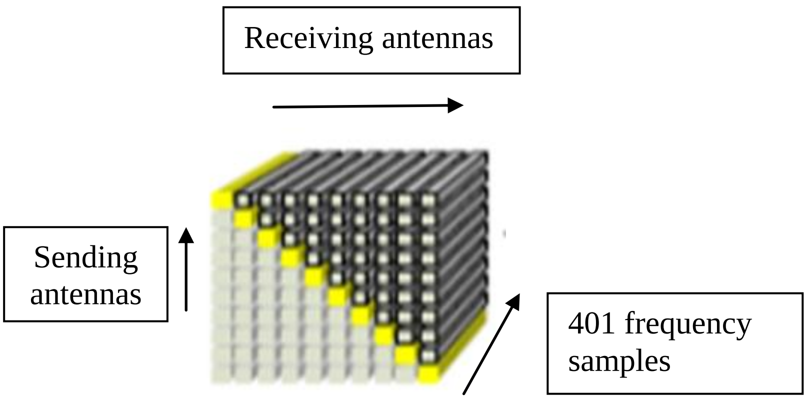


Figure 4.1 3rd order Tensor form consists of microwave scattered data with transmission coefficients in the upper and lower triangle and reflection coefficients in main diagonal

As shown in the figure 3.1, the upper triangle consists of transmission coefficients with respect to the sending and receiving antennas. The main diagonal (shown in yellow) has reflection coefficients of the same antennas, whereas the lower triangle has transmission coefficients like that of the upper triangle in the above picture, but with reversed antenna indexes. Therefore the S parameters of the upper triangle coefficients and lower triangle coefficients are same (Sij = Sji). The selected frequency range for this study is from 0.1 GHz to 3GHz and it is divided into 401 frequency samples in VNA.

The obtained 3D tensor form from the figure 4.1is then restructured into 2D tensor form which is the input data for HOSVD classifier which is described in hamed et al [20].

4.1 Feature Extraction

The feature extraction in HOSVD classifier proposed by Hamed et al [20] was used in this work. The main task of the feature extraction is to obtain the features from the measurement data. The features are extracted in accordance with the features in healthy samples. A healthy measurement acts as a reference for extracting features from the subject's measurement data.

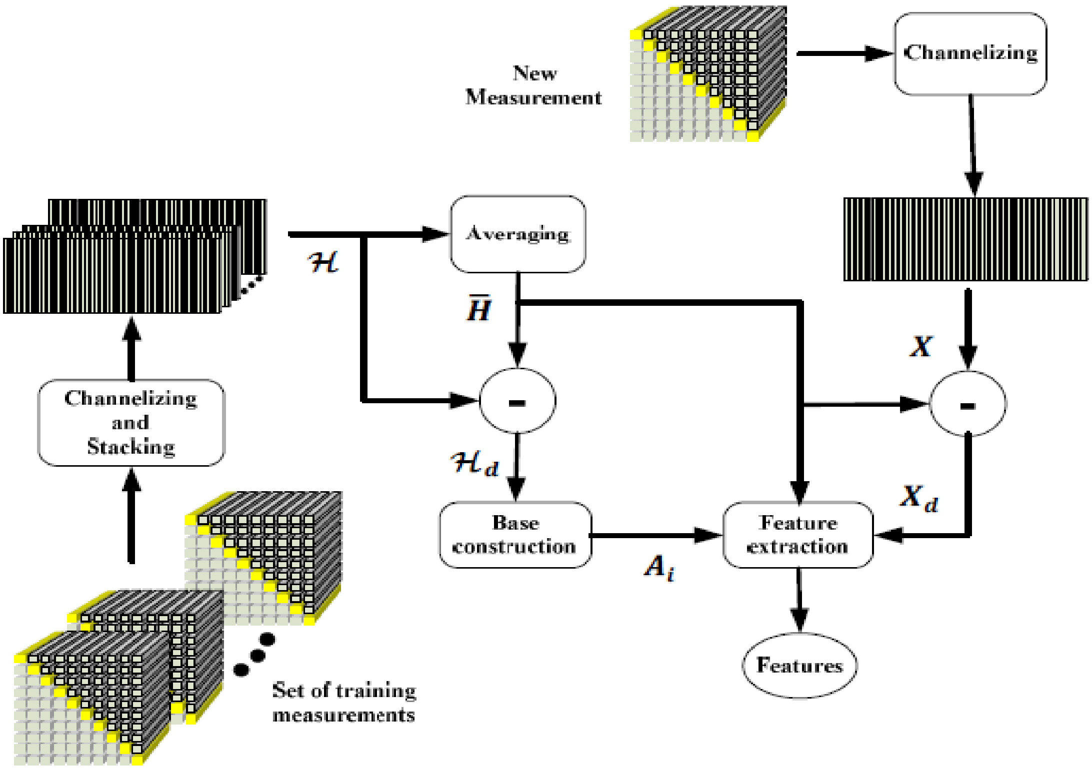


Figure 4.1.1 Feature extraction algorithm[20]

As shown in the above figure 3.1.1, the microwave scattered data were in 3D tensor form, which is then channelized into 2D form as **X**. Set of training measurement mentioned in the picture were the measurements from group of healthy volunteers which was then channelized and stacked as **H**. Mean of the healthy set of data was calculated as $\overline{H}$. From the difference between healthy training samples **H** and mean value $\overline{H}$, the deviations $\mathbf{H_d}$ was calculated.

The orthogonal bases $\mathbf{A_i}$ was calculated from $\mathbf{H_d}$ values using HOSVD method. From the difference between the new measurement samples **X** and the mean of all healthy samples $\overline{H}$, the deviation values of new measurements were calculated as $\mathbf{X_d}$. From $\mathbf{A_i}$, $\mathbf{X_d}$ and **H**, the features were extracted for classification[20].

The extracted features were correlated either to direction or norm of the data. In order to detect better changes, 8 different features were extracted in this classifier

Features	Definition
F1	$\lVert \mathbf{Xd} - \overline{H} \rVert = \lVert D \rVert$
F2	$\lVert \mathbf{Xd} \rVert$
F3	$\theta_{\mathbf{Xd,Hd}}$
F4	$\lVert \mathbf{Mxd}, \mathbf{Hd} \rVert$
F5	$\theta_{\mathbf{D,Hd}}$
F6	$\lVert \mathbf{Mxd}, \mathbf{Hd} \rVert - \lVert \mathbf{M}_{\overline{H}}, \mathbf{Hd} \rVert$
F7	$\lVert \mathbf{Mxd}, \mathbf{Hd} - \mathbf{M}_{\overline{H}}, \mathbf{Hd} \rVert$
F8	$\theta_{\overline{H},\mathbf{Hd}} - \theta_{\mathbf{Xd,Hd}}$

Table 4.1.1 Features list with their definitions

Leave one out approach

To validate the results of the classifier, leave one out approach was performed as across validation method [20]. The following steps were done in the leave out approach[20],

1. By using this method, the first data is set to be a healthy sample and the remaining data are the training samples.
2. Building orthogonal bases from the training samples.
3. Classifying the entire subject's data and left one healthy sample for validation purpose.
4. Repeating the above steps in order for the rest of the samples.

4.2 Method for calculating Amplitude and Phase for 2 antennas setup

For 2 antennas setup, the amplitude and phase values are obtained by performing the sum of the difference between the measurement data and single measurement (as reference) to the length of selected frequency range as shown in the mathematical form below

For amplitude, $\boldsymbol{\varepsilon} = \sum \lvert\lvert \mathbf{S}_{\mathbf{transN}} \rvert - \lvert \mathbf{S_0} \rvert\rvert / \mathbf{N}$

For phase, $\boldsymbol{\varepsilon} = \sum \lvert \angle \mathbf{S}_{\mathbf{transN}} - \angle \mathbf{S_0} \rvert / \mathbf{N}$

$\mathbf{S}_{\mathbf{transN}}$ is the total no. of measurement data, $\mathbf{S_0}$is the single measurement (as reference) and **N**denotes the length of selected frequency range.

Chapter 5

Experiments on Healthy Volunteers

This chapter is about the experiments carried out on healthy volunteers and its analysis results.

Healthy volunteers are prepared by operator; the one who performs the measurement. He should provide regulations to healthy volunteers and explain about the procedure in detail. Subjects are asked to switch off their mobile phones during the measurement to avoid external microwave disturbances. The operator should check the device to make sure that everything is fine before the commencement of the measurement. Then the subject is asked to lie on the bed which is near the device. Before performing the measurement, operator notes down the volunteer’s details such as name, sex, head size, hair length in the “R10 Strokefinder” application in pc. This is for later reference to see how much the head size and hair lengths are affecting the measurement.

Once the operator has noted down the details, the measurement procedure is started off with reference head model to ensure that antennas are having resonance peak of -20db.Once confirmed, the helmet is mounted on the healthy volunteer and the necessary adjustments are done with the aid of the water bag according to the individuals’ size. Before performing the measurement, it’s necessary to make sure that helmet is in perfect contact with the head in all sides with minimum amount of water in water bags. After this procedure, measurement is performed on the volunteer, meanwhile volunteer is asked to lie down on the bed without causing any external disturbances such as shaking of the head, body movements, etc. Usually a measurement completes when all the antennas are transmitted and received signals. Normally, 3 measurements are performed on the subject.

Apart from the normal measurements, certain measurements were performed by stimulating external disturbances to note the effect that a disturbance can cause. Such stimulated trial measurements are explained in the following sub-divisions.

5.1 ON OFF Helmet Stimulated Measurements

The procedure followed in the same manner like before. Eleven continuous measurements are performed on the volunteer without taking off the helmet. After performing first set of 11 measurements, operator continues the second set of 11 measurements by taking off the helmet between each measurement. So from 12 to 22, the measurement was done with a specific interval between each. These measurements are analyzed with the base values of healthy training sets from different healthy volunteers.

Among the other Features, feature no. 8 is selected to show the distribution of HOSVD angle in the figure 5.1.1. The first data in figure is a healthy sample value as a part of leave one approach. The rest of them are measurement data.

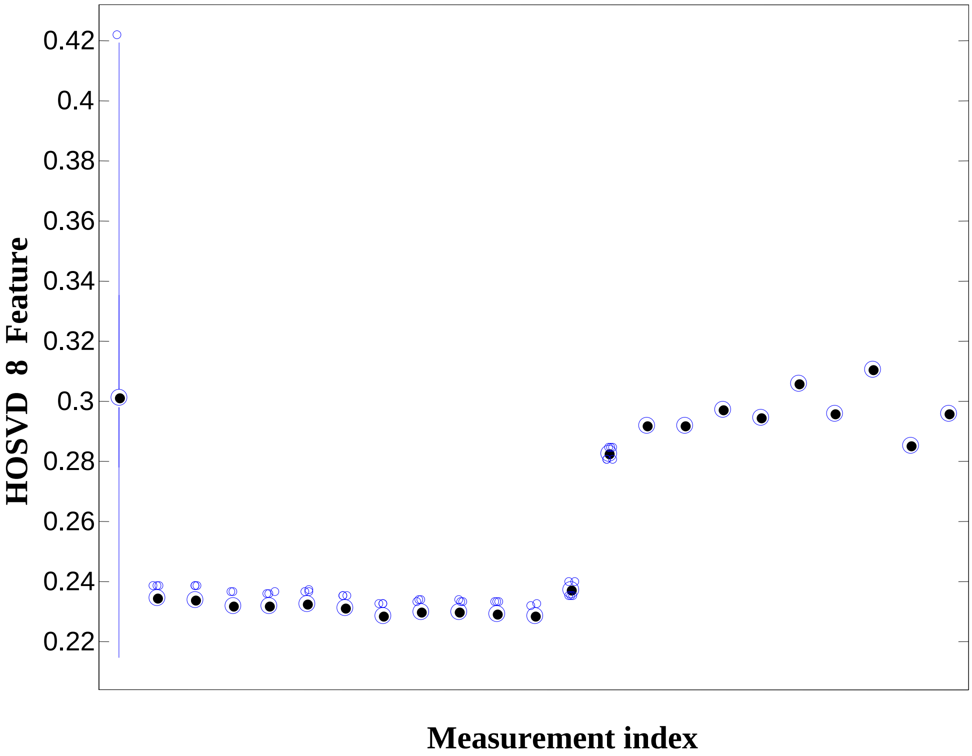


Figure 5.1.1Distribution of HOSVD angle over Measurement index for feature 8 in the frequency range of 245 MHz to 745MHz for On Off Helmet experiment

In the figure 5.1.2 and figure 5.1.3, amplitude and phase response of the transmitting antenna 8 with rest of the antennas at the receiving end respectively.

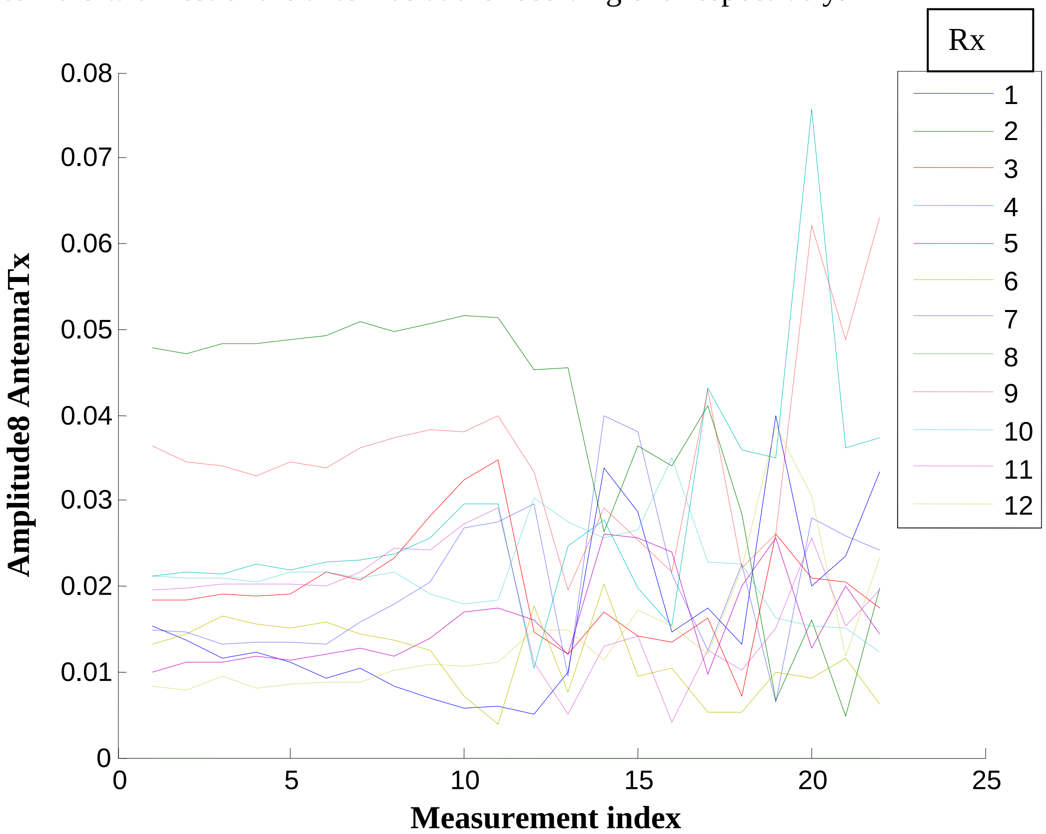


Figure 5.1.2 Amplitude values of the transmitting antenna 8 with rest of the antennas at the receiving end for On Off helmet experiment at the frequency of 745 MHz

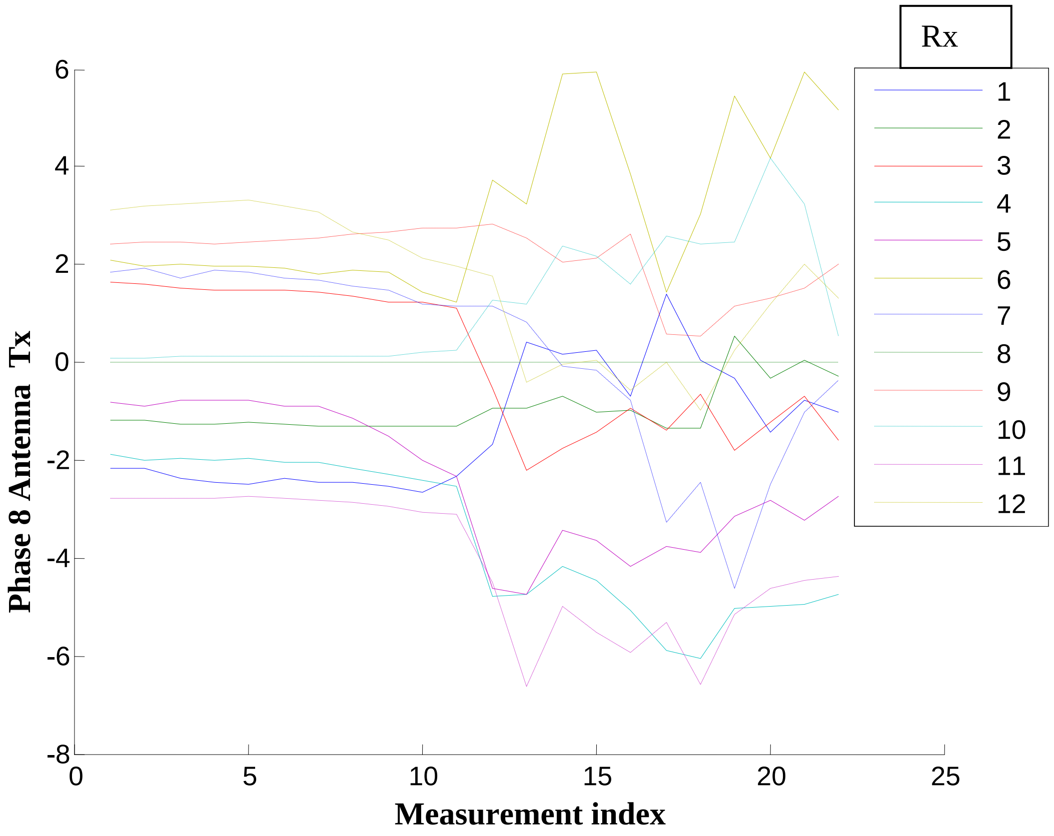


Figure 5.1.3 Phase values of transmitting antenna 8 with rest of the antennas at the receiving end for stimulated On Off helmet experiment at the frequency of 745 MHz

By this stimulated trial measurement, it can be concluded that, when the helmet is removed and placed on the subjects head between measurements, the position of the antenna with the head is considerably changed from the previous position; this causes a change in measurement values which can be seen in the measurement index from 12 to 22. In figure 5.1.1, there is a continuous trend in first 11 measurements, but when the helmet is taken off and placed again before the 12^{th} measurement index, the value changes and falls down and then the values are almost near but different till 22^{nd} measurement. This is shown in figure 5.1.2 and figure 5.1.3 with its amplitude and phase values of different antenna combinations, there's a continuous trend till 11^{th} measurement and changes in amplitude values from 12^{th} measurement index in almost most of the combinations.

5.2 Head Movement Stimulated Measurements

In this measurement protocol, the procedure is followed on the healthy volunteer as mentioned earlier in this chapter. 11 continuous measurements are performed on the volunteer without taking off the helmet. After 11 measurements, operator requests the volunteer to move the head voluntarily without taking off the helmet. First set of measurements values (1 to 11 measurement index) the helmet was placed on the head without any movement, whereas from 12^{th} to 22^{nd} measurement the volunteer forced the head movements without taking off the helmet. It should be noted that the helmet was not taken off during the whole course of the stimulated trial. These measurements are analyzed with the base values of healthy training sets from different healthy volunteers and the healthy training set denotes the first value in the measurement index.

The HOSVD angle distribution over measurement index for feature 8 is given in the figure 5.2.1

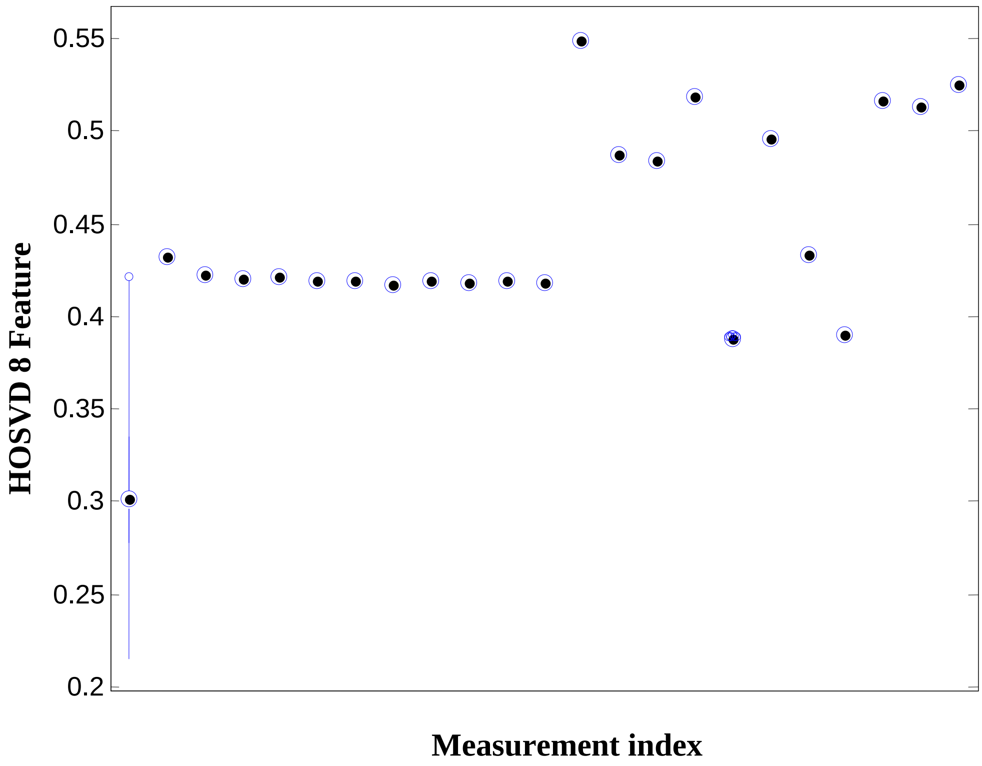


Figure 5.2.1Distribution of HOSVD angle over Measurement index for the feature 8 in the frequency range of 245 MHz to 745 MHz for stimulated head movement experiment

In the below figure 5.2.2 and figure 5.2.3, amplitude and phase response for different antenna combinations

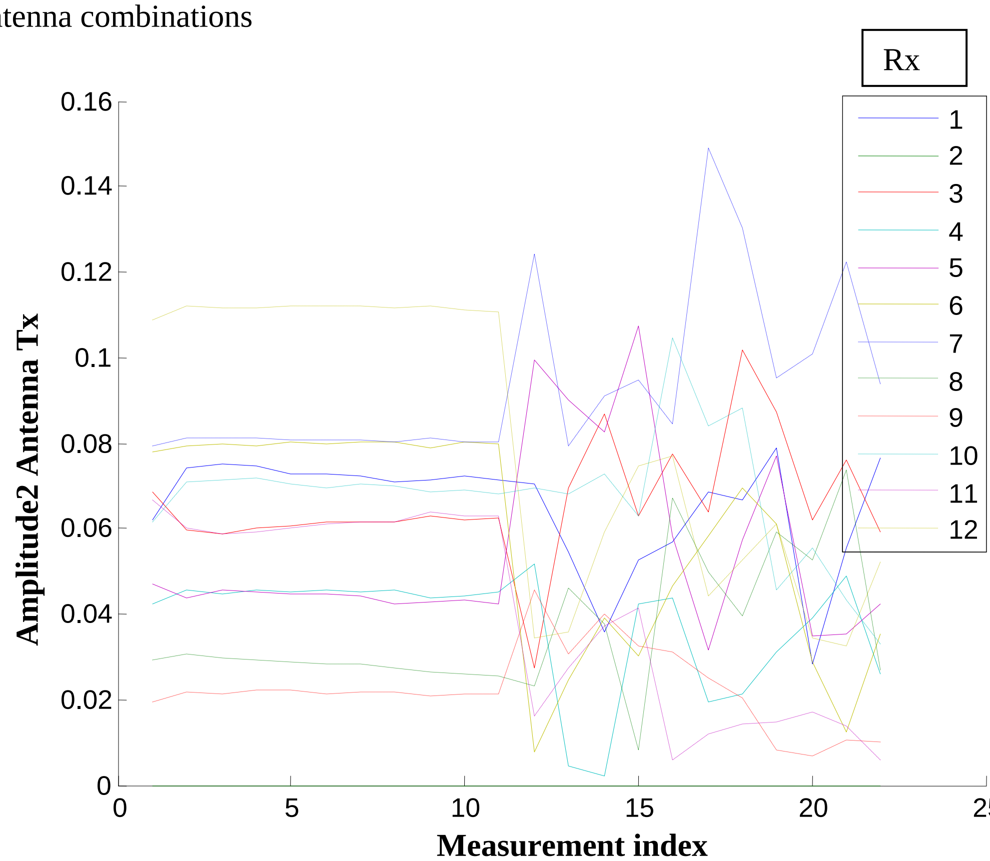


Figure 5.2.3 Amplitude values of transmitting antenna 2 with rest of the antennas at the receiving end for stimulated head movement experiment at the frequency of 745 MHz

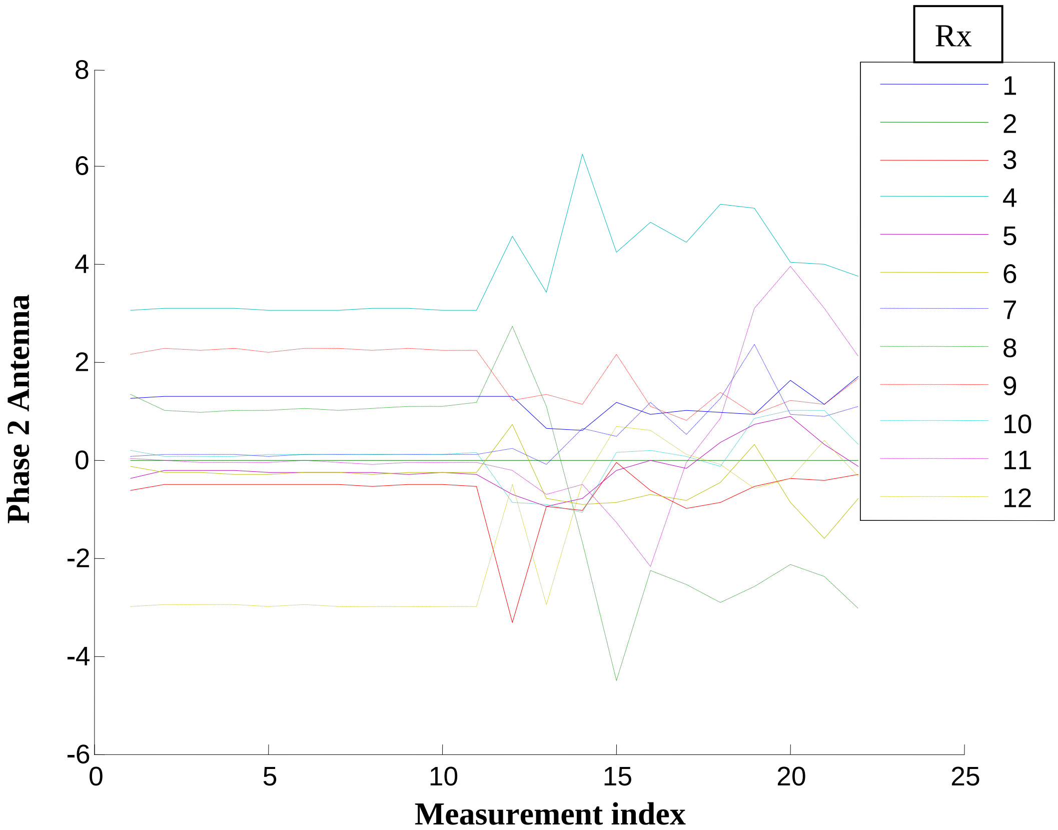


Figure 5.2.3Phase values of transmitting antenna 2 with rest of the antennas at the receiving end for stimulated head movement experiment at the frequency of 745 MHz

By this stimulated trial measurement, it can be conclude that, whenever there is no external disturbance and continuous measurement, it is possible to get a continuous trend in measurement values as shown in the figure 5.2.1 from the measurement index 1to 11. Whereas when there's a disturbance caused by the volunteer with conscious head movement from 12th to 22nd measurement index, we could clearly see the change in measurement values from the feature 8 in figure 5.2.1. Just as in figure 5.2.1, in figure 5.2.2 and figure 5.2.3also, the changes in amplitude and phase values from 12th measurement index to 22nd. Before that, there's a continuous trend from1st measurement index to 11th measurement index. Disturbances due to subjects' head movement causes considerable change in the obtained result in both HOSVD values and amplitude and phase response of the antennas, as shown in the figure 5.2.2 and figure 5.2.3.

5.3 Continuous Measurement

In this measurement trial, continuous measurement is performed on the healthy volunteer for about an hour without any interruption. Healthy volunteer lies still on the bed without any disturbances and without changing the position of Helmet. This measurement is carried out to know whether the measurement values follow the continuous trend or not. The measurement results are analyzed with the base values of healthy training set from different healthy volunteers.

The HOSVD angle distribution over the measurement index for feature 8 can be seen in figure 5.3.1 in the frequency range of 245 MHz to 745 MHz.

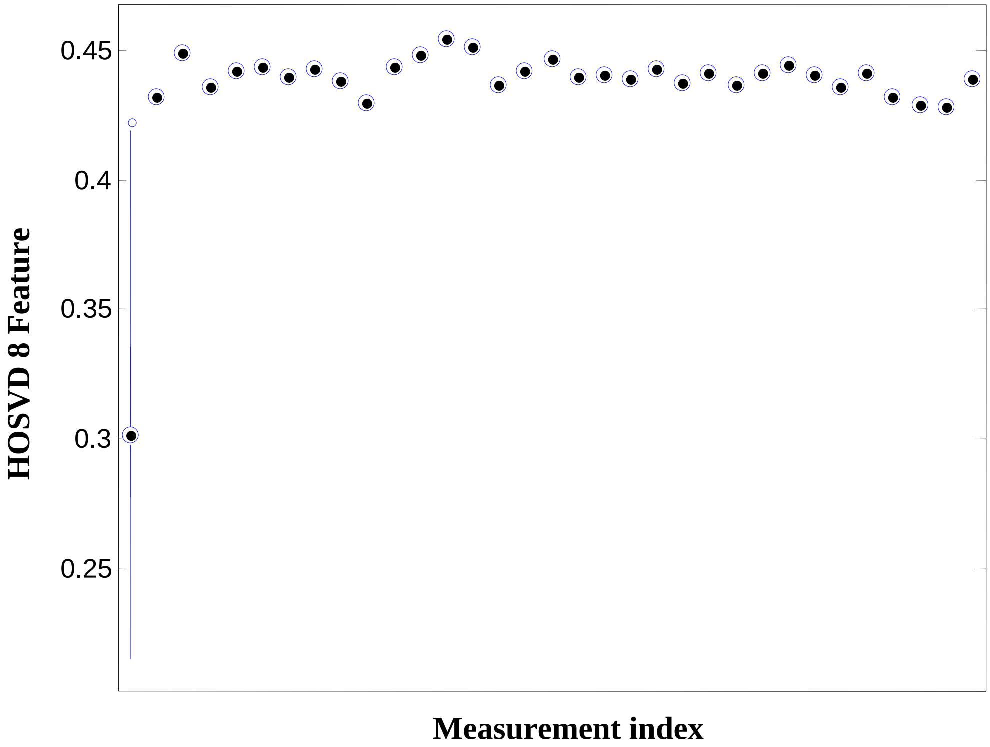


Figure 5.3.1Distribution of HOSVD angle over Measurement index for feature 8 in the frequency range of 245 MHz to 745 MHz for stimulated continuous experiment

Like the HOSVD values, the antennas amplitude and phase response is also a continuous trend that can be seen in the figure 5.3.2 and figure 5.3.3 below.

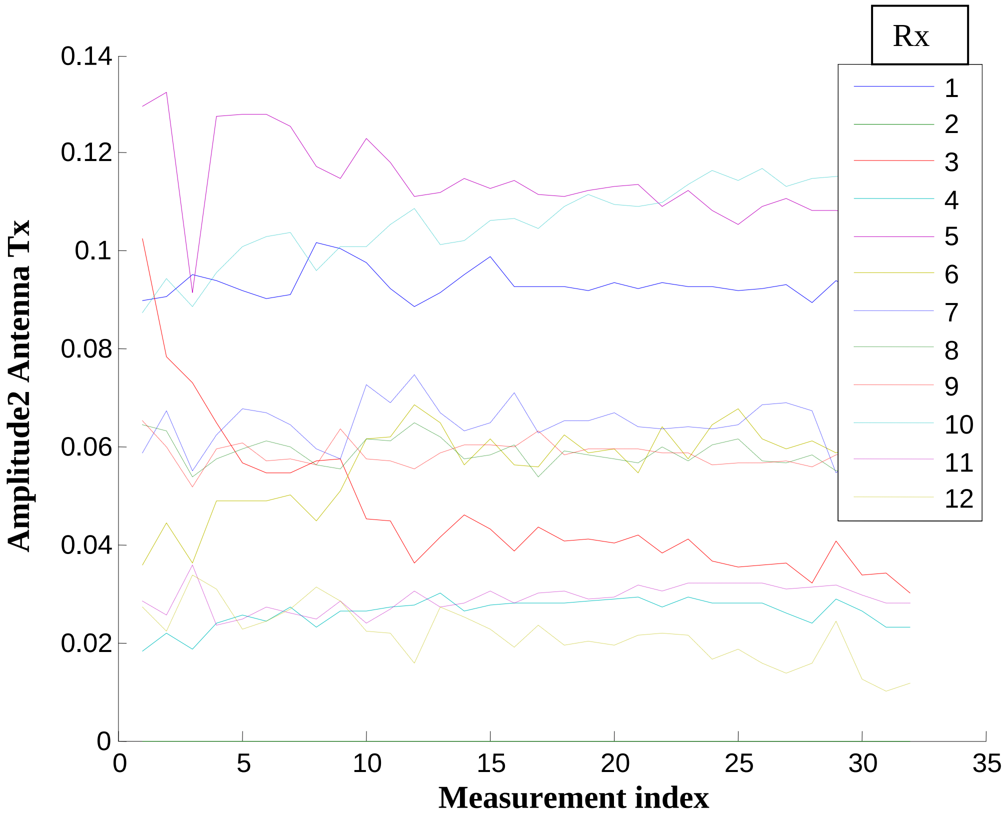


Figure 5.3.2 Amplitude values of transmitting antenna 2 with rest of the antennas at the receiving end stimulated continuous experiment at the frequency of 745 MHz

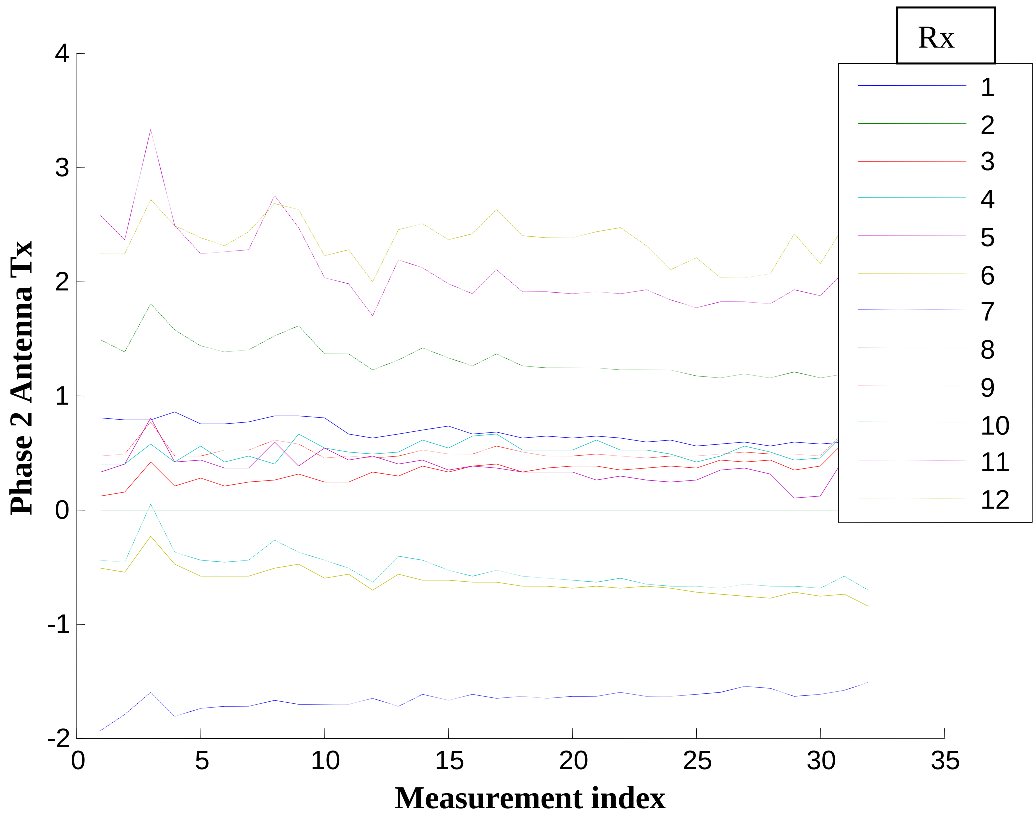


Figure 5.3.3Phase values of transmitting antenna 2 with rest of the antennas at the receiving end stimulated continuous experiment at the frequency of 745 MHz

In this experiment, the continuous trend in the measurement values with the continuous measurements without any stimulated disturbances can be noted.

Chapter 6

Experiments on Phantom model

Most of the times, it’s difficult to perform the clinical trials on patients or healthy volunteers, so the need of phantom is much important here to carry out number of experiments. The phantom model is designed with the dielectric properties of human brain and the measurement results are much close to the real time human brain measurements. The phantom is prepared with certain amount of water, sugar, salt and agar (if necessary for solidification) as explained in the phantom preparation chapter 2. Once the mixture is prepared in right constituent, the phantom model is prepared. The pipe with a balloon to its end is inserted in the phantom to make the phantom model as a bleeding brain setup as shown in the figure 6.1 below.

The balloon is filled with bleeding mixture as explained in chapter 2. It is possible to adjust the size of the balloon by increasing or decreasing the volume of bleeding mixture through a syringe provided. Before performing measurement on phantom, it’s mandatory to check whether it has no air bubble inside the phantom. Presence of air can influence on the measurement values, so it is should be get ridden through the pipe fixed with the phantom.

6.1 Experiment on Healthy brain Phantomwith bleeding mixture and air in balloon

Before carrying out the experiment, the reference test should be made on the reference head model, to ensure the position of antenna and confirm the transmission of signals. Once the initial steps are completed, the helmet is placed on the phantom model for performing12 continuous measurements with empty balloon for reference. Then the balloon is filled with 10ml, 20ml and 30ml of bleeding mixture consecutively and obtaining 3 measurements for each level.

Then instead of bleeding mixture, balloon is filled with air of 10ml, 20ml and 30ml and obtained 3 measurements for each level. This experiment is carried out to know the difference between the air and bleeding mixture.

In the figure 6.1.1shown 18 measurements were carried out. In that, 9 measurements correspond to bleeding mixture in the balloon like 10ml, 20ml and 30ml with 3 measurements each. From 10 to 18, measurements were carried out with 10ml, 20ml and 30ml of air respectively with 3 measurements for each level.

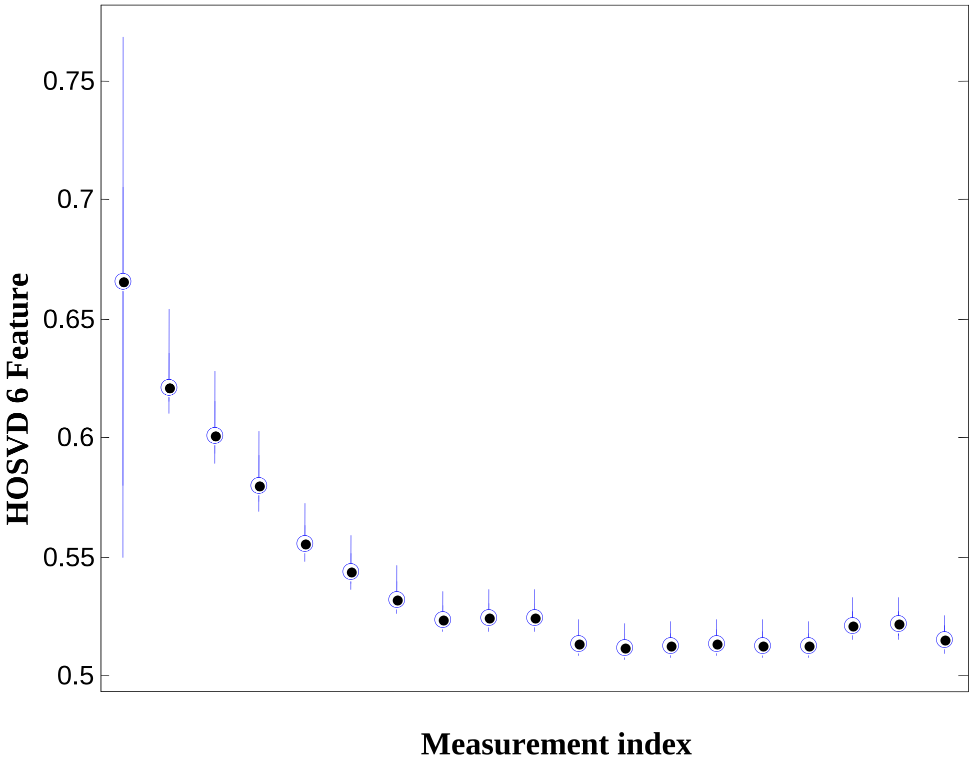


Figure 6.1.1Distribution of HOSVD over Measurement index for feature 6 in the frequency range of 245 MHz to 745 MHz for experiment on brain phantom with air and bleeding mixture in balloon

The HOSVD distribution over the measurement index for feature 6 can be seen in figure 6.1.1 in the frequency range of 245 MHz to 745 MHz.

From this Experiment, It can be inferred that whenever there is a change in volume there is a considerable change in HOSVD values for the bleeding mixture. Whereas for the air, there is not much differences as seen in feature 6 in the figure 6.1.1. The reason was quite hard to explain and several other experiments were performed to overcome this situation.

6.2 Experiment on Healthy brain phantom with bleeding setup model

This experiment is performed to figure out whether the system could identify the changes in the bleeding size or not. To make a bleeding setup, the pipe fixed with balloon was placed inside the phantom model. Trends of increasing and decreasing values were expected by filling up the balloon with different volume of bleeding mixture.

After the usual procedure, 12 continuous measurements are taken on the phantom model with empty balloon as reference. Then the balloon is filled with bleeding mixture by 0ml,5ml, 10ml, 15ml….30ml then with the descending order like 25ml, 20ml….5ml then again start with 5ml, 10ml…30ml respectively. For each ml, 3 measurements were performed.
The measurement procedure is shown in the figure 6.2.1 below, where totally 51 measurements were carried out.

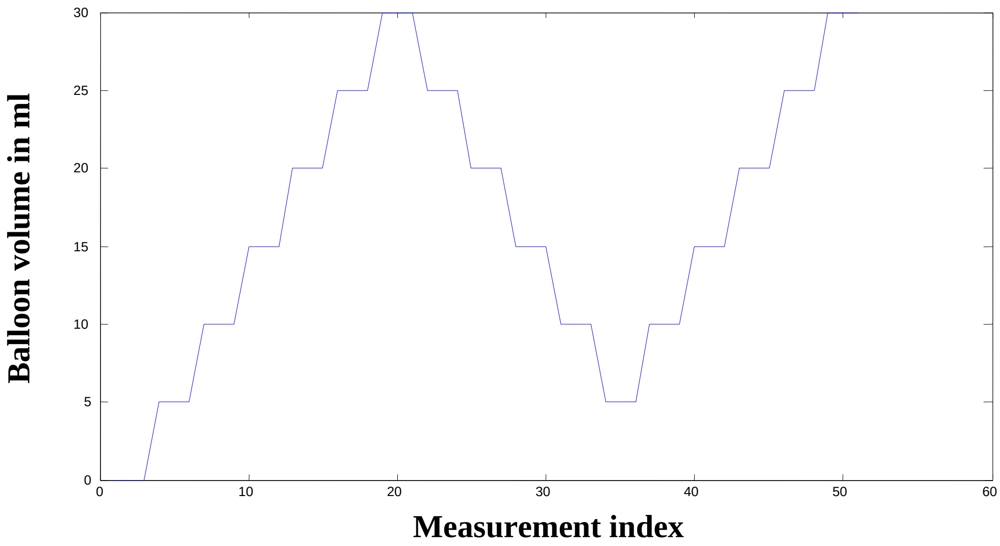


Figure 6.2.1 Balloon volume over measurement index

When we compare the Balloon volume with the measurement values, the increasing and decreasing trend can be clearly seen as shown in figure 6.2.2

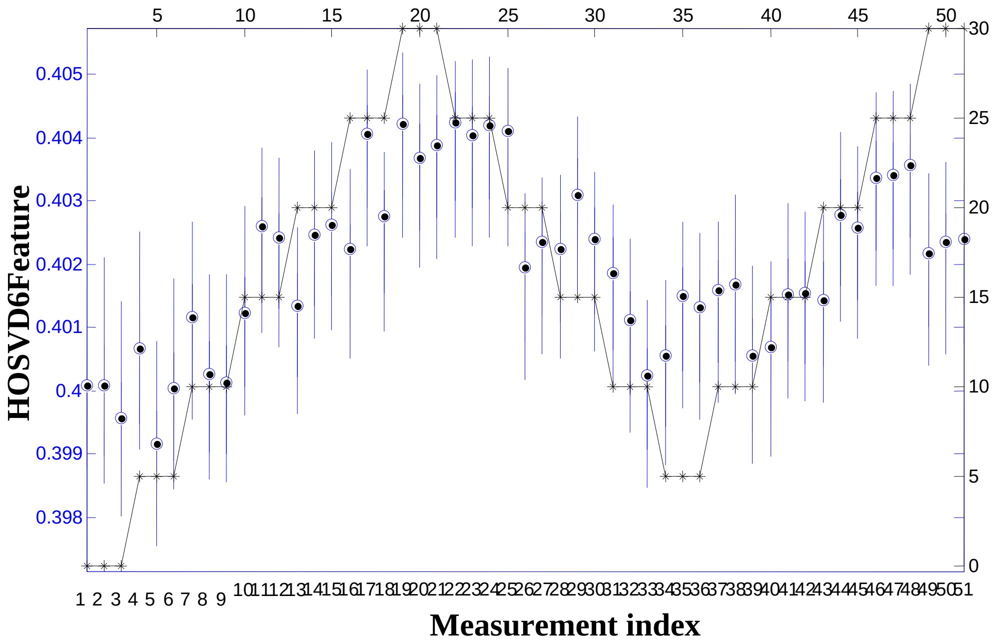


Figure 6.2.2 Distribution of HOSVD in comparison with balloon volume over measurement index for feature 6 in the frequency range of 245 MHz to 745 MHz for experiment on brain phantom with varying volume of bleeding mixture in balloon

From this experiment, it can be seen that the trend of increasing and decreasing values of HOSVD corresponds to the change of bleeding mixture volume in balloon as shown in the figure 6.2.3. The experiment is carried out mainly to visualize how the bleeding size in a real patient influences with the measured values. To understand this in detail, measurements were carried out on the bleeding brain phantom setup, by increasing and decreasing the amount of bleeding mixture in balloon. Different values for different volumes were obtained. But not at all volumes have the same values repeatedly; this is might be due to the air present inside the balloon or due to the external factors such as movement of cables, human errors.

6.3 Experiment on phantom model after heating up the system

In this clinical trial, experiment is conducted to determine how the temperature of the system affects the measurement values. The instrument is switched ON and allowed to run for one hour continuously before performing any measurement. After one hour, the reference test measurement is performed on the reference head model to test the antenna position and transmitted signals. Then the helmet placed on the Phantom head model to perform 12 continuous measurements as reference. After the reference measurement, the balloon inside the phantom model is filled up with 15ml of bleeding mixture to perform measurements continuously for 1 hour, the results of which is shown in the figure 6.3.1

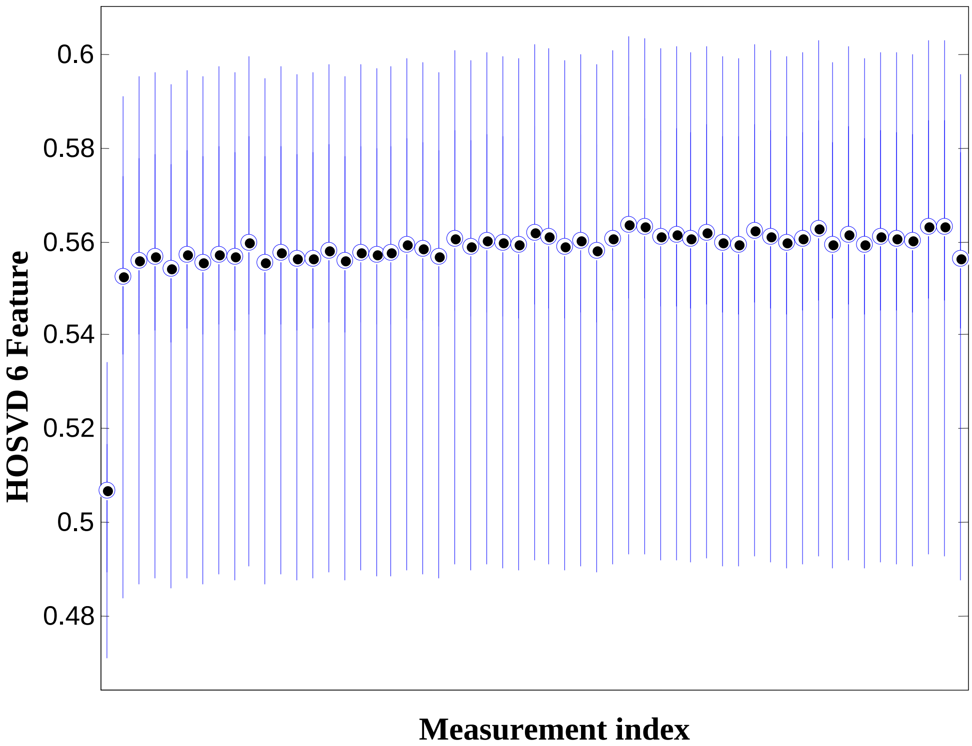


Figure 6.3.1 HOSVD distribution over measurement index for feature 6 in the frequency range of 245 MHz to 745MHz for experiment on brain phantom with 15 ml of bleeding mixture in balloon

Exactly after 1 hour, the balloon is filled with 30ml of bleeding mixture and measurements are carried out for another 1 hour as shown in the figure 6.3.2

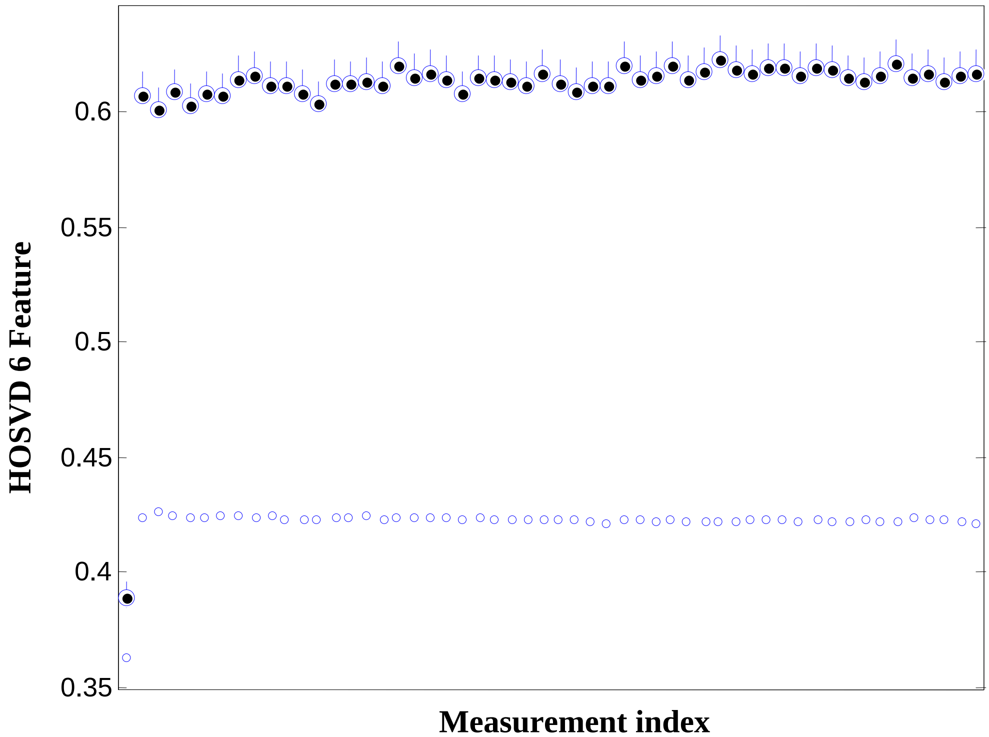


Figure 6.3.2 Distribution of HOSVD over measurement index for feature 6 in the frequency range of 245 MHz to 745MHz for experiment on brain phantom with 30ml of bleeding mixture in balloon

Then again 12 continuous measurements were performed on the phantom model(with empty balloon) continuously without touching anything. Then measurements were carried out with 0ml 5ml, 10ml, 15ml…30mlthen in the descending order and in ascending manner like 5ml,10ml, 15ml…30ml of bleeding mixture in the balloon respectively as shown in the figure 6.3.3 below.

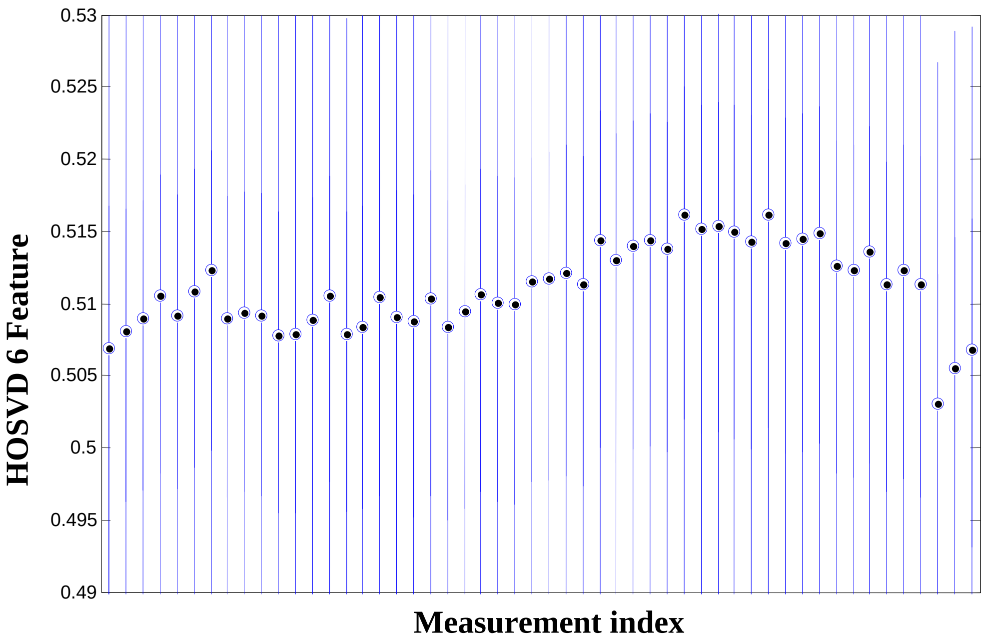


Figure 6.3.3 Distribution of HOSVD over measurement index for feature 6 in the frequency range of 245 MHz to 745 MHz for experiment on brain phantom with varying volume of bleeding mixture in balloon

This Experiment is carried out to see how the temperature influences on the measurement. For that reason, the system was turned on before start of the measurement and continuously made to run without the break. From the figure 6.3.1 and figure 6.3.2 it could be inferred that the values doesn't change whenever there is no change in volume of balloon and same value is obtained irrespective of the time and temperature.

Whereas from the Figure 6.3.3, the trend of increasing and decreasing HOSVD could be seen with minimal difference with respect to the increasing and decreasing volume of bleeding mixture in the balloon. As seen in the previous experiment 6.2, the increasing and decreasing trend in the figure 6.2.3 can be noticed but it's not repeated in this experiment with same setup.

6.4 Experiment on Phantom model with two Antennas setup

This experiment is performed on phantom model with only two antennas to get the desired trend by making it as simple setup. In this experiment, the Amplitude and Phase values of the measurement data are analyzed.

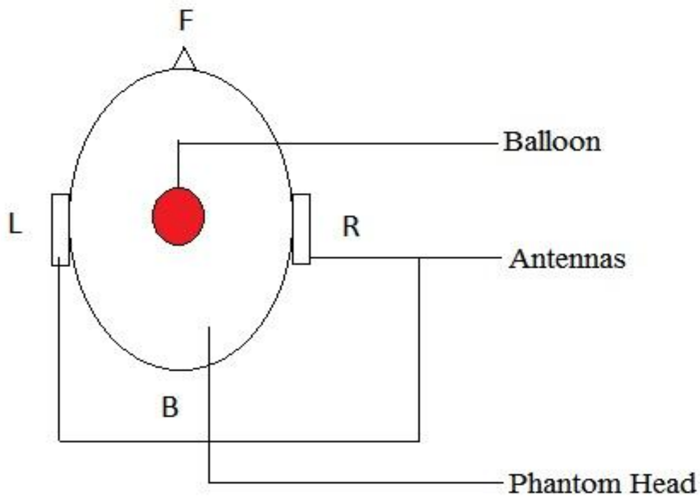


Figure 6.4.1 Two Antenna setup on Phantom model

6.4.1 Water phantom with Air in balloon

Before proceeding with the brain phantom mixture experiments, a reference experiment has carried out. Therefore in this experiment, phantom head is filled with water and balloon is filled with air. The setup is shown in the figure 6.4.1. This experiment is performed to verify whether the measurement device detects the changes in volume of balloon or not.

In this experiment, balloon is filled with air radically from 0ml, 10ml, 20ml, 30ml, 40ml, and then back to 0 ml as shown in the figure 6.4.1 (i).

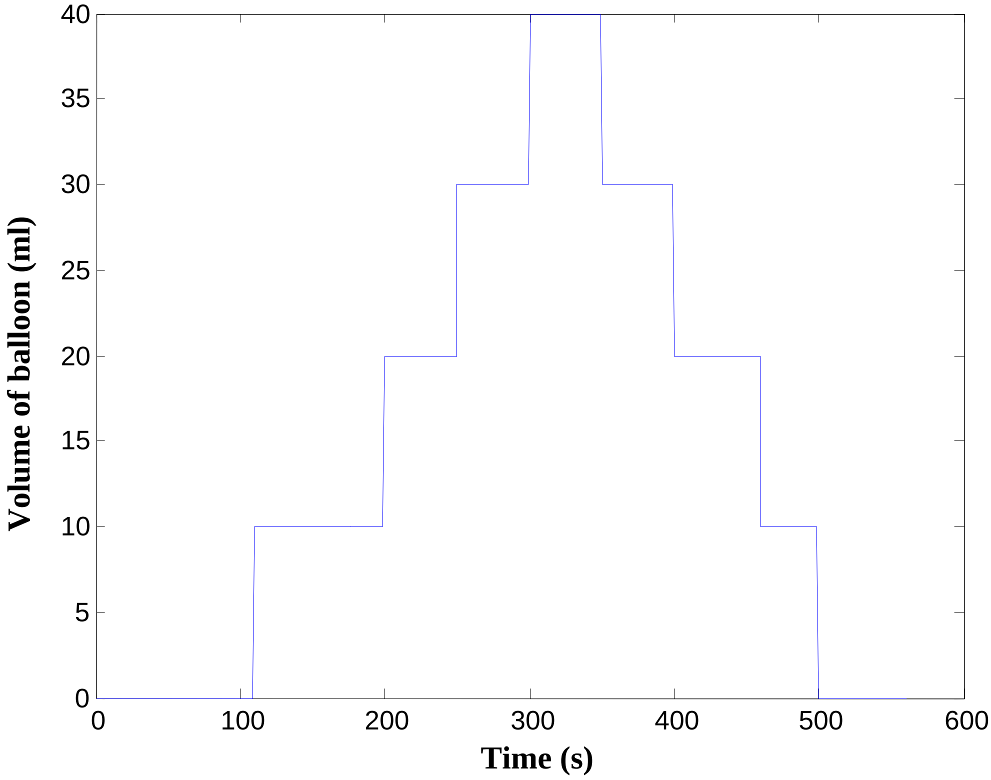


Figure 6.4.1 (i) Volume in balloon over time (secs) for the experiment phantom head containing water and air in balloon setup

The obtained amplitude and phase values can be seen in the figure 6.4.1 (ii) and figure 6.4.1(iii) respectively.

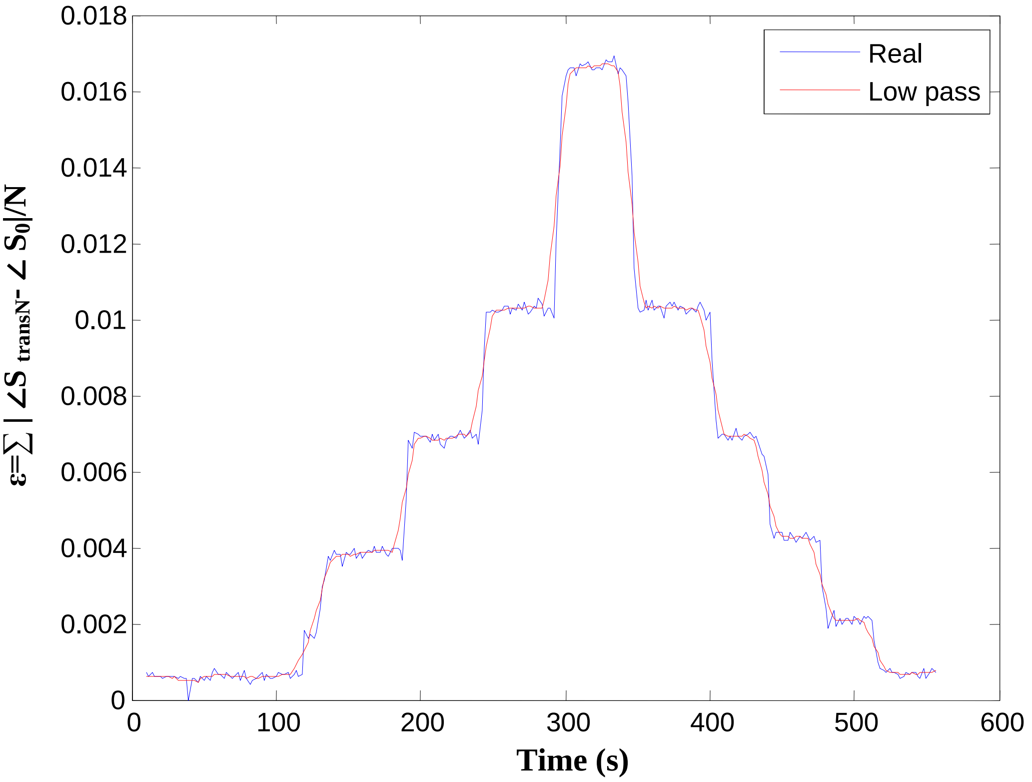


Figure 6.4.1(ii) Amplitude values of the measurement data over Time (Secs) in the frequency range of 0.8 GHz to 0.98 GHz for experiment on brain phantom containing water and balloon containing air with 2 antennas setup

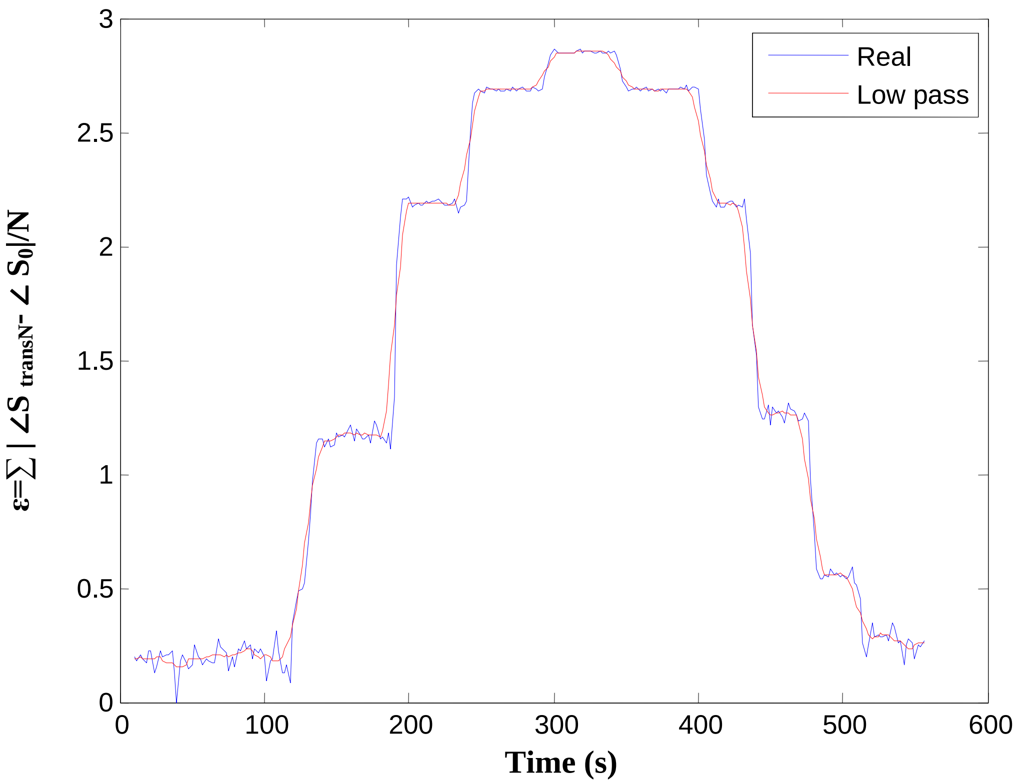


Figure 6.4.1(iii) Phase values of the measurement data over Time (Secs) in the frequency range of 0.8 GHz to 0.98 GHz for experiment on brain phantom containing water and balloon containing air with 2 antennas setup

6.4.2Brain Phantom with Air in balloon

This experiment is performed with head phantom filled with brain phantom mixture and balloon is filled with air. The setup is similar to the previous experiment.

In this experiment, balloon is filled with air radically from 0ml, 10ml, 20ml, 30ml, 40ml, and then back to 0 ml in a constant period with 200 measurements per ml as shown in the figure 6.4.2(i)

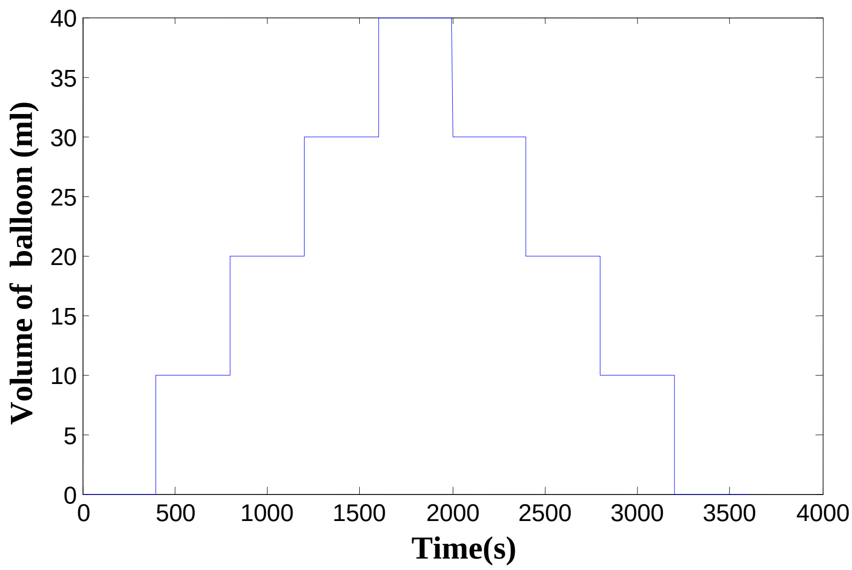


Figure 6.4.2 (i) Volume in balloon over time (secs) for experiment on brain phantom containing air in balloon with 2 antennas setup

The obtained amplitude and phase values can be seen in the figure 6.4.2 (ii) and figure 6.4.2(iii) respectively.

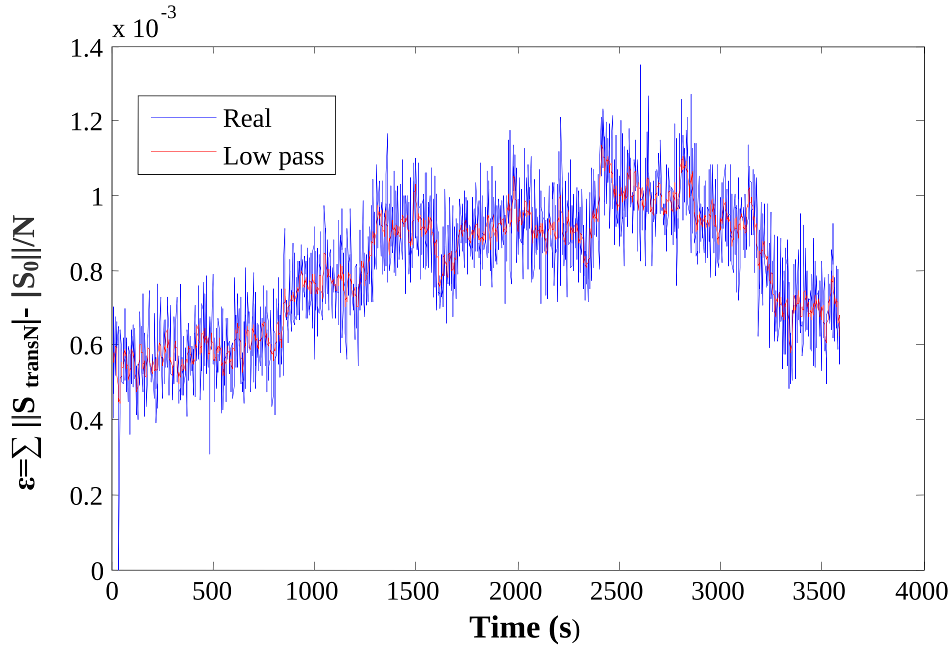


Figure 6.4.2(ii) Amplitude values of the measurement data over Time (Secs) in the frequency range of 0.8 GHz to 0.98 GHz for experiment on brain phantom containing air in balloon with 2 antennas setup

The amplitude and phase are obtained in the frequency range of 0.8 GHz to 0.98 GHz.

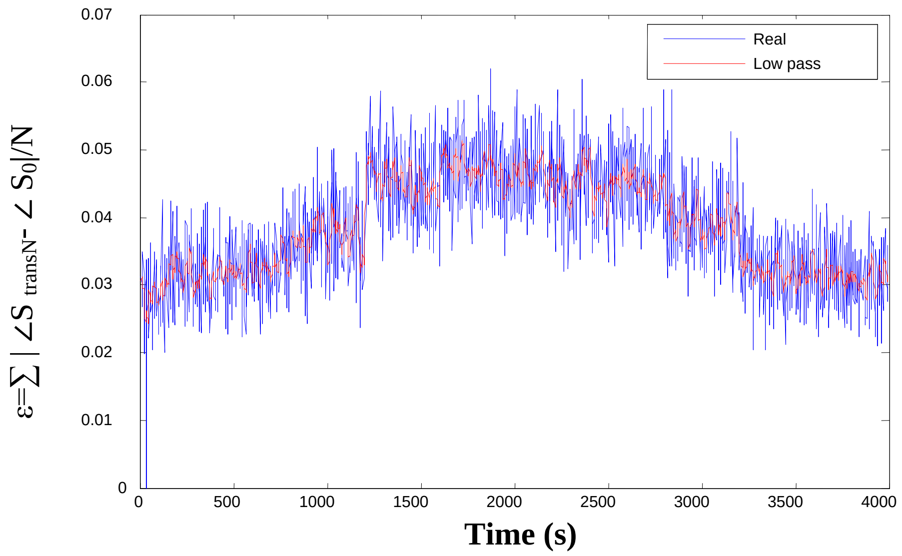


Figure 6.4.2(iii) Phase values of the measurement data over Time (Secs) in the frequency range of 0.8 GHz to 0.98 GHz for experiment on brain phantom containing air in balloon with 2 antennas setup

6.4.3Brain Phantom with Bleeding mixture in balloon

The experiment is carried out using a balloon containing bleeding mixture placed inside the brain Phantom using 2antenna setup. The bleeding mixture is varied radically from

0ml, 5ml, 10ml, 15ml….30ml then with the descending order like 25 ml, 20ml….5ml then again start with 5ml, 10ml…30ml in a constant period with 200 measurements respectively.

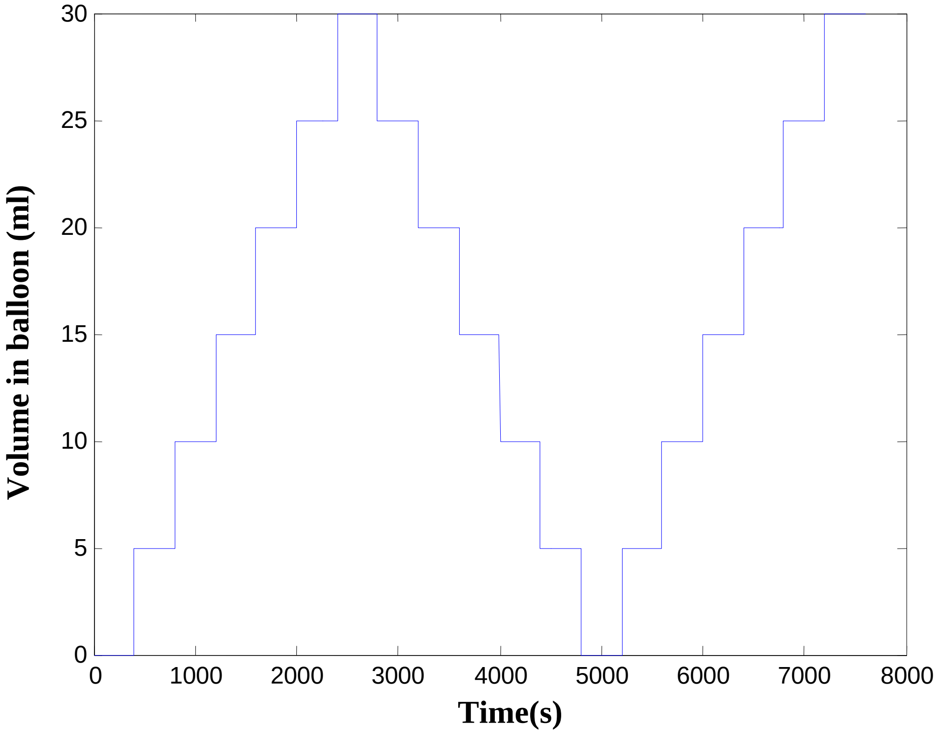


Figure 6.4.3 (i) volume of balloon over time (secs) for experiment on brain phantom containing bleeding mixture in balloon with 2 antennas setup

The obtained amplitude and phase values can be seen in the figure 6.4.3(ii) and figure 6.4.3(iii) respectively.

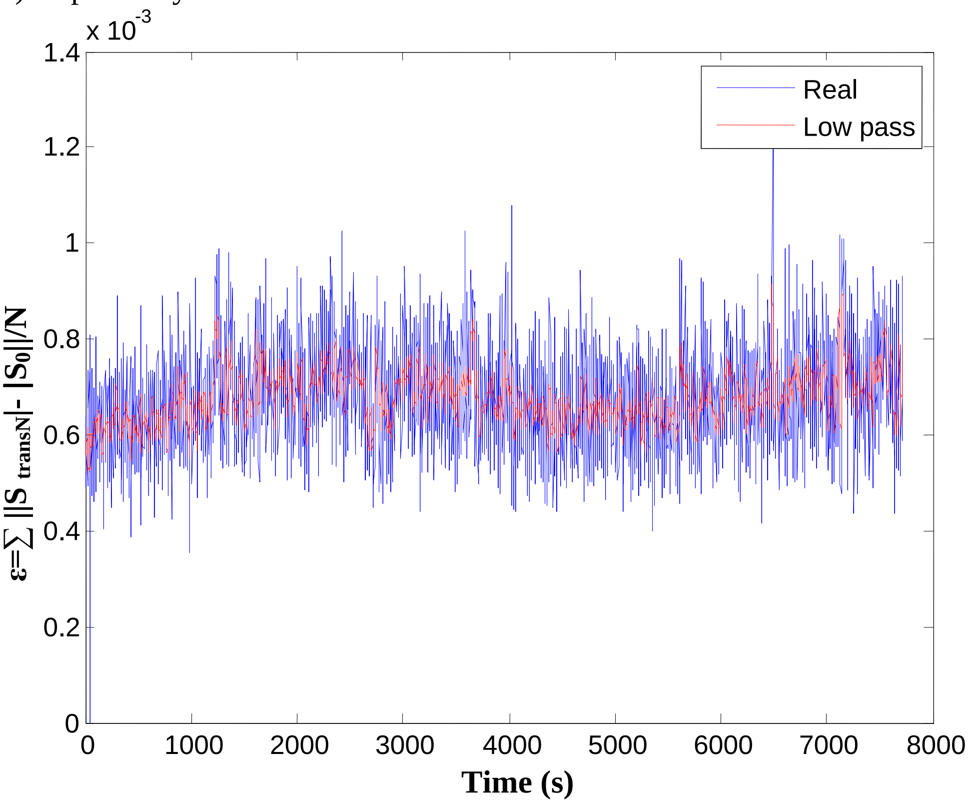


Figure 6.4.3(ii) Amplitude values of the measurement data over Time (Secs) in the frequency range of 0.8GHz to 0.98 GHz for experiment on brain phantom containing bleeding mixture in balloon with 2 antennas setup

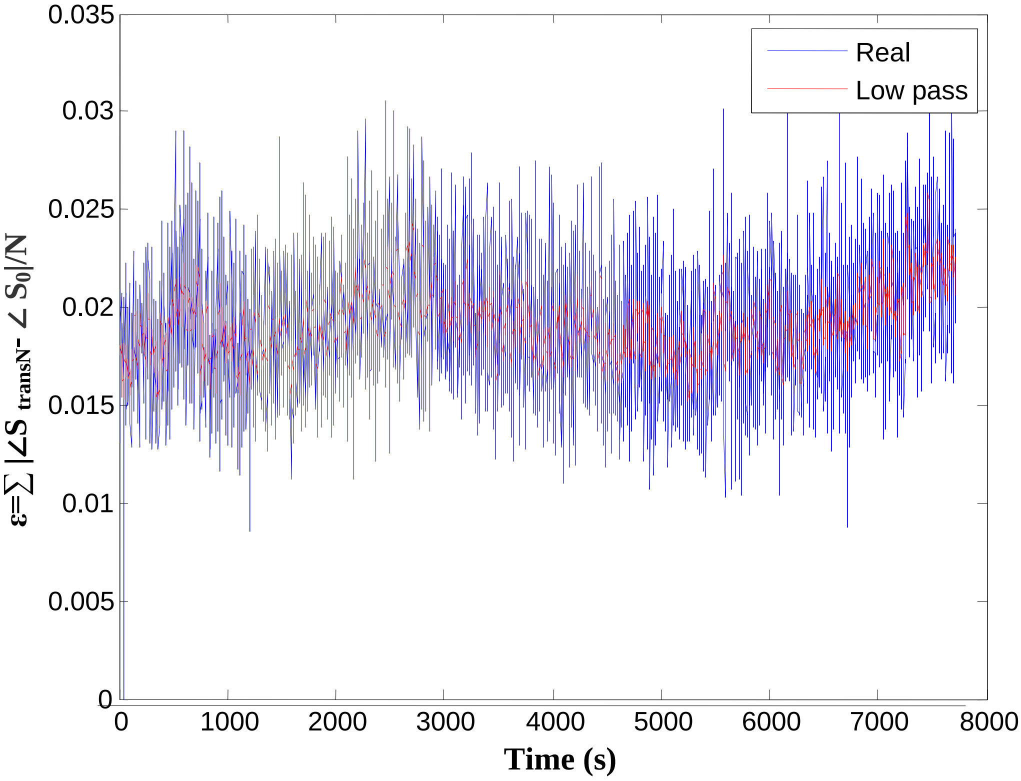


Figure 6.4.3(iii) Phase values of the measurement data over Time (Secs) in the frequency range of 0.8 GHz to 0.98 GHz for experiment on brain phantom containing bleeding mixture in balloon with 2 antennas setup

The real signal has more noise which can be observed from the amplitude and phase values from both the experiments. But the trend of increasing and decreasing trend is clearly seen according to the changes in volume of balloon.

Chapter 7

Discussion

The main objective of this thesis was to develop a phantom model with the dielectric properties of Human Brain and to perform measurements and analysis on the phantom model using the Strokefinder R10 device.

The Phantom is modelled with the dielectric properties of human brain by referring experimental work executed by fellow workers in this field. Before doing experiments on phantom model, measurements were made on the healthy volunteers to examine how well the instrument is sensible to the changes in both internal and external factors of the subject and the measured values were compared with the healthy database using classification algorithm developed by Hamed et al., [6]

The experiments on healthy volunteers have shown the influence on internal and external factors. Change in the initial position of the helmet results in significant variation from the obtained results whereas disturbance due to volunteer’s stimulated head movement causes random changes in the obtained result. In the other experiment with continuous measurements without any interruption, the continuous trend without any change can be observed. From these experiments it can be concluded that External disturbance causes more variation in the result obtained to patient artifacts (head movement).

Experiments on phantom model are followed by healthy volunteer’s measurements. After designing the phantom mixture, phantom model is developed and measurements are carried out in different setups. In the first experiment, the differences between the air and bleeding mixture were observed, by filling bleeding mixture in the balloon for 3 consecutive measurements and then filling air in the balloon for another 3 consecutive measurements with different volumes. But there are no considerable changes when there is a change in air volume in balloon and the reason could not be predicted.

Then the consecutive experiment is performed to figure out whether the system could identify the changes in the bleeding size or not. Trends of increasing and decreasing values were expected by filling up the balloon with different volume of bleeding mixture. After the usual procedure, 12 continuous measurements were taken on the phantom model with empty balloon as reference. The balloon was filled 0ml, 5ml, 10ml and 15ml….30ml then in the descending manner like 25 ml, 20ml….5ml then again start with 5ml, 10ml…30ml respectively. For each ml, 3 measurements were performed. From the analysis results, we could get the trend that we expected, but the difference is very minimal.

In order to acquire the better result and to get the clear picture of increasing and decreasing trend according to the measurement, the experiments with 2 antenna setup was undertaken. It’s more direct and simple method to acquire better results than the complex 12 antenna setup.

In simple terms, the experiments were conducted with phantom in the head model and balloon containing air as a first setup and it provides a better result. Then we tried with Phantom head containing phantom mixture with bleeding mixture in balloon. The expected trend was obtained from the measurements but with high noise level.

Conclusion

Aim of the thesis work was achieved by modelling a phantom model with the dielectric properties of human brain. Experimental studies on the healthy volunteers resulted in changes in measurement values by stimulating instabilities. With the experiments conducted on the phantom model, it can be observed that the system detects the changes in the phantom model. The trend of increasing and decreasing in the measurement values according to the changes in the balloon is inferred, which is similar to the detection of bleeding size in human brain in real time.

Future Works

In order to obtain better results from the Strokefinder R10 device, the sensitivity of the antenna can be improved. The plastic helmet should be replaced with more flexible to avoid air gaps between antenna and subject’s head. The cables are so sensitive and touching cables causes more fluctuation in readings. For that purpose, a rigid cable should be used. To obtain better measurements from phantom, the phantom should be designed as heterogeneous with dielectric properties of all brain tissues, a model similar to human brain.

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