Human Dielectric Equivalent Model
Design Document

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Project Definition

A physical model that mimics the human body's dielectric properties will be constructed. The model will be used to test low power signal transmission through the body. To increase confidence in the physical model, a computer model will be used to compare results. The computer model will use data from Yale University's voxel based human phantom.

Project Goals:

By the end of the spring 2015 semester we intend to have the following goals completed.

- Obtain a voxelized computer model of the human body.
- Have a method to convert the computer model into a form that can be used in HFSS
- Construct a mold from which we can create the physical dielectric model.
- Have a homogenous physical conductivity model of the human torso.
- Have initial test results on torso model demonstrating feasibility of materials used.

By the end of the fall 2015 semester we intend to have the following goals completed.

- Have a physical human dielectric model that is accurate to within 75%.
- Verify and validate the physical model using the results from software simulation.
- Have a working computer model that produces simulation results from ANSYS HFSS.

Deliverables

A physical model that mimics the Human body's dielectric properties with greater than or equal to 75% accuracy. This model will have the ability to be capacitive coupled to a transmission device. Additionally, this model must be able to achieve a minimum of a two week shelf life and be able to withstand multiple test cycles. This project also requires the creation and delivery of a software model to verify and validate the physical model's dielectric properties.

System Level Design

Functional Requirements

- The model will simulate the human body dielectrics with a 75% or greater accuracy
- Signal input contacts will be firmly connected to the model.
- The model will be able to be capacitively coupled to a transmission device.
- The model will simulate frequencies in the 3 kHz to 100 kHz or 10 MHz to 20 MHz range. Smaller frequency ranges can be selected from within the ranges given.
- The model must be accurate through the arms and torso.
- The model must be able to withstand multiple tests.
- Only low power signals with be used (power < 1 Watt).

Non-Functional Requirements

- The model should last at least 2 weeks.
- The model can withstand hot/cold beyond human comfort zones.
- The model has to be the same general shape as a human. The model does not have to include hair, skin color, or any other superficial detail.
- The model will not need any maintenance during its lifetime.

Functional Decomposition

Figure 1 shows a high level flow of the project design process. Due to the nature of this project, the design is very iterative in nature. Research will be conducted to determine experimental formulations for both the homogeneous model and the non-homogeneous model. Those formulations will then undergo testing (see Testing Procedure) to ensure accuracy. If the models are found to not be accurate or not structurally feasible, the formulation and design process will be repeated.

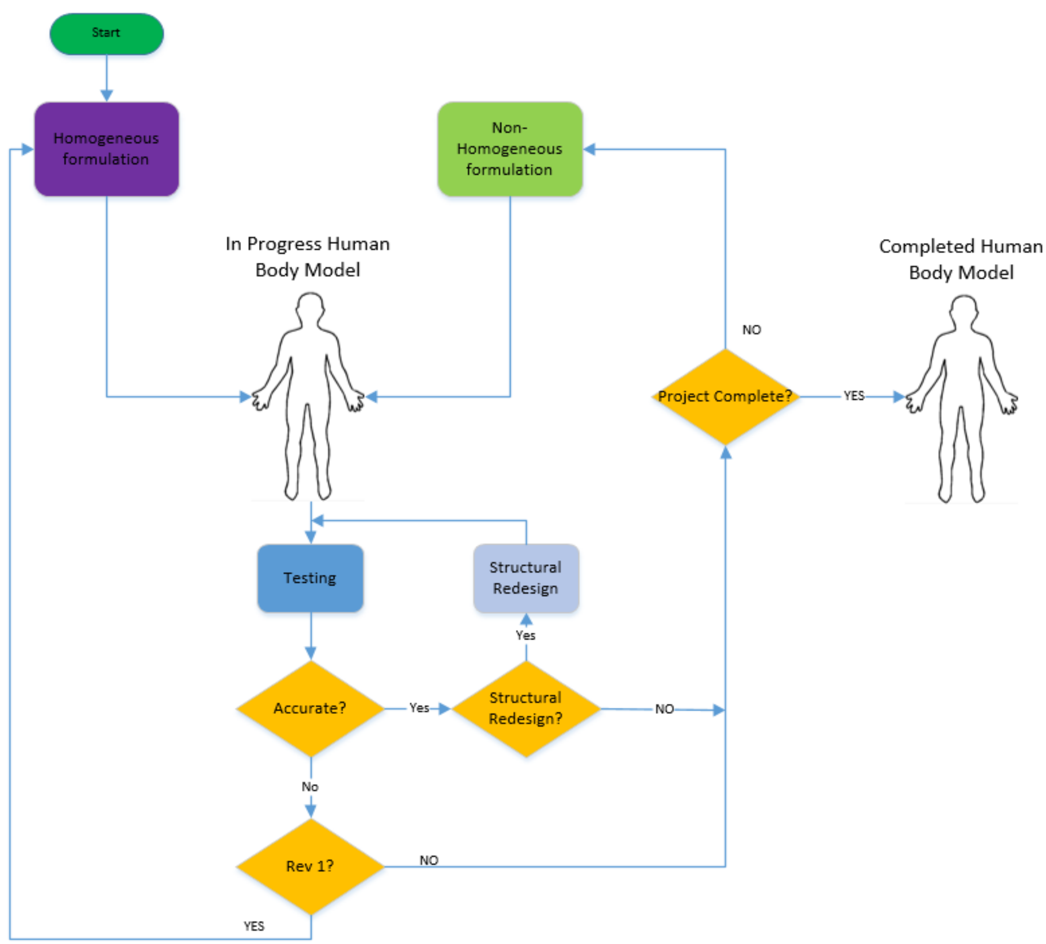

Figure 1: Design process flowchart

Computer Simulation

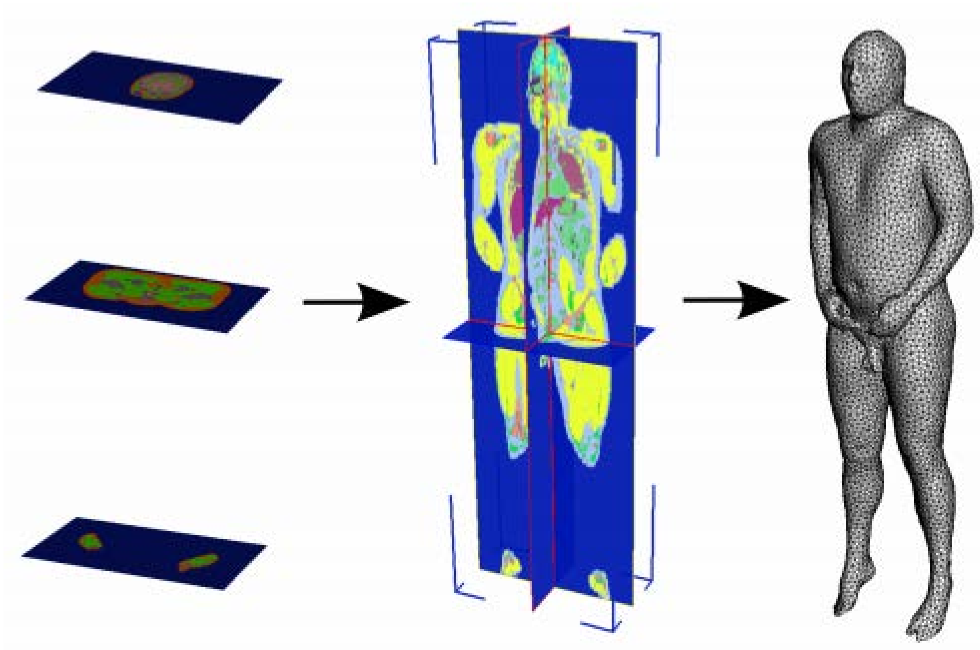

Figure 2: Shows a rendering of the computer model

The computer model is a computational human phantom designed for computer analysis and simulations by George Zubal of Yale University. This is a voxelized phantom with a cubal voxel resolution of 3.6mm. The data used to make the phantoms were taken from CT scans and MRIs. The data was obtained in a raw format and will need to be converted into a format compatible with ANSYS HFSS. The binary grayscale image must be converted into a tetrahedral mesh, because HFSS uses the finite element method to solve field equations. Figure 3 below depicts the steps needed to get the desired mesh.

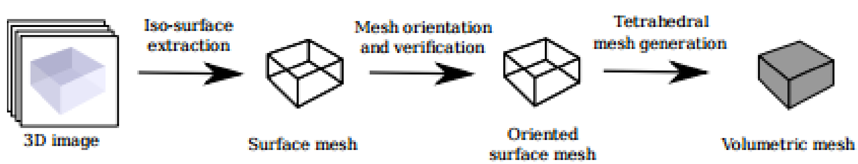

Figure 3: Shows process of creating computer model

The model we have is represented by a discrete volume dataset that represents a collection of data points in 3d space, each of which has a tissue label. The first step requires the transformation of the discrete data into a piecewise linear surface known as polygonal mesh. The simplest method for extracting these isosurface meshes is the marching cubes algorithm. The biggest concern of using this algorithm is the generation of poor quality surface triangles. The quality of the surface triangles affect the quality of the tetrahedral and the quality of the tetrahedral affects the accuracy of the numeric solver used by HFSS. Once we successfully extract the isosurface meshes we will be able to generate the tetrahedral mesh. There are a couple of options for generating the tetrahedral mesh from a surface mesh. There is CUBIT developed by Sandia National Laboratories which works with file formats compatible with HFSS. There is also TetGen developed by Hang Si which produces better quality tetrahedrals. After we have the mesh in a compatible format we will import the geometry into HFSS and use the electrical properties obtained from an online database.

Testing Procedure

In order to test our physical model for accuracy we will be using multiple testing apparatus that tests for the dielectric constant and conductivity of the model. These apparatus are a parallel plate capacitor and the use of an ohmic cell. The parallel plate capacitor will be used in conjunction with an LCR meter to determine the capacitance of the capacitor with a given dielectric media between the capacitor plates. From this we can then calculate the dielectric constant and relative permittivity of the dielectric media. The simplified parallel plate capacitor testing set up is shown in figure 4 below.

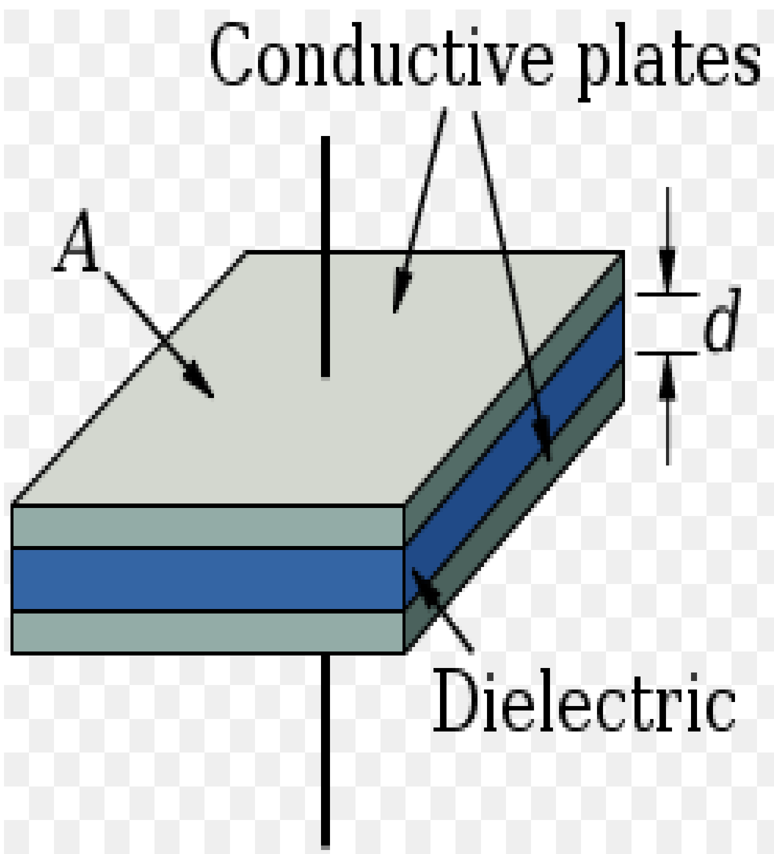

Figure 4: Illustrates a parallel capacitor

The ohmic cell testing set up shown in figure 5 will be used to determine the conductivity of a given media. The ohmic cell allows us to easily test liquid and gel solutions. Additionally, the ohmic cell ensures that there will be no air bubbles or voids in the media being tested. The leads of the ohmic cell will have a voltage placed on them. The voltage and current will be recorded from this we can determine the conductivity of the media under test. Once we determine suitable materials those materials will then be implemented into our final model.

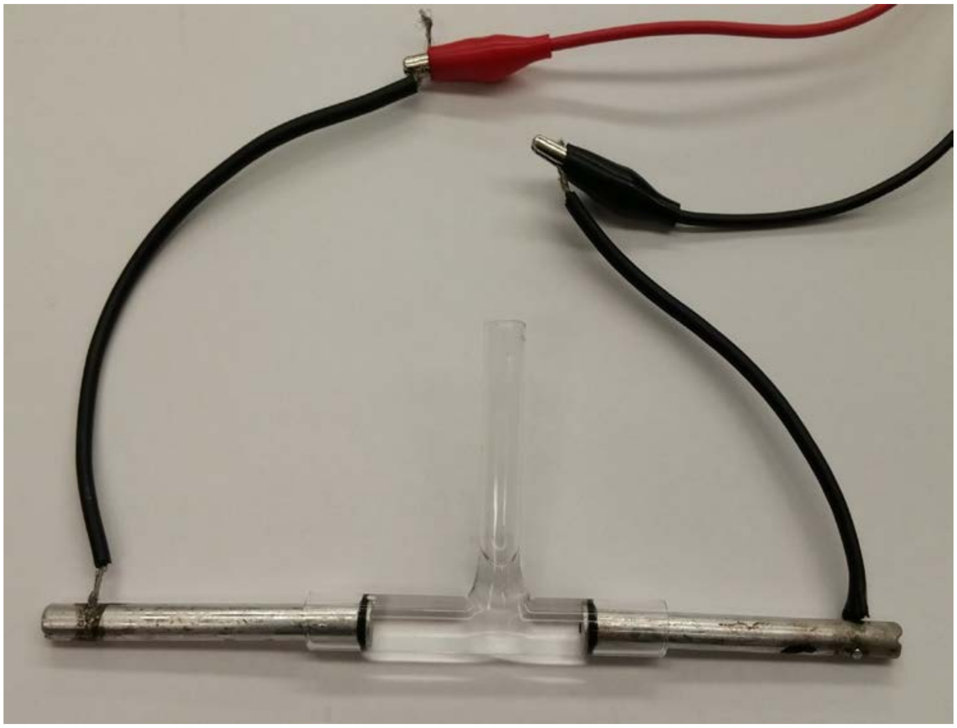

Figure 5: Shows the ohmic cell used for testing

To test our final model a signal will be sent through one arm and a receiver will be placed at the other arm in order to see how much the signal degradation occurred. The simplified flowchart of the testing process is shown in figure 6. The signals will be measured using a network analyzer because to ensure accuracy. After gathering sufficient test results, those results will then be compared to our software simulation results. If the results are similar then the physical model will not need to be adjusted, however if the results are significantly different (less than 75% accurate) then the model will need to be adjusted by adding a different composition of materials.

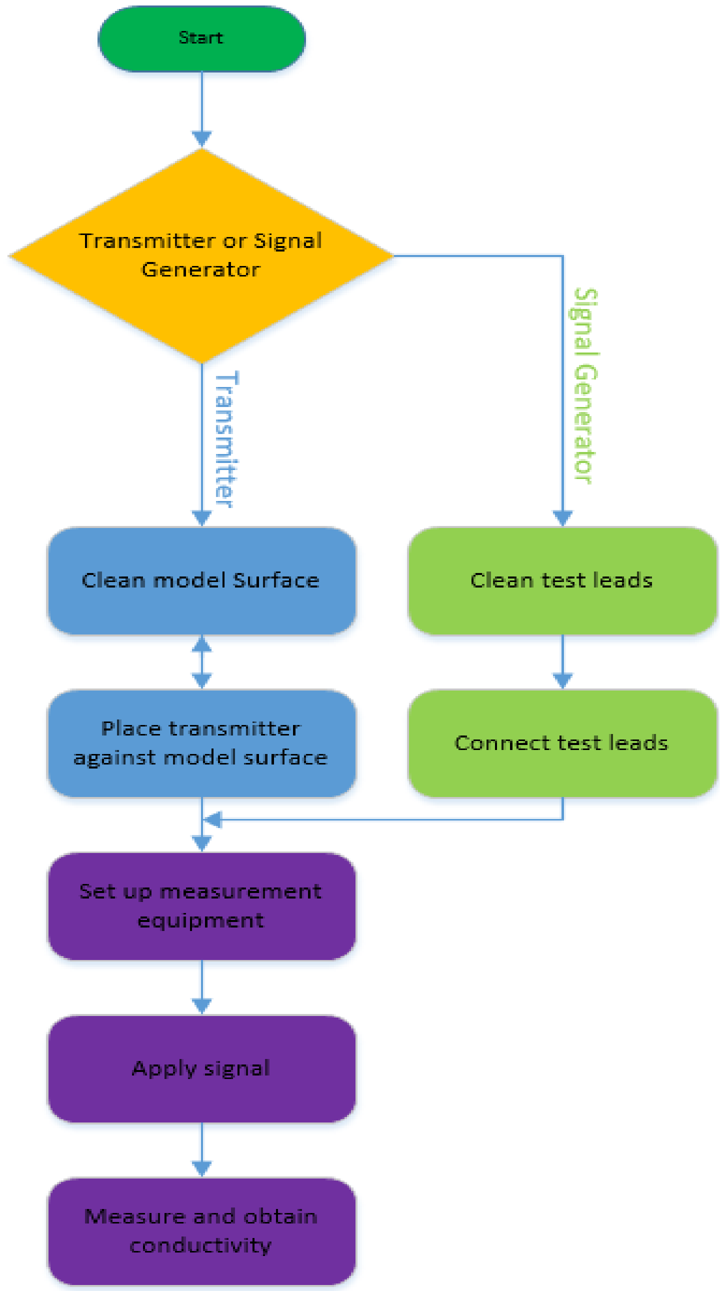

Figure 6: Testing Flowchart

Verification and Validation

Verification and validation are both necessary to ensure that a precise and accurate model will be delivered. Our team will conduct various test to verify that the model meets specification. We will perform tests identified in the testing procedure on individual components of the model prior to final assembly. Additionally, we will repeat these tests and the complete model testing daily for a period of two weeks. This will ensure consistency and shelf life of the model.

Challenges

Finding good human equivalent materials within our budget.

There are commercially available epoxies that can be used to replicate the human dielectric properties, but those epoxies cost too much for our budget ($150 per gallon). We have currently settled on a saline solution for this semester, but would like to move onto other materials next semester from improved accuracy and longevity.

Understanding the transmission path

The model is currently focused on the signal traveling from hand to the other hand through the torso. The model does not include any effects of the head, legs, or different arm positions. We are currently assuming that any disturbances caused by changing the size, shape, or layout of the model will be negligible. The computer simulation results will show whether that is a reasonable assumption.

Taking accurate measurements

Taking accurate measurements is key to verifying that our model represents a human body. If care is not taken while setting up and taking measurements, the data obtained from said measurements will be of little to no value.

Extracting conductivity/permittivity

Conductivity and permittivity of a material cannot be measured directly by a network analyzer; rather the network analyzer will generate a file of S-parameters. These S-parameters will then have to be used to calculate conductivity and permittivity.

Converting data from cubal to tetrahedral

The main concern is creating water-tight surfaces from which the tetrahedral meshes will be generated. After we have quality water-tight surface meshes there is software available to generate the tetrahedral mesh.

Translating current models into HFSS

After we obtain the tetrahedral mesh we will need to convert the file into a format compatible with HFSS. We need to make sure the conversion does not alter the underlying geometry of the model.

Readily available lab equipment

In order to test our model for conductivity and permittivity we need access to a network analyzer. There is only limited availability of network analyzers. Also network analyzers are very expensive machines, we need someone familiar with the operation and handling of the analyzer to supervise us. That way we don’t damage the machine or get incorrect readings.

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