ECE 290: Senior Design Fall 2006

Electromagnetic Phantom for the Human Body

Project Proposal

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Executive Summary

The proposal describes a senior design project that is currently being researched and designed for the MegaWave Corporation. Currently, MegaWave uses phantoms filled with a solution which imitates the electromagnetic properties of the human bodies in order to test antennas. The project aims at replacing this solution with another mixture which more accurately represents the afore mentioned electromagnetic properties of the human body. The simulating medium must be accurate for a frequency range of 20 MHz - 3000MHz. Also the medium with which the phantom will be filled should be stable, that is, it will not separate over time or due to small changes in temperature. A Laptop will control a network analyzer used to take measurements of an antenna under test that has been placed on the dummy. Once all measurements have been made, the laptop will process the data and display a horizontal radiation pattern for the antenna under test. The control software will be modified using Visual Basic. The code for the automated testing system should be modified so that graphs are automatically created after taking a measurement, as well as a way to easily compare the phantom test results with the human test results. The final mixture must be tested using the revised automated testing system developed last year for MegaWave Corporation.

Sponsor Background

Located in Bolyston, Massachusetts, MegaWave designs antennas for organizations such as DARPA, DOT, SOCOM, NASA, and the US Army and Navy. Founded in 1994, MegaWave began with development antennas for radio and television communication systems, and moved on to developing antennas for military use. Currently, MegaWave's research includes direction finding antennas, genetically optimized antennas, and portable electronic device detection for aircraft.

Introduction:

The process used by MegaWave for developing body worn antennas involves a filled phantom on a rotating platform. For a given frequency range, an antenna transmits a signal to the body worn antenna that's placed on the phantom, which rotates a full 360 degrees, measuring signal strength at previously set intervals. While a human could undergo this test, the phantom has the advantage of being perfectly still for any amount of time. Considering these tests can take several hours to conduct, using the phantom is the more practical choice for testing.

Problem Statement

In the past, the military has utilized communications that consisted of one soldier in a squad carrying a bulky antenna pack to keep in contact with headquarters. To move more efficiently in the field, antennas were soon integrated into the equipment that a soldier already carried, such as within body armor. With this evolution a new problem arose. The human body affected the properties of the antenna, and therefore a systematic way of testing body-worn antennas needed to be created. This was done last year by a senior design group sponsored by MegaWave Corporation. The final product was an automated system that through the use of a source antenna, body worn antenna mounted on a dummy, and a network analyzer, measured the

antenna properties for a 360 degree rotation of the dummy. The dummy was filled with a saline solution that possessed similar electromagnetic properties to the human body.

As body worn antennas further developed, the need for a more accurate phantom arose. While the saline solution acted similar to the human body, it was determined that it was not precise enough for MegaWave's research. Therefore, a new tissue-simulating medium is needed that more closely represents the electromagnetic properties of the human body. This would provide more accurate results when developing body-worn antennas, allowing them to be more efficient.

Project Specifications:

Environmental:

- Simulating medium should be stable in fair weather conditions.
- Testing will take place outdoors.
- Should not be harmful to the environment.

Testing:

- Mixture should closely represent the electromagnetic properties of the human body for a frequency range of 20MHz to 3000MHz.
- Small scale testing will utilize both a network analyzer and dielectric probe provided by MegaWave.
- A human will undergo the same test as the phantom in order for comparison.
- Final medium will be tested using MegaWave's testing process.

Physical:

- The medium,
  - should be cost effective and easy to prepare.
  - should be easy to handle.
  - can be inserted into the dummy as well as emptied without difficulty.

Software:

- The software should be compatible with the Windows XP operating system.
- The current control software generates a 360 degree azimuth pattern and antenna gain data.
- The modified software should automatically generate data specific graphs using excel.
- The modified software should be able to easily compare current test results with previously stored test results.

Previous Research

There has been research on gel medium. This gel solution was based on the polyethylene powder and TX-150, a gelling agent. The gel used consisted essentially of Acrylamide (C_3H_5NO) polymerized in water with dopants that were added to simulate electromagnetic properties of biological tissue. It has been used by authors to simulate high to low conductivity tissues in short wave ranges. Some of the pros are, that it is a solid elastic, easily shaped into complex forms, low cost and readily available. Some cons include that it is not easy to handle

because bacteria or mold make it difficult to maintain the integrity of the gel. Also if dealing with a full body phantom it would be difficult to fill it with gel.

Proposed Solution

Currently, the solution used at MegaWave is not an accurate enough representation of human tissues. The solution consists of 3.5g of salt per liter of water. For this concentration of salt, the permittivity ranges from 76-78. We are aiming for a medium that mimics muscle tissue, and to do that we will use values similar to those shown in the table below.

Body tissue simulating liquid

Type	BT0050F	BT0144F	BT0150F	BT0300F	BT0450F	BT0835F	BT0900F	BT0915F	BT1260F
Frequency band [MHz]	50	144	150	300	450	835	900	915	1260
Uses	amateur radio	amateur radio	mobile satellite	mobile satellite	telemeter	GSM	PDC	PDC	amateur radio
Relative Permittivity (*1)	64.37	62.05	61.90	58.20	56.70	55.20	55.00	55.00	54.36
Relative Conductivity [S/m](*1)	0.72	0.80	0.80	0.92	0.94	0.97	1.05	1.06	1.21
Color	light yellow, transparent								
Smell	minute smell								
NET [L]	8								
Container size (H*W*D[mm])	290*250*175(*2)								

Type	BT1450F	BT1610F	BT1800F	BT1950F	BT2450F	BT3000F
Frequency band [MHz]	1450	1610	1800	1950	2450	3000
Uses	PDC	mobile satellite	(*3)	PHS W-CDMA	Wireless LAN etc.	radar
Relative Permittivity (*1)	54.00	53.80	53.30	53.30	52.70	52.00
Relative Conductivity [S/m](*1)	1.30	1.40	1.52	1.52	1.95	2.73
Color	light yellow, transparent					
Smell	minute smell					
NET [L]	8					
Container size (H*W*D[mm])	290*250*175(*2)					

(*1)Standard values of relative permittivity and conductivity comply with FCC OET BULLETIN 65.
(*2)Containers are made of polyethylene.
(*3)Telecommunication

Figure1: Estimation of Body-Tissue Simulating liquid (http://www.emc-center.jp/index.html.en)

The proposed solution is to utilize both salt and sugar in the new mixture. Our research has shown that sugar added to a saline solution will decrease the permittivity slower then additional salt would. Considering the fact that muscle tissue and fat tissue are dominant in the

human torso, we plan to concentrate on mimicking muscle tissue primarily and fat tissue secondarily.

Permittivity is a measurement of a materials ability to transmit an electric field. More specifically, it is a measurement of the materials ability to polarize in response to an electric field, thus reducing the field inside the material. Conductivity is a measurement of a material's ability conduct an electric current. The loss tangent is the ratio of the imaginary part of the dielectric constant to the real part.

There are several ways to predict the effective permittivity of a medium. The equations we will be using are derived from Maxwell's Equations.

$$\nabla \times \vec{H} = j\omega\epsilon \vec{E} + \sigma \vec{E}$$
$$= j\omega\epsilon_0 \epsilon_r \vec{E} + \sigma \vec{E}$$
$$= (j\omega\epsilon + \sigma) \vec{E}$$
$$= j\omega \left(\epsilon + \frac{\sigma}{j\omega}\right) \vec{E}$$
$$= j\omega\epsilon_{eff} \vec{E} = j\omega\epsilon_0 \epsilon_{r_{eff}} \vec{E}$$

Our main focus will be on the relationship of the loss tangent, conductivity, and permittivity with regards to frequency.

$$\tan\delta = \frac{\sigma}{\omega\epsilon'}$$

$$\epsilon' = \epsilon_r \epsilon_\circ$$

$$\epsilon_\circ = 8.854\text{E-}12$$

Proposed Testing

Small scale testing will be conducted in the lab on campus using the network analyzer described in the Appendix. The testing will consist of mixing a salt and sugar solution, and measuring its properties to calculate its permittivity and conductivity. If time permits, the electromagnetic properties of a previously suggested gel solution will be analyzed. Getting the correct permittivity will require trial and error of mixing the right amounts of salt and sugar. Once the correct mixture is found with an acceptable permittivity, large scale testing will be performed. This testing will involve using the automated antenna test developed by the previous Senior Design team. In this test we will be measuring the VSWR with antenna on body, and compare VSWR to phantom and body. We will also measure the vertical pattern on phantom and body and then compare the results.

Proposed Software Solution

The current software developed by the previous Senior Design team last year was not completed. The overall program was sufficient enough to do the automated testing of the antennas. However, several functionalities were omitted and various bugs were not resolved due to time constraints. We propose to add as many features and fix as many bugs as possible.

The features that will be added are listed below:

- Produce Excel Graphs after testing

    - Current software only exports data to Excel spreadsheet
- Compare different tests
    - Phantom Tests vs. Phantom Tests
    - Phantom Tests vs. Human Tests
- Add two sequences to get VSWR and/or Impedance data.
- In automated mode allow user to choose either S_{21} or S_{12}
    - This allows the user to switch the reference and source antennas
- Make an option to measure reference antenna.

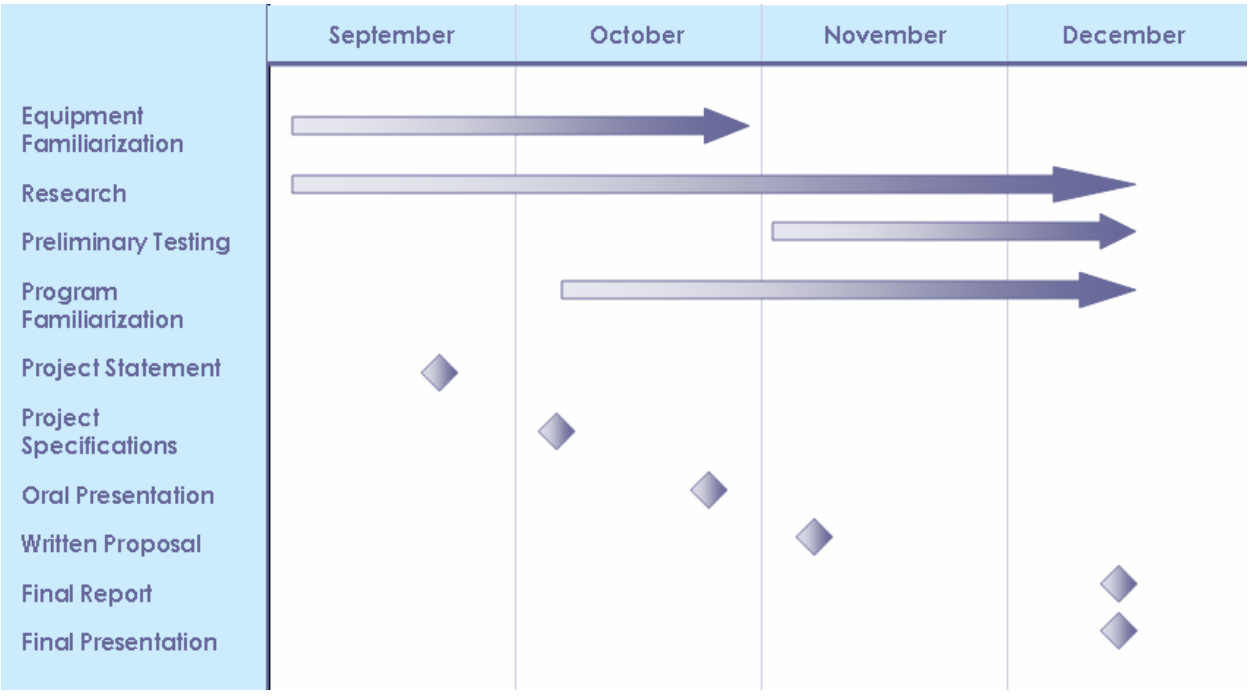
The bugs that need to be fixed are listed below.

- Add a return to zero position when program ends.
    - This will return the phantom back to the zero position. Upon returning no measurements will be taken. Currently the program hits an error upon trying to return to zero while taking measurements.
- The program crashes when it tries to create new files in manual mode.
- If user chooses a gain file outside a user selected frequency band, the program crashes.
    - Program needs to prompt user to choose another gain file with the correct frequency band.
- Program doesn't seem to collect the actual raw data from the network analyzer.

Proposed Budget

Digital Scale	$125
Solutes	$200
Cylindrical Piping\Phantom	$200
Other Costs	$475
Total Cost	$1000

Timeline



Appendix

Equipment we are going to be using:

- **Network Analyzer HP8753A**

  The Network Analyzer is used to measure complex impedances VSWR, and the losses or gains in a device. It is capable of sweeping frequencies from 300KHz to 3 GHz, and can be used in conjunction with the dielectric probe to determine additional electromagnetic properties.

- **Dielectric Probe**

  The dielectric probe can be used to determine the incident, transmitted, and reflection signal strength of a sample. These values are then used to determine the permittivity, conductivity, and reflection coefficient of that sample.

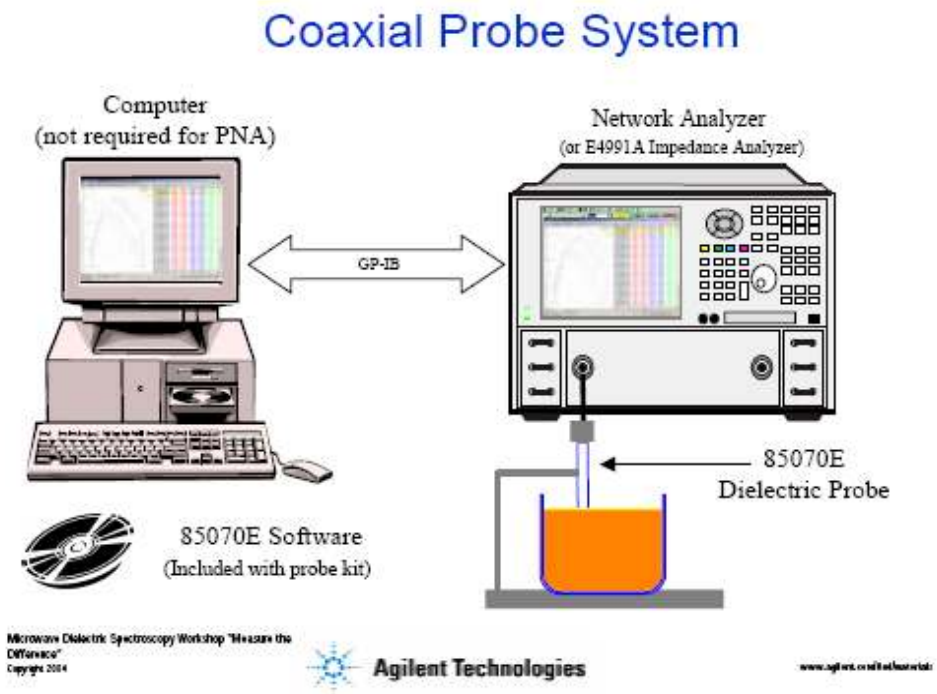


Figure 1: General Experimental Setup utilizing Network Analyzer and Dielectric Probe

Additional Equipment includes:

- Beakers
- Graduated Cylinders
- Analytical Scale